Transient studies using Subaru/Hyper Suprime-Cam

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(NAOJ/Konan)

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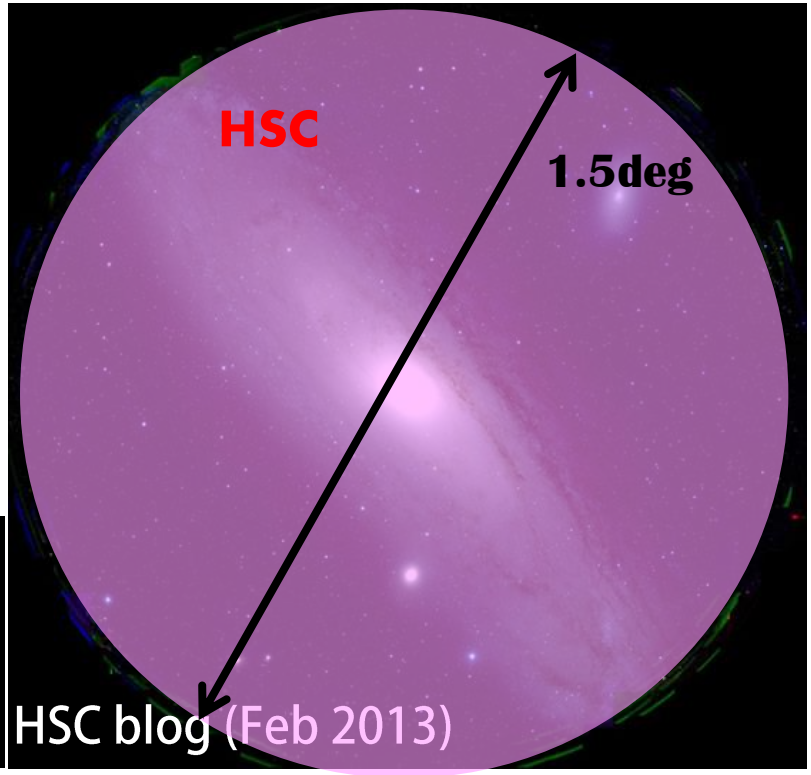
Theories of Astrophysical Big Bangs 2025

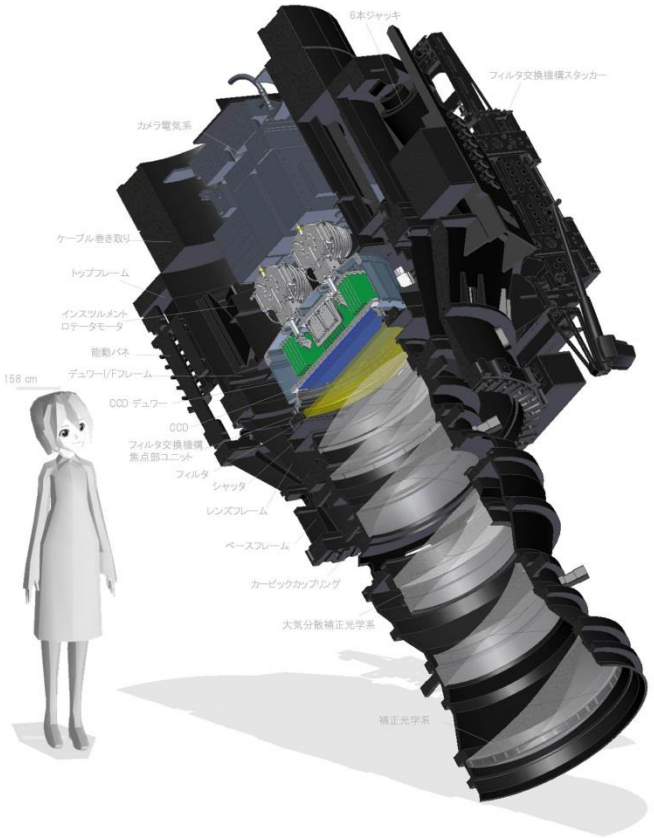
Contents

- Subaru/HSC
  - Time-domain astronomy
  - Multi-messenger astronomy
- Rubin/LSST era

