Transient Astronomy and the role of Subaru

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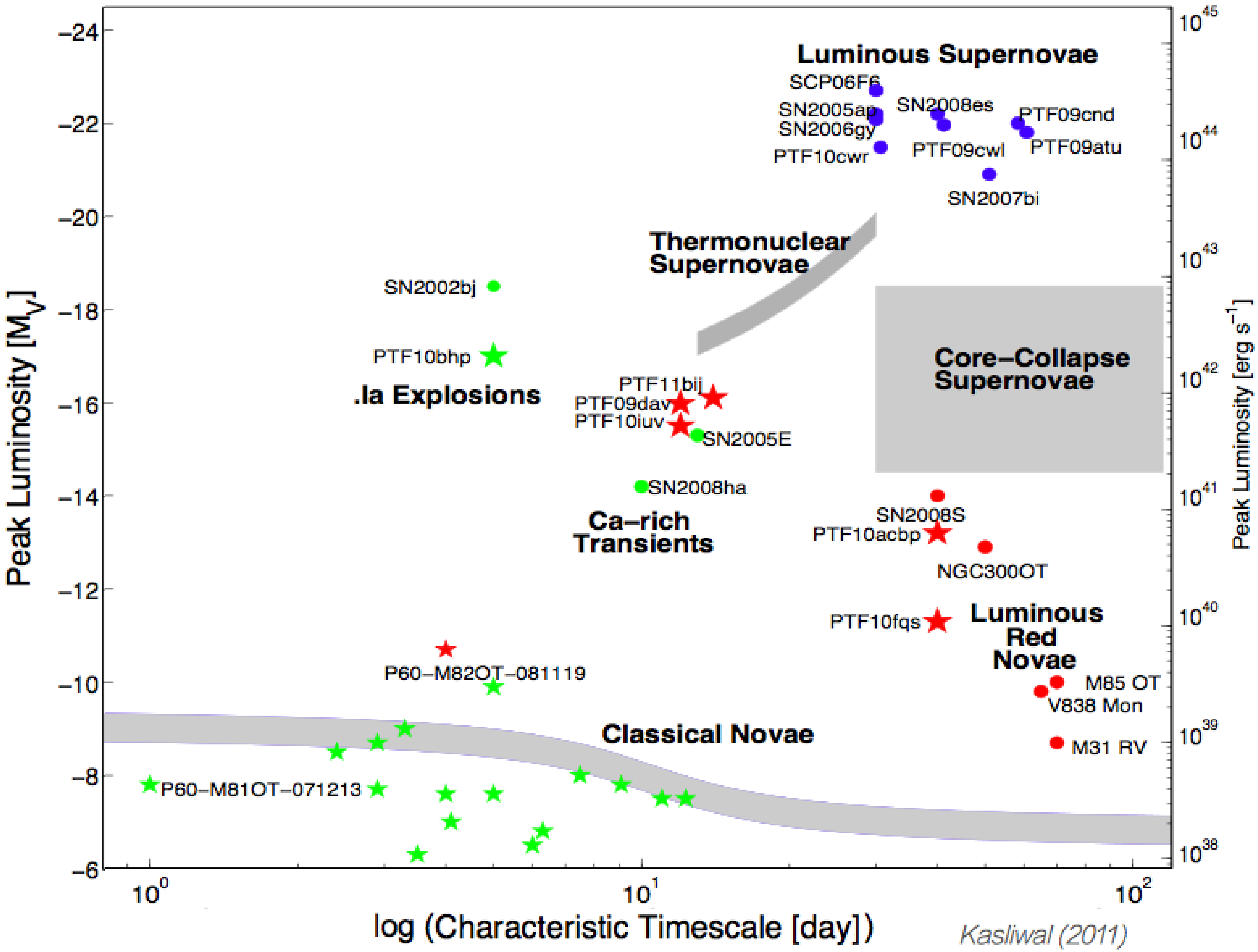
OzGrav

transients


Luminous Supernovae
SCP06F6
SN2005ap
SN2006gy
PTF10cwr
SN2008es
PTF09cwl
PTF09cnd
PTF09atu
SN2007bi
Thermonuclear Supernovae
Core–Collapse Supernovae
SN2002bj
PTF10bhp
.Ia Explosions
PTF11bij
PTF09dav
PTF10iuv
SN2005E
SN2008ha
Ca–rich Transients
SN2008S
PTF10acbp
NGC300OT
PTF10fqs
Luminous Red Novae
M85 OT
V838 Mon
M31 RV
P60–M82OT–081119
Classical Novae
P60–M81OT–071213
Peak Luminosity [M_V]
Peak Luminosity [erg s^-1]
log (Characteristic Timescale [day])
Kasliwal (2011)

brief summary of contributions

Subaru led the way in high-z supernova Ia searches

e.g., Suprime-Cam: 18 to z ~ 1.6, Poznanski et al. 2007
28 at z ~ 1-1.5 and 10 at z ~1.5-2, Graur et al. 2011, 2014
39 at z ~ 0.2 - 1.4, Okumura et al. 2014, SN Ia rates, Totani et al. 2008
HSC-SSP: 430+ Yasuda et al. 2019, Suzuki et al. 2012, HSC/HST z > 1 Ia, etc.
Beautiful cosmological results, underscored SN tension with CMB measures

Subaru spectroscopy and spectropolarimetry of interesting SNe

e.g., Morokuma et al. 2010, Fredericksen et al, 2014,
Kawabata et al. 2002, 2005, 2009, Takada-Hidai et al. 2002,
Girardy et al. 2002, Deng et al. 2004, Mazzali et al. 2005, Motohara et al. 2006,
Maeda et al. 2007, 2009, Tanaka et al., 2008, 2009, 2010, 2012,
Hamano et al. 2012, Jiang et al. 2017, Kokubo et al. 2019, and others

Ultra-long, luminous optical transients (z ~ 0.6 to 2.4)

Urata et al. 2012, Moriya et al. 2019a, 2019b, Curtin et al. 2019

SNe II standard candles, de Jaeger et al. 2017

AGN variability selection, Morokuma et al. 2008

brief summary of contributions

Fast transients

Fast rising, Tanaka et al, 2016
Fast fading, Tominaga, et al. 2019
FRB counterparts and fast transients (DWF with HSC)
Gravitational wave counterparts: BBH, Morokuma et al 2016
BNS, Tominaga et al. 2018, GCNs: Morokuma 2019, Sasada 2019, etc.
Neutrino counterparts, IceCube collaboration
GRB afterglow follow up, Watanabe et al. 2001, Kawabata et al, 2003, Hashimoto et al, 2010, 2018, Onodera 2011, Niino et al. 2012, etc.
GCNs: Kosugi 2003, Terada 2004, Kawai, Kosugi 2005, Tanaka, 2006, Terada 2007, Tanaka, 2008, Minowa, Aoki 2009, Hattori, 2010, etc

Moving object / TNO search

Chen et al. 2018, Terai et al 2018, etc

Machine learning transient/moving object detection

Morii et al. 2016, Lin et al, 2018, etc.

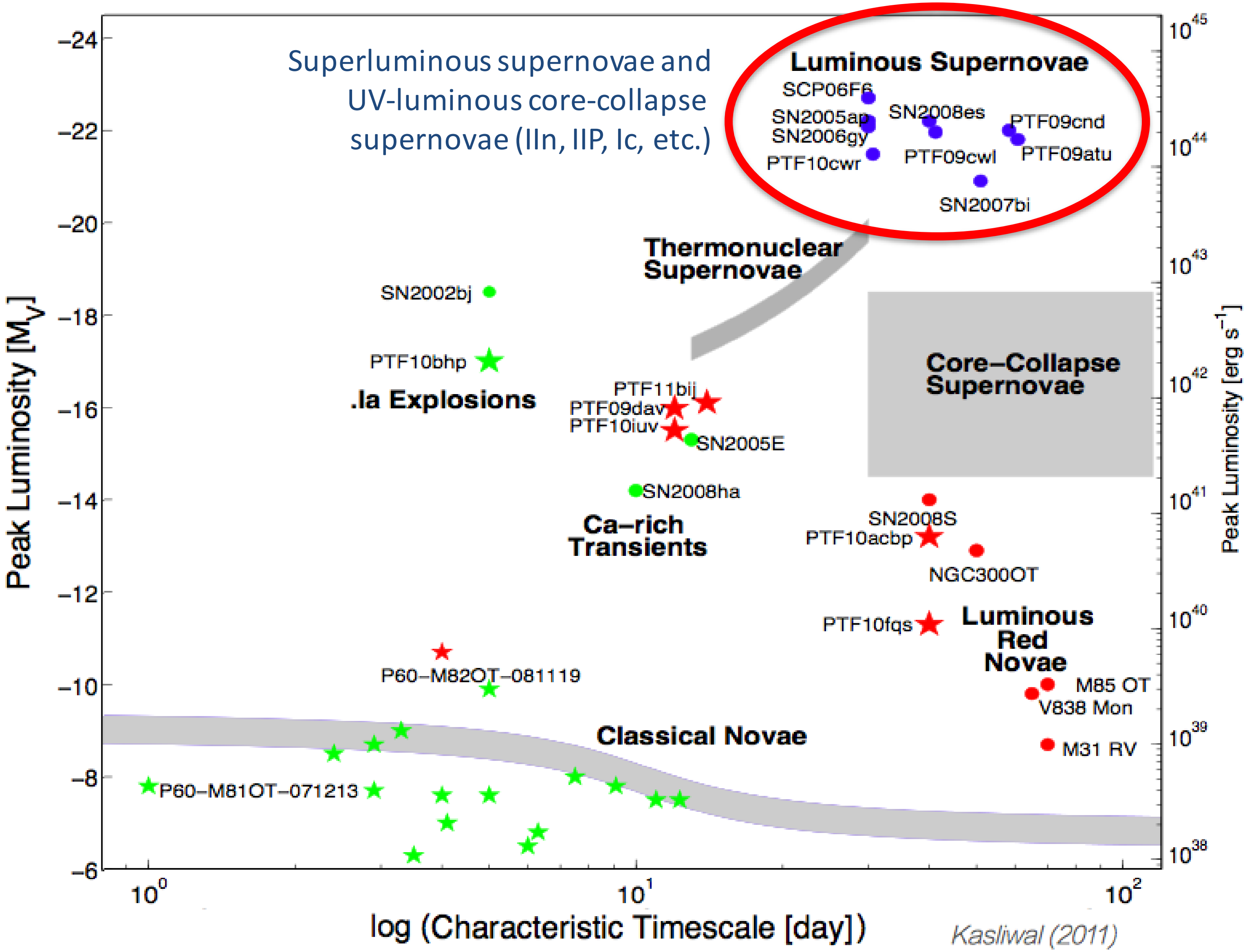
Saturn's rings seasonal IR radial variation

