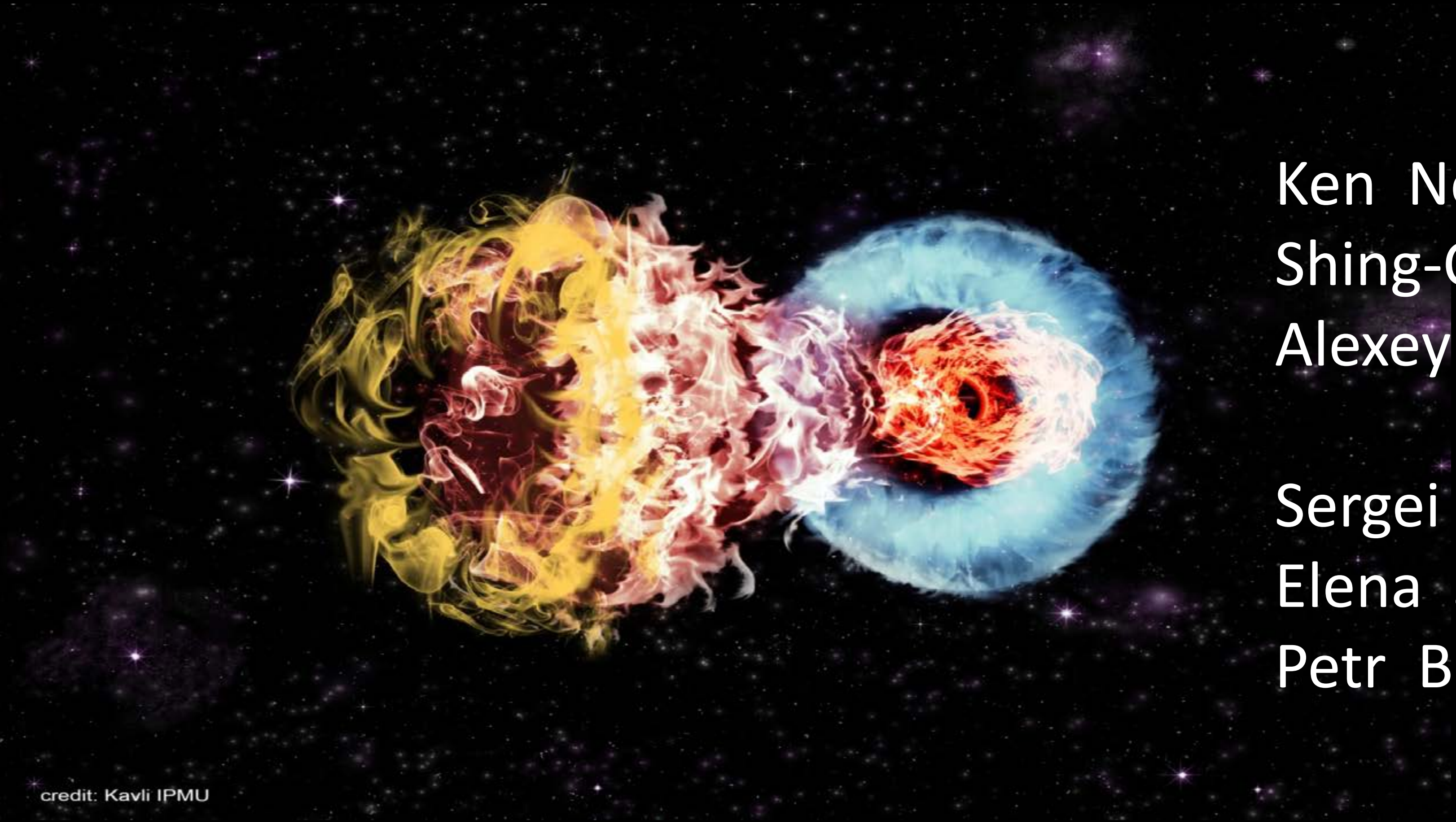
Circumstellar Interaction in Unusual Supernovae (SLSNe, FELTs)



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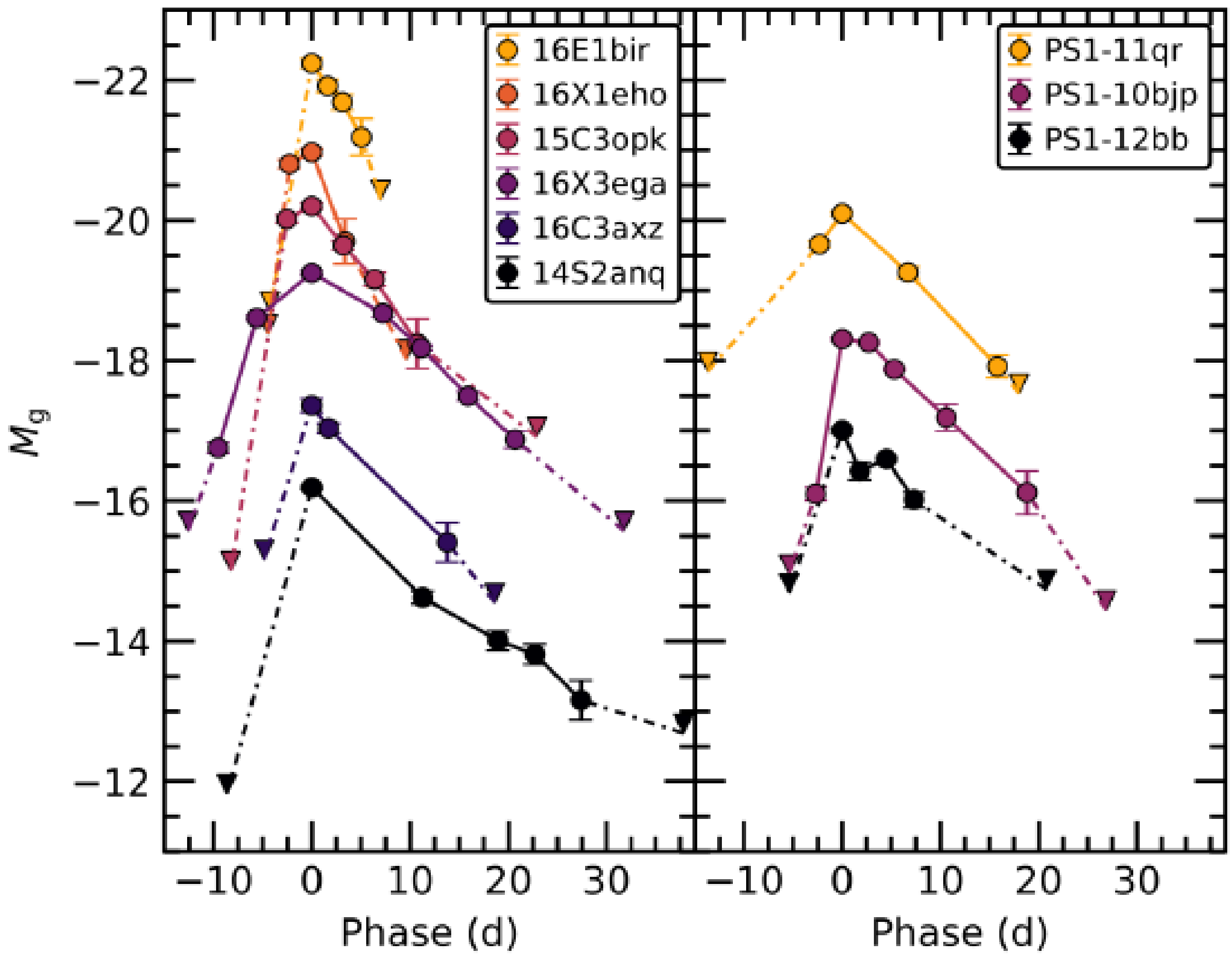
Fast Evolving Luminous Transients (FELT)

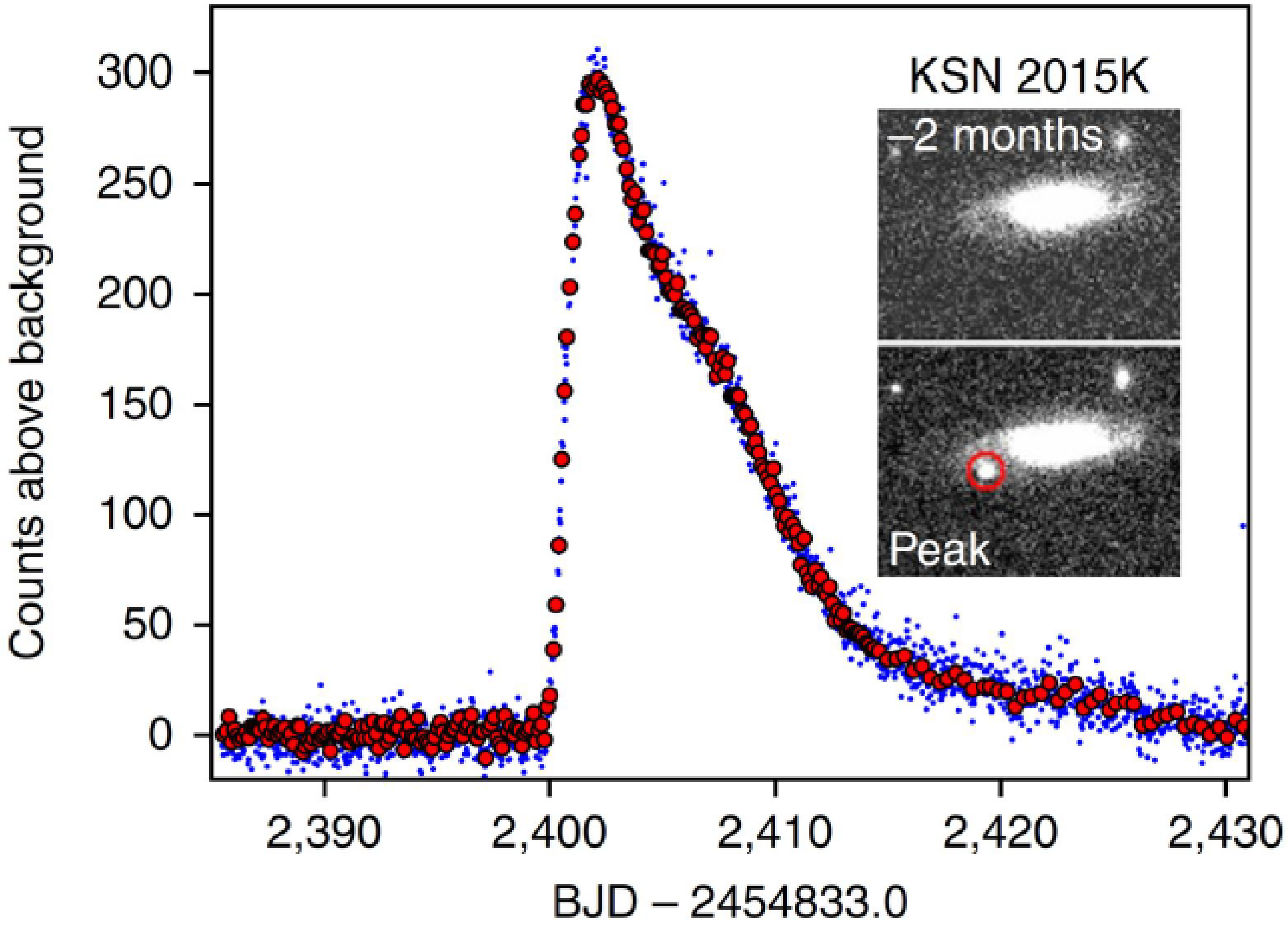
Fast Blue Optical Transients (FBOT)



- KSN 2015K (Rest+2018), AT 2018cow (Prentice+2018)

