中性子星の最小質量

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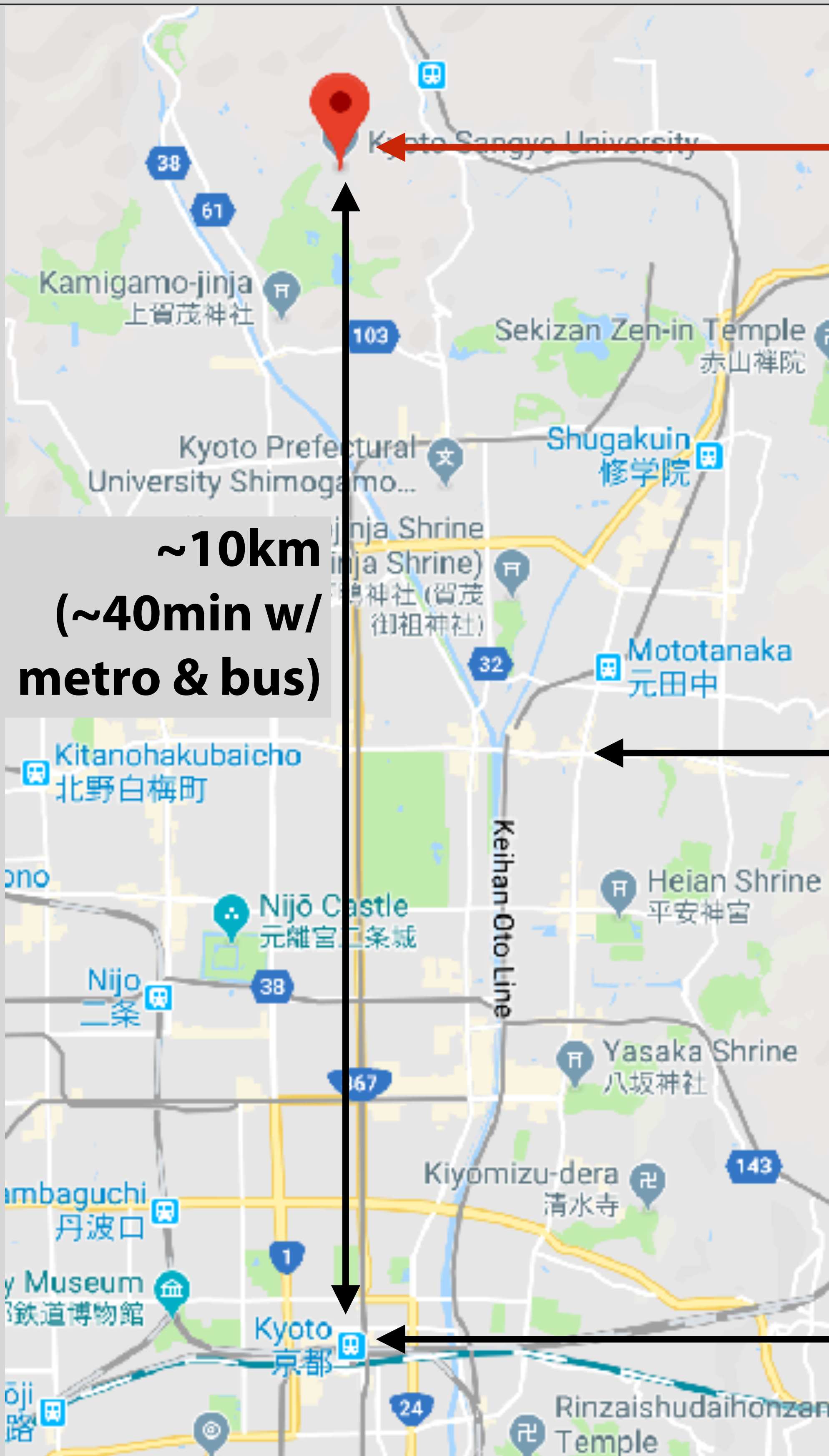
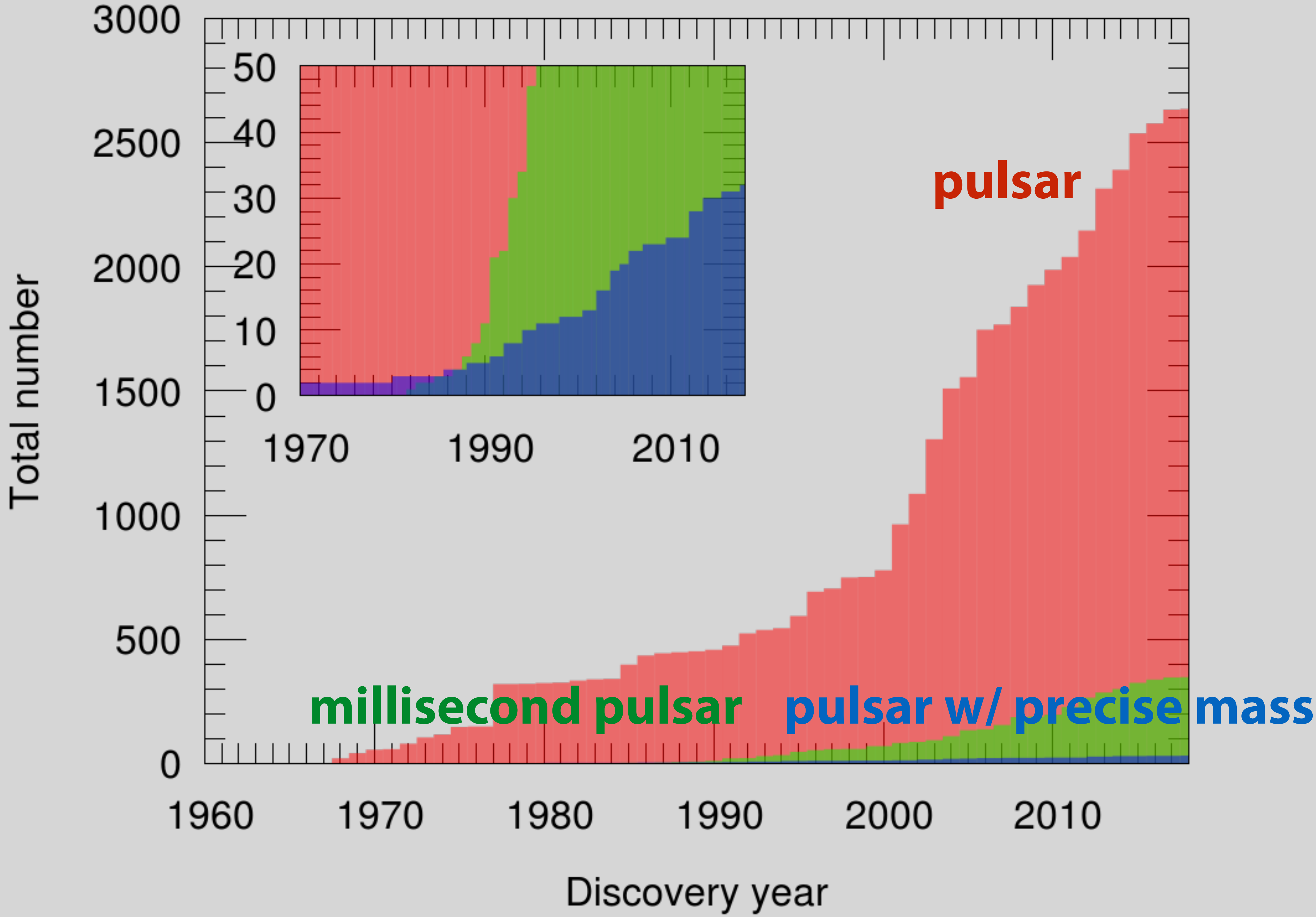


