OPTICAL SURVEYS IN THE MULTI-MESSENGER ERA

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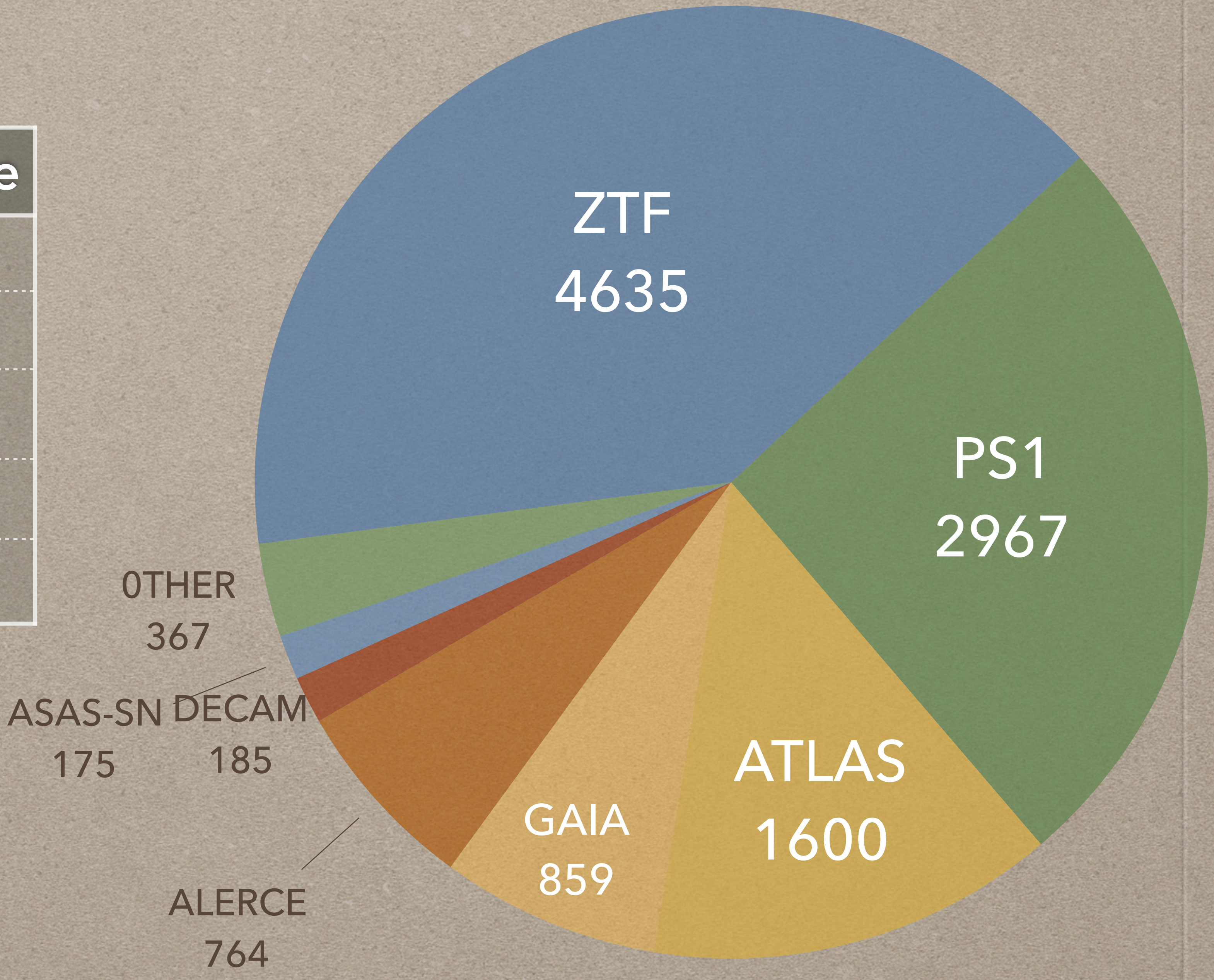
TRANSIENT SEARCHES

SUPERNOVAE

	SNe	candidate
1987	13	17
1997	111	163
2007	539	571
2017	1038	7714
2019*	*1427*	*11552*



2019 Oct 20

TRANSIENT SEARCHES

More statistics

Better S/N, resolution,
spectral range, ….

Improved temporal
sampling

"many" rare events

homogeneity
becomes diversity

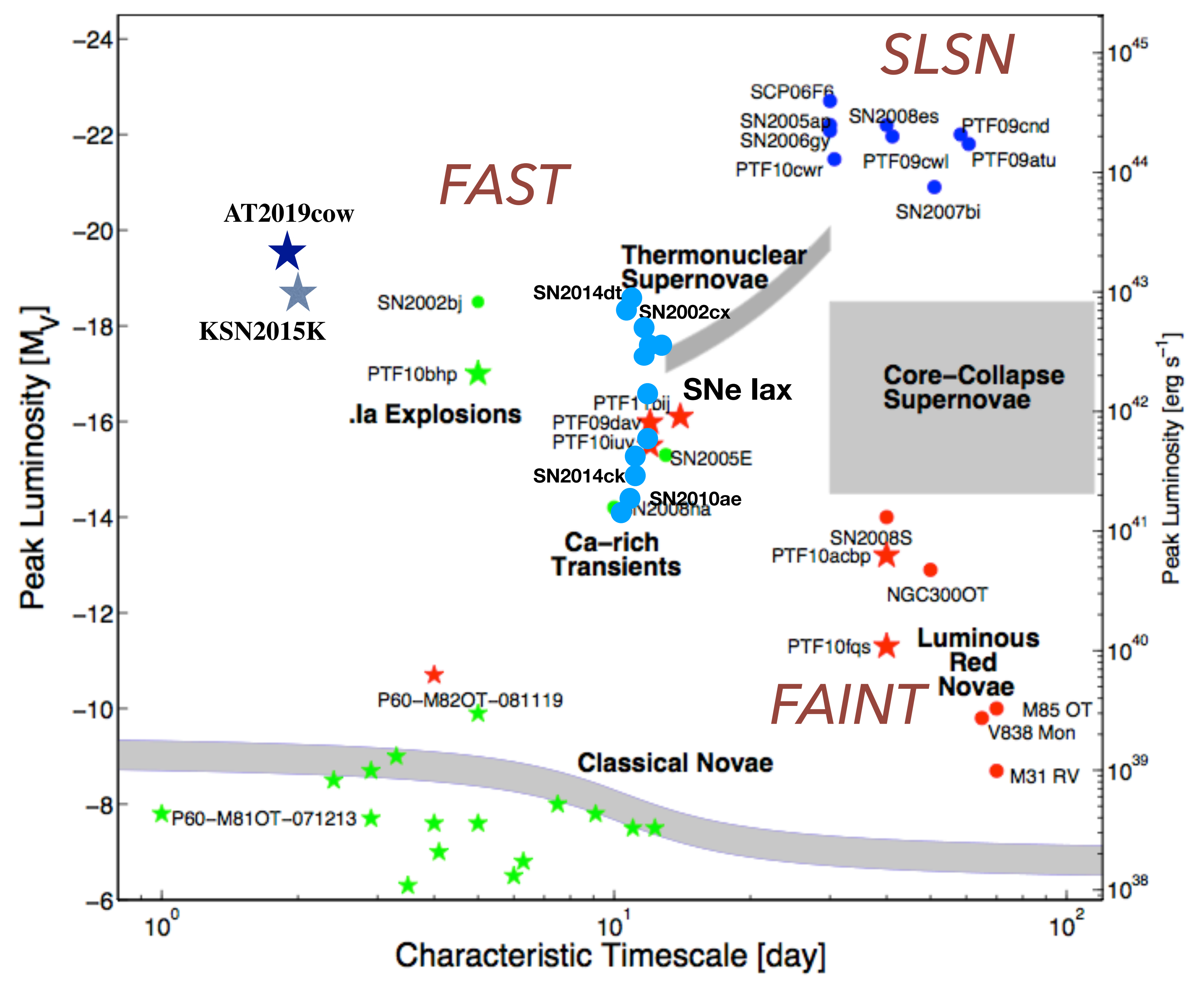
unexplored phases
eg. flash spectroscopy

… unique, unusual, peculiar, extreme ….

…… use of the word reflects incomplete knowledge.

Milisavljevic & Margutti 2018

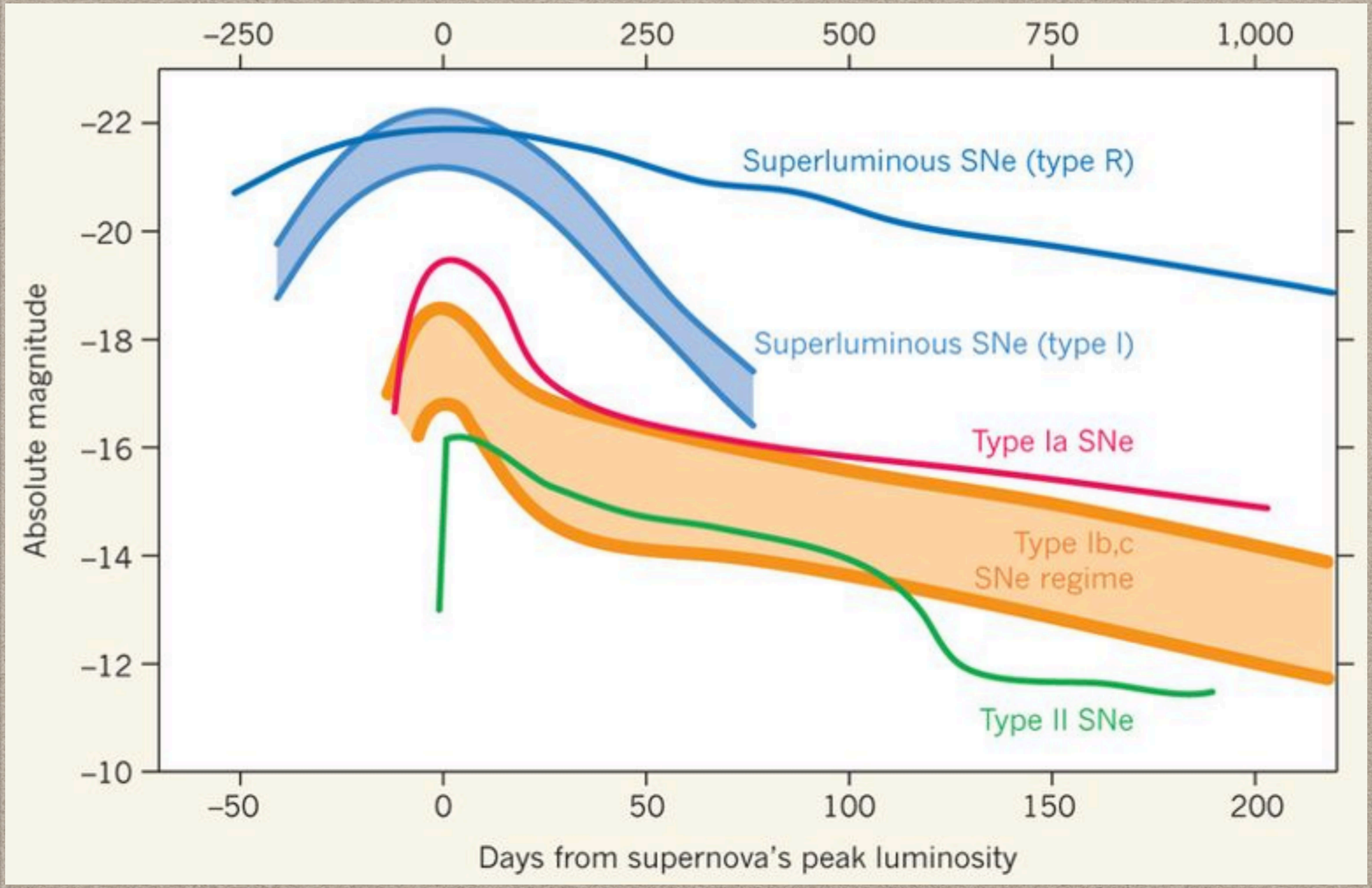
TIME DOMAIN



adapted from Kulkarni 2012

SUPER-LUMINOUS SNE

Smartt, S. 2012 Nature 491, 205



Gal-Yam 2012 Science 337, 927

M_{abs}< -21 mag

type
I H-poor OII 3000-5000 A
II H-rich either in emission (IIn)
or, later, in absorption

rise time: 20-100 d

host: faint dwarf galaxies

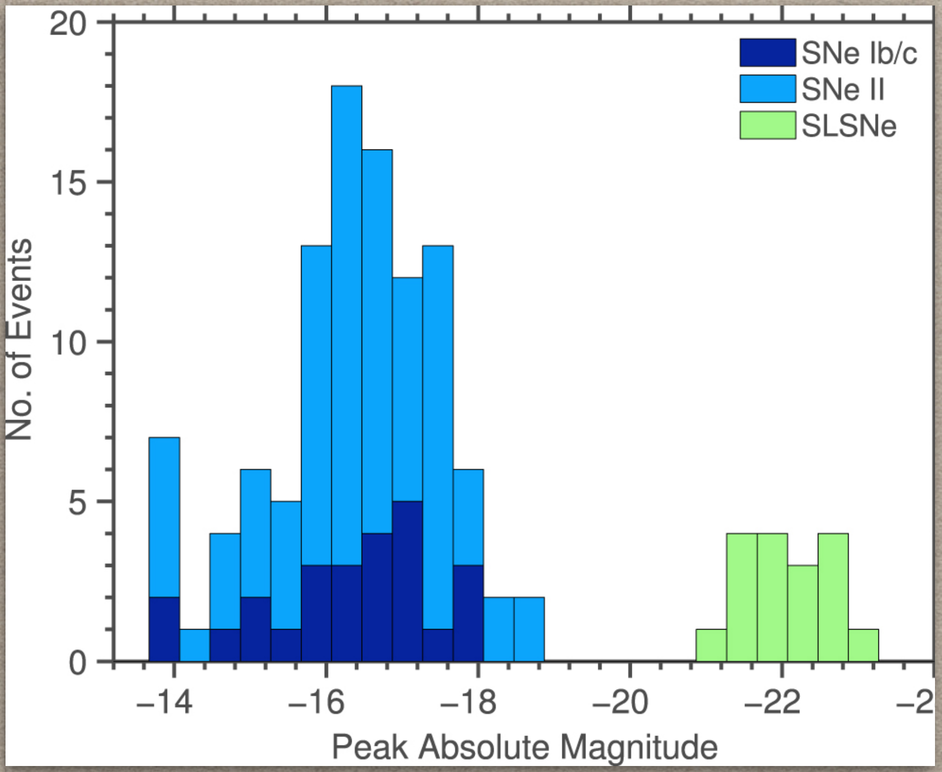
Superluminous Supernovae as Standardizable Candles and High-redshift Distance Probes

Inserra & Smartt 2014 ApJ 796,87

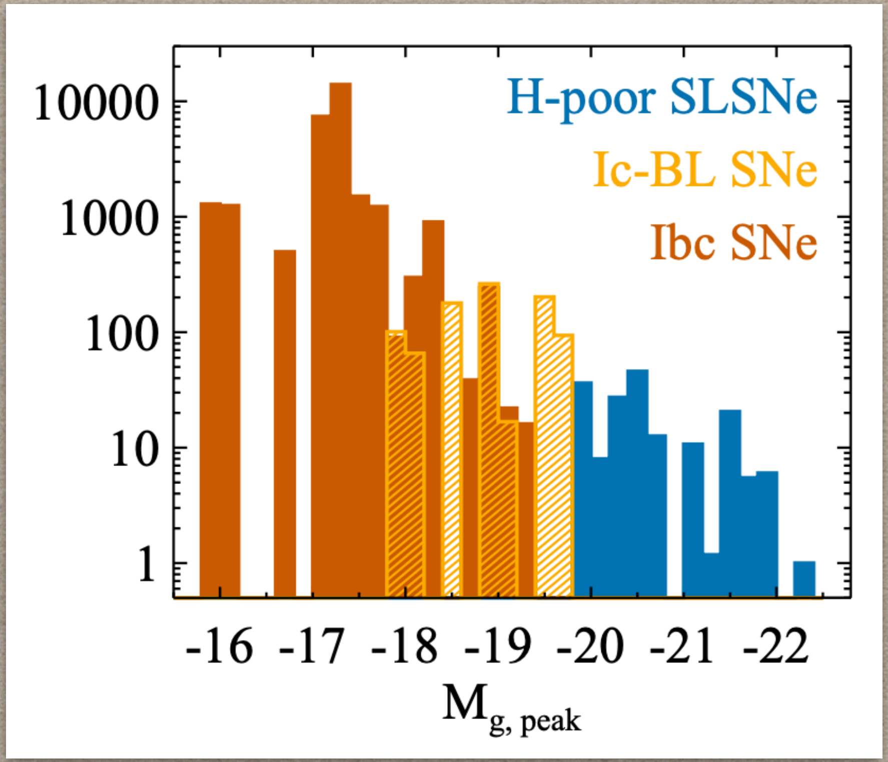
STD(M_{abs}) < 0.2 mag

SUPER-LUMINOUS SNE

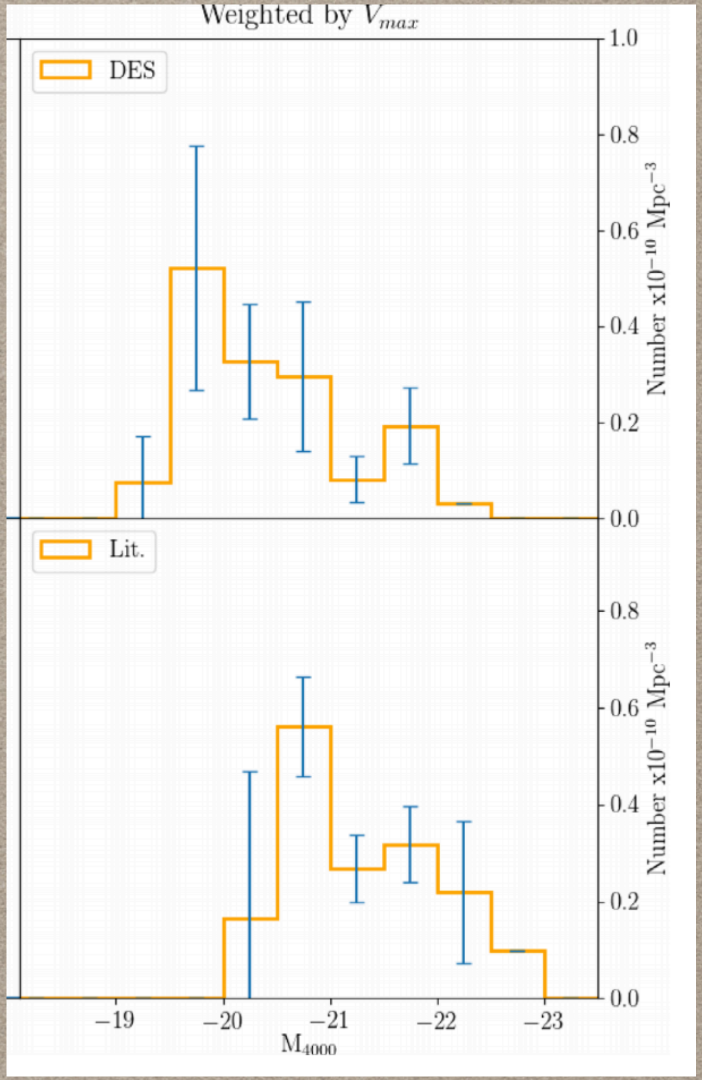
Arcavi et al. 2012



Gal Yam 2018



Angus et al. 2019



$M_{abs} < -21$

from DES, $M_{abs} < -19$

rise time:
20-100 d

SN2018bgv … the fastest-rising SLSN-I, with a … **rise time of just 10 days**

host: faint
dwarf galaxies

SN2018don adds to the small but growing sample of SLSN-I that occur in **high-mass, solar metallicity galaxies**

Lunnan et al. 2019 for ZTF

SUPER-LUMINOUS SNE

SLSN: luminous & long lasting

Why not found before 2010 ?

