Onsala Proposal

Roth 0108.F-9323

A Search for Distributed Sources in a Target of Opportunity Comet

Semester: may2021 **Science Cat.: Solar system**

Abstract

As part of a joint collaborative multi-wavelength effort, a molecular survey of multiple volatile species is proposed to be conducted towards at least one target of opportunity comet this semester. These observations will help constrain the origin of the comet in the protosolar nebula, establish accurate molecular abundances, and provide insights into comet chemistry. This proposal will be activated based on monitoring of cometary activity from observations at other facilities that our team routinely uses. Data obtained with APEX will be complementary to ALMA observations to measure the temperature, activity, and extended flux of the targeted molecules. Such complementary observations have recently proven successful in observations of comets K1/PanSTARRS, Q2/Lovejoy, and ER61/PanSTARRS

Applicants

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Is this a long term proposal: No

No overall scheduling requirements

Observing runs

run	telescope	instrument	time request (minimal)	frequency (GHz)	weather (pwv)	LST range	comments/constraints
A	APEX	SEPIA345 (277-371 GHz)	4h (4h)	350	any	0-24	This configuration will target the HCN (4-3), CO (3-2), and CS (7-6) transitions. The LST interval will be determined at the activation of the ToO proposal.
B	APEX	SEPIA345 (277-371 GHz)	4h (4h)	338	any	0-24	This setting will target multiple strong CH3OH transitions near 338 GHz and will constrain the coma rotational temperature. The LST interval will be determined upon activation of the ToO proposal.
C	APEX	SEPIA345 (277-371 GHz)	1h (1h)	357	any	0-24	This setting will target the H2CO (5-4) transition. The LST interval will be determined upon activation of the ToO proposal

Targets

Source	RA	Dec	Epoch	Vlsr (km/s)	Duration (min)	Runs	Comments
ToO Comet	00:00:00.00	+00:00:00.0	J2000	0.0	600	A B C	The LST Interval will be determined upon activation of the ToO proposal.

Scientific Rationale

Comets are among the most primitive remnants of solar system formation, and are composed of molecular ices along with crystalline silicate dust. Their ices have undergone relatively little processing since their formation [1], and characterizing their native ice composition may provide important clues to the chemistry present in the protosolar nebula where (and when) they formed. The composition of the comet nucleus is inferred predominantly through remote sensing of coma gases. These observations are interpreted using a simple Haser model [2], with species being separated into "parent" (i.e., subliming directly from the nucleus) or "product" (being produced by photolysis or other processes in the coma). However, the observed distributions of some molecules (e.g., H_2CO, HNC, CO) are inconsistent with production by direct sublimation alone and indicate production by unknown parents in the coma ("distributed" sources) [3]. Discerning the coma distributions of these species in a large number of comets will enable us to better understand which molecules are truly "parent" vs. "product" in comets, and in turn better our understanding of the formation of the solar system.

H_2CO: Millimeter studies of bright comets have indicated H_2CO production from an unknown parent source with a scale length of 7000 km at 1 AU [4,5,6], whereas ALMA studies of the inner coma suggest a scale length of 1000 - 5000 km [7]. In contrast, near-IR observations indicate H_2CO production from both nucleus ices and coma sources, including increased production from extended sources at small heliocentric distance (R_h) [8]. Polyoxymethylene (POM), the H_2CO polymer, has been suggested as a likely parent based on the comparison of laboratory studies with the R_h-dependence of H_2CO production in Hale-Bopp [9,10]. However, few comets have been imaged in H_2CO and more observations are needed to understand how this species is produced from comet-to-comet, its production dependence on R_h, and the identity of its parent.

CH_3OH: In contrast, ALMA studies have shown that CH_3OH is associated with nucleus sources, and can also be used to characterize the physical properties of the coma such as temperature [11]. Characterizing the spatial distributions of CH_3OH and H_2CO in a comet can therefore provide strong evidence regarding the nature of H_2CO production in comets, including whether H_2CO is released from nucleus sources and how its parent scale length varies with overall comet activity and R_h.

CO: Distributed sources of CO have been suggested for comets Halley [12], Hale-Bopp [13], and Hyakutake [14]; however, the observations of comet Halley are consistent with a CO-jet, and interferometric observations have provided evidence that the appearance of a distributed CO source in Hale-Bopp may have been due to optical depth effects [15]. Imaging CO along with CH_3OH and H_2CO will provide a powerful tool for discerning to what extent CO is produced from nucleus or distributed sources.

APEX observations of these molecules in comets are highly complementary to those of ALMA, which provides detailed maps yet resolves out extended flux. Only combined single dish and interferometry observations can provide a comprehensive characterization of the origins, distributions, and abundances of these molecules in comets. APEX is uniquely suited to complement our ALMA observations owing to its similar frequency ranges and close proximity to ALMA. Analysis of these observations will enable us to determine to what extent the targeted species are produced from nucleus or coma sources (or both), to examine how their spatial and velocity distributions compare, and to compare our results with laboratory measurements in order to identify possible parents for molecules originating from distributed sources.

