# Investigating Peculiar Early-Phase Signals of Type Ia Supernovae with the Subaru Deep Imaging Survey

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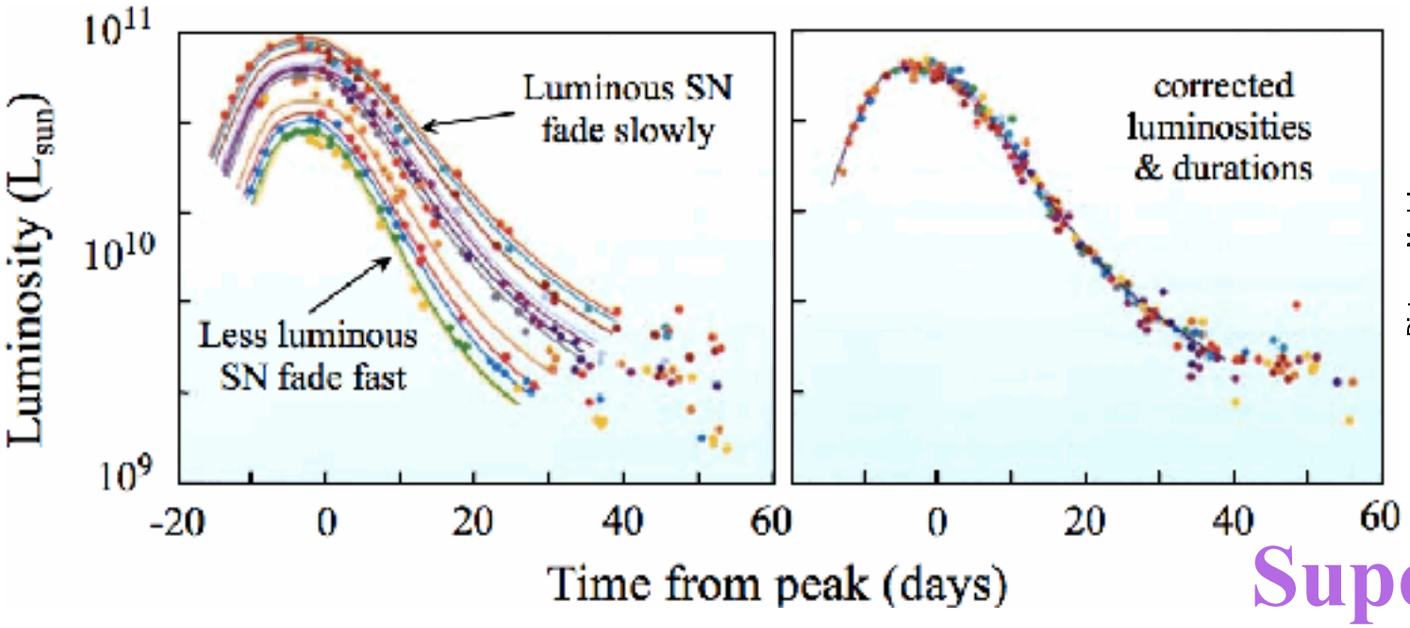
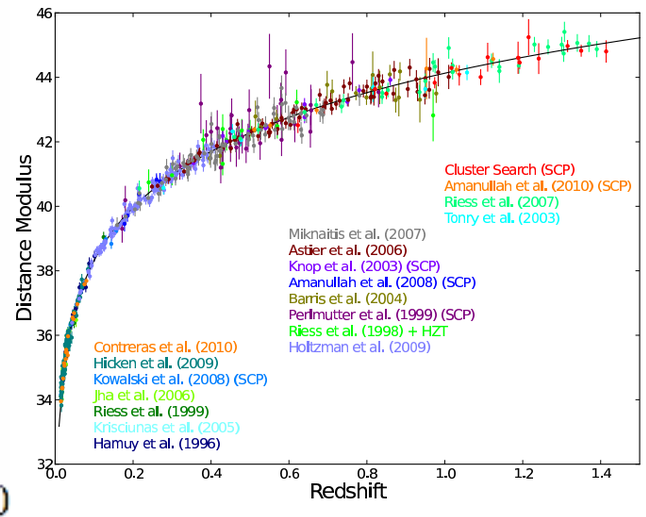
**Ref. Ji-an Jiang, et al. *Nature*, 550, 80, 2017**

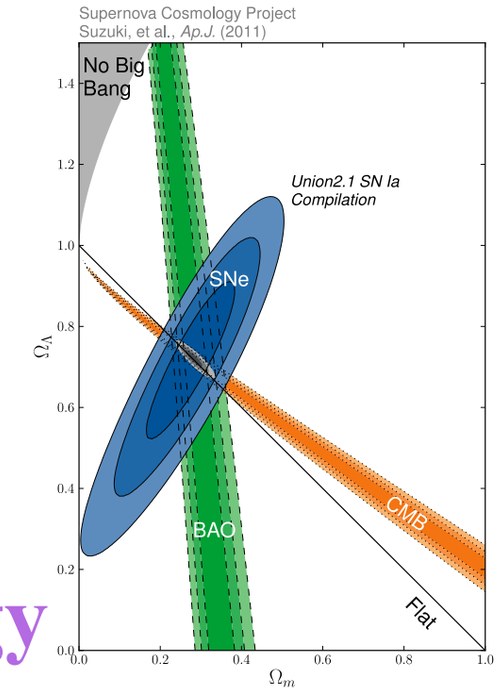
# *Outline*

- Type Ia Supernovae (SNe Ia) and their early-phase behavior
- A review of MUlti-band Subaru Survey for Early-phase SNe Ia (MUSSES)
- Research outcomes: MUSSES1604D, the smoking-gun of the He-detonation scenario
- Future work
- Summary

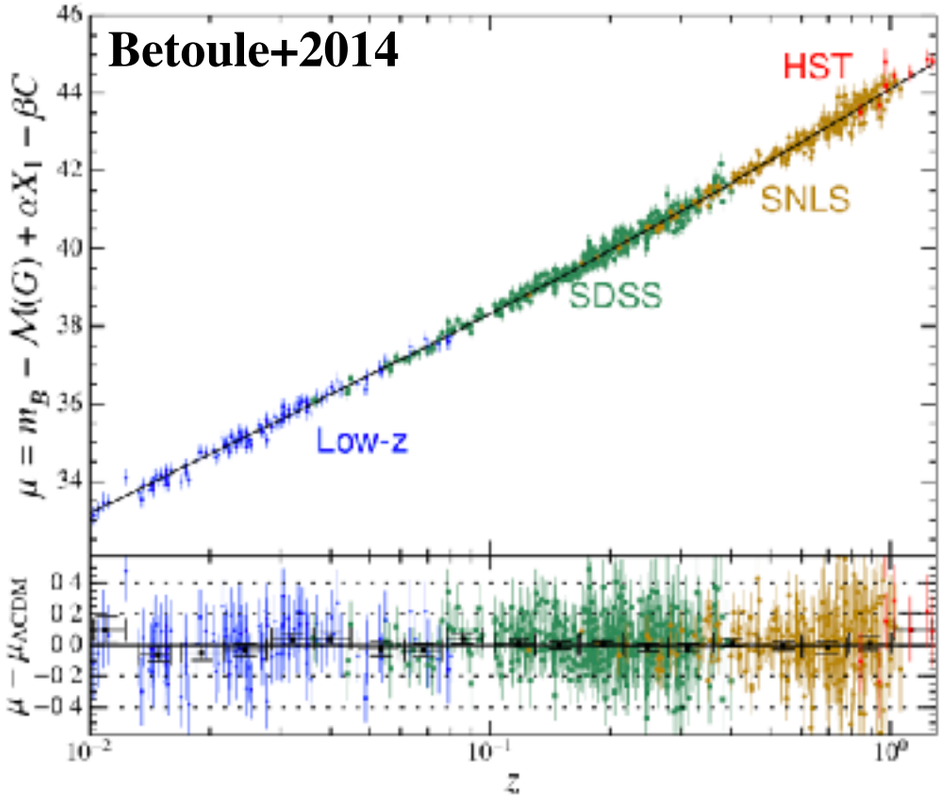
# Type Ia Supernovae and their early-phase behavior



