Rapid Robotic Followup of Transients

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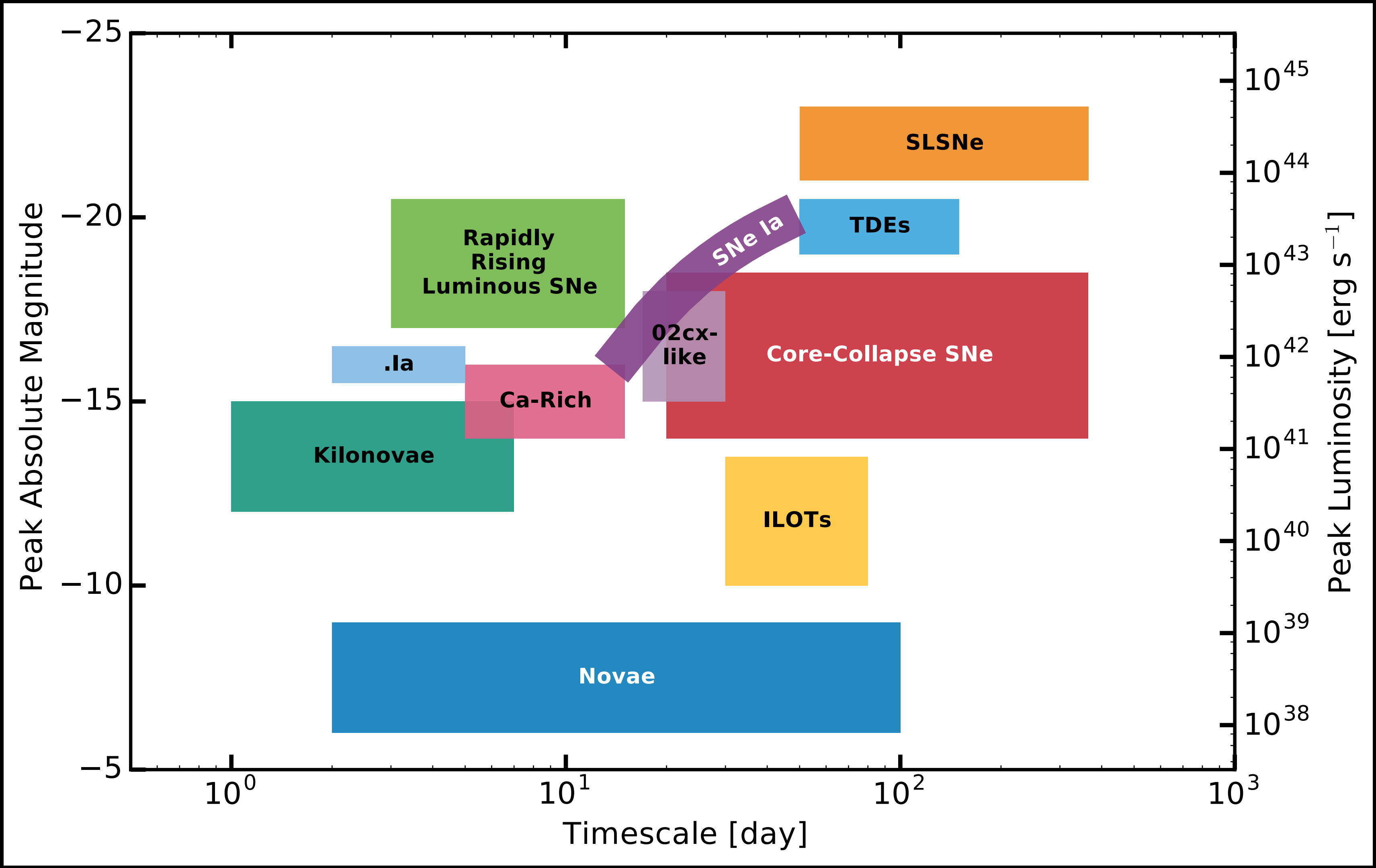
Tel Aviv University

Surveys of the Transient Sky are Flourishing

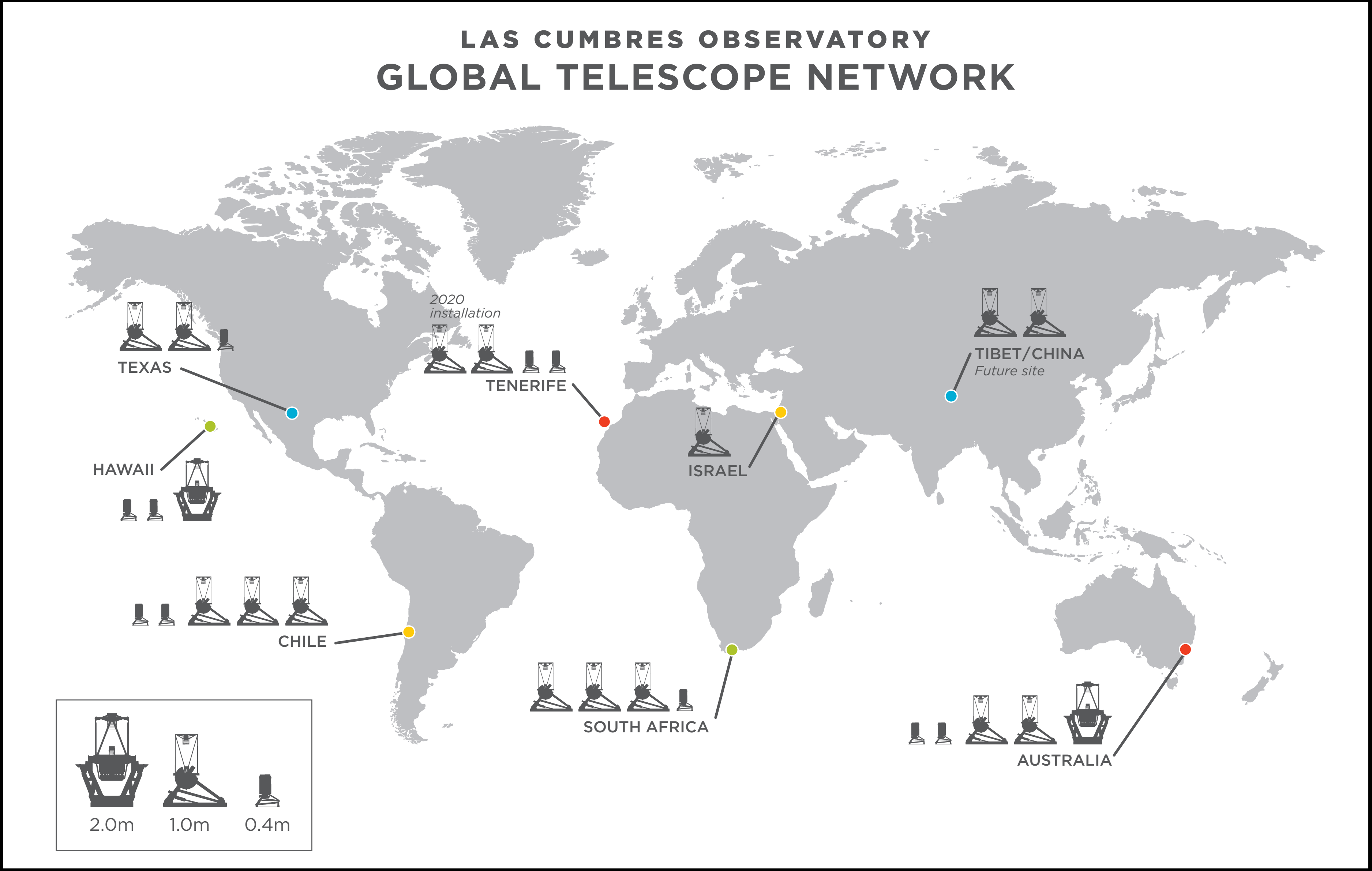
All-Sky Automated Search for Supernovae (ASAS-SN)
Catalina Sky Survey (CSS)
Catalina Real-Time Transient Survey (CRTS)
Dark Energy Survey (DES)
Evryscope
Gaia
Zwicky Transient Facility (ZTF)
Kepler-2 (K2)
Kilodegree Extremely Little Telescopes (KELT)
La Silla Quest
Optical Gravitation Lensing Experiment (OGLE)
Panoramic Survey Telescope and Rapid Response System (Pan-STARRS)
SkyMapper Southern Sky Survey

(partial list, more being planned and built)

The Phase Space of Transients is Being Filled



Las Cumbres: A Network of Robotic Telescopes



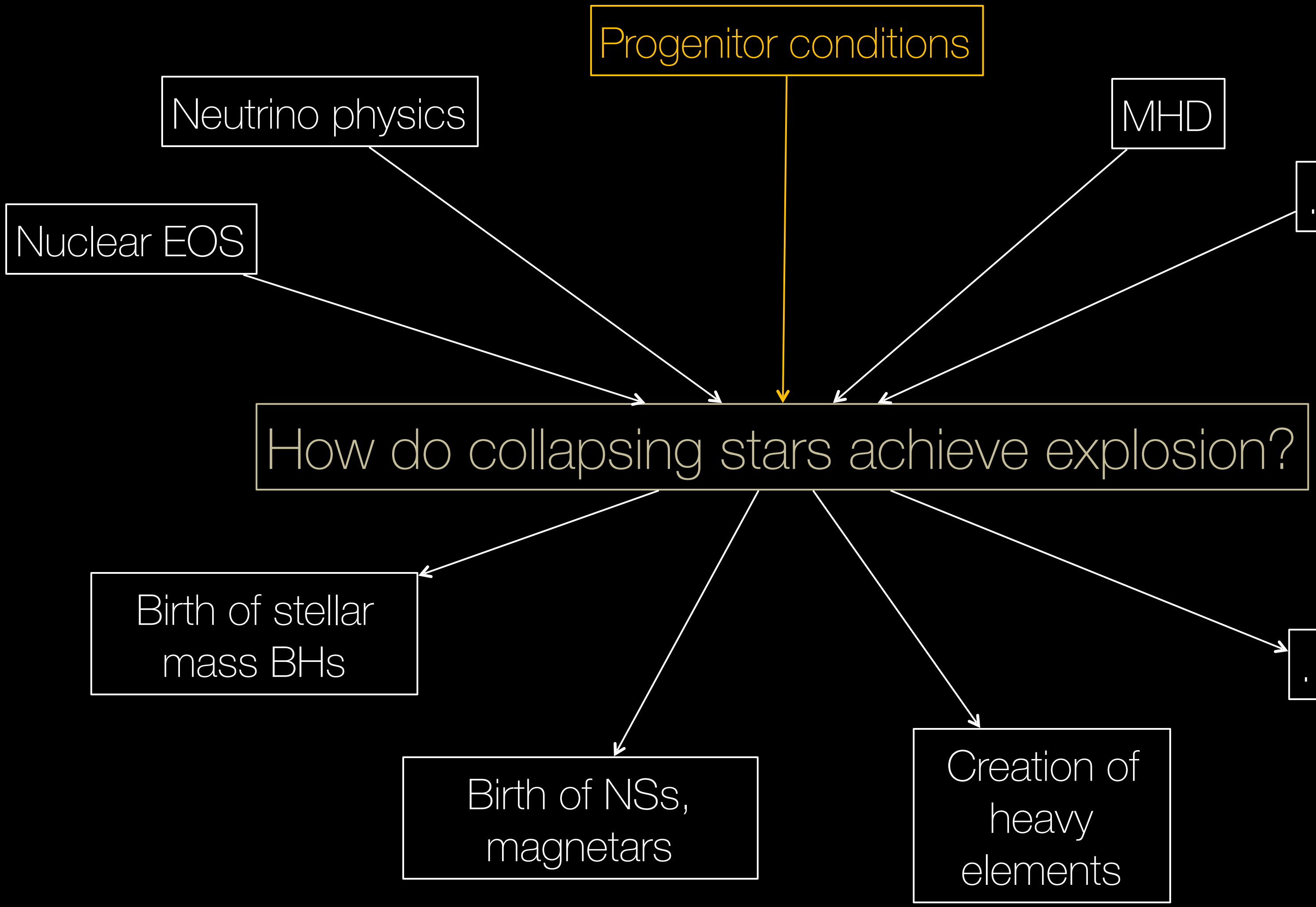
Las Cumbres: A Network of Robotic Telescopes

