Emission from thermonuclear explosions in white dwarf TDEs

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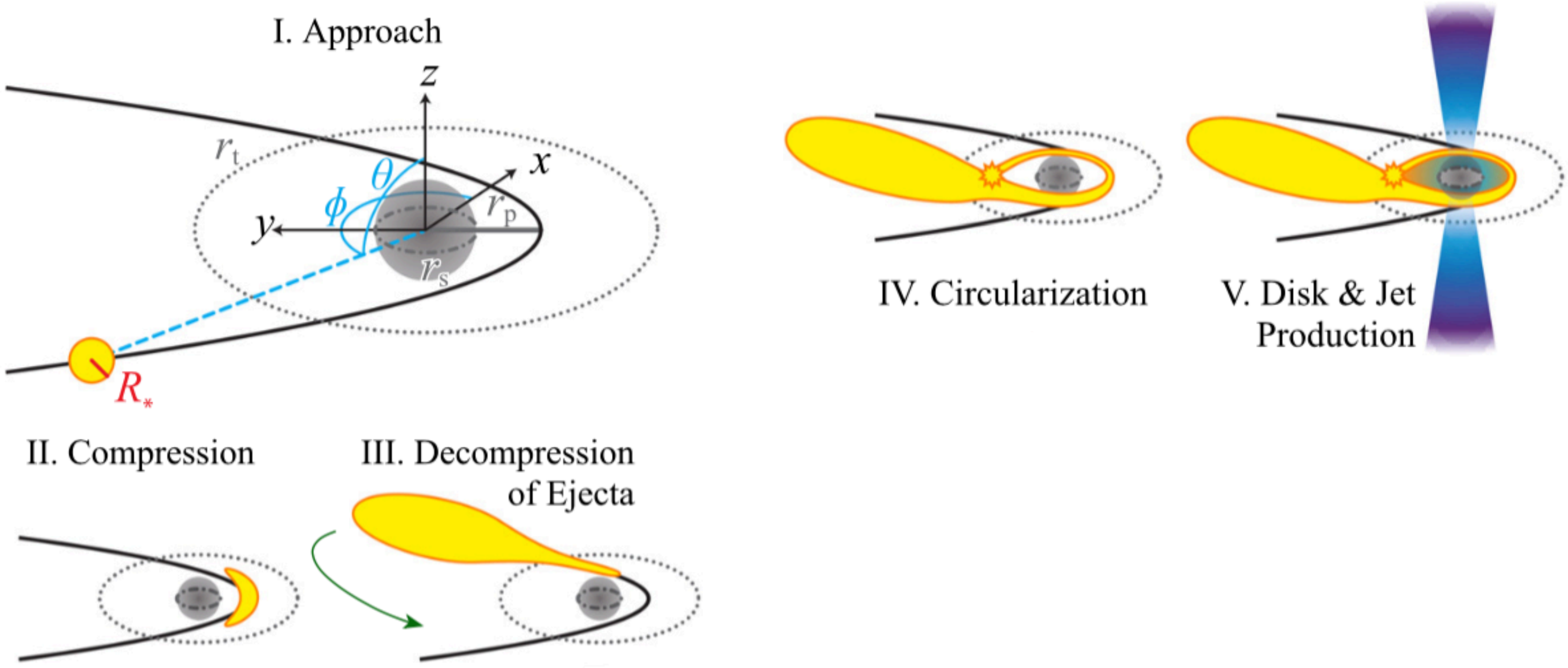
Kawana K., Tanikawa A., Yoshida N. (2018)
Kawana et al. (in prep)

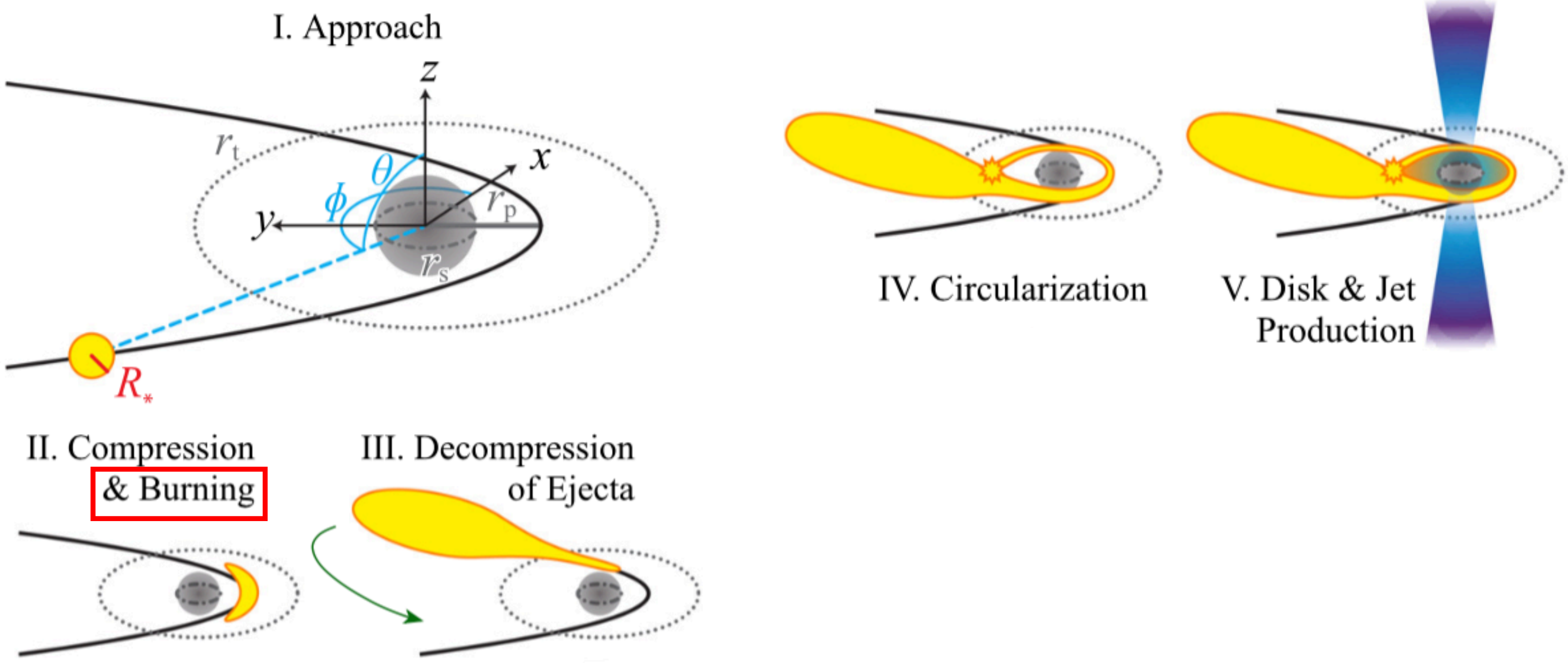
TDE of Main Sequence

Adapted from MacLeod+ (2016)



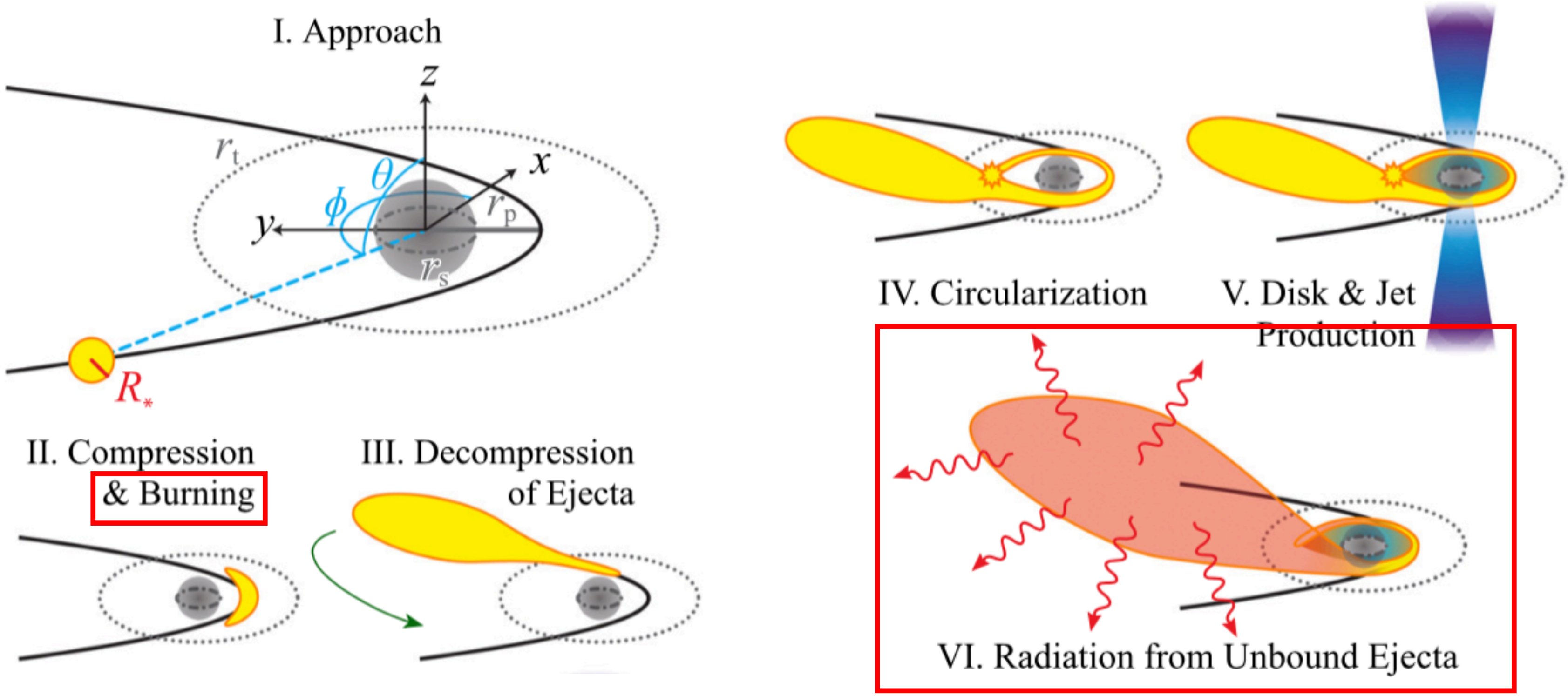
TDE of White Dwarf

Adapted from MacLeod+ (2016)



