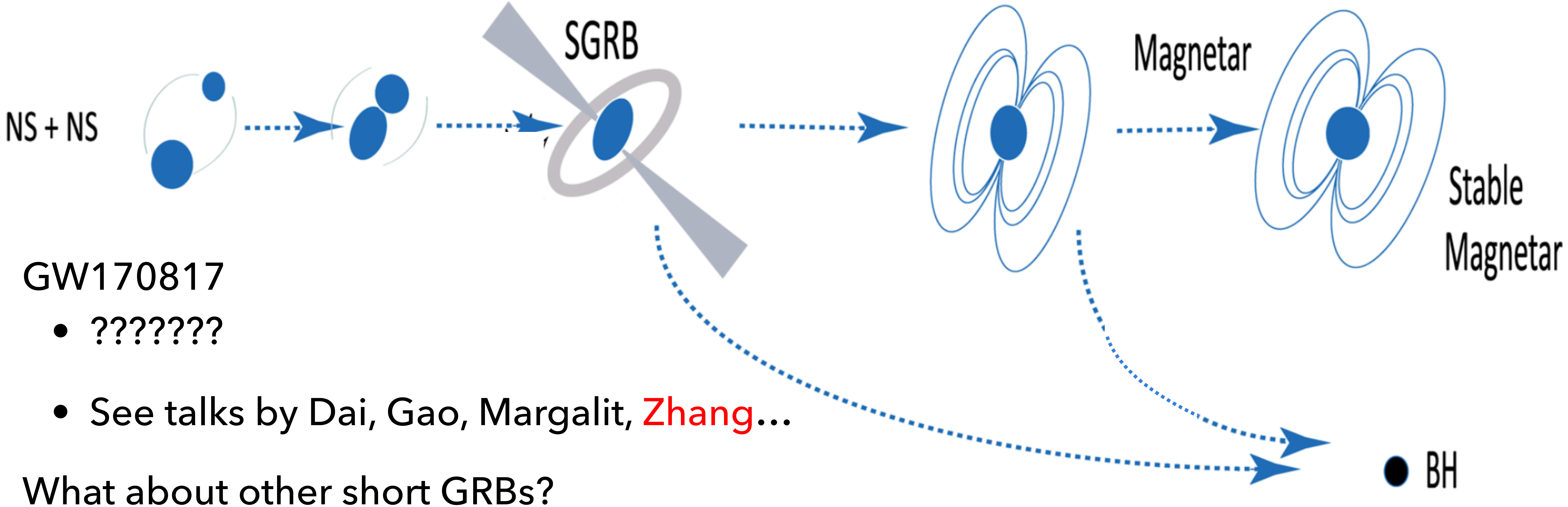
MONASH University

OzGrav

ARC Centre of Excellence for Gravitational Wave Discovery

PAUL LASKY

NEUTRON STAR MERGER REMNANTS

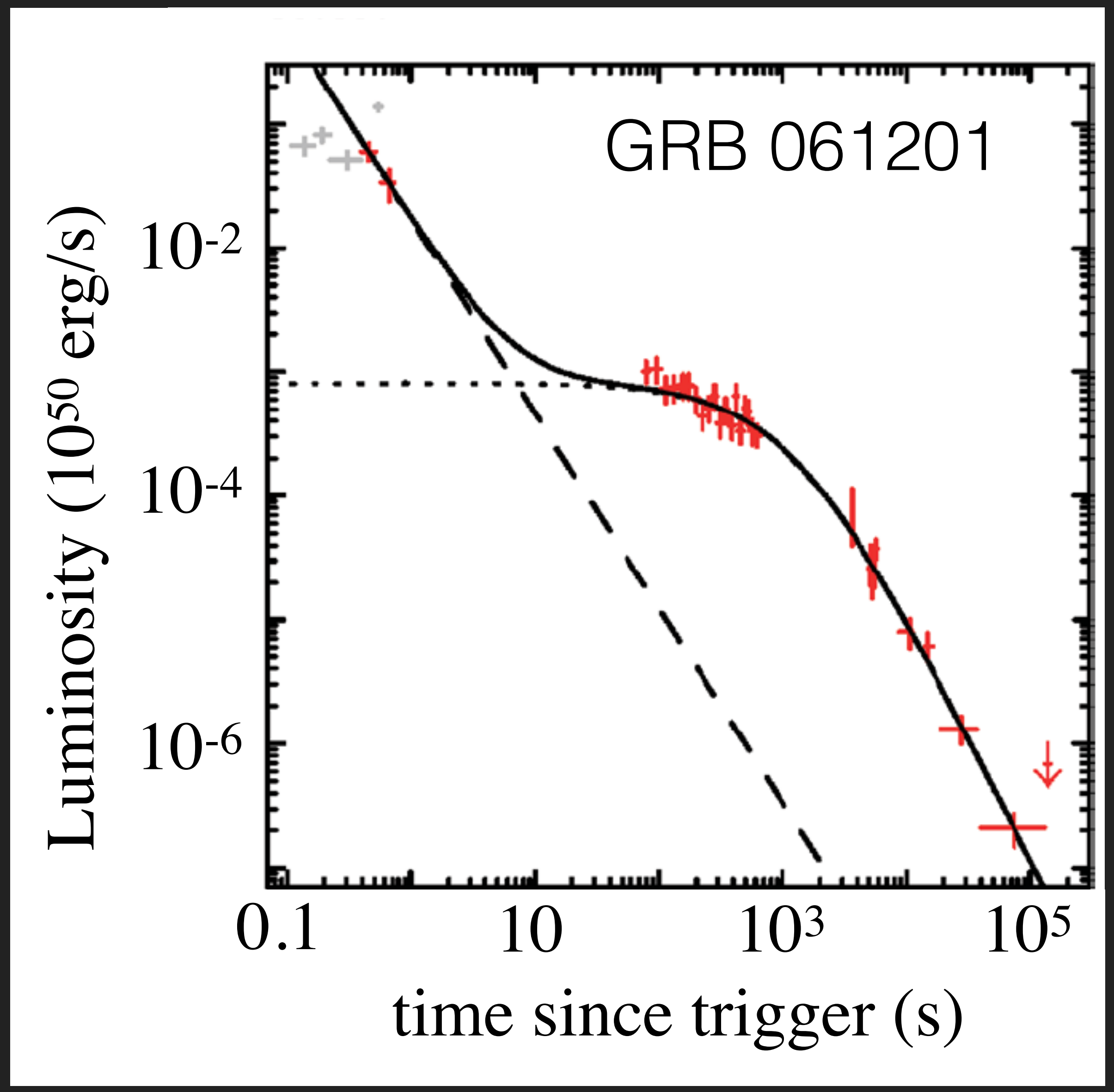


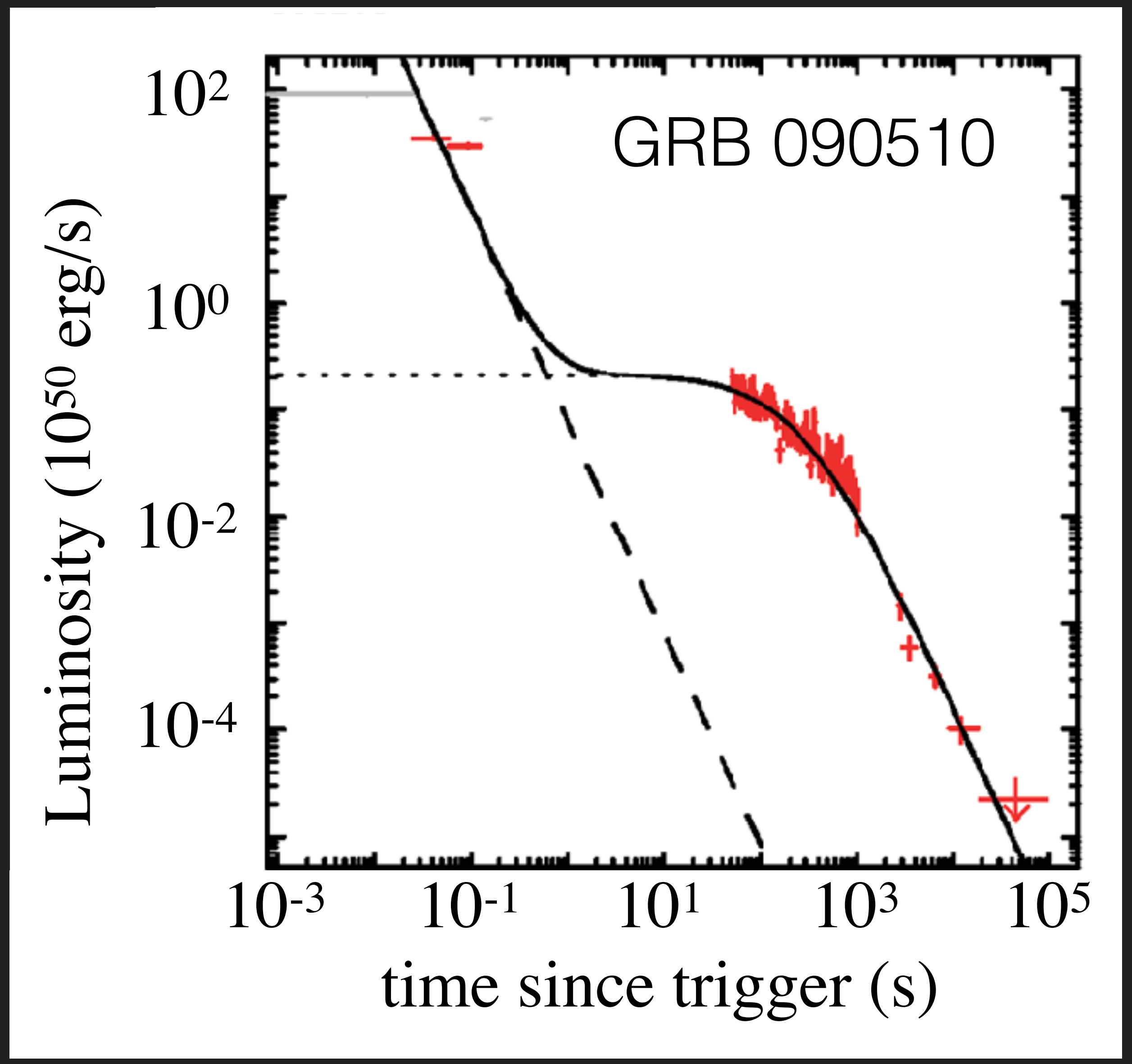
GW170817

- ???????
- See talks by Dai, Gao, Margalit, Zhang…

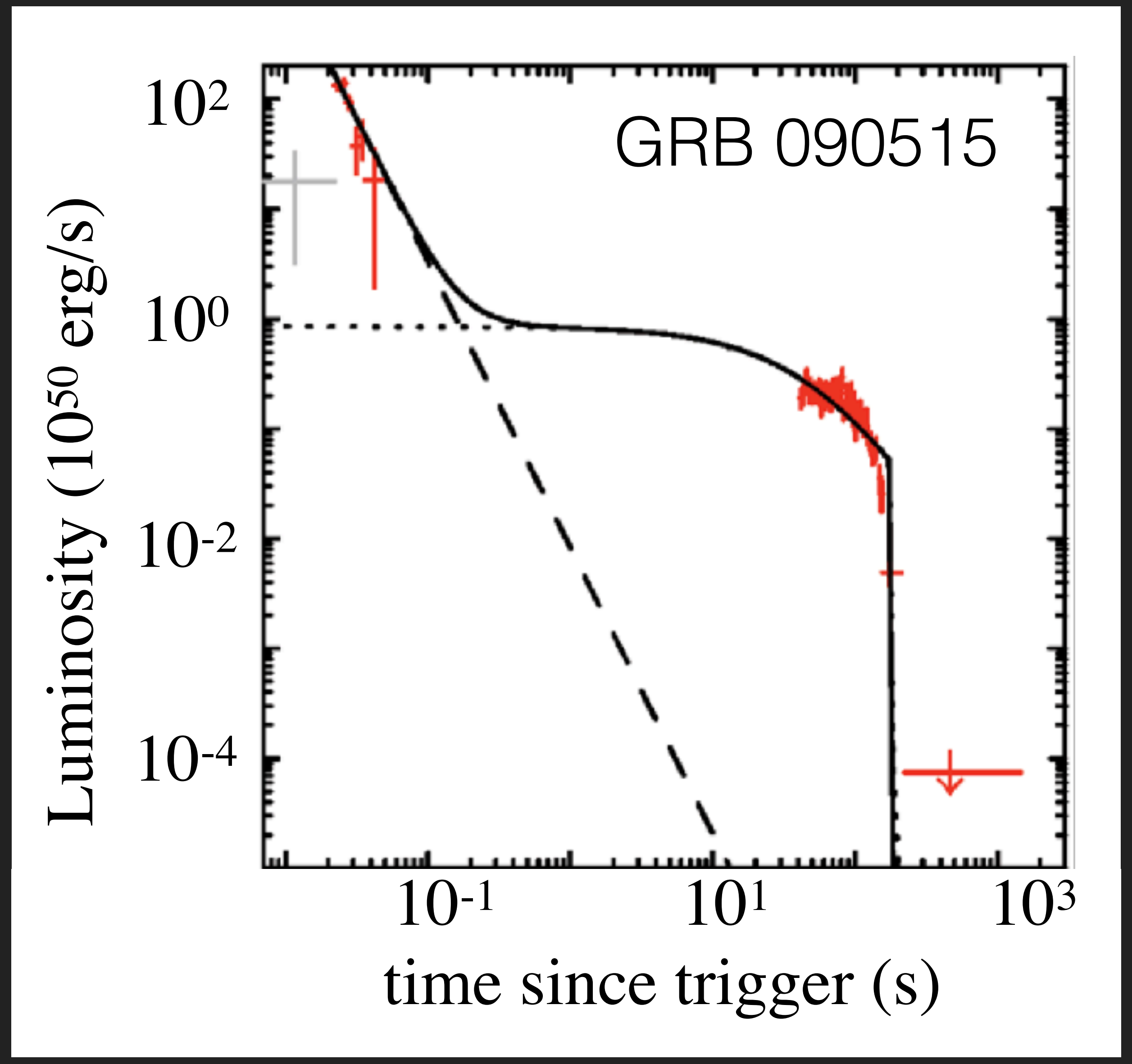
What about other short GRBs?