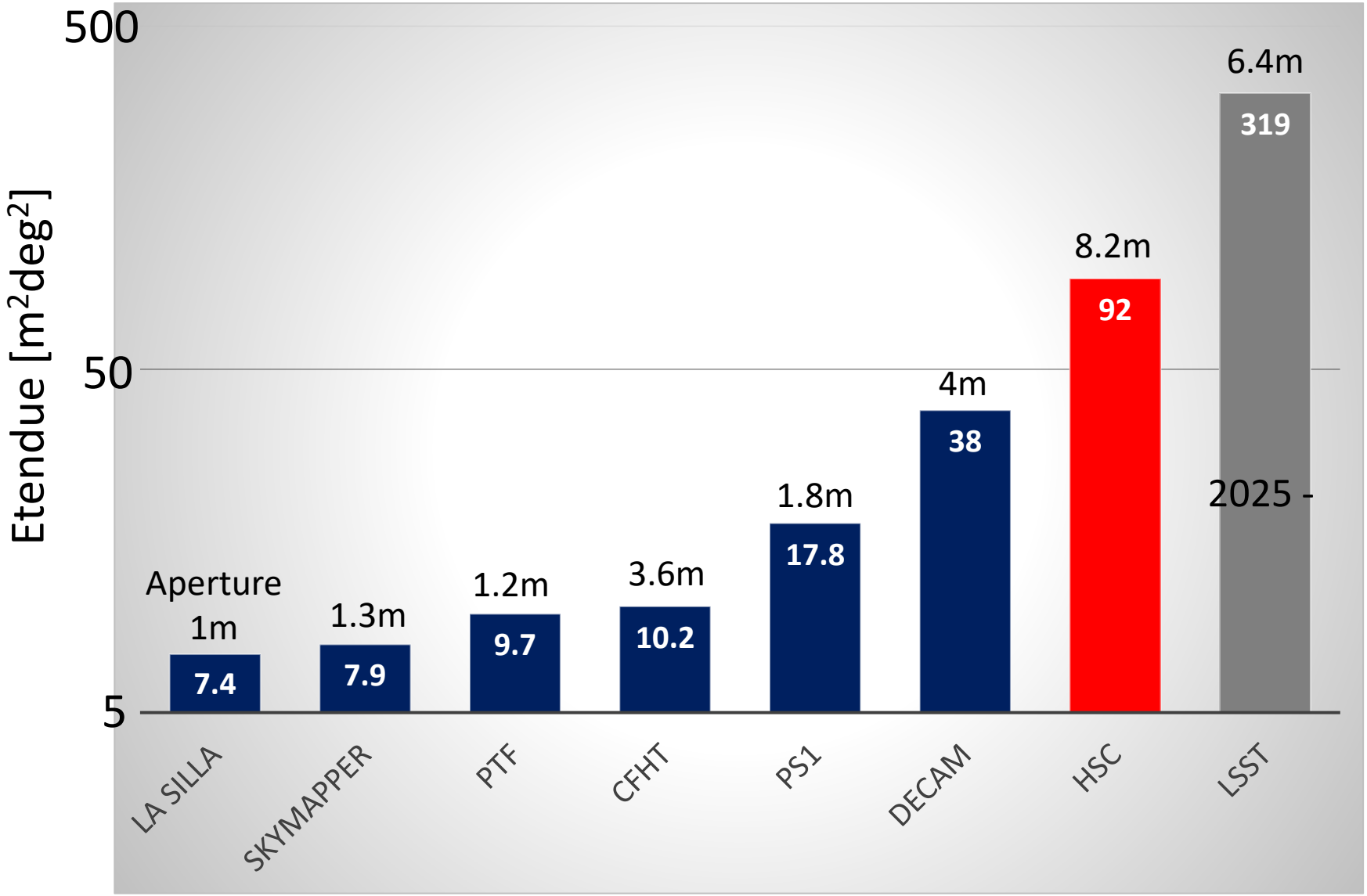
Subaru/Hyper Suprime Cam

- Hyper Suprime-Cam (HSC)
  - Diameter: 8.2m, FoV: 1.77deg^2, ~900M pixels



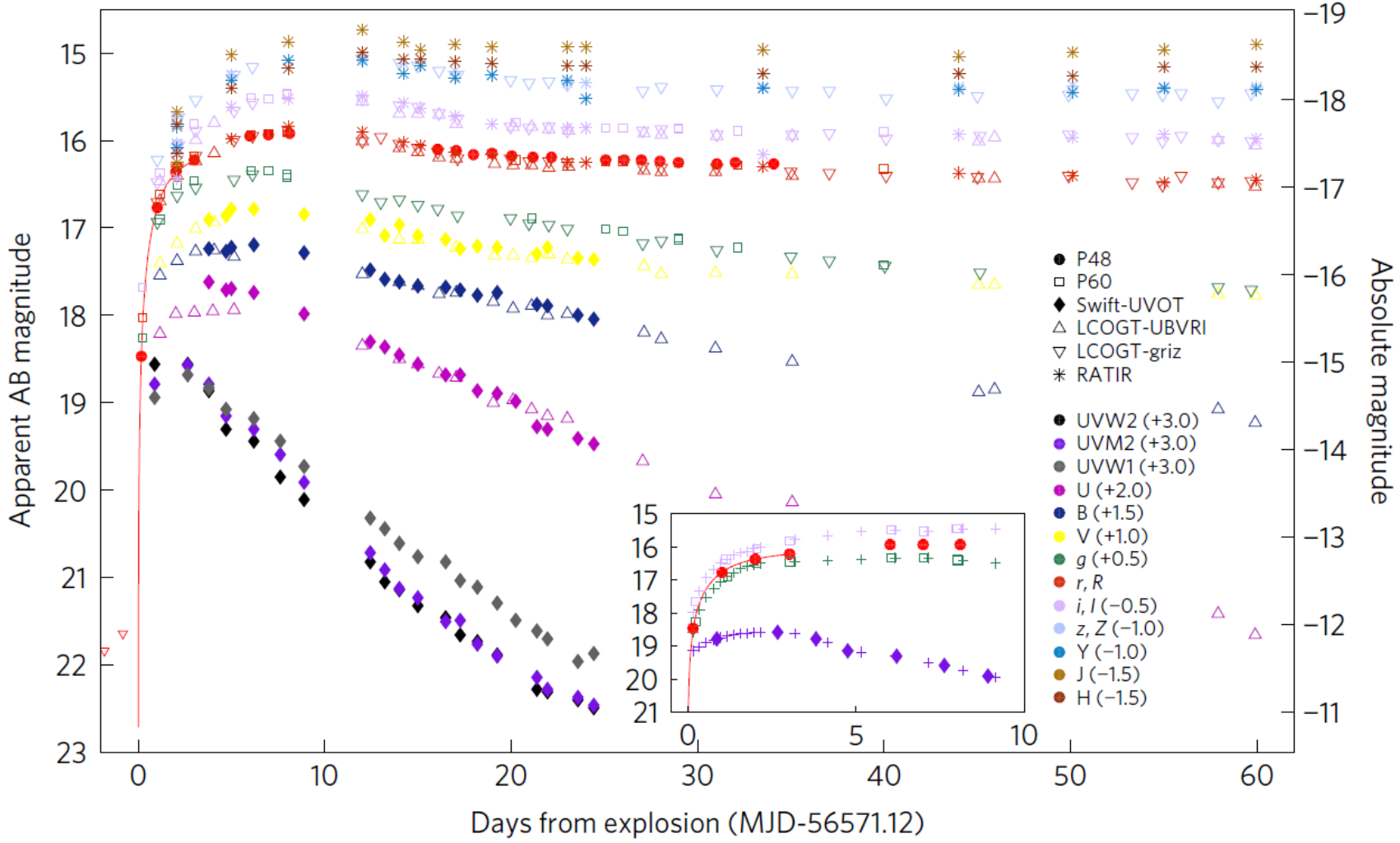


Etendue of optical telescopes



Time-domain astronomy with Subaru/HSC

Type IIP SN: SN2013fs

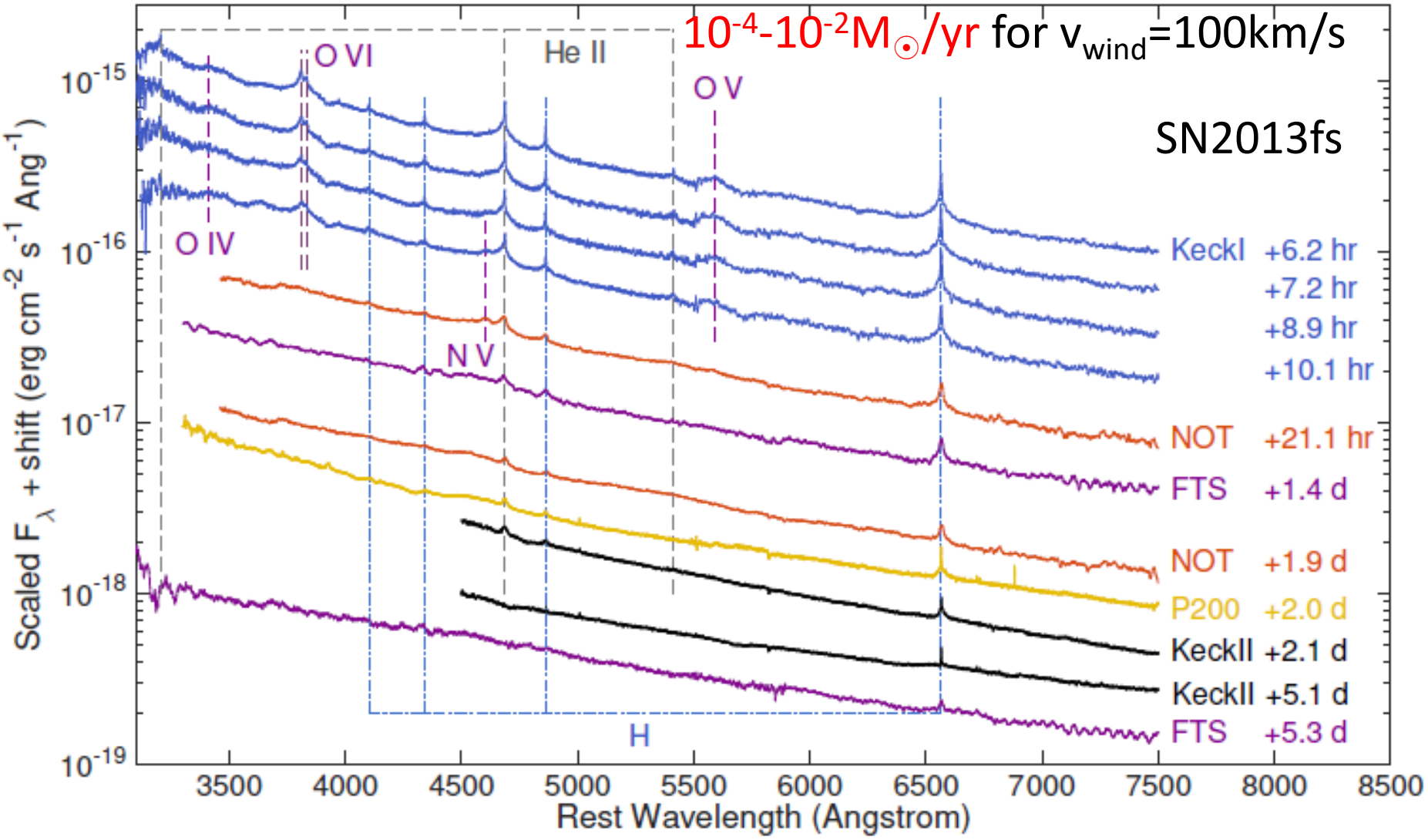


Yaron+17

SN2013fs -evidence of dense CSM-

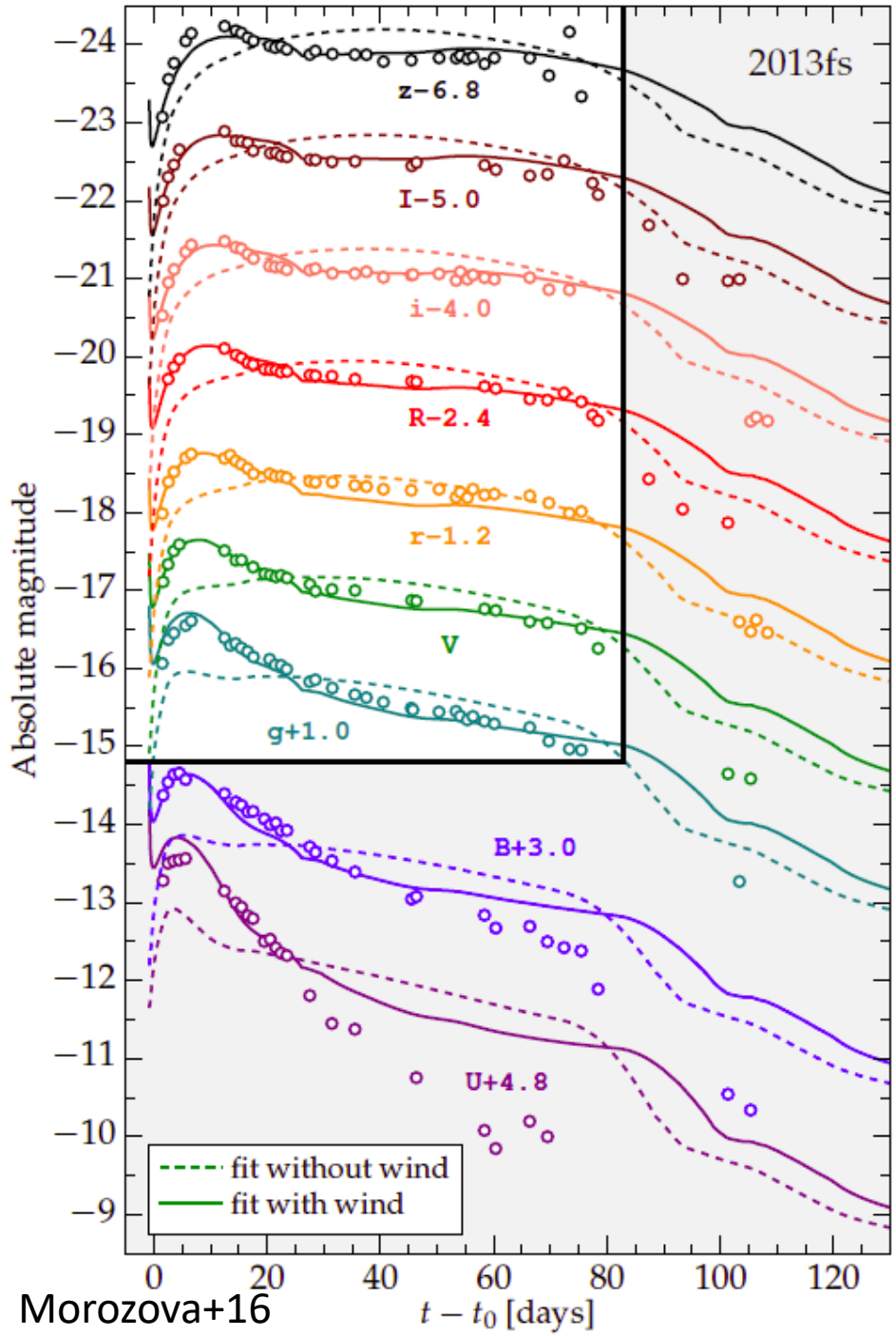
Mass loss rate:

10^{-4}-$10^{-2}M_{\odot}$/yr for v_{wind}=100km/s

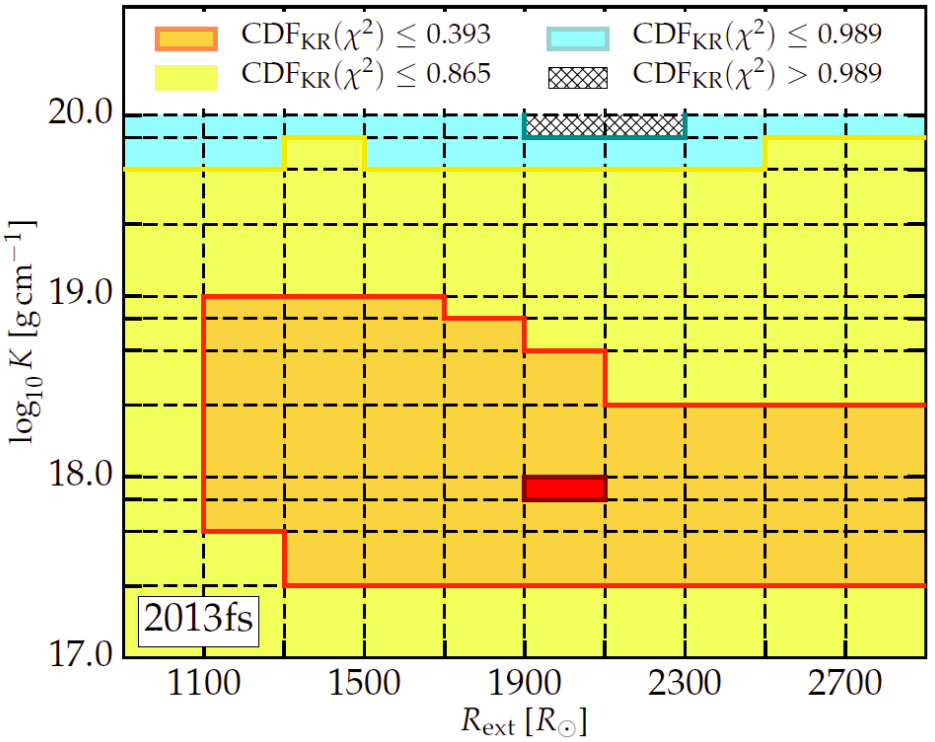


Yaron+17

SNe with dense CSM SN2013fs



Morozova+16



Mass loss rate:

