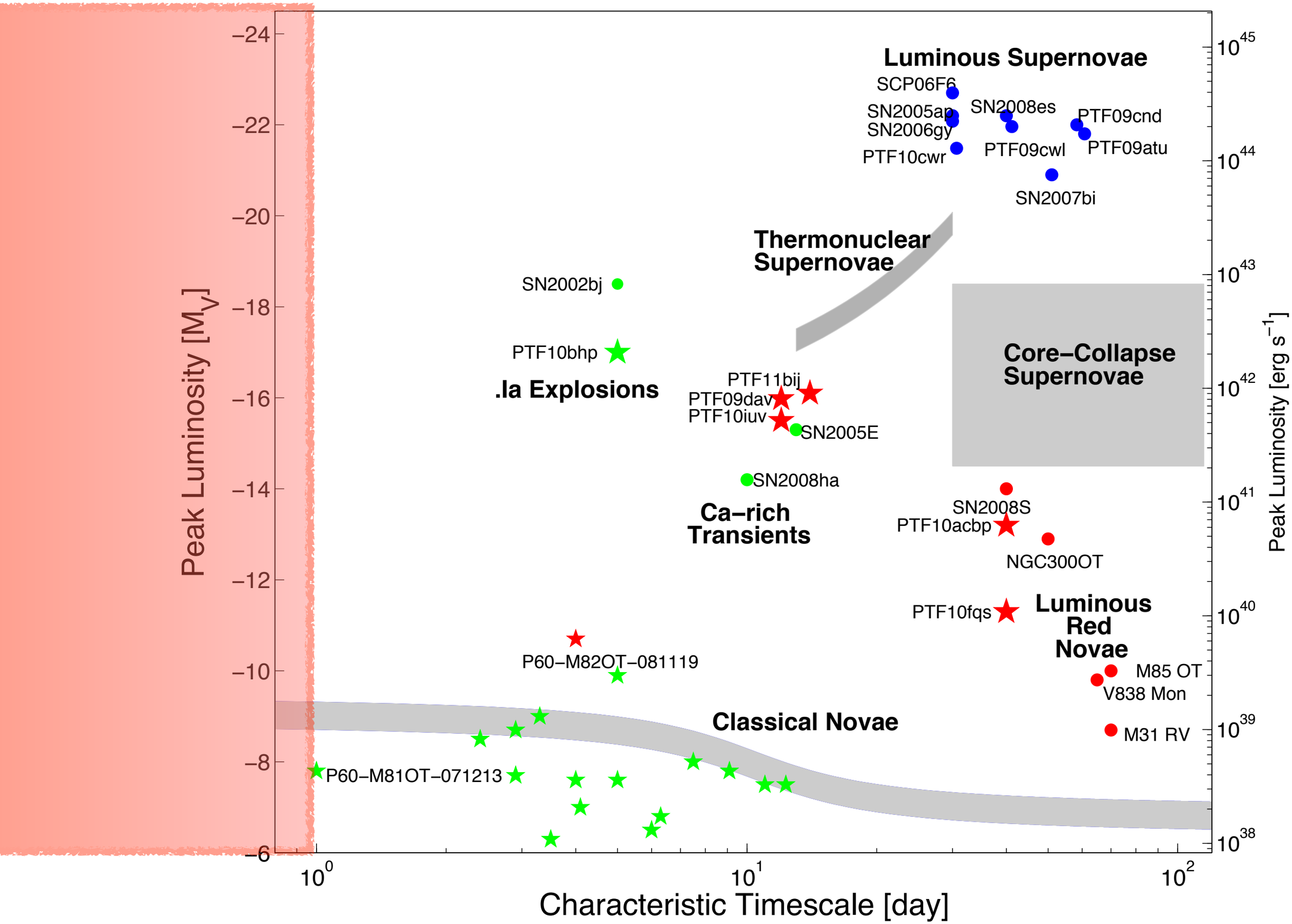
High-Cadence Transient Survey with Kiso/Tomo-e Gozen and Spectroscopic Follow-up with Seimei/KOOLS-IFU

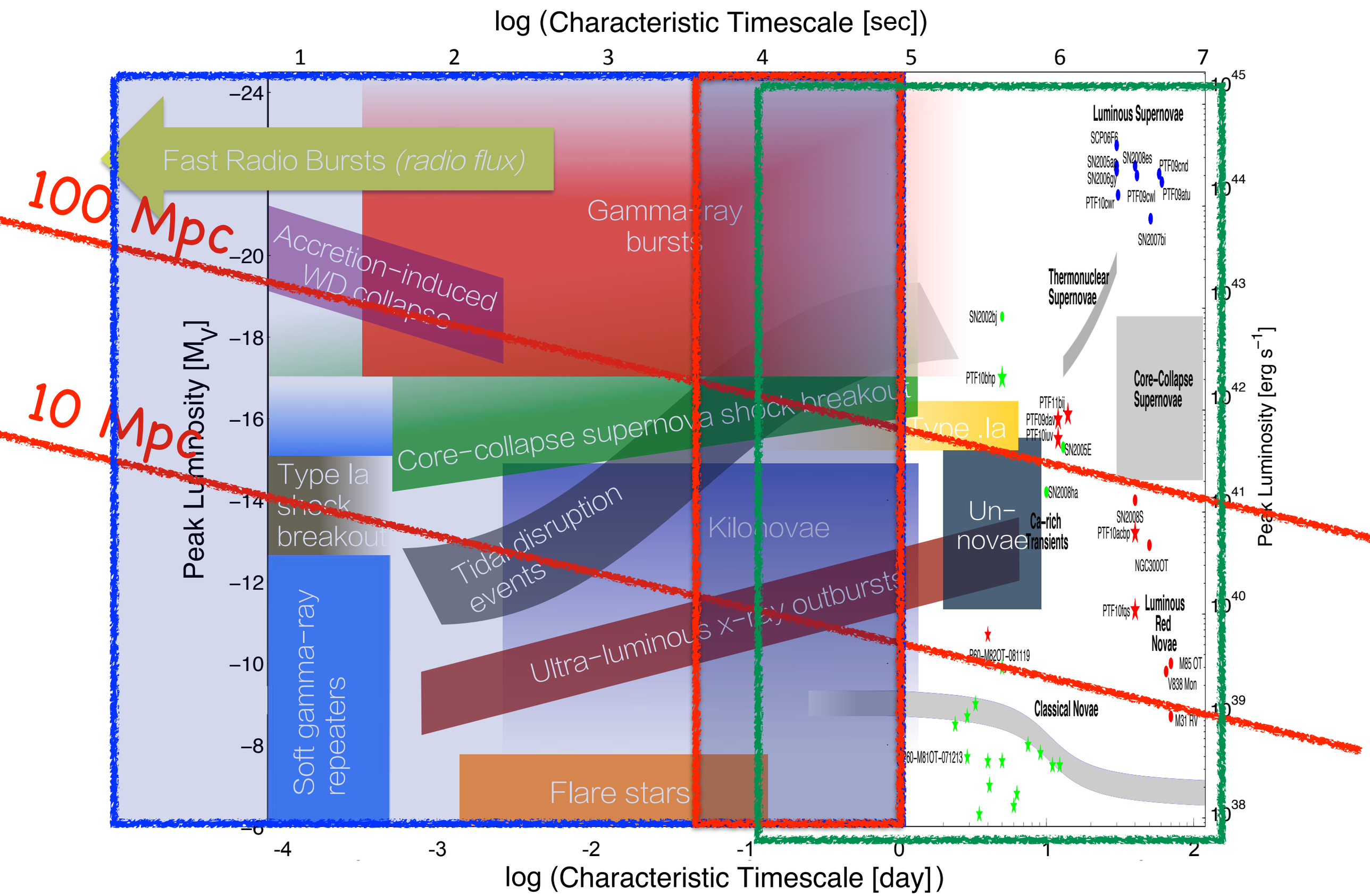
諸隈 智貴 (東京大学) ==> 田中 雅臣 (東北大学)

Tomoki Morokuma (Univ. of Tokyo/IoA)
==> Masaomi Tanaka (Tohoku Univ.)

