

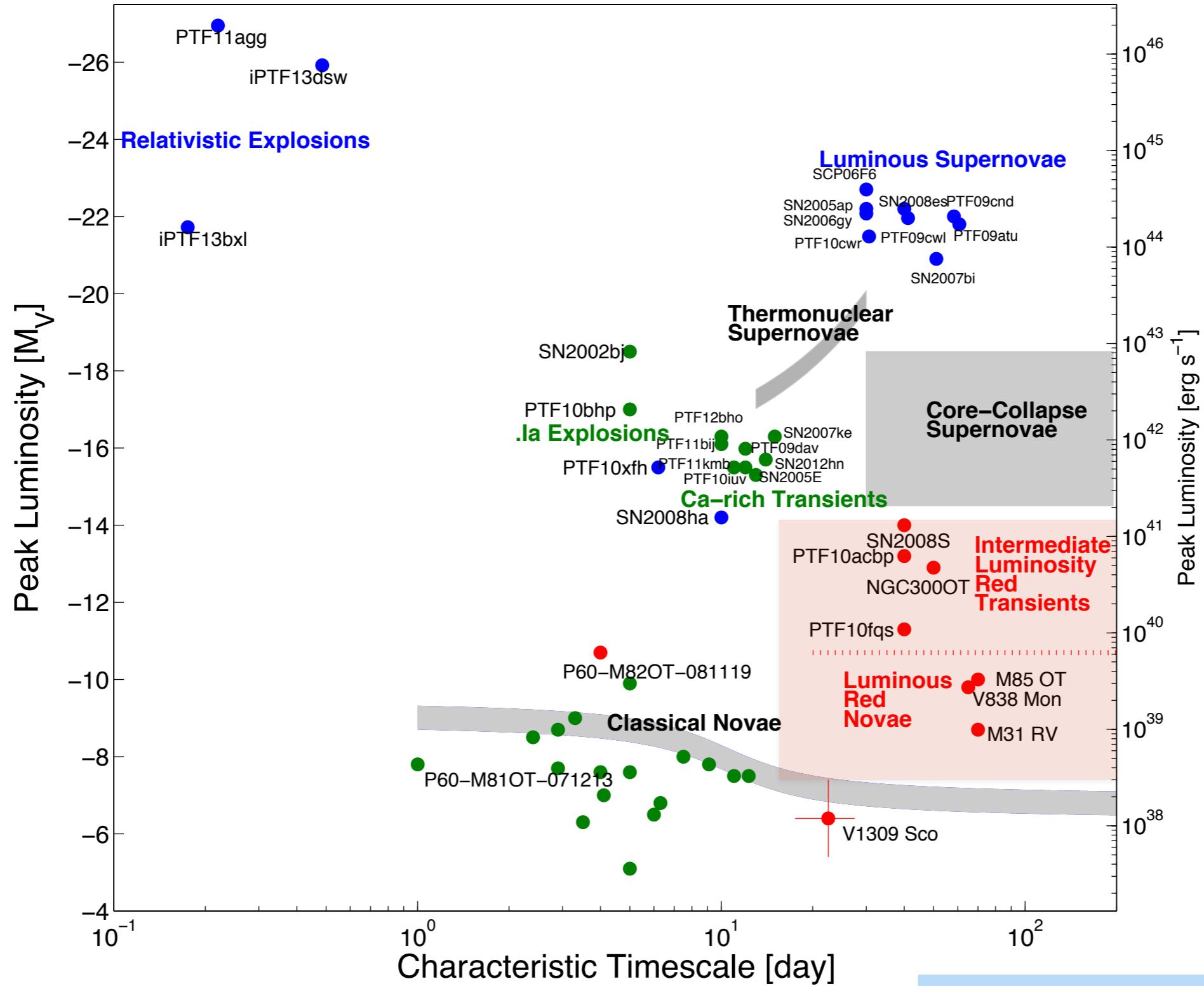
# Intermediate luminosity Red Transients

Nadia Blagorodnova

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in collaboration with  
Mansi Kasliwal, Jacob Jenson (Caltech), Rubina Kotak, Joe Polshaw (QUB)

# Transients in the “gap”



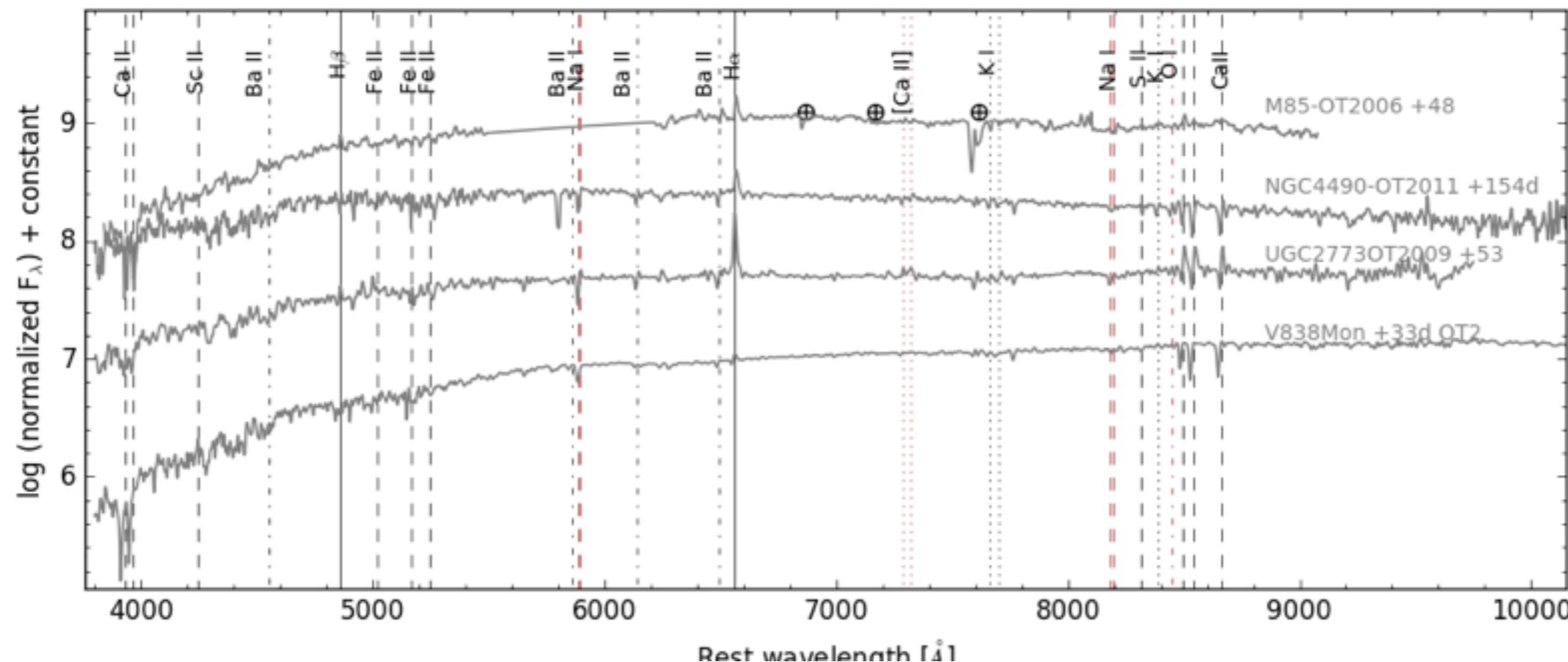
Kasliwal et. al., 2011

# Observational signature?



# Characteristics

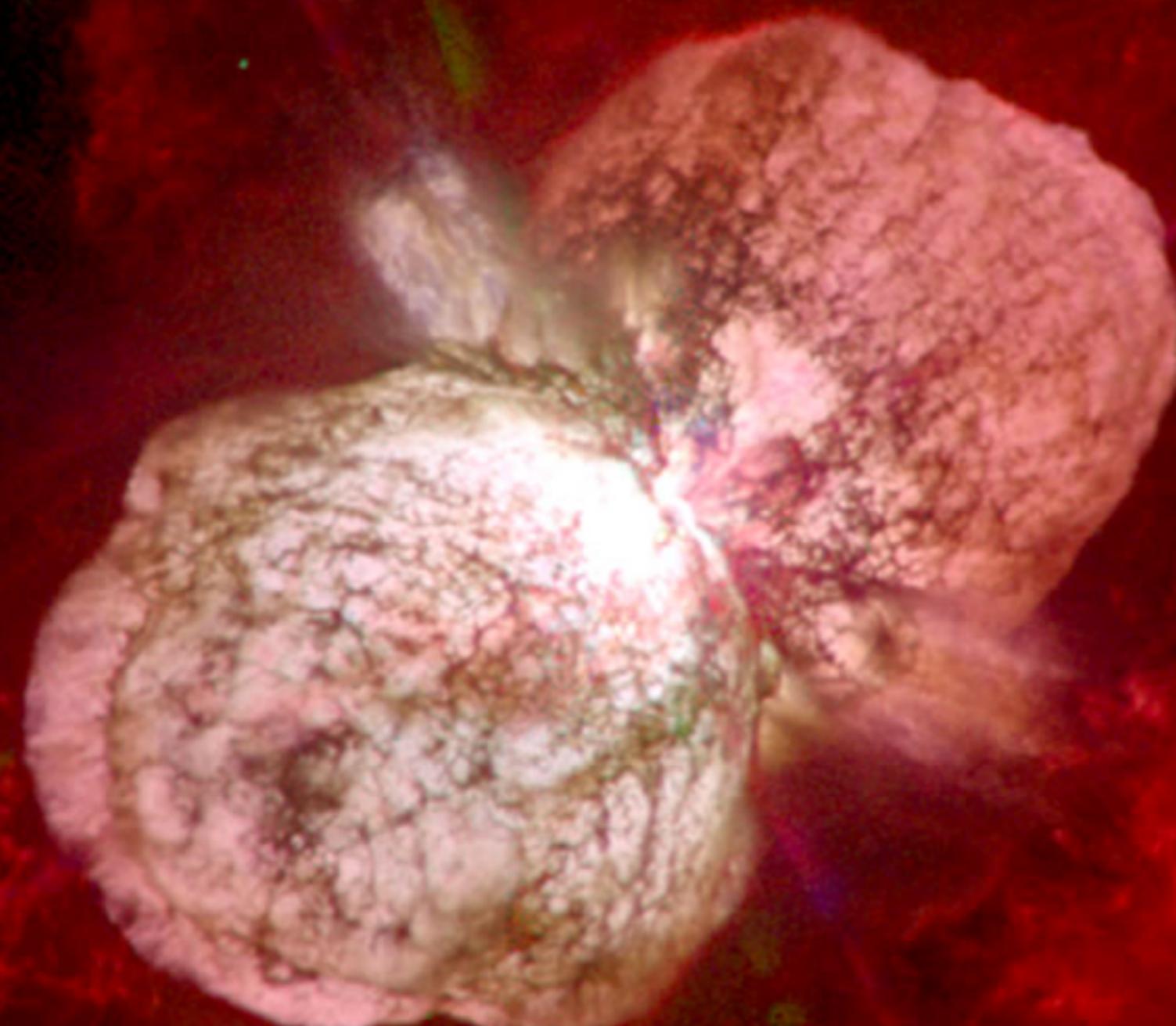
- Peak absolute mags  $-10 > M_{\text{bol}} > -15$  ( $10^6 - 10^8 L \text{ sun}$ )
- Timescales similar to SNe (~months)
- Red continuum: 3000 - 4000 K
- Spectra shows narrow H emission lines in emission (FWHM  $\sim$  few 100-2000 km/s) and other low ionization lines (e.g., Ba I, Na I, Ca II, Fe II)



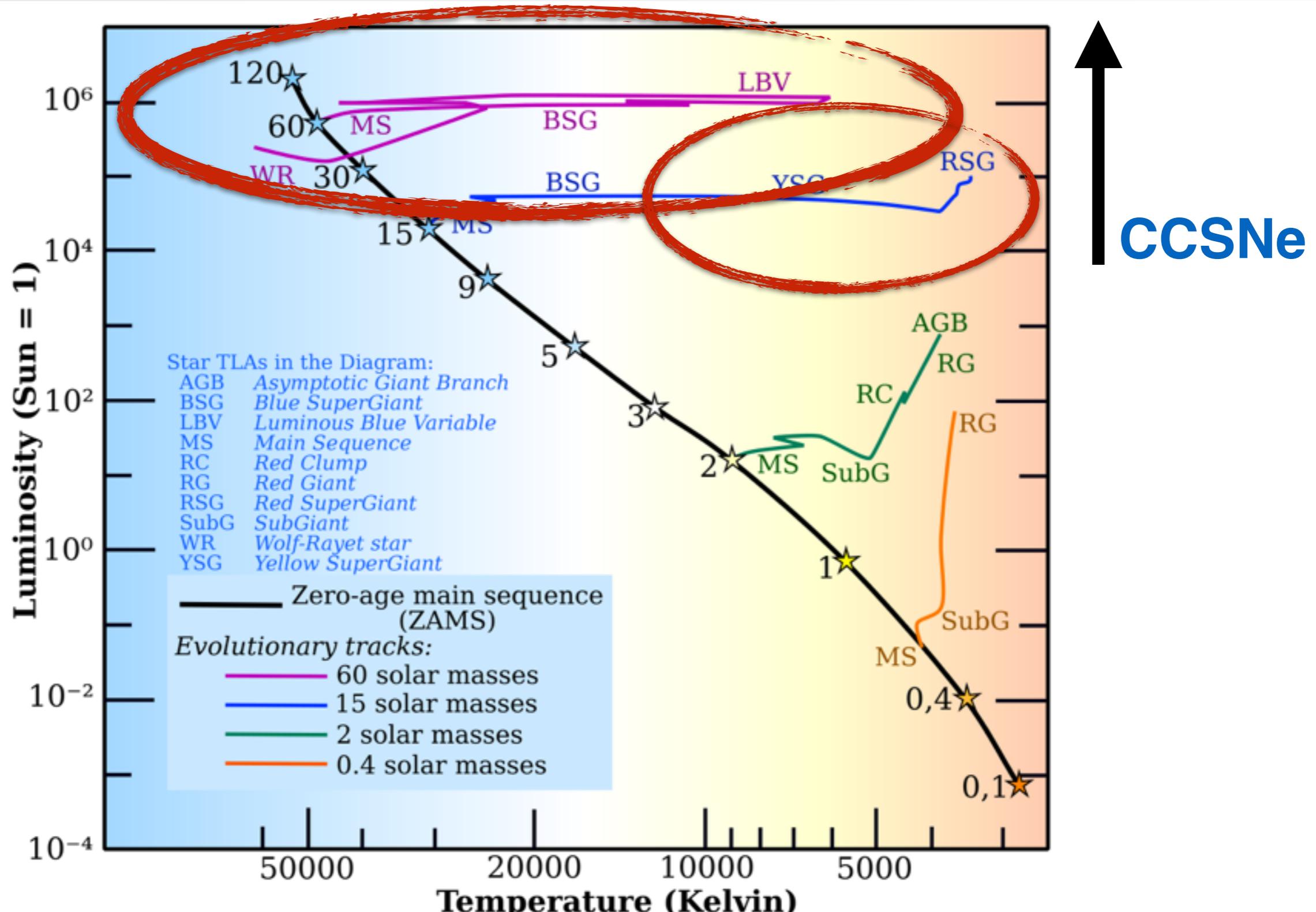
# Families of intermediate luminosity transients

- **LBV (SN impostors)**
  - Massive star eruptions
  - Multiple outbursts
  - e.g. Eta Carinae, P-Cygni, UGC 2773-OT
- **faint SNe**
  - Terminal explosion
  - Dust-obscured SNe
  - e- capture on CONe core
  - e.g. SN2008S, NGC300-OT
- **Stellar mergers**
  - Remnant is a rejuvenated star
  - Circumstellar disk
  - e.g. V1309 Sco, V838 Mon