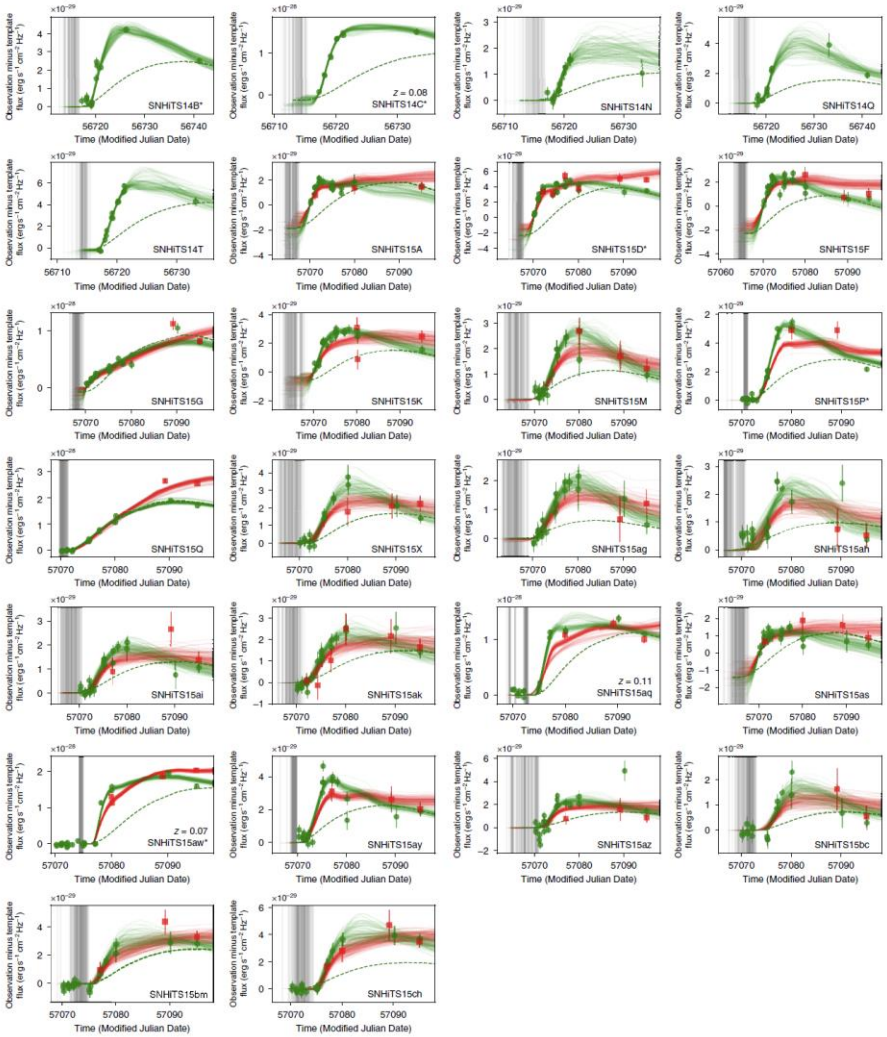
$1.5 M_\odot$/yr for v_{wind}=100km/s

Last moment of massive star

NASA's Goddard Space Flight Center
Video courtesy of ESA/Hubble/L. Calcada

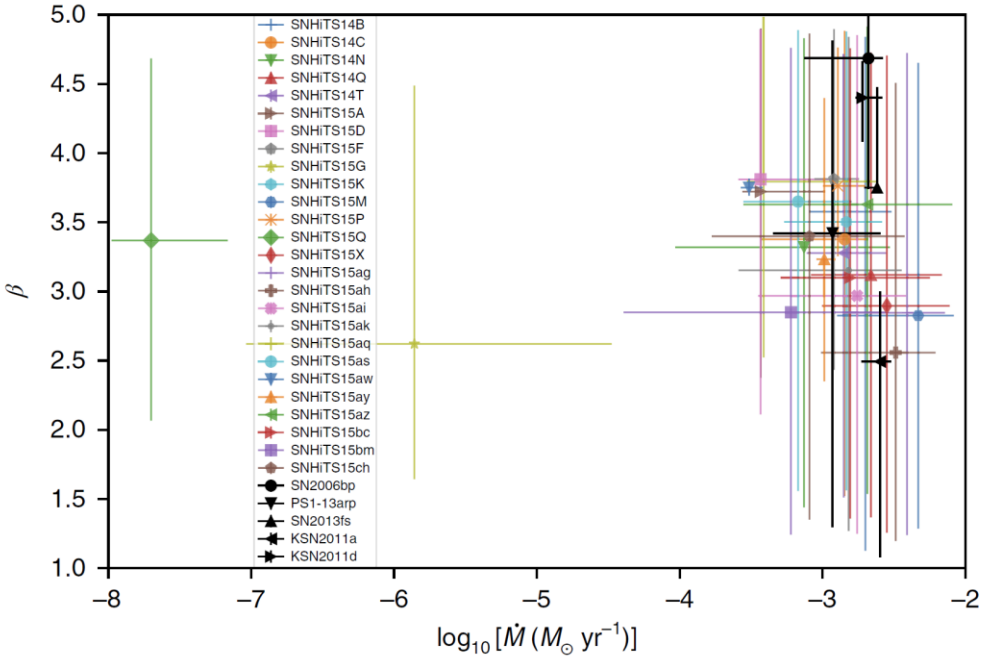
https://svs.gsfc.nasa.gov/11447

High Cadence Transient Survey (HiTS) with CTIO/DECam



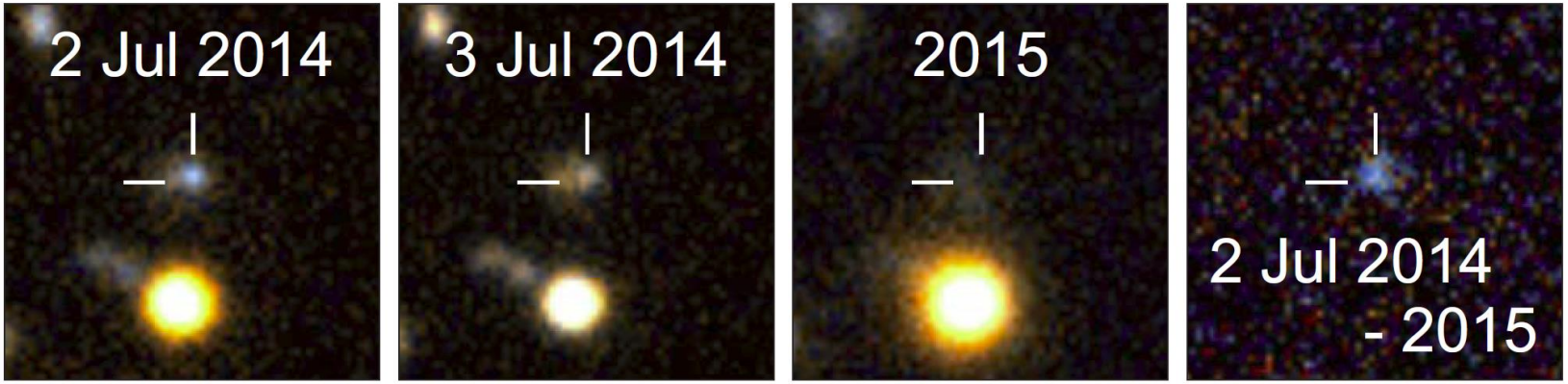
Assuming SNe with dense CSM

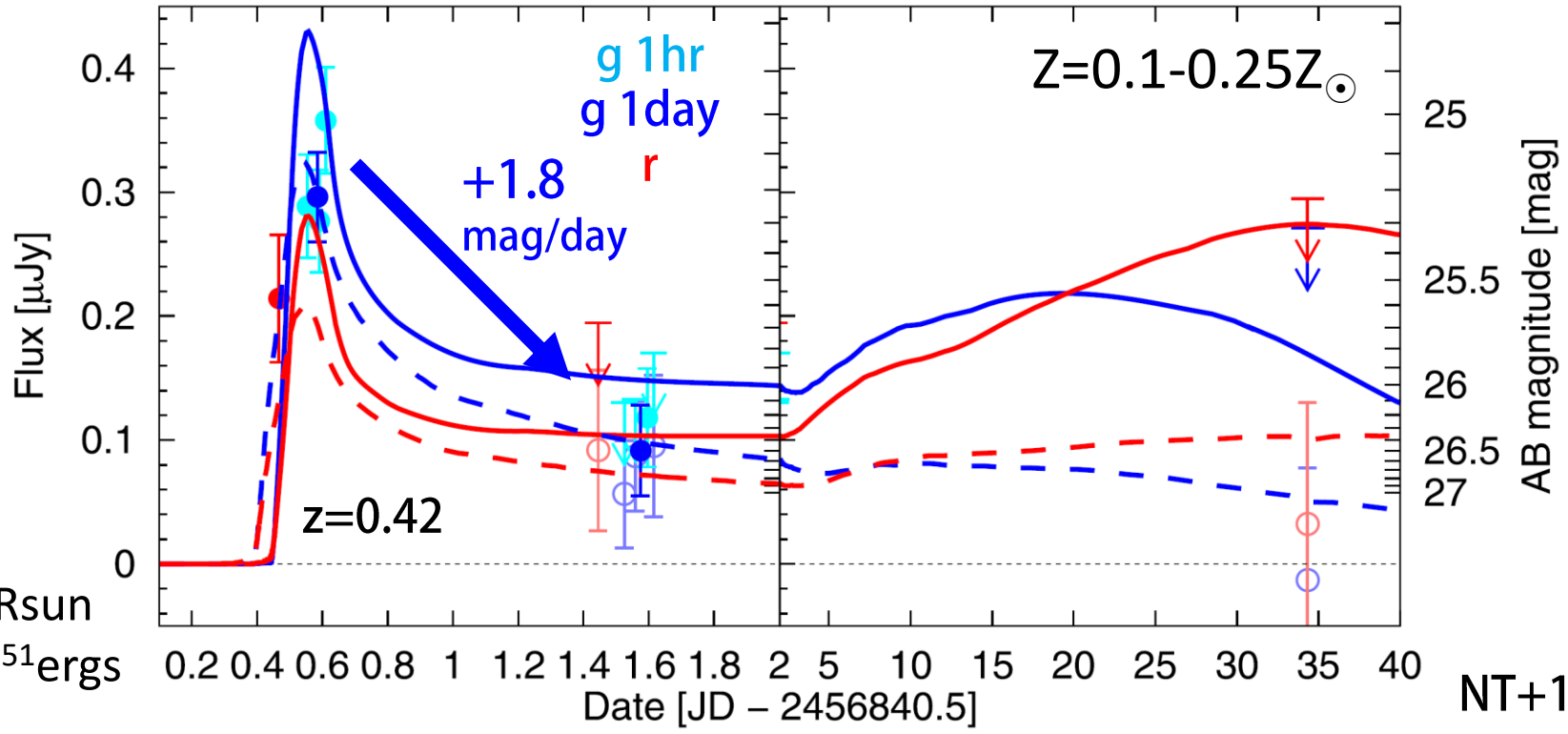
Forster+18



- 26 rising transients (24 transients are rapid |dm/dt| > 0.2mag/day)
- Detection efficiency: 28 % for low M_{dot}, 72% for high M_{dot}
- **1/5** of CCSNe could be without dense CSM.

