Osaka@2013.6.11

Neutron Star Mass Distribution in Binaries

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Astro-Hadron Group in Pusan Nat'l Univ

- Problems related to NS
  - dense matter physics/ NS equation of states
  - formation and evolution of NS
  - GW from NS binaries
- LSC members
  - Dr. Hee-Suk Cho (gave a talk yesterday)
  - Y.M. Kim (NIMS, will give a talk today)
  - M.G. Kim (1st year in Ph.D., pre-LSC member)
- Non-LSC members (2 students)
  - working on hadron physics (dense matter physics)
  - dense matter physics / NS equation of states

seen NS-NS binaries which will coalesce within Hubble time

PSR	P (ms)	P_b (hr)	e	Total Mass $M_\odot$	τ_c (Myr)	τ_{GW} (Myr)
J0737−3039A	22.70	2.45	0.088	2.58	210	87
J0737−3039B	2773	2.45	0.088	2.58	50	87
B1534+12	37.90	10.10	0.274	2.75	248	2690
J1756−2251	28.46	7.67	0.181	2.57	444	1690
B1913+16	59.03	7.75	0.617	2.83	108	310
B2127+11C	30.53	8.04	0.681	2.71	969	220
J1141−6545†	393.90	4.74	0.172	2.30	1.4	590

Can we see BH-NS binaries as pulsars even if they exist ?

Pulsar life time : 1/B

Fresh pulsar : B $\sim 10^{12}$ G

- NS-NS
  → if first-born NS is recycled by accretion
  → longer pulsar life time (B $\sim 10^{8}$ G)
  → bigger chances to be observed
- BH-NS: No recycled pulsar

Second fresh pulsar doesn't live long !

GW sources with NS

- NS-NS – already seen
- NS-BH – no evidence yet
  - contribution to GW is still unknown

Q) what is the boundary between NS & BH ?
- maximum mass of neutron stars

Contents

- Open problems in NS mass observations.
- Supercritical accretion in NS binaries
- Possibilities of `NS + high-mass NS/BH` binaries

1.97 Msun NS discovered in a NS-White Dwarf Binary

October 27, 2010

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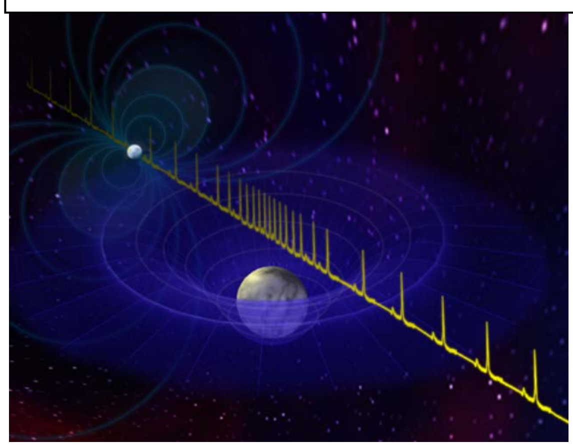
Astronomers Discover Most Massive Neutron Star Yet Known

LETTER

doi:10.1038/nature09466

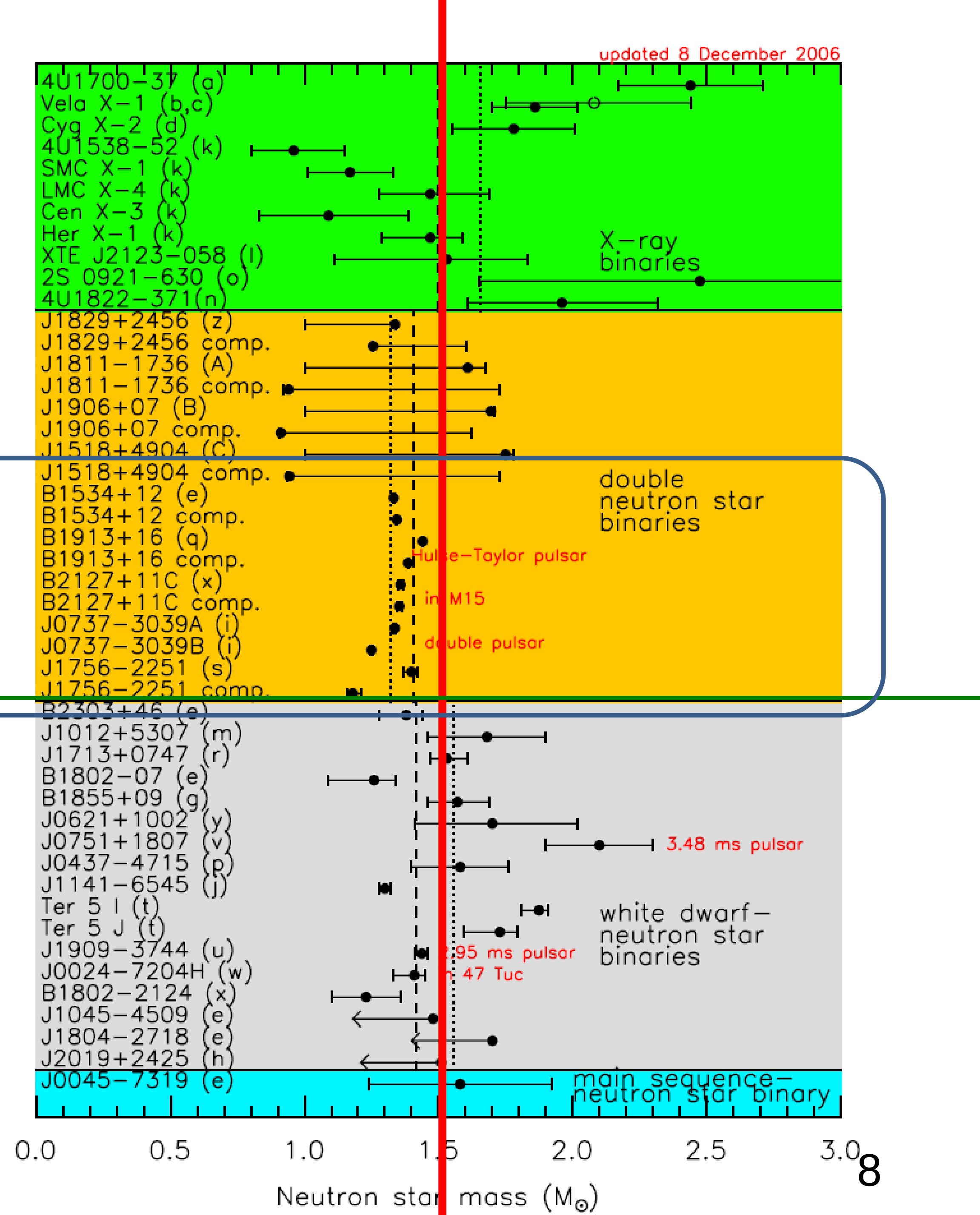
A two-solar-mass neutron star measured using Shapiro delay

