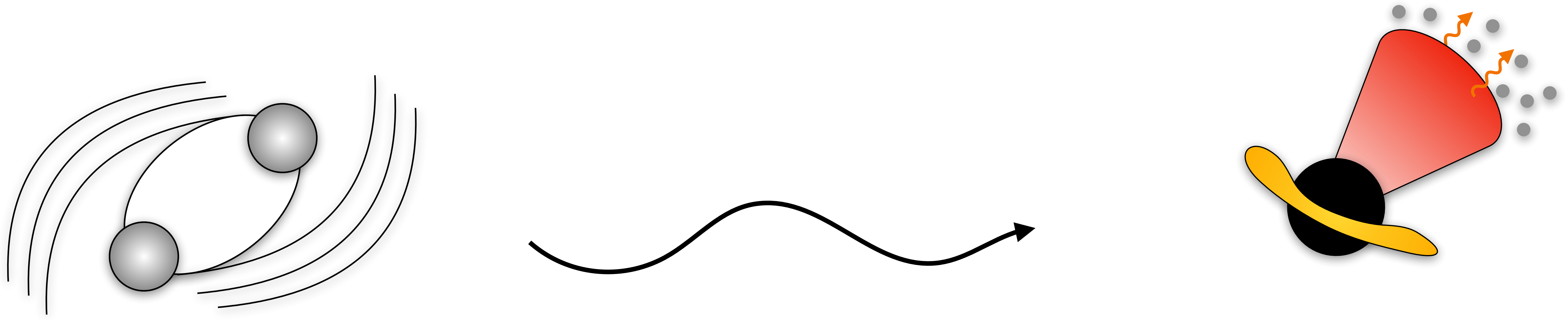
Constraints on the binary neutron star mass distribution and equation of state based on the incidence of jets in the population

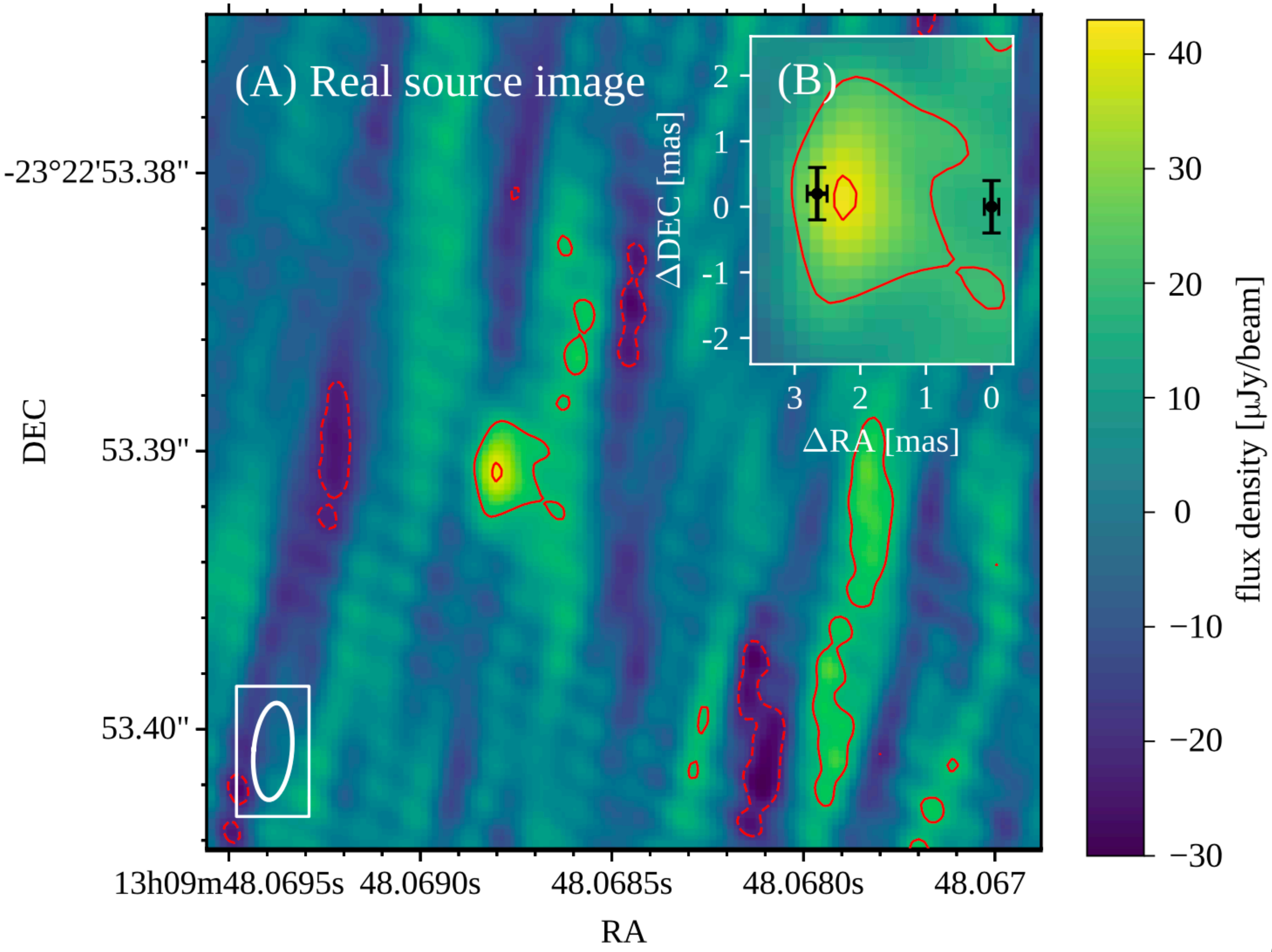


Om Sharan Salafia, Alberto Colombo, Francesco Gabrielli, Ilya Mandel

Astronomy & Astrophysics (2022), arXiv:2202.01656

Gemma2

GW170817 had a successful jet



Ghirlanda et al. (2019)
See also Mooley+18

Jet fraction from observations

Jet fraction from observations

+

Modeling the jet launch

Jet fraction from observations

+

Modeling the jet launch

Constraining the BNS mass distribution and EoS

Jet fraction in the GW-detectable BNS population

Jet fraction in the GW-detectable BNS population

Binomial likelihood:

$$P(k \,|\, n, f_{\mathrm{j,GW}}) = f_{\mathrm{j,GW}}^{k}(1 - f_{\mathrm{j,GW}})^{n-k}$$

Bayes Theorem:

$$P(f_{\mathrm{j,GW}} \,|\, k, n) \propto P(k, n \,|\, f_{\mathrm{j,GW}})\pi(f_{\mathrm{j,GW}})$$

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GW170817:

$$n = 1, k = 1$$

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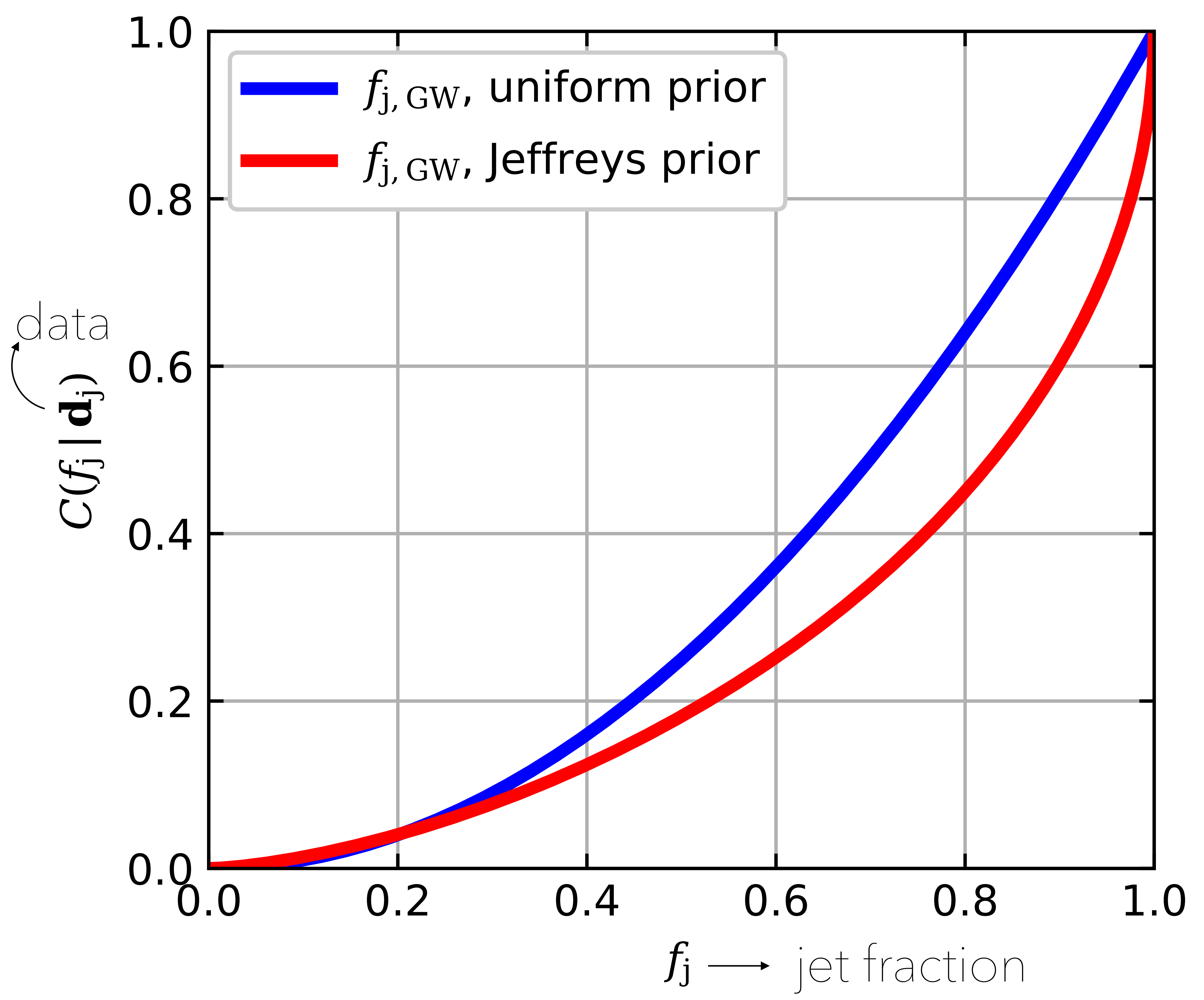

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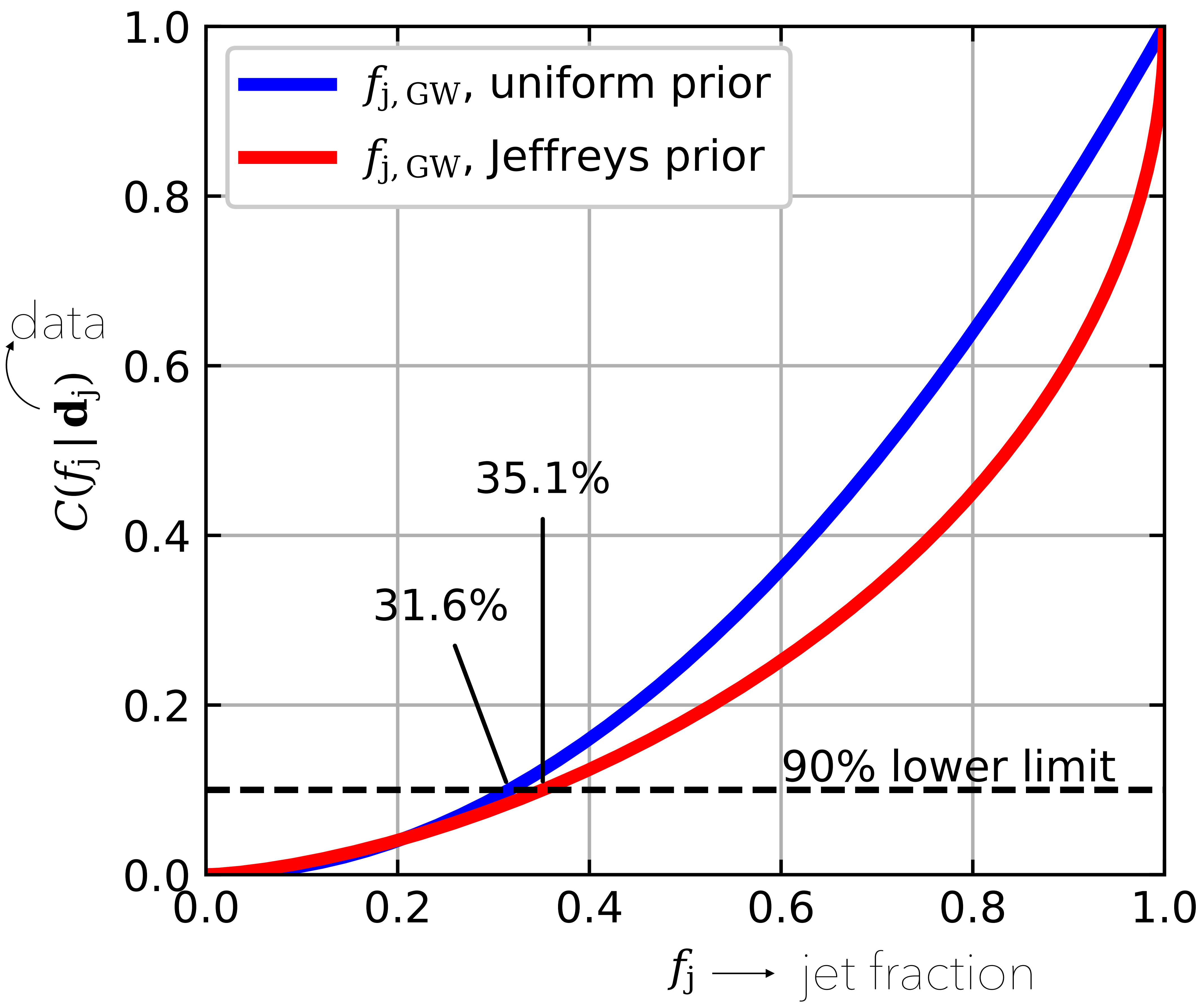

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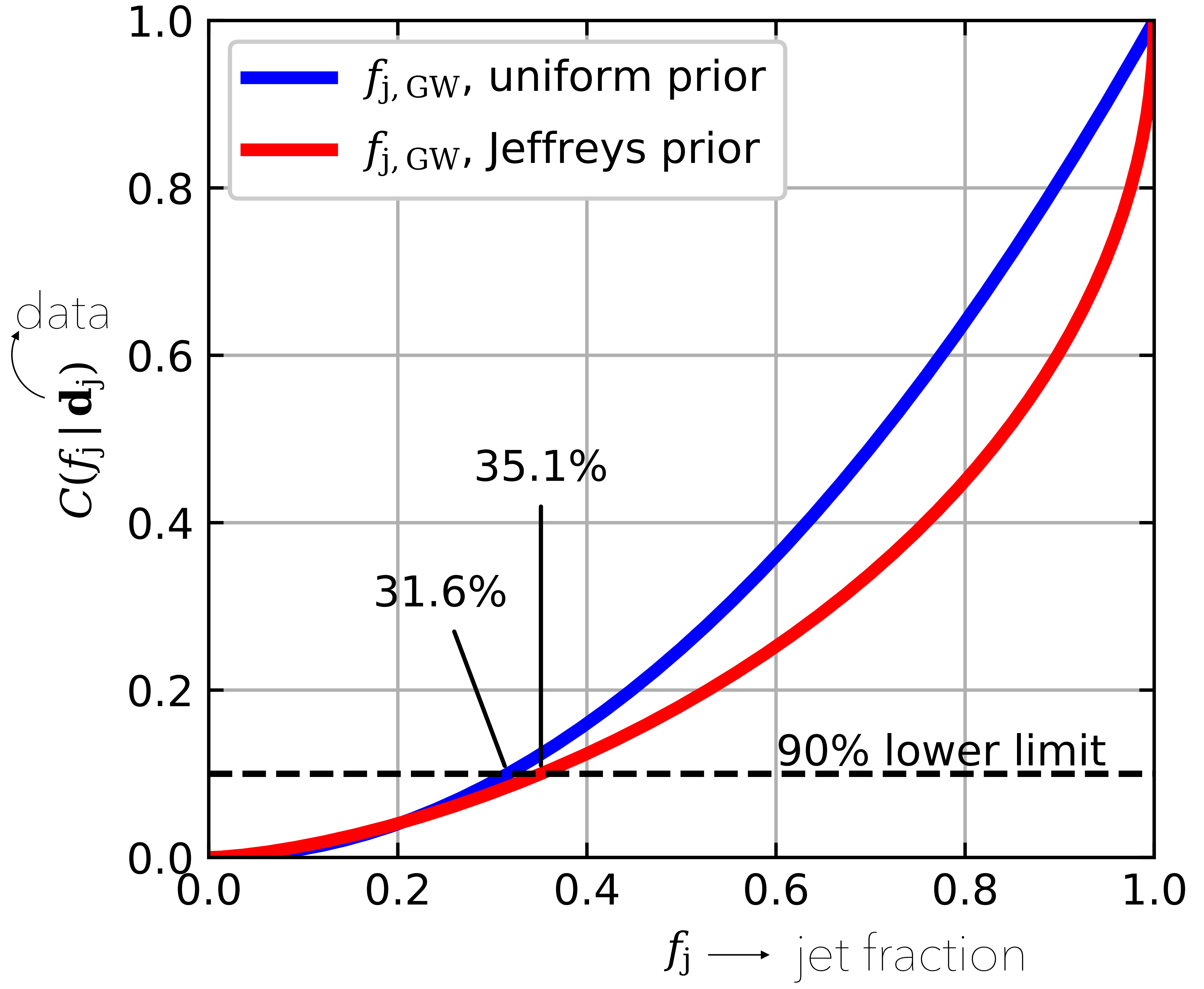
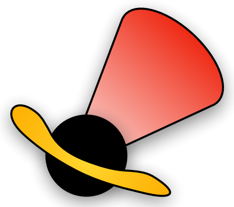


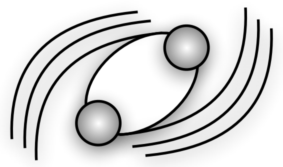
At least the 30% should have a jet!

Jet fraction in whole the BNS population

Jet fraction in whole the BNS population

local rate of SGRB 

$$f_{\rm j} = R_{0,\rm SGRB}/R_{0,\rm BNS}$$

local rate of BNS mergers 

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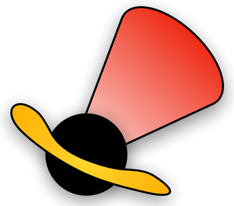

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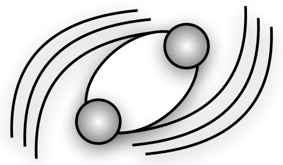

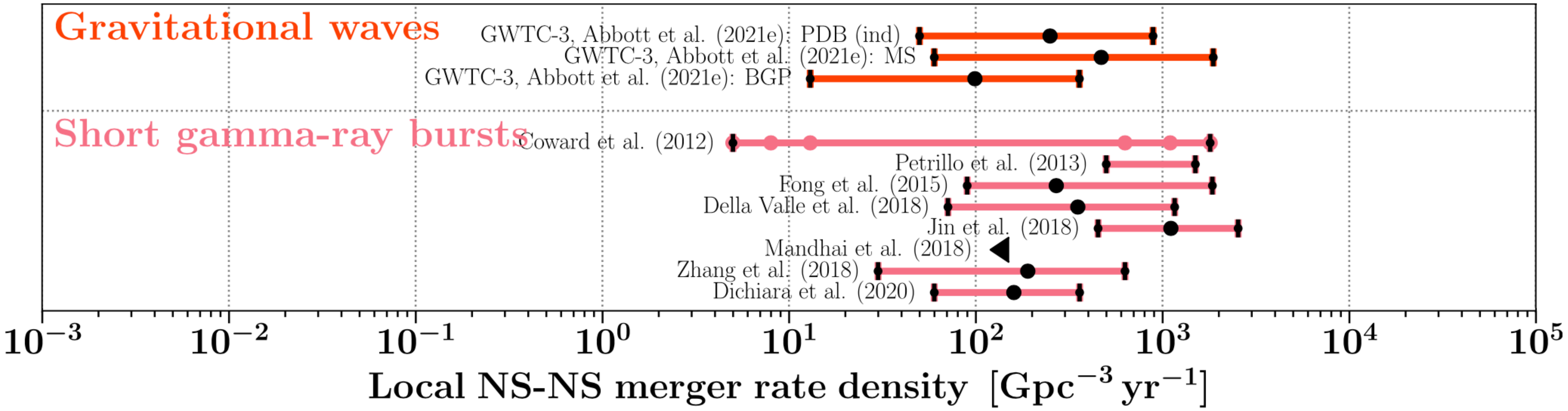

Mandel&Broekgaarden(2021)