# Luminous Blue Variables

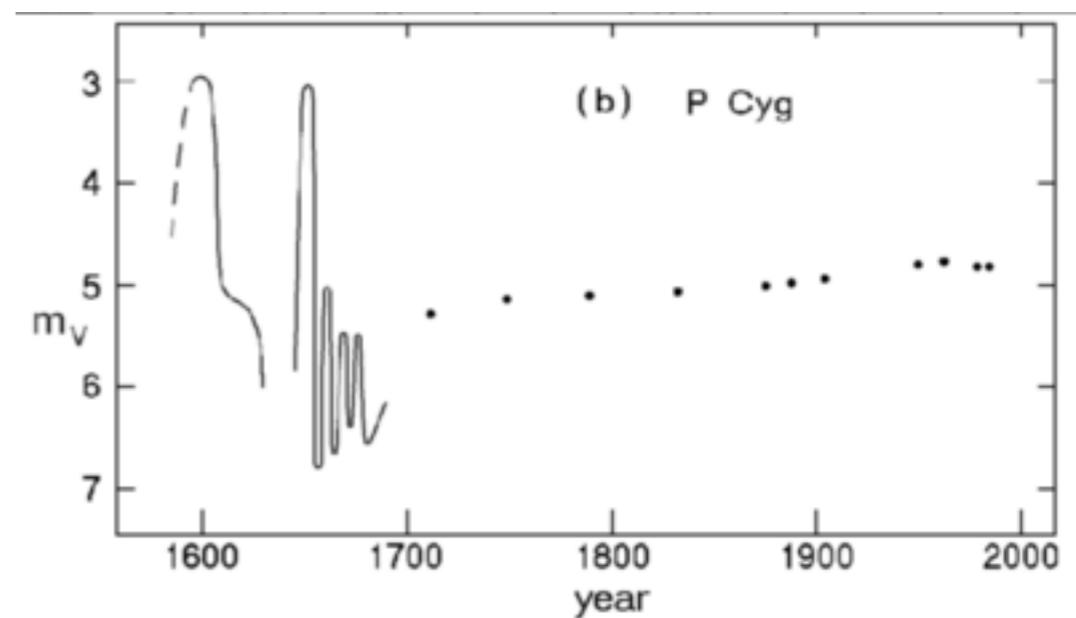
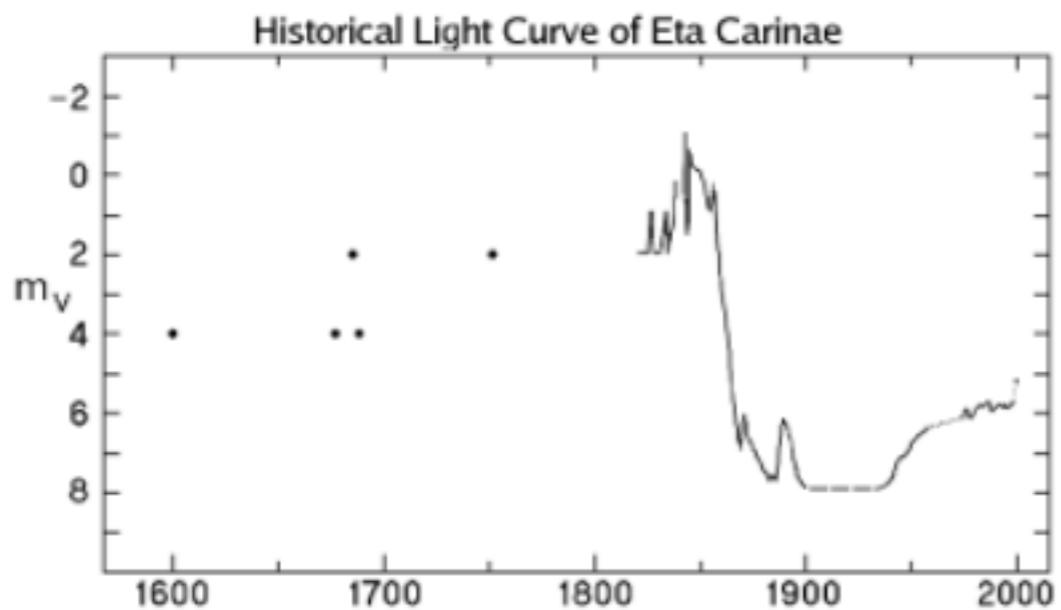


# Supermassive single stars



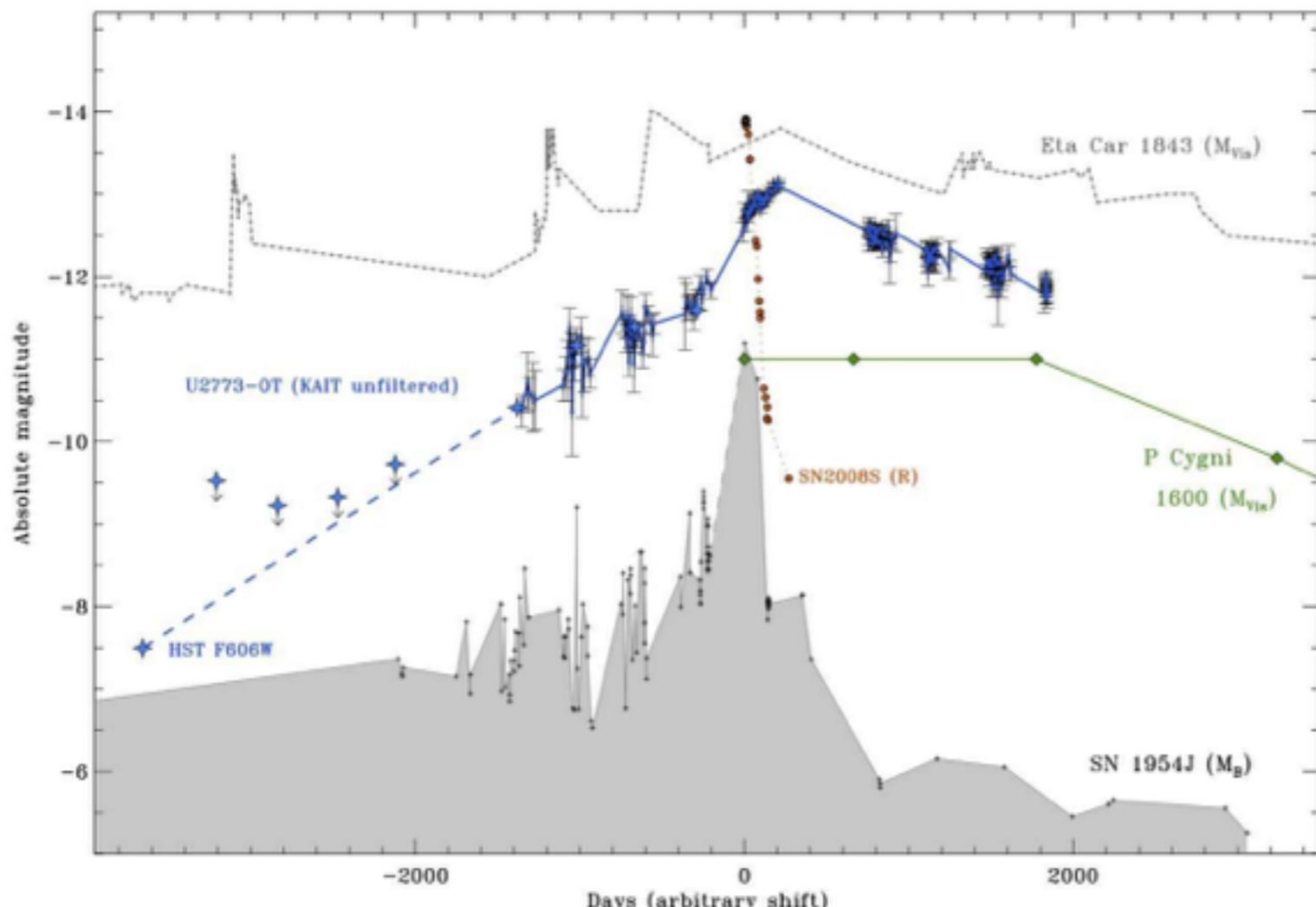
Parameters: Initial MASS + metallicity

# Classical examples



UGC2773-2009OT

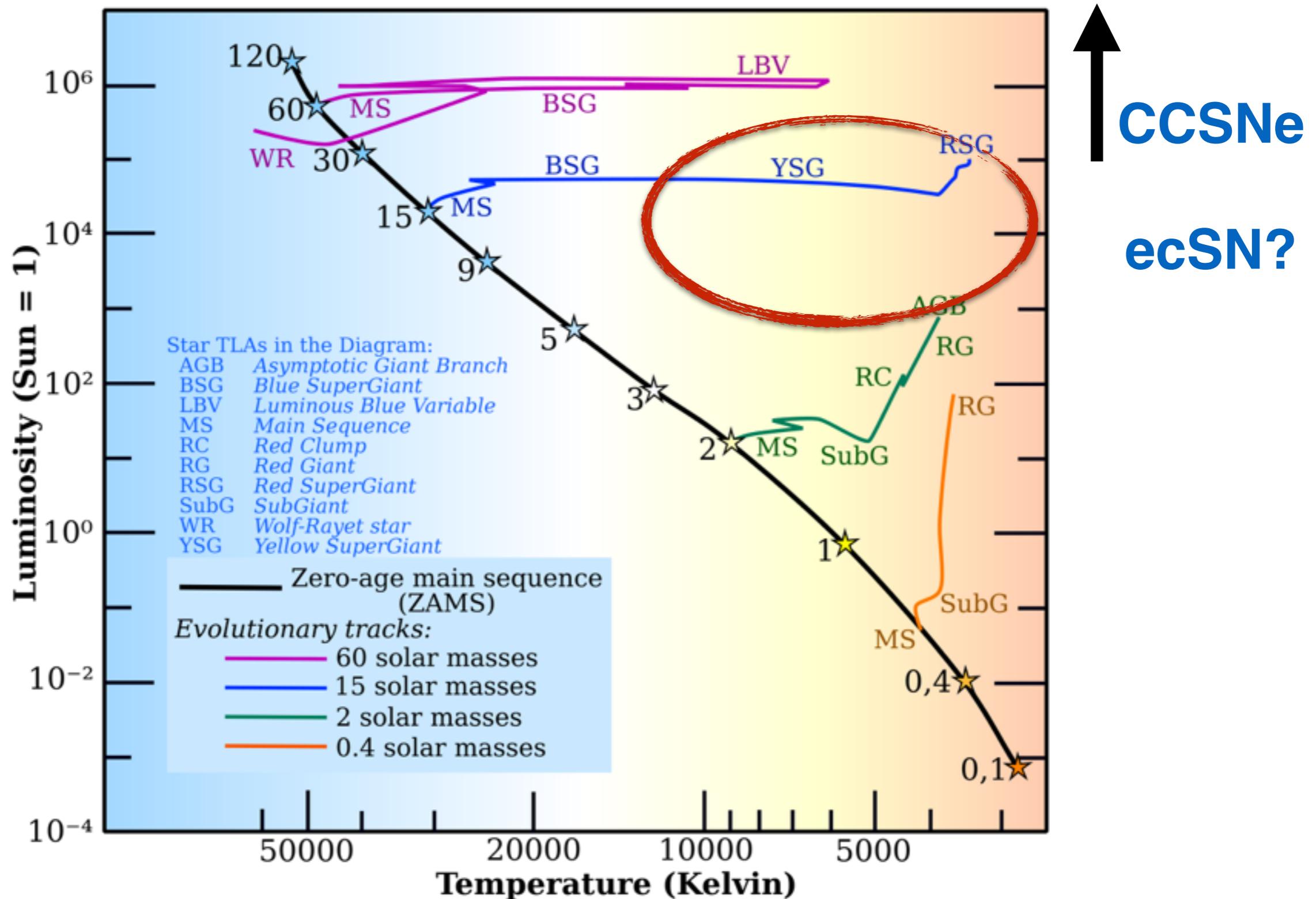
Humphreys et al. 2016



Smith et. al., 2016

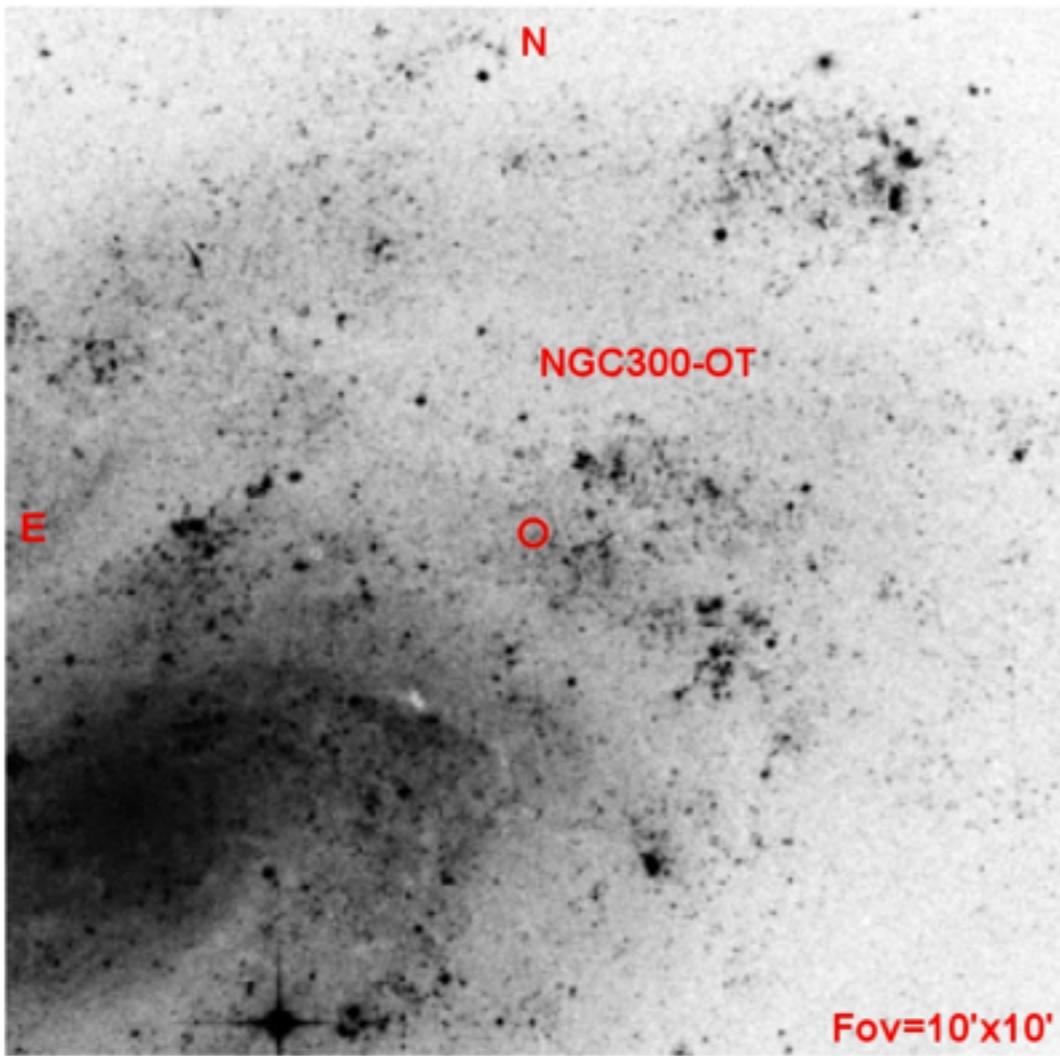
# faint SNe (with dusty progenitors?)

