Explosive nucleosynthesis in tidal disruption events of massive white dwarfs, and their debris

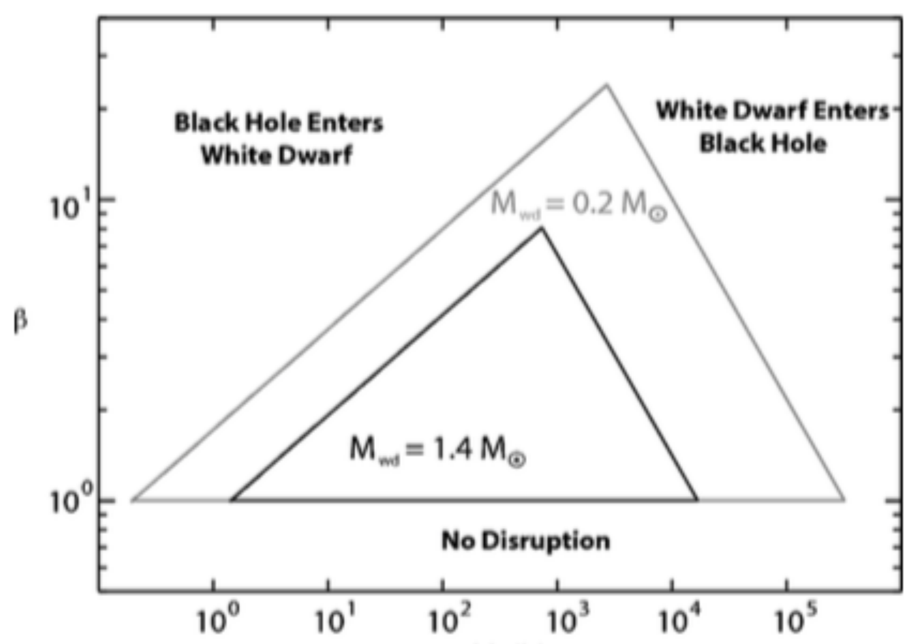
Ataru Tanikawa (Univ of Tokyo), Yushi Sato (Univ of Tokyo), Ken'ichi Nomoto (Univ of Tokyo), Keiichi Maeda (Kyoto Univ), Naohito Nakasato (Univ of Aizu), Izumi Hachisu (Univ of Tokyo)

Abstract

We investigate nucleosynthesis in tidal disruption events (TDEs) of white dwarfs (WDs) by intermediate mass black holes (IMBHs) by means of SPH simulations coupled with nuclear reactions. We consider three types of WDs with different masses and compositions: a helium (He) WD with 0.3M⊙, a carbon-oxygen (CO) WD with 0.6M⊙, and an oxygen-neon-magnesium (ONeMg) WD with 1.2M⊙. We model these WDs with different numbers of SPH particles, N, from a few 0.01 million to a few 10 million. We find that nucleosynthesis does not converge against N even for N > 10^7. For all the WDs, the amount of radioactive nuclei, such as ^{56}Ni, decreases with increasing N. Nuclear reactions might be extinguished for infinitely large N. Our SPH simulations can not resolve the scale height of a WD perpendicular to its orbital plane at the pericenter passage. This gives spurious heating to SPH particles, and triggers nuclear reactions artificially. Our results show that these kinds of TDEs, if solely powered by radioactive decays, are much dimmer optical transients similar to Type Ia supernovae as previously suggested. So, we would like to change our title to "Does explosive nuclear burning occur in TDEs of WDs by IMBHs?"

Introduction

- A number of TDEs have been found so far.
- Some of these TDEs may involve WDs (Krolik, Piran 2011; Scherbakov et al. 2013; Jonker et al. 2013).
- Since WDs are disrupted only by stellar-mass BH and IMBHs, WD TDEs can be clues to search for IMBHs.