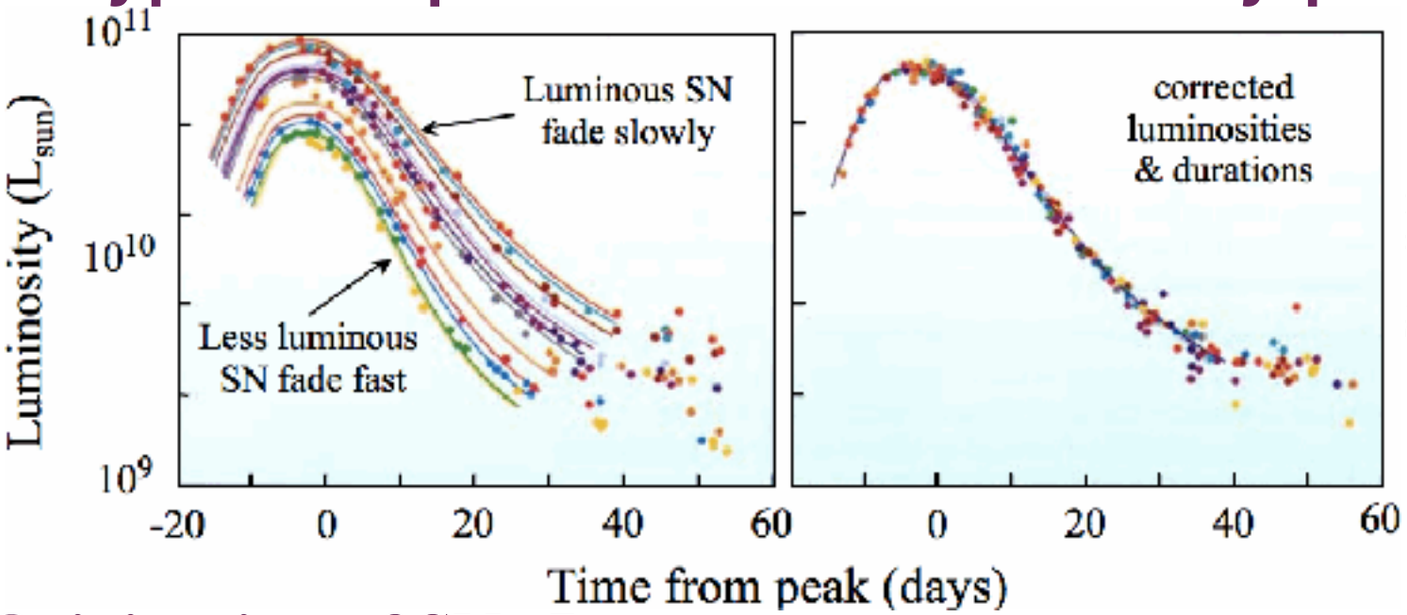

## Supernova Cosmology

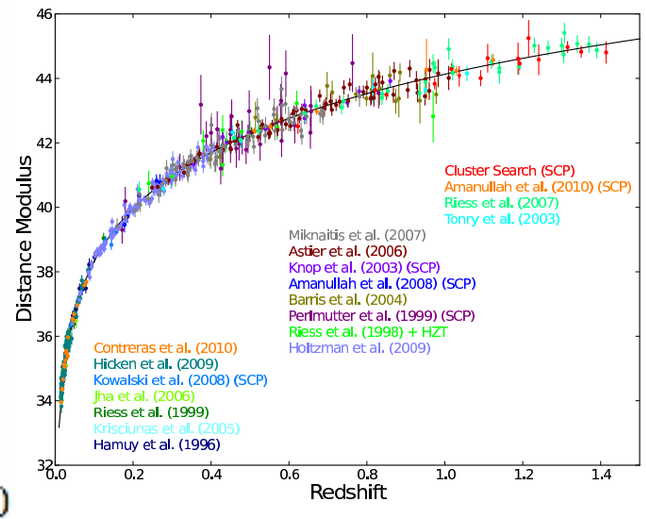



| Uncertainty sources | $\sigma_x(\Omega_m)$ | % of $\sigma^2(\Omega_m)$ |
|---|---|---|
| Calibration | 0.0203 | 36.7 |
| Milky Way extinction | 0.0072 | 4.6 |
| Light-curve model | 0.0069 | 4.3 |
| Bias corrections | 0.0040 | 1.4 |
| Host relation[a] | 0.0038 | 1.3 |
| Contamination | 0.0008 | 0.1 |
| Peculiar velocity | 0.0007 | 0.0 |
| Stat | 0.0241 | 51.6 |

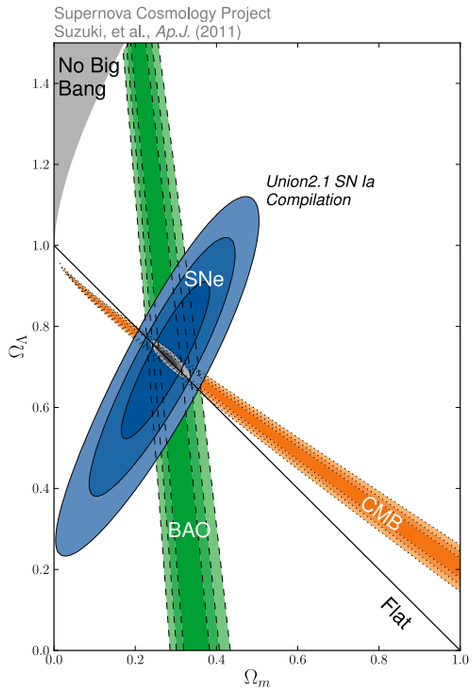
The supernova cosmology at z < 1 is systematic error limited already, and one of the key items to further improve the accuracy is to understand the scatter of SN Ia light curves.