Kyoto Sangyo University

Kyoto University

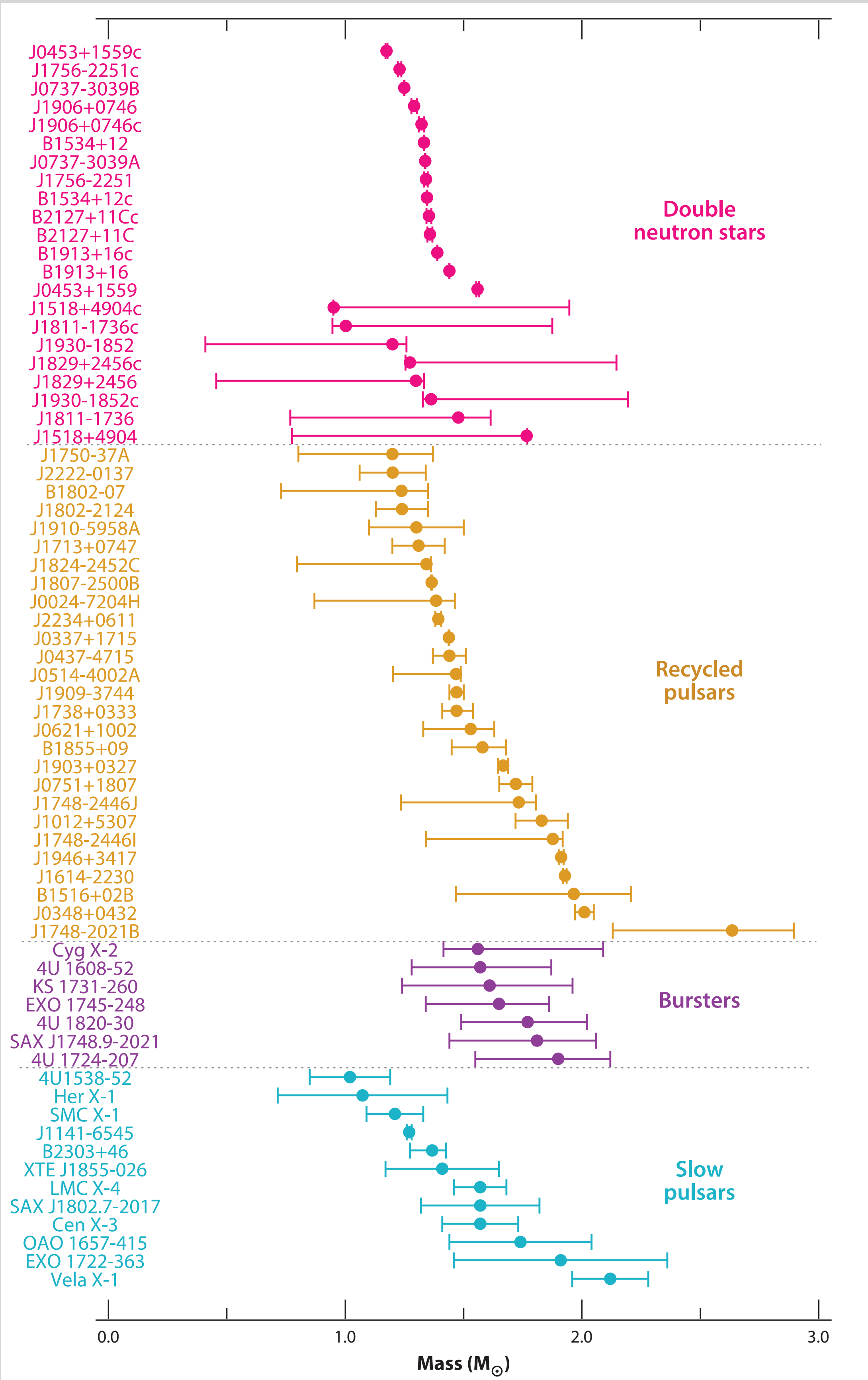
Kyoto Station

Pulsar number is increasing

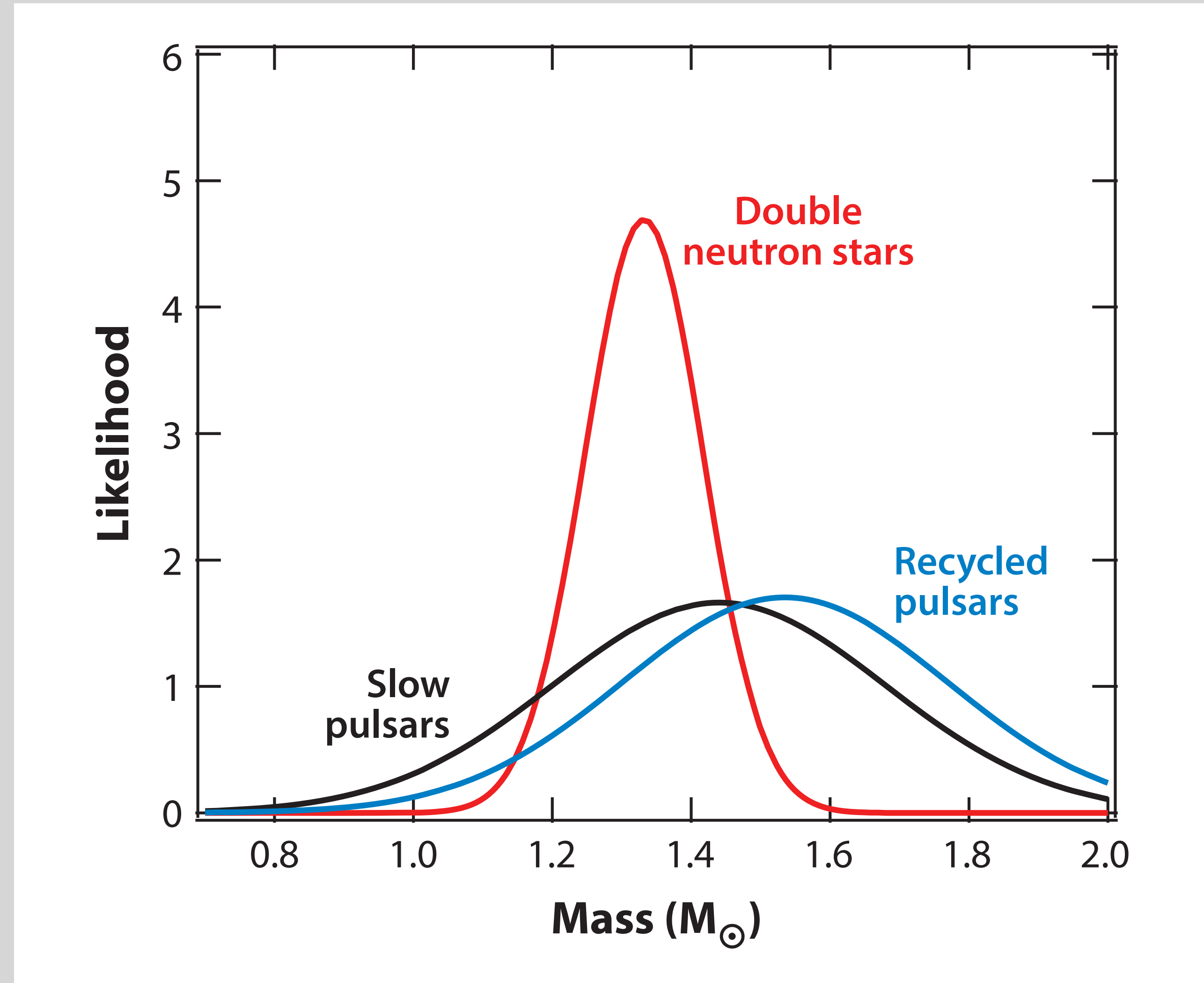


compiled data from ATNF pulsar catalog and P. Freire's table

Mass measurements of NSs



Özel & Freie 2016

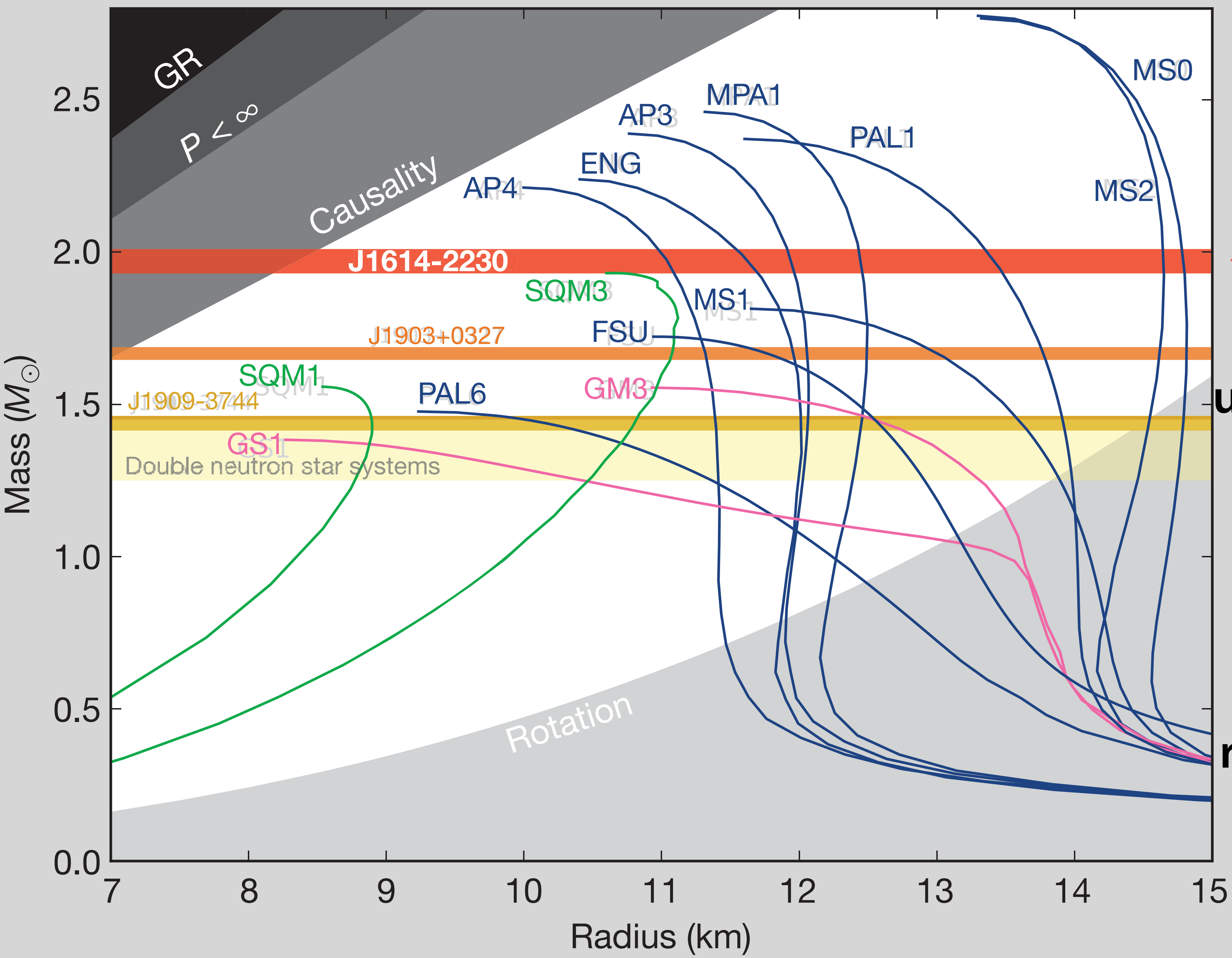


- **>2600 pulsars have been found in the Galaxy**