TDE of White Dwarf

Adapted from MacLeod+ (2016)

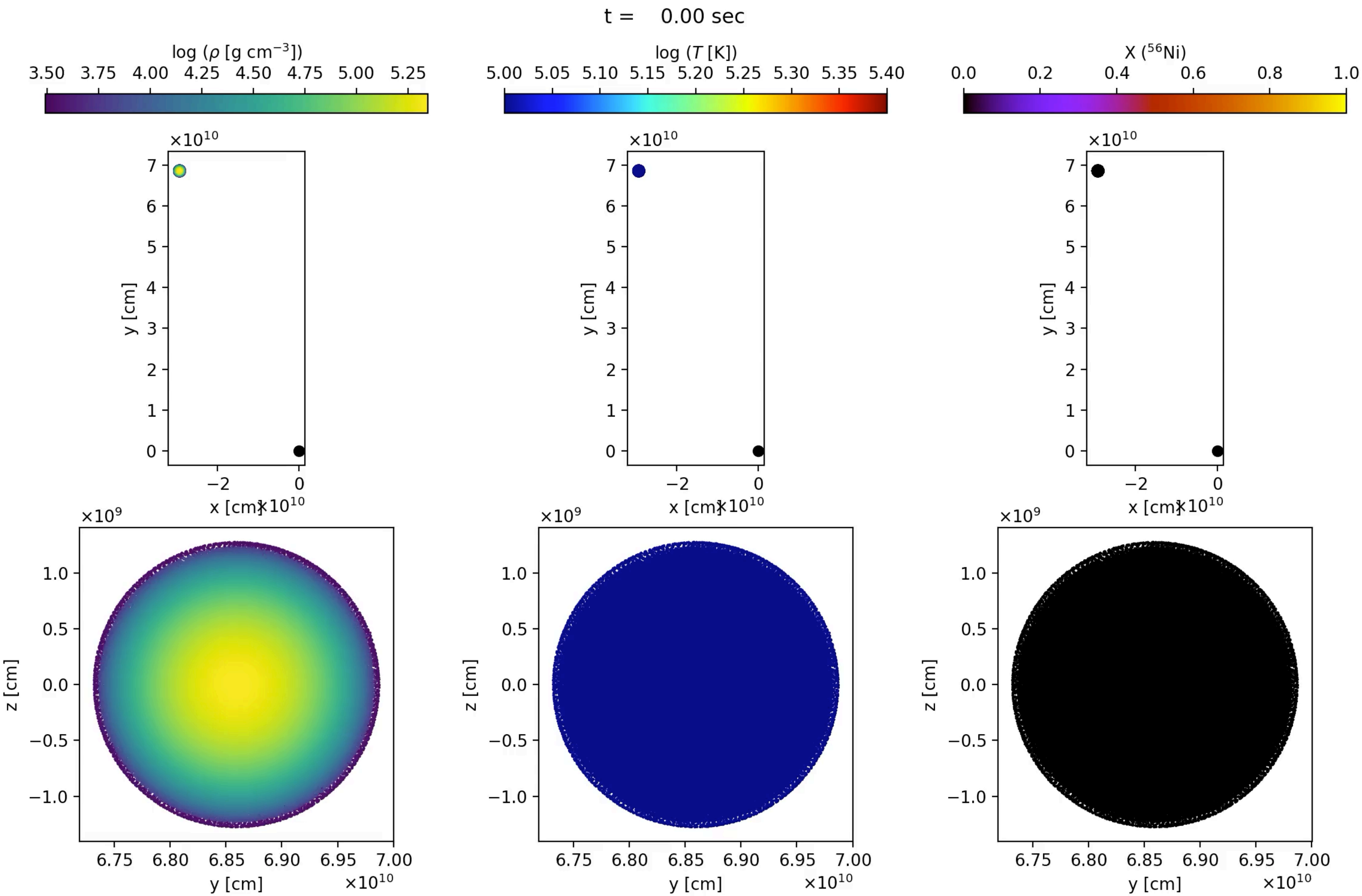


$$^{56}\mathrm{Ni} \rightarrow {}^{56}\mathrm{Co} \rightarrow {}^{56}\mathrm{Fe}$$

γ γ

WD TDE hydrodynamical simulations

$$M_{\rm BH} = 10^{2.5} M_\odot, M_{\rm WD} = 0.2 M_\odot, \beta = R_t/R_p = 5.0$$



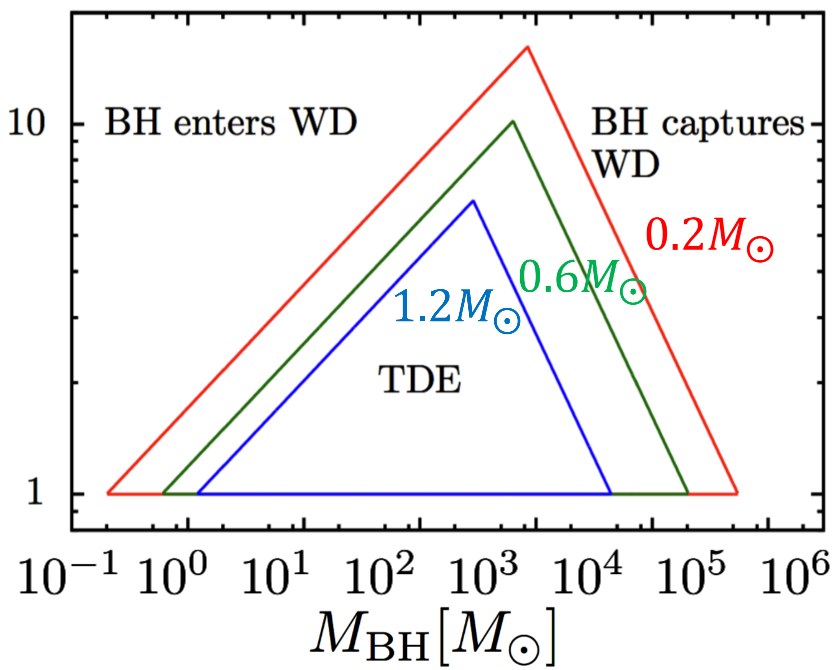
Motivations to study WD TDEs

- Tidal compression at pericenter

→ Shock heating & detonation

→ SN Ia-like transients?

$$\beta = R_t / R_p$$



- Range of $M_{\rm BH}$ is restricted.

$$R_t > R_p > R_S, R_{\rm WD}$$

=> Max. mass of BH (Hills mass):

$$M_H \simeq 2 \times 10^5\, M_\odot \left(\frac{M_{\rm WD}}{0.6 M_\odot}\right)^{-1/2} \left(\frac{R_{\rm WD}}{10^9\ {\rm cm}}\right)^{3/2}$$

SMBHs cannot tidally disrupt WDs

→ Good probe to study IMBHs

Observations of WD TDEs

- **So far**, some possible (but unconfirmed) candidates

ultra long GRB	Swift J1644+57 / GRB 110328A (Krolik & Piran 2011) GRB060218 + SN2006aj (Shcherbakov+ 2013) GRB111209A + SN2011kl (Ioka+ 2016)
X-ray transient	XRT 000519 (Jonker+ 2013) CDF-S XT1 (Bauer+ 2017)
Fast Optical Blue Transient	AT2018cow (Kuin+ 2018)

Optical counterparts from nuclear burning have not been found yet.

