A Neutral Beam Model for Blazar TXS 0506+056

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Abstract

The IceCube collaboration reported a $\sim 3.5\sigma$ excess of 13 ± 5 neutrino events in the direction of the blazar TXS 0506+56 during a ~6 month period in 2014-2015 [4], as well as a $\sim 3\sigma$ association of a ~ 290 TeV neutrino event with a major γ-ray flare in 2017 [3]. Here, we explore if the neutral beam model for blazars [1, 2], can explain the neutrino emission of TXS 0506+056 for both epochs.

Model

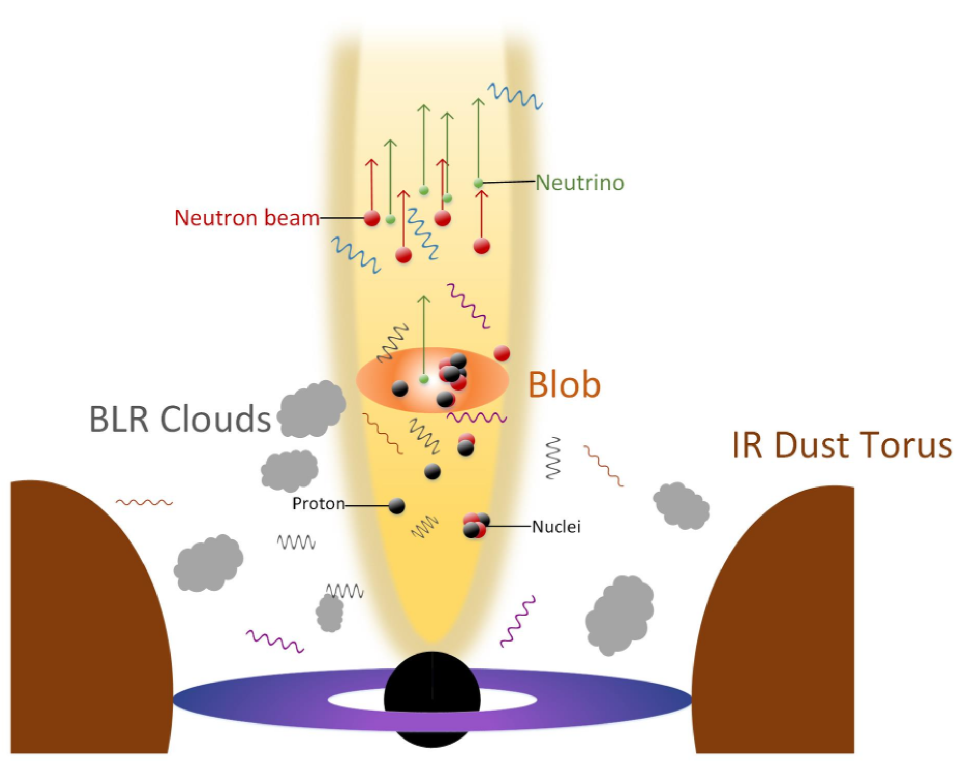

Figure 1: A schematic view of the neutral beam model for blazars (not in scale). Accelerated protons and nuclei are injected into a blob within the jet moving with Lorentz factor Γ, where they interact with various photon fields in the blazar environment to produce high-energy photons, pairs, *neutrinos*, and *neutrons*. While pairs may radiate away their energy and high-energy photons may be attenuated before they escape the blob, neutrinos and neutrons can freely escape. *Neutrons* escaping from the blob moving with Lorentz factor Γ will form a highly collimated beam with opening angle $1/\Gamma$, and continue interacting with external photons on larger scales to produce more high-energy neutrinos and pairs. The neutrino emission is still beamed, but the associated cascade emission from the pairs can be isotropized.

