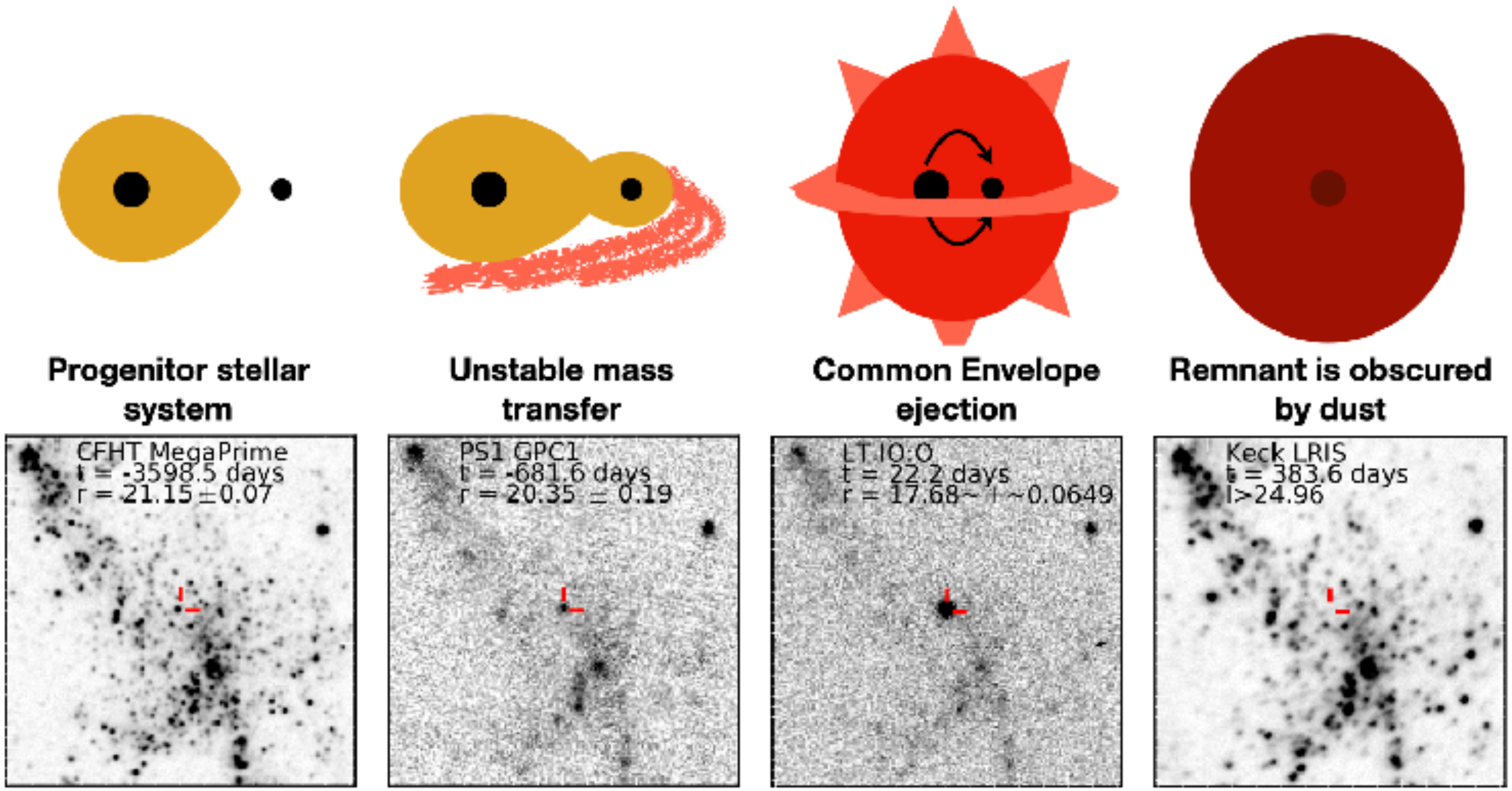
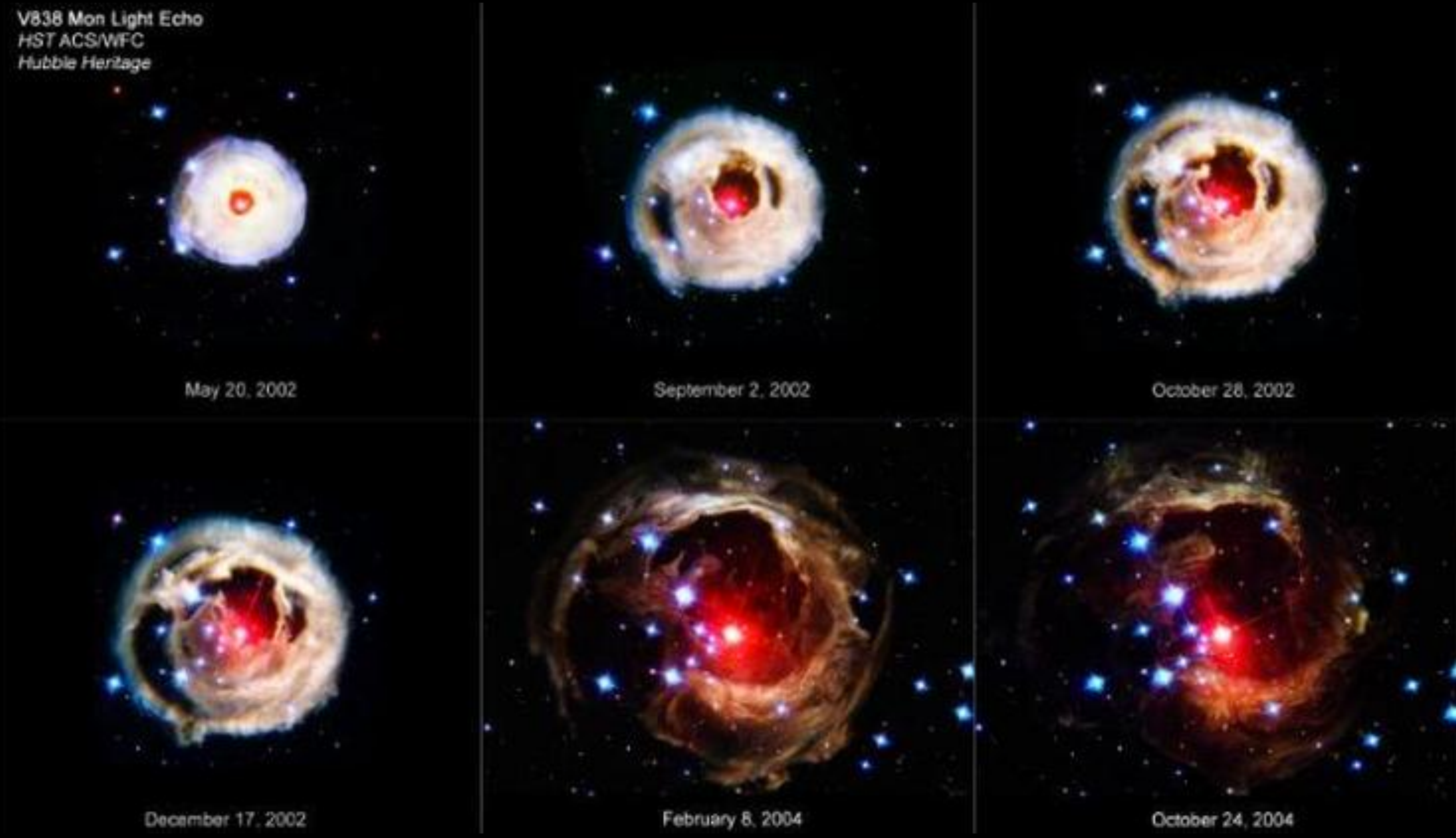
Progenitors, precursors and (optical) LRNe transients



Nadia Blagorodnova

Radboud University NWO → Universitat de Barcelona erc Starting Grant


V838 Mon Light Echo
HST ACS/WFC
Hubble Heritage
May 20, 2002
September 2, 2002
October 28, 2002
December 17, 2002
February 8, 2004
October 24, 2004

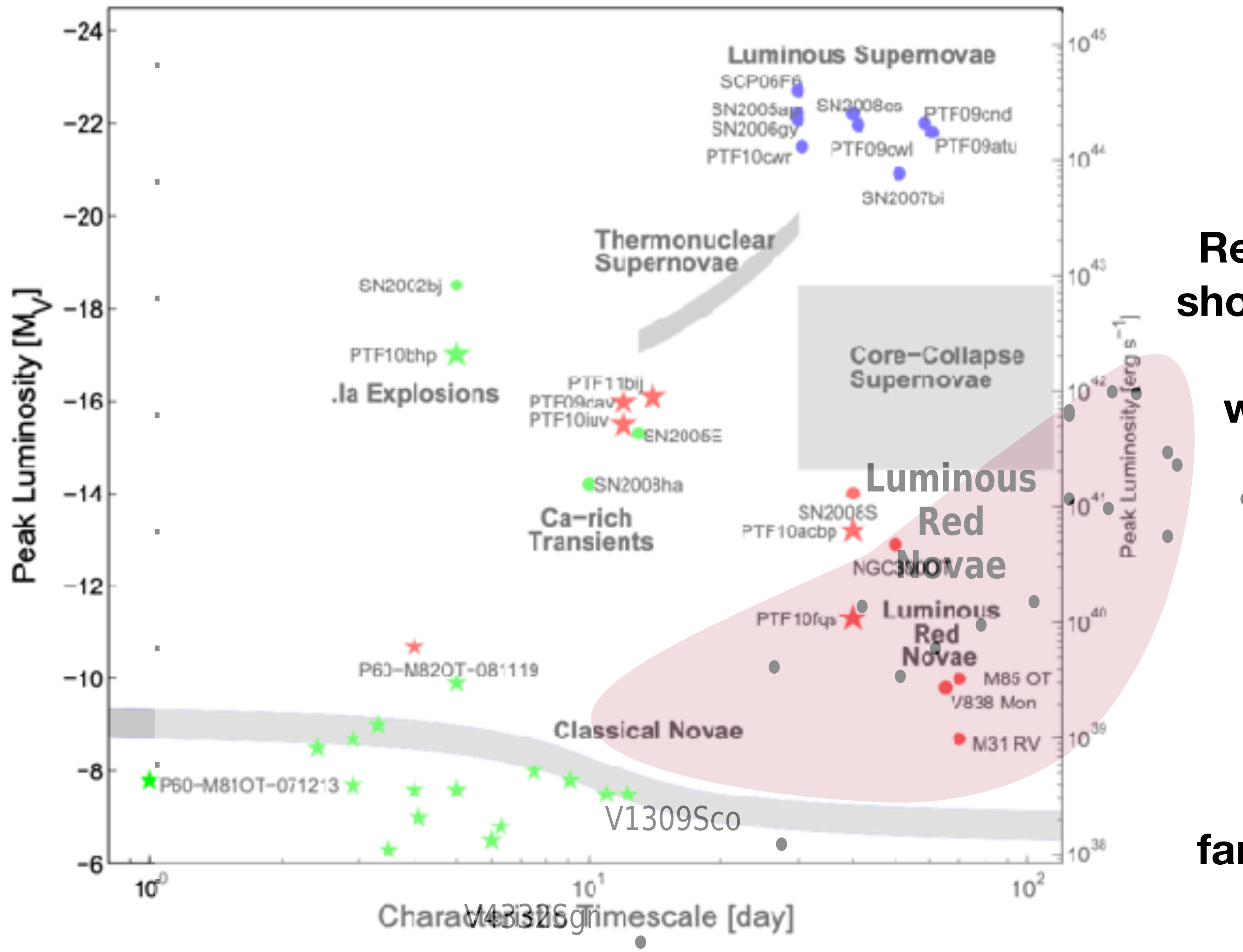
Galactic vs. Extragalactic

+ CK Vul

What makes an (optical) LRN? (I)

1. **Energetics**
    1. Gap transients with L_peak between Novae and Supernovae… (initially)
2. **Photometry**
    1. Double peak or peak+plateau
    2. Evolution towards colder temperatures
    3. Precursor emission starting ~years before outburst peak
    4. Increasingly bright in the NIR, and later MIR
3. **Spectra**
    1. Low expansion velocity
    2. Red continuum (at later times)
    3. Lack of [Ca II] usually detected in Intermediate Luminosity Optical Transients (ILOT)

The (expanding) LRN parameter space

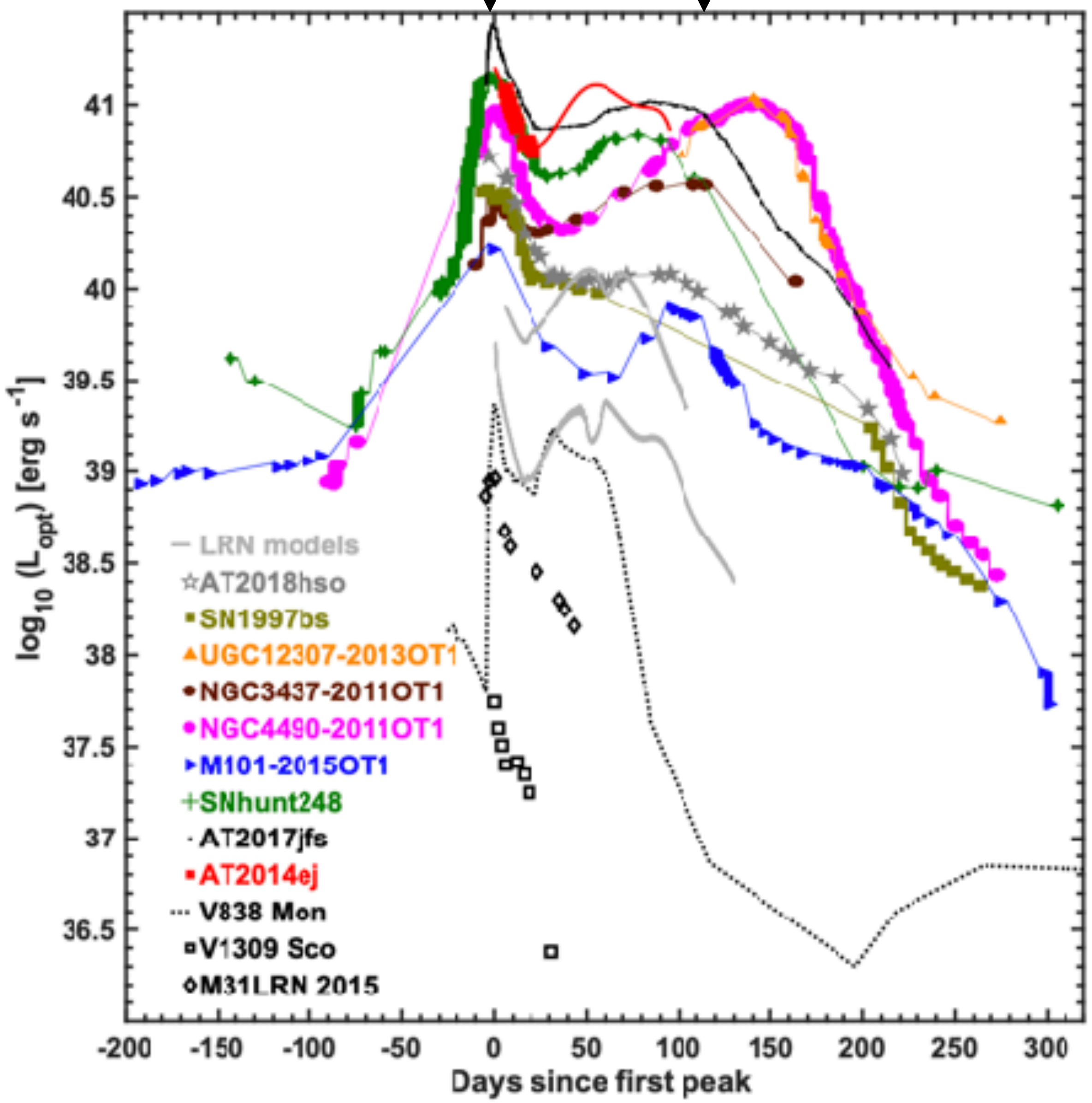


Recent discoveries show longer duration transients with higher peak luminosities

(more on transient families on Nathan's talk)

2 - Photometry

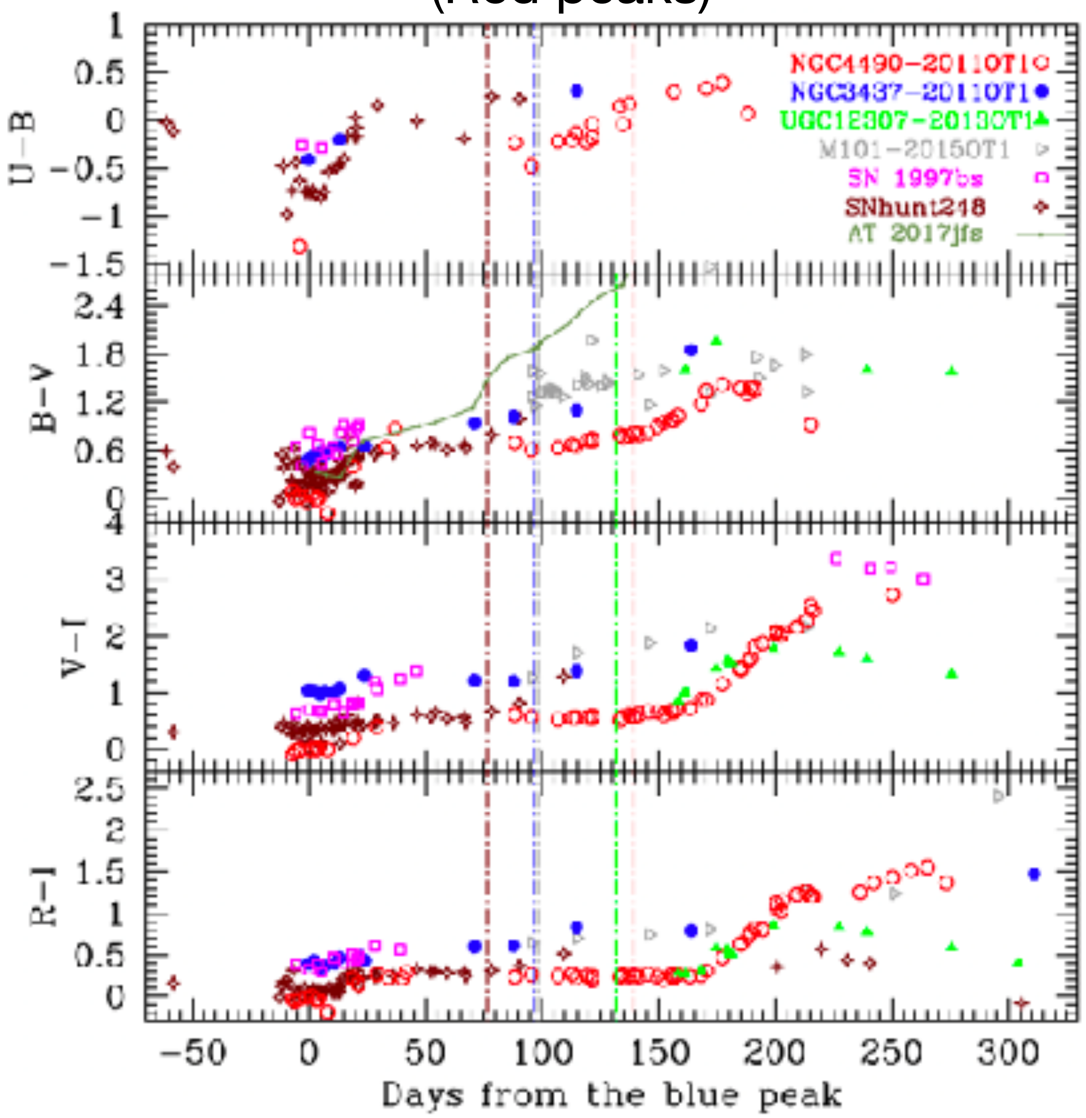
Blue peak **Red peak / plateau**



(Red peaks)