- **10% in the binary system**
  →mass measurement possible
  - **15 double NSs so far** [Tauris+ 2017]

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

Massive NSs tell us nuclear physics

Demorest+ 2010



←1.97±0.04M$_\odot$

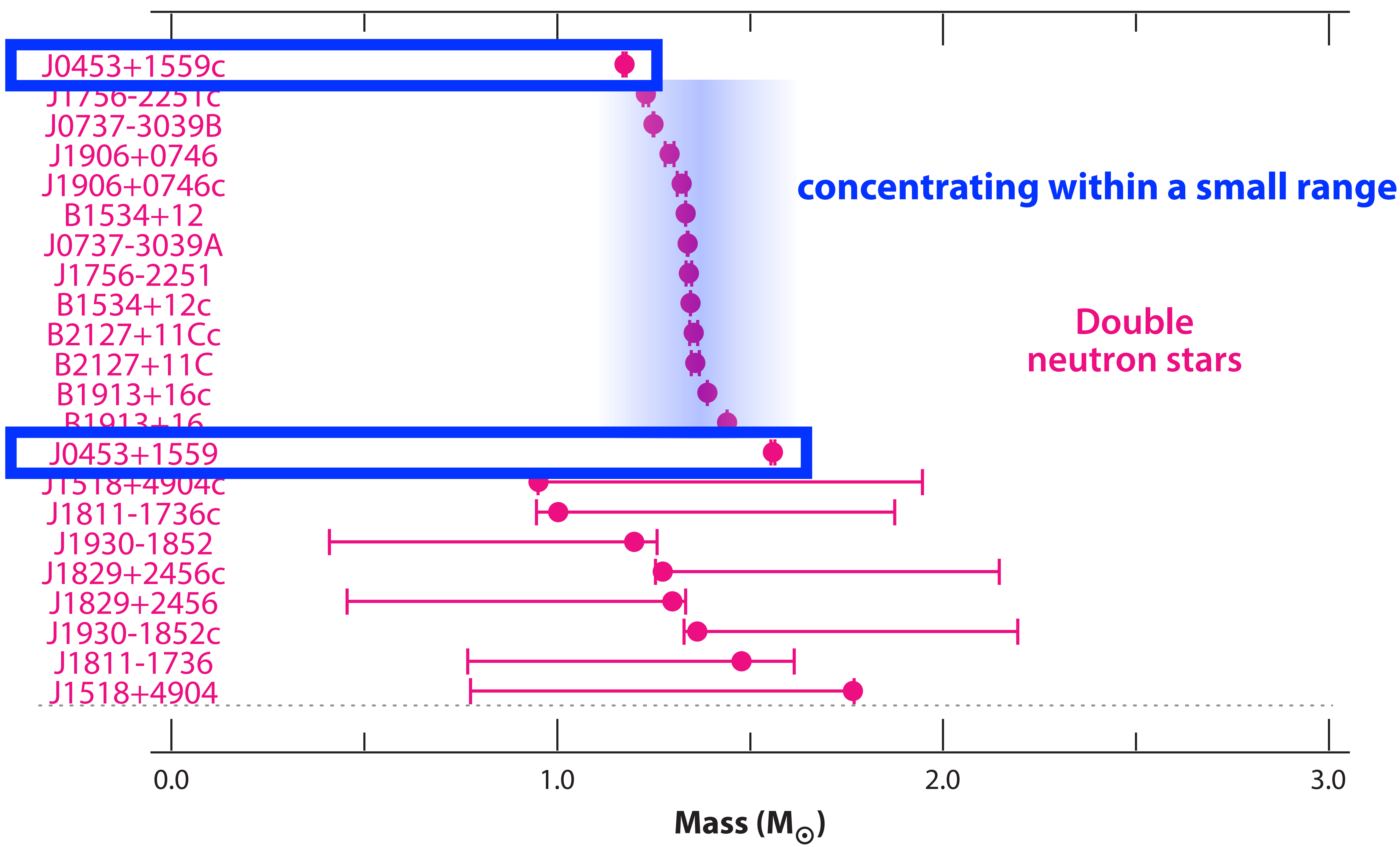
NB) mass estimation was updated by Arzoumanian+ 2018 as 1.908±0.016M$_\odot$