“popular” explanation: bias of targeted searches pointing preferentially bright galaxies

- The Palomar SN search in the ‘70 was using the same telescope/ FoV of ZTF
- Cosmological search of the ‘90 were un-targeted and sampling large volumes.
- LOSS was limited to z~0.05. From 2010, 1 SLSN found at z<0.05. The host is a bright galaxy.

The key is the transient selection criterium:

1- time scale, 2- color, 3- host properties, …..

SLSN: rare & long lasting

SUPER-LUMINOUS SNE

- A typical story for a new transient class

1	-	10	-	100
peculiar	–>	homogeneity	–>	diversity

"The energy source of SLSNe-I is still an open question, with viable models including central-engine models driven by a newborn **rapidly-spinning magnetar** or an **accreting black hole**, **interaction** with hydrogen-poor CSM, or, perhaps for the most slowly-evolving events, models powered by **large amounts of radioactive 56Ni**.
The energy source for SLSNe-II is even **less well** understood."

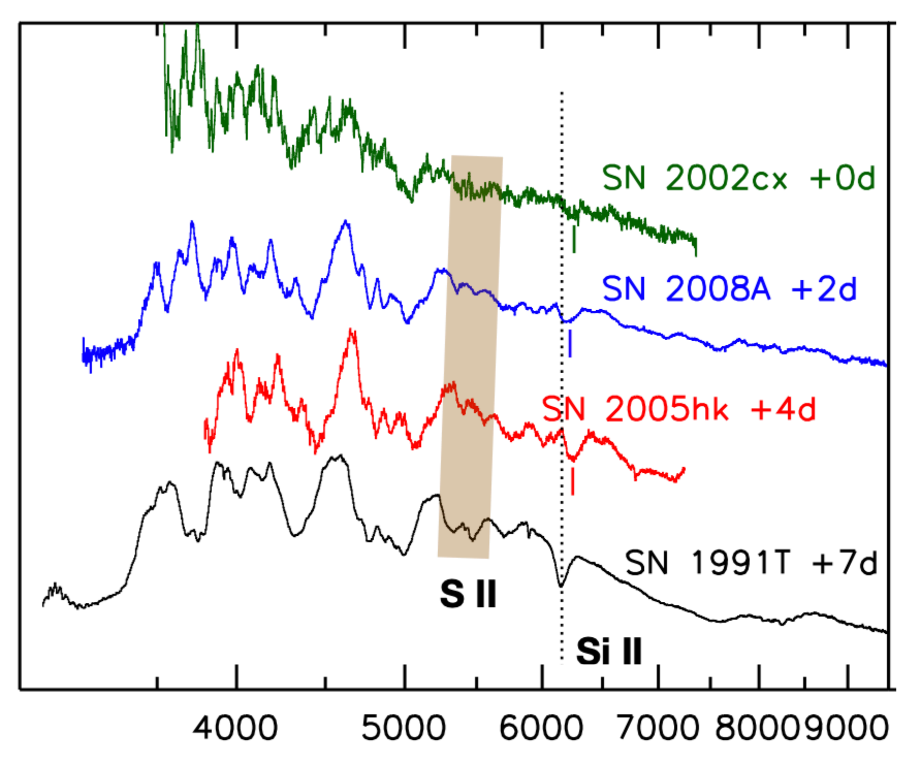
Gal Yam 2019

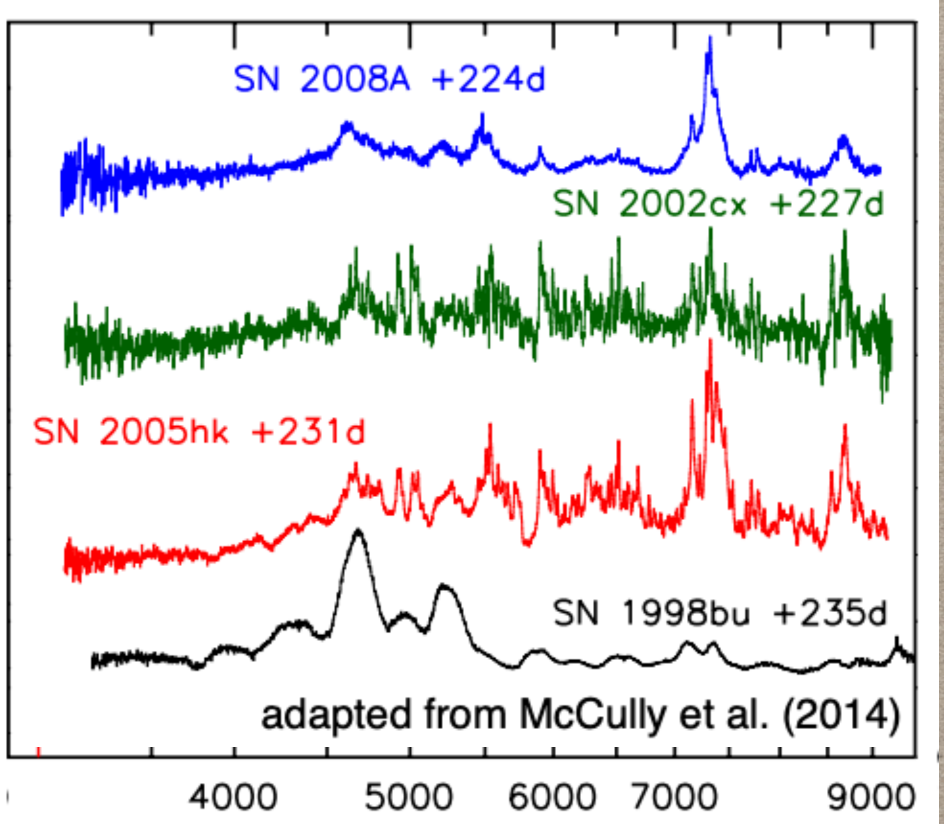
Statistics alone does not guaranties for interpretation

FAST EVOLVING OPTICAL TRANSIENTS

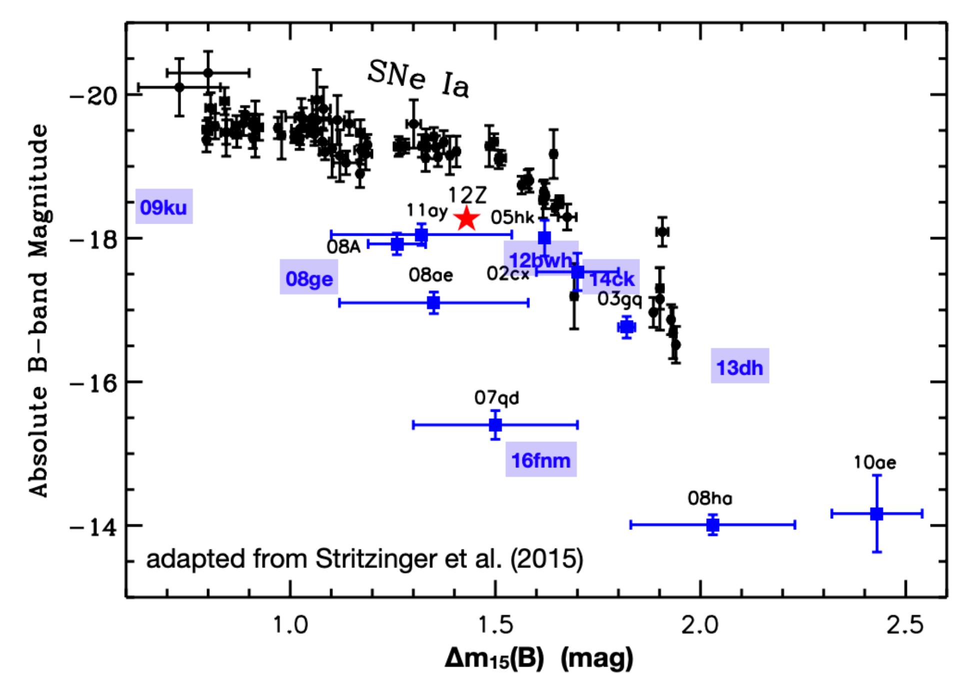
SN IAX

Fast	rise time 10-18 d
Faint (relatively)	M_{abs} -13 / -19
Slow	v_{exp} 2000-6000 km/s
host	late spirals
rate	10-40 % of SN Ia





adapted from McCully et al. (2014)



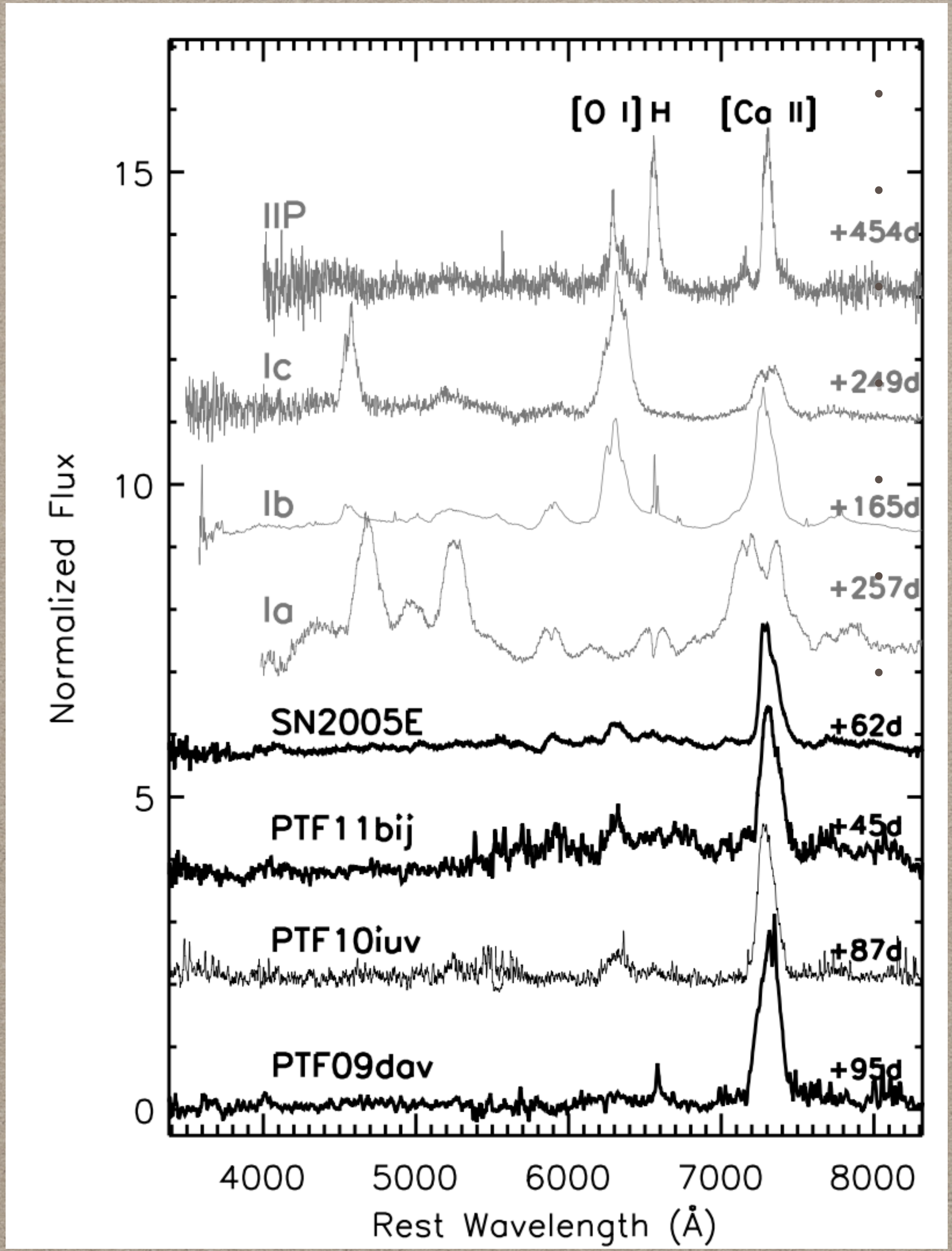
adapted from Stritzinger et al. (2015)

> …. a partial deflagration of a C-O WD
> not unbinding the progenitor star ….
> *Foley et al. 2008*

FAST EVOLVING OPTICAL TRANSIENTS

CALCIUM-RICH

Kasliwal etal. 2011



Fast t_{rise} 12-15d

Faint M_{abs} -14 / -16 mag

Fast v_{exp} 6000 -10000 km/s

- host all galaxy types
- early evolution to nebular (1-3 mo) dominated by Calcium
- rate 30-100% of SN Ia

He-shell double-detonation explosion of a C/O white dwarf: near /at Chandrasekhar mass

Galbany et al. 2019

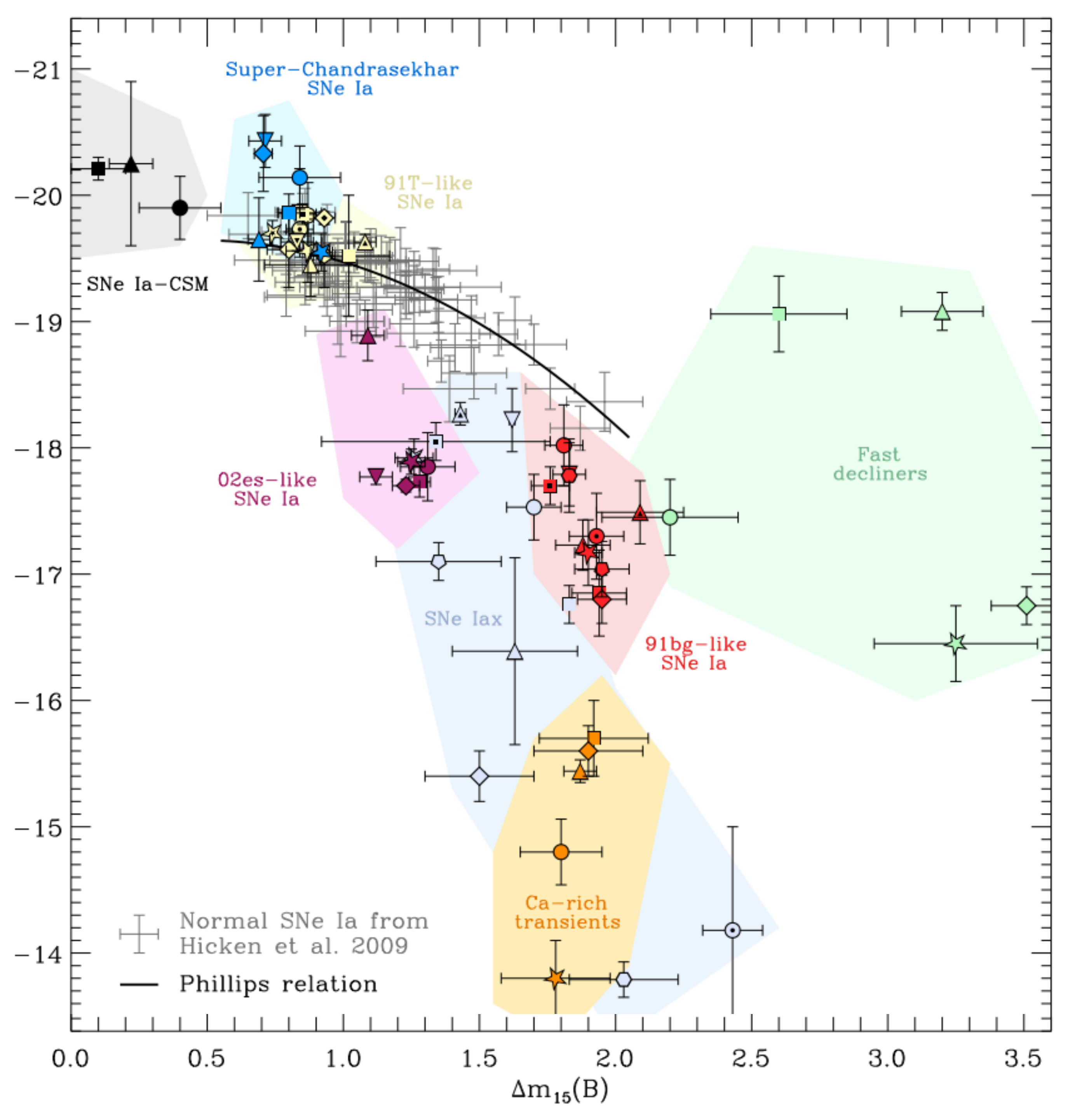
A helium shell detonation on the surface of a sub-Chandrasekhar mass (0.85 M) C/O WD

Jacobson-Galan et al . 2019

Our extensive follow-up observations rule out standard thermonuclear and standard core-collapse explosions

FAST EVOLVING OPTICAL TRANSIENTS

Thermonuclear



Taubenberger et al. 2017

Different WDs explosion mechanisms can produce very different results.

Can they produce standard candles ?

