A variety of emission from tidal disruption events of a white dwarf by a black hole

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collaborators:

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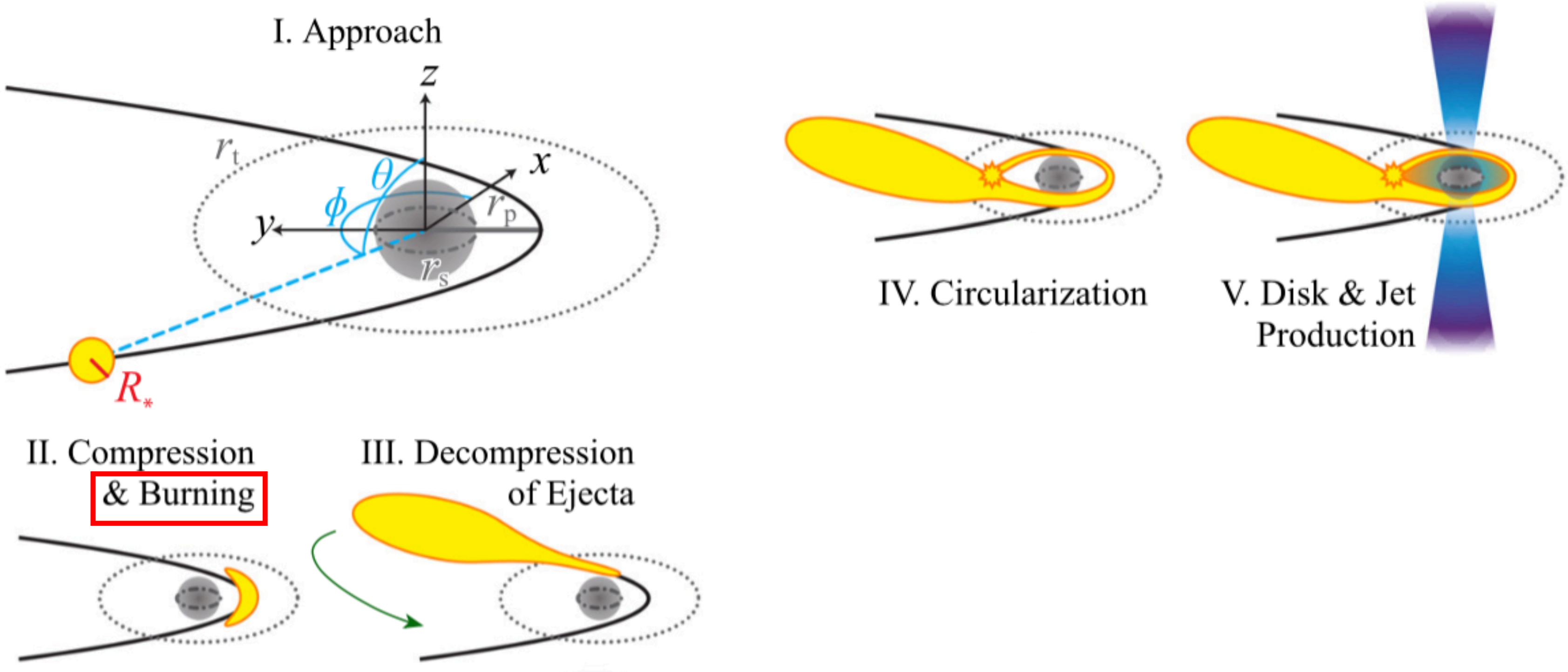
Kawana, Maeda, Yoshida & Tanikawa (2020)
Kawana, Maeda, Yoshida & Tanikawa, in prep

TDE of White Dwarf

Carter & Luminet (1982), Luminet & Pitchon (1989a,b), Rosswog+ (2009), ...

Adapted from MacLeod+ (2016)



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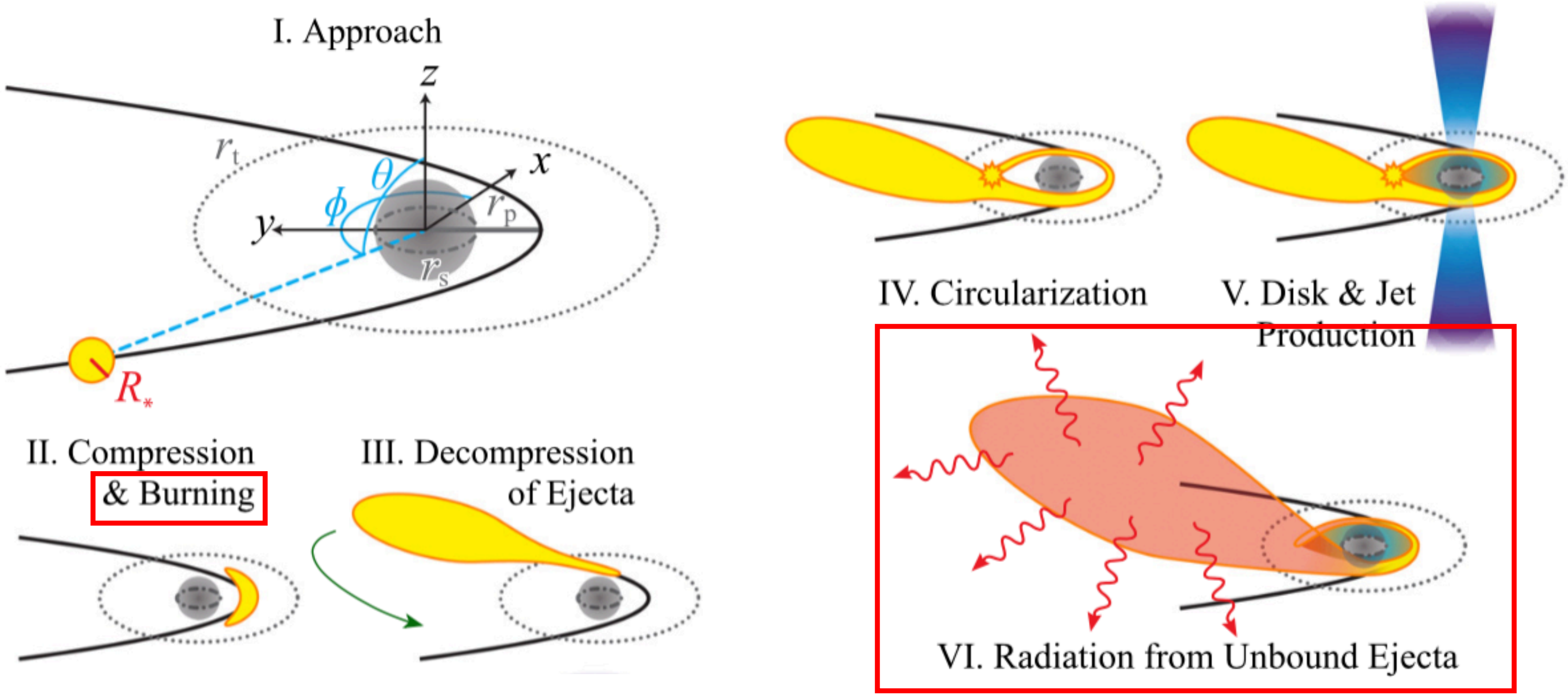