# Type Ia Supernovae and their early-phase behavior

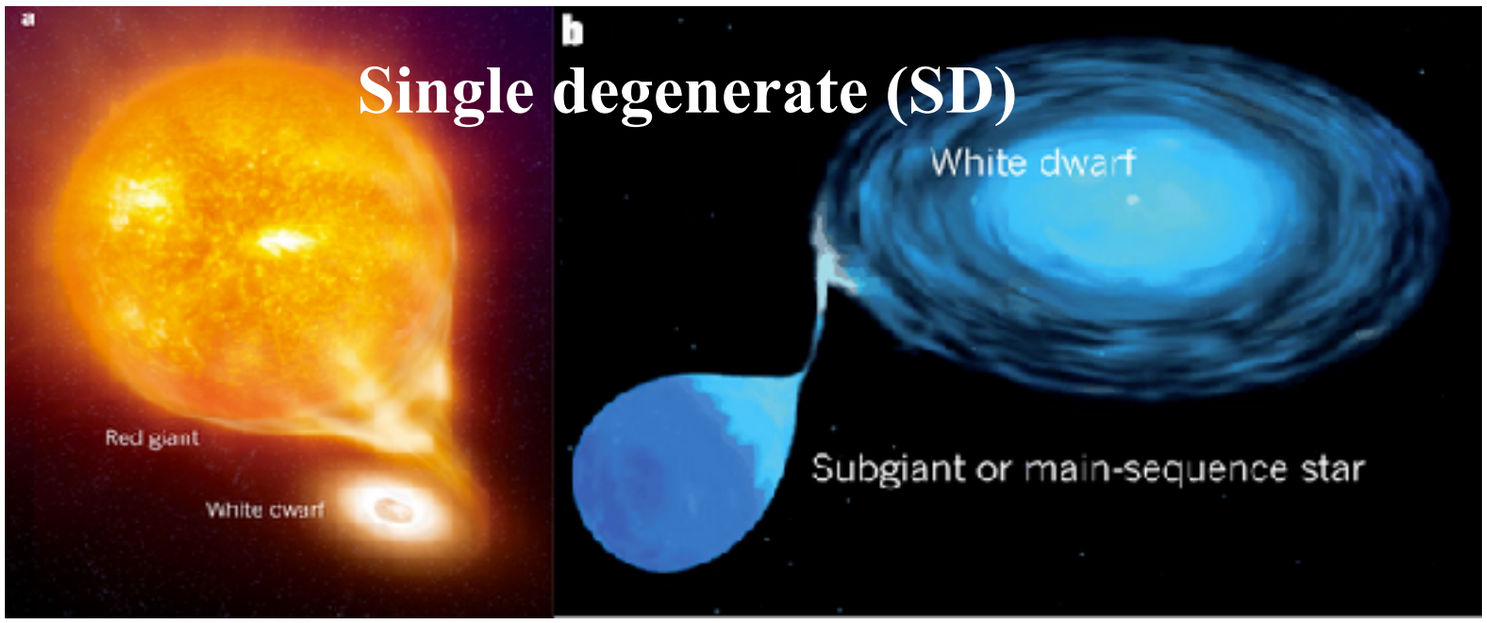


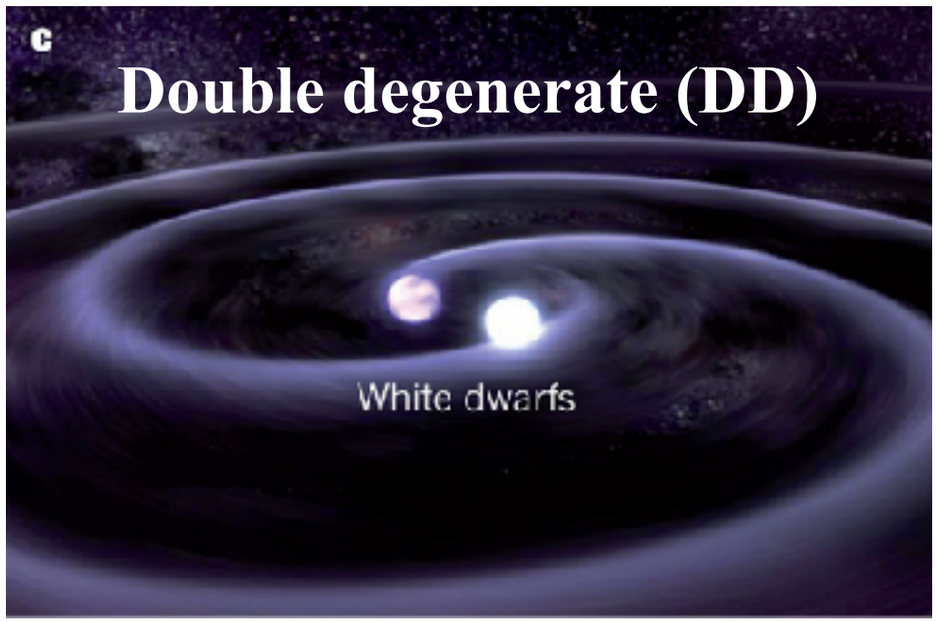




## Supernova Cosmology



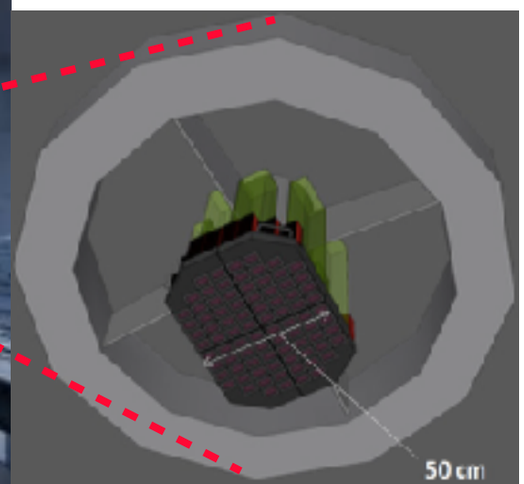

## Origination of SNe Ia

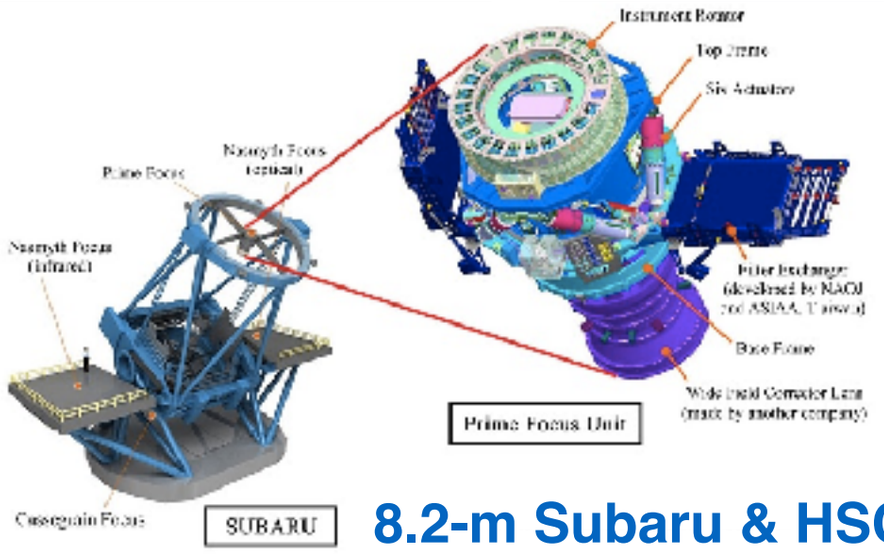




Tomo-e Gozen Camera



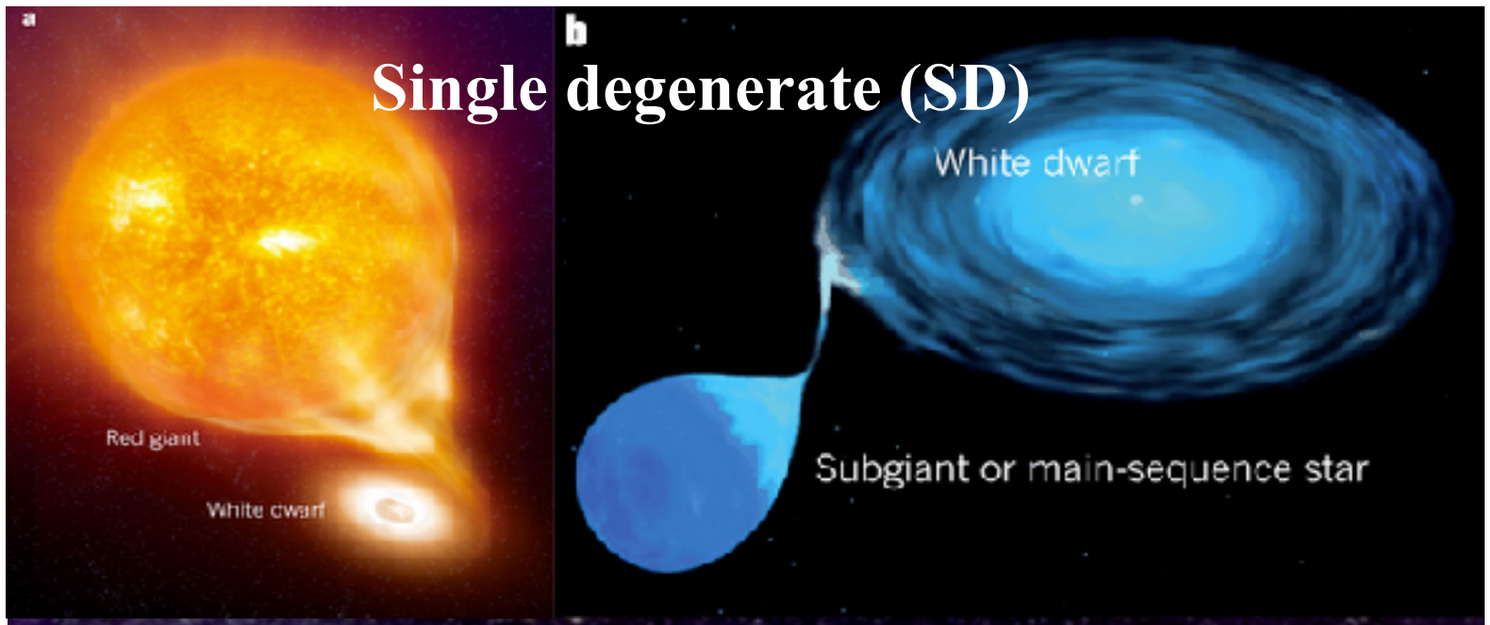



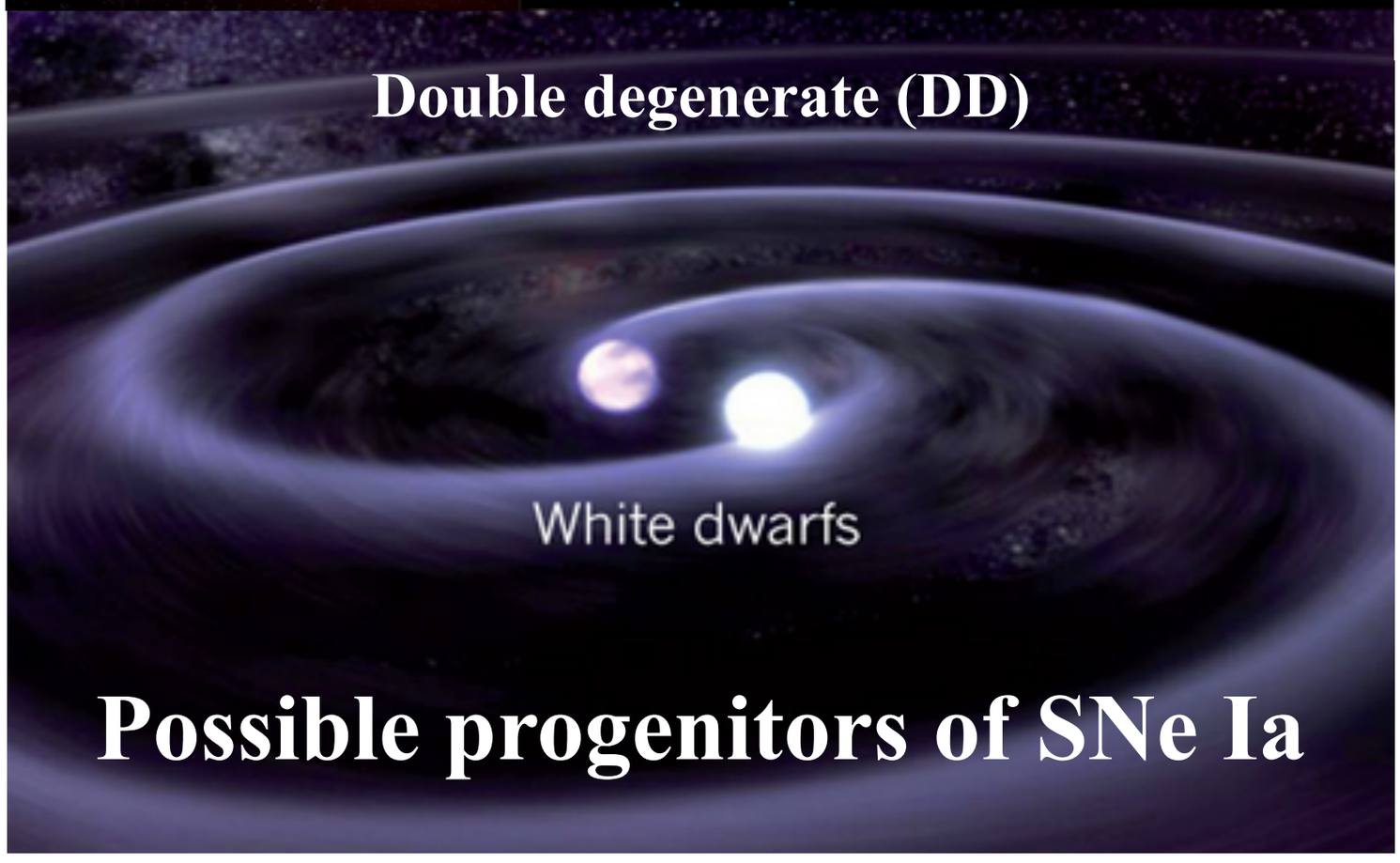

8.2-m Subaru & HSC

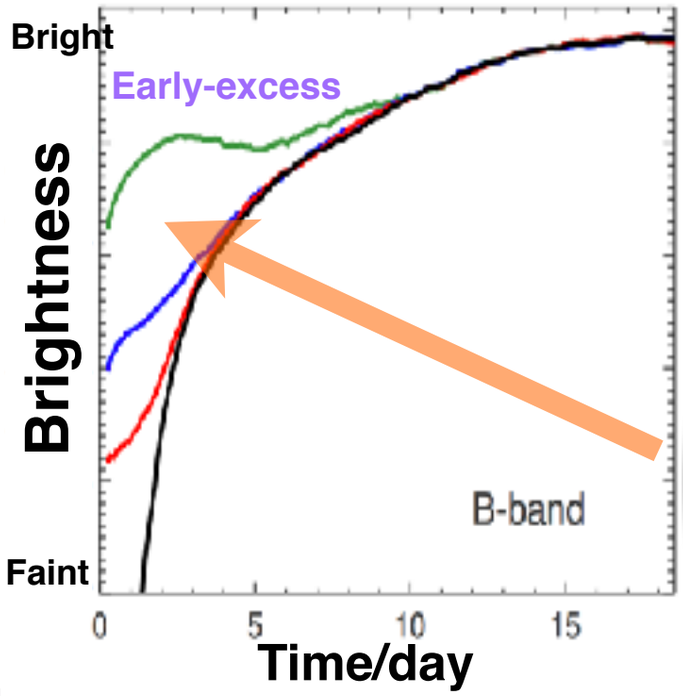
## Japanese Wide-Field Survey Facilities

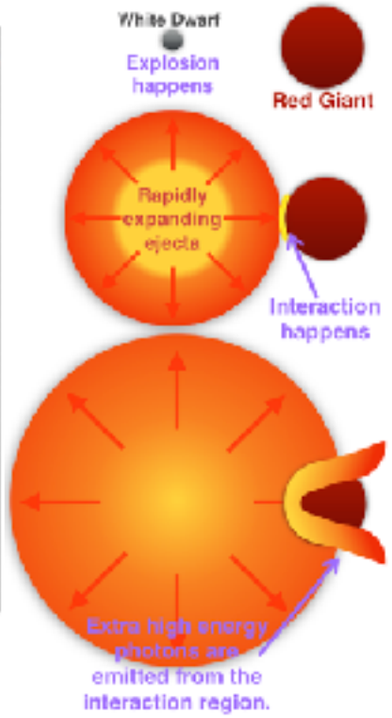
**Searching for SNe Ia soon after the explosion (early-phase SNe Ia, ESNe Ia) with the most powerful survey facilities in the world!**

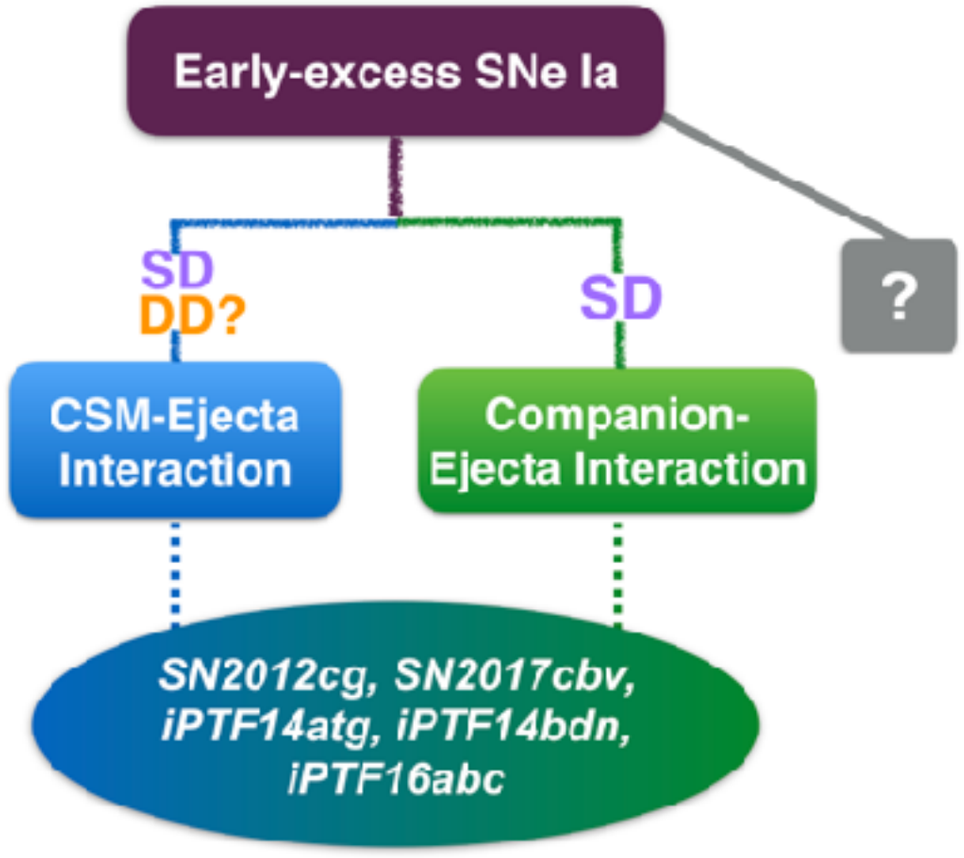
# ❁ Type Ia Supernovae and their early-phase behavior




**Figuring out the progenitor and explosion mechanism issues with early-phase light curve information.**

# The MUlti-band Subaru Survey for Early-phase SNe Ia (MUSSES)

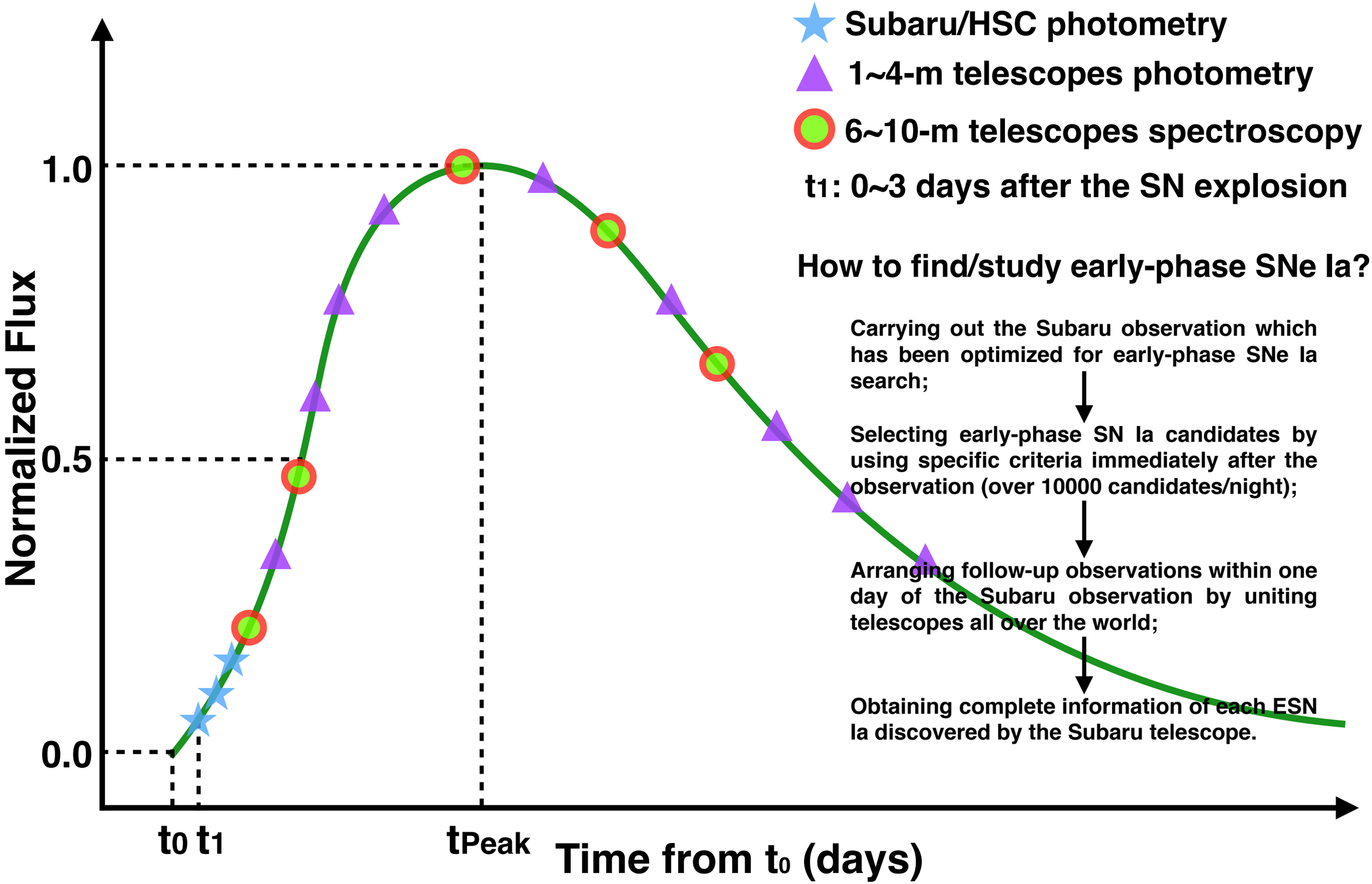