FAST EVOLVING OPTICAL TRANSIENTS

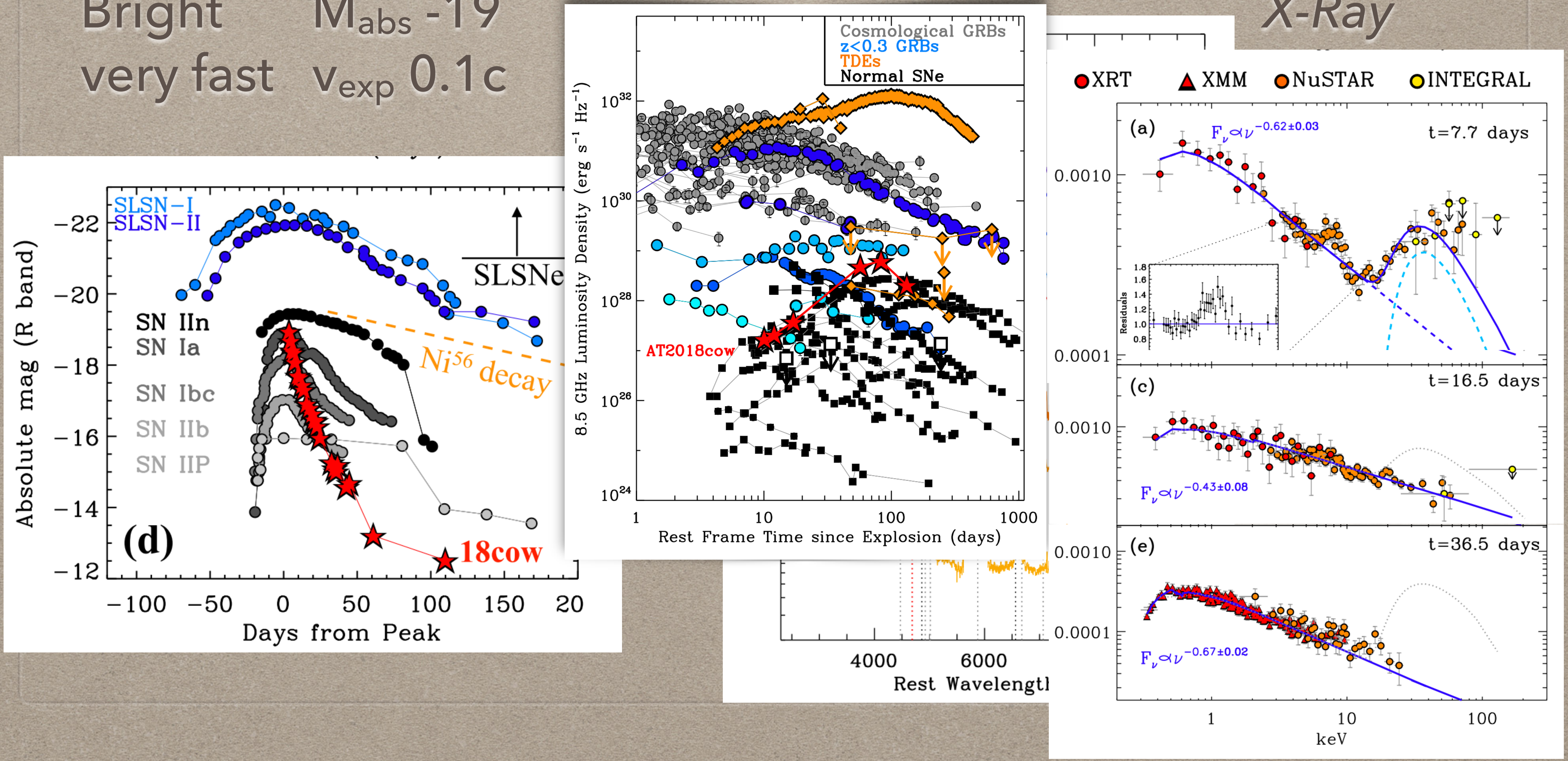
AT2018COW

Margutti et al. 2019 ApJ 872,18

very fast t_{rise} 2-5 d
Bright M_{abs} -19
very fast v_{exp} 0.1c

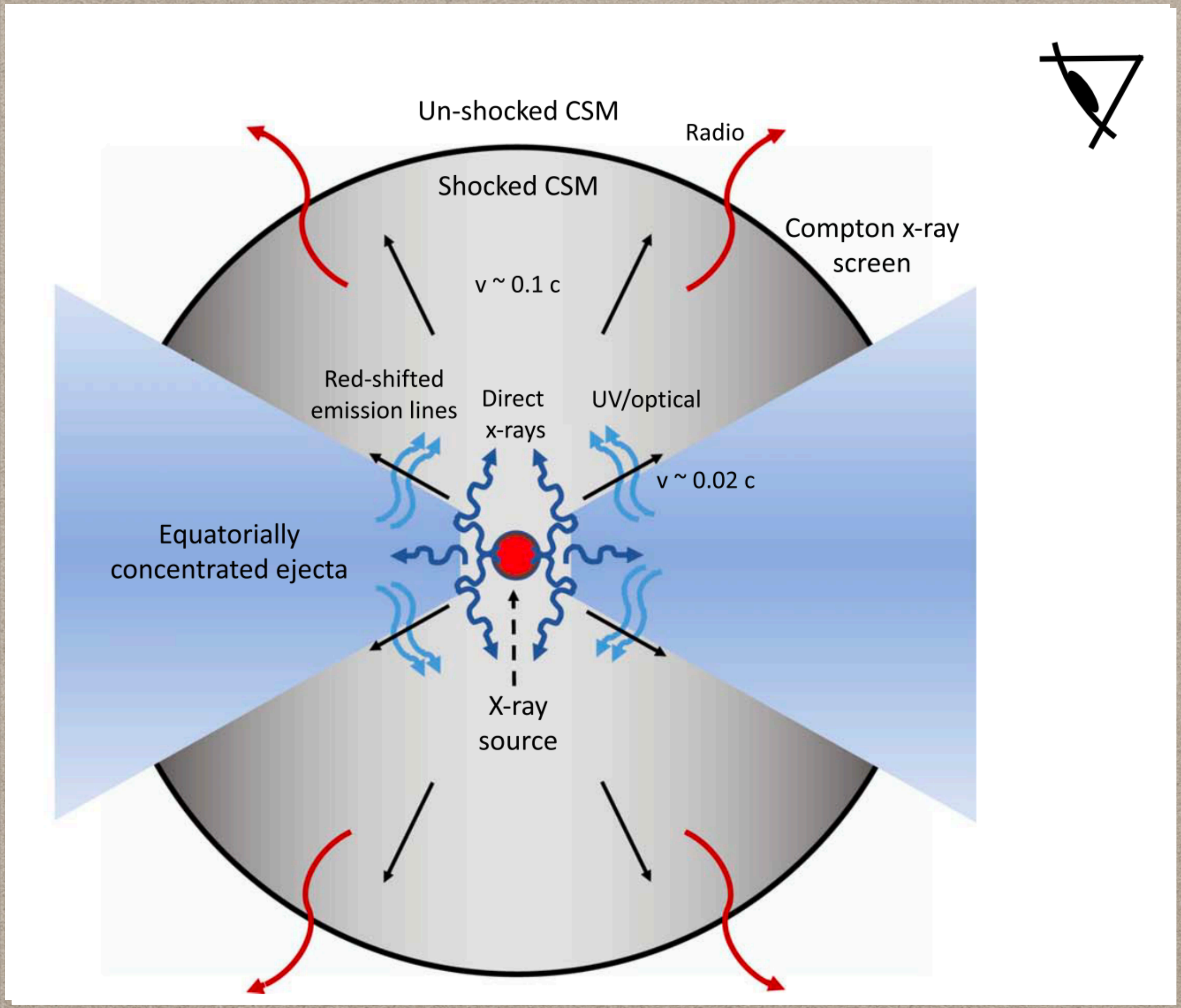
Radio

X-Ray



FAST EVOLVING OPTICAL TRANSIENTS
AT2018COW

Margutti et al. 2019 ApJ 872,18



The inner engine is hidden.
It can be an embedded internal shock produced by interaction with a compact, dense circumstellar medium.

The X-ray and UV/optical emission point toward a small amount of **asymmetrically distributed** H-/He-rich **ejecta**

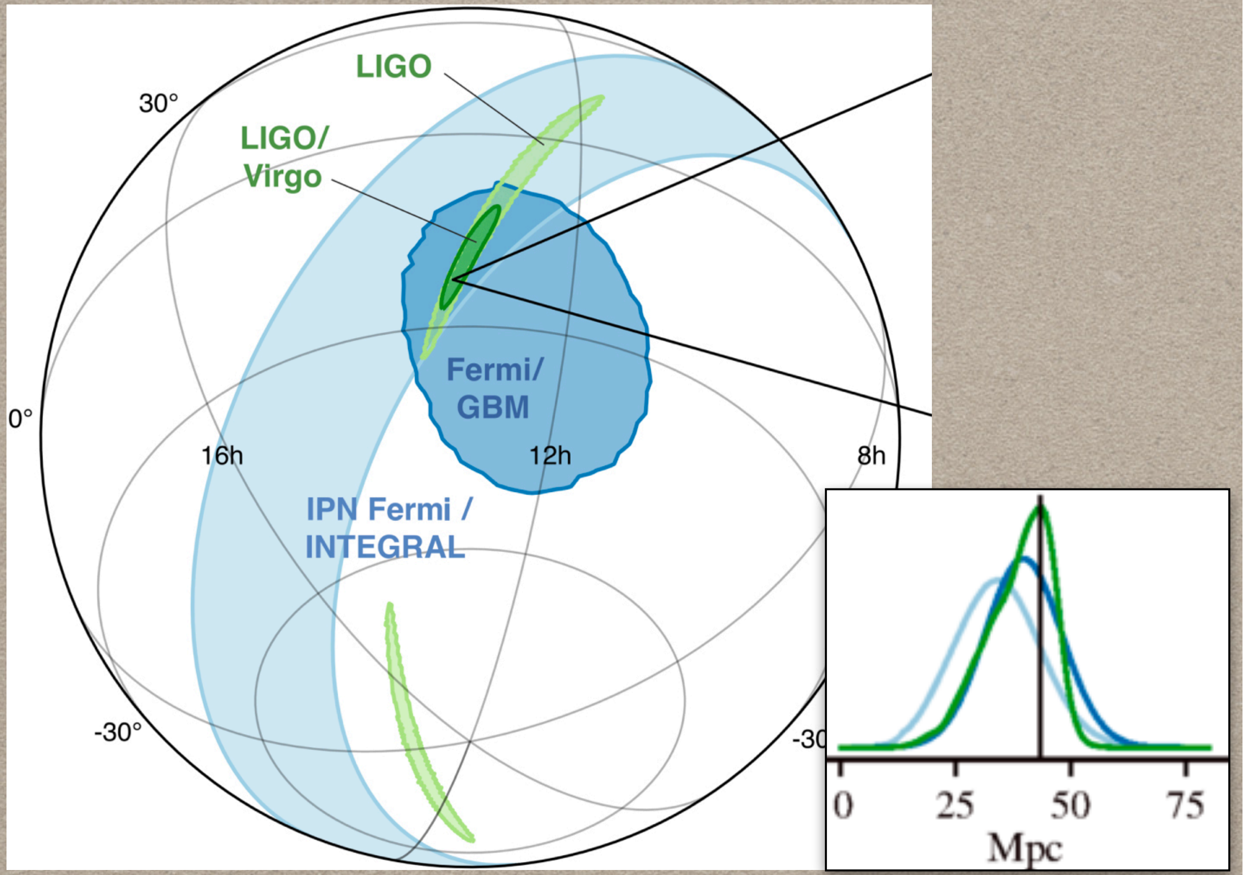
radio emissione revealed a non-relativistic **blast wave** propagating **into a relatively dense environment**

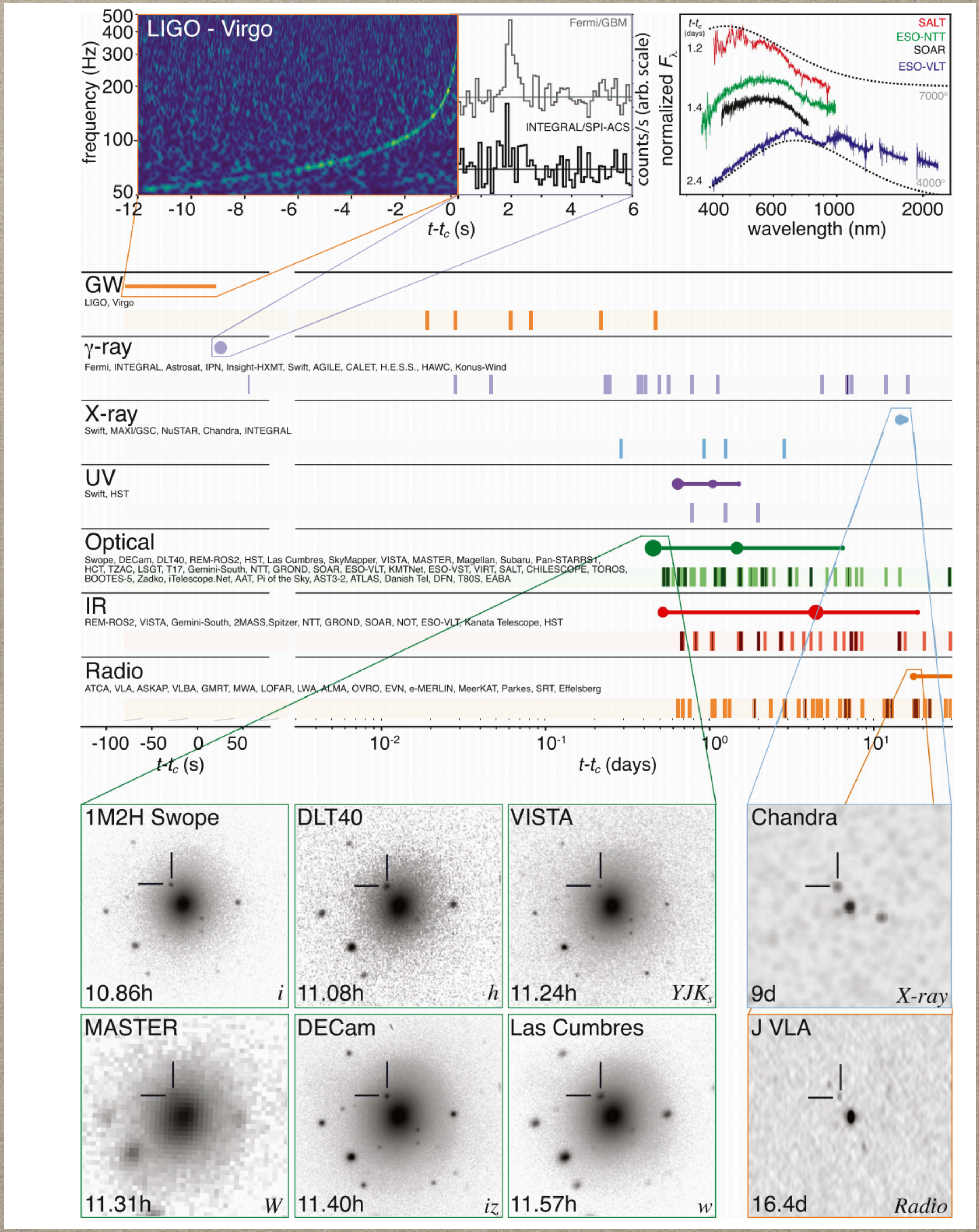
IR excess may be related to a **light echo**

FAST EVOLVING OPTICAL TRANSIENTS
AT2018COW

- Compact objects (BH/NS) engines (accretion/rotation/magnetic field) are more often invoked
    - Ejecta/shell/CSM shocks can outshine other luminosity contributions (but may also provide efficient central engine)
        - Multi-wavelenght is needed but may not be sufficient

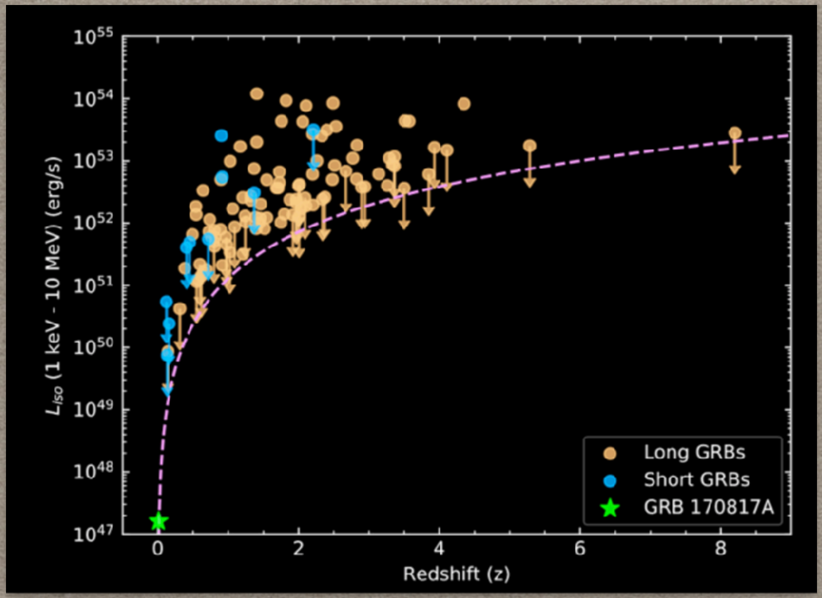
DISCOVERY OF A KILONOVA





GW1708717 12:41:04
GRB170817A 12:41:06
22:32 Sunset Chile
AT2017gfo 23:33
01:05 discovery GCN

