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INFLUENCE OF AN AGN COMPLEX PHOTON FIELD ON THE JET BULK LORENTZ FACTOR THROUGH COMPTON ROCKET EFFECT

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Abstract. Radio-loud active galactic nuclei are among the most powerful objects in the universe. In these objects, most of the emission comes from a relativistic jet getting its power from the accretion of matter on a supermassive black-hole. However, despite many studies, the jets acceleration to relativistic speeds is still misunderstood. The bulk Lorentz factor characterizing the speed of these flows cannot be precisely measured and only limits have been established.

It is widely admitted that jets are composed of relativistic particles emitting light through several physical processes, one of them being the comptonization of photons coming from external sources to the jet. It has been shown that this emission can drive a group of highly relativistic leptons placed in an external photon field to relativistic bulk motions through the Compton rocket effect. In this work, we investigate this process and compute the resulting bulk Lorentz factor in the complex photon field of an AGN composed of several external photon sources.

To do so, we model the sources present in the inner parts of an AGN (the accretion disk, the dusty torus and the broad line region), taking precisely into account their geometry and anisotropy to numerically compute the bulk Lorentz factor of the jet at every altitude.

The study shows interesting and unexpected behaviors of the bulk Lorentz factor with acceleration and deceleration zones in the jet. We investigate the patterns of the bulk Lorentz and Doppler factors along the jet for one geometry example and discuss the implications of these patterns on the AGN emission.

Keywords: AGN jets – bulk Lorentz factor – Compton Rocket – variability

1 Introduction

It is now widely admitted that AGN's jets hold relativistic flows. First evidences go back to the 70's with the observation of superluminal motions (Cohen et al. 1971) which are only possible for actual speeds of $0.7c$ at least. However, a lot of questions on the speed of these flows remain. Mainly, we still do not know the mechanism driving them to relativistic speeds or neither do we know the spatial distribution of these speeds. They are characterized by their bulk Lorentz factor $\Gamma_b = \left(1-\beta_b^2\right)^{-1/2}$ rather than their speed V_b with $\beta_b = V_b/c$. Up to now, it appears that the most complex studied variations of longitudinal bulk Lorentz factor have followed power laws with an accelerating and/or a decelerating phase (Marscher 1980, Ghisellini et al. 1985, Boutelier et al. 2008).

Our work takes place in the two-flow paradigm (Sol et al. 1989) where the jet is composed of a mildly relativistic sheath, filled with e^-/p^+ and an ultra-relativistic spine composed of e^-/e^+ pairs responsible for most of the emission. The outer jet acts as an energy reservoir for the particles of the spine, which will be continuously thermalized along the jet via the second order Fermi process. This is in agreement with diffuse X-ray emission observed in FRI which favors a distributed particle acceleration rather than localized shocks (Hardcastle et al. 2007). In this paradigm, the plasma is subject to the Compton rocket effect which will naturally drive the flow to relativistic speeds.

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2 Γ_b & equilibrium

O'dell (1981) showed that "a plasma of relativistic particles exposed to an anisotropic radiation field acts as a rocket - a Compton rocket" because of the reaction force imposed by the inverse Compton radiation from the particles. In the Thomson regime, this force is proportional to the flux in the rest frame $H^* = \frac{1}{4\pi}\int I^*_{\nu_s}(\Omega^*_s, \Gamma)\cos\theta^*_s \mathrm{d}\Omega^*_s \mathrm{d}\nu^*_s$. Thus, the bulk of particles reaches an equilibrium velocity, which can be represented by the equilibrium bulk Lorentz factor Γ_{eq}, when $H^* = 0$. In the vicinity of a supermassive black-hole, core of an AGN, lie several sources of soft photons. These sources will induce an anisotropic radiation field in the jet and thus allow the Compton rocket effect to take place. Hence, to compute the equilibrium bulk Lorentz factor along the jet, we need to compute precisely the external photon field at every altitude. Here, we model the AGN including three main sources of soft photons: a standard accretion disk, a dusty torus in thermal equilibrium and a broad line region (BLR) modeled as a spherical shell of clouds (see figure 1)

