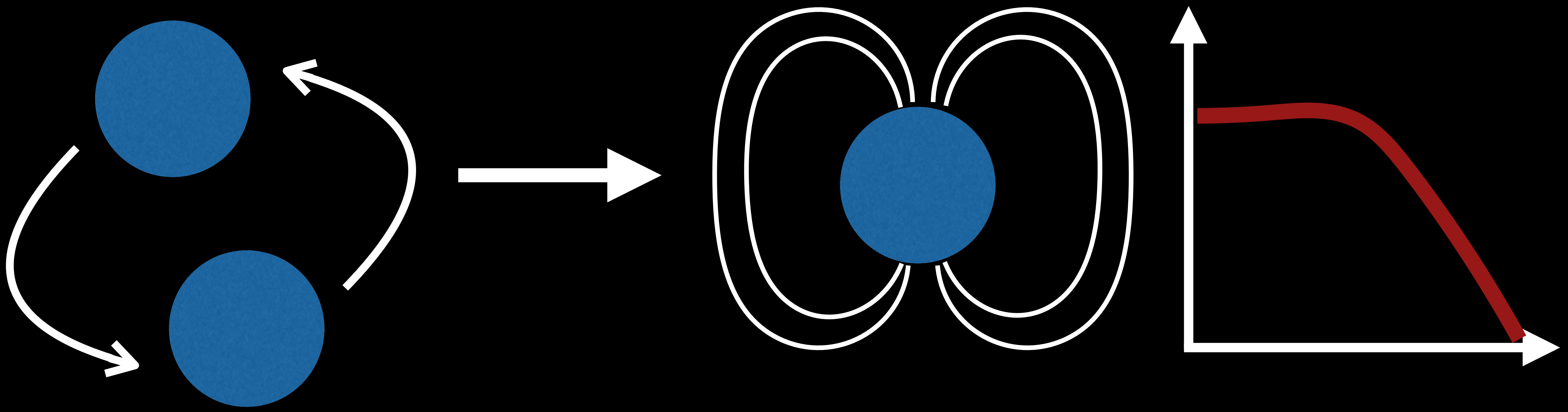
MoCA
Monash Centre for Astrophysics

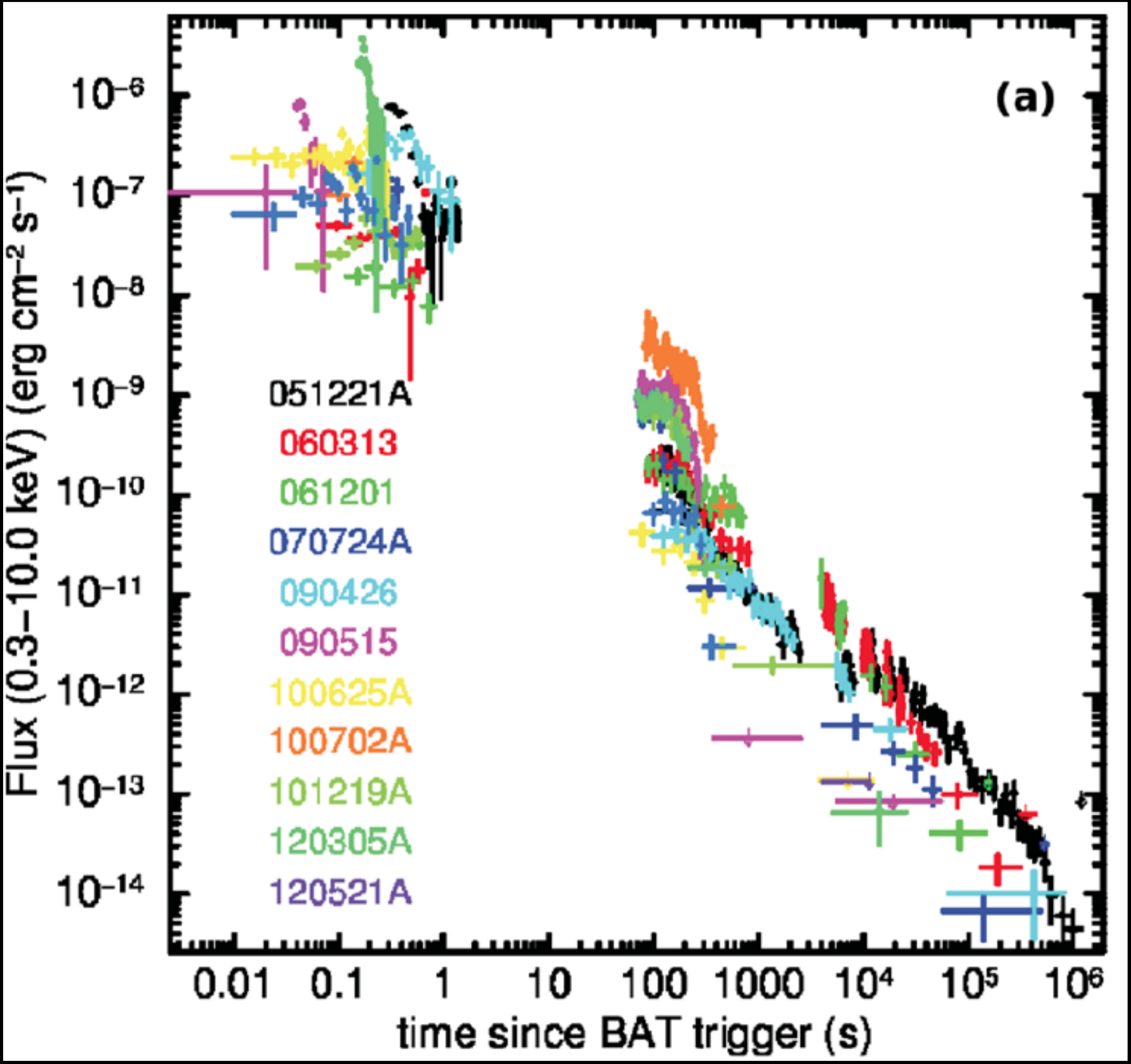
Equation of state and gravitational waves from short GRB remnants

Paul Lasky

MONASH University



Rowlinson et al. (2013), Lü, Zhang, Lei, Li & PL (2015)



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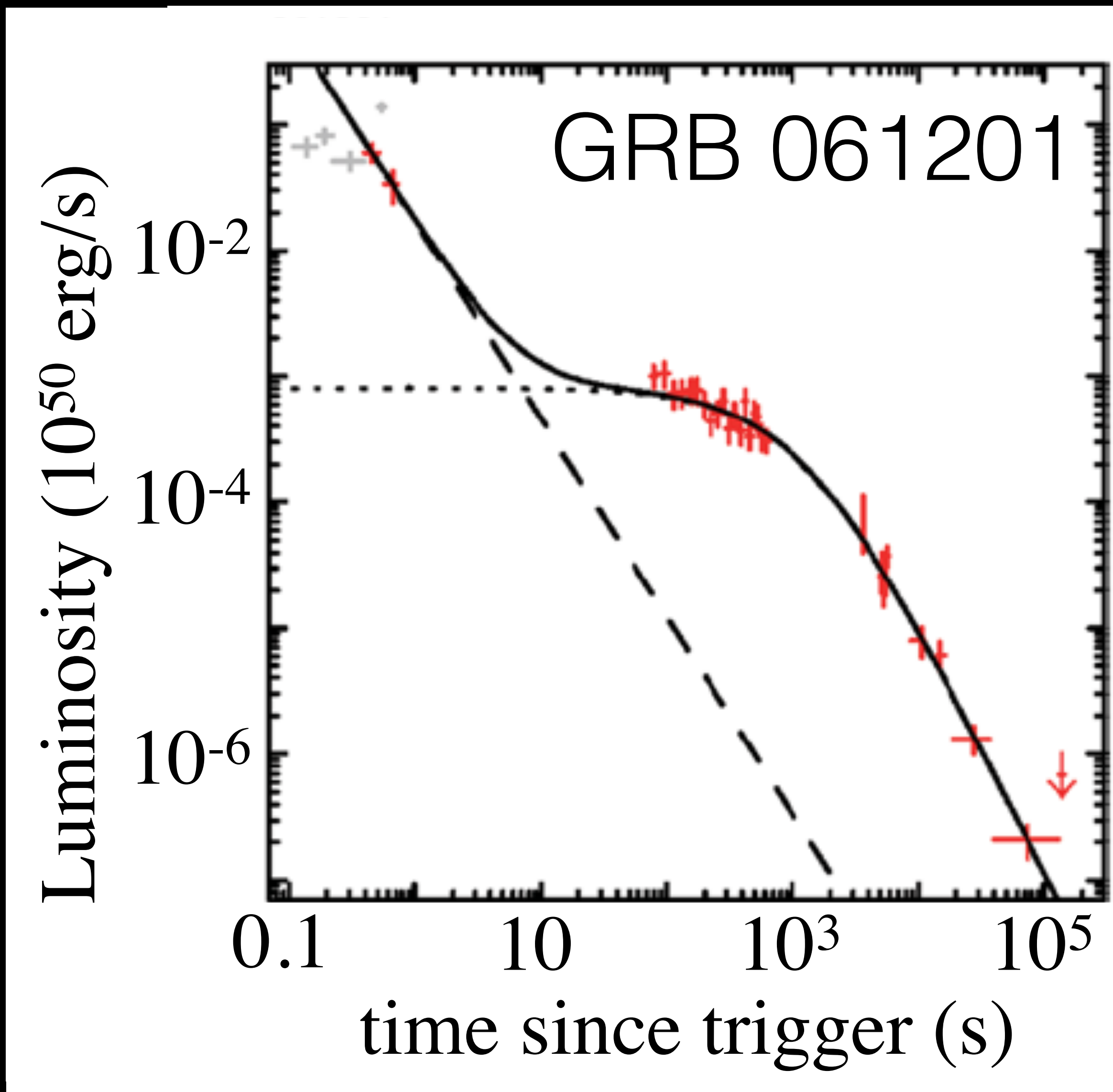
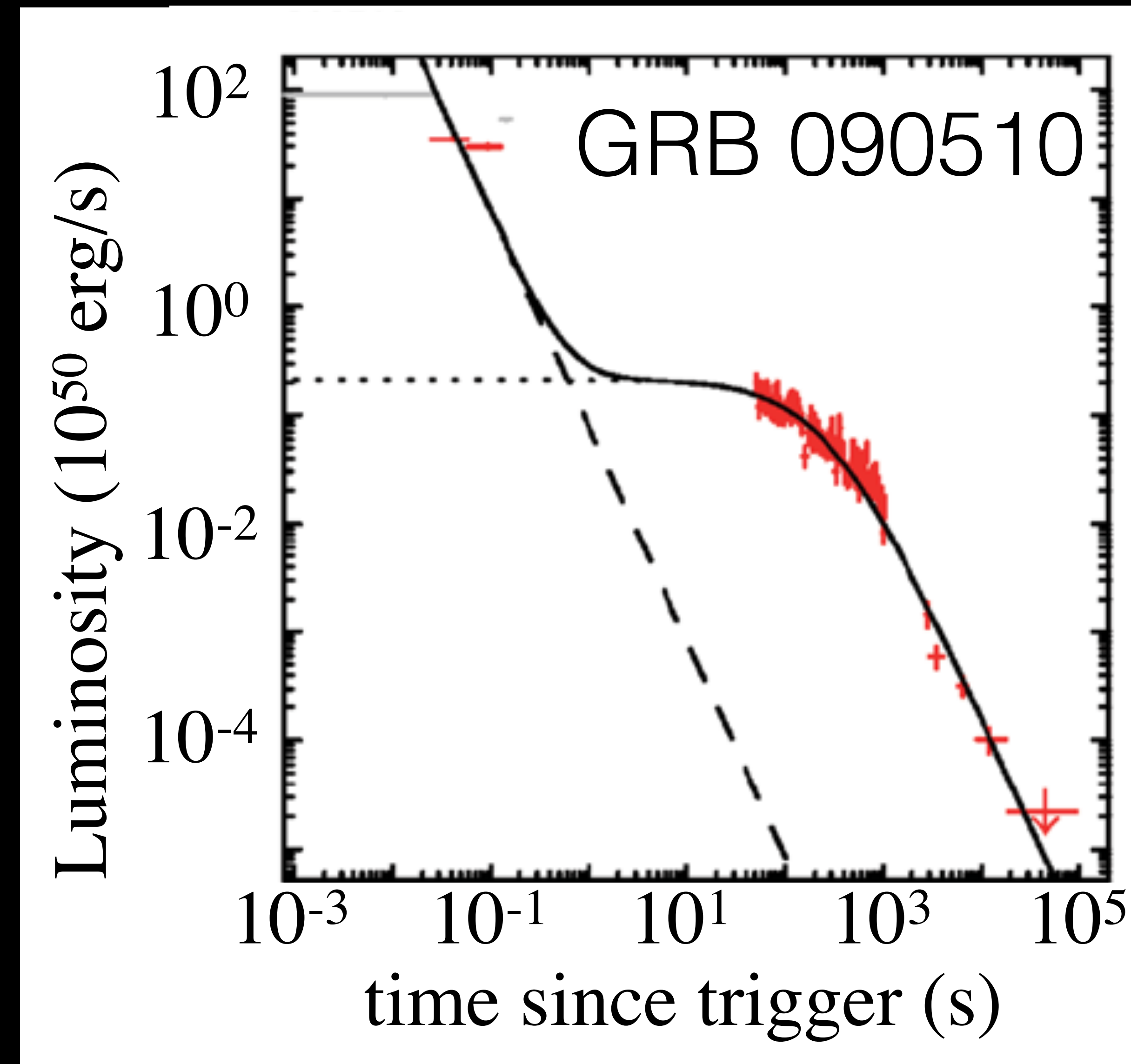


