Characterizing High-Energy Neutrino Emission Parameters in Bright Seyfert Galaxies and Quasars

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INTRODUCTION

The IceCube Collaboration first detected high-energy cosmic neutrinos in 2013 [1]. These TeV-PeV neutrinos are produced in pp or $p\gamma$ collisions involving high-energy cosmic rays (CRs). In both scenarios, charged and neutral pions are produced, the former decaying into neutrinos and the latter to γ-rays. This leads to a multimessenger connection between the two particles. However, *Fermi*-LAT's γ-ray background measurement points to γ-ray opaque sources as major contributors to the diffuse neutrino flux [2]. This realization is reinforced by the observation of high-energy neutrinos from the direction of the nearby active galaxy NGC 1068 and an excess of neutrinos from NGC 4151 [3].

The disk-corona model for neutrino emission from active galactic nuclei (AGNs) provides a compact region for stochastic particle acceleration to occur, leading to high-energy neutrinos and γ-rays [4,5]. The model can explain the observed NGC 1068 neutrino fluxes at the $\sim$ 30 TeV range. In addition, TeV photons cascade down to GeV and sub-GeV energies within this environment. Here, we use the observed neutrino and sub-GeV γ-ray fluxes to narrow the neutrino emission parameter space from AGN coronae. This can be used to identify subsets of sources similar to NGC 1068 that are strong neutrino emitters.

METHOD

We consider stochastic particle acceleration, which accelerates protons by scattering within the magnetohydrodynamic turbulence. The cosmic ray spectrum is computed via the Fokker-Planck equation

$$\frac{\partial \mathscr{F}_p}{\partial t} = \frac{1}{\varepsilon_p^2}\frac{\partial}{\partial \varepsilon_p}\left(\varepsilon_p^2 D_{\varepsilon_p}\frac{\partial \mathscr{F}_p}{\partial \varepsilon_p} + \frac{\varepsilon_p^3}{t_{\rm cool}}\mathscr{F}_p\right) - \frac{\mathscr{F}_p}{t_{\rm esc}} + \dot{\mathscr{F}}_{p,\rm inj}$$

where $\mathscr{F}_p$ is the momentum distribution function, D_{ε_p} is the diffusion coefficient, $t_{\rm cool}$ is the cooling time, $t_{\rm esc}$ is the escape time and $\dot{\mathscr{F}}_{p,\rm inj}$ is the injection term. We evolve $\mathscr{F}_p$ until the steady state is reached, obtaining the injected CR spectrum.

Within the corona, CRs interact with the surrounding protons and photons. We consider pion production via pp and $p\gamma$ processes and compute the cascades by solving the kinetic equation. The processes involved in neutrino and γ-ray production are summarized below.

Particle	Injection	Reinjection
Neutrinos	Decay of $\pi^{\pm}$ from $p\gamma$ collisions	νs escape the source
Gamma-rays	Decay of π^0 from $p\gamma$ collisions Bethe-Heitler process $p\gamma$ collisions	Two-photon annihilation Inverse Compton Synchrotron radiation