Subaru/HSC: a rapid declining transient

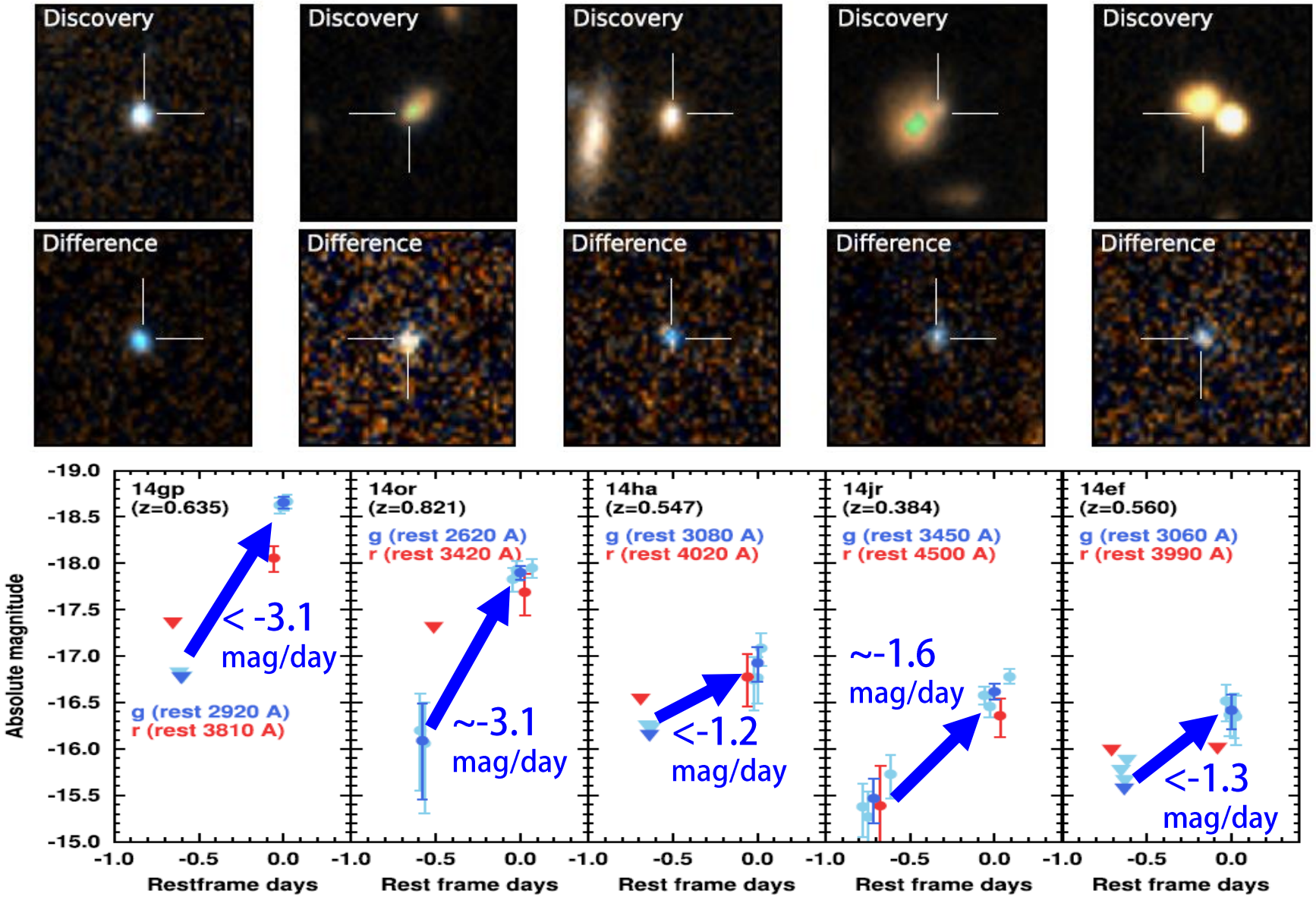




25Msun
R = 1200Rsun
E<0.4x10^{51}ergs

NT+19

Subaru/HSC: Rapidly rising transients



Tanaka, NT+ 16

Rate of rapidly varying transients

Event rate: $R = 1/\tau\Omega V_{\max}$ Schmidt 1968; Eales 1993

$$\tau V_{\max} = \frac{1}{4\pi}\sum_{\text{field}}\int_0^{z_{\max}} \max\left\{\tau_{\text{tran}}, \frac{\tau_{\text{obs,field}}}{1+z}\right\}\frac{dV}{dz}dz$$

1 rapidly declining transient and 5 rapidly rising transients
(|dm/dt|>1mag/day)

~1 x 10^{-4} /yr/Mpc^3
NT+19

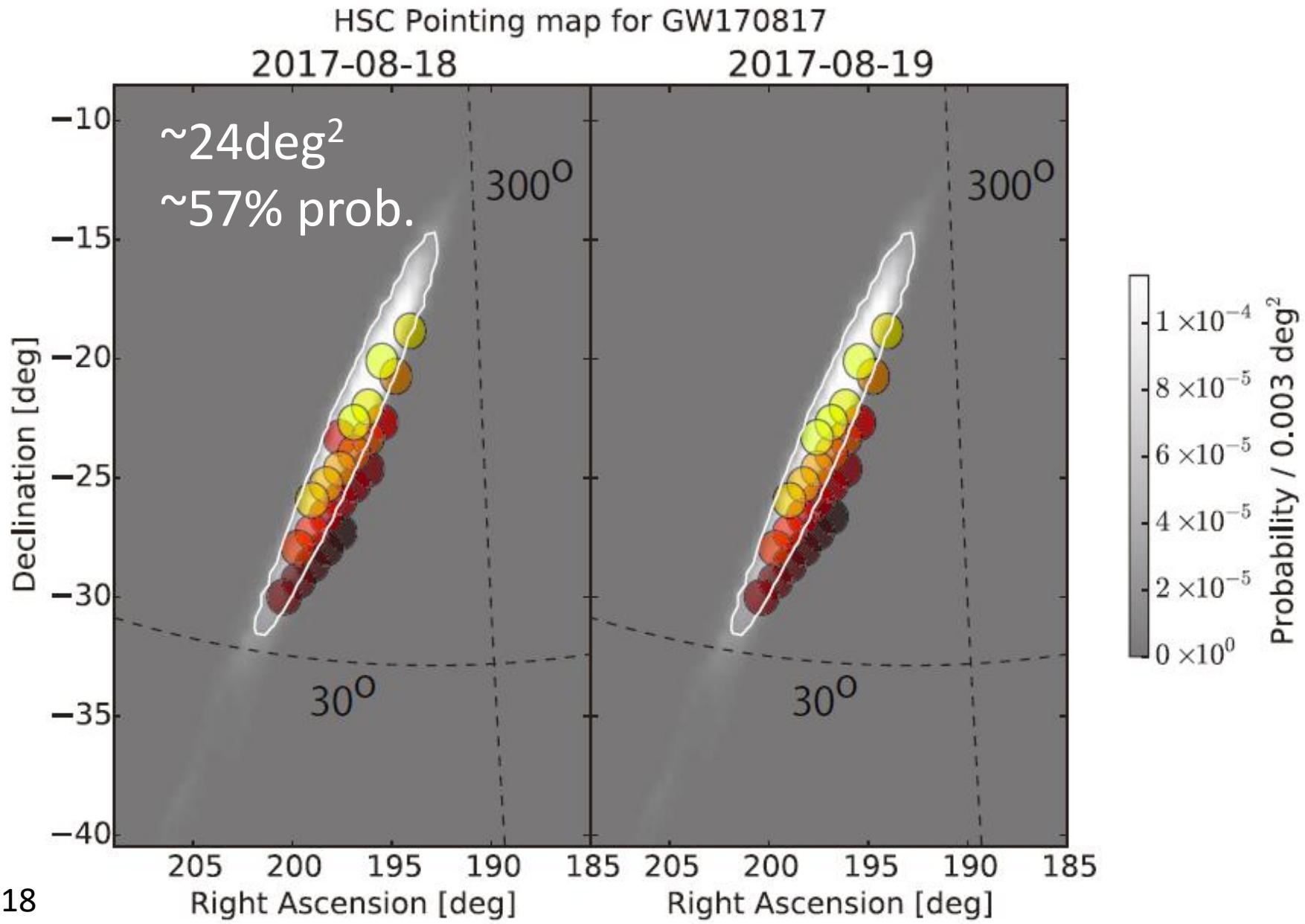
~6 x 10^{-5} (τ/1day)$^{-1}$ /yr/Mpc^3
Tanaka, NT+16

The CCSN rate is (3-7) x 10^{-4} /yr/Mpc^3 at z<1.

- SNe without dense CSM take place in 1/(3-7) of CCSNe.
- >~9% of CCSNe have a rapid rise.