Fujiwara et al. 2017

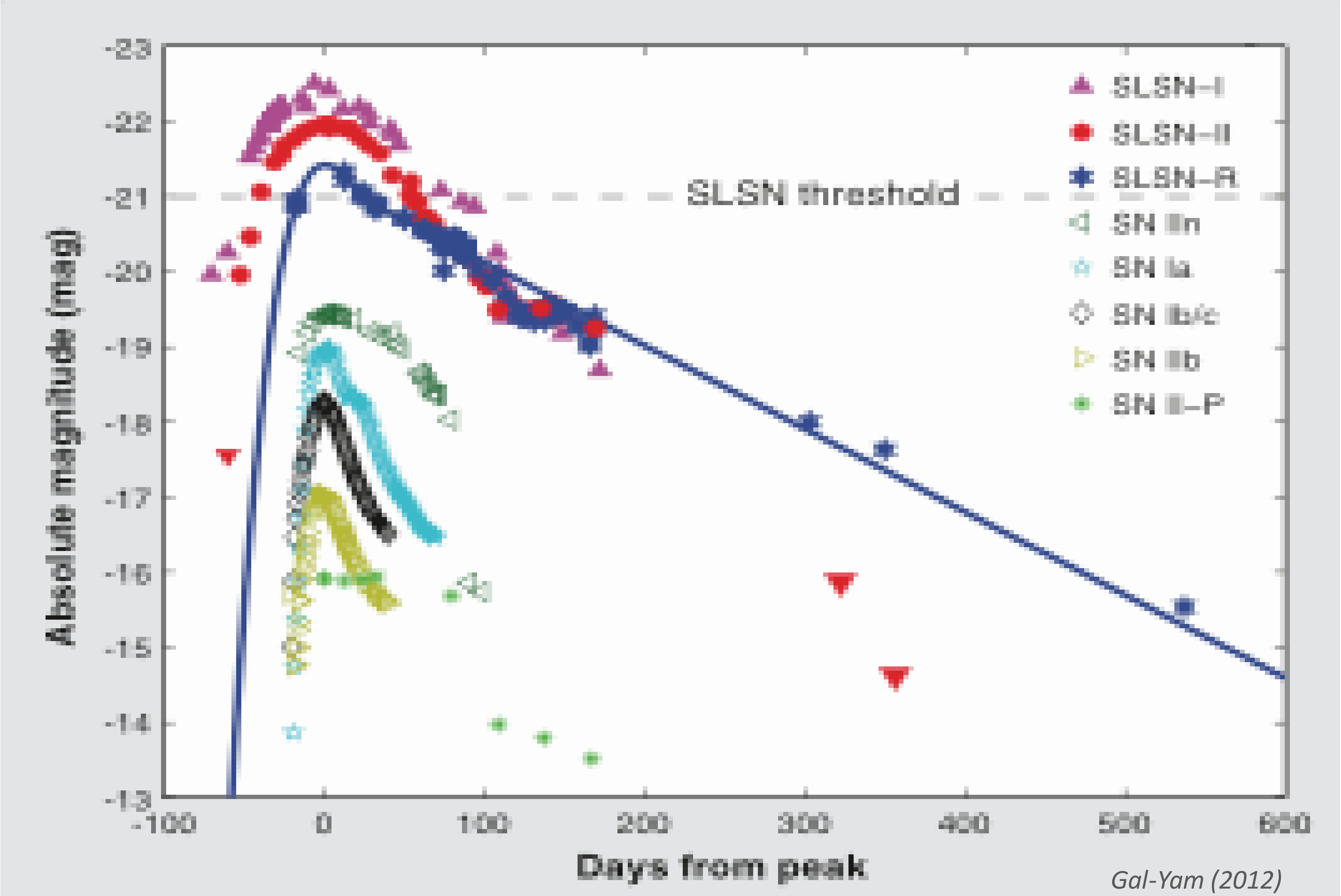
Future directions

The “Slow” and the early Universe

UV-luminous supernovae



Superluminous supernovae *(and UV-luminous supernovae)*



Gal-Yam (2012)

High redshift supernovae - *not Target of Opportunity targets*

Utility

- Volume - More SLSN candidates identified at $z > 2$ than at $z < 2$
- Probe the FUV and NUV
  - SLSN are most luminous in the UV, energies, physics and progenitors
- Rates and high-mass end of the IMF - controlled volumes at high redshift
- Cloud collapse timescale, massive star formation and low-Z environment
  - gleaned from galaxy interactions and companion separations
- Cosmic evolution and cosmology
  - progenitor insight, standard candles(?) probing deceleration to $z \sim 20$(?), *SLSNe are brighter than galaxies at those redshifts*, resolution increases
- Epoch of reionisation
  - probe beyond EoR, escaping ionising photons, can arrest SF in galaxies
- Absorption-line beacons
  - get SN environment, host ISM, CGM, and intervening IGM to $z \sim 20$
- Population III stars
  - opportunity to study PopIII deaths (i.e., pristine gas detected at $z \sim 3$)
- PISNe - best chance to detect PISN?, cosmic chemical evolution

Supernova surveys

Requirements

ULTIMATE, SWIMS
WFIRST
Hyper-SuprimeCam

Wide-field Imaging — *optical* / *infrared*

z =	2	3	4	5	6	7	10	15	
depth m ~	24.8	25.6	26.1	26.4	26.7	27.0	27.5	28.1	*(per epoch)*

for ~1 mag SLSN evolution detection

Historical (4m-class):

Canada-France-Hawaii Telescope Legacy Survey (CFHTLS)

13 spec, ~60 phot candidate z = 2.0 - 3.9 SNe, some HST imaging

Survey Using DECam for Superluminous Supernovae (SUDSS)

~40 phot candidate low and high-z (z = 2 - 4) SLSNe, some HST imaging

DES-SN program - cadence for SN Ia, accommodates high-z SLSNe

22 spec, ~40 phot candidate z ~ 0.22 - 1.99, SLSNe, some HST imaging

Ongoing (8m-class):

Hyper Suprime-Cam Subaru high-z supernova campaign, SHIZUKA

COSMOS field, ~30-band phot-zs, HST imaging, (now SXDS)