P. B. Demorest[1], T. Pennucci[2], S. M. Ransom[1], M. S. E. Roberts[3] & J. W. T. Hessels[4,5]



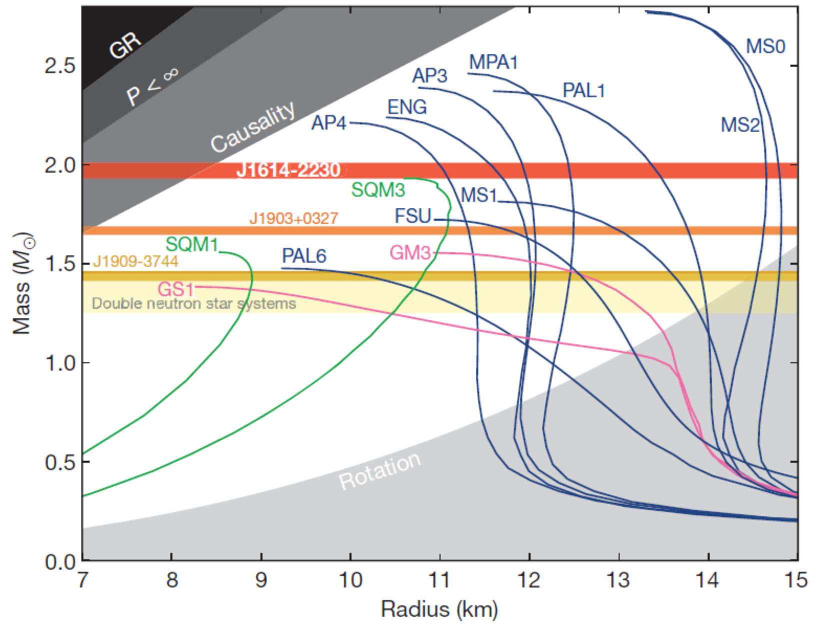
http://www.nrao.edu/pr/2010/bigns/

All well measured NS masses in NS-NS binaries are < 1.5 Msun



Lattimer & Prakash (2007)

Wanted



Nature 467, 1081

- 1.97 Msun NS was observed in a NS-WD binary
- Why all well-measured NS masses in NS-NS binaries are less than 1.5 Msun?
- NS mass may/should depend on the evolution process.