**Ji-an Jiang**, Mamoru Doi, Keiichi Maeda, Toshikazu Shigeyama, Ken'ichi Nomoto, Naoki Yasuda, Nao Suzuki, Tomoki Morokuma, Masaomi Tanaka, Hisanori Furusawa, Satoshi Miyazaki, Nozomu Tominaga, Saurabh W. Jha, Zeljko Ivezic, Andrew Connolly, Peter Yoachim, Pilar Ruiz-Lapuente, Maximilian Stritzinger, Paolo Mazzali, Christopher Ashall, Ferdinando Patat, Dietrich Baade, Jeremy Mould, Lifan Wang, David Jones

- Period: Started from April 04, 2016
- Objectives: Investigating the photometric/spectroscopic behavior of ESNe Ia
- Observing Mode: Subaru/HSC survey+ follow-up observations
- Time Allocation: 2-2.5 nights Subaru/HSC observation for each observing run
- Filters: g- and r-band for the Subaru/HSC observation
- **Limiting Magnitude (S/N = 5): 26 mag in g-band**
- **Cadence: 1 day**
- **Survey Area: ~220 deg$^2$ for each observing run**
- **Expected Number of ESNe Ia: ~15 per observing run**
- **Follow-up Network:** 10.4-m GTC, 9.2-m SALT, 8.1-m VLT, 8.0-m Gemini, 6.5-m MMT, 3.5-m ARC, 2.5-m NOT, 2.5-m INT, 2-m LT & 1-m Kiso, etc.