3(4) confirmed, ~10 candidate z ~ 1.8 - 2.4(4.3) SLSNe, can search to z ~ 6

Supernova surveys

Requirements

ULTIMATE, SWIMS

Hyper-SuprimeCam *WFIRST*

Wide-field Imaging

	optical							*infrared*	
z =	2	3	4	5	6	7	10	15	
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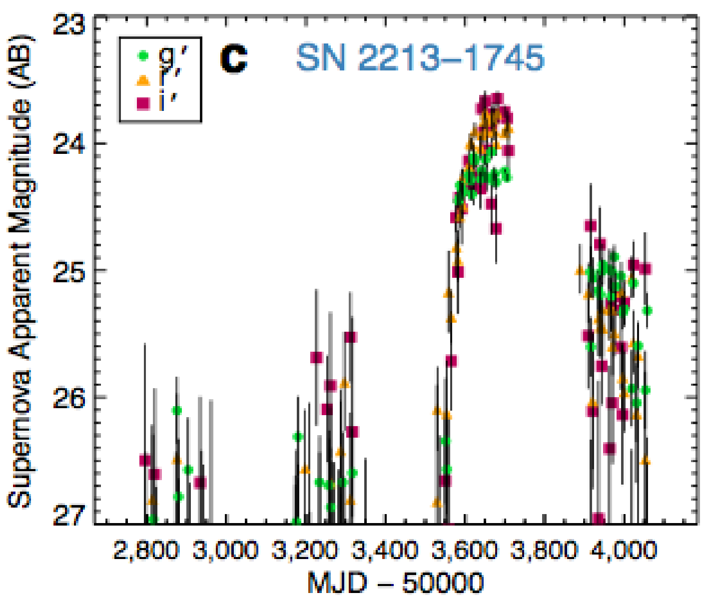
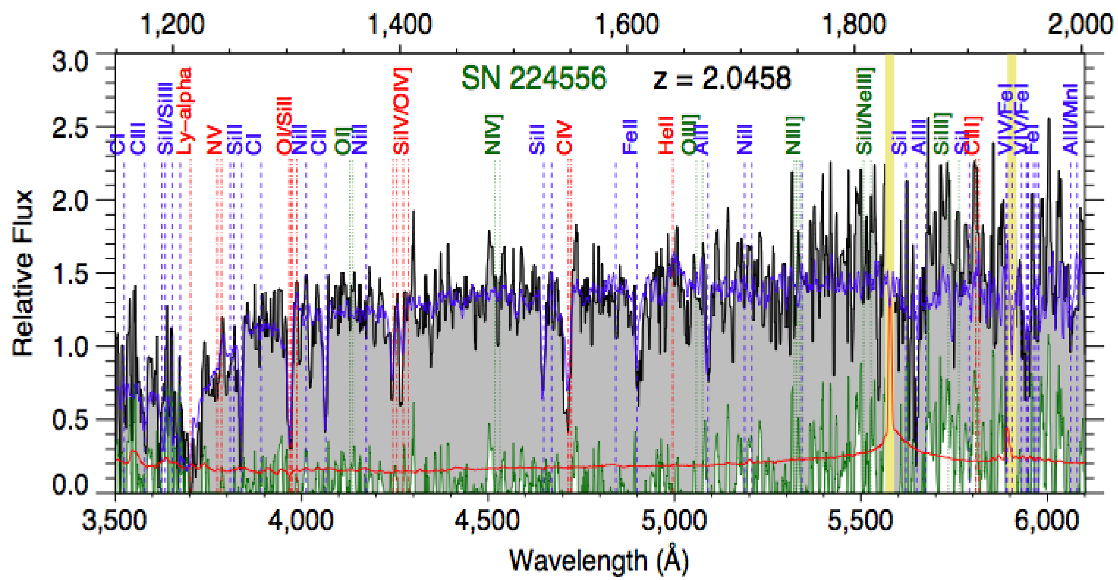


Cooke et al. (2012)



Cooke et al. (2012)

Supernova surveys

Requirements

ULTIMATE, SWIMS
Hyper-SuprimeCam *WFIRST*

Wide-field Imaging — *optical* → *infrared*

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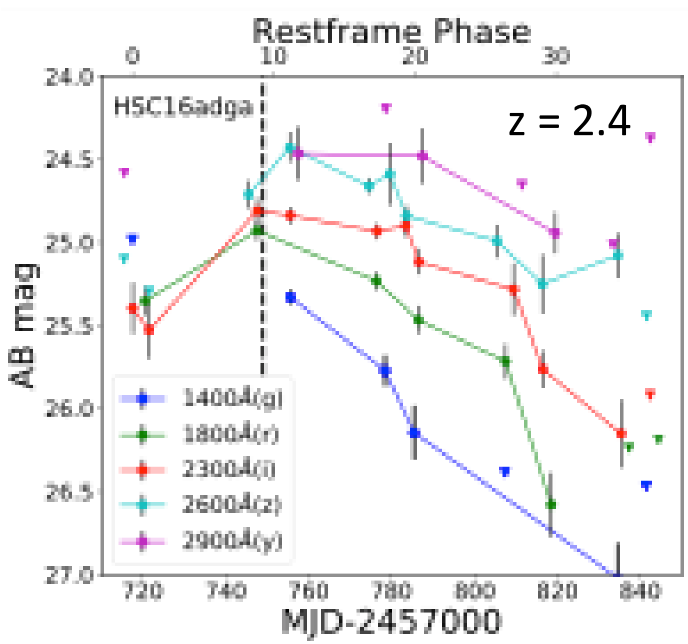
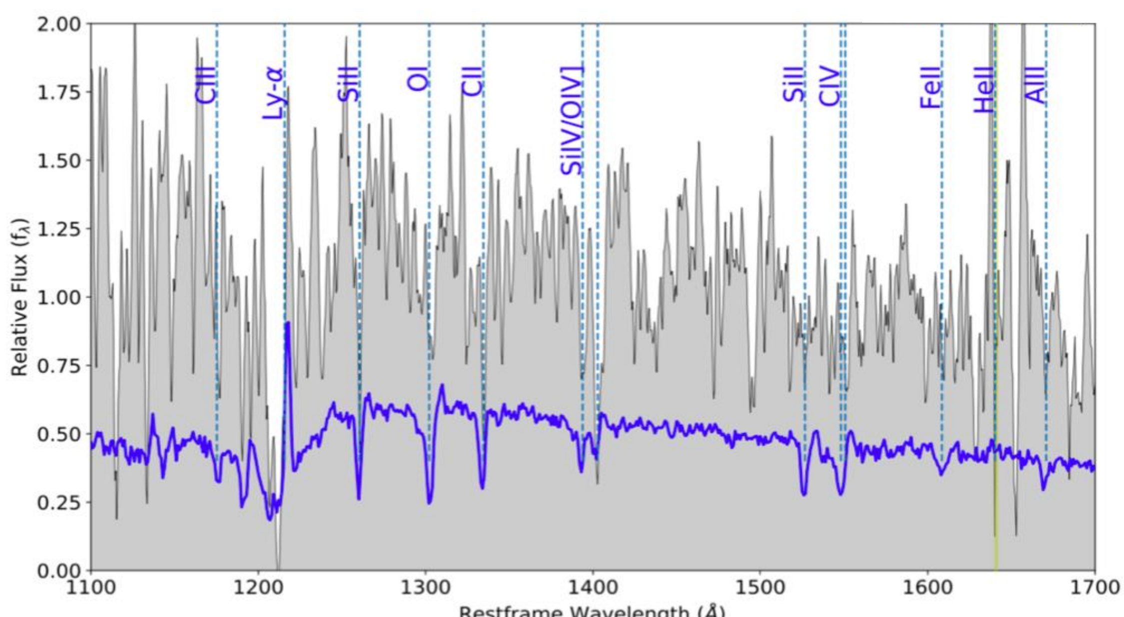


Moriya et al. (2019)



Curtin et al. (2019)

Subaru HSC - WFIRST survey

Eliminate low-z

Lyα forest

Redshift (z)	~7.5	~10	~13.5	~18	~23.5	~31.5
M = -21 (i.e., SLSNe)	26.0	26.5	26.9	27.3	27.7	28.1
m(lim) = 28	-19.0	-19.5	-19.9	-20.3	-20.7	-21.1
Physical scale (kpc)	5.0	4.2	3.5	2.7	2.2	1.7
Physical scale (pc/pixel)	550	462	385	297	242	187

Lyα forest

Balmer break

Redshift (z)	~1.7	~2.6	~3.7	~5.1	~7.0	~9.5
M = -21 (i.e., SLSNe)	23.4	24.3	24.9	25.4	25.9	26.4
m(lim) = 28	-16.4	-17.2	-17.9	-18.4	-18.9	-19.4
Physical scale (kpc)	8.5	8.1	7.2	6.2	5.2	4.3
Physical scale (pc/pixel)	935	891	792	682	572	473

- Can “double” color-select *z* ~ 2-4 galaxies *(and better understand FUV)*
- Can detect z ~ 2 supernovae events down to M ~ -17
- Can detect SLSNe/PISNe to z ~ 8-13 for JWST and 30m spectra
- Covers Pop III star “sweet spot” of *z* ~ 9 well
- Physical scales become *noticeably higher-resolution*

