The hybrid CONe WD + He star binaries as the progenitors of SNe Ia

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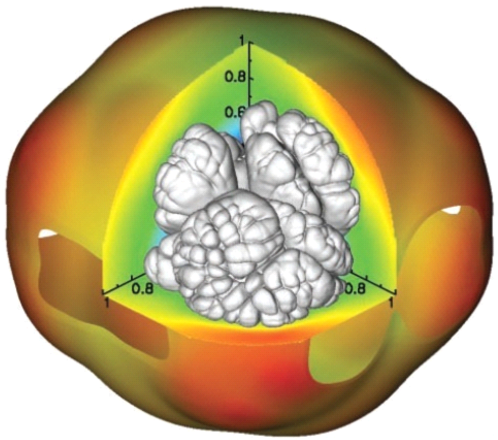
SNe Ia play an important role in astrophysics

- Distance indicators (Riess et al. 1998; Perlmutter et al. 1999)
- Galaxy chemical evolution (Greggio & Renzini 1983)



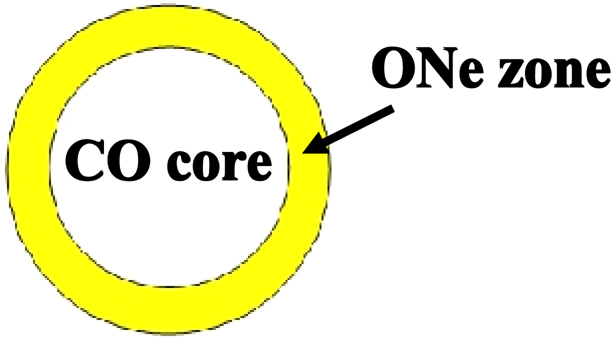
Gamezo et al. (2003)

SNe Ia are from thermalnuclear explosions of CO WDs

（see Nomoto et al. 1997; Wang & Han 2012; Maoz et al. 2014)

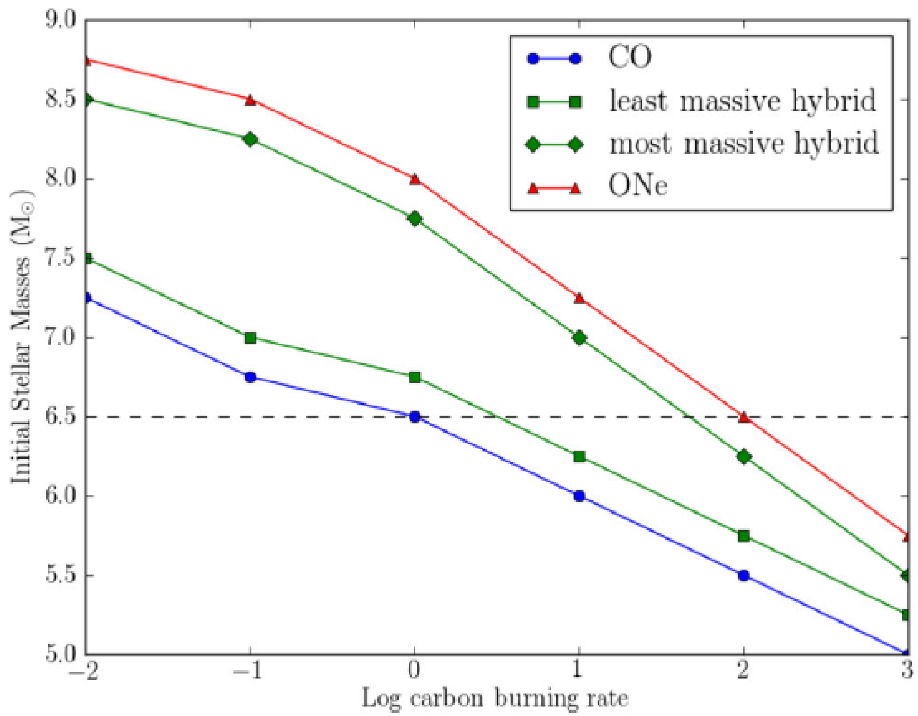
CONe WDs

- A kind of hybrid WDs
- Denissenkov et al. (2013) found that convective boundary mixing in a super-AGB star can prevent the carbon burning from reaching the center, and then form a CONe WD.
- Such a WD has an unburnt CO core surrounded by a thick ONe zone after the AGB star has lost its envelope.



CONe WDs

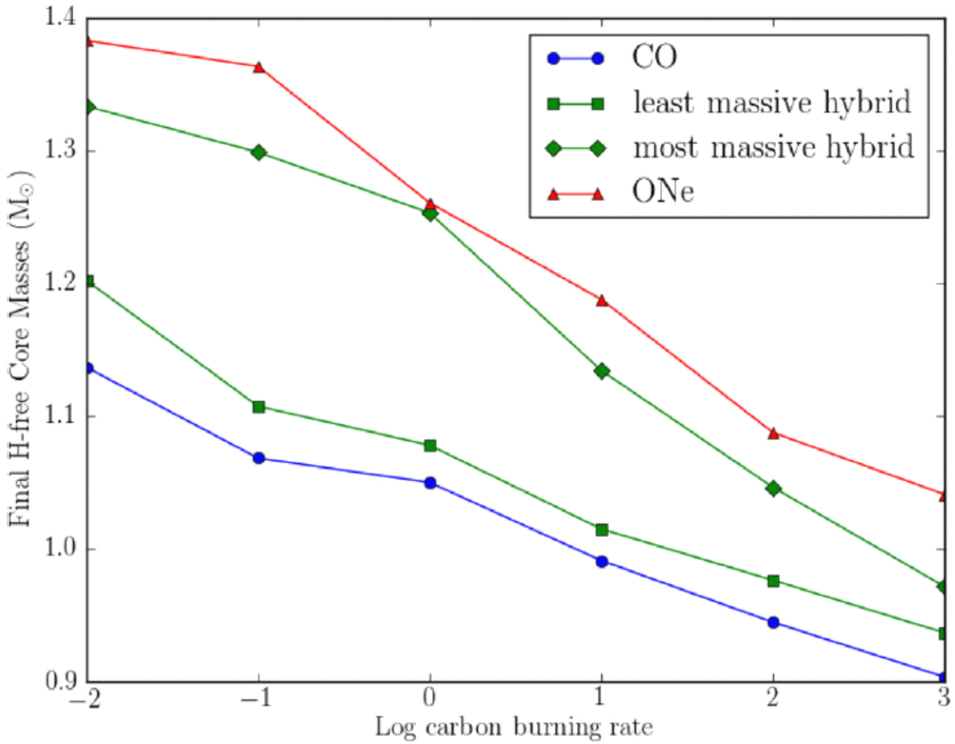
Because the carbon burning rate is still unclear, Michael Chen et al. (2014) found that CONe WDs can be produced even by stars with an initial mass $>7M_{\odot}$.