Multi-messenger astronomy with Subaru/HSC

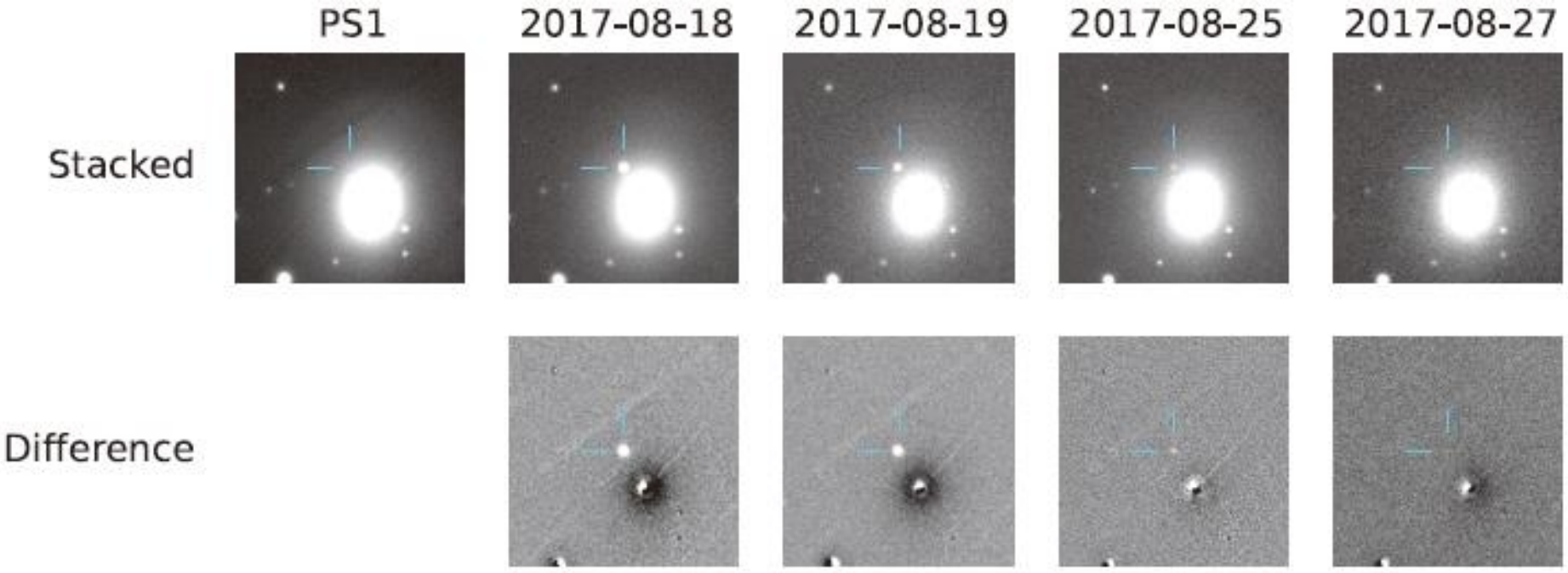
GW170817: HSC z-band follow-up

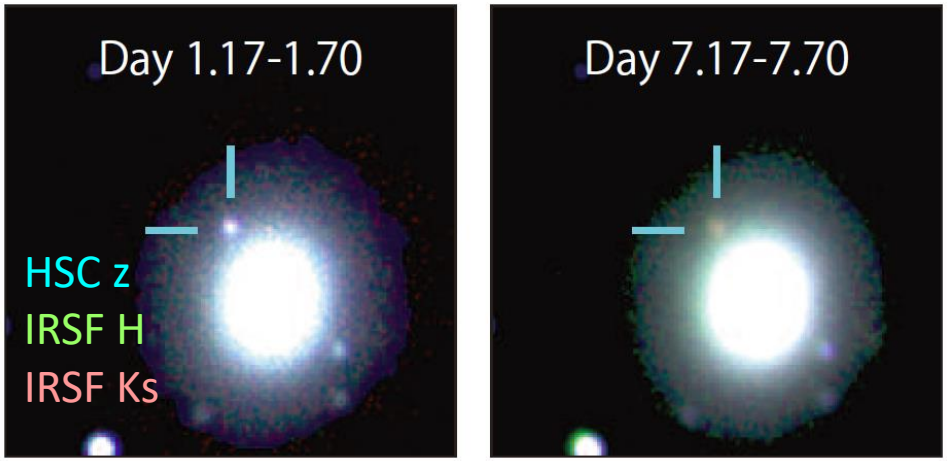


NT+18

J-GEM17btc (SSS17a/DLT17ck/AT2017gfo)

The most likely and distinguished candidate in the prob. region.





Only HSC and DECam (Soares-Santos+17) evidence the uniqueness of the counterpart.

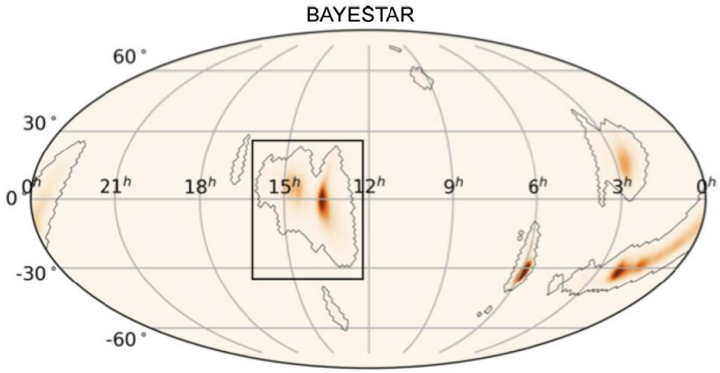
NT+18; Utsumi, Tanaka, NT+17

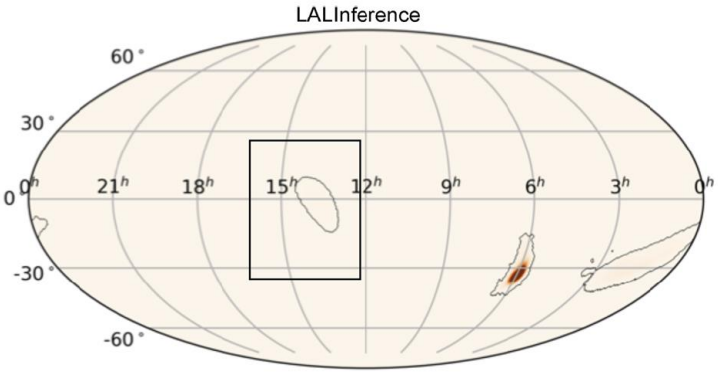
In O3

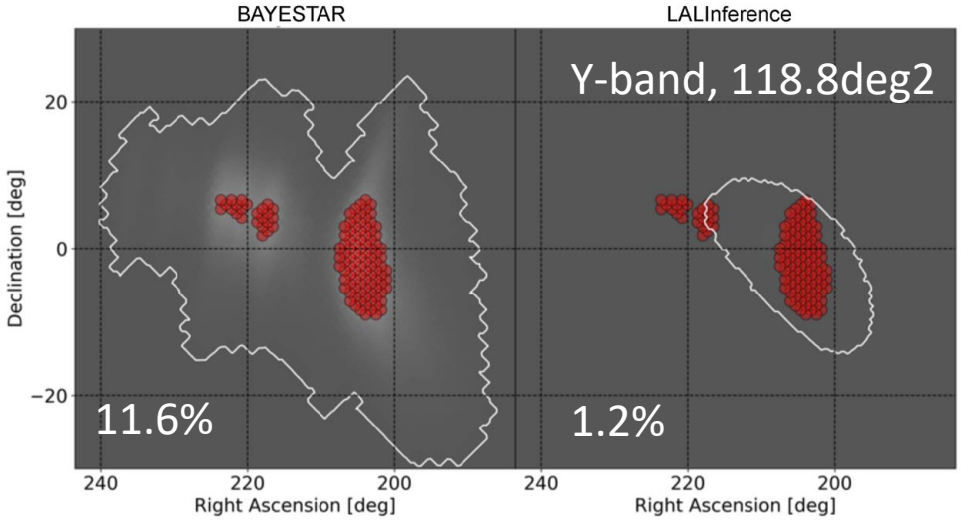
S190510g

- BNS → Terrestrial

- Depth
  - 22.3 (w/ HSC ref)
  - 21.3 (PS1, w/o HSC ref)







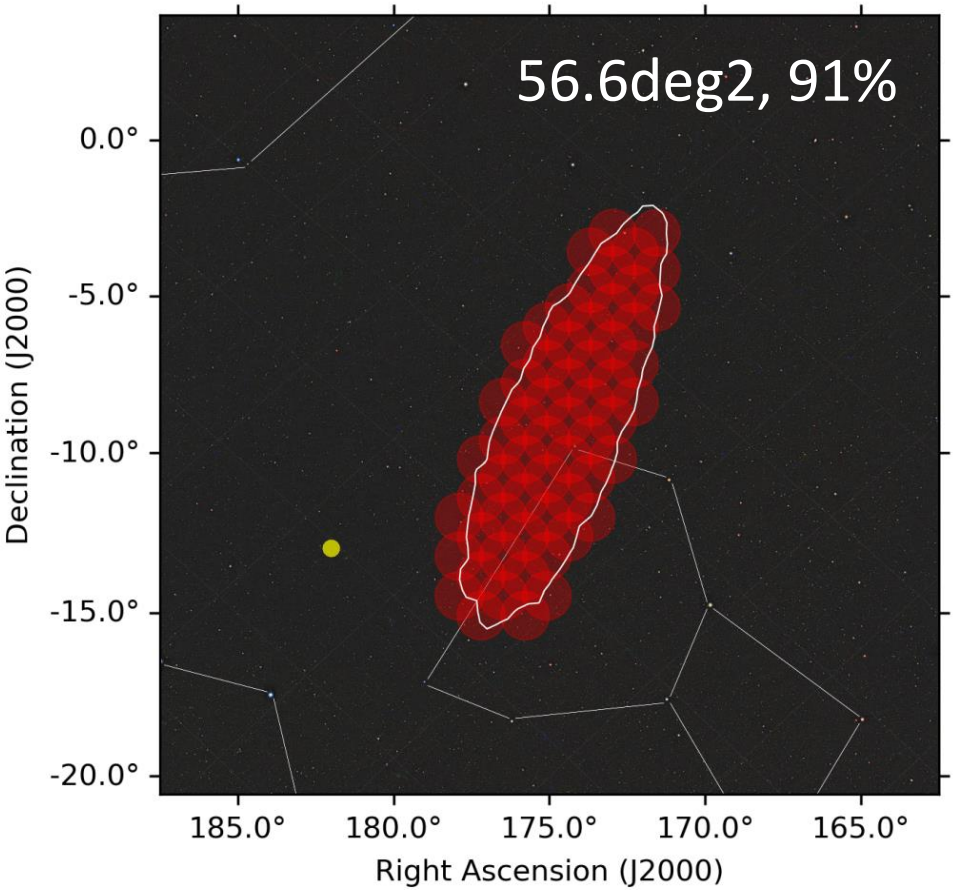
Start obs.
1.7hr after
the alert

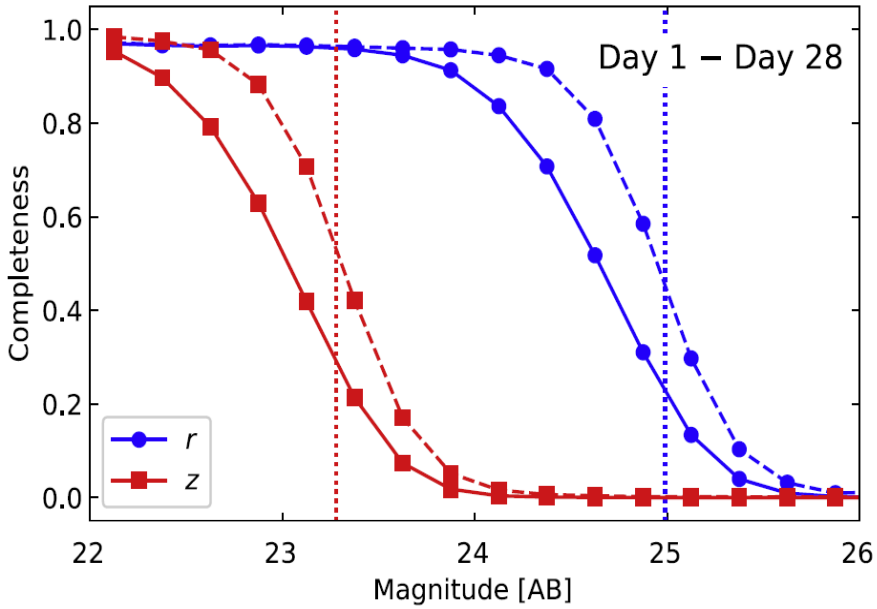
3 possible optical counterparts in LVC 3Dmap