THE FAINT SHORT GRB



off-axis relativistic jet

opening angle 6 deg

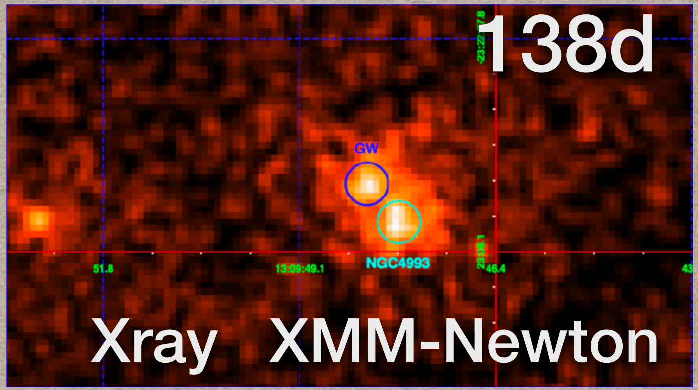
viewing angle 30 deg

Lorentz factor 160

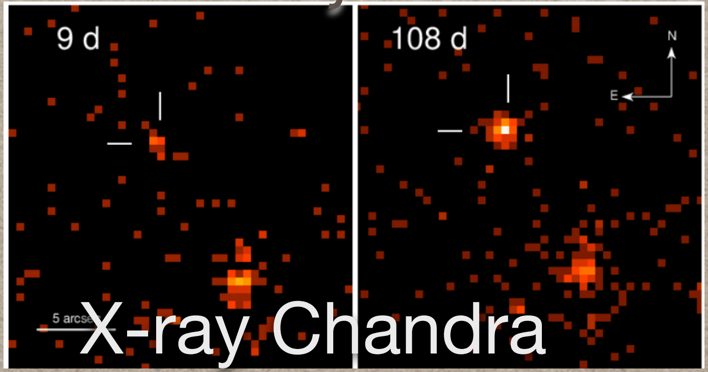
CSM density

2.5×10^{-3} cm^{-3}

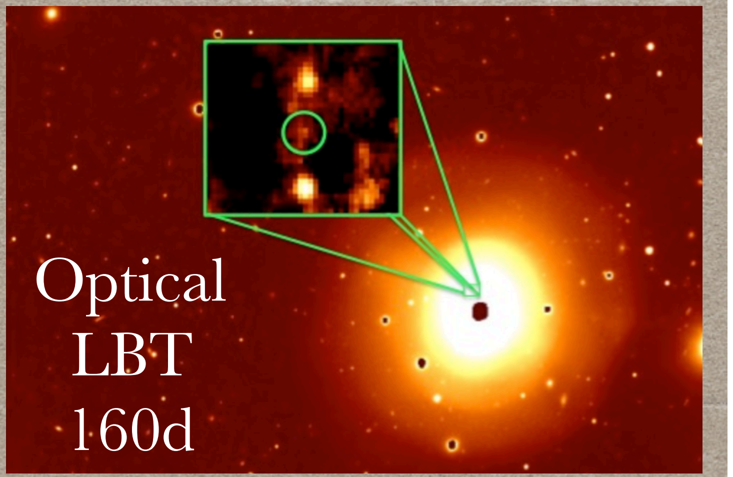
D'Avanzo et al. 2018



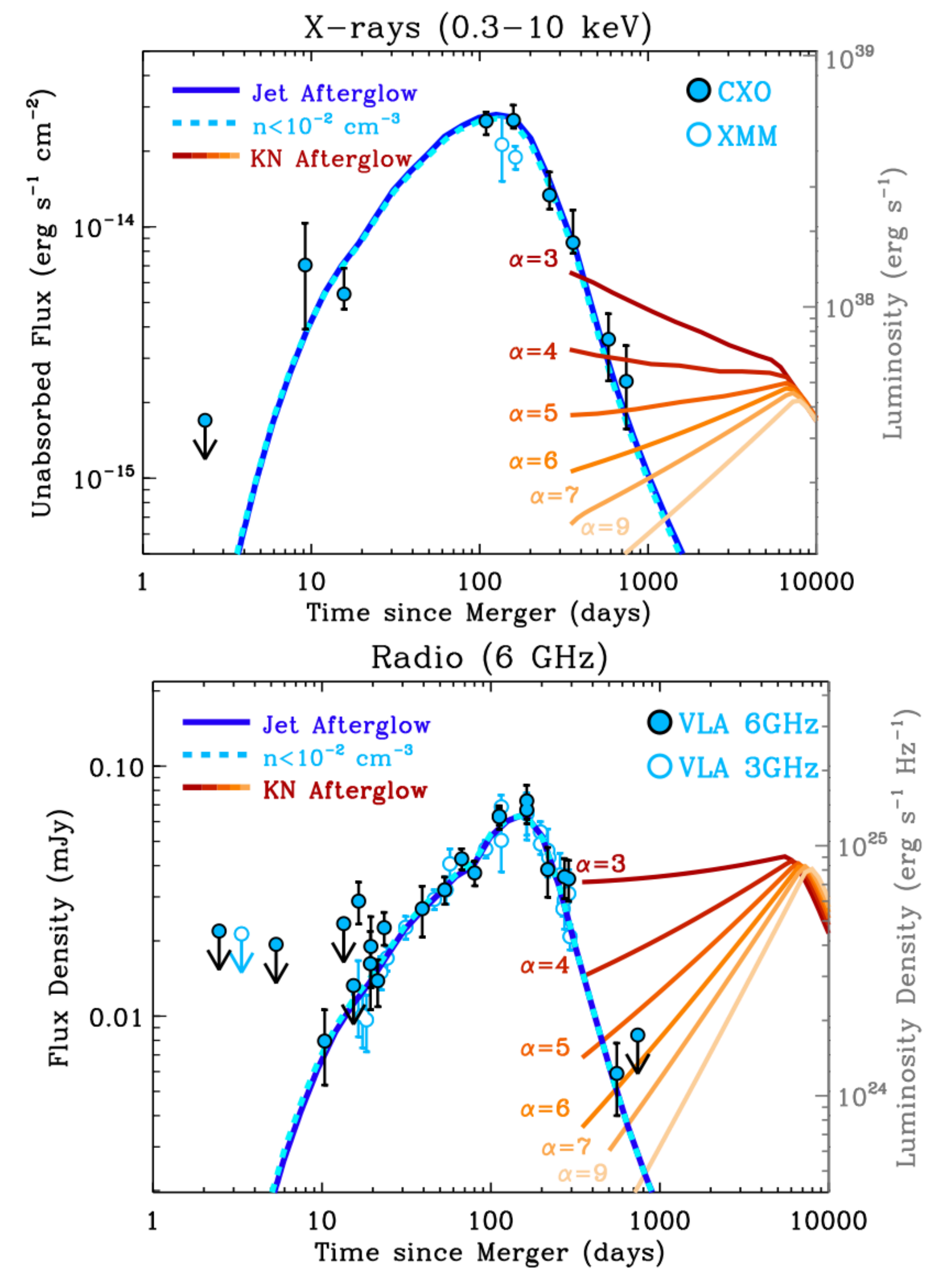
Troja et al. 2018



Rossi et al. 2018

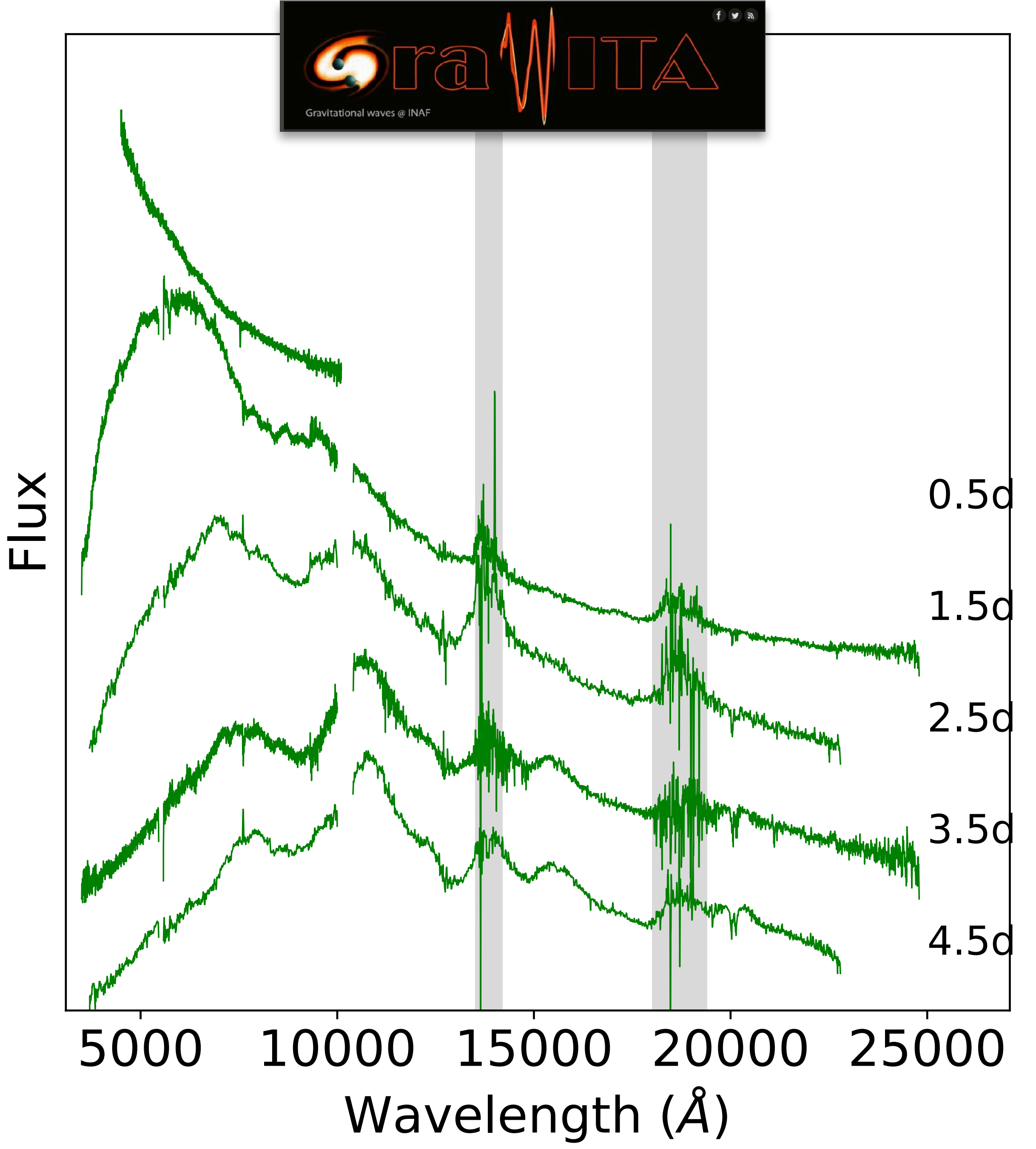


Hajela et al. 2019



KN NUCLEO-SYNTHESIS

observations
Pian et al. 2017, Smartt et al. 2017



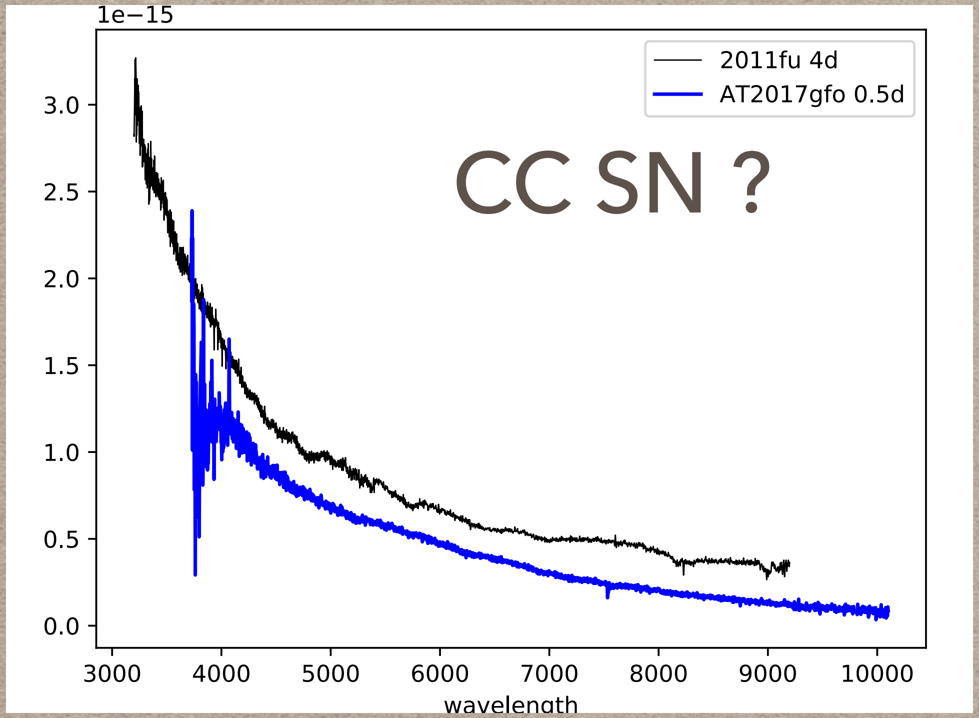
models
Kasen et al. 2017, Tanaka et al. 2017

… solving relativistic radiation transport in a radioactive plasma. Calculate the thermal and ionization/excitation state of the ejecta and derive the wavelength-dependent opacity and emissivity using atomic-structure model data for multiple ions .

Models assume spherical symmetry, local thermodynamic equilibrium, and uniform abundances… The only three tunable parameters are an ejecta mass, a mean velocity and a fractional lanthanide abundance. Uncertainties in the current atomic line data sources hinder spectral analysis

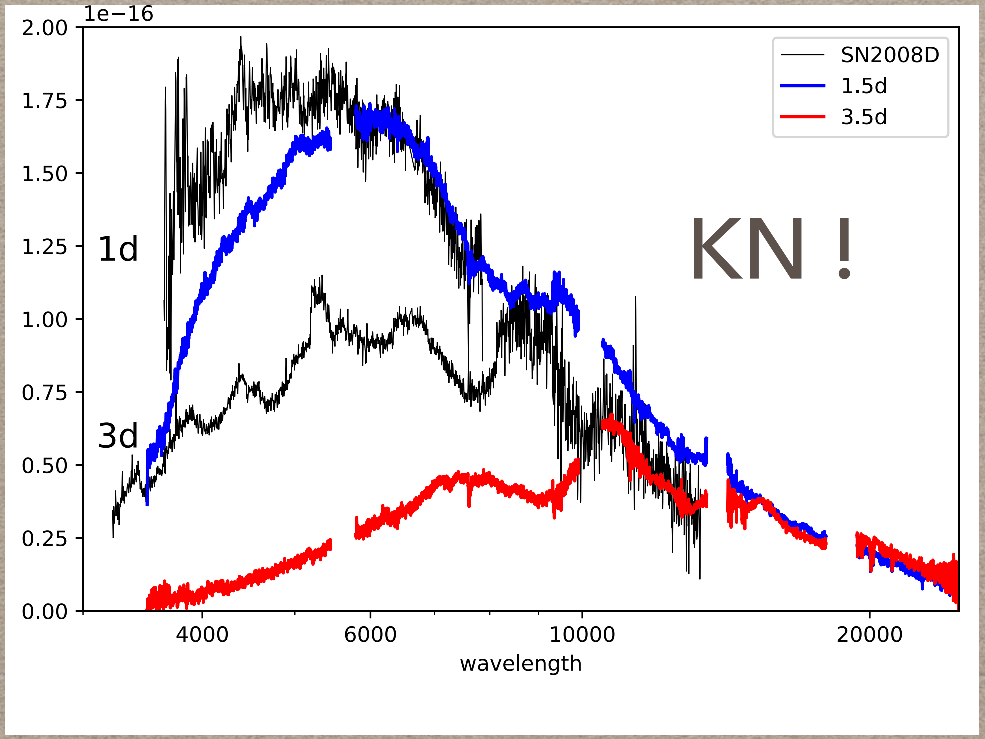
DISCOVERY OF A KILONOVA

Shappee et al. 2017

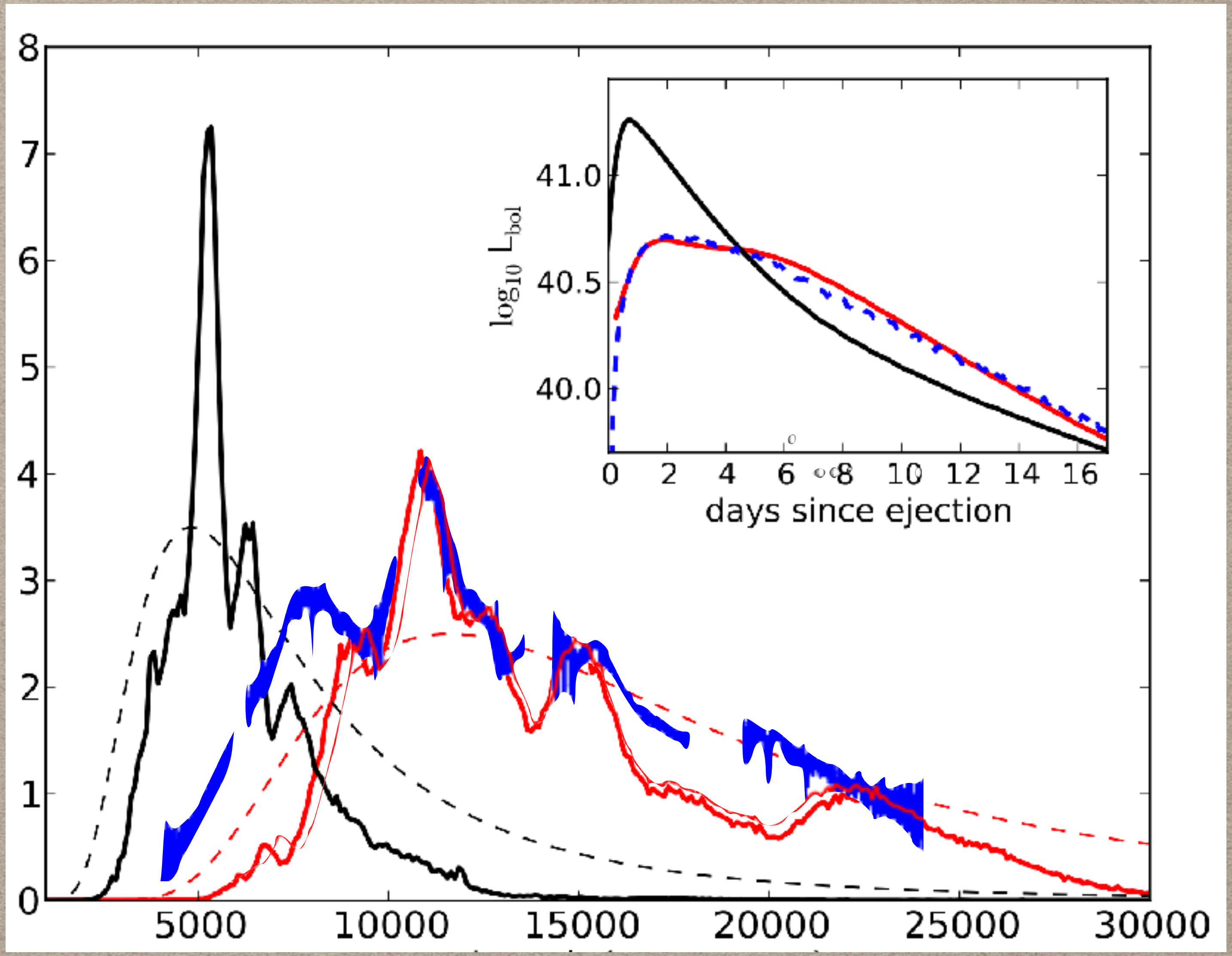


CC SN ?

Pian et al. 2017



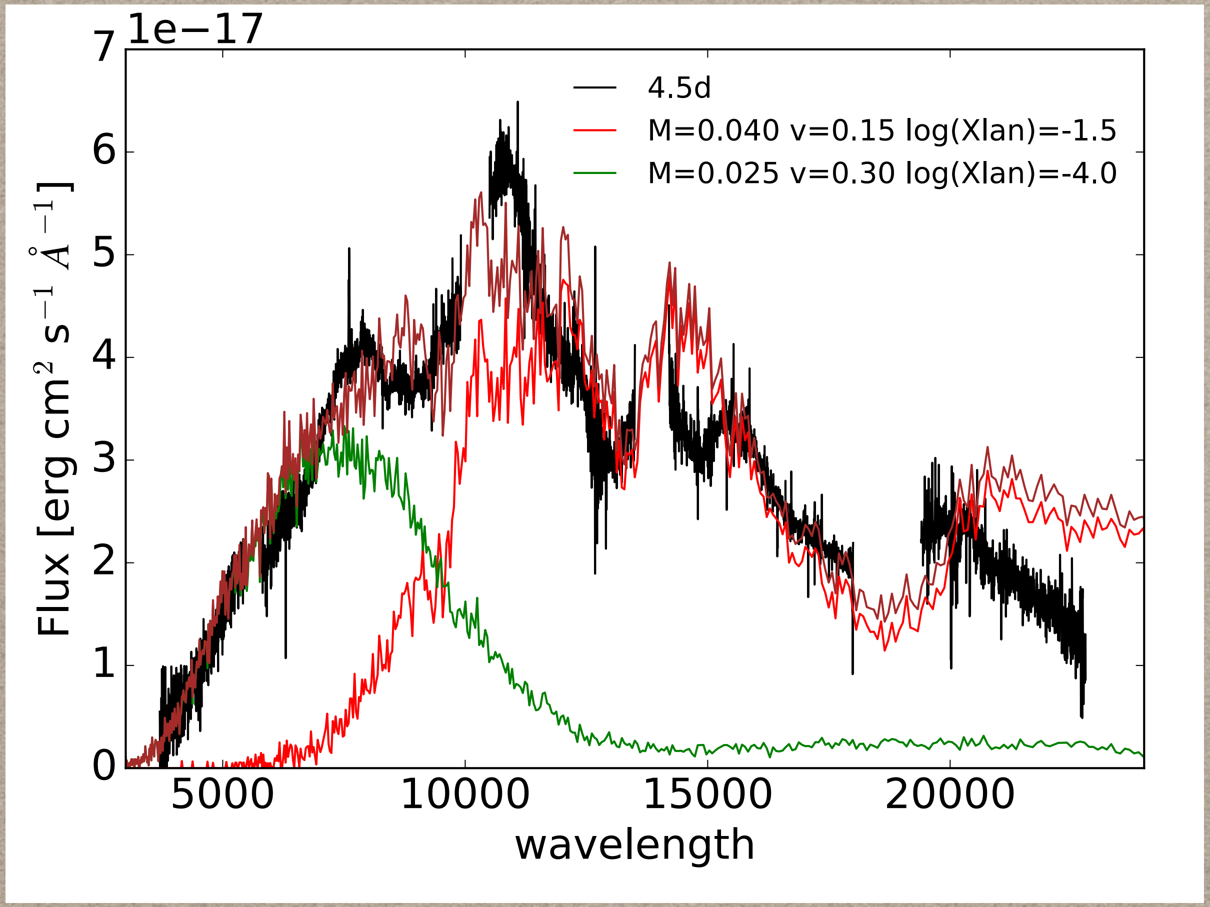
KN !

