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Methane in the Solar System

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Abstract

This paper reviews the distribution of methane (CH_4) in our Solar System, as well as its sources and sinks in the atmospheres of the main Solar System bodies. Methane is widely distributed in the Solar System. In general, the inner planets are methane-poor, being Earth a unique exception, whereas the outer planets have CH_4-rich atmospheres. In general, the atmospheric chemistry of this compound is dominated by the solar radiation although in O_2-rich atmospheres this compound participates in a reaction system that removes atmospheric CH_4. In our planet most of the atmospheric CH_4 is produced by lifeforms, reason why scientists have proposed that the simultaneous detection of methane signal along with oxygen (O_2) or ozone (O_3) signals in the atmospheric spectra of planets may be good evidence of life. Therefore, the study of this gas at planetary level is important for understanding the chemical reactions that control its abundance on the exoplanetary atmospheres and to classify possible inhabited planets.

Keywords: methane, biosignatures, Solar System.

Resumen

El objetivo del este trabajo es hacer una revisión sobre la distribución del metano (CH_4) dentro del Sistema Solar, así como sus fuentes y sumideros en las atmósferas de sus principales cuerpos. El CH_4 está ampliamente distribuido en el Sistema Solar; en general los planetas internos son pobres en este gas, con excepción de la Tierra, mientras que los planetas externos son ricos en él. La química atmosférica de este compuesto generalmente está dominada por la radiación solar, aunque en atmósferas ricas en O_2, este compuesto forma parte de un sistema de reacciones que eliminan al metano atmosférico. Dado que la mayor parte de CH_4 atmosférico es debido a la vida, los científicos han propuesto que su detección simultánea con oxígeno (O_2) u ozono (O_3) en el espectro de la atmósfera de los planetas podría ser una buena evidencia de vida. El estudio del CH_4 a nivel planetario es importante para entender las reacciones que controlan su abundancia en las atmósferas de los exoplanetas y clasificar los posibles planetas habitados.

Palabras clave: metano, bioseñales, sistema solar.

1. Distribution of methane in the Solar System

The Solar System was formed by the gravitational collapse of a primordial gas nebula. The center of this nebula collapsed faster than its outer edge, forming the Sun at the center and a protoplanetary disc around, latter processes formed planets from the dust (Cloutier, 2007). The temperature in the inner protoplanetary disc near the Sun was high enough to evaporate volatiles like methane, which is decomposed by photolysis and it is dragged later by the solar wind. In the outer regions of the protoplanetary disc, the low temperatures allowed that ices and volatiles could be preserved. The result is CH_4-poor terrestrial planets in the inner Solar System and CH_4-rich big planets in the outer (Cloutier, 2007).

Methane is preserved in ices called clathrates, these solids present structures that can capture methane in their interior. They play an important role in the stabilization and dispersion of molecules in the Solar System because they are present in many kinds of environments with a wide range of pressures and temperatures (Miller, 1961; Thompson *et al*., 1987). Here, we review the CH_4 abundances in planets and small bodies of the Solar System.

2. Inner planets

Inner planets are the four closest planets to the Sun: Mercury, Venus, Earth, and Mars. They are small planets composed of silicates and iron. Volatiles in inner planet atmospheres as Mercury, Venus, Earth and Mars, are mainly the result of degassing from their interiors (Cloutier, 2007).

2.1. Mercury and Venus

Mercury has a tiny atmosphere mainly formed by He, H_2, O_2, Na, Ca, K and water vapor (Broadfoot *et al*., 1974; Potter and Morgan, 1985, 1986). Measurements with the Mercury Laser Altimeter ─MErcury Surface, Space ENvironment, GEoche-mistry, and Ranging (MESSENGER), confirmed the long held idea that Mercury contains impact-derived deposits of volatiles than may include organics (Neumann *et al*., 2013; Paige *et al*., 2013). These deposits are located in permanently shadowed zones of the north polar region where the regolith has temperatures similar to those of the icy Galilean satellites, allowing the cold-trapping of materials from comets and rich-volatile meteorites (Neumann *et al*., 2013). Methane is present in comets but thermal stability models do not predict its presence in cold-traps due to its higher volatility compared to water (Zhang and Paige, 2009). Gibson (1977) proposed a volatile cycle for Mercury, starting with the production of simple molecules (H_2, H_2O, CH_4, NH_3, etc.) by solar-wind ions implanted into the planet's silicate surface. These chemical species would be outgassed and then cold-trapped in colder regions of the planet. Until now, no detection of methane has been reported for this planet.