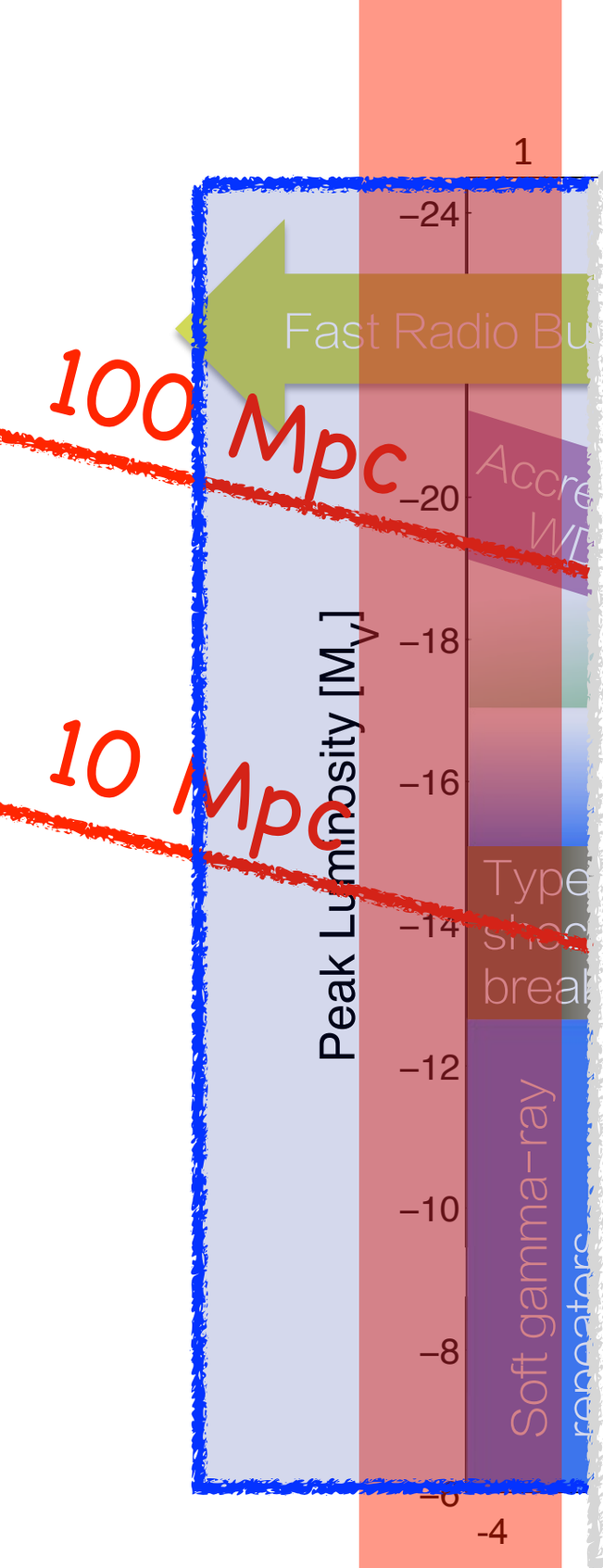
Contents



Kasliwal 2011



Kasliwal 2011, Cooke (http://www.astro.caltech.edu/~ycao/B&ETalks/B&E_FRBs_Cooke.pdf)



An optical search for transients lasting a few seconds

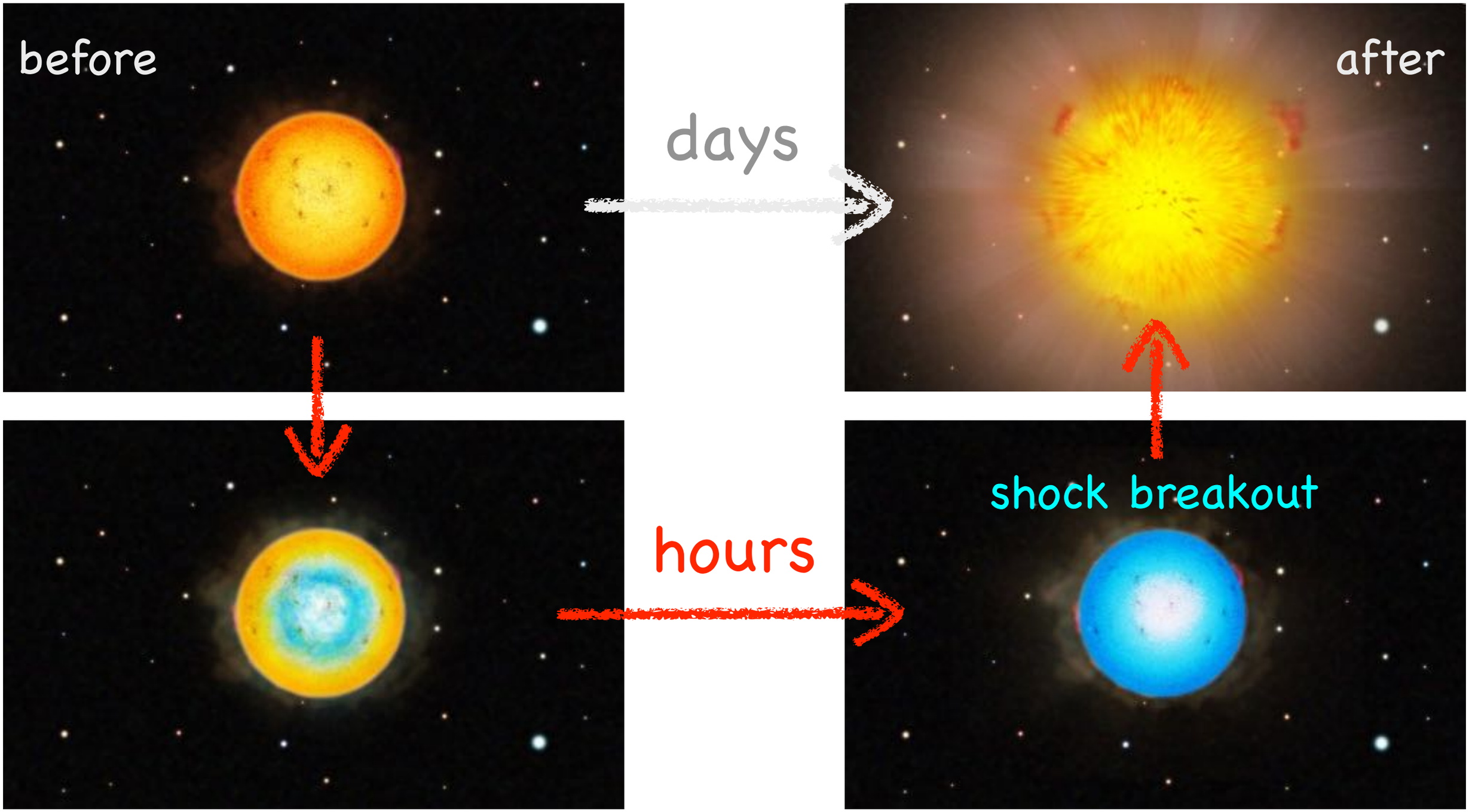
submitted

Michael W. RICHMOND[1], Masaomi TANAKA[2], Tomoki MOROKUMA[3], Shigeyuki SAKO[3], Ryou OHSAWA[3], Noriaki ARIMA[3], Nozomu TOMINAGA[4,5], Mamoru DOI[1,6], Tsutomu AOKI[7], Ko ARIMATSU[8], Makoto ICHIKI[3], Shiro IKEDA[9], Yoshifusa ITA[2], Toshihiro KASUGA[10,11], Koji S. KAWABATA[12], Hideyo KAWAKITA[11], Naoto KOBAYASHI[3,7], Mitsuru KOKUBO[2], Masahiro KONISHI[3], Hiroyuki MAEHARA[13], Hiroyuki MITO[7], Takashi MIYATA[3], Yuki MORI[7], Mikio MORII[9], Kentaro MOTOHARA[3], Yoshikazu NAKADA[3], Shin-Ichiro OKUMURA[14], Hiroki ONOZATO[15], Yuki SARUGAKU[11], Mikiya SATO[16], Toshikazu SHIGEYAMA[6], Takao SOYANO[7], Hidenori TAKAHASHI[7,3], Ataru TANIKAWA[17], Ken'ichi TARUSAWA[7], Seitaro URAKAWA[14], Fumihiko USUI[18], Junichi WATANABE[10], Takuya YAMASHITA[10] and Makoto YOSHIKAWA[19]

Kasliwal 2011, Cooke (http://www.astro.caltech.edu/~ycao/B&ETalks/B&E_FRBs_Cooke.pdf)