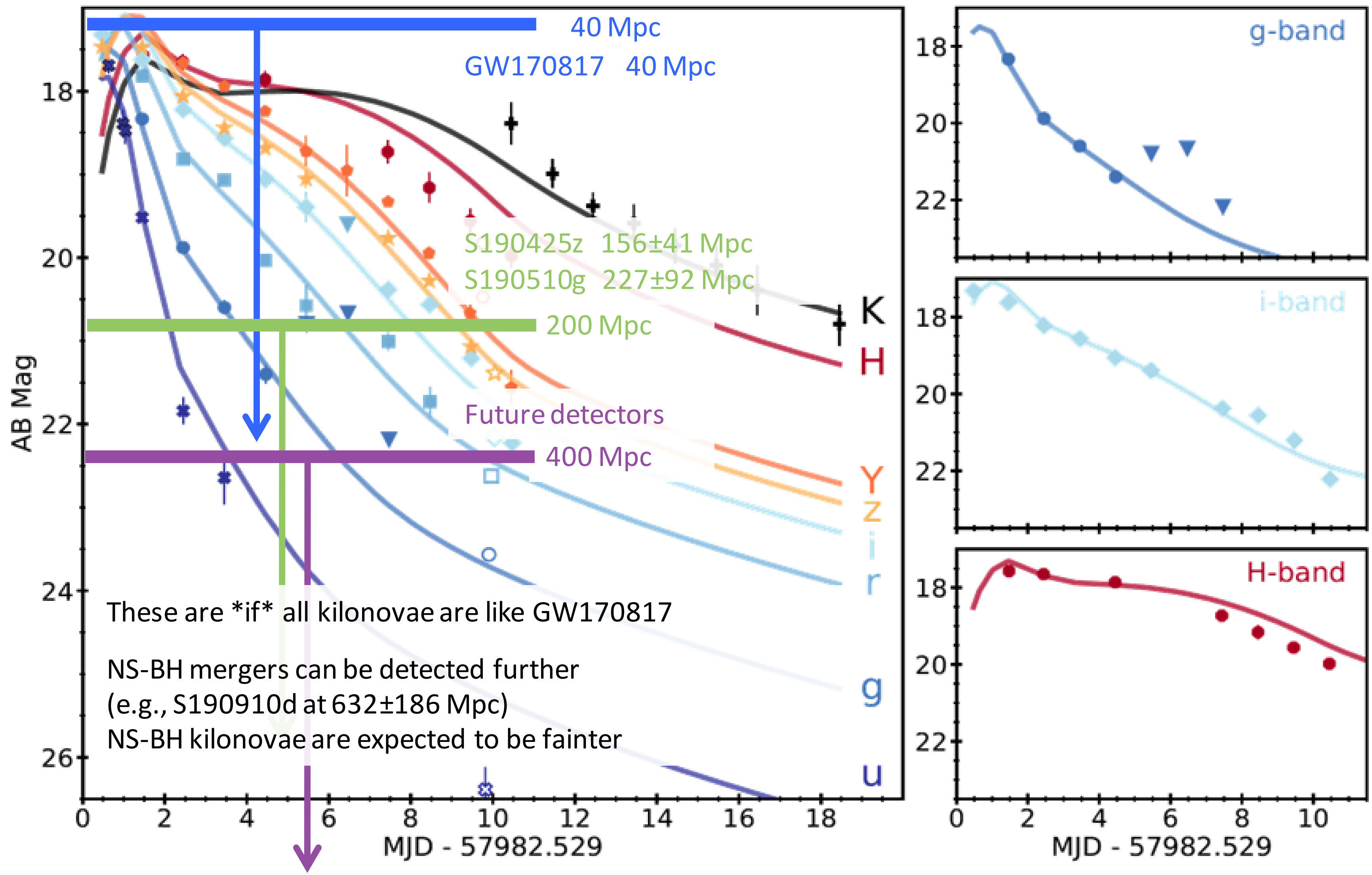
Future directions

The “Fast” and multimessenger

GW170817 - binary neutron star merger kilonova

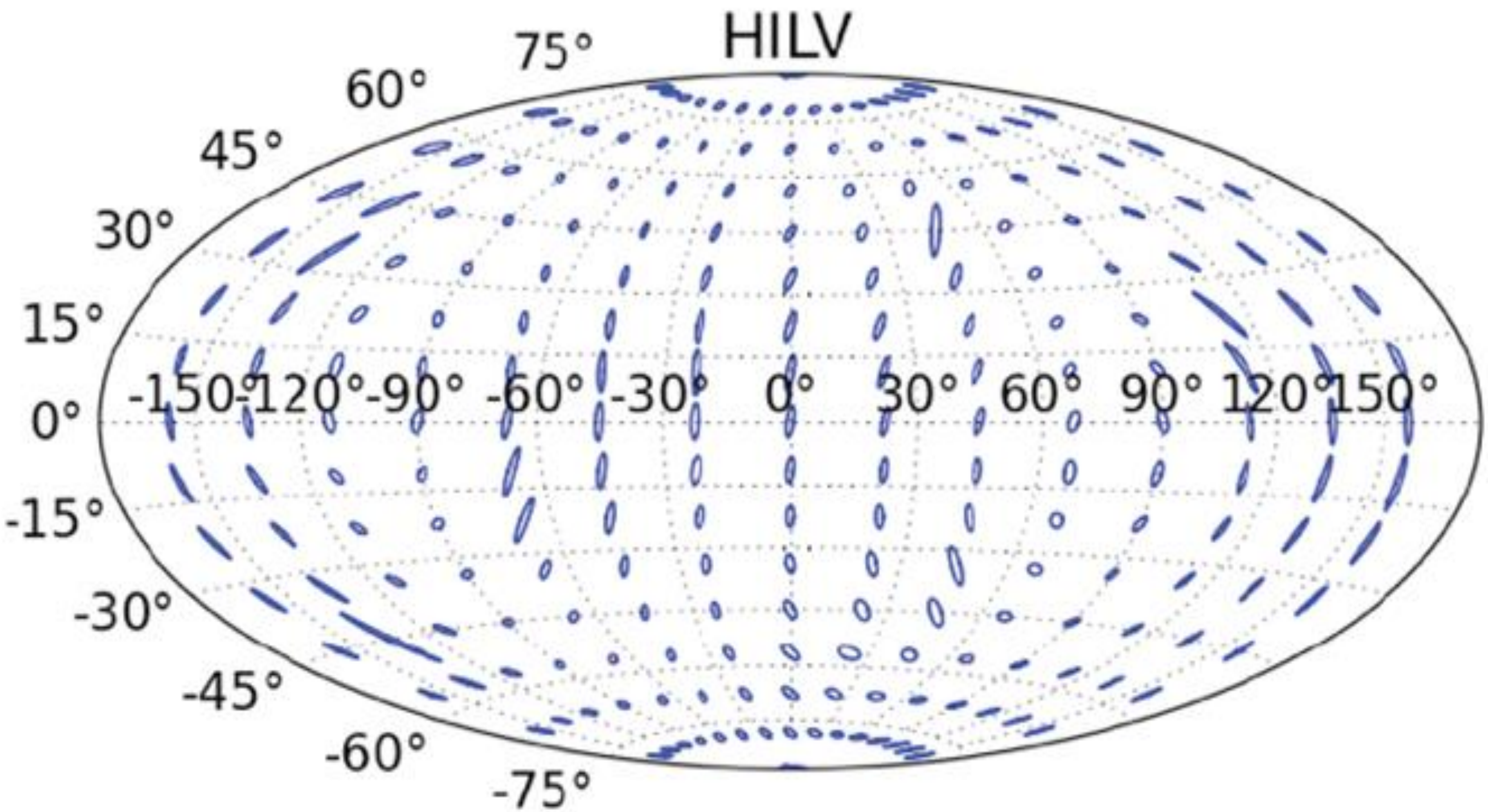
Credit: NASA/ESA, Levan, Tanvir, Fruchter, Fox

multi-messenger



Cowperthwaite et al. (2017)

multi-messenger



Fairhurst(2011)

Subaru is essential to detect faint, distant kilonovae (including NS-BH kilonovae) and to understand their variety

Kilonovae to z ~ 0.5 - *not Target of Opportunity targets*

Deep kilonova photometric searches

- Search deep nightly imaging taken for other science, such as deep galaxy research, if taken with intelligent cadence
- Enables the detection of BNS kilonovae well beyond GW detector horizons
- Enables the detection of NS-BH EM emission (expected to be fainter)

Some outcomes:

- Learn about the broader population
- Help uncover the range of event types, luminosities, chemical output
- Better determine KN rates, including dust obscured events
- Search for evolution with redshift
- More accurate H_0 measurement, etc.

