SUPERNOVAE

an observational perspective

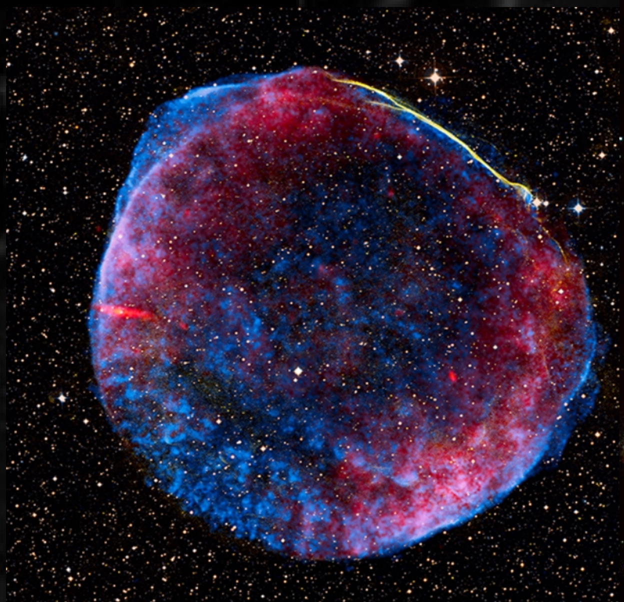
Jozsef Vinko

Konkoly Observatory CSFK, Hungary
(Univ. of Szeged, ELTE University)

***PUMA22** meeting*

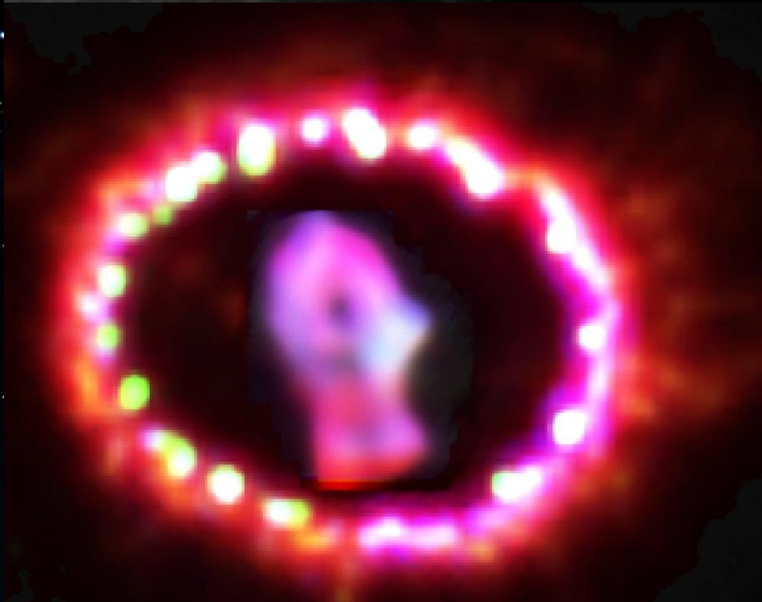
Sestri Levante, 2022. 09. 26-30.

Supernova explosions



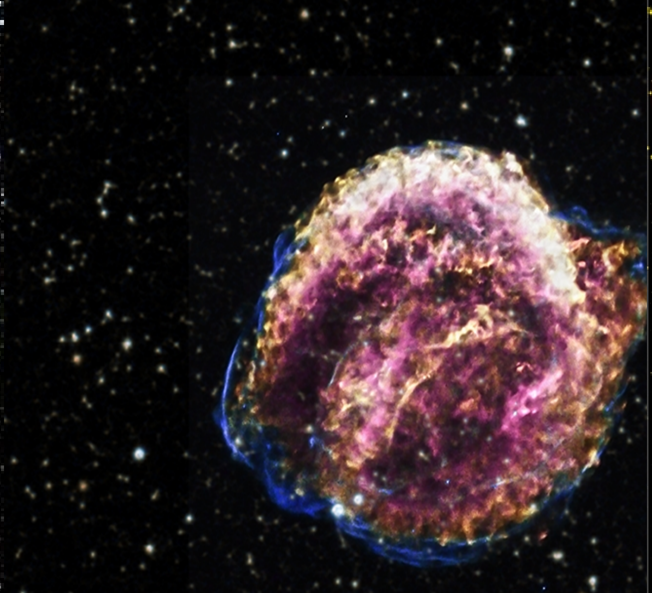
SN 1006

SN 1054 (Crab Nebula)



SN 1987A

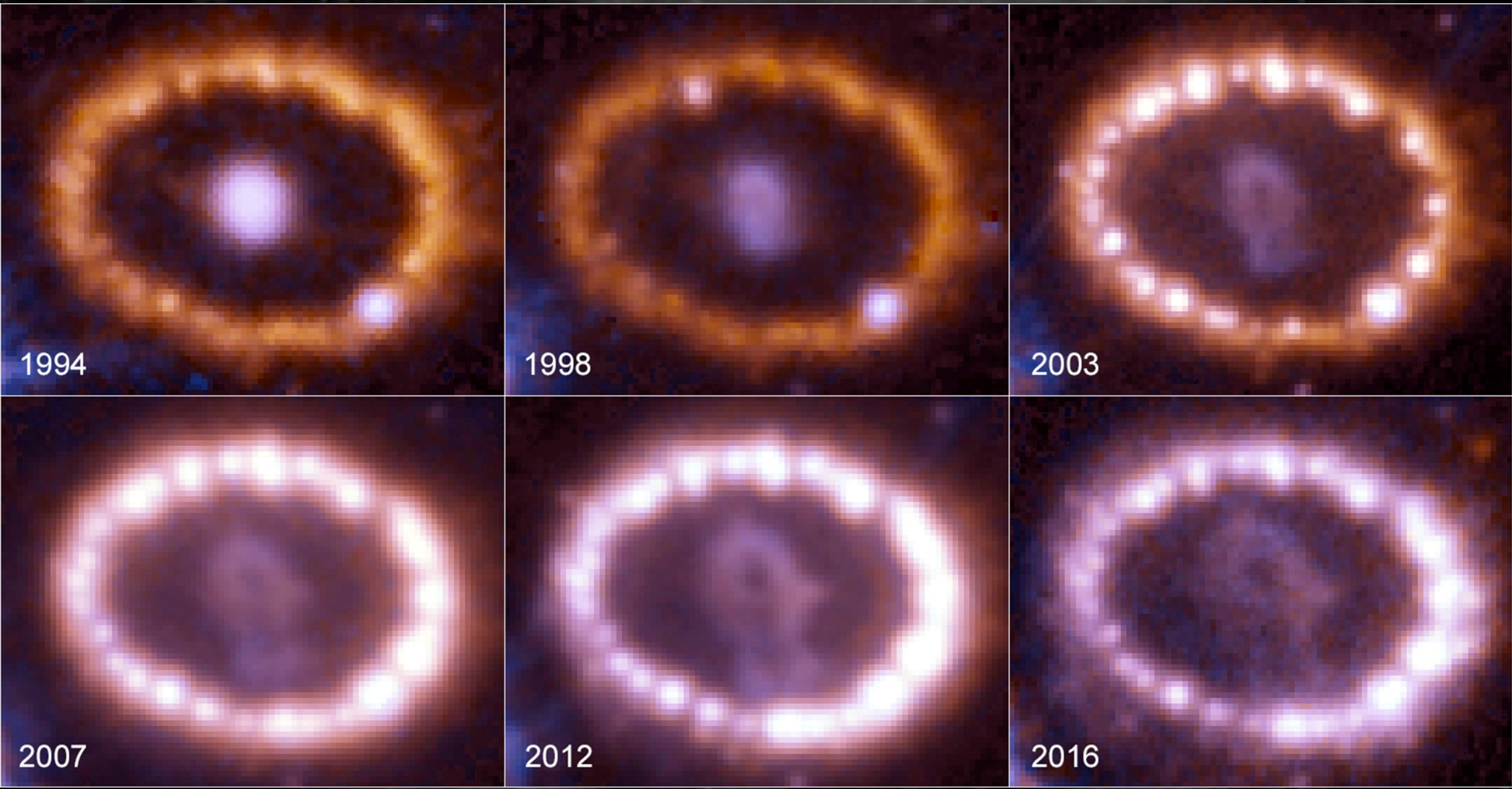
SN 1572 (Tycho)



SN 1604 (Kepler)

SN 1667 (Cas A)

