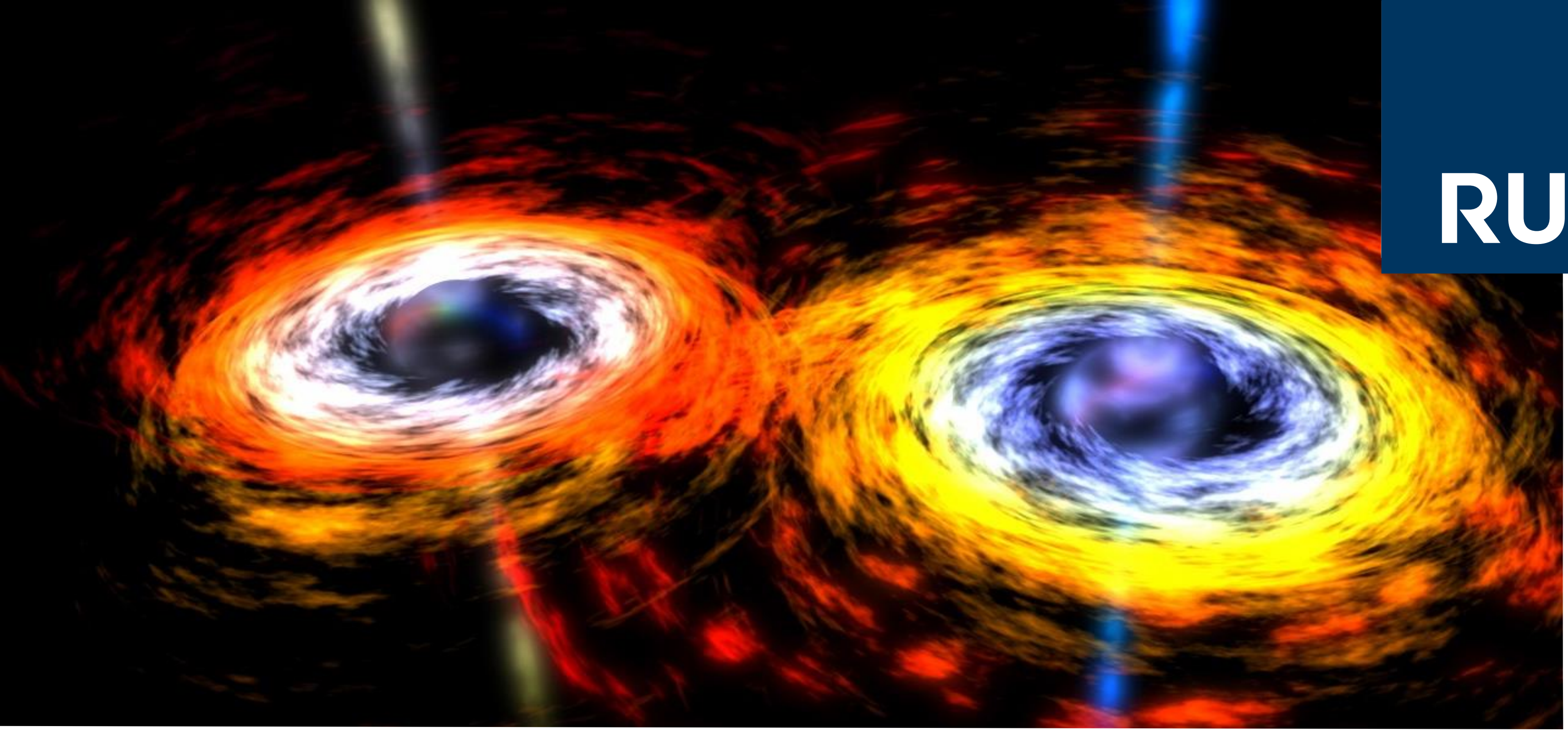

NASA.gov

Neutrino Emission from Supermassive Binary Black Hole Mergers

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Motivation

- Diffuse astrophysical neutrino flux at IceCube (Stettner 2019):

$$\boldsymbol{\Phi}(E_\nu)\Big|_{\text{obs}} = \left(1.44^{+0.25}_{-0.24}\right)\left(\frac{E_\nu}{100\ \text{TeV}}\right)^{-2.28^{+0.08}_{-0.09}} \cdot 10^{-18}\ \text{GeV}^{-1}\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$$

