MONASH University

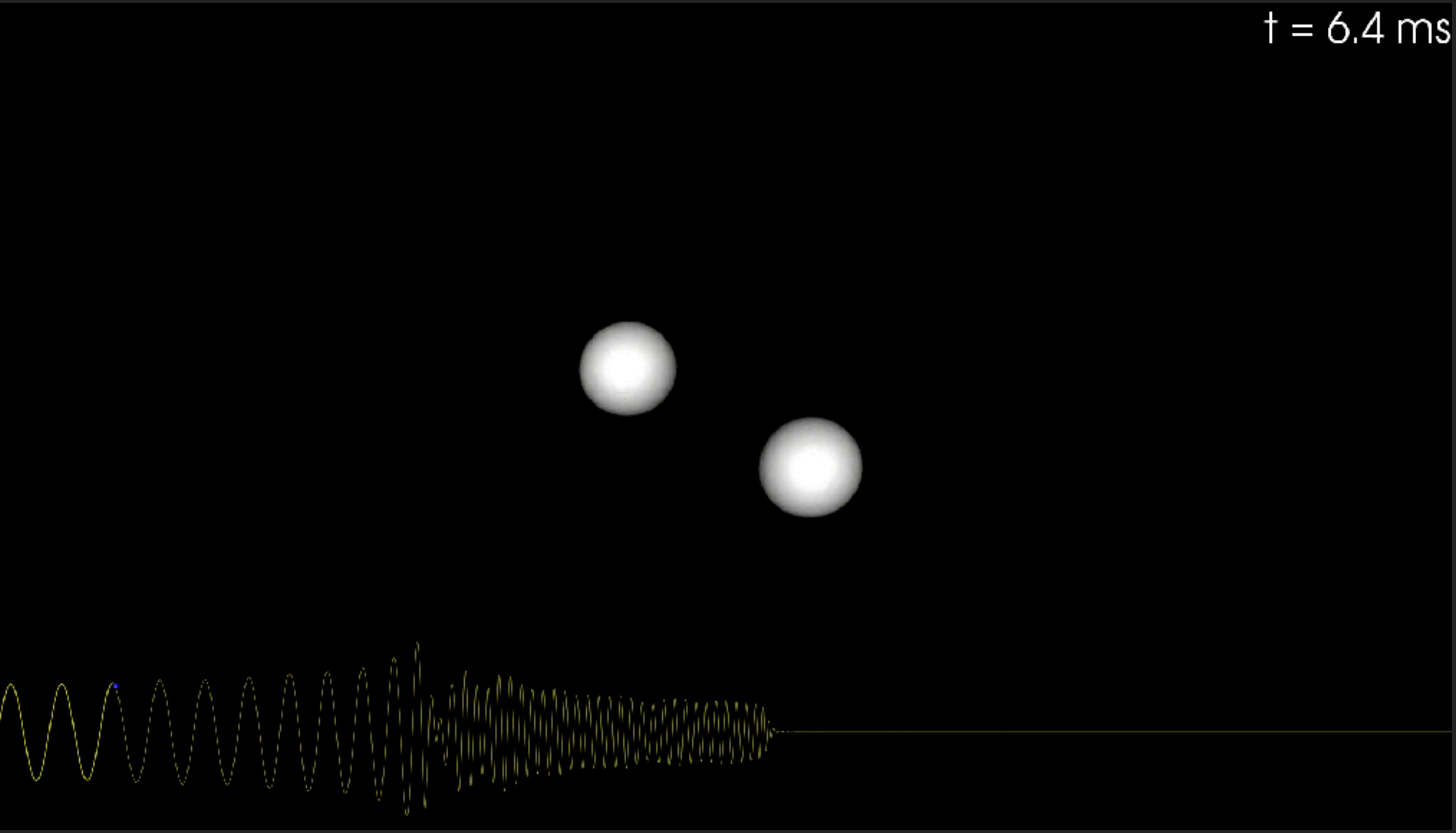
OzGrav

ARC Centre of Excellence for Gravitational Wave Discovery

PAUL LASKY

THE REMNANTS OF NEUTRON STAR MERGERS

GW170817

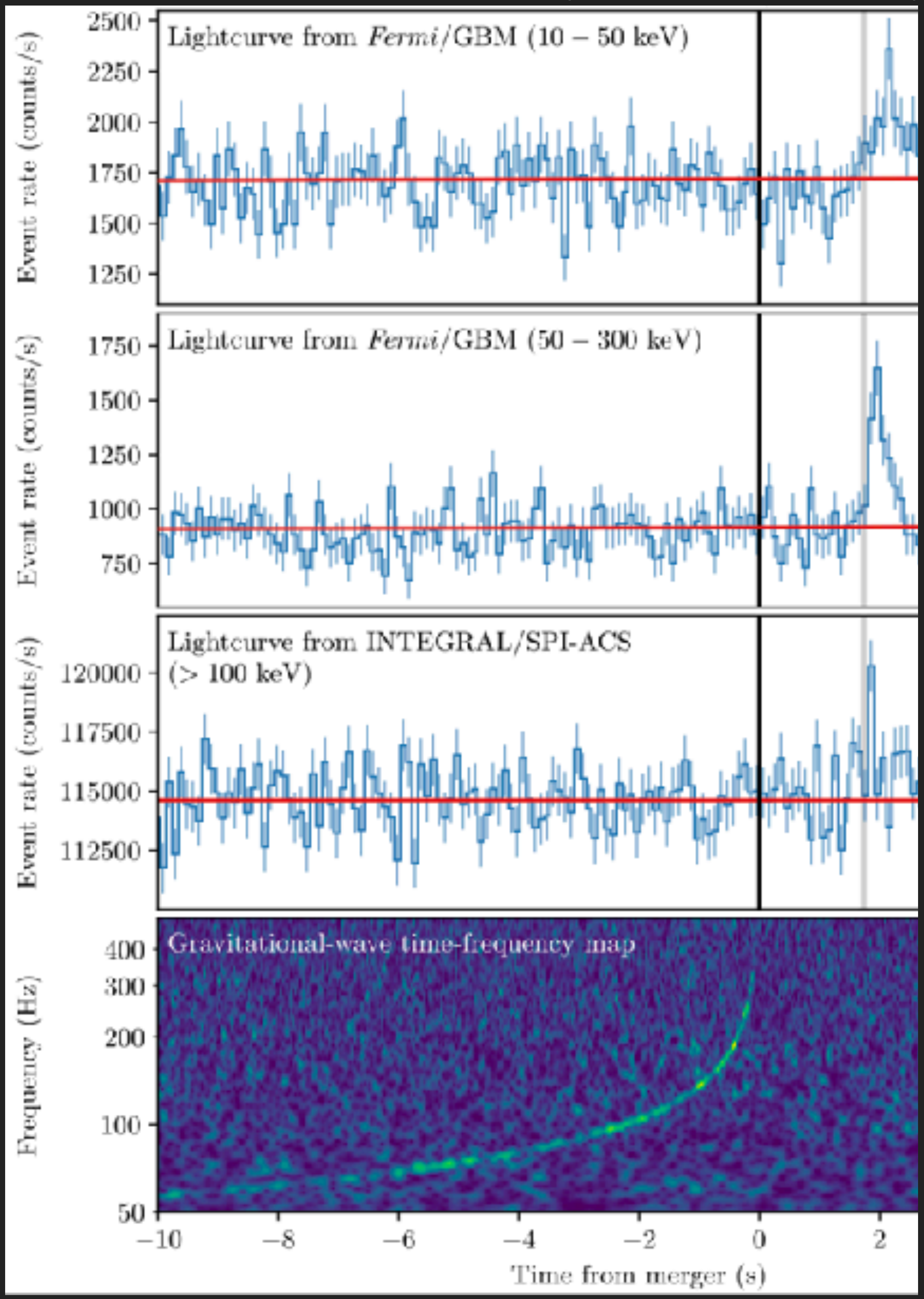


credit: Kastaun, Giacomazzo & Ciolfi

CONTENTS

- theoretical outcomes of mergers
- GW170817 post-merger outcome
- gravitational-waves:
  - < 1 s post merger
  - >> 10 s post-merger

Abbott et al. (2017; GW-GRB)

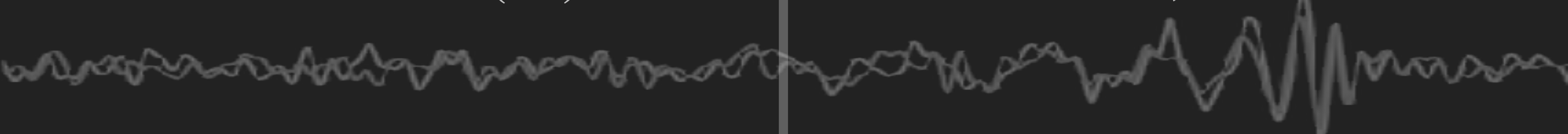


hypermassive neutron stars

- support: differential rotation
- $1.2 \lesssim M/M_{\rm TOV} \lesssim 1.5$
- collapse: Alfvén timescale
  - ~ 1 — 100 ms (??)

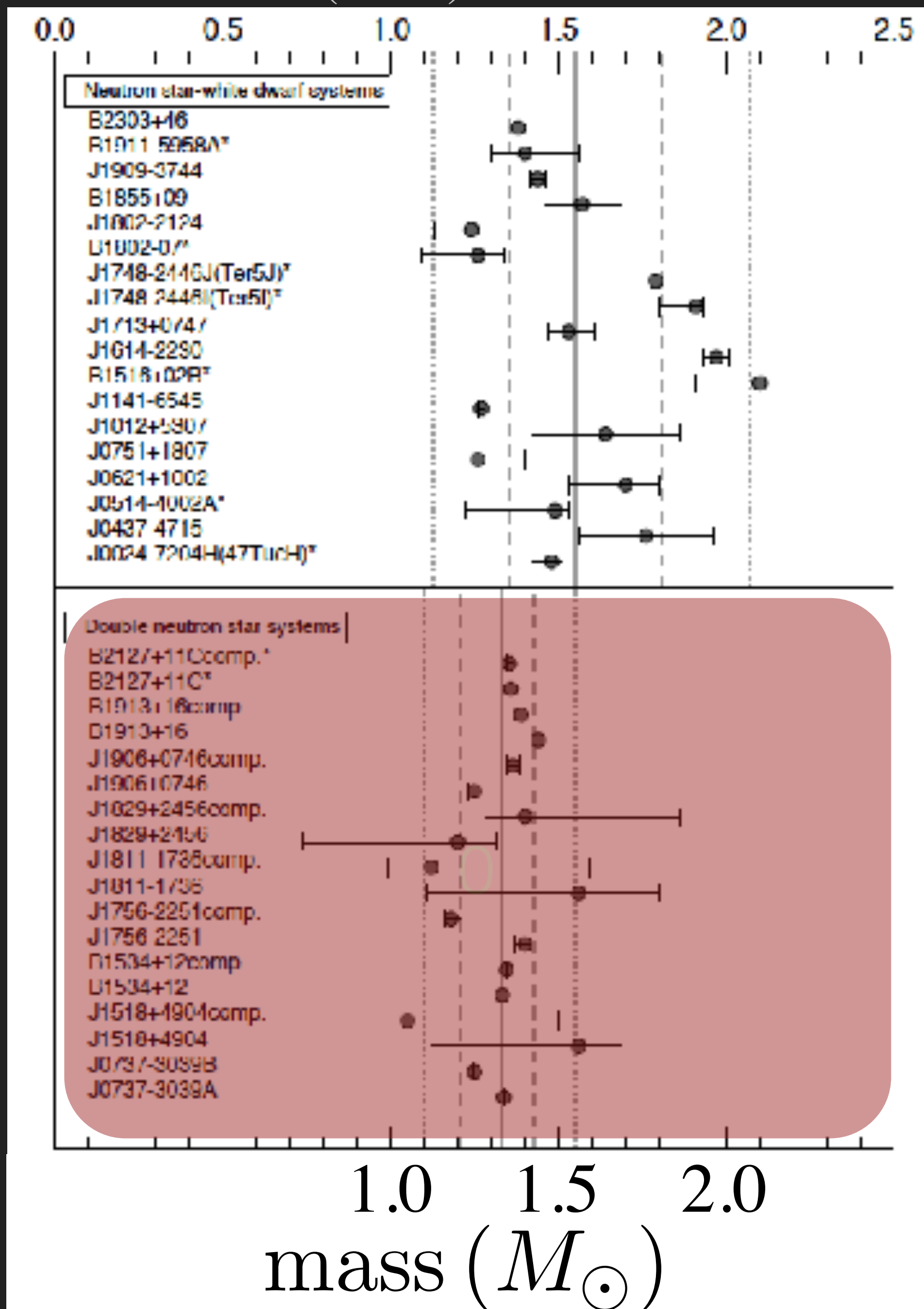
supramassive neutron stars

- support: solid-body rotation
- $1.0 \lesssim M/M_{\rm TOV} \lesssim 1.2$
- collapse: spindown timescale
  - ~ 10 — 10,000 s (Ravi & PL 2014)



SUPRA- OR HYPERMASSIVE?

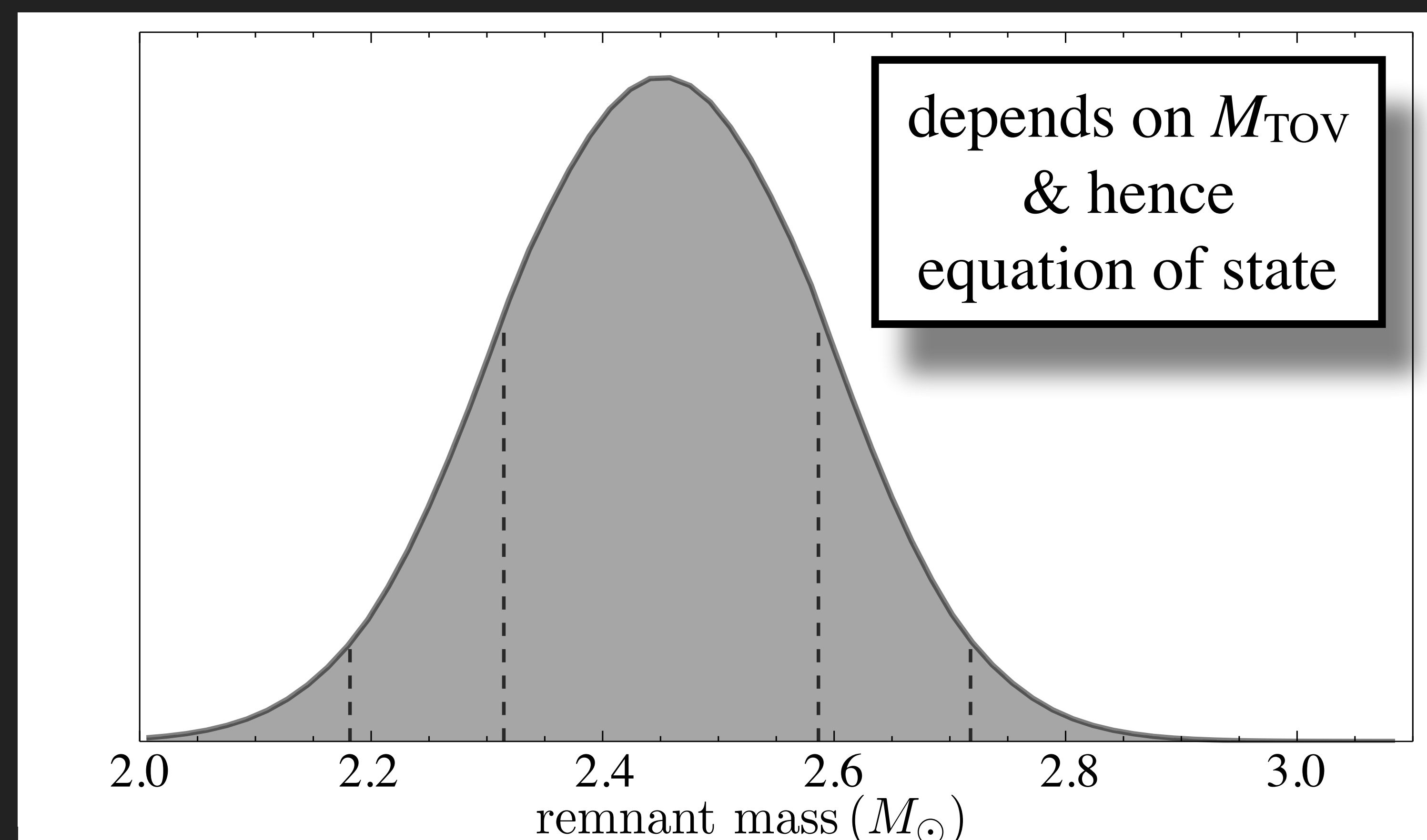
Kiziltan et al. (2013)



