Gamma-ray emitting AGN and GLAST

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Abstract. I describe the different classes of Active Galactic Nuclei (AGN) and the basic tenets of unified schemes. I then review the properties of the extragalactic sources detected in the GeV and TeV bands, showing that the vast majority of them belong to the very rare blazar class. I further discuss the kind of AGN GLAST is likely to detect, making some predictions going from the obvious to the likely, all the way to the less probable.

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THE ACTIVE GALACTIC NUCLEI ZOO

Active Galactic Nuclei (AGN) are extragalactic sources, in some cases clearly associated with nuclei of galaxies (although generally the host galaxy light is swamped by the nucleus), whose emission is dominated by non-stellar processes in some waveband(s).

Based on a variety of observations, we believe that the inner parts of AGN are not spherically symmetric and therefore that emission processes are highly anisotropic [4, 28]. The current AGN paradigm includes a central engine, almost certainly a massive black hole, surrounded by an accretion disk and by fast-moving clouds, which under the influence of the strong gravitational field emit Doppler-broadened lines. More distant clouds emit narrower lines. Absorbing material in some flattened configuration (usually idealized as a torus) obscures the central parts, so that for transverse lines of sight only the narrow-line emitting clouds are seen and the source is classified as a so-called "Type 2" AGN. The near-infrared to soft-X-ray nuclear continuum and broad-lines, including the UV bump typical of classical quasars, are visible only when viewed face-on, in which case the object is classified as a "Type 1" AGN. In radio-loud objects, which constitute $\approx 10\%$ of all AGN, we have the additional presence of a relativistic jet, likely perpendicular to the disk (see Fig. 1 of [28]).

This axisymmetric model of AGN implies widely different observational properties (and therefore classifications) at different aspect angles. Hence the need for "Unified Schemes" which look at intrinsic, isotropic properties, to unify fundamentally identical (but apparently different) classes of AGN. Seyfert 2 galaxies are though to be the "parent" population of, and have been "unified" with, Seyfert 1 galaxies, whilst low-luminosity (Fanaroff-Riley type I [FR I][7]) and high-luminosity (Fanaroff-Riley type II [FR II]) radio galaxies have been unified with BL Lacs and radio quasars respectively [28]. In other words, BL Lacs are thought to be FR I radio galaxies with their jets at relatively small ($\lesssim 15-20^\circ$) angles w.r.t. the line of sight. Similarly, we believe flat-spectrum radio quasars (FSRQ) to be FR II radio galaxies oriented at small ($\lesssim 15^\circ$) angles, while steep-spectrum radio quasars (SSRQ) should be at angles in between those of FSRQ and FR II's ($15^\circ \lesssim \theta \lesssim 40^\circ$; a spectral index value $\alpha_{\rm r} = 0.5$ at a few GHz [where $f_\nu \propto \nu^{-\alpha}$] is usually taken as the dividing line between FSRQ and SSRQ). BL Lacs and FSRQ, that is radio-loud AGN with their jets practically oriented towards the observer, make up the blazar class. Blazars, as I show below, play a very important role in γ-ray astronomy and it is therefore worth expanding on their properties.

Blazars

Blazars are the most extreme variety of AGN. Their signal properties include irregular, rapid variability, high polarization, core-dominant radio morphology (and therefore flat [$\alpha_{\rm r} \lesssim 0.5$] radio spectra), apparent superluminal motion, and a smooth, broad, non-thermal continuum extending from the radio up to the γ-rays [28]. Blazar properties are consistent with relativistic beaming, that is bulk relativistic motion of the emitting plasma at small angles to the line of sight, which gives rise to strong amplification and collimation in the observer's frame. Adopting the usual definition of the relativistic Doppler factor $\delta = [\Gamma(1-\beta\cos\theta)]^{-1}$, $\Gamma = (1-\beta^2)^{-1/2}$ being the Lorentz factor, $\beta = v/c$ being the

