THESIS FOR THE ATTAINMENT OF THE TITLE OF

"MAGISTER PHILOSOPHIAE"

BL LACERTAE OBJECTS

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Introduction.

In 1968 Schmitt identified the "variable" star BL Lacertae with the unusual radio source 42.22.01 (Mac Leod and Andrew, 1968) subsequently rapid variations in the radio spectral flux (Biraud and Véron, 1968; Andrew et al., 1969; Gower, 1969) and linear polarization (Olsen, 1969) were detected; in addition the optical radiation was shown to exhibit a continuous spectrum with neither emission nor absorption lines (Oke, Neugebauer and Becklin, 1969; Du Puy et al., 1969) and a relatively high degree of linear polarization (Visvanathan, 1969).
The peculiar character of the object was therefore well established. BL Lacertae was to be the prototype of a new class of objects of astrophysical interest, whose importance was to grow steadily with time. In fact, shortly after these discoveries, optical, IR and radio observations by several investigators allowed other sources to be recognized similar to BL Lacertae. This fact led Strittmatter et al. (1972) to suppose that BL Lac-type objects may comprise a class of quasi-stellar objects (QSO_S) with some combination of the following characteristics: (a) absence of emission lines in the core source; (b) rapid variability at radio, IR and visual wavelengths; (c) non-thermal continuum in the optical IR range with most of the luminosity radiated at IR wavelengths; (d) strong and rapidly varying polarization.
At first, BL Lacs were the exclusive domain of continuum radio astronomers and optical photometrists (for an excellent review on the status of knowledge up to about late 1975, see Stein, O'Dell and Strittmatter, 1976). Then a change of trend has occurred: BL Lacs are now being studied with the full technology of modern observational astronomy, that is through VLB, IUE, X-ray and gamma-ray techniques, through UV, V, IR spectroscopy, through VLBI mapping and so on.

This change of status can be attributed to two realizations. First, the non-thermal source in a BL Lac object is extremely compact and well-ordered, even for a QSO-like obiect (we recall that there is no direct evidence that optical continuum radiation, possibly the dominant form of energy loss, is in fact non-thermal in the case of most QSOs): therefore , BL Lacs provide the most direct link we have to the elusive "primary machine". Second, the recent discovery of a galaxian component in the optical radiation emitted by many BL Lacs (all those which lie at $z < 0.1$) provides another link: that is,between a QSO-like object and galaxy of stars; besides establishing distances, observations of the galaxian component may tell whether the BL Lac phenomenon is an evolutionary stage common to all galaxies or restricted to galaxies belonging to a special class.

In this review we shall (1) examine the proposed membership criteria and discuss how methods used to discover BL Lacs may bias the observed properties, (2) describe evidence that BL Lacs belong to a wider class of objects that include the optically violent variable QSOs (OVV), (3) examine the connection between BL Lacs and the galaxies in which they are embedded, (4) describe the range of their radio morphologies, (5) discuss their spectra, the information we can get out of them and the methods for doing that, and finally we shall(6) briefly discuss the models worked out to explain the BL Lac phenomenon .

Defining Characteristics.

A BL Lac object may defined as:

A) a radio source with a flat or inverted spectrum at cm wavelengths;

B) a star-like object that radiates nonthermal optical continuum and is possibly associated with a nebulosity;

C) an object with variable optical and radio flux densities;

D) an object with strong and rapidly varying optical polarization;

E) an object that radiates no emission lines.

Let us examine each property in turn (this discussion is largely based on Wolfe, 1980):

property (A) - Although the majority of the presently known BL Lacs were discovered in high-frequency radio surveys a few of them were discovered in low-frequency surveys (e.g., Angel and Stockman, 1980 and references therein) and several are X-ray (Piccinotti et al.,1982; Wilson et al., 1979; Griffiths et al.,1979; Stocke et al., 1982 Gioia et al., 1984) or optically selected. In all cases their radio spectrum turned out to be flat or inverted at cm wavelengths(Figures 1 and 2). Property (A) seems therefore to be genuine and not an artifact of observational bias. Moreover, the flat radio spectrum encompasses an even larger frequency range than the radio spectra of QSOs: BL Lacs in fact tend to be self-absorbed down to mm wavelengths rather than to cm wavelengths as for QSOs. (this might explain why QSOs outnumber BL Lacs, by a factor $\gtrsim 10$, in cm surveys down to a limiting flux of, say, 0.5 Jy). As noted by Condon (1978), the flux of BL Lacs at mm wavelengths in well correlated to the optical flux: the corresponding two-point spectral index is $< \alpha_{OR} > \approx 0.7$. The ratio of radio to optical luminosity for radio selected BL Lacs is considerably larger than that of QSOs: for a given high-frequency radio flux, BL Lacs are typically 1 or 2 mag brighter than QSOs.

It is thus believed that compact radio emission is a characteristic property of these objects. The reliance on radio emission, however, might introduce an obvious bias against detecting radio-quiet BL Lacs, and so a still open question is whether radio-quiet BL Lacs do exist or not, in analogy with radio-quiet QSOs which are known to constitue ~90% of optically selected QSOs. Of course the answer to this question is partly a matter of definition: radio - "quiet" does not necessarily mean radio - "silent".

property (B) - The continuum which is apparent from optical spectra is a power-law one, similarly to QSOs, although typically steeper (Figures 3 and 4). In fact, defining the shape of the continuum as $F_\nu \propto \nu^{-\alpha}$ it appears that for QSOs typically is $<\alpha_{opt}> \approx 1$, while for BL Lacs is $<\alpha_{opt}> \approx 2$. As a consequence BL Lacs tend to have more neutral colours than QSOs.

Photometrically, BL Lacs tend to be less blue than QSOs for another reason beside the abovementioned one. This reason is that up to z < 0.1 there is obser vational evidence that BL Lac sources are embedded in giant elliptical galaxies (this identification is based on the scale-height and the form of the surface-brightness distribution [Kinman, 1978]; the nuclear bulges of early-type spirals could reproduce the observed stellar spectrum, but not the extent of the light distribution), while there is no evidence for spirals; most QSOs, on the other hand, seem to be surrounded by nebulosities showing complicated structures maybe suggesting the presence of large spiral disks (Gunn, 1978). Of course we do not know if the connection BL Lac-gE spans over a much larger range in z, since detectability depends on z and on contrast of galaxy against the (bright) nucleus. Spectroscopic investigation too sets important differences between the classes of BL Lac nebulosities and the class of QSO nebulosities: the latter are comprised of giant regions of ionized gas responsible for [O III], Hβ and other nebular emission lines (Wampler et al., 1975) with no evidence for absorption lines indicating the stellar population of a galaxy, while the former show stellar absorption lines (Miller et al., 1978). The failure to find first-ranked giant ellipticals around a sample of low-luminosity QSOs supports there being intrinsic differences between the two types of nebulosities (Miller et al., ibidem). Where it is possible to optically separate galaxies and central objects, a magnitude range of $-22.5 < M_v < -21.0$ has been found,

indicating first-ranked giant ellipticals.
Conversely, there are quite a few ellipticals (such as NGC 1052, NGC 4278) containing compact radio sources resembling those in BL Lacs (Ekers, 1978) which may be considered as low-luminosity BL Lacs. These objects may provide a clue to understanding the relationship between optically quiet elliptical galaxies and BL Lacs therein embedded. Arecibo data (Knapp et al., 1978) for two such objects (NGC 1052 and NGC 4278) show in fact that they possess disks of neutral hydrogen which are inclined with respect to the symmetry plane of the galaxy. Since tidal forces would destroy the disk or bring it into the symmetry plane on a characteristic timescale of 1 Gyr, we must infer that the disk is younger than this time and is comprised of fresh stuff (HI) fallen from the intergalactic space. Obviously it is reasonable to think that this infall from the exterior might be connected to the powering of the core.

property (C) - The variability of BL Lacs is an important property that sets them apart from most QSOs The shorter timescales for BL Lac variability than for QSO variability suggests that they are more intimately related to the primary machine underlying the AGN phenomenon than is the average QSO. At optical wavelengths the difference is particularly clear-cut. Whereas the standard QSO varies by B=0.3 ---> 0.5 mag in a timescale $\Delta t \approx$ few years, most BL Lacs vary by $\Delta B > 1$ mag during $\Delta t \approx 1$ day ---> 1 week. Extreme examples of variability can be found in the 1969 outburst of BL Lac itself when $\Delta B/\Delta t \approx 1$ mag/1hr (Kinman, 1978) and in the 1975 outburst of 0235 + 164 when $\Delta B/\Delta t \approx$ 5 mag/weeks (Rieke et al., 1976). The distinction between QSOs and BL Lacs is somewhat softened in the radio domain. Wardle (1978) has shown that in a sample of flat-radio-spectrum QSOs and BL Lac the incidence of variability is about the same in both classes, but the degree of variability is higher and the duration of the outburst shorter in BL Lacs. The mean r.m.s. scatter in 3.7-cm flux density relative to the mean flux density is > 30% for 5 out of 20 BL Lacs, whereas none of the 14 QSOs varied to this extent. Moreover, Δt was of the order of months for BL Lacs, and of years for QSOs. In this respect, BL Lacs are reminiscent of the optically variables (OVVs), a subclass of radio QSOs which undergo strong bursts of short duration and have steep optical spectra (in this respect we should recall the case of the quasar 1156 + 295 [Glassgold et al., 1983]: during a large flare its appearance was undistinguishable from that of a BL Lac object). Optically-selected (that is, radio-quiet) QSOs do not show such a violent behaviour: the inference is that for some reason the presence of radio emission, presumably in the compact core, indicates emission from a region closely associated to the primary machine.

These consideration support the idea that BL Lacs and OVVs are the most compact and strongly variable sources among the general class of QSOs. Within the BL Lac-OVV there are further distinctions which are important. For instance, a comparison between optical and radio variability shows that the fractional change in optical flux density is at least one order of magnitude larger than in radio. For BL Lac itself, which was the strongest known radio variable in the early seventies (Dent, 1978 a), it is $(\Delta S_\nu/S_\nu)_{radio} \ll (\Delta S_\nu/S_\nu)_{optical}$. The strongest outbursts at these two wavelenghts can be represented as follows: $(\Delta S_\nu/S_\nu)_{radio} \approx 2 \longrightarrow 5$, $(\Delta S_\nu/S_\nu)_{opt.} \approx 30 \longrightarrow 100$. Furthermore, BL Lac - OVV outbursts typically last a week or less in the optical, and months in the radio. Extreme examples of this contrast in timescales are BL Lacs such as 1727 + 502 and 2335 + 031 which vary at optical but not at radio frequiencies.

