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(54) Title: MACROCYCLIC QUINOXALINE COMPOUNDS AS HCV NS3 PROTEASE INHIBITORS

(57) Abstract: The present invention relates to macrocyclic a compound of formula (I) and its use as inhibitors of the hepatitis C virus (HCV) NS3 protease, and in treating or preventing HCV infections. Formula (I)



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TITLE OF THE APPLICATION

MACROCYCLIC QUINOXALINE COMPOUNDS AS HCV NS3 PROTEASE INHIBITORS

FIELD OF THE INVENTION

The present invention relates to macrocyclic compounds that are useful as inhibitors of the hepatitis C virus (HCV) NS3 protease, the synthesis of such compounds, and the use of such compounds for treating HCV infection and/or reducing the likelihood or severity of HCV infection.

BACKGROUND OF THE INVENTION

Hepatitis C virus (HCV) infection is a major health problem that leads to chronic liver disease, such as cirrhosis and hepatocellular carcinoma, in a substantial number of infected individuals. Current treatments for HCV infection include immunotherapy with recombinant interferon- $\alpha$  alone or in combination with the nucleoside analog ribavirin.

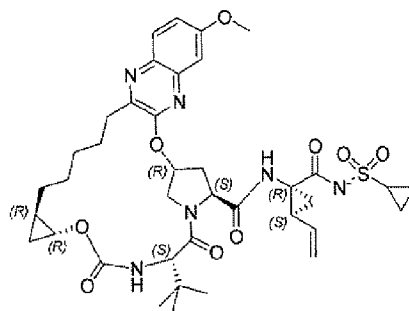
Several virally-encoded enzymes are putative targets for therapeutic intervention, including a metalloprotease (NS2-3), a serine protease (NS3), a helicase (NS3), and an RNA-dependent RNA polymerase (NS5B). The NS3 protease is located in the N-terminal domain of the NS3 protein. NS4A provide a cofactor for NS3 activity.

Potential treatments for HCV infection have been discussed in the different references including Balsano, *Mini Rev. Med. Chem.* 8(4):307-318, 2008, Rönn *et al.*, *Current Topics in Medicinal Chemistry* 8:533-562, 2008, Sheldon *et al.*, *Expert Opin. Investig. Drugs* 16(8):1171-1181, 2007, and De Francesco *et al.*, *Antiviral Research* 58:1-16, 2003.

SUMMARY OF THE INVENTION

The present invention relates to a macrocyclic compound of formula (I) and pharmaceutically acceptable salts thereof. The compound and its salts are HCV NS3 protease inhibitors. The compound and its salts have therapeutic and research applications.

Thus, a first aspect of the present invention describes a compound of formula (I), or a pharmaceutical acceptable salt thereof:



(I).

The present invention also includes pharmaceutical compositions containing a compound of the present invention and methods of preparing such pharmaceutical compositions. The present invention further includes methods of treating or reducing the likelihood or severity of HCV infection.

Other embodiments, aspects and features of the present invention are either further described in or will be apparent from the ensuing description, examples and appended claims.

### DETAILED DESCRIPTION OF THE INVENTION

The present invention includes a compound of formula (I), and pharmaceutically acceptable salts thereof. The compound and its pharmaceutically acceptable salts are useful in the inhibition of HCV NS3 protease, the treatment of HCV infection and/or the reduction of the likelihood or severity of an HCV infection. Prophylactic applications include, for example, treatment after suspected past exposure to HCV by such means as blood transfusion, exchange of body fluids, bites, accidental needle stick, or exposure to patient blood during surgery.

As pharmaceutical composition ingredients, the compounds and salts may be the primary active therapeutic agent. When appropriate, the compound may be combined with other therapeutic agents including but not limited to other HCV antivirals, anti-infectives, immunomodulators, antibiotics or vaccines.

NS3 inhibitors are also useful in the preparation and execution of screening assays for antiviral compounds. For example, such compounds can be used to isolate enzyme mutants, which are excellent screening tools for more powerful antiviral compounds. Furthermore, the compounds may be used to establish or determine the binding site of other antivirals to HCV protease, *e.g.*, by competitive inhibition.

As further described in Example 2 the formula (I) compound was compared to the compound of Examples 110 and 118 of WO 2008/057209, and has several advantages. WO 2008/057209 is not admitted to be prior art to the claimed invention.

### I. Compositions and Methods

Different embodiments include the following:

(a) A pharmaceutical composition comprising an effective amount of a compound of formula (I) and a pharmaceutically acceptable carrier.

(b) The pharmaceutical composition of (a), further comprising a second therapeutic agent selected from the group consisting of HCV antiviral agents, immunomodulators, and anti-infective agents.

(c) The pharmaceutical composition of (b), wherein the HCV antiviral agent is an antiviral selected from the group consisting of HCV protease inhibitors and HCV NS5B polymerase inhibitors.

(d) A pharmaceutical combination which is (i) a compound of formula (I) and (ii) a second therapeutic agent selected from the group consisting of HCV antiviral agents, immunomodulators, and anti-infective agents; wherein the compound of formula (I) and the second therapeutic agent are each employed in an amount that renders the combination effective for inhibiting HCV NS3 protease, or for treating HCV infection and/or reducing the likelihood or severity of HCV infection.

(e) The combination of (d), wherein the HCV antiviral agent is an antiviral selected from the group consisting of HCV protease inhibitors and HCV NS5B polymerase inhibitors.

(f) A method of inhibiting HCV NS3 protease in a subject in need thereof which comprises administering to the subject an effective amount of a compound of formula (I).

(g) A method of treating HCV infection and/or reducing the likelihood or severity of HCV infection in a subject in need thereof which comprises administering to the subject an effective amount of a compound of formula (I).

(h) The method of (g), wherein the compound of formula (I) is administered in combination with an effective amount of at least one second therapeutic agent selected from the group consisting of HCV antiviral agents, immunomodulators, and anti-infective agents.

(i) The method of (h), wherein the HCV antiviral agent is an antiviral selected from the group consisting of HCV protease inhibitors and HCV NS5B polymerase inhibitors.

(j) A method of inhibiting HCV NS3 protease in a subject in need thereof which comprises administering to the subject the pharmaceutical composition of (a), (b), or (c) or the combination of (d) or (e).

(k) A method of treating HCV infection and/or reducing the likelihood or severity of HCV infection in a subject in need thereof which comprises administering to the subject the pharmaceutical composition of (a), (b), or (c) or the combination of (d) or (e).

(l) A compound of formula (I) for use in medicine, for use in prevention or treatment of HCV infection, or for use (i) in, (ii) as a medicament for, or (iii) in the preparation of a medicament for: (a) inhibiting HCV NS3 protease, or (b) treating HCV infection and/or reducing the likelihood or severity of HCV infection. In these uses, the compounds of the present invention can optionally be employed in combination with one or more second therapeutic agents selected from HCV antiviral agents, anti-infective agents, and immunomodulators.

In all of these embodiments, the compound may optionally be used in the form of a pharmaceutically acceptable salt.

The term "or," as used herein, denotes alternatives that may, where appropriate, be combined. Thus, the term "or" includes each listed alternative separately as well as their combination if the combination is not mutually exclusive.

Reference to a compound also includes stable complexes of the compound such as a stable hydrate. A "stable" compound is a compound which can be prepared and isolated and whose structure and properties remain or can be caused to remain essentially unchanged for a period of time sufficient to allow use of the compound for the purposes described herein (*e.g.*, therapeutic or prophylactic administration to a subject).

## II. Administration and Compositions

The term "administration" and variants thereof (*e.g.*, "administering" a compound) means providing the compound or a prodrug of the compound to the individual in need of treatment. When a compound of the invention or a prodrug thereof is provided in combination with one or more other active agents (*e.g.*, antiviral agents useful for treating HCV infection), "administration" and its variants are each understood to include concurrent and sequential provision of the compound or salt and other agents.

The compounds of the present invention may be administered in the form of pharmaceutically acceptable salts. The term "pharmaceutically acceptable salt" refers to a salt of the parent compound which has activity and which is not biologically or otherwise undesirable (*e.g.*, is neither toxic nor otherwise deleterious to the recipient thereof). Suitable salts include acid addition salts which may, for example, be formed by mixing a solution of a compound with a solution of a pharmaceutically acceptable acid such as hydrochloric acid, sulfuric acid, acetic acid, trifluoroacetic acid, or benzoic acid. Compounds carrying an acidic moiety can be mixed with suitable pharmaceutically acceptable salts to provide, for example, alkali metal salts (*e.g.*, sodium or potassium salts), alkaline earth metal salts (*e.g.*, calcium or magnesium salts), and salts formed with suitable organic ligands such as quaternary ammonium salts. Also, in the case of an acid (-COOH) or alcohol group being present, pharmaceutically acceptable esters can be employed to modify the solubility or hydrolysis characteristics of the compound.

As used herein, the term "prodrug" is intended to encompass an inactive drug form or compound that is converted into an active drug form or compound by the action of enzymes, chemicals or metabolic processes in the body of an individual to whom it is administered.

As used herein, the term "composition" is intended to encompass a product comprising the specified ingredients, as well as any product which results, directly or indirectly, from combining the specified ingredients.

