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論文要旨集

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Jet Collimation Profile Analysis and Core-Shift Measurement of Low-Luminosity AGN M84 using High-Resolution VLBI Observations

(高分解能VLBI観測による低光度AGN M84のジェット収束プロファイル解析とコアシフト測定)

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The way in which the jet in active galactic nuclei (AGN) becomes collimated has been a long-standing issue in astrophysics. Although recent high-resolution VLBI analysis of an increasing number of AGN jet sources has significantly improved our understanding of jet collimation properties near supermassive black holes, previous jet collimation studies have been limited to bright and powerful jet sources. In this study, we investigate the collimation property of the nearby radio galaxy M84, which is a prototypical source of low-luminosity AGN (LLAGN), providing us with the opportunity to examine the jet collimation property at the lower end of the jet activity. We analyze the detailed jet morphology of M84 by utilizing the Very Long Baseline Array and archival Very Large Array data to investigate the jet geometry from $\sim 10^2$ Schwarzschild radii (r_s) to $\sim 10^7$ r_s. The well-fitted jet structure exhibits a transition from a semi-parabolic shape, $W(r) \propto r^{0.72}$, to a conical shape, $W(r) \propto r^{1.17}$, at approximately 10^4 r_s. The distance of the collimation break is considerably shorter than those observed in more powerful jets, indicating that the collimation of low-power jets is less effective. Additionally, we use phase referencing observations to measure the frequency-dependent core-shift effect and discuss the jet physical properties, including the magnetic field strength with an upper limit of $\lesssim 6.5$ mG. Our results suggest that M84 follows the magnetically arrested disk (MAD) mode, consistent with observations in other LLAGNs.

Atmospheric Characterization of K2-100b in the Neptunian Desert with High-Resolution Spectroscopy
ネプチューン砂漠に存在する惑星K2-100bの高分散分光による大気キャラクタリゼーション

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Abstract

With the discovery of thousands of exoplanets with various diversities, one of the most important problems beyond planet hunting is detection and characterization of the planetary atmospheres. Among the various methods to characterizing exoplanet atmospheres, transmission and emission spectroscopy for transiting planets has a unique advantage, enabling us to characterize their atmospheres using spectra during their transit or eclipse. Such research has been typically carried out on *Hot Jupiters*, massive planets close to their host stars (a < 0.1 AU). As the improvement of instrumentation, smaller and lighter planets are being possible to be characterized through this method as well. Unlike Hot Jupiters, planets with periods of < 10 d and masses of $0.03 - 0.3$ $\mathrm{M_{jup}}$ (or equivalently $9.5 - 95$ $\mathrm{M_\oplus}$) are evidently fewer than neighboring region. Such a phenomenon is coined as *Neptunian Desert* and planets in this desert are called *Hot Neptunes*.

This thesis presents an atmospheric characterization of a Hot Neptune, K2-100 b. This transiting planet discovered by the K2 mission is orbiting around a young star (0.8 Gyr, a member of the Praesepe cluster) with a semi-major axis of ~ 0.02 AU and a period of ~ 1.67 d. The planet radius is estimated to be 3.88 ± 0.16 $\mathrm{R_\oplus}$ and its mass is recently estimated to be 21.8 ± 6.2 $\mathrm{M_\oplus}$. The planet is situated in the middle of the Neptunian Desert and critically important to understand if such a planet has an atmosphere and what their compositions are. Because of its youth and its location in the desert, it might also provide information of the origin of Hot Neptunes.

The aim of this thesis is to search for molecules and to confine properties of K2-100 b with Cross-Correlation Function (CCF) analysis in its high-resolution near-infrared spectra obtained with the infrared high-dispersion spectrometer IRD on the Subaru 8.2-m telescope during the transit phases. Starting with two-dimensional echelle format spectral data, one-dimensional spectra were subtracted with a pipeline dedicated for IRD (PyIRD). Then further reductions, like masking sky emission lines, blaze function correction and masking outliers, were carried out. After that, data were passed through a de-trending algorithm, SYSREM, to remove systematic effects like stellar signals and telluric lines. Model spectra were generated with target species including H_2O, FeH, CO, CO_2, HCN and CH_4, and pre-processed before applying CCF.

The results show non-detection for above 6 species. Although there are two suspicious signals of H_2O and HCN, they are ruled out by injection test. Non-detection results and injection tests suggest the important information about K2-100 b as below. i) If the assumption of H-He dominated atmosphere is correct, water abundance is low and hazes or clouds may exist in low pressure (higher altitude), preventing us from retrieving features in relatively flat spectra. ii) If the assumption of H-He dominated atmosphere is wrong, K2-100 b may have an atmosphere consisting of heavier molecules, unlike Hot Jupiters. If this is the case, K2-100 b probably formed through loss of H-He envelope during its evolution. In order to conclude this, more extensive observations of K2-100 b and a greater number of observations on Hot Neptunes are necessary.

