Correlations between Emission Components

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EMISSION COMPONENTS IN SEYFERT GALAXIES AND QUASARS

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Abstract. The continuum emission components of Seyfert galaxies and quasars are reviewed with a particular emphasis on the correlations observed between these components. It is shown that the blue bump emission which is observed in Seyfert galaxies and quasars and not in BL Lac type objects is not hidden in the latter objects by a strong beaming of the jet emission. The shape of the blue bump is described and some consequences of these observations for the interpretation of this component are given. The relationship between the X-ray emission of quasars and the radio beaming properties of the object should be re-visited when the shape of the soft excess emission can be better established.

1. Introduction

The emission of Active Galactic Nuclei (AGN) is a mix of a large number of components of very diverse physical origin. The same component (meaning the same physical process) is observed in objects belonging to different classes of AGN. For example, synchrotron emission is observed in BL Lac objects and in radio loud QSOs and emission from warm dust is found in Seyfert galaxies as well as in quasars.

It is expected that different mixes of the components can explain the different AGN classes that are observed. One typical example for this is the difference between Seyfert galaxies of type 1 and those of type 2. Assuming that Seyfert galaxies of both types are intrinsically very similar Antonucci and Miller (1985) explained the observed differences between the two classes with the presence of a thick torus that lies in our line of sight to Seyfert 2 nuclei and thus absorbs the light emitted by the central regions (ionising continuum source and broad line region). The torus is expected to exist also in Seyfert 1 galaxies. In these objects it lies, however, outside the line of sight to the continuum source. This model explains the difference between the two types of Seyfert galaxies by taking one of the emission component from the Seyfert 1 galaxies away. Although this model is very successful attention should be brought to the paper presented by Z. Tsvetanov in this volume (Tsvetanov et al. 1994). This paper shows that, against the expectations, HST images seem to imply that in the Seyfert 1 galaxy NGC 4151, our line of sight lies outside of the ionisation cone. According to the above picture this would imply that NGC 4151 should be observed as a Seyfert 2 galaxy rather than as a Seyfert 1.

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In several unification models (e.g. Barthel 1989 but also above) the different mix of components is due to geometrical effects. Viewing an object from one direction or from another will cause a different classification, even for intrinsically very similar objects.

One emission component, the radio emission, cannot be easily hidden by interstellar matter. So extended isotropic radio emission must be a genuine component existing in only a fraction of the AGN. We will show in section 2 that there are other components that are also genuine to the class of AGN in which they are observed and cannot be due solely to geometrical considerations.

The tools we have to study the relationships between the different components in AGN are repeated observations spanning the electro-magnetic spectrum. These observations are difficult to obtain, because they imply the use of a large set of ground based and space born instruments. As a consequence, few objects have been observed well enough to be subjected to this analysis. Most of these are quoted in one place or another of the present proceedings.

2. Radio emission and the blue bump

In radio loud objects the radio emission is due to synchrotron emission. This is established from the polarisation of the emission and its variability properties (see for example the lecture notes of the 20th advanced course of the Swiss Society for Astrophysics and Astronomy, Springer 1990).

Similar models are used to explain the emission in radio loud quasars and in BL Lac objects. These models are based on the synchrotron emission of electrons moving with relativistic bulk motions at different angles to the line of sight (see the reviews by E. Valtaoja and L. Bååth, this volume).

One could wonder whether the weakness of emission lines and the absence of a blue bump in BL Lac objects is intrinsic or whether it is due to the fact that synchrotron emission is strongly beamed towards the observer in these objects and thus apparently dominates the other components. If this was the case, BL Lac objects seen from another direction than down the axis of the jet should have a significant blue bump and emission lines. Two arguments can be brought against this picture and show that the blue bump is intrinsic to the quasars and not present in BL Lac objects.

It can be shown (Courvoisier 1992) that the synchrotron emission of the radio loud quasar 3C 273 should be enhanced by a factor $\sim$ 1000 in order to be at a level similar to that of the ultraviolet flux at 1000Å. An object like 3C 273 (and at a similar red-shift) but in which beaming would be such that the blue bump and the emission lines are lost in the beamed continuum would have a radio flux of 40 Jy or more. There are no BL Lac whose radio flux is anywhere near this value. In general BL Lac object are fainter than bright QSOs (Véron-Cetty and Véron 1991).

The previous argument is based on a single object which may not be appropriate for a general argument. Using several methods Ghisellini et al. (1993) have, however, shown that the beaming factor in BL Lac objects is in average less than that of radio loud quasars. Thus if BL Lac objects had intrinsically a blue bump of the same relative strength (compared say to the radio emission measured at 90 degrees from the jet axis) as the one of quasars it would in average be apparently stronger than that of quasars (compared to the radio emission). This is in strong contrast with the fact that BL Lac objects have weak or no blue bump and emission lines.

