A Wide-Field Survey for Rapid Optical Transients with Subaru Hyper Suprime-Cam

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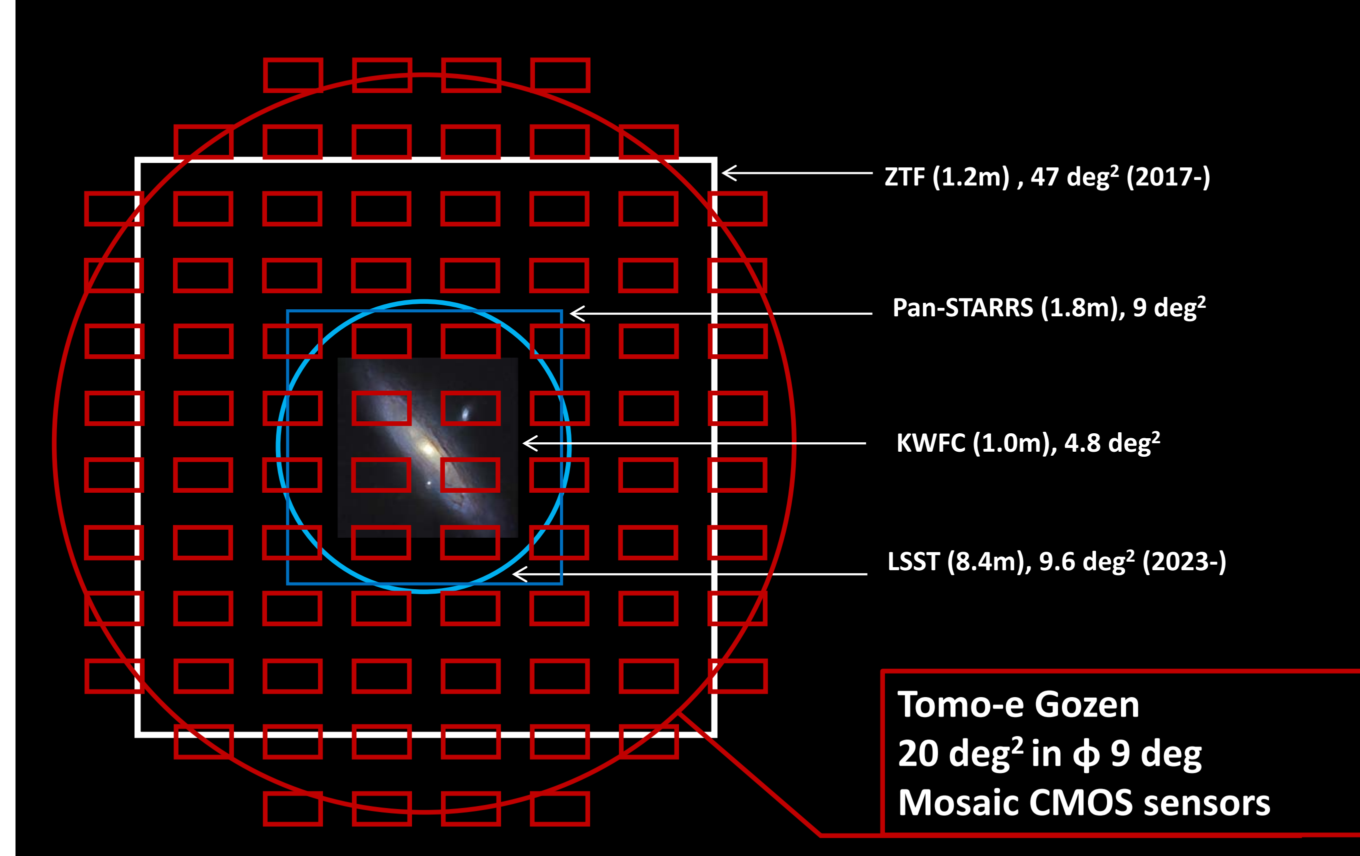
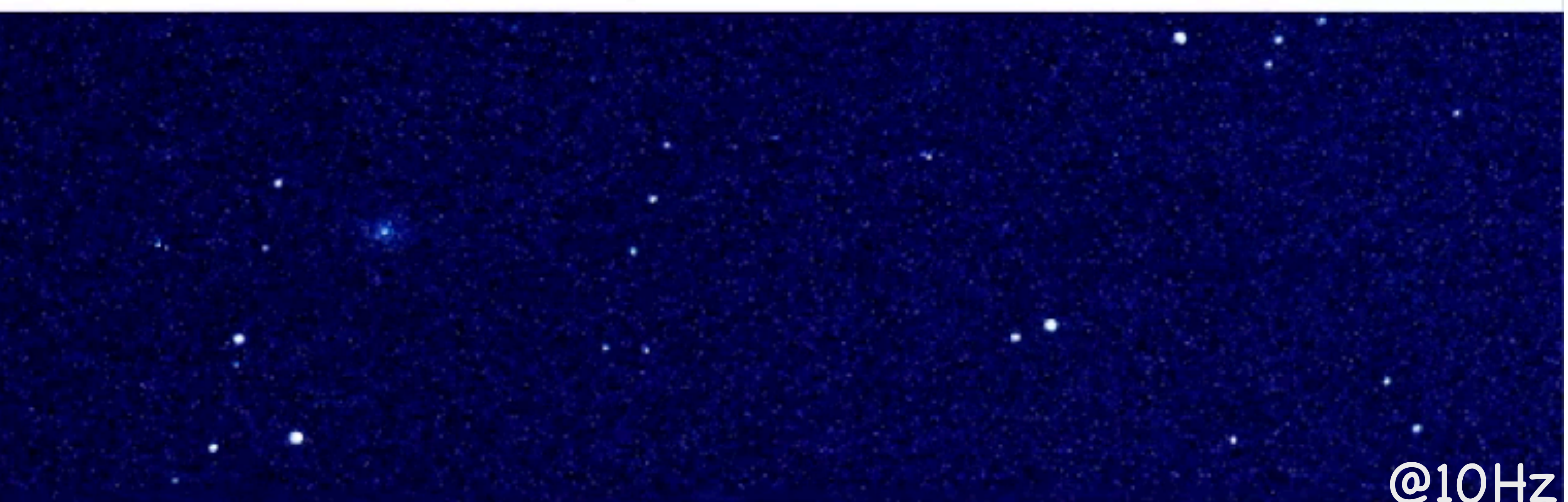
Tanaka et al. ApJ, 819, 5 (supernovae)
TM et al. 2016, PASJ, 68, 40 (AGN)
Morii et al. 2016, PASJ, in press (arXiv:1609.03249, ML)

Kiso Observatory (UT/IoA) "Tomo-e Gozen"

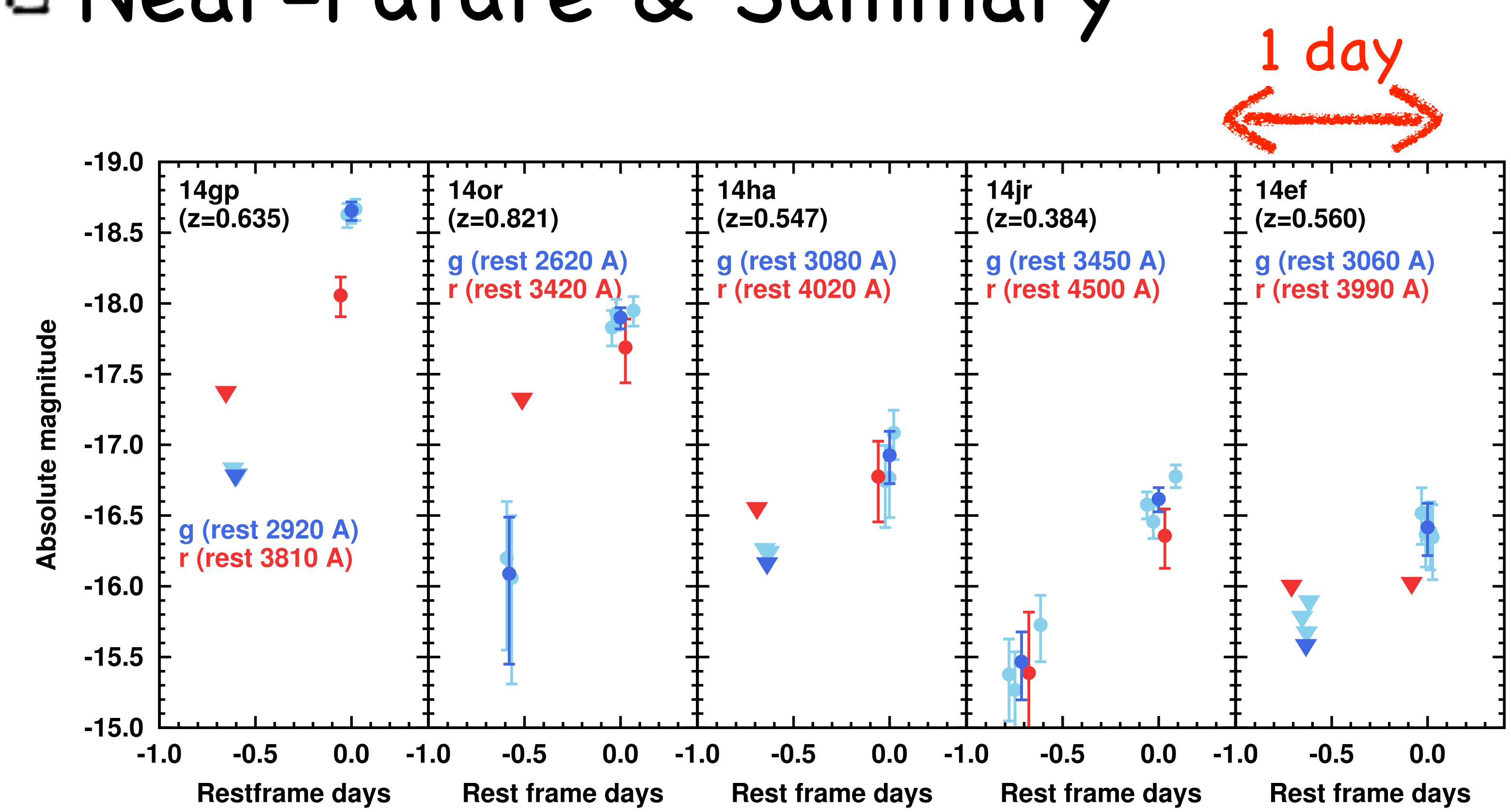
- 1.05 m Kiso Schmidt telescope
- Instrument
  - Kiso Wide Field Camera (KWFC, 2012-): 8 CCDs, 4 deg2
    - KISS (TM+2014), KISOGP
  - Tomo-e Gozen (2018-) by Sako
    - 84 CMOS sensors, 20 deg2
    - >=2 Hz readout
    - low readout noise, low dark current
    - Sako+2016, Ohsawa+2016 (SPIE)

