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GPS QUASARS AS SPECIAL BLAZARS

J. M. BAI[1,2], AND MYUNG GYONG LEE[2]
[1]Yunnan Astronomical Observatory, NAOC, Chinese Academy of Sciences, P.O. Box 110, Kunming, Yunnan 650011, China
E-mail: jinmingb@public.km.yn.cn
[2] Astronomy Program, SEES, Seoul National University, Seoul 151-742, Korea
E-mail: mglee@astrog.snu.ac.kr
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ABSTRACT

In this paper, we argue that the gigahertz peaked spectrum (GPS) quasars are special blazars, blazars in dense and dusty gas enviornment. The *ROSAT* detection rate of GPS quasars is similar to that of flat spectrum radio quasars (FSRQs), suggesting that the relativistic jets in GPS quasars are oriented at small angle to the line of sight. Due to strong inverse Compton scattering off infrared photons from dense and dusty nuclear interstellar media in GPS quasars, most of them may have significant soft gamma-ray and X-ray emission, which is consistent with *ASCA* X-ray observations. Because Compton cooling in GPS quasars is stronger than that in FSRQs, synchrotron emission in GPS quasars may less dominate over thermal emission of the accretion disk and hot dust, hence most GPS quasars show low optical polarization and small variability, consistent with observations. We suggest that it is the significant radio emission of electron/positron pairs produced by the interaction of gamma-rays with the dense gas and dust grains in GPS quasars that makes GPS quasars show steep radio spectra, low radio polarization, and relatively faint VLBI/VLBA cores. Whether GPS quasars are special blazars can be tested by gamma-ray observations with *GLAST* in the near future, with the detection rate of GPS quasars being similar to that of FSRQs.

Key words : galaxies: active — galaxies: jets — quasars: general — radiation mechanism: nonthermal — gamma-rays: theory — X-rays: galaxies

I. INTRODUCTION

Blazars, including BL Lac objects and flat-spectrum radio quasars (FSRQs), are radio-loud Active Galactic Nuclei (AGNs) characterized by highly polarized and rapidly variable non-thermal continuum emssion from radio to gamma-rays (GeV and TeV energies). It is generally believed that blazar continuum emission is produced in a relativistic jet oriented close to the line of sight (for a review see Urry 1999; Ulrich et al. 1997). About 66 AGNs have been detected as GeV (>0.1 GeV) gamma-ray sources by EGRET experiment on board the Compton Gamma Ray Observatory (CGRO) and 6 blazars have been detected to date as TeV gamma-ray sources by gound-based Atmospheric Cerenkov Imaging telescopes (ACITs) (e.g., Aharonian et al. 2004; Holder et al. 2003; Aharonian et al. 2002; Bai & Lee 2001; Hartman et al. 1999; Mattox et al. 1997; Mukherjee et al. 1997; Thompson et al. 1995). The γ-ray emission of blazars indicates a double-peak structure in their spectral energy distribution (SEDs) from radio to gamma-rays, suggesting two broad spectral components. The first component peaks in the IR to X-ray energy range, and the second peaks at gamma-ray energies. Correlated variations across blazar SEDs are consistent with the picture that a single electron population in the relativistic jet gives rise to both components, via synchrotron at low energies and inverse Compton scattering at high energies.

The gigahertz peaked-spectrum (GPS) radio sources, including GPS galaxies and quasars (GPSQs), are compact (< 1 kpc), powerful radio sources with well-defined peaks in their radio spectra (see O'Dea 1998 for a review). GPS sources make up significant fraction of the bright radio source population (~10%). Unlike blazars which have very bright cores and one-side jets on VLBI and VLBA images, most GPSQs have very faint cores and complex structures, with some showing counter-jet on VLBI and VLBA images (Stanghellini et al. 2001). About 30% of GPSQs even show two VLBI lobes (micro-lobes) on both sides ("compact doubles" or "compact symmetric objects", O'Dea 1998). In addition, GPSQs are low-polarization quasars unlike typical blazars, and seem to have little variability (e.g., Stanghellini et al. 2001, 1998; O'Dea 1998). For these reasons, it is generally believed that the morphology and luminosities are not dominated by Doppler-boosted emission (O'Dea 1998) and that the relativistic jets in GPS sources are oriented at large angle to the line of sight (e.g., Stanghellini et al. 2001; Urry & Padovani 1995).

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Three GPSQs, CTA 102, PKS 0528+134, and PKS 1127 – 145, (O'Dea et al. 1991; Zhang et al. 1994; Stanghellini et al. 1998) were detected as GeV (>0.1 GeV) gamma-ray sources by EGRET experiment on board the Compton Gamma Ray Observatory (CGRO), showing blazar properties. It is suggested that these gamma-ray GPSQs and some other GPSQs are not real GPS sources but blazars, and should be eliminated from the GPS class (Lister 2003). However, all three gamma-ray detected GPSQs also have a low polarization. Moreover, both PKS 1127 – 145 (Siemiginowska et al. 2002) and CTA 102 (Wehrle & Cohen 1989) have two bright components on VLBI and VLBA images, and PKS 0528+134 may even have a counter jet (Zhang et al. 1994). Why are they different from typical blazars?