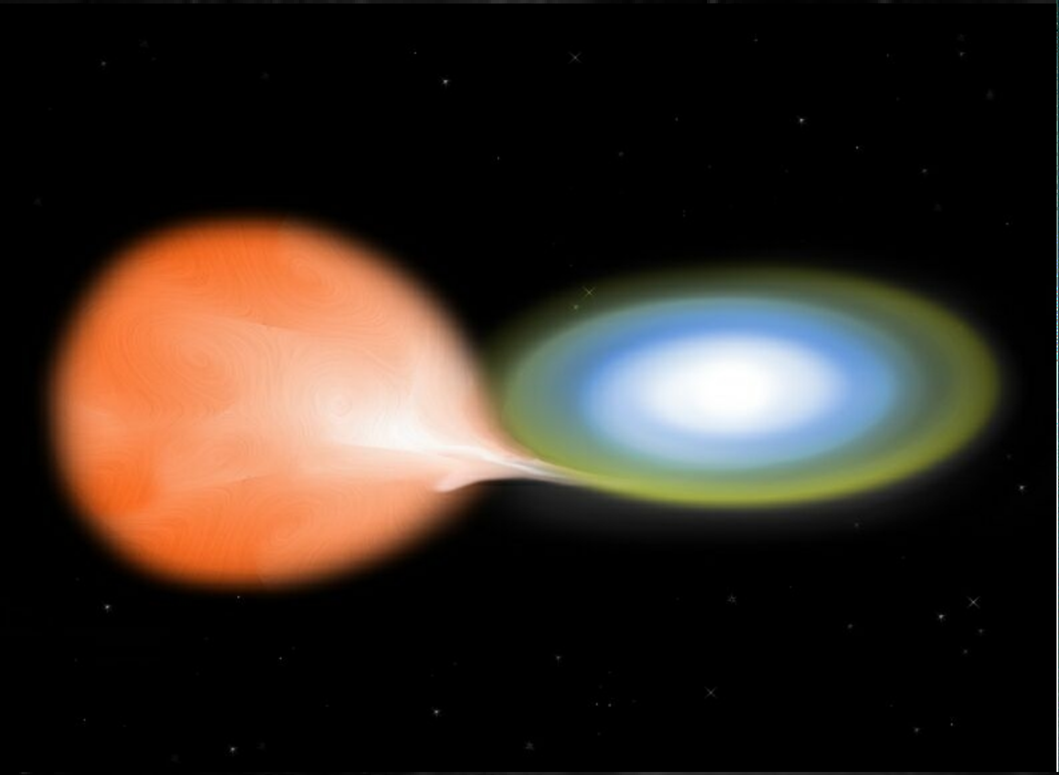
Circumstellar interaction in SN 1987A

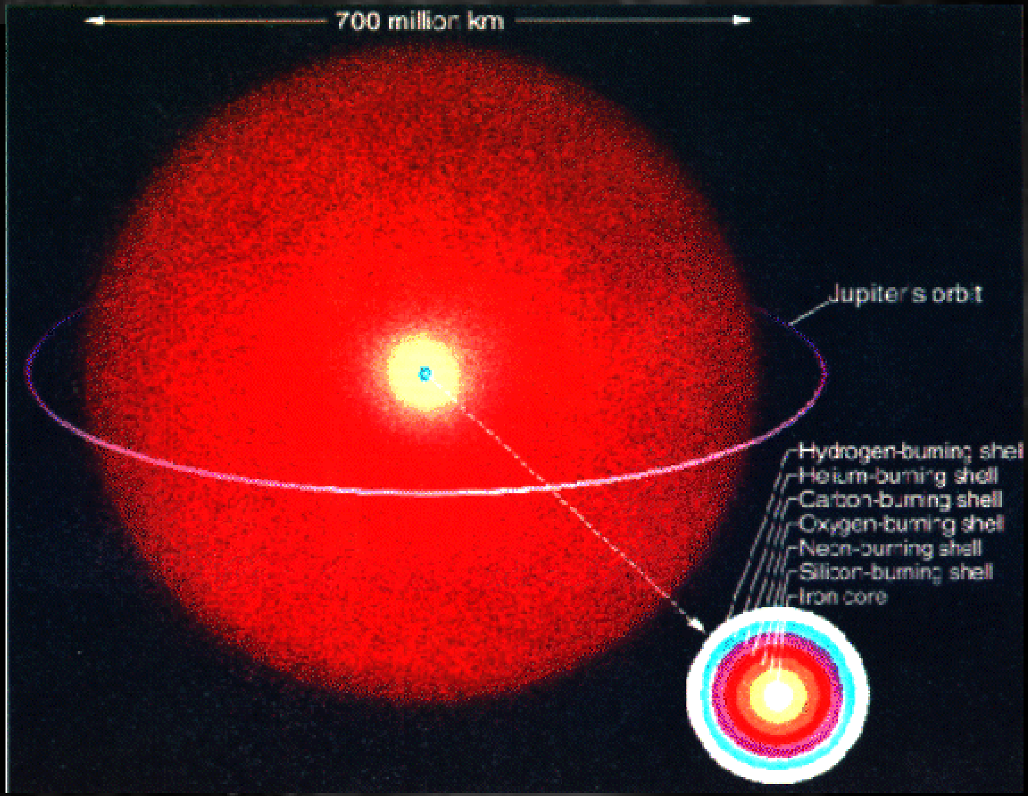


Supernova types

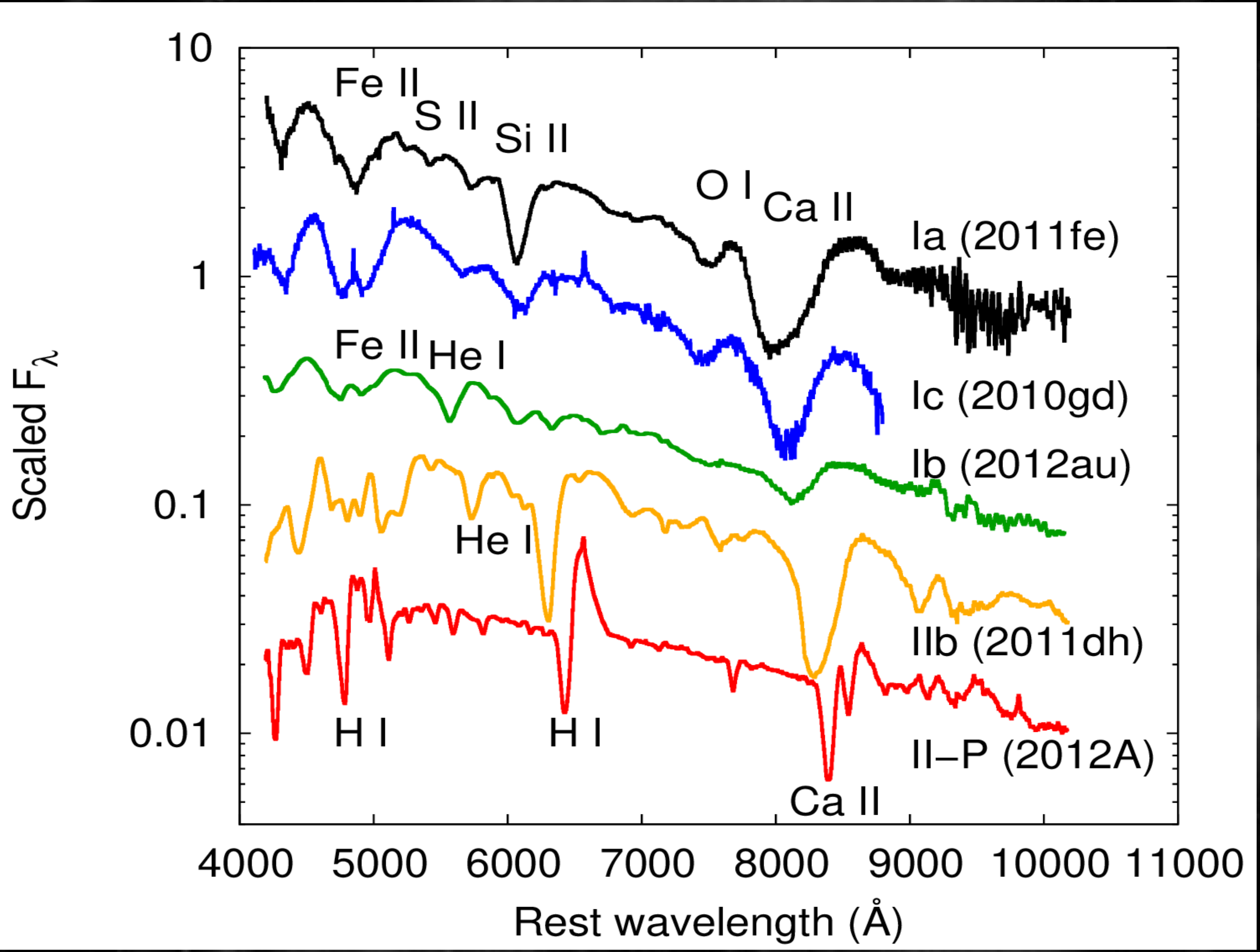
Type Ia:
thermonuclear explosion
of a M_{Ch} white dwarf