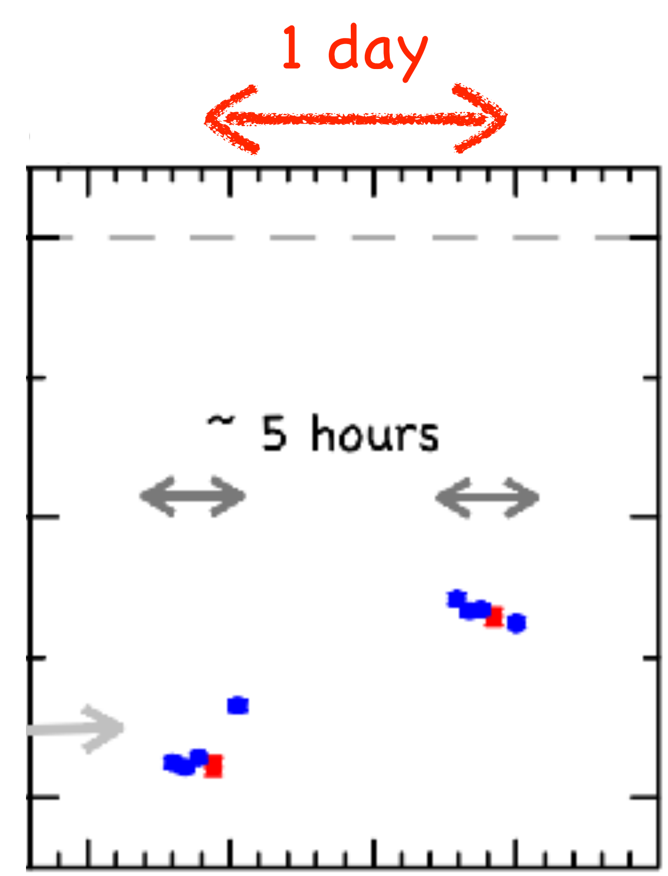




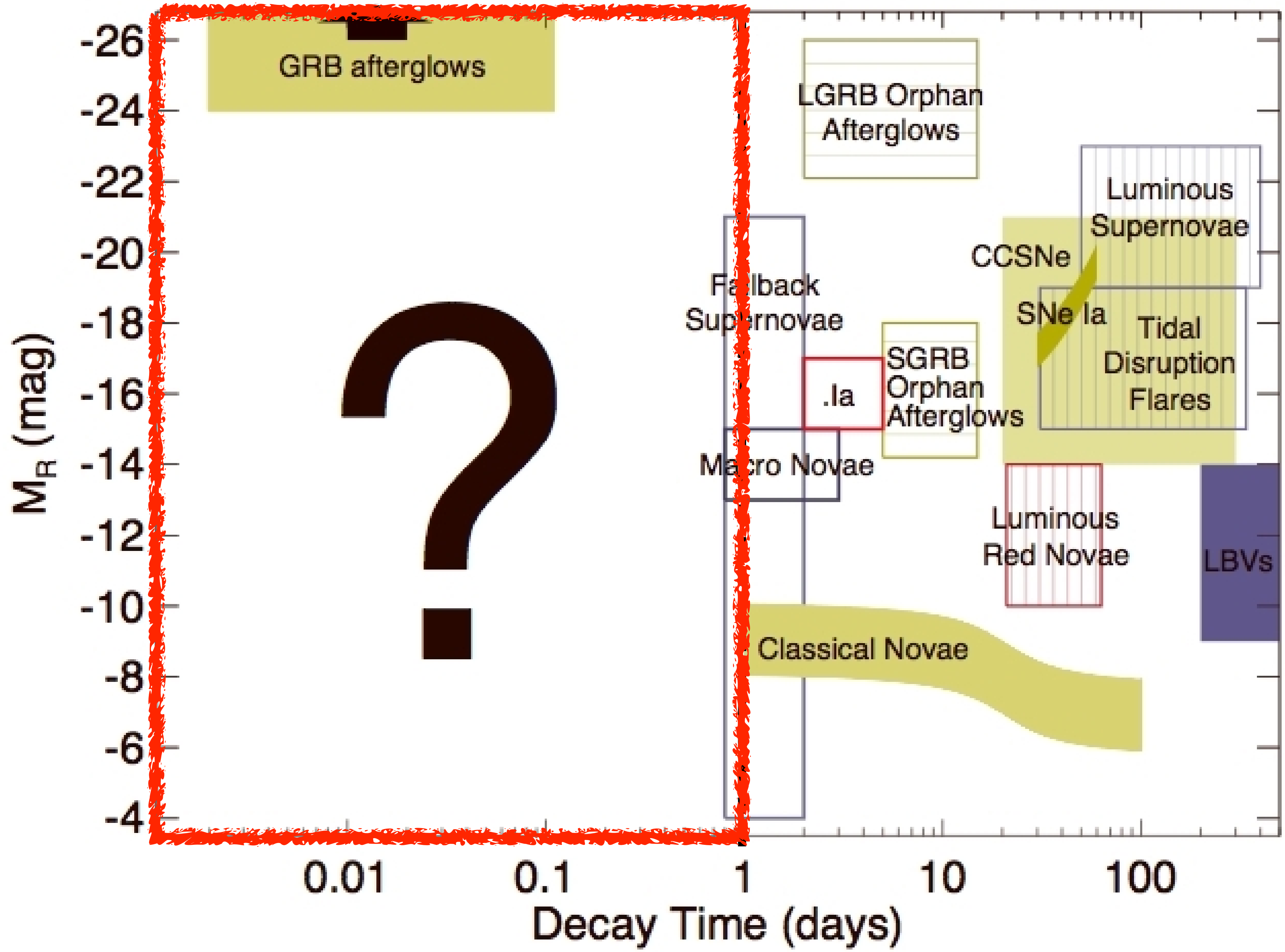
Contents

- Optical Transient Sky & Transient Survey
  w/ Subaru Telescope + Hyper Suprime-Cam (HSC)
- Machine Learning Technique for real-bogus classification
- Rapid Transients 1:
  Core-Collapse Supernovae right after Explosion
- Rapid Transients 2:
  Active Galactic Nuclei w/ Small Black Holes
- Near-Future & Summary