Facilities Requested

The powerful capability of APEX to sensitively measure these molecules has been demonstrated repeatedly through our recent observations of comets C/2012 F6 (Lemmon) (Figure 1), C/2012 K1 (PanSTARRS), C/2012 S1 (ISON), C/2015 ER61 (PanSTARRS), and C/2014 Q2 (Lovejoy)

[17]. Our observations of C/2014 Q2 formed part of a large campaign with ALMA, APEX, JCMT, IRAM 30m, and PdBI. The APEX observations precisely measured production rates for HCN, CH_3OH, H_2CO, and CO and provided stringent upper limits for acetaldehyde (CH_3CHO) and formamide (NH_2CO) [17], while our IRAM 30m observations produced the first detections of ethyl alcohol and glycoaldehyde in a comet [18]. APEX is uniquely situated as the only single dish facility that can observe targets at the same time and frequencies as ALMA, as other observatories (e.g., JCMT) are further north. Furthermore, the APEX receivers allow sampling multiple strong transitions of our targeted coma molecules, making it an ideal facility for this study. It is important to note that similar ALMA ACA observations are not guaranteed to be carried out simultaneously with more extended array observations; thus, APEX plays an integral part in fully sampling the millimeter chemistry present in comets.

Observing Requirements

We propose to use the APEX 12m telescope to measure production rates of HCN, CO, H_2CO, and CH_3OH in up to two target of opportunity comets that will be determined from monitoring observations at other facilities. The availability of bright (but currently undiscovered) comets suitable for our goals is borne out in our recent APEX ToO observations (e.g., C/2014 Q2, C/2015 ER61). We will conduct our observations simultaneously with ALMA if possible in order to fully sample the production mechanisms and coma distributions of our targeted molecules. We have been awarded time at ALMA in support of this effort (2019.1.01008.T, PI Milam), and have submitted a corresponding proposal for the upcoming ALMA Cycle 8 (beginning October 2021).

We will identify comets that satisfy our trigger conditions based on their Figure-of-Merit (FoM = $Q(H_2O[10^{28}])\Delta^{-1}$), where Q is the H_2O production rate (s^{-1}) and Δ is geocentric distance (AU). We request approximately 10 hours of observing time over 1 or more transits of the comet in coordination with ALMA. We will request observations when the comet is near perihelion (and thus peak activity) but at a reasonable solar elongation. Data will be taken in beam switching mode and employ a spectral resolution of 0.10 km s^{-1}, providing sufficient resolution to characterize jet activity of coma gases. We will upload a comet ephemeris daily. The APEX observing time calculator (V 7.1) was used to calculate observing time estimates for the targeted species (Table 1), including overhead. We assumed a nominal $Q(H_2O)$ of 1E29 s^{-1} at R_h = 1 AU, corresponding to FoM = 10, along with abundances (%) of 0.1 for HCN, 0.5 for H_2CO, 5 for CO, and 1.5 for CH_3OH. Exact abundances of each species are not known in advance and have been shown to vary from comet-to-comet, as well as from day-to-day within a particular comet. Our estimated total observing time of ~10 hours (including overhead) is for 1.5 mm pwv, 5σ rms levels, and an average elevation of 45°.

Observing Plan and Scheduling Requirements

We will assess daily cometary activity levels using the HCN (4-3) line, observed at the beginning and end of each run. We will trigger our program when a bright comet has been identified that reaches FoM ~ 10, an activity level that has proven successful for ToO programs at both APEX and ALMA for previous comets.

