A Variety of Tidal Disruptions Events of a WD by a BH

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Collaborators
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arXiv:1705.05526

Tidal Disruption Event (TDE)

When a star passes close to a black hole (BH), if

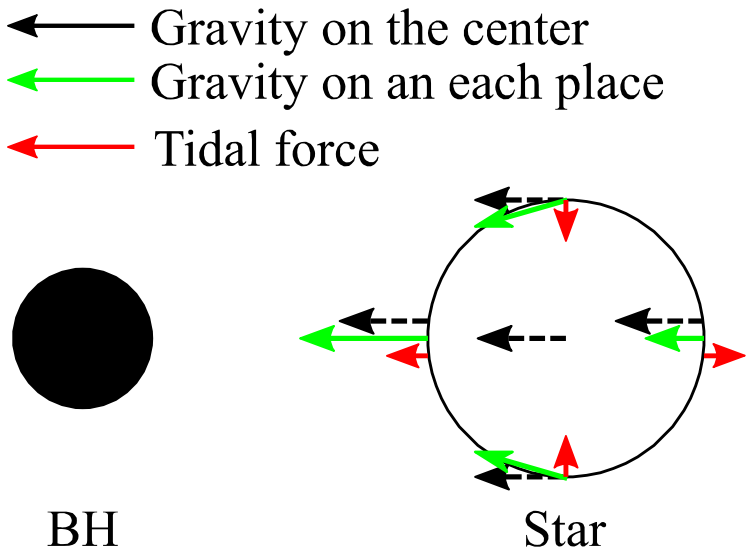
the tidal force > the star's self gravity,

the star will be disrupted.

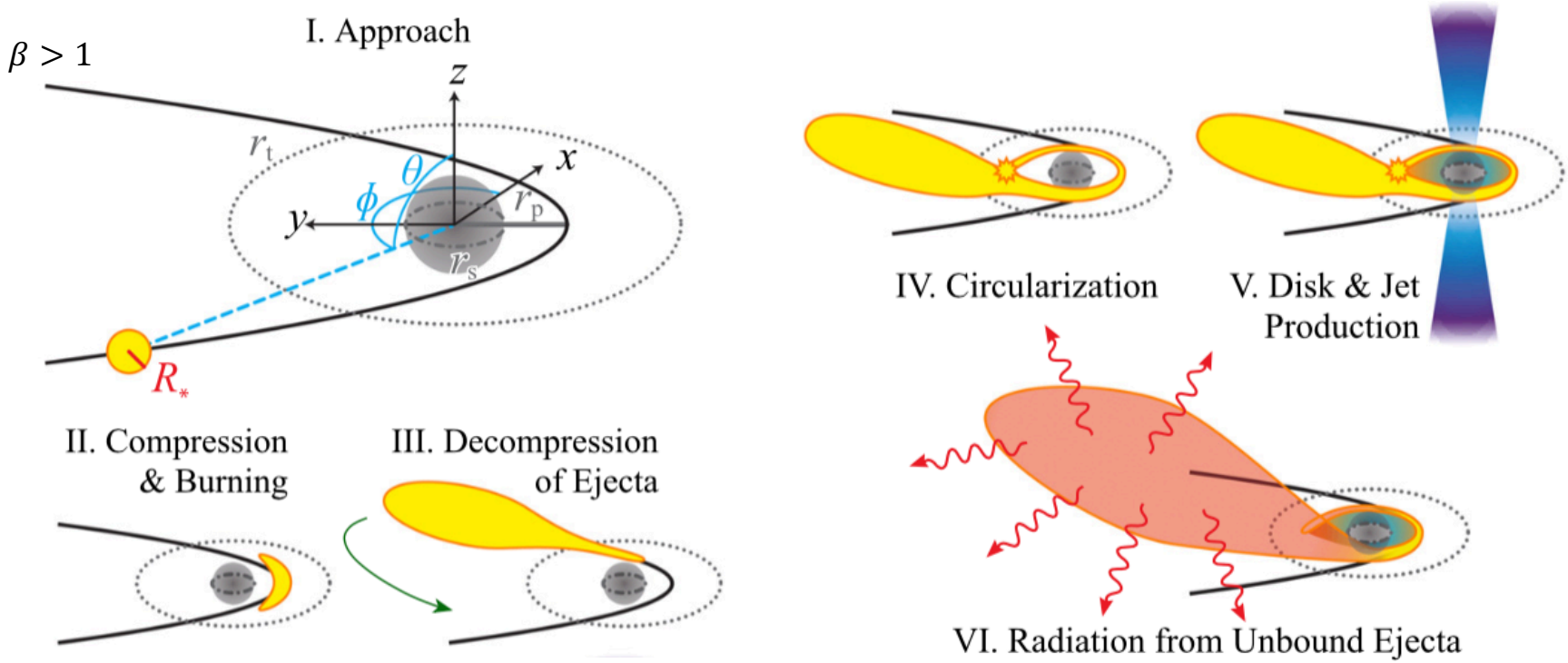
Basic quantities of TDE

- Schwarzschild radius R_S
- Tidal radius $R_t = R_* \left(\frac{M_{\rm BH}}{M_*} \right)^{1/3}$
- Penetration factor $\beta := R_t / R_p$

(R_p: the pericenter radius)

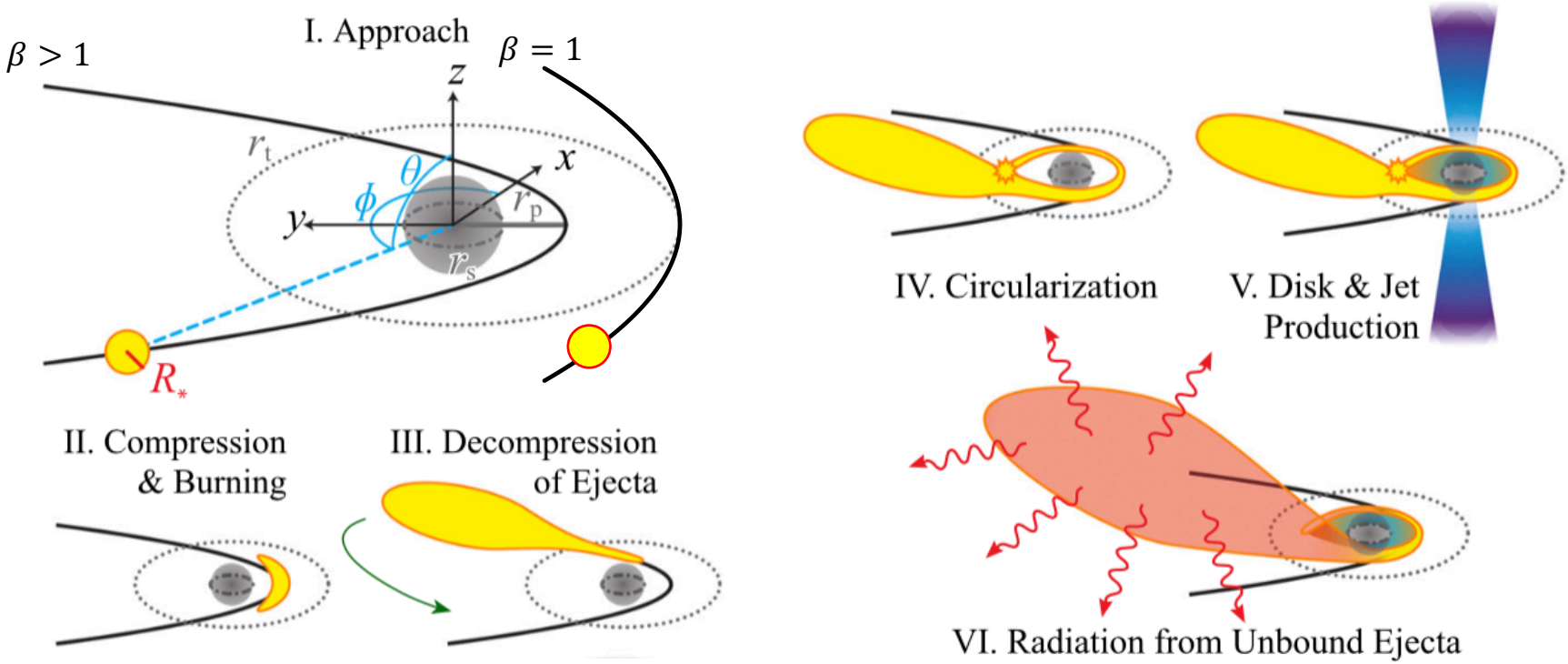


Sequence of WD–BH TDE



MacLeod+ (2016)

Sequence of WD–BH TDE



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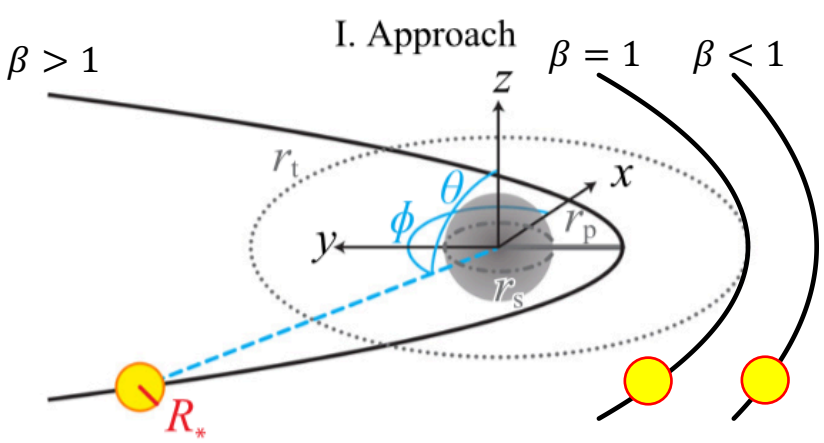
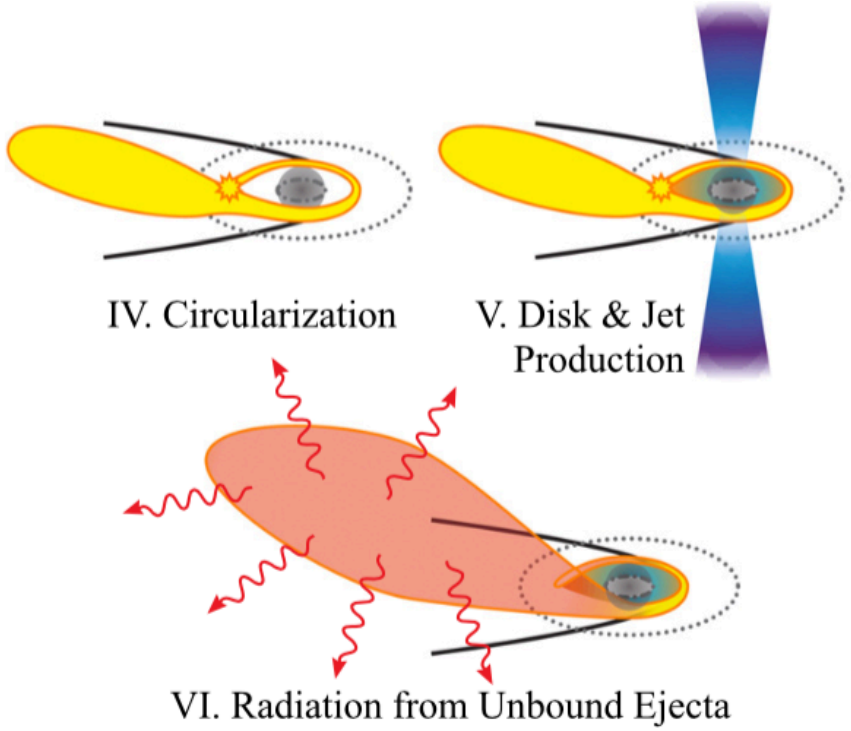
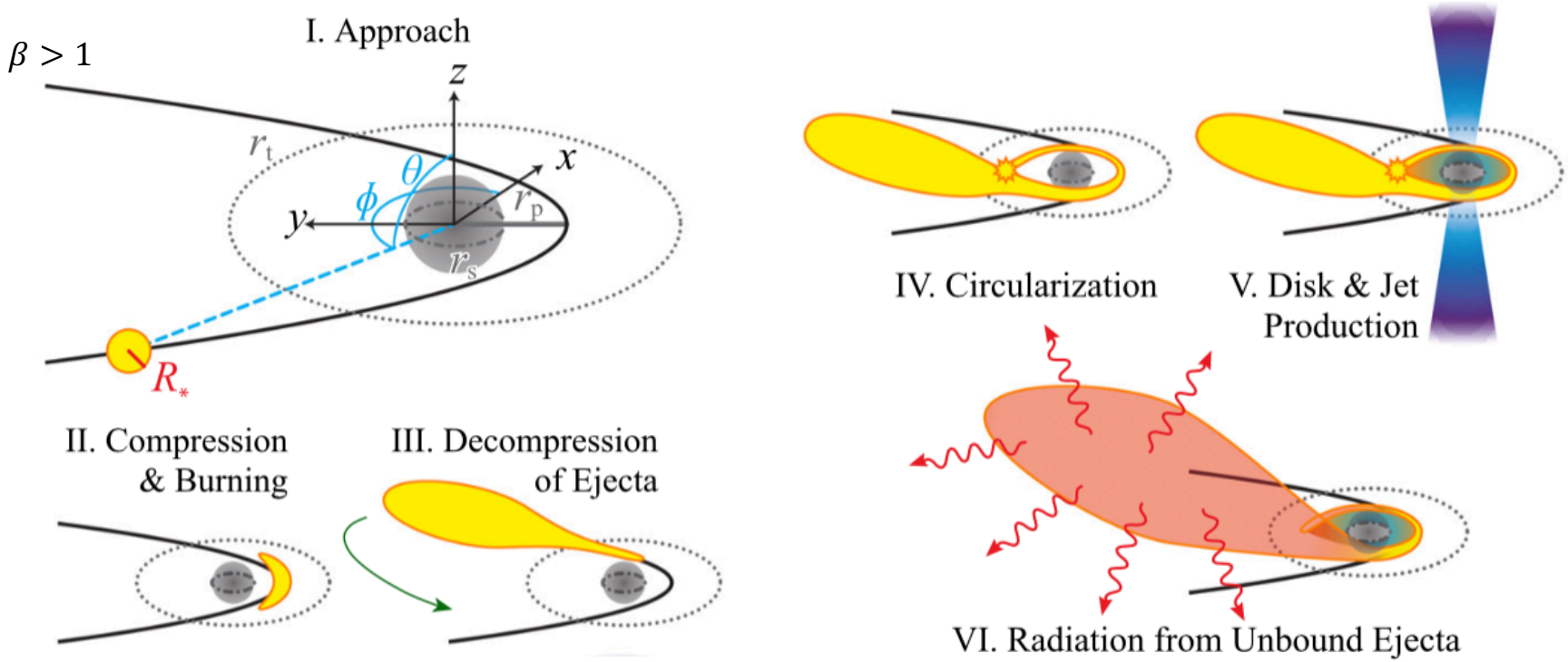




