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科研費 KAKENHI

科学研究費助成事業　　研究成果報告書

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研究課題名（和文）Unveiling the Nature of Type Ia Supernovae with Early-phase Photometry by Subaru/HSC

研究課題名（英文）Unveiling the Nature of Type Ia Supernovae with Early-phase Photometry by Subaru/HSC

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研究成果の概要（和文）：我々のチームはすばる望遠鏡を使って2019-2021年に一連の観測を実施した。すばる望遠鏡HSCによって10個以上のIa型超新星の早期発見に成功し、国内・国際連携により、様々な望遠鏡で追加観測を実施した。また、トモエゴゼンカメラによる突発天体探索によって興味深い特徴を有するIa型超新星も発見した。これらIa型超新星の早期観測はIa型超新星のサブクラスごとの爆発メカニズムや親星の理解に役立つ。加えてすばる望遠鏡の観測によってfast blue ultra-luminous transientであるMUSSES2020Jも発見し、この種の宇宙における稀で極限的な天体の研究も実施することができた。

研究成果の学術的意義や社会的意義
Ia型超新星は宇宙膨張測定に用いられてきているが、その起源はよくわかっていない。早期観測によって起源解明への重要な情報をえることができ、将来より高精度な宇宙膨張測定が可能になることが期待される。

研究成果の概要（英文）：Our team carried out a series of observations with the 8.2m Subaru telescope from 2019 to 2021. Over 10 early-phase Type Ia supernovae (SNe Ia) have been discovered by Subaru/HSC and follow-up observations have been conducted for most of them by using various telescopes through domestic and international collaborations. On the other hand, another early-phase SN Ia that shows interesting features has been found by the Tomo-e Gozen transient survey. These early-phase SNe Ia helped us to further understand the explosion mechanism and progenitor system of specific SN Ia subclasses. In addition, a fast-evolving ultra-luminous transient, MUSSES2020J, has been discovered by our Subaru observation in 2020, which provides a unique opportunity of studying these rare and extreme astronomical phenomena in the universe. Three scientific papers based on the Subaru/HSC observations have already been published/accepted.

研究分野：Astronomy

キーワード：Supernova　Observation　Survey　Transient　Time-domain

１．研究開始当初の背景

As the broad adoption of large-array CCD cameras in astronomical observations, breakthroughs in time-domain astronomy have been made by carrying out various transient surveys in the last decade. Type Ia Supernovae (SNe Ia) soon after their explosions are of great interest in time-domain astronomy as their properties not only indicate the long-standing origin issue of SNe Ia but also help us to further improve the accuracy of the distance measurement in cosmology. Although remarkable scientific outputs have been achieved through wide, shallow, and days-cadence survey observations, the limited observing depth and low time resolution of the traditional survey mode indeed prevent us from discovering early-phase SNe Ia easily. Thanks to the large telescope aperture and wide field of Subaru/Hyper Suprime-Cam (HSC), the early-phase SNe Ia can be efficiently discovered with this superior survey facility, and our ongoing survey project, **MUSSES**, has proved the great advantage of studying early-phase SNe Ia with Subaru/HSC [1].

２．研究の目的

Although the Type Ia supernova (SN Ia) have been widely applied as the cosmic distance indicator and helped us to discover the accelerating expansion of the universe, their origin is still under debate. Given that photometric information on SNe Ia within a few days of their explosions is the best indicator of SN Ia progenitor system and explosion mechanism, we are now carrying out the "**MU**lti-band **S**ubaru **S**urvey for **E**arly-phase **S**upernovae" project ("**MUSSES**") to systematically investigate early-phase SNe Ia for the first time, which will (1) give a robust constraint on the progenitor of SNe Ia, (2) investigate the mechanism of SN Ia explosion, and (3) improve the accuracy of the distance measurement by figuring out the physical origin of the SN Ia diversity.

３．研究の方法

We use the most powerful survey facility in the world, the Subaru/HSC to discover SNe Ia soon after their explosions. Then, intensive photometric/spectroscopic follow-up observations by using telescopes all over the world are immediately triggered through international collaborations. Finally, multiband light curves and spectra of early-phase SNe Ia discovered by Subaru/HSC are used to carry out systematical investigations on the progenitor and explosion mechanism of SNe Ia.

４．研究成果

(1) Seven early-phase SNe Ia were successfully discovered through the HSC Subaru Strategic Program transient survey ("HSC-SSP transient survey") [2]. In particular, a blue light-curve excess was found for a normal SN Ia, HSC17bmhk, whose rise time is longer than ~19 days, during the first four days after the discovery. Given the growing statistical evidence that normal SNe Ia with early-excess features have distinct longer rise times than the average, and a similarity in the nature of the blue excess to the luminous SN Ia subclass [3], we infer that the early excess emission of HSC17bmhk and other normal SNe Ia are most likely attributed to radioactive ^{56}Ni decay at the surface of the SN ejecta. The result also indicates a challenge of identifying early excess induced by the companion-ejecta interaction in normal SNe Ia via typical low-cadence shallow-imaging surveys. This work is published in *the Astrophysical Journal* in 2020 [4].

(2) In October 2019, the first mosaic wide-field CMOS camera, the Tomo-e Gozen camera (abbr.