Red

Blue

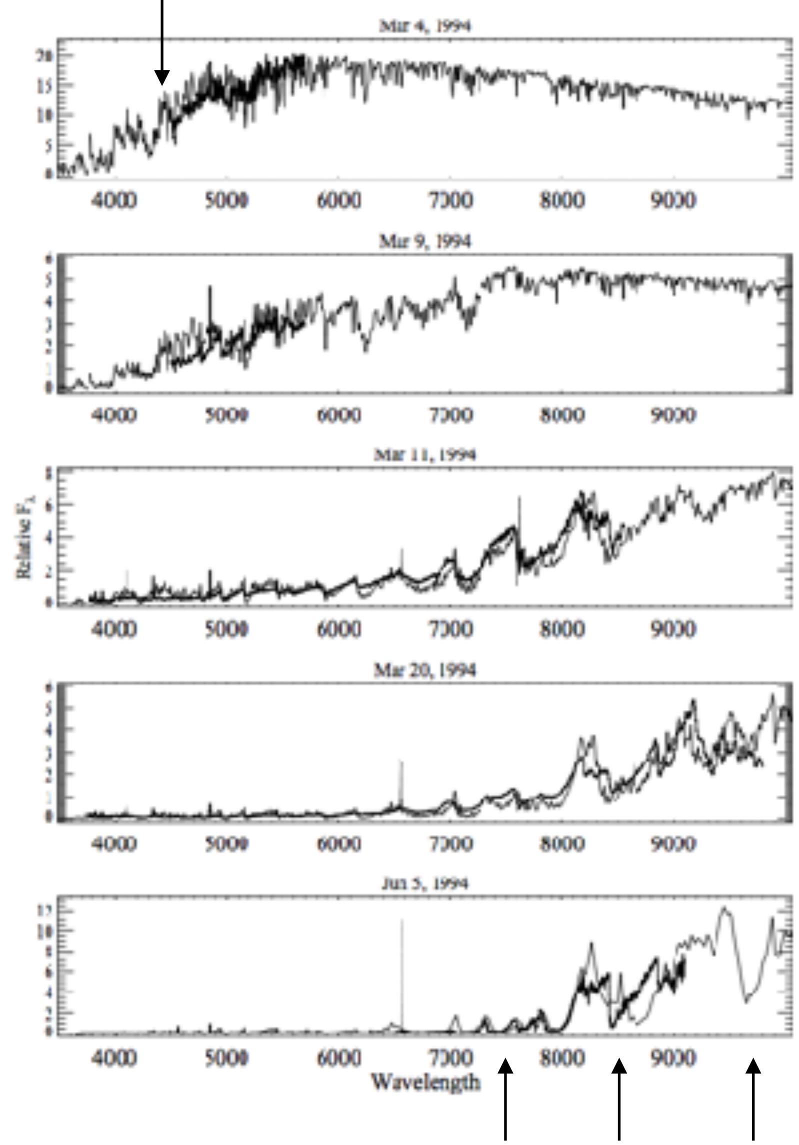


Spectroscopic evolution (I)

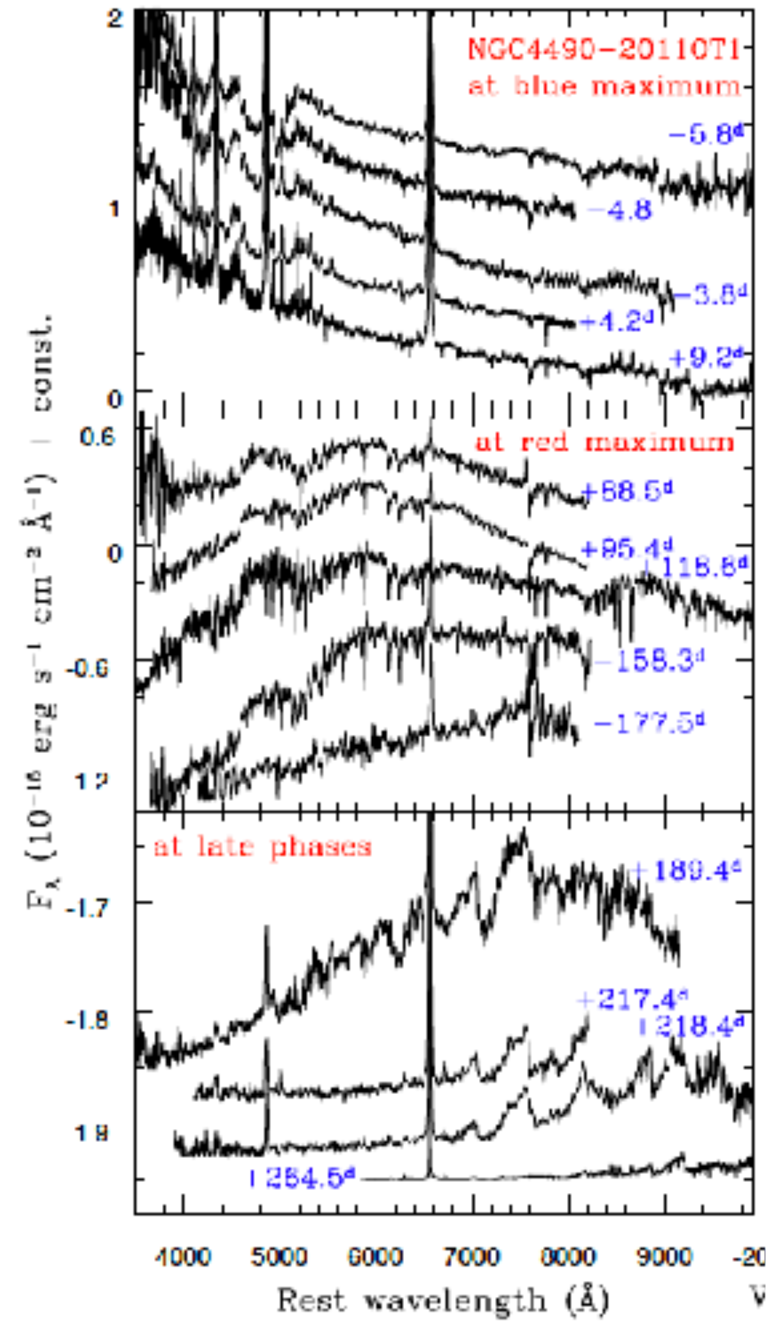
- ~~Red continuum~~ Blue (10,000K) and later red (3,000K) continuum
- Fe absorption "forest"
- Narrow Hα, low ionisation elements:
  - Na I, K I, Rb, Ba II…
- Low ejection velocities: 100-1000 km/s
- **Molecular bands at later times**