"Moment" of Supernova Explosion

Supernova Shock Breakout

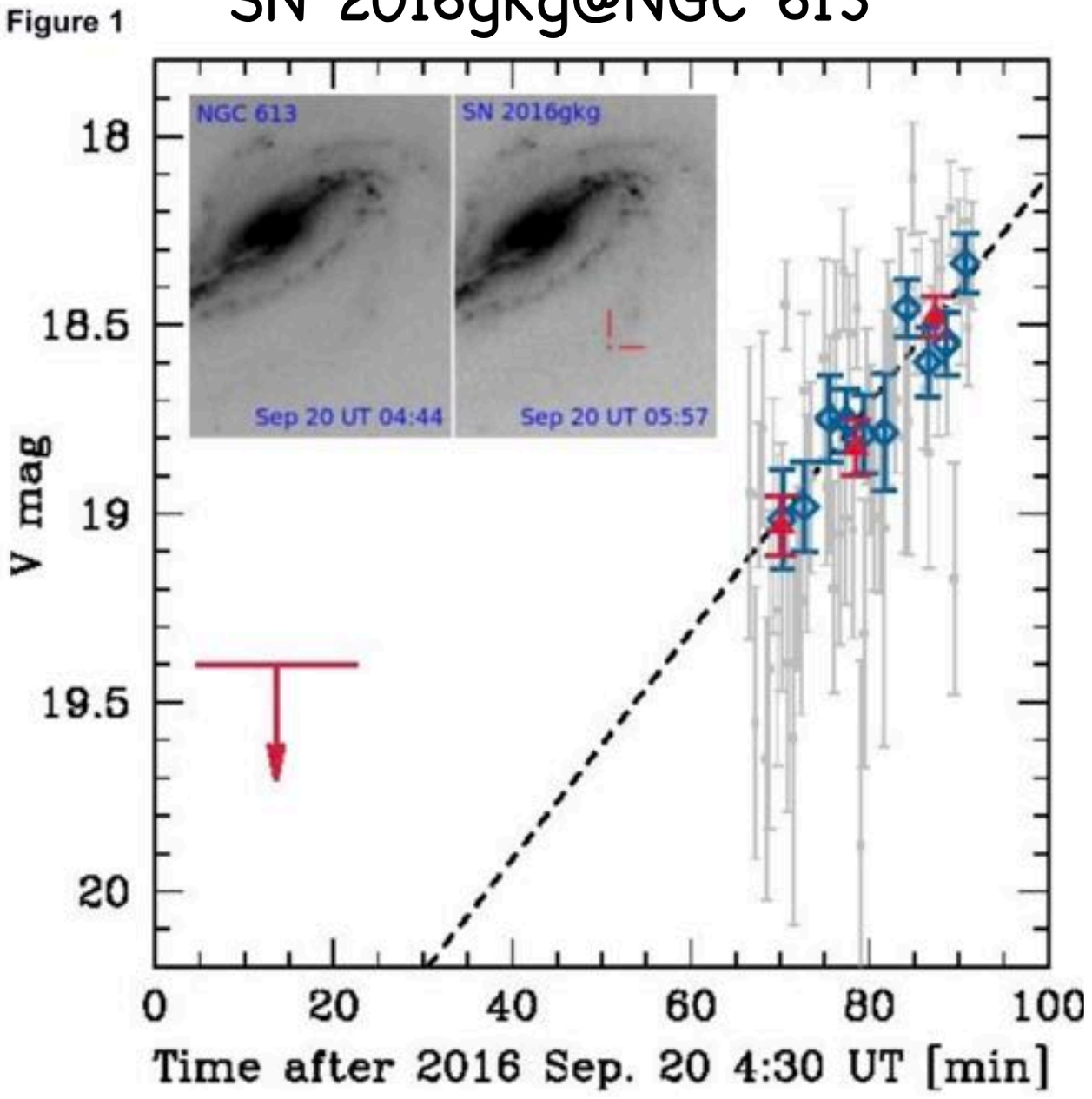


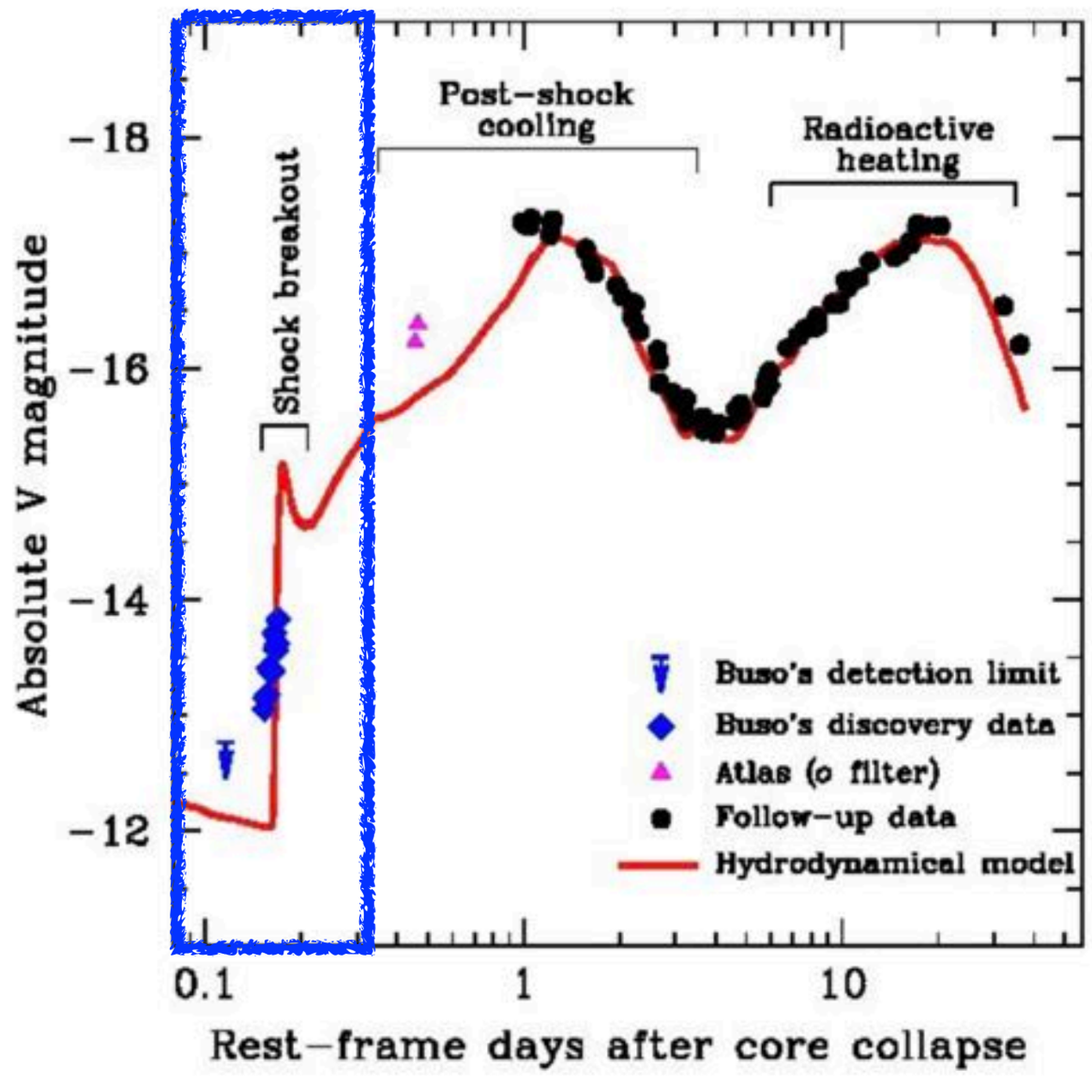
Very Early Phases of Core-Collapse Supernovae

Discovered by Victor Buso@Argentine, 16-inch telescope

SN 2016gkg@NGC 613

Bersten+2018, Nature





- possible detection with Gaia (Garnavich+2016, Rubin+2016)
- serendipitous detections with Swift/XRT (SN 2008D; Soderberg+2008), GALEX (Schawinski+2008)