All telescopes are scheduled automatically every 15 minutes

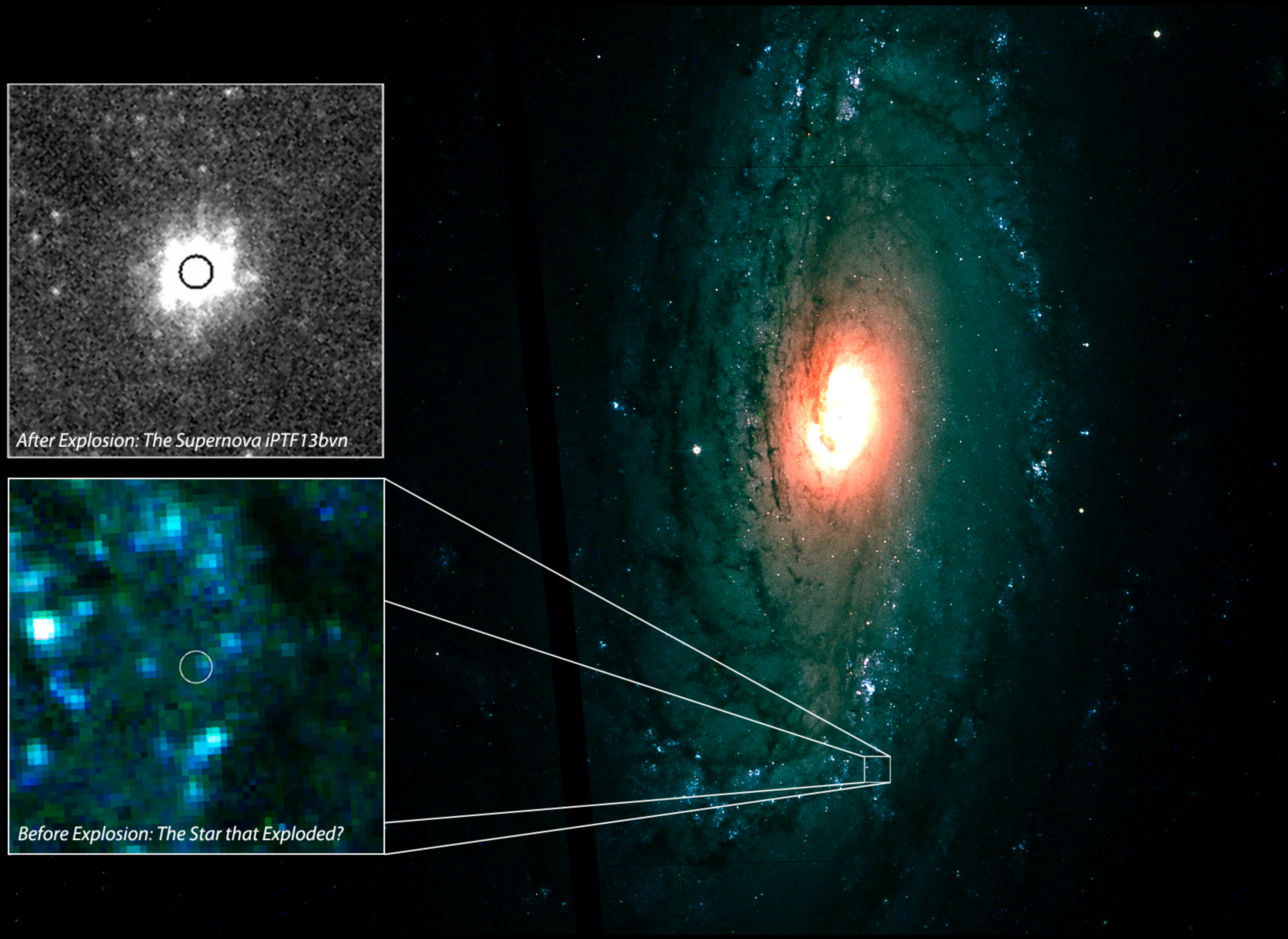
What is Robotic Followup Good For?

I: Supernova First Light

We Don't Understand Massive Stars & Their SNe



Rarely, We Can See the Star Before it Exploded



Cao, Kasliwal, Arcavi et al. 2013

Rarely, We Can See the Star Before it Exploded

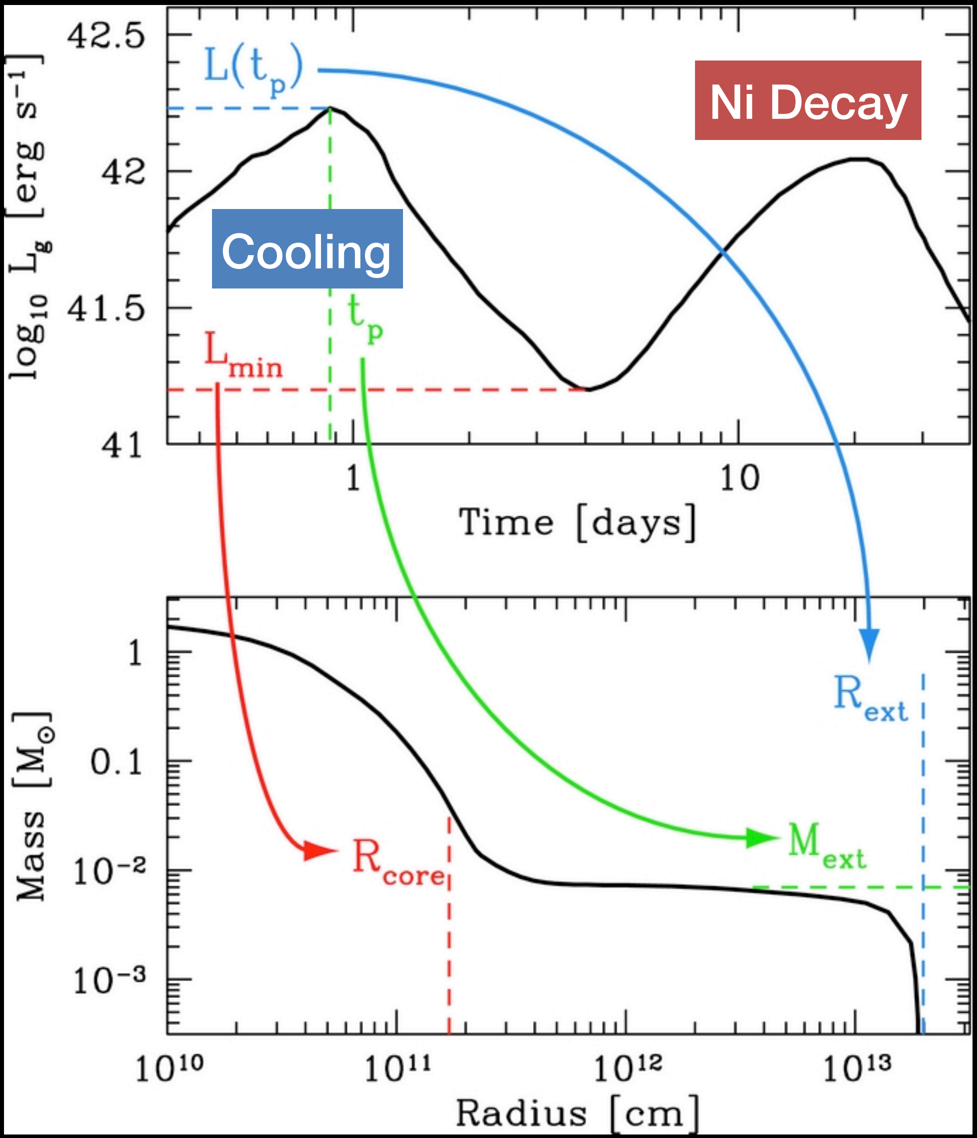
So far <20 direct progenitor detections, most for the same supernova type

Early-time supernova observations can measure the **radius**, **composition** and **mass loss history** for **hundreds** of pre-explosion massive stars

Cooling Reveals the Progenitor Structure

Measure Early Light Curve

Infer Inner Structure of Progenitor Star Right Before Explosion



Nakar & Piro 2014

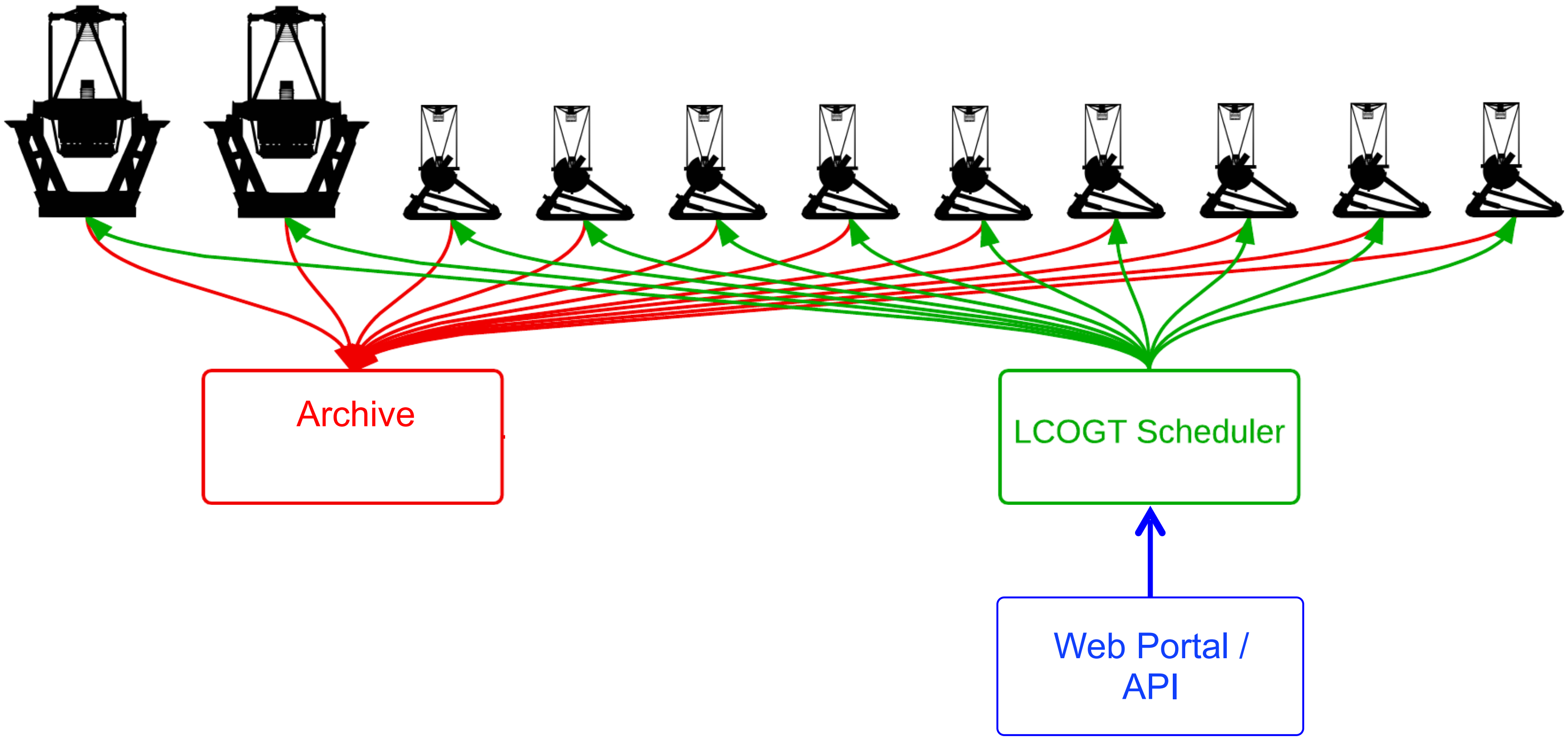
Observing the first SN photons is challenging

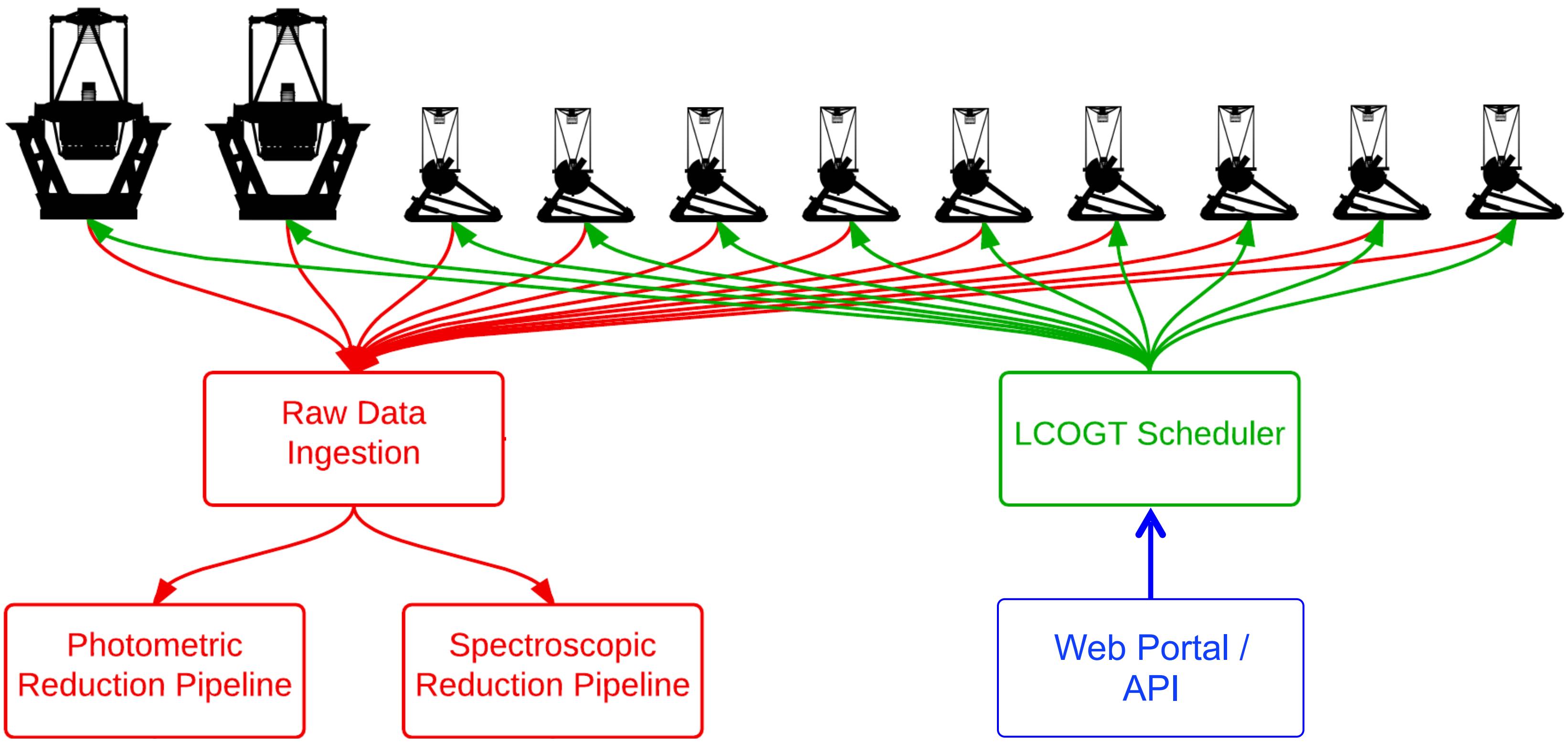
Need to find **supernovae** within hours of the explosion