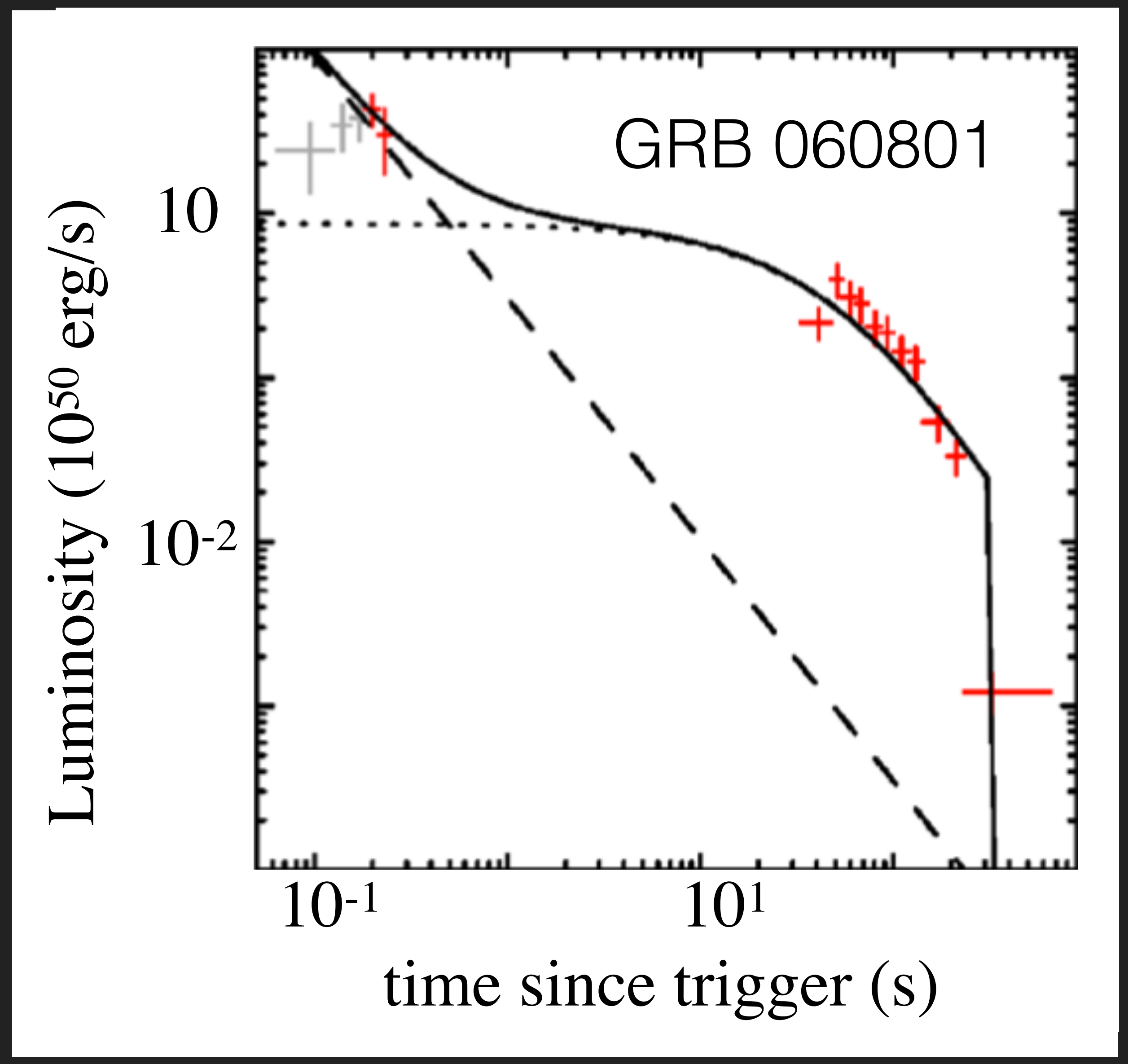
Adapted from Chu+2016





Rowlinson+2013

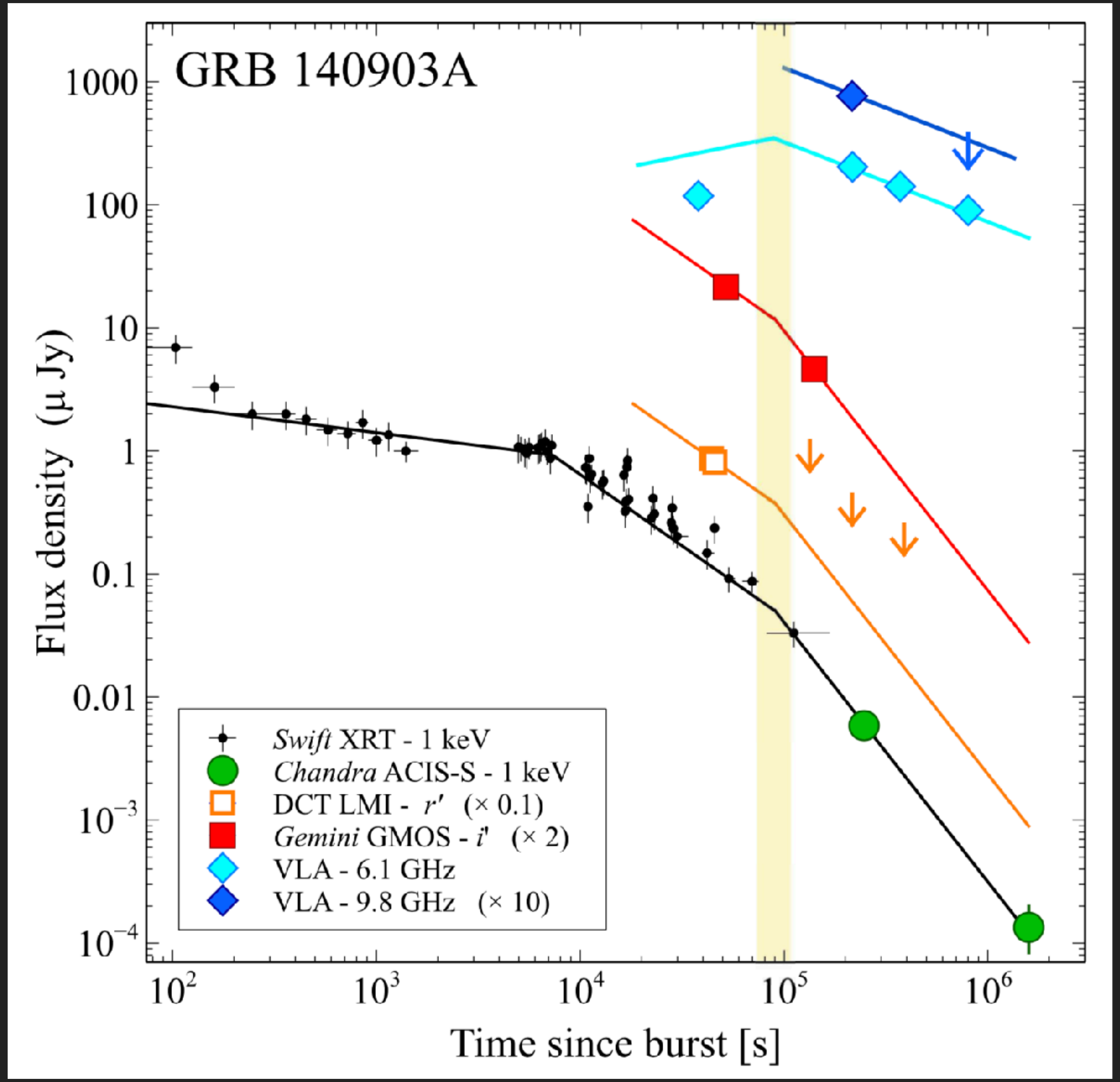




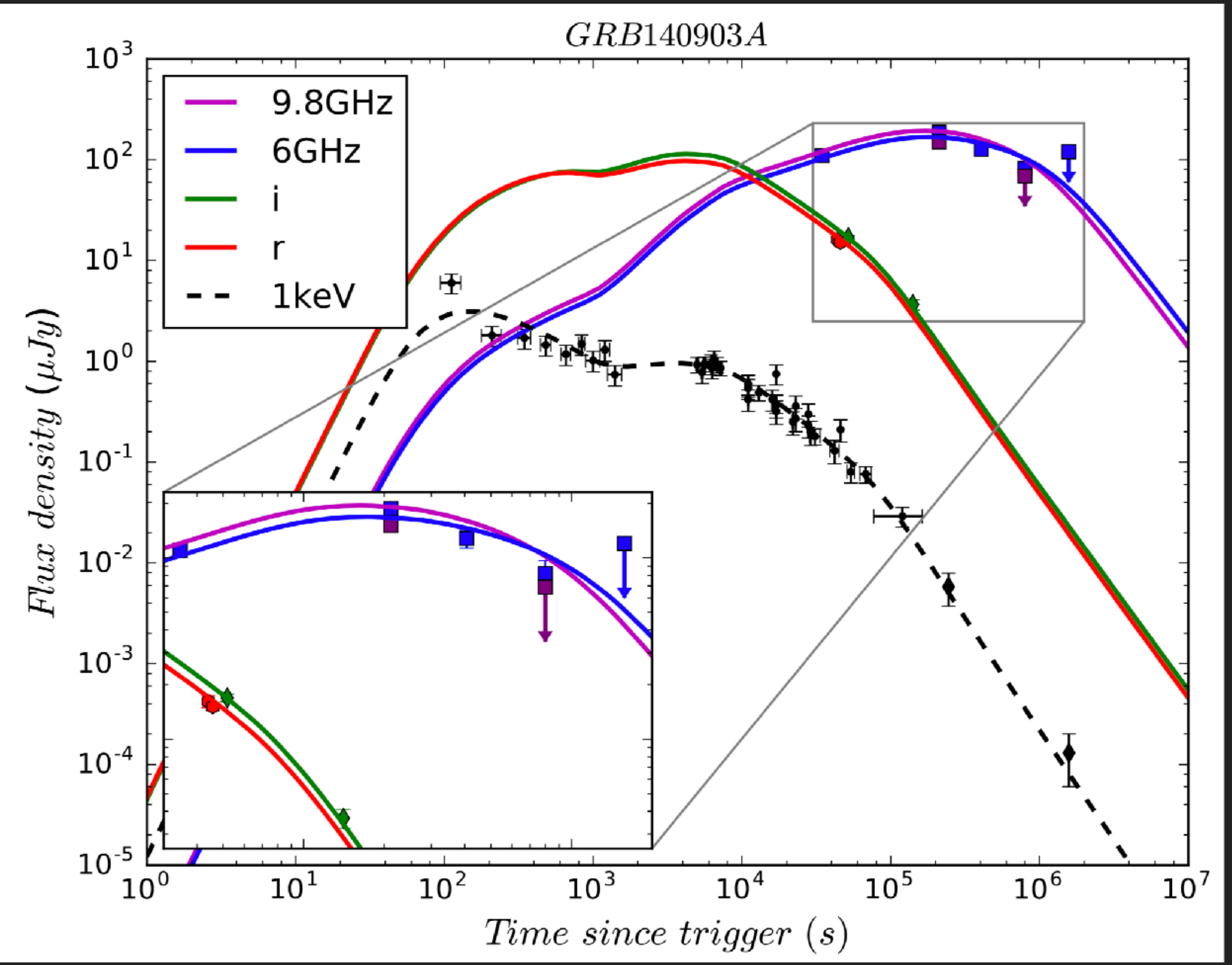
- large sample (~25) of short GRBs with x-ray plateaus (see also Lü+2015)
- fit millisecond magnetar model
  - (Zhang & Meszaros 2001)

But are these really neutron stars born in binary mergers?

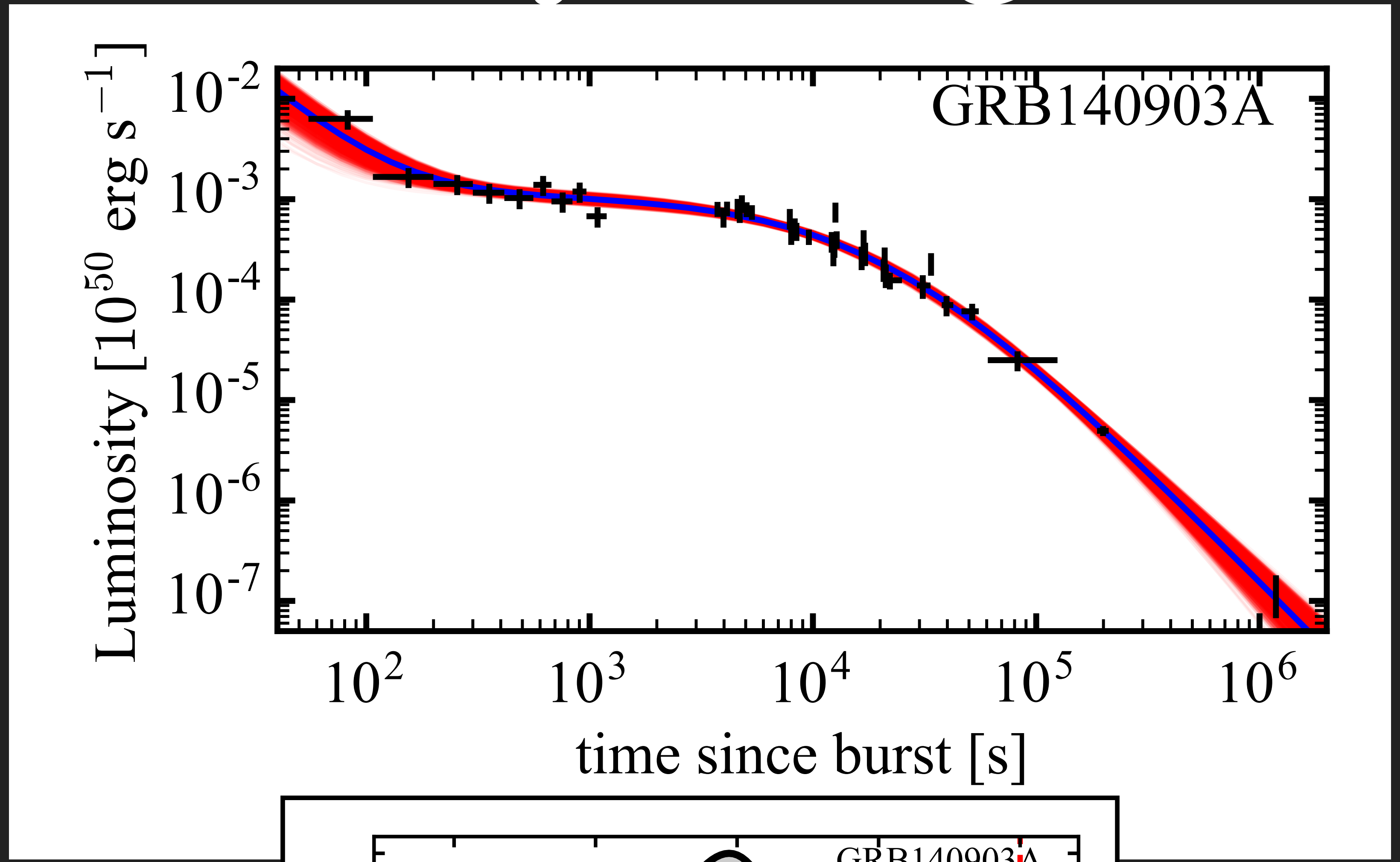
GRB140903A - a case study

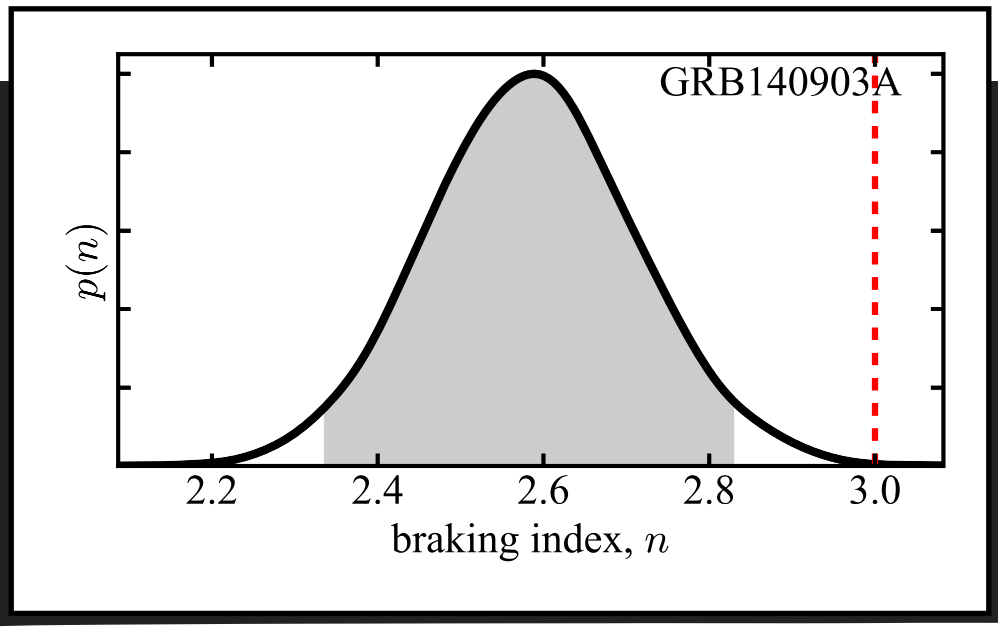


Troja+2016
energy injection not required



Zhang+2017
energy injection fits nicely
standard ms magnetar





PL+2017
energy injection fits nicely
generalised ms magnetar

But are these really neutron stars born in binary mergers?

GRB140903A - a case study

<u>Bayesian model selection!</u>

Sarin, PL, Ashton (2019)

$$\text{Bayes factor} = \frac{\text{evidence for magnetar}}{\text{evidence for fireball}}$$

But are these really neutron stars born in binary mergers?

GRB140903A - a case study

Bayesian model selection!

Sarin, PL, Ashton (2019)

$$\text{Bayes factor} = \frac{\text{evidence for magnetar}}{\text{evidence for fireball}}$$

$$= 1713!$$

But are these really neutron stars born in binary mergers?

GRB140903A - a case study

<u>Bayesian model selection!</u>

Sarin, PL, Ashton (2019)

$$\text{Bayes factor} = \frac{\text{evidence for magnetar}}{\text{evidence for fireball}}$$

$$= 1713!$$

the magnetar model is ~1700 times more likely, assuming both hypotheses are equally likely a priori

But are these really neutron stars born in binary mergers?

GRB140903A - a case study

<u>Bayesian model selection!</u>

Sarin, PL, Ashton (2019)

prior odds

$$\text{the odds} = \frac{\text{evidence for magnetar}}{\text{evidence for fireball}} \times \frac{\text{our prior believe that a magnetar exists}}{\text{our prior belief that a fireball exists}}$$

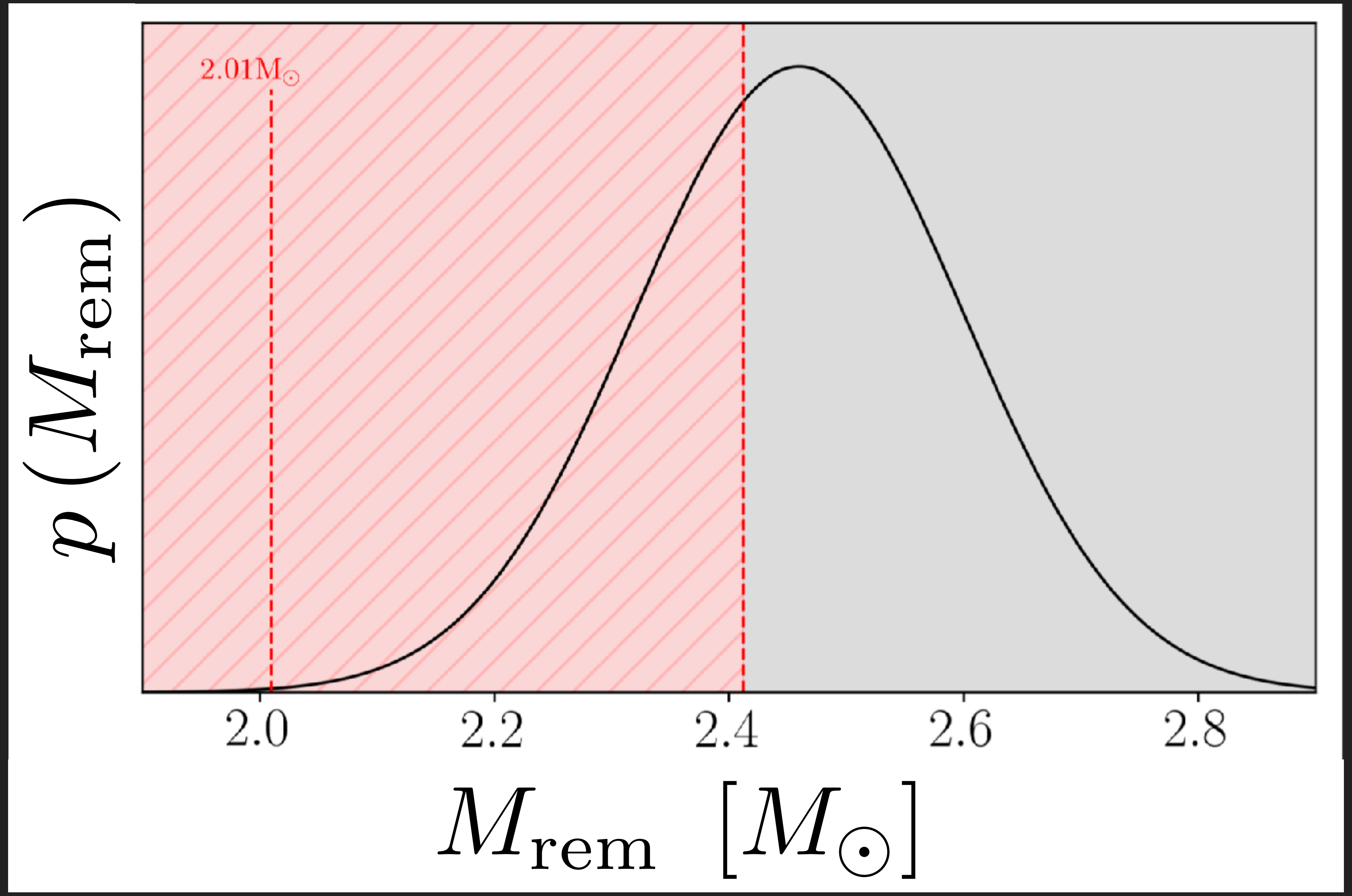
But are these really neutron stars born in binary mergers?

GRB140903A - a case study

<u>Bayesian model selection!</u>

Sarin, PL, Ashton (2019)

$$\text{prior odds} = \int_0^{M_{\mathrm{TOV}}} p\left(M_{\mathrm{rem}}\right) dM_{\mathrm{rem}}$$



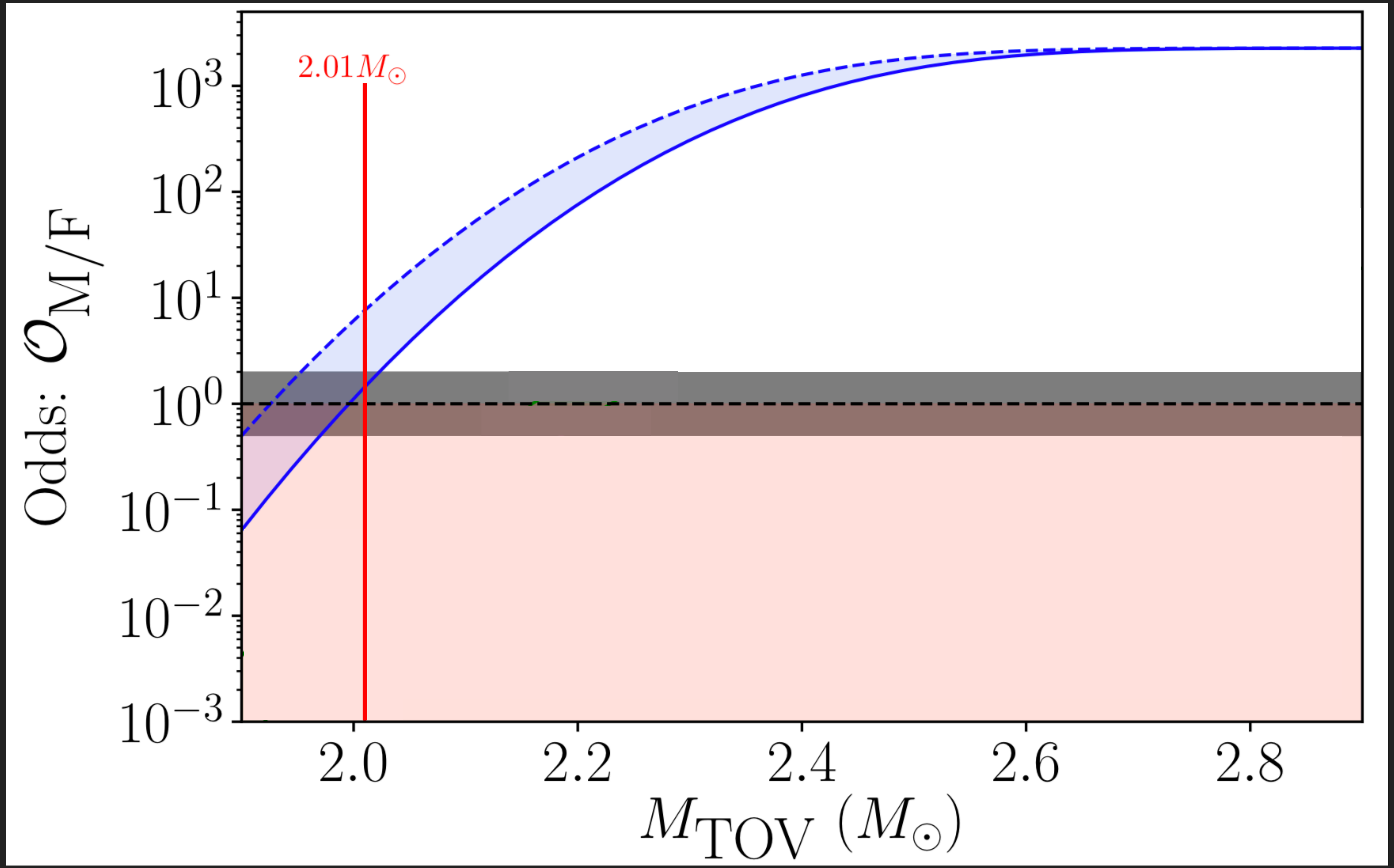
- magnetar model requires supramassive or stable neutron star
- use galactic mass distribution of double neutron star systems
  - combine and conserve rest mass (PL+ 2014)
- Odds becomes dependent on unknown TOV mass!

But are these really neutron stars born in binary mergers?

GRB140903A - a case study

Bayesian model selection!

