A comparison between the compositions of cometary and interstellar materials

I. Molecular abundances

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Abstract. Comets were created as a by-product of planet formation from pristine interstellar material. A certain similarity between the composition of both cometary nuclei and interstellar clouds has actually be observed by several authors in few last decades. We summarize the quantitative measurements of abundances of observed molecules in both the above entities and discuss their similarities and differences. The found variety of the chemical composition of comets is practically within the range of observed molecular composition of relatively cold matter in the Galaxy. It proves that the gaseous and dusty components from which the cometary nuclei were built are primordial.

Key words: comets: general – Solar System: formation – ISM: clouds – ISM: molecules

1. Introduction

From the middle of the 20-th century, the community of cometary astronomers has generally accepted the concept that comets were created as a by-product of planet formation. Therefore, these bodies had to be build from the same material as the rest of the Solar System. In contrast to the inner, planetary region, where physical and chemical processing wiped out the characteristics of primordial composition of protosolar material, the cometary nuclei, stored in a distant reservoir, seem to conserve it.

In several past decades, it was found that the abundances of organic molecules in the cometary nuclei resemble those in some interstellar (IS) clouds. It not only proves the primordial character of cometary material, but also indicates that the protosolar nebula contained some dusty grains with a developed organic chemistry before the first accumulation and coagulation of material. A comparative analysis of the chemical composition of both cometary nuclei and IS clouds can provide further information about the environment in which our planetary system was born as well as about an even earlier stage: the protosolar nebula formation. It is, for example, known that chemistry in cold molecular

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IS clouds controls the critical physical parameters of star formation such as fractional ionization and cooling of gas (van Dishoeck and Blake, 1998).

In this paper, we summarize the measurements of the abundances of molecules observed (up to the beginning of 2002) in both the above entities and discuss the similarities or differences found. We focus our scope on the quantitative determinations of relative abundances enabling a more sensible comparison. Because of the large extent of problem, the isotopic abundances are not considered, here. Their comparison is intended to be done in another paper.

2. Several remarks about abundance determinations

Electromagnetic radiation can be modified in several ways along its path from a source to us. The most common way to reveal the presence of cold matter in space is the absorption of radiation in wavelengths corresponding to the spectral lines of substance the absorbing matter contains. Another way is heating dust grains by a near heat source, with a temperature higher than that the surrounding matter, and re-emission of absorbed energy in longer, usually infrared wavelengths. A more detailed description of the interaction of electromagnetic radiation with IS matter can be found, e.g., in the paper by Sandford (1996).

If cold matter is situated in the vicinity of a very hot and efficient source, its properties can be significantly changed by the radiantion of the source. Because of this violate action, cold matter is usually studied when it surrounds cooler sources of radiation as "hot" (in a relative sense) cores of molecular clouds, protostars, or young stellar objects. Sometimes, it is possible to study cold matter, if it is situated between a distant (extragalactic) continuum source and us.

The volume of some IS clouds is so giant that one region of such a cloud can be considerably different from other region. A difference of up to a few orders can occur in quantities of state there. For example, Winnewisser and Kramer (1999), studying the Orion molecular cloud and core of IC1396 in Cepheus, found a density contrast of about 200 between local densities and average density. The variability can cause a significant difference between results of two authors observing the same cloud, but different regions.

To determine the absolute amount of a substance in a given IS cloud, it is necessary to know the distance to it. This distance is often unknown or known with a large uncertainty. Even if the distance is well-known, the relative abundance of a given species can be determined with a much higher accuracy than the absolute abundance. That is the reason why the abundance of the studied species relative to a standard molecule is usually given as the result. As the standard, one of the generally most abundant molecule is usually chosen. In the cold IS medium, the molecule of hydrogen, H_2, is usually the most abundant molecule and, so, it serves as the most common standard. In a warmer environment with a temperature above the H_2O evaporation temperature, ~ 90 K (Sandford and

Allamandola, 1993), the molecule H_2O is sometime used as the standard. A review of observational techniques concerning IS chemistry is presented in the paper by van Dishoeck and Blake (1998).

The comets, in their passage to the vicinity of a powerful source of radiation, the Sun, receive a large amount of energy, which is subsequently re-emitted by the substances of cometary coma. (Or the solar light is reflected by the dust grains lifted from the cometary surface.) Thus, emission, in contrast to the absorption in IS medium, is the main mechanism providing us information about the chemical composition of cometary gas. Recently, some measurements were also performed in-situ by spacecraft.

In comets, the molecular hydrogen is a much less abundant element than in the IS medium. Thus, the dominant substance, the molecule H_2O, is used as the standard for presentation of the relative abundance of arbitrary other cometary species. We have to note that it is difficult to find any ideal standard in comets, because the rapid change of intensity of solar radiation with changing heliocentric distance results in a considerable, but inequal variability in the production of all cometary species. For example, Schleicher et al. (1998) found an asymmetry about perihelion in the production of gas and dust, but this asymmetry was significantly less for water than for the trace molecules. Anyway, the non-unique standard in expressing the abundance of a given species in both IS medium and comets often represents a difficulty in the comparison of the abundance in both kinds of space objects.

3. Discussion of observed abundances

The summarized quantitative determinations of various molecules, observed in both comets and IS clouds, are given in Tables 1−4. Two kinds of data occur in these tables. Since the data have been published in a number of various journals and proceedings, one can scarcely comprehend everything. In an attempt to approach completeness, we also included various summaries in addition to the original measurements. They are labelled with a general title as "IS ices" or "comets" in contrast to the exact specification of the object for which the original measurement of a given molecule is presented.

The presented ratios of observed and standard molecules can be divided with respect to the degree of similarity into four groups. Each group is discussed in more detail in the following subsections.

3.1. Similar abundances (Table 1)

3.1.1. CH_4/H_2O

The comets can be divided into two groups by the abundance of methane: Halley-type with CH_4/H_2O ranging from 0.006 to 0.008 and Wilson-type with CH_4/H_2O from 0.015 to 0.045. An extremly low abundance was observed in

C/1990 K1 (Levy), less than 0.002. Apart from this single comet, there are, in the IS matter, counterparts corresponding with the comets of the first group as well as with those of the second group. The independent determinations by various authors are relatively well consistent, therefore the conclusion about a high degree of similarity can be regarded as reliable.

The general low abundance of methane and the relatively high ratio of CO/CH_4 in comets are more consistent with an IS origin of cometary volatiles than with a Solar System origin, which requires an evaporation of IS ices (Greenberg, 1993).

3.1.2. C_2H_2/H_2O

In this case, the abundance ratio of ≈ 0.003 is very similar for three comets: Halley, Hyakutake (lower limit), and Lee. The fourth known cometary abundance, that of comet Hale-Bopp, is lower, only 0.001. Nevertheless, it still is the same order of magnitude. The abundance ratio found along the line of sight toward massive embedded protostars varies from 0.0002 (< 0.0002 in G333.3-0.4) to 0.004 (Lahuis and van Dishoeck, 2000). The upper limit corresponds well with the lower limit for the interval of cometary abundances.

The cometary abundaces seem to be lower than that in the Orion plateau (Evans et al., 1991) and IS ices (as summarized by Boudin et al., 1998). However, according the summary by van Dishoeck and Blake (1998), the upper cometary limit is about 0.01, still consistent with the value observed in the Orion plateau.

3.1.3. C_2H_6/H_2O

The ratio in IS ices is in a good agreement with the known ratios in three comets: Halley, Hale-Bopp, and Hyakutake.

3.1.4. C_2H_5CN/H_2O

Summarizing some old determinations, van Dishoeck and Blake (1998) found that the upper limit of this abundance ratio in comets is about 1×10^{-4}. This limit roughly corresponds with the value detected by Geiss et al. (1999) in Halley's coma. Both the values can be regard as consistent with those found by Sutton et al. (1995) in Orion (though some region are less C_2H_5CN abundant). A worse agreement can be stated with the lower limit found by Mcdonald et al. (1996) in the hot core of G34.3+0.15 as well as with the result by Wright et al. (1996). They found one order higher abundance than Sutton et al. (1995) in the Orion hot core.

