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論文要旨集

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3-5 µm dust reverberation mapping of active galactic nuclei in the North Ecliptic Pole field

北黄極領域における活動銀河核の $3-5\,\mu$m ダスト反響マッピング

35-196121

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An active galactic nucleus (AGN) emits intense electromagnetic radiation from a very compact region in the center of the galaxy, whose huge energy comes from the mass accretion onto the supermassive black hole (SMBH). A dust torus located around the SMBH is a potential mass reservoir to the SMBH, but most of the mass is fed back to the host galaxy by outflow with energy, which will influence the star-formation activity. Therefore, investigating the properties and structure of the dust torus is important to understand the co-evolution of the SMBH and the host galaxy.

Near-infrared (NIR) emission of AGNs is dominated by thermal radiation of hot dust in the innermost region of the dust torus, which is the junction of the outer dust torus and the broad line region surrounding the accretion disk. Since direct imaging of the innermost region of the dust torus is challenging due to its compactness, dust reverberation mapping, which measures the lag between the optical and NIR flux variations as an indicator of the radius of the hot dust region in the dust torus, has a unique importance in investigating it and has been widely used for AGNs based on NIR monitoring programs by using ground-based telescopes at wavelengths of $1-2.2\,\mu$m. Recently, some studies performed dust reverberation mapping at $3-5\,\mu$m wavelength using the *WISE* satellite: however, their targets are limited only to luminous AGNs with long delays because of the cadence problem due to the satellite's orbit. Therefore, no study directly compares dust torus size at $2-5\,\mu$m with AGNs with the same luminosity.

In this study, we focused on the North Ecliptic Pole (NEP) region, where the *WISE* satellite provides continuous and high-cadence monitoring data to apply dust reverberation mapping to less luminous AGNs at $3-5\,\mu$m. First, we examined the W1- and W2-band light curves of 553 AGNs taken from the catalog of the ROSAT Raster survey in the NEP field and selected 5 AGNs based on their variability, which is suitable for the dust reverberation mapping analysis. Then, we conducted dust reverberation mapping analysis using gaussian process regression (JAVELIN; Zu et al. 2011). We measured with high accuracy about 100 days as a time lag between $3-5\,\mu$m and 477 nm light curves. After that, we estimated their AGN optical luminosities with composite SED of SDSS AGNs. Finally, we successfully compared low-luminous AGNs with at $2-4\,\mu$m wavelengths in the rest frame for the first time using the *WISE* data. The result shows that the region of the hot dust emission is almost identical at $2-4\,\mu$m. This result is consistent with the simulation of the infrared reverberation response of the dust torus (Almeyda et al. 2017; 2020), which suggests that hot dust in the innermost region of the dust torus has a clumpy structure.

TriCCSを用いたパルサー候補の可視光探査

35206129

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The time resolution of conventional optical imaging of variable objects have been limited to a minute timescale by CCD readout time, but recently, new instruments such as the Tomo-e Gozen camera on the 1.05-m Schmidt telescope at the Kiso Observatory (Institute of Astronomy, Graduate School of Science, the University of Tokyo) and TriCCS (TriColor CMOS Camera and Spectrograph) on the Seimei 3.8-m telescope at the Okayama Observatory (Kyoto University), have achieved high time resolution by using CMOS sensors, which enable optical imaging observations of variability on a timescale of one second or less.

In this study, I search the optical counterpart of a pulsar using TriCCS. The pulsar I studied was PSR J1836+5925 which is a nearby pulsar found with γ-ray observations. A script to perform a phase-folding analysis, which is a method to fold the observed data with a period, was developed and used for the extremely bright known pulsar, Crab pulsar, to confirm the method. Then PSR J1836+5925 was analyzed, but no optical periodicity was visually found among objects near PSR J1836+5925. The 3 σ limiting magnitude for detection was 21.81 mag (r band).

従来の可視光での変光天体の撮像観測はCCDの読み出し時間などの制約によりタイムスケールが分以上のものが対象であったが、東京大学大学院理学系研究科附属天文学教育研究センター木曽観測所の1.05mシュミット望遠鏡に搭載されたTomo-e Gozen カメラや京都大学岡山天文台のTriCCS(可視3 色高速撮像分光装置) は、CMOSセンサを用いることで高い時間分解能の撮像観測を実現し、可視光における秒以下のタイムスケールの変光現象の探査を可能にした。

本研究ではTriCCSを用いてパルサーの可視成分の探査を行った。調べたのはガンマ線で同定された近傍のパルサーPSR J1836+5925である。観測データを周期で折り畳む手法であるPhase-folding 解析を実行するスクリプトを作成し、既知のパルサーの中でも極めて明るいCrabパルサーのデータに対して使用して周期性を確認した。その上でPSR J1836+5925周辺領域の解析を行ったが写っている天体において目に見える周期性は確認できなかった。また天体検出の限界等級は21.81等(3σ, rバンド)であった。

Mid-Infrared Observatory MIMIZUKU of 30 micron band-pass filter and Evaluation Si:Sb detector

（中間赤外線観測装置 MIMIZUKU における 30 ミクロン帯バンドパスフィルターおよび Si:Sb 検出器の評価）

35-216116　飯田熙一

The mid-infrared is a very important wavelength band for observing circumstellar dust, but has not been studied extensively because most of it is absorbed by water vapor in the atmosphere. Our developing mid-infrared instrument MIMIZUKU has a MIR-L channel which covers 24-38μm（so called 30μm-band). In this study, I realized a 30㎛ bandpass filter and prepared for the detector drive.

Observations in the 30 ㎛ band require short-wavelength leakage to be adequately suppressed. Considering observations of high-temperature objects, I define the leakage quantitatively and set its acceptable value of less than 2%. To achieve this, I found that four of metal mesh filters need to be stacked. A jig for stacking 4 filters was fabricated. Using the jig, I measured the transmittance of the four stacked filters and found that the short-wavelength leakage was about 10 times larger than expected. The cause is not completely clear, a possible explanation is due to multiple reflections between the filters. If this is the case, this leakage is not a matter when it is mounted on the MIMIZUKU optics.

The MIR-L channel equips a Si:Sb detector manufactured by DRS. This was used in the previous instrument, but the clock and bias have been newly adjusted for installation in MIMIZUKU. I carried out the adjustments and conducted a room temperature drive test with the readout circuit ROIC alone and a low temperature drive test with the Si:Sb detector. A simple analysis confirmed that the images were obtained correctly. In addition, a temperature model of the detector box was established, and its validity was confirmed by a heat generation test using a heater. By applying this model to actual temperature data from a Si:Sb detector driven at low temperatures, a detector heat generation of 4 mW was obtained.

