Neutrino-Emission from Active Galactic Nuclei

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Introduction

AGN, active galactic nuclei, are luminous objects at cosmological distances which have been reported as sources of high energy γ-rays. The emission is probably nonthermal radiation from relativistic jets belonging to the AGN. Earlier investigations of these processes have suggested that neutrinos are among the radiation products of the jets of AGN. Our calculation of the high energetic neutrino emission from the jets of AGN is based on a recently published model for γ-ray production by a collimated, relativistic blast wave, cf. Pohl and Schlickeiser (2000). In this scenario a strong electron-proton beam, the jet of the AGN, is assumed to move with bulk Lorenz factor Γ and to collide with ambient matter. In that process the beam sweeps up interstellar matter which leads to a deceleration of the beam because of momentum conservation. It is important to note that the swept-up interstellar particles retain their relative velocities with respect to the jet plasma, but get isotropised in the jet rest frame by self-exited Alfénic turbulence. The spectral evolution of the energetic particles is determined by the interplay between the injection rate, i.e. the density of the interstellar medium, the energy losses from electromagnetic radiation, and diffusive escape. The neutrino production resulting from the proton-proton collisions in the highly relativistic plasma of the jet is calculated via pion and muon decay.

Calculation of neutrino emission

We calculate the neutrino emission resulting from the decay of charged pions[a]

$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}(\overline{\nu}_{\mu}) \tag{1}$$

and the emission arising through the subsequent decay of charged muons

$$\mu^{\pm} \rightarrow e^{\pm} + \overline{\nu}_{\mu}(\nu_{\mu}) + \nu_e(\overline{\nu}_e) \tag{2}$$

We also take into account the neutrino emission resulting from the neutron β-decay of secondary neutrons arising in the blast wave.

$$n \rightarrow p + e + \overline{\nu}_e \tag{3}$$

The resulting emission rates for neutrino production are calculated by:

$$Q(E_{\nu}, t) = \int_1^{\infty} N(\gamma_p, t)\, q(E_{\nu}, \gamma_p)\, d\gamma_p \tag{4}$$

where $N(\gamma_p, t)$ is the proton spectrum as determined by the model of Pohl and Schlickeiser (2000) and $q(E_{\nu}, \gamma_p)$ are the source functions describing the respective decays analogous to Marscher et al. (1980).

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[a] The quantities in parenthesis refer to the negatively charged particles

Discussion

- Neutrino emission must be correlated with the emission of γ-rays. This makes it possible to distinctly look for neutrino emissions from the jets of AGN by using the TeV γ-ray light curves to drastically reduce the temporal and spatial parameter space in the search for neutrino outbursts.
- Given the observed TeV photon fluxes from nearby BL Lacs the neutrino flux can exceed the atmospheric background and therefore be detectable with future neutrino observatories.
- The bulk of the neutrino emission is expected in the energy range between 100 GeV and 1 TeV.

References

- Pohl, M., Schlickeiser, R., 2000, Astron. Astrophys., 354, 395
- Marscher, A. P., Vestrand, W. T., Scott, J. S., 1980, Astrophys. J., 241, 1166

Neutrino production spectra

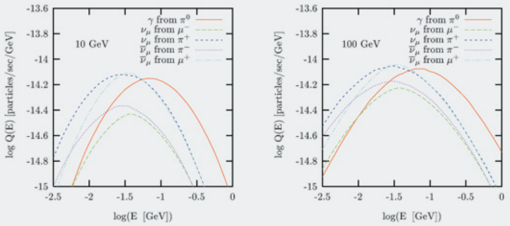

Fig. 1. The production rate of muon neutrinos resulting from the various decay modes calculated **for one proton** of kinetic energy 10 GeV and 100 GeV, respectively. The emission rate does not change in the energy regime of a proton up to a range of 100 GeV. Additionally we show the emission of γ-rays resulting from the decay $\pi^0 \rightarrow 2\gamma$ displayed by the solid line. The emission from the positively charged pions and muons is slightly higher than the emission from the negative ones. The respective pion decay is more effective.