I conclude from these two arguments that the blue bump is an intrinsic property of quasars and that it is weak or absent in BL Lac objects. The intrinsic weakness of the blue bump implies that BL Lac objects have a weak ionising flux compared to objects which have in addition to the synchrotron emission a strong blue bump that peaks in the far ultraviolet domain. The weakness of the ionising flux in BL Lac objects may explain in turn the absence (or at least the relative weakness) of the emission lines in these objects.

A further consequence of these arguments is that the blue bump may not be taken as a primary indicator for the ultimate source of energy in AGN.

The existence of intrinsic differences between radio loud quasars on one side and BL Lac objects on the other side argues in favour of having two unification schemes, one for each class. This has been suggested by Browne and Jackson (1992) who considered one such scheme for the high luminosity objects and one for the low luminosity objects. The arguments presented here tend to indicate that a strong ionising continuum is a characteristic of the high luminosity objects. It is also worth noting that weak radio galaxies, like BL Lac objects have weak or no emission lines (Woltjer 1990).

3. The blue bump

3.1. The nature of the blue bump

The large excess of continuum radiation over the extrapolation of the infrared continuum energy distribution, the blue bump, 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.

These difficulties lead us to re-examine the origin of the blue bump. We have analysed the observations taken simultaneously with IUE and ROSAT during the ROSAT all sky survey (RIASS program) for a small sample of objects (Walter et al. 1994 and Orr et al. 1994). These observations span the blue bump up to the soft excess X-ray emission. It is striking that the continuum energy distributions have their maximum and their minimum (in the soft X-rays) at energies that are in a small range (within a factor of a few), irrespective of the luminosity of the objects which differ by factors larger than 10^4. This result can be seen both in a

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model independent way by measuring flux ratios in the soft X-rays and ultraviolet domains and by modelling the blue bump with a power law and a cut-off. In this latter case, the energy of the cut-off is related to the slope of the ultraviolet power law in such a way that steeper power laws have higher energy cut-offs than flatter power laws, showing clearly that the soft excess is closely related to the blue bump.

These observations imply that the shape of the blue bump is independent of the luminosity of the object and of the strength of the blue bump relative to the other components. Walter and Fink (1993) studied a large sample of objects for which the ultraviolet and X-ray observations are not simultaneous. They find essentially the same results as those described here.

Standard accretion disk models require considerable fine tuning in order to explain these results. Comptonised disks can account for the spectral properties of individual objects. However, they too need fine tuning to explain the results described above. The importance of the Comptonised flux relative to the underlying disk flux needs be such that the position of the maximum flux and that of the minimum remain independent of the luminosity of the object.

Optically thin emission has been much discussed at this conference to explain the blue bump (Barvainis 1994 and references therein) as an alternative to the optically thick disk emission. It is possible to account for the soft X-ray emission of quasars using optically thin emission (see e.g. Bühler Courvoisier and Staubert 1994). Figure 1 shows, however, that in the temperature range most often considered the emission is dominated by the line emission of the plasma rather than by the continuum flux, an effect that needs be taken into account. It is interesting to note that the range of temperatures in which the line emission, and therefore the plasma emission, is strongest corresponds to the temperatures deduced from the modelling of the blue bump.

3.2. Ultraviolet variability

Important clues on the physical nature of the blue bump emission is expected from the study of its variability. Several papers in these proceedings deal with the variability of objects (see review by J. Clavel in this volume).

In order to probe whether the ultraviolet variability of AGN depend on their type we analysed all the data obtained with IUE on AGN up to 1988 (Paltani and Courvoisier 1994). We expected to find marked differences in the variability properties of different classes of AGN because the ultraviolet flux in BL Lac type objects and in some quasars is thought to be due to synchrotron emission, whereas the blue bump of quasars and Seyfert galaxies was thought to be of thermal origin.

Our study considered all low dispersion IUE spectra of AGN (Courvoisier and Paltani 1992). Sixty seven objects in this sample were observed 8 times or more and had data of adequate quality, these objects were the object of our variability study. This sample is not complete in any sense of the word except that it contains all available data.