Sarin, PL, Ashton (2019)



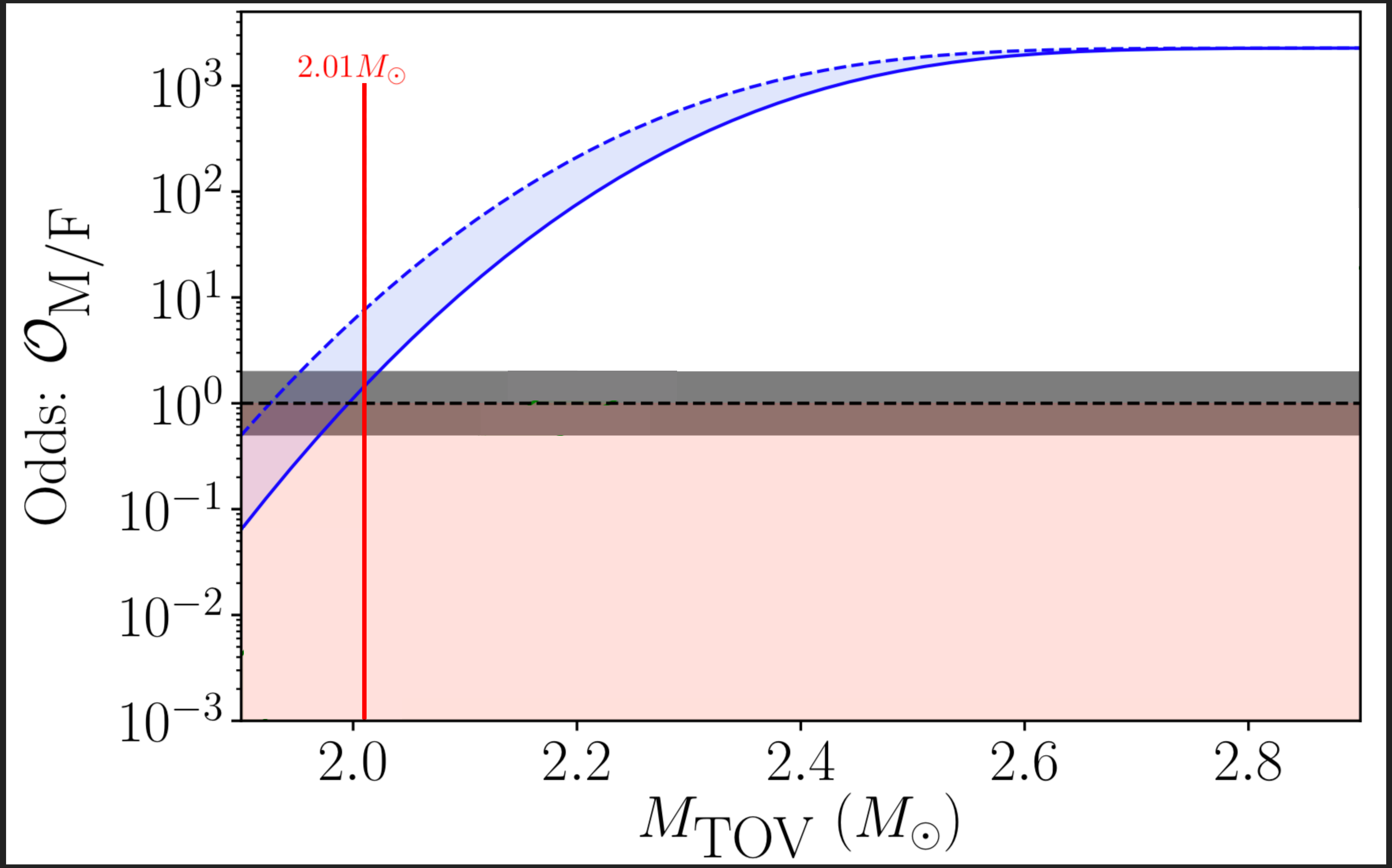
But are these really neutron stars born in binary mergers?

GRB140903A - a case study

<u>Bayesian model selection!</u>

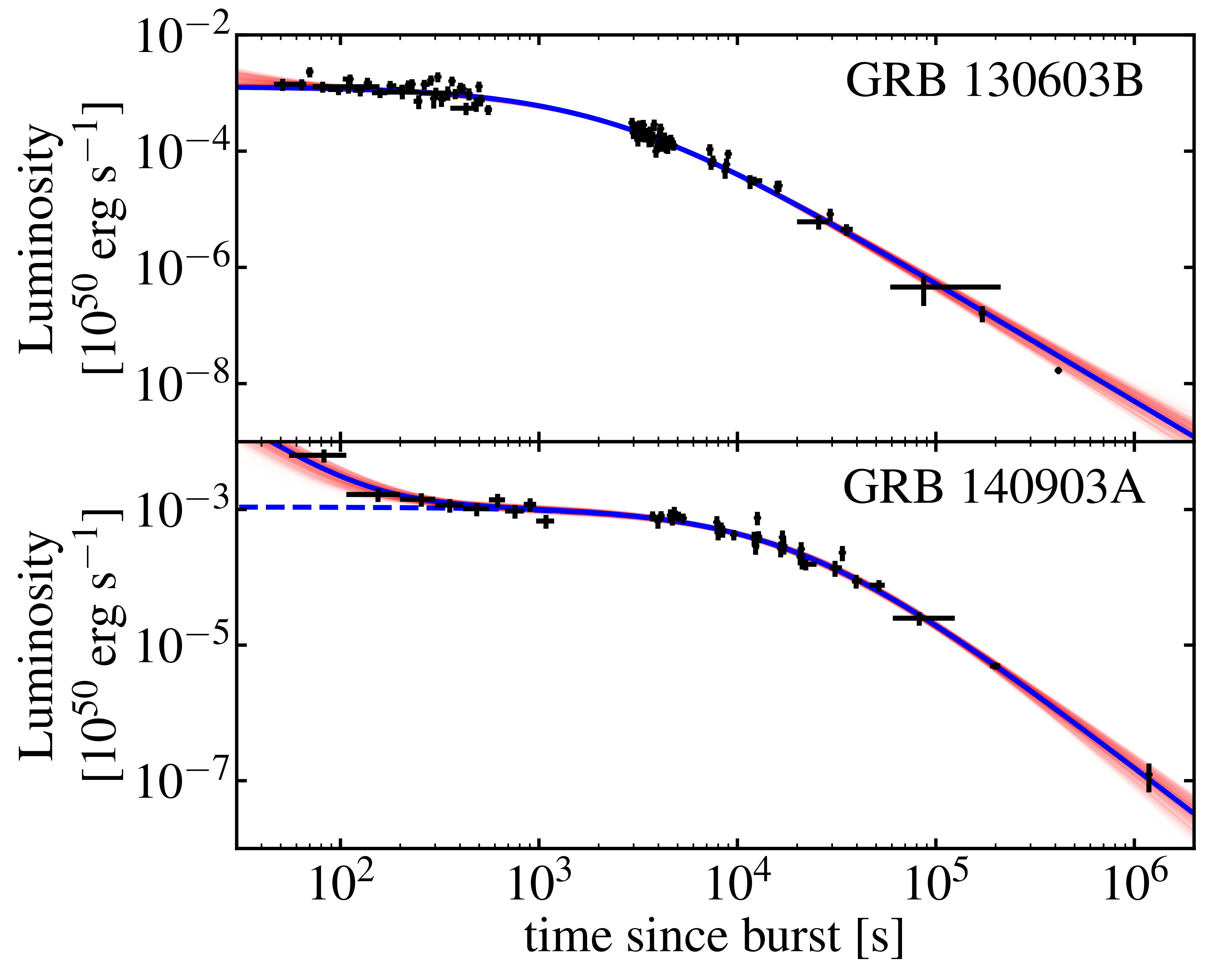
Sarin, PL, Ashton (2019)

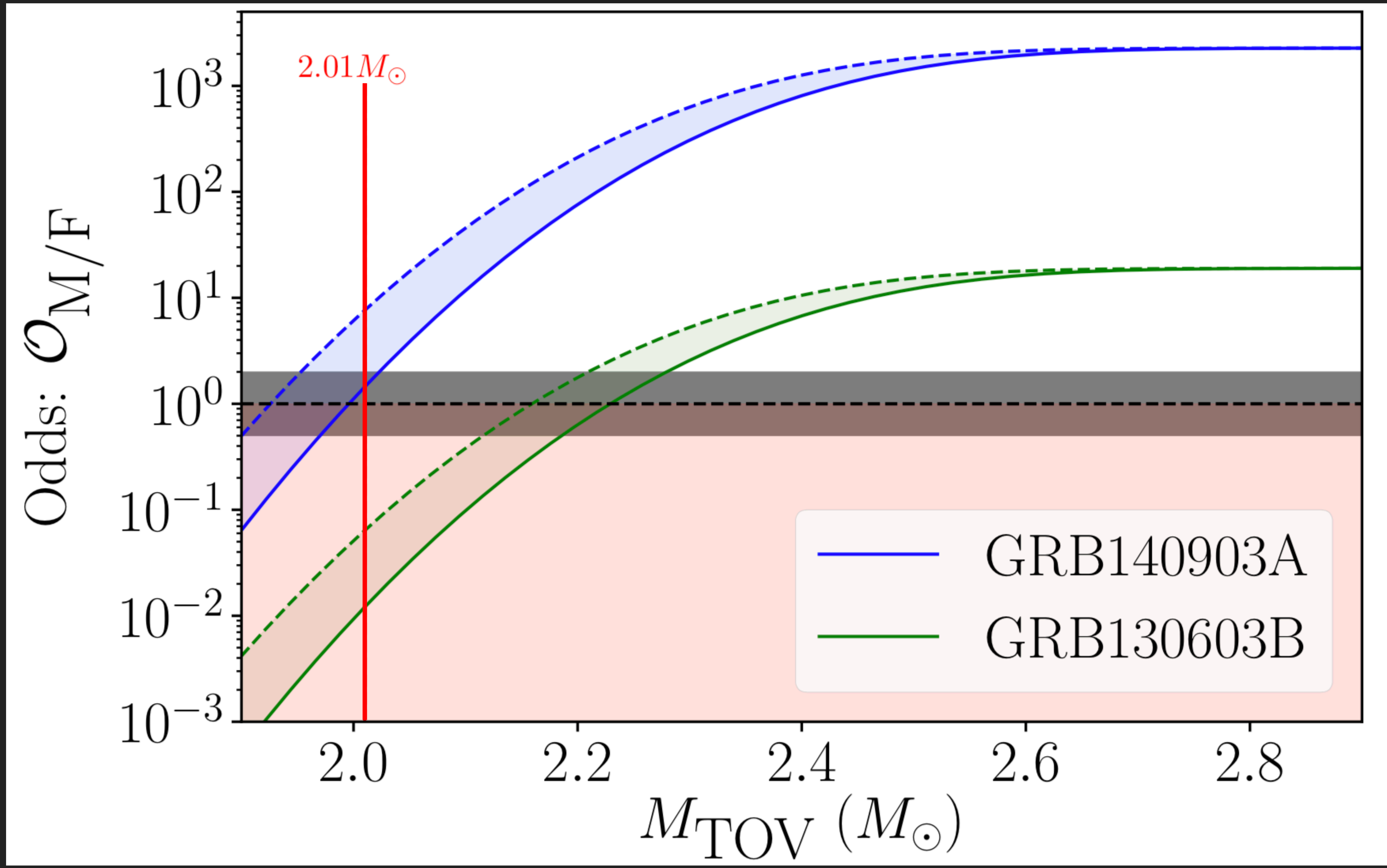
take-home message:
GRB140903A favours a magnetar model for **ALL** values of the TOV mass



But are these really neutron stars born in binary mergers?

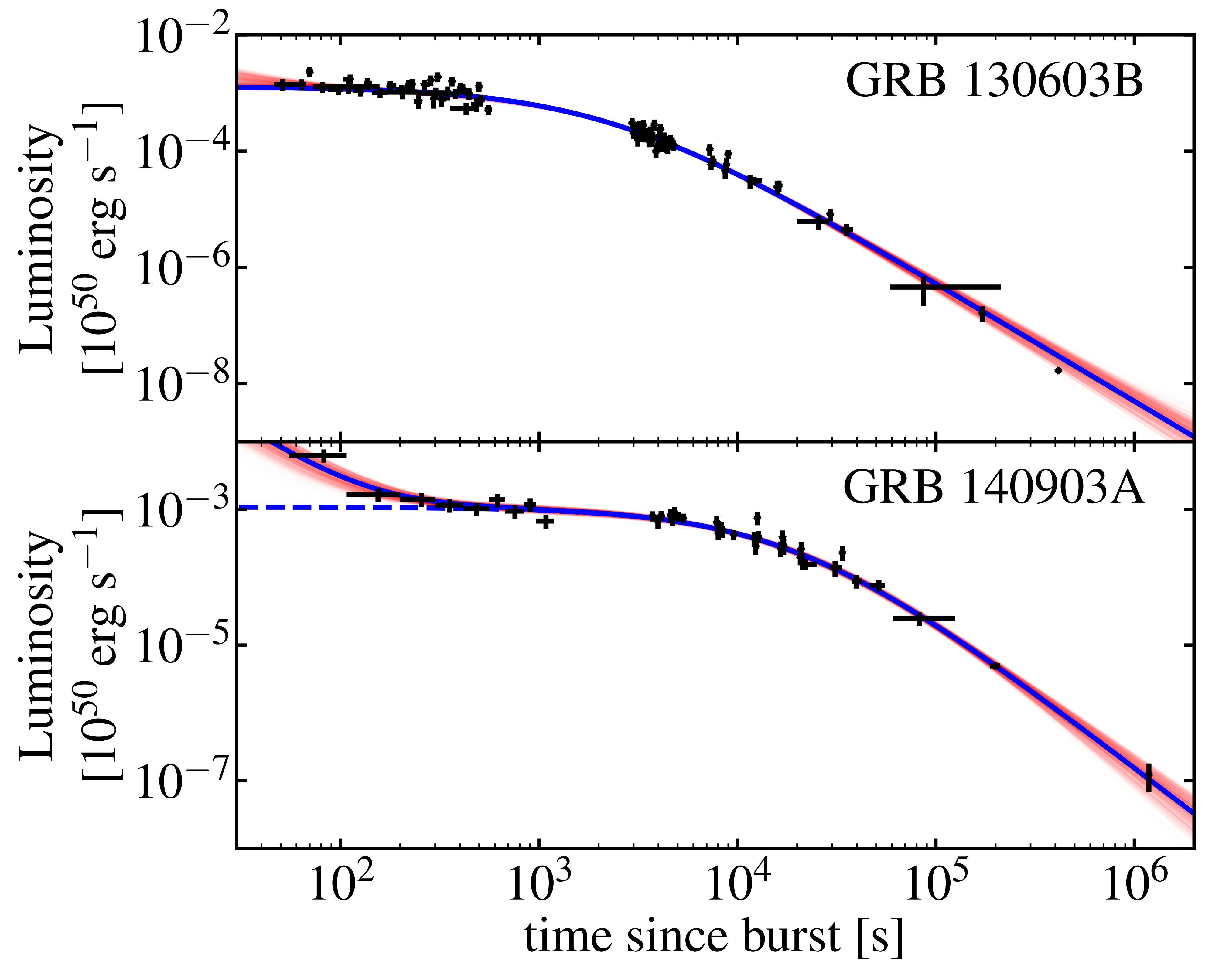
GRBs 140903A & 130603B

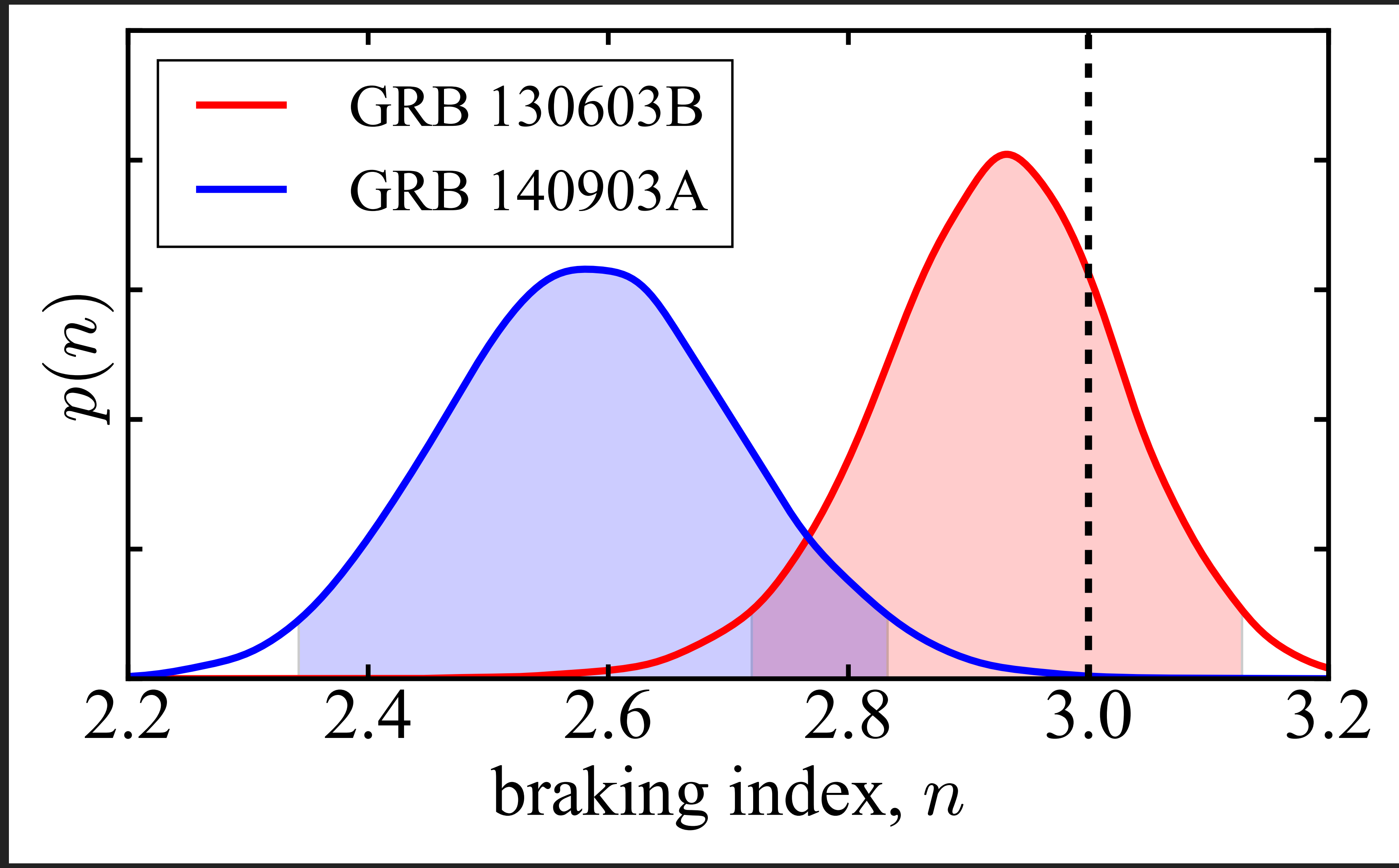


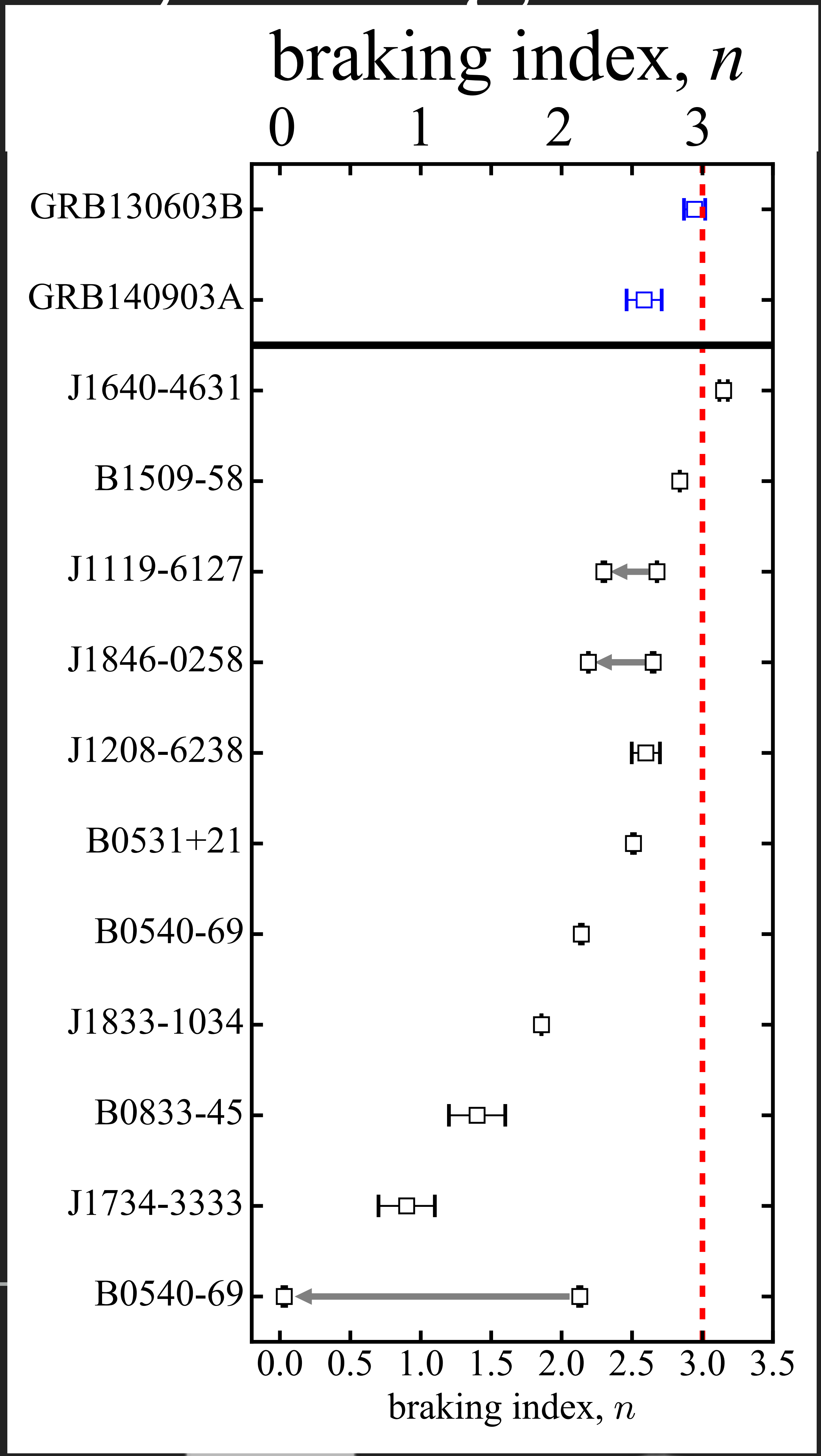


But are these really neutron stars born in binary mergers?