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Methodology

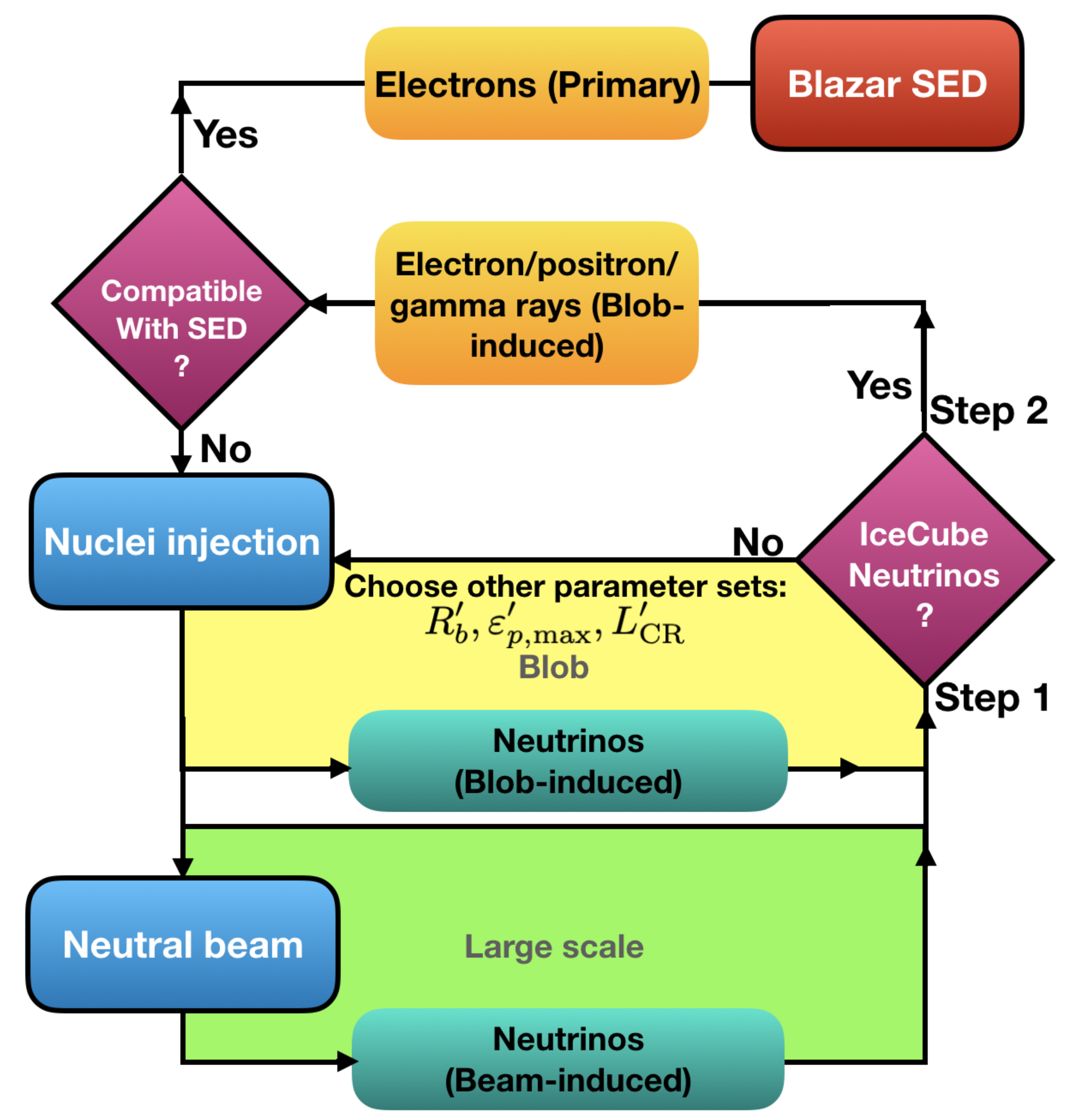

Figure 2: Flowchart demonstrating the two-step numerical approach of our study.

- We begin by injecting nuclei into the blob.
- We then calculate the neutrino emission from the blob and the beam and compare to the neutrino flux measured by IceCube.
- If the model can explain the neutrino data well (Step 1), we then check if the accompanying cascade emission in the blob is compatible with the EM data (Step 2). We also check if this model can explain the blazar SED by taking into account the emission of primary electrons in the blob.

