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Low-mass Pop III star formation due to the HD-cooling induced by weak Lyman-Werner radiation
35206132
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Lyman-Werner (LW) radiation photodissociating molecular hydrogen (H_2) influences the thermal and dynamical evolution of the Population III (Pop III) star-forming gas cloud. The effect of powerful LW radiation has been well investigated in the context of supermassive black hole formation in the early universe. However, the average intensity in the early universe is several orders of magnitude lower. For a comprehensive study, we investigate the effects of LW radiation at 18 different intensities, ranging from $J_{\rm LW}/J_{21} = 0$ (no radiation) to 30 (H-cooling cloud), on the primordial star-forming gas cloud obtained from a three-dimensional cosmological simulation. The overall trend with increasing radiation intensity is a gradual increase in the gas cloud temperature, consistent with previous works. Due to the HD-cooling, on the other hand, the dependence of gas cloud temperature on $J_{\rm LW}$ deviates from the aforementioned increasing trend for a specific range of intensities ($J_{\rm LW}/J_{21} = 0.025 - 0.09$). In HD-cooling clouds, the temperature remained below $200\,\mathrm{K}$ during $10^5\,\mathrm{yr}$ after the first formation of the high-density region, maintaining a low accretion rate. Finally, the HD-cooling clouds have only a low-mass dense core (above $10^8\,\mathrm{cm}^{-3}$) with about $1 - 16\,\mathrm{M}_\odot$, inside which a low-mass Pop III star with $\leq 0.8\,\mathrm{M}_\odot$ (so-called "surviving star") could form. The upper limit of star formation efficiency $M_{\rm core}/M_{\rm vir,gas}$ significantly decreases from 10^{-3} to 10^{-5} as HD-cooling becomes effective. This tendency indicates that, whereas the total gas mass in the host halo increases with the LW radiation intensity, the total Pop III stellar mass does not increase similarly.

High-resolution observation of photospheric Doppler velocities near the solar limb

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The solar photosphere is covered with bright cells called granules and dark lanes called intergranules. These patterns are caused by the solar surface convection. The upward flow is observed in bright granules and the downward flow is observed in dark intergranules. The spatially-averaged spectral lines show the blueshift near the disk center because bright up-flow granules have a greater contribution. The shifts of spatially-averaged spectral lines depend on the heliocentric positions so that the horizontal flow of granules contributes to the line-of-sight velocity in an observation away from the disk center. The spatially-averaged spectral lines near the solar limb are known to exhibit redshift, and it has been qualitatively understood that it is caused by the effects of the corrugated 3-dimensional iso-optical depth surface due to convection in the photosphere. However, it is difficult to perform high-resolution spectroscopic observations toward the solar limb while keeping spatial resolution. The numerical simulations of the solar photosphere have been developed, but they cannot reproduce the spectral lines very close to the solar limb because a significantly longer ray-path is required to be calculated. Therefore, the line shifts up to the solar limb are not revealed. Quantitative explanations for the effects of the corrugated 3D convection in the photosphere are still subject to debate.

In this study, we aim to show the spectrum line shifts up to the solar limb and to investigate how the redshifts near the solar limb are caused by 3D convection using observations. The seeing-free observation with the Spectro-Polarimeter (SP) in the Solar Optical Telescope (SOT) onboard the Hinode satellite provides highly accurate spectropolarimetric data up to the solar limb while keeping a high spatial resolution of about 0.3 arcsec enabling resolution of granule structure. The spectral lines of Fe I 630.15 nm, which are observed as absorption profiles on the solar disk, can be observed as emission profiles within 1 arcsec above the solar limb using SOT/SP. We have analyzed absorption lines with classification into those from granules and intergranules. In addition, we have analyzed emission lines. This study provides the following results: 1) the spatially-averaged spectral lines show an increase in redshifts, then become constant, and finally become a small Doppler shift at the solar limb, 2) the spectral line shifts of granules show an increase in redshifts toward the solar limb, but the spectral lines of intergranules show little change in their Doppler shifts, 3) the shape of spectral lines of granules changes more than that of intergranules, and 4) the emission lines show the blueshifts about 130±40 m/s. Our results show that the increase in the redshift of spatially-averaged spectral lines toward the solar limb is caused by the increase in the redshift of granules. Since the asymmetry of the spectral line shapes is caused by the convective structure of the atmosphere along the line-of-sight, our results suggest that the atmosphere on the granules may be more geometrically variable than that of intergralues.

太陽縁近傍における光球ドップラー速度の高分解観測

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太陽の光球は明るい粒模様の粒状斑とそれを囲う暗い網目状の間隙によって覆われている。このような模様は太陽大気の対流によって生じており、明るい粒状斑では上昇流が観測されて暗い間隙では下降流が観測される。太陽面中心では明るい上昇流の粒状斑の寄与が大きいため、平均スペクトル線は青方偏移して観測される。太陽面中心から離れるにつれて大気の水平方向の流れが視線速度に影響を与えるようになるため、太陽面上の位置によって平均スペクトル線の偏移が異なる。太陽の縁近傍における平均スペクトル線は赤方偏移して観測されることがわかっており、光学的厚さの等高面が光球において波打つような3次元的構造を持っているため赤方偏移が増加するような効果が引き起こされていると定性的に理解されてきた。しかし、太陽の縁まで空間分解能を保ったまま高精度な分光観測を行うことは難しかった。一方、光球対流の3次元数値シミュレーションも発展したが、太陽の縁近傍の計算で必要な光路長が長くなるためスペクトル線の再現が困難である。そのため波長偏移の変化は太陽の縁まで明らかになっておらず、太陽大気の3次元的構造がどのように赤方偏移を引き起こすか定量的な結論に至っていない。

本研究の目的はこれまで明らかにされていなかった太陽の縁までの波長偏移を示し、太陽の縁近傍における赤方偏移が太陽大気の3次元的構造によってどのように引き起こされているのかについて観測を用いて調べることである。「ひので」衛星に搭載された可視光望遠鏡(SOT)偏光分光観測装置(SP)は地球大気の影響を受けないため、太陽の縁まで約 0.3 秒角の高い空間分解能を保ったまま高精度な偏光分光観測を行っている。SOT/SPを用いると、縁近くまで粒状斑構造を分解するとともに、太陽面上で吸収線として観測されるFe I 630.15 nmのスペクトル線が太陽の縁外側1秒角以内で輝線として観測できる。この高い空間分解能を活かして、太陽表面を粒状斑部分と間隙部分に分けた場合の吸収線の解析を行い、さらに輝線の解析も行った。この解析により1)太陽の縁に向かって赤方偏移が増加した後、一定になり、さらに縁近くでは偏移が小さくなること、2)粒状斑部分のドップラー速度は太陽の縁に向かって赤方偏移が増加するが間隙部分のドップラー速度は常に赤方偏移していること、3)間隙部分よりも粒状斑部分の方が太陽の縁に向かってスペクトル線の形状が変化が大きいこと、4)輝線は 130±40 m/s青方偏移していることが明らかになった。太陽の縁近傍における赤方偏移の増加は粒状斑部分の赤方偏移の増加によって引き起こされていることを観測を用いて示した。スペクトル線の形状は視線方向の太陽大気の変化を反映しており、間隙部分よりも粒状斑部分の大気の方が幾何学的に変化が大きい可能性が示唆された。