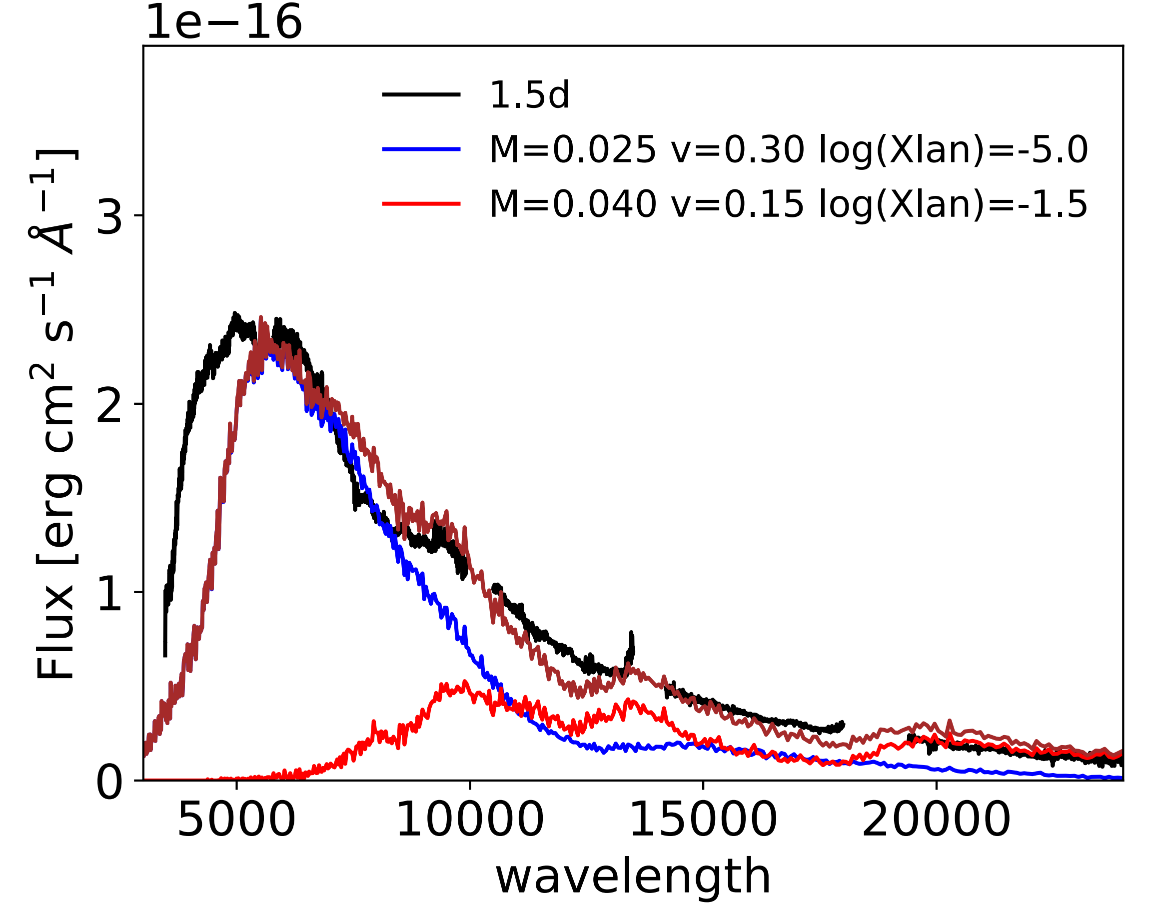


Kilonova models predict nucleosynthesis of r-process elements. Lanthanides dominate radiation transport because of high opacity

KN NUCLEO-SYNTHESIS

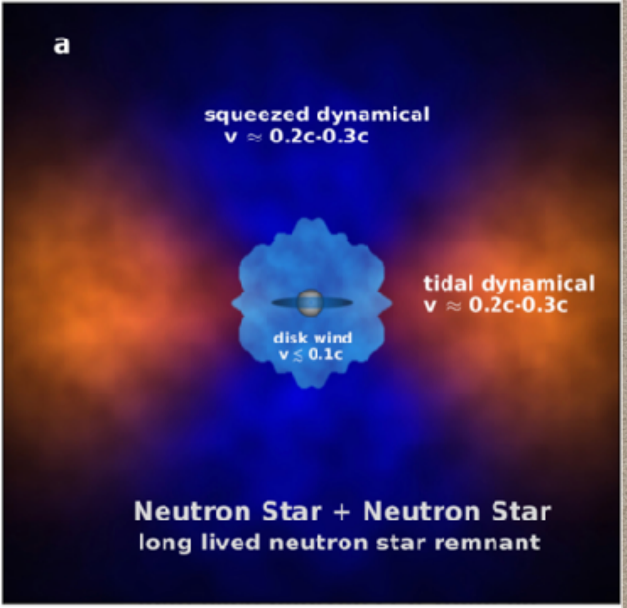
models Kasen et al 2017





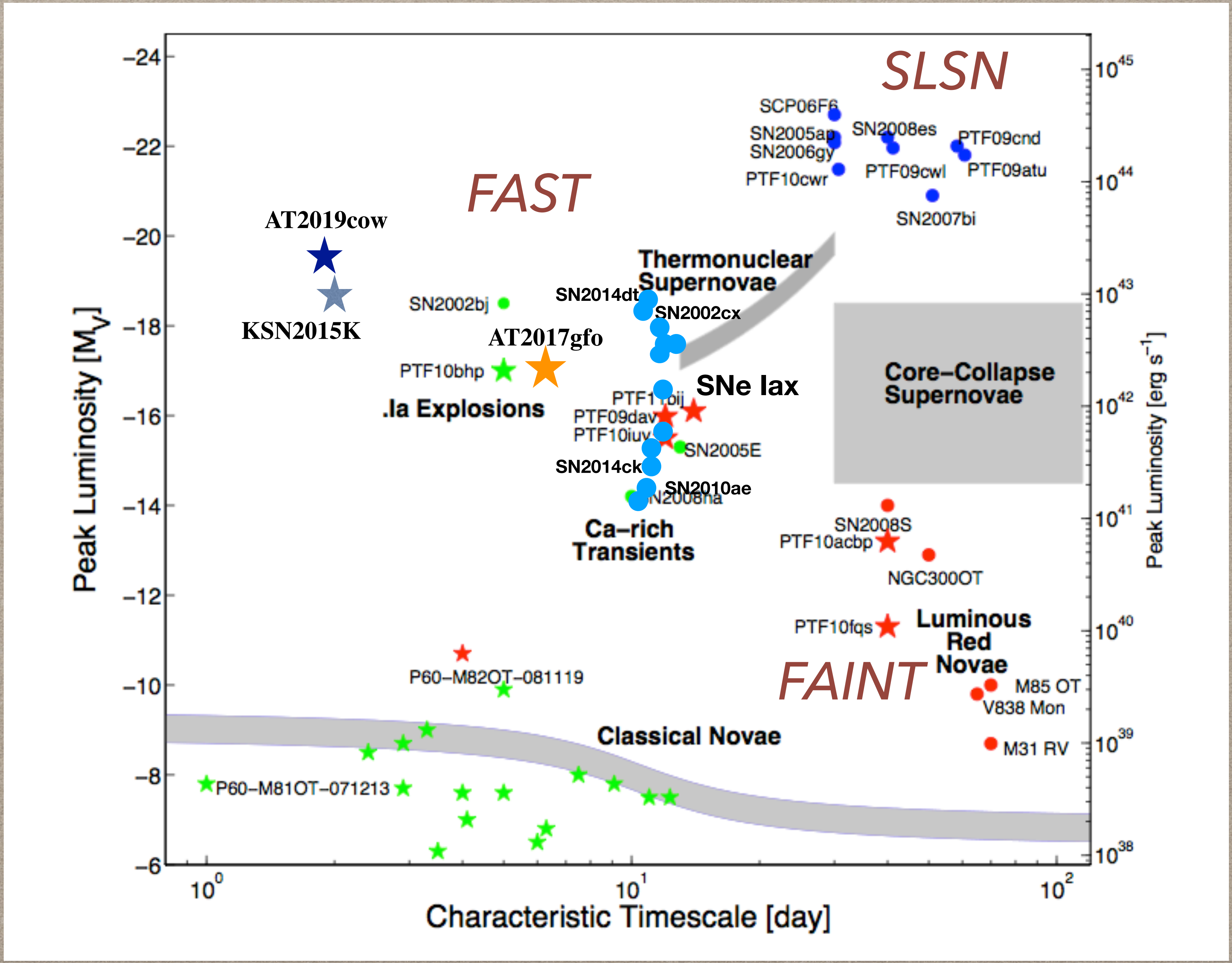
Three components

	mass (M_{sun})	velocity	log(X_{lan})	t_{rise}	t_{de}
- red	0.040	0.15c	-1.5	1d	15d
- green	0.025	0.30c	-4.0	2/3d	15d
- blue	0.025	0.30c	-5.0	<0.5d	2d



Modelling seems on the right track. Long lived NS scenario is favoured

TIME DOMAIN



adapted from Kulkarni 2012

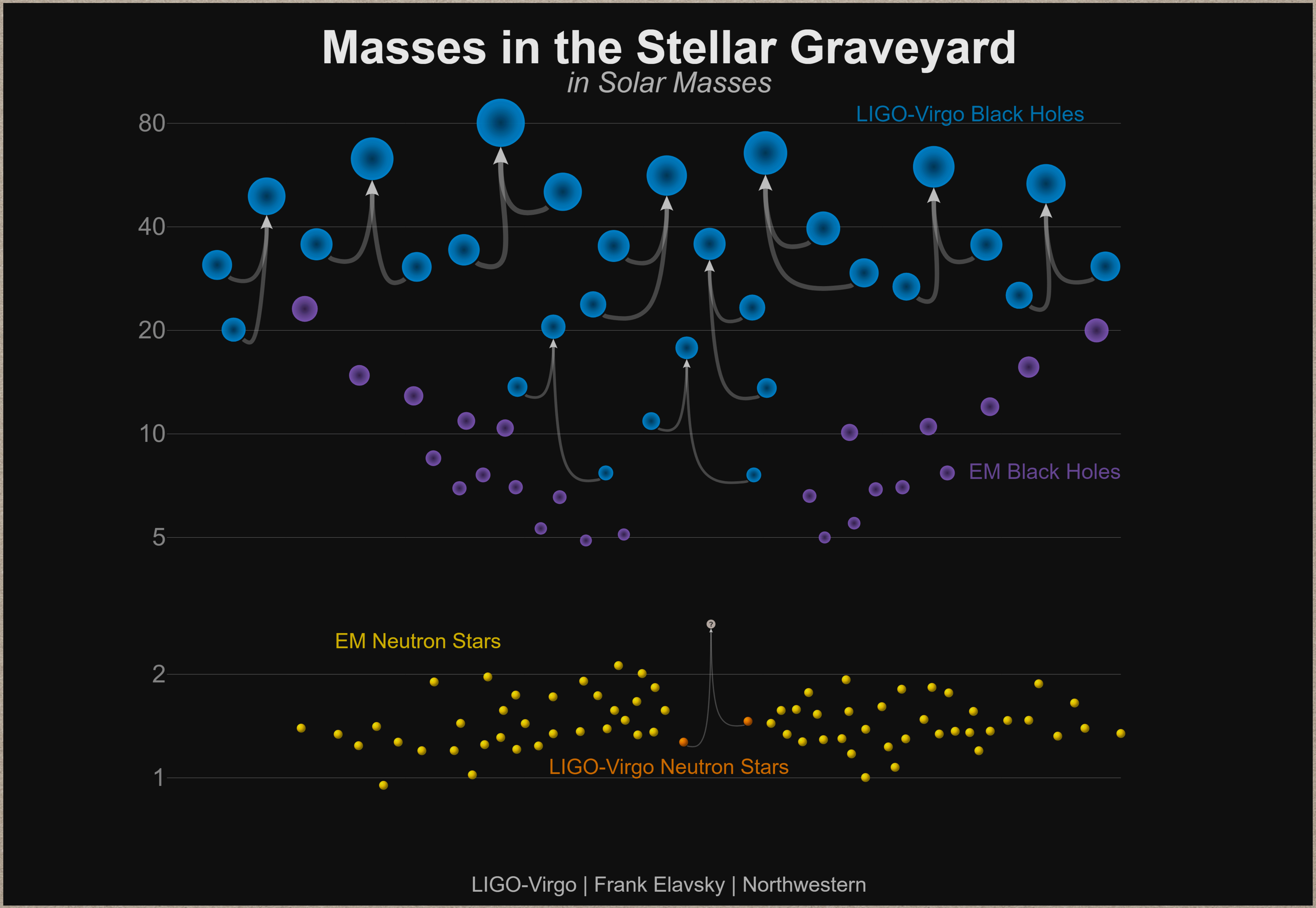
DISCOVERY OF A KILONOVA

Without GW signal AT2017gfo would not be discovered. Yet, kilo-novae are in a time domain that is monitored by current surveys

If all NS/NS merger produce kilonova they must be relatively rare

If we only had electromagnetic signal we will be left with some ambiguity.

Multi-messenger can break the degeneracy



Masses in the Stellar Graveyard

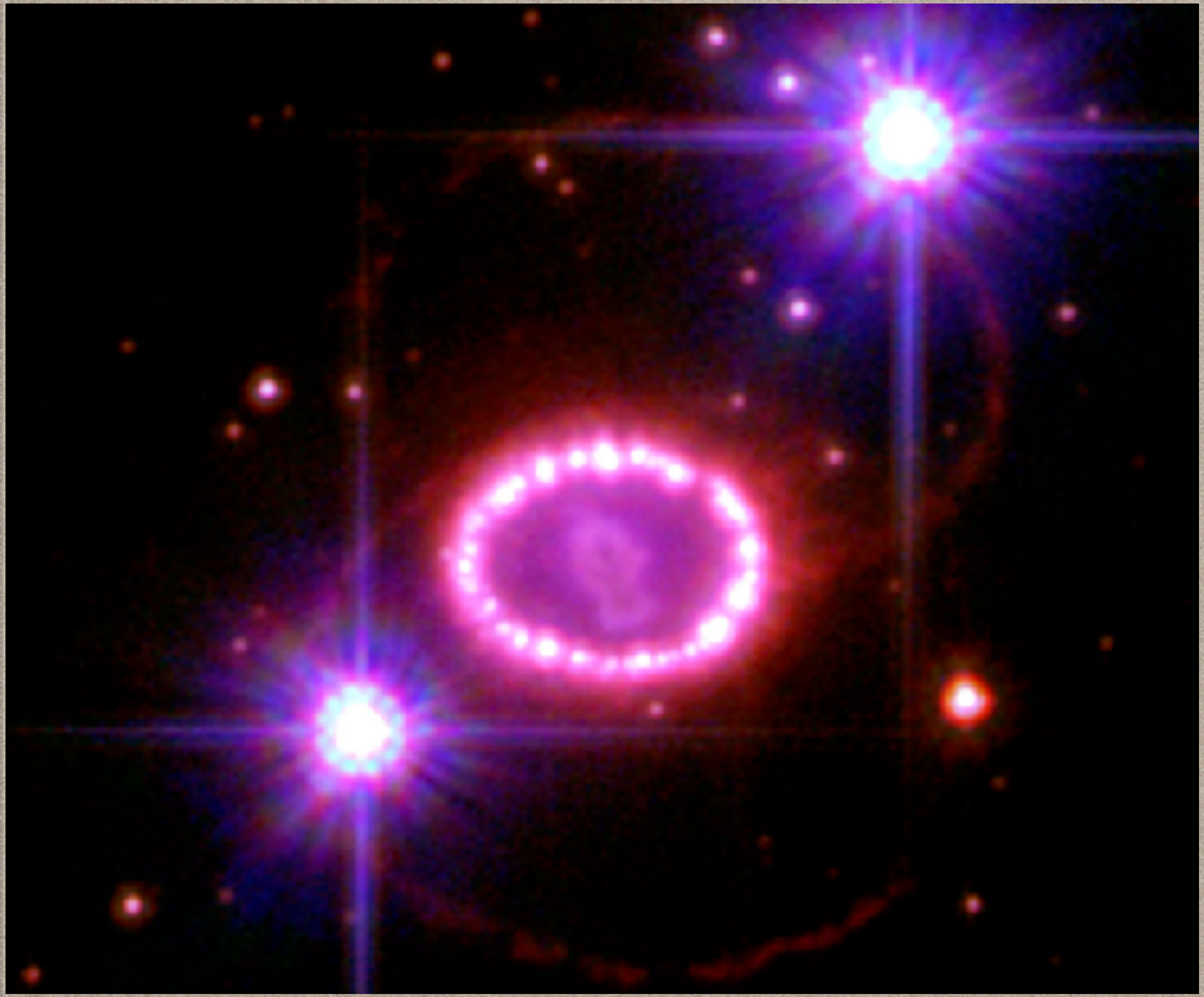
in Solar Masses

LIGO-Virgo | Frank Elavsky | Northwestern

THE FATE OF MASSIVE BINARY STARS

TRANSIENTS AND MULTI-MESSENGER

SN 1987A IN LMC



Progenitor direct identification

1-2 dozen progenitor detections

Detection of two dozen neutrinos

still unique

where is the neutron star (or the BH) ?

1985 Super-Kamiokande upgraded
1987 Nearest optical SN in ~400yr

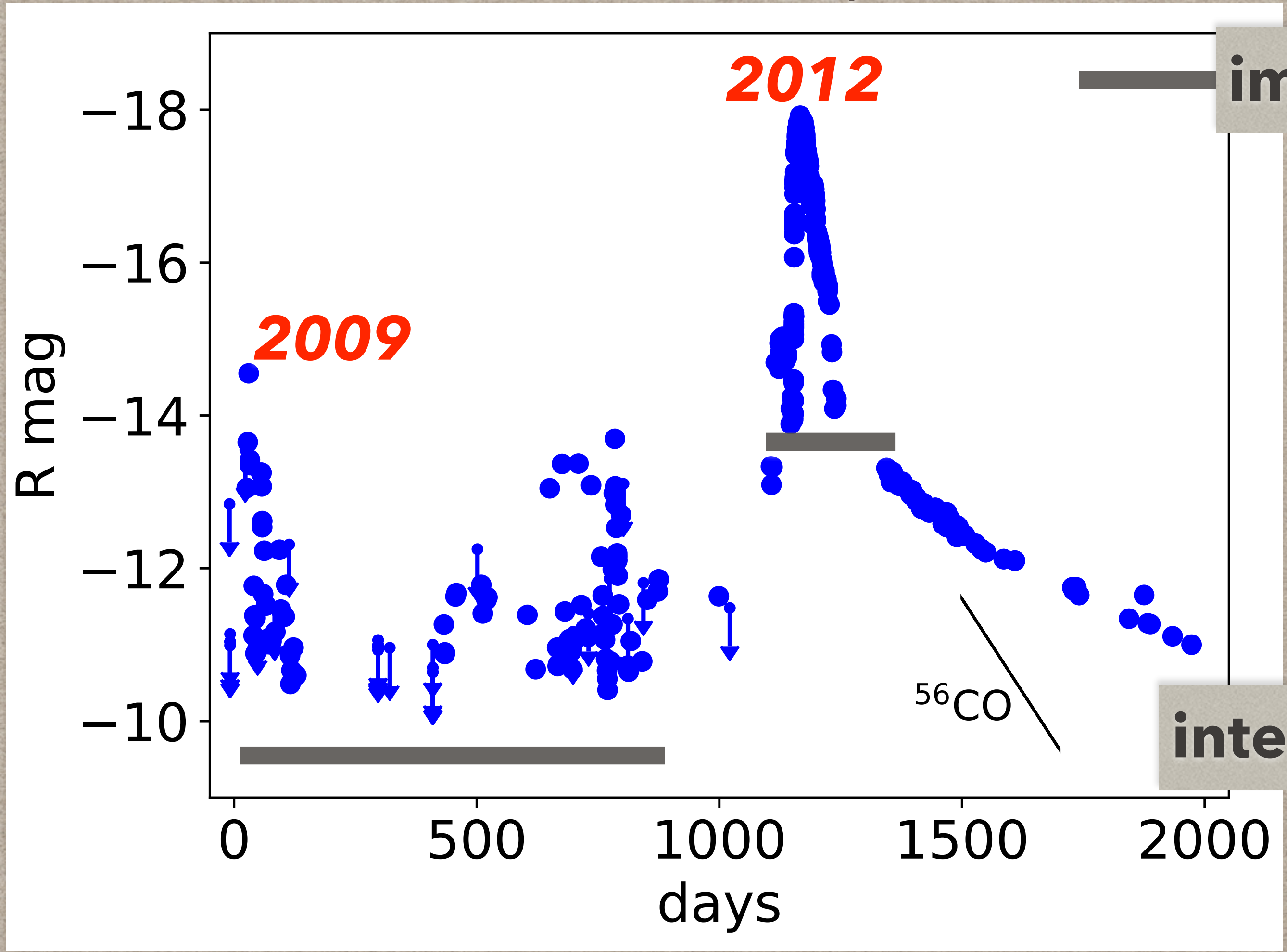
Schmitz & Gaskell 1988: ..... very common SN type .....

