Variation of AGNs jets celerity due to Compton rocket effect in a complex photon field.

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Radio-loud AGN are among the most powerful objects in the universe. In these objects, most of the emission comes from the relativistic jet getting its power from accretion processes. 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, made for a broad range of parameters, investigates the patterns of the bulk Lorentz factor depending on the external sources which show some interesting and unexpected behaviours with natural acceleration and deceleration zones in the jet.

Subject : : oral
Topics : Astrophysics

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Thomas Vuillaume, IPAG

Accretion and Outflows throughout the scales, October 2014

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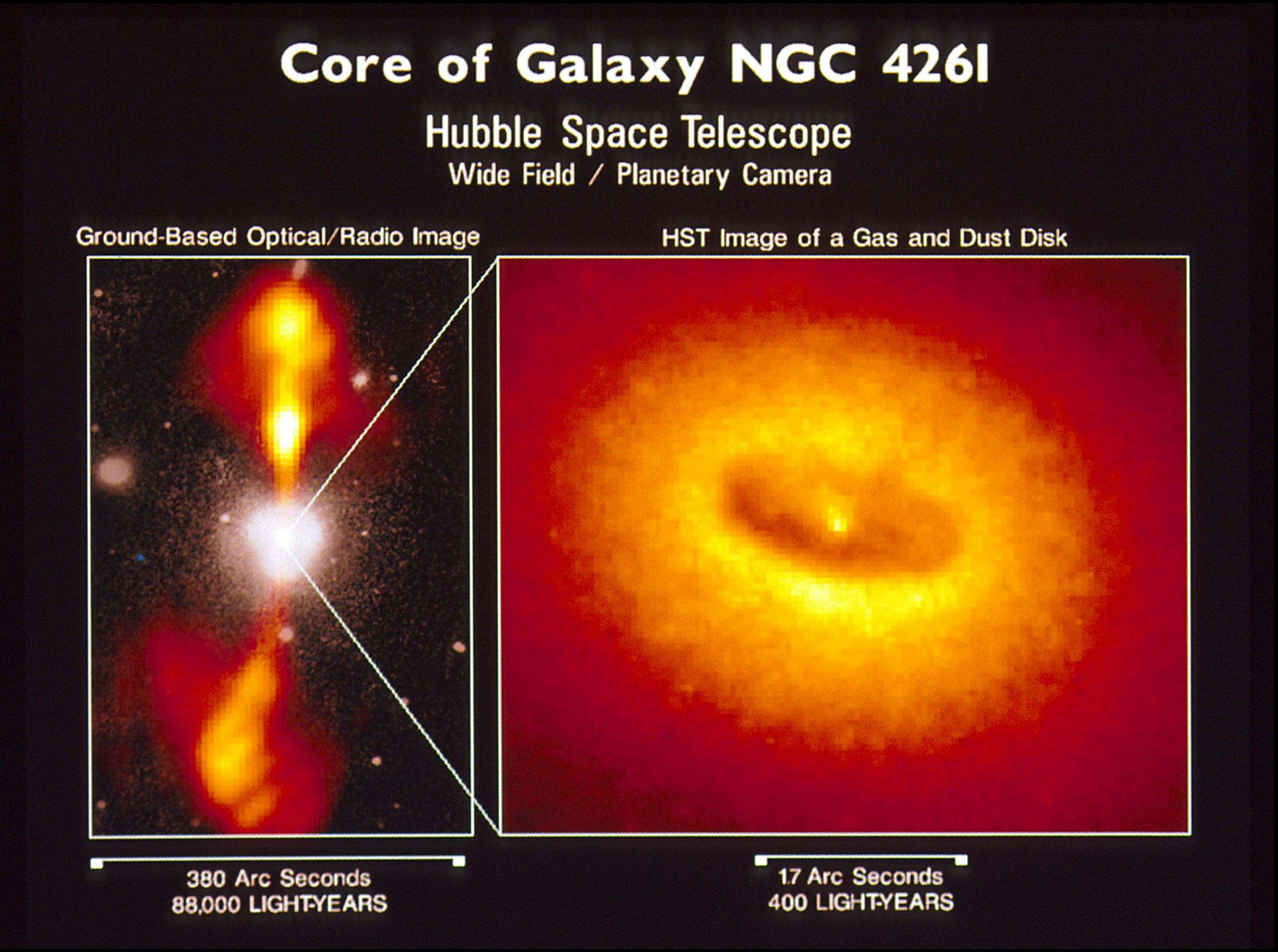
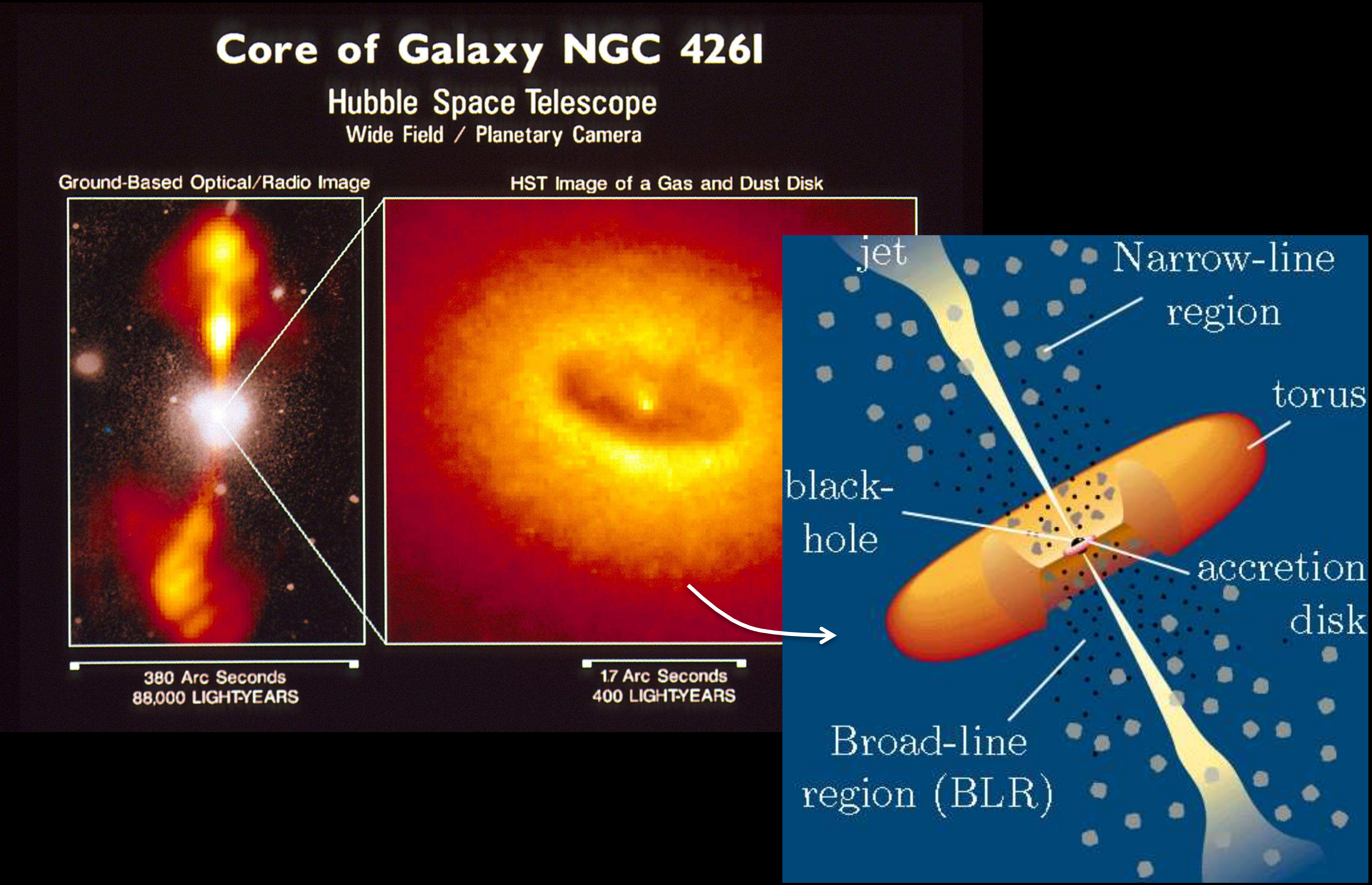
Active Galactic Nuclei



