Neutrino Emission from Supermassive Binary Black Hole Mergers

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Motivation

∗ three blazars identified as possible sources of high-energy neutrinos [1]
∗ Auger Data: 90 % of UHECRs originates from AGN, rest from starburst galaxies [2]
→ possible explanation: spin-flip of the jets due to ongoing black hole merger
▷ model for predicting arrival times of neutrinos and gravitational waves (GWs) for supermassive binary blach hole (SMBBH) mergers
▷ possible connection between the astrophysical neutrino flux, that is measured by IceCube, and the emitted GW energy during the mergers of SMBBHs and stellar mass binary black holes (BBH) in starburst galaxies

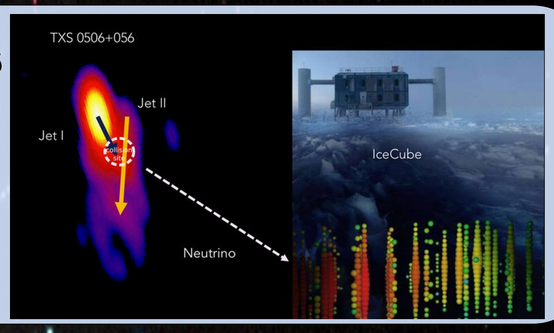

Fig. 1: TXS0506+056 as a SMBBH merger [3].

Spin-flip of the jet

∗ at sub-parsec separations: two inspiraling BHs start to realign their spins in one direction [4]
∗ this 'inspiral stage' is characteristed by GWs being the leading dissipative effect
∗ due to spin precession: orientation of the jets changes periodicaly
∗ we define the angle ϕ of the Spin $\mathbf{S}_1$ around $\mathbf{J}$:

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

ΔT_{GW}: timescale of gravitational radiation, defined as remaining time until merger
$\eta = \frac{m_1 m_2}{(m_1+m_2)^2} = \frac{q}{(1+q)^2}$
mass ratio $q = \frac{m_2}{m_1} < 1$
ϕ_0: integration constant
δ: half opening angle of the jet
$\alpha + \vartheta = \text{const.}$

stages of jet precession:
t_1: before the spin-flip of the jet
- jet is not pointing at Earth

t_2: during spin-flip of the jet
- jet precession around **J**
- points occasionally at Earth

t_3: jet no longer points towards the direction of Earth

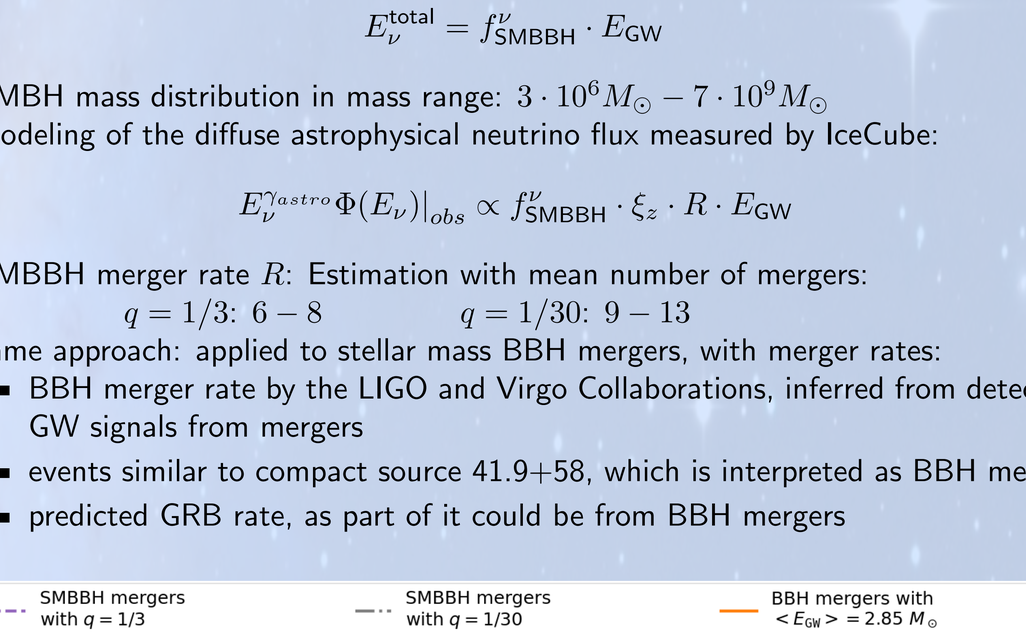

Fig. 2: Schematic representation of the jet precession during the rearrangement of the jet axis.