For each object we constructed the following measure of the variability as a

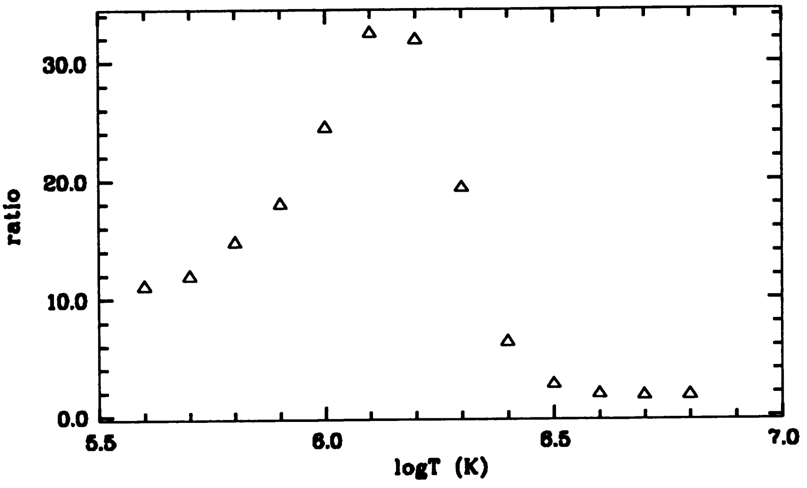

Fig. 1. Ratio of line to continuum flux in a 1.3Å to 300Å band as a function of the temperature for an optically thin plasma. The plasma model is from Mewe et al. 1986

function of wavelength:

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

where $f_{50,i}(\lambda)$ is the flux at epoch i averaged over a 50Å 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 2000Å: $\sigma_{f,2000}$ 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 2000Å using the above measure and that in general the variability increases when the wavelength decreases. Figure 2 gives the distribution of both parameters for the 67 objects considered.

Analysis of this parameterisation of the variability as a function of various properties of the AGN led to the following findings:

- The dispersion of both parameters when correlated with the luminosity of the objects, their flux, the type of object or their spectral slope is large. We conclude that none of these properties are closely related to the observed characteristics of the variability.
- There is a small increase of variability as the luminosity decreases. This trend is much less than expected for models in which the variability is due to independent events of similar luminosity (Paltani and Courvoisier 1994).
- We could not find a significant difference between the mean of the 2000Å variability and its wavelength gradient for the different types of objects (fig. 3).

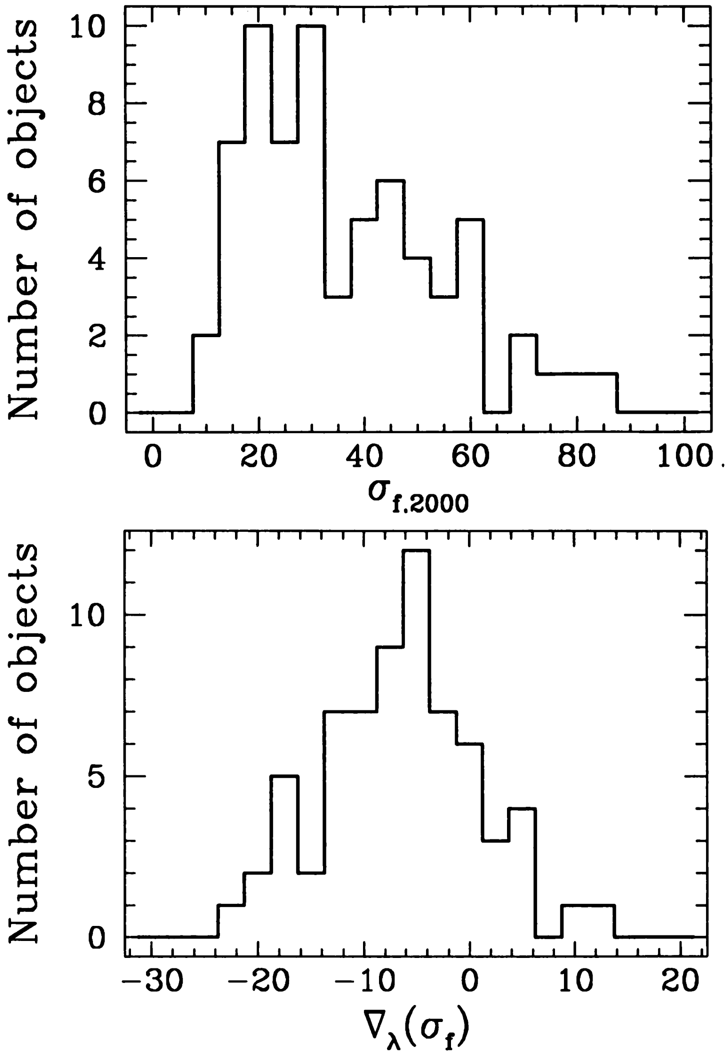

Fig. 2. Distribution of the variability at 2000Å and of the gradient of variability for 67 AGN

A more extensive study of the ultraviolet variability of AGN including the IUE data up to the end of 1992 is in preparation.