Chen et al. (2014)

CONe WDs

The mass of CONe WDs could be close to $1.3M_{\odot}$ in the extreme case by adopting a carbon burning rate of 0.1.



Chen et al. (2014)

CONe WDs

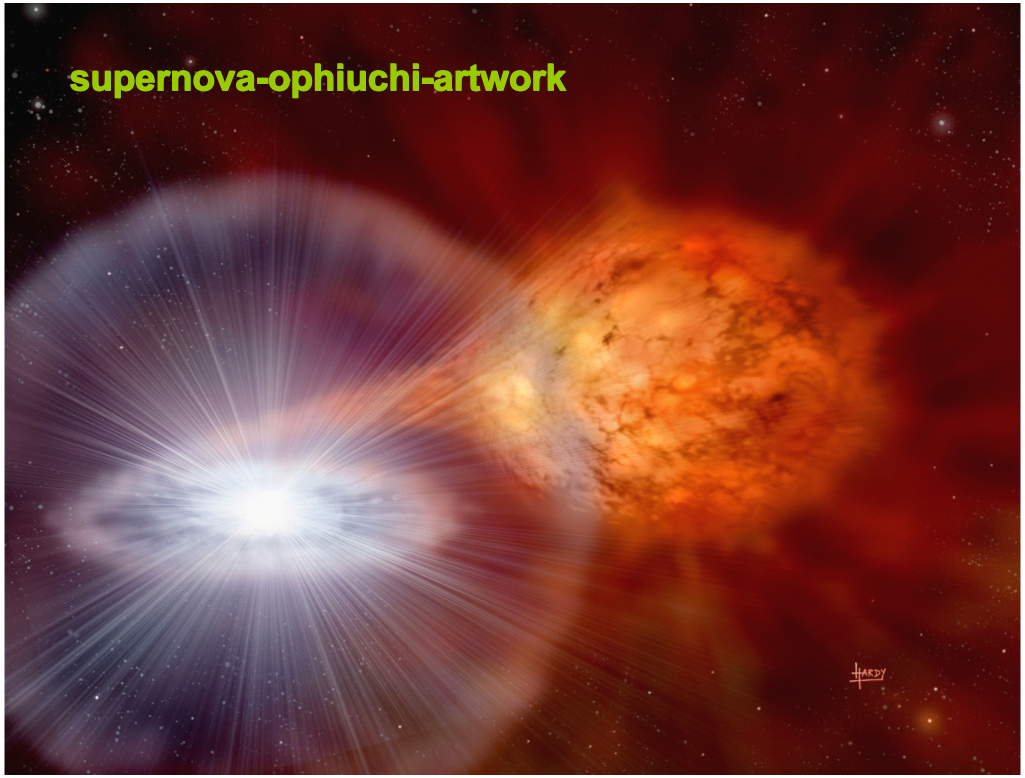
- Denissenkov et al. (2015) found that CONe WDs can reach a carbon burning condition, depending on the convective Urca process and some mixing assumptions.

- It's easy for CONe WD to increase its mass to the Chandrasekhar mass limit by accreting material, which can increase the birthrates of SNe Ia if these WDs can really produce SNe Ia.

✓ **CONe WD + MS**

✓ **CONe WD + RG**

✓ **CONe WD + He star**



Why we study WD + He star systems?

- The companion of SN 2012Z may be a He star (e.g., McCully et al. 2014).
- The mass donor of SN 2014J may also be a He star (see Diehl et al. 2014).
- US 708 (a hypervelocity He star) may be the surviving companion of a SN Ia (Geier et al. 2015; see also Jusham et al. 2009; Wang & Han 2009)
- This model can produce young SNe Ia (e.g., Wang et al. 2009).