$$^{56}\mathrm{Ni} \rightarrow {}^{56}\mathrm{Co} \rightarrow {}^{56}\mathrm{Fe}$$

γ γ

Motivations to study WD TDEs

- Tidal compression at pericenter

→ Shock heating & detonation

→ SN Ia-like transients?

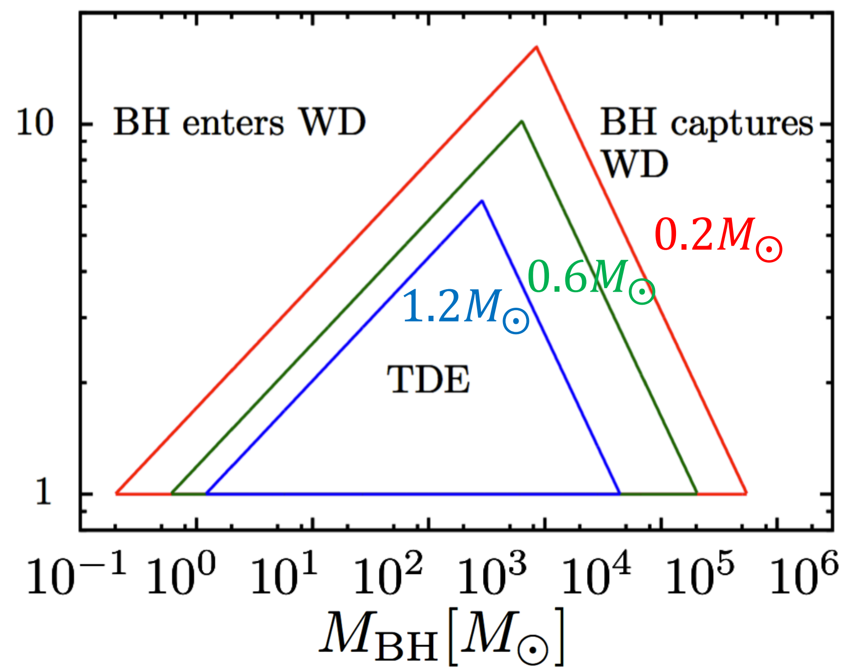
- Range of $M_{\rm BH}$ is restricted.