3.1.5. CO_2/H_2O

From the observations of comets Halley, Hale-Bopp, and Hyakutake at relatively short heliocentric distances, $r_h \lesssim 1$ AU, an abundance ratio of about an order lower than from the observations of Hale-Bopp at larger, $2.69 \leq r_h \leq 4.00$ AU, distances was obtained. It is an effect of a much steeper increase of water production than CO_2 with decreasing heliocentric distance below ≈ 3 AU. The cold IS environment better corresponds with larger heliocetric distances and, thus, the CO_2/H_2O abundance ratio observed in Hale-Bopp at mainly larger distances agrees with the ratios observed along the line of sight toward several star forming regions.

3.1.6. $HCOOCH_3/H_2O$

A good correspondence of the cometary $HCOOCH_3/H_2O$ abundance ratio can be stated with the $HCOOCH_3/H_2O$ abundance ratio in hot molecular cores Orion and G34.3+0.15, and the Orion compact ridge. A lower value than the typically cometary value was obtained for the Orion northwest plateau and Orion extended ridge. It is obvious that the abundance has to vary through the regions of a molecular cloud with different temperatures. A relatively large departure from the typical cometary abundance was only found in the Orion extended ridge.

3.1.7. SO/H_2O

The ratio in the hot core of G34.3+0.15 corresponds well with the ratio in Comet IRAS-Araki-Alcock. However, there is a large diversity in the abundance of sulfur monoxide in comets: an order higher ratios were reported in Halley's coma and Comet Hale-Bopp than in C/1983 H1 and Halley's nucleus. A single meaning comparison is impossible in this case.

3.2. Questionable similarity (Table 2)

3.2.1. CH_3CN/H_2O

The typical cometary CH_3CN/H_2 abundance ratio corresponds well with that found by Wright et al. (1996) in the hot core and plateau of Orion. As we can expect, a different value was determined for the Orion extended ridge, having a different temperature.

The cometary abundance ratio is one to two orders higher than the ratios in other molecular clouds (their hot cores) and diffuse clouds toward a sample of extragalactic continuum sources.

3.2.2. CH_3OH/H_2O

Methanol is often the second or third most abundant component in protostellar-environment ices. Gas phase methanol enhancements have been found in star and planet forming regions of dense clouds where the CH_3OH is thought to be liberated from warming ices (Allamandola et al., 1999).

Table 1. The similar relative abundances of various molecules in the interstellar medium, interstellar clouds, and comets. The abbreviations used: "LoSt" - line of sight toward, "typ." - typically, "& r.t." - and references there, "IS" - interstellar, "ISM" - interstellar medium, "PS" - protostar, "EPS" - embedded protostar, "MMIs" - mixed molecular ices, "GPMs" - gas phase molecules; r_h - heliocentric distance (in astronomical units), YSO - young stellar object, T_{gas} - temperature of gas, "EGCSs" - extragalactic continuum sources.

Object	Relative Abundance	Reference
	CH_4/H_2O:	
Orion, plateau	$0.01 - 0.02$	Boogert et al., 1998
dense ISM, MMIs	typ. ~ 0.02	Sandford, 1996 & r.t.
IS ices in LoSt: protostellar object RAFGL 7009S	~ 0.04	Ehrenfreund et al., 1997
LoSt: several PSs	$\sim 0.01 - 0.04$	Ehrenfreund, 1999 & r.t.
IS ice	typ. ~ 0.01	Allamandola et al., 1999 & r.t.
LoSt: EPS:		
NGC 7538 IRS9	0.013	Keane et al., 2001 & r.t.
GL 7009S	0.036	–"–
W33A	0.004	–"–
Elias 29	0.008	–"–
Halley's nucleus	< 0.01	Altwegg et al., 1994
Halley's coma	≤ 0.008	–"–
Halley's coma	$0 - 0.02$	Vanýsek and Moravec, 1995 & r.t.
C/1986 P1 (Wilson)	$0.015 - 0.045$	–"–
C/1990 K1 (Levy)	< 0.002	–"–
C/1995 O1 (Hale-Bopp)	0.006	Weaver et al., 1999
C/1996 B2 (Hyakutake)	0.0071	Mumma et al., 1996
C/1999 H1 (Lee)	0.0081 ± 0.0008	Mumma et al., 2001
comets	typ. 0.002−0.01	van Dishoeck and Blake, 1998 & r.t.
	C_2H_2/H_2O:	
Orion, plateau	0.006−0.020	Evans et al., 1991
IS ices	< 0.1	Boudin et al., 1998
LoSt: a sample of deeply		
LoSt: massive embedded YSO:		
AFGL 2136	0.0028 ± 0.0006	Lahuis and van Dishoeck, 2000
AFGL 2591	0.0042 ± 0.0006	–"–
AFGL 4176	0.0026 ± 0.0006	–"–
NGC 3576	0.0010 ± 0.0002	–"–
NGC 7538 IRS1	0.0018 ± 0.0004	–"–
NGC 7538 IRS9	0.0008 ± 0.0004	–"–
W33A	0.0010 ± 0.0004	–"–
W3 IRS5	0.0006 ± 0.0002	–"–

S140 IRS1	< 0.001	–”–
G333.3-0.4	< 0.0002	–”–
AFGL 2059	0.0002 ± 0.0002	–”–
Halley's nucleus	≈ 0.003	Eberhardt, 1999 & r.t.
Halley's coma	0.003	Reber, 1997
C/1995 O1 (Hale-Bopp)	0.001	Weaver et al., 1999
C/1996 B2 (Hyakutake)	$0.003 - 0.009$	Brooke et al., 1996
C/1999 H1 (Lee)	0.0027 ± 0.0003	Mumma et al., 2001
comets	0.004–0.01	van Dishoeck and Blake, 1998 & r.t.
	C_2H_6/H_2O:	
IS ices	< 0.004	Boudin et al., 1998
Halley's nucleus	≈ 0.004	Eberhardt, 1999 & r.t.
Halley's coma	0.004	Reber, 1997
C/1995 O1 (Hale-Bopp)	0.003	Weaver et al., 1999
C/1996 B2 (Hyakutake)	0.0038	Mumma et al., 1996
C/1999 H1 (Lee)	0.0067 ± 0.0007	Mumma et al., 2001
comets	0.004–0.01	van Dishoeck and Blake, 1998 & r.t.
	C_2H_5CN/H_2O:	
Orion, extended ridge	$< 1.6 \times 10^{-5}$	Sutton et al., 1995
Orion, compact ridge	1×10^{-4}	–”–
Orion, northwest plateau	3×10^{-5}	–”–
Orion, southeast plateau	8×10^{-5}	–”–
Orion, hot core	6×10^{-5}	–”–
Orion, hot core	6×10^{-4}	Wright et al., 1996
G34.3+0.15, hot core	$> 1.8 \times 10^{-5}$	MacDonald et al., 1996
Halley's coma	2.8×10^{-4}	Geiss et al., 1999
comets	$< 1 \times 10^{-4}$	van Dishoeck and Blake, 1998 & r.t.
	CO_2/H_2O:	
Orion, plateau	0.004–0.02	van Dishoeck and Blake, 1998
dense ISM, MMIs	typ. < 0.1	Sandford, 1996 & r.t.
IS ices in LoSt: RAFGL 7009S	> 0.2	Ehrenfreund et al., 1997
IS ices	0.16	van Dishoeck and Blake, 1998 & r.t.
IS ices	$0.01 - 0.1$	Allamandola et al., 1999 & r.t.
ISM	$0.12 - 0.2$	Ehrenfreund, 1999 & r.t.
LoSt: EPS:		
NGC 7538 IRS9	0.163	Keane et al., 2001 & r.t.
GL 7009S	0.21	–”–
GL 2136	0.13	–”–
W33A	0.036	–”–
W3 IRS5	0.113	–”–
Elias 29	0.108	–”–
S140 IRS1	0.075	–”–

