On the minimum mass of neutron stars

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collaboration with

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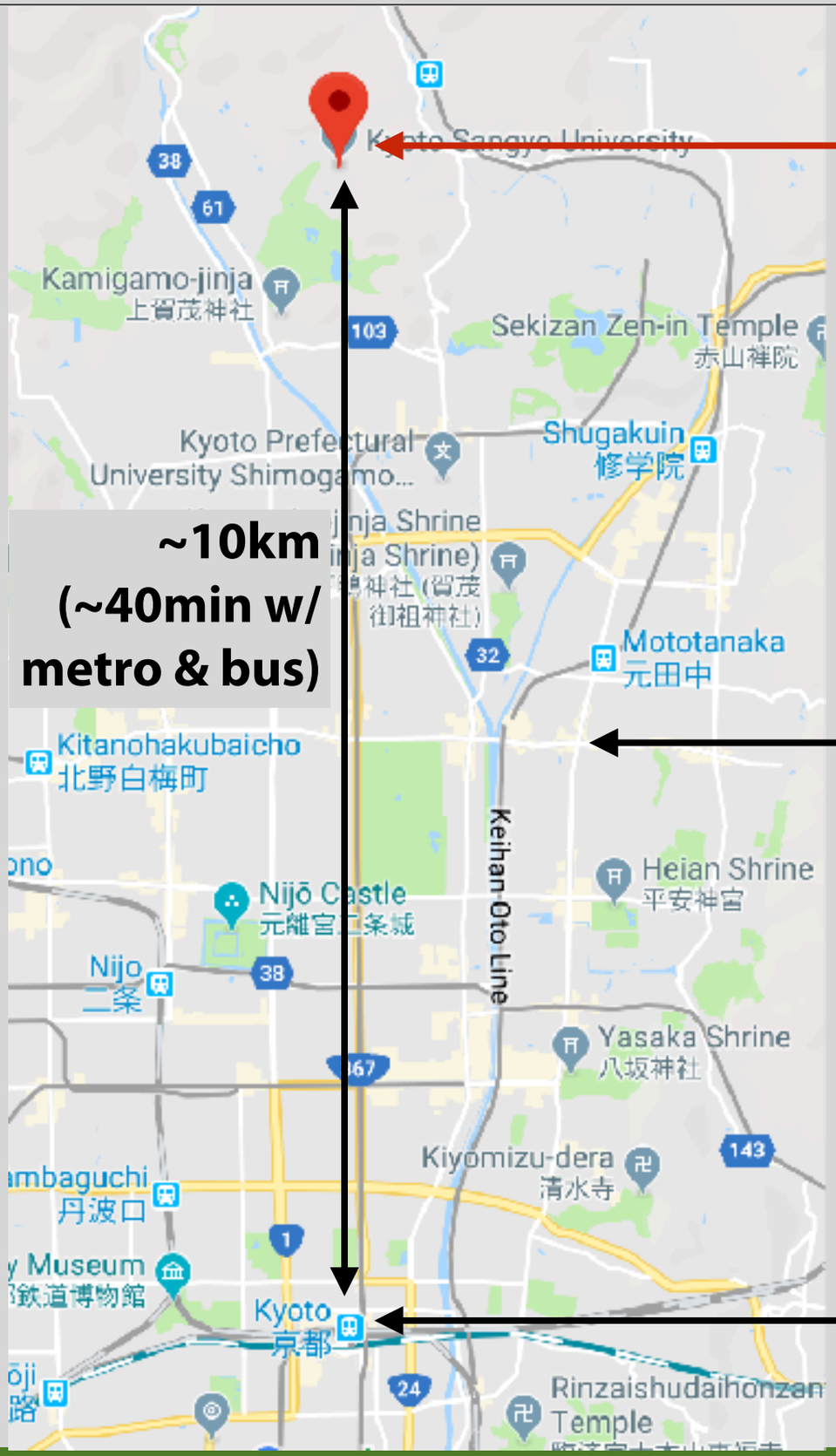