Active Galactic Nuclei



Core of Galaxy NGC 4261

Hubble Space Telescope

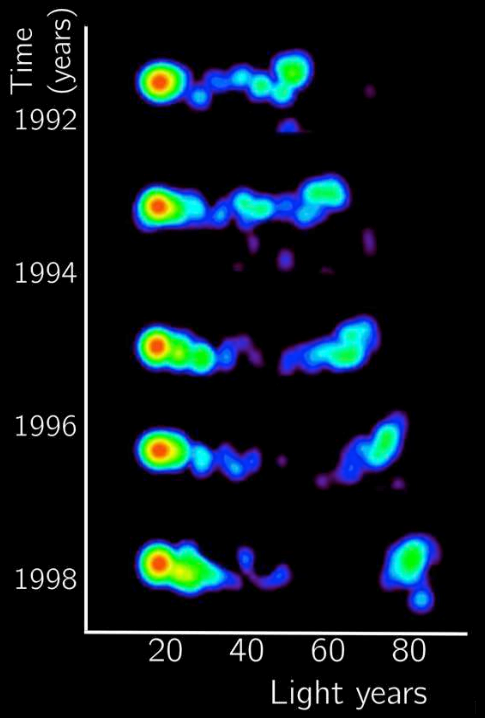
Wide Field / Planetary Camera

Active Galactic Nuclei: high Γ

Bulk

$$\beta = \frac{v}{c} \qquad \gamma = \frac{1}{\sqrt{1-\beta^2}}$$

Evolution of 3C279



Apparent superluminal motion requires relativistic speeds
$\Rightarrow$ *high* Γ

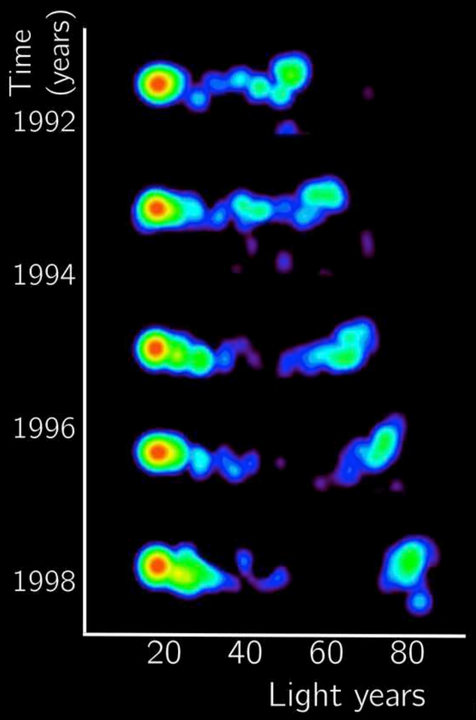
Active Galactic Nuclei: high Γ and high γ

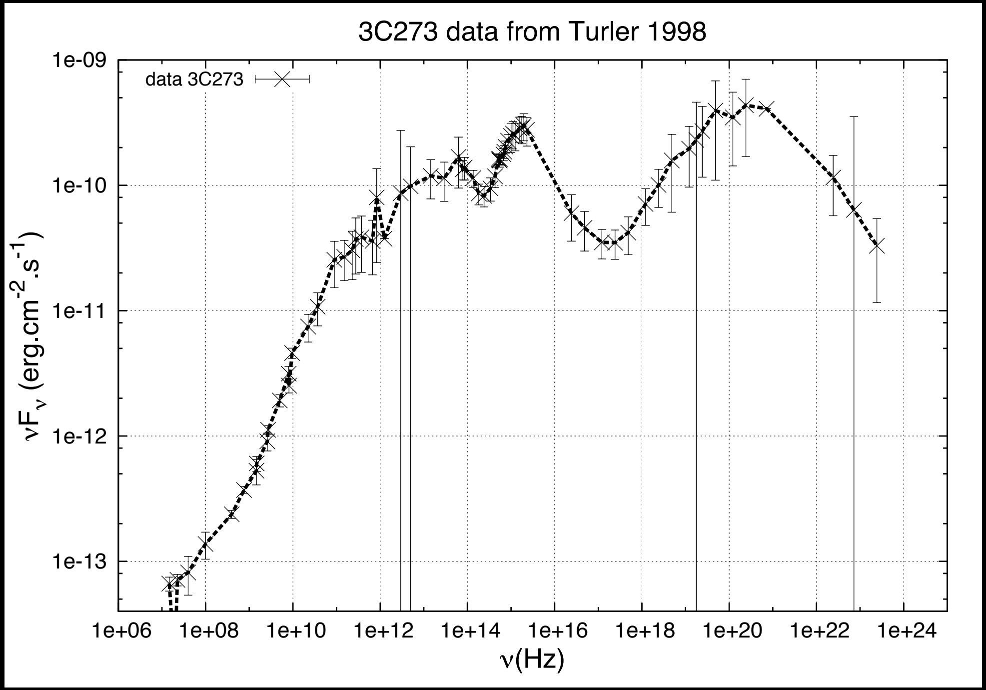
$$\beta = \frac{v}{c} \qquad \gamma = \frac{1}{\sqrt{1-\beta^2}}$$

Bulk

particles

Evolution of 3C279



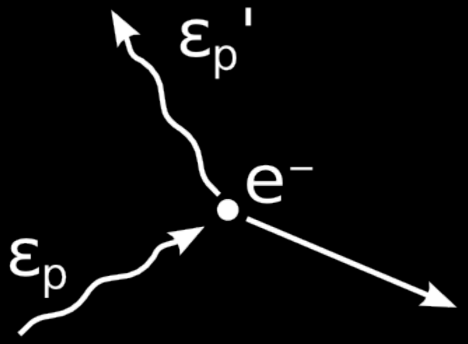


Apparent superluminal motion requires relativistic speeds
$\Rightarrow$ high Γ

Very high energy photons require very high energy particles to be produced
$\Rightarrow$ high γ

Inverse Compton process

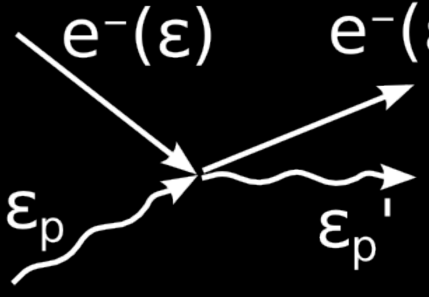
Compton scattering



$$\varepsilon_p' < \varepsilon_p$$

electron initially at rest
gains energy

Inverse Compton scattering



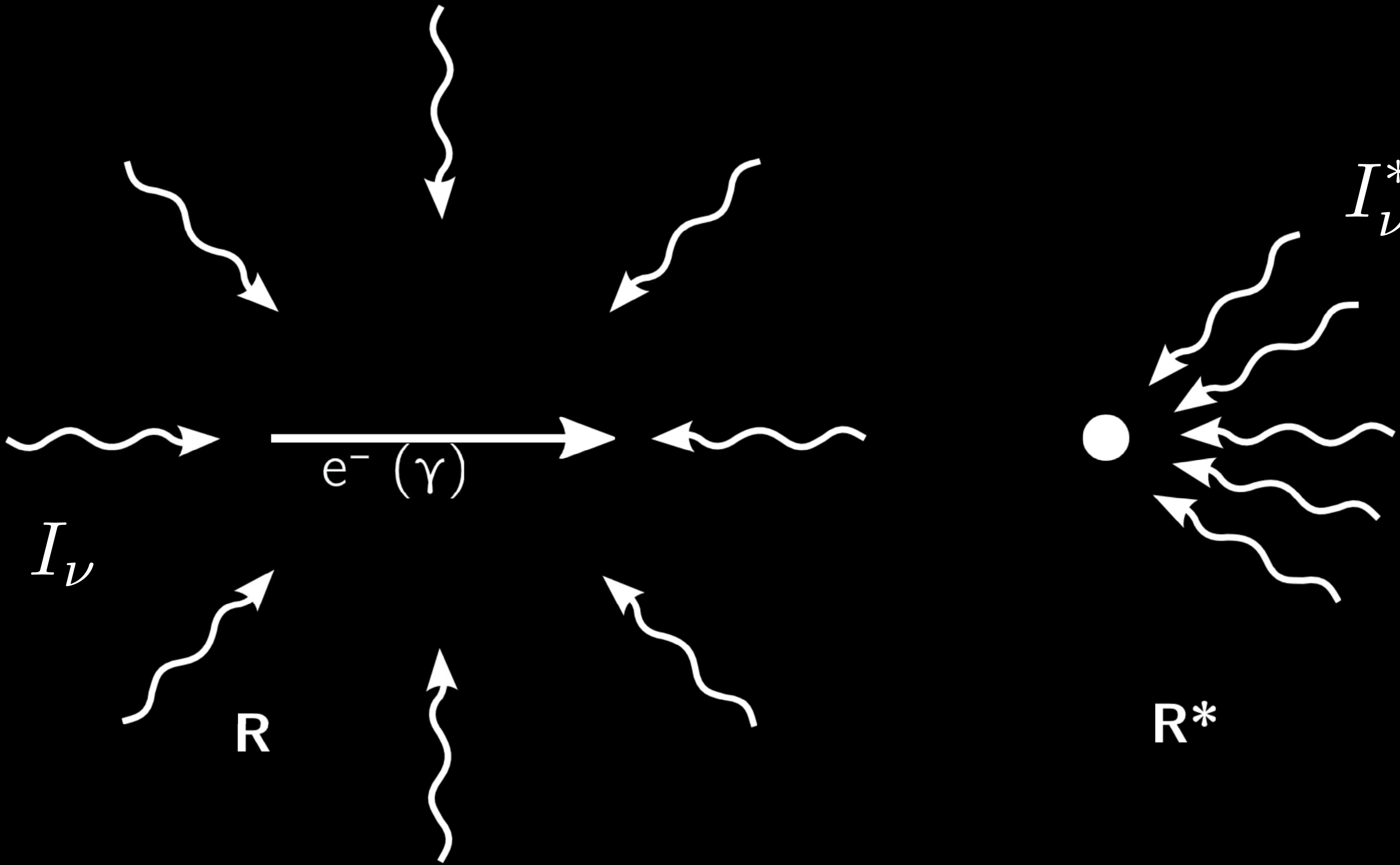
$$\varepsilon_p' > \varepsilon_p$$

high energy electron
transfers energy to the photon

Thomson regime = elastic scattering:

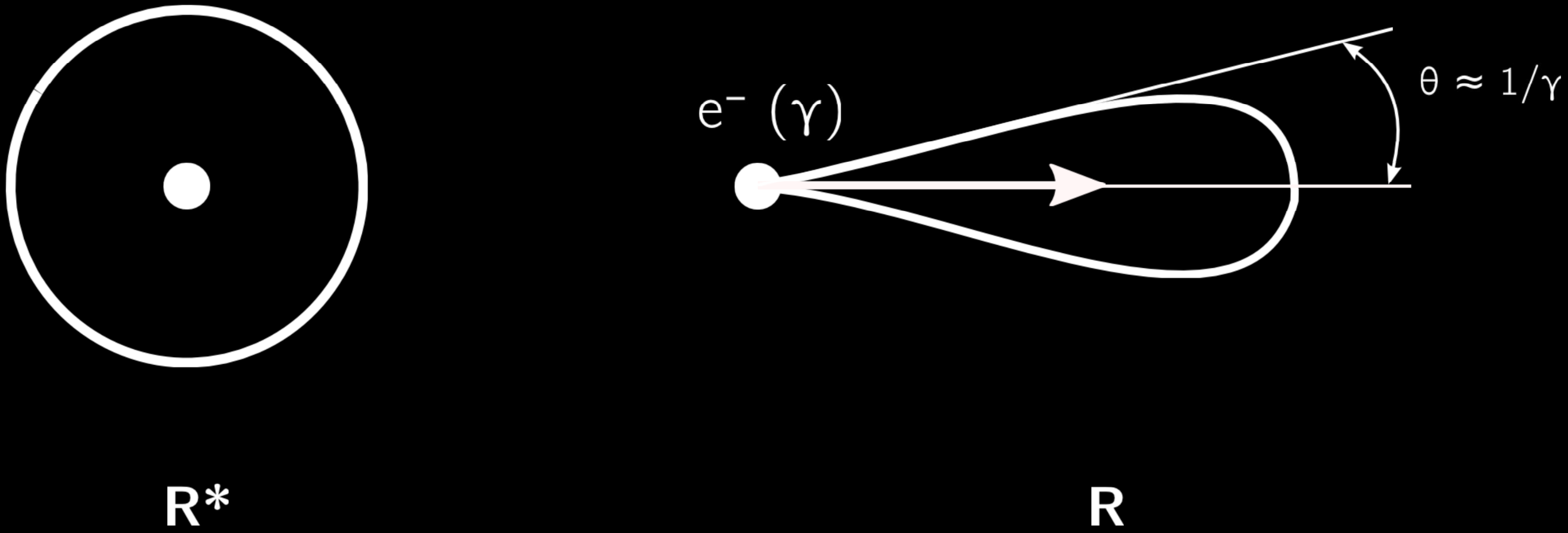
$$\varepsilon \approx \varepsilon'$$

Relativistic changes of frame: aberration



** = rest frame*

Relativistic changes of frame: beaming

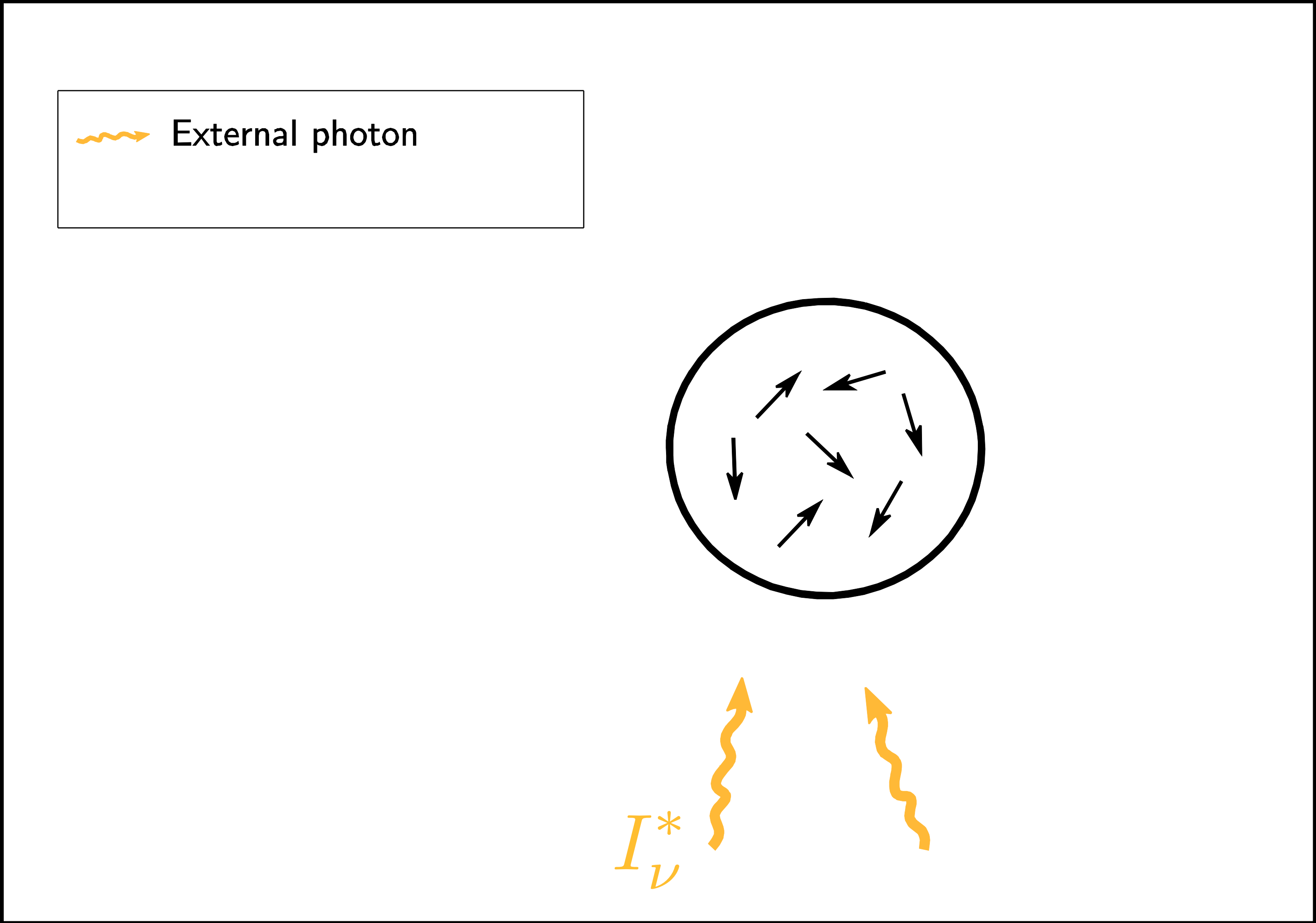


$*$ = rest frame

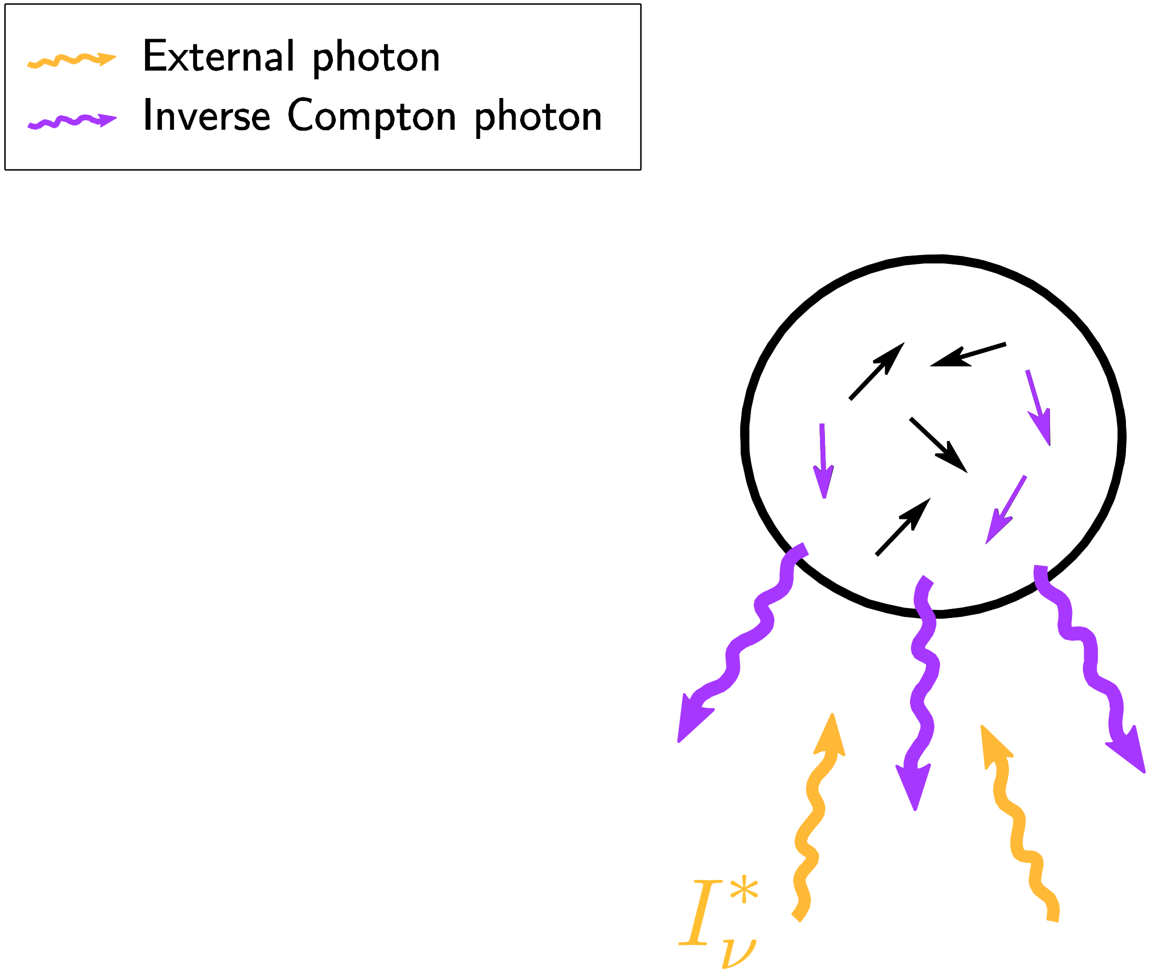
Compton rocket ?

Proposed by O'Dell 1981
"a relativistic plasma [...] when exposed to an anisotropic radiation field, acts as a rocket – a 'Compton rocket'."