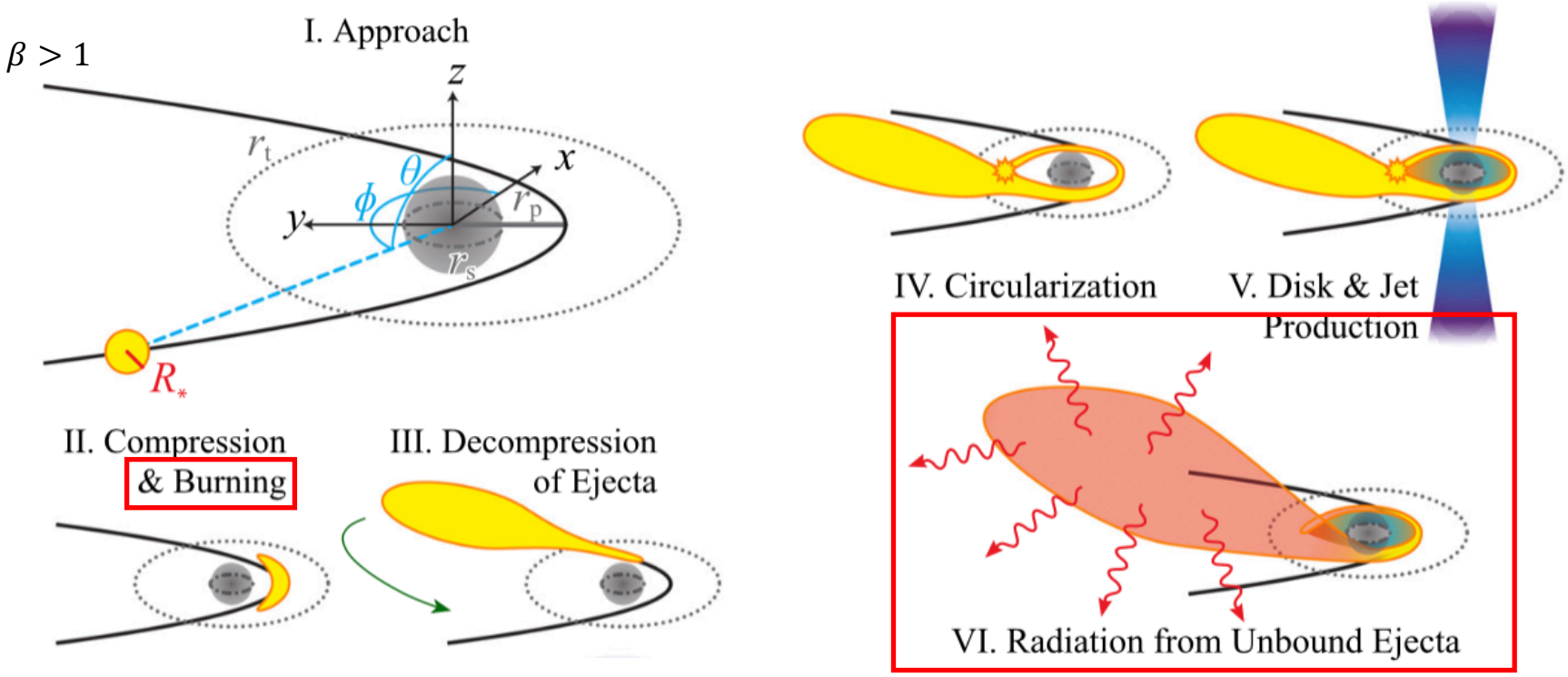
MacLeod+ (2016)

Sequence of WD–BH TDE



MacLeod+ (2016)

Sequence of WD–BH TDE



MacLeod+ (2016)

Characteristics of WD–BH TDE

Interests of WD–BH TDE

- Nuclear explosion occurs if WD is extremely compressed

→ Ia SN-like transients?

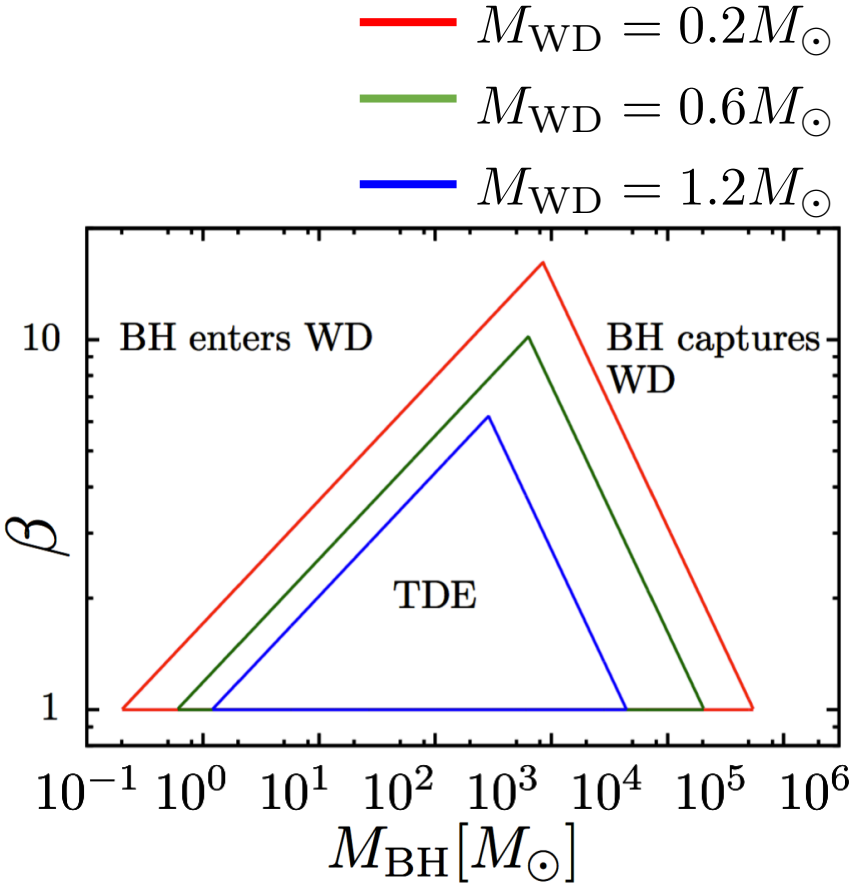
- Range of $M_{\rm BH}$ is restricted

$$R_t > R_p > R_S$$

$$\Rightarrow \begin{cases} 10^{0-1}\,M_\odot & \text{Stellar Mass BH} \\ 10^{2-5}\,M_\odot & \text{Intermediate Mass BH (IMBH)} \end{cases}$$

Main sequence and giant stars can be disrupted by SMBHs

→ good probe to study IMBHs



Observational status

So far : few possible (but still uncertain) candidates

GRB	GRB060218 + SN2006aj (Shcherbakov et al. 2013) GRB111209A (Ioka et al. 2016)
X-ray transient	XRT 000519 (Jonker et al. 2013) CDF-S XT1 (Bauer et al. 2017)