Also: Neutrino EM follow up, e.g., IceCube - 170922A


Future directions
The *“Fastest”* and the unknown

Subaru HSC survey Optimized for Optical Transients (SHOOT)
intra-day transients

5 fast rising

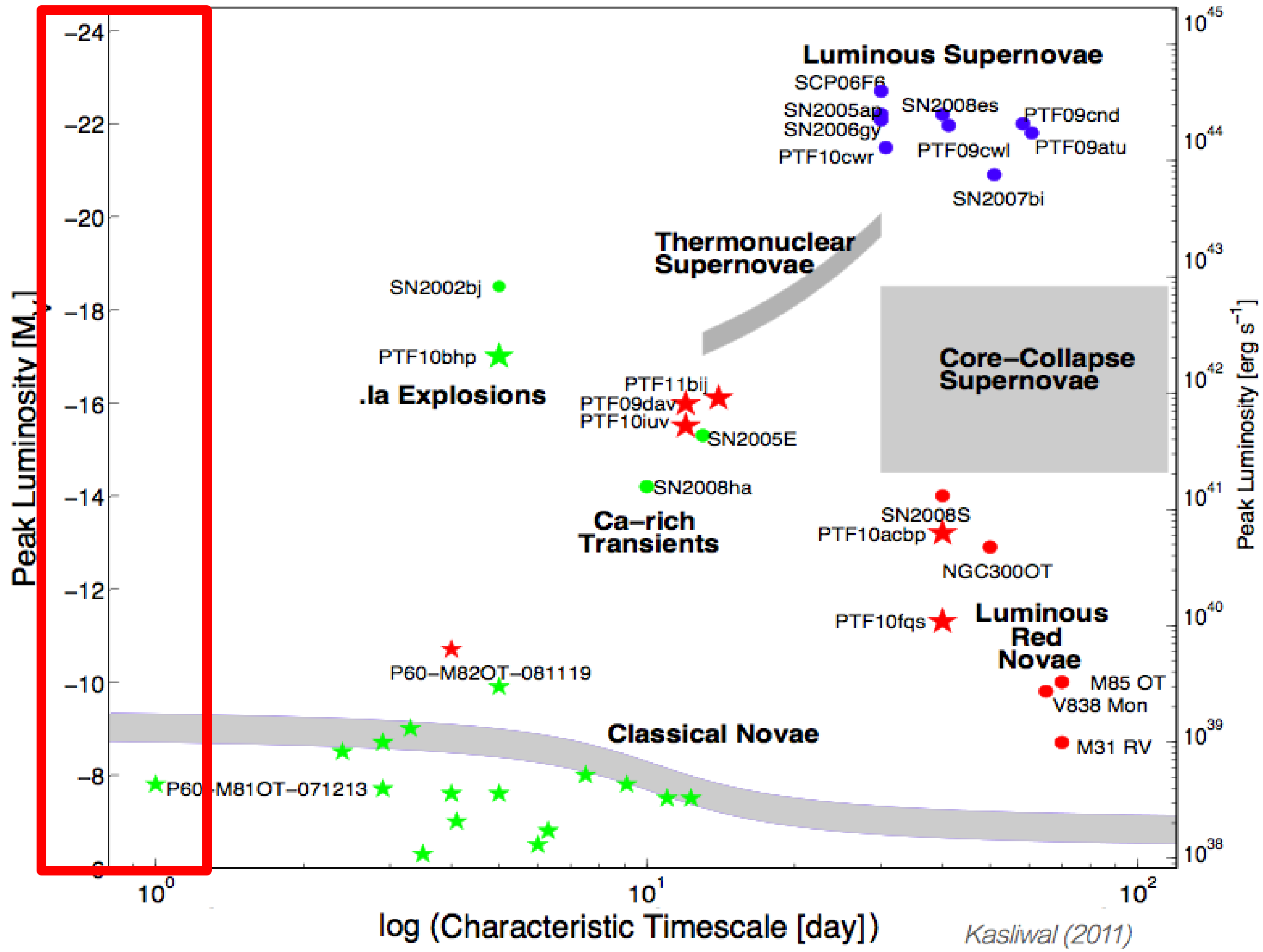
1.3-3.1 mag/day
Type?

Tanaka et al. 2016

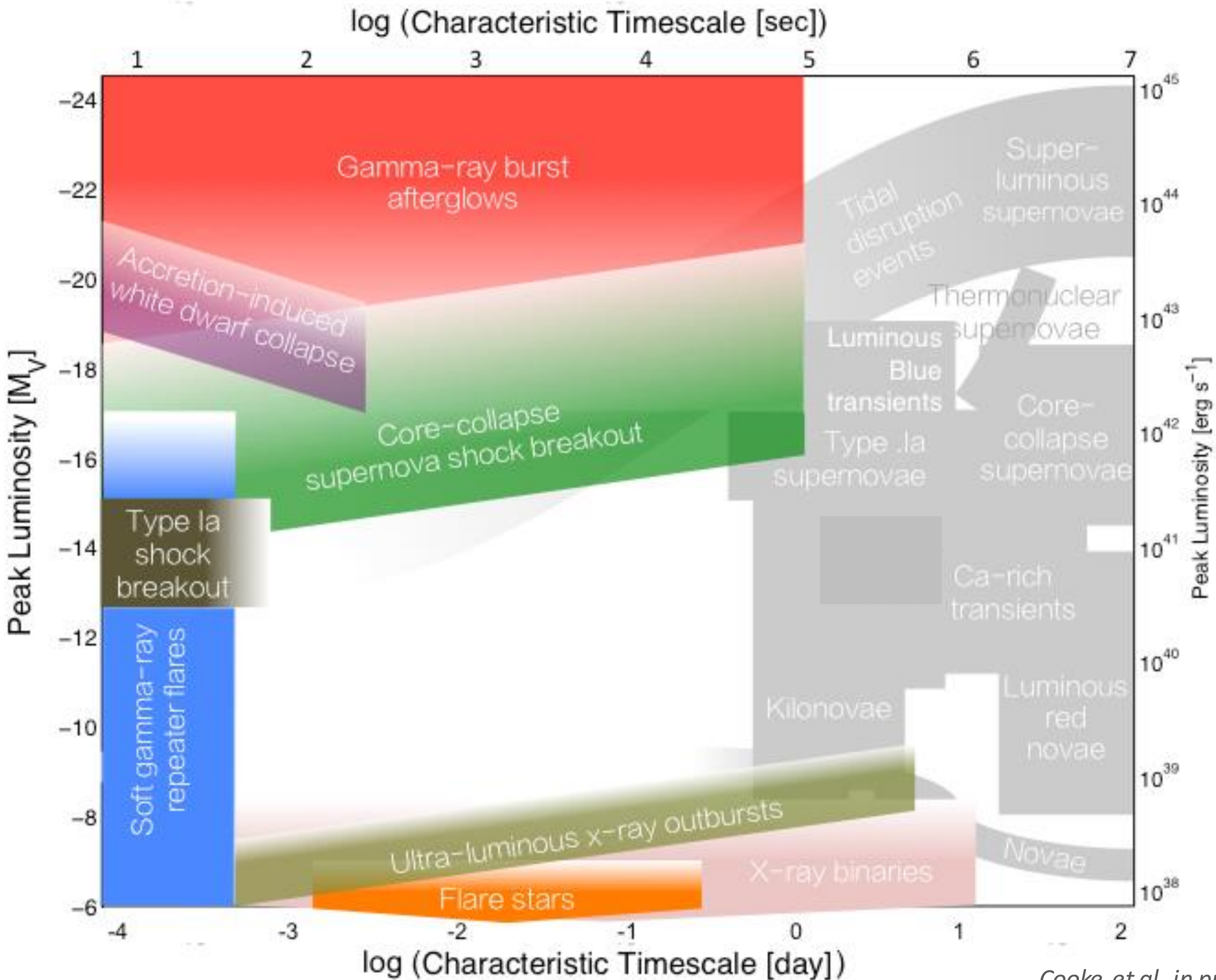
1 fast fading

1.8 mag/day
Kilonova?