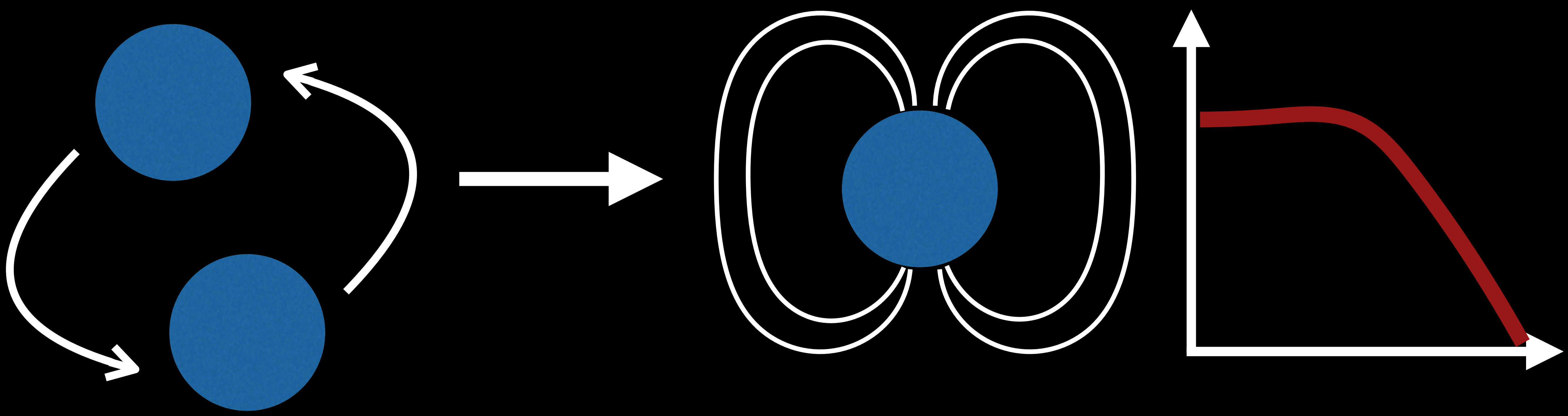


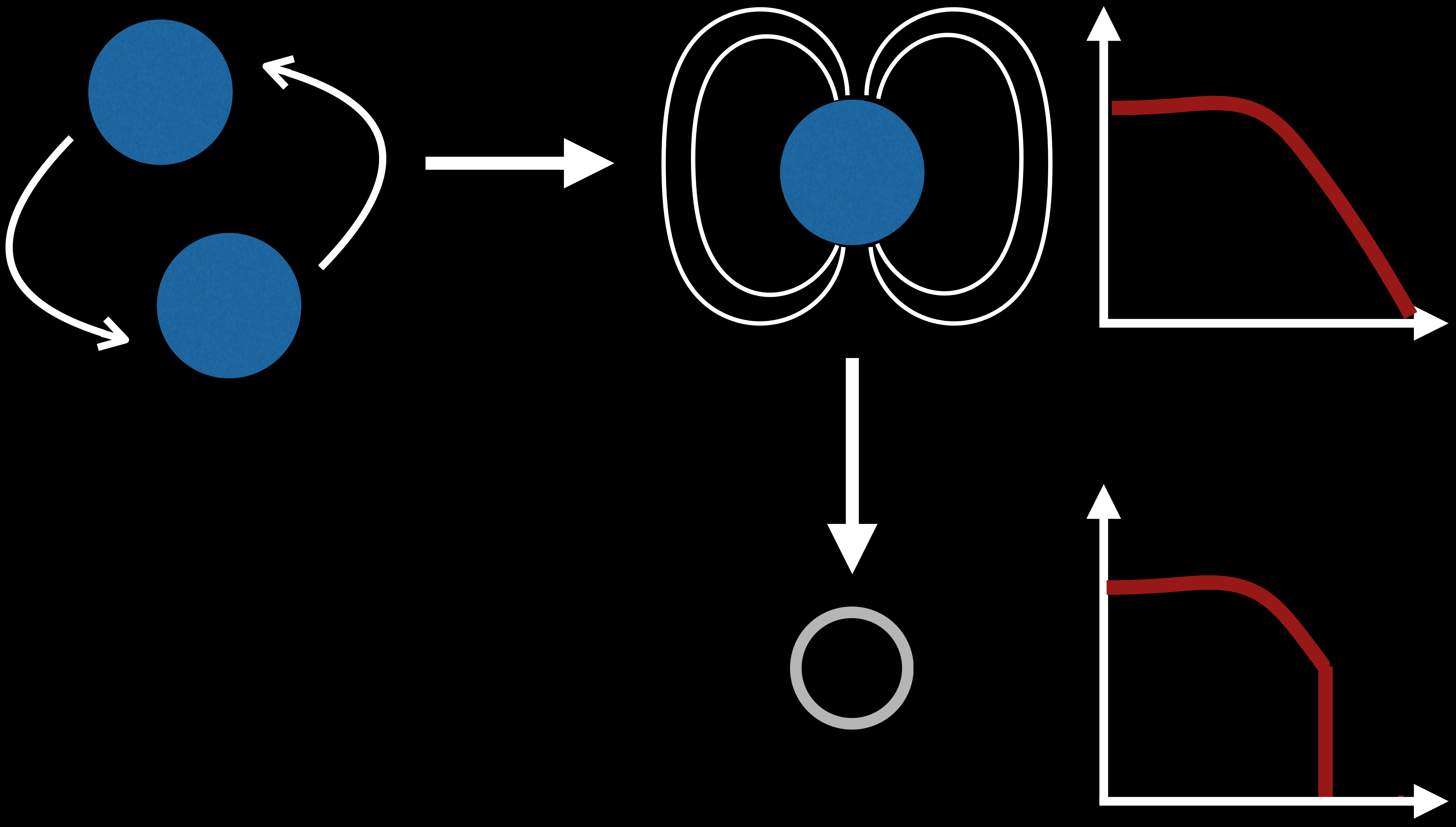
$$B_p^2 \sim \frac{I^2}{R^6 L_0 T_{\rm em}} \qquad P_0^2 \sim \frac{I}{L_0 T_{\rm em}}$$

L_0 - plateau luminosity

$T_{\rm em}$ - plateau duration

Zhang & Mészáros (2001)





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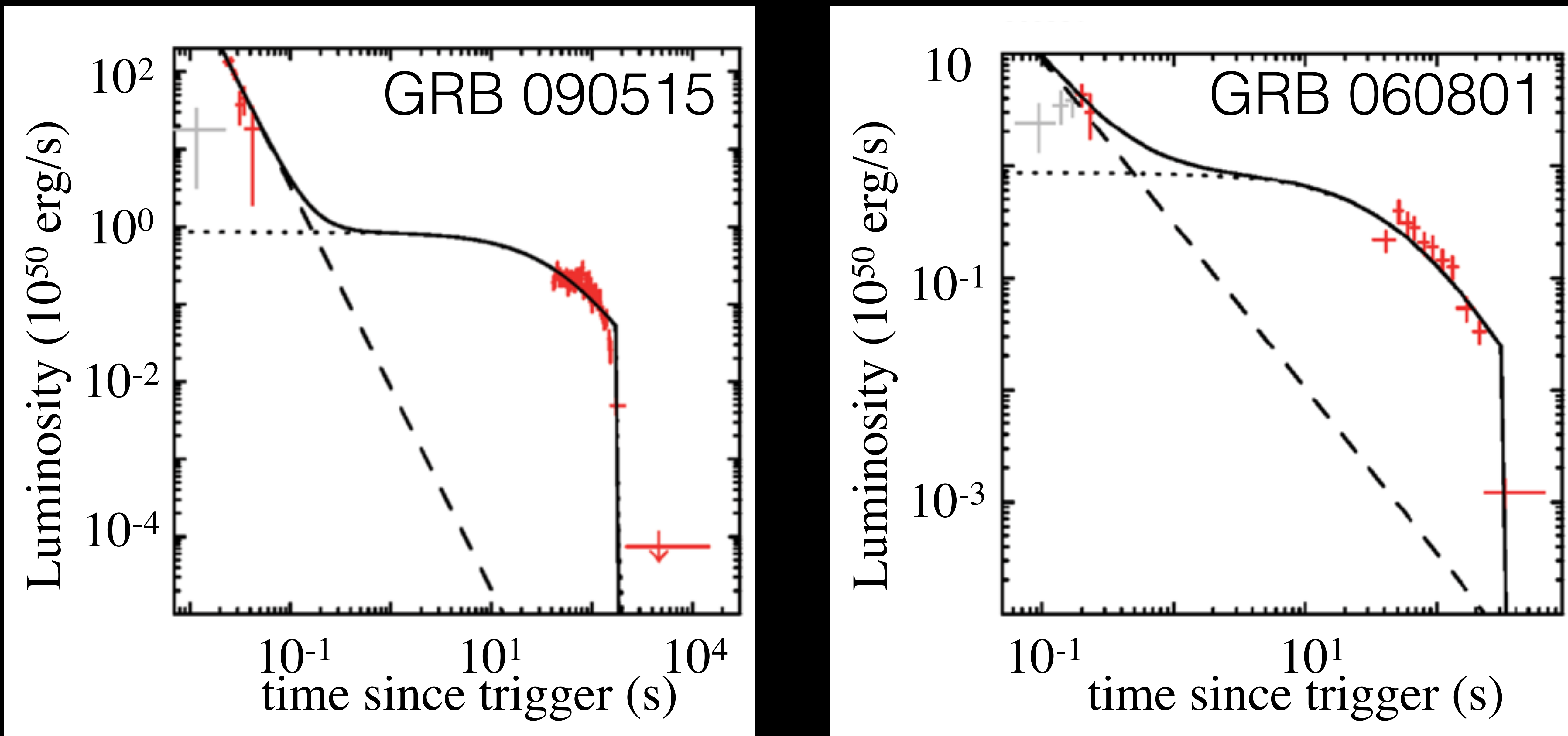
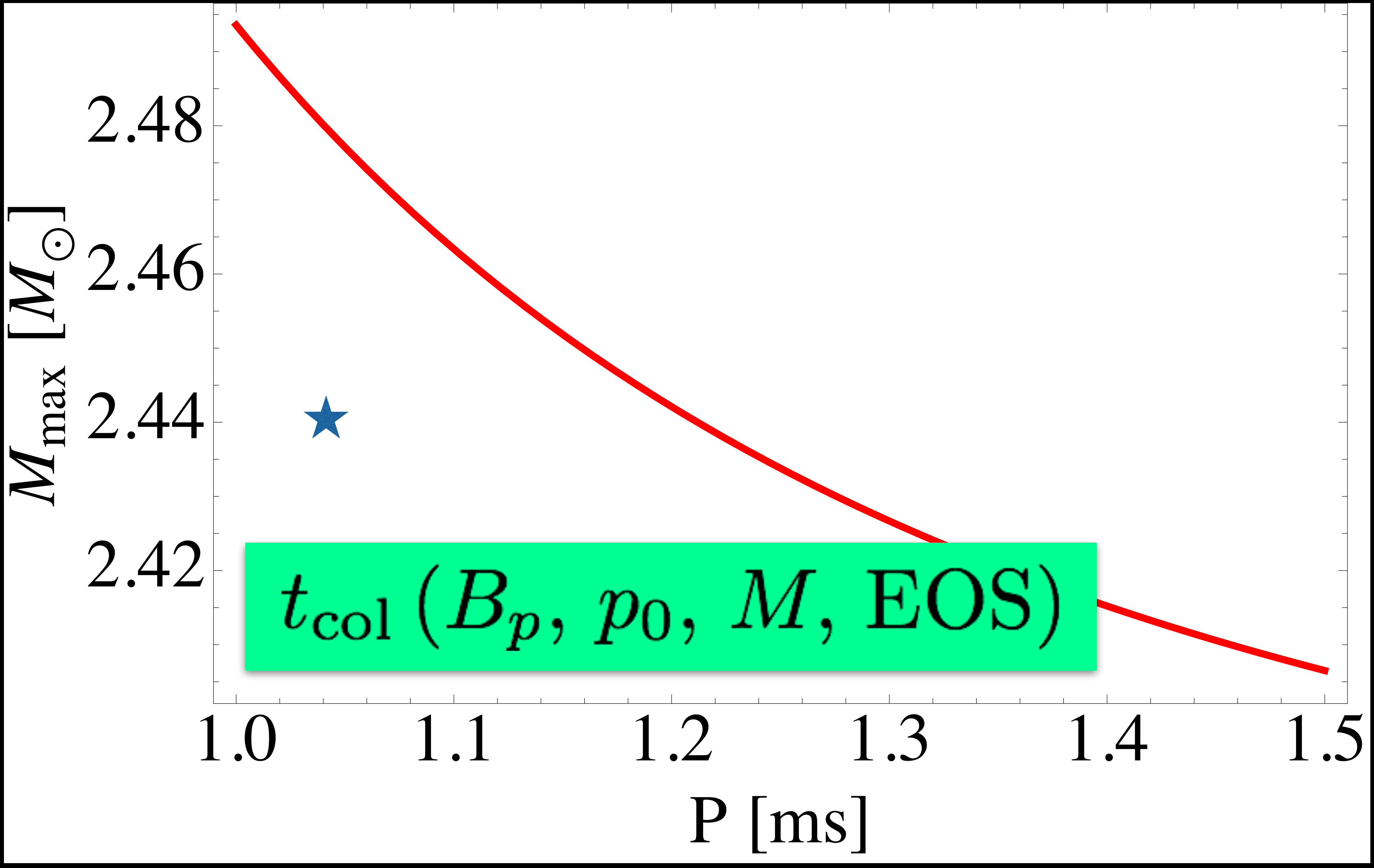


GRB	z	p_0 [ms]	B_p [10^{15} G]	t_{col} [s]
060801	1.13	$1.95^{+0.15}_{-0.13}$	$11.24^{+1.93}_{-1.78}$	326
070724A	0.46	$1.80^{+1.04}_{-0.38}$	$28.72^{+1.42}_{-1.29}$	90
080905A	0.122	$9.80^{+0.78}_{-0.77}$	$39.26^{+10.24}_{-12.16}$	274
101219A	0.718	$0.95^{+0.05}_{-0.05}$	$2.81^{+0.47}_{-0.39}$	138
051221A	0.55	$7.70^{+0.31}_{-0.28}$	$1.80^{+0.14}_{-0.13}$	–
070809	0.219	$5.54^{+0.48}_{-0.43}$	$2.06^{+0.48}_{-0.42}$	–
090426	2.6	$1.89^{+0.08}_{-0.07}$	$4.88^{+0.88}_{-0.90}$	–
090510	0.9	$1.86^{+0.04}_{-0.03}$	$5.06^{+0.27}_{-0.23}$	–

