ARTICLE IN PRESS
COMREN:3300

C. R. Physique ●●● (●●●●) ●●●–●●●

Contents lists available at ScienceDirect

Comptes Rendus Physique

www.sciencedirect.com

Gamma-ray astronomy / Astronomie des rayons gamma – Volume 2

Active galactic nuclei at gamma-ray energies

Noyaux actifs de galaxie dans le domaine des rayons gamma

Charles Dennison Dermer [a,*], Berrie Giebels [b]

[a] *Code 7653, Naval Research Laboratory, Washington, DC, USA*
[b] *LLR, École polytechnique, CNRS/IN2P3, Université Paris-Saclay, 91128 Palaiseau cedex, France*

ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Active galactic nuclei
Gamma rays
Supermassive black holes

Mots-clés :
Noyaux actifs de galaxie
Rayons gamma
Trous noirs supermassifs

ABSTRACT

Active Galactic Nuclei can be copious extragalactic emitters of MeV–GeV–TeV γ rays, a phenomenon linked to the presence of relativistic jets powered by a super-massive black hole in the center of the host galaxy. Most of γ-ray emitting active galactic nuclei, with more than 1500 known at GeV energies, and more than 60 at TeV energies, are called "blazars". The standard blazar paradigm features a jet of relativistic magnetized plasma ejected from the neighborhood of a spinning and accreting super-massive black hole, close to the observer direction. Two classes of blazars are distinguished from observations: the flat-spectrum radio-quasar class (FSRQ) is characterized by strong external radiation fields, emission of broad optical lines, and dust tori. The BL Lac class (from the name of one of its members, BL Lacertae) corresponds to weaker advection-dominated flows with γ-ray spectra dominated by the inverse Compton effect on synchrotron photons. This paradigm has been very successful for modeling the broadband spectral energy distributions of blazars. However, many fundamental issues remain, including the role of hadronic processes and the rapid variability of a few FSRQs and several BL Lac objects whose synchrotron spectrum peaks at UV or X-ray frequencies. A class of γ-ray-emitting radio galaxies, which are thought to be the misaligned counterparts of blazars, has emerged from the results of the Fermi-Large Area Telescope and of ground-based Cherenkov telescopes. Soft γ-ray emission has been detected from a few nearby Seyfert galaxies, though it is not clear whether those γ rays originate from the nucleus. Blazars and their misaligned counterparts make up most of the $\gtrsim$100 MeV extragalactic γ-ray background (EGB), and are suspected of being the sources of ultra-high energy cosmic rays. The future "Cherenkov Telescope Array", in synergy with the Fermi-Large Area Telescope and a wide range of telescopes in space and on the ground, will write the next chapter of blazar physics.

RÉSUMÉ

Les noyaux actifs de galaxie peuvent être de puissants émetteurs dans tout le domaine γ, du MeV au TeV, un phénomène dû à la présence de jets relativistes, en liaison avec un trou noir super-massif au centre de la galaxie hôte. La classe d'émetteurs de rayons γ la plus abondante parmi les noyaux actifs de galaxie, avec plus de 1500

* Corresponding author.
E-mail addresses: charlesdermer@outlook.com (C.D. Dermer), Berrie.Giebels@CNRS.fr (B. Giebels).

http://dx.doi.org/10.1016/j.crhy.2016.04.004
1631-0705/

Please cite this article in press as: C.D. Dermer, B. Giebels, Active galactic nuclei at gamma-ray energies, C. R. Physique (2016), http://dx.doi.org/10.1016/j.crhy.2016.04.004

