(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
26 January 2023 (26.01.2023)

WIPO | PCT

(10) International Publication Number
WO 2023/000081 A1

(51) International Patent Classification:
C12N 15/62 (2006.01) *C12N 15/113* (2010.01)
C12N 9/14 (2006.01) *C12N 15/861* (2006.01)

(21) International Application Number:
PCT/CA2022/051100

(22) International Filing Date:
14 July 2022 (14.07.2022)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
63/221,611 14 July 2021 (14.07.2021) US

(71) Applicant: **THE GOVERNING COUNCIL OF THE UNIVERSITY OF TORONTO** [CA/CA]; Banting Institute, 100 College Street, Suite 413, Toronto, Ontario M5G 1L5 (CA).

(72) Inventors; and
(71) Applicants: **TAIPALE, Mikko Joonas Oskari** [FI/CA]; 63 Rusholme Road, Toronto, Ontario M6J 3H3 (CA). **ALERASOOL, Nader** [CA/US]; 2823 18th St, Apt 629, San Francisco, California 94110 (US). **LENG, He** [CN/CA]; 530# 60 Saint Patrick Street, Toronto, Ontario M5T2X5 (CA).

(74) Agent: **BERESKIN & PARR LLP/S.E.N.C.R.L., S.R.L.**; 40 King Street West, 40th Floor, Toronto, Ontario M5H 3Y2 (CA).

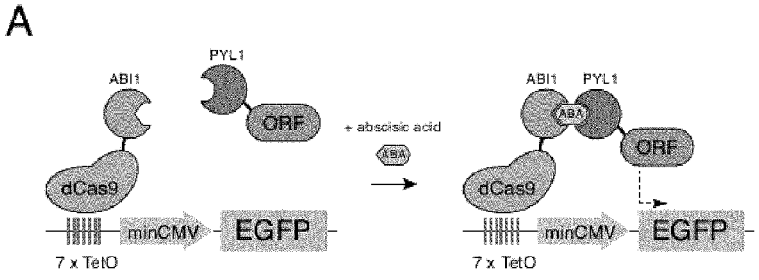
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*
— *with sequence listing part of description (Rule 5.2(a))*
— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

(54) **Title:** TRANS-ACTIVATORS AND METHODS AND USE THEREOF

Fig. 1



(57) **Abstract:** A heterologous transcriptional activator comprising a DNA targeting domain, preferably a catalytically inactive DNA targeting protein such as a CRISPR-Cas protein, and an effector domain comprising at least one transactivation domain described herein or an functional variant thereof. Also provided herein are expression constructs, vectors, and cells encoding or expressing said transcriptional activator, as well as systems and methods for transcriptional activation of a target gene, and compositions, kits and reagents employed in the making and use thereof.

WO 2023/000081 A1

TITLE: TRANS-ACTIVATORS AND METHODS AND USE THEREOF

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present disclosure claims the benefit of priority from U.S. patent application no. 63/221,611, filed on July 14, 2021, the contents of which is incorporated herein by reference in its entirety.

FIELD

[0002] The present disclosure relates to reagents and methods for transcriptional activation and in particular to the use of heterologous transactivator domains in transcriptional activators for targeted transcriptional activation.

INTRODUCTION

[0003] Transcription of protein-coding genes is orchestrated by a coordinated interplay of transcription factors (TFs) that bind DNA in a sequence-specific manner, RNA polymerase II machinery that initiates transcription from promoters, and diverse chromatin-associated factors and complexes that modulate chromatin structure and act as bridges between TFs and RNA pol II (Cramer, 2019). The human genome encodes thousands of proteins that are involved in various stages of transcriptional regulation, and the ready availability of methods such as ChIP-seq has revealed the genomic binding sites of hundreds of factors in diverse conditions (The ENCODE Project Consortium et al., 2020). At the same time, systematic studies have characterized or inferred the DNA-binding specificity of about three-quarters of human TFs (Badis et al., 2009; Jolma et al., 2013; Lambert et al., 2018; Najafabadi et al., 2015; Weirauch et al., 2014). Similarly, interaction proteomics approaches have uncovered many chromatin-associated proteins and characterized the composition of transcriptional regulatory complexes in human cells (Gao et al., 2012; Huttlin et al., 2020; Lambert et al., 2019; Li et al., 2015; Marcon et al., 2014; Mashtalir et al., 2018).

[0004] However, whether and how TFs and chromatin-associated factors promote transcriptional activation or repression (or regulate chromatin states by other means) has remained largely unknown due to the limited causal insights afforded by these methods. For example, the vast majority of genomic binding sites observed in ChIP-seq experiments are not causally associated with transcriptional events. That is, knockdown or knockout of a given transcriptional regulator does not affect the transcription of most genes that the regulator binds to. On the other hand, sequence-based annotation of transcriptional regulators has been challenging, because most transcriptional effector functions are encoded by degenerate linear

motifs rather than folded and conserved protein domains (Arnold et al., 2018; Erijman et al., 2020; Sigler, 1988; Staller et al., 2021).

[0005] Artificial recruitment, also known as activator bypass, is powerful method to characterize the transcriptional effect of diverse proteins in a defined context (Ptashne and Gann, 1997; Sadowski et al., 1988). In this approach, proteins or their fragments are ectopically recruited to a reporter gene by fusing the protein to the DNA-binding domain of a well-characterized TF such as Gal4 or TetR. The defined context alleviates the challenges posed by endogenous gene regulation, where multiple factors bind regulatory elements in concert, hindering causal inference. Artificial recruitment has been traditionally used to identify transcriptional activators or transactivation domains (TADs) in individual transcriptional regulators (Ptashne and Gann, 1997). However, recent studies have characterized the transcriptional effects of large collections of regulators in fruit flies or yeast by individually tethering them to reporter genes (Keung et al., 2014; Stampfel et al., 2015). Due to the limited scalability of the arrayed format, these studies focused on known regulators rather than potentially novel factors. Moreover, classical model organisms lack several regulatory mechanisms and layers critical for gene expression in mammals, such as enhancers (yeast) or DNA methylation (yeast and fruit flies). More recently, Tycko and colleagues implemented an unbiased pooled screening strategy to characterize the transcriptional activation potential of annotated human protein domains (Tycko et al., 2020). This study highlighted the value of unbiased approaches in identifying novel transcriptional regulators, such as the unexpected role of variant KRAB domains in transcriptional activation instead of repression. Yet, because most transcriptional activation domains are encoded by disordered regions (Arnold et al., 2018; Dyson and Wright, 2005), it is likely that a domain-focused screen misses a significant fraction of transactivators.

[0006] Thus, despite the increased knowledge of the composition of transcriptional regulator complexes and their genomic binding patterns, a complete understanding of the downstream effects elicited by TFs and diverse chromatin-associated factors is lacking.

SUMMARY

[0007] Described herein, the inventors have established a platform to systematically identify and characterize the transcriptional regulatory potential of human proteins in an unbiased manner. By screening over 13,000 proteins in a pooled format, several hundred potent activators were identified, many of which were previously poorly annotated. Transactivation domains were systematically uncovered among the hits, including some that do not adhere to the canonical “acidic blob” model of activation domains. Furthermore,

interaction proteomics were combined with chemical inhibitors to delineate the co-factor specificity of both novel and known transcriptional activators, highlighting how even highly related TFs with virtually identical DNA-binding specificities can activate transcription through distinct co-factor complexes.

[0008] The inventors describe herein the first systematic screen of transcriptional activators in human cells. Several hundred transcriptional activators were identified that were, as expected, enriched in sequence-specific transcription factors and other chromatin-associated proteins.

[0009] The results shown herein suggest that only a very limited number of TFs are strong transcriptional activators. This makes sense in the context of the known DNA-binding specificities and chromatin occupancies of human TFs (Jolma et al., 2013; The ENCODE Project Consortium et al., 2020; Yan et al., 2013). Most TFs recognize short (~6-10 bp) motifs and associate with thousands of sites across the genome. Yet, most binding events are not associated with transcriptional output. Strong transcriptional activation domains coupled to limited sequence specificity of the DNA-binding domain would lead to spurious activation of large swaths of genes, likely impeding cellular fitness. Many of the strongest activators identified herein were not DNA-binding transcription factors but other chromatin-associated proteins.

[0010] The discovery of novel and highly potent human transactivation domains has also therapeutic implications. Components derived from viral proteins, such as the VP16 transactivation domain or the tripartite VPR activator, can elicit immune responses *in vivo* and lead to adverse effects in the clinic. Designing synthetic transcriptional regulators from fully human components is expected to be advantageous in therapeutic applications (Israni et al., 2021). Furthermore, also shown herein, combining activation domains from multiple different human proteins can generate “superactivators” that are able to robustly upregulate genes even in highly compacted regions of the genome.

[0011] An aspect includes a heterologous transcriptional activator comprising:

a DNA targeting domain, optionally an enzymatically inactive CRISPR-CAS protein, a zinc finger DNA binding domain, a tet-repressor or transcriptional activator-like effector (TALE) DNA binding domain; and

an effector domain comprising:

at least one transactivation domain (TAD) selected from the TADs listed in any one of Tables 1 to 6, optionally Table 2 or Table 6, or a functional variant thereof, or

at least two TADs selected from the TADs listed in any one of Tables 1- 6, optionally Table 1 or Table 3, or functional variants of any thereof, preferably at least one TAD selected from the TADs listed in Table 4 or Table 5 or Table 6, or functional variants thereof,

wherein the DNA targeting domain and effector domain are operably linked.

[0012] An aspect includes an isolated nucleic acid encoding an effector domain described herein

[0013] An aspect includes an isolated nucleic acid encoding a heterologous transcriptional activator described herein.

[0014] An aspect includes an expression construct comprising a nucleic acid described herein operably linked to one or more promoters and one or more transcription termination sites.

[0015] An aspect includes a vector comprising a nucleic acid or expression construct described herein, optionally wherein the vector is an adenoviral or lentiviral vector.

[0016] An aspect includes a cell comprising a transcriptional activator, nucleic acid, expression construct, or vector described herein.

[0017] An aspect includes a transcriptional activation system comprising: a heterologous transcriptional activator described herein, wherein the DNA targeting domain comprises a CRISPR-Cas protein and at least one gRNA.

[0018] An aspect includes a method of activating transcription of a target gene in a cell, the method comprising: a) introducing into the cell a transcriptional activator, nucleic acid, expression construct, or vector described herein; and b) culturing the cell under suitable conditions such that the effector domain activates transcription of the target gene.

[0019] An aspect includes a screening method, the method comprising: a) introducing into a plurality of cells a transcriptional activator, one or more nucleic acids, one or more expression constructs, or one or more vectors described herein, wherein the DNA targeting domain comprises a CRISPR-Cas protein; and a plurality of gRNAs; or introducing a plurality of gRNAs into a population of cells described herein wherein the DNA targeting domain comprises a CRISPR-Cas protein; b) culturing the plurality of cells such that the one or more

gRNAs associate with the CRISPR-Cas protein and guides the transcriptional activator to a CRISPR target site such that the effector domain activates transcription of a target gene; c) optionally treating with an amount of a test drug or toxin; d) optionally culturing the plurality of cells for a period of time to allow for gRNA dropout or enrichment; and e) collecting the plurality of cells, or a subset thereof.

[0020] An aspect includes a composition comprising a transcriptional activator, nucleic acid, expression construct, vector, or cell described herein.

[0021] An aspect includes a kit comprising a vial and a heterologous transcriptional activator, nucleic acid, expression construct, vector, cell, or composition described herein and optionally one or more of: an inducing agent, a gRNA or a gRNA expression construct.

[0022] The preceding section is provided by way of example only and is not intended to be limiting on the scope of the present disclosure and appended claims. Additional objects and advantages associated with the compositions and methods of the present disclosure will be appreciated by one of ordinary skill in the art in light of the instant claims, description, and examples. For example, the various aspects and embodiments of the disclosure may be utilized in numerous combinations, all of which are expressly contemplated by the present description. These additional advantages objects and embodiments are expressly included within the scope of the present disclosure. The publications and other materials used herein to illuminate the background of the disclosure, and in particular cases, to provide additional details respecting the practice, are incorporated by reference, and for convenience are listed in the appended reference section.

DRAWINGS

[0023] Further objects, features and advantages of the disclosure will become apparent from the following detailed description taken in conjunction with the accompanying figures showing illustrative embodiments of the disclosure, in which:

[0024] Fig. 1 depicts the pooled ORFeome screen for transcriptional activators. **A,** shows a schematic of the chemically-induced dimerization system to characterize transcriptional activators in human cells. **B,** shows the percent of high GFP cells when the indicated constructs were transfected into HEK293T reporter cells and treated with abscisic acid or DMSO for 48 hours. **C,** Outline of the pooled ORFeome screen for transcriptional activators. **D,** Enrichment of high GFP cells in the pooled ORFeome screen after 48 hour ABA treatment. **E,** Enrichment of ORFs in the high GFP pool compared to the unsorted ORFeome. **F,** Enrichment of Gene Ontology categories among positive screen hits. **G,** Enrichment of

InterPro domains among positive screen hits. **H,** Enrichment of CORUM complexes among screen hits..

[0025] Fig. 2 shows transcriptional activity of transcription factor families. Transcriptional regulators were individually tested for activation of the reporter in an arrayed manner. DNA-binding specificity (shown as sequence logos) is from CisBP (Weirauch et al., 2014). Asterisks indicate statistically significant activators (FDR < 0.05). **A,** Homeobox family proteins **B,** Forkhead box proteins, **C,** Kruppel-like factors, **D,** SRY-related HMG-box (SOX) proteins, **E,** Polycomb-group RING Finger (PCGF) proteins. Composition of canonical (cPRC1) and non-canonical (ncPRC1) complexes is shown on the right. **F,** Spy1/RINGO family proteins. Statistical significance was calculated with unpaired two-tailed t-test assuming equal variance, and corrected for multiple hypotheses with False Discovery Rate (FDR) approach of Benjamini, Krieger and Yekutieli (Benjamini et al., 2006).

[0026] Fig. 3 shows systematic discovery of transactivation domains in human proteins with TAD-seq. **A,** Outline of the TAD-seq pooled assay. **B,** Examples of known transactivation domains. Domain organization is shown on top. TAD-seq plot shows the fold enrichment of RNAseq reads in the high GFP population or the medium GFP population. Each circle shows the mid-point (30th amino acid) of the 60-aa tile. Filled circles indicate statistically significant hits. Grey boxes indicate previously described transactivation domains. **C,** Examples of novel transactivation domains. Labeling is as in panel B. **D,** Location of the transactivation domain of HOXA2. **E,** Sequences of the activating fragments identified in HOXA2. Activating fragments are in bold. The region common to all three fragments that were enriched in the medium GFP population is indicated as overlap of activating fragments. The location of the antennapedia-like hexapeptide sequence is indicated as hexapeptide. **F,** Location of the transactivation domain in YAF2. **G,** Crystal structures of RING1B RAWUL domain bound to the YAF2_RYBP domain of RYBP (PDB 3IXS) and the CBX_C domain of CBX7 (PDB 3GS2). **H,** YAF2_RYBP domains and CBX_C domains from indicated proteins were individually tested for transcriptional activity. Asterisks indicate statistically significant activators (FDR < 0.05). Statistical significance was calculated with unpaired two-tailed t-test assuming equal variance, and corrected for multiple hypotheses with False Discovery Rate (FDR) approach of Benjamini, Krieger and Yekutieli (Benjamini et al., 2006). Right, *in vitro* affinity of the domains towards RING1B (Wang et al., 2008, 2010). Statistical significance was calculated with an unpaired two-tailed t-test.

[0027] Fig. 4. shows co-factor specificity of transcriptional activators. **A,** Proximity partners of indicated transcriptional regulators were identified with BioID2. Enrichment of

selected co-factor complexes is shown as a heat map. Average spectral counts (n+1) were normalized to background spectral counts (n+1) of EGFP and Nanoluc baits. **B,** Interaction patterns of activating Forkhead transcription factors based on the AP-MS study of (Li et al., 2015). Spectral counts were normalized as in panel A. **C,** Left, effect of p300/CBP inhibition by A-485 on the activity of 83 transcriptional regulators. Known p300 interactors are shown as solid dark circles, known NuA4 interactors as outlined circles. Right, p300 interactors are significantly more affected than other transcriptional regulators by A-485 treatment. Statistical significance was calculated with one-way ANOVA using Dunnett's multiple testing correction. **D,** Left, effect of BET bromodomain protein inhibition by JQ1 on the activity of 83 transcriptional regulators. Known p300 interactors are shown as solid dark circles, known NuA4 interactors as outlined circles. Right, p300 interactors are significantly more affected than other transcriptional regulators by A-485 treatment. Statistical significance was calculated with one-way ANOVA using Dunnett's multiple testing correction. **E,** Clustering of transcriptional activators based on their sensitivity on diverse inhibitors. Clustering was performed with Euclidian distance with average linkage. Clusters enriched in known CBP/p300 interactors (solid circles) and NuA4 interactors crosses are indicated.

[0028] Fig. 5 shows SRF-C3orf62 fusion generates a potent p300-dependent transcriptional activator that promotes expression of SRF/MRTF target genes. **A,** Schematic of the JAZF1-SUZ12 fusion found in low-grade endometrial stromal sarcomas. The transactivation domain identified by TAD-seq is indicated. **B,** Schematic of the SRF-C3orf62 fusion found in myofibroma/myopericytoma. The transactivation domain identified by TAD-seq is indicated. **C,** JAZF1, SUZ12 and JAZF1-SUZ12 proximity interactors were identified with BioID2. JAZF1-SUZ12 interacts with both PRC2 components and NuA4 components, generating a supercomplex. **D,** SRF, C3orf62, C3orf62-Cterm and SRF-C3orf62 proximity interactors were identified with BioID. SRF-C3orf62 fusion robustly interacts with CBP and p300. **E,** SRF-C3orf62 is a potent transcriptional activator. Indicated PYL1 fusions were individually tested for activation of the genomically integrated reporter. **F,** SRF-C3orf62 activates expression of serum response element reporter in the absence of cofactors. Indicated constructs C-terminally tagged with 3xFLAG-V5 were co-transfected into NIH3T3 cells with an SRE-Firefly luciferase reporter and a constitutive Nanoluc reporter. Relative luciferase activities were measured to assess the activity of each construct. **G,** NIH3T3 cells stably expressing doxycycline-inducible SRF-C3orf62-GFP or Nanoluc-GFP were treated with doxycycline for 46 hours, of which the last 22 hours in low-serum conditions (0.5% FCS). Gene expression patterns were analyzed by RNA-seq. Significantly upregulated (dark circles, top)

and downregulated (medium circles, bottom) genes (absolute log2 fold change > 1, FDR < 0.05). Well characterized targets of SRF/MRTF (top, labeled circles) and SRF/TCF (bottom, labeled circles) are indicated. **H**, Gene set enrichment analysis of SRF-C3orf62-GFP expressing cells compared to Nanoluc-GFP expressing cells..

[0029] Fig. 6 shows ORFeome screen for transcriptional activators. **A,** Distribution of sequencing reads across the ORFeome in pooled plasmid DNA and in infected cells. **B,** Distribution of ORF sizes in the plasmid pool and in infected cells. **C,** Transcriptional activity depends on abscisic acid treatment. ORFeome-PYL1 infected cells were treated with 100 µM ABA and the fraction of high GFP cells measured by flow cytometer over time. **D,** The effect of ABA concentration on transcriptional activity. Reporter cells transfected with the indicated constructs were treated with increasing amounts of ABA for 48 hours. **E,** No high GFP population is observed in ABA treated cells not expressing the ORFeome-PYL1 library. **F,** Enrichment of interaction hubs among the hits of the activation screen. **G,** Enrichment of yeast two-hybrid autoactivators among the hits of the activation screen. **H,** Individual validation of transcriptional activators identified in the activation screen. Indicated constructs were transfected into the reporter cell line and high GFP cell fraction was measured by flow cytometry after 48-hour treatment with ABA. Asterisks indicate statistically significant ABA-dependent increase in high GFP population (FDR < 5%). Statistical significance was calculated with unpaired two-tailed t-test assuming equal variance, and corrected for multiple hypotheses with False Discovery Rate (FDR) approach of Benjamini, Krieger and Yekutieli (Benjamini et al., 2006).

[0030] Fig. 7 shows transcriptional activity of transcription factor and chromatin-associated protein families. Transcriptional regulators were individually tested for activation of the reporter in an arrayed manner. DNA-binding specificity (shown as sequence logos) is from CisBP (Weirauch et al., 2014). Asterisks indicate statistically significant activators (FDR < 5%). Statistical significance was calculated with unpaired two-tailed t-test assuming equal variance, and corrected for multiple hypotheses with False Discovery Rate (FDR) approach of Benjamini, Krieger and Yekutieli (Benjamini et al., 2006). **A,** ETS family TFs **B,** Atonal-related bHLH factors, **C,** Myogenic factors, **D,** Twist/Hand bHLH factors, **E,** Casein kinases, **F,** Mediator components, **G,** Transcription factors identified in the primary activation screen are enriched for factors that can reprogram human iPS cells (right) or mouse ES cells (left) when ectopically expressed (Ng et al., 2021; Theodorou et al., 2009). Statistical significance was calculated with a Wilcoxon rank sum test (left) or Fisher's exact test (right).

[0031] Fig. 8 shows differential activity of transcription factors is not explained by expression levels. **A,** Schematic of the transcriptional activation assay measuring both reporter gene expression and effector protein expression. **B,** Transactivation of Kruppel-like factors (left) compared to the expression level of each factor as measured by RFP fluorescence (right). Background RFP intensity is shown as a dashed line. **C,** Forkhead TF activity. **D,** Homeodomain TF activity, **E,** SOX TF activity.

[0032] Fig. 9 shows TAD-seq identifies transactivation domains. **A,** High and medium GFP population was assessed by flow cytometry after recruiting 60aa fragments to the reporter with ABA for 48 hours. High GFP and medium GFP cells were sorted by FACS and ORFs enriched in the pools were identified by next-generationsequencing. **B,** Enrichment and depletion of amino acids among the identified transactivator fragments compared to inactive fragments in the library. Amino acids shown in bold were statistically significantly enriched or depleted. **C,** Enrichment of predicted transactivation domains among the active fragments. 9aaTADs were predicted with 9aaTAD prediction tool (https://www.med.muni.cz/9aaTAD/) using "Moderately Stringent Pattern". Only 100% confident matches were considered in the analysis. ADpred algorithm was described in (Erijman et al., 2020). Statistical significance was calculated with Fisher's exact test. **D,** Predicted TADs among active fragments are longer than those in inactive fragments. Statistical significance was calculated with two-tailed t-test assuming equal variance. **E,** Enrichment of fragments in the high GFP pool versus the medium GFP pool. Significant hits are shown as outlined circles. **F,** Individual validation of transactivating fragments. Indicated TADs were fused to PYL1 and transfected into the reporter cells in an arrayed format. Asterisks indicate statistically significant activators (FDR < 5%). Statistical significance was calculated with unpaired two-tailed t-test assuming equal variance, and corrected for multiple hypotheses with False Discovery Rate (FDR) approach of Benjamini, Krieger and Yekutieli (Benjamini et al., 2006).

[0033] Fig. 10 shows systematic discovery of transactivation domains in human proteins with TAD-seq. **A,** Examples of known transactivation domains. Domain organization is shown on top. TAD-seq plot shows the fold enrichment of RNAseq reads in the high GFP population (dark circles) or the medium GFP population (light circles). Each circle shows the mid-point (30th amino acid) of the 60-aa tile. Filled circles indicate statistically significant hits. Grey boxes indicate previously described transactivation domains. **B,** Examples of novel transactivation domains. Labeling is as in panel A.

[0034] Fig. 11 shows transactivation domains of SPDYE4 and YAF2. **A,** Alignment of five Spy1/RINGO family proteins: SPDYE4 (SEQ ID NO: 142); SPDYE1 (SEQ ID NO: 143);

SPDYE7P (SEQ ID NO: 144); SPDYE2 (SEQ ID NO: 145); and SPDYC (SEQ ID NO: 146). Four fragments screened by TAD-seq (SPDYE4-2 (SEQ ID NO: 154); SPDYE4-3 (SEQ ID NO: 90); SPDYE4-4 (SEQ ID NO: 91); and SPDYE4-5 (SEQ ID NO: 155)) are shown above the alignment, and active fragments are indicated in bold. Dashed box indicates the inferred minimal activating domain. Note that the region of the minimal activating domain is not conserved in SPDYC, which was the only Spy1/RINGO family member that did not activate transcription. **B,** Alignment of YAF2_RYBP domains of YAF2 (SEQ ID NO: 147) and RYBP (SEQ ID NO: 148), and CBX_C domains of CBX family proteins (SEQ ID NOs: 149-153). The location of the two beta sheets is indicated with arrows.

[0035] Fig. 12 shows interaction networks of transcriptional activators. **A,** BioID2 network of transcriptional activators. Bait proteins (e.g. FAM90A1, SPDYE4, SS18L2, SOX7, etc.) are shown as light grey rectangles. BAF complex members, p300/CBP, NuA4 complex members, Mediator components, and TFIID components are indicated. The width of the edges indicates average spectral counts of two replicates. For clarity, two highly connected prey proteins (ZNF518A and ZNF518B) were removed from this visualization **B,** AP-MS network of transcriptional activators. Labeling as in panel A. For clarity, nine highly connected prey proteins (APEH, ACTC1, ALDH1L1, PSDM4, LSS, FLII, PACSIN2, RPS3A, QPCTL) were removed from this visualization.

[0036] Fig. 13 shows the effect of small molecule inhibitors on the transcriptional activity of 83 transcriptional regulators. **A,** Effect of CDK9 inhibition by flavopiridol. Known p300 interactors are shown as solid dark circles, known NuA4 interactors as outlined circles. **B,** Effect of Casein kinase 2 inhibition by CX4945. Known p300 interactors are shown as solid dark circles, known NuA4 interactors as outlined circles. **C,** Effect of DYRK1A/DYRK1B inhibition by AZ191. Known p300 interactors are shown as solid dark circles, known NuA4 interactors as outlined circles. DYRK1A/DYRK1B interactor DCAF7, and DCAF7 interactor NCKISPD are highlighted. **D,** Effect of p300 inhibition by A-485 on transcriptional regulators characterized by AP-MS and BioID. Asterisks indicate statistically significant activators (FDR < 5%). Statistical significance was calculated with unpaired two-tailed t-test assuming equal variance, and corrected for multiple hypotheses with False Discovery Rate (FDR) approach of Benjamini, Krieger and Yekutieli (Benjamini et al., 2006). **E,** Effect of BET bromodomain inhibition by JQ1 on transcriptional regulators characterized by AP-MS and BioID. Asterisks indicate statistically significant activators (FDR < 5%). Statistical significance was calculated with unpaired two-tailed t-test assuming equal variance, and corrected for multiple hypotheses

with False Discovery Rate (FDR) approach of Benjamini, Krieger and Yekutieli (Benjamini et al., 2006).

[0037] Fig. 14 shows transcriptional activation by SRF-C3orf62. **A,** SRF, C3orf62, C3orf62-Cterm and SRF-C3orf62 interactors were characterized with AP-MS. SRF-C3orf62 fusion robustly interacts with CBP and p300. **B,** Analysis of differentially expressed genes in NIH3T3 cells expressing SRF-GFP, C3orf62-GFP, or SRF-C3orf62-GFP compared to cells expressing Nanoluc-GFP. **C,** Gene Ontology enrichment analysis of significantly upregulated and downregulated genes in NIH3T3 cells expressing SRF-C3orf62-GFP. **D,** Overlap of genes significantly upregulatedy by SRF-C3orf62-GFP and target genes of SRF/MRTF or SRF/TCF, published previously (Esnault et al., 2014; Gualdrini et al., 2016). Statistical significance was calculated with a hypergeometric distribution test.

[0038] Fig. 15 shows the effect of the minimal activating sequence for each individual component of SPDYE4-CITED1-P65-HSF1 fusion on transcriptional activity of an a EGFP reporter. All components were fused to PYL1 dimerization domain and recruited to the reporter with addition of 1μM abscisic acid (ABA) for 48 hours. Sequence of each fusion is shown in SEQ ID NOs: 121, 123, 127, 129, 131, 133, and 135. Sequences of each of the individual domains tested are provided in SEQ ID NOs: 47, 90, 101-104, 116, and 118.

[0039] Fig. 16 shows examples of when fusing two or more transactivation domains and targeting them to the same reporter. Addition of SPDYE4 activation domain showed a marked improvement to activity of CITED1 domain alone. This is in contrast to SPDYE4's weak activity when tethered to the reporter on its own, suggesting synergistic activity when fused to CITED1 activation domain. All fusion constructs indicate activation domains and not full-length proteins, except for "full length CITED1/2", as indicated, which were tested to compare activity with their corresponding transactivation domains. P300core is the catalytic domain EP300 (amino acids 1048-1664). Reporter cells were treated with 1μM abscisic acid (ABA) or same volume of DMSO for 48 hours before collection for flow cytometry. Error bars represent S.D. from four replicates.

[0040] Fig. 17 shows activity of tethering different combinations and orientations of activation domains from human SPDYE4, CITED1, p65, and HSF1 proteins to an EGFP reporter (left) or promoter of *CD133* gene in HEK293T cells. Recruitment was induced by addition of 1 μM abscisic acid (ABA) for either 24 or 48 hours before cells were collected.

[0041] Fig. 18 shows the effect of replacing each part of the multi-component SPDYE4-CITED1-P65-HSF1 (SCPH) activator with different activation domains. SPDYE4

activation domain appeared the most indispensable as replacing it with other individually stronger activation domains disrupted activity of the SPCH activator. On the other hand, replacing the CITED1 component with other strong human transactivation domains from our screen had no deleterious effect on activity and even seemed to improve its potency with ZXDC and C3orf62 activation domains. All constructs were tethered to the EGFP reporter by addition of 1 μM abscisic acid for 48 hours.

[0042] Fig. 19 shows the effect of 117 different effector domains comprising different combinations of transactivation domains, or fragments thereof, when used in combination with rTetR or dCas9 based recruitment systems. **A**, Transcriptional activation using the 117 effector domains in combination with a rTetR DNA targeting domain. **B**, Transcriptional activation using the 117 effector domains in combination with a dCas9 DNA targeting domain. **C**, Correlation of transcriptional activation between the rTetR and dCas9 based recruitment systems.

DESCRIPTION OF VARIOUS EMBODIMENTS

[0043] The following is a detailed description provided to aid those skilled in the art in practicing the present disclosure. Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. The terminology used in the description herein is for describing particular embodiments only and is not intended to be limiting of the disclosure. All publications, patent applications, patents, figures and other references mentioned herein are expressly incorporated by reference in their entirety.

I. Definitions

[0044] As used herein, the following terms may have meanings ascribed to them below, unless specified otherwise. However, it should be understood that other meanings that are known or understood by those having ordinary skill in the art are also possible, and within the scope of the present disclosure. All publications, patent applications, patents, and other references mentioned herein are incorporated by reference in their entirety. In the case of conflict, the present specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting.

[0045] The terms “nucleic acid”, “oligonucleotide”, “primer” as used herein means two or more covalently linked nucleotides. Unless the context clearly indicates otherwise, the term generally includes, but is not limited to, deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), which may be single-stranded (ss) or double stranded (ds). For example, the nucleic acid molecules or polynucleotides of the disclosure can be composed of single- and double-

stranded DNA, DNA that is a mixture of single- and double-stranded regions, single- and double-stranded RNA, and RNA that is a mixture of single- and double-stranded regions, hybrid molecules comprising DNA and RNA that may be single-stranded or, more typically double-stranded or a mixture of single- and double-stranded regions. In addition, the nucleic acid molecules can be composed of triple-stranded regions comprising RNA or DNA or both RNA and DNA. The term “oligonucleotide” as used herein generally refers to nucleic acids up to 200 base pairs in length and may be single-stranded or double-stranded. The sequences provided herein may be DNA sequences or RNA sequences, however it is to be understood that the provided sequences encompass both DNA and RNA, as well as the complementary RNA and DNA sequences, unless the context clearly indicates otherwise. For example, the sequence 5’-GAATCC-3’, is understood to include 5’-GAAUCC-3’, 5’-GGATTC-3’, and 5’GGAUUC-3’.

[0046] The term “functional variant” as used herein includes modifications of the polypeptide sequences disclosed herein that perform substantially the same function as the polypeptide molecules disclosed herein in substantially the same way. For example, functional variants may include active fragments of the polypeptides described herein, for example an N- and/or C-terminal truncation which retains transcriptional activation activity and/or co-activator interaction. Functional variants may include variants having one or more substituted amino acids and/or which retain at least a minimal sequence identity to the unmodified or non-variant sequence. For example, the functional variant may comprise substitutions of up to 1, 2, 3, or more amino acids for every ten amino acids. For example, the functional variant may comprise sequences having at least 80%, or at least 90%, or at least 95% sequence identity to the sequences disclosed herein. The functional variant may also comprise conservatively substituted amino acid sequences of the sequences disclosed herein. Substitutional amino acid variants are those in which at least one residue in the sequence has been removed and a different residue inserted in its place. An example of substitutional amino acid variants are conservative amino acid substitutions. Functional variants such as active fragments including minimal fragments which can for example be identified as described herein which retain transcriptional activation activity and/or co-activator interaction can be identified for example using the methods described herein.

[0047] A "conservative amino acid substitution" as used herein, is one in which one amino acid residue is replaced with another amino acid residue without abolishing the protein's desired properties. Suitable conservative amino acid substitutions can be made by substituting amino acids with similar hydrophobicity, polarity, and R-chain length for one another.

Examples of conservative substitutions include the substitution of one non-polar (hydrophobic) residue such as alanine, isoleucine, valine, leucine or methionine for another, the substitution of one polar (hydrophilic) residue for another such as between arginine and lysine, between glutamine and asparagine, between glycine and serine, the substitution of one basic residue such as lysine, arginine or histidine for another, or the substitution of one acidic residue, such as aspartic acid or glutamic acid for another. The phrase "conservative substitution" also includes the use of a chemically derivatized residue or non-natural amino acid in place of a non-derivatized residue provided that such polypeptide displays the requisite activity.

[0048] The term "heterologous transcriptional activator" or "transcriptional activator described herein" as used herein means an engineered fusion protein or engineered dimer comprising: an effector domain comprising at least one transactivation domain (TAD) selected from the TADs listed in Table 2 and functional variants thereof, or at least two TADS selected from the TADs listed in Table 1, Table 2, Table 3, Table 4, Table 5, and/or Table 6 and functional variants of any one thereof, operably linked to a DNA targeting domain.

[0049] The term "operably linked" as used herein refers to a relationship between two components that allows them to function in an intended manner. For example, a first polypeptide may be operably linked to a second polypeptide by covalent linkage (e.g. as a fusion protein), or through one or more interaction components. Similarly, where a reporter gene is operably linked to a promoter, the promoter actuates expression of the reporter gene.

[0050] The transcriptional activator may further comprise one or more interaction components of an interaction system, which provides a functional interaction between the effector domain and/or DNA targeting domain and/or target DNA. The term "interaction component" is used herein to encompass one or more components of an interaction system, which together provide said functional interaction. The term "interaction system" as used herein is intended to encompass interaction components that permit covalent or non-covalent interactions, and/or constitutive or inducible interactions. Such interaction systems may include for example a peptide linker, optionally a protease-sensitive peptide linker; one or more dimer, trimer, or higher order multimerization components such as an interaction domain, optionally inducible dimer, trimer, or multimerization components, optionally an inducible interaction domain; and/or one or more components which can modulate subcellular localization of the transcriptional activator. The interaction system can comprise two or more components.

[0051] The DNA targeting domain and the effector domain may be covalently linked, for example as domains of a single polypeptide (e.g. fusion protein), or may be linked by an interaction component such as an interaction domain for example, that interact under certain conditions (e.g. as a dimer). Accordingly, the heterologous transcriptional activator may comprise a single polypeptide, or may comprise a first polypeptide comprising a DNA targeting domain and a first interaction component such as a dimer interaction domain, and a second polypeptide comprising an effector domain and a second interaction component such as a dimer interaction domain, wherein the first and second dimer interaction domain can interact, for example under certain conditions. Higher-order multimerization systems, such as the SunTag system (Tenenbaum et al., 2014), are also contemplated herein.

[0052] The interaction between the effector domain and/or DNA targeting domain and/or target DNA can be controlled using a variety of inducible interaction systems. For example, the effector domain and DNA targeting domain may be linked by a protease-sensitive linker such as a self-cleaving NS3 protease domain, which is stabilized in the presence of an NS3 inhibitor such as grazoprevir. In another example, localization of the DNA targeting domain and/or effector domain to the nucleus can be controlled by an interaction component such as a localization domain, for example tamoxifen-regulated nuclear localization using estrogen receptor ligand binding domain variants. In a further example, the DNA targeting domain can be linked to a first interaction component such as a first interaction domain and the effector domain can be linked to a second interaction component such as a second interaction domain, such that the first and second interaction domain interact.

[0053] As used herein, the term “interaction domain” means a sequence motif in a first polypeptide (e.g. first dimer interaction domain), that is capable of interacting with a binding partner comprising a sequence motif in a second polypeptide (e.g. second dimer interaction domain) to operably link the first polypeptide and second polypeptide. In particular, the term is intended to encompass a first or second interaction dimer domain which together form a heterodimer pair that dimerizes for example under suitable inducing conditions. Other interaction domains are specifically contemplated and can be identified by the skilled person depending on the desired characteristics. Suitable inducible interaction domain pairs include, without limitation: FKBP/FRB (FK506 binding protein/FKBP rapamycin binding), which can be induced with e.g. rapamycin or AP21967; PYL/ABI which can be induced e.g. with abscisic acid; GID1/GAI, which can be induced with e.g. gibberellin or gibberellic acid; and pMag/nMag, which can be induced by e.g. blue light and/or temperature.

[0054] As used herein, “DNA targeting domain” refers to a polypeptide domain which binds DNA under DNA binding conditions, thereby targeting the polypeptide to said DNA. The DNA targeting domain can be any suitable DNA binding domain, for example an enzymatically inactive sequence-specific DNA targeting protein such as a CRISPR-Cas protein, (e.g. dCas9, dCas12, or other Cas-family proteins), a zinc-finger DNA binding domain, a transcriptional activator-like effector (TALE) DNA binding domain, bromodomains, chromodomains, Tudor domains, WD40 domains, PHD domains, PWWP domains, or other DNA-binding domains (DBDs) from eukaryotes or prokaryotes (e.g. Forkhead, basic helix-loop-helix, leucine zipper, homeodomain, nuclear hormone receptor, or a tet-repressor), or variants thereof. The DNA targeting domain may bind DNA in a sequence specific manner (e.g. Cas-family proteins, zinc-finger DNA binding domains, TALE DNA binding domains) or may bind to specific chromatin modifications (e.g. bromodomains (for acetylated histones) or chromodomains, Tudor domains, WD40 domains, PHD domains, PWWP domains etc. (for methylated histones). The DNA targeting domain may be a natural (e.g. non-engineered) DNA binding domain, such as for example a DNA binding domain found in a naturally occurring (e.g. endogenous) transcription factor, or the DNA targeting domain may be engineered for example to provide custom sequence specificity (e.g. sequence specificity that differs from the non-engineered DNA binding domain) or altered DNA binding affinity. Methods of engineering for example zinc finger DNA binding domains and TALE DNA binding domains to provide custom DNA binding specificity are known in the art, for example in Maeder et al. 2008 and Sanjana et al. 2012. Enzymatically active Cas9 can also be used when it would lead to repression, for example when the guide is a truncated guide (see for example [24]). The DNA targeting domain may have inherent target sequence specificity, for example in the case of zinc-finger DNA binding domains and TALE DNA binding domains, or target sequence specificity may be mediated by additional sequence-specific factors such as e.g. a guide RNA in the case of CRISPR-Cas proteins. Suitable DNA binding conditions depend on the DNA targeting domain and may include for example the presence of additional factors, such as for example tetracycline in the case in the case of tet-repressors, or a guide RNA in the case of Cas-family proteins.

[0055] The term “effector domain” as used herein refers to a polypeptide domain comprising at least one transactivation domain (TAD) described herein, for example the TADs listed in Tables 1-5 and functional variants thereof such as active fragments thereof. Optionally the effector domain may comprise two or more, for example two, three, four, or more transactivation domains described herein. In the activators described herein, the active fragment can be about 15 amino acids, about 20 amino acids, about 30 amino acids, about

40 amino acids, about 50 amino acids, about 60 amino acids, about 70 amino acids, or any number between 15 and 70 amino acids, or more than 70 amino acids. For example, for HSF1, the active fragment may comprise GFSVDTSALLDLFSP (SEQ ID NO: 104) which corresponds to amino acids 406 to 420 of HSF1. Accordingly, by way of example, the active fragment of HSF1 may comprise amino acids 401 to 427 of HSF1. Active fragments of other TADs can be identified by any suitable methods, for example using the methods described herein.

[0056] The heterologous transcriptional activator can be an effector N-terminal or a C terminal fusion, for example the order of the fusion can be effector domain – DNA targeting domain or DNA targeting domain – effector domain (see for example [25], [26], [27] and [28]). The effector domain can be fused to the DNA targeting domain by way of a linker. Similarly, two or more TADs may be fused together by way of one or more linkers. For example, glycine and glycine serine linkers can be used. Transcriptional activators described in the Examples used a variety of glycine serine linkers for example SGGSGGS (SEQ ID NO: 6), GGS, SGGS (SEQ ID NO: 7), and/or GSGSGS (SEQ ID NO: 8). Other linkers can also be used for example INSRSSGS (SEQ ID NO: 9).

[0057] The terms “CRISPR-Cas” or “Cas” as used herein refer to a CRISPR Clustered Regularly Interspaced Short Palindromic Repeats-CRISPR associated (CRISPR-Cas) protein that binds RNA and is targeted to a specific DNA sequence by the RNA to which it is bound. The CRISPR-Cas is a class II monomeric Cas protein for example a type II Cas such as Cas9. The Cas9 protein may be Cas9 from *Streptococcus pyogenes, Francisella novicida, A. Naesulndii*, *Staphylococcus aureus* or *Neisseria meningitidis*. Optionally the Cas9 is from *S. pyogenes*. The Cas protein can also be Cas12a (e.g. dCas12a) for example from Acidaminococcus sp., *Lachnospiraceae bacterium, or Francisella tularensis* (these have been shown to work as dCas variants), CasΦ (Cas12j) and CasX (Cas12e) may also be used.

[0058] As used herein, the term “dCas9” refers to an enzymatically inactive (or dead) Cas9, which lacks DNA endonuclease activity but retains target DNA binding activity. For example, the dCAS9 comprises the sequence of CAS9 and D10A/H840A mutations in the RuvC1 and HNH nuclease domains. Optionally the dCas9 is a protein comprising an amino acid sequence with at least 80%, at least 90%, at least 95%, at least 99% or 100% sequence identity to a protein encoded by SEQ ID NO: 1 and comprising D10A/H840A mutations and retaining Cas9 target DNA binding activity (e.g. binding the gRNA and the target site). Similarly dCas12a refers to an enzymatically inactive Cas12a.

[0059] The terms “guide RNA,” “guide,” or “gRNA” as used herein refer to an RNA molecule that hybridizes with a specific DNA sequence and minimally comprises a spacer sequence. The guide RNA may further comprise a protein binding segment that binds a CRISPR-Cas protein. The portion of the guide RNA that hybridizes with a specific DNA sequence is referred to herein as the nucleic acid-targeting sequence, or spacer sequence. The protein binding segment of the guide may comprise for example a tracrRNA and/or a direct repeat. The term “guide” or “guide RNA” may refer to a spacer sequence alone, or an RNA molecule comprising a spacer sequence and a protein binding segment, according to the context. The guide RNA can be represented by the corresponding DNA sequence. The guide can be a truncated guide, for example comprising 15 or fewer nucleotides of complementarity to a target site as described in [24] when the enzyme is Cas9. For example, when Cas9 interacts with a truncated guide, Cas9’s DNA binding capability remains intact while its nucleolytic activity is eliminated. Any length of guide that maintains Cas binding capability can be used.

[0060] The term “spacer” or “spacer sequence” as used herein refers to the portion of the guide that forms, or is capable of forming, an RNA-DNA duplex with the target sequence or a portion thereof. The spacer sequence may be complementary or correspond to a specific CRISPR target sequence. The nucleotide sequence of the spacer sequence may determine the CRISPR target sequence and may be designed or configured to target a desired CRISPR target site.

[0061] The term “tracrRNA” as used herein refers to a “trans-encoded crRNA” which may, for example, interact with a CRISPR-Cas protein such as Cas9 and may be connected to, or form part of, a guide RNA. The tracrRNA may be a tracrRNA from for example *S. pyogenes*. A tracrRNA may have for example the sequence of 5’-gtttcagagctatgctggaaacagcatagcaagttgaaataaggctagtccgttatcaacttgaaaaagtggcaccgagtcggtgc-3’ (SEQ ID NO: 2). Other tracrRNAs may also be used. Suitable tracrRNAs can be identified by a person skilled in the art, including for example 5’-GTTTTAGAGCTAGAAATAGCAAGTTAAAATAAGGCTAGTCCGTTATCAACTTGAAAAAGTGGCACCGAGTCGGTGC-3’ (SEQ ID NO: 3) or 5’-GTTTCAGAGCTACAGCAGAAATGCTGTAGCAAGTTGAAAT-3’ (SEQ ID NO: 4).

[0062] The terms “CRISPR target site” or “CRISPR-Cas target site” as used herein mean a nucleic acid to which an activated CRISPR-Cas protein (e.g. a CRISPR-Cas protein such as dCas9 bound to a guide RNA) will bind under suitable conditions. A CRISPR target site comprises a protospacer-adjacent motif (PAM) and a CRISPR target sequence (i.e.

corresponding to the spacer sequence of the guide to which the activated CRISPR-Cas protein is bound). The sequence and relative position of the PAM with respect to the CRISPR target sequence will depend on the type of CRISPR-Cas protein. For example, the CRISPR target site of Cas9 or dCas9 may comprise, from 5' to 3', a 15 to 25, 16 to 24, 17 to 23, 18 to 22, or 19 to 21 nucleotide, optionally a 20 nucleotide target sequence followed by a 3 nucleotide PAM having the sequence NGG. Accordingly, a Cas9 target site may have the sequence 5'-N_1NGG-3', where N_1 is 15 to 25, 16 to 24, 17 to 23, 18 to 22, or 19 to 21 nucleotides in length, optionally 20 nucleotides in length.

[0063] The CRISPR target site can be in any suitable genomic locus. For example, the CRISPR target site can be in a promoter, enhancer, 3'UTR, or other regulatory element, in a gene, optionally an intron or exon, in a locus corresponding to a non-coding RNA, or in an intergenic region. Optionally, the CRISPR target site is in a promoter or an enhancer.

[0064] Target DNA located in the nucleus of a cell requires a transcriptional activator that can enter the nucleus. Accordingly, the transcriptional activator may be nuclear-localized and/or may comprise for example one or more nuclear localization signals (NLS), optionally one or more SV40 NLSs. Optionally the transcriptional activator comprises two or more NLSs. Optionally the transcriptional activator may comprise one or more N-terminal NLSs, one or more C-terminal NLSs, one or more internal NLSs, or one or more N-terminal, one or more C-terminal NLSs, and/or one or more internal NLSs. Other configurations are specifically contemplated. In an embodiment, the NLS is an SV40 NLS having the sequence PKKKRKV (SEQ ID NO: 22). In an embodiment, the NLS further comprises an N- and/or C-terminal linker such as INSRSSGS (SEQ ID NO: 9), and optionally has the sequence INSRSSGSPKKKRKVGS (SEQ ID NO: 141).

[0065] The transcriptional activator can also be labelled with a tag. For example, suitable tags include but are not limited to Myc, FLAG, HA, V5, ALFA, T7, 6xHis, VSV-G, S-tag, AviTag, StrepTag II, CBP, GFP, mCherry. The label can be fused at the N-terminus, the C-terminus or between two components of the heterologous transcriptional activator such as between the DNA targeting domain and the effector domain.

[0066] Where a range of values is provided, it is understood that each intervening value, to the tenth of the unit of the lower limit unless the context clearly dictates otherwise, between the upper and lower limit of that range and any other stated or intervening value in that stated range is encompassed within the description. Ranges from any lower limit to any upper limit are contemplated. The upper and lower limits of these smaller ranges which may

independently be included in the smaller ranges is also encompassed within the description, subject to any specifically excluded limit in the stated range. Where the stated range includes one or both of the limits, ranges excluding either both of those included limits are also included in the description.

[0067] It must be noted that as used herein and in the appended claims, the singular forms "a", "an", and "the" include plural references unless the context clearly dictates otherwise.

[0068] All numerical values within the detailed description and the claims herein are modified by “about” or “approximately” the indicated value, and take into account experimental error and variations that would be expected by a person having ordinary skill in the art.

[0069] The phrase "and/or," as used herein in the specification and in the claims, should be understood to mean "either or both" of the elements so conjoined, i.e., elements that are conjunctively present in some cases and disjunctively present in other cases. Multiple elements listed with "and/or" should be construed in the same fashion, i.e., "one or more" of the elements so conjoined. Other elements may optionally be present other than the elements specifically identified by the "and/or" clause, whether related or unrelated to those elements specifically identified.