Supramassive Stars

Consider a star: p_0 = 1.05 ms

M = 2.44 M_{sun}



Supramassive Stars

Consider a star: $p_0 = 1.05$ ms

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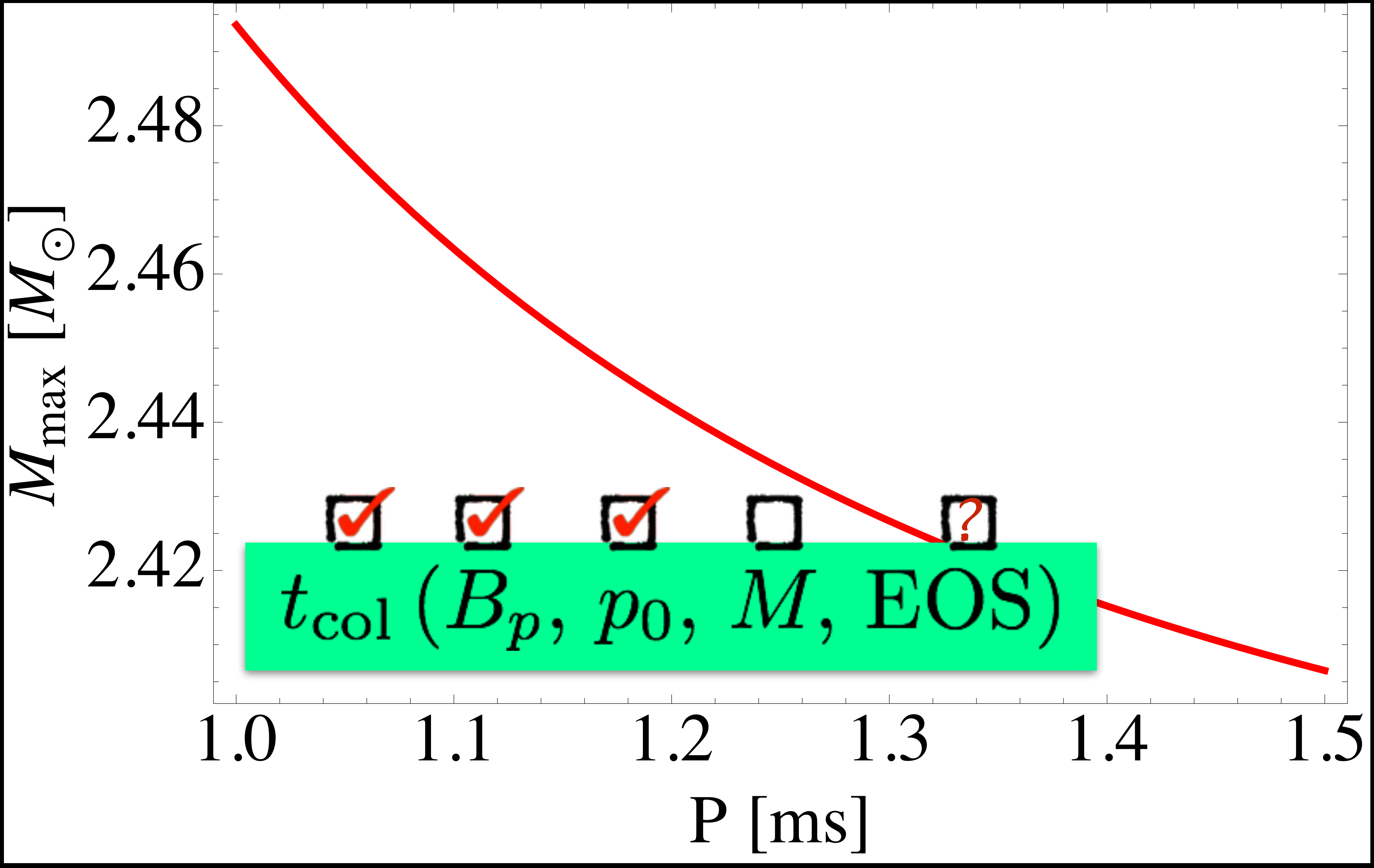
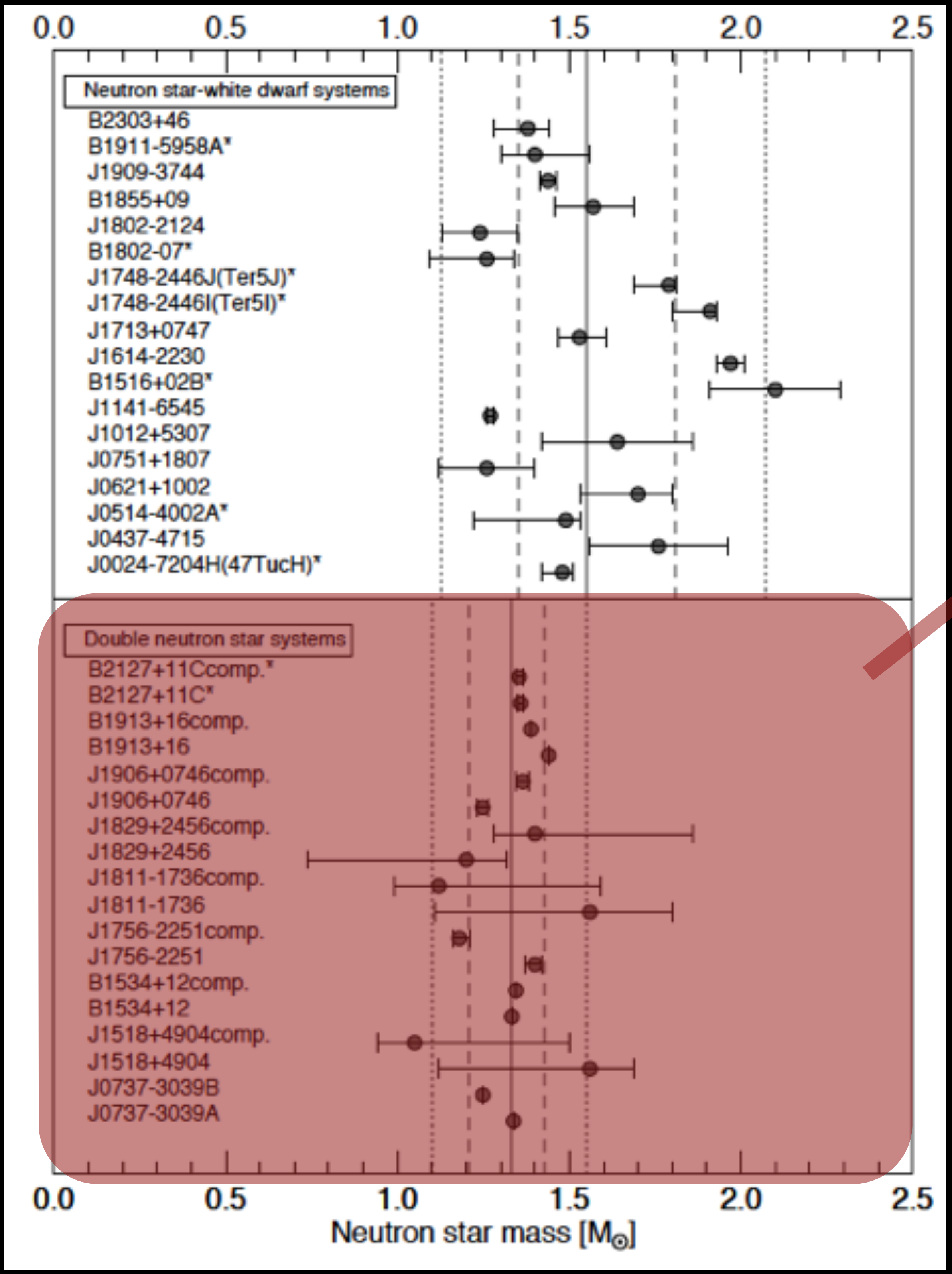
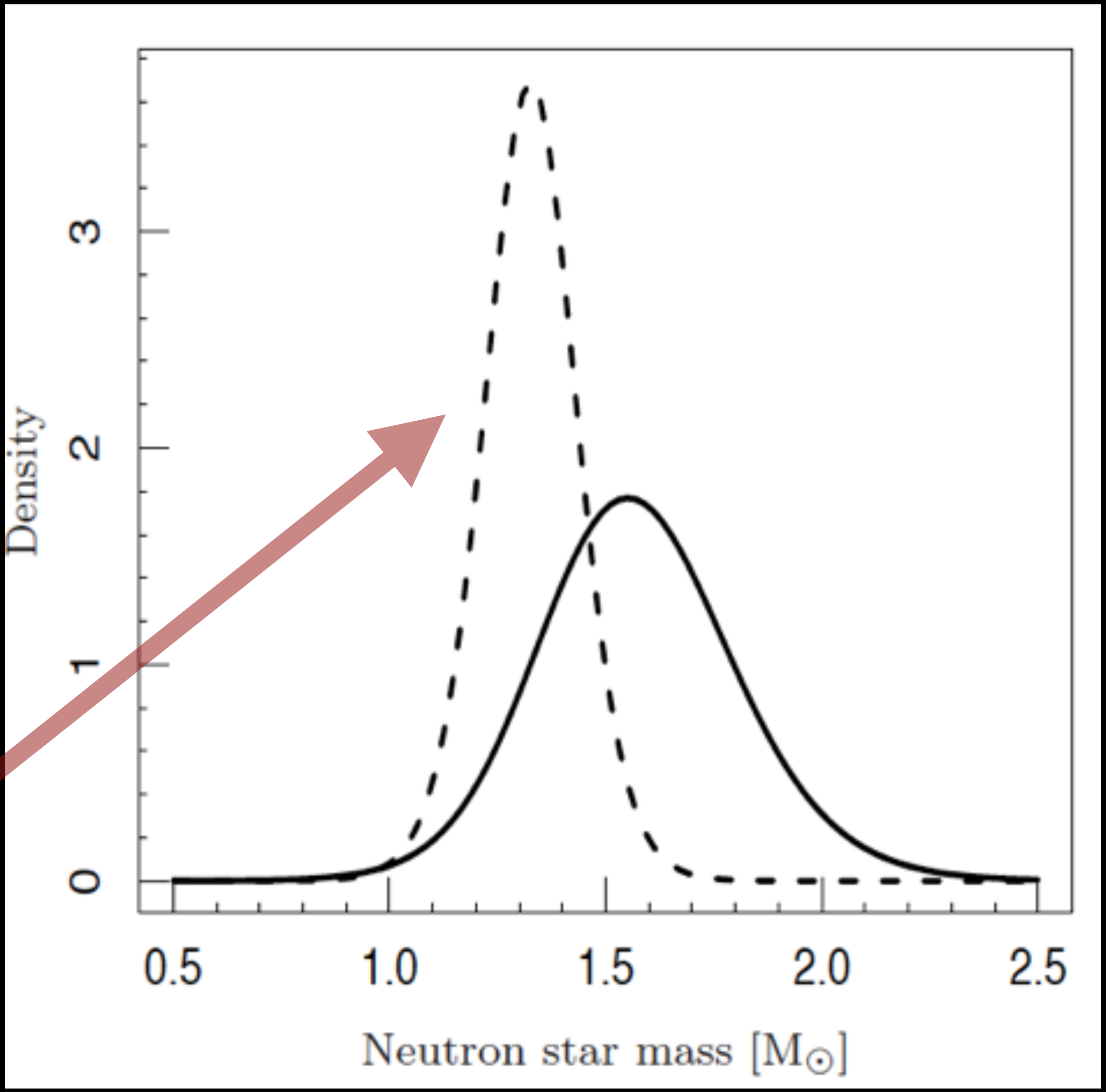


Kiziltan et al. (2013)

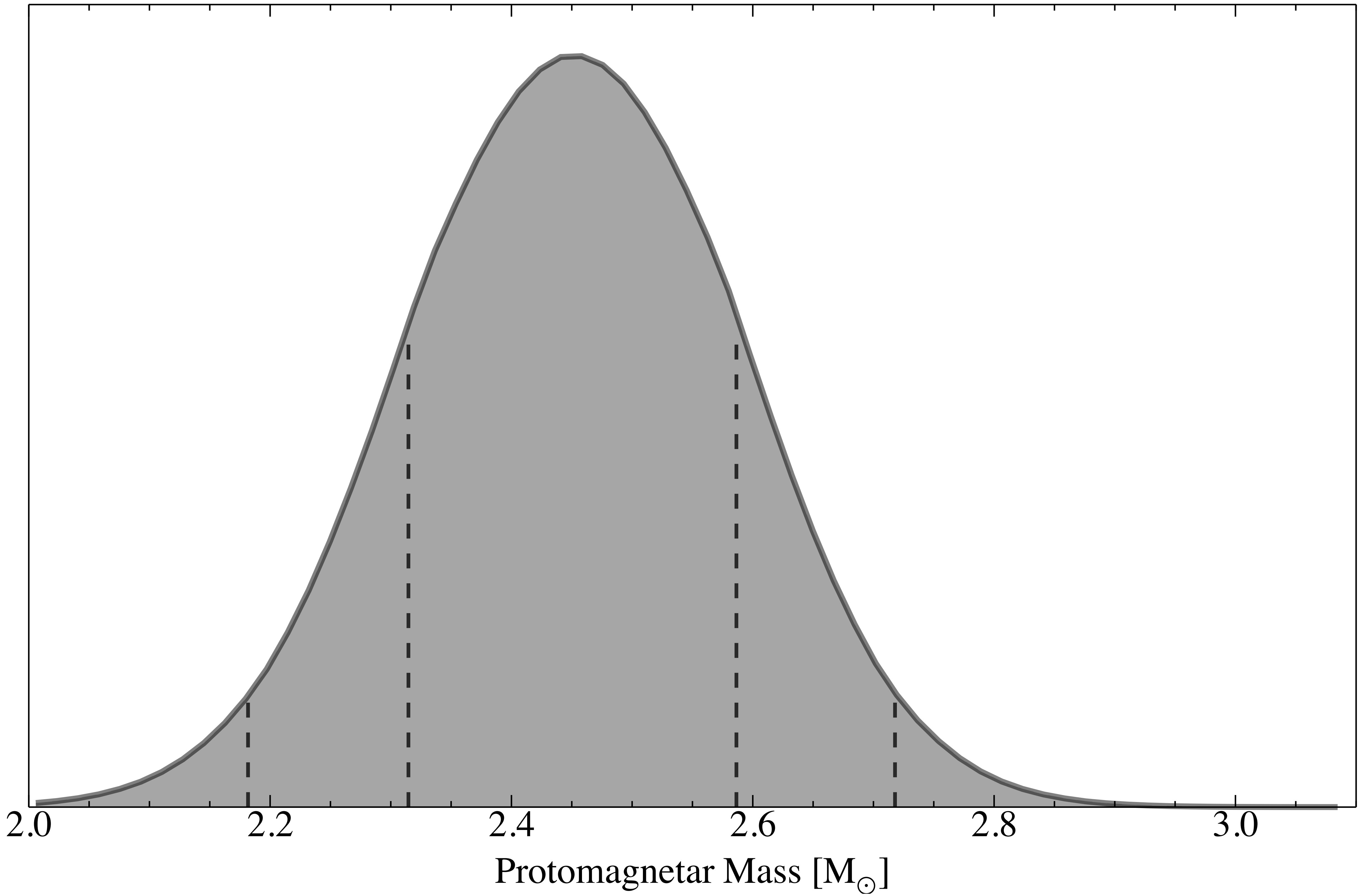




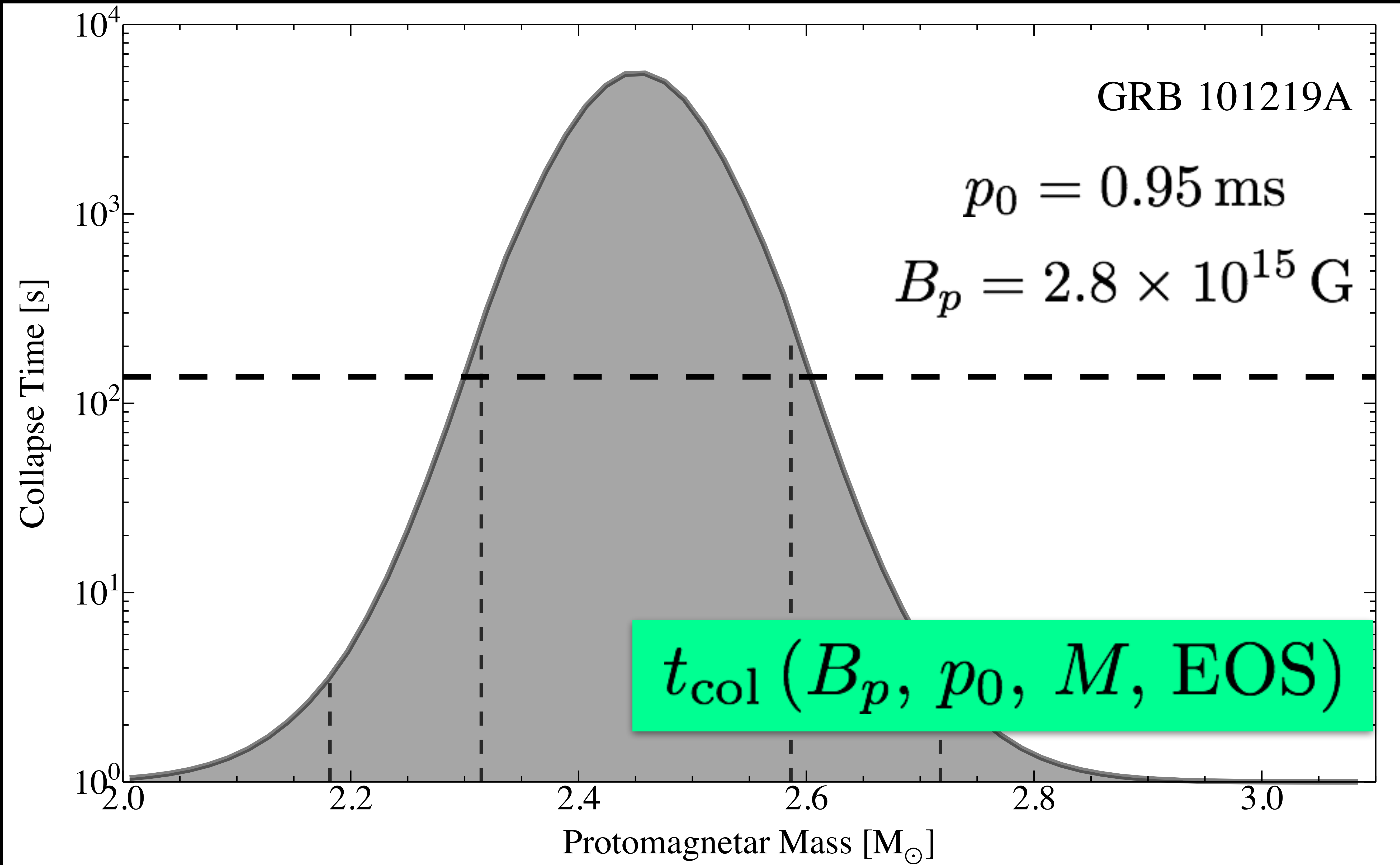
$$M = 1.32^{+0.11}_{-0.11} M_\odot$$

Rest mass conservation

$$M_p = 2.46^{+0.13}_{-0.15} M_\odot$$



PL, Haskell, Ravi, Howell & Coward (2014)