The difference between radio and optical timescales reflects the larger size of the radio source. The optical source, which has to be not larger than the solar system, is probably linked more closely to the primary machine. but the reasons for the difference between fractional changes in flux are less clear. It is possible that the actual fractional change of the variable radio component is as large as that detected optically, but the observed fractional change is smaller if there exists a constant radio component with flux density comparable to the maximum of the variable component (Dent, 1978 b) (an example of this scenario night be a constant component in BL Lacertae with $S_{10\ GHz} \approx 2$ Jy, since this radio source has never decreased below 2 Jy throughout its erratic history [Dent, 1978 a]). On the other hand, it is also possible that the fractional variabilities are intrinsically different, if the energy reservoir neede to drive the radio source were larger, possibly because of the larger volume: in this case a smaller fraction of energy would be released during a radio outburst, resulting in a lower fractional variabily (Rees, 1978). In this respect, pre - and post - burst VLB mapping should help to determine the fractional change of the variable component instead of the entire source. In passing, we note that this second scenario well accounts for the different timescales of optical and radio variability. In fact we may write

$$\frac{V^{radio}}{V^{opt.}} \sim \left(\frac{l^{radio}}{l^{opt.}}\right)^3 \sim \left(\frac{\Delta t^{radio}}{\Delta t^{opt.}}\right)^3$$

were l is the characteristic scale-length of the emitting regions we are envisaging; then

$$\frac{U^{radio}}{U^{opt.}} \sim \frac{V^{radio}}{V^{opt.}} \sim \left(\frac{\Delta t^{radio}}{\Delta t^{opt.}}\right)^3 >> 1$$

were U is the energy supply within the volume V. It then follows:

$$\left(\frac{\Delta U}{U}\right)^{radio} \sim \left(\frac{3}{\Delta t}\right)^{radio}$$

$$\left(\frac{\Delta U}{U}\right)^{opt.} \sim \left(\frac{3}{\Delta t}\right)^{opt.}$$

whence

$$\left(\frac{\Delta U}{U}\right)^{radio} << \left(\frac{\Delta U}{U}\right)^{opt.}$$

because

$$\left(\frac{1}{t}\right)^{radio} << \left(\frac{1}{t}\right)^{opt.}$$

being: $\Delta t^{radio} \sim$ months and $\Delta t^{opt.} \sim$ days. From these arguments based only on variability we then conclude that typically $(\Delta S_\nu / S_\nu)^{opt.} \sim 30\ (\Delta S_\nu / S_\nu)^{radio}$, in agreement with the optical and radio observations.

Are radio and optical variability in BL Lacs causally related ? The $\nu^{-0.7}$ extrapolation discussed above should guarantee that, although the observational parameters describing radio and optical outbursts may be different for a given object, the same distribution of particles is responsible for both optical and radio emission and that consequently a causal link betwen both types of source exists. In some instances evidence for such a link was clear, as it was the case for the 1975 burst of 0235 + 164. In that occasion, both radio (Ledden et al. 1976) and optical (Rieke et al., 1976) peaked during November 1975 and were relatively constant before and after that time. Although the duration of the optical burst was 1-->2 weeks and of the radio burst $\sim$ 2 month, a superposition of the two curves reveals an unambiguous correlation. This situation, however, is by no mean general. Cross-correlation analyses of optical and radio lightcurves in most BL Lacs do not reveal any correlation. According to Pomphrey et al. (1976) there is little evidence to support a causal connection in a large sample of BL Lacs, apart from 0851 + 202 and NRAO 512. We should point out, on the other hand, that actually occurring causal links can be masked by the effects of synchrotron self-aborption. If an expanding shell of syncrotron electrons radiates optical and radio photons the radio flux density would increase with expansion at frequencies where the shell is optically thick and the radiation is self-absorbed, while the optical flux density should always decrease. Another effect that would mask synchronous events is the occurance of a large numbers of overlapping events. Both effect were presumably absent during the activity phases of those objects for which correlation between radio and optical bursts has been observed, but probably effect and determine the appearance of outbursts in most BL Lacs and OVVs. A good example of this ambiguity can be found in the strong optical burst undergone by 2223-052 in the second half of 1977 (Miller and French, 1978). Since that time, repeated VLB observations show that the radio structure (at 10.5 GHz) of 2223-052, which was initially constant, has been changing (Briggs et al., 1981).It is of course tempting to associate the radio changes to the optical burst. On the other hand, the historical radio and optical lighcurves are correlated, so it is possible thal the coincidence of optical and radio changes in this object is random in origin.

property (D)- Of all the membership criteria, this is possibly the stronger. Since the strong optical and radio polarization of BL Lacs is such a distinctive and universal characteristic, we may think that it is intrinsically associated to the underlying radiation source. In this view, every measurement concerning polarization is directly referring to the primary machine. Moreover, high optical and radio polarization is the best indication that BL Lacs and OVVs form a well-defined subclass of QSOs. In this survey of 102 radio- and optically-selected QSOs, Angel and Stockman (1978) find no objects with optical linear polarization $p>3\%$ and a r.m.s. $\langle p \rangle = 0.6\%$ when BL Lacs and OVVs are set apart. The latter, on the contrary, show polarization in the range $\sim 5\% \lesssim p \lesssim 30\%$. In short, the distribution of optical polarization is bimodal, with BL Lacs and OVVs occupping the peak of high polarization and both optically- and radio- selected QSOs gathering at essentially zero polarization.

Further more, visible polarization is very useful for determining accurate timescales of variability, because polarization measurements have the property (Visvanathan, 1974) that the linear polarization Stokes parameters often vary as much as or even more than the total intensity. Polarization changes are easier to detect than intensity changes because the measurement is internal and does not rely on measurements of standards. In this respect an important result has been achieved by Angel et al. (1978) who report that in a sample of 12 objects polarization measurements have put lower limits on the timescale of variability seen in any object, large apmlitude changes of polarization (of both magnitude and position) taking place in $\lesssim$ 10hr.

property (E) - This has long been considered the most outstanding property of BL Lacs. Nowadays the importance of this once-widely-publicized property has been greatly reduced. Considerable effort has gone into finding mechanisms capable of suppressing emission lines, such as lack of gas (matching the connection of BL Lacs with elliptical galaxies) or lack of ionizing photons (suggested by the steepness of optical - UV spectra). Withing this latter types of models, a mechanism involving a two-phase gas heated by X-rays and accreting around a compact object has recently been proposed by Guilbert et al. (1983). According to this model, if the X-ray spectrum radiated by the central source is hard enough, substantial heating of the gas is possible, therefore the gas can turn into cold and hot bubbles (i.e., a two-phase gas) of which the cold bubbles are the Broad-Line Region (BLR), and consequently broad emission line appear; if, on the contrary, the X-ray spectrum is soft, no significant heating of the gas is possible and the gas is stable (i.e., a one-phase gas) and no BLR can be formed. Since BL Lacs have much steeper spectra than Seyfert galaxies and QSOs, emission lines are seen from the latter but not from the former. Actually, there are few exceptions to the observed correlation between the slope of the X-ray spectrum and presence of an emission line spectrum, due to the variability of the X-ray spectrum in both Seyferts and BL Lacs (Pravdo et al., 1981; Mushotzki et al., 1980; Worrall et al., 1981): if a Seyfert X-ray spectrum became soft ($\alpha > 1$), the two-phase region could dissipate, and the Seyfert turn into a BL Lac (and vice-versa). Since a timescale of about 100 yr is required for the gas already present to cool down (or to be heated up), the presence or absence of a BLR is controlled by the spectrum averaged over a century.

A substantial contribution to the solution of the problem of the suppression of emission lines has come from the work of Miller et al. (1978). They found that 6 out of 12 BL Lacs radiate weak [OIII] (and sometimes [OII] and $H\beta$) emission lines characteristic of a low-density gas. The lines appear weak because they are superposed on a strong continuum, but the power they radiate is typically ten times stronger than that radiated by the some lines in normal elliptical galaxies. Some objects do not show spectral features at all even at minimum light,as is the case of 0235 + 164, and for this object we should admit that there must be very little warm or cold gas, if any. At the ather extreme the OVVs, like 2223--052, Which show very strong and broad emission lines (comparable to those QSOs) indicating the presence of dense and turbulent gas, while sharing all the other characteristics (of spectrum and polarization) of BL Lacs. The close similary between the nonthermal emission of BL Lacs and OVVs suggests that emission line properties are peripheral to the energetics underlying the primary machine.

Radio Structure of BL Lacs.

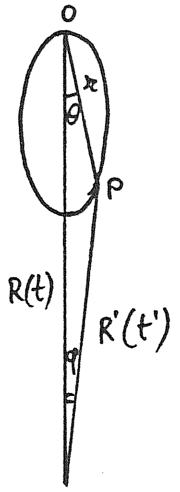
Although the radio morphology of most BL Lacs is dominated by emission from a compact core, sources such as 0219 + 428 (Stannard et al., 1982), 1101 + 384 (Kapahi, 1979) (Figure 5), 1400 + 162 (Hintzen and Owen, 1981), 2200 + 420 and many others have shown substantial extended emission as well. In several surveys (Weiler and Johnston, 1980; Perley et al., 1982; Ulvestad et al., 1983) a significant fraction of BL Lacs has found to emit on scales greater than an arcsec. This occurrence seems not to be correlated with either redshift or absolute luminosity in any spectral band.

When these larger-scale emissions are present they are diffuse, fairly symmetric, with no other compact structures away from the nuclear core (the maximum fraction of the source flux contained in these eventual peripheral spots is 1%). Both the physical sizes (a few to a few hundred Kpc) and the radio luminosities ($\sim 10^{41}$ to 10^{45} erg s^{-1}) of the extended structures lie in the same range as those found for radio galaxies and quasars(Weiler and Johnston, (Figura 6).

