measured with high-resolution infrared spectroscopy is presented. Some trends are beginning to emerge when mixing ratios in individual comets are compared to average mixing ratios obtained for all species within the population. The variation in mixing ratios for all measured species is at least an order of magnitude. Overall, Jupiter-family comets are depleted in volatile species with respect to H_2O compared to long-period Oort cloud comets, with the most volatile species showing the greatest relative depletion. There is a high positive correlation between the mixing ratios of HCN, C_2H_6, and CH_4, whereas NH_3, H_2CO, and C_2H_2 are moderately correlated with each other but generally uncorrelated or show only weak correlation with other species. CO is generally uncorrelated with the other measured species possibly because it has the highest volatility and is therefore more susceptible to thermal evolutionary effects. Molecular mixing ratios for CH_3OH, HCN, C_2H_6, and CH_4 show an expected behavior with heliocentric distance suggesting a dominant ice source, whereas there is emerging evidence that the mixing ratios of NH_3, H_2CO, and C_2H_2 may increase at small heliocentric distances, suggesting the possibility of additional sources related to the thermal decomposition of organic dust. Although this provides information on the composition of the most volatile grains in comets, it presents an additional difficulty in classifying comet chemistry because most comets within this dataset were only observed over a limited range of heliocentric distance. Optical and infrared comparisons indicate that mixing ratios of daughter species and potential parents from cometary ices are sometimes but not always consistent with one another. This suggests that in many comets there are significant sources of C_2 and/or CN from grains, and that the importance of these sources is variable within the comet population.

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330.03 – Survey for Ortho-to-Para Abundance Ratios (OPRs) of NH 2 in Comets: Revisit to the Meaning of OPRs of Cometary Volatiles

Since molecules having identical protons can be classified into nuclear-spin isomers (e.g., ortho-H_2O and para-H_2O for water) and their inter-conversions by radiative and non-destructive collisional processes are believed to be very slow, the ortho-to-para abundance ratios (OPRs) of cometary volatiles such as H_2O, NH_3 and CH_4 in coma have been considered as primordial characters of cometary molecules [1]. Those ratios are usually interpreted as nuclear-spin temperatures although the real meaning of OPRs is in strong debate. Recent progress in laboratory studies about nuclear-spin conversion in gas- and solid-phases [2,3] revealed short-time nuclear-spin conversions for water, and we have to reconsider the interpretation for observed OPRs of cometary volatiles. We have already performed the survey for OPRs of NH_2 in more than 20 comets by large aperture telescopes with high-resolution spectrographs (UVES/VLT, HDS/Subaru, etc.) in the optical wavelength region [4]. The observed OPRs of ammonia estimated from OPRs of NH_2, cluster around ~1.1 (cf. 1.0 as a high-temperature limit), indicative of ~30 K as nuclear-spin temperatures. We present our latest results for OPRs of cometary NH_2 and discuss about the real meaning of OPRs of cometary ammonia, in relation to OPRs of water in cometary coma. Chemical processes in the inner coma may play an important role to achieve un-equilibrated OPRs of cometary volatiles in coma.

This work was financially supported by MEXT Supported Program for the Strategic Research Foundation at Private Universities, 2014–2018 (No. S1411028) (HK) and by Graint-in-Aid for JSPS Fellows, 15J10864 (YS).

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330.04 – Beyond 3 AU from the Sun: "Hypervolatiles" in Distant Comets

Our understanding of inner coma composition in comets has long been biased towards heliocentric distances (R_h) smaller than 2-3 AU. However, observations far from the Sun are also of high value for better understanding the nucleus structure and outgassing of volatiles. Substantial and very important evidence for the activity of distant comets has been accumulated from photometry and analyses of light curves, but direct detections of primary (parent) volatiles are still rare. For example, comet C/2006 W3 (Christensen) remained outside 3.1 AU throughout its apparition, yet it presented the best opportunity since Hale-Bopp (1997) for detailed spectroscopic studies in a distant comet. C/2006 W3 was observed from several space- and ground-based facilities using both infrared and radio techniques. CO, CH_4, and C_2H_6 were measured via infrared spectroscopy at ESO-VLT at R_h = 3.25 AU. Production rates were found to exceed those measured for each of these species in most other comets, despite those comets being observed much closer to the Sun. With its relatively high CO/CO_2 ratio, C/2006 W3 also appears as an outlier in the *AKARI* comet survey of 18 comets. The detections of H_2O (*Herschel* Space Observatory) and CO (ESO-VLT) allow for constraining the coma abundance ratio H_2O/CO at R_h = 5 AU.
We will compare the C_2H_6/CH_4/CO ratios in C/2006 W3 with those in other comets spanning a large range in R_h: from D/2012 S1 ISON (~0.7 AU) to 29P/Schwassmann-Wachmann 1 (~ 6.3 AU). Notably in situ measurements by the *Rosetta* mission were performed in the coma of 67P/Churyumov-Gerasimenko, at a very similar heliocentric distance to C/2006 W3 (3.15 AU). While comparisons of column-integrated remote sensing measurements and abundances from in-situ mass spectrometry (as performed by the ROSINA instrument) are not straightforward, both types of measurement are of high value for constraining models of nucleus outgassing beyond 3 AU from the Sun, where the inferred nucleus structure and differences in volatility among nucleus ices are very important.

We gratefully acknowledge NASA's Planetary Astronomy, Astrobiology, Solar System Observations, and Planetary Atmospheres programs and the NSF Astronomy and Astrophysics Research Grants program.