Application on the blazar TXS0506+056

∗ two distinct episodes of neutrino emission, in 2014/2015 and September 2017
→ possible SMBBH merger
∗ periodicity of jet precession: 2.78 ± 0.15 years - assuming same flare duration
∗ parameters:
- mass ratio q between $1/3$ and $1/30$
- $M \approx 3 \cdot 10^8 M_\odot$
- $\delta = 5°$

∗ all possible parameter settings:
jet points back at Earth for the next **15 - 120 years**

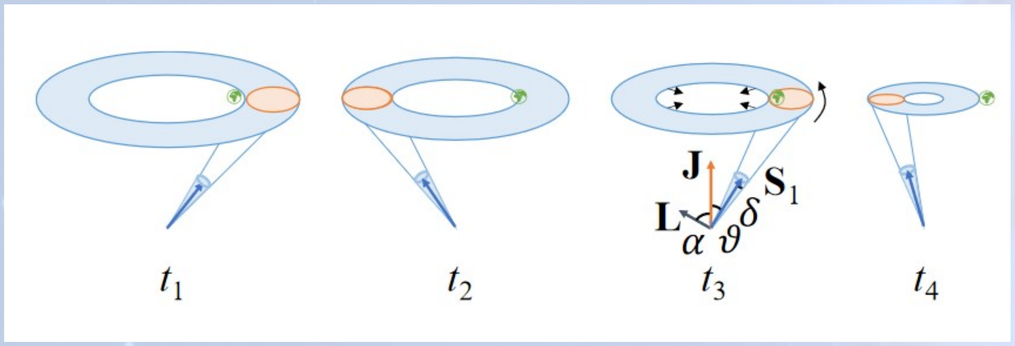

Fig. 3: Signal structure of an AGN jet that recurrently points at Earth. At time t_1, the first signal can be detected at Earth, at t_4 the last, if the orange area crosses Earth. Recurrent detectable flare (neutrino, gamma-ray) in between.

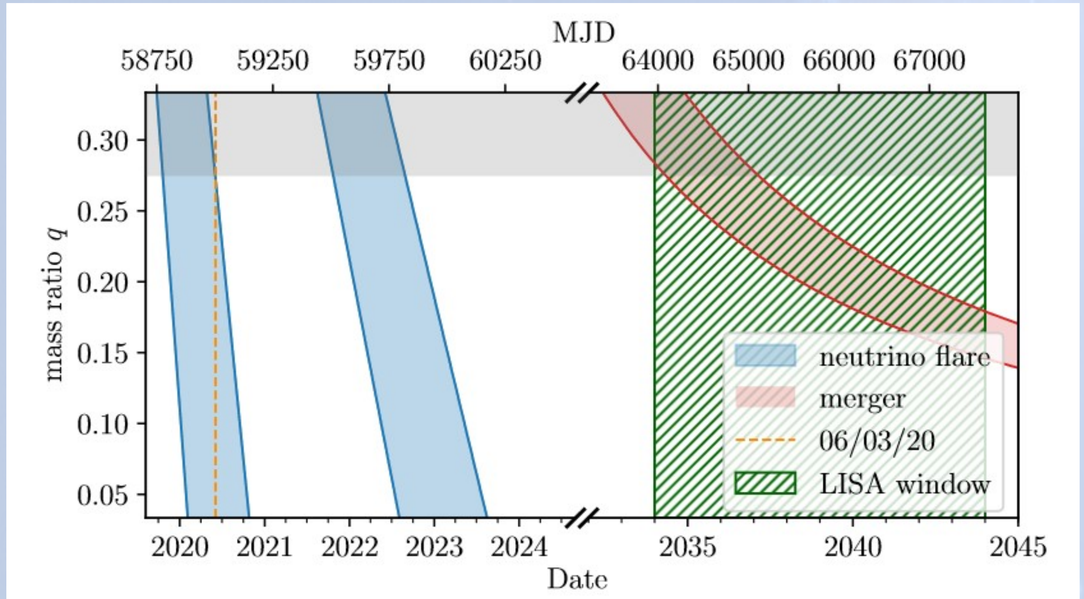

Fig. 4: Prediction for the next two future periods, in which the jet from TXS0506+056 points towards Earth and neutrino could be detectable (blue). Time of gravitational wave signature in red.