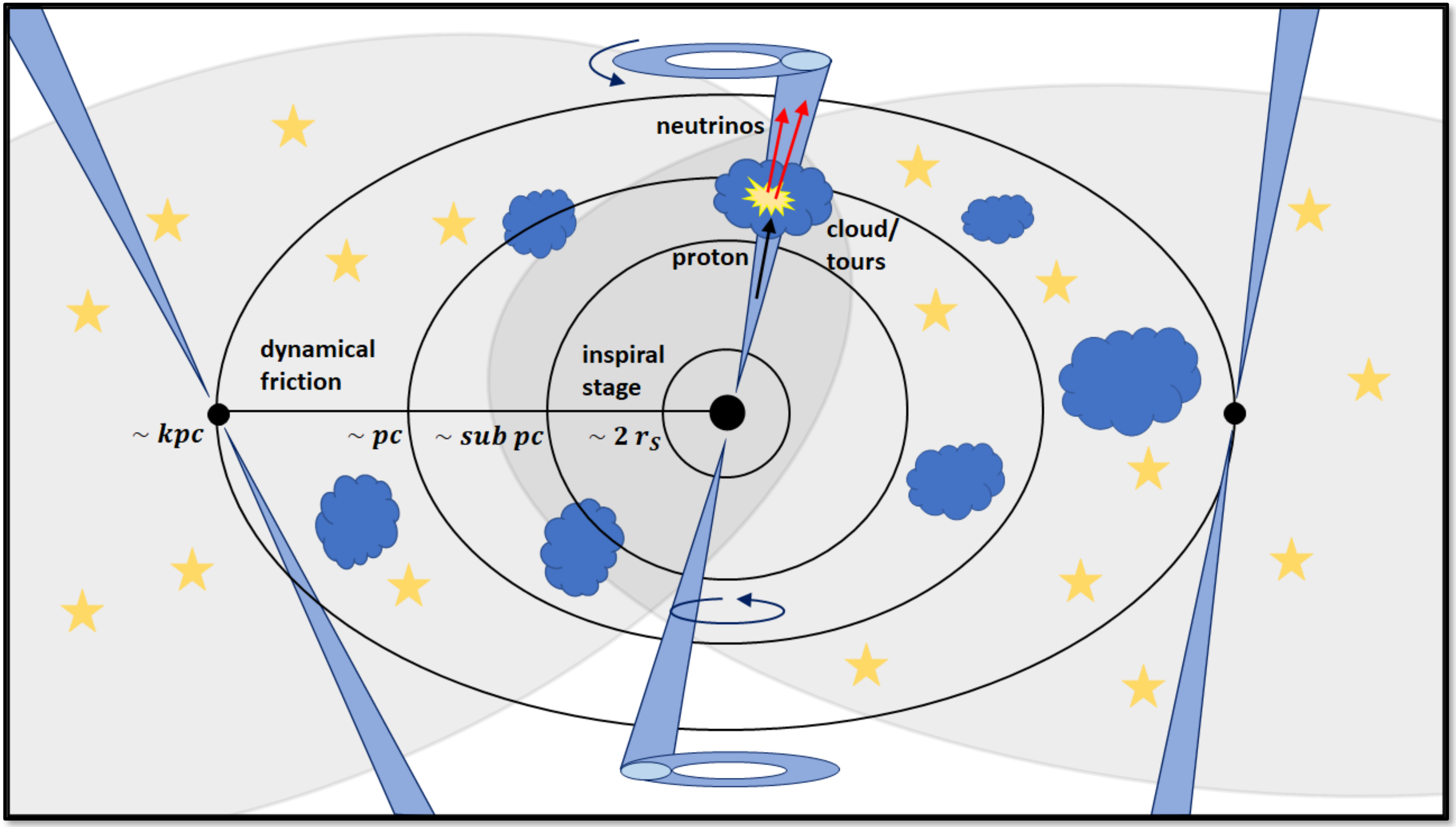
- Question: What are the sources?