Venus has a thick atmosphere mainly formed by CO_2 (96 %) and N_2 (3 %) (Niemman *et al*., 1980). The Pioneer spacecraft instruments detected CH_4 in Venus atmosphere (1000 – 6000 ppm) and many other gases (Oyama *et al*., 1980). Nevertheless, measurements of CH_3D/CH_4 ratio of 5×10^{-3} caused controversy because atmospheric evolution models predicted a CH_3D/CH_4 ratio of 9×10^{-2}. A plausible explanation is that the CH_4 was the result of the reaction between some highly deuterated molecules in Venus atmosphere and terrestrial CH_4 that contaminated the instruments (Donahue and Hodges, 1993).

Based on the detection of NH_3, HCl, and H_2O in the Venus atmosphere, along with the fact that there is a strong possibility of electrical discharge in the atmosphere as a result of thermal convective turbulence, Otroshchenko and Surkov (1974) proposed that organic compounds could be formed in the atmosphere. Their hypothesis was experimentally tested, finding CH_4 and other low-mass molecules. The studies of Otroshchenko and Surkov (1974) show that presence of organic compounds in the Venus atmosphere is a strong possibility.

2.2. Earth

CH_4 levels in the atmosphere are currently around 1.6 – 1.8 ppmv, the enhanced greenhouse effect caused by a molecule of methane is about 8 times that of a molecule of CO_2 (Houghton, 2005). CH_4 is homogeneously mixed in the troposphere while in the upper atmosphere the highest concentrations are at the Ecuador (http://earthobservatory.nasa.gov). CH_4 levels have changed over the history of the Earth, before the emergence of life, CH_4 sources were geological.

The emergence of life increased the levels of CH_4 in an atmosphere without free oxygen, where CH_4 could have lifetimes of 5000 – 10000 years and reach concentrations of 1000 ppmv (Kasting and Siefert, 2002). Then, when oxygenic photosynthesis increased O_2 levels in the atmosphere, CH_4 decreased because of a set of reactions that will be described at the end of this section. Numerical models show that, today, the thermodynamic equilibrium value for CH_4 is $> 10^{-35}$, in volume fraction, however its abundance is approximately 1.7×10^{-6} (Sagan *et al*., 1993). CH_4 is almost totally produced by biological sources and the abiotic sources represent less than 10 % (Levine *et al*., 2010). The pristine ice cores store a record of CH_4 concentrations of thousands of years. Analysis of these cores show that CH_4 abundances ranged from 0.35 ppmv to 0.8 ppmv corresponding to glacial and interglacial periods (*e.g*., Legrand *et al*., 1988; Chappellaz *et al*., 1990; Raynaud *et al*., 1993; Brook *et al*., 1996; Petit *et al*., 1999; Spahni *et al*., 2005; Loulergue *et al*., 2008). CH_4 has increased its atmospheric concentration since pre-industrial time to be relatively constant around 1.7 ppmv (Dlugokencky *et al*., 2003). Recently, CH_4 is calling the attention of scientists

studying climate change due to its capability as greenhouse gas. Today near to 50 % of CH_4 global emissions are produced by human activity (mining, industry, farming, and ranching) causing an imbalance between their sources and sinks of 30 Tg $year^{-1}$, approximately, contributing from 4 % to 9 % of greenhouse effect (Lelieveld *et al*., 1998; Wuebbles and Hayhoe, 2002; Houghton, 2005).

It is estimated that all CH_4 sources produce 600 Tg yr^{-1}, approximately. There are no chemical reactions forming CH_4 in atmospheres such as Earth (Levine *et al*., 1985). Here, almost all CH_4 is produced by methanogen microorganisms. Methanogens can form CH_4 by two ways: 1) using CO_2 in the reaction $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ (Thauer, 1998) or, 2) using organic molecules as electron terminal acceptors, for example acetic acid, methanol, or methylamine, in the reaction $CH_3COOH \rightarrow CH_4 + CO_2$ (Fukuzaki *et al*., 1990). Table 1 summarizes the CH_4 sources. The major biological sources of methane are wetlands, followed by digestion of animals such as ruminants and decomposition of biomass. An important source, linked to human activity, is the production of energy. Other minor sources are the animal activity such as arthropods and decomposition of sediments and bacterial activity in marine environments. While the only known abiotic source is the serpentinization process and contributes with 3 % of methane emissions.