Another massive NS was reported by Antoniadis+ (2013), J0348+0432, 2.01±0.04M$_\odot$

So, what does a small NS tell?

Double NSs

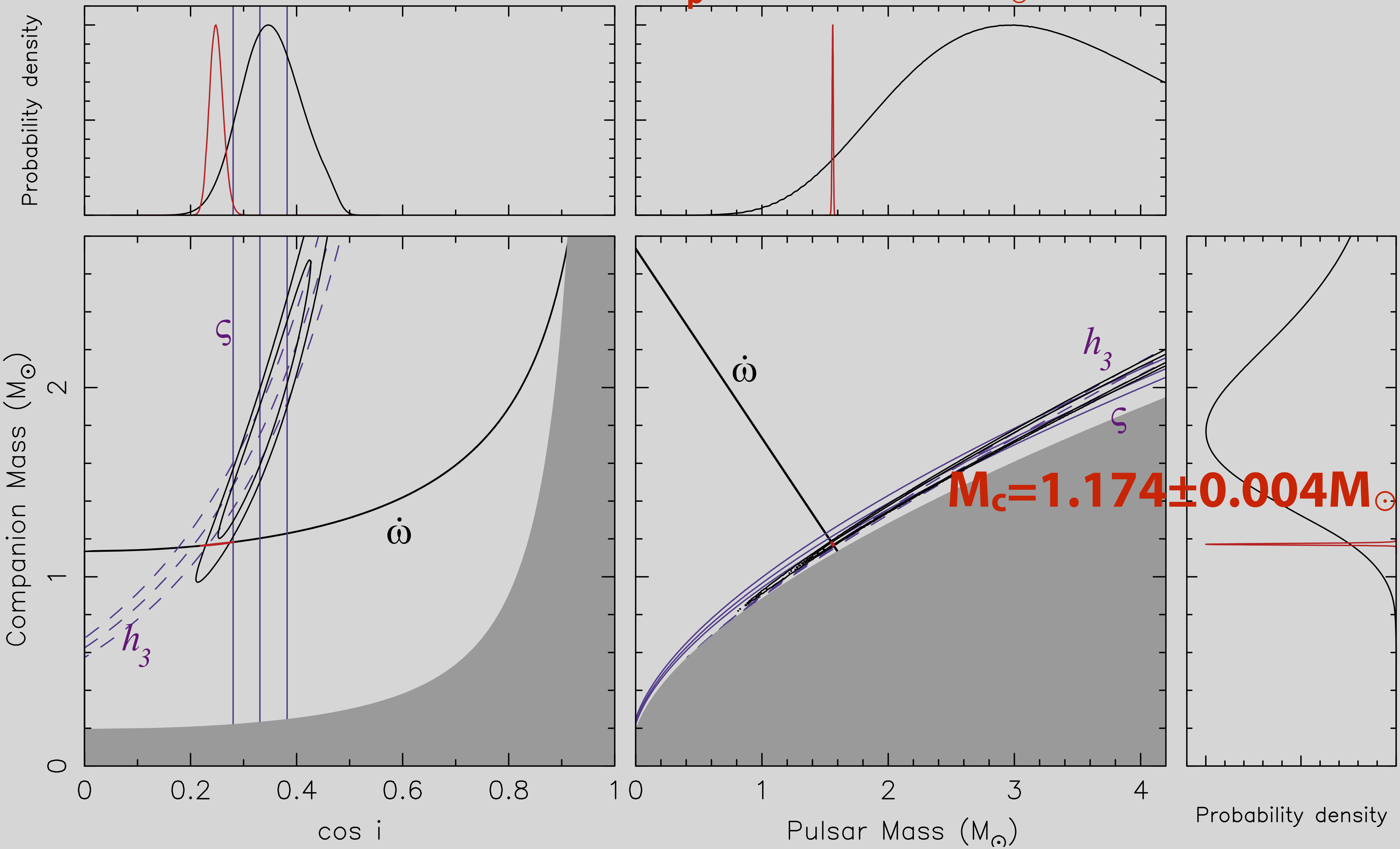
Özel & Freie 2016



First asymmetric DNS system

Martinez+ 2015

M_p=1.559±0.005$M_\odot$