- Possible correlation of a high-energy neutrino with a gamma-ray flare from the blazar TXS 0506+056 in 2017 (Aartsen+ 2018)
- 2014/2015 long-duration TeV neutrinos flare without gamma-ray flare from TXS 0506+056 (Aartsen+ 2018)

- Idea by Gergely & Biermann 2009
  → SMBBH merger accompanied with a spin-flip of the jet

How can a merger produce neutrinos?

SMBBH mergers



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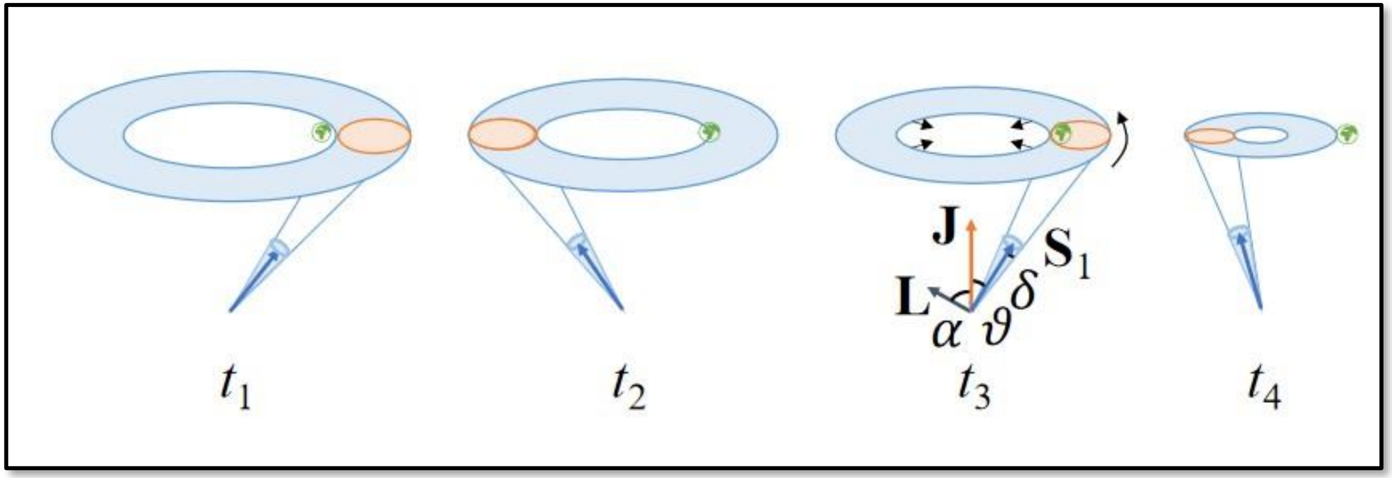
Recurring Jet

$$\phi(\Delta T_{\mathrm{GW}}) = -8\left(\frac{5c}{32G^{1/3}M^{1/3}} \cdot \frac{(1+q)^2}{q}\right)^{3/4} \Delta T_{\mathrm{GW}}^{1/4} + \phi_0$$

Mass ratio: $q = \frac{m_2}{m_1} \leq 1$

$$\phi(\Delta T_{\mathrm{GW}}) = \phi\left(\Delta T_{\mathrm{GW}} + t_{\mathrm{Jet}}\right) = \phi_{\mathrm{Earth}} \pm \delta$$



