

Study of IGM through high energy radiation from blazar

Jayashri Medhi, H L Duorah, A G Barua, and K Duorah

Department of Physics, Gauhati University, Guwahati 781014, Assam, India.

E-mail: jayashri.medhi@rediffmail.com

Abstract. The high energy gamma rays from blazar affects the intergalactic medium (IGM) to large distances at different redshifts. The blazar radiation has been taken as the result of synchrotron and Inverse Compton scattering of electrons. It is found that the intergalactic medium is clumpy. Our estimated values lie within the suggested limit of $\Omega_{IGM} \cong 0.03$ at redshift $z = 3$.

1. Introduction

Blazars are subclass of active galactic nuclei (AGN) where high energy emission makes them ideal candidates for gamma ray observations. Blazars jointly comprise flat spectrum radio quasars (FSRQs) with broad, strong emission lines and BL Lacertae (“BL Lac”) objects, which show no evidence for emission lines [1, 2]. Blazars are characterised by a relativistic plasma jet oriented at a small angle with respect to the observer’s line of sight. They are broadband sources often accompanied by prominent emission of electromagnetic radiation throughout the entire electromagnetic spectrum. Radio to optical emission in the blazar, s spectrum is produced by synchrotron radiation of relativistic electrons while gamma rays are most naturally to be produced by the inverse Compton scattering of soft photons by the same electron population [3, 4]. In this paper we present synchrotron and Inverse Compton mechanism for γ -ray production in blazar. As very high energy gamma rays (VHEGRs) propagate through the Universe, they interact with the soft photons that comprise the extragalactic background light (EBL) and heats the intergalactic medium (IGM) efficiently by producing ultra- relativistic pairs. Due to blazar heating the temperature of the IGM increases to 10^4 K- 10^6 K [5].

2. Synchrotron emission

Synchrotron radiation is produced when the energetic electrons spiraling in a magnetic field of blazar jets. The photons emitted as synchrotron radiation have characteristic frequency given by

$$\omega_c = \frac{3}{2}\gamma^2 \left(\frac{eH}{mc} \right), \quad (1)$$

where e and m are the charge and mass of the electron, H is the strength of the magnetic field, γ is the Lorentz factor and c is the speed of light. If we take a power-law spectrum of the form $I_e(E) = K_e E^{-\Gamma}$ for electron energy $E = \gamma mc^2$, the differential flux given by [6] is

$$I_{\text{sync}}(E_\gamma) = 9.46 \times 10^{-10} \left(8.15 \times 10^{-6} \right)^\Gamma a(\Gamma) L \times K_e H^{\frac{(\Gamma+1)}{2}} E^{-\frac{(\Gamma+1)}{2}}, \quad (2)$$



Table 1. Intensities and fluxes for Synchrotron radiation in the energy range from 10^{-3} eV to 10^3 eV

Energy (eV)	$I(E_\gamma) \text{ cm}^{-2}\text{s}^{-1}\text{sr}^{-1}\text{GeV}^{-1}$	Flux ($\times 10^{-21} \text{ ergs cm}^{-2}\text{s}^{-1}\text{sr}^{-1}\text{Hz}^{-1}$)
10^{-3}	8.13×10^{18}	66
10^{-2}	14.6×10^{16}	11.8
10^{-1}	26×10^{13}	2.1
10^1	8.13×10^{11}	0.66
10^2	14×10^9	0.012
10^3	26×10^7	0.002

Where $a(\Gamma)$ is a numerical coefficient with values $a(2.5) = 0.85$, $a(3) = 0.074$ and $a(4) = 0.072$. Taking $\Gamma = 2.5$ and the magnetic field in emission region $H = 0.1$ G we have calculated the differential flux for the energy range from 10^{-3} eV to 10^3 eV.