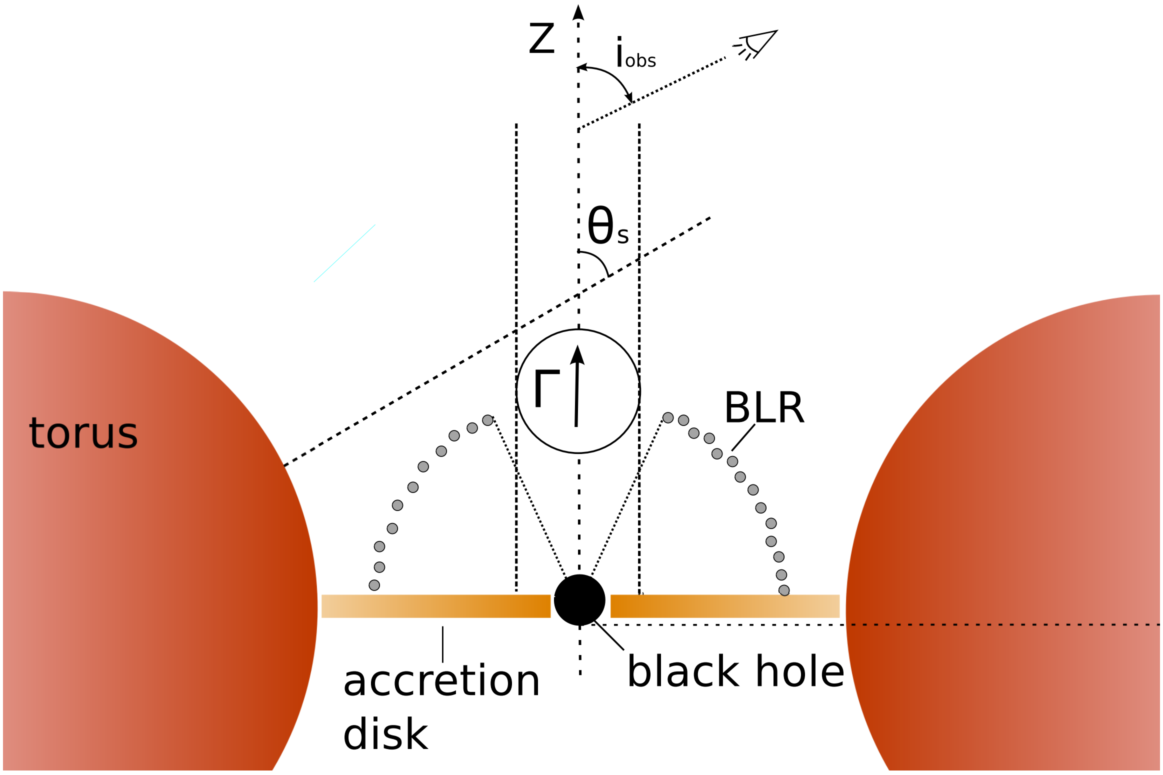

Fig. 1. The big picture: sketch edge on of the global model geometry (not to scale) with the accretion disk, the dusty torus and the BLR.

3 Evolution of Γ_{eq} along the jet

Figure 2 represents Γ_{eq} for different configurations of external sources.

Let's start with the simplest feature, an infinite accretion disk. Photons from the accretion disk are moving upward parallel to the axis which corresponds to a positive flux in the bulk rest frame $H^* > 0$. This leads to an inverse Compton emission backward and thus a reaction force forward, which at the end is accelerating the flow (Γ_{eq} increases).

However, because of aberration effects, the situation is more complex for the dusty torus and the BLR. Until a certain altitude, photons from the dusty torus or from the BLR generate a negative rest frame flux, $H^* < 0$ which provoke a backward force, or Compton drag, decelerating the flow. It is only up to a point, depending on the sources size, that the flow is able to accelerate again.