arXiv:0907.3219v1

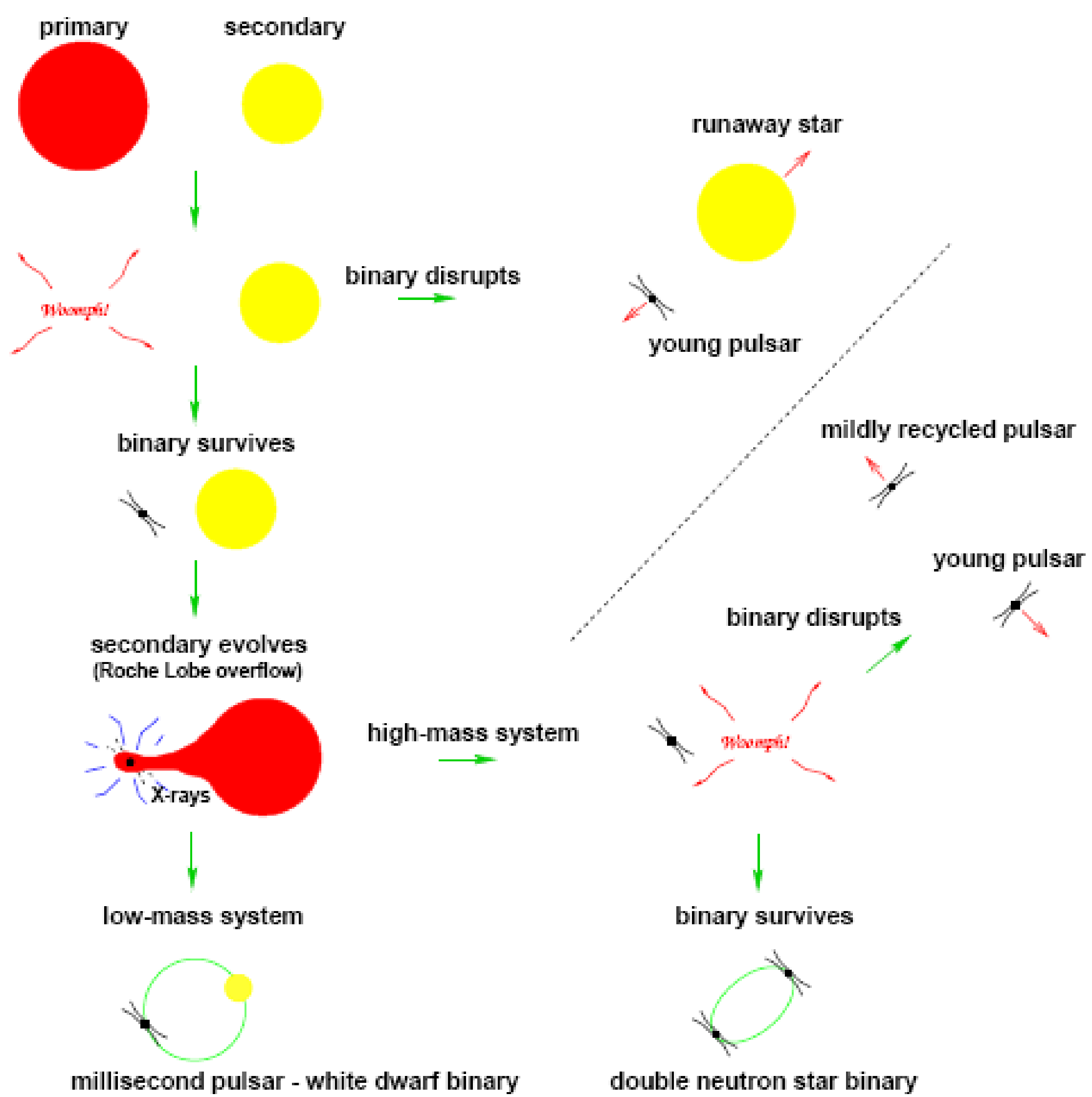


FIGURE 1. Formation of millisecond pulsars. From Lorimer (2008).

Accretion process is essential in understanding NS binaries

Contents

- Open problems in NS mass observations.
- Supercritical accretion in NS binaries
- Possibilities of \`NS + high-mass NS/BH\` binaries

Eddington Luminosity & Eddington Limit

$$L_{\rm Edd} = \frac{4\pi c G M}{\kappa} \approx 1.3 \times 10^{38} \frac{M}{M_\odot} \,{\rm erg\ s^{-1}}$$

$$\kappa = \sigma_T N_A$$

Thomson scattering cross section σ_T

Avogadro's number N_A

$$L_{\rm Edd} = \eta \dot{M}_{\rm Edd} c^2$$

$$\dot{M}_{\rm Edd} = \frac{4\pi G M}{\kappa c \eta} \approx \frac{1}{\eta} 0.45 \times 10^{-8} \left(\frac{M}{M_\odot}\right) M_\odot \,{\rm yr^{-1}}$$

[Lee,Park,Brown,ApJ 670,741(2007)]

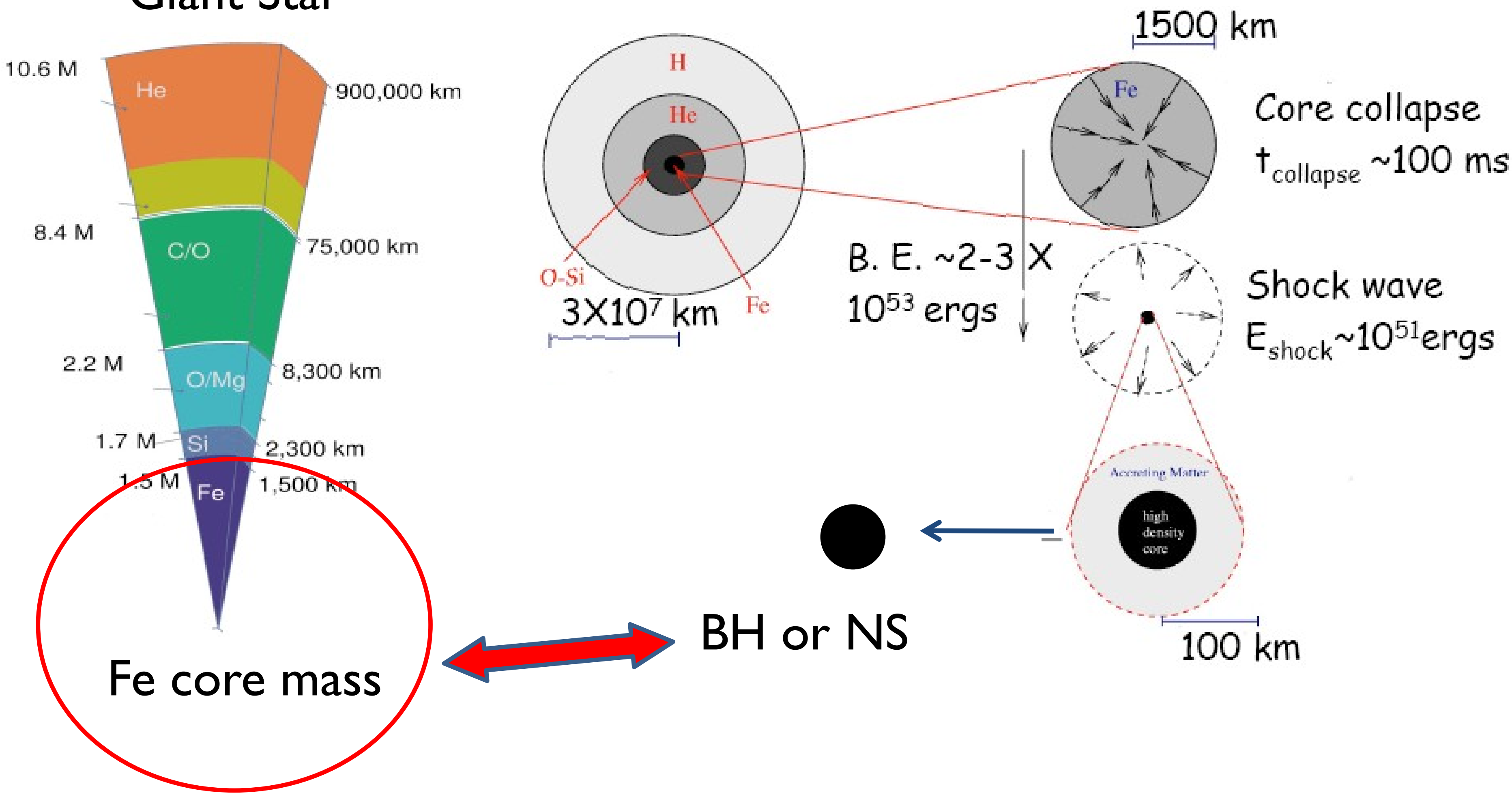
Supercritical Accretion onto first-born NS

- Eddington Accretion Rate : photon pressure balances the gravitation attraction
- If this limit holds, neutron star cannot be formed from the beginning (e.g. SN1987A; 10^8 Eddington Limit).
- Neutrinos can take the pressure out of the system allowing the supercritical accretion when accretion rate is bigger than 10^4 Eddington limit !
  (T > 1 MeV : Thermal neutrinos dominates !)