Parameters

Parameter	Symbol	2014-2015 flare	2017 flare
External photon field radius	$R_{\rm ex}$ [cm]	2×10^{17}	2×10^{19}
External energy density	$u'_{\rm ex}$ [erg/cm^3]	100	0.08
External photon spectral index	$s_{\rm ex}$	1.5	2
Minimum photon energy	$\varepsilon'_{\rm min}$ [eV]	0.01	0.5
Maximum photon energy	$\varepsilon'_{\rm max}$ [eV]	200	5×10^3
Blob Lorentz factor	Γ	10	25
Blob radius	R'_b [cm]	10^{15}	10^{17}
Minimum proton energy	$\varepsilon'_{p,\rm max}$ [GeV]	1	1
Nuclei acceleration spectral index	$s_{\rm acc}$	1	1
Number ratio of CR nuclei	$f_{\rm He}/f_{\rm P}$	5:1	5:1
Maximum proton energy	$\varepsilon'_{p,\rm max}$ [PeV]	0.4	2.5
Observed CR luminosity	$L_{\rm CR}^{(iso)}$ [erg/s]	9×10^{49}	1.5×10^{49}

Figure 3: List of model parameters and values used to describe the 2014-2015 neutrino flare (Figure 4)) and the 2017 γ-ray flare (Figure 5).

The 2014-2015 ν Flare

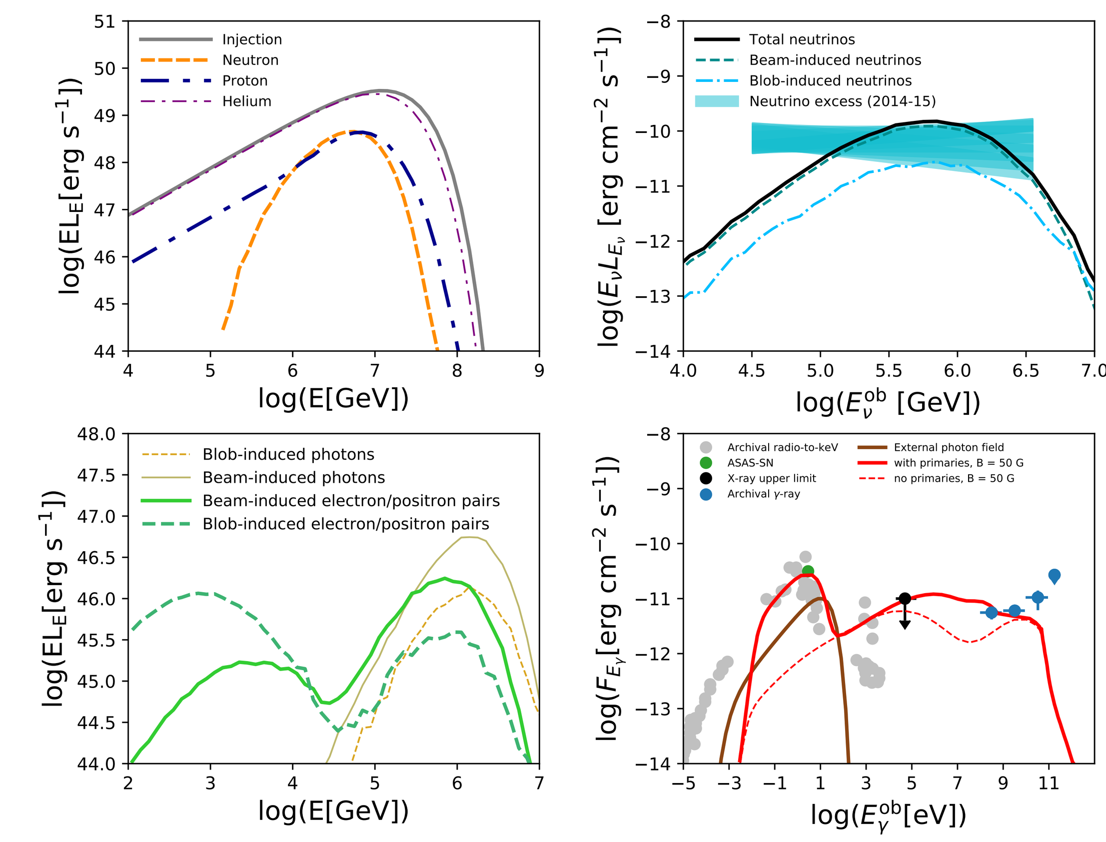

Figure 4: **Top left**: Energy spectra of CR nuclei in observer's frame. **Top right**: Energy spectrum of the all-flavour neutrino flux (solid black line), including the contributions of the beam (dashed green line) and the blob (dotted-dashed cyan line). **Bottom left**: The injection luminosity of Bethe-Heitler (BH) pairs (green lines) and γ-ray photons (orange lines). **Bottom right**: SED of TXS 0506+56. Solid and dashed red lines show the SED with and without, respectively, the contribution of primary electrons, for $B' = 50$ G. The SED of the external radiation field is also shown (solid brown line).