The core-extended emission morphology of BL Lacs is very different from the collimated twin-outer-lobe structure commonly found in radio galaxies and steep-spectrum quasars (see, e.g., Miley, 1982). When the structure is resolved as a one-sided pattern (Figures 7 and 8) it always happens that the flux density from the detected components overpowers that from the "un detected" lobe by a factor > 10 up to 100 (as is the case of 2251 + 158 Perley et al., 1982). Although this case occurs less frequently in BL Lacs than in core-dominated QSOs (which is turn are 10% of all QSOs), a comparison the two classes is possible (table 1). It shows that the fractional contribution to the flux due to core and halo are respectively similar for the two classes, a strong difference on the contrary being attached to the compact one-side jet emission, which happens to be much weaker in BL Lacs. When on the othet hand the structure is resolved as a two-sided pattern (Fig. 9), the two lobes often show different morphologies and the whole structure can be misaligned. The ratio of the fluxes is mostly about 5:1 (Perley et al., 1982).This latter evidence also occur in contrast with the statistics of classical dou bles (Fomalont, 1969; Mc Kay, 1971; Neff and Rudnick, 1980) which show that majority of classical doubles have a flux ratio < 2:1 between the lobes (only less than 10% of the objects showing this ratio > 5).This indicates that the extended emission of BL Lacs - when resolved in their structure - is more asymmetric than that of classical doubles. Such asymmetries, however, can not be ascribed to lack of dynamic range in the maps or to the blending of radio components because to lack of dynamic range in the maps or to the blending of radio componants because of projection effects since the detected lobes are well separated from the core. It may also happen, on the other hand, that significant larger-scale emission is missed by high-resolution arrays (such as MERLIN, VLA, etc.): if this were the case , it would correspond to the asymmetric lobes, while the asymmetric structure which is observed with high resolution should correspond to a Doppler-enhanced core and to a jet with relativistic flow near the line of sight (see aftewards the discussion on the models). In this respect, we should add that discrepancies exist between the flux density of a source derived from a single antenna and that derived from an array, although confusion from nearby sources may still be a problem for single-antenna observations. In addition to these somewhat defined structures, other more complex morphologies have been found, with a wide range of patterns (jets, elongated structures, lobes, haloes: Figures 10 and 11).

At this point one may reasonably ask why this variety of radio morphology is present, and whether they reflect intrinsic differences in structure or are mainly due to relativistic - projection - effects. A feature that may help in throwing light on the radio structures is the evidence for superluminal expansion. BL Lacertae the archetypal object of this class, has long been VLBI - monitored. In June 1981 the 10.6 GHz map (Phillips and Mutel, 1982) shows an elongated, complex structure about 12 lightyears in extent, at least for times larger than that observed in December 1980 (Mutel et al., 1981) (Figures 12 and 13). The two maps are so different that only the dominant axis gives indication that some features are moving apart with apparent velocity of about 5c. For the object 1641 + 399 a similar picture holds (Angel and Stockman, 1980).

Appendix to Radio Structure of BL Lacs.



How to explain superluminal motions (Rees, 1967).

Let us suppose that an event in O is observed at the instant $t_{obs}=0$. It then took place at the instant $t_{em}=-\frac{R}{c}$.

Analogously, for the event observed in P at the instant t and due to the lump of matter which was previously in O at the time $t_{em}=-\frac{R}{c}$ and which subsequently moved to P, we can write:

$$t'_{em}= t-\frac{R'}{c} \sim t-\frac{R'}{c}\cos\varphi = t- \frac{R-r\cos\theta}{c} =t-\frac{R}{c}+\frac{r}{c}\cos\theta$$

Since it is

$$t'_{em} - t_{em} = \frac{r}{v},$$

from the expressions of t'_{em} and t_{em} we get

$$t'_{em} = t_{em} + \frac{r}{v} = t-\frac{R}{c}+\frac{r}{c}\cos\theta = -\frac{R}{c}+\frac{r}{v}$$

hence

$$r = vt + \frac{v}{c}r\cos\theta$$

and finally

$$r = \frac{vt}{1-\frac{v}{c}\cos\theta}.$$

The transverse velocity is then

$$u_{\perp} = \frac{d}{dt}(r\sin\theta) = \frac{v\sin\theta}{1-\frac{v}{c}\cos\theta}$$

which attains its maximum value of $v\gamma^{-1}/(1-\beta^2)$ for $\cos\theta = \beta$ (or, equivalently, $\sin\theta = \gamma^{-1}$). It is straig htforward that the apparent separation velocities of two blobs of matter which start from O symmetrically to the observer is

$$u_{\perp}^{sep} = \frac{2\ v\ \sin\Theta}{1 - \beta^2 \cos^2\vartheta} \quad \left(\leq \frac{2\ v\ \gamma^{-1}}{1 - \beta^4}\right) .$$

Spectral Flux Distribution

The overall spectral flux distribution of BL Lacs is typically a non-thermal one. All the objects for which detailed multiband observations are available show spectra which can be fitted locally by a single power-law of the form $F_\nu \propto \nu^{-\alpha}$. For few objects a single power-law seems adequate to describe the whole spectrum from radio to X - rays, while in most cases several power-laws must be joined to fit the whole spectral profile (Figures 14-17).
The two-point spectral index is defined as $\alpha_{12} = \log (F_2/F_1)/\log (\nu_1/\nu_2)$, where ν_1 and ν_2 are the extremes of the considered frequency band and F_1 and F_2 are the corresponding flux densities. In this way several spectral indices con be constructed: their usefulness is primarily that they allow, straight ahead from their definition, an evaluation of the relative intensities at two different points in the spectrum. A meaningful choice of them may be:

- α_R which, according to different authors, refers to various radio domains between 0.18 and 90 GHz;
- α_{IR} which refers to various infrared bends between 1 and 10 μm;
- α_O which refers to the optical band (3600-7000 Å);
- α_{OIR} which refers to the band between 2500 Å and 2.2 μm;
- α_{OX} vhich usually refers to the band between 2500 Å and 2 KeV;
- α_{RX} which usually refers to the band between 2 KeV and 5 GHz;
- α_{RI} which usually refers to the band between 5 GHz and 2.2 μm;
- α_{IX} which usually refers to the band between 2.2 μm and 2 Kev.

These spectral indices are useful, in particular, to the purpose of checking if one single emission mechanism is responsible for the continuum emission in all the regions of the spectra. Moreover the study of correlations among the various pairs of indices entails useful indications on the underlying emission mechanism. At this point, hovever, one should be aware of the fact that the variability of the sources in specific regions of the spectrum can strongly affect the spectral indices: in this respect emblematic are the cases of 2200+420 (Kinman, 1976) and of 0735+178 (Bregman et al., 1984). The latter shows an X-ray flux which keeps nearly constant and therefore seems not to be correlated to neither the IR-UV flux whose changes, on the contrary, range up to 350% (with a change in slope from 1.0 to 2.7) in a one-year time nor to the radio flux (between 8 and 90 GHz) which increased by 8% - 40% (depending on frequency) between 1979 and 1980. One further a priori reason for dispersion of points in the diagrams is not uniform data base, such as data from different observers at different observing times with different apertures, etc. In fact ~~there~~ are interesting positive correlations (Cruz-Gonzales and Huchra, 1984) only among a few pairs of indices, such as α_{IR}/α_{o}, α_{IR}/α_{R}, α_{RI}/α_{RX}, α_{R}/α_{RX}. In view of the above considerations, however the possibility that other correlations are hidden by the previonsly mentioned sources of scatter can not be ruled out. As we shall see right now, we have confidence that the overall BL Lac spectral flux distributions can be explained by basically one emission mechanism.

Let us now describe in some detail the specific regions of a BL lac spectrum.

Radio The flat or inverted shape of the radio continuum is considered a defining chareceteristic of BL Lacs. The flatness is usually interpreted as the superposition of synchrotron self-absorbed components (Figure 18), because if the emitting region were homogeneous a $\nu^{5/2}$ slope would be expected at frequencies below the turnover. The inhomogeneous structure is pointed towards also by the absence of correlation in the variations of both the degree of polarization and of the polarization angle, because the detailed polarization behaviour of a source is strongly dependent upon spatial structure (especially if a source becomes self-absorbed), so the current absence of any trend may result in part from a complex spatial structure, which makes it difficult to isolate the properties of individual radio components.

The intrinsic quantity which characterizes a compact radio source is its brightness temperature in the source's proper frame (as indicated by an asterisk):

$$2KT_b^*\left(\frac{\nu}{c}\right)^2 = I_\nu(1+z) \approx \frac{F_\nu}{\pi\theta^2}(1+z) \qquad (1)$$

whence

$$\left(\frac{T_b^*}{K}\right) \approx 5\cdot 10^8\left(\frac{F_\nu}{Jy}\right)\left(\frac{\lambda}{cm}\right)^2\left(\frac{\theta}{marc\,sec}\right)^{-2}(1+z) \qquad (2)$$

where F_ν is the spectral flux density expressed in Jansky. If the radiation mechanism is incoherent electron synchrotron (as strongly appears the case), the synchrotron self-absorption constrains the maximum brightness temperature in the range $10^{11}K \leq T_b^* \leq 10^{12}K$ unless highly relativistic bulk motion is present In this range of temperatures the superior limit is 10^{12} K (because (Kellermann and Pauliny-Toth 1969) for $T_b^* > 10^{12}K$ the energy losses due to inverse Compton scattering are much more important than synchrotrom emission, according to the approximate relation $L_c/L_s \sim \left(T_b^*/10^{11}\right)^{10}$ and become catastrophic thus the brightness temperature decreases to between 10^{11} and 10^{12} K, where inverse Compton losses are of the same order as the synchrotron losses.

The inferior limit, on the other hand, comes from observations (Kellermann and Pauliny - Toth, ibidem).

The fact that no sources are totally unresolved at the larges VLBI baselines (Clark et al., 1975; Broderick and Condon, 1975; Kellermann et.al., 1977) tends to confirm that $T_b^* \approx 10^{12} K$. Owing to the narrow range of maximum brightness temperature,

$$\left(\frac{\theta}{marcsec}\right) \approx 0.03 \left(\frac{F_\nu}{Jy}\right)^{1/2} \left(\frac{\lambda}{cm}\right) \qquad (3)$$

or $\theta \propto \lambda$ for self-absorbed components of comparable spectral flux. Interpretation of the obseverd low-frequency turnover in terms of synchrotron self-absorption allows one to estimate the Lorentz factor γ_t of electrons radiating near the turnover frequency ν_t from the observed maximum brightness temperature using

$$\gamma_t \approx k T_b^* / m_e c^2 \qquad (4)$$

or, since it is

$$2k T_{b_t}^* \left(\frac{\nu_t}{c}\right)^2 \simeq \frac{F_\nu}{\pi \theta^2} (1+z)$$

it follows

$$\gamma_t \approx \frac{F_\nu (1+z)}{2\pi \theta^2 m_e c^2} \left(\frac{c}{\nu_t}\right)^2 . \qquad (5)$$

From the Lorentz factor and the turnover frequency one obtains - - through the cyclotrom frequency at the turnover $\nu_{B_\perp} = \nu_t (1+z)$ - the magnetic field $B_\perp$:

$$B_\perp = m_e c 2\pi \gamma_t (1+z) \nu_t / e \qquad (6)$$

and then the number density N_r of relativistic electrons necessary to account for the observed synchrotron self-alsorption (at the tur nover, in fact, it is possible to write

$$A(\nu_B, q, N_r) \nu_t^{-q} = 2kT_b^* \left(\frac{\nu_t}{c}\right)^2 \qquad (7)$$

where $A(\nu_B, q, N_r)$ is a function of the cyclotron at the turnover ν_B, of the number density relativistic electrons N_r, and of other quantities which depend upon the spectral index of the electron energy distribution $\left[q = \alpha_{RI} = \frac{n-1}{2}\right]$. Since (7) may be regarded as an equation in the unkno wn N_r, the latter can be calculated).