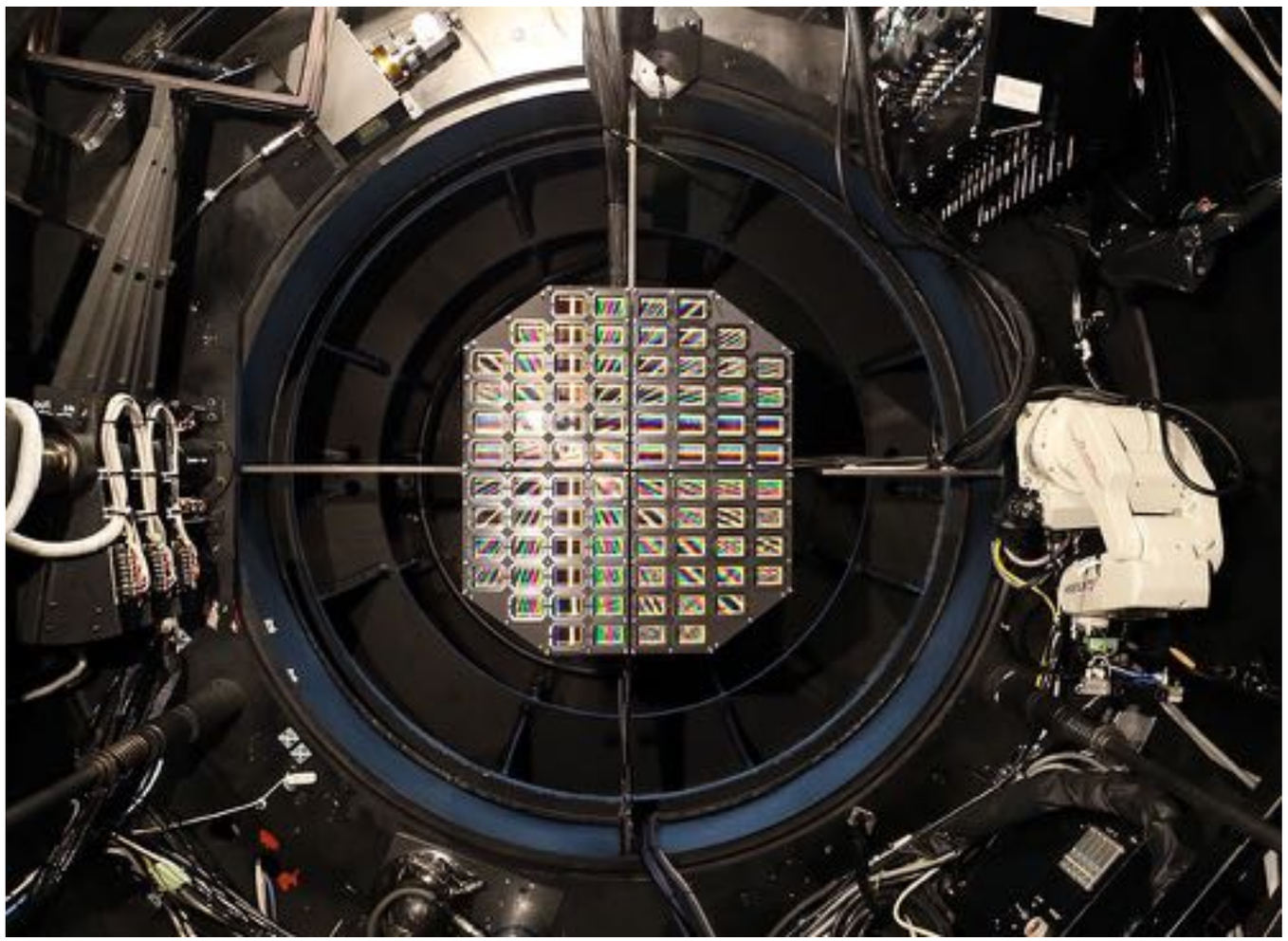
105cm Kiso Schmidt Telescope

- @Nagano, Kiso
- 105 cm Schmidt telescope (4th largest)
- since 1974
- open-use ==> collaboration basis (2018-)

Tomo-e Gozen

April 2019 completed

- 84 CMOS sensors
- low dark current, readout noise
  - operated in room temp. (no cooler)
- effective area: 20 deg2 (9 deg in diameter)
  - 1k x 2k ~ 20 x 40 arcmin2
- no filter (gri, Ha, ... sometimes)
- 2 Hz readout (nominal): up to ~200 Hz



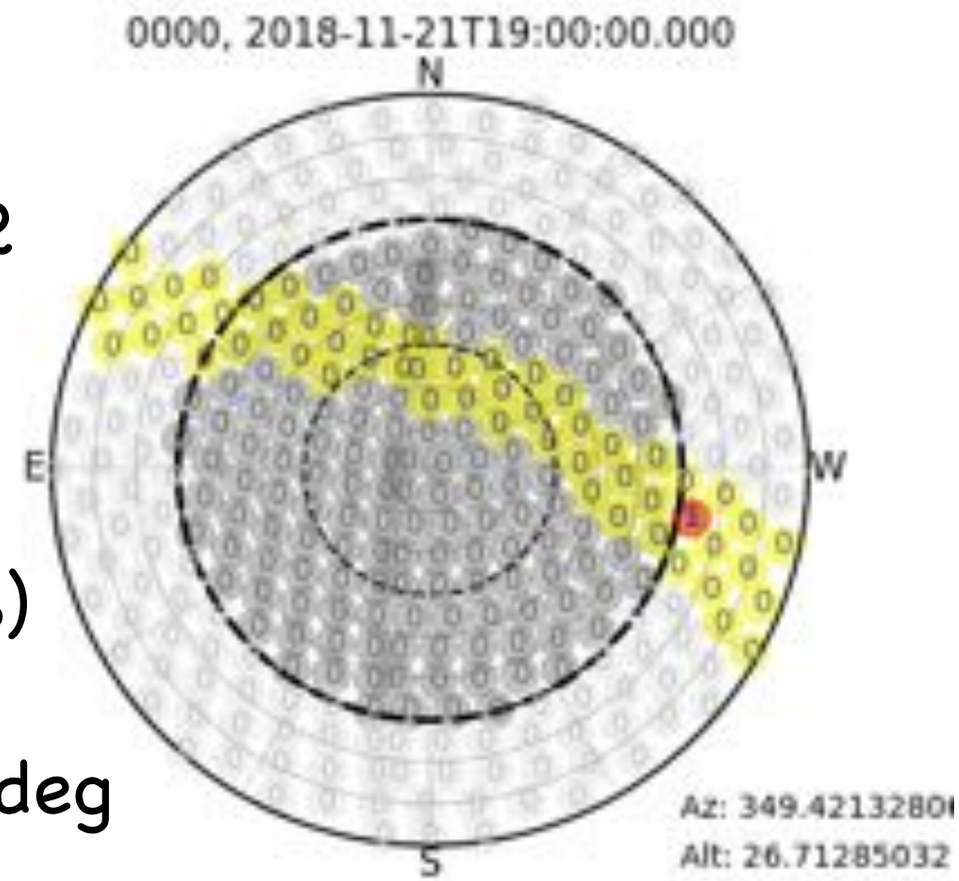
蔀関月作,「巴御前出陣図」,
東京国立博物館,
©Image: TNM Image Archives

