PKS1502+10 as a Neutrino-Radio bright VLBI Object with Proton Jet

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Abstract

High energy neutrino (up to PeV) production in bright blazars within parsec-scale jet and a presence of accelerated ultrarelativistic protons there are discussed continously (Plavin et al., 2020). In order to produce neutrino the presence of high energy protons in AGN jets is necessary. On the other hand, a lower ultrarelativistic energy part of the proton energy distribution (from GeVs up to TeVs) has to generate a synchrotron radio emission in the same parsec-scale jet, in addition (may be) to the electron synchrotron emission. We report the results of testing possibilities of numerical fitting the earlier suggested Hedgehog model for an electron jet or/and a proton jet in the strong longitudinal magnetic field to multi-frequency radio spectrum of PKS 1502+106 obtained with the RATAN-600 and other telescopes in the frequency range from 0.1 up to 1000 GHz. The proton jet can provide a magnetic fields and brightness temperatures for VLBI at $m_p/m_e = 1836$ times higher as well as angular size at $\sqrt{m_p/m_e} = 43$ times less than in the same case for an electron synchrotron jet.

Introduction

After ultra-high energy neutrino events (Aartsen et al., 2018) active galactic nuclei (AGN) have become intriguing candidates in astrophysical neutrino sources and effective proton accelerators. Sources of neutrinos are still unknown, but it turned out the sky areas where the ultra-high-energy neutrinos come from (IceCube) statistically associate with VLBI-bright quasars positions, and the moments of their arrival coincide with powerful flares of synchrotron emission in compact jets of these objects (Plavin et al., 2020a, b). This let suggest the neutrinos are produced in their central parsec-scale regions, probably in protonphoton or proton-proton interactions. The proton synchrotron emission is considered based on the Hedgehog model (Kovalev et al., 2000, 2002, 2020) with a jet in the strong longitudinal magnetic field. The aim is to study main VLBI features of proton synchrotron jets in comparison with jets of electron synchrotron emitters, which have the same gammafactors and geometry of sources. The object PKS 1502+106 is used as an example of possible neutrino-radio VLBI-bright blazar with proton jet emitting neutrino in a photon-proton process (Plavin et al., 2020; Hovatta et al., 2021). The earlier similar comparison see in Kovalev et

Magnetic field, brightness temperature and angular diameter for electron/proton synchrotron emission

The model dependence of magnetic field B on the distance r along the jet is $B = B_0 (r/r_0)^{-2}$. The task is to compare main jet parameters if its geometry and $\gamma_E = (E/m_e c^2) = (E/m_p c^2)$ are the same both for electron jet and for proton one, which are observed within the same angle $\vartheta = const$. The following spectra parameters have been estimated from fitting the jet model to the observational data above: the frequency $\nu_m (\lambda_m = c/\nu_m)$ and the flux density S_m in the maximum of the jet spectrum, γ_E and the index γ in the energy spectrum for electrons or protons. We use the following equations (1)-(3) to estimate the main jet parameters.

$$B_{\perp}/M_{2e} \sim 0.82 \cdot 10^{-6} \cdot \nu_m \cdot \gamma_E^{-2},$$
 (1)

$$T_b \sim 1.5 \cdot 10^8 \cdot \gamma_E \cdot M_{2e} \,, \tag{2}$$

$$\Theta \sim \lambda_m \left(\frac{2S_m}{\pi k_B T_b}\right)^{1/2}.$$
(3)

Here $B_{\perp} = B \sin \vartheta$, $M_{2e} = 1$ for electrons and $M_{2e} = 1836$ for protons, Θ is an angular diameter of the emitted jet in the picture plan, k_B is the Boltsman constant, T_b is the brightness temperature.

Broadband radio spectra of PKS 1502+106. RATAN-600 and literature data are shown with the blue and black circles, respectively. The black dotted line represents the linear fitting optically thin model synchrotron emission of extended structures up to kpc scales. The blue dotted line represents high frequency model component associated with the parsec scale jet and dominates at several GHz and above. The red line is the sum of the black and blue dotted lines.

Results

We tested numerical fitting the average spectrum in the Hedgehog model to the many epochs observed data. It is calculated and fitted an electron or proton synchrotron emission in the jet model with strong longitudinal magnetic field using many-years multi-frequency observational data of PKS 1502+106. Such temporal average spectra could be observed in the model if the continuous flux dN/dt(t) of emitted particles across the start of the jet is constant during a long time (of the order of 10 years in general). The variability of this flux for synchrotron emitted protons or electrons is converted to variability of the observed emission in the model (Kovalev et al., 2000). Main results of estimation for jet parameters using (1)-(3) above and fitting the model to observations (Figure) see in the Table. We add also the time $t_{1/2}$ of the energy loss due to the synchrotron emission at ν_m — in the last column of the Table.

Estim. Jet Parameters from (1) - (3) :	B, Gauss	T_b, K	Θ, mas	$t_{rac{1}{2}},\mathrm{s}$
electrons	7	$5 \cdot 10^{10}$	0.6	$1 \cdot 10^{8}$
protons	$1 \cdot 10^4$	$9 \cdot 10^{13}$	0.014	$2 \cdot 10^{11}$

Common fitted parameters: $\vartheta = 1^{\circ}, \nu_m = 13 \; GHz, S_m = 1.5 \; Jy, \gamma = 2.4, \gamma_E = 300,$ $M_{2e} = 1 \; (\text{electrons}), \; M_{2e} = 1836 \; (\text{protons}), \; B^2/(8\pi) \gg W_E \; \text{as for electrons as for protons} \; (W_E \; \text{is the energy density of emitted particles}).$



Conclusion. The many years multi-frequency average variable spectra of PKS 1502+106 can be explained both by proton and by electron synchrotron emission. If to explain it by emitted electrons or protons with equal gamma-factor and jet geometry then the magnetic field and brightness temperature of the proton jet can gain up to $m_p/m_e = 1836$ times greater than they for the electron jet (m_p and m_e are the mass of proton and electrons, respectively). The angular size of this proton jet can be up to ~43 times less than it for such electron jet. VLBA results are in agreement with these angular sizes. **References** Hovatta, T., Lindfors, E., Kiehlmann, S., et al., 2021, AA, 650, id. A83, 17.

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