Mon R2 IRS3	0.0017	–"–
HH100	0.058	–"–
LoSt: Elias 13	0.19	Nummelin et al., 2001 & r.t.
Elias 16	0.13	–"–
Elias 18	0.37	–"–
S255 IRS1	0.09	–"–
HH57 IRS	0.21	–"–
HH100 IR	0.26	–"–
R CrA	0.30	–"–
RAFGL 989	0.34	Nummelin et al., 2001
Halley's coma	0.035	Krankowsky et al., 1986
Halley's coma	0.03	Vanýsek and Moravec, 1995 & r.t.
C/1995 O1 at $r_h = 2.93$	0.22	Crovisier et al., 1997
C/1995 O1, $2.69 \leq r_h \leq 4.00$	$0.13 - 0.71$, resp.	Weaver et al., 1997
C/1995 O1 at $r_h = 1$	0.06	Bockelée-Morvan et al., 2000 & r.t.
C/1996 B2 (Hyakutake)	0.05	Weaver et al., 1996
C/1996 B2 (Hyakutake)	< 0.07	Allamandola et al., 1999 & r.t.
comets	0.02−0.12	van Dishoeck and Blake, 1998 & r.t.
	$HCOOCH_3/H_2O$:	
Orion, compact ridge	6.0×10^{-4}	Sutton et al., 1995
Orion, extended ridge	$< 8 \times 10^{-5}$	–"–
Orion, northwest plateau	1.2×10^{-4}	–"–
Orion, southeast plateau	2.2×10^{-4}	–"–
Orion, hot core	2.8×10^{-4}	–"–
W3, hot core	1.4×10^{-4}	Helmich and van Dishoeck, 1997
G34.3+0.15, hot core	6.0×10^{-4}	MacDonald et al., 1996
G34.3+0.15, hot core	2.8×10^{-4}	Hatchell et al., 1998c
G34.3+0.15, hot core	0.001	Millar et al., 1997
C/1995 O1 (Hale-Bopp)	8×10^{-4}	Bockelée-Morvan et al., 2000
comets	4×10^{-4}	van Dishoeck and Blake, 1998 & r.t.
	SO/H_2O:	
G34.3+0.15, hot core	0.0002	Irvine, 1999 & r.t.
C/1983 H1	$< 1.5 \times 10^{-4}$	Bockelée-Morvan et al., 2000
Halley's coma	≤ 0.005	Altwegg et al., 1999
1P/Halley	$< 4 \times 10^{-4}$	Bockelée-Morvan et al., 2000
C/1995 O1 (Hale-Bopp)	~ 0.005	Fegley, 1999 & r.t.
C/1995 O1 (Hale-Bopp)	0.0029	Bockelée-Morvan et al., 2000

The CH_3OH/H_2O abundance ratio in comets varies from about 0.01 to 0.04 (to 0.06 according van Dishoeck and Blake, 1998) and it is significantly lower than the ratio in a dense IS medium or mixed molecular ices. On the contrary, it is one to two orders higher than that in Orion, the hot core of G34.3+0.15, or the line of sight toward several massive young stars. It is however similar to the ratios along the line of sight toward some embedded protostars.

The value for the Orion plateau found by Wright et al. (1996) does not agree with that found by Sutton et al. (1995), which could be caused by the authors observing different parts of the plateau. Such an idea can be supported by the determination of, e.g., the $HCOOCH_3/H_2O$ abundance ratio, where Sutton et al. (1995) found the value two times higher in the southeast Orion plateau than in the northwest plateau.

However, the controversial independent determinations of CH_3OH/H_2O in W3 IRS5, where the value of 0.084 was obtained by Keane et al. (2001) and the value 8×10^{-6} by van der Tak et al. (2000a), indicate that the results are affected by a systematic error rather than observing different parts of the object. This makes the comparison of the abundance of this compound unreliable.

3.2.3. CN/H_2O

We have noticed only one measurement of this ratio in comets: 0.0024 in the coma of C/1999 J3 by Korsun and Jockers (2002). It corresponds with that observed in the bipolar outflow L1157 and, to a lesser degree, in the Orion compact ridge. In a variety of other IS objects, the abundance ratio is significantly lower.

3.2.4. CO/H_2O

Carbon monoxide is a single molecule with a well recognized spectrum. This fact in combination with a relatively high abundance of CO in arbitrary cold regions of space has resulted in frequent observations of its spectral lines, not only to determine the appropriate abundance, but also to determine the mass density of given region or to trace the eventual mass flow.

Carbon monoxide can be observed in polar ice as well as in non-polar ice. It is impossible to observe non-polar molecules on millimeter and submillimeter wavelengths. The latter causes a selection effect, since the millimeter and submillimeter observations can be made with a great sensitivity and extremly high spectral resolution (Irvine, 1999). A comparison of abundance is, moreover, obscured by fact that some authors have not distinguished between these kinds of ice.

In comets, a large fraction of CO originates from the refractory organic component in the coma, rather than directly from the volatiles in the nucleus (Li and Greenberg, 1999).

In numerous independent observations, the ratio of CO/H_2O in comets has been determined ranging from 0.01 to 0.7, typically from 0.02 to 0.1. The wide interval is, in part, a consequence of the large variation of water production with heliocentric distance and, thus, uncertainty of the abundance determination of the standard. It can be documented with the contrast of the relatively low $CO/H_2O = 0.23$ observed in Hale-Bopp at heliocentric distance $r_h = 1$ AU (Bockelée-Morvan et al., 2000) to the highest $CO/H_2O = 0.70$, at $r_h = 2.93$ AU (Crovisier et al., 1997). The main reason of the extension of the CO abundance interval is the creation of this molecule directly in cometary comae by the photodissociation of H_2CO (Eberhardt, 1999). We note that the lowest CO/H_2O cometary ratio, about 0.02, was measured in comets C/1979 Y1 (Bradfield) and C/1989 X1 (Austin).

Generally, we can state that the cometary CO/H_2O abundance ratio is consistent with some clouds in the line of sight toward embedded protostars. The abundance ratios in some of these clouds are however lower than the lower limit of interval of typical values. The cometary CO/H_2O abundance ratio is lower than the ratio found in a dense IS medium, generally, or in the entire region of the Orion molecular cloud, hot cores of W3 and G34.3+0.15, and bipolar outflow L1157. On the other hand, it is consistent with the ratio in IS ices or ζ Oph and gas in the AB Aur system.

3.2.5. HCN/H_2O

The cometary HCN/H_2 abundance ratio varies from ≈ 0.0002 to 0.0025, i.e. it is, as concluded by Liszt and Lucas (2001), of the order 10^{-3}. Its typical value is consistent with that for the matter in the line of sight toward a sample of deeply embedded massive young stellar objects and some hot cores, including the bipolar outflow L1157.

There is a very problematic determination of the value in G34.3+0.15 hot core, since MacDonald et al. (1996) found the lower limit equal to 1.4×10^{-6}, but Hatchell et al. (1998b) found the proper value about three orders higher, 0.001. Such a large difference can scarcely be explained as a consequence of abundance variation throughout the relatively compact core. More probably, it appeared due to a systematic error. The outer region of the Orion cloud, the dark cloud TMC-1, and the hot core of W3, as well as diffuse clouds toward a sample of extragalactic continuum sources have a lower HCN/H_2O abundance ratio than comets. Mousis et al. (2000) suggested that the most hydrogen cyanide in cold clouds must be in icy grains and, therefore, unobservable. This could account for the deficit. The upper limit of the HCN/H_2O ratio in IS ices presented by van Dishoeck and Blake (1998) is, on the contrary, an order higher than its upper limit in comets.

3.2.6. HNC/H_2O

This ratio observed in Comet Hale-Bopp at the heliocentric distance equal to 1 AU is consistent with that in TMC-1 and, roughly, in the Orion hot core and the bipolar outflow L1157. The ratios in various parts of W3 and diffuse clouds toward a sample of extragalactic continuum sources are about one order lower.

3.2.7. H_2CO/H_2O

In the nucleus of the Comet Halley, the ratio of H_2CO/H_2O was found to be less than 0.004 (Meier et al., 1993) increasing to about 0.04 in Halley's coma (Altwegg et al., 1999) and further increasing up to 0.075, when an extended source, up to 25000 km, was included. Eberhardt (1999) suggested that such an observation is fully compatible with the H_2CO release by a direct sublimation from polymerized formaldehyde on the dust.