LSST may find ~10 events / yr (highly dependent on IMBH density)

MacLeod+ (2016)

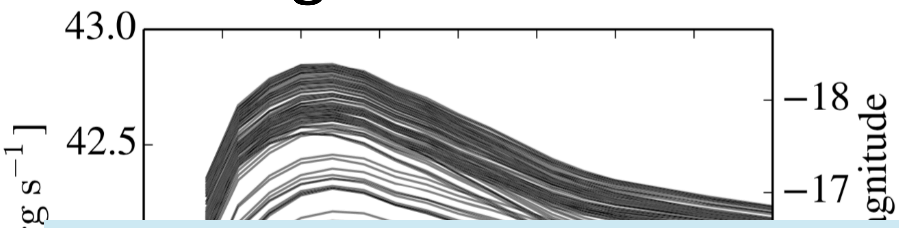
Observational signatures

MacLeod+ 2016

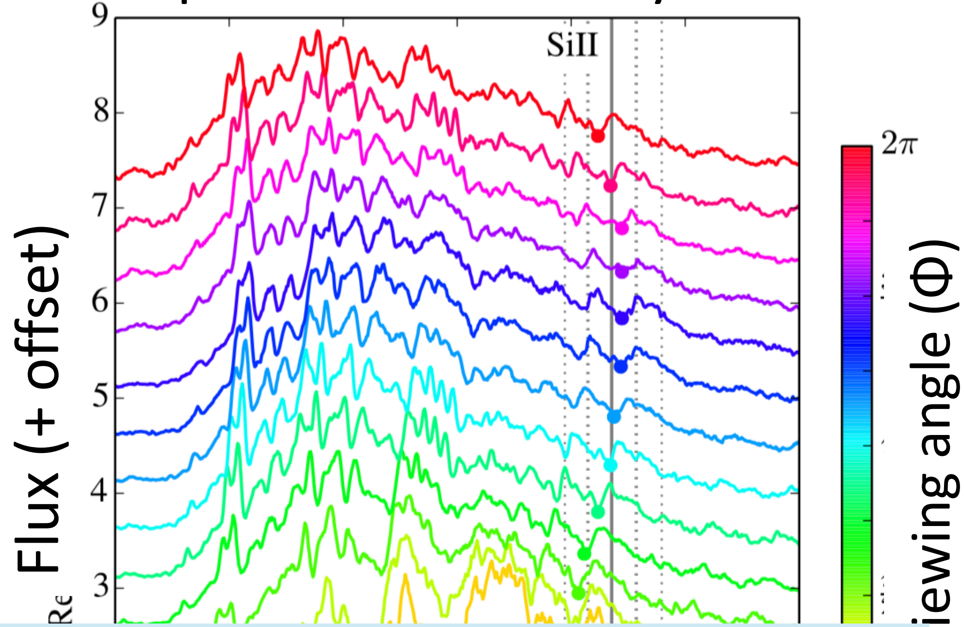
CO WD, $M_{\rm WD} = 0.6 M_{\odot}$, $M_{\rm BH} = 500 M_{\odot}$, $\beta = R_t / R_p = 5.0$ Rosswog+ (2009)

- Similar to SNe Ia
- Strong viewing angle dependence
- Key feature:
  Doppler shift ~ 10^4 km s^{-1}

Lightcurve



Spectra at t = 20 days



Questions

- How about variety of observational signatures?

→ Observational signatures for other parameter cases?

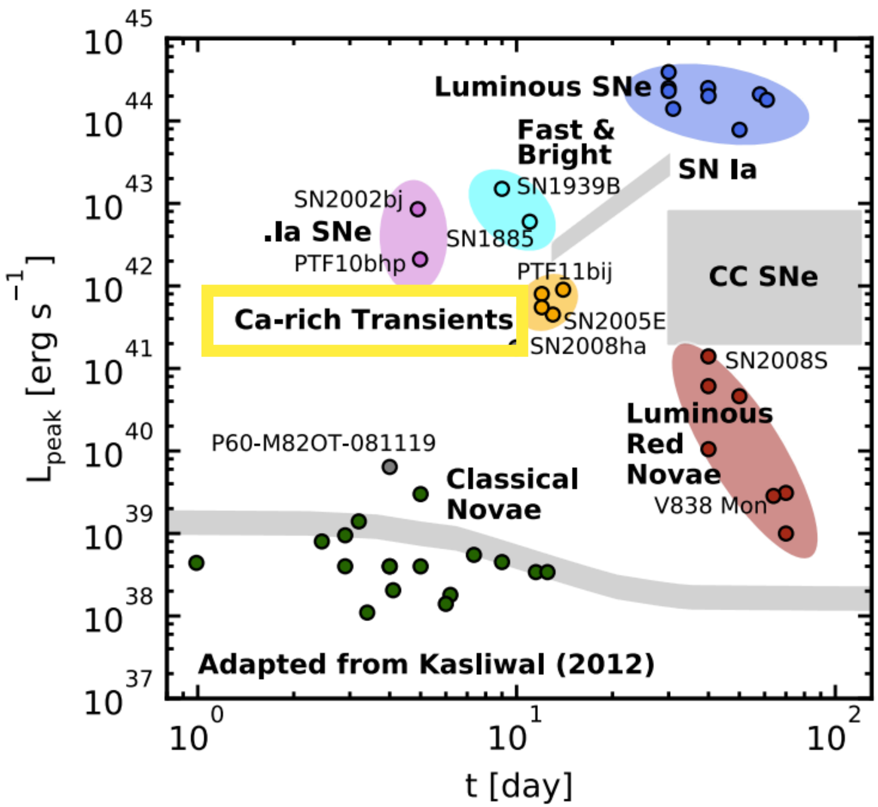
Helium WD TDE => Calcium-rich transients?

Our study: thermonuclear emission from Helium WD TDEs

Ca-rich transients

- Similar to SNe Ia
- Fainter, faster than SNe Ia
- Large calcium abundance
- Small nickel abundance
- In the outskirts of galaxies
- Event rate: 33–94% of the local volumetric SN Ia rate

Perets+ (2010), Kasliwal+ (2012), Valenti+ (2014), Frohmaier+ (2018)

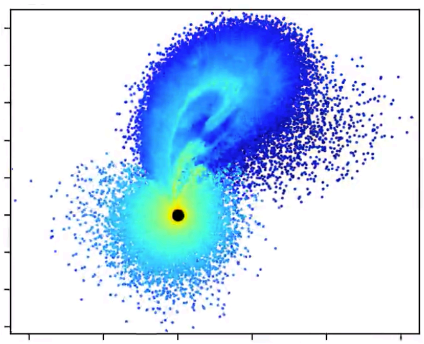


Garcia-Berro (2017)

Methods

Tanikawa+ (2017)
Kawana+ (2018)

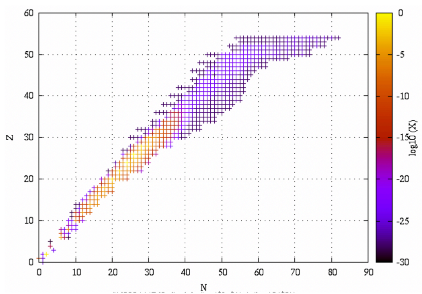
1. SPH simulation coupled with simplified nuclear reactions



- M_{WD} = 0.2 Msun, ^{4}He composition, HELMHOLTZ EoS
- $M_{BH} = 10^{2.5}$ Msun, $\beta := R_t / R_p = 5.0$
- $N_{particle} \simeq 800{,}000$
- α- chain network w/ 13 nuclear species Timmes+ (2000)
- Follow until homologous expansion is realized (2000 sec)

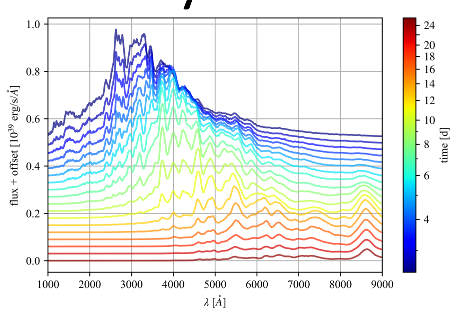
2. Detailed nucleosynthesis calculation with **`torch`**

Timmes (1999)
Timmes+ (2000)



- Follow nuclear reaction during tidal detonation phase
- 495 isotopes are considered