**"Wide"+"Deep"**

**世界一!!**

# Observational Strategy of MUSSES




Subaru/HSC photometry

1~4-m telescopes photometry

6~10-m telescopes spectroscopy

$t_1$: 0~3 days after the SN explosion

**How to find/study early-phase SNe Ia?**

Carrying out the Subaru observation which has been optimized for early-phase SNe Ia search;

↓

Selecting early-phase SN Ia candidates by using specific criteria immediately after the observation (over 10000 candidates/night);

↓

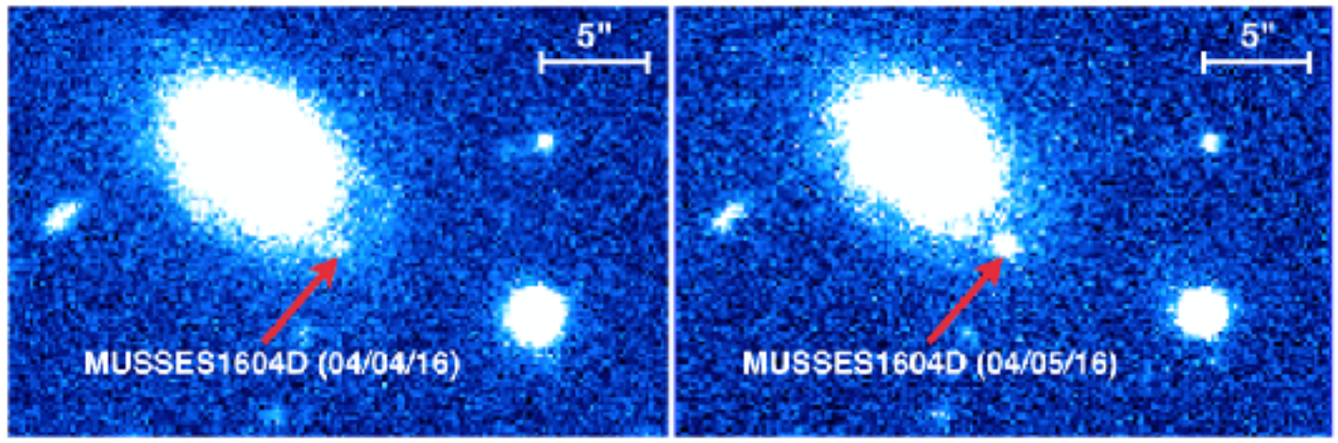
Arranging follow-up observations within one day of the Subaru observation by uniting telescopes all over the world;

↓

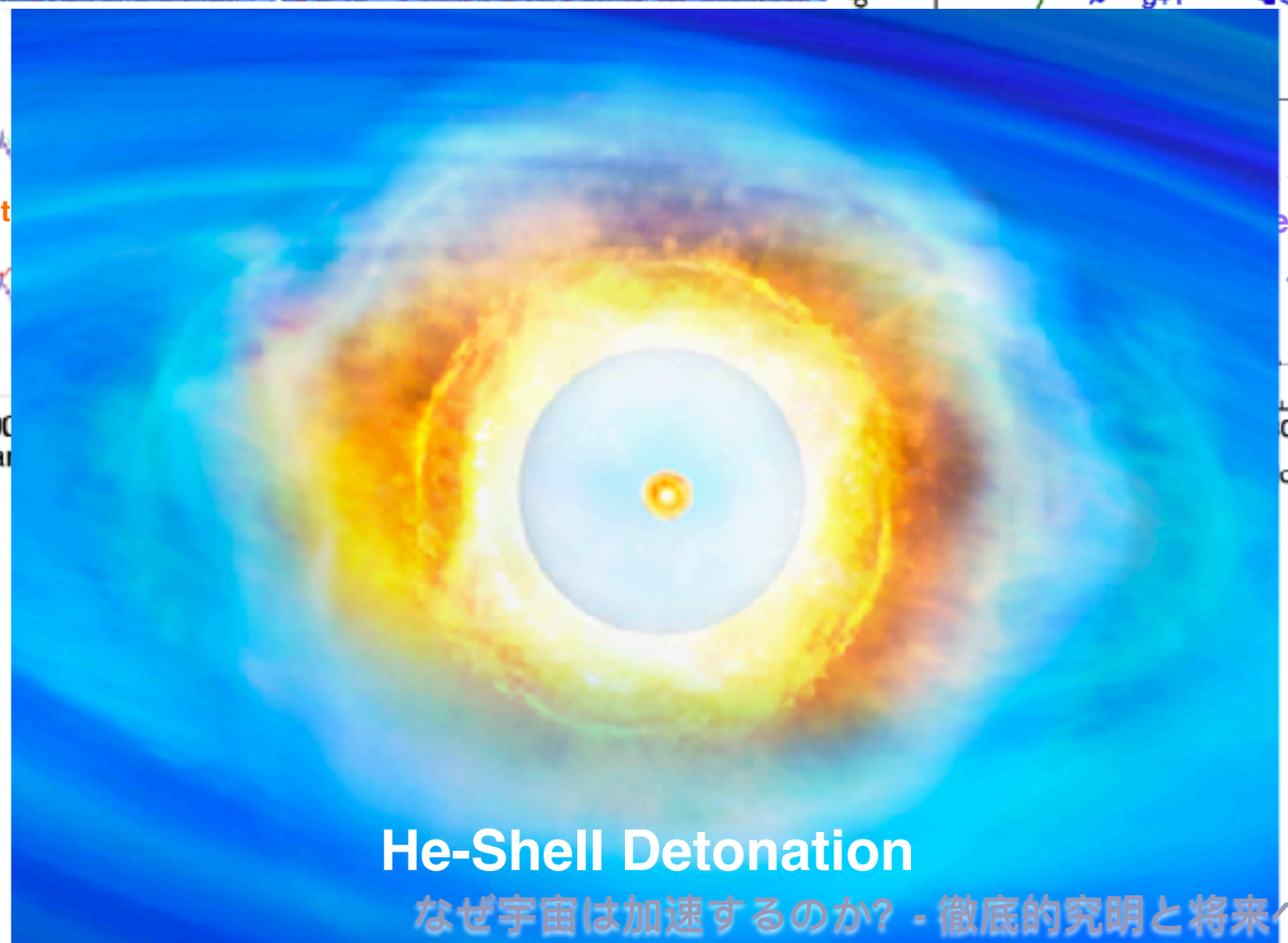
Obtaining complete information of each ESN Ia discovered by the Subaru telescope.