Rosswog et al. (2009)

- WD TDEs can be transients powered by mass accretion onto IMBHs, and by radioactive nuclei produced through explosive thermonuclear reactions (Rosswog et al. 2008; 2009; Macleod et al. 2016).
- In this study, we investigated WD TDEs with respect to the explosive thermonuclear reactions.
- The explosive thermonuclear reactions require not only adiabatic heating but also shock heating in WD TDEs.
- If the shock wave occurs, its wave front is parallel to the orbital plane of a WD.
- SPH simulations need sufficient mass resolution in the direction perpendicular to the orbital plane in order to correctly deal with the shock wave.
- We performed SPH simulations with N > 10 million particles, unprecedentedly large N in this field, in order to examine whether the simulations correctly deal with the shock wave, and whether the explosive thermonuclear reactions occur correctly.

Method

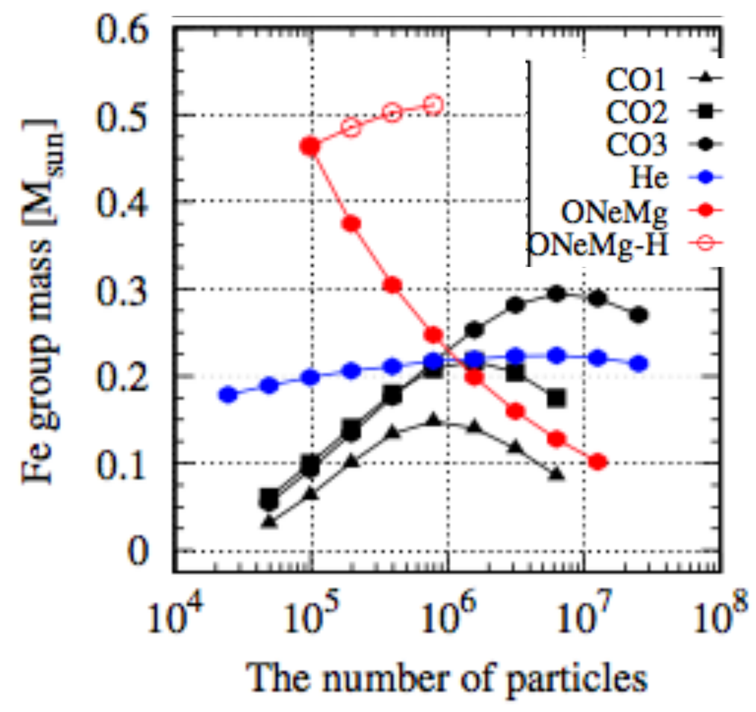
- SPH simulation optimized with FDPS (Iwasawa et al. 2016) and AVX intrinsic functions (e.g. Tanikawa et al. 2012ab)
- The number of particle: > 10 million
- EoS: Helmholtz equation of state (FLASH module)
- Nuclear reaction: Aprox13 (FLASH module)
- IMBH gravity
  - Newtonian potential (NP)
  - Paczynski-Wiita potential (PW)
  - A generalized Newtonian potential (Tejeda, Rosswog 2013) (TR)
- WD: 0.3M⊙ HeWD, 0.6M⊙ COWD, 1.2M⊙ ONeMgWD
- Parabolic orbit

Model	M_{wd}	R_{wd}	M_{bh}	β	R_p	Compositions	CC	IMBH	N	Comments
CO1	0.6	0.75	500	5.0	1.4	^{12}C 50% ^{16}O 50%	w/o	NP	up to 6.3M	Rosswog's run 8
CO2	0.6	0.75	500	5.0	1.4	^{12}C 50% ^{16}O 50%	w/	TR	up to 6.3M	
CO3	0.6	0.75	500	5.0	1.4	^{12}C 50% ^{16}O 50%	w/	PW	up to 25M	
He	0.3	1.00	500	5.0	2.4	^{4}He 100%	w/	PW	up to 25M	
ONeMg	1.2	0.35	100	3.0	0.52	^{16}O 60% ^{20}Ne 35% ^{24}Mg 5%	w/	PW	up to 13M	

