MULTIWAVELENGTH OBSERVATIONS OF RECENT COMETS.

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Introduction: Comets provide important clues to the physical and chemical processes that occurred during the formation and early evolution of the Solar System, and could also have been important for initiating prebiotic chemistry on the early Earth [1]. Comets are comprised of molecular ices, that may be pristine interstellar remnants of Solar System formation, along with high-temperature crystalline silicate dust that is indicative of a more thermally varied history in the protosolar nebula [2]. Comparing abundances of cometary parent volatiles, and isotopic fractionation ratios, to those found in the interstellar medium, in disks around young stars, and between cometary families, is vital to understanding planetary system formation and the processing history experienced by organic matter in the so-called interstellar-comet connection [3]. We will present a comparison of molecular abundances in these comets to those observed in others, supporting a long-term effort of building a comet taxonomy based on composition.

We are currently conducting multiwavelength observations towards a number of recent comets (C/2009 P1 (Garradd); C/2012 S1 (ISON); C/2012 F6 (Lemmon); and C/2011 L4 (PanSTARRS)) to determine their taxonomy and cosmogonic quantities, such as the ortho:para ratio and isotope ratios, as well as probe the origin of cometary organics. Comets provide important clues to the processes that occurred during the formation and early evolution of the Solar System. Past observations, as well as laboratory measurements of cometary material obtained from Stardust, have shown that comets appear to contain a mixture of the products from both interstellar and nebular chemistries. A major observational challenge in cometary science is to quantify the extent to which chemical compounds can be linked to either reservoir.

It is well known that some comets exhibit volatile activity at large heliocentric distances (R_h), where water ice cannot sublime efficiently. The dynamically new Oort cloud (OC) comet C/2009 P1 Garradd is a recent example. Like Hale-Bopp at 7.2 AU, Garradd exhibited unusual activity at discovery (R_h = 8.68 AU), displaying a 15" diameter circular coma (IAUC 9062). Activation by a hypervolatile ice was implied. *Akari* later detected CO_2 and CO (at 3.6 AU), but not H_2O [4]. Early (Sep 08th) infrared (IRTF + CSHELL, $5\mu m=2153cm^{-1}$) spectroscopy of Garradd showed clear CO (R1 & R2) emission, as well as methane and ethane that were also detected at a heliocentric distance >2AU [5]. This comet reached perihelion in late December 2011 and had its closest approach to Earth 5 March 2012. We have monitored the abundance of parent volatiles in this object through perigee at multiple facilities. The latest detection of the J=4-3 transition of HCN was made at the JCMT on 7 Nov 2012 (R_h~4.1 AU, Δ~4.4 AU), see Fig. 1. Three other targets are also being observed: the new comet C/2012 F6 (Lemmon), C/2011 L4 (PanSTARRS), and the "comet of the century" C/2012 S1 (ISON), see Fig. 2. All targets have exceptional predictions for being highly active targets and visual magnitudes >3. Comet ISON was discovered at R_h~6 AU this past September. This target will pass perihelion on 29 Nov. 2013 at a mere distance of only 0.012 AU, reaching an estimated

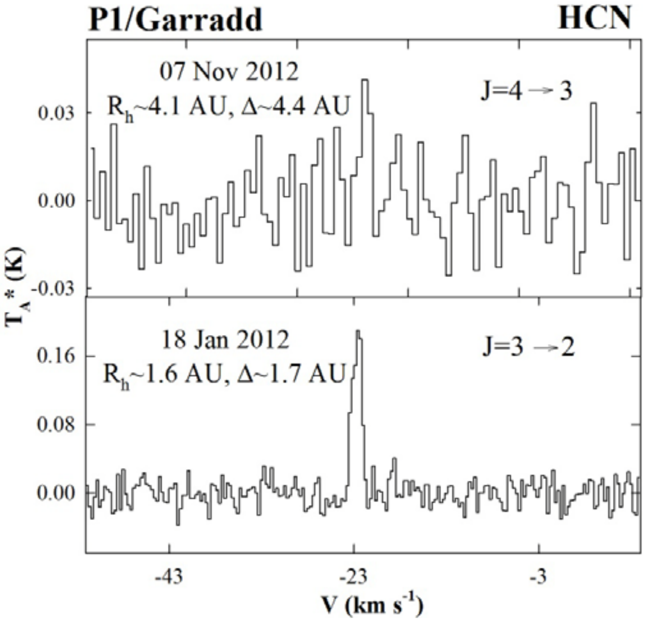

Figure 1: Spectra of HCN obtained towards comet C/2009 P1 (Garradd) from the Arizona Radio Observatory (J=3-2, lower) on Jan. 18, 2012 and the JCMT on November 7, 2012 (J=4-3, upper). These data show the pre- and post-perihelion activity that has been monitored by our group.