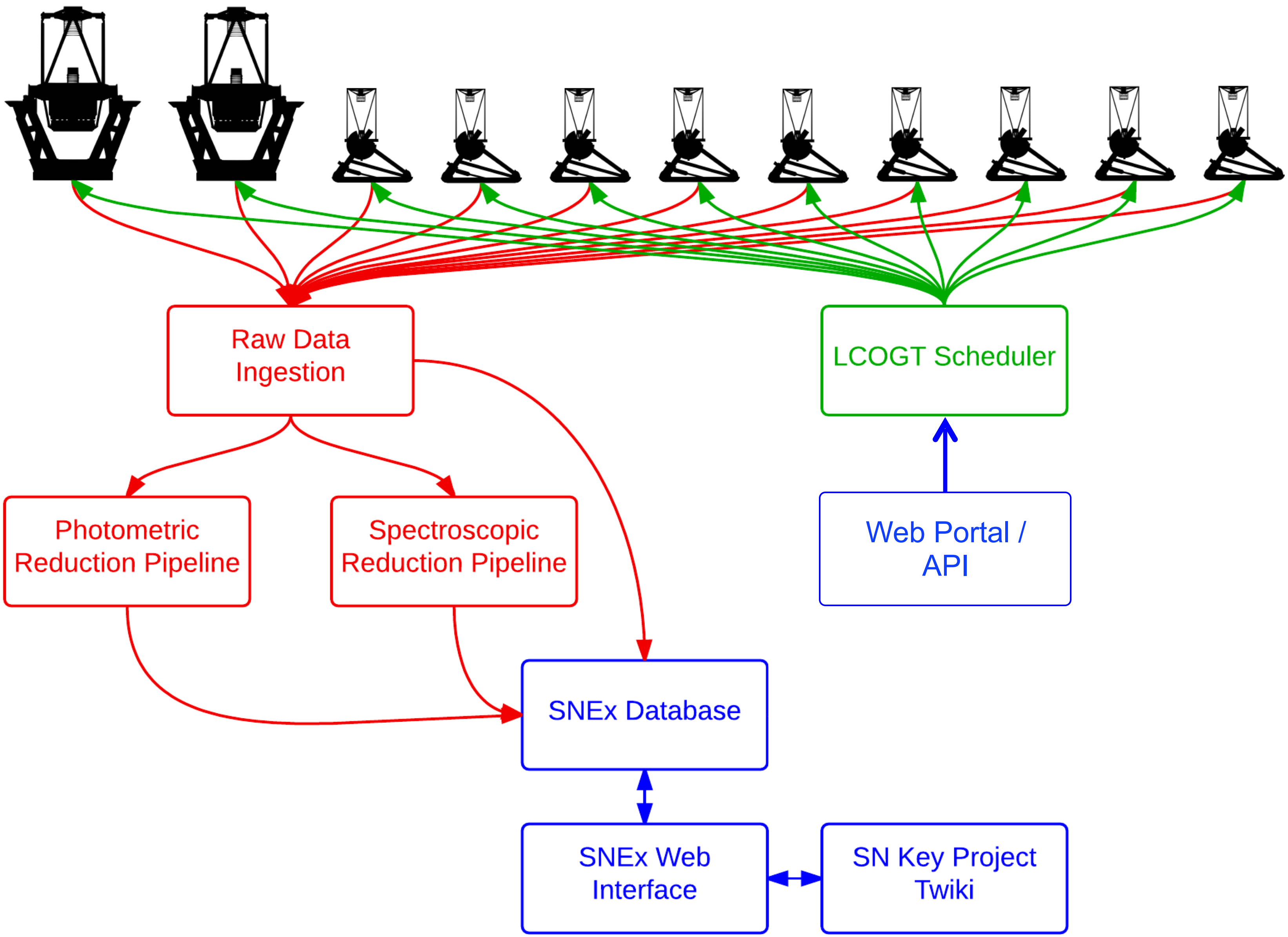
Need to **identify** them in real-time

Need to **trigger** multi-wavelength followup observations immediately

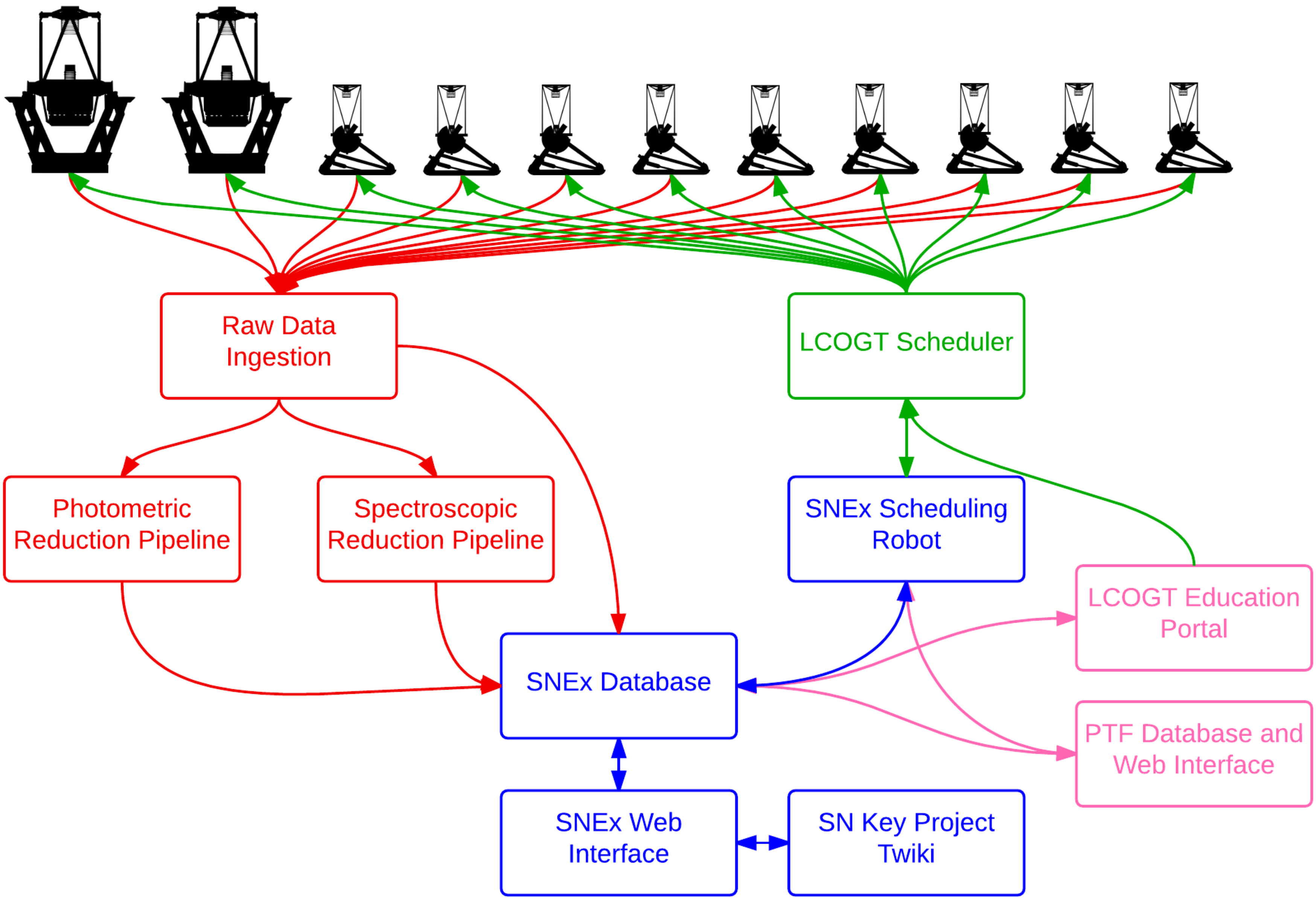
Need to obtain observations **continuously** for the first hours-days after discovery

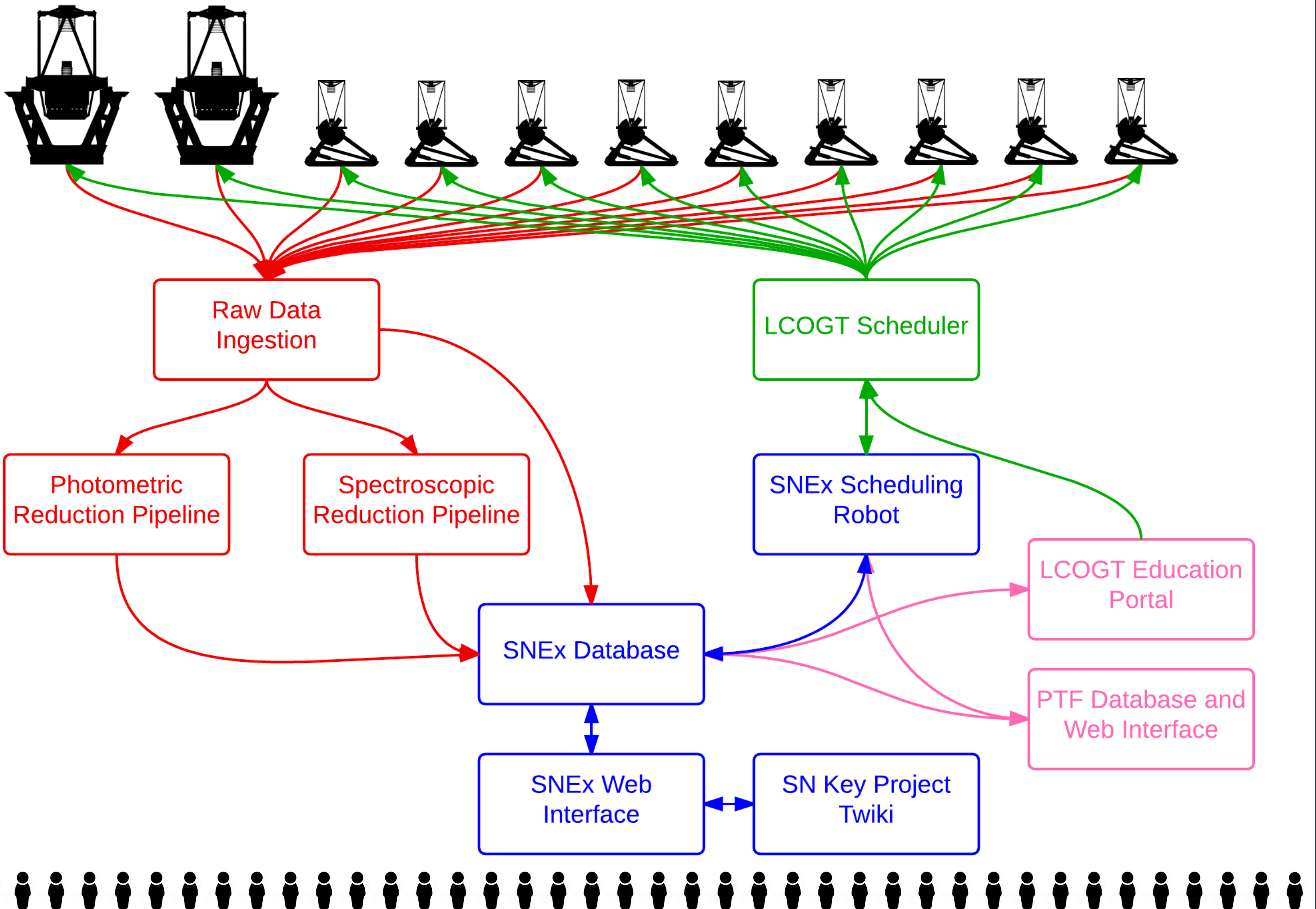

Archive
LCOGT Scheduler
Web Portal /
API


Raw Data Ingestion
LCOGT Scheduler
Photometric Reduction Pipeline
Spectroscopic Reduction Pipeline
Web Portal / API