GRBs 140903A & 130603B

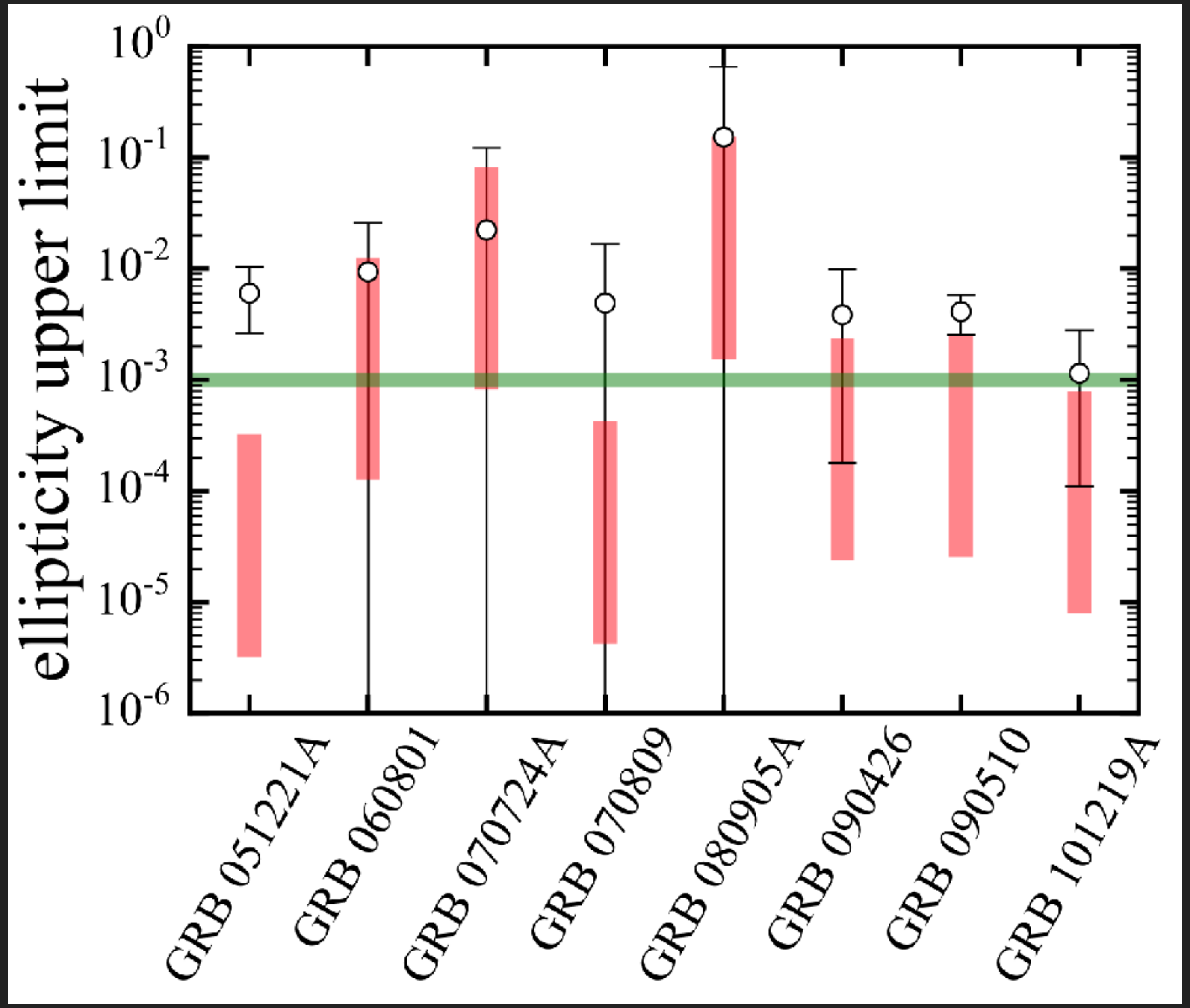




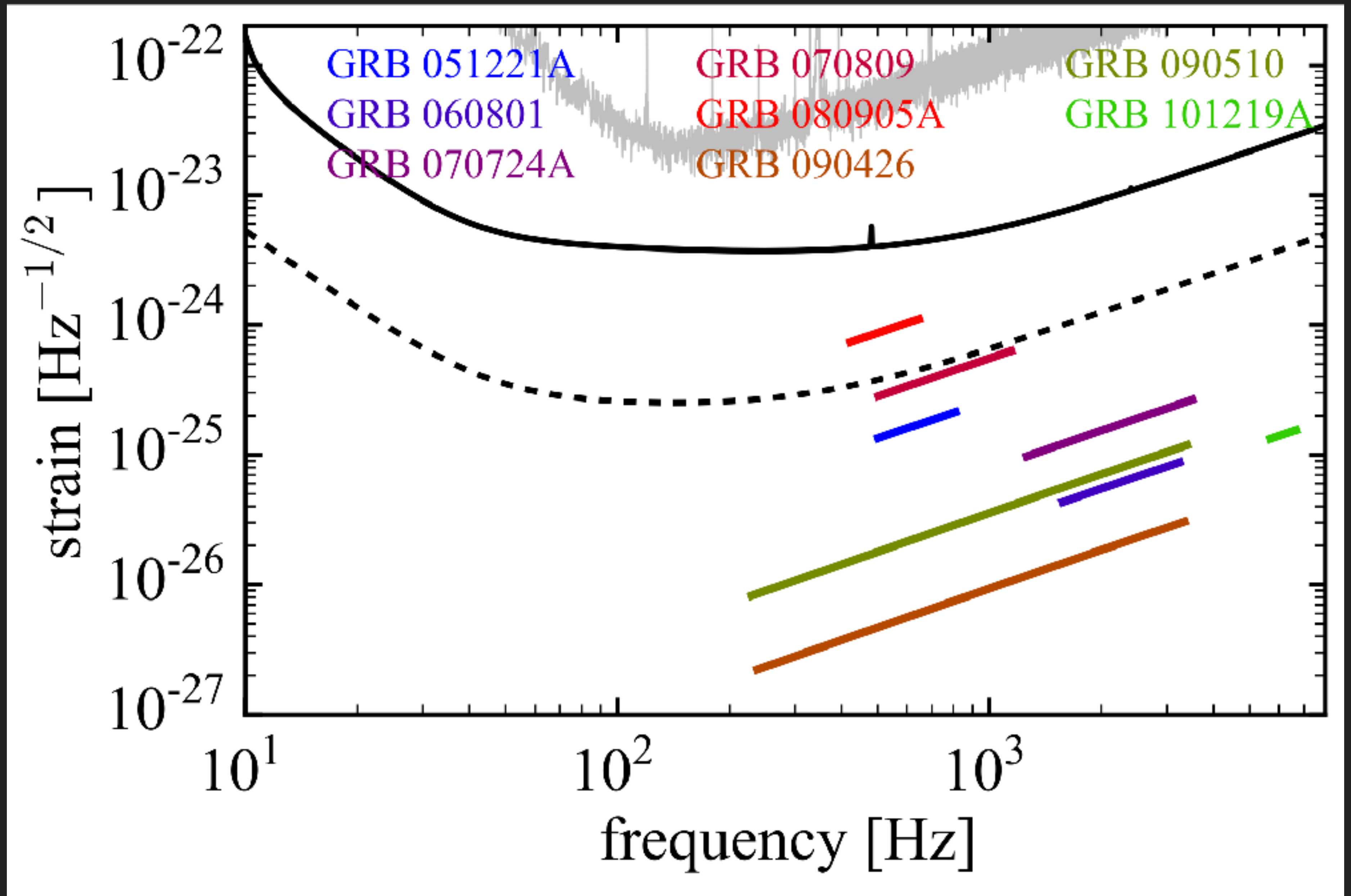


PL+2017

braking indices ≠ 5 can constrain gravitational-wave emission!



PL & Glampedakis 2016



- Pessimistic for detection anytime soon!
- “horizon distance” for:
  - aLIGO ~ 2Mpc
  - Einstein Telescope ~ 45 Mpc
  - (Sarin, PL, Ashton, Sammut 2018)

GW170817 - what did LIGO see?

GW170817 - what did LIGO see?

bugger all

(translation: nothing)

GW170817 - what did LIGO see?

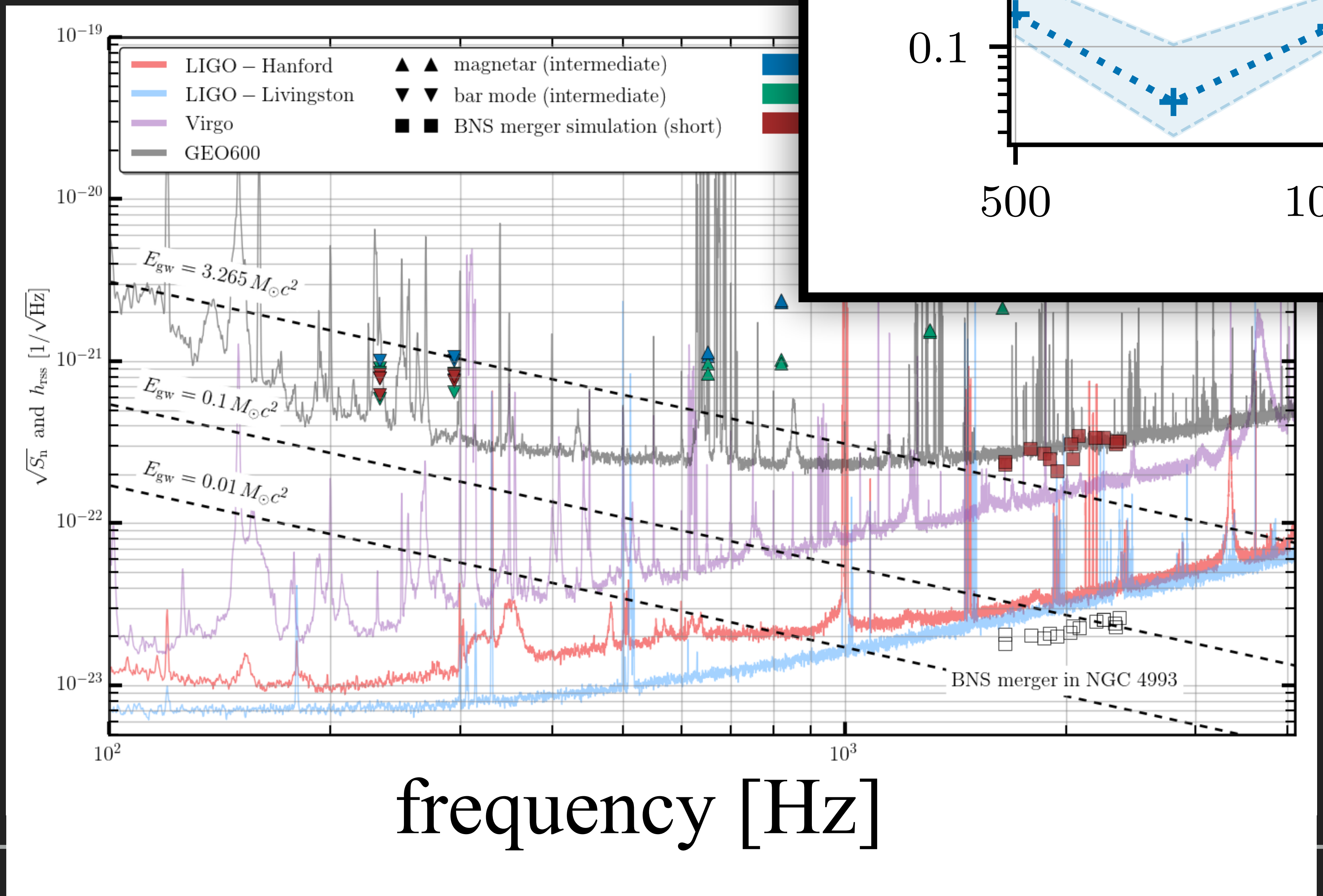
bugger all

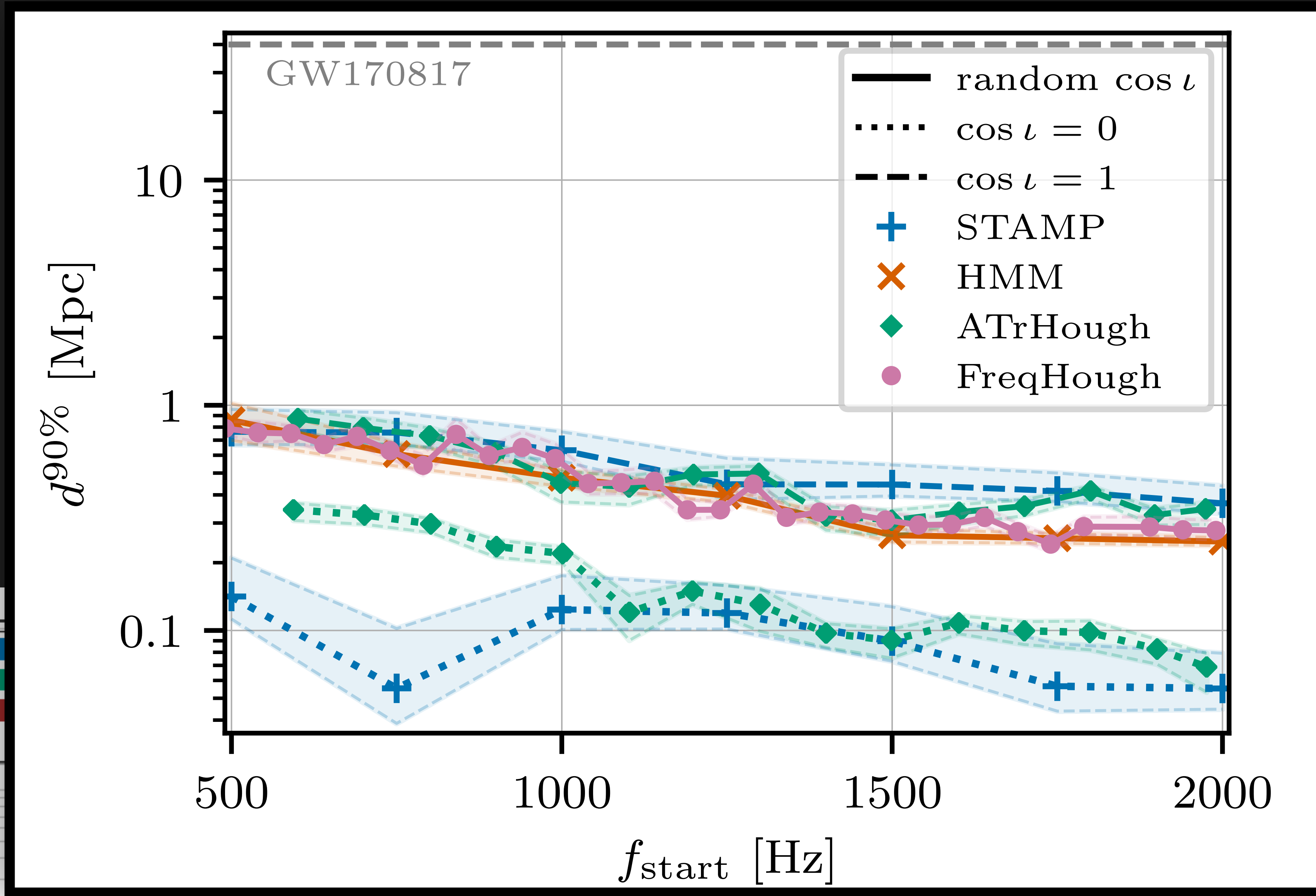
(translation: nothing)

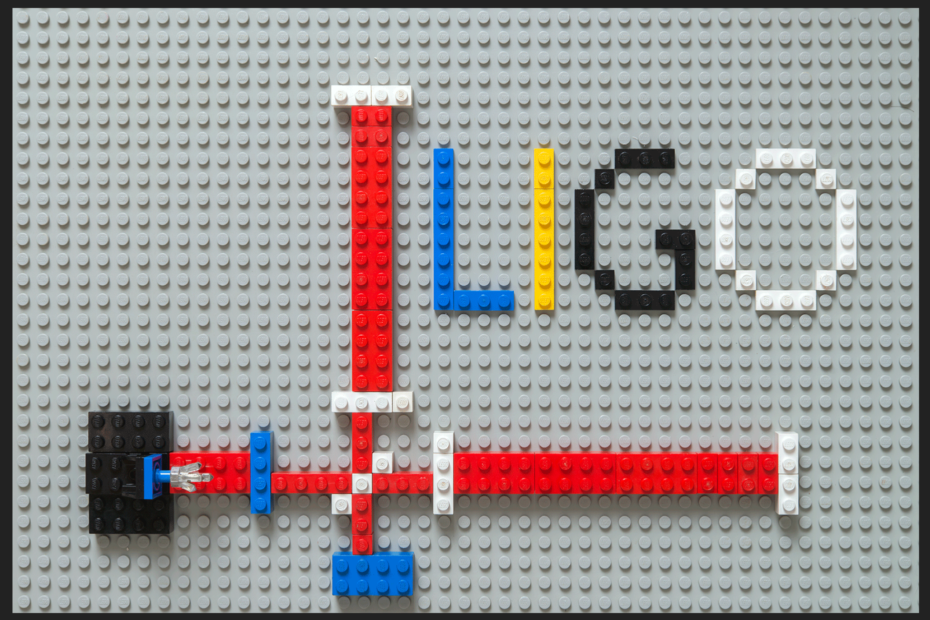
- I apologise sincerely for this figure being uninterpretable!

- In a fancy way, it says that we saw bugger all!

Abbott+2017, 2019



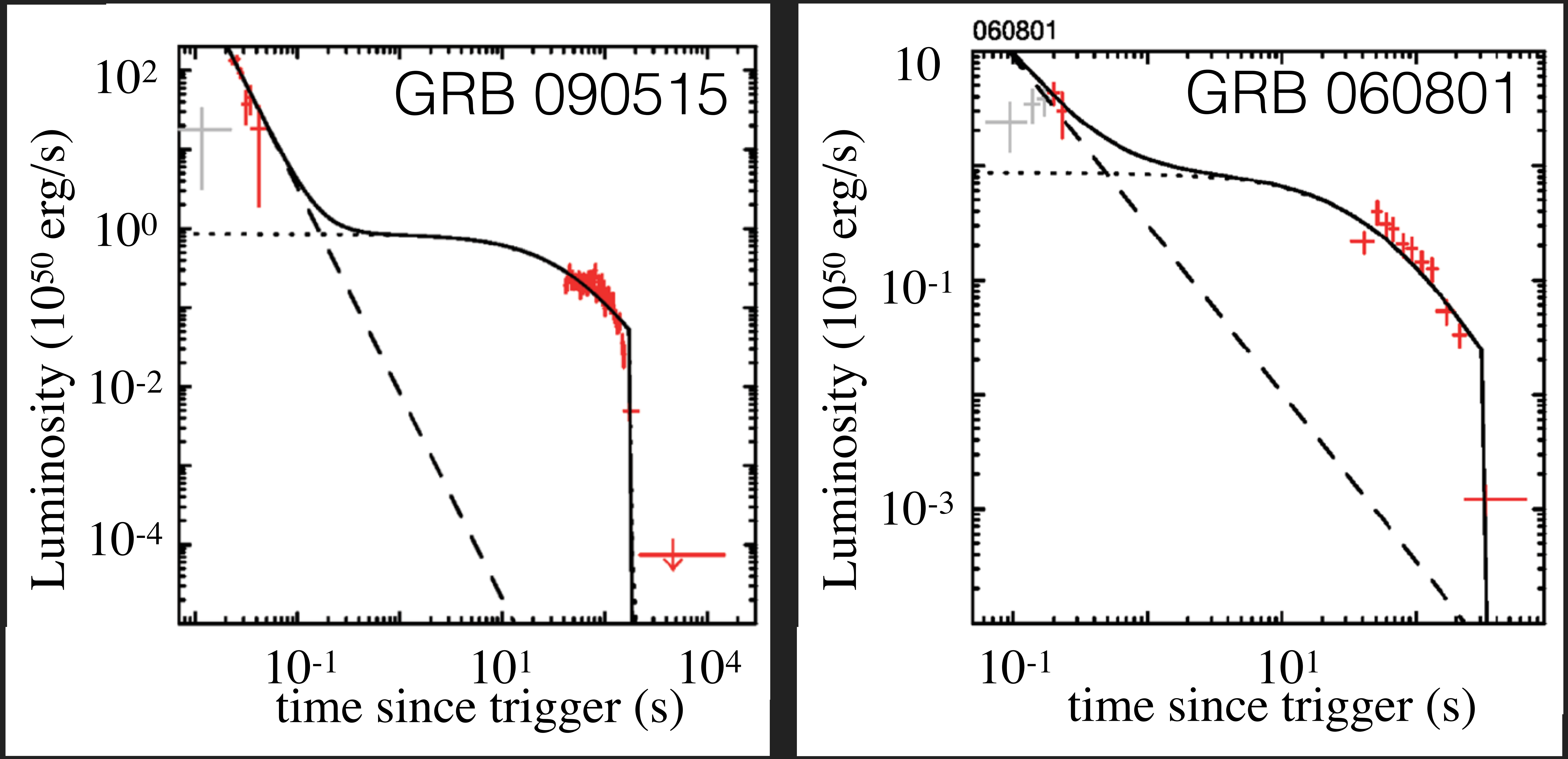




what about equation of state constraints?