初代星星団：個数・質量分布の Streaming Velocity の依存性

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概要

星形成や銀河形成において星質量はその進化に大きな影響を与えるため, 質量分布を知ることは大きな課題である. 近年, 初代星形成において Streaming Velocity(以下 SV) の影響を考慮すべきであるという報告がある (Tseliakhovich and Hirata 2010, Greif et al. 2011). SV は, ダークマターとバリオンの相対速度のことであり, 大きさの分布は, 赤方偏移 $z = 1089$ の宇宙全体において正規分布をなし, その標準偏差は $\sigma_{SV} = 30\mathrm{km/s}$ であるとされている. また, SV は $1 + z$ に比例するため, 特に初期宇宙においてその効果が顕著に現れる. SV は, 一般的に初代星形成を遅らせ, ハロー内部の高密度領域 (本研究ではガス密度が $10^6\mathrm{cm}^{-3}$ 以上) に含まれるガス質量を大きくする作用があるとされている. 他の複数のチームの研究においても SV は調べられているが, 一般に星形成シミュレーションはガス密度が上がるほど計算能力が必要なため, Hirano et al. (2017, 2018) を除き, ハロースケールが解像できる密度までしか調べられていない ($10^4\mathrm{cm}^{-3}$ 程度). また, Hirano et al. (2017, 2018) では, 星形成まで解像できる密度まで調べているものの, 質量の大きいハローの一例のみに注目しており, SV の効果を含めた最終星質量の統計的調査は行われていなかった. そこで本研究では複数のガス雲に対し, 最大数密度を $10^6\mathrm{cm}^{-3}$ とし, 20 ハローに対して SV を含めた計算を行うことで, ガス雲の合体・分裂まで詳細に追跡し, 質量分布を求めた.

本研究では, 20 モデルのハローに対し 6 種類の SV を加えた初期条件に対しジーンズ不安定性により重力収縮するような高密度ガス雲 (数密度 $10^6\mathrm{cm}^{-3}$ 以上) がハロー内で最初に生じてから 2.00 Myr の数値シミュレーションを行った. そののち, 高密度ガス雲の合体を merger tree を作成することにより調べ, 生じてから free-fall time 経過したものを初代星とみなした. これらの星の質量降着率からHirano et al. (2014) に従って初代星質量を見積もった.

計算および解析の結果, SV が大きくなるにつれて星形成効率が下がり, 星形成ハローの高密度ガス雲の合計質量が大きくなる傾向が確認された. また, ハロー内部で形成される初代星について, SV が $1.5 - 3.0\sigma_{SV}$ と大きい領域における初代星形成では, 1 つのハローにおいて $10 - 50$ 個程度の星形成ガス雲が形成される場合があることが示された. 同じ初期条件を用い, 時刻 2.00 Myr での星形成ガス雲の個数のみを数えた Hirano(in prep) よりも 1-3 倍程度の個数になることが確認され, 最大密度 $10^6 cm^{-3}$ で行った初代星形成シミュレーションにおいては, 2.00 Myr 時点で 1 つのように見えるガス雲の内部に複数 (0-5 個) の初代星が存在する可能性が無視できないことが示された. SV の大きさごとの星質量分布をまとめたところ, ハローがホストする初代星の合計質量はハロー内部の高密度ガス雲の合計質量と強い相関を持つが, ガス雲の分裂・合体を考慮すると, 1 つ 1 つの平均星質量は SV によらず $\sim 200\mathrm{M}_\odot$ 程度であることが示された. $1.0\sigma_{SV}$ より大きな SV では $1,000\mathrm{M}_\odot$ 以上の初代星の存在が許されるものの上限は $3,000\mathrm{M}_\odot$ 程度であった. また, Super Massive Black Hole(SMBH) の候補となるような $10,000\mathrm{M}_\odot$ 以上の初代星は形成されなかった.

宇宙の SV が $1.0\sigma_{SV}$ より領域において, SV はハロー内の高密度ガス雲の性質だけでなく, 初代星の個数や質量にも影響を与えていることが確認された. 今後, SV を考慮した初期質量関数 (IMF) を適用することで初代銀河形成シミュレーションや宇宙の元素進化について今までより詳細にそれらの性質が解明されることが期待される.

Abstract

Since stellar mass has a significant impact on the evolution of star formation and galaxy formation, the mass distribution is a major issue. Recently, it has been reported that the effect of Streaming Velocity (SV) should be taken into account in first star formation(Tseliakhovich and Hirata 2010, Greif et al. 2011). SV is relative velocity between dark matter and baryons, and its magnitude distribution is assumed to be normally distributed throughout the universe at redshift $z = 1089$ with a standard deviation of $\sigma_{SV} = 30\text{km/s}$. Since magnitude of SV is proportional to $1 + z$, the effect is particularly pronounced in the early universe. In general, SV delays the formation of first stars and increase the gas mass in the high-density regions of the halo interior (gas density above 10^6cm^{-3} in this study). Although SV has been studied by several other teams, in general, star formation simulations require more computational power as the gas density increases, and therefore, with the exception of Hirano et al. (2017, 2018), they have only been studied up to the density at which the halo scale can be resolved (10^4cm^{-3}). In addition, although the density up to star formation was investigated in Hirano et al. (2017, 2018), they focused on only one example of a heavy halo, and no statistical investigation of the final stellar mass including the effect of SV were performed. In this study, we obtained first star mass distribution by calculating 20 models of gas clouds with maximum density of 10^6cm^{-3} including SV, and tracing mergers and breakups of high-density gas clouds.