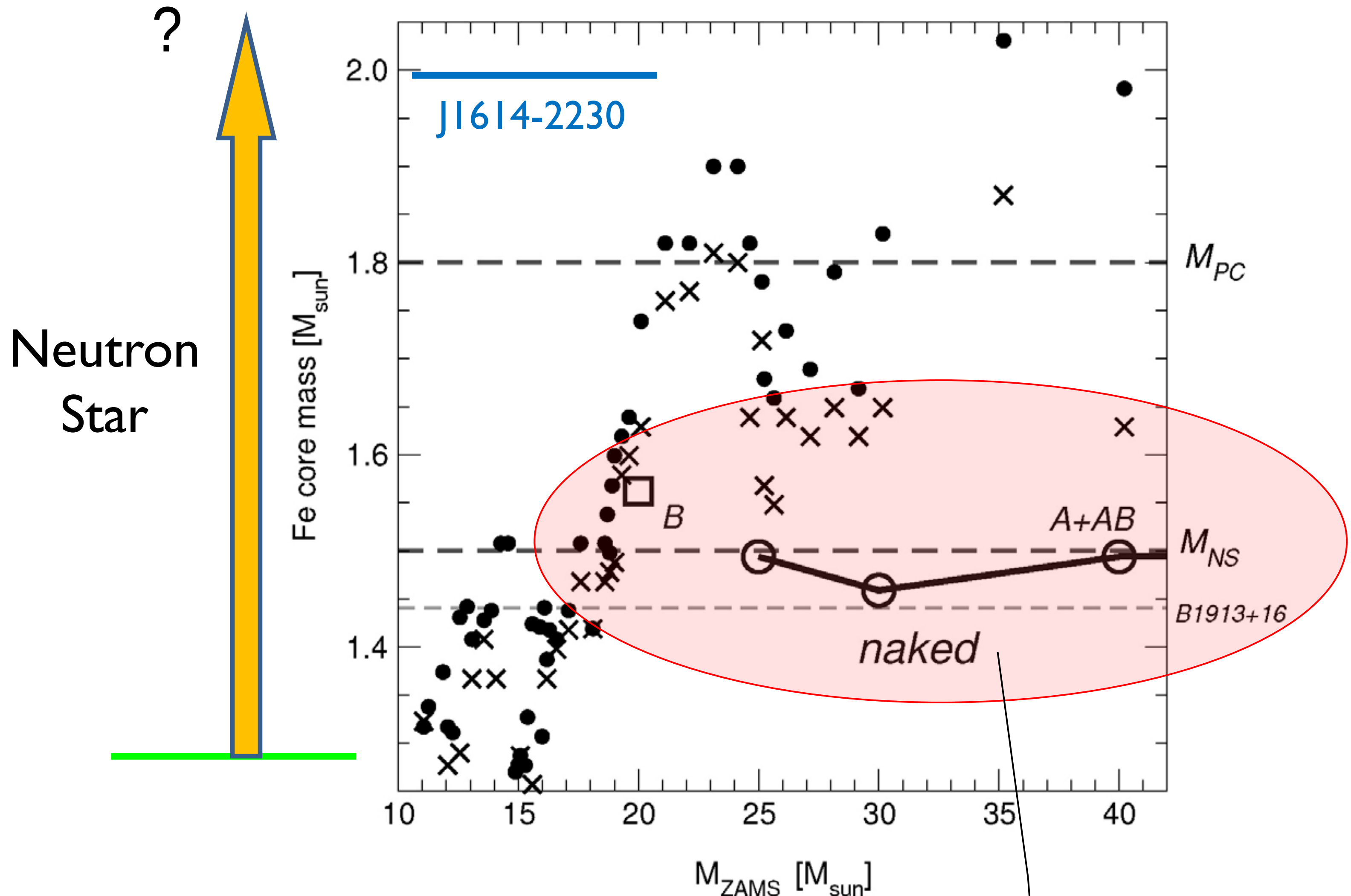
Q) What is the implications of supercritical accretion ?

One has to understand formation of BH/NS

Giant Star



Fe core mass before collapse (Brown et al. New Aston. 6,457)



□ & ○ : evolution without H envelope

Fresh NS mass from Fe core collapse

In close binaries (evolution without H envelope)

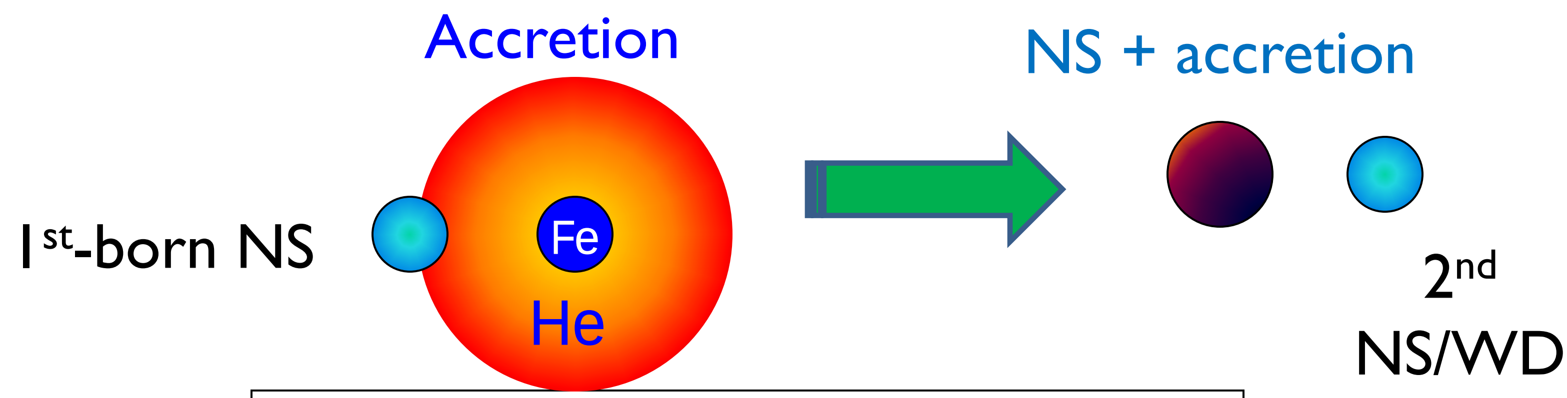
low Fe core mass ⇒ NS mass = 1.3 - 1.5 Msun