De Bruijn+ 2020

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Application on TXS0506+056

Mass ratio:
$q \in \left[\frac{1}{3}, \frac{1}{30}\right]$

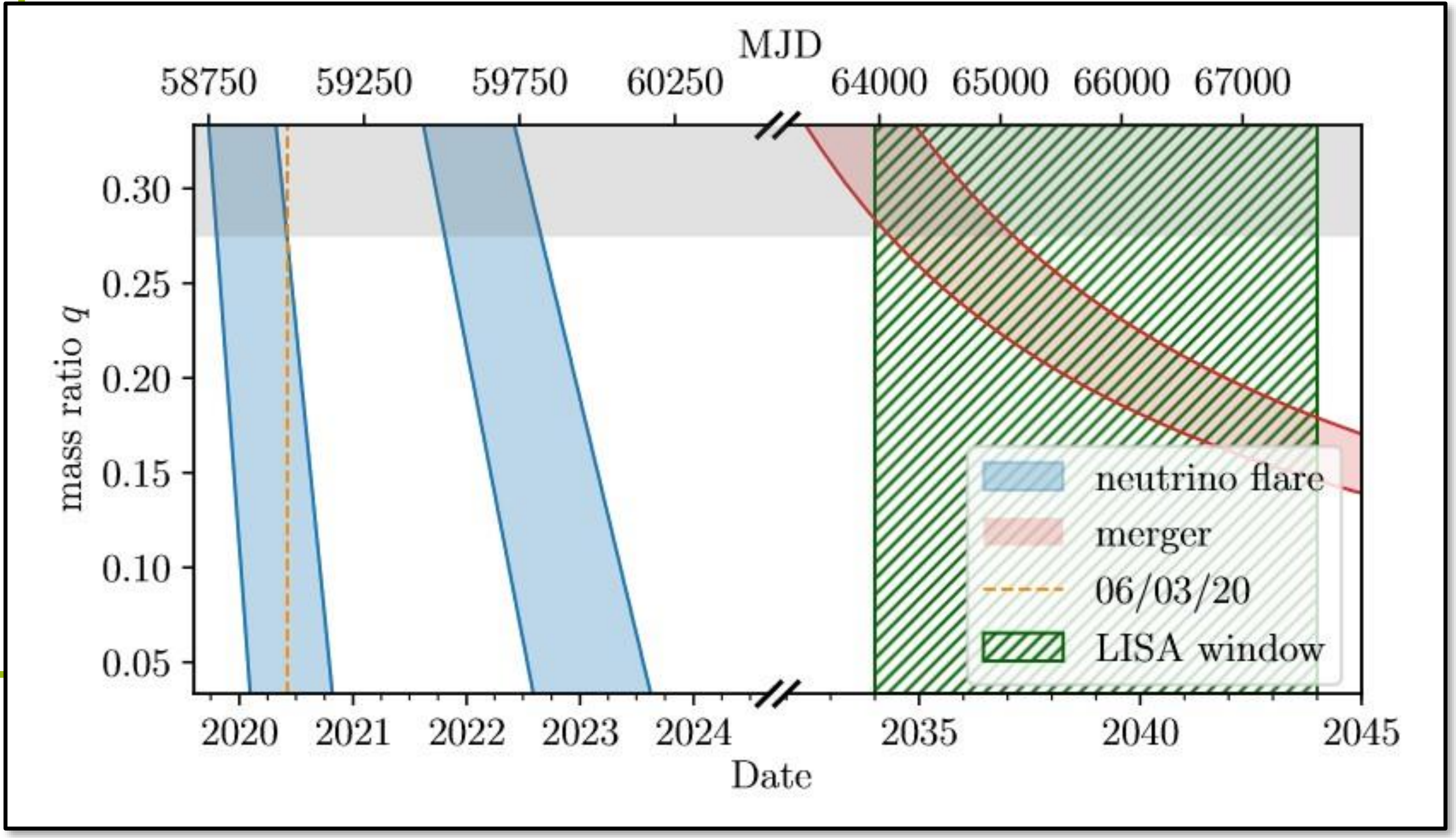
Signal periodicity:

$t_{\mathrm{Jet}} = 2.78 \pm 0.15\ \mathrm{yrs}$

Jet opening angle:

$\delta = 5°$

Combined mass
$M = 3 \cdot 10^8 M_\odot$



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Jet points back at Earth for the next **15 – 120 years**

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SMBBH mergers – common occurrences

- Every radio galaxy with a central black hole $\gtrsim 3 \cdot 10^6 M_\odot$ underwent at least one supermassive black hole merger with a spin-flip of the jet
- Time scale of neutrino production is the same as the time scale for gravitational wave radiation → inspiral stage at sub-pc separation
- Mass ratio $q = \frac{1}{3}$: $\mathbf{4 \cdot 10^6 - 8 \cdot 10^8}$ **yr**
- Smaller mass ratio $q = \frac{1}{3}$ – about factor 5 greater

$$\boldsymbol{E_\nu^{\text{total}} = f_{\text{SMBBH}}^{\nu} \cdot E_{\text{GW}}}$$

Neutrino – GW – Connection

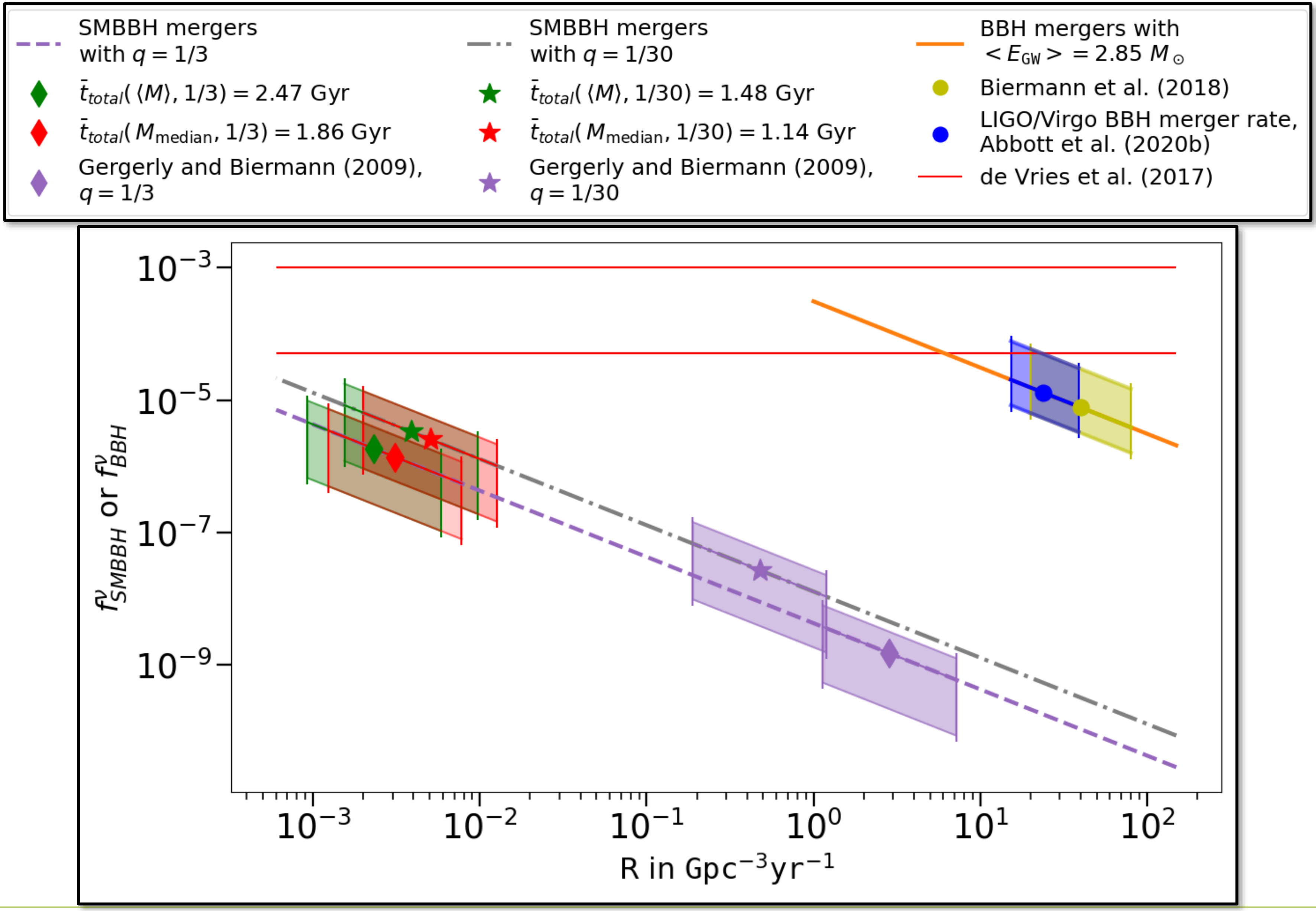
$$E_\nu^{\text{total}} = f_{\text{SMBBH}}^{\nu} \cdot E_{\text{GW}}$$