（和文）

中間赤外線は星周ダストを観測する上で非常に重要な波長帯であるが、その大部分は大気中の水蒸気に吸収されるため、これまであまり観測研究が進められていなかった。そこで現在開発が進められているのが、TAO6.5m 望遠鏡に搭載予定の中間赤外線観測装置 MIMIZUKU である。MIMIZUKU の光学チャンネルのうち、MIR-L チャンネルは波長 24–38 ㎛ (30 ㎛帯)をカバーする。本研究では MIR-L チャンネルについて、30 ㎛帯バンドパスフィルターの実現および検出器駆動に向けた開発を行った。

30 ㎛帯の観測には短波長のリークを十分に抑える必要がある。高温の天体を観測した場合を想定してリーク量を定義し、その許容量を 2%以下と定めた。これを達成するには我々が用いるメタルメッシュフィルターを４枚重ねる必要があることを計算で求め、フィルター４枚を重ねて設置するための治具を製作した。製作した治具を用いて４枚重ねフィルターの透過率を測定した結果、短波長リークが想定の約 10 倍大きいことが分かった。その原因は必ずしも明らかではないが、フィルター間の多重反射によるものだと推測している。なお、MIMIZUKU 本体に搭載した際は多重反射の影響は無視できる。

検出器駆動に向けた研究では、MIR-L チャンネルに搭載する DRS 社製の Si:Sb 検出器を駆動するために必要な検証・準備を行った。この検出器は以前別の装置で用いられていたものであるが、今回新たに MIMIZUKU 搭載用にクロックやバイアスを整備した。これを用いて読み出し回路 ROIC 単体での常温駆動試験と Si:Sb 検出器での低温駆動試験を実施し、画像が取得できていることを確認した。また、検出器箱の温度モデルを構築し、ヒーターによる発熱試験でその有効性を確認した。さらに、Si:Sb 検出器を実際に低温駆動した温度データにこのモデルを適用することで、現在のバイアス・クロックでの検出器駆動時の発熱が 4 mW であると求まった。

国内電波望遠鏡を用いた Fast Radio Burst の初検出

35-216117 池邊蒼太

Abstract

Fast Radio Bursts (FRBs), which were detected in 2007 for the first time, are astronomical phenomena that emit short-time radio pulses. The duration time is typically $\sim$ milliseconds. We have not obtained a whole understanding of progenitors and emission mechanisms of FRBs yet although a lot of research has been carried out since its discovery. Multi-frequency observation is important to constrain emission mechanisms.

Therefore we carried out observations at various frequencies by using Japanese radio telescopes in this work. The frequencies we observed were higher than those where many FRBs have been detected. The lowest frequency was $\sim$ 2 GHz, and the highest was $\sim$ 22 GHz. Japanese radio telescopes are less sensitive and have a narrower field of view than overseas, so we aimed to nearby and bright repeating FRBs, from which multiple FRBs have been detected. The FRB sources we observed in this research were SGR 1935+2154 and FRB 20201124A. We performed $\sim$193 hours of observations in total, and I analyzed all of them.

As a consequence, we detected an FRB at S-band ($\sim$2 GHz) on February 18th, 2022 from FRB 20201124A by using the 64 m radio dish of Usuda Deep Space Center (UDSC)/JAXA. This is the first FRB observed by using a Japanese facility. This FRB was so bright that the digital system was saturated and a dent occurred around the FRB. This phenomenon is called digitization artifact. The detected FRB was also affected by this phenomenon, so we could not measure a correct flux/fluence. We obtained a lower limit the flux of $>$ 114 Jy, and the fluence of $>$ 189 Jy ms. We placed an upper limit on the spectral index $\alpha = -2.14$ from the detection of the S-band and non-detection of the X-band at the same time. For a while, I estimated rough sensitivities of VERA 20 m at 2 GHz and 22 GHz, Hitachi 32 m at 6 GHz, Takahagi 32 m telescope at 22 GHz from other observation results.

I compared the FRB detected in this work with the previous FRBs. I compared the event rate of the FRB with those from previous research by correcting differences in frequency and sensitivity between different telescopes. I propose that the power law of the luminosity function might be broken at lower fluence ($\ll$ a few Jy ms) and the fluences of bright FRBs might be distributed up to over 2 GHz with the power law against frequency as a result. In addition, we represent that the energy density of the FRB is comparable to the bright population of one-off FRBs, from which only one FRB has been detected in contrast to repeating FRBs. This result suggests the possibility that repeating FRBs are capable to emit as bright FRBs as one-off FRBs; that is, some FRBs classified as one-off FRBs might be repeating FRBs intrinsically. To investigate this possibility, further observations of both repeating and one-off FRBs are needed.

The detailed chemical abundance analysis of RR Lyrae variables with high-resolution near-IR spectroscopy

近赤外高分散分光観測に基づく RR ライリ型変光星の化学組成解析

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35-216118

RR Lyrae variables, the target of this thesis, are old ($> 10\,\mathrm{Gyr}$), low-mass ($0.5 - 0.8\,M_\odot$) variable stars located on the horizontal branch in the Hertzsprung-Russel diagram, with a typical pulsation periods around 0.2–1 days. They are distance indicators thanks to their period-luminosity-metallicity relationship but also good tracers of old Galactic components. There have been many studies measuring the chemical abundances of RR Lyrae by high-resolution spectroscopy, but these works are dominated by optical spectroscopy. Near-infrared spectroscopy would enable us to investigate wider areas of the Galaxy, because it is less affected by interstellar absorption.

In this study, we observed four RR Lyrae stars (RR Lyr, TT Lyn, TU UMa and SU Dra) multiple times with the near-infrared high-resolution spectrograph named WINERED, $\lambda/\Delta\lambda$ around 28,000 covering 0.9–1.35 μm. With the help of spectrum synthesis, we made up the near-infrared zYJ-band line list for RR Lyrae stars, and established the method of deriving chemical abundances using this line list. This method includes the calibration of the systematics of line-by-line abundances, mainly because the correct oscillator strength values ($\log gf$) of near-infrared range are yet to be established.

As the result, we found lines of 10 kinds of species (C I, Mg I, Mg II, Si I, S I, Ca I, Ca II, Fe I, Fe II and Sr II), among which silicon lines are the largest in number, 22. We succeeded in deriving these abundances with the error about 0.05–0.1 dex, except for a few elements with a limited number of lines. The measurements with multi-phase spectra of each target give consistent abundances within the error except for a few species, which might be affected by systematics caused by phase-dependent stellar parameters. Our results agree more-or-less with previous works based on optical spectra, whereas there were comparable scatters, $\gtrsim 0.2\,\mathrm{dex}$, among the measurements in those previous works. This is the first work which derived the abundances of RR Lyrae stars in the zYJ band, and it paves a way for measuring chemical abundances of obscured RR Lyrae, like the one in the Bulge. As metallicities of our targets are concentrated to [Fe/H]~ -1.5, the follow-up observations of RR Lyrae with a wider range of metallicity are required for broader applications of RR Lyrae.

Extremely high-resolution simulations of dwarf galaxies

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Abstract

The core-cusp problem is a problem that dark matter halos of dwarf galaxies have a cuspy core ($\rho \propto r^{-1}$) in the dark matter only simulations, but ones in observations have flat cores ($\rho = \text{Const.}$). This problem can be solved by considering baryonic feedback. Recent simulations of dwarf galaxies suggest a diversity of the halo density profiles from cusp to core, but the results still depend on baryon models adopted in the simulations. Therefore, recent numerical studies have focused on smaller dwarf galaxies, which are more dominated by dark matter and where the baryonic effect is smaller. For small dwarf galaxies, the cores can be at or below the numerical convergence radii, which depends on the mass resolution (Power et al. 2003). However, it is not easy to reduce the convergence radius beyond its current value, because the Simple Stellar Population (SSP) approximation (treating a single particle as a group of stars with a certain mass distribution) is used in conventional galaxy formation simulations, and it limits the resolution. In this study, I developed a new method based on the Star-by-Star method (Hirai et al. 2021), in which stars are modeled as individual particles. I implemented the new scheme in an N-body/smoothed-particle hydrodynamics code ASURA+BRIDGE. Using this code, I carried out three types of dwarf galaxy formation simulations with a halo mass of $M_{\text{halo}} \sim 10^9\,M_\odot$. The mass resolution of the particles reached $\sim 100\,M_\odot$ and $\sim 20\,M_\odot$ for dark matter and gas, respectively. In my simulated dwarf galaxy, there were no obvious cores in the dark matter density distributions, and the difference between the dark-matter-only (DMO) and hydrodynamical (Hydro) models was small. The power-law fit ($\rho \propto r^\alpha$) to the dark matter density profiles within $1-2\%$ of the virial radius gave $\alpha^{\text{DMO}} = -1.504$ for the DMO model and $\alpha^{\text{Hydro}} = -1.561 \pm 0.004$ for the Hydro model, which are cuspy. Although the difference between the DMO model and the Hydro model is small, I found that baryon made the power-law slope of the central region of the halo steeper in my simulation. The dark matter density profiles were well fitted by the NFW and Einasto profiles, but I found that the fitting method can affect the decision between core and cusp. I also compared the $M_\star/M_{\text{halo}} - \alpha$ relation to those of observations and other numerical studies and confirmed that my result is consistent with previous simulations of dwarf galaxy formation and not significantly different from observations.