Type II / Ib /Ic:
collapse of the Fe core
in a M > 8 Mo star

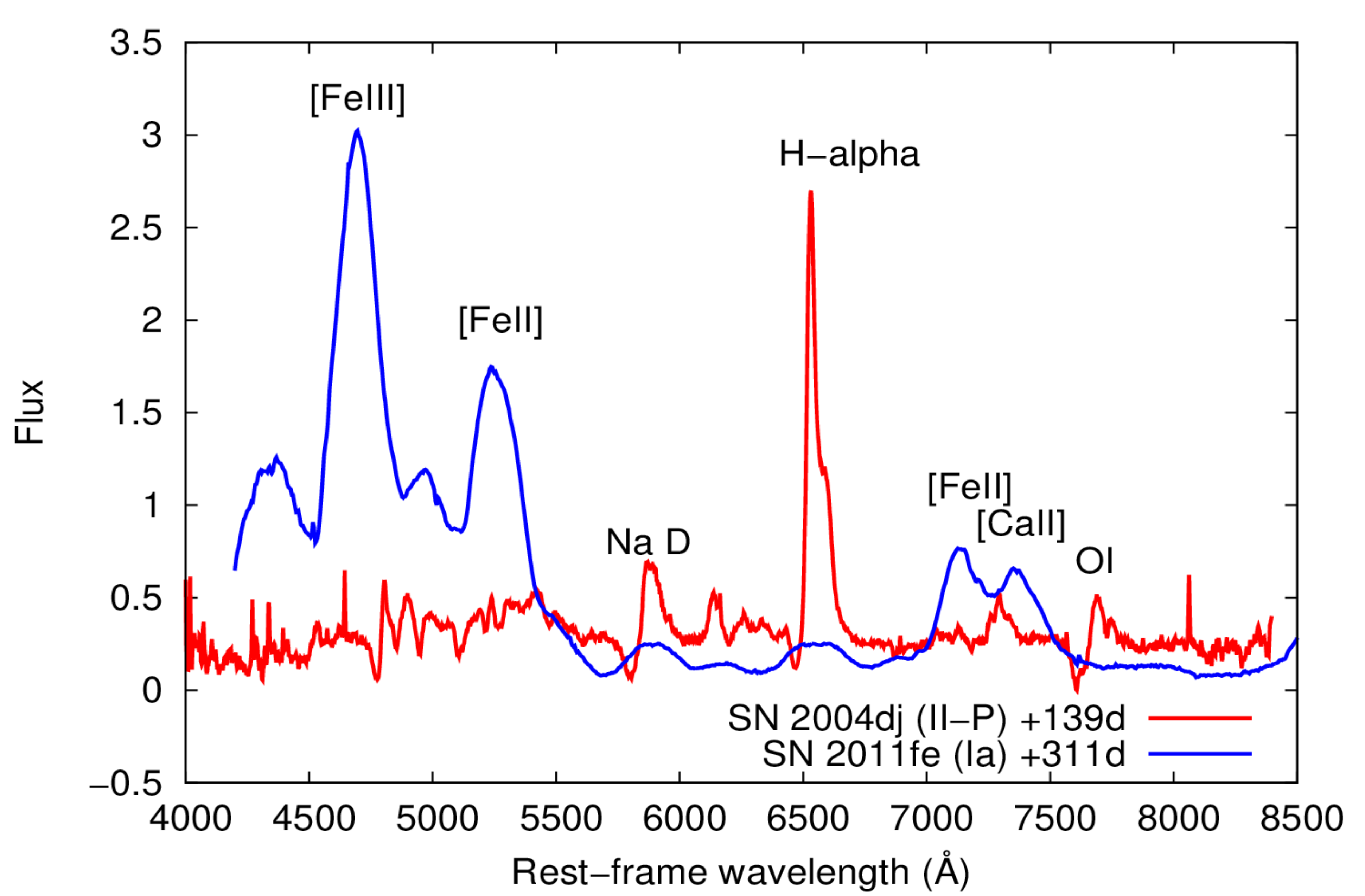




Classification of supernovae

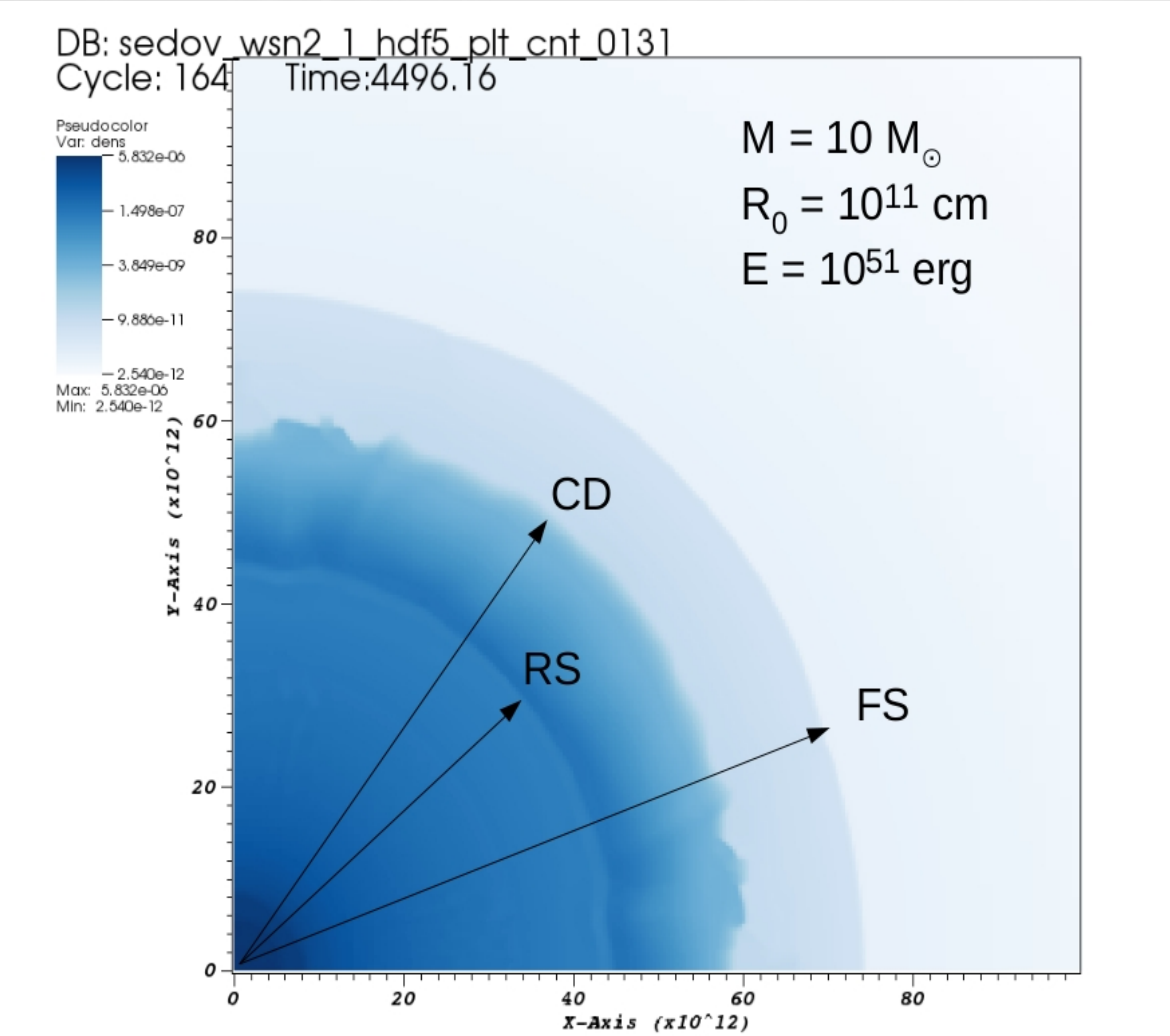


Classification of supernovae

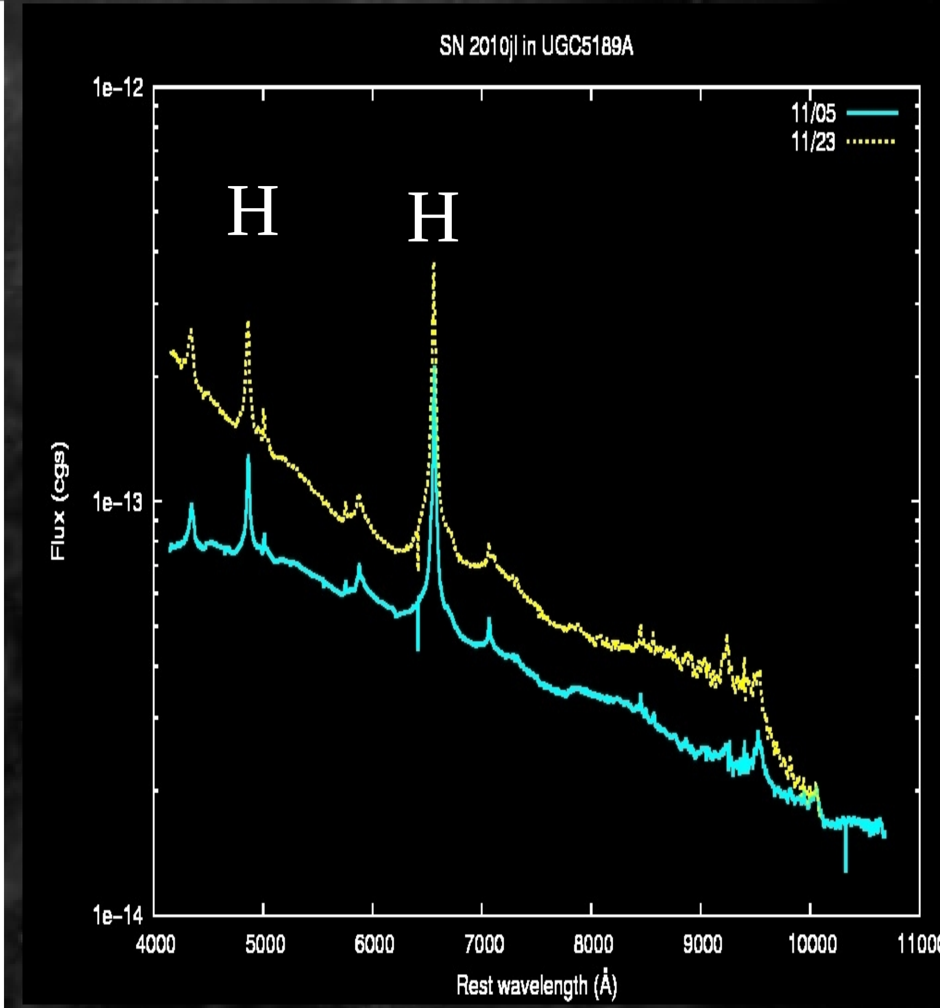


Supernova types

Type IIn: interaction with nearby CSM



FLASH simulation



Observed spectra

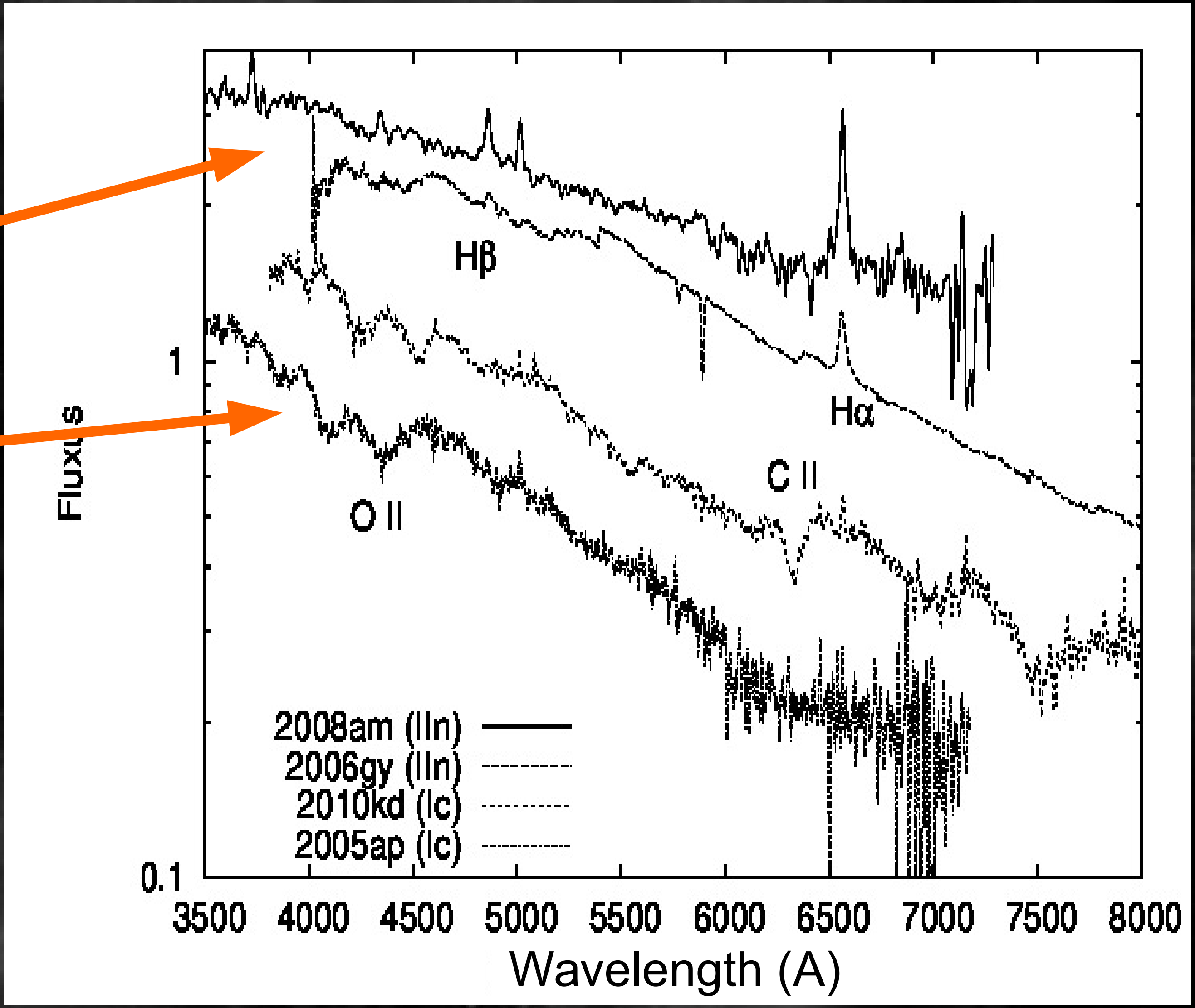
Supernova types

Superluminous supernovae (SLSNe): Quimby+ 2011

Two subclasses:

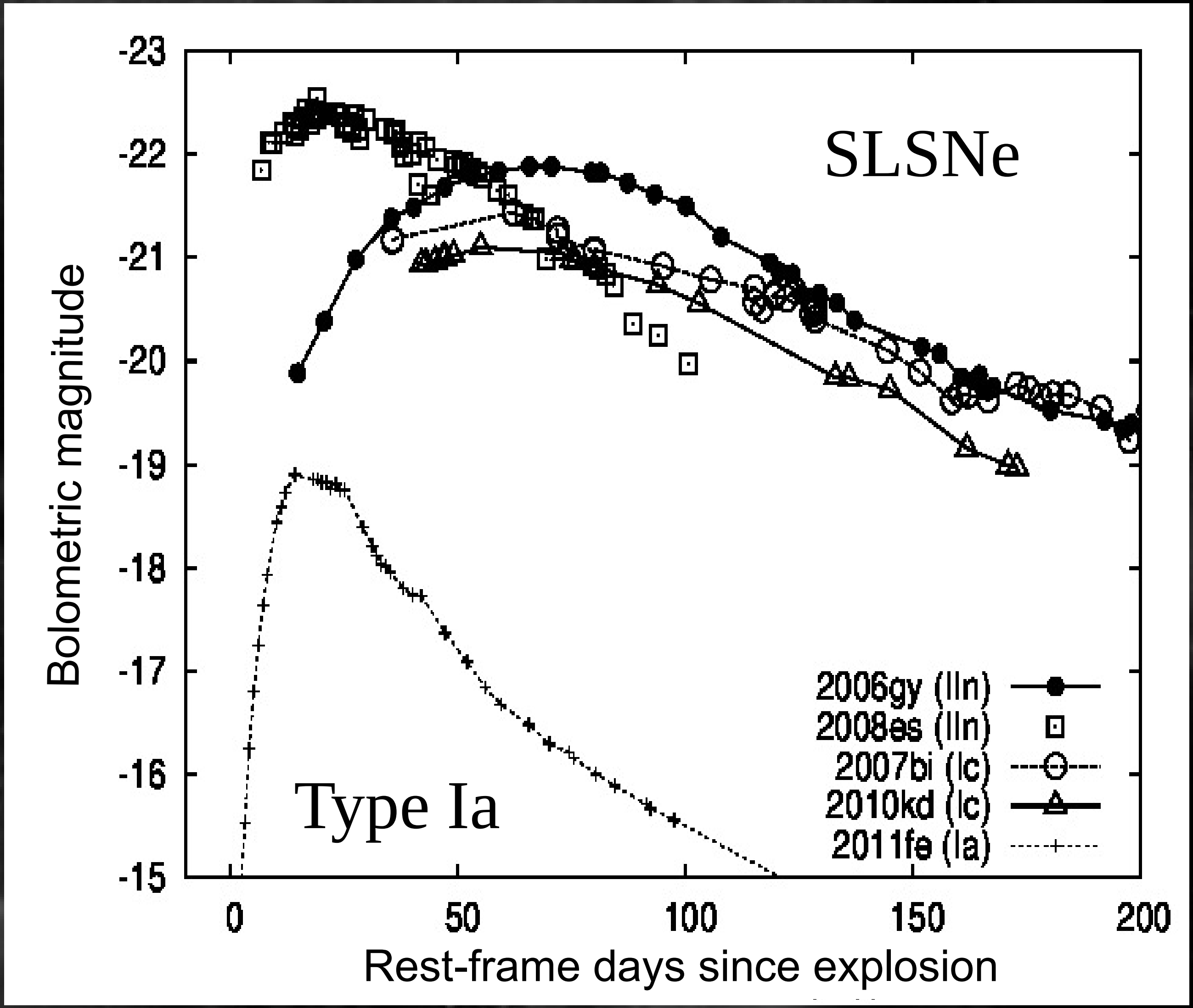
- H-rich: SLSN-II (rare)
- H-poor: SLSN-I

progenitor: ???



Superluminous Supernovae

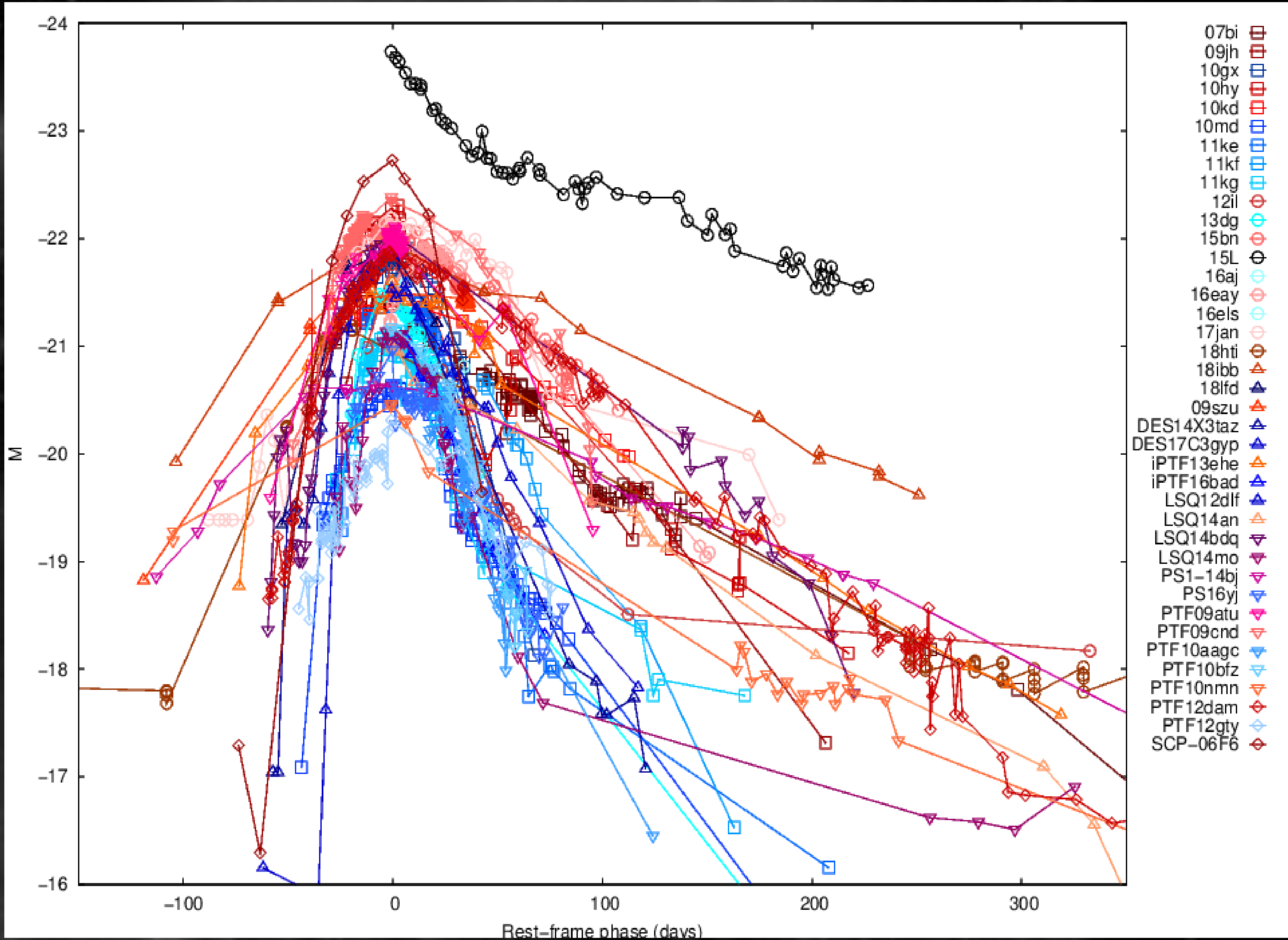
- peak brightness
  ~ -20 ... -23 mag
- light curve timescale
  can be very long,
  but not always
- light curve powering
  mechanism: ???



Superluminous Supernovae

Light curves seem to show two categories:
Fast decline
vs.
Slow decline

based on data from the Open Supernova Catalog: https://sne.space



Könyves-Tóth, in preparation

Superluminous Supernovae

From velocity evolution:

High velocity gradient ("Fast")
vs.
Low velocity gradient ("Slow")

(Inserra+, 2018)