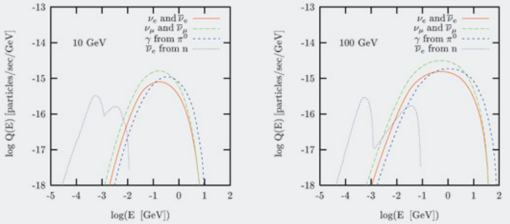

Fig. 2. For a proton with the same kinetic energy as above the electron neutrino emission is shown here. The production of $\overline{\nu}_e$ and ν_e resulting from the muon decay is displayed by the solid line. The energy of anti-electron neutrinos produced by β-decay is about 2 orders of magnitude smaller. For the description of the neutron source function $q_n(\gamma_n, t)$ we use a discrete sum of intensities of monoenergetic neutrons, each one modelled as a δ-distribution. So one assumes that the thermal protons of the jet take part in the collision process as well as the relativistic ones from the interstellar medium. The complete rates of muon neutrinos and γ-rays are also depicted for reference.

Results

In Fig. 3 and Fig. 4 we show two examples of spectral evolution of total muon neutrino emission calculated with the blast wave model for the proton spectra. We assume a constant density of the background plasma. The production rate of γ-rays resulting from the decay $\pi^0 \rightarrow 2\gamma$ is depicted as well for reference. The bulk of muon neutrino emission is in the range between 100 GeV and 1 TeV and strictly follows the evolution of γ-ray production. The strong correlation between neutrino production and γ-ray production makes it possible to specifically search for neutrino emission from AGN. If time and location of neutrino emission from an AGN are known, we might have a chance to detect a signal with a future neutrino observatory.

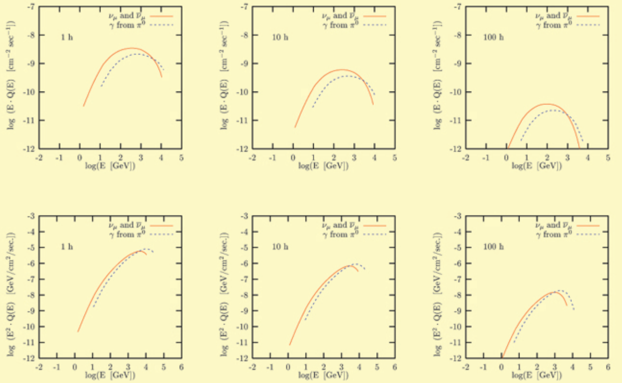

Fig. 3. The evolution of the muon neutrino emission resulting from the protons in the blast wave. In this example the following parameters have been used: The radius of the plasma disk is $R = 10^{14}$ cm, the thickness of the disk amounts to $d = 3 \cdot 10^{13}$ cm and the initial Lorentz factor is $\Gamma_0 = 300$. The constant densities inside and outside the jet are $n_b = 5 \cdot 10^8\,\mathrm{cm}^{-3}$ and $n_i^* = 0.2\,\mathrm{cm}^{-3}$, respectively. Note that the mentioned time refers to the observer frame and therefore depends on the viewing angle θ, which we choose to be 0.1° in this example. The emission is calculated for a redshift of the AGN of $z = 0.5$. In the top row we depict the F_ν spectra and in the bottom row the $\nu\, F_\nu$ spectra. The spectral evolution of the γ-ray production spectra has also been displayed for reference.

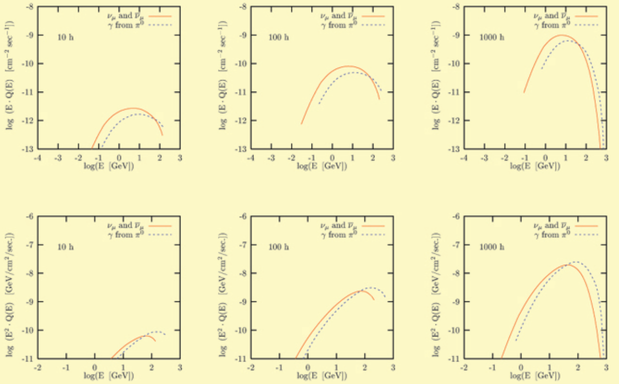

Fig. 4. The emission spectra calculated with another set of parameters. Here we use $R = 2 \cdot 10^{15}$ cm for the radius of the plasma disk and $d = 10^{14}$ cm for the thickness of the disk. The initial Lorentz factor stays at $\Gamma_0 = 300$. The density in the jet has changed to $n_b = 10^8\,\mathrm{cm}^{-3}$ and for the density outside the blast wave $n_i^* = 1.5\,\mathrm{cm}^{-3}$ is assumed. Again we depict the F_ν spectra in the top row and the $\nu\, F_\nu$ spectra in the bottom row. Here the specified time refers to some viewing angle of $\theta = 2°$. The strong dependence of the observed emission on the angle θ is due to the high Lorentz factors in our model. This is responsible for the strong rise after 1000 h. The redshift of the AGN is again $z = 0.5$.