K2/Kepler light curve of KSN 2018K

Rest+ 2018



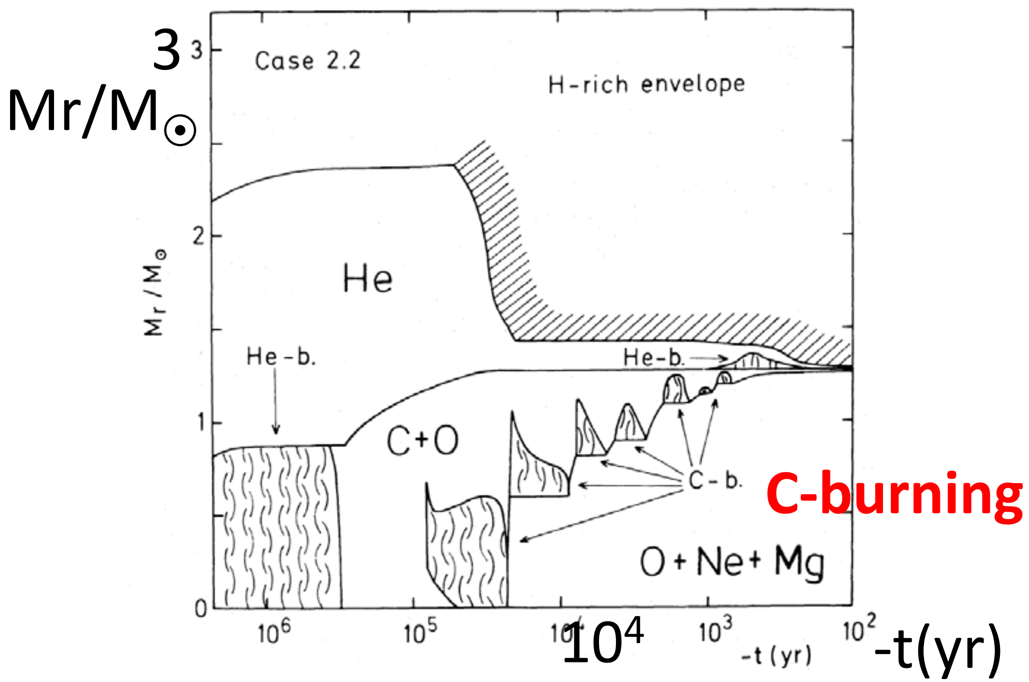
Evolution of 8-10 $M_\odot$ Stars:

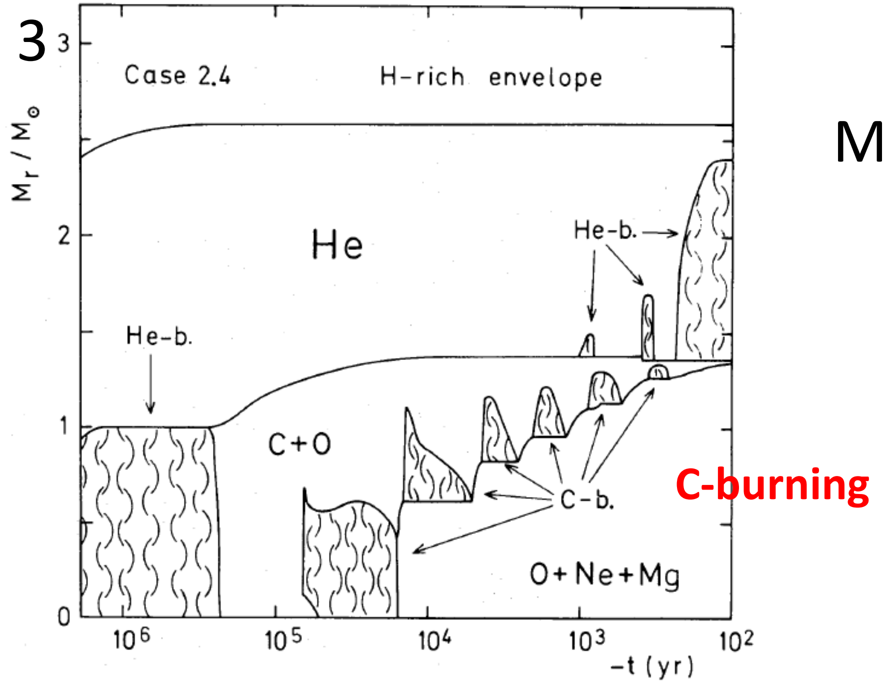
Formation of an electron degenerate ONeMg core

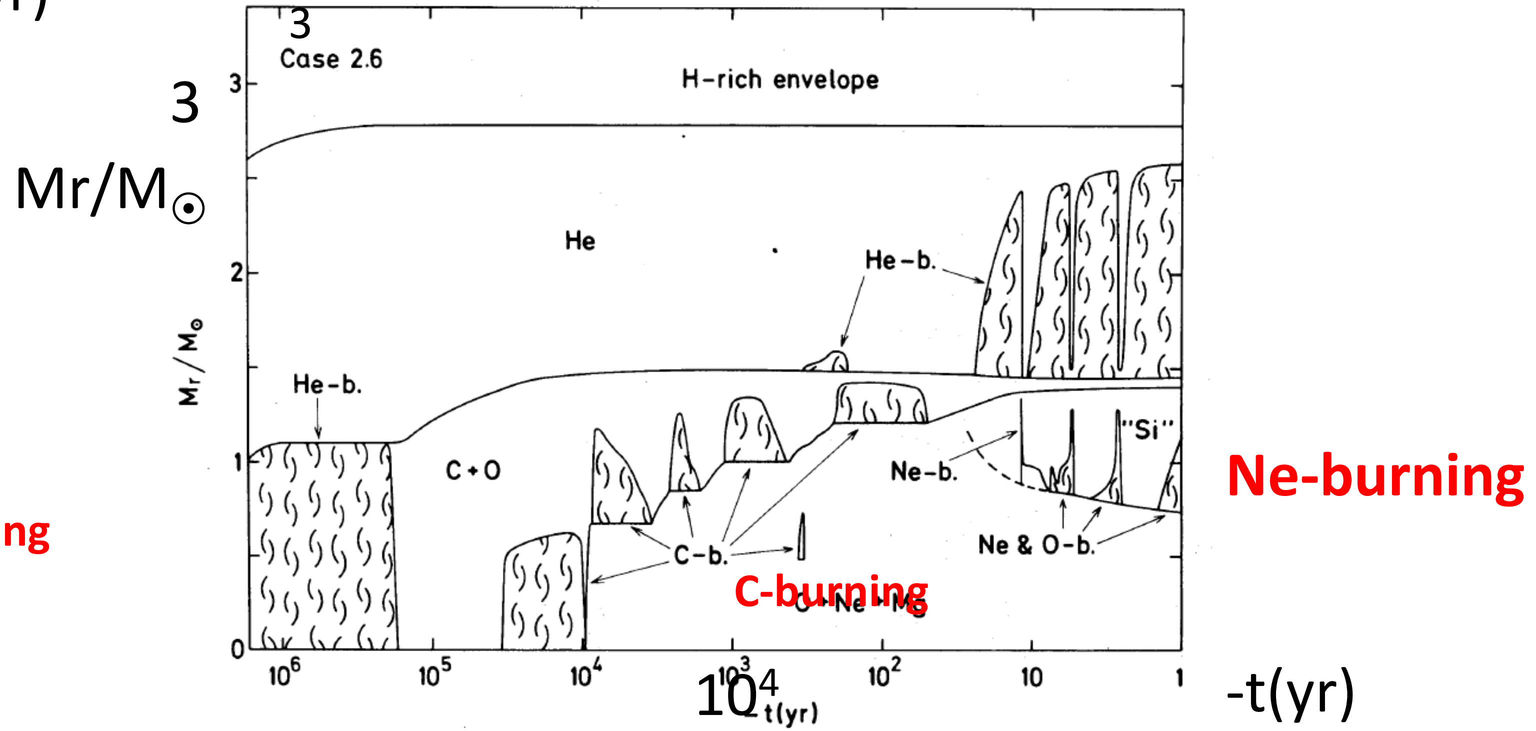
(Nomoto 1982, 84, 87)

Slow Evolution (nuclear timescale)

➔ Importance of Mass Loss







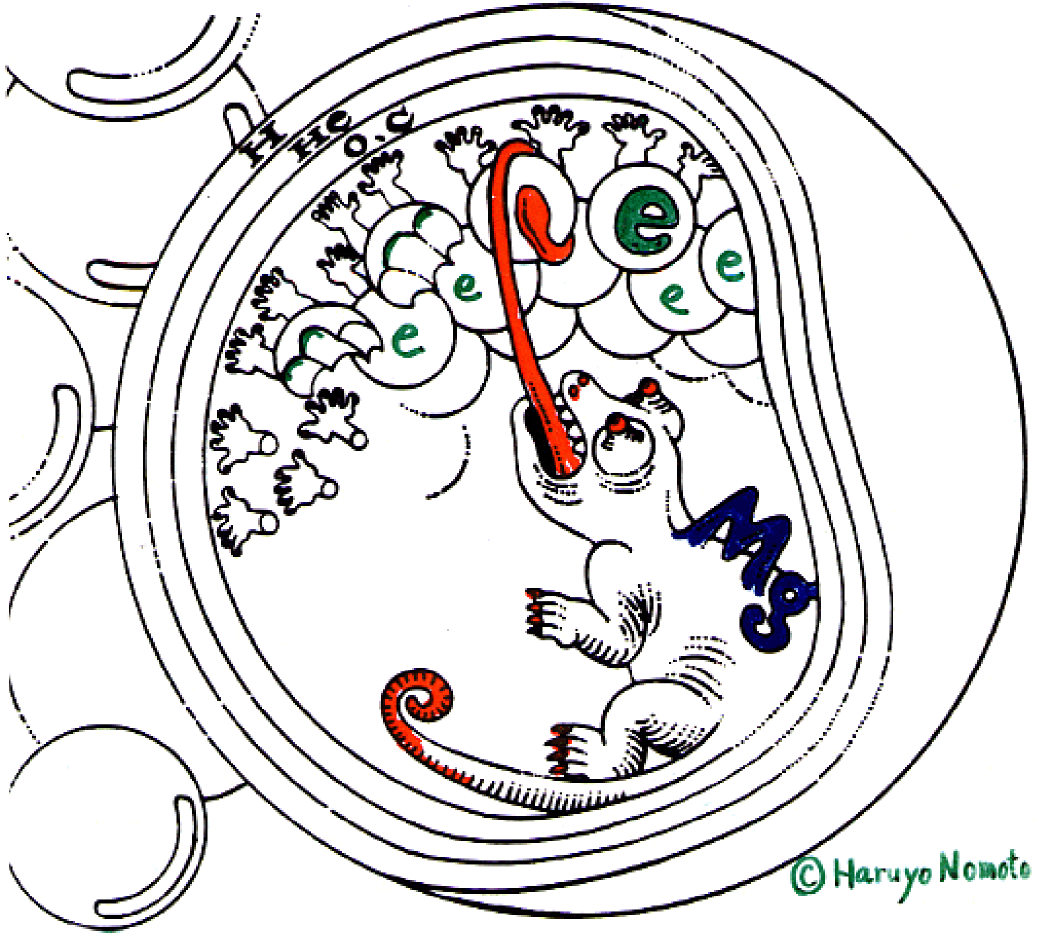
Electron Capture (EC) in 8-10 $M_\odot$ Stars

Electron-degenerate
O+Ne+Mg Core

- $^{24}Mg(e^-,\nu)^{24}Na\ (e^-,\nu)^{24}Ne$
- $\rho > 4.0 \times 10^9 gcm^{-3}$

- $\rightarrow$collapse

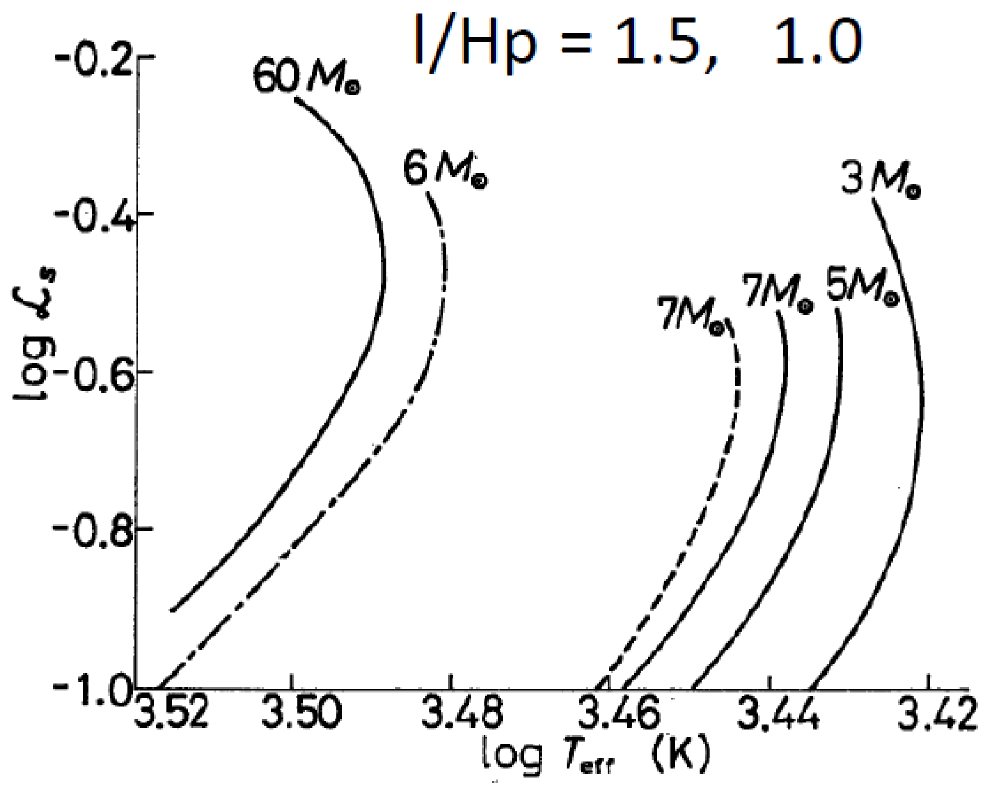
(Nomoto 1984)