Tominaga et al. 2019

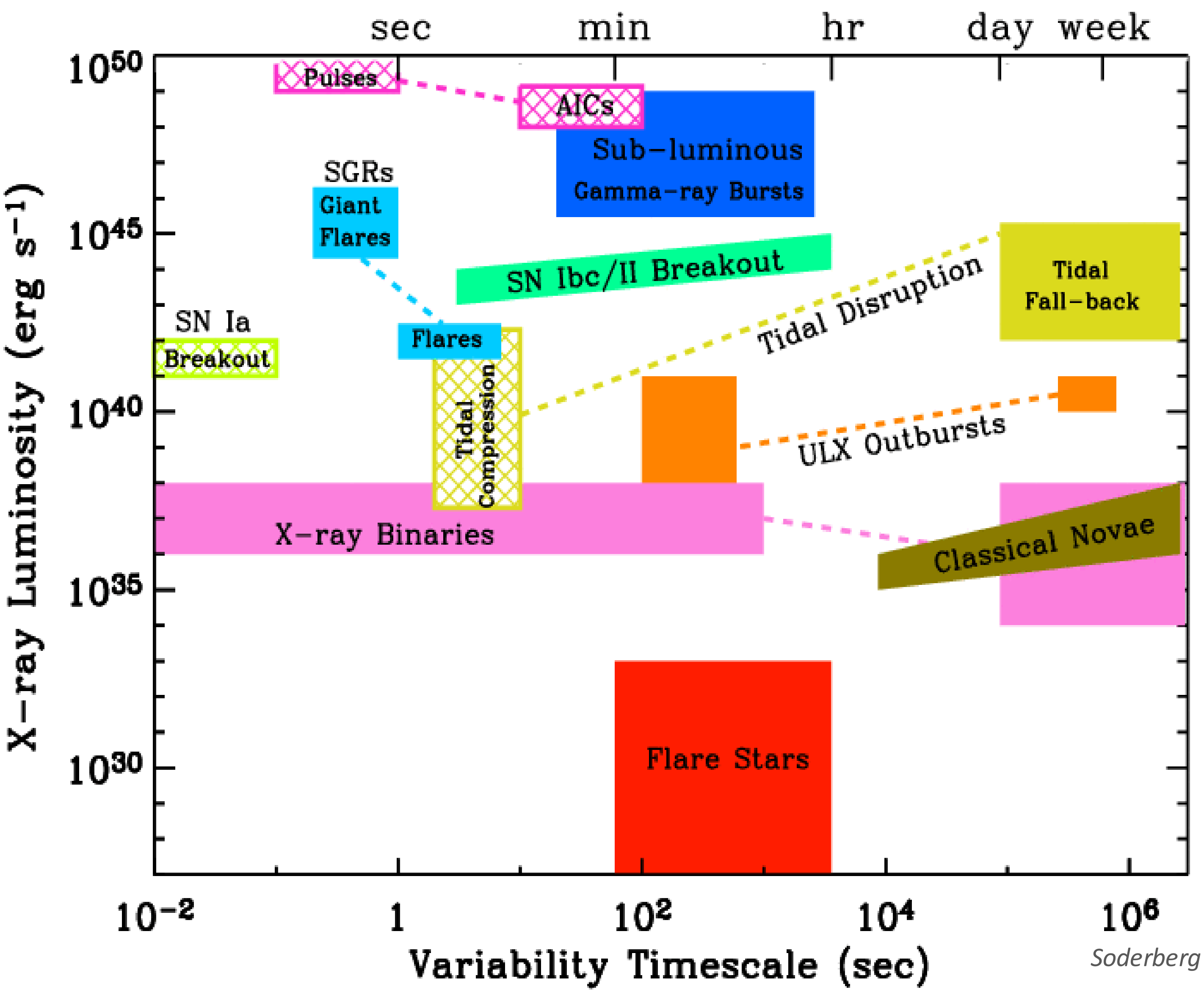


fast and unknown



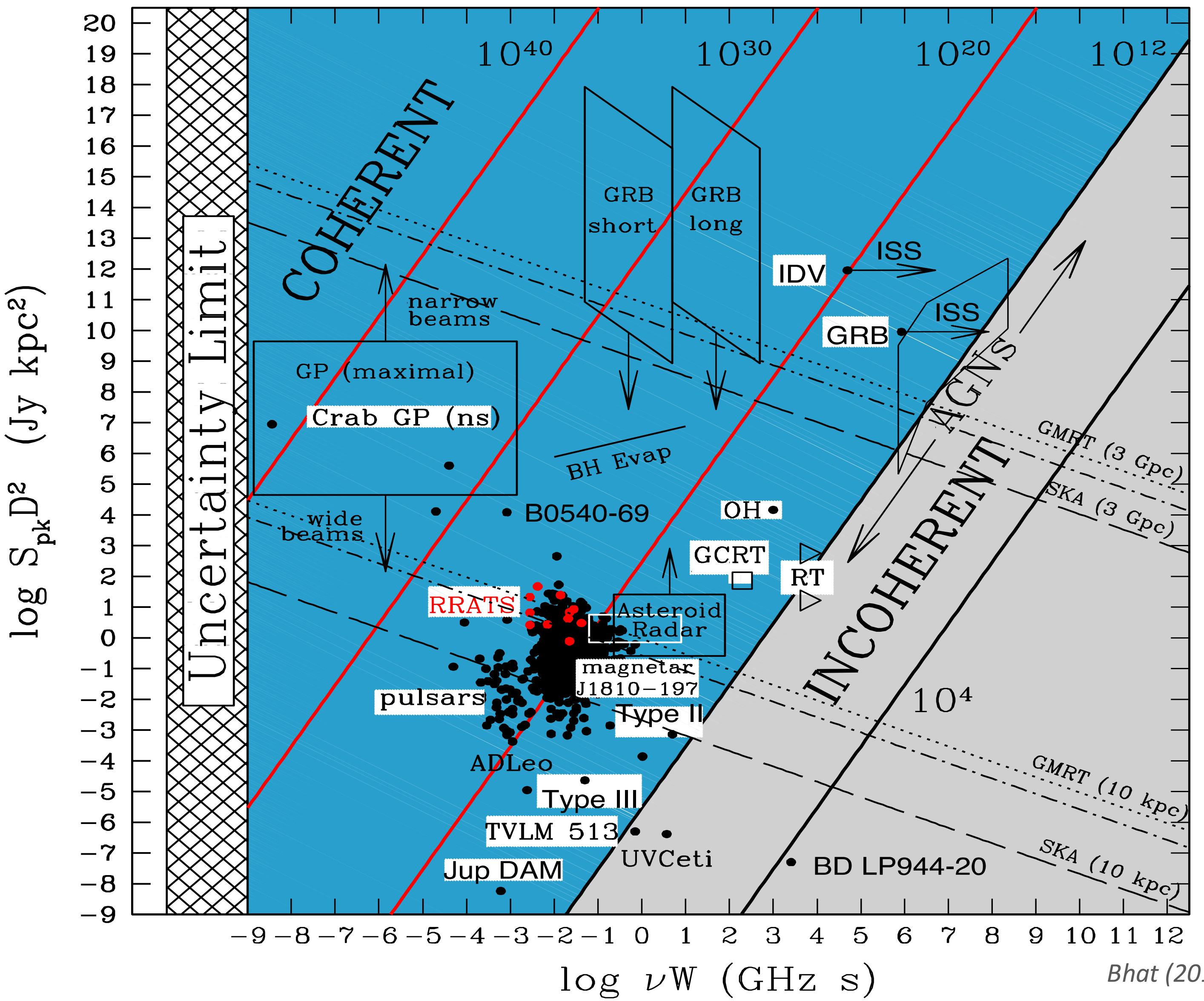
Cooke et al. in prep.

fast and unknown



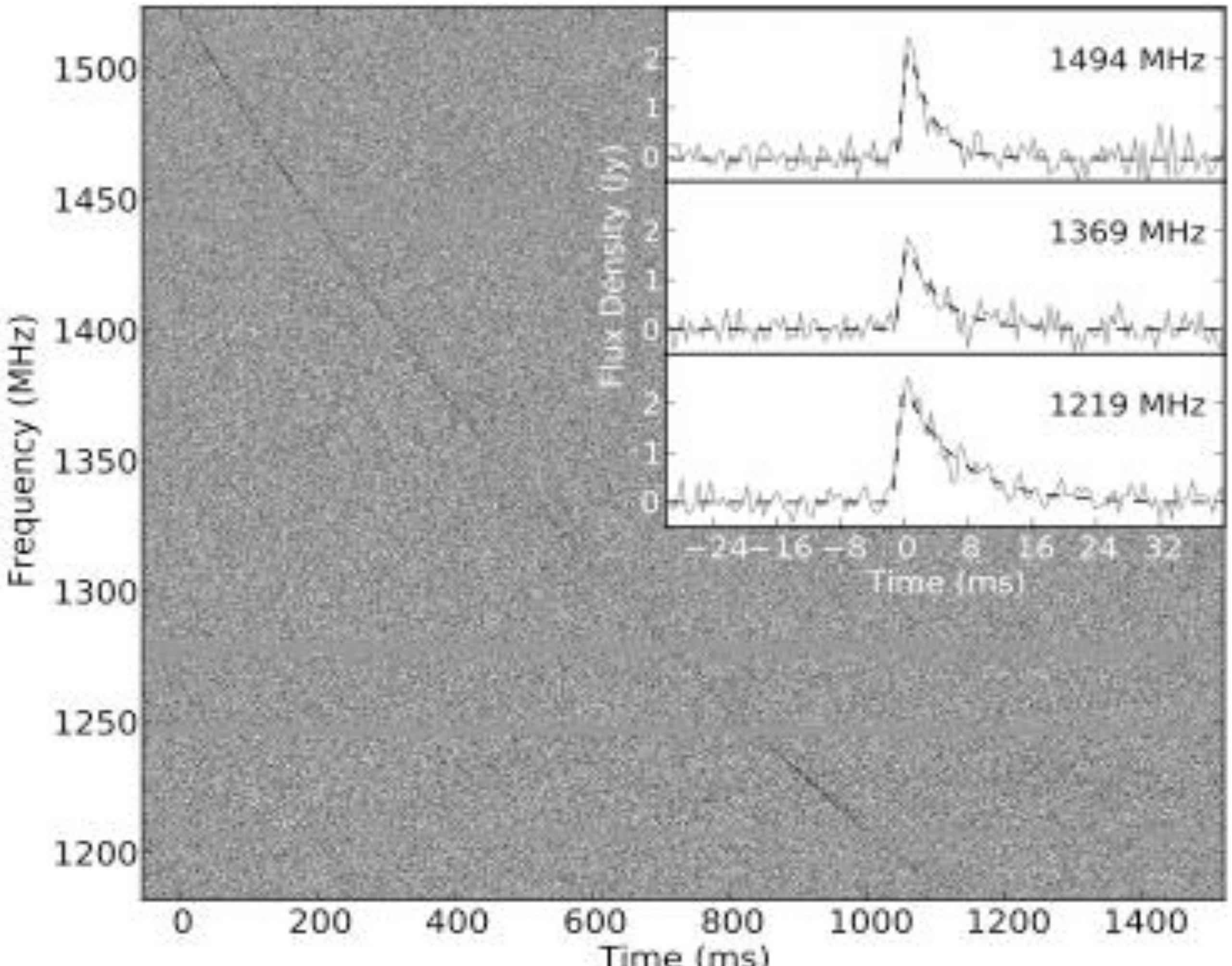
Soderberg (2010)

fast and unknown



Bhat (2011)