Raw Data Ingestion
LCOGT Scheduler
Photometric Reduction Pipeline
Spectroscopic Reduction Pipeline
Web Portal / API
SNEx Database
SNEx Web Interface
SN Key Project Twiki


Raw Data Ingestion
LCOGT Scheduler
Photometric Reduction Pipeline
Spectroscopic Reduction Pipeline
SNEx Scheduling Robot
LCOGT Education Portal
SNEx Database
PTF Database and Web Interface
SNEx Web Interface
SN Key Project Twiki



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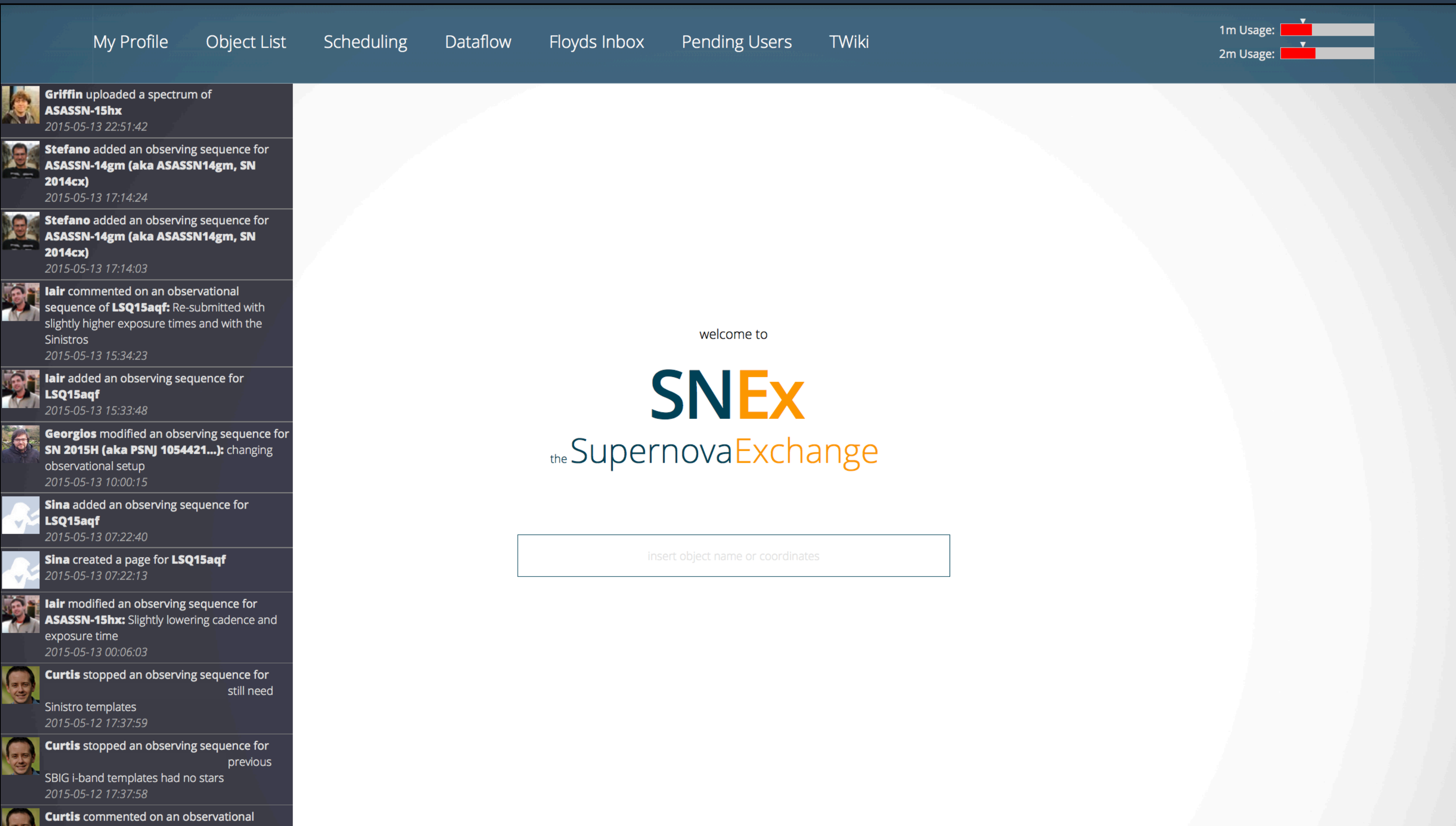


My Profile
Object List
Scheduling
Dataflow
Floyds Inbox
Pending Users
TWiki
1m Usage:
2m Usage:
Griffin uploaded a spectrum of ASASSN-15hx
2015-05-13 22:51:42
Stefano added an observing sequence for ASASSN-14gm (aka ASASSN14gm, SN 2014cx)
2015-05-13 17:14:24
Stefano added an observing sequence for ASASSN-14gm (aka ASASSN14gm, SN 2014cx)
2015-05-13 17:14:03
Iair commented on an observational sequence of LSQ15aqf: Re-submitted with slightly higher exposure times and with the Sinistros
2015-05-13 15:34:23
Iair added an observing sequence for LSQ15aqf
2015-05-13 15:33:48
Georgios modified an observing sequence for SN 2015H (aka PSNJ 1054421...): changing observational setup
2015-05-13 10:00:15
Sina added an observing sequence for LSQ15aqf
2015-05-13 07:22:40
Sina created a page for LSQ15aqf
2015-05-13 07:22:13
Iair modified an observing sequence for ASASSN-15hx: Slightly lowering cadence and exposure time
2015-05-13 00:06:03
Curtis stopped an observing sequence for
still need
Sinistro templates
2015-05-12 17:37:59
Curtis stopped an observing sequence for
previous
SBIG i-band templates had no stars
2015-05-12 17:37:58
Curtis commented on an observational
welcome to
SNEx
the Supernova Exchange
insert object name or coordinates

PS15sv SN Ia 91T-like z = 0.038

16:13:11.74 +01:35:31.1
243.298917 +1.591972

Known as:
PS15sv

Known to:
ANU
ASASSN
Boulder
CfA
Chase
China
CSP
ex-LCOGT
iPTF
KMTNet
LBNL
LCOGT
LSQ
OKC
Padova
PESSTO
PS1
PTF
Public
QUB
SAAO
SDSU
Skymapper
UCB
UT
Grant to all sharing groups

Interested Persons:

I'm interested in this object

Science Interests:
Peculiar SNe Ia

Object Comments

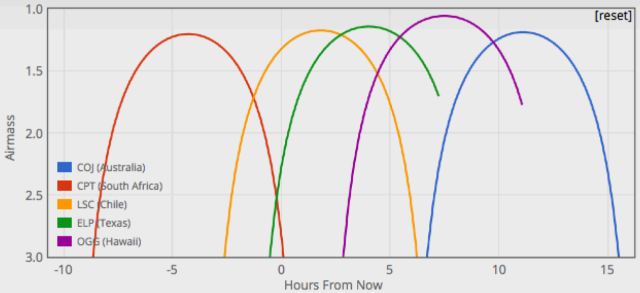
Andy 91T-like at -6d according to PESSTO
2015-03-29 03:02:15

Griffin pointing is off on 2015-04-15, but object is still visible
2015-04-17 17:55:11

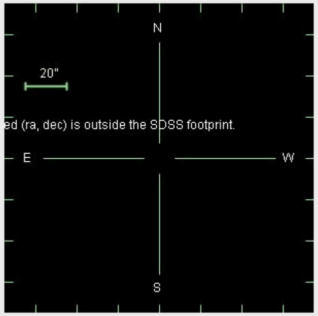
Curtis Should increase exposure times next week.
2015-05-08 01:00:57

Add a comment...

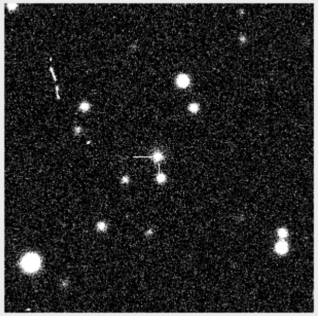
Current Visibility at LCOGT



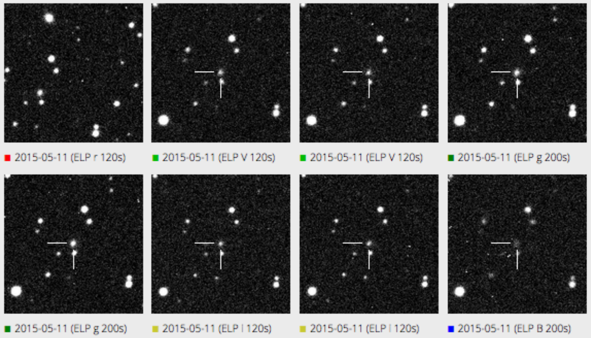
SDSS



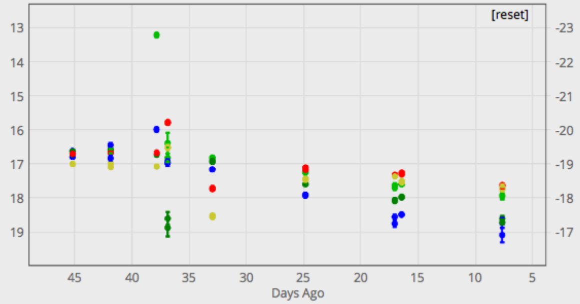
Latest LCOGT Images



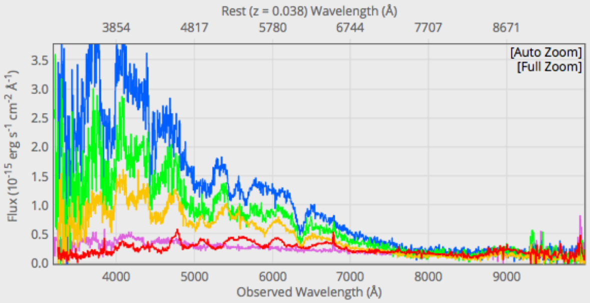
2015-05-11 (ELP r 120s)



Calibrated Photometry Display instrumental photometry



Spectroscopy (binned)



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QUB
SAAO
SDSU
Skymapper
UCB
UT
Grant to all sharing groups

Interested Persons:

I'm interested in this object

Science Interests:
Peculiar SNe Ia

Submitted Sequences

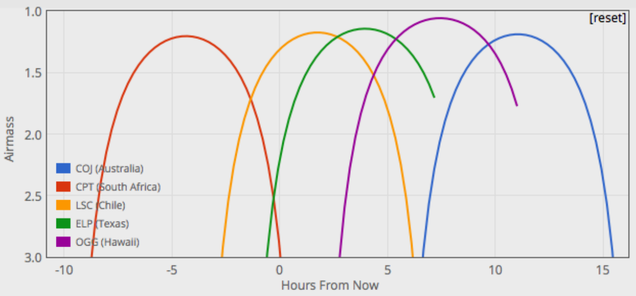
Active Photometry: 3-day cadence observations of B (2x200s), V (2x120s), g (2x200s), r (2x120s), i (2x120s) starting 2015-03-29 using Sbig (Tags: Peculiar SNe Ia), requested by Andy Howell
Track this sequence
Stop this sequence

Inactive Spectroscopy: Single observation of 2700s starting 2015-03-29, ending 2015-03-31, using Floyds (Tags: Peculiar SNe Ia), requested by Andy Howell
Track this sequence

Inactive Spectroscopy: 3-day cadence observations of 2700s starting 2015-04-03, ending 2015-04-12, using Floyds (Tags: Peculiar SNe Ia), requested by Curtis McCully
Iair: Object is getting fainter and there aren't any obvious spectral differences at this signal to noise every 3 days. Increasing exp time and lowering cadence.
Track this sequence

Active Spectroscopy: 7-day cadence observations of 3600s starting 2015-04-12 using Floyds (Tags: Peculiar SNe Ia), requested by Iair Arcavi
Track this sequence
Stop this sequence

Current Visibility at LCOGT



Add a Photometric Sequence

	Exposure Time	No. of Exposures	Block No.
U	0	2	1
B	200	2	1
V	120	2	1
R	0	2	1
I	0	2	1
u	0	2	1
g	200	2	1
r	120	2	1
i	120	2	1
z	0	2	1

Repeating every 3 days

Airmass Limit 2
Camera SBIG (1m)
Program SN Key Project
Priority Normal
Reminder in 7 days