V4332Sgr

Fe lines

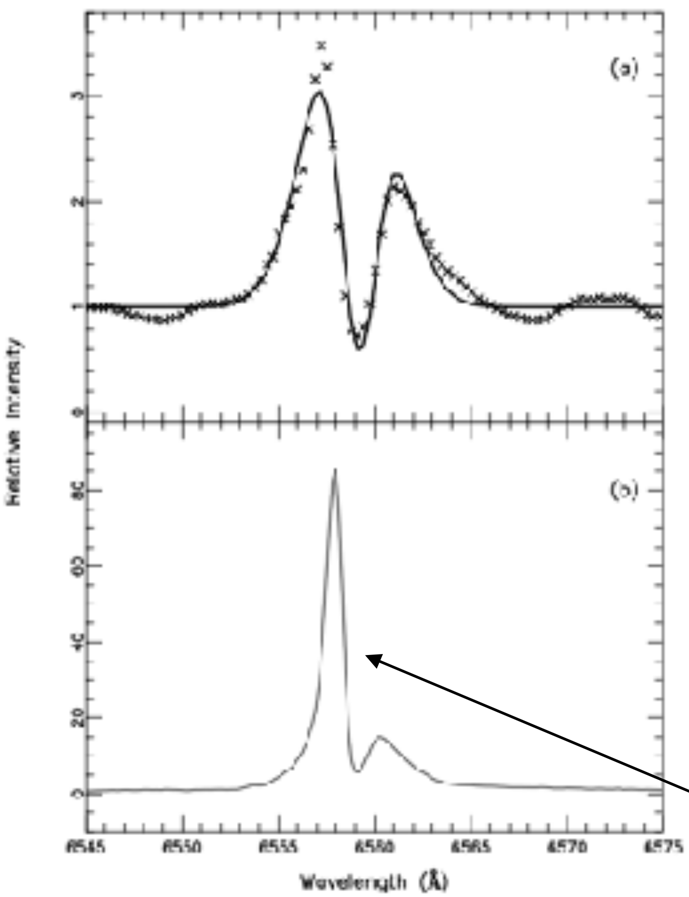


Tio/VO bands

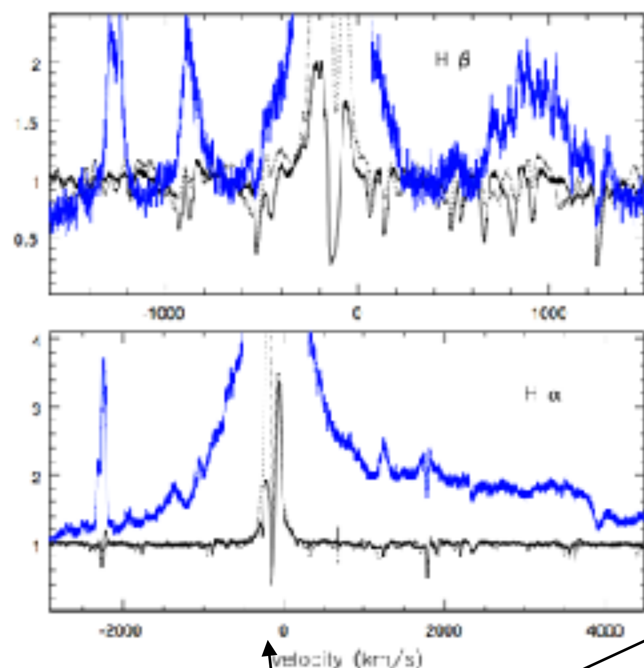


Spectroscopic evolution (II) - Hα profile

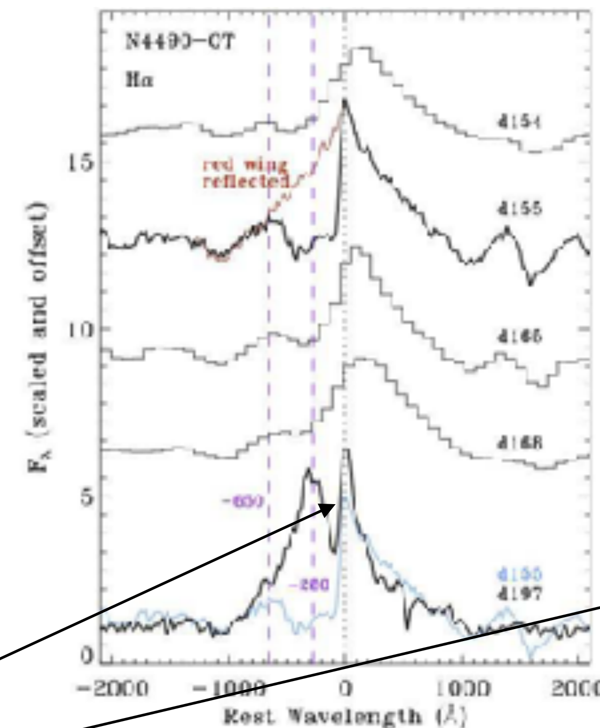
V4332 Sgr



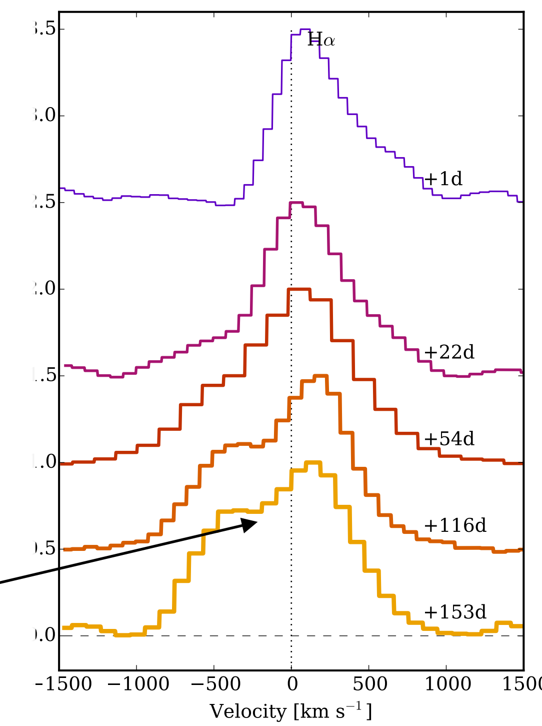
V1309 Sco



NGC4490-OT



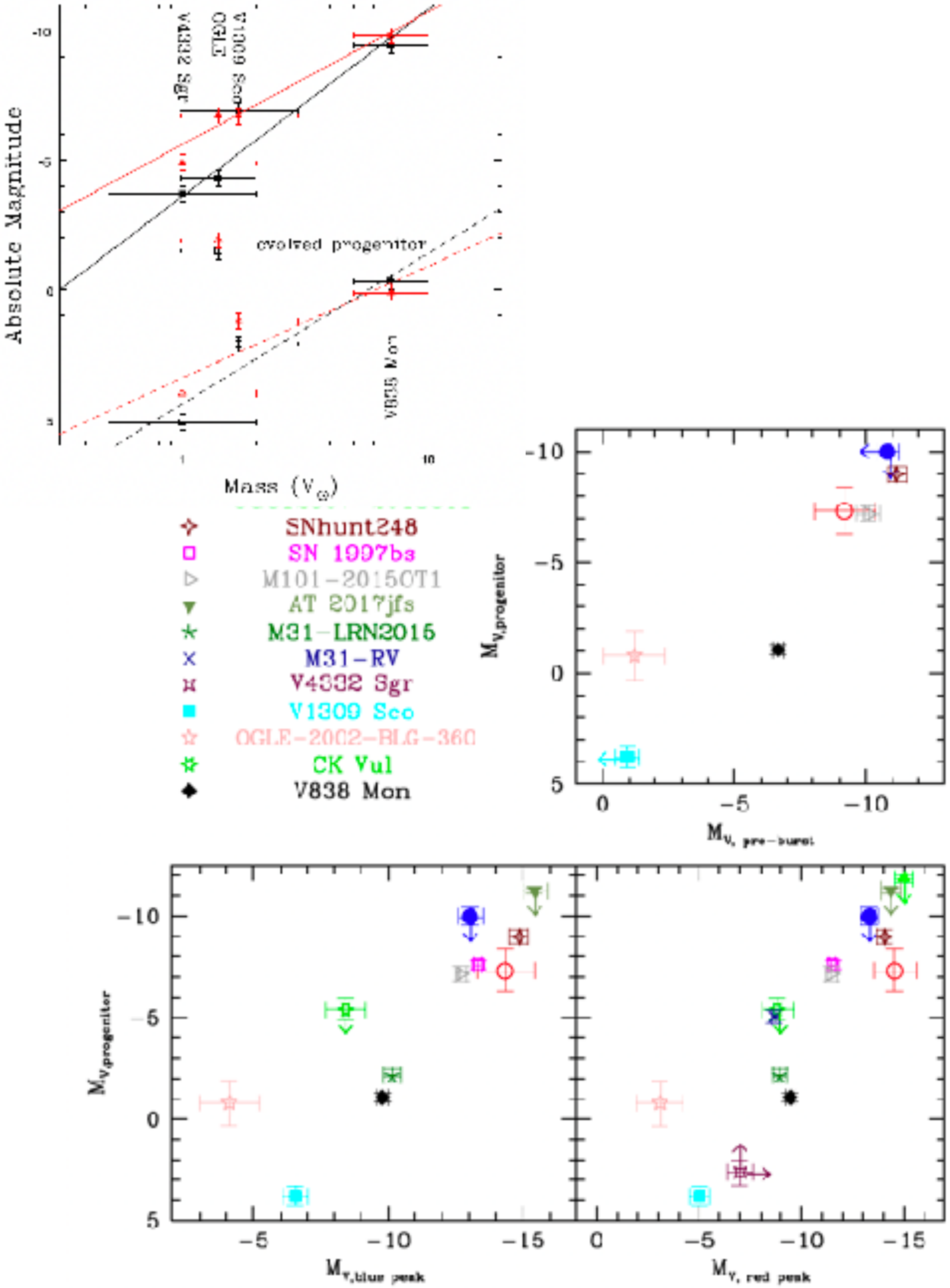
M101-OT



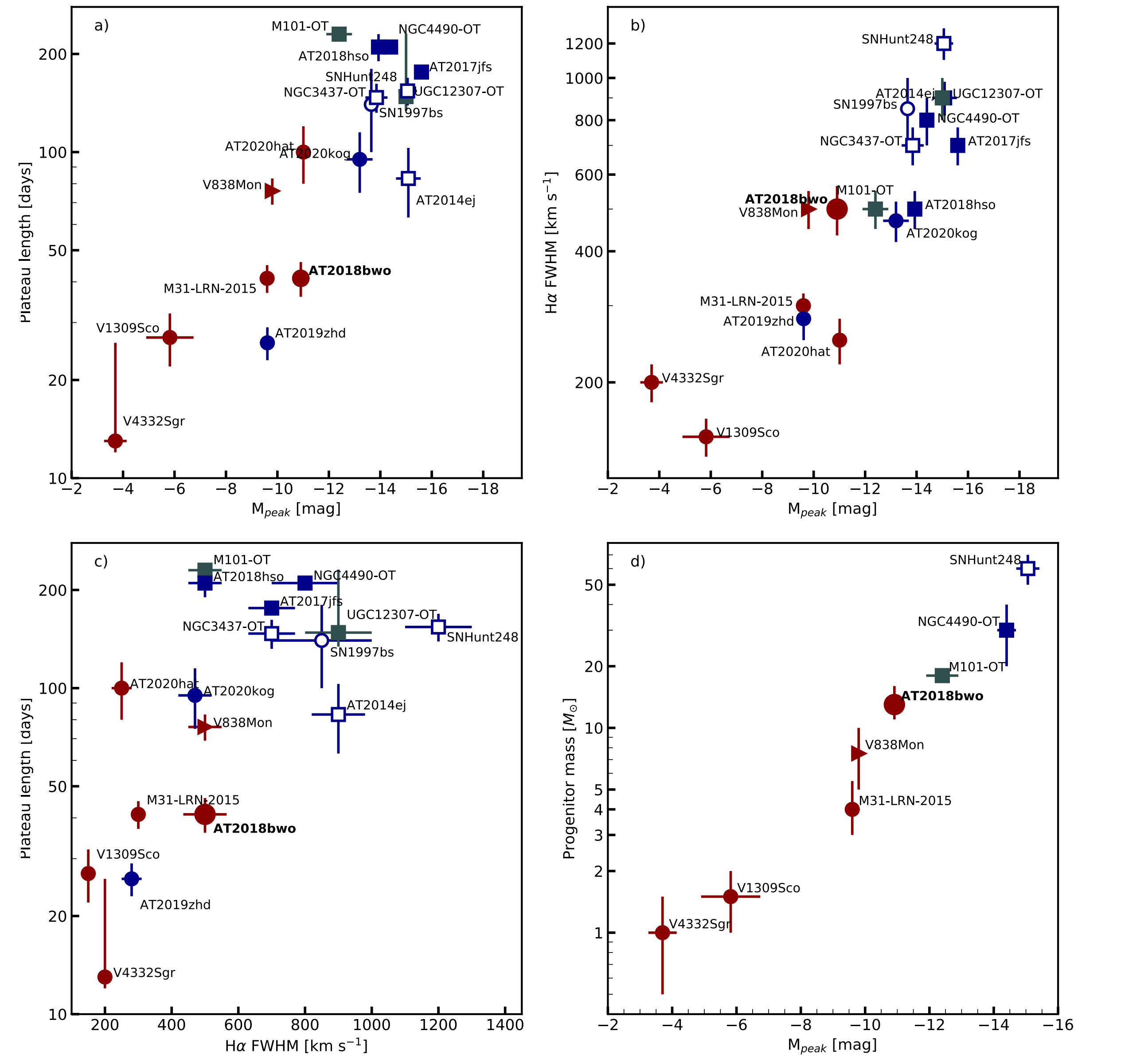
Narrow (blueshifted) absorption in Hα

Martini et al. 1999, Mason+2010, Smith+2016, Blagorodnova+2017

Correlations

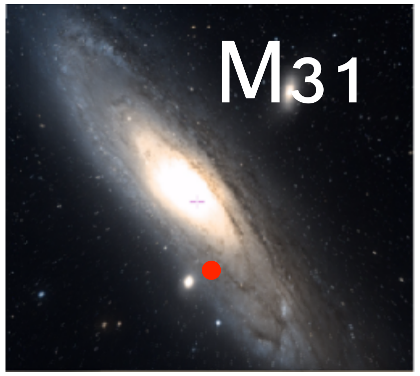


Early-time red **Early-time blue**



● **Peak + plateau** ■ **Blue+red peaks**

What can we lean from observations of LRNe?

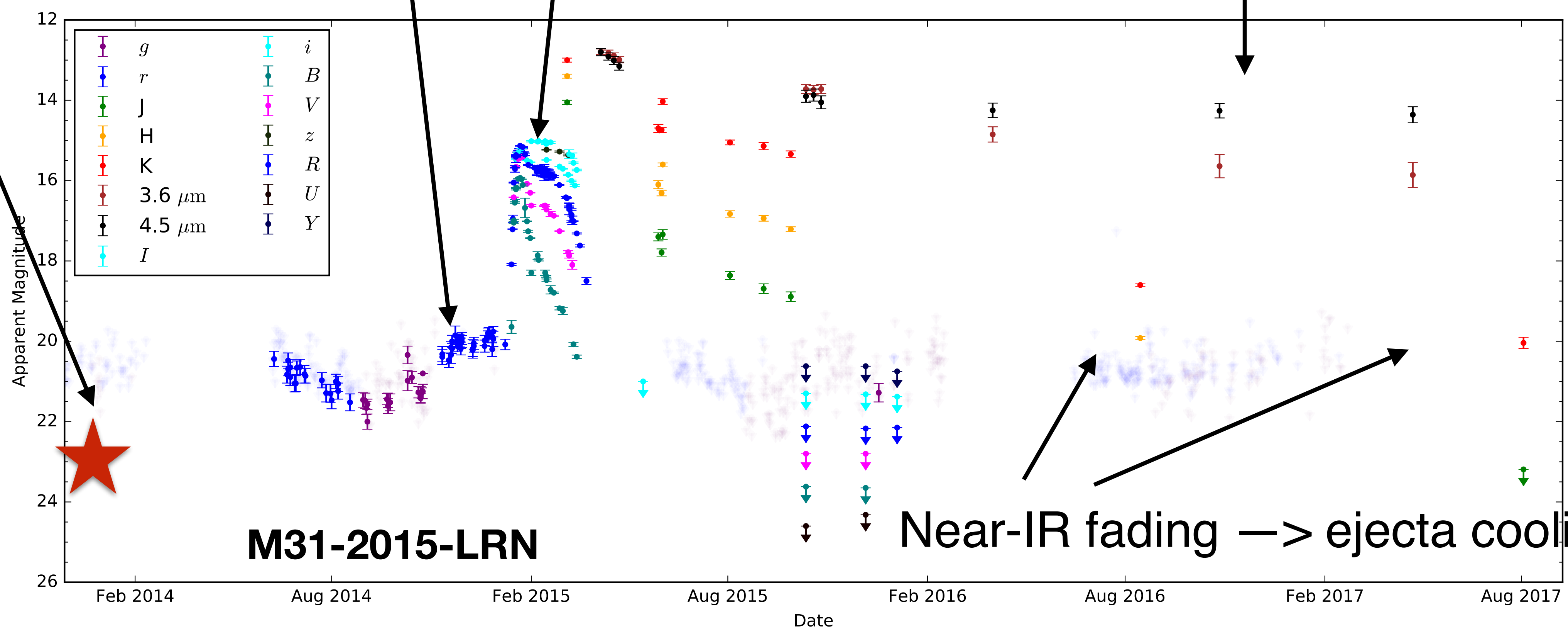


Progenitors:
what binaries are unstable to CE evolution?

Precursor:
how binaries lose angular momentum?

Outbursts:
what energy sources power the emission?
how the envelope is ejected?

Remnants:
dust formation-timescales & characteristics

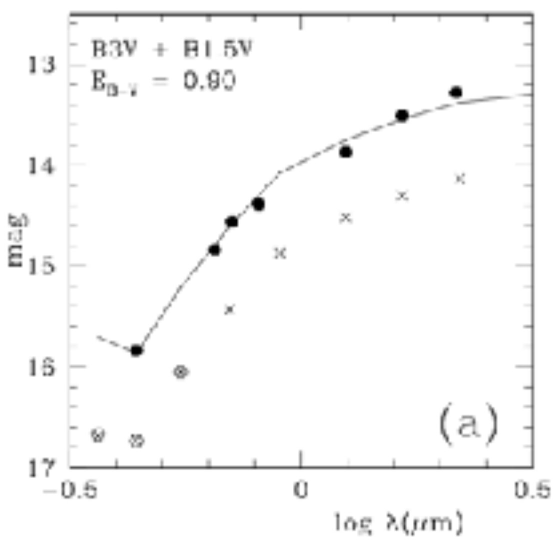


Near-IR fading —> ejecta cooling

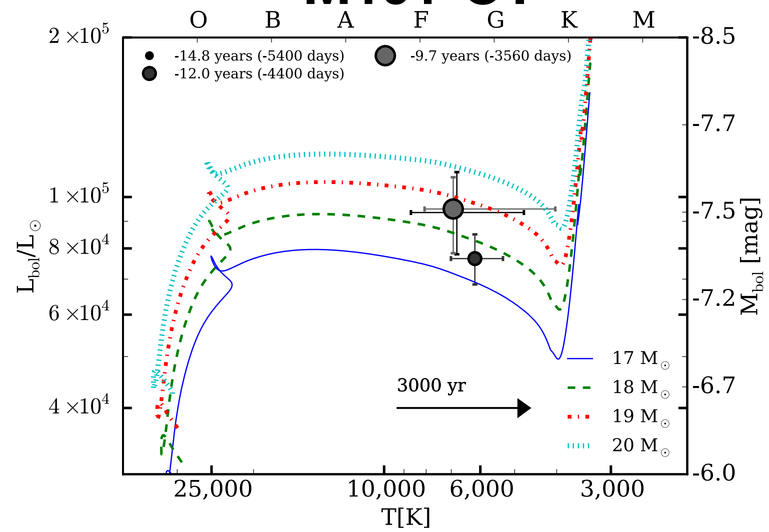
Rates:
assumptions on CE in BPS

Progenitors (I)