Thus the observed spectral flux and turnover together with the VLBI-determined angular size and the redshift specify the physical conditions $T_b^*, \gamma_t, N_r, B_\perp, \vartheta$ of a self-absorbed synchrotron source.

The various ratios of inferred energy densities in relativistic electrons $u_e \left(= N_r m_e c^2 \int_{\gamma_1}^{\gamma_2} \gamma^{1-n} d\gamma\right)$, in magnetic field $u_m \left(= B^2/8\pi\right)$ and in radiation u_r are particularly informative. The ratio of energy density in relativistic electrons to that in the magnetic field

$$\frac{u_e}{u_m} \approx \frac{P_e}{P_m} \qquad (8)$$

reflects the degree of particle dominance in the total pressure P; the ratio

$$\frac{u_e}{u_r} \approx \frac{ct_r}{R} \tag{9}$$

measures the radiative lifetime t_r of relativistic electrons in units of the light-travel time across the source; and the final combination

$$\frac{u_r}{u_m} \approx \frac{L_{ssc}}{L_s} \tag{10}$$

indicates the importance of synchrotron self-compton luminosity L_{ssc} relative to the synchrotron luminosity L_s (topic to be discussed in some more detail later on). Observational data coupled with (8), (9), (10) suggest that the dynamics is frequently particle - -dominated ($P_e > P_m$), that observed radiative losses do not require acceleration in situ ($t_r < R:c$) in order for the particles to fill the volume involved in the emission, and that SSC losses are energetically important ($L_{ssc} \gtrsim L_s$). One should be rather cautious about the reliability of most of the derived parameters, however, because they are extremely sensitive to observed quantities (particularly to θ and to the assumption of non - relativistic bulk motion). For instance, by letting

$$\delta_k \equiv \left[\gamma(1-\beta\cos\theta)(1+z)\right]^{-1} \tag{11}$$

represent the kinematic Doppler factor of a non-relativistically evolving cloud which is being relativistically ejected with line-of-sight velocity $c\beta\cos\theta$ and corresponding Lorentz factor γ, one gets the following dependences:

$$\mu_r \propto \theta^2 \delta_k^{-4} \qquad (12)$$

$$\mu_m \propto \theta^8 \delta_k^{2} \qquad (13)$$

$$\mu_\theta \propto \theta^{-1} \delta_k^{-5} D^{-1} \qquad (14)$$

where D is the distance to the object. In view of the strength of these dependences, one should not attach much significance to the values derived according to the method outlined above. For example, with the adoption of a somewhat larger angular radius and a mildly relativistic Doppler factor (say $\delta_k \approx 3$) the derived quantities are rapidly driven toward equipartition, L_{ssc} decreases and the importance of L_s is slightly enhanced.

Although the strong dependences illustrated in (12), (13), (14) preclude eccurate determinations of most physical parameters, the inversion of these relations permits reliable predictions of angular radii even in absence of VLBI observations (Jones and O'Dell, 1974). Thus upon inversion and manipulation of (12), (13), (14) one obtains

$$\theta_{rm} \propto \left(\frac{L_c}{L_s}\right)^{-1/10} \delta_k^{-3/5} \qquad (15)$$

$$\theta_{em} \propto \left(\frac{P_e}{P_m}\right)^{-1/17} \delta_k^{-7/17} D^{-1/17} \qquad (16)$$

$$\theta_{er} \propto \left(\frac{c t_r}{R}\right)^{1/7} \delta_k^{-1/7} D^{-1/7}. \qquad (17)$$

These very weak dependendences of angular size upon the physical parameters of a source provide en explanation for the observed small range in T_b^* .

The timescale for variability is, in the source's rest frame

$$t^* = t_\nu \delta_k = \left| \frac{d \ln F_\nu}{dt} \right|^{-1} \delta_k \qquad (18)$$

and introduces an additional estimate for the angular size, namely

$$\theta_\nu = i_\nu \left(\frac{c t_\nu^*}{D}\right) \qquad (19)$$

where i_v is the ratio of θ_v to the angular size otherwise derived (observed or predicted). If relativistic effects such as bulk motions are absent, then $i_\nu \lesssim 1$ and $\theta_\nu \lesssim \frac{c t_\nu^*}{D}$ which is the usual non-relativistic causal restriction. In principle, one can compare a theoretically estimated angular radius (estimated from $\theta_{rm}, \theta_{em}, \theta_{er}$) with the VLBI - determined angular radius θ_o and with the angular radius θ_v inferred from temporal variations. When this is done for the best -studied extragalactic radio sources, it often turns out (Jones et al., 1974)

$$\theta_{th} \approx \theta_o \approx \theta_\nu$$

that is mildly relativistic motions are required. In the case of several BL Lacs, such as 2200+420, 0235+164 and 2251+158, things are much more troublesome because, although $\theta_{th} \approx \theta_o$ it also results that $\theta_{th} \approx \theta_\nu$ only for $i_\nu > 10$. A help may came from the occurence of sub - GHz variability, which is published - up to our knowledge - only in the case of 2251+158 (Hunstead, 1972) Although in this case $\theta_o \approx \theta_{th}$ it is $\theta_{th} \approx \theta_\nu$ for $i_\nu \approx 50$ at 408 MHz. Such a discrepancy between size and timescale could be explained only if the variable part of the flux originates in regions much smaller than the angular size observed for most of the flux (thus requiring a coherent emission mechanism, or relativistic ejection) or if relativistic shocks are present (Blandford + Mc Kee 1976, 1977), etc. However, none of these solutions appears to be particularly promising. Although the question of sub-GHz variability is as yet unsettled, there remain a few cases (for QSOs as well) in which rapid radio variations require $i_v > 10$ in order that theoretically allowed angular sizes be compatible with observed timescales. Perhaps the best documented case is the late - 1975 outburst of 0235+164 (McLeod et al., 1976; Ledder et al., 1976; Rieke et al., 1976): the observed timescale for the radioburst (60 days at 8 GHz) implies an angular size $\theta_v \approx 0.006$ marcsec, in contrast wilh $\theta_{th} \approx 0.2$ marcsec, hance $i_v \approx 30$ is required in order to bring the two values into agreement, if the emission is to be explained in tems of incoherent synchrotron (in terms of relativistic ejection a $\delta_k \approx 10$ would be needed).

To sum up the radio observations of BL Lacs (and QSOs as well), the observed properties of most sources are in principle adequately interpreted in terms of incoherent synchrotron from relativistic electrons in compact components which may evolve at mildly relativistic rates. A consistent argument for moderately relativistic evolution ($\gamma\beta \approx 1$) can be made as follows:

i) relativistic separation velocities are present in some sources, indipendent of the emission mechanism;

ii) the timescale for variations in spectral flux in many sources are comparable to the light-travel times corresponding to observed angular sizes;

iii) the apparent particle dominance would lead to relativistic expansion (unless confined by external pressure or internal inertia of non-relativistic matter), inversely dependent upon distance.

iv) the absence of Faraday depolarization indicates that mass of cospatial non - relativistic particles may be insufficient to retard expansion, independent of distance.

Infrared - Optical

In most cases the optical-to-near-infrared spectral flux distribution of BL Lacs are adequately represented by a single power-law. The cases where there is not such an occurrence are often those of nuclei surrounded by nebulosities: in their spectra the presence of a galaxian component is apparent as a hump in the optical domain. Cruz-Gonzales and Huchra (1984) separate the galaxian contribution from the nonthermal one by assuming that the contribution of the galaxy starlight is that of a typical gE galaxy; increasing percentages of observed flux are removed at those optical - near IR frequencies until the spectrum shows the smallest kinks or humps. However, even after the removal of the galaxy, several objects in their sample still show a large break in the OIR continuum ($\Delta\alpha \gtrsim 0.5$). Some objects without detectable galaxy component also show a strong break . Cruz-Gonzales and Huchra (ibidem) argue that these breaks connot be due to absorption by dust because reddening corrections tend to introduce additional distorsions of the shape of the continuum, rather than straightening it. This occurrence of knees of different entity which are due neither to galaxian starlight nor to dust is considered in fact as a manifestation of different injection mechanisms within the sources (e.g., Tucker 1975) which seem to be distributed more or less randomly among the sources (Cruz-Gonzales and Huchra, 1984). The sources having $\alpha_{oir} \gtrsim \alpha_{ri}$ may be interpreted as young sources where synchrotron losses have not yet taken their toll or alternatively as sources observed soon after the particle injection; in the sources having a steepening of one half power at OIR frequencies there exist particles whose radiative lifetime t_{sy} is longer than the interbust period τ, so the injection of particles can be considered quasi-continuous, while at lower frequencies after each injection the effect of radiation losses will not be important and the spectrum retains its initial form (the frequency of the breack is $\nu_B = 10^{24} B_\perp^{-3} t^{-2}$ where t is the time elapsed from the last injection); in the objects for which the steepening is $\Delta\alpha \geq 1 + \alpha_{IR}/3$ the rate of injection is not sufficient to balance the radiation losses since $t_{sy} < t$ and therefore the injection can be considered as a succession of delta functions in time; the (few) objects whose overall spectra are better described by one single power-law from radio turnover to rays are observed soon after a burst of injection, such that high-frequency tails of their spectra are still dominated by fresh electrons which have not yet decayed. Unlike in the radio domain, in the optical BL Lacs cannot be resolved - letting apart those at z < 0.1 - owing to seeing and diffraction limits. Moreover their optical spectra do not undergo synchrotron self-absorption, even if in the optical the emission mechanism is still synchrotron with very high degree of confidence (we recall that this item is very controversial in the case of QSOs). As a consequence, it is not possible to employ the methods outlined in the section devoted to radio spectra to derive the physical parameters of the optically-observed component; furthermore, the arguments regarding maximum brightness temperature are no longer as useful as at radio frequencies. There is, however, a related - but less conclusive - argument which can be applied to optically variable objects (Hoyle et al., 1966). From the observed flux F_ν and timescale for variability Δt one can calculate the minimum radiation energy density if the distance to the object is known and if relativistic bulk motion are absent:

$$u_r^{min} = \int_{\nu_1}^{\nu_2} \frac{F_\nu \, 4\pi D^2(q,z) \, (1+z)^{(1-\alpha)} \, \Delta t}{\frac{4}{3}\pi (c\Delta t)^3} \, d\nu$$

which trasforms into $u_r^{min} = \frac{3[(\nu_2/\nu_1)^{(1-\alpha)} - 1]\nu_1 F_{\nu_1} D^2 (1+z)^{(1-\alpha)}}{c^3 \Delta t^2 (1-\alpha)} \leq u_r$

provided $F_\nu = F_{\nu_1} (\frac{\nu}{\nu_1})^{-\alpha}$. One then determines the maximum radiative lifetime to the charateristic time t of synchrotron and (possibly combined) synchrotron self-Compton losses:

$$t = \frac{W}{P} \leq t^{max} = \frac{W}{u_r^{min}} = \int_{\gamma_1}^{\gamma_2} N_r \gamma m_e c^2 \gamma^{-n} d\gamma \Big/ \left\{ \frac{3[(\nu_2/\nu_1)^{(1-\alpha)} - 1]\nu_1 F_{\nu_1} D^2 (1+z)^{(1-\alpha)}}{c^3 \Delta t^2 (1-\alpha)} \right\}$$

where γ_1 and γ_2 are connected to ν_1 and ν_2 respectively, n is connected to the optical slope α in one of the three manners envisaged obove and N_r can be worked out from the power radiated in the optical band coupled with the slope (see the section devoted to the radio spectrum).