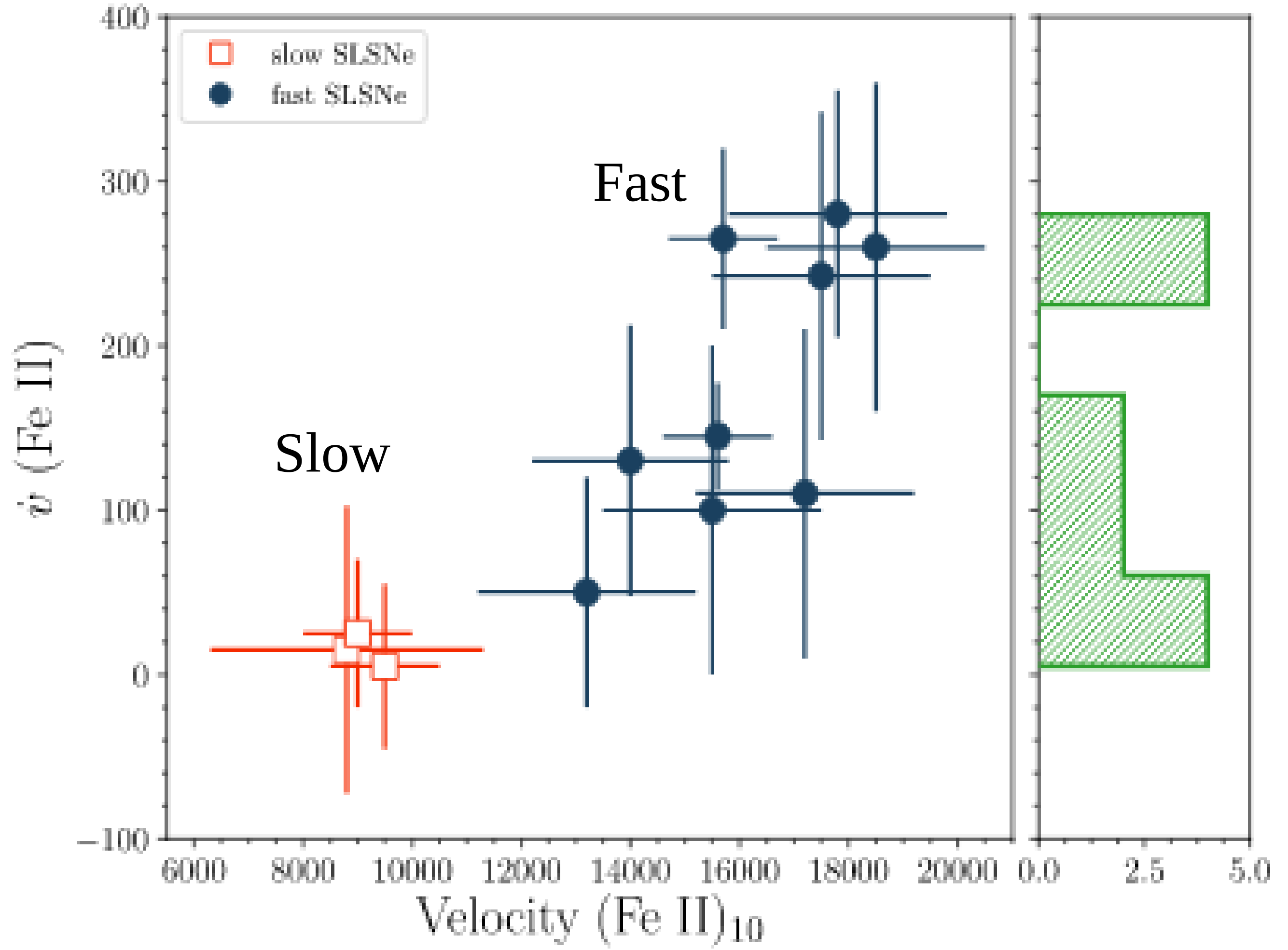
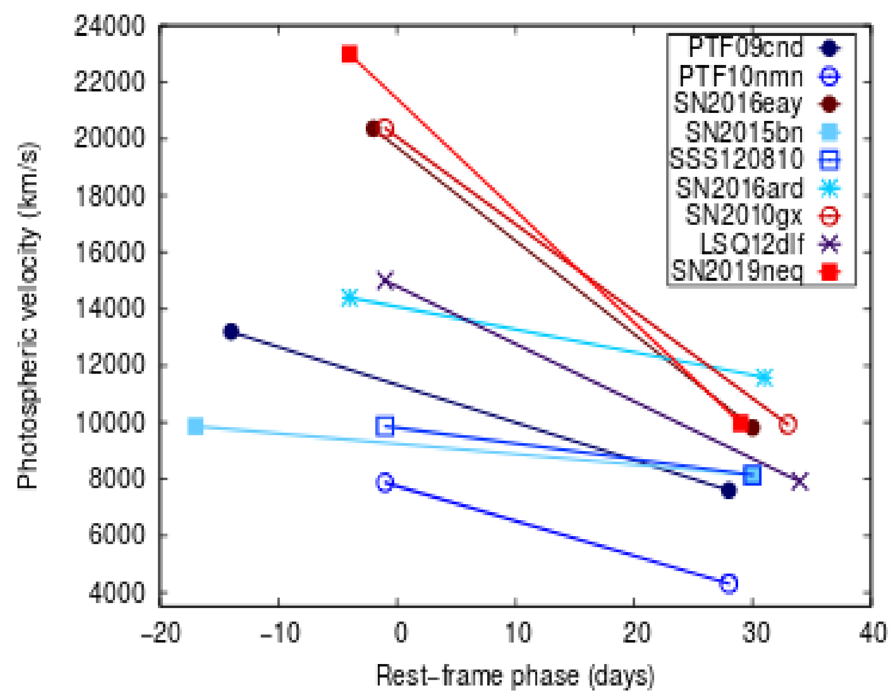


Figure 7. Left panel: Fe II λ5169 velocity evolution from +10 to +30 days ($\dot{v}$) vs. Fe II λ5169 velocities at +10 days. Right panel: histogram of the velocity

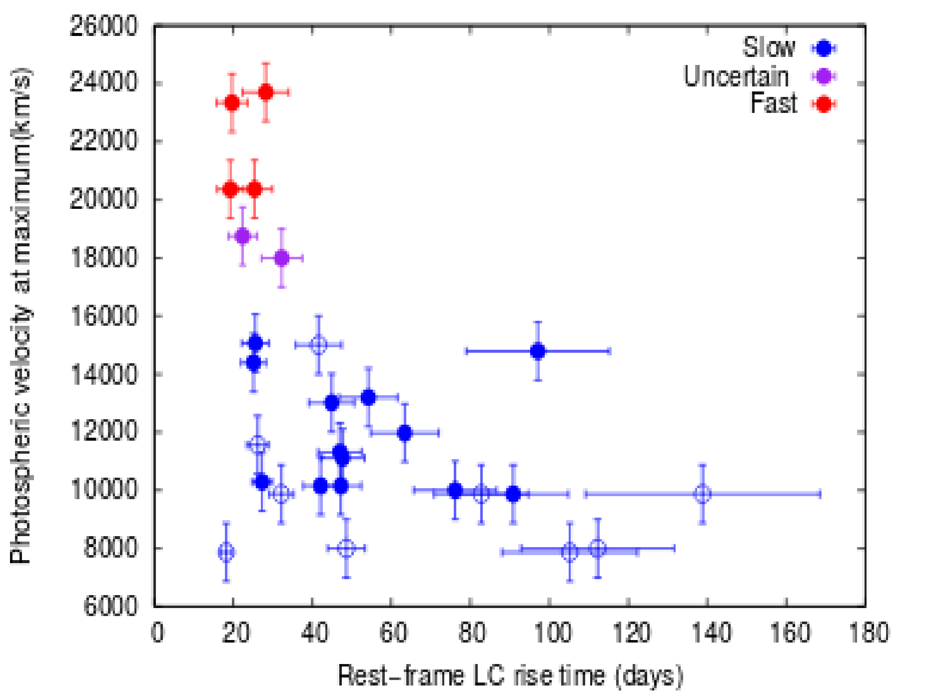
Inserra et al. (2018) ApJ 854, 175

Superluminous Supernovae

Velocity gradients of
Fast and Slow SLSNe-I



Velocities against
light curve timescales



Type Ia

Könyves-Tóth & Vinkó, 2021

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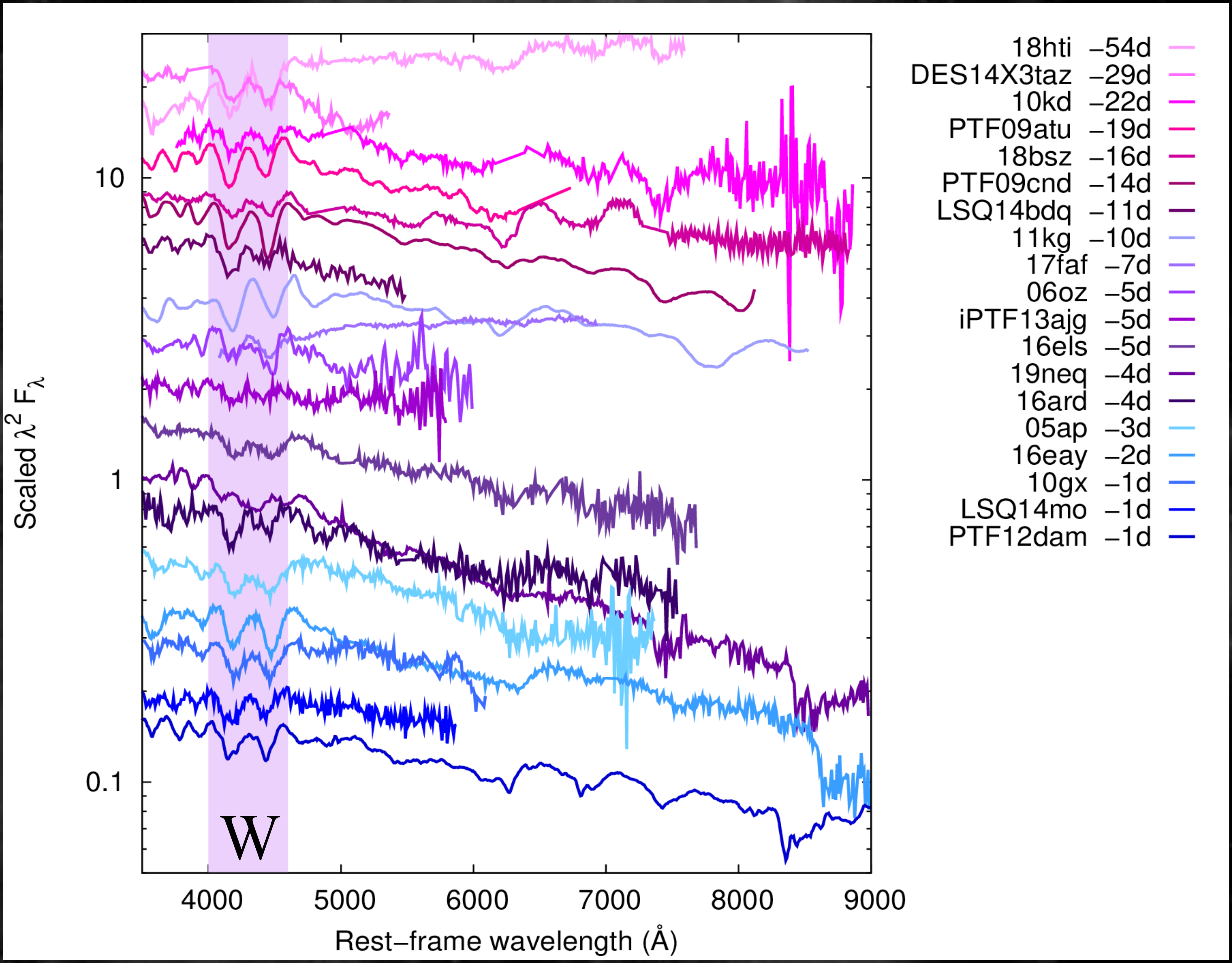
A spectroscopic diversity in SLSNe-I