「XRISM 衛星搭載極低温検出器における電磁干渉の影響評価と低減」　35-216120　栗原明稀

A cryogenic detector is a thermal detector that operates at sub-Kelvin temperatures. With its high sensitivity, there are many plans to adopt it in astronomical instruments. In order to achieve optimal performance, stable and low noise levels are required. One of the major noise risks is electromagnetic interference (EMI) from other equipment, which has caused performance degradation in previous astronomical instruments. However, the methodology for EMI control design has not yet been consolidated in contrast to other satellite design methods such as in thermal and structural design.

The X-ray imaging spectroscopy satellite mission (XRISM), scheduled for launch in 2023, will be equipped with an X-ray microcalorimetry-based cryogenic spectrometer, *Resolve*. The *Resolve* detector operates at 50 mK and has an almost identical design to the soft X-ray spectrometer (SXS) on the short-lived X-ray astronomy satellite ASTRO-H. *Resolve* is highly promising to open up new frontiers in science by inheriting the innovative spectroscopic capability in the X-ray band ($\Delta E_{\mathrm{FWHM}} \sim 5$ eV@6 keV on orbit) achieved by SXS.

SXS suffered from EMI originating from the satellite bus system. The exact coupling mechanism could not be fully determined during ground testing, and part of the evaluation was left to be performed in-orbit. This paper addresses this problem passed down to the successor *Resolve*. Specifically, we evaluated the impact of the following three EMI risks.

1. Low-frequency magnetic EMI from the attitude orbit control system of the satellite
2. Radio-frequency EMI from the satellite communication system
3. Conductive EMI from the satellite power supply system

For each, defining the electromagnetic interface between the satellite bus part (the interferer) and the mission equipment part (*Resolve*), we conducted ground tests at the subsystem level (with the mission part) and system level (with the satellite bus + the mission part). In addition, we took advantage of electromagnetic simulations to achieve an end-to-end quantitative evaluation as well as illustrate the physical interpretation of the phenomena. Overall, the risk of performance degradation of the *Resolve* detector due to satellite EMI was sufficiently reduced prior to launch. Summaries of the results obtained for each are as follows.

(1) Low-frequency magnetic EMI: Magnetic torquers (MTQs), one of the satellite attitude actuators, are driven with 127 Hz pulse-width modulation. In SXS, the line noises detected at the driving frequency and its harmonics caused the degradation of spectral resolution, though the coupling nature was not well understood. Therefore, under the assumption that the magnetic field created by the MTQs caused this degradation, we tested the possible coupling between the MTQs and *Resolve*. In the subsystem level test, we drove a spare MTQ from ASTRO-H under different configurations and examined the detector response. The line noise was observed at 127 Hz and its harmonics similar to SXS. Furthermore, by changing the distance between the MTQ and the detector, we found that the magnetic field from the MTQ accounts for a large part of the line noises. The magnetic field simulation calculations also support this result. In the system level test, we measured the noise contribution in all three MTQ axes and found the results are qualitatively consistent with what was observed in SXS. Based on the results obtained, we speculated the coupling mechanism. Moreover, we executed test runs of in-orbit operations and confirmed the degradation of energy resolution was less than that of SXS. We also developed a tool to calculate the degradation at a given MTQ operating condition as a preparation for the unexpected aggravation in orbit.

(2) Radio-frequency (RF) EMI: There is a metal lid called a gate valve on the top of the vacuum chamber (dewar) in which the *Resolve* detector is housed. The gate valve remains closed on the ground to maintain vacuum and the dewar works as a Faraday cage. However, once it is opened for scientific observation in orbit and the cage is broken, RF signals from the satellite communication system can potentially jeopardize the *Resolve* detector. This RF EMI has not yet been investigated in SXS, so we arranged and executed a new evaluation test. The potential optical coupling path from the communication antennas to the detector was divided into two parts with the interface at the gate valve: the first half was evaluated by electromagnetic simulation whereas the second half by measurement. In the simulation, we solved the Maxwell equations numerically to calculate the worst-case electric field strength at the interface due to the communication antennas. The simulation model includes satellite structures taken from a detailed satellite CAD model and the results were calculated using the supercomputer Fugaku. In the measurement, radio signals sufficiently stronger than the simulated value were injected from the interface into the interior of the dewar. No significant response was observed at the detector, and we concluded that the performance degradation due to RF EMI from the satellite communication system can be negligible.

(3) Conductive EMI from the power supply system: XRISM satellite has various power-consuming devices that share a single bus power supply. Thus, the electromagnetic noise generated by each device can propagate to one another through the bus power supply. We investigated this conductive EMI with *Resolve*. The interface for conductive EMI testing and the requirement noise level there were set accordingly to the mission criteria. In the subsystem level test, we injected artificial sinusoidal fluctuations of the bus voltage from the interface and obtained the detector response. In the system level test, we measured the noise level at the interface and detector outputs under various satellite operating conditions. End-to-end evaluations based on the tests conclude that there is no change in the observation performance due to conductive EMI under nominal operation conditions.

「XRISM 衛星搭載極低温検出器における電磁干渉の影響評価と低減」 35-216120 栗原明稀

極低温検出器はサブケルビンオーダーの極低温下で動作する熱検出器である。光子に対して非常に高い感度が実現できるため、天文学分野で盛んに研究が進んでおり、今後の多くの天文観測装置で採用の計画がある。しかし、その性能を引き出すには、安定した低雑音環境が必要である。主要な雑音源の一つに検出器外部からの電磁干渉が知られており、これまでの天文観測装置でも性能の劣化が報告されている。しかし、電磁干渉設計についての方法論は、標準化が進んでいる衛星設計分野でも、未確立である。

2023 年打ち上げ予定の X 線撮像分光衛星 XRISM には、X 線マイクロカロリメトリをベースとした極低温分光装置 *Resolve* が搭載される。50 mK 下で動作し、その設計は短命に終わってしまった X 線天文衛星 ASTRO-H に搭載された軟 X 線分光装置 SXS を踏襲している。SXS が実現した X 線帯域での革新的な分光能力（軌道上で $\Delta E_{\mathrm{FWHM}} \sim 5$ eV@6 keV）を引き継ぎ、新たなサイエンスを切り拓くことが期待される。

この SXS においても、衛星バス系から検出器への電磁干渉が見られた。しかし、そのメカニズムの理解は確立せず、また一部は軌道上での評価に委ねられていた。これらの課題は SXS の後継機たる *Resolve* に引き継がれた。これに取り組むのが本論文である。以下の 3 つの課題を設定する。