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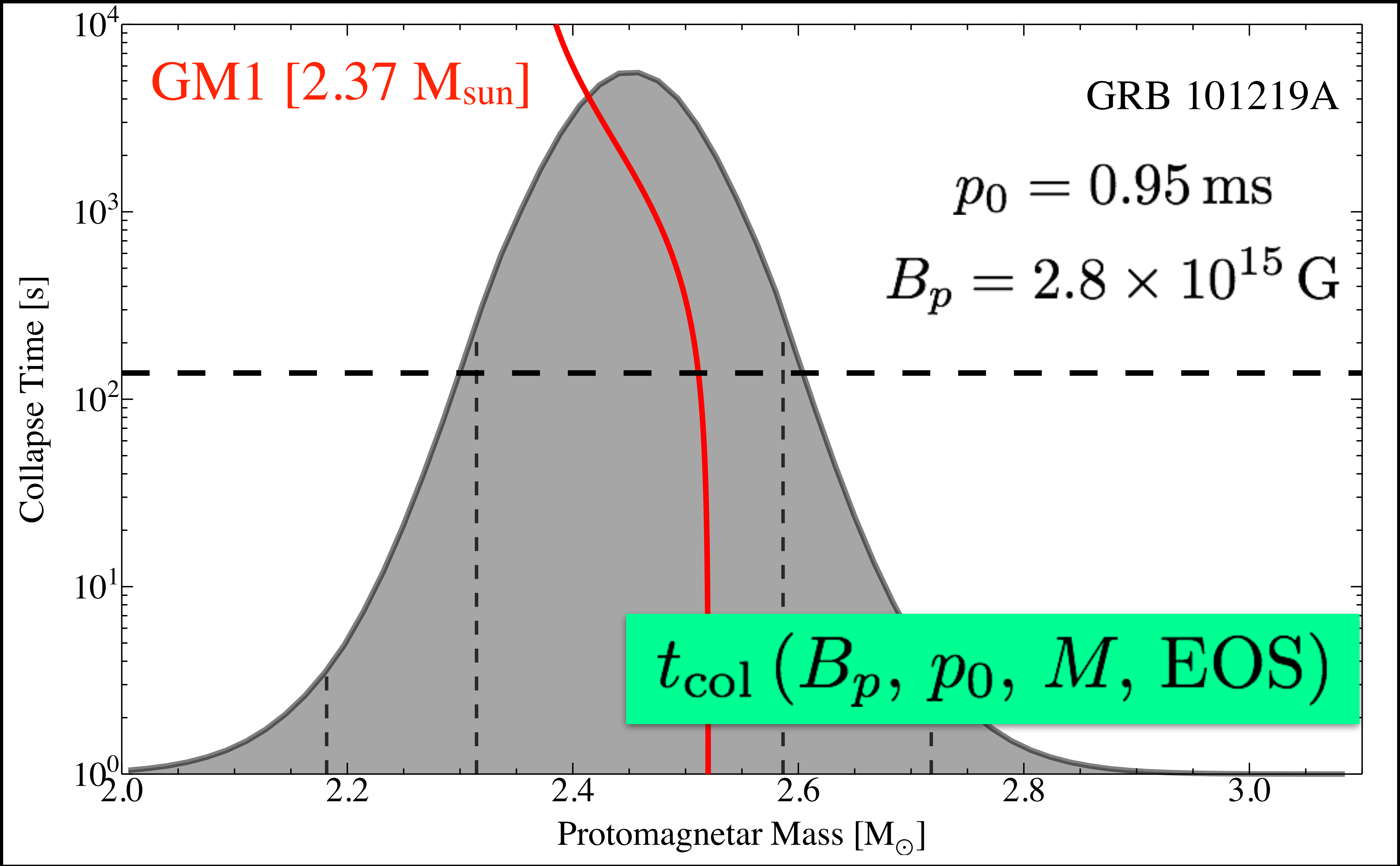
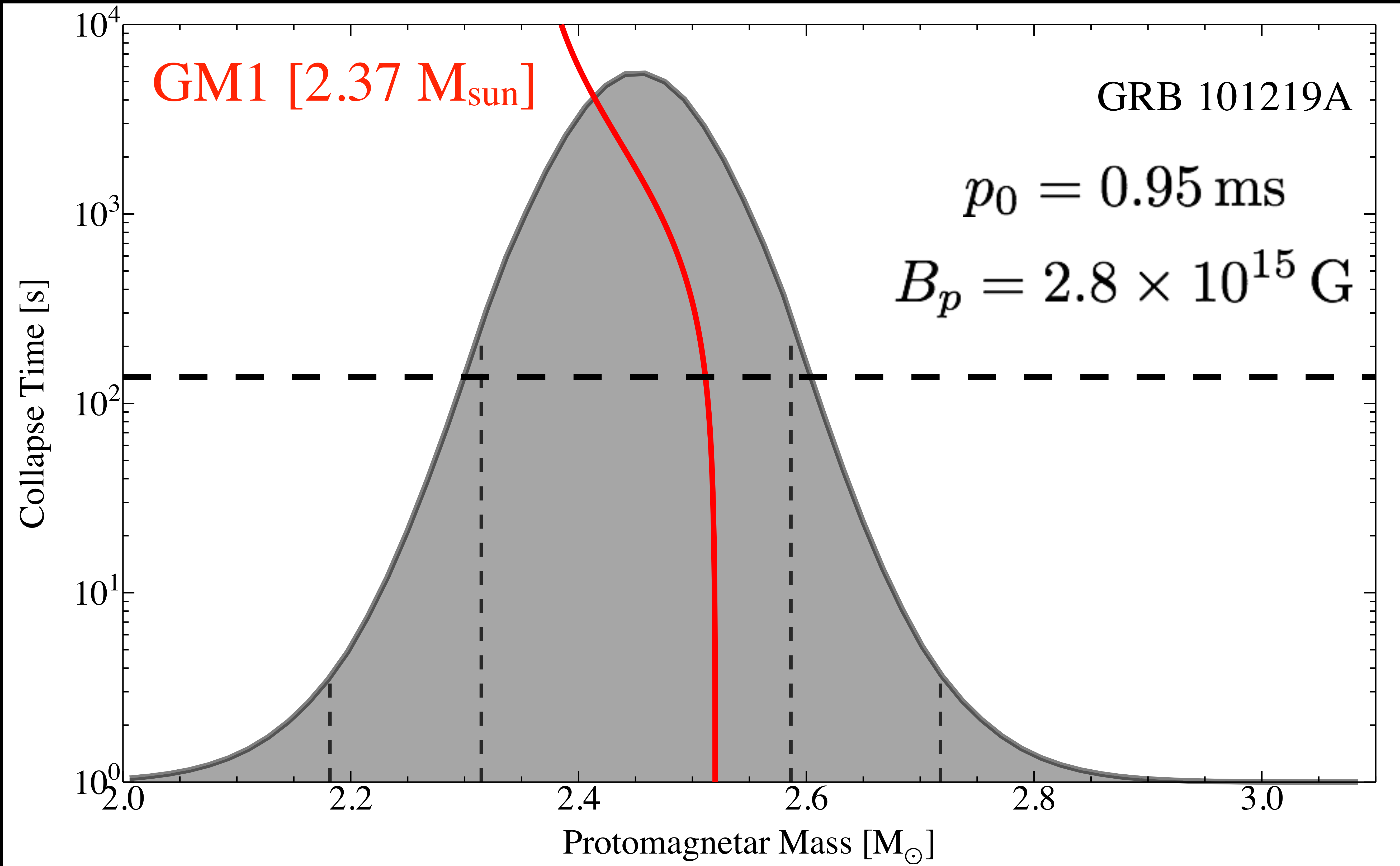


PL, Haskell, Ravi, Howell & Coward (2014)



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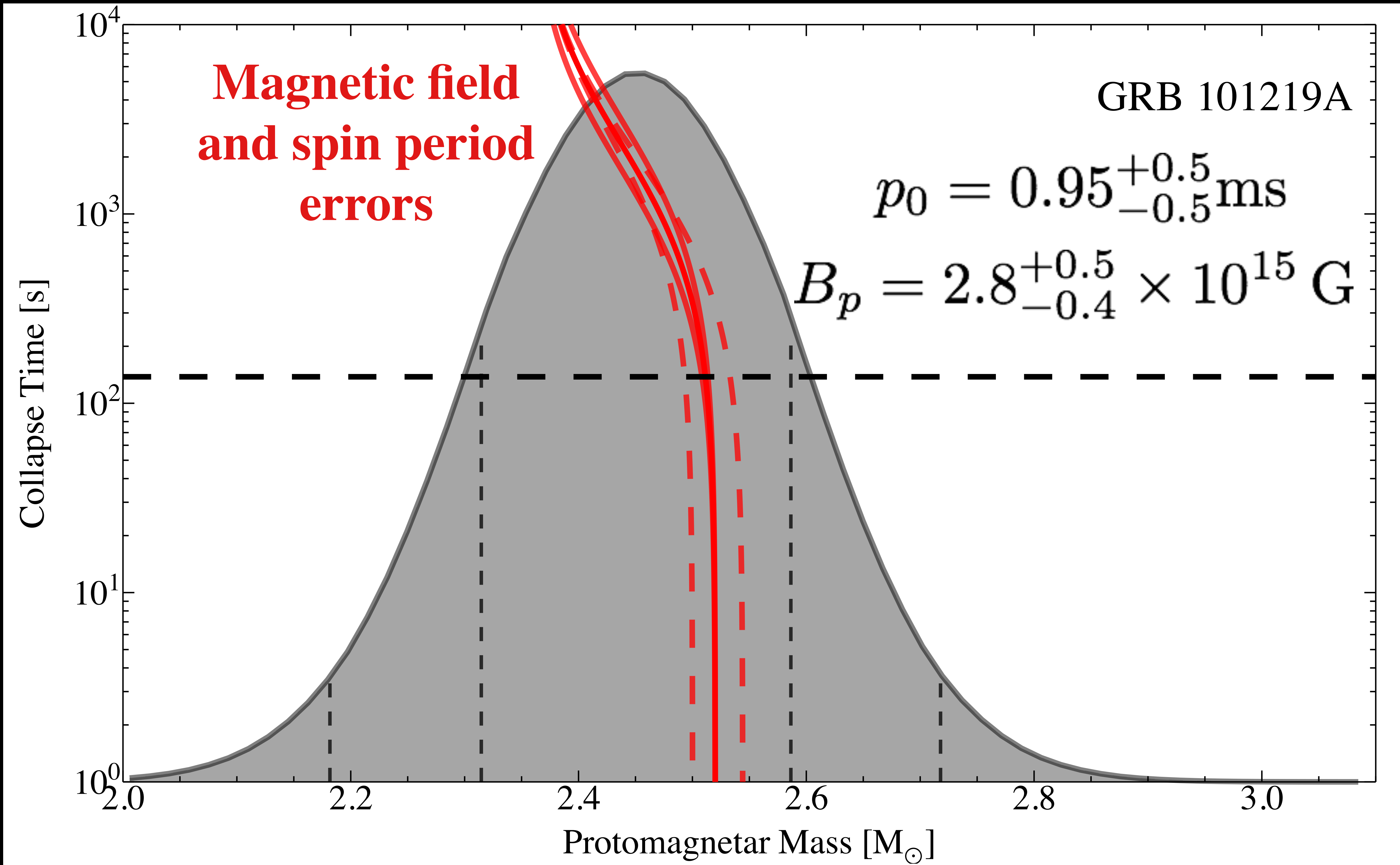

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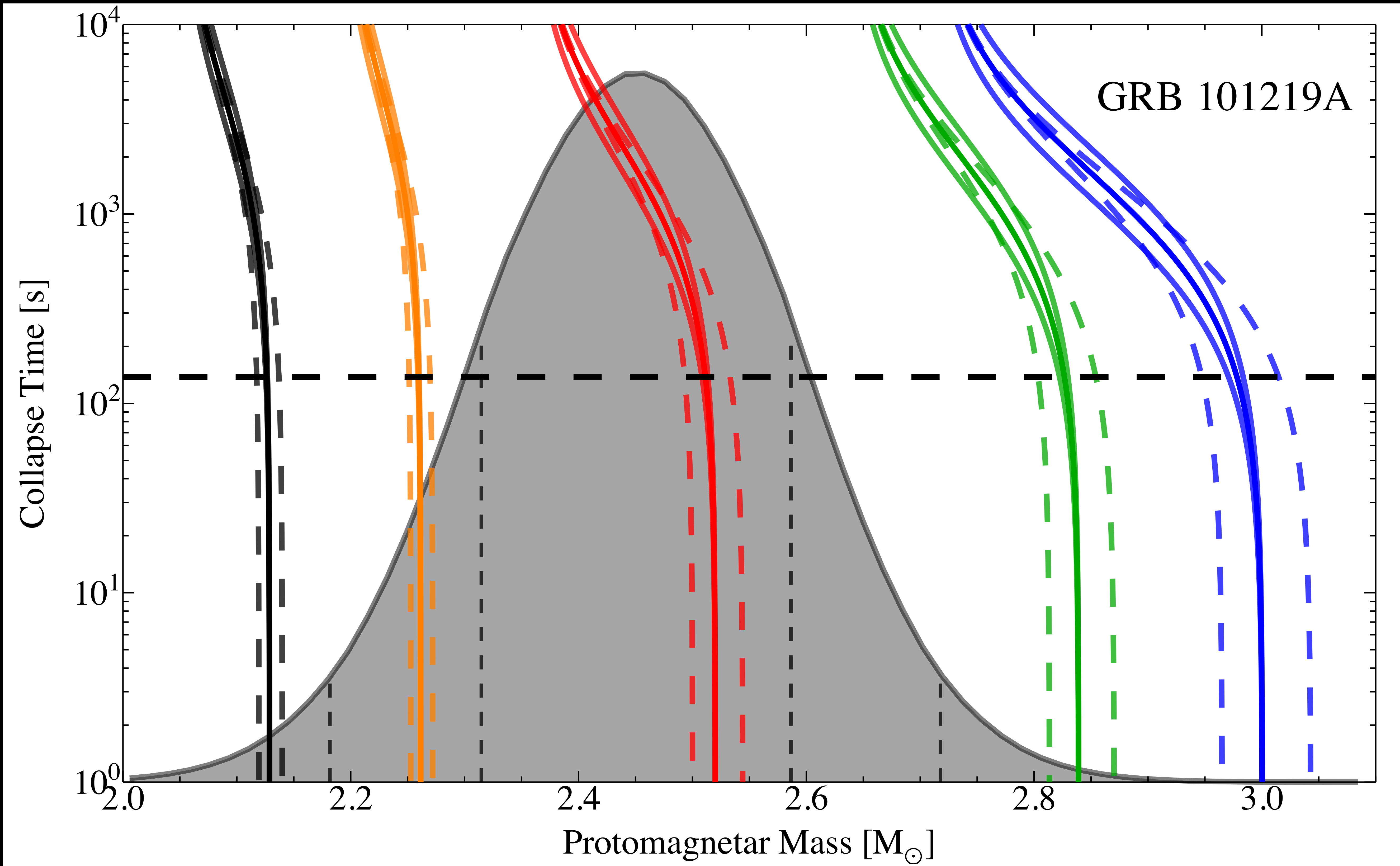
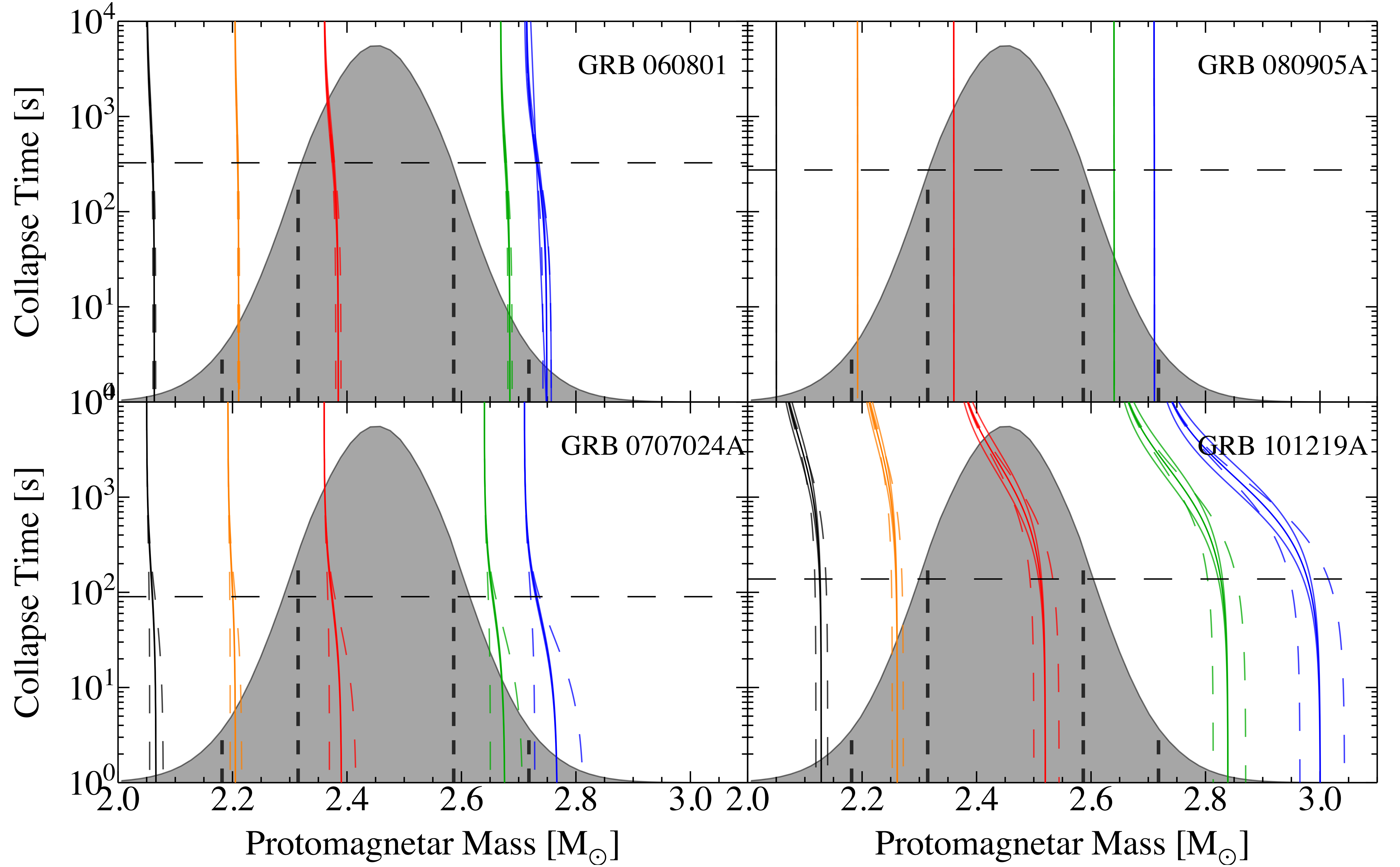