# Low mass single stars

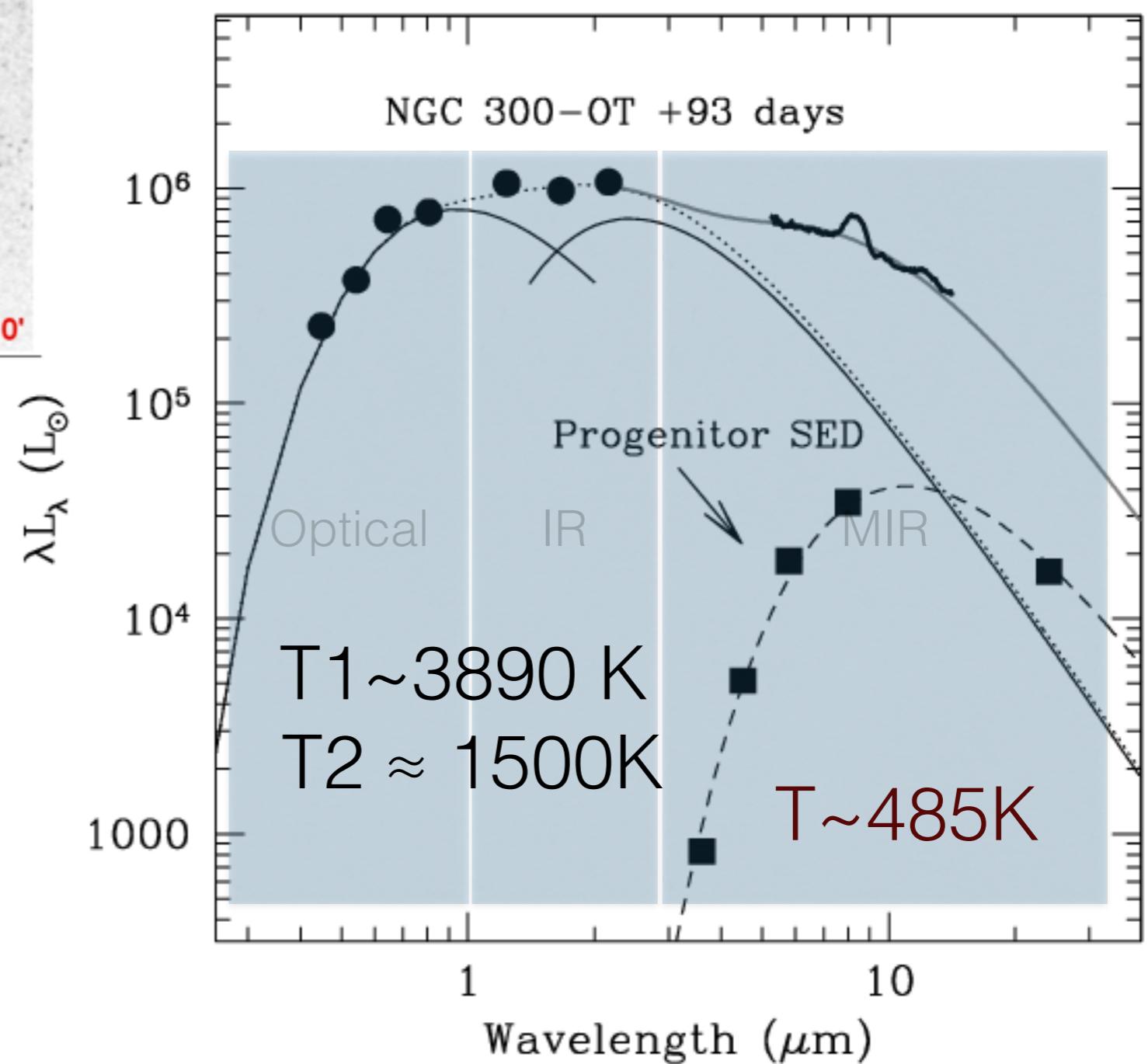


Parameters: Initial MASS + metallicity

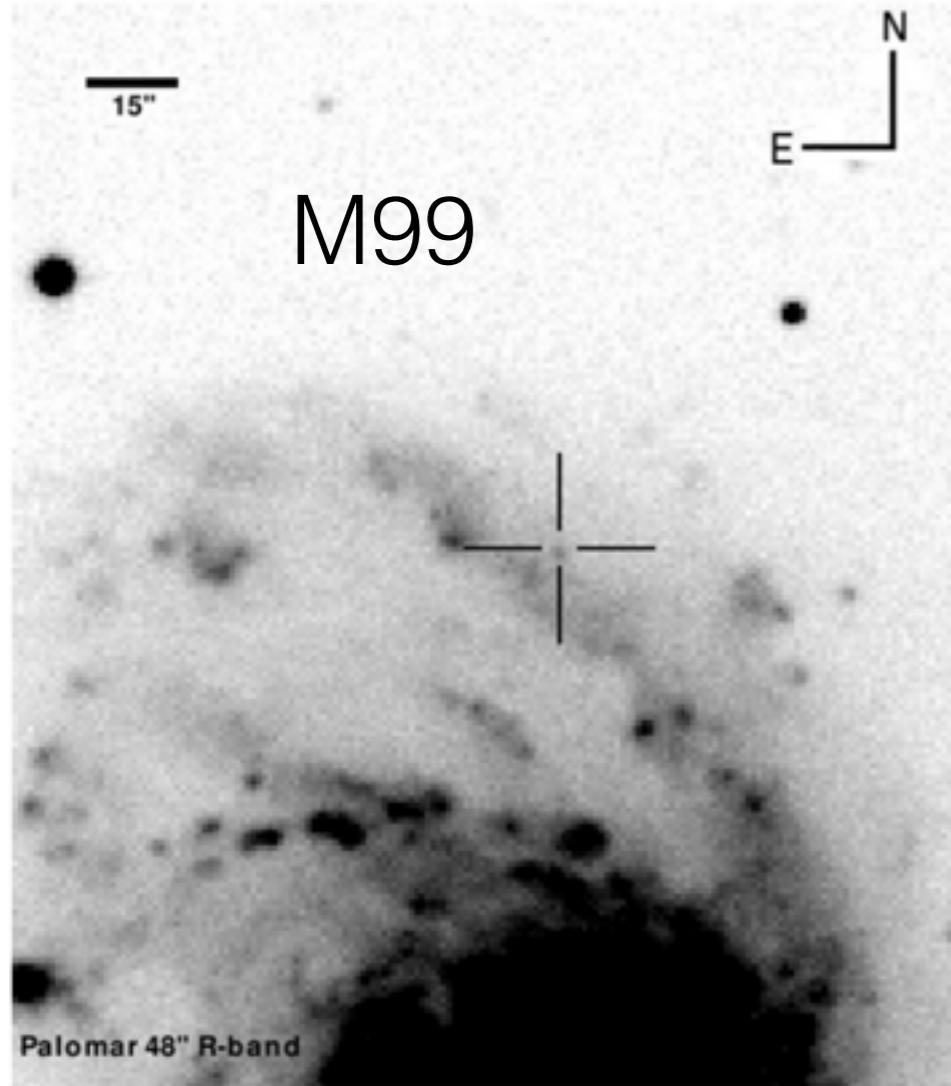
# NGC 300-OT



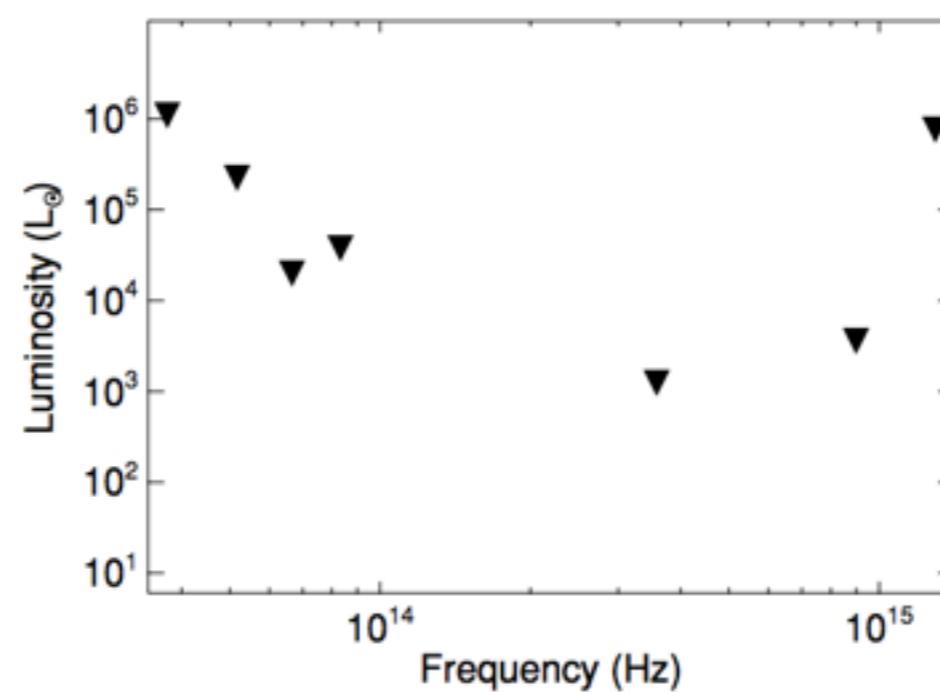
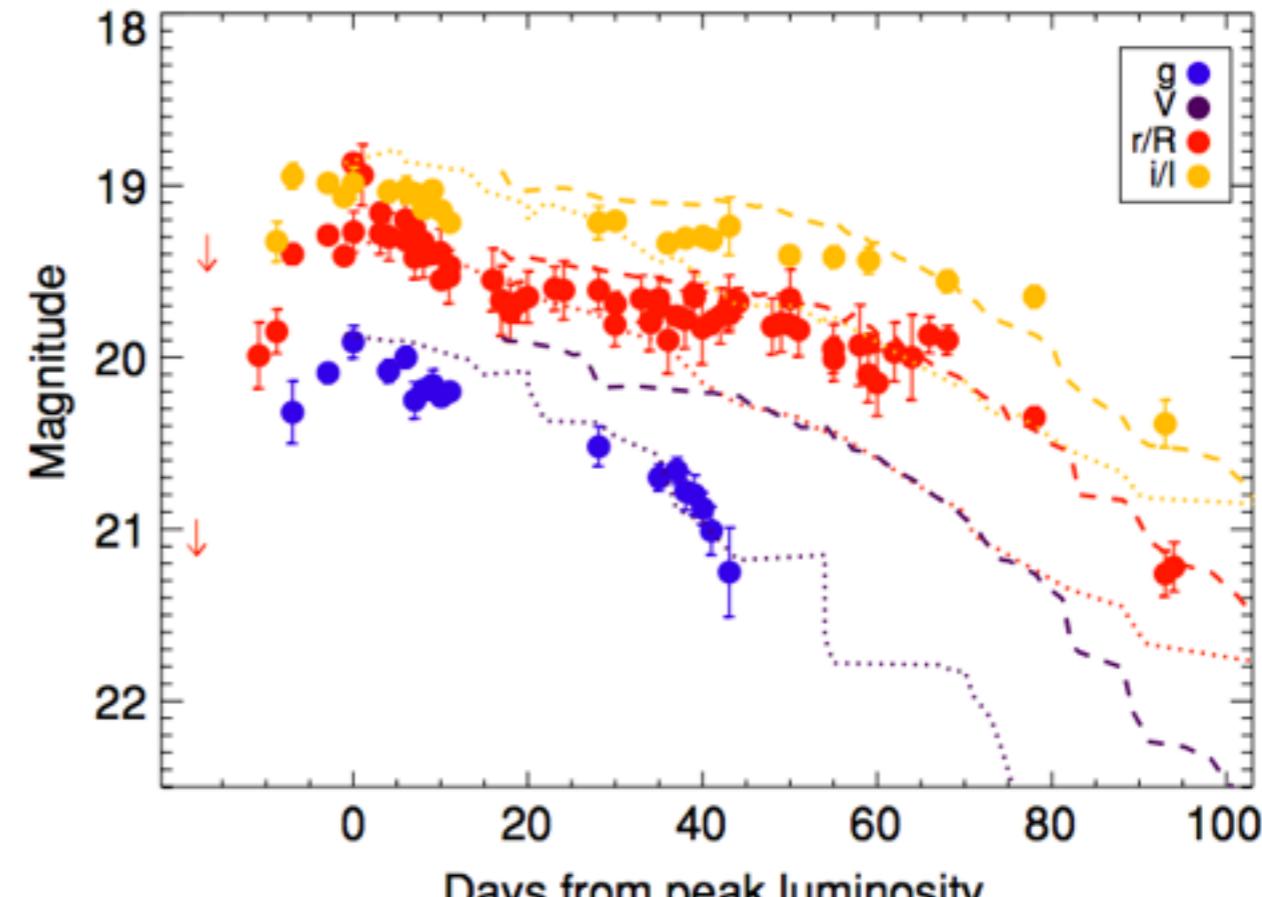
Prieto et. al., 2009



# PTF10fqs



Kasliwal et. al., 2011



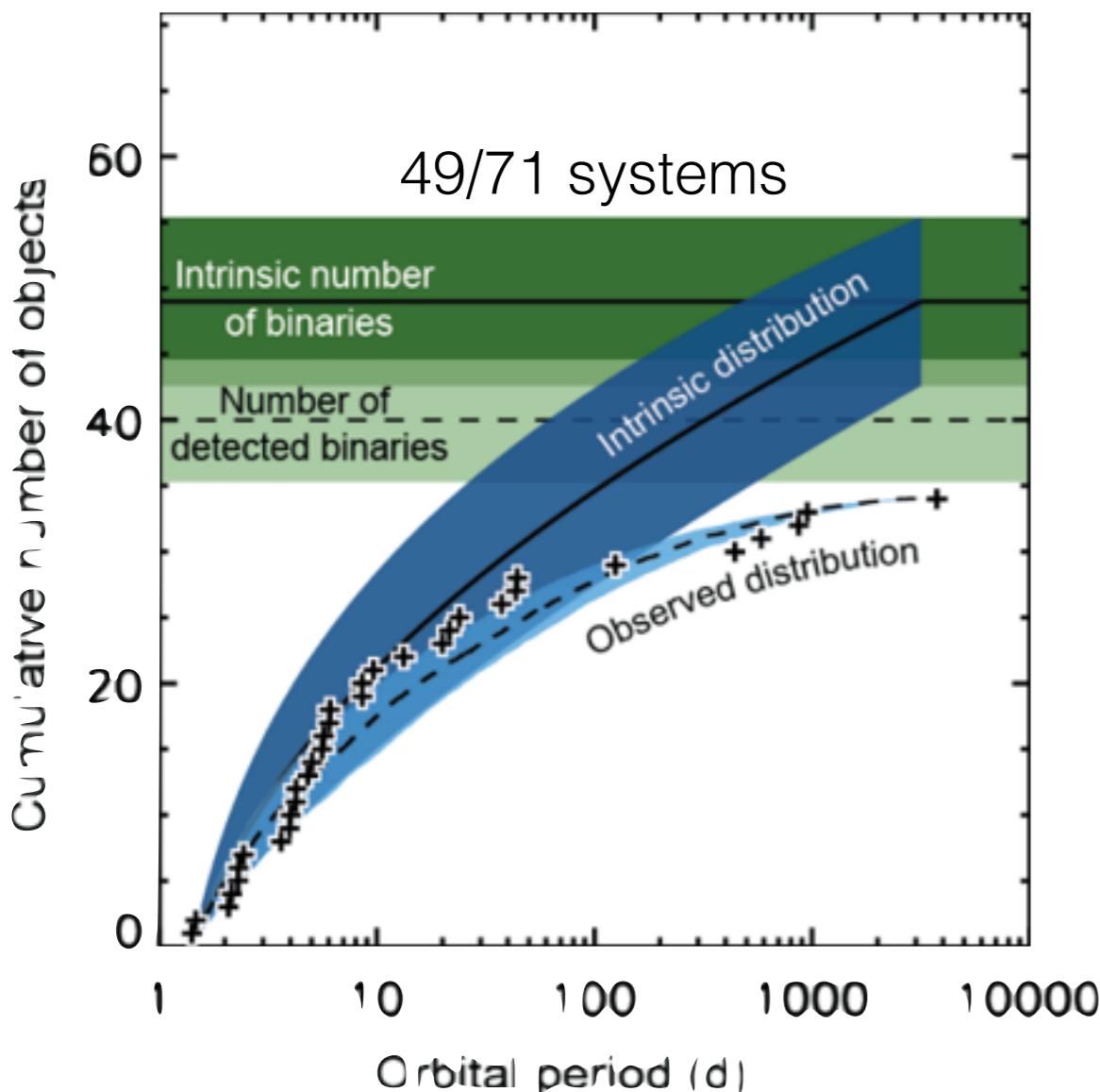
Progenitor limits:  
 $Mg \approx -4$  ( $< 7 \text{ Msun}$ )