This value is independent of NS equation of state.

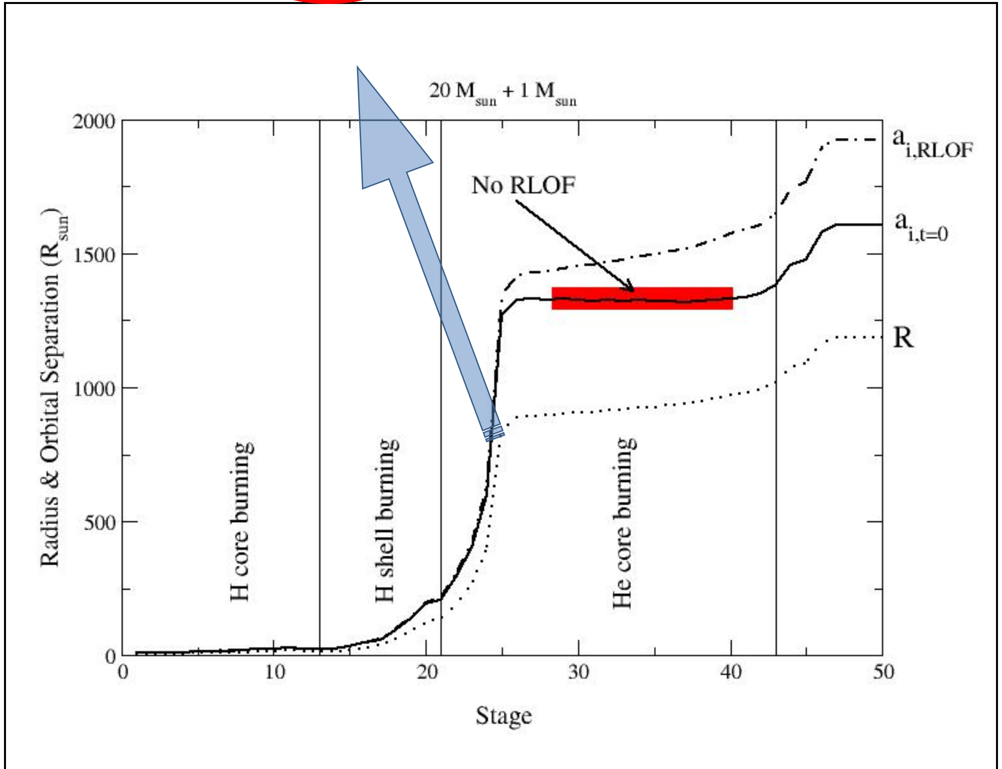
Q) What is the fate of primary (first-born) NS in binaries ?