Type W:

a W-shaped O II feature in premax spectra

$T_{phot} \sim 20$ kK before max

Könyves-Tóth, submitted to ApJ



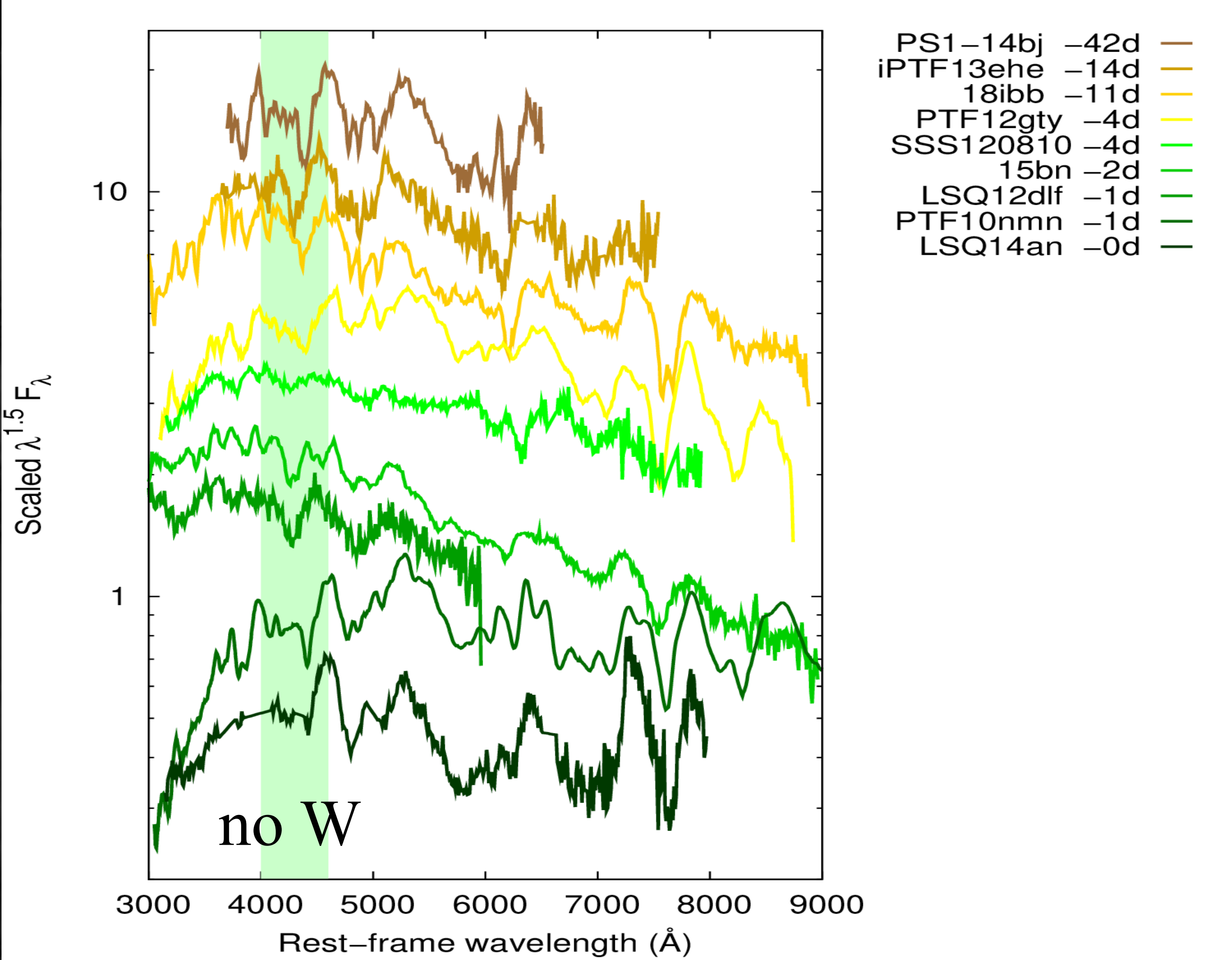
A spectroscopic diversity in SLSNe-I

Type 15bn:

no W-shaped O II feature in premax spectra

$T_{phot} \sim 10$ kK before max

Könyves-Tóth, submitted to ApJ



Light curve powering mechanisms

1. Circumstellar interaction

forward + reverse shock waves in the CSM + in the ejecta (major)

radioactive decay of ^{56}Ni - ^{56}Co in the ejecta (minor)

pure Ni-Co decay does not work

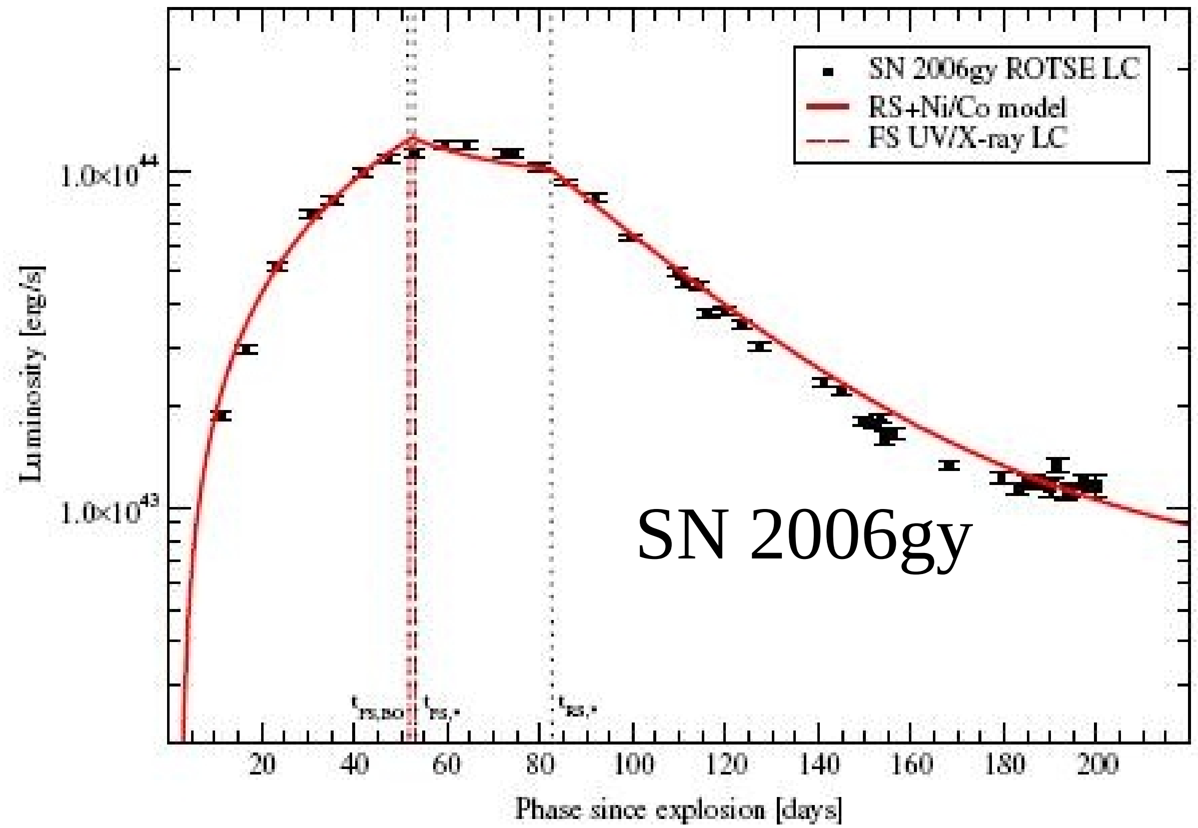


Figure 13. Fit of a hybrid ejecta–CSM interaction plus ^{56}Ni and ^{56}Co radioactive decay LC model (solid red curve) to the ROTSE LC of SLSN 2006gy. The parameters for this model are the following: $\delta = 0$, $n = 12$, $s = 0$, $E_{SN} = 4.4 \times 10^{51}$ erg, $M_{ej} = 40\,M_{\odot}$, $M_{CSM} = 5\,M_{\odot}$, $R_p = 5 \times 10^{14}$ cm, $\rho_{CSM,1} = 1.5 \times 10^{-13}$ g cm^{-3}, and $M_{Ni} = 2\,M_{\odot}$. The dashed curve shows the

Chatzopoulos, Wheeler & Vinkó (2012)

Light curve powering mechanisms

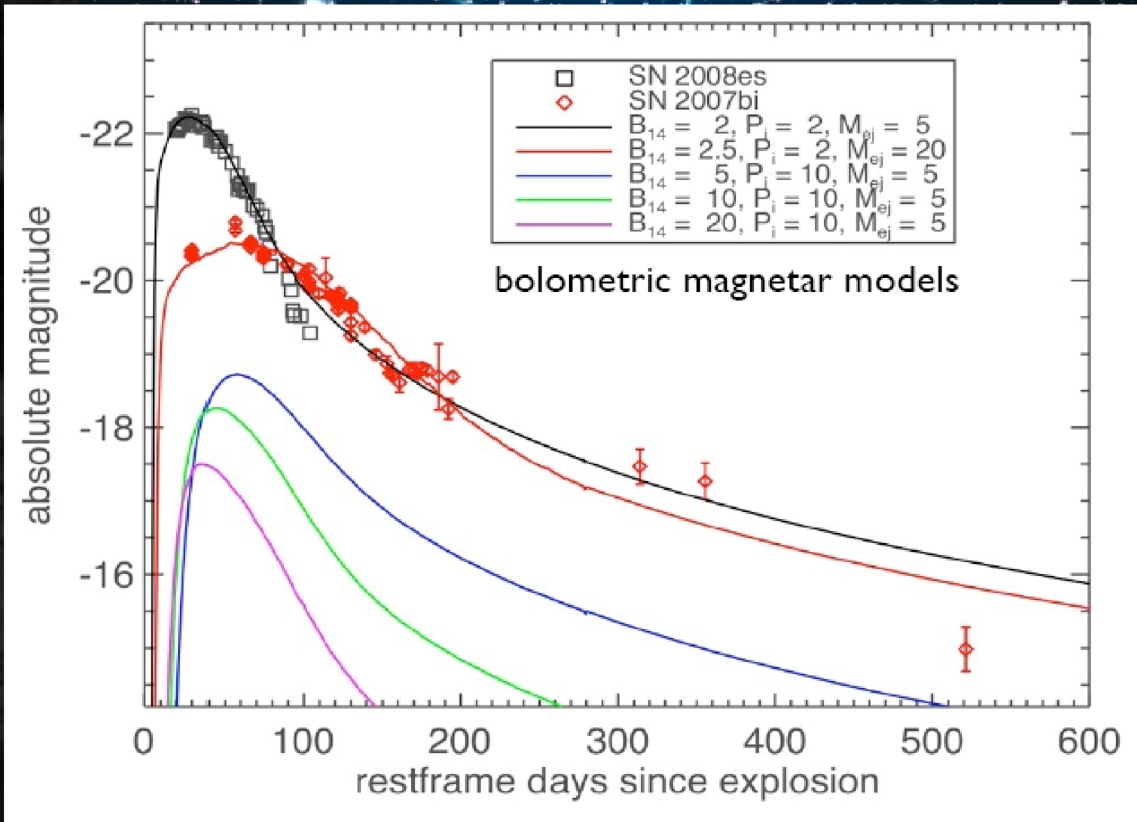
2. Magnetar spin-down

spin-down of a magnetar (extremely strongly magnetized neutron star)