# Luminous Red Novae



# LRN originate from binaries... which are common!

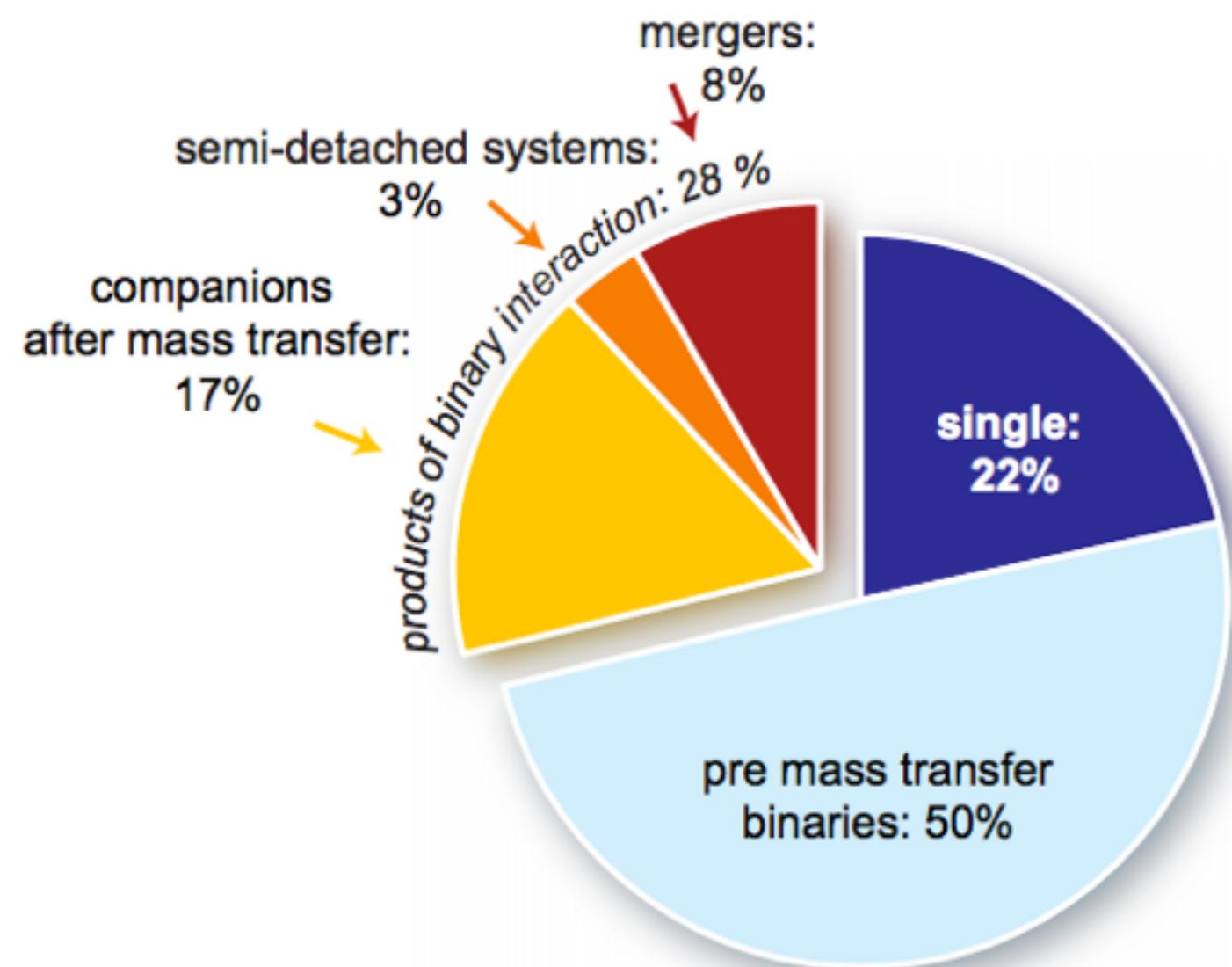
## Observational



$$f_{\text{bin}} = 0.69 \pm 0.09$$

Sana et al. (2012)

## Theoretical



De Mink et al. (2013)

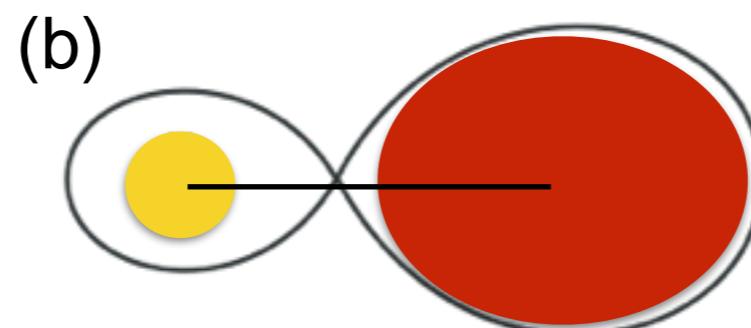
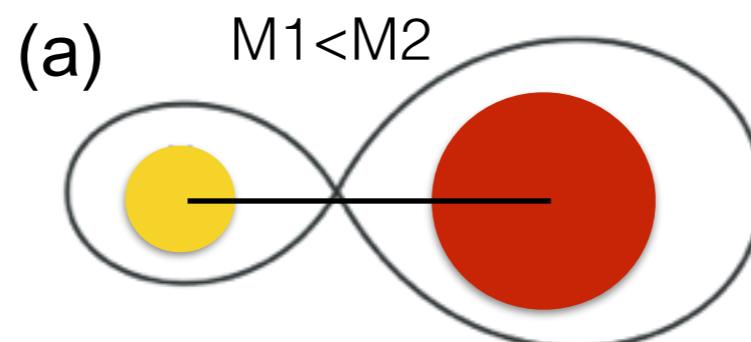
# Binary stars

Parameters: Initial MASSES  $M_1+M_2$ , period, metallicity

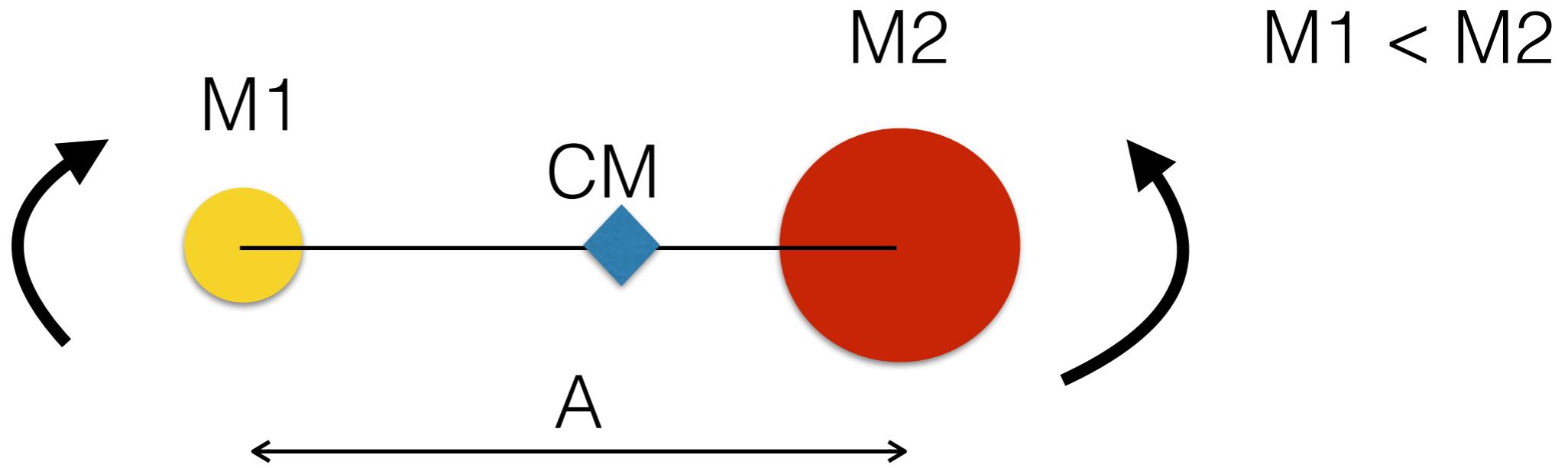
CASE 1 : not interacting



CASE 2 : interacting



# Roche Lobe



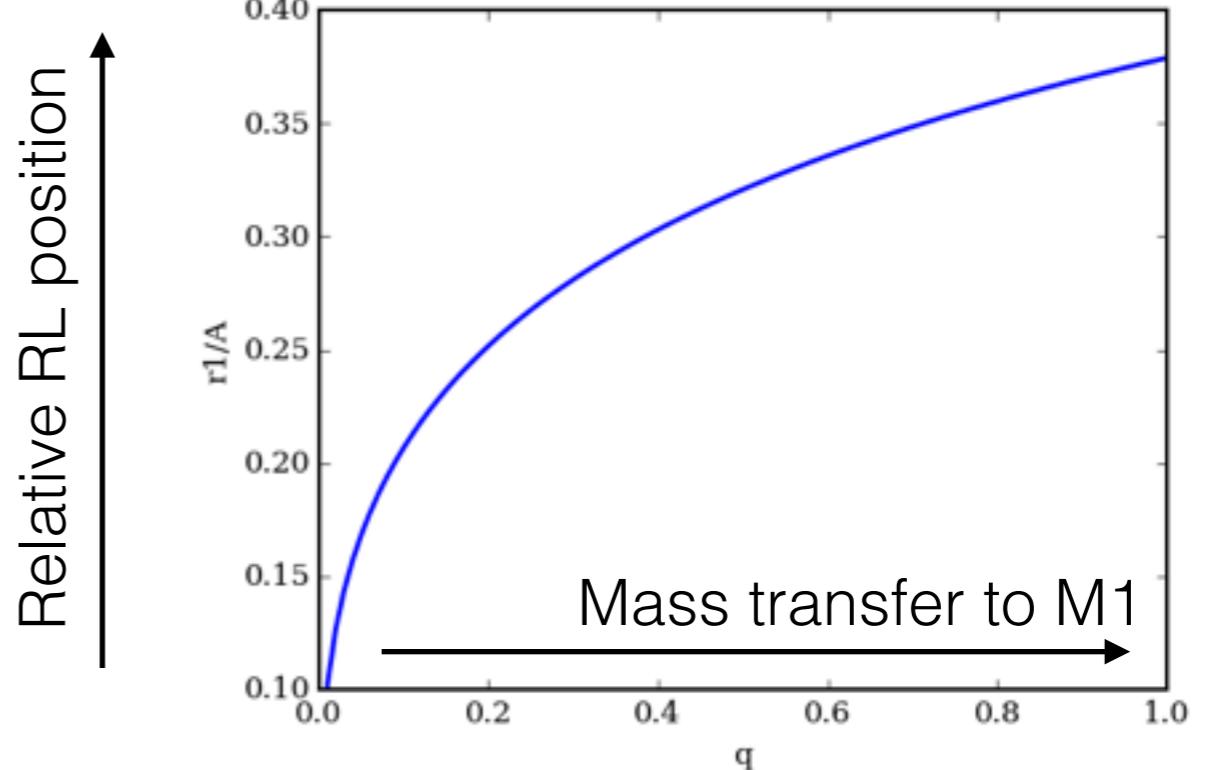
Numerical approximation to the radius of Roche Lobe (RL):