[0070] As used herein in the specification and in the claims, "or" should be understood to have the same meaning as "and/or" as defined above. For example, when separating items in a list, "or" or "and/or" shall be interpreted as being inclusive, i.e., the inclusion of at least one, but also including more than one, of a number or list of elements, and, optionally, additional unlisted items. Only terms clearly indicated to the contrary, such as "only one of' or "exactly one of" or, when used in the claims, "consisting of" will refer to the inclusion of exactly one element of a number or list of elements. In general, the term "or" as used herein shall only be interpreted as indicating exclusive alternatives (i.e., "one or the other but not both") when preceded by terms of exclusivity, such as "either," "one of," "only one of," or "exactly one of."

[0071] In the claims, as well as in the specification above, all transitional phrases such as "comprising," "including," "carrying," "having," "containing," "involving," "holding," "composed of," and the like are to be understood to be open-ended, i.e., to mean including but not limited to. Only the transitional phrases "consisting of” and "consisting essentially of” shall be closed or semi-closed transitional phrases, respectively

[0072] As used herein in the specification and in the claims, the phrase "at least one," in reference to a list of one or more elements, should be understood to mean at least one

element selected from any one or more of the elements in the list of elements, but not necessarily including at least one of each and every element specifically listed within the list of elements and not excluding any combinations of elements in the list of elements. This definition also allows that elements may optionally be present other than the elements specifically identified within the list of elements to which the phrase "at least one" refers, whether related or unrelated to those elements specifically identified.

[0073] Similarly, it is specifically contemplated herein that the phrase “one or more” in reference to a group of elements includes at least one member of the stated group but not necessarily including one of each of the members of the stated group. For example, where an element comprises one or more of group members A, B, and/or C, the element may comprise A; B; C; A and B; A and C; B and C; or A, B, and C. Additional members not specifically listed in the group may also be present, for example with reference to the example above, the element may additionally comprise unlisted member D, and accordingly may comprise A and D; B and D; A, C and D; etc.

[0074] The term “about” as used herein means plus or minus 10%-15%, 5-10%, or optionally about 5% of the number to which reference is being made.

[0075] It should also be understood that, in certain methods described herein that include more than one step or act, the order of the steps or acts of the method is not necessarily limited to the order in which the steps or acts of the method are recited unless the context indicates otherwise. Further, the definitions and embodiments described in particular sections are intended to be applicable to other embodiments herein described for which they are suitable as would be understood by a person skilled in the art. For example, in the following passages, different aspects of the disclosure are defined in more detail. Each aspect so defined may be combined with any other aspect or aspects unless clearly indicated to the contrary. In particular, any feature described herein may be combined with any other feature or features described herein.

[0076] Although any materials and methods similar or equivalent to those described herein can also be used in the practice or testing of the present disclosure, the following materials and methods are now described.

II. Materials and Methods

[0077] Described herein is a collection of heterologous transcriptional activators, comprising one or more transactivation domains (TADs), and combinations thereof (“effector domains”) that can be operably linked to a DNA targeting domain to generate a heterologous

transcriptional activator, and which can be used to activate gene expression of a desired gene, including an endogenous gene, for example for therapeutic purposes. In the heterologous transcriptional activators described herein, effector domains are operably linked to a DNA-targeting domain that can direct binding of the fusion construct to any locus in the genome. As demonstrated in the Examples, heterologous transcriptional activators comprising dCas9 or rTetR functionally associated with an effector domain comprising any one of the TADs listed in Table 1, active fragments thereof, for example those of SEQ ID NOs: 100-104, 107-115, 118-119, 156-160, 162, 164, and 166-185, and combinations of two or more of the TADs or active fragments thereof, for example as listed in Table 3, can be used to activate transcription of a target gene. The TAD or active fragment thereof may additionally comprise a linker and/or additional natural sequence e.g. 1, 2, 3, 4, 5, 6, 7 or more, for example up to 5, up to 10, up to 20, up to 30, or up to 40 (or any number in between), N- and/or C-terminal amino acids on the end of the TAD or active fragment. For example, the TAD labeled "ZXDC short" in Table 3 (SEQ ID NO: 107) comprises a 40 amino acid fragment found in both ZXDC-12 and 13 and comprises an additional 6 N-terminal amino acids of ZXDC-12 natural sequence and an additional 5 C-terminal amino acids of ZXDC-13 natural sequence. In an embodiment, the active fragment may be shorter than a fragment identified. For example, the active fragment may be 20 amino acids, or 25 amino acids of the 40 amino acid fragment found in for example both ZXDC-12 and ZXDC-13, optionally for example an internal portion of SEQ ID NO: 107. Shorter active fragments are exemplified for example by SEQ ID NO: 119 which comprises a 20 amino acid fragment found in both HSF1-20 and HSF1-21. Active fragments can be identified as described elsewhere herein. For example, the minimal fragment can be identified by comparing active fragments, for example for ATF6, the overlapping fragment shown in Table 5 is HRLDEDWDSALFAELGYFTDTDELQLEAANETYENNFDNL and for KLF7 the overlapping fragment is YFSALPSLEETWQQTCLELERYLQTEPRRISETFGEDLDC.

[0078] Accordingly, one aspect of the disclosure includes a heterologous transcriptional activator comprising a DNA targeting domain, and an effector domain comprising at least one TAD selected from the group consisting of any one of the TADs listed in any one of Tables 1-6, optionally Table 1 or optionally Table 2 or Table 6, active fragments thereof, and combinations thereof for example at least two TADs selected from the TADs listed in Table 1 or Table 3, or functional variants thereof, preferably at least one TAD selected from the TADs listed in Table 4, or Table 5 or Table 6, and/or functional variants thereof, wherein the DNA targeting domain and effector domain are operably linked.

[0079] In an embodiment, the at least one TAD is selected from Table 1.

[0080] In an embodiment, the at least one TAD is selected from Table 2.

[0081] In an embodiment, the at least one TAD is selected from Table 3.

[0082] In an embodiment, the at least one TAD is selected from Table 4.

[0083] In an embodiment, the at least one TAD is selected from Table 5.

[0084] In an embodiment, the at least one TAD is selected from Table 6.

[0085] It is understood that the at least two TADs or functional variants thereof can be selected from any Table, for example one from each of Table 3 and Table 4, two or more, for example 3 or 4, from Table 3 etc. It is also contemplated that the grouping can include any sub-combination of the TADS described in any of Tables 1 – 6, for example one or more TADs may be excluded.

[0086] The DNA targeting domain and the effector domain may be operably linked by covalent linkage, for example as domains of a single polypeptide, and/or may be operably linked via one or more interaction components such as interaction domains and/or interact under certain conditions. Accordingly, in one embodiment, the heterologous transcriptional activator is a single polypeptide. In another embodiment, the heterologous transcriptional activator further comprises a pair of (i.e. a first and a second) interaction domains, optionally dimer interaction domains, optionally a pair of inducible dimer interaction domains that dimerize under suitable conditions. For example, the heterologous transcriptional activator may comprise a first polypeptide comprising a DNA targeting domain and a first dimer interaction domain, optionally an inducible dimerization domain, and a second polypeptide comprising an effector domain and a second dimer interaction domain, optionally an inducible dimerization domain, wherein the first dimer interaction domain and second dimer interaction domain interact, optionally the first inducible dimerization domain and second inducible dimerization domain interact in the presence of one or more inducing agents.

[0087] As shown in the Examples, the dimerization of a heterologous transcriptional activator comprising ABI1 and PYL1 may be induced with the addition of abscisic acid. Accordingly, in an embodiment, the transcriptional activator comprises a first and second inducible dimerization domain that provide for inducible transcriptional activation in the presence of an inducing agent. The skilled person can readily identify and select suitable inducible dimerization domains that may be used together. Any suitable inducible dimerization domains may be used, for example the dimerization of ABI1 and PYL1 may be induced with the addition of abscisic acid. Other inducible systems include those based on induction with rapamycin, gibberellic acid/gibberellin, and split dCas9-based systems. For example,

dimerization of GID1 and GAI can be induced by gibberellin, and dimerization of FKBP and FRB can be induced with rapamycin or its analogs, e.g., rapalogs. Higher-order multimerization systems, such as the SunTag system (Tenenbaum et al., 2014) are also contemplated herein.

[0088] Interaction between the DNA targeting domain and effector domain can also be controlled using other inducible systems. Other systems (that are not dependent on dimerization) include grazoprevir-induced stabilization (Tague et al. 2018) or tamoxifen-regulated nuclear localization using estrogen receptor ligand binding domain variants. In the case of grazoprevir-induced stabilization, the DNA targeting domain and effector domain would be linked by a self-cleaving NS3 protease domain. Only in the presence of grazoprevir (which inhibits NS3 activity), DNA targeting domain and effector domain would stay together and regulate gene expression.

[0089] The DNA targeting domain can be selected from a variety of DNA binding domains, for example a zinc finger DNA binding domain, transcriptional activator-like effector (TALE) DNA binding domain, dCas9, dCas12 or other Cas-family proteins, or other DNA-binding domains (DBDs) from eukaryotes or prokaryotes (e.g. Forkhead, basic helix-loop-helix, leucine zipper, homeodomain, nuclear hormone receptor, or a tet-repressor), or variants thereof. The DNA targeting domain may be a natural (e.g. non-engineered) DNA binding domain, such as for example a DNA binding domain found in a naturally occurring (e.g. endogenous) transcription factor, or the DNA targeting domain may be engineered for example to provide custom sequence specificity (e.g. sequence specificity that differs from the non-engineered DNA binding domain) or altered DNA binding affinity. Methods of engineering for example zinc finger DNA binding domains and TALE DNA binding domains to provide custom DNA binding specificity are known in the art, for example in Maeder et al. 2008 and Sanjana et al. 2012. In the case where a heterologous transcriptional activator described herein comprises a DNA targeting domain comprising a natural DNA-binding domain, the effector domain would be targeted to all loci that the transcription factor endogenously binds to, thereby augmenting/replacing the function of the endogenous transcription factor. For example, it is known that replacing Oct4 transactivation domain with VP16 increases the efficiency of reprogramming fibroblasts to iPS cells. Similarly, a heterologous transcriptional activator comprising a natural DNA binding domain operably linked to an effector domain could promote e.g., wound healing, transdifferentiation, or tissue regeneration by activating transcription of target genes that are regulated by the endogenous transcription factor. In the case of engineered (e.g. custom sequence specificity) zinc finger DNA binding domains, TALE

DNA binding domains or Cas family proteins, an effector domain could be brought to one or more specific loci, or optionally a single locus in the genome in a controlled manner.

[0090] In an embodiment, the DNA targeting domain comprises a CRISPR-Cas protein such as dCas9. Enzymatically inactive CRISPR-Cas proteins which retain gRNA and target DNA binding activity can be used. For example, mutation of D10A/H840A in Cas9 introduces mutations in the RuvC1 and HNH nuclease domains and results in inactivation. In an embodiment, the CRISPR-Cas protein is dCas9 having an amino acid sequence of SEQ ID NO: 1 or an amino acid sequence with at least 80%, at least 90%, at least 95%, or at least 99% sequence identity to SEQ ID NO: 1 and comprises D10A/H840A and which retains gRNA and target DNA binding activity. Other enzymatically inactive CRISPR-Cas proteins are also contemplated can be identified by the skilled person.

[0091] In an embodiment, the DNA targeting domain comprises a zinc finger DNA binding domain. In an embodiment, the zinc finger DNA binding domain is an engineered zinc finger DNA binding domain which has been engineered to bind a specific DNA sequence.

[0092] The effector domain comprises at least one transactivation domain (TAD) described herein, or an active fragment thereof. As shown in the Examples, various full-length ORFs and TADs identified herein can be used, alone or in combination, to activate transcription of a GFP reporter construct or an endogenous gene such as CD133. Also shown in the Examples, the effector domain can comprise at least one TAD domain shown in Table 1, and/or an active fragment thereof, such as for example as shown in Table 3. Accordingly, in an embodiment, the effector domain comprises at least one TAD shown in Table 2, Table 4, and/or Table 5 and/or Table 6 and/or a functional variant of any one thereof, or two or more TADs shown in Table 1, Table 2, Table 3, Table 4, Table 5, and/or Table 6 and functional variants of any one thereof. In an embodiment, the TAD comprises a polypeptide having a sequence with at least 80%, at least 90%, at least 95%, or at least 99% sequence identity to any one of the TAD domains in Table 1, Table 2, Table 3, Table 4, Table 5, and/or Table 6 and functional variants of any one thereof, and which retains (e.g. is as at least 80% as effective at) transcriptional activation activity and/or interaction with specific transcriptional co-activators such as for example CBP/p300, NuA4, and/or BRD4.

[0093] Variants and combinations thereof may also be used. In an embodiment, the effector domain comprises two or more tandem TADs, optionally two TADs, three TADs, four TADs, or more than four TADs, for example 5 TADs, 10 TADs, 15 TADs, 20 TADs, 25 TADs, 30 TADs, or any number of TADs between 5 TADs and 30 TADs, or more than 30 TADs. In

an embodiment, the effector domain comprises two or more TADs or functional variants thereof selected from those listed in Table 1, Table 2, Table 3, Table 4, Table 5, and/or Table 6 and functional variants of any one thereof. In an embodiment, the effector domain comprises three or four TADs selected from those listed in Table 3. In an embodiment, the effector domain comprises one or more of SEQ ID NO: 185, SEQ ID NO: 103, SEQ ID NO: 167, SEQ ID NO: 105, SEQ ID NO: 106, and/or SEQ ID NO: 104. In an embodiment, the effector domain comprises SEQ ID NO: 185, optionally SEQ ID NO: 90, 91, 102, or 157. In an embodiment, the effector domain comprises SEQ ID NO: 103, optionally SEQ ID NO: 46, 47, or 162. In an embodiment, the effector domain comprises SEQ ID NO: 167, optionally SEQ ID NO: 101, 110, 166, or 172. In an embodiment, the effector domain comprises SEQ ID NO: 105, optionally SEQ ID NO: 116, 117, or 165. In an embodiment, the effector domain comprises SEQ ID NO: 106, optionally SEQ ID NO: 116 or 117. In an embodiment, the effector domain comprises SEQ ID NO: 104, optionally SEQ ID NO: 118, 119, or 159. In an embodiment, the effector domain comprises SPDYE4-CITED1-RELA-HSF1 (SEQ ID NO: 121); SPDYE4-CITED1-RELA (SEQ ID NO: 123); HSF1-RELA-SPDYE4-CITED1 (SEQ ID NO: 125); SPDYE4-CITED1-p65-miniHSF1 (SEQ ID NO: 127); miniSPDYE4-CITED1-p65-HSF1 (SEQ ID NO: 129); SPDYE4-miniCITED1-p65-HSF1 (SEQ ID NO: 131); SPDYE4-CITED1-minip65(C)-HSF1 (SEQ ID NO: 133); or SPDYE4-CITED1-minip65(N)-HSF1 (SEQ ID NO: 135). In an embodiment, the effector domain comprises SPDYE4-CITED1-SERTAD2-HSF1; SPDYE4-CITED1-KLF6-HSF1; SPDYE4-CITED1-ZXDC-HSF1; SPDYE4-CITED1-ATF6-HSF1; SPDYE4-CITED1-FOXO1-HSF1; SPDYE4-CITED1-ATMIN-HSF1; SPDYE4-CITED1-p65-SERTAD2; SPDYE4-CITED1-p65-KLF6; SPDYE4-CITED1-p65-ZXDC; SPDYE4-CITED1-p65-ATF6; SPDYE4-CITED1-p65-FOXM1; SPDYE4-CITED1-p65-ATMIN; SPDYE4-C3orf62-p65-HSF1; SPDYE4-DDIT3-p65-HSF1; SPDYE4-FOXO1-p65-HSF1; SPDYE4-ATMIN-p65-HSF1; SPDYE4-ZXDC-p65-HSF1; C3orf62-CITED1-p65-HSF1; C11orf74-CITED1-p65-HSF1; KLF6-CITED1-p65-HSF1; ZXDC-CITED1-p65-HSF1; or SOX7-CITED1-p65-HSF1. In an embodiment, the effector domain comprises SPDYE4-C3orf62.2-P_AD-HSF1 (SEQ ID NO: 174); SPDYE4-C3orf62.3-P_AD-HSF1 (SEQ ID NO: 176); SPDYE4-C3orf62_MT-P_AD-HSF1 (SEQ ID NO: 178); SPDYE4-DDIT3_MT-P_AD-HSF1 (SEQ ID NO: 180); SPDYE4-CITED1-P_AD-HSF1_MT (SEQ ID NO: 182); or 3 x ZNF473_KRAB (SEQ ID NO: 184). Other combinations are specifically contemplated herein.

[0094] The effector domain may comprise two or more TADs with different transcriptional co-activator preferences. For example, the effector domain may comprise a TAD which interacts with CBP/p300 components for example a FOXO TAD, and a TAD which

interacts with BET components for example a SPDYE4 TAD. The effector domain may comprise two or more TADs with similar transcriptional co-activator preferences. For example, the effector domain may comprise two TADs which interact with CBP/p300 components, for example the effector domain may comprise a FOXO1 TAD and a CITED1 TAD. Other combinations are specifically contemplated herein.

[0095] With respect to functional variants, "as effective" as used herein means the functional variant retains at least 80%, at least 85%, at least 90%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, 100%, or more than 100% transcriptional activation activity and/or co-activator interaction compared to the unmodified or non-variant TAD (e.g. wild-type or full-length TAD). Transcriptional activation activity and/or co-activator interaction of variants such as truncations can be determined for example using the methods described herein. For example transcriptional activation activity can be determined using the GFP reporter system described in the Examples. Variants can be tethered to the same reporter or endogenous context while controlling for expression levels of each DNA targeting domain (e.g. dCas9). Any differences detected in induced expression of the reporter or target genes when compared to the parental TAD can be contributed to the effect of the variant. Co-activator interaction can be determined for example by AP-MS and/or BioID e.g. as shown in the Examples.

[0096] Exemplary TAD and effector domain nucleic acids and polypeptides are provided in Tables 1-6 and SEQ ID NOs: 120-135 and 173-184. In an embodiment, the effector domain may comprise an amino acid sequence encoded by said nucleic acids, or an amino acid sequence with at least 80%, at least 90%, at least 95%, at least 96%, at least 97%, at least 98%, or at least 99% sequence identity to an amino acid sequence encoded by the TAD of SEQ ID NOs: 120-135 and 173-184. The activity of the encoded polypeptides (fusion or when expressed and activated) of such polypeptides is as effective (e.g. provides at least 80% as effective transcriptional activation) as for example SEQ ID NOs: 120-135 and 173-184.

[0097] In an embodiment, the effector domain is fused to the DNA targeting domain by way of a linker. In an embodiment, two or more TADs are fused together by way of one or more linkers. For example, glycine and glycine serine linkers can be used. Transcriptional activators described in the Examples used a variety of glycine serine linkers for example SGGSGGS (SEQ ID NO: 6), GGS, SGGS (SEQ ID NO: 7), and/or GSGSGS (SEQ ID NO: 8). Other linkers can also be used for example INSRSSGS (SEQ ID NO: 9).

[0098] In an embodiment, the transcriptional activator comprises one or more nuclear localization signals (NLS). Any suitable NLS can be used. Optionally the NLS is an SV40 NLS. The one or more NLS can be one or more N-terminal NLS, one or more C-terminal NLS, one or more internal NLS, and/or combinations thereof. Optionally, the NLS may comprise an NLS of SEQ ID NO: 22. In an embodiment, the NLS further comprises an N- and/or C-terminal linker such as INSRSSGS (SEQ ID NO: 9), and optionally has the sequence INSRSSGSPKKKRKVGS (SEQ ID NO: 141).

[0099] As described herein, the transcriptional activator or effector domain may be encoded by a nucleic acid and/or expressed from an expression construct. Accordingly, one aspect of the disclosure is a nucleic acid encoding a transcriptional activator described herein. Another aspect of the disclosure is a nucleic acid encoding an effector domain of a transcriptional activator described herein. For example, the nucleic acid may encode a TAD as provided in any one of Tables 1 to 6, optionally Tables 2, 4, 5 and/or 6, optionally Table 2 or Table 4 or Table 6, or two or more TADs as provided in Tables 1-6. In an embodiment, the nucleic acid may comprise a nucleic acid of any one of SEQ ID NOs: 120, 122, 124, 126, 128, 130, 132, 134, 173, 175, 177, 179, and 180, or a sequence with at least 80%, at least 90%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99% or 100% sequence identity to SEQ ID NOs: 120, 122, 124, 126, 128, 130, 132, 134, 173, 175, 177, 179, and 180, wherein the heterologous transcriptional activator, for example activates transcription about as effectively as the effector domains encoded by SEQ ID NO: 120, 122, 124, 126, 128, 130, 132, 134, 173, 175, 177, 179, and 180, for example at least 80% as effectively, at least 85% as effectively, or at least 90% as effectively, at least 95% as effectively, at least 96% as effectively, at least 97% as effectively, at least 98% as effectively, at least 99% as effectively, at least 100% as effectively, or more than 100% as effectively for example as assessed in an assay as described herein. The sequence identity is for example relative to the full effector domain sequence or relative to one or more TADs or TAD fragments encoded therein. Other portions, linkers, NLS etc. can be completely different. The nucleic acid encoding the effector domain may be suitable for generating a nucleic acid encoding a transcriptional activator described herein. For example, the nucleic acid encoding the effector domain may be flanked by suitable cloning sites, or an expression construct or vector comprising said nucleic acid may comprise a cloning site to facilitate insertion of a DNA targeting domain to operably link the effector domain and DNA targeting domain.

[00100] The term “cloning site” as used herein refers to a portion of a nucleic acid molecule into which a nucleic acid molecule of interest may be inserted, or to which a nucleic

acid molecule of interest may be joined, using recombinant DNA technology (cloning). In the context of an expression cassette, the cloning site may be located between the promoter and the polyadenylation signal, such that a nucleic acid molecule of interest may be cloned into the expression cassette in operable linkage with the promoter and the polyadenylation site. Several cloning techniques are known to the skilled person and the cloning site will include the necessary characteristics (such as restriction endonuclease site(s), recombinase recognition site(s), or blunt or overhanging end(s)) to allow insertion of the nucleic acid molecule of interest at the cloning site. The cloning site may, for example, be a multiple cloning site (MCS) or polylinker region comprising a plurality of unique restriction enzyme recognition sites to allow a nucleic acid molecule of interest to be inserted. Alternately, or in addition, the cloning site may include one or more recombinase recognition sites to allow DNA insertion by recombinational cloning; employing site-specific recombinase(s), such as Integrase or Cre Recombinase, to catalyze DNA insertion. Examples of recombinational cloning systems include Gateway® (Integrase), Creator™ (Cre Recombinase), and Echo Cloning™ (Cre Recombinase). For some cloning strategies, an expression cassette or vector may be provided as a linear molecule, allowing blunt or overhanging ends of a nucleic acid molecule of interest to be joined to blunt or overhanging ends of the expression cassette or vector, for example by ligation or polymerase activity, thus forming a circular molecule. In this case, the blunt or overhanging ends of the expression cassette or vector may together be viewed as the cloning site. Such an approach is commonly used to clone PCR products.

[00101] A related aspect is an expression construct comprising the nucleic acid encoding the transcriptional activator operably linked to a promoter and a transcription termination site. Any suitable promoter may be used. Suitable promoters can be identified by a person skilled in the art, and may include for example CMV, EF1A, or PGK. For example, the promoter and/or enhancer sequences of e.g. SEQ ID NOs: 25, 26, 27, and/or 28 can be used in an expression construct. Inducible promoters may also be used.

[00102] In one embodiment, the construct is a vector. Any suitable vector may be used. Suitable vectors can be identified by a person skilled in the art, and may include a viral vector, optionally a lentiviral vector or an adenoviral vector. Suitable vectors may comprise for example a promoter for expressing effector construct, polyA tail, 3'UTR elements like WPRE to increase stability of expression, insulator sequences, lentiviral packaging signals, a fluorescent protein, and/or an antibiotic resistance marker. Additional suitable components can be identified by a person skilled in the art.

[00103] In another embodiment, the transcriptional activator, nucleic acid, construct, or vector is in a cell. Any suitable cell may be used and can be determined by the skilled person on the basis of the desired application. The cell may be from any organism. Optionally the cell is a mammalian cell such as a human cell or a mouse cell. Optionally the cell is a cell line. The cell line may be any suitable cell line.

[00104] The transcriptional activator, nucleic acid, construct, or vector may be introduced into the cell in any suitable manner, for example by transfection. Suitable transfection reagents and methods are routinely practiced in the art and can be identified by the skilled person. Optionally, the construct is a viral vector, optionally a lentiviral vector, and is introduced into the cell by transduction. Suitable transduction methods are routinely practiced in the art and can be identified by the skilled person.

[00105] In some embodiments the cell is stably expressing the heterologous transcriptional activator, optionally the cell is stably transduced, for example prepared using a virus comprising a nucleic acid encoding the heterologous transcriptional activator.

[00106] Another aspect is a transcriptional activation system comprising the transcriptional activator described herein, a nucleic acid encoding the transcriptional activator, or construct or vector comprising said nucleic acid or a cell expressing the transcriptional activator. In the case of a system based on CRISPR-Cas, the system comprises at least one gRNA. In the case of a system based on inducible dimerization domains, the system optionally comprises at least one inducing agent.

[00107] Also provided is a composition comprising a heterologous transcriptional activator described herein, a nucleic acid described herein, a construct described herein, a vector described herein, a cell described herein and/or a transcriptional activation system described herein. The composition can comprise a carrier, such as BSA, or a diluent suitable according to the composition components, optionally water or buffered saline. The composition can comprise multiple components such as transcriptional activators, nucleic acids, constructs, vectors or cells comprising the same or different elements.

[00108] Also provided herein is a kit for example for activating transcription of a target gene or performing a method described herein, the kit comprising a transcriptional activator described herein, a nucleic acid, expression construct, or vector encoding a transcriptional activator described herein, or a cell expressing the transcriptional activator described herein, and optionally a vial housing the transcriptional activator, nucleic acid, expression construct, vector, cell or composition. The kit can comprise multiple of one or more of the aforementioned

components. Optionally the kit comprises a gRNA expression construct, an inducing agent, and/or instructions for carrying out the methods described herein.

[00109] Also described herein are methods of activating transcription of a target gene in a cell. As demonstrated in the Examples, a transcriptional activator of the disclosure can be targeted to a genomic locus such as a promoter to activate transcription of a target gene in a cell.

[00110] The transcriptional effectors identified herein may be full-length proteins, fragments thereof (transactivation domains), functional variants thereof or combinations of transactivation domains or functional variants thereof. They cover multiple different transcriptional activation strengths from very powerful to moderate to weak. This can be used to achieve a desired expression level of endogenous genes, particularly in cases where too high expression can cause deleterious phenotypes. Activation strength can be tuned by selecting different TADs or functional variants (e.g. active fragments) for inclusion in the effector domain. The activation strength of an effector domain can be determined by the skilled person for example using the MFI or percent GFP positive cells in the recruitment assays shown in the Examples described herein. For example, the relative strength of an effector domain can be determined by comparing the MFI or percent GFP positive cells of the specific effector domain in combination with a specific DNA targeting domain and specific DNA target relative to a control such as Renilla in combination with the same DNA targeting domain and specific DNA target. High activation can be considered to be for example at least or above 50X control, at least or above 75X control, at least or above 100X control, or at least or above 150X control. Medium activation can be considered to be for example at least or above 10X, at least or above 20X, at least or above 30X, or at least or above 40X control, and up to 50X, up to 75X, up to 100X, or up to 150X control. Low activation can be considered to be for example at least 2X, at least 2.5X, at least 3X, at least 4X, or at least 5X control and up to 10X, up to 20X, up to 30X, or up to 40X control. For example, as shown in Figure 19A and 19B, high activation may be considered to be >50-fold, medium may be 20X to 50X, and low may be at least 3X up to 20X relative to the Renilla control. Suitable activation levels may be selected depending on the desired application.

[00111] As described herein another level of control for transcriptional regulation can be added with chemically induced dimerization with e.g. rapalogs or abscisic acid. In this case, one half (e.g. a DNA targeting domain) would be fused to FKBP or PYL1, and the other half (e.g. the effector domain) fused to FRB or ABI1. Treatment with rapalog or abscisic acid would induce the interaction between FKBP and FRB or PYL1 and ABI1, respectively, leading to

temporally regulated gene expression. As shown in the Examples, the dimerization of a heterologous transcriptional activator comprising ABI1 and PYL1 may be induced with the addition of abscisic acid. The skilled person can readily identify and select suitable inducible dimerization domains and inducing agents that may be used together. Any suitable inducible combination of protein dimerization domains and inducing agents may be used, for example the dimerization of ABI1 and PYL1 may be induced with the addition of abscisic acid. Other inducible systems include those based on induction with rapamycin, gibberellic acid/gibberellin, and split dCas9-based systems. For example dimerization of GID1 and GAI can be induced by gibberellin, and dimerization of FKBP and FRB can be induced with rapamycin or its analogs, e.g. rapalogs. Higher-order multimerization systems, such as the SunTag system (Tenenbaum et al., 2014) are also contemplated herein.

[00112] Interaction between the DNA targeting domain and effector domain can also be controlled using other inducible systems. Other systems (that are not dependent on dimerization) include grazoprevir-induced stabilization (Tague et al. 2018) or tamoxifen-regulated nuclear localization using estrogen receptor ligand binding domain variants. In the case of grazoprevir-induced stabilization, the DNA targeting domain and effector domain would be linked by a self-cleaving NS3 protease domain. Only in the presence of grazoprevir (which inhibits NS3 activity), DNA binding domain and effector domain would stay together and regulate gene expression.

[00113] Accordingly, one aspect of the disclosure is a method of activating expression of a target gene in a cell, the method comprising introducing into the cell a transcriptional activator described herein, and culturing the cell under suitable conditions such that the DNA targeting domain guides the transcriptional activator to the target site and the effector domain activates transcription of the target gene. In an embodiment, the target gene is an endogenous gene. In an embodiment, where the transcriptional activator comprises CRISPR-Cas, the method further comprises introducing into the cell at least one gRNA that targets a desired genomic locus in the cell, and culturing the cell under suitable conditions such that the at least one gRNA associates with the CRISPR-Cas protein and guides the CRISPR-Cas protein to guide the transcriptional activator to a CRISPR target site such that the effector domain activates transcription of the target gene. In an embodiment where the transcriptional activator comprises an inducible dimerization domain in each of the DNA targeting domain and in the effector domain, the method further comprises introducing into the cell at least one inducing agent and culturing the cell under suitable conditions that the first and second inducible

dimerization domains associate such that the at least one effector domain activates transcription of the target gene.

[00114] The methods described herein can be used to modulate gene expression of a target gene for example to induce expression of an endogenous gene or modulate chromatin opening in defined regions of the genome. By way of example, some TADs could promote chromatin opening in intergenic regions (i.e. not promoters or enhancers), which could lead to chromatin opening and rearrangement of chromosome folding.

[00115] The methods described herein can be used to identify or screen for one or more genomic loci that are important for cell viability or a phenotype of interest. By way of example, the methods described herein can be used to screen for genes or regulatory elements thereof that are important for resistance or sensitivity to a toxin of interest such as diphtheria toxin. In another example, the methods described herein can be used to identify regulatory elements that are important for expression of a protein of interest such as CD81. In a further example, the methods described herein can be used in high-throughput screening methods to identify essential or non-essential genes in a cell type by screening for gRNAs that are over- or under-represented in a cell population under certain conditions e.g. drug treatment over time. Other applications can be determined by a person skilled in the art.

[00116] The above disclosure generally describes the present application. A more complete understanding can be obtained by reference to the following specific examples. These examples are described solely for the purpose of illustration and are not intended to limit the scope of the disclosure. Changes in form and substitution of equivalents are contemplated as circumstances might suggest or render expedient. Although specific terms have been employed herein, such terms are intended in a descriptive sense and not for purposes of limitation.

[00117] The following non-limiting examples are illustrative of the present disclosure:

III. Examples

Example 1. Platform for identifying transcriptional activators in human cells.

[00118] To identify transcriptional regulators in a systematic manner, a chemically-induced dimerization (CID) system was used, where catalytically inactive Cas9 (dCas9) is tagged in its N terminus with the protein phosphatase ABI1 and the potential transcriptional activator is fused to the abscisic acid receptor PYL1 (**Figure 1A**)(Gao et al., 2016; Liang et al., 2011). Treatment of cells with abscisic acid (ABA) induces an interaction between ABI1 and PYL1, thereby recruiting the potential transcriptional activator to a specific genomic locus

defined by the guide RNA (gRNA). As a reporter, a HEK293T cell line that contains a stably integrated construct with a 7xTetO array and a basal CMV promoter driving the expression of EGFP was used (Gao et al., 2016). A monoclonal cell line that expresses ABI1-dCas9 and a single gRNA targeting TetO was generated by lentiviral infection. Transfection of this cell line with known transcriptional activators VPR, VP64, and p300 fused to PYL1 led to robust induction of GFP upon ABA treatment (**Figure 1B**), consistent with a previous report (Gao et al., 2016). Recruitment of luciferase or RFP to the promoter did not induce GFP expression, demonstrating that ABA alone does not activate the reporter (**Figure 1B**).

[00119] To scale up from individual clones, a pooled library of human ORFeome 8.1 and ORFeome collaboration clones (ORFeome Collaboration, 2016; Yang et al., 2011) in a lentiviral vector containing a C-terminal PYL1 was generated. Together, these open reading frame (ORF) libraries contain 14,821 clones corresponding to 13,571 unique genes. The reporter cell line was infected with the pooled library at low multiplicity of infection, thus ensuring that most cells were infected with only one lentivirus (**Figure 1C**). The pooled library covered 96% and 93% of the ORFeome before and after infection, respectively, demonstrating wide coverage of the library despite significant diversity in insert size (**Figure 6A and B**). After treating the infected cells with ABA, a clear induction of GFP in a subset of cells was observed (**Figure 1D**). Reporter induction was dependent on treatment time, ABA concentration, and presence of the ORFeome (**Figures 6C-6E**). Furthermore, withdrawal of ABA led to rapid loss of high GFP population (**Figure 6C**), demonstrating that continuous promoter occupation is required for activation. To identify transcriptional activators, the top 1% of GFP positive cells of ABA treated cells was sorted in duplicate and the ORFs in the high GFP population were identified by sequencing (**Figure 1D**).

[00120] Methods are as described in Example 7.

Example 2. ORFeome-wide screen identifies known and novel transcriptional activators.

[00121] 248 putative transcriptional activators were identified, using a cut-off of 5% false discovery rate and at least 4-fold change in read counts between top 1% GFP positive cells and unsorted cells (**Figure 1E**). Gene ontology (GO) analysis revealed significant enrichment for multiple functional categories related to transcriptional activation (**Figure 1F**). The hits were also highly enriched in protein domains found in many transcriptional regulators (**Figure 1G**), subunits of chromatin-associated protein complexes (**Figure 1H**), and in interactors of central hubs of transcription, such as RNA polymerase II and histone

acetyltransferases CBP and p300 (**Figure 6F**). Moreover, the hits were significantly overlapping with human proteins that function in yeast two-hybrid assays as autoactivators (11% in the proteome vs. 29% among the hits; $p<0.0001$, Fisher's exact test; **Figure 6G**), which are proteins that activate reporter gene expression in yeast when ectopically recruited to the promoter (Luck et al., 2020). The screen results were also validated by assaying a collection of 90 hits and non-hits by individually transfecting them into the same reporter cell line. The results were highly consistent with the screen: almost all hits reproduced when tested individually, and conversely, most non-hits did not activate the reporter (**Figure 6H**), suggesting low false positive and false negative rates in this setting. Together, these results indicate that the screen identified functionally relevant transcriptional activators in a reproducible manner.

[00122] Individual screen hits included well-characterized factors regulating distinct stages of transcription (**Figure 1E**). For example, among sequence-specific transcription factor hits were known activators RELB and MYCL (Barrett et al., 1992; Ryseck et al., 1992) in addition to several master TFs regulating stress response, such as HSF1, ATF6, and DDIT3/CHOP (Vihervaara et al., 2018). Co-activators that do not bind DNA themselves but associate with TFs included STAT2, CITED1, and SERTAD1 (Bousoik and Montazeri Aliabadi, 2018; Hsu et al., 2001; Yahata et al., 2001). Both subunits of TFIIE (GTF2E1 and GTF2E2), a general transcription factor regulating the assembly of the pre-initiation complex (Cramer, 2019), were also prominent hits, as were proteins promoting RNA polymerase II release (the P-TEFb complex subunit CDK9) and transcriptional elongation (e.g., ELL3 and MLLT1)(Chen et al., 2018; Cramer, 2019). Other prominent activators included subunits of chromatin-modifying complexes such as SAGA (ATXN7L3, TADA3, SGF29) and NuA4 (EPC1, MGRBP), and GADD45 family proteins that mediate DNA demethylation (GADD45A, GADD45B, GADD45G)(Barreto et al., 2007). Finally, 13 of the 15 Mediator subunits that were present in the library were identified. These highlighted examples illustrate that the screen uncovered factors promoting transcription by multiple different mechanisms and at distinct stages of the transcription cycle.

[00123] In addition to known transcriptional regulators, a large collection of proteins were identified in the screen that have not been previously linked to transcription (e.g. C11orf74/IFTAP, NCKIPSD, DCAF7, HFM1) or are completely uncharacterized (e.g. C3orf62, FAM90A1, SPDYE4, SS18L2, FAM9A, C21orf58)(**Figure 1H**). These results suggest that the human genome encodes many previously unknown transcriptional regulators. Detailed characterization of several of these factors is described below.

[00124] Methods are as described in Example 7.

Example 3. Distinct transcriptional activities within TF families.

[00125] Transcription factors comprise multiple families, characterized by their distinct DNA-binding and auxiliary domains (Lambert et al., 2018). TFs that belong to the same family often have highly similar or even identical sequence specificities (Jolma et al., 2013; Lambert et al., 2018; Weirauch et al., 2014). Nevertheless, even highly related TFs can have distinct effects on transcription and chromatin due to their unique auxiliary domains. In line with this, only some members of transcription factor families were identified as hits in the pooled screen. To rule out sensitivity of the pooled approach as the cause, members of Forkhead-box (FOX), SRY-related HMG-box (SOX), E-twenty-six (ETS), atonal-related basic helix-loop-helix (bHLH), Twist/Hand, Krüppel-like factor (KLF), and Homeobox protein (HOX) families were individually assayed (**Figure 2A** and 7A). Two protein families linked to transcription and chromatin (Polycomb group RING finger (PCGF) and casein kinase family), one family (Spy1/RINGO) not previously linked to transcription (Gastwirt et al., 2007), and 24 Mediator subunits, which are not evolutionarily related but are integral components of the same, conserved complex were also included.

[00126] Consistent with the pooled screen, activation profiles for many highly homologous transcription factors were markedly different even when tested one at a time. For example, only five of the 37 Forkhead TFs, one of the 14 SOXs, five of 14 KLFs, and two of the 36 HOX proteins activated reporter expression (**Figure 2A-2D** and 7). To exclude the trivial explanation that the difference in activity was due to expression, several TFs were assayed as RFP-PYL1 fusions to account for fusion protein expression levels. The results were highly consistent with PYL1-only fusions and did not correlate with RFP levels (**Figure 8**), indicating that the differences in transcriptional activity reflected the intrinsic potential of the TFs.

[00127] Notably, activating TFs identified in the screen were significantly enriched for factors that can induce differentiation of mouse embryonic stem cells and human induced pluripotent cells (iPSCs) when ectopically expressed (**Figure 7G**)(Ng et al., 2021; Theodorou et al., 2009), suggesting that activation differences in the assay are related to differences in biological function. For example, of the related bHLH family transcription factors, NEUROG1, NEUROG2, NEUROD1, and NEUROD2 can induce neuronal differentiation of iPSCs whereas NEUROD6 cannot (Goparaju et al., 2017). This pattern is concordant with their ability to activate the reporter gene (**Figure 7B**). Similarly, only four HOX factors (HOXA1, HOXA2, HOXB1, HOXB2) can activate the b1-ARE autoregulatory element located in the *Hoxb1* locus

(Di Rocco et al., 1997), and three of these were characterized as activators in the assay (HOXA2 and HOXB2 in the pooled screen and the arrayed assay, HOXA1 in the screen) (**Figure 2A**). Moreover, recent work revealed a striking collinearity between the repressive potential, expression pattern, and genomic location of HOX genes (Tycko et al., 2020), with HOX transcription factors in the 5' end of homeobox clusters being repressive. Consistent with this, the HOX family activators in the assay are encoded by the most or the next-to-last 3' genes in their HOX gene clusters.

[00128] A particularly interesting case was that of PCGF family proteins, which are mutually exclusive components of canonical and non-canonical Polycomb Repressive Complexes 1 (PRC1) (Gahan et al., 2020; Gao et al., 2012)(**Figure 2E**). Although generally thought to act in chromatin compaction and gene silencing in the context of PRC1, PCGF3 was identified as an activator in the original screen. PCGF3 robustly activated the reporter when tested individually, as did PCGF5 (which was not present in the original pooled screen) **(Figure 2E)**. In contrast, three other PCGF family members (PCGF1, PCGF2, and PCGF4/BMI1) were neither screen hits nor activated the reporter when individually tested (**Figure 2E**). PCGF5 has been previously shown to regulate transcriptional activation (Gao et al., 2014), but no such role has been described for PCGF3. Interestingly, in the PCGF family phylogeny, PCGF3 and PCGF5 form a distinct group that arose early during animal evolution (Gahan et al., 2020), suggesting that their transcriptional activation function is of ancient origin.

[00129] Some studies have indicated that subunits of the Mediator complex can have distinct regulatory functions, with some subunits promoting transcriptional activation and others promoting repression (Conaway and Conaway, 2011; Stampfel et al., 2015). In the assay, 20 of the 24 assayed Mediator subunits robustly activated the reporter, with no difference between Mediator submodules (**Figure 7F**). For example, MED29 has been suggested to have transcriptional repressor activity (Wang et al., 2004), but it was both a hit in the pooled screen and validated as an activator when tested individually (**Figure 7F**). Thus, at least in the context of the reporter system, almost all Mediator subunits promote transcriptional activation.

[00130] The primary activation screen identified two proteins (SPDYE4 and SPDYE7P) that belong to the Spy1/RINGO (Rapid INducer of G2/M progression in Oocytes) family of cell cycle regulators. Spy1/RINGO proteins bind to and activate Cdk1 and Cdk2 in a cyclin-independent manner, thereby promoting cell cycle progression (Gonzalez and Nebreda, 2020). However, they have not been previously implicated in transcriptional regulation. As a result of recent expansion (Chauhan et al., 2012), the human genome contains at least 19

Spy1/RINGO family genes and multiple pseudogenes. Five Spy1/RINGO proteins were individually tested for transcriptional activation, and four of them robustly activated the reporter (**Figure 2F**). These results suggest that Spy1/RINGO proteins may promote cell cycle progression in part by functioning as transcriptional activators.

[00131] Methods are as described in Example 7.

Example 4. TAD-seq reveals novel human transactivation domains.

[00132] Transcription factors generally activate transcription through transactivation domains (TADs) that interact with co-activators, such as the Mediator, CBP/p300 acetyltransferases, or TFIID. Most TADs are short, unstructured sequences rich in acidic and hydrophobic residues (Sigler, 1988). Despite intensive efforts, no clear consensus motifs have emerged, making computational prediction of TADs challenging (Erijman et al., 2020; Ravarani et al., 2018; Staller et al., 2021). Several groups have recently implemented pooled recruitment approaches to identifying TADs from known transcriptional regulators or from random sequences (Arnold et al., 2018; Erijman et al., 2020; Ravarani et al., 2018; Sanborn et al., 2020). The screening platform described above was modified to identify the region(s) responsible for transcriptional activation among the hits. This approach was similar to the previously published TAD-seq method (Arnold et al., 2018) except that synthesized fragments were used instead of randomly fragmented DNA.

[00133] A fragment library of 75 activators identified in our screen was generated, using 60 amino-acid tiles every 20 aa such that every amino acid was represented by three different fragments (**Figure 3A**). The pooled fragment library was fused to PYL1 and recruited to the same GFP reporter used in the original ORFeome screen (**Figure 3A**). Again, ABA-dependent GFP expression was observed in a subset of reporter cells infected with the fragment library (**Figure 9A**). The GFP positive population was sorted into two independent replicates, and fragments in each population were quantified by sequencing. However, in contrast to the ORFeome screen, both high GFP cells (top 1%) and medium GFP cells (top 2-5%) were sorted to potentially identify transactivators of different strength.

[00134] The pooled approach revealed 70 activating fragments in 39 different proteins. As expected, these fragments were enriched in acidic and hydrophobic amino acids, and depleted of positively charged (basic) amino acids (**Figure 9B**), indicating that many represent “canonical” TADs consistent with the “acid blob” idea (Sigler, 1988). Indeed, activating fragments contained more predicted TADs based on two different algorithms (Erijman et al., 2020; Piskacek et al., 2007)(**Figure 9C**) and the predicted TADs were longer in activating

fragments than in inactive fragments (**Figure 9D**). However, many active fragments were not predicted by any algorithm, highlighting the need for experimental approaches.

[00135] Of the 70 active fragments, the majority (44 = 63%) was identified in only the high GFP or the medium GFP population, suggesting that the fragments have distinct activation potential (**Figure 9E**). For example, VP64 was enriched in the high GFP population but depleted in the medium GFP population when compared to the unsorted fragment library (**Figure 9E**). This is consistent with the unusual potency of VP16 in transcriptional activation (VP64 consists of four VP16 peptides in tandem)(Sadowski et al., 1988). 10 fragments identified in the screen were individually tested, and 9 of them robustly activated the reporter (**Figure 9F**), suggesting low false positive rate.

[00136] The fragment screen recovered several known TADs. For example, known TADs in KLF6, KLF7, KLF15, ATF6, and CITED2 were identified (**Figure 3B** and **10A**). Additionally, since the overlap between active fragments can pinpoint the minimum sequence required for activity, the regions required for activity of previously identified TADs, such as those for KLF6, KLF7, and SERTAD2 were narrowed (**Figure 3B** and **10A**). Many previously unknown TADs in both canonical transcriptional regulators and novel proteins were discovered in the ORFeome-wide screen (**Figure 3C** and **10B**). TADs were uncovered in previously uncharacterized proteins SPDYE4, C3orf62, FAM22F, and FAM90A1 (**Figure 3C**). Interestingly, the novel TAD in SPDYE4 was adjacent to its Spy1 domain that interacts with and activates Cdk2, indicating that the potential transcriptional activity and Cdk-regulating activity are mediated by distinct domains of Speedy family proteins (**Figure 3C** and 11A)(McGrath et al., 2017). Moreover, consistent with the transcriptional activation profiles of Spy1/RINGO family proteins, the TAD region is conserved in all family members except SPDYC, the only Spy1/RINGO family protein that was inactive in the recruitment assay (**Figure 2F** and 11A).

[00137] Interestingly, some of the uncovered TADs did not have characteristics of typical transactivation domains. For example, the three overlapping fragments in HOXA2 that activated transcription spanned a polyalanine stretch between the homeobox DNA-binding domain and the antennapedia-like hexapeptide motif (**Figure 3D** and **3E**), which interacts with the PBX1 co-activator (Piper et al., 1999). However, a fragment lacking the hexapeptide motif still activated transcription, suggesting that the activity is not regulated via PBX1 (**Figure 3E**). Polyalanine stretches are functionally important in Ultrabithorax (Ubx) proteins in *Drosophila*, and recently they were suggested to have a role in driving phase separation of many TFs such

as HOXD13 (Basu et al., 2020). The results herein suggest that polyalanine stretches may have additional roles in transcriptional activation.

[00138] Another non-canonical activating region was from YAF2, which is a component of the Polycomb Repressive Complex 1 (PRC1) (Gao et al., 2012) and a prominent hit in the original ORFeome screen (**Figure 3F**). This region contained the YAF2_RYBP domain, which folds into an antiparallel beta sheet that binds RING1B, a core PRC1 subunit (Wang et al., 2010) (**Figure 3G**). The YAF2_RYBP domain of YAF2 and its close homolog RYBP shares sequence and structural homology with the CBX-C domain present in the CBX family Polycomb proteins (Wang et al., 2010)(**Figure 11B**). CBX-C domain containing proteins and YAF2/RYBP interact in a mutually exclusive manner with RING1A and RING1B to form canonical (cPRC1) and non-canonical (ncPRC1) Polycomb complexes (**Figure 3G**).

[00139] To test if all CBX-C and YAF2_RYBP domains can promote transcriptional activation, the YAF2_RYBP domains of YAF2 (SEQ ID NO: 96) and RYBP (SEQ ID NO: 140) and the CBX-C domains of CBX2 (SEQ ID NO: 136), CBX4, CBX6 (SEQ ID NO: 138), CBX7, and CBX8 (SEQ ID NO: 139) were cloned and assayed for activity with the reporter system. The YAF2_RYBP motif from both YAF2 and RYBP robustly activated the reporter, consistent with the TADseq results for YAF2 (**Figure 3H**). Some CBX-C domains were also activators: CBX-C from CBX2 was the most potent activator, whereas those from CBX6 and CBX8 activated the reporter weakly (**Figure 3H**). In contrast, CBX4 and CBX7 CBX-C domains had no effect on the reporter. This pattern reflected the evolutionary ancestry of the CBX-C domain proteins (**Figure 3H**). Interestingly, the CBX-C domains of CBX4 and CBX7 bind RING1B with ~10-fold higher affinity than the same domains from CBX proteins that activate transcription, or the YAF2_RYBP domain of RYBP ($p = 0.008$, two-tailed t-test)(**Figure 3H**)(Wang et al., 2008, 2010). Thus, the differences in the transcriptional activity of CBX-C and YAF2_RYBP domains might be explained by their binding affinity for RING1B or by differential binding to other factors. In any case, these results suggest that the differences in CBX protein function (Morey et al., 2012; Vincenz and Kerppola, 2008) could be at least partially explained by the intrinsic differences in their CBX-C domains. More broadly, these results reveal another layer of complexity in the assembly and function of noncanonical and canonical PRC2 complexes.

