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Review paper to be published in NATO Meeting, "The Gamma-ray sky with Compton GRO and SIGMA", Les Houches, France, 25 January to 4 February 1994

Série C :

PRÉ - PUBLICATIONS

Fascicule 137 (1994)

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Multi-wavelength Observations of Active Galactic Nuclei

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Abstract

Simultaneous or near simultaneous observations spanning wide bands of the electro-magnetic spectrum form a powerful tool to study the structure of Active Galactic Nuclei. They allow to place tight constraints on the emission mechanisms at the origin of the observed flux and, to some extent, to study the geometry of the inner regions of these sources.

The present review briefly describes some of the recent developments in the field.

1 Introduction

The electro-magnetic radiation observed from Active Galactic Nuclei (AGN) is truly multi-wavelength. It spans the spectrum from the radio domain at about $10^{10} Hz$ to the gamma ray domain above 1 GeV ($= 2.4 \cdot 10^{23} Hz$). The emission is due to a large number of physical processes, including emission from hot dust, synchrotron radiation, Comptonisation and emission linked with the accretion process. How the sources of these components are organised and which are primary and which re-processed components is very unclear at present, so is the relationship between the flux we observe and the actual source of energy. The latter is most probably accretion onto a very massive black hole.

AGN are variable sources. They vary with relatively large amplitudes (factors of two or more are not seldom) in most spectral domains on a variety of time-scales.

Figure 1: The flux ($\nu \cdot f_\nu$) as a function of time and $\log(\nu)$ for the bright quasar 3C 273. The intensity is given by the size of the points.

The driving mechanism of variability is, however, not understood yet, nor are the relations between the variations of the different continuum emission components. The line emission variations are, on the other hand, closely related to those of the ionising continuum source (Peterson 1993).

The observed flux of AGN is therefore a two dimensional function of frequency (or wavelength) and time. Figure 1 gives as an example a set of data on the quasar 3C 273 covering approximately 10 years and spanning the spectrum from the radio domain to the X-rays. Several campaigns have been organised in the last few years, often centred on ultraviolet data from IUE. These campaigns are characterised by a variety of spectral coverage and resolution and different temporal durations and sampling. For recent reviews of some of these campaigns see Peterson (1993), Clavel (1994) and Edelson (1994).

Among the most important results of these campaigns, I count the discovery that, in Seyfert galaxies, the emission lines follow the continuum variations with a very short lag and that lines of different ionisation levels follow the continuum with lags that increase as the level of ionisation decreases, thus indicating a layered structure of the Broad Emission Line Region (BLR) (Peterson 1993). Also of great interest is the observation that the continuum varies with no observable lag between the short

UV wavelengths and the long optical wavelengths in Seyfert galaxies and Quasars. The implications of this result for disk accretion models have been discussed in Courvoisier and Clavel (1991). A further important result is that the continuum variations between the X-ray domain and the optical domain in the BL Lac object PKS 2155-304 were nearly simultaneous, the X-ray emission preceding the longer wavelength emission by about 2 hours (Edelson et al. 1994). These results have markedly changed our views on the physics of inner regions of most categories of AGN in the past few years.

The data set presented in fig. 1 has a very sparse coverage with many zones devoid of observation. This property is shared by most if not all other data sets obtained during multi-wavelength campaigns. Understanding the physics of AGN and their complex spectral and temporal behaviour is therefore like reconstructing the complete image based on the very patchy data available.

It should be remarked that, although the techniques needed to obtain multi-wavelength data are straight forward and do not (in most cases) require new observation technologies, multi-wavelength campaigns require large amounts of data, and therefore of observing time, from many very different instruments, on the ground and in space. These facilities have different celestial constraints, different scheduling habits and are located in very different places. Several ground based sites are also necessary to alleviate meteorological uncertainties. As a result, these campaigns are difficult to organise and the data difficult to reduce in a homogeneous way. It is therefore not surprising that only relatively few bright AGN have been studied with these techniques to date.

2 Unification Schemes

The emission of AGN is due to many components associated with the processes mentioned in the introduction, to which one should add the presence of jets with their specific properties like large bulk velocities that boost the radiation along the direction of the jet. AGN, on the other hand, come in several classes characterised by observed properties. These include quasars (the most luminous active nuclei, some are radio loud and most are radio quiet), Seyfert 1 and Seyfert 2 galaxies (these are galaxies with a very bright nucleus, Seyfert 1 galaxies show broad permitted emission lines and narrow forbidden emission lines whereas all the lines are narrow in Seyfert 2 galaxies), radio galaxies BL Lac objects and several other categories (see Woltjer 1990 for a description of the observed properties of the different AGN classes).

It seems that the physical processes at work in the nuclei of the different AGN

classes are very similar. The differences between the AGN classes could then be caused by the presence or absence of some of the components in the observed data. It is therefore natural to look for schemes under which the different classes could be unified in a single type of objects. The different mixes of components making up the different observational categories of AGN should then follow “naturally” from the properties of the archetype AGN and the variation of some parameter such as the orientation of the source (plane of an accretion disk or jet axis for example) with respect to the line of sight. Such schemes are called Unification schemes. A recent review of these has been given by Antonucci (1993).