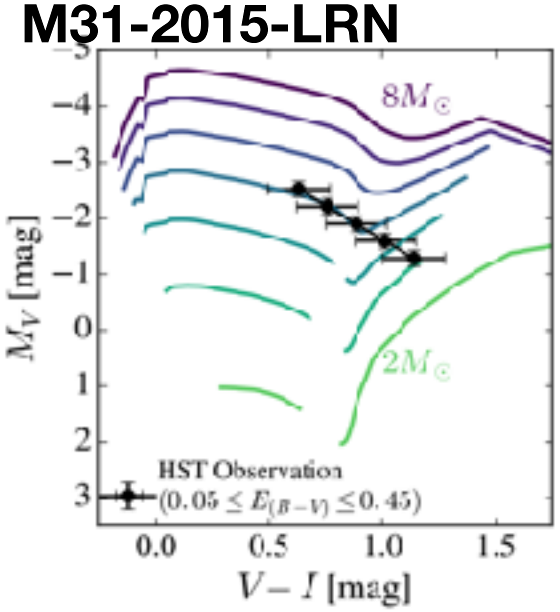
V838Mon



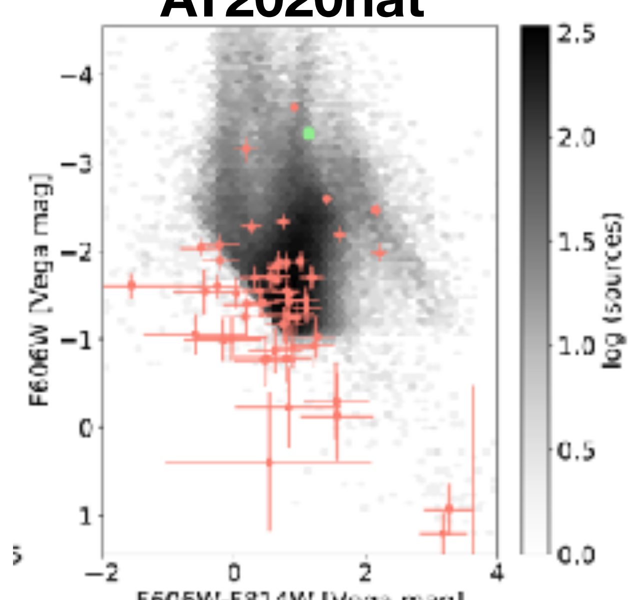
M101-OT



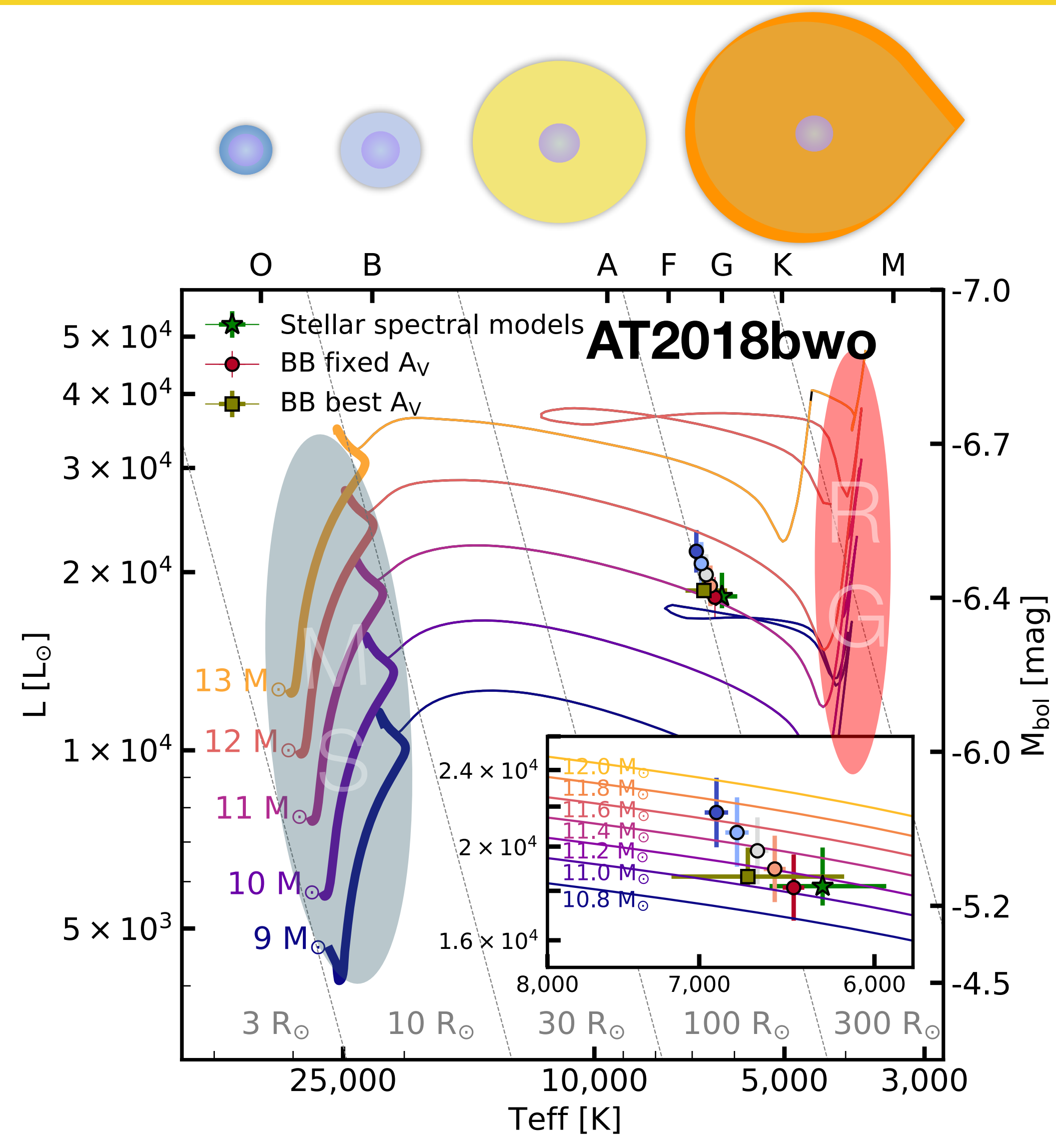
M31-2015-LRN



AT2020hat

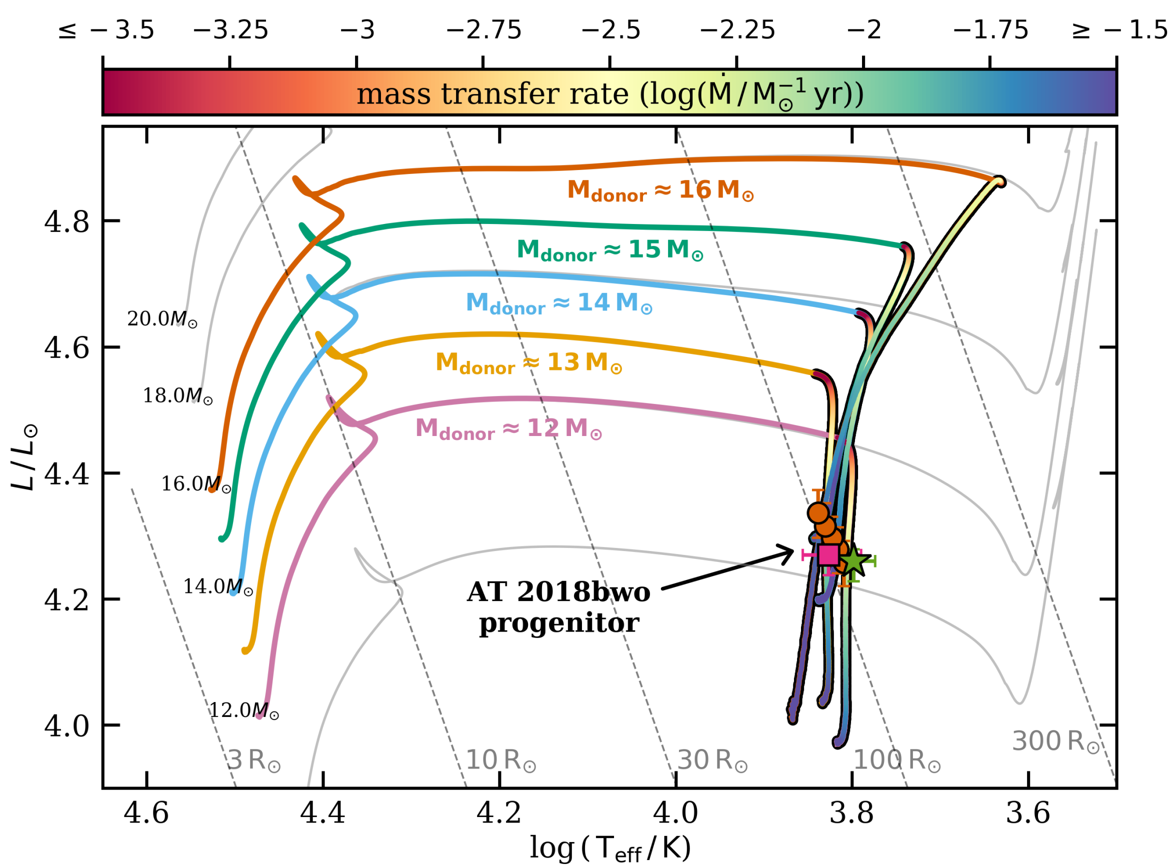


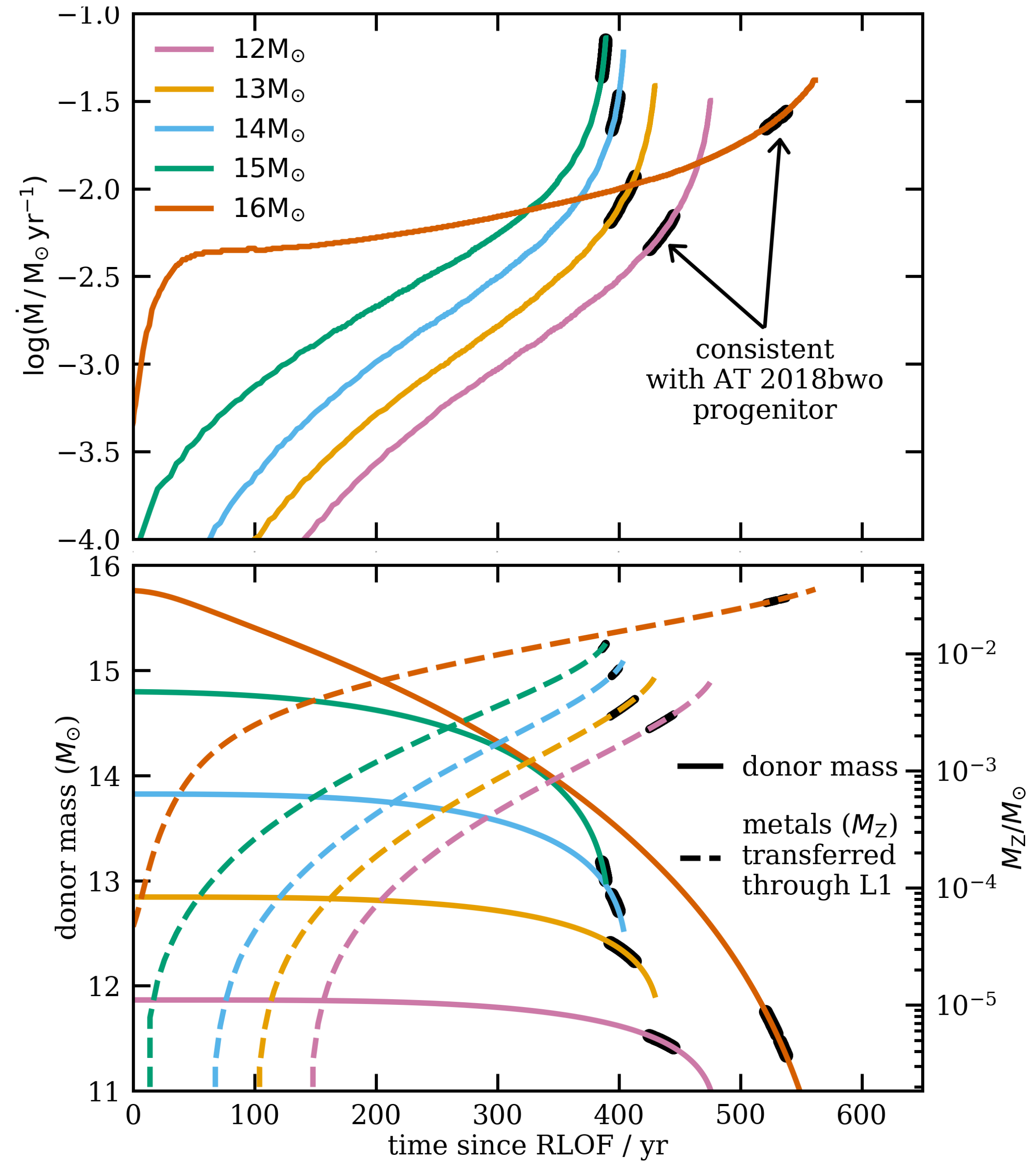
Progenitor is a Hertzsprung Gap star
(case B mass transfer)



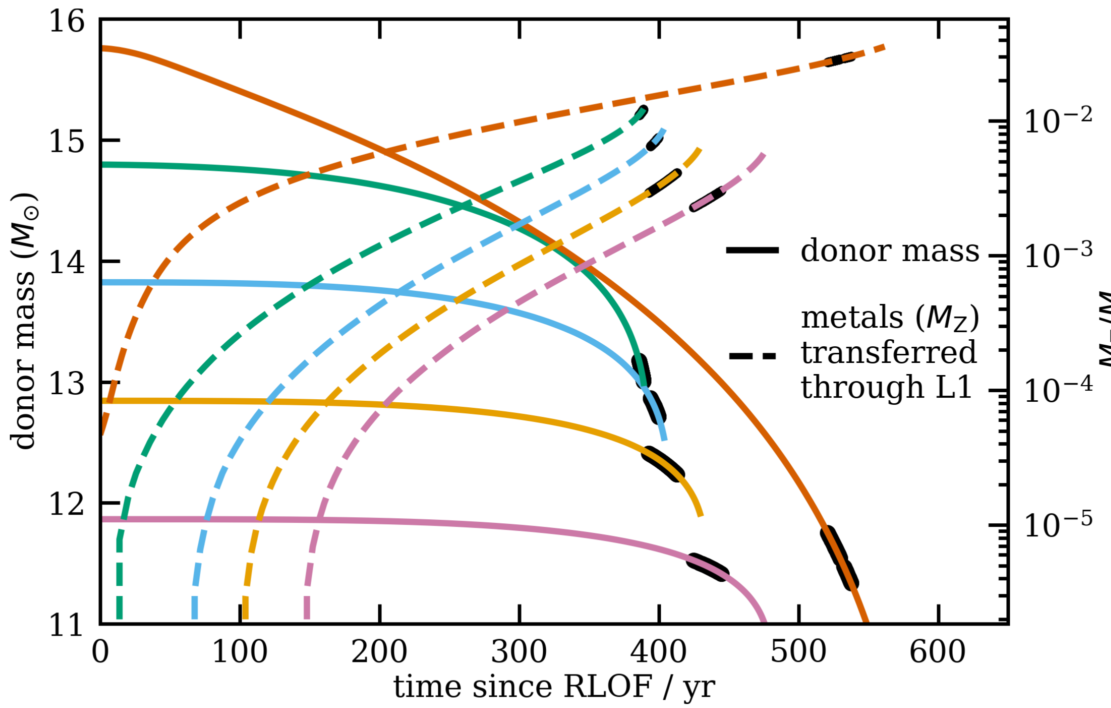
MESA models for single stars

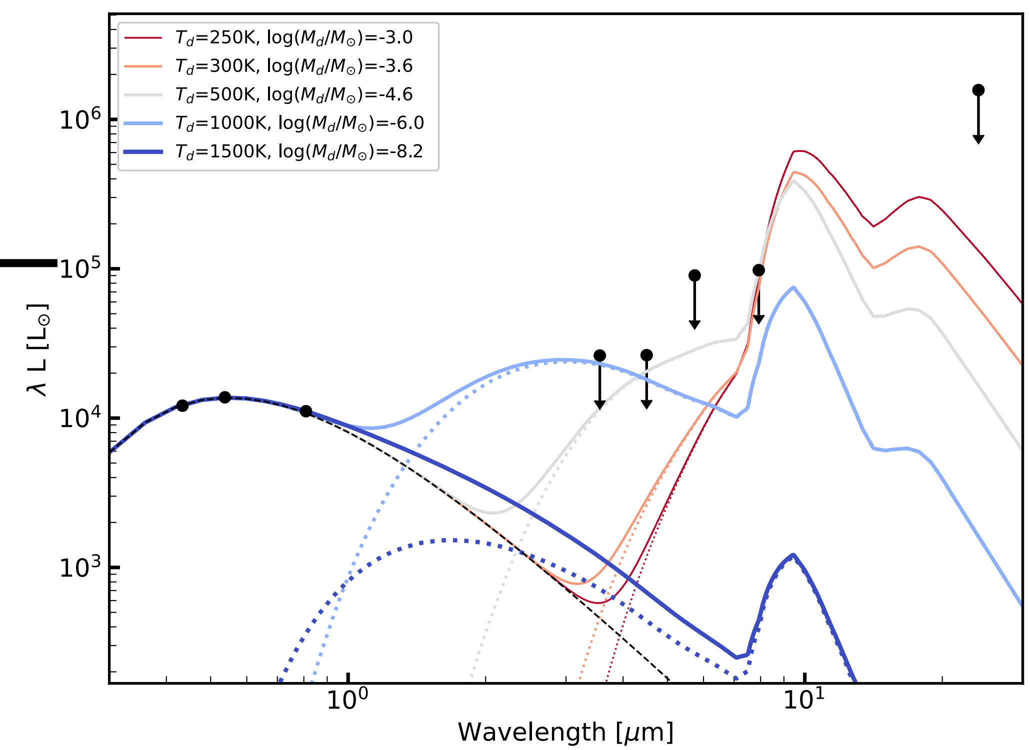
(Binary) Progenitors (II)

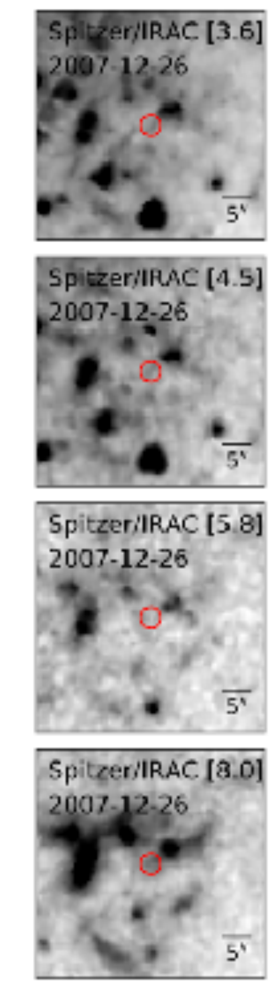




Progenitors - Dust constraints



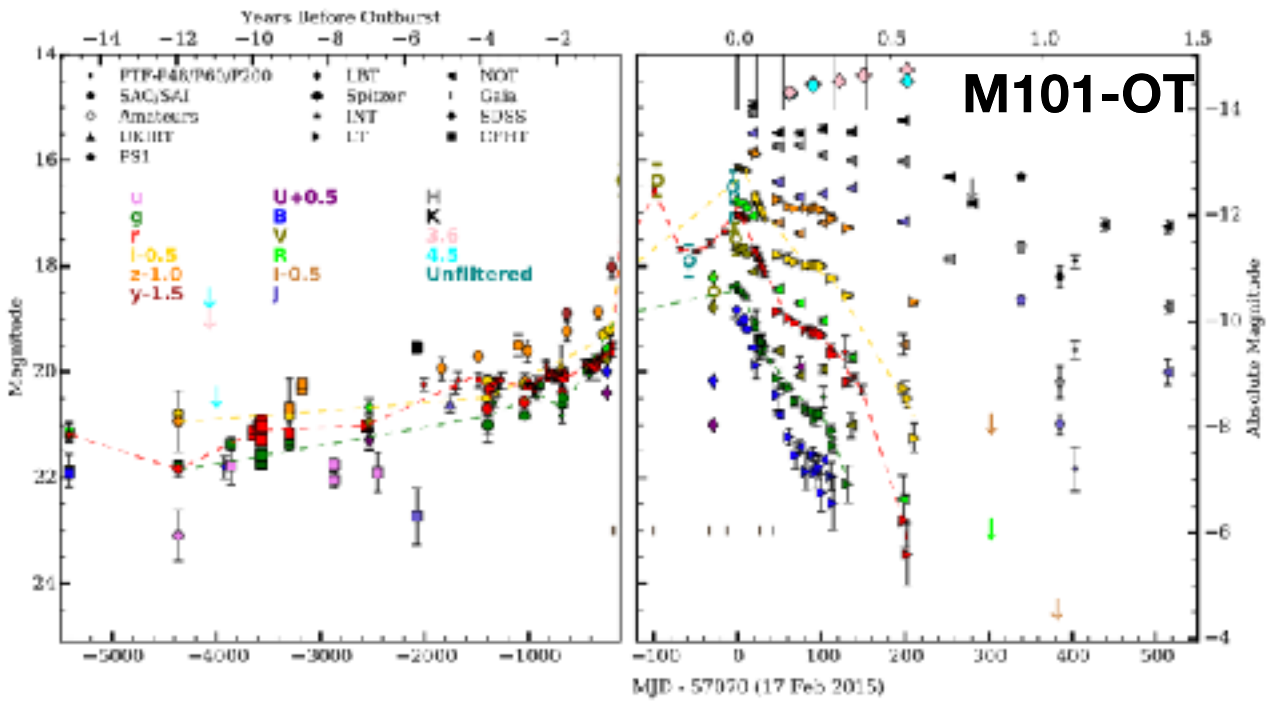


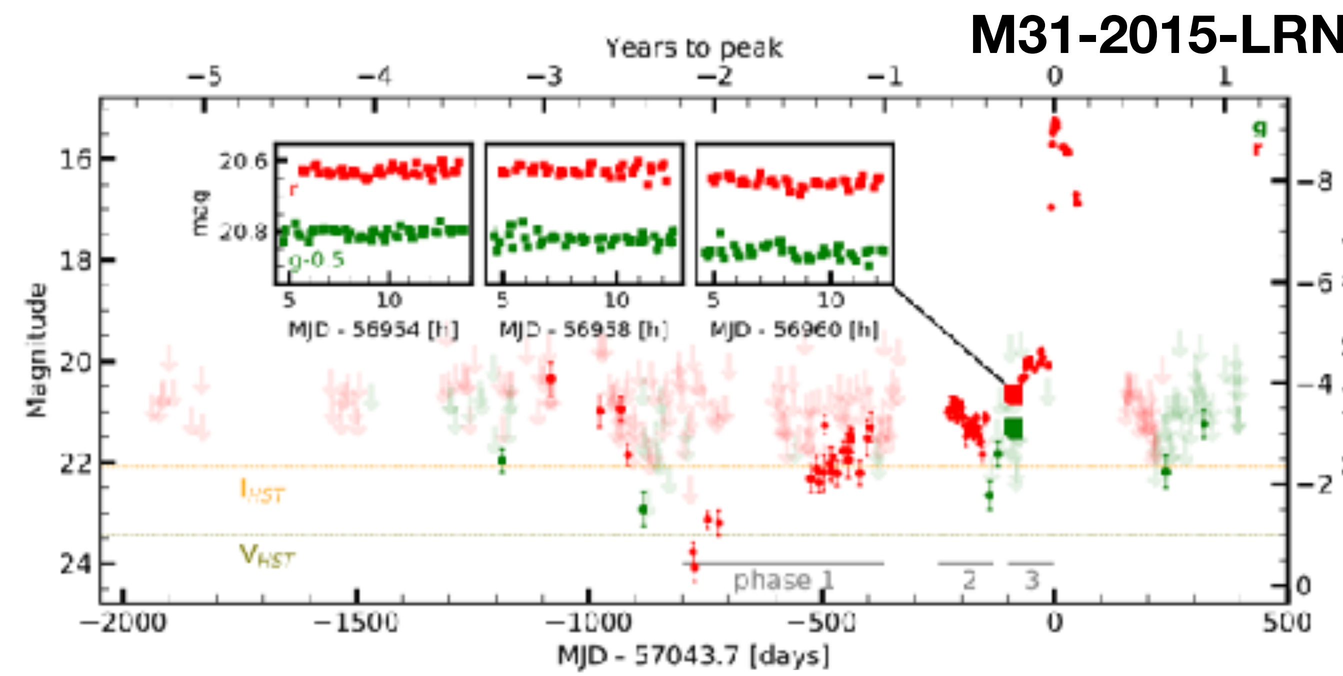


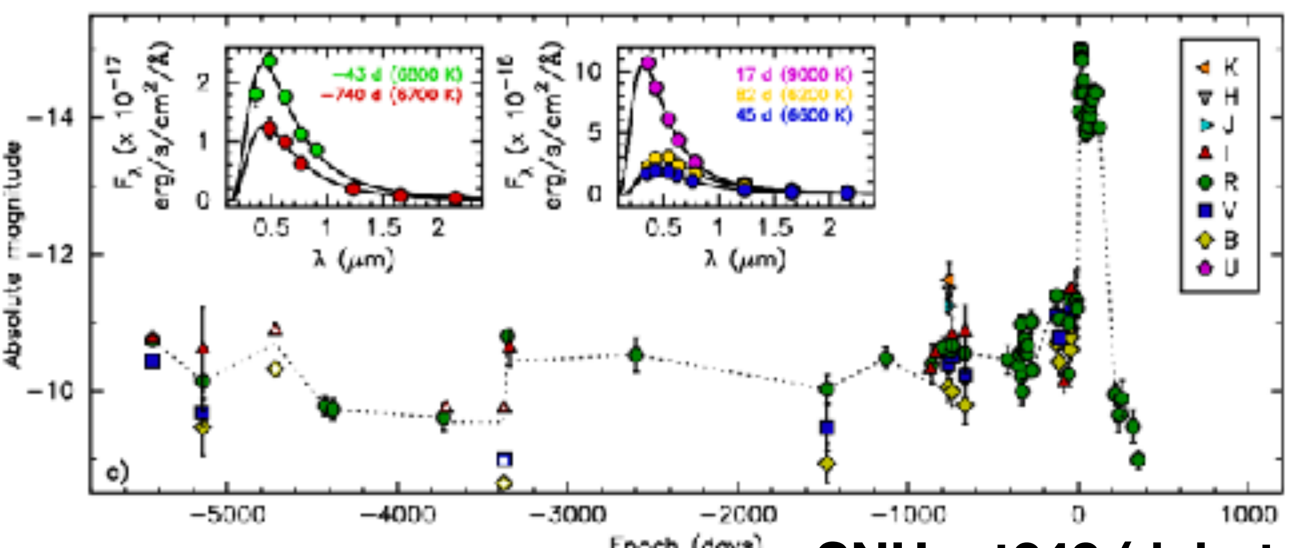
1.- Dust formation near the star is destroyed by shocks.
- Dust forms only at larger radii (and it’s colder thank 250K).

2. - Outflow is radiatively inefficient.
- The energy is lost in adiabatic expansion of the gas rather than in radiation.