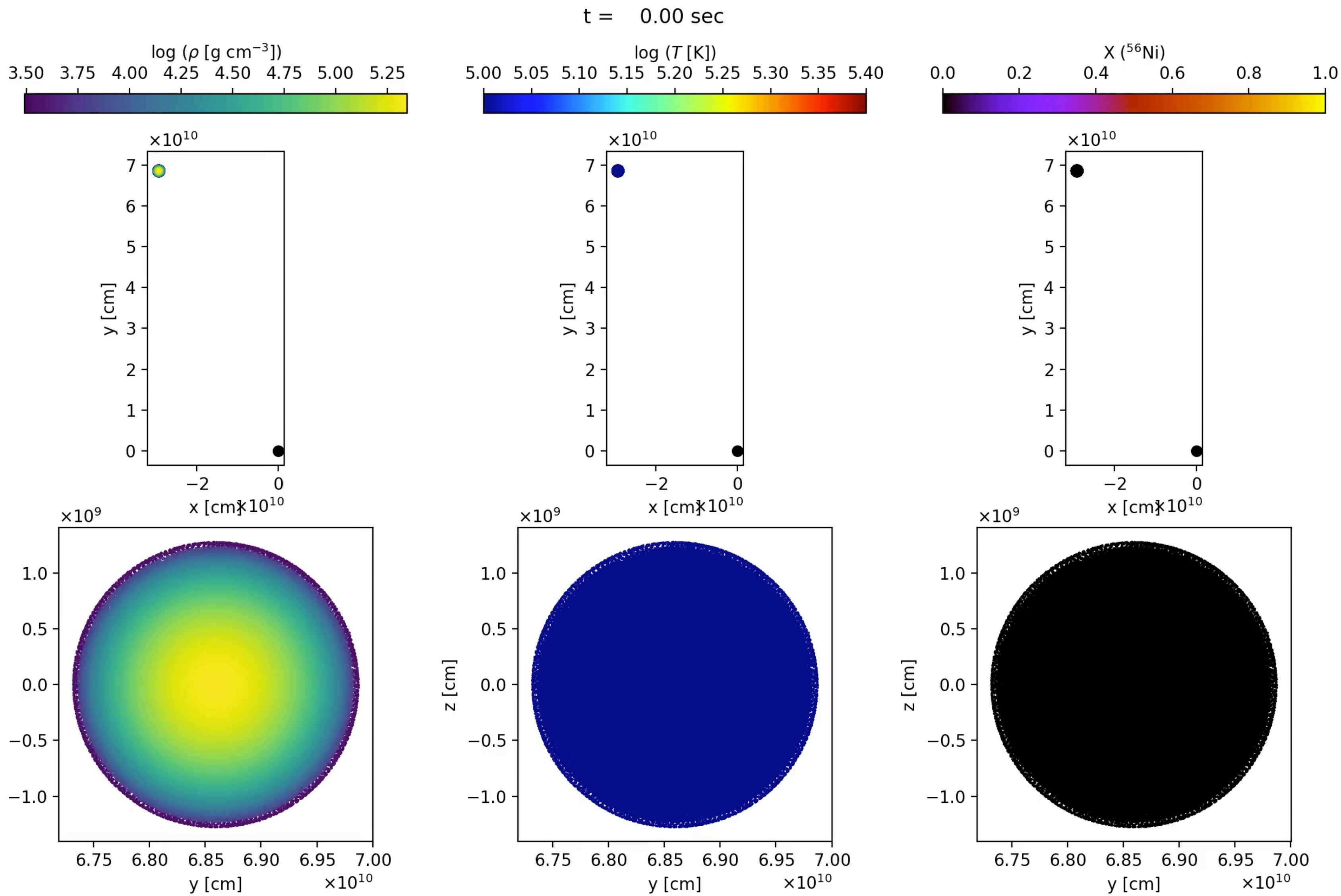
3. Synthetic observation with Monte Carlo radiative transfer



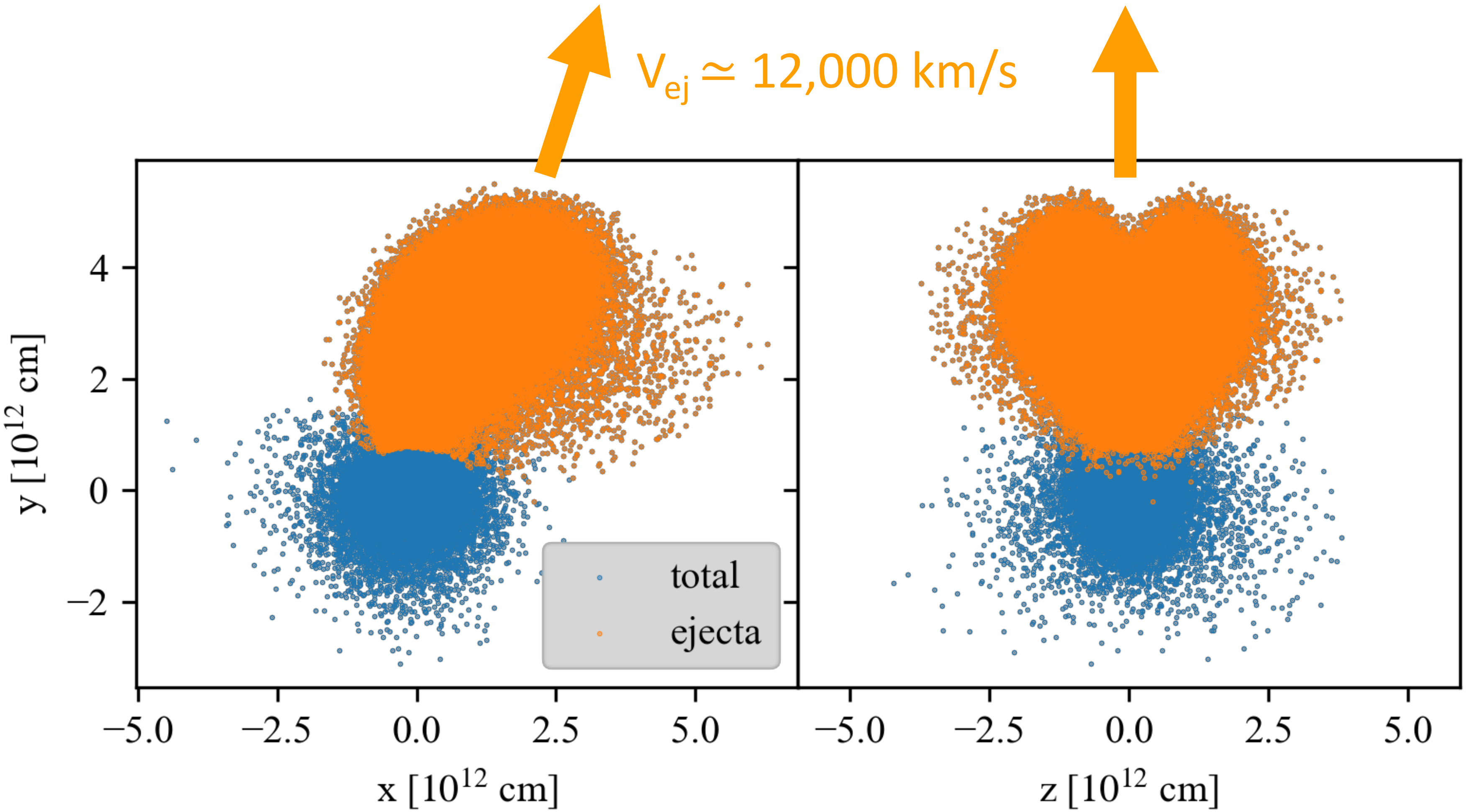
- use **`HEIMDALL`** Maeda (2006), Maeda+ (2014)
- In 3D, under approximation of homologous expansion

WD TDE hydrodynamical simulations

$$M_{\mathrm{BH}} = 10^{2.5} M_{\odot}, M_{\mathrm{WD}} = 0.2 M_{\odot}, \beta = R_t/R_p = 5.0$$