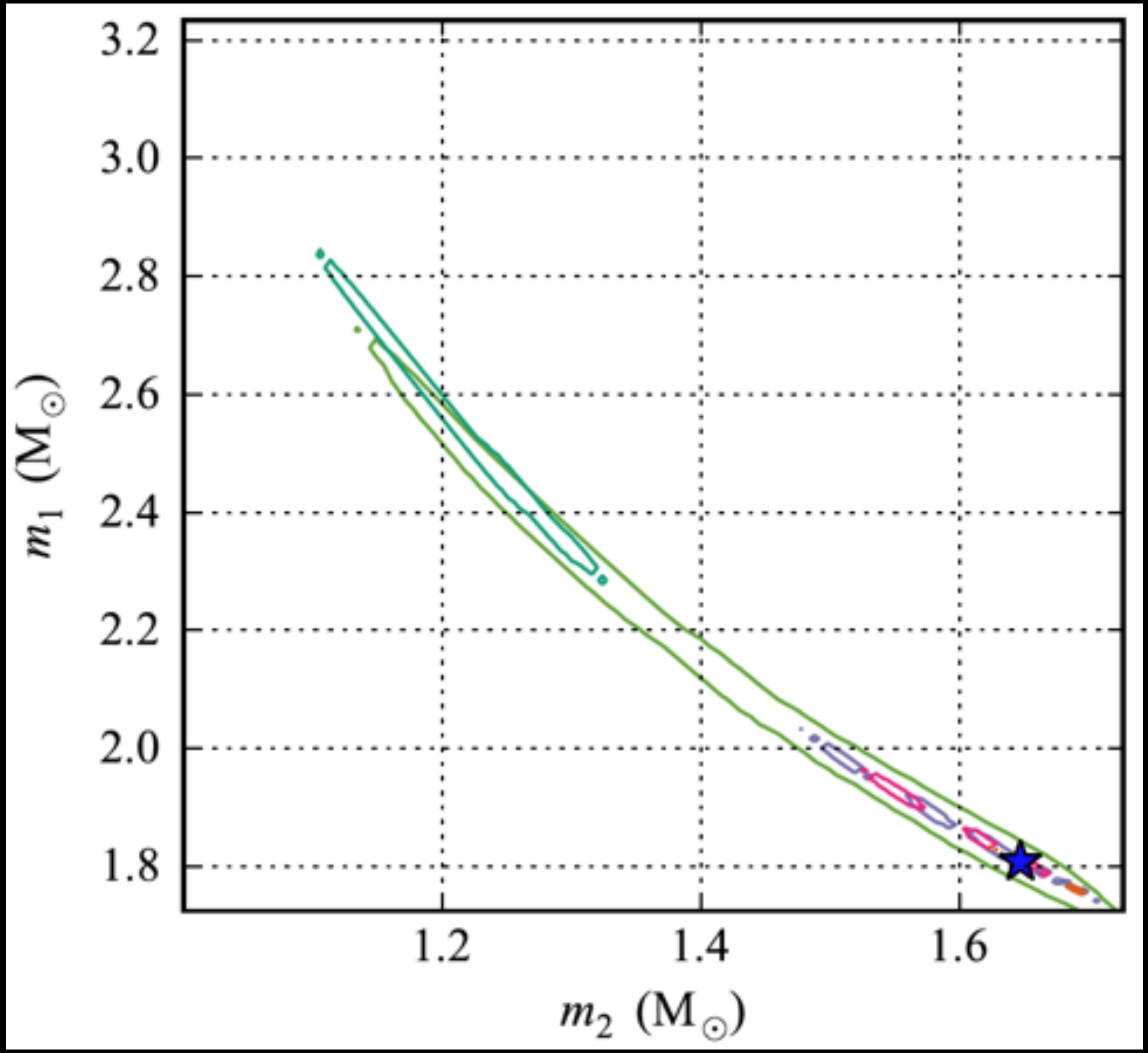
PL, Haskell, Ravi, Howell & Coward (2014)

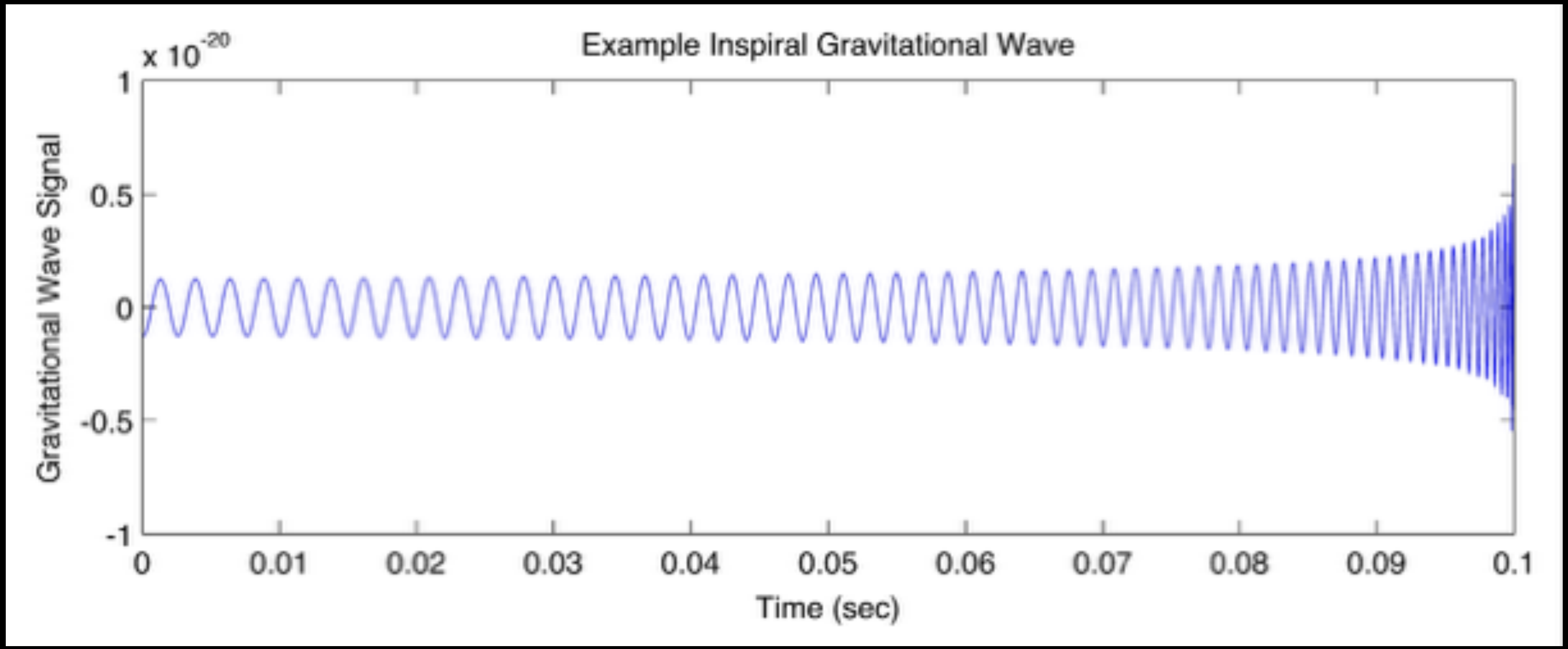


PL, Haskell, Ravi, Howell & Coward (2014)

Gravitational Waves

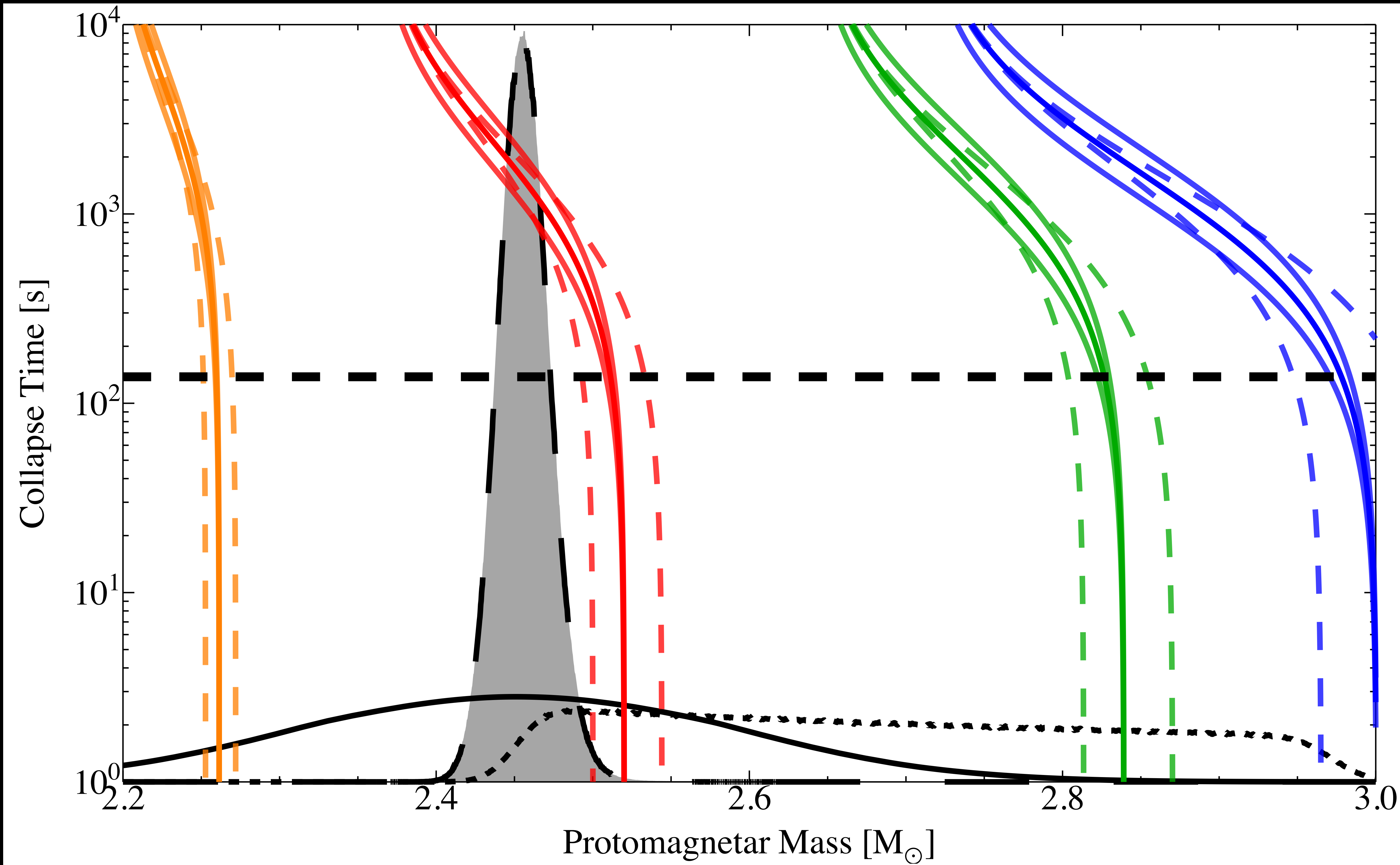
Aasi et al. (2013)





$$\mathcal{M} = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{-1/5}}$$

$$\eta = \frac{m_1 m_2}{(m_1 + m_2)^2}$$



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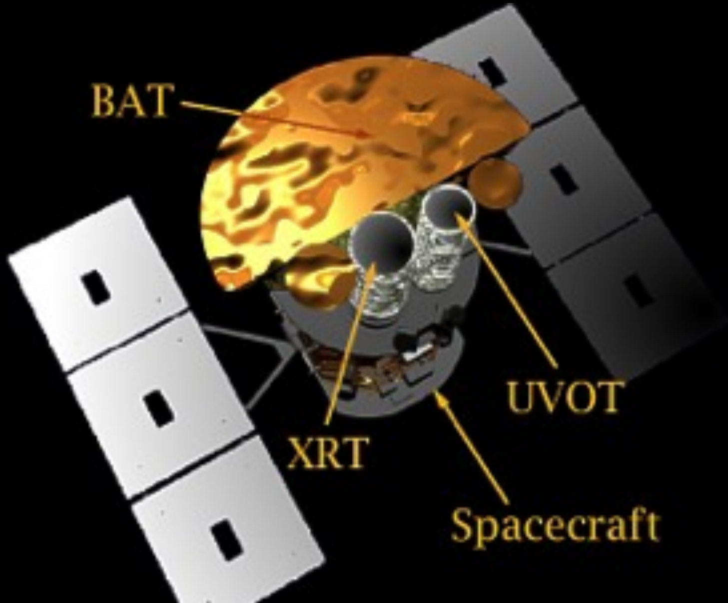
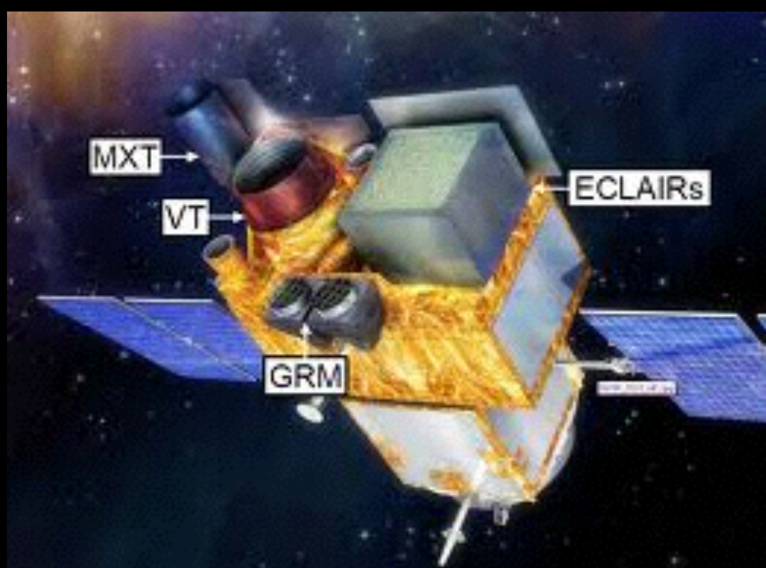


+

$\approx 0.2\ \mathrm{yr}^{-1}$

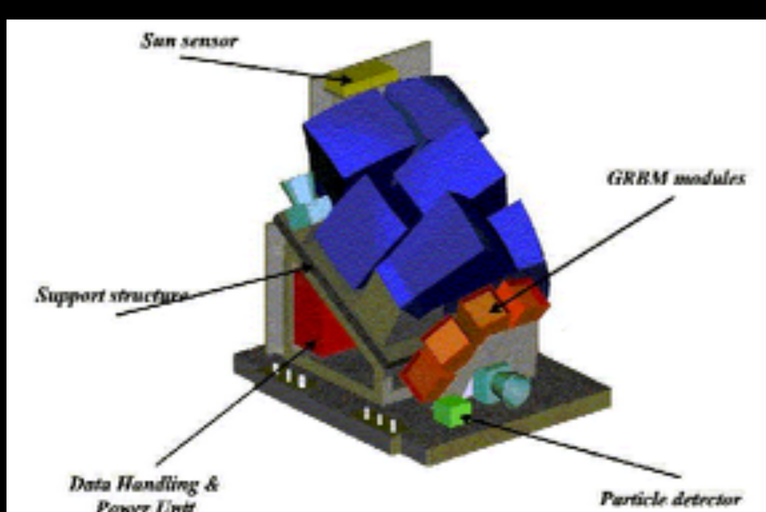
Burst and Transient Source Experiment (BATSE-XRT)



+

$\approx 0.4\ \mathrm{yr}^{-1}$

Space-based multi-band astronomical Variable Object Monitor (SVOM)