Future surveys would detect ~100 WD TDEs

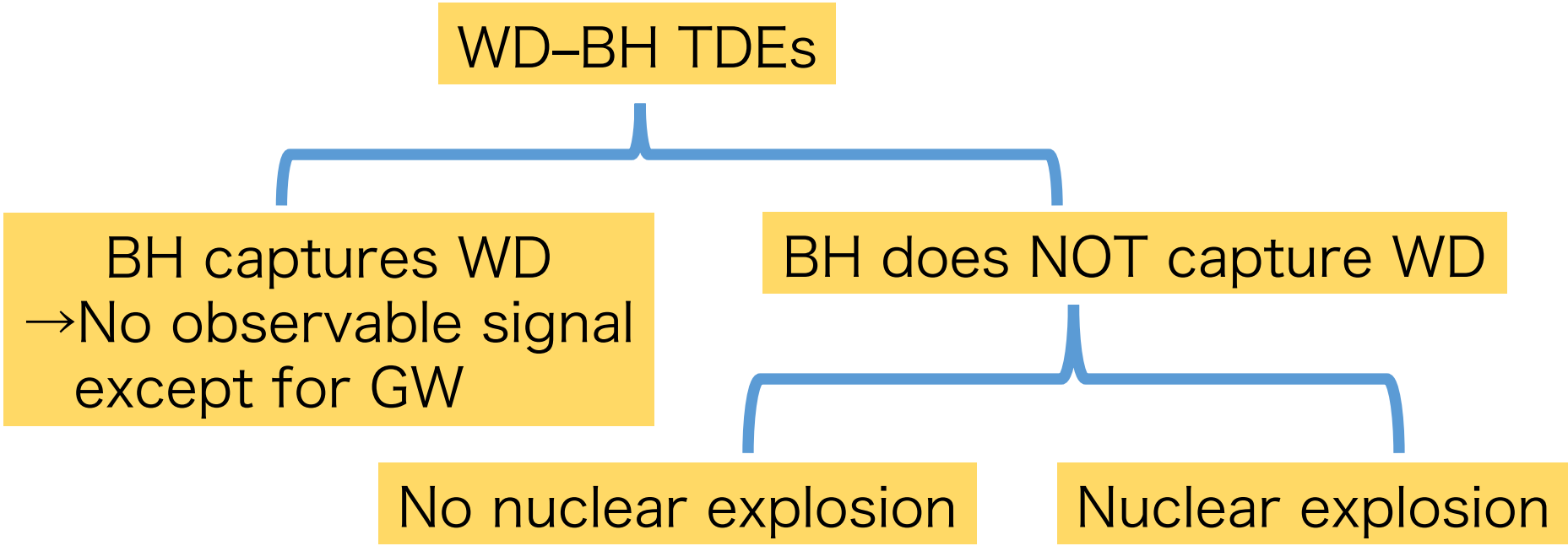
Optical : ZTF, LSST

X-ray : LOFT, Einstein Probe

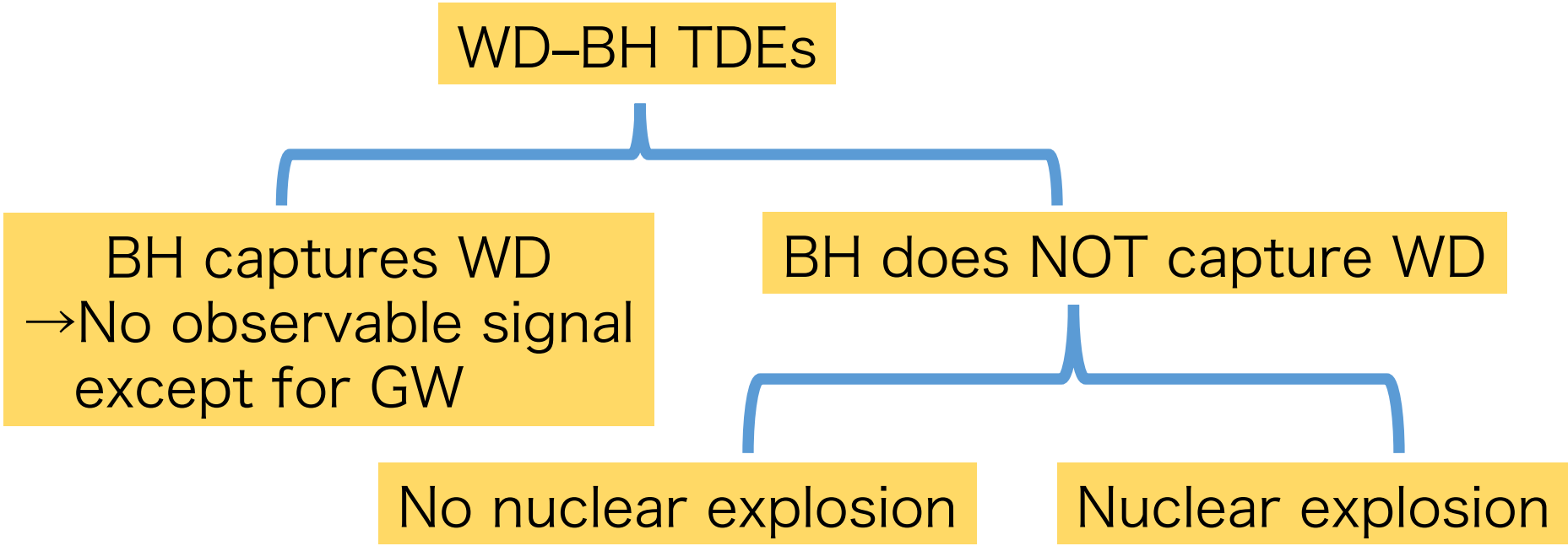
radio : SKA

GW : DECIGO, BBO, (Advanced LIGO, KAGRA)

Motivation


WD–BH TDEs
BH captures WD
→No observable signal
except for GW
BH does NOT capture WD
No nuclear explosion
Nuclear explosion

Motivation



Questions

- How often does each case occur?
- How about the variety of observational signals?

Description of our simulations

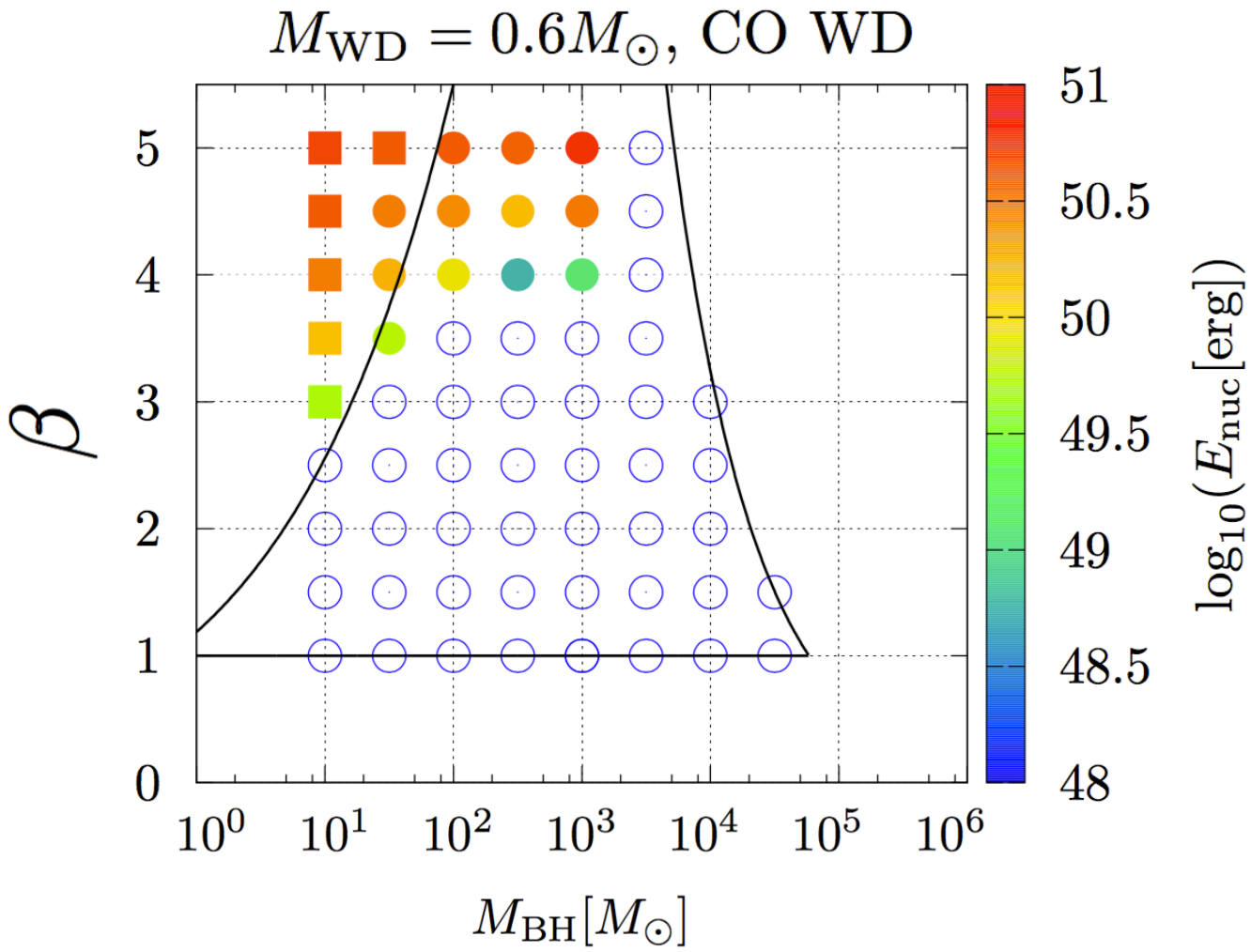
- Parameter study varying M_{BH}, M_{WD}, and β

→ study the nucleosynthesis in the TDEs

- 3D SPH simulations coupled with nuclear reactions

- Nuclear reactions: α-Chain Network from ^{4}He to ^{56}Ni (13 species)
- BH：static gravity source (Schwarzschild BH)
- WD：self-gravity fluid represented with ≈800,000 SPH particles

3 Types of WD-BH TDE



Interests of WD–BH TDE

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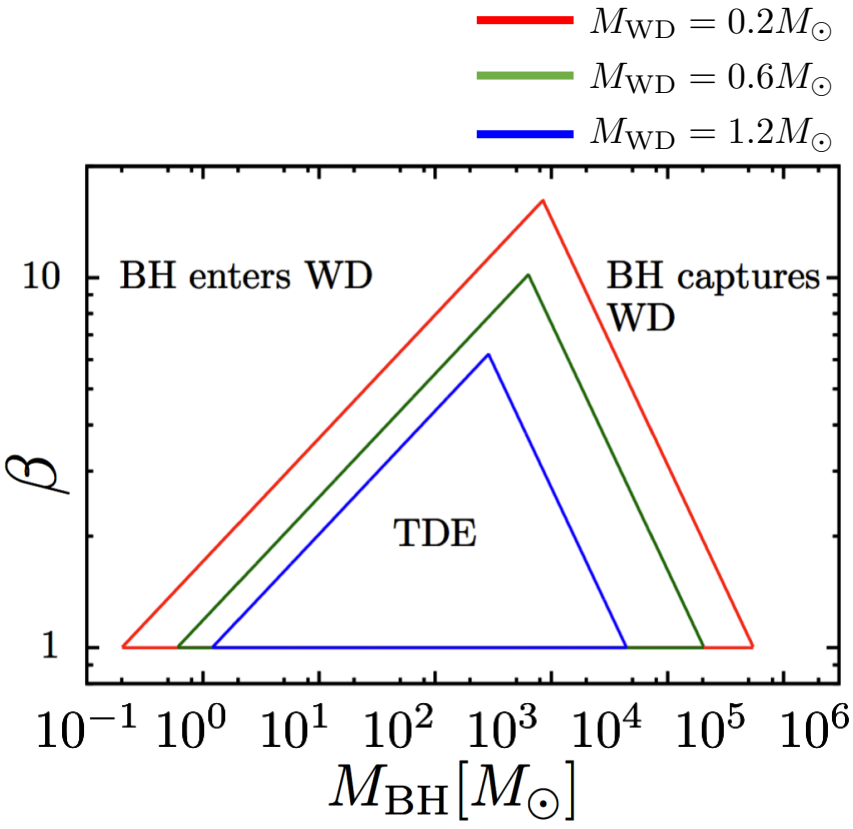
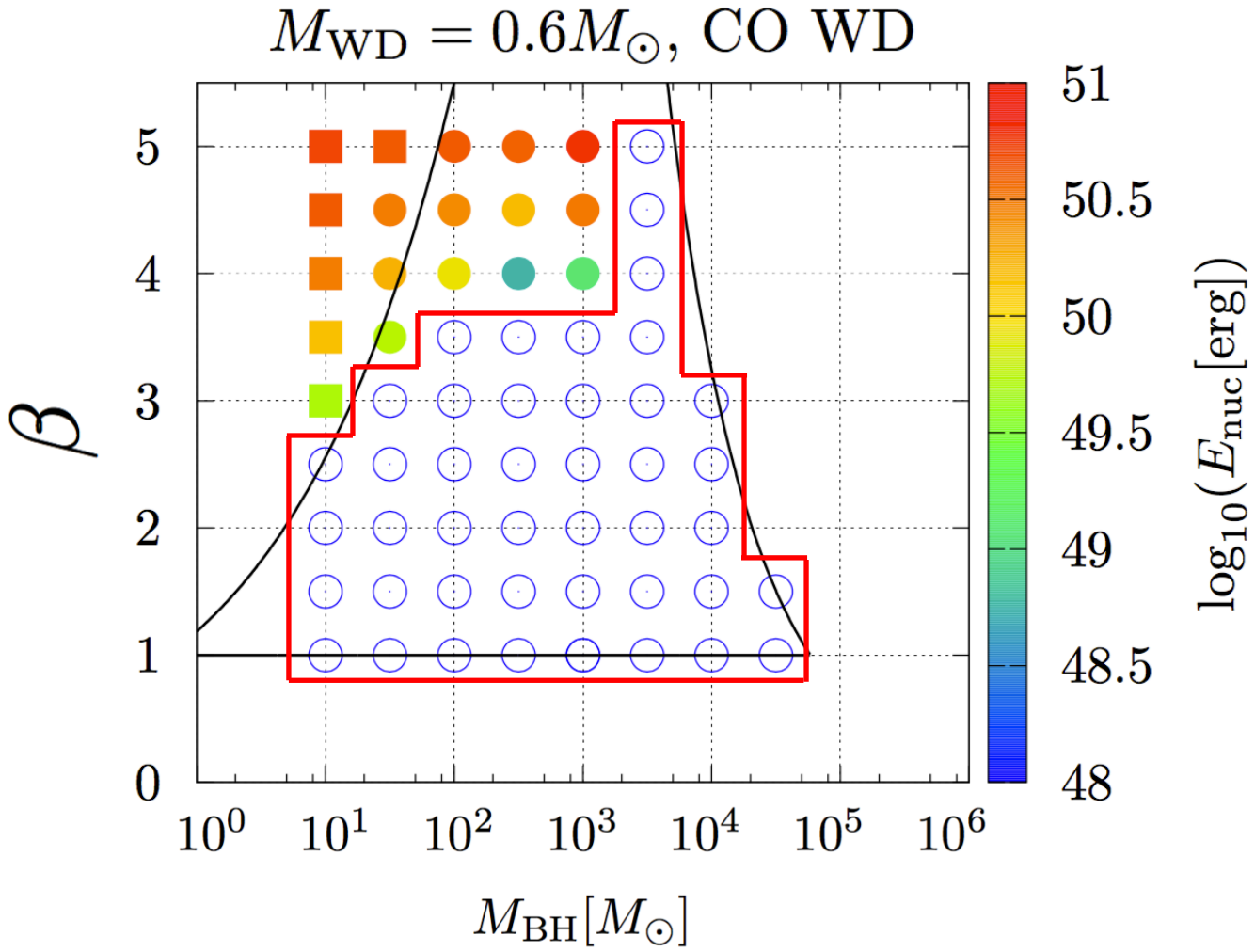
$\begin{cases} 10^{0-1} M_\odot \text{ Stellar Mass BH} \\ 10^{2-5} M_\odot \text{ Intermediate Mass BH} \end{cases}$