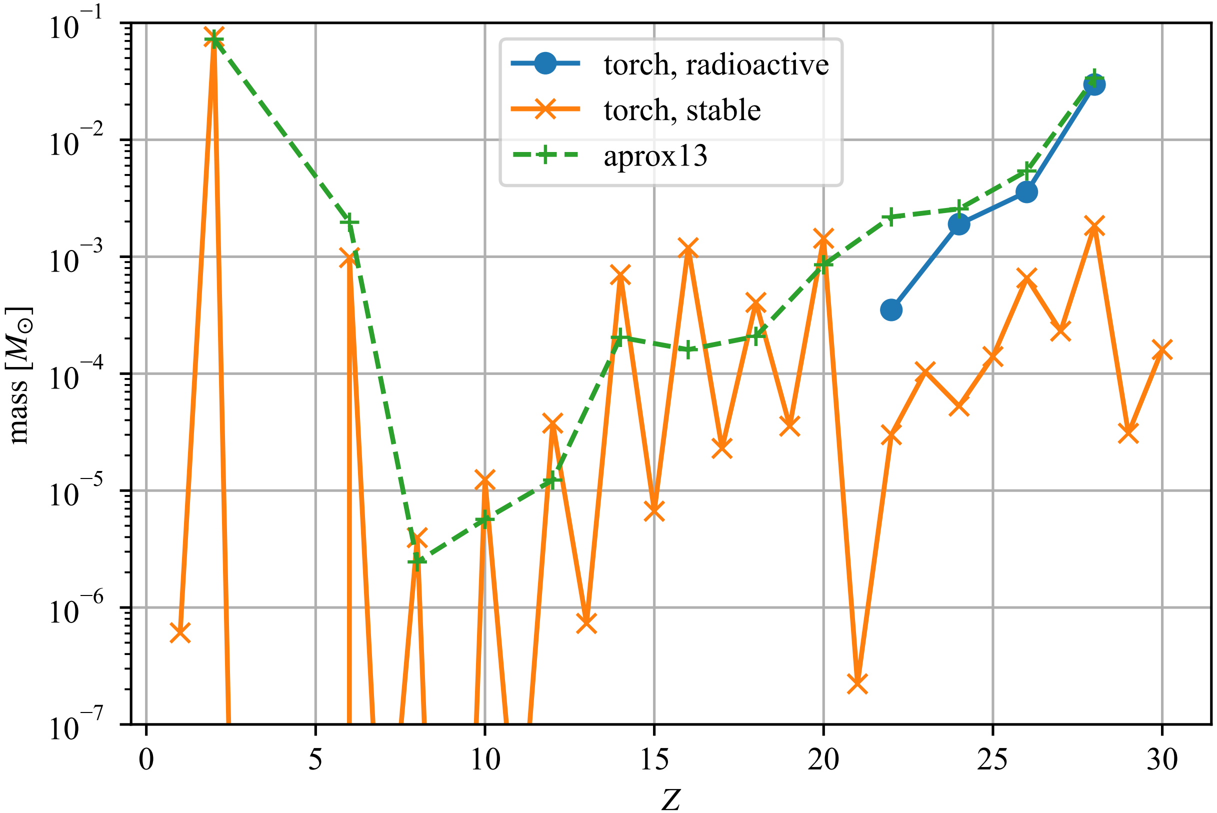


Distribution of unbound ejecta



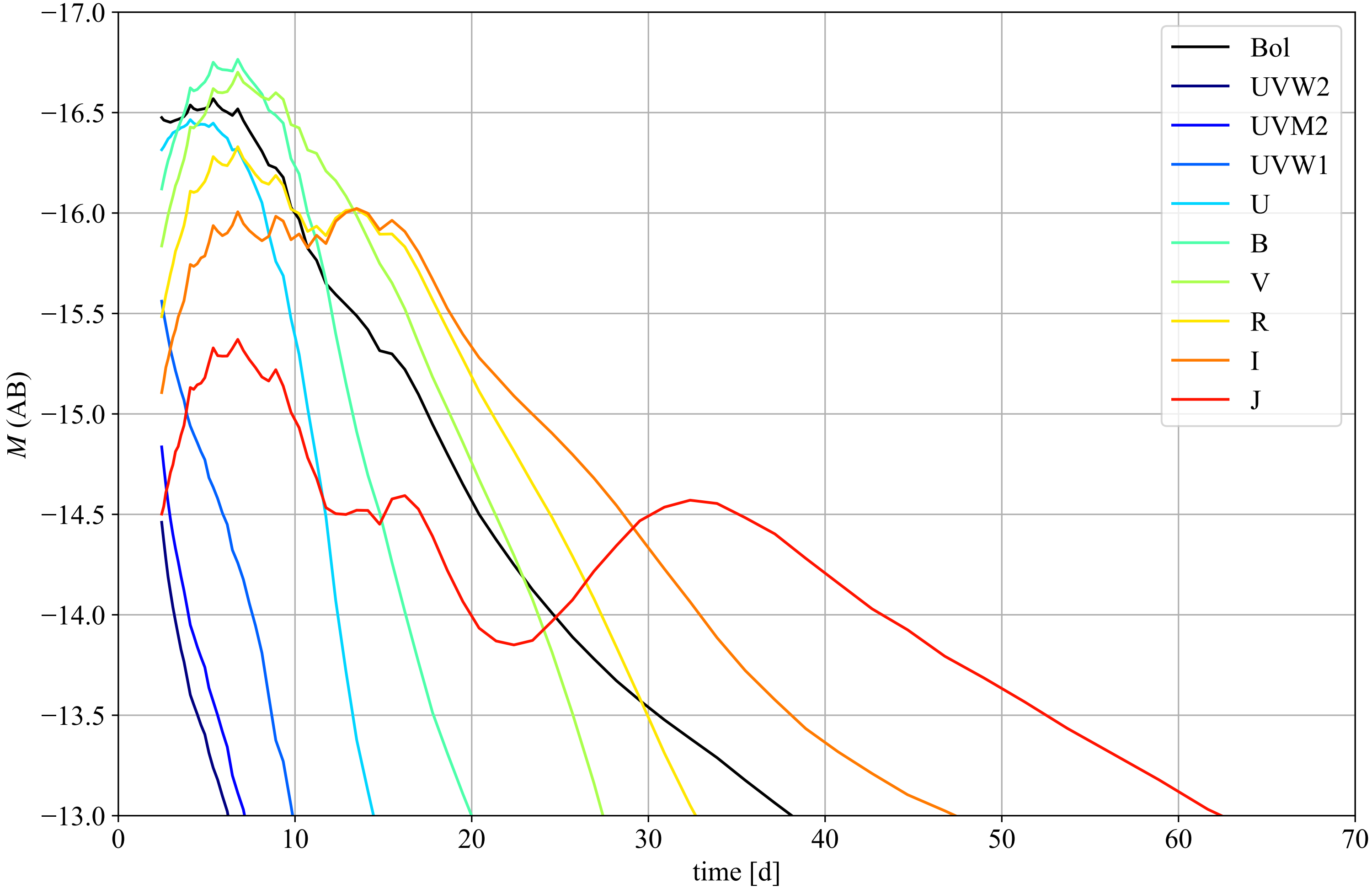
Dynamics & Nuclear Composition of Ejecta

- M_{ej} = 0.12 Msun
- bulk velocity: 12,000 km/s
- $E_{kin} = 6.5 \times 10^{49}$ erg (wrt ejecta center)



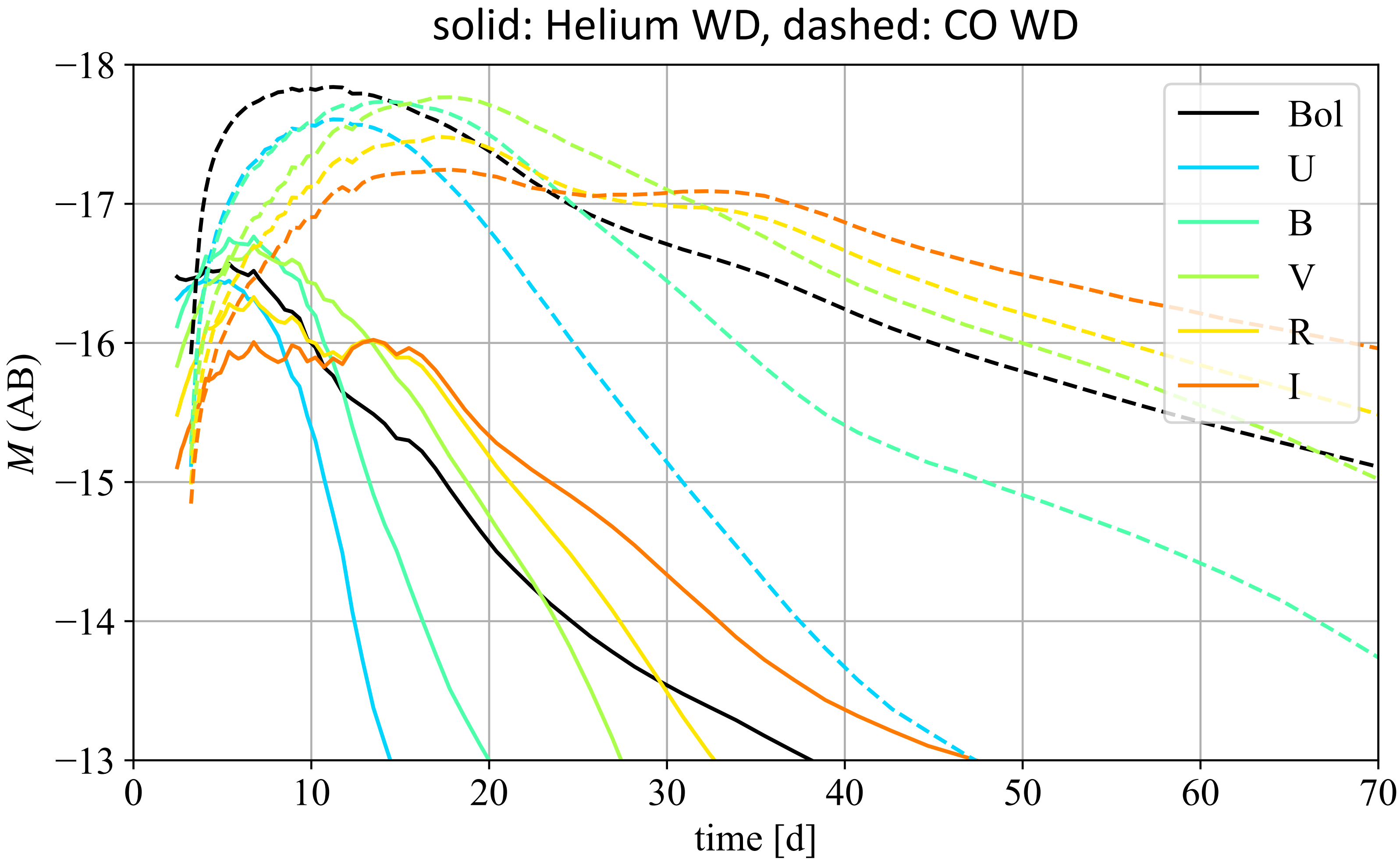
- M_{Ni} = 0.03 Msun, $M_{Ca} = 1.4 \times 10^{-3}$ Msun
- Intermediate Mass Elements are dominated by ^{40}Ca, ^{28}Si subdominant

Lightcurve: mean over all the angle



- $\Delta t_{1mag} \simeq 10$ d, $M_{peak} \simeq -16.5$ mag ($L_{peak} \simeq 1.2 \times 10^{42}$ erg/s)
- Rapid color evolution from blue to red