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

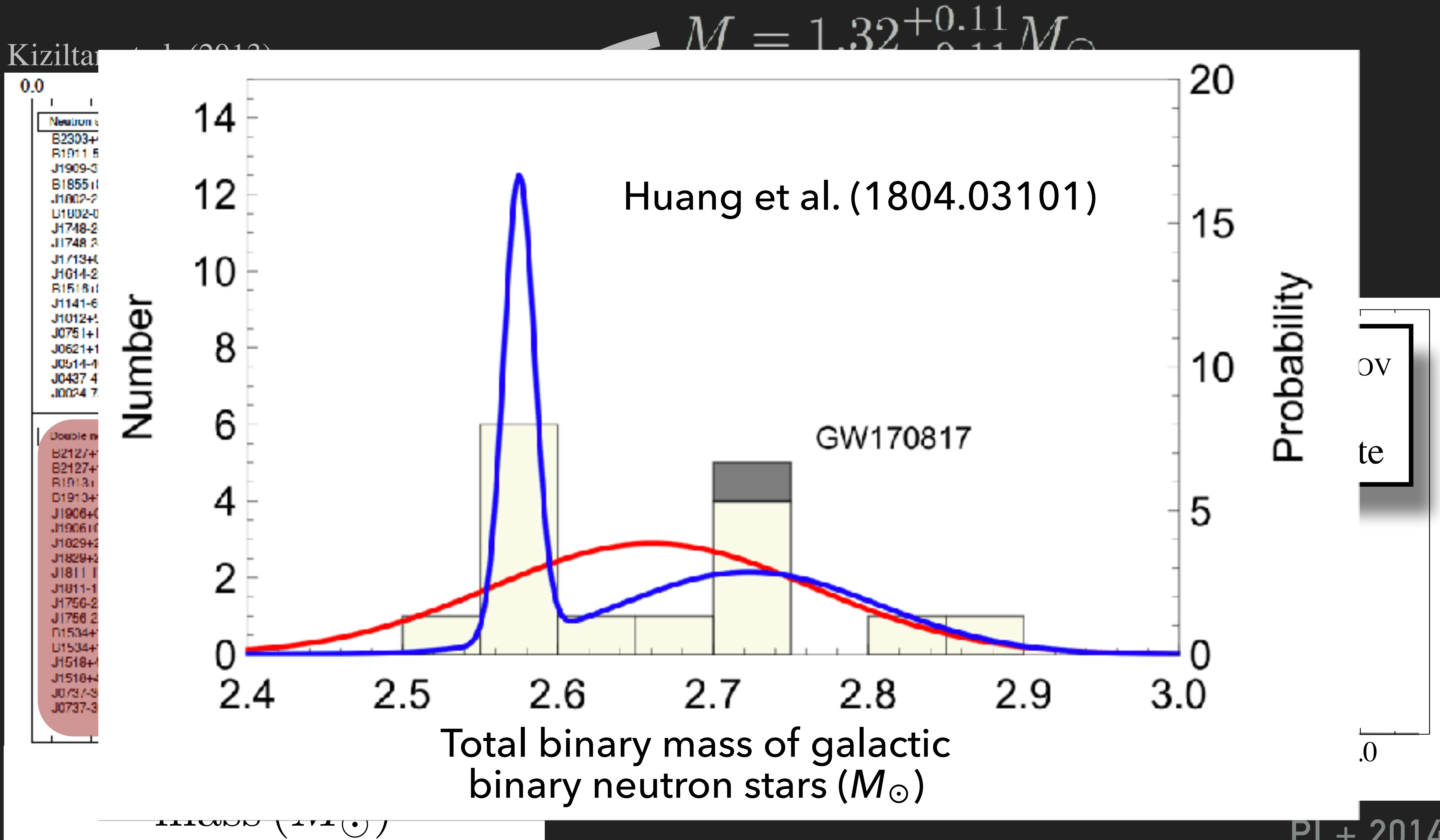
Rest mass conservation

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

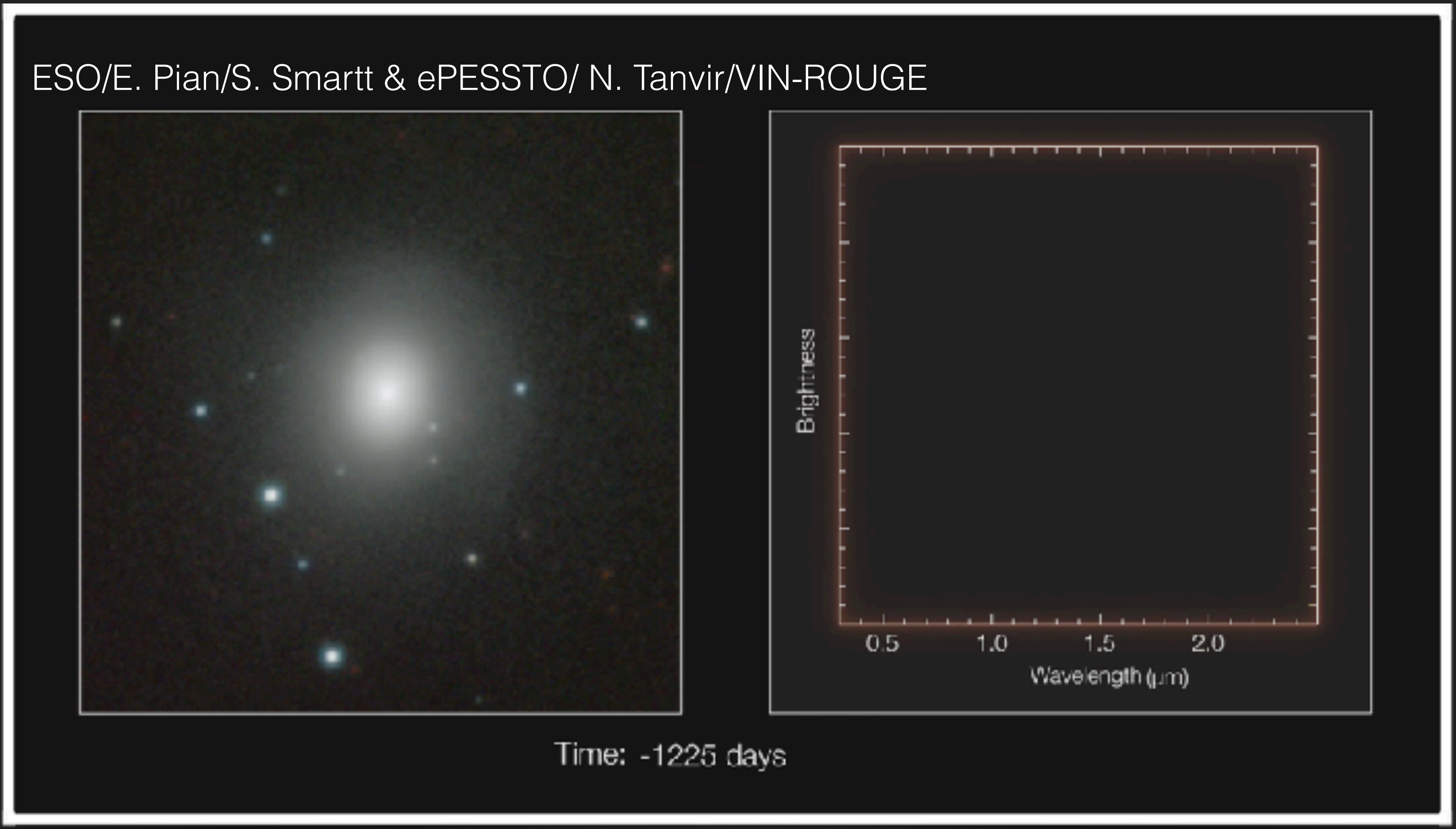


PL+ 2014

SUPRA- OR HYPERMASSIVE?



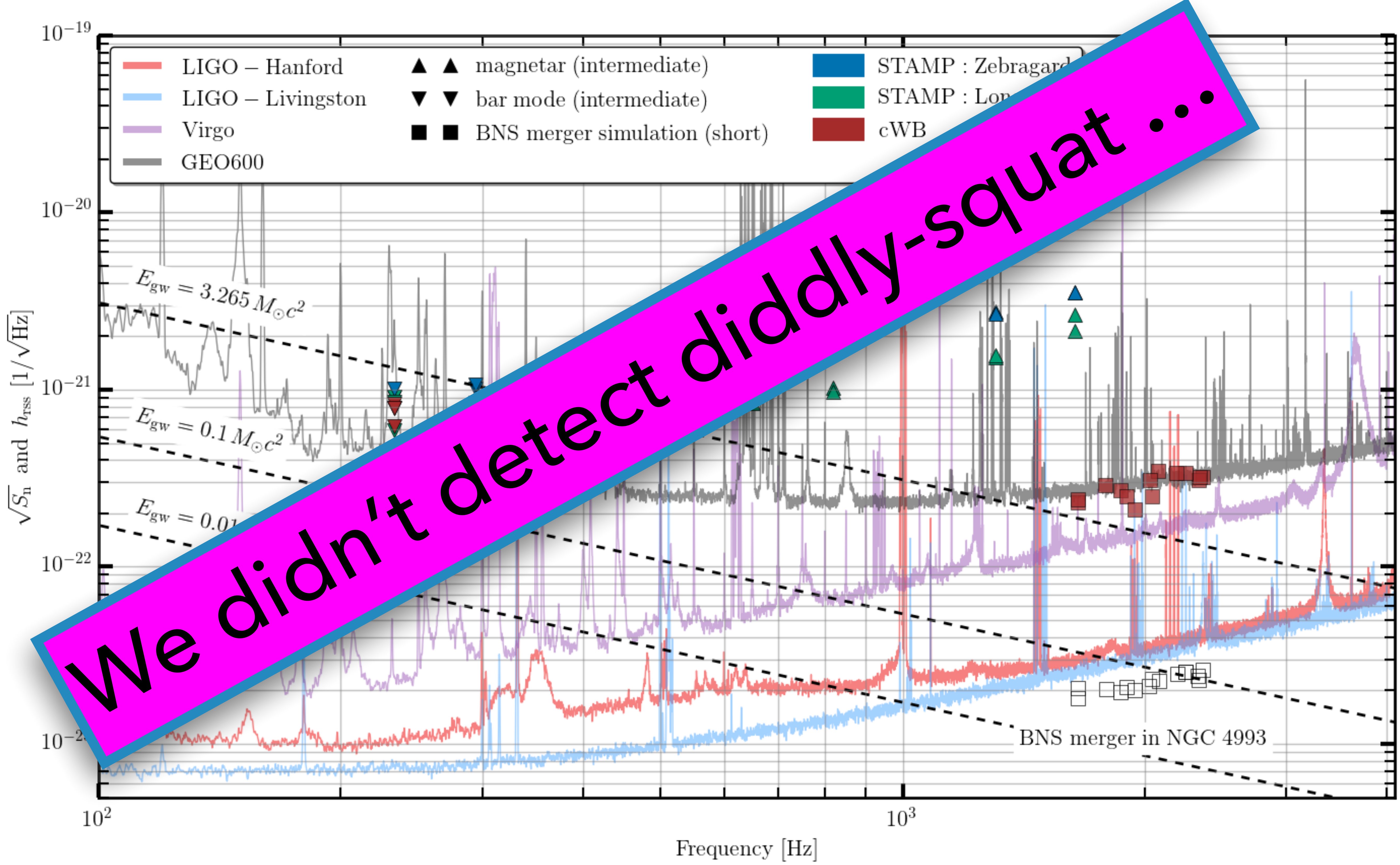
PL+ 2014



WHAT ABOUT

GW170817?

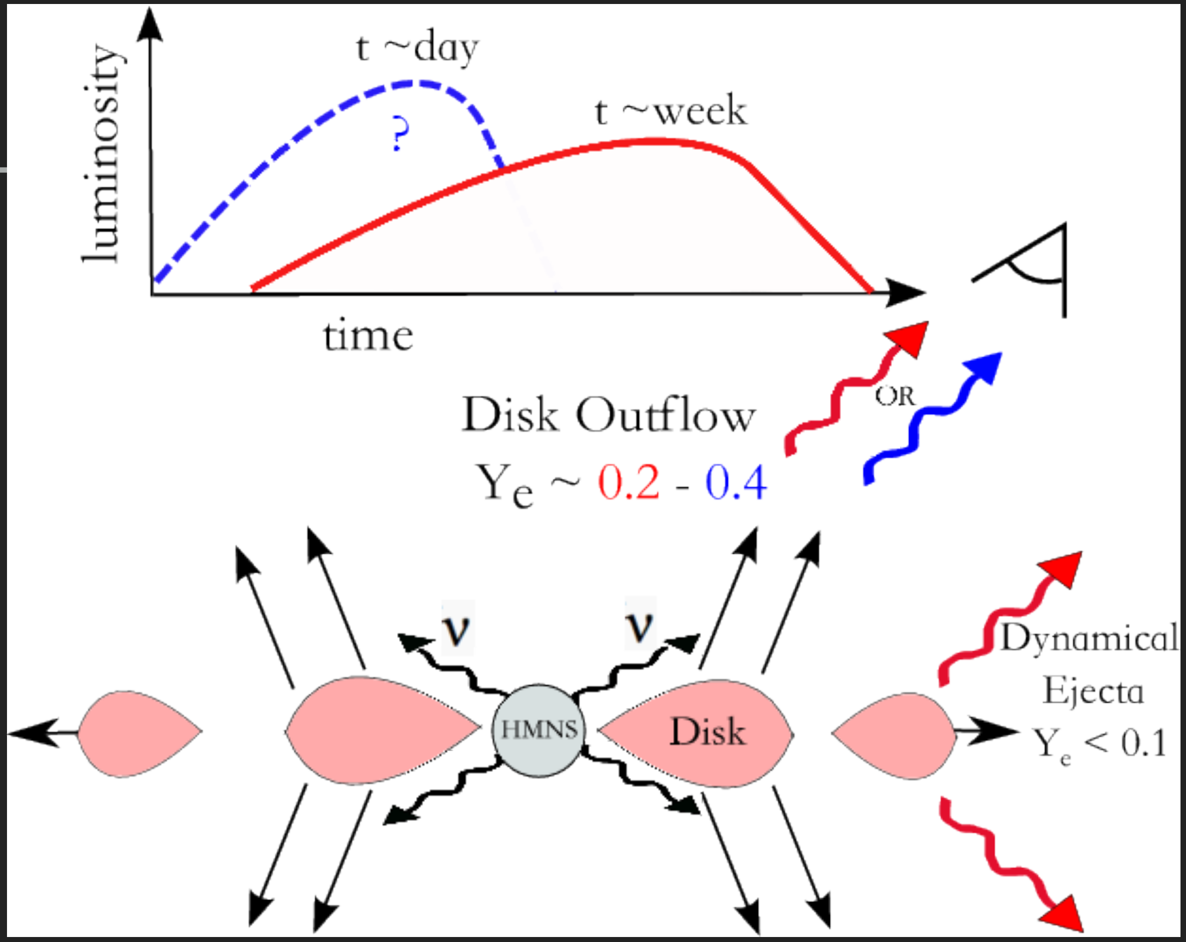
searching for a GW170817 post-merger remnant

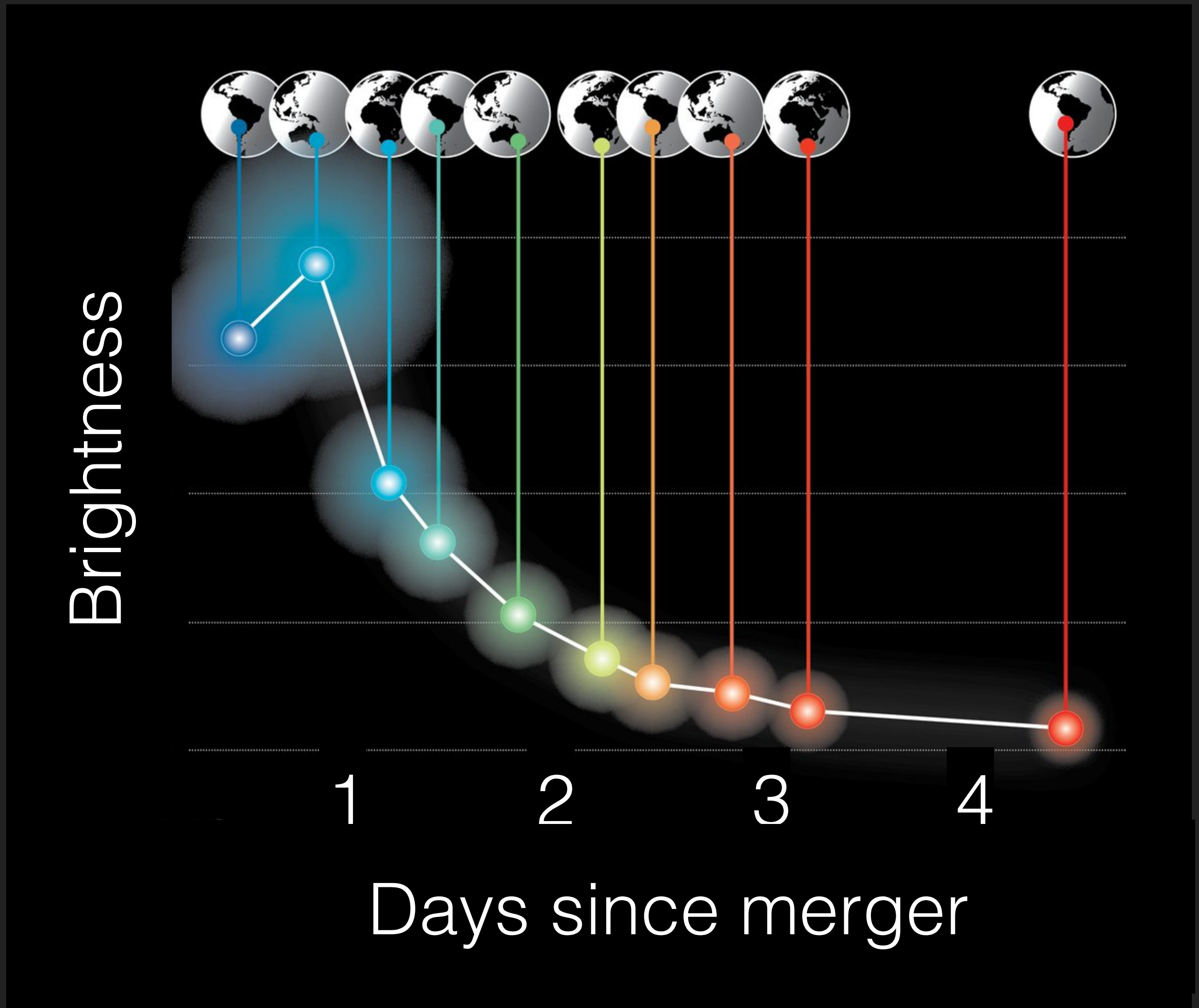


Abbott+ (2017; GW170817 "post-merger paper")

WHAT DOES THE KILONOVAE TELL US?

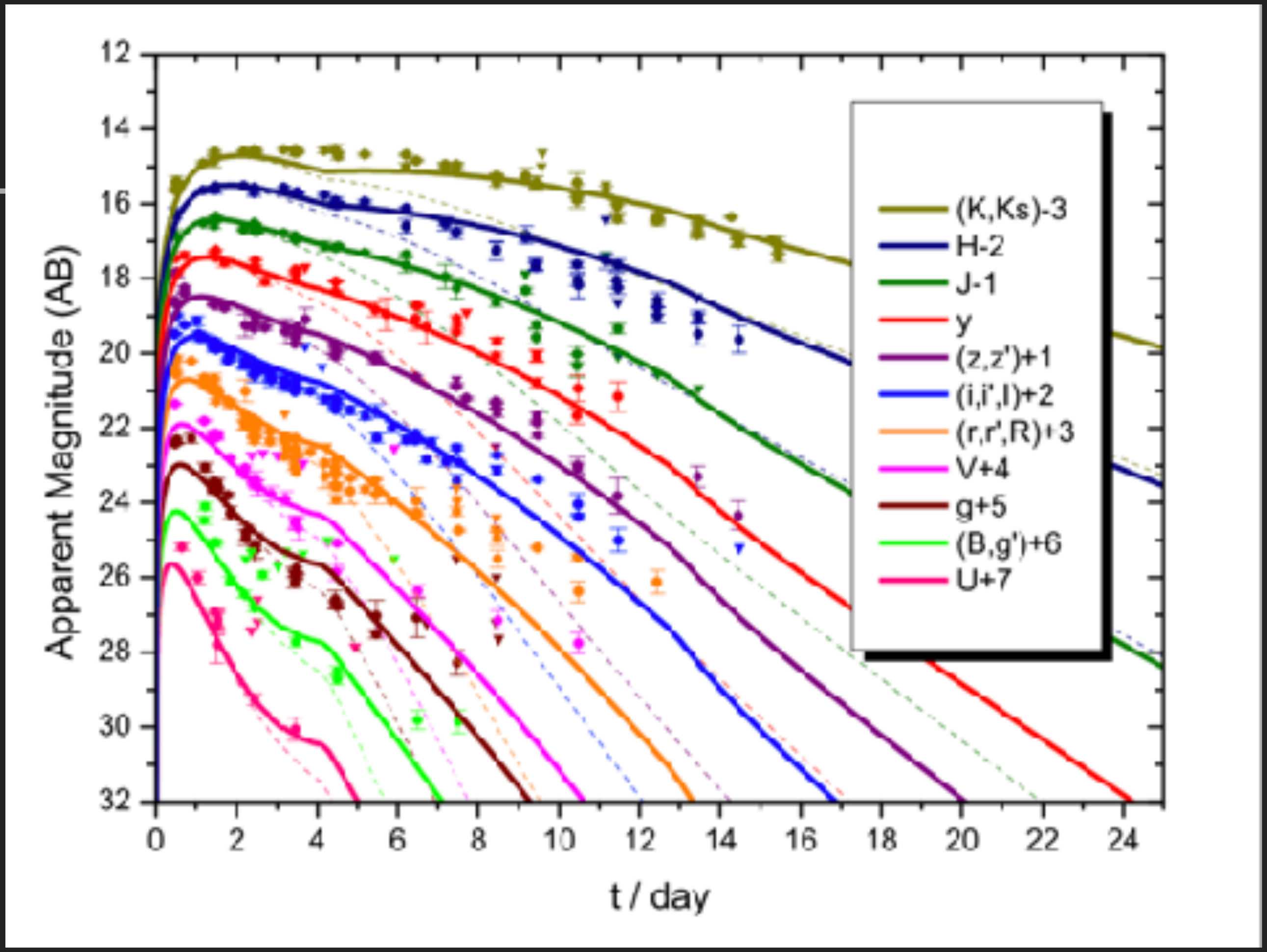
- "blue bump"
  - neutrinos from remnant raises electron fraction in disk wind
  - Lanthanide-free outflow –> bright blue bump
  - indicative of hypermassive neutron star lasting ~100s of ms