In this study, we performed numerical simulations for 20 models of halo with 6 different SVs added to the initial conditions for 2.00 Myr since the first occurrence of dense gas cloud(number density 10^6cm^{-3} or more) that would cause gravitational contraction due to Jeans instability. The mergers of high-density gas clouds are then investigated by constructing a merger tree, and the stars that have passed the free-fall time are considered to be first stars. From the mass accretion rates of these high-density gas clouds, we estimated the mass of the first stars according to the formula used in Hirano et al. (2014).

The calculation and analysis results show that, as magnitude of SV increases, the star formation efficiency decreases, and the total mass of the dense gas clouds in the star-forming halo tends to increase. It is also shown that in the case of first star formation with SV as large as $1.5 - 3.0\sigma_{SV}$, about $10 - 50$ star-forming gas clouds can be formed in a single halo. The number of star-forming gas clouds is 1-3 times larger than Hirano (in prep), which counted only the number of star-forming gas clouds at time 2.00 Myr under the same initial conditions. Therefore, the possibility of multiple(0-5) first stars in a gas cloud, which appears to be single at 2.00 Myr, cannot be ignored. The distribution of stellar mass for different magnitudes of SVs shows that the total mass of the first stars hosted by halo is strongly correlated with the total mass of the dense gas clouds inside the halo. However, the logarithmic mean stellar mass of each star is about $\sim 200\text{M}_\odot$ regardless of magnitude of SV when the breakup and merger of the gas cloud are taken into account. When magnitude of SV is larger than $1.0\sigma_{SV}$, although the existence of first stars larger than $1,000\text{M}_\odot$ is allowed, the upper limit of the mean stellar mass is about $3,000\text{M}_\odot$. In addition, no first stars larger than $10,000\text{M}_\odot$, which would be candidates for Super Massive Black Hole (SMBH), were formed in our simulations.

In the region where the SV is larger than $1.0\sigma_{SV}$, it is confirmed that SV affects not only the properties of dense gas clouds in halos but also the number and mass of first stars. In future works, it is expected that the application of the initial mass function (IMF) taking into account the SV will lead to a more

detailed understanding of the properties of the simulation of first galaxy formation and the evolution of elements in the Universe.

The Dark Matter Halo Mass of Quasars at $z \sim 6$
$z \sim 6$ におけるクェーサーのダークマターハロー質量に対する観測的制限

35-226100
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Quasars are important objects for studying unresolved questions in the early universe because they shine exceedingly bright driven by the supermassive black holes (SMBHs) at their centers. One of the significant questions is how and when the correlation between galaxies and SMBHs is formed. To answer the question, it is essential to understand the physical property of dark matter halo (DMH) because DMH governs both galaxies and SMBHs. We present, for the first time, DMH mass measurement of quasars at $z \sim 6$ based on a clustering analysis of 107 quasars. Spectroscopically identified quasars are homogeneously extracted from the HSC-SSP wide layer over 891 deg^2. We evaluate the clustering strength by three different auto-correlation functions: projected correlation function, angular correlation function, and redshift-space correlation function. The DMH mass of quasars at $z \sim 6$ is evaluated as $5.0^{+7.4}_{-4.0} \times 10^{12}\, h^{-1} M_\odot$ with the bias parameter $b = 20.8 \pm 8.7$ by the projected correlation function. The other two estimators agree with these values, though each uncertainty is large. The DMH mass of quasars is found to be nearly constant $\sim 10^{12.5}\, h^{-1} M_\odot$ throughout cosmic time, suggesting that there is a characteristic DMH mass where quasars are always activated. As a result, quasars appear in the most massive halos at $z \sim 6$, but in less extreme halos thereafter. The DMH mass does not appear to exceed the upper limit of $10^{13}\, h^{-1} M_\odot$, which suggests that most quasars reside in DMHs with $M_{\rm halo} < 10^{13}\, h^{-1} M_\odot$ across most of the cosmic time. Our results supporting a significant increasing bias with redshift are consistent with the bias evolution model with inefficient AGN feedback at $z \sim 6$. The duty cycle is estimated as 0.019 $\pm$ 0.008 by assuming that DMHs in some mass interval can host a quasar. The average stellar mass is evaluated from stellar-to-halo mass ratio as $M_* = 6.5^{+9.6}_{-5.2} \times 10^{10}\, h^{-1} M_\odot$, which is found to be consistent with ALMA and JWST results.

Design of an ultra-wideband and easy-to-array planar Magic-T
for millimeter-submillimeter continuum imaging

35-226101 Shuhei Inoue

We aim to definitively detect the kinematic Sunyaev-Zel'dovich effect, which has been challenging to detect so far, and capture the gas motion of individual distant galaxy clusters. This endeavor is intended to unravel the dynamic evolutionary processes of galaxy clusters and reduce uncertainties in cluster mass estimation associated with gas motion, thereby driving a new phase of precision cosmology. To achieve this goal, we are developing an ultra-wideband and multi-chroic camera covering the millimeter and submillimeter wavelength range (130-710 GHz), capable of simultaneous imaging in six bands (three millimeter-wave bands at 130-295 GHz and three submillimeter-wave bands at 330-710 GHz). In this study, we established a design method to realize an ultra-broadband Magic-T (180° Hybrid Coupler), a key component of the detector for six-color cameras, in a single-layer dielectric/metal structure that is relatively easy to fabricate for multi-pixel arrays. The Magic-T has the function of combining two signals with phase differences of 0° and 180°, respectively. Astronomical signals pass through a horn antenna and are sent to an Ortho-mode Transducer (OMT) on the detector substrate, which has sensitivity to both polarizations. The OMT converts the signals into circuit signals using two pairs of probes, each corresponding to one polarization. For signals derived from the fundamental mode of the horn, the phases are opposite in the probe pairs corresponding to each polarization. Therefore, the Magic-T is used to differentially combine them. Additionally, unwanted in-phase signals derived from higher-order even modes are terminated or removed by the Magic-T's summing function, playing a role in shaping the beam profile. The basic configuration of the Magic-T consists of three transmission lines of 1/4 wavelength and one transmission line of 3/4 wavelength. The phase difference of 180° is achieved through the difference in line lengths. However, the frequency dependence of the achievable phase difference is significant, resulting in a narrow bandwidth. In previous studies, an ultra-wideband Magic-T has been realized using a coupled-line, short stubs, and multi-stage impedance transformers. However, the optimal solution for the impedance in the previous studies with a single-layer coupled-line requires a very wide full width, which is difficult to achieve. In this study, we removed the unnecessary constraint condition imposed in the previous studies, and we investigated the wider impedance range than that of the previous analytical solution. As a result, it was found that there is a solution that can satisfy the required bandwidth with 2 to 10 times narrower full width than the conventional solution. This discovery opens up a practical path for using single-layer coupled-line configurations. To compensate for the impact of non-ideal transitions in the transmission lines, which can be a factor leading to performance degradation, the transmission line lengths were optimized across a broad parameter space without bias. This design approach was applied to both a readily manufacturable and performance-verifiable 10 GHz-scale model and the 130-295 GHz model for the 6-color camera in millimeter-wave 3-color bands. In the case of the 10 GHz-scale model, the design achieved reflection and isolation levels below -20 dB, amplitude imbalance below ±0.1 dB, and phase imbalance below ±0.1 degrees over a fractional bandwidth (highest/lowest frequency) of 2.3, meeting the requirements with margin. Similarly, for the millimeter-wave model, the design demonstrated reflection and isolation levels below -15 dB across a bandwidth ratio of 2.3, amplitude imbalance below ±0.2 dB, and phase imbalance below ±2°, exceeding the requirements with ample margin and exhibiting resilience to manufacturing errors.