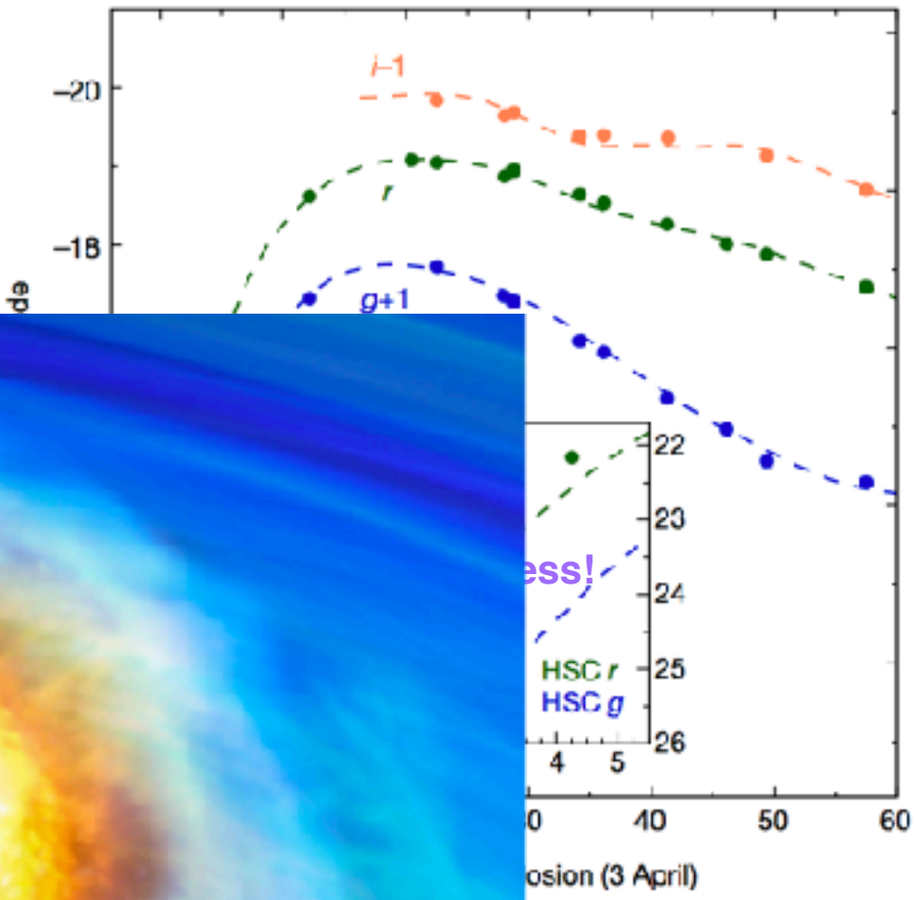
# Research outcomes

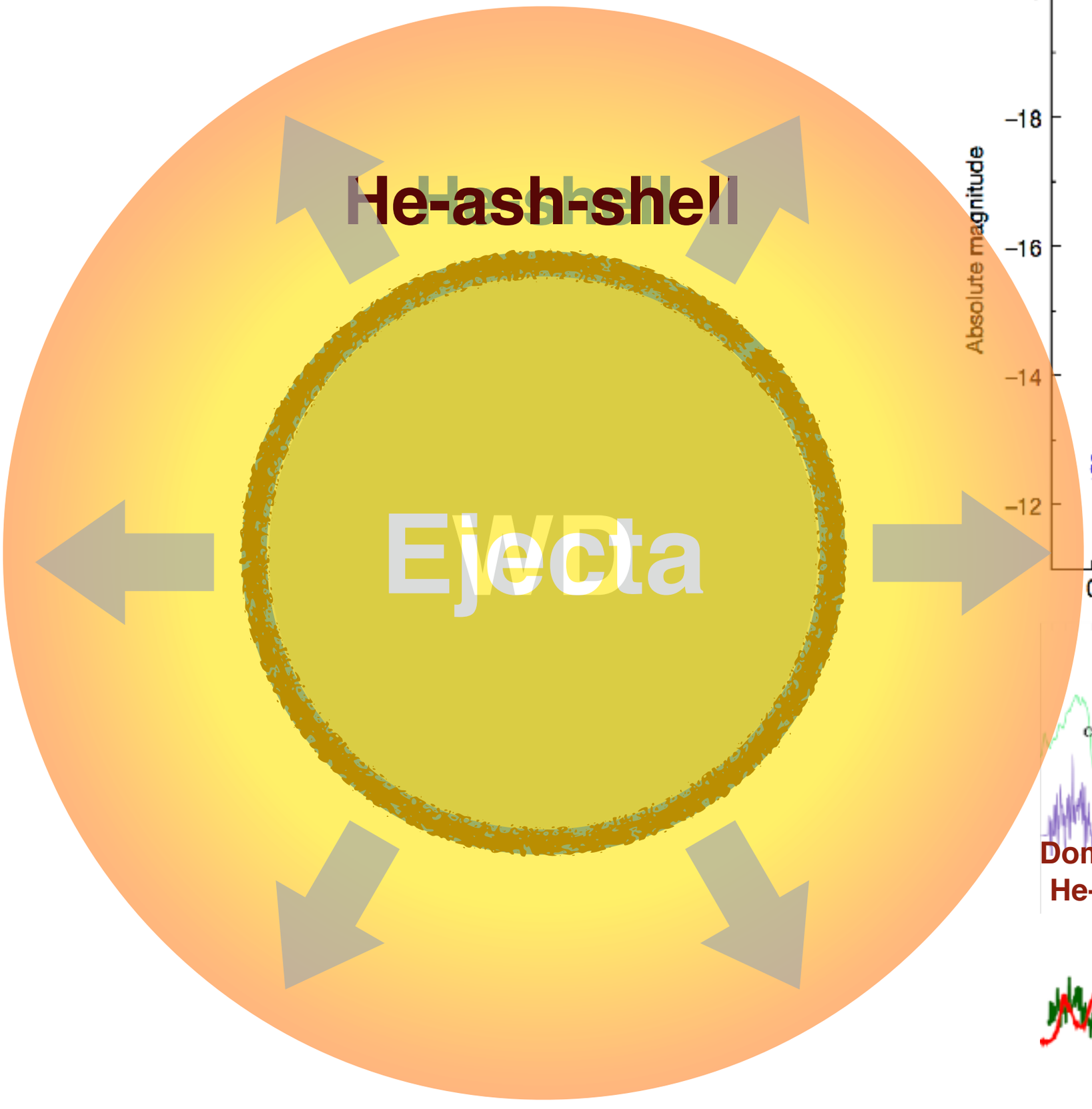
**[1] Ji-an Jiang, et al. "A hybrid type Ia supernova with an early flash triggered by helium-shell detonation", *Nature* 550, 80-83, 2017.**