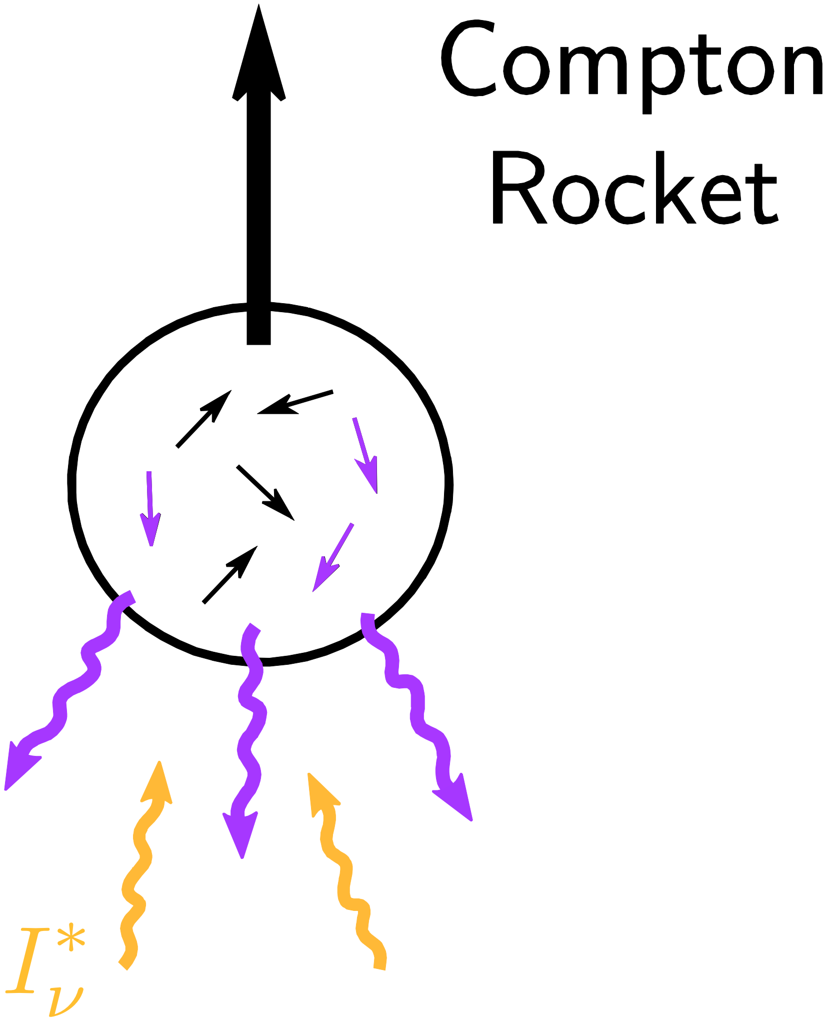
Compton rocket ?



Compton rocket ?



Compton rocket ?



〰 External photon
〰 Inverse Compton photon

⚠ *Energy source = relativistic particles NOT external photon field*

Equilibrium bulk Lorentz factor

$$\boxed{F_{CR} \propto H^*}$$

frequency

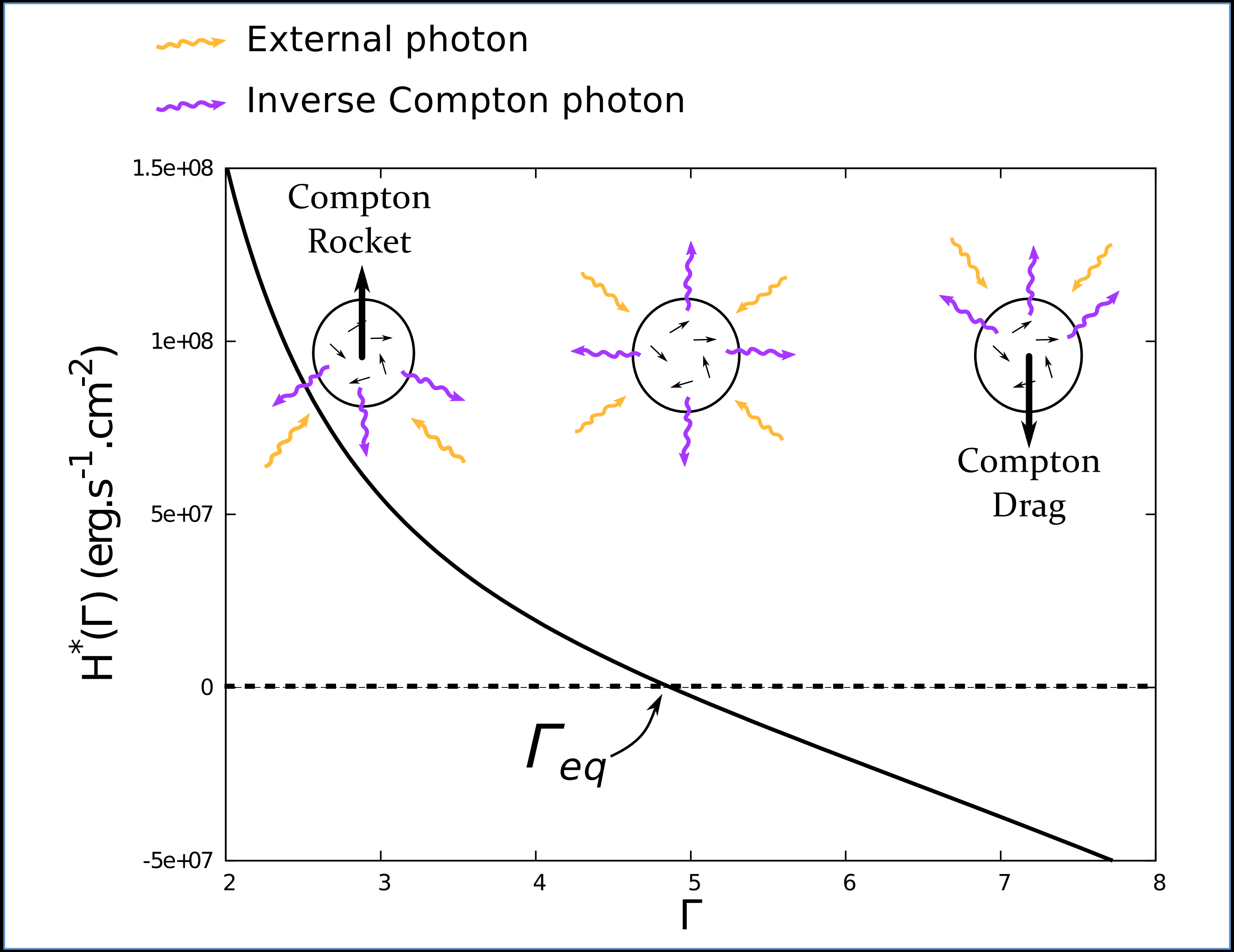
$$\text{with } H^* = \int I^*_\nu(\Gamma, \Omega^*)\ \cos\theta^*_s\, \mathrm{d}\Omega^*\, \mathrm{d}\nu^*$$