$$\frac{r_1}{A} = \frac{0.49q^{2/3}}{0.6q^{2/3} + \ln(1 + q^{1/3})}$$

where

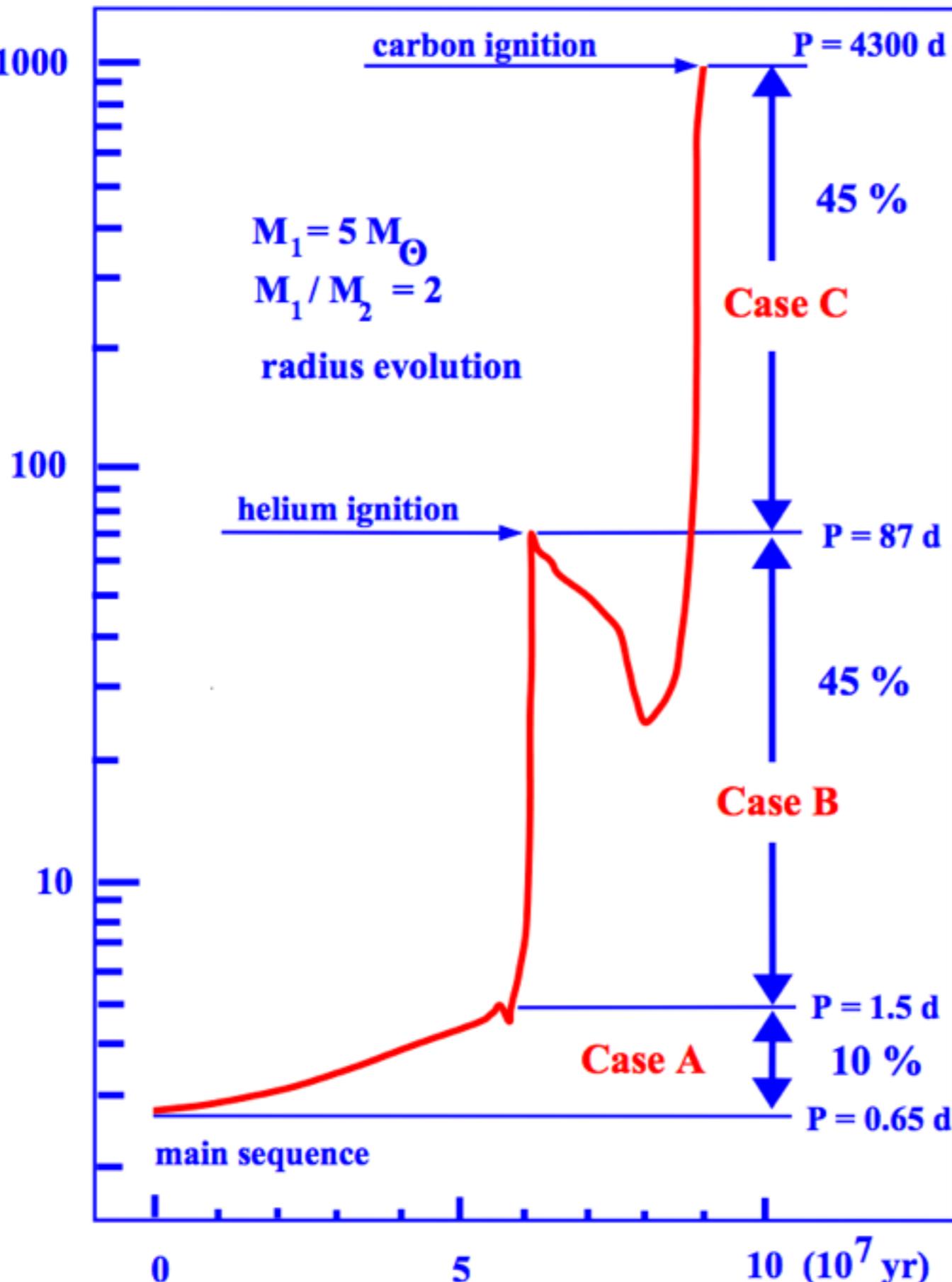
$$q = \frac{M_1}{M_2}$$

Eggleton, 1984



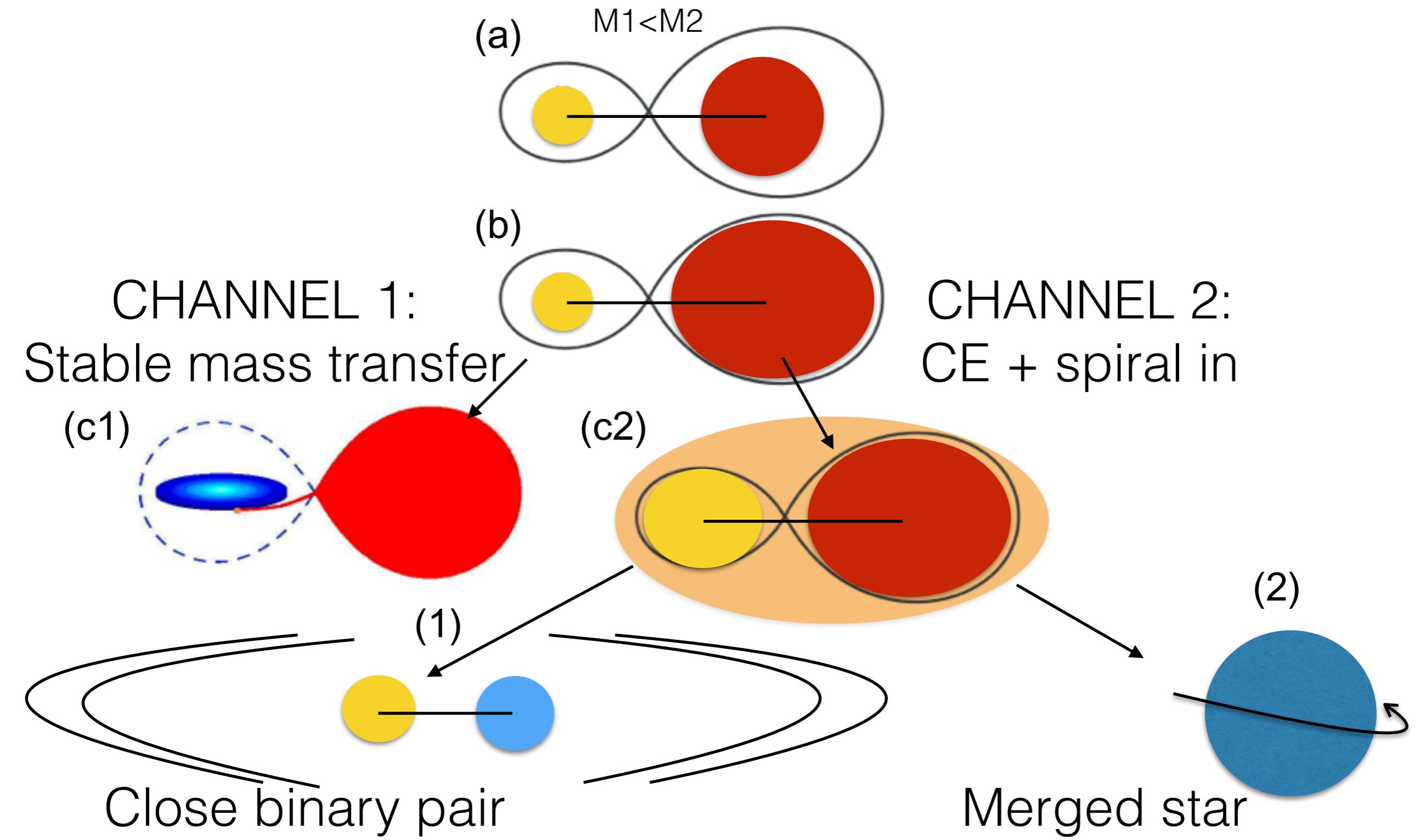
## Classification of Roche-lobe overflow phases

(Paczynski)

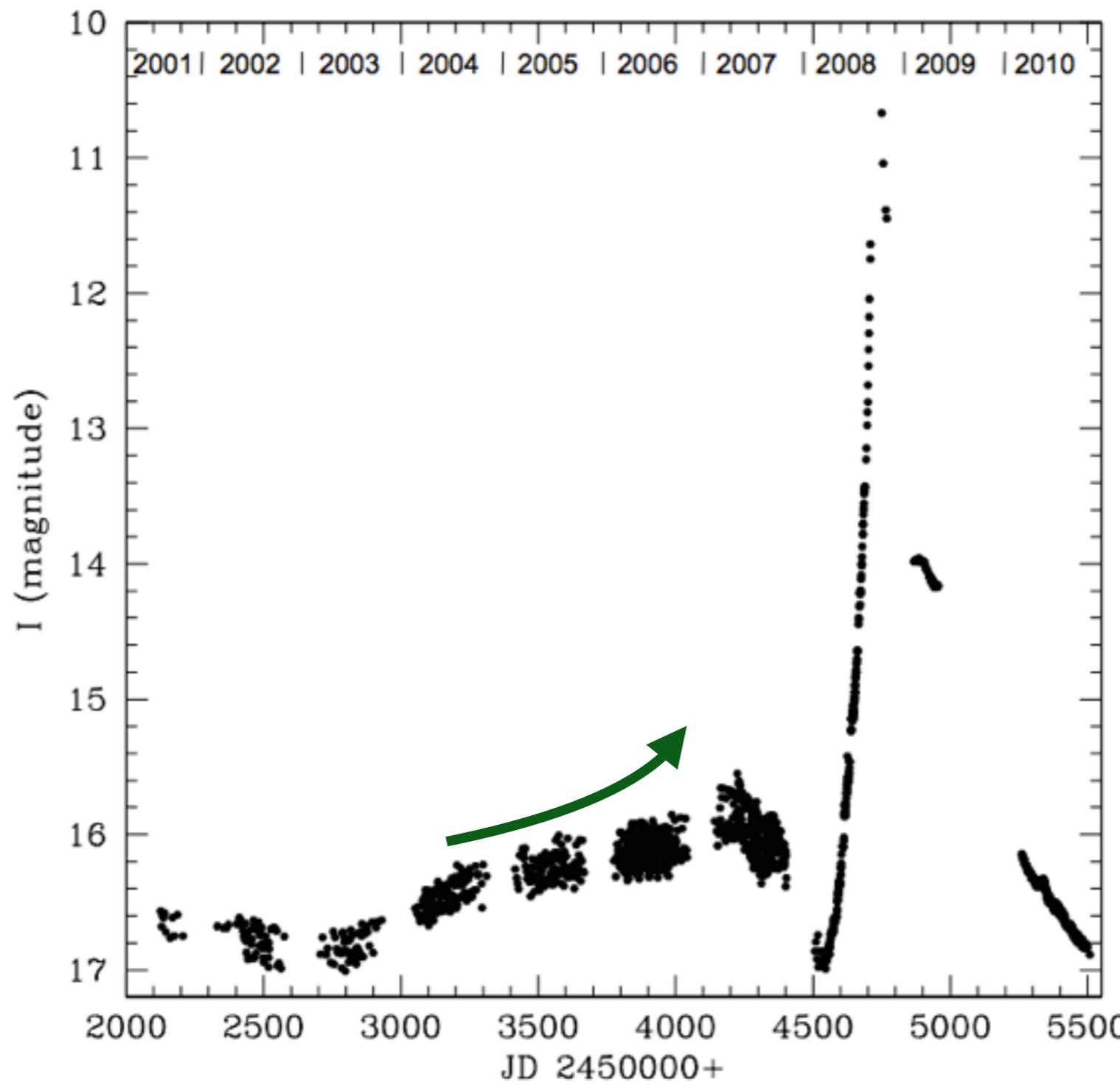


- Case A: main sequence burning hydrogen
- Case B: finished hydrogen burning, but not helium burning in the core
- Case C: the star has completed core helium burning

# Evolution channels

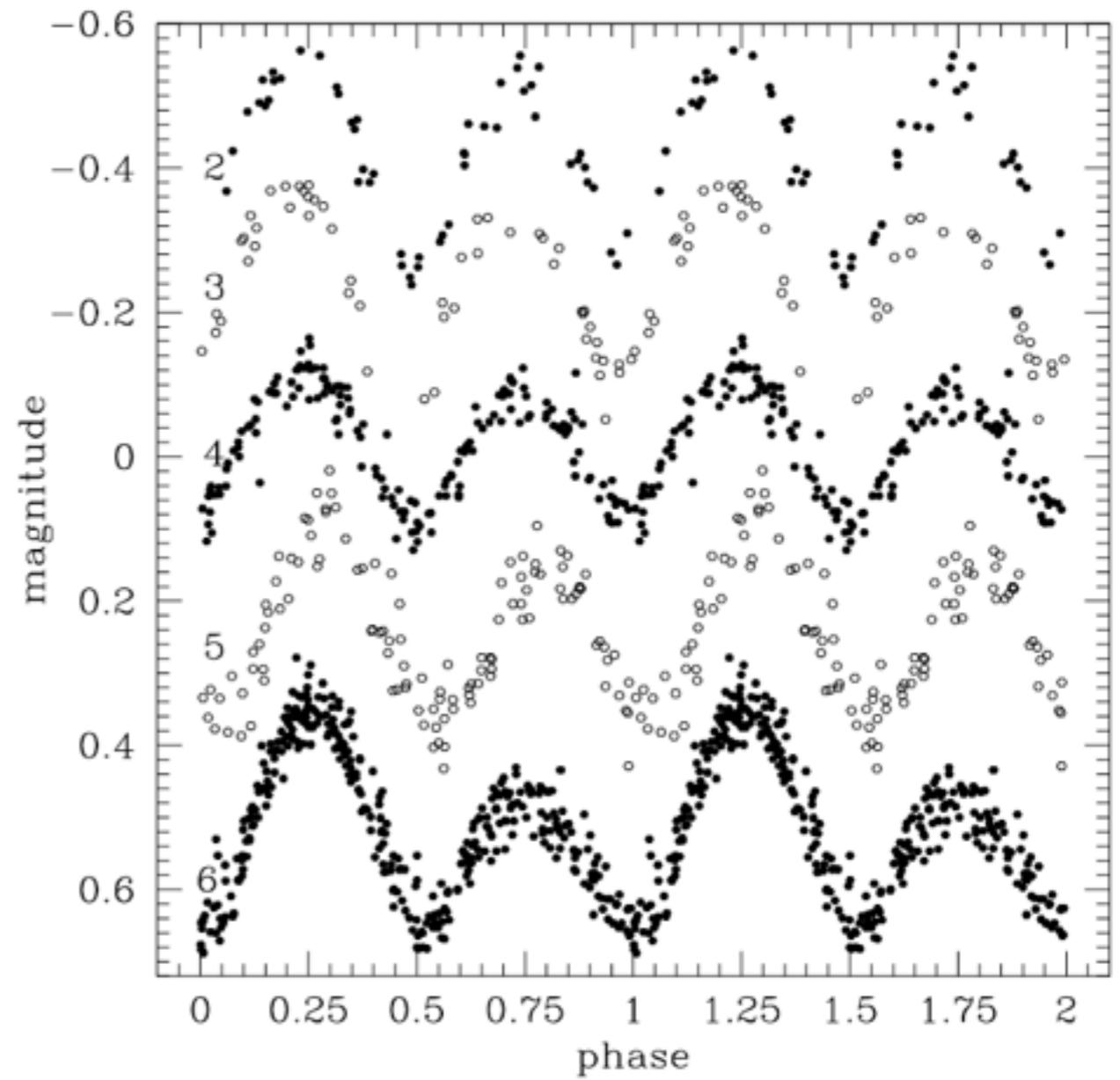
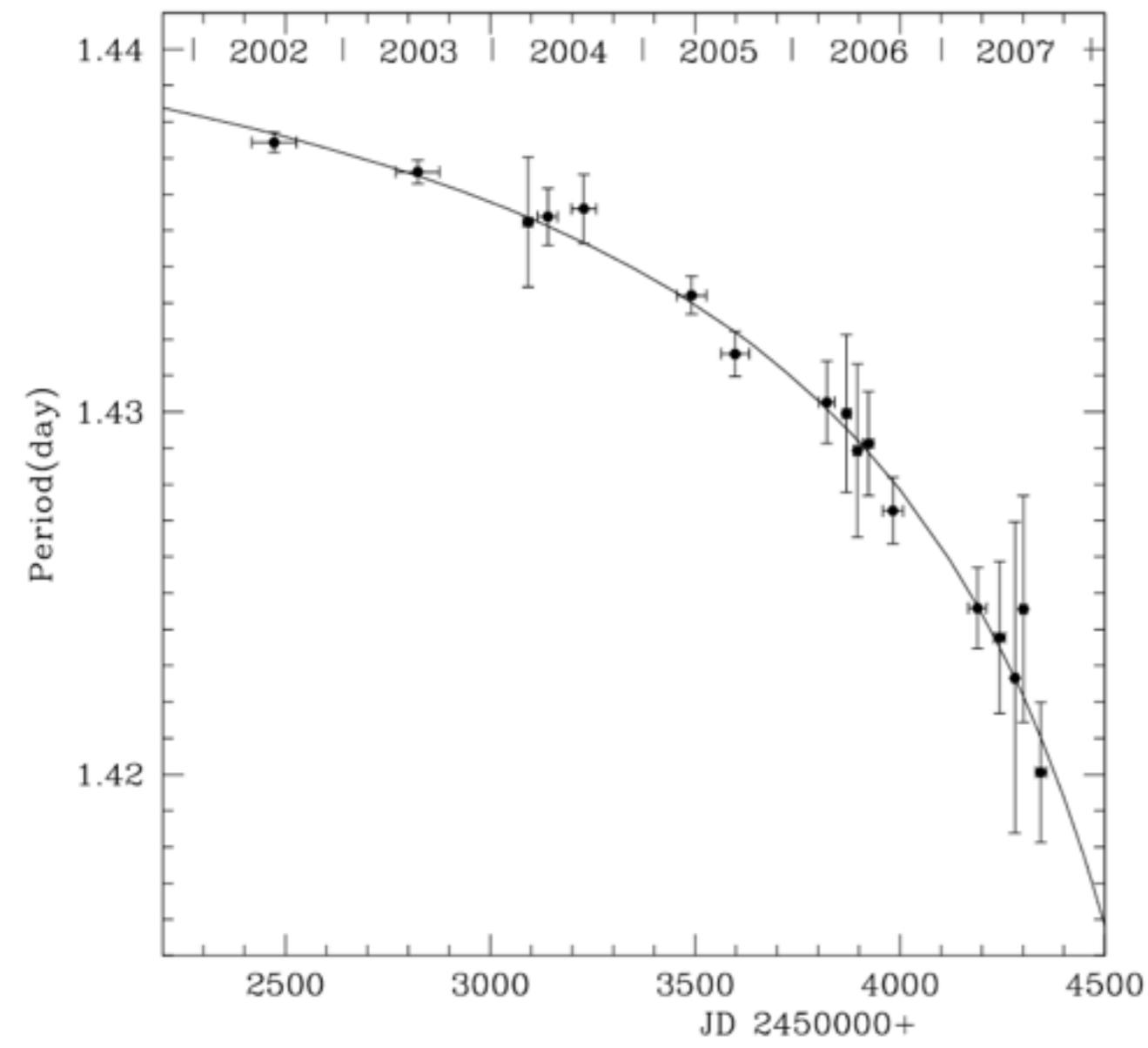