Unless this maximum lifetime exceeds the inferred light-time across the source (t^{max} > R/c), radiative losses will be important and the relativistic electrons cannot fill the observed volume except if acceleration occurs in situ.

As a last item on the observed properties in the optical one can add that although correlated optical and radio variations are rare, the degree of optical variability seems to be anticorrelated with α_{or}, or, equivalently, sources showing a stronger cm excess seem to be more variable (Pollock, 1975; Usher, 1975).

IUE Band. All IUE-observed BL Lacs and BL Lac condidates (25 objects) listed by Maraschi et al. (1983) have an average spectral index $<\alpha_{uv}> = 1.57 \pm 0.14$, while for the same sample $<\alpha_o> = 1.54 \pm 0.16$. This indicates that all the physical considerations reported for the optical domain may apply to the satellite - UV band.

A plot of α_{ux} vs. α_{uv} does not show significant correlation between the indices, indicating that the radiation mechanisms in the two bands may not be directly related. The correlation between absolute UV and X-ray luminosities, on the other hand, is very significant and yields $L_x \propto L_{uv}^{0.7}$ (Maraschi et al., ibidem), further strengthening the case for the uniqueness of the underlying energy source, from radio to X-rays, for BL Lacs. Comparing the average properties with those of QSOs, as derived from the optical observations of Richstone and Schmidt (1980) and the X-ray observations of Zamorani et al. (1981), Maraschi et al. (1983) find that while in the optical - UV the spectra of QSOs are much flatter ($<\alpha_{uv}> \approx 0.6$ for QSOs), the average UV-X shope is very similar for both populations, $<\alpha_{xu}> \approx 1.32$. Also the relations L_x/L_{uv} given above is similar to that found for QsOs ($L_x \propto L_{2500}^{0.66}$ [Zamorani, 1982] ; $L_x \propto L_{2500}^{0.47}$ [Tanambaum et al., 1983]). There seems not to exist a correlation between hardness of spectrum and brightness level (Ulrich et al., 1978) contrary to variable Seyfert galaxies, whose spectrum is harder when the continuum is brighter. The difference in variability between BL Lacs and Seyferts may be due to differences in the properties of the nonthermal continuum or even to the presence of different continuum components in Seyfert galaxies while in BL Lacs the satellite - UV spectrum is - with all likelihood - synchrotron radiation from an optically thin source. The argument which refers to radiative lifetime upon assumption of synchrotron emission (and which we have considered as next-to-last item in the previsions paragraph) enables Ulrich et al. (ibidem) to conclude that in 1101 + 384 the lifetime of the particles appears to be shorter than light-crossing time through the emitting region, thus calling for anisotropic distribution of particles or particle acceleration in situ.

X - rays. Many objects such as 1101 + 384, 2155 - 304, 1219 +

305, 0548 - 322, 1652 + 398) are found to exhibit a two-component shape (Worrall, 1981 and references therein) and variations, over a six-month period, in both spectral shape and intensity. Several experiments carried out onboard HEAO 1 have revealed a strong tendence for presence of a softer component at energies below 5 KeV with a photon spectral index $\Gamma \approx 2.5$ (which means $\alpha_x \approx 1.5$) and of a harder component $\Gamma < 1.5$, which means $\alpha_x \approx 0.5$) above 5 Kev. Very little is known about the variability of the hard X-ray component, although in the cases of 0548 - 322, 1101 + 384 and 1652 + 398 positive detections are reported (Worrall et al., ibidem). The soft spectrum, on the other hand, shows large changes of slope with time. The original results by Worrall et al. (ibidem) and those quoted from other works by several authors and gathered there, show that the slope can change by up to 100% starting from values which are quite close to those of the optical slopes.

The spectral characteristics of BL Lacs in the X-ray domain appear to be significantly different from those of other X-ray-emitting active nuclei. Seyfert 1 galaxies are well fitted by power-laws of $\Gamma \approx 1.65$, and only in one case, ESO 141 - G55, is there evidence for spectral variability (Mushotzki et al., 1980). Multiple observations of the quasars 3C 273 and 0241 + 622 (Worrall et al., 1979, 1980) also give no indication of the spectral variability, although the indices for the two are statistically different from each other. These differences in the X-ray energy band between classes of objects often interpreted as similar in their emission mechanisms may provide strong observational constraints on possible theoretical models. One may also argue that this peculiar X - ray behaviour of BL Lacs within the more general class of

AGNs could also be used as a possible further sixth membership criterion.

X - rays properties of BL Lacs bring some troubles, havever, to the clean scenario in which the synchrotron processes alone can account for the characteristics of the whole BL Lac spectrum. In the case of 0548 - 322, for example, observations have been made in which the optical and X-ray bands do not smothly join and yet the radio and the optical region connect with a slope of the same index as that measured in the hard X-ray band (Weistrop et al., 1979; Riegler et al., 1979). Since the observations were not simultaneous, the equivalence of the two indices may be fortuitous, nevertheless it is suggestive of a physical connection. Both sets of authors interprete the data with a model which predicts this spectral characteristic, namely the SSC mechanism: hence, since the radio spectra of BL Lacs are usually flat, it is quite reasonable to expect a flat-spectrum X-ray component from Compton production. This led several authors to apply the SSC model to this class of sources (Margon et al., 1978; Schwartz et al., 1978, 1979 just to quote some among the earlier authors). We shall see in the next chapter how and up to what extent SSC models match the observations.

The Models.

In the same region where they are produced, synchrotron photons interact with the relativistic electrons by which they were emitted. As long as $\gamma h\nu \ll m_e c^2$ the interaction is via Thompson scattering. After each scattering their kinetic energy increases by a factor γ^2 , i. e. $\nu_{ssc} \approx \gamma^2 \nu_s$. Thus X - and gamma - rays can be produced (e.g., Tucker 1975). This mechanism, called inverse Compton effect, has been used to explain the hardness of the high-energy tail of X-ray spectrum. In fact, the power radiatied by a power-law distribution of relativistic particles, $N(\gamma) = N\,\gamma^{-n} \cdot \Theta(\gamma - \gamma_1) \cdot \Theta(\gamma_2 - \gamma)$, scattering a radiation field $F_\nu \propto \nu^{-\alpha}$, is still a power law of the same slope as that as that of the parent radiation field (e.g., Tucker, ibidem) (Figure 19).

A photon may undergo several scattering events because where the sychrotron becomes self-absorbed (below the turnover frequency) the optical depth is much greater than unity, so the number of scatterings tends to be high, too. In the frame of the observer we can write

$$m_e c^2 \gamma_i + h\nu_i = m_e c^2 \gamma_f + h\nu_i \gamma_i^2 \qquad (1)$$

whence

$$(\gamma_f - \gamma_i) m_e c^2 = h\nu_i (1 - \gamma_i^2)$$

Setting $(\gamma_f - \gamma_i) = \Delta\gamma$ we also write

$$\frac{\Delta\gamma}{\gamma_i} = \frac{h\nu_i}{m_e c^2} \frac{(1-\gamma_i^2)}{\gamma_i} \simeq \frac{h\nu_i \gamma_i}{m_e c^2} << 1 \qquad (2)$$

since we suppose a Thompson-regime ambient. From (2) it is also readily seen that the energy spectrum of the electrons is not significantly changed and the energy transferred from electrons to more and more energetic photons through successive scatterings would keep pratically constant over several events.

There is a problem, though. The frequency of multiple - Compton - scattered photons grows higher and higher, until either the Klein-Nishina regime is reached, so that the frequency of scatterings is drastically reduced, or the electrons are catastrophically cooled . Of course, in order to account for observed spectra, this process, referred to as the "Compton catastrophe", must be avoided.

However, observations indicate that at high (> 1 GHz) radio frequencies the fluxes vary on time scales roughly proportional to the wavelength; this suggests the presence of a constant brightness temperature (e.g. O' Dell, 1978) which is generally slightly greater than the inverse-Compton limit for a non relativistic source. This has been confirmed by VLBI measurements (Blandford and Königl, 1979).

The above mentioned difficulties with the Compton catastrophe could be considered as a first indication that SSC theory may in fact not be the only one viable explanation of the observed spectra of BL Lacs. Moreover, for a sizable fraction of the brighter sources there is further ample evidence that simple physical models (such as pure incoherent synchrotron radiation from a monthermal distribution of relativistic electrons e.g., Jones et al., 1974) are inadequate and must be replaced by more complex models. For examples, for some sources the variability timescales are so short that the radio brightness temperatures, based on an estimated source size of ct_{var}, largely exceed the inverse - Compton - limit of 10^{12} K. For same sub-GHz variables, which we have already mentioned, temperatures as high as 10^{15} K are derived in this fashion (e.g., Hunstead, 1972) and current indications are that this phenomenon is not rare (Condon et al., 1979). Then, VLBI observations of compact sources usually show an elongated radio structure, the position angle of which is roughly fixed and in some cases is related to larger radio structure. Moreover, apparent superluminal motion of individual components has been measured convincingly in a few cases and appears to be fair ly common among strong sources (Cohen et al., 1979). Of course, a model which explains the shape of spectra should also take these major items into account.

Next, for many sources the timescale of variability is longer than the light-travel time across the source. This argues for particle accelerations within the emitting region, such that the relativistic particles can fill the whole region.

Finally, the quantitative agreement with observations must be met: for all the 16 BL Lacs listed by Madejski and Schwartz (1983), the observed 1-KeV flux densities differ by factors $10^{-8} - 10^{6}$ from those predicted assuming a static, single-component synchrotron self-Compton emission mechanism. Those authors argue then that such a mechanism by itself does not apply to BL Lacs as a class.

All these items suggest - directly or indirectly - the presence of relativistic motion within the emitting region. Taking this as a starting hypothesis, several interesting conclusions can be drawn (e.g., Blandford and Königl, 1979; Marscher, 1980; Königl, 1981 and references therein).