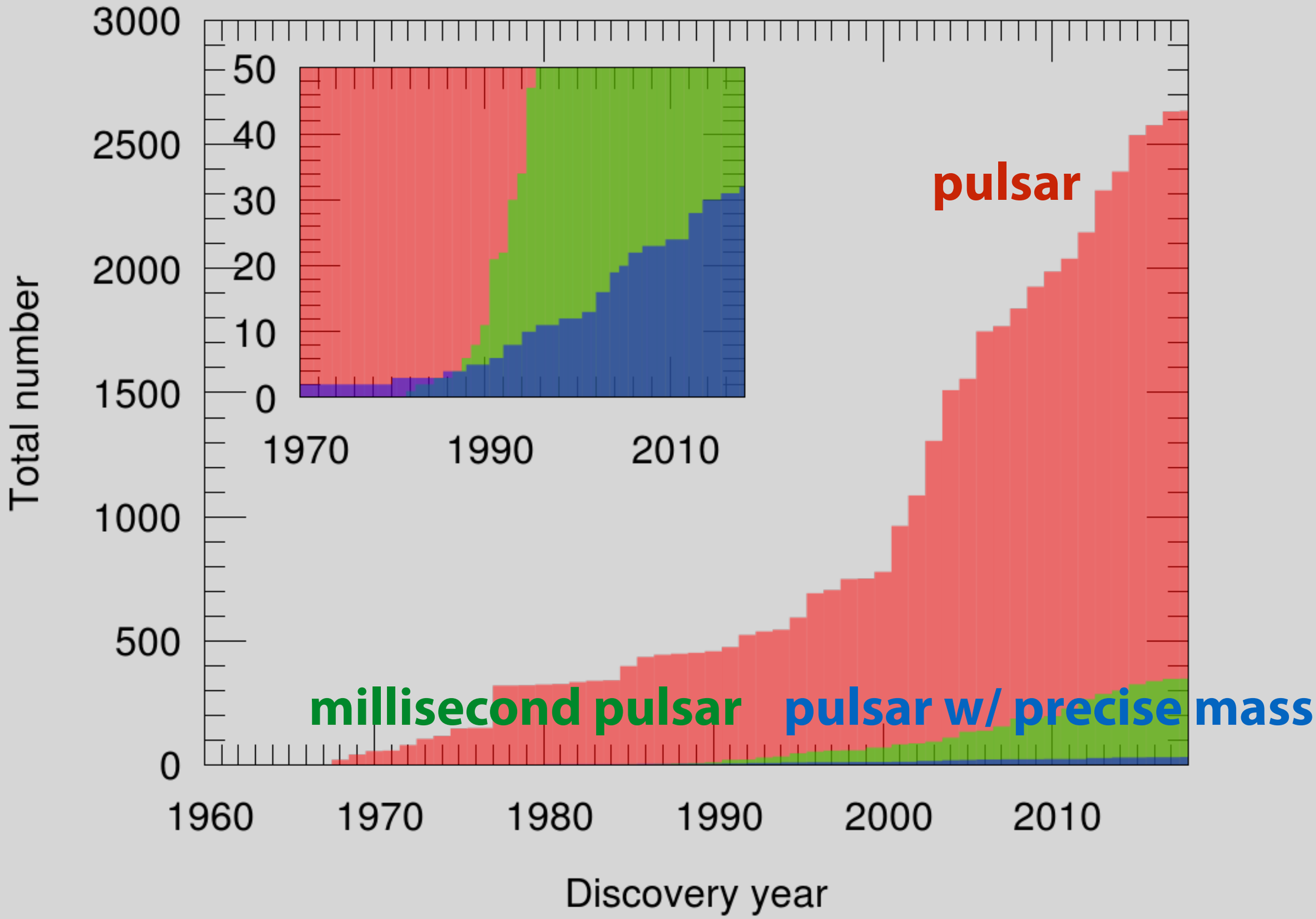
Kyoto Sangyo University

Kyoto University

Kyoto Station

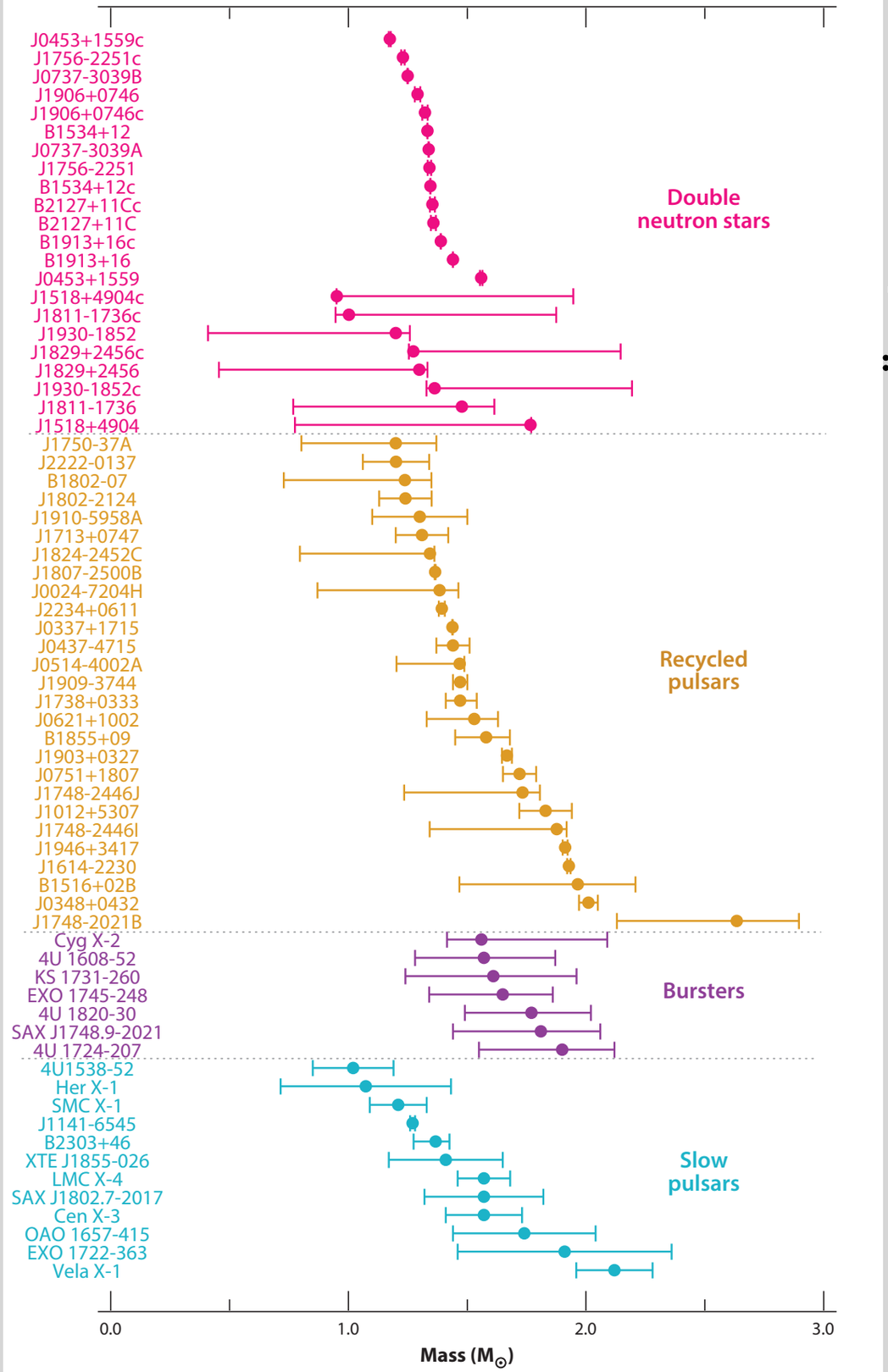
Long-term workshop
"Multi-messenger astrophysics in the GW era"
(24 Sep.-25 Oct. 2019)
incl. YKIS conference
(7 Oct.-11 Oct. 2019)