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

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

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

$$\beta = R_t / R_p$$

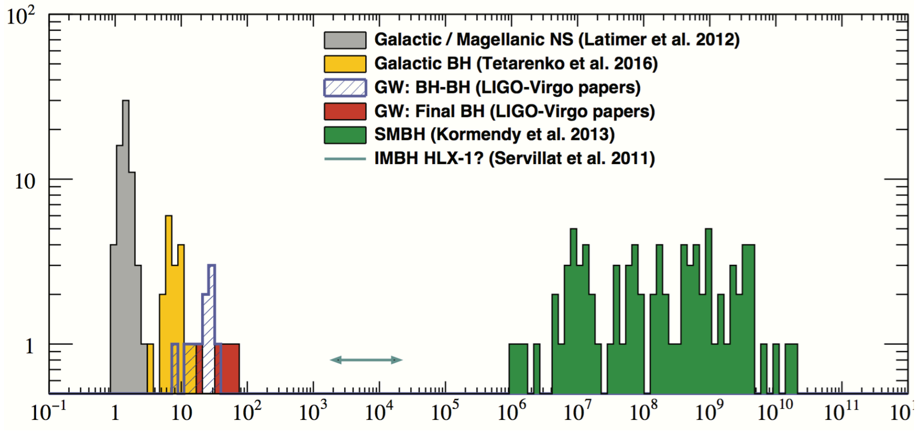


SMBHs cannot tidally disrupt WDs

→ Good probe to study IMBHs

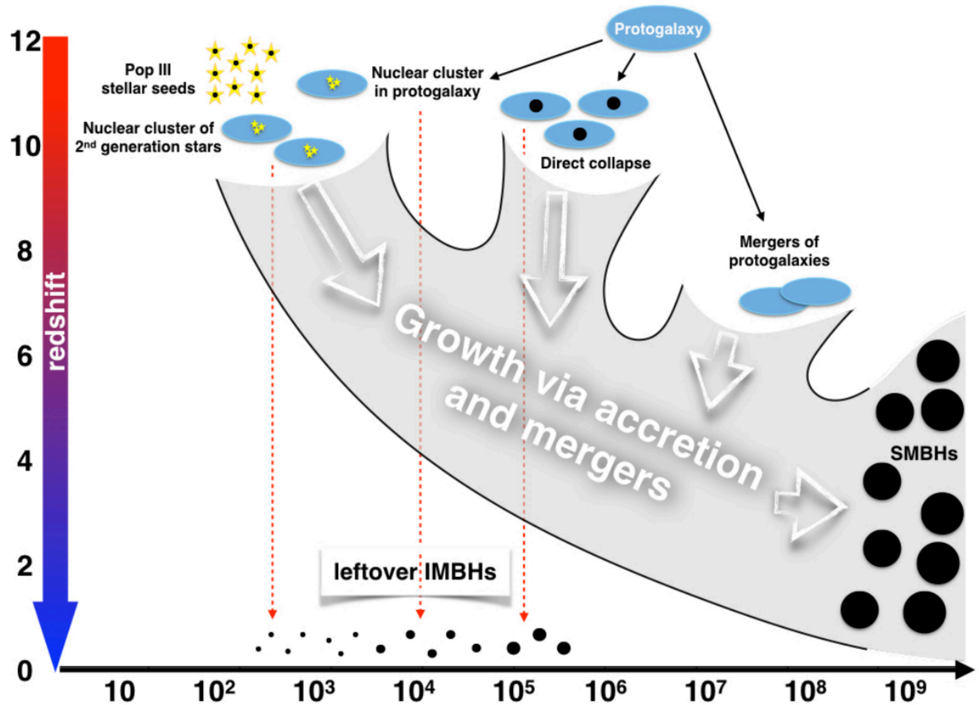
IMBH as a key remnant of SMBH formation

Histogram of observed BH masses



$M_{BH}\ [M_\odot]$

Redshift



$M_{BH}\ [M_\odot]$

from Enoto. T's slide

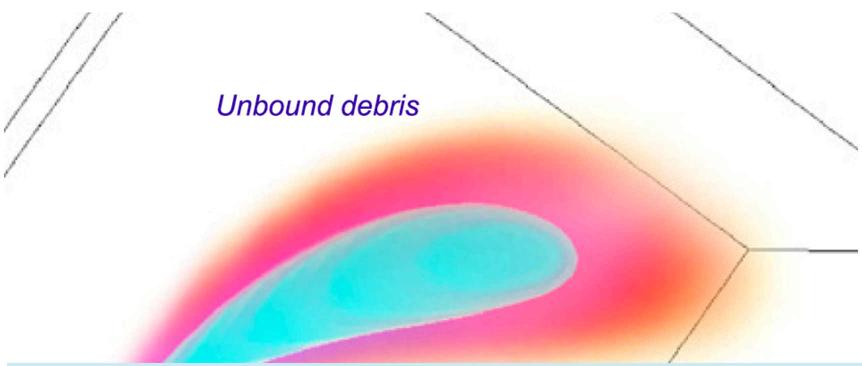
Mezcua (2017)