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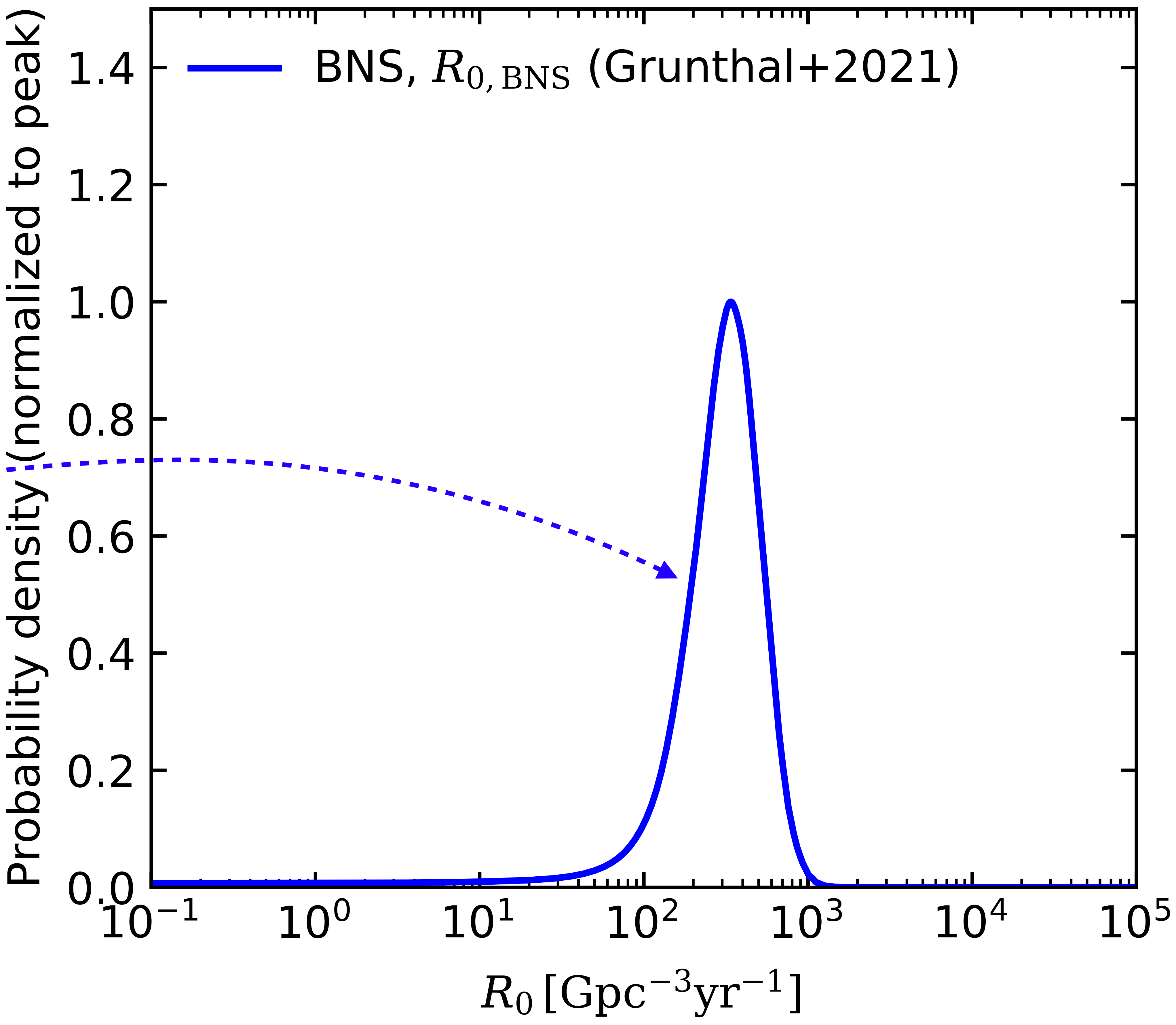

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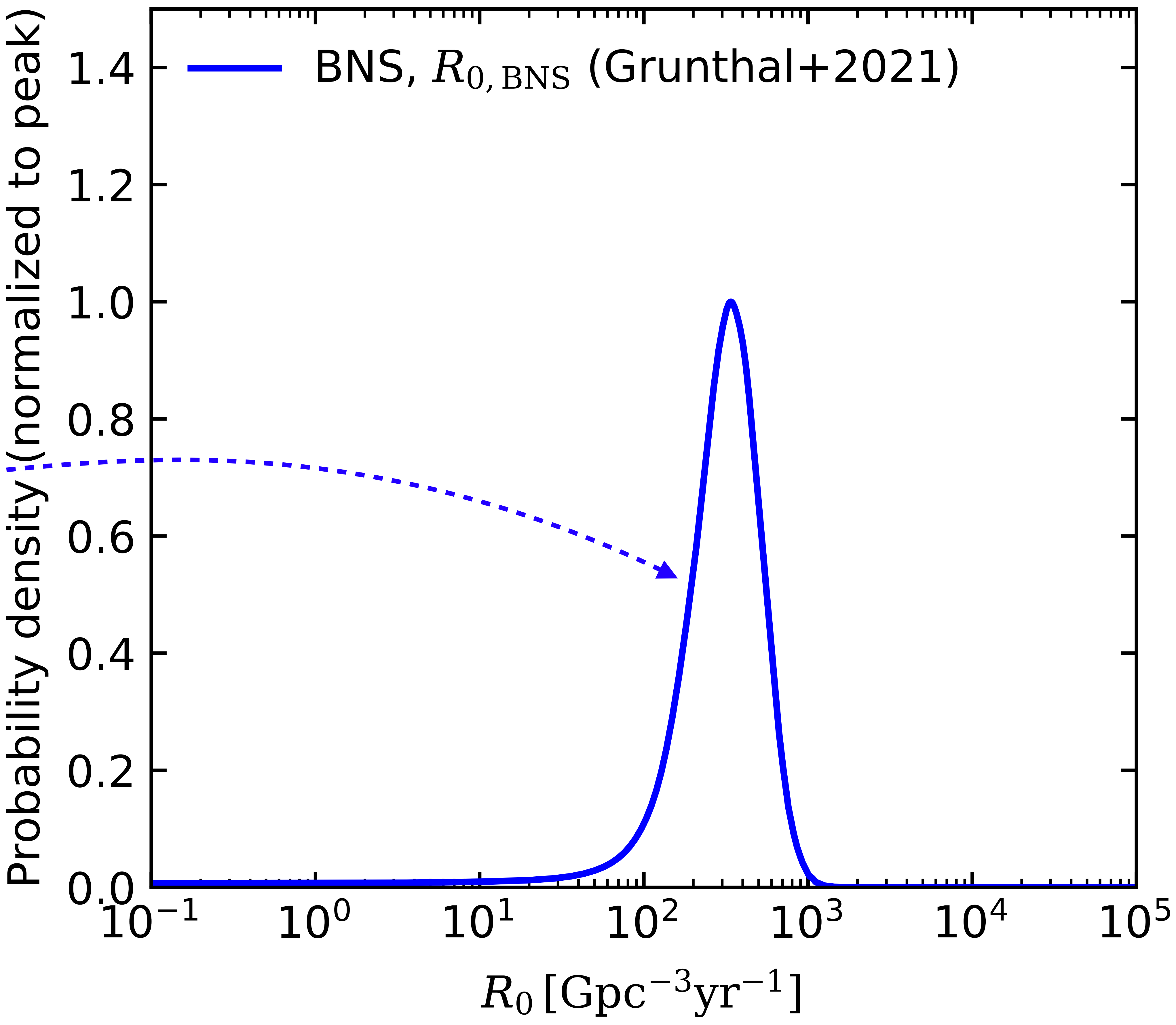
Fermi/GBM sensitivity model

↓

Single-event rate of GRB170817A

↓

Strict lower limit to SGRB rate



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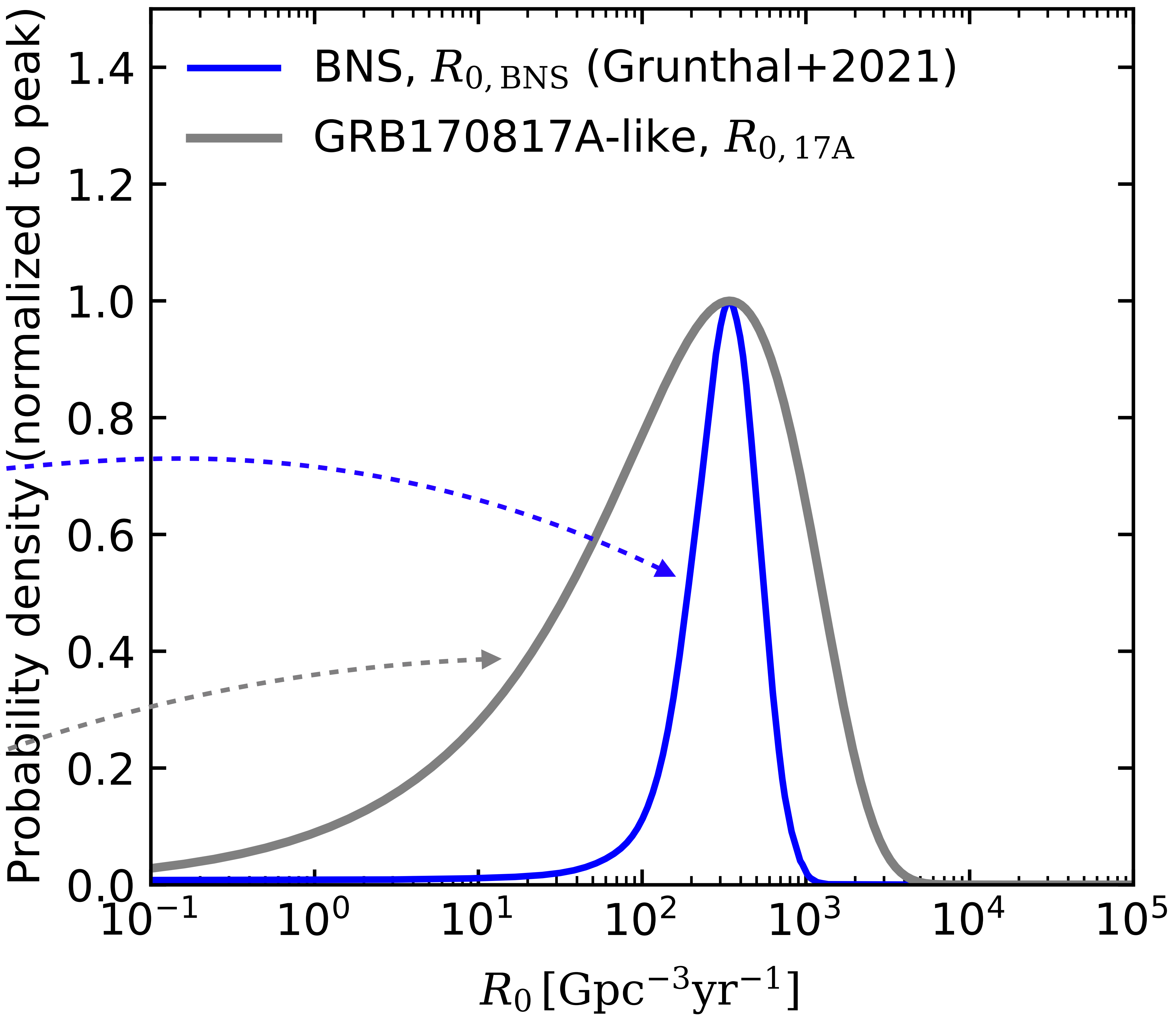

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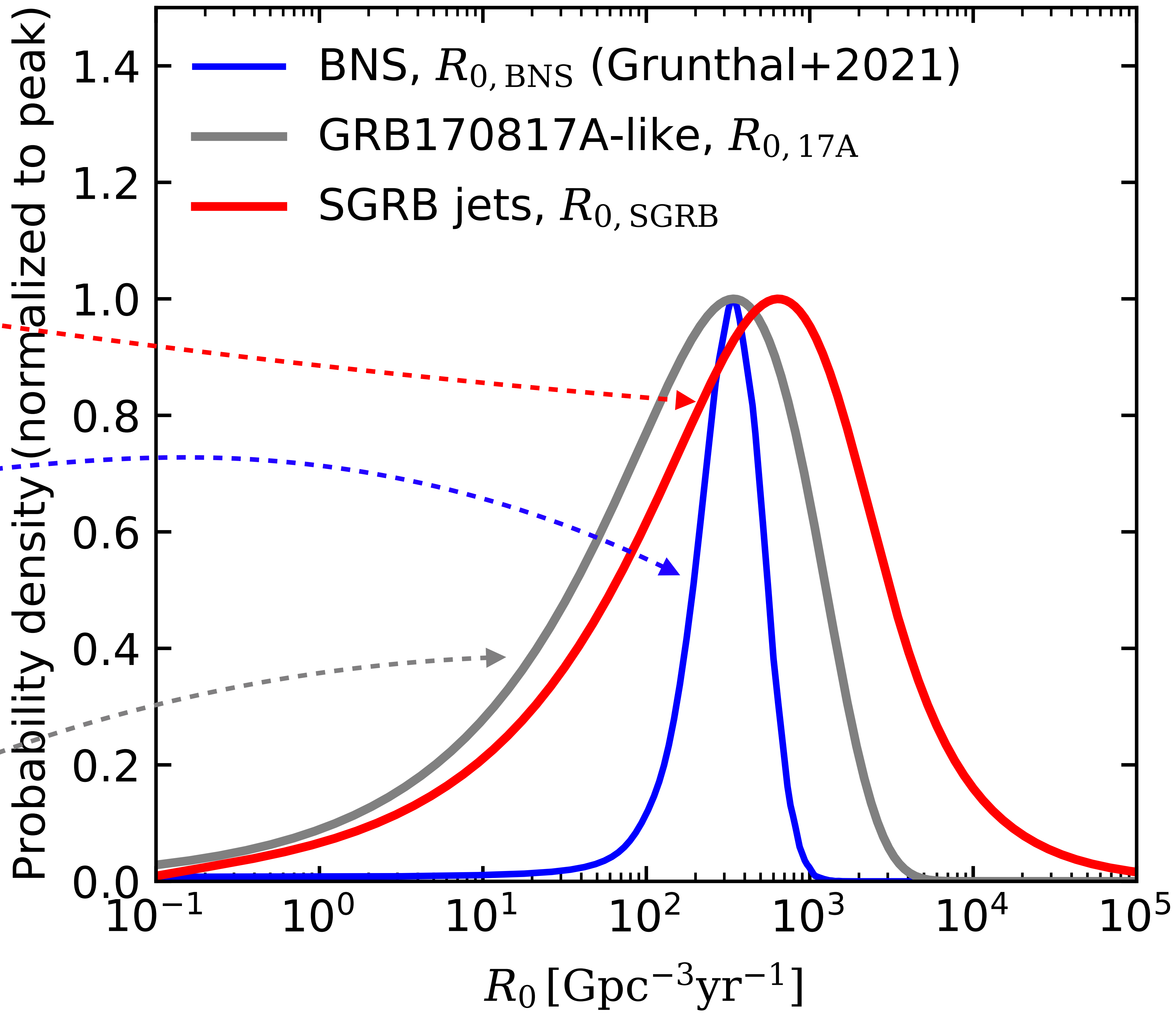
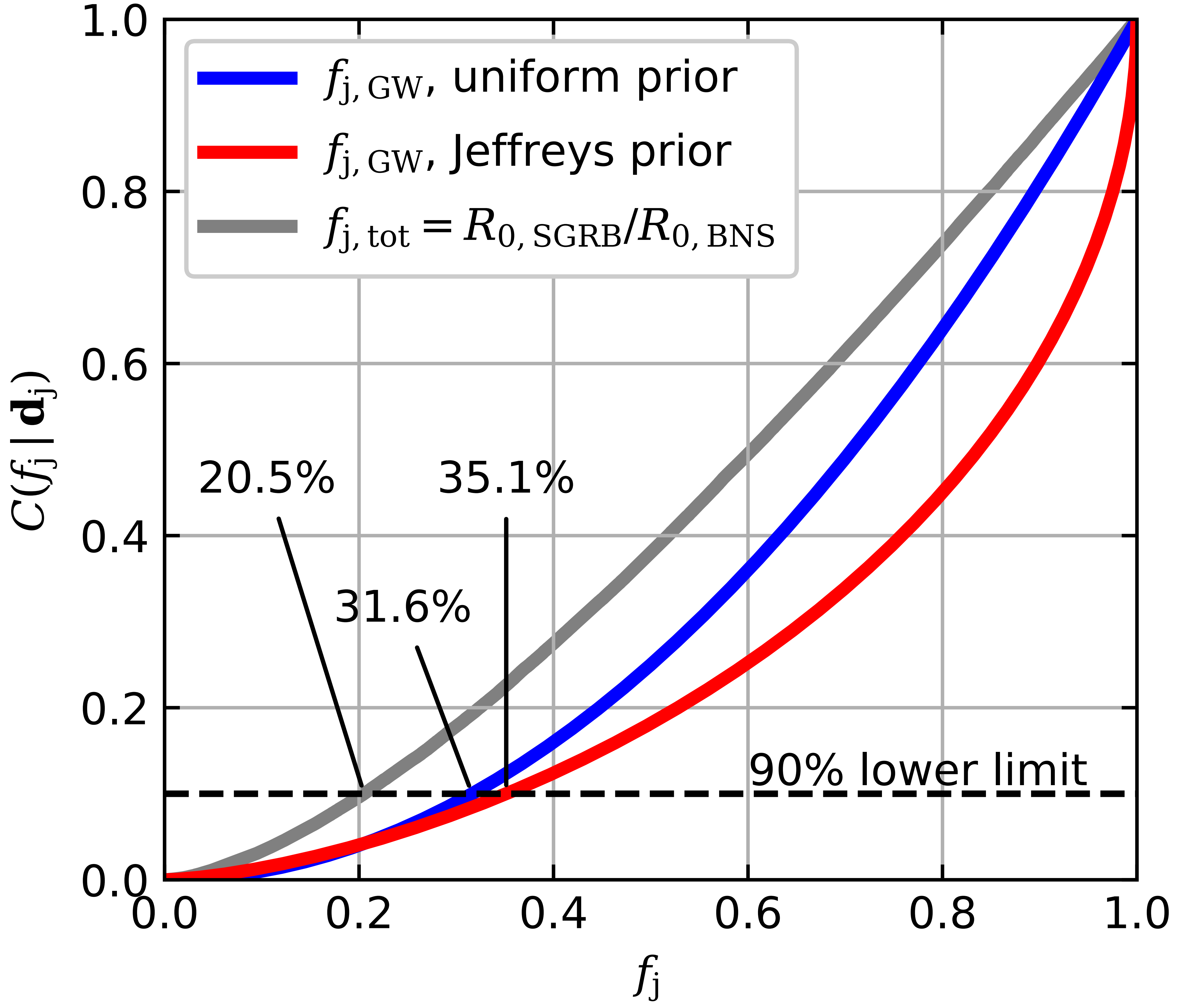
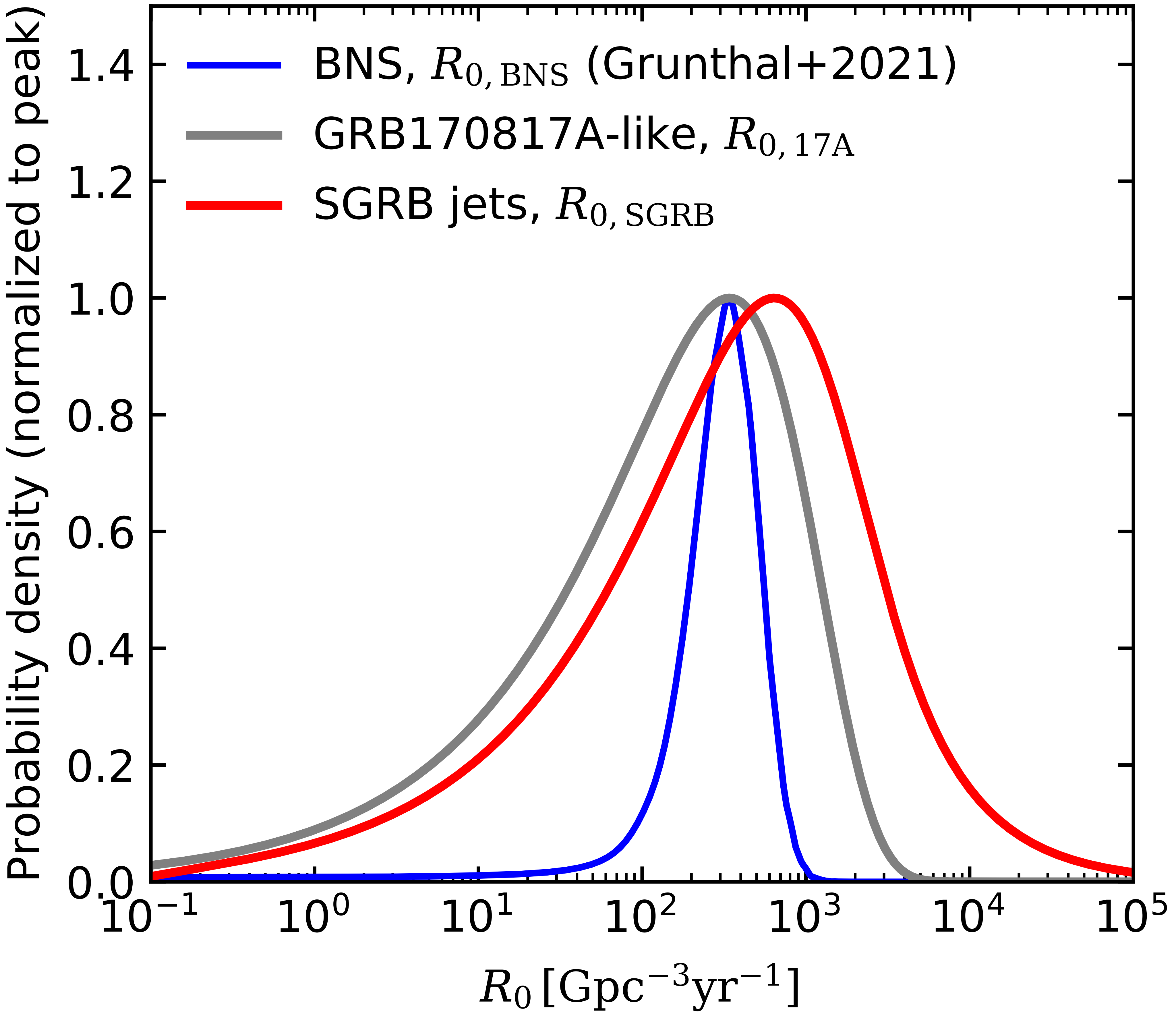


Jet fraction in whole the BNS population





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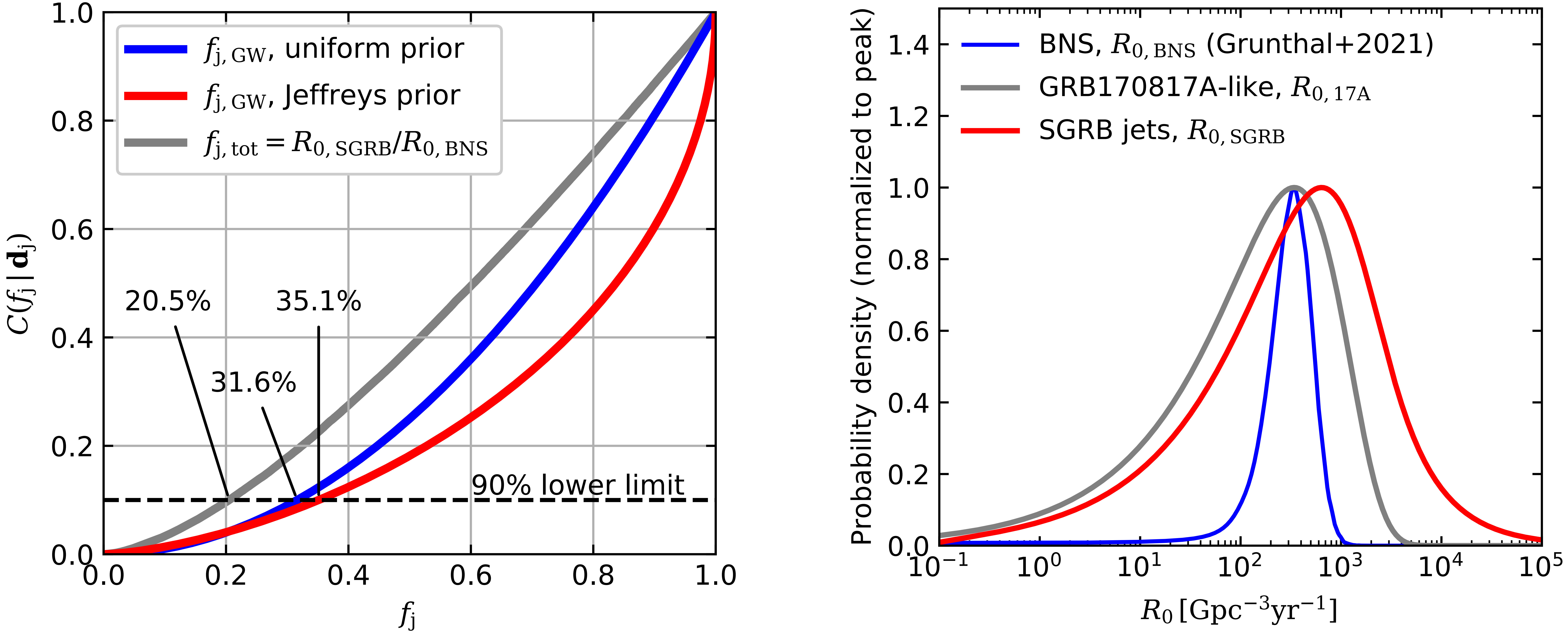


At least the 20% should have a jet!