1. 衛星姿勢制御系由来の低周波磁場干渉
2. 衛星通信系由来の高周波電磁場干渉
3. 衛星電源系由来の伝導性干渉

それぞれの課題に対して、衛星バス部と装置ミッション部の間の電磁的インターフェースを定義した上で、サブシステム（装置ミッション部）レベル、システム（衛星バス部 + 装置ミッション部）レベルの試験を実施し、電磁シミュレーションを行って、end-to-end の定量的評価を行った。これにより、衛星電磁干渉による *Resolve* 検出器の観測性能劣化のリスクを打ち上げ前に十分低減することができた。各課題で得た具体的成果は以下の通りである。

(1) 低周波磁場干渉について。SXS では、衛星姿勢アクチュエータの 1 つである磁気トルカ (MTQ) のパルス幅変調駆動周波数 127 Hz 及びその高調波が検出器の線ノイズとして顕著に現れ、分光性能を劣化させていたものの、そのメカニズムは理解されていなかった。そこで、巨大ソレノイドである MTQ が作る磁場がミッション系とカップルするという仮定のもと調査した。サブシステム試験では、ASTRO-H 衛星 MTQ の予備品を条件を変えて駆動し検出器の応答を調べたところ、SXS と同じく、127 Hz およびその高調波に線ノイズが観測された。更に、MTQ と検出器の距離を変更することで、磁場寄与成分が大半であることがわかった。磁場シミュレーションの結果もこれを支持する。システム試験では MTQ3 軸のノイズ寄与について SXS と定性的に整合する結果が得られた。得られた結果を元に、結合のメカニズムを推定した。更に、軌道上のノミナル運用を模擬した試験を行って、観測性能の劣化は SXS と同程度以下であることがわかった。また、MTQ 駆動条件に応じた観測性能劣化をシミュレートするモデルも作成し、軌道上での変化にも対応できるように準備した。

(2) 通信系由来の高周波電磁場干渉について。*Resolve* の極低温検出器が格納されている真空槽 (Dewar) の上部にはゲートバルブという金属蓋がある。地上では真空を保つために閉じているが、軌道上で本格観測が始まると開かれ、Faraday ケージが破れる。このときに衛星通信系の用いる高周波電波が検出器に与える影響を評価した。これは本格運用開始前に終了した SXS で未評価の課題である。通信系アンテナからの検出器までの光路を、ゲートバルブ上をインターフェースとして 2 つに分け、前半を電磁界シミュレーション、後半を試験で評価した。シミュレーションでは、スーパーコンピュータ富岳と衛星詳細 CAD モデルを用いて、Maxwell 方程式の数値計算をし、軌道上運用でインターフェース点に作られる電場強度の最悪ケースを見積もった。試験では、その見積もり値より十分強い電波をインターフェースから Dewar 内部へ入射した。検出器で有意な応答はみられなかったことから、通信系由来の高周波電磁場干渉による観測性能の劣化は無視してよいと結論付けた。

(3) 電源系由来の伝導性干渉について。XRISM 衛星には様々な電力消費機器があり、それらが 1 つのバス電源を共有する。従って、各機器から発生する電磁雑音がバス給電を通して *Resolve* 装置へと侵入する。この伝導性干渉を評価した。まず、衛星と装置間のインターフェイスレベルを設定し、サブシステム試験では人工的な正弦波ゆらぎを持つバス電圧を給電することで、検出器の応答を測定した。また、システム試験では、様々な衛星運用条件で、インターフェース点におけるノイズレベルや検出器の出力を測定した。これにより、end-to-end 評価を行って、定常運用の範囲内で伝導性干渉による観測性能の変化はほぼ見られないことを示した。

連星白色矮星合体によるIax型超新星 SN 1181残骸のモデル構築

35-216121 黄 天鋭

abstract

Binary white dwarf mergers are theoretically predicted to cause diverse phenomena such as Type Ia supernova explosions, collapse into neutron stars through accretion-induced collapse, and the formation of massive white dwarfs. These phenomena are thought to be highly dependent on the composition and mass of the binary white dwarf system, but the details are under debate. A massive white dwarf, J005311, with properties similar to those predicted by theoretical studies of binary white dwarf mergers to form massive white dwarfs, has recently been observed. This object was subsequently observed at multiple wavelength bands from infrared to X-rays and was found to be multi-layered. The location of the object and the expansion velocity of the nebula surrounding it make it a leading candidate for the remnant of a historical supernova SN 1181, whose corresponding object was undiscovered.

In this study, we assume that the nebula IRAS 00500+6713, which contains the white dwarf J005311, was the remnant of SN 1181, and investigate the structure of IRAS 00500+6713 in detail and compare it with observations at multiple wavelengths to determine the mass and explosion energy of ejecta. We also found that fast winds from the surface of the white dwarfs started blowing nearly 1000 years after the merger, and we also made restrictions on when they started blowing. Therefore, this study is the first quantitative evaluation of the evolution of a remnant containing a massive white dwarf after a binary white dwarf merger. In addition, this study strongly supports that IRAS 00500+6713 is a remnant of SN 1181 from our self-consistent dynamical model that explains the multi-wavelength observations.

In addition, we construct axisymmetric self-similar solutions of transonic outflows emanating from a point source including the effect of its rotation. The solutions are constructed exclusively on the equatorial plane. The features of solutions are determined by three parameters; the adiabatic index γ, the dimensionless coordinate of the transonic point, and the dimensionless azimuthal velocity at the transonic point. We classify the solutions into five groups according to the asymptotic behaviors. We find that the behaviors of the self-similar solutions differ depending on whether the value of γ exceeds 11/9 or not. In addition, some solutions show double-power-law density profiles, which are usually seen in ejecta from a binary merger or nova-like explosion. Thus, our self-similar solutions can be applied not only to the outflow blowing from the central spinning objects, but also to the ejecta erupted from the binary merger or nova-like explosion.

Diversity of Type Ia Supernova Optical Light Curves Among Different Spectral Classes

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Type Ia supernovae (SNe Ia) are explosions of a white dwarf that approaches the Chandrasekhar mass ($\sim 1.4 M_{\odot}$) in a binary system. They are worth studying because they give us insight into stellar evolution, they contribute to the chemical enrichment of the universe, they work as standardizable candles to estimate cosmological distances, and for many other reasons.

The progenitor of SNe Ia is unknown, although several hypotheses have been proposed, such as the single-degenerate scenario and the double-degenerate scenario. However, SNe Ia are known to have some unique observational properties. One famous characteristic is that the shapes of their light curves are relatively homogeneous, especially after applying correction using the Phillips relation (Phillips 1993), which states that brighter SNe Ia have wider light curves. Nonetheless, diversity still remains after the correction, and finding an explanation for this diversity is an issue in order to establish a better understanding of these objects and improve their accuracy as standard candles.

The goal of this work is to study the diversities of SNe Ia light curves in terms of spectral subclassification. We adopted the Branch scheme (Branch et al. 2006), which classifies SNe Ia into 4 subgroups according to the pseudo-equivalent widths of SiII absorption lines near maximum light at around 6100Å and 5750Å. The subgroups are core normal (CN), broad line (BL), cool (CL), and shallow silicon (SS).

We used public optical light curve data of 99 SNe Ia (∼20-35 SNe for each subgroup) to make average UBVRI light curves (light curve templates) for each subgroup. Cross-filter K-correction was done to process light curves observed in different filters together, and light curves were fitted to a common template with the least-square method. Taking the average of the fitted light curves, we made template light curves for each Branch subgroup. We also made color curves based on the template light curves.