Pulsar number is increasing

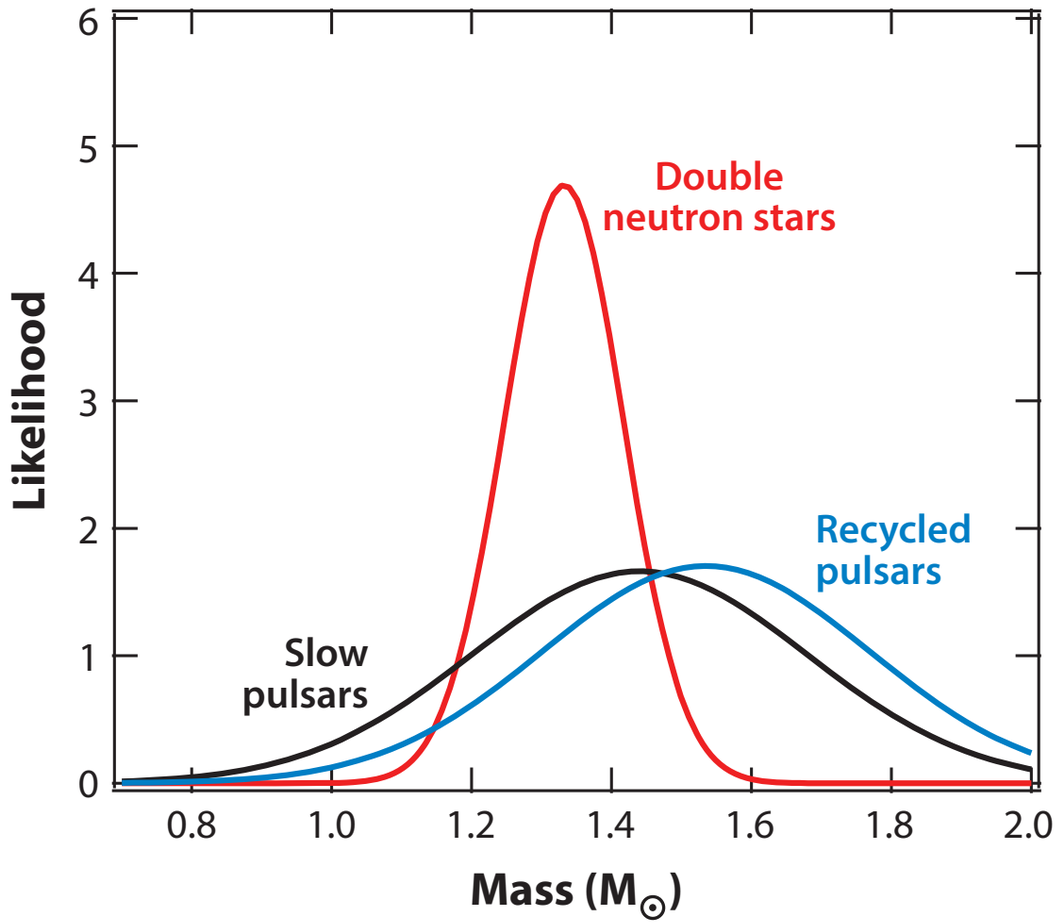


compiled data from ATNF pulsar catalog and P. Freire's table

Mass measurements of NSs



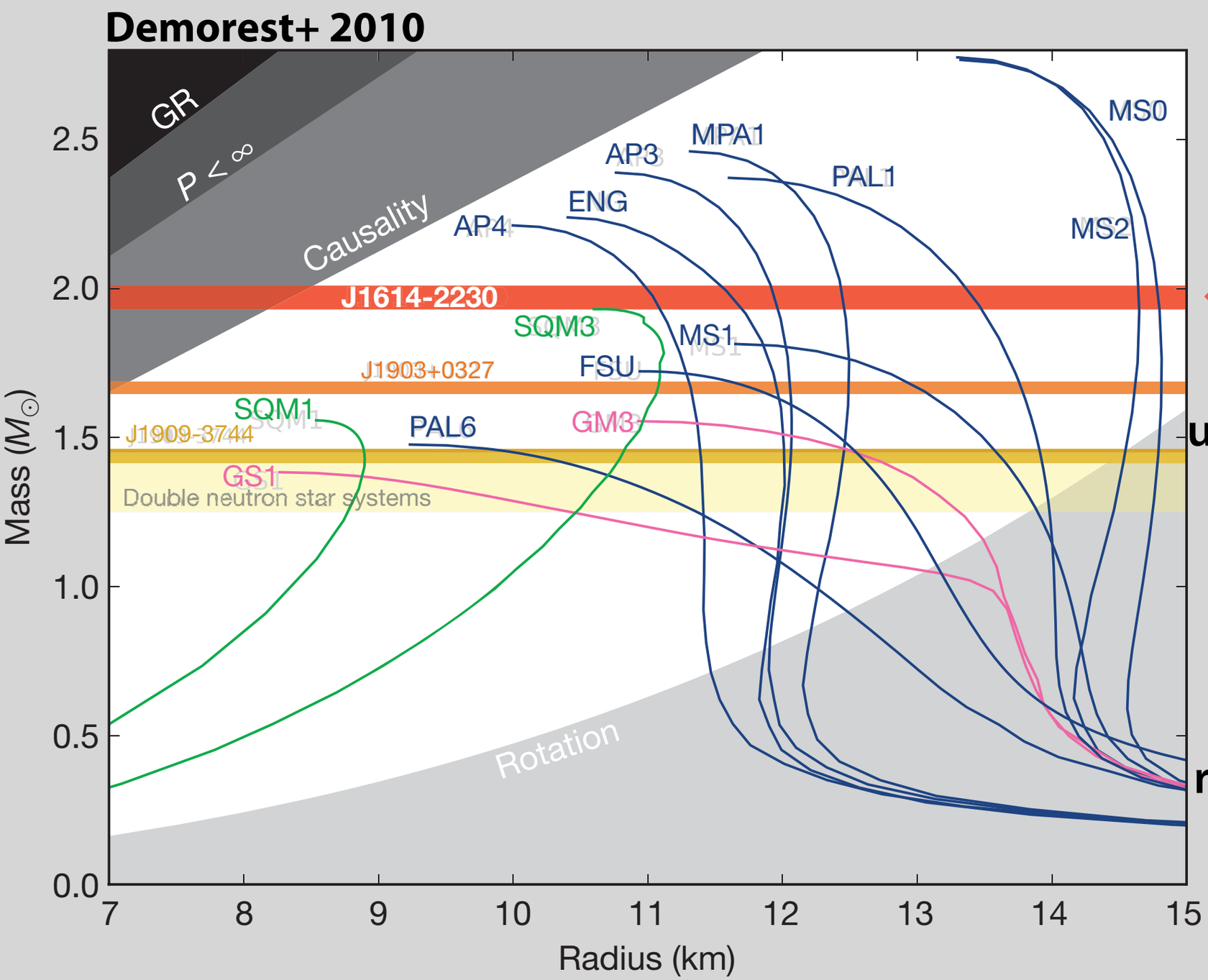
Özel & Freie 2016



- >2600 pulsars have been found in the Galaxy
- 10% in the binary system
  → mass measurement possible
  - 15 double NSs so far [Tauris+ 2017]