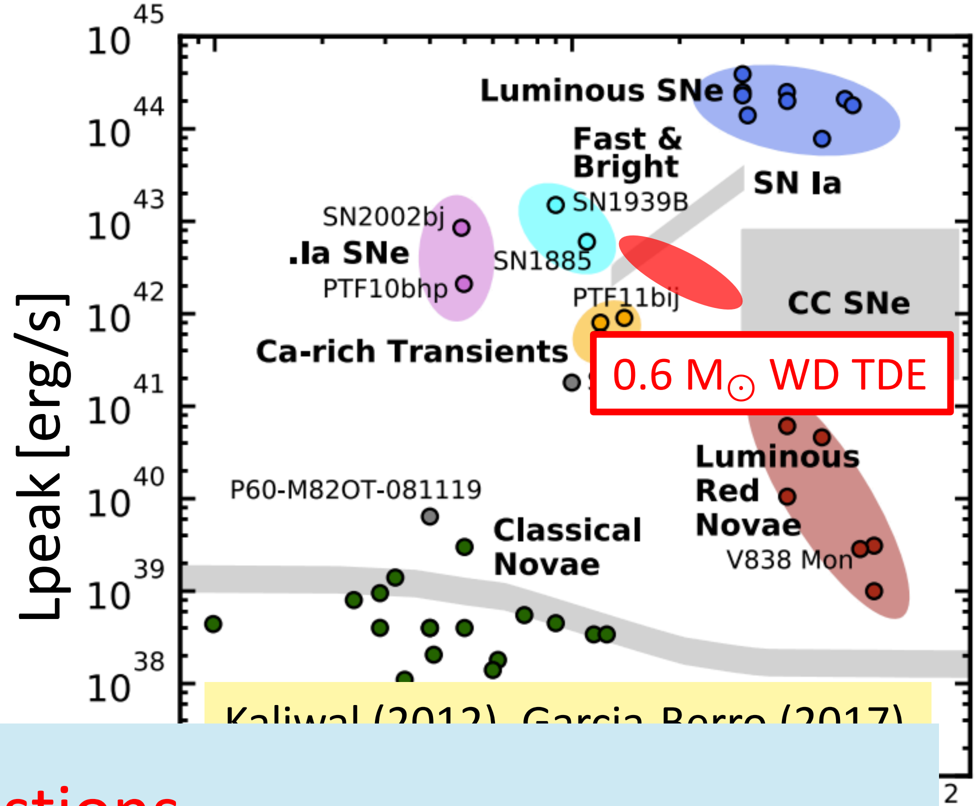
Observational signatures

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





Questions

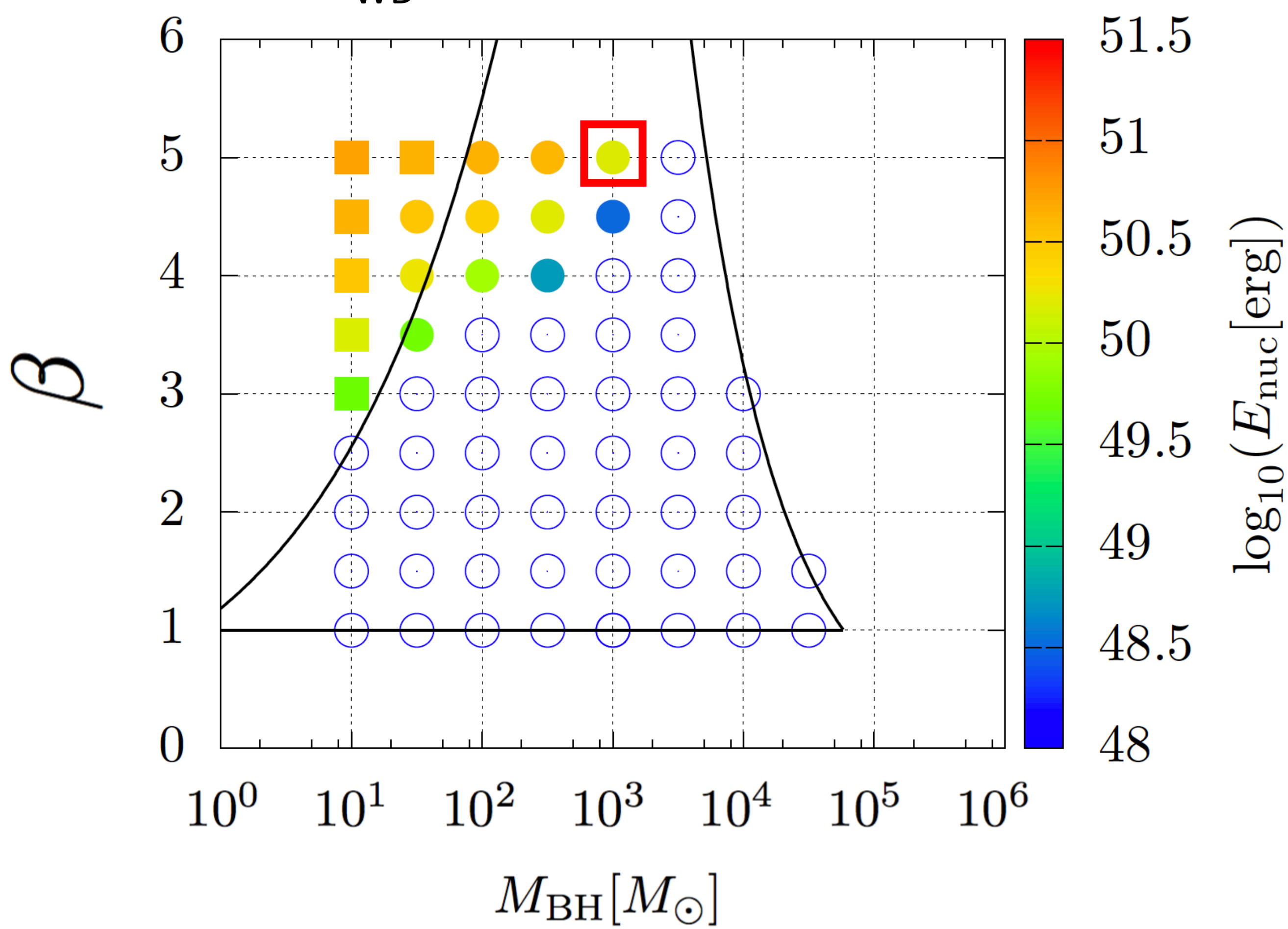
- How about variety of observational signatures?

→ Observational signatures for other parameter cases?

Variety of WD TDEs **Kawana+ (2018)**

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

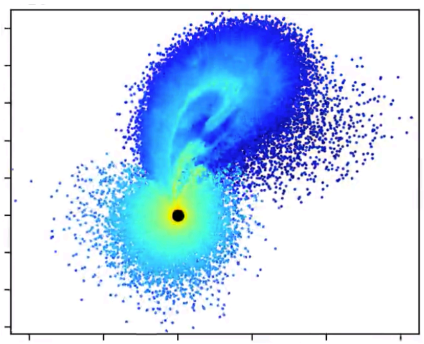
M_{WD} = 0.6 Msun, CO WD