Note: Accurate mass estimates of NS come from binaries

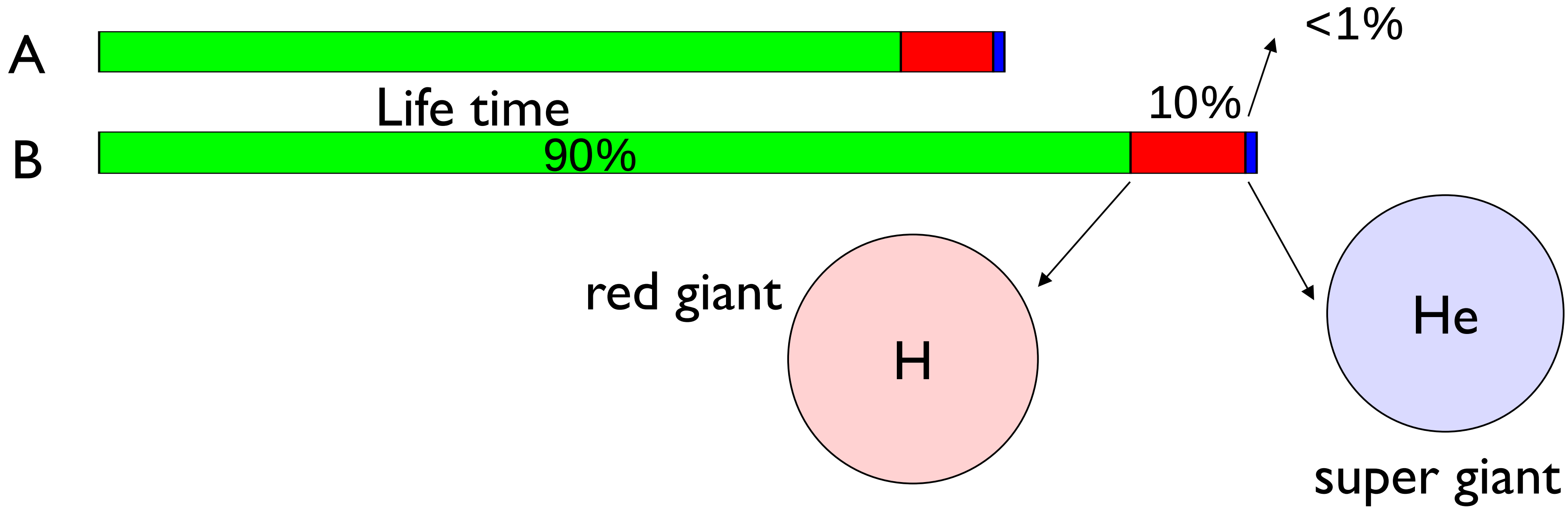
Final fate of first-born NS



Evolution of Companion



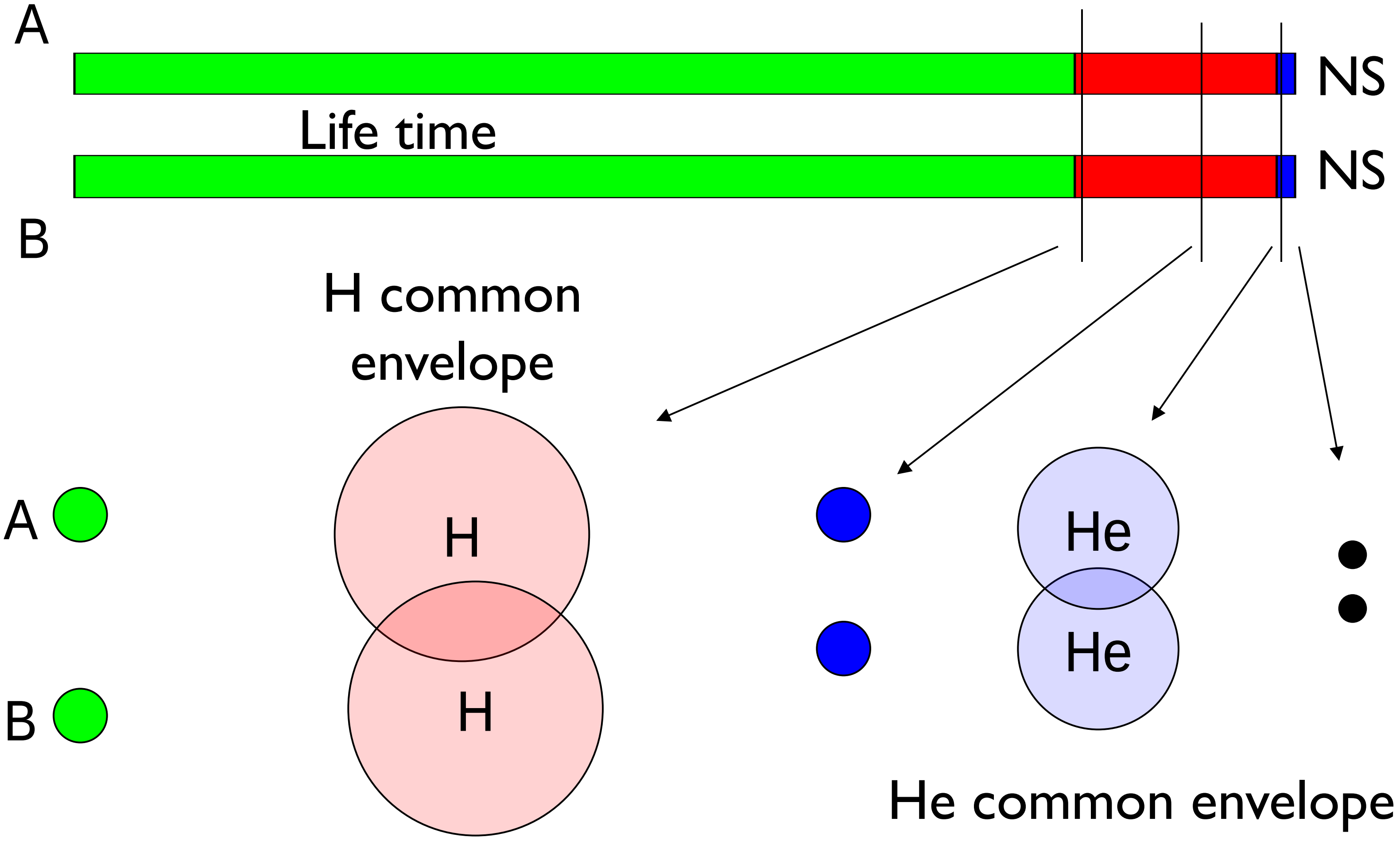
Evolution of binary stars



<u>Original ZAMS(Zero Age Main Sequence) Stars</u>