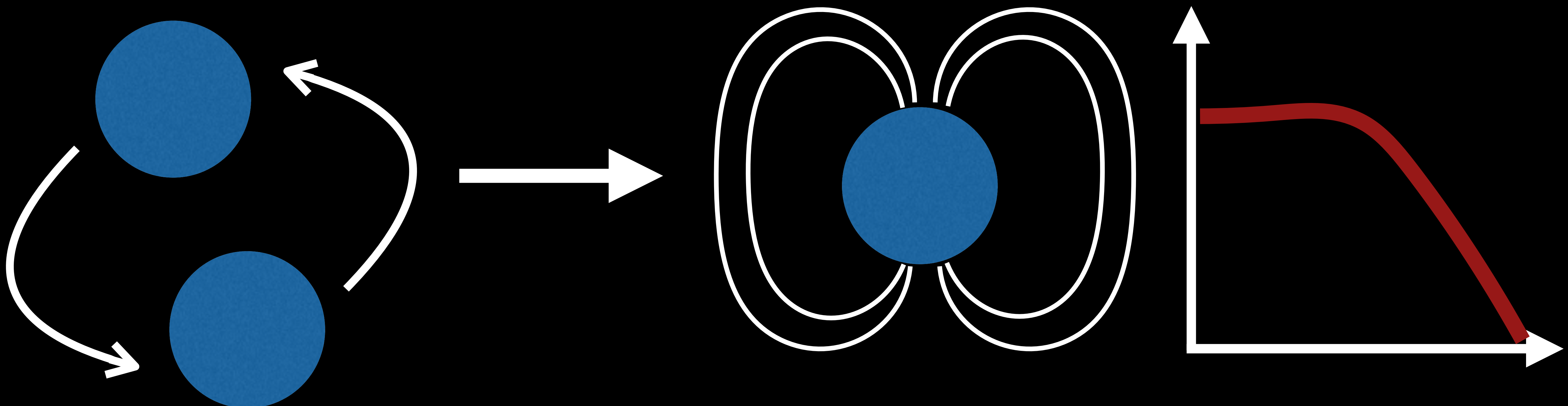


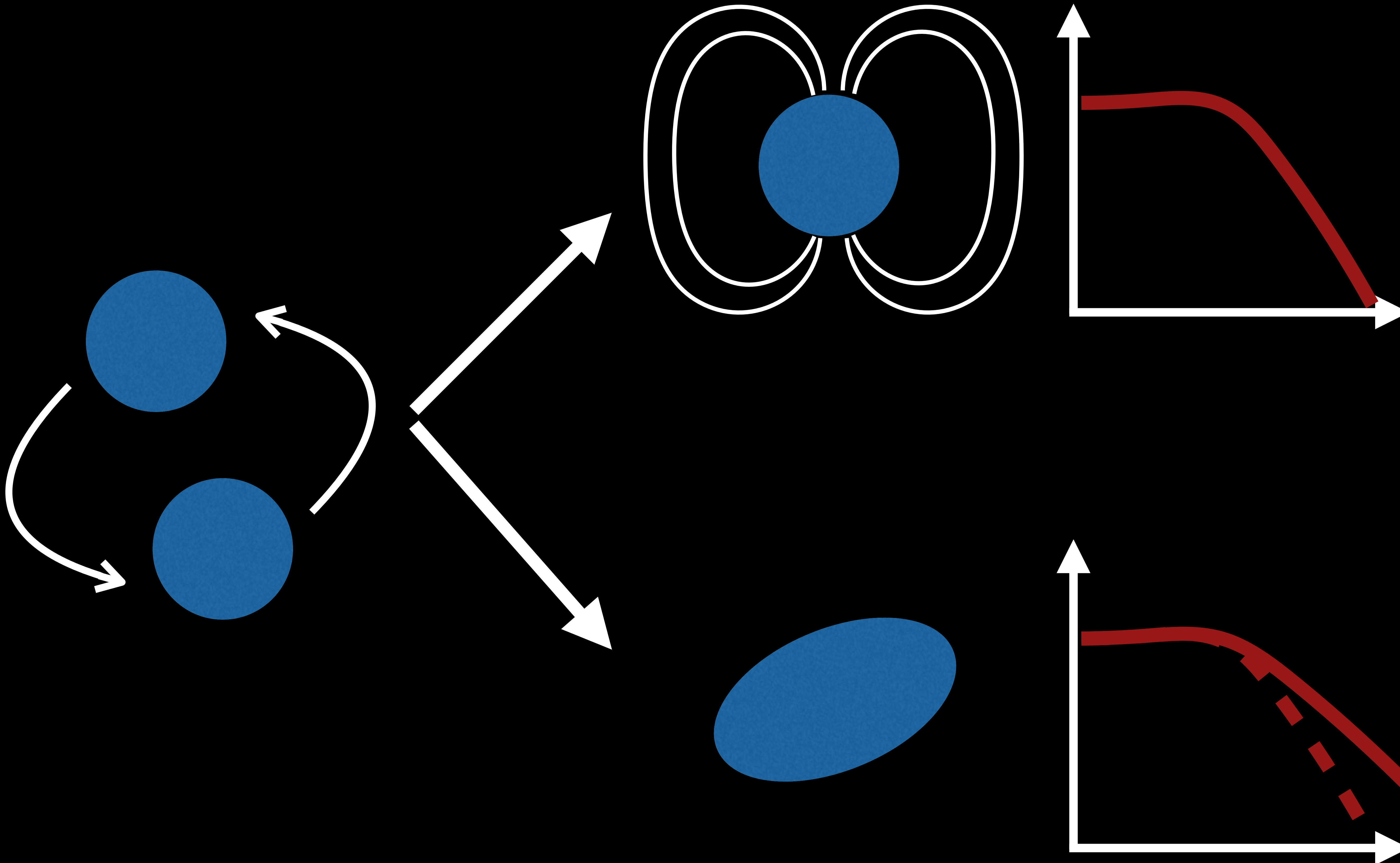
+

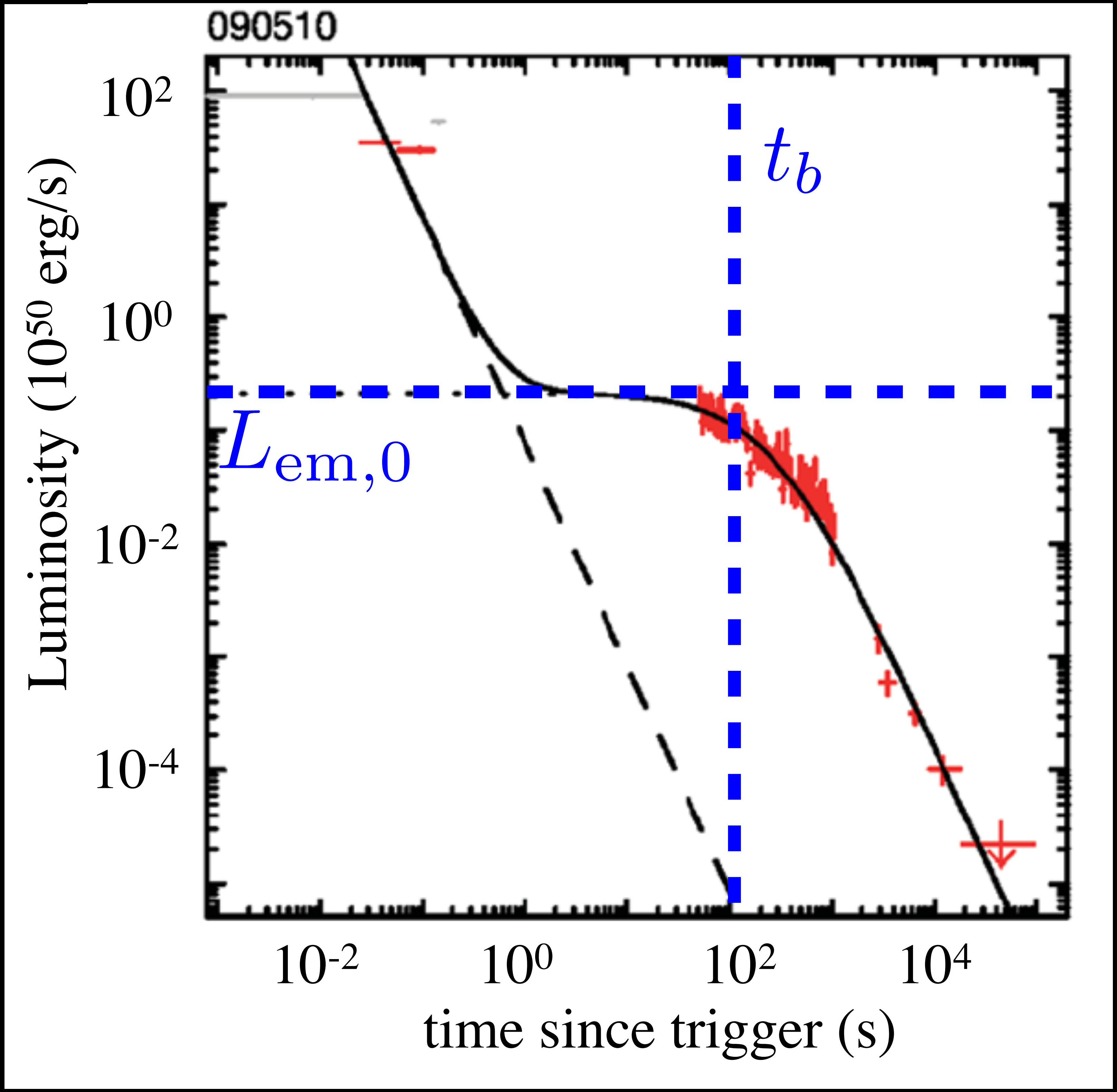
$\approx 1\ \mathrm{yr}^{-1}$

ISS-Lobster

What else can we learn?

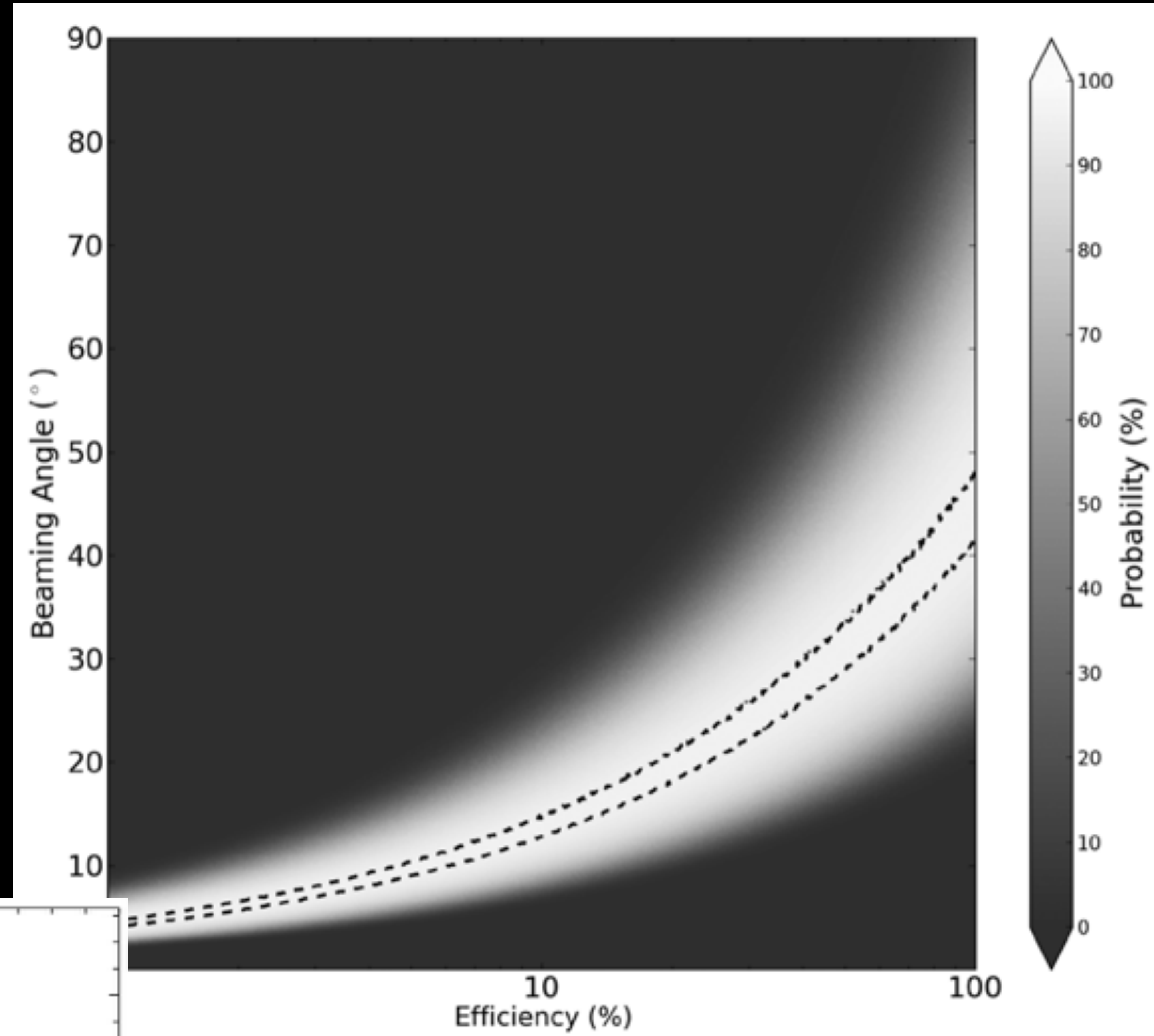


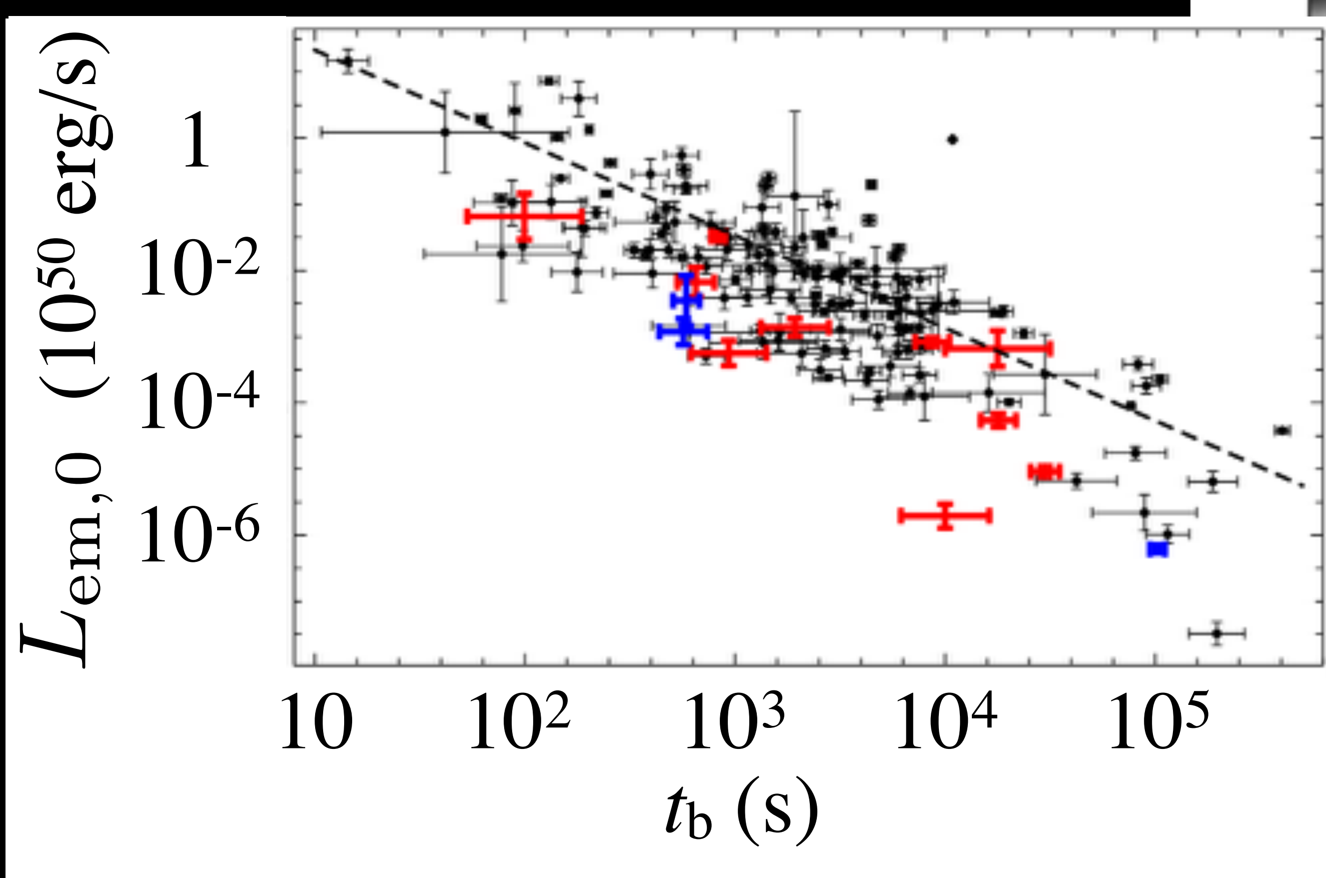




$$\epsilon \leq 0.33\eta \left(\frac{I}{10^{45}\,\mathrm{g\,cm^2}}\right)^{1/2} \left(\frac{L_{\rm em,0}}{10^{49}\,\mathrm{erg\,s^{-1}}}\right)^{-1} \left(\frac{t_b}{100\,\mathrm{s}}\right)^{-3/2}$$