Fast radio bursts



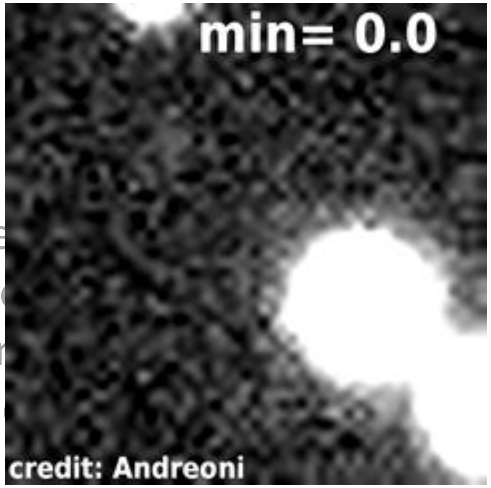
Thornton et al. (2013)

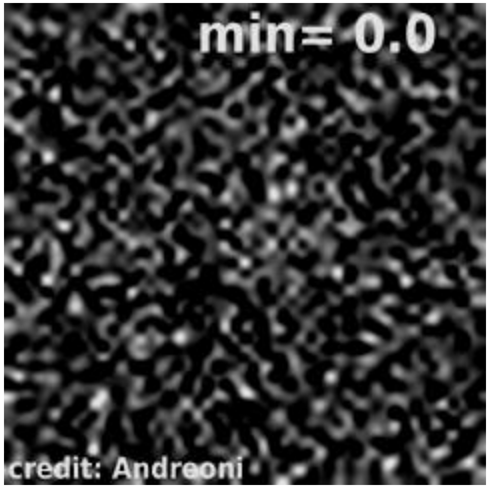
fast and unknown

Fast transients

Search all wavelengths

- Some only in one wavelength re
  wavelengths, and may evolv
- Some emit at unknown wavelen
- Some include high-energy parti



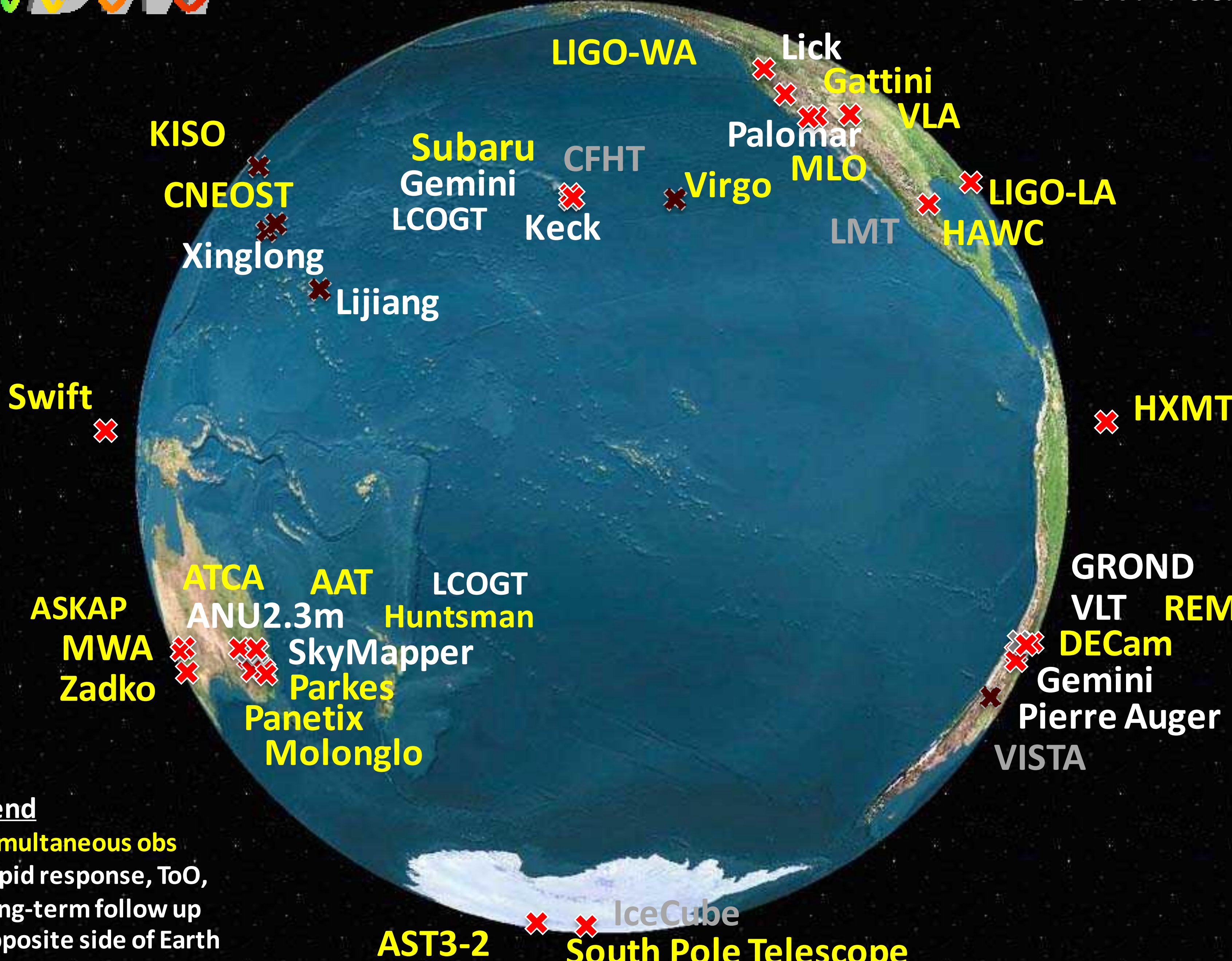


Need to act fast to catch and identify them

- Deep, wide-field simultaneous coverage–*also for coherent bursts*
- Fast exposures to sample event evolution
- Real-time data processing and analysis, *fast event identification* to trigger follow up before they fade
- Deep rapid-response spectroscopy and imaging
- Later-time follow up, as some fast transients are associated with slower durations events *(e.g., SBO, SN Ia companion bursts)*

All this needs to be done in minutes *(or faster)* from the moment the light hits the telescopes

DWF-Pacific



Legend

- simultaneous obs
- rapid response, ToO, long-term follow up
- opposite side of Earth

DWF-Atlantic

What is needed *(DWF)*

(1) Coordinated simultaneous detection

Deep (m ~ 24-27), wide-field, fast-cadenced observations,
~20 of the world's best telescopes. All λs + particles (+ GWs)

(2) Real-time data processing and identification

Fast data transfer, supercomputer processing *(in seconds)*
Software + human identification & confirmation (in minutes)

(3) Rapid-response and conventional ToOs

Deep, multi-wavelength RRM and ToO spectroscopy and imaging
~10 space-based and 1-10m class ground-based telescopes