Though the typical value, 0.04, in Halley's coma and, in part, the value found in Hale-Bopp, 0.01 (Bockelée-Morvan et al., 2000), correspond with the abundance ratios found in the line of sight toward embedded protostars, hot cores, and the inner "hot-core" like region of IRAS 16293-2422, the intrinsic H_2CO abundance in both IS medium and comets strongly depends on the amount of delivered heat and consequent rate of sublimation (then observability) and cannot be regarded as a reliable tracer of similarity.

We note that the Orion cloud, cooler regions of IRAS 16293-2422 as well as the matter concentrated around massive young stars are less abundant with H_2CO than comets. The H_2CO/H_2O ratio in comet Hyakutake was several times lower than that in Halley and Hale-Bopp.

3.2.8. H_2S/H_2O

The H_2S/H_2O abundance ratio in Orion hot core (Blake et al., 1996) and plateau (Blake et al., 1987) is consistent with the values found in Halley's coma and comets C/1989 X1 and C/1990 K1. In Halley's nucleus, this ratio is twice as large. A certain degree of consistence can also be stated between the ratios in comets and the bipolar outflow L1157 as well as the hot core of G34.3+0.15. In the extended ridge of Orion and W3, the ratio is significantly lower than in comets. It is very difficult to explain an extreme, four-orders difference between the values presented by Blake et al. (1996) and Minh et al. (1990) in the Orion hot core.

In Hale-Bopp at heliocentric distance 1 AU, the ratio was an order higher than in the other comets.

3.2.9. N_2/H_2O

The upper limit of this ratio found by Eberhardt et al. (1987) for Comet Halley equals the lower limit of interval observed in IS ices according to the summary by Allamandola et al. (1999). However, there are other controversial determinations: for Halley's coma, Balsiger et al. (1986) found a value about one order and Wyckoff et al. (1991) about two orders lower than the upper limit by Eberhardt et al. Thus, the abundance of molecular nitrogen in Halley is uncertain enough.

Table 2. Relative abundances of various molecules, whose similarity of appearance in the interstellar medium and clouds is questionable with that observed in comets. The same abbreviations are used as in Table 1.

	CH_3CN/H_2O:	
TMC-1	2×10^{-5}	Ohishi et al., 1992
Orion, plateau	$< 6 \times 10^{-5}$	Sutton et al., 1995
Orion, extended ridge	1×10^{-5}	Wright et al., 1996
Orion, plateau	1.8×10^{-4}	–”–
Orion, hot core	3.4×10^{-4}	–”–
W3 IRS4	$< 5.6 \times 10^{-6}$	Helmich and van Dishoeck, 1997
W3 IRS5	$< 2.8 \times 10^{-6}$	–”–
W3(H_2O)	5.6×10^{-6}	–”–
G34.2+0.15, hot core	9.0×10^{-6}	MacDonald et al., 1996
G34.3+0.15, hot core	0.004	Irvine, 1999 & r.t.
diffuse clouds toward a sample of EGCSs	$< 8 \times 10^{-7}$	Liszt and Lucas, 2001
Halley’s coma	0.0014	Geiss et al., 1999
C/1995 O1 at $r_h = 1$	2.0×10^{-4}	Bockelée-Morvam et al., 2000
comets	typ. 10^{-4}	van Dishoeck and Blake, 1998 & r.t.
	CH_3OH/H_2O:	
dense ISM, MMIs	typ. 0.1 or less	Sandford, 1996 & r.t.
dense ISM, GPMs	typ. $\approx 10^{-2}$ or less	–”–
Orion, extended ridge	1.6×10^{-4}	Wright et al., 1996
Orion, plateau	≤ 0.002	–”–
Orion, extended ridge	1.2×10^{-4}	Sutton et al., 1995
Orion, compact ridge	0.008	–”–
Orion, northwest plateau	8×1^{-4}	–”–
Orion, southeast plateau	0.0044	–”–
Orion, hot core	0.0028	–”–
G34.3+0.15, hot core	$\sim 7.0 \times 10^{-4}$	MacDonald et al., 1996
W3 IRS4	1.2×10^{-4}	Helmich and van Dishoeck, 1997
W3 IRS5	2.4×10^{-5}	–”–
W3(H_2O)	0.0018	–”–
bipolar outflow L1157	0.08−0.44	Bachiller and Pérez Gutiérrez, 1997
LoSt: EPS:		
NGC 7538 IRS9	0.032	Keane et al., 2001 & r.t.
GL 7009S	0.30	–”–
W33A	0.05	–”–
GL 2136	0.045	–”–
Elias 29	0.02	–”–
S140 IRS1	0.068	–”–
W3 IRS5	0.084	–”–
Mon R2 IRS3	0.015	–”–

LoSt: massive young star:		
W3 IRS5	8.0×10^{-6}	van der Tak et al., 2000a
GL 490	2.0×10^{-5}	–”–
W33A, $T_{gas} < 90\ K$	6.2×10^{-5}	–”–
W33A, $T_{gas} > 90\ K$	0.0018	–”–
GL 2136	2×10^{-5}	–”–
GL 7009S	1.4×10^{-5}	–”–
GL 2591, $T_{gas} < 90\ K$	5.2×10^{-5}	–”–
GL 2591, $T_{gas} > 90\ K$	0.0016	–”–
S140 IRS1	2.4×10^{-5}	–”–
NGC 7538 IRS1, $T_{gas} < 90\ K$	4.0×10^{-5}	–”–
NGC 7538 IRS1, $T_{gas} > 90\ K$	0.0012	–”–
NGC 7538 IRS9	4.6×10^{-5}	–”–
W3 (H_2O)	1.2×10^{-4}	–”–
NGC 6334 IRS1	4.8×10^{-4}	–”–
IRAS 20126	5.2×10^{-5}	–”–
W28 A2	2.4×10^{-4}	–”–
IS ices	0.08	van Dishoeck and Blake, 1998 & r.t.
IS ice	$< 0.04 - 0.10$	Allamandola et al., 1999 & r.t.
Halley’s nucleus	0.017	Eberhardt et al., 1994
Halley’s coma	~ 0.01	Vanýsek and Moravec, 1995 & r.t.
Halley’s coma	0.0125	Altwegg, 1996
P/Swift-Tuttle	0.043 ± 0.005	DiSanti et al., 1995
C/1995 O1 at $r_h = 1$	0.024	Bockelée-Morvan et al., 2000
C/1996 B2 (Hyakutake)	0.02	Lis et al., 1997
C/1999 H1 (Lee)	0.021 ± 0.005	Mumma et al., 2001
comets	0.01–0.06	van Dishoeck and Blake, 1998 & r.t.
	CN/H_2O:	
TMC-1	6×10^{-4}	Ohishi et al., 1992
Orion, extended ridge	6×10^{-5}	Sutton et al., 1995
Orion, compact ridge	0.0016	–”–
Orion, northwest plateau	1.4×10^{-5}	–”–
Orion, southeast plateau	2.6×10^{-5}	–”–
Orion, hot core	1.6×10^{-5}	–”–
G34.3+0.15, hot core	$> 2.2 \times 10^{-5}$	MacDonald et al., 1996
bipolar outflow L 1157	0.0010–0.0052	Bachiller and Pérez Gutiérrez, 1997
W 3 IRS4	9.6×10^{-5}	Helmich and van Dishoeck, 1997
W 3 IRS5	2.8×10^{-5}	–”–
W 3(H_2O)	2.2×10^{-5}	–”–
ζ Oph	1.1×10^{-4}	Liszt and Lucas, 2001
diffuse and translucent clouds toward a sample of EGCSs	$(2 - 7) \times 10^{-4}$	–”–