By "pharmaceutically acceptable" is meant that the ingredients of the pharmaceutical composition must be compatible with each other and not deleterious to the recipient thereof.

The term "subject" (alternatively referred to herein as "patient") as used herein refers to an animal, preferably a mammal, most preferably a human, who has been the object of treatment, observation or experiment.

The term "effective amount" indicates a sufficient amount to exert a therapeutic or prophylactic effect. For a patient infected with HCV, an effective amount is sufficient to achieve one or more of the following effects: reduce the ability of HCV to replicate, reduce HCV load, and increase viral clearance. For a patient not infected with HCV, an effective amount is sufficient to achieve one or more of the following: a reduced susceptibility to HCV infection, and a reduced ability of the infecting virus to establish persistent infection for chronic disease.

For the purpose of inhibiting HCV NS3 protease and treating HCV infection and/or reducing the likelihood or severity of symptoms of HCV infection, the compounds of the present invention, optionally in the form of a salt, can be administered by means that produces contact of the active agent with the agent's site of action. They can be administered by conventional means available for use in conjunction with pharmaceuticals, either as individual therapeutic agents or in a combination of therapeutic agents. They can be administered alone, but typically are administered with a pharmaceutical carrier selected on the basis of the chosen route of administration and standard pharmaceutical practice.

Compounds can, for example, be administered by one or more of the following routes: orally, parenterally (including subcutaneous injections, intravenous, intramuscular, intrasternal injection or infusion techniques), by inhalation (such as in a spray form), or rectally, in the form of a unit dosage of a pharmaceutical composition containing an effective amount of the compound and conventional non-toxic pharmaceutically-acceptable carriers, adjuvants and vehicles. Liquid preparations suitable for oral administration (*e.g.*, suspensions, syrups, elixirs and the like) can be prepared according to techniques known in the art and can employ any of the usual media such as water, glycols, oils, alcohols and the like. Solid preparations suitable for oral administration (*e.g.*, powders, pills, capsules and tablets) can be prepared according to techniques known in the art and can employ such solid excipients as starches, sugars, kaolin, lubricants, binders, disintegrating agents and the like. Parenteral compositions can be prepared according to techniques known in the art and typically employ sterile water as a carrier and optionally other ingredients, such as solubility aids. Injectable solutions can be prepared according to methods known in the art wherein the carrier comprises a saline solution, a glucose solution or a solution containing a mixture of saline and glucose. Further guidance for methods suitable for use in preparing pharmaceutical compositions of the present invention and of

ingredients suitable for use in said compositions is provided in Remington's Pharmaceutical Sciences, 20<sup>th</sup> edition (ed. A. R. Gennaro, Mack Publishing Co., 2000).

The compounds of this invention can be administered orally in a dosage range of 0.001 to 1000 mg/kg of mammal (e.g., human) body weight per day in a single dose or in divided doses. One dosage range is 0.01 to 500 mg/kg body weight per day orally in a single dose or in divided doses. Another dosage range is 0.1 to 100 mg/kg body weight per day orally in single or divided doses. For oral administration, the compositions can be provided in the form of tablets or capsules containing 1.0 to 500 mg of the active ingredient, particularly 1, 5, 10, 15, 20, 25, 50, 75, 100, 150, 200, 250, 300, 400, 500, and 750 mg of the active ingredient for the symptomatic adjustment of the dosage to the patient to be treated. The specific dose level and frequency of dosage for any particular patient may be varied and will depend upon a variety of factors including the activity of the specific compound employed, the metabolic stability and length of action of that compound, the age, body weight, general health, sex, diet, mode and time of administration, rate of excretion, drug combination, the severity of the particular condition, and the host undergoing therapy.

### III. Combination Treatment

The quinoxaline macrocyclic compounds described herein can be used in a combination treatment involving one or more additional therapeutic agents. Additional therapeutic agents include those also targeting HCV, targeting a different disease causing agent, or those enhancing the immune system. Agents enhancing the immune system include those generally enhancing an immune system function and those producing a specific immune response against HCV. Additional therapeutic agents targeting HCV include agents targeting NS3 and agents targeting other HCV activities such as NS5A and NS5B, and agents targeting host cell activities involved in HCV replication.

Different HCV inhibitors are described in different publications. Macrocyclic compounds useful as inhibitors the HCV protease inhibitors are described in WO 06/119061, WO 7/015785, WO 7/016441, WO 07/148135, WO 08/051475, WO 08/051477, WO 08/051514, WO 08/057209. Additional HCV NS3 protease inhibitors are disclosed in International Patent Application Publications WO 98/22496, WO 98/46630, WO 99/07733, WO 99/07734, WO 99/38888, WO 99/50230, WO 99/64442, WO 00/09543, WO 00/59929, WO 02/48116, WO 02/48172, British Patent No. GB 2 337 262, and U.S. Patent No. 6,323,180.

Additional examples of therapeutic agents that may be present in a combination include ribavirin, levovirin, viremagine, thymosin alpha-1, interferon- $\beta$ , interferon- $\alpha$ , pegylated interferon- $\alpha$  (peginterferon- $\alpha$ ), a combination of interferon- $\alpha$  and ribavirin, a combination of peginterferon- $\alpha$  and ribavirin, a combination of interferon- $\alpha$  and levovirin, and a combination of peginterferon- $\alpha$  and levovirin. Interferon- $\alpha$  includes recombinant interferon- $\alpha$ 2a (such as



ROFERON interferon available from Hoffmann-LaRoche, Nutley, NJ), pegylated interferon- $\alpha$ 2a (PEGASYS), interferon- $\alpha$ 2b (such as INTRON-A interferon available from Schering Corp., Kenilworth, NJ), pegylated interferon- $\alpha$ 2b (PEGINTRON), a recombinant consensus interferon (such as interferon alfacon-1), and a purified interferon- $\alpha$  product. Amgen's recombinant consensus interferon has the brand name INFERGEN. Levovirin is the L-enantiomer of ribavirin which has shown immunomodulatory activity similar to ribavirin. Viramidine represents an analog of ribavirin disclosed in WO 01/60379. The individual components of the combination can be administered separately at different times during the course of therapy or concurrently in divided or single combination forms.

Ribavirin, levovirin, and viramidine may exert their anti-HCV effects by modulating intracellular pools of guanine nucleotides via inhibition of the intracellular enzyme inosine monophosphate dehydrogenase (IMPDH). IMPDH is the rate-limiting enzyme on the biosynthetic route in *de novo* guanine nucleotide biosynthesis. Ribavirin is readily phosphorylated intracellularly and the monophosphate derivative is an inhibitor of IMPDH. Thus, inhibition of IMPDH represents another useful target for the discovery of inhibitors of HCV replication. Therefore, the compounds of the present invention may also be administered in combination with an inhibitor of IMPDH, such as VX-497, which is disclosed in International Patent Application Publications WO 97/41211 and WO 01/00622; another IMPDH inhibitor, such as that disclosed in WO 00/25780; or mycophenolate mofetil. See A.C. Allison and E.M. Eugui, 44 (Suppl.) Agents Action 165 (1993).

For the treatment of HCV infection, the compounds of the present invention may also be administered in combination with the antiviral agent amantadine (1-aminoadamantane). For a comprehensive description of this agent, see J. Kirschbaum, 12 Anal. Profiles Drug Subs. 1-36 (1983).

For the treatment of HCV infection, the compounds of the present invention may also be administered in combination with the antiviral agent polymerase inhibitor R7128 (Roche).

The compounds of the present invention may also be combined for the treatment of HCV infection with antiviral 2'-C-branched ribonucleosides disclosed in R. E. Harry-O'Kuru *et al.*, 62 J. Org. Chem. 1754-59 (1997); M. S. Wolfe *et al.*, 36 Tet. Lett. 7611-14 (1995); U.S. Patent No. 3,480,613; and International Patent Application Publications WO 01/90121, WO 01/92282, WO 02/32920, WO 04/002999, WO 04/003000 and WO 04/002422; the contents of each of which are incorporated by reference in their entirety. Such 2'-C-branched ribonucleosides include, but are not limited to, 2'-C-methyl-cytidine, 2'-C-methyl-uridine, 2'-C-methyl-adenosine, 2'-C-methyl-guanosine, and 9-(2-C-methyl- $\beta$ -D-ribofuranosyl)-2,6-diaminopurine, and the corresponding amino acid ester of the ribose C-2', C-3', and C-5'

hydroxyls and the corresponding optionally substituted cyclic 1,3-propanediol esters of the 5'-phosphate derivatives.

The compounds of the present invention may also be combined for the treatment of HCV infection with other nucleosides having anti-HCV properties, such as those disclosed in International Patent Application Publications WO 02/51425, WO 01/79246, WO 02/32920, WO 02/48165 and WO2005/003147 (including R1656, (2'*R*)-2'-deoxy-2'-fluoro-2'-C-methylcytidine, shown as compounds 3-6 on page 77); WO 01/68663; WO 99/43691; WO 02/18404 and WO2006/021341, and U.S. Patent Application Publication US 2005/0038240, including 4'-azido nucleosides such as R1626, 4'-azidocytidine; U.S. Patent Application Publications US 2002/0019363, US 2003/0236216, US 2004/0006007 and US 2004/0063658; and International Patent Application Publications WO 02/100415, WO 03/026589, WO 03/026675, WO 03/093290, WO 04/011478, WO 04/013300 and WO 04/028481; the content of each is incorporated herein by reference in its entirety.