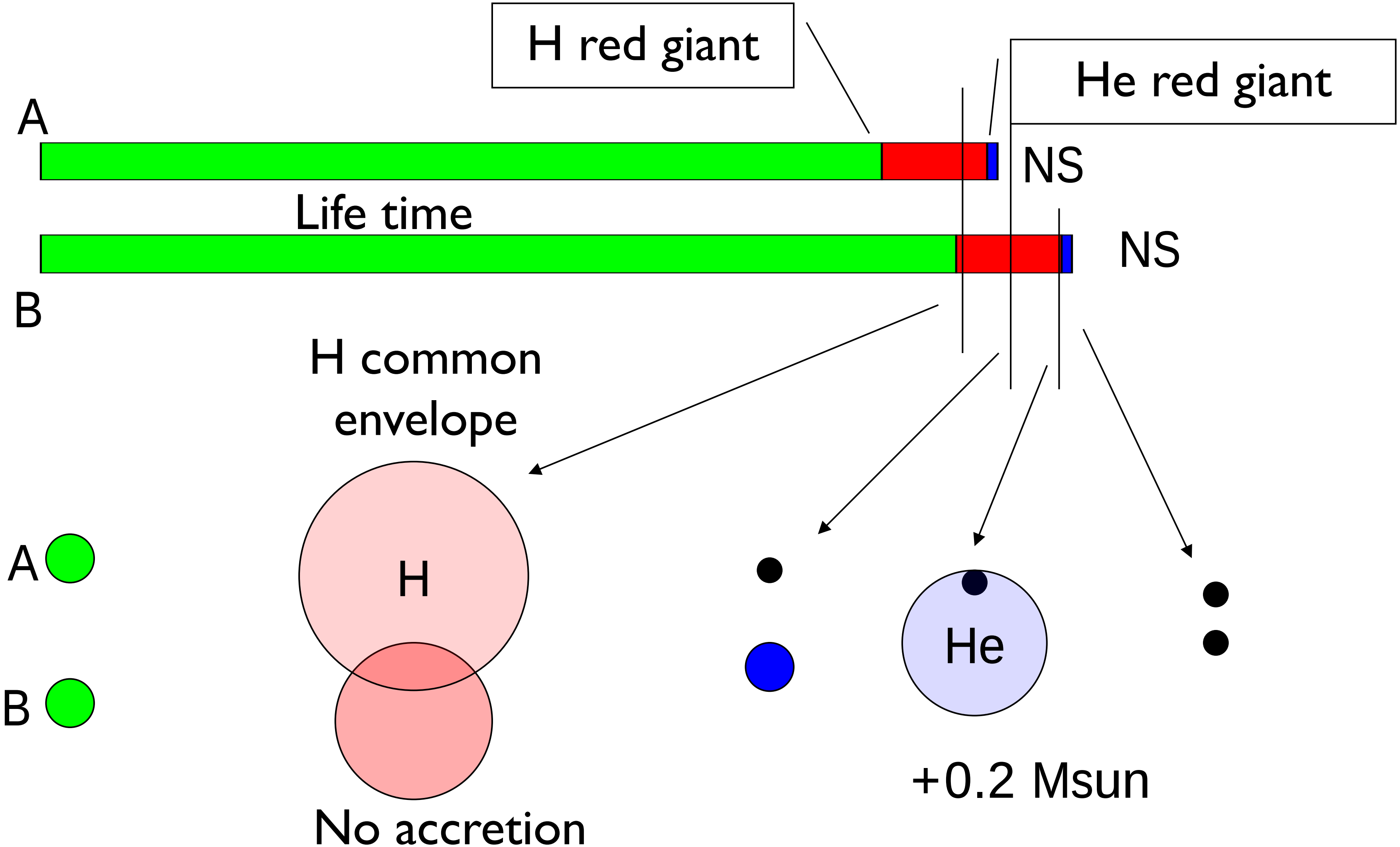
- Probability = $1/M^{2.5}$
- Life Time = $1/M^{2.5}$
- ΔM=4%,
  $\Delta T_{life}=(1 - 1/1.04^{2.5})$= 10%,
  ΔP=10% (population probability)

Case 1 : $\Delta T < 1\%$



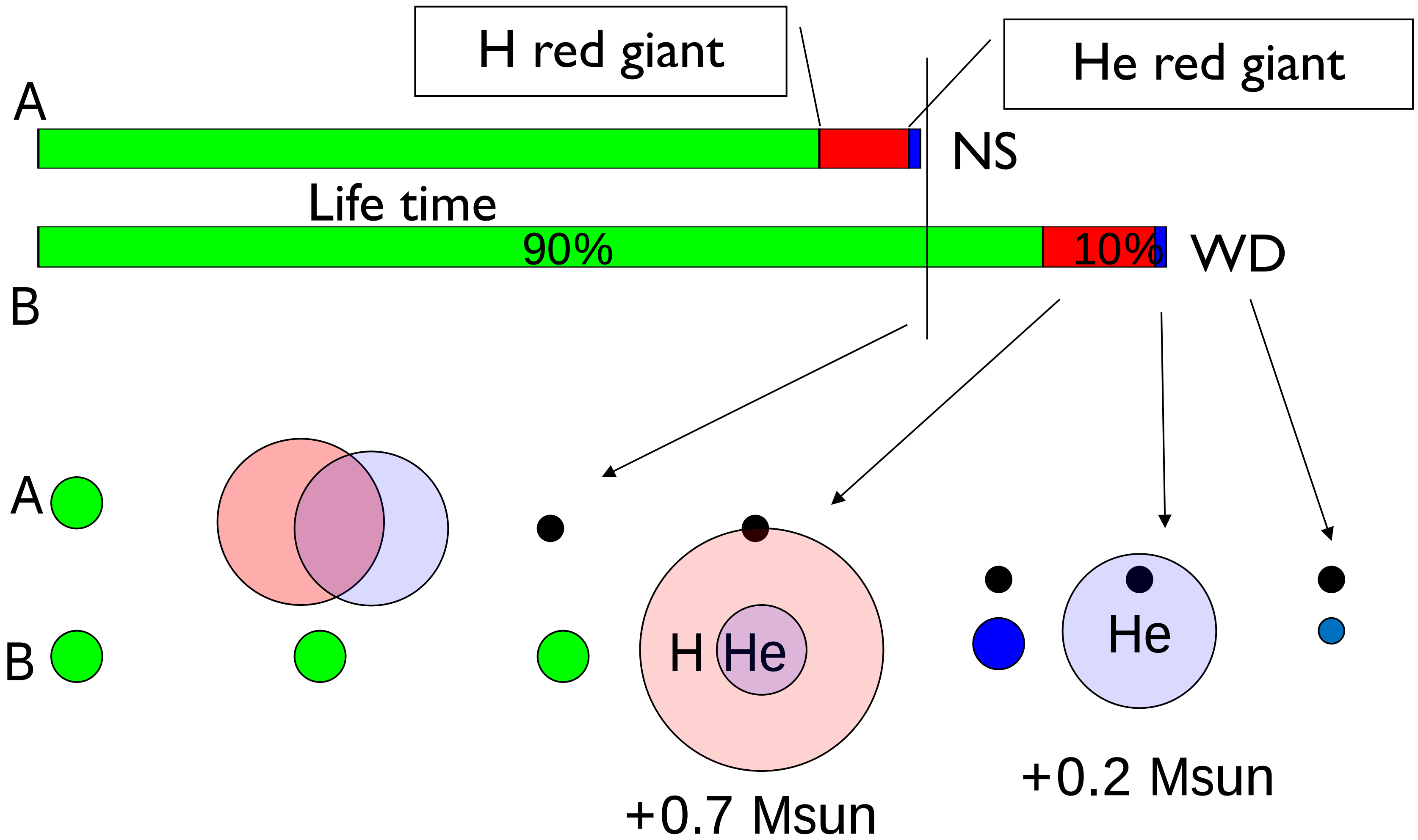
No accretion : nearly equal mass NS-NS binary!