See also talks by He Gao & Bing Zhang

Rowlinson+2013



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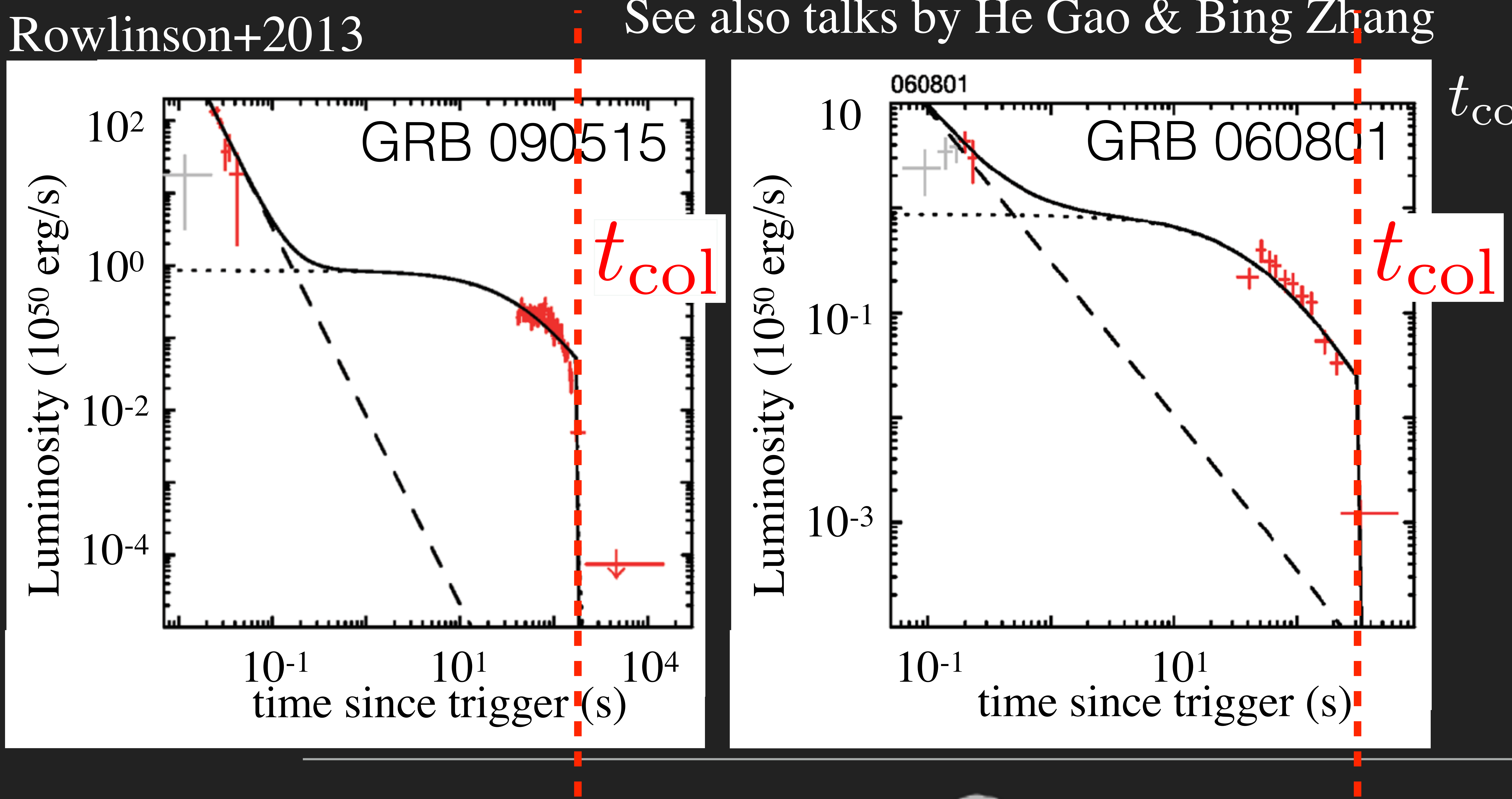
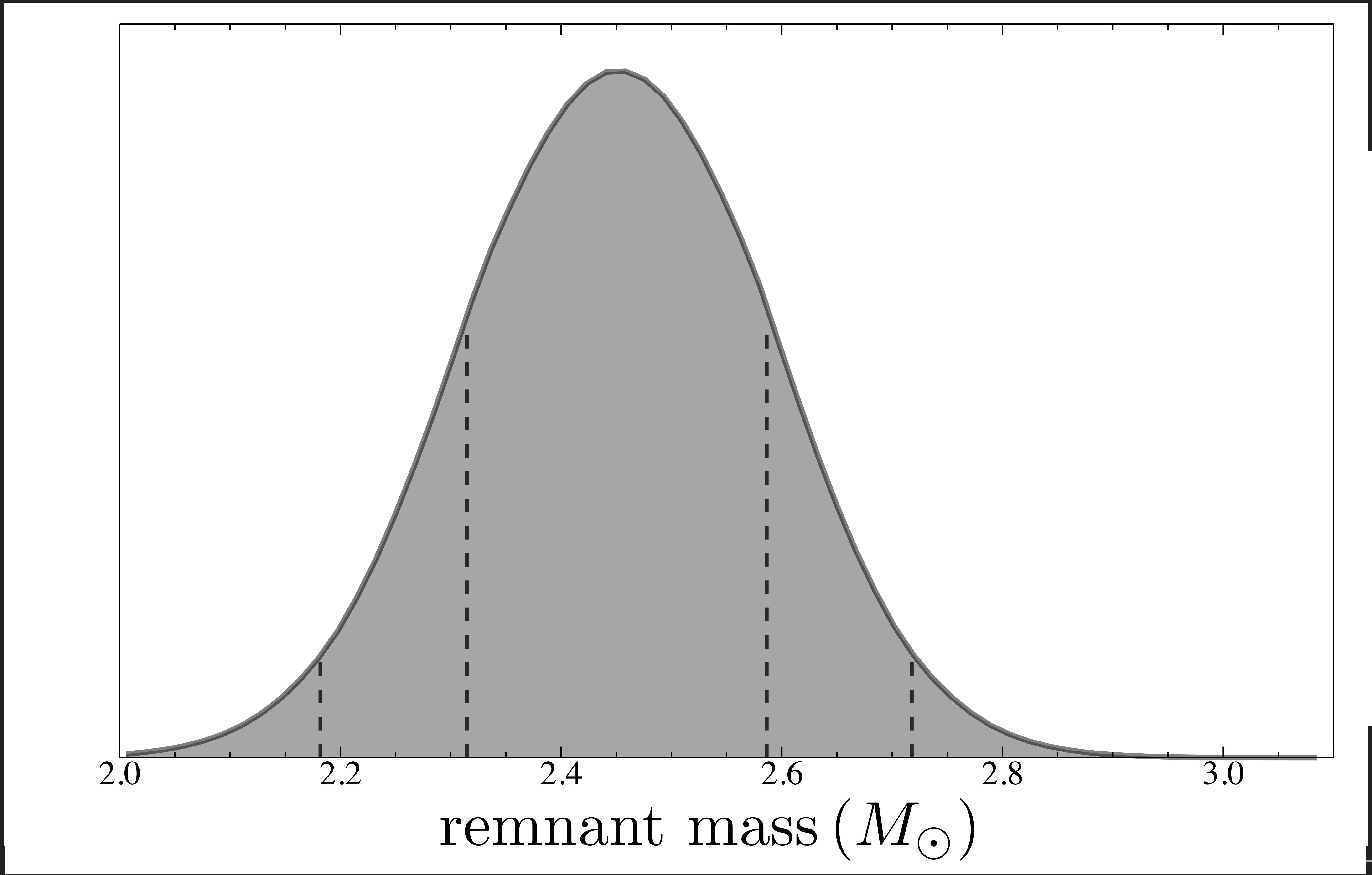


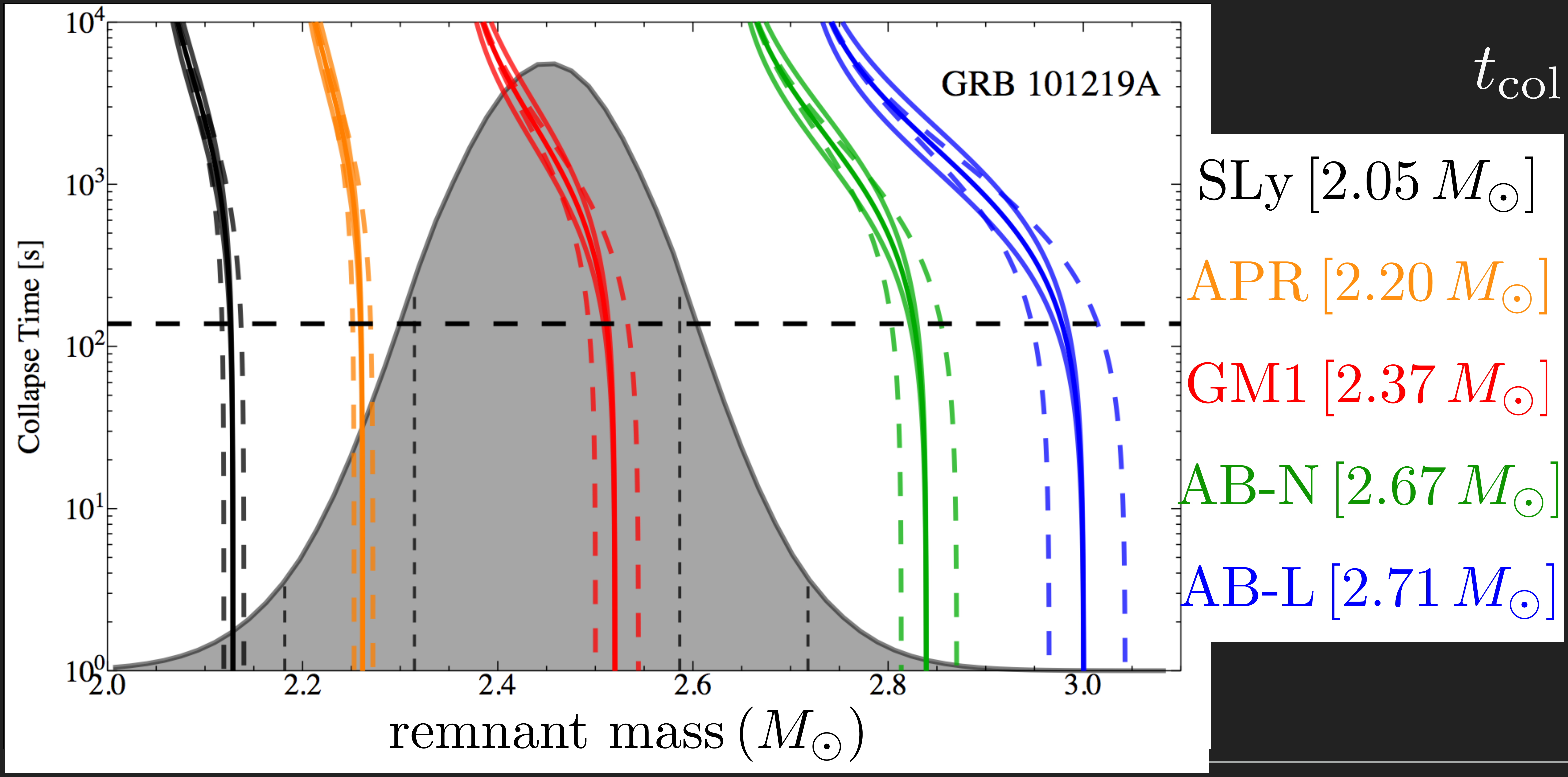
$$t_{\rm col}\,(B_{\rm p},\, p_0,\, M,\, {\rm EOS})$$

what about equation of state constraints?



PL+2014

what about equation of state constraints?

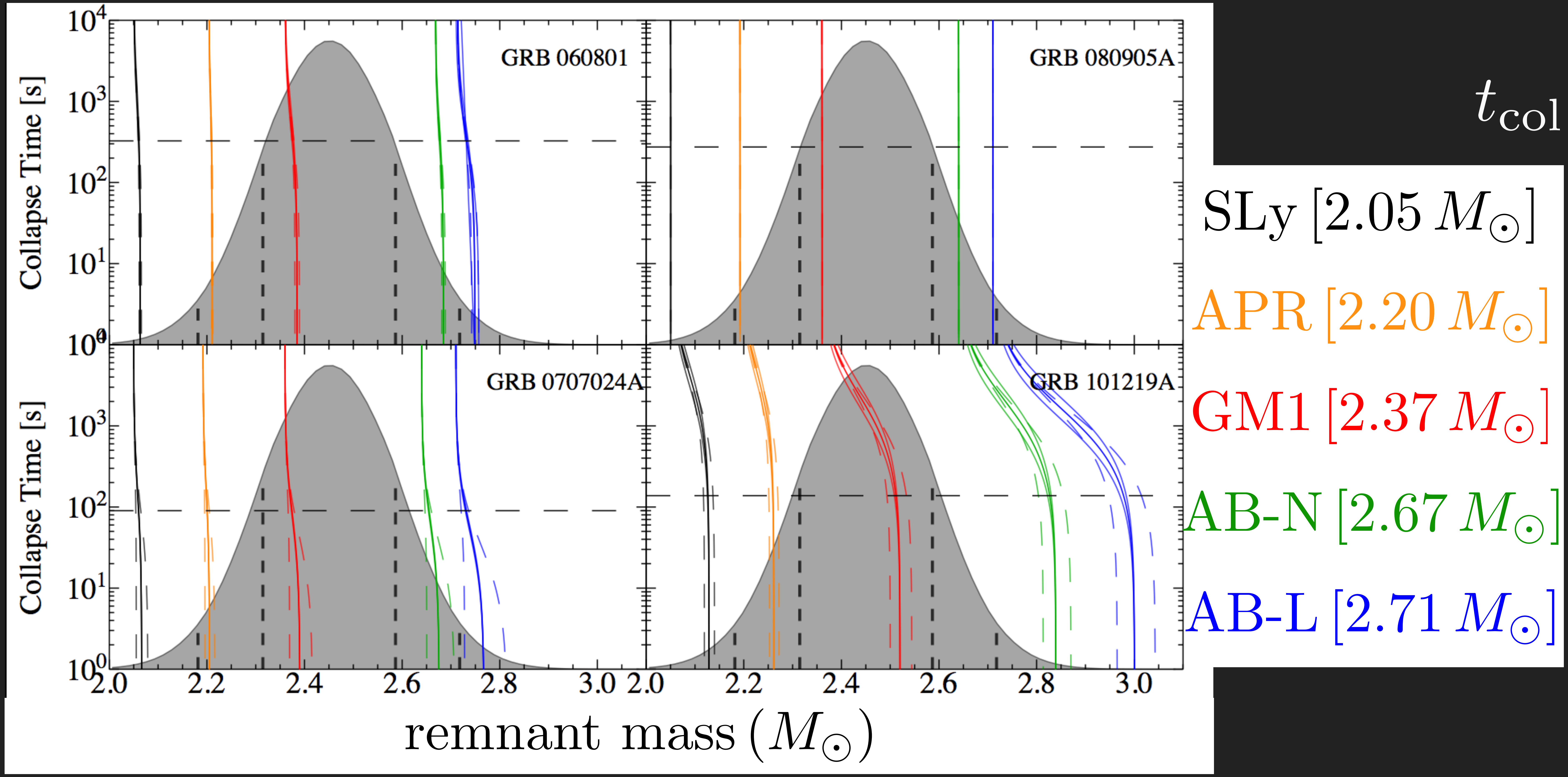


$t_{\rm col}\,(B_{\rm p},\ p_0,\ M,\ {\rm EOS})$

PL+2014

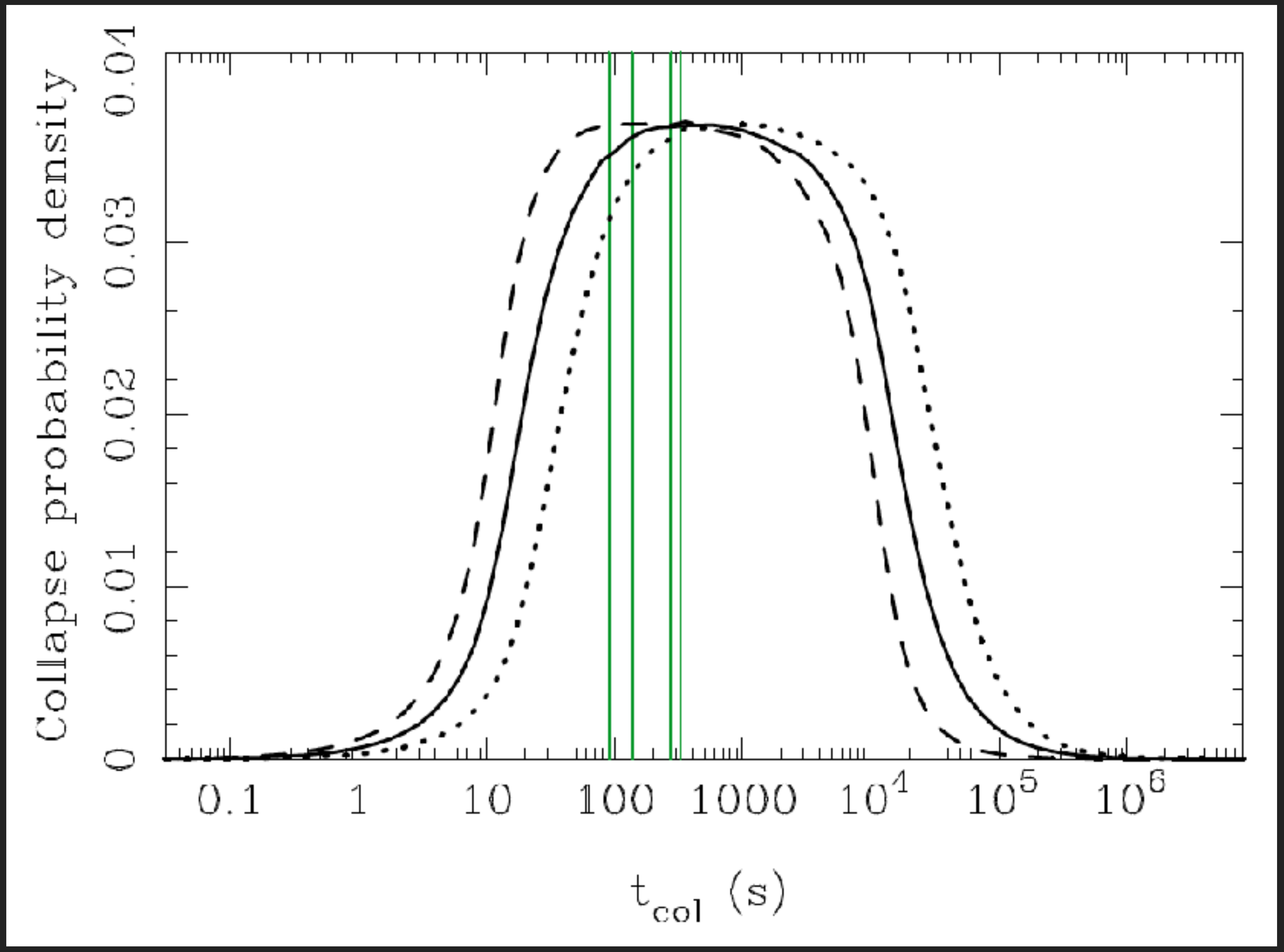
what about equation of state constraints?

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



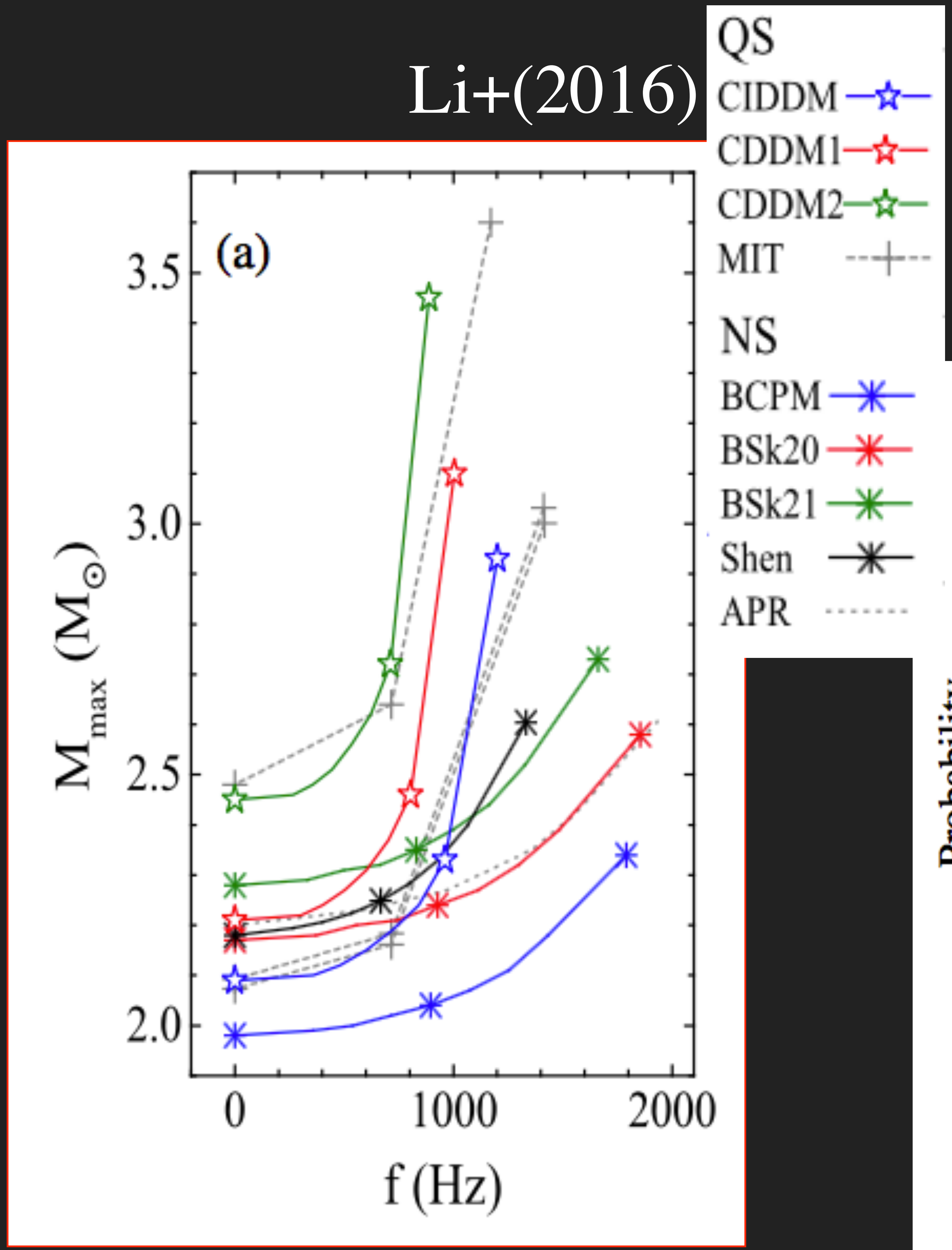
PL+2014

what about equation of state constraints?

