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[P-CG19] 宇宙における物質の形成と進化

コンピーナ: 瀧川 晶(東京大学 大学院理学系研究科 地球惑星科学専攻)、三浦 均(名古屋市立大学大学院理学研究科)、大坪 貴文(自然科学研究機構 国立天文台)、野村 英子(国立天文台 科学研究部)

近年の天文観測・室内実験・惑星探査・理論的研究の進展は、銀河系・原始惑星系円盤・晩期型巨星周囲等に存在する物質(ダスト・ガス)を物質科学的観点から理解することを可能としている。銀河や星・惑星系の進化においてダストやガスが果たす役割を理解するためには、これまで以上に天文学的・宇宙物理学的研究と物質科学的研究をリンクさせることが重要である。本セッションでは、高温の星周環境から低温の分子雲まで多様な場を想定した室内実験や地球外試料の分析の成果と、現在大きな成果を挙げている ALMA を含めた最新の天文観測結果、および太陽系内外のフロンティアを拓いていくと期待される地上大型望遠鏡計画 TMT などによる将来的な観測を見据えた議論を持ち寄り、宇宙の物質進化や形成を理解するために、天文観測と物質科学からどのようなアプローチが可能なのかを双方向から議論する。

太陽系物質の起源や進化に関する発表は「太陽系における惑星物質の形成と進化」セッションへの投稿を推奨します。太陽系物質の研究にもとづいて宇宙での物質形成全般を議論する発表は、ぜひ本セッションにご投稿ください。

[PCG19-P01] 星形成領域 Sagittarius B2(N) における前生物的分子 CH_3NCO の塵表面生成の調査

*荒木 光典¹、出岡 恭一¹、大野 有紀¹、小山 貴裕²、高野 秀路³、久世 信彦²、築山 光一¹ (1. 東京理科大学、2. 上智大学、3. 日本大学)

[PCG19-P02] Phyllosilicate minerals in comet P/2016 BA14 (PANSTARRS)

*大坪 貴文¹、河北 秀世²、新中 善晴² (1. 国立天文台、2. 京都産業大学)

[PCG19-P03] 50m 大型ミリ波望遠鏡 LMT/2mm 帯受信機 B4R による Orion-KL 領域の試験観測

*米津 鉄平¹、前澤 裕之¹、川邊 良平²、吉村 勇紀³、廿日出 文洋³、河野 孝太郎³、竹腰 達哉⁴、酒井 剛⁵、田中 邦彦⁶、谷口 暁星⁷、田村 陽一⁷、大島 泰²、島尻 芳人²、David Hughes⁸、David Sanchez-Arguelles⁸、Arturo Gomez-Ruiz⁸、Ivan Rodriguez-Montoya⁸、Javier Zaragoza-Cardiel⁸、Edgar Colin⁸、Miguel Chavez-Dagostino⁸、Sergio Rojas⁸、Pete Schloerb⁹、Kamal Souccar⁹、Min Yun⁹ (1. 大阪府立大学、2. 国立天文台、3. 東京大学、4. 北見工業大学、5. 電気通信大学、6. 慶應義塾大学、7. 名古屋大学、8. INAOE、9. UMass)

[PCG19-P04] Modeling of Nitrogen Fractionation in the Protoplanetary Disk around TW Hya

*Seokho Lee¹、Hideko Nomura¹、Kenji Furuya¹、Jeong-Eun Lee² (1. National Astronomical Observatory of Japan、2. Kyung Hee University)

[PCG19-P05] Effects of deposition temperature on structural changes of amorphous ice in heating process

*大野 友維¹ (1. 明治大学)

[PCG19-P06] Phase transition of KOH-doped amorphous ice

*吉田 大輝¹ (1. 明治大学)

星形成領域Sagittarius B2(N)における前生物的分子CH₃NCOの塵表面生成の調査

Investigation of Dust-Surface Formation of Prebiotic Molecule CH₃NCO in Star-Forming Region Sagittarius B2(N)

*荒木 光典¹、出岡 恭一¹、大野 有紀¹、小山 貴裕²、高野 秀路³、久世 信彦²、築山 光一¹

*Mitsunori Araki¹, Kyoichi Izuoka¹, Yuki Ohno¹, Takahiro Oyama², Shuro Takano³, Nobuhiko Kuze², Koichi Tsukiyama¹