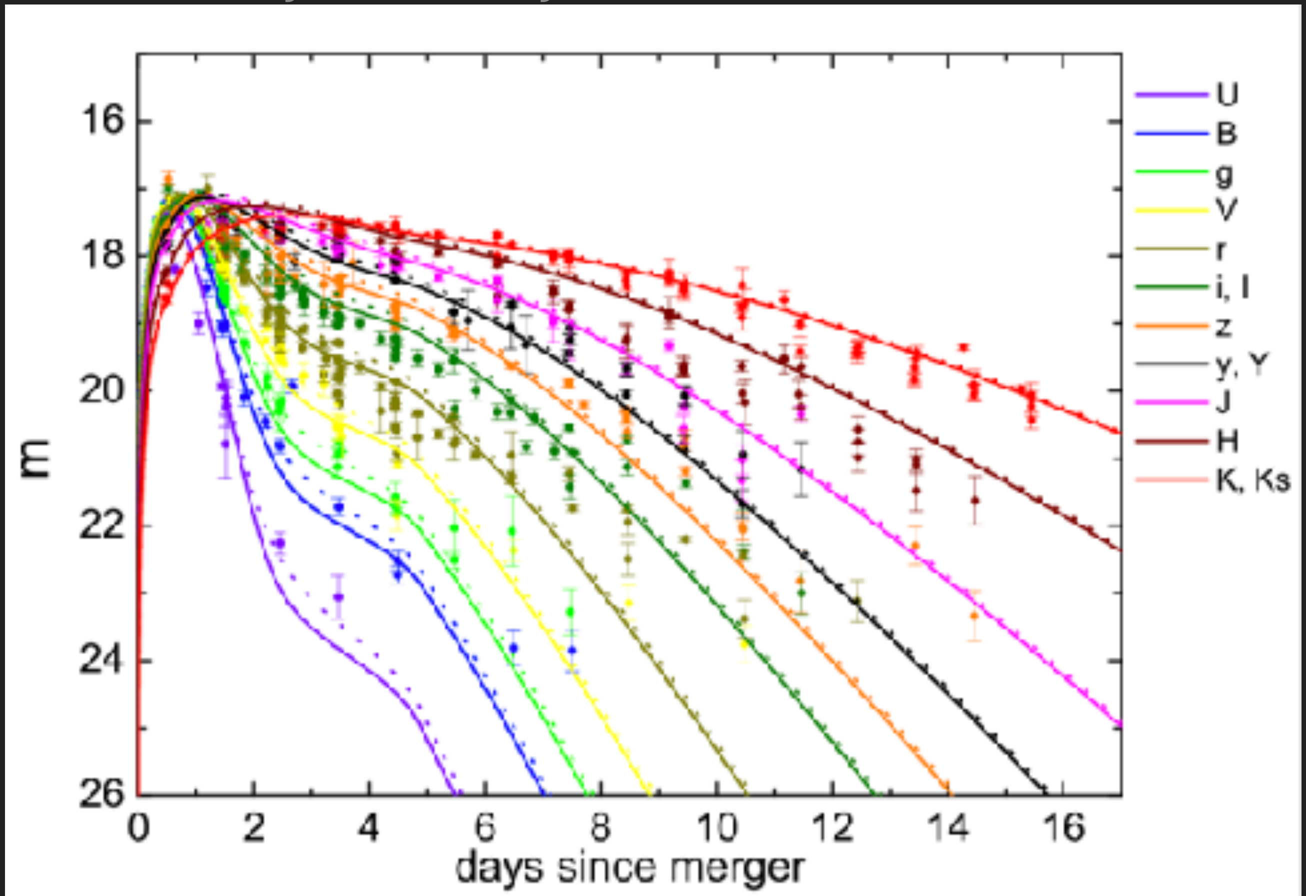
WHAT DOES THE LONG TERM EMISSION TELL US?

- ??????
    - Personal opinion: not likely a long-lived neutron star
    - many people have fit models;
        - requires B~10^{12} G, ε ~ 0.003
        - magnetic burial, …
- If no collapse, can learn about EOS (maximum mass, …)
    - but need to know inspiral masses better.

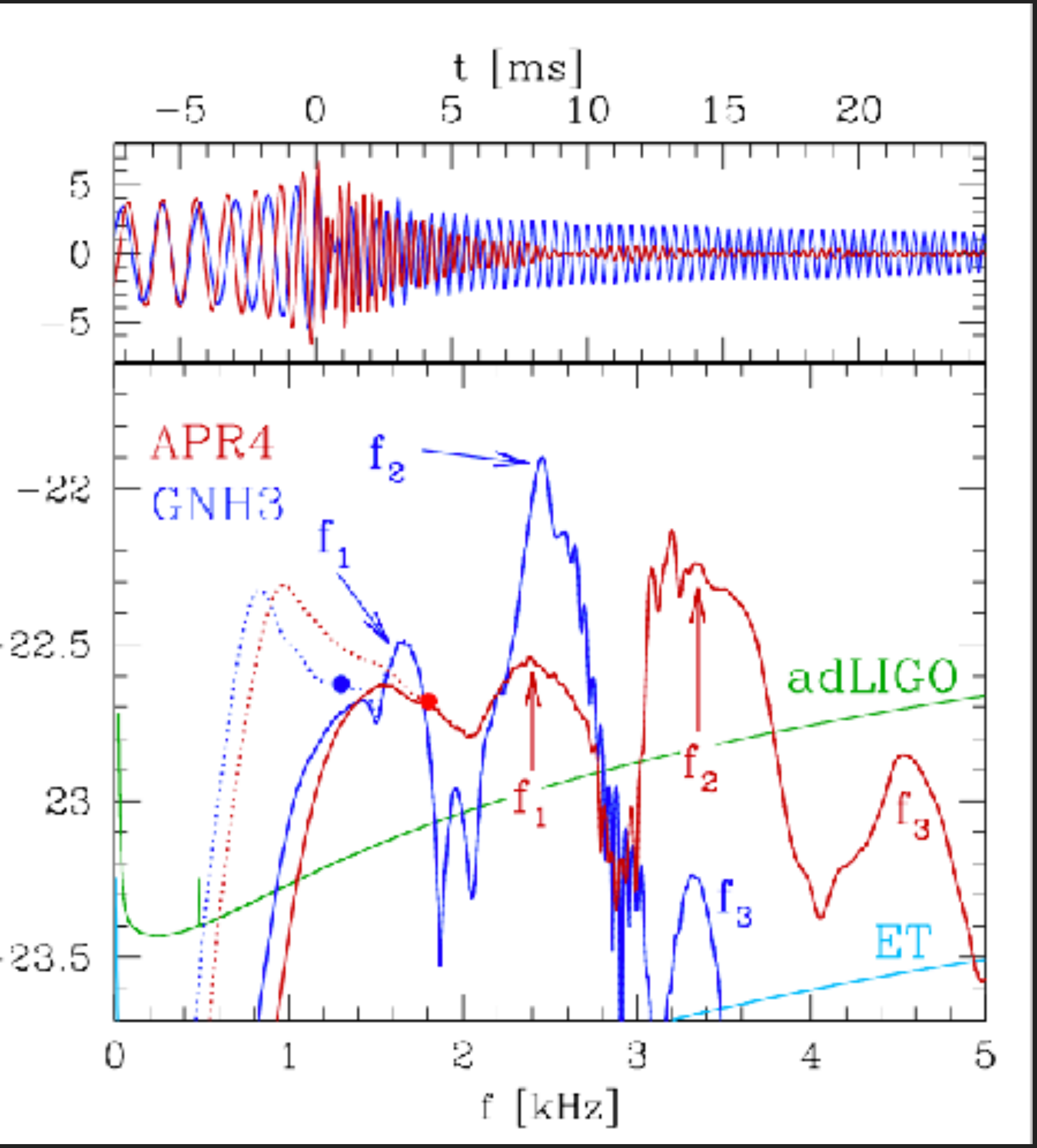


Yu & Dai (2018)

Li et al. (yesterday)



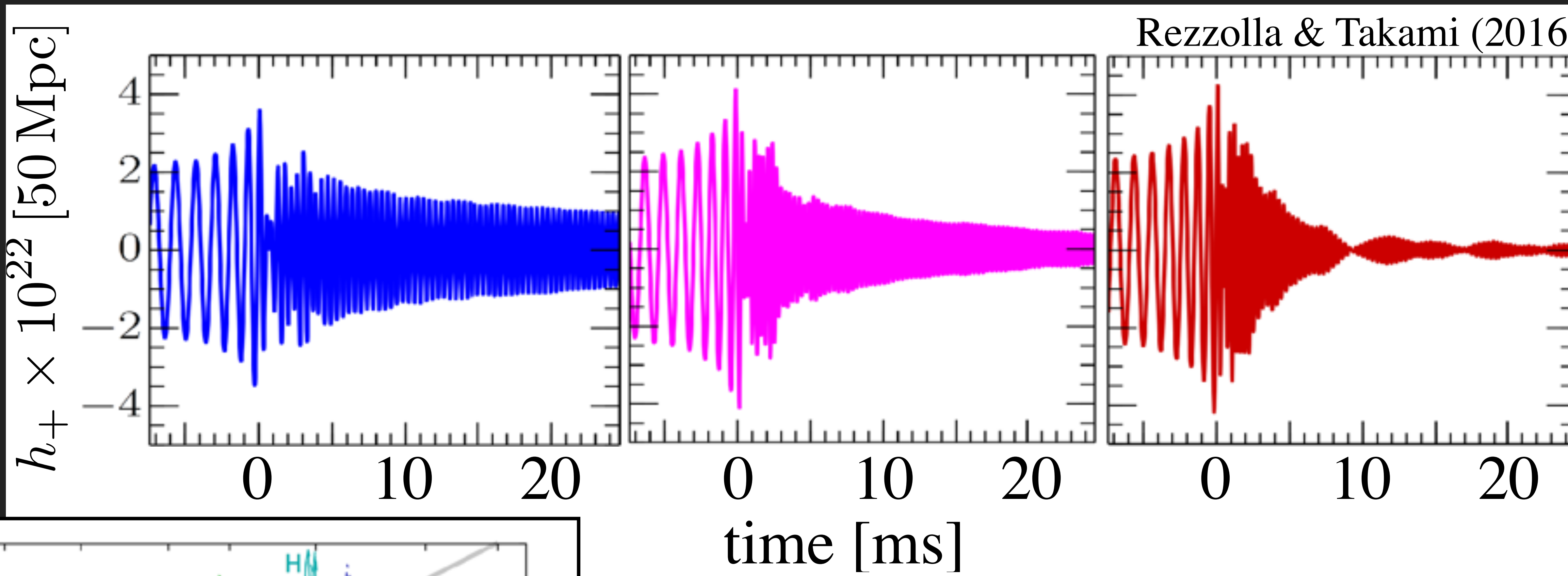
Takami, Rezzolla & Baiotti (2014)

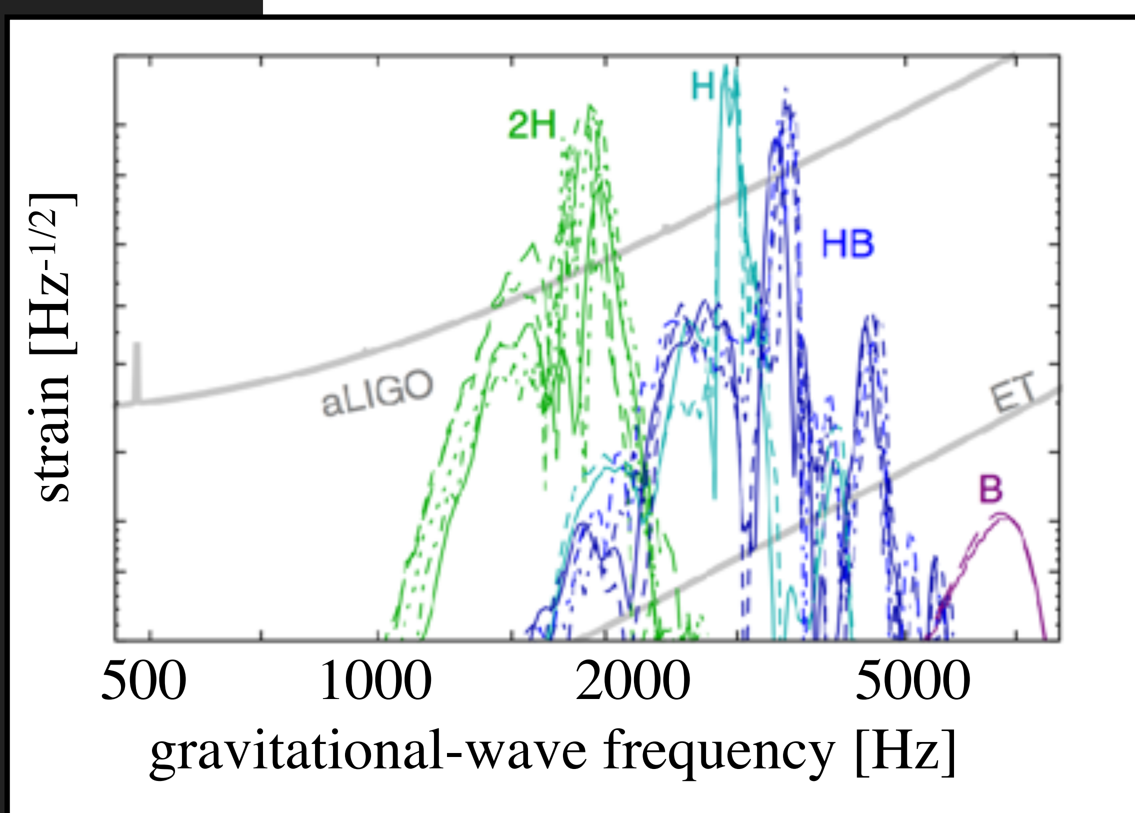


GRAVITATIONAL WAVES FROM…

HYPERMASSIVE NEUTRON STARS

GRAVITATIONAL WAVES FROM HYPERMASSIVE NEUTRON STARS





Potentially excellent equation of state discriminator

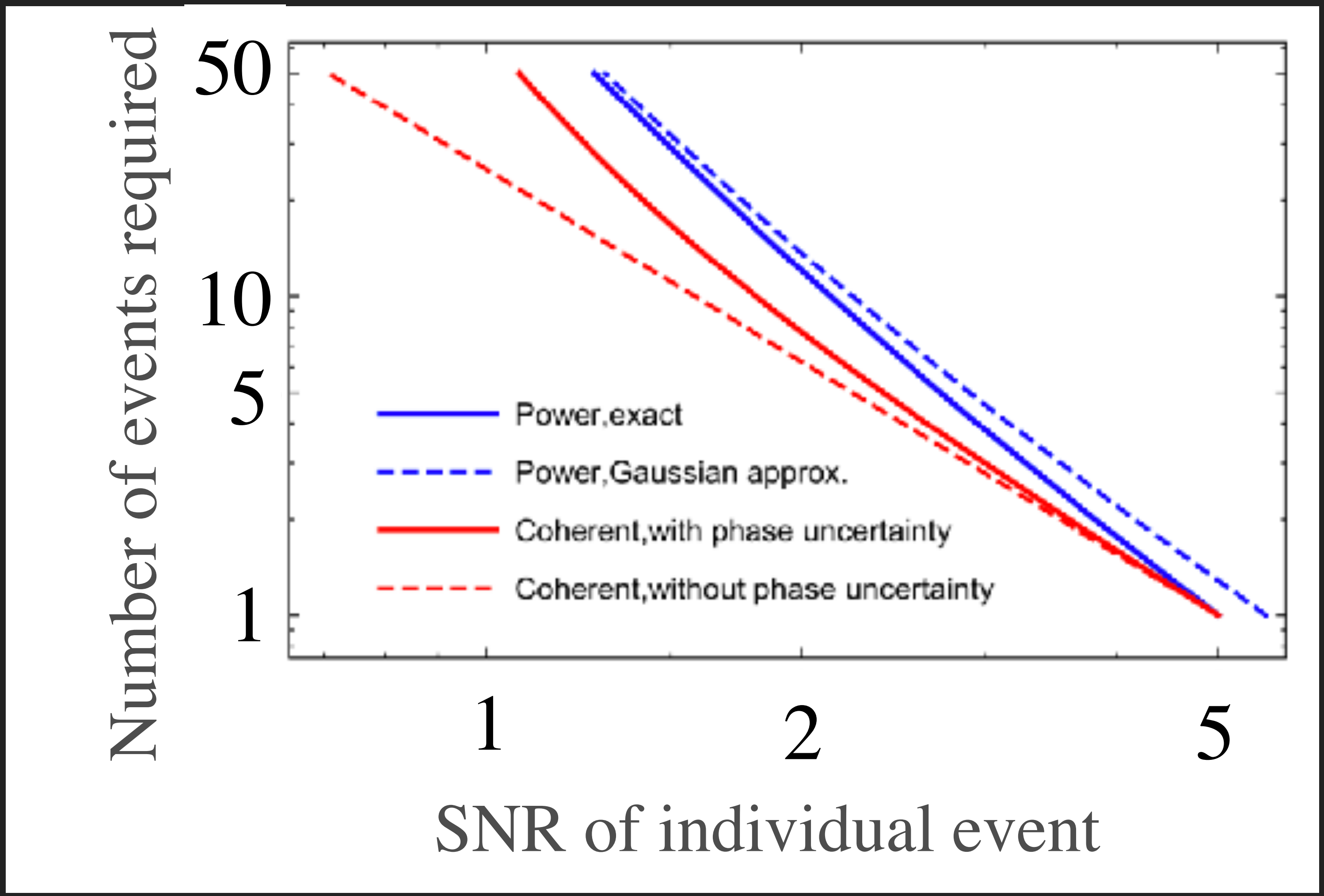
Clark et al. (2016)