✓ Jet fraction from observations

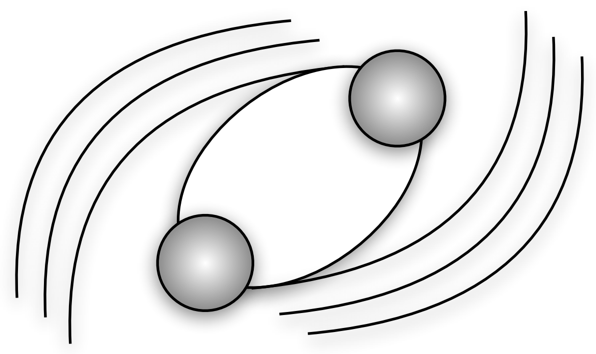
\+

Modeling the jet launch

}

Constraining the BNS mass distribution and EoS

The launch of a relativistic jet



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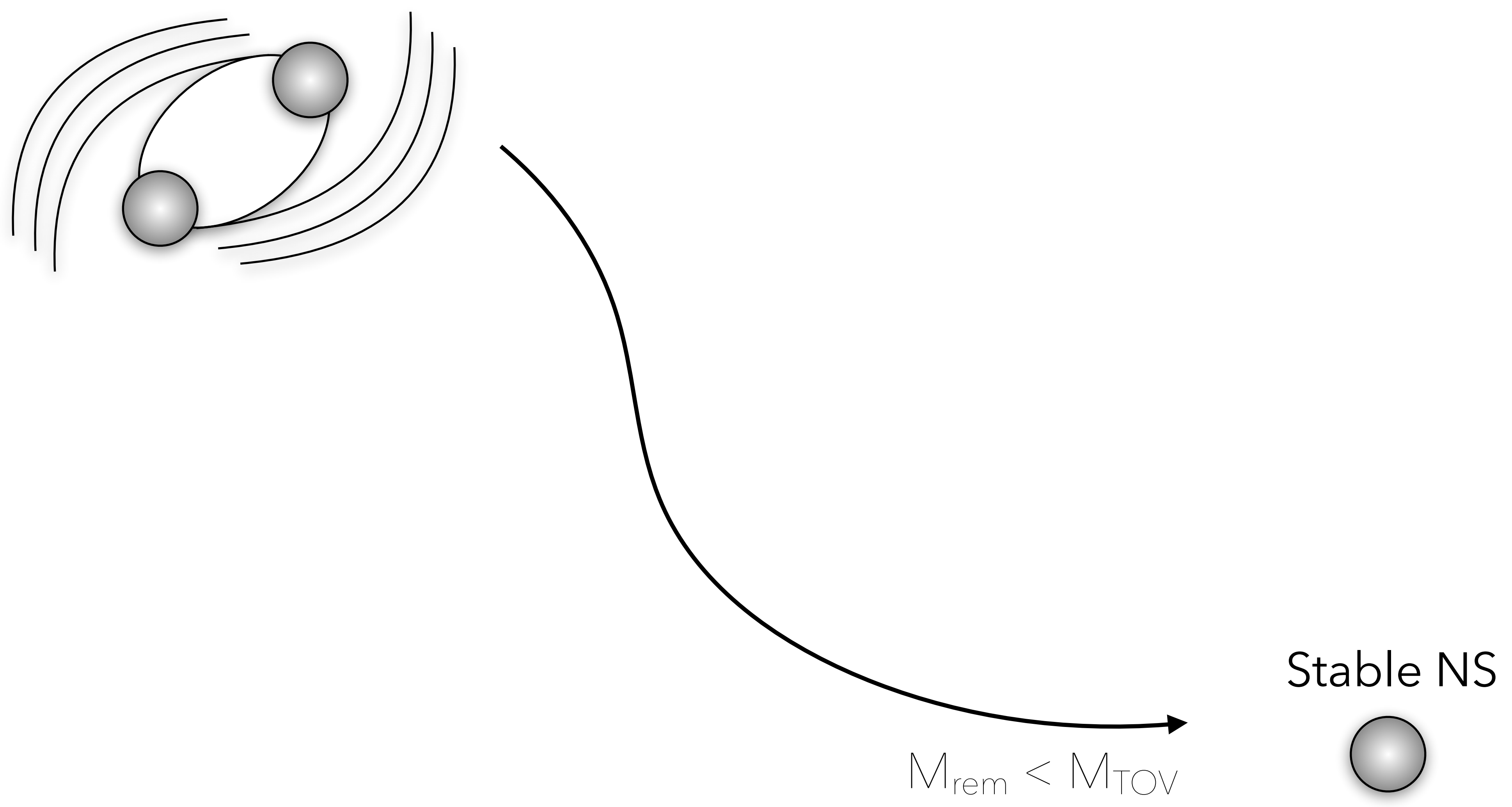

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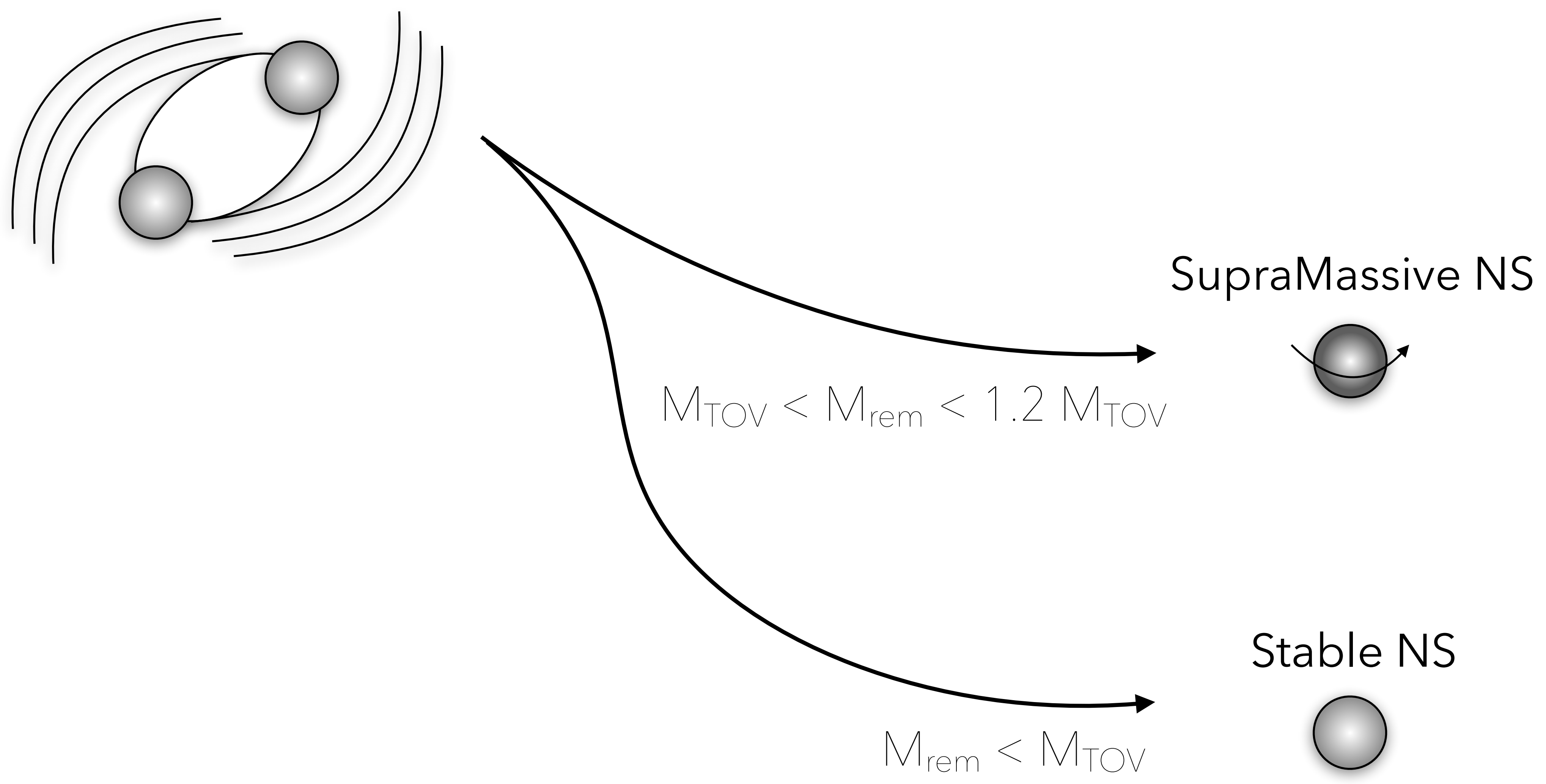

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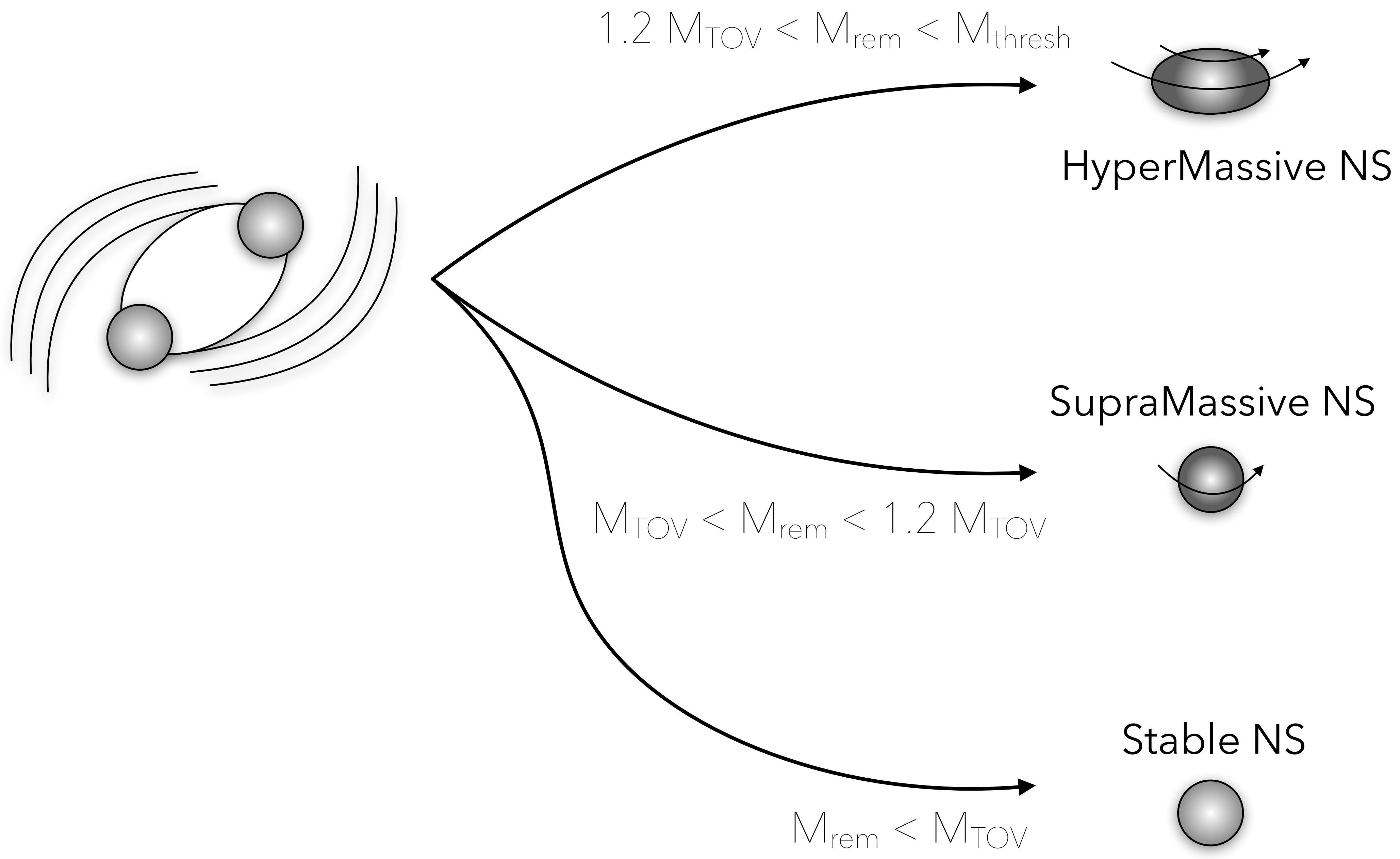

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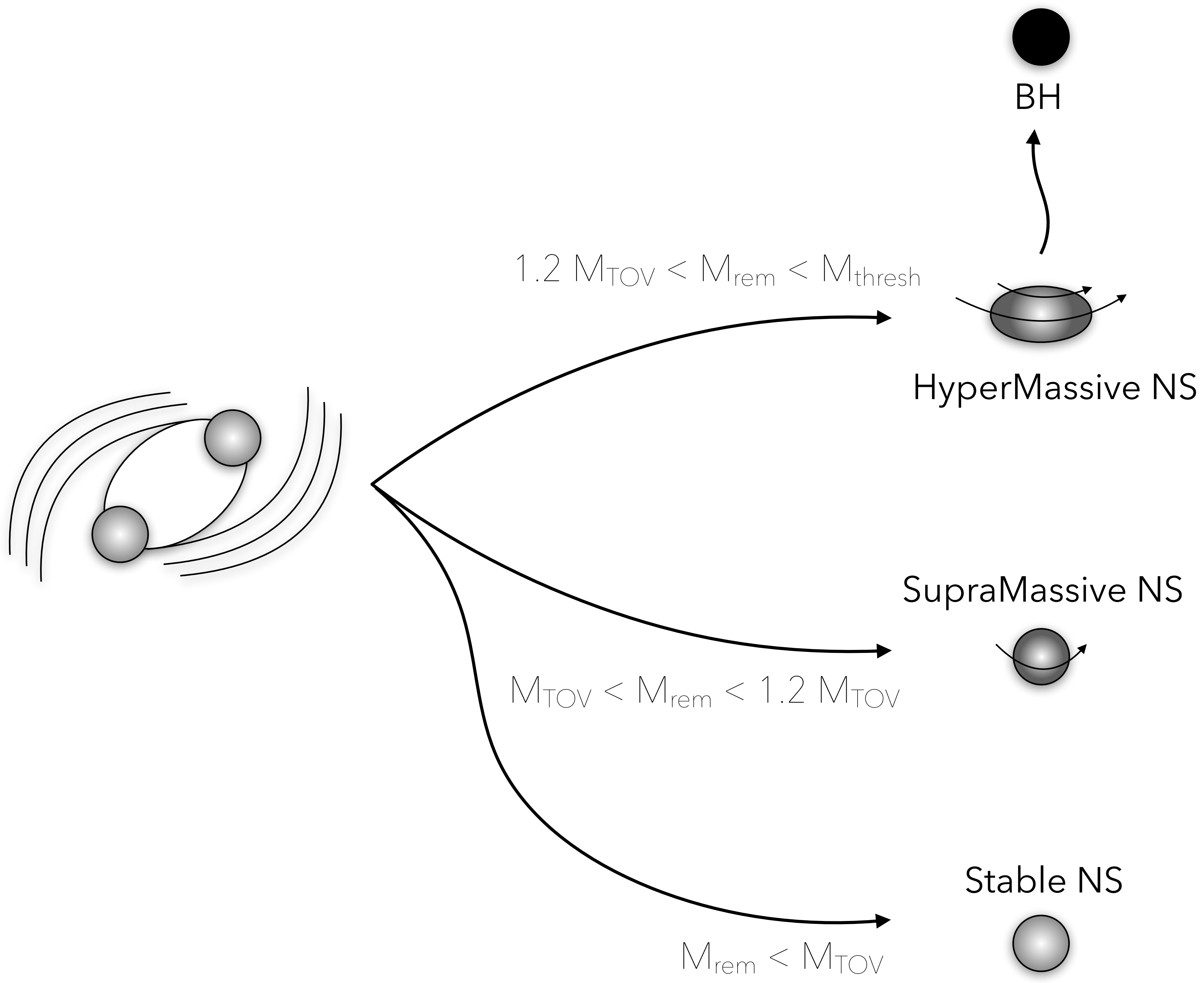

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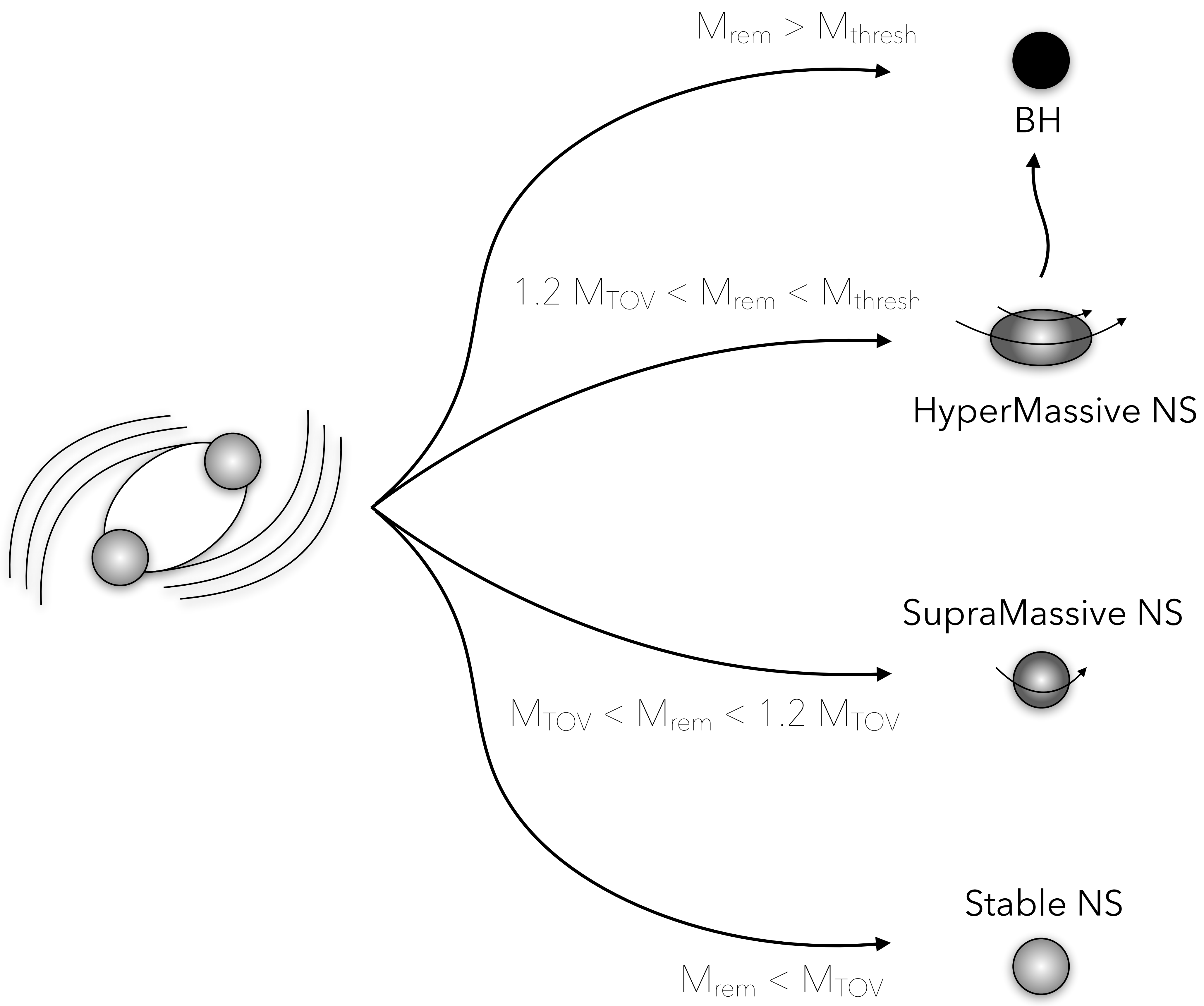