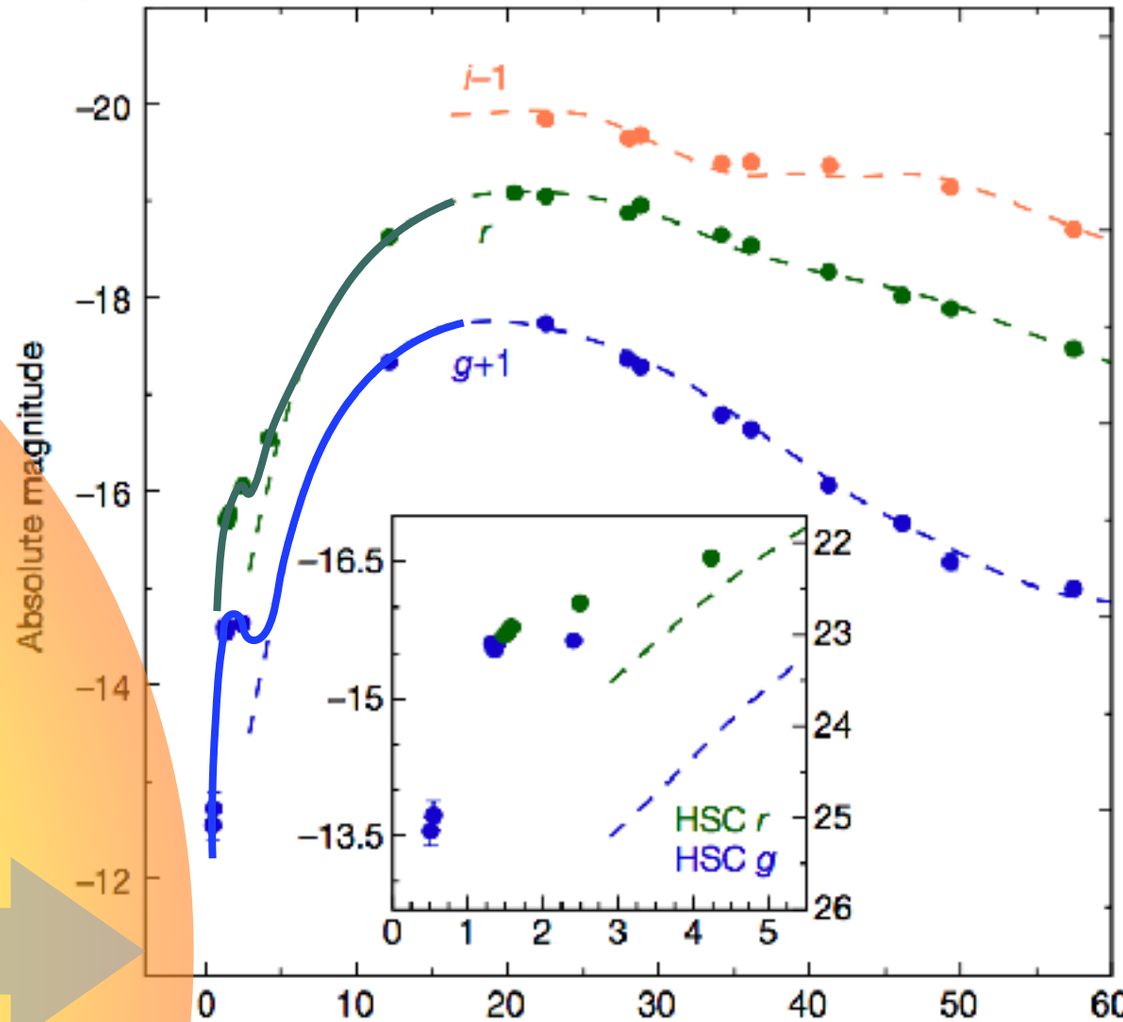


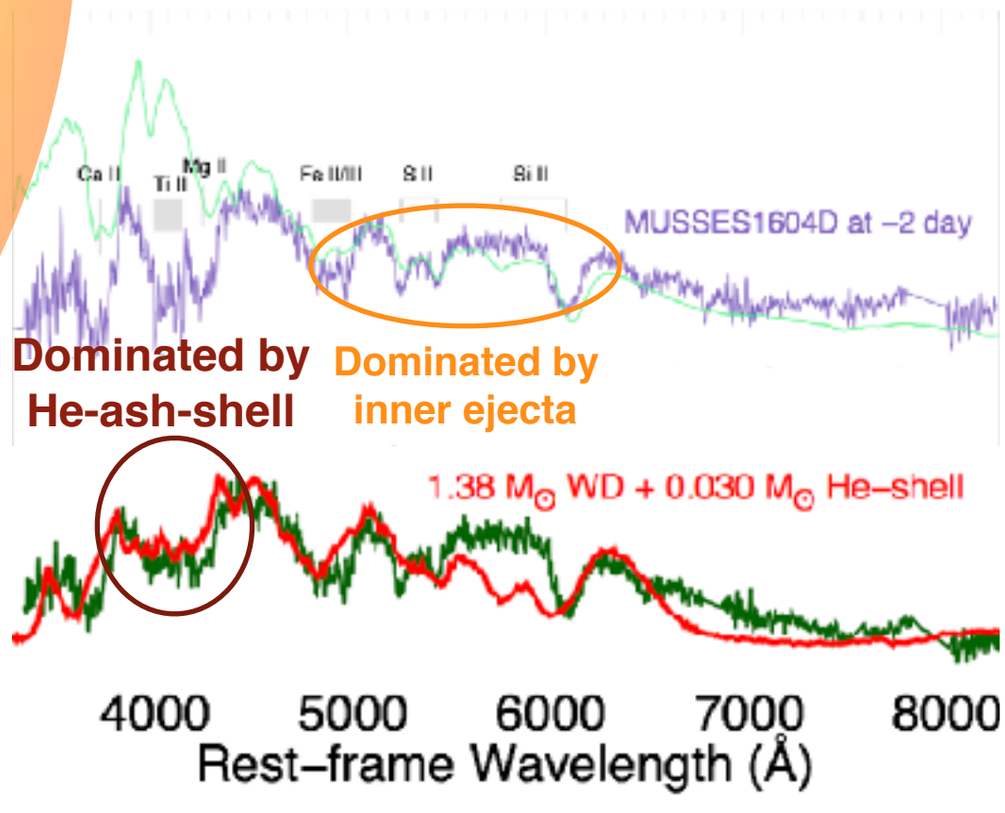




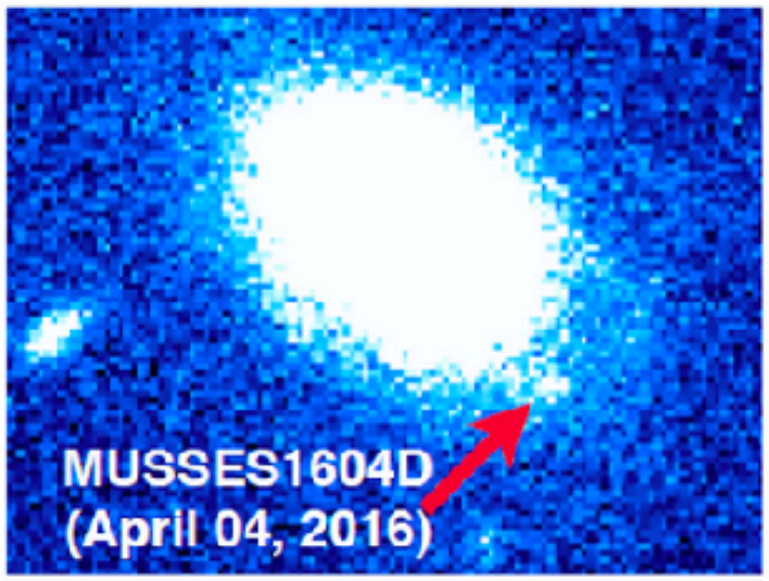



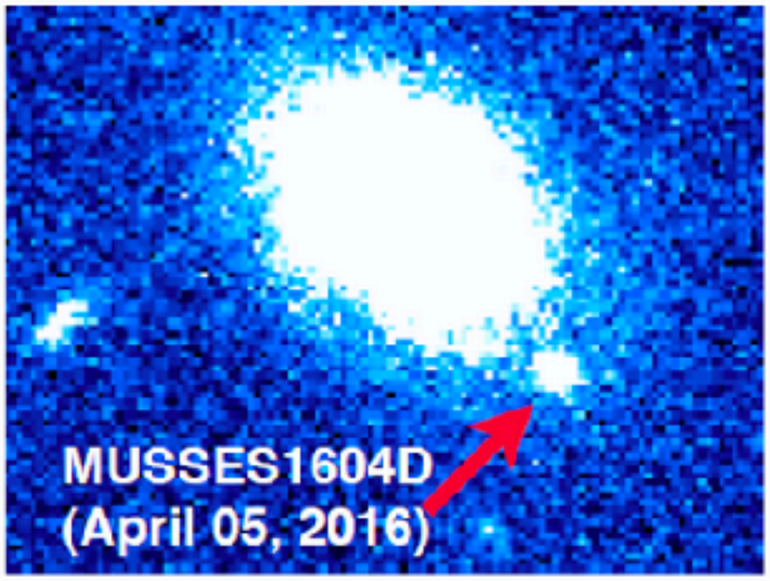

He-ash-shell
Ejecta
WD


Absolute magnitude
i–1
r
g+1
HSC r
HSC g
Rest–frame Wavelength (Å)

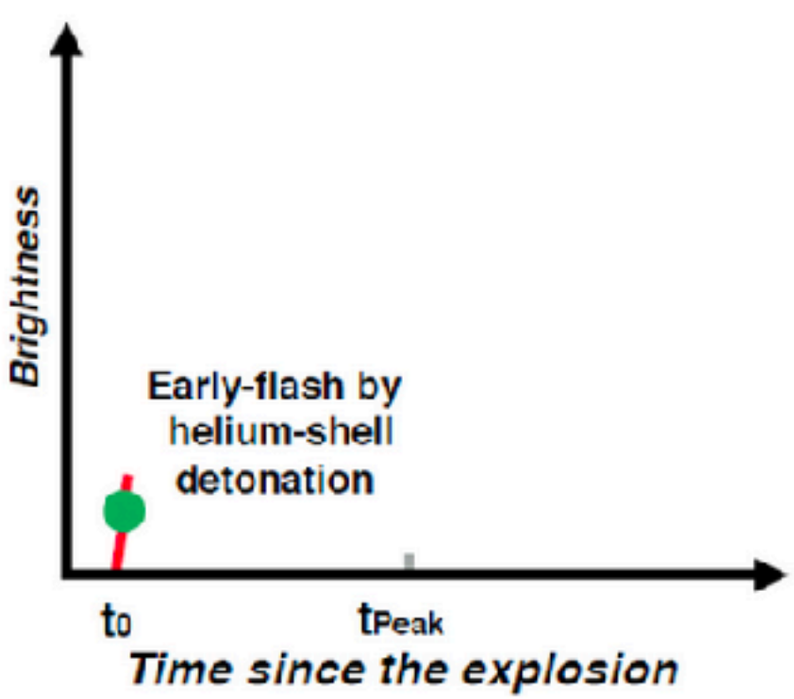

Ca II
Ti II
Mg II
Fe II/III
S II
Si II
MUSSES1604D at –2 day
Dominated by He-ash-shell
Dominated by inner ejecta
1.38 M⊙ WD + 0.030 M⊙ He–shell
Rest–frame Wavelength (Å)

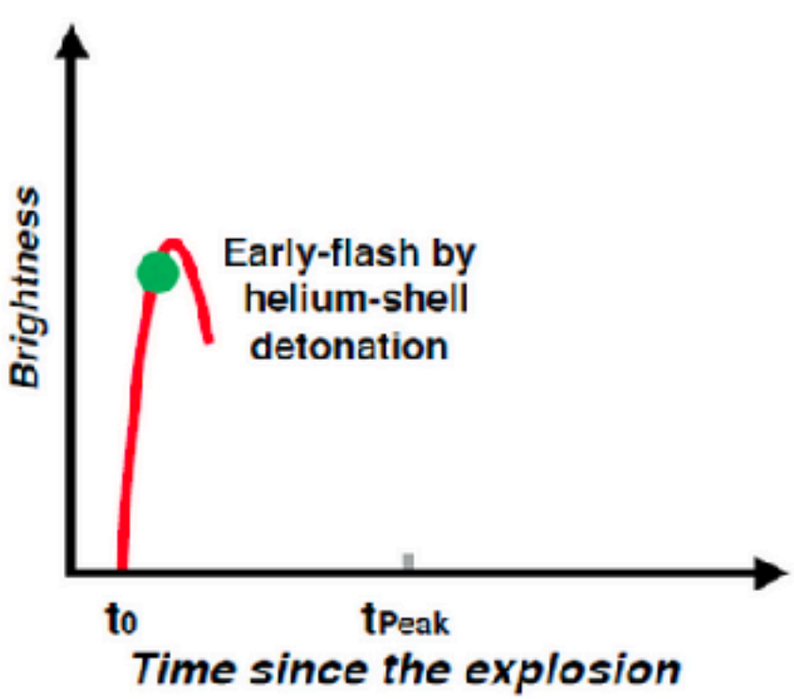
# ❁ MUSSES1604D, the smoking-gun of the He-detonation scenario