Northern Sky Transient Survey w/ Tomo-e Gozen

7,000 deg2 - 2 hr cadence - 18 mag depth

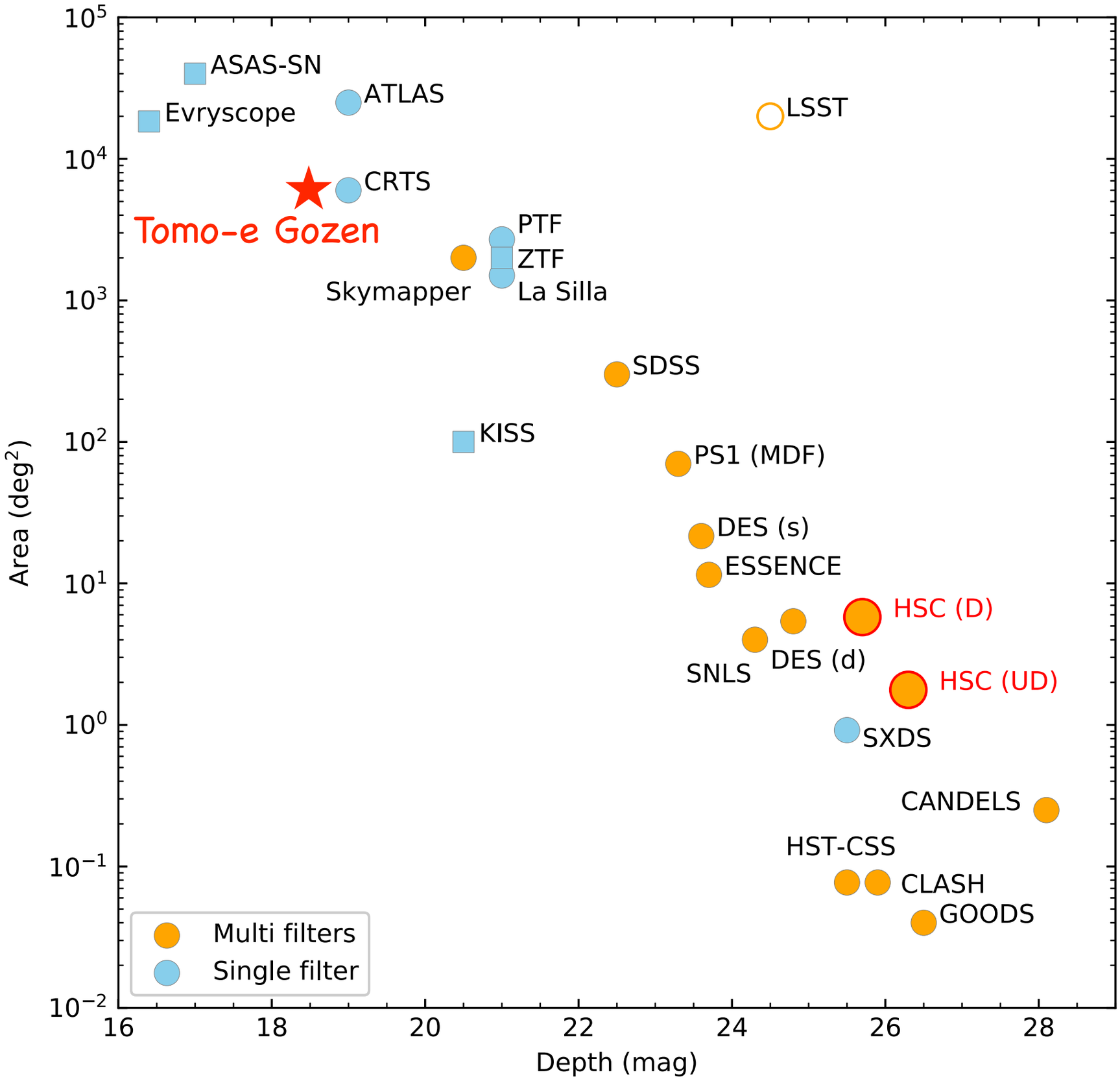
7,000 deg2 - 1 day cadence - 19 mag depth

- no filter: effectively g+r bands
- 1 visit
  - 6 sec exposure: [0.5 sec exposure] x 12
    - ~18-19 mag
  - 2x3 or 2x2 dithering
    - ~8% missed
  - ~60 deg2 (partially vignetted by ~30%)
- cadence: ~2 hours
- survey area / 2 hrs: ~7,000 deg2, EL>40 deg
- 2-4 times visits per night
  - ~19 mag for daily stacked data (not yet implemented)
- survey simulation (Joao, Ikeda+)
- reference: PS1 r-band