$$L_{\mathrm{em},0} \propto \frac{\eta}{1-\cos\theta}\frac{1}{t_b}$$

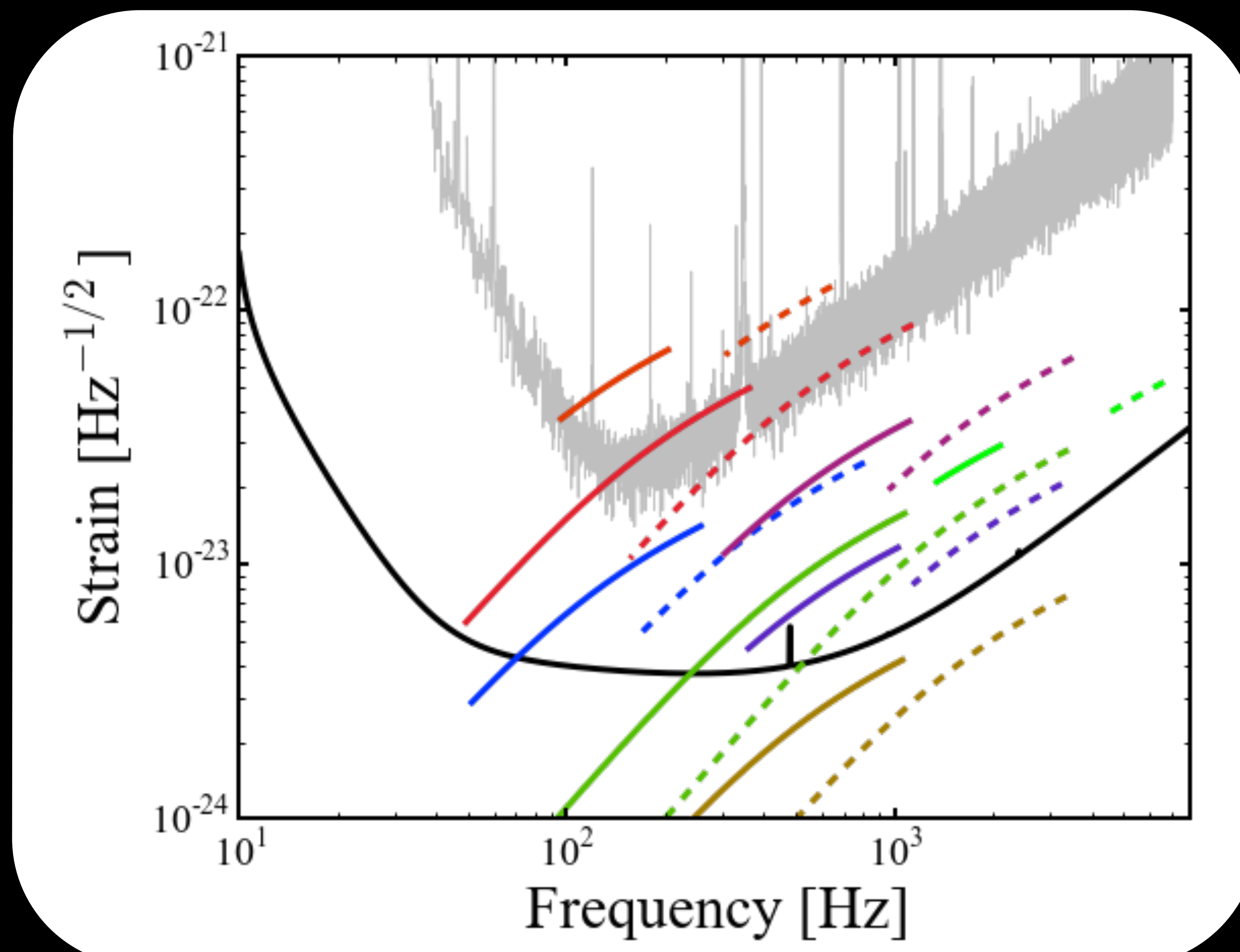




Rowlinson et al. (2014)

efficiency: $\eta = 0.1$

GRB	ϵ
GRB051221A	0.0061
GRB060801	0.0094
GRB070724A	0.0223
GRB070809	0.0049
GRB080905A	0.1532
GRB090426	0.0039
GRB090510	0.0041
GRB101219A	0.0012



PL & Glampedakis (2015; in prep)

efficiency: $\eta = 0.1$

GRB	ϵ
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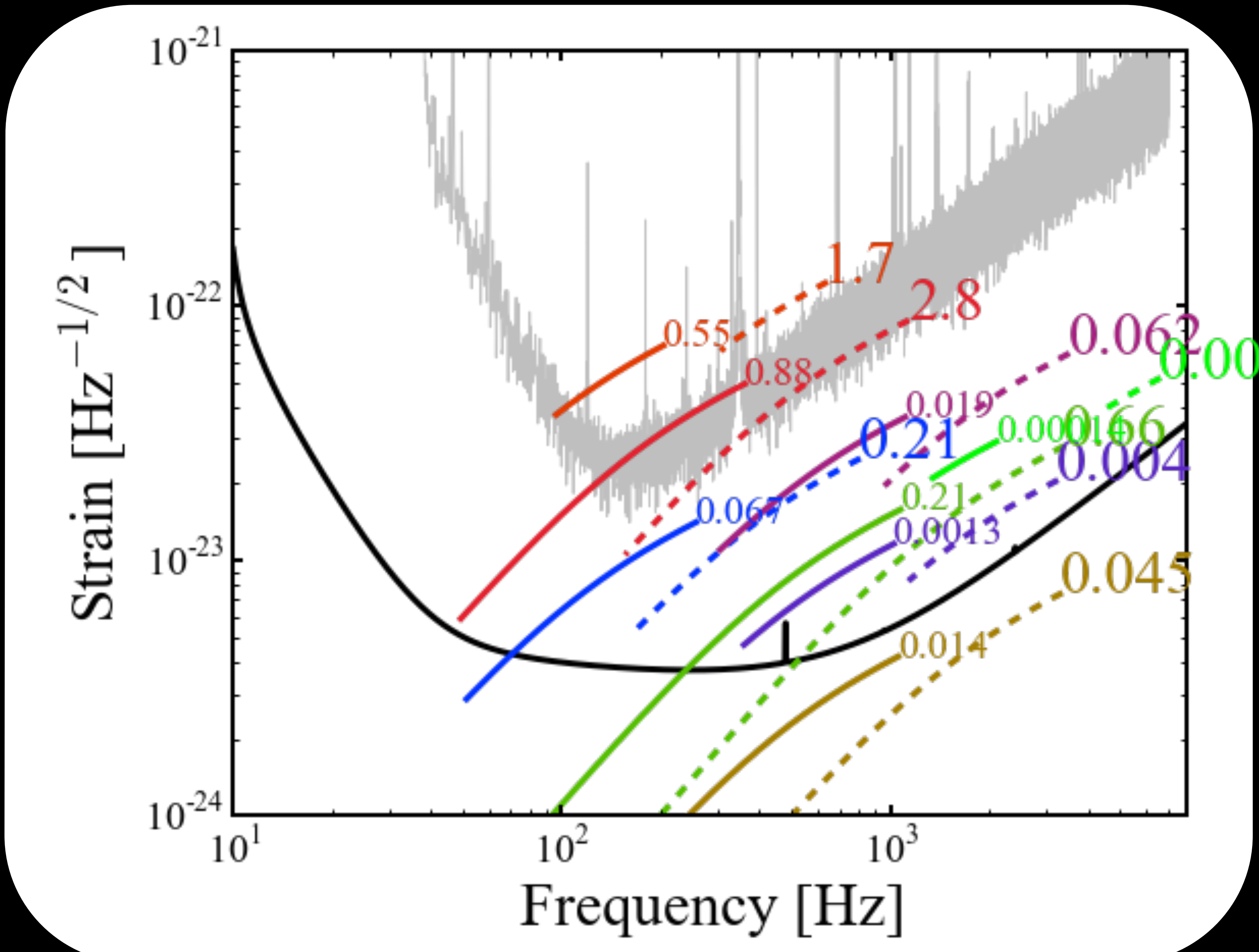
GRB070809	0.0049
GRB080905A	0.1532
GRB090426	0.0039
GRB090510	0.0041
GRB101219A	0.0012

cf. Fan et al. 2013,
Dall'Osso et al. (2015)



PL & Glampedakis (2015; in prep)