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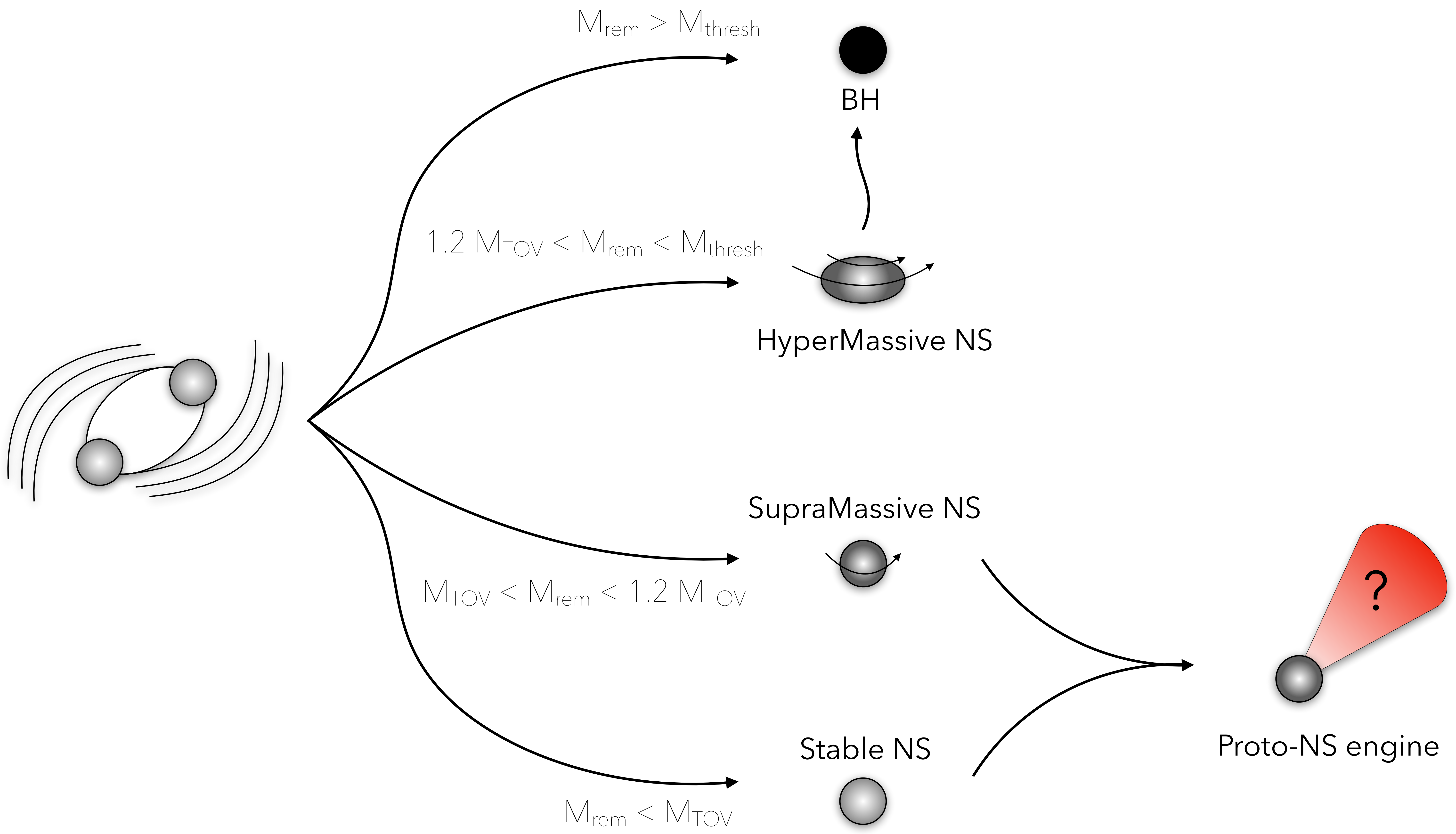

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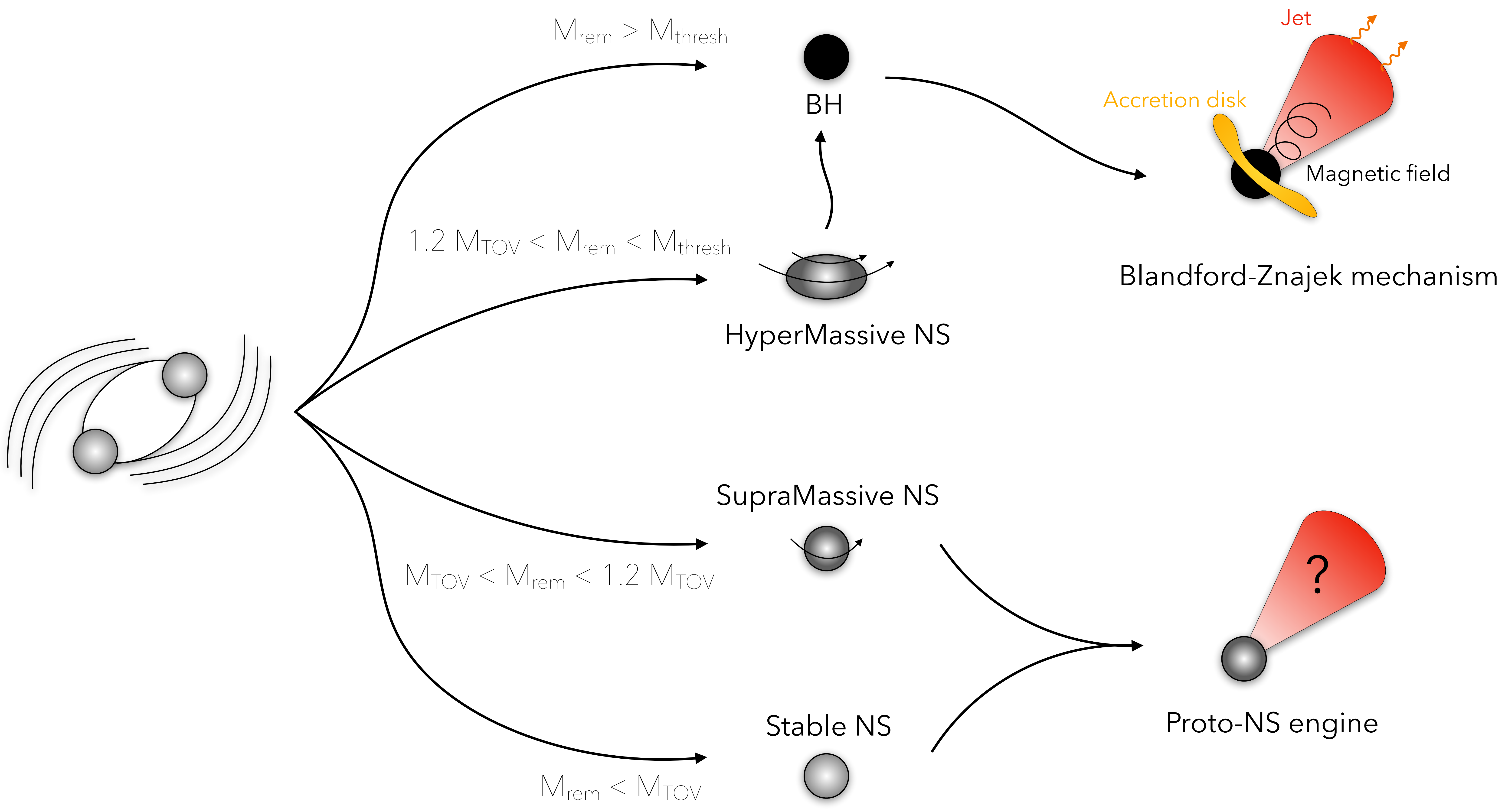

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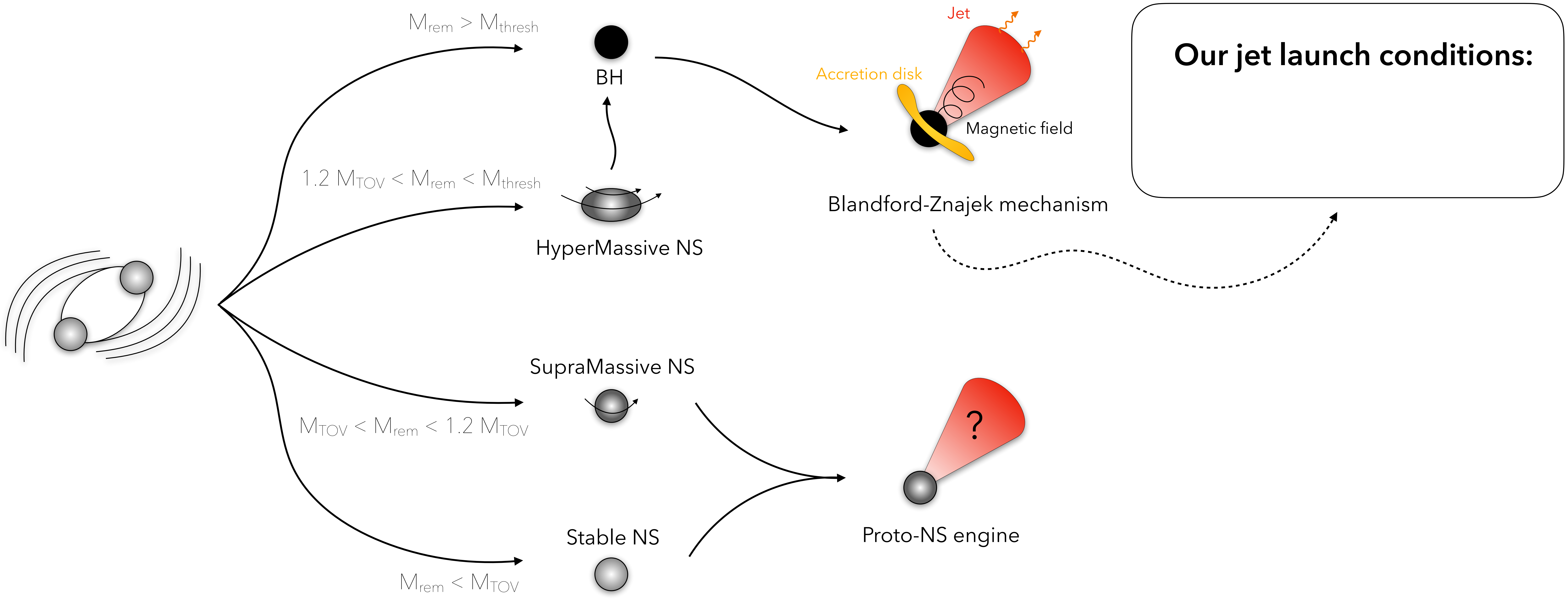

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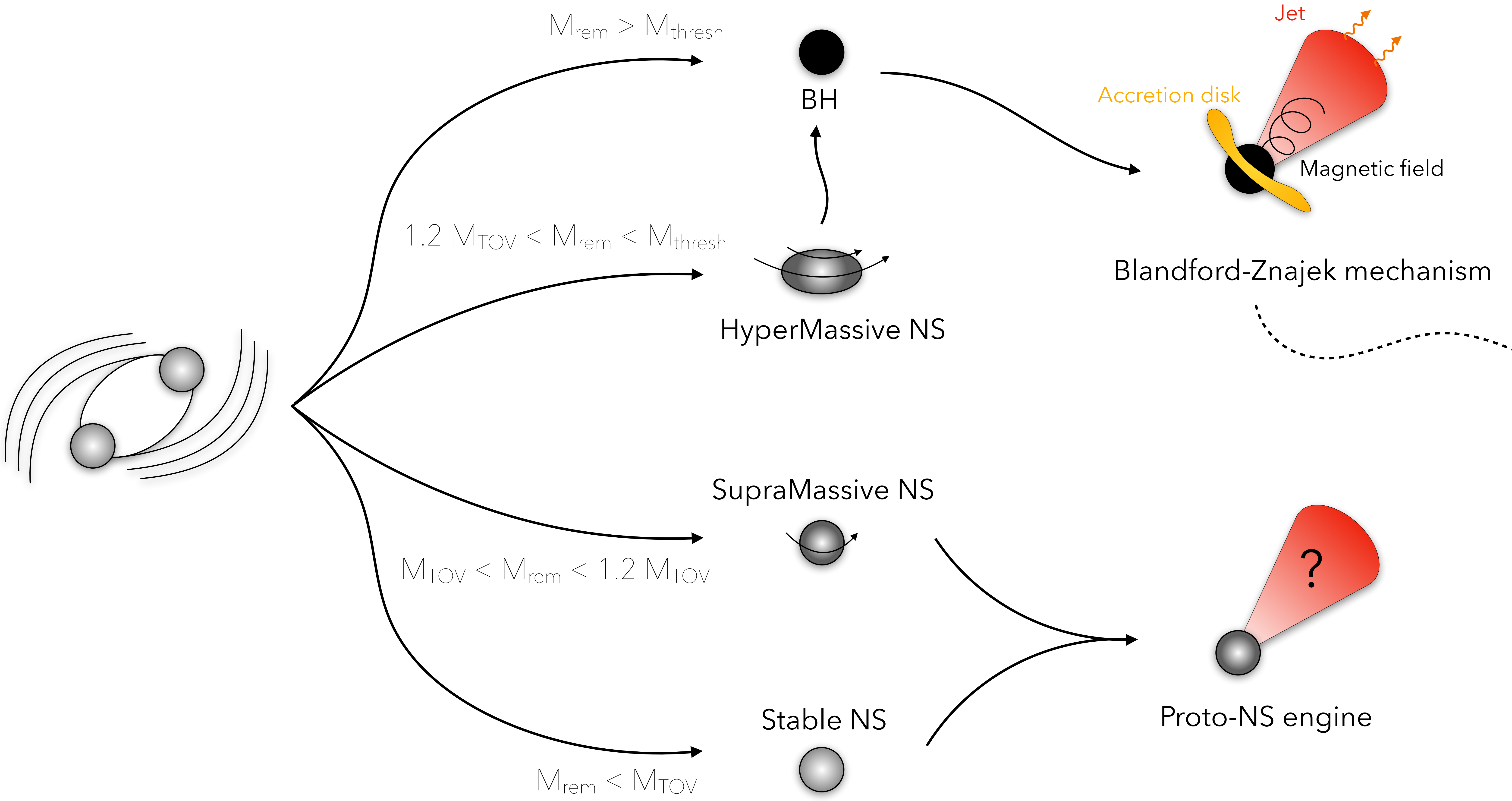
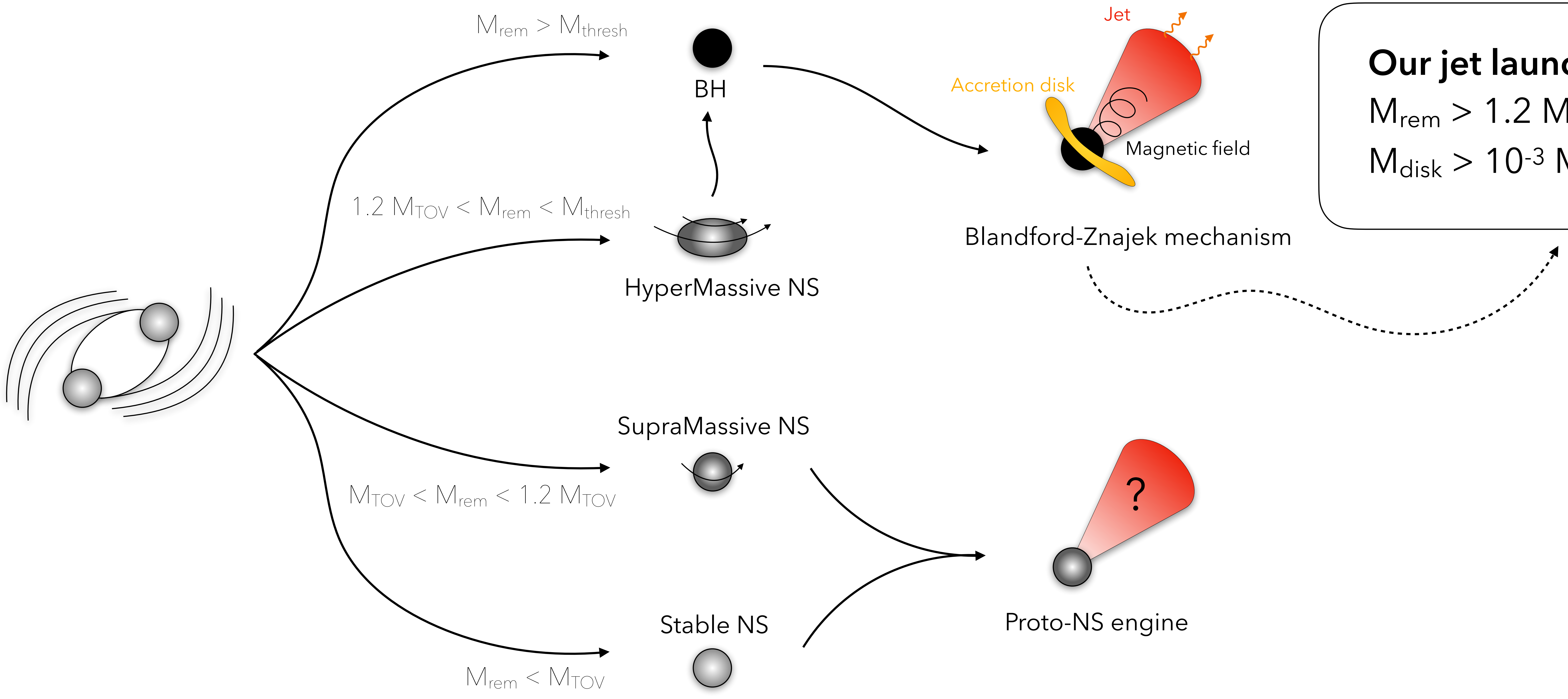


Our jet launch conditions:

$M_{rem} > 1.2\ M_{TOV}$

The launch of a relativistic jet



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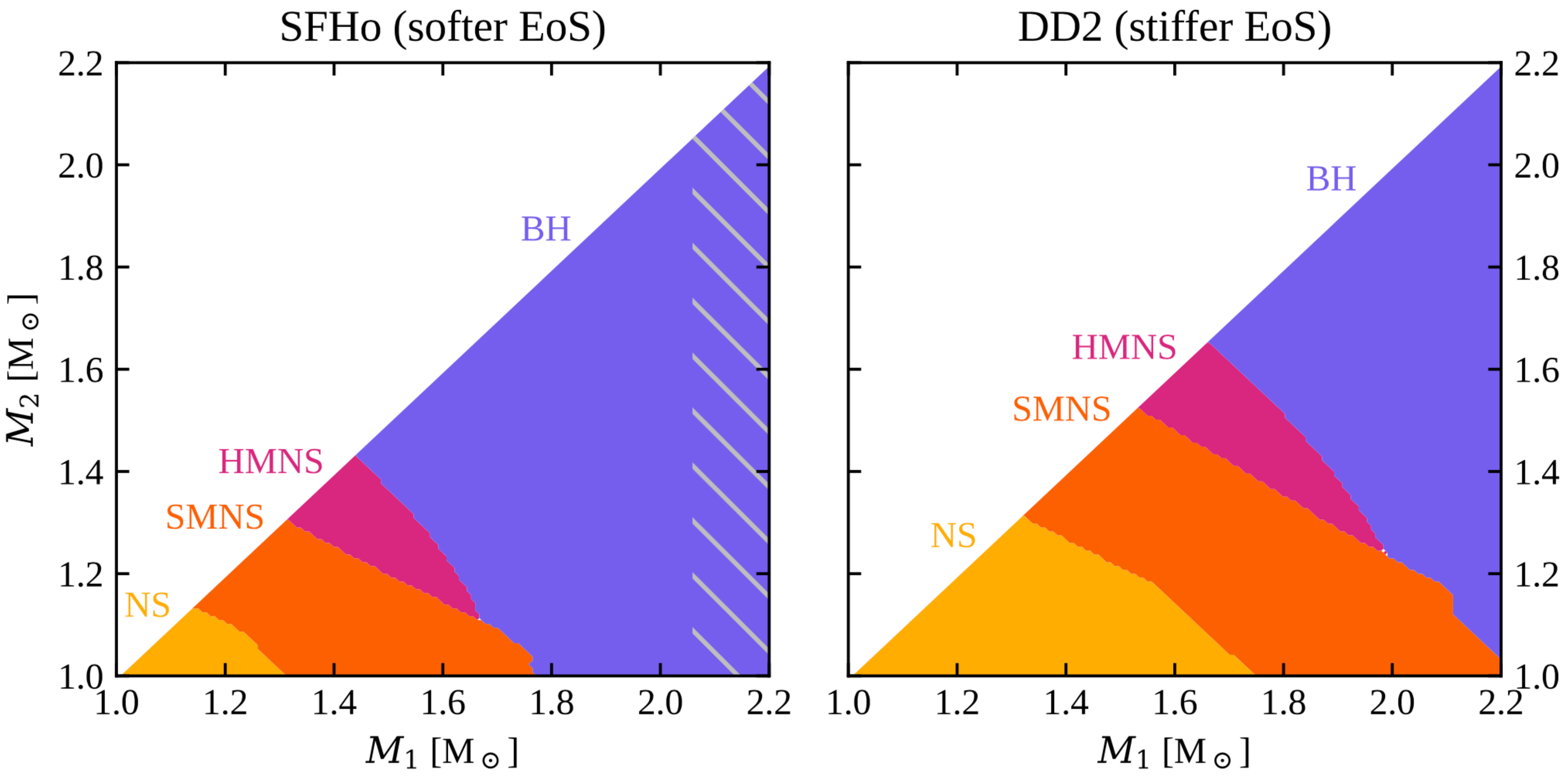
$M_{disk} > 10^{-3}\ M_{\odot}$