3. Inverse Compton emission

Inverse Compton scattering is generally thought to be responsible for the production of high energy gamma rays in blazars. Several suggestions have been made for the origin of the target photons : optical/uv photons from an accretion disk [7], optical photons from the broad line region and infrared emission of dusty torus [8, 9] can produce the target photons. This radiation mechanism is usually called External Comptonization (EC). Synchrotron photons produced in the jet can also act as target photons for inverse Compton scattering, a process referred to as Synchrotron Self Compton (SSC) scattering [3, 10]. Here we have assumed SSC model for gamma ray emission from blazar. Application of this model to the observations of TeV γ -ray emission from Mrk 421 has been recently tested by [11]. Based on the detected variability time scales of TeV γ -ray emission, observations of coincident flares in X-rays and TeV γ -rays and the observed multiwavelength photon spectrum of Mrk 421, the constraints has been placed on the allowed parameter space (magnetic field in the emission region and its Doppler factor) for the homogeneous SSC model. For the 1 day flare, the magnetic field in the blob has to be limited to the range $\sim 0.025 \div 0.15$ G and the corresponding Doppler factors to the range $\sim 20.5 \div 10.7$. For the 15 min flare these limits are following: $\sim 0.4 \div 1.3$ G and $\sim 37.6 \div 24$.

For homogenous, isotropic electron intensity distribution, the differential γ -ray intensity produced by Inverse Compton scattering of relativistic electrons suggested by [12] is

$$I(E_\gamma) = \frac{1}{2} L \rho_{\text{ph}} \sigma_T \left(mc^2 \right)^{1-\Gamma} (\bar{\epsilon})^{\frac{(\Gamma-3)}{2}} K_e E_\gamma^{-\frac{1}{2}(\Gamma+1)} f(\Gamma), \quad (3)$$

Where $f(\Gamma) \cong 1$ for Γ in the range 1 to 2. We assume $L = 7 \times 10^{22}$ cm, radiation density $\rho_{\text{ph}} = 4.75 \times 10^{-8}$ GeV cm^{-3} , $\sigma_T = 6.65 \times 10^{-25}$ cm^2 , Mean photon density $\bar{\epsilon} = 2.3 \times 10^{-5}$ GeV and $\Gamma = 2$.

4. Impact of blazar on the intergalactic medium (IGM)

When the high energy gamma rays emitted from the blazar passes through the IGM they interact with the optical light produced by the galaxies and transforming it into the elementary particles electrons and positrons. These very high energy gamma ray photons are efficiently converted

Table 2. Intensities and fluxes due to Inverse Compton Scattering in the energy range 10 GeV-10 TeV

Energy (GeV)	$I(E_\gamma) \text{ cm}^{-2}\text{s}^{-1}\text{sr}^{-1}\text{GeV}^{-1}$	Flux ($\times 10^{-31} \text{ ergs cm}^{-2}\text{s}^{-1}\text{sr}^{-1}\text{Hz}^{-1}$)
10	1.5×10^{-5}	12
100	4.6×10^{-7}	3.7
1,000	1.5×10^{-8}	1.2
2,000	0.53×10^{-8}	0.8
4,000	0.19×10^{-8}	0.6
6,000	0.1×10^{-8}	0.48
8,000	0.066×10^{-8}	0.4
10,000	0.047×10^{-8}	0.38

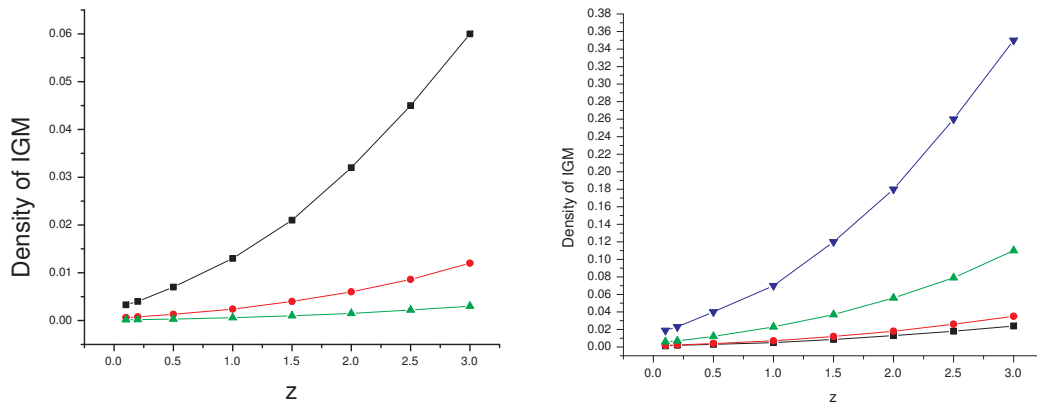


Figure 1. IGM density vs. redshift in case of Synchrotron radiation(left)/IGM density vs. redshift in case of Inverse Compton radiation (right)