Diffusive astrophysical Neutrino Flux

∗ Neutrinos receive a fraction f^{ν}_{SMBBH} of the emitted GW energy during each merger:

$$E_\nu^{\mathrm{total}} = f^{\nu}_{\mathrm{SMBBH}} \cdot E_{\mathrm{GW}} \tag{2}$$

∗ SMBH mass distribution in mass range: $3 \cdot 10^6 M_\odot - 7 \cdot 10^9 M_\odot$
∗ modeling of the diffuse astrophysical neutrino flux measured by IceCube:

$$E_\nu^{\gamma_{astro}} \Phi(E_\nu)|_{obs} \propto f^{\nu}_{\mathrm{SMBBH}} \cdot \xi_z \cdot R \cdot E_{\mathrm{GW}} \tag{3}$$

∗ SMBBH merger rate R: Estimation with mean number of mergers:
$q = 1/3$: $6 - 8$ $\qquad$ $q = 1/30$: $9 - 13$
∗ same approach: applied to stellar mass BBH mergers, with merger rates:
- BBH merger rate by the LIGO and Virgo Collaborations, inferred from detected GW signals from mergers
- events similar to compact source 41.9+58, which is interpreted as BBH merger
- predicted GRB rate, as part of it could be from BBH mergers

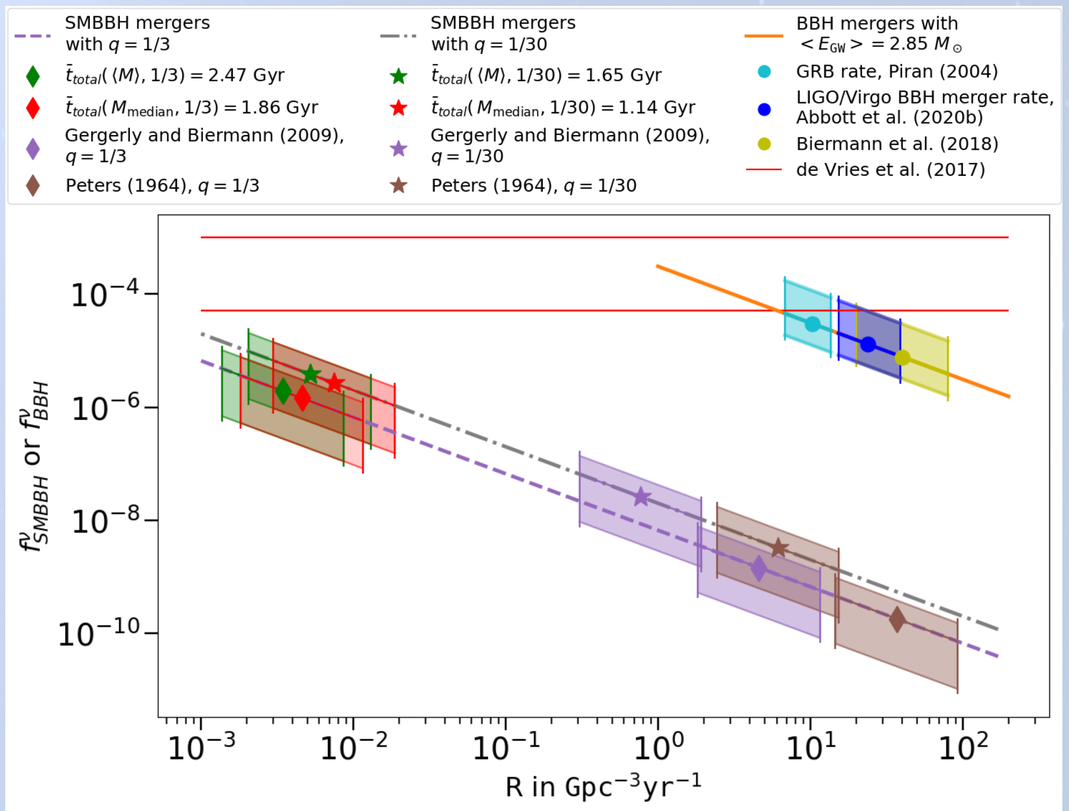

Fig. 5: SMBBH and BBH merger rates in relation to the fraction of emitted GW energy, which neutrinos receive during each merger. 90 % of the neutrino flux originates from SMBBH mergers, rest from BBH mergers in starburst galaxies.

Conclusions

∗ Periodic neutrino emission from TXS0506+056 explainable with a current SMBBH merger
∗ Prediction: the next neutrino flare will happen before the end of 2021
⟶ blind IceCube data analysis could reveal a flare, if signal strong enough
∗ During SMBBH and BBH merger: same fraction of $10^{-4} - 10^{-6}$ of the GW energy goes into neutrinos

References

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