[00140] Methods are as described in Example 7.

Example 5. Novel transcriptional activators interact with known co-factors.

[00141] The ORFeome-wide screen revealed several potent transactivators that were either poorly or completely uncharacterized. To understand how these factors regulate

transcription, stable, tetracycline-inducible HEK293 cell lines were established, expressing nine poorly characterized screen hits (C3orf62, C11orf74/IFTAP, NCKIPSD, DCAF7, SS18L2, SPDYE4, FAM90A1, FAM22F/NUTM2F, JAZF1), five known transcriptional regulator hits (SOX7, KLF6, KLF15, CTBP1, HOXA2, and HOXB2), two synthetic transactivators (VP64 and VPR), and negative controls (EGFP and Nanoluc) fused to biotin ligase BirA from *Aquifex aeolicus* and FLAG epitope tag. Their protein interactomes were characterized with affinity-purification coupled to mass spectrometry (AP-MS) and proximity partners with proximity-dependent biotinylation (BioID2)(Kim et al., 2016). AP-MS is an ideal method for characterizing stable protein complexes, whereas BioID excels in identifying interactions that are weaker or involve poorly soluble proteins, such as those tightly bound to chromatin (Lambert et al., 2015).

[00142] The interactomes of transcriptional activators revealed two patterns. First, they indicated that the transactivation potential of the novel hits likely reflects their endogenous function rather than being an artefact of the tethering assay. Second, the interactomes uncovered a striking preference of the activators for specific co-activator complexes, converging on five distinct co-factors (CBP/p300, BAF, NuA4, Mediator, and TFIID).

[00143] Supporting a native role for the novel activators in transcriptional regulation, eight of the nine poorly characterized hits associated with known transcriptional co-factors in AP-MS, BioID, or both (**Figure 4A**, **Figure 12**). C3orf62, DCAF7, and FAM22F/NUTM2F interacted with p300 and/or CBP, which are known transcriptional co-activators. JAZF1, in contrast, associated with multiple subunits the NuA4 histone acetyltransferase complex in BioID, suggesting that it is a novel subunit of this highly conserved complex. SS18L2, in turn, interacted with the BAF chromatin remodeling complex, including core BAF members SMARCA2 and SMARCA4 as well as subunits specific to the canonical BAF (cBAF) and non-canonical BAF (ncBAF) (**Figure 4A** and 12)(Centore et al., 2020). SPDYE4 and FAM90A1 interacted with the BET family bromodomain proteins BRD2, BRD3, and BRD4, which regulate transcriptional elongation (Fujisawa and Filippakopoulos, 2017). NCKIPSD, also known as SPIN90, interacted with the survival of motor neurons (SMN) complex, which regulates the assembly of ribonucleoprotein complexes but has also been linked to transcriptional activation (Pellizzoni et al., 2001; Singh et al., 2017; Strasswimmer et al., 1999) (**Figure 12**). Interestingly, NCKIPSD also interacted with DCAF7 (**Figure 12B**). Both DCAF7 and NCKIPSD have been implicated in the regulation of actin dynamics in the cytoplasm (Cao et al., 2020; Morita et al., 2006), suggesting that these proteins may have distinct roles in the cytoplasm and in the nucleus.

[00144] Known transcriptional regulators also associated with co-activator complexes (**Figures 4A** and 12). KLF6 bait identified the NuA4 subunit EPC1 as a proximity interactor, whereas HOXB2, KLF15, CTBP1, and SOX7 baits had CBP and p300 as proximity partners. In addition, SOX7 also associated with BAF subunits. In contrast to all native activators except for SOX7, the powerful synthetic activators VP64 and VPR identified multiple different co-activators as proximity partners. VP64, which consists of four tandem copies of the viral VP16 transactivation motif, associated with CBP/p300 and mediator subunits MED14 and MED15, consistent with previous reports (Kundu et al., 2000; Yang et al., 2004). VPR, which is a fusion of VP64, human p65/RELA transactivation domain, and Epstein-Barr virus R transactivator (Chavez et al., 2015), associated with even more co-factors, including CBP/p300 and multiple subunits of the Mediator and TFIID (**Figures 4A** and 12A). Such association with multiple co-factors likely explains the exceptional transactivation potency of VPR when fused to dCas9 (Chavez et al., 2015, 2016).

[00145] These results suggest that activating transcription factors and other transcriptional regulators have a strong intrinsic preference for specific co-factors. To further investigate this, a previously published AP-MS interaction dataset of Forkhead family TFs (Li et al., 2015) was analyzed and compared with the transcriptional activation results in this assay. Notably, only those Forkhead TFs that activated transcription when recruited to the reporter interacted with co-activators in AP-MS (**Figure 4B**). In addition, similar to the mass spectrometry results, activating Forkhead TFs had distinct co-factor preferences: FOXO1 and FOXO3 interacted specifically with CBP and p300, FOXN1 interacted with both p300 and subunits of the BAF complex, whereas FOXR1 and FOXR2 preferred the NuA4 complex (**Figure 4B**). These data strongly suggest that related transcription factors, which recognize highly similar sequences and activate transcription nearly to the same extent, can promote transcription through distinct co-activator complexes.

[00146] To functionally investigate the connection between transcriptional activators and co-factors, a panel of 83 robust activators was arrayed. Their activation potential was tested using the reporter assay, but now in the presence of small-molecule inhibitors targeting multiple transcriptional co-regulators. Three kinase inhibitors targeting transcriptional kinases (flavopiridol for CDK9, CX-4945 for casein kinase 2, and AZ191 for DYRK1A and DYRK1B), and two compounds inhibiting transcriptional co-factors (A-485 for CBP/p300, and JQ1 for BET family bromodomain proteins) were employed.

[00147] The three kinase inhibitors affected nearly all activators, although to a different degree. Inhibiting CDK9 with flavopiridol led to nearly complete loss of activity of all activators,

consistent with the key role of p-TEFb in promoter clearance (**Figure 13A**). Inhibition of casein kinase 2, which regulates transcriptional elongation (Basnet et al., 2014), also led to a general albeit modest attenuation of transcriptional activation (**Figure 13B**). DYRK1A/DYRK1B inhibition had a more subtle effect than the other two compounds, slightly attenuating the activity of most activators (**Figure 13C**). Interestingly, two activators that were not affected by the DYRK1A/DYRK1B inhibitor AZ191 were DCAF7, which forms a conserved complex with DYRK1A (Breitkreutz et al., 2010; Yu et al., 2019), and NCKIPSD, which interacts with DCAF7 (**Figure 13C**).

[00148] In contrast to kinase inhibitors that had broad effects on transcription, inhibiting the acetyltransferase activity of CBP/p300 strongly affected the activity of some but not all transactivators (**Figure 4C**). Importantly, these effects were consistent our AP-MS and BioID results: the activity of four of the six CBP/p300 interactors was significantly decreased, whereas only one of the seven non-interactors was affected by A-485 (**Figure 13D**). For example, A-485 inhibited the activity of KLF15, whereas it had no effect on the related Kruppel-like factor KLF6 (**Figure 13D**). More broadly, the activity of proteins known to interact with CBP/p300 was significantly more inhibited by A-485 than that of non-interacting transactivators (**Figure 4C**). In comparison, interactors of NuA4 complex were not significantly affected by CBP/p300 inhibition (**Figure 4D** and 13D).

[00149] Similar to CBP/p300 inhibition, BET family inhibition with JQ1 had distinct effects on some transactivators. Interestingly, in most cases JQ1 treatment led to an increase in reporter gene activity (**Figure 4D**). Although JQ1 treatment leads to rapid downregulation of BRD4 target genes in many cases (Lovén et al., 2013; Muhar et al., 2018), it has also been linked to transcriptional activation of reporter genes (Sdelci et al., 2016), which likely explains the effect observed. Nevertheless, not all transactivators responded similarly to JQ1 treatment. In particular, factors interacting with subunits of NuA4 complex were not affected by JQ1 treatment (e.g., JAZF1 and KLF6; **Figure 4D** and **13D**). Indeed, NuA4 interactors were significantly less affected by JQ1 treatment that CBP/p300 interactors or other transactivators (**Figure 4D**). Although the mechanism by which NuA4 interactors respond to JQ1 treatment in a unique manner requires further research, these results demonstrate how transcriptional activators promote transcription via different co-activator complexes in the context of a single promoter. Indeed, hierarchical clustering of the activators based on their sensitivity to the five compounds revealed multiple distinct groups (**Figure 4E**). Many paralogous factors (such as CITED1 and CITED2, or PCGF3 and PCGF5) clustered next to each other, indicating that clustering produced functionally relevant groups. Moreover, known CBP/p300 interactors were

primarily in two distinct clusters, as were NuA4 interactors (**Figure 4E**). It is likely that other members of these clusters similarly use CBP/p300 or NuA4 as co-activators, such as YAF2 or MYOG for p300, or NOM1 for NuA4.

[00150] Methods are as described in Example 7.

Example 6. SRF-C3orf62 fusion interacts with CBP/p300 and promotes SRF/MRTF transcriptional program.

[00151] Fusion proteins involving transcriptional regulators are common hallmarks of certain cancers, such as leukemias and sarcomas. Hits from our ORFeome-wide screen were significantly enriched for genes documented in the COSMIC database (cancer.sanger.ac.uk) as fusion partners in diverse cancers ($p = 0.019$; hypergeometric distribution test). These included well-characterized fusion partners such as ERG, which is fused to EWSR1 in Ewing sarcoma and to TMPRSS2 in prostate cancer; DDIT3/CHOP, fused to EWSR1 or FUS in myxoid liposarcoma; CRTC1, fused to MAML2 in mucoepidermoid carcinoma; and ENL/MLLT1, fused to MLL in mixed lineage leukemia. In addition, several hits have been described in literature as fusion partners but not functionally characterized. For example, BTBD18 and NCKIPSD were identified as KMT2A/MLL fusion partners leukemia (Alonso et al., 2010; Sano et al., 2000). Moreover, the fragment of BTBD18 that is fused to MLL contains the transactivation domain identified by TAD-seq (**Figure 10B**), implicating the TAD in the oncogenic potential of the fusion product. Most MLL fusions involve genes regulating transcriptional elongation, such as the super elongator complex (Winters and Bernt, 2017). Interestingly, BTBD18 has also been shown to promote transcriptional elongation (Zhou et al., 2017).

[00152] To gain more insight into the mechanisms by which the activation screen hits might promote tumorigenesis as fusion partners, two poorly characterized fusions, JAZF1-SUZ12 and SRF-C3orf62 were selected for further characterization. The JAZF1-SUZ12 fusion is a hallmark of low-grade endometrial stromal sarcoma (LG-ESS)(Hrzenjak, 2016), bringing together the Polycomb protein SUZ12 and JAZF1 (**Figure 5A**)(Piunti et al., 2019). SRF-C3orf62 was recently described in a pediatric case of myofibroma/myopericytoma (Antonescu et al., 2017). In this fusion, the DNA-binding domain of Serum Response Factor (SRF) is fused to the C-terminus of C3orf62 (**Figure 5B**). Notably, in both cases the transactivation domain that identified by TAD-seq (**Figure 3C and 10B**) is retained in the fusion constructs (**Figure 5A** and **5B**)

[00153] SUZ12, SRF, JAZF1-SUZ12, SRF-C3orf62, and the C-terminal fragment of C3orf62 fused to SRF (C3orf62-Cterm) were tagged with BirA-FLAG and their interactomes were analyzed with BioID and AP-MS, to complement the data we obtained for JAZF1 and C3orf62. As expected, SUZ12 proximity partners included other components of the PRC2 complex, such as EZH2, MTF2/PCL2 and C10orf12 (Alekseyenko et al., 2014)(**Figure 5C**). Strikingly, the JAZF1-SUZ12 fusion protein had both PRC2 and NuA4 subunits as proximity partners (**Figure 5C**), indicating that this fusion assembles into a supercomplex of two chromatin-associated complexes that are normally associated with opposing transcriptional activities. Consistent with this, EPC1-PHF1 fusion that is also associated with LG-ESS similarly assembles the PRC2-NuA4 supercomplex, which leads to aberrant expression of Polycomb targets (Sudarshan et al., 2021). Moreover, both JAZF1-SUZ12 and EPC1-PHF1 were recently shown to be strong transcriptional activators (Sudarshan et al., 2021). Thus, NuA4 integration into the oncogenic supercomplex can override the normally repressive function of PRC2 complexes.

[00154] SRF proximity partners included multiple transcription factors such as ELK1, which forms a ternary complex with SRF on serum response elements (SREs)(Buchwalter et al., 2004)(**Figure 5D**). However, it did not associate with any transcriptional co-activators. In contrast, both C3orf62-Cterm construct and the SRF-C3orf62 fusion robustly identified both CBP and p300 as proximity partners (**Figure 5D**). AP-MS similarly identified CBP and p300 as prominent SRF-C3orf62 interactors (**Figure 14A**). Consistent with these results, both C3orf62-Cterm and SRF-C3orf62 strongly activated the GFP reporter when tethered to the reporter (**Figure 5E**). This activity was highly sensitive to CBP/p300 inhibition with A-485 (**Figure 5F**), in line with the interaction patterns of SRF-C3orf62.

[00155] SRF functions together with either ternary complex factors (TCFs; e.g. ELK1) or myocardin-related transcription factors (MRTFs; e.g. MAL) to regulate target gene expression (Buchwalter et al., 2004; Olson and Nordheim, 2010). The results suggested that SRF-C3orf62 can activate SRF target genes without such cofactors. To test this further, the activity of different constructs was assayed in NIH3T3 fibroblasts using a luciferase-based serum response element reporter (Vartiainen et al., 2007). SRF or C3orf62 alone did not activate the reporter whereas SRF-C3orf62 robustly did so (**Figure 5G**), further confirming that the cancer-associated fusion bypasses the requirement for SRF cofactors in transcriptional activation.

[00156] The SRF/TCF pathway, which is regulated by MAP kinase signaling, regulates the expression of immediate-early genes (Gualdrini et al., 2016), whereas the actin-Rho

signaling dependent SRF/MRTF pathway targets genes involved in cell motility and adhesion (Miralles et al., 2003). To test if SRF-C3orf62 can regulate target genes of both pathways, stable doxycycline-inducible NIH3T3 cell lines stably expressing SRF, C3orf62, SRF-C3orf62 and Nanoluc fused to GFP were generated. Transgene expression was induced with doxycycline for 24 hours and changes in gene expression were analyzed by RNA-seq. While expression of GFP-tagged C3orf62 or SRF had very limited or no effects on the transcriptome compared to Nanoluc (**Figure 14B**), expression of SRF-C3orf62-GFP led to upregulation of 564 genes and downregulation of 471 genes (with log2 fold change > 1, FDR < 0.05; **Figure 5H** and **14B**). Gene set enrichment analysis (GSEA) and Gene Ontology analysis revealed that the upregulated genes were highly enriched in genes involved in DNA replication, cell cycle progression, and mitosis (**Figure 5I** and 14C), whereas downregulated genes were related to extracellular matrix (**Figure 14C**). Upregulated genes were also significantly enriched in targets of the E2F transcription factor, a key regulator of cell proliferation (**Figure 5I**). These signatures are consistent with the oncogenic nature of the SRF-C3orf62 fusion. In addition, many of the most upregulated genes were involved in actin dynamics and myogenesis. For example, one of the most upregulated genes was smooth muscle actin (ACTA2), a known target of SRF/MTRF and a hallmark of SRF fusion positive myofibromas/myopericytomas (Antonescu et al., 2017)(**Figure 5H**). Consistent with this, another significant signature of the upregulated genes was myogenesis (**Figure 5I**). In contrast, many well-characterized immediate-early target genes of SRF/TCF such as FOS, EGR1, or EGR2 were not affected by ectopic SRF-C3orf62 expression (**Figure 5H**). Interestingly, fusion of SRF to VP16 can potently upregulate FOS, suggesting that there are intrinsic differences in the ability of different TADs to activate target gene expression (Schratt et al., 2002). Indeed, there was a significant overlap between genes upregulated by SRF-C3orf62 and previously reported target genes of SRF/MRTF, but not with those of SRF/TCF (**Figure 14D**)(Esnault et al., 2014; Gualdrini et al., 2016). Taken together, these results indicate that SRF-C3orf62 expression leads a proliferative and myogenic gene expression signature and preferential expression of SRF/MRTF target genes over SRF/TCF targets.

[00157] Methods are as described in Example 7.

Example 7. Methods:

[00158] **Cell culture.** All HEK293T cells, including the pTRE3G-EGFP reporter cell line (gift from Lei Stanley Qi lab, Stanford University) used for screens, were maintained in DMEM with 10% fetal bovine serum (FBS). NIH-3T3 cells were obtained from Dr. Sachdev Sidhu's lab (University of Toronto) and maintained in Dulbecco's Modified Eagle's Medium (DMEM)

with 10% bovine calf serum (BCS). All culture media were supplemented with 1% penicillin-streptomycin. Cells were maintained at 37°C in a humidified incubator at 5% CO2 and routinely tested for mycoplasma contamination.

[00159] **Lentivirus production.** Lentiviral particles containing the pooled ORFeome and transactivation libraries were produced by transfecting 293T cells with pLX301-ORFs/TADs-PYL1, psPAX2 (Addgene #12260) and pVSV-G (Addgene #8454) at a ratio of 8:6:1. Transfection was performed using XtremeGENE 9 (Roche) on 15-cm dishes according to the manufacturer's protocol. The medium was changed 6-8 hours post-transfection to harvest medium (DMEM + 1.1 g per 100 mL BSA). 72 hours after transfection, supernatant was filtered (0.45 µM), pooled and collected. A similar protocol was followed for small scale virus production when establishing individual stable cell lines with transfection being performed on 6-well plates using Lipofectamine 2000 (Thermo Fisher Scientific, 11668019) reagent.

[00160] **Cell line generation.** A clonal line of the EGFP reporter line was generated expressing ABI-dCas9 (blastacidin, 6 µg/mL) and gRNA (SEQ ID NO: 10) (co-expressing EBFP2) targeting the pTRE3G promoter. Single cells were sorted (FACS Aria IIIu, BD) and expanded and a clone showing induction by a strong transcriptional activator was selected for subsequent experiments. To generate NIH3T3 cells expressing doxycycline-inducible EGFP tagged proteins, entry clones were picked from the hORFeome collection and subcloned into the Gateway compatible pSTV6-TetO-ccdB-EGFP lentiviral plasmid (a kind gift from Payman Samavarchi-Tehrani). NIH-3T3 cells were infected in the presence of 8 µg/mL polybrene and selected with 2 µg/mL puromycin 24 hours post infection.

[00161] **Pooled ORFeome library generation.** Entry clones from the human ORFeome collection (v8.1) were collected into 40 standardized subpools each containing ~384 ORFs and cloned into the lentiviral Gateway-compatible destination vector pLX301-DEST-PYL1. LR reactions were set up in duplicates with 150 ng of each entry ORF subpool, combined with 1 µl of Gateway LR clonase II in a total of 5 µl reaction volume and incubated overnight in TE buffer at room temperature. For the next two days, 1 µl additional LR enzyme was added in 4 µl TE and 150 ng destination vector to each reaction. Colonies were transformed into chemically competent DH5alpha *E. coli* and spread on LB agar plates containing carbenicillin (100 µg/µl) overnight at 30°C. Colonies were counted to ensure >200-fold coverage, collected in SOC on ice, pelleted and maxiprepped on multiple columns based on weight of the dry pellets.

[00162] **Activation domain tiling library generation.** A tiling library was generated from 75 proteins identified as activators in the ORFeome screen. Oligonucleotides containing a 5' adapter GGAAGTCAGGGTAGCGGAAGTATG (SEQ ID NO: 23) and a 3' adapter GGAGGTAGTGTTGAACGCGAAGGC (SEQ ID NO: 24) to generate a 5' adapter (GSQGSGSM) (SEQ ID NO: 11) and a 3' adapter (GGSVEREG) (SEQ ID NO: 12) were synthesized as pooled libraries (Twist Biosciences). 6x50 µl PCR reactions were set up using NEBNext Ultra II Q5 master mix (New England Biolabs) with 5 nM oligos as template. PCR conditions were optimized to find the lowest cycle with a clean visible product at the expected 300 bp length. The thermocycling condition was an initial 30 s at 98°C, then 2 cycles of 98°C for 10 s, 63°C for 20 s, and 72°C for 15 s, followed by 10 more cycles of 98°C for 10 s and 72°C for 30 s with a final extension at 72°C for 5 min. Primers were designed to have Gateway compatible flanking sequences. The resulting libraries were gel extracted by QIAgen gel extraction kit after loading on a 2% TAE gel for 2 hrs at 60V and subsequently cloned into pDONR221 using 20 separate BP reactions in total of 5 µl reactions. The entry plasmid pool was transformed after an overnight reaction into DH5alpha competent *E. coli* and incubated overnight on LB agar plates containing kanamycin (100 µg/µl). Colonies were collected and plasmid DNA purified. 20 LR reactions were then set up as described in the previous section. Each reaction was transformed into NEB 10-beta chemically competent *E. coli* and grown on LB agar plates containing carbenicillin (100 µg/µl) overnight at 30°C. Colonies were counted to ensure >200-fold coverage at each step of cloning, pooled and maxiprepped.

[00163] **Pooled activation screens.** ORFeome and transactivation tiling libraries tagged at the C-terminus with PYL1 were packaged into lentiviral particles. A clonal EGFP reporter cell line stably co-expressing ABI-dCas9 and a gRNA targeting the promoter were transduced at low multiplicity of infection (MOI) with approximately 30% cell survival after puromycin (1 µg/mL) selection. Untransduced cells under the same condition were fully eliminated. Sufficient cells were transduced to maintain >500 fold coverage of the libraries. Recruitment was induced by treating cells with 100 µM abscisic acid (ABA, Sigma) for 48 hours. In parallel, a control batch of cells were treated with equal total volume of DMSO. Cells were then washed in PBS, treated with dissociation buffer (1 mM EDTA, 10 mM KCl, 150 mM NaCl, 5mM sodium bicarbonate, 0.1% glucose) and resuspended in flow buffer (5 mM EDTA, 25 mM HEPES pH 7, 1% BSA, PBS). High GFP population for each library, top 1% for ORFeome and two bins of top 1% and the next 4% for the TAD screen, were sorted and their genomic DNA directly extracted using QIAmp DNA Blood Mini Kit (QIAGEN).

[00164] **ORFeome sequencing.** Nested PCR was performed using all the purified genomic DNA from sorted populations or at least 5 µg of genomic DNA from presort populations. The target ORFeome region was amplified from genomic DNA using primers targeting the T7 promoter and PYL1. The product of this reaction was pooled for each sample and further amplified by primers targeting outside the Gateway attB sites for an additional 10 cycles. Amplicons were subsequently separated on 1% agarose gel and any visible PCR product excluding primer dimers were gel purified. After quantifying DNA using the Quant-iT 1X dsDNA HS kit (Thermo Fisher Scientific, Q33232), 50 ng per sample was processed using the Illumina DNA Prep, (M) Tagmentation kit (Illumina, 20018705), with 6 cycles of amplification. 2 µl of each purified final library was run on an Agilent TapeStation HS D1000 ScreenTape (Agilent Technologies, 5067-5584). The libraries were quantified using the Quant-iT 1X dsDNA HS kit (Thermo Fisher Scientific, Q33232) and pooled at equimolar ratios after size-adjustment. The final pool was quantified using NEBNext Library Quant Kit for Illumina (New England Biolabs, E7630L) and paired-end sequenced on an Illumina MiSeq.

[00165] **TAD sequencing.** Performed nested PCR on the purified genomic DNA using primers targeting T7 promoter and PYL1 of the backbone vector in the first step creating a ~470 bp product. Products of the first reaction were then pooled and amplified for an additional 10 steps using primers targeting outside the Gateway sites creating a ~300 bp product. Libraries were quantified on Qubit dsDNA Broad Range kit and paired-end sequenced on an Illumina MIseq with a custom PAGE-purified R1 sequencing primer.

[00166] **Analysis of sequencing data from pooled activation screens.** An index of the ORFeome reference sequences was created using the STAR aligner v2.7.8a with the length of the pre-indexing string set to 11 to account for the smaller 'genome' size. Reads from the ORFeome libraries were aligned with the STAR aligner allowing a maximum of 3 mismatches. For the TAD sequencing reads, cloning adapter sequences were first removed from both ends using cutadapt with CCAGTGTGGTGGAATTCTGCAGATATCAACAAGTTTGTACAAAAAAGTTGGCGGAAGTC AGGGTAGCGGAAGT (SEQ ID NO: 20) for 5' and CCGCCACTGTGCTGGATATCAACCACTTTGTACAAGAAAGTTGGGTAGCCTTCGCGTTC AACACTACCTCC (SEQ ID NO: 21) for 3' adapters. Bowtie reference was generated, and reads were mapped using Bowtie v1.2.3 allowing 0 mismatches. To identify activators, the edgeR package (Robinson et al., 2010) was used to calculate log2 fold change, p-value, and false discovery rate (FDR) for each ORF by comparing changes in counts from sorted samples to unsorted cells.

[00167] **Arrayed recruitment assays.** Reporter cells stably co-expressing ABI-dCas9 and TetO gRNA were seeded either on 48-well or 96-well plates (Sarstedt) to reach 50-70% confluency on the day of transfection. 150 ng of each construct to be tested was transfected with polyethylenimine (PEI) at a ratio of 0.6 µl reagent. The day after transfection, recruitment was induced by treatment with ABA (100 µM). For tethered reporter assays in the presence of inhibitors, recruitment was similarly induced with 100 µM ABA the day after transfection but in the presence of either an inhibitor or the same volume of any additional DMSO. Inhibitors were dissolved in DMSO to a stock concentration of 10 mM. The final concentrations used were 100 nM for flavopiridol, 300 nM for JQ1, 1 µM for A-485, 2.5 µM for CX-4945 and 3 µM for AZ191. All inhibitors were a kind gift from the Structural Genomics Consortium (SGC). 48 hours after induction, cells were dissociated and resuspended in flow buffer using a liquid handing robot (TECAN) and analyzed by LSR Fortessa (BD). Cells were gated on high EBFP2 and RFP as a measure of gRNA and transfection control, respectively. Flow cytometry data was analyzed using FlowJo (v10).

[00168] **SRF reporter assay.** 30,000 NIH-3T3 cells on 24-well plates were transfected with 8ng SRF reporter (p3DA.luc), 20 ng reference reporter (pcDNA3.1-Nanoluc-3xFLAG-V5) and 50 ng 3xFLAG tagged constructs (Addgene #87063). Transfection was carried out using Lipofectamine 3000 reagent (Thermo Fisher Scientific, L3000001) according to the manufacturer's protocols. Luciferase constructs were a kind gift from Dr. Maria Vartiainen (University of Helsinki). Cells were maintained in low-serum media (0.5% BCS) for 18 hours and stimulated for 7 hours (15% BCS), after which luciferase activity was measured. Firefly luciferase was normalized to Renilla luciferase activity using data from four independent transfections.

[00169] **RNA sequencing and analysis.** NIH-3T3 cells with stable integrations of SRF, C3orf62, SRF-C3orf62 or Nanoluc tagged at the C-terminus with EGFP were induced with 1 µg/mL doxycycline for 24 hours. RNA was extracted from cells maintained in low-serum conditions (0.5% calf serum) for 22 hours using RNeasy purification kit (Qiagen) and treated with DNase on column. Samples were induced and collected in technical duplicates from 6-well plates. Libraries were prepared using the NEBNext Ultra II Directional RNA-seq with Poly-A selection kit, pooled and sequenced on a 100-cycle NovaSeq 6000 SP. Reads were aligned to the Gencode mouse primary assembly (GRCm39) with STAR aligner v2.7.8a. Counts for each gene were generated using the Gencode vM26 transcript annotations. Changes in gene expression compared to cells expressing Nanoluc-EGFP were quantified using the edgeR package (Robinson et al., 2010).

[00170] **Mass spectrometry samples.** Entry clones were from the human ORFeome collection (Yang et al., 2011). Clones were transferred into pDEST-pcDNA5 vector carrying a C-terminal BioID2-FLAG tag (Kim et al., 2016) using Gateway recombinase. Stable HEK293 Flp-In T-REx cell lines were generated as previously reported (Piette et al., 2021).

[00171] For AP-MS, cells were grown to 70% confluence on 150 mm dishes before inducing bait expression with 1 µg/mL tetracycline for 24 hours. Cells were then washed once with 1xPBS, scraped, pelleted, flash-frozen, and stored at -80°C until processing. AP-MS was performed as previously described (Lambert et al., 2015). Briefly, cells were resuspended in cold lysis buffer (50 mM HEPES-NaOH pH 8.0, 100 mM KCl, 2 mM EDTA, 0.1% NP40, 10% glycerol, 1 mM PMSF, 1 mM DTT, 15 nM Calyculin A and protease inhibitor cocktail (Sigma-Aldrich P8340)) using a 1:4 pellet weight:volume ratio. Cells were lysed by one round of freeze-thaw, and lysates sonicated at 4°C using three 10-second bursts at 35% amplitude with 2 s pauses. Sonicated lysate was treated with 100U benzonase for 30 minutes at 4°C prior to clearing by centrifugation at 20,000g for 20 minutes at 4°C. An equal amount of supernatant from all samples processed within a batch was transferred to a tube containing 25 µL of pre-washed anti-FLAG magnetic bead 50% slurry (Sigma, M8823) and incubated for two hours at 4°C. Beads were recovered by magnetization and the supernatant discarded. Beads were washed once in lysis buffer, and once in 20 mM Tris-HCl pH8.0 with 2 mM $CaCl_2$ and digested on beads with trypsin in two stages (1 µg trypsin for 4 hours followed by the addition of 0.5 µg trypsin to the supernatant and overnight incubation at 37°C), as previously described (Taipale et al., 2014). Finally, samples were acidified with 5% formic acid (final concentration) and stored at -80°C.

[00172] For BioID, cells were grown to 70% confluence in 150 mm dishes before inducing gene expression with 1 µg/mL tetracycline for 18 hours. 50 µM biotin was then added to each plate for 6 hours. Cell pellets were collected as for AP-MS, and resuspended in lysis buffer (50 mM Tris-HCl pH 7.5, 150 mM NaCl, 0.1% SDS, 1% Igepal CA-630, 1mM EDTA, 1 mM $MgCl_2$, protease inhibitor cocktail (Sigma-Aldrich P8340, 1:500), and 0.5% sodium deoxycholate) using a 1:10 pellet weight:volume ratio. After sonication, each sample was treated with 250U Turbonuclease (BioVision 9207-50KU) and 1 µL RNase A solution (Sigma-Aldrich R6148) and incubated for 30 minutes at 4°C. SDS was then added to a final concentration of 0.25% and after mixing the samples were incubated for another 10 minutes at 4°C followed by centrifugation at 20,000g for 20 minutes. The supernatant was transferred to a tube containing 30 µl of pre-washed packed streptavidin beads (GE Healthcare, 17-5113-01). Streptavidin pulldown was done for 3 hours at 4°C. Beads were washed once in 1 ml of

SDS buffer (2% SDS/50 mM Tris-HCl pH7.5), once in 1 ml lysis buffer, and once in TAP buffer (50 mM HEPES-KOH pH 8.0, 100 mM KCl, 10% glycerol, 2 mM EDTA, 0.1% Igepal CA-630), followed by three 1 ml washes with 50 mM ammonium bicarbonate pH 8.0. After the washes, beads were resuspended in ABC buffer containing 1 µg trypsin and incubated overnight at 37°C. The following day, the supernatant was collected and the streptavidin beads were washed with 50 µl water, which was combined with the first supernatant fraction. 0.5 µg trypsin was added to the combined supernatant sample, which was then incubated at 37°C for 4 hours. Beads were then spun down and the supernatant recovered. Beads were rinsed twice using ABC buffer and these rinses were combined with the original supernatant. Combined supernatants were dried by centrifugal evaporation.

[00173] **Mass spectrometry data acquisition and analysis.** Samples were analyzed on a TripleTOF 5600 instrument (AB SCIEX, Concord, Ontario, Canada) as previously described (Piette et al., 2021) using Data-Dependent Acquisition (DDA). Data were processed and analyzed as previously described (Piette et al., 2021), using Proteowizard (Adusumilli and Mallick, 2017) implemented in ProHits v4.0 (Liu et al., 2016), Mascot, and Comet (Eng et al., 2013). The results were subsequently analyzed with the Trans-Proteomic Pipeline using iProphet (Shteynberg et al., 2011), and proteins with an iProphet probability ≥ 0.95 were further analyzed.

[00174] Significant interactors were identified with SAINTexpress (Teo et al., 2014). EGFP-BioID2-FLAG and EGFP-BioID2-FLAG were used as negative controls, using 2-fold compression for stringency as previously described (Mellacheruvu et al., 2013). SAINTexpress analysis used default parameters, and prey proteins were considered significant if they passed calculated Bayesian FDR cutoff of ≤5%. Dot plot figures were generated with ProHits-viz webserver (Knight et al., 2017).

Example 8. Multiple TADs can be combined to activate transcription

[00175] Multiple TADs were fused together with PYL1 and tested for transcriptional activity using the PYL1-ABI EGFP reporter system described above. The following TAD fragments were used: CITED1-8 (SEQ ID NO: 47), CITED2-12 (SEQ ID NO: 49), C3orf62-12 (SEQ ID NO: 45), BRD8-25 (SEQ ID NO: 40), ZXDC-12 (SEQ ID NO: 97), KLF7-1 (SEQ ID NO: 72), ATXN7L3-1 (SEQ ID NO: 35), FAM90A1-20 (SEQ ID NO: 60), SPDYE4-3 (SEQ ID NO: 90), YAF2-7 (SEQ ID NO: 96).

[00176] As shown in Figure 16, the SPDYE4-CITED1 TAD fusion protein resulted in a marked increase in transcriptional activation compared to either TAD alone.

[00177] Up to 2 additional TADs selected from p65 and HSF1 were combined with SPDYE4-CITED1 TADs in different orders and tested for the ability to activate transcription of the PYL1-ABI EGFP reporter system (Figure 17, left panel) or the endogenous *CD133* gene (Figure 17, right panel). The SPDYE4-CITED1-P65-HSF1 (SCPH) effector provided the most robust activation in both systems tested.

[00178] To test additional TAD combinations, each part of the multi-component SPDYE4-CITED1-P65-HSF1 (SCPH) effector was individually replaced with another TAD identified in Example 4 (see e.g. Table 1). Results are shown in Figure 18.

[00179] To test whether shorter TAD sequences could be used in the SCPH effector, each TAD was independently replaced with a short or mini TAD component. Results are shown in Figure 15. Mini-TAD sequences were selected as follows:

[00180] miniSPDYE4 (SEQ ID NO: 102): Sequence was selected based on the overlap between the two enriched fragments from our tiling screen of the SPDYE4 full length protein. The minimal sequence was designed to include either the acidic rich region or the following beta hairpin.

[00181] miniHSF1: The 150 amino acid C-terminal region of HSF1 which contains its activation domain comprises of two known TADs. The longer TAD is between amino acids 431-529 and the shorter one ("mini-HSF1 (401-420)" or "H(mini)"; SEQ ID NO: 119) is between amino acids 401-420. We selected the shorter domain rich in hydrophobic residues to test due to its more compact size and as it was previously reported to have more potency than the longer TAD. (Newton et al., 1996; 10.1128/MCB.16.3.839)

[00182] miniP65: RelA or p65 is known to have two distinct transactivation domains within its C-terminus. The first TAD ("P(mini N-term)"; SEQ ID NO: 105) comprises amino acids 428-520 and the second ("P(mini C-term)"; SEQ ID NO: 106) is the proceeding 521-551 residues. (Schmitz and Baeuerle, 1991; 10.1002/j.1460-2075.1991.tb04950.x)

[00183] miniCITED1 ("C(mini)"; SEQ ID NO: 103) was selected to include the C-terminal acidic-rich region within the overlapping region between CITED1-7 and CITED1-8.

[00184] Methods: Cells were seeded on 48-well plates. Next day, after cells were between 70-90% confluent, 250 ng of each construct was transfected in each well using (Thermo Fisher Scientific, 11668019) reagent. Each construct was either directly fused TagRFP either directly fused to each component or being co-expressed from the same plasmid was used as a measure of transfection. In each experiment, the same gate for RFP+ cells were used to control for the effect of each construct's expression levels on activity. EGFP

reporter cells were expanded from a clonal line to control for level of ABI-dCas9 and gRNA targeting the TetO7 sites upstream of the promoter. For the CD133 induction experiment, a 293T cell line stably expressing ABI-dCas9 and a pool of 5 gRNAs targeting the promoter were used for all activators. CD133 antibody conjugated to APC (Miltenyi Biotec, 130-113-668) was used. All activator constructs were fused to PYL1 at their C-terminus and were recruited to their targets by treating the cells with 1 μM abscisic acid for either 24 or 48 hours.

Example 9.

[00185] A further 117 different combinations of activation domains or fragments of individual activation domains were assayed by fusing them either to PYL1 (to test with the dCas9-ABI1 system) or to rTetR, a transcription factor that binds DNA in the presence of doxycycline. All constructs were tested with the same TetO reporter construct. Large differences were observed in the activity of these constructs, ranging from no activity to very high potency (**Figure 19A-B**). In general, there was a good correlation between the results with rTetR and dCas9 based recruitment systems (**Figure 19C**), suggesting that most activation domains function similarly in both contexts. However, for example VPR was much less active as an rTetR fusion than as a dCas9 fusion. Consistent with previous experiments, SCPH and its variants were still the most active constructs in the system. For example, a construct containing a miniaturized activation domain of C3orf62 instead of that from CITED1 ("C" in the SCPH construct) and a shorter version of p65 activation domain ("P") was more potent than the original SCPH construct despite being significantly smaller (1059 bp vs 1611 bp) (**Figure 19A-B**).

[00186] Methods: 200 ng of plasmid expressing superactivators fused to rTetR in their C terminus and 50 ng DsRed was transfected into HEK293T cells stably expressing 7xTetO-EGFP reporter. One day after transfection, cells were treated with 1 μg/ml doxycycline for 48 hours. After the treatment, cells were analyzed by flow cytometry for EGFP expression

[00187] While the present application has been described with reference to what are presently considered to be the preferred examples, it is to be understood that the application is not limited to the disclosed examples. To the contrary, the application is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims. The scope of the claims should not be limited by the preferred embodiments and examples, but should be given the broadest interpretation consistent with the description as a whole.

[00188] All publications, patents and patent applications are herein incorporated by reference in their entirety to the same extent as if each individual publication, patent or patent application was specifically and individually indicated to be incorporated by reference in its entirety.

Table of Sequences

Glycine serine linker (SEQ ID NO: 6) SGGSGGS

Glycine serine linker (SEQ ID NO: 7) SGGS

Glycine serine linker (SEQ ID NO: 8) GSGSGS

linker (SEQ ID NO: 9) INSRSSGS

NLS (SEQ ID NO: 22) PKKKRKV

Linker + NLS (SEQ ID NO: 141) INSRSSGSPKKKRKVGS

> YAF2_RYBP domain of YAF2 (SEQ ID NO: 147)

RPRLKNVDRSSAQHLEVTVGDLTVIITDFKEKT

> YAF2_RYBP domain of RYBP (SEQ DI NO: 148)

RPRLKNVDRSTAQQLAVTVGNVTVIITDFKEKT

>CBX-C domain of CBX2 (SEQ ID NO: 149)

QDWKPTRSLIEHVFVTDVTANLITVTVKESPTSV

> CBX-C domain of CBX6 (SEQ ID NO: 150)

GDWRPEMSPCSNVVVTDVTSNLLTVTIKEFCNPE

> CBX-C domain of CBX8 (SEQ ID NO: 151)

ESWSPSLTNLEKVVVTDVTSNFLTVTIKESNTDQ

> CBX-C domain of CBX4 (SEQ ID NO: 152)

SEFKPFFGNIIITDVTANCLTVTFKEYVTV

> CBX-C domain of CBX7 (SEQ ID NO: 153)

PPWTPALPSSEVTVTDITANSITVTFREAQAAE

>SPDYE4-2 (SEQ ID NO: 154)

VRSPEVVVDDEVPGPSAPWIDPSPQPQSLGLKRKSEWSDESEEELEEELELERAPEPEDT

>SPDYE4-5 (SEQ ID NO: 155)

WVVETLCGLKMKLKRKRASSVLPEHHEAFNRLLGDPVVQKFLAWDKDLRVSDKYLLAMVI

Table 1: Fragments identified as TADs by TADseq. Fragments marked with * were independently validated.

Gene	Fragment	Sequence	SEQ ID NO:	logFC high GFP	FDR high GFP	Hit high GFP	logFC medium GFP	FDR medium GFP	Hit medium GFP
ATF6	ATF6-1	MGEPAGVAGTMESPFSPGLFHRLDEDWDS ALFAELGYFTDTDELQLEAANETYENNFDNL	29	3.145276 698	0.021211 47	hit	1.56329 6241	6.04E-06	hit
ATF6	ATF6-2*	HRLDEDWDSALFAELGYFTDTDELQLEAAN ETYENNFDNLDFDLDLVPWESDIWDINNQI	30	4.687561 89	2.94E-05	hit	1.47726 3549	4.41E-05	hit
ATF6B	ATF6B-1	MAELMLLSEIADPTRFFTDNLLSPEDWGLQ NSTLYSGLDEVAEEQTQLFRCPEQDVPFDG	31	1.916896 584	0.006654 41	hit	0.99309 4738	0.001024 406	hit
ATMIN	ATMIN-24	NPGPDTQLPSGPAQNPGIDFDIEEFFSASNI QTQTEESELSTMTTEPVLESLDIETQTDF	32	1.232649 648	0.053448 55		0.98800 755	0.000965 273	hit
ATMIN	ATMIN-32	ETQTMSSGFETLGSLFFTSNETQTAMDDFL LADLAWNTMESQFSSVETQTSAEPHTVSNF	33	0.635515 75	0.305513 7		0.81975 9214	0.009050 433	hit
ATOH1	ATOH1-1	MSRLLHAEEWAEVKELGDHHRQPQPHHLP QPPPPPQPPATLQAREHPVYPPELSLLDST D	34	0.721822 453	0.305068 74		0.91935 1522	0.017130 359	hit
ATXN7L 3	ATXN7L3-1*	MKMEEMSLSGLDNSKLEAIAQEIYADLVEDS CLGFCFEVHRAVKCGYFFLDDTDPDSMKD	35	1.637901 718	0.025735 55	hit	1.68389 3477	1.80E-05	hit
ATXN7L 3	ATXN7L3-2	QEIYADLVEDSCLGFCFEVHRAVKCGYFFLD DTDPDSMKDFEIVDQPGLDIFGQVFNQWK	36	0.765431 613	0.283064 69		0.89105 9001	0.002440 708	hit
ATXN7L 3	ATXN7L3-4	FEIVDQPGLDIFGQVFNQWKSKECVCPNCS RSIAASRFAPHLEKCLGMGRNSSRIANRRI	37	0.764101 911	0.204500 75		0.75143 9597	0.022410 022	hit
BRD8	BRD8-23	KEECFRSGVAEAPVGSKAPSIDGKEELDLA EKMDIAVSYTGEELDFETVGDIIAIIEDKV	38	0.588420 958	0.357877 82		0.59149 4577	0.032988 887	hit
BRD8	BRD8-24	IDGKEELDLAEKMDIAVSYTGEELDFETVGDI IAIIEDKVDDHPEVLDVAAVEAALSFCE	39	1.593193 215	0.046626 26	hit	1.56564 5971	2.69E-05	hit
BRD8	BRD8-25*	GEELDFETVGDIIAIIEDKVDDHPEVLDVAAV EAALSFCEENDDPQSLPGPWEHPIQQER	40	1.567478 812	0.020721 39	hit	1.83374 7802	6.04E-06	hit
BTBD18	BTBD18-24	IDCREPYAFDTALLEQPCEAEEYRITSAAAT SELEEILDFMLCGSDIEPPIGSLESPGAE	41	1.246176 755	0.150333 88		0.85610 7889	0.003217 538	hit
BTBD18	BTBD18-25	EEYRITSAAATSELEEILDFMLCGSDIEPPIG SLESPGAEGCRTPTYHLTETGKNWIEGE	42	1.470635 679	0.070028 76		1.41332 8465	7.30E-05	hit
C11orf74	C11orf74-1	MSAHMSGLEIMDEDQLIKDVLDKFLNCHEQ TYDEEFLNTFTHLSQDLLLLPGEVEQDVST	43	2.356356 482	0.012114	hit	1.55123 4476	7.99E-06	hit

C3orf62	C3orf62-11	NHMCGHCQDSPFKEEAWALLMDKSPQKATDADPGSLKQAFDDHNIVETVLDLEEDYNVMT	44	6.022714 51	7.93E-06	hit	-0.52607 8624	0.221475 633
C3orf62	C3orf62-12*	QDSPFKEEAWALLMDKSPQKATDADPGSLKQAFDDHNIVETVLDLEEDYNVMTSFKYQIE	45	6.492950 845	6.25E-06	hit	-0.60666 4208	0.124701 907
CITED1	CITED1-7	LQNWDFGAQAGGAESLSPSAGAQSPAIIDSDPVDEEVLMSLVVELGLDRANELPELWLGQ	46	4.313811 14	8.10E-05	hit	1.59663 8925	0.000505 651	hit
CITED1	CITED1-8*	ESLSPSAGAQSPAIIDSDPVDEEVLMSLVVELGLDRANELPELWLGQNEFDFTADFPSSC	47	6.826260 035	6.25E-06	hit	-1.16553 1748	0.000242 099	
CITED2	CITED2-11	MPASVAHVPAAMLPPNVIDTDFIDEEVLMSLVIEMGLDRIKELPELWLGQNEFDFMTDFV	48	6.164977 472	6.48E-06	hit	-0.94909 5547	0.000563 063	
CITED2	CITED2-12*	AMLPPNVIDTDFIDEEVLMSLVIEMGLDRIKELPELWLGQNEFDFMTDFVCKQQPSRVSC	49	6.147579 295	7.93E-06	hit	-0.90047 8069	0.002440 708	
CSRNP1	CSRNP1-28	DNIEAPHFPLPGLSPPGDASSCFLESLMGFSEPAAEALDPFIDSQFEDTVPASLMEPVPV	50	0.502869 407	0.460189 96		0.69553 5008	0.015779 736	hit
DDIT3	DDIT3-1	MAAESLPFSFGTLSSWELEAWYEDLQEVLSSDENGGTYVSPPGNEEEESKIFTTLDPASL	51	2.372684 704	0.006465 38	hit	1.50177 8634	6.04E-06	hit
DDIT3	DDIT3-2	WYEDLQEVLSSDENGGTYVSPPGNEEEESKIFTTLDPASLAWLTEEEPEPAEVTSTSQSP	52	1.138253 747	0.115021 25		1.27997 9309	0.000330 392	hit
ELF4	ELF4-1	MAITLQPSDLIFEFASNGMDDDIHQLEDPSVFPAVIVEQVPYPDLLHLYSGLELDDVHNG	53	0.662555 474	0.257873 99		0.72870 8968	0.015524 531	hit
ELF4	ELF4-2	DDIHQLEDPSVFPAVIVEQVPYPDLLHLYSGLELDDVHNGIITDGTLCMTQDQILEGSFL	54	1.466757 956	0.020721 39	hit	1.36369 7693	6.52E-05	hit
FAM22F	FAM22F-19	PRPQRPAETNAHLPPPRPQRPAETKVPEEIPPEVVQEYVDIMEELLGSHPGDTGEPEGQR	55	0.999831 925	0.178073 84		0.98835 3867	0.015779 736	hit
FAM22F	FAM22F-20	PAETKVPEEIPPEVVQEYVDIMEELLGSHPGDTGEPEGQREKGKVEQPQEEDGITSDPGL	56	3.214335 785	0.000947 72	hit	2.10101 2353	6.76E-07	hit
FAM22F	FAM22F-22	EKGKVEQPQEEDGITSDPGLLSYIDKLCSQEDFVTKVEAVIHPRFLEELLSPDPQMDFLA	57	4.760133 648	8.76E-06	hit	2.32487 9314	1.46E-05	hit
FAM22F	FAM22F-23	LSYIDKLCSQEDFVTKVEAVIHPRFLEELLSPDPQMDFLALSQELEQEEGLTLAQLVEKR	58	5.822230 419	6.25E-06	hit	0.27368 5646	0.466208 757	