Keywords: exoplanets, Hot Neptunes, atmosphere, high-resolution, spectroscopy

THE LUMINOSITY AND MASS FUNCTIONS OF HOST GALAXIES FROM SDSS SUPERNOVAE UTILIZING SUBARU HSC WIDE FIELD SURVEY DATA

すばる望遠鏡 HSC 広視野サーベイデータを活用した SDSS 超新星母銀河の光度関数と質量関数

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Type Ia supernovae (SNe Ia) occur in low-mass white dwarf (WD) binary systems, and they are expected to undergo a long-term evolution. On the other hand, core-collapse SNe (CC SNe) originate from massive progenitors, and their properties are believed to be closely related to star-forming activities. Over the past decades, substantial studies have found correlations between SN properties and their host galaxy environments. However, reliable statistical studies on SN hosts based on uniform SN surveys remain incomplete, especially that the SN host luminosity functions and stellar mass functions have not yet been well understood. In this thesis, I present the derivation of SN host luminosity functions and stellar mass functions based on the homogeneous samples from the Sloan Digital Sky Survey II (SDSS-II) Supernova Survey. The survey SN efficiencies are inferred from the reported supernova rates (SNRs). Subsequently, SN host properties, such as stellar mass and star formation rate (SFR), are estimated using the high-signal-to-noise ratio (SNR) photometry from the Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP) WIDE survey and the state of the art spectral energy distribution (SED) fitting technique (Boquien et al., 2019, `CIGALE`). The SED fitting results are validated by comparison with an independent SED fitting software, `MIZUKI` (Tanaka, 2015), and by fitting infrared photometry with the Wide-field Infrared Survey Explorer (WISE) W3 band for some host galaxies. Moreover, synthesized SED models are compared with the SDSS spectra for some SN hosts. I also divide SN hosts into the star-forming group and the passive group based on the SED fitting results. Afterwards, the luminosity functions and stellar mass functions are derived using the $1/V_{\rm max}$ estimator, and the Schechter function fits are performed. I find the Schechter luminosity parameters set $[\phi^*, M^*_{^{0.1}r} - 5\log h, \alpha]$ of $[(3.25 \pm 1.09)\times 10^{-5}, (-20.68 \pm 0.28), (-0.62 \pm 0.18)][h^3{\rm Mpc}^{-3}{\rm mag}^{-1}, {\rm mag}, 1]$ for SN Ia hosts, and the set of $[(2.14 \pm 0.65)\times 10^{-4}, (-19.01 \pm 0.25), (-0.19 \pm 0.30)][h^3{\rm Mpc}^{-3}{\rm mag}^{-1}, {\rm mag}, 1]$ for CC SN hosts. I also find the stellar mass parameters set $[\phi^*_\star, \log(M^*_\star/M_\odot), \alpha]$ of $[(2.91 \pm 0.59)\times 10^{-5}, (11.00 \pm 0.05), (-0.606 \pm 0.08)][h^3{\rm Mpc}^{-3}{\rm mag}^{-1}, {\rm dex}, 1]$ for SN Ia hosts, and the set of $[(2.91 \pm 1.49)\times 10^{-4}, (10.36 \pm 0.14), (-0.067 \pm 0.30)][h^3{\rm Mpc}^{-3}{\rm mag}^{-1}, {\rm dex}, 1]$ for CC SN hosts. Through the homogeneous SN survey and the consistent estimations for galaxy properties, solid comparisons between SN Ia hosts and CC SN hosts, and between star-forming hosts and passive hosts, can be discussed. Results are found to be consistent with previous studies. The derived functions can serve as good references for the future SN host statistics and the SNR studies.

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Thesis Abstract

Unveiling the Atmosphere of a Hot-Saturn with High-Resolution Spectroscopy: Evidence of Water Vapor in the Atmosphere of HD 149026 b

高分散分光によるホットサターンの大気の解明：HD 149026 bの大気における水蒸気の証拠

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Transmission spectroscopy has emerged as a highly productive method for characterizing exoplanet atmospheres. This technique takes advantage of the planet passing in front of its host star, causing the planet's atmosphere to absorb a fraction of the starlight, imprinting the planetary absorption onto the observed stellar spectrum. By effectively "separating" the stellar and planet spectra, we can eventually detect and study the planet's atmosphere. High-resolution spectroscopy is particularly valuable for this study. It allows us to probe higher atmospheric levels and resolve the planet's atmospheric features into individual lines. This enables us to separate the Doppler-shifted planetary lines from the relatively (quasi-)static stellar and telluric lines, allowing for robustly detect atmospheric species, as well as the dynamics. Hot Jupiters have been the primary targets for transmission spectroscopy observations due to their large size, high temperature, and close proximity to their host stars. As a result, they generate strong transmission signals. By studying the chemical composition of these atmospheres, we can gain insights into their formation history, as the atmospheric composition reflects the surrounding chemical environments.

We analyzed the near-infrared high-resolution transmission spectrum of a hot Saturn, HD 149026 b, taken by CARMENES spectrograph ($\mathcal{R} \sim 80,400$). We found evidence of H_2O at an S/N of ~4.8 and, using a likelihood framework, a detection significance of 4.7-σ. Using this signal, we constrained the orbital velocity K_p and systemic velocity V_sys to $159.48^{+9.97}_{-9.70}$ km s^{-1} and $-13.94^{+0.60}_{-0.67}$ km s^{-1}, respectively. Whilst the retrieved K_p value is consistent with theoretical prediction, the retrieved V_sys value is surprisingly highly red-shifted (6-σ away from the expected value). This might be an indication of anomalous atmospheric dynamics at play, although the quality of our data prevents us from doing further analysis. Additionally, we searched for HCN but no successful detection has been made, implying either a solar C/O ratio atmosphere or that our data cannot be used to detect the species due to its limited quality. The detection of H_2O and subsequent abundance retrieval, coupled with analysis of other species such as CO at the K-band, for example, might help us to get some information about the atmospheric C/O ratio and metallicity, which in turn could give us some insight into the planet formation scenario.