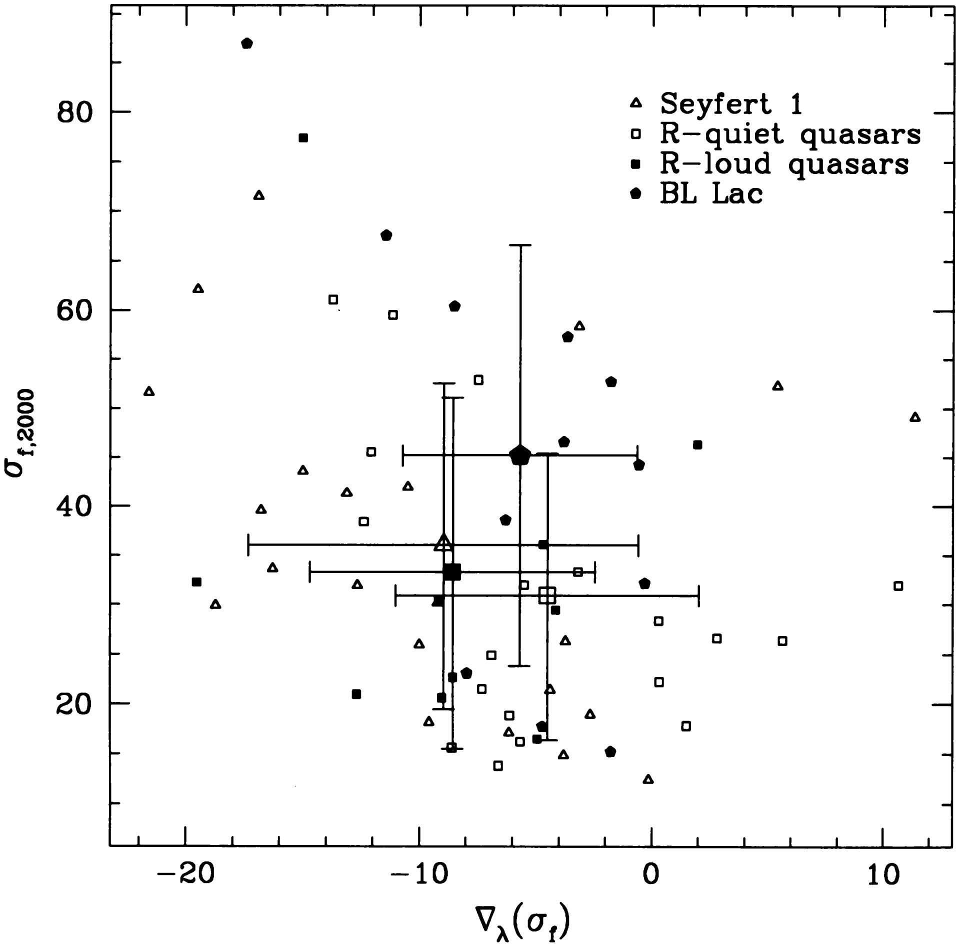

Fig. 3. Variability at 2000Å and gradient of the variability for 67 AGN. The data include all IUE observations up to 1988. The different symbols correspond to different classes of AGN. The average of each class of AGN is indicated together with the dispersion of the subsample. No significant differences can be measured between the different classes of AGN.

4. Blue bump and radio emission flux correlations

A very significant correlation is observed between the light curves of the blue bump and the radio domain for the bright quasar 3C 273 (Courvoisier et al. 1990). Recent data confirm this correlation (fig. 4). The correlation is observed when the blue bump is sampled through the ultraviolet emission, but also when it is sampled with optical data. The lag between the two light curves indicates that the blue

