Constraining the NS EOS with Multi-Messenger Observations of GW170817

[or – yet another extraordinary gift from the riches of GW170817]

Ben Margalit,
Columbia University

Astrophysics from a NS Merger,
KITP, Dec. 12th 2017

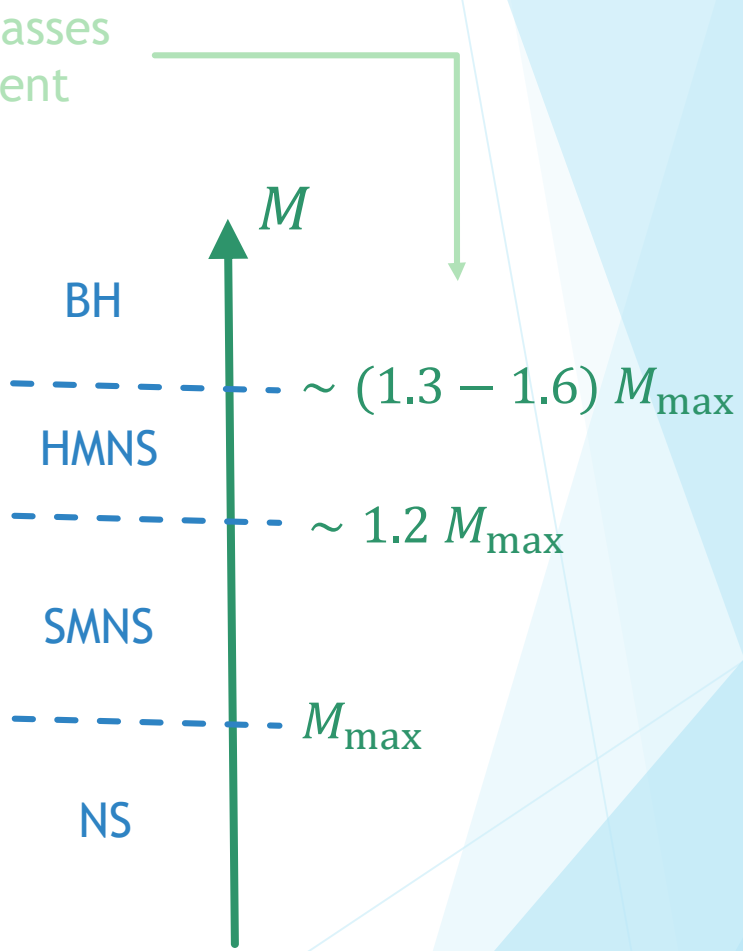
GW170817 & the NS EOS (constraining $M_{\rm max}$)

Ben Margalit
Columbia University

Merger Outcome:

- merger can produce:
  - stable NS
  - rigidly rotating rotationally-supported *supramassive* NS (SMNS)
  - differentially rotating rotationally-supported *hyper-massive* NS (HMNS)
  - black-hole (BH) ["prompt collapse"]
- qualitatively different EM counterparts!

(e.g. Bauswein+13; Metzger&Fernandez14)



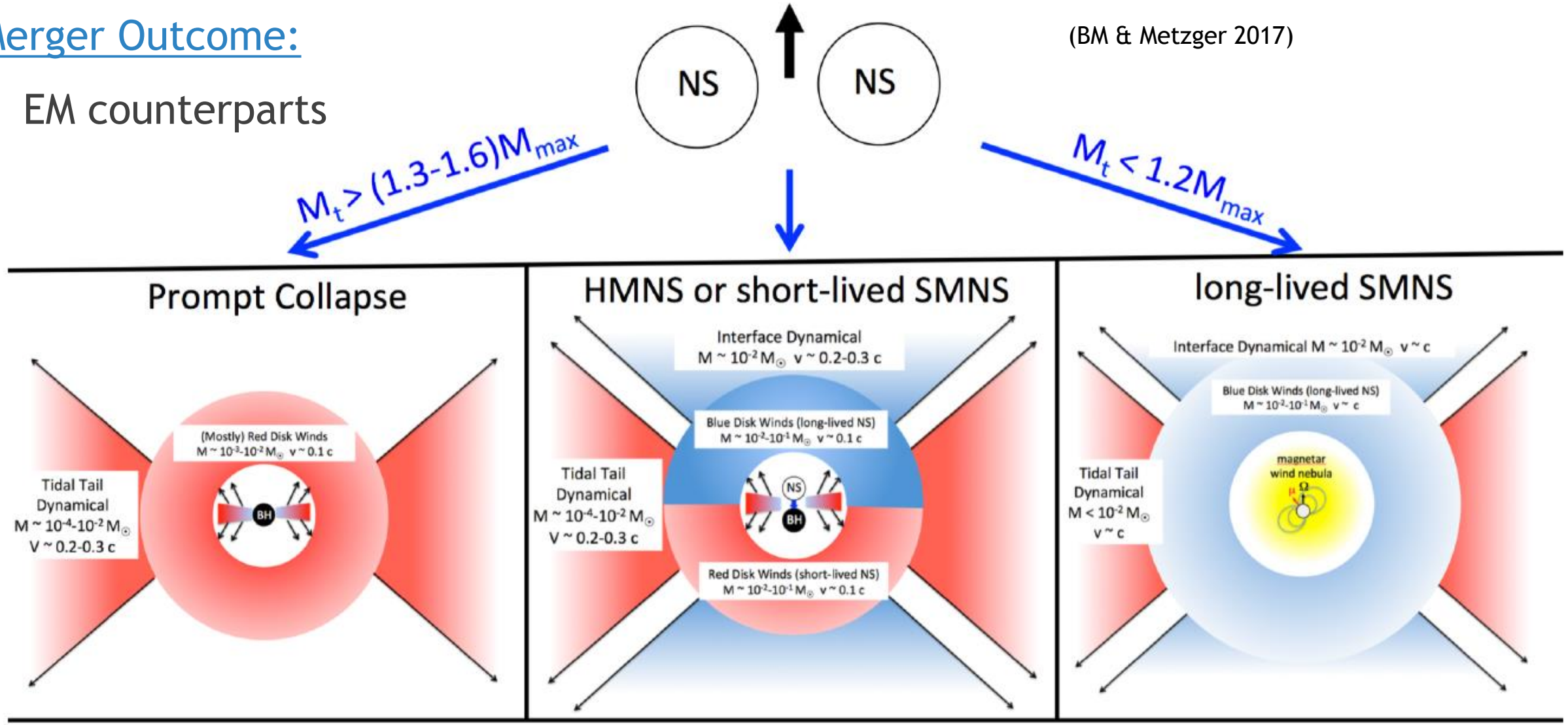
GW170817 & the NS EOS (constraining $M_{\rm max}$)

Ben Margalit
Columbia University

Merger Outcome:

- EM counterparts

(BM & Metzger 2017)



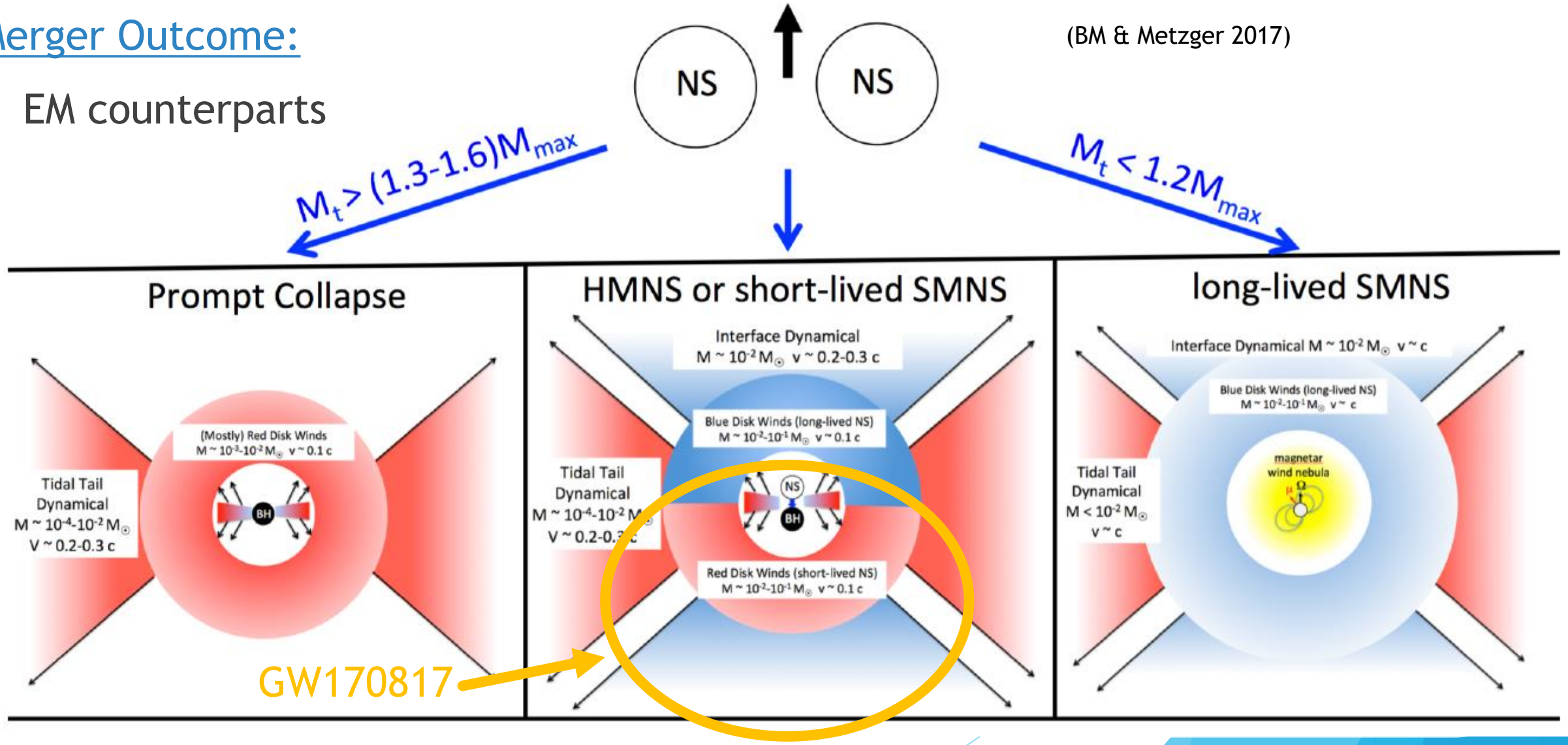
GW170817 & the NS EOS (constraining $M_{\rm max}$)

Ben Margalit
Columbia University

Merger Outcome:

- EM counterparts

(BM & Metzger 2017)



GW170817 & the NS EOS (constraining $M_{\rm max}$)

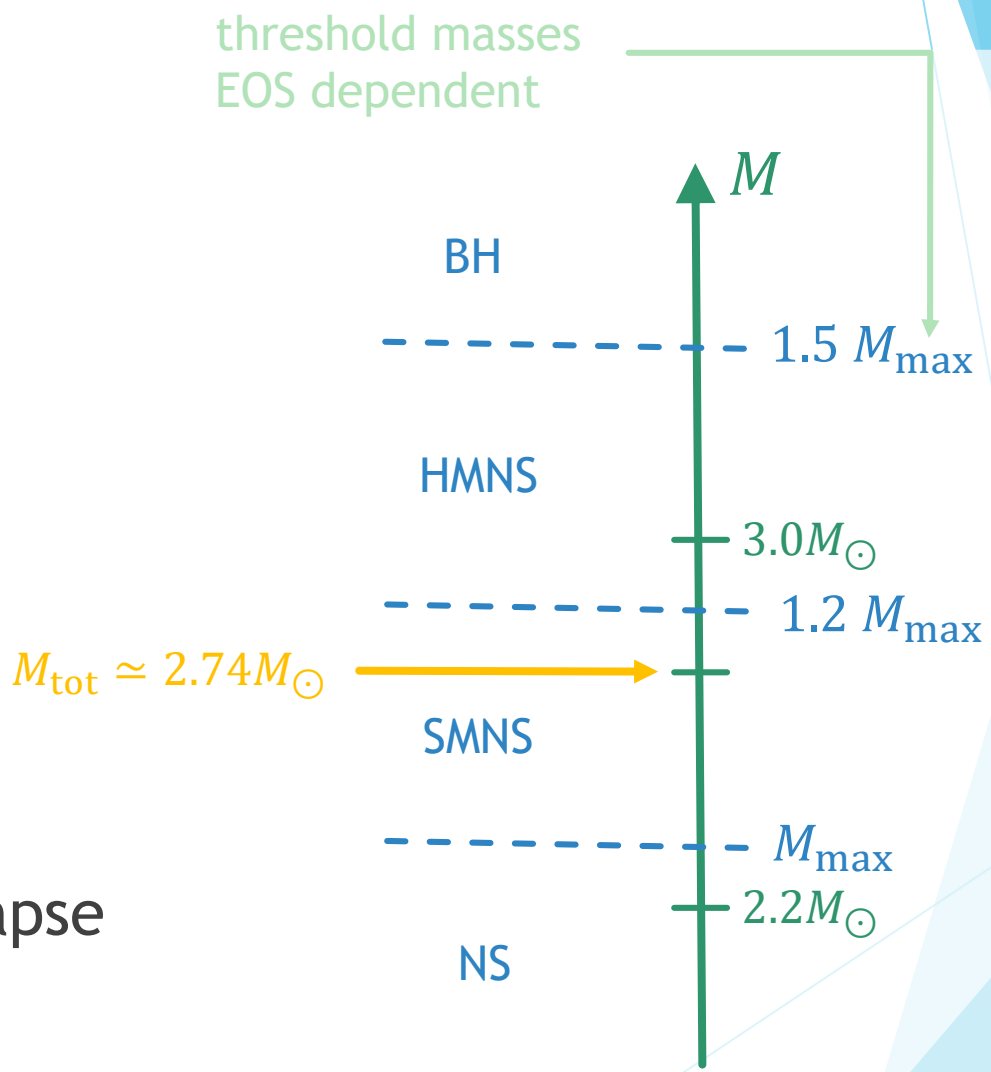
Ben Margalit
Columbia University

Merger Outcome:

- ruling out long-lived NS

  ⇒ upper limit on $M_{\rm max}$

- similarly, ruling out prompt-collapse
  ⇒ lower limit on $M_{\rm max}$



GW170817 & the NS EOS (constraining $M_{\max}$)

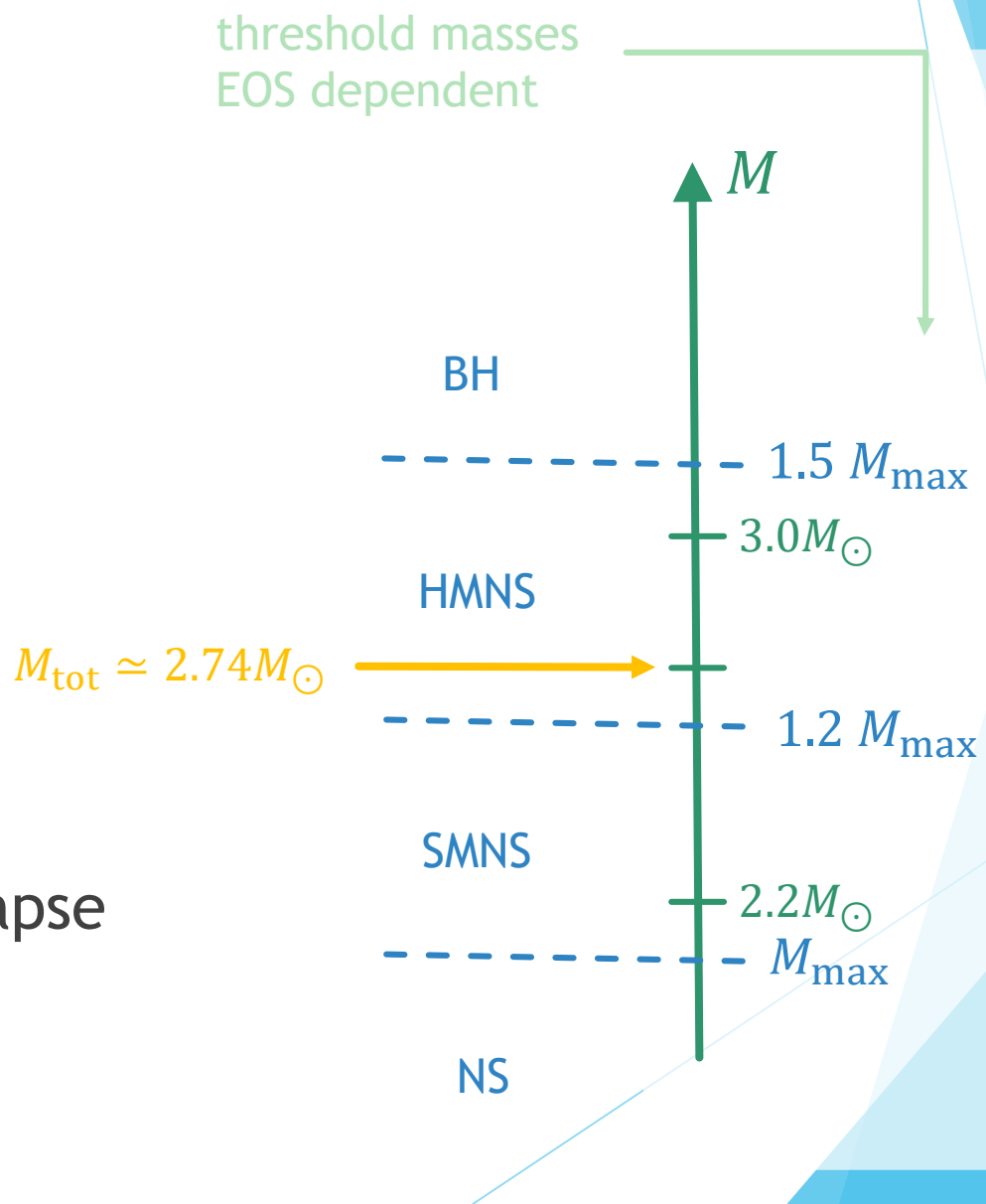
Ben Margalit
Columbia University

Merger Outcome:

- ruling out long-lived NS

  ⇒ upper limit on $M_{\max}$

- similarly, ruling out prompt-collapse
  ⇒ lower limit on $M_{\max}$



GW170817 & the NS EOS (constraining $M_{\rm max}$)