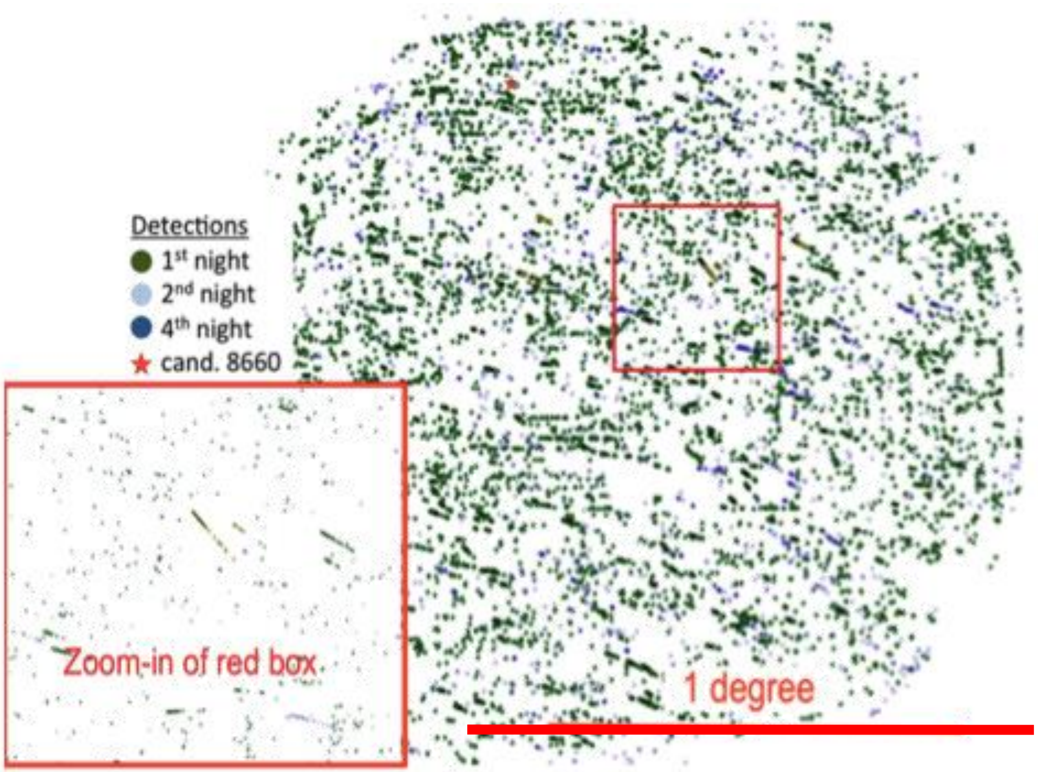
(4) Longer-term cadenced observations

Network of ~30 follow-up telescopes (1-4m class)
Important for confirmation, classification, host galaxies, etc.

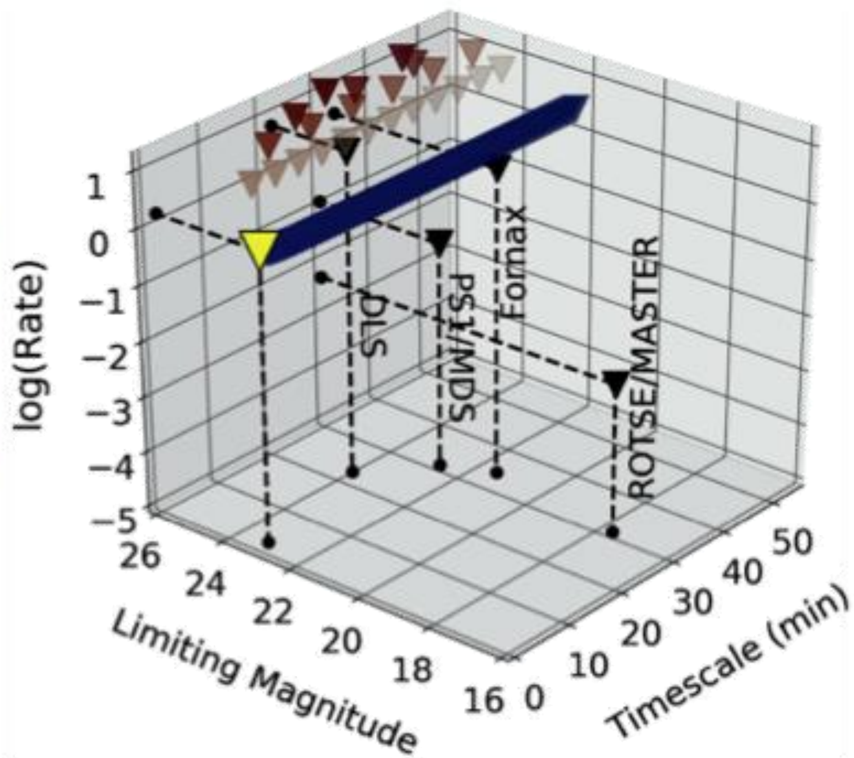
From 2014, DWF was designed as a model for the future

In 2017, GW170817 promoted MMA. Encouragingly, other groups have been pursuing multiple wavelength coordinated searches

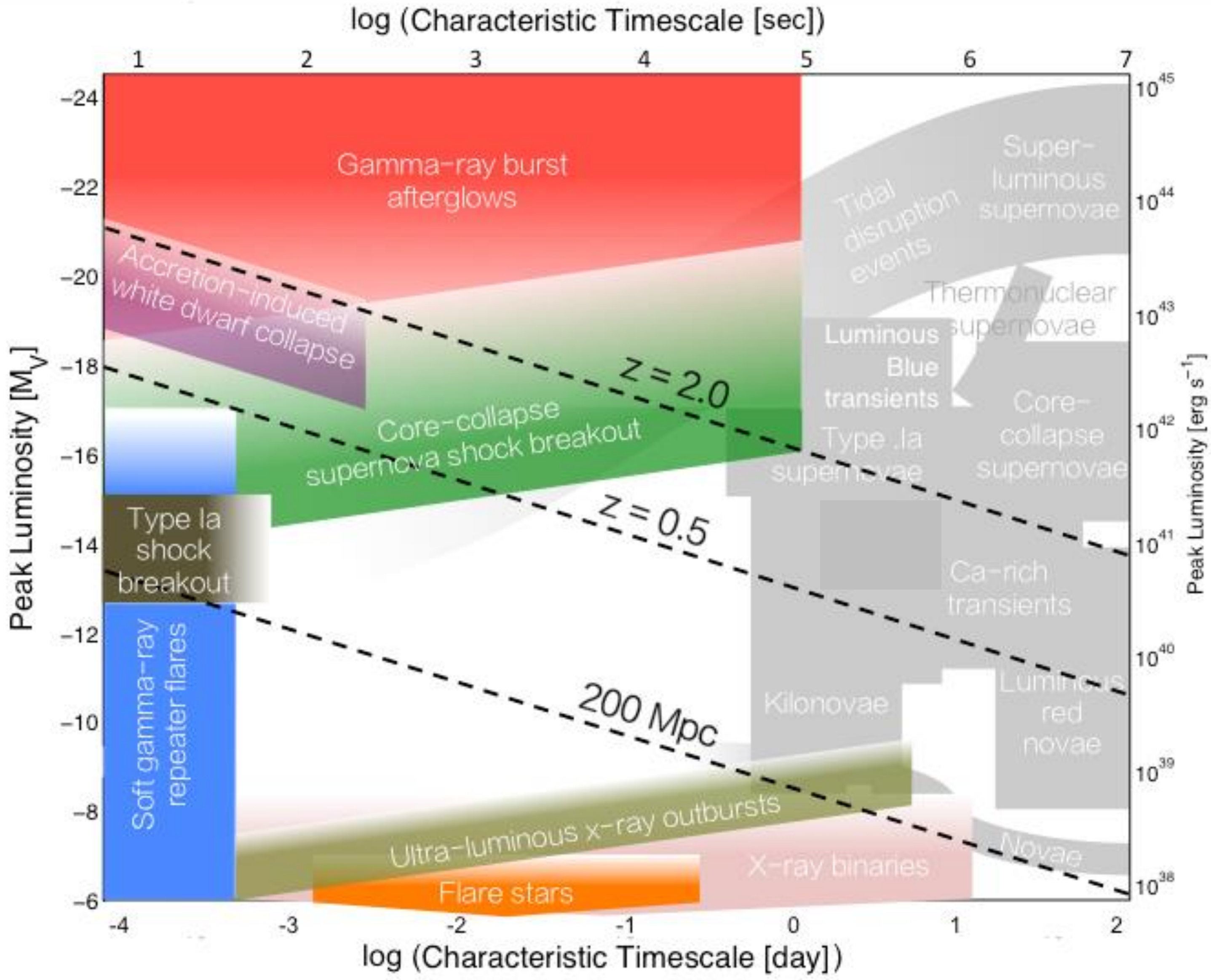
Hundreds of detections



New parameter space



fast and unknown



Subaru has contributed greatly to time domain astronomy

- Continue to progress excellent SN work *(Ia and core-collapse)*
- Capitalize on the unique 8m-aperture and wide-field of HSC to understand the physics and observable features of SLSNe
  - Lead the world in exploring SLSNe as a tool to understand the early Universe and regimes beyond the reach of galaxies
  - Discover the first PISN and the first Pop III star deaths
  - Subaru detections enable the full utility of SLSNe with 30m and JWST
- Progress GW follow up work and use the power of Subaru to detect distant and faint BNS and discover the first NS-BH counterparts
  - Also perform well-cadenced galaxy and other deep surveys to discover z ~ 1 kilonovae *(beyond LIGO/Virgo horizon)* to understand the population
- Continue to progress neutrino EM counterpart searches
- Push into the relatively unexplored fast transient time domain
  - The sensitivity of Subaru enables deep, wide-field fast exposures
  - Multi-wavelength program coordination can uncover the nature of FRBs for the first time, the physics of fast transients, and unknown phenomena