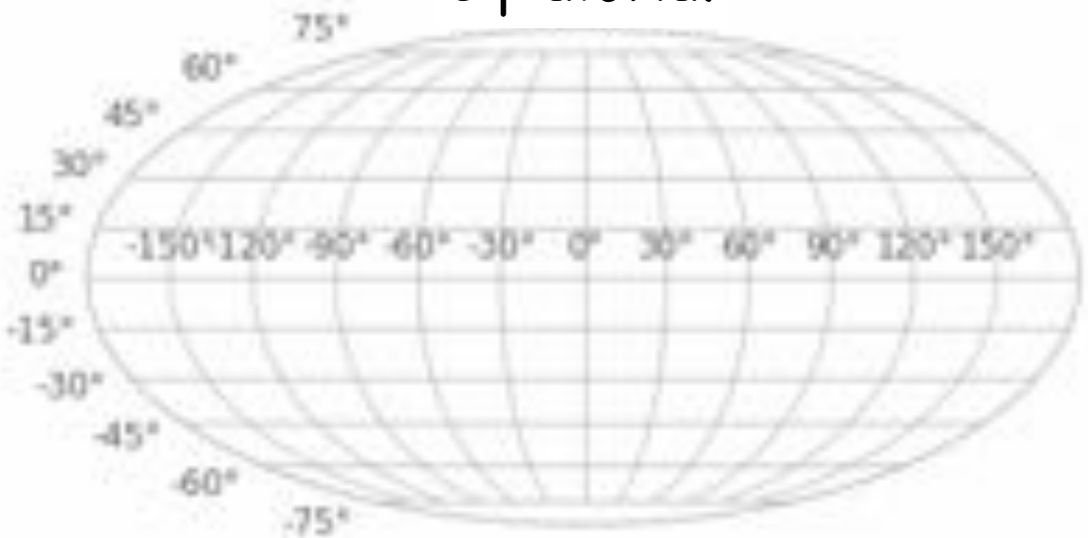
Tomo-e Gozen Survey Power

Yasuda+2019, in press

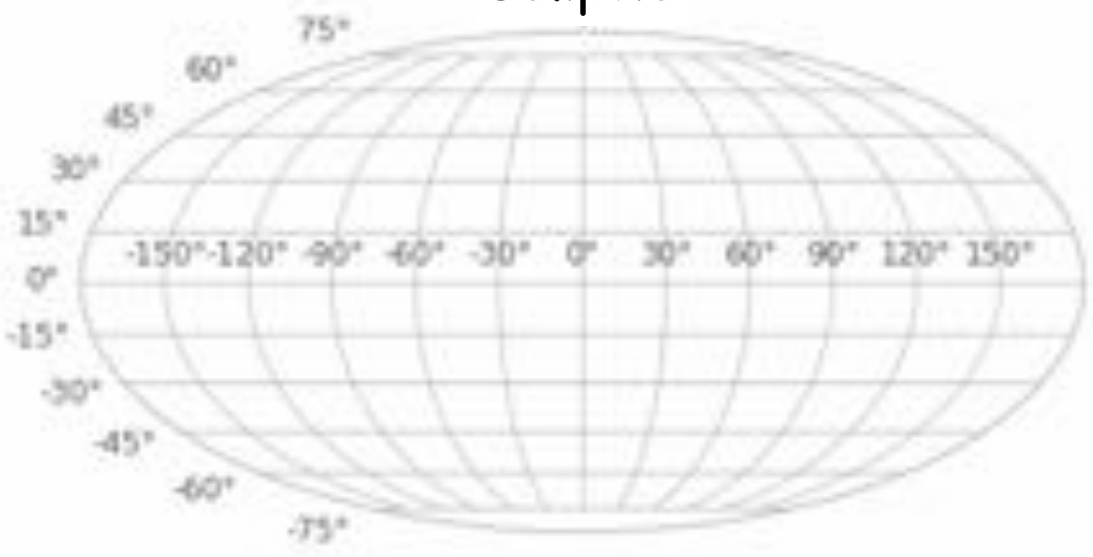


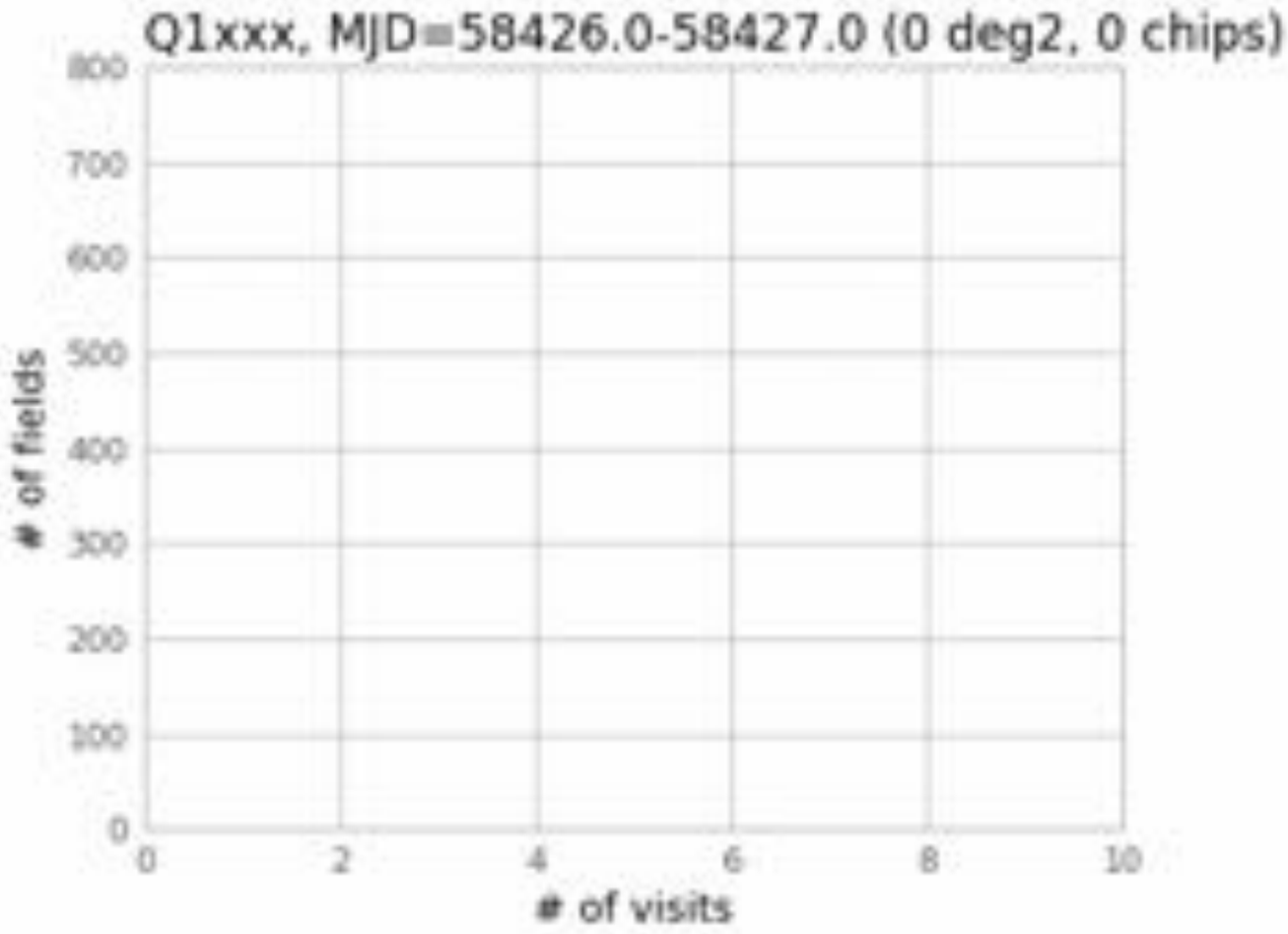
Survey Statistics (as of 2019/07/05)

equatorial



ecliptic



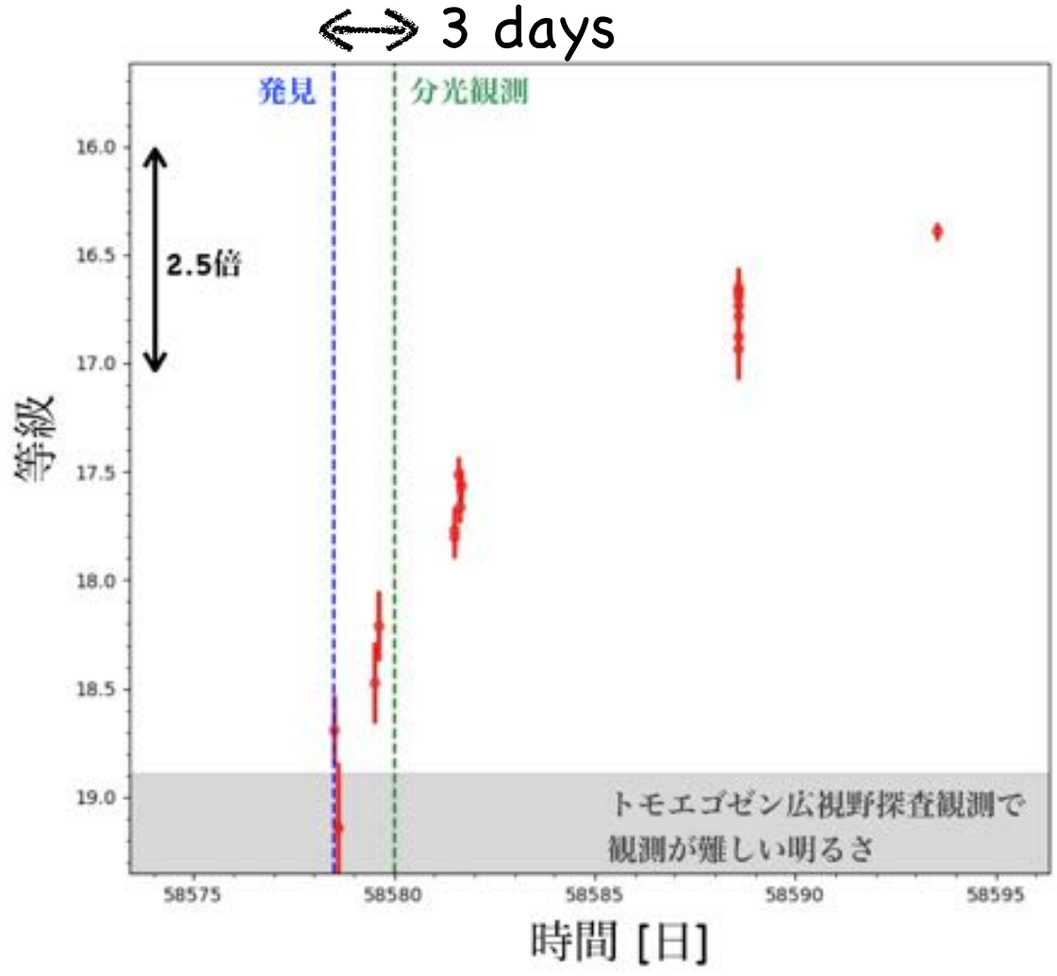


red: tonight

blue: previously observed (thicker, more visits)

First Discovery of A Supernova (SN 2019cxx)

- April 2019
- Type Ia supernova@z=0.025
- follow-up observations
  - Spectroscopy
    - Gemini-N/GMOS (Tanaka+)
    - Seimei/KOOLS-IFU (Maeda+)
    - Kanata/HOWPol
  - Imaging
    - Kanata/HOWPol