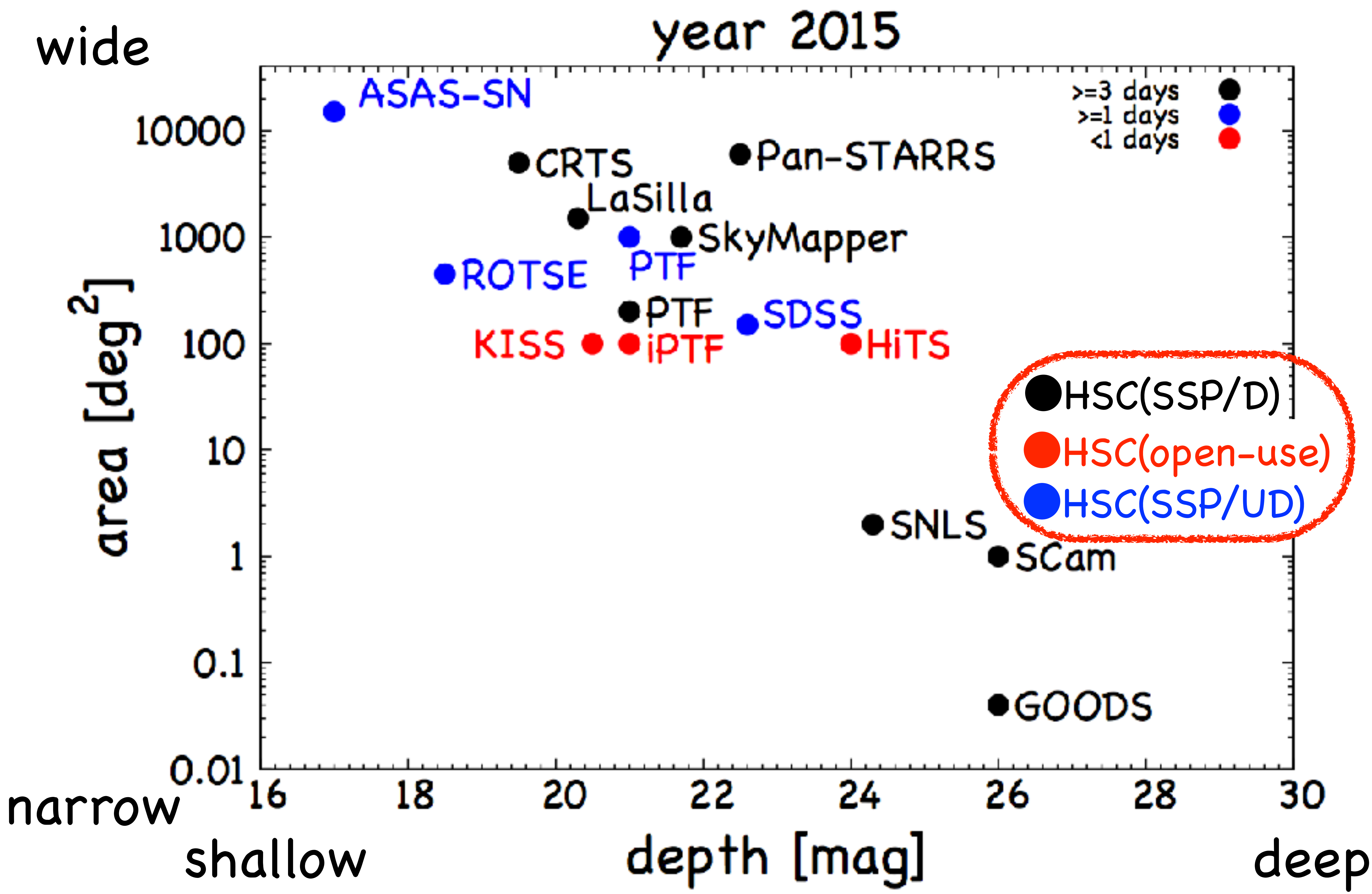




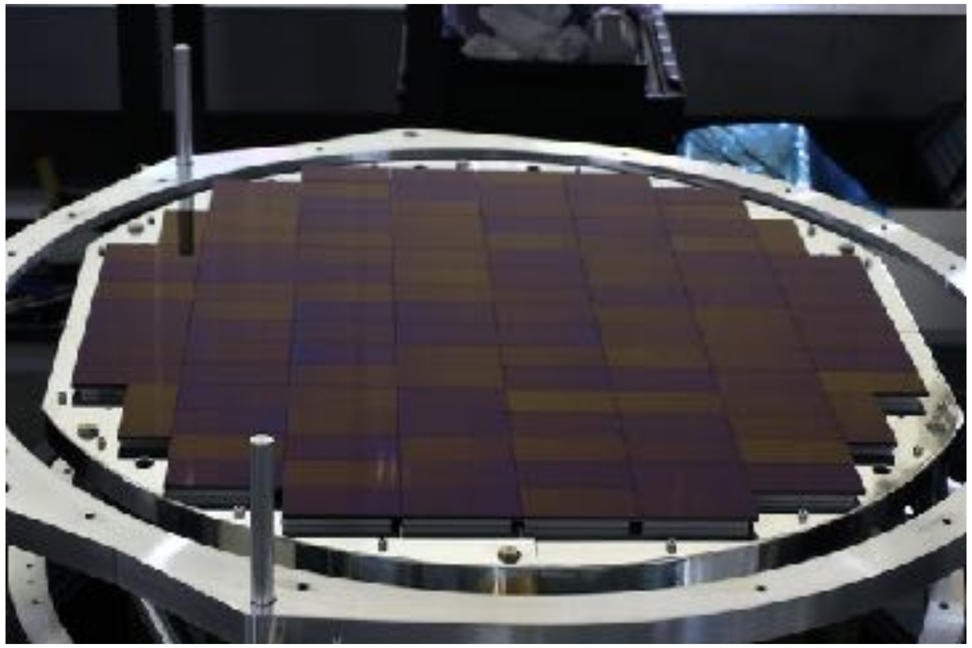
Frontier of transient sky



LSST Science Book (after Rau+09, Kasliwal+,Kulkarni+)


year 2015
wide
narrow
shallow
deep
area [deg^2]
depth [mag]
10000
1000
100
10
1
0.1
0.01
16
18
20
22
24
26
28
30
>=3 days
>=1 days
<1 days
ASAS-SN
CRTS
Pan-STARRS
LaSilla
SkyMapper
PTF
ROTSE
PTF
SDSS
KISS
iPTF
HiTS
HSC(SSP/D)
HSC(open-use)
HSC(SSP/UD)
SNLS
SCam
GOODS

Subaru/HSC Transient Survey



- Subaru (8.2m) + Hyper Suprime-Cam (HSC)
- from Suprime-Cam to HSC
  - CCDs: 10 ==> 108
  - ~800 Mpixel
  - field-of-view: 0.25 deg^2 ==> 1.8 deg^2
- **high-cadence survey** (Tominaga, TM, Tanaka, et al.)
  - **1-hour interval**
    - aiming at detecting supernova shock breakouts
      - the moment of supernova explosions
    - by-product
      - AGN w/ low-mass active BHs
  - July 2 & 3, 2014
  - 12 deg^2
  - imaging & spectroscopic follow-up observations

"Well Organized" HSC Observation

Data Reduction w/ On-Site System

Image Subtraction

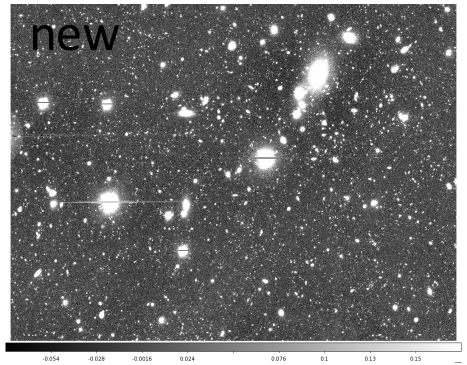
Transient Object Catalog w/ many bogus

"Real" Transient Object Catalog

Follow-Up Observations

Science !!!

new



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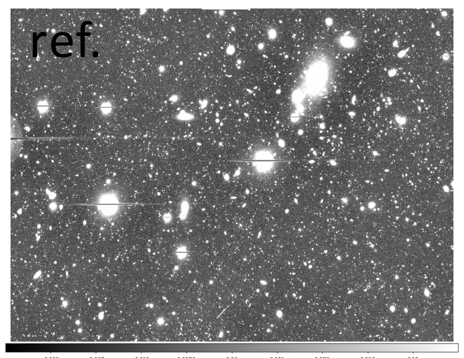

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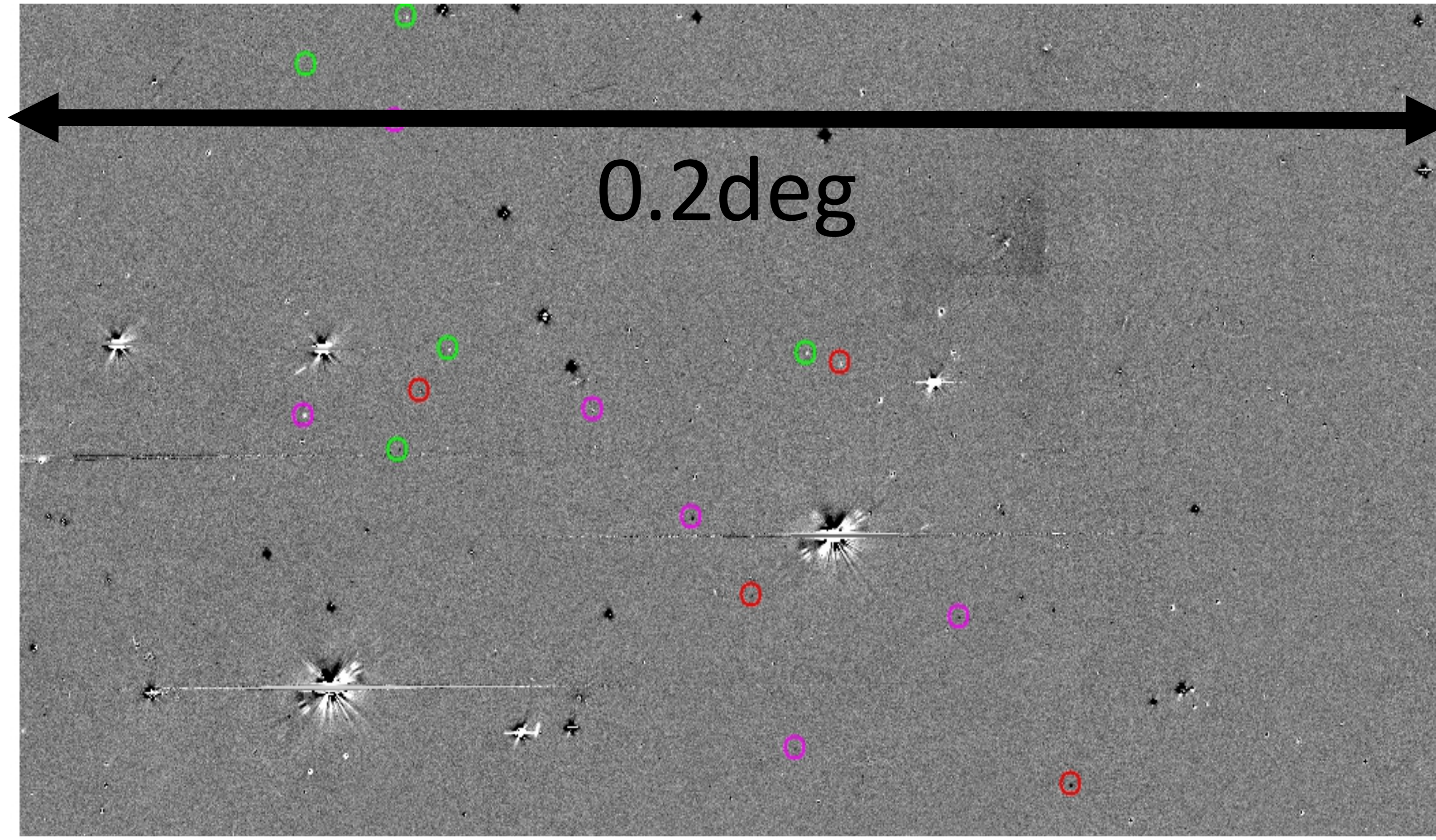
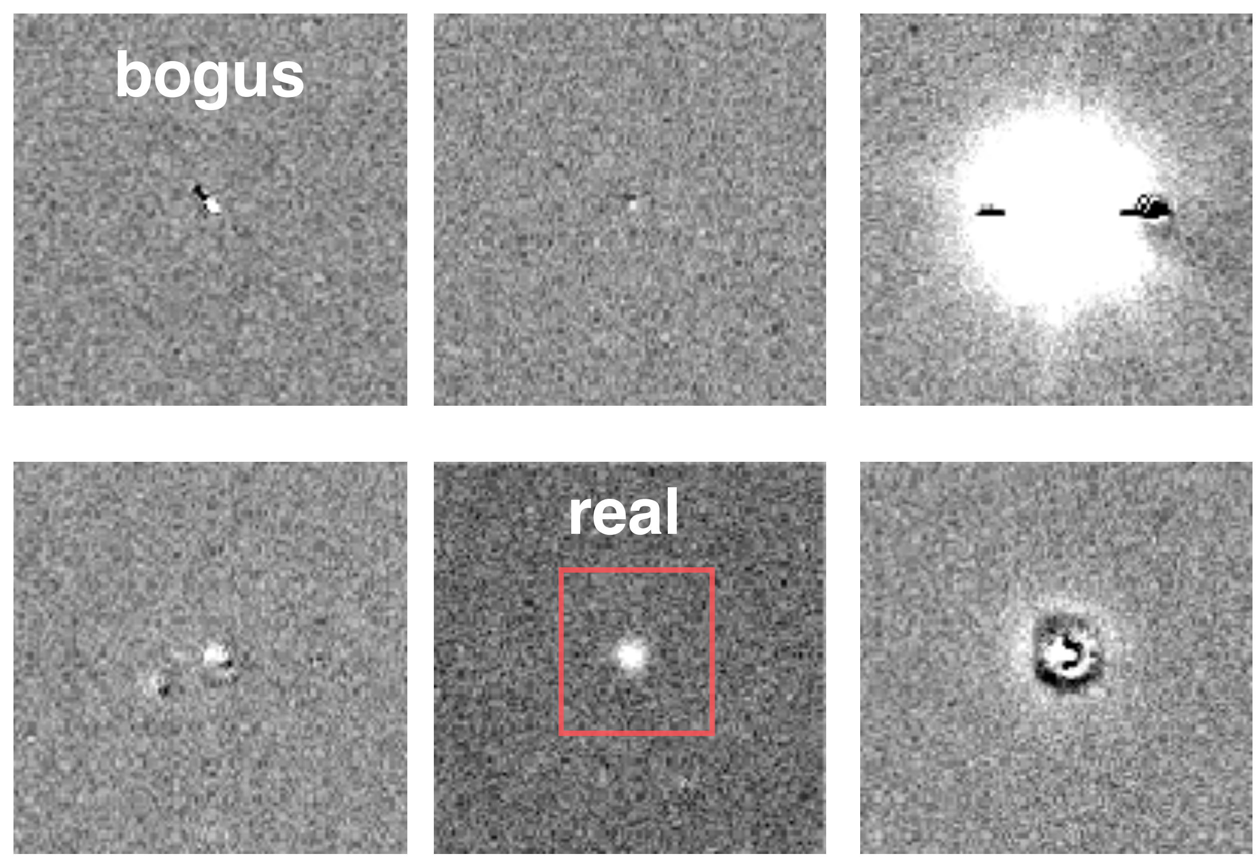