C/1999 J3, coma	0.0024	Korsun and Jockers, 2002
	CO/H_2O:	
TMC-1	1.6	Ohishi et al., 1992
Orion, extended ridge	1.8	Sutton et al., 1995
Orion, compact ridge	2.2	–"–
Orion, northwest plateau	1.4	–"–
Orion, southeast plateau	2.0	–"–
Orion, hot core	1.8	–"–
LoSt: Sgr A* and GCS3:		
$CO_{gas+ice}/H_2O_{gas+ice}$	$\simeq 5$	Moneti et al., 2001
$CO/H_2O_{warm\ gas}$	$\simeq 350$	–"–
dense ISM, GPMs	typ. $\approx 10^0$	Sandford, 1996 & r.t.
dense ISM, MMIs	typ. $0.1 - 0.4$	–"–
bipolar outflow L1157	2.0	Bachiller and Pérez Gutiérrez, 1997
IS ices in LoSt: protostellar object RAFGL 7009S	~ 0.18	Ehrenfreund et al., 1997
IS polar ice	typ. $0.01 - 0.1$	Allamandola et al., 1999 & r.t.
IS non-polar ice	typ. $0.1 - 0.4$	–"–
polar CO, LoSt: EPS:		
NGC 7538 IRS9	0.12	Keane et al., 2001
GL 7009S	0.15	–"–
W33A	0.022	–"–
GL 989	0.052	–"–
GL 2136	0.019	–"–
Elias 29	0.030	–"–
S140 IRS1	0.004	–"–
W3 IRS5	0.025	–"–
HH100	0.117	–"–
apolar CO, LoSt: EPS:		
NGC 7538 IRS9	0.116	Keane et al., 2001
GL 989	0.015	–"–
W33A	0.005	–"–
W3 IRS5	0.017	–"–
Elias 29	0.024	–"–
HH100	0.079	–"–
W3, hot core	5.4	Helmich and van Dishoeck, 1997
G34.3+0.15, hot core	3.0	Millar et al., 1997
ζ Oph	0.096	Lucas and Liszt, 2000
gas in AB Aur system	0.021 ± 0.002	Roberge et al., 2001
IS ices	typ. $0.01{-}0.2$	van Dishoeck and Blake, 1998 & r.t.
C/1975 V1-A (West)	0.2	Vanýsek and Moravec, 1995 & r.t.
C/1979 Y1 (Bradfield)	0.02	–"–

1P/Halley	$\sim 0.07 - 0.08$	–"–
Halley's nucleus	≤ 0.17	Eberhardt et al., 1987
Halley's inner coma	$0.05 - 0.15$	–"–
Halley's nucleus	0.035	Eberhardt, 1996
Halley's nucleus	0.06	Greenberg and Li, 1998
non-polar ice in Hyakutake	$0.06 - 0.3$	Allamandola et al., 1999 & r.t.
non-polar ice in Hale-Bopp	0.20	–"–
C/1989 X1 (Austin)	$0.01 - 0.03$	–"–
C/1995 O1 at $r_h = 2.93$	0.70	Crovisier et al., 1997
C/1995 O1, native ice in nucleus	$0.10 - 0.14$	DiSanti et al., 1999
C/1995 O1, all sources	$\approx 0.2 - 0.3$	–"–
C/1995 O1 at $r_h = 1$	0.23	Bockelée-Morvan et al., 2000
C/1996 B2 (Hyakutake)	0.058	Mumma et al., 1996
C/1996 B2 (Hyakutake)	0.05	Weaver et al., 1996
C/1999 J3 (Lee)	0.018 ± 0.002	Mumma et al., 2001
comets	typ. 0.02–0.2	van Dishoeck and Blake, 1998 & r.t.
	HCN/H_2O:	
TMC-1	4×10^{-4}	Ohishi et al., 1992
Orion, extended ridge	6×10^{-4}	Wright et al., 1996
Orion, plateau	0.018	–"–
Orion, hot core	0.008	–"–
bipolar outflow L1157	0.0066–0.011	Bachiller and Pérez Gutiérrez, 1997
W3 IRS4	2.4×10^{-4}	Helmich and van Dishoeck, 1997
W3 IRS5	8.0×10^{-5}	–"–
W3(H_2O)	2.6×10^{-4}	–"–
G34.3+0.15, hot core	$> 1.4 \times 10^{-6}$	MacDonald et al., 1996
G34.3+0.15, hot core	0.001	Hatchell et al., 1998b
G34.3+0.15, hot core	9×10^{-5}	Irvine, 1999 & r.t.
LoSt: a sample of deeply embedded massive YSOs	$\sim (0.0002 - 0.008)$	Lahuis and van Dishoeck, 2000
diffuse clouds toward a sample of EGCSs	$(2.8 - 10.0) \times 10^{-5}$	Liszt and Lucas, 2001
IS ices	< 0.06	van Dishoeck and Blake, 1998 & r.t.
Halley's nucleus	≈ 0.002	Eberhardt, 1999 & r.t.
Halley's coma	0.001	Geiss et al., 1991
Halley's coma	$< 0.0002 - 0.001$	Vanýsek and Moravec, 1995 & r.t.
several comets	$0.0003 - 0.002$	–"–
C/1995 O1 at $r_h = 1$	0.0025	Bockelée-Morvan et al., 2000
C/1996 B2 (Hyakutake)	≈ 0.0016	Irvine et al., 1996
C/1996 B2 (Hyakutake)	0.001	Lis et al., 1997

C/1999 H1 (Lee)	0.0023 ± 0.0002	Mumma et al., 2001
comets	10^{-3}	van Dishoeck and Blake, 1998 & r.t.
	HNC/H_2O:	
TMC-1	4×10^{-4}	Ohishi et al., 1992
Orion, hot core	6.2×10^{-4}	Schilke et al., 1992
bipolar outflow L 1157	$(6.2 - 9.6) \times 10^{-4}$	Bachiller and Pérez Gutiérrez, 1997
W 3 IRS4	5.6×10^{-5}	Helmich and van Dishoeck, 1997
W 3 IRS5	3.0×10^{-5}	–"–
W 3(H_2O)	1.9×10^{-5}	–"–
diffuse clouds toward a samle of EGCSs	$(0.6 - 2.0) \times 10^{-5}$	Liszt and Lucas, 2001
C/1995 O1 at $r_h = 1$	3.5×10^{-4}	Bockelée-Morvan et al., 2000
	H_2CO/H_2O:	
Orion, extended ridge	4×10^{-5}	Wright et al., 1996
Orion, extended ridge	$< 2 \times 10^{-4}$	Sutton et al., 1995
Orion, compact ridge	8×10^{-4}	–"–
Orion, hot core	1.4×10^{-4}	–"–
Orion, compact ridge	8.0×10^{-4}	–"–
Orion, hot core	2×10^{-4}	Wright et al., 1996
G34.3+0.15, hot core	$> 6.4 \times 10^{-6}$	MacDonald et al., 1996
bipolar outflow L1157	0.004–0.012	Bachiller and Pérez Gutiérrez, 1997
W3 IRS4	2.2×10^{-5}	Helmich and van Dishoeck, 1997
W3 IRS5	1.2×10^{-5}	–"–
W3(H_2O)	8.4×10^{-5}	–"–
dense ISM, MMIs	typ. < 0.1	Sandford, 1996 & r.t.
IS ices in LoSt: RAFGL 7009S	0.03	Ehrenfreund et al., 1997
IS ices	≤ 0.04	van Dishoeck and Blake, 1998 & r.t.
IS ices	$0.01 - 0.04$	Allamandola et al., 1999 & r.t.
LoSt: massive young star:		
W3 IRS5	6×10^{-5}	van der Tak et al., 2000b
W3 (H_2O)	6×10^{-5}	–"–
W33A	8×10^{-5}	–"–
GL 490	2×10^{-5}	–"–
GL 2136	1.6×10^{-4}	–"–
GL 2591	8×10^{-5}	–"–
S140 IRS1	1×10^{-4}	–"–
NGC 7538 IRS1, IRS9	2×10^{-4}	–"–
NGC 6334 IRS1	1.4×10^{-4}	–"–
NGC 7538 IRS9	0.02	Keane et al., 2001 & r.t.