http://www3.mpifr-bonn.mpg.de/staff/pfreire/NS_masses.html

Massive NSs tell us nuclear physics



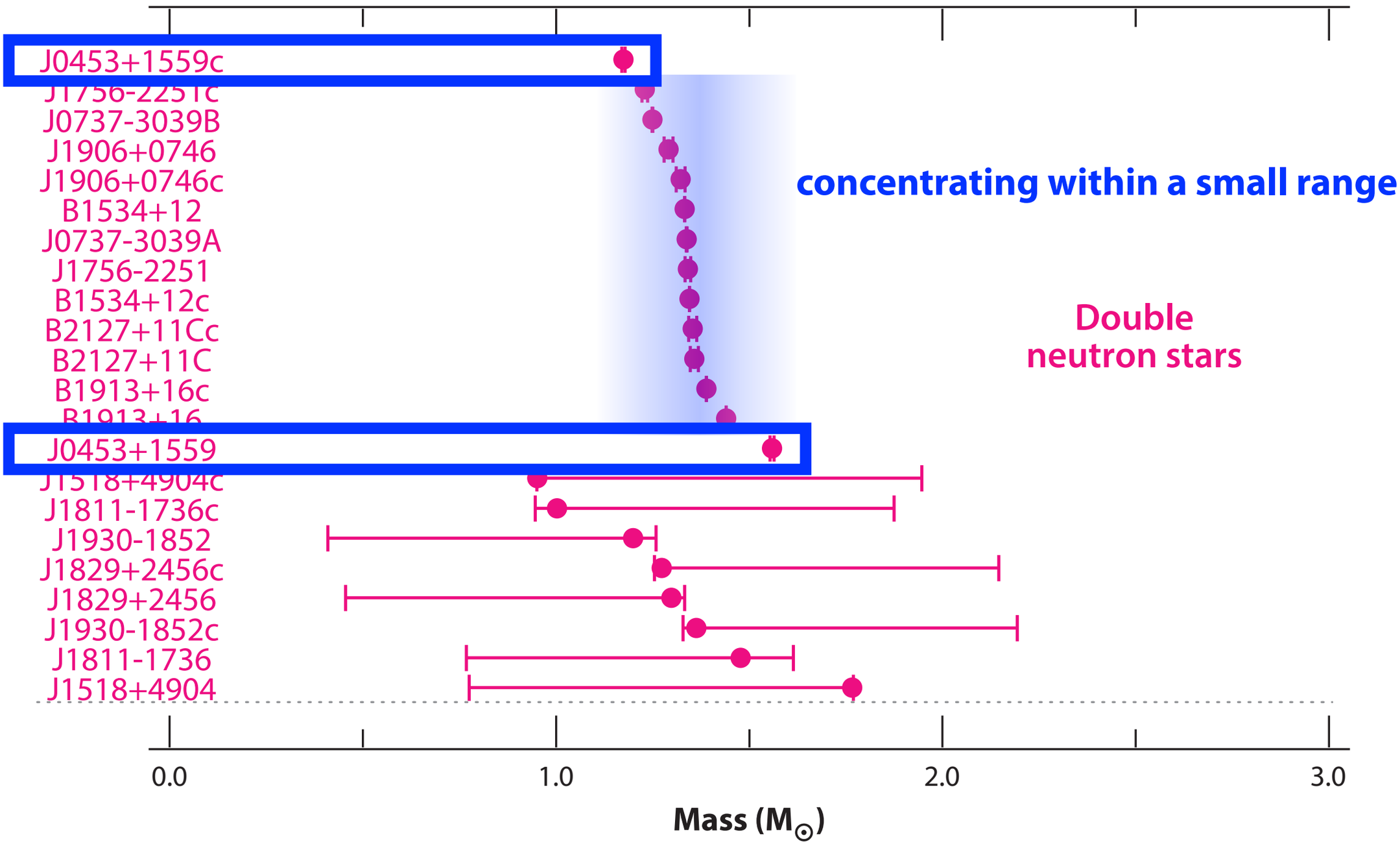
←1.97±0.04M⊙

NB) mass estimation was updated by Arzoumanian+ 2018 as 1.908±0.016M⊙

Another massive NS was reported by Antoniadis+ (2013), J0348+0432, 2.01±0.04M⊙

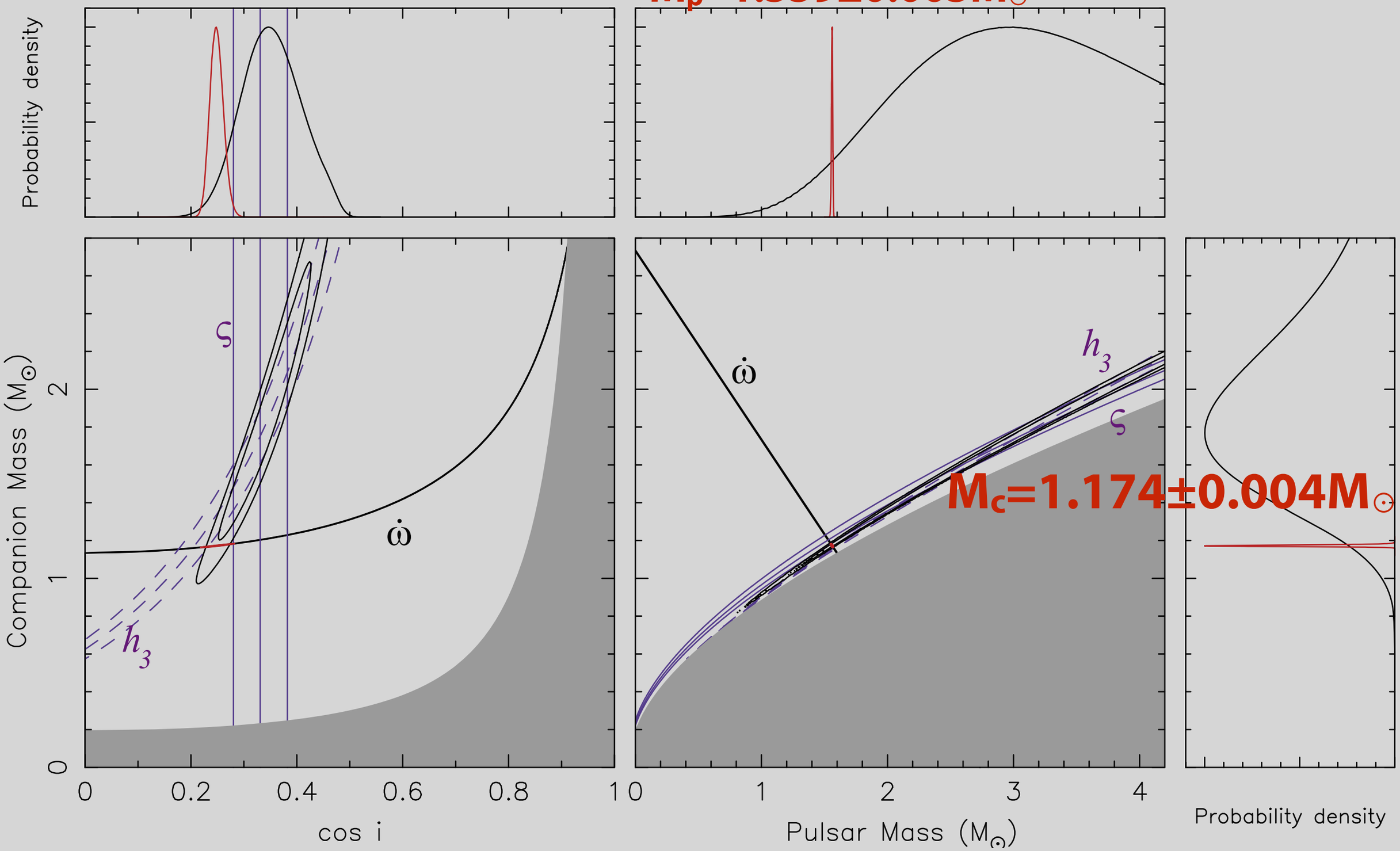
So, what does a small NS tell?