Data granted to
☑ ANU ☑ KMTNet ☐ Public
☐ ASASSN ☑ LBNL ☑ QUB
☑ Boulder ☑ LCOGT ☑ SAAO
☐ CfA ☑ LSQ ☐ SDSU
☐ Chase ☐ OKC ☑ Skymapper
☑ China ☑ Padova ☐ UCB
☑ CSP ☑ PESSTO ☑ UT
☑ ex-LCOGT ☐ PS1
☐ iPTF ☐ PTF
☐ Grant to all sharing groups

☑ **Pre-approved / urgent observations**

Science Tags
No tags selected +

Comments

Submit

Add a Spectroscopic Sequence

Once in the next 1 days

Exposure Time 1800
Airmass limit 2
Site Any
Slit Best
Program SN Key Project
Priority Normal
Reminder in 1 days

Science Tags
No tags selected +

Data granted to
☑ ANU ☑ KMTNet ☐ Public
☐ ASASSN ☑ LBNL ☑ QUB
☑ Boulder ☑ LCOGT ☑ SAAO
☐ CfA ☑ LSQ ☐ SDSU
☐ Chase ☐ OKC ☑ Skymapper
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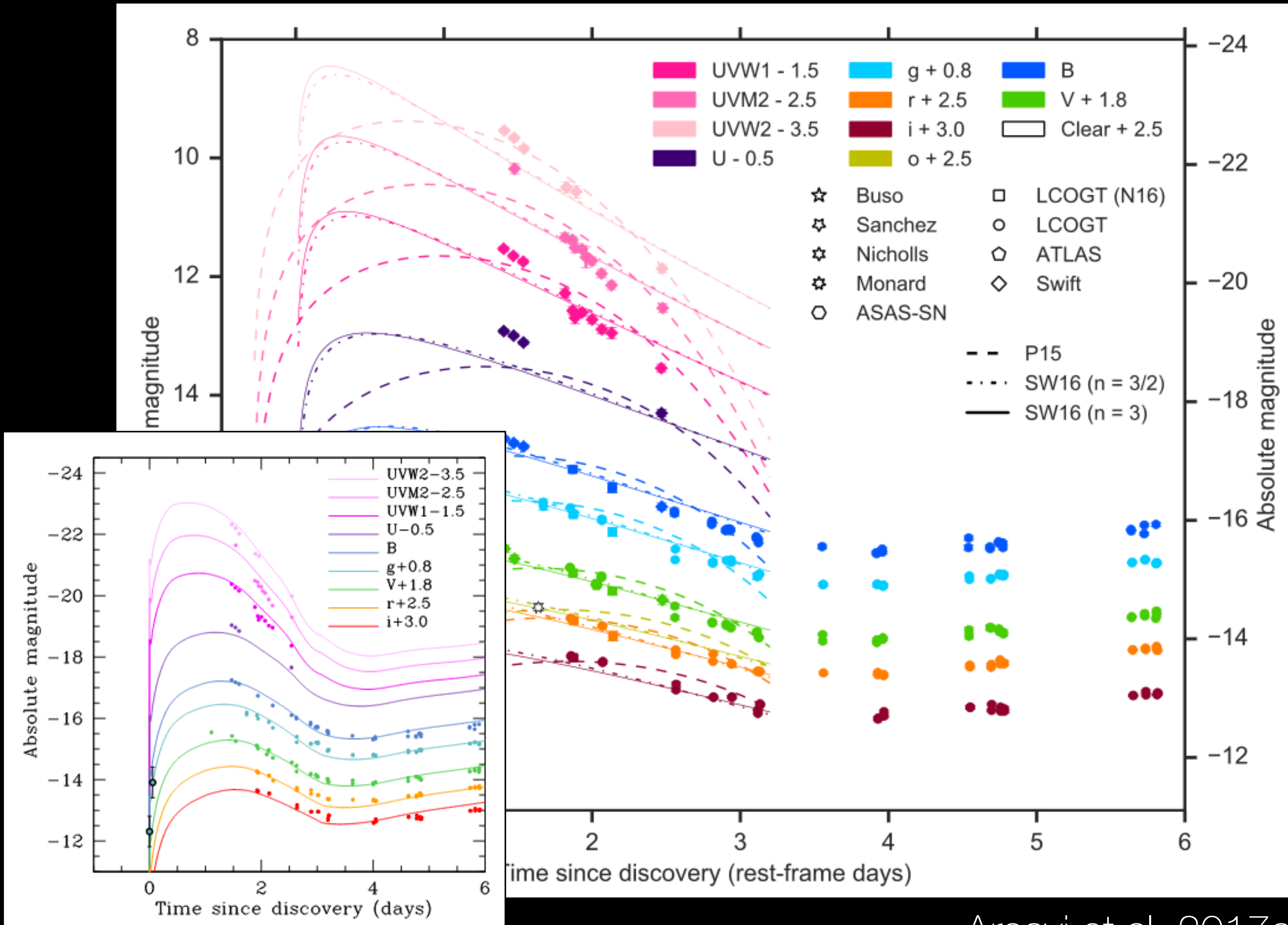
☑ CSP ☑ PESSTO ☑ UT
☑ ex-LCOGT ☐ PS1
☐ iPTF ☐ PTF
☐ Grant to all sharing groups

☑ **Pre-approved / urgent observations**

Comments

Submit

Unprecedented Coverage of Cooling Emission



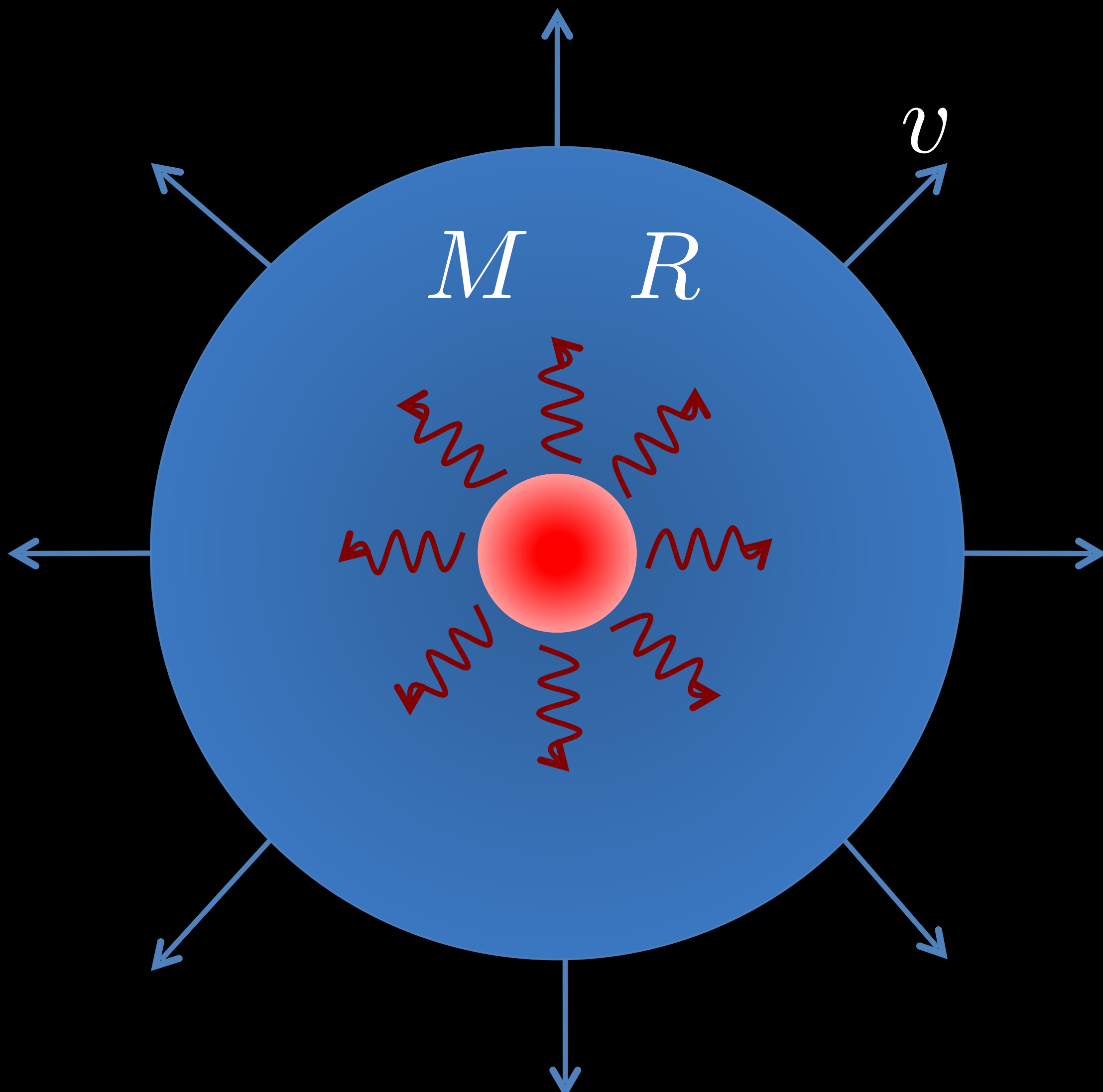
Piro, Muhleisen, Arcavi et al. 2017

Arcavi et al. 2017a

What is Robotic Followup Good For?

II: Rapidly Evolving Events

Rise Time ~> Mass Ejected in Explosion



$$\tau_{\mathrm{diff}} \sim \frac{N\lambda}{c} \sim \frac{R^2}{\lambda c} \sim \frac{\kappa M}{Rc}$$