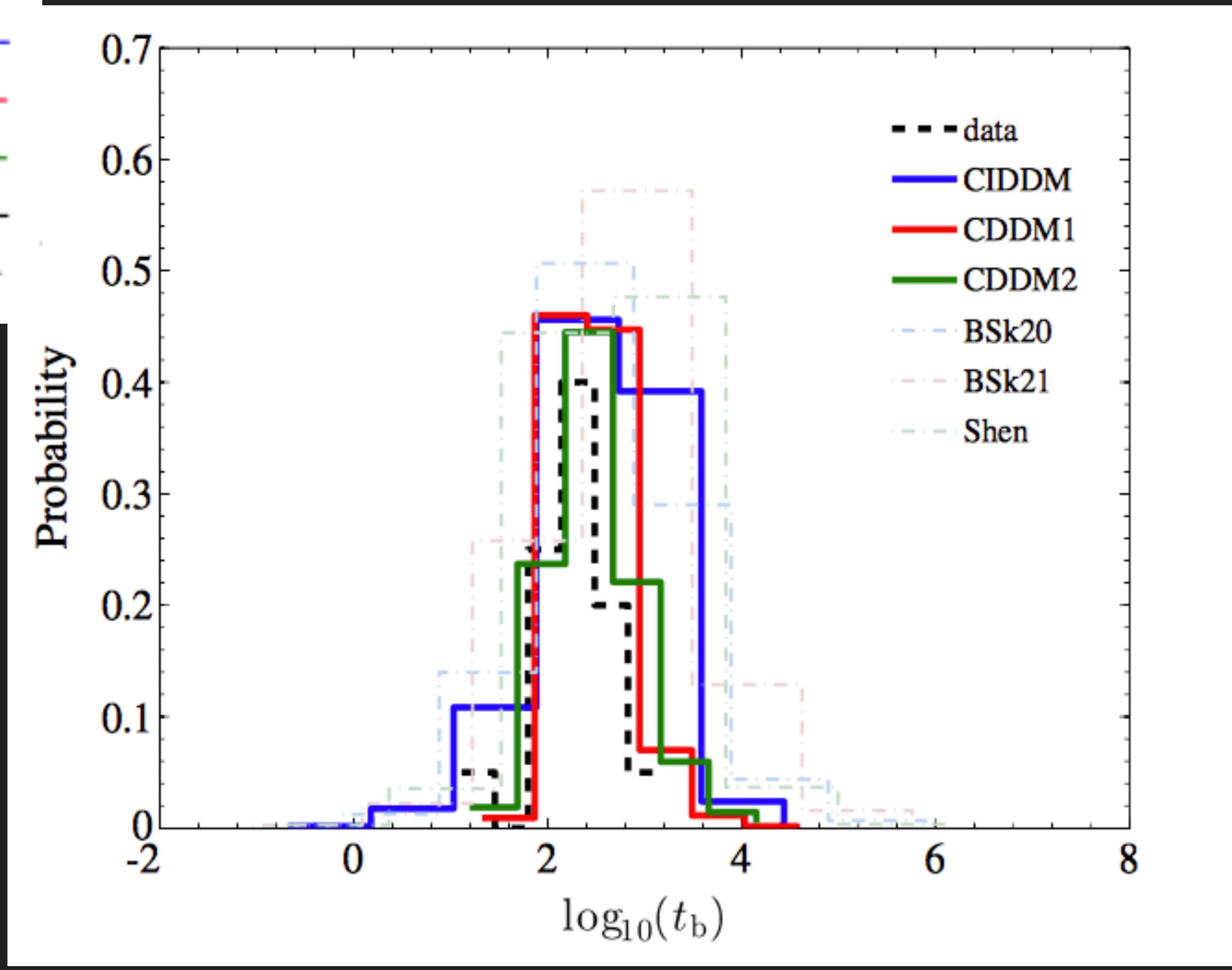


Ravi & PL (2014)

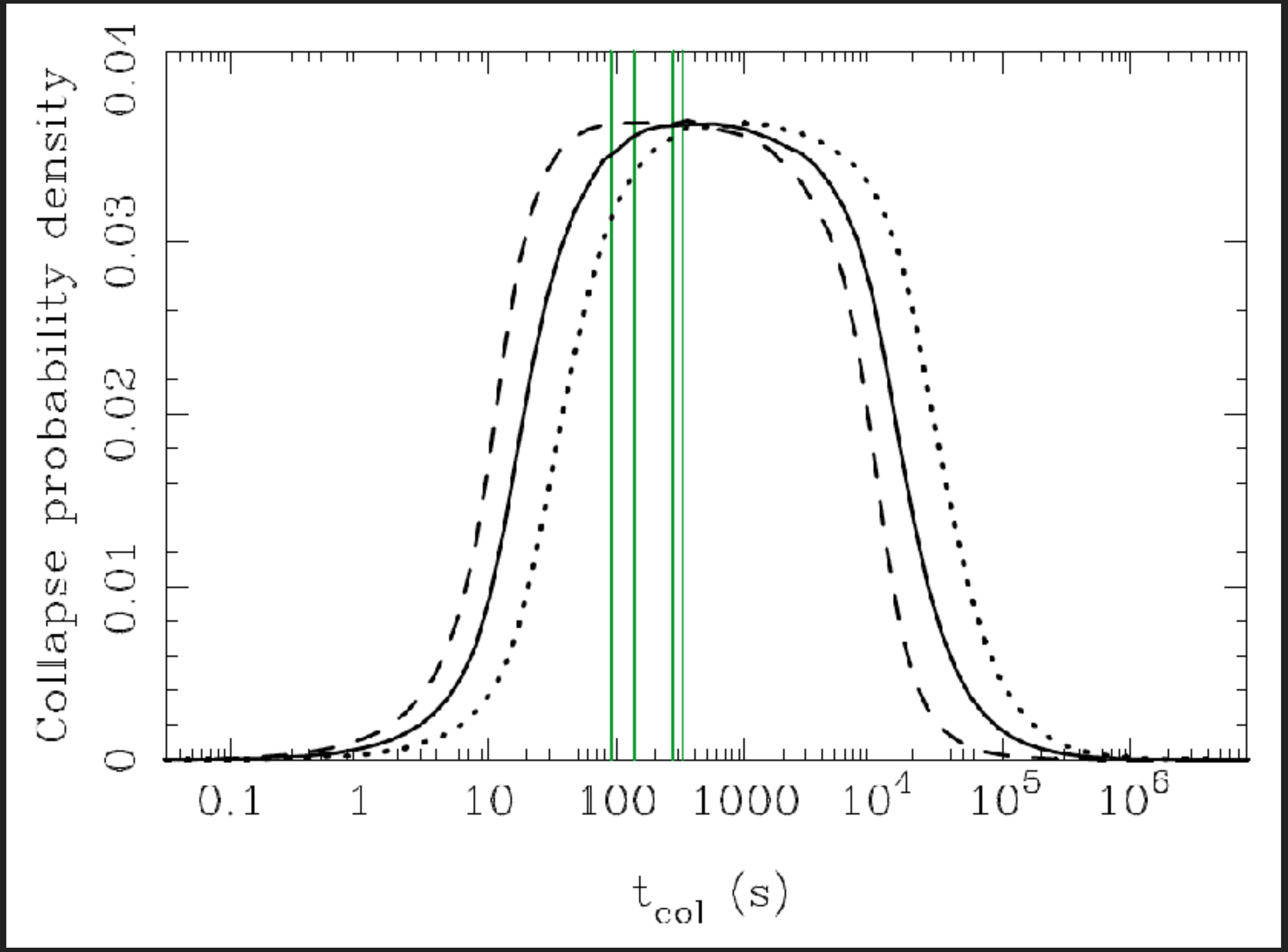
Li+(2016)



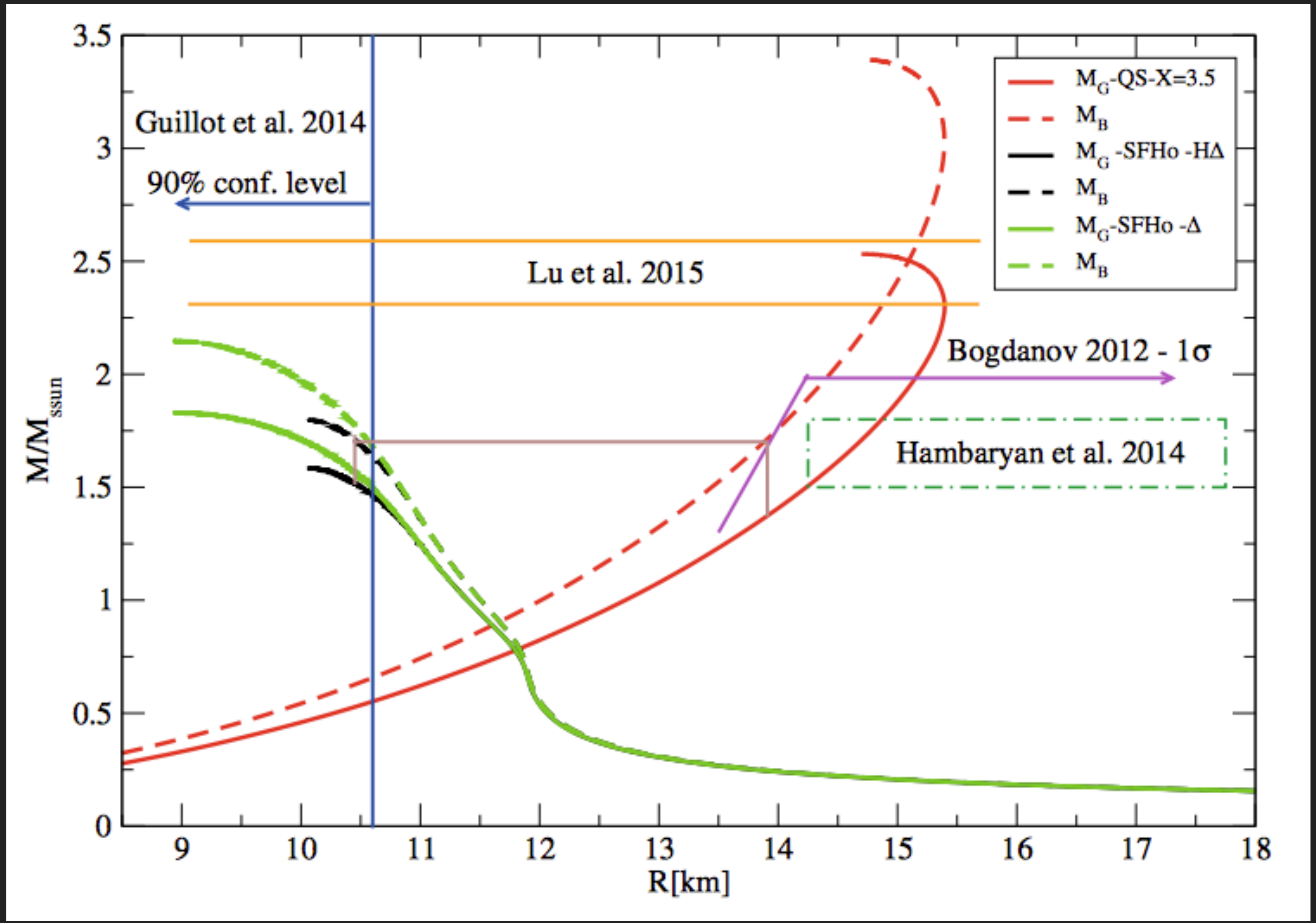
quark stars?



what about equation of state constraints?



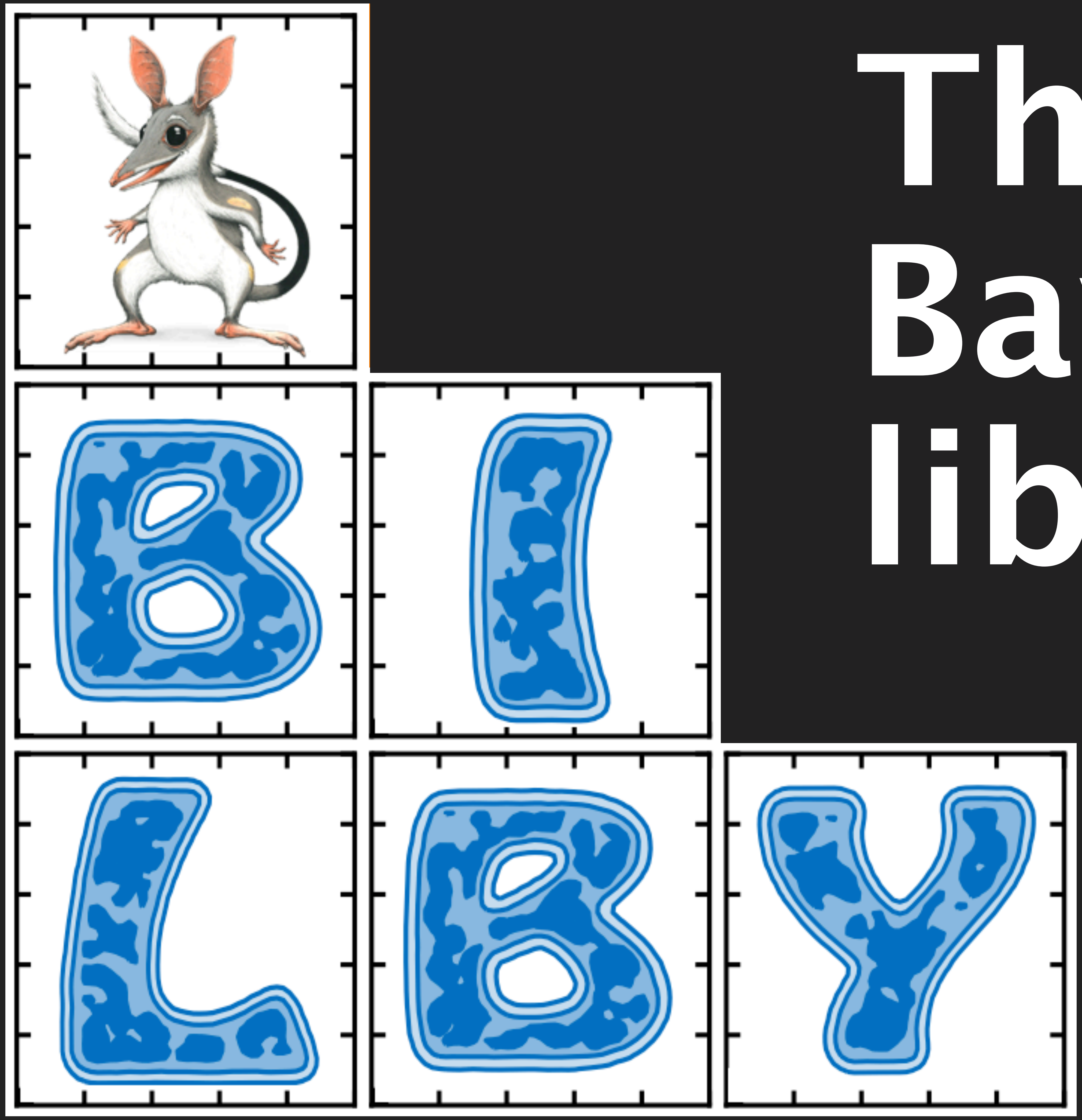
Ravi & PL (2014)



Drago+2016 - and next talk!?







The user-friendly Bayesian inference library

Ashton, Huebner, PL, Talbot + (2018)

A versatile parameter-estimation code being adopted for production science in next LIGO observing run

git.ligo.org/lscsoft/bilby/

Our Aims:

- **Lower the entry point for doing gravitational-wave and astrophysics Bayesian calculations**
  - **user friendly, intuitive syntax**
  - **robust, yet adaptable code base**
  - **open source**
  - **well documented**
  - **many examples**