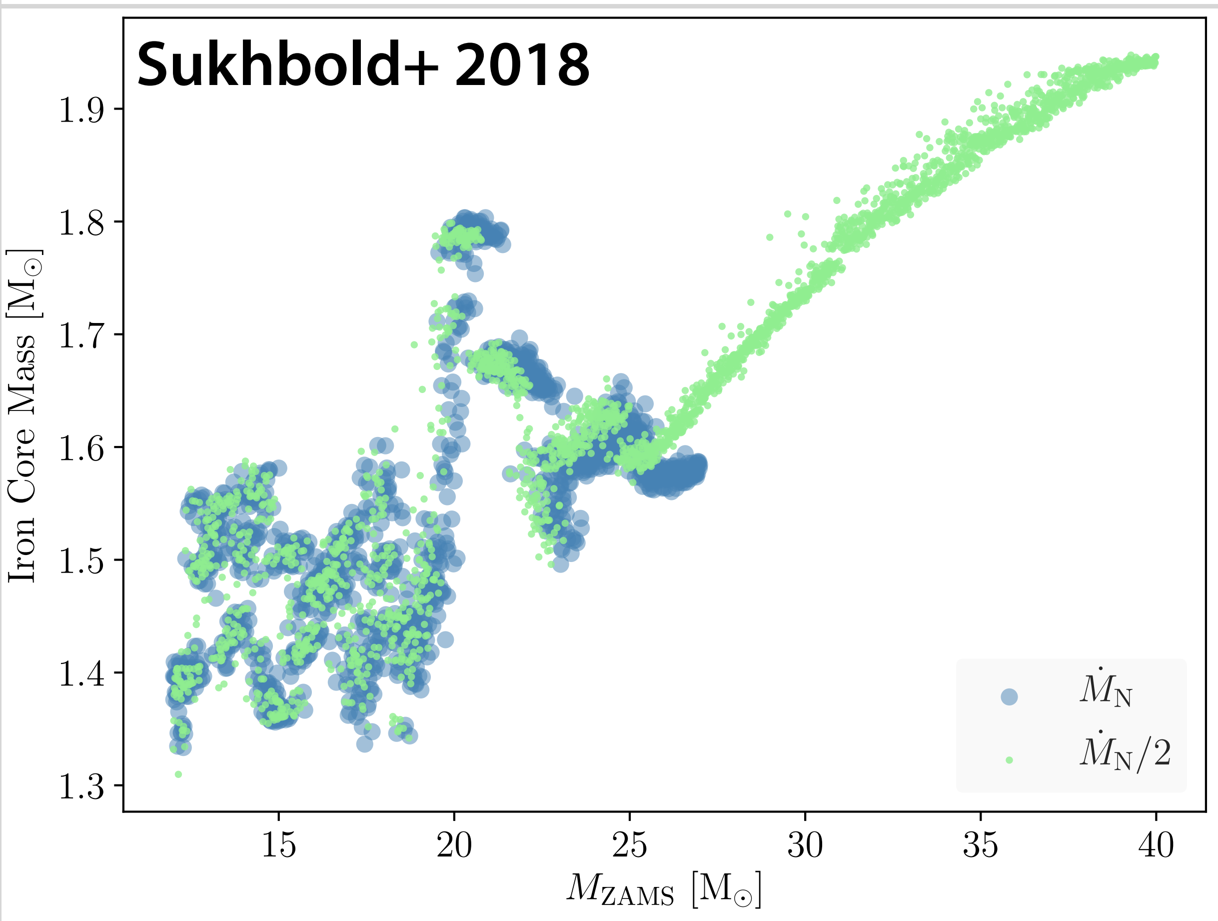
M_c=1.174±0.004$M_\odot$

A low-mass NS

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

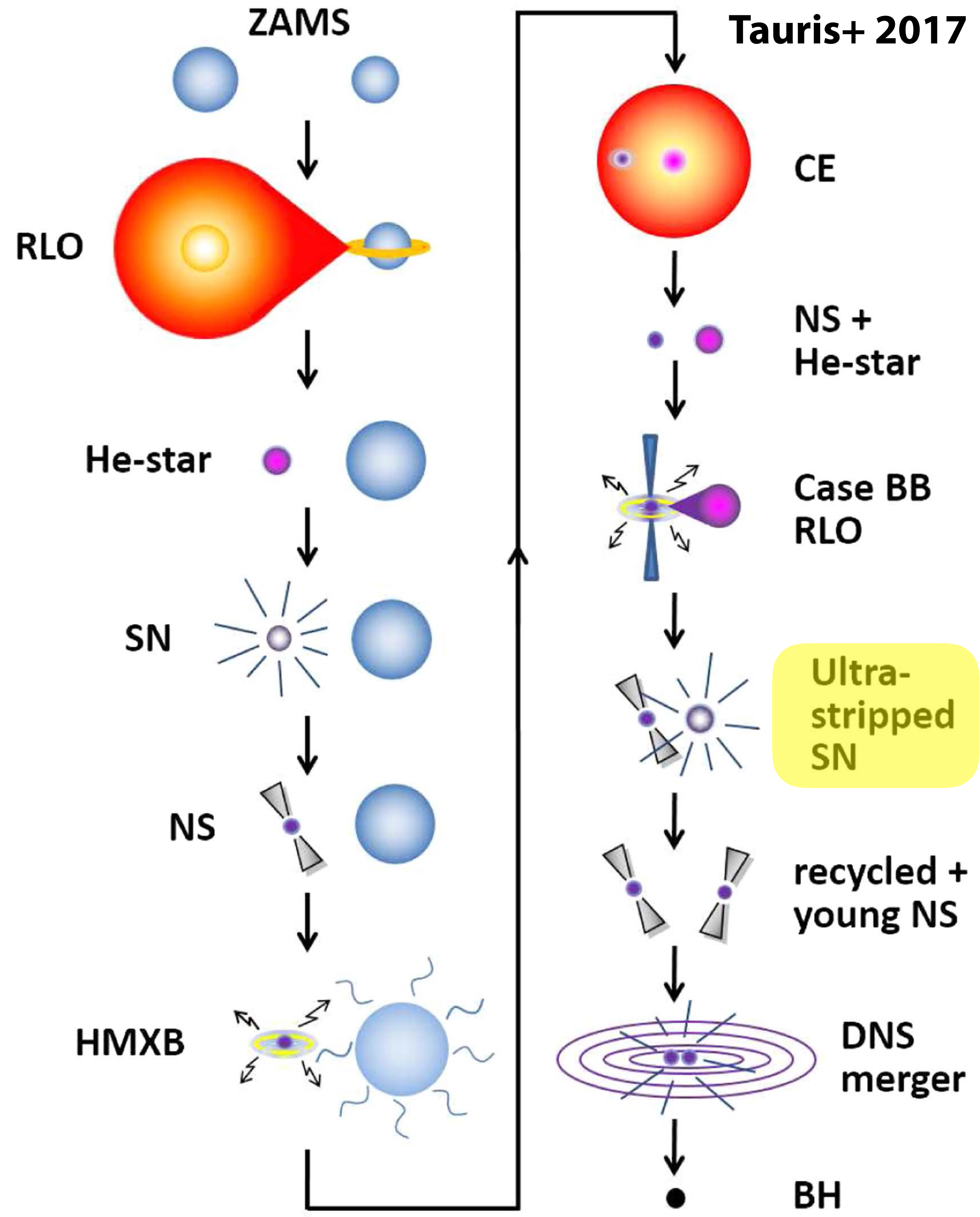
- **Is it a white dwarf? Maybe no**
  - a large eccentricity (e=0.112) is difficult to explain by slow evolution into a WD