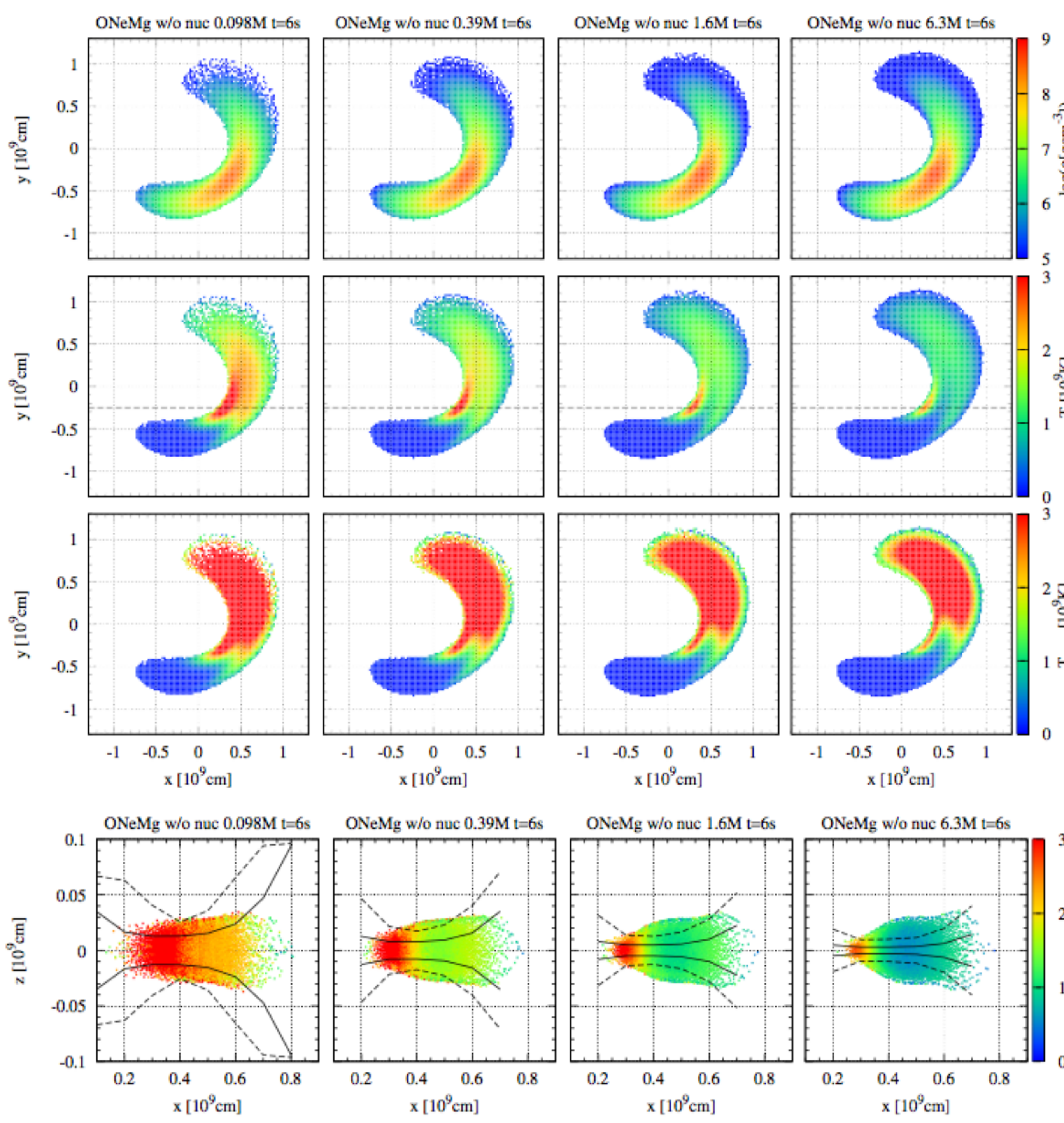
NOTE—M_{wd} and M_{bh} are, respectively, the masses of a WD and IMBH in units of $M_⊙$. R_{wd} and R_p are, respectively, the WD radius and pericenter distance in units of 10^9 cm. β is the ratio of the WD tidal radius to the pericenter distance. CC is an abbreviation for Coulomb correction. IMBH indicates the gravitational potential of the IMBH, where NP, PW, and TR are abbreviations for Newtonian, the Paczyński-Wiita, and the Tejeda-Rosswog potentials, respectively.