Double NSs


J0453+1559c
J1756-2251C
J0737-3039B
J1906+0746
J1906+0746c
B1534+12
J0737-3039A
J1756-2251
B1534+12c
B2127+11Cc
B2127+11C
B1913+16c
B1913+16
J0453+1559
J1518+4904c
J1811-1736c
J1930-1852
J1829+2456c
J1829+2456
J1930-1852c
J1811-1736
J1518+4904
concentrating within a small range
Double neutron stars
0.0
1.0
2.0
3.0
Mass ($M_\odot$)

First asymmetric DNS system

Martinez+ 2015

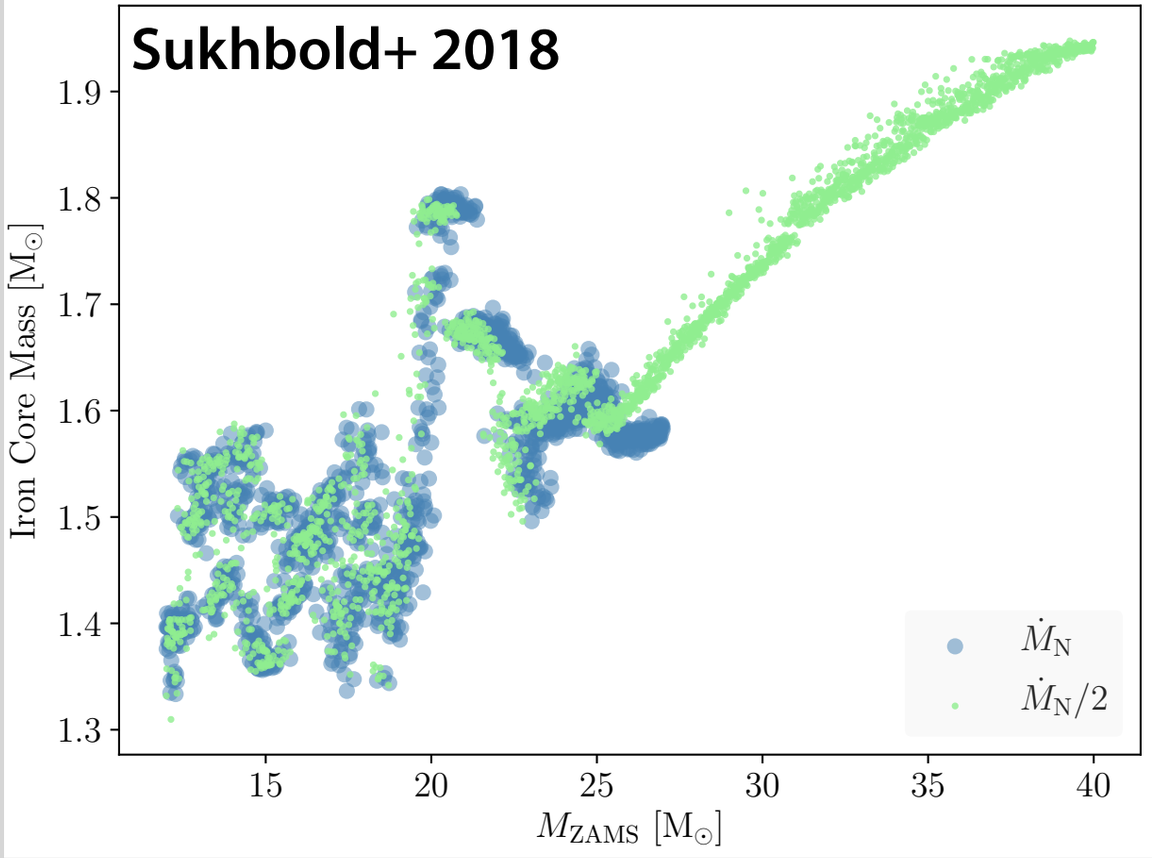


A low-mass NS

* **$M_{NS}=1.174M_{\odot}$! (NB, it's gravitational mass, baryonic mass is ~$1.28M_{\odot}$)**

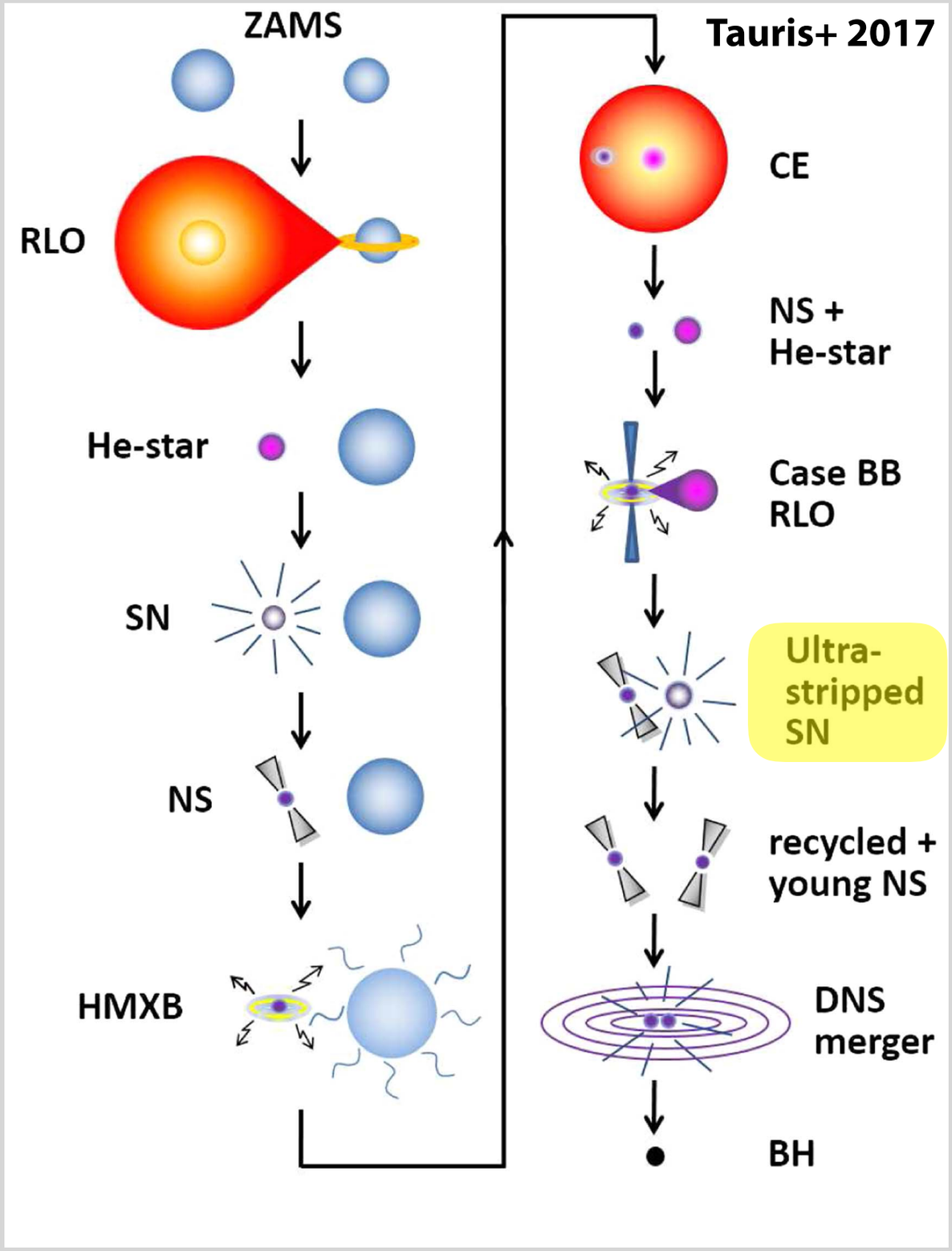
* **Is it a white dwarf? Maybe no**
  - **a large eccentricity (e=0.112) is difficult to explain by slow evolution into a WD**