H-rich Envelope of Super-AGB Stars

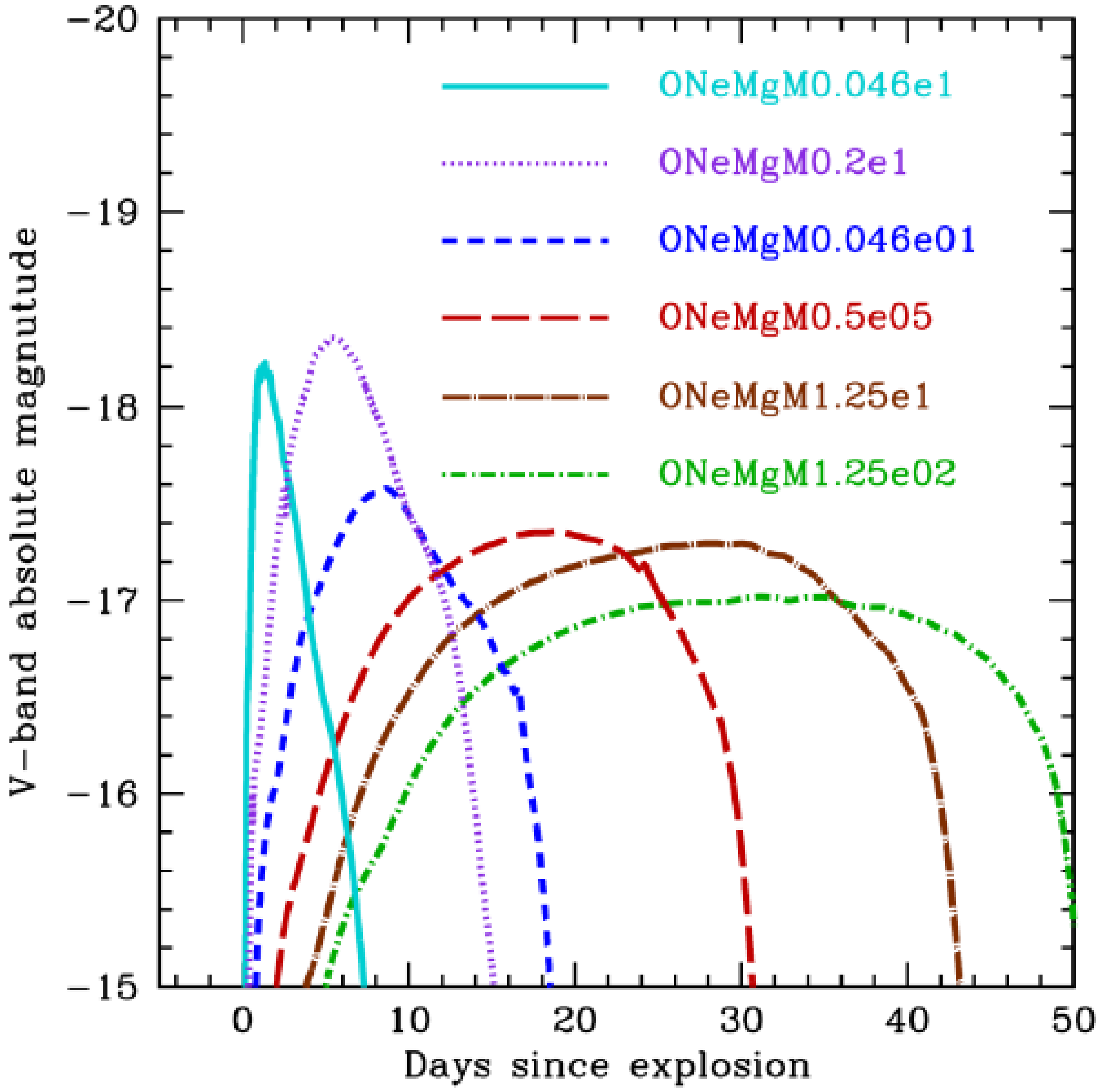
- Thin He shell
  - ➔ Thermal pulses of He shell burning (C, s-process synthesis)
  - ➔ 3rd Dredge-up of the He layer

- **Extensive mass loss** (C-dust ?)
  - ➔ Small mass H-rich envelope and dense Circumstellar Matter (dusty)
  - ➔ SN IIn ? II-L ?? II-pec ??



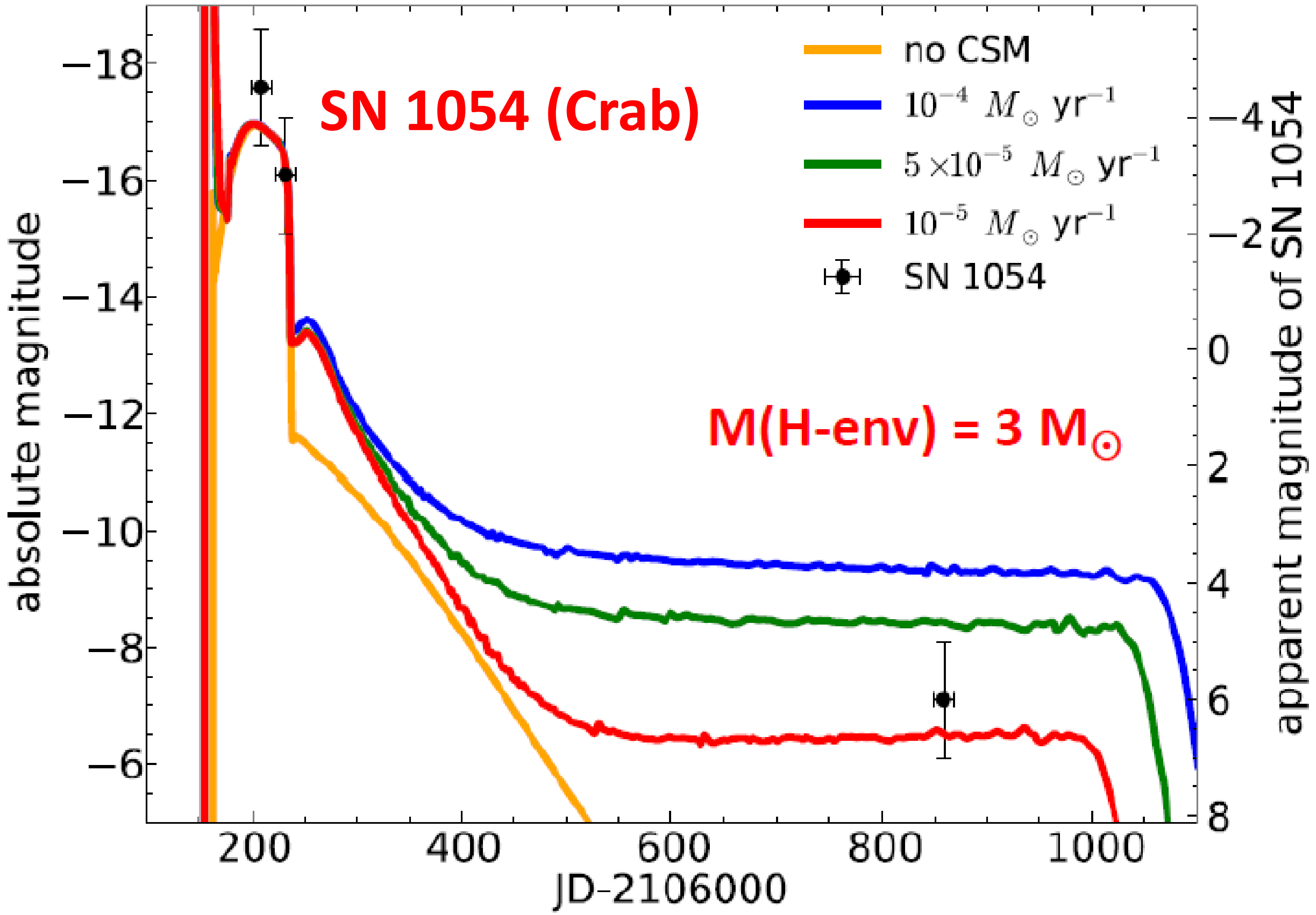
(Nomoto et al. 1972)

V-band light curve simulations (M ~ 0.05 – 1.25 $M_\odot$)



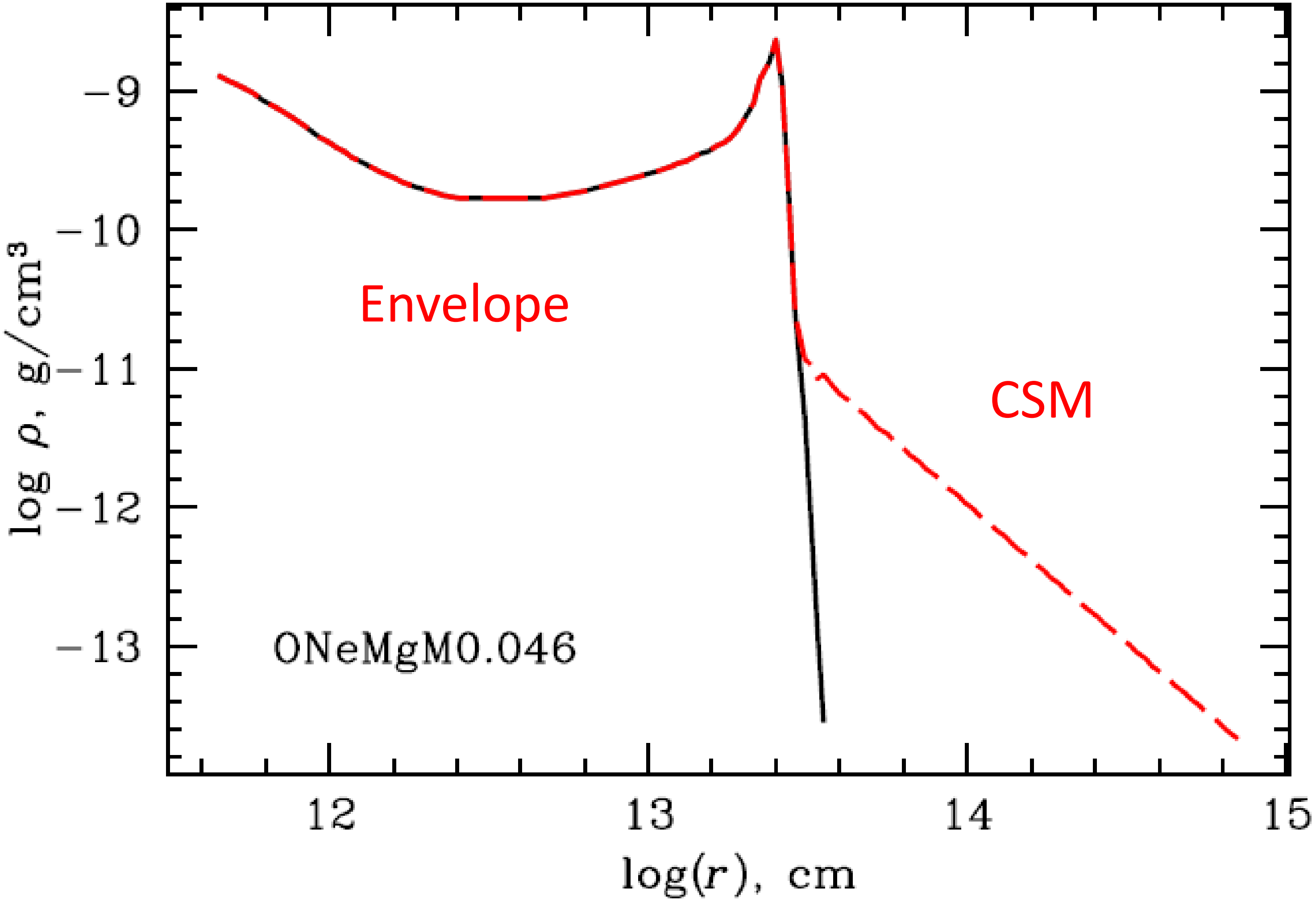
- Rise-time t_{rise} versus width of the peak Δ
- M ~ 1 $M_\odot$:
  t_{rise} > 10 d
  Δ ~ 10 – 30 d
- M ~ 0.1 $M_\odot$:
  t_{rise} ~ 2-5 d
  Δ < 10 d