Observations: (4 massive WD＋He star systems)

- **KPD 1930+2572** (Maxted et al. 2000; Geier et al. 2007)

- **CD-30 11223** (Vennes et al. 2012; Geier et al. 2013)

- **V445 Pup**

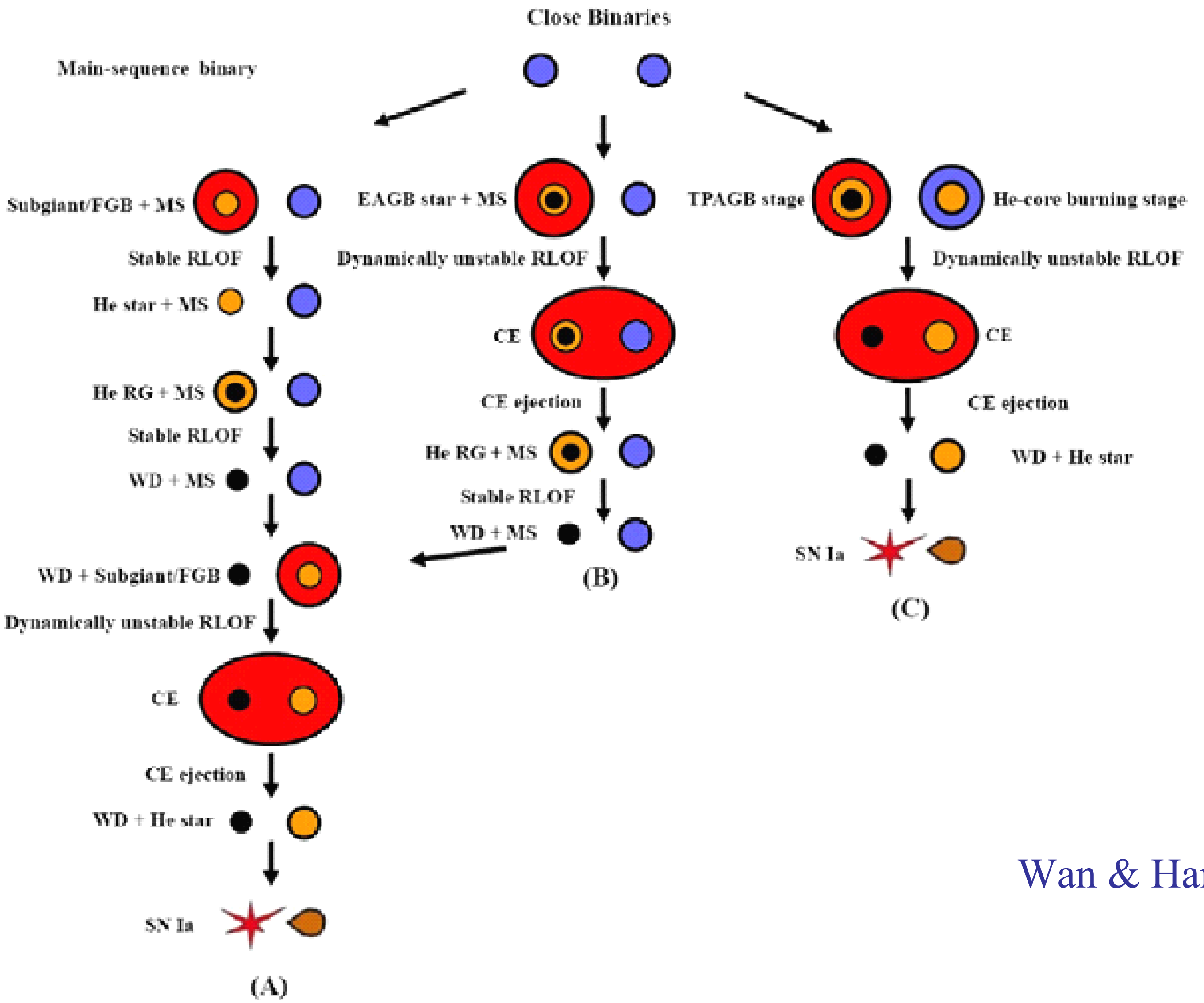
  A He nova, considered to be a WD accreting He from its companion, $M_{WD}>1.35M_{\odot}$ (Kato et al. 2008; Woudt et al. 2009)

- **HD 49798 with its massive WD companion**

  $M_{WD}=1.28M_{\odot}$, $M_{He}=1.5M_{\odot}$, $P^{i}=1.548d$

  （Mereghetti et al. 2009, 2011)

Three channels to WD+He star systems

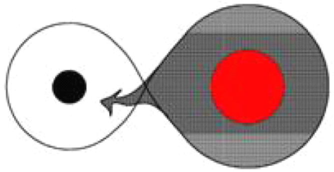


Wan & Han (2012)

Two mass-transfer processes to SNe Ia

Case 1. the He star fills its Roche lobe at the main-sequence stage

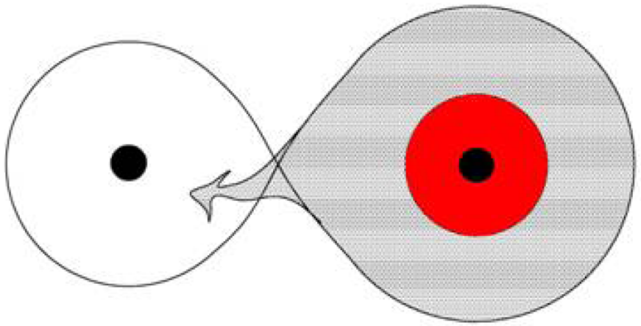
CONe WD



He star

Case 2. the He star fills its Roche lobe at the subgiant stage

CONe WD



He subgiant

Wang et al. (2014, ApJL, 794, L28)

Contours for producing SNe Ia

Wang et al. (2014, ApJL, 794, L28)

