29th International Cosmic Ray Conference Pune (2005) **4**, 403–406

Probing BL Lac VHE γ-ray emission models with optical spectra of PKS 2155-304

A.M. Brown[a], P.M. Chadwick[a], T.J.L. McComb[a] and A. Reimer[b]

(a) Durham University, Department of Physics, Durham, U.K DH1 3LE

(b) Institut für Theoretische Physik, Lehrstuhl IV:Weltraum und Astrophysik, Ruhr Univsersität Bochum, Germany

Presenter: A.M. Brown (a.m.brown@durham.ac.uk), uki-brown-AM-abs1-og23-poster

We are currently undertaking a study to look for the presence of emission lines in the optical spectra of the high energy BL Lac object, PKS 2155-304, and to investigate if there is any relation between VHE γ-ray emission and H_α, H_β emission line variation. The detection of emission lines in high energy BL Lac objects, such as PKS 2155-304, would help to pin down the contribution by the accretion disc and broad line region (BLR) to the external photon field, thus probing the relative importance of the External Compton versus Synchrotron Self-Compton models in the production of VHE γ-rays.

1. Introduction

Active Galactic Nuclei, or AGN, is a general term used to describe the existence of extremely energetic phenomena in the central regions of some galaxies. Known to emit radiation over the entire electromagnetic spectrum, from radio to VHE γ-rays, AGN are extremely compact and have luminosities up to 10^4 times greater than the host galaxy. Although the observational characteristics of AGN differ greatly from sub-class to sub-class, a unified model has emerged [1]. Widely accepted, this model consists of a supermassive black hole (10^7-10^{10} $M_\odot$) surrounded in the inner regions by an accretion disc and broad line region (BLR), and in the outer regions by a dusty torus and narrow line region (NLR). Around 10% of AGN are classed as radio loud, with the radio emission being attributed to a highly relativistic bipolar outflow of energetic particles. The array of AGN classifications are believed to result from viewing the AGN from different angles with respect to this bipolar outflow.

At the time of writing, ∼90% of all known extra-galactic VHE γ-ray sources are high energy BL Lac objects (HBL). HBLs are a small subclass of radio loud AGN, dominated by non-thermal radiation from a relativistic jet aligned close to the line of sight. The spectral energy distributions (SED) of HBLs are characterised by two broad peaks, (in a $\log \nu - \log \nu F_\nu$ plot), with the first peak in the UV / X-ray regime and the second peak in the GeV - TeV regime. HBLs exhibit some of the most extreme characteristics of all AGN, with large variations in luminosity, frequency and spectral index on timescales ranging from minutes to many years.

The aim of current TeV BL Lac research has been to explain the two-humped nature of the blazar's SED. The presence of relativistic particles in the jet is clear, but the acceleration mechanism and even the identity of these particles is still the subject of much debate. The current favoured model has the non-thermal emission attributed to a population of highly relativistic electrons. The lower energy peak is due to the synchrotron emission of the electrons and the high energy peak is due to the Compton up-scattering of a population of seed photons. The seed photons can either be the synchrotron photons (Synchrotron Self Compton model, SSC [2]), or photons from a source external to the jet such as the accretion disc and BLR clouds (External Compton model, EC [3]).

The SSC model, with the relativistic electron population being responsible for both the production of the seed photons and the Comptonisation of the seed photons up to higher energies, makes two simple predictions. Firstly, that the continuum of the Compton emission should be similar to the continuum of the seed synchrotron photons. Secondly, that a variation in the flux of the seed photons should result in a quasi-simultaneous variation in the flux of the Compton emission, or vice versa. However, during a multiwavelength campaign on a northern hemisphere BL Lac object, 1ES 1959+650, Krawcynski et al. detected an 'orphan' VHE γ-ray flare, [4], i.e. an increase in VHE emission with no associated increase in X-ray emission. The detection of an orphan VHE flare contradicts the second prediction made by the SSC model and has therefore brought into question the validity of a pure SSC model. While it is most likely that both the SSC and EC models are occurring at the same time, to determine which is the dominant process we need to determine which is the dominant source of seed photons. For the Compton scattering of external radiation to be dominant over SSC emission, the energy density of the external radiation field, as measured in the frame comoving with the relativistic blob within jet, must be greater then the energy density of the synchrotron radiation field produced by the jet. The detection of emission lines from PKS 2155-304 can help us to determine the energy density of the external photon field and thus restrict the relative importance of the External Compton versus Synchrotron Self-Compton models.