Light Curves of ECSNe with CSM Interaction



Moriya, Tominaga, Langer, Nomoto, Blinnikov, Sorokina (2014)

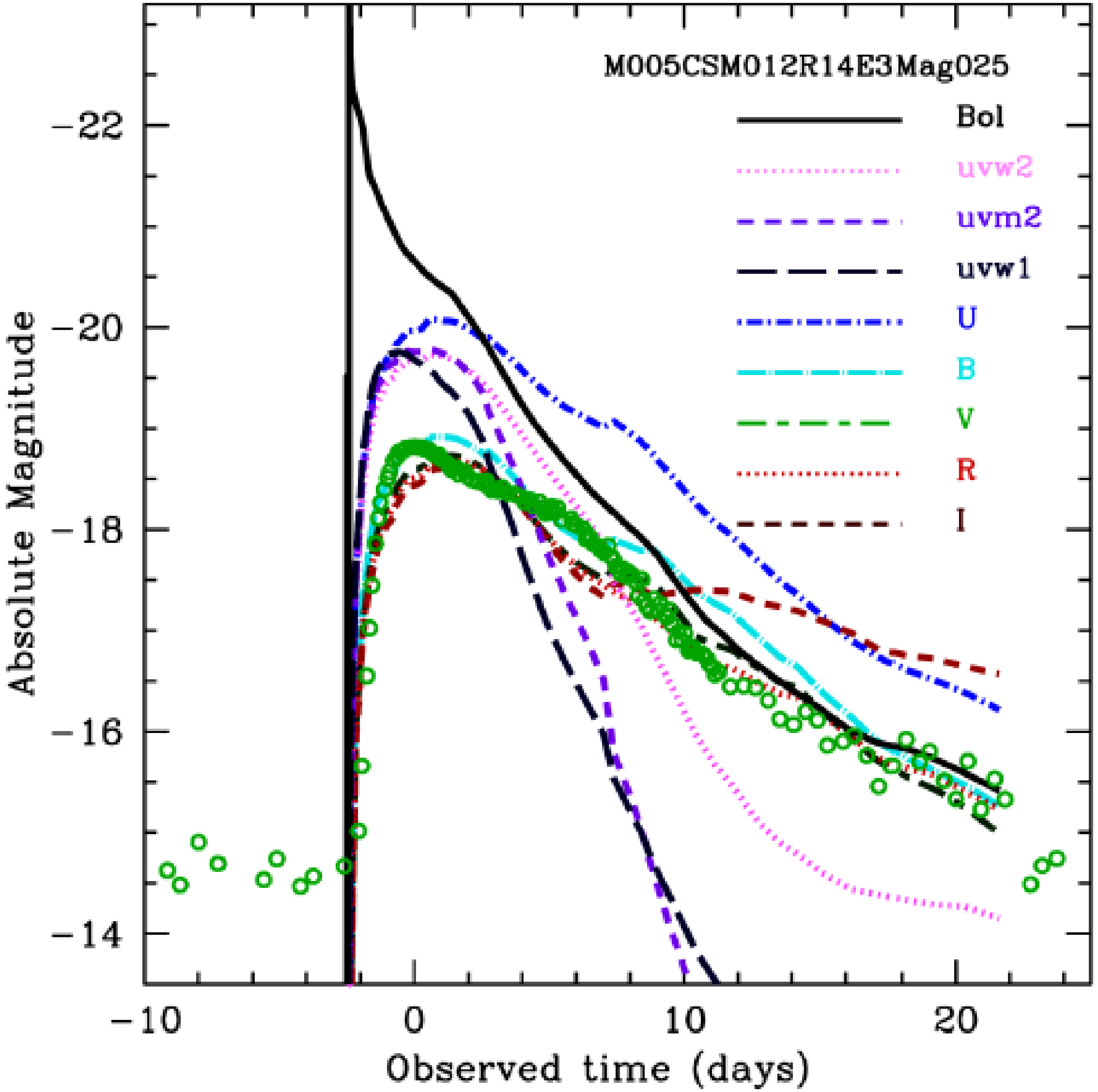
Super AGB H-rich Envelope + Circumstellar Matter



- $M_{ej} \sim 10^{-2} M_\odot$
- $M_{CSM} \sim 0.10\text{-}0.12\ M_\odot$
- $R_{ph} \sim 10^{14}$ cm
- $E_{kin} \sim 10^{50}$ erg
- Pulsar(?):
  $P \sim 20$ ms
  $B \sim 2{\cdot}10^{12}$ G

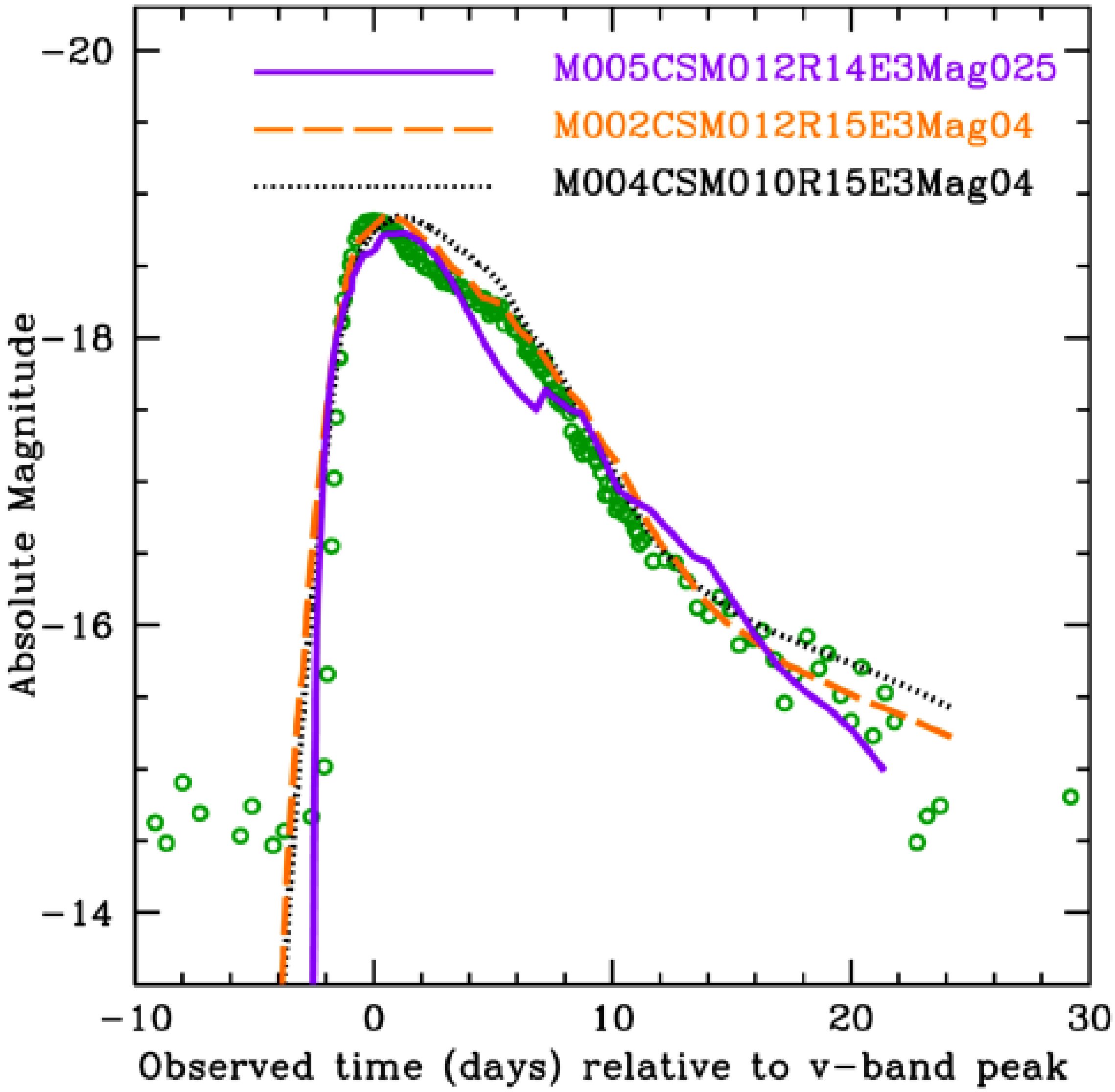
CSM formation ~ a few years

KSN 2015K multiband LC simulations



- Peak: soft X-rays (100 eV)
- Bright U-band and UV emission
- g-r ~ - 0.3 (peak)
  g-r ~ - 0.2 (+8 d)
- $V_{ph} \geq 10{,}000$ km/s

KSN 2015K V-band light curve simulations



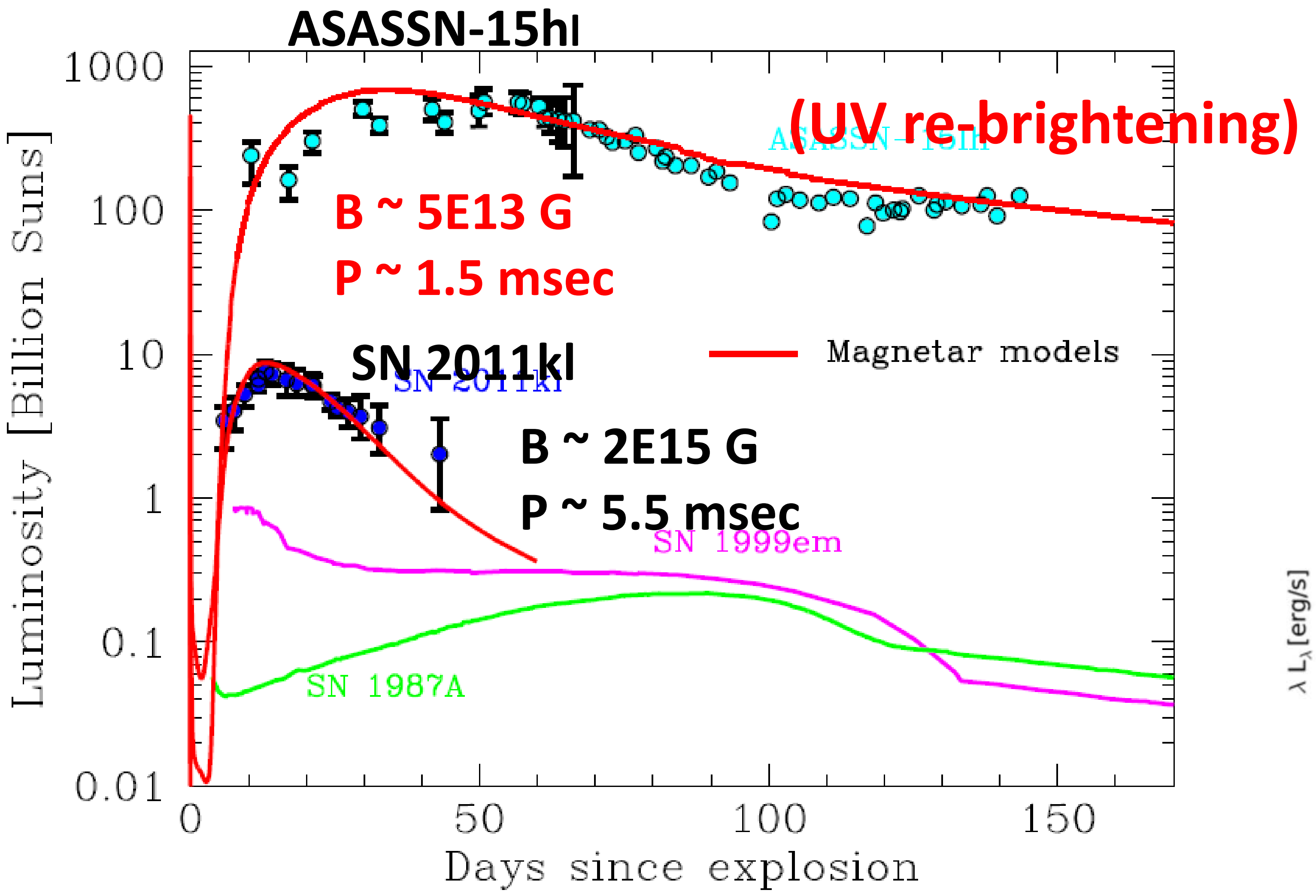
- $M_{ej} \sim 10^{-2} M_{\odot}$
- $M_{CSM} \sim 0.10\text{-}0.12\ M_{\odot}$
- $R_{ph} \sim 10^{14}$ cm
- $E_{kin} \sim 10^{50}$ erg
- Pulsar(?):
  $P \sim 20$ ms
  $B \sim 2{\cdot}10^{12}$ G
- Smearing term:
  Multi-D is required

Superluminous Supernovae
(Progenitors, Mechanisms??)