One very successful unification scheme is that unifying Seyfert galaxies of type 1 and 2. The idea here is that Seyfert nuclei are surrounded by a thick torus of absorbing material which hides the central regions of the nucleus when the line of sight from the observer to the nucleus intercepts the torus. The objects viewed through the torus show no broad absorption lines (the broad permitted lines are generated very close to the nucleus and are hidden by the torus) but do show the narrow permitted emission lines generated at a much larger distances from the nucleus in regions which are unobscured by the torus. This idea has been confirmed by spectropolarimetric observations of the Seyfert 2 nucleus NGC 1068 (Antonucci and Miller 1985) in which broad lines were detected in polarised light. The implication of this result is that the broad line region exists in Seyfert 2 galaxies as well as in Seyfert 1 galaxies but that it is hidden to the direct line of sight and revealed only by that part of the light which is scattered into the line of sight above the plane of the torus.

Not all categories of AGN can be so conveniently merged into larger classes of objects. Browne and Jackson (1992) have shown that there are two types of beamed active nuclei, those of low intrinsic luminosity (essentially BL Lac objects) which are associated with low luminosity radio galaxies (Faranov and Riley type 1 radio galaxies) and luminous radio quasars associated with luminous radio galaxies (Faranov and Riley type 2 radio galaxies). One can show that both classes of beamed sources differ not only in their statistical distributions as shown by Browne and Jackson (1992), but also in their intrinsic properties and that the presence of a blue bump in quasars is a genuine difference between quasars and BL Lac objects (Courvoisier 1994).

3 The Nature of the Blue Bump

The overall spectral energy distribution of the quasar 3C 273 is given in fig. 2. Although this distribution is flat (in $\log(\nu \cdot f_\nu) \times \log(\nu)$ space) to the first approx-

Figure 2: The flux ($\nu \cdot f_\nu$) of the bright quasar 3C 273 as observed in December 1990 at frequencies less than 10^{18} Hz (work in progress). The high energy data is from Lichti et al. (1994), it was obtained in June 1991.

imation, it shows two important “bumps”, one in the UV domain and one in the hard X-ray domain. The first of these is called the blue bump. This feature of the continuum spectral energy distribution has very often been associated with accretion disks as originally suggested by Shields (1978). This association has met difficulties in recent years (Courvoisier and Clavel 1991). The main problem is that the observed properties of the UV and optical continuum variability do not match those expected from accretion disks.

In view of these difficulties it is important to re-examine the possible origin of the optical to X-ray emission in the blue bump. In order to do this we have obtained simultaneous IUE and ROSAT data during the ROSAT all sky survey at the beginning of the mission. These data indicate that the continuum spectral energy distributions are characterised by a marked minimum at a few 100 eV. This feature is independent of the luminosity of the object over several orders of magnitude (Walter et al. 1994).

It is difficult to see which physical process can generate this property. Thin accretion disks have a maximum temperature (and hence a spectral cut-off) that decreases with the mass of the central object to the power 1/4 and therefore with

the luminosity to the same power provided that the ratio of the luminosity to the Eddington luminosity does not change in a systematic way with the mass. Therefore hot coronae which might modify the observed properties of accretion disks must do this in a strongly constrained way to explain the similarity of the far UV and soft X-ray continuum spectral energy distributions of sources of very different luminosities.

Barvainis (1993) has proposed that the emission at the origin of the blue bump is due to optically thin free free emission from a hot plasma organised in a large number of small dense clouds. This type of emission process alleviates many of the difficulties of accretion disk models. There is no mechanism proposed to date, however, that would constrain the temperature of these plasma clouds to the narrow range suggested by the observations described above. Further work is in progress to include the line emission of the plasma and to see how this will modify its observed properties and cooling curve (Courvoisier 1994, and Gehrels and Williams 1993).

4 Ultraviolet Variability

Following an analysis of all AGN related IUE data (Courvoisier and Paltani 1992) we selected all the objects for which a sufficient number of IUE observations are available in order to systematically analyse the UV variability of AGN. Our selection provided 93 objects, and more than 3000 spectra. The variability of these objects was quantified and studied as a function of other parameters characterising the sources, like AGN class, luminosity, red-shift and spectral shape. Flux and number of observations were also included in our analysis to study possible systematic biases in the data. The results are published in Paltani and Courvoisier (1994).

The variability was quantified using the standard deviation of the flux as a function of the wavelength, $s(\lambda)$, (rather than the peak to peak maximum observed excursion) for each object in the following way:

$$s(\lambda) = \frac{[\frac{1}{N-1} \sum [f_{50,i}(\lambda) - \bar{f}_{50}(\lambda)]^2]^{1/2}}{\bar{f}_{50}(\lambda)},$$

where $f_{50,i}(\lambda)$ is the flux at epoch i averaged over a $50 \text{ \AA}$ bin and $\bar{f}_{50}(\lambda)$ is the same quantity averaged over all epochs. The wavelength dependence of $s(\lambda)$ was then parameterised using the variability at $2000 \text{ \AA}$: $\sigma_{f,2000}$ and the gradient of $s(\lambda)$ as a function of λ : $\Delta_\lambda(\sigma_f)$.