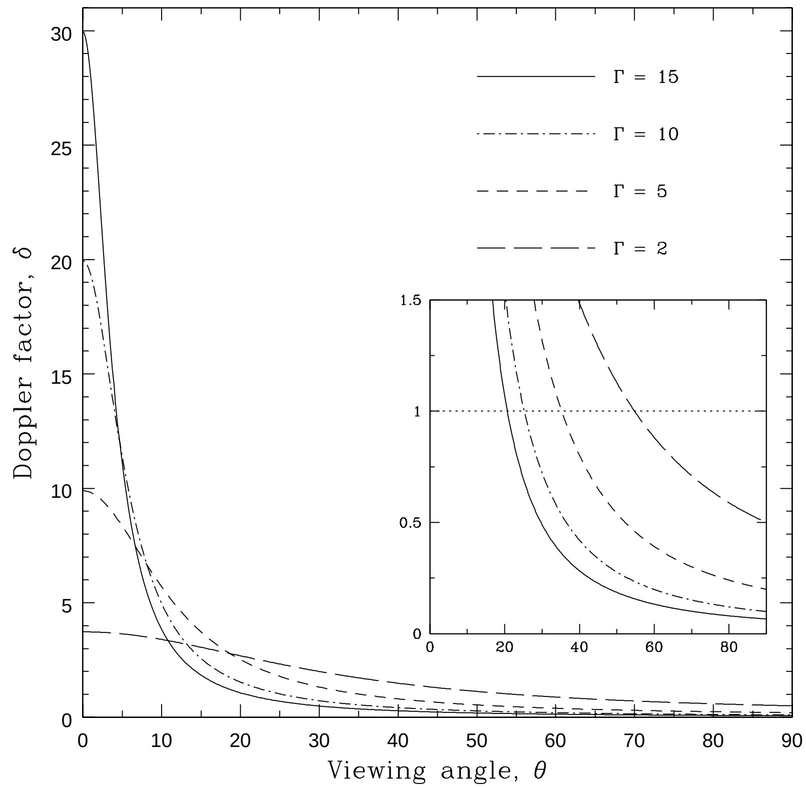

FIGURE 1. The dependence of the Doppler factor on viewing angle. Different curves correspond to different Lorentz factors Γ. The expanded scale on the inset shows the angles for which $\delta = 1$.

ratio between jet speed and the speed of light, and θ the angle w.r.t. the line of sight, and applying simple relativistic transformations, it turns out that the observed luminosity at a given frequency is related to the emitted luminosity in the rest frame of the source via $L_{\rm obs} = \delta^p L_{\rm em}$ with $p \sim 2-3$. For $\theta \sim 0^\circ$, $\delta \sim 2\Gamma$ (Fig. 1) and the observed luminosity can be amplified by factors 400 – 10,000 (for $\Gamma \sim 10$ and $p \sim 2-3$, which are typical values). That is, for jets pointing almost towards us the emitted luminosity can be overestimated by up to four orders of magnitude. For more typical angles $\theta \sim 1/\Gamma$, $\delta \sim \Gamma$ and the amplification is $\sim 100-1,000$.

In a nut-shell, blazars can be defined as sites of very high energy phenomena, with bulk Lorentz factors up to $\Gamma \approx 30$ [6] (corresponding to velocities ~ 0.9994c) and photon energies reaching the TeV range (see below).

Given their peculiar orientation, blazars are very rare. Assuming that the maximum angle w.r.t. the line of sight an AGN jet can have for a source to be called a blazar is $\sim 15^\circ$, only $\sim 3\%$ of all radio-loud AGN, and therefore $\approx 0.3\%$ of all AGN, are blazars. For a $\sim 1-10\%$ fraction of galaxies hosting an AGN, this implies that only 1 out of $\approx 3,000-30,000$ galaxies is a blazar!

Blazar spectral energy distributions (SEDs) are usually explained in terms of synchrotron and inverse Compton emission, the former dominating at lower energies, the latter being relevant at higher energies. Blazars have a large range in synchrotron peak frequency, $\nu_{\rm peak}$, which is the frequency at which the synchrotron energy output is maximum (i.e., the frequency of the peak in a $\nu - \nu f_\nu$ plot). Although the $\nu_{\rm peak}$ distribution appears now to be continuous, it is still useful to divide blazars into low-energy peaked (LBL), with $\nu_{\rm peak}$ in the IR/optical bands, and high-energy peaked (HBL) sources, with $\nu_{\rm peak}$ in the UV/X-ray bands [21]. The location of the synchrotron peaks suggests in fact a different origin for the X-ray emission of the two classes. Namely, an extension of the synchrotron emission responsible for the lower energy continuum in HBL, which display steep ($\alpha_{\rm x} \sim 1.5$) X-ray spectra [29], and inverse Compton (IC) emission in LBL, which have harder ($\alpha_{\rm x} \sim 1$) spectra [20]. This distinction applies almost only to BL Lacs, as most known FSRQ are of the low-energy peak type and, therefore, with the X-ray band dominated by inverse Compton emission. Very few “HFSRQ” (as these sources have been labelled), i.e., FSRQ with high (UV/X-ray energies) $\nu_{\rm peak}$ are in fact known. Moreover, $\nu_{\rm peak}$ for all these sources (apart from one) appears to be $\sim 10-100$ times smaller than the values reached by BL Lacs (see [19] for a review).