The light curve templates were mostly similar in the U, B, and V bands, but showed diversity in the R and I bands, especially in the second peak of the I band. To explain the diversity, we investigated spectra of some of the samples used in this research at 20-30 days after maximum, where the dispersion was greatest. As a result, we found that BL and CL SNe tend to have a strong calcium feature in the I-band, which indicates that these SNe have lower ionization temperatures in that epoch. Together with the color curve, we conclude that BL SNe may have lower temperatures than CN SNe, especially from ∼10 days after peak luminosity. There were also a few SNe with extremely strong calcium features in the BL subgroup. These samples had red colors at peak luminosity, which suggests that there may be a group of SNe with low temperatures and/or dusty stellar environments within the BL regime.

Direct Imaging around a Young Stellar Object: Orbital Evolution of CI Tau b

(直接撮像法を用いた若い惑星 CI Tau b の軌道進化の考察)

35−216124
Toshinori Shimizu
清水 利憲

Giant planets around young stars provide a clue to understanding their formation history and planetary orbital evolution. Recently, some close-in giant planets (hot Jupiters) around young stellar objects (YSOs) whose ages are $\lesssim 10\,\mathrm{Myr}$ have been reported by indirect method. The standard formation scenario of a hot Jupiter predicts that planets formed further out from a star and migrated inward. There are several mechanisms that cause planetary migration. A gap-opening planet migrates inward by planet-disk interactions (Type II migration). This mechanism predicts small eccentricities of hot Jupiter since the disk gas can damp the eccentricity. Gravitational perturbations from other outer companions could also cause orbital migration, such as Kozai-Lidov oscillations. In this mechanism, hot Jupiter should have high eccentricity. In general, this high-e migration occurs in $\sim 0.1 - 1$ Gyr after disk dispersal. Therefore, it is essential to study young planetary systems around YSOs to obtain information of their evolution including orbital evolution. CI Tau is a 2 Myr-classical T-Tauri star, which is known as one of the YSOs having hot Jupiter CI Tau b. Previous research of radial velocity method shows that predicted eccentricity of CI Tau b is $e = 0.28 \pm 0.16$. A high eccentricity of a hot Jupiter around YSOs is a challenging to the two migration scenarios. We would like to know how massive outer companions exist around this system in order to unveil orbital evolution of CI Tau b. In addition to this, the Atacama Large Millimeter / submillimeter Array (ALMA) continuum observations show that CI Tau disk has three annular gaps at ∼13, 39 and 100 au, which indicates the existence of additional unseen outer companions. For these reasons, we present high-contrast imaging around CI Tau taken from Keck/NIRC2 L'-band filter and vector vortex coronagraph to confirm the existence of an outer companion around this unique YSO. High-contrast imaging allows us to study around host star suppressing the light of this. We got two imaging data sets and used ADI (angular differential imaging) reduction with pyKLIP package, which is python library to remove the stellar halo and speckles. As a result, we did not detect any other companion. We can derive the detection limits from ADI-reduced images and ruled out the existence of an outer companion beyond ∼ 30 au that can cause the Kozai-Lidov migration of CI Tau b. Regarding three annular gaps at ∼13, 39 and 100 au, the innermost annular gap at 13 au is located inside the inner working angle. For two outer gaps, we confirmed that there is no outer companion with $\geq 2\,M_{\mathrm{Jup}}$ at 100 au and with $\geq 4\,M_{\mathrm{Jup}}$ at 39 au. We reconsider the possibility of Type II migration scenario by calculating a timescale of migration rate of CI Tau b, assuming CI Tau's disk model. Our results suggest that Type II migration from position of snowline still could explain the current orbit of CI Tau b. The eccentricity damping of a migrating planet, however, occurs more quickly than the orbital decay in this scenario. Therefore, a high eccentricity of CI Tau b may not be compatible with a Type II migration scenario unless the eccentricity of CI Tau b may be overestimated. Further follow-up observations are required to determine the eccentricity of CI Tau b more accurately and observe the inner region with deep high-contrast imaging.

Mining for the Protoclusters at $z \sim 4$ from HSC-SSP photometric dataset with Deep Learning

(深層学習を駆使した HSC-SSP 測光観測データによる $z \sim 4$ 原始銀河団探査)

35-216125
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Abstract

Protoclusters are high-density regions at high-z that are expected to evolve into clusters by $z = 0$. Frequent galaxy collisions and mergers and cold gas inflows are expected to accelerate the evolution of galaxies in protoclusters. They are suitable targets for understanding the environmental effects on galaxy evolution. However, the number of identified protoclusters beyond $z > 3$ is small so far and has not been sufficient for a systematic study. In particular, it has been difficult to detect relatively lower-mass protoclusters because a sufficiently large surface number density is required for a conventional detection method using only photometric data, which inevitably have large redshift errors.

In this study, we develop a new point-based deep learning model, PCFNet, to detect protocluster member candidates from the spatial distribution of g-dropout galaxies at $z \sim 4$. We use the sky distribution, i-band magnitude, $(g - i)$ color, and the redshift probability density function of galaxies surrounding a target galaxy in the sky. The PCFNet is trained and evaluated using PCcone, a semi-analytic model. The PCFNet achieves a recall of 7.5 ± 0.2% and a precision of 44 ± 1% when using a detection threshold of 2.5σ, while a conventional model based only on the surface number density of g-dropout galaxies has a recall of 1.5 ± 0.1% and a precision of 38 ± 2%. The PCFNet is found to be able to detect five times more protocluster member candidates with higher accuracy. The protocluster candidates are detected by the peak of the sky distribution of protocluster member candidates. The detection performance of the PCFNet is 13.5 ± 0.8% for completeness, which is defined as the number of detected protocluster candidates relative to the number of true protoclusters in the data for evaluation, and 71 ± 4% for purity, which is defined as the number of correctly detected protoclusters relative to the number of detected protocluster candidates, while the conventional method is $2.6 \pm 0.7\%$ and $65 \pm 9\%$ for completeness and purity. This higher performance of the PCFNet allows more protoclusters to be detected. In addition, the PCFNet can detect lower-mass ($\log M_{z=0,\mathrm{halo}} = 14.0$-$14.5$) protocluster candidates, providing a wider dynamic range of halo mass to allow us to achieve a more general picture of protoclusters.

We apply the PCFNet to the observational data of the HSC-SSP Deep/UltraDeep layer, 112 protocluster candidates are detected from an effective survey area of about $13\,\mathrm{deg}^2$. They show the bright-end excess in the luminosity distribution, which is consistent with previous observations. We are proposing the spectroscopic observation and plan to apply the PCFNet to larger regions such as the HSC-SSP Wide layer. The PCFnet is applicable not only to g-dropout galaxies but also to other dropout galaxies, and this study is expected to be extended to a wide redshift over $z = 2$-6.

Physical characterization of submillimeter-selected dusty galaxies at z=2-6 with strong gravitational lensing

(強い重力レンズ効果を用いて探る サブミリ波帯で選択したダストを豊富に含む z=2-6 の銀河の物理的特徴)

35-216126　Akiyoshi Tsujita/辻田旭慶

Dusty star-forming galaxies play an important role in the evolution of massive galaxies in the universe. Although ALMA has made a breakthrough in our understanding of these submillimeter-selected galaxies, there are still many things that remain unknown about DSFGs, even with the ALMA-era, including detection of dust-obscured AGN in the early universe and physical characterization of mm-faint NIR dark sources. We investigated gravitationally lensed DSFGs to tackle the above problems with the help of lens magnification.