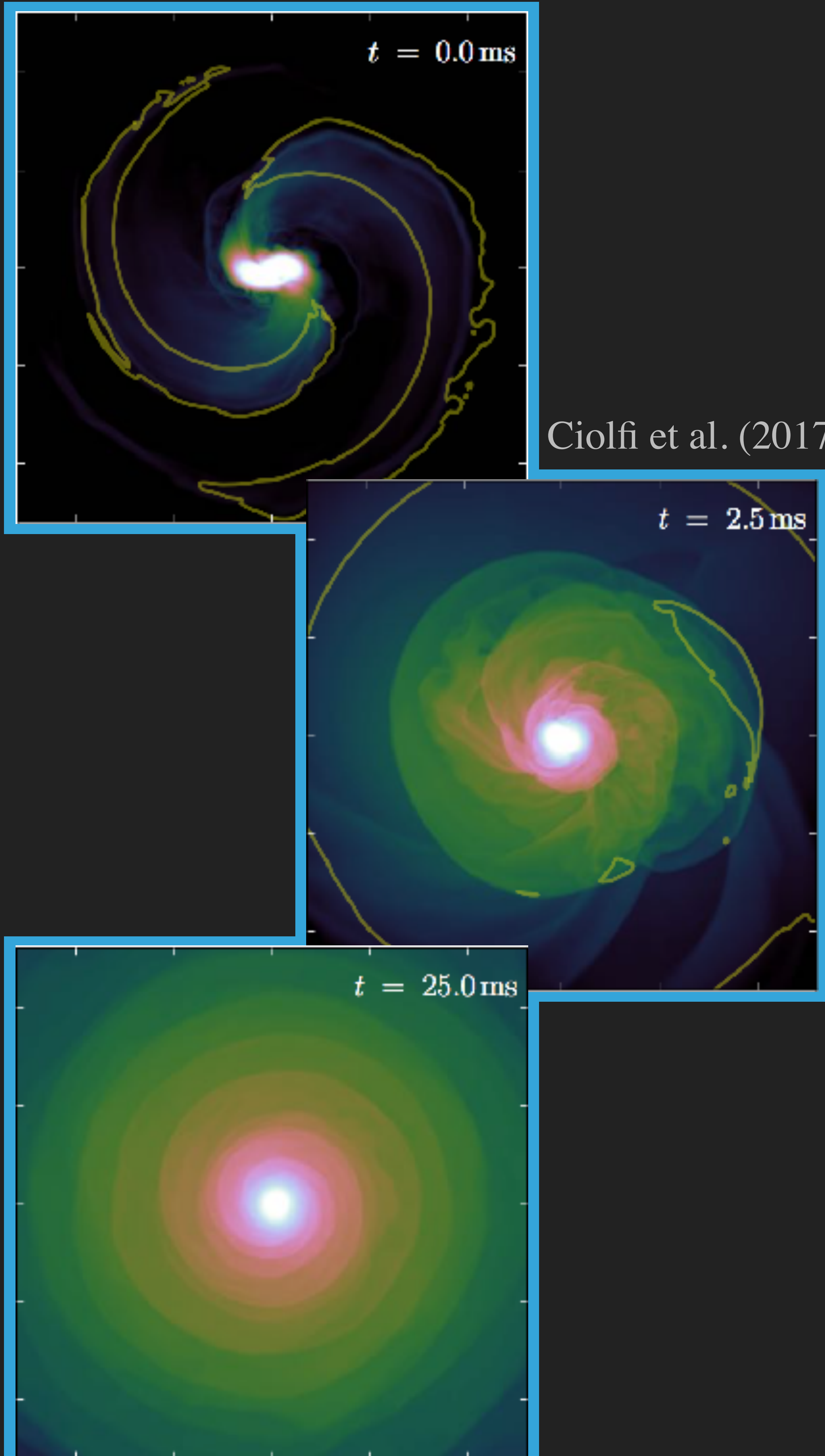
	SNR (@ 50 Mpc)	horizon distance (Mpc)	detection rate (year^{-1})
aLIGO (design sensitivity)	~ 3	~ 30	~ 0.01
Einstein Telescope	~ 27	~ 270	~ 3

ENSEMBLE DETECTIONS

- Bayes-factor summing
- coherent mode stacking
  - use information from inspiral

Yang+ (2018)



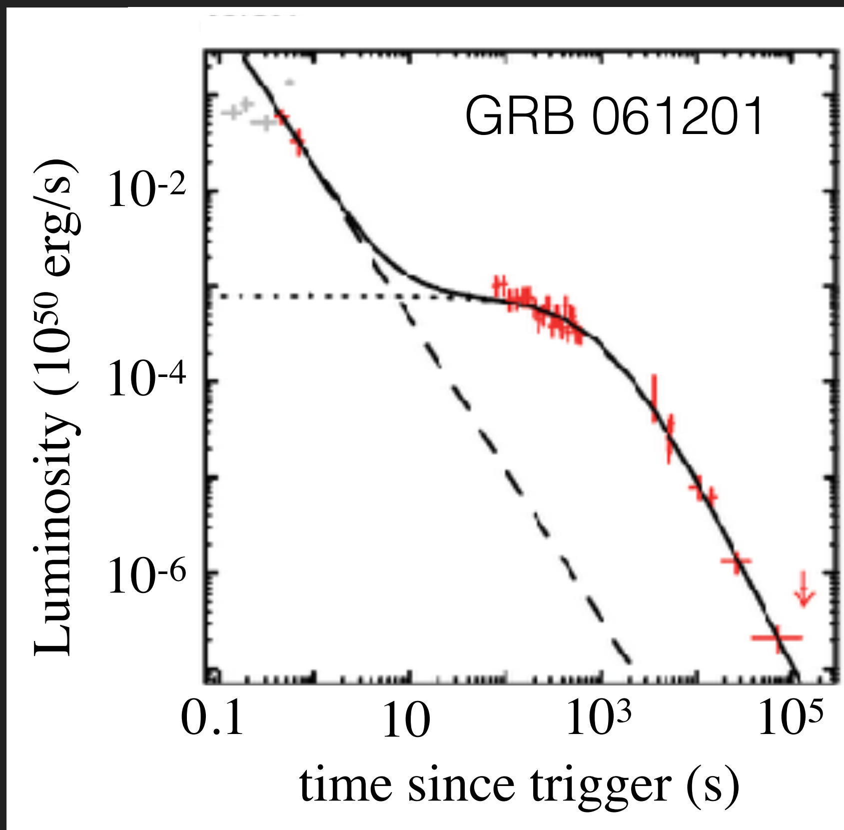


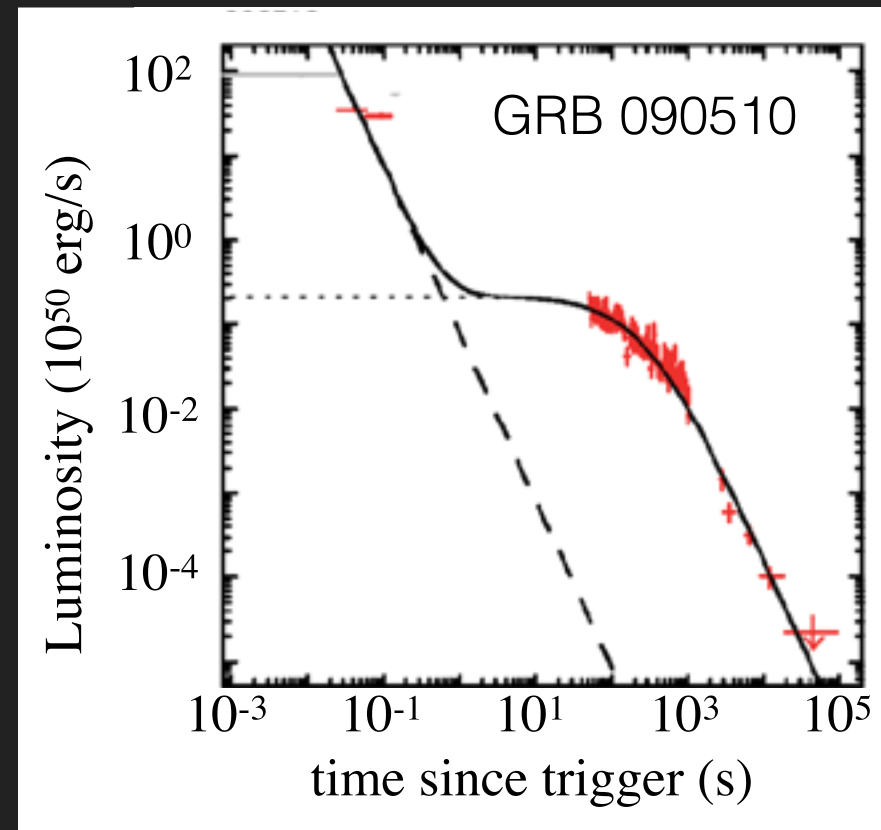
Ciolfi et al. (2017)

GRAVITATIONAL WAVES FROM…

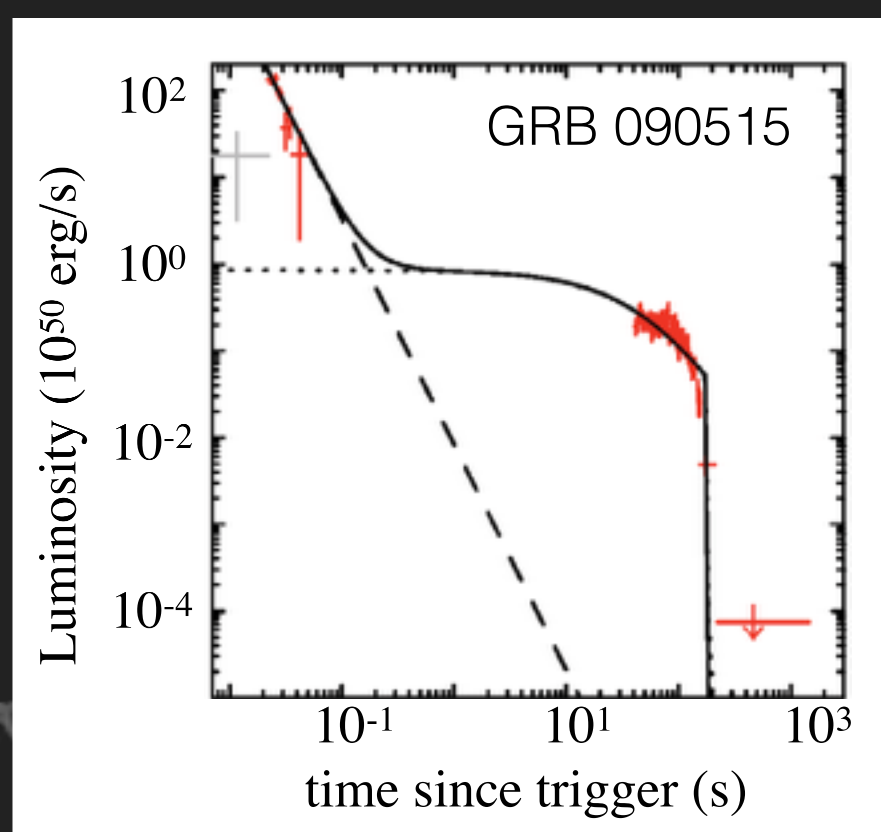
SUPRAMASSIVE & LONG-LIVED NEUTRON STARS

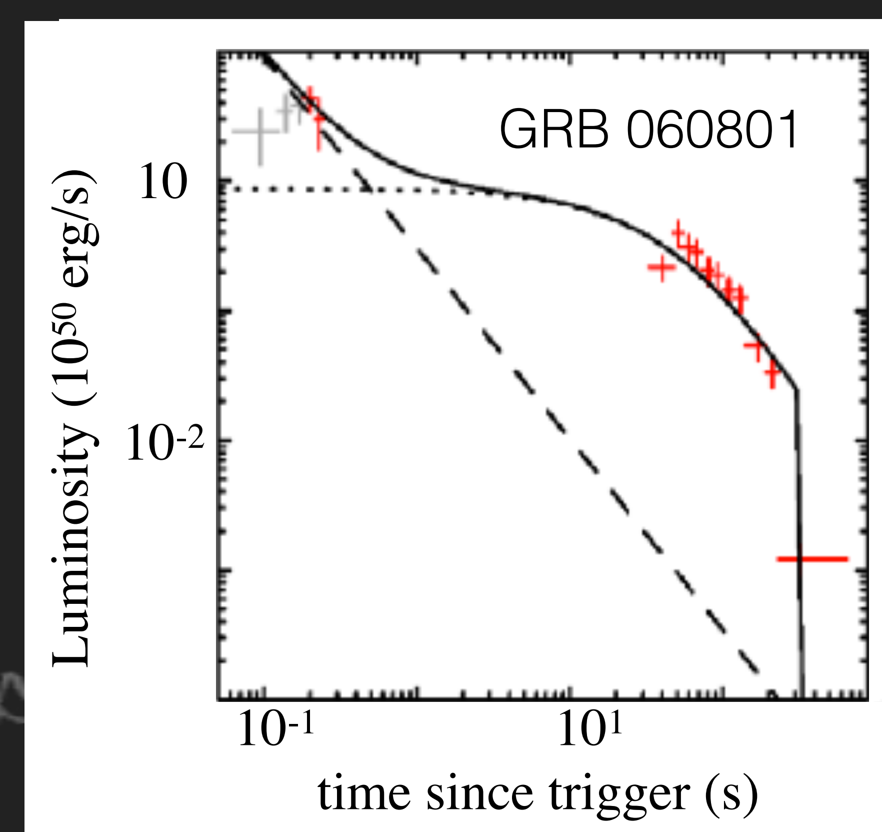
LONG-LIVED NEUTRON STARS





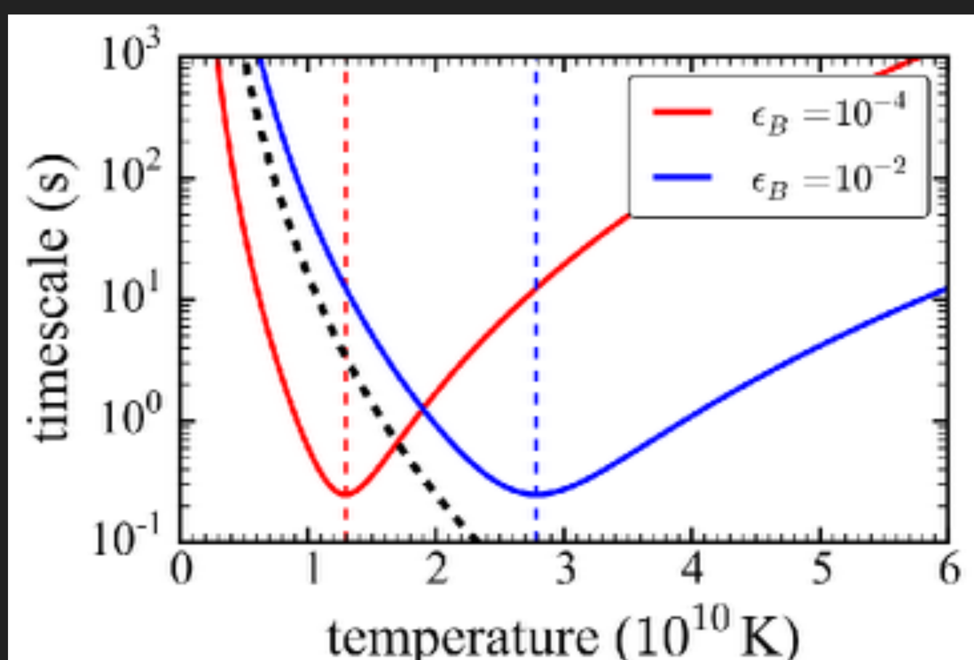
Rowlinson et al. (2013)

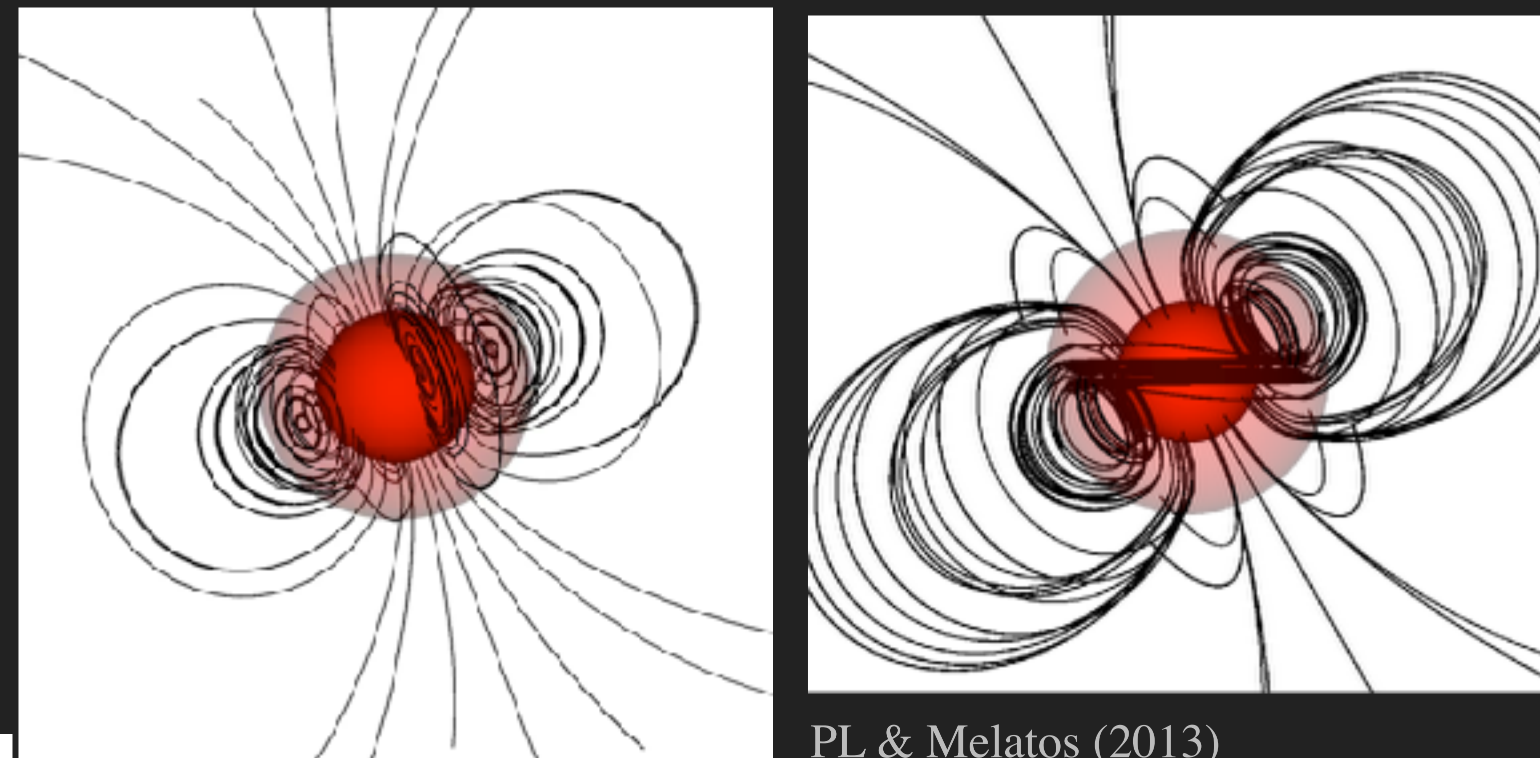




- toroidal magnetic field + spin flip

e.g., Cutler 2002,
Dall'Osso et al. (2015),
PL & Glampedakis (2016)





PL & Melatos (2013)

$$\epsilon_{\rm sf} \approx 5 \times 10^{-3} \left(\frac{\rho}{10^{15}\,{\rm G}}\right) \left(\frac{P}{1\,{\rm ms}}\right)^{-2}$$

