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ALMA Spectral Imaging of Volatiles and Dust from Jupiter Family Comets: 21P/Giacobini-Zinner and 46P/Wirtanen

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Abstract

We present the first interferometric observations of mm/sub-mm molecular (and dust) emission from the Jupiter Family Comets 21P/Giacobini-Zinner and 46P/Wirtanen, obtained using the Atacama Large Millimeter/submillimeter Array (ALMA) during their extremely favorable 2018 apparitions. The ALMA array configuration was moderately compact for both sets of observations, resulting in a beam size $\sim 0.3''$. This, combined with the small geocentric distances, resulted in an unprecedented ~ 90 km spatial resolution in the plane of the sky for 21P and ~ 20 km for 46P, in the sub-mm band. Spectral/spatial maps were obtained for HCN, HNC, CS, H_2CO, CH_3OH, and CH_3CN, enabling the derivation of coma temperatures and outgassing rates as a function of distance from the nucleus. Highlights of these observations will be presented, including the detailed morphology, chemical composition and thermal properties of the innermost molecular comae of these Jupiter Family Comets.

1. Introduction

Cometary ices are believed to have been relatively unaltered since the birth of the solar system, and their compositions provide a unique record of ice chemistry in the protosolar disk midplane. Gravitational scattering by the young giant planets is believed to have redistributed comets among the inner solar system and into their various present-day dynamical reservoirs: in particular, the Oort cloud and the Kuiper belt. Most comets discovered each year come from the Oort cloud, while the scattered Kuiper disk is considered to be the source of Jupiter family comets (JFCs). However, dynamical models make various predictions regarding the formative regions of cometary nuclei, spanning a diverse range of heliocentric distances [3,4]. Compositional studies of Oort cloud comets (OCCs) and JFCs therefore have the potential to probe a diversity of physical and chemical conditions during the epoch of planet formation.

The 2018 apparitions of the Jupiter Family Comets 21P/Giacobini-Zinner and 46P/Wirtanen were extremely favorable, offering a rare opportunity to study JFC coma chemistry and physics in unprecedented detail. Here we present spectral imaging observations of these two comets using the Atacama Large Millimeter/submillimeter Array (ALMA), obtained near to the time of closest approach to Earth, with the objective of performing a deep exploration of the physical and chemical state of the inner coma, including 3D outgassing/jet morphology, kinematics and coma molecular distributions and mixing ratios.

2. Results

Observations of 21P were obtained during the period 2018-09-16 to 2018-09-25 (at Geocentric distance $\Delta \approx 0.4$ au), and 46P was observed between 2018-12-02 and 2018-12-07 (at $\Delta \approx 0.1$ au. Simultaneous use of the main array of 46×12-m antennas and the compact array of 12×7-m antennas enabled spatially complete interferometric imaging over size scales $0.3'' \sim 20''$, corresponding to sky-projected distances $90 \sim 6000$ km for 21P and $20 \sim 1500$ km for 46P. This has enabled the measurement of molecular gas properties in the immediate vicinity of JFC

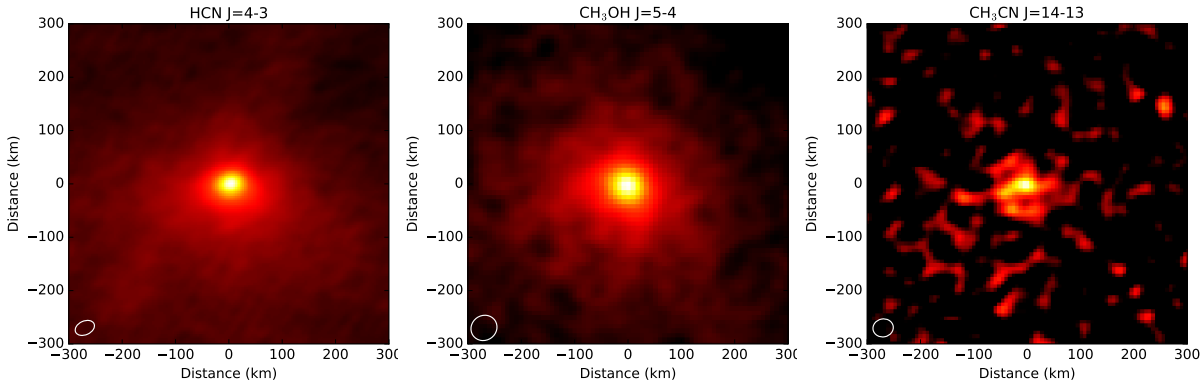

Figure 1: December 2018 ALMA images of molecular emission from comet 46P/Wirtanen.

nuclei, for the first time from the ground.

Interferometric maps were obtained of HCN, CS, H_2CO, CH_3OH, and CH_3CN in both comets, examples of which are shown in Figure 1 for 46P. HNC was also detected in 21P. This is the first time CH_3CN has been mapped in any comet to-date, revealing a clear, nucleus-centered emission peak similar to CH_3OH and HCN, consistent with relatively isotropic production of these gases from the nucleus. The $\Delta J, \Delta K = 1, 0$ transitions of CH_3CN provide a particularly powerful probe of the coma kinetic temperature (T_{kin}) due to the lack of allowed radiative transitions between the K levels of this molecule, resulting in a distribution of (K) rotational levels close to local thermodynamic equilibrium. For comet 46P, the CH_3CN line strength ratios indicate a temperature of 108 K inside the ($0.3''$) ALMA beam centered upon the nucleus, whereas a cooler temperature of 60 K was found inside a larger, $8''$ aperture. This temperature drop is qualitatively consistent with adiabatic cooling as the CH_3CN gas expands with increasing distance from the nucleus. Comparison of the coma temperature distributions from CH_3CN and CH_3OH with theoretical models (e.g. [1,2]) will enable detailed tests for our understanding of coma heating and cooling in the immediate vicinity of the JFC nucleus.

The observed, high-resolution coma gas distributions allow molecular production to be mapped as a function of spatial coordinate, revealing molecular contributions from nucleus outgassing, icy grain sublimation, and photochemical synthesis, from which unprecedented insights into the activity and coma chemistry of JFCs can be obtained. Maps of the mm/submm continuum emission provide a uniquely detailed view of the distribution of large (thermally emitting) grains close to the nucleus.

3. Summary

We present the first interferometric observations of mm/sub-mm molecular emission from the Jupiter Family Comets 21P/Giacobini-Zinner and 46P/Wirtanen, obtained using ALMA during their extremely favorable apparitions in 2018 September and December, respectively. Emission was detected from HCN, HNC, CS, H_2CO, CH_3OH, CH_3CN and dust, enabling the distributions of these species to be mapped at unprecedented detail (with a spatial resolution of up to 20 km for 46P). The morphology, chemical composition and thermal properties of the innermost molecular comae of these comets is thus revealed.

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