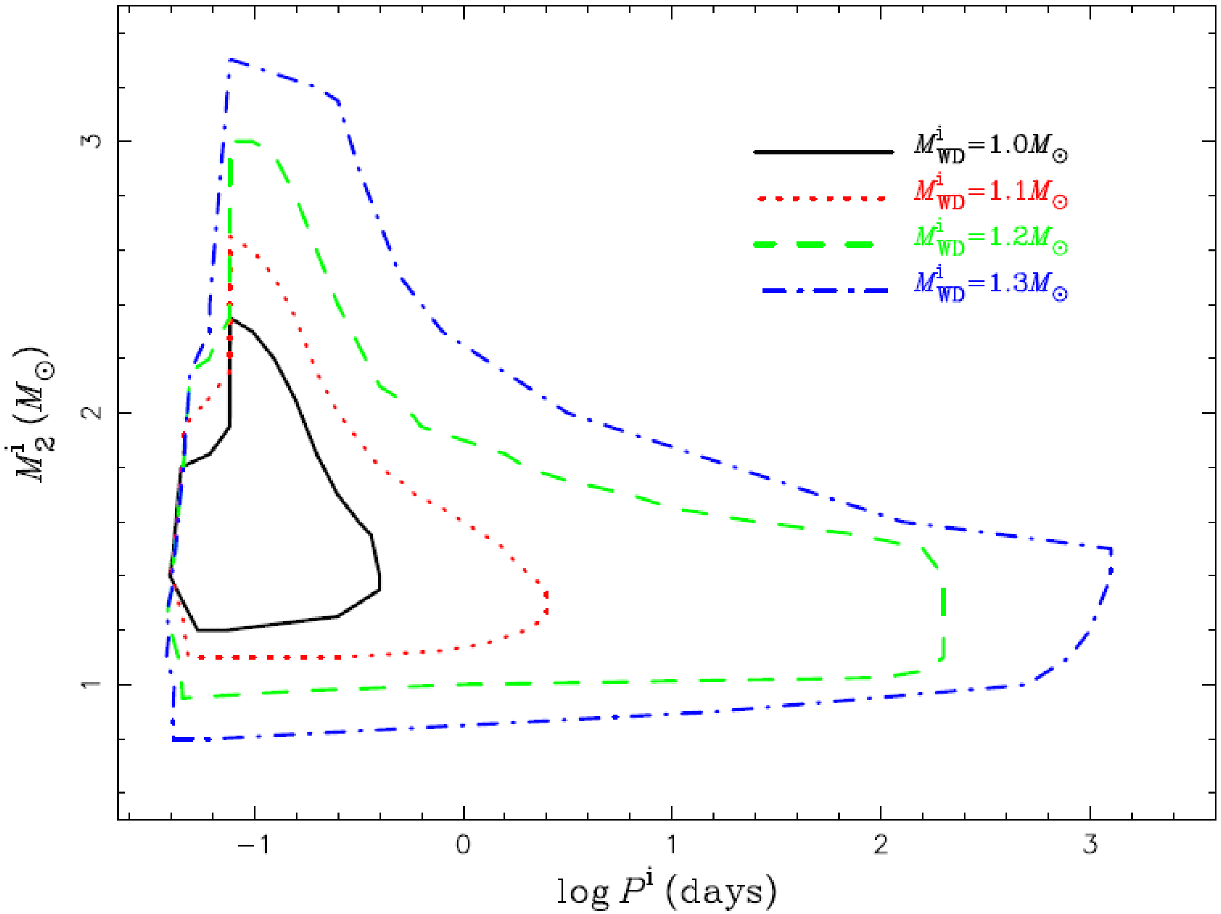


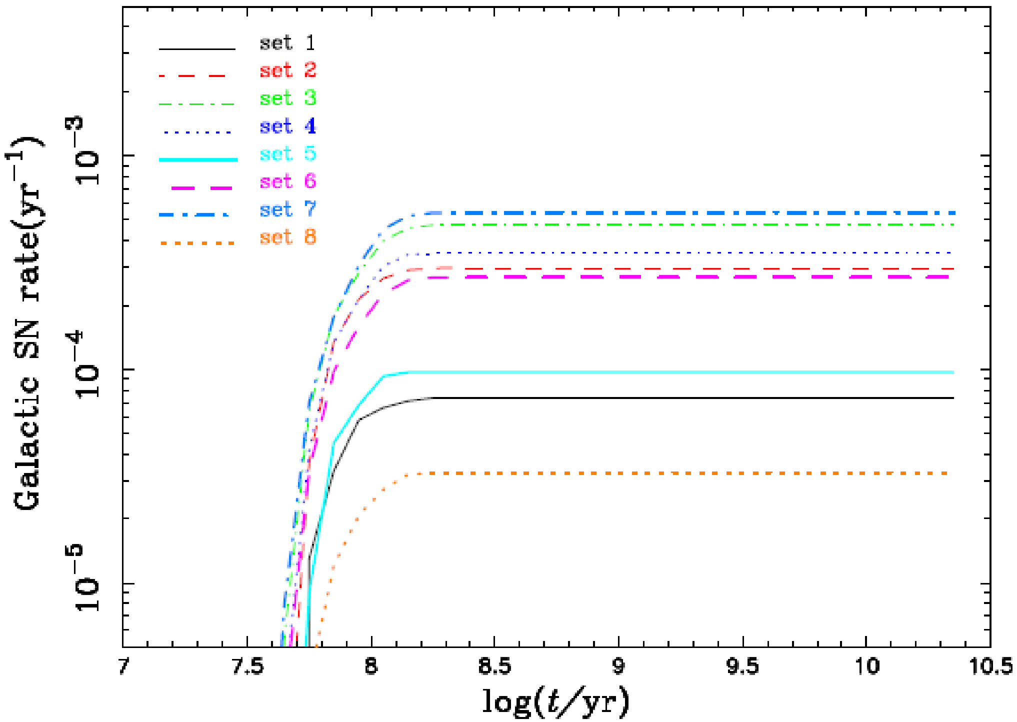
Figure 1. Contours in the initial orbital period and initial companion mass plane for CONe WD binaries that produce SNe Ia for various initial WD masses.