Figures

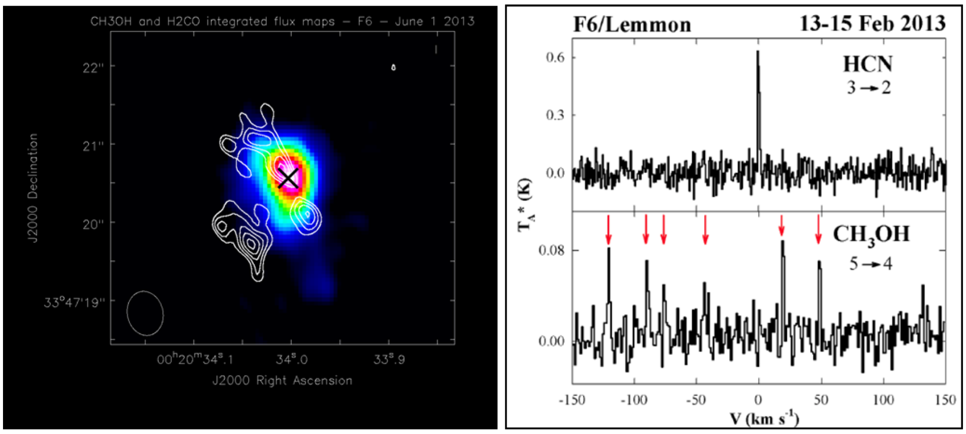

Figure 1: (left): ALMA Band 7 maps of CH_3OH (color map) and H_2CO (white contours) observed in comet F6 (Lemmon) on June 1st 2013. These show a compact 'primary' source for CH_3OH and an extended/distributed source with scale-length ∼1000 km for H_2CO. A black cross denotes the 0.9 mm continuum peak. All observations were performed simultaneously and the on-source integration time was 22 min. The lowest flux levels displayed are 3:5σ. (right): Sample spectra recently obtained for Comet C/2012 F6 (Lemmon) from APEX in February 2013, FOM=28, of HCN (3-2) (18 min integration time) and multiple lines of CH_3OH near 242 GHz (47 min integration time) used to determine the comet's volatile composition and probe the temperature in the coma.

Table 1: Target Molecules and Transitions

Transition	$\nu_{\rm rest}$ (GHz)	Estimated Time (hr)	Transition	$\nu_{\rm rest}$ (GHz)	Estimated Time (hr)
HCN$(4-3)$	355	0.35	CO(3-2)	346	4.2
CS(7-6)	342	0.35	H_2CO ($5_{1,5}$-$4_{1,4}$)	352	0.7
CH_3OH (multiple)	338	4.2			

Note: Estimated total integration times for 5σ detections. (a) All estimates assume a nominal water production of 1E29 s^{-1} at R_H=1 au, which would correspond to a FoM=10. (b) The total time includes ON+OFF time with observational overheads (setup and calibration). We assumed a water column of 1.5mm for all species.

References

REFERENCES: [1] Mumma, M. & Charnley, S. 2011, ARAA, 49, 471 [2] Haser, L. 1957, Bull. Classe des Sciences Aca. Roy. Belgique, 43, 740 [3] Cottin, H. & Fray, N. 2008, SSRv, 138, 179, [4] Biver, N. et al. 1999, AJ, 118, 1850 [5] Milam, S. et al. 2006, ApJ, 649, 1169 [6] Bockelee-Morvan, D. et al. 2000, A&A, 353, 1101 [7] Cordiner, M. et al. 2014, ApJ, 792, L2 [8] Dello Russo, N. et al. 2016, Icarus, 278, 301 [9] Biver, N. et al. 1997, Science, 275, 1915 [10] Fray, N. et al. 2006, Icarus, 184, 239 [11] Cordiner, M. et al. 2017, ApJ, 838, 147 [12] Eberhardt et al. 1987, A&A, 187, 481 [13] DiSanti, M. et al. 2001, Icarus, 153, 361 [14] DiSanti, M. et al. 2003, JGRE, 108, 5061 [15] Bockelee-Morvan, D. et al. 2010, Icarus, 210, 898 [17] de Val-Borro, M. et al. 2018, MNRAS, 474, 1099 [18] Biver, N. et al. 2015, Science Advances, 1, 1500863

No PhD Students involved

Linked proposal submitted to this TAC: No

Linked proposal submitted to other TACs: No

Relevant previous Allocations: Yes

"A Search for Distributed Sources in a Target of Opportunity Comet" designated 0107.F-9314. Not triggered due to lack of suitable target within the semester.

"A Search for Distributed Sources in a Target of Opportunity Comet" designated 0105.F-9315. All observing time lost due to APEX COVID shutdown.

"Determining the HDO/H2O ratio and chemical composition in a ToO comet" designated 100.F-9320(A,B), publication in progress

"Investigating isotopic composition and chemistry in a ToO comet", 099.F-9323, publication in progress

"Complementary Multiwavelength studies of comet C/2012 K1 (PanSTARRS) designated 094.F-9321, publication in preparation

"Constraining Comet Chemistry in a New Dynamic Comet: A Target of Opportunity Proposal" designated 094.F-9307, 5 hours, not triggered

"Multiwavelength Observations of the 'Comet of the Century': Comet C/2012 S1 (ISON)" designated 092.F-9321(A), 4 hours, in preparation

"Multiwavelength Observations of the Oort Cloud Comet C/2011 L4 (PanSTARRS)" designated 091.F-9324(A), 18 hours, time reallocated to F6 Lemmon. Publication in preparation.

"APEX observations of comet C/2012 F6 (Lemmon) in support to Open-Time Herschel measurement of the D/H ratio in water" designated 091.F-9331(A), 16 hours, complete. Publication in preparation.

"Determining the Origin and Composition of Oort Cloud Comet C/2010 X1 (Elenin)" designated 088.F-9312(A), 25 hours, not observed due to no comet activity

"A Multiwavelength Effort to Determine Comet Taxonomy: A Target of Opportunity Proposal" designated 093.F-93016(A), 5 hours, not triggered.

Additional remarks

ESO = nxrq67

Observing run info :