Lightcurve compared with CO WD TDE

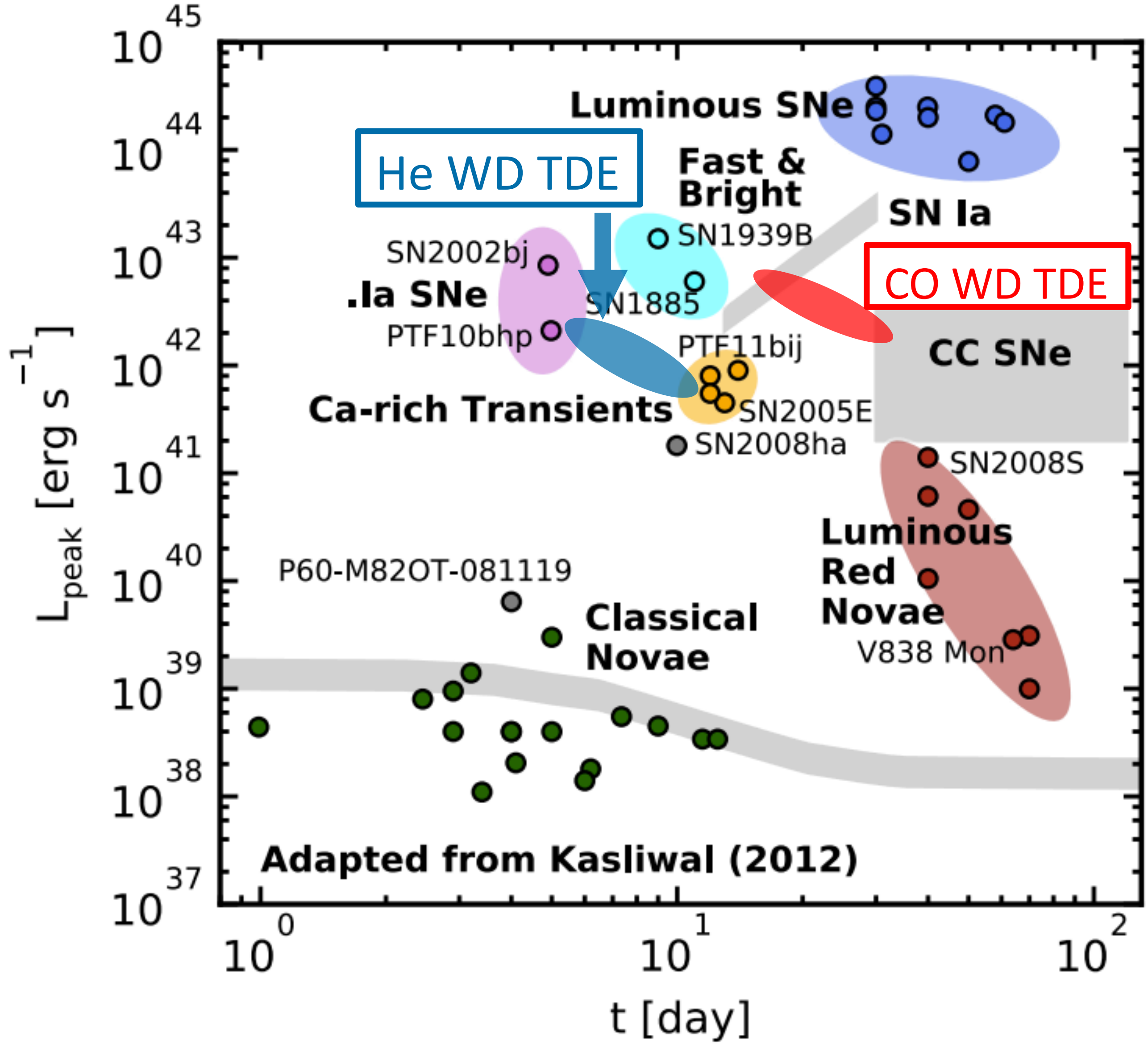


Helium WD TDE shows faster & fainter lightcurve than CO WD TDE

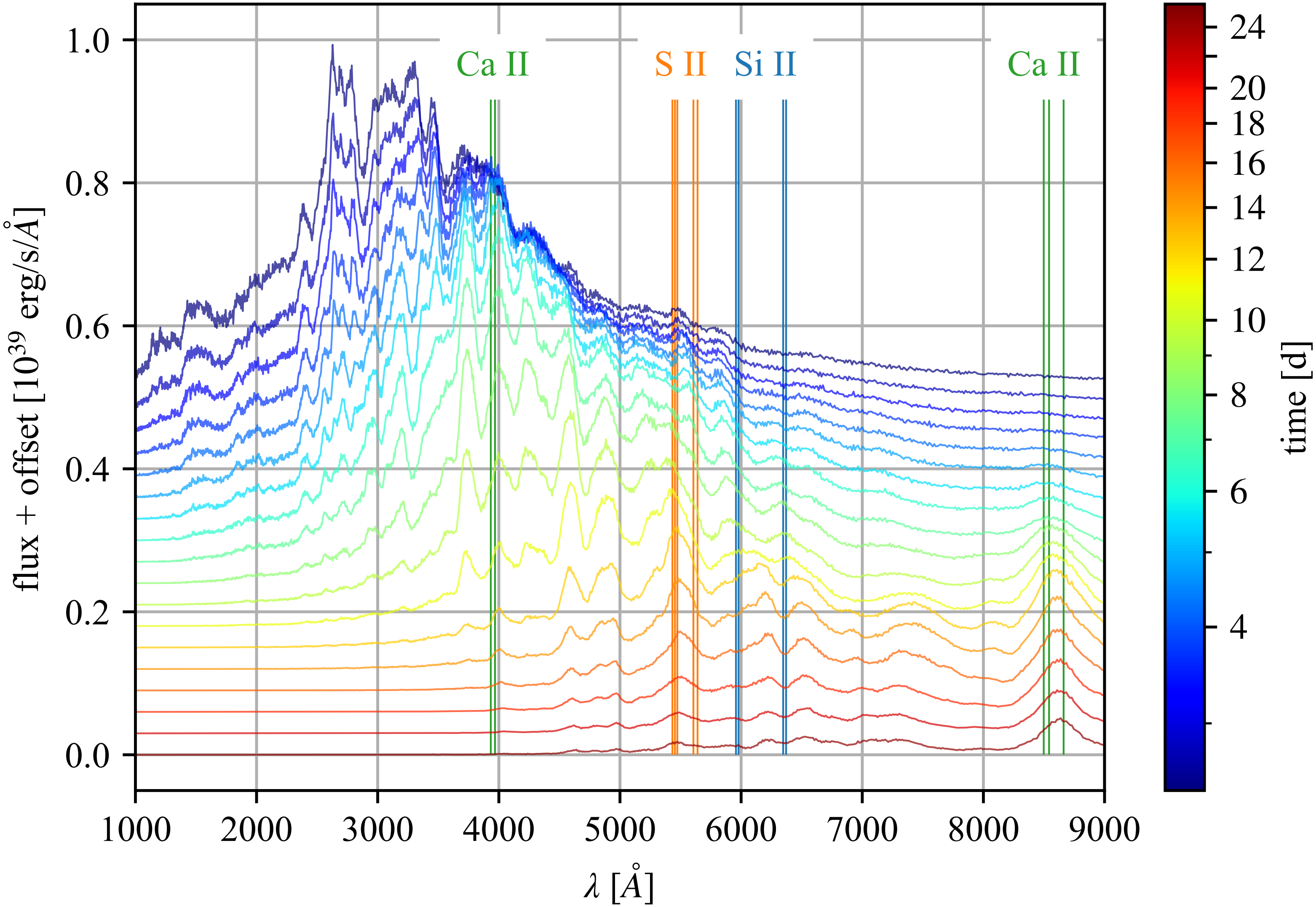
<= smaller amount of ejecta and ^{56}Ni

Timescale - Luminosity diagram

adapted from Kasliwal (2012), Garcia-Berro (2017)