トモエゴゼンを用いた活動銀河核の変光の評価と銀河の諸性質

35-226102　生方すばる

概要

In this study, using the Tomoe-Gozen Camera, we carried out repeated photometry of a sample of galaxies selected from the Sloan Digital Sky Survey and investigated the variability of galaxies. Prior to studying the variability of galaxies, we simulated the impact of seeing, and the resulting variability was approximately 0.1 mag. Correction of photomtery was performed using stars within 4 arcmin radius from the target galaxies. As a result, using the standard deviation as an indicator of the magnitude of variability, four galaxies with significant variability (standard deviation > 0.35 mag were identified. Among these four, one was a Type Ia supernova within a galaxy and another a galaxy. The galaxy may have active galactic nuclei (AGN). Galaxies exhibiting small variability were analyzed in terms of color and radial profile properties. Galaxies with confirmed AGN appeared red. No galaxies with small variability were found among the bluer galaxies, which were identified as galaxies with active star formation. One of bluer galaxies with significant variability may host AGN. The correction method used in this study demonstrated its ability to search for AGN candidates or supernovae in the presence of bright stars in the vicinity, but it is not applicable when only faint stars are present. Additionally, beyond spectroscopic classification using the BPT diagram, further exploration for AGN based on variability is necessary.

本研究では、スローンデジタルスカイサーベイから選んだ銀河のサンプルをトモエゴゼンを用いて繰り返し撮像し、銀河の変光を調べた。銀河の変光を調べる前に、シーイングの影響をシミュレーションしたが、それによる変光は 0.1 mag 程度だった。半径 4 arcmin の星を用いて補正した。この結果、変光の大きさを表す指標として標準偏差を用いると、大きく変光する銀河が 4 つあった。この 4 つのうち、1 つは銀河に出現した Ia 型超新星による変光であり、もう 1 つは銀河による変光であり、この銀河には活動銀河核 (AGN) がある可能性がある。小さい変光を示した銀河はカラーと明るさの半径分布の性質についての図を作った。AGN が確認されている銀河は赤かった。青い銀河で変光が小さい銀河は発見されず、青い銀河は星形成が活発な銀河であった。青く大きく変光する銀河のうち 1 つは AGN を持っている可能性がある。本研究で用いた補正の手法 は、周囲に明るい星があれば AGN の候補や超新星を探せることを示したが、暗い星しかない場合は適用できない。また、BPT ダイアグラムを用いた分光的な分類以外にも変光によって AGN を探していく必要がある。

破局的進化段階にあるほうおう座銀河団の中心巨大楕円銀河からのAGNジェット電波観測

Radio observation of AGN jets from the central cD galaxy of Phoenix Galaxy Cluster which is in the catastrophic evolution phase

35-226103
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Abstract

Galaxy clusters constitute a major structure in the universe, and developments in this field will enable discussions about the evolution of the universe as a whole. The central region of a galaxy cluster is filled with a dense plasma that is cooled by X-ray radiation, and it is expected that there is a cooling flow of gas from the periphery to the center. However, this cooling flow has not been observed in nearby clusters. The active galactic nucleus (AGN) feedback theory is one of the potential explanations for the cooling flow problem, and its mechanism remains to be understood. Recently, the co-existence of intense central gas cooling and AGN jets has been observed in the Phoenix Galaxy Cluster, located at a redshift of 0.596. This is a new aspect in this research field.

The Phoenix Galaxy Cluster is an exceptional cooling-flow cluster candidate with coexisting radio jets associated with X-ray cavities. In order to understand the properties of the supermassive black hole (SMBH) launching the jets, we conducted observations of the central radio source, J2344-4243C, associated with the Phoenix's brightest cluster galaxy (BCG) using the East Asian VLBI Network (EAVN), Japanese VLBI Network (JVN), and Yamaguchi Interferometer (YI), all at the 6 GHz band. Using EAVN and JVN, we confirmed no fringe signal from the central compact component, J2344-4243C1, and imposed an upper limit of 2 mJy at 5σ for a spatial scale of 33 pc or less, while our simultaneous YI monitor measured the flux density of 6 mJy for J2344-4243C. These results indicate that the active galactic nucleus core, which is bright in X-ray, does not dominate J2344-4243C1 at centimeter wavelengths. We discussed the possibility of alternative radio sources in J2344-4243C1 and suggested that sub kpc-scale diffuse jets and/or diffuse synchrotron emission from star-forming regions are possible components, both of which are tightly linked to understanding cooling flow and AGN feedback.

微惑星リングからの惑星形成
(Planet formation from planetesimal rings)

35-226105
Yuki Kambara / 神原祐樹

In the standard planet formation scenario, planets are formed in protoplanetary disks composed of gas and dust. Km-sized solid bodies called planetesimals are formed from dust. They collide and merge to grow up to planets. In the standard scenario, planetesimals have been assumed to form throughout the protoplanetary disk and to be smoothly distributed in the radial direction. Recently, however, simulations of gas and dust evolution have shown that planetesimals form only in radially limited locations, such as gas pressure bumps and snowlines, and are concentrated in ring-like regions. Simulations starting from protoplanets arranged in a narrow annulus successfully reproduced the mass distribution of terrestrial planets in the solar system. In addition, the existence of ring structures in the planet formation process has been supported by observations of protoplanetary disks.