$$R = vt$$

$$\tau_{\mathrm{diff}} \sim \frac{\kappa M}{vtc}$$

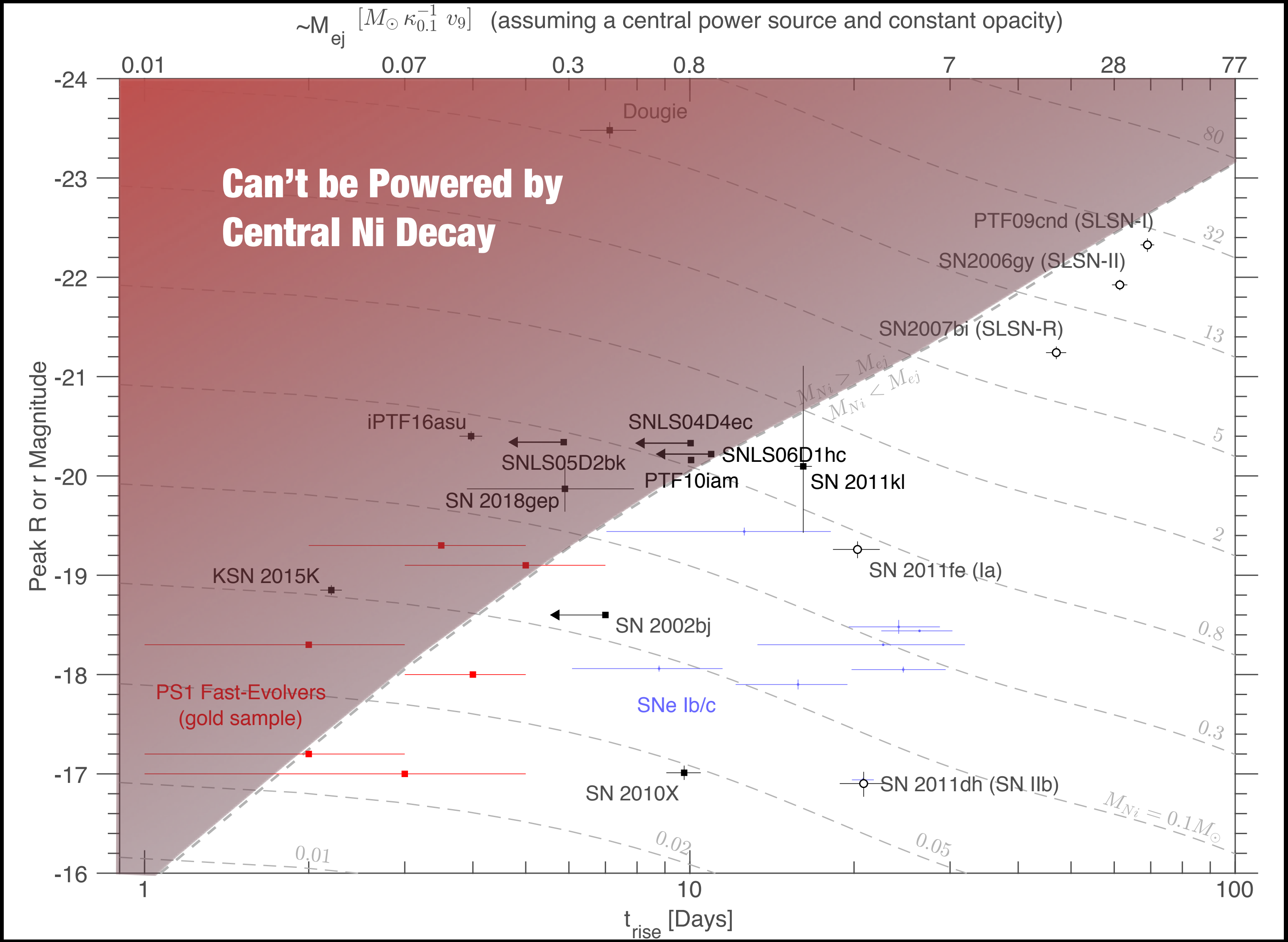
$$t = \tau_{\mathrm{diff}}$$

$$t \sim \sqrt{\frac{\kappa M}{vc}}$$

time to peak luminosity

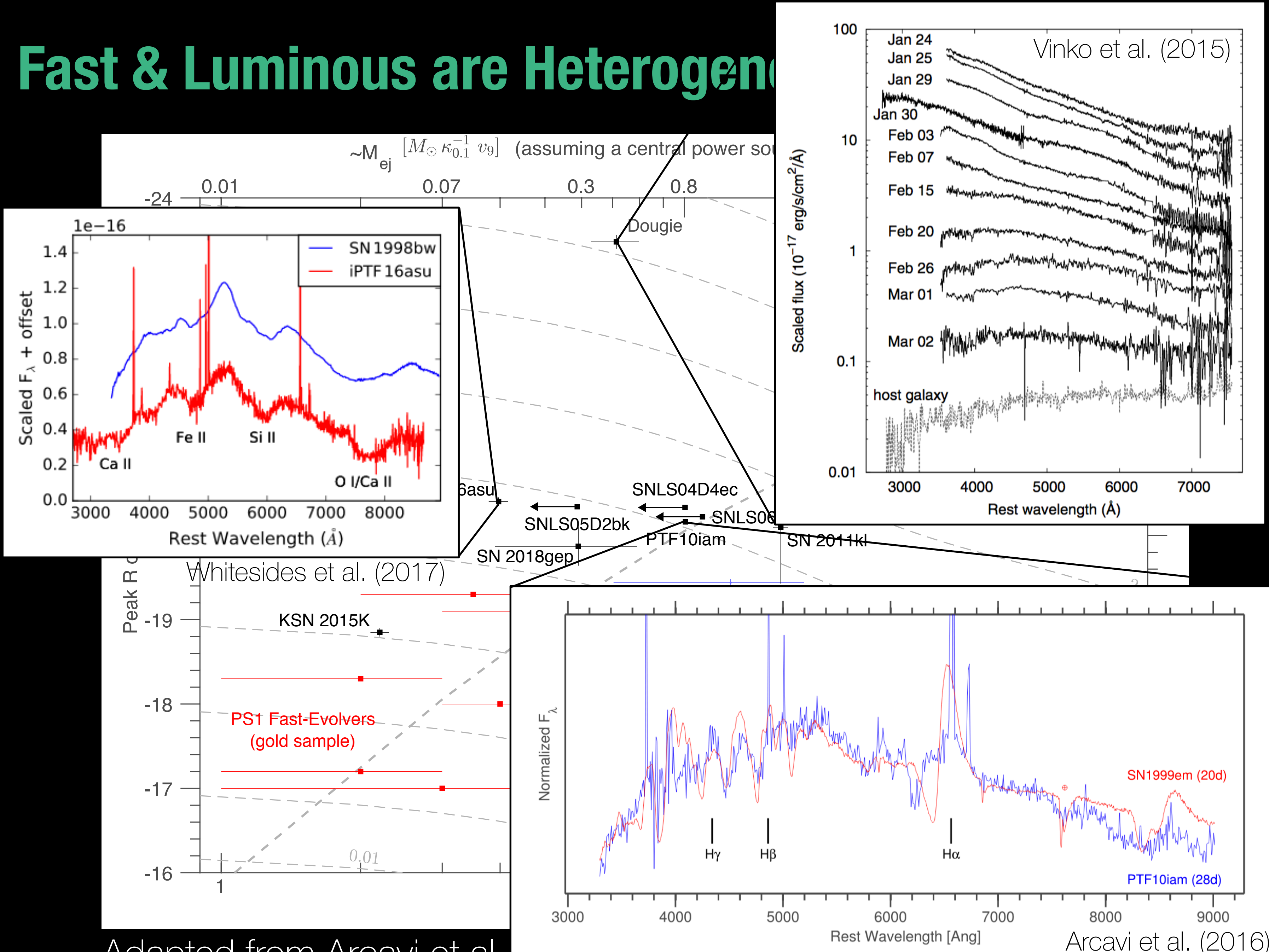
Fast & Luminous Can't be Ni-Powered

$$t_{\mathrm{peak}} \approx \sqrt{\frac{\kappa M}{vc}}$$



Adapted from Arcavi et al. (2016)

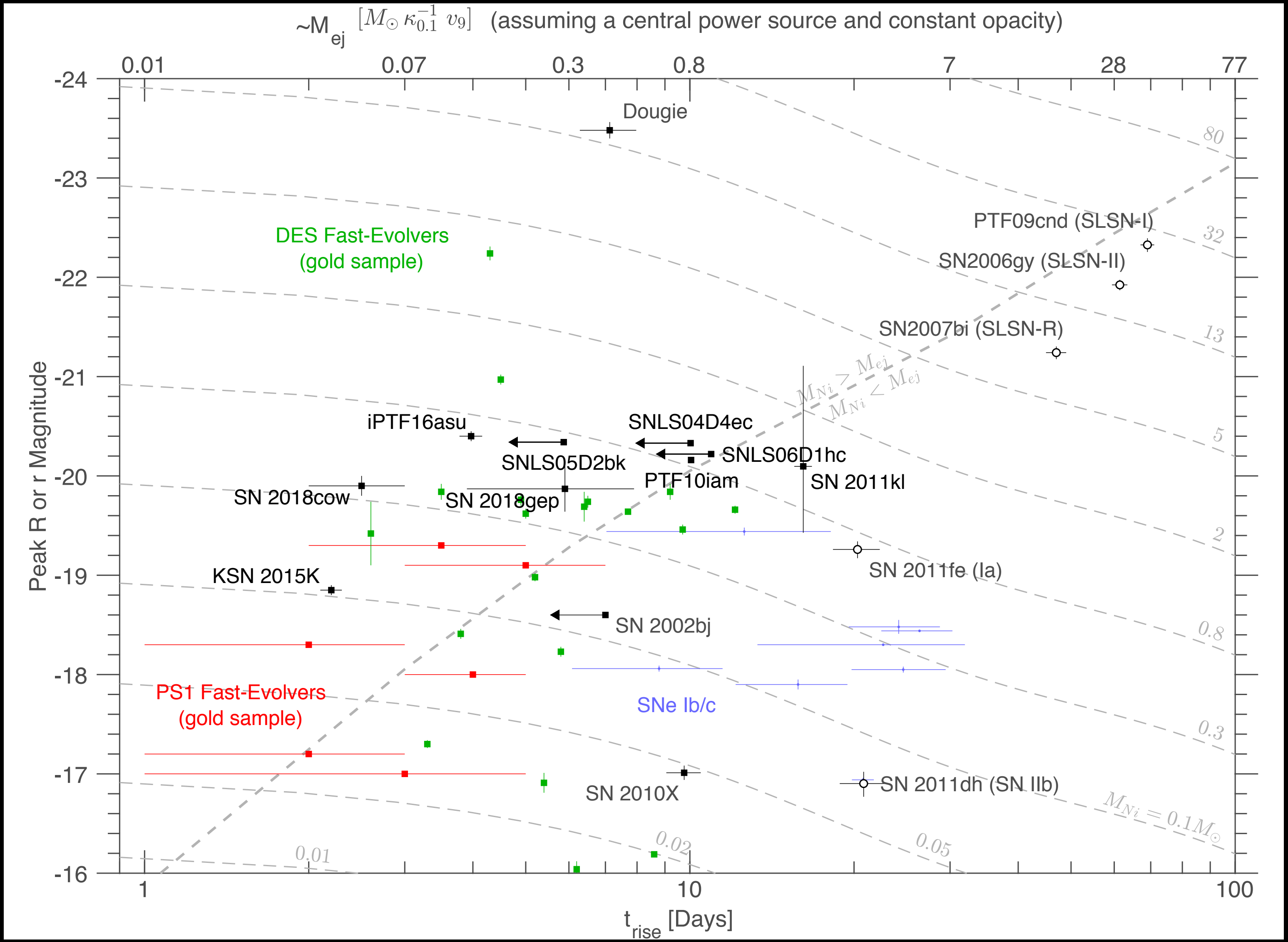
Fast & Luminous are Heterogene



Adapted from Arcavi et al.

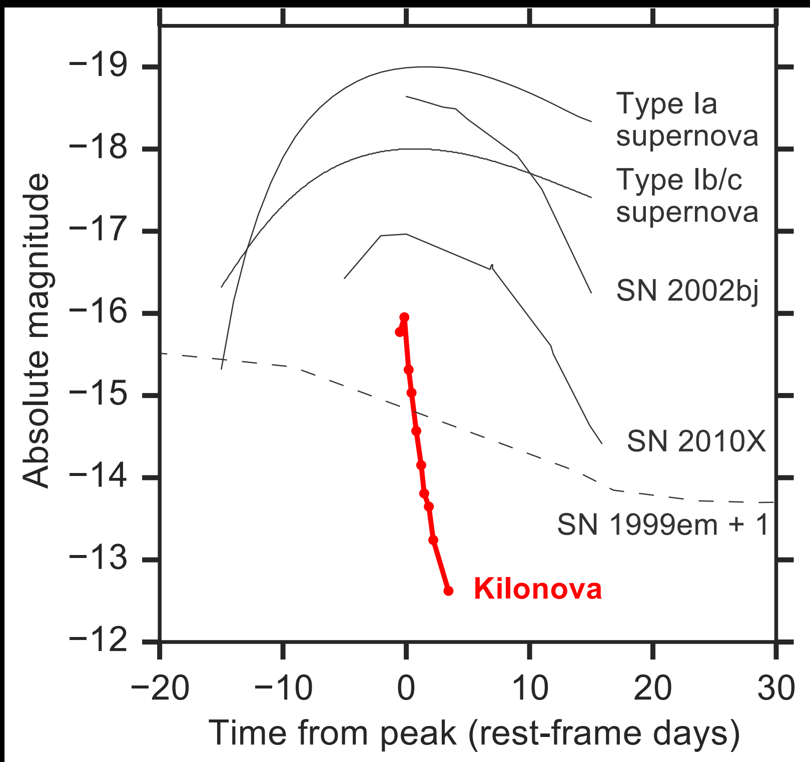
Luminous Rapidly Evolving Events

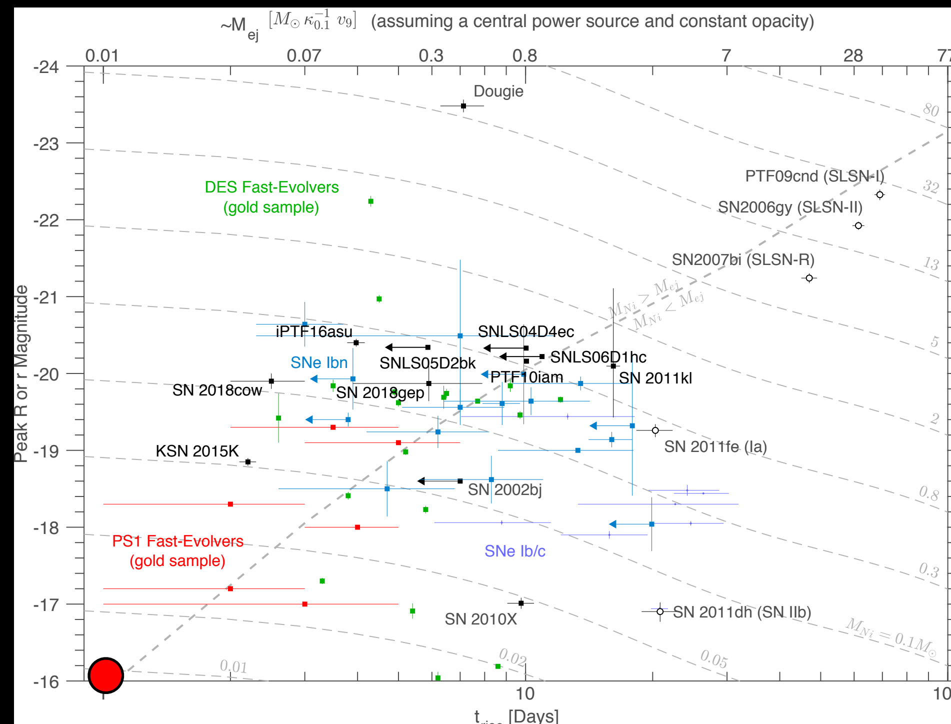
$$t_{\text{peak}} \approx \sqrt{\frac{\kappa M}{vc}}$$