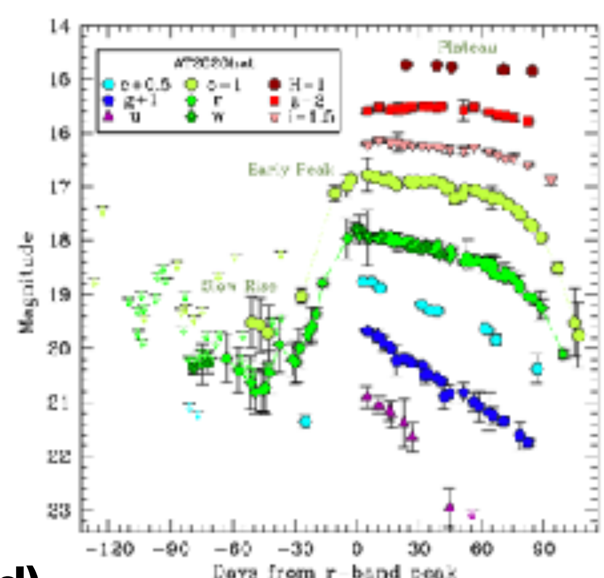
Precursors (I)

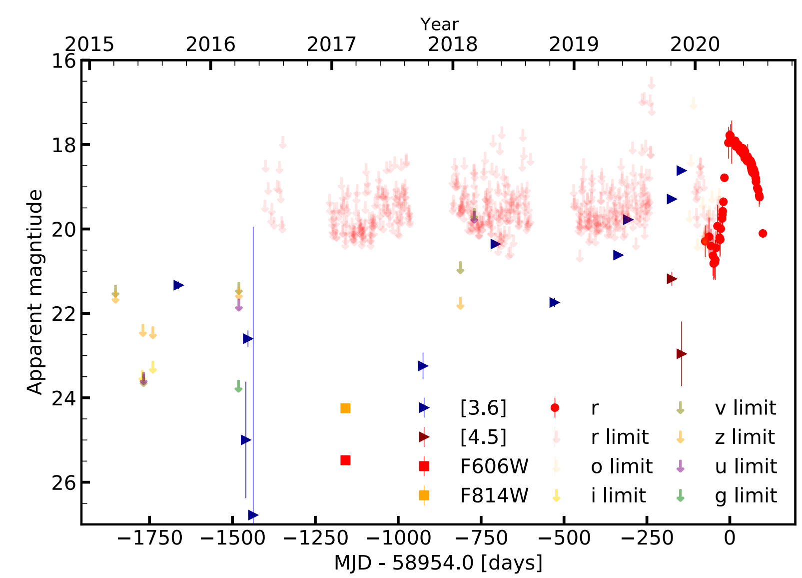




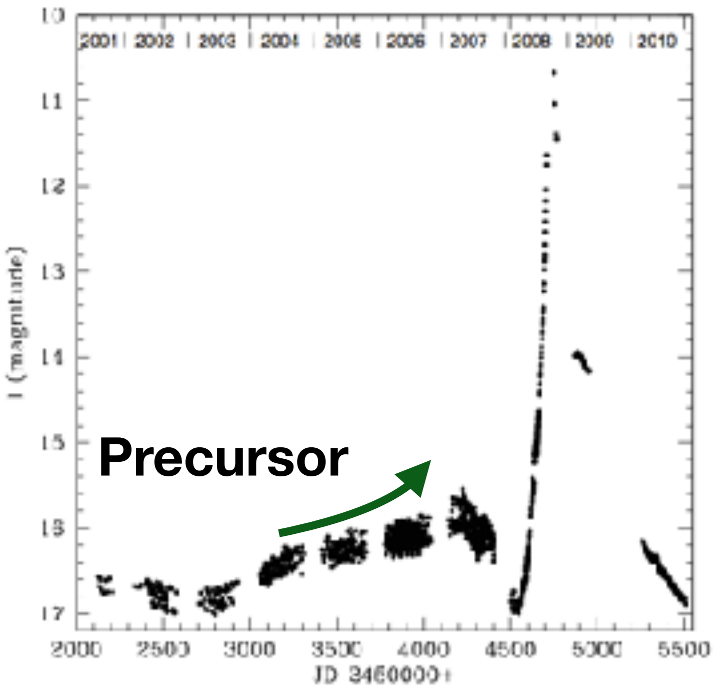


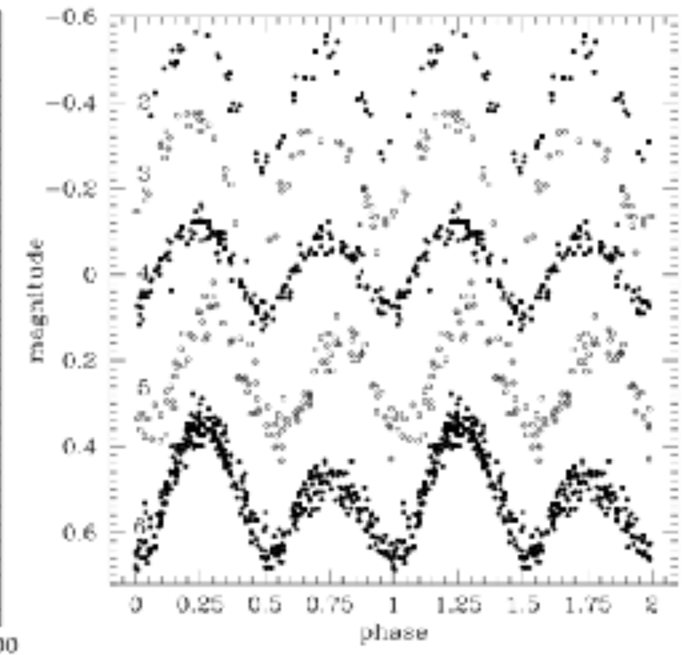
SNHunt248 (debated)

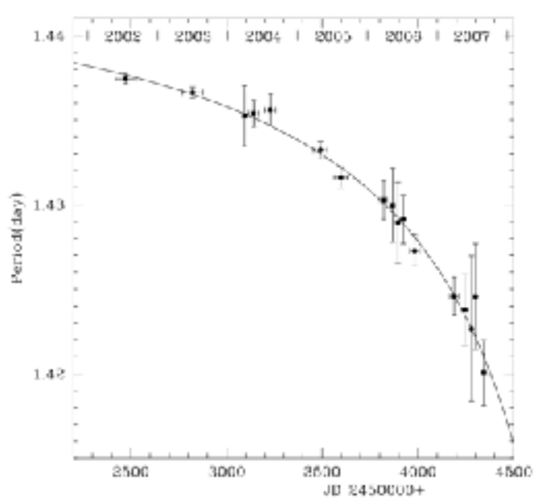


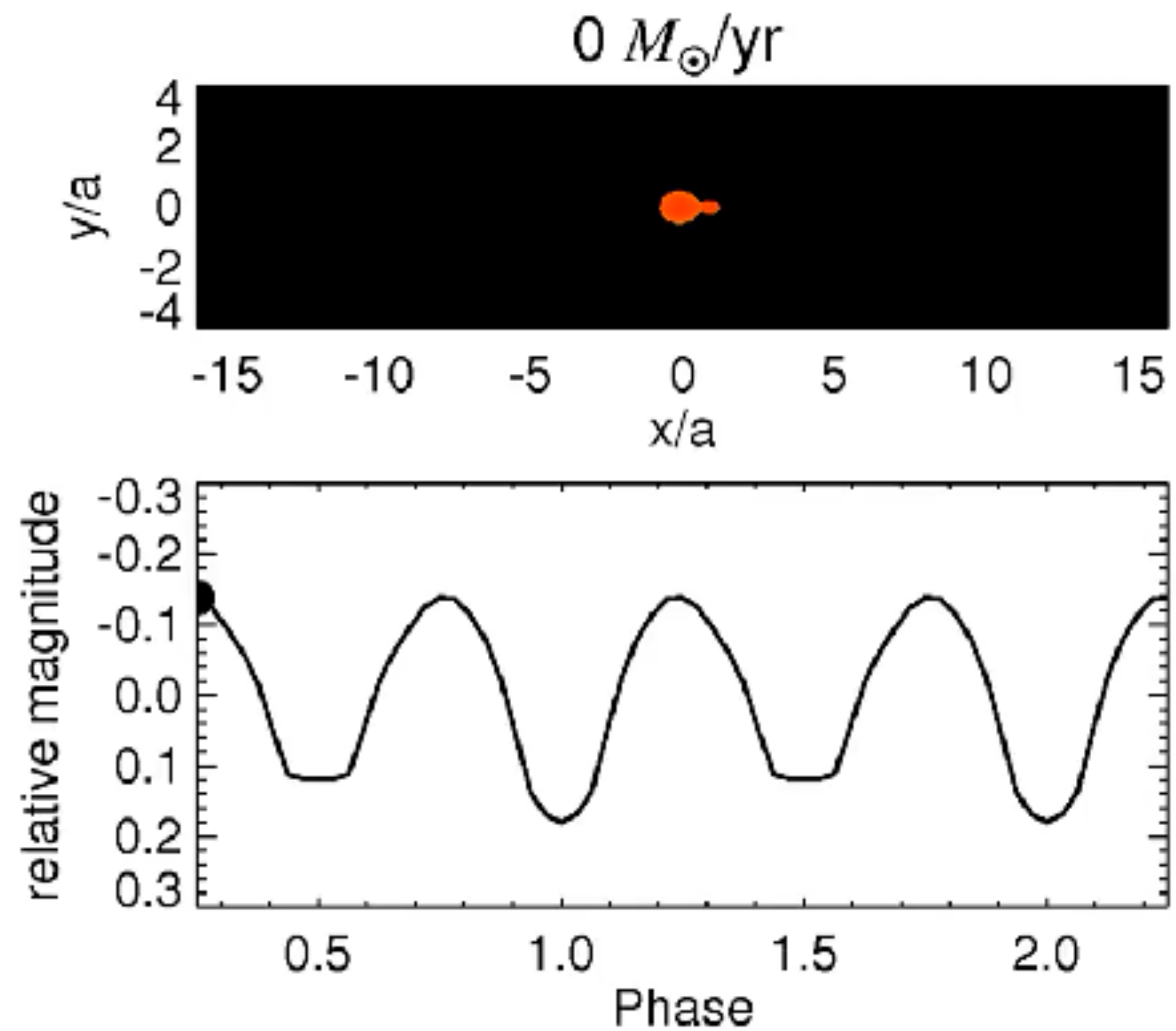


V1309Sco


Precursor
I (magnitude)
JD 2450000+

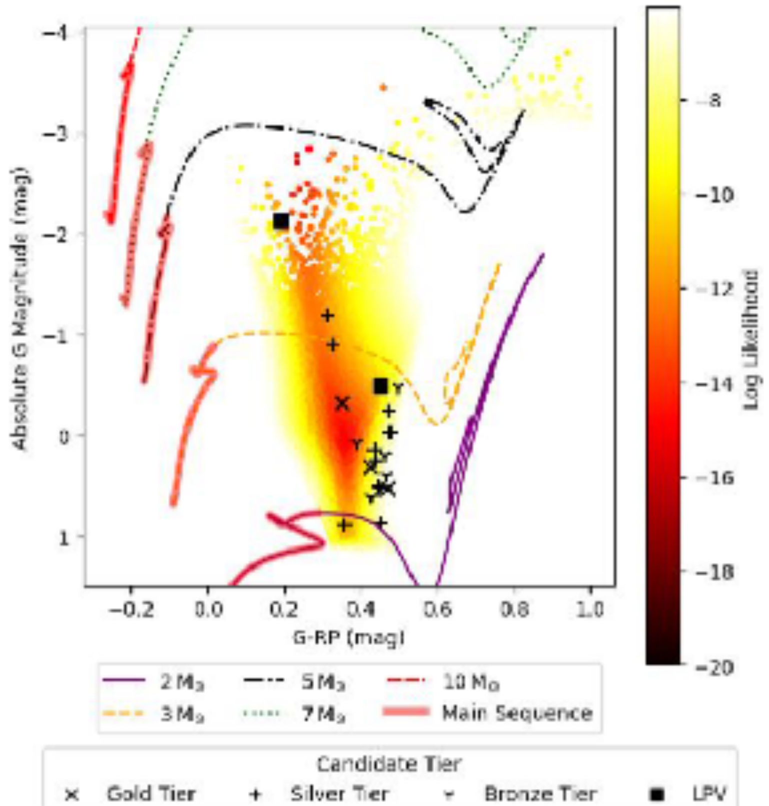

magnitude
phase


Period(day)
JD 2450000+

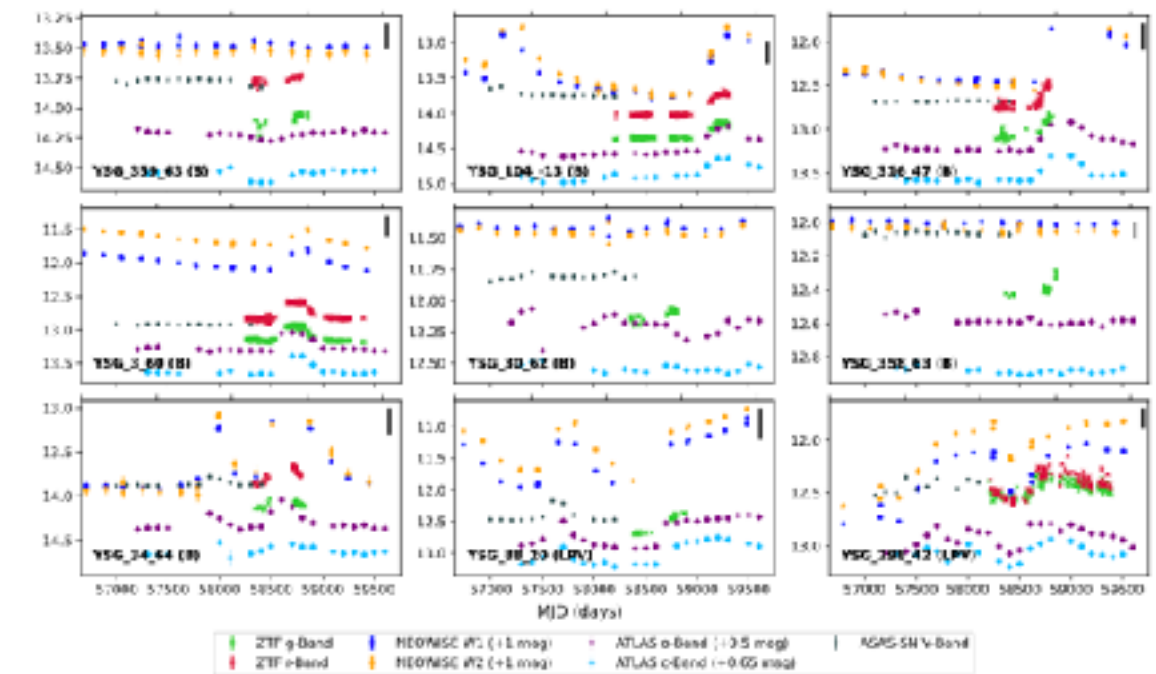

0 $M_\odot$/yr
y/a
x/a
relative magnitude
Phase

Precursors - Searching for the next Galactic LRN

1 - Search for Gaia sources in "the gap"