We first present the detection of the CO(12-11) line emission toward G09-83808, a strongly-lensed submillimeter galaxy at z = 6.02, with ALMA observations. A source-plane reconstruction reveals that the region of the CO(12-11) emission is compact (Re ~ 0.5 kpc) and roughly coincides with that of the dust continuum. Non-local thermodynamic equilibrium radiative transfer modeling of CO spectral-line energy distribution reveals that most of the CO(12-11) emission comes from a warm (kinetic temperature of Tkin = 320±170 K) and dense ($\log(n_{H2}/\mathrm{cm}^{-3}) = 5.4 \pm 0.6$) gas, indicating that the warm and dense molecular gas is concentrated in the central 0.5-kpc region. The luminosity ratio in G09-83808 is estimated to be $L_{CO(12-11)}/L_{CO(6-5)} = 1.1 \pm 0.2$. The high ratio is consistent with those in local active galactic nuclei (AGNs) and $6 < z < 7$ quasars, the fact of which implies that G09-83808 would be a good target to explore dust-obscured AGNs in the epoch of reionization.

Next we present ALMA band 3/4 follow-up line scan observations toward three mm-faint NIR-dark sources in two massive clusters which are detected by ALMA Lensing Cluster Survey, a 1.2 mm survey in the 33-lensing cluster regions. We successfully detected CO emission lines and confirmed their spectroscopic redshifts to be z=3.652, 2.391, and 2.985.

We constrained their physical parameters such as stellar mass, star formation rate, gas depletion time, and size of dust-emitting region utilizing rich archival data from HST, Spitzer, and Herschel. One of the sources has a compact dust-emitting region (Re~0.8 kpc) and exhibits high star formation efficiency and far-infrared surface brightness, similar to classical SMGs and previously reported (mm-bright) NIR-dark sources with spectroscopic redshifts, which can be interpreted to be in a merger phase. In contrast, the other one has an extended dust emitting region (Re~2.0 kpc) and exhibits modest star formation efficiency and far-infrared surface brightness, as well as an elongated projected axis ratio. These results suggest that normal dusty star-forming galaxies with edge-on disks can be NIR-dark and may have been missed in previous observations. This is also consistent with recent findings from early JWST observations (Nelson et al. 2022)..

Master Thesis

Weakened magnetic braking mechanism through latitudinal differential rotation on spin-down of solar-type star

by Takato TOKUNO (35-216127)

Abstract

The solar-type stars spin down as a consequence of the removal of the angular momentum (AM) transport by magnetised stellar wind. Such a magnetic braking mechanism has been widely studied by theoretical modelling for wind torque. Although the previous model assuming rigid-body rotation can explain observed basic trends, the two major unsolved problems remained: the wind torque inferred from stellar observations yields about twice as large as the directly measured one in the solar wind; the modelled spin-down rate is overestimated for stars rotating slower than the sun ("weakened magnetic braking").

In order to solve these problems, we investigate the role of latitudinal differential rotation (DR) in the spin evolution of solar-type stars. Recent asteroseismic observation detected the strong equator-fast DR in some solar-type stars. Numerical simulations show that the strong equator-fast DR is a typical feature of young fast-rotating stars and that this tendency is gradually reduced with stellar age. Incorporating these properties, we develop a model for the long-term evolution of stellar rotation. The magnetic braking is assumed to be regulated dominantly by the rotation rate in the low-latitude region. Therefore, in our model, stars with the equator-fast DR spin down more efficiently than those with the rigid-body rotation. We calculate the evolution of stellar rotation in ranges of stellar mass, $0.9\,\mathrm{M}_\odot \leq M \leq 1.2\,\mathrm{M}_\odot$, and metallicity, $0.5\,\mathrm{Z}_\odot \leq Z \leq 2\,\mathrm{Z}_\odot$, where $\mathrm{M}_\odot$ and $\mathrm{Z}_\odot$ are the solar mass and metallicity, respectively.

Our model, using the observed torque in the present solar wind, nicely explains both the current solar rotation and the average trend of the rotation of solar-type stars, including the dependence on metallicity. In addition, our model naturally reproduces the observed trend of the weakened magnetic braking in old slowly rotating solar-type stars because strong equator-fast DR becomes reduced. Our results indicate that latitudinal DR and its transition are essential factors that control the stellar spin down.

ボロメータアレイ検出器搭載望遠鏡のアンテナパターン測定に向けたホログラフィー近傍界測定法の開発

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The primordial gravitational waves predicted by inflation theory are expected to have produced a unique polarization pattern, called B-modes, in the polarization component of the Cosmic Microwave Background (CMB) radiation. In order to observe these weak signals with high precision, we need a telescope with high throughput and a large diffraction-limited field-of-view. Such a telescope also requires a low-noise detector array at its focal plane that is operated at cryogenic temperatures. A crossed-Dragone telescope is an advantageous optical system for wide field-of-view telescopes, but can be prone to stray light systematics, which can contaminate the CMB signal with radiation from the Galactic plane. Such stray light systematics appear as far-sidelobes of the telescope antenna pattern, and therefore we need to accurately characterize the telescope's sidelobe patterns.

LiteBIRD is a satellite mission to investigate the CMB polarization, and the Low Frequency Telescope (LFT; 34 – 161 GHz) is one of telescopes. The LFT is a crossed- Dragone telescope with 400 mm aperture diameter and the FoV is 18° × 9°. The LFT has 1080 transition edge sensors on the focal plane. The required far sidelobes knowledge is －56 dB.

The antenna patterns of the LFT have been characterized with a 1/4-scaled antenna of the LFT and a heterodyne receiver using vector near-field measurement, which directly measure the complex electric fields near the aperture by a millimeter-wave vector network analyzer.

In this study, we present a holographic phase-retrieval method that enables near-field measurements using telescope-equipped bolometric detector array as it is. We place a reference emitter at a fixed position and scan a signal emitter at the telescope aperture. These two emitters are phase-locked and generates interference patterns (holograms) on the focal plane, from which the amplitude and phase of the aperture field can be retrieved. We measured antenna patterns of LFT 1/4-scaled antenna for the three different focal positions at 180 GHz (corresponding to 45 GHz in the real-scale). Antenna patterns derived from the phase retrieval measurements are consistent with those from the vector near field measurements at the sidelobe level of -60 dB for the center and edges of the focal plane. We also measured the cross polarization pattern for the center of the focal plane, and confirmed that it is also consistent at the sidelobe level of -60 dB.

次世代重力波望遠鏡に向けた偏光循環型スピードメーターの制御法の検討

35-216130

西野耀平

In laser interferometric gravitational wave detectors, quantum radiation pressure noise will be the ultimate limit of its sensitivity at low frequencies, which is a back action of the measurement of the mirror position. Speed meters are one of the solutions to reduce quantum radiation pressure noises, which has never been employed in the large-scale gravitational detectors due to its difficulties for practical implementation. The Polarization Circulation Speed Meter (PCSM) is a most promising candidate for the next upgrade, since it requires a small modification only in the anti-symmetric port. This paper is about a new control scheme of the PCSM, which is critical for the practical implementation but has never been investigated so far. Our new scheme, Dual-Retardation Control, will enable a stable control of the PCSM, and bring us closer to its realization in the future gravitational detectors.¥¥ ¥¥