Type I SLSNe: No Hydrogen

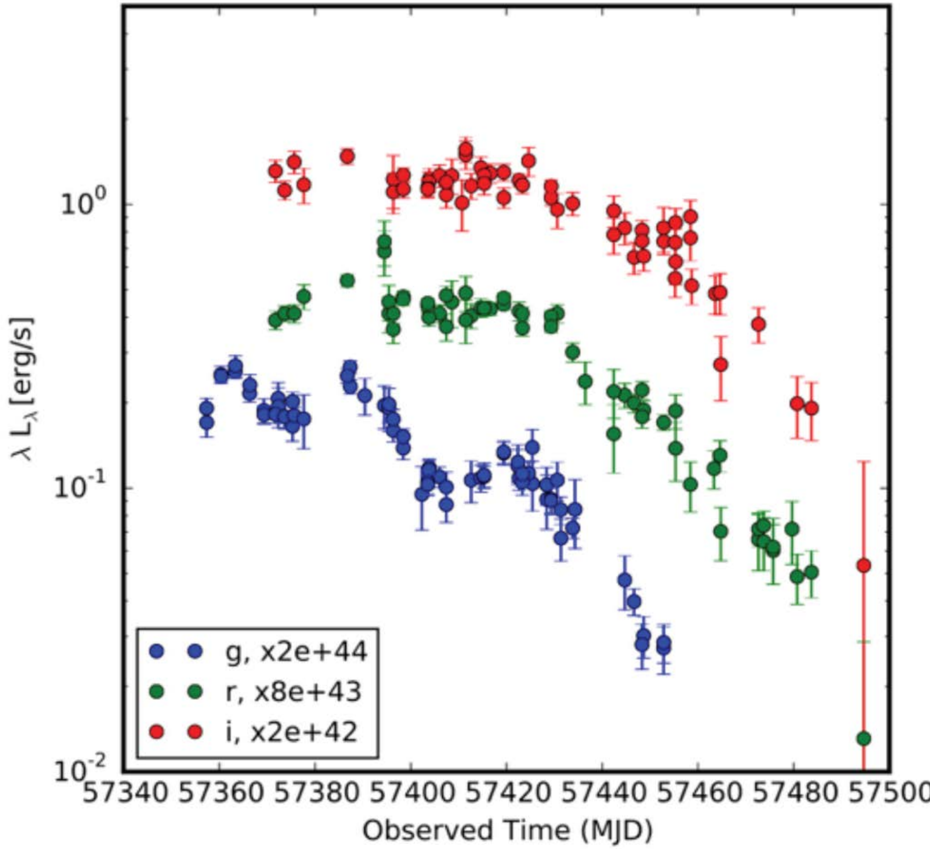
*__Radioactive Decays__ (Core-Collapse SN
Pair Instability SN)
*__Magnetar__
*__Black Hole Accretion__
*__Circumstellar Interaction__

Magnetar models for SLSN-I: CSM signature?

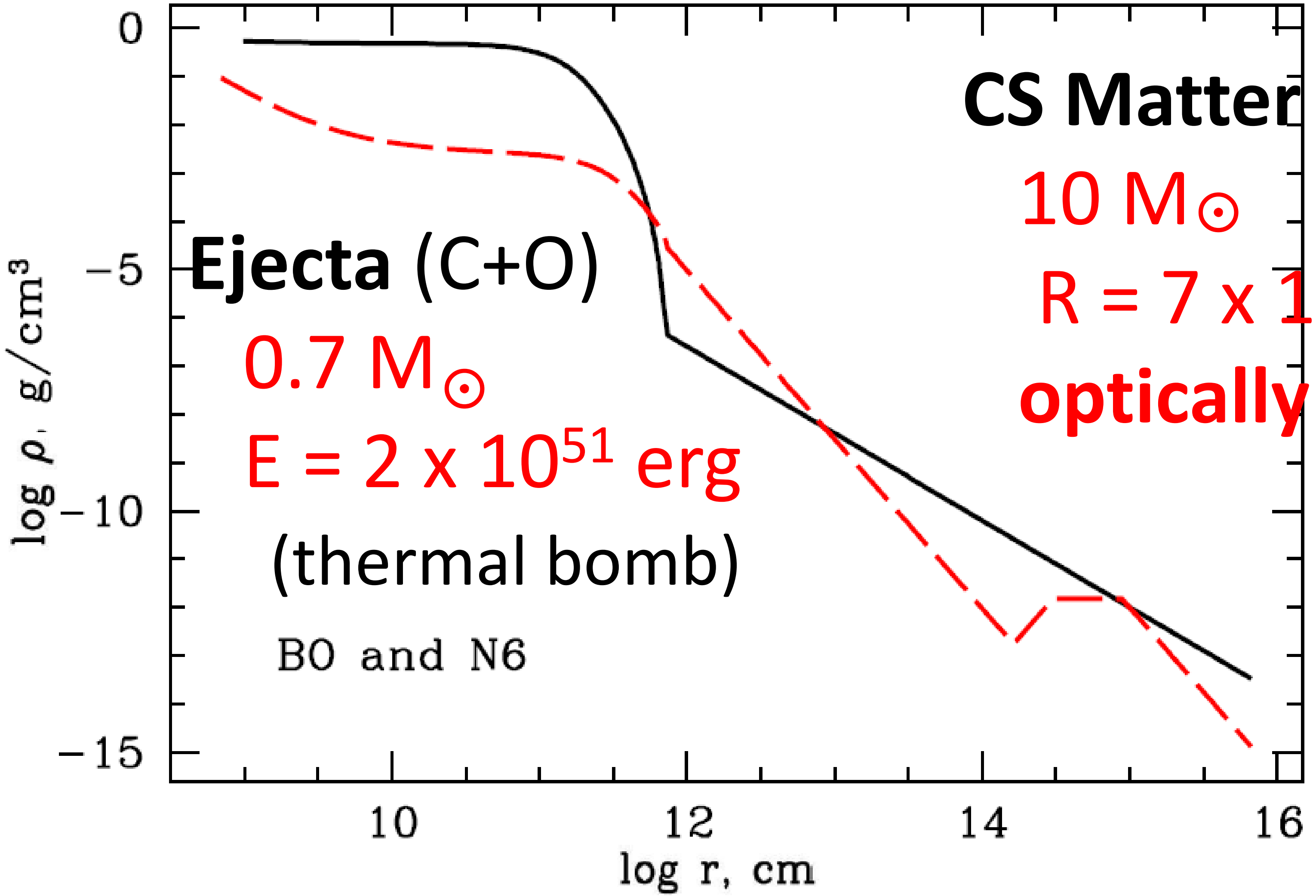


(Radiation-Hydro Models: Bersten, KN+16)

SLSN-I PTF15esb: Bumpy Light Curve



Circumstellar Interaction model for SN 2010gx (Sorokina, KN+16)



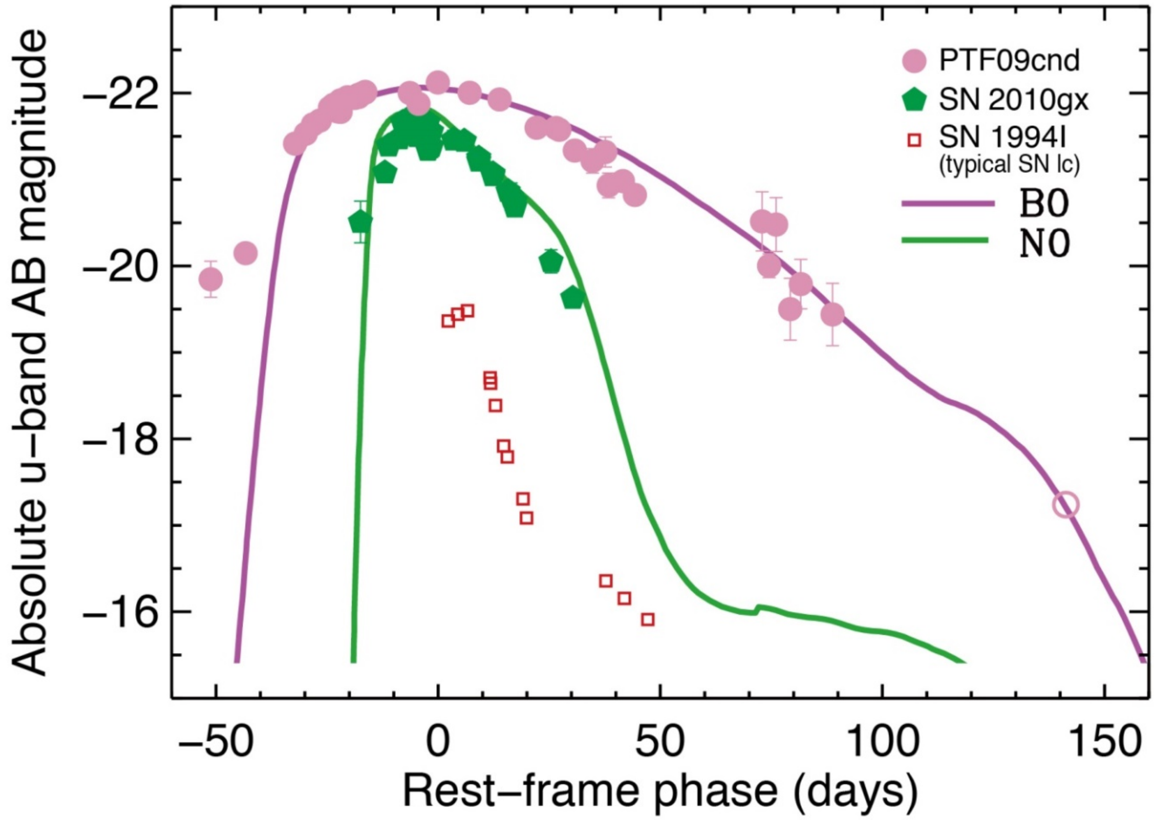
Ejecta (C+O)
0.7 M⊙
E = 2 x 10^{51} erg
(thermal bomb)