Spectra: in comoving frame, mean over all the angle

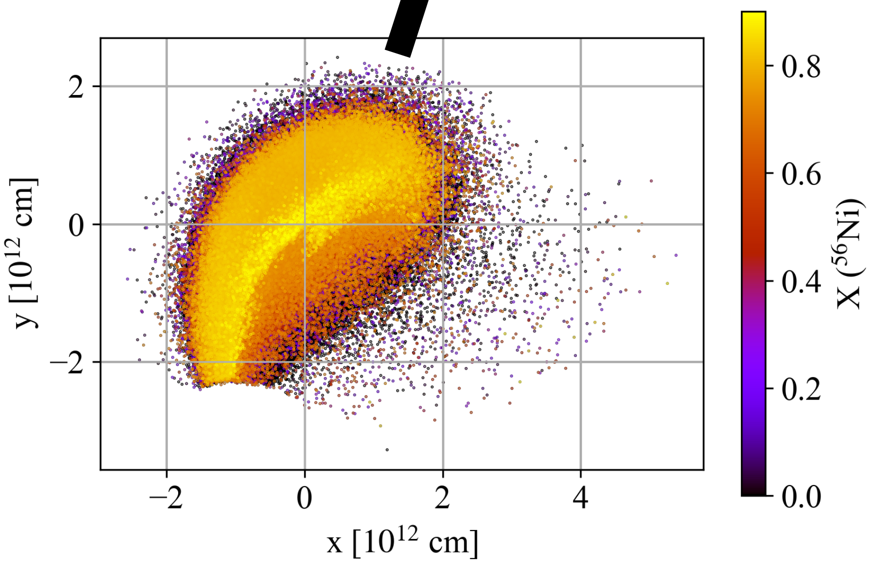


- Weak (No) silicon lines
- Fe lines + Strong Ca lines

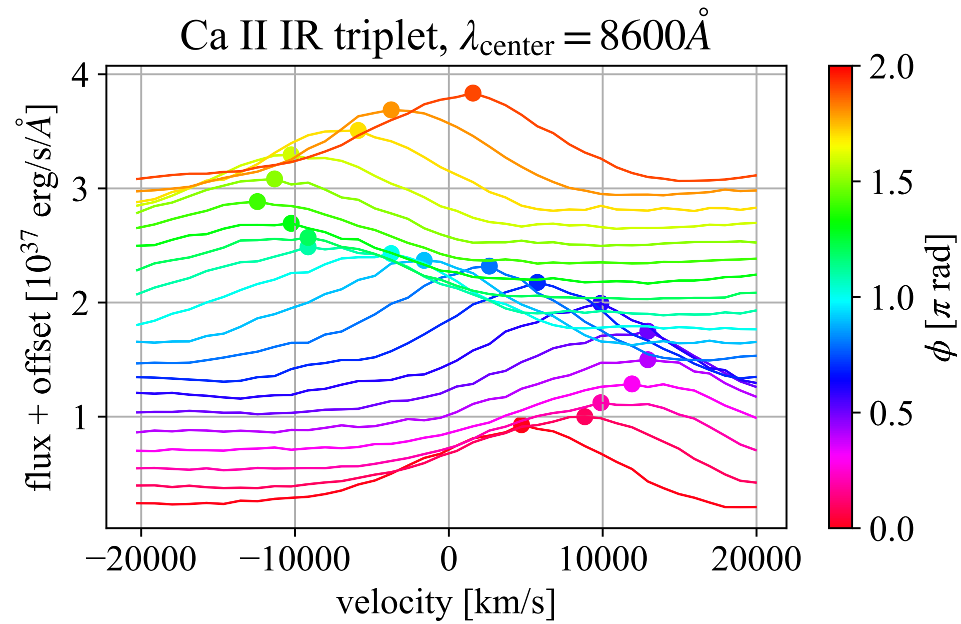
⇐ peculiar composition arising from He burning

Viewing angle effect

$V_{ej} \simeq 12{,}000$ km/s



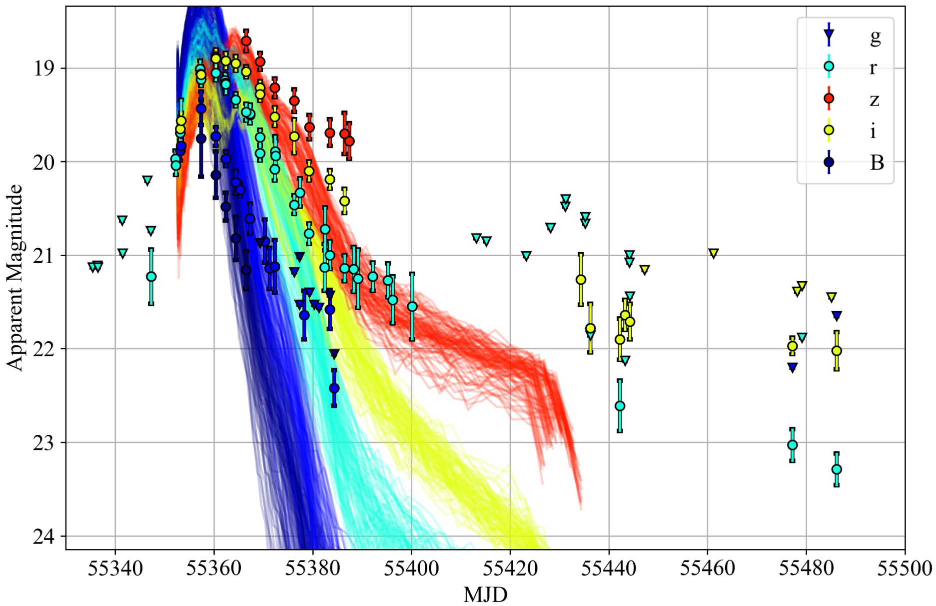
t = 15 d, orbital plane



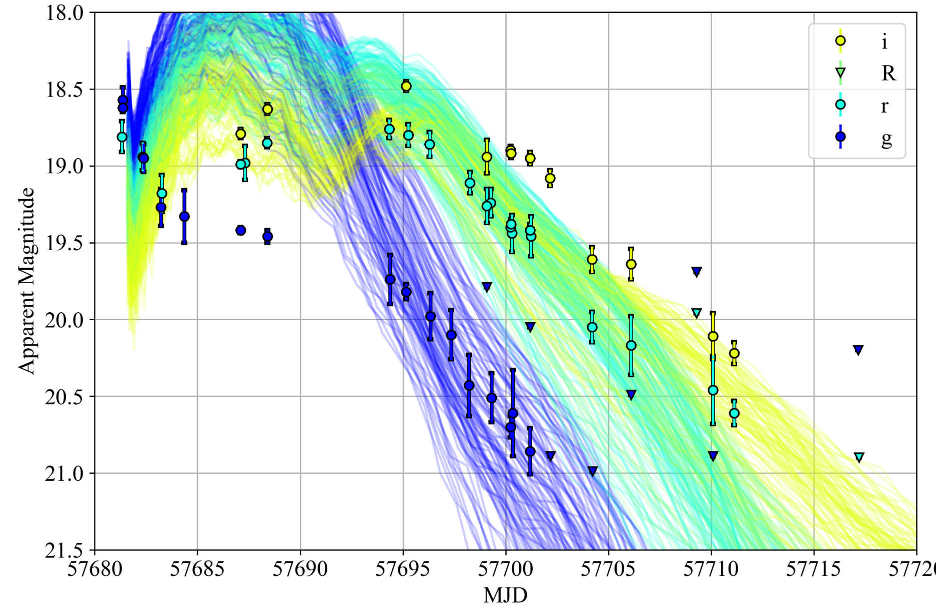
Doppler shift w/ v $\lesssim$ 12,000 km/s, which reflects bulk motion of ejecta

Comparison with Ca-rich transients: lightcurve

SN2010et/PTF10iuv Kasliwal+ (2012)



SN2016hgs De+ (2016)



Compared with Ca-rich transients, helium WD TDEs are

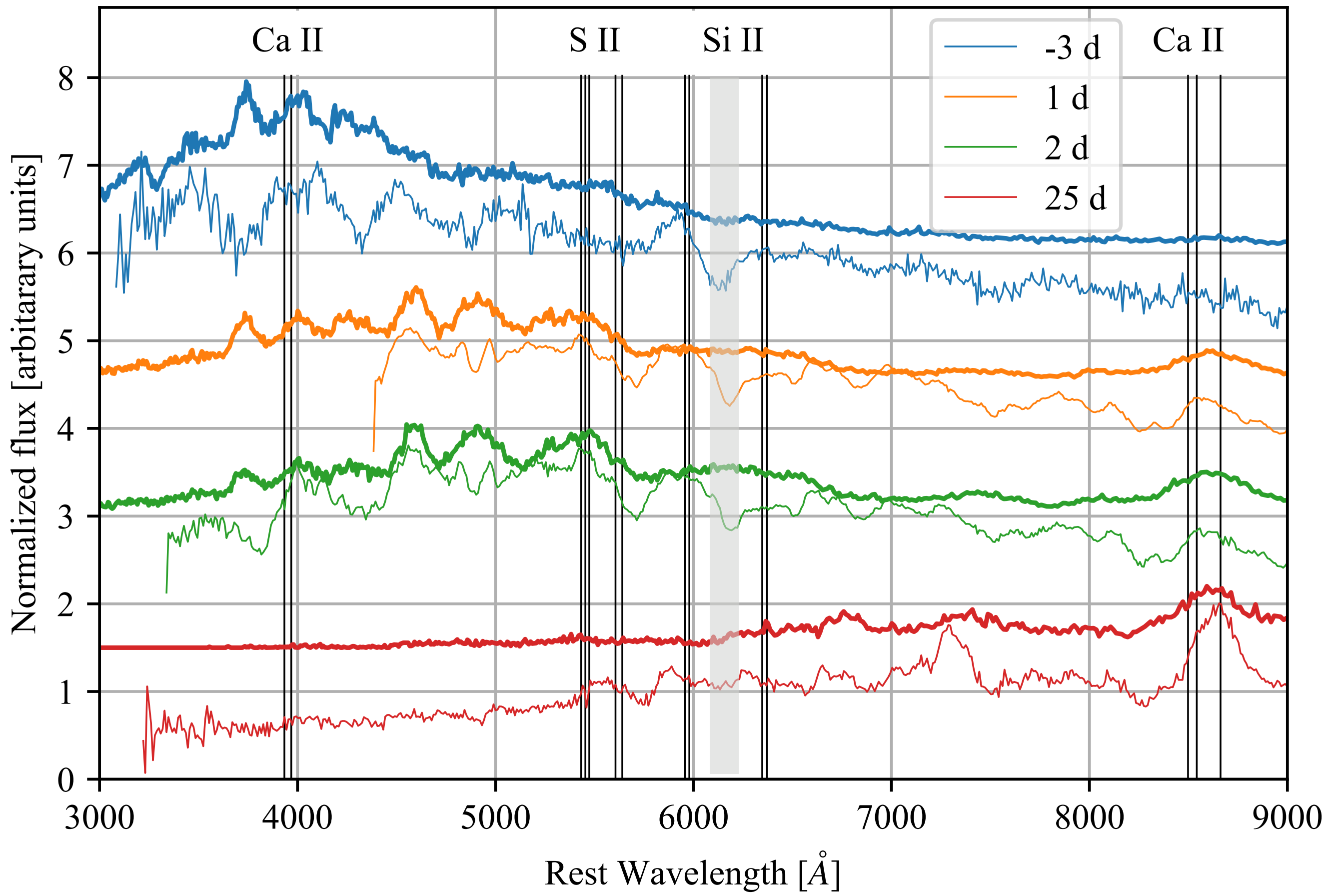
- Brighter by ~1-2 mag at the peak
- bluer at early phase