Main sequences and red giants can be disrupted by SMBHs

→ good probe to study IMBHs



1: TDE w/o explosive nuclear reactions



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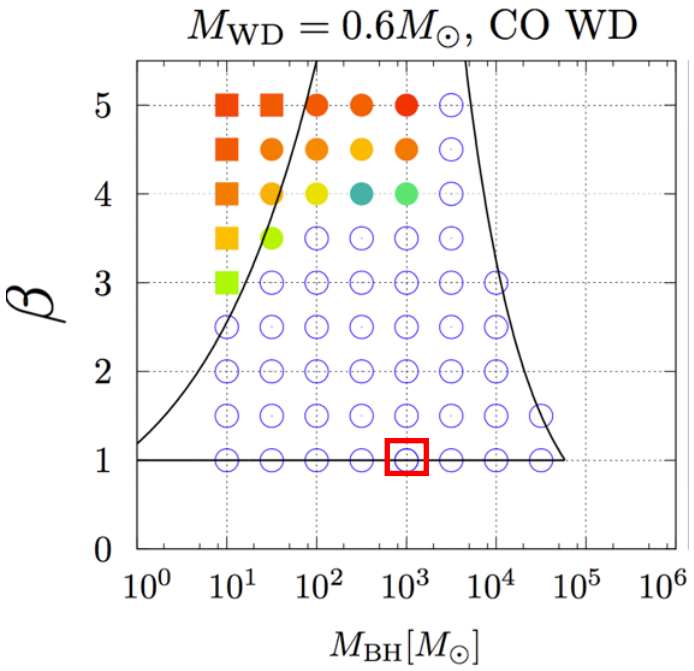
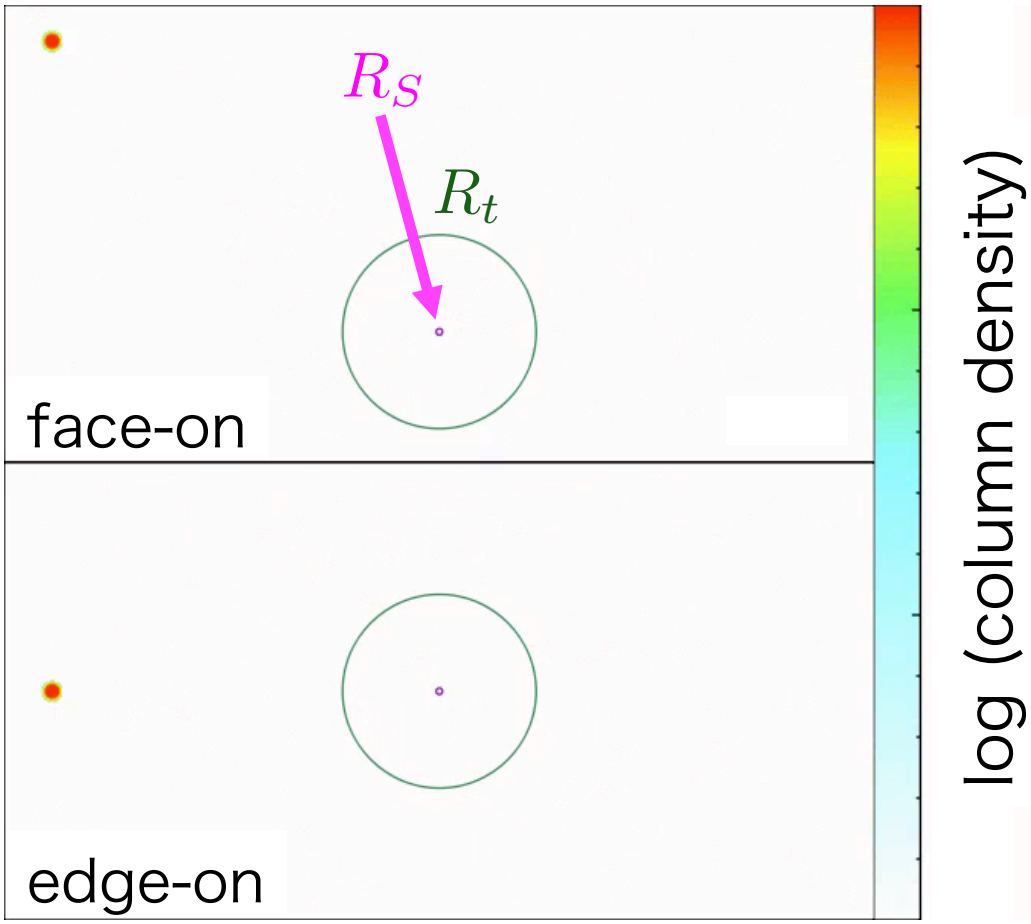
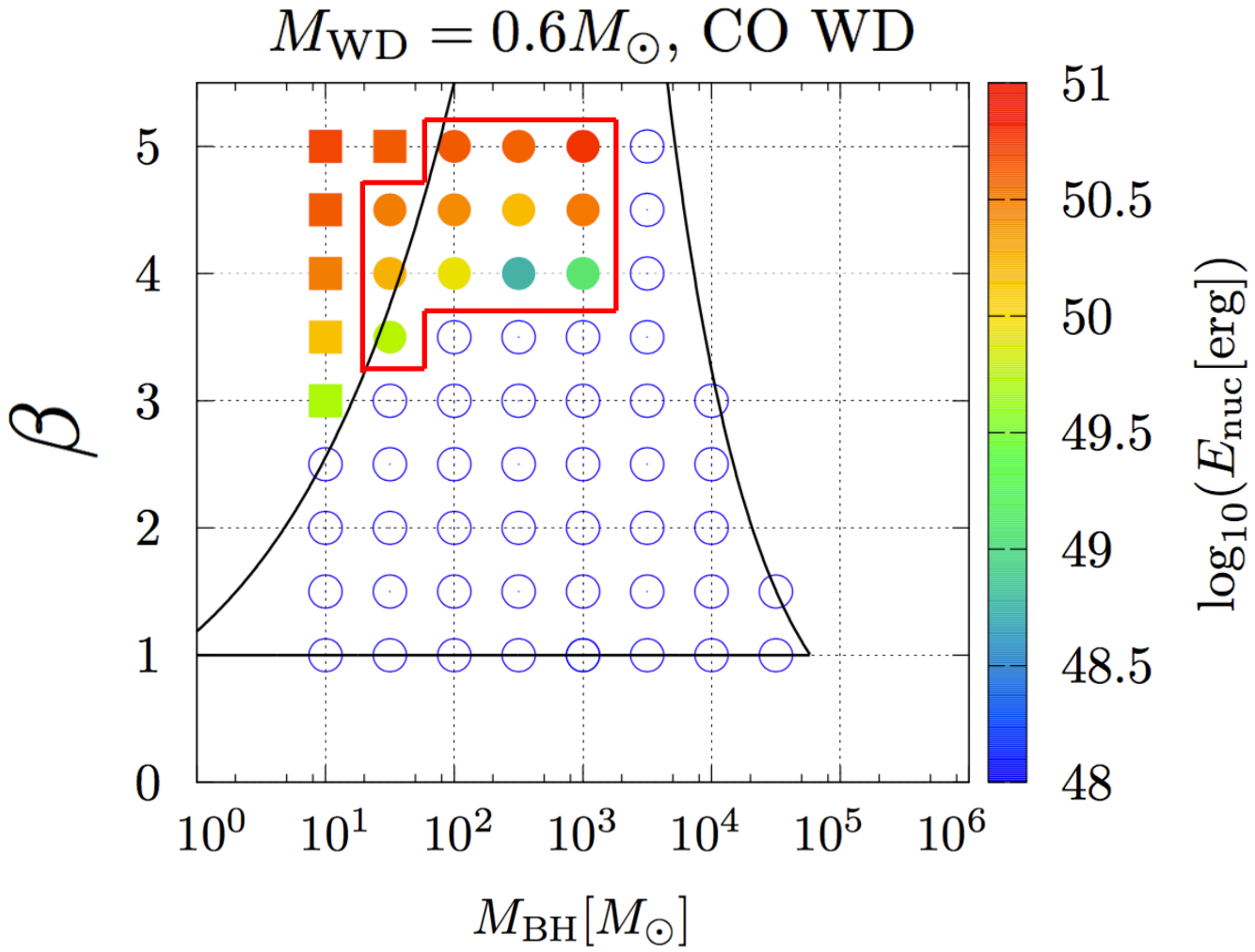




2: TDE w/ explosive nuclear reactions



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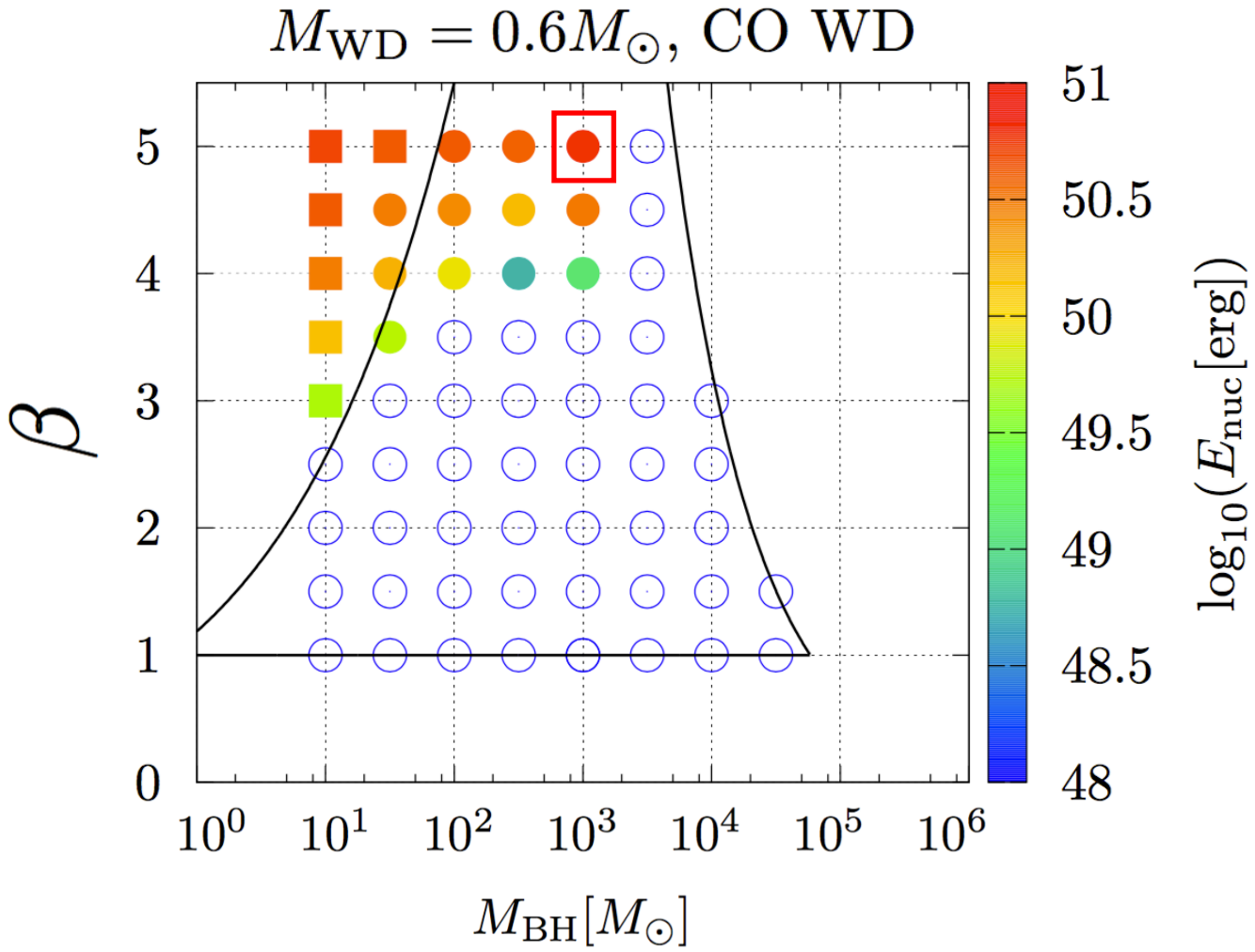
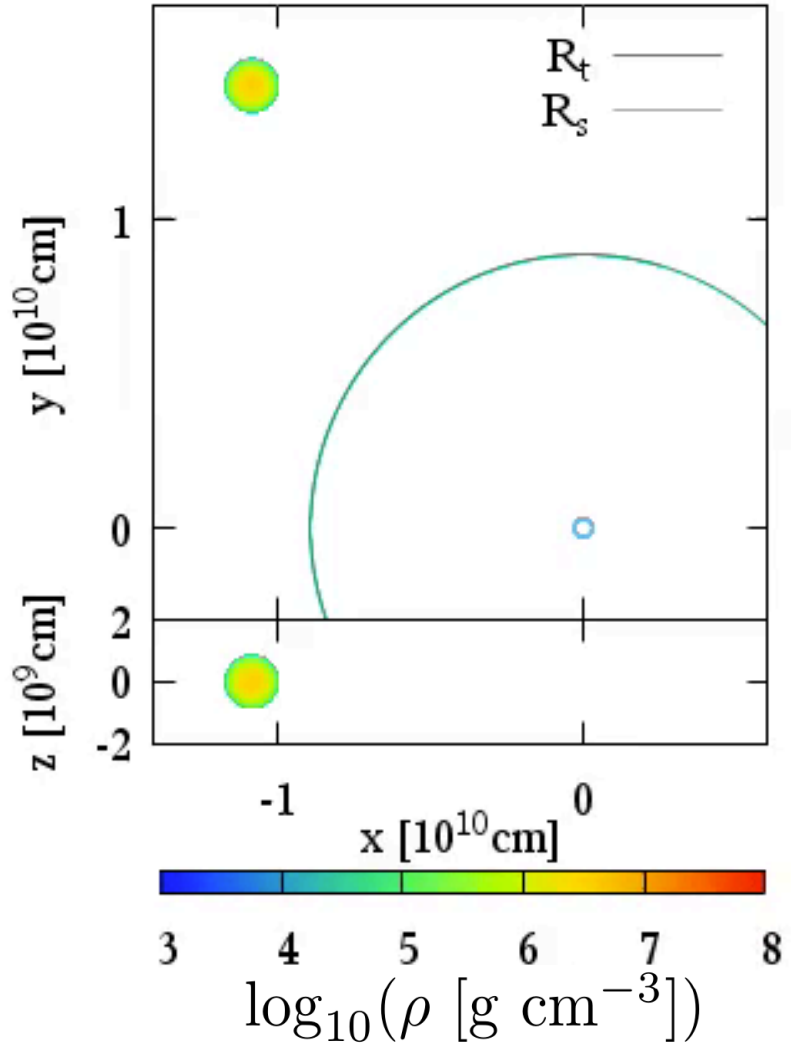
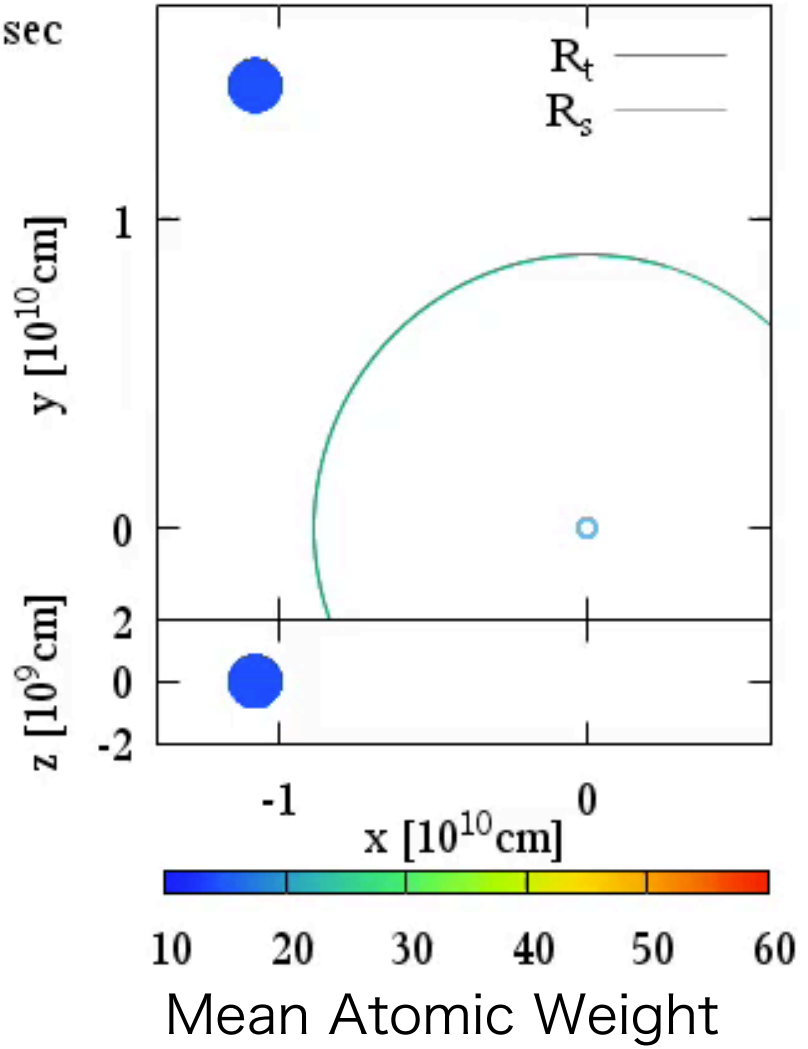