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

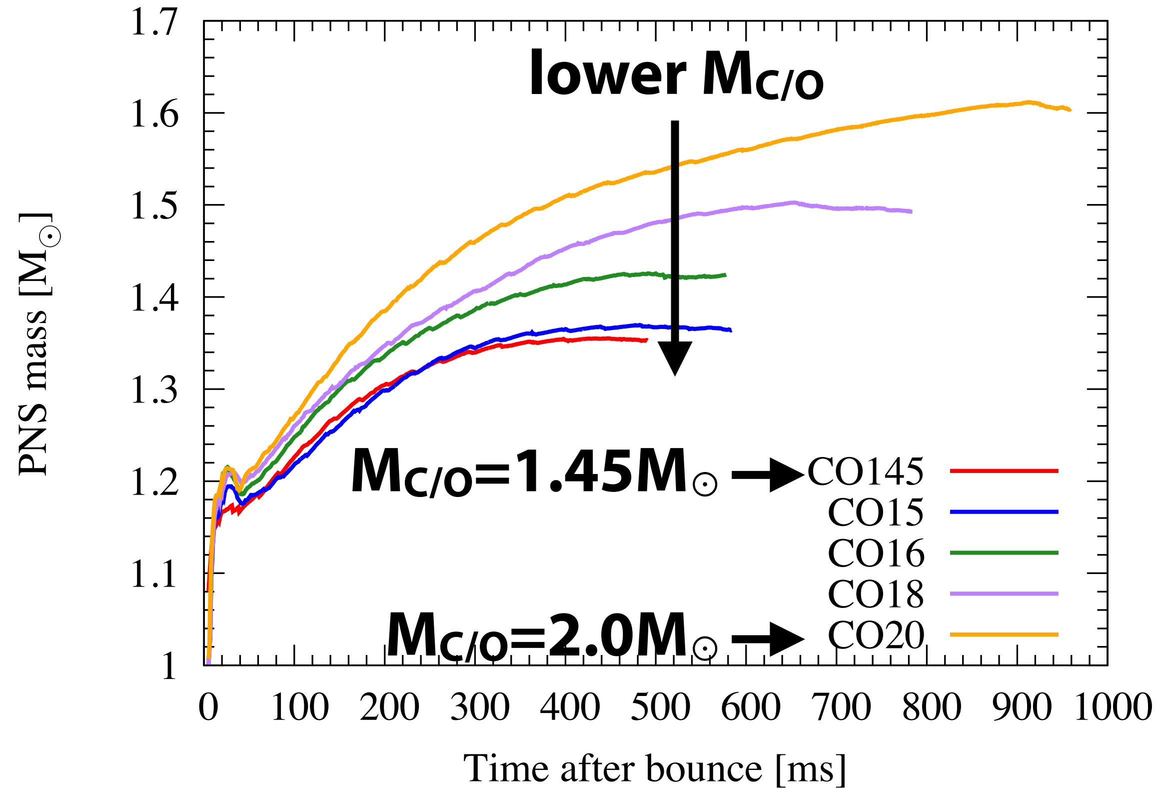


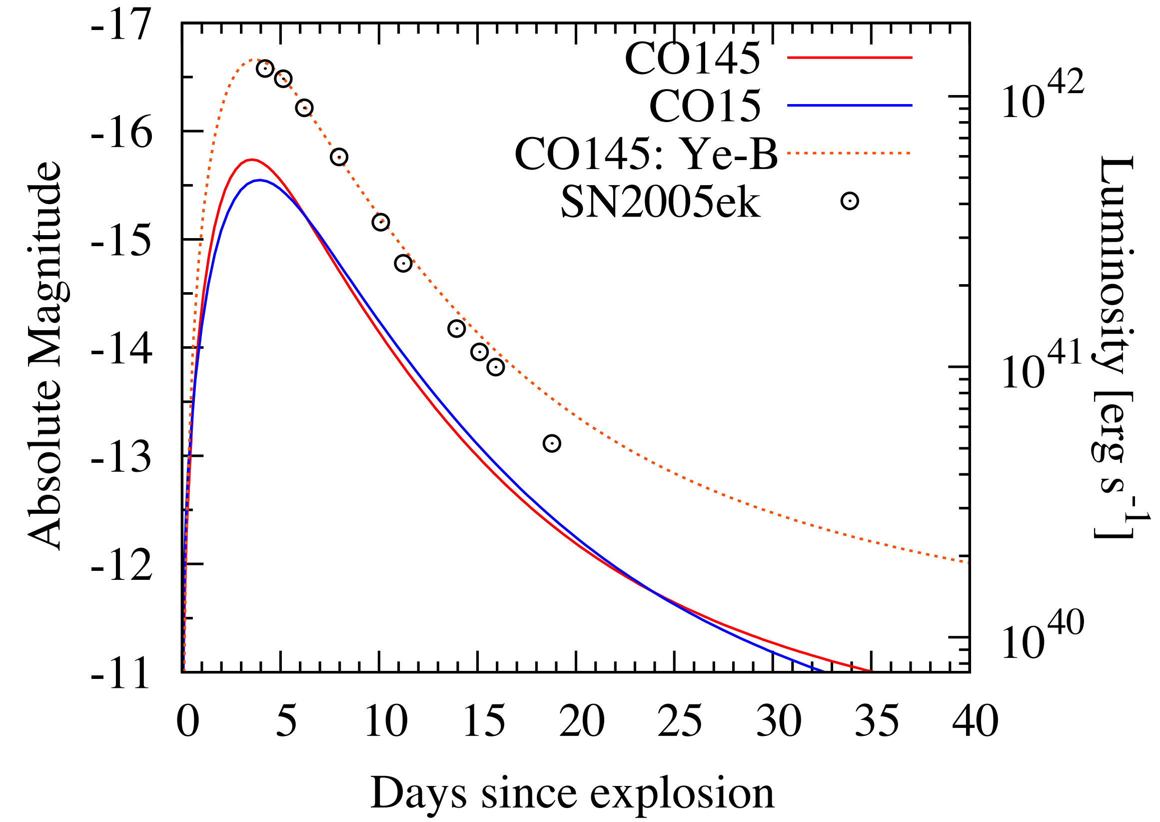
A path toward a low mass NS?: SN in close binary