Pastorello et al 2012: ...... 1-3% of all core-collapse

FROM IMPOSTORS TO REAL SNE

SN2009IP

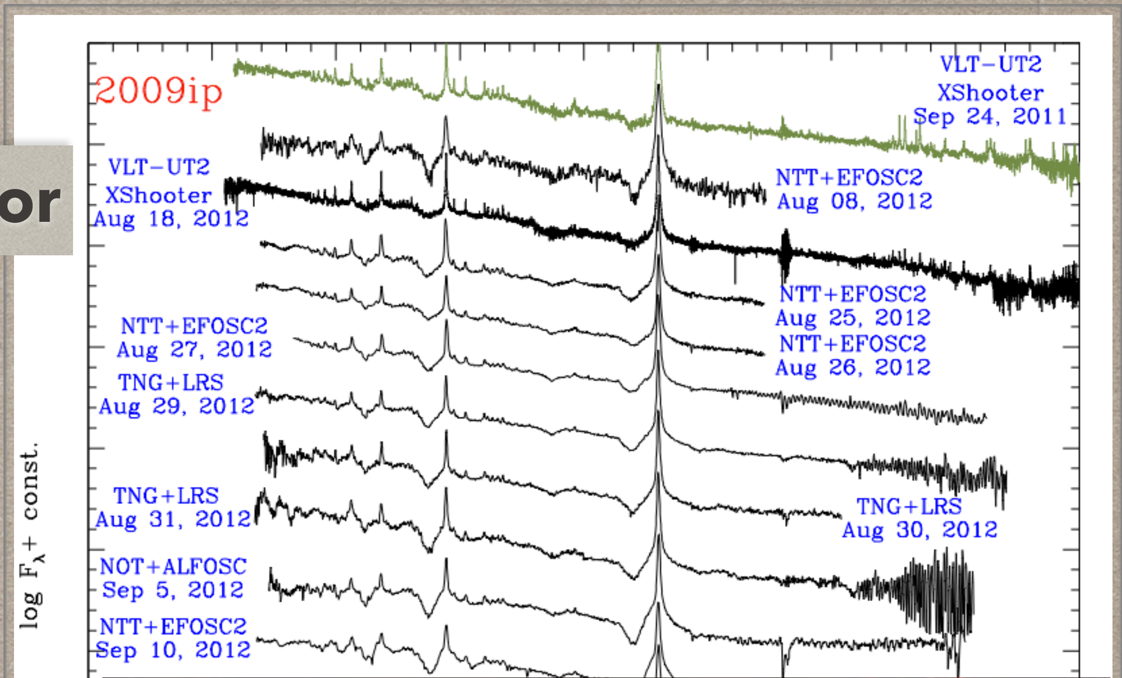
Pastorello et al. 2013 ApJ 767,1
Frazer et al. 2015 MNRAS 453, 3886

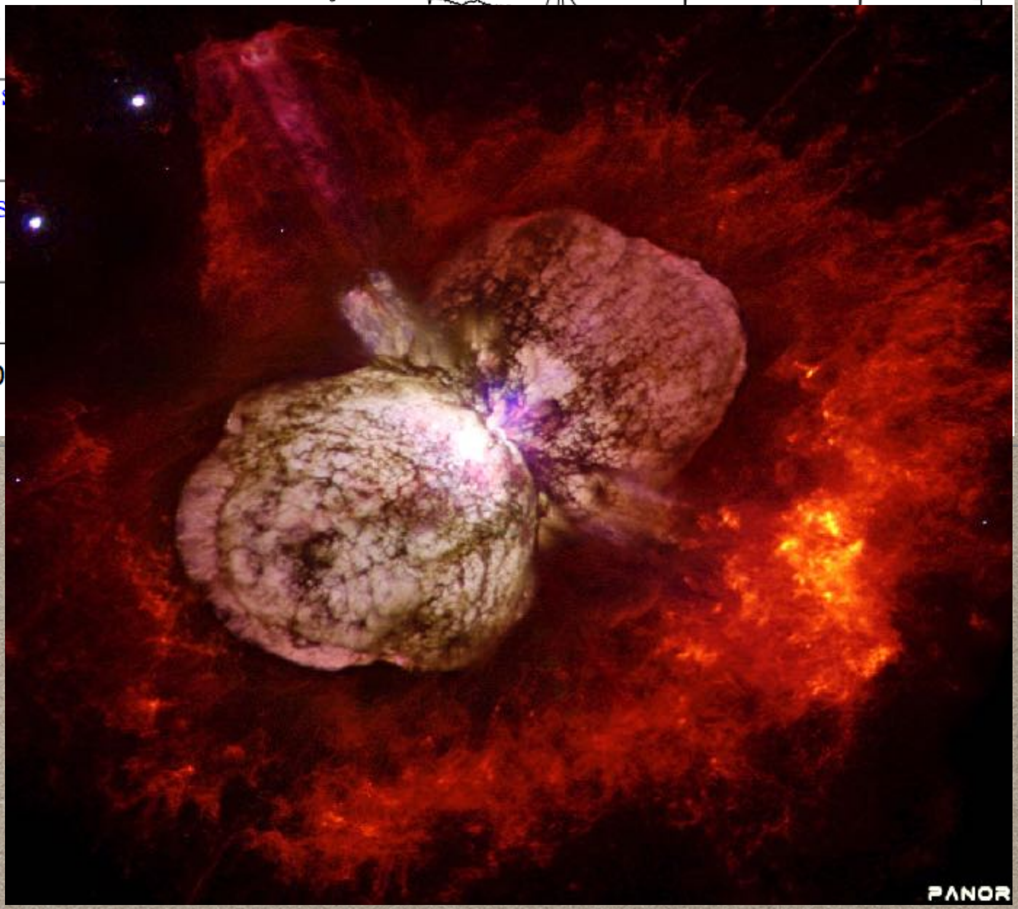


impostor

SN

interaction



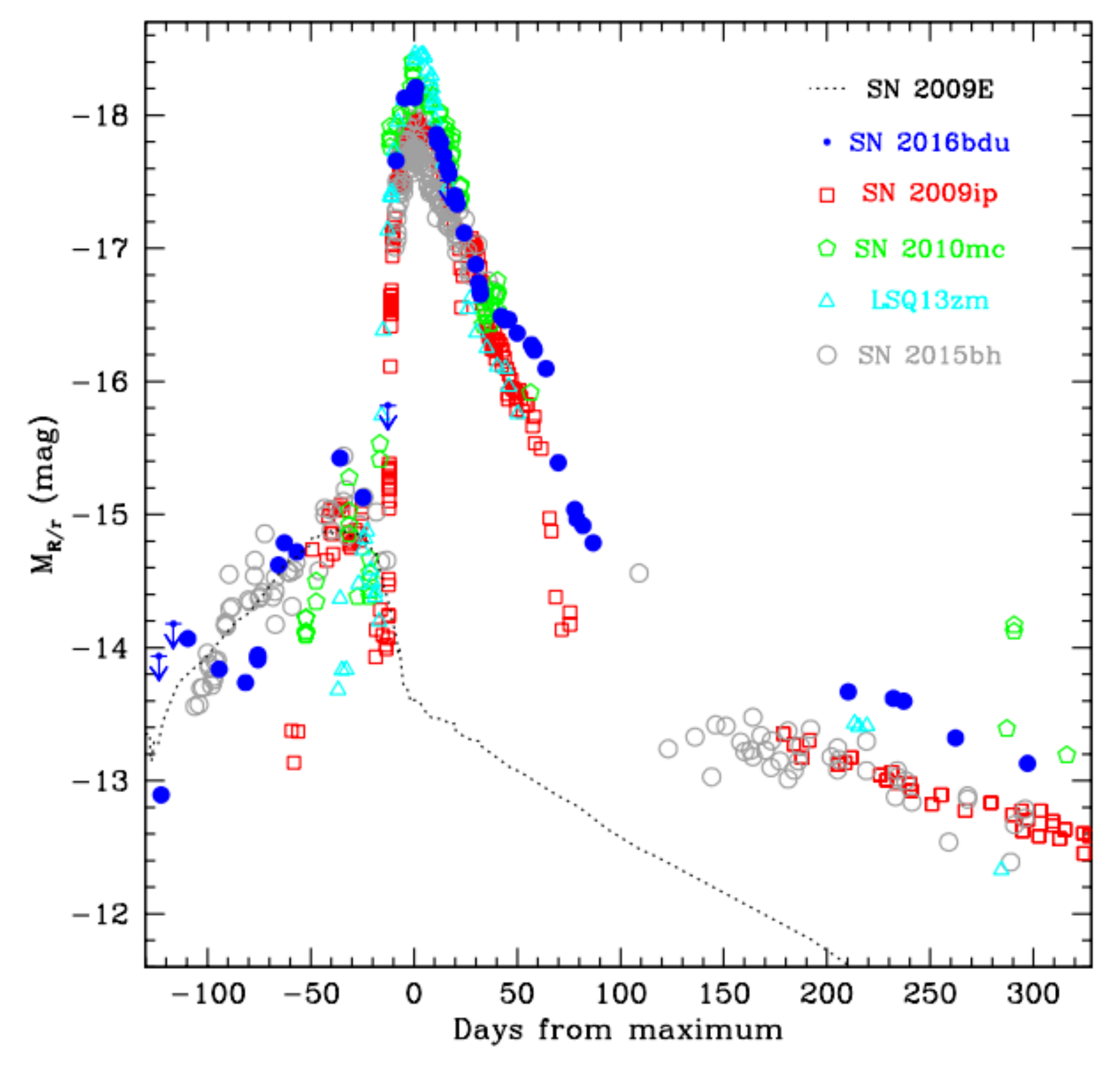


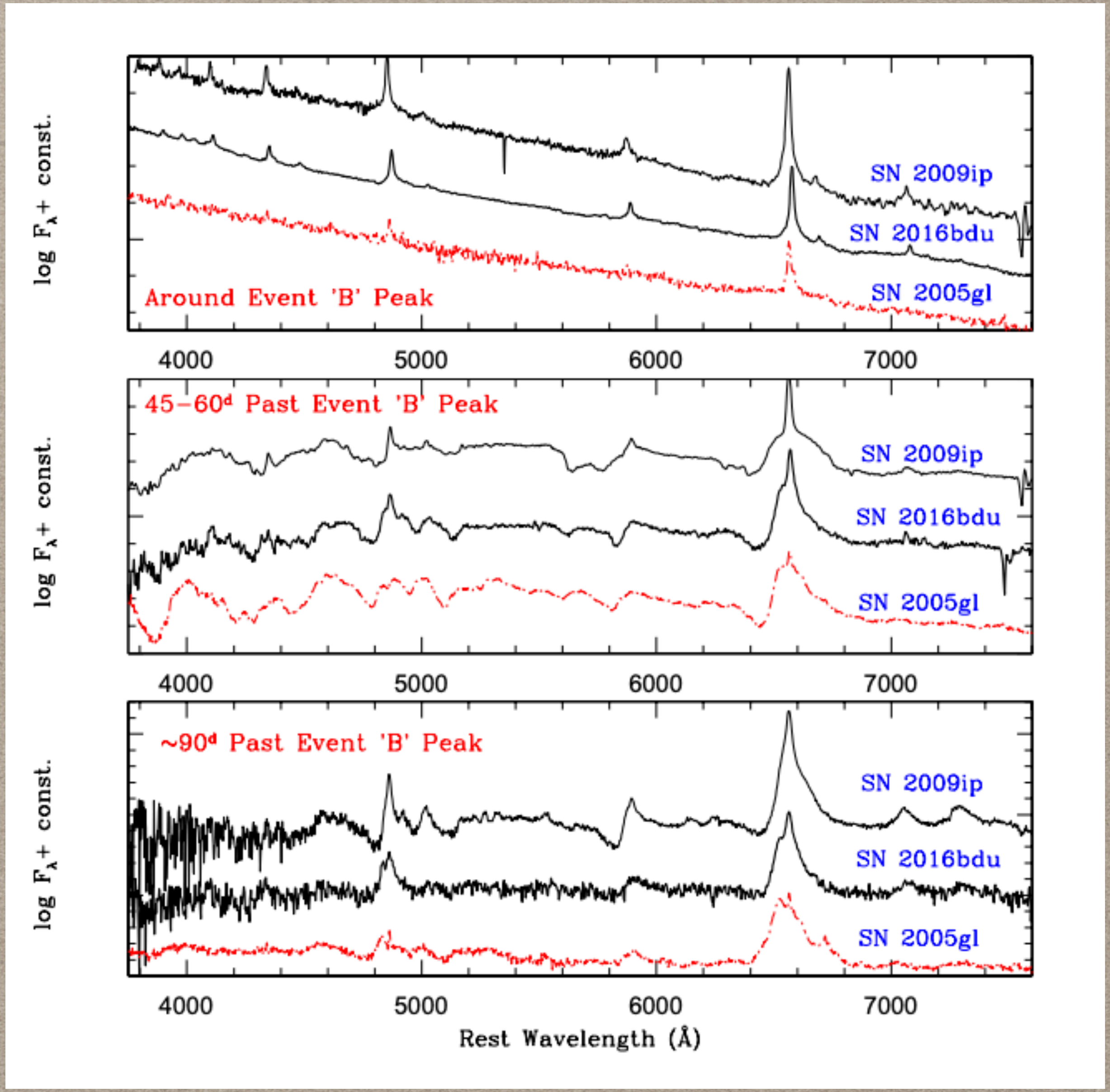
A binary system with:
LBV 150-250 $M_\odot$ (30 $M_\odot$ mass loss)
hot supergiant 30-80 $M_\odot$

FROM IMPOSTORS TO REAL SNE

clones are being discovered (too many ?)

Pastorello et al. 2018





STELLAR MERGERS ARE COMMON

Kochanek et al. 2014

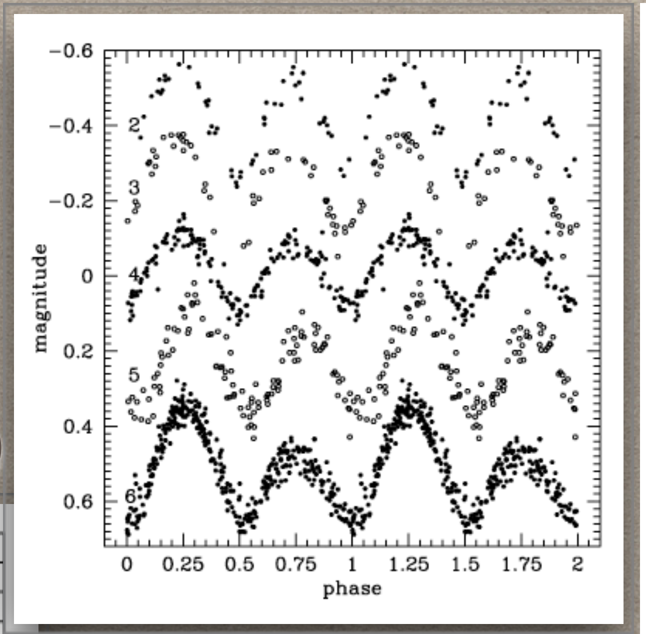
V838 Mon: A major outburst in 2002 (Munari et al. 2002)

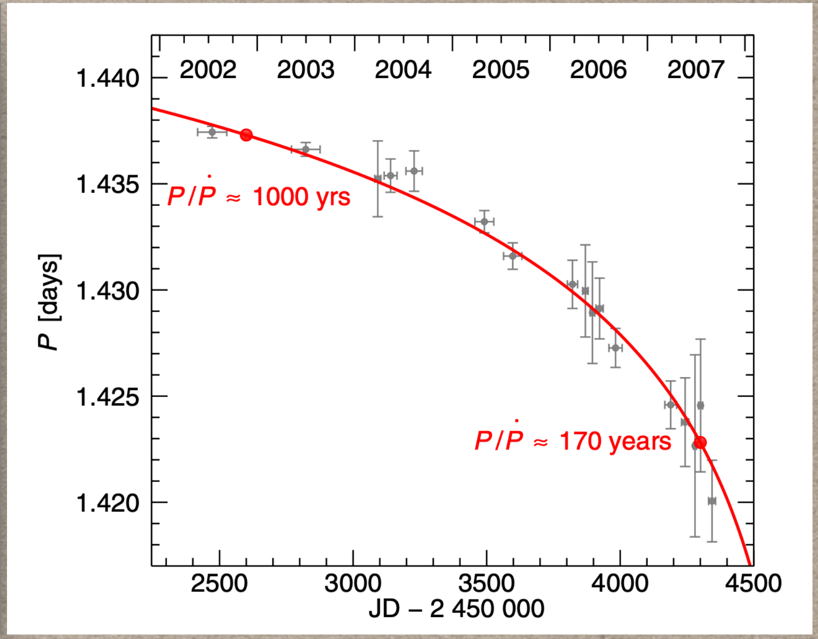
Most likely the merger of 5-10 $M_\odot$ + 0.3 ? $M_\odot$ (Tylenda & Soker 2006)

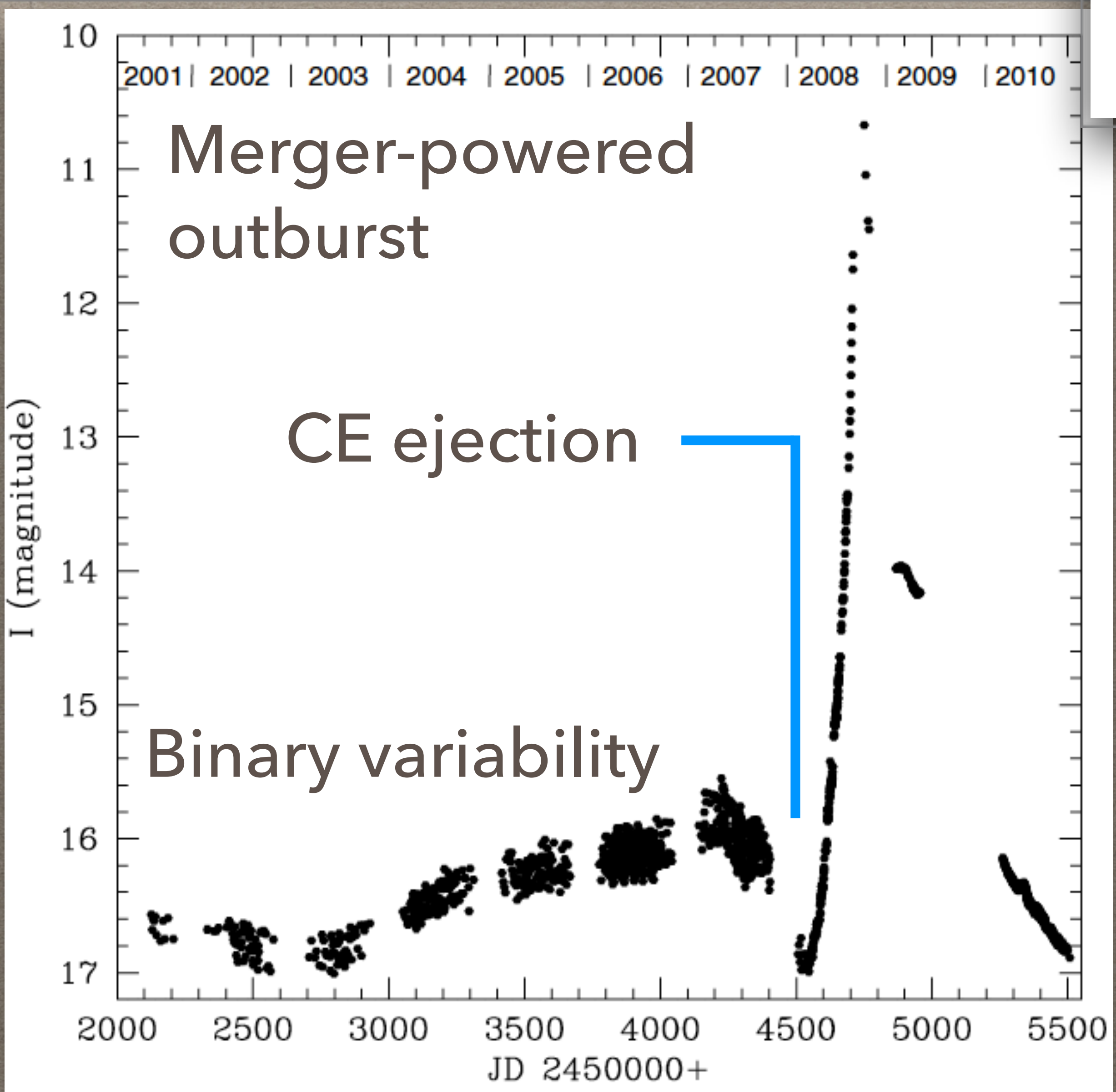
STELLAR MERGER V1309 SCO

Tylenda et al. 2011, A&A, 528, A114
(see also Mason+ 2010, A&A, 516, A108)