Specific intensity of the radiation

angle and solide angle
under which the source is seen

** = in the rest frame*

Equilibrium bulk Lorentz factor



$H^* > 0$ *$H^* = 0$* *$H^* < 0$*

Equilibrium bulk Lorentz factor

In the Thomson regime:

$$H^* = (J + K)\beta_{eq} - H(\beta_{eq}^2 + 1) = 0$$

with J, H, K, the Eddington parameters depending on the radiation field

$$J = \frac{1}{4\pi}\int I_\nu(\Omega)\,\mathrm{d}\Omega\,\mathrm{d}\nu$$
$$H = \frac{1}{4\pi}\int I_\nu(\Omega)\cos\theta_s\,\mathrm{d}\Omega\,\mathrm{d}\nu$$
$$K = \frac{1}{4\pi}\int I_\nu(\Omega_s)\cos^2\theta_s\,\mathrm{d}\Omega\,\mathrm{d}\nu$$

Application to (AGN) jets

- *Phinney 1982:*
  - *inefficient for protons*
  - *the particles cool down quickly*

end of the Compton rocket ?

Application to (AGN) jets

- *Phinney 1982:*
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} end of the Compton rocket ?

- *Sol et al 1989 & the two-flow model: pair plasma energized by MHD jet*

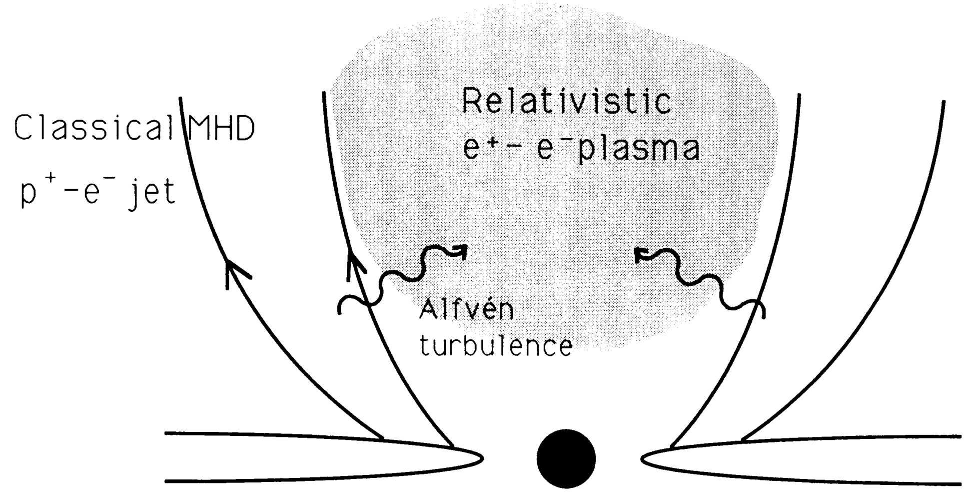
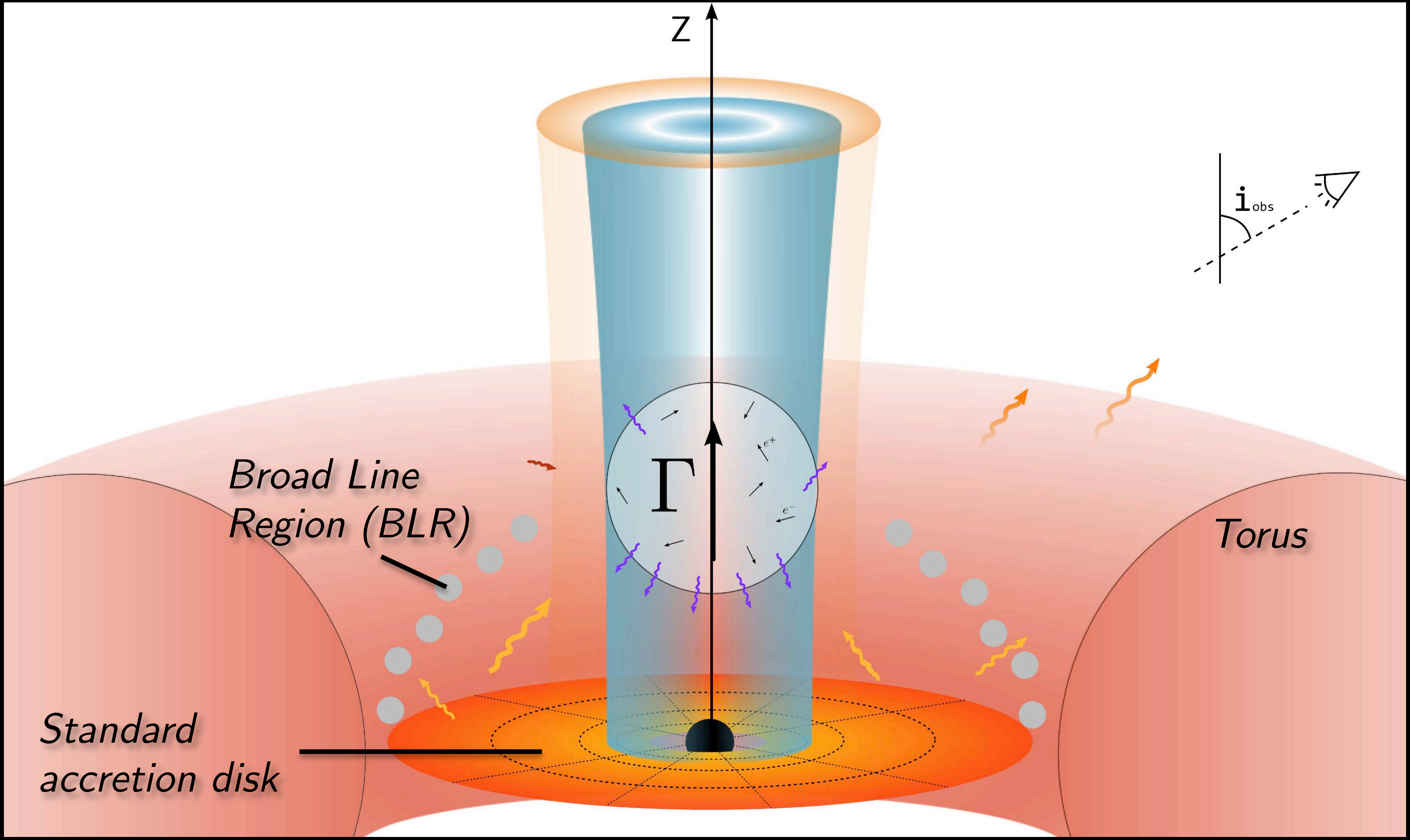


FIG. 1.—Schematic picture of the source of the two flows: a subrelativistic outflow from the accretion disk is driven by the opened magnetic field lines, and its Alfvén turbulence heats the pair plasma that escapes with a relativistic speed along the inner flux tubes.