Birthrates of SNe Ia in the Galaxy

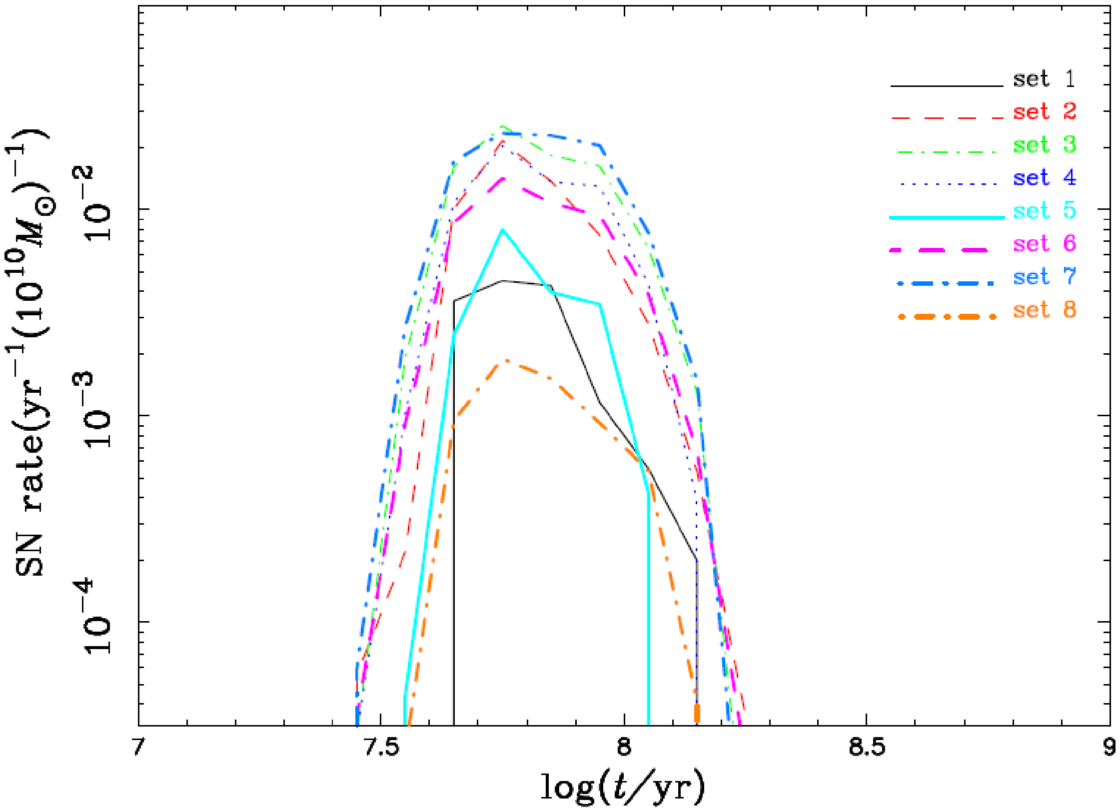
$$\sim 0.03\text{–}0.5\times 10^{-3}\,\mathrm{yr}^{-1}$$

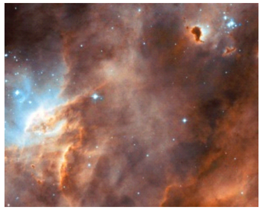
Set	$\alpha_{ce}\lambda$	CBR	IMF	$n(q)$	Rate (10^{-3} yr^{-1})
1	0.5	0.1	MS79	Constant	0.073
2	1.0	0.1	MS79	Constant	0.298
3	1.5	0.1	MS79	Constant	0.473
4	1.5	1	MS79	Constant	0.348
5	1.5	10	MS79	Constant	0.097
6	1.5	0.1	S86	Constant	0.269
7	1.5	0.1	MS79	Rising	0.539
8	1.5	0.1	MS79	Uncorrelated	0.033

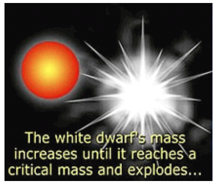
Wang et al. (2014, ApJL, 794, L28)



Delay times of SNe Ia







~30-200Myr

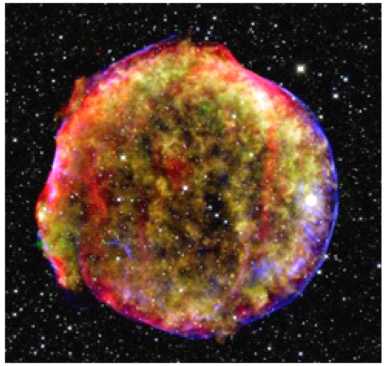
Wang et al. (2014, ApJL, 794, L28)

SNe Ia from CONe WD + He star channel may show some special properties

- SNe Ia from this channel are very young and have delay times as short as ~30Myr. Such SNe Ia may be observed in galaxies with recent star formation.
- SN Ia birthrates can account for up to 10% of all SNe Ia.
- He lines in their early spectra.
- Compared with normal CO WDs, CONe WDs have a relatively low carbon abundance. Therefore, SNe Ia from CONe WDs could have a lower peak luminosity, and thus a relatively low ejecta velocity (see also Meng & Podsiadlowski 2014).

Wang et al. (2014, ApJL, 794, L28)

Type Iax SNe



- A special kind of SNe Ia (Foley et al. 2013).
- SNe Iax have peak luminosities as low as that of the faint events, but the spectra like bright objects.
- About 25 SNe Iax have been observed, in which two of them show strong He lines in their spectra.
- Most of them have been found in late-type galaxies.
- The birthrates of SNe Iax may account for 5%–30% of total SNe Ia (e.g., Li et al. 2011; Foley et al. 2013).