THE GEV AND TEV SKIES

Before moving on to GLAST we need to assess the present status of the γ-ray sky. I do this first at GeV and then TeV energies.

The third EGRET catalogue [15] includes 271 sources ($E > 100$ MeV), out of which 95 were identified as extragalactic (including 28 lower confidence sources). Further work [17, 24, 25], which provided more identifications, allows us to say that EGRET has detected at least ~ 130 extragalactic sources (since a large fraction of sources is still unidentified), all of them AGN apart from the Large Magellanic Cloud. Furthermore, all the AGN are radio-loud and $\sim 97\%$ of them are blazars, with the remaining sources including a handful of radio galaxies (e.g., Centaurus A, NGC 6251). Most of the blazars are FSRQ, in a ratio $\sim 3/1$ with BL Lacs. Finally, $\sim 80\%$ of the BL Lacs are LBL and the few HBL are all local ($z < 0.12$). As all of the FSRQ are also of the LBL type, $\sim 93\%$ of EGRET detected blazars are of the low-energy peak type.

The situation at TeV energies is at first order similar to that in the GeV band, with some significant differences. All confirmed extragalactic TeV sources are radio-loud AGN and include 16 BL Lacs and one radio galaxy (M87) (a starburst galaxy is also a possible TeV source) [18, 3]. That is, the blazar fraction is $\sim 94\%$. Unlike the GeV band, however, no FSRQ is detected and all but one BL Lacs are HBL. This is due to the fact that in HBL the very high-energy flux is higher than in LBL, as both peaks of the two humps in their SED are shifted to higher frequencies.

The fact that the GeV and TeV skies are dominated by blazars seems to be at odds with these sources being extremely rare (see previous section). The explanation has to be found in the peculiar properties of the blazar class and rests on the fact that blazars are characterized by:

1. high-energy particles, which can produce GeV and TeV photons;
2. relativistic beaming, to avoid photon-photon collision and amplify the flux;
3. strong non-thermal (jet) component.

Point 1 is obvious. We know that in some blazars synchrotron emission reaches at least the X-ray range, which reveals the presence of high-energy electrons which can produce γ-rays via inverse Compton emission (although other processes can also be important: e.g., [5]). Point 2 is vital, as otherwise in sources as compact as blazars all GeV photons, for example, would be absorbed through photon-photon collisions with target photons in the X-ray band (see, e.g., [16]). Beaming means that the intrinsic radiation density is much smaller than the observed one and therefore γ-ray photons manage to escape from the source. The flux amplification in the observer’s frame makes also the sources more easily detectable. Point 3 is also very important. γ-ray emission is clearly non-thermal (although we still do not know for sure which processes are responsible for it) and therefore related to the jet component. The stronger the jet component, the stronger the γ-ray flux.

GLAST AND AGN

We can know ask which (and how many) AGN GLAST will detect. This I describe in the following, in decreasing order of "obviousness".

Blazars

Given that blazars are well know γ-ray sources, GLAST will certainly detect many flat-spectrum radio quasars and BL Lacs. How many exactly depends on a variety of factors. These include blazar evolution and intrinsic number density (which can to some extent be estimated from deep surveys in other bands), their duty cycle in the γ-ray band (as we know that EGRET was detecting mostly sources in outburst), and their SED (see below). Finally, any prediction will have not to violate the extragalactic γ-ray background.

To get an order of magnitude estimate, I make the following simple assumptions: a) EGRET has detected 130 blazars, which is likely to be a lower limit given the still unidentified sources; b) the number counts are Euclidean, that is $N(>S) \propto S^{-1.5}$, where S is the flux density; this is a very likely upper limit as we know that, after the initial steep rise, number counts of extragalactic sources tend to flatten out at lower fluxes; c) GLAST is 30 times more sensitive than EGRET. The total number of blazars GLAST will detect over the whole sky is then $\lesssim 20,000$. This corresponds to $\lesssim 0.5$ objects/deg^2, which, interestingly enough, is the surface density of blazars down to ~ 50 mJy at 5 GHz in the Deep X-ray Radio Blazar Survey (DXRBS) [22]. Note also that by means of Monte Carlo simulations a value around 5,000 has been predicted all-sky (extrapolating from the high Galactic latitude value of [10]; see also [11]).