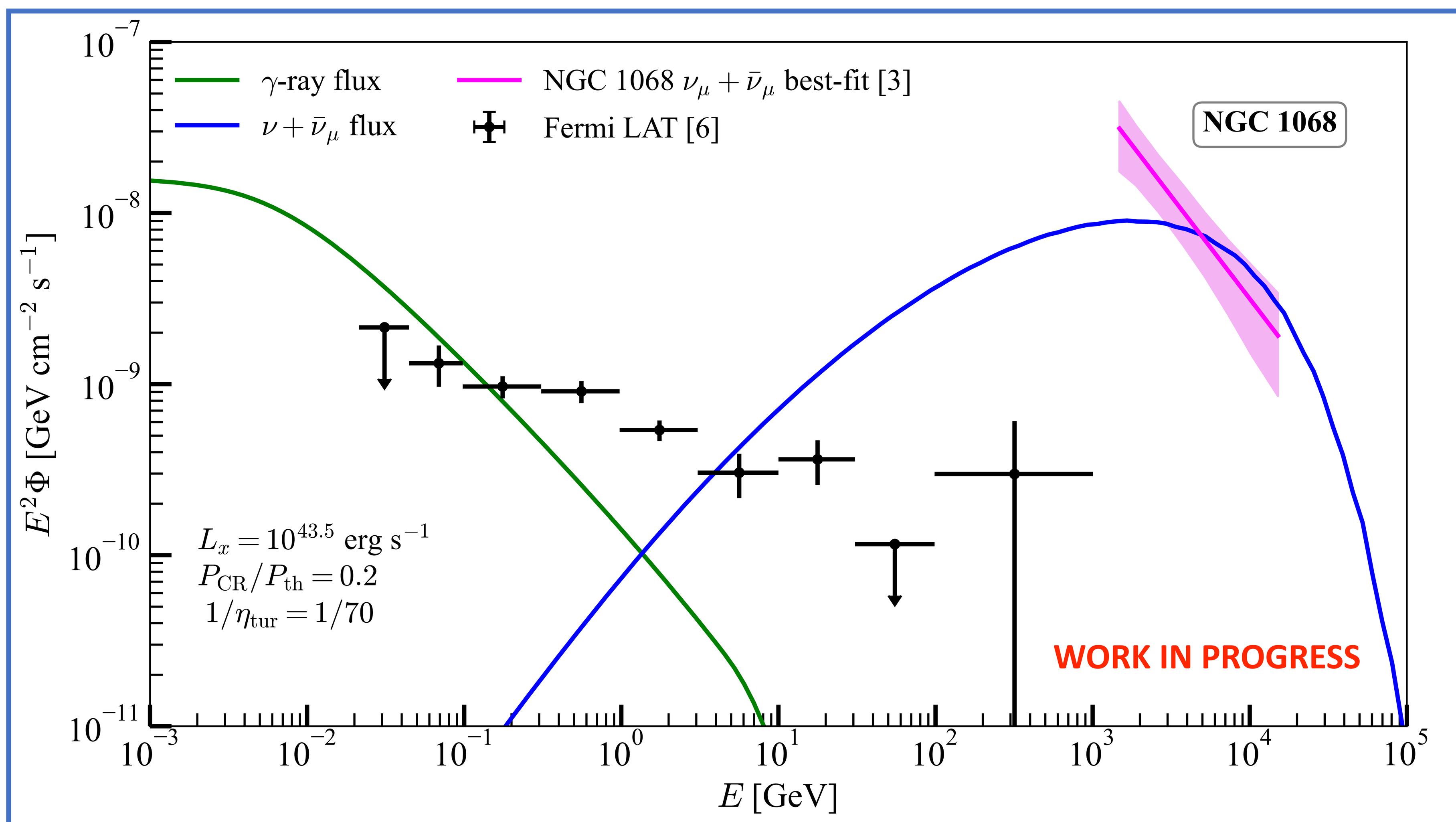

Figure 1. Spectral energy distribution for NGC 1068 using a sample set of parameters. Best-fit ν power-law flux taken from [3] and *Fermi*-LAT limits from [6]

PARAMETER FIT

In this work, we will study three parameters: the intrinsic X-ray luminosity L_X, the CR to thermal pressure ratio $P_{\rm CR}/P_{\rm th}$, and the turbulence strength parameter $1/\eta_{\rm tur}$. The pressure ratio is correlated to the normalization of the CR spectrum. The acceleration timescale $t_{\rm acc} \propto \eta_{\rm tur}$, such that $\eta_{\rm tur}$ affects the maximum CR energy. We perform a likelihood analysis, where we define

$$\ln \mathscr{L} = \ln \frac{1}{1+B_{21}} + \sum_i \ln P_i \,.$$

The first term contains the information of the neutrino spectrum and B_{21} is the Bayes factor which compares the reported ν power-law flux hypothesis against the corona model. The second term accounts for the $\gamma-$rays (binned) measurements by Fermi-LAT. We use this likelihood to construct a Markov Chain Monte Carlo (MCMC) to look at the posterior distributions of the corona model parameters.