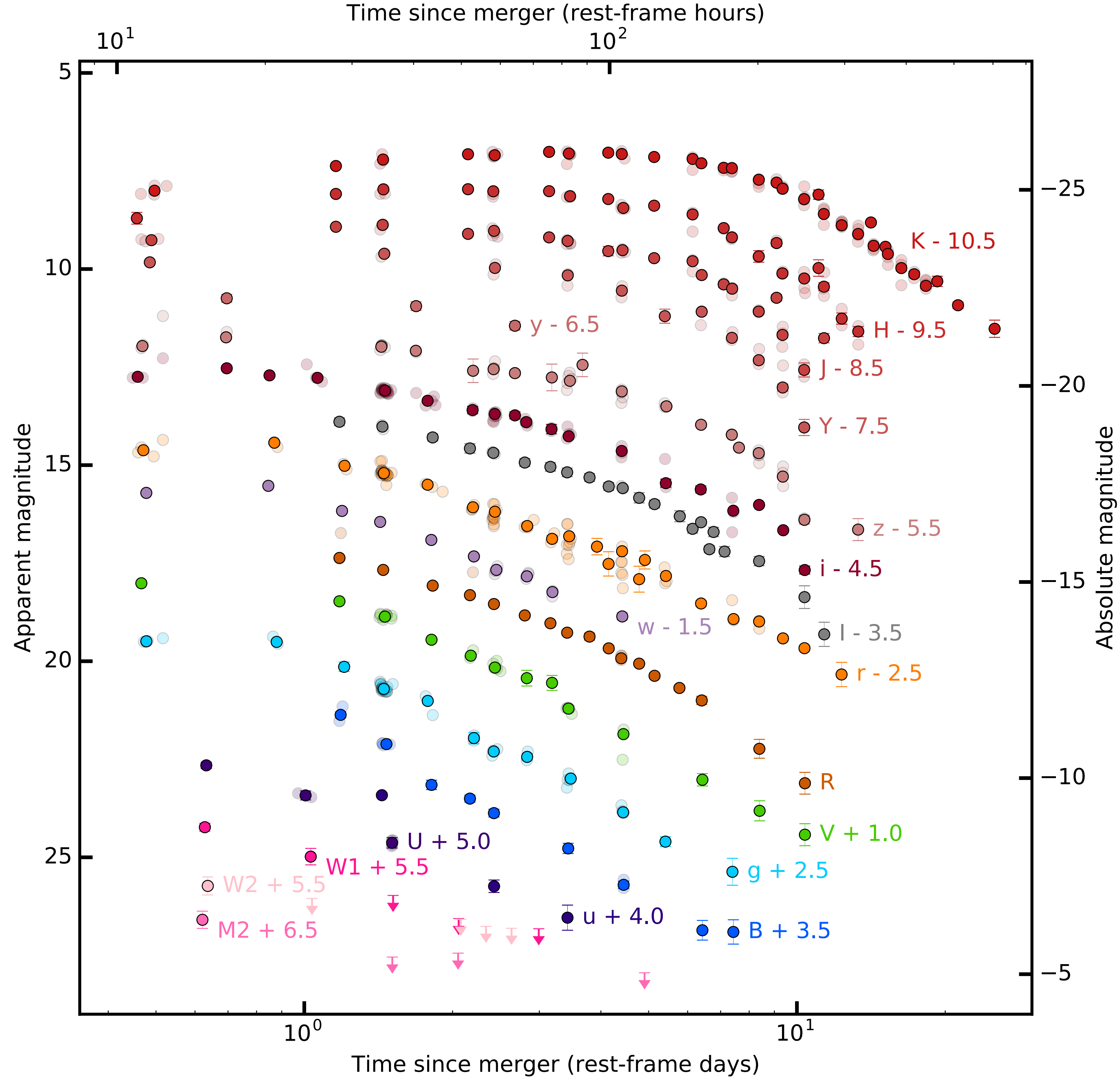
Adapted from Arcavi et al. (2016)

Fastest ‘Bright’ Transient: The GW170817 Kilonova





Arcavi et al. 2017

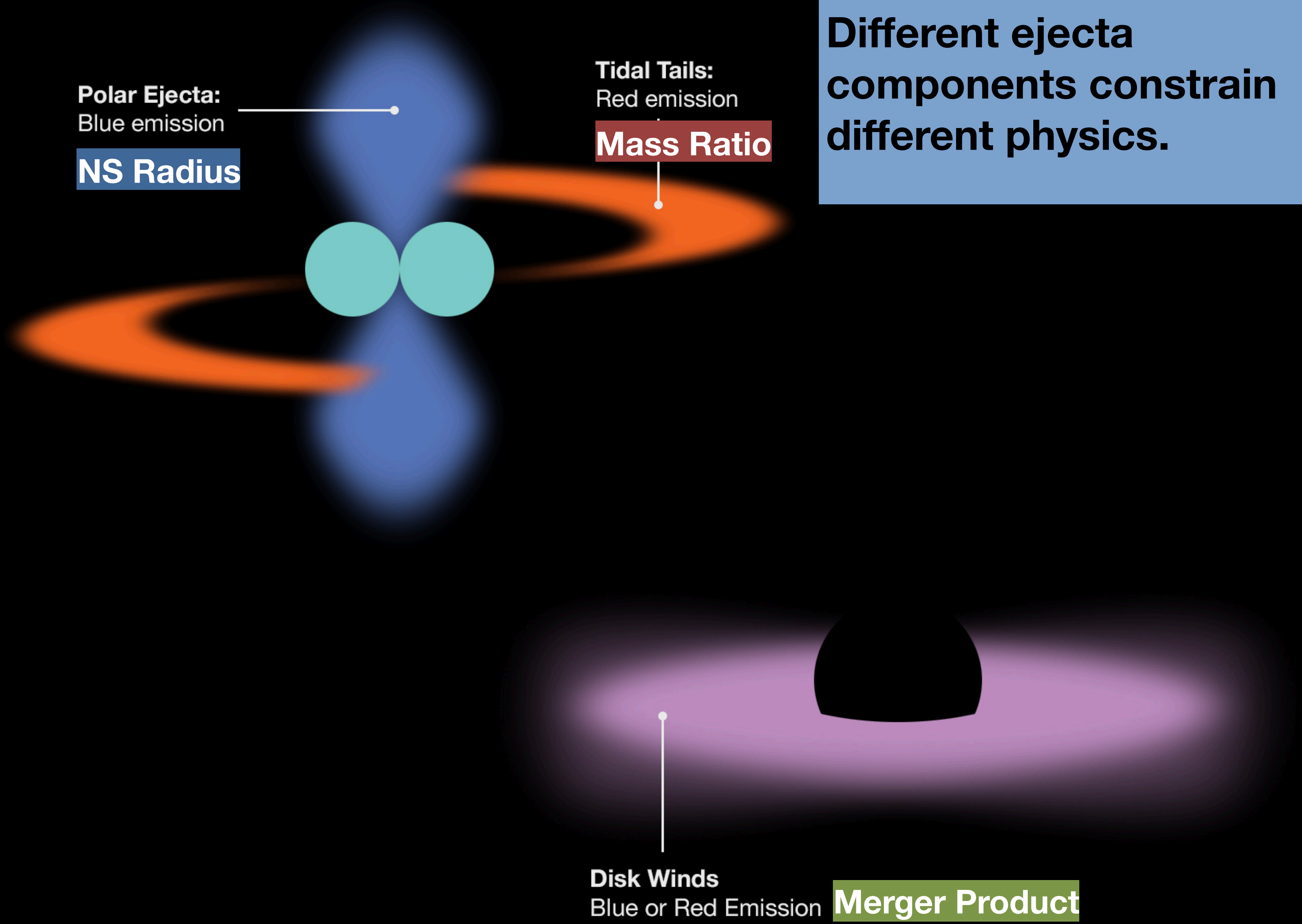


Compilation from:
Arcavi 2018

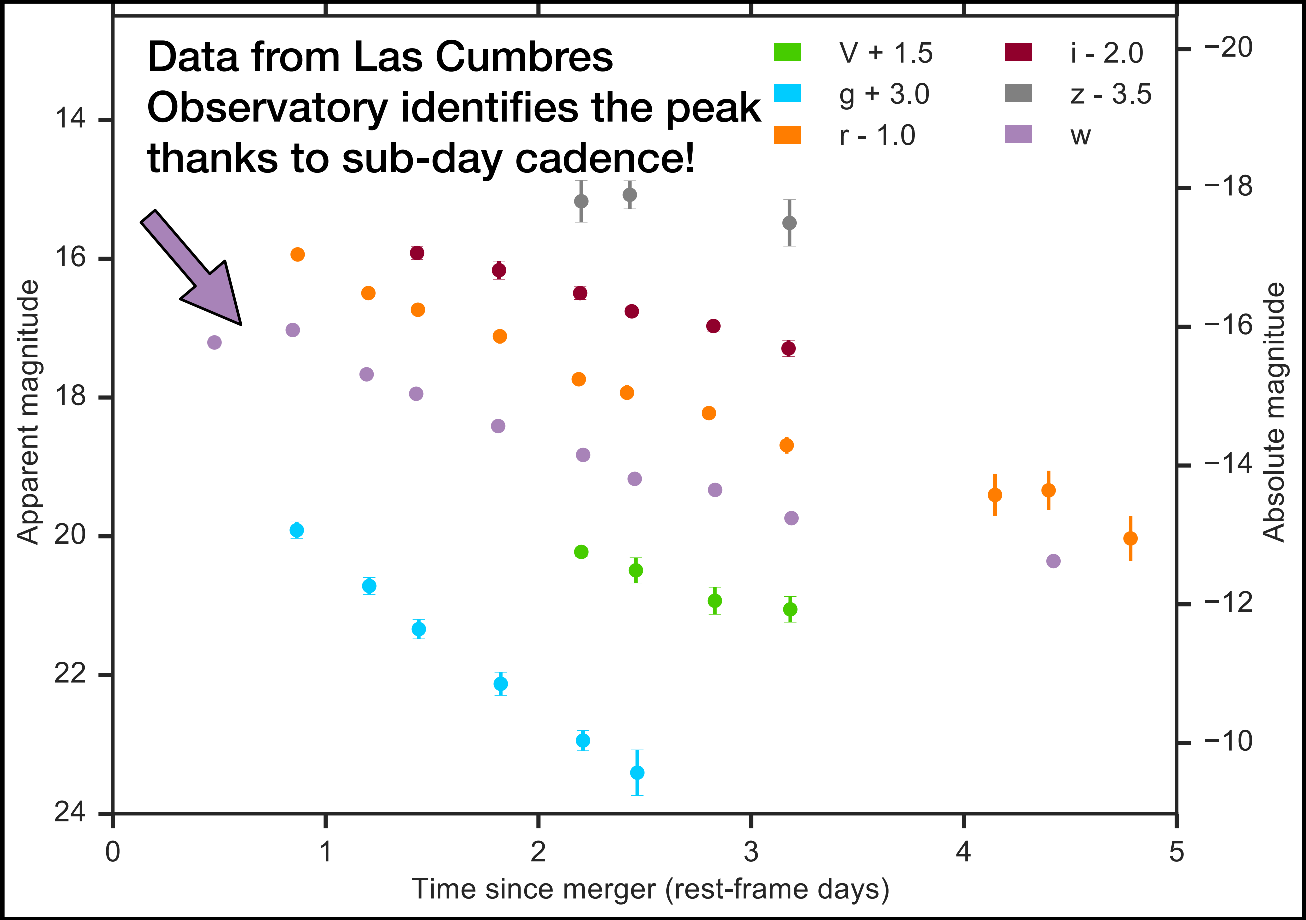
Data from:
Andreoni et al. 2017,
Arcavi et al. 2017,
Cowperthwaite et al. 2017,
Coulter et al. 2017,
Diaz et al. 2017,
Drout et al. 2017,
Evans et al. 2017,
Hu et al. 2017,
Kasliwal et al. 2017,
Lipunov et al. 2017,
Pian et al. 2017,
Pozanenko et al. 2017,
Shapee et al. 2017,
Smartt et al. 2017,
Tanvir et al. 2017,
Troja et al. 2017,
Utsumi et al. 2017,
Valenti et al. 2017.

Retrieved via:
kilonovae.space

Different ejecta components constrain different physics.