It was found that 80% of the objects vary by more than 20% at $2000 \text{ \AA}$ using the above measure, confirming that AGN are strongly variable UV sources. In general the variations at shorter wavelengths are more pronounced than at longer wavelength (see also Kinney et al. 1991).

The more surprising result of our analysis is that the main characteristics of the variability are very similar for different classes of AGN. In average the amplitude of the flux variations in Seyfert galaxies (of type 1; there are not enough Seyfert 2 galaxies to include them in this analysis) is similar to that of quasars, be they radio loud or radio quiet. The dispersion of the variability parameters in the different classes is also similar. These results are summarised in the figure 3.

It is also clear when looking at the correlations between the observed UV variability and other source parameters, that although some weak trends are significant, the dispersion around the best correlation is always large (Paltani and Courvoisier 1994). This indicates that the physical properties driving the variations in individual sources have not been properly identified yet.

5 X-ray Emission

For a long time it was thought that the X-ray emission of AGN is well described by a featureless power law continuum emission. As the sensitivity, energy resolution and bandwidth of X-ray detectors improved, it became more and more clear that this description represents a gross oversimplification of the reality.

Several features have been discovered in the X-ray emission of AGN in recent years. A review is given in Mushotzky, Done and Pounds (1993). Among the main modifications from a single power law, there is the existence of a soft excess at low energies. This component is observed in a large fraction of AGN (Turner and Pounds 1989). It is described either by a soft thermal component or by a steep power law. The origin of this component is probably related to the blue bump, as the parameters describing it seem to be related to the UV continuum (Walter et al. 1994). The physical origin of the component is, however, not conclusively identified yet.

Other features of the X-ray emission include an emission line from Fe, a spectral curvature probably due to a Compton reflection component and possibly the existence of intrinsic absorption by partially ionised material (hot absorber). See Mushotzky, Done and Pounds (1993) for a description of these components and the references to the original papers.

The X-ray emission of AGN is variable in flux and in spectral shape in time on many time-scales. This may be due to a varying hot absorber, a change in the amount of reflected flux or a variation of the intrinsic X-ray component. For the objects in which there is no evidence of a reflection component, the latter possibility is the most likely. Walter and Courvoisier (1992) have proposed in the case of 3C 273 that the variation in the X-ray flux and spectral shape may be due to modifications

Figure 3: Distribution of the variability at 2000Å (observed wavelength) and of the gradient of variability for 67 AGN. The average and dispersion of both parameters are indicated for the different classes of AGN. Open triangles: Seyfert 1, open squares: radio quiet quasars, filled squares: radio loud quasars, filled pentagons: BL Lac objects. From Paltani and Courvoisier (1994)

in the thermal Comptonisation which they suggest is at the origin of the intrinsic X-ray power law.

6 γ -Ray Emission

Before the launch of CGRO there were 4 AGN which had observed γ -ray fluxes. These were NGC 4151, 3C 273, Cen A and MCG 8-11-11. There is now more than 20 radio loud Quasars and BL Lac objects which have been detected at energies higher than 100 MeV (Kurfess J.D. 1994 and reviews in the present volume). This emission is a single power law. The sources which have been detected at these high energies are all associated with strong core dominated superluminal radio sources. This suggests that the high energy γ -ray emission is closely associated with the presence of jets in these sources.

In strong contrast with the radio sources, the γ -ray emission of Seyfert galaxies shows a marked steepening at energies close to 50 KeV, with no evidence in the CGRO data for a hard γ -ray component (Kurfess 1994).

7 Conclusion

We are now in a position to describe reasonably well the spectral energy distribution and the temporal variability of AGN, from the radio domain to the γ -rays, with the exception of the extreme UV where very few observations are available (Marshall 1994). Although we do have this description, we still often do not have a clearly identified physical origin for several of the components. This is particularly the case in the optical-UV-soft X-ray domains. The origin of the big blue bump which constitutes most of the flux in this spectral region is still very controversial. At longer wavelengths it seems established that the flux is emitted by synchrotron emission, often associated with the jets or by hot dust particularly in radio quiet objects.

Each of the several components that make up the emission of single AGN is described by a large number of parameters which include particle distributions and geometrical considerations. The number of observed parameters is, on the other hand, relatively small because the continua are smooth. The consequence of these remarks is that, at present, the models that are developed to explain AGN often lack predictive power. Progress is therefore needed in two areas: multi-wavelength campaigns on several sources providing extensive data sets that increase the coverage in time and frequency should be sought. These data should then be confronted with increasingly self-consistent models. The progress made recently is already important

and our view of the central regions of AGN has been significantly modified in the last few years.

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