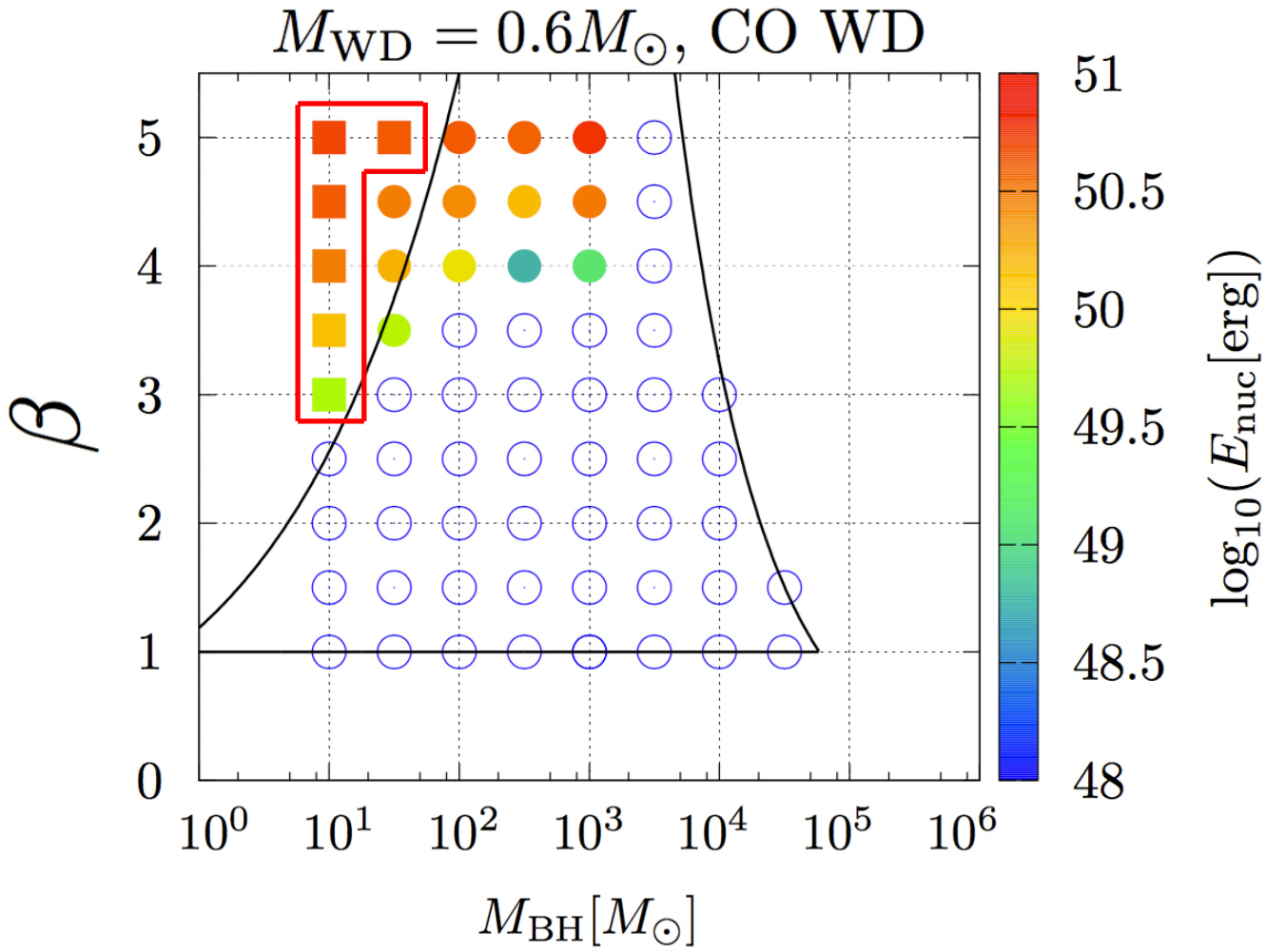
2: TDE w/ explosive nuclear reactions

$$M_{\mathrm{BH}} = 1000 M_{\odot}, M_{\mathrm{WD}} = 0.6 M_{\odot}, \beta = 5.0$$





3: TDE w/ immediate self-intersection



3: TDE w/ immediate self-intersection

$$M_{\rm WD} = 0.2 M_\odot,\ M_{\rm BH} = 10^{1.5} M_\odot,\ \beta = 4.5$$

→ promote formation of accretion disk

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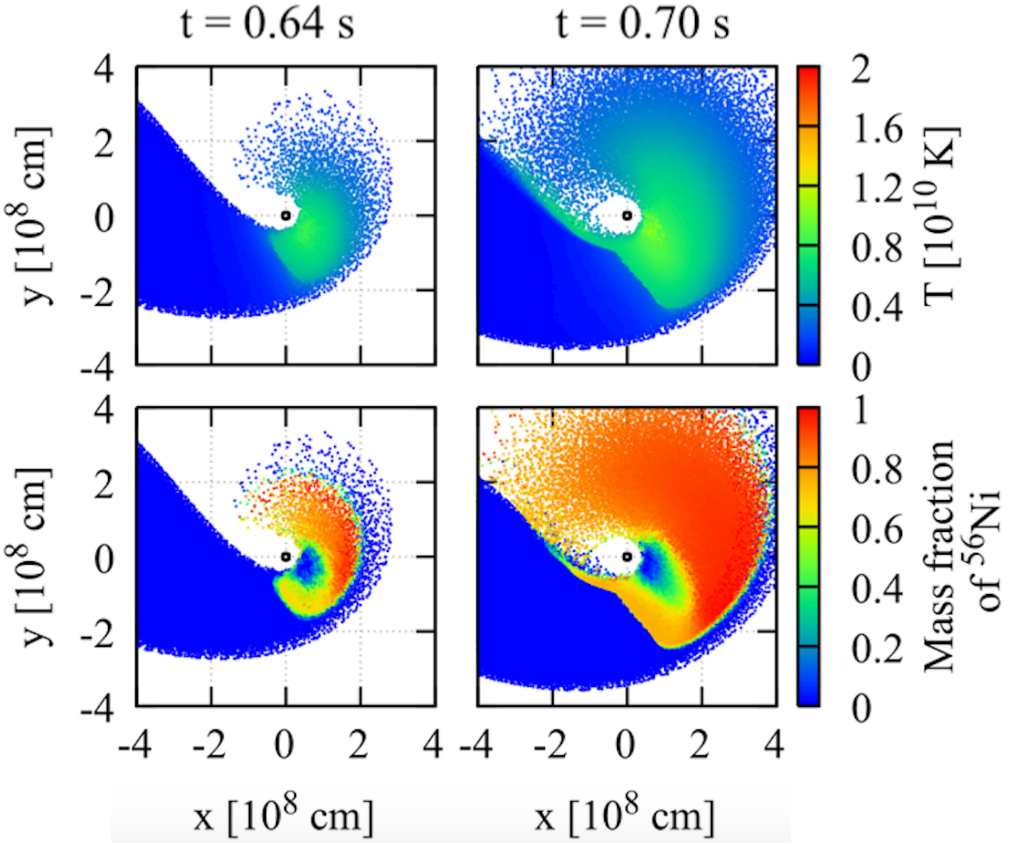


Self-intersection
enhances nuclear reactions

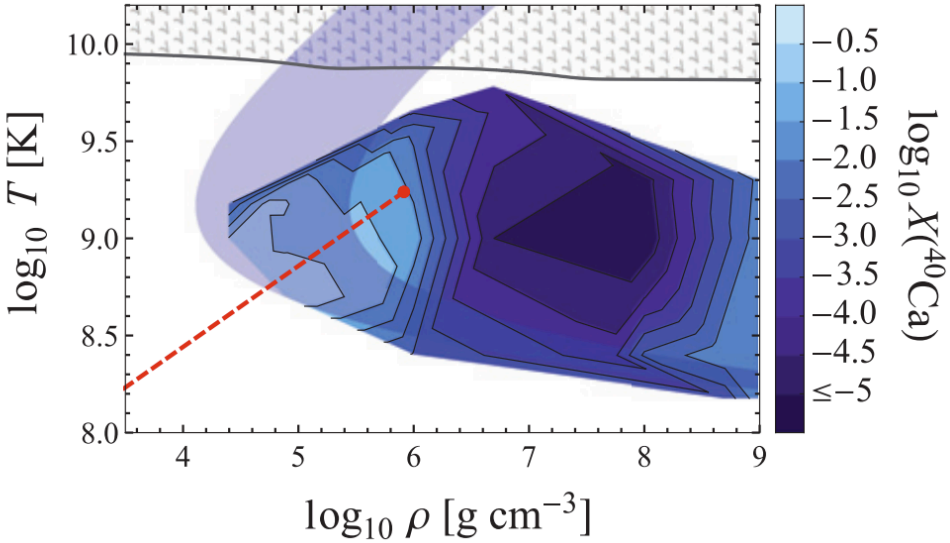
Calcium-rich gap transients: tidal detonations of white dwarfs?