Serpentinization takes place in hydrothermal systems similar to the Lost City, located in the middle of Atlantic Ocean. In these sites, it is commonly said that CH_4 is formed by serpentinization but in fact, CH_4 is byproduct of a Fischer–Tropsch type reaction after to serpentinization process. In the Fischer–Tropsch reaction, CO_2 is reduced by H_2 forming CH_4: $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$. This reaction needs metal catalysts such as Fe, Co, and Ni, and temperatures and pressures in the range of 200 ºC to 350 ºC and 20 bars to 30 bars (Schulz, 1999). The H_2 used in the Fischer–Tropsch reaction is a product of serpentinization. In serpentinization, hydrolysis of olivine minerals ($(Mg,Fe)2SiO_4$) form serpentine ($Mg_3Si_2O_5(OH)_4$), brucite ($Mg(OH)_2$), magnetite (Fe_3O4), and H_2:

$$3Fe_2SiO_4 + 2H_2O \rightarrow 3SiO_2 + 2Fe_3O_4 + 2H_{2(ac)}$$

$$3Mg_2SiO_4 + SiO_2 + 4H_2O \rightarrow 2Mg_3Si_2O_5(OH)_4$$

$$2Mg_2SiO_4 + 3H_2O \rightarrow Mg_3Si_2O_5(OH)_4 + Mg(OH)_2$$

Serpentinization reactions are possible from 1 bar to 5 kbars, temperatures from 0 ºC to 500 ºC, and Fe^{2+} abundances from 1 % to 50 % (Oze and Sharma, 2005).

In contrast to the numerous CH_4 sources, there are only three sinks. Table 2 summarizes the sinks of CH_4. The major of those occur in the troposphere where the reaction of oxidation of CH_4 by hydroxyl radical (OH) leads mainly formaldehyde (CH_2O); such reaction is responsible for removing almost 90 % of atmospheric CH_4. OH radical is byproduct in photolysis of O_3 by UV-B radiation (Rohrer y Berresheim, 2006). OH radical rapidly reacts with CH_4 removing it from the atmosphere:

$$O_2 + h\nu\ (180 - 240\ nm) \rightarrow O + O$$

$$O_2 + O \rightarrow O_3$$

$$O_3 + h\nu\ (200 - 300\ nm) \rightarrow O(^1D) + O_2$$

$$O(^1D) + H_2O \rightarrow 2OH$$

$$CH_4 + OH \rightarrow CH_3 + H_2O$$

Where $h\nu$ is the energy of a photon with frequency ν and h is the Panck constant. The remaining CH_4 is removed trough soil oxidation, and transport to the stratosphere (Wuebbless and Hayhoe, 2002; Houweling *et al*., 2006; Anderson *et al*., 2010). After being produced, either by biological activity or serpentinization, methane may be stored in clathrates. Gas hydrates belong to a general class of inclusion compounds commonly known as clathrates. Clathrates owe their existence to the ability of H_2O molecules to assemble via hydrogen bonding and form polyhedral cavities. Molecules like methane or carbon dioxide are of an appropriate size such that they fit within cavities formed by the host material (*e.g.*, Kvenvolden, 1993). Methane hydrates are particularly important (Mahajan *et al*., 2007). Within clathrates there are no chemical bond involved between the water molecules and the gas molecules other than Van der Waals forces, but the presence of guest molecules inside the ice crystals makes the structure more stable. In fact, the guest molecules stabilize the structure enough for raising the melting point

Table 1. CH_4 sources on Earth.

Source	Tg $year^{-1}$	%
Biogenic		
Wetlands[a,b] (Including crops such as rice)	225	37
Decomposition of biomass[a,b] (Litter, humus, landfills)	105	17
Animals[a] (Including livestock)	115	19
Arthropods[b]	20	3
Oceans and water bodies[a,b] (Including decomposition of sediment and bacterial activity in marine environments)	15	3
Energy Production[a] (Extraction of fuels)	110	18
Abiogenic		
Serpentinization [a,b]	16	3

Sources reported by (a) Houweling *et al*., 2006, (b) Anderson *et al*., 2010.

Table 2. CH_4 sinks on Earth.