YAHOO! JAPAN ニュース

完成直前の快挙！ 観測装置「トモエゴゼン」が3億5000万光年先の超新星爆発を発見

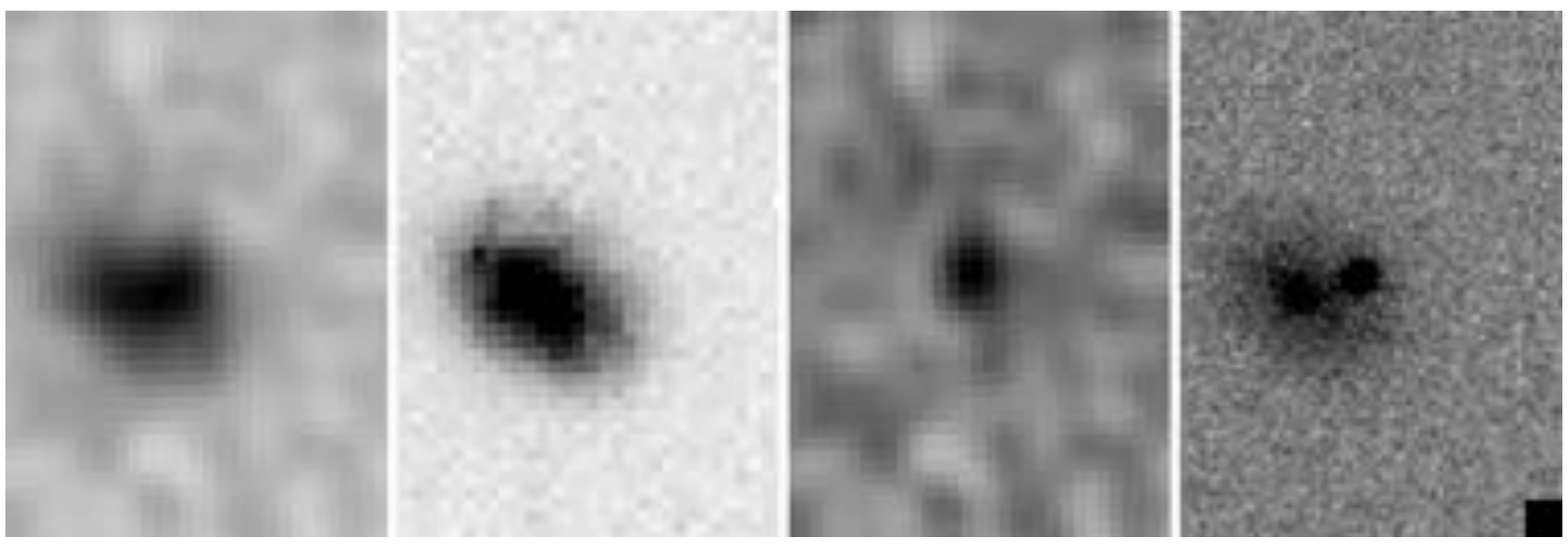
4/25(木) 21:38配信

sorae 宇宙へのポータルサイト

東京大学木曽観測所は4月23日、超広視野CMOSカメラ「Tomo-e Gozen（トモエゴゼン）」を用いた観測により、3億5000万光年先の銀河で起きた超新星爆発を発見したと発表しました。超新星には「SN 2019cxx」の名称が付与されています。

超広視野CMOSカメラ「Tomo-e Gozen（トモエゴゼン）」

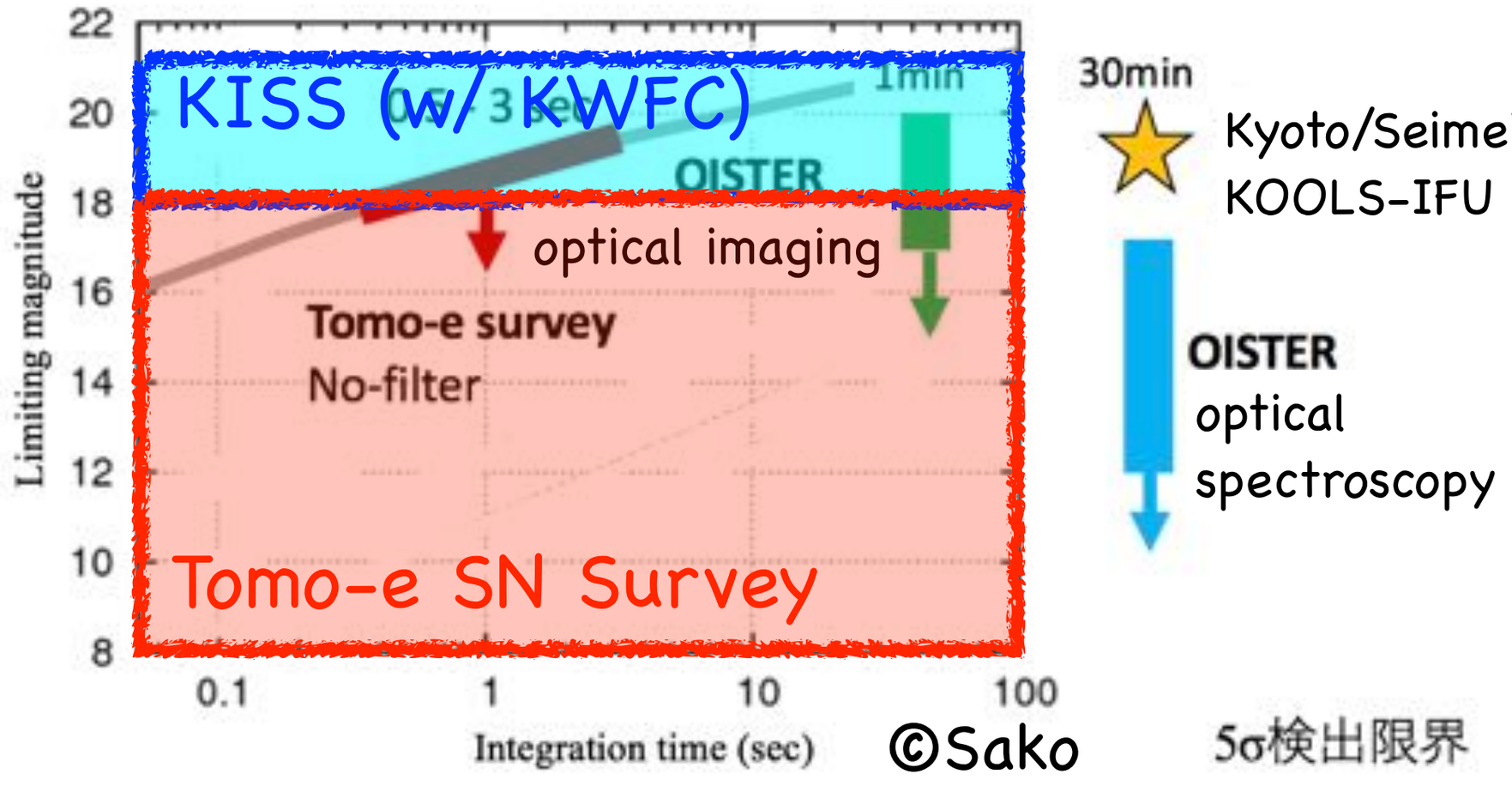
超新星を発見した「トモエゴゼン」は、完成時点で84個のCMOSセンサーを組み合わせた、大掛かりなデジタルカメラのような最新鋭の観測装置です。木曽観測所に設置されている105cmシュミット望遠鏡に搭載することで、満月の見かけの直径の18倍という広い範囲を一度に観測するこ



http://www.ioa.s.u-tokyo.ac.jp/kisohp/NEWS/SN2019cxx/index.html

Follow-up Scheme

- After discovering transient candidates...
  - spectroscopic identification
    - flash spectroscopy w/ Seimei/KOOLS-IFU
  - multi-band light curves
- KISS w/ KWFC: KISS international collaboration + OISTER
  - # of spectroscopic observations (29 spec-ID+) limited: too faint
    - TM+2014, Tanaka+2014, TM+2017, Gabanyi+2018, Kokubo+2019
- Tomo-e Gozen survey: bright enough for OISTER domestic telescopes
  - discovery ==> follow-up within the same night
- Approved programs
  - Seimei/KOOLS-IFU
  - Gemini-N/GMOS
  - (Kanata, MITSuME)



Proposed Observations for Seimei/KOOLS-IFU

- ~15 candidates w/ ~> 1 mag day^{-1} (up to 150 Mpc)
  - "flash spectroscopy" (<1 day after Tomo-e discovery)
- ~4 objects
  - more (~4 more times) follow-up w/ Seimei/KOOLS-IFU
  - more follow-up w/ Kanata, MITSuME, ...
- Discoveries, identification, & characterization of a few rapidly evolving transients