If relativistic bulk motion is present, then we can relate the observed flux density S_ν to the comoving - frame flux density $S_{\nu'}$, through the relation

$$\nu' = \nu(1+z)[\Gamma(1 \mp \beta\cos\theta)] \tag{1}$$

which links the emitted frequency ν', the observed frequency ν, the redshift, the Doppler factor $\Gamma = (1-\beta^2)^{-1/2}$ and the angle θ between the bulk velocity and the line of sight. Then, the relation linking the proper luminosity and the observed flux is

$$S_\nu = \frac{P_0 \nu'^{-\alpha} d\nu'}{4\pi D^2(z)(1+z)^2(1+z')^2} \tag{2}$$

where D(z) is the cosmological distance between the source and the observer in the rest frame of the moving component (its expression is

$$D(z) = D_o(z) \cdot (1 + z') \qquad (3)$$

in terms of the distance D_o in the observer's frame) and where we have put

$$(1 \mp \beta \cos\theta) \equiv 1 + z';$$

the "minus" sign refers to the approaching components, the "plus' sign refers to the receding components. We shall call $(1+z')^{-1}$ the boosting factor $\mathcal{D}$.

Inserting (3) and (1) in (2) one gets

$$S_\nu = \frac{P_o \nu^{-\alpha} [\gamma(1 \mp \beta\cos\theta)]^{-(3+\alpha)}}{4\pi D_o^2(z)(1+z)^{1+\alpha}} = S_{o_\nu} \mathcal{D}^{3+\alpha} . \qquad (4)$$

It is seen from (4) that the observed flux density of a relativistically moving component differs by a factor $\mathcal{D}^{3+\alpha} = [\gamma \cdot (1 \mp \beta\cos\theta)]^{-(3+\alpha)}$ from that of a static component. As we have seen in the Appendix to the chapter on Radio Structures of BL Lacs, the maximum value of the apparent separation velocity is attained for $\sin\theta = \gamma^{-1}$ (or, equivalently, for $\cos\vartheta = \beta$).

Even for a mildly relativistic value of $\gamma = 2$ if the intrinsic powers of the receding and approaching components are equal, the observed power from the approaching component would exceed the observed power of the receding component by a factor ~ 350. By letting $\sin\theta$ become larger and larger than γ^{-1} up to $\vartheta = \pi/2$, the observed powers from the two components would gradually become comparable and finally equal. This scenario should then naturally explain the occurrence of double - and single - sided structures in terms of the orientation of the relativistic stream (or jet) to the observer: symmetric structures are seen asymmetric for small ($\vartheta < \gamma^{-1}$) viewing angles and symmetric for larger angles. Is is moroever possible to state - according to this scenario - that the brightest double-structure sources are intrinsically the brightest sources in the sky because, being viewed at large θ , their moving componet(s) is (are) not Doppler-boosted, while the brightest compact sources (like 1641 + 399) comprise a fraction of beamed sources in the larger population of intrinsecally fainter doubles. However, in a randomly oriented sample of source, relatively few have small enough θ as to attain large observed powers and large apparent (that is, superluminal) separation velocities; this is in contrast with the fairly large proportion of superluminal VLBI observations (Scheuer and Readhead, 1979). But this difficulty may be overcome by thinking of a selection effect: sources approaching with high γ and small θ are observed move often due to their apparent radio power (we recall that the radio-lond quasars constitue only $\sim$5% of all quasars!)

Also the bending of the jet observed in some cases is explained in terms of small viewing angels. In fact the observed curvature increases as csc θ , therefore for small θ the curvature is enhanced by a factor γ . Thus bended one-side sources should have large γ and small θ , while symmetrical doubles and not bended one sided sources can have other combination of the two parameters.

What we have said up to now refers to morphology. What about the spectral properties of jets their flux variations, their polarization? Let's discuss the various item in turn, largely following Blandford and Königl (1979) and Königl (1981).

Polarization. An important feature of the radiation from an accelerating source is the characteristic swing in the polarization angle (Figure 20): the data points there reproduce the behaviour of the polarization position angle in the 1975 outburst of 0235 + 164, from Ledden and Aller, 1978). This can be successfully calculated, under the assumption of bulk acceleration, through rather simple considerations (Blandford and Königl, 1979) in terms of the angles between the coordinate axes of the comoving frame and the observed magnetic field, the bulk velocity, the electric field (of synchrotron radiation) and their projections on the (velocity, line-of-sight) plane. The data points in Fig. 20 are suitably fitted with $\gamma = 10$ and $\theta = 5^{\circ}$ (besides a number of other parameter values which must be inserted in the equation for the polarization position angle reported in the quoted reference. For this last set of input parameters the choice of the values which give rise to the fitting curve is not unique).

Radiations properties and flux changes. In the radio domain, since an $\alpha = 0.5$ slope can be considered as typical for optically thin spectra of BL Lacs, a distribution function of continuously accelerated electrons of the form $N(\gamma) = N_r \gamma^{-2} \theta(\gamma - \gamma_1) \cdot \theta(\gamma_2 - \gamma)$ can also be considered representative for the particle injection within the jet. Together with this assumption, it is also assumed that the jet is thin and conical, with small aperture semiangle φ_o whose axis makes an angle θ with the direction to the observer (the observed opening angle is $\varphi = \varphi_o \csc\theta$). Following from these assumptions, the radio of the comoving synchrotron-radiation energy density to the magnetic energy density is

$$\frac{u_s}{B^2/8\pi} \approx \beta \gamma \varphi_o \qquad (5)$$

if $\theta > \varphi_o$, as we expect (that is $\gamma < \varphi_o^{-1}$), (7) implies that Compton losses will not exceed synchrotron losses, since it is

$$\frac{u_s}{u_m} = \frac{u_r}{u_m} = \frac{P_c}{P_s} \qquad (6)$$

For $\Gamma < \varphi_o^{-1}$ and $\beta \sim 1$, (8) will be smaller than unity. The Compton catastrophe is then avoided. Furtherly, the brightness temperature in the comoving frame will not greatly differ from the critical value $T_b^* \approx 10^{12}K = \mathcal{D}\cdot(1+z)^{-1}\cdot T_b$. It reaches its maximum value, independent of frequency, at a projected radius (that is, at a projected distance from the apex of the jet) which varies with frequency as ν^{-1}. It follows that the observed flux $S \propto \nu^2 \; T_{max} \; r^2$ from the region of maximum brightness temperature is independent of frequency too, so the ject will have a flat spectrum within some frequency range; at higher frequencies the spectrum is dominated by the contribution from projected redii which are smaller than that where the brigtness temperature attains its maximum value (at a given frequency) and steepens to $\alpha \gtrsim 1$ as a consequence of synchrotron losses.

This scenario explains steady radio emission from a relativistic jet. However, compact radio sources as BL Lacs characterized by variability in both their total flux and radio structure, besides flat radio spectrum.

Two mechanisms where time-dependent phenomena can arise, namely acceleration of clouds and propagation of shocks within the jet are able to generate such variabilities. In fact a large fraction of the bulk kinetic energy flux in the jet which is incident upon a cloud will be dissipated in the strong bow shock, and some of this energy may apper in relativistic electrons behind the shock. This is therefore a likely site for synchrotron and inverse -Compton radiation (e.g., Blandford and Mckee, 1977; Jones and Tobin, 1977). Alternatively, a non-steady motion in the form of a shock propagating within the jet itself could also give

rise to radio variability. In fact dissipative behaviour close to the origin, resulting perhaps from surface instabilities, may lead to fluctuations in the radial velocity; even if the amplitude of these disturbances is initially small, they may grow and from shocks farther out in the jet (Rees, 1978). A third possible cause for radio variability may be small disturbances in the trajectory of the beam. The contribution of all these possibilities is gathered in an analytical expression (Blandford and Königl, 1979).
Differentiating (4) we obtein

$$\delta \ln S = \delta \ln S_0 + (3+\alpha)\left\{\left(\frac{\mathcal{D}-\gamma}{\gamma\beta^2}\right)\delta \ln \gamma + \gamma\beta\mathcal{D}\,\delta\cos\theta\right\} \qquad (7)$$

which becomes, in the small-angle, ultrarelativistic approximation,

$$\delta \ln S = \delta \ln S_0 + \left(\frac{3+\alpha}{1+\gamma^2\theta^2}\right)\left[(1-\gamma^2\theta^2)\,\delta \ln \gamma - 2\gamma^2\theta\, d\theta\right]. \qquad (8)$$

In these formulae both intrinsic variations of the intrinsic luminosity and apparent variations due to disturbances in the trajectory play a role. From (8) one can see that the third term, associated with curvature, is most likely to dominate the variations. In the case of 1641 + 399, for example, by assuming $\theta \sim 8°$, $\gamma \sim 7$ and $\alpha = 0.5$ in (8) one can reproduce in a natural way the low-frequency variability, which would otherwise require $T_b^* \approx 10^{15}$ K, such that the proper maximum brightness temperature does not exceed 10^{12} K.

At this point we can see how the jet model also seems to solve a problem connected with superluminal expansion which must be overcome in any viable physical model. In order to see a systematic superluminal expansion, there must be a high relative velocity between two source components which should be positive. However the ejection velocities of the two components should not be too different, for too different, for otherwise it would require an implausible coincidence to explain why the component in which the emitting material is moving faster is not considerably brighter than the slower one.

An attractive way out of this difficulty has been put forward by Blandforf and Königl (1979). They propose that the unresolved core be identified with the innermost, radio-thick region of the approachin jet and comprise essentially time-independent emission. The location of the observed core should coincide with the peak in the surface brightness of the jet, which occurs roughly where the jet becomes radio-thin at the observing frequency (we recall that the apparent distance from the apex of the jet to the point of maximum brightness temperetu-re is proportional to ν^{-1}). The moving radio component can be identified with perhaps either an accelerating cloud or a propagating shock. If the component is formed inside the radio-thich region of the jet, then it will not be visible at projected radii smaller than that where the peak of T_b^* is attained, but at larger radii it will appear to separate from the stationary component. The observed separation velocity would thus correspond to the kinematical velocity of the moving component, which may be highly relativistic and yet the ejection velocities of the two source components could remain comparable and also highly relativistic. The fact that the separating components have usually been observed to have comparable fluxes and surface brightnesses could be due to a selection effect resulting from the limited dynamical range and resolution of the VLBI observations. However from Blandford and Königl's (ibidem) model one expects the volume emissivities and the sizes of the two components to be similar, thus the observed emission from the core and a shock moving with a γ similar to that of the jet should be roughly comparable.