Sink	Tg $year^{-1}$	%
Tropospheric OH[c]	500	88
Soil oxidation[a,b,c]	30	5
Transport to stratosphere[a,c]	40	7

Sinks reported by (a) Houweling *et al*., 2006, (b) Anderson *et al*., 2010, (c) Wuebbless and Hayhoe, 2002.

of the ice to several degrees above 0 °C (Miller, 1961). There are two different reservoirs for clathrates. They can be found both within and under permafrost in arctic regions and also within a few hundred meters of the seafloor on continental slopes and in deep seas and lakes (Hester and Brewer, 2008).The permafrost is soil, sediment, or rock that is continuously frozen (temperature < 0 °C) for at least two consecutive years (Anderson *et al*., 2010). Permafrost is the largest CH_4 reservoir in Earth. Estimates of the global inventory of methane clathrate may be 3×10^{18} g of carbon (Buffett and Archer, 2004). Permafrost acts as an impermeable lid, preventing CH_4 escape through the seabed. Moreover, sub-sea permafrost is potentially more vulnerable to thawing than terrestrial permafrost. A consequence of climate warming is the partial thawing and failure of sub-sea permafrost and thus an increased permeability for gases. Shakhova *et al.* (2010a) estimate the total amount of carbon preserved within permafrost, only in the East Siberian Arctic Shelf (ESAS), to be ~1.4×10^{15} g. Shakhova *et al.* (2010b) estimated the annual outgassing from the shallow ESAS of 7.98 Tg CH_4. This amount is of the same magnitude as existing estimates of total methane emissions from the entire world ocean (*e.g*., Anderson *et al*., 2010).

Because methane is also a greenhouse gas, release of even a small percentage of total deposits could have a serious effect on Earth's atmosphere. A conservative estimate by Boswell and Collett (2011) for the global gas hydrate inventory is ~1.8×10^{15} g C, corresponding to a CH_4 volume of ~3.0×10^{15} m^3 if CH_4 density is considered to be 0.717 kg m^{-3}. In the unlikely event that 0.1 % (1.8 Tg C) of this CH_4 were instantaneously released to the atmosphere, CH_4 concentrations would increase to ~2900 ppb from the 2005 value of ~1774 ppb (IPCC, 2007).

2.3. Mars

Mars is an especial case. Thermodynamic calculations predict CH_4 should not exist in its atmosphere (Levine *et al*., 2010), however a CH_4 signal was discovered by Krasnopolsky *et al*. (1997) using the Fourier Transform Spectrometer of the Kitt Peak National Observatory (Arizona, USA). The authors estimated 0.07 ppm of atmospheric CH_4. Later, in 2004, two groups (Krasnopolsky *et al*., 2004; Formisano *et al*., 2004) reported abundances of 0.01 ppm using the instruments on board of the Mars Express. Zahnle *et al*. (2011) doubt the detection of CH_4 in Mars, arguing that CH_4 abundances estimated by Krasnopolsky *et al*. (2004) and Formisano *et al*. (2004) were supported on tenuous signals slightly distinguishable from the noise, however Mumma *et al*. (2009) reported a clear signal of CH_4 and his calculations confirm CH_4 abundances of 0.01 ppm.

In 2010, Fonti and Marzo made distribution map of methane on the Martian surface. They identify three localized sources on the Martian surface, related to probable underground water reservoirs. Their analyses suggest that CH_4 abundances vary throughout seasonal cycles.

There are some hypotheses about the sources and sinks of CH_4 in Mars. For example, Krasnopolsky *et al*. (2004) considered that degassing from the interior of the planet is unlikely due to the lack of geologic activity. Bar-Nun and Dimitrov (2007) proposed that photolysis of H_2O in the presence of CO can generate CH_4, however Krasnopolsky (2007) argues that it is not possible due to the kinetic chemistry of Mars. Serpentinization has also been proposed (*e.g.* Oze and Sharma, 2005; Lyons *et al*., 2005; Szponar *et al*., 2013; Etiope *et al*., 2013), this hypothesis is supported by the spatial correlation of underground water reservoirs and volcanoes where serpentinization may be possible. The origin of CH_4 on Mars is still not clear, some authors have proposed biogenic sources such as methanogenesis via metabolic pathways (*e.g*. Weiss *et al*., 2000; Chapelle *et al*., 2002; Jakosky *et al*., 2003; Varnes *et al*., 2003; Buford, 2010). CH_4 lifetime is 340 years and methane should be uniformly mixed in the atmosphere. Heterogeneous loss of atmospheric methane is probably negligible, while the sink of CH_4 during its diffusion through the regolith may be significant. There are no processes of CH_4 formation in the atmosphere, so the photochemical loss must therefore be balanced by its sources (Krasnopolsky *et al*., 2004). It was thought that the main sink of CH_4 was its direct photolysis around 80 km from the surface. Other sink is the reaction between CH_4 and Martian soil, but theoretical studies calculate the collision probability between CH_4 y O of 2×10^{-11}. Therefore, this reaction is negligible versus its direct photolysis (Krasnopolsky *et al*., 2004).