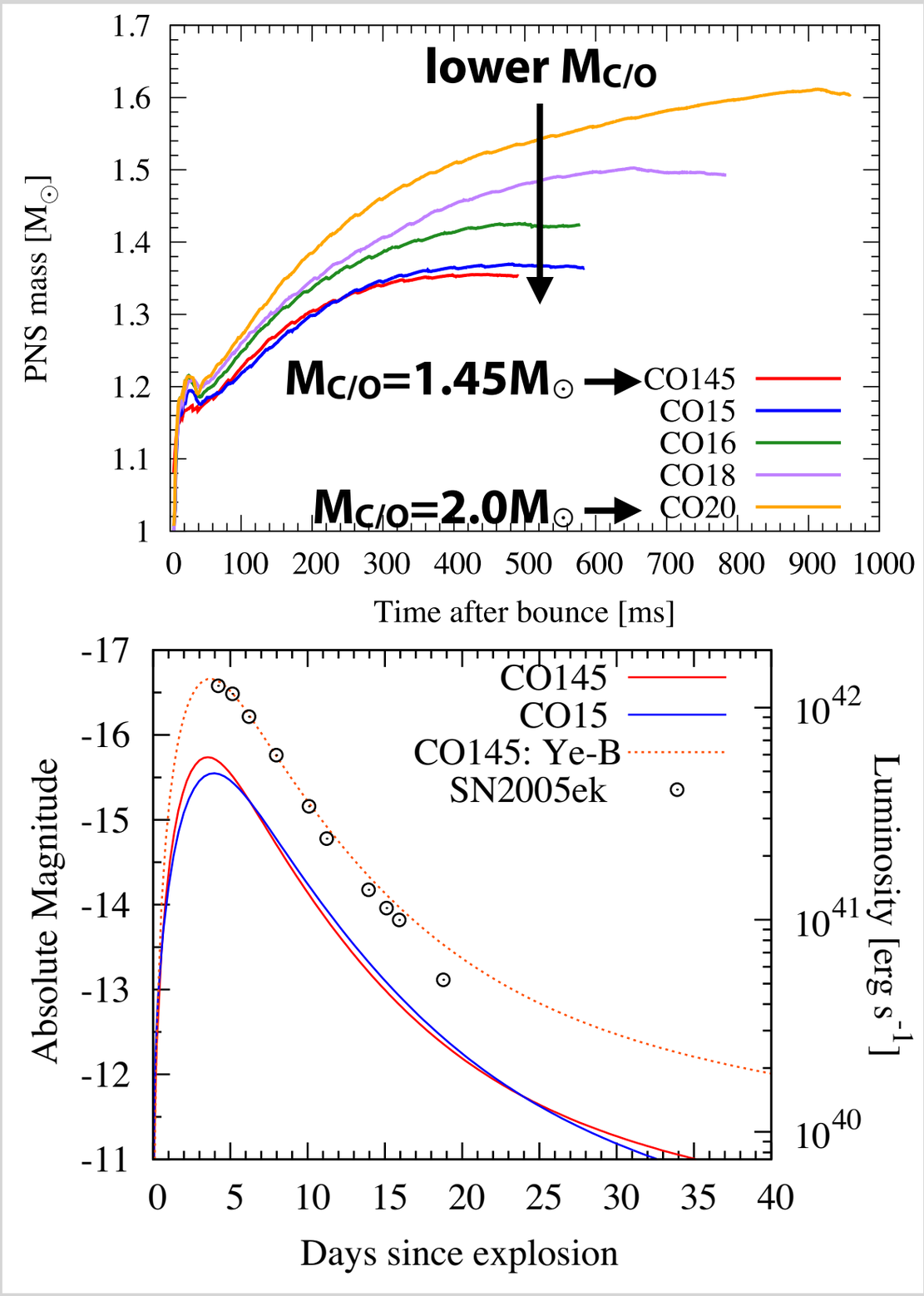
* **How to make it?**
  - **a small iron core of massive star? (typically M_{Fe}~1.4–$1.8M_{\odot}$)**
  - **getting rid of mass from a NS?**