Methods

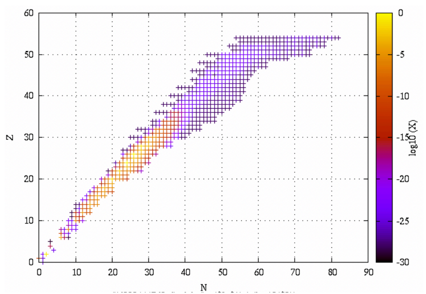
Tanikawa+ (2017), Kawana+ (2018)

1. SPH simulation coupled with simplified nuclear reactions



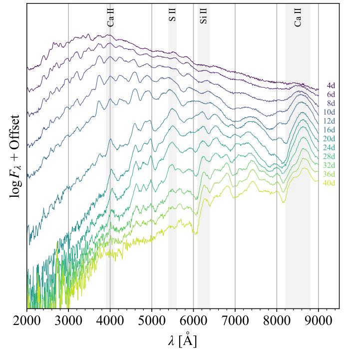
- M_{WD} = 0.2 Msun, ^{4}He composition, HELMHOLTZ EoS
- $M_{BH} = 10^{2.5}$ Msun, $\beta := R_t / R_p = 5.0$
- $N_{particle} \simeq 800{,}000$
- α- chain network w/ 13 nuclear species — Timmes+ (2000)
- Follow until homologous expansion is realized (2000 sec)