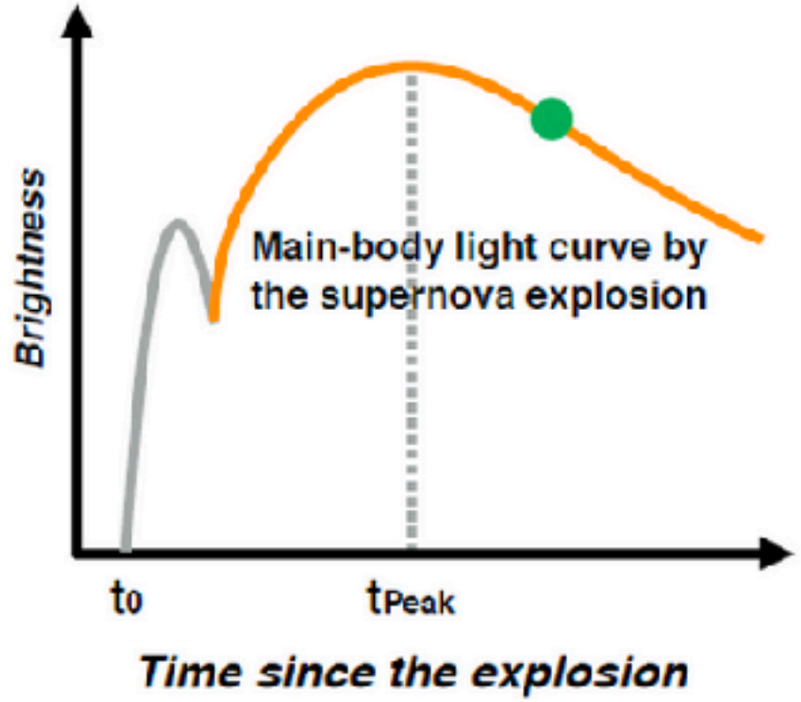






# ❁ Research outcomes

**This is the first robust evidence that one theoretically predicted stellar explosion mechanism proposed in early 1980's, does truly exist in our universe!**

**Our work has been reported by over 100 social media in Japan and foreign countries!**

## For further information, see *J. Jiang et al. 2017.*

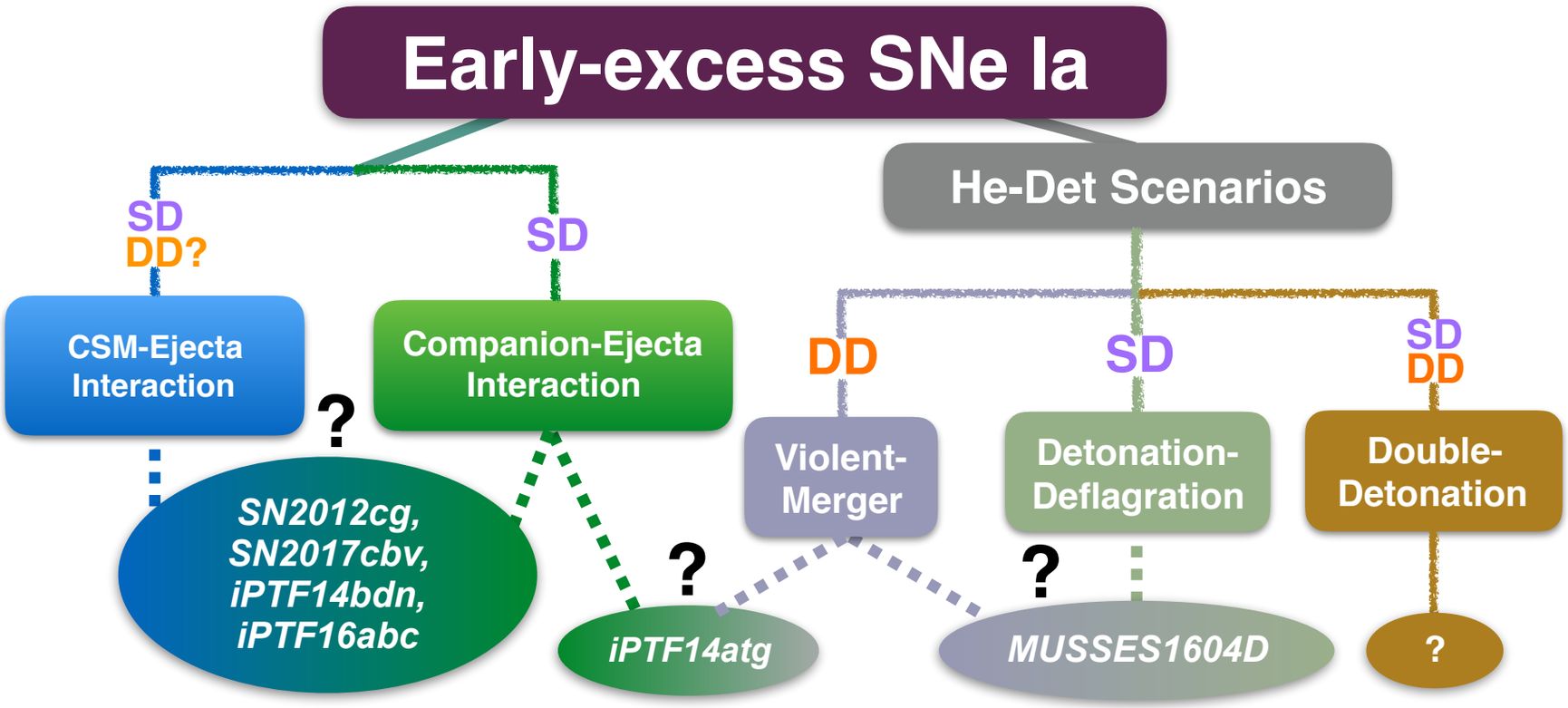
"*A hybrid type la supernova with an early flash triggered by helium-shell detonation*"

# ❃ Publications for further discussions

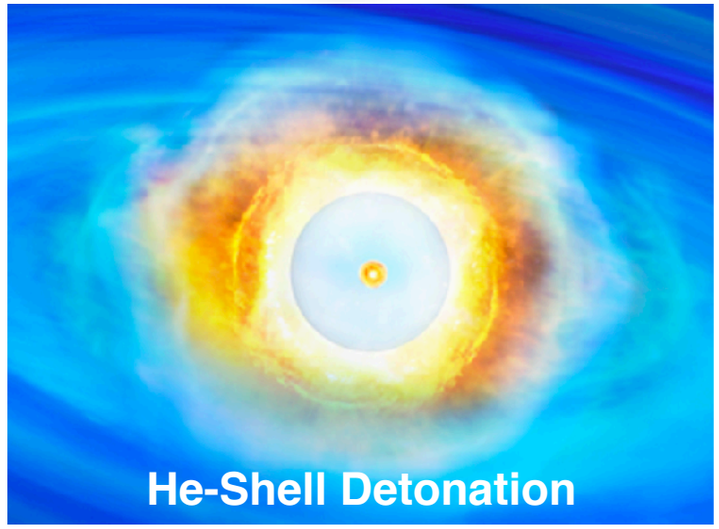

**[2] Keiichi Maeda, Ji-an Jiang, et al. "Type Ia Supernovae in The First Few Days: Signatures of Helium Detonation Versus Interaction" (submitted)**

**[3] Ji-an Jiang, et al. "The Multiple ..." (soon be submitted)**

# ❁ Future work








**Finding more early-excess SNe Ia is the most effective way to further understand the role these scenarios play in the origin and the diversity of SNe Ia.**

## ❋ Improvements for cosmology

Light curve scatter of SNe Ia ⟨ Progenitor: SD, DD or both / Explosion mechanisms ⟩ Can be directly reflected by the early-phase information

**Finally, we expect to reduce the systematic error for the supernova cosmology by**

**1. constraining the ratio of different scenarios and their evolution as the redshift gets higher;**

**2. making observational criteria for further purifying "standardizable" SN Ia samples;**

# ❁ Future work

## ❋ On-going/Upcoming observations

**The second Subaru/HSC observing run will be carried out in June, 2018;**

**The next generation wide-field camera, the Tomo-e Gozen Camera, will be put into use for Kiso 1.05m Schmidt telescope in July, 2018, the Tomo-e transient survey project will be started soon.**


## ❋ Prospects

- **ESN Ia samples in the last 20 years: < 30 in total;**
- **ESNe Ia expected from Tomo-e Survey in 2018: ~ 10**
- **ESNe Ia expected from next Subaru observing run: ~ 15**

**25** → **Comparable to all reported ESNe Ia so far! Statistical analysis for ESNe Ia can be realized.**

**We expect to find about 3 or even more early-excess SNe Ia in 2018. Further investigations for the early light curve behavior can be well conducted.**

**More breakthroughs in SN astronomy can be highly expected in the Subaru/HSC—Kiso/Tomo-e era!**

# ❁ Summary

❋ The early-phase observational information plays an irreplaceable role in addressing the progenitor and explosion mechanism issues of SNe Ia.

❋ The deep imaging capability and the high SNe Ia survey efficiency of Subaru/HSC ensure that **MUSSES is one of the most powerful ESNe Ia surveys in the world**.

❋ Several ESNe have been successfully discovered in the first observing run of MUSSES. In particular, we discovered **MUSSES1604D at around half days of its explosion**, which is **the first evidence** of **(i) the He-detonation-triggered scenario** and **(ii) the multiple origins of the early light curve excess.**

❋ The great success of the first MUSSES observing run motivates us to keep running this promising project. As **the early-phase color/spectral information of SNe Ia is very important to understand the scatter of light curves,** we are looking forward to breakthroughs not only in understandings of SNe Ia themselves but also the supernova cosmology through MUSSES and the upcoming Tomo-e transient survey project.

# Thank you for your attention!

This work is in part supported by JSPS grant 16H01087.
A contributed research program (B02)
*"Studying the progenitor of Type-Ia supernovae by early phase photometry"*
(PI: Mamoru Doi , The University of Tokyo)
加速宇宙公募研究B02
「Ia型超新星の早期測光による親星の研究」（代表　東京大学　土居　守）