git.ligo.org/lscsoft/bilby/

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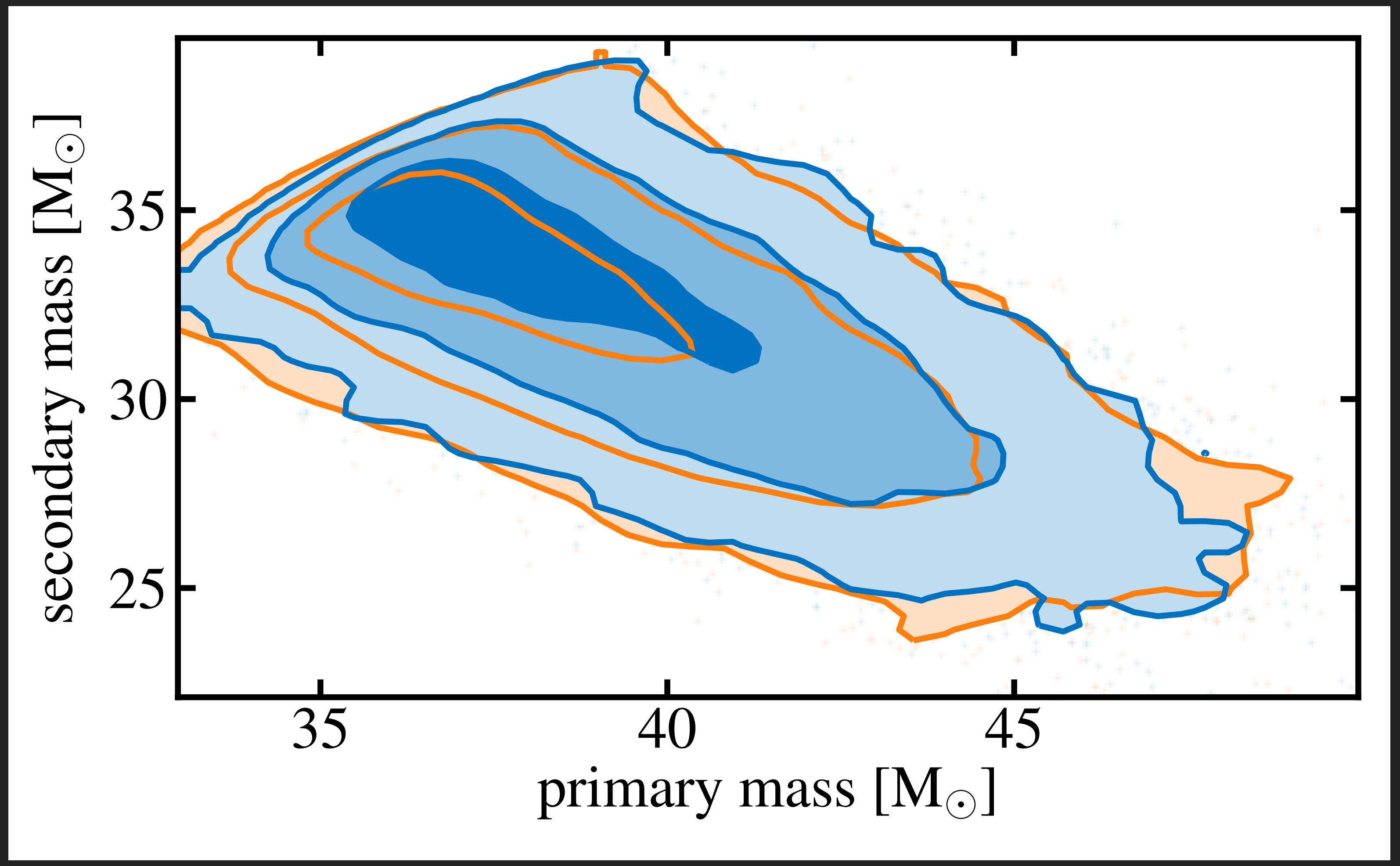
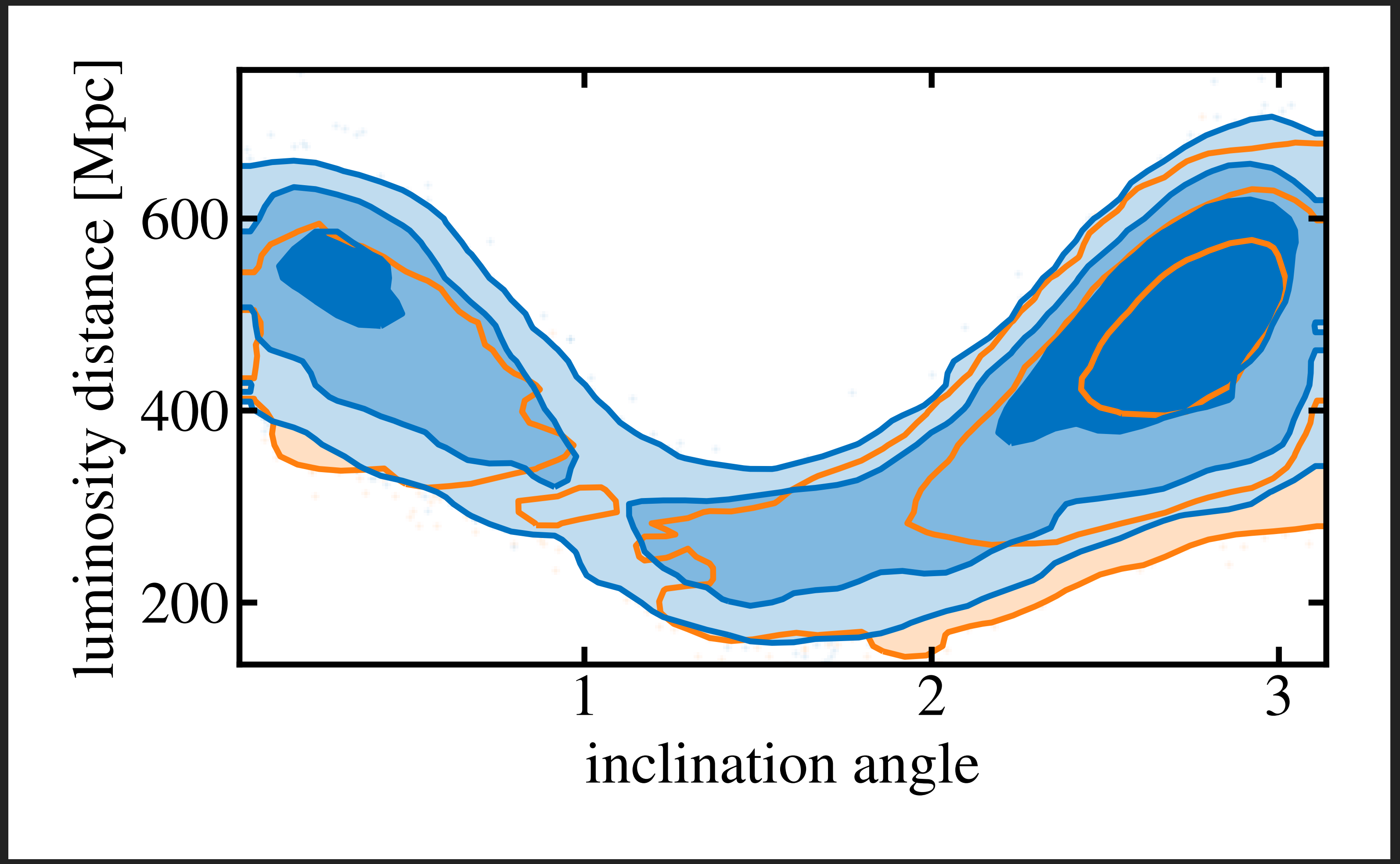
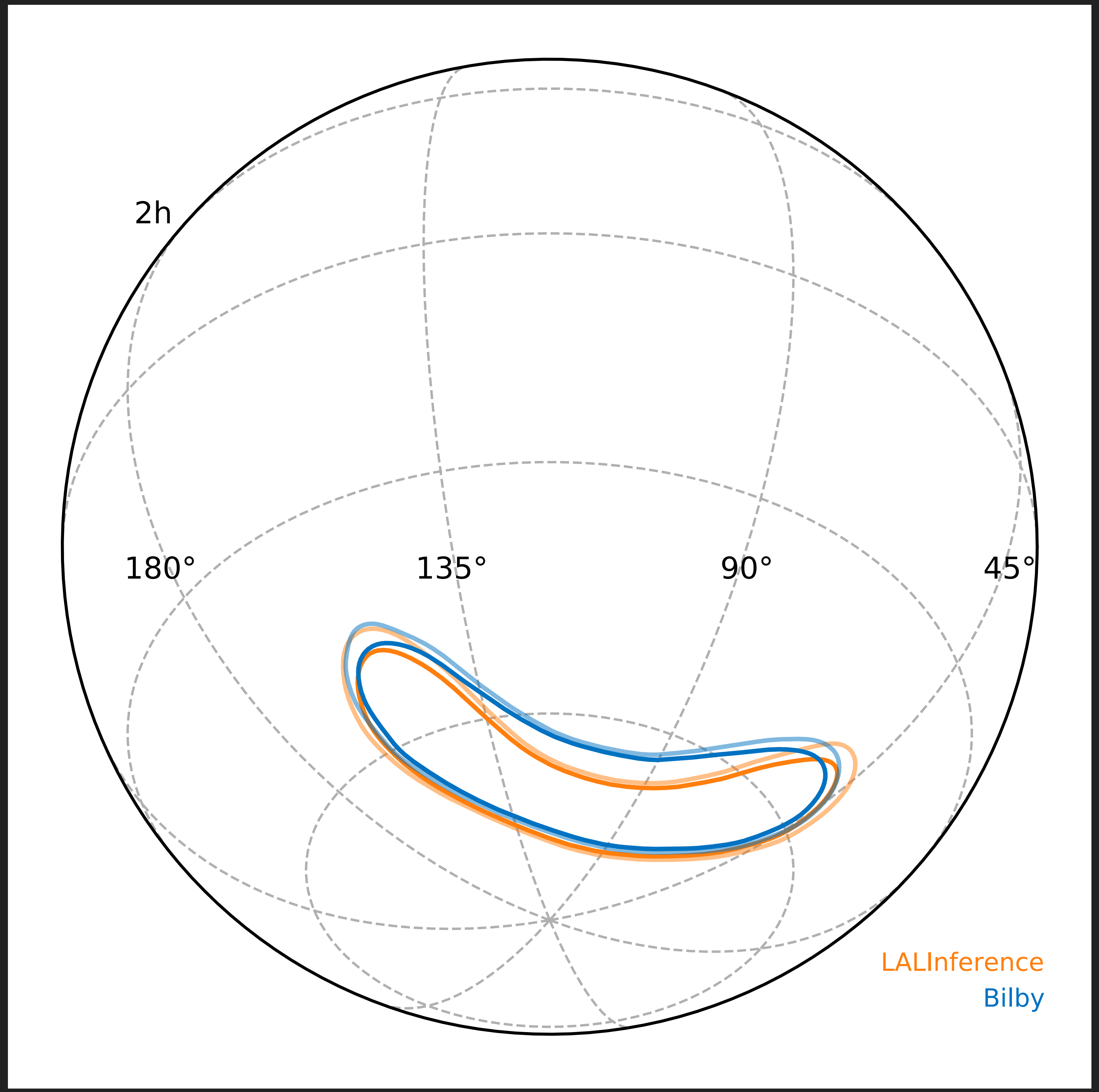


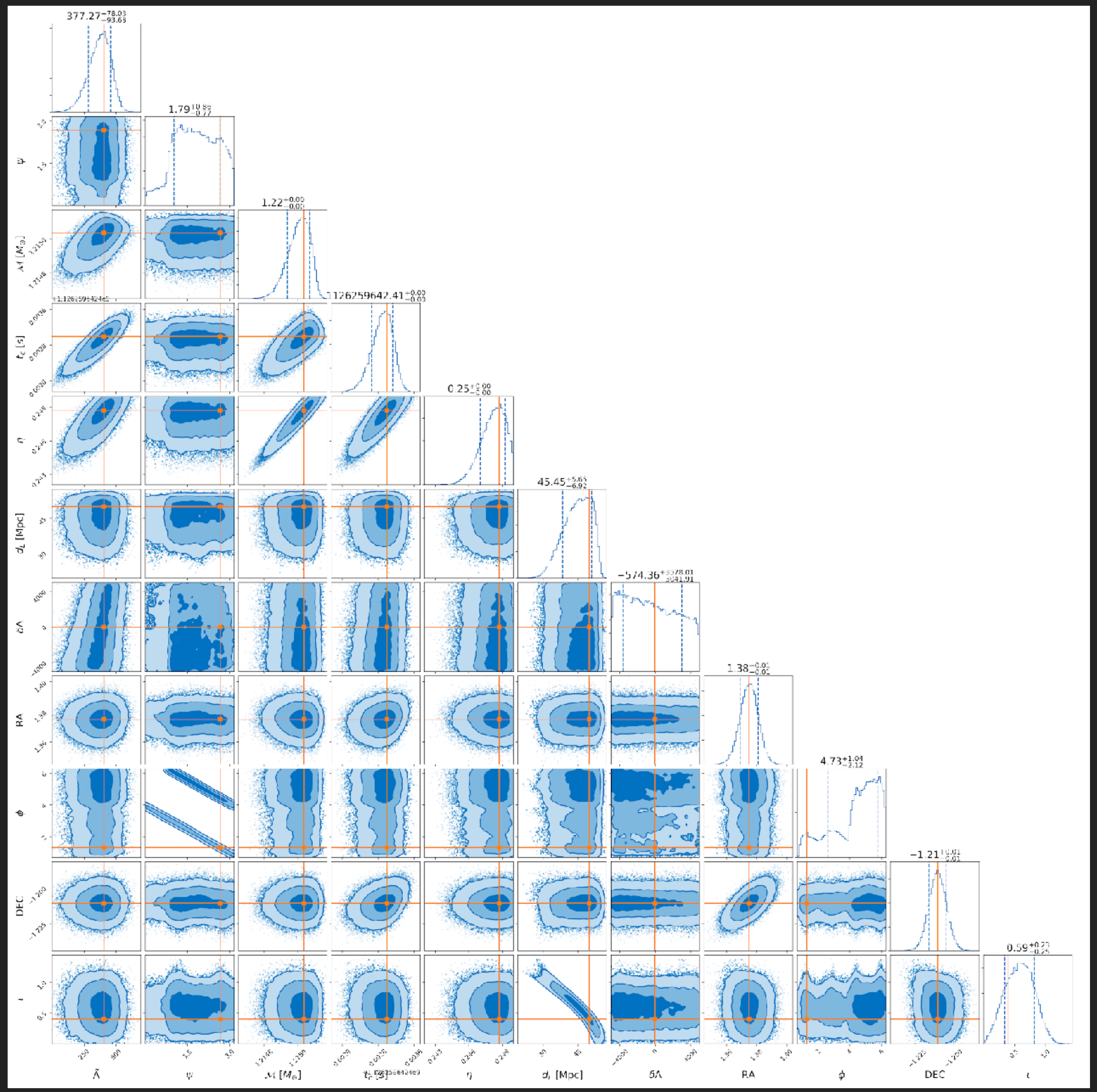




open gravitational-wave data

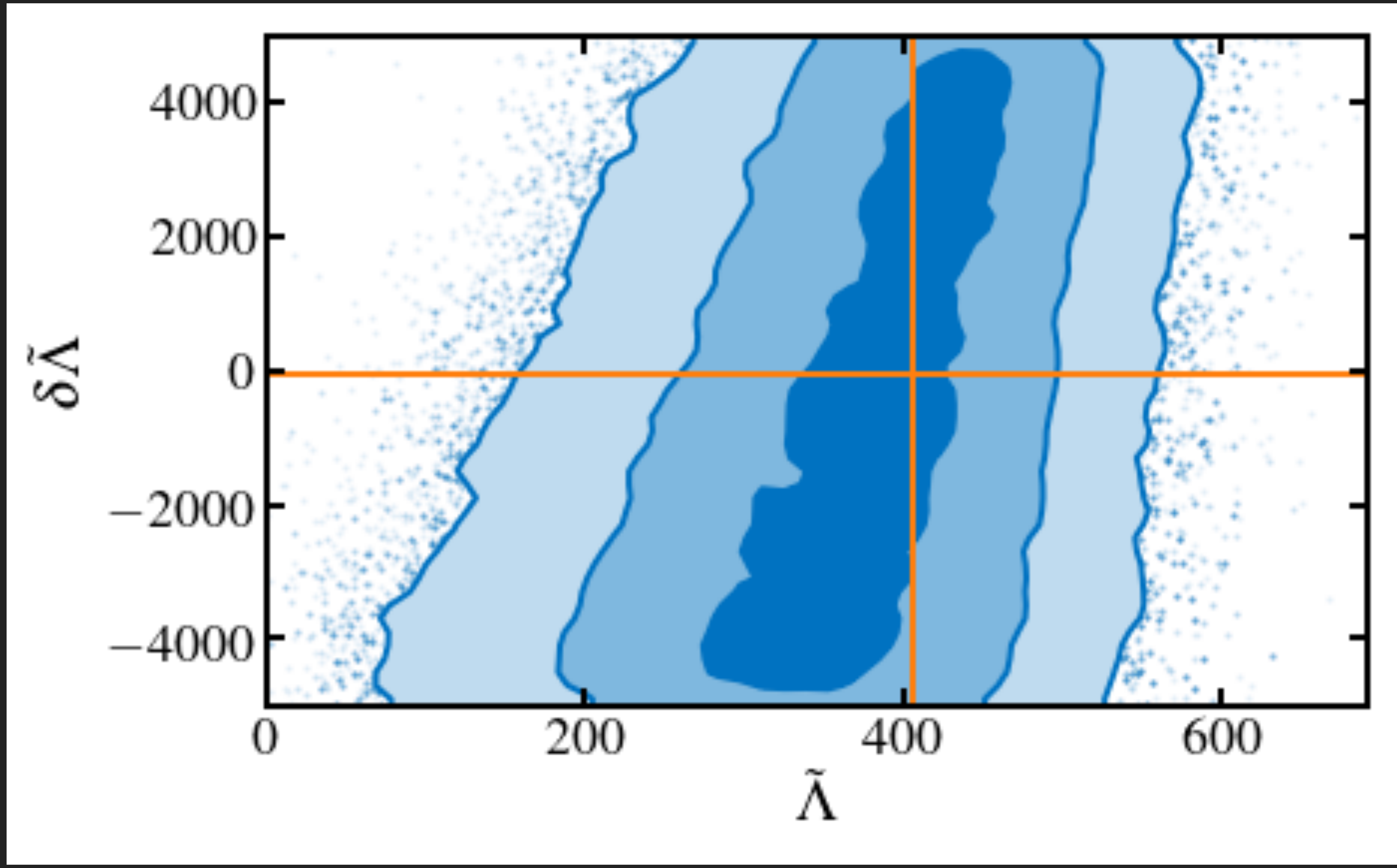
GW150914

Ashton, Hübner, PL, Talbot + (2018)



git.ligo.org/lscsoft/bilby/

synthetic neutron star injections



Ashton, Hübner, PL, Talbot + (2018)

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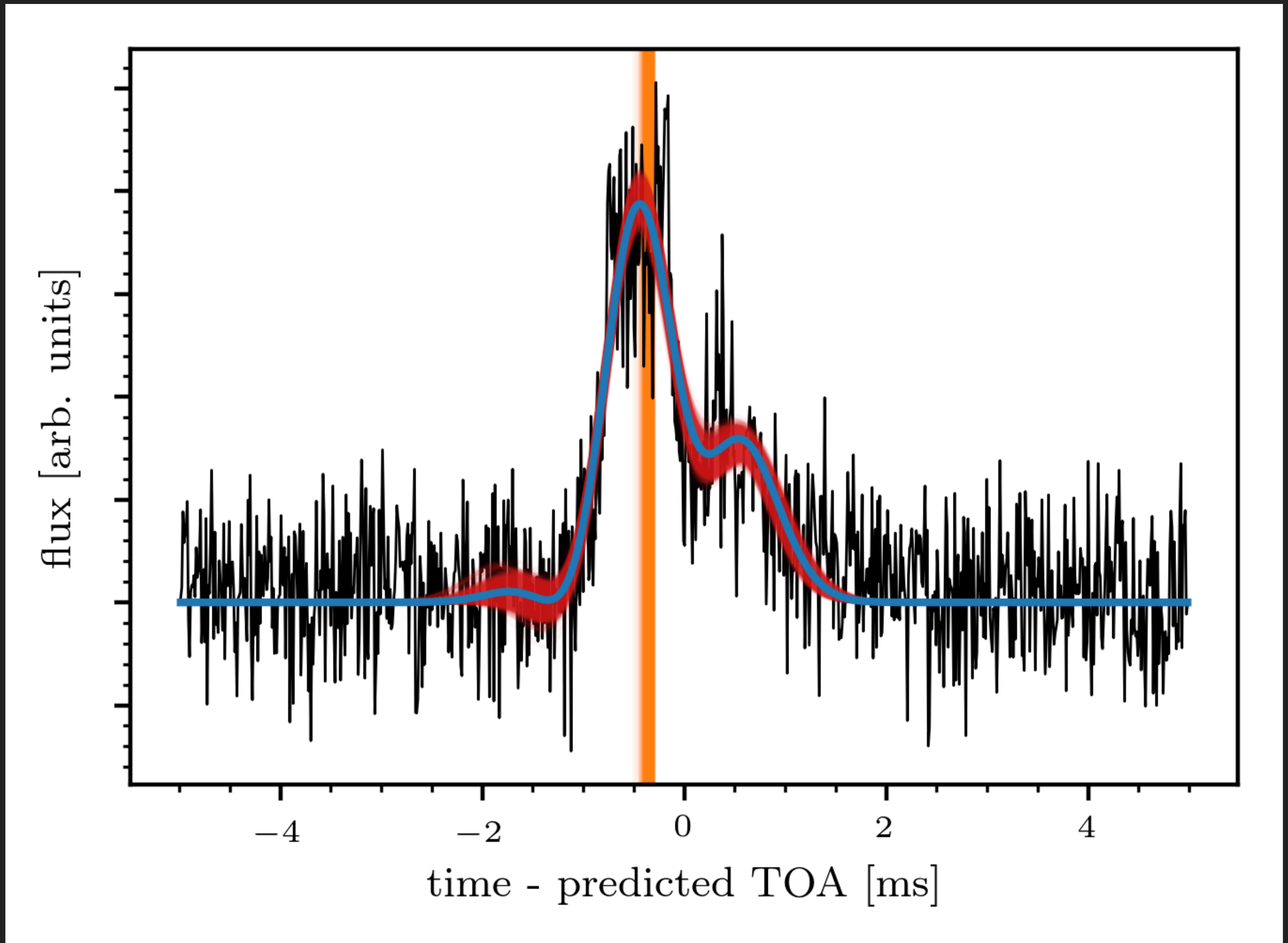
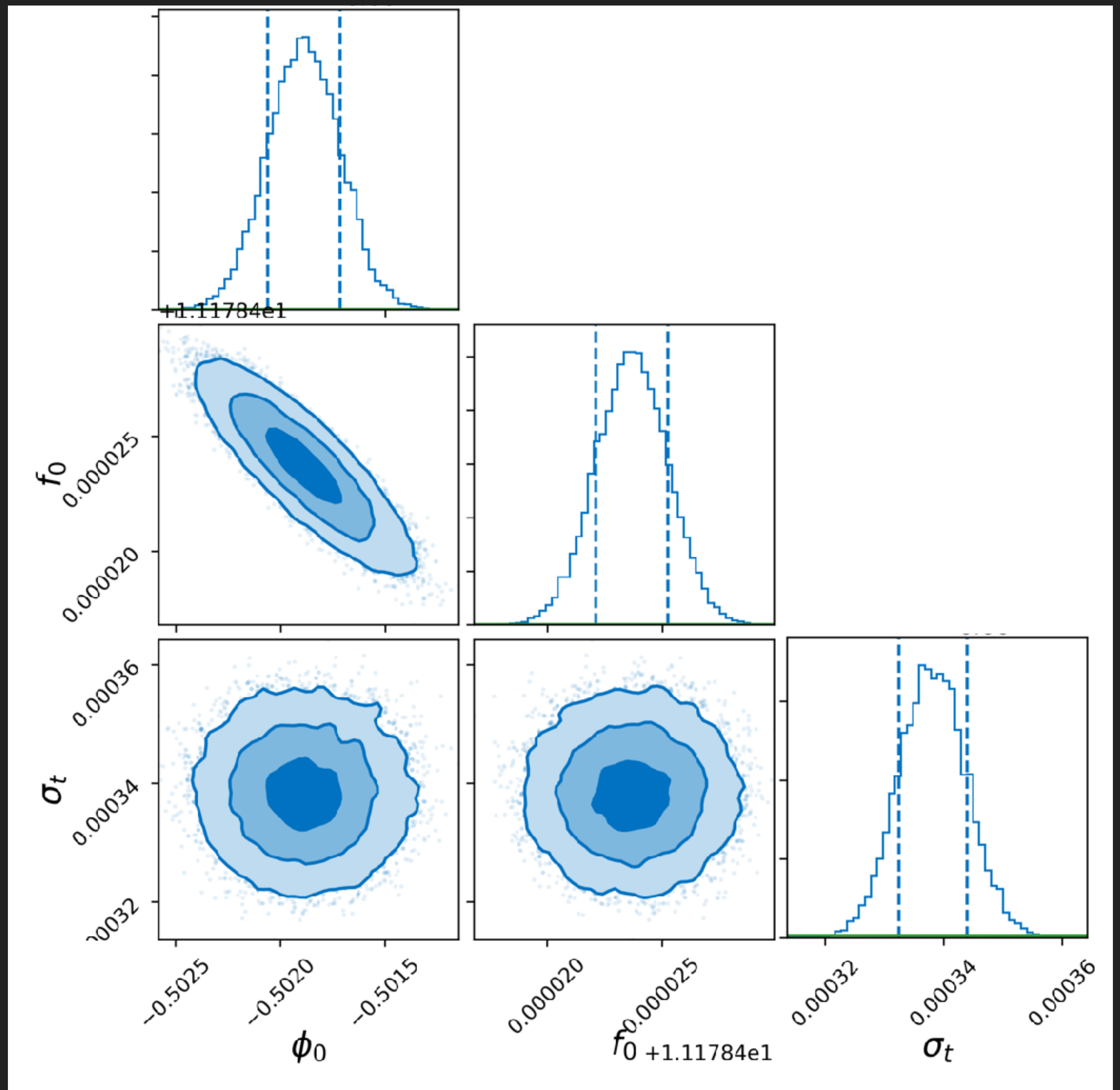