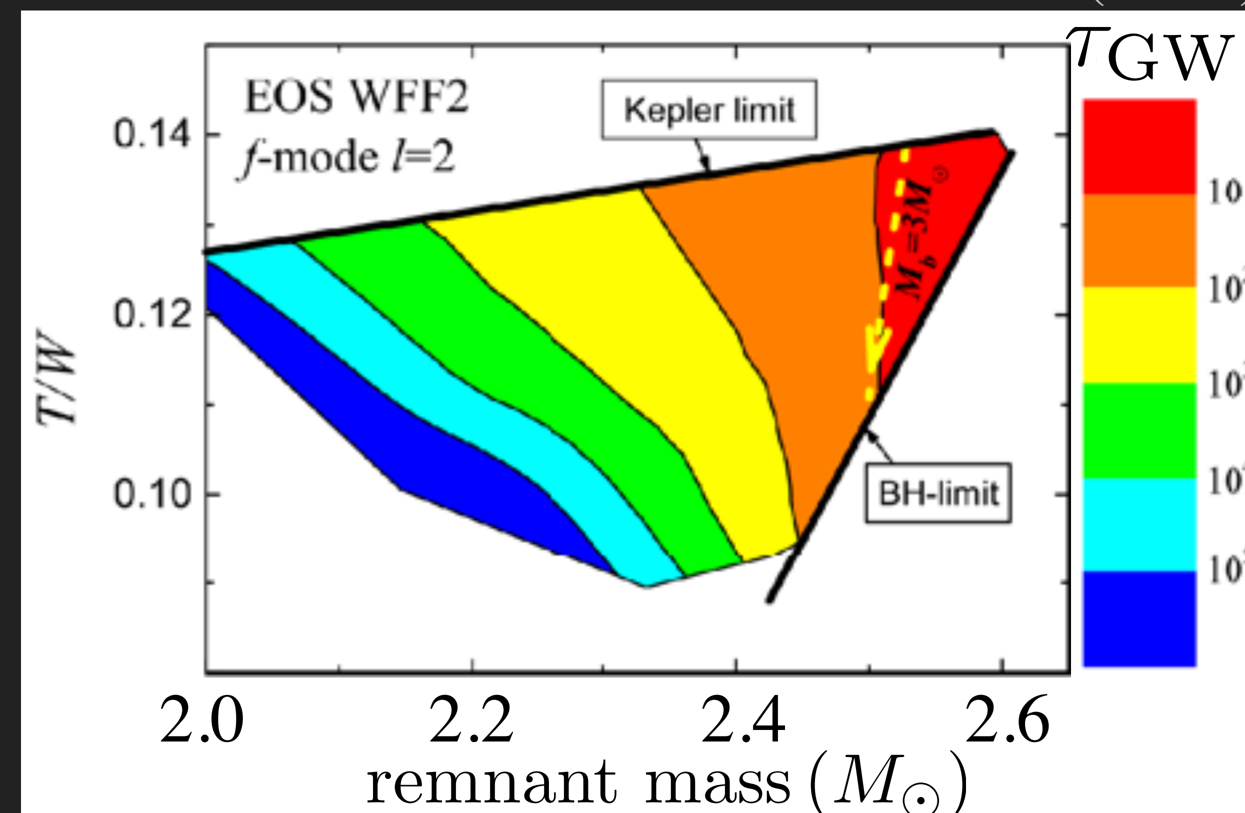
- toroidal magnetic field + spin flip

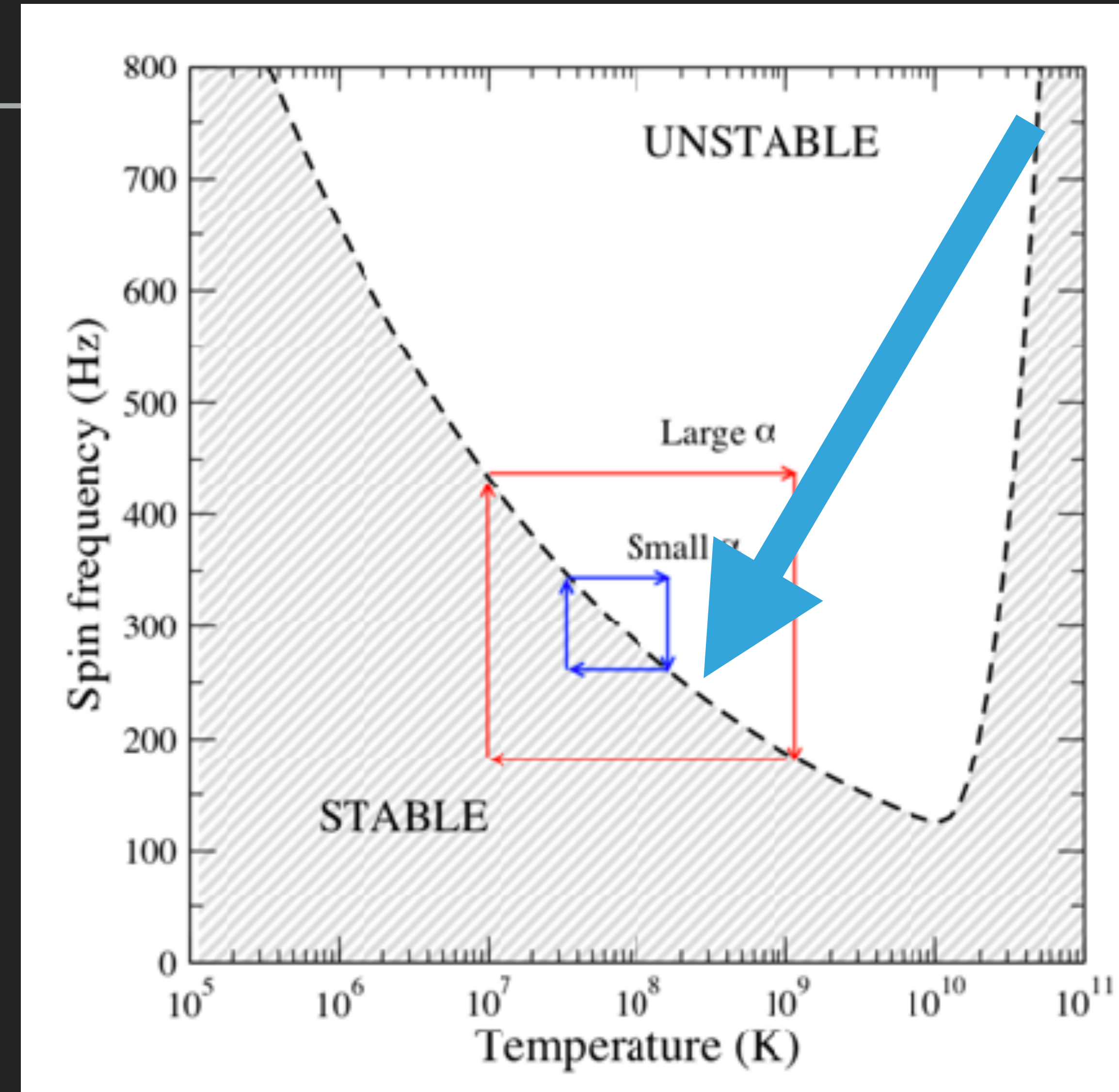
- secular bar-mode instability

e.g., Corsi & Meszaros (2009)
Doneva et al. (2015)

$$\epsilon_f \approx 10^{-3}$$

Doneva et al. (2015)





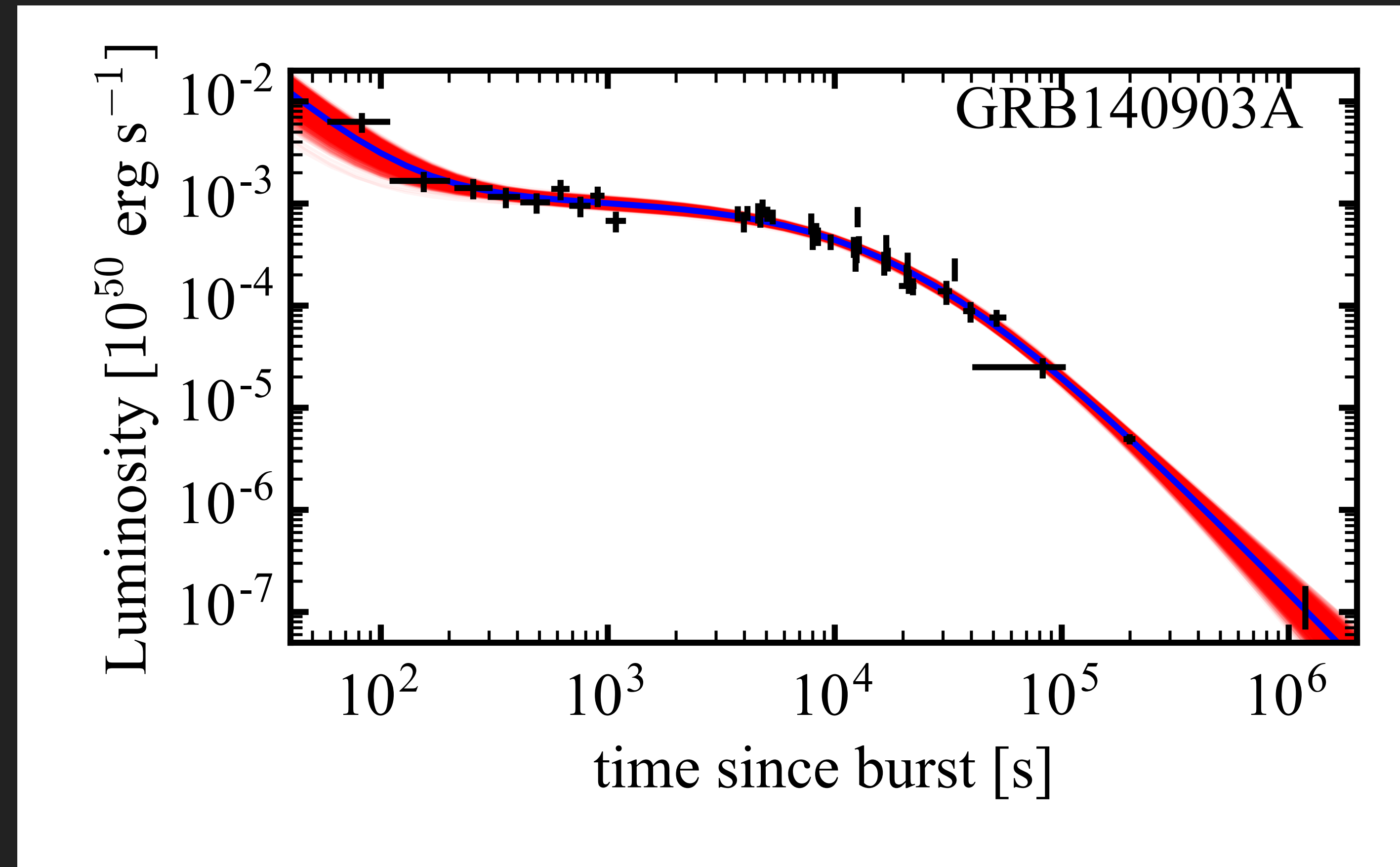
- toroidal magnetic field + spin flip
- secular bar-mode instability
- unstable inertial modes

spin down timescale: $$\tau_{\rm GW} \sim 5 \times 10^9 \left(\frac{P}{1\,{\rm ms}}\right)^6 \left(\frac{10^{-4}}{\alpha_{\rm max}}\right)^2 \,{\rm s}$$

~~(Owen et al. 1998)~~ PL & Glampedakis (2016)

Can constrain GW emission from X-ray observations

$$\dot{\Omega} \propto \Omega^{n}$$



PL+ 2017

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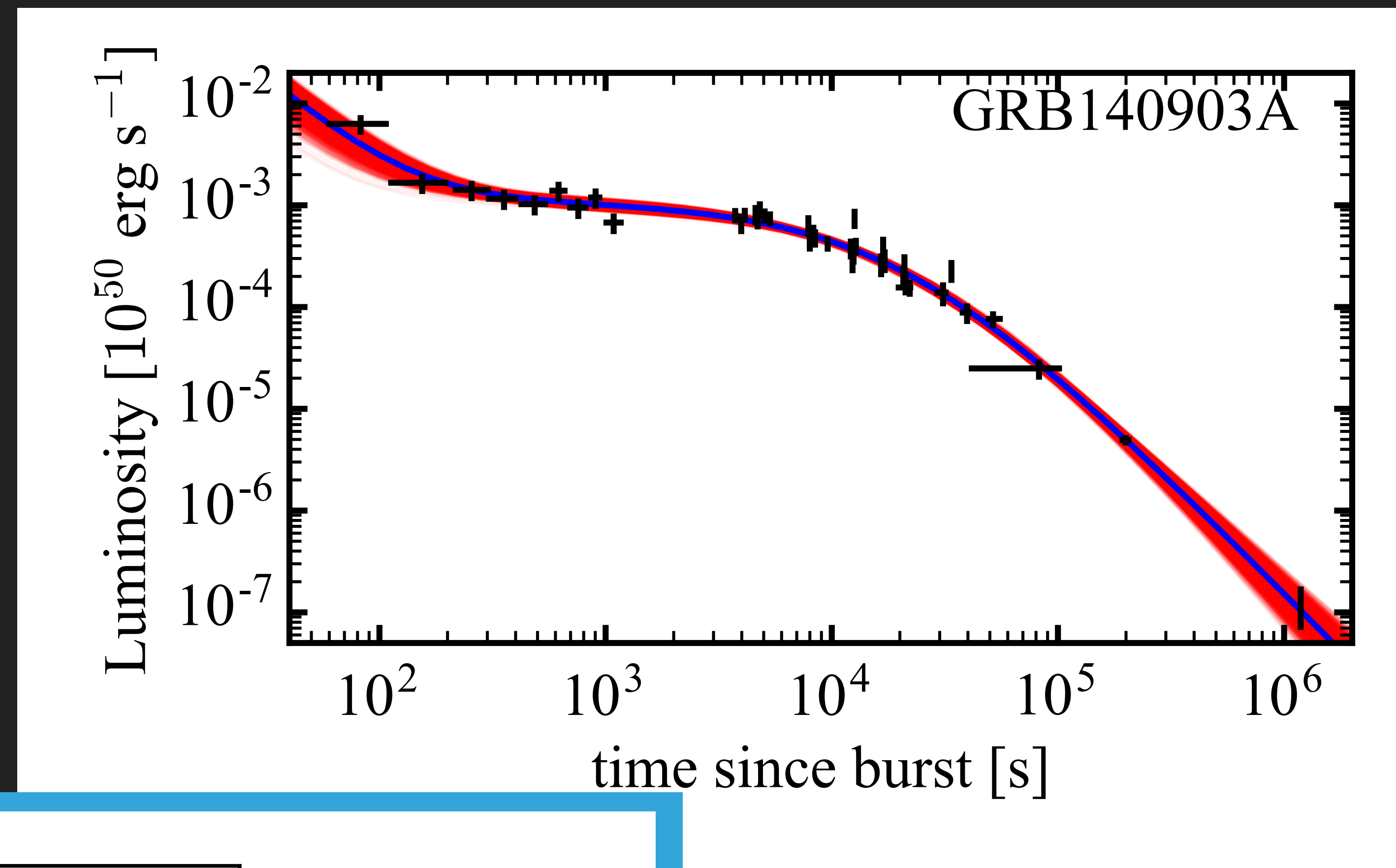
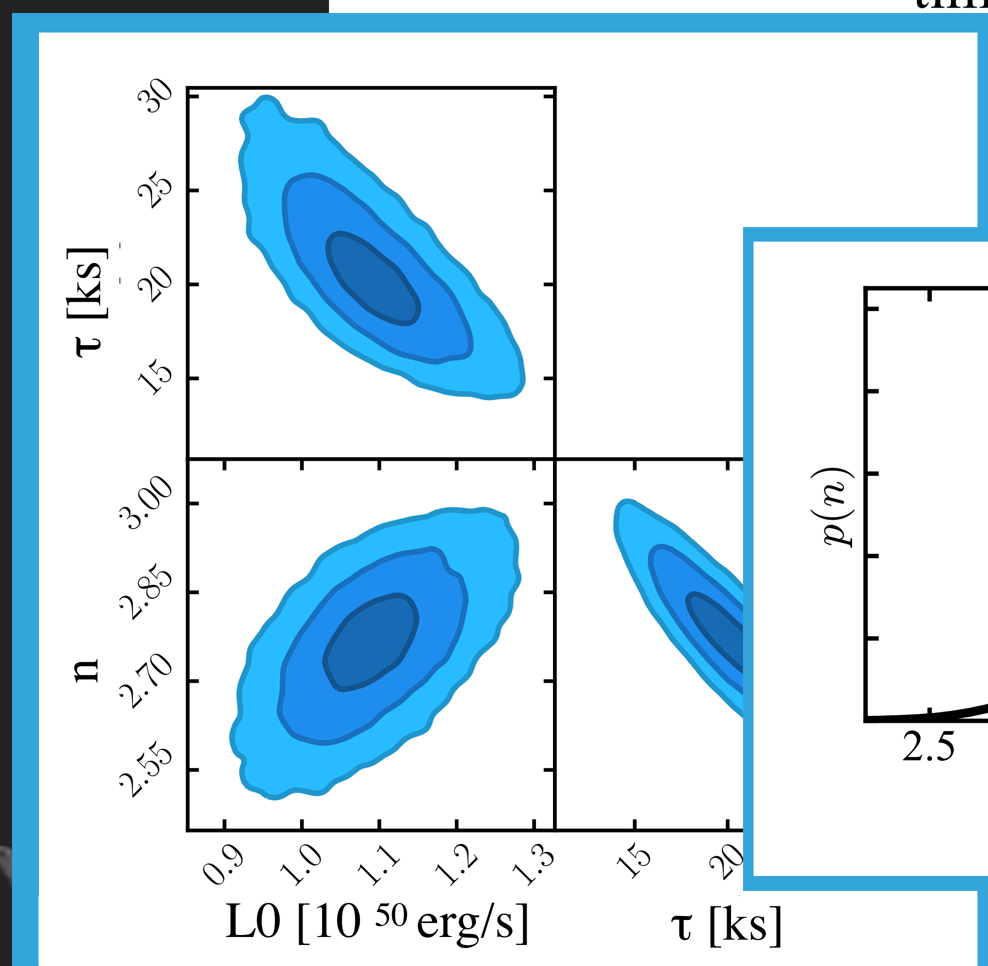
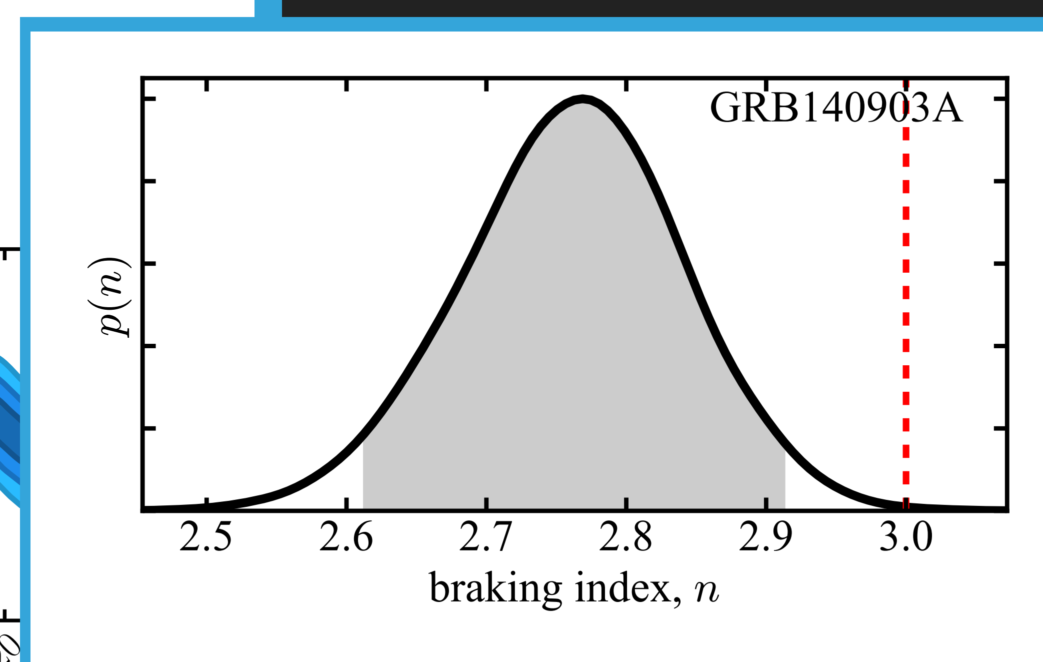