HBL

As discussed above, EGRET has detected very few blazars of the high-energy peak type (HBL). This is because the EGRET band was sampling the "valley" between the two (synchrotron and IC) humps in their SED. A look at the SED of some of the TeV detected HBL [1, 2, 27] shows that many, if not all, of them should be easily detected by GLAST.

Radiogalaxies

Unified schemes predict that the "parent" population of blazars is made up of radio-galaxies, a much more numerous class (by a factor ≈ 30 for a dividing angle between the two classes $\sim 15^\circ$). However, at large angles w.r.t. the line of sight, jet emission is not only not-amplified but actually de-amplified. Fig. 1 shows that for typical Lorentz factors $\delta < 1$ for viewing angles $\gtrsim 20-30^\circ$. This implies that radio-galaxies on average are weaker sources (by factors $\approx 1,000$) than blazars, in all bands. And indeed, the handful of GeV/TeV-detected radio-galaxies are all local ($z < 0.02$).

Large scale, that is kpc-scale jet emission, as opposed to the small, pc-scale, one, is also unlikely to be relevant in the γ-ray band for the bulk of radio-galaxies [26, 23].

However, the radio-galaxy cause might not be totally lost. It has been proposed that blazar jets are structured or decelerated. The first scenario [9], which ties in with Very Long Baseline Interferometry (VLBI) observations of limb brightening [12], suggests the presence of a fast spine surrounded by a slower external layer. In the other case [8], which tries to reconcile the low δ values from VLBI observations of TeV BL Lacs with the high values inferred from SED modeling of the same sources, the jet is supposed to decelerate from a Lorentz factor $\Gamma \sim 20$ down to $\Gamma \sim 5$ over a length of ~ 0.1 pc. In both instances the presence of the two velocity fields implies that each of the two components sees an enhanced radiation field produced by the other. The net result is that IC emission gets boosted and therefore the GeV flux is higher than that predicted in the simpler case of an homogeneous jet (at the price of having a larger number of free parameters). Assuming that the γ-ray/radio flux ratio observed for the three GeV/TeV-detected radio-galaxies sources is typical, at least 10 3CR radio-galaxies should to be detected by GLAST [9].

Note that some Broad Line Radio Galaxies (BLRG), which are Type 1 sources in which the jet is at angles intermediate between those of blazars and radio-galaxies, are also likely to be detected by GLAST [13, 14].

Radio-Quiet AGN

The large majority of AGN are of the radio-quiet type, that is they are characterized by very weak radio emission, on average $\sim 1,000$ times fainter than in radio-loud sources. Radio-quiet does not mean radio-silent, however, and the nature of radio emission in these sources is still debated. Two extreme options ascribe it either to processes related to star-formation (synchrotron emission from relativistic plasma ejected from supernovae) or to a scaled down version of the non-thermal processes associated with energy generation and collimation present in radio-loud AGN. In the latter case, one would expect also radio-quiet AGN to be (faint) γ-ray sources. Assuming their GeV flux to scale roughly as the radio flux this would be, on average, a factor ≈ 30 below the GLAST detection limit. Detection might be possible, however, for the (few) high core radio flux radio-quiet AGN. Even a negative detection, supported by detailed calculations, could prove very valuable in constraining the nature of radio-emission in these sources.

SUMMARY

The main conclusions are as follows:

1. Blazars, even though they make up a small minority of AGN, dominate the γ-ray sky;
2. GLAST will certainly detect "many thousand" blazars, with the exact number being somewhat model dependent;
3. GLAST will most likely detect "many" high-energy peaked blazars, which have so far escaped detection at GeV energies due to the fact that EGRET was sampling the "valley" between the two (synchrotron and IC) humps in their spectral energy distribution;
4. GLAST will possibly detect a "fair" number of radio-galaxies;
5. GLAST might also detect some radio-quiet AGN, depending on the nature of their radio emission.

In any case, GLAST will constrain (radio-loud) AGN physics and populations, as described very well at this conference!

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