"Tomo-e"), mounted on the 1.05-m Kiso Schmidt telescope started the scientific operation. By carrying out a high-cadence transient survey with Tomo-e, we successfully discovered the SN Ia 2020hvf within about 5 hours of the explosion and a prompt early flash was perfectly captured via the high-cadence observing mode. Follow-up observations indicate that the brightness of the SN 2020hvf is comparable to the brightest SN Ia subclass (i.e., the so-called "super-Chandrasekhar" SN Ia) and such a fast prominent early flash has never been discovered before. Numerical simulations indicate that the prominent and blue early flash is most likely generated from an interaction between a confined circumstellar-material (CSM) envelope and supernova ejecta soon after the explosion. The peculiar early photometric behavior and the derived CSM distribution conflict with the prevailing extended CSM-interaction and the asymmetric ^{56}Ni distribution hypotheses that have been proposed to interpret the "super-Chandrasekhar" SN Ia with the classical white dwarf progenitor. The SN 2020hvf is one of the earliest SNe Ia and might be the most reliable super-Chandrasekhar SN Ia candidate so far, and the prompt early excess discovered by the Tomo-e high-cadence transient survey helps us to stringently constrain the explosion mechanism of this extreme SN Ia. This work is published in *the Astrophysical Journal Letters* in 2021 [5].

(3) In addition to the early-phase SN Ia study, research progresses in other peculiar transients have been made during the 2020 MUSSES campaign (hereafter "MUSSES2020"). In December 2020, 20 transients that show fast-rising behavior were discovered by our Subaru observation. Out of the 20 fast transients, five are considered as fast blue optical transients ("FBOTs") and the rest are early-phase SNe and candidates. A good number of fast transients discovered in MUSSES2020 not only shows the powerful survey capability of Subaru/HSC but also indicates the advantage of searching rare but luminous fast transients with MUSSES. More interestingly, one out of the five MUSSES2020 FBOTs, internally designated MUSSES2020J, is a reminiscent of an ultra-luminous FBOT, AT 2018cow [6,7]. Thanks to the deep imaging capability and the high survey cadence of MUSSES, we successfully get the first rising-phase light curve of the ultra-luminous FBOT within one day of its occurrence. Follow-up observations confirmed that MUSSES2020J is the most luminous and distant FBOT so far. The rise time of about 5 days with a UV peak luminosity of ~ 20 times higher than that of the typical SN Ia conflict with most of scenarios that have been proposed to interpret this newly confirmed transient type. The discovery of MUSSES2020J shows that deep wide-field surveys could be an efficient approach of studying such extreme transients in the universe. This work is accepted for being published in *the Astrophysical Journal Letters* very recently [8].

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〔雑誌論文〕　計9件（うち査読付論文　9件／うち国際共著　9件／うちオープンアクセス　8件）

１．著者名 Jiang Ji-an, Yasuda Naoki, Maeda Keiichi, Tominaga Nozomu, Doi Mamoru, Ivezic zeljko, Yoachim Peter, Uno Kohki, Moriya Takashi J., Kumar Brajesh, Pan Yen-Chen, Tanaka Masayuki, Tanaka Masaomi, Nomoto Ken'ichi, Jha Saurabh W., Ruiz-Lapuente Pilar, Jones David, Shigeyama Toshikazu, Suzuki Nao, Kokubo Mitsuru, et al.	４．巻 -
２．論文標題 MUSSES2020J: The Earliest Discovery of A Fast Blue Ultra-luminous Transient at redshift 1.063	５．発行年 2022年
３．雑誌名 The Astrophysical Journal Letters (in press)	６．最初と最後の頁 －
掲載論文のDOI（デジタルオブジェクト識別子） なし	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

１．著者名 Jiang Ji-an, Maeda Keiichi, Kawabata Miho, Doi Mamoru, Shigeyama Toshikazu, Tanaka Masaomi, Tominaga Nozomu, Nomoto Ken'ichi, Niino Yuu, Sako Shigeyuki, Ohsawa Ryou, Schramm Malte, Yamanaka Masayuki, Kobayashi Naoto, Takahashi Hidenori, Nakaoka Tatsuya, Kawabata Koji S., Isogai Keisuke, Aoki Tsutomu, et al.	４．巻 923
２．論文標題 Discovery of the Fastest Early Optical Emission from Overluminous SN Ia 2020hvf: A Thermonuclear Explosion within a Dense Circumstellar Environment	５．発行年 2021年
３．雑誌名 The Astrophysical Journal Letters	６．最初と最後の頁 L8～L8
掲載論文のDOI（デジタルオブジェクト識別子） 10.3847/2041-8213/ac375f	査読の有無 有
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２．論文標題 The HSC-SSP Transient Survey: Implications from Early Photometry and Rise Time of Normal Type Ia Supernovae	５．発行年 2020年
３．雑誌名 The Astrophysical Journal	６．最初と最後の頁 25～25
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2．論文標題 A repeating fast radio burst associated with a persistent radio source	5．発行年 2022年
3．雑誌名 Nature (in press)	6．最初と最後の頁 ―
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2．論文標題 Deep simultaneous limits on optical emission from FRB 20190520B by 24.4 fps observations with Tomo-e Gozen	5．発行年 2022年
3．雑誌名 The Astrophysical Journal (in press)	6．最初と最後の頁 ―
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3．雑誌名 The Astrophysical Journal	6．最初と最後の頁 30～30
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1．著者名 Moriya Takashi J.、Jiang Ji-an、Yasuda Naoki、Kokubo Mitsuru、Kawana Kojiro、Maeda Keiichi、Pan Yen-Chen、Quimby Robert M.、Suzuki Nao、Takahashi Ichiro、Tanaka Masaomi、Tominaga Nozomu、Nomoto Ken'ichi、Cooke Jeff、Galbany Lluis、Gonzalez-Gaitan Santiago、Lee Chien-Hsiu、Pignata Giuliano	4．巻 908
2．論文標題 Constraints on the Rate of Supernovae Lasting for More Than a Year from Subaru/Hyper Suprime-Cam	5．発行年 2021年
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〔図書〕　計0件

〔産業財産権〕

〔その他〕

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6．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

7．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

8．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関