For the treatment of HCV infection, the compounds of the present invention may also be administered in combination with an agent that is an inhibitor of HCV NS5B polymerase. Such HCV NS5B polymerase inhibitors that may be used as combination therapy include, but are not limited to, those disclosed in International Patent Application Publications WO 02/057287, WO 02/057425, WO 03/068244, WO 2004/000858, WO 04/003138 and WO 2004/007512; U.S. Patent No. 6,777,392 and U.S. Patent Application Publication US2004/0067901; the content of each is incorporated herein by reference in its entirety. Other such HCV polymerase inhibitors include, but are not limited to, valopicitabine (NM-283; Idenix) and 2'-F-2'-beta-methylcytidine (*see also* WO 2005/003147).

In one embodiment, nucleoside HCV NS5B polymerase inhibitors that are used in combination with the present HCV NS3 protease inhibitors are selected from the following compounds: 4-amino-7-(2-C-methyl-β-D-arabinofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 4-amino-7-(2-C-methyl-β-D-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 4-methylamino-7-(2-C-methyl-β-D-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 4-dimethylamino-7-(2-C-methyl-β-D-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 4-cyclopropylamino-7-(2-C-methyl-β-D-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 4-amino-7-(2-C-vinyl-β-D-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 4-amino-7-(2-C-hydroxymethyl-β-D-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 4-amino-7-(2-C-fluoromethyl-β-D-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 4-amino-5-methyl-7-(2-C-methyl-β-D-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 4-amino-7-(2-C-methyl-β-D-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine-5-carboxylic acid; 4-amino-5-bromo-7-(2-C-methyl-β-D-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 4-amino-5-chloro-7-(2-C-methyl-β-D-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 4-amino-5-fluoro-7-(2-C-methyl-β-D-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 2,4-diamino-7-(2-C-methyl-β-D-ribofuranosyl)-

7*H*-pyrrolo[2,3-*d*]pyrimidine; 2-amino-7-(2-*C*-methyl-β-*D*-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 2-amino-4-cyclopropylamino-7-(2-*C*-methyl-β-*D*-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 2-amino-7-(2-*C*-methyl-β-*D*-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidin-4(3*H*)-one; 4-amino-7-(2-*C*-ethyl-β-*D*-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 4-amino-7-(2-*C*,2-*O*-dimethyl-β-*D*-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 7-(2-*C*-methyl-β-*D*-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidin-4(3*H*)-one; 2-amino-5-methyl-7-(2-*C*, 2-*O*-dimethyl-β-*D*-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidin-4(3*H*)-one; 4-amino-7-(3-deoxy-2-*C*-methyl-β-*D*-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 4-amino-7-(3-deoxy-2-*C*-methyl-β-*D*-arabinofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 4-amino-2-fluoro-7-(2-*C*-methyl-β-*D*-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 4-amino-7-(3-*C*-methyl-β-*D*-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 4-amino-7-(3-*C*-methyl-β-*D*-xylofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 4-amino-7-(2,4-di-*C*-methyl-β-*D*-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; 4-amino-7-(3-deoxy-3-fluoro-2-*C*-methyl-β-*D*-ribofuranosyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine; and the corresponding 5'-triphosphates; or a pharmaceutically acceptable salt thereof.

The compounds of the present invention may also be combined for the treatment of HCV infection with non-nucleoside inhibitors of HCV polymerase such as those disclosed in International Patent Application Publications WO 01/77091; WO 01/47883; WO 02/04425; WO 02/06246; WO 02/20497; WO 2005/016927 (in particular JTK003); the content of each is incorporated herein by reference in its entirety; and HCV-796 (Viropharma Inc.).

In one embodiment, non-nucleoside HCV NS5B polymerase inhibitors that are used in combination with the present HCV NS3 protease inhibitors are selected from the following compounds: 14-cyclohexyl-6-[2-(dimethylamino)ethyl]-7-oxo-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxylic acid; 14-cyclohexyl-6-(2-morpholin-4-ylethyl)-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxylic acid; 14-cyclohexyl-6-[2-(dimethylamino)ethyl]-3-methoxy-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxylic acid; 14-cyclohexyl-3-methoxy-6-methyl-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxylic acid; methyl ({[(14-cyclohexyl-3-methoxy-6-methyl-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocin-11-yl)carbonyl]amino}sulfonyl)acetate; ({[(14-cyclohexyl-3-methoxy-6-methyl-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocin-11-yl)carbonyl]amino}sulfonyl)acetic acid; 14-cyclohexyl-*N*-[(dimethylamino)sulfonyl]-3-methoxy-6-methyl-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxamide; 3-chloro-14-cyclohexyl-6-[2-(dimethylamino)ethyl]-7-oxo-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine 11-carboxylic acid; *N*-(11-carboxy-14-cyclohexyl-7,8-dihydro-6*H*-indolo[1,2-*e*][1,5]benzoxazocin-7-yl)-*N,N*-dimethylethane-1,2-diaminium bis(trifluoroacetate); 14-cyclohexyl-7,8-dihydro-6*H*-indolo[1,2-*e*][1,5]benzoxazocine-11-carboxylic acid; 14-cyclohexyl-6-methyl-7-oxo-5,6,7,8-tetrahydroindolo

[2,1-*a*][2,5]benzodiazocine-11-carboxylic acid; 14-cyclohexyl-3-methoxy-6-methyl-7-oxo-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxylic acid; 14-cyclohexyl-6-[2-(dimethylamino)ethyl]-3-methoxy-7-oxo-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxylic acid; 14-cyclohexyl-6-[3-(dimethylamino)propyl]-7-oxo-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxylic acid; 14-cyclohexyl-7-oxo-6-(2-piperidin-1-ylethyl)-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxylic acid; 14-cyclohexyl-6-(2-morpholin-4-ylethyl)-7-oxo-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxylic acid; 14-cyclohexyl-6-[2-(diethylamino)ethyl]-7-oxo-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxylic acid; 14-cyclohexyl-6-(1-methylpiperidin-4-yl)-7-oxo-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxylic acid; 14-cyclohexyl-*N*-[(dimethylamino)sulfonyl]-7-oxo-6-(2-piperidin-1-ylethyl)-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxamide; 14-cyclohexyl-6-[2-(dimethylamino)ethyl]-*N*-[(dimethylamino)sulfonyl]-7-oxo-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxamide; 14-cyclopentyl-6-[2-(dimethylamino)ethyl]-7-oxo-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxylic acid; 14-cyclohexyl-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxylic acid; 6-allyl-14-cyclohexyl-3-methoxy-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxylic acid; 14-cyclopentyl-6-[2-(dimethylamino)ethyl]-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxylic acid; 14-cyclohexyl-6-[2-(dimethylamino)ethyl]-5,6,7,8-tetrahydroindolo[2,1-*a*][2,5]benzodiazocine-11-carboxylic acid; 13-cyclohexyl-5-methyl-4,5,6,7-tetrahydrofuro[3',2':6,7][1,4]diazocino[1,8-*a*]indole-10-carboxylic acid; 15-cyclohexyl-6-[2-(dimethylamino)ethyl]-7-oxo-6,7,8,9-tetrahydro-5*H*-indolo[2,1-*a*][2,6]benzodiazonine-12-carboxylic acid; 15-cyclohexyl-8-oxo-6,7,8,9-tetrahydro-5*H*-indolo[2,1-*a*][2,5]benzodiazonine-12-carboxylic acid; 13-cyclohexyl-6-oxo-6,7-dihydro-5*H*-indolo[1,2-*d*][1,4]benzodiazepine-10-carboxylic acid; and pharmaceutically acceptable salts thereof.

#### IV. Compound Evaluation

Compounds described herein can be evaluated for different activities such as the ability to inhibit HCV NS3 activity, HCV replicon activity, and HCV replication activity using techniques well-known in the art. (See, for example, Carroll *et al.*, *J. Biol. Chem.* 278:11979–11984, 2003.)

One such assay is HCV NS3 protease time-resolved fluorescence (TRF) assay as described below and in Mao *et al.*, *Anal. Biochem.* 373:1-8, 2008 and International Patent Application Publication WO 2006/102087. A NS3 protease assay can be performed, for example, in a final volume of 100  $\mu$ l assay buffer containing 50 mM HEPES, pH 7.5, 150 mM NaCl, 15 % glycerol, 0.15 % TRITON X-100, 10 mM DTT, and 0.1 % PEG 8000. NS3 and NS4A protease is pre-incubated with various concentrations of inhibitors in DMSO for 30

minutes. The reaction is initiated by adding the TRF peptide substrate (final concentration 100 nM). NS3 mediated hydrolysis of the substrate is quenched after 1 hour at room temperature with 100  $\mu$ l of 500 mM MES, pH 5.5. Product fluorescence is detected using either a VICTOR V2 or FUSION fluorophotometer (Perkin Elmer Life and Analytical Sciences) with excitation at 340 nm and emission at 615 nm with a 400  $\mu$ s delay. Testing concentrations of different enzyme forms are selected to result in a signal to background ratio (S/B) of 10-30. IC<sub>50</sub> values are derived using a standard four-parameter fit to the data. K<sub>i</sub> values are derived from IC<sub>50</sub> values using the following formula,

$$IC_{50} = K_i (1 + [S] / K_M), \quad \text{Eqn (1),}$$

where [S] is the concentration of substrate peptide in the reaction and K<sub>M</sub> is the Michaelis constant. See P. Gallinari *et al.*, 38 BIOCHEM. 5620-32(1999); P. Gallinari *et al.*, 72 J. VIROL. 6758-69 (1998); M. Taliani *et al.*, 240 ANAL. BIOCHEM. 60-67 (1996); Mao *et al.*, *Analytical Biochemistry* 373: 1-8, 2008.