2. Detailed nucleosynthesis calculation with **`torch`** — Timmes (1999)



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

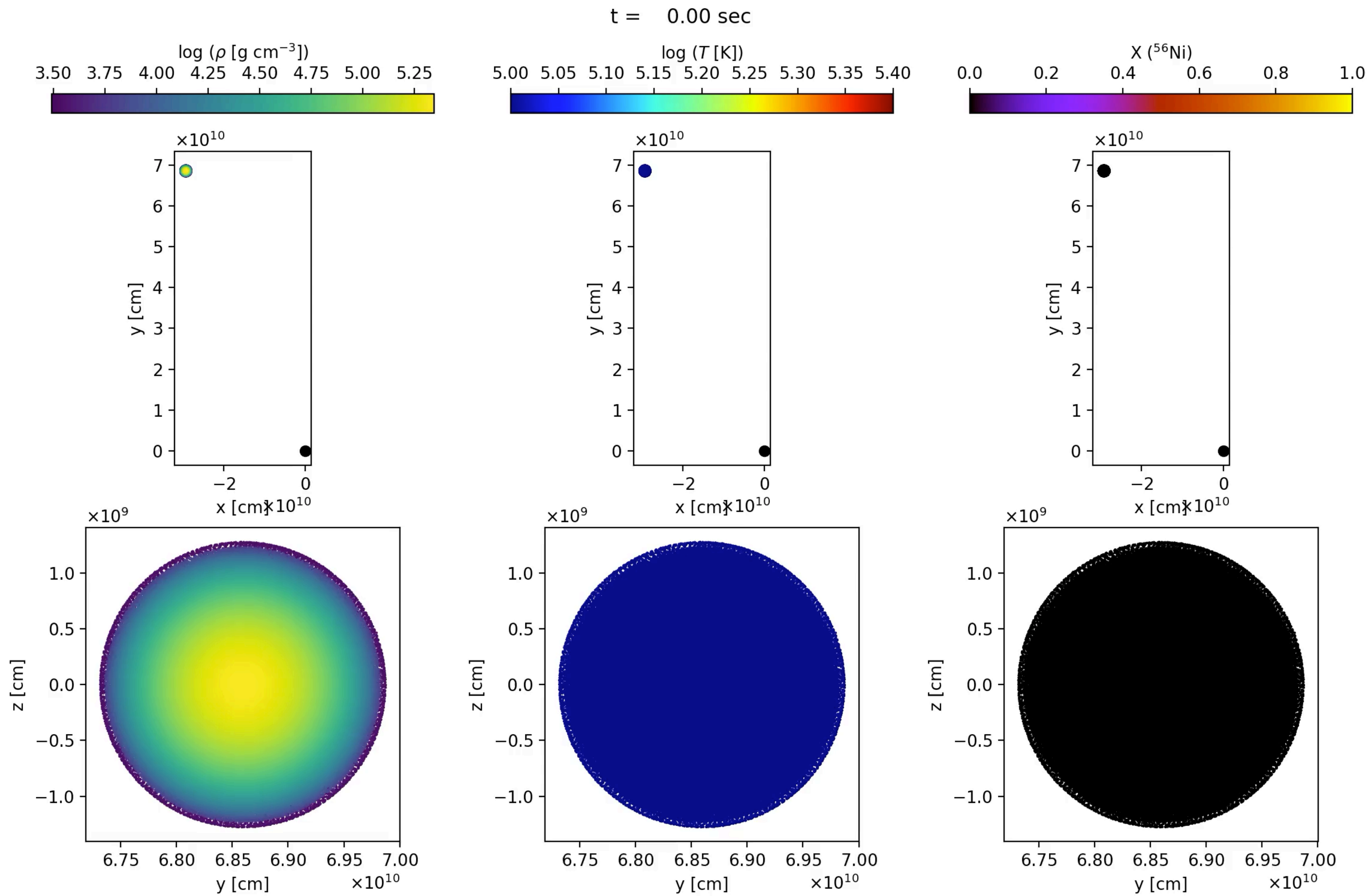
3. Synthetic observation with Monte Carlo radiative transfer



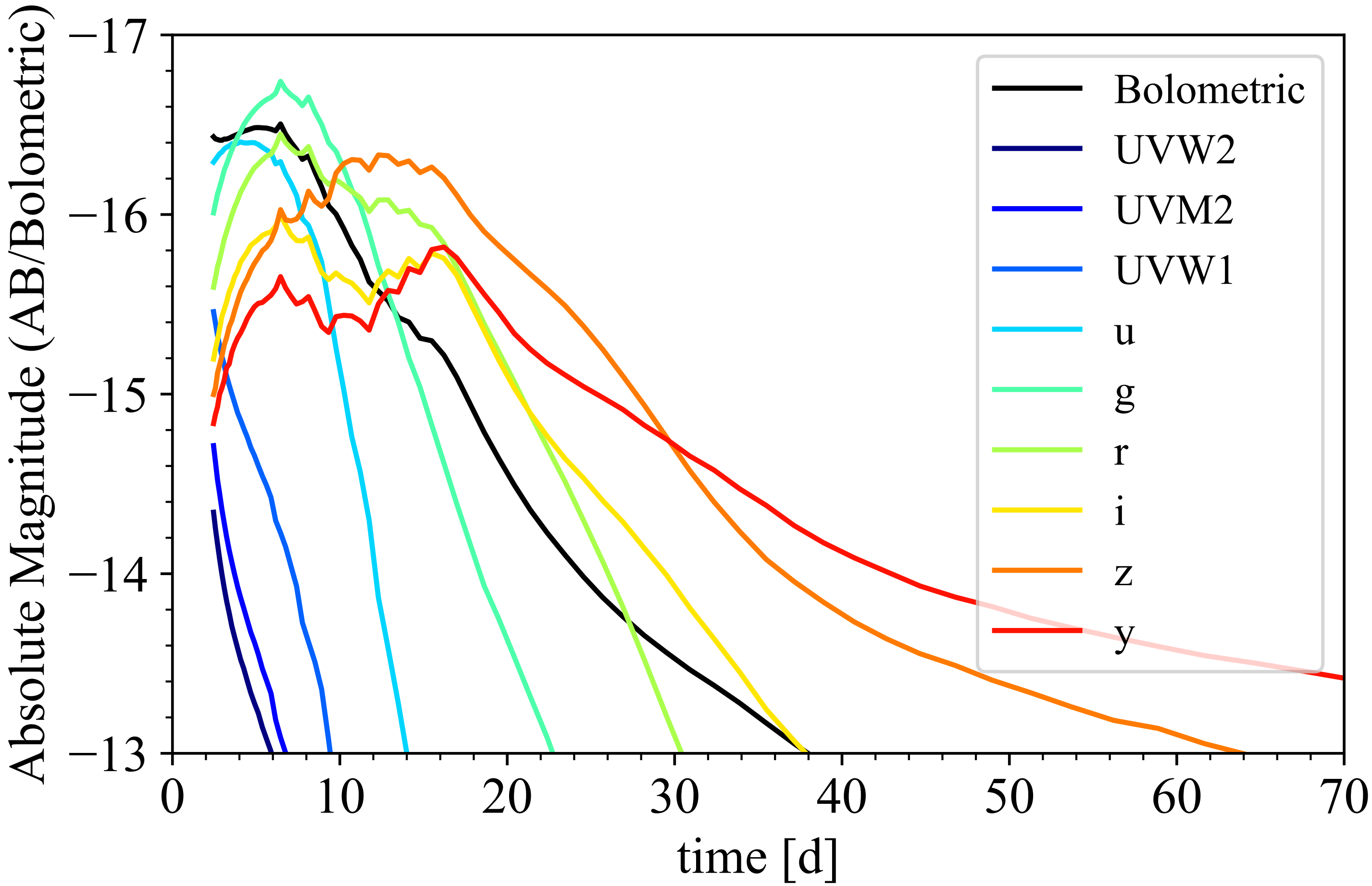
- use **`HEIMDALL`** — Maeda (2006), Maeda+ (2014)
- In 3D, under approximation of homologous expansion