sources établies aux énergies du GeV, et plus de 60 aux énergies du TeV, sont les « blazars ». Le paradigme actuel du blazar met en jeu un jet de plasma magnétisé, orienté à faible angle de la ligne de visée, et éjecté depuis le voisinage d'un trou noir accrétant et super-massif en rotation. Les observations permettent de distinguer deux types de blazars : les quasars radio à spectre plat (ou FSRQ) comprennent des champs de rayonnement externes puissants, des zones avec des raies d'émission optiques larges, et des tores de poussières. La classe des BL Lac (du nom d'un de ses membres, BL Lacertae) possède des flots d'accrétion plus faibles, dominés par l'advection, et dans lequel l'émission des rayons γ vient essentiellement de l'effet Compton inverse sur les photons synchrotron. Ce paradigme permet de modéliser l'émission des blazars sur tout le spectre électromagnétique. Cependant, beaucoup de problèmes fondamentaux restent sans réponse, notamment le rôle des processus hadroniques, et la variabilité très rapide de l'émission de certains objets BL Lac, ceux dont le spectre synchrotron émet le maximum de puissance dans les domaines UV et X. Les observations du satellite Fermi-LAT et celles des observatoires Tcherenkov au sol ont également mis en évidence une nouvelle classe de radio-galaxies émettrices de rayons γ, considérées comme les contreparties non alignées des blazars. On a aussi détecté l'émission de rayons γ de basse énergie provenant de galaxies de type Seyfert, mais il n'est pas encore sûr que cette émission vienne du noyau. Les blazars avec leurs contreparties non alignées sont à l'origine de la plus grande partie de l'émission gamma extragalactique diffuse au-dessus de 100 MeV, et sont soupçonnés d'être les sources des rayons cosmiques d'ultra-haute énergie. Le futur réseau *Cherenkov Telescope Array* (CTA), en synergie avec le télescope spatial Fermi et une grande variété de télescopes dans l'espace et au sol, écriront le prochain chapitre de la physique des blazars.

1. Introduction: AGN detected at γ-ray energies

Among the astrophysical γ-ray emitters located well beyond the Milky Way are the γ-ray galaxies. From the recent advances in the field we can classify, simply, two types of γ-ray galaxies. First are the *black-hole galaxies*, which are powered by infalling gas onto a massive black hole in their center, and will be thoroughly discussed here. Second are the generally much weaker and likely more numerous *cosmic-ray galaxies* with their γ-ray emission powered by stellar explosions rather than black holes, which make shocks that accelerate cosmic rays [1]. Indeed, galaxies hardly have to harbor a radio-luminous black hole to be γ-ray luminous, as confirmed by a quick glance at the Fermi-LAT all-sky image, which shows the Milky Way lit up by cosmic rays colliding with diffuse gas and dust. Besides most γ rays produced by nuclear collisions of cosmic rays to make pions, cosmic-ray galaxies are also illuminated in γ rays by pulsars and pulsar-wind nebulae. Analysis shows that black-hole galaxies make the bulk of the high-energy (HE; $\gtrsim$100 MeV) and Very High Energy (VHE; $\gtrsim$100 GeV) extragalactic γ-ray background (EGB, [2]). Cosmic-ray galaxies, because they essentially partake in hadronic processes, should have comparable neutrino and γ-ray luminosities. Note how different these two types of γ-ray galaxies are in comparison with the two types of γ-ray emitting black-hole galaxies, namely Seyferts and blazars, identified in the CGRO days [3].

The black-hole γ-ray galaxies are Active Galactic Nuclei (AGN), which are among the most powerful known astrophysical sources of non-thermal radiation and most luminous known electromagnetic emitters, with luminosities in the range 10^{35}–10^{41} W.

1.1. The active galaxy zoo

The observational classification of AGN, dominated by the dichotomy between radio-quiet and radio-loud classes, with the latter constituting 10% of the population, is represented in the chart of Fig. 1. The less numerous radio-loud AGN are about 3 orders of magnitude brighter in the radio band than their radio-quiet counterparts.

The AGN unification scheme is based on the sketch by Urry and Padovani [4] (see Fig. 2) which displays the composite AGN phenomenon (black hole, disk, torus, clouds and jet), and illustrates how orientation effects, different accretion powers, and different spin parameters[1] a/M of the black hole could account for the wide range of AGN types. According to Fig. 2, the appearance of an AGN depends crucially on the orientation of the observer with respect to the symmetry axis of the accretion disk. In this picture, the difference between radio-loud and radio-quiet AGN depends on the presence or absence of radio-emitting jets powered by the central nucleus, which in turn may be induced by the rotation of the black hole. In Fig. 2, at high accretion rates (relative to the Eddington limit) and large luminosities, both radio-loud and radio-quiet AGN have dusty tori, broad-line regions (BLRs), narrow-line regions, and strong big blue/UV bump emissions from an optically thick accretion disk. BLR clouds illuminated by the accretion-disk radiation are obscured in Seyfert 2 AGN when viewing

[1] The spin parameter is the ratio of the angular momentum a of the black hole to its mass M.

Please cite this article in press as: C.D. Dermer, B. Giebels, Active galactic nuclei at gamma-ray energies, C. R. Physique (2016), http://dx.doi.org/10.1016/j.crhy.2016.04.004