subtracted image

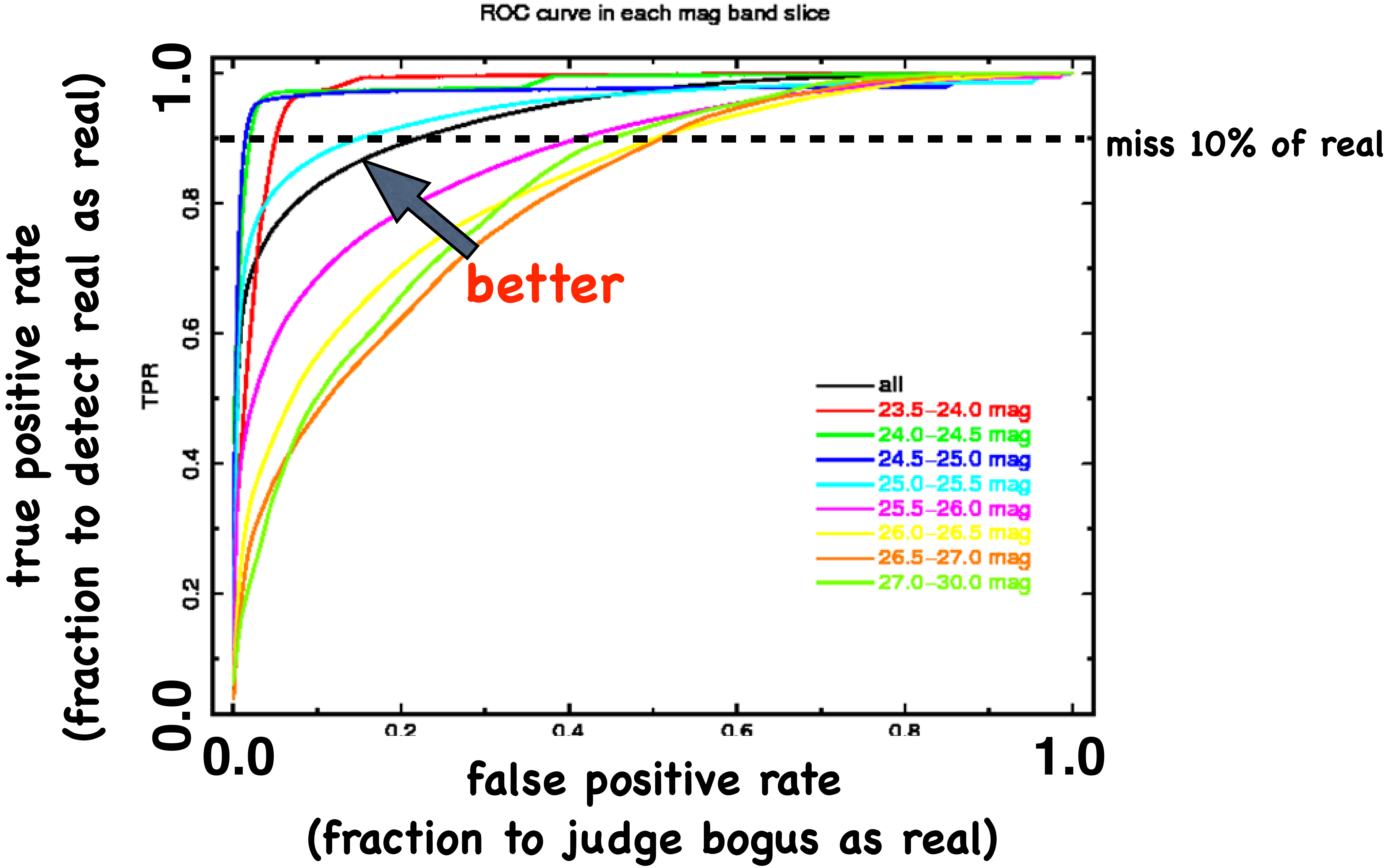
real vs bogus
~ 1 : 1000



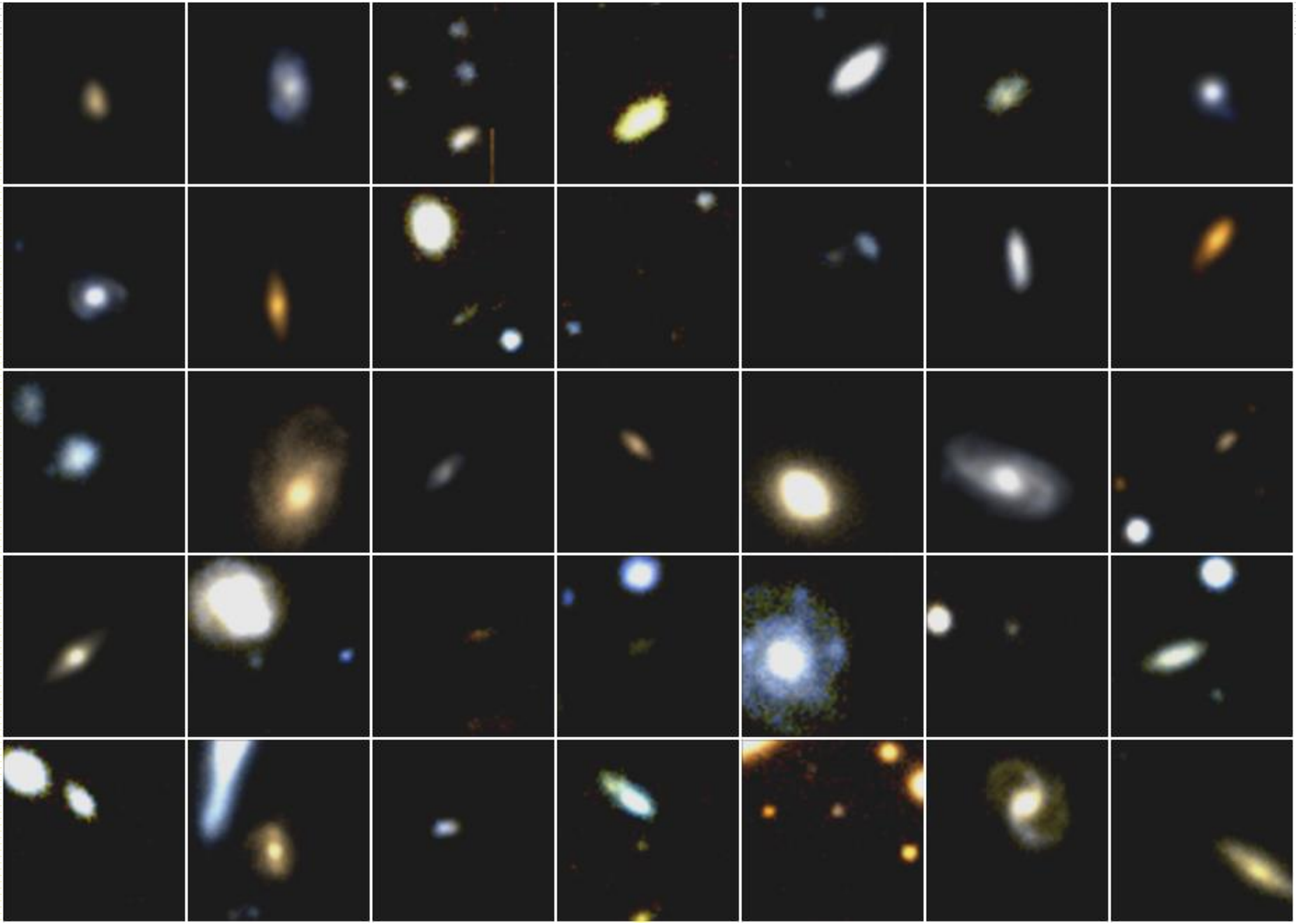
Machine Learning for Transient Detection

Morii+2016, PASJ, in press (arXiv:1609.03249)

JST/CREST collaboration; Kavli IPMU, Institute for Statistical Mathematics, NTT Communication Science, and Tsukuba Univ.)