#### V. General Compound Production

The present invention also includes processes for making compounds of formula (I). The compounds of the present invention can be readily prepared according to the following reaction schemes and examples, or modifications thereof, using readily available starting materials, reagents and conventional synthesis procedures. In these reactions, it is also possible to make use of variants which are themselves known to those of ordinary skill in this art. Other methods for preparing compounds of the invention will be readily apparent to the person of ordinary skill in the art in light of the following reaction schemes and examples. Unless otherwise indicated, all variables are as defined above. The following reaction schemes and examples serve only to illustrate the invention and its practice.

Olefin metathesis catalysts include the following Ruthenium based species: F. Miller *et al.*, 118 J. AM. CHEM. SOC. 9606 (1996); G. Kingsbury *et al.*, 121 J. Am. Chem. Soc. 791 (1999); H. Scholl *et al.*, 1 ORG. LETT. 953 (1999); U.S. Patent Application Publication US2002/0107138; K. Furstner *et al.*, 64 J. ORG. CHEM. 8275 (1999). The utility of these catalysts in ring closing metathesis is well known in the literature (e.g. Trnka and Grubbs, 34 ACC. CHEM. RES. 18 (2001).

The following examples serve only to illustrate the invention and its practice. The examples are not to be construed as limitations on the scope or spirit of the invention.

#### List of Abbreviations

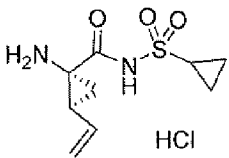
##### List of Abbreviations

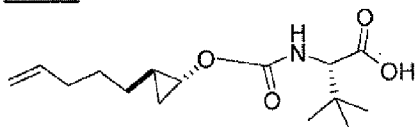
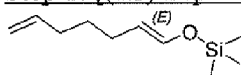
DCM / CH <sub>2</sub> Cl <sub>2</sub>	dichloromethane
DCE	1,2-dichloroethane

DIEA	diisopropylethylamine
DMF	dimethylformamide
DMSO	dimethyl sulfoxide
Dppf	diphenylphosphinoferrocene
Et <sub>2</sub> O	diethyl ether
EtOAc	ethyl acetate
HATU	<i>O</i> -(7-azabenzotriazol-1-yl)- <i>N,N,N',N'</i> -tetramethyluronium hexafluorophosphate
HCl	hydrochloric acid
TMSCl	Chlorotrimethylsilane
TBAF	Tetra-butyl ammonium fluoride
DMAP	Dimethylamino pyridine
MeCN	acetonitrile
MeOH	methanol
Pd/C	palladium on carbon
TBTU	<i>O</i> -benzotriazol-1-yl- <i>N,N,N',N'</i> -tetramethyluronium tetrafluoroborate
TFA	trifluoroacetic acid
THF	tetrahydrofuran
Flash Chromatography	Purification using Biotage Horizon using silica gel cartridge and specified mobile phase gradient
HPLC	Automated mass or UV triggered high performance liquid chromatography using acidified MeCN and H <sub>2</sub> O gradients as mobile phase
MHz	Megahertz

### Synthesis of Intermediates

#### Intermediates A

Intermediate #	Structure	Name	Lit. Reference
A1		(1 <i>R</i> ,2 <i>S</i> )-1-Amino- <i>N</i> -(cyclopropylsulfonyl)-2-vinylcyclopropanecarboxamide hydrochloride	Wang et al, US 6,995,174

**Intermediate B1: 3-methyl-N-({[(1*R*,2*R*)-2-pent-4-en-1-ylcyclopropyl]oxy}carbonyl)-L-valine****Step 1: [(1*E*)-hepta-1,6-dien-1-yl]oxy(trimethyl)silane**

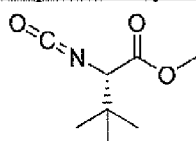
A solution (0.5 M) of butenyl magnesium bromide in THF (1.4 eq) was treated at  $-78^{\circ}\text{C}$  with  $\text{Cu(I)Br}\cdot\text{SMe}_2$  (0.05 eq) and HMPA (2.4 eq). The mixture was stirred for 10 min then a solution (1 M) of acrolein (1 eq) and  $\text{TMSCl}$  (2 eq) in THF was added over 1 h such that the internal temperature remained below  $-68^{\circ}\text{C}$ . The resulting mixture was stirred at  $-78^{\circ}\text{C}$  for 2 h then treated with excess  $\text{Et}_3\text{N}$  and diluted with hexane. After reaching room temperature the mixture was treated with a small portion of  $\text{H}_2\text{O}$  and filtered through CELITE. The filtrate was washed 10 times with  $\text{H}_2\text{O}$  and then with brine. The organic layer was dried and the volatiles were removed to give a residue that was distilled under reduced pressure (20 mbar). The fraction collected at  $80\text{--}86^{\circ}\text{C}$  contained the title compound (58%) as a colorless liquid.  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  6.19 (d,  $J = 11.6$  Hz, 1H), 5.85–5.75 (m, 1H), 5.02–4.92 (m, 3H), 2.08–2.02 (m, 2H), 1.94–1.88 (m, 2H), 1.46–1.38 (m, 2H), 0.18 (s, 9H).

**Step 2: *trans*-2-pent-4-en-1-ylcyclopropanol**

A solution (0.45 M) of the preceding compound in hexane was treated with a solution (15%) of  $\text{Et}_2\text{Zn}$  (1.2 eq) in toluene and the resulting solution was cooled in an ice bath. Diiodomethane (1.2 eq) was added dropwise then the solution was stirred for 1 h before being warmed to  $20^{\circ}\text{C}$ . Pyridine (6 eq) was added and the slurry was stirred for 15 min then poured onto petroleum ether. The mixture was filtered repeatedly through CELITE until a transparent solution was obtained. This mixture was concentrated at 100 mbar and the solution which remained (that contained trimethyl{[(*trans*)-2-pent-4-en-1-ylcyclopropyl]oxy}silane, toluene and pyridine) was further diluted with THF. The mixture was cooled to  $0^{\circ}\text{C}$  then treated dropwise with a solution (1 M) of TBAF (1.2 eq) in THF. After 10 min the mixture was allowed to warm to  $20^{\circ}\text{C}$ , and after a further 1 h was poured into  $\text{H}_2\text{O}$ . The aqueous phase was extracted with  $\text{EtOAc}$  and the combined organic extracts were washed with brine then dried. Removal of the

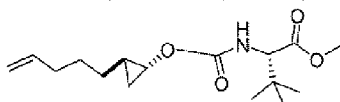
volatiles afforded a residue that was purified by flash chromatography (eluent 0-66% Et<sub>2</sub>O/petroleum ether) to furnish the title compound (71%) as a colorless liquid. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 5.85-5.75 (m, 1H), 5.00 (dd, *J* = 17.1, 1.6 Hz, 1H), 4.94 (br d, *J* = 10.4 Hz, 1H), 3.20 (apparent dt, *J* = 6.4, 2.5 Hz, 1H), 2.10-2.04 (m, 2H), 1.52-1.44 (m, 2H), 1.29-1.19 (m, 1H), 1.15-1.07 (m, 1H), 0.95-0.87 (m, 1H), 0.71-0.66 (m, 1H), 0.31 (apparent q, *J* = 6.0 Hz, 1H).

Step 3: methyl 3-methyl-*N*-(oxomethylene)-L-valinate



A solution (0.39 M) of methyl 3-methyl-L-valinate in a 2:1 mixture of saturated aqueous NaHCO<sub>3</sub> and CH<sub>2</sub>Cl<sub>2</sub> was cooled in an ice bath and stirred rapidly. The mixture was treated with triphosgene (0.45 eq) in one portion and the resulting mixture was stirred for 0.5 h. The reaction was diluted with CH<sub>2</sub>Cl<sub>2</sub> and the layers were separated. The aqueous phase was extracted with CH<sub>2</sub>Cl<sub>2</sub> then the combined organics were washed with brine and dried. Removal of the solvent gave the title compound as clear oil that was kept for 12 h under vacuum (0.1 mbar) then used directly in the subsequent step. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 3.79 (s, 3H), 3.75 (s, 1H), 1.00 (s, 9H).