3. Outer planets (Jupiter, Saturn, Uranus and Neptune)

3.1. Jupiter and Saturn

They are giant planets with atmospheres mainly constituted by H_2 (> 80 %) and He as the second more important constituent. Their composition and chemistry are relatively similar in those planets. Jupiter is the largest planet in the Solar System with 318 M. Methane is the most abundant species in the upper Jovian troposphere after hydrogen and helium, accounting for approximately 0.2 % of the molecular abundance (Taylor *et al*., 2005). Different calculations estimate that CH_4/H_2 ratio is from 1.9×10^{-3} to 2.3×10^{-3} (Hanel *et al*., 1979; Gautier *et al*., 1982; Wong *et al*., 2004). Methane does not condense at the temperatures found on Jupiter, and is chemically stable except in the upper atmosphere (P < 1 mbar), where it is dissociated by solar ultraviolet radiation. Higher hydrocarbons are produced from methane by photochemical processes in the upper atmosphere of Jupiter (Taylor *et al*., 2005). Photolysis of CH_4 is the only sink (Moses *et al*., 2000), but it is not an effective way to destroy it in the Jupiter's atmosphere because the large excess of H_2 that suggests that radicals

like CH_3, byproducts of the CH_4 photolysis, react with the H radical reforming CH_4 (McNesby, 1969). Saturn is the second largest planet in our solar system. Observations from the Cassini spacecraft suggest mole fractions of CH_4 of 4.7×10^{-3} (Fletcher *et al*., 2009). The chemistry of CH_4 in Saturn is similar to Jupiter.

3.2. Uranus and Neptune

The only known photochemically active volatile in the atmosphere of Uranus is methane. From observations of the Ultraviolet Spectrometer in the Voyager spacecraft, the calculated abundance for CH_4 is 10^{-4} near 0.1 mbar. Other species normally present in the atmospheres of Jupiter and Saturn are not likely to be gaseous in the photolytic regime of the upper troposphere and stratosphere of Uranus due to the low tropopause temperature (Atreya *et al*., 1991). The stratospheric CH_4 is photolyzed forming acetylene, methyl-acetylene, ethane, and ethylene (Orton *et al*., 1987; Bézard *et al*., 1991; Schulz *et al*., 1999; Meadows *et al*., 2008). However, CH_4 photolysis is relatively inefficient on Uranus. Only 10 to 15 % of CH_4 molecules, which absorb ultraviolet photons, produce higher hydrocarbons resulting in a loss rate of 6×10^6 CH_4 molecules cm^{-2} s^{-1} at the equator. For comparison, the loss rate on Jupiter is 30 % (Atreya *et al*., 1991).

In Neptune, the mixing ratios of methane suggested by photochemical models is ~2 % at pressures > 0.1 bars (*e.g.*, Baines *et al*., 1995), but there is evidence from remote observations that its abundance may be up to 4 % at P > 3.3 bars (Karkoschka and Tomasko, 2011). At lower pressures, methane is not homogenously distributed at all latitudes. The expected mixing ratio at the mean temperature of Neptune's tropopause (~52 K) is $\sim5\times10^{-5}$ but values of $(1.5 \pm 0.2)\times10^{-3}$ have been derived from Herschel-PACS observations (Lellouch *et al*., 2010). This is consistent with the hypothesis that CH_4 leaking through the warm south polar tropopause (62 – 66 K) is globally redistributed by stratospheric motion (Fletcher *et al*., 2010). Voyager 2 observed Neptune's atmosphere. Their images show that Neptune contains clouds of methane ice (Smith *et al*., 1989). Similar to Uranus, CH_4 is photolyzed in the stratosphere, producing hydrocarbons like acetylene and ethane (Romani and Atreya, 1989; Romani *et al*., 1993).

4. Methane in small bodies

4.1. Pluto

Pluto's atmosphere is the result of the sublimation of superficial ices, in consequence, it is expected that the atmosphere is in vapor-pressure equilibrium with the surface (*e.g.*, Young *et al*., 1997). Owen *et al*. (1993) estimated that the surface contains 1.5 % of solid CH_4. Later, Young *et al*. (1997) detected gaseous methane in Pluto for the first time, calculating a partial pressure of 0.072 μbar. In 2008 and 2012 this body was observed using the CRIRES instrument in the Very Large Telescope (VLT) to constrain the spatial and vertical distribution of methane in Pluto's atmosphere (Lellouch *et al*., 2015). From these observations, the calculated methane-mixing ratio is 0.44 % with negligible longitudinal variations. Because Pluto has not yet been observed with any spacecraft, all its parameters have been inferred using instruments on the ground. In 2015, the mission New Horizons will be able to characterize the surface and atmosphere of Pluto and its satellite, Charon.