P. H. Sell,[1★] T. J. Maccarone,[1] R. Kotak,[2] C. Knigge[3] and D. J. Sand[1]

Characteristics of Ca-rich gap transients

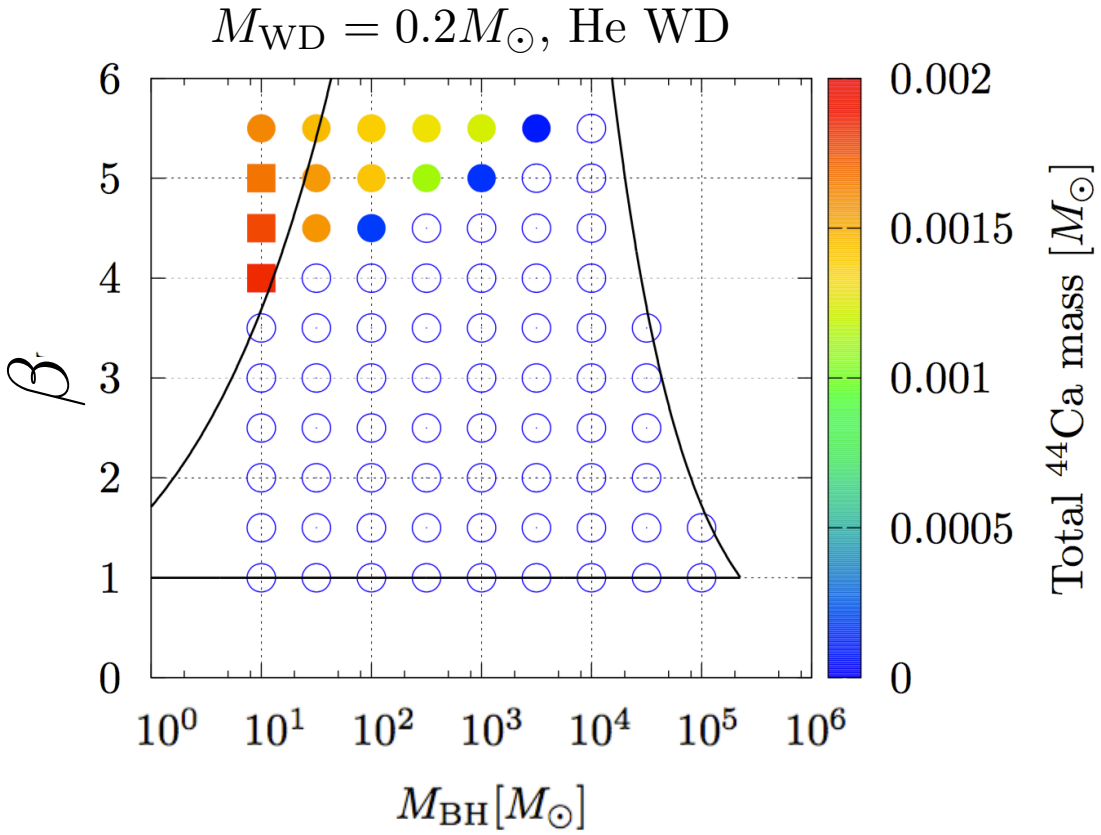
- Similar to Type Ia SNe
- Fainter
- Faster evolution
- Large calcium abundances
- High velocity (6000 - 11000 km/s)
- Occur in the outskirts of galaxies

Outcome of nucleosynthesis from pure He



Holcomb+ (2015)

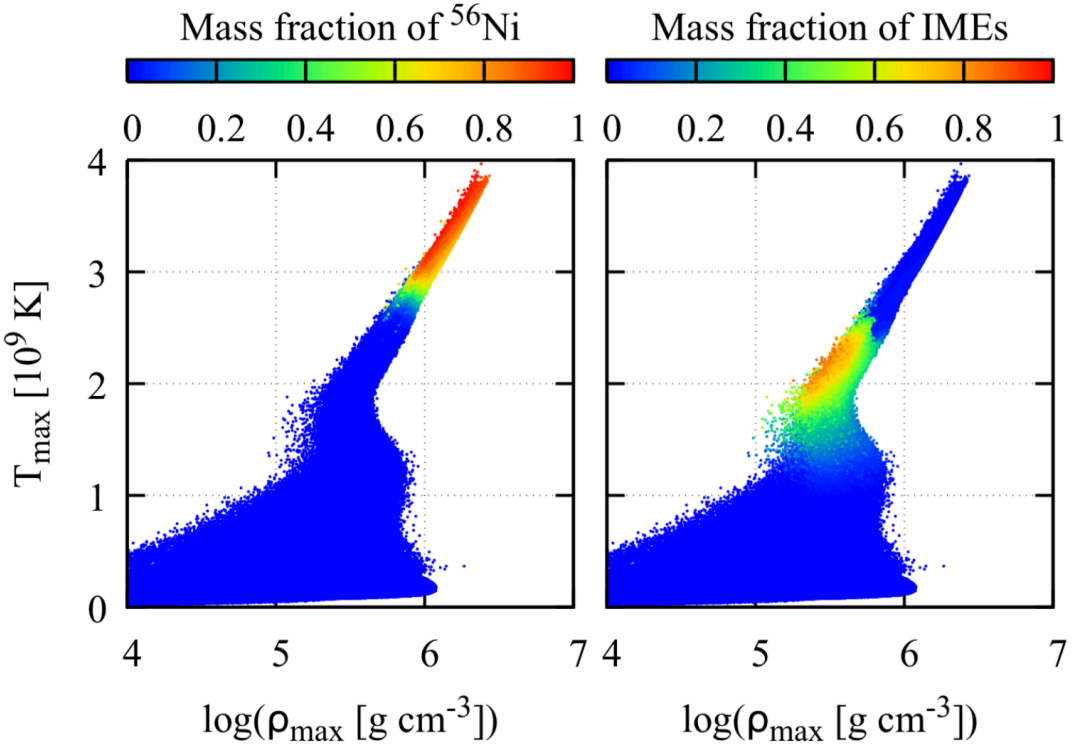
He WD TDEs as Ca-rich gap transients?
→ Our results deny!



Too small amount
($\sim 0.001\, M_\odot$) of ^{40}Ca

He WD TDEs as Ca-rich gap transients?

$$M_{\rm WD} = 0.2 M_\odot,\ M_{\rm BH} = 10^2 M_\odot,\ \beta = 5.0$$



strong compression
→ heavier elements are synthesized

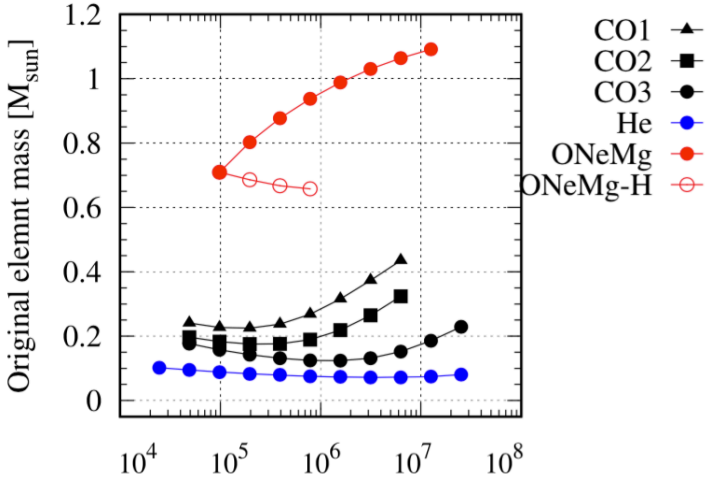
Summary

- WD-BH TDEs are interesting transients;
  nuclear reactions, good probe to study IMBH.
- We performed parameter study using 3D SPH simulations coupled with nuclear reactions.
- The TDEs are categorized into the 3 groups.
  We derive boundaries of these groups in the parameter space.
- Type 3 TDEs involve immediate self-intersection.
- He WD TDEs are not the origin of Ca-rich gap transients

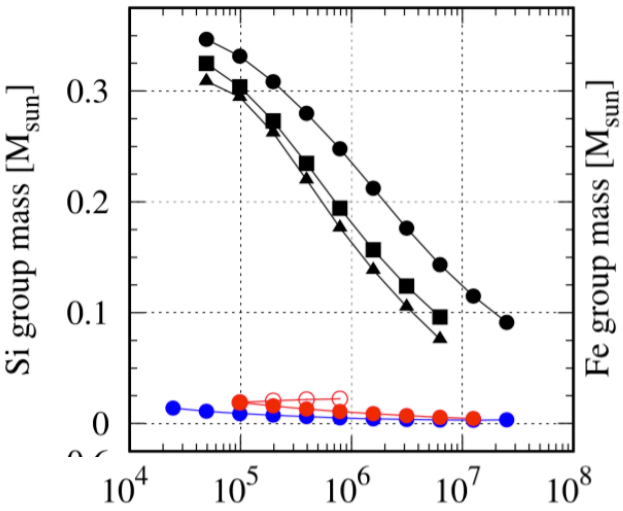
This research was supported by CREST, JST.

additional pages

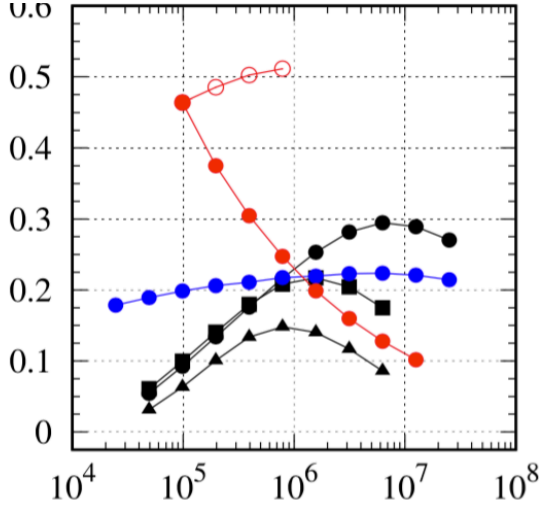
Problem:
Unconvergence on numerical resolution



# of SPH particles



# of SPH particles



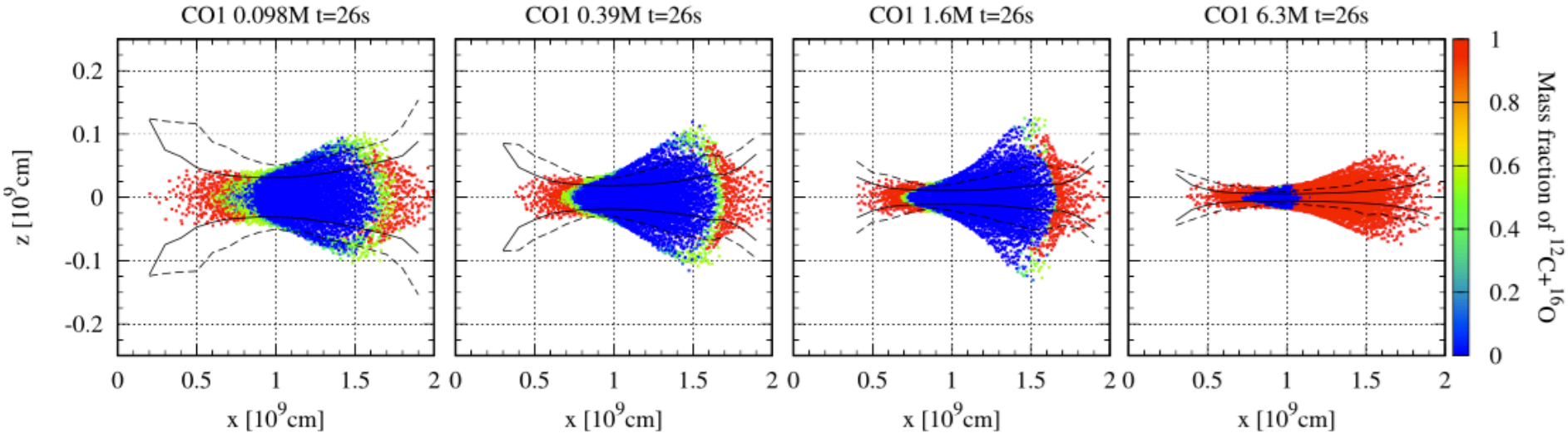
# of SPH particles

Tanikawa+ (2017)