2002-2006







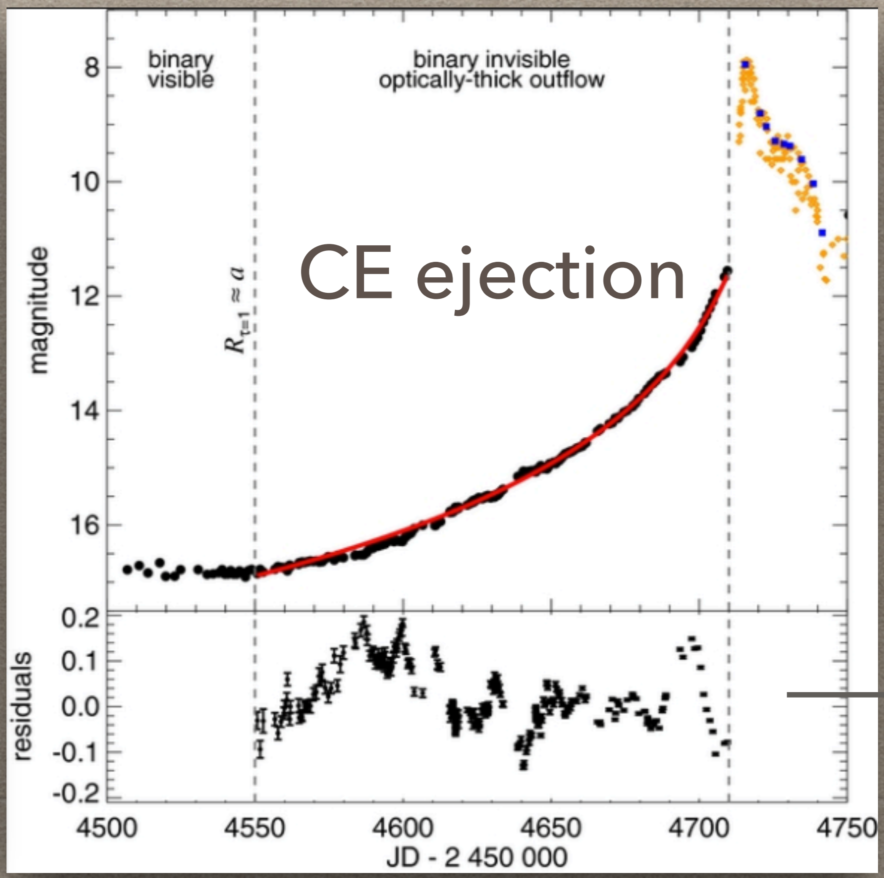
Merger-powered outburst

CE ejection

Binary variability

2007

Merger-powered outburst



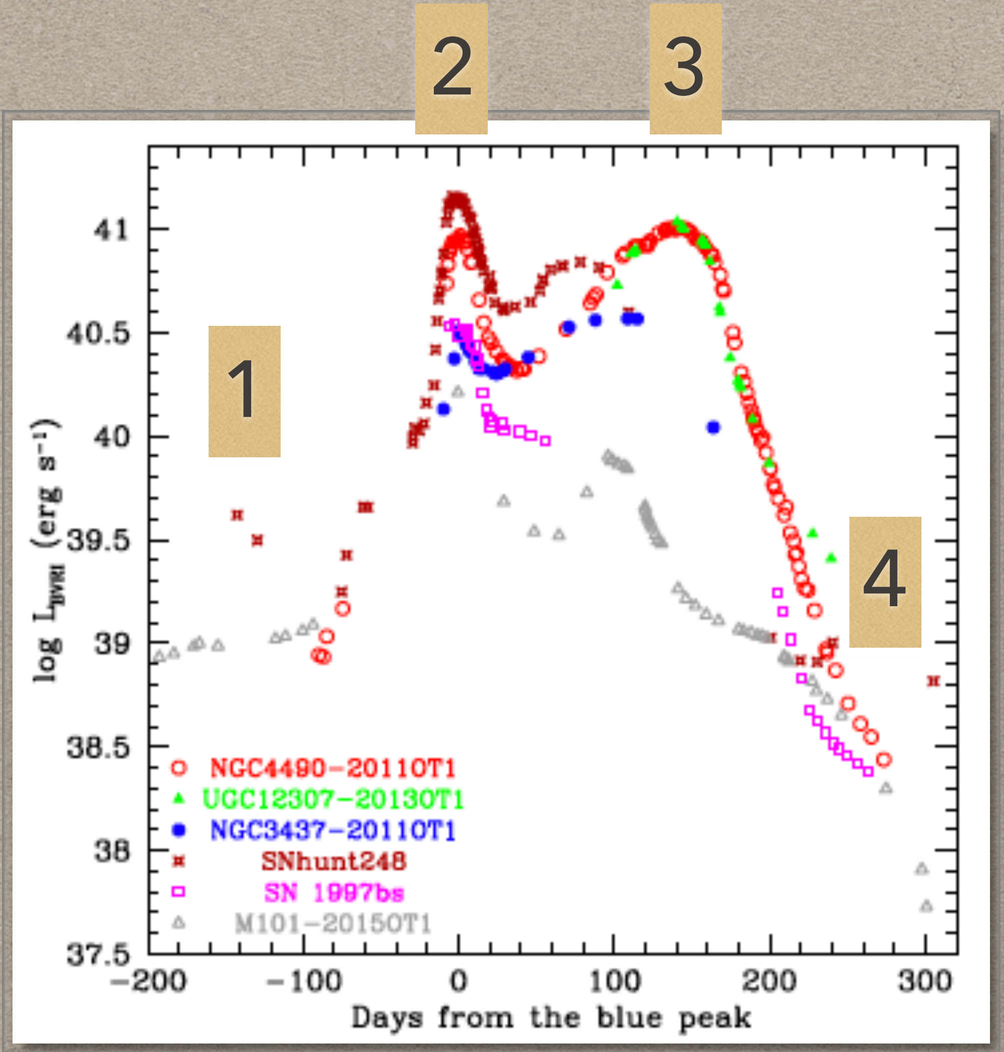
CE ejection

→ ***G to M-type***

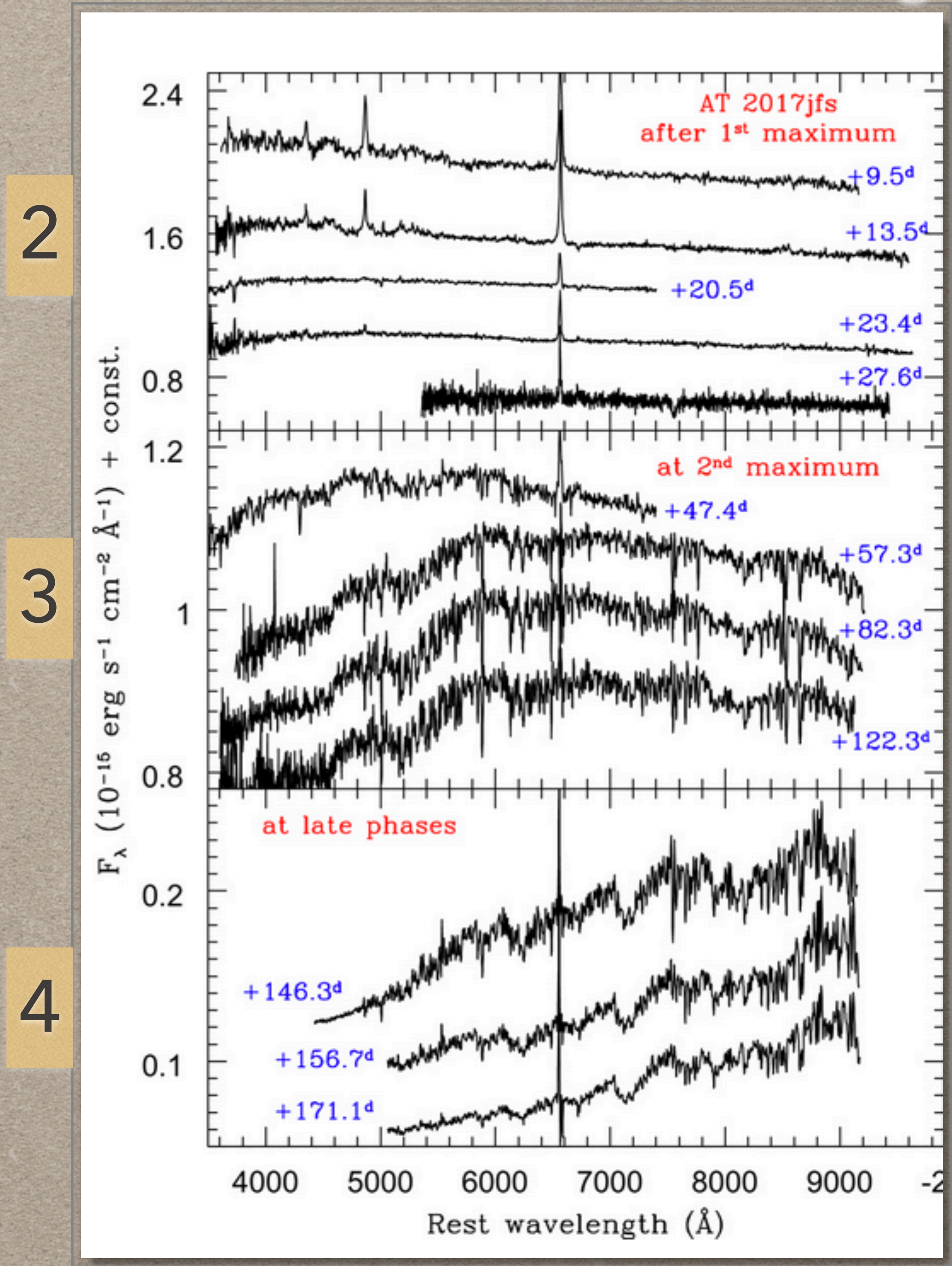
STELLAR MERGERS

Peak absolute magnitudes:

- RNe: $M_V < -10$ (to -4) mag
- LRNe: $M_V > -10$ (to -15) mag



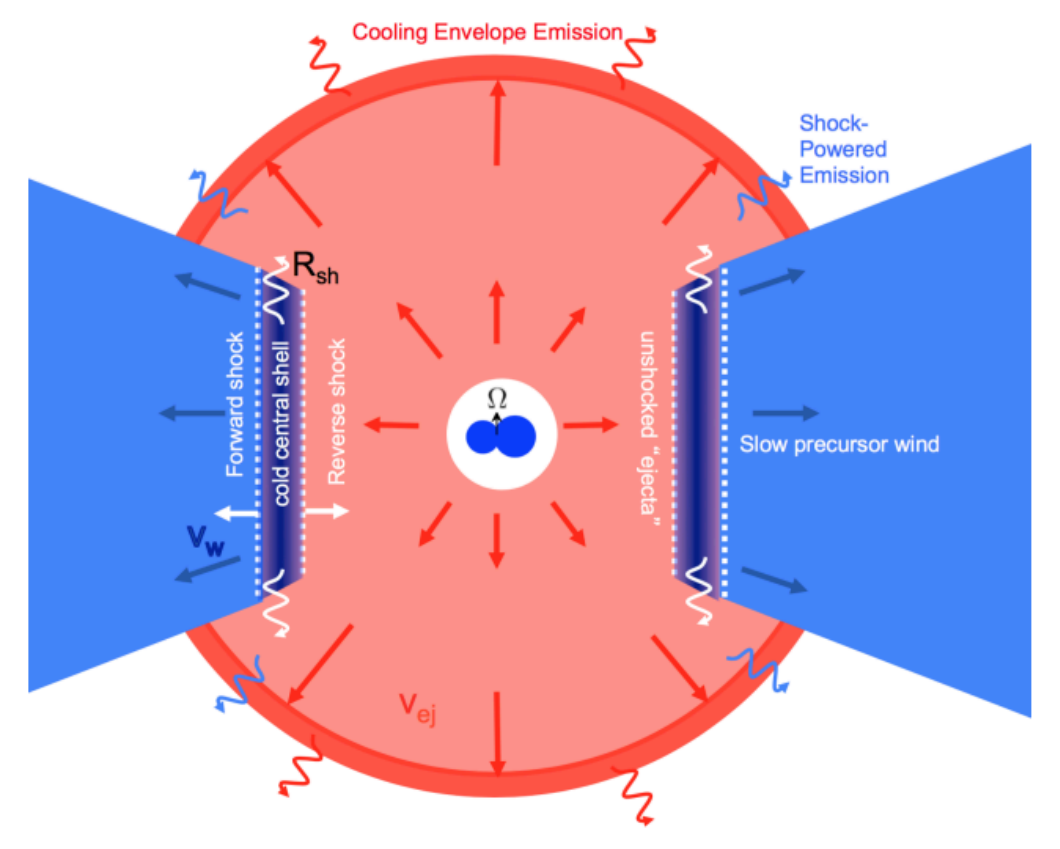
1. Pre-outburst brightening
2. Early short-duration blue peak
3. Late red peak or a plateau (forest line FeII, ScII, TiII)
4. Rapid decline. Molecular bands



Pastorello et al. 2019a A&A, 630, A75

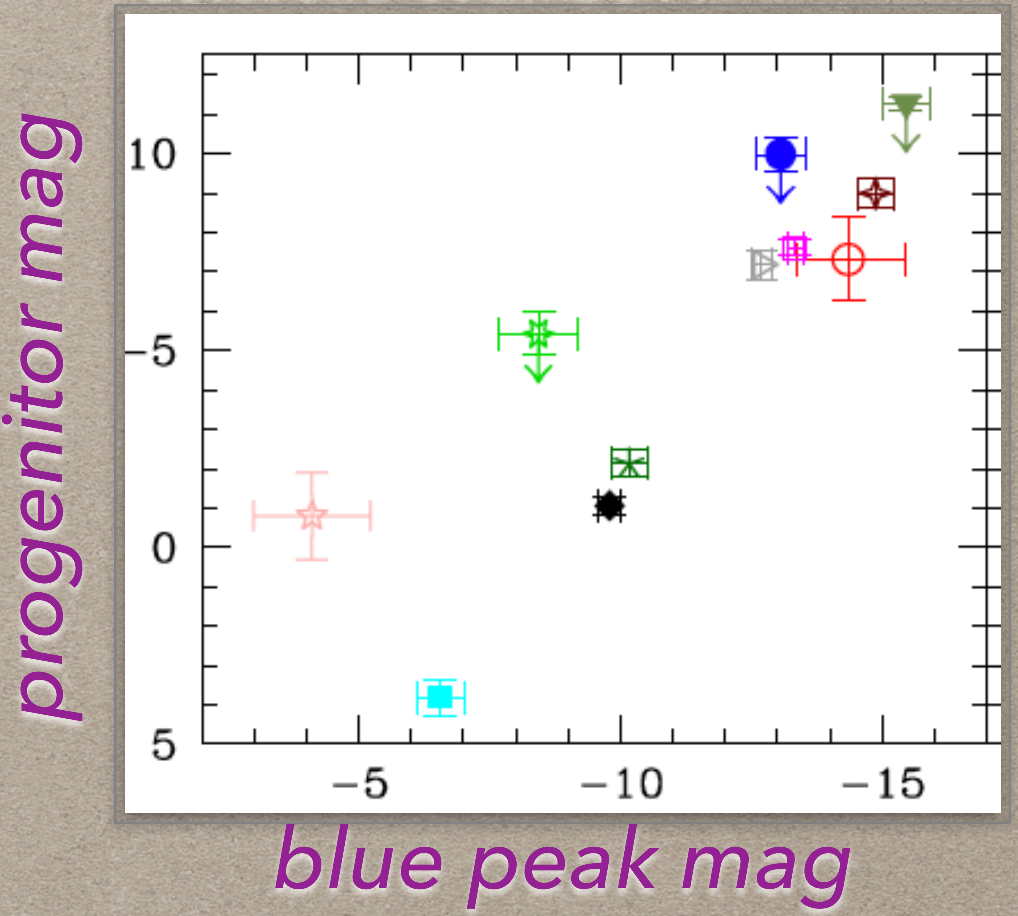
STELLAR MERGERS

Metzger & Pejcha 2017



- I peak: fast ejecta expanding in polar direction
- II peak: shock in the equatorial plane
- red tail: dust formation in a coll dense shell