FAM90A1	FAM90A1-19	RQPPHSRPCLPTAQACTMSHHPAASHDGAQPLRVLFRRLENGRWSSSLLTAPSFHSPEKP	59	2.051462115	0.03110723	hit	1.556796738	7.06E-05	hit
FAM90A1	FAM90A1-20*	HPAASHDGAQPLRVLFRRLENGRWSSSLLTAPSFHSPEKPGAFLAQSPHVSEKSEGPCVR	60	3.016551155	0.00281867	hit	1.616164006	0.000292	hit
HOXA2	HOXA2-4	PGSHPRHGAGGRPKPSPAGSRGSPVPAGALQPPEYPWMKEKKAAKKTALLPAAAAAATAA	61	1.664427181	0.23442147		1.594816728	0.021805285	hit
HOXA2	HOXA2-5	RGSPVPAGALQPPEYPWMKEKKAAKKTALLPAAAAATAATGPACLSHKESLEIADGSG	62	1.684064934	0.24906108		2.311483338	0.000384794	hit
HOXA2	HOXA2-6	KKAAKKTALLPAAAAATAAATGPACLSHKESLEIADGSGGGSRRLRTAYTNTQLLELEK	63	1.951001869	0.24906108		1.737795426	0.015779736	hit
HSF1	HSF1-20	KNELSDHLDAMDSNLDNLQTMLSSHGFSVDTSALLDLFSPSVTVPDMSLPDLDSSLASIQ	64	0.623357487	0.30974031		0.707735867	0.026141316	hit
HSF1	HSF1-21	MLSSHGFSVDTSALLDLFSPSVTVPDMSLPDLDSSLASIQELLSPQEPPRPPEAENSSPD	65	0.431982684	0.45359875		0.899190622	0.002496242	hit
HSF1	HSF1-24	SGKQLVHYTAQPLFLLDPGSVDTGSNDLPVLFELGEGSYFSEGDGFAEDPTISLLTGSEP	66	0.676280443	0.54433041		0.809218277	0.008149744	hit
HSF1	HSF1-25	AQPLFLLDPGSVDTGSNDLPVLFELGEGSYFSEGDGFAEDPTISLLTGSEPPKAKDPTVS	67	0.772548781	0.22014105		1.152582348	0.000292	hit
JAZF1	JAZF1-1	MTGIAAASFFSNTCRFGGCGLHFPTLADLIEHIEDNHIDTDPRVLEKQELQQPTYVALSY	68	0.284758647	0.67306899		0.663877674	0.031991955	hit
KLF15	KLF15-6	GPVAWGPWRRAAAPVKGEHFCLPEFPLGDPDDVPRPFQPTLEEIEEFLEENMEPGVKEVP	69	2.466557755	0.00312371	hit	1.201854423	0.000203701	hit
KLF6	KLF6-1	MDVLPMCSIFQELQIVHETGYFSALPSLEEYWQQTCLELERYLQSEPCYVSASEIKFDSQ	70	5.453107649	6.25E-06	hit	1.867753689	6.47E-06	hit
KLF7	KLF7-1*	MDVLASYSIFQELQLVHDTGYFSALPSLEETWQQTCLELERYLQTEPRRISETFGEDLDC	72	5.997661437	6.25E-06	hit	1.289603101	0.002206825	hit
KLF7	KLF7-2	YFSALPSLEETWQQTCLELERYLQTEPRRISETFGEDLDCFLHASPPPCIEESFRRLDPL	73	1.430957654	0.17621033		1.165159905	0.000666098	hit
LIN9	LIN9-25	SRLTAILLQIKCLAEGGDLNSFEFKSLTDSLNDIKSTIDASNISCFQNNVEIHVAHIQSG	74	2.093964257	0.03526736	hit	1.079966726	0.075362785	
MYCBP	MYCBP-1	MAHYKAADSKREQFRRYLEKSGVLDTLTKVLVALYEEPEKPNSALDFLKHHLGAATPENP	75	1.016587 98	0.11503602		0.729980644	0.007112247	hit
MYCL1	MYCL1-1	MDYDSYQHYFYDYDCGEDFYRSTAPSEDIWKKFELVPSPPTSPPWGLGPGAGDPAPGIGP	76	1.136770705	0.05636799		0.796782271	0.011564 06	hit

MYOD1	MYOD1-2	CSFATTDDFYDDPCFDSPDLRFFEDLDPRL MHVGALLKPEEHSHFPAAVHPAPGAREDEH	77	0.702539998	0.30142347		0.84860 2054	0.002496 242	hit
NEURO D1	NEUROD 1-6	LRRMKANARERNRMHGLNAALDNLRKVVP CYSKTQKLSKIETLRLAKNYIWALSEILRSG	78	0.670794426	0.29541863		0.95333 8619	0.001354 227	hit
NEURO G3	NEUROG 3-5	RRSRRKKANDRERNRMHNLNSALDALRGV LPTFPDDAKLTKIETLRFAHNYIWALTQTLR	79	0.060387059	0.91793719		0.67133 1782	0.038396 908	hit
NPAS4	NPAS4-31	DVPLVPEGLLTPEASPVKQSFFHYSEKEQN EIDRLIQQISQLAQGMDRPFSAEAGTGGLE	80	1.220084575	0.14208522		0.85633 903	0.034713 147	hit
NPAS4	NPAS4-34	PLGGLEPLDSNLSLSGAGPPVLSLDLKPWK CQELDFLADPDNMFLEETPVEDIFMDLSTP	81	0.945976876	0.14289484		0.91864 2828	0.003190 486	hit
NPAS4	NPAS4-36	DNMFLEETPVEDIFMDLSTPDPSEEWGSGD PEAEGPGGAPSPCNNLSPEDHSFLEDLATY	82	0.670986209	0.25560821		1.20937 9094	6.61E-05	hit
NPAS4	NPAS4-37	DPSEEWGSGDPEAEGPGGAPSPCNNLSPE DHSFLEDLATYETAFETGVSAFPYDGFTDEL	83	1.645174283	0.01967705	hit	0.70187 8979	0.055839 582	
NPAS4	NPAS4-39	CNNLSPEDHSFLEDLATYETAFETGVSAFPY DGFTDELHQLQSQVQDSFHEDGSGGEPTF	84	0.798049889	0.38225133		0.76839 0862	0.019277 289	hit
RBPJ	RBPJ-13	GMALPRLIIRKVDKQTALLDADDPVSQLHKC AFYLKDTERMYLCLSQERIIQFQATPCPK	85	1.431035271	0.02573555	hit	- 0.03148 1589	0.974213 707	
RELB	RELB-2	RRVARPPAAPELGALGSPDLSSLSLAVSRS TDELEIIDEYIKENGFGLDGGQPGPGEGLP	86	2.146540297	0.00281867	hit	1.71086 7835	6.99E-06	hit
RELB	RELB-3	SSLSLAVSRSTDELEIIDEYIKENGFGLDGGQ PGPGEGLPRLVSRGAASLSTVTLGPVAP	87	1.768392783	0.01126942	hit	1.80290 1174	6.76E-07	hit
SERTAD 1	SERTAD1 -10	IDTSMYDNELWAPASEGLKPGPEDGPGKEE APELDEAELDYLMDVLVGTQALERPPGPGR	88	0.234946196	0.84161029		0.83850 7882	0.032988 887	hit
SERTAD 2	SERTAD2 -11	SEAGTQKLDGPQESRADDSKLMDSLPGNF EITTSTGFLTDLTLDDILFADIDTSMYDFDP	89	2.480489855	0.00665441	hit	1.82176 6531	4.96E-06	hit
SPDYE4	SPDYE4-3*	DPSPQPQSLGLKRKSEWSDESEEELEEELE LERAPEPEDTWVVETLCGLKMKLKRKRASS	90	4.820495878	2.26E-05	hit	2.40936 057	1.30E-07	hit
SPDYE4	SPDYE4-4	SEEELEEELELERAPEPEDTWVVETLCGLK MKLKRKRASSVLPEHHEAFNRLLGDPVVQK	91	4.316060433	0.00020711	hit	1.91429 1641	6.04E-06	hit
SS18L2	SS18L2-2	QETIQRLLEENDQLIRCIVEYQNKGRGNECV QYQHVLHRNLIYLATIADASPTSTSKAME	92	1.011535 92	0.09853126		1.16614 8268	0.000386 437	hit
TP53-AD1-2	TP53-AD1-2	PQSDPSVEPPLSQETFSDLWKLLPENNVLS PLPSQAMDDLMLSPDDIEQWFTEDPGPDEA	93	1.108562999	0.28306469		0.98557 8432	0.017581 223	hit

VP64	VP64	DALDDFDLDMLGSDALDDFDLDMLGSDALD DFDLDMLGSDALDDFDLDMLGGSVEREG	94	5.475850 36	6.48E-06	hit	- 2.37426 6586	1.76E-07	
YAF2	YAF2-6	EKKDKVEKEKSEKETTSKKNSHKKTRPRLK NVDRSSAQHLEVTVGDLTVIITDFKEKTKS	95	4.315999 866	0.000465 06	hit	1.77148 7421	0.000612 967	hit
YAF2	YAF2-7*	SHKKTRPRLKNVDRSSAQHLEVTVGDLTVII TDFKEKTKSPPASSAASADQHSQSGSSSSD	96	4.986869 359	1.91E-05	hit	1.82837 5134	7.30E-05	hit
ZXDC	ZXDC-12*	SPAEQHGAQDTELSAGTGNFYLESGGSAR TDYRAIQLAKEKKQRGAGSNAGASQSTQRK I	97	3.965748 255	0.019677 05	hit	2.49606 1078	8.08E-08	hit
ZXDC	ZXDC-13	YLESGGSARTDYRAIQLAKEKKQRGAGSNA GASQSTQRKIKEGKMSPPHFHASQNSWLC G	98	2.377281 872	0.003076 46	hit	1.73423 1119	8.57E-06	hit
ZXDC	ZXDC-16	SLVVPSGGRPGPAPAAGVQCGAQGVQVQL VQDDPSGEGVLPSARGPATFLPFLTVDLPV Y	99	0.478496 057	0.417287 61		0.72925 6459	0.017925 843	hit

Table 2: Subset of fragments identified as TADs by TADseq from Table 1.

Gene	Fragment	Sequence	SEQ ID NO:
ATMIN	ATMIN-24	NPGPDTQLPSGPAQNPGIDFDIEEFFSASNIQTQTEESELS TMTTEPVLESLDIETQTDF	32
ATMIN	ATMIN-32	ETQTMSSGFETLGSLFFTSNETQTAMDDFLLADLAWNTM ESQFSSVETQTSAEPHTVSNF	33
ATOH1	ATOH1-1	MSRLLHAEEWAEVKELGDHHRQPQPHHLPQPPPPPQPP ATLQAREHPVYPPELSLLDSTD	34
ATXN7L 3	ATXN7L3-1	MKMEEMSLSGLDNSKLEAIAQEIYADLVEDSCLGFCFEVH RAVKCGYFFLDDTDPDSMKD	35
ATXN7L 3	ATXN7L3-2	QEIYADLVEDSCLGFCFEVHRAVKCGYFFLDDTDPDSMK DFEIVDQPGLDIFGQVFNQWK	36
ATXN7L 3	ATXN7L3-4	FEIVDQPGLDIFGQVFNQWKSKECVCPNCSRSIAASRFAP HLEKCLGMGRNSSRIANRRI	37
BRD8	BRD8-23	KEECFRSGVAEAPVGSKAPSIDGKEELDLAEKMDIAVSYT GEELDFETVGDIIAIIEDKV	38
BRD8	BRD8-24	IDGKEELDLAEKMDIAVSYTGEELDFETVGDIIAIIEDKVDD HPEVLDVAAVEAALSFCE	39
BRD8	BRD8-25	GEELDFETVGDIIAIIEDKVDDHPEVLDVAAVEAALSFCEEN DDPQSLPGPWEHPIQQER	40
BTBD18	BTBD18-24	IDCREPYAFDTALLEQPCEAEEYRITSAAATSELEEILDFML CGSDIEPPIGSLESPGAE	41
BTBD18	BTBD18-25	EEYRITSAAATSELEEILDFMLCGSDIEPPIGSLESPGAEGC RTPTYHLTETGKNWIEGE	42
CSRNP1	CSRNP1-28	DNIEAPHFPLPGLSPPGDASSCFLESLMGFSEPAAEALDP FIDSQFEDTVPASLMEPVPV	50
HOXA2	HOXA2-4	PGSHPRHGAGGRPKPSPAGSRGSPVPAGALQPPEYPW MKEKKAAKKTALLPAAAAAATAA	61
HOXA2	HOXA2-5	RGSPVPAGALQPPEYPWMKEKKAAKKTALLPAAAAAATA AATGPACLSHKESLEIADGSG	62
HOXA2	HOXA2-6	KKAAKKTALLPAAAAAATAAATGPACLSHKESLEIADGSG GGSRRLRTAYTNTQLLELEK	63
JAZF1	JAZF1-1	MTGIAAASFFSNTCRFGGCGLHFPTLADLIEHIEDNHIDTD PRVLEKQELQQPTYVALSY	68
LIN9	LIN9-25	SRLTAILLQIKCLAEGGDLNSFEFKSLTDSLNDIKSTIDASNI SCFQNNVEIHVAHIQSG	74
MYCBP	MYCBP-1	MAHYKAADSKREQFRRYLEKSGVLDTLTKVLVALYEEPEK PNSALDFLKHHLGAATPENP	75
MYCL1	MYCL1-1	MDYDSYQHYFYDYDCGEDFYRSTAPSEDIWKKFELVPSP PTSPPWGLGPGAGDPAPGIGP	76
NEURO D1	NEUROD1-6	LRRMKANARERNRMHGLNAALDNLRKVVPCYSKTQKLSK IETLRLAKNYIWALSEILRSG	78
NEURO G3	NEUROG3-5	RRSRRKKANDRERNRMHNLNSALDALRGVLPTFPDDAKL TKIETLRFAHNYIWALTQTLR	79
RBPJ	RBPJ-13	GMALPRLIIRKVDKQTALLDADDPVSQLHKCAFYLKDTER MYLCLSQERIIQFQATPCPK	85

Table 3: Exemplary sequences of TADs and functional variants and active fragments thereof.

TAD	SEQ ID NO:	Sequence
YAF2 short	100	SHKKTRPRLKNVDRSSAQHLEVTVGDLTVIITDFKEKTKSPPASSA
C3orf62 short	101	MDKSPQKATDADPGSLKQAFDDHNIVETVLDLEEDYNVMTSFKYQ IE

“miniSPDYE4” or “S(mini)”	102	SDESEEELEEELELERAPEPEDTWVVETL
“miniCITED1” or “C(mini)”	103	DSDPVDEEVLMSLVVELGLDRANEL
HSF1 short	104	GFSVDTSALLDLFSP
“p65 short (N-term)”; “P(mini N-term)”; or “P_Nt”	105	PTQAGEGTLSEALLQLQFDDEDLGALLGNSTDPAVFTDLASVDNS EFQQ
“p65 short (C-term)”; “P(mini C-term)”; or “P_Ct”	106	APGLPNGLLSGDEDFSSIADMDFSALL
ZXDC short	107	AGTGNFYLESGGSARTDYRAIQLAKEKKQRGAGSNAGASQSTQR KIKEGKM
RELB short	108	SSLSLAVSRSTDELEIIDEYIKENGFGLDGGQPGPGEGLP
FAM22F short	109	LSYIDKLCSQEDFVTKVEAVIHPRFLEELLSPDPQMDFLA
KLF6-TAD	71	DVLPMCSIFQELQIVHETGYFSALPSLEEYWQQTCLELERYLQSEP CYVSASEIKFDSQ
“C3orf62-TAD”; or “miniC3orf62”	110	QDSPFKEEAWALLMDKSPQKATDADPGSLKQAFDDHNIVETVLDL EEDYNVMTSFKYQIEGSS
SOX7 C-term	111	LGQLSPPPEHPGFDALDQLSQVELLGDMDRNEFDQYLNTPGHPD SATGAMALSGHVPVSQV
FOXM1 (697-762)	112	DVPKPGSPEPQVSGLAANRSLTEGLVLDTMNDSLSKILLDISFPGL DEDPLGPDNINWSQFIPELQ
ATF6	113	HRLDEDWDSALFAELGYFTDTDELQLEAANETYENNFDNLDFDLD LVPWESDIWDINNQIGSS
“SERTAD2_NAHL”	89	SEAGTQKLDGPQESRADDSKLMDSLPGNFEITTSTGFLTDLTLDDI LFADIDTSMYDFDP
“DDIT3-1”; or “miniDDIT3”	51	MAAESLPFSFGTLSSWELEAWYEDLQEVLSSDENGGTYVSPPGN EEEESKIFTTLDPASL
ELF4	54	DDIHQLEDPSVFPAVIVEQVPYPDLLHLYSGLELDDVHNGIITDGTL CMTQDQILEGSFL
C11orf74	114	SAHMSGLEIMDEDQLIKDVLDKFLNCHEQTYDEEFLNTFTHLSQDL LLLPGEVEQDVST
“miniATMIN”	32	NPGPDTQLPSGPAQNPGIDFDIEEFFSASNIQTQTEESELSTMTTE PVLESLDIETQTDF
“miniZXDC”	115	YLESGGSARTDYRAIQLAKEKKQRGAGSNAGASQSTQRKI
“SPDYE4”; or “S”	90	DPSPQPQSLGLKRKSEWSDESEEELEEELELERAPEPEDTWVVE TLCGLKMKLKRKRASS
“CITED1” or “C”	47	ESLSPSAGAQSPAIIDSDPVDEEVLMSLVVELGLDRANELPELWLG QNEFDFTADFPSSC
“RELA (p65)”; “RELA” or “p65”	116	QYLPDTDDRHRIEEKRKRTYETFKSIMKKSPFSGPTDPRPPPRRIA VPSRSSASVPKPAPQPYPFTSSLSTINYDEFPTMVFPSGQISQASA LAPAPPQVLPQAPAPAPAPAMVSALAQAPAPVPVLAPGPPQAVAP PAPKPTQAGEGTLSEALLQLQFDDEDLGALLGNSTDPAVFTDLAS VDNSEFQQLLNQGIPVAPHTTEPMLMEYPEAITRLVTGAQRPPDP APAPLGAPGLPNGLLSGDEDFSSIADMDFSALL
“p65-AD”; “P_short”; or “P”	117	PTQAGEGTLSEALLQLQFDDEDLGALLGNSTDPAVFTDLASVDNS EFQQLLNQGIPVAPHTTEPMLMEYPEAITRLVTGAQRPPDPAPAPL GAPGLPNGLLSGDEDFSSIADMDFSALL
“HSF1-TAD”; “H_TAD”; “HSF1” or “H”	118	GFSVDTSALLDLFSPSVTVPDMSLPDLDSSLASIQELLSPQEPPRP PEAENSSPDSGKQLVHYTAQPLFLLDPGSVDTGSNDLPVLFELGE GSYFSEGDGFAEDPTISLLTGSEPPKAKDPTVS
“mini-HSF1 (401-420)” or “H(mini)”	119	MLSSHGFSVDTSALLDLFSP
CBX2 (CBX-C)	136	SASPPSTGQNPSVSVQTSQDWKPTRSLIEHVFVTDVTANLITVTVK ESPTSVGFFNLRHY

CBX6 (CBX-C)	138	GASSEPEAGDWRPEMSPCSNVVVTDVTSNLLTVTIKEFCNPEDFE KVAAGVAGAAGGGGSIGASK
CBX8 (CBX-C)	139	RPSLIARIPVARILGDPEEESWSPSLTNLEKVVVTDVTSNFLTVTIKE SNTDQGFFKEKR
RYBP-C (YAF2_RYBP)	140	IQSANATTKTSETNHTSRPRLKNVDRSTAQQLAVTVGNVTVIITDFK EKTRSSSTSSSTVTSSAGSEQQNQS
DDIT3_MT	156	SFGTLSSWELEAWYEDLQEVLSSDENGGTYVSPPGNEEEESKIFT TLDPASLAWLT
SPDYE4_MT	157	ERAPEPEDTWVVETLCGLKMKLKRKRASS
ZXDC_MT	158	TGNFYLESGGSARTDYRAIQLAKEKKQRGAGSNAGASQSTQRKI
HSF1_MT	159	GFSVDTSALLDLFSPSVTVPDMSLPDLDSSLASIQELLSPQEPPR
SERTAD2_MT	160	LMDSLPGNFEITTSTGFLTDLTLDDILFADIDTSMYDFDP
ZNF473	161	MAEEFVTLKDVGMDFTLGDWEQLGLEQGDTFWDTALDNCQDLFL LDPPRPNLTSHPDGSEDLEPLAGGSPEATS
CITED1_MT	162	AIIDSDPVDEEVLMSLVVELGLDRANELPELWLGQNEFDFTADF
ZNF496	163	MQQVTTLQLPPSRVSPFKDMILCFSEEDWSLLDPAQTGFYGEFIIG EDYGVSMPPNDLAAQPDLSQGEENEPRVPELQDLQGKE
CITED2_MT	164	VIDTDFIDEEVLMSLVIEMGLDRIKELPELWLGQNEFDFMTDFV
mini-p65_MT	165	PTQAGEGTLSEALLQLQFDDEDLGALLGNSTDPAVFTDLASVDNS EFQQLLNQG
C3orf62-2	166	ATDADPGSLKQAFDDHNIVETVLDLEEDYNVMT
C3orf62-3	167	DDHNIVETVLDLEEDYNVMT
miniC3orf62_1	168	DADPGSLKQAFDDHNIVETVLDLEED
miniC3orf62_2	169	DSPFKEEAWALLMDKSPQKATDADPGSL
miniDDIT3_1	170	DLQEVLSSDENGGTYVSPPGNEEEESKIFTTLD
miniDDIT3_2	171	LSSWELEAWYEDLQEVLSSDE
miniC3orf62_MT	172	ATDADPGSLKQAFDDHNIVETVLDLEEDYNVMTSFKYQIEGSS
miniSPDYE4_1	185	ERAPEPEDTWVVETL

Table 4: Subset of fragments identified as TADs by TADseq from Table 1.

Gene	Fragment	Sequence	SEQ ID NO:
ATMIN	ATMIN-24	NPGPDTQLPSGPAQNPGIDFDIEEFFSASNIQTQTEE SELSTMTTEPVLESLDIETQTDF	32
ATMIN	ATMIN-32	ETQTMSSGFETLGSLFFTSNETQTAMDDFLLADLAW NTMESQFSSVETQTSAEPHTVSNF	33
ATOH1	ATOH1-1	MSRLLHAEEWAEVKELGDHHRQPQPHHLPQPPPPP QPPATLQAREHPVYPPELSLLDSTD	34
ATXN7L3	ATXN7L3-1	MKMEEMSLSGLDNSKLEAIAQEIYADLVEDSCLGFCF EVHRAVKCGYFFLDDTDPDSMKD	35
ATXN7L3	ATXN7L3-2	QEIYADLVEDSCLGFCFEVHRAVKCGYFFLDDTDPDS MKDFEIVDQPGLDIFGQVFNQWK	36
ATXN7L3	ATXN7L3-4	FEIVDQPGLDIFGQVFNQWKSKECVCPNCSRSIAASR FAPHLEKCLGMGRNSSRIANRRI	37
BRD8	BRD8-23	KEECFRSGVAEAPVGSKAPSIDGKEELDLAEKMDIAV SYTGEELDFETVGDIIAIIEDKV	38
BRD8	BRD8-24	IDGKEELDLAEKMDIAVSYTGEELDFETVGDIIAIIEDK VDDHPEVLDVAAVEAALSFCE	39

BRD8	BRD8-25	GEELDFETVGDIIAIIEDKVDDHPEVLDVAAVEAALSFC EENDDPQSLPGPWEHPIQQER	40
BTBD18	BTBD18-24	IDCREPYAFDTALLEQPCEAEEYRITSAAATSELEEIL DFMLCGSDIEPPIGSLESPGAE	41
BTBD18	BTBD18-25	EEYRITSAAATSELEEILDFMLCGSDIEPPIGSLESPGA EGCRTPTYHLTETGKNWIEGE	42
C11orf74	C11orf74-1	MSAHMSGLEIMDEDQLIKDVLDKFLNCHEQTYDEEFL NTFTHLSQDLLLLPGEVEQDVST	43
C3orf62	C3orf62-11	NHMCGHCQDSPFKEEAWALLMDKSPQKATDADPGS LKQAFDDHNIVETVLDLEEDYNVMT	44
C3orf62	C3orf62-12	QDSPFKEEAWALLMDKSPQKATDADPGSLKQAFDD HNIVETVLDLEEDYNVMTSFKYQIE	45
FAM22F	FAM22F-19	PRPQRPAETNAHLPPPRPQRPAETKVPEEIPPEVVQ EYVDIMEELLGSHPGDTGEPEGQR	55
FAM22F	FAM22F-20	PAETKVPEEIPPEVVQEYVDIMEELLGSHPGDTGEPE GQREKGKVEQPQEEDGITSDPGL	56
FAM22F	FAM22F-22	EKGKVEQPQEEDGITSDPGLLSYIDKLCSQEDFVTKV EAVIHPRFLEELLSPDPQMDFLA	57
FAM22F	FAM22F-23	LSYIDKLCSQEDFVTKVEAVIHPRFLEELLSPDPQMDF LALSQELEQEEGLTLAQLVEKR	58
FAM90A1	FAM90A1-19	RQPPHSRPCLPTAQACTMSHHPAASHDGAQPLRVL FRRLENGRWSSSLLTAPSFHSPEKP	59
FAM90A1	FAM90A1-20	HPAASHDGAQPLRVLFRRLENGRWSSSLLTAPSFHS PEKPGAFLAQSPHVSEKSEGPCVR	60
HOXA2	HOXA2-4	PGSHPRHGAGGRPKPSPAGSRGSPVPAGALQPPEY PWMKEKKAAKKTALLPAAAAAATAA	61
HOXA2	HOXA2-5	RGSPVPAGALQPPEYPWMKEKKAAKKTALLPAAAAA ATAAATGPACLSHKESLEIADGSG	62
HOXA2	HOXA2-6	KKAAKKTALLPAAAAAATAAATGPACLSHKESLEIAD GSGGGSRRLRTAYTNTQLLELEK	63
JAZF1	JAZF1-1	MTGIAAASFFSNTCRFGGCGLHFPTLADLIEHIEDNHI DTDPRVLEKQELQQPTYVALSY	68
LIN9	LIN9-25	SRLTAILLQIKCLAEGGDLNSFEFKSLTDSLNDIKSTID ASNISCFQNNVEIHVAHIQSG	74
MYCBP	MYCBP-1	MAHYKAADSKREQFRRYLEKSGVLDTLTKVLVALYE EPEKPNSALDFLKHHLGAATPENP	75
MYCL1	MYCL1-1	MDYDSYQHYFYDYDCGEDFYRSTAPSEDIWKKFELV PSPPTSPPWGLGPGAGDPAPGIGP	76
NEUROD1	NEUROD1-6	LRRMKANARERNRMHGLNAALDNLRKVVPCYSKTQ KLSKIETLRLAKNYIWALSEILRSG	78
NEUROG3	NEUROG3-5	RRSRRKKANDRERNRMHNLNSALDALRGVLPTFPD DAKLTKIETLRFAHNYIWALTQTLR	79
RBPJ	RBPJ-13	GMALPRLIIRKVDKQTALLDADDPVSQLHKCAFYLKD TERMYLCLSQERIIQFQATPCPK	85
SPDYE4	SPDYE4-3	DPSPQPQSLGLKRKSEWSDESEEELEEELELERAPE PEDTWVVETLCGLKMKLKRKRASS	90
SPDYE4	SPDYE4-4	SEEELEEELELERAPEPEDTWVVETLCGLKMKLKRK RASSVLPEHHEAFNRLLGDPVVQK	91
SS18L2	SS18L2-2	QETIQRLLEENDQLIRCIVEYQNKGRGNECVQYQHVL HRNLIYLATIADASPTSTSKAME	92
YAF2	YAF2-6	EKKDKVEKEKSEKETTSKKNSHKKTRPRLKNVDRSS AQHLEVTVGDLTVIITDFKEKTKS	95
YAF2	YAF2-7	SHKKTRPRLKNVDRSSAQHLEVTVGDLTVIITDFKEKT KSPPASSAASADQHSQSGSSSD	96
ZXDC	ZXDC-12	SPAEQHGAQDTELSAGTGNFYLESGGSARTDYRAIQ LAKEKKQRGAGSNAGASQSTQRKI	97

ZXDC	ZXDC-13	YLESGGSARTDYRAIQLAKEKKQRGAGSNAGASQST QRKIKEGKMSPPHFHASQNSWLCG	98
ZXDC	ZXDC-16	SLVVPSGGRPGPAPAAGVQCGAQGVQVQLVQDDPS GEGVLPSARGPATFLPFLTVDLPVY	99

Table 5: Subset of active fragments identified as TADs by TADseq.

Gene	Fragment	Sequence	SEQ ID NO:	Previously identified TAD location
ATF6	ATF6-1	MGEPAGVAGTMESPFSPGLF*HRLDEDWDS ALFAELGYFTDTDELQLEAANETYENNFDN*L	29	aa 1-150
ATF6	ATF6-2	*HRLDEDWDSALFAELGYFTDTDELQLEAANE TYENNFDNL*DFDLDLVPWESDIWDINNQI	30	aa 1-150
ATF6B	ATF6B-1	MAELMLLSEIADPTRFFTDNLLSPEDWGLQN STLYSGLDEVAEEQTQLFRCPEQDVPFDG	31	aa 2-86
CSRNP1	CSRNP1-28	DNIEAPHFPLPGLSPPGDASSCFLESLMGFS EPAAEALDPFIDSQFEDTVPASLMEPVPV	50	aa 493-583
KLF6	KLF6-1	MDVLPMCSIFQELQIVHETGYFSALPSLEEY WQQTCLELERYLQSEPCYVSASEIKFDSQ	70	aa 1-200
KLF7	KLF7-1	MDVLASYSIFQELQLVHDTG*YFSALPSLEET WQQTCLELERYLQTEPRRISETFGEDLDC*	72	aa 1-75
KLF7	KLF7-2	*YFSALPSLEETWQQTCLELERYLQTEPRRIS ETFGEDLDC*FLHASPPPCIEESFRRLDPL	73	aa 1-75

Table 6: Subset of fragments identified as TADs.

Gene	Fragment	Sequence	SEQ ID NO:
ATMIN	ATMIN-24	NPGPDTQLPSGPAQNPGIDFDIEEFFSASNIQTQTEE SELSTMTTEPVLESLDIETQTDF	32
ATMIN	ATMIN-32	ETQTMSSGFETLGSLFFTSNETQTAMDDFLLADLAW NTMESQFSSVETQTSAEPHTVSNF	33
ATOH1	ATOH1-1	MSRLLHAEEWAEVKELGDHHRQPQPHHLPQPPPPP QPPATLQAREHPVYPPELSLLDSTD	34
ATXN7L3	ATXN7L3-1	MKMEEMSLSGLDNSKLEAIAQEIYADLVEDSCLGFCF EVHRAVKCGYFFLDDTDPDSMKD	35
ATXN7L3	ATXN7L3-2	QEIYADLVEDSCLGFCFEVHRAVKCGYFFLDDTDPDS MKDFEIVDQPGLDIFGQVFNQWK	36
ATXN7L3	ATXN7L3-4	FEIVDQPGLDIFGQVFNQWKSKECVCPNCSRSIAASR FAPHLEKCLGMGRNSSRIANRRI	37
BRD8	BRD8-23	KEECFRSGVAEAPVGSKAPSIDGKEELDLAEKMDIAV SYTGEELDFETVGDIIAIIEDKV	38
BRD8	BRD8-24	IDGKEELDLAEKMDIAVSYTGEELDFETVGDIIAIIEDK VDDHPEVLDVAAVEAALSFCE	39
BRD8	BRD8-25	GEELDFETVGDIIAIIEDKVDDHPEVLDVAAVEAALSFC EENDDPQSLPGPWEHPIQQER	40
BTBD18	BTBD18-24	IDCREPYAFDTALLEQPCEAEEYRITSAAATSELEEIL DFMLCGSDIEPPIGSLESPGAE	41
BTBD18	BTBD18-25	EEYRITSAAATSELEEILDFMLCGSDIEPPIGSLESPGA EGCRTPTYHLTETGKNWIEGE	42
FAM22F	FAM22F-19	PRPQRPAETNAHLPPPRPQRPAETKVPEEIPPEVVQ EYVDIMEELLGSHPGDTGEPEGQR	55

FAM22F	FAM22F-20	PAETKVPEEIPPEVVQEYVDIMEELLGSHPGDTGEPEGQREKGKVEQPQEEDGITSDPGL	56
HOXA2	HOXA2-4	PGSHPRHGAGGRPKPSPAGSRGSPVPAGALQPPEYPWMKEKKAAKKTALLPAAAAAATAA	61
HOXA2	HOXA2-5	RGSPVPAGALQPPEYPWMKEKKAAKKTALLPAAAAAATAAATGPACLSHKESLEIADGSG	62
HOXA2	HOXA2-6	KKAAKKTALLPAAAAAATAAATGPACLSHKESLEIADGSGGGSRRLRTAYTNTQLLELEK	63
JAZF1	JAZF1-1	MTGIAAASFFSNTCRFGGCGLHFPTLADLIEHIEDNHIDTDPRVLEKQELQQPTYVALSY	68
LIN9	LIN9-25	SRLTAILLQIKCLAEGGDLNSFEFKSLTDSLNDIKSTIDASNISCFQNNVEIHVAHIQSG	74
MYCBP	MYCBP-1	MAHYKAADSKREQFRRYLEKSGVLDTLTKVLVALYEEPEKPNSALDFLKHHLGAATPENP	75
MYCL1	MYCL1-1	MDYDSYQHYFYDYDCGEDFYRSTAPSEDIWKKFELVPSPPTSPPWGLGPGAGDPAPGIGP	76
NEUROD1	NEUROD1-6	LRRMKANARERNRMHGLNAALDNLRKVVPCYSKTQKLSKIETLRLAKNYIWALSEILRSG	78
NEUROG3	NEUROG3-5	RRSRRKKANDRERNRMHNLNSALDALRGVLPTFPDDAKLTKIETLRFAHNYIWALTQTLR	79
RBPJ	RBPJ-13	GMALPRLIIRKVDKQTALLDADDPVSQLHKCAFYLKDTERMYLCLSQERIIQFQATPCPK	85
SS18L2	SS18L2-2	QETIQRLLEENDQLIRCIVEYQNKGRGNECVQYQHVLHRNLIYLATIADASPTSTSKAME	92
YAF2	YAF2-6	EKKDKVEKEKSEKETTSKKNSHKKTRPRLKNVDRSSAQHLEVTVGDLTVIITDFKEKTKS	95
YAF2	YAF2-7	SHKKTRPRLKNVDRSSAQHLEVTVGDLTVIITDFKEKTKSPPASSAASADQHSQSGSSSD	96
ZXDC	ZXDC-12	SPAEQHGAQDTELSAGTGNFYLESGGSARTDYRAIQLAKEKKQRGAGSNAGASQSTQRKI	97
ZXDC	ZXDC-13	YLESGGSARTDYRAIQLAKEKKQRGAGSNAGASQSTQRKIKEGKMSPPHFHASQNSWLCG	98
ZXDC	ZXDC-16	SLVVPSGGRPGPAPAAGVQCGAQGVQVQLVQDDPSGEGVLPSARGPATFLPFLTVDLPVY	99

SPDYE4-CITED1-RELA-HSF1 nucleotide sequence (SEQ ID NO: 120)

SPDYE4-CITED1-RELA-HSF1 protein sequence (SEQ ID NO: 121)

MDPSPQPQSLGLKRKSEWSDESEEELEEELELERAPEPEDTWVVETLCGLKMKLKRKRASSGGSGGSESLSPSAGA
QSPAIIDSDPVDEEVLMSLVVELGLDRANELPELWLGQNEFDFTADFPSSCGGSINSRSSGSPKKKRKVGSQYLPDT
DDRHRIEEKRKRTYETFKSIMKKSPFSGPTDPRPPPRRIAVPSRSSASVPKPAPQPYPFTSSLSTINYDEFPTMVFPSG
QISQASALAPAPPQVLPQAPAPAPAPAMVSALAQAPAPVPVLAPGPPQAVAPPAPKPTQAGEGTLSEALLQLQF
DDEDLGALLGNSTDPAVFTDLASVDNSEFQQLLNQGIPVAPHTTEPMLMEYPEAITRLVTGAQRPPDPAPAPLGA
PGLPNGLLSGDEDFSSIADMDFSALLGSGSGSGFSVDTSALLDLFSPSVTVPDMSLPDLDSSLASIQELLSPQEPPRP
PEAENSSPDSGKQLVHYTAQPLFLLDPGSVDTGSNDLPVLFELGEGSYFSEGDGFAEDPTISLLTGSEPPKAKDPTVS

linker and NLS sequences are indicated with underlining

SPDYE4-CITED1-RELA nucleotide sequence (SEQ ID NO: 122)

SPDYE4-CITED1-RELA protein sequence (SEQ ID NO: 123)

MDPSPQPQSLGLKRKSEWSDESEEELEEELELERAPEPEDTWVVETLCGLKMKLKRKRASSGGSGGSESLSPSAGA
QSPAIIDSDPVDEEVLMSLVVELGLDRANELPELWLGQNEFDFTADFPSSCGGSINSRSSGSPKKKRKVGSQYLPDT
DDRHRIEEKRKRTYETFKSIMKKSPFSGPTDPRPPPRRIAVPSRSSASVPKPAPQPYPFTSSLSTINYDEFPTMVFPSG
QISQASALAPAPPQVLPQAPAPAPAPAMVSALAQAPAPVPVLAPGPPQAVAPPAPKPTQAGEGTLSEALLQLQFD
DEDLGALLGNSTDPAVFTDLASVDNSEFQQLLNQGIPVAPHTTEPMLMEYPEAITRLVTGAQRPPDPAPAPLGAP
GLPNGLLSGDEDFSSIADMDFSALL

linker and NLS sequences are indicated with underlining

HSF1-RELA-SPDYE4-CITED1 nucleotide sequence (SEQ ID NO: 124)

HSF1-RELA-SPDYE4-CITED1 protein sequence (SEQ ID NO: 125)

MGFSVDTSALLDLFSPSVTVPDMSLPDLDSSLASIQELLSPQEPPRPPEAENSSPDSGKQLVHYTAQPLFLLDPGSVD
TGSNDLPVLFELGEGSYFSEGDGFAEDPTISLLTGSEPPKAKDPTVSINSRSSGSPKKKRKVGSQYLPDTDDRHRIEEK
RKRTYETFKSIMKKSPFSGPTDPRPPPRRIAVPSRSSASVPKPAPQPYPFTSSLSTINYDEFPTMVFPSGQISQASALA
PAPPQVLPQAPAPAPAPAMVSALAQAPAPVPVLAPGPPQAVAPPAPKPTQAGEGTLSEALLQLQFDDEDLGALL
GNSTDPAVFTDLASVDNSEFQQLLNQGIPVAPHTTEPMLMEYPEAITRLVTGAQRPPDPAPAPLGAPGLPNGLLS
GDEDFSSIADMDFSALLGSGSGSDPSPQPQSLGLKRKSEWSDESEEELEEELELERAPEPEDTWVVETLCGLKMKLK
RKRASSGGSGGSESLSPSAGAQSPAIIDSDPVDEEVLMSLVVELGLDRANELPELWLGQNEFDFTADFPSSCGGS

linker and NLS sequences are indicated with underlining

SPDYE4-CITED1-p65-miniHSF1 nucleotide sequence (SEQ ID NO: 126)

SPDYE4-CITED1-p65-miniHSF1 protein sequence (SEQ ID NO: 127)

MDPSPQPQSLGLKRKSEWSDESEEELEEELELERAPEPEDTWVVETLCGLKMKLKRKRASSGGSGGSESLSPSAGA
QSPAIIDSDPVDEEVLMSLVVELGLDRANELPELWLGQNEFDFTADFPSSCGGSINSRSSGSPKKKRKVGSPTQAGE
GTLSEALLQLQFDDEDLGALLGNSTDPAVFTDLASVDNSEFQQLLNQGIPVAPHTTEPMLMEYPEAITRLVTGAQR
PPDPAPAPLGAPGLPNGLLSGDEDFSSIADMDFSALLGSGSGSMLSSHGFSVDTSALLDLFSP

linker and NLS sequences are indicated with underlining

miniSPDYE4-CITED1-p65-HSF1 nucleotide sequence (SEQ ID NO: 128)

miniSPDYE4-CITED1-p65-HSF1 protein sequence (SEQ ID NO: 129)

MSDESEEELEEELELERAPEPEDTWVVETLSGGSGGSESLSPSAGAQSPAIIDSDPVDEEVLMSLVVELGLDRANELP
ELWLGQNEFDFTADFPSSCGGSINSRSSGSPKKKRKVGSPTQAGEGTLSEALLQLQFDDEDLGALLGNSTDPAVFT
DLASVDNSEFQQLLNQGIPVAPHTTEPMLMEYPEAITRLVTGAQRPPDPAPAPLGAPGLPNGLLSGDEDFSSIADM
DFSALLGSGSGSGFSVDTSALLDLFSPSVTVPDMSLPDLDSSLASIQELLSPQEPPRPPEAENSSPDSGKQLVHYTAQ
PLFLLDPGSVDTGSNDLPVLFELGEGSYFSEGDGFAEDPTISLLTGSEPPKAKDPTVS

linker and NLS sequences are indicated with underlining

SPDYE4-miniCITED1-p65-HSF1 nucleotide sequence (SEQ ID NO: 130)

SPDYE4-miniCITED1-p65-HSF1 protein sequence (SEQ ID NO: 131)

MDPSPQPQSLGLKRKSEWSDESEEELEEELELERAPEPEDTWVVETLCGLKMKLKRKRASSGGSGGS
DSDPVDEEVLMSLVVELGLDRANELGGSINSRSSGSPKKKRKVGSPTQAGEGTLSEALLQLQFDDEDLGALLGNST
DPAVFTDLASVDNSEFQQLLNQGIPVAPHTTEPMLMEYPEAITRLVTGAQRPPDPAPAPLGAPGLPNGLLSGDED
FSSIADMDFSALLGSGSGSGFSVDTSALLDLFSPSVTVPDMSLPDLDSSLASIQELLSPQEPPRPPEAENSSPDSGKQL
VHYTAQPLFLLDPGSVDTGSNDLPVLFELGEGSYFSEGDGFAEDPTISLLTGSEPPKAKDPTVS

linker and NLS sequences are indicated with underlining

SPDYE4-CITED1-minip65(C)-HSF1 nucleotide sequence (SEQ ID NO: 132)

SPDYE4-CITED1-minip65(C)-HSF1 protein sequence (SEQ ID NO: 133)

MDPSPQPQSLGLKRKSEWSDESEEELEEELELERAPEPEDTWVVETLCGLKMKLKRKRASSGGSGGSESLSPSAGA
QSPAIIDSDPVDEEVLMSLVVELGLDRANELPELWLGQNEFDFTADFPSSCGGSINSRSSGSPKKKRKVGSAPGLPN
GLLSGDEDFSSIADMDFSALLGSGSGSGFSVDTSALLDLFSPSVTVPDMSLPDLDSSLASIQELLSPQEPPRPPEAENS
SPDSGKQLVHYTAQPLFLLDPGSVDTGSNDLPVLFELGEGSYFSEGDGFAEDPTISLLTGSEPPKAKDPTVS

linker and NLS sequences are indicated with underlining

SPDYE4-CITED1-minip65(N)-HSF1 nucleotide sequence (SEQ ID NO: 134)

SPDYE4-CITED1-minip65(N)-HSF1 protein sequence (SEQ ID NO: 135)

MDPSPQPQSLGLKRKSEWSDESEEELEEELELERAPEPEDTWVVETLCGLKMKLKRKRASSGGSGGSESLSPSAGA
QSPAIIDSDPVDEEVLMSLVVELGLDRANELPELWLGQNEFDFTADFPSSCGGSINSRSSGSPKKKRKVGSPTQAGE
GTLSEALLQLQFDDEDLGALLGNSTDPAVFTDLASVDNSEFQQGSGSGSGFSVDTSALLDLFSPSVTVPDMSLPDLD
SSLASIQELLSPQEPPRPPEAENSSPDSGKQLVHYTAQPLFLLDPGSVDTGSNDLPVLFELGEGSYFSEGDGFAEDPTI
SLLTGSEPPKAKDPTVS

linker and NLS sequences are indicated with underlining

> S-C3orf62.2-P_AD-H nucleotide sequence (SEQ ID NO: 173)

> S-C3orf62.2-P_AD-H protein sequence (SEQ ID NO: 174)

MDPSPQPQSLGLKRKSEWSDESEEELEEELELERAPEPEDTWVVETLCGLKMKLKRKRASSGGSATDADPGSLKQA
FDDHNIVETVLDLEEDYNVMTGGSINSRSSGSPKKKRKVGSPTQAGEGTLSEALLQLQFDDEDLGALLGNSTDPAV
FTDLASVDNSEFQQLLNQGIPVAPHTTEPMLMEYPEAITRLVTGAQRPPDPAPAPLGAPGLPNGLLSGDEDFSSIA
DMDFSALLGSGSGSGFSVDTSALLDLFSPSVTVPDMSLPDLDSSLASIQELLSPQEPPRPPEAENSSPDSGKQLVHYT
AQPLFLLDPGSVDTGSNDLPVLFELGEGSYFSEGDGFAEDPTISLLTGSEPPKAKDPTVS

linker and NLS sequences are indicated with underlining

> S-C3orf62.3-P_AD-H nucleotide sequence (SEQ ID NO: 175)

> S-C3orf62.3-P_AD-H protein sequence (SEQ ID NO: 176)

MDPSPQPQSLGLKRKSEWSDESEEELEEELELERAPEPEDTWVVETLCGLKMKLKRKRASSGGSDDHNIVETVLDL
EEDYNVMTGGSINSRSSGSPKKKRKVGSPTQAGEGTLSEALLQLQFDDEDLGALLGNSTDPAVFTDLASVDNSEFQ
QLLNQGIPVAPHTTEPMLMEYPEAITRLVTGAQRPPDPAPAPLGAPGLPNGLLSGDEDFSSIADMDFSALLGSGSG
SGFSVDTSALLDLFSPSVTVPDMSLPDLDSSLASIQELLSPQEPPRPPEAENSSPDSGKQLVHYTAQPLFLLDPGSVDT
GSNDLPVLFELGEGSYFSEGDGFAEDPTISLLTGSEPPKAKDPTVS

linker and NLS sequences are indicated with underlining

> S-C3orf62_MT-P_AD-H nucleotide sequence (SEQ ID NO: 177)

> S-C3orf62_MT-P_AD-H protein sequence (SEQ ID NO: 178)

MDPSPQPQSLGLKRKSEWSDESEEELEEELELERAPEPEDTWVVETLCGLKMKLKRKRASSGGSATDADPGSLKQA
FDDHNIVETVLDLEEDYNVMTSFKYQIEGSSGGSINSRSSGSPKKKRKVGSPTQAGEGTLSEALLQLQFDDEDLGAL
LGNSTDPAVFTDLASVDNSEFQQLLNQGIPVAPHTTEPMLMEYPEAITRLVTGAQRPPDPAPAPLGAPGLPNGLLS
GDEDFSSIADMDFSALLGSGSGSGFSVDTSALLDLFSPSVTVPDMSLPDLDSSLASIQELLSPQEPPRPPEAENSSPD
SGKQLVHYTAQPLFLLDPGSVDTGSNDLPVLFELGEGSYFSEGDGFAEDPTISLLTGSEPPKAKDPTVS

linker and NLS sequences are indicated with underlining

> S-DDIT3_MT-P_AD-H nucleotide sequence (SEQ ID NO: 179)

> S-DDIT3_MT-P_AD-H protein sequence (SEQ ID NO: 180)

MDPSPQPQSLGLKRKSEWSDESEEELEEELELERAPEPEDTWVVETLCGLKMKLKRKRASSGGSGGSSFGTLSSWE
LEAWYEDLQEVLSSDENGGTYVSPPGNEEEESKIFTTLDPASLAWLTGGSINSRSSGSPKKKRKVGSPTQAGEGTLS
EALLQLQFDDEDLGALLGNSTDPAVFTDLASVDNSEFQQLLNQGIPVAPHTTEPMLMEYPEAITRLVTGAQRPPDP
APAPLGAPGLPNGLLSGDEDFSSIADMDFSALLGSGSGSGFSVDTSALLDLFSPSVTVPDMSLPDLDSSLASIQELLS

PQEPPRPPEAENSSPDSGKQLVHYTAQPLFLLDPGSVDTGSNDLPVLFELGEGSYFSEGDGFAEDPTISLLTGSEPPK
AKDPTVS

linker and NLS sequences are indicated with underlining

> S-C-P_AD-HSF1_MT nucleotide sequence (SEQ ID NO: 181)

> S-C-P_AD-HSF1_MT protein sequence (SEQ ID NO: 182)

MDPSPQPQSLGLKRKSEWSDESEEELEEELELERAPEPEDTWVVETLCGLKMKLKRKRASSGGSGGSESLSPSAGA
QSPAIIDSDPVDEEVLMSLVVELGLDRANELPELWLGQNEFDFTADFPSSCGGSINSRSSGSPKKKRKVGSPTQAGE
GTLSEALLQLQFDDEDLGALLGNSTDPAVFTDLASVDNSEFQQLLNQGIPVAPHTTEPMLMEYPEAITRLVTGAQR
PPDPAPAPLGAPGLPNGLLSGDEDFSSIADMDFSALLGSGSGSGFSVDTSALLDLFSPSVTVPDMSLPDLDSSLASIQ
ELLSPQEPPR

linker and NLS sequences are indicated with underlining

> 3 x ZNF473_KRAB nucleotide sequence (SEQ ID NO: 183)

> 3 x ZNF473_KRAB protein sequence (SEQ ID NO: 184)

MAEEFVTLKDVGMDFTLGDWEQLGLEQGDTFWDTALDNCQDLFLLDPPRPNLTSHPDGSEDLEPLAGGSPEATS
MAEEFVTLKDVGMDFTLGDWEQLGLEQGDTFWDTALDNCQDLFLLDPPRPNLTSHPDGSEDLEPLAGGSPEATS
MAEEFVTLKDVGMDFTLGDWEQLGLEQGDTFWDTALDNCQDLFLLDPPRPNLTSHPDGSEDLEPLAGGSPEATS

References:

Adusumilli, R., and Mallick, P. (2017). Data Conversion with ProteoWizard msConvert. Methods Mol. Biol. Clifton NJ *1550*, 339–368.