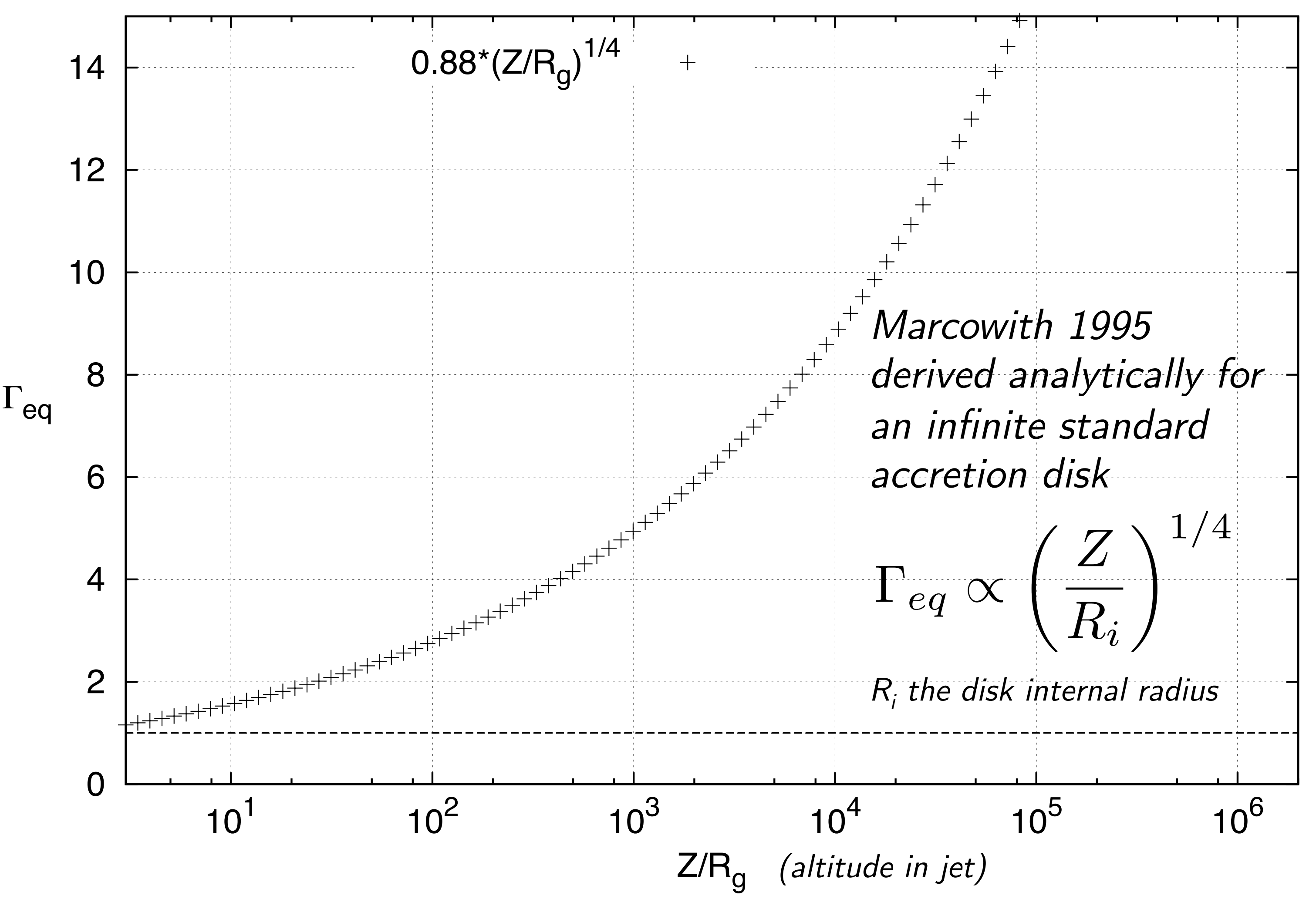
**extracted from Henri & Pelletier 1991*

Application to AGN jets: full model



$\Rightarrow$ *Compute H and derive* Γ_{eq} *such as* $H^*(\Gamma_{eq}) = 0$ *at every altitude in the jet*

Γ_{eq} *in an AGN photon field*

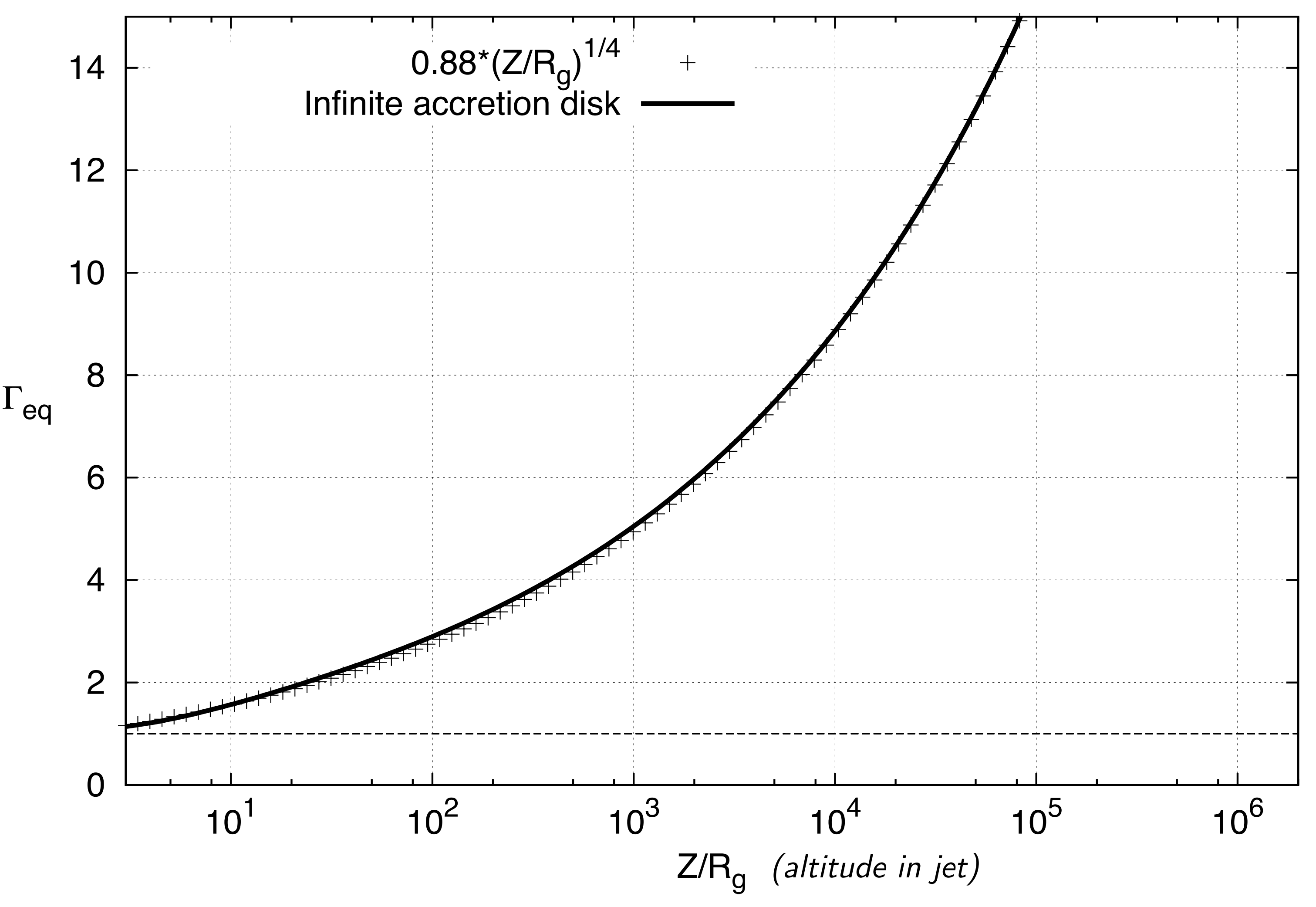


Marcowith 1995 derived analytically for an infinite standard accretion disk

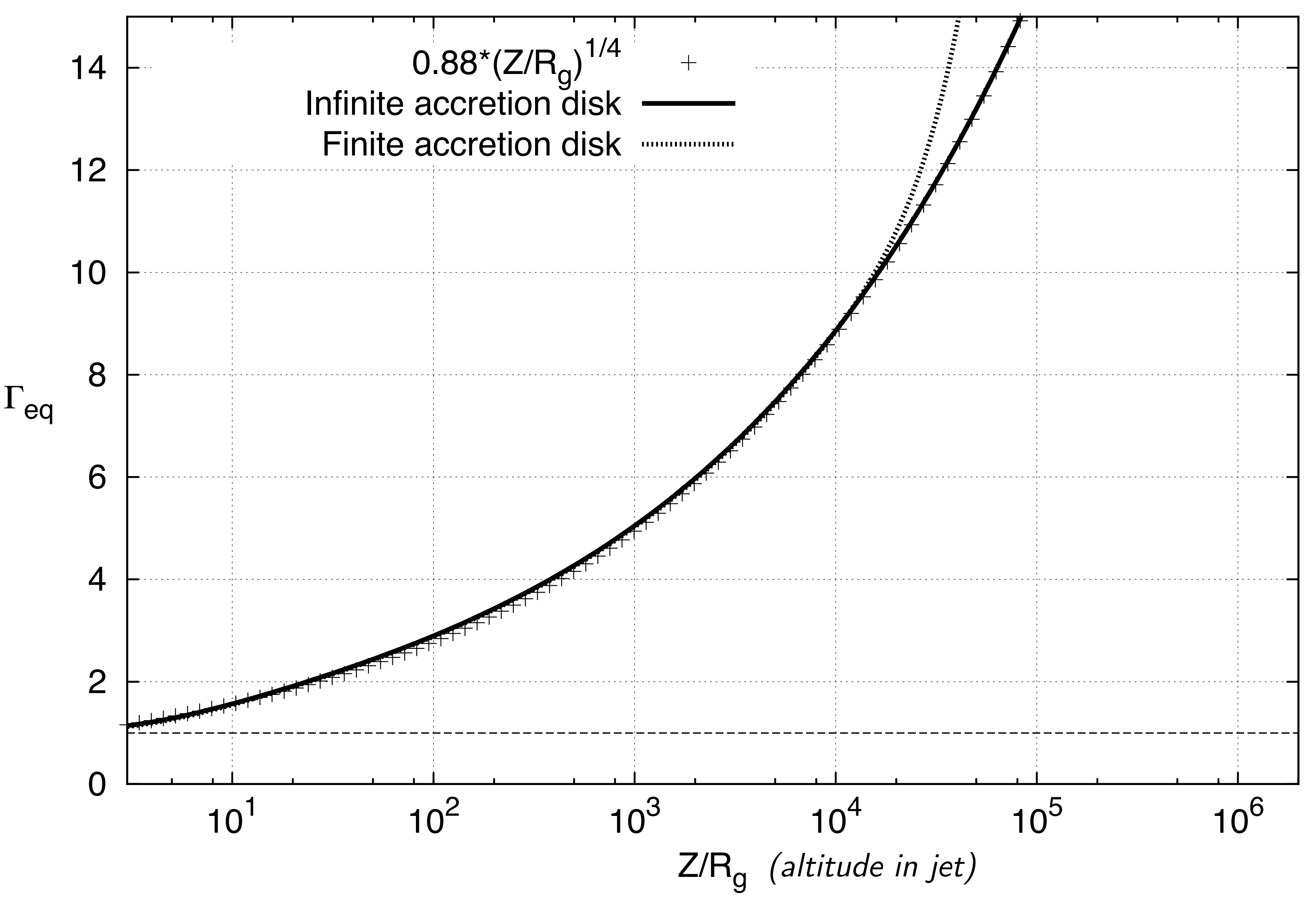
$$\Gamma_{eq} \propto \left(\frac{Z}{R_i}\right)^{1/4}$$