BNS merger remnants



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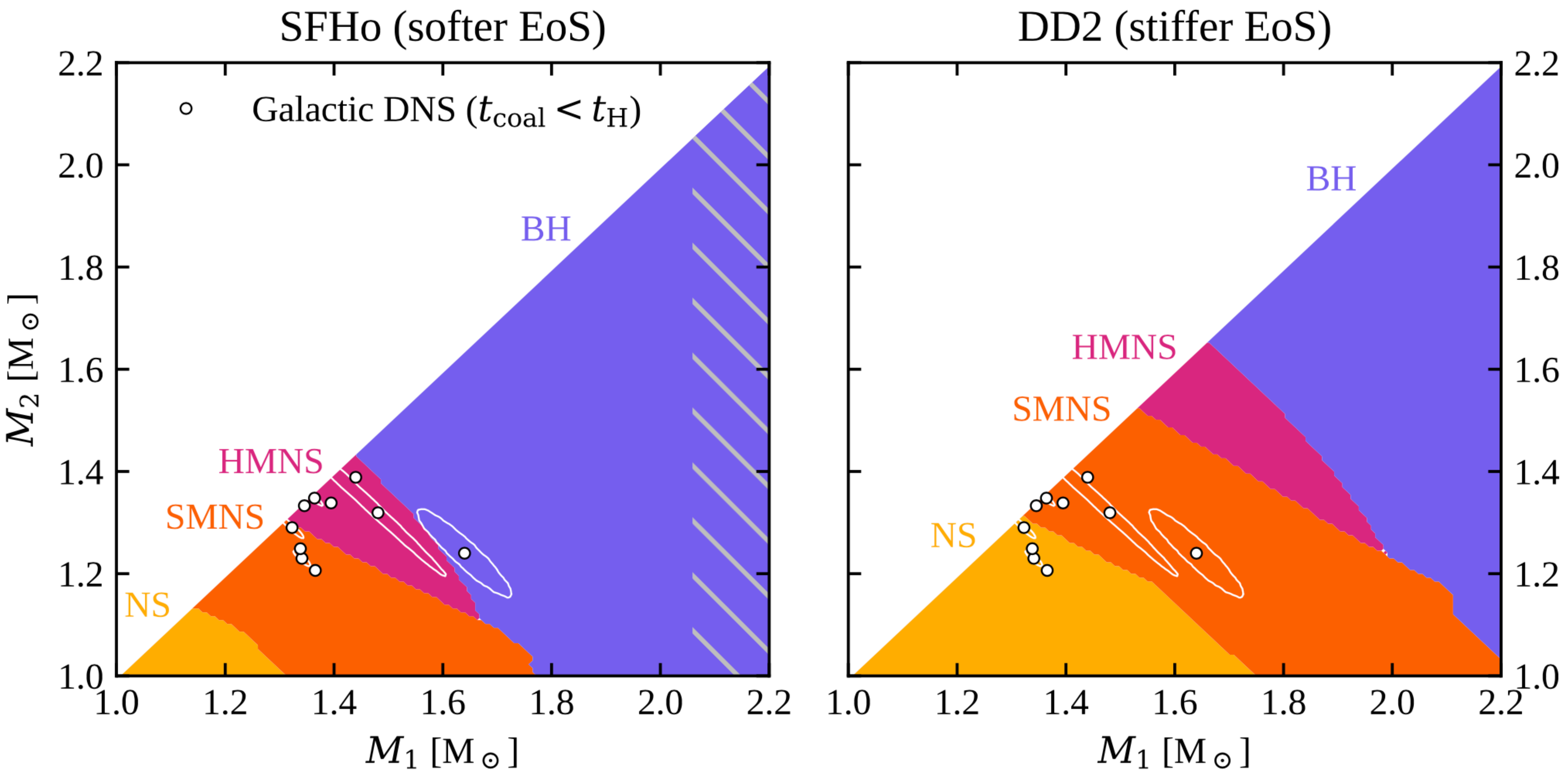
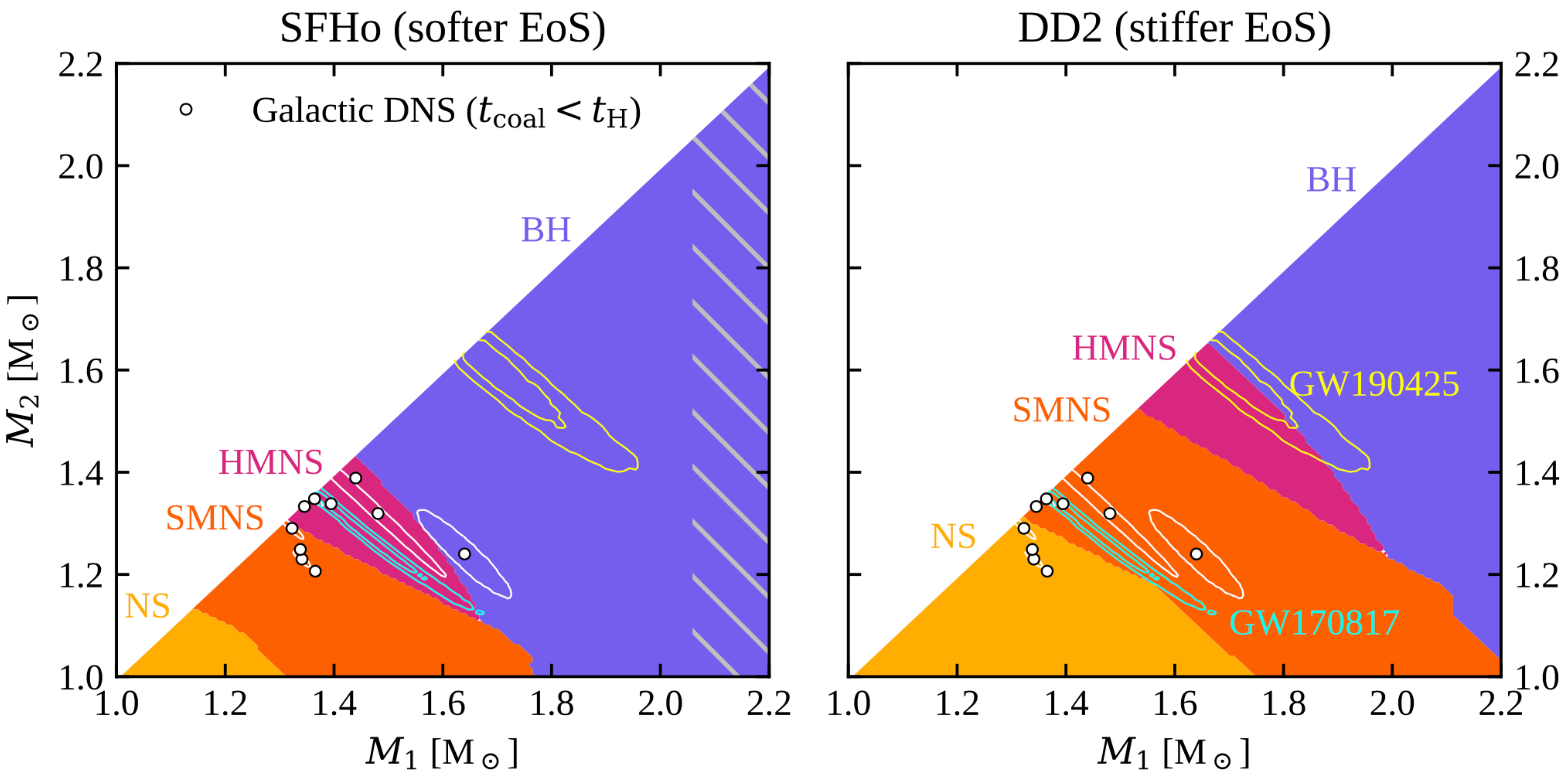


Farrow+19

BNS merger remnants



Farrow+19; Abbott+19,20

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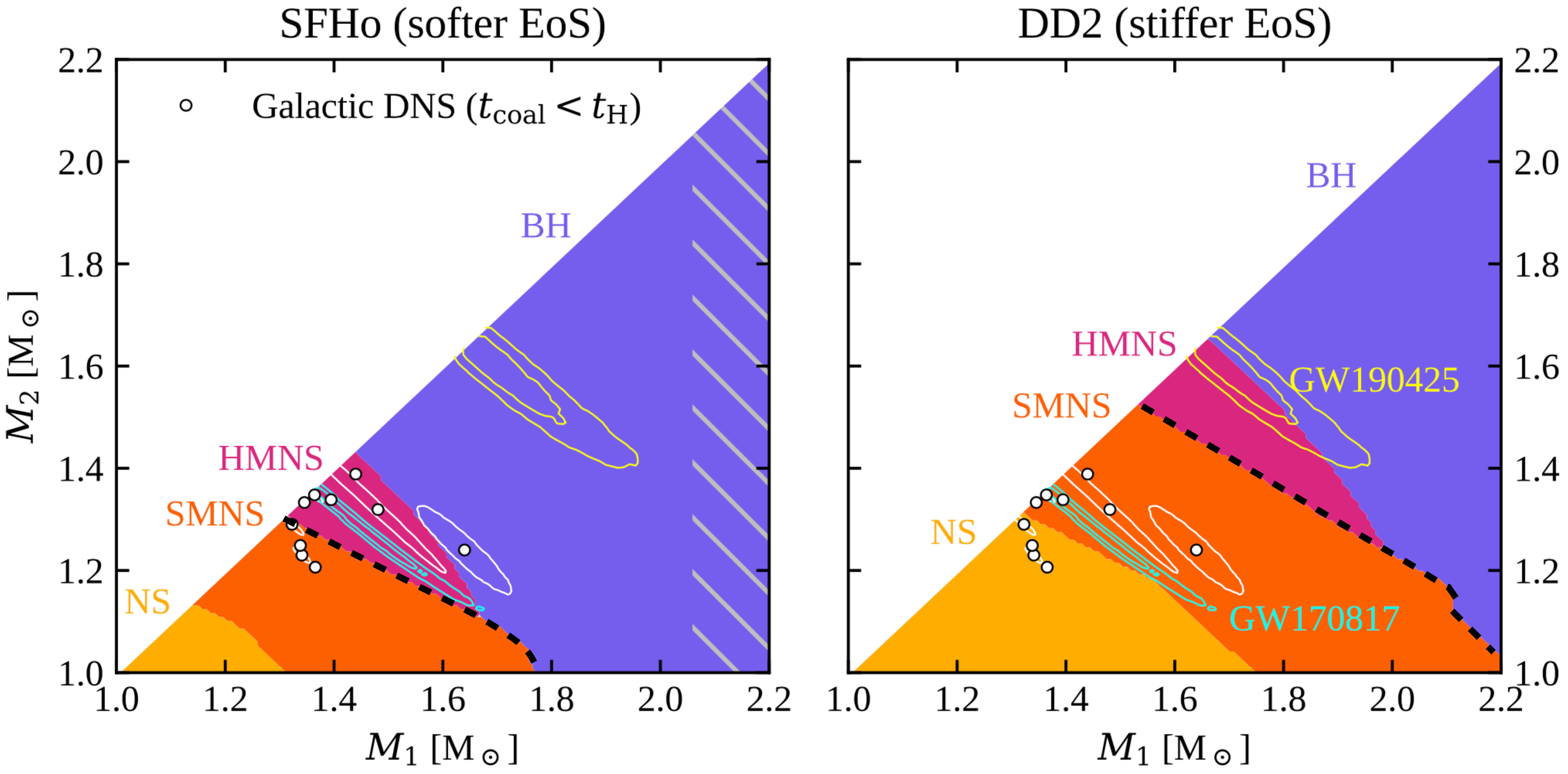

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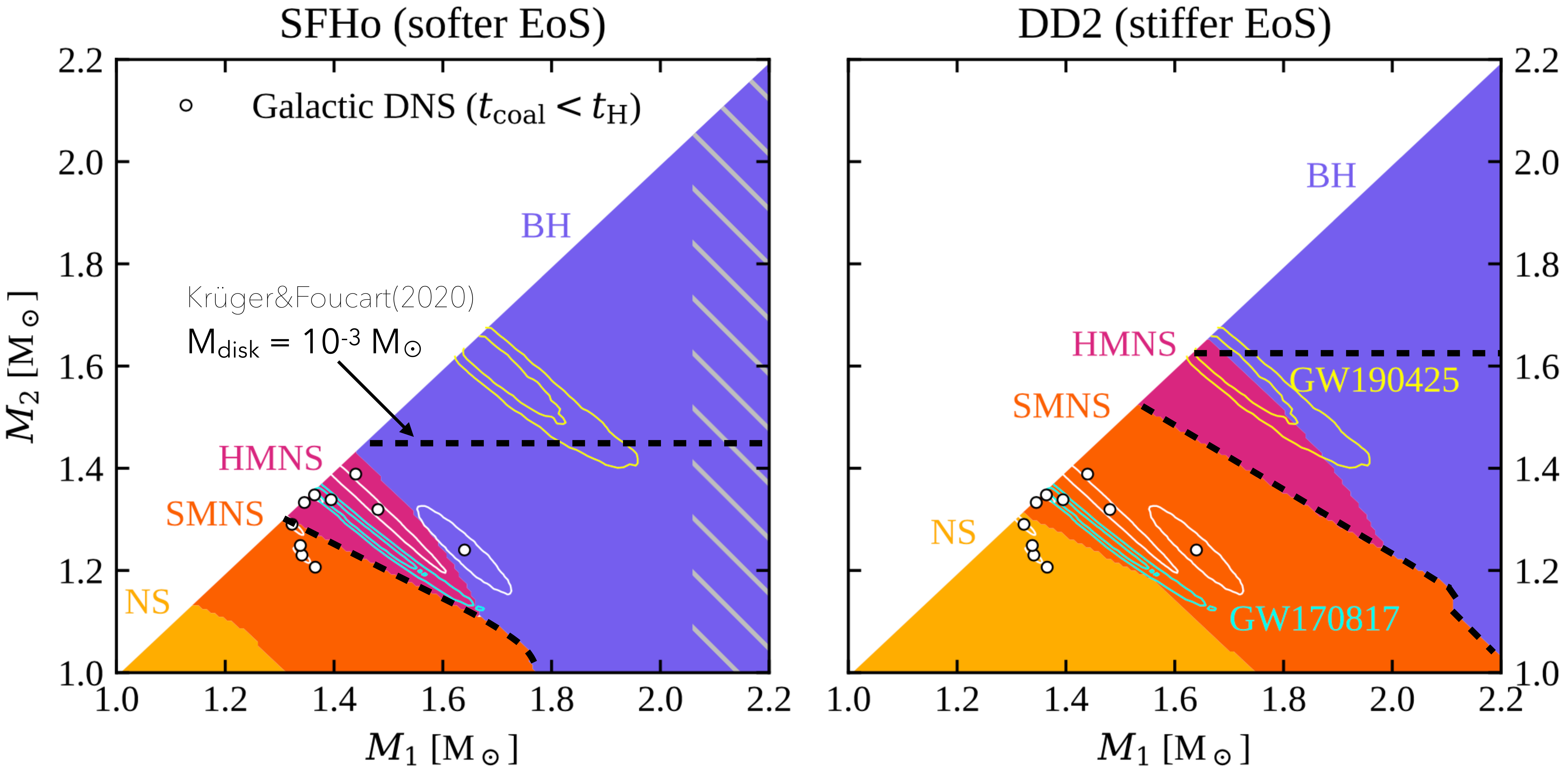

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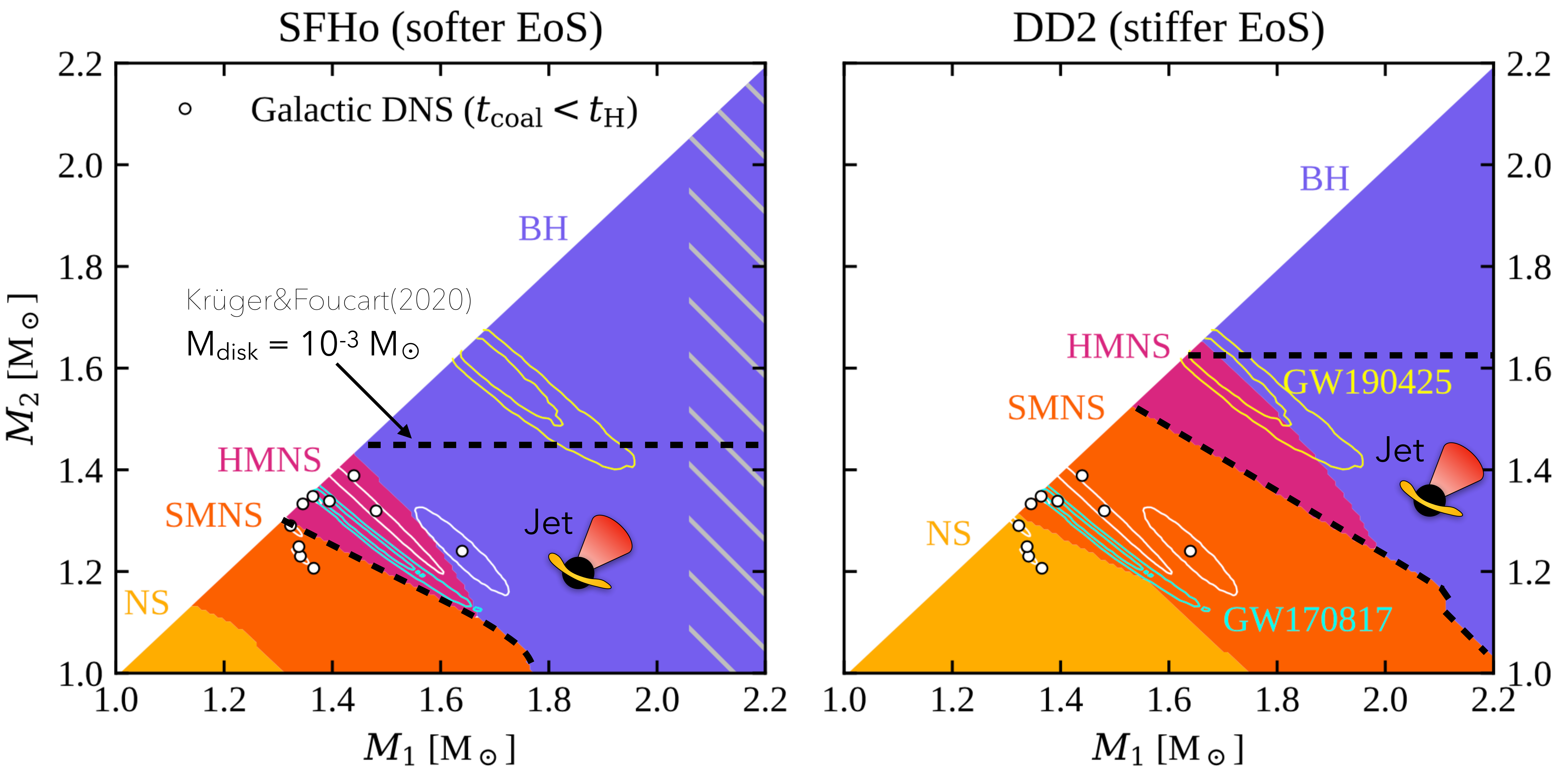

Farrow+19; Abbott+19,20

Simplified EoS dependence: $R_{1.4}$ and M_{TOV}

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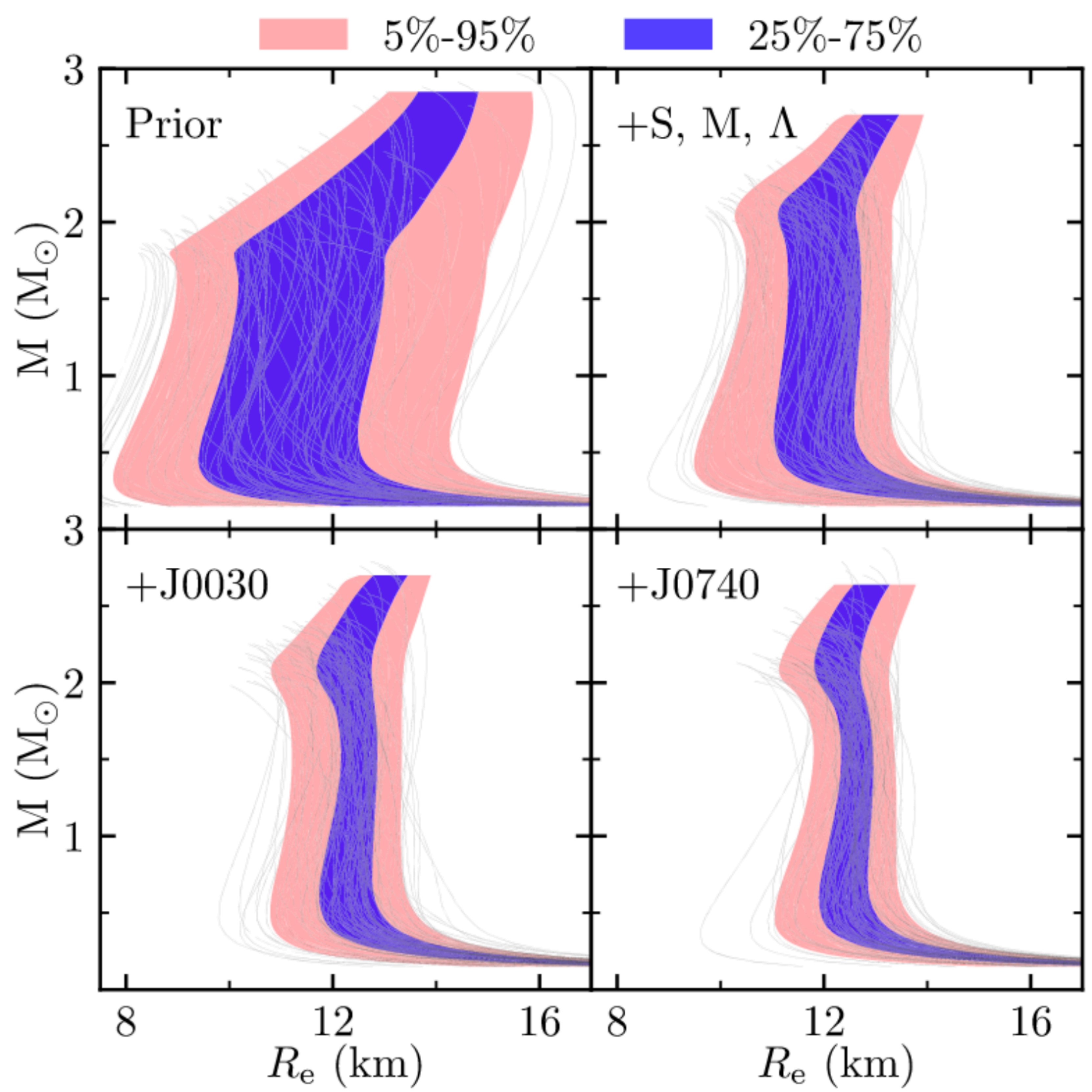
$R_{1.4}$ prior