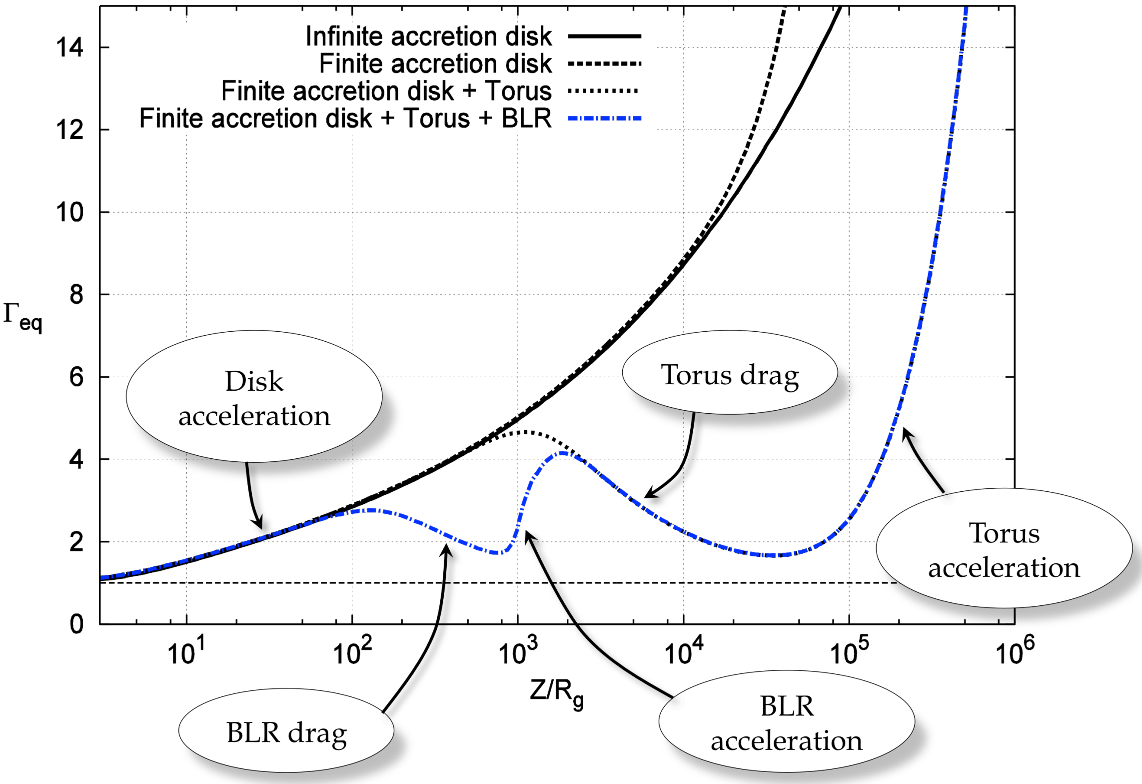

Fig. 2. Γ_{eq} resulting of the Compton rocket effect for different external photon sources. The geometry is described in figure 1 with the following parameters: finite and infinite accretion disk have an inner radius $R_{in} = 3R_g$. The finite disk has an outer radius $R_{out} = 5 \times 10^4 R_g$. $D_{torus} = 10^5 R_g$, $R_{torus} = 5 \times 10^4 R_g$, $R_{BLR} = 10^3 R_g$

4 Evolution of δ_{eq} along the jet

The relativistic bulk Doppler factor is defined as:

$$\delta_b = \frac{1}{\Gamma_b \left(1 - \beta_b \, \mu_{obs}\right)} \tag{4.1}$$

with $\mu_{obs} = \cos i_{obs}$ (see figure 1 for a definition of i_{obs}).

Figure 3 represents the evolution of the Doppler factor δ_{eq} along the jet for different observational angles but for the same bulk Lorentz factor Γ_{eq} corresponding to the one computed in figure 2.

The luminosity seen by an observer goes as $L_{obs} = \delta^4 L^*$. This is why an observer will mainly (or preferentially) see emission zones of maximum δ_{eq}. Because of the variations of Γ_{eq} along the jet, an observer will see preferentially certain zones of the jet, and thus brighter spots. But, high δ_{eq} correspond to different zones depending on the observational angle. For face-on objects, high δ_{eq} correspond to high Γ_{eq} whereas for edge-on objects, high δ_{eq} correspond to low Γ_{eq} and thus an observer will not see the same parts of the same jet depending on how he looks at it.