Ohgami, NT+21

In O3

GW200224_222234 BBH



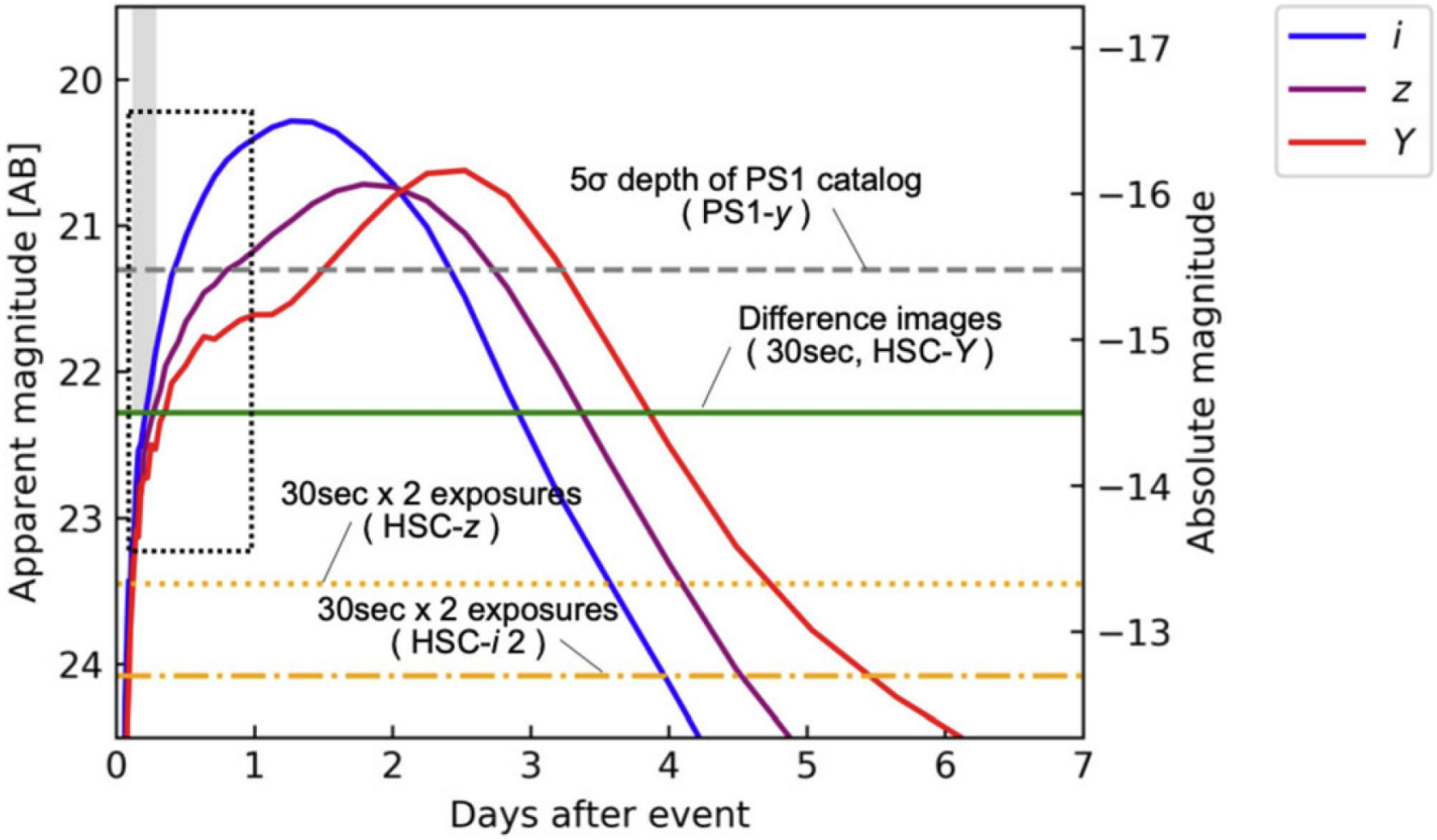


- Deep and (almost) complete follow-up was realized.

19 transients could be possible counterparts of GW200224_222234.

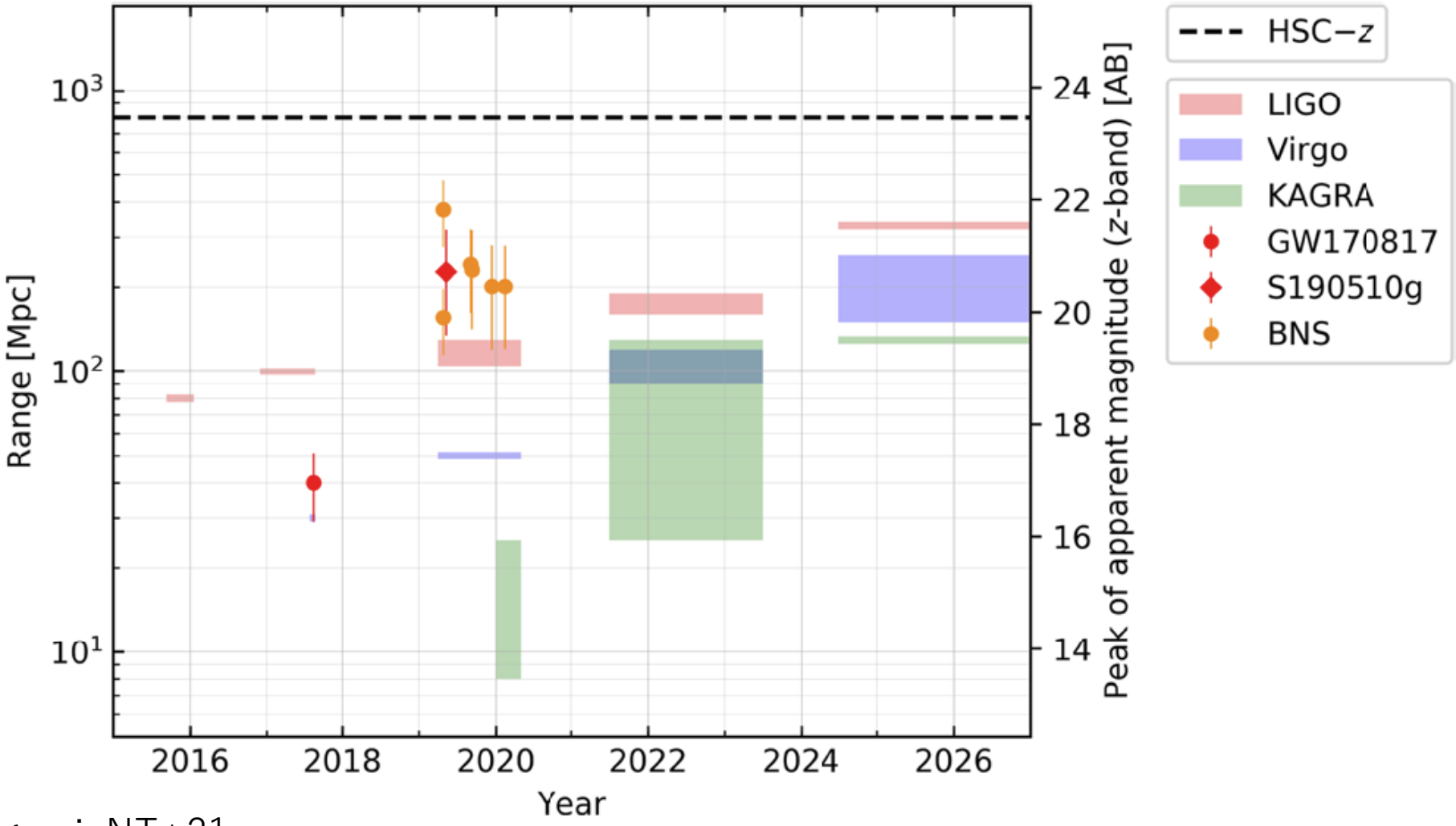
Ohgami, NT+23

Fast and deep follow-up was realized



Ohgami, NT+21

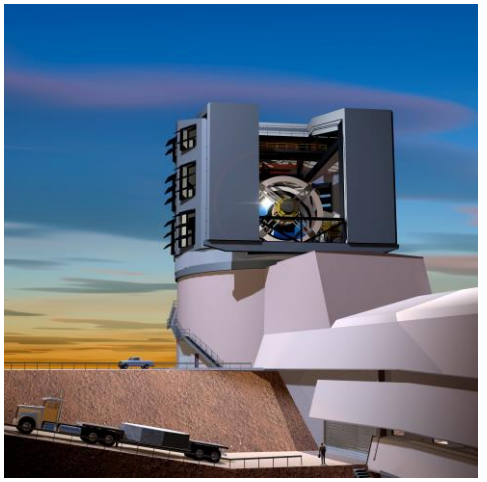
Subaru/HSC is deep enough



Ohgami, NT+21

Rubin/LSST era
2025-

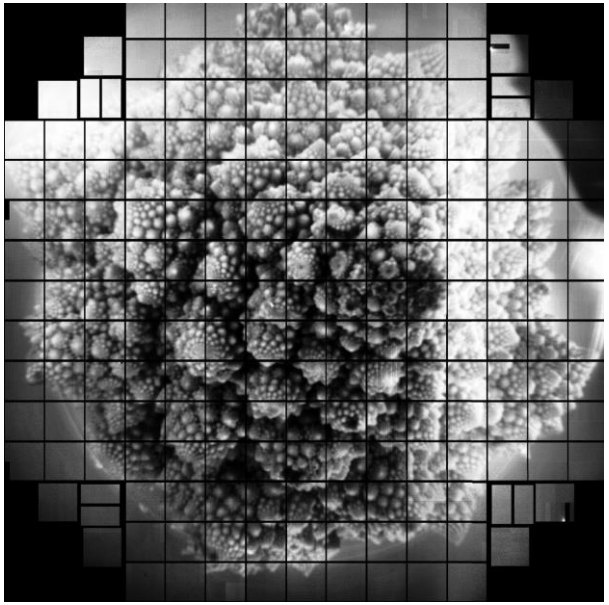
Rubin/Legacy Survey of Space and Time (LSST)



Effective aperture: 6.5m, FoV: 9.6deg2

Science goals

- Probing dark energy and dark matter.
- Taking an inventory of the solar system.
- Exploring the transient optical sky.
- Mapping the Milky Way.