　レーザー干渉計型重力波検出器の感度は究極的には量子雑音に支配され、高周波では主に散射雑音が、低周波では測定の反作用である量子輻射圧雑音が感度を制限すると考えられている。スピードメーターは量子輻射圧雑音を低減する手法の一つであり低周波の感度を大きく改善するが、現状はまだアイデアの段階であり大型の重力波検出器には実装には至っていない。偏光循環型スピードメーターは現在の検出器の主流のデザインの検出ポートに若干の修正を加えるだけで達成できるデザインとして、将来のスピードメーターの実現の最有力候補である。一方で偏光循環型スピードメーターの制御法についてはこれまで検討されてこなかった。本研究は偏光循環型スピードメーターの制御法の現実的な解を世界で初めて示し、将来の大型検出器への導入に向けて当デザインを大きく前進させるものである。

深層学習を用いた太陽高解像度画像のシーイング除去

35–216131　　福満 翔

The Earth's turbulent atmosphere is an obstacle to obtain high-resolution solar images with a ground based telescope. The degradation of images is called seeing. One possible solution to remove the seeing is Adaptive Optics (AO), but it is usually difficult to correct high-order aberrations. In a case of solar observation, especially, AO can correct only the limited Field of View (FOV) although objects have a spreading structure. Another method is post-processing image restoration such as Multi-Frame Blind Deconvolution (MFBD) and Speckle Masking Method, but these methods are insufficient for bad seeing because structures seen in an image are highly diluted. Furthermore, it requires a huge computational cost and is not possible to analyze the images in real-time during an observation. Several studies to use a deep neural network have been proposed in recent years for real-time image restoration. It is important to demonstrate reliability in terms of how close the restored images represent the true solar images in order to use the method based on deep neural networks for actual observations although quantitative evaluation of the reliability is still insufficient in the past studies. In this study, we develop a method to restore images from seeing-degraded images using a deep neural network and evaluate its performance. For quantitative evaluation of the accuracy of the image restoration, solar images obtained by a numerical MHD simulation are degraded by artificial seeing involving simulated wavefront errors. This allows us to compare restored images by the deep neural network with true images before degradation, i.e., the diffraction-limited ideal images without seeing. We demonstrate that the network can achieve the required performance in which errors of the restored images are smaller than the typical noise in imaging observations when the seeing condition is good. We investigate the relationship between various observation conditions and the accuracy of the image restoration by changing telescope apertures, seeing conditions represented by a Fried parameter, observing objects such as granules and sunspots, and observation wavelengths. As a result, although the deep neural network improves the resolution of the restored images, the accuracy of the image restoration is not enough yet and it is more difficult in observations with a large aperture telescope, short observation wavelengths, and bad seeing. The accuracy could be improved by changing how to learn the deep neural network and using the more number of input images.

Development of detector system for high-dispersion near-infrared spectrograph TARdYS and evaluation of detectors

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Abstract

Since the first discovery in 1995, exoplanets have been searched for using various methods: such as radial velocity, transits, astrometry, gravitational microlensing, direct imaging, and pulsar timing. The radial velocity method uses a spectrograph with high spectral resolution to measure the Doppler shift of stellar lines caused by the motion of orbiting planets. Despite increasing number of exoplanet candidates found with the transit method over the past several years, radial velocity measurements are an indispensable method for revealing their nature. Exoplanet exploration has been conducted mainly around sun-like stars, however, in recent years, exploration around M-type stars, which are more abundant in the solar system's vicinity, has been gaining momentum. M-type stars are faint in the visible light due to their low temperature, thus infrared observations are essential.

TARdYS (The Tao Aiuc high Resolution (d) Y band Spectrograph) is a near-infrared high-resolution spectrograph being developed mainly to measure the radial velocity of M-type stars. In this study, we have developed a detector system for TARdYS that drives and reads out the detector and processes its images and evaluated its detector and readout system. For the detector system, an InGaAs photodiode array detector of large format ($1.3k \times 1.3k$) and a data acquisition software MESSIA6 developed at NAOJ are used. MESSIA6 has two sampling modes: Fowler Sampling and Up-the-Ramp Sampling. The detector system can generate final images from unprocessed images sampled by these modes. It is also possible to correct for detector non-linearity on a pixel-by-pixel basis during the generation of the final images.

We then evaluated the performances of the detector and the readout system, that are non-linearity, conversion factor, readout noise, detector glow, dark current, and persistence. The non-linearity is found to be 5% at 1.51×10^5[e^-] (66% of full-well), the conversion factor 3.9[e^-/ADU], the readout noise 3.4[e^-] with Fowler-16 sampling, the median detector glow 0.12 [e^-/read], the dark current 1.5×10^{-3}[e^-/s/pix] at 120[K], and the persistence fraction 0.7% of the exposure level. In addition, our evaluation revealed that as the number of readouts increases, the readout noise initially decreases but then increases due to the detector glow.

We also evaluated detectors of SWIMS (Simultaneous-color Wide-field Multi-object Spectrograph). SWIMS is one of the first generation instrument of TAO 6.5m telescope capable of simultaneous two-color imaging, multi-object spectroscopy, and integral field spectroscopy, and is equipped with four HAWAII-2RGs, two each for the shorter wavelength and longer wavelength foci. The detectors at the shorter wavelength focal plane are named B1 and B2, and those at the longer wavelength focal plane are named R1 and R2. Evaluation was conducted concerning non-linearity, conversion factor, readout noise, etc. The non-linearity of B1, B2, R1, and R2 detectors is found to be 10% at $1.10 \times 10^4, 1.03 \times 10^5, 1.00 \times 10^5$, and 1.05×10^5[e^-], the conversion factor $2.08, 3.13, 2.28, 2.19$[e^-/ADU], and the readout noise $21.0, 29.3, 22.1, 21.6$[e^-], respectively. Furthermore, our analysis indicated that B2 has lower quantum efficiency compared to the other detectors.

With the development of the TARdYS detector system in this study, it is now ready to be handed over to the Universidad Católica de Chile for integration with the optical system. Moreover, the findings obtained in this study will contribute to the development and evaluation of other instruments that utilize near-infrared detectors of similar types.

The Dynamics of the Planetesimal Ring

35-216133 Yohsuke Mizutani

Recently, ALMA observation shows that protoplanetary disks around the young stars commonly have ring-like structures in their dust disk. In the standard scenario of planet formation , dust grows into planetesimals Thus it is expected that planetesimal rings are common in the planet formation. Moreover, there are some studies that predict such planetesimal ring stage in the planet formation. Therefore, the theoretical studies on planet formation from planetesimal rings are attracting attention. However, most of such studies focus on the growth from protoplanets that are formed from planetesimal rings and skip the pranetesimal growth in the planetesimal ring. It is necessary to study the evolution of planetesimal rings, because the planetesimal rings assumed in the previous works do not necessarily evolve into their initial condition of N-body simulation. As the first step to study the evolution of planetesimal rings, I investigated the orbital evolution of such rings, which is the basis of planetesimal accretion.

To study this, I developed an N-body simulation code based on the fourth order Hermite scheme. Hermite scheme is one of predictor-corrector integrators. This scheme is high precision and autostart method, which allows the code to be concise. In order to reduce the computation time, the block timestep method was used. In this method, each particles are given a discretized timestep which is in the form of 2 to the power of n. This allows particle timesteps to be equal in an period. The gas drag effect on the planetesimals was included in the code. Moreover, GPU was used to accelerate calculation on the gravitational interaction. In the GPU calculations specialized in gravitational force is done. Model parameters were mass of a planetesimal m,the eccentricity e and the inclination i of planetesimal orbit. Calculation was done for 1500 years to observe their orbital evolution. The mean value and dispersion of semimajor axis a and the range of semimajor axis Δa was used to see the ring spreading and the ring migration. The eccentricity and the inclination of orbits were observed to see how much ring initial conditions are maintained. Then, these results with different value of m were compared to reveal the dependence of the ring orbital evolution on m.