1. 東京理科大学、2. 上智大学、3. 日本大学

1. Tokyo University of Science, 2. Sophia University, 3. Nihon University

最初の有機物は彗星によって原始地球にもたらされたと考えられている。しかし有機物を運搬する彗星と生成する分子雲では、化学組成に大きな相違が見られる。その顕著な例が前生物的分子と呼ばれているCH₃NCOである。この分子は彗星67P [1]、星形成領域Sagittarius B2(N) [2]等で検出されている。炭素数が少なく同様の構造を持つHNCOとの存在量比[CH₃NCO]/[HNCO]は、彗星67Pでは4.33[1]と大きく、分子雲では0.1未満[2]と小さい。この化学組成の大きな差が前生物的分子の起源における問題となっている。近年のMajumdarらの理論研究は、この差をCH₃NCOの塵表面生成で説明している[3]。もしこの説明が正しければ、星形成領域の中心部には塵表面から脱離した高温・高濃度のCH₃NCOが存在するはずである。本研究では、Sgr B2(N)のALMAアーカイブによるデータを用い、高い空間分解能 (<0.04 pc) でこの理論研究の検討を行った。CH₃NCOの94-113 GHz帯の回転遷移計24本の強度と速度を解析した。強度分布からは、降着円盤と双極分子流の中の両方にCH₃NCOが分布する様子がわかった。回転温度は降着円盤では50-60 K、双極分子流では20-50 Kとなり、柱密度は共に $\sim 10^{16} \text{cm}^{-2}$ となった。Sgr B2(N)の広範囲観測の結果[2]と比較すると、中心部での高温・高密度が示された。これらの結果はMajumdarらのモデルでのCH₃NCOの塵表面生成と矛盾なく、このモデルで分子雲と彗星の存在量比の差を説明できる可能性が高まった。

[1] Goesmann *et al.*, 2015, *Sci.*, 349, 6247. [2] Halfen *et al.*, 2015, *ApJL*, 812, L5. [3] Majumdar *et al.*, 2018, *MNRAS*, 473, L59.

キーワード：ALMA、前生物的分子、イソシアヌ酸メチル

Keywords: ALMA, Prebiotic Molecule, Methyl isocyanate

Phyllosilicate minerals in comet P/2016 BA14 (PANSTARRS)

*大坪 貴文¹、河北 秀世²、新中 善晴²

*Takafumi Ootsubo¹, Hideyo Kawakita², Shinnaka Yoshiharu²

1. 国立天文台、2. 京都産業大学

1. National Astronomical Observatory of Japan, 2. Kyoto Sangyo University

Comets are thought to contain pristine materials formed in the early solar nebula. In periodic comets that have orbited the Sun many times, compared to dynamically new comets, with progressively smaller perihelion distances, the nucleus exhibits clues to investigate significant physical and chemical evolution, including the influence of solar heating on cometary nuclei. Thus, conducting observational and theoretical studies on evolved comets is essential. The evolutionary track of exceedingly weakly active comets is considered to lead up to their dormancy or extinction.

Here, we report on the mid-infrared imaging and spectroscopic observations of comet P/2016 BA14 (PANSTARRS). Its gas and dust production rates were notably low, even near the perihelion passage around 1 au from the Sun. We observed the comet P/2016 BA14 on UT 2016 March 21.3 at heliocentric and geocentric distances of 1.01 au and 0.026 au, respectively, approximately 30 hours before its closest approach to Earth (0.025 au). Low-resolution ($R \sim 250$) spectroscopic observations in the *N*-band and imaging observations centered at 8.8, 12.4, 17.7, and 18.8 microns were carried out using the Cooled Mid-Infrared Camera and Spectrometer (COMICS) mounted on the 8.2m Subaru telescope. The observed image of the comet has a spatial profile that is consistent with a point-spread function.

The normalized emissivity spectrum of the comet exhibits abrupt-like features around 10 microns. The features are not reproduced by the anhydrous silicate minerals typically found in cometary coma dust, such as olivine and pyroxene. By comparing with the thermal emissivity spectra measured for various minerals in the laboratory, the shape and position of the observed ~ 10 -micron feature observed for P/2016 BA14 are more similar to those of phyllosilicates rather than anhydrous silicates, which are usually not observed in the mid-infrared comet spectra.