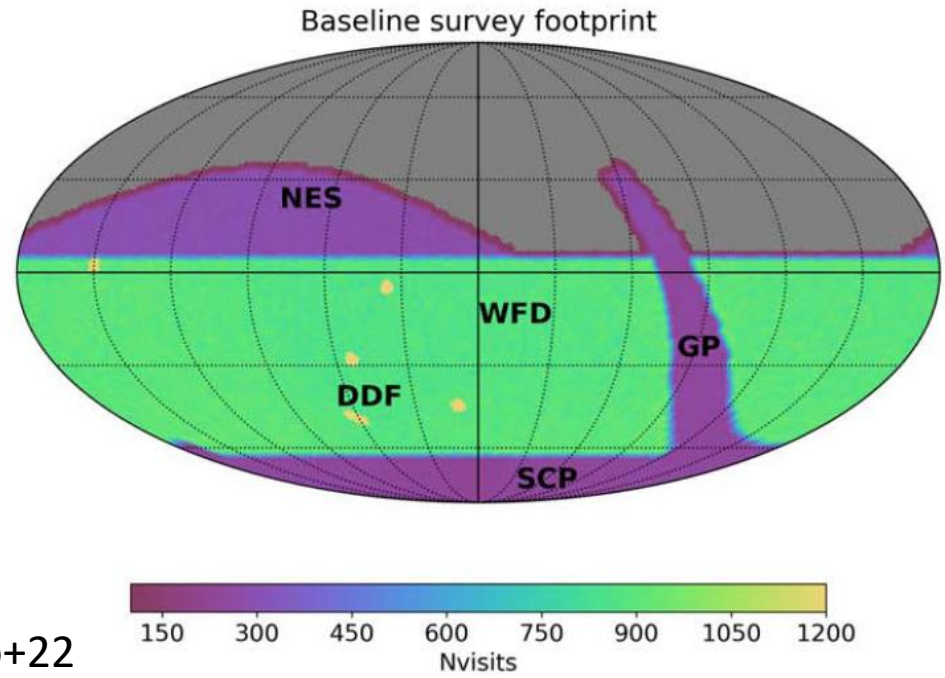


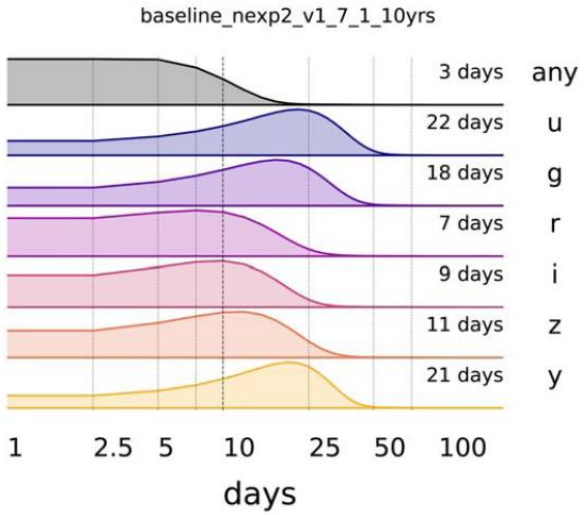
LSST+;SLAC+

A main survey
Wide-Fast-Deep (WFD)

- 10years
- 6 filters (ugrizy)
- 18,000deg2 (825 visits x 30s)

Depth (single, all)
u : 23.8, 25.6
g : 24.5, 26.9
r : 24.03, 26.9
i : 23.41, 26.4
z : 22.74, 25.6
y : 22.96, 24.8





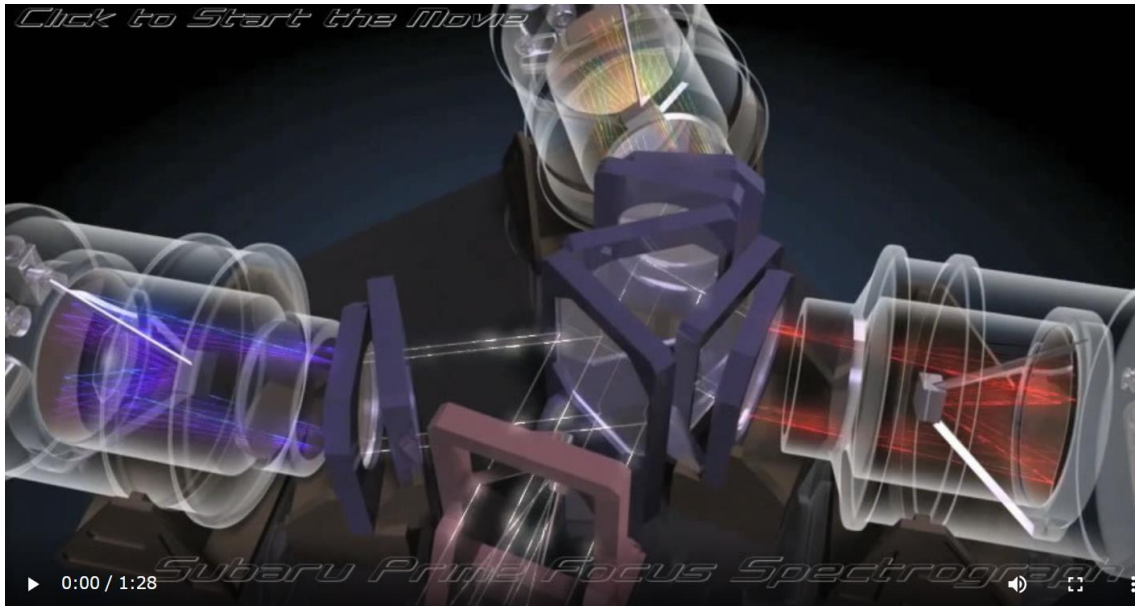
Bianco+22

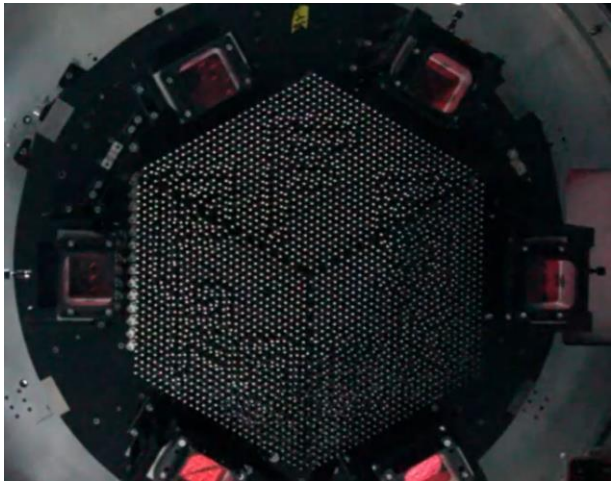
Alert stream

- Full alert stream is accessible only from community brokers. (Filtered alert stream may be received by the LSST users.)
- Latency: <60sec after image readout
- Rate: $<10^7$ alerts/night (2×10^4 for the filtered alerts)
- Alerts include
  - ID, filter name
  - Coordinate, proper motion, parallax, flux, error
  - Nearby object in catalog
  - 12 months history
  - Cutout images (stamps)

Our strategy

Subaru/Prime Focus Spectrograph





Specifications

- 2400 fibers/1.1deg2
- ~21.5mag/15min (in i-band)
- 360-1260nm

Takada+14

Time domain astronomy Rubin/LSST + Subaru/PFS

Under discussion for Subaru operation

Rubin/LSST
Wide imaging survey
18,000deg2/3days
(45% of all sky)

Data

Brokers of transients

ALeRCE
Automatic Learning for the Rapid Classification of Events

FINK

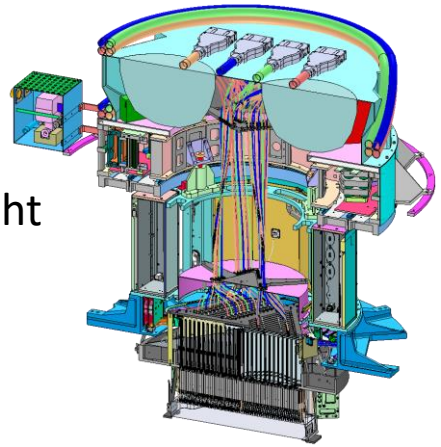
ANTARES

Transient infos

10^7objs/night

Subaru/PFS
Immediate spectroscopy

Several objs/FoV

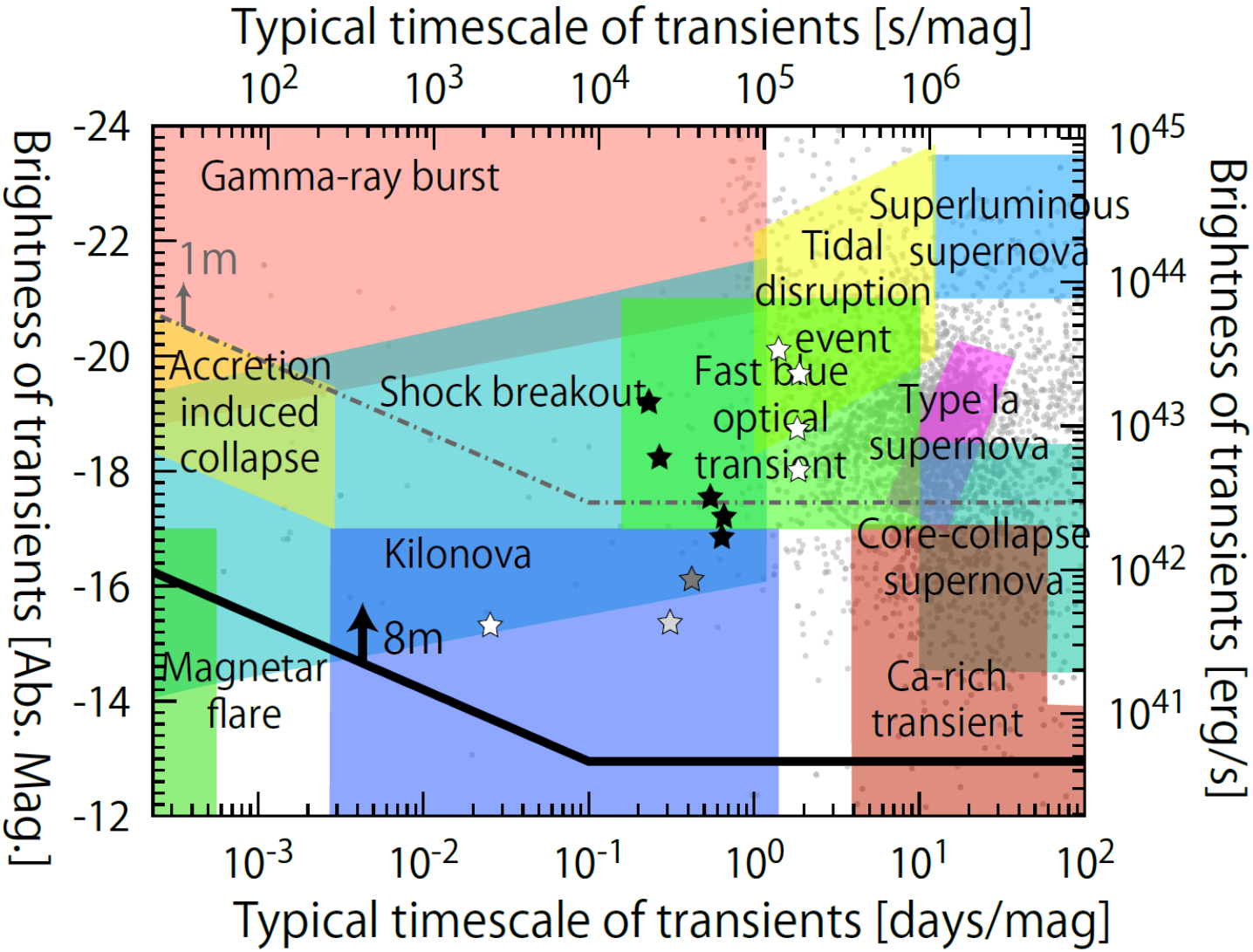


Ultimate spectra catalog of transients
>10,000 objs in the nearby Universe (z<1)