The above observed properties of SNe Iax may be comparable to those from the CONe WD + He star channel. Wang et al. (2014, ApJL, 794, L28)

LETTER

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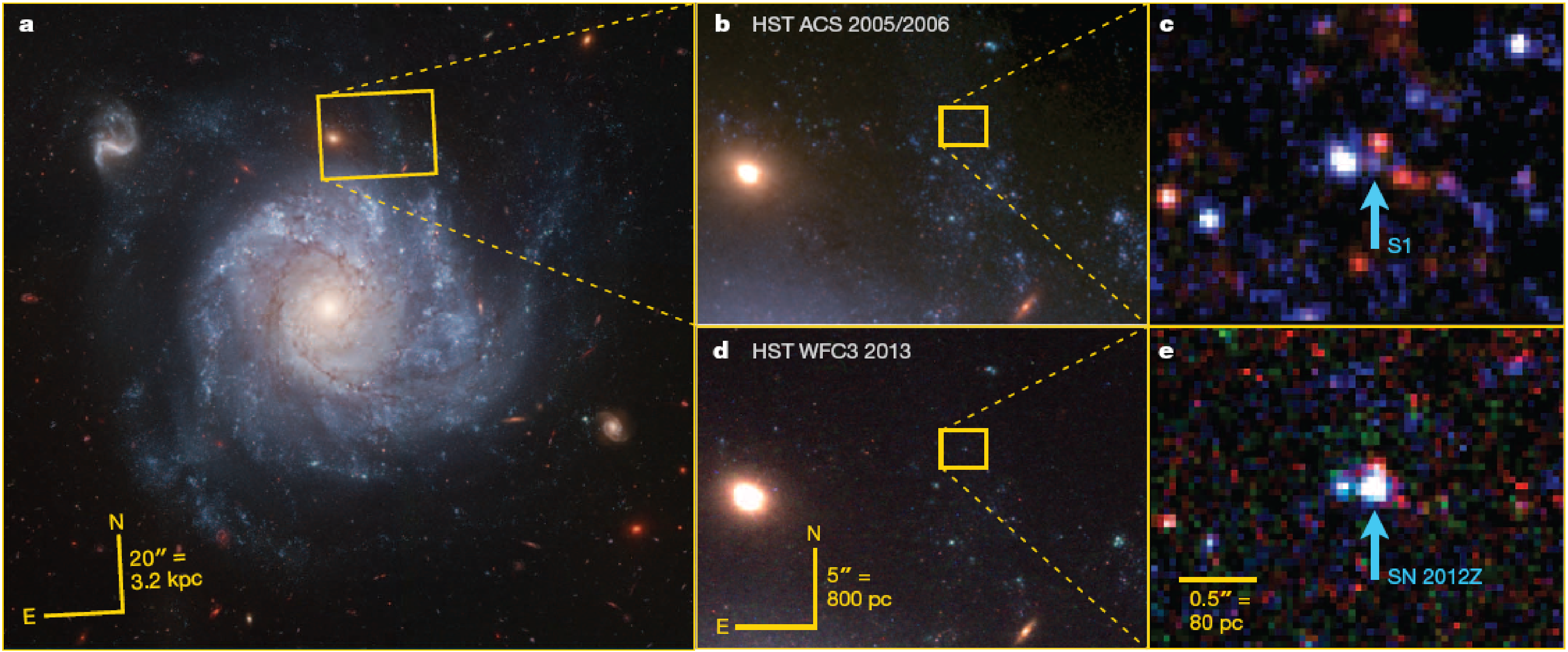
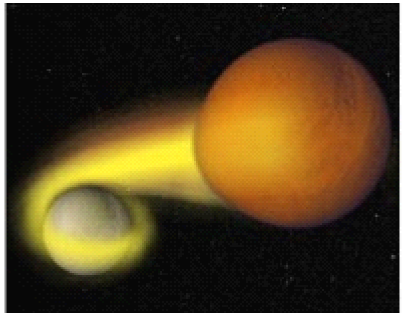
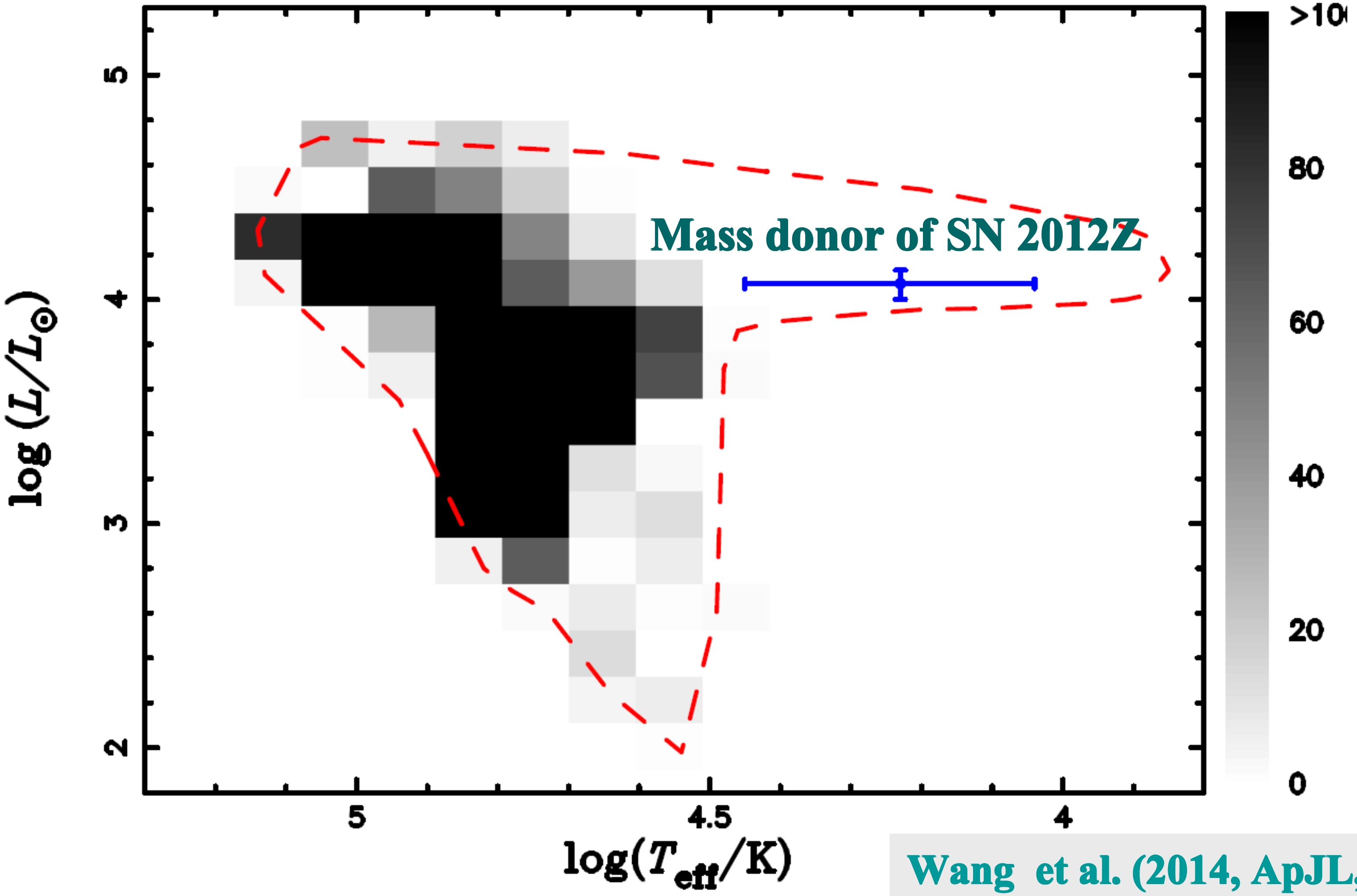
A luminous, blue progenitor system for the type Iax supernova 2012Z