PL+ 2017





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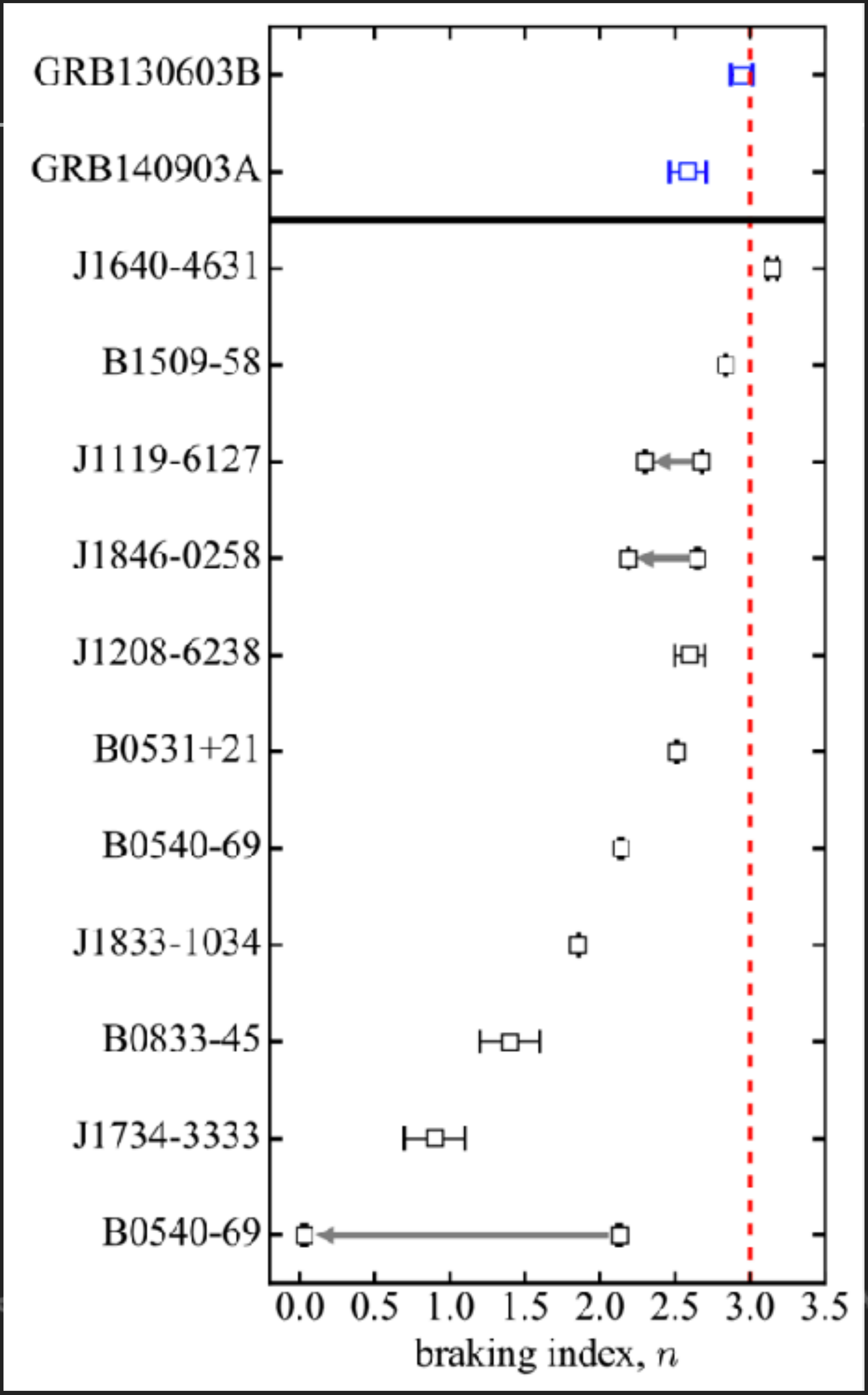
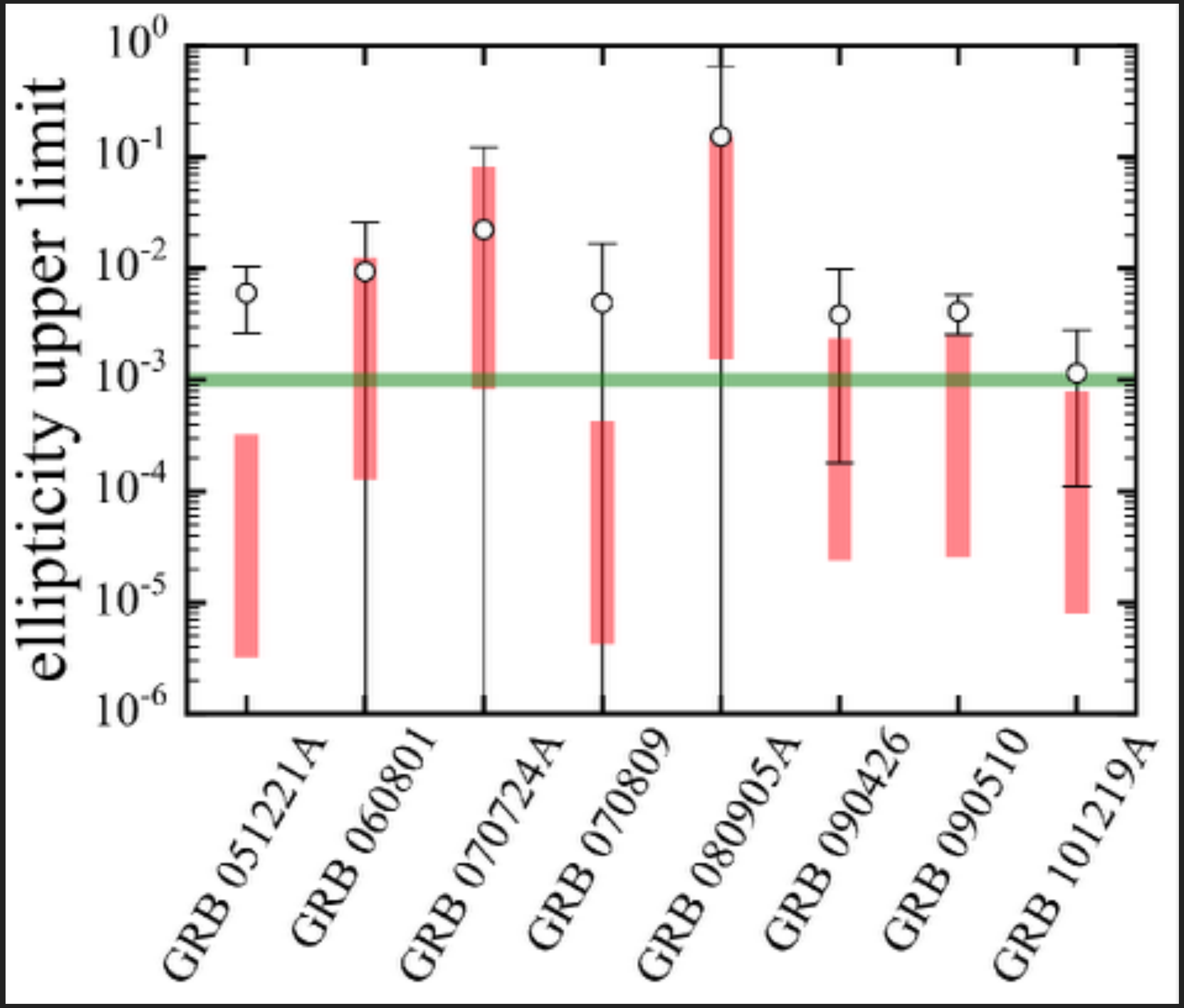
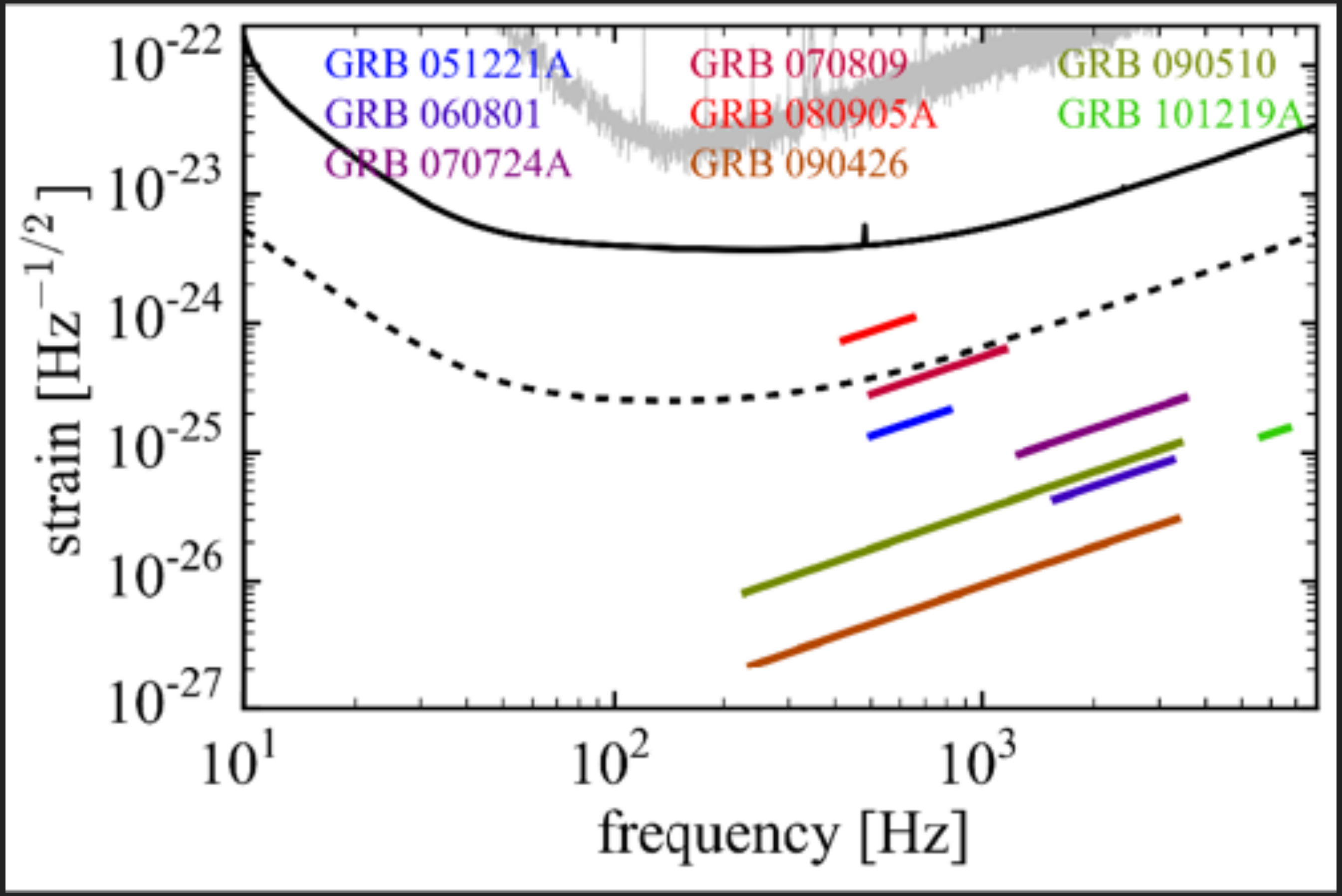
PL+ 2017



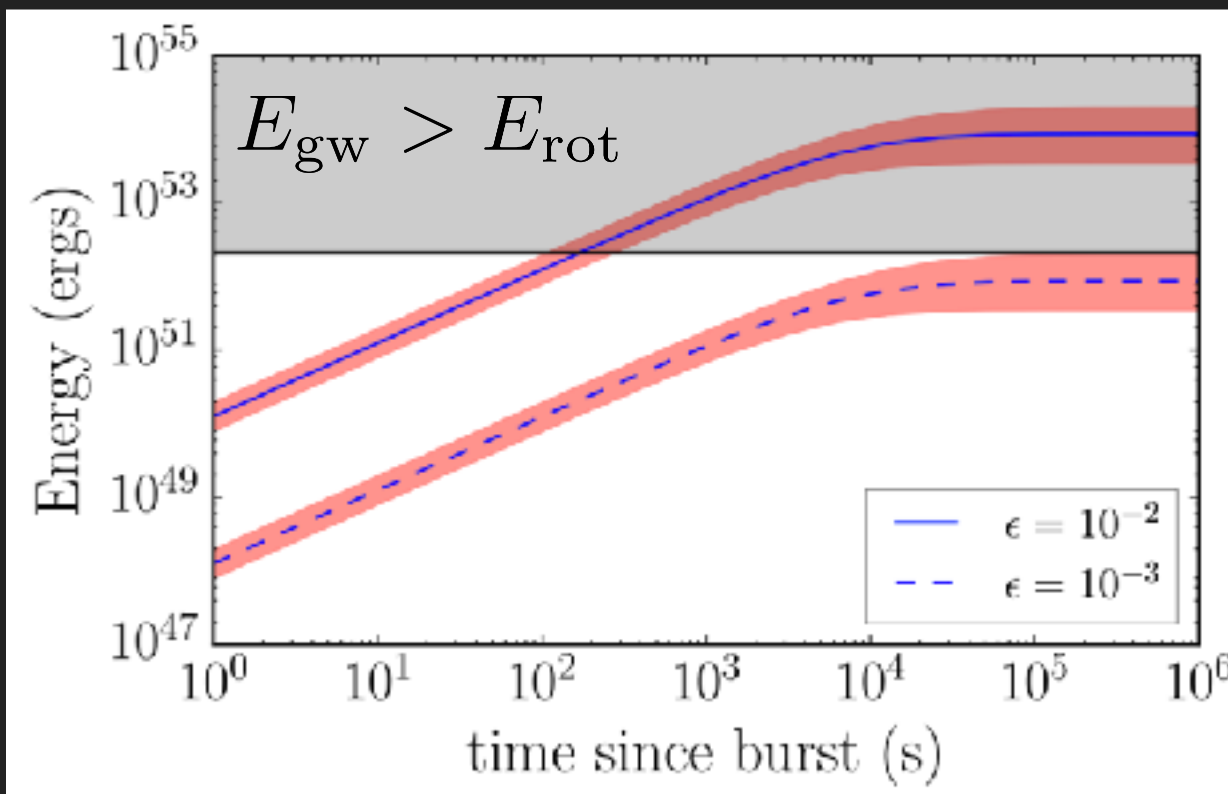
- Can constrain GW emission from X-ray observations



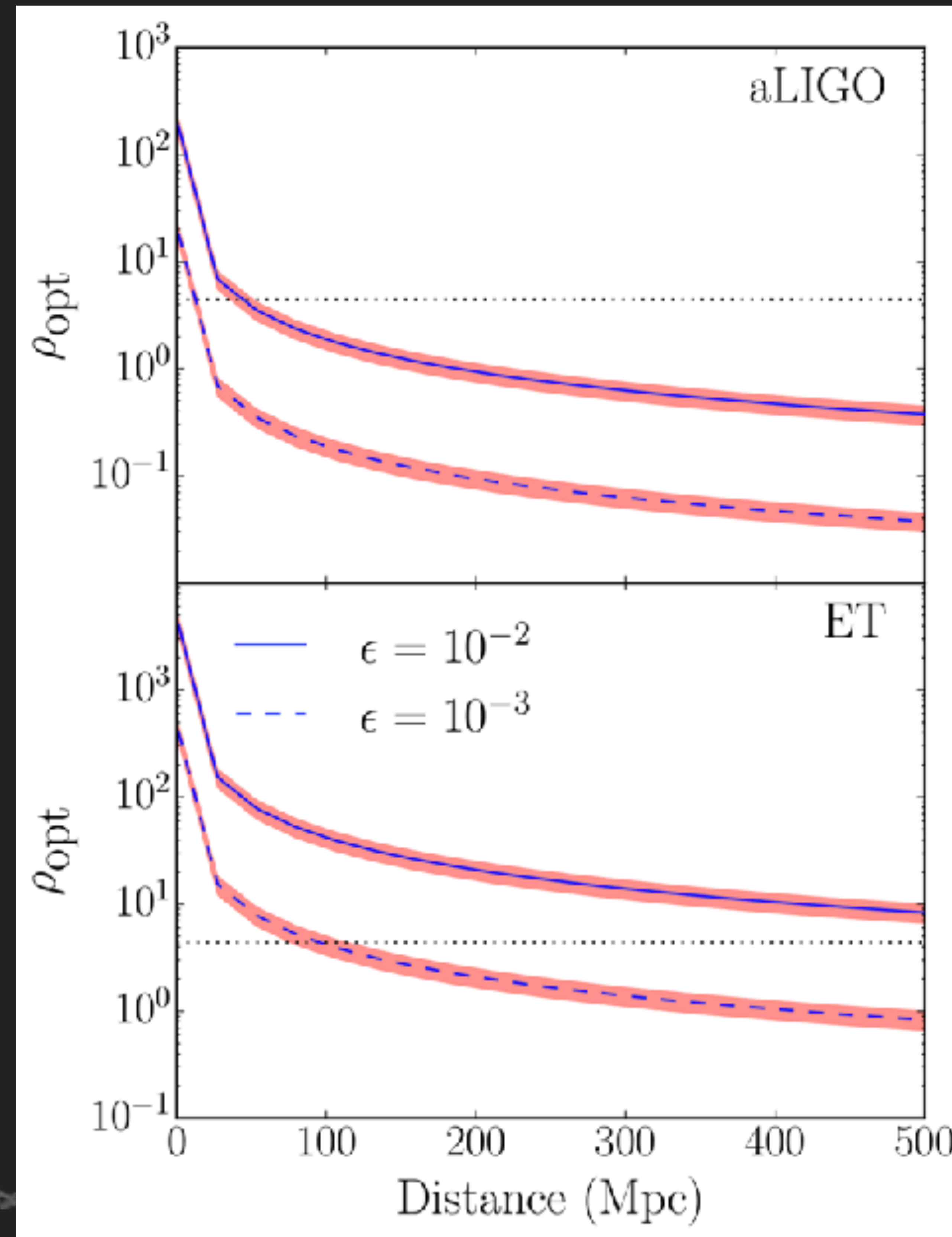


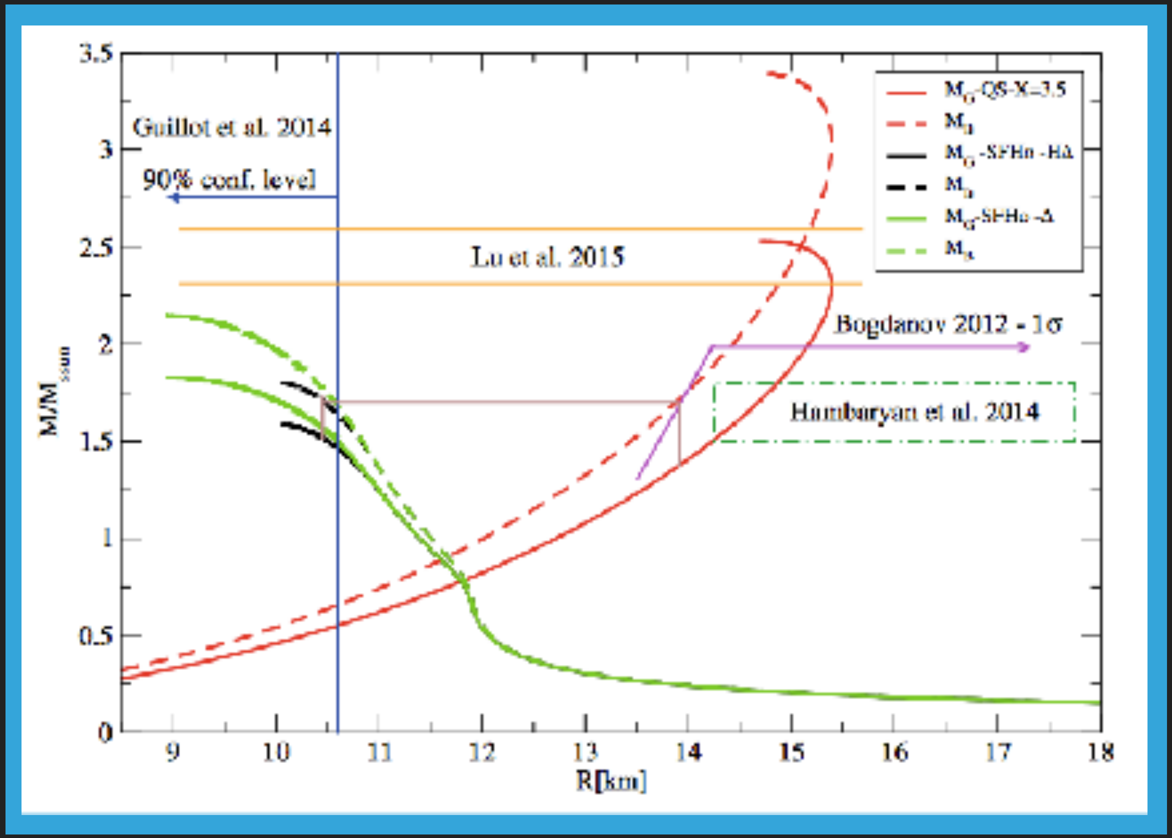
PL & Glampedakis (2016)

Energy budget



Sarin, PL, Sammut (in prep.)