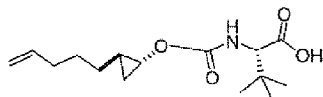
Step 4: methyl 3-methyl-*N*-({[(1*R*,2*R*)-2-pent-4-en-1-ylcyclopropyl]oxy}carbonyl)-L-valinate and methyl 3-methyl-*N*-({[(1*S*,2*S*)-2-pent-4-en-1-ylcyclopropyl]oxy}carbonyl)-L-valinate



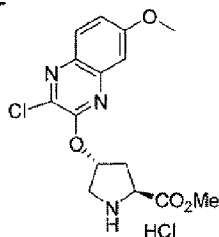
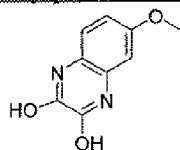
A solution (0.45 M) of *trans*-2-pent-4-en-1-ylcyclopropanol in toluene was treated with methyl 3-methyl-*N*-(oxomethylene)-L-valinate (1.1 eq) and then DMAP (1 eq). The resulting mixture was heated under reflux for 12 h then cooled to 20 °C. H<sub>2</sub>O and EtOAc were added and the organic layer was separated and washed with 1N HCl, brine and dried. Removal of the volatiles afforded a residue that was purified twice by flash chromatography (eluent 0-30% Et<sub>2</sub>O/petroleum ether). The first fractions contained methyl 3-methyl-*N*-({[(1*R*,2*R*)-2-pent-4-en-1-ylcyclopropyl]oxy}carbonyl)-L-valinate (38%) as an oil. MS (ES<sup>+</sup>) *m/z* 298 (M+H)<sup>+</sup>

The later fractions contained methyl 3-methyl-*N*-({[(1*S*,2*S*)-2-pent-4-en-1-ylcyclopropyl]oxy}carbonyl)-L-valinate (28%) as an oil. MS (ES<sup>+</sup>) *m/z* 298 (M+H)<sup>+</sup>

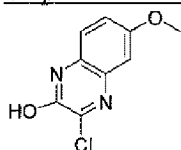


Step 5: 3-methyl-N-({[(1*R*,2*R*)-2-pent-4-en-1-yl]cyclopropyl}oxy)carbonyl)-L-valine

A solution (0.1 M) of methyl 3-methyl-N-({[(1*R*,2*R*)-2-pent-4-en-1-yl]cyclopropyl}oxy)carbonyl)-L-valinate in 2:1 mixture of MeOH/H<sub>2</sub>O was treated with LiOH.H<sub>2</sub>O (4 eq) and then heated at 60 °C for 4 h. The mixture was cooled and concentrated to half volume then diluted with EtOAc and acidified with aqueous HCl (1 N). The organic layer was separated and washed with brine then dried. Removal of the volatiles afforded the title compound (98%) as an oil. MS (ES<sup>+</sup>) *m/z* 284 (M+H)<sup>+</sup>

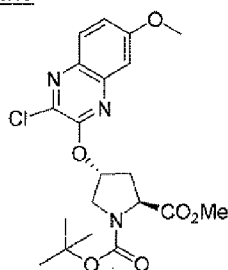
**Intermediates C****Intermediate C1: methyl (4*R*)-4-[(3-chloro-7-methoxyquinoxalin-2-yl)oxy]-L-prolinate hydrochloride**Step 1: 6-methoxyquinoxaline-2,3-diol

A suspension of 4-methoxybenzene-1,2-diamine dihydrochloride in diethyl oxalate (8 eq) was treated with Et<sub>3</sub>N (2 eq) and then heated at 150 °C for 2 h. The mixture was cooled and filtered, and then the collected solid was washed with H<sub>2</sub>O and EtOH. The residue was dried to give the title compound (69%). MS (ES<sup>+</sup>) *m/z* 193 (M+H)<sup>+</sup>

Step 2: 3-chloro-6-methoxyquinoxalin-2-ol

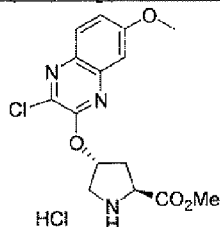
A solution (1.53 M) of 6-methoxyquinoxaline-2,3-diol in DMF was treated with  $\text{SOCl}_2$  (1 eq) and heated at 110 °C. After 1.5 h the reaction mixture was cooled and poured into aqueous HCl (1 N). The resulting precipitate was filtered and washed with  $\text{H}_2\text{O}$  and  $\text{Et}_2\text{O}$ . The dried solid contained predominantly the title compound as a mixture with 6-methoxyquinoxaline-2,3-diol and 2,3-dichloro-6-methoxyquinoxaline. This material was used directly in the subsequent step. MS ( $\text{ES}^+$ )  $m/z$  211 ( $\text{M}+\text{H}^+$ )

Step 3: 1-*tert*-butyl 2-methyl (2S,4R)-4-[(3-chloro-7-methoxyquinoxalin-2-yl)oxy]pyrrolidine-1,2-dicarboxylate



A solution (0.35 M) of 3-chloro-6-methoxyquinoxalin-2-ol in NMP was treated with  $\text{Cs}_2\text{CO}_3$  (1.5 eq) and 1-*tert*-butyl 2-methyl (2S,4S)-4-[(4-bromophenyl)sulfonyl]oxy]pyrrolidine-1,2-dicarboxylate (1.1 eq). The resulting mixture was stirred at 50 °C for 18 h then a further portion (0.1 eq) of 1-*tert*-butyl 2-methyl (2S,4S)-4-[(4-bromophenyl)sulfonyl]oxy]pyrrolidine-1,2-dicarboxylate was added. After stirring for 2 h the mixture was cooled and diluted with  $\text{H}_2\text{O}$  and  $\text{EtOAc}$ . The organic phases were washed with aqueous HCl (1 N), saturated aqueous  $\text{NaHCO}_3$  and brine. The dried organic phase was concentrated to a residue that was purified by flash-chromatography (0-60%  $\text{EtOAc}$ /petroleum ether) to give the title compound (35% for two steps) as a solid. MS ( $\text{ES}^+$ )  $m/z$  438 ( $\text{M}+\text{H}^+$ )

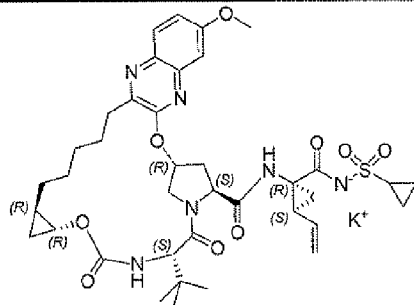
Step 4: methyl (4R)-4-[(3-chloro-7-methoxyquinoxalin-2-yl)oxy]-L-prolinate hydrochloride



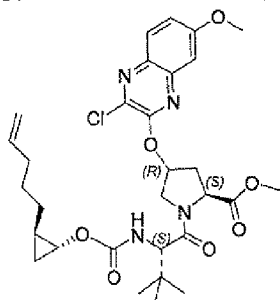
A solution (0.62 M) of 1-*tert*-butyl 2-methyl (2S,4R)-4-[(3-chloro-7-methoxyquinoxalin-2-yl)oxy]pyrrolidine-1,2-dicarboxylate in  $\text{CH}_2\text{Cl}_2$  was treated with a solution (4 M) of HCl in dioxane (5 eq). The mixture was stirred at 20 °C for 2 h then treated with a

solution (4 M) of HCl in dioxane (2 eq). After 5 h the reaction was judged complete and the mixture was concentrated under reduced pressure. The residue was triturated with Et<sub>2</sub>O to give the title compound (95%) as a solid. MS (ES<sup>+</sup>) *m/z* 338 (M+H)<sup>+</sup>

**Example 1: Potassium {[ (1R,2S)-1-({[(1aR,5S,8S,10R,22aR)-5-tert-butyl-14-methoxy-3,6-dioxo-1,1a,3,4,5,6,9,10,18,19,20,21,22,22a-tetradecahydro-8H-7,10-methanocyclopropa[18,19][1,10,3,6]dioxadiazacyclononadecino[11,12-b]quinoxalin-8-yl]carbonyl}amino)-2-vinylcyclopropyl]carbonyl}(cyclopropylsulfonyl)azanide**

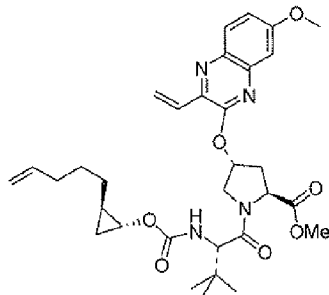


**Step 1: methyl 3-methyl-N-({[(1R,2R)-2-pent-4-en-1-ylcyclopropyl]oxy}carbonyl)-L-valyl-(4R)-4-[(3-chloro-7-methoxyquinoxalin-2-yl)oxy]-L-prolinate**



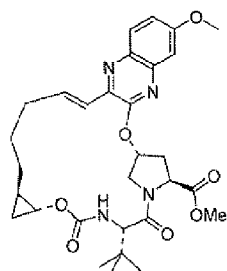
A solution (0.2 M) of methyl (4R)-4-[(3-chloro-7-methoxyquinoxalin-2-yl)oxy]-L-prolinate hydrochloride in DMF was treated with 3-methyl-N-({[(1R,2R)-2-pent-4-en-1-ylcyclopropyl]oxy}carbonyl)-L-valine (1.1 eq), DIEA (5 eq) and HATU (1.2 eq). The resulting mixture was stirred at 20 °C for 5 h then diluted with EtOAc. The organic layer was separated and washed with aqueous HCl (1 N), saturated aqueous NaHCO<sub>3</sub> and brine. The dried organic phase was concentrated under reduced pressure to give a residue that was purified by flash chromatography (eluent 10-30% EtOAc/petroleum ether) to furnish the title compound (96%) as an oil. MS (ES<sup>+</sup>) *m/z* 604 (M+H)<sup>+</sup>