When planetesimals are distributed in a narrow ring, their evolution would change from the standard scenario, and the distribution of protoplanets and planets formed from them would also change. However, the evolution of planetesimal rings has not been studied in detail. Therefore, we investigate the evolution of planetesimal rings using N-body simulations. We systematically change the initial width and the total mass of planetesimal rings and investigated the dependence of protoplanet properties on the initial conditions. In all simulations, planetesimals initially grow effectively due to higher surface density than the standard scenario. Growing protoplanets start to scatter small planetesimals effectively, and the ring width expands. Finally, grown protoplanets and remaining planetesimals are distributed on a broader region than the initial width. The width of the expanded planetesimal ring does not depend on the initial ring width but on the total ring mass. In planetesimal rings, massive protoplanets tend to be formed around the ring center, while protoplanets far from the center of rings are less massive. The maximum mass of protoplanets depends strongly on the total ring mass and weakly on the initial ring width.

Master Thesis

Chemical evolution during molecular cloud formation triggered by an interstellar shock wave

by Yuto Komichi (35-226106)

Abstract

Molecular cloud formation is an important astrophysical process that initiates the formation of various interstellar molecules from atomic gas. One of the important triggers for cloud formation is the interstellar shock wave that originates in energetic events such as supernovae. Until today, a few theoretical works adopted the one-dimensional shock model to investigate the chemical evolution in the molecular cloud formation stage. On the other hand, the detailed physical process of cloud formation has been studied by multi-dimensional magnetohydrodynamics (MHD) simulations. Since chemical processes depend on physical quantities (e.g. number density, temperature, and visual extinction A_V), we need to take into account the multi-dimensional physical structure in order to study the chemical evolution of the compression layers behind the shock wave. However, it is computationally too expensive to solve multi-dimensional MHD and detailed chemical networks simultaneously.

In order to solve this problem, we studied the chemical evolution in the cloud formation stage focusing on the mean physical evolution of the compression layers. First, We conducted 3D MHD simulations of supersonic converging flows of atomic gas. We consider a wide parameter range including the initial inclination angle of the magnetic field against the shock wave, shock velocity, and density, which determine the structure of the compression layer. We analyzed the averaged evolution of the physical conditions in the compression layer by tracing the trajectories of fluid elements that advect along the mean velocity field. Then we conducted the detailed chemical network calculations along the trajectories.

Our MHD simulations show that the efficiency of shock compression (i.e. the post-shock density) depends on the shock parameters, which is consistent with previous works. The results of our network calculations show that the formation of various molecules proceeds as the gas accumulates and A_V increases. The water ice starts to form at $A_V > 1$ mag and the C/O ratio in the gas phase accordingly enhances. This accelerates the formation of carbon-bearing molecules such as CCH. They become abundant at lower A_V when the post-shock density is high and the gas accumulation is slow because of the dependence of water ice formation on the gas density and the depletion timescale of oxygen atoms.

The typical gas number density and A_V of the compression layers are 10^{2-3} cm^{-3} and several mags. Therefore, we compared our results with the observations of diffuse and translucent clouds. The calculated column densities of carbon-chain molecules show reasonable agreement with the observations. The variation of carbon-chain column densities due to the different shock parameters is comparable to that of observations, which indicates that observed clouds experienced different shock compressions. On the other hand, our models cannot reproduce the variations in observed nitrogen-bearing molecules. This suggests that there should be other causes of their variation than shock parameters.

親星水素外層と超新星フォールバックの相関性

篠田兼伍
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A gravitational collapse supernova (supernova) is the final stage in the stellar evolution of a massive star with a mass exceeding 8 $M_{\odot}$. Since a supernova forms a neutron star or a black hole at its center during the explosion process, a part of the ejecta falls back and accretes due to the gravitational field of the central object in the explosion.

One of the most important problems of fallback accretion in supernovae is the ^{56}Ni problem in Type II supernovae with a hydrogen outer layer and Stripped-Envelope supernovae (SE supernovae) without a hydrogen outer layer. The only difference between these two supernovae is the outer layer, and the internal structure was thought to be the same (Smartt, 2009) . However, recent observations have shown that the amount of ^{56}Ni reflecting the internal structure is smaller in SE supernovae than in Type II supernovae (Meza & Anderson, 2020) , leading to the conclusion that the nature of the explosion centers in SE and Type II supernovae may be different.

On the other hand, there is a possibility that reverse shock waves are formed as the shock wave propagates through the outer hydrogen layer, increasing fallback accretion (Woosley & Weaver, 1995; Zhang et al., 2008) . This reverse shock wave may suppress ^{56}Ni ejection in Type II supernovae, but no quantitative calculations have been performed to date to quantify the increase in fallback accretion due to the hydrogen outer layer. In addition, there is a problem that fallback accretion cannot be quantitatively calculated for systems where reverse shock waves fall into the center because of reflected waves from the inner boundary (Ugliano et al., 2012; Ertl et al., 2016; Gabler et al., 2021) .

A boundary condition that does not generate pulse waves is the non-reflective boundary condition (Thompson, 1987), which changes the equation of evolution of the fluid for each characteristic velocity of the fluid. In fact, it has been reported that this boundary condition suppresses reflected waves in magnetohydrodynamic calculations in 1D spherical coordinates (Suzuki & Inutsuka, 2006) . However, the behavior of the non-reflective boundary condition in a system with gravity and an incoming discontinuity such as an impulsive wave has not been considered.

In order to solve the ^{56}Ni problem, we calculate the effect of the presence or absence of a hydrogen outer layer on the fallback accretion rate, and find that quantitative evaluation in the typical supernova explosion energy region is difficult due to the presence of pulse waves.

In this study, we first confirmed that the evaluation of fallback accretion in the typical explosion energy region is difficult due to the generation of unphysical pulse waves, and then attempted to prevent this difficulty and develop new boundary conditions that enable the quantitative evaluation of fallback accretion. Using the shock-tube problem (Sod, 1978) as a test problem, we report that the accuracy of this boundary condition is significantly higher than that of the commonly used boundary condition with zero divergence.

近傍 U/LIRG における分子ガスと星形成活動の関係

35-226108 車彩乃

Previous studies have shown that there is a strong correlation between the stellar mass (M_*) and star formation rate (SFR) in galaxies, called the star formation main sequence. Galaxies located above the star-forming main sequence in the $SFR - M_*$ plane are particularly active in star formation and are called luminous infrared galaxies (LIRGs) or ultra-luminous infrared galaxies (ULIRGs) based on their infrared emission. One of the causes of active star formation in U/LIRGs is thought to be the interaction between galaxies, and many U/LIRGs are known to interact with each other. To understand the formation and evolution of galaxies, it is important to study these active star-forming activities.