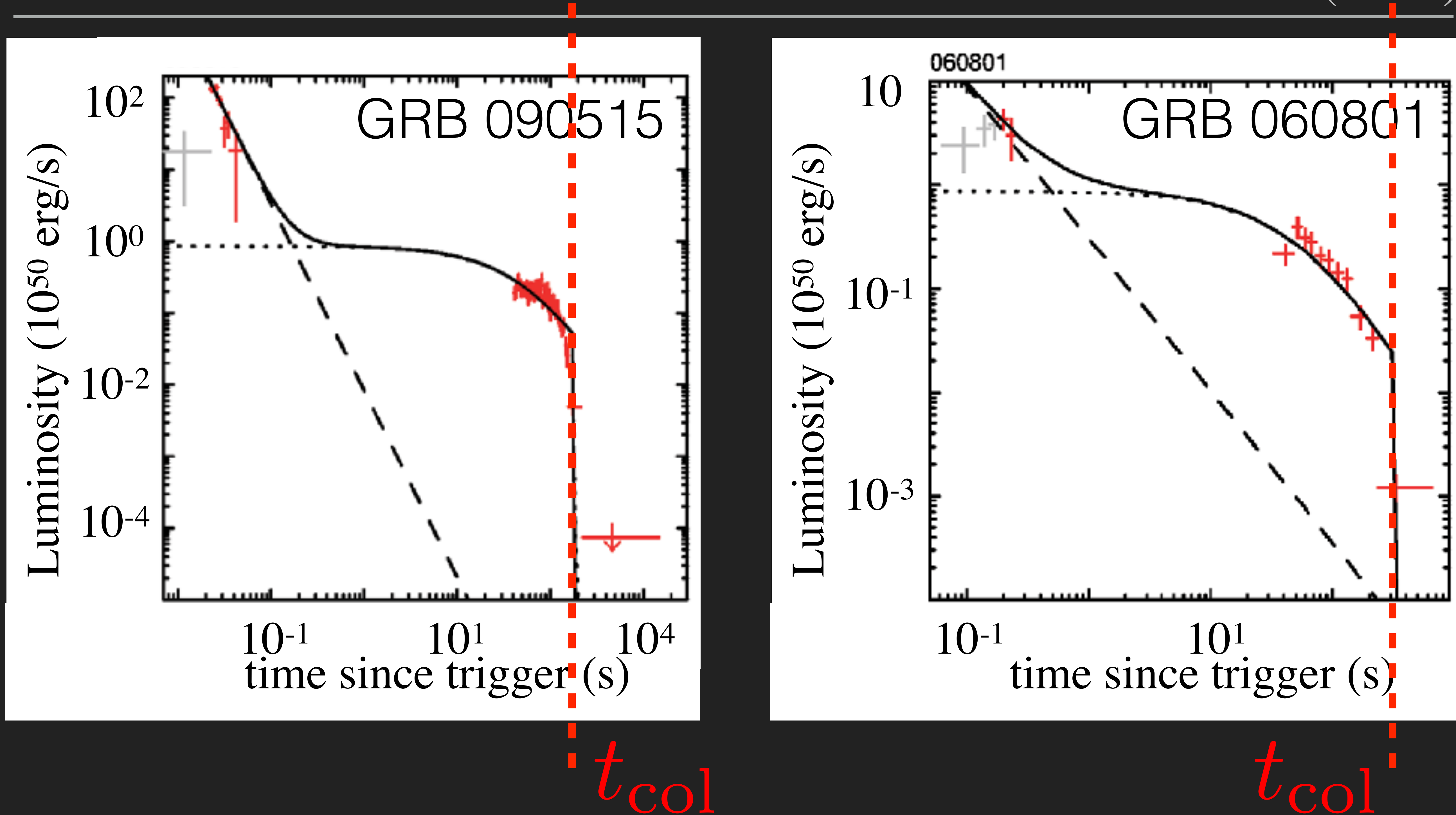


Drago et al. (2016)

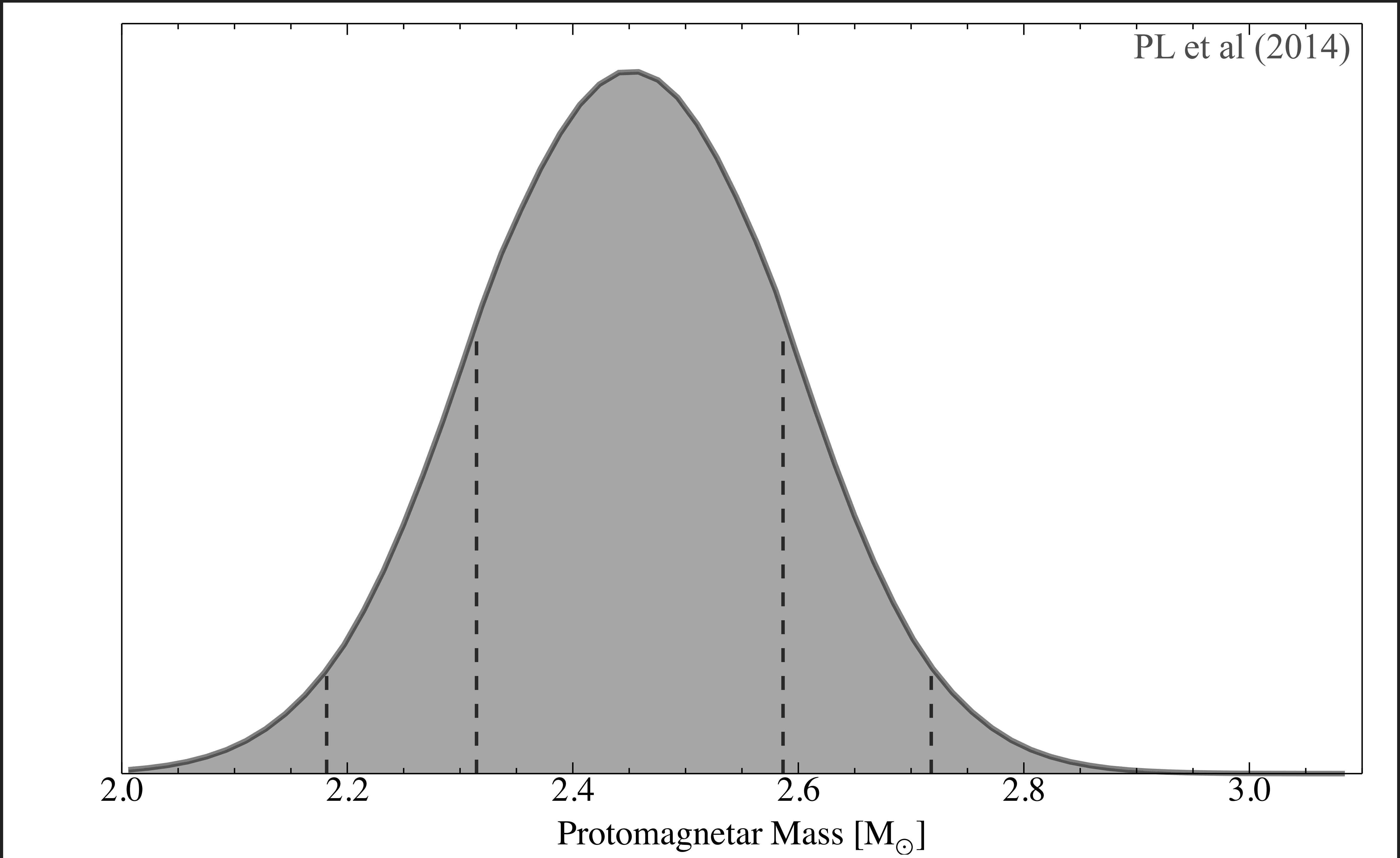
GRAVITATIONAL COLLAPSE AND …

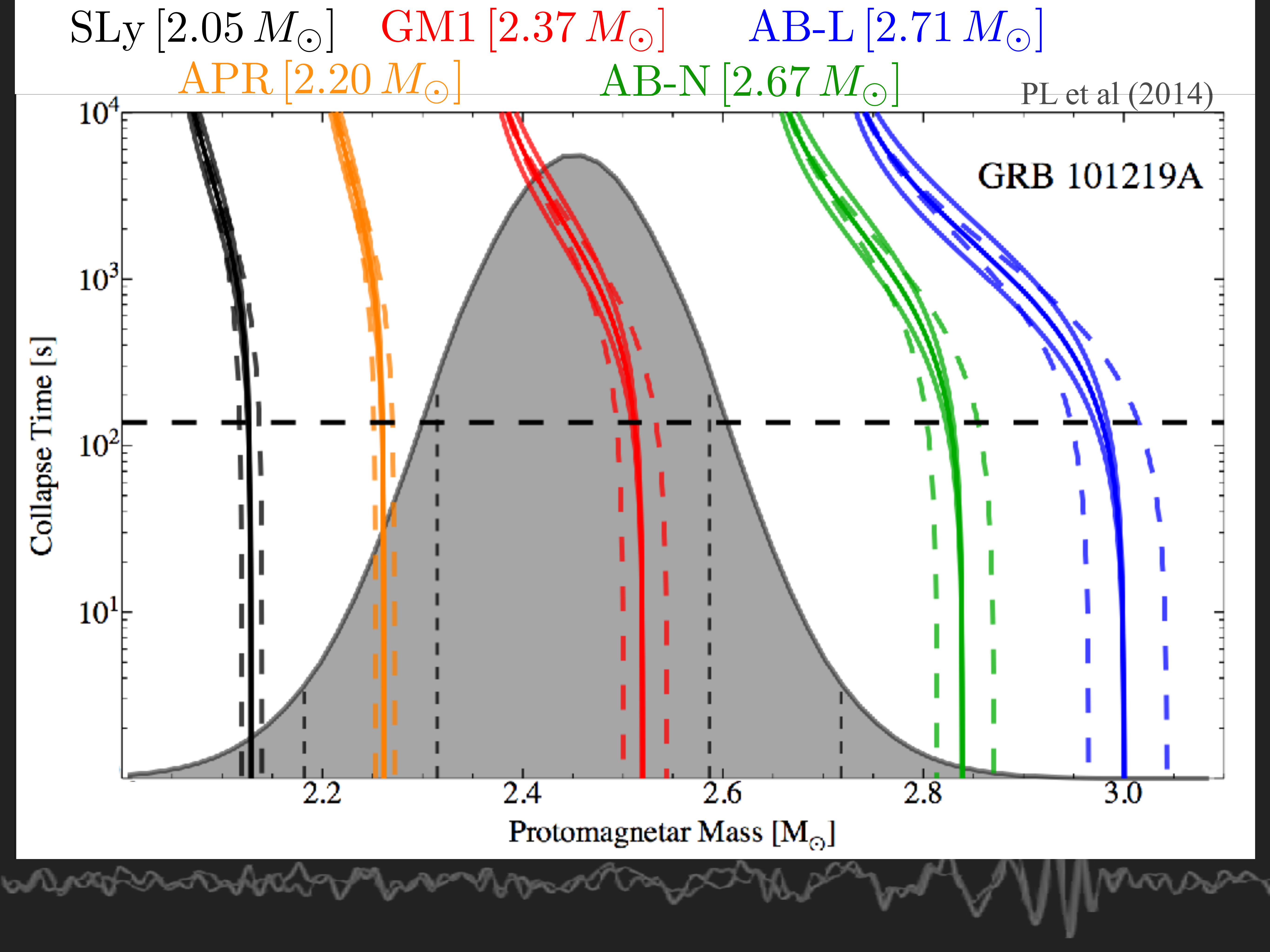
THE EQUATION OF STATE

Rowlinson et al. (2013)

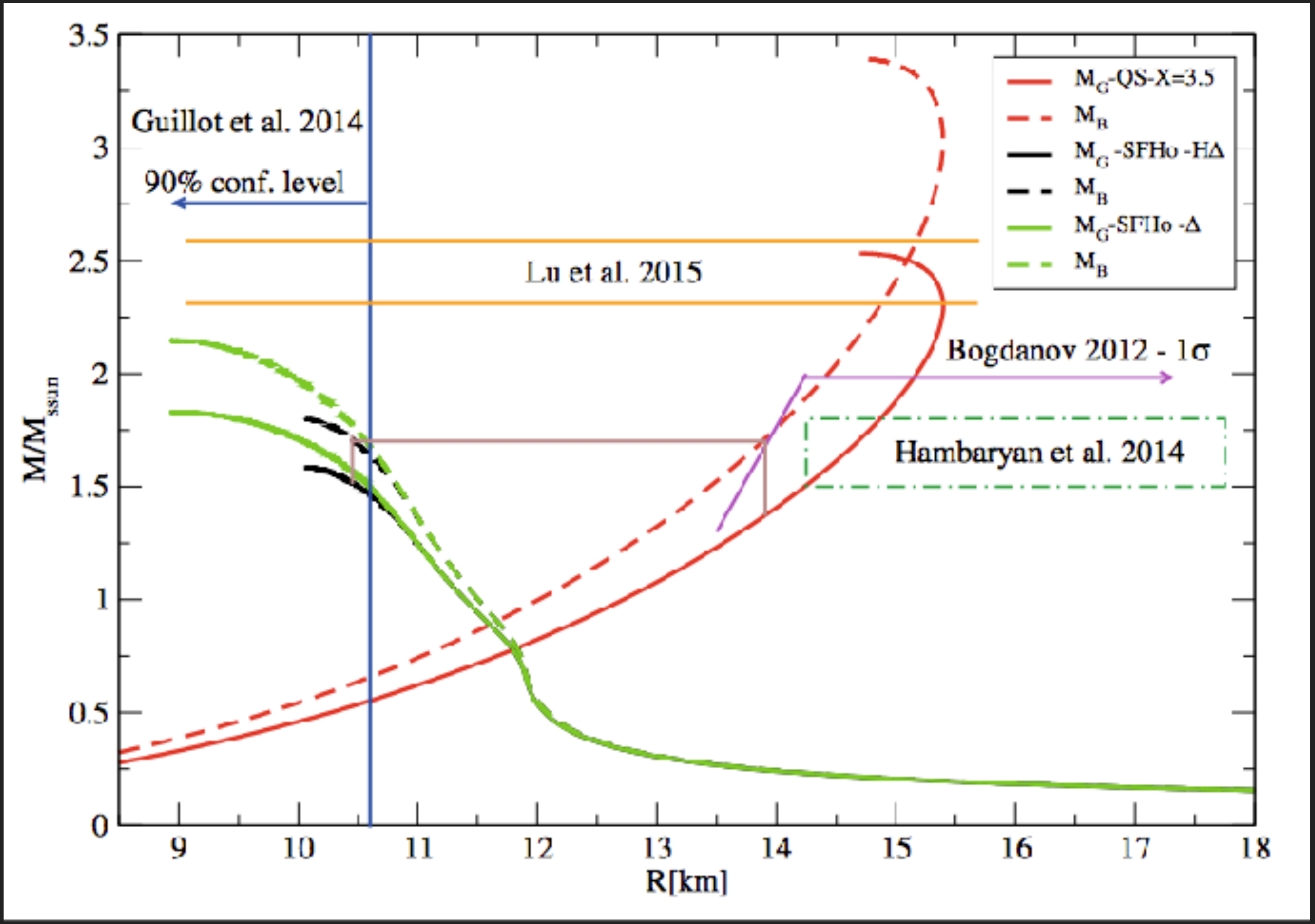


$$t_{\rm col} = t_{\rm col}\left(B_{\rm p},\, p_0,\, M,\, {\rm EOS}\right)$$


PL et al (2014)
2.0
2.2
2.4
2.6
2.8
3.0
Protomagnetar Mass [$M_\odot$]

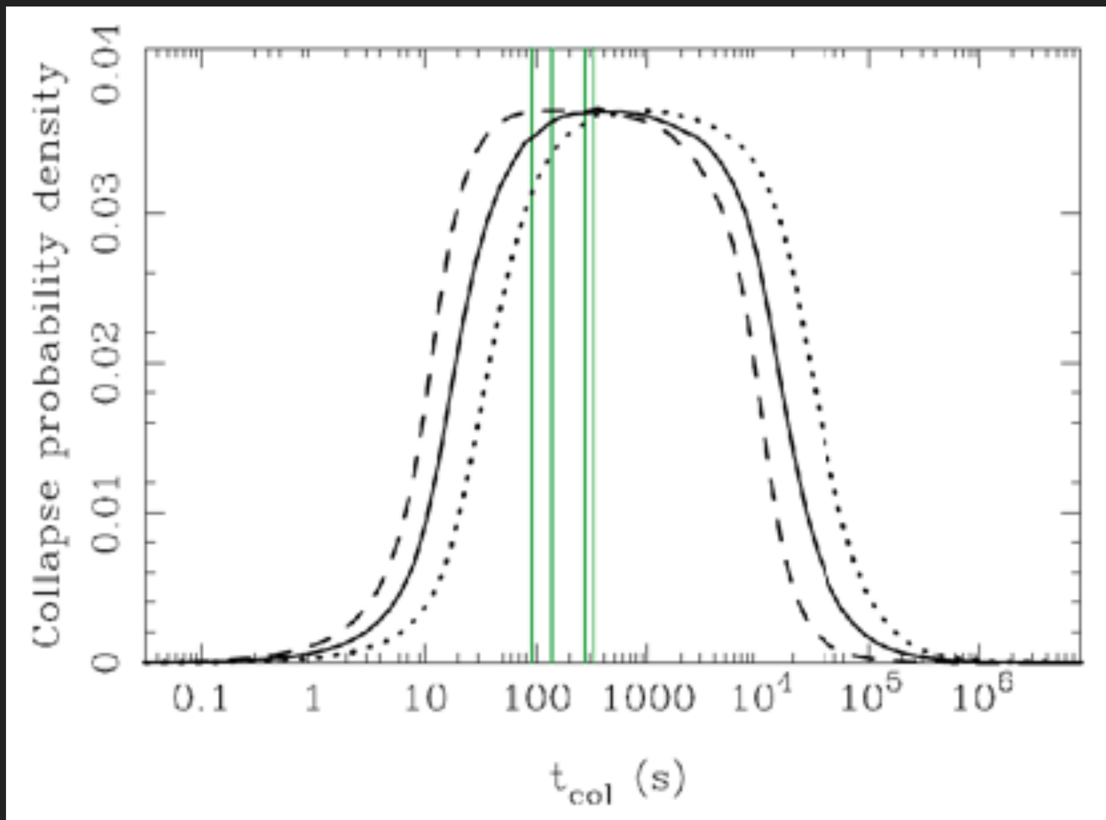


SLy [2.05 $M_\odot$]
GM1 [2.37 $M_\odot$]
AB-L [2.71 $M_\odot$]
APR [2.20 $M_\odot$]
AB-N [2.67 $M_\odot$]
PL et al (2014)
GRB 101219A
10^4
10^3
10^2
10^1
Collapse Time [s]
2.2
2.4
2.6
2.8
3.0
Protomagnetar Mass [$M_\odot$]