Step 2: methyl 3-methyl-N-({[(1R,2R)-2-pent-4-en-1-ylcyclopropyl]oxy}carbonyl)-L-valyl-(4R)-4-[(7-methoxy-3-vinylquinoxalin-2-yl)oxy]-L-prolinate



A solution (0.1 M) of methyl 3-methyl-N-({[(1R,2R)-2-pent-4-en-1-ylcyclopropyl]oxy}carbonyl)-L-valyl-(4R)-4-[(3-chloro-7-methoxyquinoxalin-2-yl)oxy]-L-prolinate in EtOH was treated with potassium trifluoro(vinyl)borate (1.5 eq) and triethylamine (1.5 eq). The resulting mixture was degassed, then PdCl<sub>2</sub>(dppf)-CH<sub>2</sub>Cl<sub>2</sub> adduct (0.1 eq) was added. The mixture was heated under reflux for 1 h then cooled to room temperature and diluted with H<sub>2</sub>O and EtOAc. The organic phase was separated, washed with H<sub>2</sub>O and brine then dried. Removal of the volatiles afforded a residue that was purified by flash chromatography (20-30% EtOAc/petroleum ether) to give the title compound as a yellow foam that was used directly in the subsequent step. MS (ES<sup>+</sup>) *m/z* 595 (M+H)<sup>+</sup>

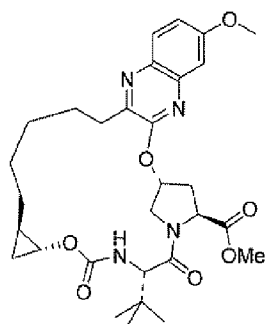
Step 3: methyl (1aR,5S,8S,10R,18E,22aR)-5-tert-butyl-14-methoxy-3,6-dioxo-1,1a,3,4,5,6,9,10,20,21,22,22a-dodecahydro-8H-7,10-methanocyclopropa[18,19][1,10,3,6]dioxadiazacyclononadecino[11,12-b]quinoxaline-8-carboxylate



A solution (0.02 M) of methyl 3-methyl-N-({[(1R,2R)-2-pent-4-en-1-ylcyclopropyl]oxy}carbonyl)-L-valyl-(4R)-4-[(7-methoxy-3-vinylquinoxalin-2-yl)oxy]-L-prolinate in DCE was heated to 80 °C then treated with Zhan 1 catalyst (0.15 eq). The resulting mixture was stirred at 80 °C for 1 h then cooled to room temperature and concentrated under reduced pressure. The residue was purified by flash chromatography (20-50% EtOAc/

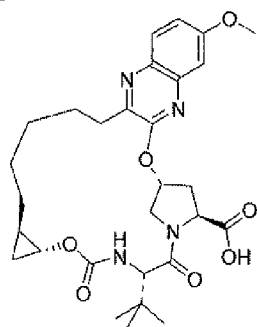
petroleum ether) to give the title compound (25% for 2 steps) as a foam. MS ( $ES^+$ )  $m/z$  567 ( $M+H$ )<sup>+</sup>

Step 4: methyl (1aR,5S,8S,10R,22aR)-5-tert-butyl-14-methoxy-3,6-dioxo-1,1a,3,4,5,6,9,10,18,19,20,21,22,22a-tetradecahydro-8H-7,10-methanocyclopropa[18,19][1,10,3,6]dioxadiazacyclononadecino[11,12-b]quinoxaline-8-carboxylate



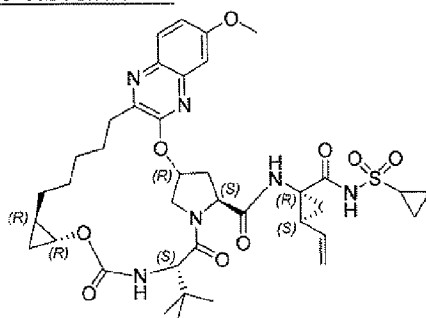
A solution (0.05 M) of methyl (1aR,5S,8S,10R,18E,22aR)-5-tert-butyl-14-methoxy-3,6-dioxo-1,1a,3,4,5,6,9,10,20,21,22,22a-dodecahydro-8H-7,10-methanocyclopropa[18,19][1,10,3,6]dioxadiazacyclononadecino[11,12-b]quinoxaline-8-carboxylate in MeOH/dioxane (1:1 ratio) was treated with Pd/C (8% in weight). The resulting mixture was stirred under atmosphere of hydrogen for 4 h. The catalyst was filtered off and the filtrate was concentrated under reduced pressure to give the title compound (98%) as a solid. MS ( $ES^+$ )  $m/z$  569 ( $M+H$ )<sup>+</sup>

Step 5: (1aR,5S,8S,10R,22aR)-5-tert-butyl-14-methoxy-3,6-dioxo-1,1a,3,4,5,6,9,10,18,19,20,21,22,22a-tetradecahydro-8H-7,10-methanocyclopropa[18,19][1,10,3,6]dioxadiazacyclononadecino[11,12-b]quinoxaline-8-carboxylic acid



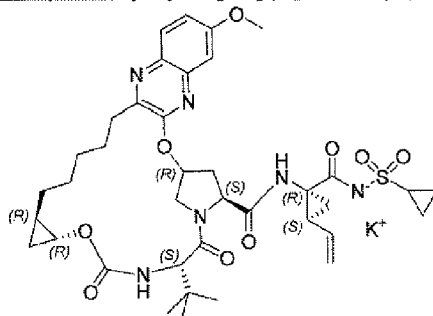
A solution (0.1 M) of methyl (1aR,5S,8S,10R,22aR)-5-tert-butyl-14-methoxy-3,6-dioxo-1,1a,3,4,5,6,9,10,18,19,20,21,22,22a-tetradecahydro-8H-7,10-methanocyclopropa[18,19][1,10,3,6]dioxadiazacyclononadecino[11,12-b]quinoxaline-8-carboxylate in a 1:1 mixture of H<sub>2</sub>O/THF was treated with LiOH.H<sub>2</sub>O (3 eq). The resulting mixture was stirred at 20 °C for 18 h, acidified with aqueous HCl (0.2 M) and diluted with EtOAc. The organic phase was separated, washed with aqueous HCl (0.2 M) and brine then dried. Removal of the volatiles afforded the title compound (98%) as a solid. MS (ES<sup>+</sup>) *m/z* 555 (M+H)<sup>+</sup>

Step 6: (1aR,5S,8S,10R,22aR)-5-tert-butyl-N-((1R,2S)-1-[[[(cyclopropylsulfonyl)amino]carbonyl]-2-vinylcyclopropyl]-14-methoxy-3,6-dioxo-1,1a,3,4,5,6,9,10,18,19,20,21,22,22a-tetradecahydro-8H-7,10-methanocyclopropa[18,19][1,10,3,6]dioxadiazacyclononadecino[11,12-b]quinoxaline-8-carboxamide



A solution (0.1 M) of (1aR,5S,8S,10R,22aR)-5-tert-butyl-14-methoxy-3,6-dioxo-1,1a,3,4,5,6,9,10,18,19,20,21,22,22a-tetradecahydro-8H-7,10-methanocyclopropa[18,19][1,10,3,6]dioxadiazacyclononadecino[11,12-b]quinoxaline-8-carboxylic acid in CH<sub>2</sub>Cl<sub>2</sub> was treated with (1R,2S)-1-[[[(cyclopropylsulfonyl)amino]carbonyl]-2-vinylcyclopropanaminium chloride (1.3 eq), DIEA (3 eq), DMAP (1.5 eq) and TBTU (1.45 eq). The resulting mixture was stirred at 20 °C for 18 h and then diluted with EtOAc. The solution was washed with aqueous HCl (0.2 M), saturated aqueous NaHCO<sub>3</sub> and brine. The organic phases were dried and concentrated to give a residue that was purified by flash-chromatography (eluent 2.5% MeOH/CH<sub>2</sub>Cl<sub>2</sub>) to give the title compound (89%) as a solid. <sup>13</sup>C NMR (100 MHz, DMSO-*d*<sub>6</sub>) δ 172.32, 170.63, 169.04, 159.86, 156.95, 154.74, 148.10, 140.41, 133.55 (2 signals), 128.94, 118.21, 117.58, 105.89, 74.88, 59.75, 58.71, 55.68, 54.13, 54.01, 40.13, 34.49, 34.04, 33.76, 32.68, 30.71, 30.43, 28.55, 27.69, 27.28, 26.38, 21.98, 18.49, 10.67, 5.69, 5.46; MS (ES<sup>+</sup>) *m/z* 767 (M+H)<sup>+</sup>

Step 7: potassium {[ (1R,2S)-1-({[(1aR,5S,8S,10R,22aR)-5-tert-butyl-14-methoxy-3,6-dioxo-1,1a,3,4,5,6,9,10,18,19,20,21,22,22a-tetradecahydro-8H-7,10-methanocyclopropa[18,19][1,10,3,6]dioxadiazacyclononadecino[11,12-b]quinoxalin-8-yl]carbonyl}amino)-2-vinylcyclopropyl]carbonyl}(cyclopropylsulfonyl)azanide