Since stars are formed by the self-gravitational contraction of molecular gas in galaxies, it is important to know the molecular gas mass in order to study the star formation activity of galaxies, and the molecular gas mass can be estimated from the radio spectrum of CO(1-0) lines. To understand the physics behind the active star formation of U/LIRGs, we estimated the molecular gas masses of local U/LIRGs and investigated the relationship between the properties of molecular gas and star formation activity based on the behavior of the molecular gas mass ratio and star formation efficiency.

In this study, we used ^{12}CO(1-0) line data observed by the Nobeyama 45 m radio telescope for 36 local U/LIRGs to estimate the molecular gas masses. These sources (PARADISES galaxies) were selected from the sample of the PARADISES project, a near-infrared narrow-band imaging survey of the Paα emission lines of local U/LIRGs, which covers a wide area above the star formation main sequence in the $SFR - M_*$ plane. When estimating the molecular gas mass, we used two conversion factors to convert CO luminosity to molecular gas mass: one commonly used in nearby star-forming galaxies ($\alpha_{CO}[const]$) and the other depending on metallicity ($\alpha_{CO}[metal]$).

Adopting an $\alpha_{CO}[const]$, the molecular gas mass is estimated to be $2.32 - 59.08 \times 10^9\ M_\odot$, and adopting an $\alpha_{CO}[metal]$, $1.73 - 52.82 \times 10^9\ M_\odot$.

Molecular gas masses of PARADISES galaxies and samples from two previous studies were examined in relation to molecular gas mass, molecular gas fraction, star formation efficiency, and galaxy properties. The results show that even in galaxies with high stellar mass and high sSFR, such as PARADISES galaxies, the increase in star formation rate is affected by both the molecular gas mass ratio and the star formation efficiency.

In order to investigate the relationship between interactions and star formation activity in PARADISES galaxies, the objects in our sample were classified into merger stages based on their morphology to see if there are any trends in their molecular gas content and star formation efficiency. The results show that PARADISES galaxies have no trend in the merger stage.

In the future, we need to establish more accurate and detailed morphological classification methods, increase the number of morphologically classified samples, and compare the size and morphology of star formation regions obtained from Pa α images with the results obtained in this study to better understand the star formation activity of nearby U/LIRGs.

Tomo-e Gozen 広域サーベイの最適化システムの開発

津々木里咲 (学生証番号：35-226109)

The wide-field CMOS camera Tomo-e Gozen, mounted on the 1.05 m Schmidt telescope at Kiso Observatory, is advancing the time-domain astronomy on phenomena with timescales shorter than a day. Currently, we conduct an all-sky transient survey covering the entire northern sky and a high-cadence transient survey within a restricted area. In order to increase the detection probability of transient and fast-moving objects in the surveys using ground-based telescopes, it is essential to determine survey routes along scientific objectives while minimizing data acquisition loss due to cloud overlapping and time loss caused by telescope pointing. However, in addition to not having methods to monitor cloud distribution over the entire sky at Kiso Observatory, we cannot deal with real-time information on weather conditions and alerts of transient phenomena using the existing survey-route optimization system of Tomo-e Gozen. Therefore, we have developed an all-sky infrared cloud monitor and a dynamic survey-route optimization system optimized for the Tomo-e Gozen surveys.

Optical cameras with a fisheye lens are widely used to monitor the cloud distribution in the sky. However, it is challenging to quantify an actual cloud distribution due to the scattering of the moon and city lights. Mid-infrared radiation, less affected by scattering, is suitable for measuring the cloud distribution. In previous studies, developments of mid-infrared all-sky cameras faced challenges regarding sensor stability, system complexity, physical size, and ensuring an all-sky field of view. To solve these problems, we have developed a compact all-sky infrared camera with a silicon-type microbolometer and a unique magnifying mirror opposite each other. The concave mirror with an arched cross-section, newly devised in this study, enables us to view the entire sky without vignetting the zenith direction due to the camera body itself.

We have been using a traveling salesman problem-based algorithm in optimizing survey observations. The existing system determines a survey route for the entire night at starting observations. In this study, we have developed a dynamic route optimization system that performs surveys incorporating real-time information. This new system recalculates the survey route approximately every six minutes during the observations, referring to clear sky areas derived by the infrared all-sky cloud monitor. We have successfully reduced the rate at which the survey data is discarded by analysis pipeline software. However, the change in cloud distribution between moments measuring the cloud distribution and executing the planned observations sometimes led to observing cloudy areas. To further improve survey performance, we have attempted to predict the future of cloud distribution using a deep learning model. We have constructed a model using the convolutional GRU to predict the subsequent ten frames from the past ten frames of the infrared all-sky images and confirmed that introducing the prediction model reduces instances of observing cloudy areas.

Resemblance of aftershock properties among fast radio burst, magnetars and earthquakes

35-226110 Yuya Tsuzuki

Abstract

The production mechanism of repeating fast radio bursts (FRBs) remain unveiled, and correlations between burst occurrence times and energies may provide important clues to clarify it. While time correlation studies of FRBs have been mainly performed using wait time distributions, here we report the results of a correlation function analysis of repeating FRBs (FRB20121102A, 20201124A and 20220912A) in the two-dimensional space of time and energy. Also, we peform the same amalysis to the radio pulsations and X-ray short bursts from SGR 1935+2154, the Galactic magnetar and emitter of FRB20200428, to investigate the relation between FRB and other emission. For FRBs and the radio pulsations, a clear power-law signal of the correlation function is seen, extending to the typical burst duration ($\sim 10\,\mathrm{msec}$) toward shorter time intervals (Δt) although the radio pulses are concentrated near the fixed phase of the rotational cycle and FRBs are not. The correlation function indicates that every single burst has about a 10–60% chance of producing an aftershock at a rate decaying by a power-law as $\propto (\Delta t)^{-p}$ with $p = 1.5$–2.5, like the Omori-Utsu law of earthquakes. The correlated aftershock rate is stable regardless of source activity changes, and there is no correlation between emitted energy and Δt. We demonstrate that all these properties are quantitatively common to earthquakes, but different from solar flares and X-ray bursts in many aspects, by applying the same analysis method for the data on these phenomena. These results suggest that repeater FRBs and the radio pulsations are a phenomenon in which energy stored in rigid neutron star crusts is released by seismic activity. Furthermore, for the periodic radio pulses, we suggest that the first pulse within one cycle is triggered by external force or torque periodically exerted on the crust due to, most likely, the interaction with the magnetosphere and the ejected matter in X-ray outbursts. Since the energy of extragalactic FRBs can be released from the magnetic energy and that of the radio pulses from SGR 1935+2154 can be from magnetar's rotational energy, it is suggested that the essence of FRB-like phenomena is starquakes, regardless of the energy source and scale, and it is important to search for FRBs from neutron stars with various properties or environments. This may provide a new opportunity for future studies to explore the physical properties of the neutron star crust.