Curtis McCully[1], Saurabh W. Jha[1], Ryan J. Foley[2,3], Lars Bildsten[4,5], Wen-fai Fong[6], Robert P. Kirshner[6], G. H. Marion[6,7], Adam G. Riess[8,9] & Maximilian D. Stritzinger[10]





CONe WD + He star



Wang et al. (2014, ApJL, 794, L28)

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Deflagrations in hybrid CONe white dwarfs: a route to explain the faint Type Iax supernova 2008ha

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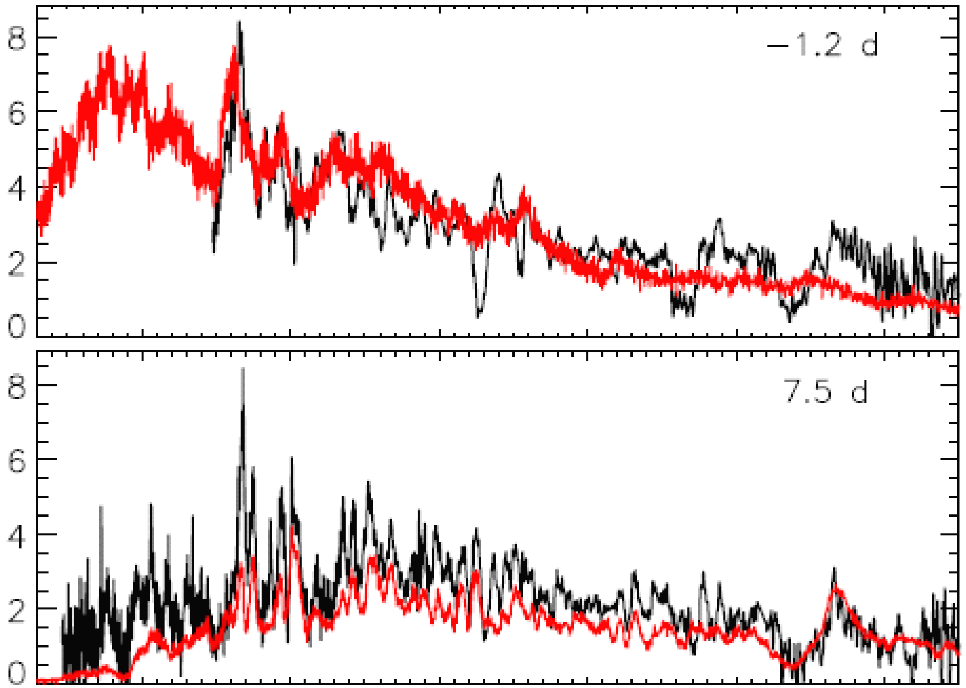
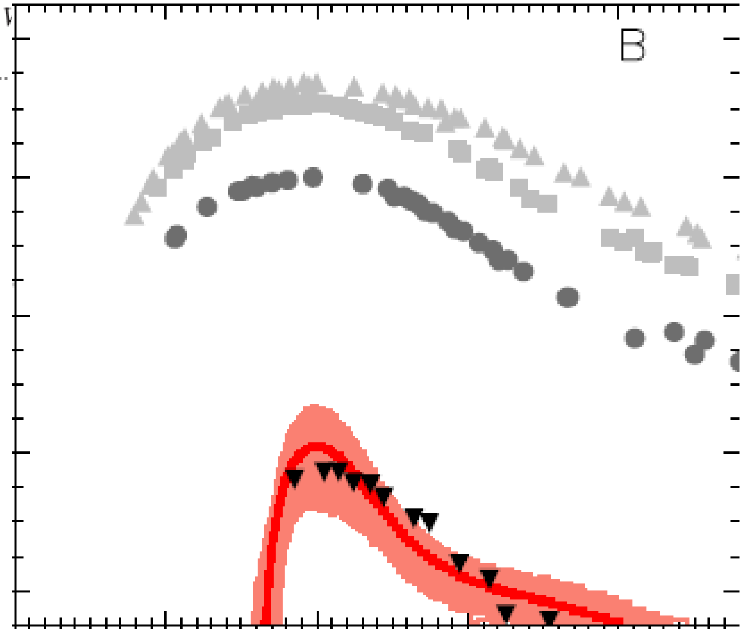
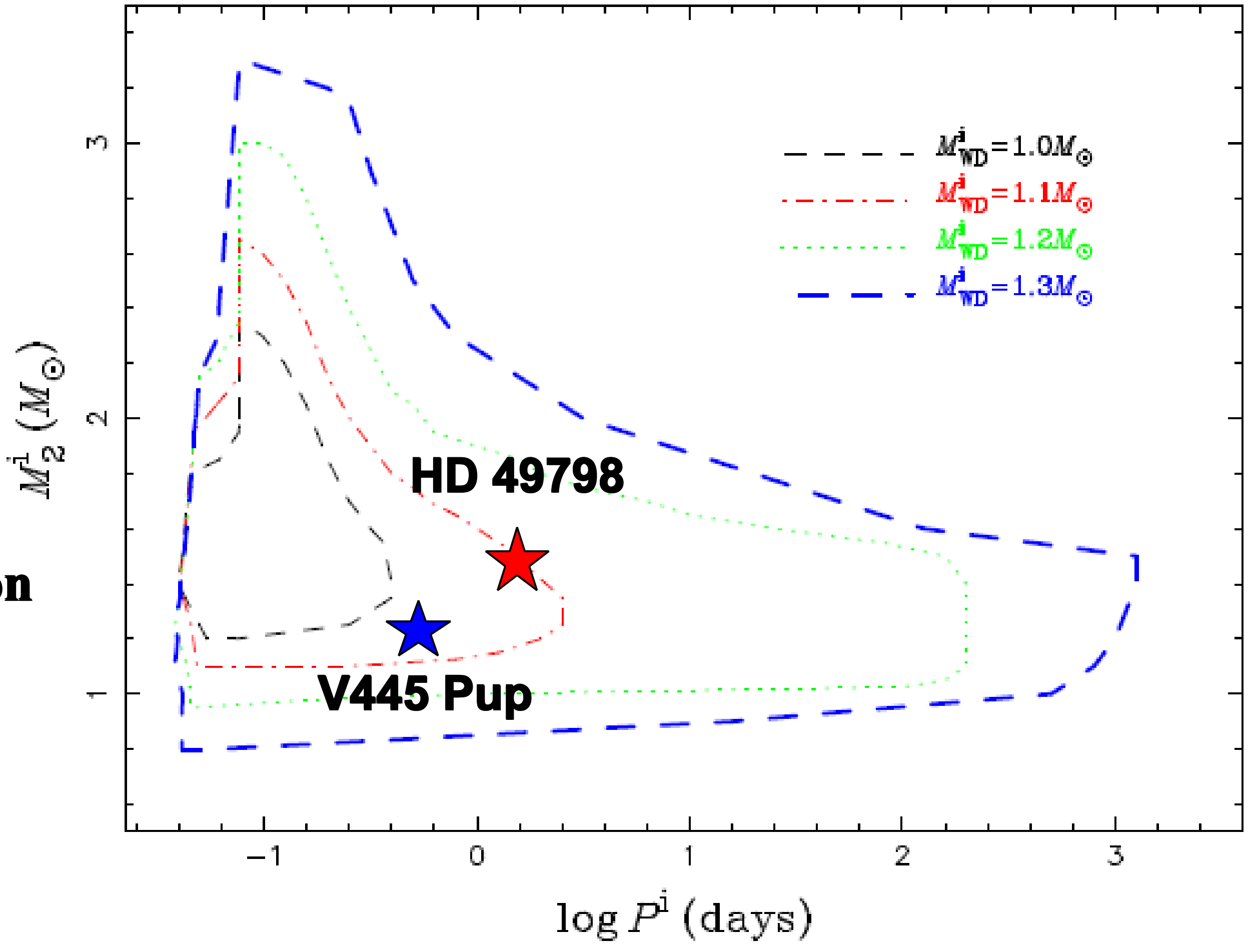




Two progenitor candidates

- **V445 Pup, a He nova**
  M_{WD}=1.35-1.38$M_{\odot}$,
  M_{He}=1.2$M_{\odot}$
  P=0.65 d
  (Kato et al. 2008; Woudt et al. 2009; Goranskij et al. 2010)

- **HD 49798 with its massive WD companion**
  $M_{WD}=1.28M_{\odot}$,
  $M_{He}=1.5M_{\odot}$
  $P^{i}=1.548$d
  (Mereghetti et al. 2009, 2011)



Summary

- Birthrates of SNe Ia from this channel roughly account for 10% of all SNe Ia.
- The delay times are ~30-200Myr, which are the youngest SNe Ia produced by any progenitor model so far.
- SNe Ia from this channel may provide an alternative way for the production of Iax SNe.
- We obtained many properties of the surviving companions of this channel, which may be verified by future observations.

Thanks !

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