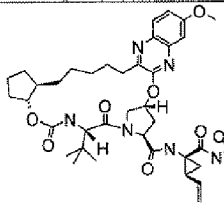
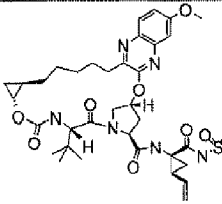
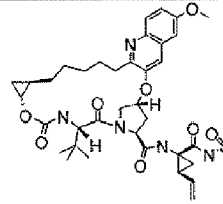


The preceding material was taken up in EtOH and the resulting solution (0.025 M) was cooled to 0 °C. A solution (0.02 M) of *tert*-BuOK (1.5 eq) in EtOH was added leading to the formation of a precipitate. The mixture was stirred at 20 °C for 18 h then the solid was collected by filtration. This material was washed with EtOH and dried to give the title compound (93%) as a white crystalline solid. MS (ES<sup>+</sup>) *m/z* 767 (M+H)<sup>+</sup>

### **Example 2: Comparison of Different Compounds**

The compound of Example 1 was compared to the compound of Examples 110 and 118 of WO 2008/057209. The results are shown in Tables 1 and 2 below. As illustrated in the tables and the discussion of the results, the compound of formula (I) appears to have several advantageous properties compared to both the WO 2008/057209 Example 118 compound and the WO 2008/057209 Example 110 compound.

Table 1

	WO 2008/057209 Example 118	Example 1	WO 2008/057209 Example 110
Structure			
NS 3/4A Inhibitory Activity <sup>1</sup> (Ki) 1b	< 0.016 nM	< 0.016 nM	< 0.016 nM
Replicon Activity <sup>2</sup> EC <sub>50</sub> gt1b	3 nM	2 nM	5 nM
Rat Plasma AUC @ 25mpk per os <sup>3</sup>	38.5 μM.h	20.6 μM.h	5.8 μM.h
Rat Liver Concentration @ 24h (25 mpk per os) <sup>3</sup>	18.4 μM	27.9 μM	8.5 μM
Dog Plasma AUC @ 5mpk per os <sup>3</sup>	10.9 μM.h	48.6 μM.h	1.0 μM.h
Dog Liver Concentration @ 24h (5mpk per os) <sup>3</sup>	Not Available	120 μM	3.3 μM
Covalent Protein Binding In Vivo <sup>4</sup>	Rat @ 6h plasma = BLQ , liver = 30±3pmol/mg protein	Rat @ 6h plasma = LOQ , liver = LOQ	Rat @ 6h plasma = BLQ, liver = BLQ
Physical properties <sup>5</sup>	Potassium salt does not disproportionate in solution.	Potassium salt does not disproportionate in solution.	Potassium salt disproportionates to crystalline neutral form in solution

Ki: Inhibition constant, reference to < 0.016 nM indicates that the observed activity is less than 0.016 nM, the exact amount less than 0.016 nM was not determined by the assay; EC50: Effective concentration achieving 50% viral replication suppression; gt: Genotype; AUC: Area Under the plasma concentration/time curve; LOQ: Limit of quantitation (3 pmol/mg); BLQ: Below limit of quantitation.

*Formula (I) Compound Compared to WO 2008/057209 Example 110*

Advantageous properties of the formula (I) compound versus the WO 2008/057209 Example 110 compound are the following:



- 1) Physical properties (no salt disproportionation for the Compound of formula (I));
- 2) Pharmacokinetic profile in rats following administration of the potassium salt; and
- 3) Liver (target organ) exposure.

The differences in properties are particularly advantageous for the formulation and administration of the formula (I) compound compared to the WO 2008/057209 Example 110 compound. The lack of salt disproportionation for the formula (I) compound enables dissolution of 1.8 mg/ml of the K<sup>+</sup> salt form of the Compound of Example 1 in water. Although the K<sup>+</sup> salt form of the WO 2008/057209 Example 110 compound has improved aqueous solubility (9.7 mg/mL), the compound thus dissolved disproportionates to give a crystalline zwitterionic form which has low aqueous solubility (<0.009 mg/ml). The lack of this behavior for the Compound of Example 1 provides an unexpected advantage in its formulation for pharmaceutical administration and results in improved pharmacokinetic properties as reported in Table 1 (plasma AUC and liver exposure for rat and dog). High plasma and liver exposure in preclinical species is advantageous for the selection of safe and efficacious doses for use in the treatment of patients.

*Formula (I) Compound Compared to WO 2008/057209 Example 118*

An observed advantage of the compound of formula (I) compared to WO2008/057209 Example 118 is its resistance profile against different mutant enzymes. In line with data from clinical studies with antiviral agents from related classes (*e.g.* HIV protease inhibitors), and also from studies with HCV NS3 protease inhibitors (*e.g.*, VX-950, telaprevir), it is expected that viral resistance may develop in response to treatment with the current compounds. The compound of Example 1 showed improved enzyme affinity ( $K_i$ ) against different mutant enzymes that are known to confer resistance to HCV NS3 protease inhibitors. Table 2 summarizes activity against different mutant enzymes. Thus, an advantage of compound 1 may be an increased barrier to the development of resistant virus when administered to patients. It also provides the potential advantage to treat patients who have failed other therapies because of the development of resistance, since compound 1 may inhibit this resistant virus.

Table 2 Ki values<sup>1</sup> vs. 1b mutant enzyme (nM)

1b SHIFT	D168T	D168A	D168E	D168G	D168V	D168Y	D168Q
Example 1	0.18	0.43	0.04	0.08	0.14	0.22	0.12
cmp 118	0.78	0.86	0.12	0.45	0.65	1.5	0.42
1b SHIFT	A156S	A156T	A156V	R155K	R155Q	R155G	R155N
Example 1	0.05	5.2	11	0.07	0.43	0.63	0.13
cmp 118	0.10	3.4	15	0.08	1.9	2.3	0.56

<sup>1</sup>Comparative data collected in the same run of the enzyme assays

Further expected advantageous properties of the formula (I) compound versus the WO 2008/057209 Example 110 compound include the following:

- 1) Low *in vivo* covalent binding; and
- 2) High plasma and liver exposure.

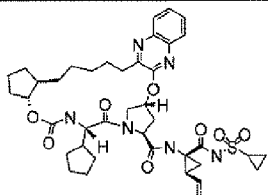
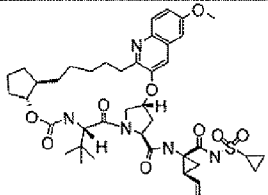
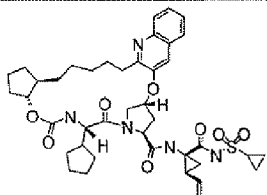
The formula (I) compound was found to have very good covalent binding *in vivo* characteristics and pharmacokinetic properties. Based on observed covalent binding *in vivo* and pharmacokinetic properties of the Example 1 compound and the WO 2008/057209 Example 118 compound, the formula (I) compound has significantly better *in vivo* covalent binding characteristics and pharmacokinetic properties.

Compounds which covalently bind to proteins, or which form metabolites that subsequently become covalently bound to proteins, potentially give rise to adverse events in patients such as immunological toxicities mediated by antibody responses to the drug-protein conjugate, and other idiosyncratic toxicities. (See Chem. Res. Toxicol. 2004, 17, 3-16.)

The compound of Example 1 showed undetectable binding to plasma proteins following oral administration of a single 20 mg/kg dose to rats. (See Table 1.) Under analogous conditions, the WO 2008/057209 Example 118 compound demonstrated detectable binding to rat liver proteins (see Table 1), and therefore may be considered a less advantageous compound for administration to human subjects than the compound of formula (I).

Table 3 provides some additional *in vivo* covalent binding data observed for related compounds from WO 2008/057209 that contain the (R,R)-trans-2-alkylcyclopentanol moiety incorporated in Example 118.

Table 3

	WO 2008/057209 Example 108	WO 2008/057209 Example 103	WO 2008/057209 Example 96
Structure			
Covalent Protein Binding In Vivo <sup>4</sup>	Rat @ 6h plasma = 15 pmol eq./mg liver = 38 pmol eq./mg	Rat @ 6h plasma = 6 pmol eq./mg liver = 24 pmol eq./mg	Rat @ 6h plasma = 6 pmol eq./mg liver = 63 pmol eq./mg

It is advantageous to have high plasma and liver exposure in preclinical species to effectively demonstrate that the potential drug candidate does not elicit undesired toxicities. It is also more likely that a compound that has high liver and plasma exposure in animals displays the same behavior in man than one that does not. For such a compound, the required efficacious exposure in man can be reached with a lower dose, advantageous both for the cost and ease of manufacturing the drug, but also potentially lowering the likelihood of adverse effects. Target organ exposure in multiple preclinical species provides a rationale that high target organ exposure is achievable for the compound in patients, and high liver exposure in both rat and dog allows for confident evaluation of preclinical toxicity. High liver exposure is especially advantageous for HCV since this is the target organ for the drug.