Due to more ^{56}Ni mass (0.03 Msun) than Ca-rich ($\lesssim$ 0.015 Msun)

Perets+ (2010), Kasliwal+ (2012), Valenti+ (2014)

Comparison with Ca-rich transients: spectra

Thick: our model (θ=0.5 π, φ =0.9 π) , thin: SN2010et/PTF10iuv



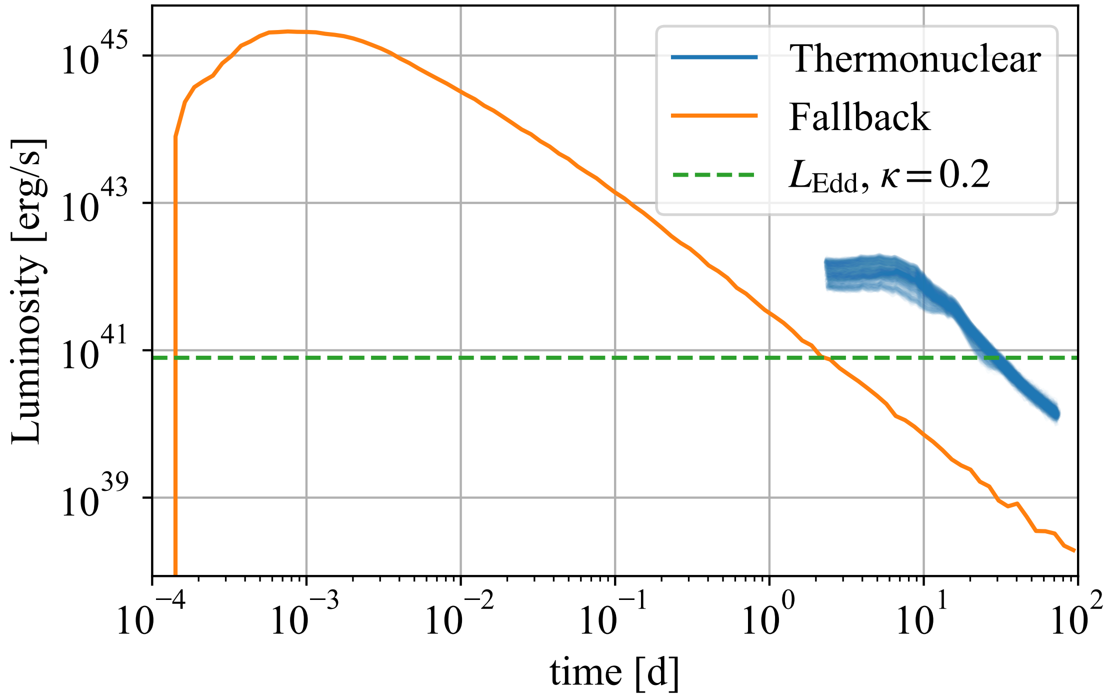
Kasliwal+ (2012)

Spectra of He WD TDE compared with those of Ca-rich:

- commonly show strong Ca lines
- lack of silicon lines in He WD TDE

Fallback accretion => what kind of emission?

- Ultra long GRB (t ~ 10^4 sec) if on-axis — Shcherbakov+ (2013), MacLeod+ (2014)
- X-ray transients (t ~ 10^4 sec) — Jonker+ (2013), Bauer+ (2017)
- Eddington limited X-ray emission from accretion disk — MacLeod+ (2016)
- Fast & bright optical transients like AT2018cow — Kuin+ (2018)

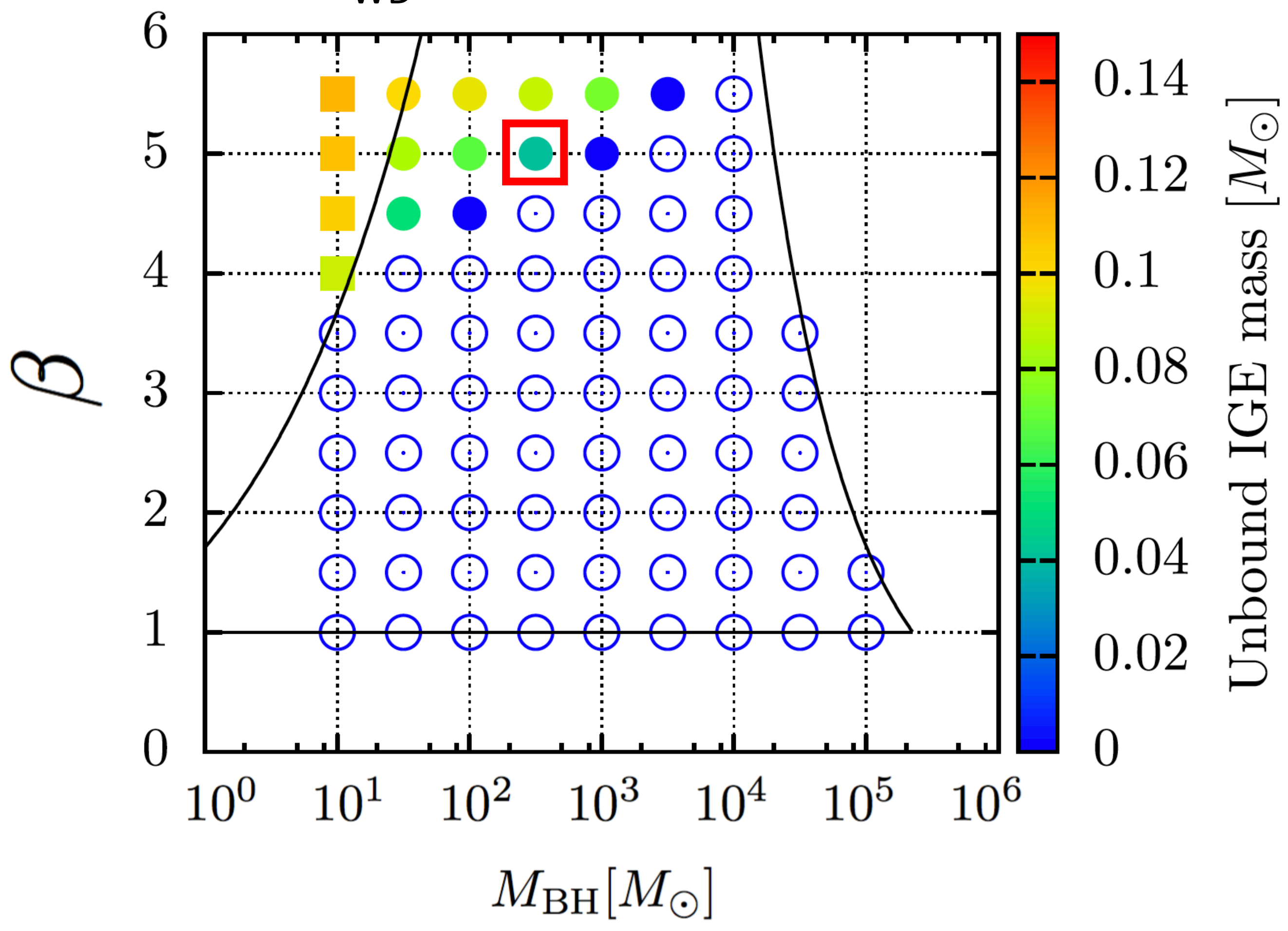


If Eddington limited or if luminosity follows the fallback rate, thermonuclear emission dominates t $\gtrsim$ day

Future work: Variety of emission from WD TDEs

3 parameters: M_{WD}, M_{BH}, β (impact parameter)

M_{WD} = 0.2 Msun, He WD



Summary

WD TDEs uniqueness: IMBH search & thermonuclear explosion

We perform SPH simulations of Helium WD TDEs and Monte Carlo radiative transfer simulation for synthetic observation.

Helium WD TDE characteristics:

- rapid evolution ($\Delta t_{1mag} \simeq$ 5-10 d)
- rapid color evolution from blue to red
- $L_{peak} \simeq 1\text{-}2 \times 10^{42}$ erg/s, $M_{bol,\,peak} \simeq -16.5$ mag
- Weak (No) silicon lines, strong Ca lines
- Doppler shift w/ $v \lesssim 12{,}000$ km/s, depending on viewing angle

Helium WD TDE as an origin of Ca-rich transients?

- ✓ strong Ca lines, similar timescale ($t \simeq 10$ d)
- • Doppler shift w/ $v \lesssim 12{,}000$ km/s, but okay if we see the TDE ejecta from side
- ✗ weak silicon lines in Helium WD TDEs
- ✗ bluer and brighter than Ca-rich transients.

Emission from WD TDEs have a large variety, depending on parameters