Alekseyenko, A.A., Gorchakov, A.A., Kharchenko, P.V., and Kuroda, M.I. (2014). Reciprocal interactions of human C10orf12 and C17orf96 with PRC2 revealed by BioTAP-XL cross-linking and affinity purification. Proc. Natl. Acad. Sci. *111*, 2488–2493.

Ali, R.H., and Rouzbahman, M. (2015). Endometrial stromal tumours revisited: an update based on the 2014 WHO classification. J. Clin. Pathol. *68*, 325–332.

Alonso, C.N., Meyer, C., Gallego, M.S., Rossi, J.G., Mansini, A.P., Rubio, P.L., Medina, A., Marschalek, R., and Felice, M.S. (2010). BTBD18: A novel MLL partner gene in an infant with acute lymphoblastic leukemia and inv(11)(q13;q23). Leuk. Res. *34*, e294–e296.

Antonescu, C., Sung, Y.-S., Zhang, L., Agaram, N., and Fletcher, C. (2017). Recurrent SRF-RELA Fusions Define a Novel Subset of Cellular Myofibroma/Myopericytoma: A Potential Diagnostic Pitfall With Sarcomas With Myogenic Differentiation. Am. J. Surg. Pathol. *41*, 677–684.

Arnold, C.D., Nemčko, F., Woodfin, A.R., Wienerroither, S., Vlasova, A., Schleiffer, A., Pagani, M., Rath, M., and Stark, A. (2018). A high-throughput method to identify trans-activation domains within transcription factor sequences. EMBO J. *37*.

Badis, G., Berger, M.F., Philippakis, A.A., Talukder, S., Gehrke, A.R., Jaeger, S.A., Chan, E.T., Metzler, G., Vedenko, A., Chen, X., et al. (2009). Diversity and Complexity in DNA Recognition by Transcription Factors. Science *324*, 1720–1723.

Barreto, G., Schäfer, A., Marhold, J., Stach, D., Swaminathan, S.K., Handa, V., Döderlein, G., Maltry, N., Wu, W., Lyko, F., et al. (2007). Gadd45a promotes epigenetic gene activation by repair-mediated DNA demethylation. Nature *445*, 671–675.

Barrett, J., Birrer, M.J., Kato, G.J., Dosaka-Akita, H., and Dang, C.V. (1992). Activation domains of L-Myc and c-Myc determine their transforming potencies in rat embryo cells. Mol. Cell. Biol. *12*, 3130–3137.

Basnet, H., Su, X.B., Tan, Y., Meisenhelder, J., Merkurjev, D., Ohgi, K.A., Hunter, T., Pillus, L., and Rosenfeld, M.G. (2014). Tyrosine phosphorylation of histone H2A by CK2 regulates transcriptional elongation. Nature *516*, 267–271.

Basu, S., Mackowiak, S.D., Niskanen, H., Knezevic, D., Asimi, V., Grosswendt, S., Geertsema, H., Ali, S., Jerković, I., Ewers, H., et al. (2020). Unblending of Transcriptional Condensates in Human Repeat Expansion Disease. Cell *181*, 1062-1079.e30.

Benjamini, Y., Krieger, A.M., and Yekutieli, D. (2006). Adaptive linear step-up procedures that control the false discovery rate. Biometrika *93*, 491–507.

Bousoik, E., and Montazeri Aliabadi, H. (2018). "Do We Know Jack" About JAK? A Closer Look at JAK/STAT Signaling Pathway. Front. Oncol. *8*.

Breitkreutz, A., Choi, H., Sharom, J.R., Boucher, L., Neduva, V., Larsen, B., Lin, Z.-Y., Breitkreutz, B.-J., Stark, C., Liu, G., et al. (2010). A global protein kinase and phosphatase interaction network in yeast. Sci. N. Y. NY *328*, 1043–1046.

Brien, G.L., Remillard, D., Shi, J., Hemming, M.L., Chabon, J., Wynne, K., Dillon, E.T., Cagney, G., Van Mierlo, G., Baltissen, M.P., et al. (2018). Targeted degradation of BRD9 reverses oncogenic gene expression in synovial sarcoma. ELife *7*, e41305.

Buchwalter, G., Gross, C., and Wasylyk, B. (2004). Ets ternary complex transcription factors. Gene *324*, 1–14.

Cao, L., Yonis, A., Vaghela, M., Barriga, E.H., Chugh, P., Smith, M.B., Maufront, J., Lavoie, G., Méant, A., Ferber, E., et al. (2020). SPIN90 associates with mDia1 and the Arp2/3 complex to regulate cortical actin organization. Nat. Cell Biol. *22*, 803–814.

Centore, R.C., Sandoval, G.J., Soares, L.M.M., Kadoch, C., and Chan, H.M. (2020). Mammalian SWI/SNF Chromatin Remodeling Complexes: Emerging Mechanisms and Therapeutic Strategies. Trends Genet. *36*, 936–950.

Chauhan, S., Zheng, X., Tan, Y.Y., Tay, B.-H., Lim, S., Venkatesh, B., and Kaldis, P. (2012). Evolution of the Cdk-activator Speedy/RINGO in vertebrates. Cell. Mol. Life Sci. *69*, 3835–3850.

Chavez, A., Scheiman, J., Vora, S., Pruitt, B.W., Tuttle, M., Iyer, E.P.R., Lin, S., Kiani, S., Guzman, C.D., Wiegand, D.J., et al. (2015). Highly efficient Cas9-mediated transcriptional programming. Nat. Methods *12*, 326–328.

Chavez, A., Tuttle, M., Pruitt, B.W., Ewen-Campen, B., Chari, R., Ter-Ovanesyan, D., Haque, S.J., Cecchi, R.J., Kowal, E.J.K., Buchthal, J., et al. (2016). Comparison of Cas9 activators in multiple species. Nat. Methods *13*, 563–567.

Chen, F.X., Smith, E.R., and Shilatifard, A. (2018). Born to run: control of transcription elongation by RNA polymerase II. Nat. Rev. Mol. Cell Biol. *19*, 464–478.

Conaway, R.C., and Conaway, J.W. (2011). Function and regulation of the Mediator complex. Curr. Opin. Genet. Dev. *21*, 225–230.

Core, L., and Adelman, K. (2019). Promoter-proximal pausing of RNA polymerase II: a nexus of gene regulation. Genes Dev. *33*, 960–982.

Cramer, P. (2019). Organization and regulation of gene transcription. Nature *573*, 45–54.

Davis, R.L., Weintraub, H., and Lassar, A.B. (1987). Expression of a single transfected cDNA converts fibroblasts to myoblasts. Cell *51*, 987–1000.

Di Rocco, G., Mavilio, F., and Zappavigna, V. (1997). Functional dissection of a transcriptionally active, target-specific Hox-Pbx complex. EMBO J. *16*, 3644–3654.

Dyson, H.J., and Wright, P.E. (2005). Intrinsically unstructured proteins and their functions. Nat. Rev. Mol. Cell Biol. *6*, 197–208.

Eng, J.K., Jahan, T.A., and Hoopmann, M.R. (2013). Comet: an open-source MS/MS sequence database search tool. PROTEOMICS *13*, 22–24.

Erijman, A., Kozlowski, L., Sohrabi-Jahromi, S., Fishburn, J., Warfield, L., Schreiber, J., Noble, W.S., Söding, J., and Hahn, S. (2020). A High-Throughput Screen for Transcription Activation Domains Reveals Their Sequence Features and Permits Prediction by Deep Learning. Mol. Cell *78*, 890-902.e6.

Esnault, C., Stewart, A., Gualdrini, F., East, P., Horswell, S., Matthews, N., and Treisman, R. (2014). Rho-actin signaling to the MRTF coactivators dominates the immediate transcriptional response to serum in fibroblasts. Genes Dev. *28*, 943–958.

Fujisawa, T., and Filippakopoulos, P. (2017). Functions of bromodomain-containing proteins and their roles in homeostasis and cancer. Nat. Rev. Mol. Cell Biol. *18*, 246–262.

Gahan, J.M., Rentzsch, F., and Schnitzler, C.E. (2020). The genetic basis for PRC1 complex diversity emerged early in animal evolution. Proc. Natl. Acad. Sci. *117*, 22880–22889.

Gao, Y., Xiong, X., Wong, S., Charles, E.J., Lim, W.A., and Qi, L.S. (2016). Complex transcriptional modulation with orthogonal and inducible dCas9 regulators. Nat. Methods *13*, 1043–1049.

Gao, Z., Zhang, J., Bonasio, R., Strino, F., Sawai, A., Parisi, F., Kluger, Y., and Reinberg, D. (2012). PCGF Homologs, CBX Proteins, and RYBP Define Functionally Distinct PRC1 Family Complexes. Mol. Cell *45*, 344–356.

Gao, Z., Lee, P., Stafford, J.M., von Schimmelmann, M., Schaefer, A., and Reinberg, D. (2014). An AUTS2–Polycomb complex activates gene expression in the CNS. Nature *516*, 349–354.

Gastwirt, R.F., McAndrew, C.W., and Donoghue, D.J. (2007). Speedy/RINGO Regulation of CDKs in Cell Cycle, Checkpoint Activation and Apoptosis. Cell Cycle *6*, 1188–1193.

Gerritsen, M.E., Williams, A.J., Neish, A.S., Moore, S., Shi, Y., and Collins, T. (1997). CREB-binding protein/p300 are transcriptional coactivators of p65. Proc. Natl. Acad. Sci. U. S. A. *94*, 2927–2932.

Gonzalez, L., and Nebreda, A.R. (2020). RINGO/Speedy proteins, a family of non-canonical activators of CDK1 and CDK2. Semin. Cell Dev. Biol. *107*, 21–27.

Goparaju, S.K., Kohda, K., Ibata, K., Soma, A., Nakatake, Y., Akiyama, T., Wakabayashi, S., Matsushita, M., Sakota, M., Kimura, H., et al. (2017). Rapid differentiation of human pluripotent stem cells into functional neurons by mRNAs encoding transcription factors. Sci. Rep. *7*, 42367.

Gualdrini, F., Esnault, C., Horswell, S., Stewart, A., Matthews, N., and Treisman, R. (2016). SRF Co-factors Control the Balance between Cell Proliferation and Contractility. Mol. Cell *64*, 1048–1061.

Guo, Z., Zhang, L., Wu, Z., Chen, Y., Wang, F., and Chen, G. (2014). In vivo direct reprogramming of reactive glial cells into functional neurons after brain injury and in an Alzheimer's disease model. Cell Stem Cell *14*, 188–202.

Haberle, V., Arnold, C.D., Pagani, M., Rath, M., Schernhuber, K., and Stark, A. (2019). Transcriptional cofactors display specificity for distinct types of core promoters. Nature *570*, 122–126.

Hirai, H., Tani, T., Katoku-Kikyo, N., Kellner, S., Karian, P., Firpo, M., and Kikyo, N. (2011). Radical acceleration of nuclear reprogramming by chromatin remodeling with the transactivation domain of MyoD. Stem Cells Dayt. Ohio *29*, 1349–1361.

Horb, M.E., Shen, C.-N., Tosh, D., and Slack, J.M.W. (2003). Experimental Conversion of Liver to Pancreas. Curr. Biol. *13*, 105–115.

Hrzenjak, A. (2016). JAZF1/SUZ12 gene fusion in endometrial stromal sarcomas. Orphanet J. Rare Dis. *11*, 15.

Hsu, S.I., Yang, C.M., Sim, K.G., Hentschel, D.M., O'Leary, E., and Bonventre, J.V. (2001). TRIP-Br: a novel family of PHD zinc finger- and bromodomain-interacting proteins that regulate the transcriptional activity of E2F-1/DP-1. EMBO J. *20*, 2273–2285.

Huttlin, E.L., Bruckner, R.J., Navarrete-Perea, J., Cannon, J.R., Baltier, K., Gebreab, F., Gygi, M.P., Thornock, A., Zarraga, G., Tam, S., et al. (2020). Dual Proteome-scale Networks Reveal Cell-specific Remodeling of the Human Interactome (Systems Biology).

Israni, D.V., Li, H.-S., Gagnon, K.A., Sander, J.D., Roybal, K.T., Joung, J.K., Wong, W.W., and Khalil, A.S. (2021). Clinically-driven design of synthetic gene regulatory programs in human cells (Synthetic Biology).

Jolma, A., Yan, J., Whitington, T., Toivonen, J., Nitta, K.R., Rastas, P., Morgunova, E., Enge, M., Taipale, M., Wei, G., et al. (2013). DNA-binding specificities of human transcription factors. Cell *152*, 327–339.

Karanian, M., Pissaloux, D., Gomez-Brouchet, A., Chevenet, C., Le Loarer, F., Fernandez, C., Minard, V., Corradini, N., Castex, M.-P., Duc-Gallet, A., et al. (2020). SRF-FOXO1 and SRF-NCOA1 Fusion Genes Delineate a Distinctive Subset of Well-differentiated Rhabdomyosarcoma. Am. J. Surg. Pathol. *44*, 607–616.

Keung, A.J., Bashor, C.J., Kiriakov, S., Collins, J.J., and Khalil, A.S. (2014). Using targeted chromatin regulators to engineer combinatorial and spatial transcriptional regulation. Cell *158*, 110–120.

Kim, D.I., Jensen, S.C., Noble, K.A., Kc, B., Roux, K.H., Motamedchaboki, K., and Roux, K.J. (2016). An improved smaller biotin ligase for BioID proximity labeling. Mol. Biol. Cell *27*, 1188–1196.

Knight, J.D.R., Choi, H., Gupta, G.D., Pelletier, L., Raught, B., Nesvizhskii, A.I., and Gingras, A.-C. (2017). ProHits-viz: a suite of web tools for visualizing interaction proteomics data. Nat. Methods *14*, 645–646.

Kundu, T.K., Palhan, V.B., Wang, Z., An, W., Cole, P.A., and Roeder, R.G. (2000). Activator-dependent transcription from chromatin in vitro involving targeted histone acetylation by p300. Mol. Cell *6*, 551–561.

Lambert, J.-P., Tucholska, M., Go, C., Knight, J.D.R., and Gingras, A.-C. (2015). Proximity biotinylation and affinity purification are complementary approaches for the interactome mapping of chromatin-associated protein complexes. J. Proteomics *118*, 81–94.

Lambert, J.-P., Picaud, S., Fujisawa, T., Hou, H., Savitsky, P., Uusküla-Reimand, L., Gupta, G.D., Abdouni, H., Lin, Z.-Y., Tucholska, M., et al. (2019). Interactome Rewiring Following Pharmacological Targeting of BET Bromodomains. Mol. Cell *73*, 621-638.e17.

Lambert, S.A., Jolma, A., Campitelli, L.F., Das, P.K., Yin, Y., Albu, M., Chen, X., Taipale, J., Hughes, T.R., and Weirauch, M.T. (2018). The Human Transcription Factors. Cell *172*, 650–665.

Lecoq, L., Raiola, L., Chabot, P.R., Cyr, N., Arseneault, G., Legault, P., and Omichinski, J.G. (2017). Structural characterization of interactions between transactivation domain 1 of the p65 subunit of NF-κB and transcription regulatory factors. Nucleic Acids Res. *45*, 5564–5576.

Li, X., Wang, W., Wang, J., Malovannaya, A., Xi, Y., Li, W., Guerra, R., Hawke, D.H., Qin, J., and Chen, J. (2015). Proteomic analyses reveal distinct chromatin-associated and soluble transcription factor complexes. Mol. Syst. Biol. *11*.

Liang, F.-S., Ho, W.Q., and Crabtree, G.R. (2011). Engineering the ABA plant stress pathway for regulation of induced proximity. Sci. Signal. *4*, rs2–rs2.

Liu, G., Knight, J.D.R., Zhang, J.P., Tsou, C.-C., Wang, J., Lambert, J.-P., Larsen, B., Tyers, M., Raught, B., Bandeira, N., et al. (2016). Data Independent Acquisition analysis in ProHits 4.0. J. Proteomics *149*, 64–68.

Lovén, J., Hoke, H.A., Lin, C.Y., Lau, A., Orlando, D.A., Vakoc, C.R., Bradner, J.E., Lee, T.I., and Young, R.A. (2013). Selective inhibition of tumor oncogenes by disruption of super-enhancers. Cell *153*, 320–334.

Luck, K., Kim, D.-K., Lambourne, L., Spirohn, K., Begg, B.E., Bian, W., Brignall, R., Cafarelli, T., Campos-Laborie, F.J., Charloteaux, B., et al. (2020). A reference map of the human binary protein interactome. Nature *580*, 402–408.

Maeder ML, Thibodeau-Beganny S, Osiak A, Wright DA, Anthony RM, Eichtinger M, Jiang T, Foley JE, Winfrey RJ, Townsend JA, Unger-Wallace E, Sander JD, Müller-Lerch F, Fu F, Pearlberg J, Göbel C, Dassie JP, Pruett-Miller SM, Porteus MH, Sgroi DC, Iafrate AJ, Dobbs D, McCray PB Jr, Cathomen T, Voytas DF, Joung JK. Rapid "open-source" engineering of customized zinc-finger nucleases for highly efficient gene modification. Mol Cell. 2008 Jul 25;31(2):294-301.

Marcon, E., Ni, Z., Pu, S., Turinsky, A.L., Trimble, S.S., Olsen, J.B., Silverman-Gavrila, R., Silverman-Gavrila, L., Phanse, S., Guo, H., et al. (2014). Human-Chromatin-Related Protein Interactions Identify a Demethylase Complex Required for Chromosome Segregation. Cell Rep. *8*, 297–310.

Mashtalir, N., D'Avino, A.R., Michel, B.C., Luo, J., Pan, J., Otto, J.E., Zullow, H.J., McKenzie, Z.M., Kubiak, R.L., St Pierre, R., et al. (2018). Modular Organization and Assembly of SWI/SNF Family Chromatin Remodeling Complexes. Cell *175*, 1272-1288.e20.

McGrath, D.A., Fifield, B.-A., Marceau, A.H., Tripathi, S., Porter, L.A., and Rubin, S.M. (2017). Structural basis of divergent cyclin-dependent kinase activation by Spy1/RINGO proteins. EMBO J. *36*, 2251–2262.

Mellacheruvu, D., Wright, Z., Couzens, A.L., Lambert, J.-P., St-Denis, N.A., Li, T., Miteva, Y.V., Hauri, S., Sardiu, M.E., Low, T.Y., et al. (2013). The CRAPome: a contaminant repository for affinity purification-mass spectrometry data. Nat. Methods *10*, 730–736.

Miralles, F., Posern, G., Zaromytidou, A.-I., and Treisman, R. (2003). Actin Dynamics Control SRF Activity by Regulation of Its Coactivator MAL. Cell *113*, 329–342.

Morey, L., Pascual, G., Cozzuto, L., Roma, G., Wutz, A., Benitah, S.A., and Di Croce, L. (2012). Nonoverlapping Functions of the Polycomb Group Cbx Family of Proteins in Embryonic Stem Cells. Cell Stem Cell *10*, 47–62.

Morita, K., Celso, C.L., Spencer-Dene, B., Zouboulis, C.C., and Watt, F.M. (2006). HAN11 binds mDia1 and controls GLI1 transcriptional activity. J. Dermatol. Sci. *44*, 11–20.

Muhar, M., Ebert, A., Neumann, T., Umkehrer, C., Jude, J., Wieshofer, C., Rescheneder, P., Lipp, J.J., Herzog, V.A., Reichholf, B., et al. (2018). SLAM-seq defines direct gene-regulatory functions of the BRD4-MYC axis. Science *360*, 800–805.

Najafabadi, H.S., Mnaimneh, S., Schmitges, F.W., Garton, M., Lam, K.N., Yang, A., Albu, M., Weirauch, M.T., Radovani, E., Kim, P.M., et al. (2015). C2H2 zinc finger proteins greatly expand the human regulatory lexicon. Nat. Biotechnol. *33*, 555–562.

Narayan, S., Bryant, G., Shah, S., Berrozpe, G., and Ptashne, M. (2017). OCT4 and SOX2 Work as Transcriptional Activators in Reprogramming Human Fibroblasts. Cell Rep. *20*, 1585–1596.

Nasrin, N., Ogg, S., Cahill, C.M., Biggs, W., Nui, S., Dore, J., Calvo, D., Shi, Y., Ruvkun, G., and Alexander-Bridges, M.C. (2000). DAF-16 recruits the CREB-binding protein coactivator complex to the insulin-like growth factor binding protein 1 promoter in HepG2 cells. Proc. Natl. Acad. Sci. *97*, 10412–10417.

Ng, A.H.M., Khoshakhlagh, P., Rojo Arias, J.E., Pasquini, G., Wang, K., Swiersy, A., Shipman, S.L., Appleton, E., Kiaee, K., Kohman, R.E., et al. (2021). A comprehensive library of human transcription factors for cell fate engineering. Nat. Biotechnol. *39*, 510–519.

Olson, E.N., and Nordheim, A. (2010). Linking actin dynamics and gene transcription to drive cellular motile functions. Nat. Rev. Mol. Cell Biol. *11*, 353–365.

ORFeome Collaboration (2016). The ORFeome Collaboration: a genome-scale human ORF-clone resource. Nat. Methods *13*, 191–192.

Pellizzoni, L., Charroux, B., Rappsilber, J., Mann, M., and Dreyfuss, G. (2001). A Functional Interaction between the Survival Motor Neuron Complex and RNA Polymerase II. J. Cell Biol. *152*, 75–86.

Piette, B.L., Alerasool, N., Lin, Z.-Y., Lacoste, J., Lam, M.H.Y., Qian, W.W., Tran, S., Larsen, B., Campos, E., Peng, J., et al. (2021). Comprehensive interactome profiling of the human Hsp70 network highlights functional differentiation of J domains. Mol. Cell *0*.

Piper, D.E., Batchelor, A.H., Chang, C.-P., Cleary, M.L., and Wolberger, C. (1999). Structure of a HoxB1–Pbx1 Heterodimer Bound to DNA: Role of the Hexapeptide and a Fourth Homeodomain Helix in Complex Formation. Cell *96*, 587–597.

Piskacek, S., Gregor, M., Nemethova, M., Grabner, M., Kovarik, P., and Piskacek, M. (2007). Nine-amino-acid transactivation domain: Establishment and prediction utilities. Genomics *89*, 756–768.

Piunti, A., Smith, E.R., Morgan, M.A.J., Ugarenko, M., Khaltyan, N., Helmin, K.A., Ryan, C.A., Murray, D.C., Rickels, R.A., Yilmaz, B.D., et al. (2019). CATACOMB: An endogenous inducible gene that antagonizes H3K27 methylation activity of Polycomb repressive complex 2 via an H3K27M-like mechanism. Sci. Adv. *5*, eaax2887.

Ptashne, M., and Gann, A. (1997). Transcriptional activation by recruitment. Nature *386*, 569–577.

Ravarani, C.N., Erkina, T.Y., De Baets, G., Dudman, D.C., Erkine, A.M., and Babu, M.M. (2018). High-throughput discovery of functional disordered regions: investigation of transactivation domains. Mol. Syst. Biol. *14*, e8190.

Robinson, M.D., McCarthy, D.J., and Smyth, G.K. (2010). edgeR: a Bioconductor package for differential expression analysis of digital gene expression data. Bioinforma. Oxf. Engl. *26*, 139–140.

Ryseck, R.P., Bull, P., Takamiya, M., Bours, V., Siebenlist, U., Dobrzanski, P., and Bravo, R. (1992). RelB, a new Rel family transcription activator that can interact with p50-NF-kappa B. Mol. Cell. Biol. *12*, 674–684.

Sadowski, I., Ma, J., Triezenberg, S., and Ptashne, M. (1988). GAL4-VP16 is an unusually potent transcriptional activator. Nature *335*, 563–564.

Sanborn, A.L., Yeh, B.T., Feigerle, J.T., Hao, C.V., Townshend, R.J.L., Aiden, E.L., Dror, R.O., and Kornberg, R.D. (2020). Simple biochemical features underlie transcriptional activation domain diversity and dynamic, fuzzy binding to Mediator. BioRxiv 2020.12.18.423551.

Sanjana, N., Cong, L., Zhou, Y. et al. A transcription activator-like effector toolbox for genome engineering. Nat Protoc 7, 171–192 (2012).

Sano, K., Hayakawa, A., Piao, J.-H., Kosaka, Y., and Nakamura, H. (2000). Novel SH3 protein encoded by the AF3p21 gene is fused to the mixed lineage leukemia protein in a therapy-related leukemia with t(3;11) (p21;q23). Blood *95*, 1066–1068.

Schratt, G., Philippar, U., Berger, J., Schwarz, H., Heidenreich, O., and Nordheim, A. (2002). Serum response factor is crucial for actin cytoskeletal organization and focal adhesion assembly in embryonic stem cells. J. Cell Biol. *156*, 737–750.

Sdelci, S., Lardeau, C.-H., Tallant, C., Klepsch, F., Klaiber, B., Bennett, J., Rathert, P., Schuster, M., Penz, T., Fedorov, O., et al. (2016). Mapping the chemical chromatin reactivation landscape identifies BRD4-TAF1 cross-talk. Nat. Chem. Biol. *12*, 504–510.

Shteynberg, D., Deutsch, E.W., Lam, H., Eng, J.K., Sun, Z., Tasman, N., Mendoza, L., Moritz, R.L., Aebersold, R., and Nesvizhskii, A.I. (2011). iProphet: multi-level integrative analysis of shotgun proteomic data improves peptide and protein identification rates and error estimates. Mol. Span Classnocasespan Cell. Proteomics MCP *10*, M111.007690.

Sigler, P.B. (1988). Transcriptional activation. Acid blobs and negative noodles. Nature *333*, 210–212.

Singh, R.N., Howell, M.D., Ottesen, E.W., and Singh, N.N. (2017). Diverse role of survival motor neuron protein. Biochim. Biophys. Acta BBA - Gene Regul. Mech. *1860*, 299–315.

Skapek, S.X., Ferrari, A., Gupta, A.A., Lupo, P.J., Butler, E., Shipley, J., Barr, F.G., and Hawkins, D.S. (2019). Rhabdomyosarcoma. Nat. Rev. Dis. Primer *5*, 1–19.

Staller, M.V., Ramirez, E., Holehouse, A.S., Pappu, R.V., and Cohen, B.A. (2021). Design principles of acidic transcriptional activation domains. BioRxiv 2020.10.28.359026.

Stampfel, G., Kazmar, T., Frank, O., Wienerroither, S., Reiter, F., and Stark, A. (2015). Transcriptional regulators form diverse groups with context-dependent regulatory functions. Nature *528*, 147–151.

Strasswimmer, J., Lorson, C.L., Breiding, D.E., Chen, J.J., Le, T., Burghes, A.H.M., and Androphy, E.J. (1999). Identification of Survival Motor Neuron as a Transcriptional Activator-Binding Protein. Hum. Mol. Genet. *8*, 1219–1226.

Sudarshan, D., Avvakumov, N., Lalonde, M.-E., Alerasool, N., Jacquet, K., Mameri, A., Rousseau, J., Lambert, J.-P., Paquet, E., Setty, S.T., et al. (2021). Recurrent chromosomal translocations in sarcomas create a mega-complex that mislocalizes NuA4/TIP60 to Polycomb target loci. BioRxiv 2021.03.26.436670.

Tague, E.P., Dotson, H.L., Tunney, S.N. *et al.* Chemogenetic control of gene expression and cell signaling with antiviral drugs. *Nat Methods* **15,** 519–522 (2018).

Taipale, M., Tucker, G., Peng, J., Krykbaeva, I., Lin, Z.-Y., Larsen, B., Choi, H., Berger, B., Gingras, A.-C., and Lindquist, S. (2014). A quantitative chaperone interaction network reveals the architecture of cellular protein homeostasis pathways. Cell *158*, 434–448.

Tanenbaum ME, Gilbert LA, Qi LS, Weissman JS, Vale RD. A protein-tagging system for signal amplification in gene expression and fluorescence imaging. *Cell.* 2014;159(3):635-646. doi:10.1016/j.cell.2014.09.039

Teo, G., Liu, G., Zhang, J., Nesvizhskii, A.I., Gingras, A.-C., and Choi, H. (2014). SAINTexpress: Improvements and additional features in Significance Analysis of INTeractome software. J. Proteomics *100*, 37–43.

The ENCODE Project Consortium, Moore, J.E., Purcaro, M.J., Pratt, H.E., Epstein, C.B., Shoresh, N., Adrian, J., Kawli, T., Davis, C.A., Dobin, A., et al. (2020). Expanded encyclopaedias of DNA elements in the human and mouse genomes. Nature *583*, 699–710.

Theodorou, E., Dalembert, G., Heffelfinger, C., White, E., Weissman, S., Corcoran, L., and Snyder, M. (2009). A high throughput embryonic stem cell screen identifies Oct-2 as a bifunctional regulator of neuronal differentiation. Genes Dev. *23*, 575–588.

Tycko, J., DelRosso, N., Hess, G.T., Aradhana, Banerjee, A., Mukund, A., Van, M.V., Ego, B.K., Yao, D., Spees, K., et al. (2020). High-Throughput Discovery and Characterization of Human Transcriptional Effectors. Cell *0*.

Vannam, R., Sayilgan, J., Ojeda, S., Karakyriakou, B., Hu, E., Kreuzer, J., Morris, R., Herrera Lopez, X.I., Rai, S., Haas, W., et al. (2021). Targeted degradation of the enhancer lysine acetyltransferases CBP and p300. Cell Chem. Biol. *28*, 503-514.e12.

Vartiainen, M.K., Guettler, S., Larijani, B., and Treisman, R. (2007). Nuclear Actin Regulates Dynamic Subcellular Localization and Activity of the SRF Cofactor MAL. Science *316*, 1749–1752.

Vihervaara, A., Duarte, F.M., and Lis, J.T. (2018). Molecular mechanisms driving transcriptional stress responses. Nat. Rev. Genet. *19*, 385–397.

Vincenz, C., and Kerppola, T.K. (2008). Different polycomb group CBX family proteins associate with distinct regions of chromatin using nonhomologous protein sequences. Proc. Natl. Acad. Sci. *105*, 16572–16577.

Wang, R., Ilangovan, U., Robinson, A.K., Schirf, V., Schwarz, P.M., Lafer, E.M., Demeler, B., Hinck, A.P., and Kim, C.A. (2008). Structural transitions of the RING1B C-terminal region upon binding the polycomb cbox domain. Biochemistry *47*, 8007–8015.

Wang, R., Taylor, A.B., Leal, B.Z., Chadwell, L.V., Ilangovan, U., Robinson, A.K., Schirf, V., Hart, P.J., Lafer, E.M., Demeler, B., et al. (2010). Polycomb Group Targeting through Different Binding Partners of RING1B C-Terminal Domain. Structure *18*, 966–975.

Wang, Y., Li, Y., Zeng, W., Zhu, C., Xiao, J., Yuan, W., Wang, Y., Cai, Z., Zhou, J., Liu, M., et al. (2004). IXL, a new subunit of the mammalian Mediator complex, functions as a transcriptional suppressor. Biochem. Biophys. Res. Commun. *325*, 1330–1338.

Wang, Y., Chen, J., Hu, J.-L., Wei, X.-X., Qin, D., Gao, J., Zhang, L., Jiang, J., Li, J.-S., Liu, J., et al. (2011). Reprogramming of mouse and human somatic cells by high-performance engineered factors. EMBO Rep. *12*, 373–378.

Weirauch, M.T., Yang, A., Albu, M., Cote, A.G., Montenegro-Montero, A., Drewe, P., Najafabadi, H.S., Lambert, S.A., Mann, I., Cook, K., et al. (2014). Determination and Inference of Eukaryotic Transcription Factor Sequence Specificity. Cell *158*, 1431–1443.

Winters, A.C., and Bernt, K.M. (2017). MLL-Rearranged Leukemias—An Update on Science and Clinical Approaches. Front. Pediatr. *5*.

Yahata, T., Shao, W., Endoh, H., Hur, J., Coser, K.R., Sun, H., Ueda, Y., Kato, S., Isselbacher, K.J., Brown, M., et al. (2001). Selective coactivation of estrogen-dependent transcription by CITED1 CBP/p300-binding protein. Genes Dev. *15*, 2598–2612.

Yan, J., Enge, M., Whitington, T., Dave, K., Liu, J., Sur, I., Schmierer, B., Jolma, A., Kivioja, T., Taipale, M., et al. (2013). Transcription factor binding in human cells occurs in dense clusters formed around cohesin anchor sites. Cell *154*, 801–813.

Yang, F., DeBeaumont, R., Zhou, S., and Näär, A.M. (2004). The activator-recruited cofactor/Mediator coactivator subunit ARC92 is a functionally important target of the VP16 transcriptional activator. Proc. Natl. Acad. Sci. U. S. A. *101*, 2339–2344.

Yang, X., Boehm, J.S., Yang, X., Salehi-Ashtiani, K., Hao, T., Shen, Y., Lubonja, R., Thomas, S.R., Alkan, O., Bhimdi, T., et al. (2011). A public genome-scale lentiviral expression library of human ORFs. Nat. Methods *8*, 659–661.

Yu, D., Cattoglio, C., Xue, Y., and Zhou, Q. (2019). A complex between DYRK1A and DCAF7 phosphorylates the C-terminal domain of RNA polymerase II to promote myogenesis. Nucleic Acids Res. *47*, 4462–4475.

Zhou, L., Canagarajah, B., Zhao, Y., Baibakov, B., Tokuhiro, K., Maric, D., and Dean, J. (2017). BTBD18 Regulates a Subset of piRNA-Generating Loci through Transcription Elongation in Mice. Dev. Cell *40*, 453-466.e5.

24. Kiani S et al. Cas9 gRNA engineering for genome editing, activation and repression. *Nature Methods* **12**, 1051 (2015).

25. Beerli R.R. et al Toward controlling gene expression at will: Specific regulation of the *erbB-2/HER-2* promoter by using polydactyl zinc finger proteins constructed from modular building blocks *PNAS* 95, 14628 (1995).

26. Cong, L., Zhou, R., Kuo, Yc. *et al.* Comprehensive interrogation of natural TALE DNA-binding modules and transcriptional repressor domains. *Nat Commun* **3,** 968 (2012).

27. Gilbert LA, Larson MH, Morsut L, Liu Z, Brar GA, Torres SE, Stern-Ginossar N, Brandman O, Whitehead EH, Doudna JA, Lim WA, Weissman JS, Qi LS Cell. 2013 Jul 9. pii: S0092-8674(13)00826-X.

28. Sanson, K.R., Hanna, R.E., Hegde, M. *et al.* Optimized libraries for CRISPR-Cas9 genetic screens with multiple modalities. *Nat Commun* **9,** 5416 (2018).

CLAIMS:

1. A heterologous transcriptional activator comprising:

a DNA targeting domain, optionally an enzymatically inactive CRISPR-CAS protein, a zinc finger DNA binding domain, a tet-repressor, or transcriptional activator-like effector (TALE) DNA binding domain; and

an effector domain comprising

at least one transactivation domain (TAD) selected from the TADs listed in Table 2 or Table 6, or a functional variant thereof, optionally Table 6, or

at least two TADs selected from the TADs listed in Table 1 or Table 3, or functional variants thereof, preferably at least one TAD selected from the TADs listed in Table 4, or Table 5 or Table 6, and/or functional variants thereof,

wherein the DNA targeting domain and the effector domain are operably linked.

2. The transcriptional activator of claim 1, wherein the effector domain comprises at least three, or at least 4 transactivation domains selected from the TADs listed in Table 1 or Table 3 or functional variants thereof.

3. The transcriptional activator of claim 1 or claim 2, further comprising at least one interaction component.

4. The transcriptional activator of any one of claims 1 to 3, wherein the DNA targeting domain and effector domain are domains of a single polypeptide.

5. The transcriptional activator of claim 3, comprising

a first polypeptide comprising the DNA targeting domain and a first interaction component, and

a second polypeptide comprising an effector domain and a second interaction component,

wherein the first and second interaction components interact under suitable conditions.

6. The transcriptional activator of claim 5, wherein the first and second interaction components form an inducible heterodimer pair which interact under inducing conditions, optionally ABI1 and PYL1.

7. The transcriptional activator of any one of claims 1 to 6, wherein the DNA targeting domain comprises a zinc-finger domain.

8. The transcriptional activator of any one of claims 1 to 7, wherein the effector domain comprises at least one TAD selected from any one of the TADs of SEQ ID NO: 103, 104, 105, 106, 167, and 185, optionally at least one TAD selected from any one of the TADs of SEQ ID NO: 90, 91, 46, 47, 101-106, 110, 116-119, 156, 157, 159, 162, 165, 166, 167 and 172.

9. The transcriptional activator of any one of claims 1 to 8, further comprising one or more nuclear localization signals (NLS), optionally an SV40 NLS.

10. The transcriptional activator of any one of claims 1 to 9, wherein the effector domain comprises an amino acid sequence of SEQ ID NO: 121, 123, 125, 127, 129, 131, 133, 135, 174, 176, 178, 180, or 182, or at least 80%, 85%, 90%, 95% or 99% sequence identity to the TADs therein.

11. An isolated nucleic acid encoding the transcriptional activator of any one of claims 1 to 10 or an effector domain of any one of claims 1 to 10.

12. An expression construct comprising the nucleic acid of claim 11 operably linked to one or more promoters and one or more transcription termination sites.

13. A vector comprising the nucleic acid of claim 11 or the expression construct of claim 12, optionally wherein the vector is an adenoviral or lentiviral vector.

14. A cell comprising the transcriptional activator of any one of claims 1 to 10, the nucleic acid of claim 11, the expression construct of claim 12, or the vector of claim 13.

15. A transcriptional activation system comprising:

a) the heterologous transcriptional activator of any one of claims 1 to 10, wherein the DNA targeting domain comprises a CRISPR-Cas protein and
b) at least one gRNA.

16. The transcriptional activation system of claim 15, wherein the at least one gRNA targets a regulatory element of a gene, optionally the regulatory element is a promoter region, an enhancer region, or a distal regulatory site.

17. A method of activating transcription of a target gene in a cell, the method comprising:

a) introducing into the cell the transcriptional activator of any one of claims 1-10, the nucleic acid of claim 11, the expression construct of claim 12, or the vector of claim 13; and

b) culturing the cell under suitable conditions such that the effector domain activates transcription of the target gene.

18. The method of claim 17, wherein the DNA targeting domain comprises a CRISPR-Cas protein, the method further comprises introducing into the cell at least one gRNA, and culturing the cell under suitable conditions such that the at least one gRNA associates with the CRISPR-Cas protein to guide the transcriptional activator to a CRISPR target site.

19. A screening assay, the assay comprising:

a) introducing into a plurality of cells the transcriptional activator of any one of claims 1 to 10, the one or more nucleic acids of claim 11, the one or more expression constructs of claim 12, or the one or more vectors of claim 13, wherein the DNA targeting domain comprises a CRISPR-Cas protein; and a plurality of gRNAs; or introducing a plurality of gRNAs into a population of cells according to claim 14 wherein the DNA targeting domain comprises a CRISPR-Cas protein;

b) culturing the plurality of cells such that the one or more gRNAs associate with the CRISPR-Cas protein and guides the transcriptional activator to a CRISPR target site such that the effector domain activates transcription of a target gene;

c) optionally treating with an amount of a test drug or toxin;

d) optionally culturing the plurality of cells for a period of time to allow for gRNA dropout or enrichment; and

e) collecting the plurality of cells, or a subset thereof.

20. The assay of claim 19, wherein the method further comprises identifying one or more gRNAs that are over- or under-represented in the plurality of cells or subset thereof.

21. A composition comprising the transcriptional activator of any one of claims 1 to 10, the nucleic acid of claim 11, the expression construct of claim 12, the vector of claim 13, or the cell of claim 14.

22. A kit comprising a vial and the heterologous transcriptional activator of any one of claims 1 to 9, the nucleic acid of claim 11, the expression construct of claim 12, the vector of claim 13, the cell of claim 14, or the composition of claim 21 and optionally one or more of: an inducing agent, a gRNA or a gRNA expression construct.

Fig. 1

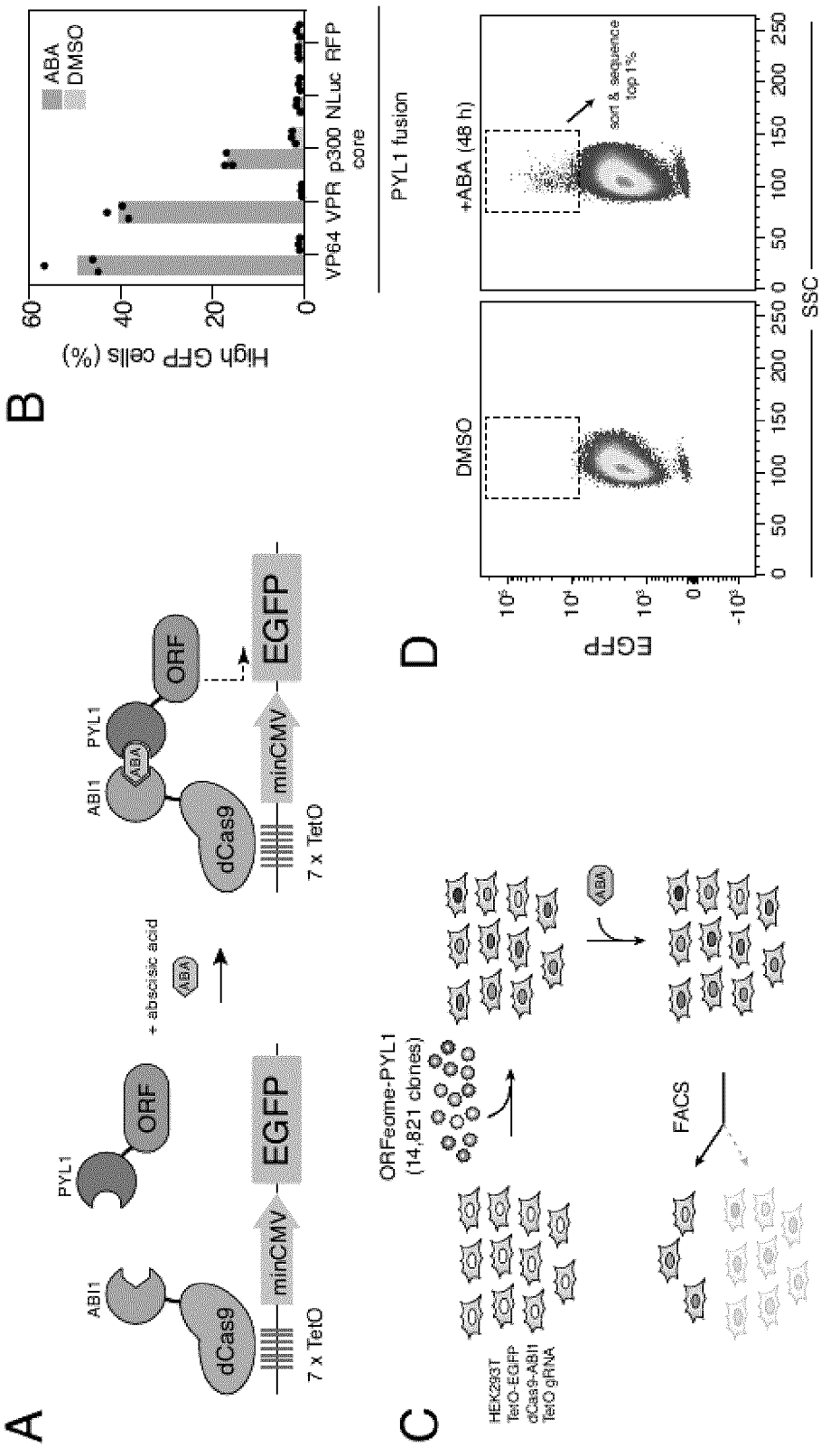

A
ABI1
dCas9
7 x TetO
minCMV
EGFP
PYL1
ORF
+ abscisic acid
ABA
B
High GFP cells (%)
60
40
20
0
ABA
DMSO
VP64 VPR p300 NLuc RFP core
PYL1 fusion
C
HEK293T
TetO-EGFP
dCas9-ABI1
TetO gRNA
ORFeome-PYL1
(14,821 clones)
FACS
D
DMSO
+ABA (48 h)
sort & sequence top 1%
EGFP
SSC
0
50
100
150
200
250

Fig. 1 (cont.)