W33A	0.02	–"–
GL 7009S	0.03	–"–
GL 989	0.013	–"–
GL 2136	0.03	–"–
around IRAS 16293-2422:		
inner "hot-core" like region	$\sim 10^{-3}$	Ceccarelli et al., 2001
intermediate "warm envelope"	8×10^{-5}	–"–
outer "cold envelope" region	8×10^{-6}	–"–
Halley's nucleus	< 0.004	Meier et al., 1993
Halley including extended source to 25000 km	0.075	–"–
Halley's coma	$0 - 0.05$	Vanýsek and Moravec, 1995 & r.t.
Halley's coma	0.038	Altwegg et al., 1999 & r.t.
C/1995 O1 at $r_h = 1$	0.011	Bockelée-Morvan et al., 2000
C/1996 B2 (Hyakutake)	$0.002 - 0.01$	Lis et al., 1997
comets	0.002–0.04	van Dishoeck and Blake, 1998 & r.t.
	H_2S/H_2O:	
Orion, extended ridge	$< 10^{-5}$	van Dishoeck and Blake, 1998
Orion, plateau	0.002	Blake et al., 1987
Orion, hot core	≤ 0.002	Blake et al., 1996
Orion, hot core	0.11	Minh et al., 1990
bipolar outflow L1157	0.0056–0.0084	Bachiller and Pérez Gutiérrez, 1997
W3 IRS4	3.2×10^{-5}	Helmich and van Dishoeck, 1997
W3 IRS5	3.0×10^{-5}	–"–
W3(H_2O)	2.0×10^{-4}	–"–
IS ices	$< 10^{-3}$	van Dishoeck and Blake, 1998 & r.t.
IS ices	< 0.002	Irvine, 1999 & r.t.
G34.3+0.15, hot core	0.0008	–"–
G34.3+0.15, hot core	9.0×10^{-4}	Bockelée-Morvan et al., 2000
Halley's nucleus	0.0041	Eberhardt et al., 1994
Halley's coma	0.0015	Altwegg, 1996
C/1989 X1 and C/1990 K1	0.002	Vanýsek and Moravec, 1995 & r.t.
C/1995 O1 at $r_h = 1$	0.015	Bockelée-Morvan et al., 2000
comets	10^{-3}	van Dishoeck and Blake, 1998 & r.t.
comets	$0.002 - 0.016$	Fegley, 1999 & r.t.
	N_2/H_2O:	
IS ices	$0.1 - 0.4$	Allamandola et al., 1999 & r.t.
Halley's coma	≤ 0.015	Balsiger et al., 1986

Halley's coma	0.0002	Wyckoff et al., 1991
1P/Halley	≤ 0.1	Eberhardt et al., 1987
	NH_3/H_2O:	
Orion, extended ridge	10^{-4}	van Dishoeck and Blake, 1998 & r.t.
Orion, plateau	10^{-3}	Evans et al., 1991
Orion, hot core	0.02	Hermsen et al., 1988
W3, hot core	2.6×10^{-4}	Maursberger et al., 1988
G34.3+0.15, hot core	0.28	Heaton et al., 1989
bipolar outflow L1157	0.032	Umemoto et al., 1992
dense ISM, GPMs	typ. $\approx 10^{-3}$	Sandford, 1996 & r.t.
dense ISM, MMIs	typ. < 0.1	–"–
IS ices	< 0.04	van Dishoeck and Blake, 1998 & r.t.
IS ices	$0.05 - 0.10$	Allamandola et al., 1999 & r.t.
NGC 6334 I(N)w region	$(1.2 \pm 0.5) \times 10^{-4}$	Caproni et al., 2000
NGC 6334 I(N)e region	$(1.4 \pm 0.6) \times 10^{-4}$	–"–
LoSt: Sgr A*	$0.2 - 0.3$	Chiar et al., 2000
Sgr A*, cold dust around YSO	$< 0.11 - 0.17$	Dartois and d'Hendecourt, 2001
cold dust envelope around YSO:		
S140	$< 0.034 - 0.053$	–"–
Orion	$< 0.044 - 0.069$	–"–
NGC 7538 IRS1	$< 0.16 - 0.25$	–"–
NGC 2024 IRS2	$< 0.065 - 0.10$	–"–
IRAS 17424	$< 0.12 - 0.19$	–"–
GL 989	$< 0.045 - 0.071$	–"–
GL 490	$< 0.12 - 0.19$	–"–
GL 2136	$< 0.16 - 0.25$	–"–
RCRA	$< 0.17 - 0.27$	–"–
Elias 16	$< 0.099 - 0.15$	–"–
LoSt: EPS:		
NGC 7538 IRS9	0.093	Keane et al., 2001 & r.t.
W33A	0.045	–"–
Elias 29	0.046	–"–
HH100	0.042	–"–
Barnard object B217	0.0006−0.001	Hotzel et al., 2001
Halley's nucleus	0.015	Meier et al., 1994
Halley's coma	$0.001 - 0.02$	Vanýsek and Moravec, 1995 & r.t.
1P/Halley	~ 0.01	Eberhardt, 1996
C/1995 O1 (Hale-Bopp)	0.007	Bird et al., 1999
C/1996 B2 (Hyakutake)	0.005	Palmer et al., 1996
C/1996 B2, on March 26.3−26.5, 1996	$(3.5 \pm 1.0) \times 10^{-3}$	Meier et al., 1998
comets	0.004−0.012	van Dishoeck and Blake, 1998 & r.t.

	OCS/H_2O:	
Orion, extended ridge	6×10^{-6}	Wright et al., 1996
Orion, plateau	0.0016	–”–
Orion, hot core	0.001	–”–
Orion, hot core	2.2×10^{-4}	Sutton et al., 1995
Orion, extended ridge	$< 6 \times 10^{-5}$	–”–
Orion, compact ridge	6×10^{-4}	–”–
Orion, northwest plateau	1×10^{-4}	–”–
Orion, southeast plateau	2.8×10^{-4}	–”–
G34.3+0.15, hot core	5.0×10^{-5}	MacDonald et al., 1996
dense ISM, mixed mulecular ices	typ. 4×10^{-4}	Sandford, 1996 & r.t.
bipolar outflow L1157	0.0006−0.0032	Bachiller and Pérez Gutiérrez, 1997
W3 IRS4	1.4×10^{-5}	Helmich and van Dishoeck, 1997
W3 IRS5	1.4×10^{-5}	–”–
W3(H_2O)	4.8×10^{-5}	–”–
IS ices in LoSt: RAFGL 7009S	~ 0.002	Ehrenfreund et al., 1997
IS ices	4×10^{-4}	van Dishoeck and Blake, 1998 & r.t.
LoSt: several PSs	≈ 0.002	Ehrenfreund, 1999
LoSt: EPS:		
GL 7009S	0.0017	Keane et al., 2001 & r.t.
GL 989	0.0004	–”–
W33A	0.0005	–”–
Elias 29	0.0004	–”–
Halley’s coma	0.002	Altwegg, 1996
C/1995 O1 (Hale-Bopp)	0.003	Crovisier and Bockelée-Morvan, 1999 & r.t.
C/1995 O1 (Hale-Bopp)	0.0040	Bockelée-Morvan et al., 2000
C/1995 O1, mainly extended source and C/1996 B2 (whole)	$\sim 0.003 - 0.005$	Fegley, 1999 & r.t.
C/1996 B2 (Hyakutake)	0.001	Woodney et al., 1997
comets	typ. 10^{-3}	van Dishoeck and Blake, 1998 & r.t.
	SO_2/H_2O:	
Orion, extended ridge	4×10^{-6}	Wright et al., 1996
Orion, plateau	0.006	–”–
Orion, hot core	0.0012	–”–
Orion, hot core	0.0024	Sutton et al., 1995
Orion, extended ridge	3.0×10^{-5}	–”–
Orion, compact ridge	0.032	–”–
Orion, northwest plateau	0.0006	–”–
Orion, southeast plateau	0.0026	–”–
G34.3+0.15, hot core	$\sim 8 \times 10^{-5}$	MacDonald et al., 1996
G34.2+0.15, hot core	3.0×10^{-4}	Hatchell et al., 1998a

G34.3+0.15, hot core	0.001	Irvine, 1999 & r.t.
bipolar outflow L1157	0.0042−0.011	Bachiller and Pérez Gutiérrez, 1997
W3 IRS4	4.4×10^{-5}	Helmich and van Dishoeck, 1997
W3 IRS5	8.0×10^{-4}	–”–
W3(H_2O)	2.0×10^{-4}	–”–
IS ices	$< 10^{-3}$	van Dishoeck and Blake, 1998 & r.t.
C/1983 H1 (IRAS-Araki-Alcock)	$< 8 \times 10^{-7}$	Bockelée-Morvan et al., 2000
Halley's coma	$< 2 \times 10^{-5}$	Vanýsek and Moravec, 1995 & r.t.
1P/Halley	$< 5 \times 10^{-5}$	Bockelée-Morvan et al., 2000
C/1995 O1 (Hale-Bopp)	0.0023	–”–
C/1995 O1 (Hale-Bopp)	~ 0.001	Fegley, 1999 & r.t.
comets	typ. 10^{-3}	van Dishoeck and Blake, 1998 & r.t.