neutron star pulse-profile modelling

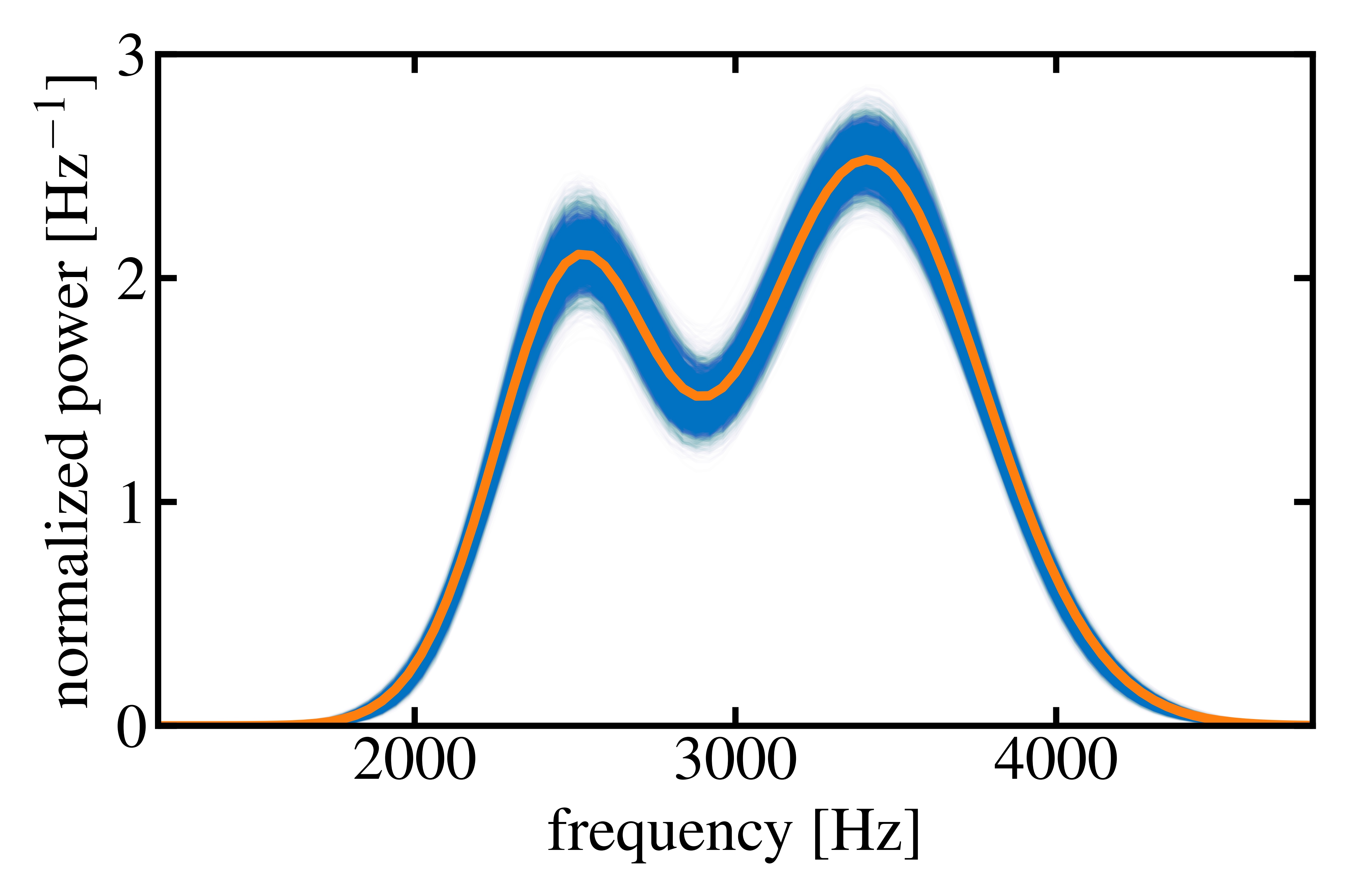


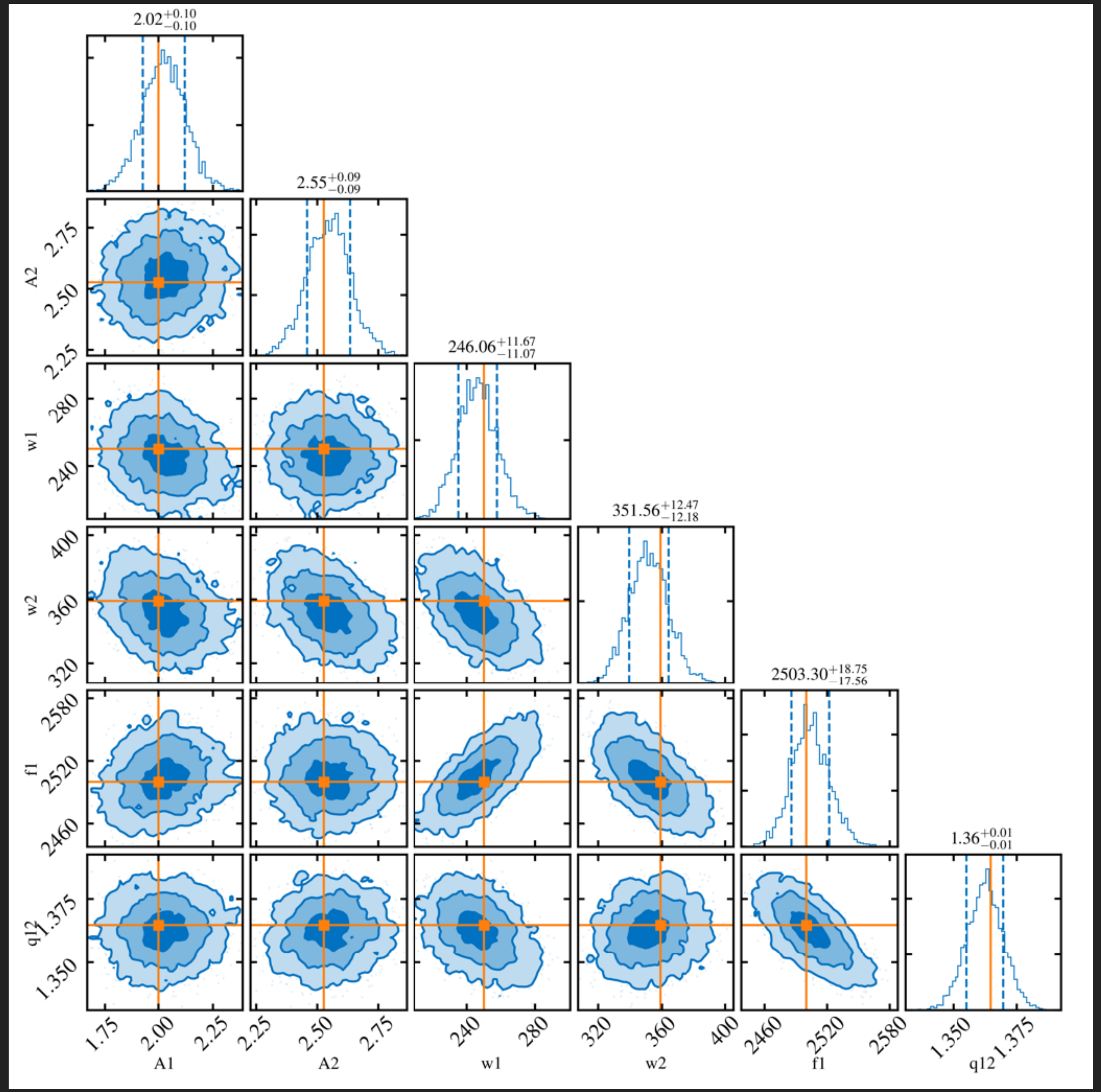
VELA!!!

Ashton, Graber, PL (in prep.)

git.ligo.org/lscsoft/bilby/

gravitational-waves from hypermassive neutrons stars





Ashton, Hübner, PL, Talbot + (2018)

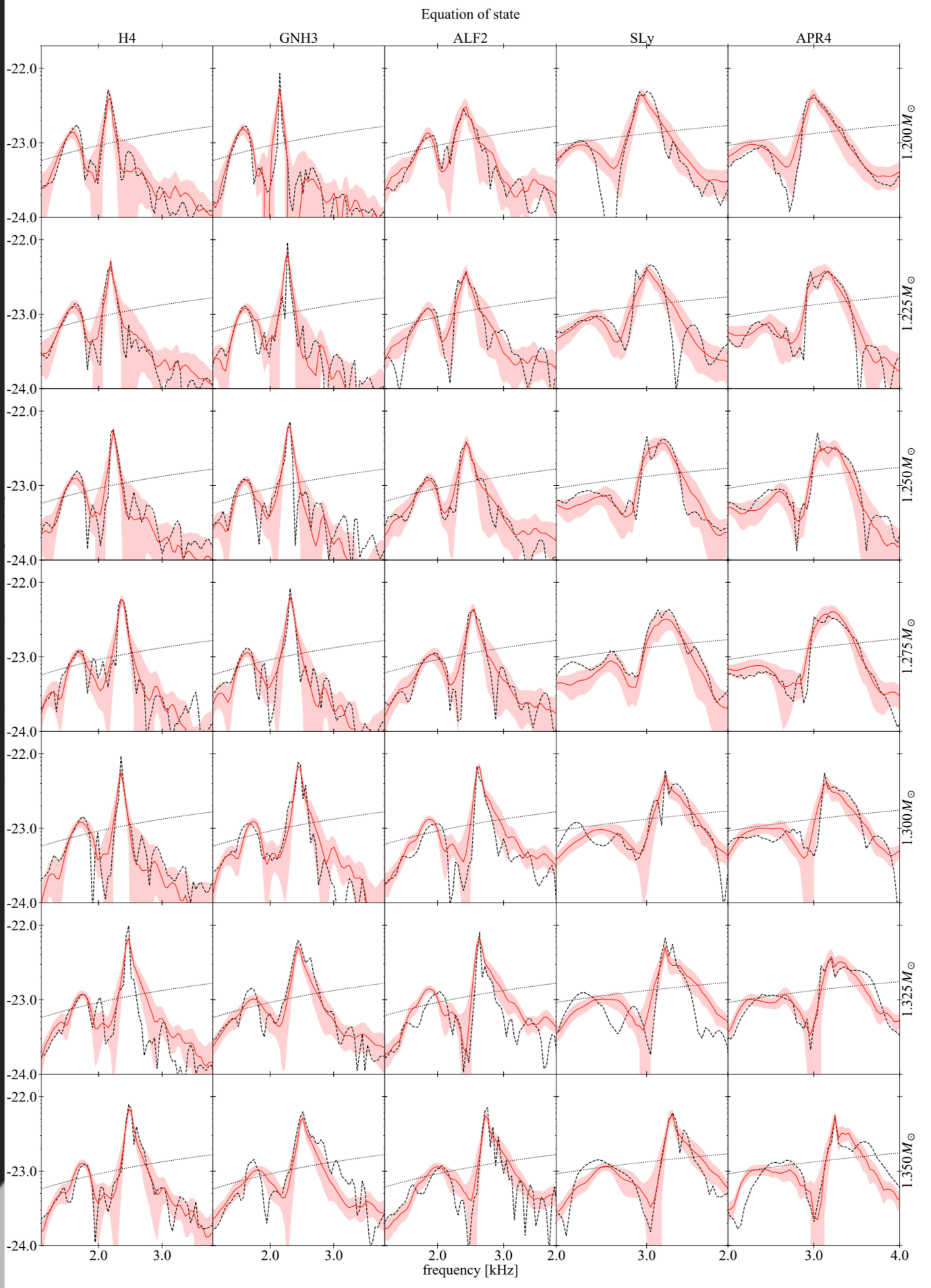
Conclusions

- GW170817:
  - I'm not convinced we know the merger outcome
  - many hints, some potentially contradictory
- Many other SGRBs show evidence of long-lived neutron-star remnants
- Rich physics to understand: e.g.,
  - nuclear equation of state
  - gravitational-wave emission
- the dream: gravitational-wave inspiral with well-behaved kilonova and x-ray light curve

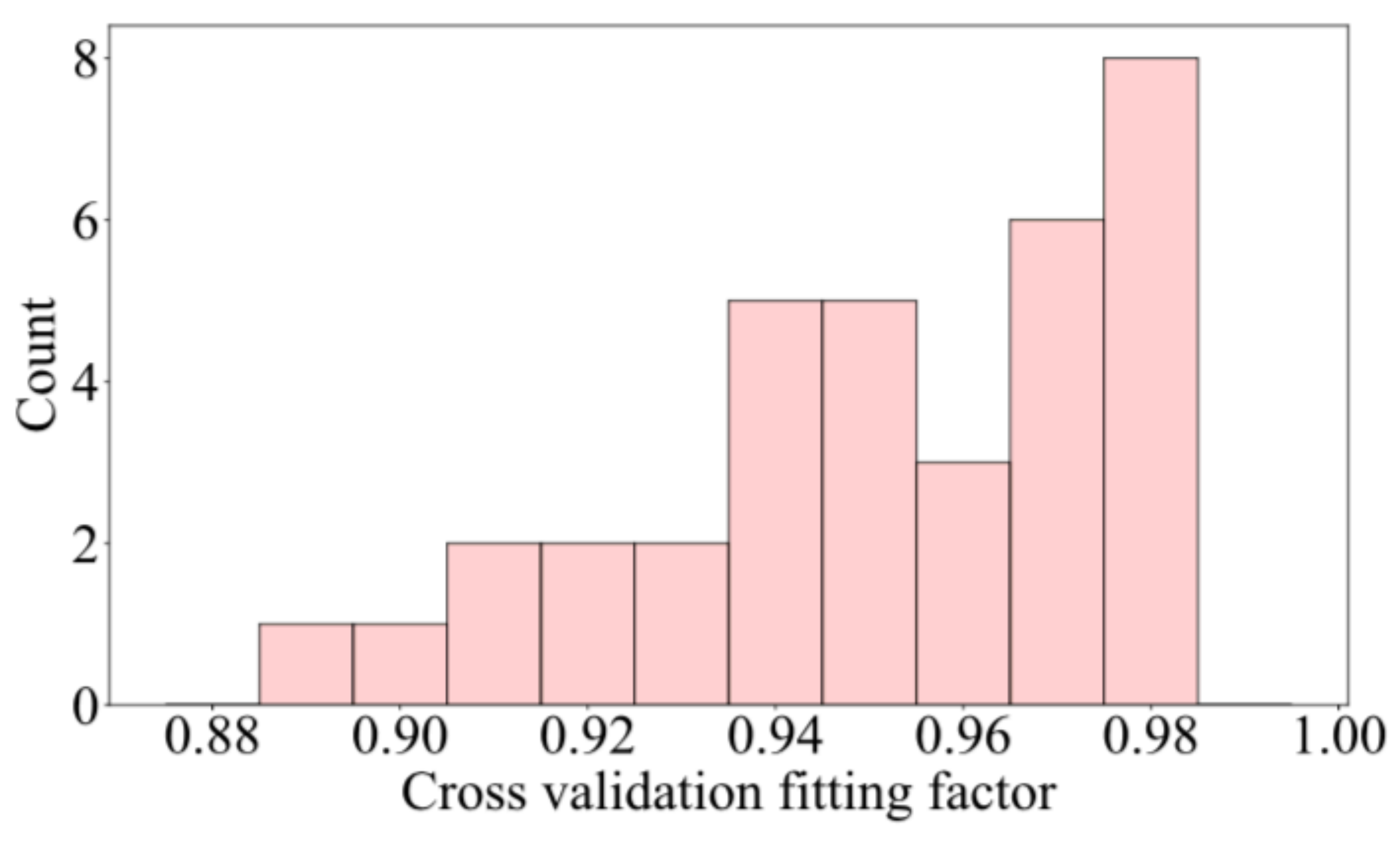
"Putting the power of Bayesian statistics into the hands of people who probably shouldn't have it."

Ian Jones

EXTRA SLIDES

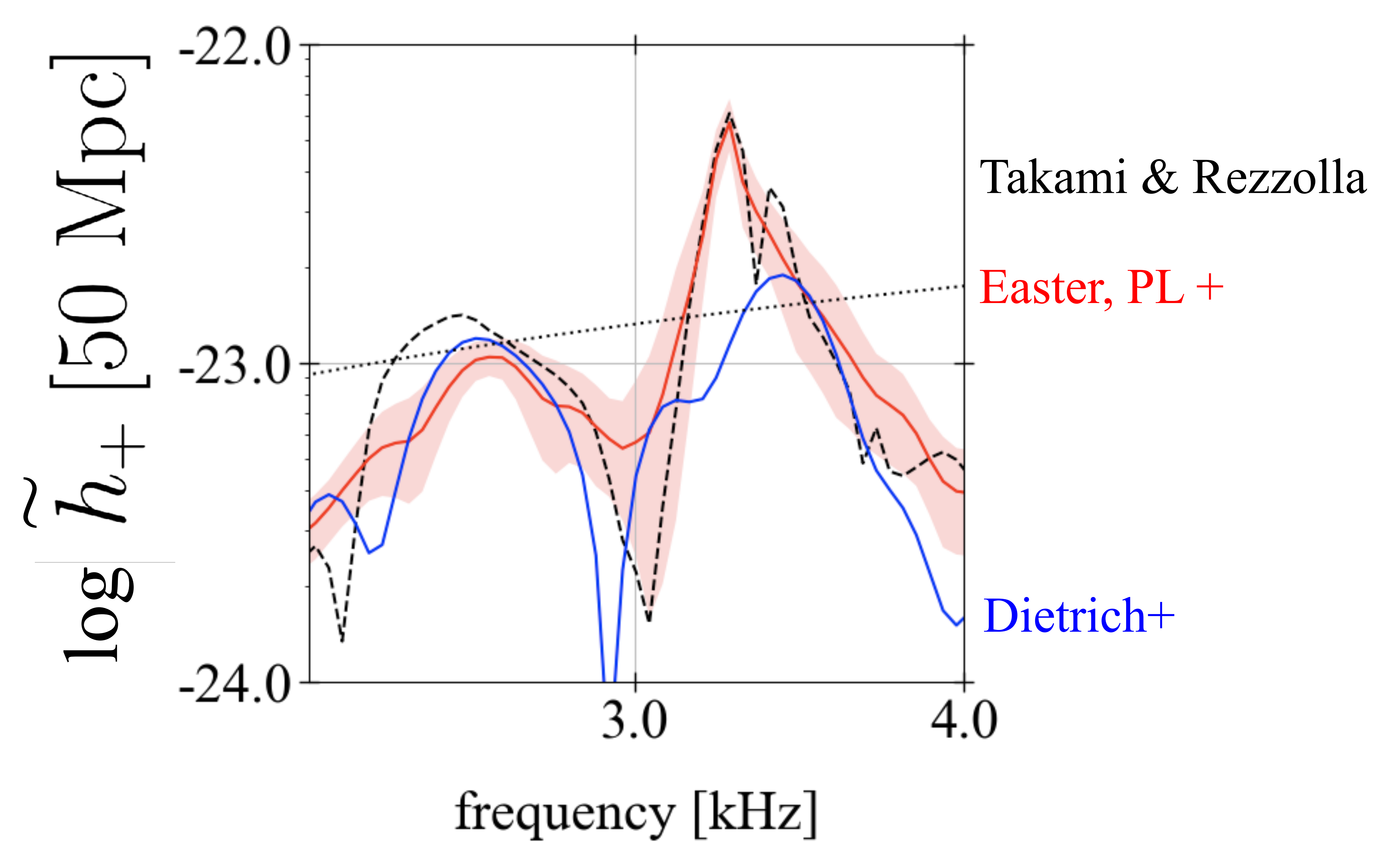


- **Machine learning**
  - train on post-merger gravitational waveforms (equal mass progenitors)
  - only require two parameters: M, κ_2
  - generate new, accurate waveforms in a fraction of a second
  - to be used in gravitational-wave searches and parameter estimation



Easter, PL + 2019

numerical-relativity simulations: the dirty little secret!



- fitting factor between two codes with same physical set up = 0.76 and 0.85!
- our worst fitting factor = 0.88

our method is limited only by the accuracy of the numerical-relativity simulations!

Easter, PL + 2019