$$E_\nu^{\gamma_{astro}} \, \Phi(E_\nu)\Big|_{obs} = k \cdot \kappa_{\gamma_{astro}} \cdot \xi_z \cdot c \cdot t_H \cdot f_{\text{SMBBH}}^{\nu} \cdot \int_M \frac{\mathrm{d}E_{\text{GW}}}{\mathrm{d}t} \cdot \frac{n(M)}{M} \, \mathrm{d}M$$

$n(M)$: Schechter function in mass range: $3 \cdot 10^6\ \mathrm{M}_\odot$ - $7 \cdot 10^9\ \mathrm{M}_\odot$

Fraction of total mass emitted in GWs: $E_{\text{GW}} = h(q) \cdot Mc^2$

$$\int_M \frac{\mathrm{d}\left(h(q) \cdot Mc^2\right)}{\mathrm{d}t} \cdot \frac{n(M)}{M} \, \mathrm{d}M = h(q) \cdot \langle M \rangle c^2 \cdot \frac{n_{\text{SMBH}}}{\bar{t}_{total}} = h(q) \cdot \langle M \rangle c^2 \cdot R$$


SMBBH mergers with $q = 1/3$
$\bar{t}_{total}(\langle M \rangle, 1/3) = 2.47$ Gyr
$\bar{t}_{total}(M_{median}, 1/3) = 1.86$ Gyr
Gergerly and Biermann (2009), $q = 1/3$
SMBBH mergers with $q = 1/30$
$\bar{t}_{total}(\langle M \rangle, 1/30) = 1.48$ Gyr
$\bar{t}_{total}(M_{median}, 1/30) = 1.14$ Gyr
Gergerly and Biermann (2009), $q = 1/30$
BBH mergers with $< E_{GW} > = 2.85\ M_\odot$
Biermann et al. (2018)
LIGO/Virgo BBH merger rate, Abbott et al. (2020b)
de Vries et al. (2017)
10^{-3}
10^{-5}
10^{-7}
10^{-9}
f^{ν}_{SMBBH} or f^{ν}_{BBH}
10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2}
R in $\mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$

Summary and Outlook

- Next neutrino from TXS0506+056 **might already be here**, blind analysis of IceCube data could reveal it
- TXS0506+056 could be seen in **gravitational waves by LISA**
- If 90% of the diffuse astrophysical neutrino flux that is detected by IceCube comes from SMBBH mergers and the rest from stellar mass BBH mergers, it is explainable, if only
  $\mathbf{10^{-5}}$ **to** $\mathbf{10^{-6}}$
  of the emitted gravitational wave energy goes into neutrinos
  → **same accelerator physics?**
- Gravitational wave detectors such as LISA or SKA will put a constrain on the SMBH mass distribution and SMBBH merging rate
  → improve this model

Thank you!