3.2.10. NH_3/H_2O

The cometary abundance ratio decreases from the value of about 0.01 observed in Comet Halley to the 0.007 observed in Hale-Bopp and, further, to 0.005 (Allamandola et al., 1999) or 0.0035 (Meier et al. 1998) in Hyakutake. Therefore, it is difficult to speak about a typical cometary value. We can state that the ratio in Halley is similar to the typical ratios in mixed molecular ices, dense IS matter, and the ratios in some cold dust envelopes around young stellar objects. Other cold dust envelopes as well as embedded protostars contain a higher amount of ammonia.

3.2.11. OCS/H_2O

The mutually consistent cometary abundance ratios of carbonyl sulfide and water, for Comets Halley and Hale-Bopp (a lower ratio has been found in Hyakutake), are very similar to the ratios determined for IS ices in the Orion molecular cloud and those in the line of sight of embedded protostar RAFGL 7009S as well as several other protostars. A less degree of similarity can be stated for the bipolar outflow L1157. In other protostars than RAFGL 7009S, the abundance ratios are, however, about an order lower. The cometary abundance ratio is also about one order higher than the typical value found for mixed molecular ices in a dense IS medium.

3.2.12. SO_2/H_2O

The SO_2/H_2O abundance ratio was reported to be of order 10^{-3} in both IS ices and the hot cores of Orion (its plateau including) and G34.3+0.15. This is consistent with the ratio found in Comet Hale-Bopp, but much higher than the ratios in Comets IRAS-Araki-Alcock and Halley. The ratios in the Orion extended ridge and W3 IRS5 are consistent with the ratio in Halley. Since SO_2/H_2O ratios in IS matter vary from 4×10^{-6} to 0.032 and in comets from a value lower than 8×10^{-7} to 0.0023, i.e. within very large intervals, a conclusion on the similarity is problematic.

3.3. Different abundances (Table 3)

3.3.1. CS/H_2O

The typical cometary CS/H_2O abundance ratio is from one to two orders higher than the ratios found in the Orion molecular cloud, hot cores W3, G34.3+0.15, and other IS matter. Only rough agreement between the cometary and interstellar abundance ratios has been detected in the case of the bipolar outflow L1157 for this species.

3.3.2. CH_3CHO/H_2O

The ratio found in the hot core of G34.3+0.15 is about two orders lower than the ratio reported in Halley's coma. A conclusion on the diversity of this compound in IS medium and comets is however not reliable due to the lack of data.

3.3.3. C_3H_2/H_2O

The C_3H_2/H_2O ratios in TMC-1, the bipolar outflow L1157, and diffuse and traslucent clouds toward a sample of extragalactic continuum sources are from one to three orders lower than the ratio reported in Halley's coma. However, there is not enough cometary data for a reliable conclusion.

3.3.4. HC_3N/H_2O

The HC_3N/H_2O abundance ratio in the hot core of G34.3+0.15 is about two orders lower than the ratios reported in Halley's coma and Hale-Bopp. Because of the lack of data we cannot make a reliable comparison.

3.3.5. $HCOOH/H_2O$

The cometary abundance of HCOOH relative to H_2O has been quantitatively measured only in Comet Hale-Bopp. The value found is about one order lower than that found in a sample of embedded protostars. However, the value is two orders higher than those found in Orion and G34.3+0.15 hot cores.

Table 3. Relative abundances of various molecules, in which appearance in the interstellar medium and clouds is different from that observed in comets. The same abbreviations are used as in Table 1.

	CS/H_2O:	
Orion, extended ridge	2.2×10^{-4}	Sutton et al., 1995
Orion, compact ridge	2.0×10^{-4}	–"–
Orion, northwest plateau	6×10^{-5}	–"–
Orion, southeast plateau	8×10^{-5}	–"–
Orion, hot core	1×10^{-4}	–"–
Orion, hot core	10^{-4}	Chandler and Wood, 1997
bipolar outflow L1157	0.0038	Bachiller and Pérez Gutiérrez, 1997
W3 IRS4	1.2×10^{-4}	Helmich and van Dishoeck, 1997
W3 IRS5	3.0×10^{-5}	–"–
W3(H_2O)	2.0×10^{-4}	–"–
G34.3+0.15, hot core	$> 3.2 \times 10^{-6}$	MacDonald et al., 1996
G34.3+0.15, hot core	1.4×10^{-4}	Hatchell et al., 1998a
G34.3+0.15, hot core	0.0008	Irvine, 1999 & r.t.
Halley's coma	0.002	Feldman et al., 1987
Halley's coma	0.001	Altwegg, 1996
comets	typ. 10^{-3}	van Dishoeck and Blake, 1998 & r.t.
	CH_3CHO/H_2O:	
G34.3+0.15, hot core	1.6×10^{-5}	Nummelin et al., 1998
Halley's coma	0.005	Altwegg et al., 1999
	C_3H_2/H_2O:	
TMC-1	6×10^{-4}	Ohishi et al., 1992
bipolar outflow L 1157	5.8×10^{-6}	Bachiller and Pérez Gutiérrez, 1997
diffuse and translucent clouds toward a sample of EGCSs	$(1-3) \times 10^{-5}$	Liszt and Lucas, 2001
Halley's coma	0.001	Altwegg et al., 1999
	HC_3N/H_2O:	
G34.3+0.15, hot core	$> 1.9 \times 10^{-6}$	Millar et al., 1997
Halley's coma	$\leq 4 \times 10^{-4}$	Geiss et al., 1999
C/1995 O1 (Hale-Bopp)	2.1×10^{-4}	Bockelée-Morvan et al., 2000
	$HCOOH/H_2O$:	
Orion, extended ridge	$< 3.6 \times 10^{-5}$	Sutton et al., 1995
Orion, plateau	$< 10^{-5}$	Blake et al., 1996
G34.3+0.15, hot core	$> 3.4 \times 10^{-5}$	MacDonald et al., 1996
IS ices	≤ 0.02	van Dishoeck and Blake, 1998 & r.t.
LoSt: EPS:		
NGC 7538 IRS9	$\lesssim 0.03$	Keane et al., 2001 & r.t.
W33A	$\lesssim 0.03$	–"–
GL 989	0.01	–"–