It is also interesting noticing that objects seen at more extremes angles ($\mu \approx 1$ or $\mu \approx 0$) will show more ample variations of δ_{eq} and thus highest differences of luminosity between parts of the jet whereas jets seen at moderate angles ($\mu = 0.6 \approx \beta$ here) will seem more homogeneous.

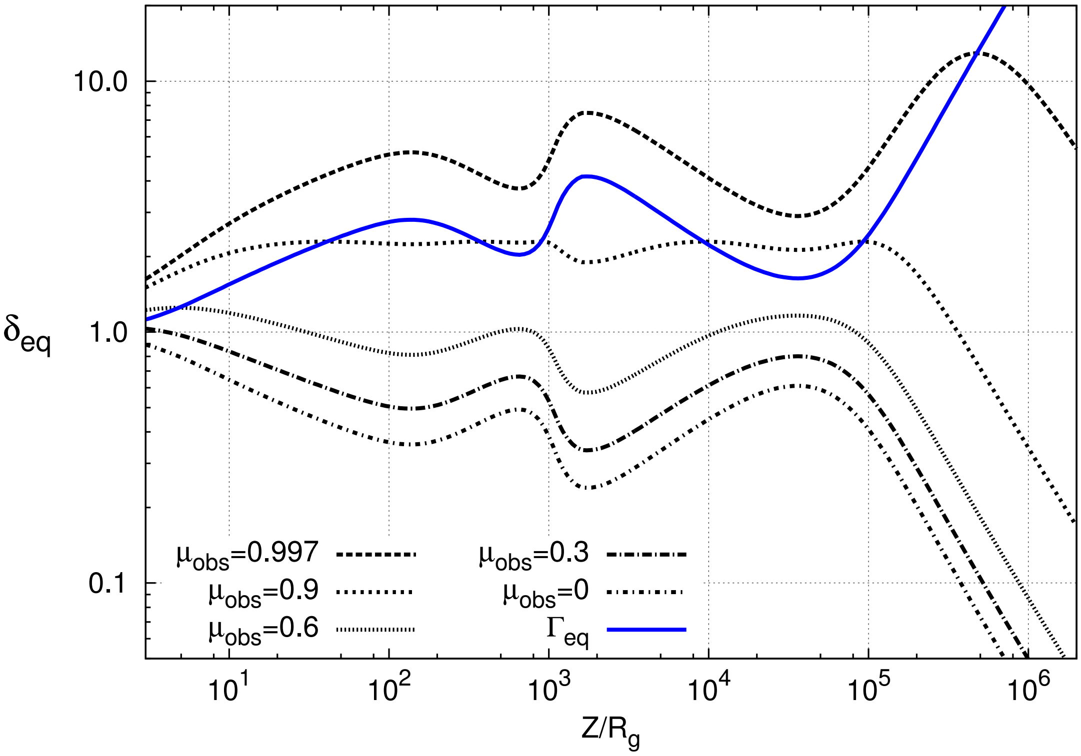

Fig. 3. Equilibrium bulk Doppler factor in function of the altitude for several observational angles i_{obs} ($\mu_{obs} = \cos i_{obs}$). The geometry is described figure1. The Doppler factors are computed for the same Lorentz factor computed figure 2 (blue line).

5 Conclusions

The question of the acceleration of AGNs jets is still a matter of discussion as we do not know the underlying processes nor the precise speeds of the flows. The solution implied by the Compton rocket effect is elegant as it can naturally lead to relativistic speeds and is viable in the two-flow paradigm. In this work, we embrace this framework and study the influence of several external photon sources (the accretion disk, the dusty torus and the broad line region) on the Compton rocket effect and on the induced bulk Lorentz factor. To do so, we carefully computed the resulting equilibrium bulk Lorentz factor, Γ_{eq}, of a flow driven by the Compton rocket effect taking into account the anisotropy of the emission. With several external sources, Γ_{eq} will show important changes along the jet, leading to acceleration and deceleration phases. We also discussed the implications of this variations on the Doppler factor and on observations of jets.

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