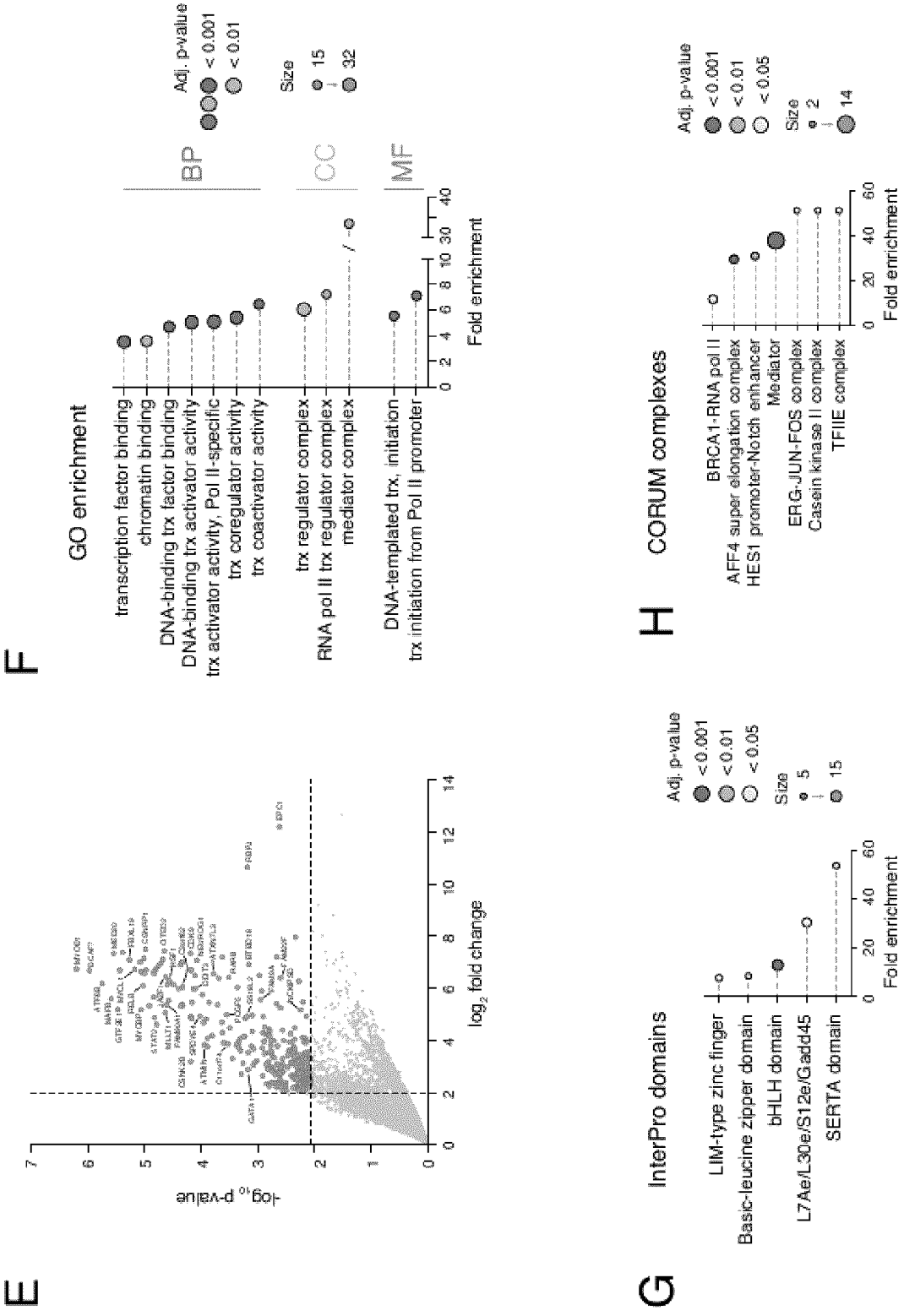

E
-log10 p-value
log2 fold change
F
GO enrichment
transcription factor binding
chromatin binding
DNA-binding trx factor binding
DNA-binding trx activator activity
trx activator activity, Pol II-specific
trx coregulator activity
trx coactivator activity
trx regulator complex
RNA pol II trx regulator complex
mediator complex
DNA-templated trx, initiation
trx initiation from Pol II promoter
BP
CC
MF
Adj. p-value
< 0.001
< 0.01
Size
15
32
Fold enrichment
G
InterPro domains
LIM-type zinc finger
Basic-leucine zipper domain
bHLH domain
L7Ae/L30e/S12e/Gadd45
SERTA domain
Adj. p-value
< 0.001
< 0.01
< 0.05
Size
5
15
Fold enrichment
H
CORUM complexes
BRCA1-RNA pol II
AFF4 super elongation complex
HES1 promoter-Notch enhancer
Mediator
ERG-JUN-FOS complex
Casein kinase II complex
TFIIE complex
Adj. p-value
< 0.001
< 0.01
< 0.05
Size
2
14
Fold enrichment

Fig. 2

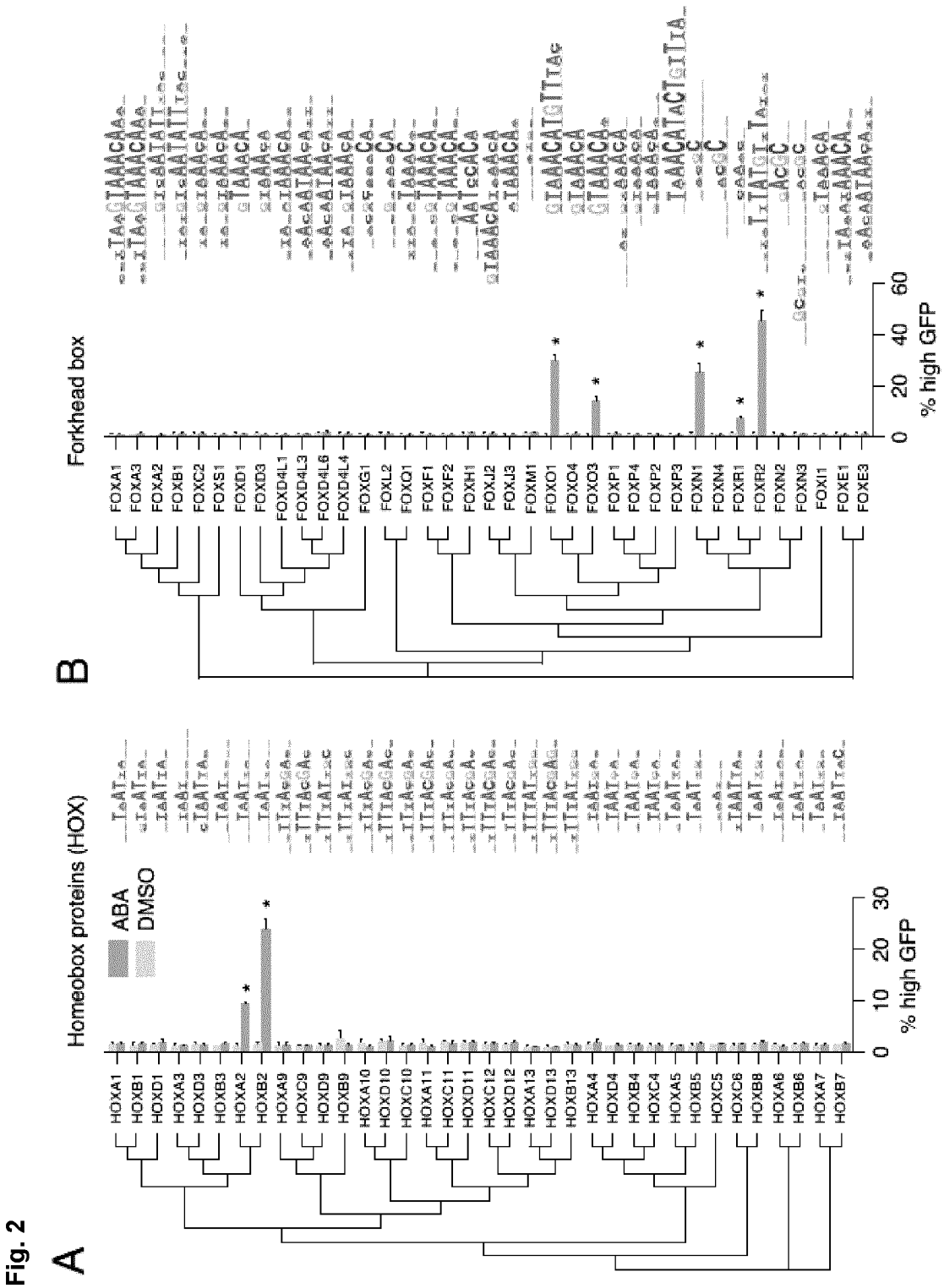

A
Homeobox proteins (HOX)
ABA
DMSO
HOXA1
HOXB1
HOXD1
HOXA3
HOXD3
HOXB3
HOXA2
HOXB2
HOXA9
HOXC9
HOXD9
HOXB9
HOXA10
HOXD10
HOXC10
HOXA11
HOXC11
HOXD11
HOXC12
HOXD12
HOXA13
HOXD13
HOXB13
HOXA4
HOXD4
HOXB4
HOXC4
HOXA5
HOXB5
HOXC5
HOXC6
HOXB8
HOXA6
HOXB6
HOXA7
HOXB7
0
10
20
30
% high GFP
B
Forkhead box
FOXA1
FOXA3
FOXA2
FOXB1
FOXC2
FOXS1
FOXD1
FOXD3
FOXD4L1
FOXD4L3
FOXD4L6
FOXD4L4
FOXG1
FOXL2
FOXQ1
FOXF1
FOXF2
FOXH1
FOXJ2
FOXJ3
FOXM1
FOXO1
FOXO4
FOXO3
FOXP1
FOXP4
FOXP2
FOXP3
FOXN1
FOXN4
FOXR1
FOXR2
FOXN2
FOXN3
FOXI1
FOXE1
FOXE3
0
20
40
60
% high GFP

Fig. 2 (cont.)

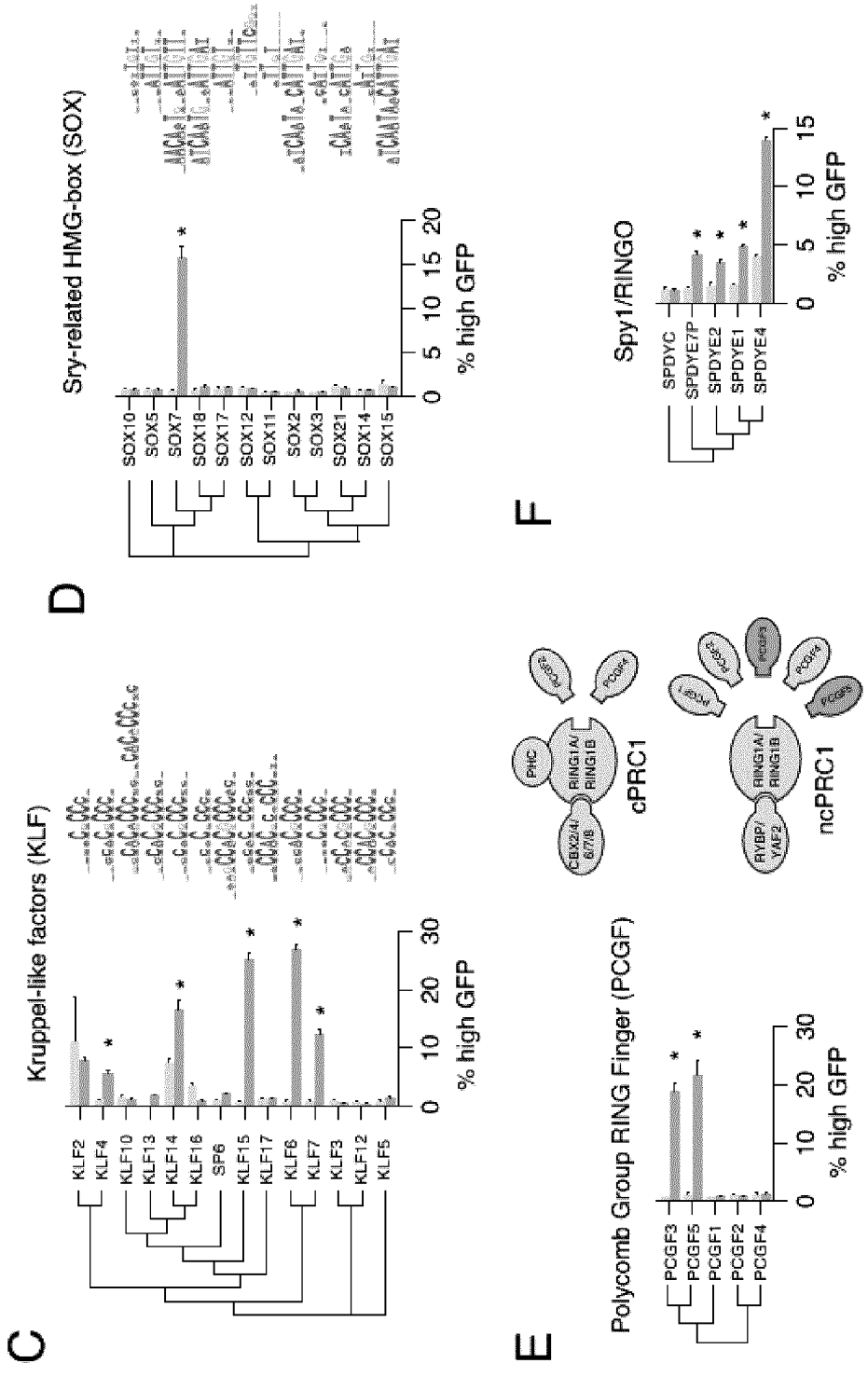

C
Kruppel-like factors (KLF)
KLF2
KLF4
KLF10
KLF13
KLF14
KLF16
SP6
KLF15
KLF17
KLF6
KLF7
KLF3
KLF12
KLF5
0 10 20 30
% high GFP
D
Sry-related HMG-box (SOX)
SOX10
SOX5
SOX7
SOX18
SOX17
SOX12
SOX11
SOX2
SOX3
SOX21
SOX14
SOX15
0 5 10 15 20
% high GFP
E
Polycomb Group RING Finger (PCGF)
PCGF3
PCGF5
PCGF1
PCGF2
PCGF4
0 10 20 30
% high GFP
PHC
RING1A/
RING1B
CBX2/4/
6/7/8
cPRC1
RYBP/
YAF2
ncPRC1
F
Spy1/RINGO
SPDYC
SPDYE7P
SPDYE2
SPDYE1
SPDYE4
0 5 10 15
% high GFP

Fig. 3

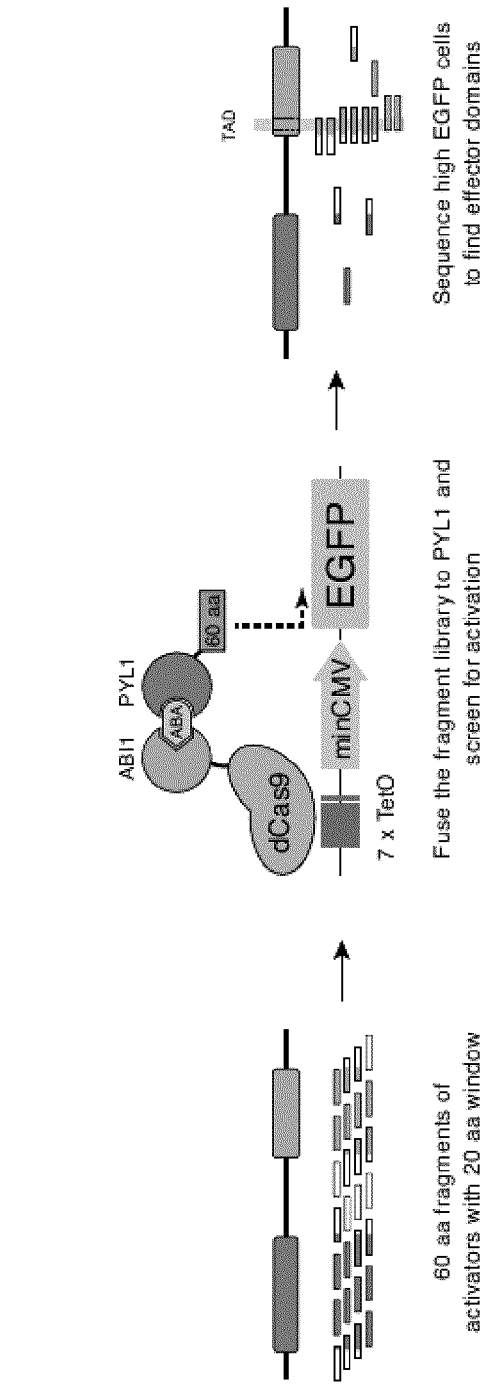

A
60 aa fragments of
activators with 20 aa window
ABI1
PYL1
ABA
60 aa
dCas9
7 x TetO
minCMV
EGFP
Fuse the fragment library to PYL1 and
screen for activation
TAD
Sequence high EGFP cells
to find effector domains

Fig. 3 (cont.)

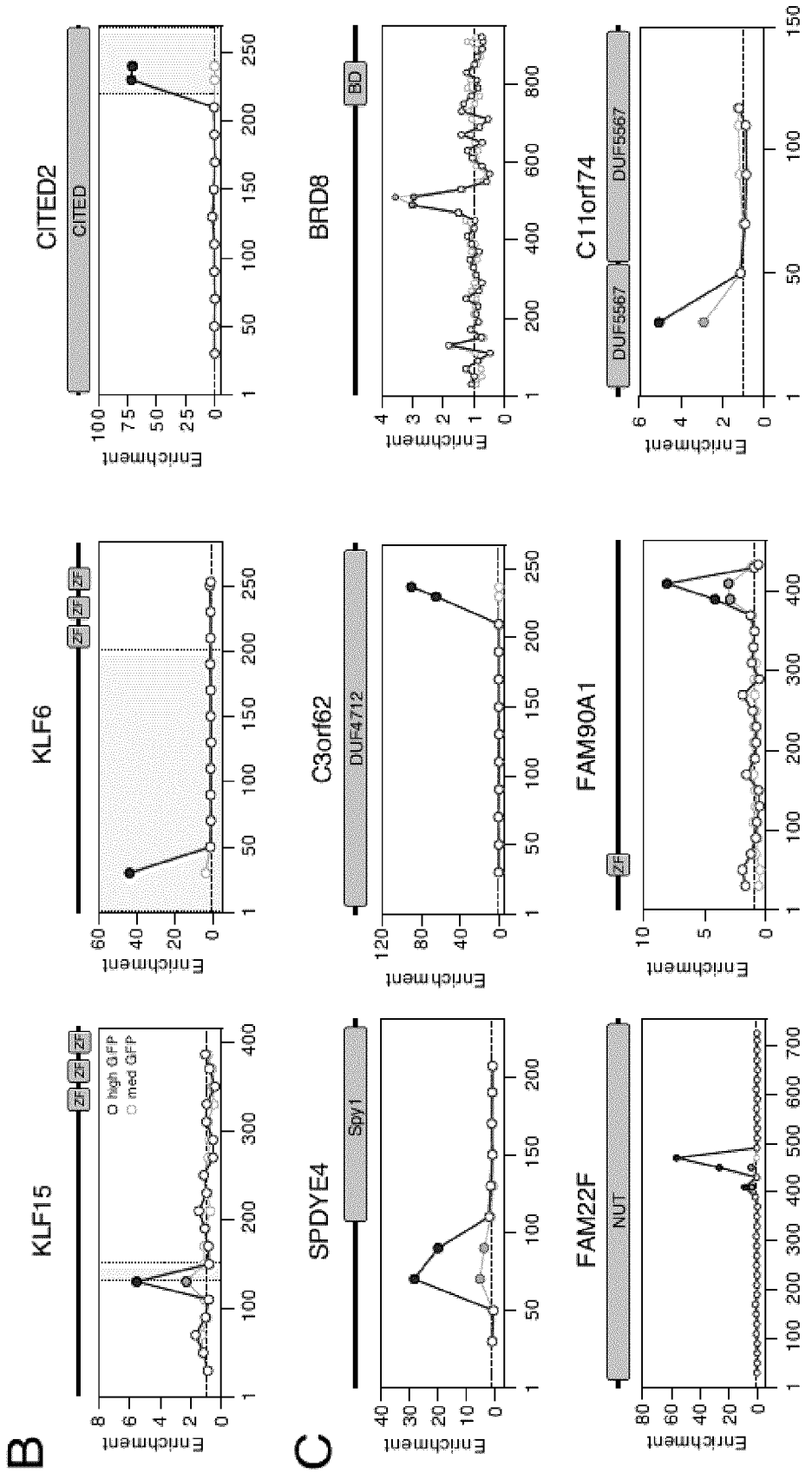
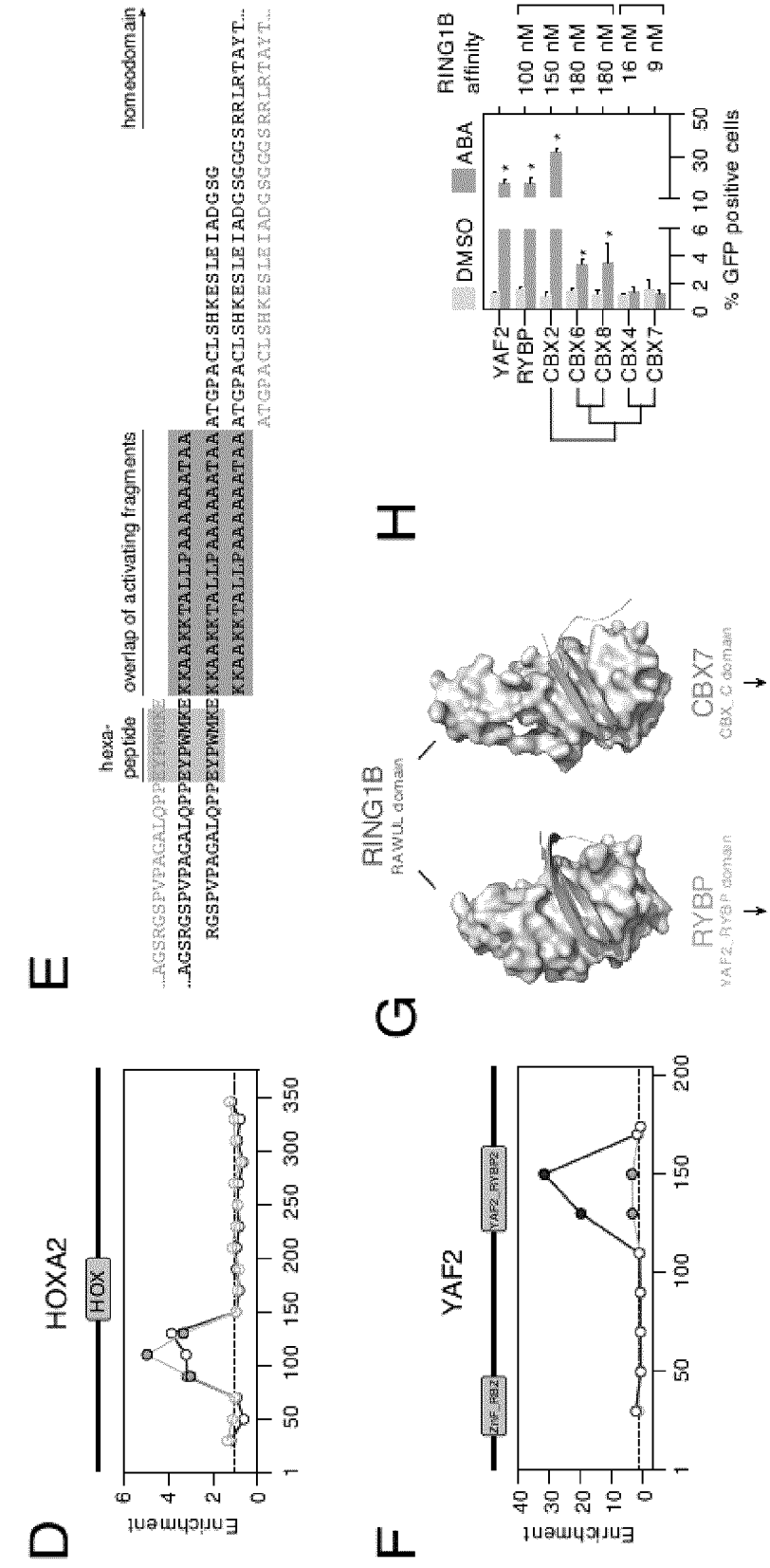
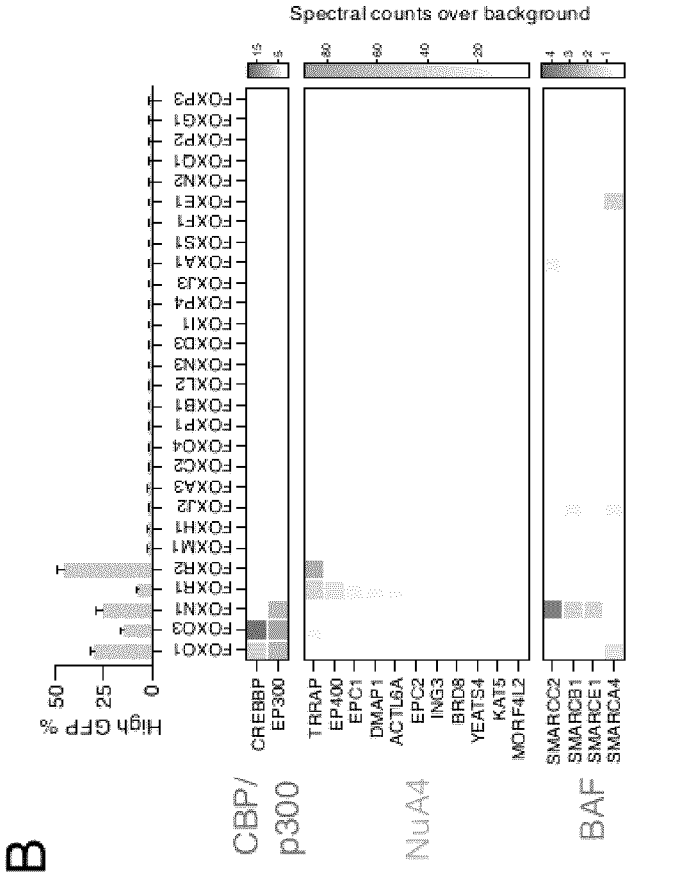

B
KLF15
ZF
high GFP
med GFP
Enrichment
KLF6
CITED2
CITED
C
SPDYE4
Spy1
C3orf62
DUF4712
BRD8
BD
FAM22F
NUT
FAM90A1
C11orf74
DUF5567

Fig. 3 (cont.)


D
HOXA2
HOX
Enrichment
E
hexa-peptide
overlap of activating fragments
homeodomain
F
YAF2
ZnF_RBZ
YAF2_RYBP2
Enrichment
G
RING1B
RAWUL domain
RYBP
YAF2_RYBP domain
ncPRC1
CBX7
CBX_C domain
cPRC1
H
RING1B affinity
DMSO
ABA
YAF2
RYBP
CBX2
CBX6
CBX8
CBX4
CBX7
100 nM
150 nM
180 nM
180 nM
16 nM
9 nM
p = 0.008
% GFP positive cells


B
Spectral counts over background
High GFP %
0
25
50
FOXO1
FOXO3
FOXN1
FOXR1
FOXR2
FOXM1
FOXH1
FOXJ2
FOXA3
FOXC2
FOXO4
FOXP1
FOXB1
FOXL2
FOXN3
FOXD3
FOXI1
FOXP4
FOXJ3
FOXA1
FOXS1
FOXF1
FOXE1
FOXN2
FOXQ1
FOXP2
FOXG1
FOXP3
CREBBP
EP300
TRRAP
EP400
EPC1
DMAP1
ACTL6A
EPC2
ING3
BRD8
YEATS4
KAT5
MORF4L2
SMARCC2
SMARCB1
SMARCE1
SMARCA4
CBP/ p300
NuA4
BAF

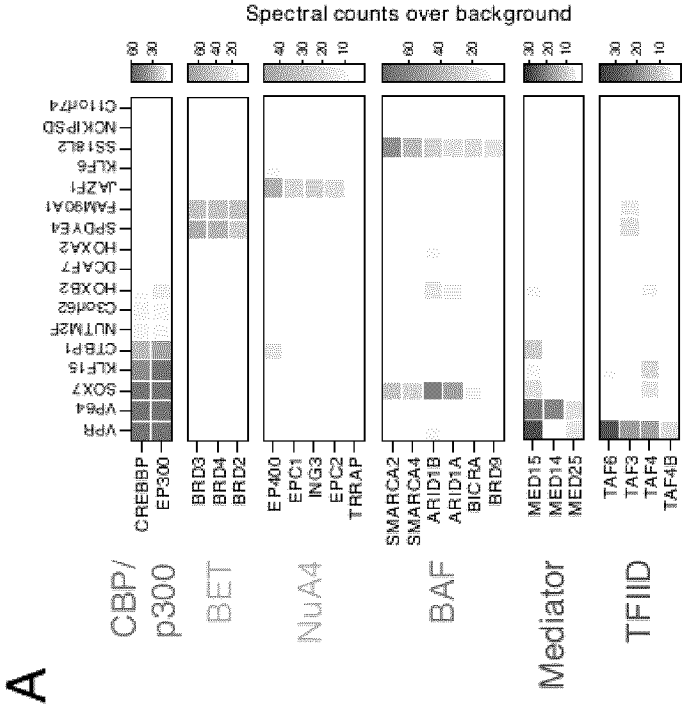

A
Spectral counts over background
VPR
VP64
SOX7
KLF15
CTBP1
NUTM2F
C3orf62
HOXB2
DCAF7
HOXA2
SPDYE4
FAM90A1
JAZF1
KLF6
SS18L2
NCKIPSD
C11orf74
CREBBP
EP300
BRD3
BRD4
BRD2
EP400
EPC1
ING3
EPC2
TRRAP
SMARCA2
SMARCA4
ARID1B
ARID1A
BICRA
BRD9
MED15
MED14
MED25
TAF6
TAF3
TAF4
TAF4B
CBP/ p300
BET
NuA4
BAF
Mediator
TFIID

Fig. 4

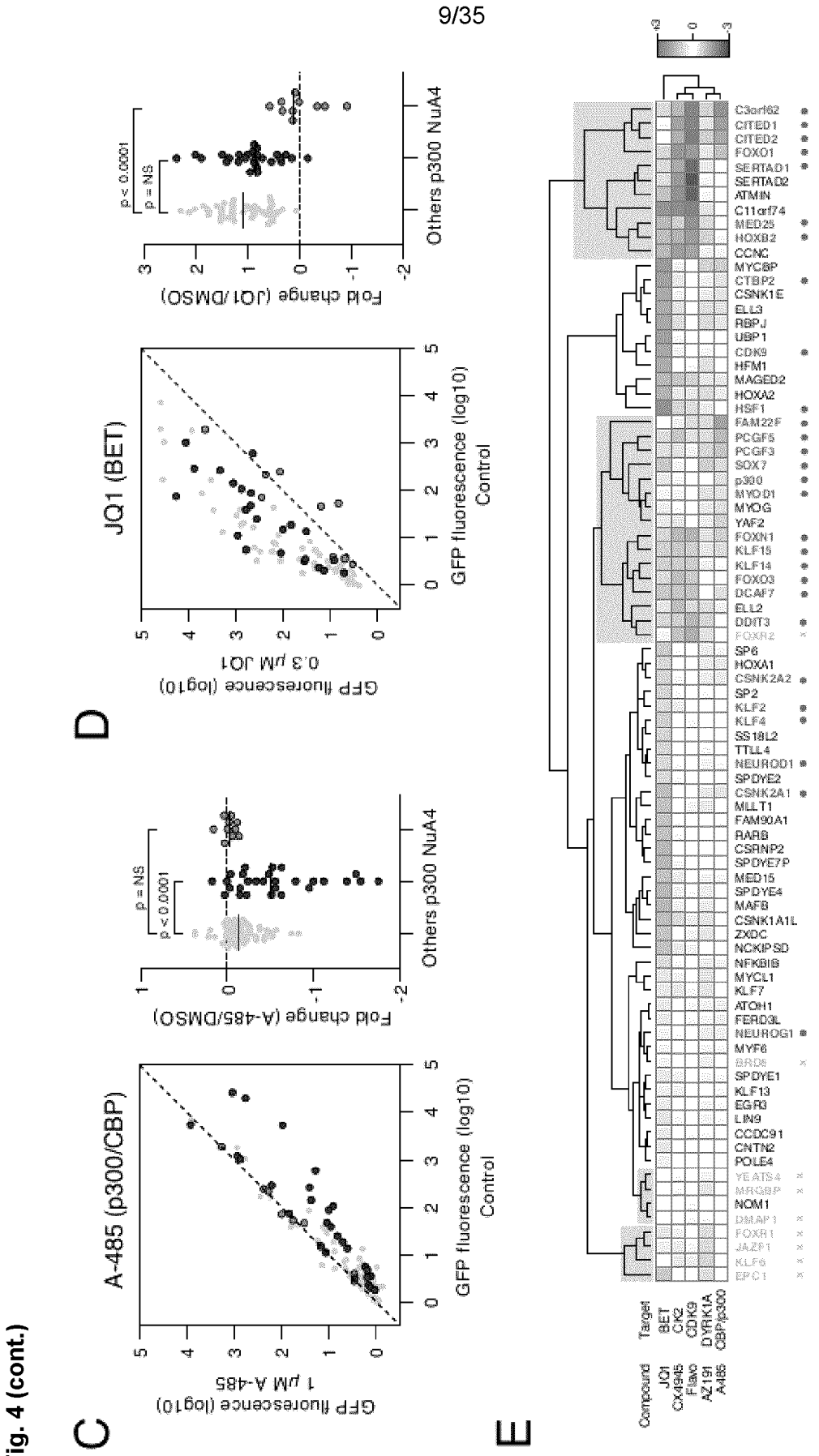
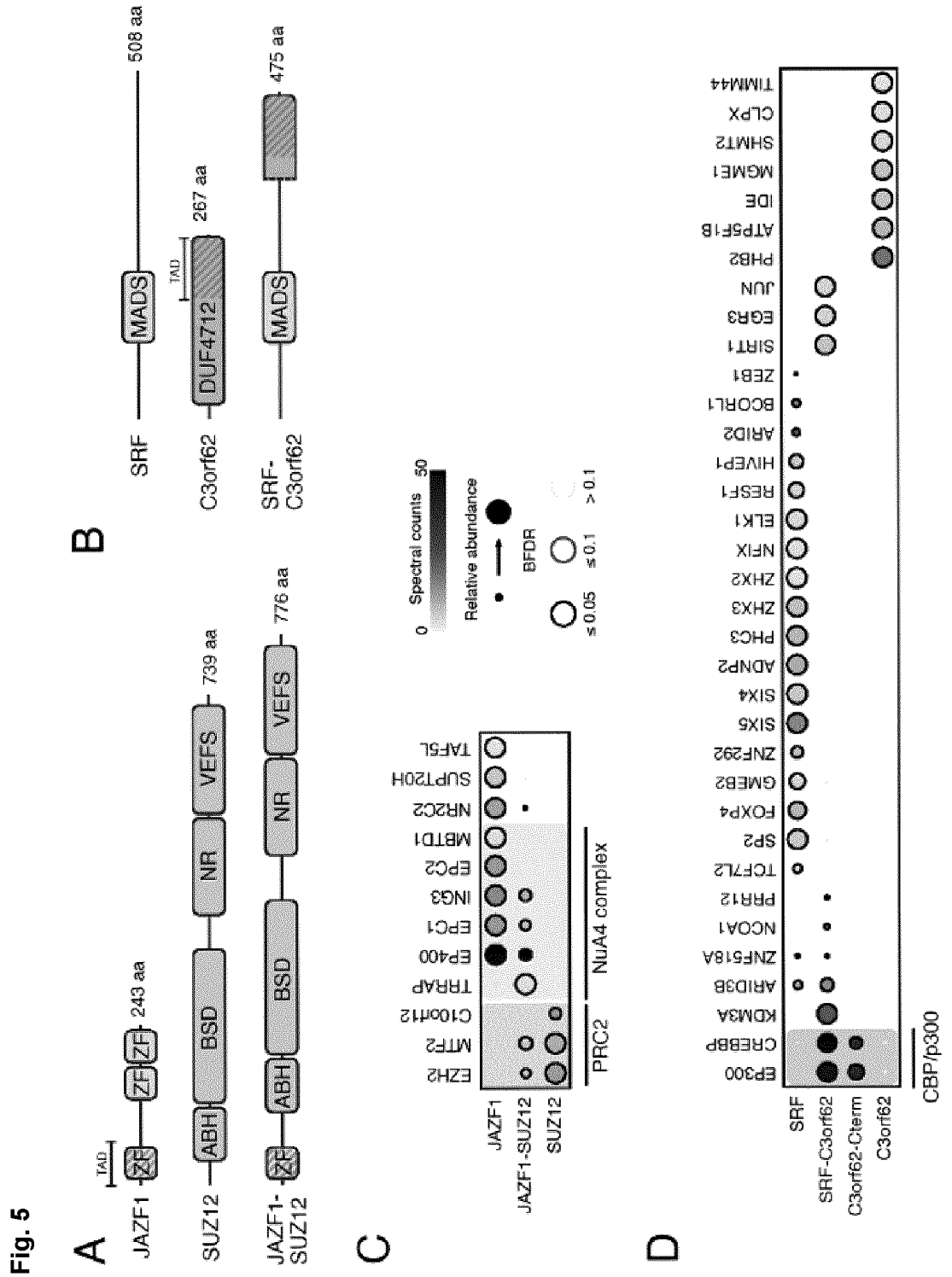

C
A-485 (p300/CBP)
1 μM A-485
GFP fluorescence (log10)
Control
GFP fluorescence (log10)
Fold change (A-485/DMSO)
p = NS
p < 0.0001
Others p300 NuA4
D
JQ1 (BET)
0.3 μM JQ1
GFP fluorescence (log10)
Control
Fold change (JQ1/DMSO)
p < 0.0001
p = NS
Others p300 NuA4
E
Compound
JQ1
CX4945
Flavo
AZ191
A485
Target
BET
CK2
CDK9
DYRK1A
CBP/p300
C3orf62
CITED1
CITED2
FOXO1
SERTAD1
SERTAD2
ATMIN
C11orf74
MED25
HOXB2
CCNC
MYCBP
CTBP2
CSNK1E
ELL3
RBPJ
UBP1
CDK9
HFM1
MAGED2
HOXA2
HSF1
FAM22F
PCGF5
PCGF3
SOX7
p300
MYOD1
MYOG
YAF2
FOXN1
KLF15
KLF14
FOXO3
DCAF7
ELL2
DDIT3
FOXR2
SP6
HOXA1
CSNK2A2
SP2
KLF2
KLF4
SS18L2
TTLL4
NEUROD1
SPDYE2
CSNK2A1
MLLT1
FAM90A1
RARB
CSRNP2
SPDYE7P
MED15
SPDYE4
MAFB
CSNK1A1L
ZXDC
NCKIPSD
NFKBIB
MYCL1
KLF7
ATOH1
FERD3L
NEUROG1
MYF6
BRD8
SPDYE1
KLF13
EGR3
LIN9
CCDC91
CNTN2
POLE4
YEATS4
MRGBP
NOM1
DMAP1
FOXR1
JAZF1
KLF6
EPC1
+3
0
-3

Fig. 4 (cont.)

Fig. 5


A
JAZF1
TAD
ZF
ZF
243 aa
SUZ12
ABH
BSD
NR
VEFS
739 aa
JAZF1-SUZ12
ABH
BSD
NR
VEFS
776 aa
B
SRF
MADS
508 aa
C3orf62
TAD
DUF4712
267 aa
SRF-C3orf62
MADS
475 aa
C
Spectral counts
0
50
Relative abundance
BFDR
≤ 0.05
≤ 0.1
> 0.1
JAZF1
JAZF1-SUZ12
SUZ12
EZH2
MTF2
C10orf12
TRRAP
EP400
EPC1
ING3
EPC2
MBTD1
NR2C2
SUPT20H
TAF5L
PRC2
NuA4 complex
D
SRF
SRF-C3orf62
C3orf62-Cterm
C3orf62
CBP/p300
EP300
CREBBP
KDM3A
ARID3B
ZNF518A
NCOA1
PRR12
TCF7L2
SP2
FOXP4
GMEB2
ZNF292
SIX5
SIX4
ADNP2
PHC3
ZHX3
ZHX2
NFIX
ELK1
RESF1
HIVEP1
ARID2
BCORL1
ZEB1
SIRT1
EGR3
JUN
PHB2
ATP5F1B
IDE
MGME1
SHMT2
CLPX
TIMM44

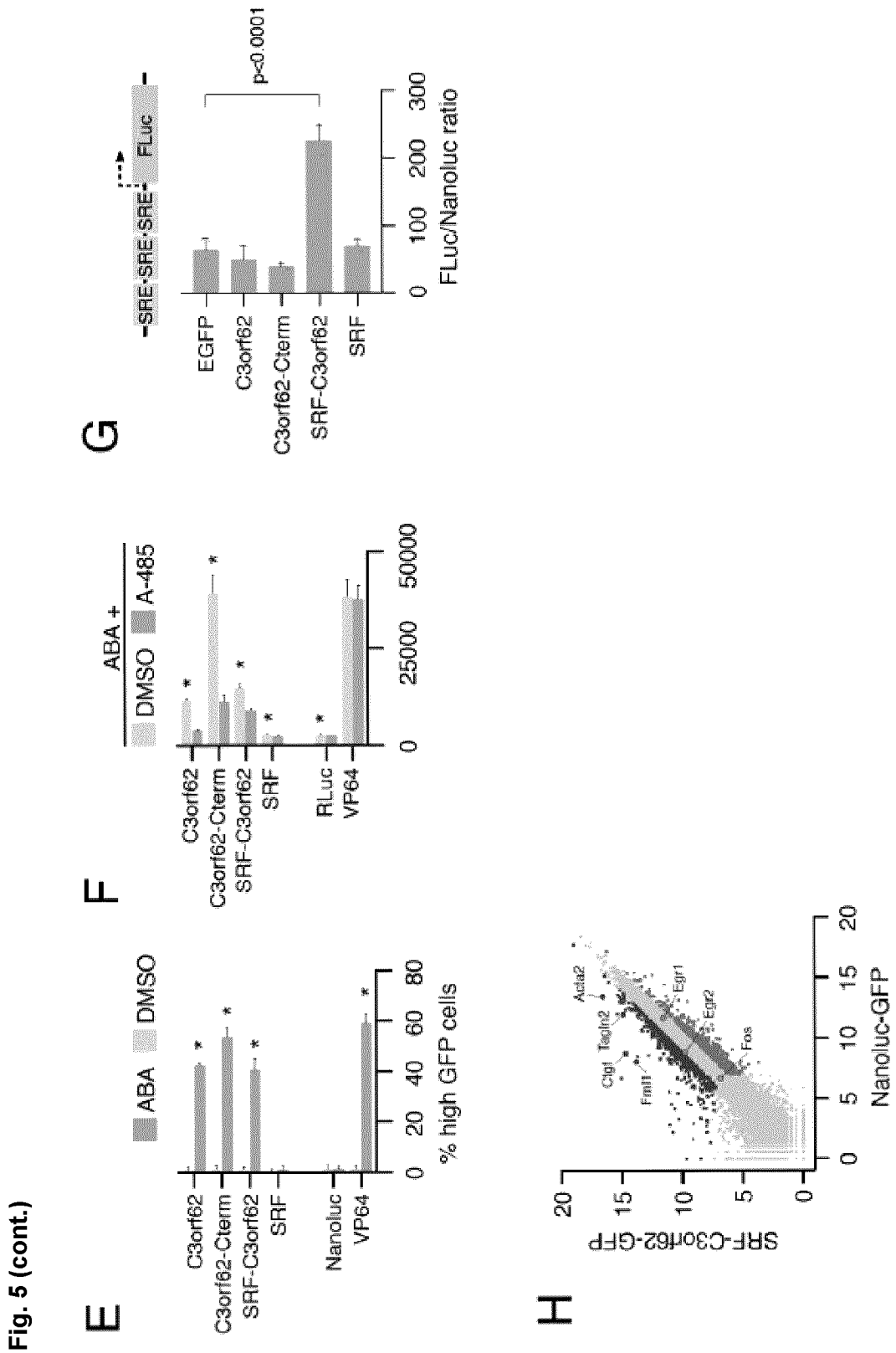
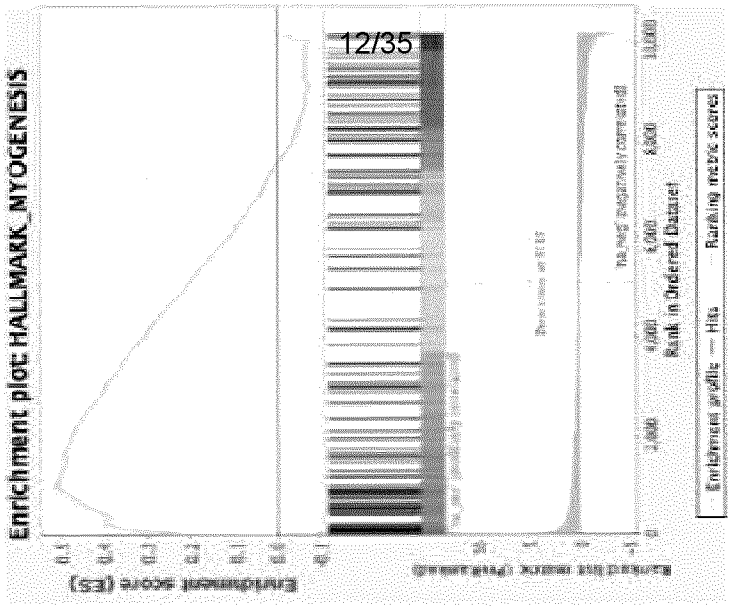
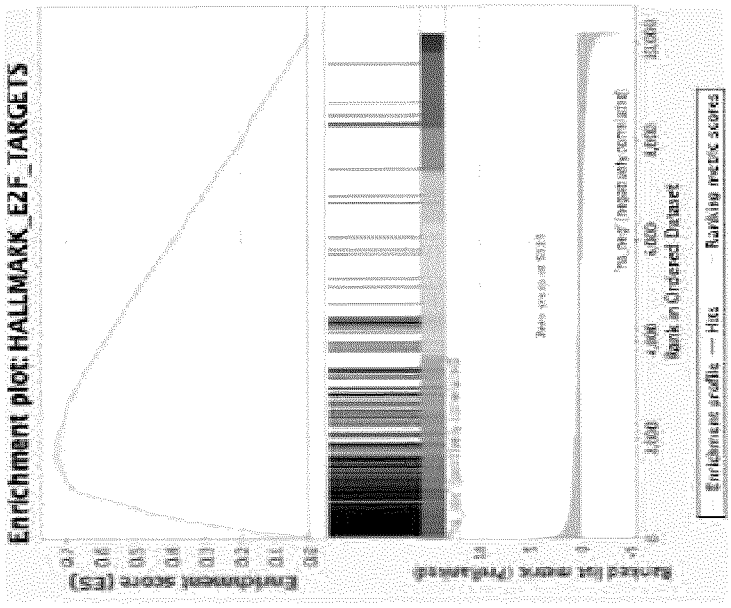

G
-SRE-SRE-SRE- FLuc -
p<0.0001
EGFP
C3orf62
C3orf62-Cterm
SRF-C3orf62
SRF
0 100 200 300
FLuc/Nanoluc ratio
F
ABA +
DMSO A-485
C3orf62
C3orf62-Cterm
SRF-C3orf62
SRF
RLuc
VP64
0 25000 50000
E
ABA DMSO
C3orf62
C3orf62-Cterm
SRF-C3orf62
SRF
Nanoluc
VP64
0 20 40 60 80
% high GFP cells
H
Acta2
Tagln2
Clg1
Fmn1
Egr1
Egr2
Fos
SRF-C3orf62-GFP
Nanoluc-GFP
0 5 10 15 20
0 5 10 15 20

Fig. 5 (cont.)


Enrichment plot: HALLMARK_MYOGENESIS
Enrichment score (ES)
Ranked list metric (PreRanked)
Rank in Ordered Dataset
Enrichment profile
Hits
Ranking metric scores


Enrichment plot: HALLMARK_E2F_TARGETS
Enrichment score (ES)
Ranked list metric (PreRanked)
Rank in Ordered Dataset
Enrichment profile
Hits
Ranking metric scores

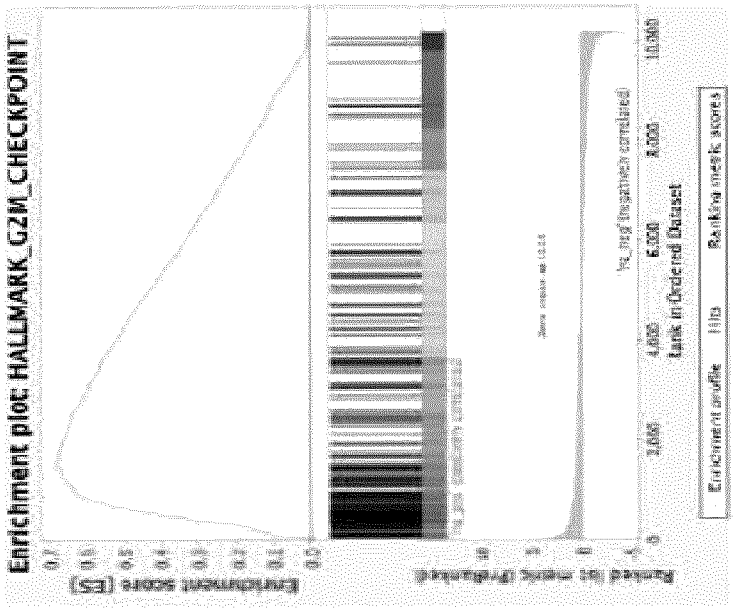

Enrichment plot: HALLMARK_G2M_CHECKPOINT
Enrichment score (ES)
Ranked list metric (PreRanked)
Rank in Ordered Dataset
Enrichment profile
Hits
Ranking metric scores

Fig. 5 (cont.)

Fig. 6

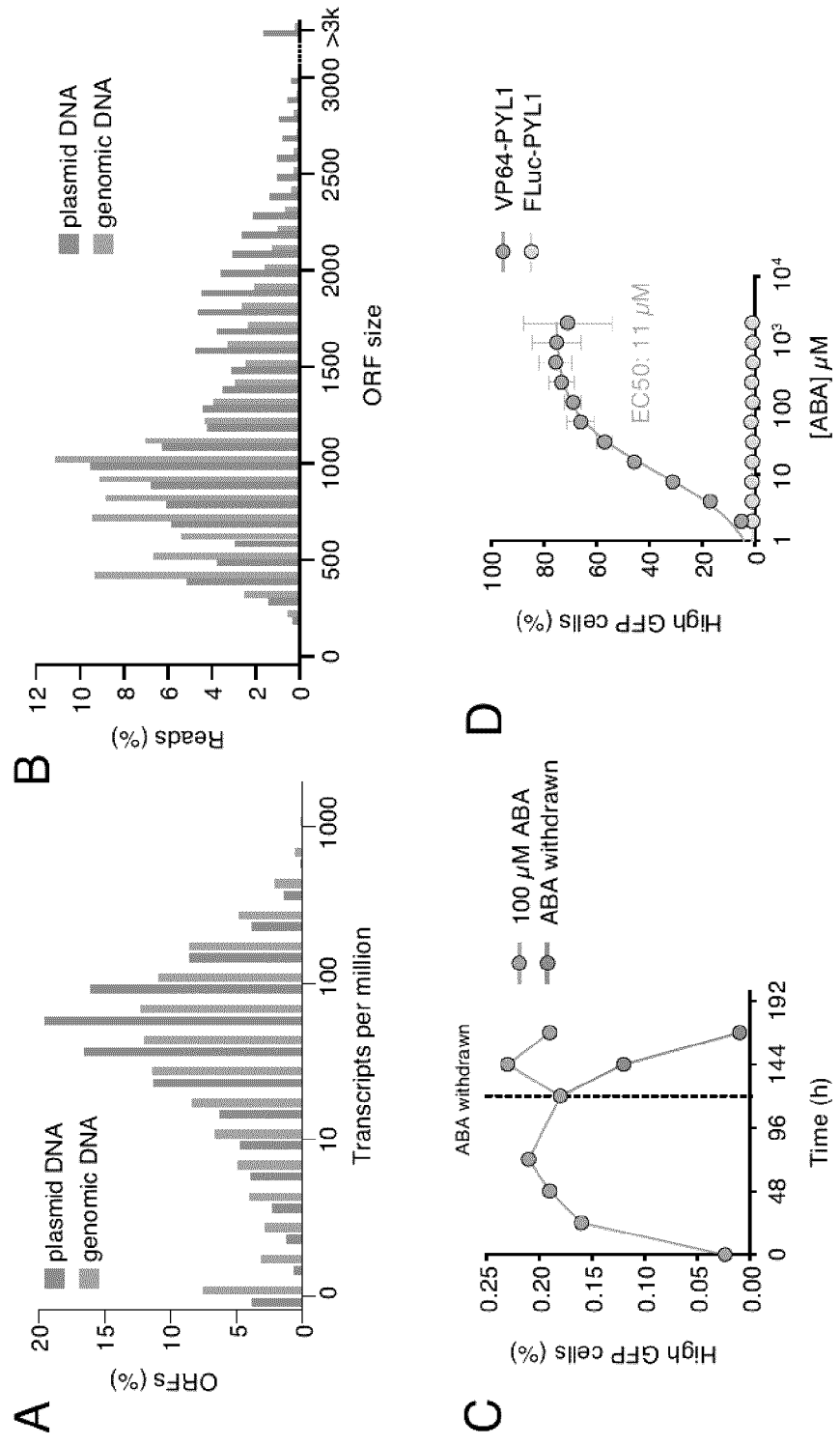

A
ORFs (%)
plasmid DNA
genomic DNA
Transcripts per million
B
Reads (%)
plasmid DNA
genomic DNA
ORF size
C
High GFP cells (%)
100 μM ABA
ABA withdrawn
ABA withdrawn
Time (h)
D
High GFP cells (%)
VP64-PYL1
FLuc-PYL1
EC50: 11 μM
[ABA] μM

Fig. 6 (cont.)