Ben Margalit
Columbia University

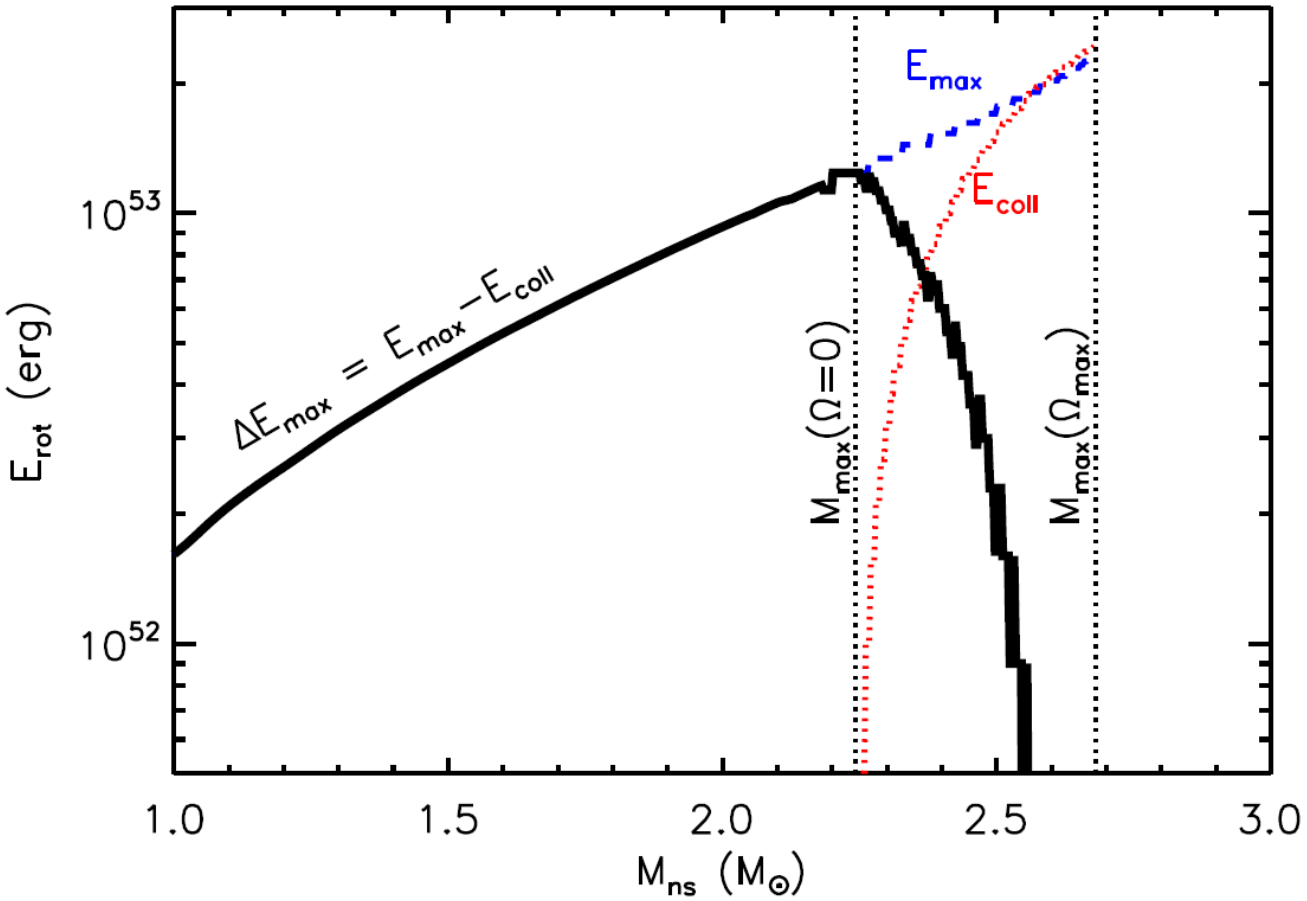
Spindown of SMNS:

- merger remnant maximally rotating

$\Rightarrow \sim 10^{53}$ erg energy reservoir!

- total rotational energy increases with M, but extractable energy drops for $M > M_{\rm max}$

(Metzger, BM, Kasen & Quataert 2015)



GW170817 & the NS EOS (constraining $M_{\rm max}$)

Ben Margalit
Columbia University

Spindown of SMNS:

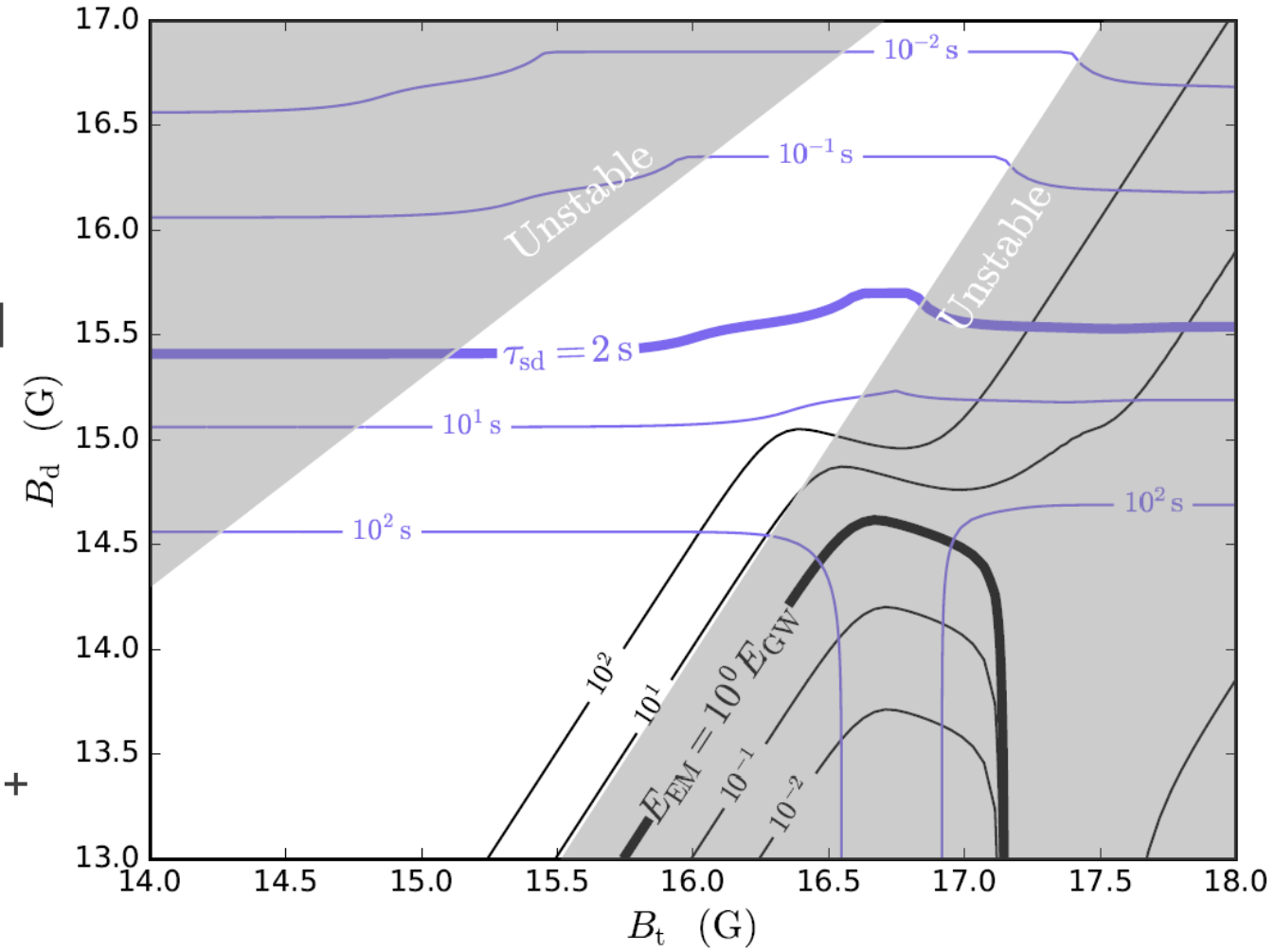
- merger remnant maximally rotating

$\Rightarrow \sim 10^{53}$ erg energy reservoir!