Results

The amount of Fe group element decreases as the number of SPH particles increases.

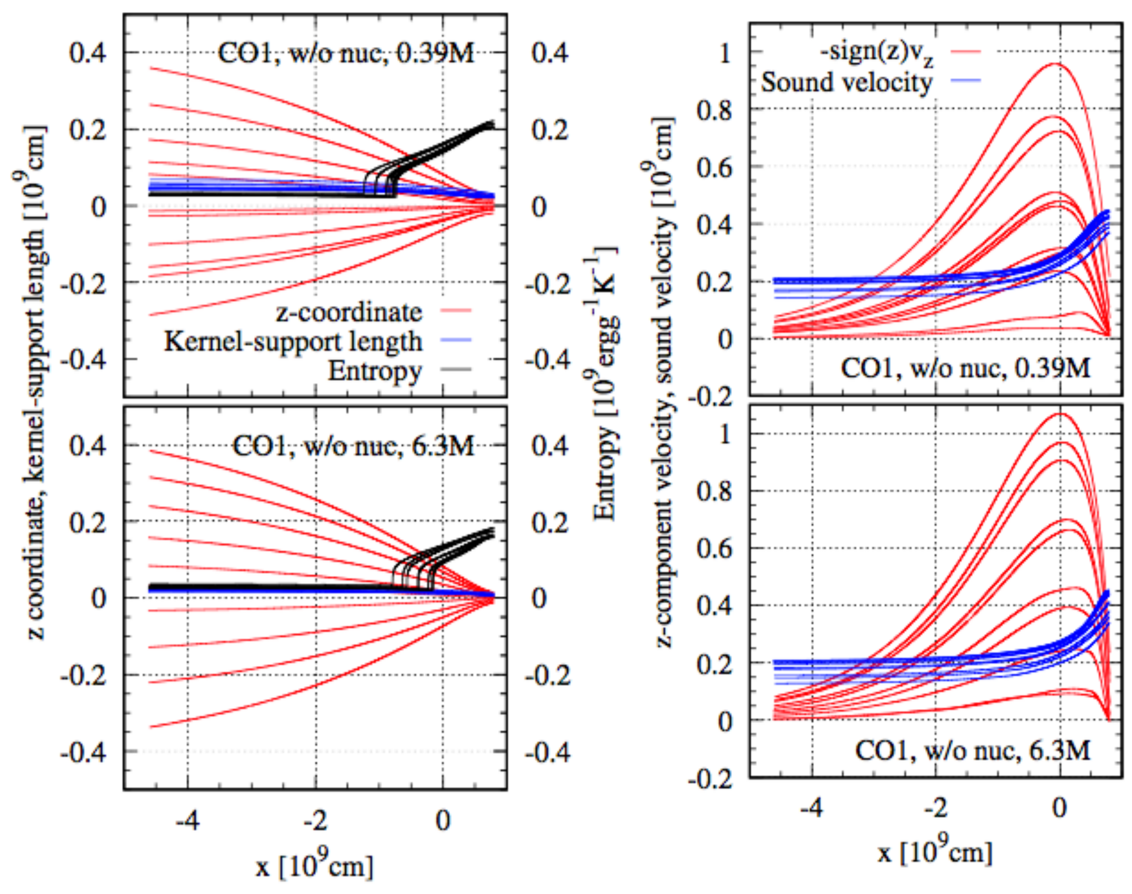


Model ONeMg w/o nuc



- SPH kernel radii exceed the scale height of WDs, in particle low-N.
- SPH particles artificially get high temperature when SPH kernel radii are comparable to the scale height.

Discussion



- Entropy is generated despite of the absence of shock wave.
- Entropy in N=0.39M is generated eariler than that in N=6.3M
- Entropy is generated through the interaction between particles on the orbital plane and the outermost particles.