$R_{1.4}$ =12.45 ± 0.65 km

Miller+21

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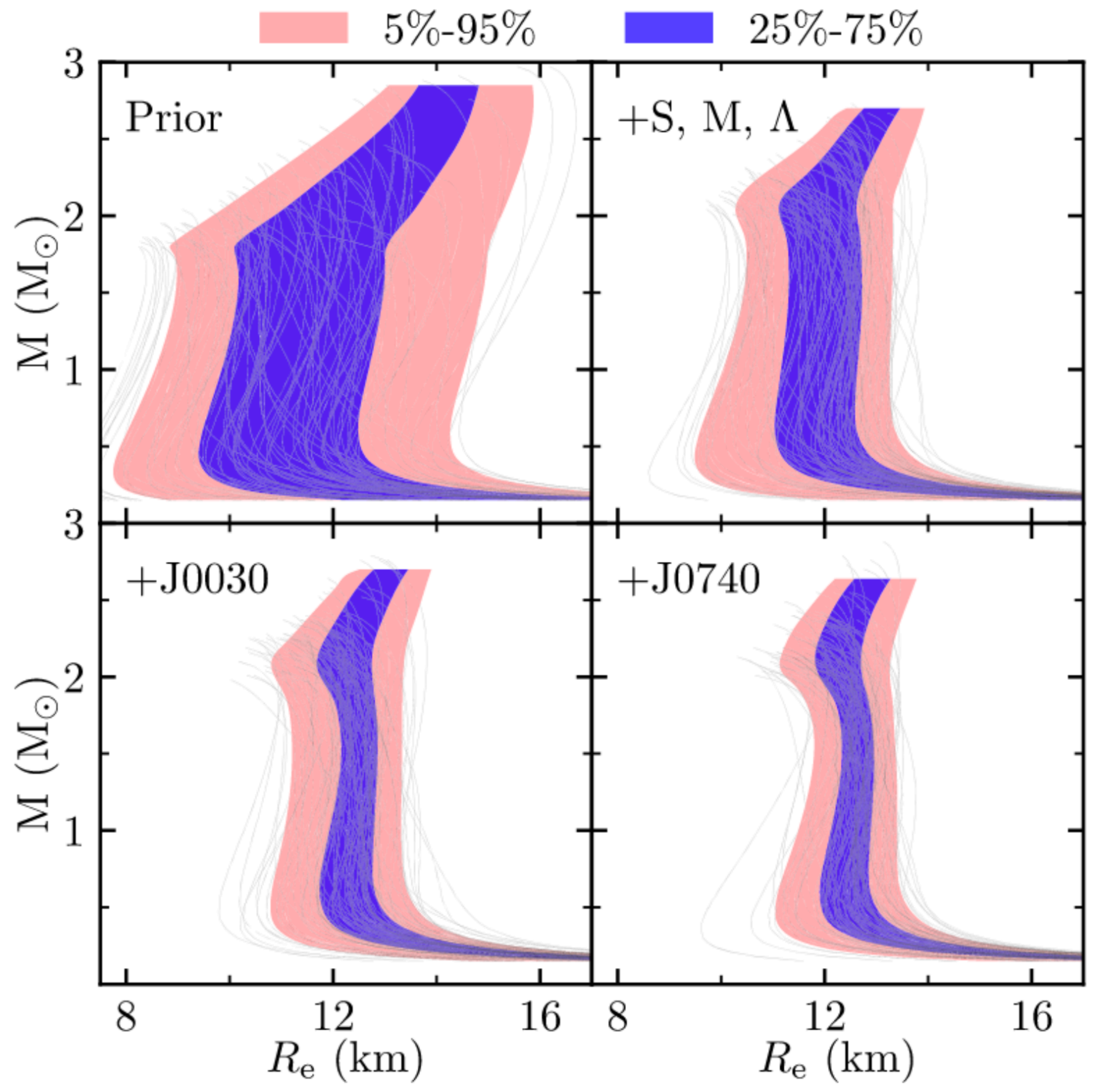

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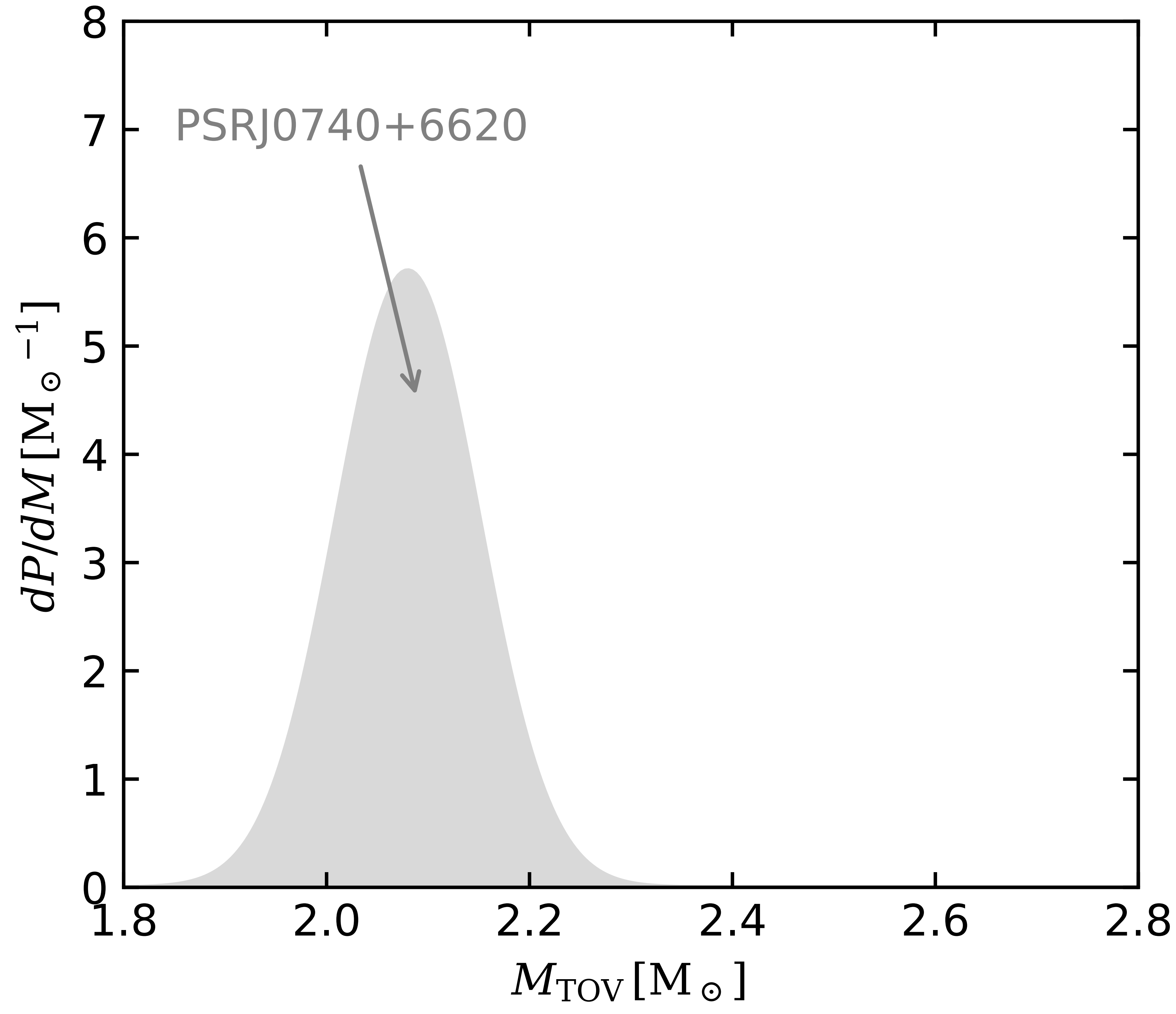

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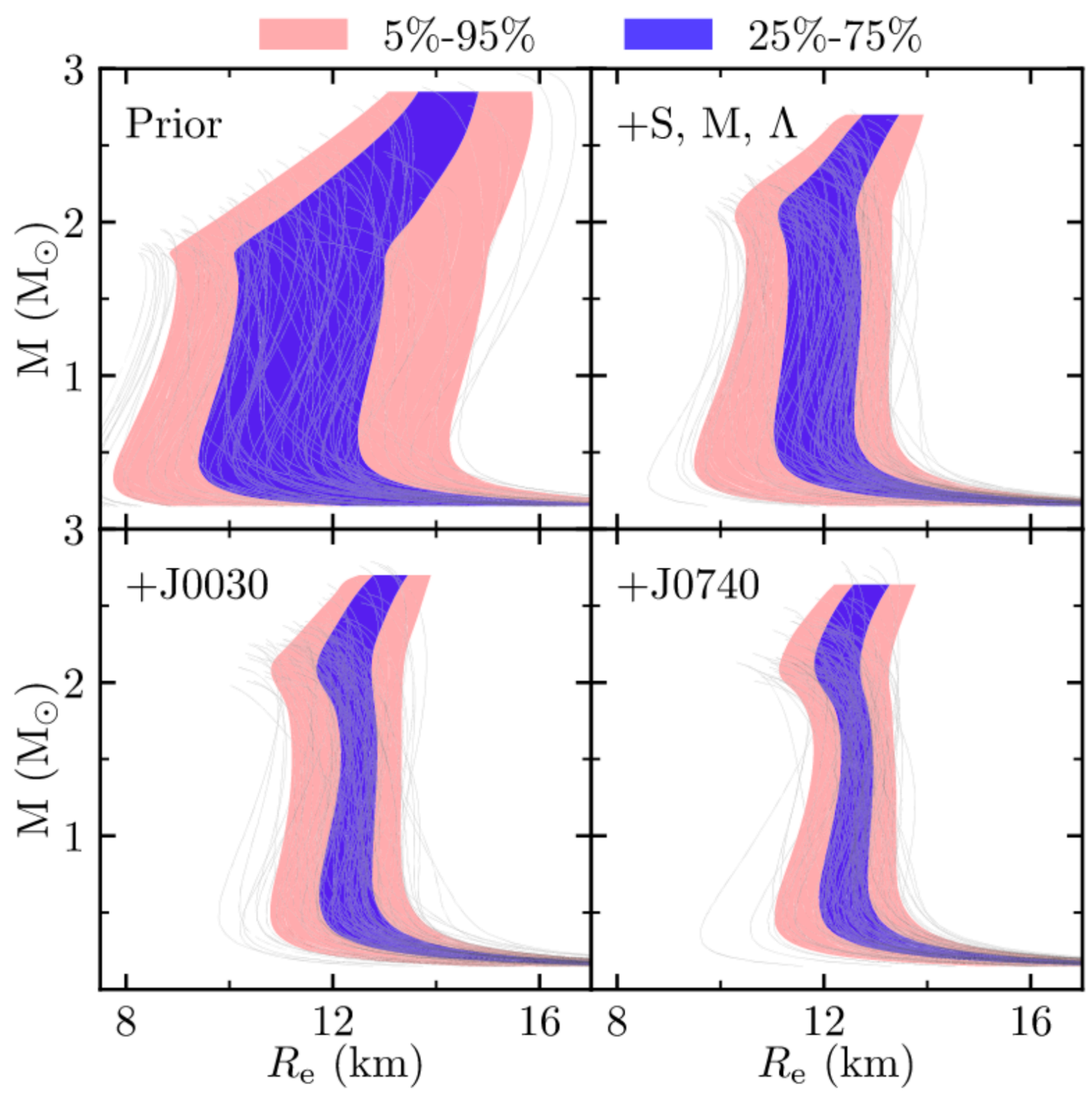

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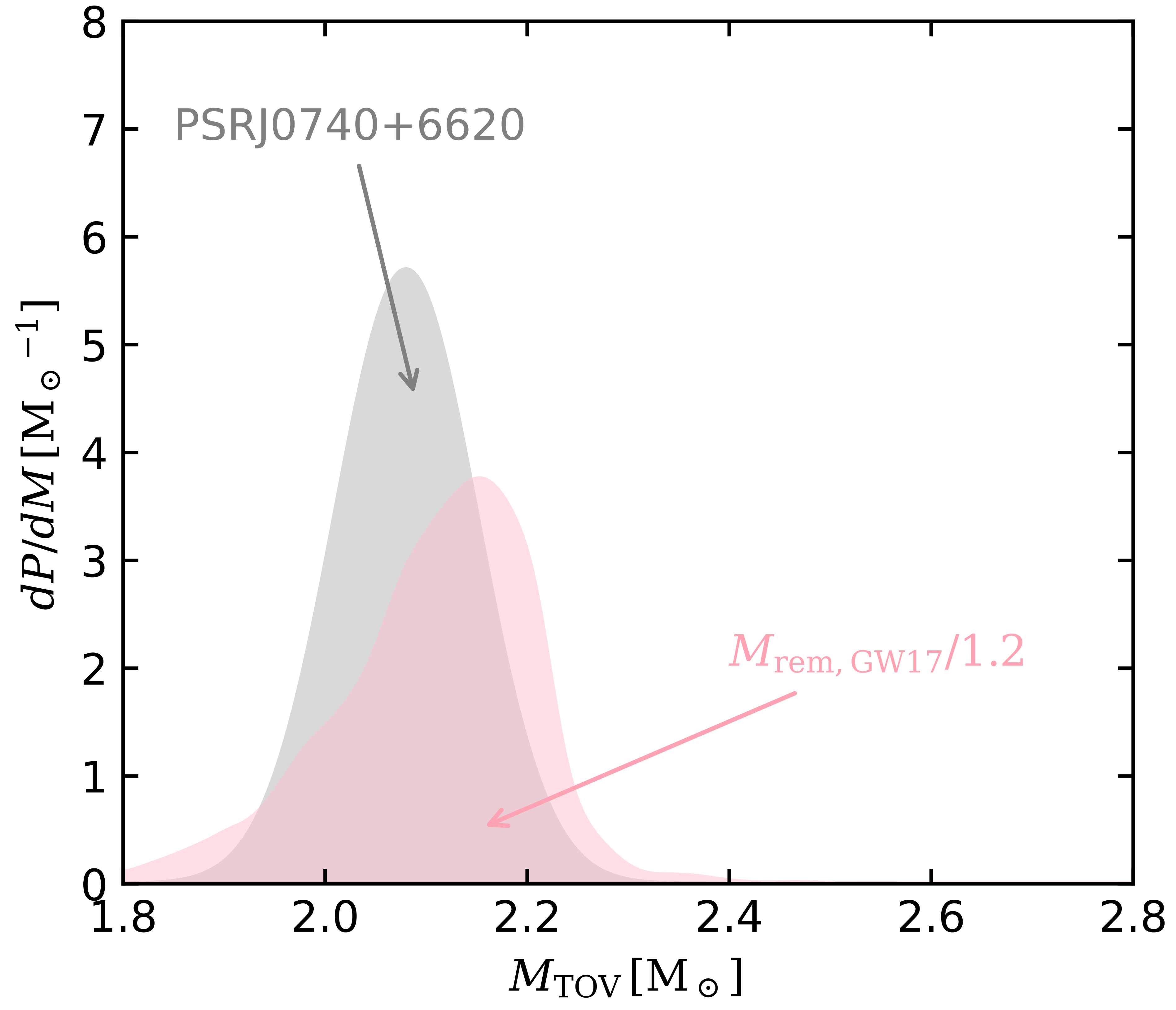

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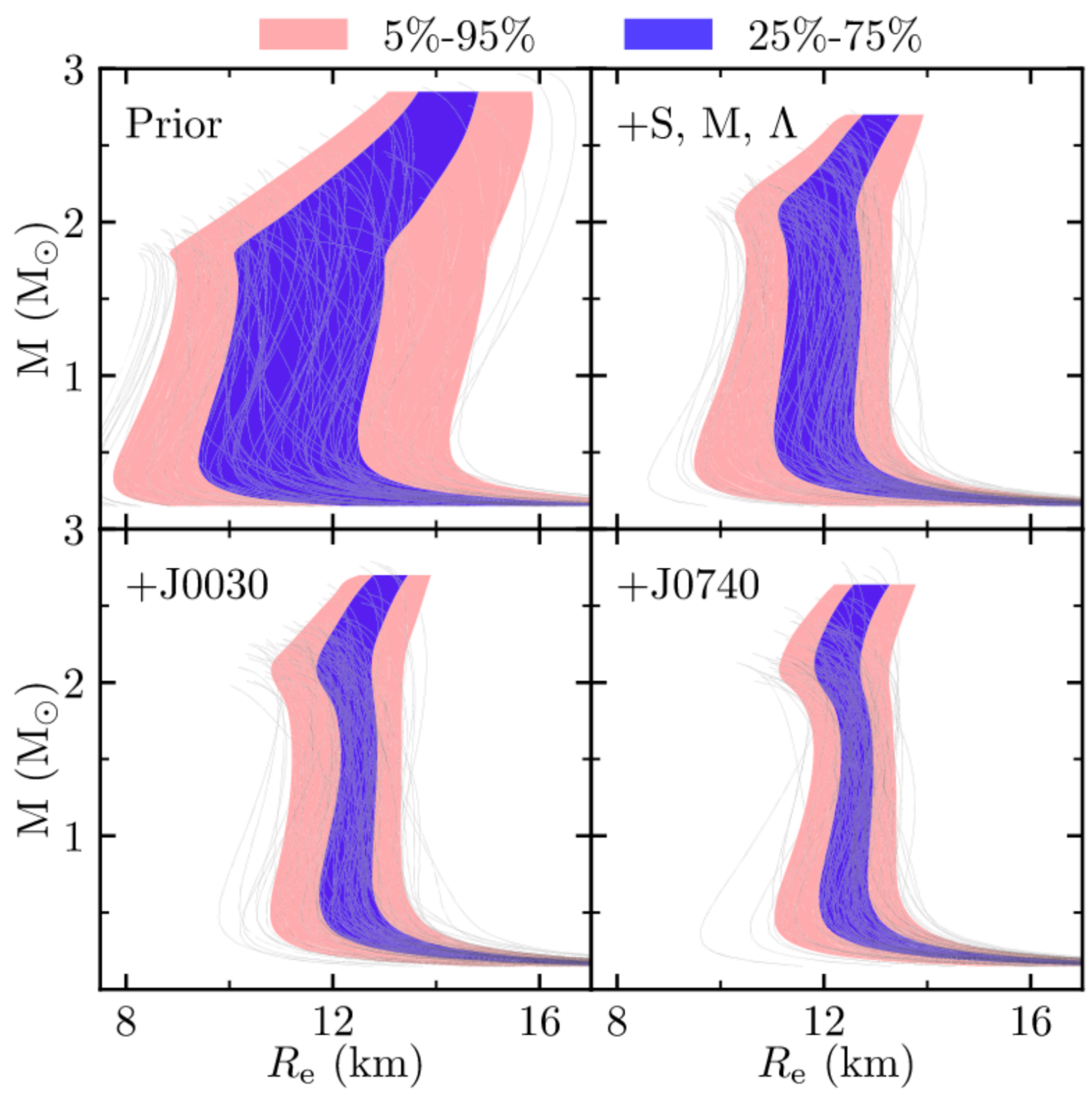

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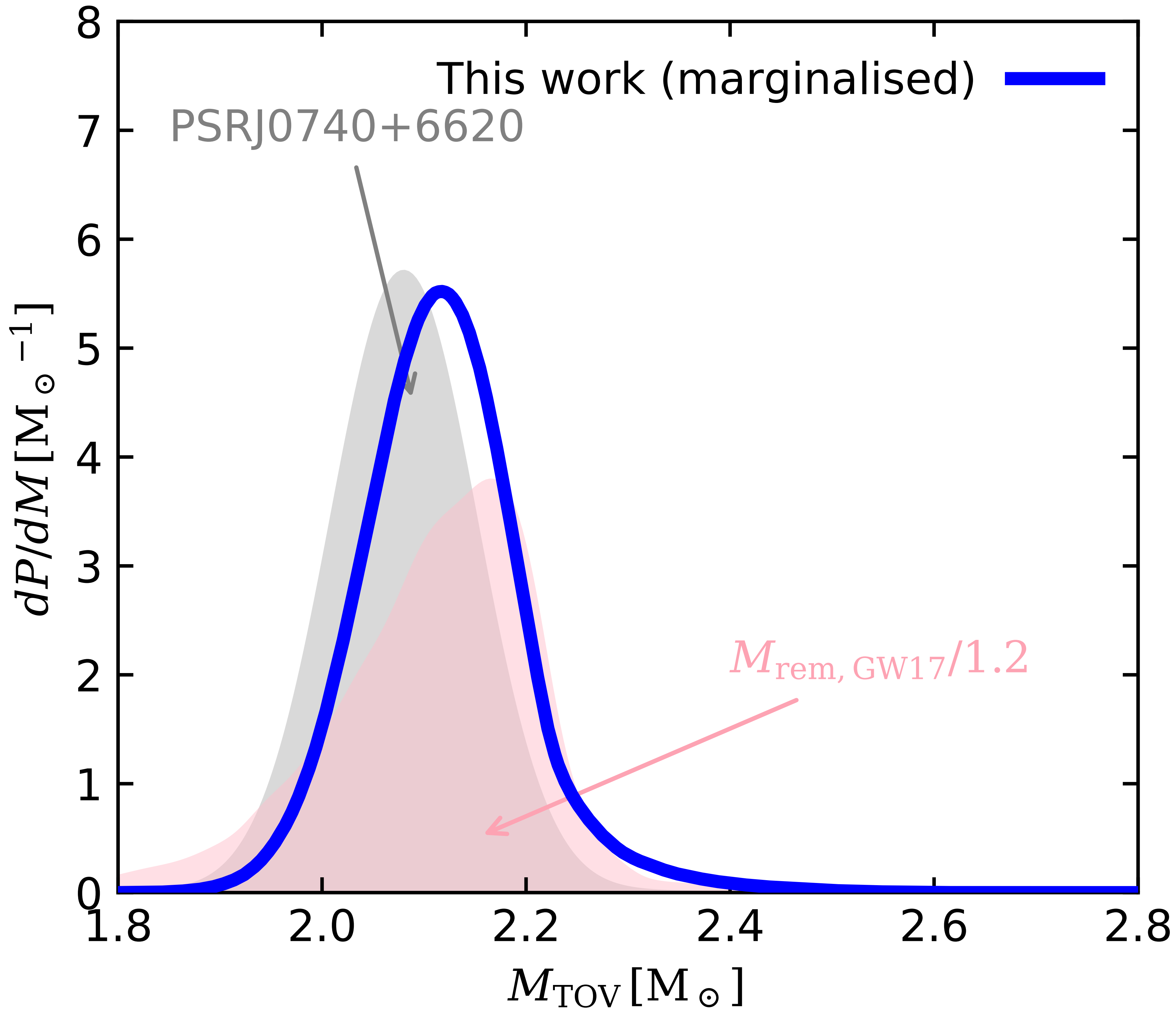