- for stable NS / SMNS - will be tapped by magnetic-dipole spindown

- GW spindown unlikely:
  - requires unstable $B_{\rm t} \gtrsim 100 B_{\rm d}$
  - long $\tau_{\rm sd} \sim 100{\rm s}$, in tension with GRB + not detected by LIGO

(BM & Metzger 2017)



GW170817 & the NS EOS (constraining $M_{\rm max}$)

Ben Margalit
Columbia University

Spindown of SMNS:

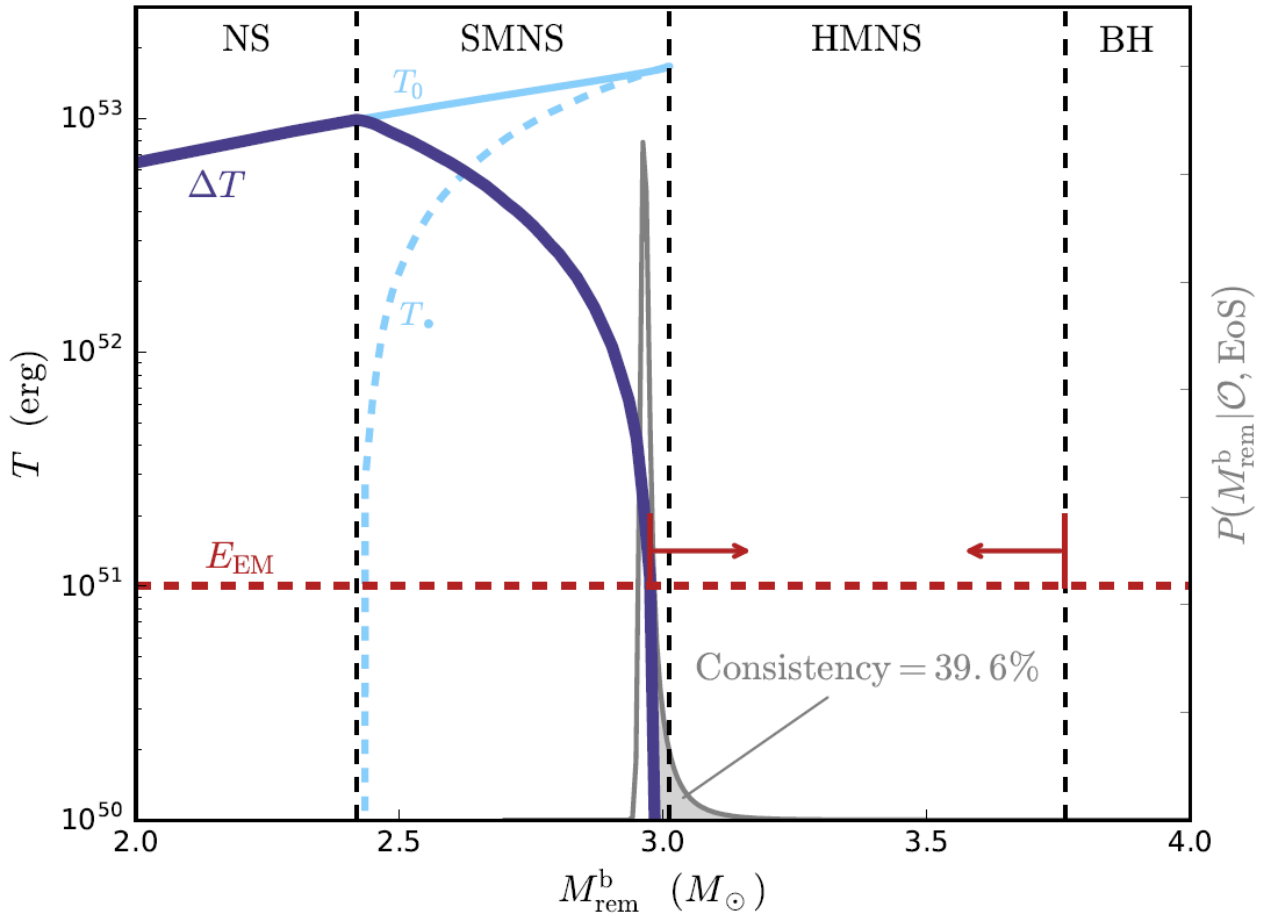
- merger remnant maximally rotating

$\Rightarrow \sim 10^{53}$ erg energy reservoir!

- for stable NS / SMNS - will be tapped by magnetic-dipole spindown

- EM spindown inconsistent with kilonova + GRB energetics

(BM & Metzger 2017)



GW170817 & the NS EOS (constraining $M_{\max}$)

Ben Margalit
Columbia University

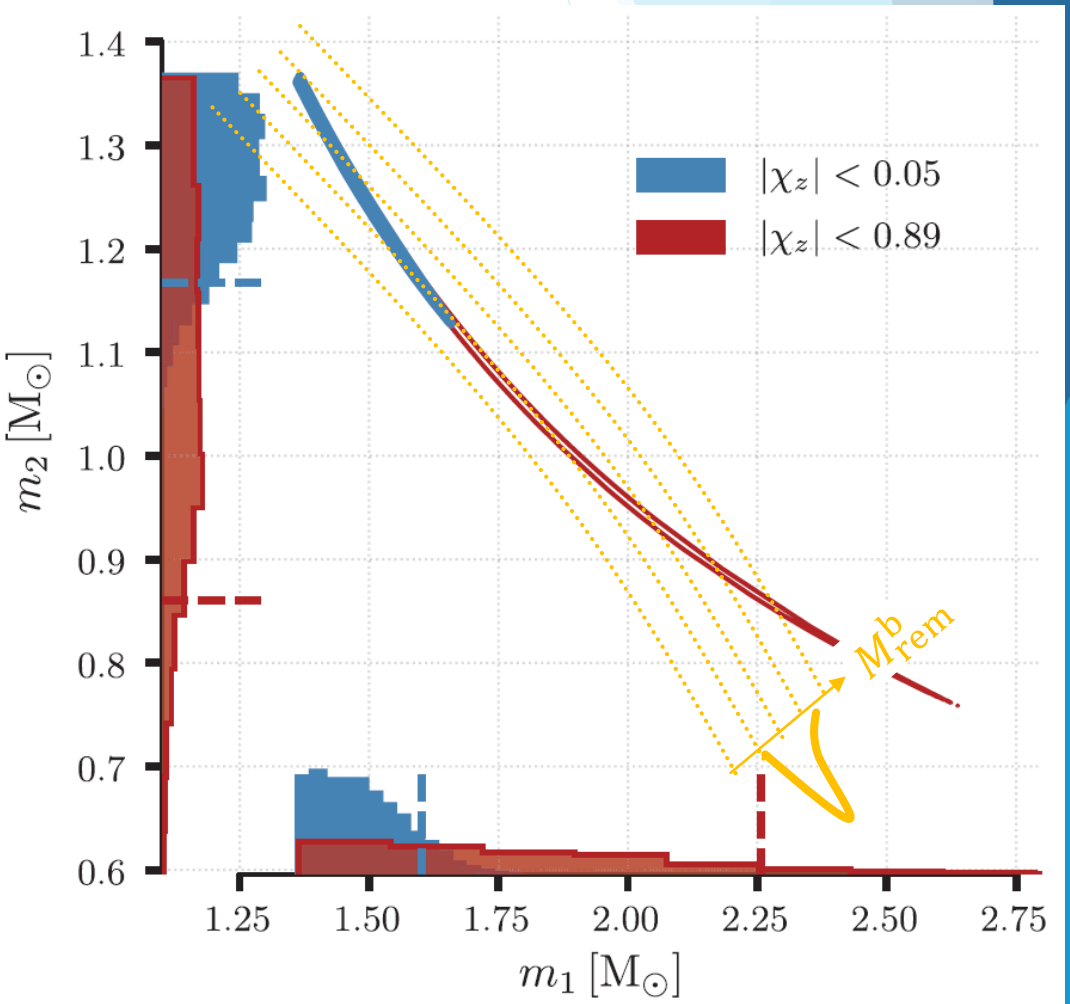
Consistency of given EOS:

- GW inferred $P(m_1^{\rm g}, m_2^{\rm g})$ implies, for a given EOS:

$$P(M_{\rm rem}^{\rm b}|{\rm EOS})$$

$$[M_{\rm rem}^{\rm b} \approx M^{\rm b}(m_1^{\rm g};{\rm EOS}) + M^{\rm b}(m_2^{\rm g};{\rm EOS}) - M_{\rm ej}]$$

(LIGO Virgo Collaboration 2017)



GW170817 & the NS EOS (constraining $M_{\rm max}$)

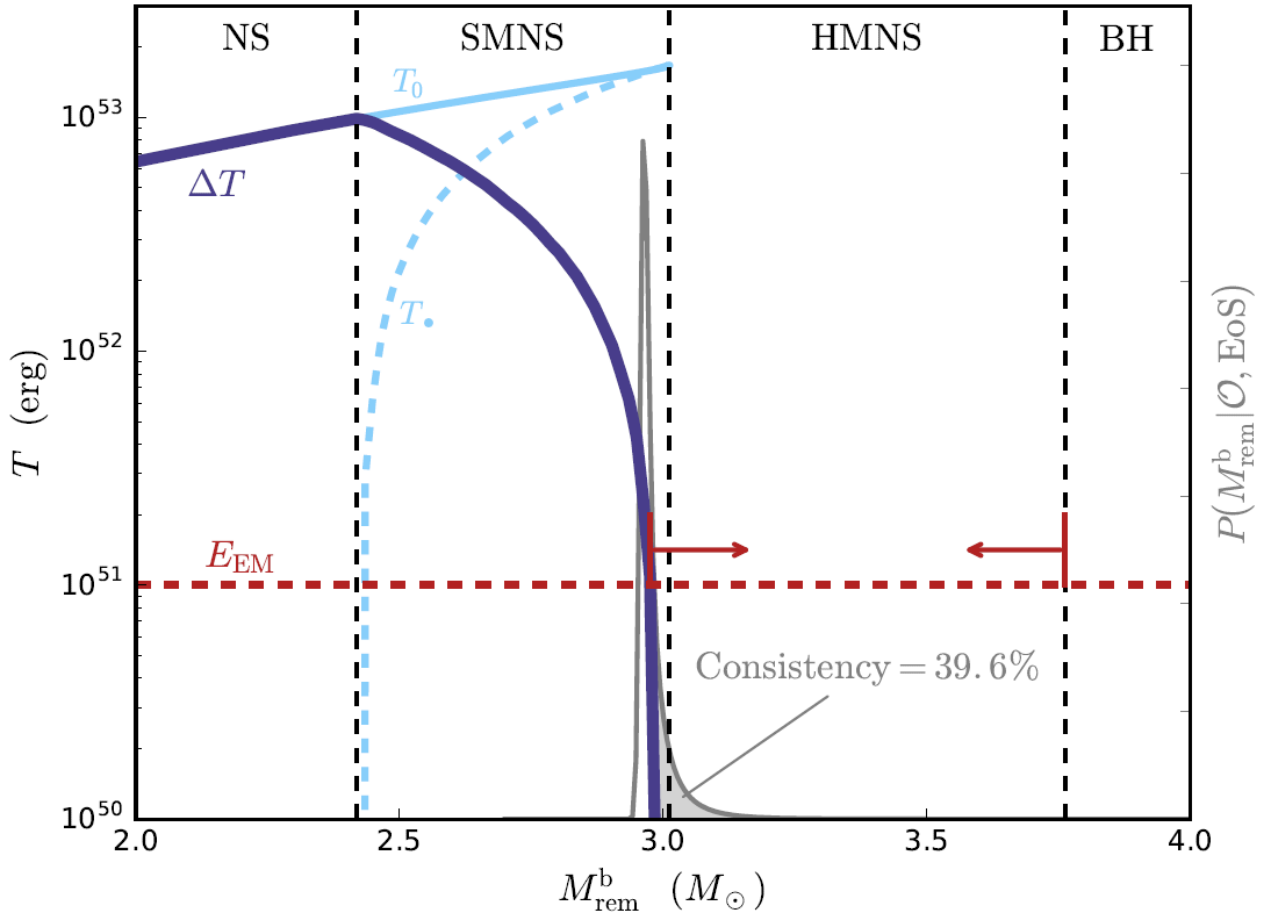
Ben Margalit
Columbia University

Consistency of given EOS:

- process:
  1. construct an EOS (Read+09; BM+15)
  2. create rotating NS sequences for EOS using RNS code (Stergioulas&Friedman95)

  ⇒ calculate: $M_{\rm max}$, $R_{1.3}$, ΔT, $M_{\rm thres}$ (Bauswein+13)
  3. get $P(M^{\rm b}_{\rm rem}|{\rm EOS})$

(BM & Metzger 2017)



GW170817 & the NS EOS (constraining $M_{\rm max}$)