WD TDE hydrodynamical simulations

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

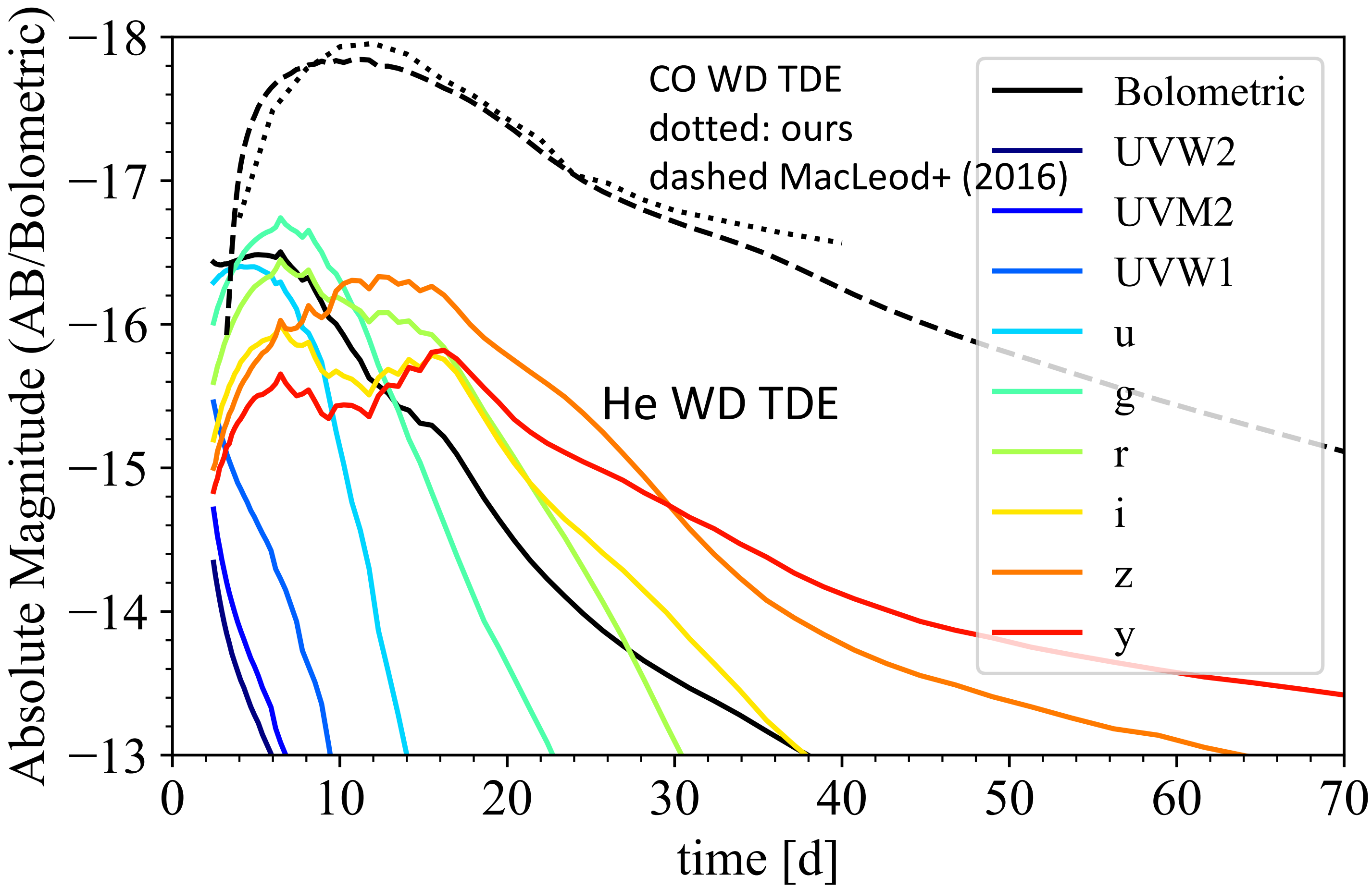


Light curve: mean over all the angle



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

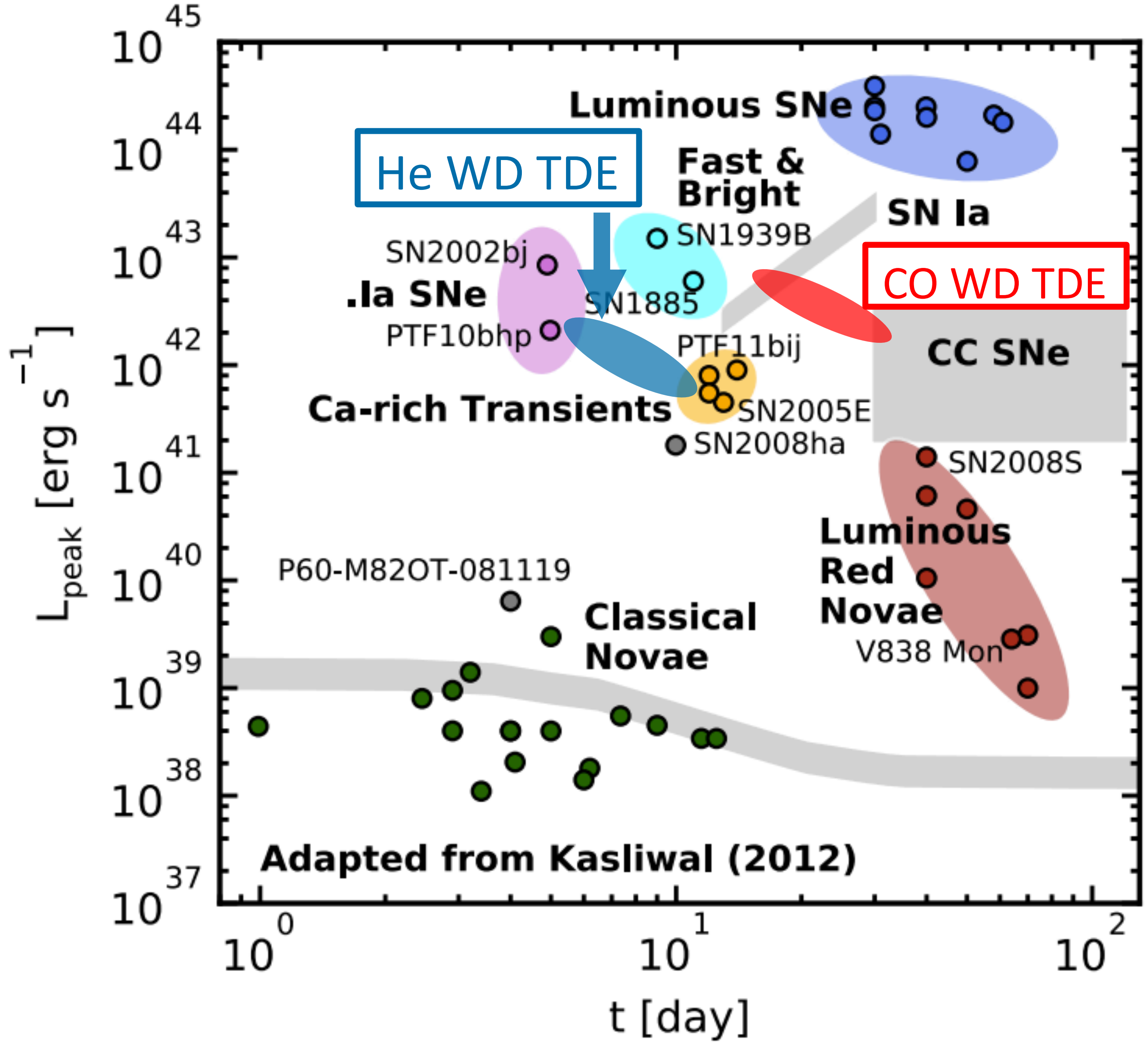
Light curve compared with CO WD TDE



Helium WD TDE shows faster & fainter light curve than CO WD TDE
<= smaller masses of ejecta and ^{56}Ni