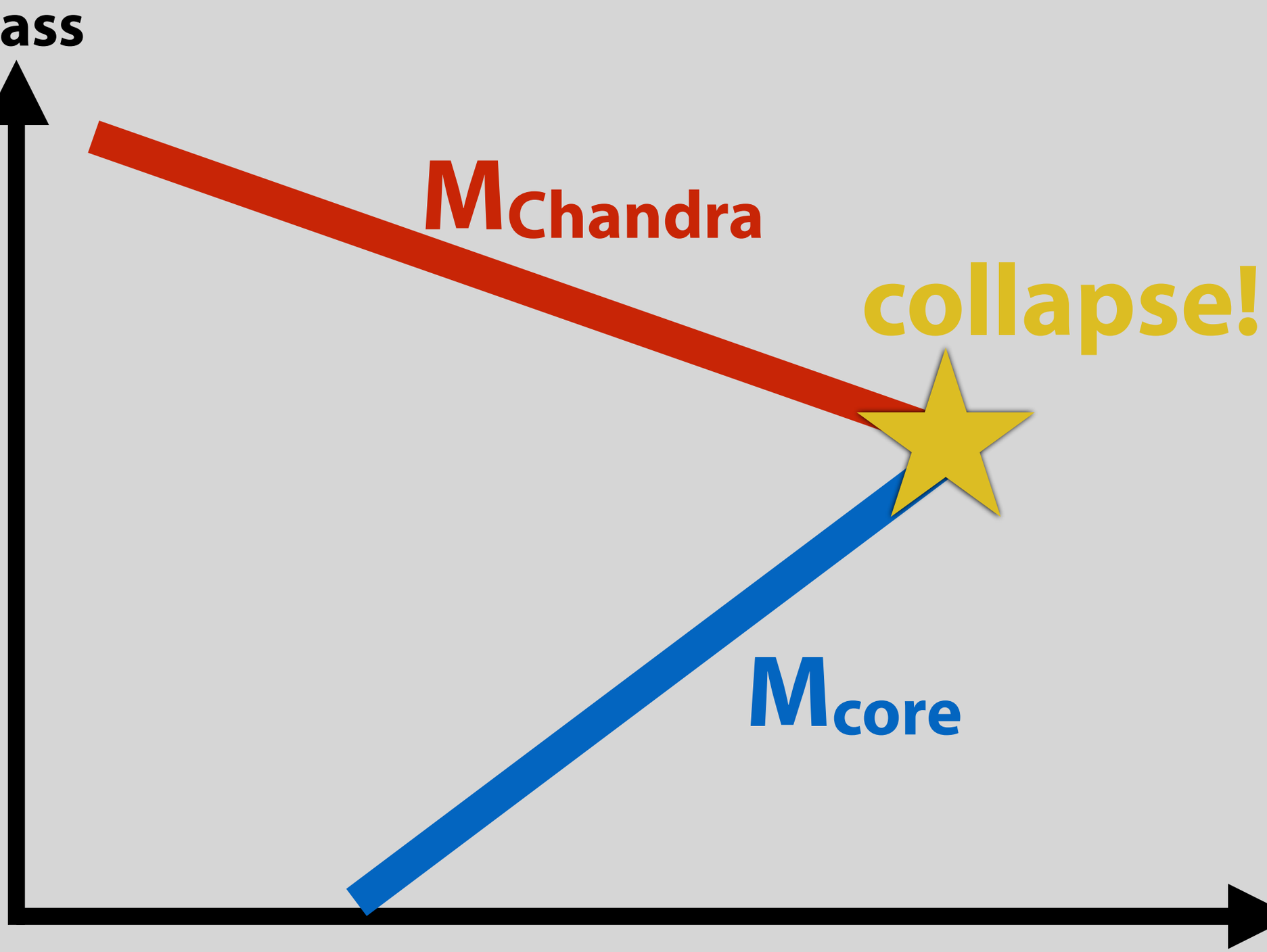
A path toward a low mass NS?: Ultra-stripped SN

[Suwa+, MNRAS, **454**, 3073 (2015); Yoshida+, MNRAS, **471**, 4275 (2017)]





When does a core collapse?



Modified Chandrasekhar mass

* **Chandrasekhar mass *without* temperature correction**

$$M_{\rm Ch0}(Y_e) = 1.46 M_\odot \left(\frac{Y_e}{0.5}\right)^2$$

* **Chandrasekhar mass *with* temperature correction**

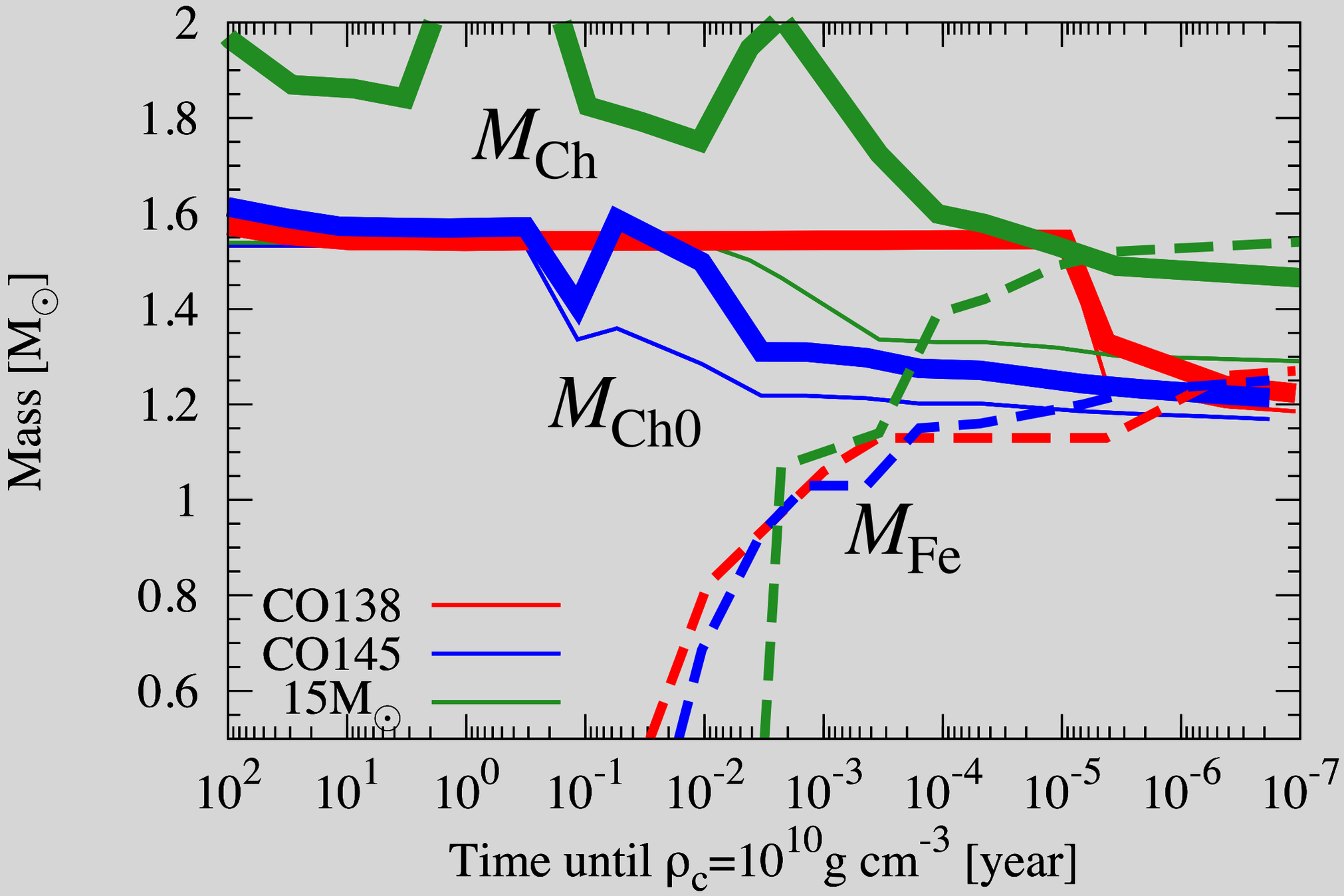
$$M_{\rm Ch}(T) = M_{\rm Ch0}(Y_e)\left[1+\left(\frac{s_e}{\pi Y_2}\right)^2\right] \quad s_e = 0.5\rho_{10}^{-1/3}(Y_e/0.42)^{2/3}T_{\rm MeV}$$