Case 2 : 1% < ΔT < 10%



First born NS should accrete only < 0.2 $M_{\odot}$!

Case 3 : ΔT > 10%



Supercritical Accretion:
First born NS can accrete up to 0.9 $M_\odot$!

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How mass & orbit change during the evolution?

A few efficiencies (not calculable from first principles)

$$\dot{E}_{\rm acc} = \frac{1}{2} c_d \frac{G(M_{\rm NS} + M_{\rm giant})}{a} \dot{M}_{\rm NS}$$

$$-\dot{E}_{\rm orb} = \frac{1}{2}\frac{GM_{\rm giant}}{a}\dot{M}_{\rm NS} + \frac{1}{2}\frac{GM_{\rm NS}}{a}\dot{M}_{\rm giant} - \frac{1}{2}\frac{GM_{\rm NS}M_{\rm giant}}{a^2}\dot{a}$$

$$\dot{E}_{\rm acc} = -\dot{E}_{\rm orb}$$

$$\alpha_{\rm ce}\frac{dE_{\rm orb}}{dM_{\rm giant}} = -\frac{dE_{\rm bind}}{dM_c}$$

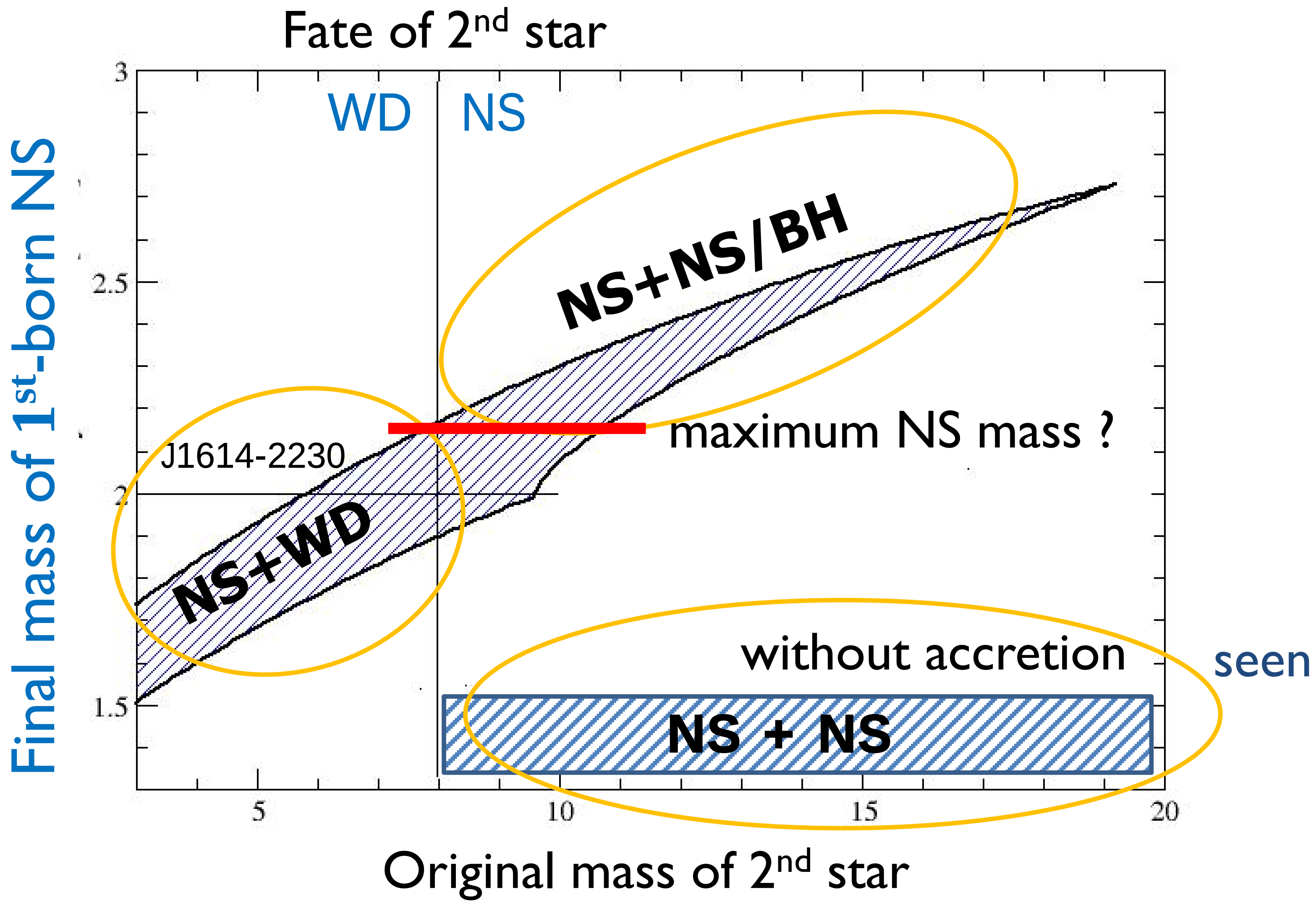
c_d=6, $\alpha_{ce}\lambda$=0.2 are consistent with SXT(Soft X-ray Transient)

Lee, Brown, Wijers, ApJ (2002)

$$E_{\rm bind} = -\frac{1}{\lambda}\frac{GM_{\rm giant}(M_{\rm giant} - M_{\rm giant,core})}{a}$$

Belczynski et al., ApJ, 572, 407

Final mass of first-born NS with supercritical accretion



Consequences of supercritical accretion

- possibilities of different class of NS binaries

  → typical NS + high mass NS/BH (> 2 solar mass)

- could be hidden GW sources

Many Thanks