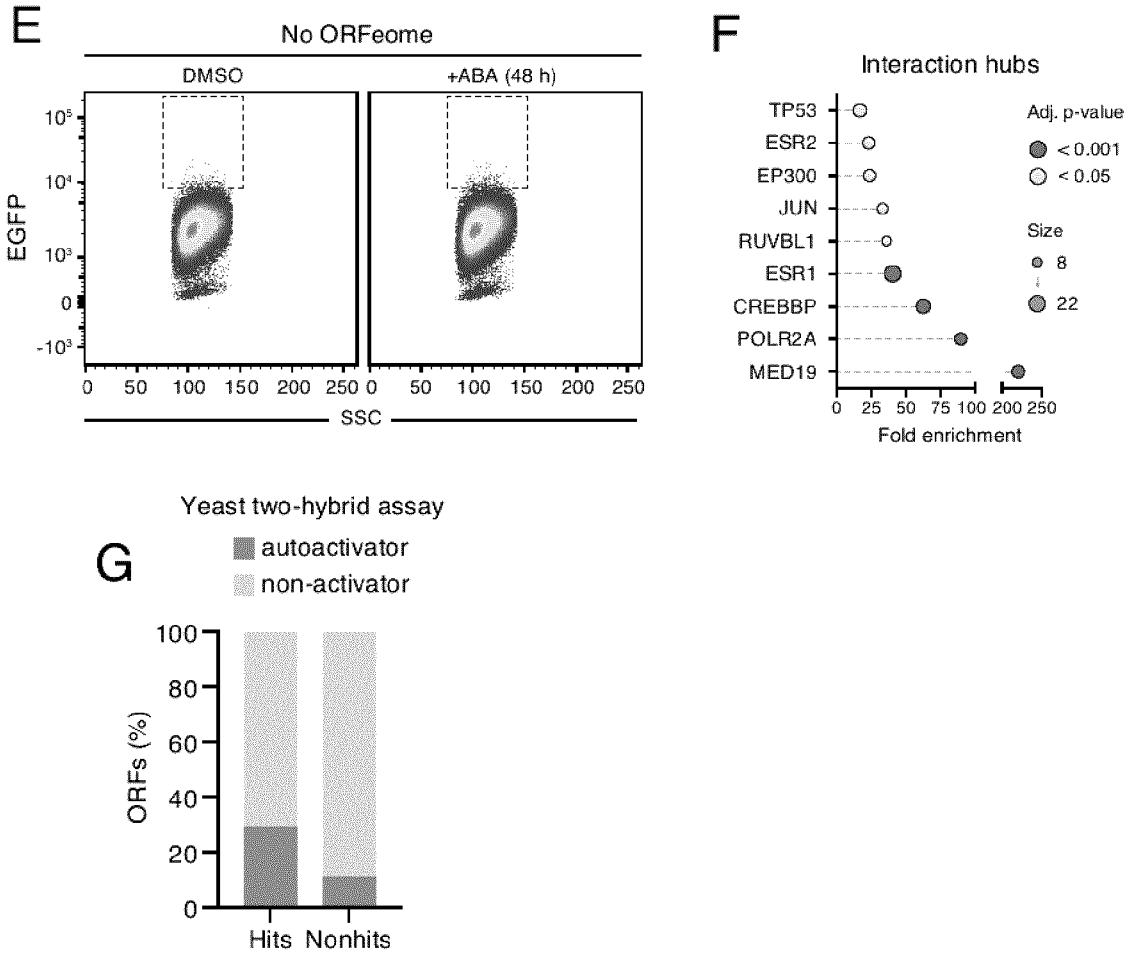

E
No ORFeome
DMSO
+ABA (48 h)
EGFP
SSC
F
Interaction hubs
TP53
ESR2
EP300
JUN
RUVBL1
ESR1
CREBBP
POLR2A
MED19
Adj. p-value
< 0.001
< 0.05
Size
8
22
Fold enrichment
G
Yeast two-hybrid assay
autoactivator
non-activator
ORFs (%)
Hits
Nonhits

Fig. 6 (cont.)

H

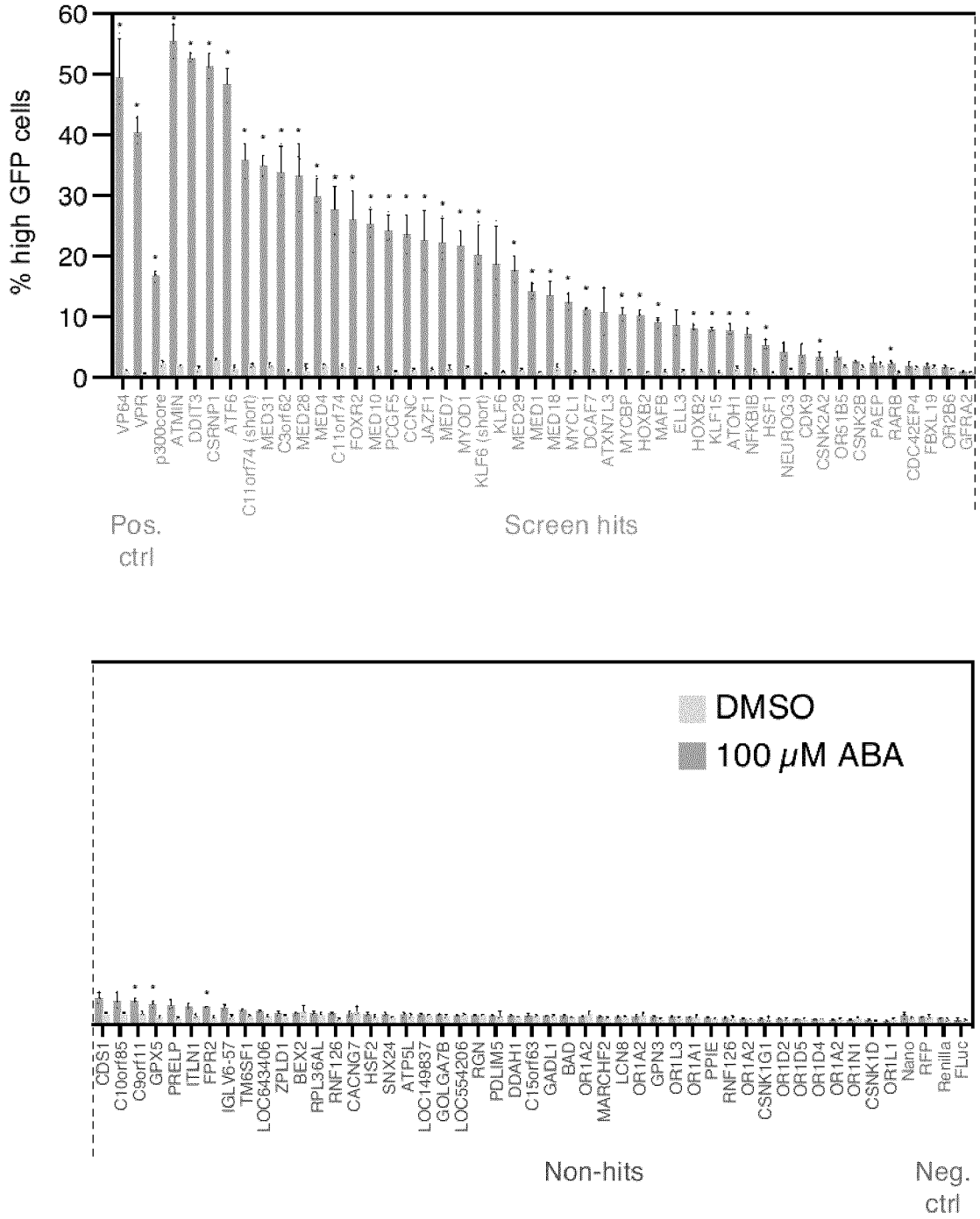
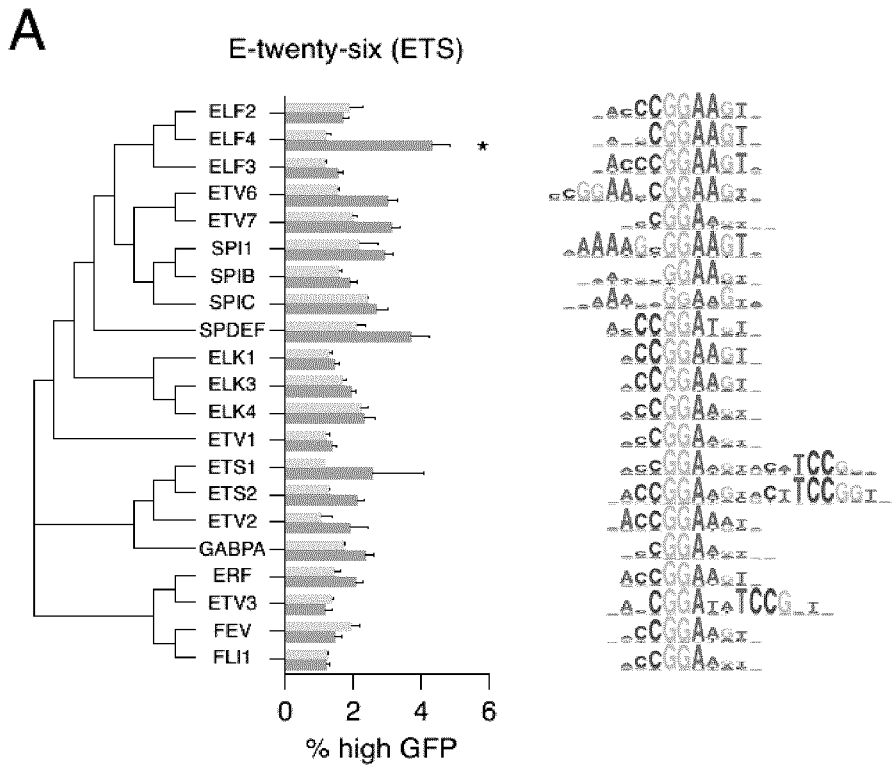
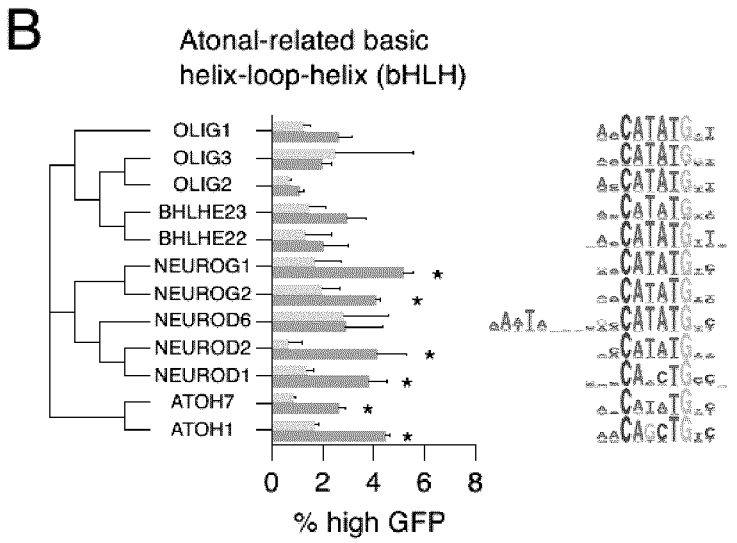

% high GFP cells
60
50
40
30
20
10
0
VP64
VPR
p300core
ATMIN
DDIT3
CSRNP1
ATF6
C11orf74 (short)
MED31
C3orf62
MED28
MED4
C11orf74
FOXR2
MED10
PCGF5
CCNC
JAZF1
MED7
MYOD1
KLF6 (short)
KLF6
MED29
MED1
MED18
MYCL1
DCAF7
ATXN7L3
MYCBP
HOXB2
MAFB
ELL3
HOXB2
KLF15
ATOH1
NFKBIB
HSF1
NEUROG3
CDK9
CSNK2A2
OR51B5
CSNK2B
PAEP
RARB
CDC42EP4
FBXL19
OR2B6
GFRA2
Pos. ctrl
Screen hits
DMSO
100 μM ABA
CDS1
C10orf85
C9orf11
GPX5
PRELP
ITLN1
FPR2
IGLV6-57
TM6SF1
LOC643406
ZPLD1
BEX2
RPL36AL
RNF126
CACNG7
HSF2
SNX24
ATP5L
LOC149837
GOLGA7B
LOC554206
RGN
PDLIM5
DDAH1
C15orf63
GADL1
BAD
OR1A2
MARCHF2
LCN8
OR1A2
GPN3
OR1L3
OR1A1
PPIE
RNF126
OR1A2
CSNK1G1
OR1D2
OR1D5
OR1D4
OR1A2
OR1N1
CSNK1D
OR1L1
Nano
RFP
Renilla
FLuc
Non-hits
Neg. ctrl

Fig. 7


A
E-twenty-six (ETS)
ELF2
ELF4
ELF3
ETV6
ETV7
SPI1
SPIB
SPIC
SPDEF
ELK1
ELK3
ELK4
ETV1
ETS1
ETS2
ETV2
GABPA
ERF
ETV3
FEV
FLI1
0 2 4 6
% high GFP


B
Atonal-related basic
helix-loop-helix (bHLH)
OLIG1
OLIG3
OLIG2
BHLHE23
BHLHE22
NEUROG1
NEUROG2
NEUROD6
NEUROD2
NEUROD1
ATOH7
ATOH1
0 2 4 6 8
% high GFP

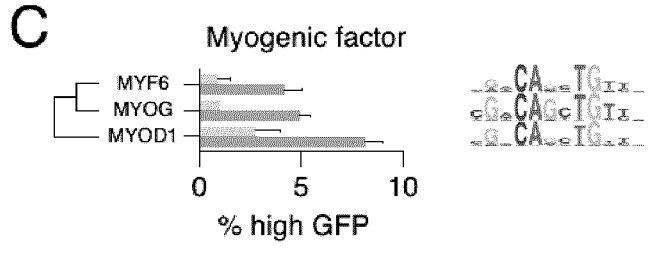

C
Myogenic factor
MYF6
MYOG
MYOD1
0 5 10
% high GFP

Fig. 7 (cont.)

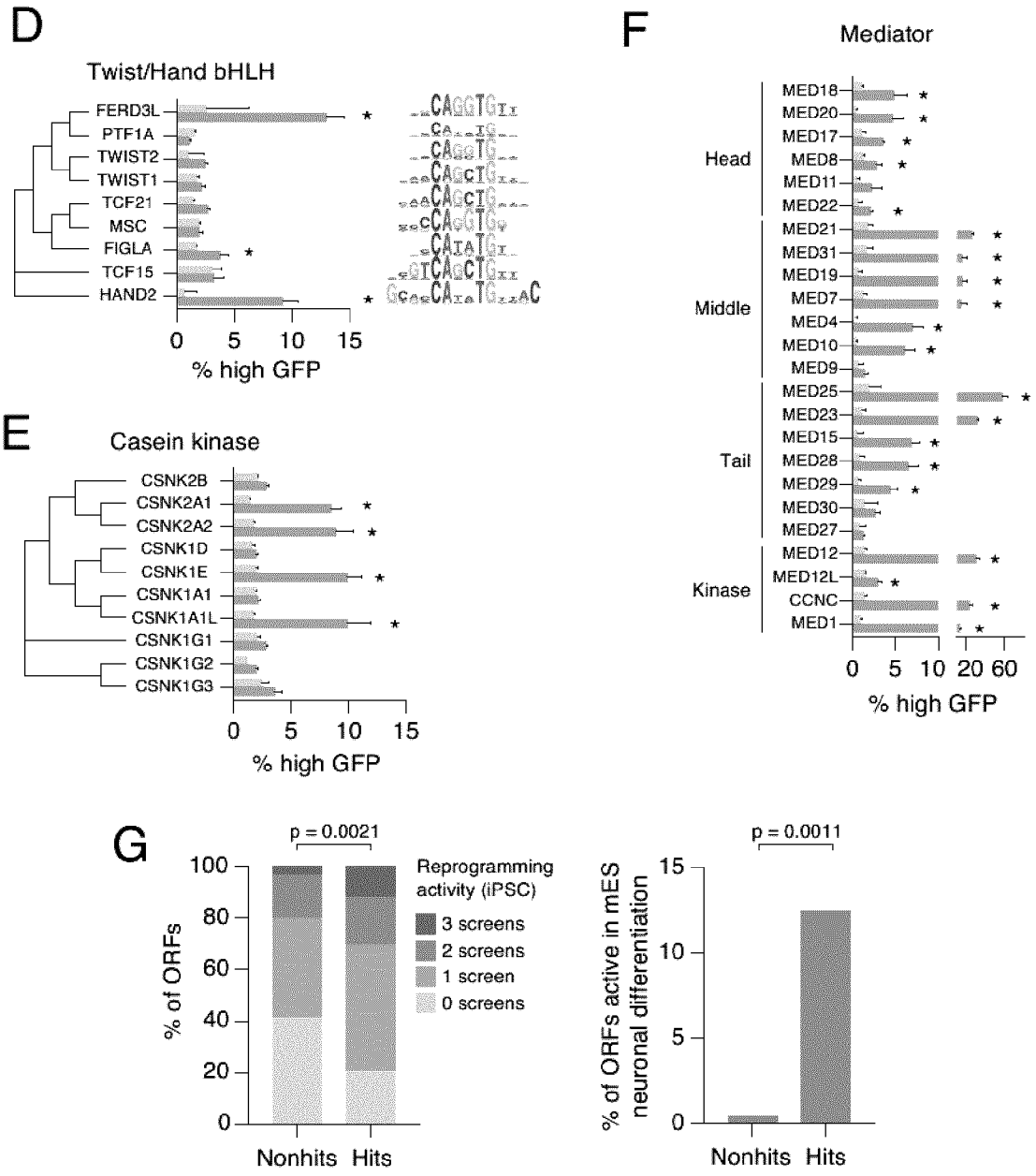

D
Twist/Hand bHLH
FERD3L
PTF1A
TWIST2
TWIST1
TCF21
MSC
FIGLA
TCF15
HAND2
0 5 10 15
% high GFP
E
Casein kinase
CSNK2B
CSNK2A1
CSNK2A2
CSNK1D
CSNK1E
CSNK1A1
CSNK1A1L
CSNK1G1
CSNK1G2
CSNK1G3
0 5 10 15
% high GFP
F
Mediator
Head
Middle
Tail
Kinase
MED18
MED20
MED17
MED8
MED11
MED22
MED21
MED31
MED19
MED7
MED4
MED10
MED9
MED25
MED23
MED15
MED28
MED29
MED30
MED27
MED12
MED12L
CCNC
MED1
0 5 10 20 60
% high GFP
G
p = 0.0021
% of ORFs
100
80
60
40
20
0
Nonhits Hits
Reprogramming activity (iPSC)
3 screens
2 screens
1 screen
0 screens
p = 0.0011
% of ORFs active in mES neuronal differentiation
15
10
5
0
Nonhits Hits

Fig. 8

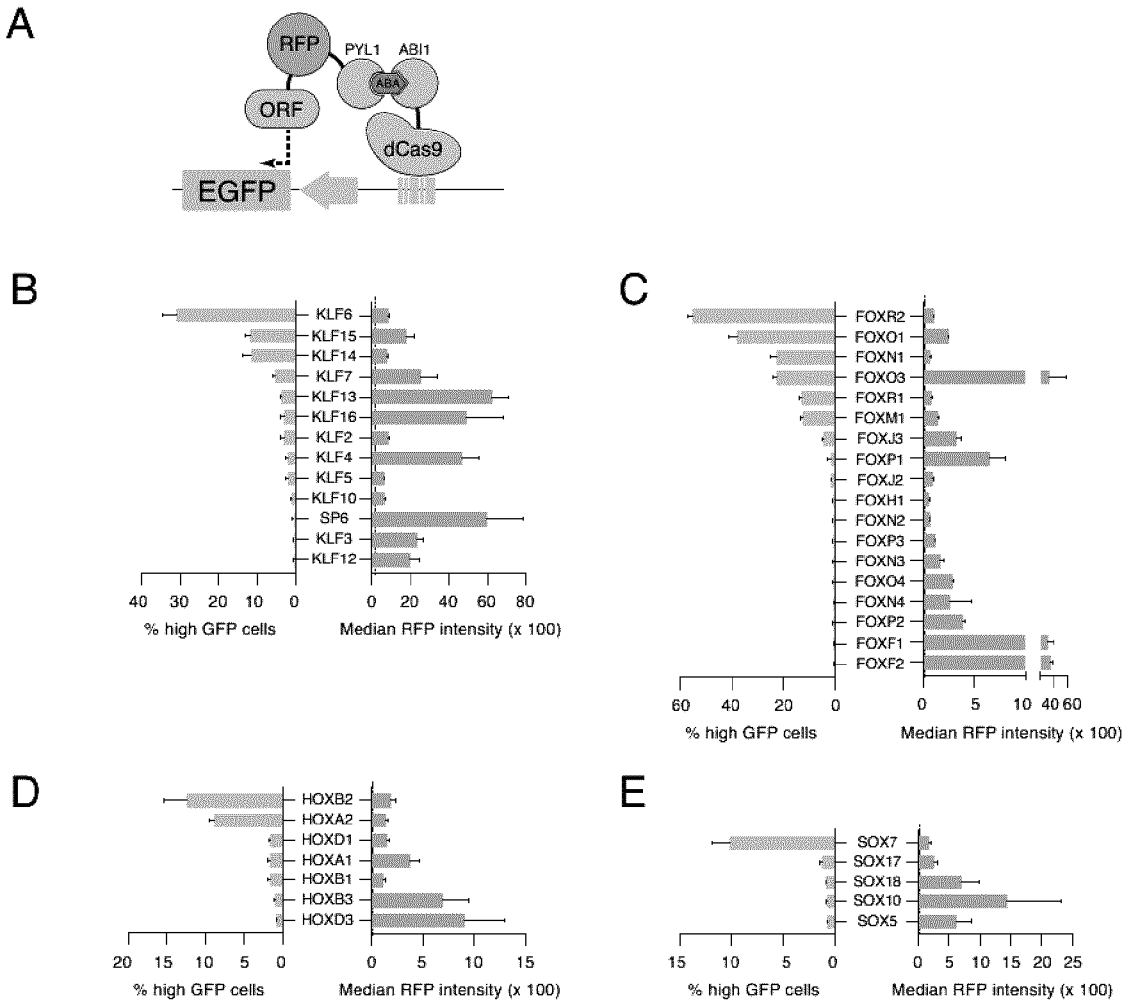

A
RFP
PYL1
ABI1
ABA
ORF
dCas9
EGFP
B
KLF6
KLF15
KLF14
KLF7
KLF13
KLF16
KLF2
KLF4
KLF5
KLF10
SP6
KLF3
KLF12
40 30 20 10 0
% high GFP cells
0 20 40 60 80
Median RFP intensity (x 100)
C
FOXR2
FOXO1
FOXN1
FOXO3
FOXR1
FOXM1
FOXJ3
FOXP1
FOXJ2
FOXH1
FOXN2
FOXP3
FOXN3
FOXO4
FOXN4
FOXP2
FOXF1
FOXF2
60 40 20 0
% high GFP cells
0 5 10 40 60
Median RFP intensity (x 100)
D
HOXB2
HOXA2
HOXD1
HOXA1
HOXB1
HOXB3
HOXD3
20 15 10 5 0
% high GFP cells
0 5 10 15
Median RFP intensity (x 100)
E
SOX7
SOX17
SOX18
SOX10
SOX5
15 10 5 0
% high GFP cells
0 5 10 15 20 25
Median RFP intensity (x 100)

Fig. 9

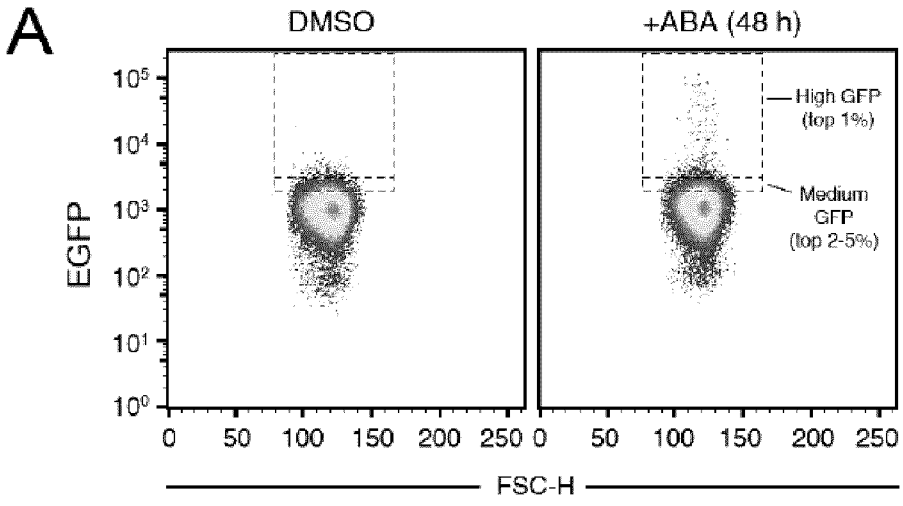
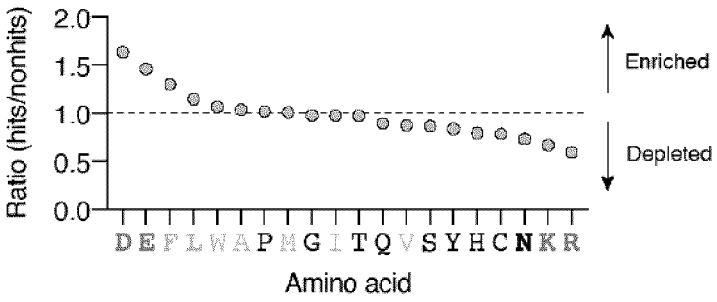
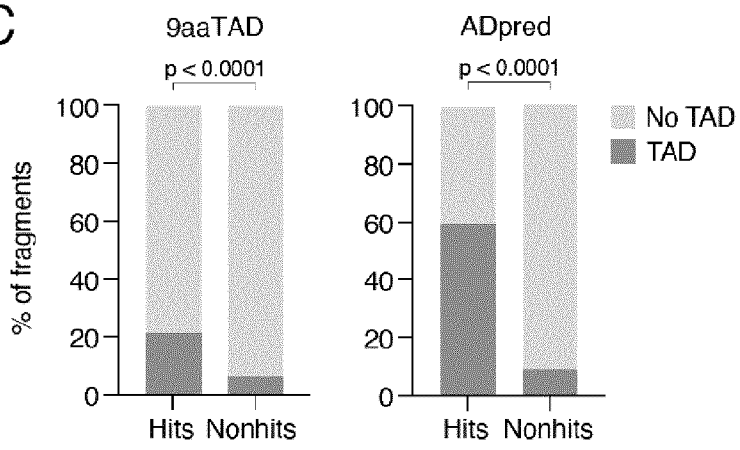

A
DMSO
+ABA (48 h)
High GFP
(top 1%)
Medium
GFP
(top 2-5%)
EGFP
10^5
10^4
10^3
10^2
10^1
10^0
0 50 100 150 200 250
0 50 100 150 200 250
FSC-H

Fig. 9 (cont.)

B



C



D

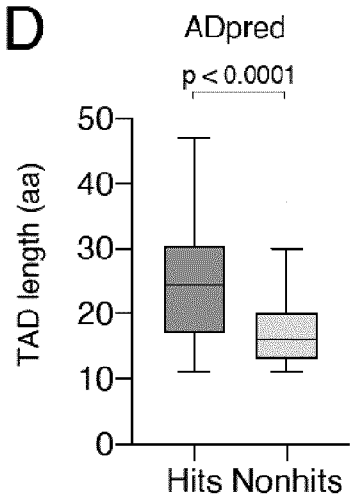
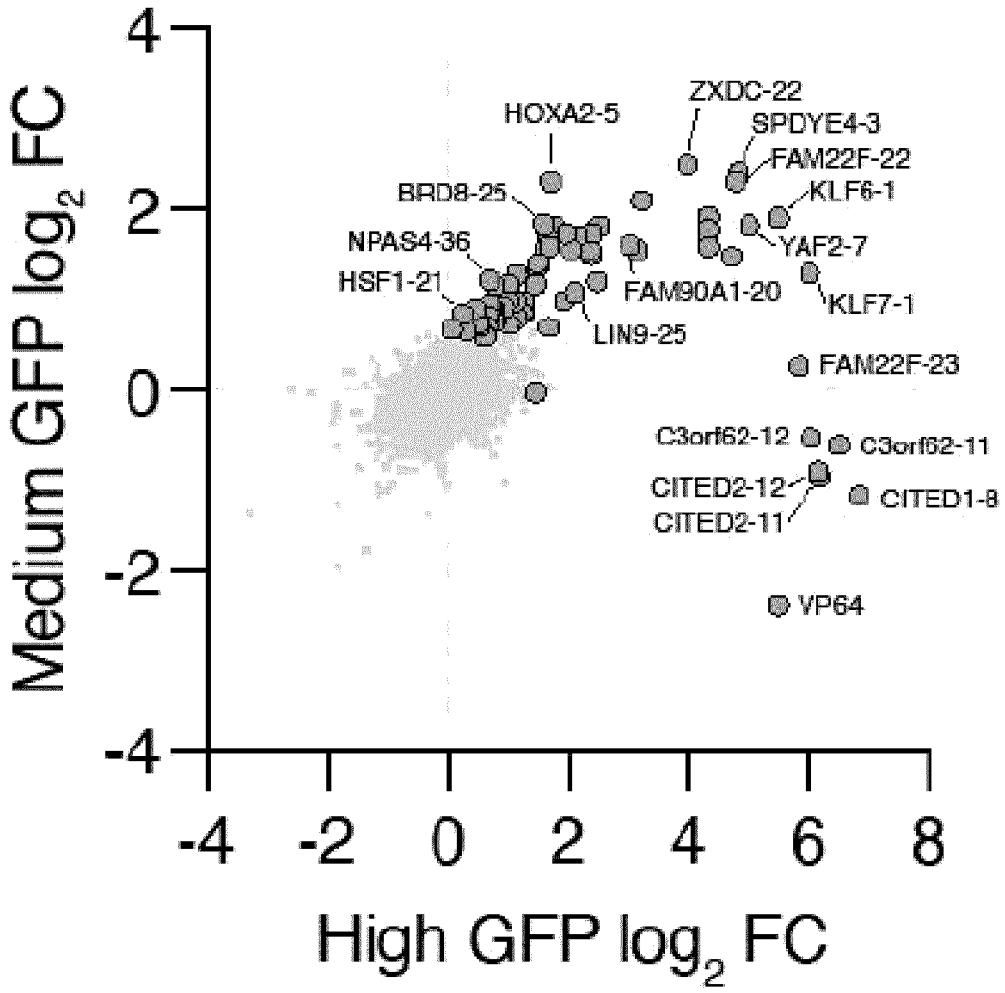


Fig. 9 (cont.)

E


Medium GFP log2 FC
High GFP log2 FC
4
2
0
-2
-4
-4 -2 0 2 4 6 8
HOXA2-5
ZXDC-22
SPDYE4-3
FAM22F-22
KLF6-1
BRD8-25
NPAS4-36
YAF2-7
HSF1-21
FAM90A1-20
KLF7-1
LIN9-25
FAM22F-23
C3orf62-12
C3orf62-11
CITED2-12
CITED1-8
CITED2-11
VP64

F

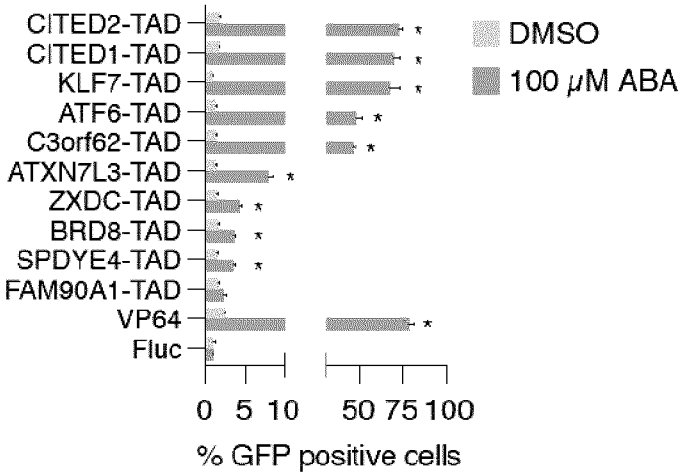
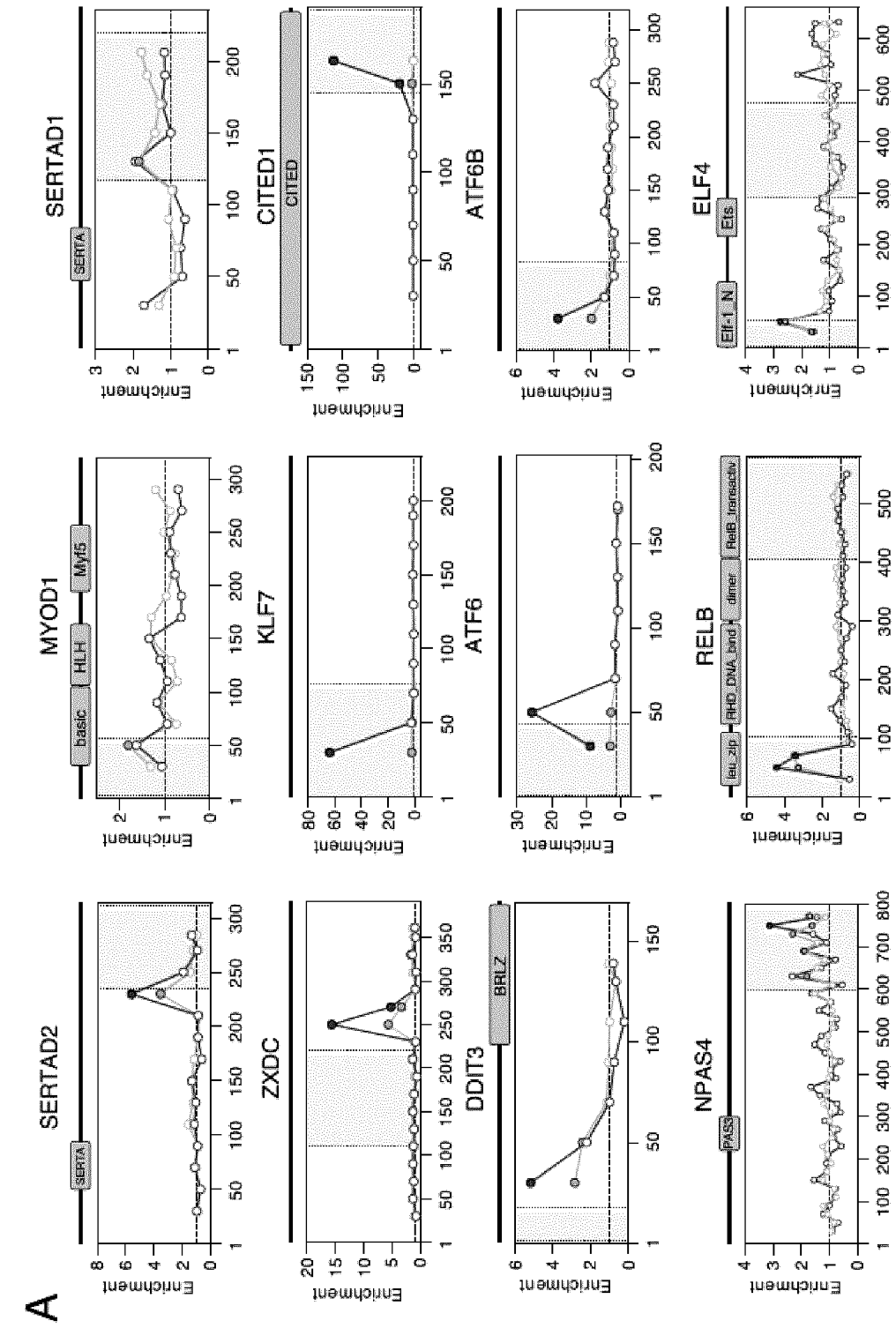

CITED2-TAD
CITED1-TAD
KLF7-TAD
ATF6-TAD
C3orf62-TAD
ATXN7L3-TAD
ZXDC-TAD
BRD8-TAD
SPDYE4-TAD
FAM90A1-TAD
VP64
Fluc
DMSO
100 μM ABA
0 5 10 50 75 100
% GFP positive cells

Fig. 10


A
SERTAD2
SERTA
ZXDC
DDIT3
BRLZ
NPAS3
PAS
MYOD1
basic
HLH
MyfS
KLF7
ATF6
SERTAD1
SERTA
CITED1
CITED
ATF6B
RELB
IaU_zip
RHD_DNA_bind
dimer
RelB_transactiv
ELF4
Elf-1_N
Ets
Enrichment

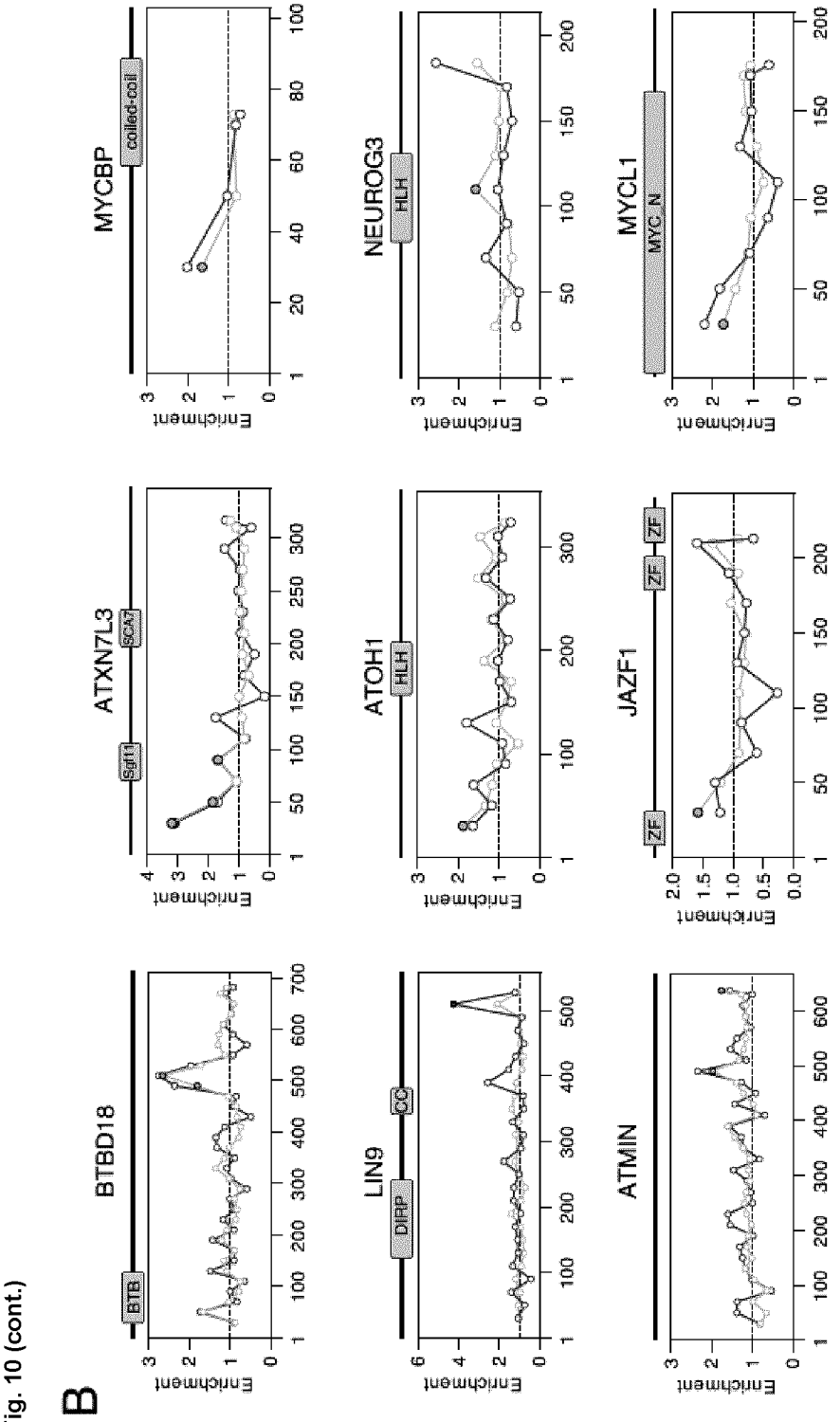
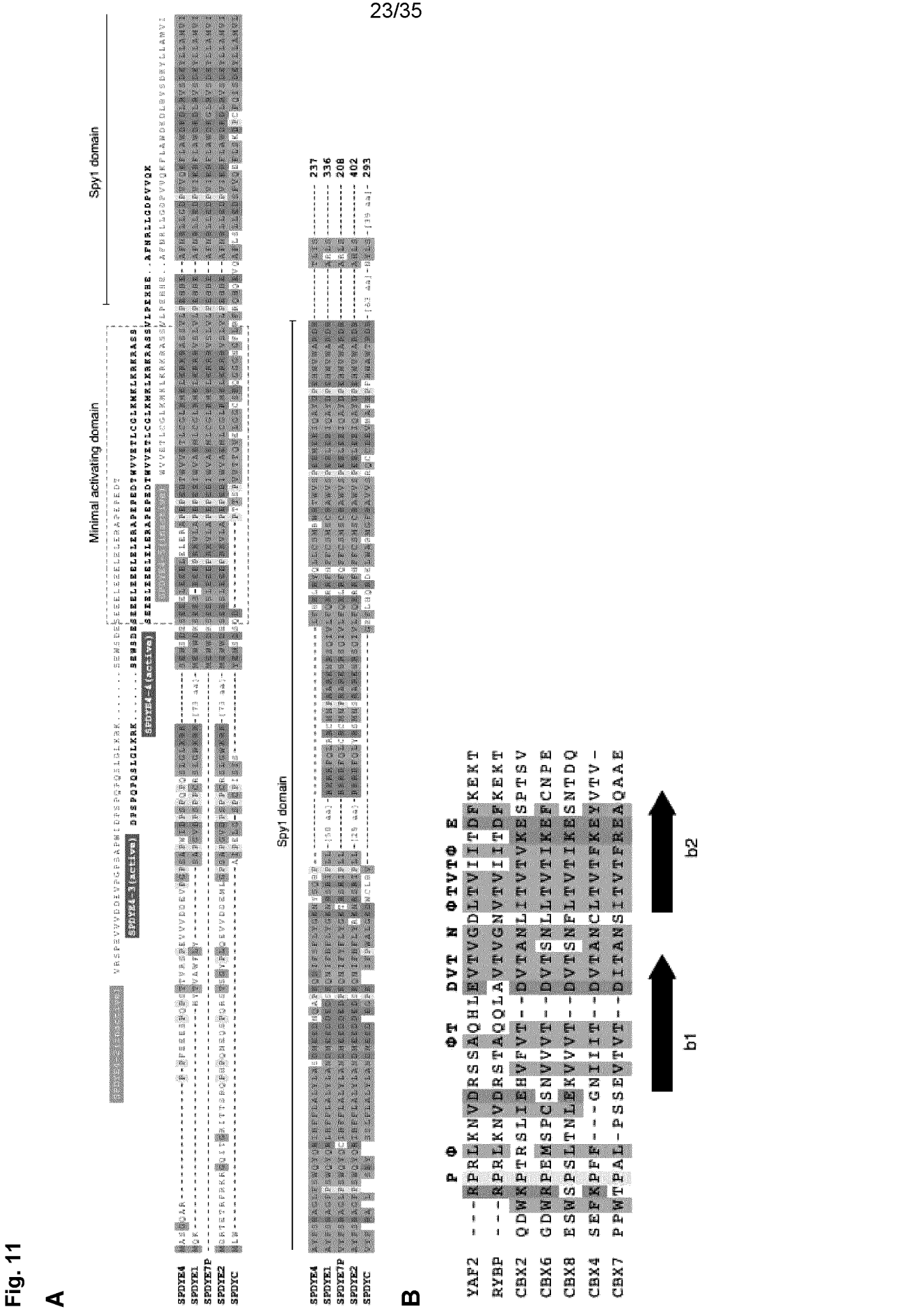

B
BTBD18
BTB
LIN9
DIRP
CC
ATMIN
ATXN7L3
Sgf11
SCA7
ATOH1
HLH
JAZF1
ZF
MYCBP
coiled-coil
NEUROG3
HLH
MYCL1
MYC_N
Enrichment

Fig. 10 (cont.)

Fig. 11


A
Minimal activating domain
Spy1 domain
SPDYE4-1(active)
SPDYE4-4(active)
SPDYE4
SPDYE1
SPDYE7P
SPDYE2
SPDYC
Spy1 domain
B
b1
b2

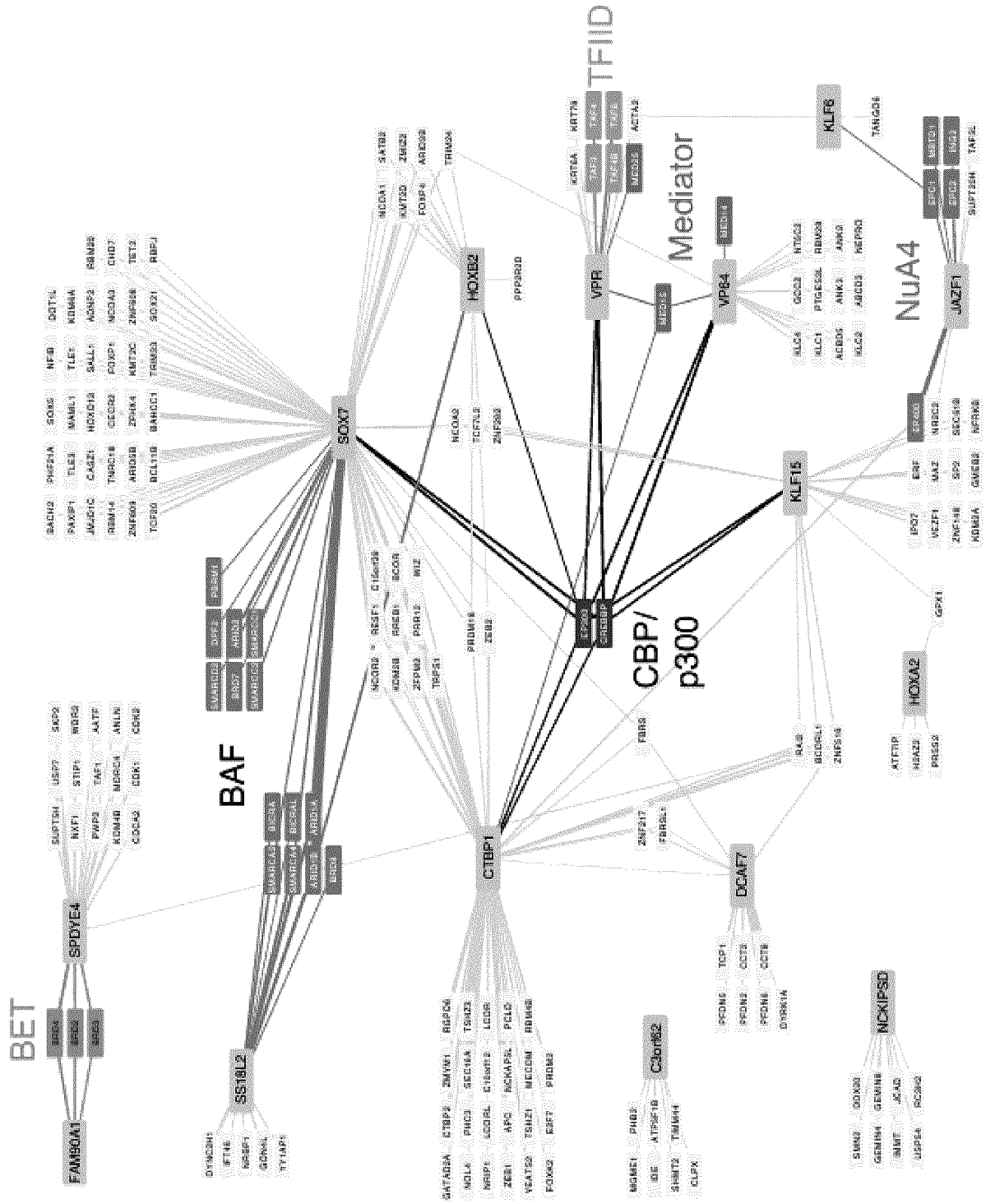

BET
BRD4
BRD2
BRD3
SPDYE4
FAM90A1
BAF
SS18L2
SOX7
HOXB2
CTBP1
CBP/
p300
VPR
VPR4
Mediator
TFIID
KLF15
KLF6
DCAF7
C3orf62
NCKIPSD
HOXA2
JAZF1
NuA4

Fig. 12
A

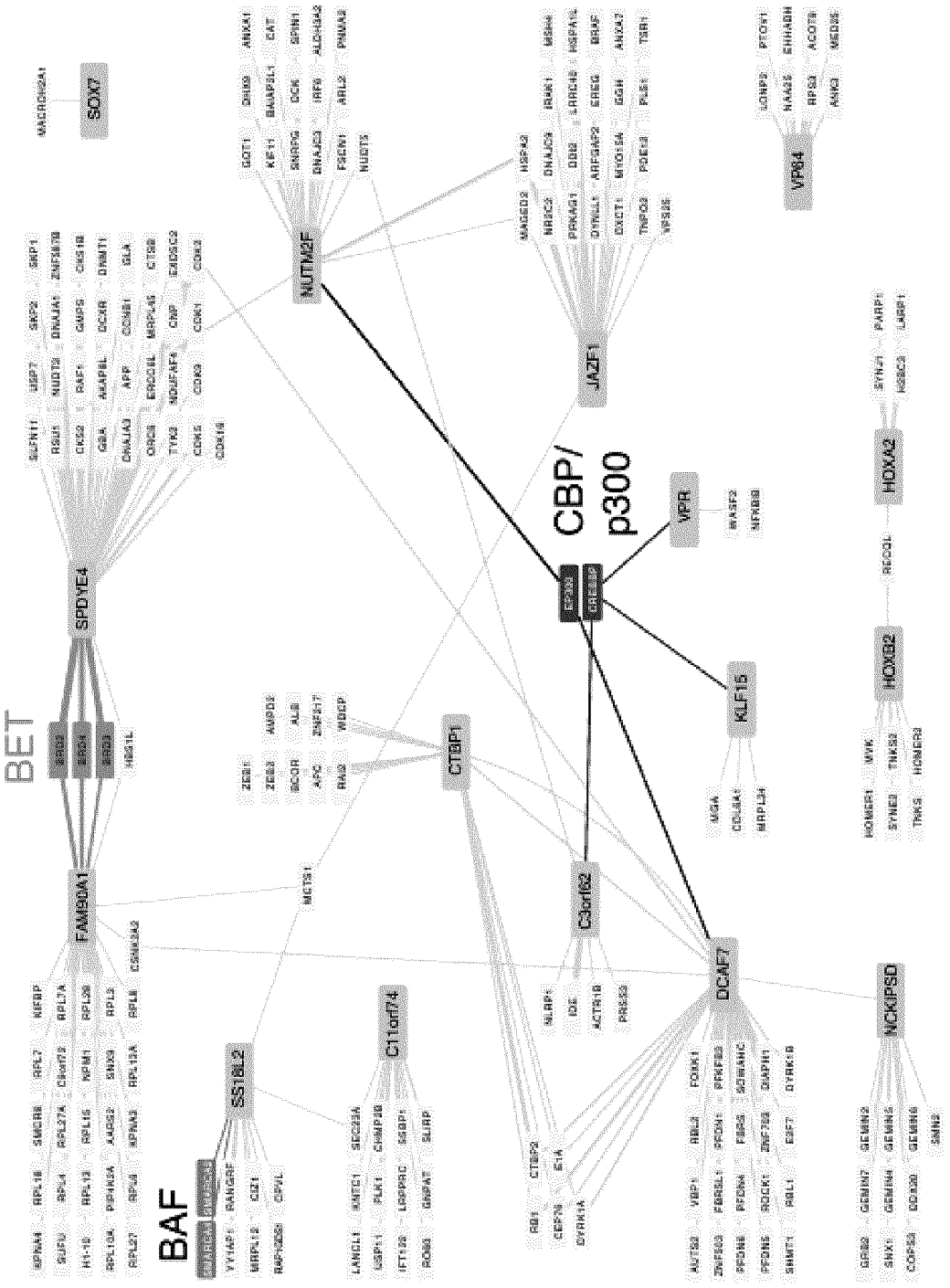

BET
BRD2
BRD4
BRD3
SPDYE4
FAM60A1
BAF
SS18L2
C11orf74
CTBP1
NUTM2F
JAZF1
CBP/
p300
EP300
CREBBP
C3orf62
DCAF7
VPR
KLF16
HOXA2
HOXB2
VPS64
WDR37
SOX7

Fig. 12 (cont.)