Sub-Day Cadence Critical for Constraining Models



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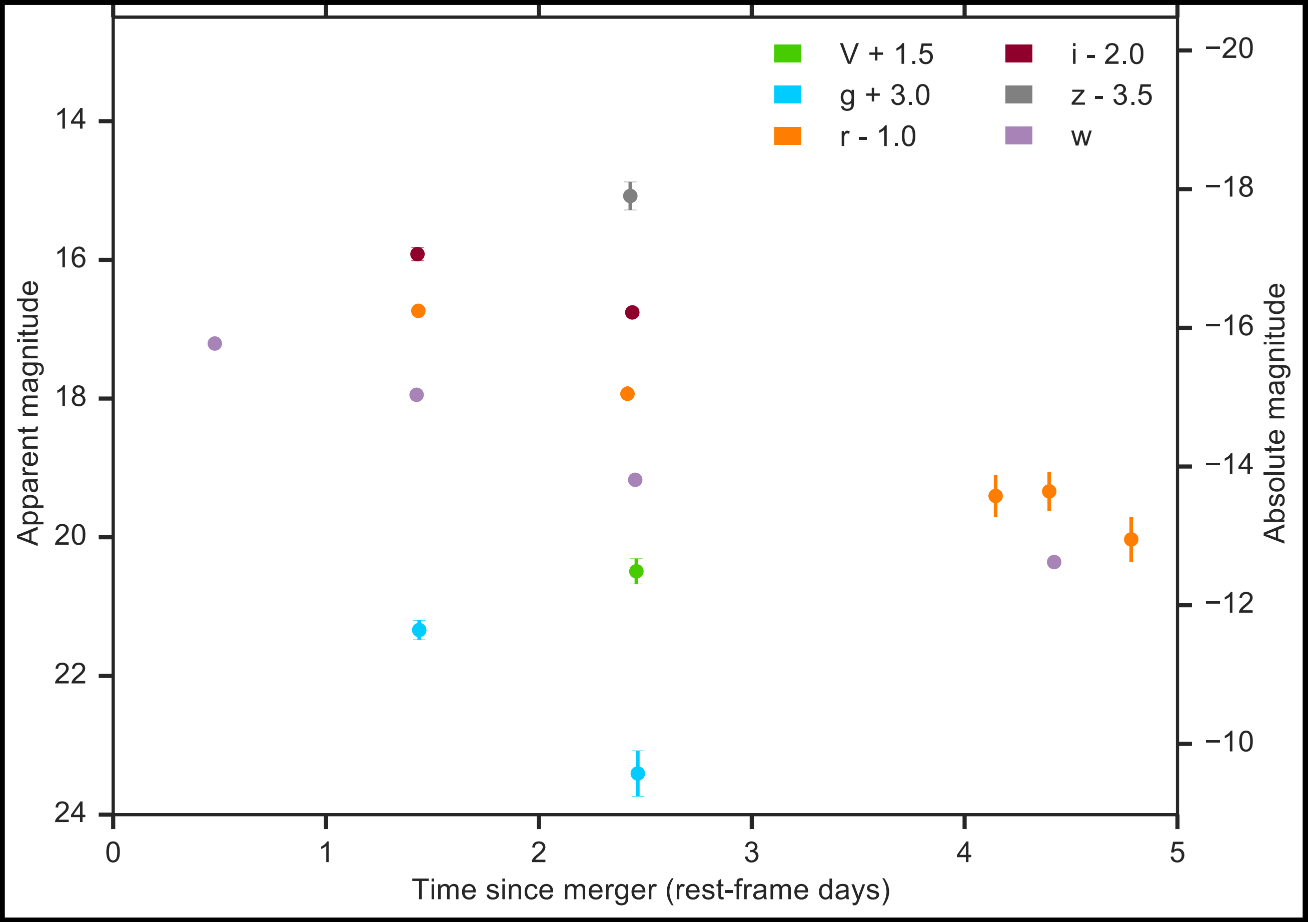


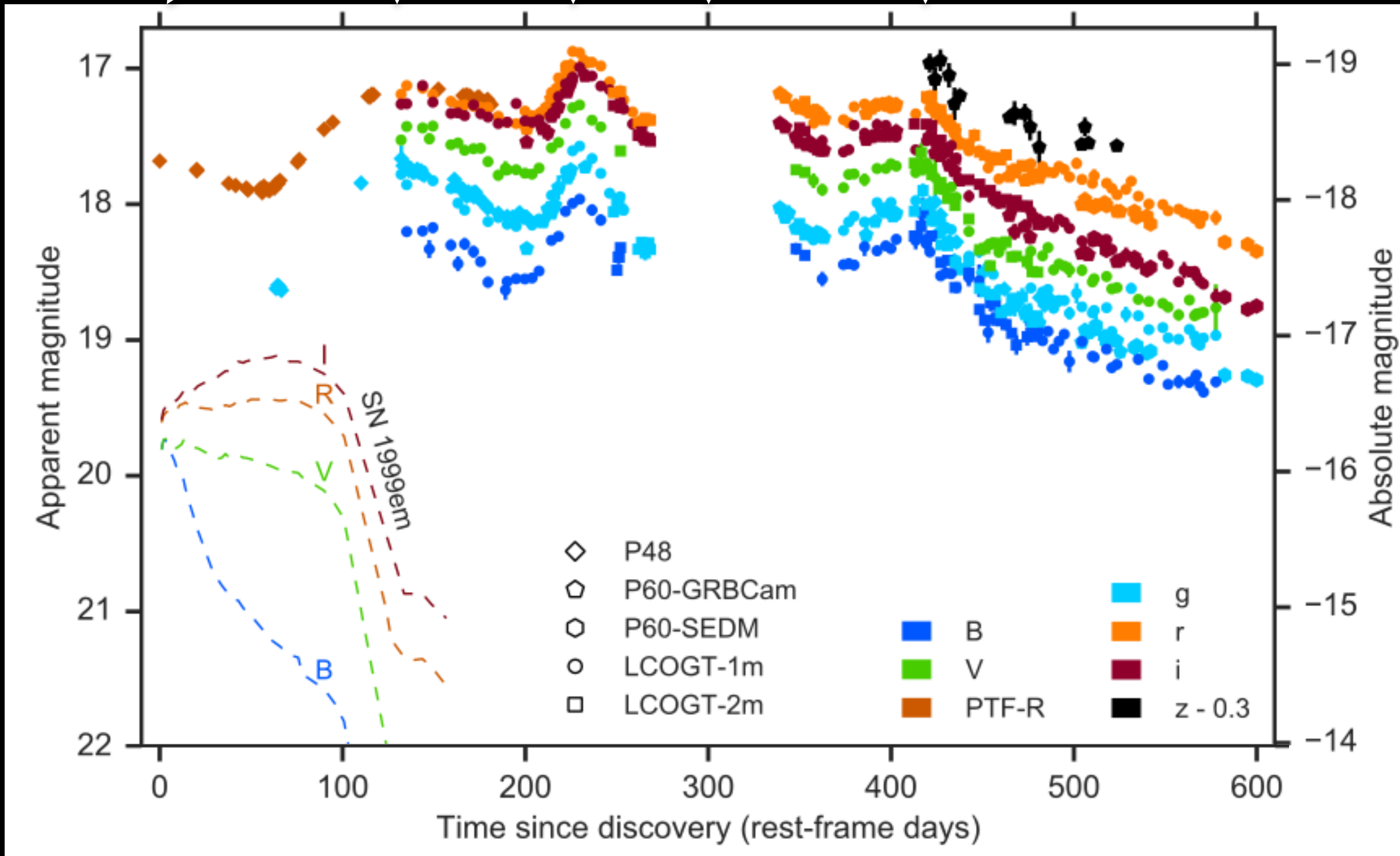
http://treasuremap.space

What is Robotic Followup Good For?

III: Long-Term Monitoring

iPTF14hls: “The Star That Wouldn’t Die”

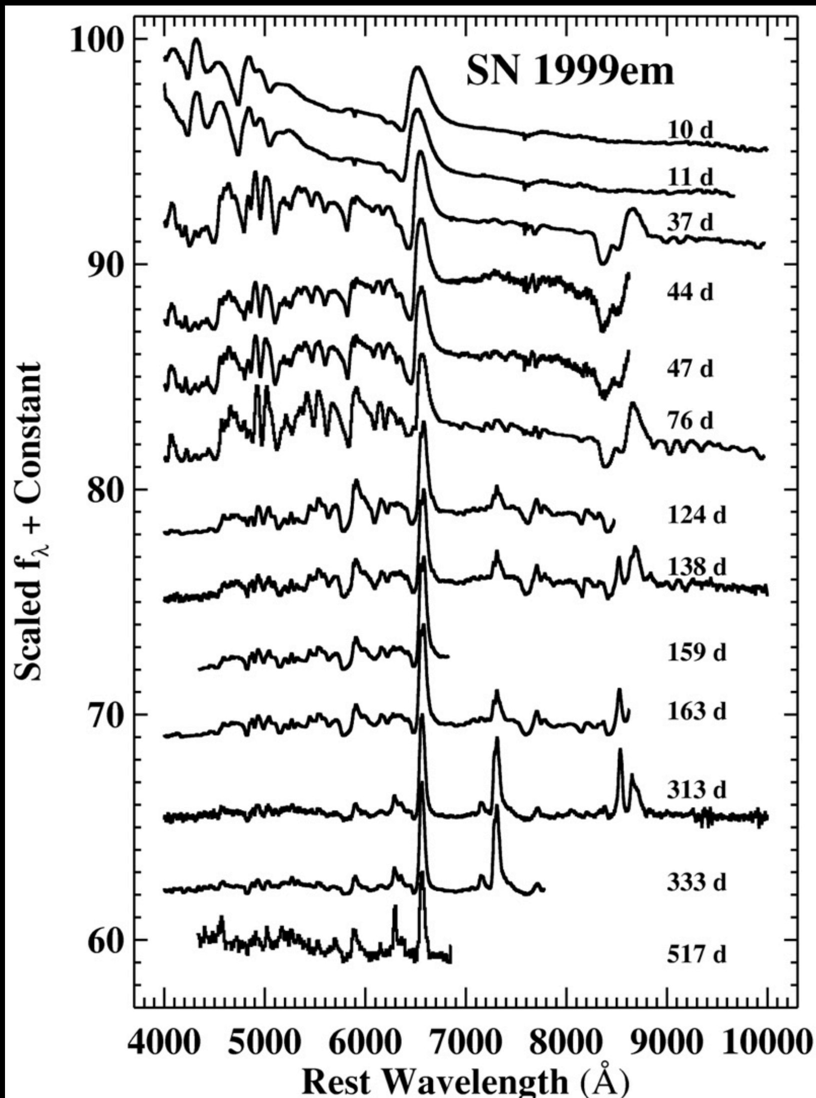
At least 5 peaks



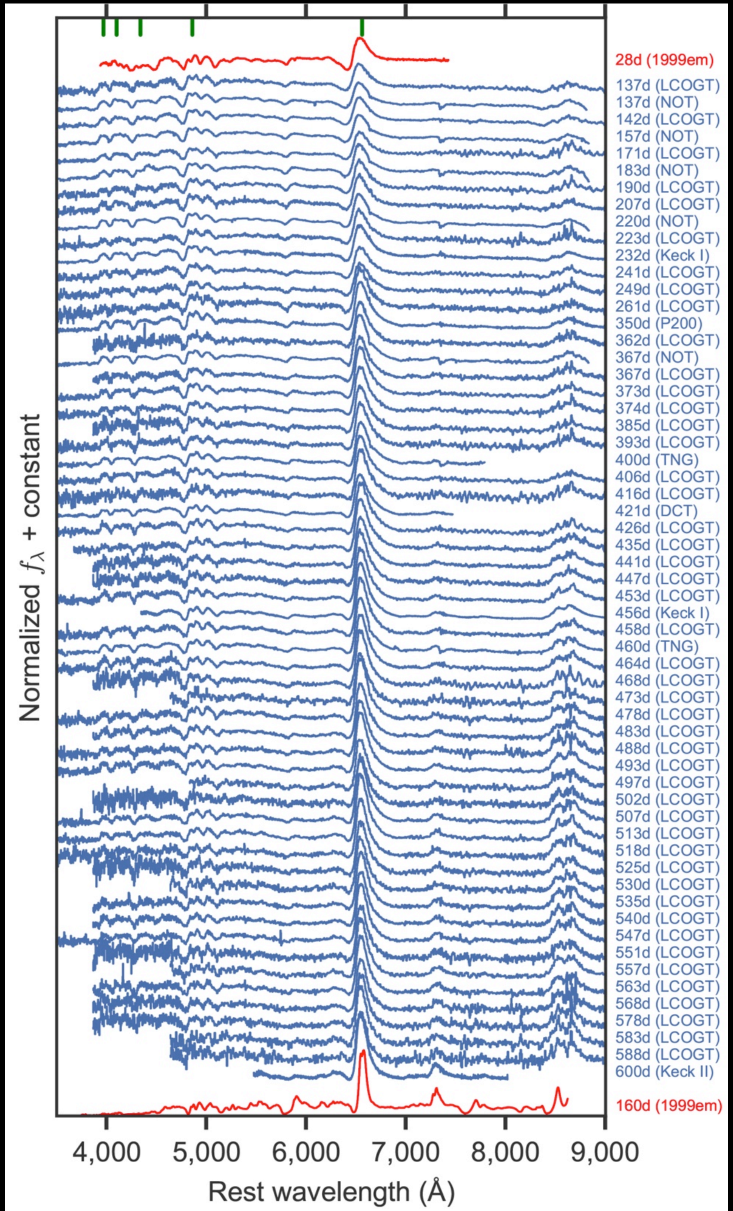
Last non-det is 140d before discovery

Arcavi et al. 2017b, Nature

SN 1999em
(typical IIP)



iPTF14hls



Summary - Global Robotic Followup → Science

Early Emission from Supernovae: Constrains the progenitor star (radius, internal structure, mass loss history…).

Rapidly Evolving Events & Rare Long-Lived Supernovae: Teach us about non-standard supernova power mechanisms.

Kilonovae: Reveal nuclear physics, extreme gravity, accretion, cosmology…

All of these science cases (and many more!) rely on robotic dynamical observing for (1) rapid response, (2) continuous and (3) long-term regular monitoring.