R_i the disk internal radius

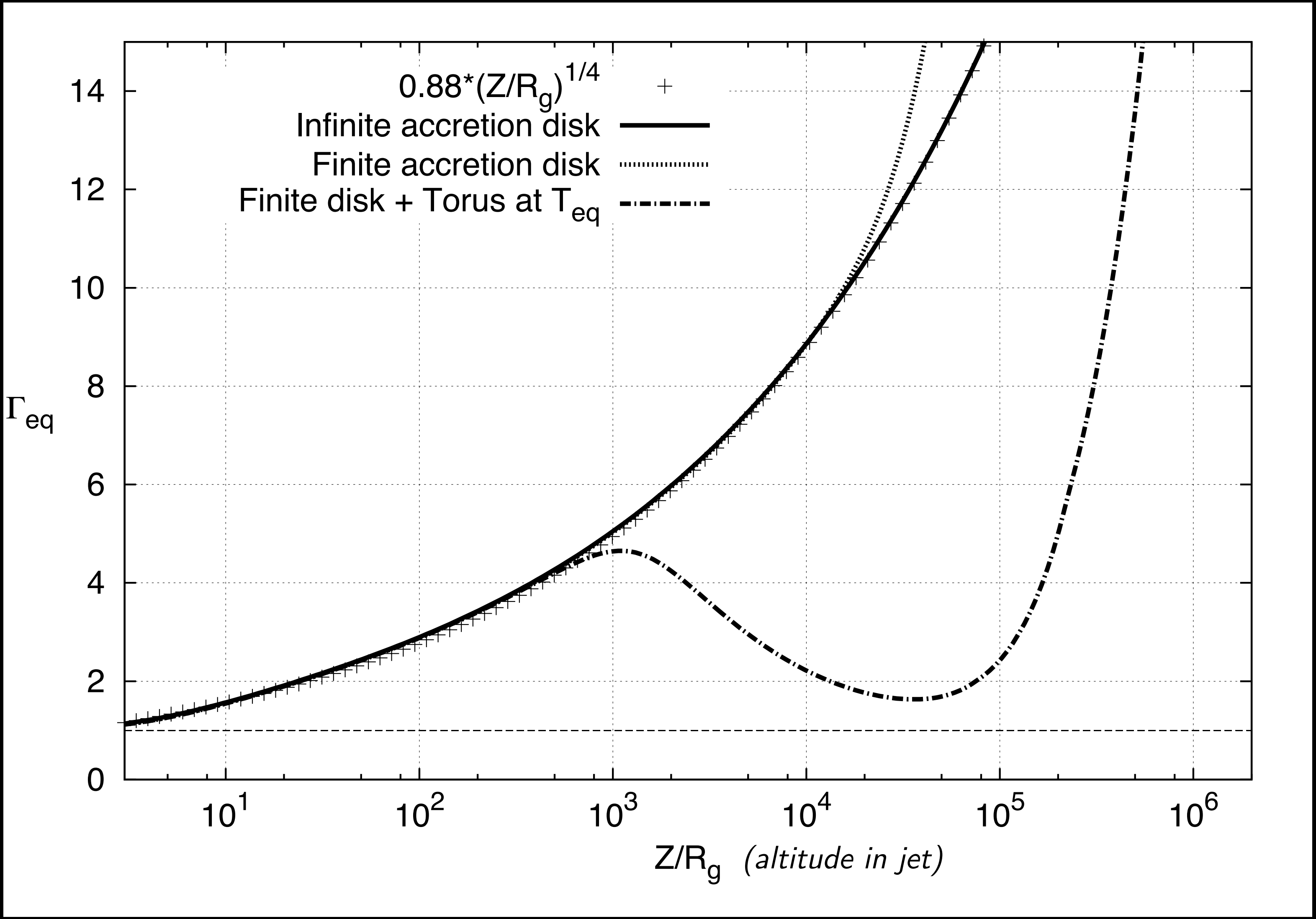
Γ_{eq} *in an AGN photon field*



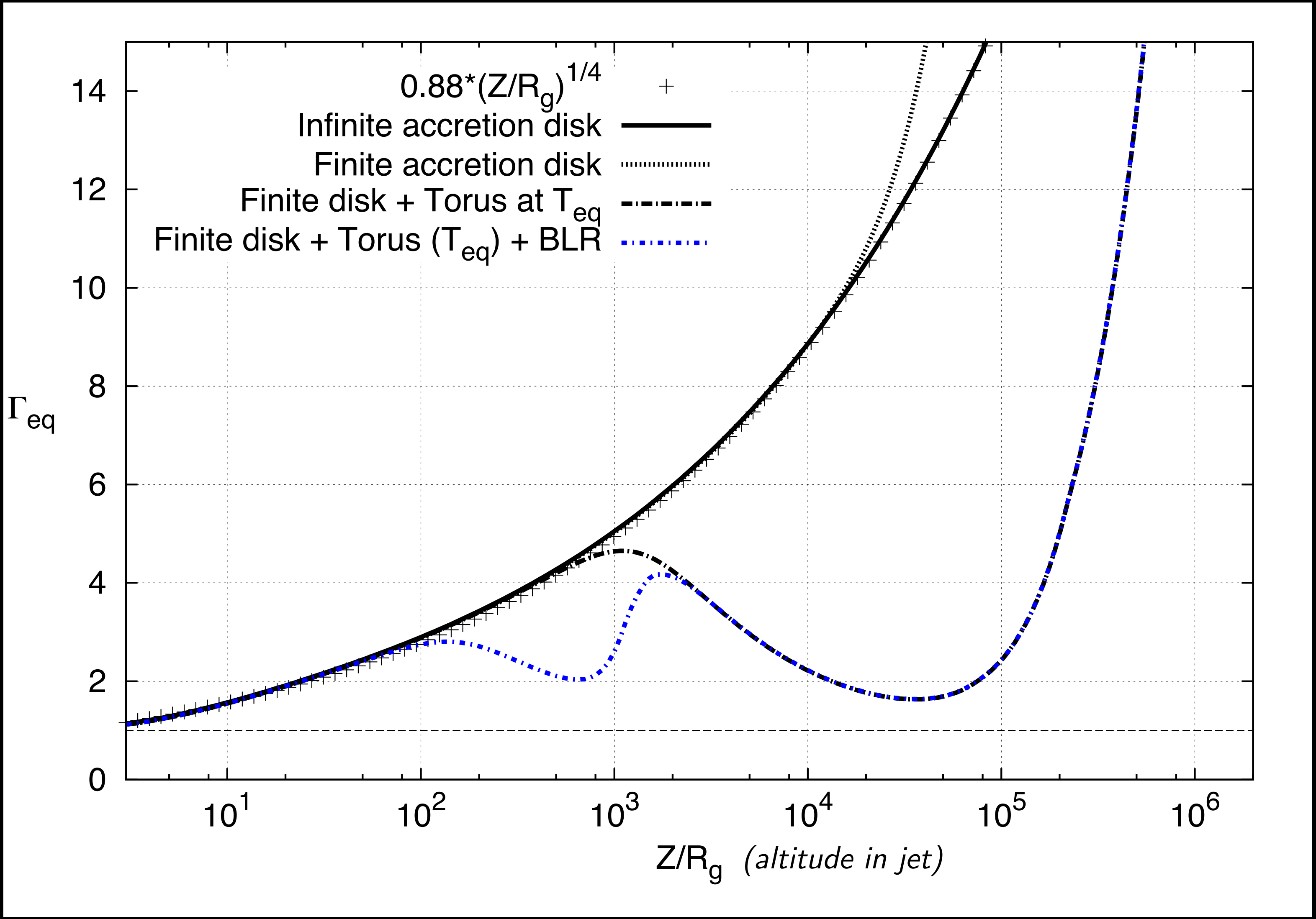
Γ_{eq} *in an AGN photon field*



Γ_{eq} *in an AGN photon field*



Γ_{eq} *in an AGN photon field*

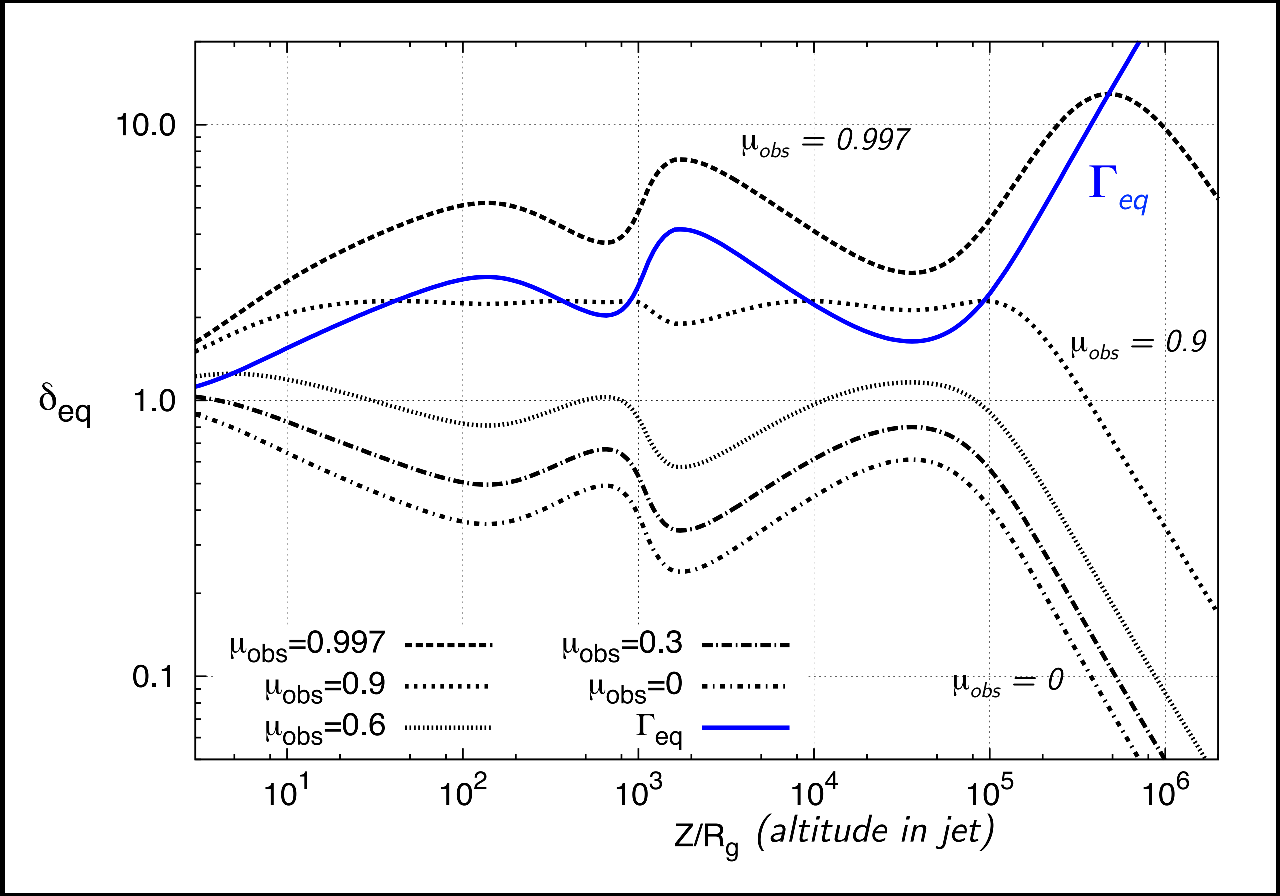


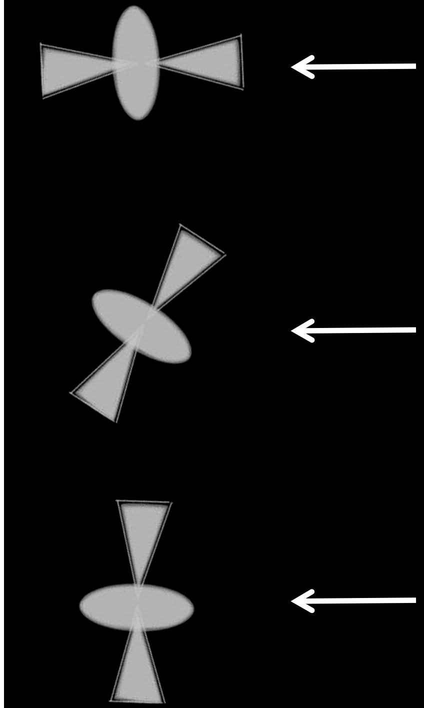
δ_{eq} *in an AGN photon field*

$$\delta = \frac{1}{\Gamma(1-\beta\mu_{obs})}$$

$$L_{obs} = \delta^4 L^*$$

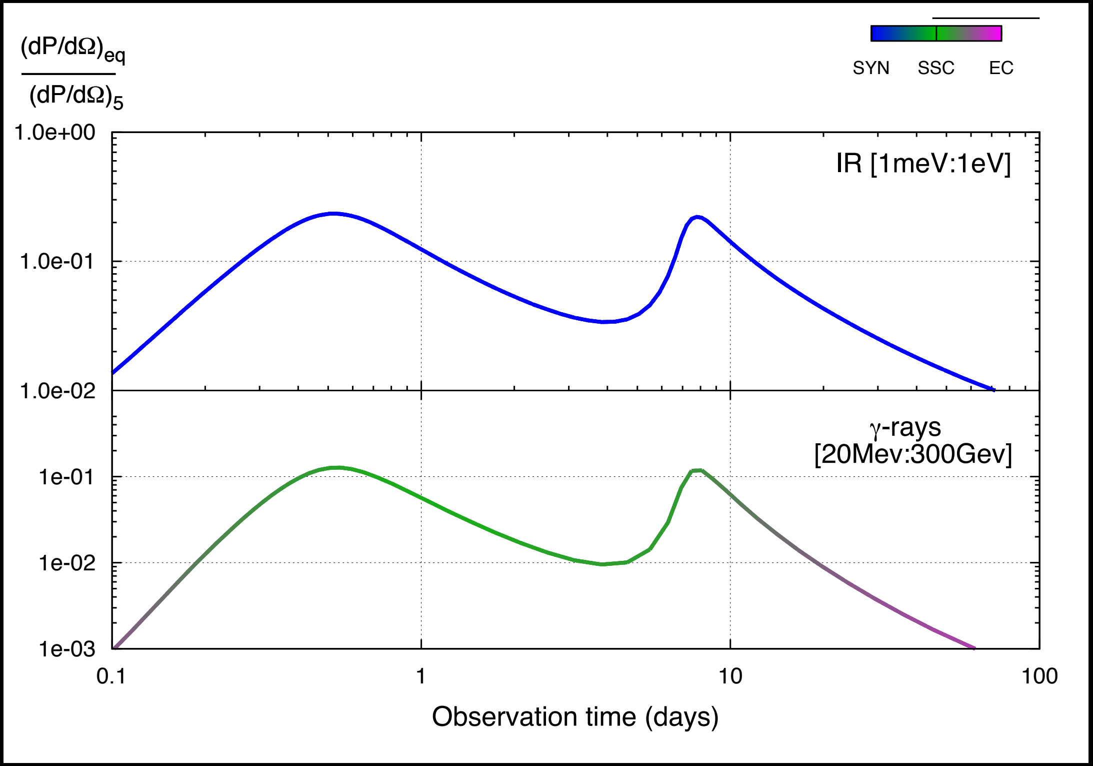
$$\mu_{obs} = \cos i_{obs}$$





Implied variability ?

Emission seen by an observer integrated over two energy band as a blob moves along the jet



$$t_{obs} = \int_{Z_0}^{Z_f} \frac{1}{\beta\, c} \left(1 - \beta\, \mu_{obs}\right) \mathrm{d}Z$$

**see Vuillaume et al 2014, in prep, for more*

Summary

- *Compton rocket is an elegant mechanism to accelerate jets to relativistic speeds in the two-flow paradigm*

- *A complex photon field imply variations of* Γ *along the jet*

- *These variations can have effects on:*
    - *the localization of bright spots*
    - *the time variability*