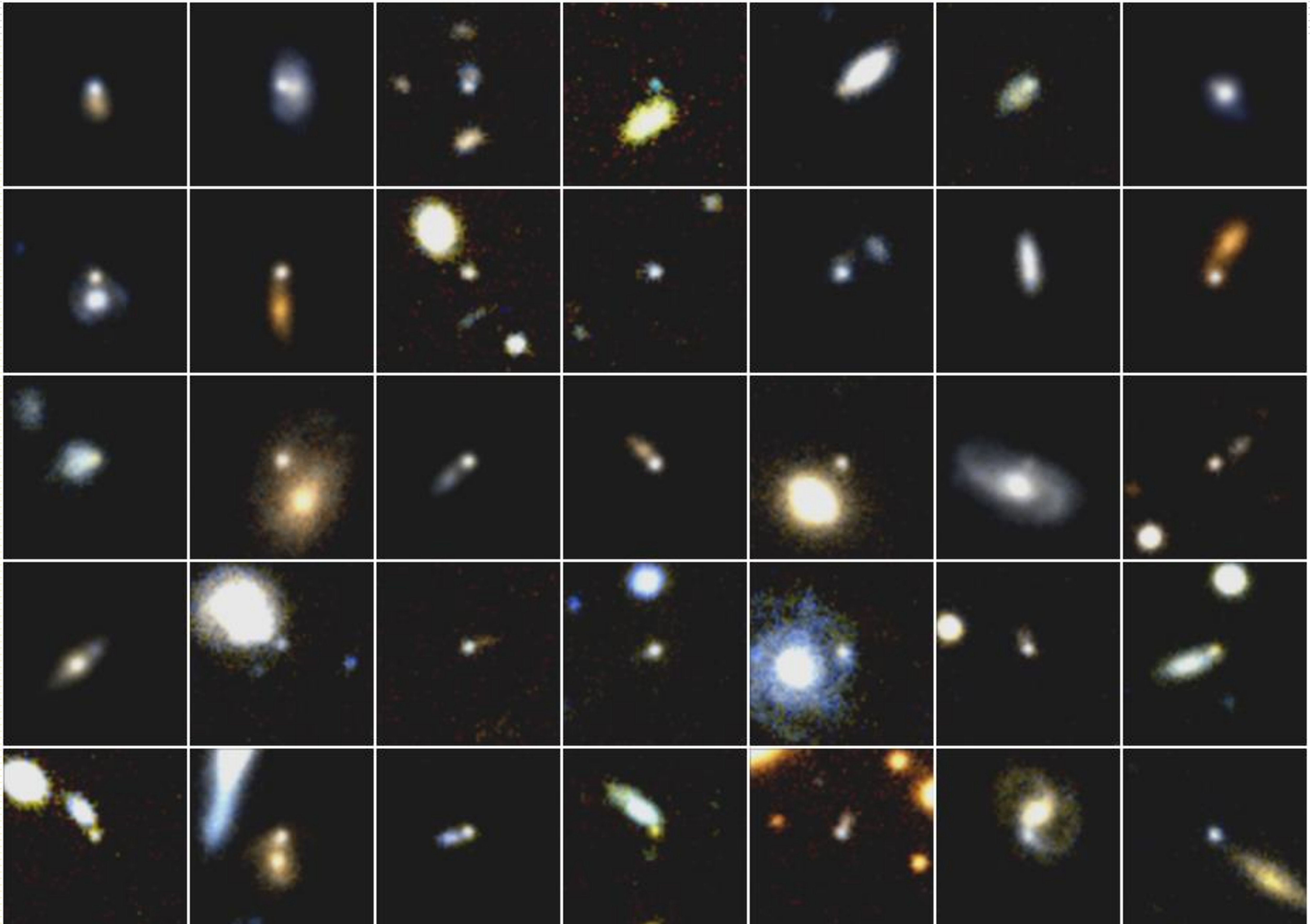


July 2014 (reference)



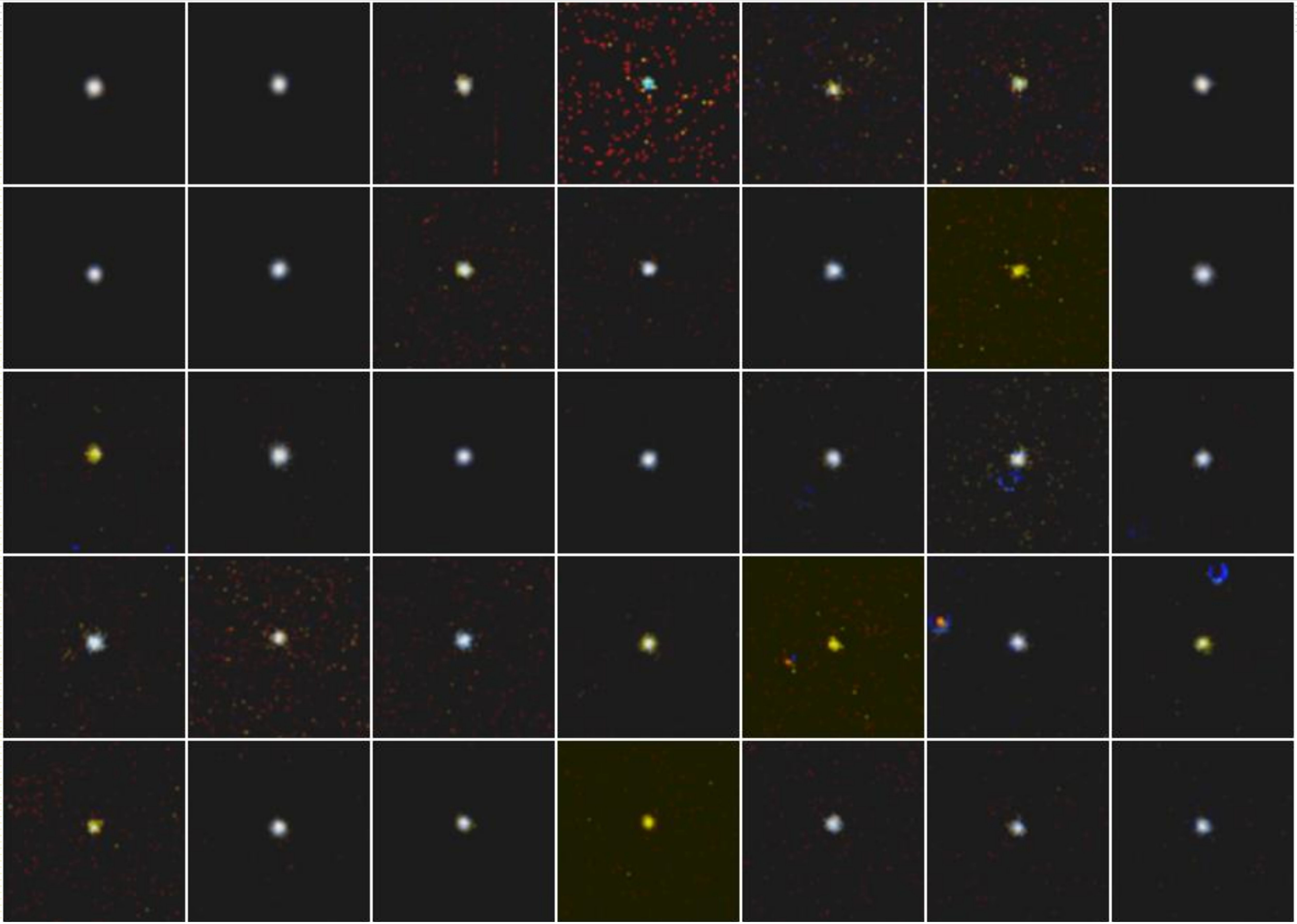
Tominaga+2015, ATel, 7565

May 2015 (search)



Tominaga+2015, ATel, 7565

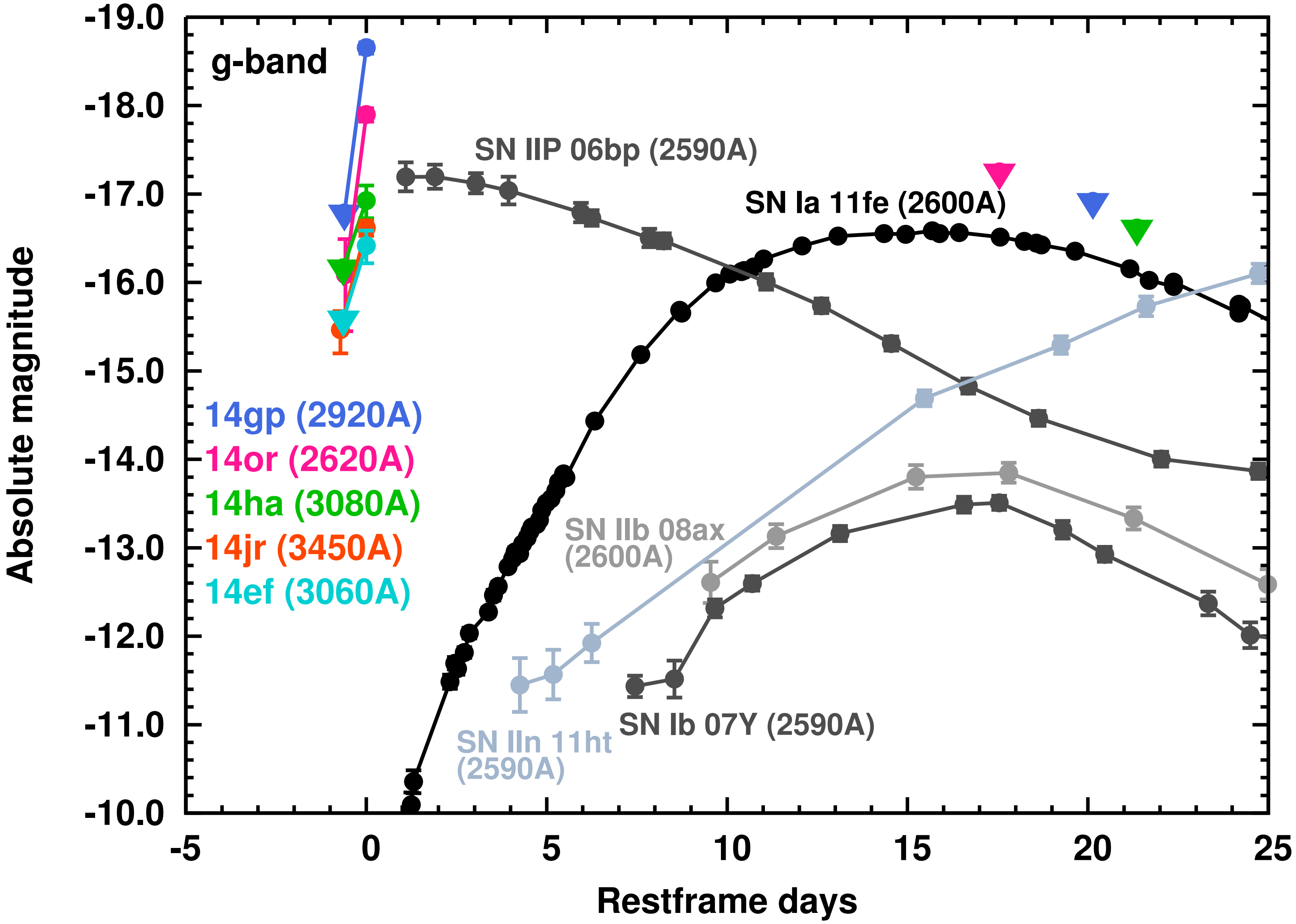
[May 2015] - [July 2014] (subtraction)