Problem:
Unconvergence on numerical resolution

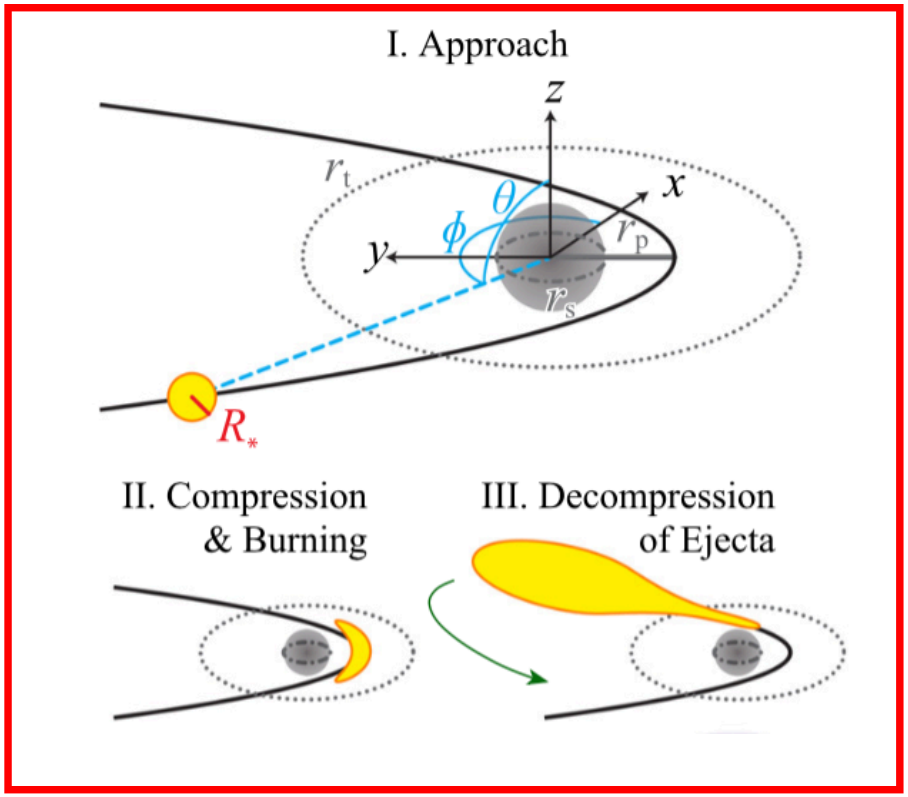
of SPH particles

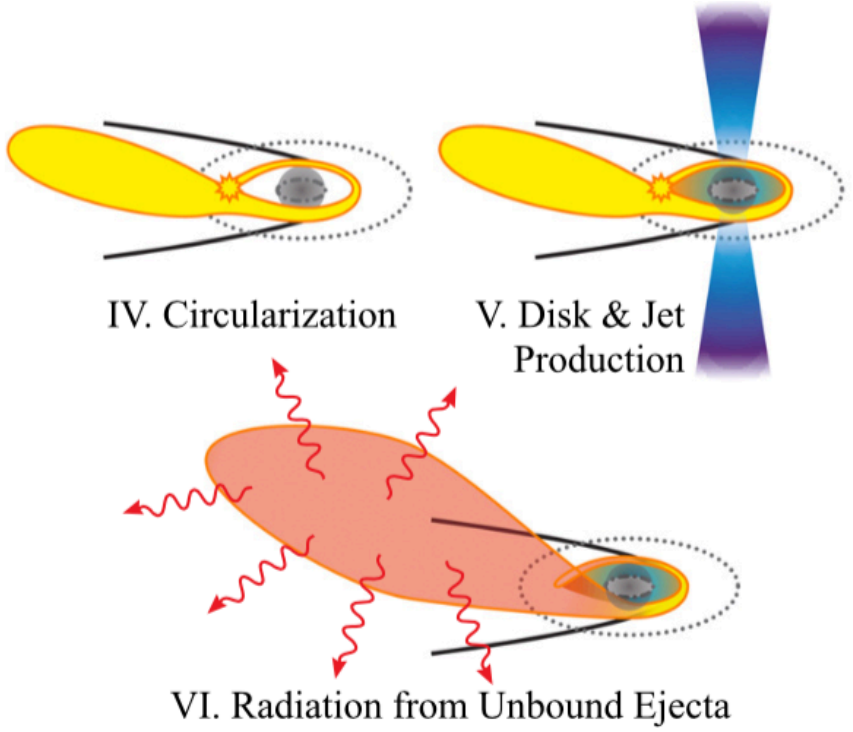
small ⟵ ⟶ large



Tanikawa+ (2017)

TDE of WD – IMBH





MacLeod+ (2016)

Methods

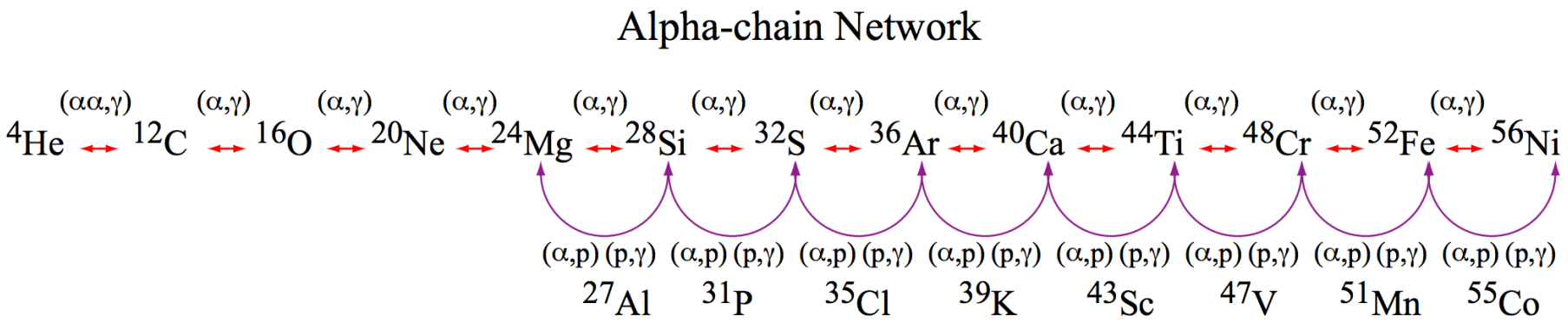
Other settings

- SPH: Wendland C2 kernel, vanilla-ice equations
- Optimization: FDPS (Framework for Developing Particle Simulator)
- Solving EoS and nuclear reactions: FLASH
- EoS of WD: HELMHOLTZ EoS
- WD has no spin
- Oribit: $e = 1$ (parabolic) in Newtonian gravity
- At $t = 0$, the distance between WD and IMBH is 2 or 4 R_t
- The compositions of WDs

$$M_{\mathrm{WD}} = \begin{cases} 0.2\ M_\odot\ (^4\mathrm{He}\ 100\%) \\ 0.6\ M_\odot\ (^{12}\mathrm{C}\ 50\%\ ^{16}\mathrm{O}\ 50\%) \\ 1.2\ M_\odot\ (^{16}\mathrm{O}\ 60\%\ ^{20}\mathrm{Ne}\ 35\%\ ^{24}\mathrm{Mg}\ 5\%) \end{cases}$$