energy deposited via magnetic braking

problem: too easy to fit, can "explain" almost every kind of light curve

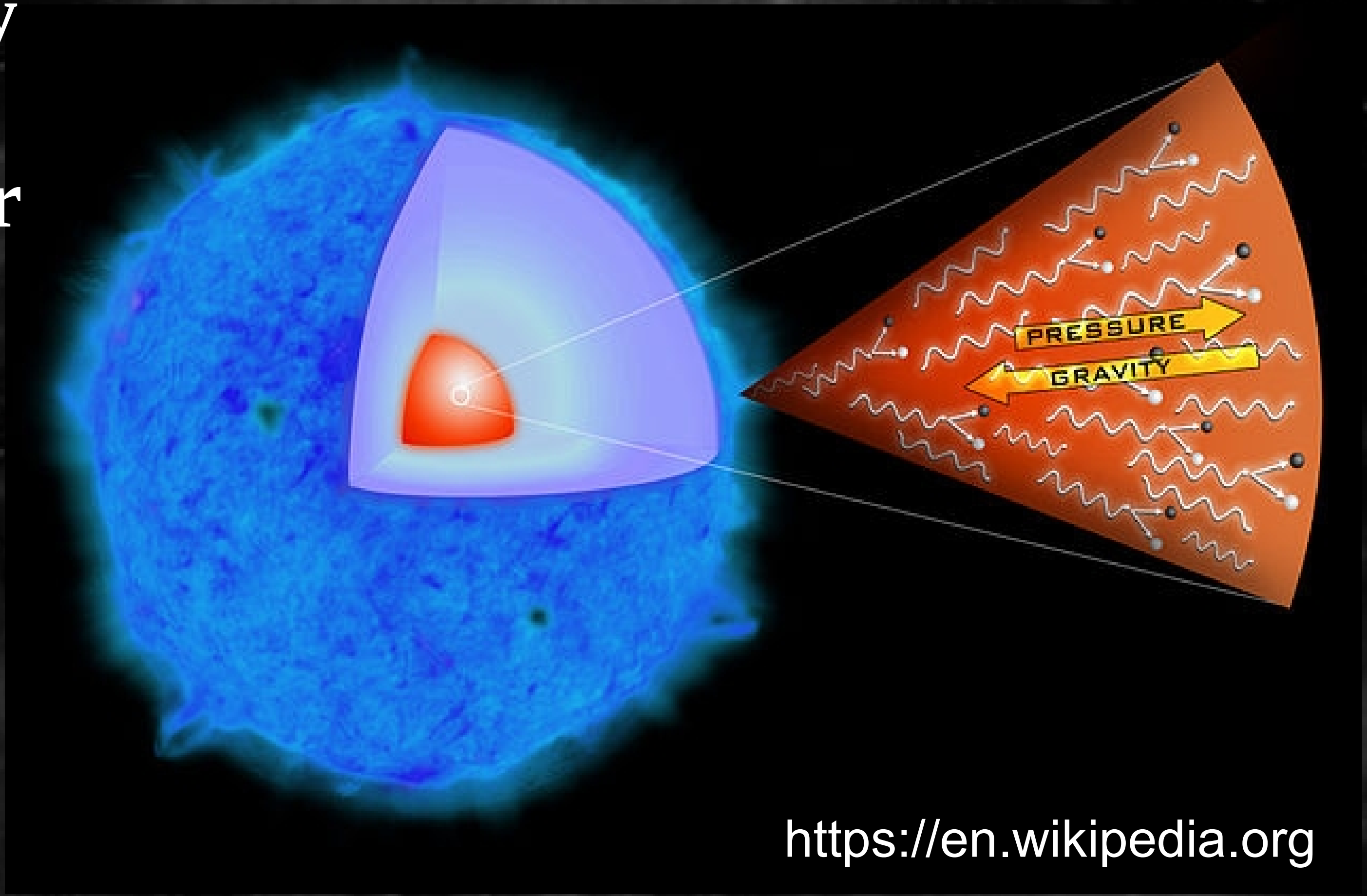
no W



Kasen & Bildstein (2010)

Light curve powering mechanisms

3. Pair instability explosion of a very massive star



hard gamma-rays create e^{-} - e^{+} pairs

core becomes unstable, collapses

thermonuclear runaway of C/O fusion

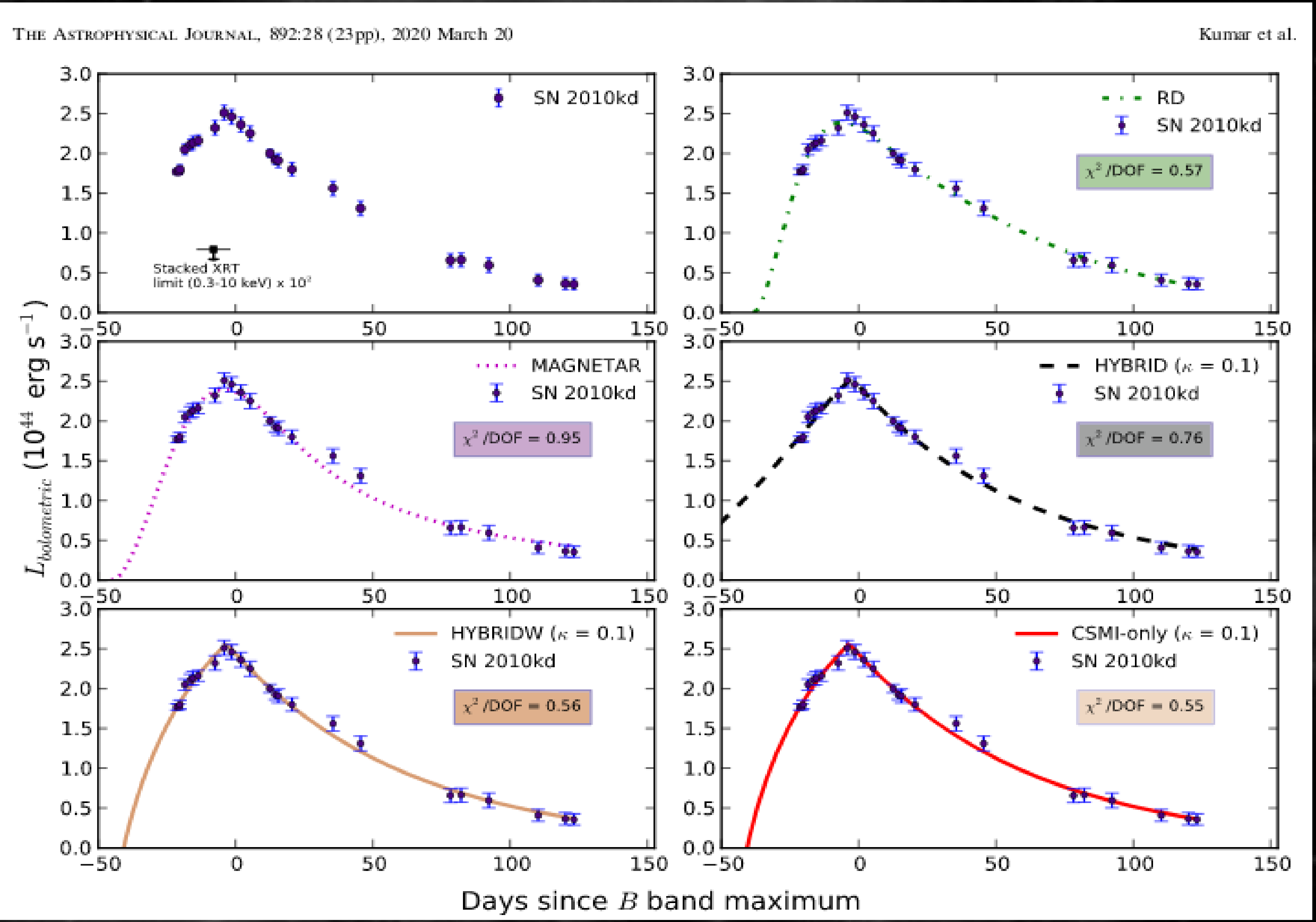
can create >5 M_O of ^{56}Ni

Fraley (1968)
Fryer, Woosley & Heger (2001)
Smith et al. (2007)
Chatzopoulos et al. (2012)

Light curve powering mechanisms

Light curves can be fit with either magnetar or CSM

Light curves alone do not constrain the possible models



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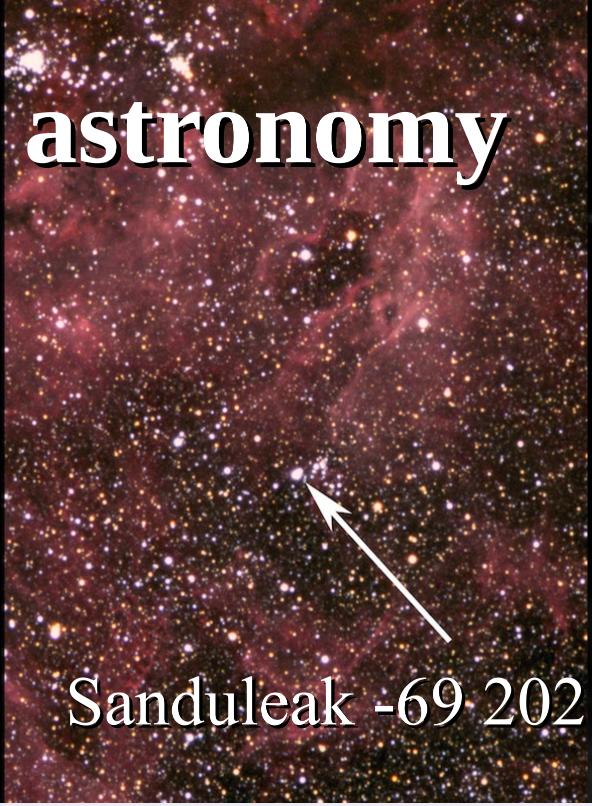
Prospects for multimessenger astronomy