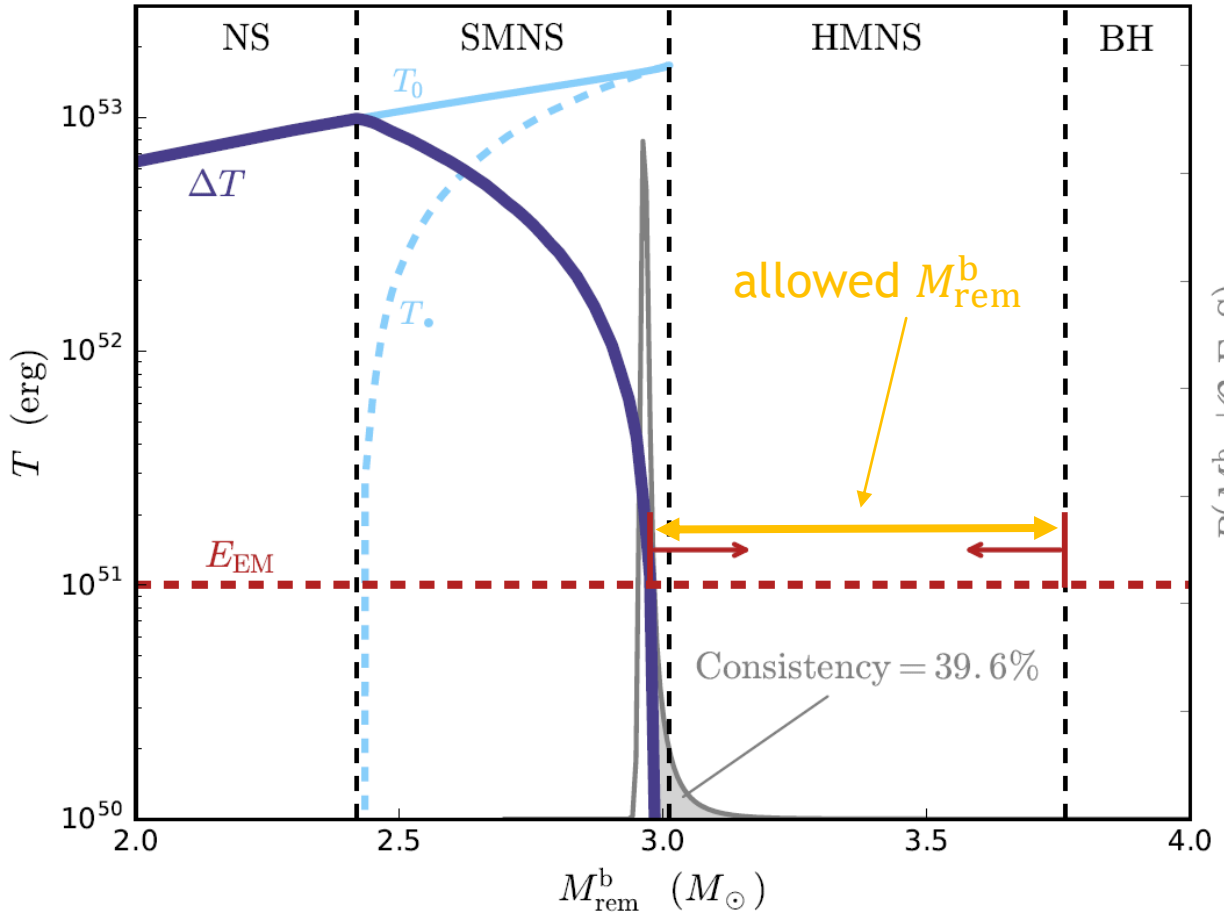
Ben Margalit
Columbia University

Consistency of given EOS:

(BM & Metzger 2017)

- process:
  1. construct an EOS (Read+09; BM+15)
  2. create rotating NS sequences for EOS using RNS code (Stergioulas&Friedman95)

  ⇒ calculate: $M_{\rm max}$, $R_{1.3}$, ΔT, $M_{\rm thres}$ (Bauswein+13)
  3. get $P(M^{\rm b}_{\rm rem}|{\rm EOS})$
  4. calculate EOS 'consistency'



GW170817 & the NS EOS (constraining $M_{\rm max}$)

Ben Margalit
Columbia University

(BM & Metzger 2017)

Results / EOS survey:

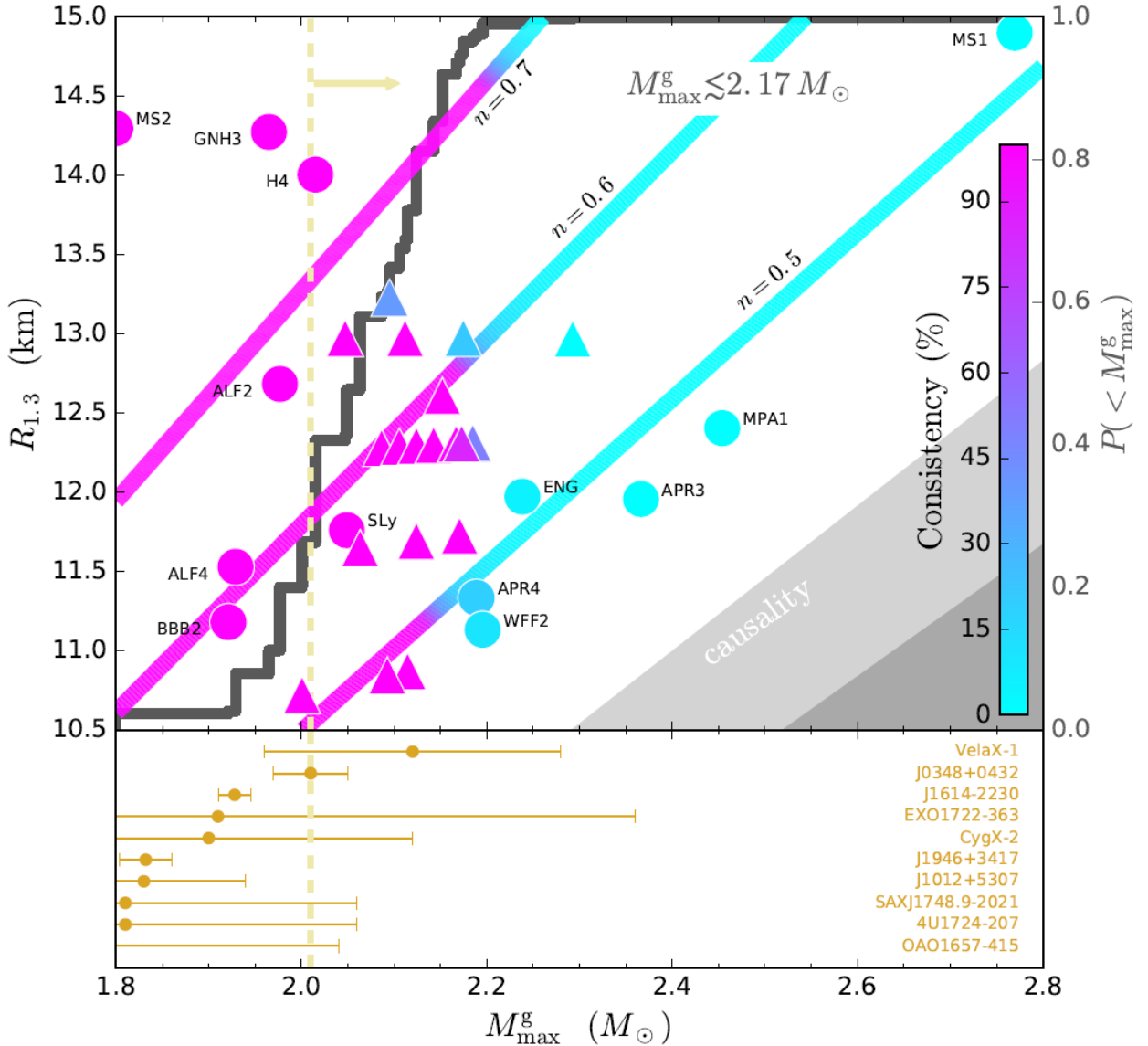
- rule out stiff EOS!
- largely independent on NS radius or compactness