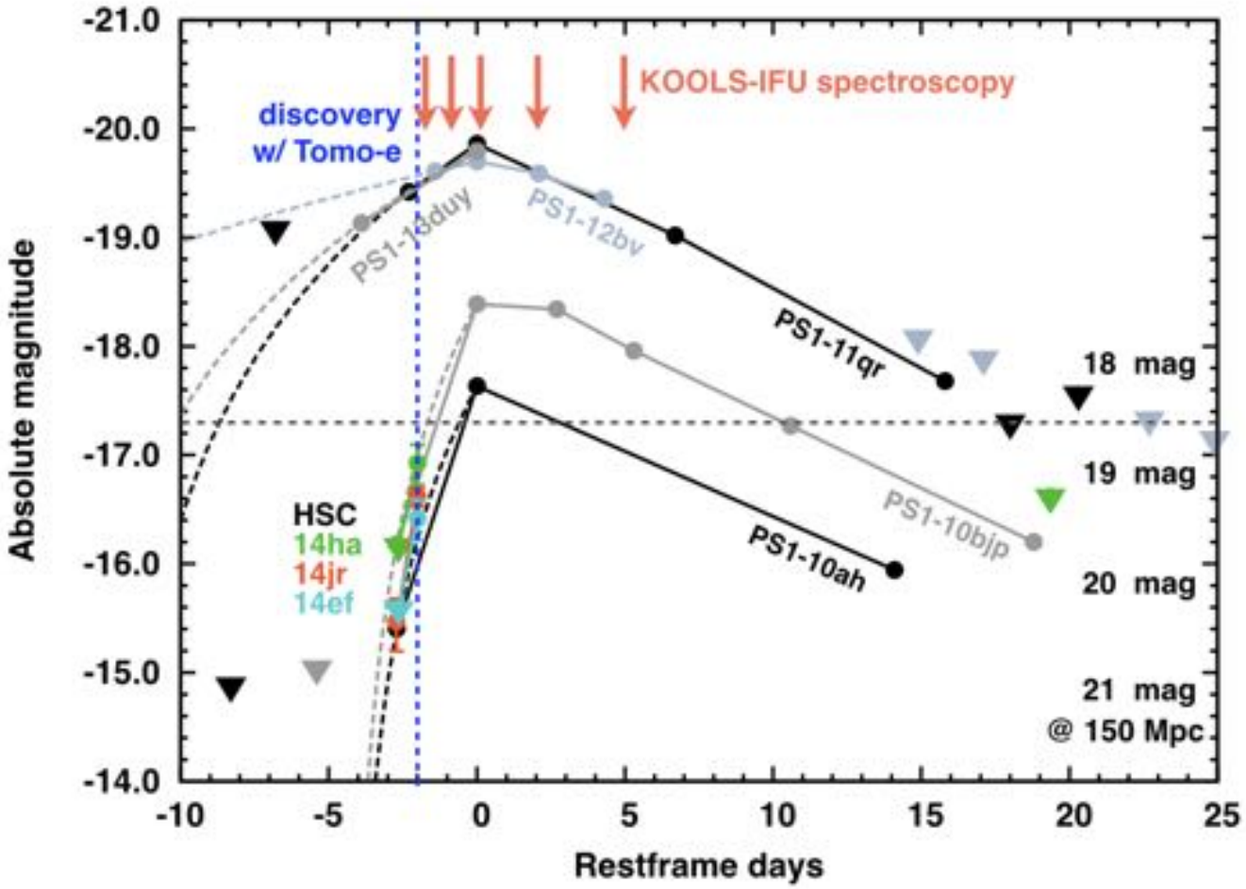
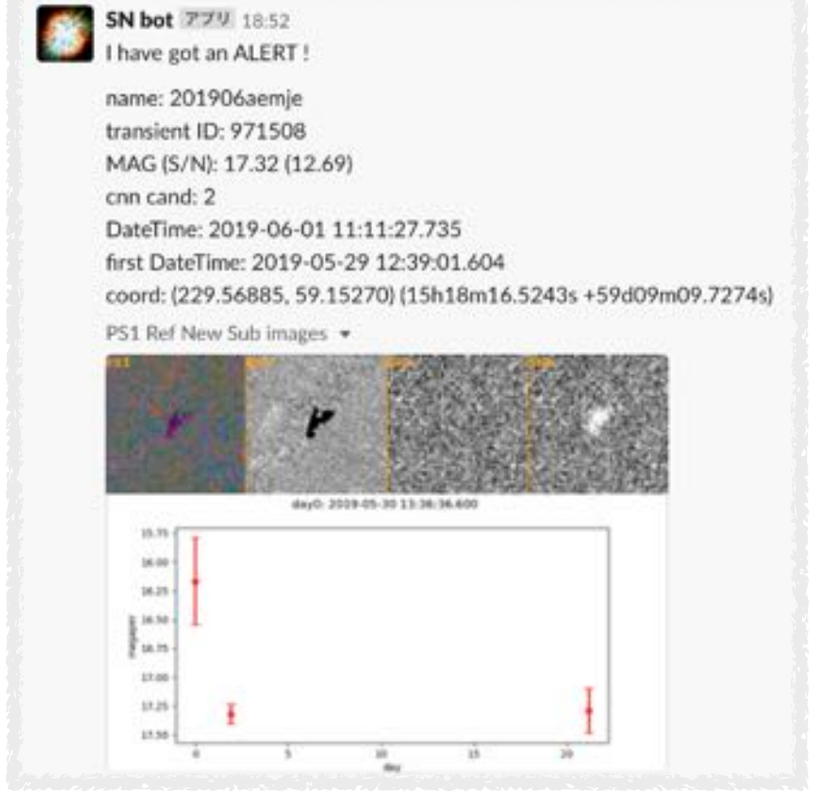
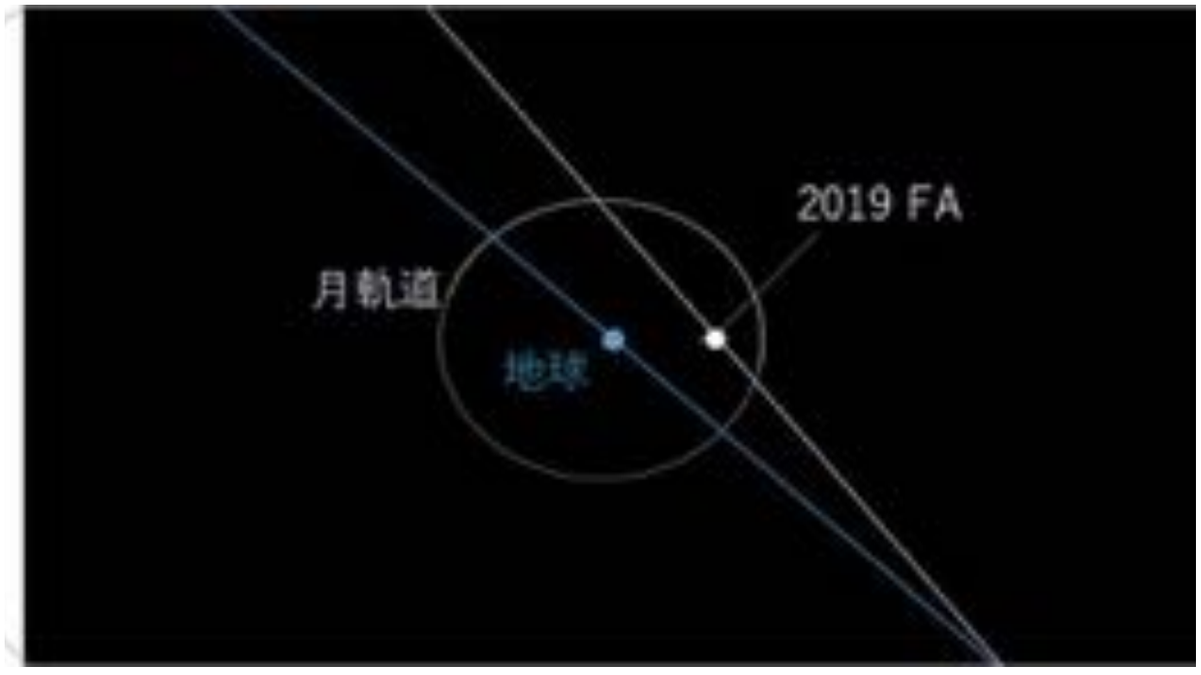


Figure 3 Light curves of rapid transients with planned epochs of KOOLS-IFU spectroscopy. @Our proposal (from Tanaka+2016)

Data Products

- **after image subtraction**: being developed
  - Subtracted images relative to PS1 r-band
    - CNN ==> automatic alert for bright transients
  - photometry@subtracted images
- before image subtraction for variable stars etc.
  - photometry & light curves
- **motion detection**
  - NEO search
    - Discovery of 2019 FA
      - size: ~8m (http://www.ioa.s.u-tokyo.ac.jp/kisohp/NEWS/2019FA/2019FA.html)





Summary

- Let's catch supernovae (and other transient phenomena) in early-phase (right after explosions).
- Tomo-e Gozen was completed in April 2019.
- Northern Sky Transient Survey has been started since Nov. 2018 (w/ Q1).
  - Fully ready this fall.
- 2x2 dithering, 7,000 deg / 2 hours, 18 mag depth
- 2-4 visits / night
  - Effective survey by simulation (Joao, Ikeda et al. in prep.)
    - additionally consider weather conditions (avoid cloudy region and choose clear sky region) <== ongoing
- Development of automatic data reduction pipeline & website I/F: almost done.
  - Machine-learning technique (CNN) to pick up only real sources: being developed
  - Automatic alert (to ourselves): being tested
- First SN (Type Ia) was successfully discovered & identified.
- quick follow-up observations w/ Seimei, Kanata, Gemini, ...
  - "flash" spectroscopy w/ KOOLS-IFU