magnitude of -6! ISON is currently at a heliocentric distance of ~5 AU and will become more and more favorable throughout the year. We have established an extensive multiwavelength observing campaign to monitor the volatile activity of this target as it approaches perihelion. The preliminary results of this campaign will be presented. Comet F6/Lemmon is a very southernly target that is also being observed by a number of facilities including Herschel. The ground-based data are complimentary to Herschel and will provide the temperature of the coma as well as abundances of other volatile species not accessible by the space-craft or the program. Comet L4/PanSTARRS will be observed regularly throughout perigee and will reach closest approach to Earth just before this meeting. All available data will be presented.

While we have ample evidence that comets are indeed primitive bodies formed early in the history of our planetary system (and perhaps in others, see [6]), we still face serious uncertainties in decoding the meaning of measured abundances. What we have learned to date is: 1) we see no correlation between chemical composition and dynamical class -- ecliptic (Kuiper-disk) versus nearly-isotropic (from the OC); and 2) comets are chemically diverse, i.e., mixing ratios vary substantially among observed comets [7,8,9], although the number of targets measured is still small (~20) and attempts to define chemical taxonomic classes are often questioned by observations of additional comets; e.g., 8P/Tuttle [10] and C/2007 N3 [11]. The inventory of volatiles throughout a comet's apparition can help decipher the natal composition as well as the chemistry that may occur during various sublimation phases of these primitive ices.

Observations: Observations were conducted from four facilities: the Arizona Radio Observatory's 12m telescope, Kitt Peak, AZ, and Submillimeter telescope, Mt. Graham, AZ, as well as the James Clerk Maxwell Telescope, Mauna Kea, HI and the Greenbank 100m telescope, Greenbank, WV, covering 20 cm, 3 cm, and 0.8-3 mm. Data were obtained, collectively, from early December 2012 - present. Data were collected in position switching mode at all facilities with spectral resolutions of *dv* ~0.05 – 0.6 km/s. Ephemeris were generated from JPL Horizons daily and positional accuracy was monitored approximately every hour by pointing/focusing on nearby planets and/or quasars.

Results and Discussion: About a dozen species will be targeted towards these bright apparitions. These include deuterated isotopologues of HCN, H_2CO, and H_2O. Data will also be obtained for ortho and para-H_2CO in multiple transitions, and simultaneously. Cosmogonic measurements such as the D/H and *o/p* ratios will help further constrain the formation temperature and environment where these simple organics were formed.

Other species in these surveys include: CH_3OH, HNC, CS, H_2S, c-C_3H_2, and SO_2. Detailed analysis of all these data will help constrain the temperature, abundances, variance or periodicity of a given species, and can be compared to results from other comets. The full analysis of these data and comparisons will be presented.

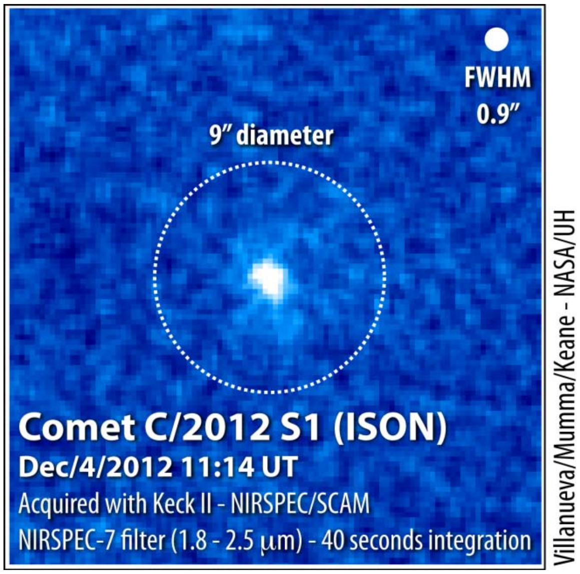

Figure 2: Image acquired for comet C/2012 S1 (ISON) on December 4, 2012 from the Keck II observatory. The GBT beam size at 89 GHz (~9") is shown for comparison. Molecular emission for comet ISON will be monitored from a number of facilities through perihelion.

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