Large sample

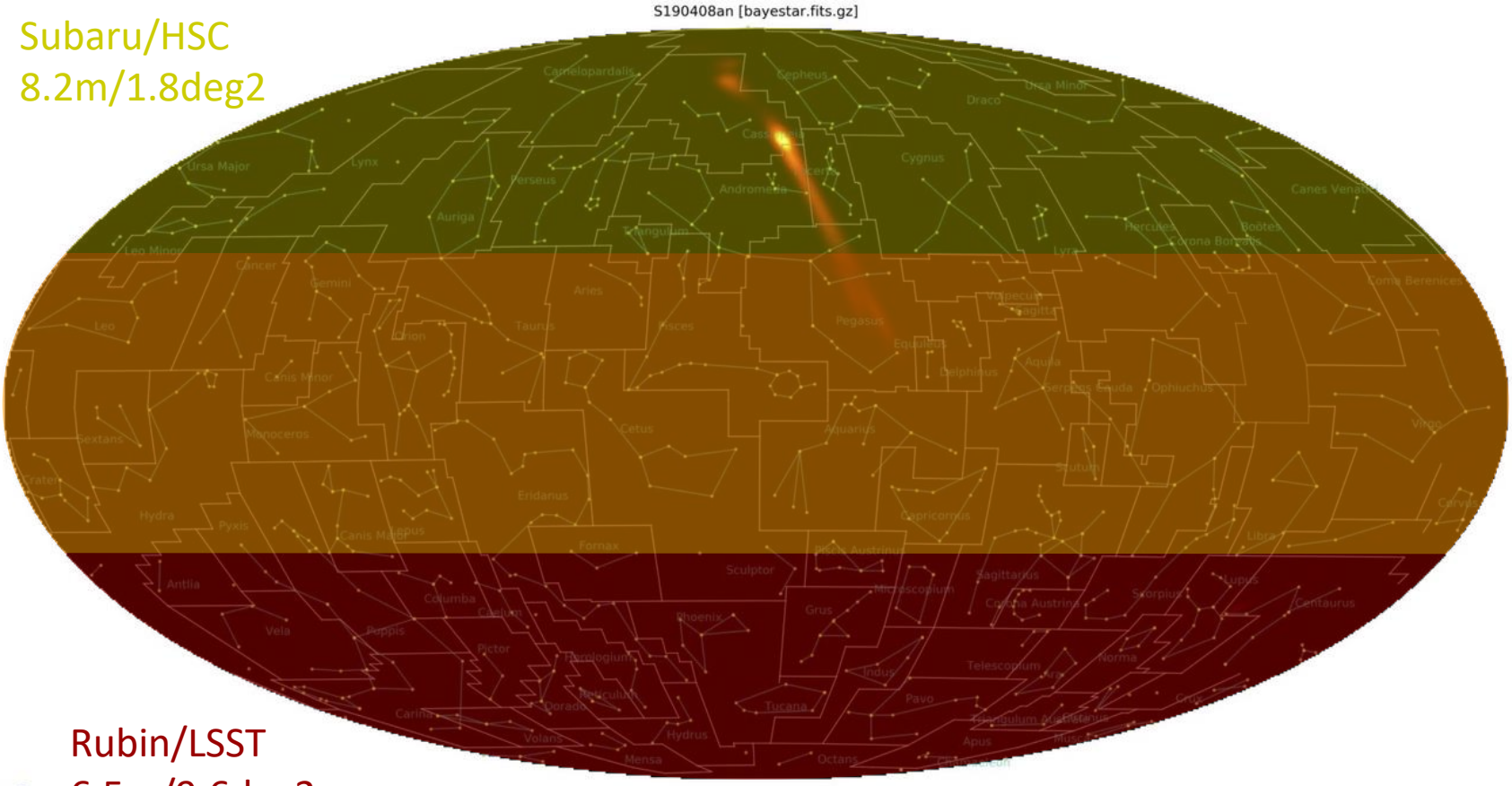
- **Variation of transients**, such as mass of metals, explosion energies
- **Nature of rare transients**, such as pair-instability supernovae

Time domain astronomy
Census of transients



Multi-messenger astronomy Rubin/LSST (S) or Subaru/HSC (N) + Subaru/PFS

Subaru/HSC
8.2m/1.8deg2



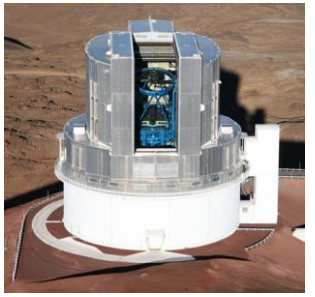
Rubin/LSST
6.5m/9.6deg2

Credit: LIGO-Virgo/Cardiff Uni./C. North

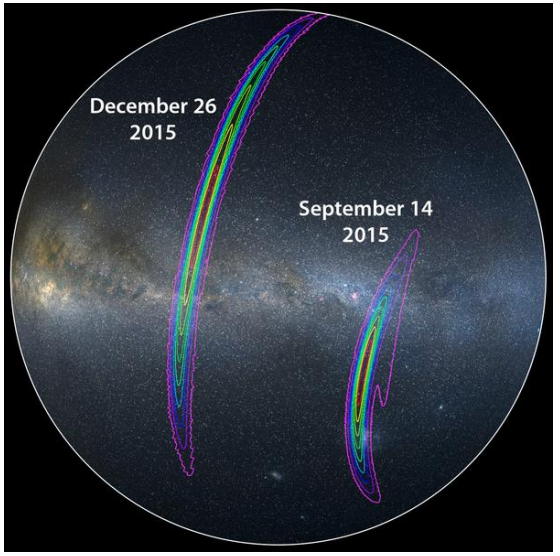
Target of opportunity observation

- 3% of LSST sky time (9 nights/year)
- Targets
  - Gravitational waves
  - High-energy neutrinos
  - Galactic supernovae (MeV neutrinos)
  - Solar system objects

Multi-messenger astronomy with Subaru



- Gravitational waves (~10-100deg2)
- High-energy neutrinos (~1deg2)
- Neutrinos (~ several deg2)
- Fast radio bursts (<sec2-0.05deg2)

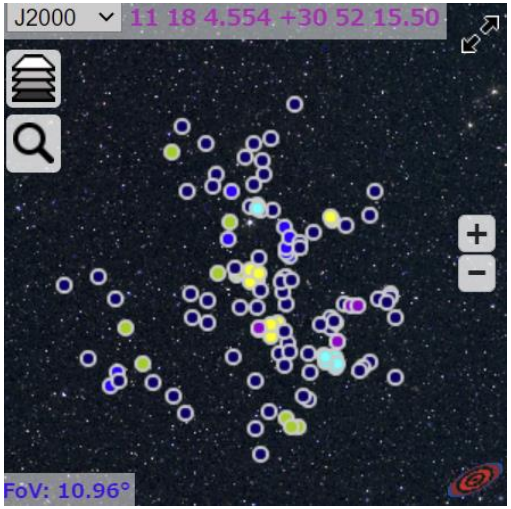


Wide-field capability of Subaru

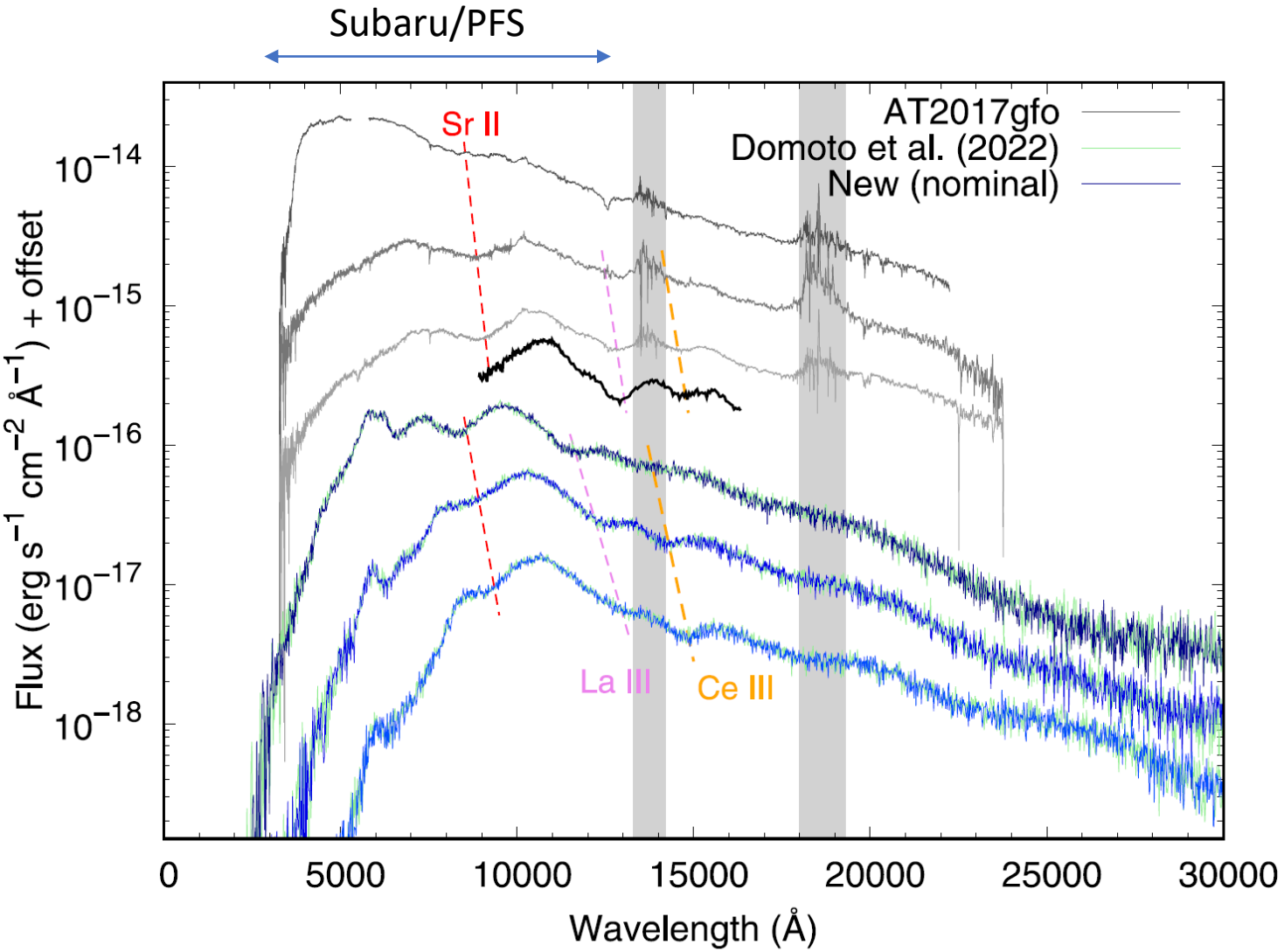
- Cover all probable region or targets

HSC (Iwata-san)

PFS (Zhang-san [Haibin])



Multi-messenger astronomy with PFS
Elemental features in spectra



Domoto+23

Summary

- Subaru/HSC is the most powerful wide-field imaging instrument until Rubin/LSST launches or in the northern hemisphere.
  - Time-domain astronomy: Early SNe IIP are found in the high-cadence HSC survey. One object could be an energetic SN IIP with dense CSM.
  - Multi-messenger astronomy: Follow-ups had been performed using Subaru/HSC. Subaru/HSC is deep enough and can be fast enough for the follow-ups.
- Rubin/LSST, an ultimate optical imaging survey, will be online in 2025.
  - Full alert stream up to 10^7 alerts/night.
  - Alert brokers classify and filter them and make them public.
- **Synergy between Rubin/LSST and Subaru/HSC and PFS**
  - Time-domain astronomy: census of transients
  - Multi-messenger astronomy: r-process nucleosynthesis