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The volatile composition of comets C 2009/P1 (Garradd) and C 2012/F6 (Lemmon) from ground-based radio observations

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Abstract

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]. Comparing abundances and cosmogonic values (isotope and *ortho:para* (o/p) ratios) of cometary parent volatiles 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 [2]. A major observational challenge in cometary science is to quantify the extent to which chemical compounds can be linked to either the interstellar or nebular reservoirs. We report an analysis of ground-based radio observations towards comets C/2009 P1 (Garradd) and C/2012 F6 (Lemmon) to constrain the chemical history of these bodies.

1. Introduction

A record of the physical and chemical conditions in the protosolar nebula between about 5-40 AU is preserved in cometary matter, during the epoch when the populations now comprising the Oort Cloud and the Kuiper Belt were being assembled [3,4]. One viewpoint for the origin of cometary materials is that they are pristine remnants of the interstellar material that collapsed to form the protosolar nebula [5]. Although there are some differences, the volatile composition of cometary ices is generally similar to inventory of molecules detected in the ices and gas of dense molecular clouds [1,6]. However, the discovery of crystalline silicates in comets, such as Hale-Bopp, and the Stardust samples, indicates that pre-cometary amorphous silicates experienced a significant degree of processing [7,8,9]. Any component derived from interstellar chemistry may either be pristine, or may have been modified in the outer nebula, as the accreted material was transported inwards [2]. The noble gas differentiation, deuterium enrichment, and low *ortho:para* o/p ratio measured in water are all consistent with formation of precometary ices at ~30 K, similar to the conditions in the Uranus-Neptune region [6]. Comet-forming material in the Jupiter-Saturn region (5-10 AU) experienced higher temperatures and may also have been exposed to a much higher degree of radiation processing before assembly into comets. However, the detection of various organics on the Stardust exposed foils suggests that some volatile molecular material may not have been subjected to intense processing [10], and thus may retain a component of interstellar heredity.

Comets are primarily located in two distinct regions of the solar system. The Oort cloud, the source of long period (P>200 years) comets, is a spherically symmetric distribution of comets that encompasses the solar system out to a distance of nearly 100,000 AU. The Kuiper-Edgeworth belt that lies in the ecliptic plane just beyond the orbit of Pluto out to several hundred AU is the source of short period (P<200 years) comets [11]. Recent models have suggested that the Oort cloud comets may have had origins in the entire giant planet region between Jupiter and Neptune. These models suggest that comets were formed in a much wider range of nebular environments than previously thought and probably experienced thermal and collisional processing before they were ejected into the Oort cloud [12]. This processing may have ``homogenized" the cometary nuclei of Oort cloud comets. Given the gradient in physical conditions expected across the nebula, chemical diversity in the comet population is to be expected, as has been inferred for both JFCs [13] and Oort Cloud comets [14,15].

2. Observations

We have conducted multiwavelength observations towards the recent comets C/2009 P1 (Garradd), see Figure 1, and C/2012 F6 (Lemmon) 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. 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). *Akari* later detected CO_2 and CO (at 3.6 AU), but not H_2O [14]. Early (Sep 08th) infrared (IRTF + CSHELL, 5μm=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 [1]. This comet reached perihelion in late December 2011 and had its closest approach to Earth 5 March 2012. We 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). Additionally, we have conducted observations towards C/2012 F6 (Lemmon), which was discovered on 23 March 2012.

Observations were conducted from five facilities: Atacama Pathfinder Experiment in Chile, 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. About a dozen species have been targeted towards these bright apparitions. These include deuterated isotopologues of HCN, *ortho* and *para*-H_2CO in multiple transitions, and other species including: CH_3OH, HNC, CS, and CO.

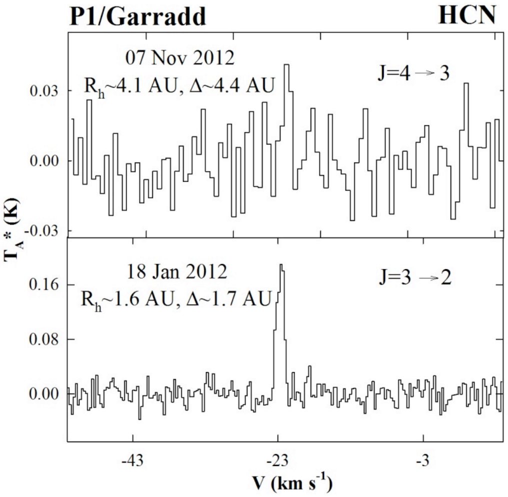

Figure 1: Spectra of HCN obtained towards comet C/2009 P1 (Garradd) from the Arizona Radio Observatory (J=3-2, lower) on Jan. 18, 2012 and the JCMT on November 7, 2012 (J=4-3, upper). These data show the pre- and post-perihelion activity that has been monitored by our group.

3. Conclusion

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 to constrain the chemical history on comets will be presented.

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