In this paper, we show evidence that the relativistic jets in GPSQs are oriented at small angle to the line of sight, and that GPSQs are special blazars, blazars in dense and dusty gas environment. We argue that it is the surrounding dense gas and dust that makes GPSQs show non-blazar properties. In Section 2, we describe the general assumptions used in our calculations of emission spectra. We then investigate the dominant emission mechanisms in GPSQs and present some pieces of evidence for gamma-ray emission in GPSQs. $H_0 = 50\mathrm{km\,s^{-1}Mpc^{-1}}$, and $q_0 = 0.5$ are assumed throughout this study.

II. EVIDENCE FROM *ROSAT* OBSERVATIONS

The luminosity of line emission in GPSQs is similar to that in FSRQs (O'Dea 1998, and reference there in), so the luminosity of accretion disk and the intrinsic jet power in GPSQs are roughly the same as those in FSRQs. If the relativistic jets in GPSQs have larger viewing angles than those in blazars, i.e., the jet emission in GPSQs is not beamed towards the Earth, GPSQs should be less luminous at X-rays than FSRQs. However, this is not the case. Though GPS sources usually show extra absorption in the soft X-ray band, *ROSAT* X-ray (0.1–2.4keV) observations show that 9 out of 13 GPSQs in O'Dea's complete sample of GPS sources have been detected, with a detection rate of 70% (see Table 1). O'Dea's complete sample of GPS sources was selected from 1-Jy radio catalog (1Jy at 5 GHz, Stickel, Meisenheimer & Kühr 1994). Among 214 FSRQs in 1Jy radio catalog, 124 of them were detected by *ROSAT*, with a detection rate of 57.9% which is even lower than that of GPSQs. This implies that the X-ray emission in GPSQs is relativistically beamed towards the Earth, as FSRQs do. The relativistic jets in GPSQs are thus oriented at small angle to the line of sight.

III. COMPTON COOLING IN GPSQS

In AGN jets, relativistic electrons emit via synchrotron process at low energies and via inverse Compton scattering at high energies. The seed photons of inverse Compton scattering may be synchrotron photons within the jet (synchrotron self-Compton [SSC] mechanism, e.g., Königl 1981; Marscher & Gear 1985; Ghisellini, & Maraschi 1989; Tavecchio et al 1998), or may come from sources external to the jet (external radiation Compton [ERC] mechanism), including UV photon from the accretion disk (Dermer & Schlickeiser 1993), or disk UV radiation reprocessed/reflected by broad-line region (BLR) clouds (Sikora, Begelman, & Rees 1994; Blandford & Levinson 1995), or jet emission reprocessed/reflected by the BLR (Ghisellini & Madau 1996), or near-IR radiation from hot dust (Wagner et al. 1995; Sikora, Begelman, & Rees 1994; Blazejowski et al. 2000; Sikora et al. 2002). Probably, several seed photon sources work at the same time, but one or two are dominant. The relative importance between two radiation processes depends on the corresponding energy densities U_{r1}, and U_{r2}, as

$$P_{c1}(\gamma)/P_{c2}(\gamma) = U_{r1}/U_{r2}\,, \tag{1}$$

Studies on the SED properties of blazars suggest that from high-frequency peaked BL Lac Objects to low-frequency peaked ones to FSRQs, blazar SEDs show a remarkable continuity, and that while gamma-rays in BL Lac objects are likely produced via the SSC mechanism, in line-emission blazars – FSRQs, cooling is dominated by Comptonization UV photons reprocessed/reflected by BLR clouds, peaking power output at GeV gamma-ray energies (e.g., Sambruna 1997; Fosatti et al. 1998; Kubo et al. 1998; Mukherjee et al. 1999; Hartman et al. 2001). Up-scattering IR photons, the same population of electrons in FSRQs could produce softer gamma-rays peaking at MeV energies (Sikora, Begelman, & Rees 1994; Blazejowski et al. 2000). Among GeV FSRQs, only five of them (PKS 0208−512, PKS 1622−297, 3C 279, 3C 454.3, and 3C 273) show gamma-ray spectra extending downward to MeV energies (Schönfelder et al. 2000; McNaron-Brown et al. 1995), indicating that in most FSRQs, U_{IR} is negligible compared to U_{UV}.

There are several pieces of evidence suggesting that GPS sources contain dense and dusty nuclear interstellar media (O'Dea 1998 and reference therein; Siemiginowska et al. 2003). It is possible that in most GPSQs, U_{IR} is not negligible or even larger than U_{UV} in some sources. Comptonization of IR photons are thus comparable to that of UV photons from BLR, or even dominant in some sources. That is to say, most GPSQs have not only luminous GeV gamma-ray emission, but may also have comparable MeV gamma-ray emission. This may be why CTA 102 and PKS 0528+134 are bright at both MeV and GeV energies.