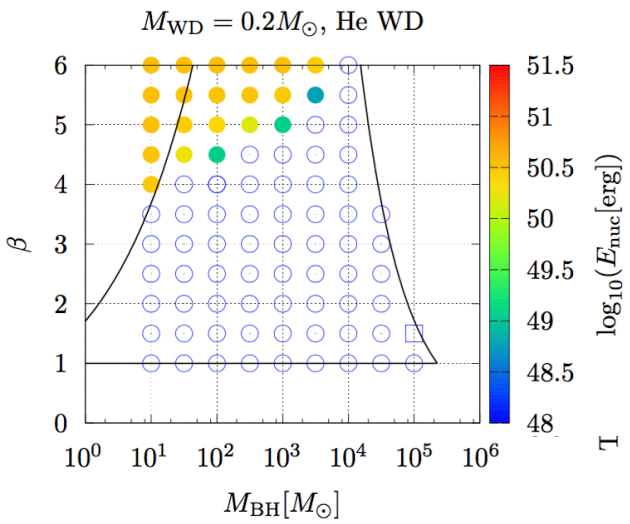
The nuclear reactions

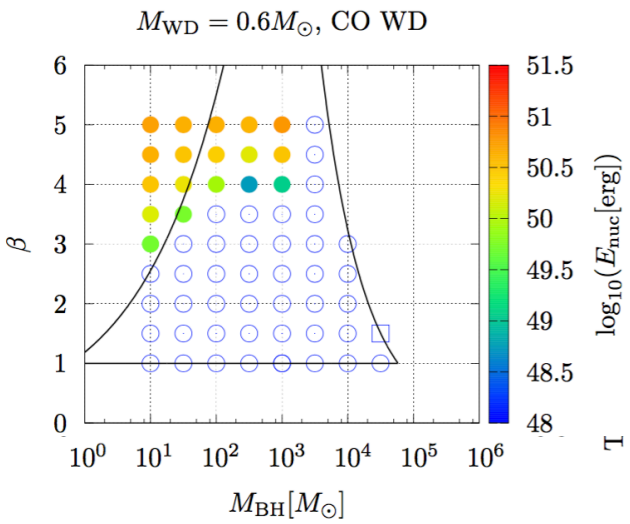
α-chain network reaction of 13 species

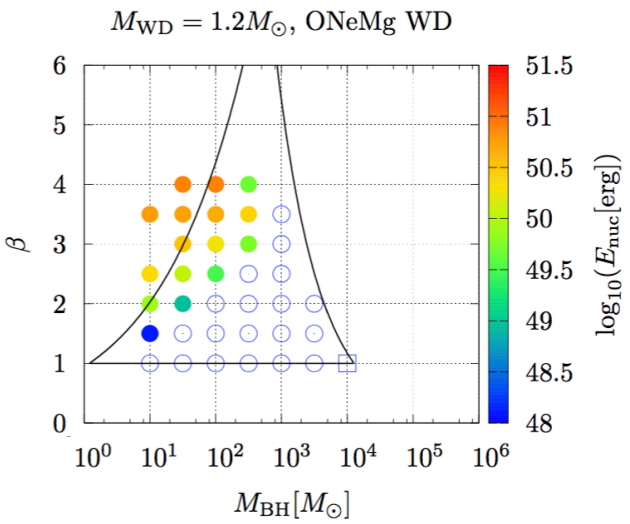


http://cococubed.asu.edu/

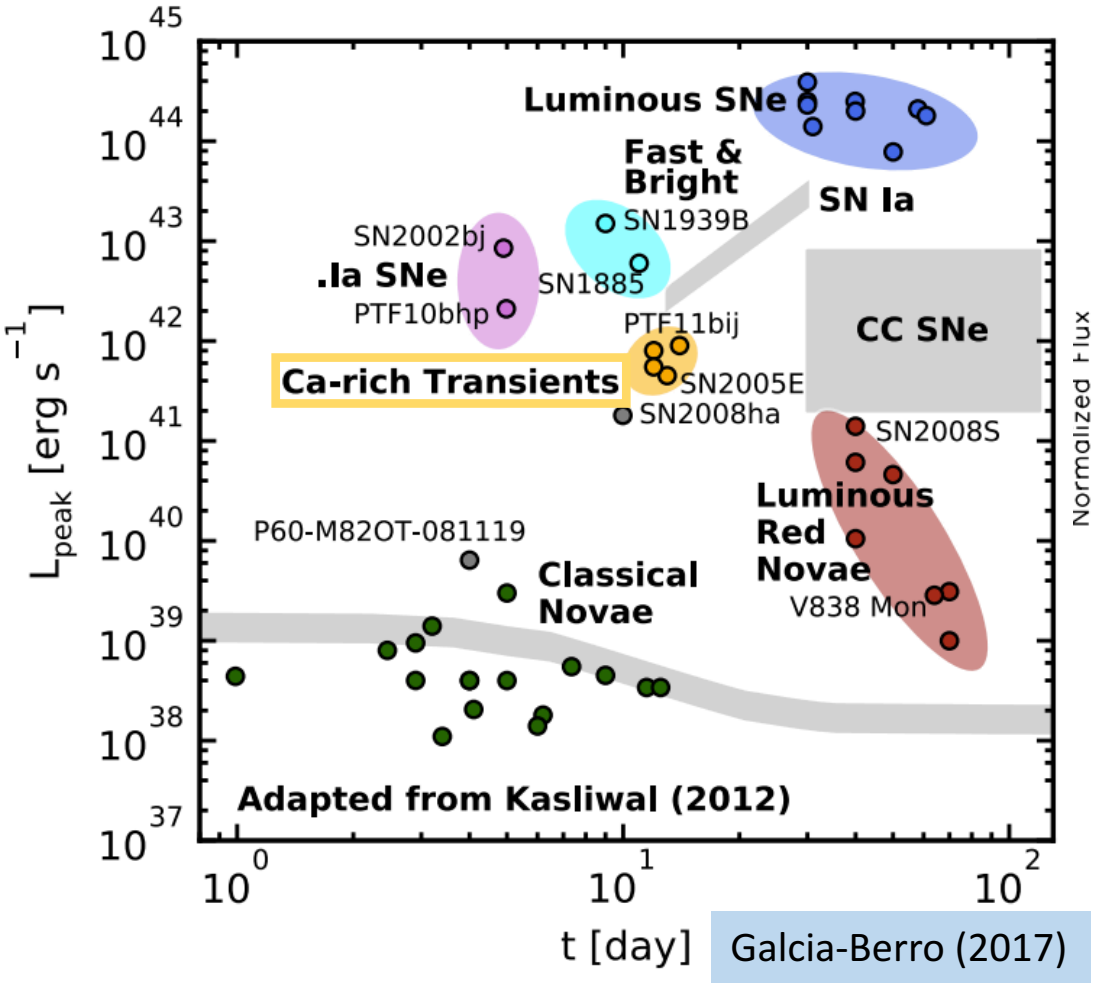
$M_{\rm WD}$ dependence



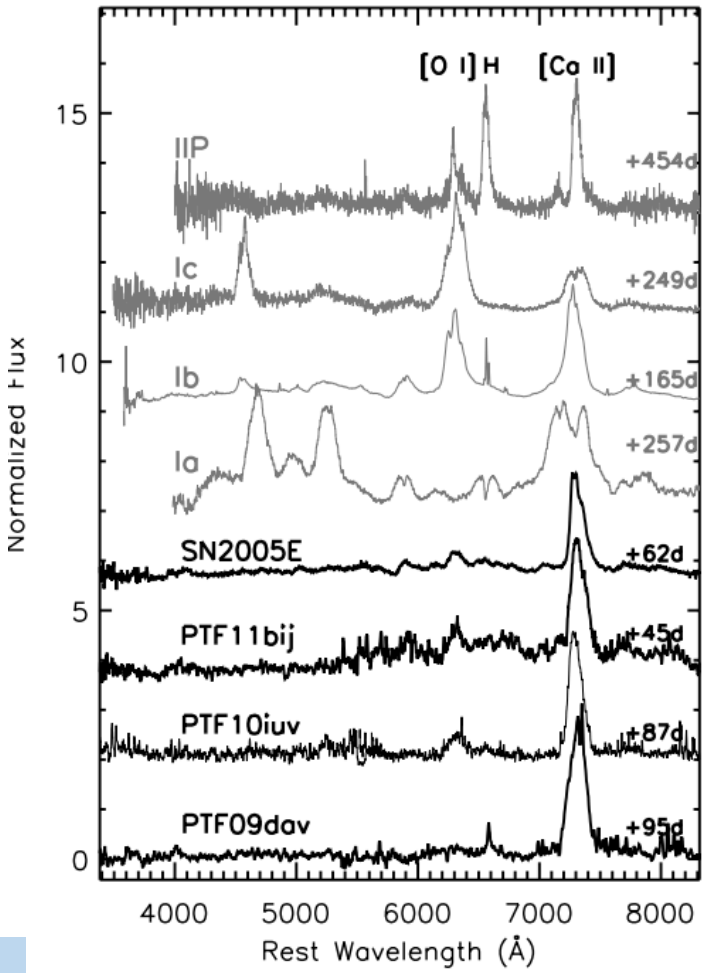




He WD TDEs as Ca-rich gap transients?



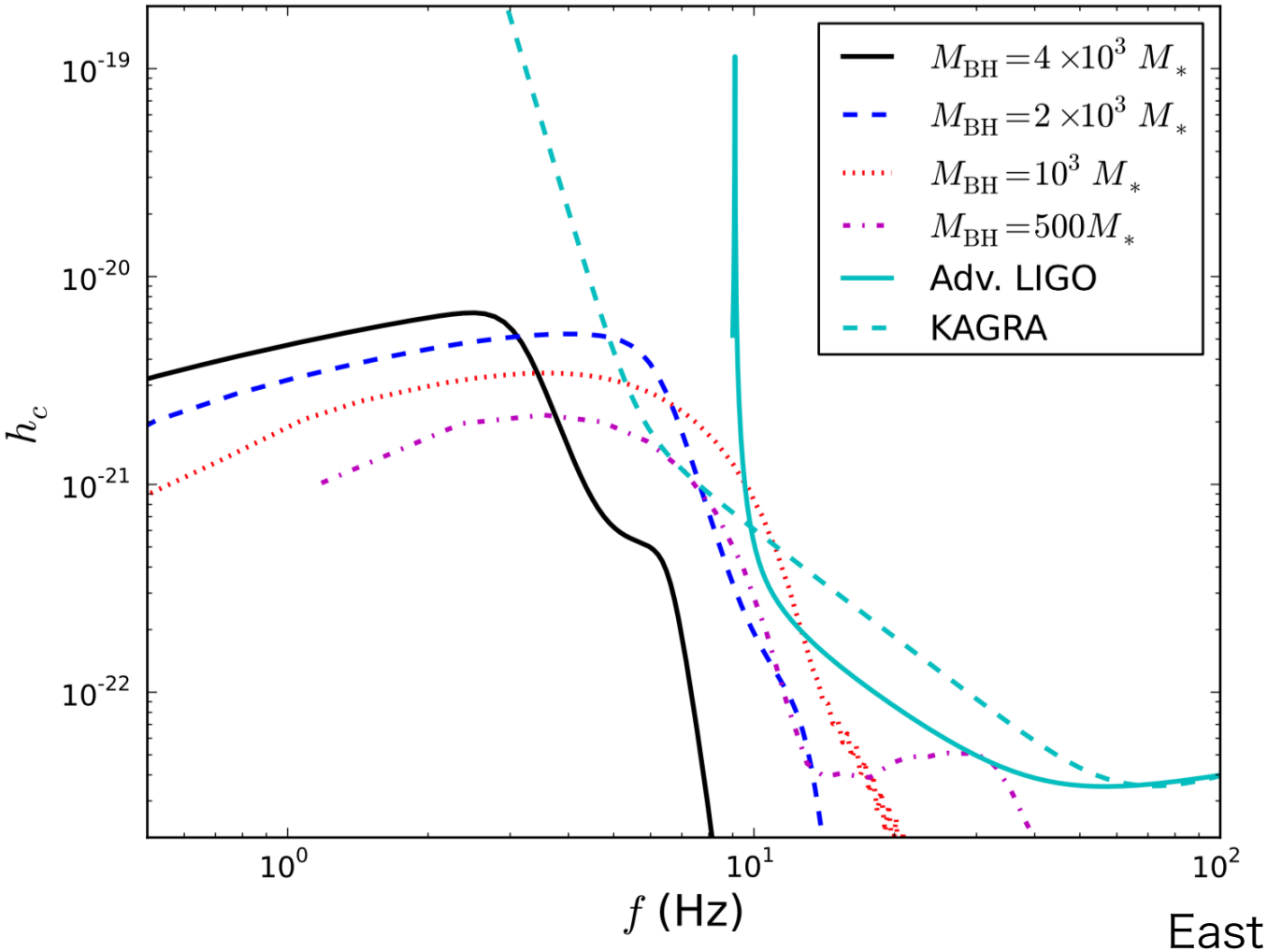
Galcia-Berro (2017)



Kasliwal+ (2012)

GW emission

$M_{\rm WD} = M_{\rm sun}$, $d = 1$ Mpc



East 2014

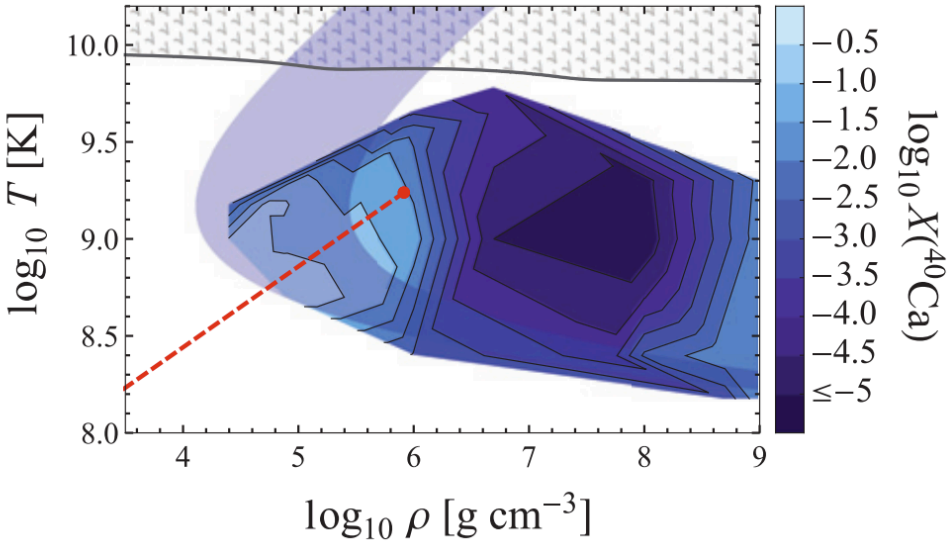
Previous research: Rosswog+ (2009)

Table 1
Summary of the Performed Runs

Run	M_{wd}	M_{BH}	β	Grav.	SPH Particles	$\log(E_{burn})$	"Fe" ($M_\odot$)	Comments
1	0.2	1000	12	N	4034050	50.46	0.025	Expl.
2	0.2	1000	12	PW	4034050	50.44	0.034	Expl.
3	0.2	1000	12	PW	200452	50.44		$\Gamma = 5/3$-polytrope
4	0.2	100	5	PW	100027	49.57	$<10^{-10}$	Explore BH influence, expl.
5	0.2	500	5	PW	100027	49.64	$<10^{-10}$	Explore BH influence, expl.
6	0.2	1000	5	PW	100027	49.76	$<10^{-10}$	Explore BH influence, expl.
7	0.2	5000	5	PW	100027	49.93	$<10^{-10}$	Explore BH influence, expl.
8	0.6	500	5	N	502479	50.68	0.18	Expl.
9	0.6	500	5	N	502479	50.62	0.13	Hot, initial WD
10	0.6	1000	0.9	N	1006446	0.00	0.	No nuclear burning
11	0.6	1000	5	PW	502479	50.43	3×10^{-4}	
12	0.6	10000	1.5	PW	502479	45.07	$<10^{-10}$	
13	1.2	100	3.5	N	100027	51.01	0.58	Expl.
14	1.2	500	2.6	PW	502479	51.16	0.66	Expl.
15	1.2	1000	1.5	PW	502479	49.63	0.014	
16	1.2	1000	3.0	N	502479	51.10	0.63	Expl.

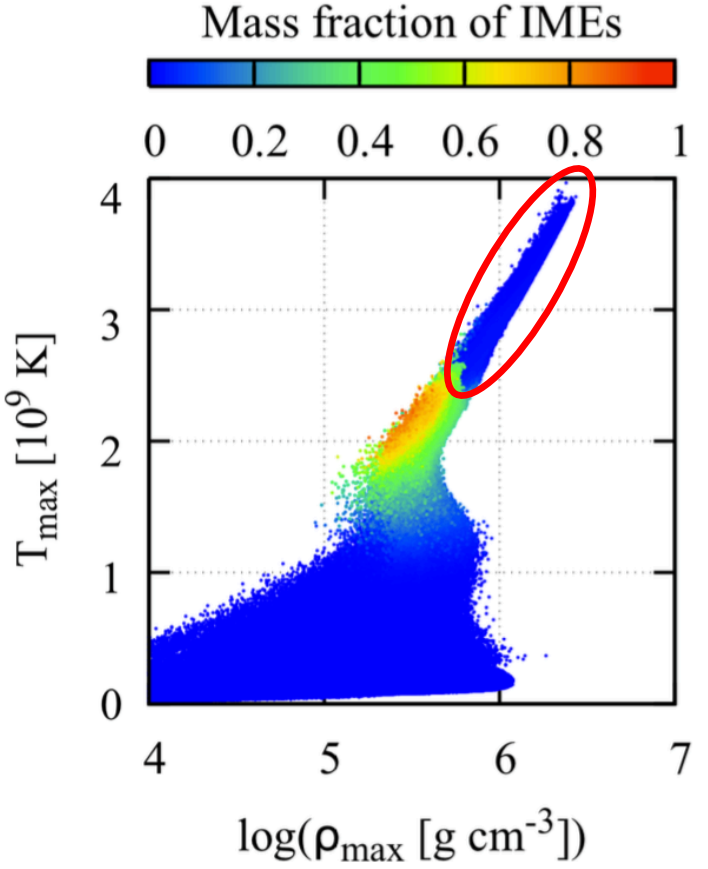
He WD TDEs as Ca-rich gap transients?

Outcome of nucleosynthesis in He WD



Holcomb+ (2013)

highly compressed so that
heavier elements are synthesized...



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