4.2. Triton

The Voyager 2 spacecraft observed Triton (Neptune's largest moon) in 1989 and it has been later studied using instruments on Earth's surface and the Hubble Space Telescope (Buratti *et al*., 2011 and references therein). Similar to Pluto, its atmosphere is the result of the sublimation of the more volatile ices on its surface. The surface of Triton contains approximately 0.05 % CH_4 in ices (Tyler *et al*., 1989; Cruikshank *et al*., 1993) and its atmospheric mixing ratio was calculated to be 10^{-4} from the Voyager observations (Tyler *et al*., 1989) and confirmed by the VLT/CRIRES instrument (Lellouch *et al*., 2011).

4.3. Titan

Titan is the largest moon of Saturn. Its bulk composition has nearly equal mass fractions of silicates and ices (Grasset *et al*., 2000). Titan's atmosphere is mainly composed by N_2, with 5 % of CH_4 near to surface (Tobie *et al*., 2006). Methane was likely to be present in the materials that built Titan and is possible that cometary impacts were a significant source in the far past (*e.g.* Tobie *et al*., 2006; Mousis *et al*., 2009). Present abundances of CH_4 have not been possible to explain, because it is photochemically active in the atmosphere and requires a constant replenishment over geologic time scales (Davies *et al*., 2013). Liquid filled basins in the polar regions of Titan (Stofan *et al*., 2007; Turtle *et al*., 2009) composed by methane mixed with ethane (Brown *et al*., 2008) and a number of other organic species (Cordier *et al*., 2010) were identified using Cassini spacecraft observations.

In 2005, the Huygens spacecraft descended to the surface of Titan measuring in situ the CH_4 mole fraction when it descended. Huygens found that the CH_4 mole fraction is relatively constant in the stratosphere; it increases between 32 and 8 km, and remains constant near the surface (Atreya *et al*., 2006). Titan has pressures and temperatures near to the methane triple-point, for this reason the CH_4 can evaporate from the surface to atmosphere, where it can condense and rain, forming a CH_4 cycle similar to water on Earth (Roe, 2009; Lunine, 2012).

Mathematical models based on the Voyager's measurements suggest that the lifetime of CH_4 is from 10

to 100 millions of years (*e.g*. Yung *et al*., 1984; Lara *et al*., 1996; Lebonnois *et al*., 2001; Wilson and Atreya, 2004). In the stratosphere CH_4 is photolized to CH_3, CH_2 or CH, forming ethane, propane, and benzene (Strobel, 1974). There are not reactions to generate CH_4 in the Titan's atmosphere, so it is proposed that CH_4 may come from clathrates formed in the subnebula that originated the satellite (Mousis *et al*., 2002, Davies *et al*., 2013). Other authors proposed the activity of bacteria as a likely CH_4 source (*e.g*. McKay and Smith, 2005; Schulze-Makuch and Grinspoon, 2005), nevertheless there is not evidence about it (Atreya *et al*., 2006). Another possibility is the serpentinization (Niemann *et al*., 2005) but according to Mousis *et al*. (2009) this source of methane is not able to reproduce the deuterium over hydrogen (D/H) ratio observed at present in methane in its atmosphere.

4.4. Comets

These icy bodies have been studied with flyby missions and ground infrared and radio observations. Methane is a primary volatile in comets, this means that it is stored as ice in the cometary nucleus and released as gas into the coma. This compound has been detected in eleven comets and its abundance relative to water ranges from ~0.4 % to 2 % (Allen *et al*., 1988; Drapatz *et al*., 1987; Mumma *et al*., 1996; Bockelée-Morvan *et al*., 2000; Gibb *et al*., 2003; Mumma and Charnley, 2011).

5. Final comments

The study of methane is relevant to understand the process of synthesis and distribution of organic molecules during the formation of the Solar System. On potentially habitable planets around other stars its presence maybe the result of geological or biological activity. The bodies of our Solar System, especially Earth, serve as benchmarks for understanding the origin, sources and reservoirs of this compound to identify possible inhabitable worlds around other stars.

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