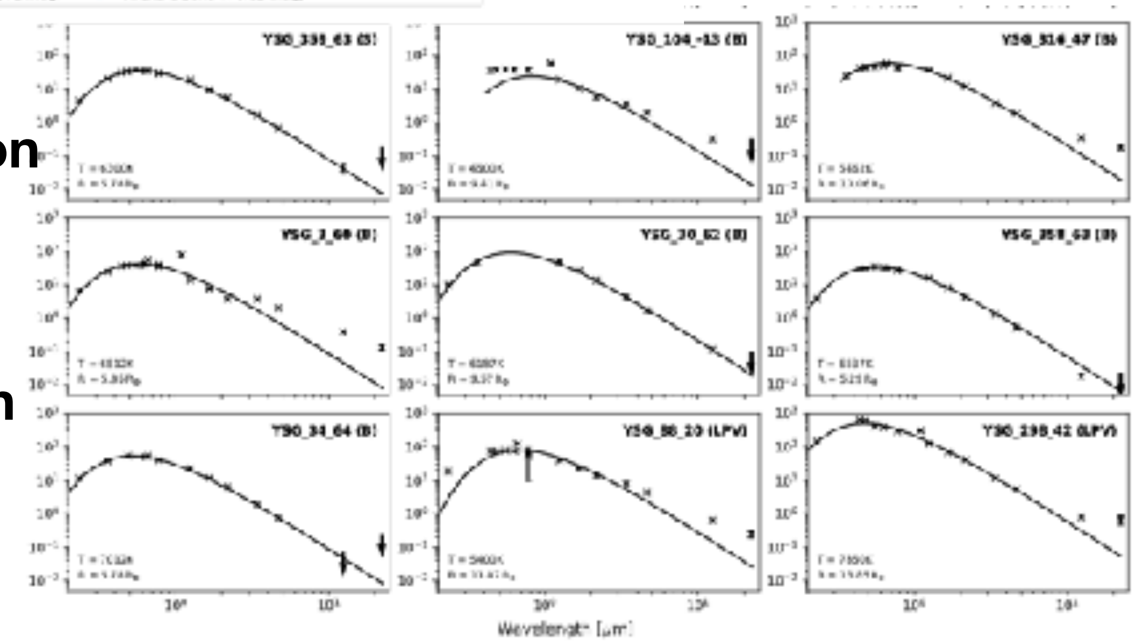


2 - variability study



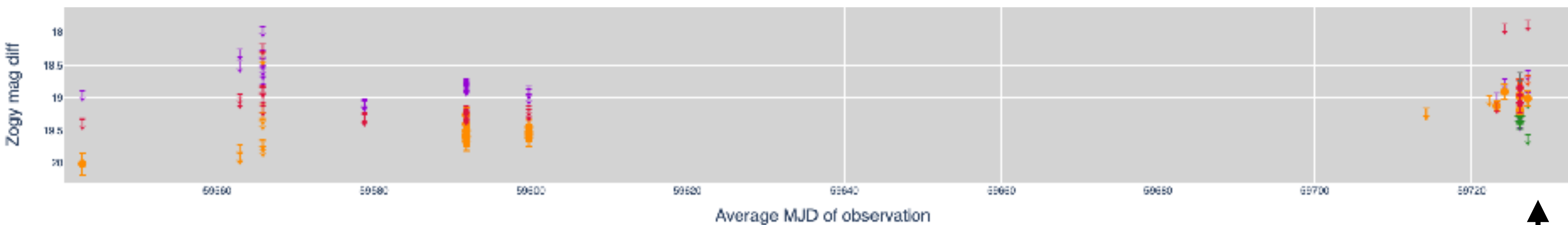
3 - characterisation

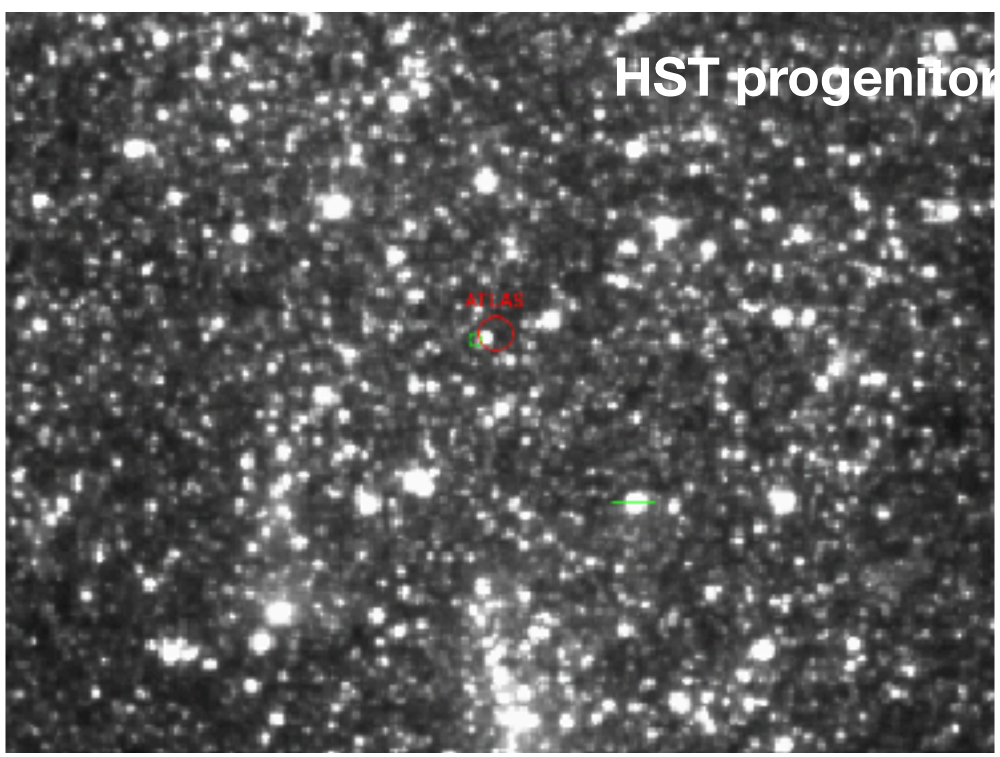
IR excess + Hα emission

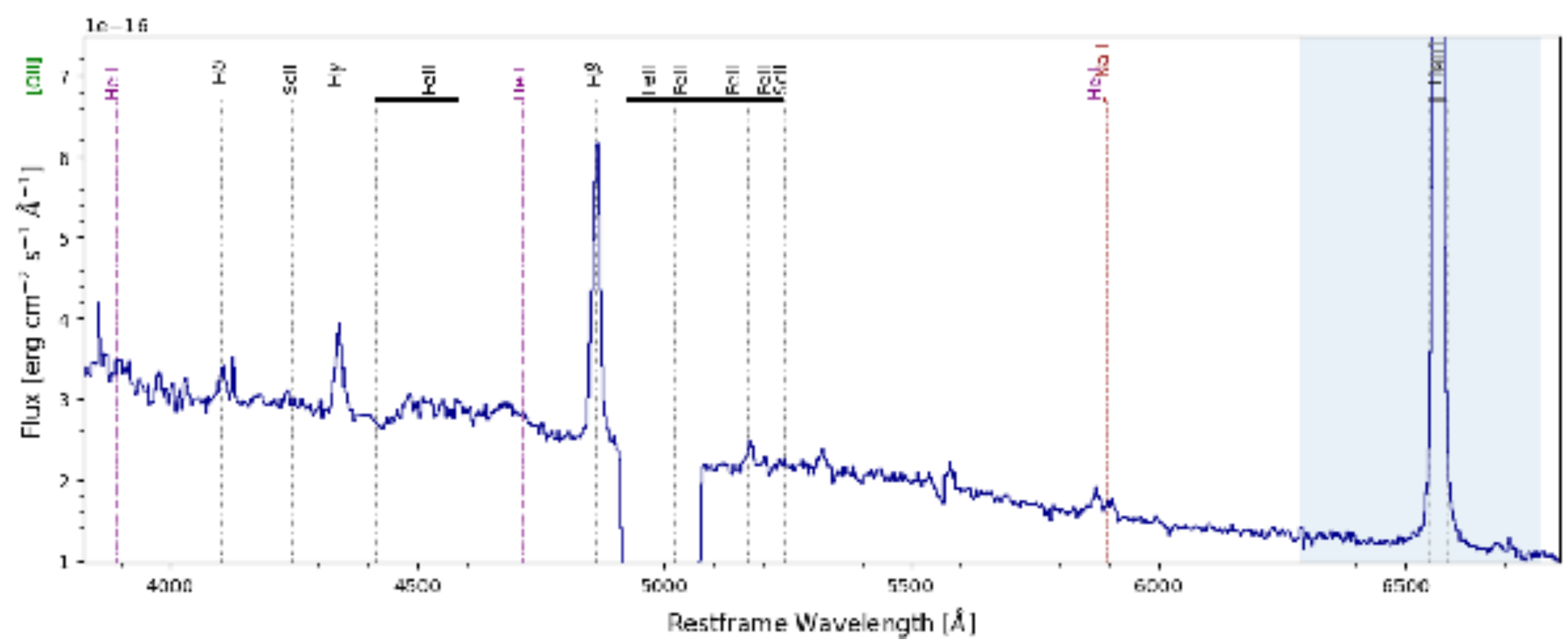


First real-time precursor detection? - AT2022kms

Novembre 2021 **May 25 2022**

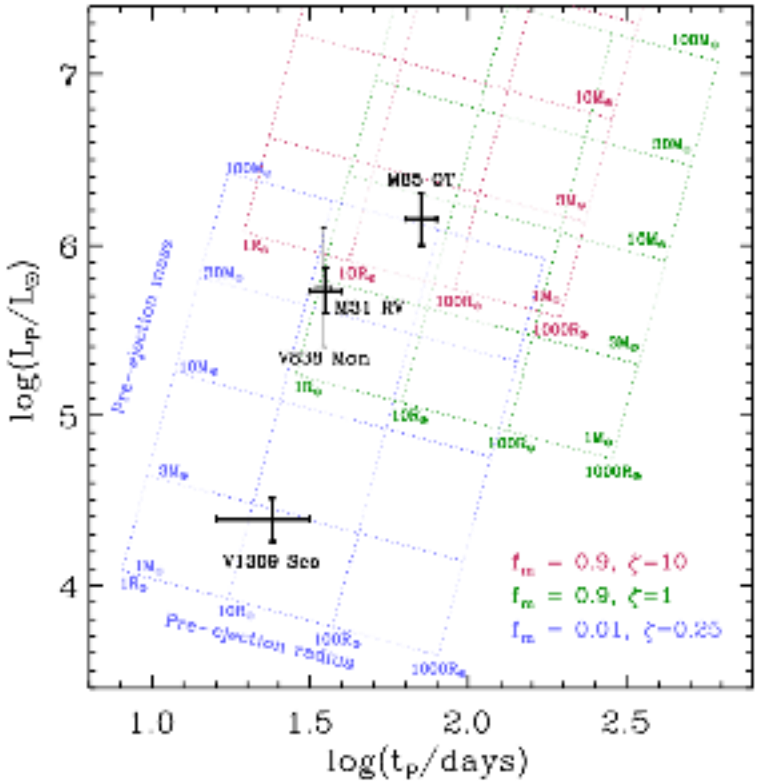


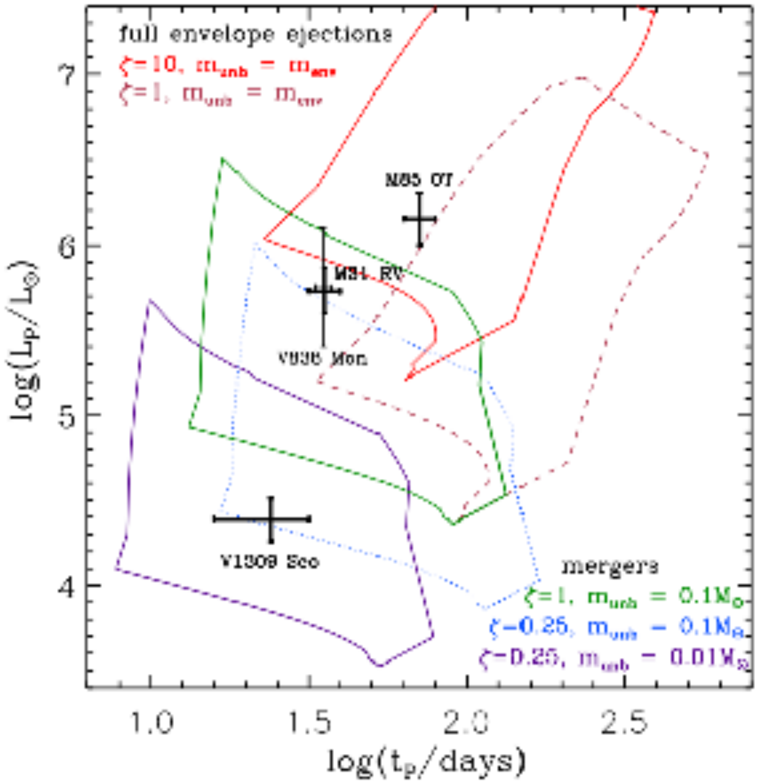


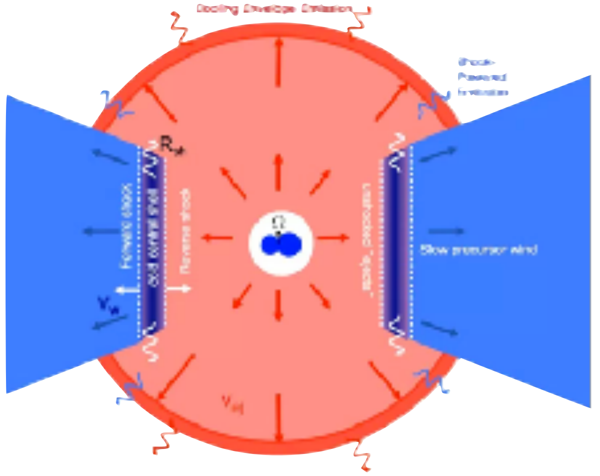


What powers the ligthcurves?

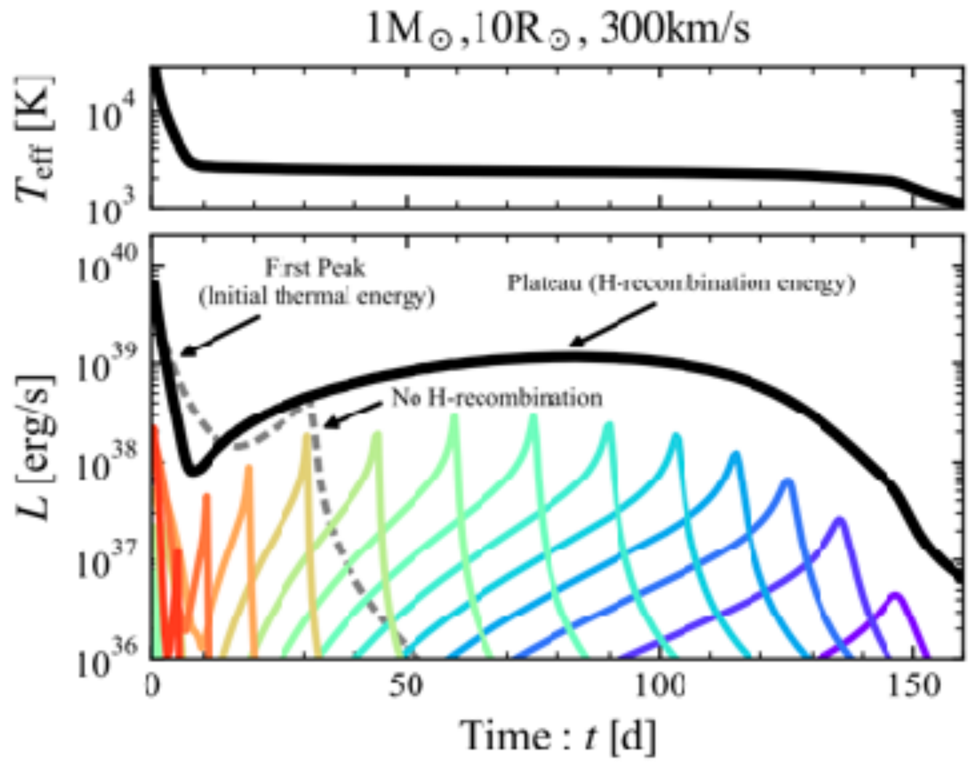
Recombination energy (e.g. scaling from SN II)



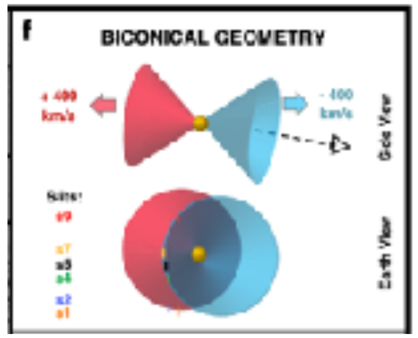


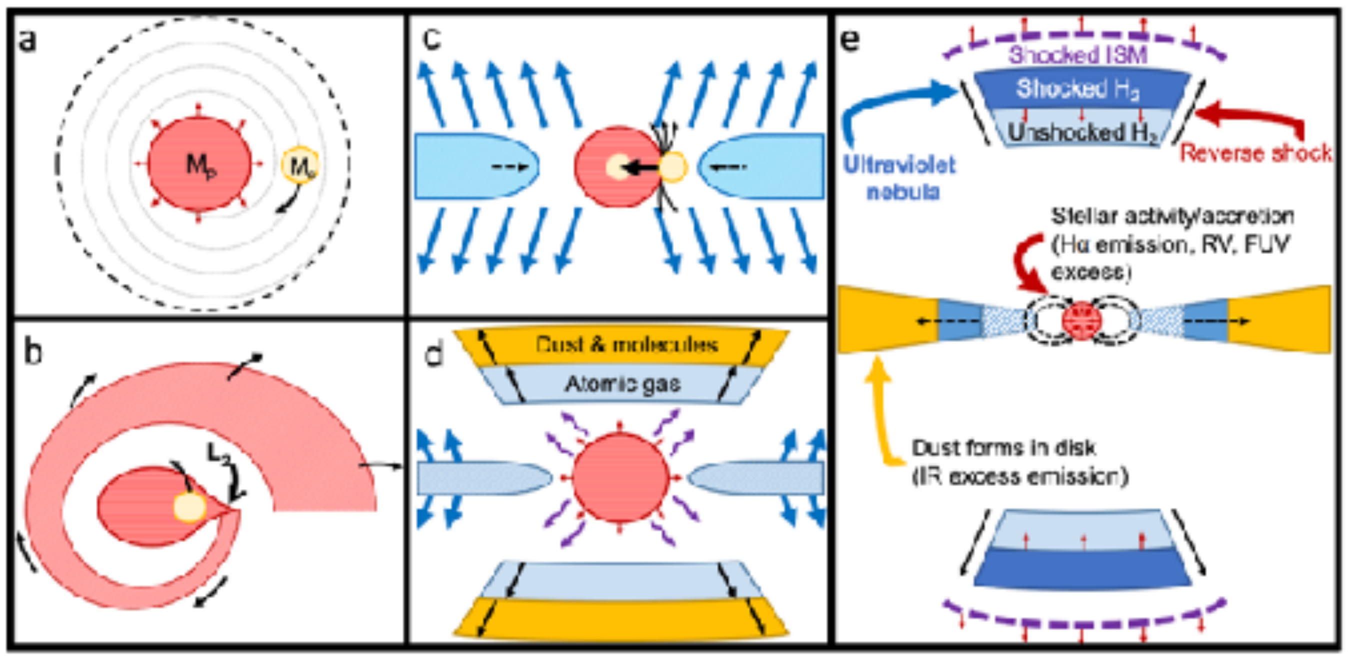


Thermal + recombination + shocks

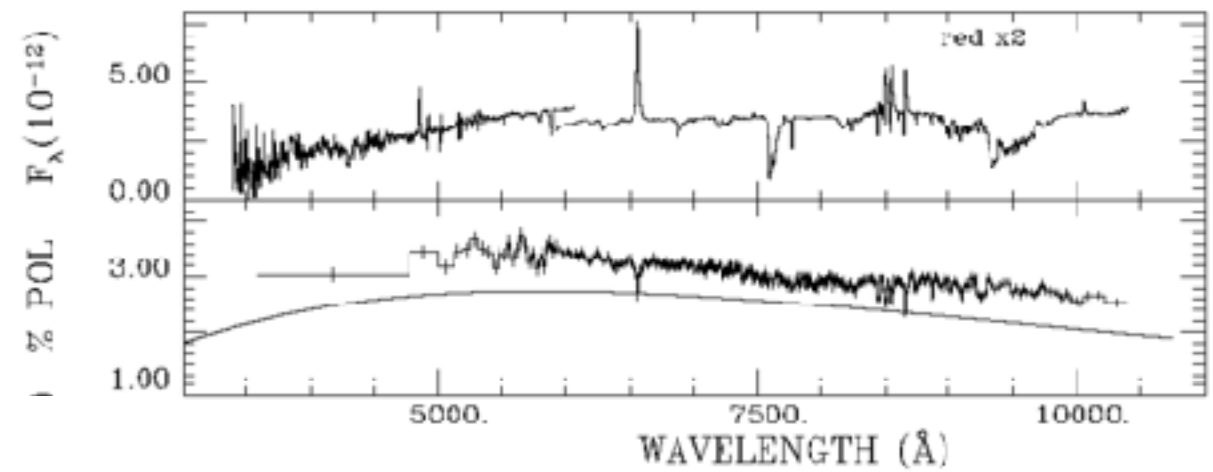


Outbursts (II) - Geometry

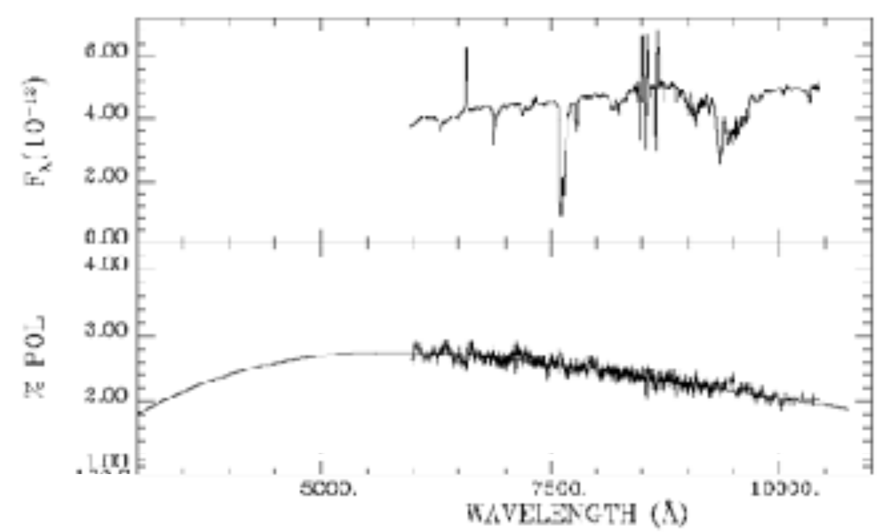




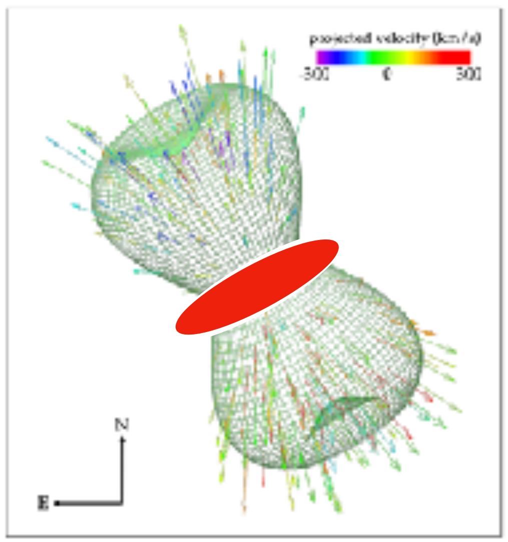
8th February 2002 (V838 Mon)



14th February 2002 (V838 Mon)

