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公転運動に起因するタイタン大気の時間変動

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Time variations in the atmosphere of Titan caused by its orbital motion

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The atmosphere of Saturn's moon Titan has a layered structure (troposphere, stratosphere, mesosphere, and thermosphere) similar to that of the Earth's atmosphere, and is composed mainly of nitrogen and methane. The methane concentration is 5% in the troposphere and about 1% in the upper atmosphere, and the other components are mostly nitrogen. Titan orbits Saturn with a period of about 16 days and passes through the plasma sheet in Saturn's magnetosphere. The Cassini spacecraft observed the heating of the thermosphere by energetic particles in the plasma sheet (e.g., Westlake et al., 2011). High-energy particles in Saturn's magnetosphere ionize nitrogen and methane, producing tholins that form the haze layer of the upper atmosphere (Sagan et al., 1984). Therefore, as Titan passes through the plasma sheet, variations in methane concentration and the optical thickness of the haze layer can be expected. Conventional observations avoid the methane absorption wavelengths, and the variation of methane concentration due to orbital motion remains unresolved. Observations of the haze layer by ground-based telescopes (Nichols-Fleming et al., 2021) report that the opacity of the haze layer fluctuates by 5 - 10% in a few weeks. However, no analysis of temporal variation in the haze layer has focused on orbital motion, and it is unclear whether there is any variation caused by orbital motion.

In this study, we conducted multi-wavelength imaging observations including methane absorption wavelengths (727 and 889 nm) from 2021 to 2024 using the Multispectral Imager (MSI) on the Pilika Telescope owned by Hokkaido University. Spectral analysis was performed based on aperture photometry to determine the reflectance of the methane absorption lines. The relationship between the reflectance and Titan's orbital motion was investigated. The reflectance was compared with an atmospheric radiative transfer model to quantify the methane concentration and the optical thickness of the haze layer. Data from the Huygens probe (Niemann et al., 2010; Tomasko et al., 2007) and HITRAN (Kochanov et al., 2016) were used as input to the atmospheric radiative transfer model and the optical properties of the tholins. The analysis suggests that reflectance at methane absorption wavelengths is related to orbital motion and tends to be smaller at the perihelion and larger at the aphelion. Three hypotheses were considered as possible reasons for this: energetic particle flux from Saturn's magnetosphere, solar flux, and variations in the height of the Haze layer. In this presentation, we discuss the validity of the hypotheses based on the quantitative evaluation of temporal variations in methane absorption and the optical thickness of the haze layer.

土星衛星タイタンの大気圏は地球大気圏と同様に層構造 (対流圏，成層圏，中間圏，熱圏) を持ち，主に窒素とメタンで構成されている．対流圏の上には光学的に厚いヘイズ層が存在する．タイタンは約 16 日周期で土星を公転し，土星磁気圏のプラズマシートを通過する．カッシーニ探査機はプラズマシート内の高エネルギー粒子が熱圏加熱を観測した (e.g., Westlake et al., 2011)．高エネルギー粒子は窒素とメタンを電離させ，ヘイズ層を形成する (Sagan et al., 1984)．したがって，タイタンのプラズマシート通過に伴う，メタン濃度及びヘイズ層の光学的厚さの変動が予想できる．しかし，従来の観測はメタン吸収波長を避けており，公転運動によるメタン濃度の変動は未解明である．また，地上望遠鏡によるヘイズ層の観測では，ヘイズ層の不透明度が数週間で 5 - 10% 変動すると報告している (Nichols-Fleming et al., 2021) が，ヘイズ層の時間変動について公転運動に注目して解析した例はなく，公転運動に起因する変動は不明である．

本研究は北海道大学が所有するピリカ望遠鏡のマルチスペクトル撮像装置 (MSI) を用いて，2021 年から 2024 年にわたりメタン吸収波長 (727, 889 nm) を含む多波長撮像観測を行った．得られた観測データからメタン吸収波長付近の反射率を導出し，さらに反射率とタイタン公転運動との関連性を調査した．得られた反射率を，大気放射伝達モデルと比較し，メタン濃度とヘイズ層の光学的厚さを定量した．大気放射伝達モデルに入力する大気モデルとヘイズ粒子の光学特性は，ホイヘンス探査機 (Niemann et al., 2010; Tomasko et al., 2007) 及び HITRAN(Kochanov et al., 2016) のデータを用いた．解析の結果，メタン吸収波長の反射率は公転運動に関係し，近土点で小さく，遠土点で大きい傾向が示唆された．この要因として，高エネルギー粒子フラックス，太陽光フラックス，ヘイズ層高度の変動の 3 つの仮説を検討した．本発表ではメタン吸収量及びヘイズ層の光学的厚さの時間変動の定量的評価に基づき，仮説の妥当性について議論する．