CS Matter (C+O +He)
10 M⊙
R = 7 x 10^{15} cm
optically thick

Interaction Light Curves: Narrow & Wide

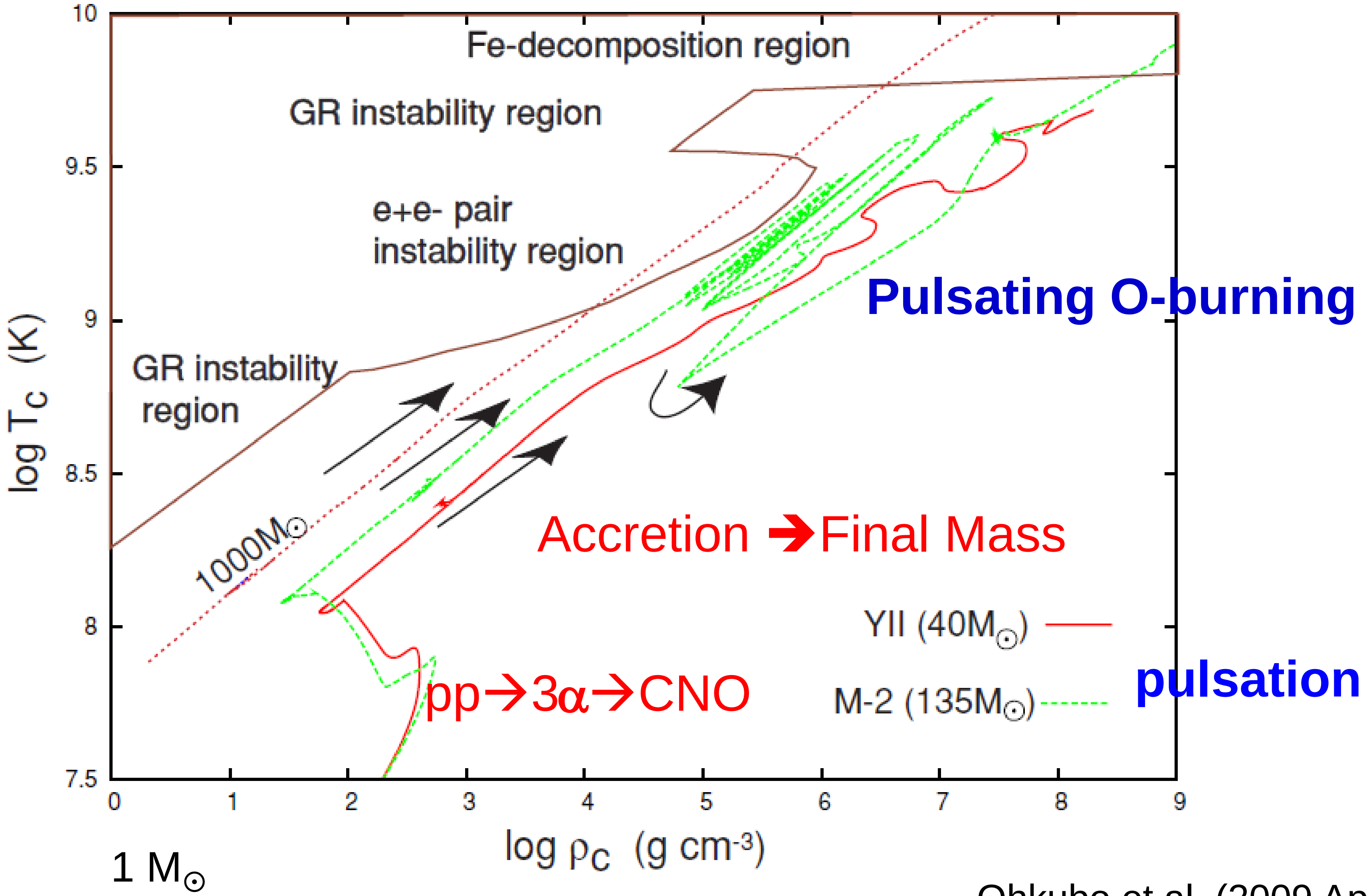
	SN 2010gx (N0)	PTF09cnd (B0)	
M(CSM)/M⊙	**10**	**50**	**(H-free massive CSM)**
M(ejecta)/M⊙	0.7	5	
E (10^{51} erg)	2	5	

u-band



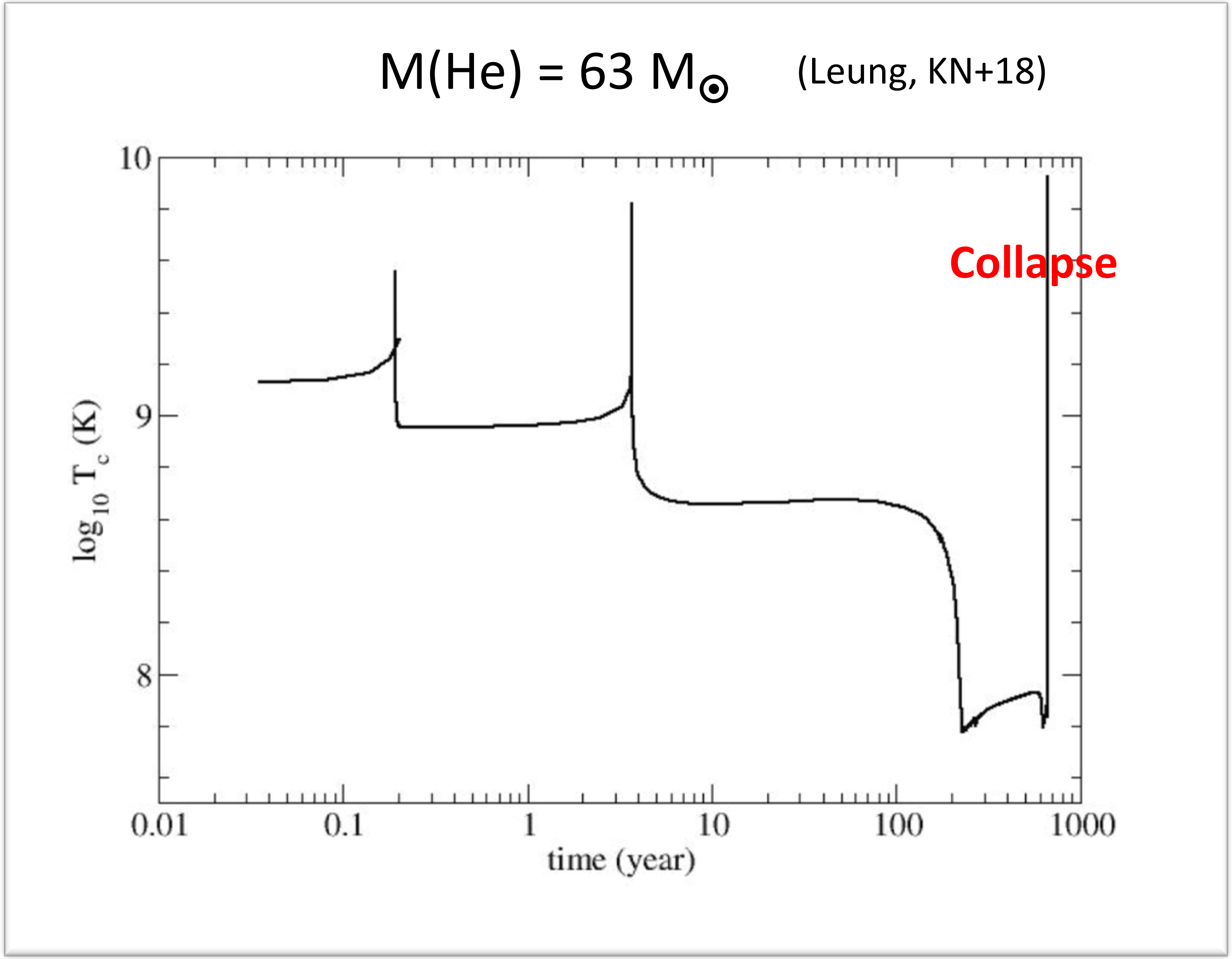
Pulsating O & Si Burning ➔ CSM ?

Pulsational Pair-Instability (80-140 $M_\odot$)

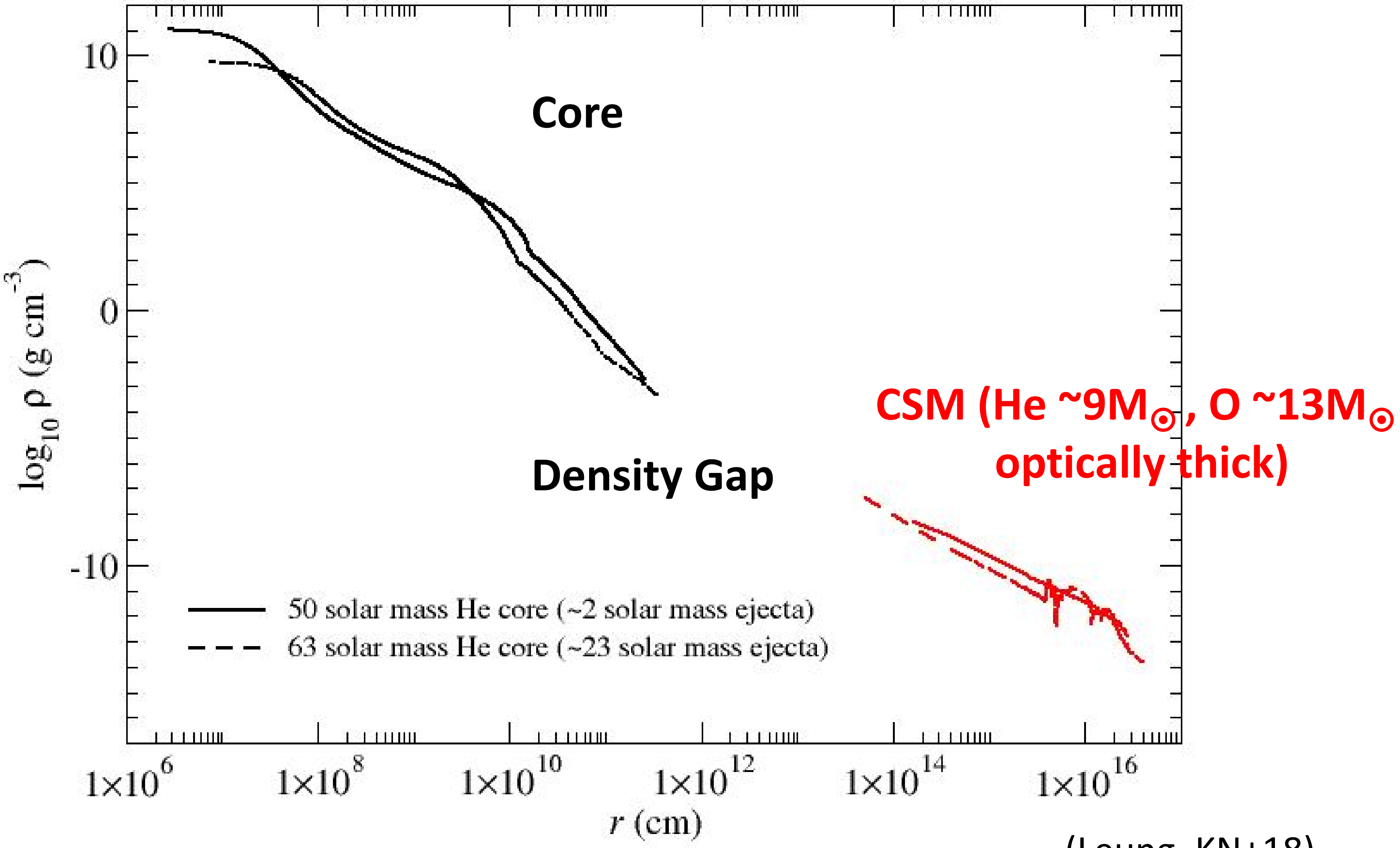


Ohkubo et al. (2009 ApJ)

Pair Instability Pulsations



Pre-Collapse Core and CSM after PPI



(Leung, KN+18)

~80 – 140 $M_\odot$ Stars

Pulsational Pair-Instability (PPI: Barkat+)

➔ Pulsational Mass Ejection (Woosley, Marchant+, Leung-KN)

➔ Dense Circumstellar Matter

M(CSM: He, C, O) ~ 4 – 40 $M_\odot$

Circumstellar Interaction ➔

Type I Superluminous Supernovae ?