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

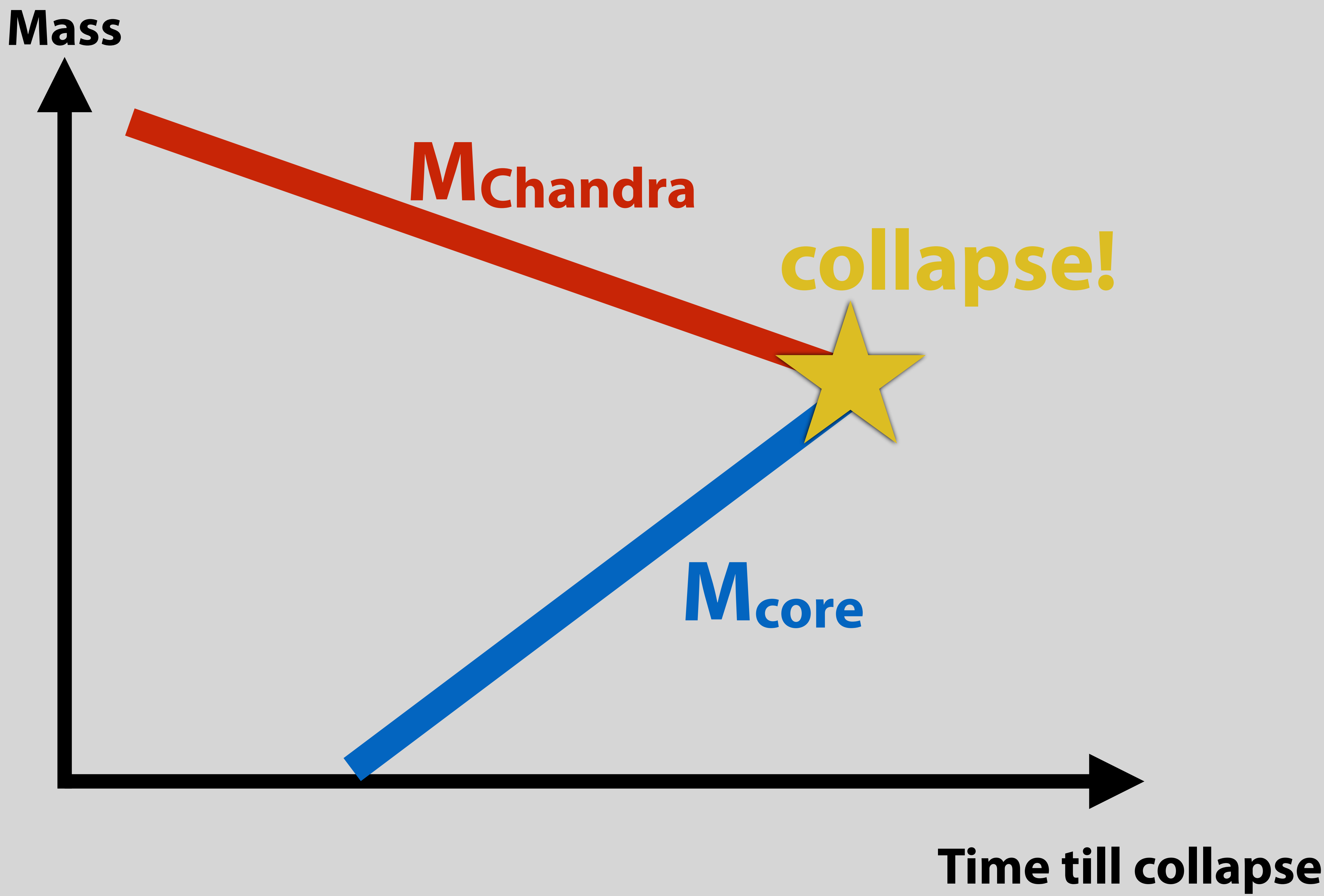


see poster by Hijikawa-san





When does a core collapse?



Modified Chandrasekhar mass

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

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

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

$$M_{\mathrm{Ch}}(T) = M_{\mathrm{Ch0}}(Y_e)\left[1 + \left(\frac{s_e}{\pi Y_2}\right)^2\right]$$

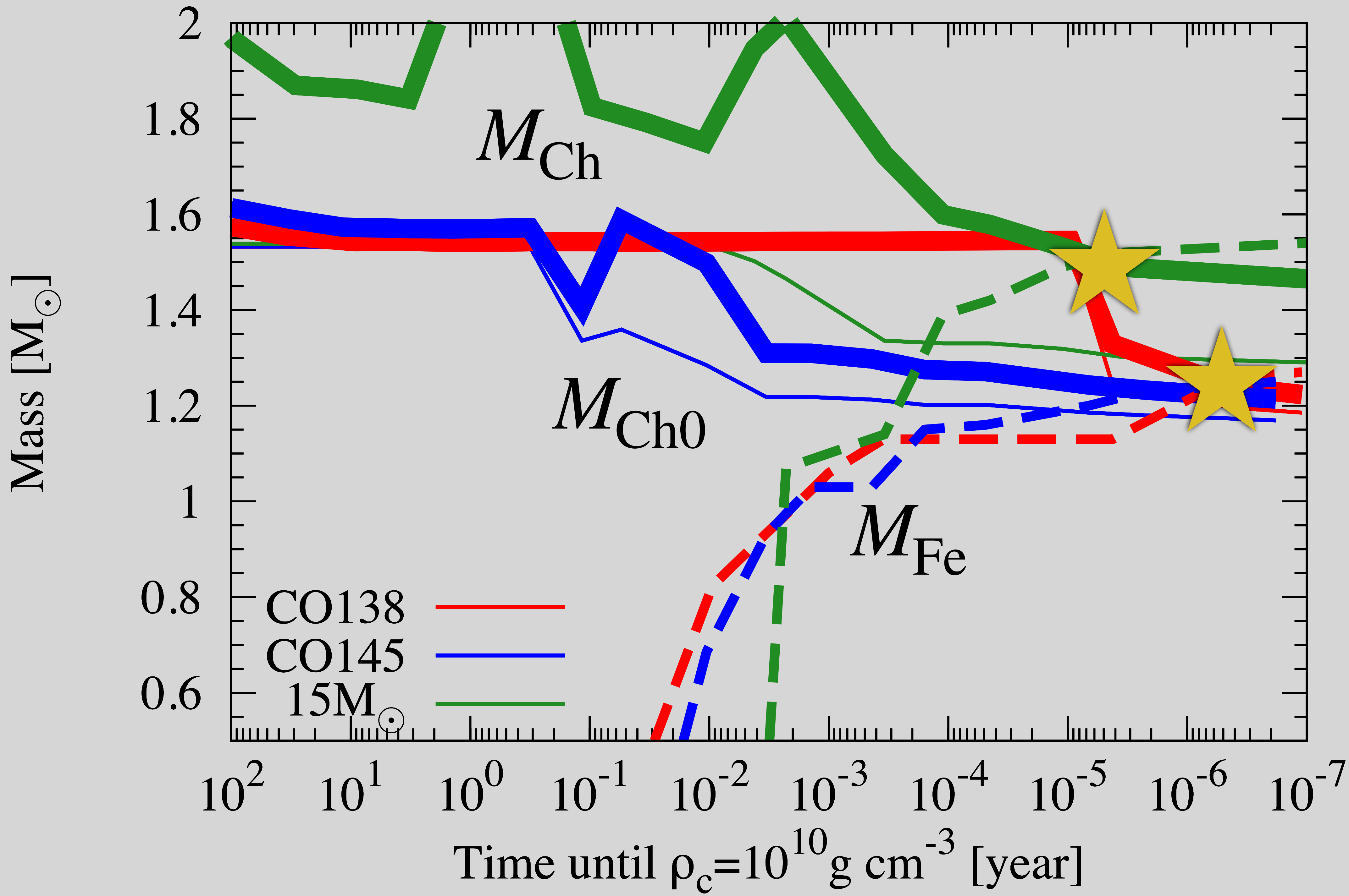
$$s_e = 0.5 \rho_{10}^{-1/3} (Y_e/0.42)^{2/3} T_{\mathrm{MeV}}$$

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)]



What do simulations solve?