Parkes Pulsar Timing Arrays

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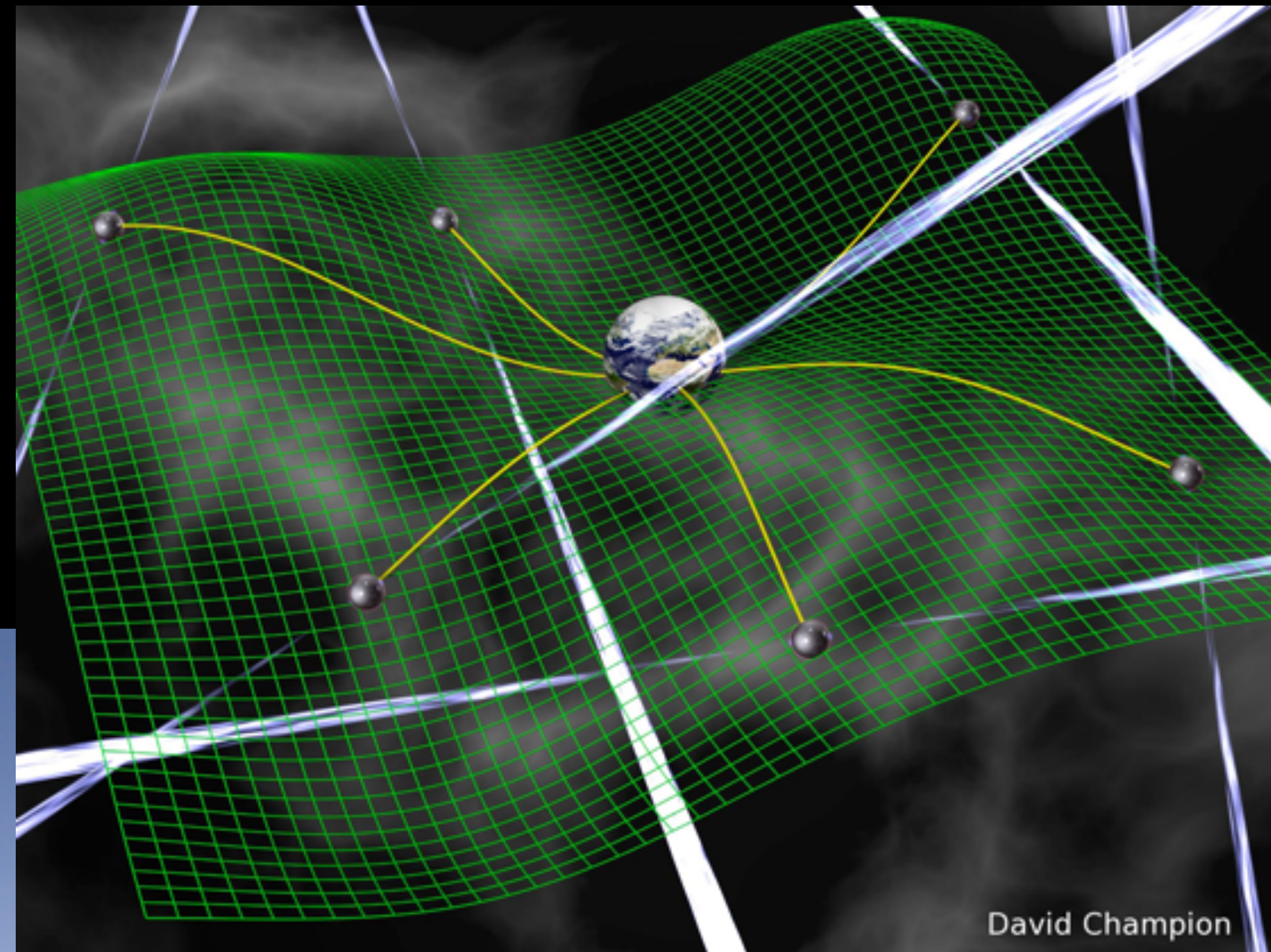
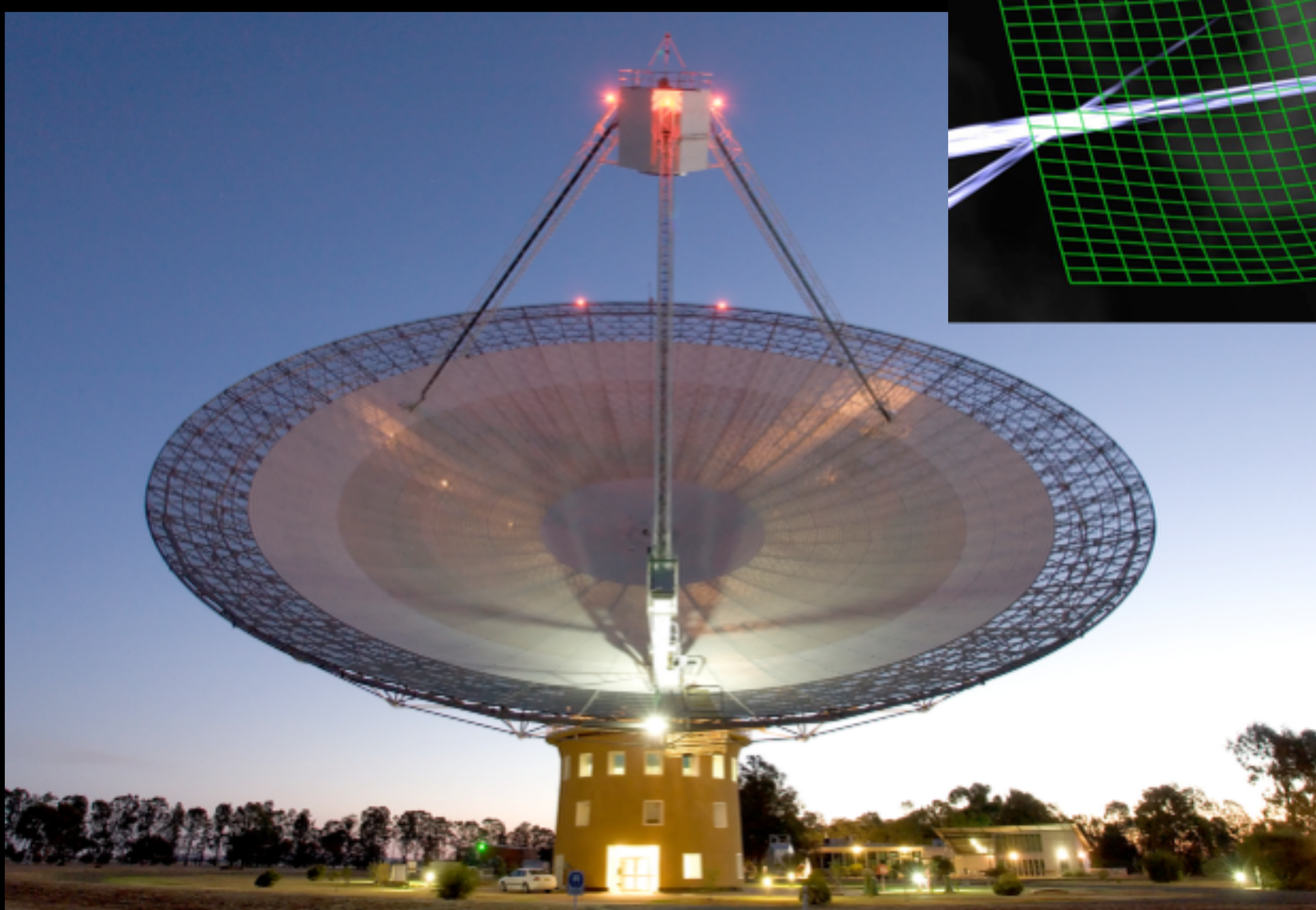
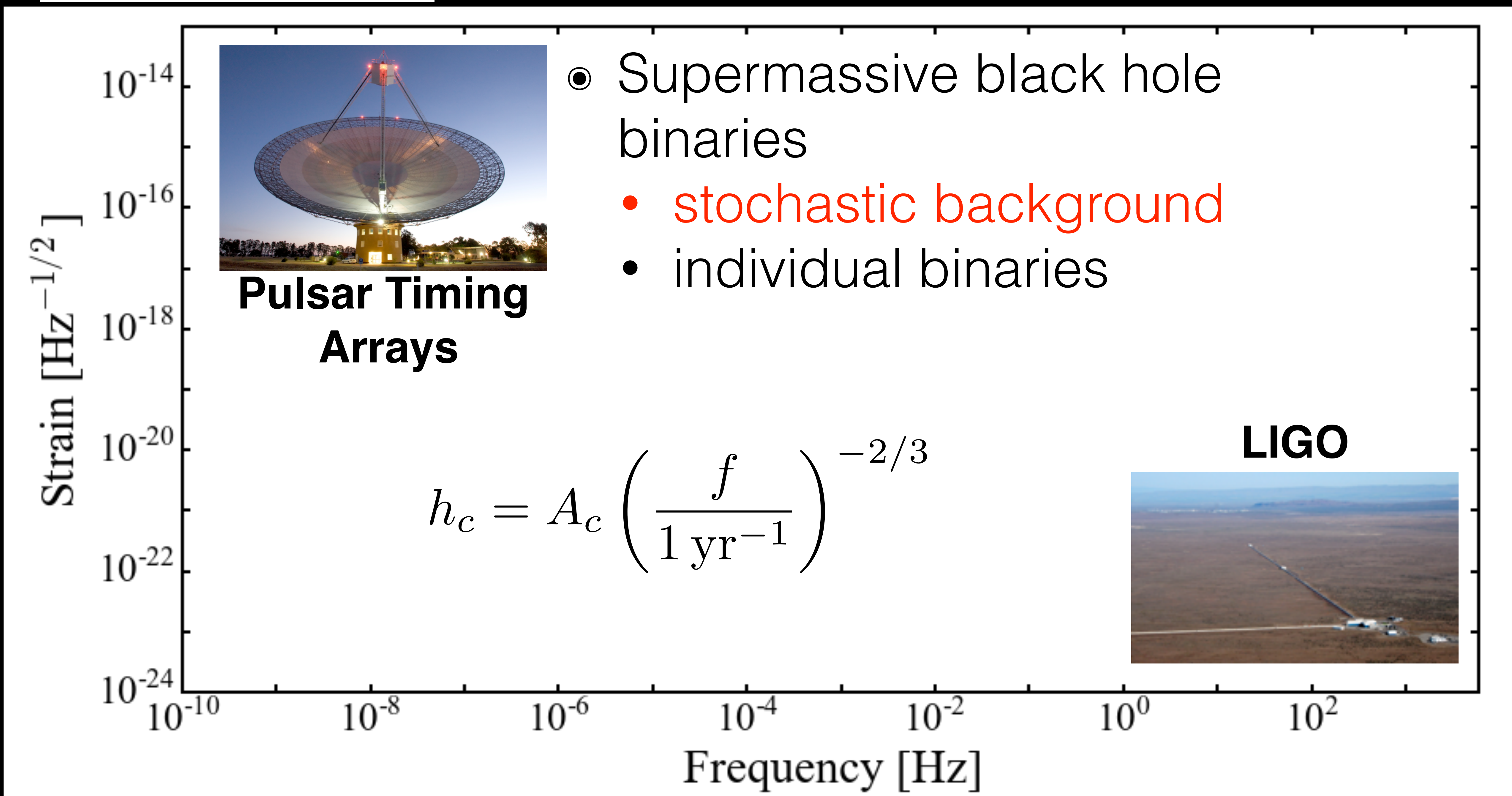
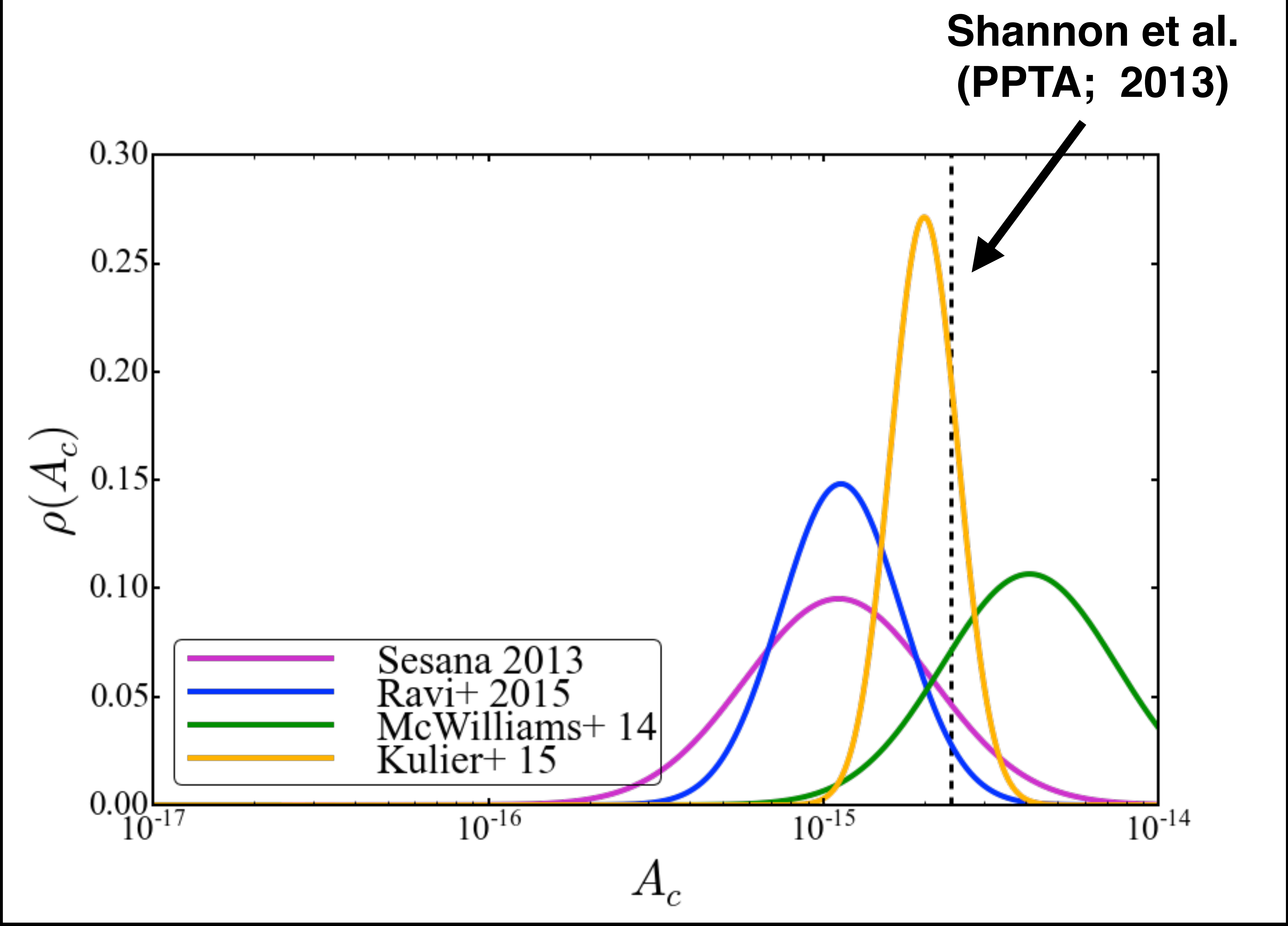
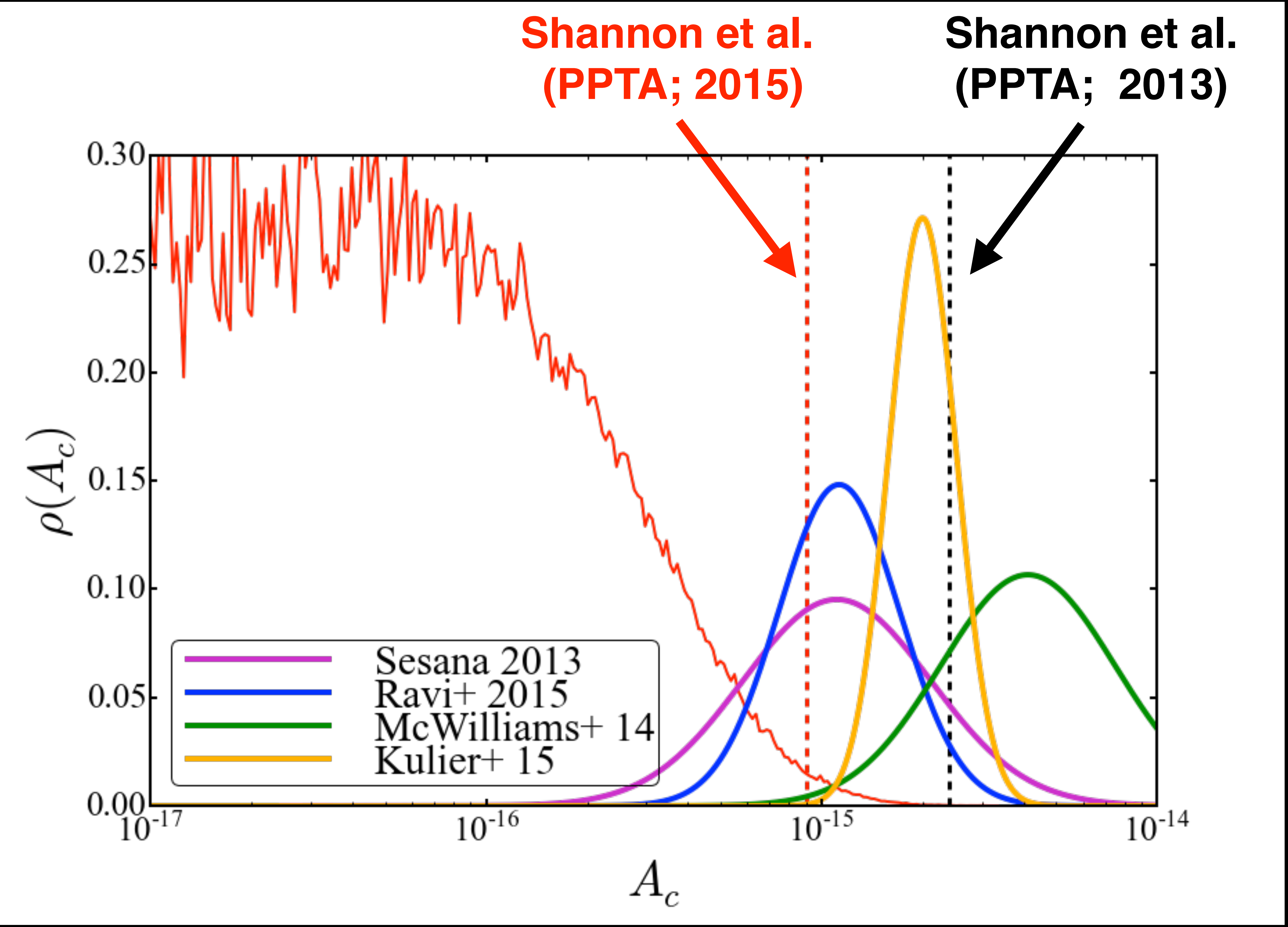





Supermassive black hole binaries
stochastic background
individual binaries
Pulsar Timing Arrays
LIGO
$$h_c = A_c \left(\frac{f}{1\,\mathrm{yr}^{-1}} \right)^{-2/3}$$
Strain [$\mathrm{Hz}^{-1/2}$]
Frequency [Hz]
10^{-14}
10^{-16}
10^{-18}
10^{-20}
10^{-22}
10^{-24}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
10^{0}
10^{2}



Shannon et al.
(PPTA; 2013)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
$\rho(A_c)$
Sesana 2013
Ravi+ 2015
McWilliams+ 14
Kulier+ 15
10^{-17}
10^{-16}
10^{-15}
10^{-14}
A_c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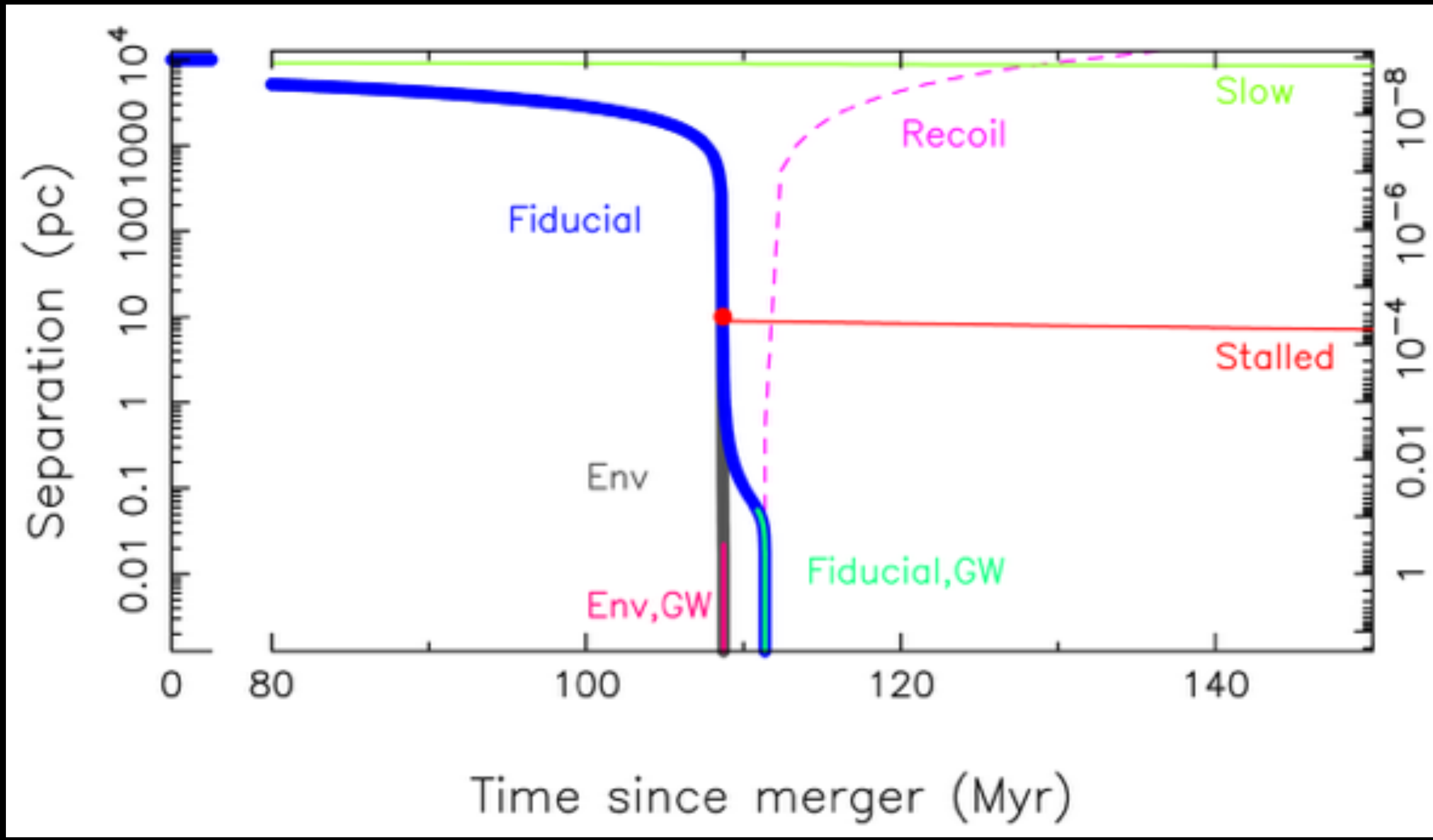
0.30
0.25
0.20
0.15
0.10
0.05
0.00
$\rho(A_c)$
10^{-17}
10^{-16}
10^{-15}
10^{-14}
A_c
Sesana 2013
Ravi+ 2015
McWilliams+ 14
Kulier+ 15

Astrophysical Inference

- Massive end of galaxy mass function?
- Black hole — bulge relations?
- Galaxy merger rate?
- Environmental factors: stars, gas, … ?



Shannon et al.
(PPTA; submitted)

Conclusions

- If **millisecond magnetar** model is correct

  (doesn't work with Rezzolla & Kumar (2015), Ciolfi & Siegel (2015) model)

  - allows for **equation of state** measurements
    - gravitational wave observations will help
  - allows us to study (in a limited sense) neutron star dynamics

- Parkes Pulsar Timing Array at 'design sensitivity'
  - no detection; important cosmological implications