The compound of Example 1 had a very good rat plasma and liver exposure. The observed rat liver exposure was at a level greater than for WO 2008/057209 compound 118 and compound 110. (See Table 1) Based on these results and on testing several different compounds from WO 2008/057209 by oral administration to both rat (25mpk) and dog (5mpk), the compound of formula (I) is also expected to have dog liver exposures greater than WO2008/057209 compound 118 and compound 110.

#### Methods

NS 3/4A Inhibitory Activity<sup>1</sup> (K<sub>i</sub>): NS 3/4A Inhibitory Activity was determined as described in Section IV. Compound Evaluation *supra.*, and Mao *et al.*, *Anal Biochem* 373:1-8, 2008.

Replicon Activity<sup>2</sup> EC<sub>50</sub>: Replicon Activity was determined using the procedures described in Carroll *et al.*, *J. Biol. Chem.* 278:11979–11984, 2003 and Olsen *et al.*, *Anti Microb. Agents* 48:3944-3953, 2004.

Rat Plasma AUC @ 25mpk per os<sup>3</sup>: Test compounds were dissolved in a suitable dosing vehicle for iv administration (e.g. 20%:60%:20% DMSO:PEG400:Water) or per os administration (e.g., 10% POLYSORBATE80: 90% Water or 100% PEG400). Animals were administered (n = 3) using a crossover study design for non-rodents. Plasma samples were collected at time points between 2 minutes and 24 h, and compound levels were determined by RP-HPLC. Liver samples were collected post mortem in rat and following anesthesia (0.5 h prior to biopsy) in dog. Liver samples were weighed, homogenized, and diluted using techniques known to those skilled in the art, and compound levels were determined by RP-HPLC.

Pharmacokinetic parameters were calculated based on non-compartmental analysis (e.g. using WATSON®, WINNOLIN®). Predose concentrations that were below the limit of quantitation (BLQ) were assigned a value of 0. For oral AUC estimation, the first BLQ value in the terminal phase were given a value equal to 1/2 Lowest Limit Of Quantitation, while subsequent values in the terminal phase were assigned a value of 0. Standard pharmacokinetic parameters CL<sub>p</sub>, V<sub>dss</sub>, half-life (only for IV), % F, C<sub>max</sub>, T<sub>max</sub>, AUC<sub>0-last</sub>, AUC<sub>0-infinity</sub> were calculated. AUC values were calculated using linear trapezoidal method for ascending concentrations and the log trapezoidal method for descending concentrations.

In-Vivo Covalent Binding<sup>4</sup>: Test compounds were suitably radiolabeled (3H) and a 20 mg/kg dose containing 25-75 mCi/rat (purity >98.5%) radioactivity was prepared by combination of the cold compound and evaporated radiotracer stock solution. This mixture was dissolved in a dosing vehicle suitable for per os administration (see above) then administered orally to rat (n = 3 per timepoint, 2h, 6h, 24h). Plasma and liver were collected and flash frozen/stored at -80°C before analysis.

Counting of the plasma samples: Place a 200 µL aliquot in a 20 mL scintillation vial. Add 500 µL of SOLVABLE™ and incubate at 1 h with shaking at 55°C. Remove, allow to cool prior to the addition of 15 mL scintillation cocktail, and count. Plasma samples (200 µL aliquot) were then processed as described below for liver proteins.

Tissue homogenization: Weighed liver samples were diluted with 2 vol 100 mM phosphate buffer (pH 7.4) and homogenized on ice.

Counting of the liver homogenate: Aliquots were placed in a 20 mL scintillation vial, diluted with 1 mL of SOLVABLE™ and incubated for 1 h with shaking at 55°C. After removal from the incubator and cooling 15 mL scintillation cocktail and 30% H<sub>2</sub>O<sub>2</sub> were added and the radioactivity counted.

*Protein precipitation:* Take 500  $\mu$ L aliquot, add 1:8 homogenate:acetonitrile (if compound is suspected to have low solubility in acetonitrile, another solvent may be selected), vortex and centrifuge (3500 rcf for 20 min). Discard the supernatant.

*Protein precipitate resuspension:* Sonication (minimal intensity, < 5 sec) and vortexing until the pellet crumbles in 80% MeOH:20% water.

*Wash of the protein pellet:* 2-5 mL 80:20 MeOH: water. If needed, remove 1.0 mL of the supernatant, add 15 mL of scintillation cocktail and count. Continue to wash the protein pellet until radioactivity in supernatant is < 200 DPM or DPMs cease to decrease by more than 200 in consecutive washes.

*Dissolution of the final pellet:* 1 mL of 1 N NaOH or SOLVABLE™, incubated at 50°C overnight or until completely dissolved.

*Counting of the final pellet:* 1 mL of dissolved pellet, 15 mL scintillation cocktail (if another scintillation cocktail other than ULTIMA GOLD™ is used, pellet may require neutralization using 1 N HCl), and count.

*Protein concentration of the final pellet:* BCA or BIO-RAD kit using BSA as a standard.

*Counting blank samples:* 15 mL scintillation cocktail, in duplicate.

*Counting of the dosing solution:* Count a known volume of the dosing solution in triplicate.

*Data Analysis:* Average the radioactivity counts (DPM) of the dosing solution and calculate the specific activity of the dosing solution in  $\mu$ Ci/mol. Average the radioactivity counts of the blank samples. Subtract the counts of the averaged blank sample from the counts obtained from each liver and plasma pellet. Calculate the amount of radioactivity ( $\mu$ Ci) per unit volume (L) for each liver and plasma pellet. Calculate the concentration of radioactivity in each plasma and liver pellet by dividing the value obtained above ( $\mu$ Ci/L) by the specific activity ( $\mu$ Ci/mol). Calculate the amount of covalently bound radioactivity to protein in pmol/mg protein.

*Counting blank samples:* 15 mL scintillation cocktail, in duplicate.

*Counting of the dosing solution:* count a known volume of the dosing solution in triplicate.

Physical properties<sup>5</sup>: The crystalline test compounds (potassium salt, ca. 5 mg) was weighed in a glass vial and water or aqueous buffer was added (100  $\mu$ L). The slurry obtained was stirred for 24 h at room temperature. After centrifuging, the supernatant was analyzed by reversed-phase HPLC and the equilibrium solubility determined by comparison with a calibration curve. The solid material was in part transferred onto an XRPD plate, dried and then analyzed by X-Ray Powder Diffraction. The XRPD pattern was compared with positive

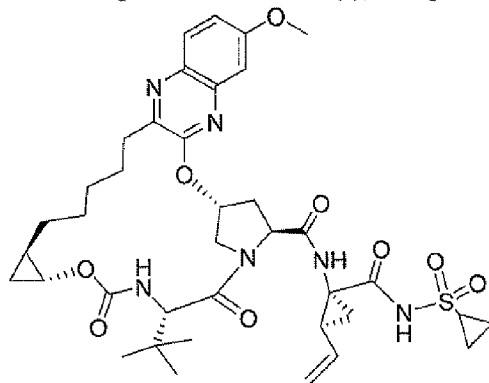
controls for crystalline K<sup>+</sup> salt, crystalline zwitterionic (or acidic) and amorphous forms of the test compound. A further determination of the salt form was obtained from a second portion of the solid material which was analyzed by 400 MHz NMR (Bruker) following dissolution in DMSO-*d*<sub>6</sub>. <sup>1</sup>H-NMR spectra were compared to positive controls described above.

None of the references described throughout the present application are admitted to be prior art to the claimed invention.

Other embodiments are within the following claims. While several embodiments have been shown and described, various modifications may be made without departing from the spirit and scope of the present invention.

## WHAT IS CLAIMED IS:

1. A compound of formula (I), or a pharmaceutically acceptable salt thereof:



(I)

2. A pharmaceutical composition comprising an effective amount of the compound of claim 1 and a pharmaceutically acceptable carrier.
3. The pharmaceutical composition of claim 2, further comprising a second therapeutic agent selected from the group consisting of a HCV protease inhibitor and a HCV NS5B polymerase inhibitors.
4. The compound of claim 1 for use in medicine.
5. The compound of claim 1 for use in prevention or treatment of HCV infection.
6. Use of the compound or composition according to anyone of claims 1-3 in the preparation of a medicament for inhibiting HCV NS3 protease activity in a subject in need thereof.
7. Use of the compound or composition according to anyone of claims 1-3 in the preparation of a medicament for preventing or treating infection by HCV in a subject in need thereof.
8. A method of treating a patient infected with HCV comprising the step of administering to said patient an effective amount of the compound or composition of anyone of claims 1-3.

9. A method of treating a patient infected with HCV comprising the step of administering to said patient an effective amount of the compound or composition of any one of claims 1 to 3 for inhibiting HCV NS3 protease activity.
10. A compound or composition of any one of claims 1 to 3, substantially as hereinbefore described with reference to any one of the examples, or the description
11. A method of preparing a compound of claim 1, substantially as hereinbefore described with reference to any one of the examples, , reaction schemes, or the description

**Dated 19 June 2012**

**Merck Sharp & Dohme Corp.**

**Istituto Di Ricerche Di Biologia Molecolare P. Angeletti S.P.A.**

**Patent Attorneys for the Applicant/Nominated Person**

**SPRUSON & FERGUSON**