The 2017 γ-ray Flare

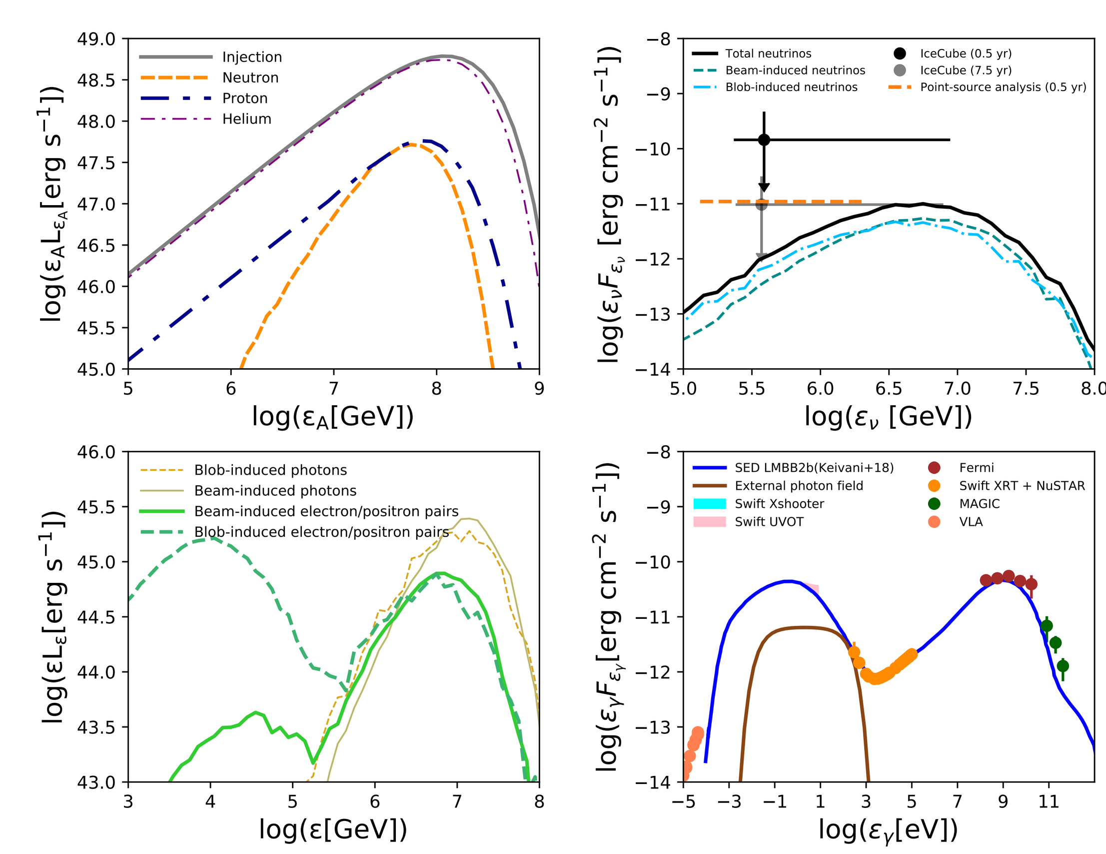

Figure 5: Same as Fig. 4, but for the 2017 neutrino flare. The external photon field (brown line in the lower right panel) and the blob properties are the same as in the model LMPL2b of [5].

Conclusions

- We demonstrated that the neutral beam model provides a consistent explanation for the 2014-2015 neutrino flare as well as for the 2017 γ-ray flare without violating X-ray and γ-ray constraints.
- For the 2017 flare, we showed that the beam-induced neutrino flux is comparable to the blob-induced neutrino flux, thus leading to ~ 2 times higher neutrino flux compared to single-zone models.
- The basic model requirements for explaining the data of both epochs are: (i) a light CR composition (i.e., protons and He), (ii) a time-variable large-scale external photon field (e.g., radiation from the outer layer of a structured jet), and (iii) a high CR luminosity (i.e., $L_{\rm CR}^{(\rm iso)} \sim (1-9) \times 10^{49}$ erg s^{-1}).
- According to the neutral beam model, TXS 0506+56 should be an efficient accelerators of light nuclei that carry a significant fraction of the power available via mass accretion onto a super massive black hole or via the Blandford-Znajek process.

References

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