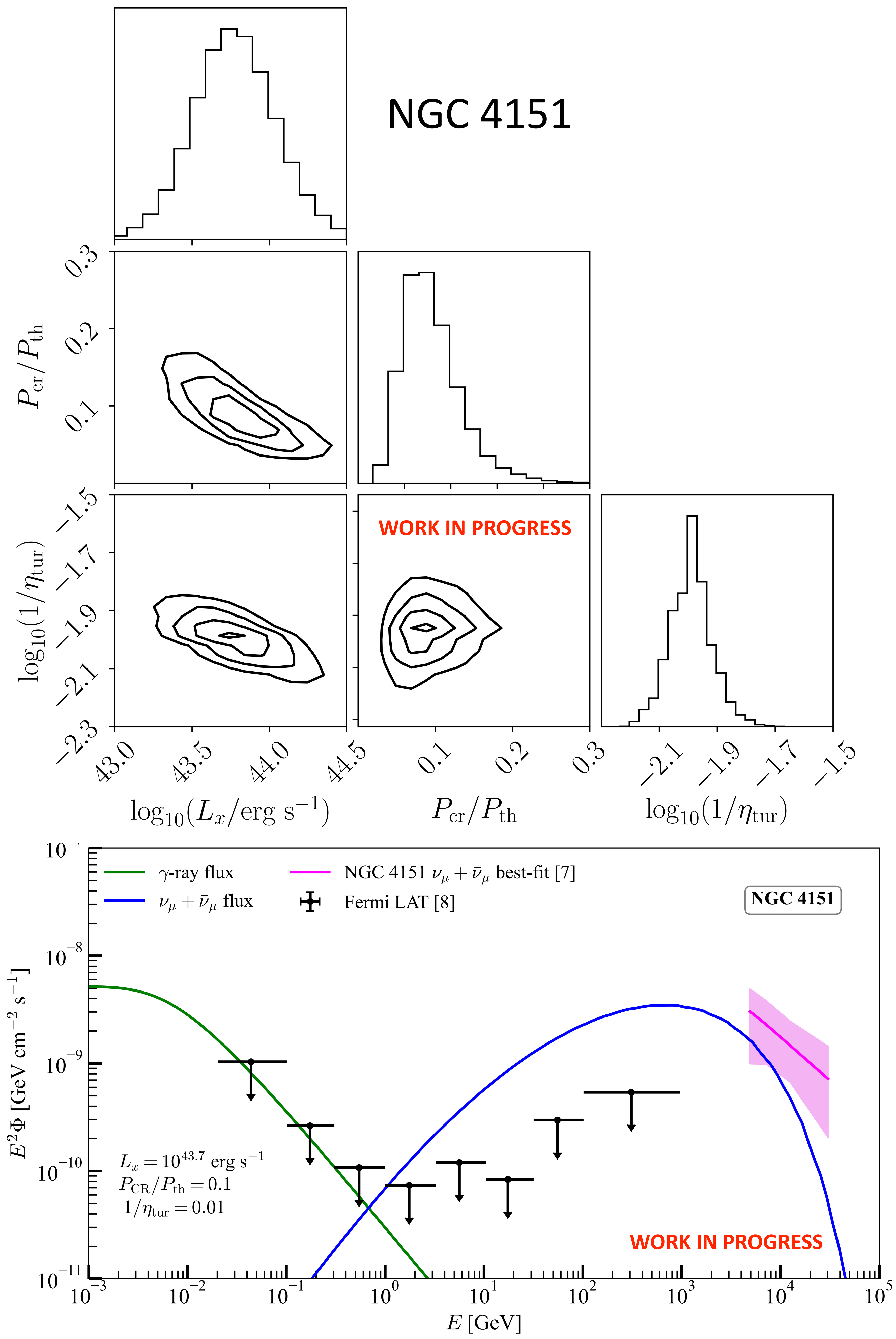

Figure 2. Top panel: MCMC parameter distribution for NGC 4151. The $\nu_\mu + \bar{\nu}_\mu$ flux is obtained from [7] and *Fermi*-LAT limits from [8] . Bottom panel: NGC4151 spectral energy distribution using sample parameters.

RESULTS

In Figure 1 we show the fluxes for NGC 1068, where we can account for the ν flux, but not for the γ-ray flux above 1 GeV. Production in the starburst region can create this additional component (e.g., [6]). The top panel of Figure 2 shows the MCMC simulation of NGC 4151. In the corona model, the pressure ratio is limited to $P_{\rm CR}/P_{\rm th} \lesssim 0.2$ when $L_X \gtrsim 10^{43.5}$ erg s^{-1} and $L_X \lesssim 10^{44.2}$ erg s^{-1} order to satisfy the *Fermi* γ-ray bounds (see bottom panel of Figure 2). Hence, the associated neutrino flux is not fully within the 1σ band reported by IceCube.

OUTLOOK

With this MCMC approach, we can characterize sources based on their neutrino and γ-ray spectra. This can be used to identify and classify additional sources based on their multimessenger signatures.

REFERENCES

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