$M_{TOV} > M_{PSR}$ & $1.2M_{TOV} < M_{rem,GW170817}$

Simplified EoS dependence: $R_{1.4}$ and M_{TOV}

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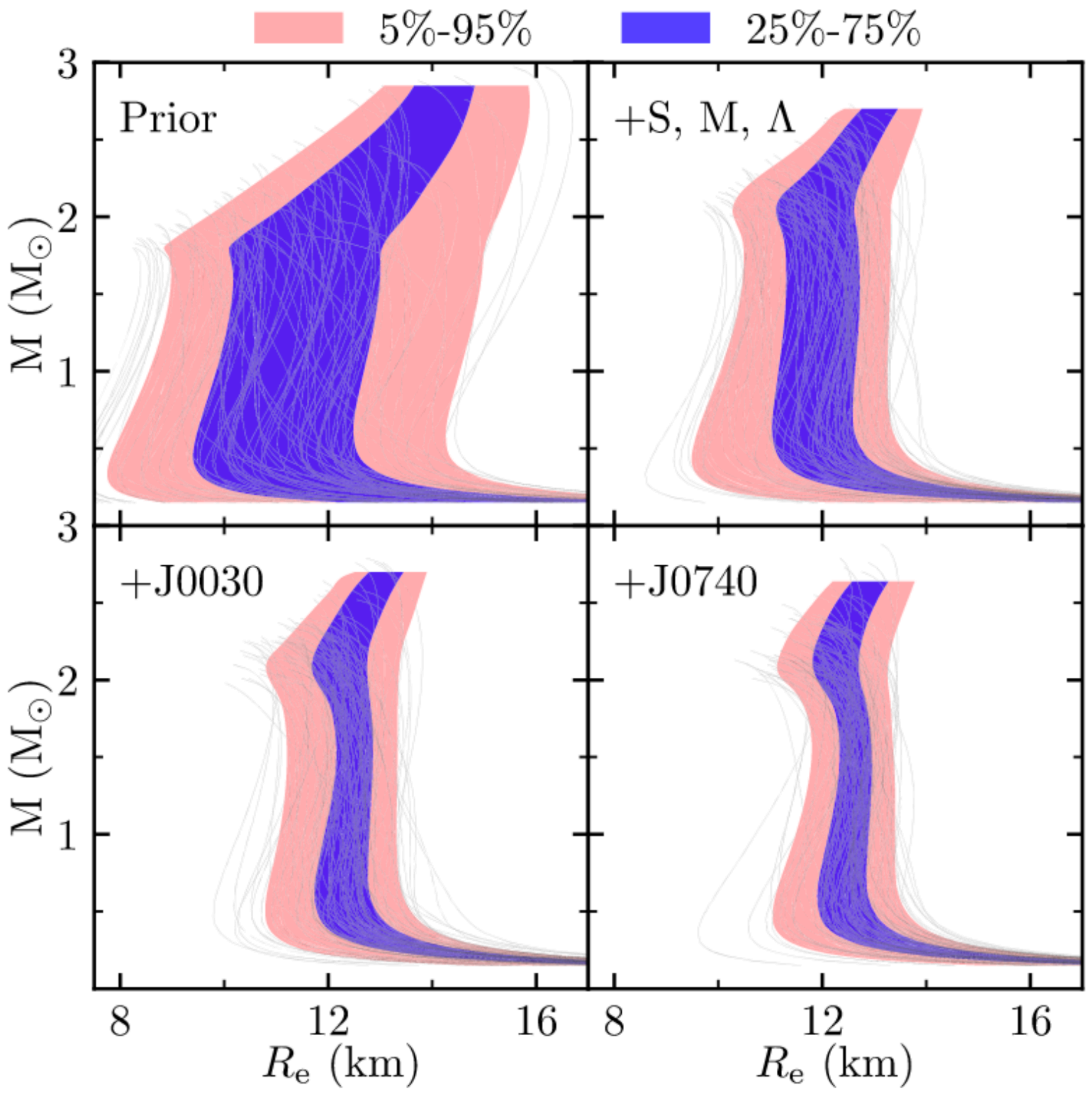

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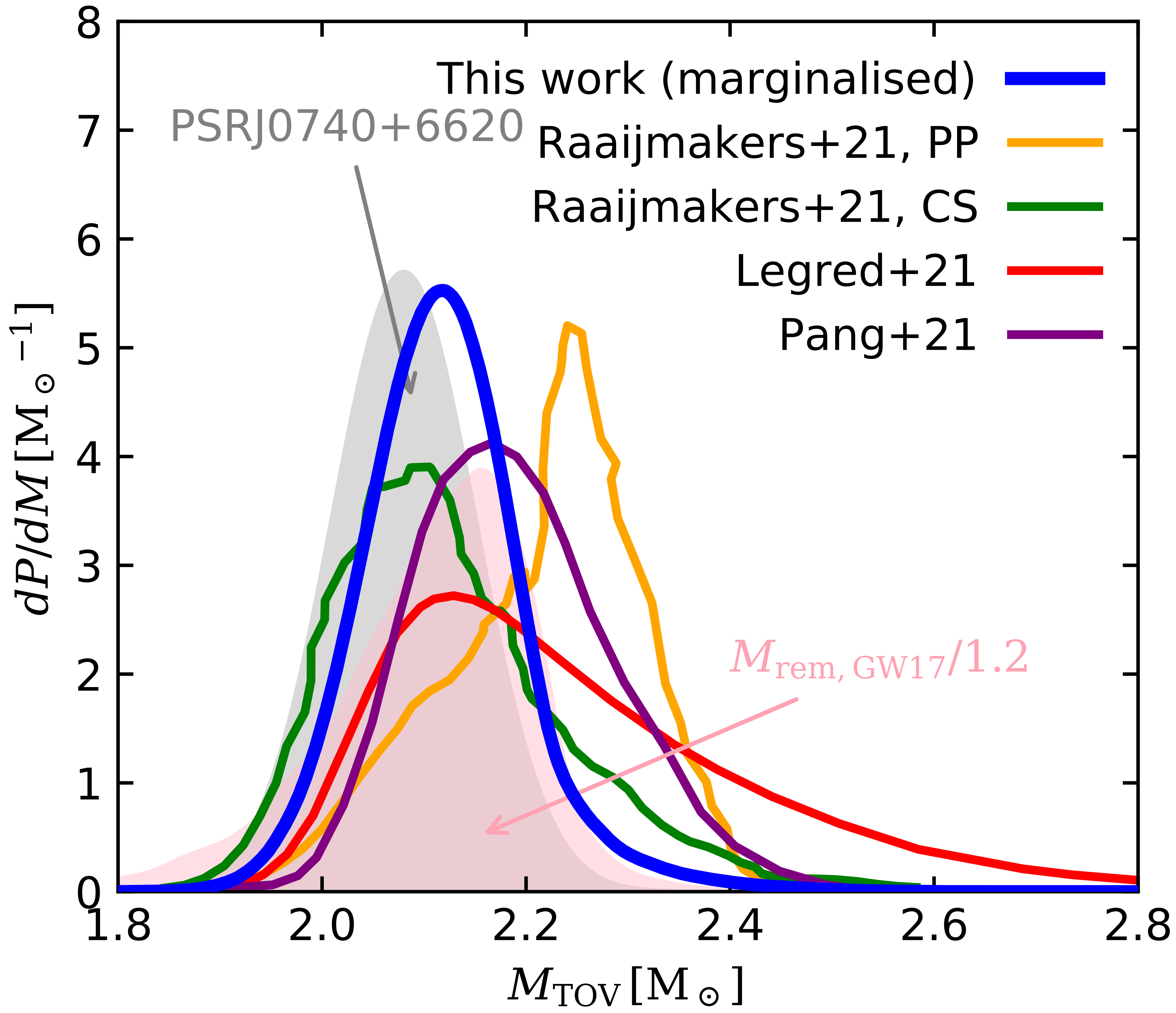

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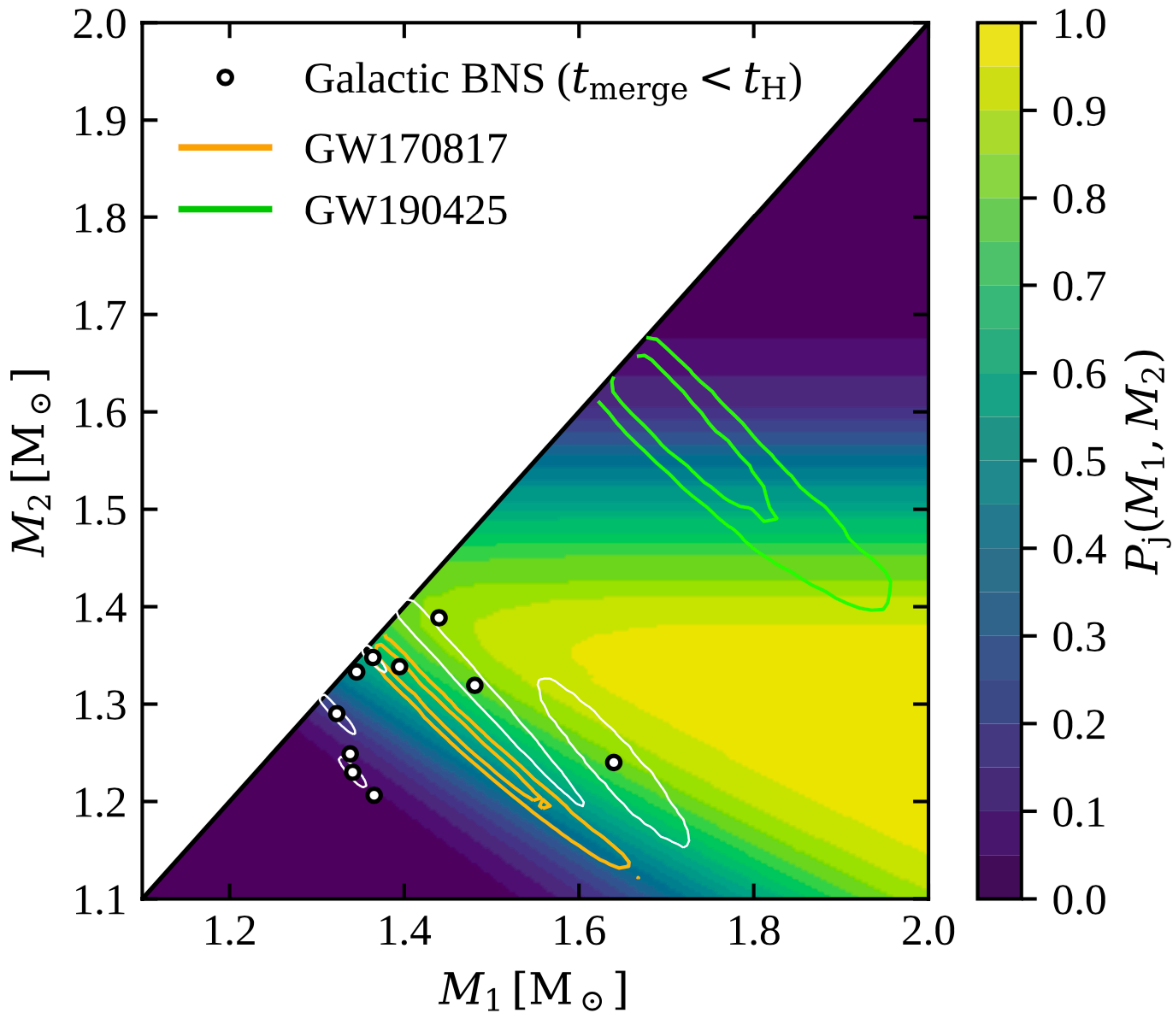
Jet-launching probability (EoS-marginalised)



✓ Jet fraction from observations

\+

✓ Modeling the jet launch

} Constraining the BNS mass distribution and EoS

Mass distribution and EoS constraint from jet fraction

mass dis. params

EoS params

obs. data

$$P(\vec{\theta}_{\rm m}, \vec{\theta}_{\rm EoS} \,|\, d) \propto P\left(f = \tilde{f}(\vec{\theta}_{\rm m}, \vec{\theta}_{\rm EoS}) \,|\, d\right) \pi(\vec{\theta}_{\rm m}, \vec{\theta}_{\rm EoS})$$

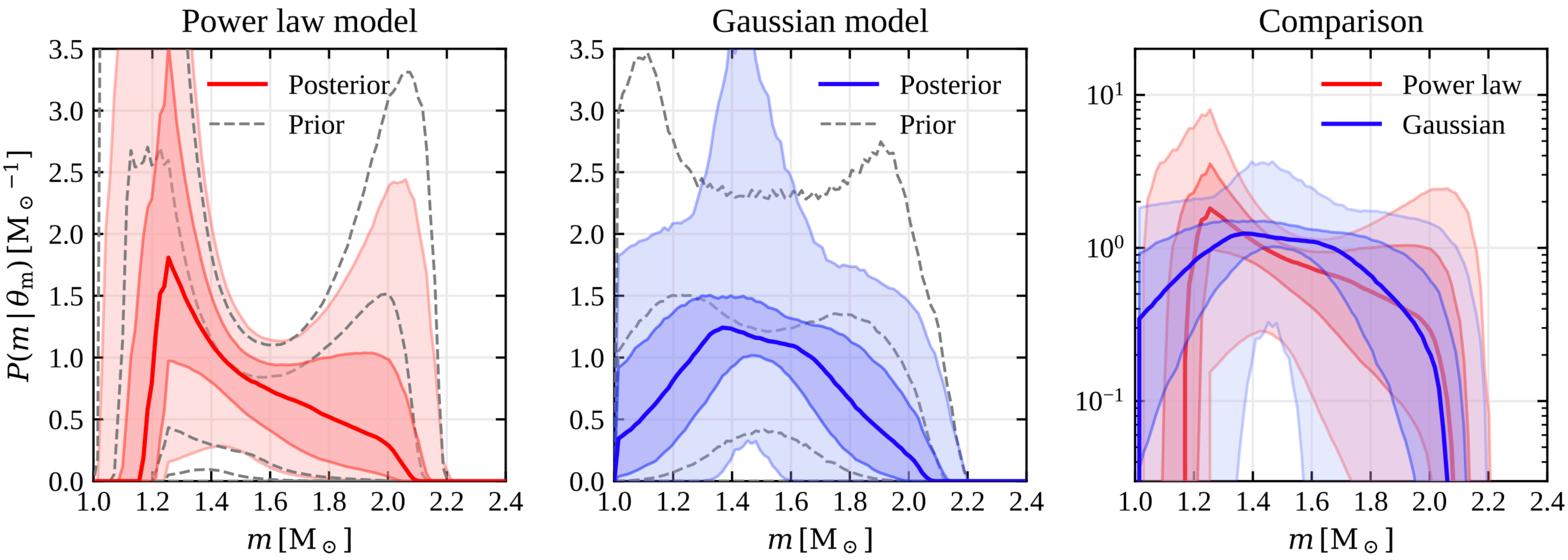
$$\tilde{f}_{\rm j} = \int\int \frac{{\rm d}^2 P}{{\rm d}M_1 {\rm d}M_2} \Theta_{\rm j} \, {\rm d}M_1 {\rm d}M_2$$

Jet fraction

$$\Theta_{\rm j} = \Theta(M_{\rm rem} - 1.2 M_{\rm TOV}) \Theta(M_{\rm disc} - M_{\rm disc,min})$$

Jet-launching conditions

Mass distribution constraints



EoS constraints

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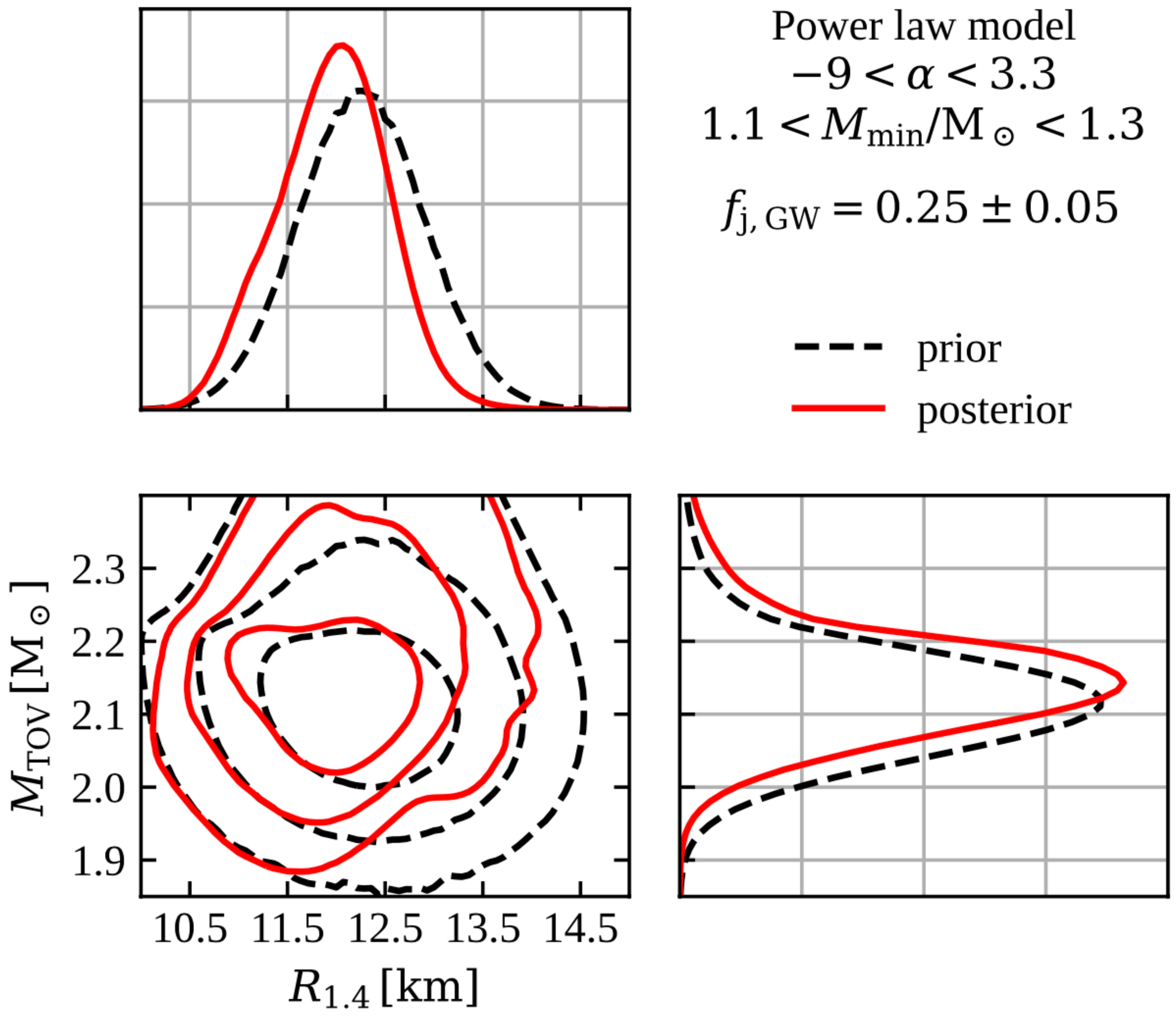

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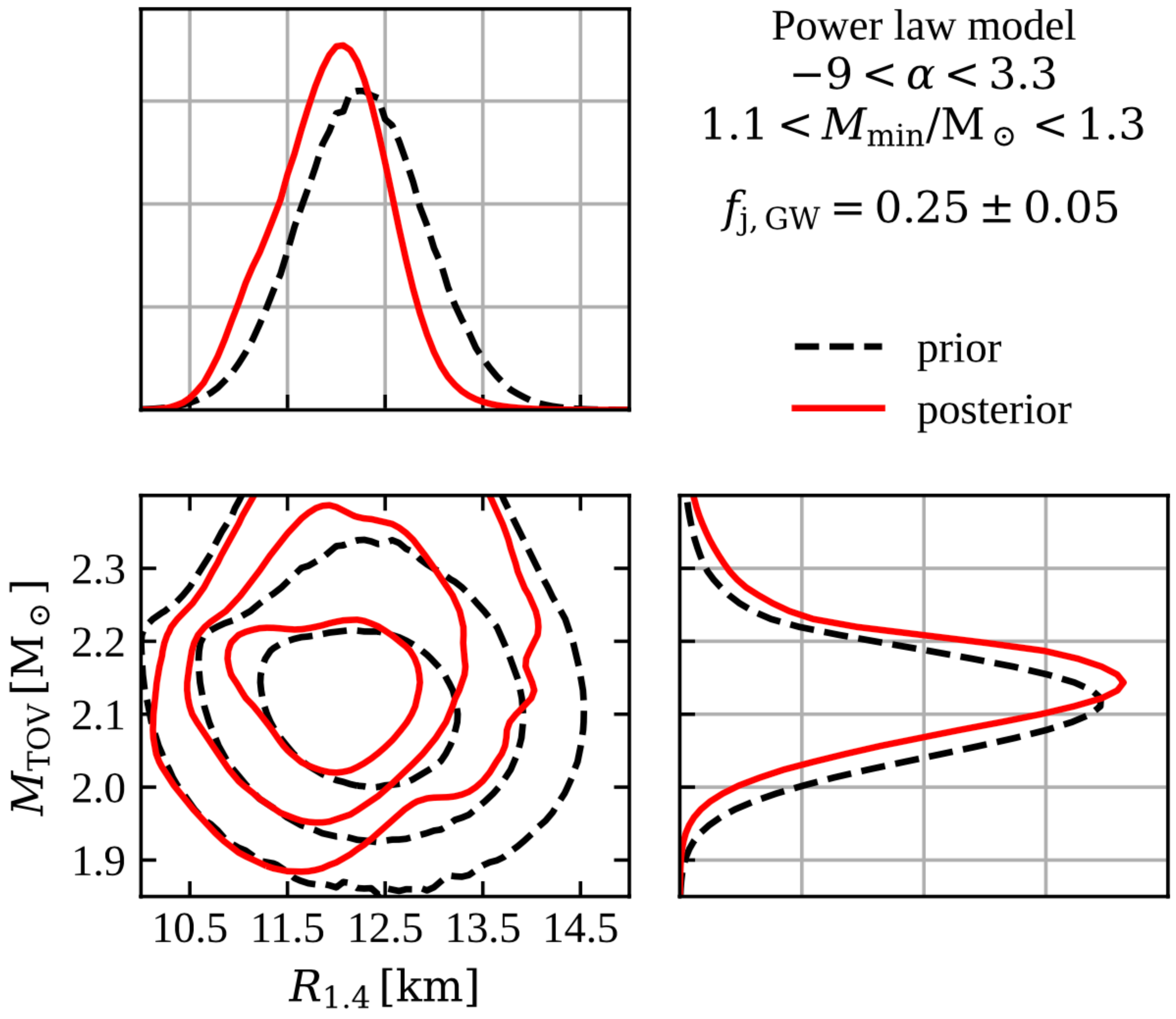
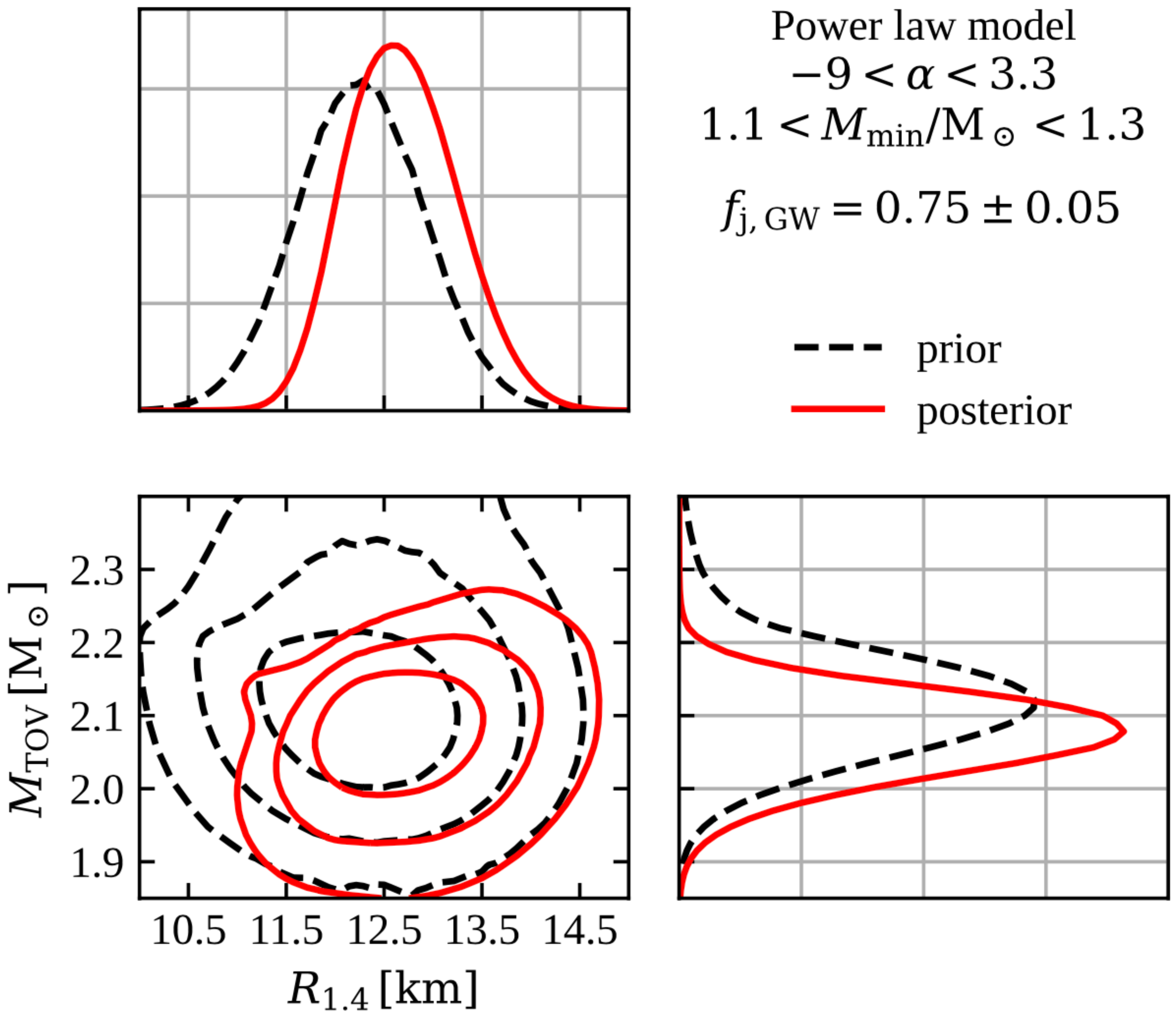