By allowing for a parametric dependence on r of the magnetic field and of the number density of relativistic electrons in an unresolved jet (Königl, 1981), two power-law spectra for X - ray emission are found, one related to synchrotron emission and the other to self - Compton emission (Figure 21). The slopes are rather complicated functions of the parameters on which the radial behaviour of B an N_r depend, then they reflect the inhomogeneity of the source. The higher - order inverse Compton spectra, display similar behaviour, but in the frequency range of interest they generally lay below (by a factor 10^6) the once-scattered photon spectrum for typical radio-jet parameters (each successive Compton scattering produces a contribution to the spectrum which is 10^6 times fainter than the previous one).

The observed values of the ratio of the X-ray to radio fluxes are, for most X-ray emitting BL Lacs, some units in 10^{-6}. In some cases, like 2155-304 (Griffiths et al., 1979) when there is a higher ratio of X-ray to radio flux densities, the hard component is not visible, overwhelmed by the synchrotron component at observing frequencies, Nevertheless, Königl's model (1981) predicts a hard X-ray component above some energy for all the objects. This hard component would arise from the inner region of the jet, at the height where the jet starts to be optically thin, and interpreted as a once-scattered inverse-Compton emission. The soft component would arise, on the contrary, from outer regions of the beam. It is therefore expected that the hard component would show a higher degree of variability, and the reported timescale of $\lesssim 1$ yr (Worrall et al ., 1981) would agree well with theoretical predictions. It is possible, in the context of this model, find the likely values of γ for the BL Lacs which emit in the X-rays. For first-order Compton scattering X-ray flux density it is possible to write (Madejski and Schwartz, 1983)

$$F_{meas} = F_{pred} \, \delta^{-2(2+\alpha)} \qquad (9)$$

where F_{meas} is the measured flux density and F_{pred} is the value predicted for no beaming (that is, isotropic emission). The distribution of the boosting factor δ (Madejski and Schartz, ibidem) indicate that large (>10) bulk Lorentz factors are not required in general for BL Lacs, although some objects need high values of γ. Typical values are $\gamma \approx 2-5$.

The underlying assumption which we have taken as good all along is that the spectrum of the relativistic electrons is a power-law one. If one relaxes this condition by assuming arbitrary distributions a qualitatively similar picture holds (Reynolds, 1982). In particular, anisotropies can lead to lower the entire inverse-Compton contribution and to increase the curvature at various spectral features, and for jets not seen end-on the whole inverse-Compton spectrum would move to lower frequencies (Reynolds, ibidem).

Summarizing, the advantages of the relativistic-beaming model are:

i) there is agreement between predicted and observed X-ray to radio flux ratios although each object is to be handled individually;

ii) variability is very naturally explained through inhomogeneities in the jet, clouds which are accelerated or shocks;

iii) superluminal motions and related problems are also explained;

iv) the swing of the polarization position angle can be readily understood;

v) the range in radio morphology is accounted for;

vi) the Compton catastrophe is avoided.

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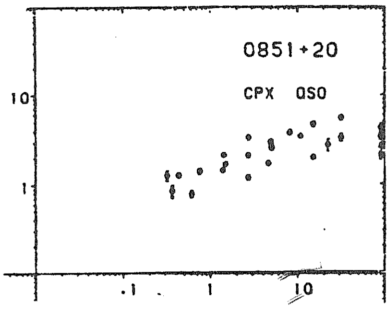


Fig. 1

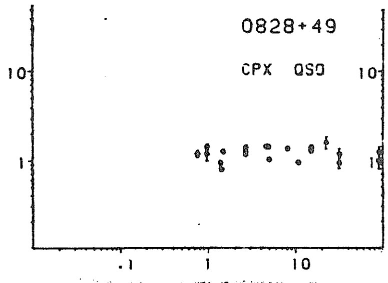
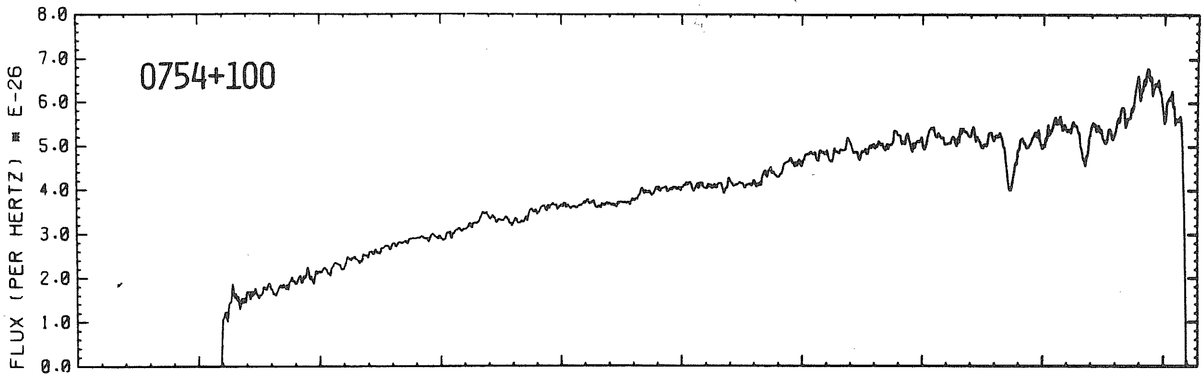


Fig. 2



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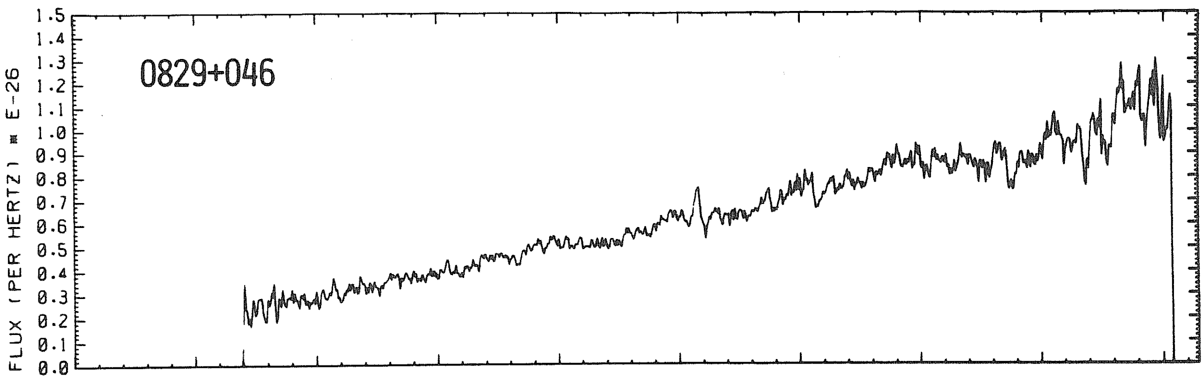
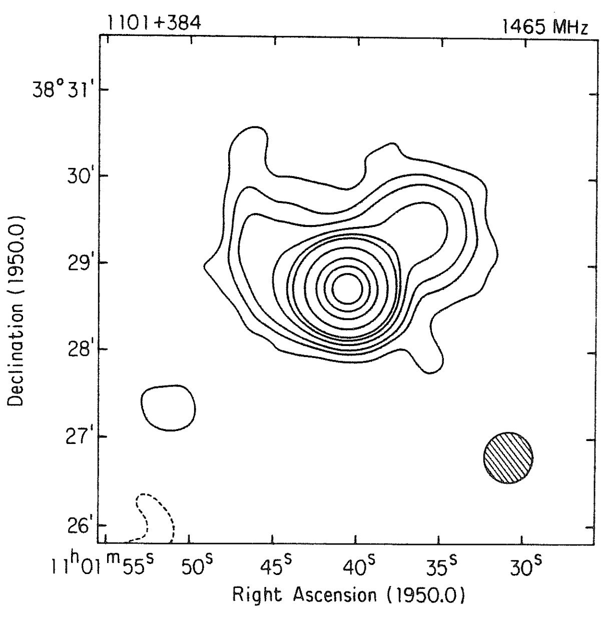


Fig. 4

Fig. 5



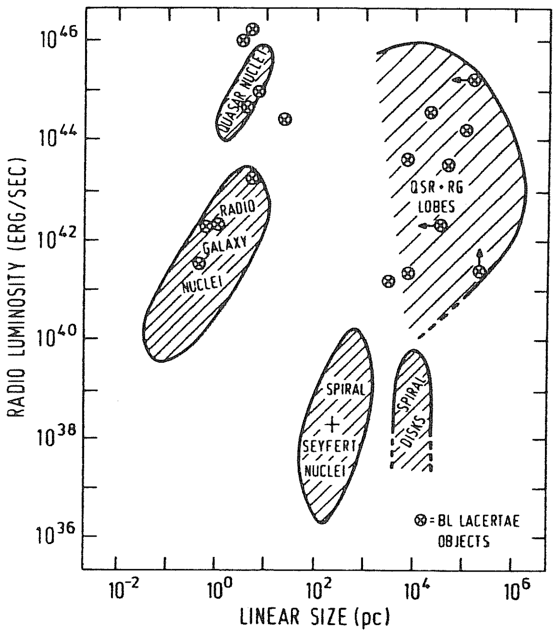


Fig. 6

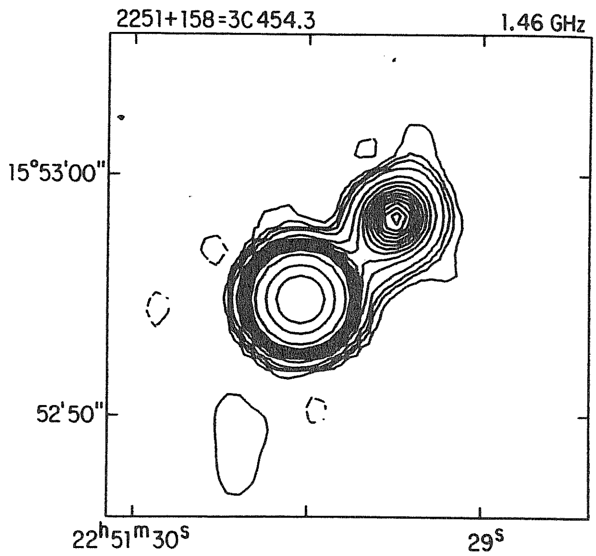


Fig. 7

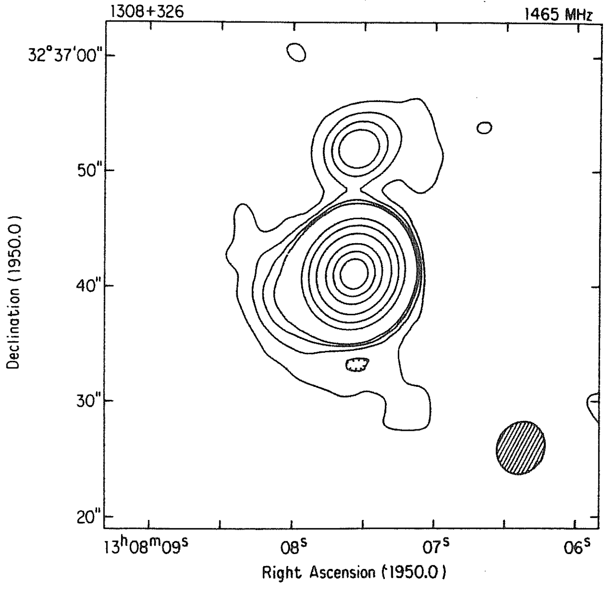


Fig. 8

Table 1 Comparison of the radio structures of BL Lacs and quasars

	Fraction of 0.4 GHz flux contained in:		
	Core	Compact jet	Diffuse halo
Core dominated quasars	0.49	0.31	0.20
BL Lac type objects	0.65	≤0.05	0.30