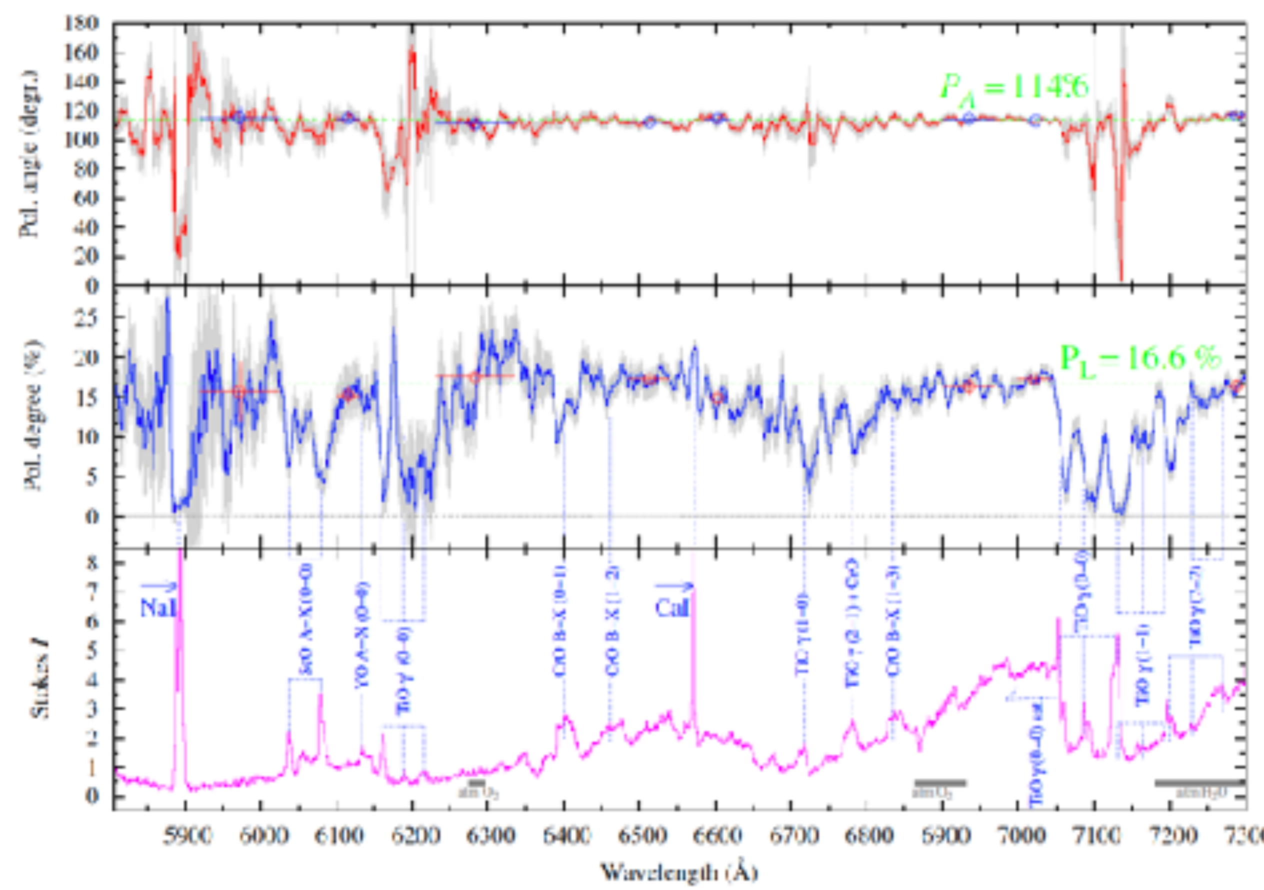


e⁻ scattering in a flattened shell

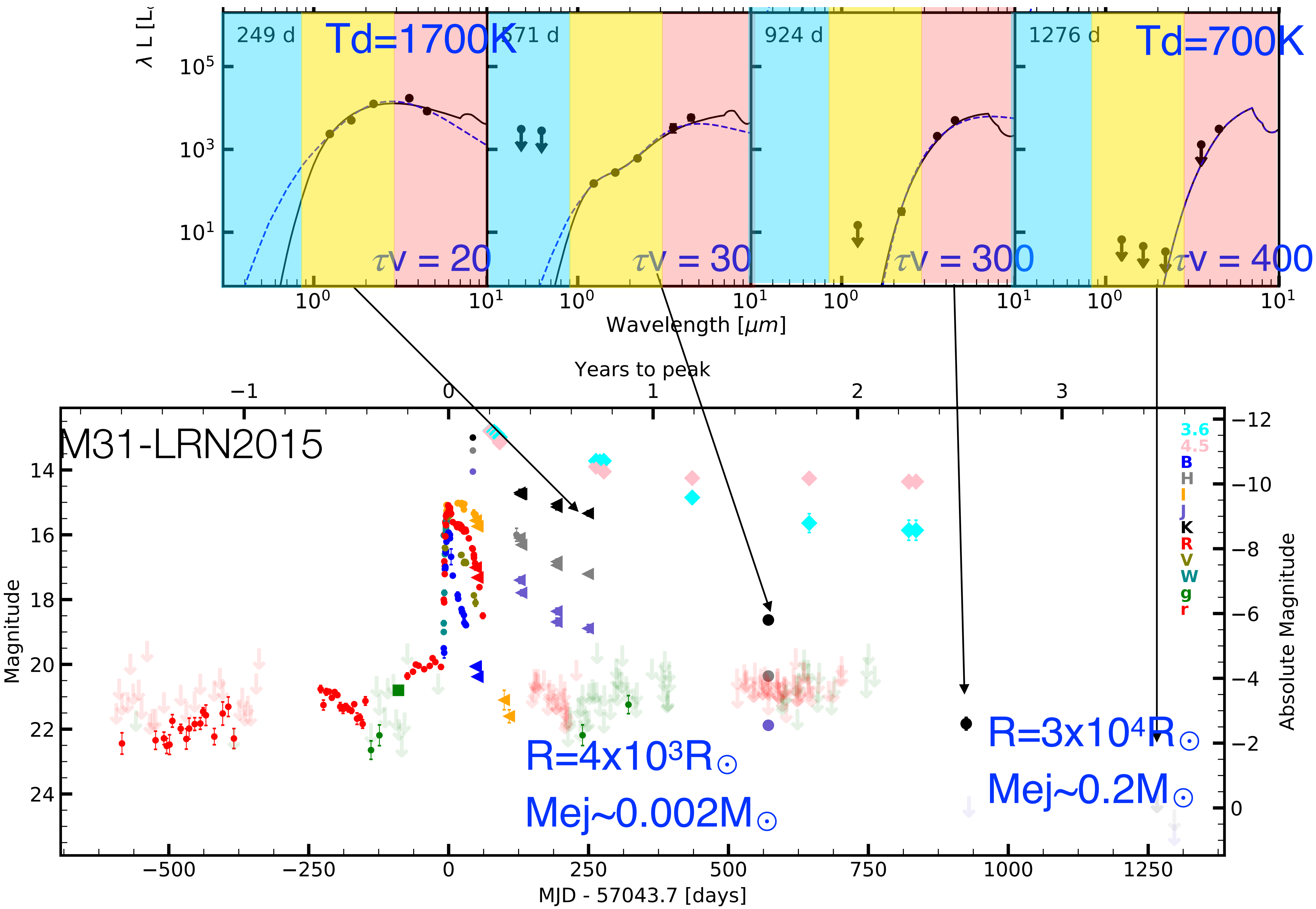


photon scattering on dusty disk

V4332 Sgr



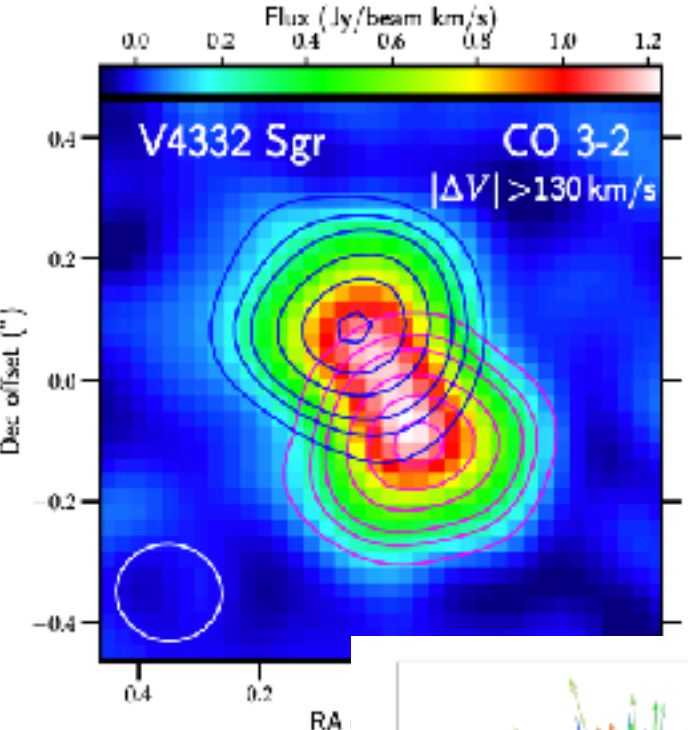
Remnants (I) - Dust formation

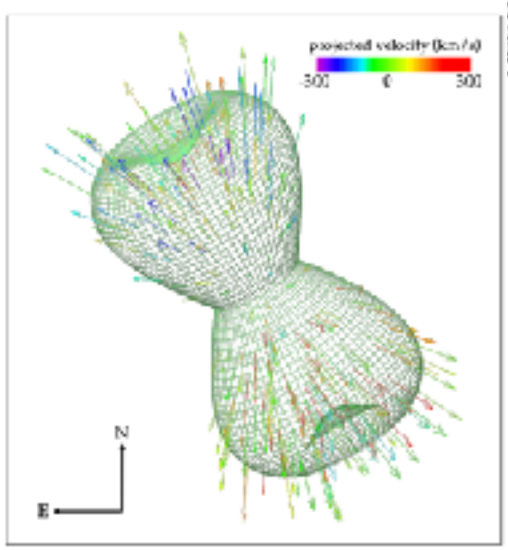


(see Jacob's talk!)

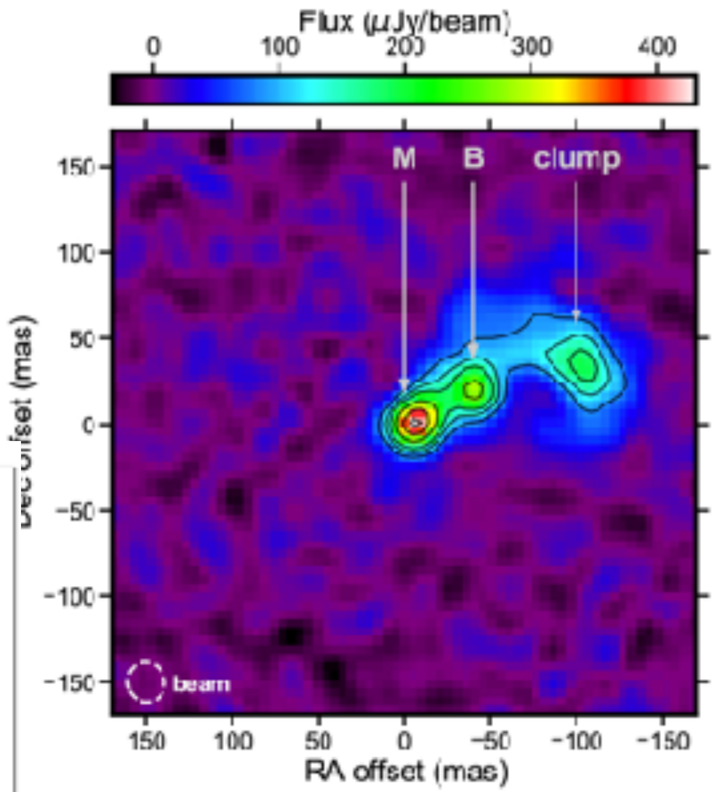
Remnants (II) - Geometry and dust chemistry

(see Tomasz's talk!)

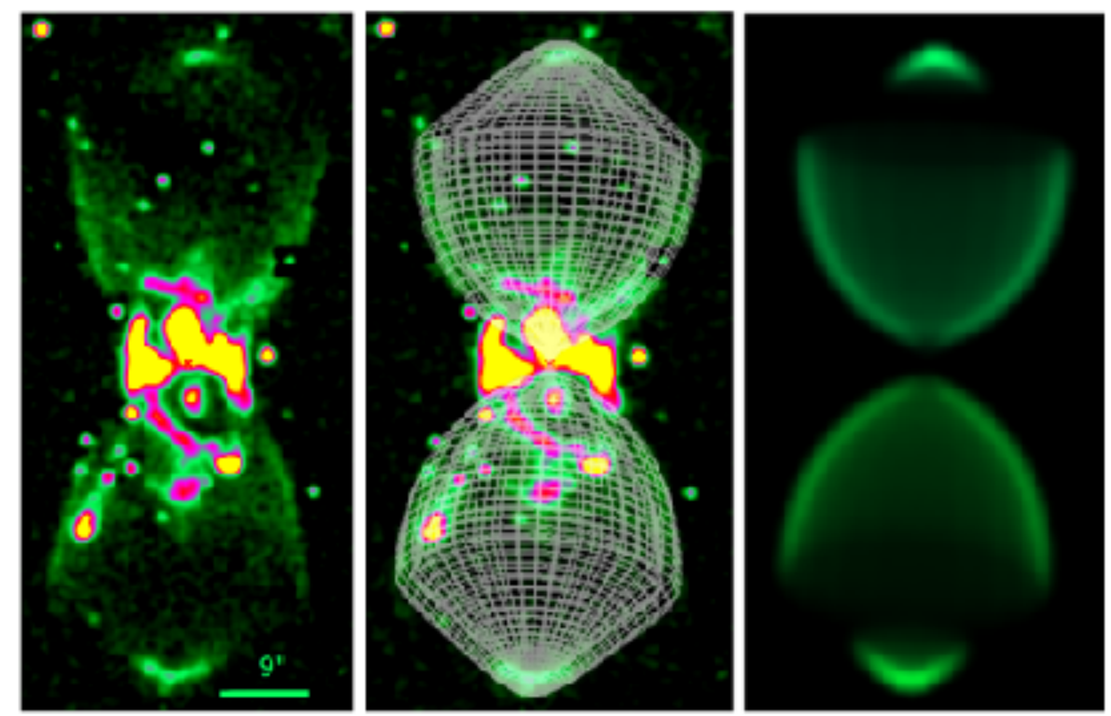




V838Mon



CK Vul



LRN Rates - ZTF Census of the Local Universe

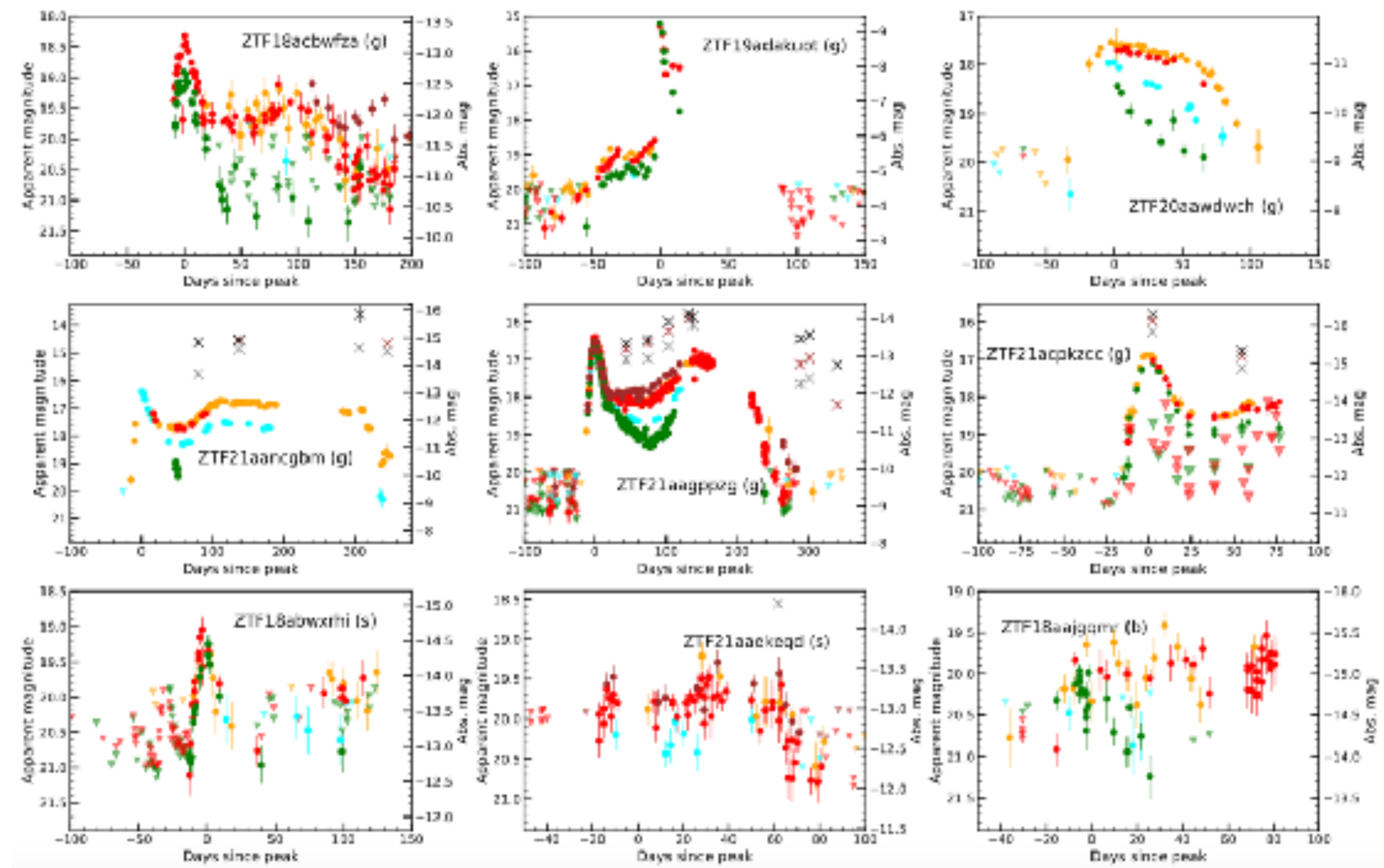
- Spectroscopically classify ZTF transients that are associated with nearby galaxies in the CLU galaxy catalog

- ZTF Phase 1 (pre Oct. 2020)—
    - m < 20 mag
    - offset < 100 arcsec, D < 200 Mpc

- ZTF Phase 2 (post Oct. 2020)-
    - m < 20.5 mag
    - offset < 30 kpc, D < 140 Mpc
    - $M_{g,r} > -17$ mag