B

Fig. 13

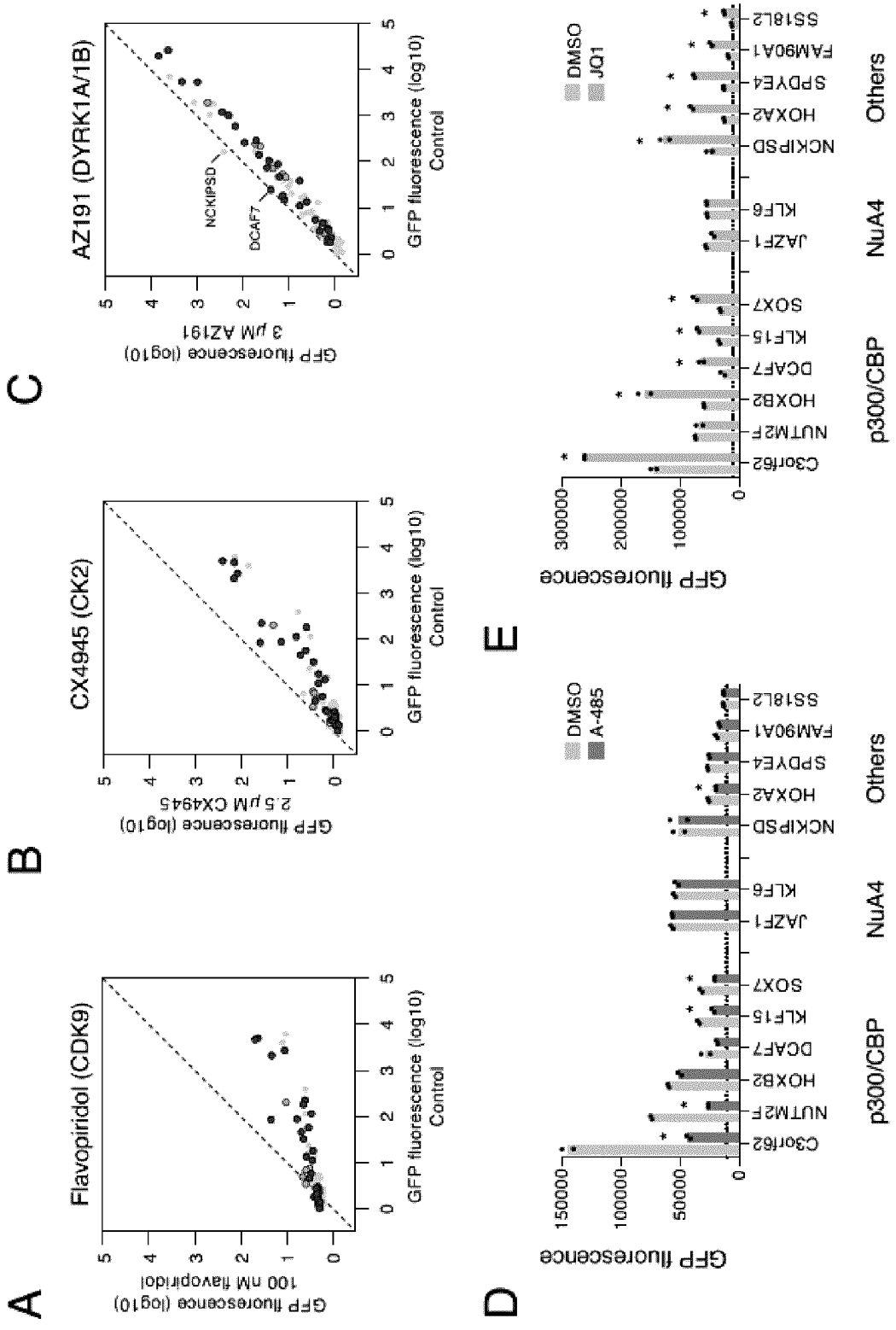

A
Flavopiridol (CDK9)
GFP fluorescence (log10)
100 nM flavopiridol
GFP fluorescence (log10)
Control
B
CX4945 (CK2)
GFP fluorescence (log10)
2.5 μM CX4945
GFP fluorescence (log10)
Control
C
AZ191 (DYRK1A/1B)
GFP fluorescence (log10)
3 μM AZ191
NCKIPSD
DCAF7
GFP fluorescence (log10)
Control
D
DMSO
A-485
GFP fluorescence
150000
100000
50000
0
C3orf62
NUTM2F
HOXB2
DCAF7
KLF15
SOX7
JAZF1
KLF6
NCKIPSD
HOXA2
SPDYE4
FAM90A1
SS18L2
p300/CBP
NuA4
Others
E
DMSO
JQ1
GFP fluorescence
300000
200000
100000
0
C3orf62
NUTM2F
HOXB2
DCAF7
KLF15
SOX7
JAZF1
KLF6
NCKIPSD
HOXA2
SPDYE4
FAM90A1
SS18L2
p300/CBP
NuA4
Others

Fig. 14

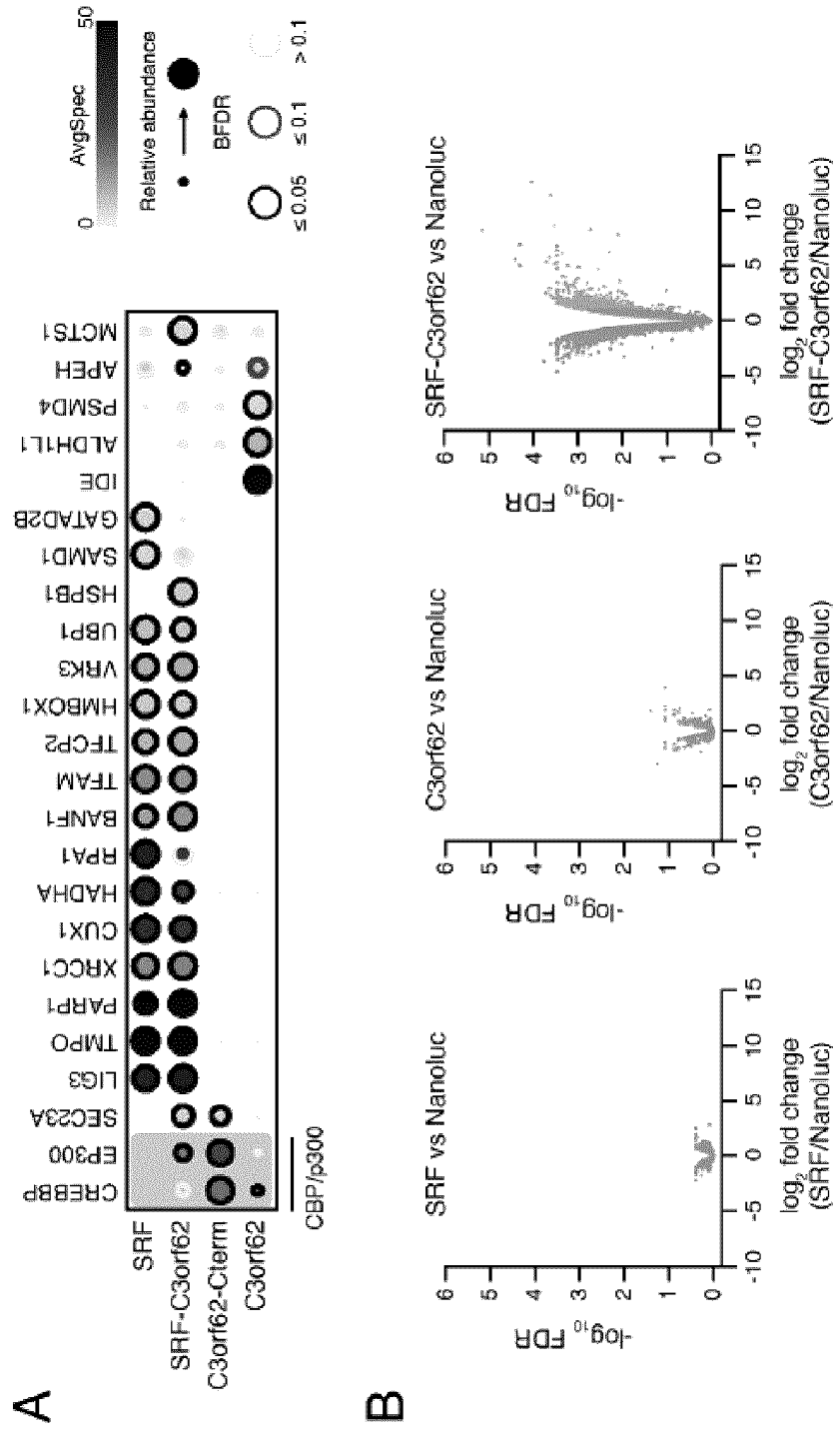

A
AvgSpec
0
50
Relative abundance
BFDR
≤ 0.05
≤ 0.1
> 0.1
SRF
SRF-C3orf62
C3orf62-Cterm
C3orf62
CBP/p300
CREBBP
EP300
SEC23A
LIG3
TMPO
PARP1
XRCC1
CUX1
HADHA
RPA1
BANF1
TFAM
TFCP2
HMBOX1
VRK3
UBP1
HSPB1
SAMD1
GATAD2B
IDE
ALDH1L1
PSMD4
APEH
MCTS1
B
SRF vs Nanoluc
C3orf62 vs Nanoluc
SRF-C3orf62 vs Nanoluc
-log10 FDR
log2 fold change
(SRF/Nanoluc)
(C3orf62/Nanoluc)
(SRF-C3orf62/Nanoluc)

Fig. 14 (cont.)

C

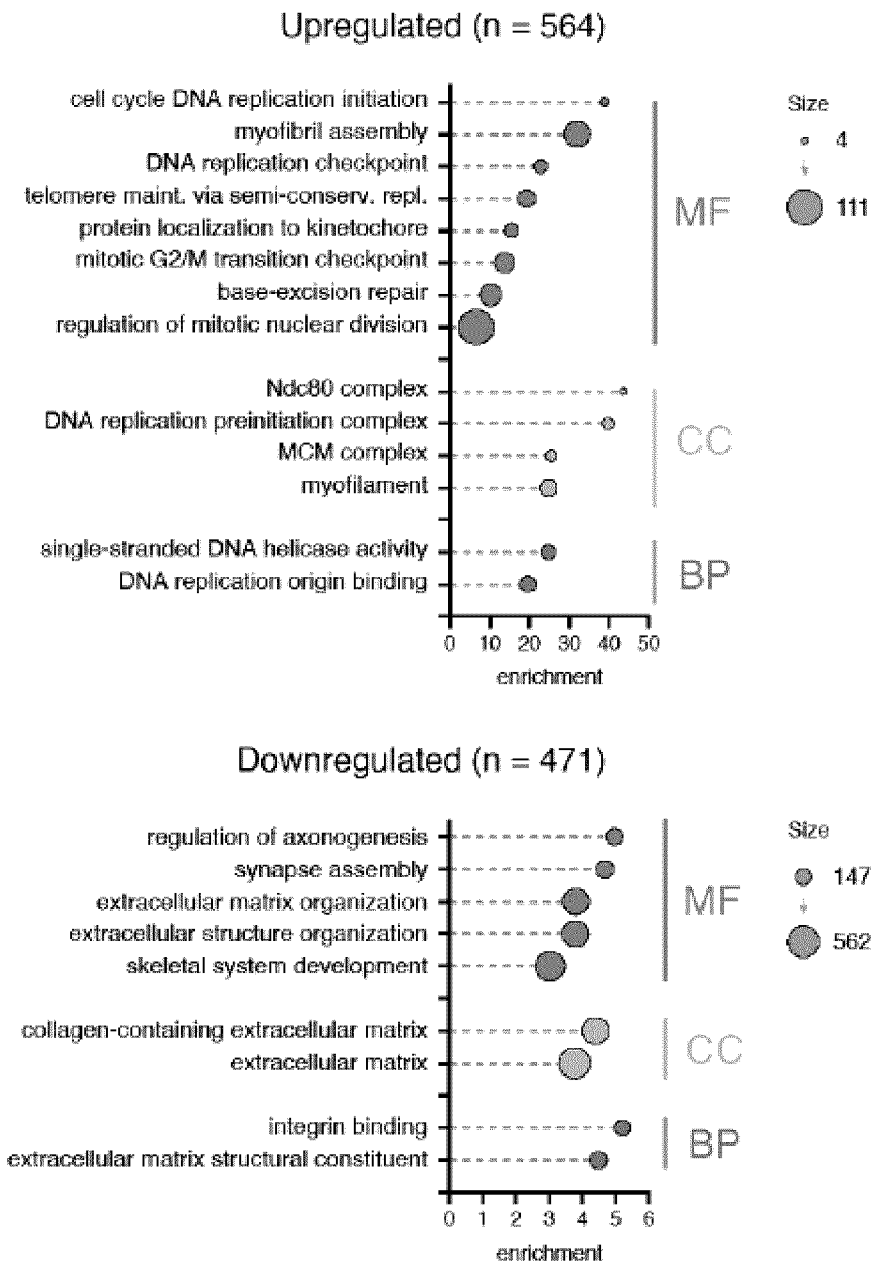

Upregulated (n = 564)
cell cycle DNA replication initiation
myofibril assembly
DNA replication checkpoint
telomere maint. via semi-conserv. repl.
protein localization to kinetochore
mitotic G2/M transition checkpoint
base-excision repair
regulation of mitotic nuclear division
Ndc80 complex
DNA replication preinitiation complex
MCM complex
myofilament
single-stranded DNA helicase activity
DNA replication origin binding
MF
CC
BP
0 10 20 30 40 50
enrichment
Size
4
111
Downregulated (n = 471)
regulation of axonogenesis
synapse assembly
extracellular matrix organization
extracellular structure organization
skeletal system development
collagen-containing extracellular matrix
extracellular matrix
integrin binding
extracellular matrix structural constituent
MF
CC
BP
0 1 2 3 4 5 6
enrichment
Size
147
562

Fig. 14 (cont.)

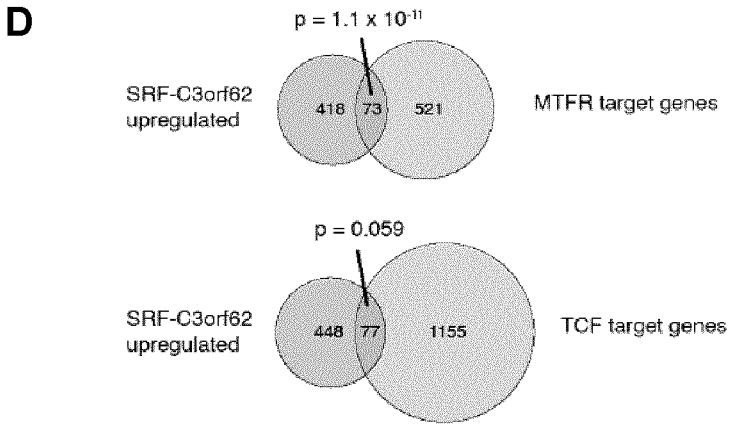


Fig. 15

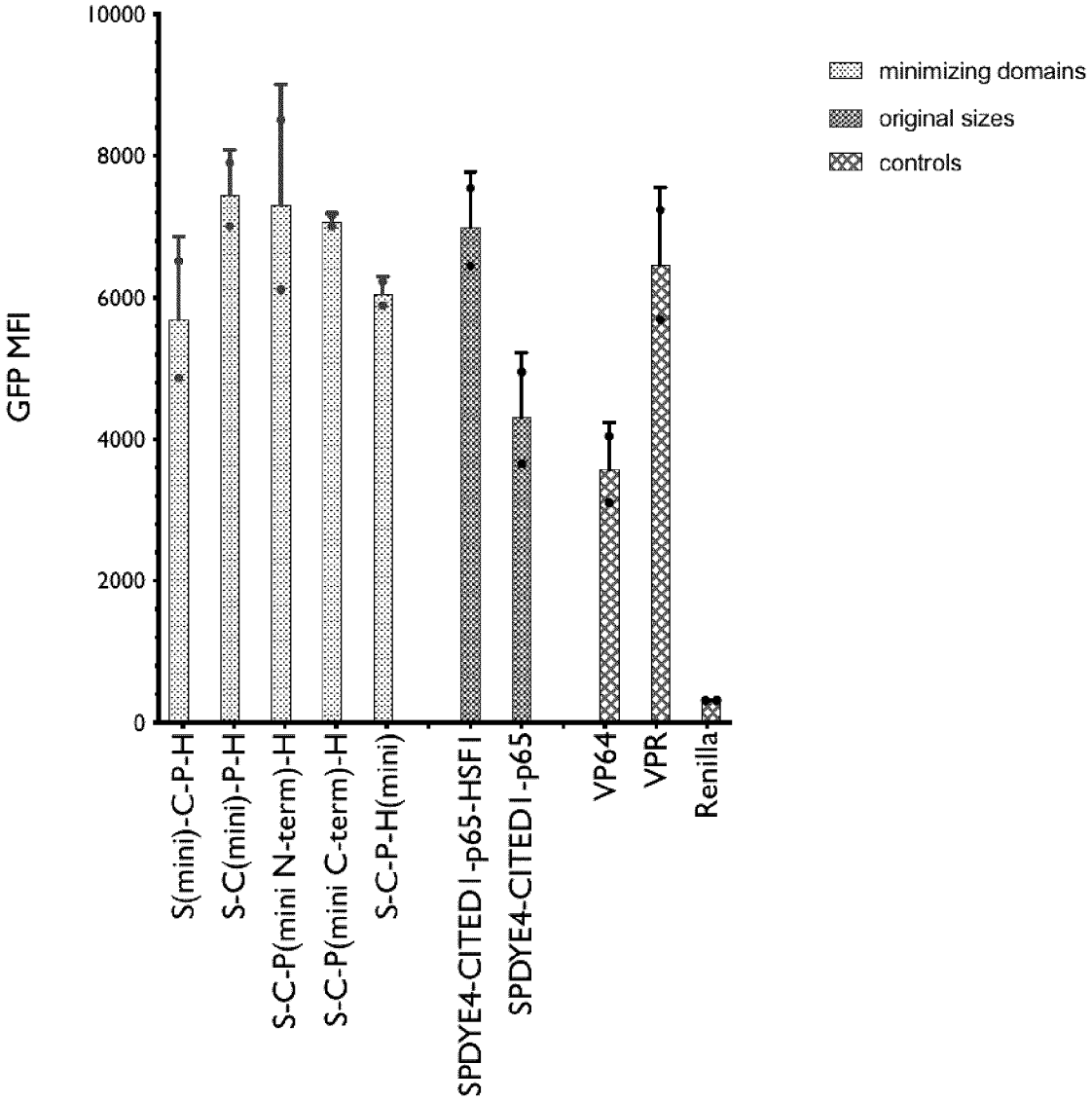


Fig. 16

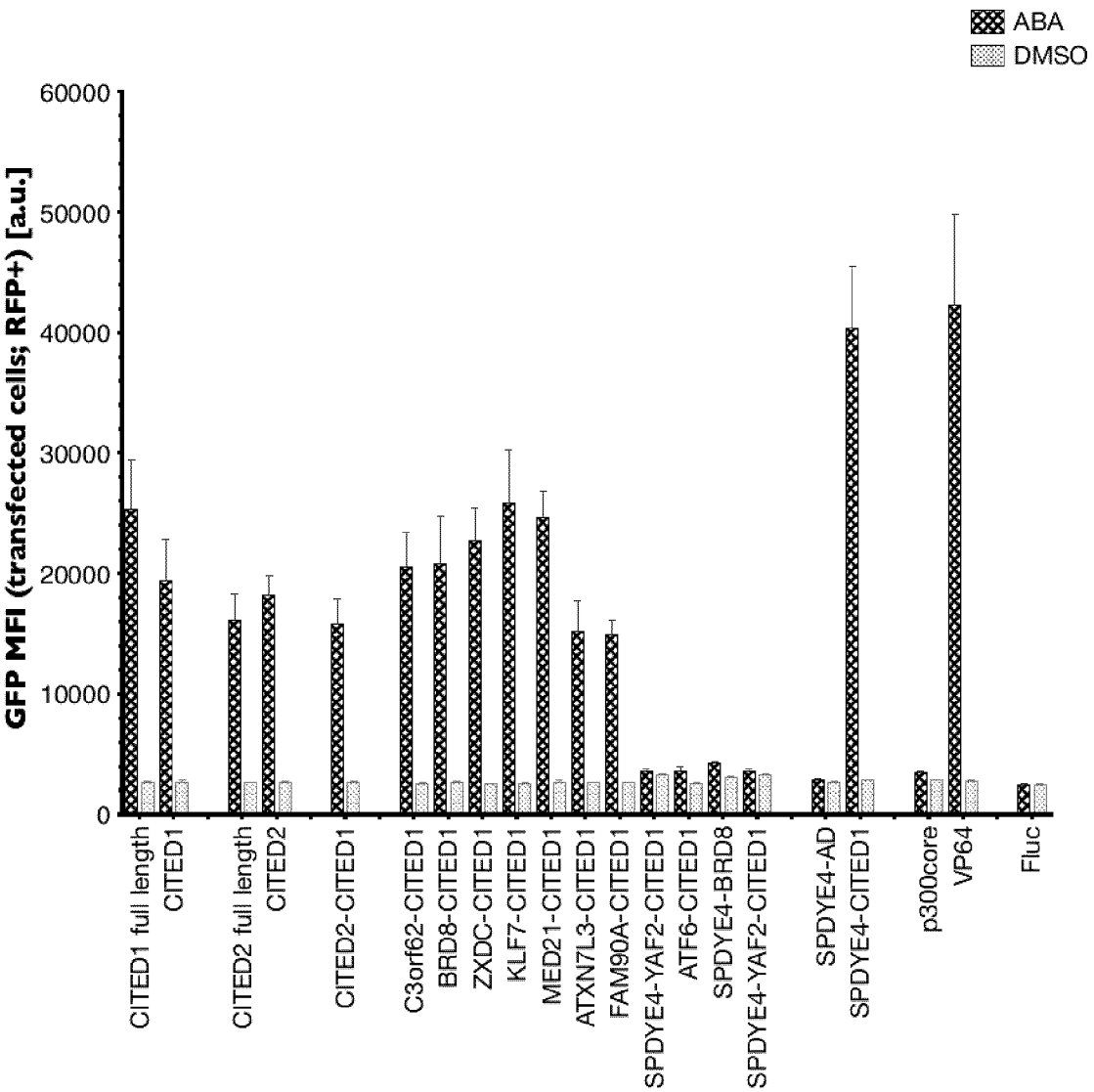
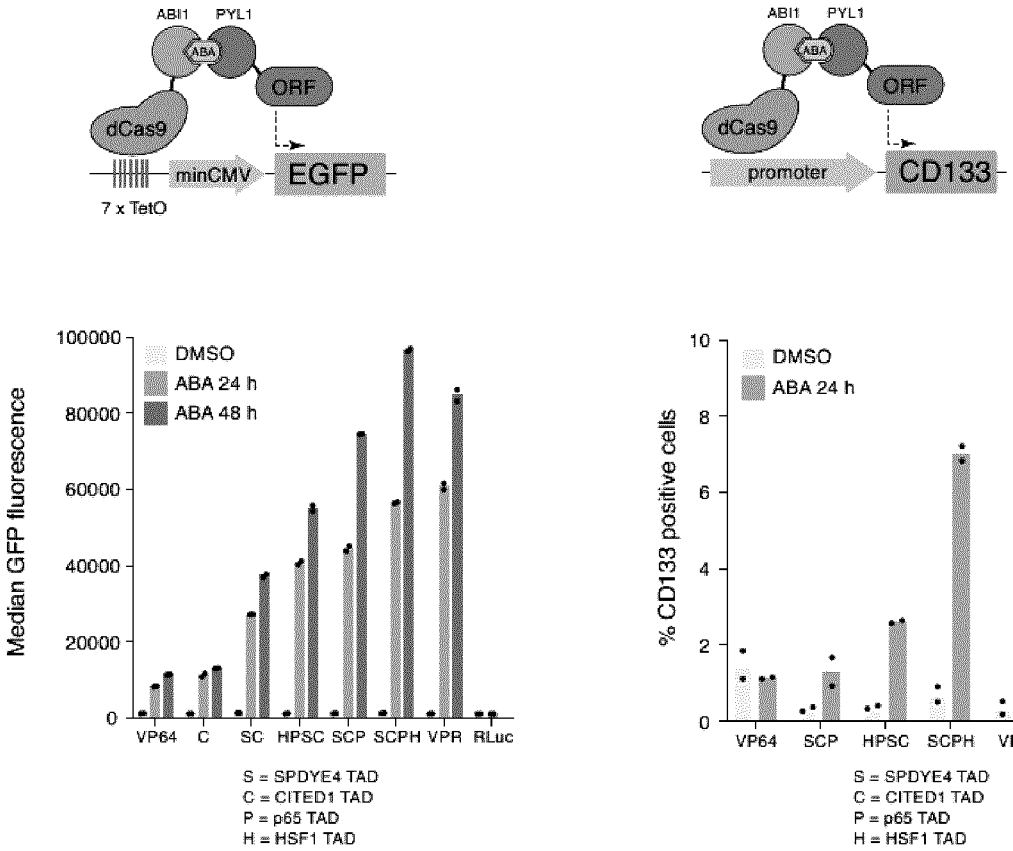

ABA
DMSO
GFP MFI (transfected cells; RFP+) [a.u.]
60000
50000
40000
30000
20000
10000
0
CITED1 full length
CITED1
CITED2 full length
CITED2
CITED2-CITED1
C3orf62-CITED1
BRD8-CITED1
ZXDC-CITED1
KLF7-CITED1
MED21-CITED1
ATXN7L3-CITED1
FAM90A-CITED1
SPDYE4-YAF2-CITED1
ATF6-CITED1
SPDYE4-BRD8
SPDYE4-YAF2-CITED1
SPDYE4-AD
SPDYE4-CITED1
p300core
VP64
Fluc

Fig. 17


ABI1
PYL1
ABA
ORF
dCas9
minCMV
EGFP
7 x TetO
promoter
CD133
Median GFP fluorescence
DMSO
ABA 24 h
ABA 48 h
VP64
C
SC
HPSC
SCP
SCPH
VPR
RLuc
S = SPDYE4 TAD
C = CITED1 TAD
P = p65 TAD
H = HSF1 TAD
% CD133 positive cells

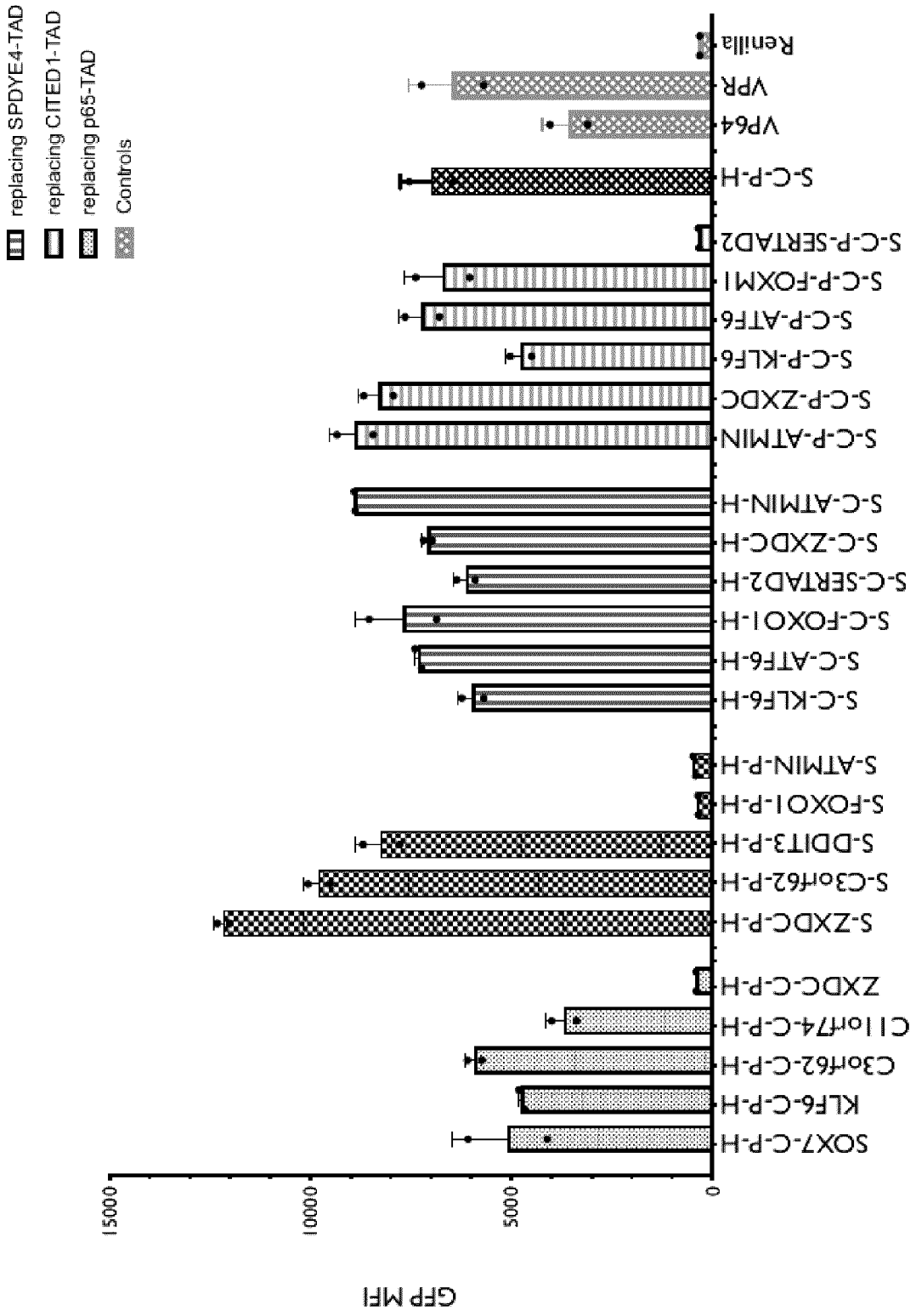

replacing SPDYE4-TAD
replacing CITED1-TAD
replacing p65-TAD
Controls
GFP MFI
15000
10000
5000
0
SOX7-C-P-H
KLF6-C-P-H
C3orf62-C-P-H
C11orf74-C-P-H
ZXDC-C-P-H
S-ZXDC-P-H
S-C3orf62-P-H
S-DDIT3-P-H
S-FOXO1-P-H
S-ATMIN-P-H
S-C-KLF6-H
S-C-ATF6-H
S-C-FOXO1-H
S-C-SERTAD2-H
S-C-ZXDC-H
S-C-ATMIN-H
S-C-P-ATMIN
S-C-P-ZXDC
S-C-P-KLF6
S-C-P-ATF6
S-C-P-FOXM1
S-C-P-SERTAD2
S-C-P-H
VP64
VPR
Renilla

Fig. 18

Fig. 19

A

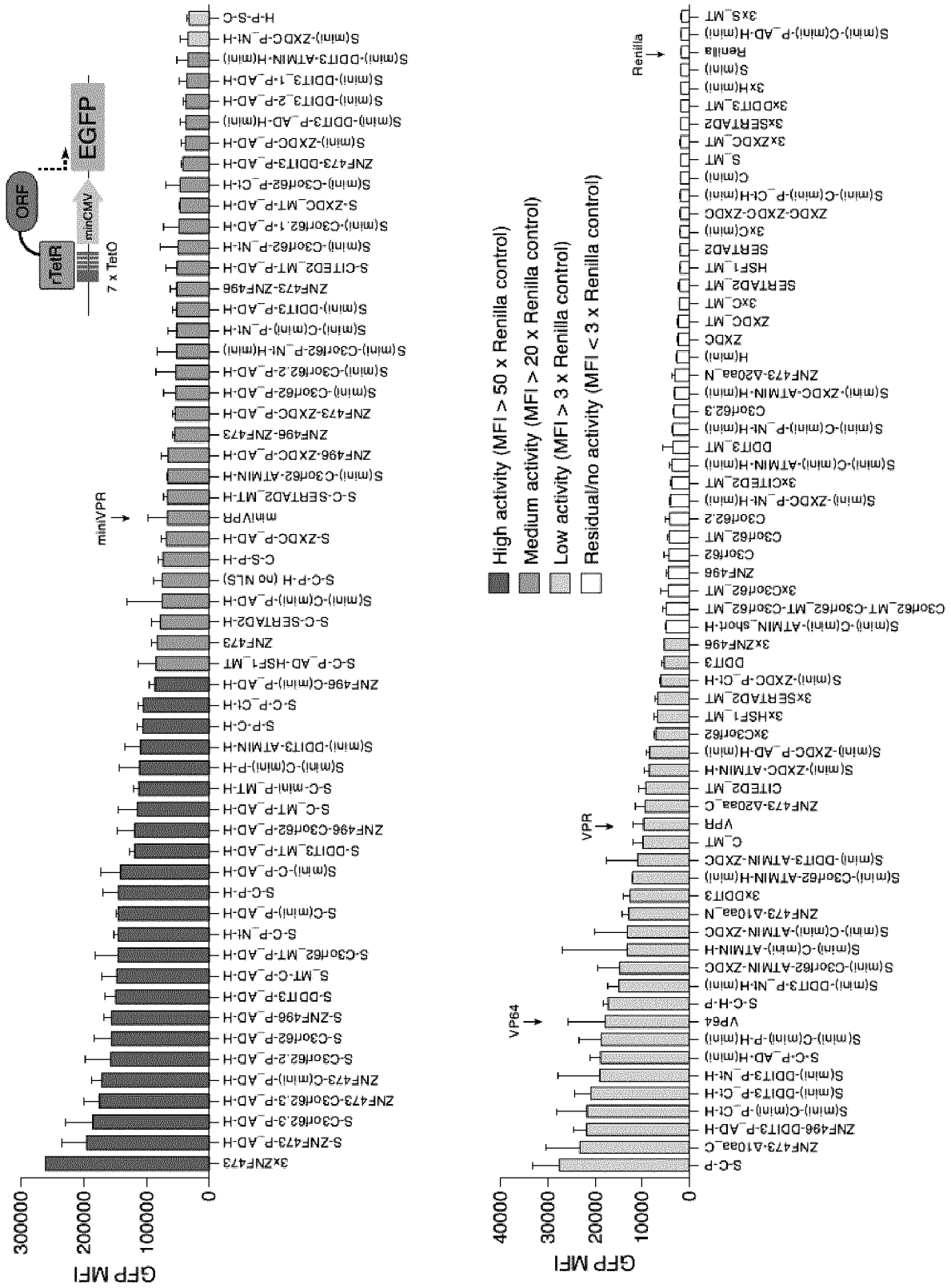

ORF
rTetR
7 x TetO
minCMV
EGFP
GFP MFI
miniVPR
VP64
VPR
Renilla
High activity (MFI > 50 x Renilla control)
Medium activity (MFI > 20 x Renilla control)
Low activity (MFI > 3 x Renilla control)
Residual/no activity (MFI < 3 x Renilla control)

Fig. 19 (cont.)

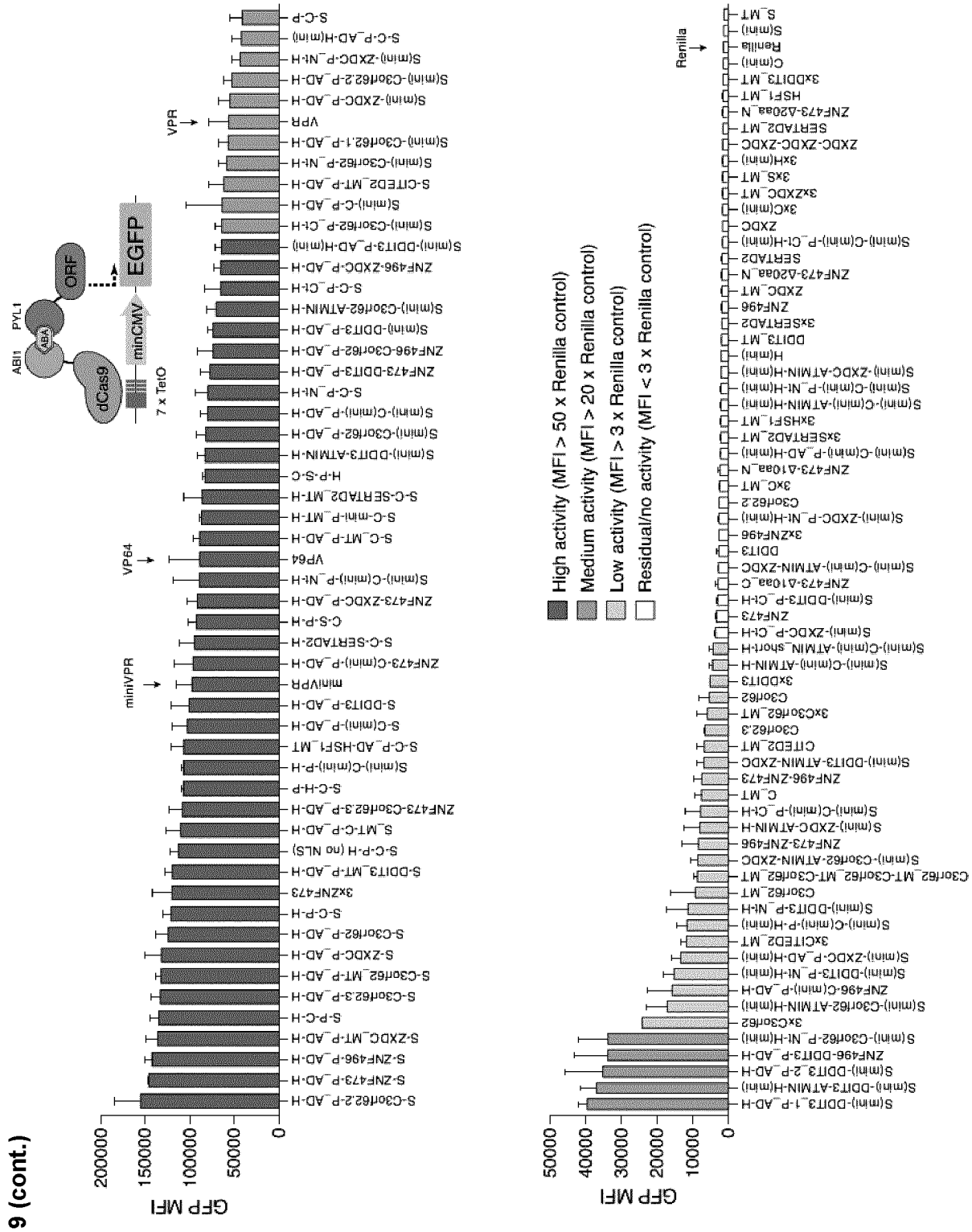
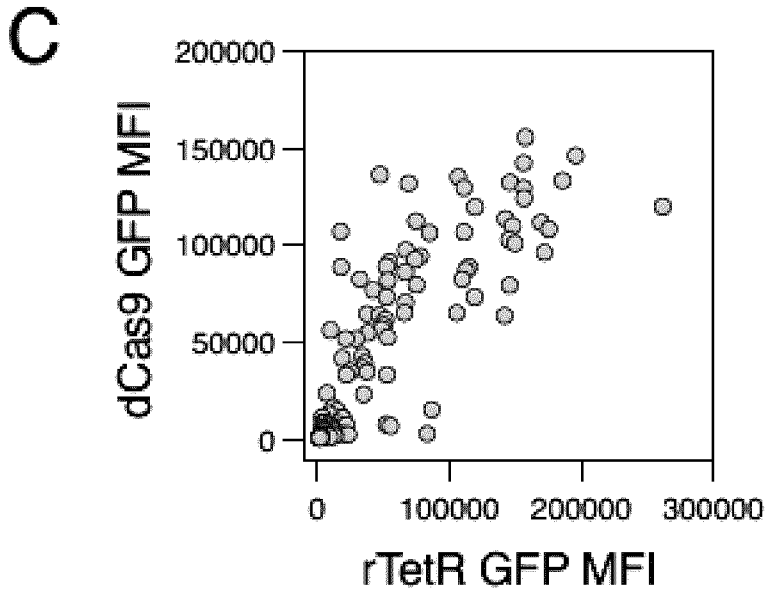

B
GFP MFI
200000
150000
100000
50000
0
dCas9
ABI1
PYL1
ABA
ORF
7 x TetO
minCMV
EGFP
miniVPR
VP64
VPR
S-C-P
S(mini)-C30rf62-P_AD-H
S(mini)-ZXDC-P_Nt-H
S(mini)-C-P_AD-H(mini)
S-C-P_AD-H(mini)
S-C30rf62.2-P_AD-H
S-ZNF473-P_AD-H
S-ZNF496-P_AD-H
S-ZXDC_MT-P_AD-H
S-P-C-H
S-C30rf62.3-P_AD-H
S-C30rf62_MT-P_AD-H
S-ZXDC-P_AD-H
S-C30rf62-P_AD-H
S-C-P-H
3xZNF473
S-DDIT3_MT-P_AD-H
S-C-P-H (no NLS)
S_MT-C-P_AD-H
ZNF473-C30rf62.3-P_AD-H
S-C-H-P
S(mini)-C(mini)-P-H
S-C-P_AD-HSF1_MT
S-C(mini)-P_AD-H
S-DDIT3-P_AD-H
miniVPR
ZNF473-C(mini)-P_AD-H
S-C-SERTAD2-H
C-S-P-H
ZNF473-ZXDC-P_AD-H
S(mini)-C(mini)-P_Nt-H
VP64
S-C_MT-P_AD-H
S-C-mini-P_MT-H
S-C-SERTAD2_MT-H
H-P-S-C
S(mini)-DDIT3-ATMIN-H
S(mini)-C30rf62-P_AD-H
S(mini)-C(mini)-P_AD-H
S-C-P_Nt-H
ZNF473-DDIT3-P_AD-H
ZNF496-C30rf62-P_AD-H
S(mini)-DDIT3-P_AD-H
S(mini)-C30rf62-P_Ct-H
S(mini)-DDIT3-P_AD-H(mini)
ZNF496-ZXDC-P_AD-H
S-C-P_Ct-H
S(mini)-C30rf62-ATMIN-H
S-CITED2_MT-P_AD-H
S(mini)-C-P_AD-H
S(mini)-C30rf62-P_Nt-H
S(mini)-C30rf62.1-P_AD-H
VPR
S(mini)-ZXDC-P_AD-H
S(mini)-C30rf62.2-P_AD-H
S(mini)-ZXDC-P_Nt-H
S(mini)-C-P-H(mini)
S-C-P
High activity (MFI > 50 x Renilla control)
Medium activity (MFI > 20 x Renilla control)
Low activity (MFI > 3 x Renilla control)
Residual/no activity (MFI < 3 x Renilla control)
GFP MFI
50000
40000
30000
20000
10000
0
S(mini)-DDIT3_1-P_AD-H
S(mini)-DDIT3-ATMIN-H(mini)
S(mini)-DDIT3_2-P_AD-H
ZNF496-DDIT3-P_AD-H
S(mini)-C30rf62-P_Nt-H(mini)
3xC30rf62
S(mini)-C30rf62-ATMIN-H(mini)
ZNF496-C(mini)-P_AD-H
S(mini)-DDIT3-P_Nt-H(mini)
S(mini)-ZXDC-P_AD-H(mini)
3xCITED2_MT
S(mini)-C(mini)-P-H(mini)
S(mini)-DDIT3-P_Nt-H
C30rf62_MT
C30rf62_MT-C30rf62_MT-C30rf62_MT
S(mini)-C30rf62-ATMIN-ZXDC
ZNF496-ZNF473
S(mini)-ZXDC-ATMIN-H
S(mini)-C(mini)-P_Ct-H
C_MT
ZNF496-ZNF473
S(mini)-DDIT3-ATMIN-ZXDC
CITED2_MT
C30rf62.3
3xC30rf62_MT
C30rf62
3xDDIT3
S(mini)-C(mini)-ATMIN-H
S(mini)-C(mini)-ATMIN_short-H
ZNF473
S(mini)-ZXDC-P_Ct-H
S(mini)-DDIT3-P_Ct-H
ZNF473-A10aa_C
S(mini)-C(mini)-ATMIN-ZXDC
DDIT3
3xZNF496
S(mini)-ZXDC-P_Nt-H(mini)
C30rf62.2
3xC_MT
ZNF473-A10aa_N
S(mini)-C(mini)-P_AD-H(mini)
3xSERTAD2_MT
3xHSF1_MT
S(mini)-C(mini)-ATMIN-H(mini)
S(mini)-C(mini)-P_Nt-H(mini)
S(mini)-ZXDC-ATMIN-H(mini)
H(mini)
DDIT3_MT
3xSERTAD2
ZNF496
ZXDC_MT
ZNF473-A20aa_N
SERTAD2
S(mini)-C(mini)-P_Ct-H(mini)
ZXDC
3xC(mini)
3xZXDC_MT
3xS_MT
3xH(mini)
ZXDC-ZXDC-ZXDC
SERTAD2_MT
ZNF473-A20aa_N
HSF1_MT
3xDDIT3_MT
Renilla
C(mini)
Renilla
S(mini)
S_MT

Fig. 19 (cont.)


C
200000
150000
100000
50000
0
dCas9 GFP MFI
0
100000
200000
300000
rTetR GFP MFI