キーワード：彗星、ダスト、層状ケイ酸塩

Keywords: comets, dust, phyllosilicate

50m大型ミリ波望遠鏡LMT/2mm帯受信機B4RによるOrion-KL領域の試験観測

Test observations toward Orion-KL region using 2mm Band 4 Receiver onboard 50m Large Millimeter Telescope

*米津 鉄平¹、前澤 裕之¹、川邊 良平²、吉村 勇紀³、廿日出 文洋³、河野 孝太郎³、竹腰 達哉⁴、酒井 剛⁵、田中 邦彦⁶、谷口 暁星⁷、田村 陽一⁷、大島 泰²、島尻 芳人²、David Hughes⁸、David Sanchez-Arguelles⁸、Arturo Gomez-Ruiz⁸、Ivan Rodriguez-Montoya⁸、Javier Zaragoza-Cardiel⁸、Edgar Colin⁸、Miguel Chavez-Dagostino⁸、Sergio Rojas⁸、Pete Schloerb⁹、Kamal Souccar⁹、Min Yun⁹

*Teppey Yonetsu¹、Hiroyuki Maezawa¹、Ryohei Kawabe²、Yuki Yoshimura³、Bunyo Hatsukade³、Kotaro Kohno³、Tatsuya Takekoshi⁴、Takeshi Sakai⁵、Kunihiko Tanaka⁶、Akio Taniguchi⁷、Yoichi Tamura⁷、Tai Oshima²、Yoshito Shimajiri²、David Hughes⁸、David Sanchez-Arguelles⁸、Arturo Gomez-Ruiz⁸、Ivan Rodriguez-Montoya⁸、Javier Zaragoza-Cardiel⁸、Edgar Colin⁸、Miguel Chavez-Dagostino⁸、Sergio Rojas⁸、Pete Schloerb⁹、Kamal Souccar⁹、Min Yun⁹

1. 大阪府立大学、2. 国立天文台、3. 東京大学、4. 北見工業大学、5. 電気通信大学、6. 慶應義塾大学、7. 名古屋大学、8. INAOE、9. UMass

1. Osaka Prefecture University, 2. NAOJ, 3. University of Tokyo, 4. Kitami Institute of Technology, 5. The University of Electro-Communications, 6. Keio University, 7. Nagoya University, 8. INAOE, 9. UMass

我々は、メキシコの標高4600 mにある口径50 m大型ミリ波望遠鏡Large Millimeter Telescope (LMT)に搭載した2 mm帯高感度超伝導SIS受信機Band 4 Receiver(B4R)を用いて試験観測を行なってきた。B4Rは、2SB方式と2つの直交偏波の観測を採用することで、125-163 GHzのRF周波数帯の内、4-8 GHzのIF周波数帯の観測が可能であり、受信機雑音温度は60 K未満である。試験観測は、2018年10月と2019年11月に大質量星形成領域であるOrion-KL領域において、on the fly(OTF)法により実施している。観測領域は、10' x10' (2018年)、5' x5' (2019年)であり、観測周波数帯域は127.9-130.4,131.9-134.4,141.6-144.1,145.6-148.1 GHz帯(2018年)、131.4-133.9,136.2-138.7,145.1-147.6, 149.9-152.4 GHz帯(2019年)である。