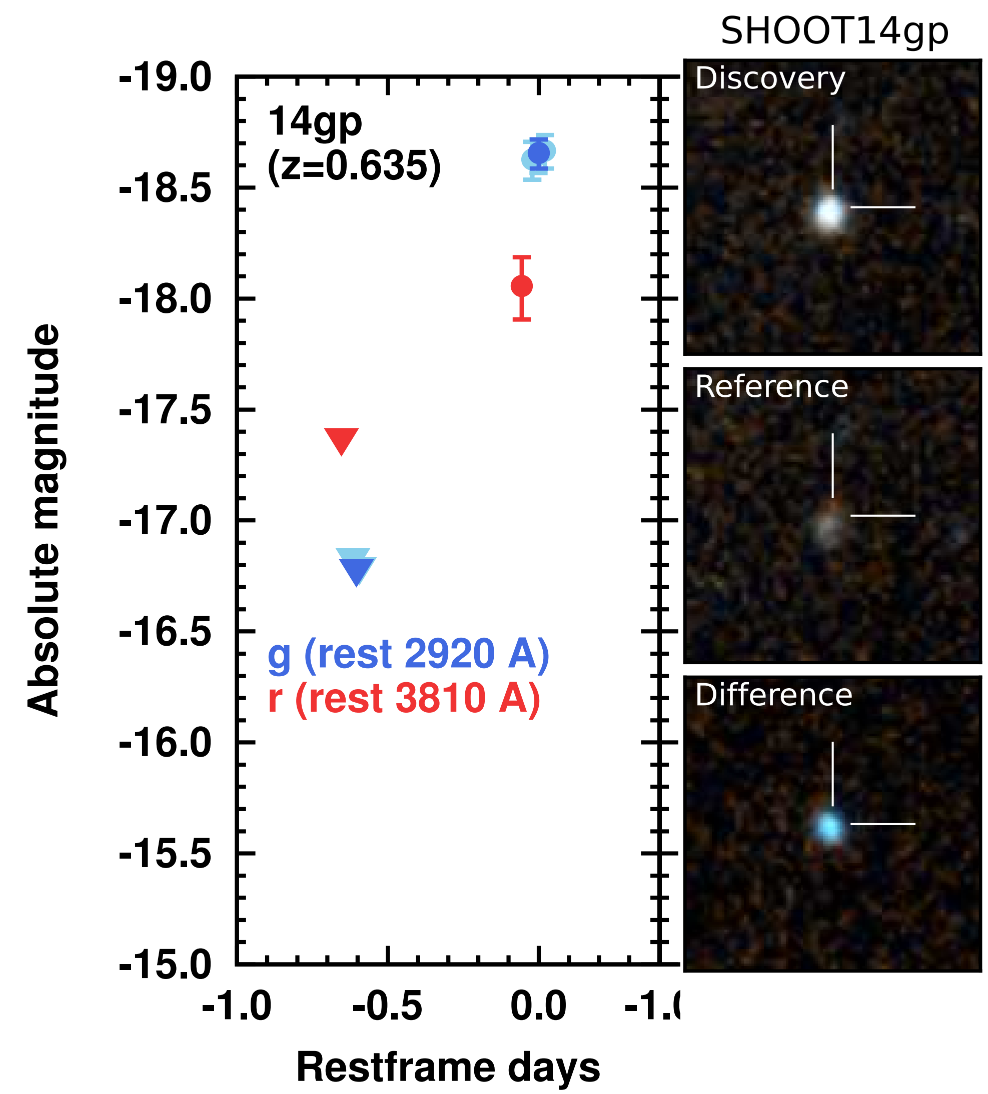


Tominaga+2015, ATel, 7565

Rapidly rising transients from HSC surveys

Faster than the rising part of supernovae as luminous as supernova peaks

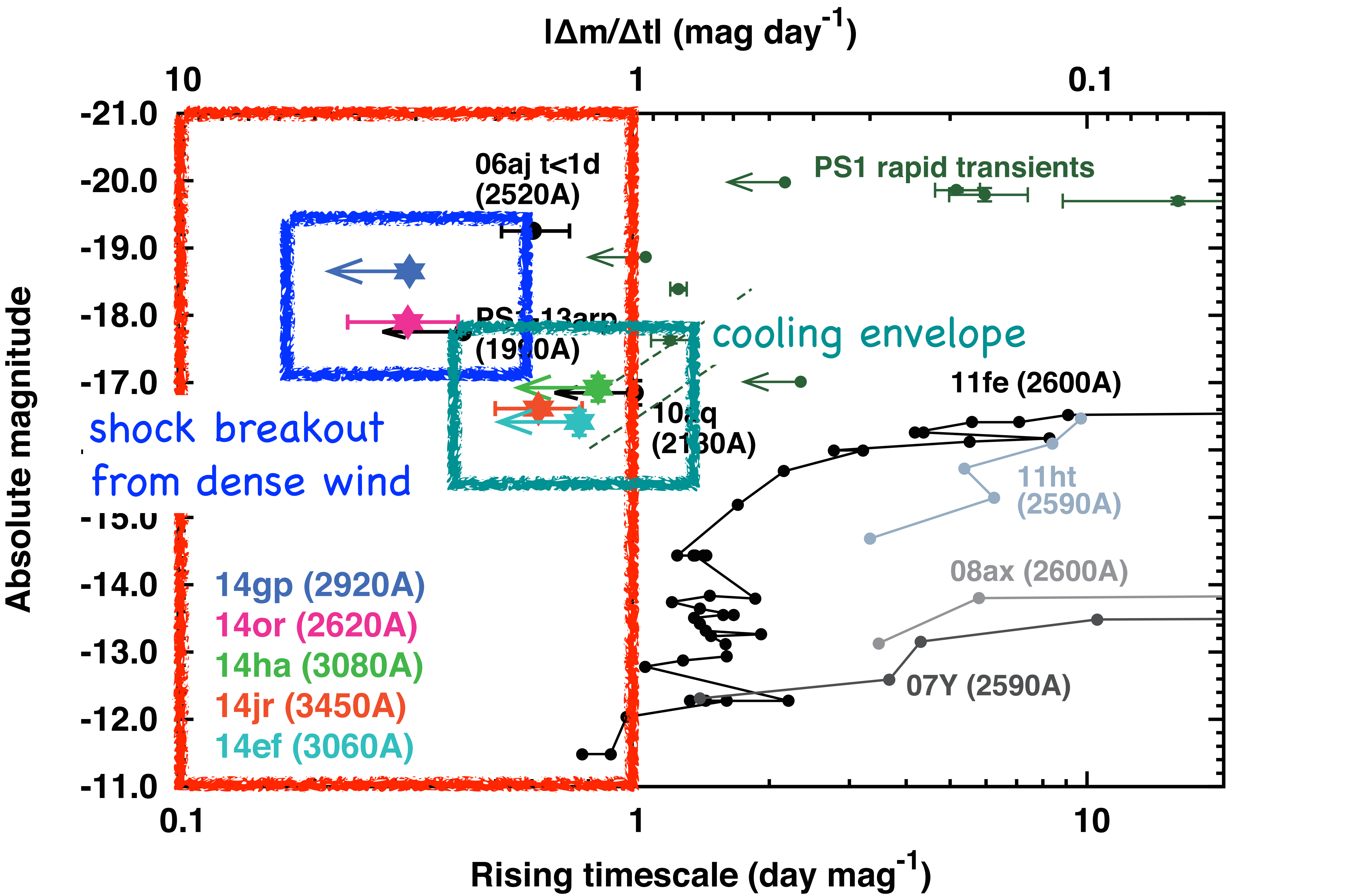




2014 July: HSC survey (PI: Tominaga)
2014 Aug: FOCAS spectroscopy (PI: Tanaka)
2015 May, Aug: HSC reference (PI: Tominaga)