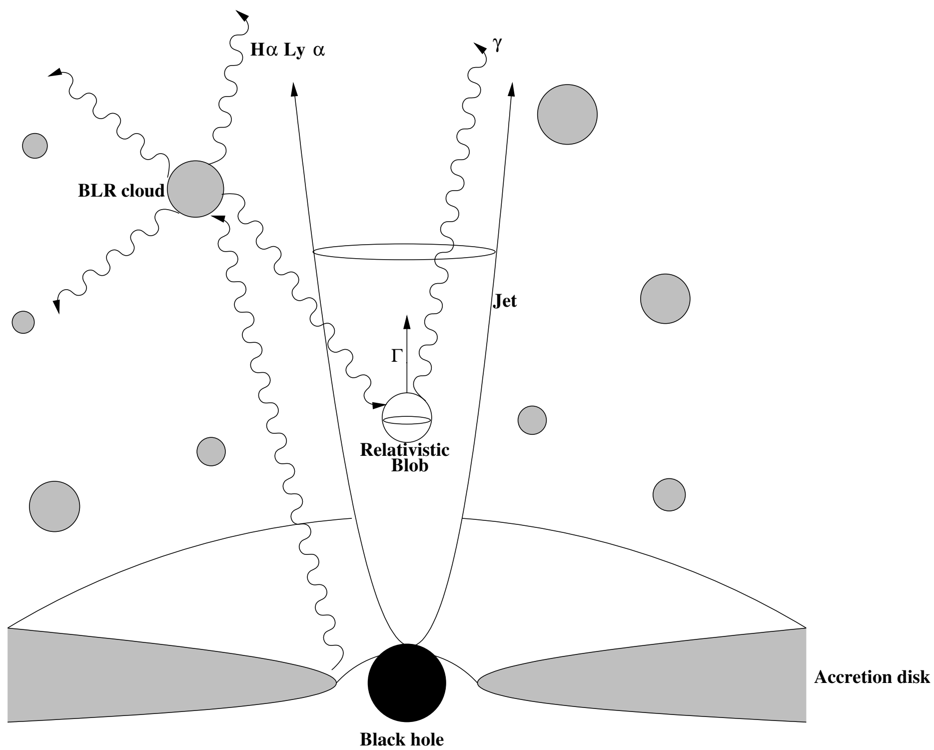

Figure 1. Diagram of the inner region of a AGN. The inner part of the accretion disc emits thermal UV radiation which is reprocessed by the BLR clouds back towards the jet. The energy of the reprocessed light depends upon the composition and state of the BLR clouds. Note diagram is not to scale.

Historically, BL Lac objects were distinguished from other AGN by their lack of spectroscopic features. This classification is beginning to become less clear with recent detections of emission lines in the optical spectra of BL Lacertae, a low energy BL Lac object (LBL). During May 1995 and over an extended period during 1997, BL Lacertae was observed to have H_α, H_β, O_{III} and N_{II} emission lines, [5], [6]. On both occasions, the H_α emission line was clearly visible with an equivalent width between 1.6 and 7.3 Angstroms and a flux between 1.7×10^{-14} ergs cm^{-2} s^{-1} and 4.8×10^{-14} ergs cm^{-2} s^{-1}. Further more, during the 1995 observations, BL Lacertae was not particularly faint, with a V band magnitude of 16.0. It should be noted that the H_α line would have been detected even if BL Lacertae's continuum was 3-4 magnitudes brighter, [5]. Likewise, if BL Lac was at the redshift of PKS 2155-304, the expected flux of the H_α emission line of 1.57 $\times 10^{-14}$ ergs cm^{-2} s^{-1} is easily detectable. The presence of these lines, believed to come from BLR clouds photoionised by the accretion disc, brings into question of the role of the external photon field in BL Lac objects.

2. Discussion

We are currently undertaking a study to look for the presence of emission lines, primarily H_α, in the optical spectra of PKS 2155-304 using the 3.6 m ESO New Technology Telescope (NTT) in Chile. The observations are being taken over a 3 month period, during which time we hope to obtain spectra from the source in an active and quiescent state. PKS 2155-304 is a high energy BL Lac object, at a redshift of 0.117. It was first detected at TeV energies with Durham University's Mark VI telescope during the late 1990s [7], and subsequently confirmed as a TeV emitter by H.E.S.S. in 2002 [8]. While we except to incorporate our optical spectral observations into a larger multiwavelength study of PKS 2155-304, optical spectra of this source are important in their own right.