# The smoking gun... V1309 Sco



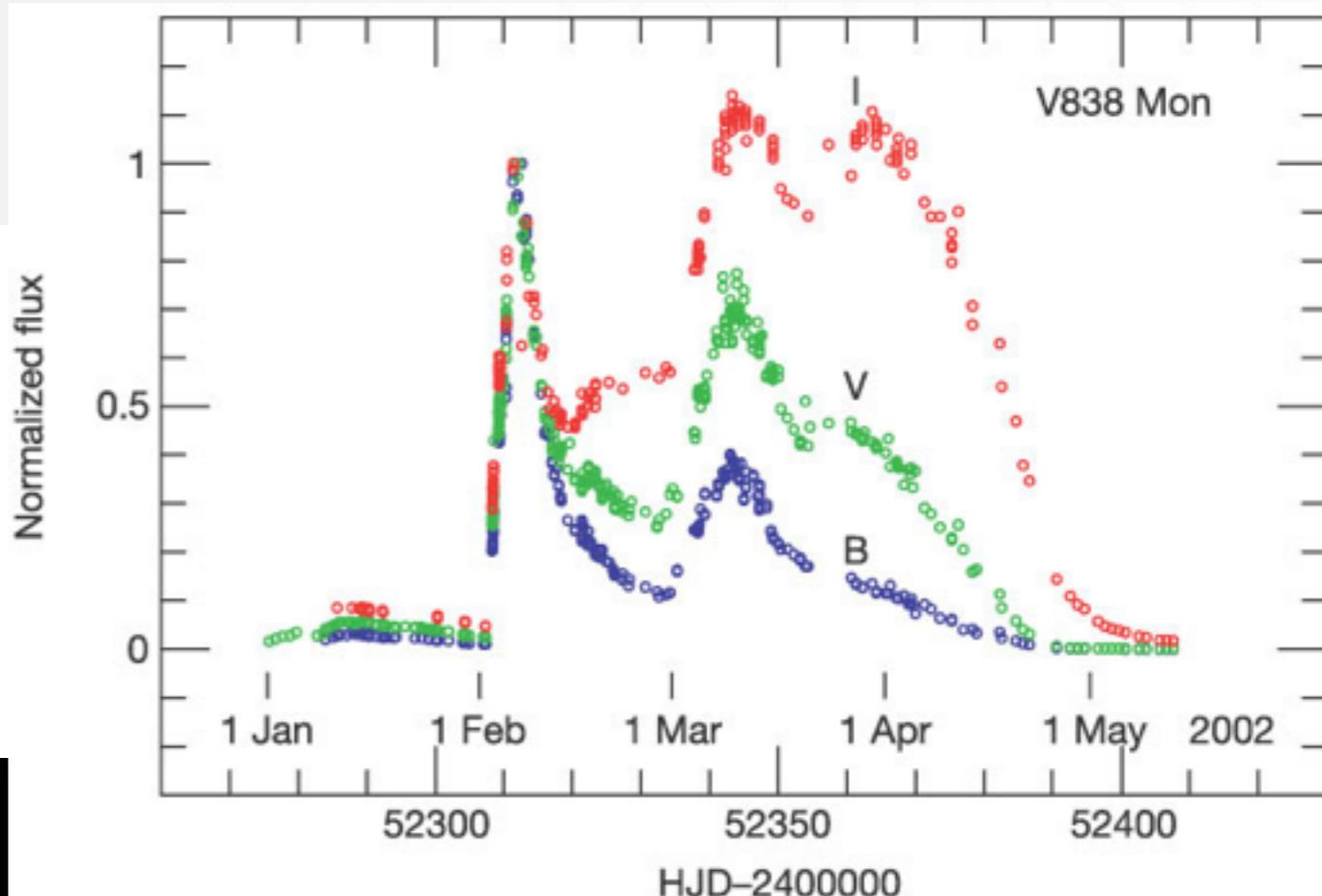
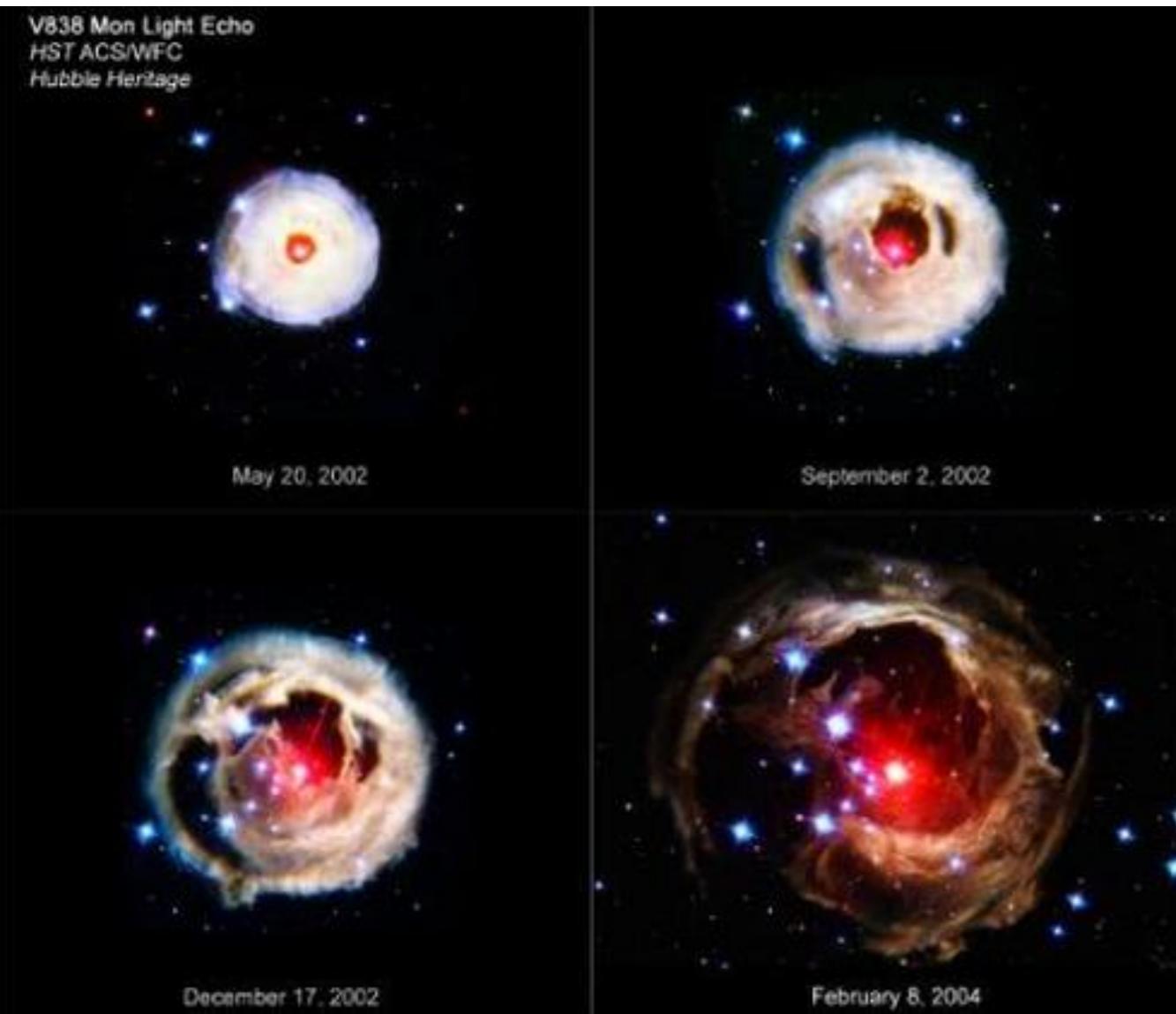
Tylenda et. al., 2011

# Exponential period decay



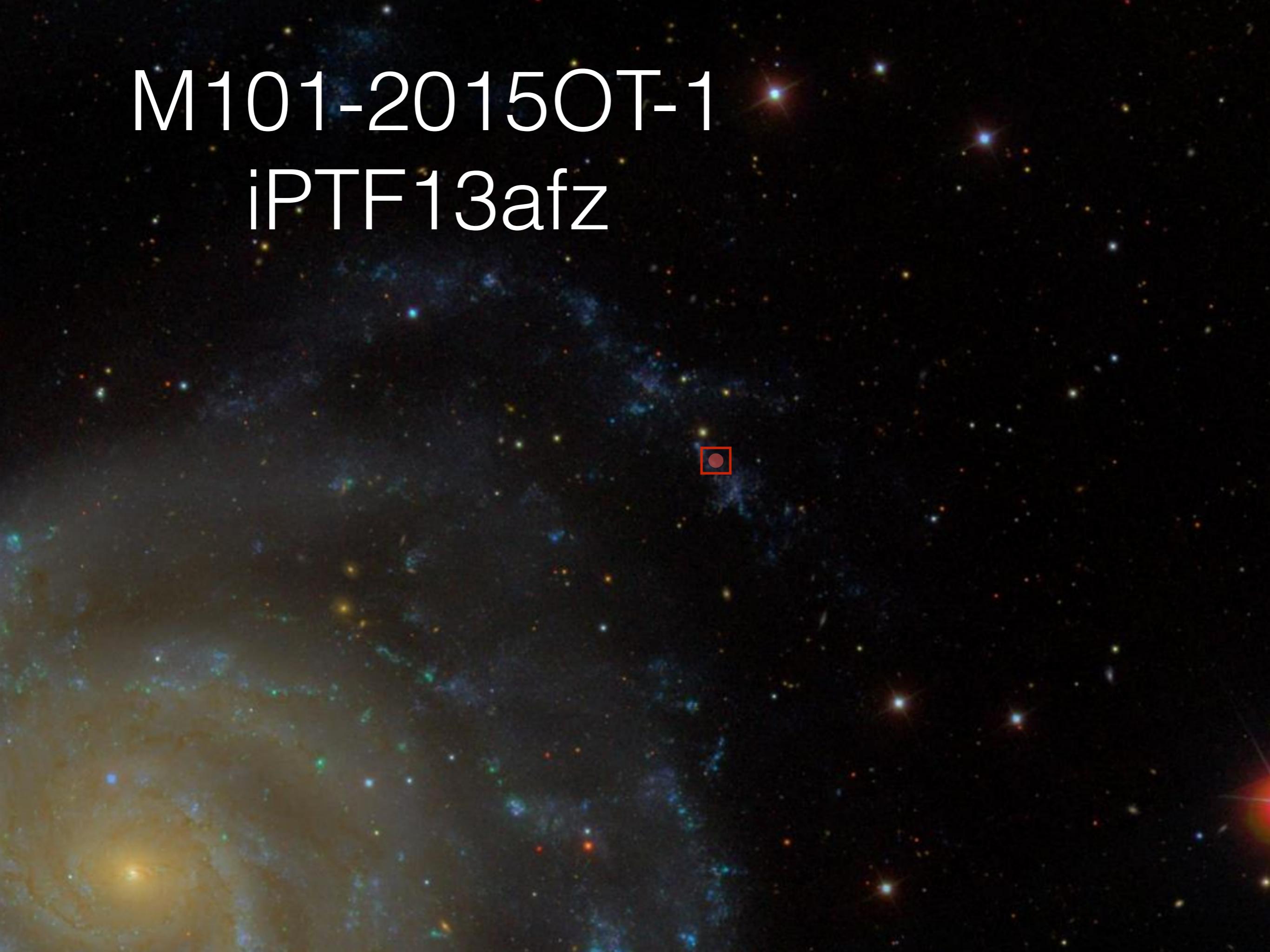
# V838 Mon

Galactic merger at 6.1 kpc

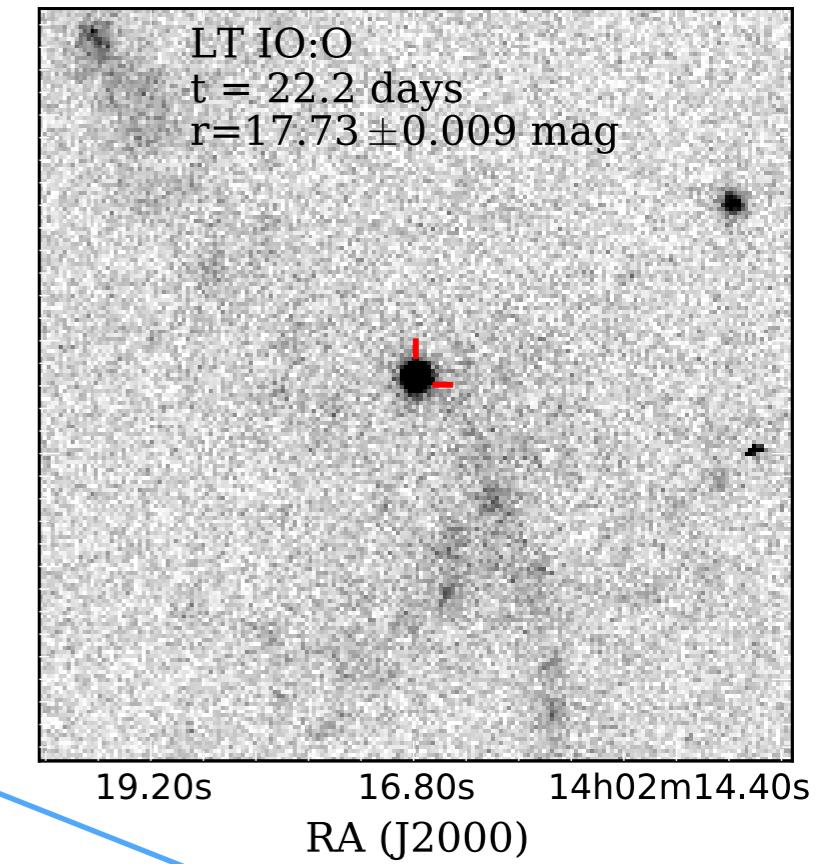
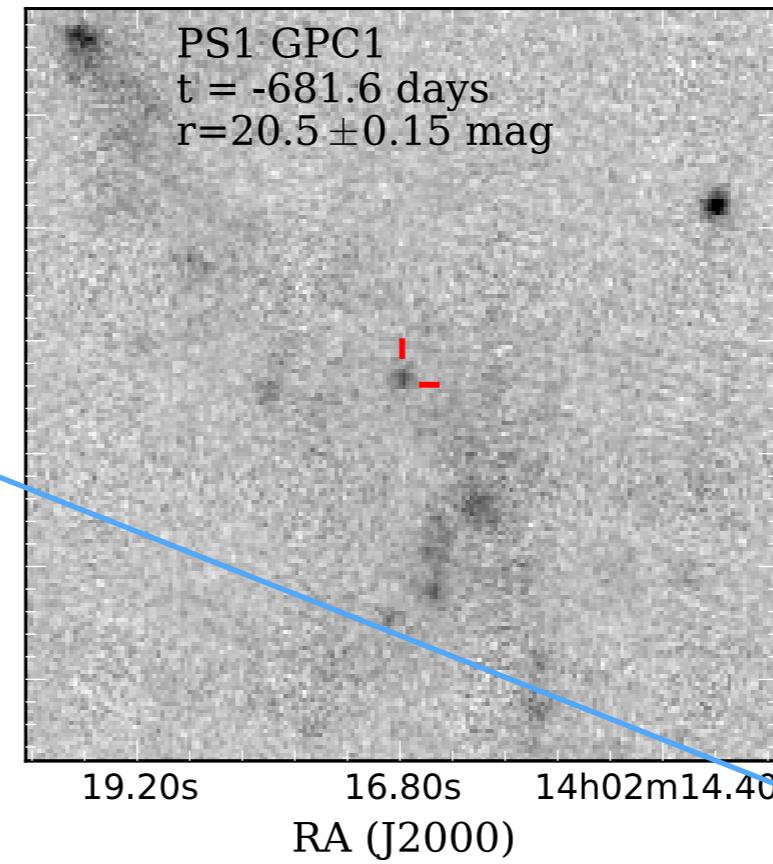
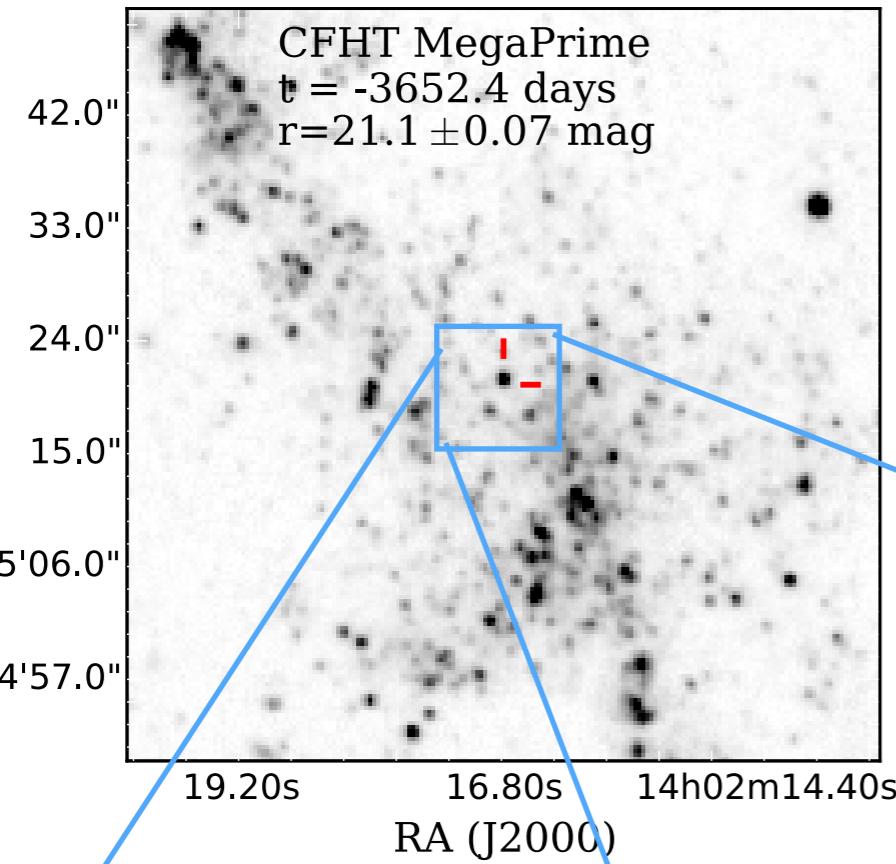