Time evolution of accretion gas and circumstellar structure due to core mergers

35-216134
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Abstract

A star forms from a dense molecular cloud core. In the classical model, the effects of the surroundings are neglected in course of the gravitational contraction of a star-forming core. In other words, all the physical properties of stars formed are determined by the physical condition of a parental core. Recently, there is growing observational evidence that the surrounding environments significantly influence the evolution of star-forming cores and the properties of stars formed (e.g., Shimajiri et al. 2019; Takemura et al. 2021). Also, the non-axisymmetric cloud structures around protostellar systems, which are called the streamers, are discovered by observations and numerical simulations (e.g., Pineda et al. 2020). Here, we consider core merger as an example of such environmental effects. In molecular clouds, filaments are common structures and cores are distributed along the filaments. Therefore, core merging along the filaments is expected to occur frequently.

We study the interaction of two dense cores with 3D numerical simulations with adaptive mesh refinement (AMR) and Sink Particle. Our simulation shows that after a protostar (a sink particle) is created, the secondary core merges to form a rotationally-supported disk with a length of $\sim 10^3$ AU which appears to be gravitationally unstable, exciting the spiral structure which accelerates the gas accretion toward the central star, causing the time variability of the mass accretion rate. We observe a time variability of at least 10% at intervals of 0.005 Myr. Besides, the angular momentum of the disk is appeared to be injected from the external secondary core. At the same time of the core merger, the secondary core creates a compressed layer with a length of $\sim 10^4$ AU, which has a non-axisymmetric structure that is reminiscent of the streamer around protostars. Moreover, the streamers have been suggested to be chemically young by observations (e.g., Tokuda et al. 2018; Pineda et al. 2020), assuming that the secondary core is chemically young, the chemical characteristics of the streamers in our simulation could be consistent with that of the observations.

令和 4 年度修士論文

活動銀河核ダストトーラスのガウス過程回帰による多波長同時反響マッピング

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概要

AGN is one of the brightest objects in the universe due to mass accretion into a central supermassive black hole. From studies of AGN's infrared SED, it is believed that there is a structure called a dust torus that emits thermal radiation from the dust. The dust torus is considered to be a source of accreting material to the central black hole. Detailed investigation of their properties is expected to provide important information not only on the properties of AGNs but also on understanding the co-evolution of SMBHs and their parent galaxies, one of the most important issues in astronomy.

A method to examine the dust torus in detail is called dust reverberation mapping. This technique uses flux variability radiation from AGN to obtain information on structures that cannot be directly imaged by compacts. Since infrared radiation from the dust torus is emitted from the gas and dust that received accretion disk radiation, its flux variability is observed after the flux variability of the visible radiation from the accretion disk. This time difference is proportional to the distance from the accretion disk to the dust torus, and the inner radius of the dust torus can be estimated.

Since the high-temperature dust is heated from the center, it is expected that the temperature is lower in the outer part of the dust torus and a radial temperature structure appears. So wavelength dependency of dust emission lag reflects temperature structure of the innermost dust torus. However, the wavelength dependence of the delay in the $J(1.25\ \mu\mathrm{m}), \mathrm{H}(1.65\ \mu\mathrm{m}), \mathrm{K}(2.2\ \mu\mathrm{m})$ bands has not been statistically investigated.

In this study, we first developed a multiwavelength reverberation mapping analysis algorithm for more than three bands as an extension of the JAVELIN method, which uses Gaussian processes, has been used recently. This method simultaneously fits the infrared radiation component from the accretion disk, which changes with the optical flux without delay. The dependence of delay detection accuracy on the number of observed bands is investigated by simulation using mock light curves. As a result, the delay measurement accuracy was improved by increasing the number of simultaneous analysis bands.

Next, we performed a simultaneous multi-wavelength dust reverberation mapping analysis of the $J(1.25\ \mu\mathrm{m})$, $H(1.65\ \mu\mathrm{m})$, and $K(2.2\ \mu\mathrm{m})$ bands for 17 Seyfert galaxies from the MAGNUM project to estimate the systematic inter-wavelength delay differences. As a result, the delay difference between the H and K bands is $\tau_H/\tau_K \sim 0.823^{+0.108}_{-0.074}$, that between the J and K bands is $\tau_J/\tau_K \sim 0.695^{+0.142}_{-0.105}$, and that between the J and H bands is $0.847^{+0.118}_{-0.114}$. The results of this analysis are consistent within error with the predicted inter-wavelength delay ratio of 0.84 - 1.12 calculated for Almeyda et al. (2020), suggesting that the dust torus structure is a clumpy dust torus structure.

概要

AGN は、中心の超巨大ブラックホールへの質量降着によって宇宙で最も明るく輝く天体の一つである。AGN の赤外線 SED の研究から、ダストの熱放射を放つダストトーラスと呼ばれる構造があると考えられている。ダストトーラスは、中心ブラックホールへの降着物質を供給する物質供給源と考えられており、その性質を詳細に調査することは AGN の性質のみならず、天文学の最重要課題の一つである SMBH と母銀河の共進化を理解にも重要な情報を与えることが期待される。

ダストトーラスを詳細に調べる手法として、ダスト反響マッピングと呼ばれる手法がある。AGN からのフラックス変動放射を利用して、コンパクトで直接撮像できない構造の情報を得る手法である。ダストトーラスからの赤外線放射は、降着円盤放射を受けたガスやダストから放射されるため、そのフラックス変動は降着円盤由来の可視光放射のフラックス変動から少し遅れて観測される。この時間差は、降着円盤からダストトーラスまでの距離に比例し、ダスト・トーラスの内半径を推定することができる。高温ダストは中心から加熱されているため、ダストトーラスの外側ほど温度が低くなり、半径温度構造が現れることが予想され、ダスト放射の遅延の波長依存性は、最内部のダストトーラスの温度構造を反映していると考えられる。しかし、$J(1.25\ \mu\mathrm{m}), \mathrm{H}(1.65\ \mu\mathrm{m}), \mathrm{K}(2.2\ \mu\mathrm{m})$ バンドにおける遅延の波長依存性は、統計的に調べられていない。

本研究では、まず、近年よく用いられているガウス過程を用いた反響マッピングアルゴリズム JAVELIN の手法の拡張として 3 バンド以上の同時測光反響マッピング解析アルゴリズムを開発し、遅延検出精度と観測バンド数との依存関係を擬似光度曲線を用いたシミュレーションで調査した。結果、同時解析バンド数を増やすことで遅延測定精度は向上した。

次に、MAGNUM プロジェクトで得られた 17 個の Seyfert 銀河に対し、$J(1.25\ \mu\mathrm{m})$、$H(1.65\ \mu\mathrm{m})$、$K(2.2\ \mu\mathrm{m})$ バンドの多波長同時ダスト反響マッピング解析を行い、系統的な波長間の遅延差を推定した。結果、H,K バンド間の遅延差は $\tau_H/\tau_K \sim 0.823^{+0.108}_{-0.074}$ 、J,K バンド間の遅延差は $\tau_J/\tau_K \sim 0.695^{+0.142}_{-0.105}$ 、J,H バンド間の遅延差は $0.847^{+0.118}_{-0.114}$ であることがわかった。本解析結果は、Almeyda et al. (2020) で計算された波長間遅延比 0.84 - 1.12 の予測と誤差の範囲で一致しており、ダストトーラス構造が clumpy ダストトーラス構造であることを示唆している。