Broad emission lines hold fundamental clues about the kinematics, structure and composition of the broad line regions of AGN. Understanding the structure of the broad line region helps us to probe the contribution of the external photon field to the production of VHE photons in the jet. The principal broad lines in the optical domain from a source at redshift 0.117 are H_α and H_β, both of which are low ionisation lines (LILs). The medium from which these LILs are emitted is optically thick, being photoionised by the accretion disc, [9], [10], [11].The photons principally responsible for the photoionising are the Lyman and He_{I} continua and 'soft' 300-800 eV X-rays, [12]. Observing the H_α and H_β emission lines could therefore be used as an indicator to probe the contribution to the external photon field from a range of photon energies, not just H_α and H_β.

To understand fully the contribution of the external photon field to the VHE emission, we need to understand both the energy density of the external photon field and the structure of the BLR. For a seed photon to be Comptonised to VHE energies, its initial energy, in the frame of the VHE emitting relativistic blob, must be in the UV/X-ray regime. While the temperatures at the inner orbits of the accretion disc are in excess of 10^5 K (UV blackbody radiation), due to the relativistic Doppler effect (eq. 1) this radiation would be shifted to lower energies in the relativistic blob's frame of reference. Radiation from the accretion disc would not, therefore, directly contribute to the VHE emission.

$$\nu = \frac{\nu'}{\gamma}(1 - \beta \cos\theta)^{-1} \tag{1}$$

The external radiation must therefore be emitted by sources ahead of the relativistic blob, ideally at small angles, θ, to the jet. Possible sources include the BLR clouds and the messy wind that is blown off the surface of the accretion disc. This accretion disc wind however, has its maximum density at angles greater then 60 degrees to the jet [13], [14]. Radiation scattered off the accretion disc wind would not significantly contribute to the external photon field for VHE production. Radiation reprocessed by the BLR clouds on the other hand, does have the ability to significantly contribute to the external photon field in the jet. The extent of this significance depending upon the structure of the BLR. Detecting broad emission lines would therefore not only help in determining the energy density of the external photon field, but can also be used to probe the structure of the BLR and thus determine the energy density of the external photon field in the frame of the relativistic blob.

Due to the wealth of information emission lines can tell us, there have been numerous studies of broad emission lines from AGN, [10] and references therein. However, due to the original description of BL Lac object spectra being featureless, none of these studies have questioned the role of the BLR in BL Lac objects in any great depth. The detection of emission lines in the spectrum of PKS 2155-304 would further the case for investigating broad line emission from BL Lac objects; a case that was first raised by the detection of emission lines from BL Lacertae [5].

Finally, any emission lines that we detect in the spectra of PKS 2155-304 would be a first. While emission lines have been detected in low energy BL Lac objects, none have been detected in high energy BL Lac objects such as PKS 2155-304. Detecting emission lines from a source that has historically be distinguished from other AGN by their lack of spectroscopic lines, brings into question the current classification of AGN subclasses.

3. Conclusions

Through the use of optical spectral observations, we hope to probe the inner regions of a high energy BL Lac object. The fundamental information the broad emission lines contain about the kinematics, structure and composition of the broad line region of AGN can be used to probe the contribution of the external photon field to the production of VHE photons in the jet. Thus helping us to restricting the relative importance of the External Compton versus Synchrotron Self-Compton models in the production of VHE γ-rays.

4. Acknowledgements

We would like to thank members of the Very High Energy group at Durham University, Nic Schurch and the H.E.S.S. collaboration at large for their useful comments and discussions. The British members acknowledge the financial support of the U.K. Particle Physics and Astronomy Research Council (PPARC).

References

[1] Urry & Padovani, PASP v107, p803 (1995)
[2] Maraschi, Ghisellini & Celotti ApJ 397 L5 (1992)
[3] Sikora et al. ApJ 421 153S (1994)
Ghisellini & Madau MNRAS 280 67 (1996)
[4] Krawcynski et al. ApJ 601 151 (2004)
[5] Vermeulen et al. ApJ 452 L5 (1995)
[6] Corbett et al. MNRAS 281 737 (1996)
Corbett et al. MNRAS 311 485 (2000)
[7] Chadwick et al. ApJ 513, 161 (1999)
[8] Aharonian et al. A&A 430 865 (2005)
[9] Baldwin et al. ASP Conf. Ser. 113 80 (1997)
[10] Sulentic et al. Annu. Rev. Astron. Astrophysics 38 521 (2000)
[11] Dultzin-Hacyan et al. Rev. Mex. AA 9 308 (2000)
[12] Krolik & Kallman ApJ 324 714 (1998)
[13] Proga & Kallman ApJ 616 688 (2004)
[14] Proga et al. ApJ 543 686 (2000)