Tanaka, Tominaga, TM et al. 2016, ApJ, 819, 5

Rising timescale vs magnitudes



Tanaka, Tominaga, TM et al. 2016, ApJ, 819, 5

Evolution of Seed BHs

Volonteri 2011, Greene 2012

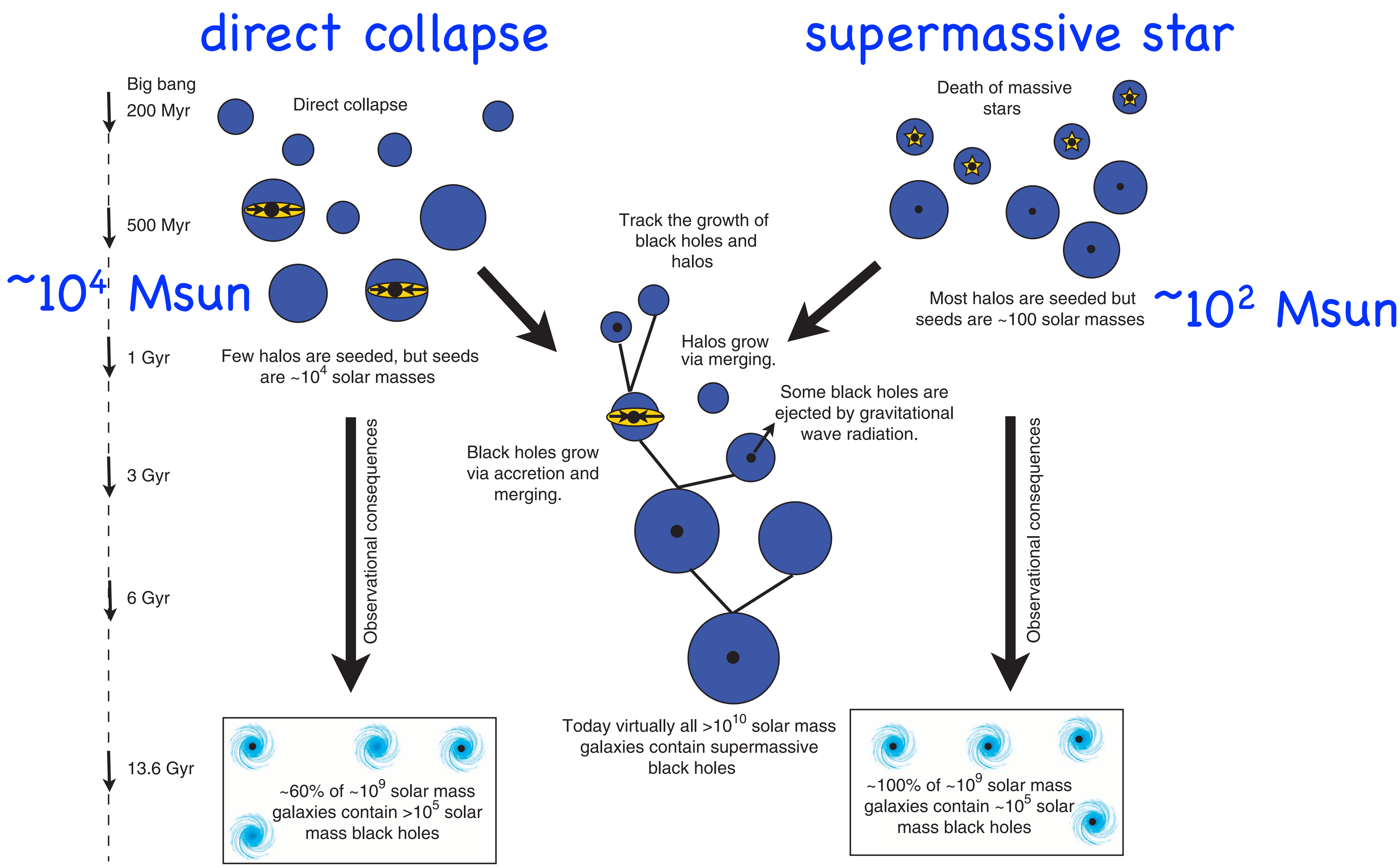
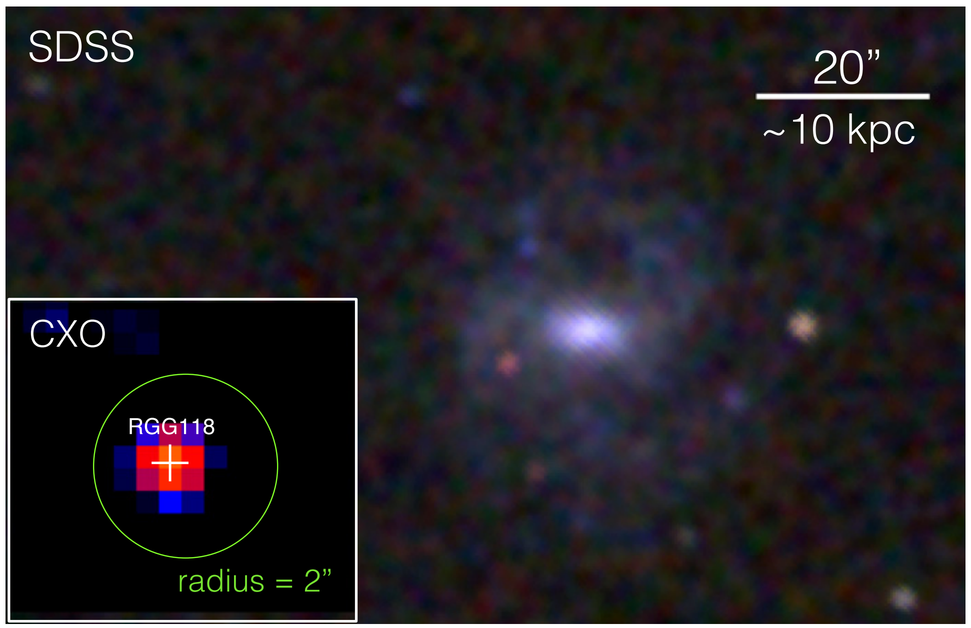
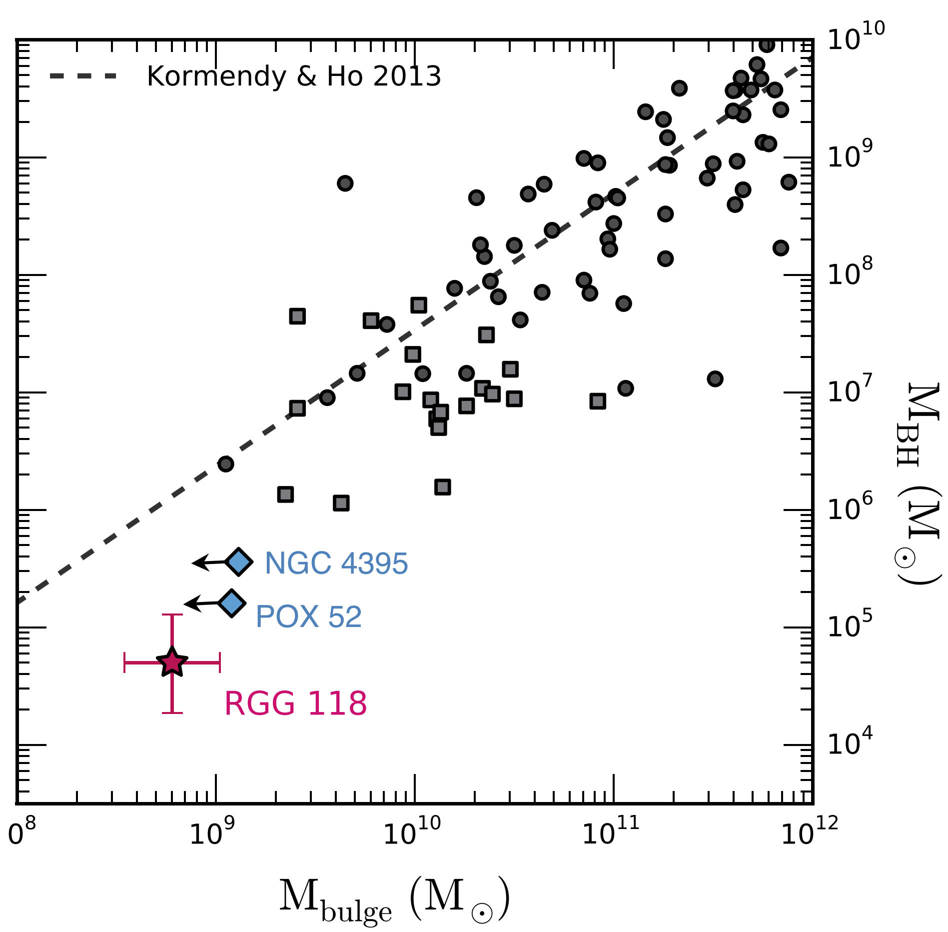


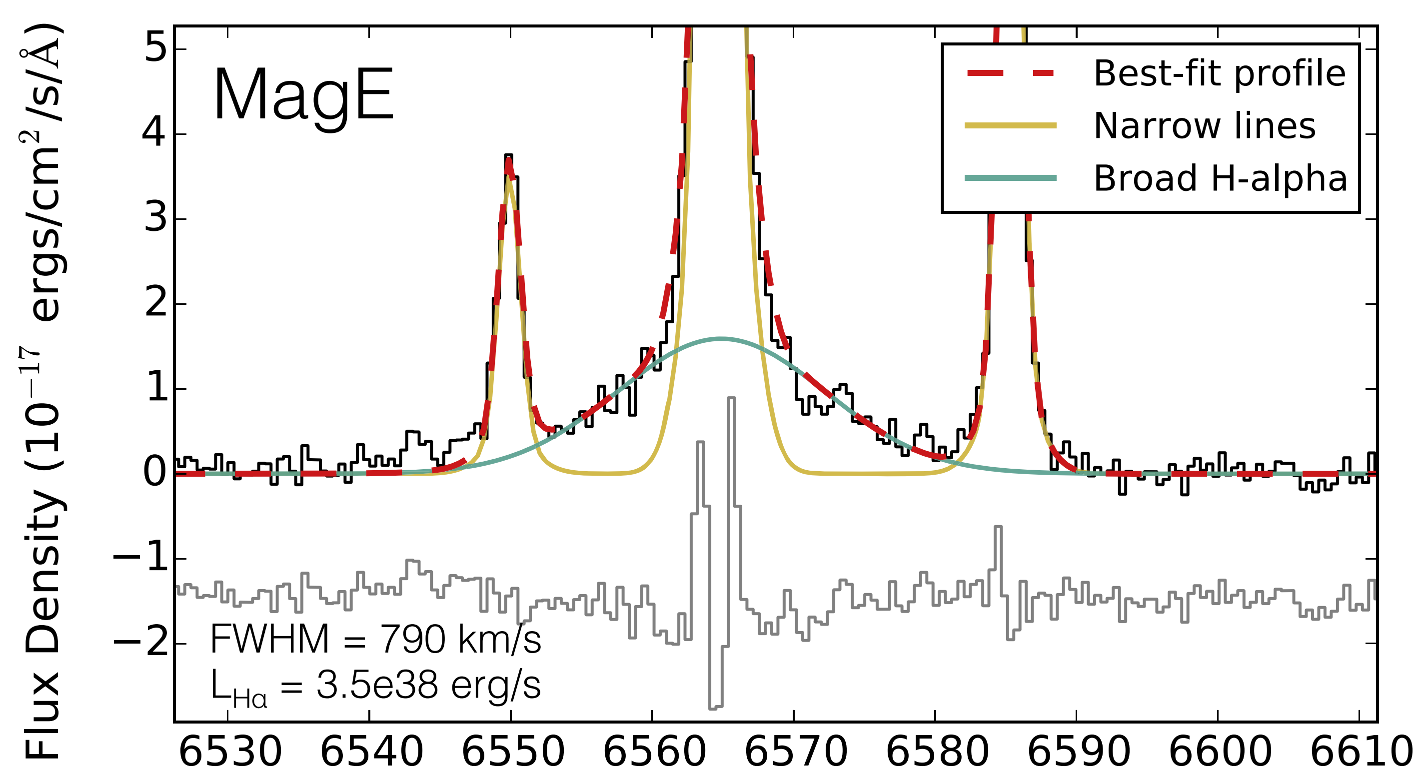
Figure 1 | Evolution of seed black holes. Schematic of the evolution of seed black holes assuming two different formation mechanisms (the death of the first generation of massive stars versus the direct collapse of gas into a black hole). Dark matter halos and the galaxies in them grow through merging. Black holes grow both via merging and by accreting gas. One additional complication is that after merging, gravitational radiation 'recoil' (see text for details) may send the black hole out of the galaxy. At present, we can distinguish between the two scenarios based on the fraction of small galaxies that contain massive black holes (we call this the 'occupation fraction').