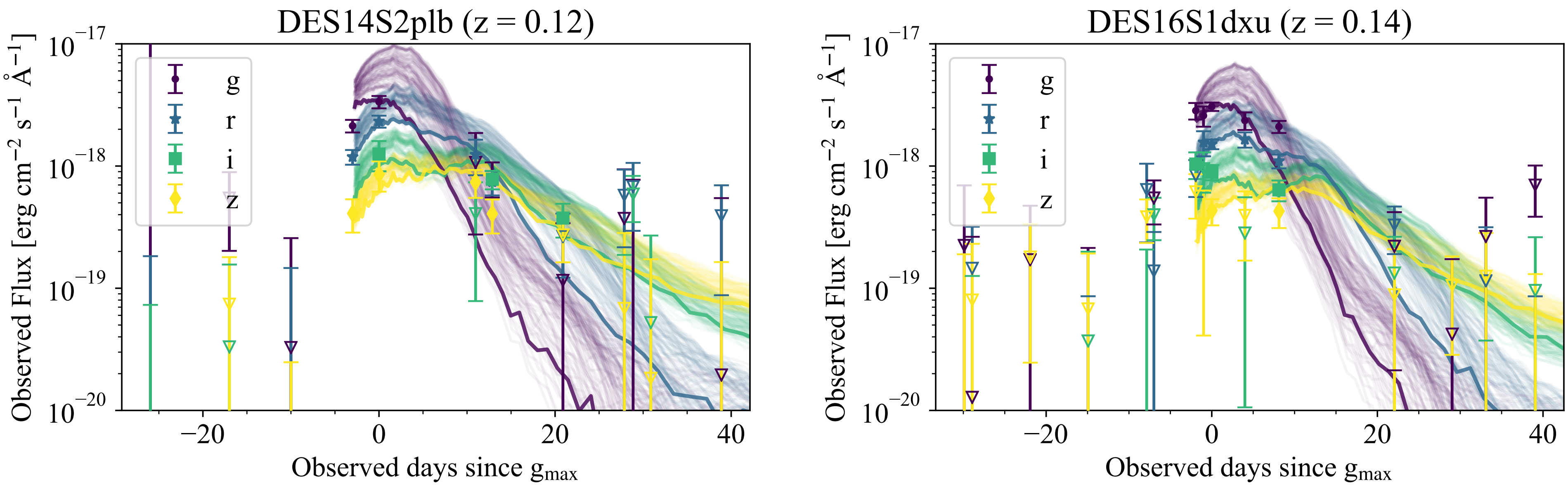
Timescale - Luminosity diagram

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



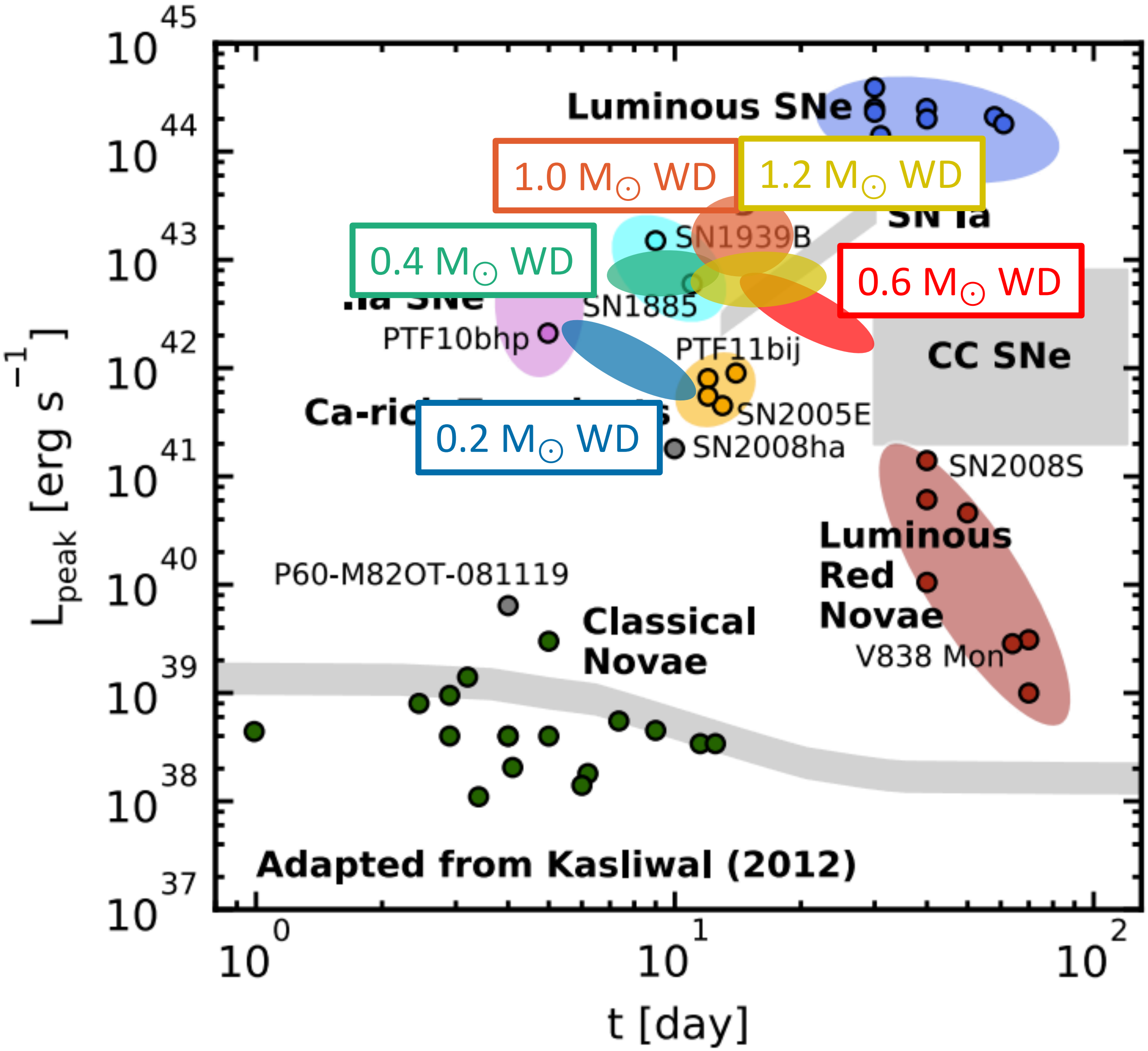
Rapid transients found by Dark Energy Survey

Pursiainen+ (2018)



- Relatively faint, rapid transients match with our WD TDE model
- No spectra when the transients are brighter than host.

Variety of emission from WD TDEs



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

Summary

WD TDEs uniqueness: IMBH search & thermonuclear explosion

We predict observational signatures by performing SPH simulations, nucleosynthesis simulations, and radiative transfer simulations.

Helium WD TDE characteristics:

- rapid evolution ($\Delta t_{1mag} \simeq$ 5-10 d)
- rapid color evolution from blue to red
- Relatively faint $L_{peak} \simeq 1\text{-}2 \times 10^{42}$ erg/s, $M_{bol,\,peak} \simeq -16.5$ mag

WD TDEs show a large variety depending on parameters

- Low-mass helium WD TDEs show rapid evolution. Peak luminosity ranges $L_{bol} \simeq 10^{42}\text{-}10^{43}$ erg/s.
- High-mass WD TDEs are similar to SNe Ia, but their variety is larger than that of SNe Ia.