近赤外線視線速度法による系外惑星探査を目指した高安定モードスクランブラーの開発

学生証番号 : 35226111 氏名: 中島健

Abstract

Precise measurement of Doppler shift in a stellar spectrum is crucial for detecting exoplanets through the radial velocity method. To enhance the stability in radial velocity measurements, it is essential to minimize modal noise, which is one of the main factors causing the instability of radial velocity measurement. One major solution to that effect is a mode scrambler.　In this study, we constructed a benchmark system for a mode scrambler for the near-infrared high-dispersion spectrometer SAND, which is currently under development. using a comprehensive system comprising 4 components: simulating seeing conditions, injecting beams into a fiber at an optimal F-ratio, introducing fiber misalignment through an automatic stage, and projecting the outgoing end face onto a detector with magnification. We verified that the designed image formation performance and simulated seeing effects were achieved through the optimal combination of these optical systems. Monitoring the centroids of two single-mode fiber (SMF) projection images devoid of modal noise over an extended period confirmed the stability of the experimental system for measuring the scrambling effect. Subsequently, we assessed the stability by measuring the relative position of the centroid of the outgoing multi-mode fiber (MMF) image, responsible for modal noise, to the SMF image, acting as the positional reference, across various scramblers. Shifting the position of the incident fiber's end face, the primary cause of modal noise, revealed the relative centroid shift of the outgoing image. The evaluated scramblers included a 200 m fiber static scrambler, an octagonal fiber, and a combination of both. Notably, the 200 m fiber static scrambler exhibited a larger scrambling effect than the octagonal fiber. Among the combinations, the scrambler with two 200 m fibers demonstrated the highest stability. In the near future, we will focus on dynamic scramblers with moving fibers and double scramblers that interchange the image and pupil planes.

QSO J1851+0035 方向の銀河系内分子ガスの物理状態・化学組成

35-226112 成田　佳奈香

Molecular clouds change their structure, physical conditions, and chemical composition due to external and internal disturbances, self-gravity, and magnetic fields. This process is called the “evolution” of molecular clouds and is a key to understanding the formation of filamentary structures and the star formation that proceeds within them. However, in diffuse clouds, which correspond to the early stages of molecular cloud evolution, and in molecular cloud envelopes, which are most strongly affected by external disturbances, most molecular emission lines are not sufficiently excited and are not well understood observationally. Observing absorption lines against bright radio continuum sources behind the Galactic plane allows these low-density molecular gases to be sampled without bias.

ALMA archive data toward QSO J1851+0035 (l=$33.498°$, b=$+0.194°$) mainly obtained for calibration purposes were used to study absorption lines by Galactic molecular gas. A total of 17 species (CO, ^{13}CO, C^{18}O, HCO^{+}, H^{13}CO^{+}, HCO, H_2CO, C_2H, c-C_3H, c-C_3H_2, CN, HCN, HNC, CS, SO, SiO, and C) were detected. About 20 independent velocity components located between 4.7 and 10.9 kpc from the Galactic Center were identified in CO, ^{13}CO, and HCO^{+} lines. Their column density and excitation temperature estimated from the absorption study, as well as the CO intensity distributions obtained from the FUGIN survey, indicate that most of them correspond to diffuse clouds or cloud outer edges. Simultaneous multiple-Gaussian fitting of CO J=1–0 and J=2–1 absorption lines shows that these are composed of narrow- and broad-line components. The kinetic temperature deduced from the high HCN/HNC isomer ratio ($\gtrsim$4) reaches $\gtrsim$40 K and the corresponding thermal width accounts for the line widths of the narrow-line components. CN-bearing molecules and hydrocarbons have tight and linear correlations within the groups. The CO/HCO^{+} abundance ratio showed a dispersion as large as 3 orders of magnitude with the smaller ratio in the smaller N(HCO^{+}) (or lower $A_{\rm V}$) range. Some of the velocity components are detected in single-dish CO emission and ALMA HCO^{+} absorption but without corresponding ALMA CO absorption. This may be explained by the mixture of clumpy CO emitters not resolved with the $\sim$1 pc single-dish beam surrounded by extended components with a very low CO/HCO^{+} abundance ratio (i.e., CO-poor gas).

TAO/MIMIZUKU による中間赤外線モニタ観測の実現に向けた高精度フラット補正システムの開発

35226113　成瀬日月

Time-domain astronomy is an important field in modern astronomy, and monitoring observations in the mid-infrared region with 1% photometric accuracy to study the variables and transients is becoming essential. The non-uniformity of the sensitivity caused by the optical characteristics of instruments and differences in the response curves of individual detector pixels degrade photometric accuracy. Therefore, to achieve 1% photometric accuracy, a flat-field correction for the non-uniformity with an accuracy of better than 1% is required. In this study, we developed a flat calibration unit consisting of a silicon lens, a blackbody source, and two flat folding mirrors. We conducted proof-of-concept tests of the calibration unit by measuring the accuracy and stability of flat frames obtained using the calibration unit. The accuracies of the flat frames were 0.23, 0.43, 0.34, and 0.84% at 7.7, 9.6, 11.5, and 20.9 μm, respectively, which are sufficient to achieve 1% photometric accuracy. The flat frames obtained using the calibration unit were stable throughout 29 h within the accuracies of 0.13, 0.12, 0.22, and 0.52% at 7.7, 9.6, 11.5, and 20.9 μm, respectively, indicating that it is sufficient to obtain flat frames once per night. The calibration unit was installed so as not to interrupt the optical path of the observation. The photometric accuracy, including correction for atmospheric absorption, will be evaluated in actual observations.