GL 2136	0.017	–”–
C/1995 O1 (Hale-Bopp)	0.0009	Bockelée-Morvan et al., 2000
comets	typ. 10^{-3}	van Dishoeck and Blake, 1998 & r.t.
	$HNCO/H_2O$:	
G34.3+0.15, hot core	$> 5.6 \times 10^{-6}$	MacDonald et al., 1996
W 3 IRS4	$< 8.0 \times 10^{-6}$	Helmich and van Dishoeck, 1997
W 3 IRS5	6.8×10^{-6}	–”–
W 3(H_2O)	1.0×10^{-4}	–”–
Orion, hot core	1.2×10^{-4}	Bachiller and Pérez Gutiérrez, 1997
Orion A, molecular core	1.7×10^{-4}	Zinchenko et al., 2000
molecular core associated with:		
G 301.12	1.4×10^{-5}	–”–
G 305.20	9.4×10^{-6}	–”–
G 308.80	2.0×10^{-5}	–”–
G 329.03	2.4×10^{-5}	–”–
G 330.88	9.2×10^{-6}	–”–
G 332.83	4.4×10^{-6}	–”–
G 337.40	5.2×10^{-6}	–”–
G 340.06	1.7×10^{-5}	–”–
G 345.00	1.7×10^{-5}	–”–
G 351.41	1.4×10^{-5}	–”–
G 351.58	8.2×10^{-6}	–”–
G 351.78	2.6×10^{-5}	–”–
S 158	1.2×10^{-5}	–”–
S 255	1.4×10^{-5}	–”–
W 49 N	5.2×10^{-5}	–”–
W 51 M	3.6×10^{-5}	–”–
W 75 N	2.4×10^{-5}	–”–
W 75(OH)	1.7×10^{-5}	–”–
Sgr A	1.3×10^{-4}	–”–
C/1995 O1 (Hale-Bopp)	0.001	Bockelée-Morvan et al., 2000
C/1996 B2 (Hyakutake)	0.0007	Lis et al., 1997
	H_2CS/H_2O:	
G34.3+0.15, hot core	0.004	Irvine, 1999 & r.t.
C/1995 O1 (Hale-Bopp)	$\sim 2 \times 10^{-4}$	Bockelée-Morvan et al., 2000 & r.t.
	NO/H_2O:	
G34.3+0.15, hot core	$> 2.2 \times 10^{-4}$	MacDonald et al., 1996
Halley’s coma	≤ 0.005	Geiss et al., 1991
	O_2/H_2O:	
IS ices	$0.1 - 0.4$	Allamandola et al., 1999 & r.t.
Halley’s coma	≤ 0.005	Léger et al., 1999

XCN/HNCO:		
Orion, extended ridge	2×10^{-9}	Blake et al., 1987
Orion, plateau	$< 10^{-10}$	Blake et al., 1996
Orion, hot core	6×10^{-9}	Blake et al., 1987
IS ices	$\sim 10^{-6}$	van Dishoeck and Blake, 1998 & r.t.
comets	10^{-7}	–"–

3.3.6. HNCO/H_2O

The HNCO/H_2O abundance ratios in IS medium are a few orders lower than the single value known for Comet Hale-Bopp. The lack of cometary data does not allow a serious comparison.

3.3.7. H_2CS/H_2O

Concerning this abundance ratio, we can compare its value found in the hot core of G34.3+0.15 with that reported for Hale-Bopp, which is about one order lower. Another determinations would be desirable as then a conclusive comparison could be done.

3.3.8. NO/H_2O

The molecule NO does not seem to be frequently observed. We have noticed its values determined for Halley's coma and hot core of G34.3+0.15, only. The values differ considerably.

3.3.9. O_2/H_2O

In the Halley's coma, much less abundance of molecular oxygen than in IS ices was observed. The disagreement is however not very conclusive due to the lack of data.

3.3.10. XCN/HNCO

The 4.62-μm "XCN" absorption feature, for a long time attributed to CN-bearing molecules in solids, was suggested to be identified with the corresponding feature of negative ion OCN^- (Grim and Greenberg, 1987; Schutte and Greenberg, 1997; Demyk et al., 1998). Recently, the suggestion was confirmed (Novozamsky et al., 2001) and the identification is secure.

The specific XCN/HNCO abundance ratio in comets has been found to be clearly different from the ratios in IS matter: it is from about one to three orders higher than in the Orion molecular cloud and about one order lower than in IS ices.

Table 4. Relative abundances of various molecules detected in comets. The same abbreviations are used as in Table 1.

	CH_2/H_2O:	
Halley's coma	0.0027	Altwegg et al., 1994
	C_2H_4/H_2O:	
Halley's nucleus	≈ 0.003	Eberhardt, 1999 & r.t.
Halley's coma	0.003	Reber, 1997
	CH_3CN/OH:	
C/1995 O1 at $r_h = 1$	6.7×10^{-4}	Biver et al., 1997
	CH_3NH_2/H_2O:	
Halley's coma	≤ 0.0015	Geiss et al., 1999
	CH_3OH/OH:	
C/1995 O1 at $r_h = 1$	0.02	Biver et al., 1997
	CO/OH:	
C/1995 O1 at $r_h = 1$	0.13	Biver et al., 1997
	CS/OH:	
C/1995 O1 at $r_h = 1$	0.002	Biver et al., 1997
	CS_2/H_2O:	
Halley's coma	0.002	Feldman et al., 1987
Halley's coma	0.001	Altwegg, 1996
C/1995 O1, $2.69 \leq r_h \leq 4.79$	$0.001 - 0.006$, resp.	Weaver et al., 1997
C/1995 O1 at $r_h = 1$	0.0017	Bockelée-Morvan et al., 2000
	HCN/OH:	
C/1995 O1 at $r_h = 1$	0.0017	Biver et al., 1997
	H_2CO/OH:	
C/1995 O1 at $r_h = 1$	0.02	Biver et al., 1997
	HNC/OH*:	
C/1995 O1 at $r_h = 1$	6.7×10^{-4}	Biver et al., 1997
	HNC/HCN*:	
C/1995 O1 at $r_h = 1$	0.40	Biver et al., 1997
C/1996 B2 (Hyakutake)	≈ 0.06	Irvine et al., 1996
	H_2S/OH:	
C/1995 O1 at $r_h = 1$	0.017	Biver et al., 1997
	NH_2/H_2O:	
C/1999 J3, coma	0.0043	Korsun and Jockers, 2002
	NH_2CHO/H_2O:	
C/1995 O1 (Hale-Bopp)	$(1 - 2) \times 10^{-4}$	Bockelée-Morvan et al., 2000
	NH_2CHO/CO:	
Orion, hot core	2×10^{-6}	Irvine, 1999 & r.t.
	S_2/H_2O:	
C/1983 H1	2.5×10^{-4}	Vanýsek and Moravec, 1995 & r.t.
C/1996 B2	0.05	Weaver et al., 1996

3.4. Non-comparable species (Table 4)

The list of quantitatively determined abundances in comets is completed in Table 4. The abundances given there have not been measured in IS medium. More specifically, molecule HNC (marked with an asterisk in Table 4) was also measured in IS matter, but gauged relative to other standards than that in comets and, thus, its ratios are hard to compare to their cometary counterparts.

We note that the list of all reported IS and circumstellar molecules can be found on the WWW:

http://www.cv.nrao.edu/~awootten/allmols.html

Other molecular astrophysics resources are accessible through, e.g.:

http://www.strw.leidenuniv.nl/~iau34/links.html

A listing of species detected in Comet Hale-Bopp is located on:

http://iraux2.iram.fr/HB/comet.html

4. Conclusion

The Galaxy consists of a hot matter, the temperature of which exceeds $\approx 1000\,\mathrm{K}$, and cold matter with temperature below $\approx$ 100 K. The regions between the sources of heat and cold regions can be populated by matter having an intermediate temperature. The chemical composition of cold matter varies over a wider or narrower range. The variety is conditioned by the different compositions of various Galactic regions.

We can suppose that a certain individuality was characteristic for the Solar System forming region as well, therefore a perfect similarity of original pristine material in the Solar System with the cold Galactic matter cannot be expected. Since the composition of only a relatively small numbers of both IS regions and comets has been determined, the known variety of composition cannot be regarded as complete. So, an occurence of some departures of observed cometary chemical composition from that reported for the IS medium, even if both these compositions are actually identical, is obvious.

Taking into account these circumstances, the variety of the chemical composition of comets is, according to our analysis, practically within the range of observed molecular composition of relatively cold matter in the Galaxy. It proves that the gaseous and dusty components, from which the cometary nuclei were built, are primordial. No considerable processing of the material of cometary nuclei has occurred since the time of formation of the nuclei. This conclusion agrees with that by other authors (most recently see: Meier and Owen, 1999; Bockelée-Morvan et al., 2000). On the contrary, some authors, e.g. Ehrenfreund

(1999), have advocated that the comets contain, beside the pristine IS material, an admixture of processed material.

The most frequent reason for the few detected departures of the cometary composition from the Galactic composition so far, which obviously are not any relict of original conditions of comet creation, come from the present-day chemistry in coma, when comets approach the hot Sun. In a few cases, an error in the abundance determination cannot be excluded. It is implied by the few apparently controversial measurements noticed.

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