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330.05 – The OD/OH Isotope Ratio in Comets 8P/Tuttle and C/2012 F6 (Lemmon)

The determination of isotopic ratios in solar system objects is an important source of information about their origin, especially for

comets. Among these ratios the D/H is of particular importance because of its sensitivity to fractionation processes and physical environment, and the abundance of hydrogen in the solar system. The main molecule used to derive this ratio in comets is water. So far, apart water, only HCN has permitted to derive D/H ratio and not only upper limits.
Most of the existing determinations of D/H in water molecules have been obtained by spectroscopic observations of water lines in the sub-mm or near infrared range [1,2]. So far only one measurement has been based on OD/OH emission lines radicals in the near-UV [3] and another one on the Lyman-alpha D emission [4]. In situ measurements have also been obtained in comets 1P/Halley and 67P/Churyumov-Gerasimenko using mass spectrometer [5,6,7,8].
In this work we have used the OH and OD ultraviolet bands at 310 nm observed with the ESO 8-m Very Large Telescope feeding the Ultraviolet-Visual Echelle Spectrograph (UVES) for measuring the D/H ratio in comets 8P/Tuttle and C/2012 F6 (Lemmon). The OH and OD being the photodissociation products of H_2O and HDO such observations allow to derive D/H ratio for water molecules. This work constitutes an independant determination of the D/H ratios already published for these comets and based on observations performed in the sub-mm and near infrared range of H_2O and HDO lines. We present our modeling, data analysis and numerical values obtained for this ratio.
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330.06 – Gaseous activity of distant comets

The activity of most comets within 3AU of the Sun is dominated by the sublimation of frozen water, the most abundant ice in comets. Some comets, however, are active well beyond the water-ice sublimation limit. Studying distantly active comets provides valuable opportunities to explore primitive bodies when water-ice sublimation is largely dormant, which is the case for most of a comet's lifetime. Beyond 4 AU, super-volatiles such as CO or CO_2 are thought to play a major role in driving observed activity. Carbon monoxide is of special interest because it is a major contributor to comae and has a very low sublimation temperature. Three bodies dominate the observational record and modeling efforts for distantly active small bodies: the long-period comet C/1995 O1 Hale-Bopp and the short-period comets (with centaur orbits) 29P/Schwassmann Wachmann 1 and 2060 Chiron. Hale-Bopp's long-period orbit means it has experienced very little solar heating in its lifetime and is analogous to dynamically new comets making their first approach to the Sun. Because Chiron and 29P have much smaller orbits closer to the Sun, they have experienced much more thermal processing than Hale-Bopp and this is expected to have changed their chemical composition from their original state. We point out that the observed CO production rates and line-widths in these three distantly active objects are consistent with each other when adjusted for heliocentric distance. This is particularly interesting for Hale-Bopp and 29P, which have approximately the same radius. The consistent CO production rates may point to a similar CO release mechanism in these objects. We also discuss how observed radio line profiles support that the development and sublimation of icy grains in the coma at about 5-6 AU is probably a common feature in distantly active comets, and an important source of other volatiles within 6 AU, including H_2O, HCN, CH_3OH, and H_2CO.
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330.07 – Spectroscopic observations of $^{14}N/^{15}N$ ratios in both NH_2 and CN in comet C/2013 US10 (Catalina)

Comet is one of the primordial small bodies in the solar system and probably it has kept the information about the evolution of materials from the pre-solar molecular cloud to the solar nebula. Isotopic ratio in volatiles is one of the primordial properties of comets. A heavier isotopes trend to be captured into a molecule by chemical reactions under very low-temperature conditions (called as fractionation). For instance, D/H ratio of water (HDO/H_2O) in comet is enriched in D atom than the elemental abundance ratios of D/H in entire solar system [1]. Based on the observed D/H ratios in cometary water, a presumed temperature is ~20–50 K as the formation temperature of water (most abundant volatiles in cometary nucleus), by assuming water formed in gas-phase chemistry [2].
Besides, the nitrogen isotopic ratios ($^{14}N/^{15}N$) have been determined from CN and HCN (which is believed a dominant “parent” species of CN in the coma) in >20 comets [3,4]. They demonstrated cometary HCN and CN show high ^{15}N-fractionation with respect to the proto-solar value by a factor of ~3 and with a small diversity.
Moreover, $^{14}N/^{15}N$ ratios in NH_3 in comets has been determined from intensity ratios of NH_2 isotopologues [5,6,7], and both ^{15}N-fractionation as much as HCN in comets and a small diversity are seen in those $^{14}N/^{15}N$ ratios in NH_3. However, there is a few reports about $^{14}N/^{15}N$ ratios in both HCN and NH_3 in the same comets, and discussions about the relationship between these $^{14}N/^{15}N$ ratios have not been yet.
We present $^{14}N/^{15}N$ ratios in both NH_2 and CN in comet C/2013 US10 (Catalina). High-resolution optical spectra of the comet were taken with the HDS spectrograph mounted on the Subaru Telescope (Hawaii) on UT 2016 January 2–3. We will discuss about the origins of these volatiles based on the $^{14}N/^{15}N$ ratios.
This work was supported by Graint-in-Aid for JSPS Fellows, 15J10864 (YS).
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331 – Comets: Origins and Theory Posters

331.01 – Unveiling clues from Spacecraft Missions to Comets and Asteroids through Impact Experiments

The Deep Impact Spacecraft mission was the first to boldly face the challenge of impacting the surface of a comet, 9P/Tempel 1, to investigate surface and subsurface ‘pristine’ materials. The Stardust mission to Comet 81P/Wild 2 brought back an exciting surprise: shocked minerals which were likely altered during the comet’s lifetime. Signatures of shock in meteorites also suggest that the