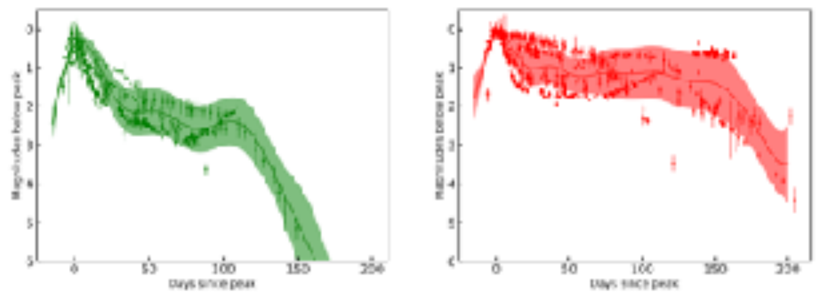
- Overall spectroscopic completeness ~80 %

- Ideal for volume limited sample studies
    - Ca-rich type Ias (De et al. 2020), Ca-rich type II (Das et al. in prep)
    - Type II SNe (Tzanidakis et al. in prep), SN1987A-like SNe (Sit et al., in prep)



Rates

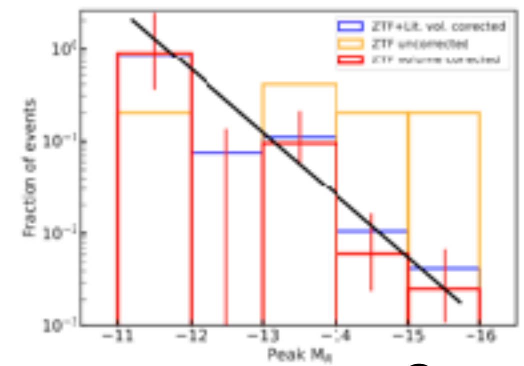
Template lightcurves



Simulate the full ZTF survey for a range of LRN rates and compare to observed sample

+

Luminosity function

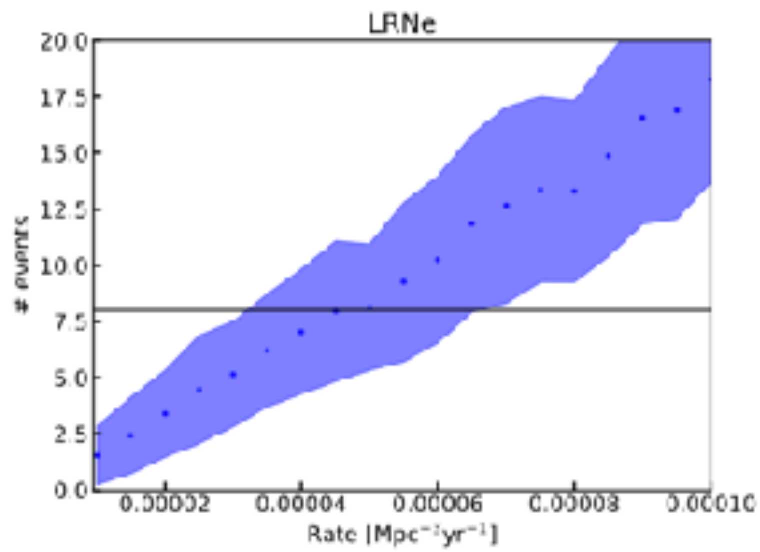


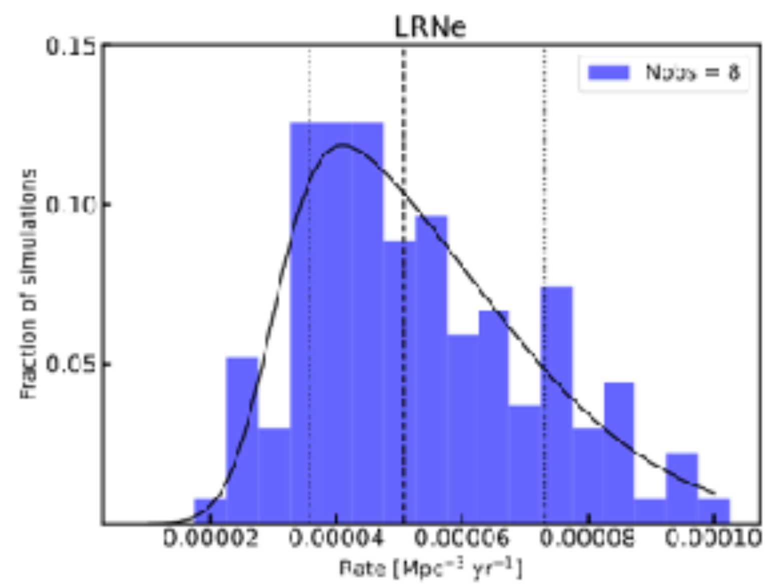
$dN/dL \sim L^{-2.8+/-0.3}$

for $-11 > M_r > -16$

Steeper compared to $\sim L^{-1.4}$ for

$M_V > -10$ LRNe (Kochanek et al. 2014)





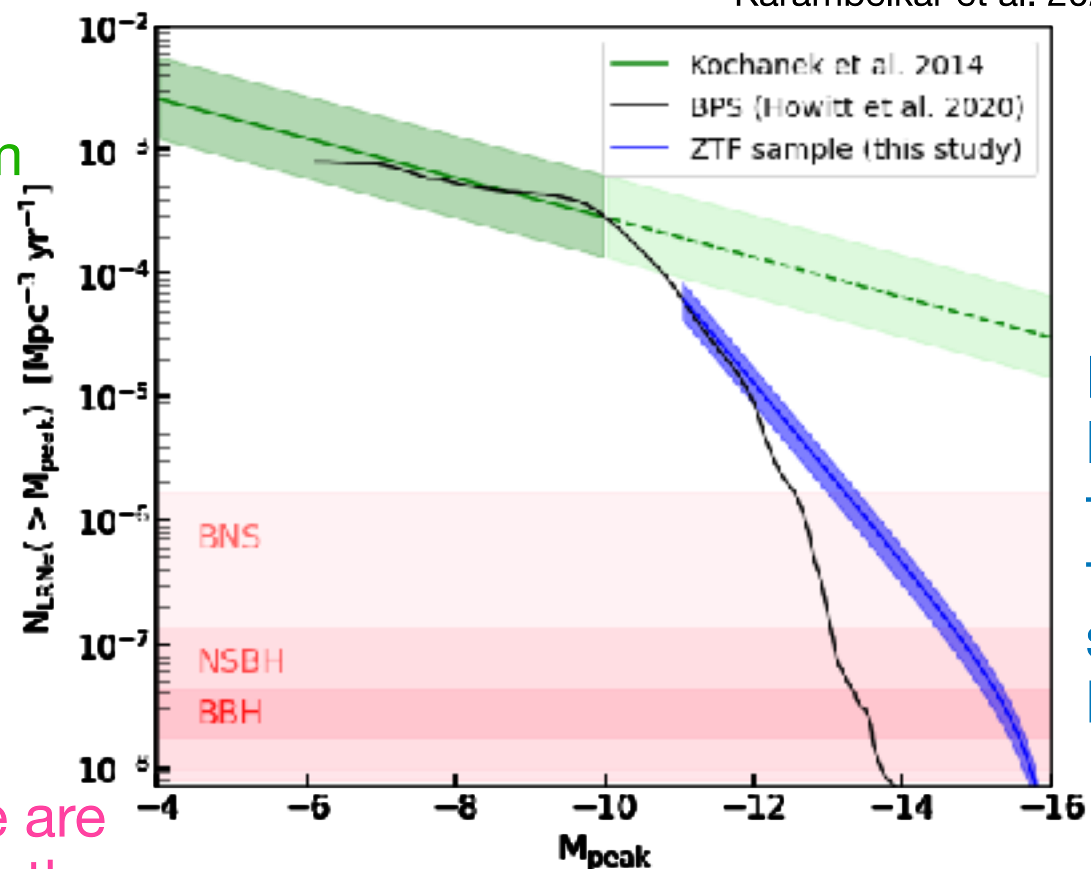
* correcting for survey/ catalog completeness

$r_{LRNe,-11>M>-16} \sim 7^{+3}_{-3} \times 10^{-5}$ Mpc^{-3} yr^{-1}

LRN rates

Rate of low-luminosity mergers based on 3 events from the Milky Way

Karambelkar et al. 2022, in prep



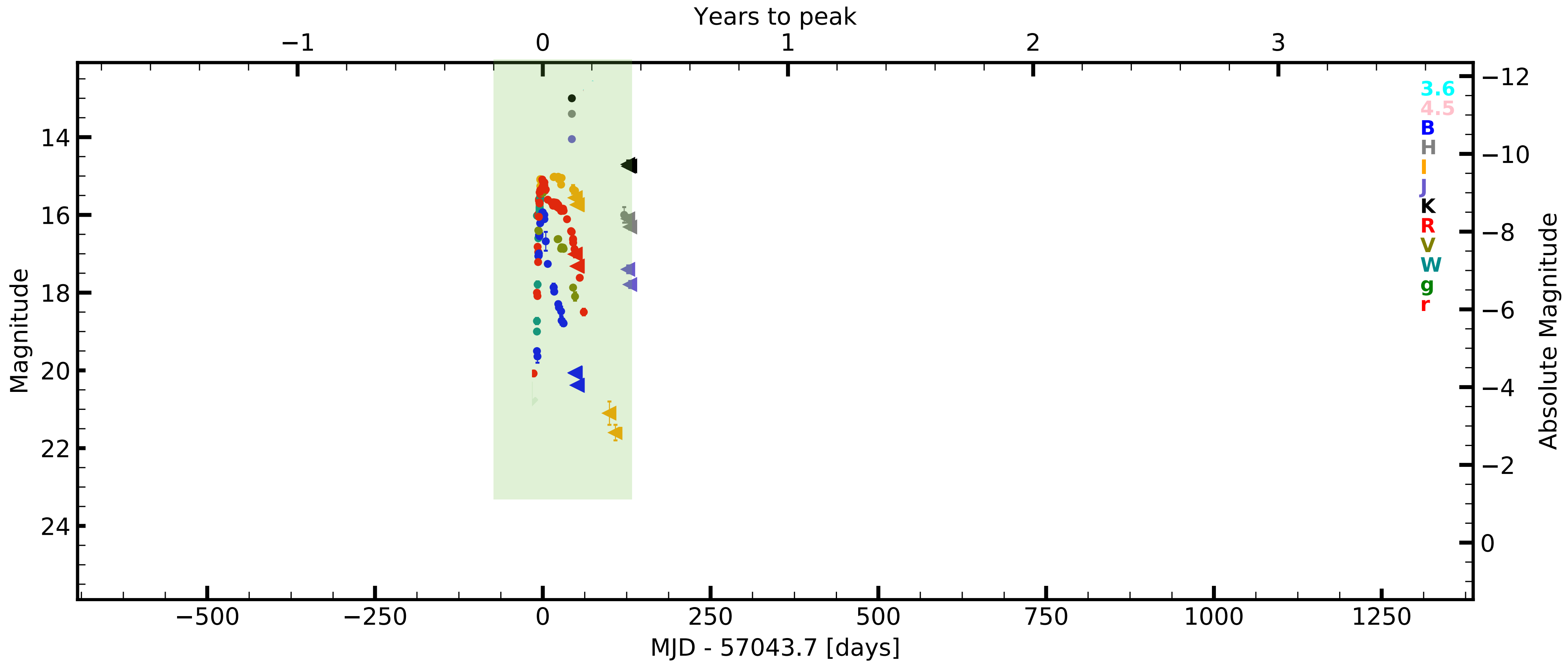
For higher luminosity LRNe, the luminosity function falls steeper than at lower luminosities.

Rates of the brightest LRNe are consistent with them being progenitors of double compact object systems

Discrepancies between BPS and ZTF rate likely due to uncertainties in CE parameters

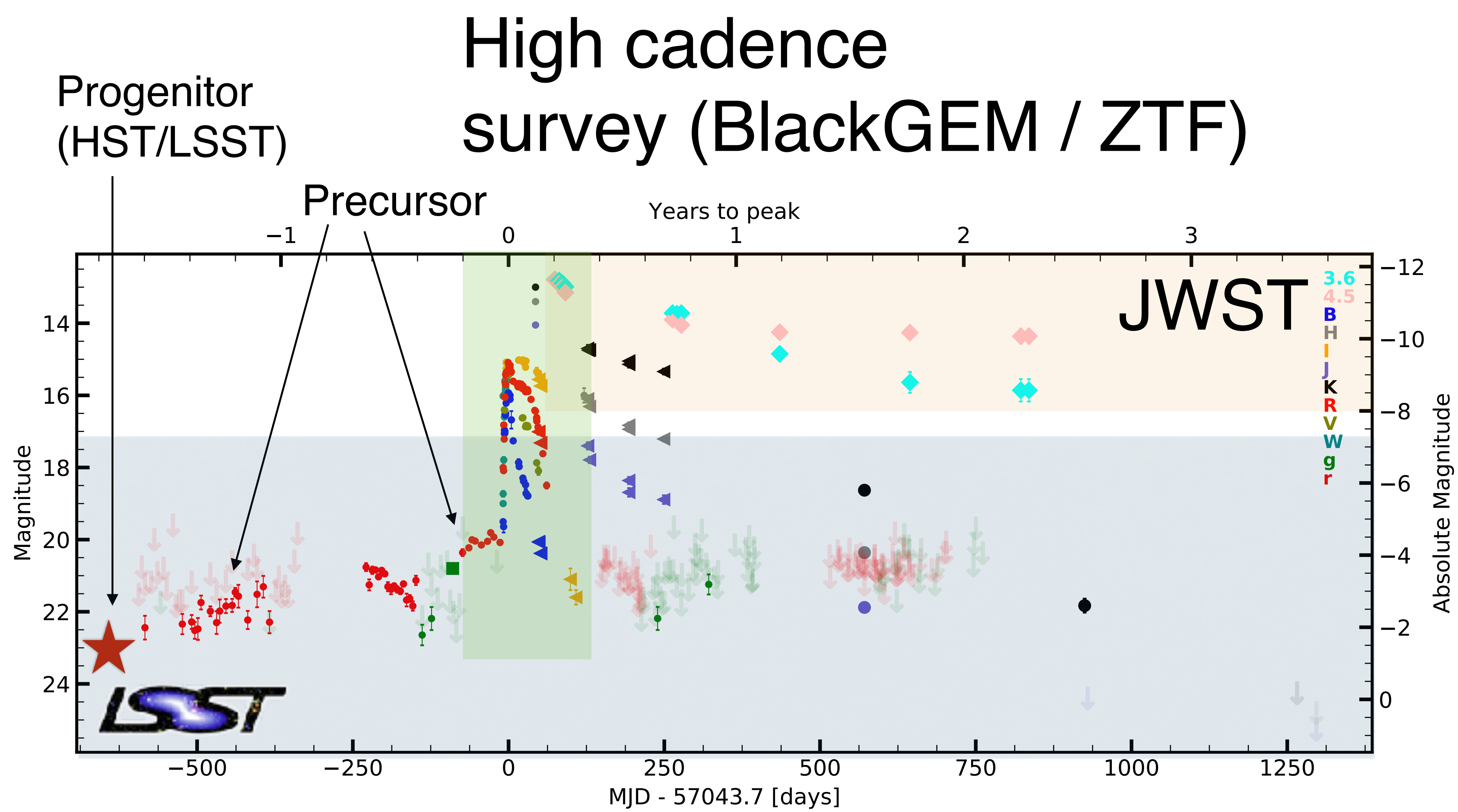
Present - tip of the iceberg

High cadence survey (BlackGEM / ZTF)



Example: M31-2015LRN

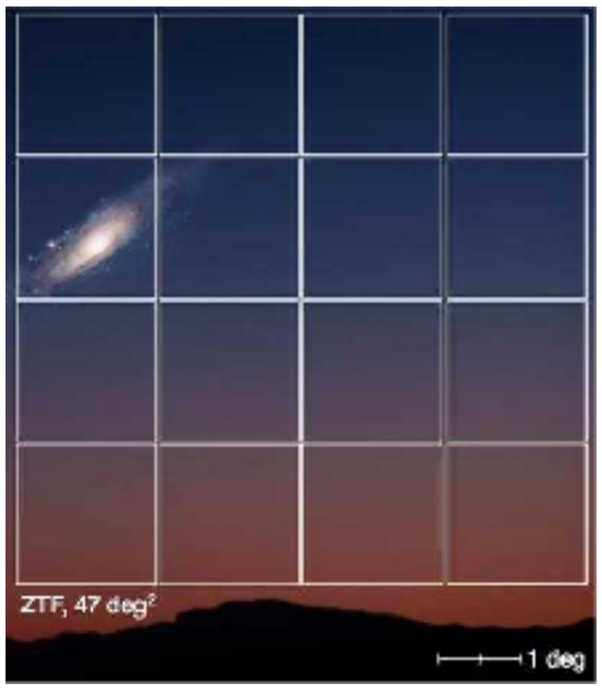
Future - 360° observational approach



Example: M31-2015LRN

Present and future surveys

ZTF (North)
g+r(+i) full sky survey
< 21 mag
3 night cadence



BlackGEM (South)
uqi-band survey g<23 mag
nightly Nearby Universe
survey

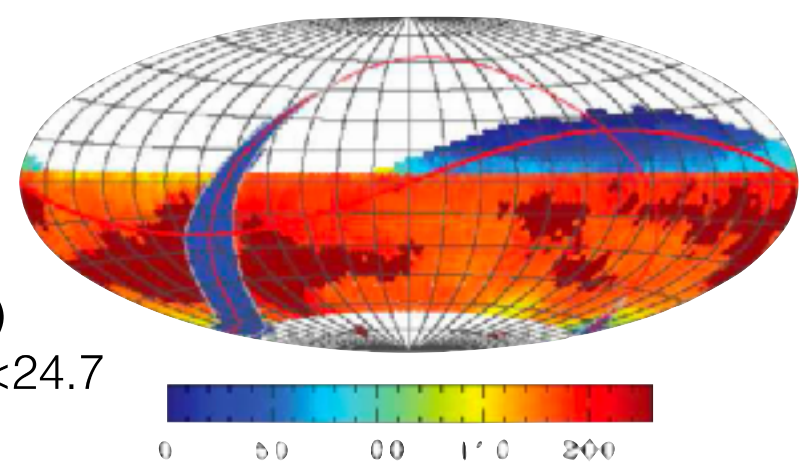
NIR - WINTER

J-band time domain survey @Palomar

1 sq. deg FOV, 1 m telescope
first light by end of Summer 2022

All northern sky <21 mag

A nearby, galaxy-targeted, weekly cadence survey to search for dusty LRNe that may be missed by optical surveys



LSST (South)
u,g,r,i,z,y survey r<24.7
mag
200 visits filter / 10 years

Conclusions

- **LRNe are powerful probes for the study of CE phase in binary systems**
  - Progenitors reveal the parameter space for unstable mass transfer
  - Precursors allow to estimate the pre-CE mass transfer
  - Outburst observations reveal the energetics / geometry of the mass ejection
  - Late-time remnant shows the geometry of mass ejection and a correlation to existing stellar populations
  - LRN rates allow to test CE approximations for different populations of binaries
- **How observations can be used to improve current assumptions / approximations on CE?**
- **What observations are needed to enable a self-consistent model of CE ejection?**