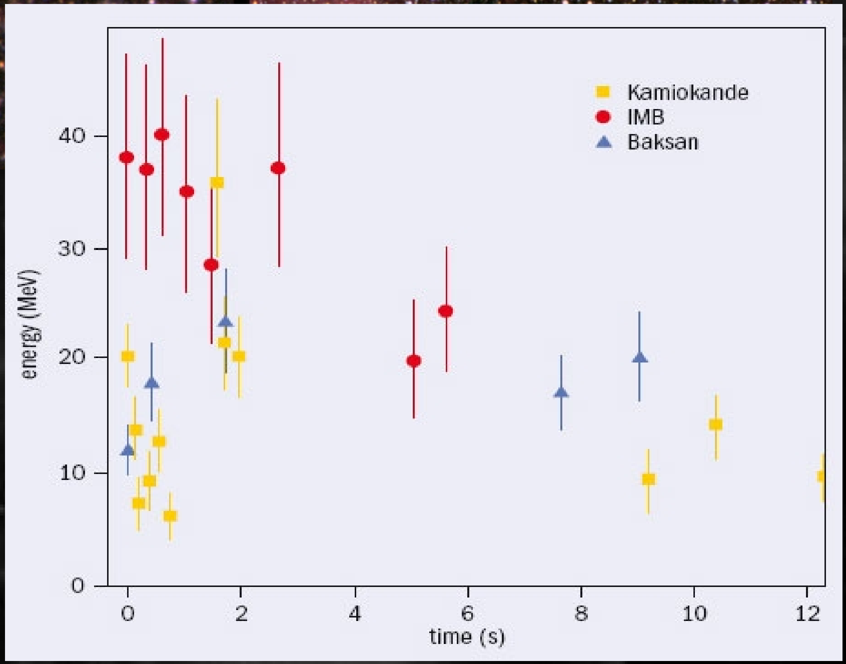
1. Neutrino detection from core collapse

neutronization:

$$p + e^{-} \rightarrow n + \nu_e$$



Detections from SN 1987A:
24 events within 12 seconds
~ 3 hours before first light



Prospects for multimessenger astronomy

Detection of pre-discovery
neutrinos from a SLSN-I:
==> proof of core collapse
and formation of a magnetar?

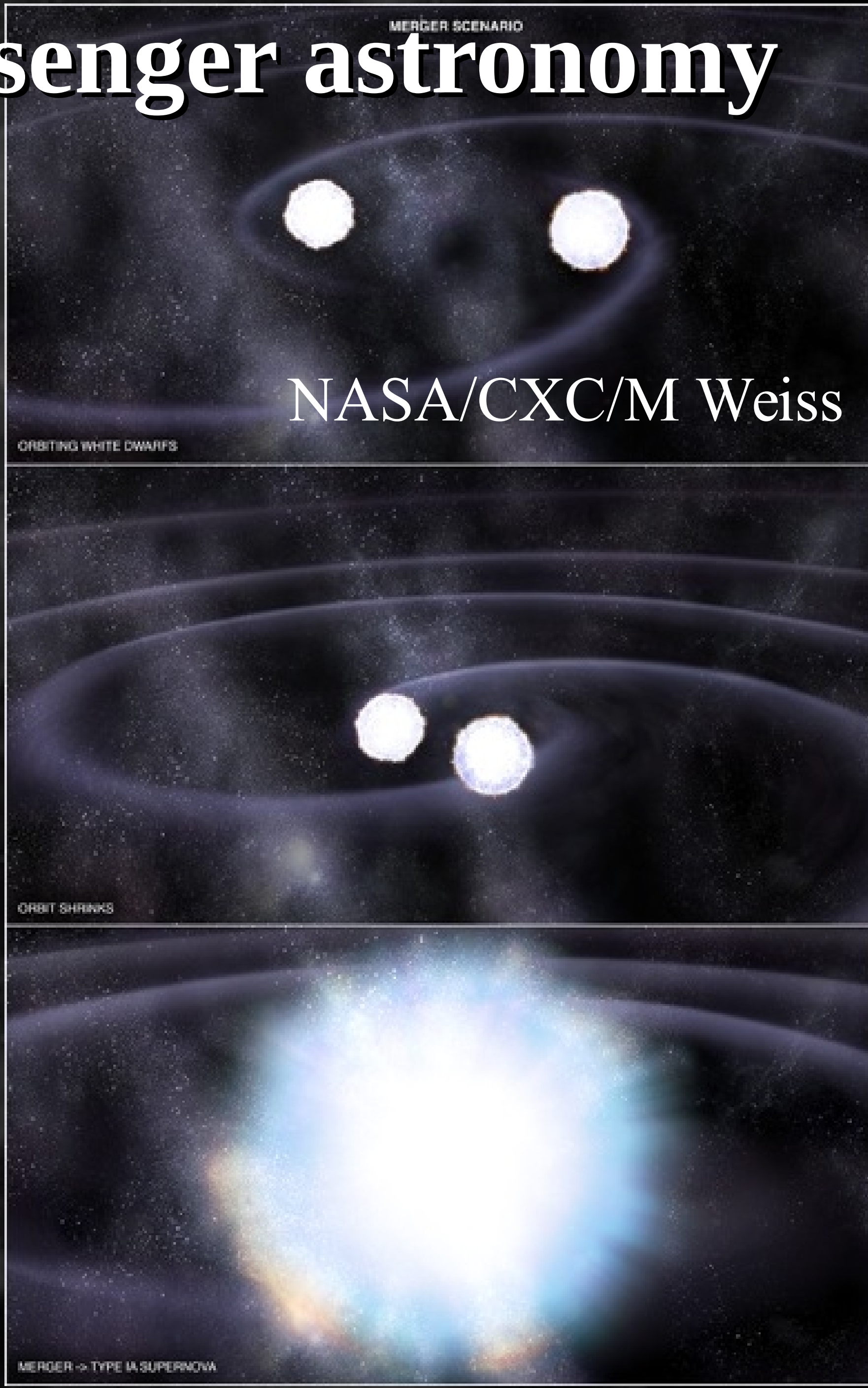
But: SLSNe are rare in the
local Universe
(nearest one was at D > 100 Mpc)

new generation of neutrino
detectors may be necessary

SN 1987A ~50 kpc

SN 2017egm ~120 Mpc

Prospects for multimessenger astronomy



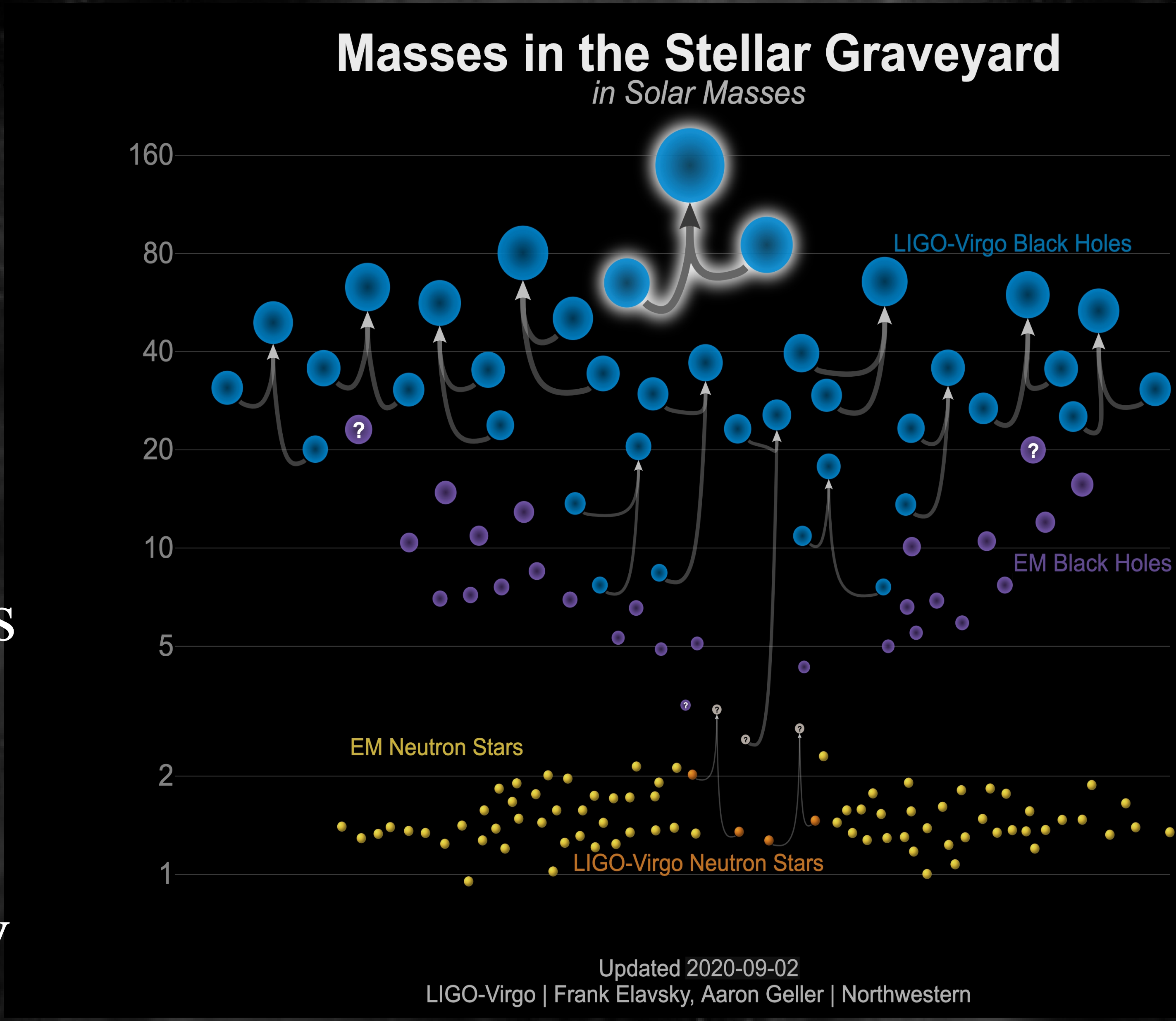
2. Detection of gravitational waves from a merging white dwarf pair

possible mechanism for producing a Type Ia SN

observations do not agree with model predictions except stellar statistics

Prospects for multimessenger astronomy

LIGO + Virgo is sensitive only for black hole & neutron star mergers ==> enhanced sensitivity is necessary



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Conclusions

- Supernovae are hot
- Supernovae are cool
- Some fundamental questions are still open (e.g. Type Ia progenitors, SLSN mechanism, ...)
- Multimessenger astronomy could provide the missing pieces in the puzzle
- New, better data and theoretical models are essential

Thank you for your attention