X-ray stacking reveals average SMBH accretion properties of star-forming galaxies and their cosmic evolution over $4 \lesssim z \lesssim 7$

(X線スタッキングが明かす$4 \lesssim z \lesssim 7$における星形成銀河の超大質量ブラックホール平均降着特性とその進化)

35-226116

Suin MATSUI

松井 思引

Abstract

With an X-ray stacking analysis of $\simeq 12,000$ Lyman-break galaxies (LBGs) using the Chandra Legacy Survey image, we investigate average supermassive black hole (SMBH) accretion properties of star-forming galaxies (SFGs) at $4 \lesssim z \lesssim 7$. Although no X-ray signal is detected in any stacked image, we obtain strong 3σ upper limits for the average black hole accretion rate (BHAR) as a function of star formation rate (SFR). At $z \sim 4$ (5) where the stacked image is deeper, the 3σ BHAR upper limits per SFR are ~ 1.5 (1.0) dex lower than the local black hole-to-stellar mass ratio, indicating that the SMBHs of SFGs in the inactive (BHAR $\lesssim 1 M_\odot$ yr^{-1}) phase are growing much more slowly than expected from simultaneous evolution. We obtain a similar result for BHAR per dark halo accretion rate. QSOs from the literature are found to have ~ 1 dex higher SFRs and $\gtrsim 2$ dex higher BHARs than LBGs with the same dark halo mass. We also make a similar comparison for dusty starburst galaxies and quiescent galaxies from the literature. A duty-cycle corrected analysis shows that for a given dark halo, the SMBH mass increase in the QSO phase dominates over that in the much longer inactive phase. Finally, a comparison with the TNG300, TNG100, SIMBA100, and EAGLE100 simulations finds that they overshoot our BHAR upper limits by $\lesssim 1.5$ dex, possibly implying that simulated SMBHs are too massive.

第三世代重力波望遠鏡用２段低周波防振装置の開発

35-226117

三橋康平

In laser interferometer gravitational wave telescope, seismic noise is one of the dominatable noises that determine the lower limit of sensitivity in the observation band. To protect gravitational waves telescope from seismic noise, AdVirgo and KAGRA employ Vibration Isolation System (VIS) that is mechanical low pass filter based on pendulum and spring application. The Einstein Telescope (ET), one of the futures and the third-generation gravitational wave telescopes, plans to push sensitivity limitation at low frequency from 20Hz of present 2nd generation GW telescopes like KAGRA down to 3Hz. To meet this requirement, ET needs to employ the VIS which has higher vibration attenuation level from 0.1 Hz than present telescopes. Currently, to achieve vibration isolation in 0.1Hz band, a low frequency vibration isolation system specially named Seismic Attenuation System (SAS) utilizing structures and material properties, such as Inverted Pendulum (IP), has been developed. For ET, there is a conceptual plan that is connecting two IPs seriesely. However, this conceptual plan has inability to tune two IPs performances independently because of how to tune IP performance. To solve this issue, we need to develop other type of SAS.

One idea is the combination of IP and Roberts' Linkage (RL). Double SASs connecting IP and RL serially had been studied and developed in 2000s by the university of Western Australia, and we can tune their performances independently. However, their RL is 4 wire suspension. In RL is 4 wire suspension, there is possibility that hindering the performance of vibration isolation system because it is practically impossible that we prepare suspension wires which lengths are precisely the same.

Therefore, this study aims to develop a RL that is 3 wire suspension, which can tune own performance independently from IP and has no risk of hindering own performance caused by the wire length problem. I made the prototype of RL that is 3 wire suspension and measured how much the resonant frequency of it can be lowed. The reason why I measured the resonant frequency is that we can comprehensive performances of pendulums as VIS. Generally, the lower resonant frequency means a higher VIS performance.

The lowest resonant frequency measured is 34mHz and 46mHz. These results are comparable to the lowest reported resonant frequency in RL that is 4 wire suspension. It shows that a RL that is 3 wire suspension has a potential to be used as SAS and we can make double SASs using IP and RL that is 3 wire suspension。

And I made IP+RL pendulums and measured transfer function. Results say that this is actually double pendulums.

XRISM 衛星搭載極低温検出器の地上・軌道上データを用いた X 線イベント処理最適化

35226118 望月雄友

The XRISM (X-Ray Imaging and Spectroscopy Mission) satellite was launched from the Tanegashima Space Center on September 6, 2023 and was put into low Earth's orbit. The *Resolve* instrument onboard XRISM is equipped with an X-ray microcalorimeter detector aiming to achieve non-dispersive X-ray spectroscopy with a wide energy range (0.3–12 keV), a high energy resolution ($\leq$ 7 eV; FWHM at 6 keV), and a high throughput. Observations began on October 9. Since then, the detector has been continuously operated through the commissioning and calibration phases. The detector has already met many performance requirements.

To maximize the scientific return of the valuable and unexplored observational data, event screening to discriminate X-ray signal events from noise events is crucial. This is especially important for instruments like *Resolve* with a wide dynamic range of energy range and X-ray flux. For the previous X-ray microcalorimeter missions, SXS onboard the ASTRO-H satellite, some items were developed for event screening. As a consequence, a very low background was achieved, and new scientific results were obtained even with a dozen events. However, SXS ended its mission early due to the loss of the spacecraft attitude control, yielding only 366 ks exposures of the background data in the orbit.

This thesis aims to validate event screening for *Resolve* and to propose the optimal screening conditions. Compared to the previous SXS mission, *Resolve* has obtained data of better quality and quantity:

- Rich X-ray data sets were obtained during the ground tests using calibration X-ray sources for two months as opposed to three days for SXS. The data covered an energy range of 0.1–25 keV far beyond the required energy range of 0.3–12 keV.
- X-ray data were acquired during ground tests in the cryogen-free mode without using superfluid helium as a coolant.
- X-ray data were obtained during ground tests with the gate valve opened, allowing X-ray observations below $\lesssim$2 keV.
- In-orbit operation has been ongoing for more than three months. The total background data exposure is now 655 ks, which is expected to grow steadily.

We processed these rich but inhomogeneous data sets to make them as homogeneous as possible. For each screening item, we selected the most appropriate data sets as a subsample of the large volume of the database and derived the optimum screening conditions.

Event screening consists of three categories with 18 items: (1) those based on the microcalorimeter pulse shapes (7 items), (2) those based on relative time differences among multiple events (5 items), and (3) those based on data acquisition time periods (6 items). Among the 18 items, we investigated 15 items. Separately for each item, we derived the optimum screening conditions based on appropriately chosen data sets. Some screening items were newly introduced for *Resolve*, which we studied. For some other screening items, we proposed screening conditions better than those used for SXS.

We applied a combination of screening items to the actual data and evaluated the improvement in signal-to-noise ratio. We used the ground test data covering the entire required energy range (0.3–12 keV), the background data in the orbit taken during the night Earth occultation, and the astronomical data in the orbit with X-rays from celestial sources in 2–12 keV. We found that the proposed combination of screening items reduced signal events only by 5% and noise events by 93%. As a result, the background requirement of $< 2\times10^{-3}$ counts/s/keV is satisfied with a good margin. Furthermore, the proposed screening works beyond the required energy range to 0.1–20 keV, and thereby extends the usable energy range beyond the requirement of 0.3–12 keV.