Summary

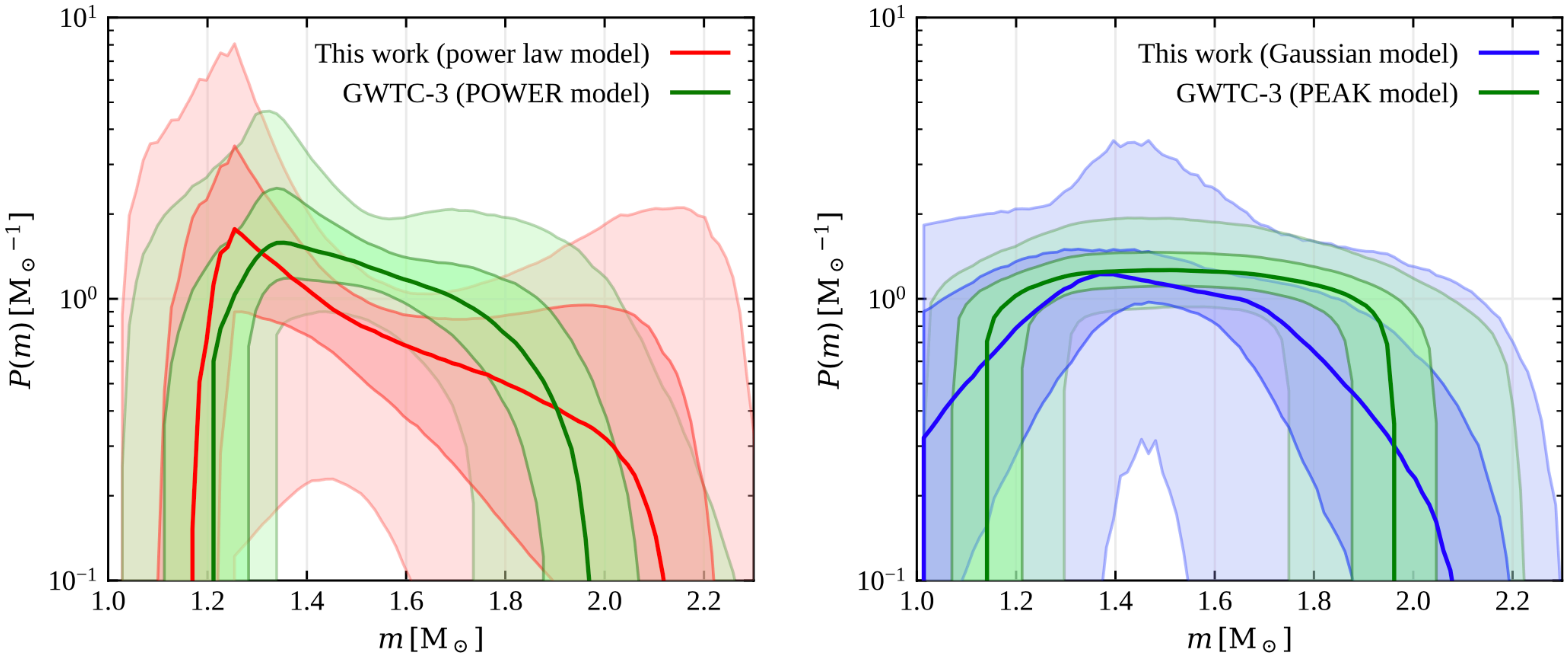
- One jet in one well-localised BNS: **jets cannot be** (very) **rare**
- Jet fraction from observation: at least **20-30%** of BNS **should have a jet**
- Modeling the **jet launch** assuming the Blandford-Znajek mechanism
- **Mass distribution** constraints already **informative**: broad distribution, masses between 1.3-1.6 $M_\odot$
- **EoS constraints** currently too **shallow**, but good prospects
- Method can be extended to **more events**, but need many events to pinpoint jet incidence
- Including **jet-launching conditions** in hierarchical Bayesian population studies likely a better approach
- See also Sarin et al. (2022)

Have a look at the paper

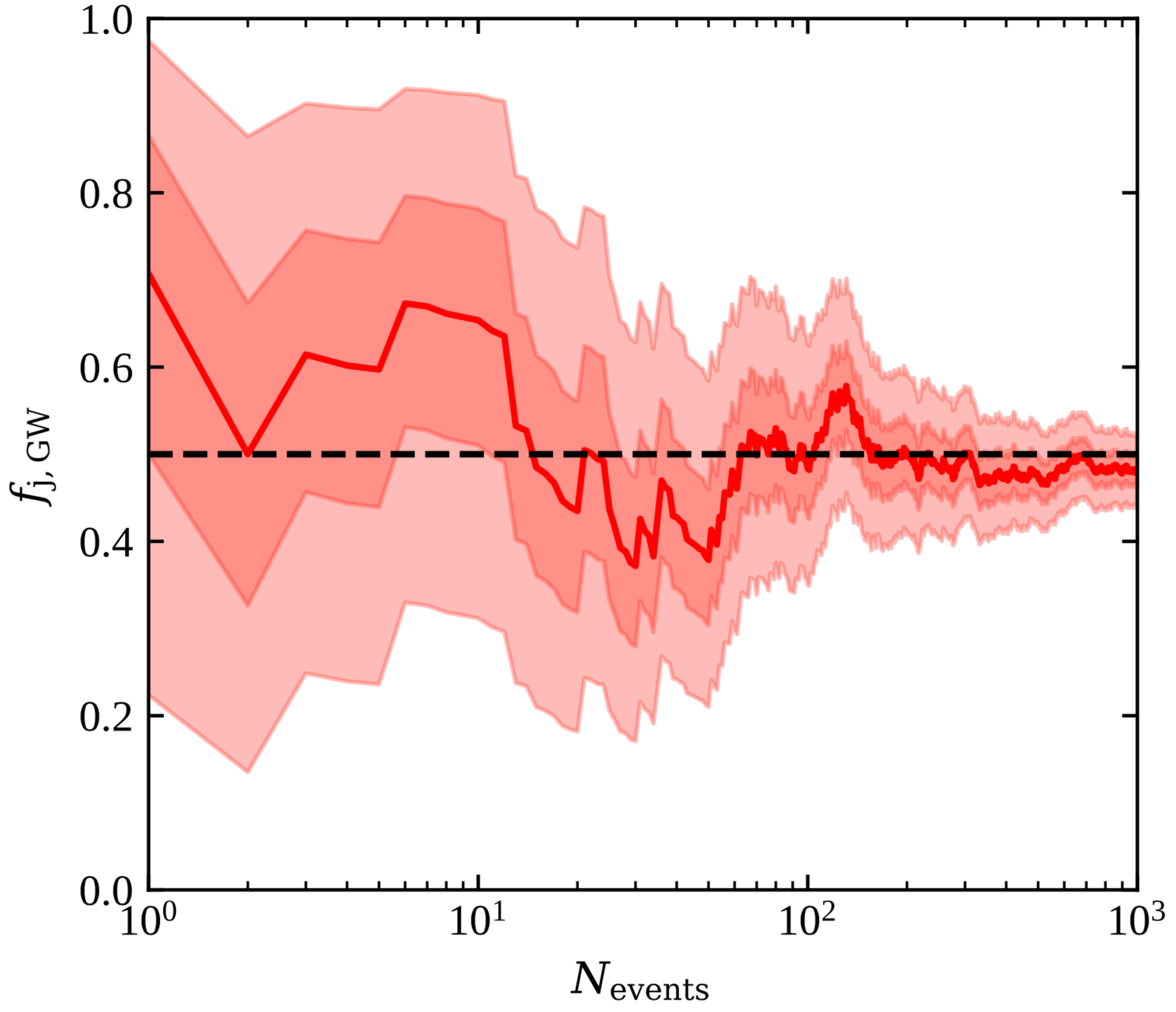
O.S. Salafia, A. Colombo et al. (2022)

Back up

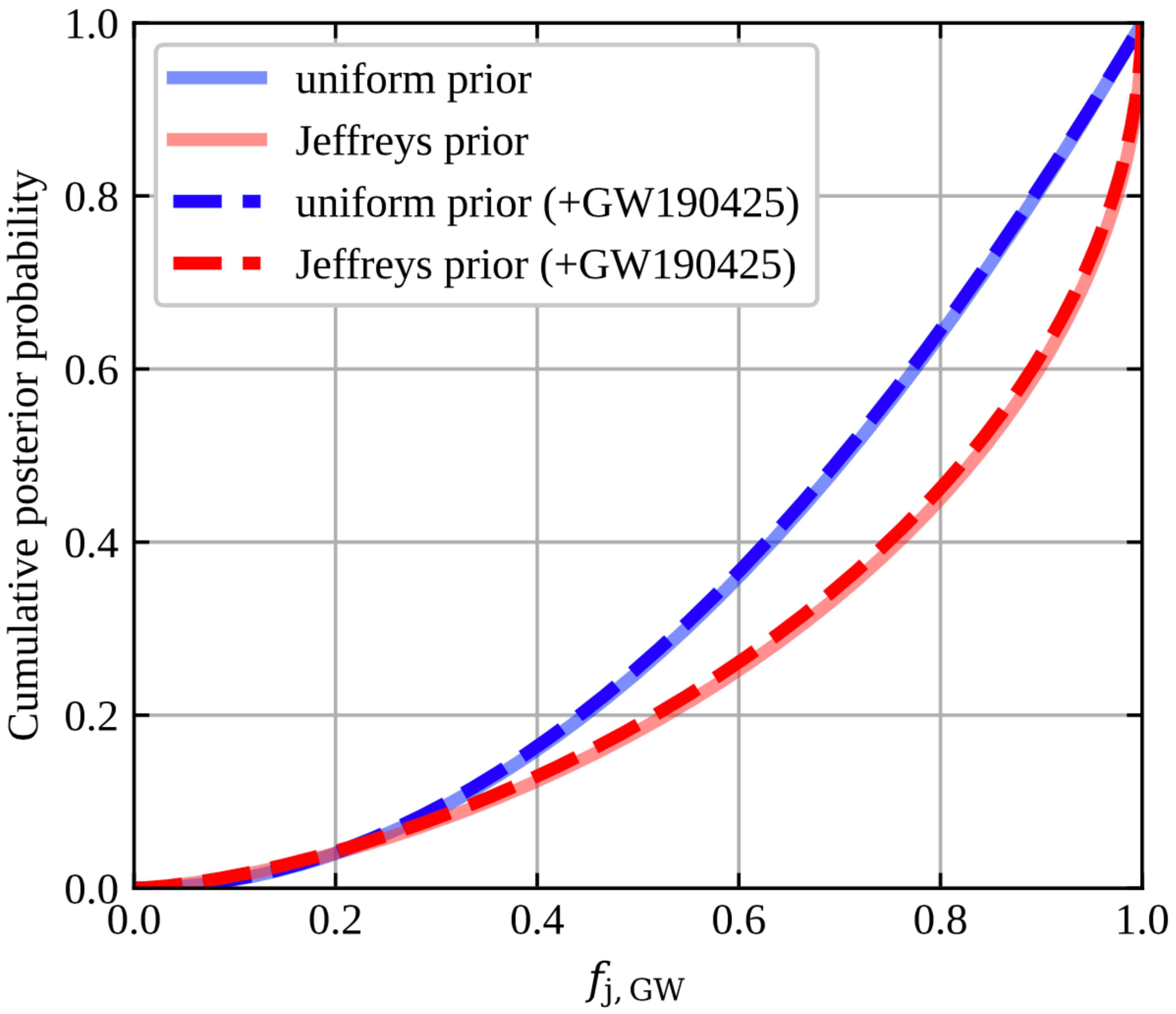
Mass distribution constraints: comparison with GWTC-3



Future GW events

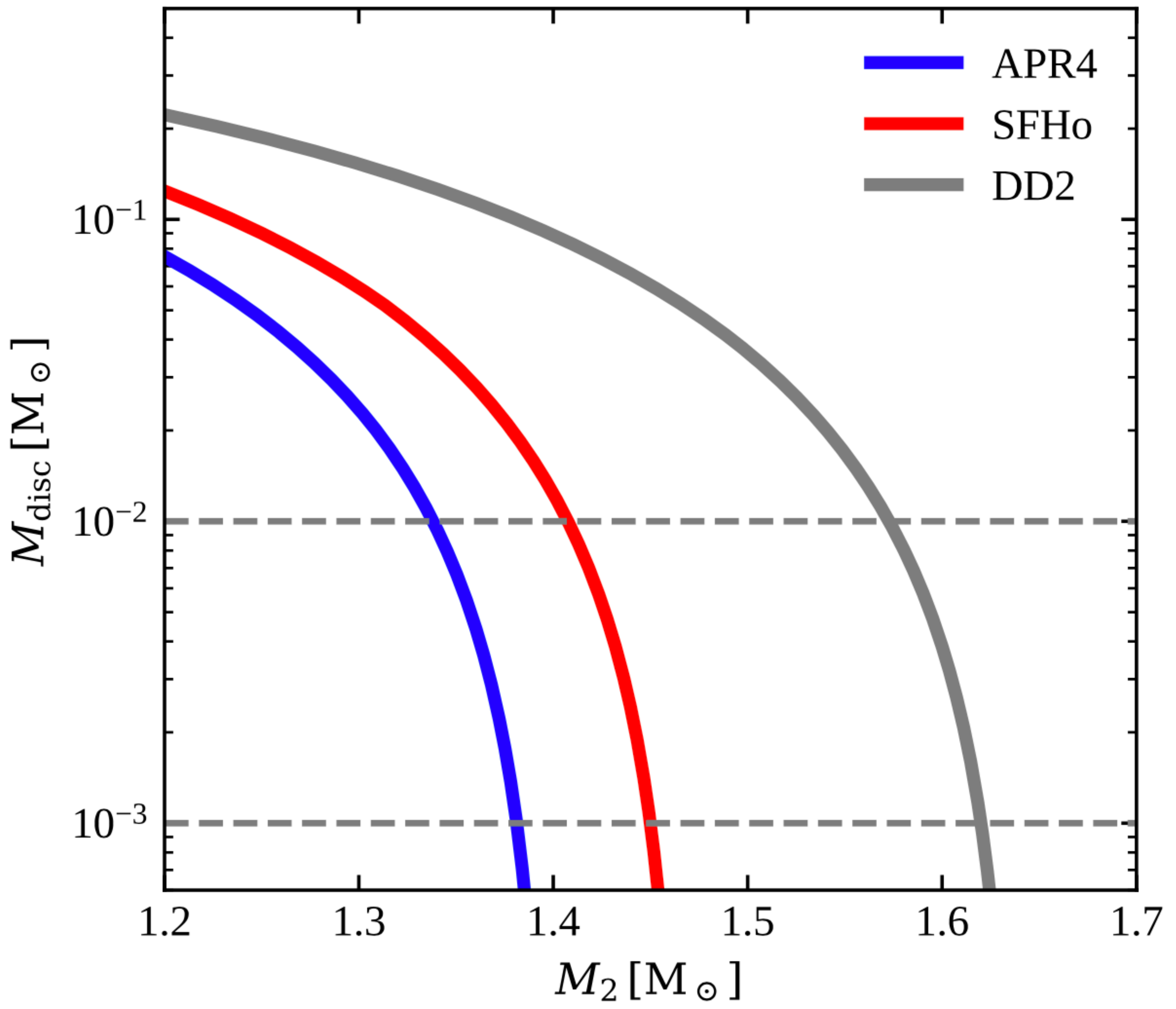


GW190425



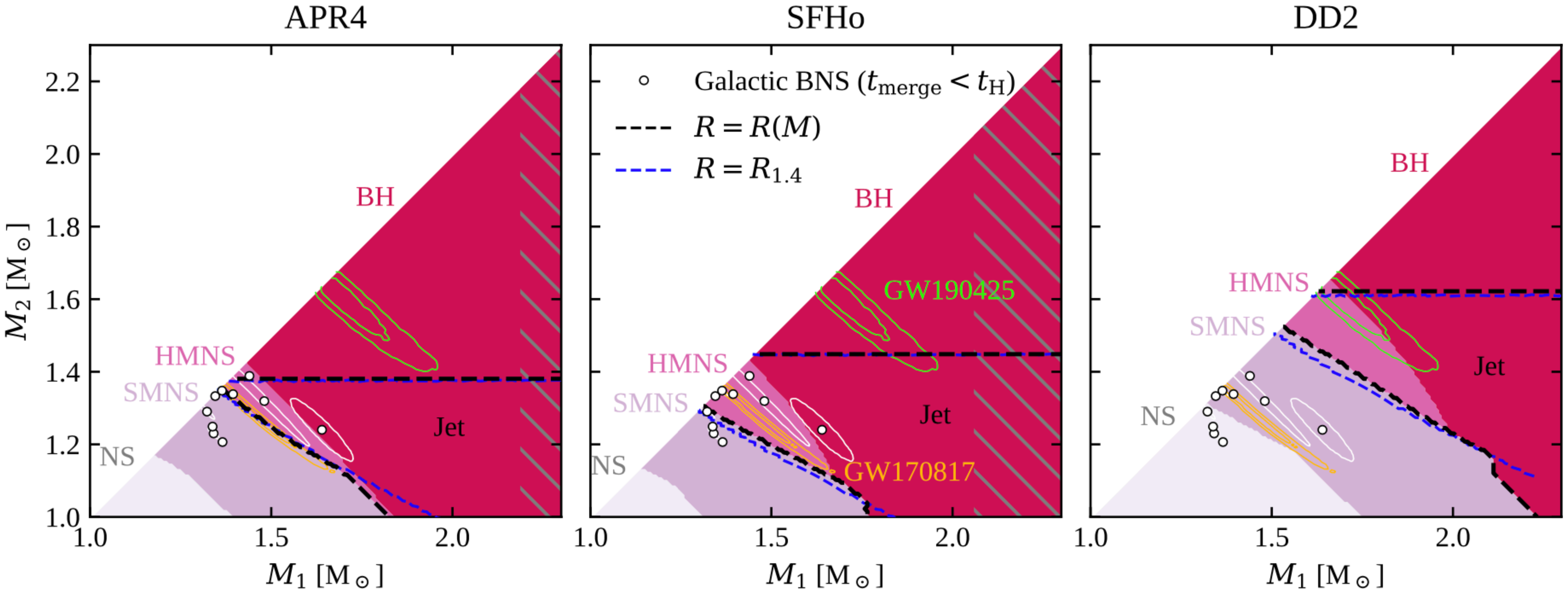
uniform prior
Jeffreys prior
uniform prior (+GW190425)
Jeffreys prior (+GW190425)
Cumulative posterior probability
0.0
0.2
0.4
0.6
0.8
1.0
$f_{\mathrm{j,\,GW}}$

Disk mass dependence on M_2



Computing M_{rem}

$$Mc^2 = M_{\mathrm{rem}}c^2 + E_{\mathrm{GW}} + E_{\mathrm{disc}} + E_{\mathrm{ej}} + E_{\nu}$$



APR4
SFHo
DD2
Galactic BNS ($t_{merge} < t_H$)
$R = R(M)$
$R = R_{1.4}$
BH
HMNS
SMNS
NS
Jet
GW190425
GW170817
M_2 [$M_\odot$]
M_1 [$M_\odot$]
2.2
2.0
1.8
1.6
1.4
1.2
1.0
1.5