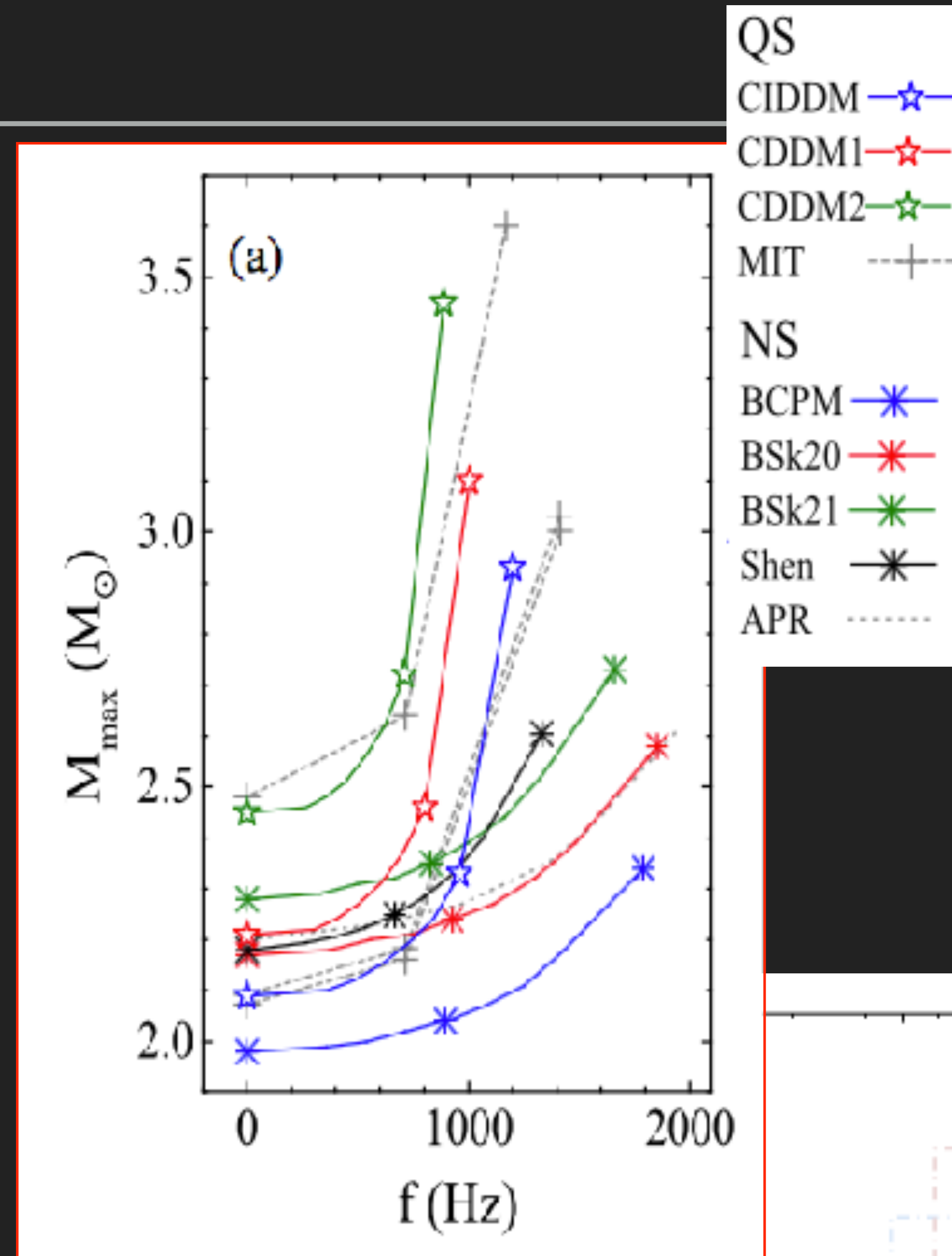


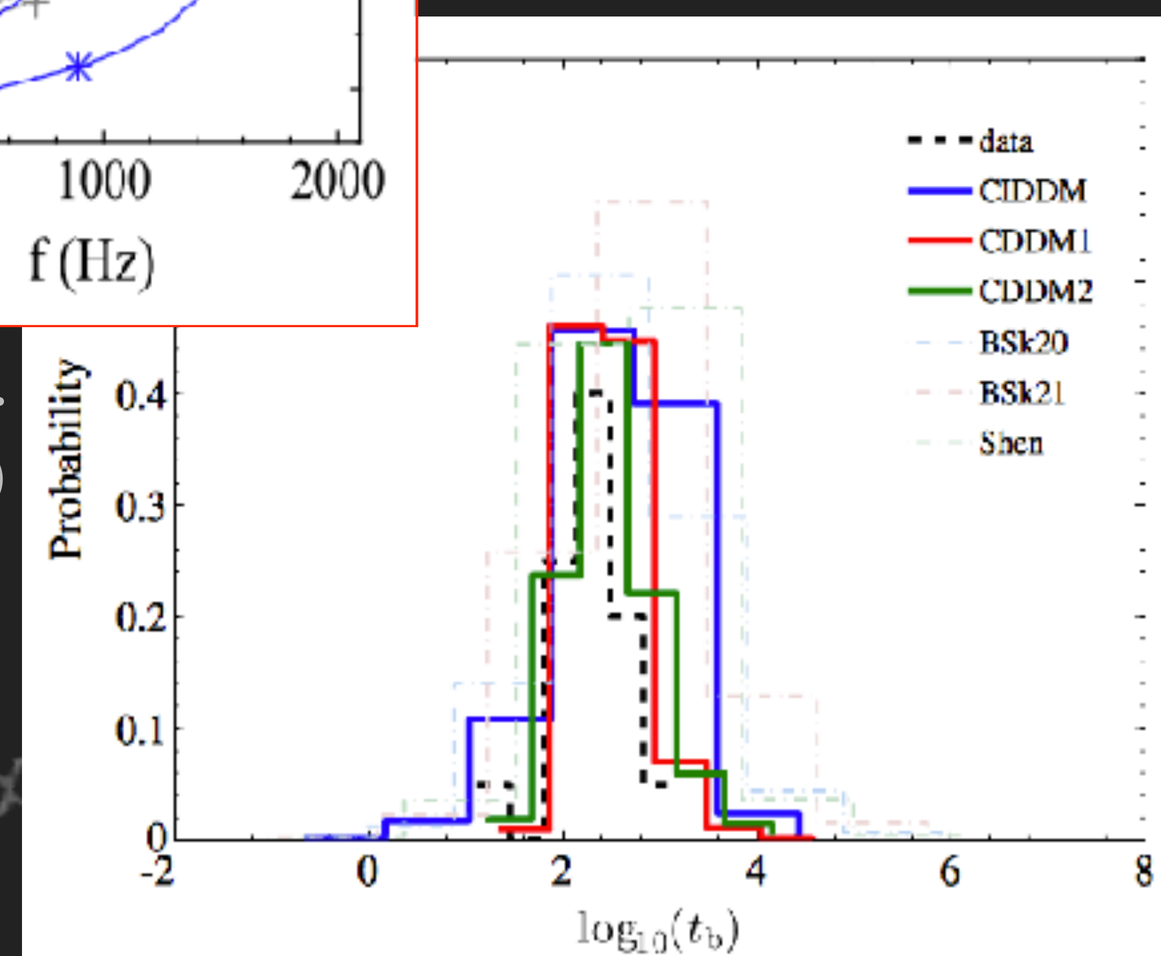
Drago et al. (2016)

quark stars?



Ravi & PL (2014)



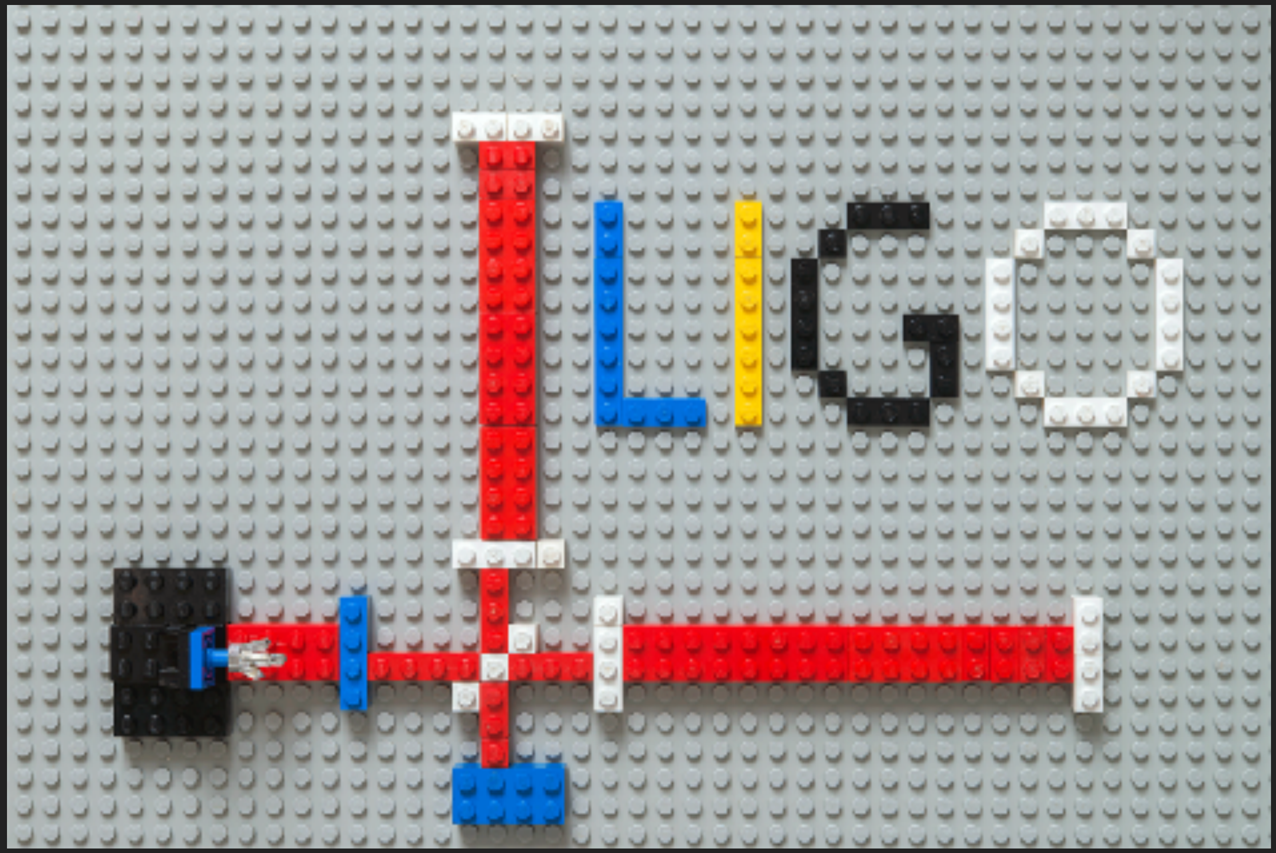


Li et al. (2016)

quark stars?

CONCLUSIONS

- rich physics of post-merger remnants not well understood
- potential for multi-messenger analysis:
  - radio, optical, x ray, gamma ray
  - gravitational wave



OPEN CHALLENGES FOR DETECTION

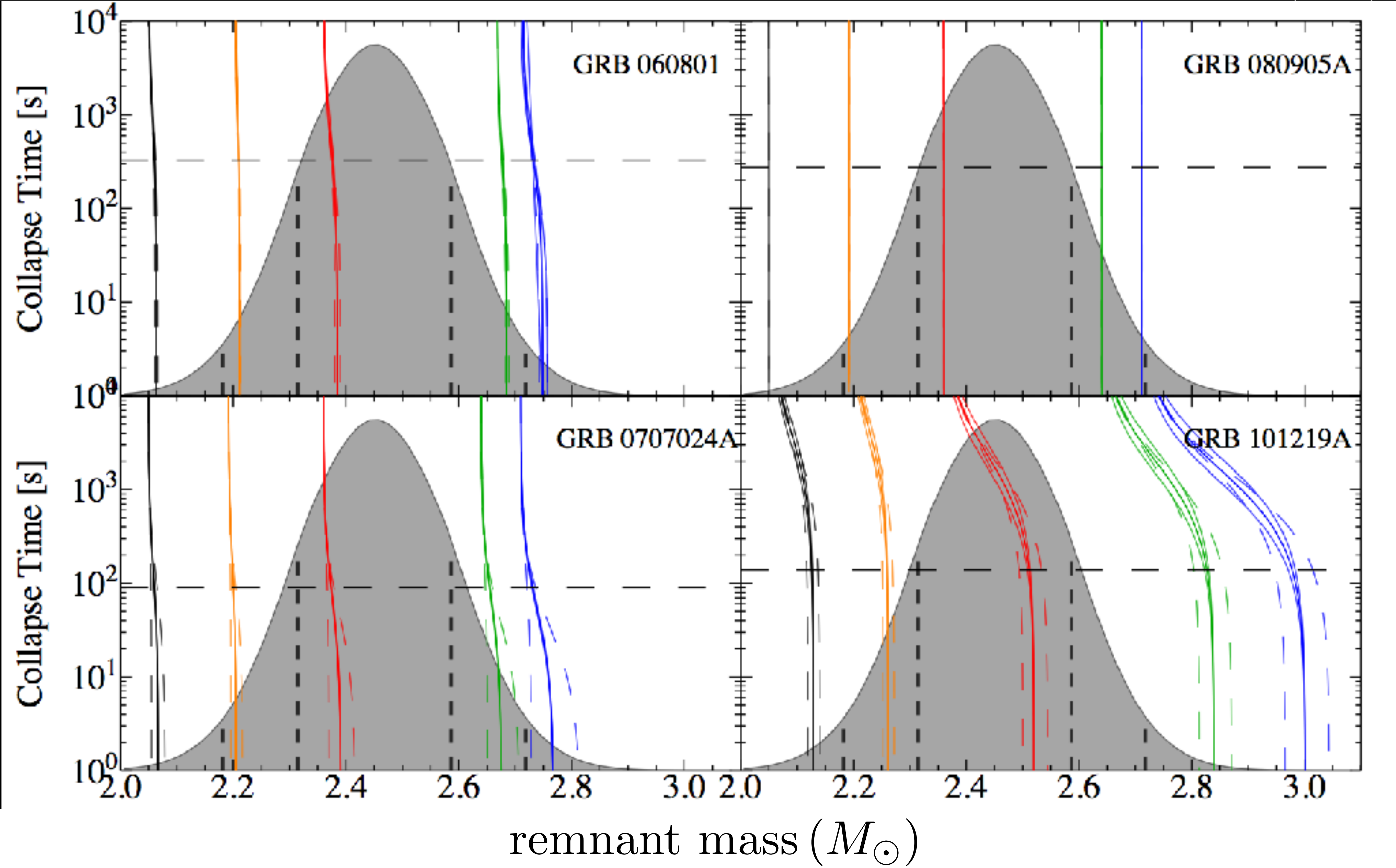
- data-analysis algorithms
  - many developed, and looking.
  - can get better sensitivity if we have better models!
- Binary neutron star simulations:
  - numerical convergence?
  - dissipative effects?
  - magnetic fields under-resolved/not understood,
  - …

OPEN CHALLENGES FOR DETECTION

- data-analysis algorithms
  - many developed, and looking.
  - can get better sensitivity if we have better models!
- Understanding the physics
  - What B-field do we get?
  - Does the spin flip happen, Ian? Timescale?
  - Are bar modes, r-modes relevant?
- We need better detectors….

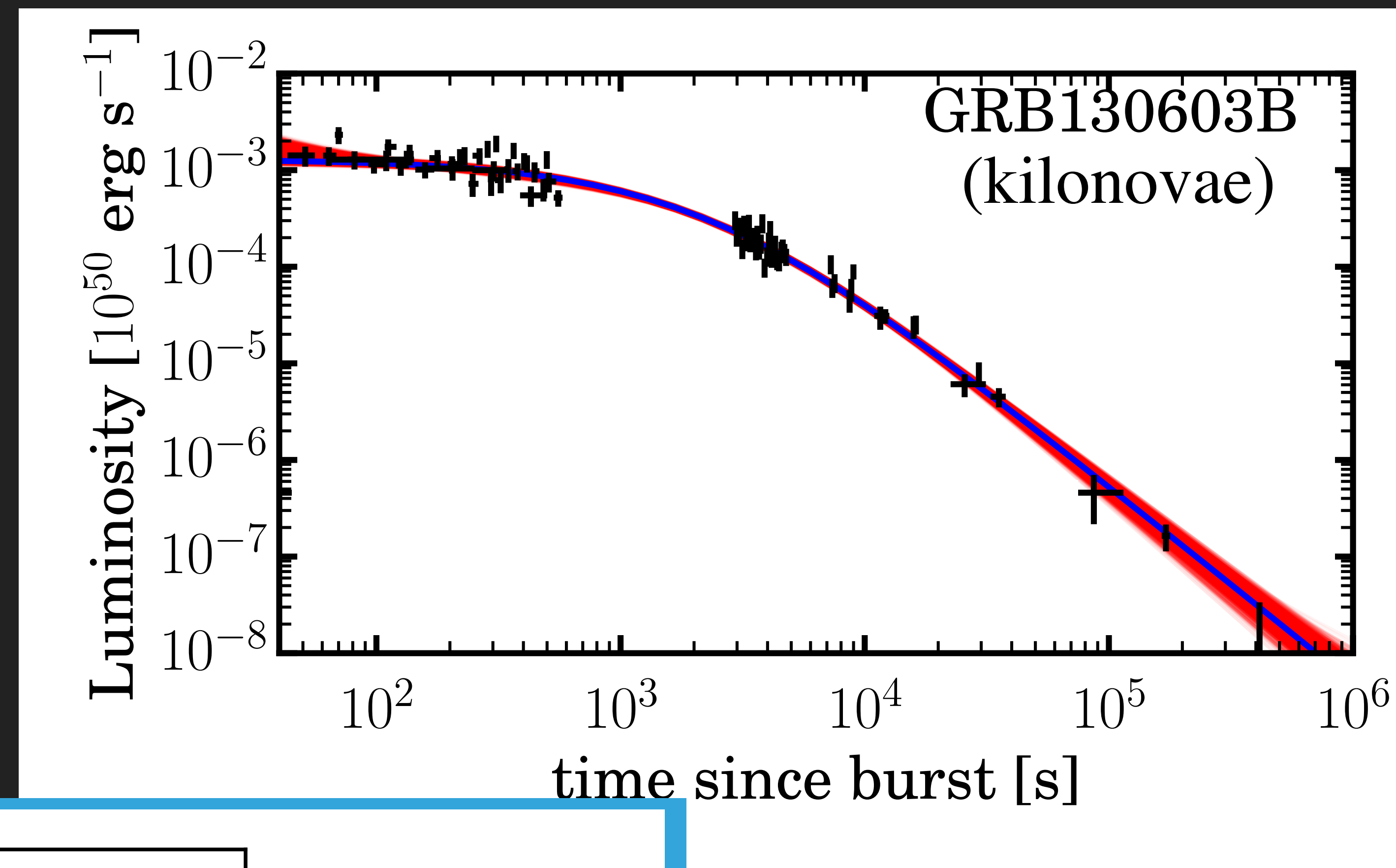
EXTRA SLIDES

PL et al (2014)


GRB 060801
GRB 080905A
GRB 0707024A
GRB 101219A
Collapse Time [s]
Collapse Time [s]
10^4
10^3
10^2
10^1
10^0
2.0
2.2
2.4
2.6
2.8
3.0
remnant mass $(M_\odot)$

Can constrain GW emission from X-ray observations

$$\dot{\Omega} \propto \Omega^n$$



PL+ 2017