Bond et. al., 2003

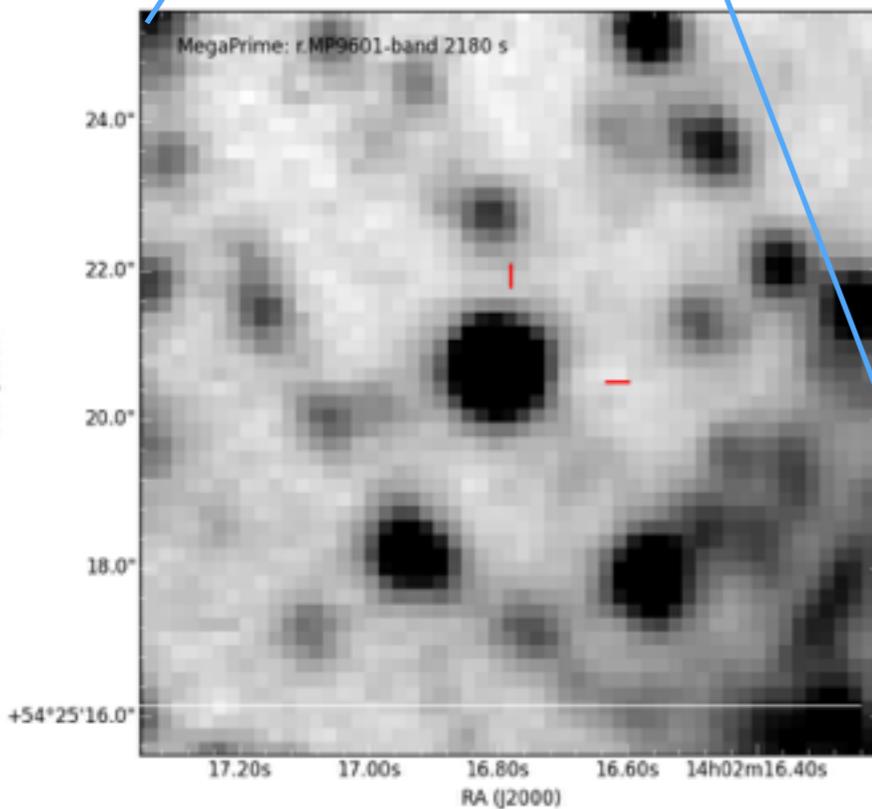
M101-2015OT-1  
iPTF13afz



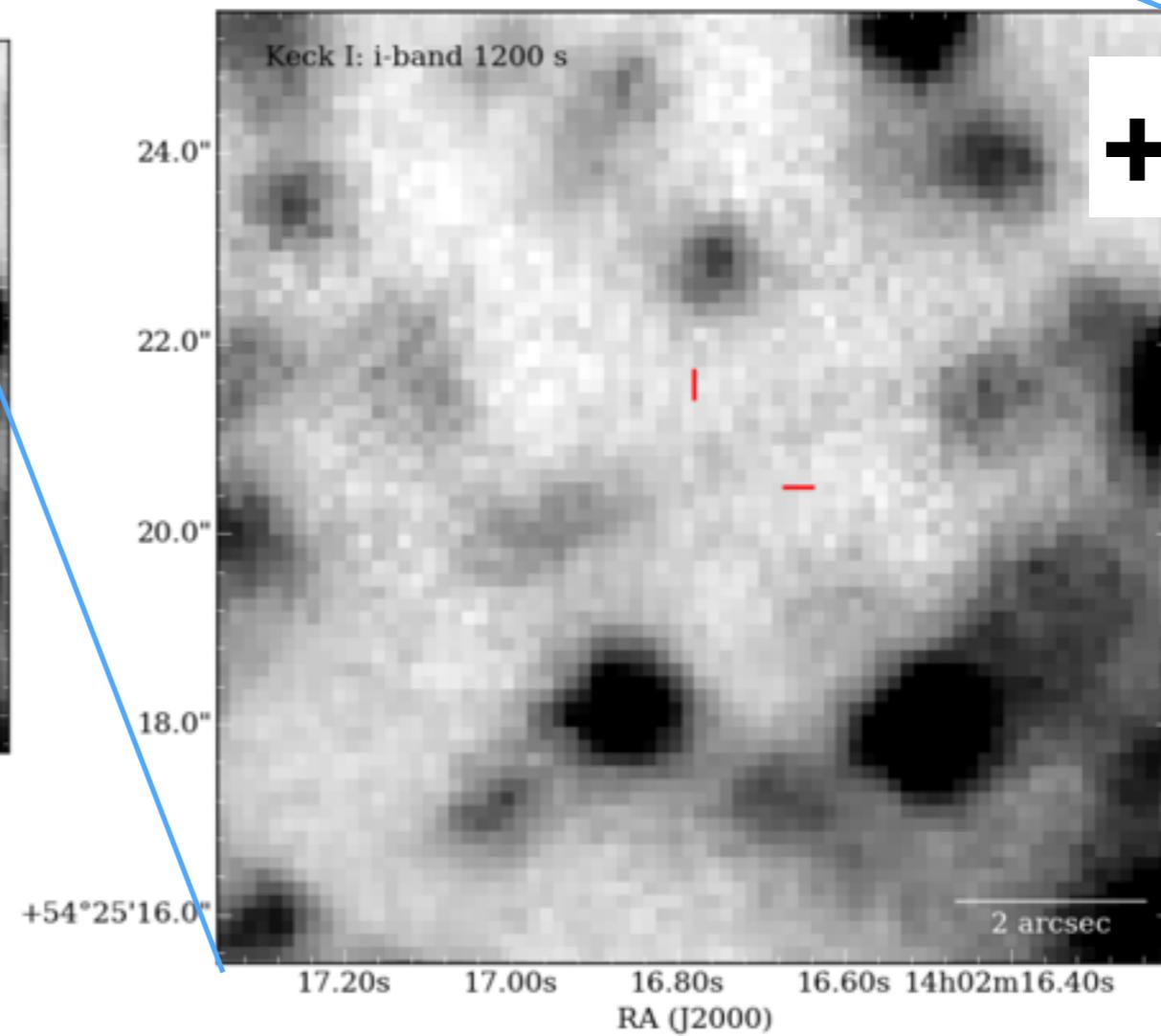
Dec (J2000)



Dec (J2000)