この観測領域は、太陽から約414 pcほど離れており、熱源となっている埋もれた若い星を付随するホットコアを含む。ホットコアでは複雑な炭素鎖分子が豊富に存在することがすでに知られている。さらにホットコアの約7秒角程度南西には、ホットコアよりも低温なコンパクトリッジ領域と呼ばれる高密度領域が分布し、ここではOxygen-bearingなどの複雑な有機分子も豊富に存在する。これらの領域の特徴の違いは、高密度コアの進化過程や温度などの物理的環境の違いを反映しているとされ、星形成や星間化学の理解に重要な領域となっており、単一鏡やALMA、SMAなどの干渉計を用いた豊富な先行研究が存在する。本観測においても、Oxygen-bearing分子(CH₃OCHO, CH₃OCH₃など)がコンパクトリッジを中心に広範囲に広がっている様子が捉えられた。さらにNitrogen-bearingの炭素鎖分子(C₂H₅CN, C₂H₃CN, HC₃Nなど)やSulfur-bearing分子など(SO₂, OCSなど)はホットコアで相対的に強く広がり、これらの領域で化学組成の分布が系統的に変化する様子を明瞭に捉えることができた。また、CH₃OCHO(v₁₈=1)の高励起線や、水素の再結合線なども同定され、2mm帯では初めての観測結果も得た。本講演では、50m-LMT/B4Rにより、約10秒角の空間解像度(~0.02 pc)で見た大質量星形成領域の上記分子種の空間分布や温度環境の解析結果について報告を行う。

キーワード：星間分子、アストロケミストリー、星形成、電波輝線、望遠鏡

Keywords: ISM molecules, astrochemistry, star formation, radio lines, telescopes

Modeling of Nitrogen Fractionation in the Protoplanetary Disk around TW Hya

*Seokho Lee¹, Hideko Nomura¹, Kenji Furuya¹, Jeong-Eun Lee²

1. National Astronomical Observatory of Japan, 2. Kyung Hee University

Observations conducted using the Atacama Large Millimeter/submillimeter Array on the protoplanetary disk around TW Hya show the nitrogen fractionation of HCN molecules in $\text{HC}^{14}\text{N}/\text{HC}^{15}\text{N} \sim 120$ at a radius of ~ 20 AU. In this study, we investigated the physical and chemical conditions that control this nitrogen fractionation process. To this end, a new disk model was developed, in which the isotope-selective photodissociation of molecular nitrogen and isotope-exchange chemical reactions have been incorporated. Our model can successfully reproduce the observed HCN column density when the elemental abundances of the gas-phase carbon and oxygen are depleted by two orders of magnitude relative to those in the interstellar medium and carbon is more abundant than oxygen ($[\text{C}/\text{O}]_{\text{elem}} > 1$). The isotope-selective photodissociation of molecular nitrogen is the dominant nitrogen fractionation process in our models. The observed $\text{HC}^{14}\text{N}/\text{HC}^{15}\text{N}$ ratio, which increases outwards, can also be reproduced by the model by assuming that the small dust grains in the atmosphere of the outer disk are depleted more than those in the inner disk. This is consistent with grain evolution models, according to which small dust grains are continuously replenished in the inner disk due to fragmentation of the large dust grains that radially drift from the outer disk.

Keywords: Astrochemistry, Numerical, protoplanetary disk, isotope, TW Hya

Effects of deposition temperature on structural changes of amorphous ice in heating process

*大野 友維¹

*Yui Ono¹

1. 明治大学

1. Meiji University

In interstellar molecular clouds, various molecules such as H₂O, CO₂, NH₃, CH₄, H₂CO, and CH₃OH are formed from deposited elements such as hydrogen, oxygen, carbon, and nitrogen. The deposited H₂O exists as amorphous ice. The deposited molecules undergo chemical evolutions through various processes on amorphous ice. Amorphous ice formed from a vapor deposition is principally classified into two types: low-density amorphous (LDA) and high-density amorphous (HDA) ices. HDA ice is transformed into LDA ice with heating [1]. However, the mechanism of the phase transition is less conclusive, because the transition temperature depends on experiments [2]. To investigate the effects of deposition temperature on structural change in heating process, infrared spectra and temperature programmed desorption (TPD) curves of amorphous ice with heating were analyzed.

Amorphous ice was prepared with vapor deposition of distilled and degassed water on a substrate of oxygen-free copper at a temperature of 43.5–120.5 K. The total pressure in the vacuum chamber was kept at about 5.0×10^{-5} Pa during the deposition. After the deposition of amorphous ice, the substrate was cooled to 43.5 K at a rate of 2 K/min. Then, the sample was heated to 176 K at a rate of 1–4 K/min. The IR spectra were measured using Shimadzu IRPrestage-21 at every 15 seconds during deposition, and measured at 2 K intervals during cooling and heating. The TPD curves were measured using a quadrupole mass spectrometer. Q-mass (Pfeiffer QME220) during heating.