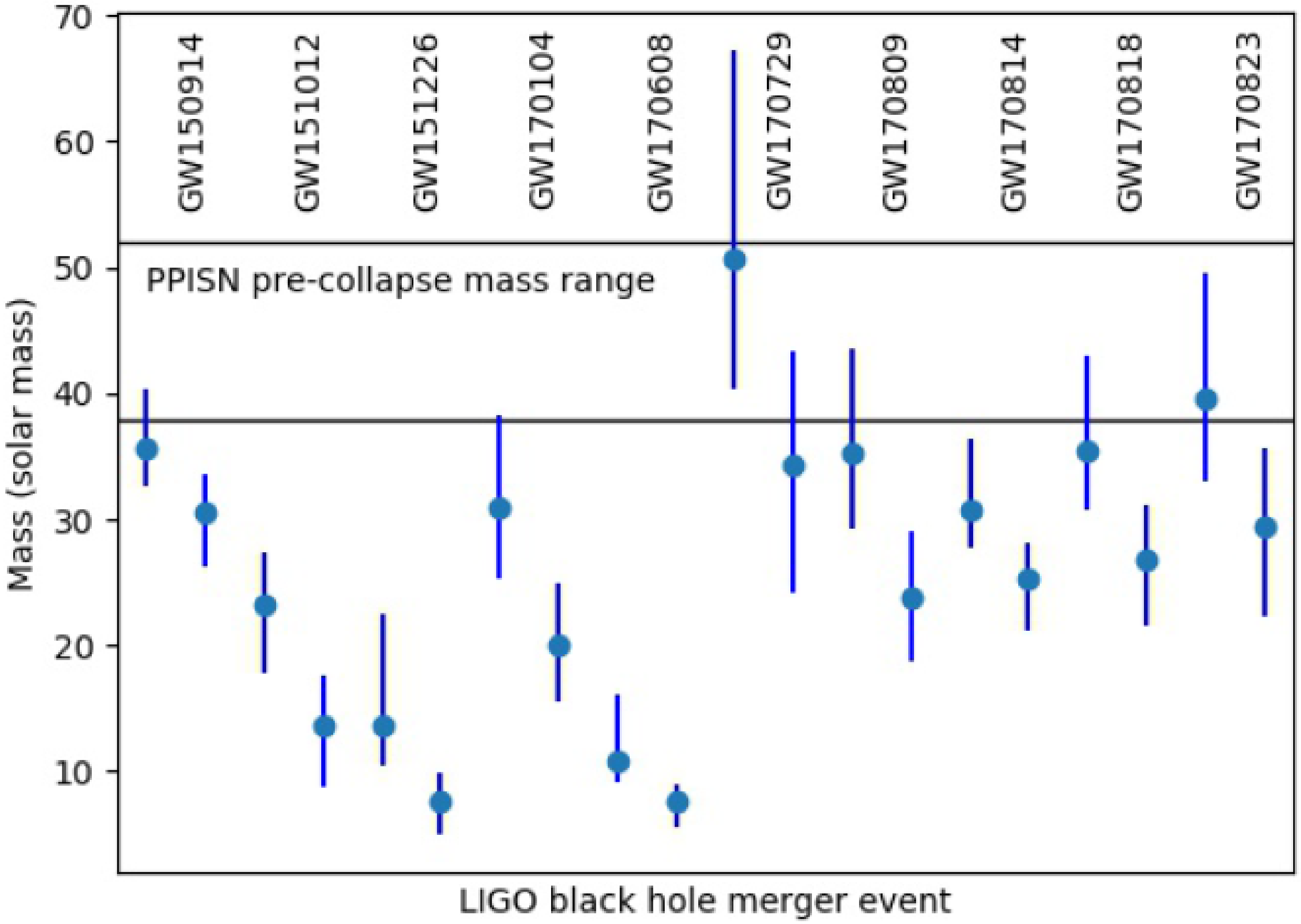
➔ Collapse (BH formation):

M(BH) = 38 – 51 $M_\odot$ if no-mass ejection (e.g., Leung-KN)

(cf. Binary BH masses from GW)

r-process in accretion disk, if jet-induced ejection ??

LIGO BH masses vs. PPISN masses



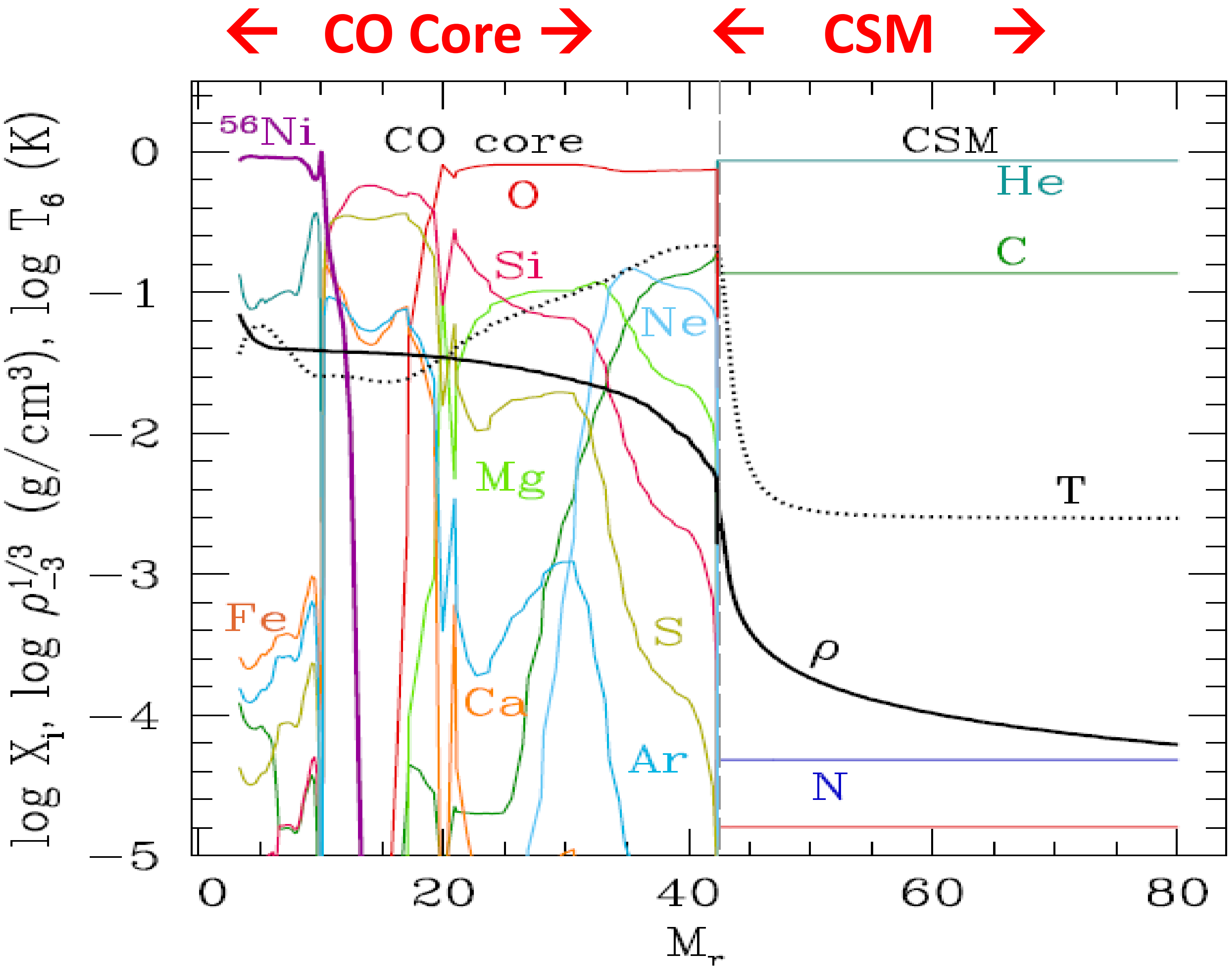
Pulsational Pair-Instability Supernova (CSM+ ^{56}Ni decay)

M(ZAMS) = 100 $M_\odot$
M(ejecta) = 40 $M_\odot$
M(CSM) = 37 $M_\odot$

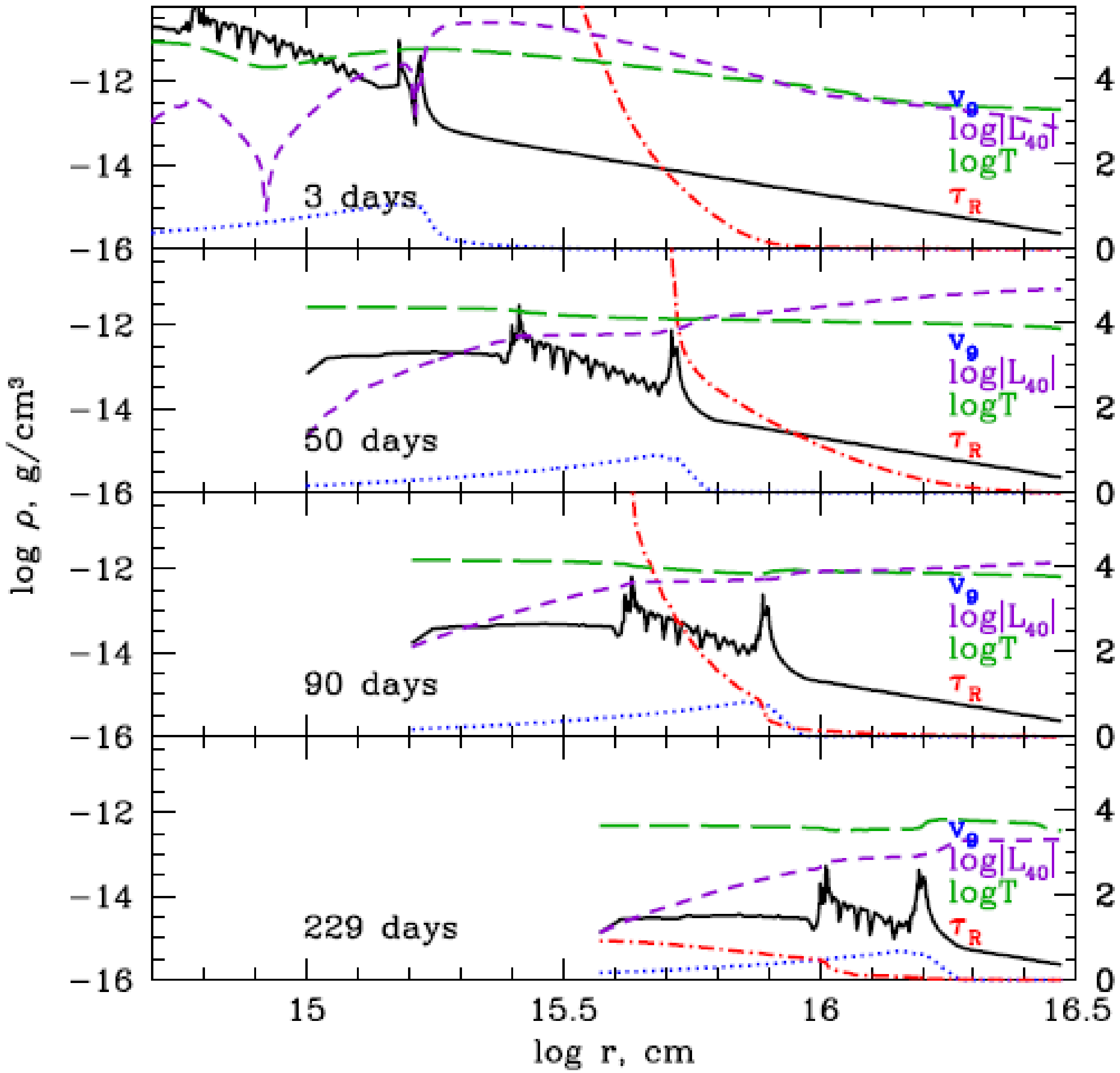
M(^{56}Ni) = 6 $M_\odot$

E = 2 x 10^{52} erg

(Tolstov, KN+16)



PPI SN ➔ Circumstellar Interaction



(Tolstov, KN+16)