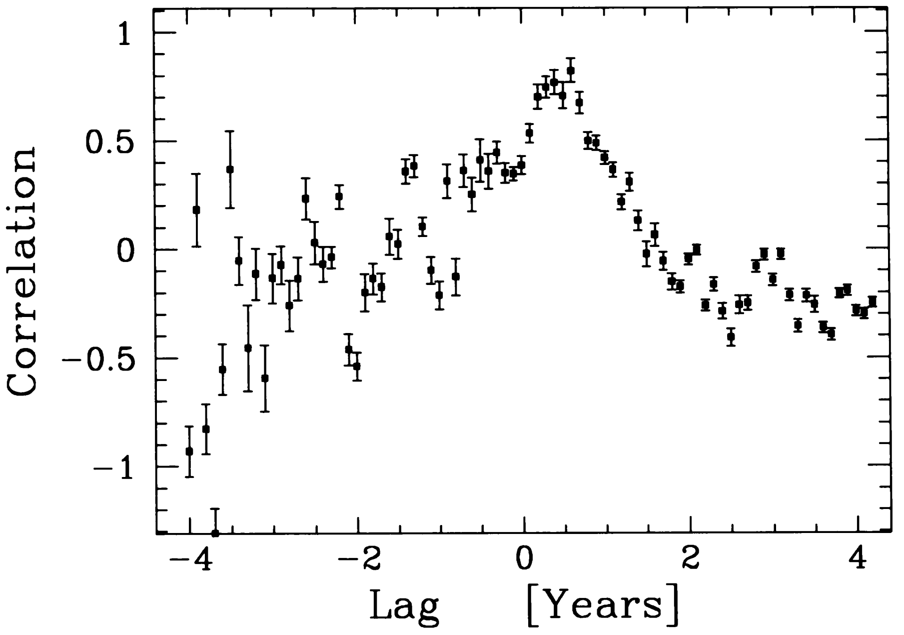

Fig. 4. Cross correlation between the V and the 22 GHz light curves of 3C 273.

bump flux leads the radio emission by approximately 6 months. It is difficult to quote a formal uncertainty on this lag.

Paltani et al. (1994) used this result together with the findings of VLBI repeated observations (Zensus et al. 1990) to estimate the distance of the 22GHz emitting region from the blue bump under the hypothesis that the observed lag is due to the time needed for a central perturbation (possibly a shock) signalled by the ultraviolet variability to move down the jet at the speed of the VLBI components. This distance was found to be $6.5/h^2 l.y.$, where $H_0 = 100hkm/(s \cdot Mpc)$.

Tornikoski et al. (1994) also studied the possible existence of correlations between the blue bump emission and the radio emission of AGN. They find a significant correlation between the two components in a number of objects. This shows that flux correlations between the ultraviolet and radio parts of the spectrum may well be a characteristic of AGN rather than an exception.

5. X-ray emission

High energy emission from AGN is reviewed in several papers in these proceedings. I therefore limit this section to a few remarks relating the X-ray emission to other components.

X-ray emission apparently results from several components: the soft excess which may be the high energy tail of the blue bump (see above), a steep isotropic power law, a flatter beamed power law (e.g. Jackson, Browne and Warwick 1993 and references therein) and signatures of the reflection of an "intrinsic" power law by cold material (Pounds, Nandra and Stewart 1992).

Jackson et al. (1993 and this volume) attempted to correlate the X-ray slopes in the ROSAT and EINSTEIN energy domains with the radio properties of the AGN. Their aim was to measure how the hard power law depends on the beaming properties of the objects. Their study could not confirm such a link. Bühler, Courvoisier and Staubert (1994), however, show that this difficulty is related to the assumed shape of the soft excess. Jackson et al. (1993) describe the soft excess with a power law which extends to high energies. Modelling the soft excess with a thermal model (or equivalently with a power law with cut-off) leads to very different results for the normalisation of the other power laws used to model the X-ray emission. Since the energy resolution of ROSAT is insufficient to uniquely characterise the shape of the soft excess, the data available cannot be used to discard a model in which part of the X-ray flux is beamed.

6. Conclusions

The emission of AGN and in particular of Seyfert galaxies and quasars results from many different components. These include line emitting gas (Broad Emission Line Region and Narrow Emission Line Region), a synchrotron emitting jet, emission from dust with a large range of temperatures, accretion disk (with or without a Comptonising corona), optically thin emission, soft X-ray excess, X-ray power laws, a reflection hump, Comptonised components, and emission resulting from pair processes.

These components are described by a large number of parameters to take into account the physical conditions of the emitting gas or plasma but also the geometrical arrangement of the emission region and its bulk velocity with respect to the observer. It is therefore quite natural that we can produce reasonable fits to the observed multi-wavelength spectra of AGN, even if not all components are present in each object. The wealth of parameters is also the cause of the lack of predictive power that many models of AGN have shown.

Although this state of affairs is not very satisfactory, significant progress has been obtained in recent years with the identification of several of the emission components and a much better description of those not firmly identified. In particular, it seems that the long wavelength emission of radio loud and radio quiet AGN is well described with the models of beamed synchrotron emission and dust emission, even if the details of the jet models are not well established yet.

In contrast, several of the discussions during the meeting showed that the nature of the blue bump emission is not understood, nor is that of the X-ray emitting components. The question as to why some AGN are radio loud whereas the majority is radio quiet is also still unanswered.

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