  ⇒ constraint on $M_{\rm max}$

- find $M_{\rm max} < 2.17 M_\odot$ (90%)

[PSR J0348+0432: $M_{\rm max} \geq 2.01 \pm 0.04 M_\odot$]

(Antoniadis+13)



GW170817 & the NS EOS (constraining $M_{\rm max}$)

Ben Margalit
Columbia University

Results / EOS survey:

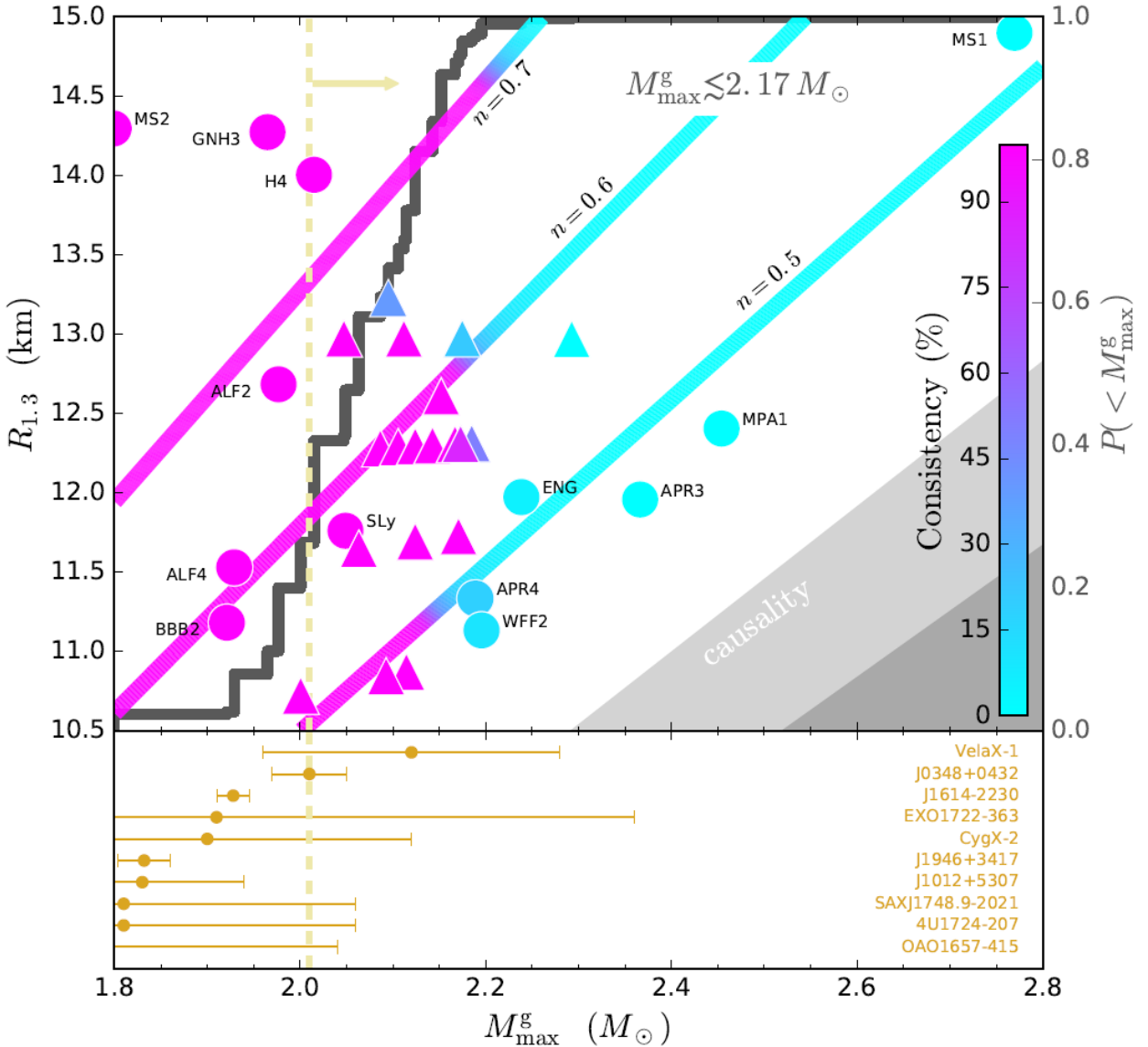
- simplistic analytic estimate of result:
  - $M^{\rm b} \approx M^{\rm g} + 0.058(M^{\rm g})^2 + 0.013(M^{\rm g})^3$

    (from Lattimer talk)
  - $\Rightarrow M^{\rm b}_{\rm rem} \lesssim M^{\rm b}_{\rm tot} \lesssim 3.07 M_\odot$

    (for $1.17 M_\odot$ + $1.60 M_\odot$ component masses)
  - $M^{\rm b}_{\rm smns} \approx 1.18 M^{\rm b}_{\rm max}$ (rotational support)
  - demand: $M^{\rm b}_{\rm smns} \lesssim M^{\rm b}_{\rm rem}$

$\Rightarrow M^{\rm g}_{\rm max} \lesssim 2.19 {\rm M}_\odot$ (for conservative $M_{\rm ej} = 0$)

(BM & Metzger 2017)



GW170817 & the NS EOS (constraining $M_{\rm max}$)

Ben Margalit
Columbia University

Conclusions:

- multi-messenger science is here!
- strong inferences from only single event
- future events may probe different regimes (e.g. high $M_{\rm tot}$ binary with similar EM counterpart ⇒ lower limit on $M_{\rm max}$)
- maximal mass not much above $2M_\odot$, $2.01M_\odot \lesssim M_{\rm max} \lesssim 2.17M_\odot$
- derived from simple energetic arguments

(Ozel & Freire 2016)