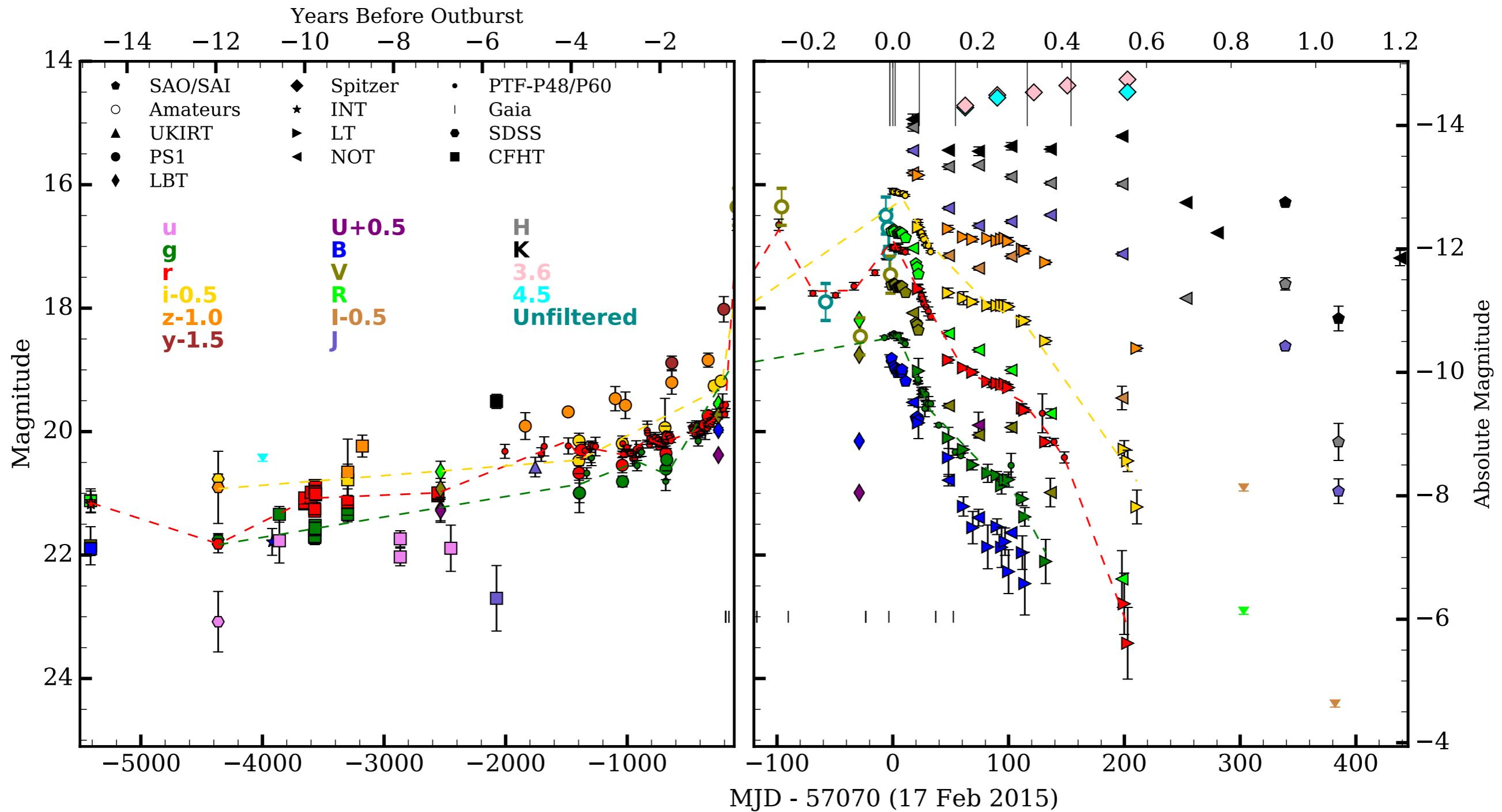


-10 yr

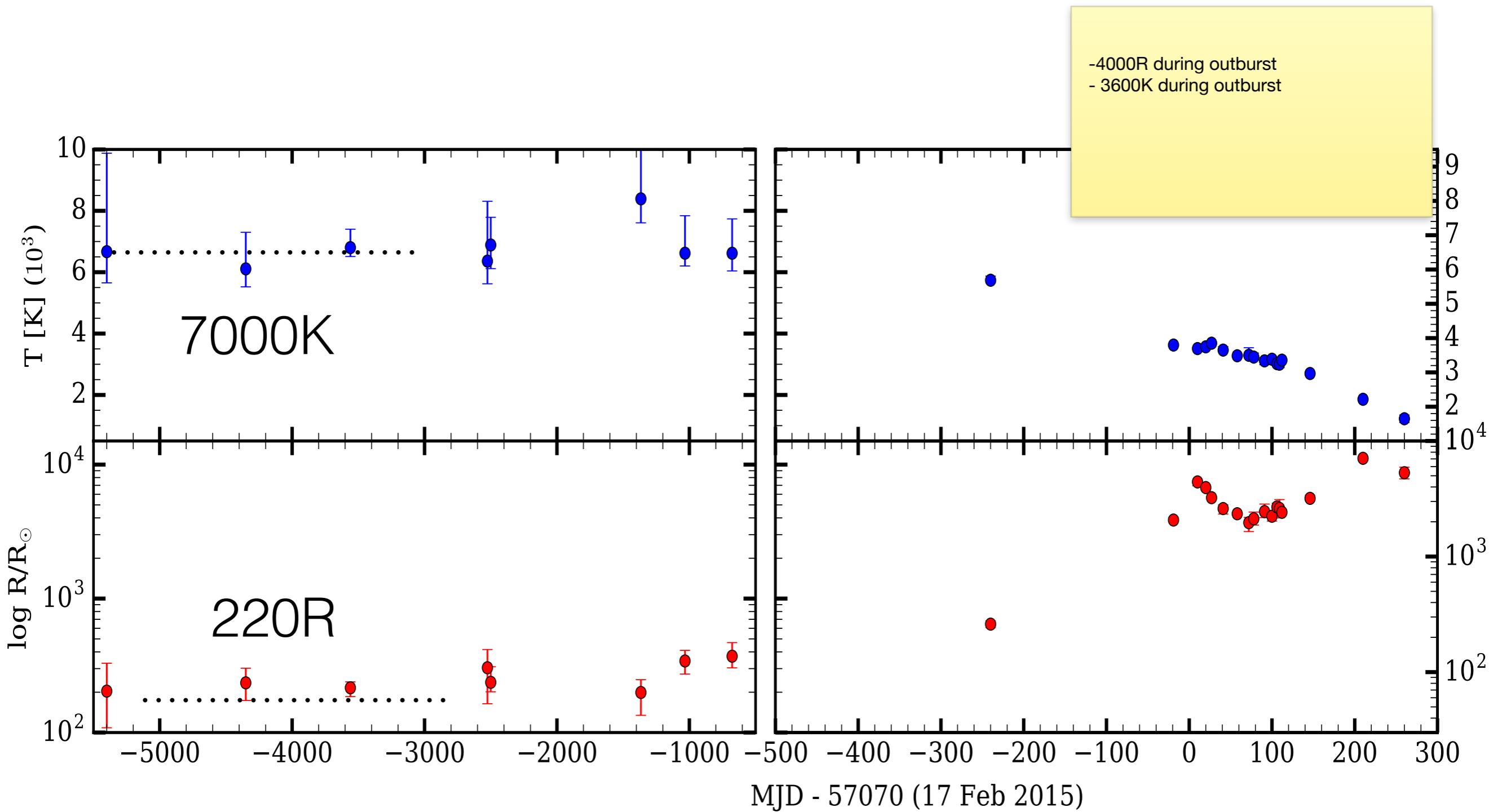


+400 days

# The 16 year light curve



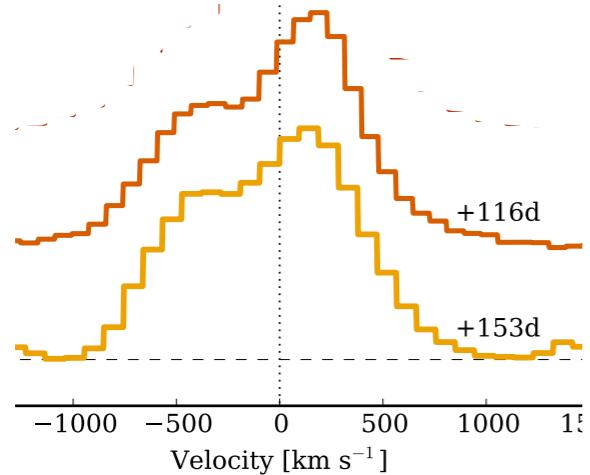
# Radius-temperature evolution



# Spectral evolution

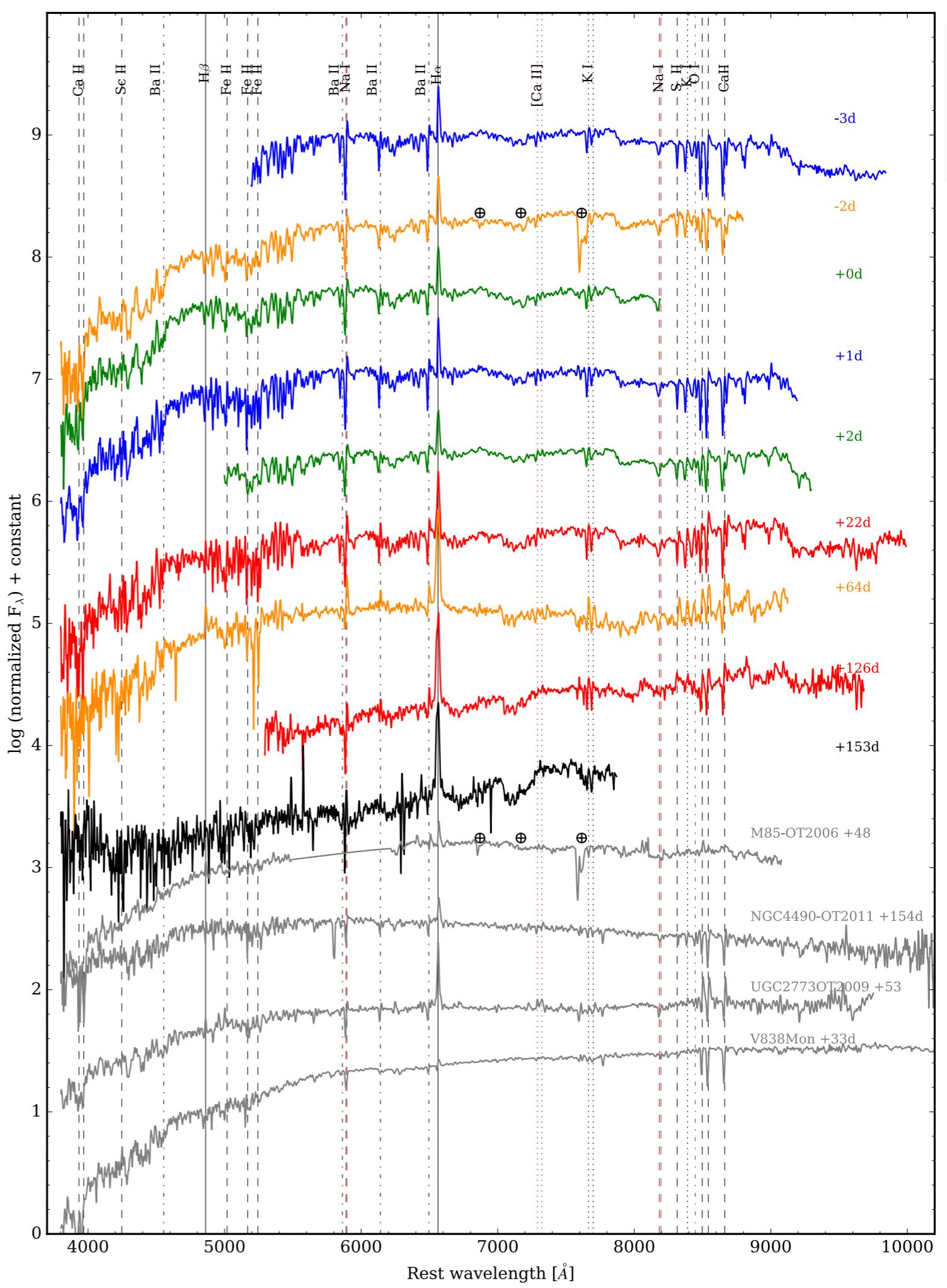
Continuum = 3600K

H alpha at 300km/s

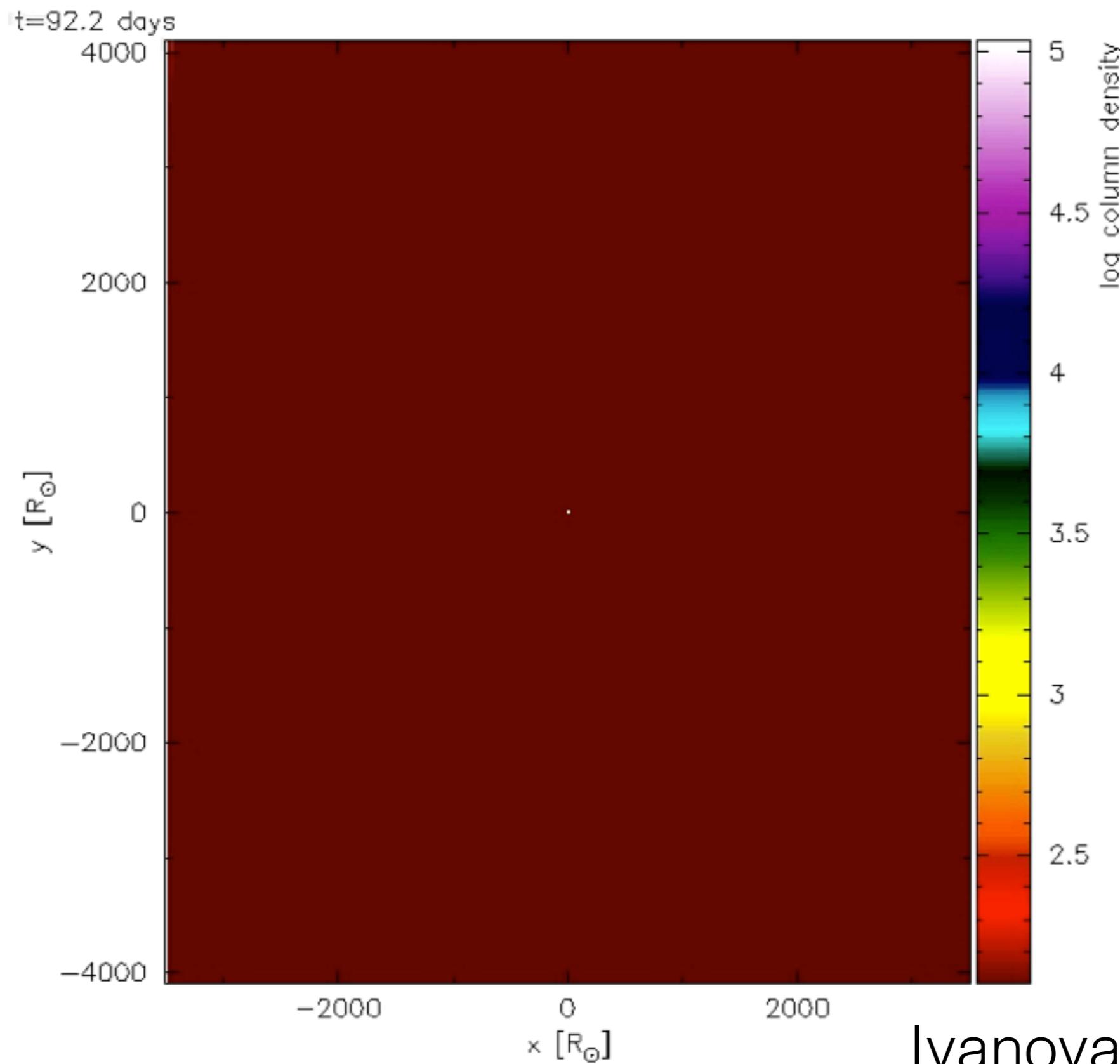


TiO molecular bands

Other red transients

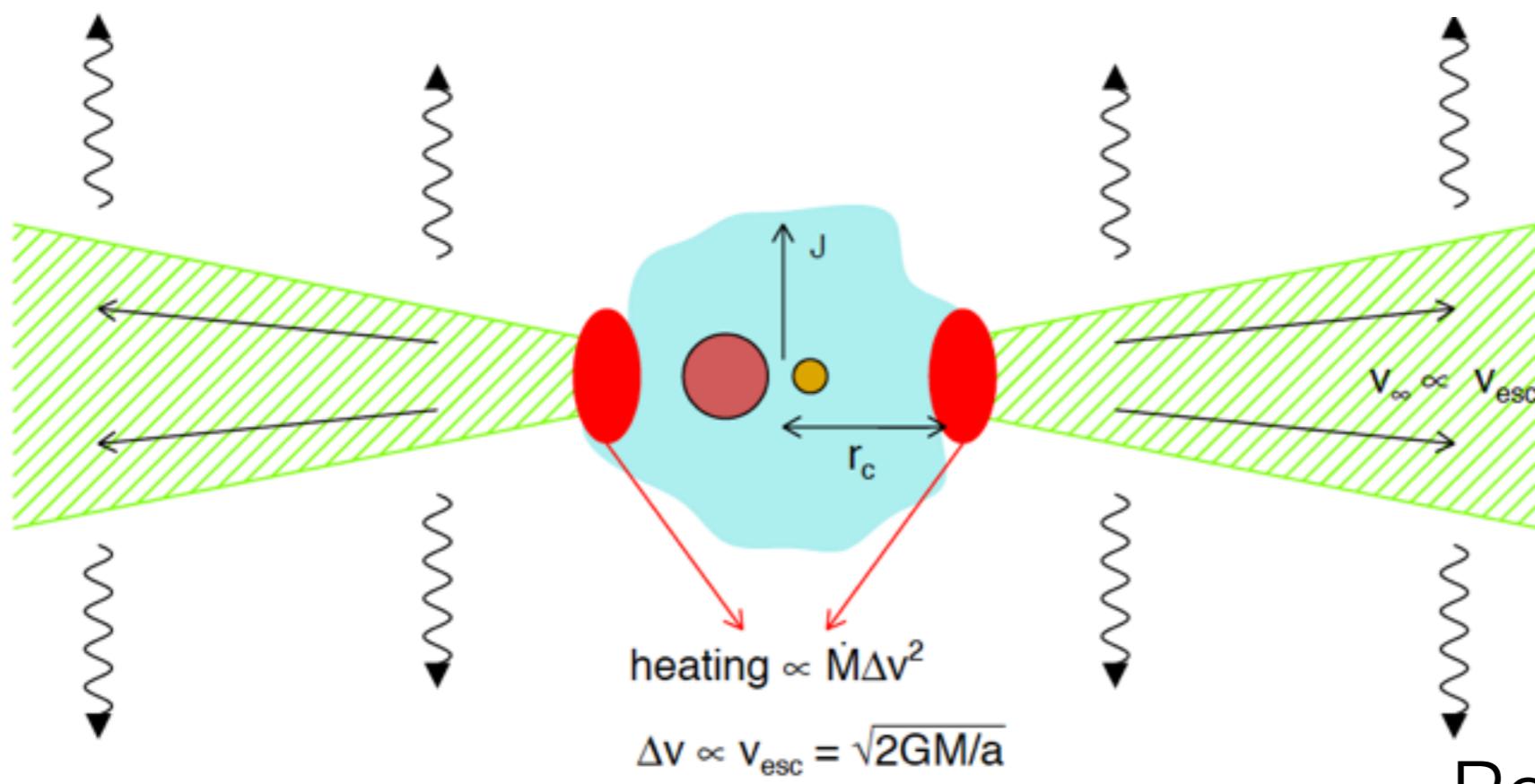
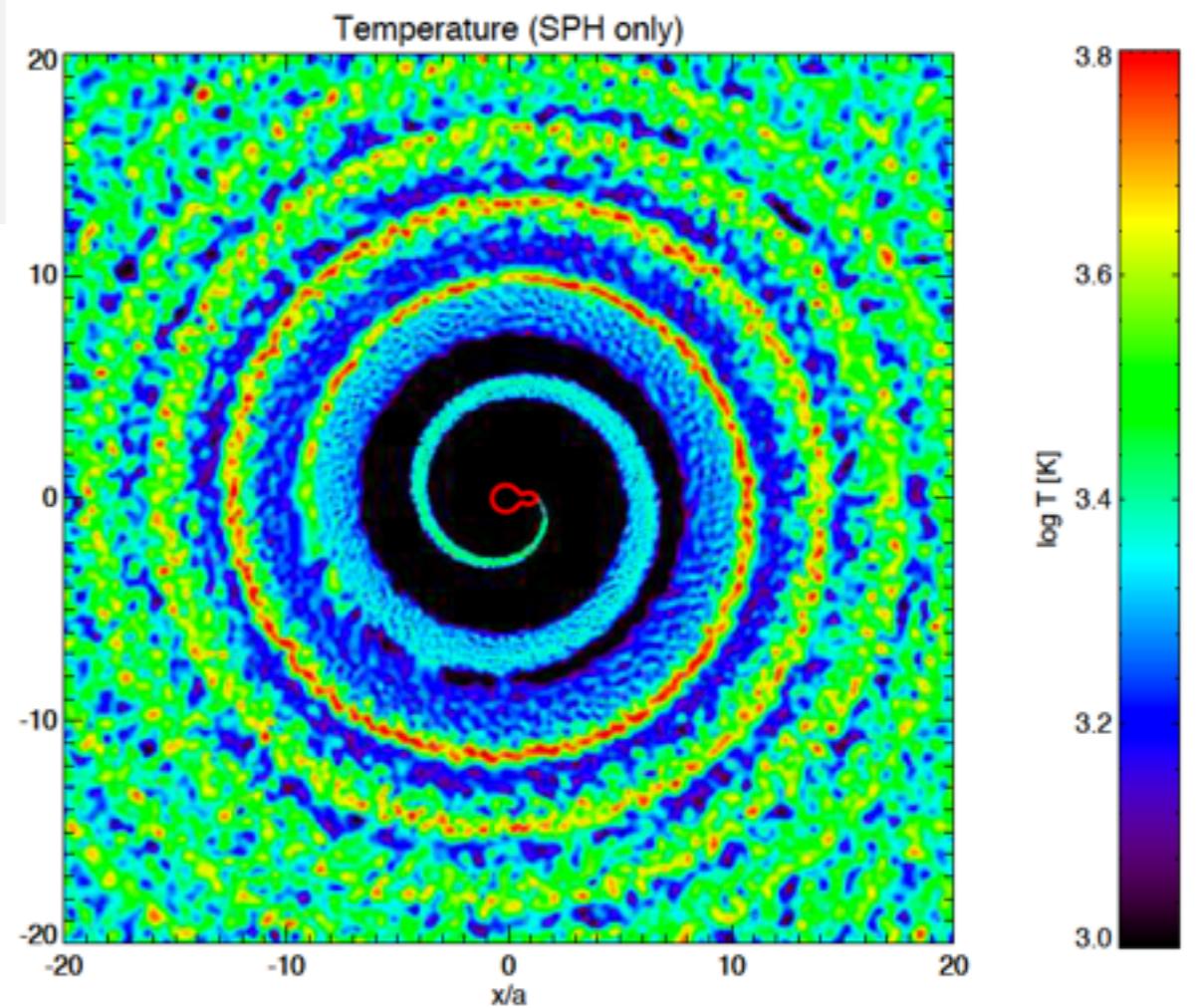


# Recombination of the ejecta?



Ivanova et. al. 2013

# Shocks in outflows from L2?



Pejcha et. al. 2016

# Conclusions

- Intermediate luminosity red transients have a well defined observational locus
- Disentangling the true nature of the outburst is a complex scenario
  - Long time multi-wavelength monitoring
  - Need for models to constrain the parameters of the system given the observables
- PTF has detected a sample (~20) of red transients in nearby galaxies.
- Further reading:
  - Humphreys & Davidson, 1994 (LBV)
  - Ivanova, et. al. 2013 (Common Envelope)
  - Tylenda et. al. 2011 (V1309 Sco LRN)