EPSC Abstracts
Vol. 6, EPSC-DPS2011-1535-1, 2011
EPSC-DPS Joint Meeting 2011

The formation heritage of Jupiter Family Comet 10P/Tempel 2 as revealed by infrared spectroscopy

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Abstract

Comet 10P/Tempel 2 (hereafter 10P) was observed after its perihelion passage in 2010 using high-dispersion infrared spectroscopy. We present production rates, abundances, and spatial information of eight major volatile species: H_2O, HCN, C_2H_6, CH_3OH, NH_3, and (3σ) upper limits for NH_2, C_2H_2, and H_2CO. In particular, our campaign was contemporaneous with a jet-like feature observed at optical and visual wavelengths in 2010 mid-July. Spatial profiles of primary volatiles display strong enhancements toward the jet direction and to a lesser extent in the anti-jet direction, which favors the idea of direct sublimation in response to local insolation. We discuss possible formation scenarios for this Jupiter Family Comet based on chemical composition and cosmogonic parameters retrieved by our observations.

1. Introduction

Jupiter Family Comets (JFCs) are often characterized by weak outgassing activity during their perihelion passage, which makes infrared spectroscopy a challenging task. It is not yet clear whether the observed composition might be related to possible thermo-chemical characteristics at the time when cometary ices agglomerated, or is a consequence of multiple perihelion passages. During the last decade, however, we have witnessed three spectacular exceptions to this common behavior: comets 73P/SW-3 [1, 2, 3], 17P/Holmes [4], and 103P/Hartley-2 [5, 6]. These comets developed a significant increase of gas productivity, and measurement of their chemical abundances tends to confirm that volatile composition result from intrinsic characteristics at the time of formation rather than being evolutionary (i.e., due to repeated and frequent perihelion passages).

In this investigation we report 10P's gas productivity, chemical composition, and spatial properties of primary volatiles and, within the context of other existing IR observations of JFCs, attempt to distinguish possible formation scenarios for this comet through cosmogonic parameters led by our observational results.

2. Observations

Astronomical observations of comet 10P/Tempel 2 were conducted using the Near Infrared Echelle Spectrograph (NIRSPEC) at the 10m W. M. Keck Observatory (Keck II) atop Mauna Kea, Hawaii, on UT 2010 Jul 26 and 2010 Sep 18. NIRSPEC is a cross-dispersed echelle grating spectrometer which features a 1024 × 1024 InSb array detector with a pxiel size of $0.144''$ (spectral) × $0.198''$ (spatial). For the observations of comet 10P we used a $0.432'' \times 24''$ slit configuration, resulting in a spectral resolving power of ~24,000. This arrangement allowed six spectral orders of 40 cm^{-1} (each) within the L band (2.8–4.1 μm).

3. Results and Discussion

On 2010 July 26, we detected several lines of H_2O and OH^* prompt emission using KL1 and KL2 settings combined; along with spectral lines of ethane (C_2H_6) and methanol (CH_3OH) using the KL1 setting alone. The KL2 setting allowed detection of hydrogen cyanide (HCN) and ammonia (NH_3), as well as upper limits of formaldehyde (H_2CO), acetylene (C_2H_2), and amidogen radical (NH_2, a by-product of NH_3). Even though the comet did not show clear spectral features in UT 2010 September observations, these data allowed us to obtain sensitive upper limits of water production. After applying fluorescence models to the calibrated spectra, we retrieved production rates and rotational temperatures for all detected molecules.

In addition, we oriented the slit along the jet (i.e., 20° CCW from North) in order to sample the gas activity, and to investigate spatial profiles of primary volatiles as revealed in the IR. Spatial profiles show strong release of volatiles extending in the jet direction, and to larger distances compared to dust outgassing (see Fig. 1). In the anti-jet direction, these four volatiles follow a distribution similar to that of the dust continuum.

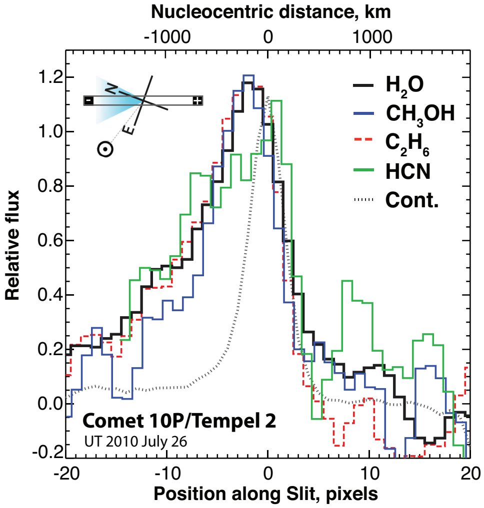

Figure 1: Spatial profiles of primary volatiles in comet 10P reveal significant release of major volatiles at a P.A. = 20°, which was coincident with a jet-like feature observed by optical and visual observers in 2010 mid-July. We aligned the slit along the jet, which is placed horizontally in this plot. The ends of the slit (+ , -) corresponds to pixels displayed on the abscissa.

We observe a strong correlation of these spatial profiles of primary volatiles with the jet direction observed by visual observers in 2010 mid-July. Other contemporaneous observations in the optical (not yet published) will help to further understand the chemical processes within the cometary coma, such as the possible role of HCN as progenitor for the CN radical [3].

The molecular composition and taxonomy of comets, as revealed by high-dispersion infrared spectroscopy, plays a key role for tracing the primordial conditions of the early Solar System. The large diversity of chemical compounds and relative composition measured in comets, however, denotes considerable constrains to classify these objects and determine suitable formation scenarios.

Even though it is challenging to establish unambiguous formation mechanisms of these cometary volatiles, the molecular inventory in comet 10P might have been supported by different dynamical processes (such as chemical processing at different stages during the evolution of the solar nebula), gas-phase chemistry, and dust surface chemistry, or a combination of all these [7]. Future infrared observations, aided by laboratory experiments, will provide more evidence linking composition and chemical taxonomy, increase the existing database, and provide further insights into the heritage of Jupiter Family comets.

Acknowledgements

The authors acknowledge support by the NSF Astronomy and Astrophysics Research Grants Program, and by the NASA's Planetary Astronomy, Planetary Atmospheres, and Postdoctoral Programs.

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