Strong Comptonization of IR photons makes a GPSQ not only a bright MeV gamma-ray source but also a

Table 1.
ROSAT Observations of GPSQs in the Complete Sample

IAU Name	Other Name	Redshift	F_{5GHz} Jy	V mag	$F_{0.1-2.4keV}$ erg/cm^2/s
0237−233	PKS	2.223	3.34	16.6	1.61×10^{-12}
0248+430	S4	1.316	1.24	15.5	
0457+024	PKS	2.384	1.57	19.4	1.02×10^{-12}
0500+019	PKS	0.583	1.89	20.2	1.76×10^{-13}
0738+313	B2	0.630	3.62	16.1	6.4×10^{-13}
0743−006	PKS	0.994	2.05	17.5	1.68×10^{-12}
1127−145	PKS	1.187	3.82	16.9	2.26×10^{-12}
1143−245	OM 272	1.950	1.40	18.5	
1245−197	PKS	1.280	2.34	20.5	
1442+101	OQ 172	3.535	1.20	17.8	6.0×10^{-13}
2126−158	PKS	3.270	1.17	17.3	4.26×10^{-12}
2134+004	PKS	1.936	8.50	16.8	1.53×10^{-12}
2342+821	S5	0.735	1.28	20.5	

powerful X-ray emitter, especially in hard X-rays. GPSQs are thus on an average brighter at X-ray energies than FSRQs. This is consistent with *ASCA* X-ray observations. Among all 35 radio-loud quasars detected by *ASCA* (0.5–10keV, Reevs & Turner 2000), 6 of them are GPSQs. Except for 1614+051, other five of them (0237−233, 0528+134, 2000−330, 2126−158, and 2230+114) are in 1-Jy catalog. Considering the small ratio between the populations of GPSQs and FSRQs (e.g., ∼ 11 : 100 in 1-Jy catalog), the detection rate of GPSQs by *ASCA* is much higher than that of FSRQs, suggesting that GPSQs are on an average brighter than FSRQs in hard X-rays.

The luminosity of line emission in GPSQs is similar to that in FSRQs (O'Dea 1998, and reference there in), so the energy density of UV photons U_{UV} in GPSQs is roughly the same as that in FSRQs. Thus Compton cooling in GPSQs is on an average stronger than that in FSRQs owing to extra Compton cooling of dense IR photons in GPSQs. Synchrotron emission in GPSQs is thus a smaller fraction of bolometric luminosity than it is in FSQRs. Synchrotron emission in GPSQs may less dominate thermal emission of the accretion disk and hot dust, or even be dominated by thermal emission during low states, showing low optical polarization and small variability. This may be why most GPSQs are less violent variables in the optical bands and have lower optical polarization than FSRQs (O'Dea 1998 and references therein).

IV. DISCUSSION AND CONCLUSIONS

As mentioned above, in GPS sources there may be a very dense and dusty nuclear interstellar media. The $e^{\pm}$ pair production by the interaction of gamma-rays with atoms and protons in dust grains and gas may be significant in GPSQs, though the cross section is only about $0.01\sigma_T$. The gamma-rays are beamed to the surrounding gas and dust grains, and the pairs are produced within the beam on both sides of the central engine. Suppose the gamma-ray optical depth to be ∼0.001 for a geometrical length of ∼ 100 pc (corresponding to a Thomson depth of ∼0.1), pairs on each side can get a power of $> 10^{44}$ ergs s^{-1} (assuming $L_\gamma > 10^{47}$ ergs s^{-1}).

The created pairs are relativistic particles with an energy of about half of the gamma-ray energy ($\gamma < 1000$ for most pairs). The bulk motion of pairs is unlikely relativistic, so most pairs emit mainly via synchrotron in the radio band with steep spectra, forming two very bright jet "knots" or micro-lobes on two sides, and offer an extra contribution to radio luminosity, $> 10^{44}$ ergs s^{-1} on each side of the core, which is comparable to or even large than the total radio power emitted by electrons in FSRQ compact jets (the VLA cores). This may be the reason why all GPSQs have relatively faint VLBI/VLBA cores, most GPSQs have low apparent jet speeds, and some GPSQs evne show two-side radio structures (the jet has a relatively larger viewing angle), and the reason why all GPSQs have steep radio spectra, and show low radio polarization. The radio luminosity of pairs is proportional to the gamma-ray luminosity, hence is "indirectly" Doppler boosted. This may be the reason why GPSQs follow the same correlation between luminosities of radio and X-ray as FSRQs (Brinkmann, Yuan & Siebert 1997).

In summary, GPSQs are probably special blazars. It is bescause they are in a dense and dusty gas environment that makes them show non-blazar properties. with the relativistic jets oriented at small angle to the line of sight. Besides strong GeV gamma-ray emission, more than 50% GPSQs may have significant

MeV gamma-ray emission due to strong Comptonization of IR photons. This can be tested by gamma-ray observation of the *GLAST* to be launched in the near future. The detection rate of GPSQs by *GLAST* should be similar to that of FSRQs.

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