"Lowest-Mass" Black Hole in a nearby dwarf galaxy

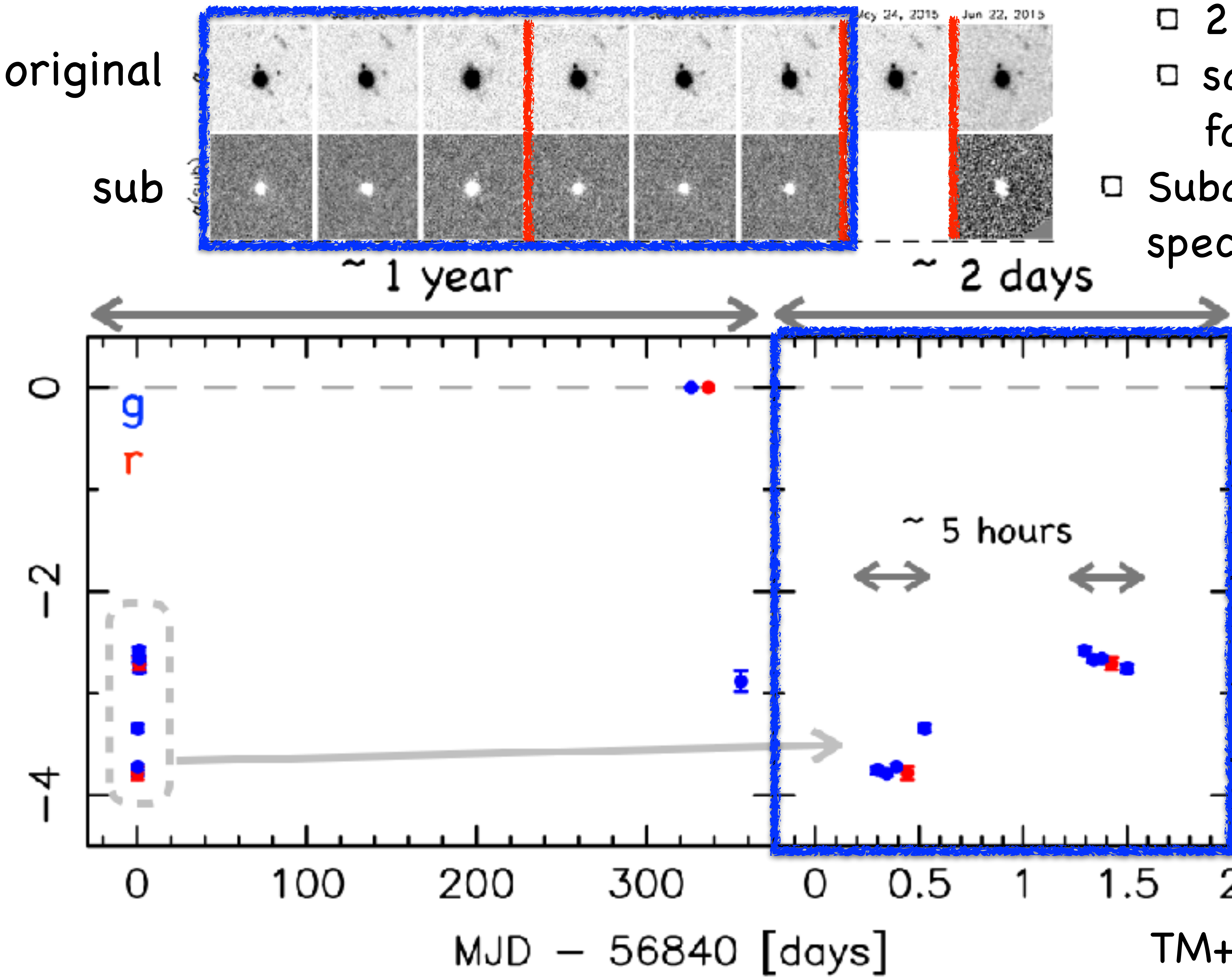


- blind survey (SDSS optical spectroscopy) + follow-up spectroscopy (Baldassare+2015)
  - RGG 118
  - z = 0.0243 (~100 Mpc)
  - 5×10^4 Msun BH
- X-ray + SED (Schramm+2013)
- rapid optical variability (TM+2016)





Light Curve (optical, ~4000A@rest-frame)

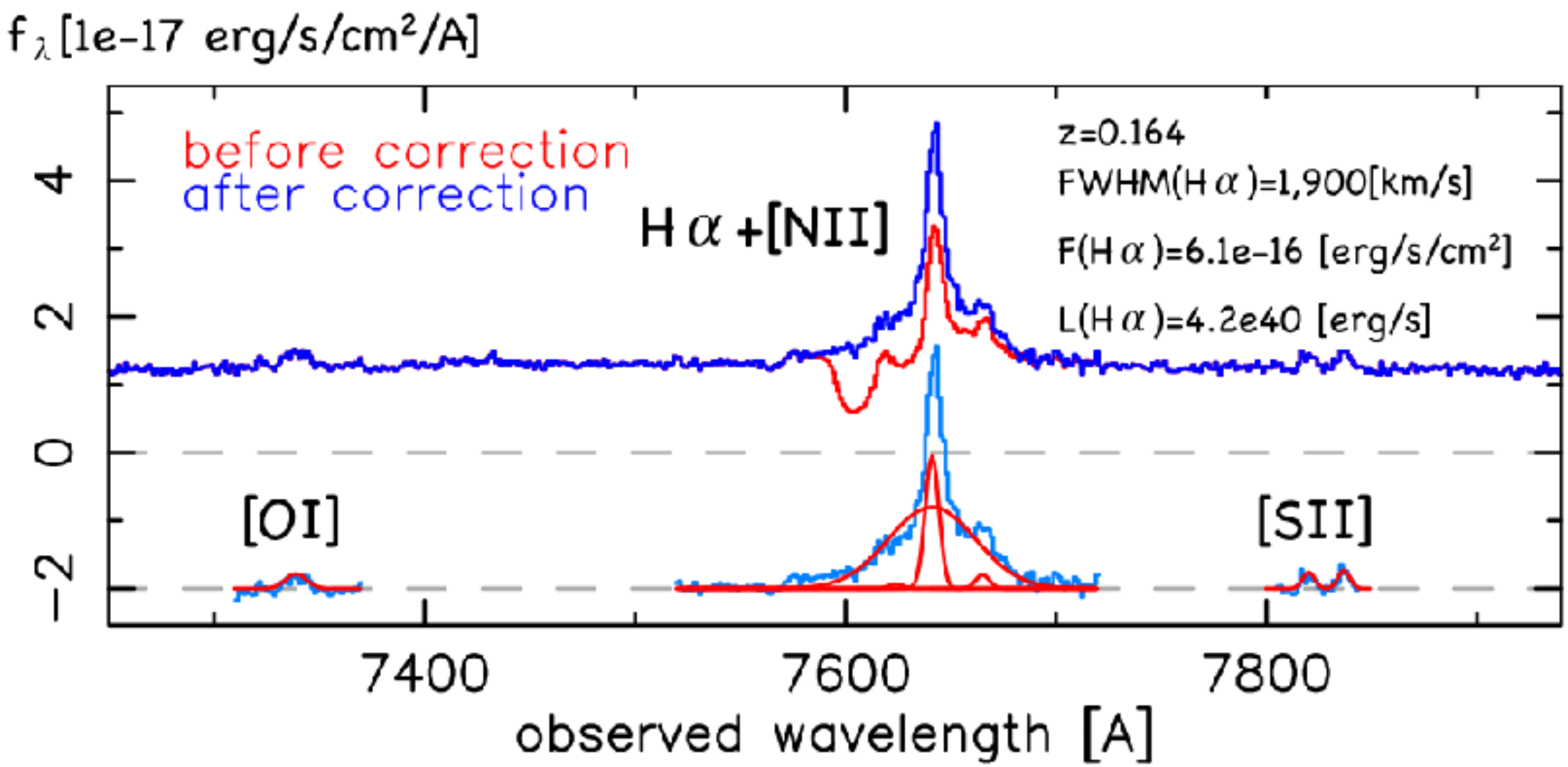


- Subaru/HSC
  - 2 consecutive nights
  - same data as that for SN studies
- Subaru/FOCAS spectroscopy

TM+2016, PASJ, 68, 40

Identification: Subaru/FOCAS Observation

- 2 candidates observed
  - AGN w/ 2.7×10^6 Msun BH @ z=0.164

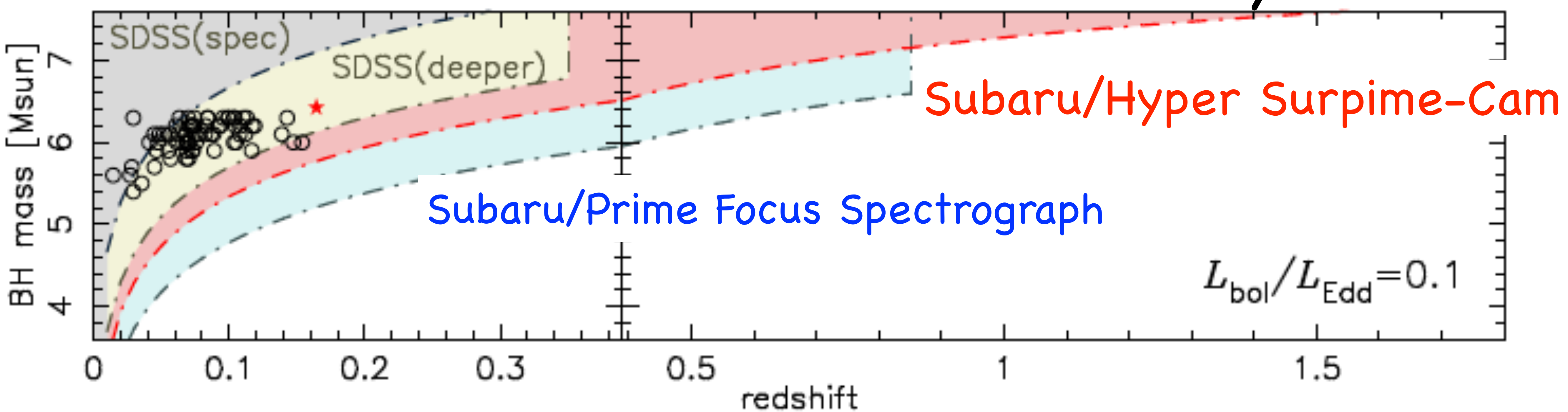


TM+2016, PASJ, 68, 40

Compared with SDSS spectroscopic survey...

- **fainter / lower luminosity**
- larger FWHM(Ha)
- **lower L(Ha)**
- high-end BH mass
- **lower Eddington rate**

10% variability assumed



TM+2016, PASJ, 68, 40

Summary & Near-Future

- Subaru+HSC is powerful for rapid transient studies.
- Machine learning technique works well for efficient real-time selection of real transients.
- One-hour cadence surveys were done.
    - several rapidly rising supernovae found at z=0.3-0.8
        - shock breakout from a dense wind and cooling envelope
    - 3×10^6 Msun BH identified via broad Ha emission line.
- Transient Surveys in COSMOS (2016-2017) & SXDS (2017-2018) within HSC Strategic Survey Program.