into heat in IGM. Blazar increases the temperature of the IGM above 10^4 K [4]. At temperature 10^4 K,

$$\Omega_{IGM} < 0.4 I_{21} \Omega^{\frac{1}{2}} h^{-\frac{3}{2}} (1+z)^{\frac{9}{2}}, \quad (4)$$

where I_{21} is the ionizing flux and is measured in the units of $10^{-21} \text{ ergs cm}^{-2} \text{ s}^{-1} \text{ Hz}^{-1} \text{ sr}^{-1}$ [13]. Here we have calculated the value of Ω_{IGM} for different intensities of radiation emitted by the blazar at redshift $Z = 3, 2.5, 2, 1.5, 1, 0.5, 0.2$, and 0.1 .

5. Result and discussion

In this work, we have explored the γ -ray emission mechanisms due to synchrotron and Inverse Compton scattering at different energy range. From the graph, we may say that density of IGM is different at different Z showing that the intergalactic medium is basically clumpy. This clumpiness may be due to the radiation pressure driving the intergalactic matter away in space. It is seen that density of IGM increases at higher redshift and decreases as ionizing flux decreases. The straight line parallel to x -axis shows the upper limit of $= 0.03$. This gives us an idea about the region of same density of the intergalactic medium for different ionizing flux of blazar radiation at different redshift.

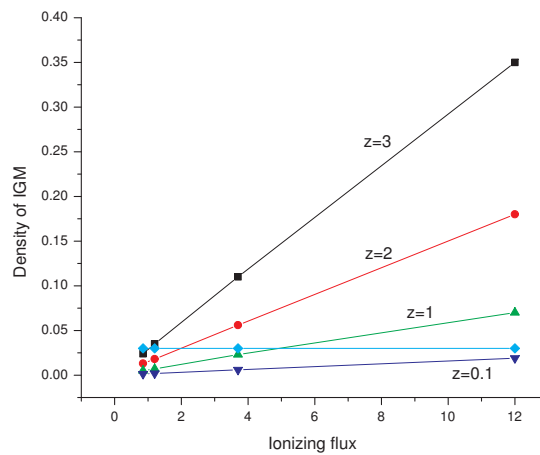


Figure 2. Density of IGM vs ionizing flux at redshift $z = 3, 2, 1$, and 0.1 in case of IC scattering. Ionizing flux in the units of $10^{-31} \text{ergs cm}^{-2} \text{s}^{-1} \text{Hz}^{-1} \text{sr}^{-1}$

References

- [1] Angle J R P , Stockman H S 1980 *Ann. Rev. of Astron. Ap.* 18 321-361
- [2] Urry C M , Padovani P 1995 <http://arxiv.org/abs/astro-ph/9506063>
- [3] Maraschi L, Ghisellini G and Celotti A 1992 *ApJ* 397 L5.
- [4] Dermer C D and Schlickeiser R 1993 *The Astrophysical Journal* 416, 458
- [5] Broderick A E , Chang P, and Pfrommer C 2012 *ApJ* in print arXiv:1106.5494
- [6] Ginzburg V L and Syrovatskii S I 1965 *Ann. Rev. Astron. Ap.* 3 297-350
- [7] Dermer C D, Schlickeiser R and Mastichiadis A 1992 *Astron. Ap.* 256 (2)27-30.
- [8] Sikora M , Begelman M C and Rees M J 1994 *The Astrophysical Journal* 421 153
- [9] Blazejowski M, Sikora M, Moderski R and Madejski G M 2000 *The Astrophysical Journal* 545 107
- [10] Bloom S D and Marscher A P 1996 *Astrophysical Journal* 461 657-663
- [11] Bednarek W 1997 arXiv: astro-ph/9711189
- [12] Felten J E 1965 (Ph.D. thesis, Cornell University)
- [13] Coles P and Lucchin F *Cosmology The Origin and Evolution of Cosmic structure* second edition 20 430