Pastorello et al. 2019

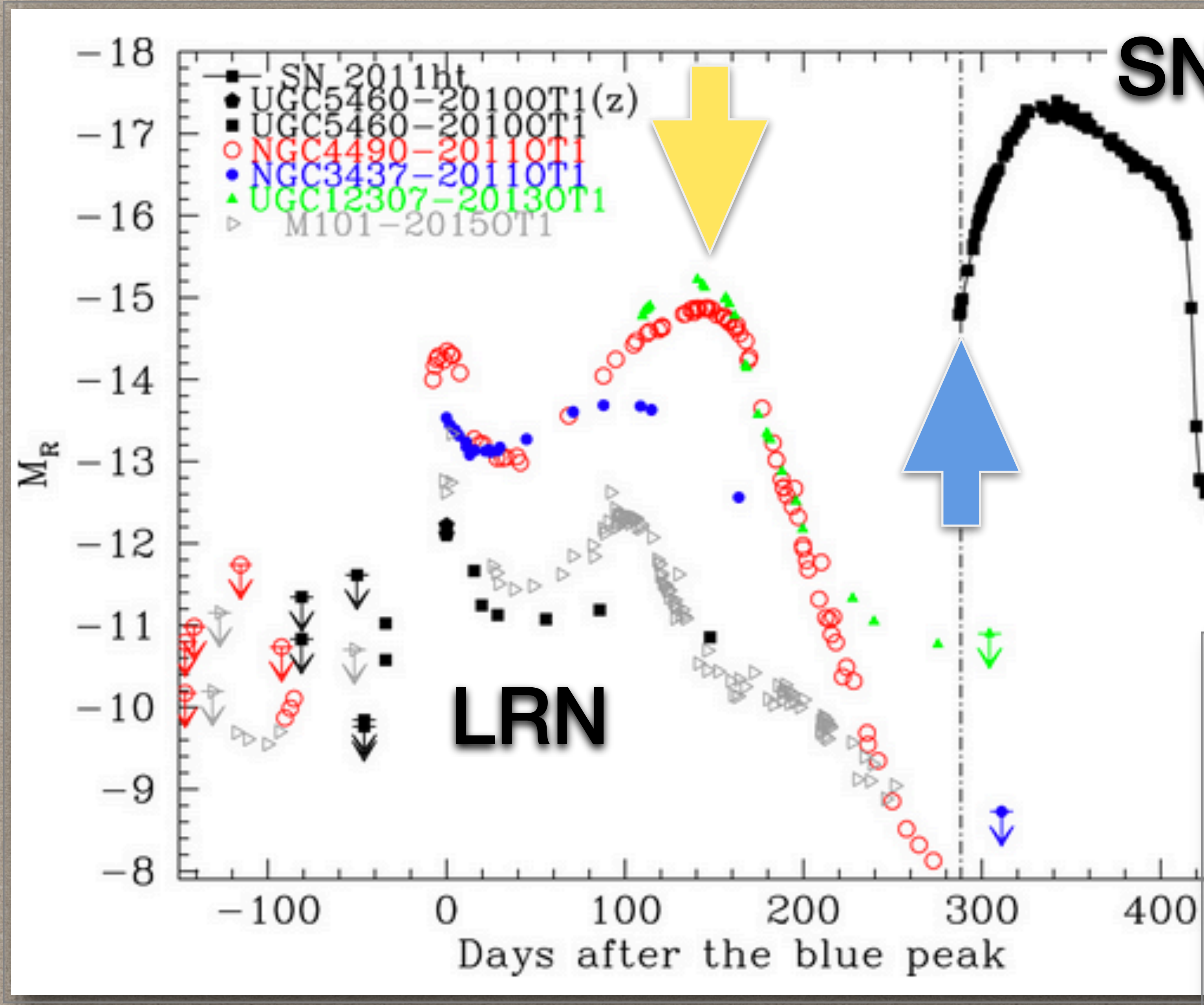


$L \propto M^{2\text{-}3}$ *Kochanek et al. 2014*

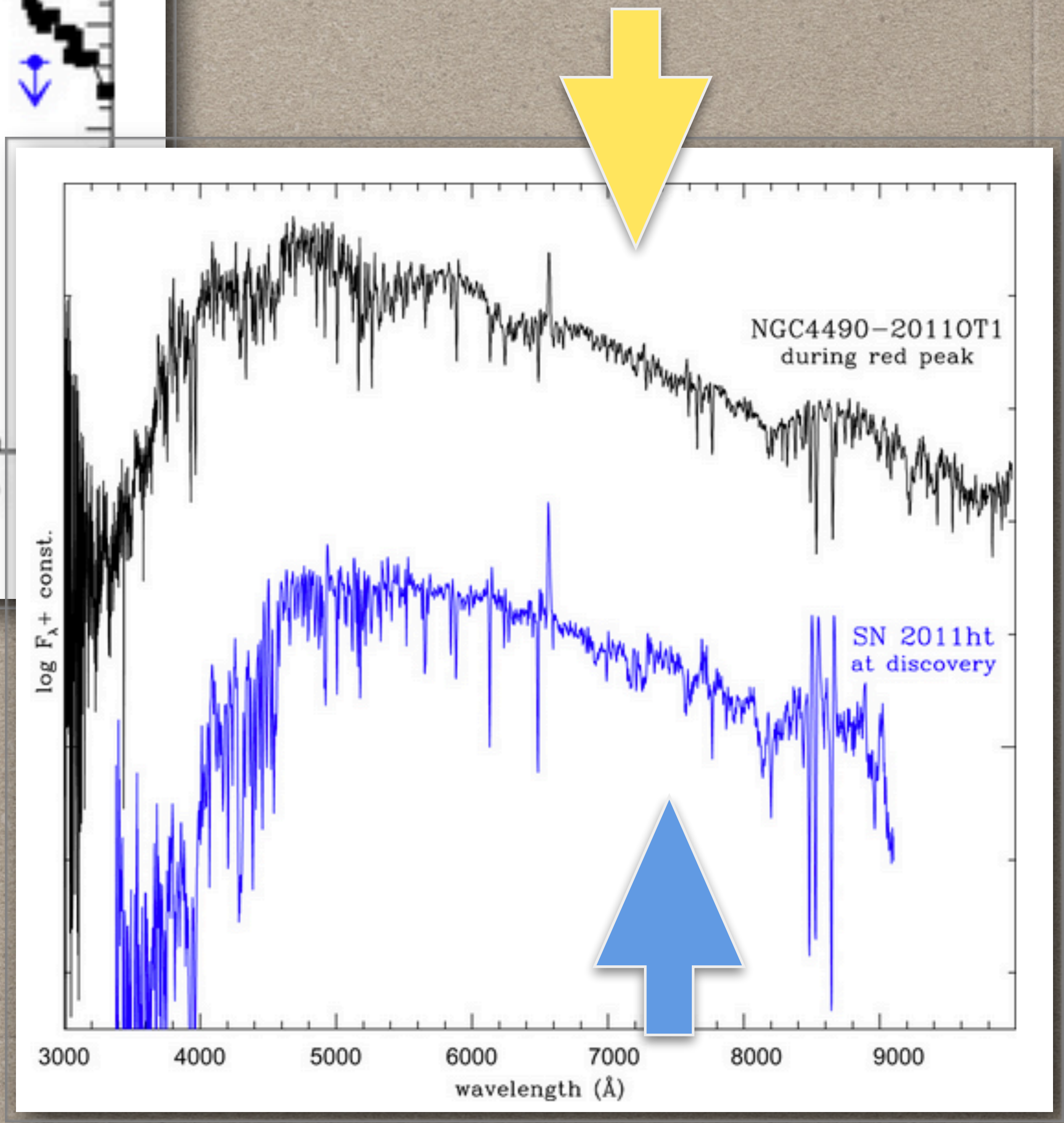
Current discovery rates

- 1-2 per decade in the MW
- 1-2 per year within 40 Mpc

LRN
TO
SN IIN?



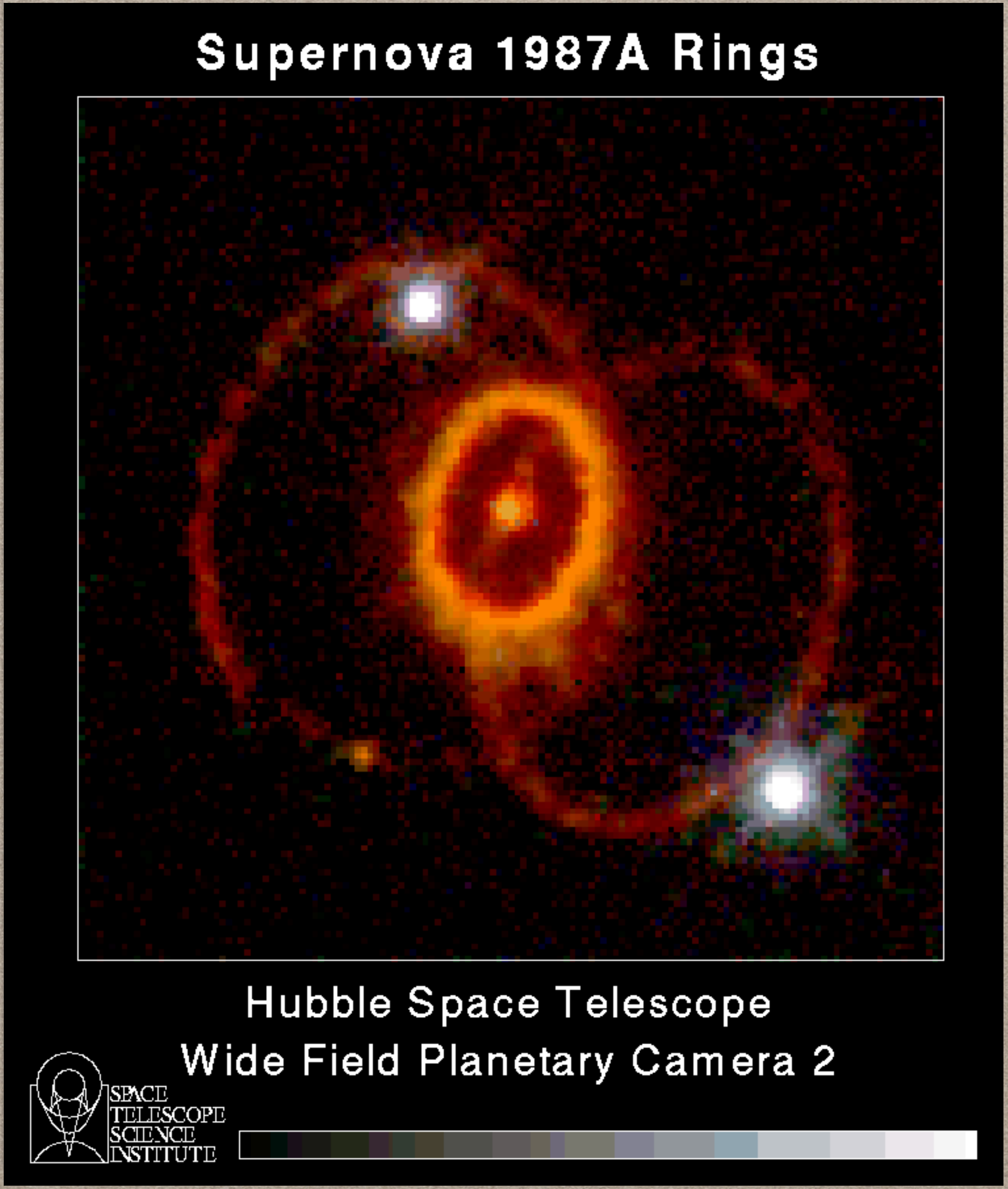
Pastorello et al. 2019a, A&A, 630, A75

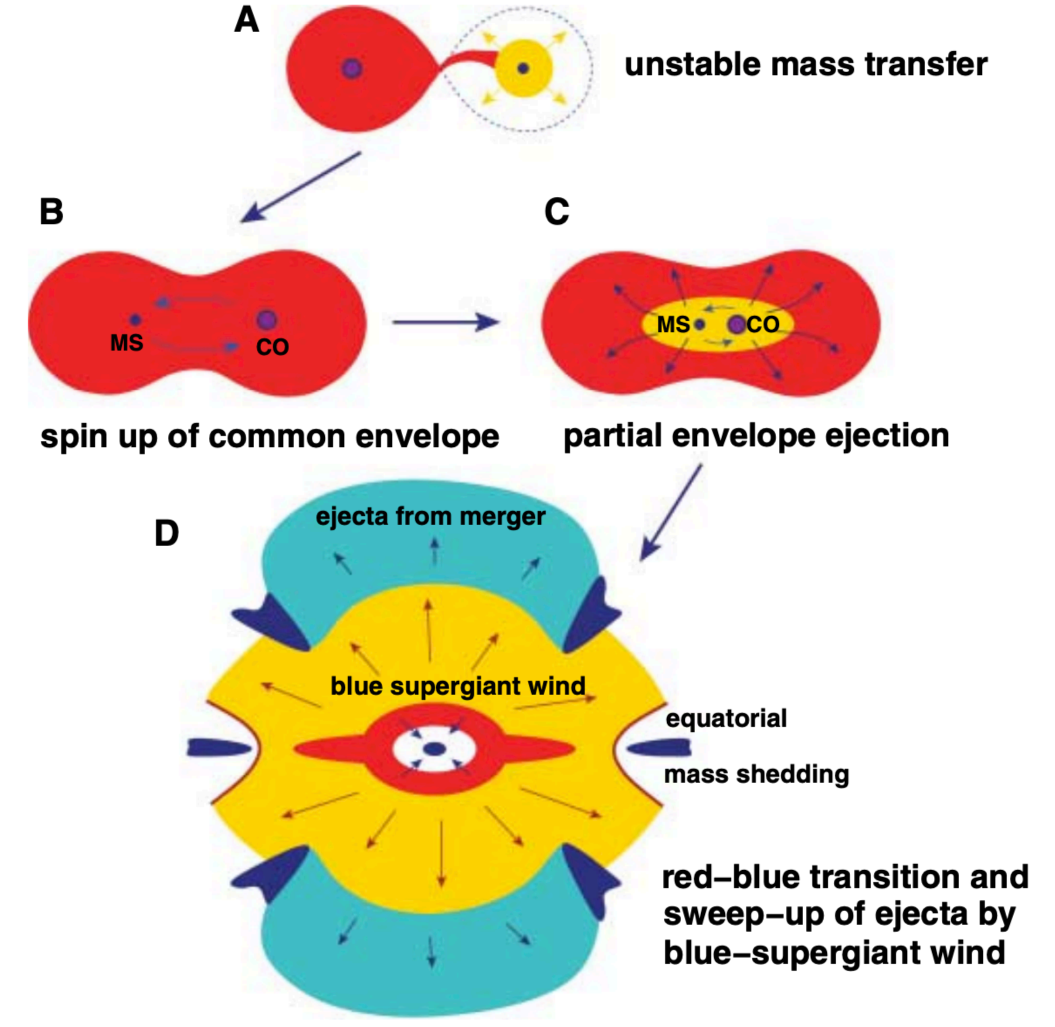


LRN TO SN II

Morris & Podsiadlowski 2007

Merging of a 15M⊙ and a 5M⊙ 20.000 yr ago explains the blue supergiant progenitor and the triple ring



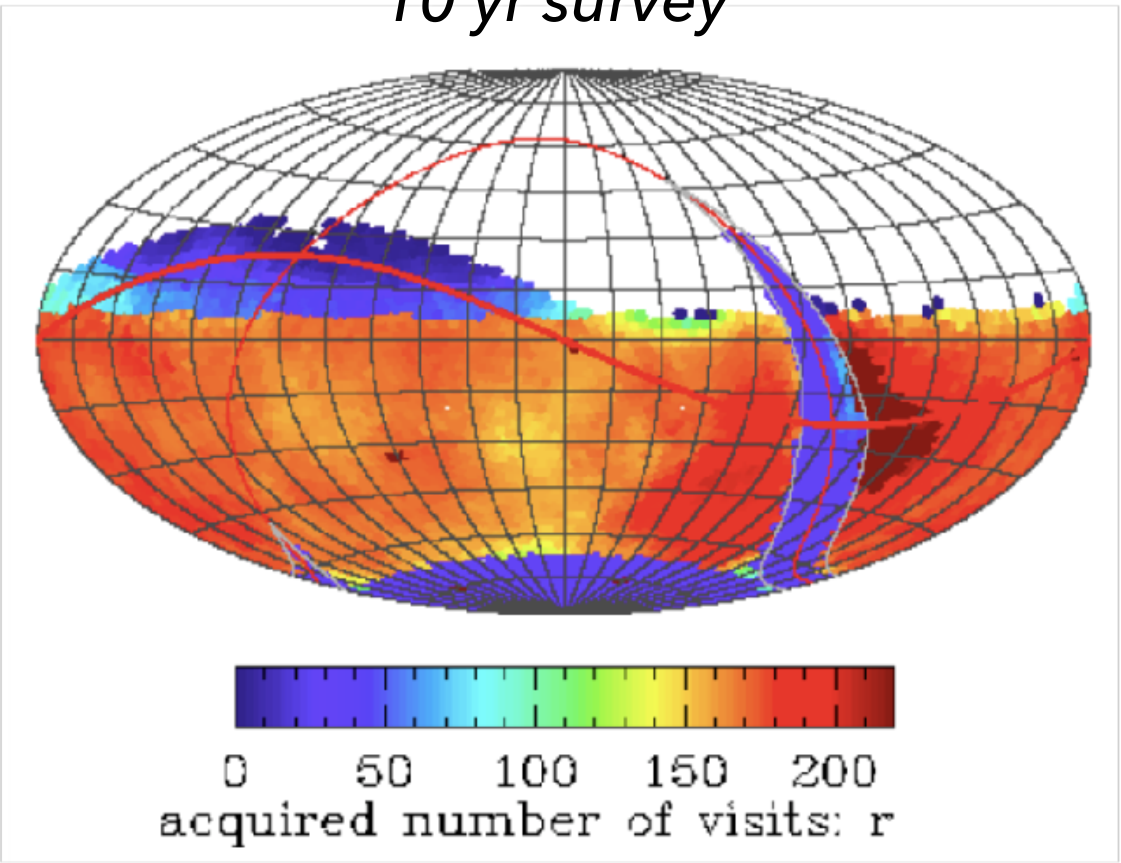


Current transient alert rate ~40 x night

8.4m telescope
FoV 9.6 deg^2

The Large Synoptic Survey Telescope Corporation

10 yr survey



10.000 deg^2 per night

limit 24 mag × visit.
stacked mag 27

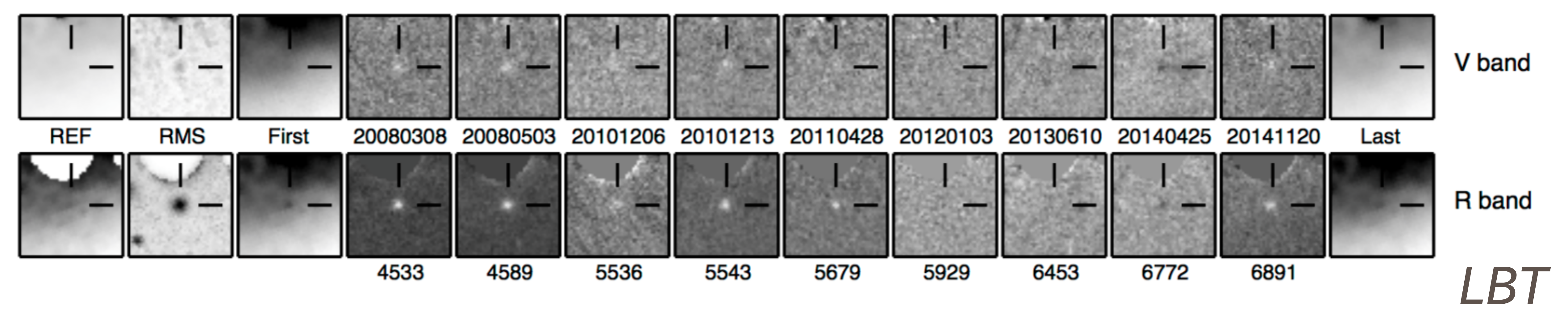
real time alert latency 60 sec

start 2024

alerts per night 10.000.000

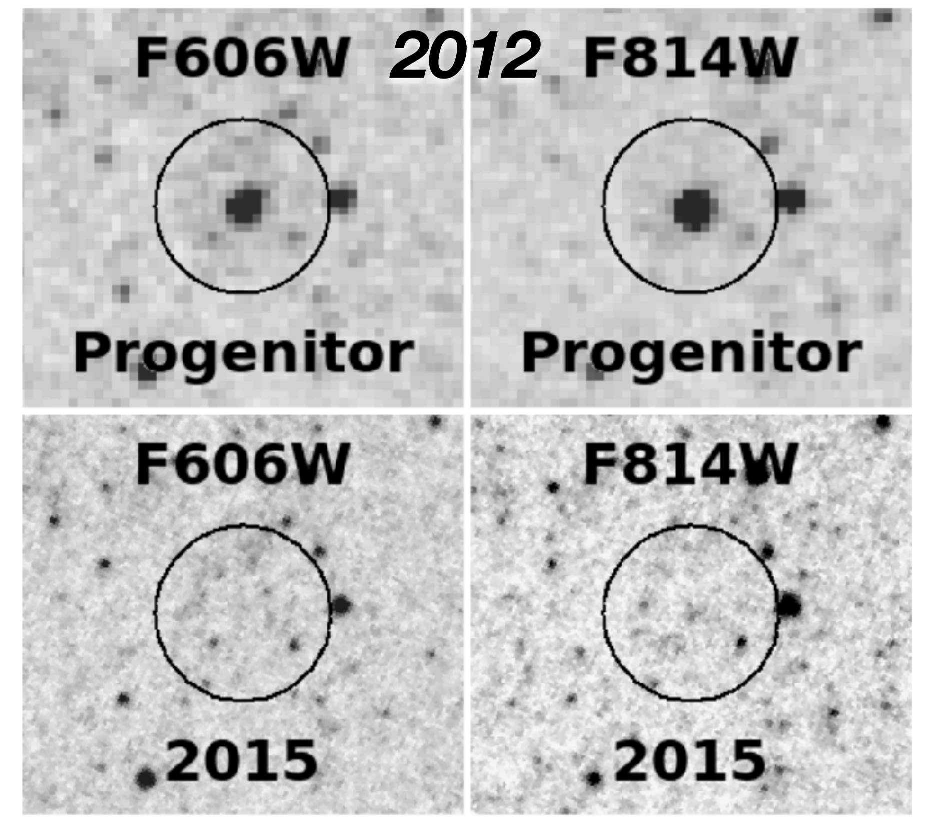
SEARCH FOR FAILED SUPERNOVAE

Gerke et al. 2015 MNRAS 450, 3289



Adams et al. 2017

HST



A best candidate for direct collapse to black holeof a 25 $M_\odot$ RSG star

Not yet confirmed

Correlation of the rate of Type Ia supernovae with the parent galaxy properties: Light and shadows

Greggio & Cappellaro 2019