Baron+ 1990; Timmes+ 1996

* **To make a small core, *low* Y_e and *low* entropy are necessary**

M_{ch} vs. M_{core}

[Suwa, Yoshida, Shibata, Umeda, Takahashi, MNRAS, 481, 3305 (2018)]



Explosion simulations and NS masses

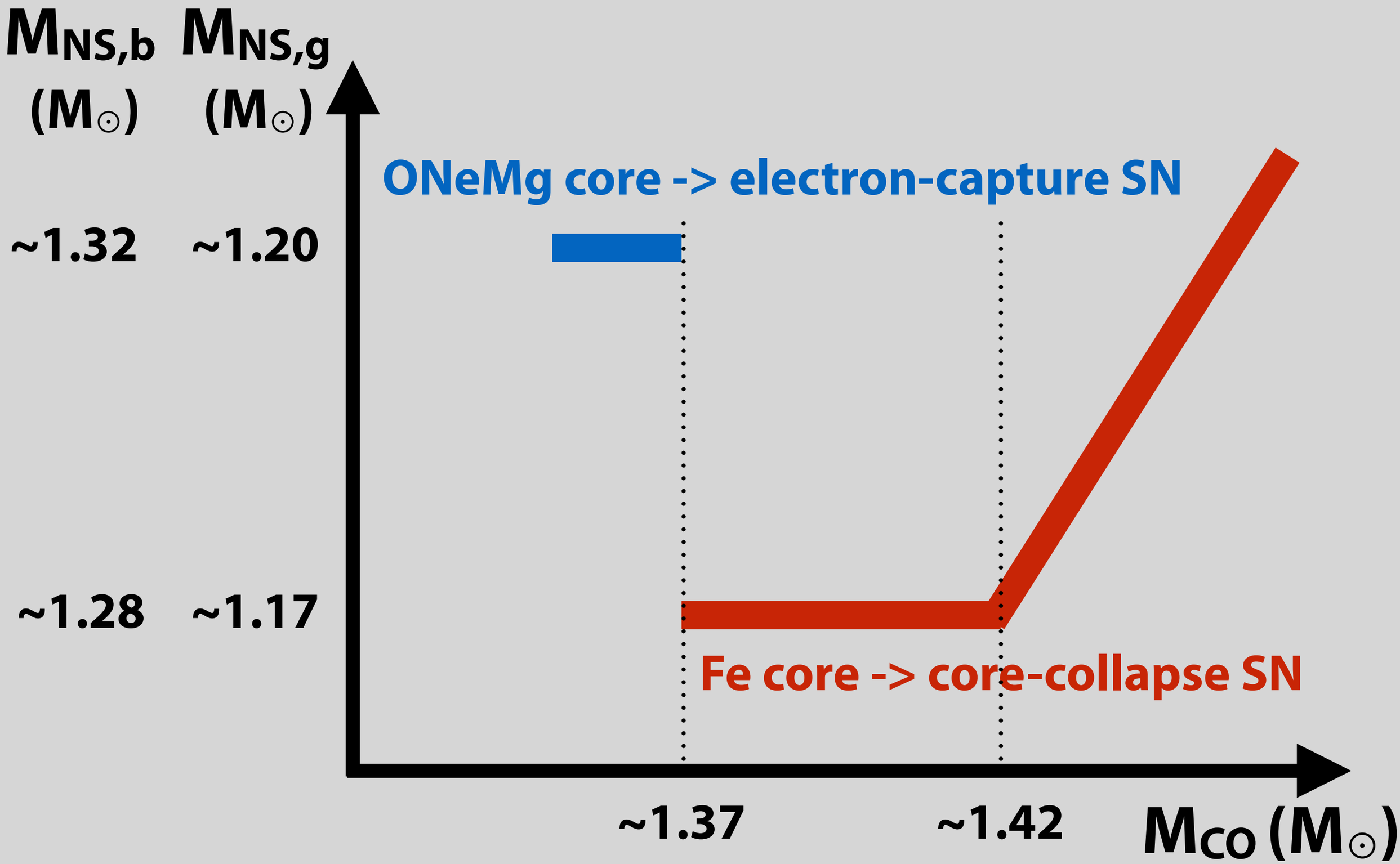
[Suwa, Yoshida, Shibata, Umeda, Takahashi, MNRAS, 481, 3305 (2018)]

Model	M_{CO} ($M_\odot$)	M_{ZAMS} ($M_\odot$)	M_{Fe} ($M_\odot$)	$M_{NS,b}$ ($M_\odot$)	$M_{NS,g}$ ($M_\odot$)
CO137	1.37	9.35	1.280	1.289	**1.174**
CO138	1.38	9.4	1.274	1.296	**1.179**
CO139	1.39	9.45	1.258	1.302	1.184
CO140	1.4	9.5	1.296	1.298	1.181
CO142	1.42	9.6	1.265	1.287	**1.172**
CO144	1.44	9.7	1.234	1.319	1.198
CO145	1.45	9.75	1.277	1.376	1.245

$M_{NS,b}$-$M_{NS,g}$=**0.084**$M_\odot(M_{NS,g}/M_\odot)^2$
(Lattimer & Prakash 2001)

Discussion

[Suwa, Yoshida, Shibata, Umeda, Takahashi, MNRAS, **481**, 3305 (2018)]



Summary

* **A low-mass NS of $M_{NS,g}=1.174M_{\odot}$ was found**

* **Q: *Is it possible to make such a low-mass NS with standard modeling of SN?***

* **A: Yes, it is.**
  - **The minimum mass is ~$1.17M_{\odot}$.**
  - **If a new observation finds even lower mass NS, we cannot make it. Something wrong.**