Blazar Demographics with MOJAVE and GLAST

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Abstract.
MOJAVE is a long term VLBA program to investigate the kinematics and polarization evolution of a complete sample of 133 active galactic nuclei selected on the basis of compact, relativistically beamed jet emission at 15 GHz. By fitting to the apparent distributions of superluminal speed and jet luminosity, we can constrain the Lorentz factor distribution and intrinsic luminosity function of the radio-selected blazar parent population. These low-energy peaked blazars formed a significant fraction of all EGRET detections, and should figure prominently in the GLAST source catalog. Using simple models, we investigate the predicted distribution of GLAST blazars in the gamma-ray/radio flux density plane, and describe an extension of the MOJAVE survey that will provide extensive parsec-scale jet information in complete regions of this plane. We find that if a population of intrinsically radio bright yet gamma-ray weak blazars exists, its signal will be largely wiped out by the large gamma-ray flux scatter associated with Doppler beaming.

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MONTE CARLO BLAZAR POPULATION SIMULATIONS

Many of the overall characteristics of blazars and their parent population are poorly known, mainly because of the inherent difficulties in disentangling beaming and selection effects from flux-limited samples. These issues can be addressed, however, given a general knowledge of the distribution of bulk Lorentz and Doppler factors in the blazar parent population. Since 1994 we have been carrying out a large VLBA survey to determine these quantities for the brightest AGN jets in the sky at a wavelength of 2 cm [3]. In 2002, full polarization imaging was added as part of the MOJAVE (Monitoring Of Jets in Active galactic nuclei with VLBA Experiments; [4]), and the sample was refined to include all AGN with J2000 declination > -20°, galactic latitude |b| > 2.5°, and VLBA 2 cm flux density ≥ 1.5 Jy (2 Jy for decl. < 0°) at any epoch between 1994 and 2003. There are 133 AGN that satisfy these criteria, ~ 95% of which are flat-spectrum blazars. Superluminal speeds have been obtained for nearly the entire sample, and the speed distribution is consistent with a power-law distribution of bulk Lorentz factors in the parent population (Lister et al., in preparation).

In principle, the beamed flux density from an AGN jet should be a function of the bulk Lorentz factor of the emitting region, its intrinsic (un-beamed) luminosity, the observer viewing angle, and the redshift. Under the simplifying assumptions of a non-varying Lorentz factor, straight jets, and flat radio spectral index, the probability density functions for these four quantities can be derived in connection with Monte Carlo techniques to produce simulated flux-limited AGN samples (e.g., [5]). If we can assume an intrinsic scaling law between the un-beamed luminosities of jets in the radio and gamma-ray regimes, it is possible to produce a simulated distribution of blazars in the radio/gamma-ray plane. For this study, we have chosen a simple linear scaling (e.g., [8, 2]) of the form $f = \sigma L_{\gamma} / L_{\text{radio}} + \text{const.}$, where $\sigma$ is a Gaussian deviate of unit width. We then calculate the beamed jet luminosities according to $P_{\text{radio}} = L_{\text{radio}} \delta^{2}$, $P_{\text{SSC}} = L_{\text{radio}} \delta^{2-\alpha} f$, and $P_{\text{ECS}} = L_{\text{radio}} \delta^{3-2\alpha} f$, where $\delta$ is the jet Doppler factor and $\alpha = -1.4$ is the typical gamma-ray spectral index [7]. The synchrotron-self Compton (SSC) and external Compton scattering (ECS) models differ mainly in the source of the seed photons for the inverse-Compton emission, and therefore have different beaming dependencies [2].

Fig. 1 shows the predicted distributions in the gamma-ray/radio flux density plane for these two emission models. In these simulations we use the fitted intrinsic luminosity parameters of [1], and assume a parent Lorentz factor distribution of the form $n(\Gamma)d\Gamma \propto \Gamma^{-1.5}d\Gamma$, with $\Gamma_{\text{max}} = 30$. The latter limit, which comes from the highest speeds observed in radio-loud blazar jets [3], creates an upper envelope in Figure 1 that corresponds to sources with the maximum possible Doppler factors ($\delta \approx 60$).

These simulations indicate that despite a relatively small scatter in the intrinsic radio/gamma-ray luminosity ratio, a very large range of gamma-ray flux density is expected at a given radio flux density level. This is entirely due to...
FIGURE 1. Simulated blazar populations based on the MOJAVE radio quasar sample. Plotted on the x-axis is compact radio jet (VLBA) luminosity at 15 GHz. The y-axis represents the predicted gamma-ray flux density, assuming a simple linear scaling between intrinsic radio and gamma-ray jet luminosity with Gaussian scatter. The left panel uses an external synchrotron seed photon model to calculate the beamed gamma-ray emission, while the right panel assumes a synchrotron self-Compton model.

the large range of possible Doppler factor values in the population, and the larger amount of Doppler boosting in the gamma-ray regime. This implies that if a population of intrinsically radio bright yet gamma-ray weak blazars exists, its signal will likely be wiped out by the large gamma-ray flux scatter associated with Doppler beaming. Although the SSC model predicts a slightly lower median gamma-ray flux for bright radio-loud blazars, it will be difficult to distinguish between these two emission models without additional jet Doppler factor information.

THE EXTENDED MOJAVE SURVEY

The MOJAVE survey will continue to provide publicly available high-resolution VLBA data on bright blazars throughout the GLAST mission. The sample has recently been expanded to include all known high confidence EGRET blazars above declination $-20^\circ$, as well as 33 nearby, low-luminosity AGN. Following the launch of GLAST, we will also add up to 100 of the brightest gamma-ray AGN above declination $-30^\circ$ which have sufficient flux density for direct VLBA fringe detection ($\sim 200$ mJy at 2 cm). This will provide complete kinematic information in regions A through D in Figure 1. Each individual AGN will be observed at a cadence appropriate to its angular expansion rate, such that individual jet features can be reliably identified across the epochs. These cadences range from once every two months for fast sources like BL Lac, 3C 273, and 3C 120, to once every two to three years for the slowest-varying jets. Additional programs at the U. Michigan, Owens Valley, and Effelsberg radio observatories will also provide dense flux-density monitoring data at cm and mm wavelengths on the entire sample.

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