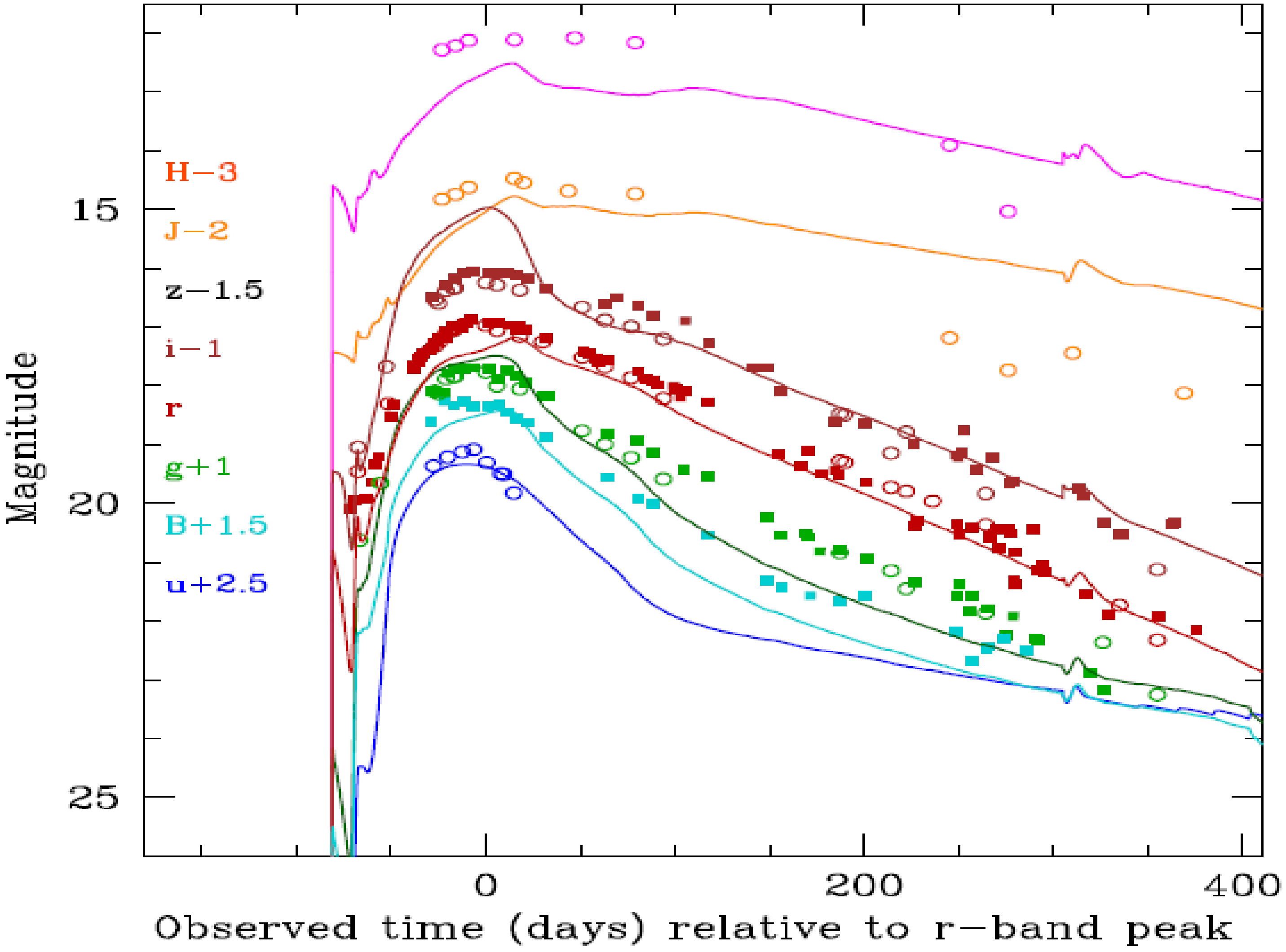
Pulsational Pair-Instability Model for PTF 12dam (Interaction + Radioactive Decays)

$M(ZAMS) = 100\ M_\odot$
$M(ejecta) = 40\ M_\odot$
$M(CSM) = 37\ M_\odot$
$R(CSM) = 5 \times 10^5 R_\odot$

$M(^{56}Ni) = 6\ M_\odot$

$E = 2 \times 10^{52}$ erg

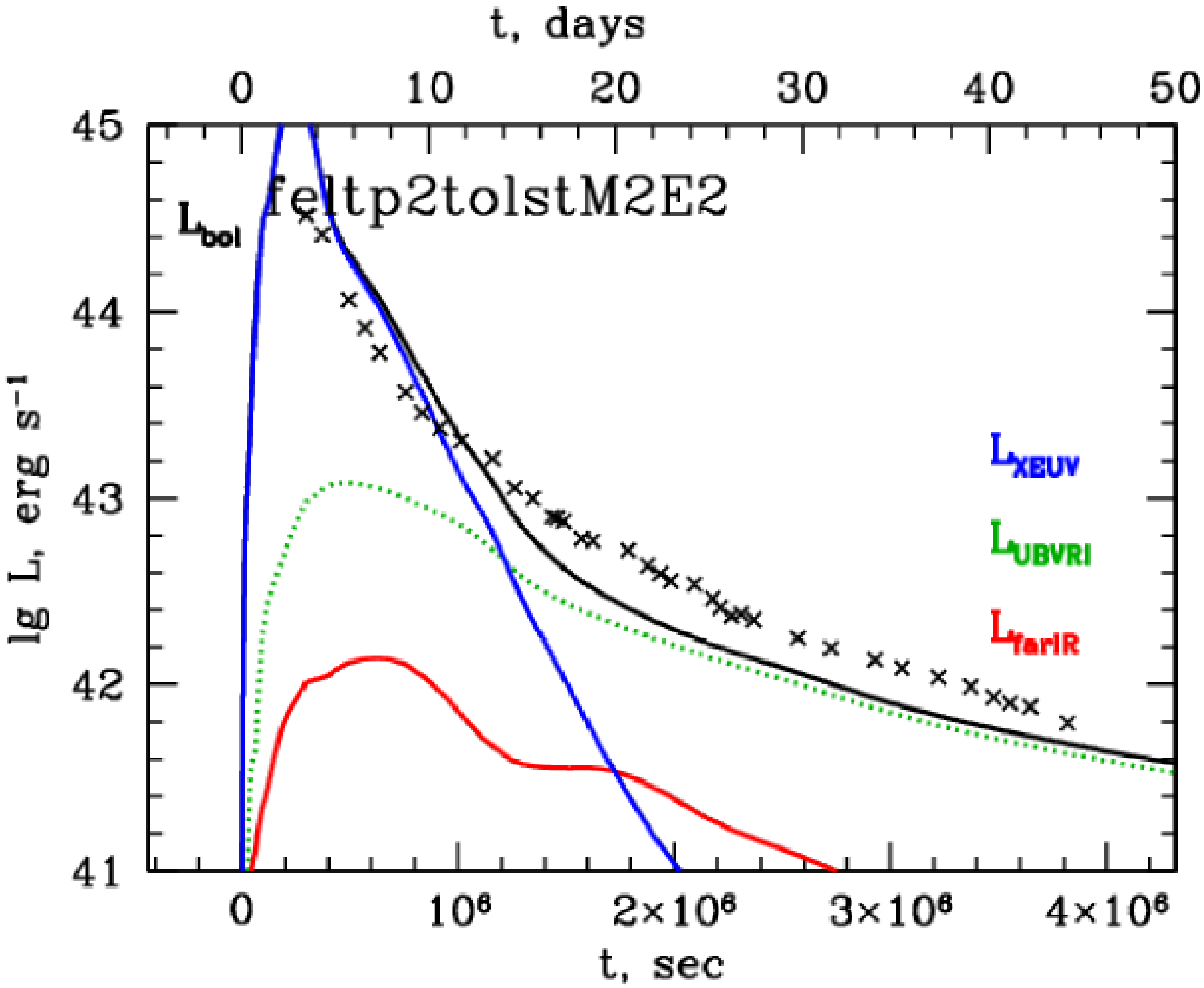
(STELLA: Tolstov, KN+16)



Type I Superluminous Supernovae

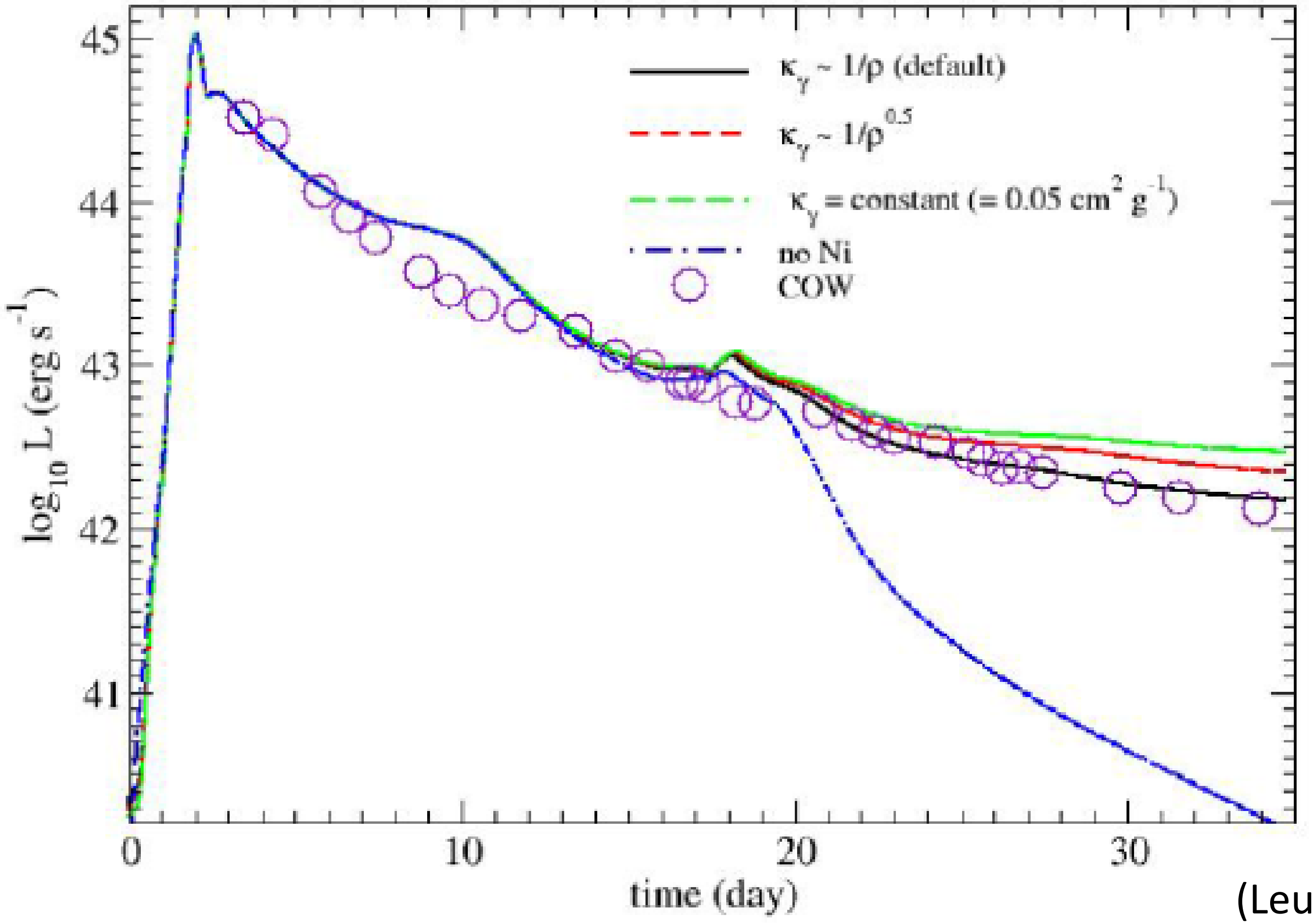
- Double Power Source Models ➔ good for UVLCs with Multiple Peaks
  Circumstellar Interaction + Pulsar or Radioactive decay
- The origin of massive He, O-rich CSM can be **Pulsational Pair-Instability.**
- If Pulational Pair-Instability ➔ COHe CSM,
  progenitors : 80 $M_\odot$ < M < 140 $M_\odot$
  ➔ CSM + BH accretion
  ➔ CSM + Radioactive decay (core collapse)
  ➔ CSM (multiple ejection)
  or: M(magnetar) > 80 $M_\odot$?? (CSM + Magnetar)
- Metallicity constraint ($Z < 0.5\ Z_\odot$)
- Ejected mass and the remaining core mass are
  consistent with the observed BH mass (~50 $M_\odot$)

Multiband LC simulations for AT 2019cow



(Tolstov +19)

Pulsational Pair Instability Model for AT2018cow



(Leung+19)

M(He core) = 43 $M_\odot$

M(CSM) = 0.5 $M_\odot$

E = 5 x 10^{51} erg

t < 20 d : CS interaction

t > 20 d : BH accretion ?

Magnetar ?

Radioactivity ?

Fast-Evolving Luminous Transients (e.g., KSN 15K)

- Double power source models for light curves:

  Circumstellar Interaction

  + Pulsar or Radioactive decay
- Progenitors with dense CSM can be Super-AGB stars or PPI (or Wolf Rayet) stars ??
- Mass loss just before SNe in other mass range ??
- Nucleosynthesis ?
- AT2018cow (CS interaction:

  PPISN or ECSN in Super-AGB or Binary Merger ??)