The wave number of the O–H stretching mode of the deposited amorphous ice changes in heating process due to a structural change. The result shows that the variation process of the wave number in heating process depends on the deposition temperature. The transition points can be analyzed from the variation in a changing rate of wave number with heating. For the ice deposited at temperatures below 82 K, three transition points exist in the temperature range of 43.5–160 K. The transitions observed at ~60 and ~100 K are attributed to the transition from HDA ice into LDA ice via an intermediate structure. The transition observed at around 150 K is crystallization to the cubic ice Ic from the LDA ice. For the ice deposited at temperatures above 85 K, only two transitions occur from the intermediate structure into LDA ice at ~100 K and the crystallization to Ic at ~150 K. The transition points depend on the deposition temperature before the heating. On the other hand, the beginning of the desorption of H₂O analyzed from TPD curves are ~50, ~90 and ~140 K. These values are approximately independent of the deposition temperature. This suggests that the transition of amorphous ice is induced by the desorption of H₂O due to a rearrangement of H₂O.

キーワード：アモルファス氷、赤外分光法

Keywords: Amorphous ice, Infrared spectroscopy

Phase transition of KOH-doped amorphous ice

*吉田 大輝¹

*Daiki Yoshida¹

1. 明治大学

1. Meiji University

In interstellar molecular clouds, dust grains from a silicate mineral surrounded by amorphous ice exist [1]. The elements such as H, O, C, and N are adsorbed on the dust grains and form various molecules such as H₂O, CO₂, NH₃, CH₄, H₂CO, and CH₃OH. The molecules undergo chemical evolutions to organic molecules through various reaction processes. A photochemical reaction caused by ultraviolet (UV) irradiation is one of the dominant reaction processes [2]. Since amorphous ice is a reaction field in interstellar molecular clouds, it is important to understand the mechanism of structural change of amorphous ice due to the UV irradiation. Recently, Tachibana et al. [3] found that the viscosity of the UV-irradiated amorphous ice decreases at around 50 K.

The OH⁻ defects formed by UV irradiation are expected as a cause of the decrease in viscosity. To investigate the effect of OH⁻ on the structural changes during heating, the infrared (IR) spectra of KOH-doped amorphous ice were analyzed. KOH, has an effect to introduce the OH⁻ defect on ice and to promote the rotational motion of water molecules in ice [4].

Amorphous ice was prepared with vapor deposition of a solution of KOH on a substrate of oxygen-free copper at a temperature of 43.5 K. The concentrations of KOH were 0.0049–0.1 M. The total pressure in the vacuum chamber was kept at about 5.0×10^{-5} Pa during the deposition. After the deposition of amorphous ice, the substrate was heated to 176 K at a rate of 1–4 K/min. The IR spectra were measured using Shimadzu IRPrestage-21 at every 15 seconds during the deposition, and measured at 2 K intervals during the heating.

The structural transitions during the heating in the temperature range of 43.5–176 K are classified into the following four processes (i) transition from high density amorphous (HDA) ice to an intermediate structure at around 60 K, (ii) transition from the intermediate structure to low density amorphous (LDA) ice at around 100–120 K via the glass transition, (iii) crystallization to cubic ice (Ic) at around 145 K, and (iv) phase transition from Ic to hexagonal ice (Ih) at around 175 K. These transition temperature can be analyzed from the variation in a changing rate of wave number of the O–H stretching mode in IR spectrum with heating. The result shows that the transition temperatures of the transition (ii) depends on KOH concentration. The doped KOH has effect to promote the rotational motion of H₂O, because the decomposed OH⁻ from KOH is introduced in the hydrogen-bonding network and acts as a defect. This indicates that the rotational motion is a dominant mechanism for the transition (ii). Furthermore, it was found that the transition temperature of the transition (iii) depends on the wave number of the O–H stretching mode at the deposited temperature (i.e., 43.5 K), whereas no dependence was observed for the transition (i). This suggests that the surface structure is a dominant factor for the crystallization, and a rearrangement of water molecules due to the translational motion of oxygen is a cause for the formation of the intermediate structure.

[1] S. C. Creighan, J. S. A. Perry, and S. D. Price, *J. Chem. Phys.* **124** (2006) 114701.

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