stellar evolution

input: $\rho(r), T(r), Z_i(r), v_r(r)$

Numerical table based on nuclear physics
e.g.) 10^3 g cm^{-3} $< \rho < 10^{15}$ g cm^{-3}
0.1 MeV $< T <$ 100 MeV
$0.03 < Y_e < 0.56$

strong interaction

Nuclear equation of state

general relativity

Gravity

electro-magnetic interaction

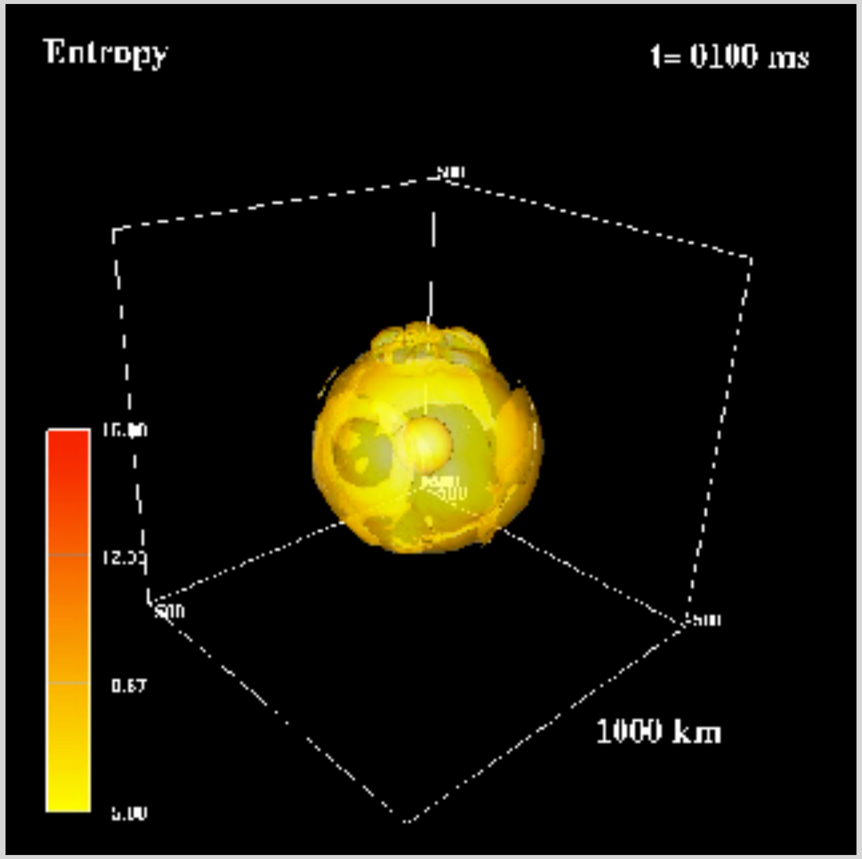
(Magneto-)hydrodynamics

weak interaction

Neutrino transfer

Number of interactions;

$pe^- \leftrightarrow n\nu_e$, $ne^+ \leftrightarrow p\bar{\nu}_e$
$\nu e^\pm \leftrightarrow \nu e^\pm$, $\nu A \leftrightarrow \nu A$, $\nu N \leftrightarrow \nu N$
$\nu\bar{\nu} \leftrightarrow e^-e^+$, $NN \leftrightarrow \nu\bar{\nu}NN$, $\nu\bar{\nu} \leftrightarrow \nu\bar{\nu}$



Takiwaki, Kotake, Suwa (2014)

as first-principles as possible.
parameter free simulation!

Explosion simulations and NS masses

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

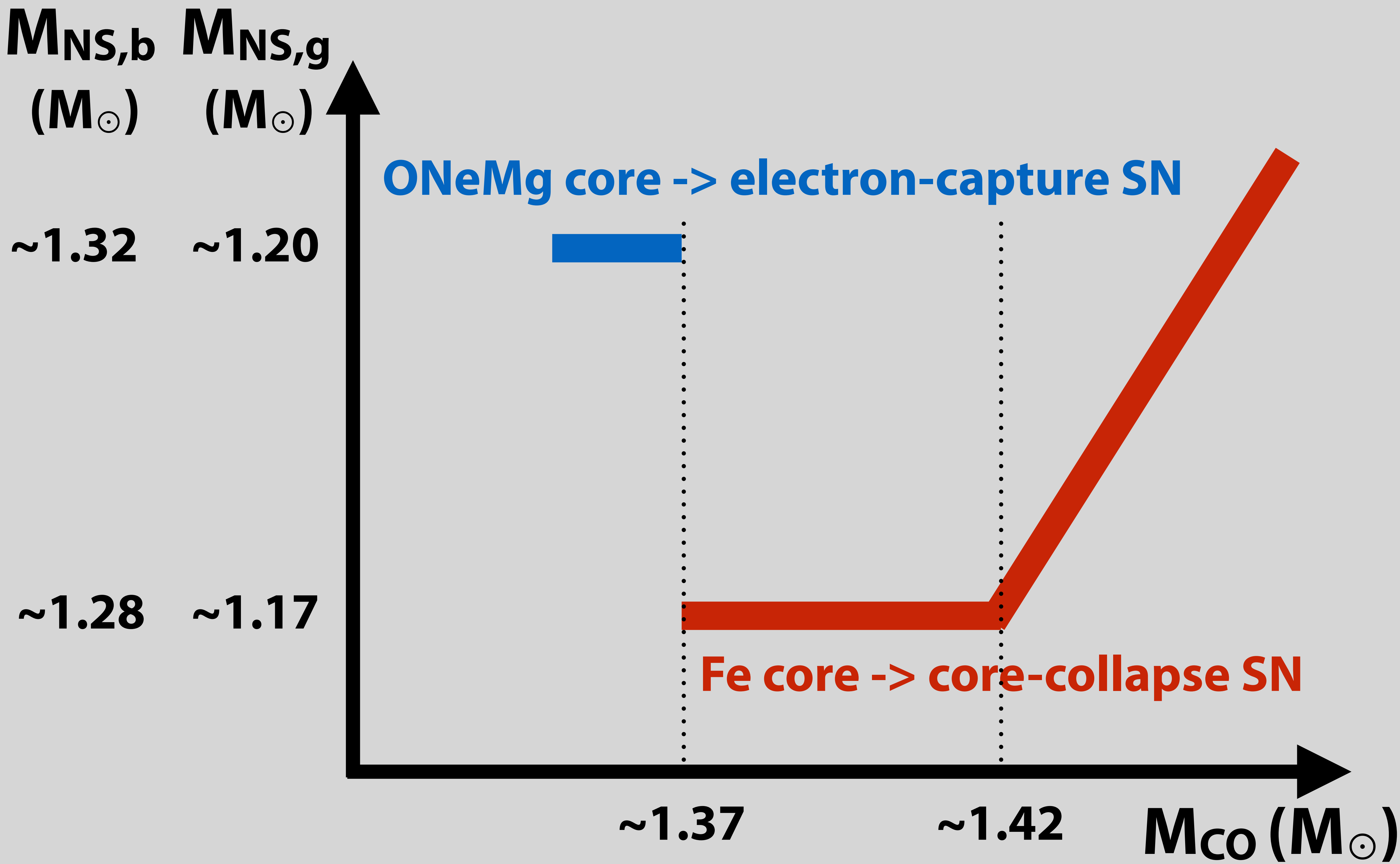
Model	M_{CO} ($M_\odot$)	M_{ZAMS} ($M_\odot$)	M_{Fe} ($M_\odot$)	$M_{NS,b}$ ($M_\odot$)	$M_{NS,g}$ ($M_\odot$)
CO137	1.37	9.35	1.280	1.289	**1.174**
CO138	1.38	9.4	1.274	1.296	**1.179**
CO139	1.39	9.45	1.258	1.302	1.184
CO140	1.4	9.5	1.296	1.298	1.181
CO142	1.42	9.6	1.265	1.287	**1.172**
CO144	1.44	9.7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

$M_{NS,b}-M_{NS,g}=0.084M_\odot(M_{NS,g}/M_\odot)^2$

(Lattimer & Prakash 2001)

Discussion

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



Summary

- **A low-mass NS of $M_{NS,g}$=1.174$M_\odot$ 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 ~1.17$M_\odot$.
  - If a new observation finds even lower mass NS, we cannot make it. Something wrong.