Fig. 9

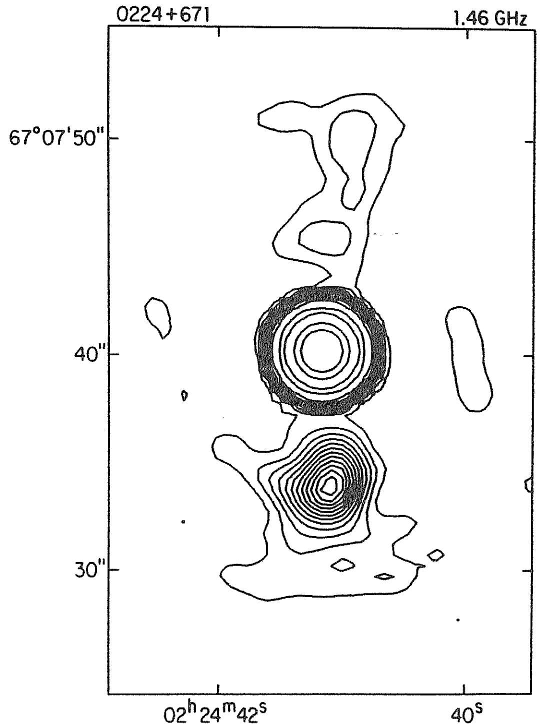
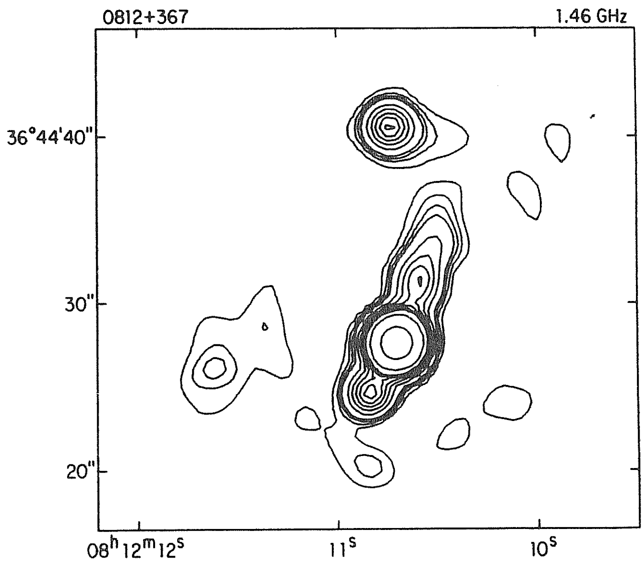
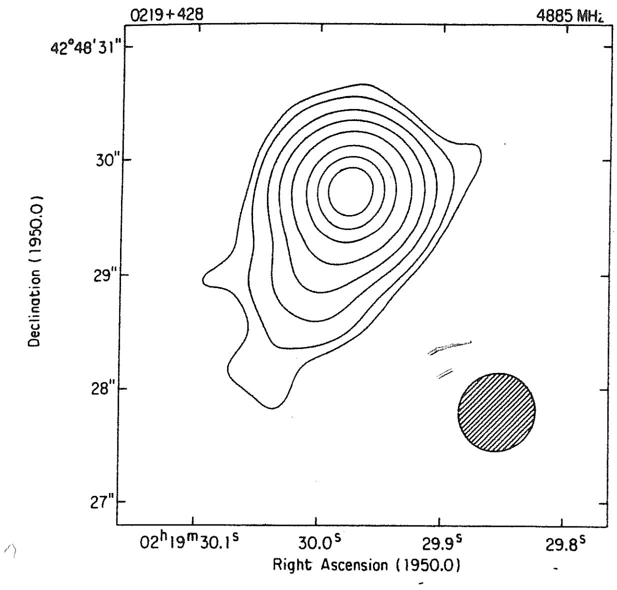
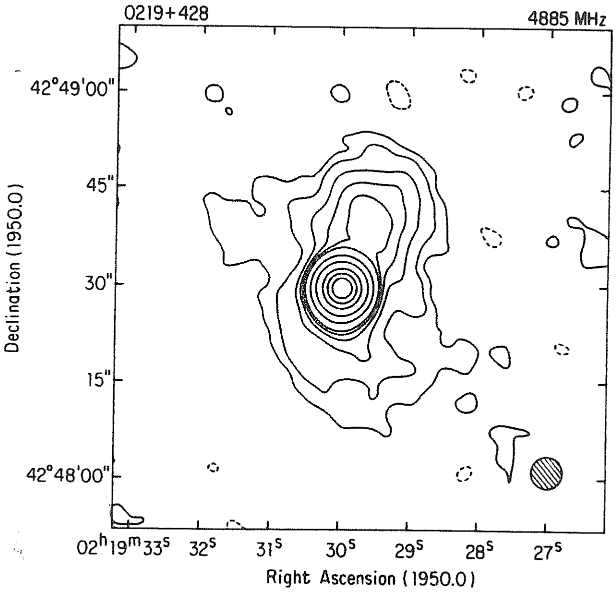


Fig. 10







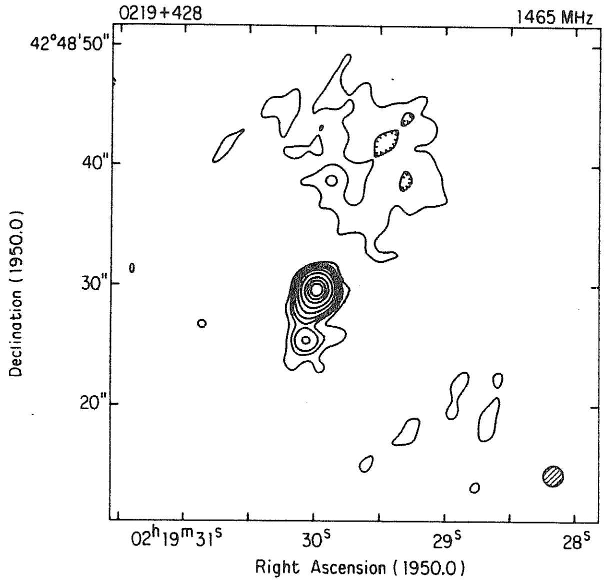


Fig. 11

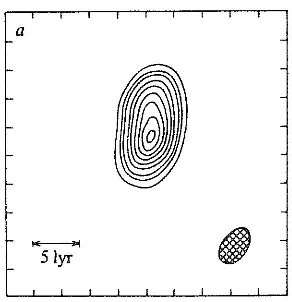


Fig. 12

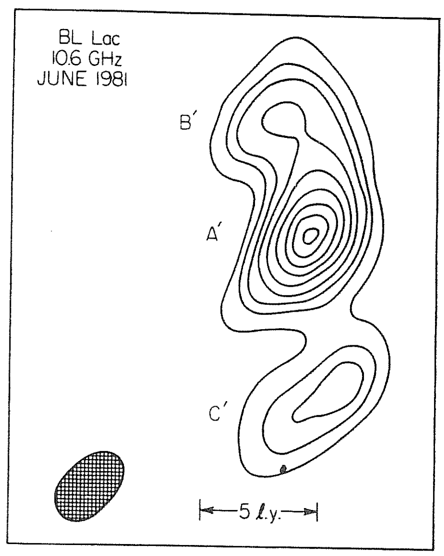
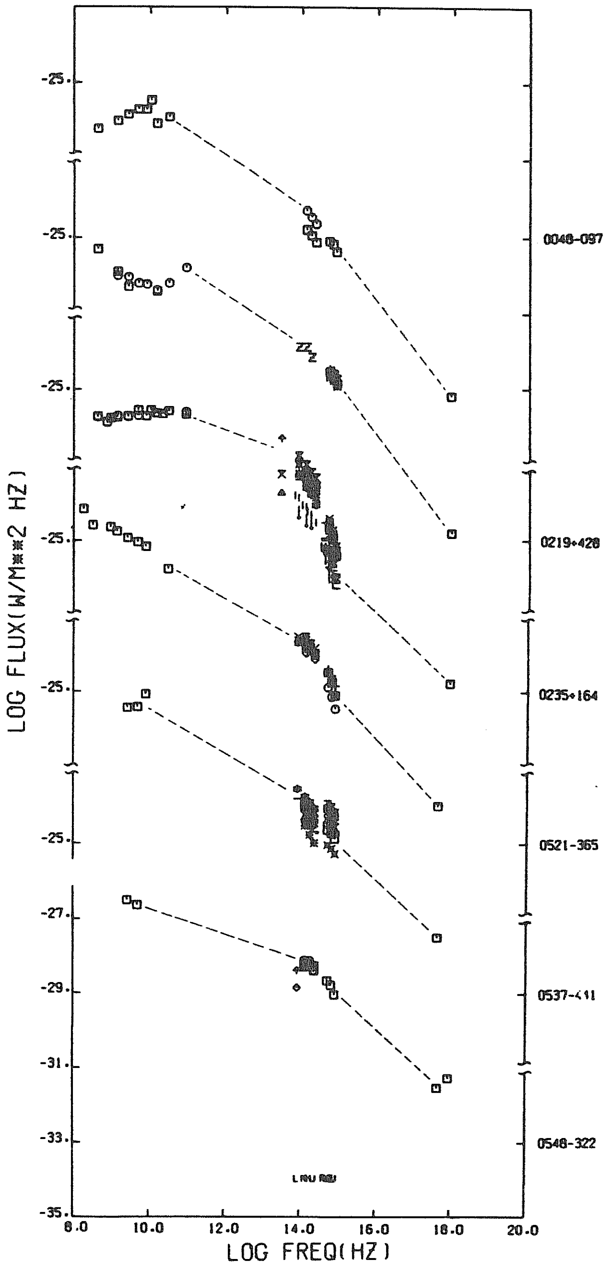
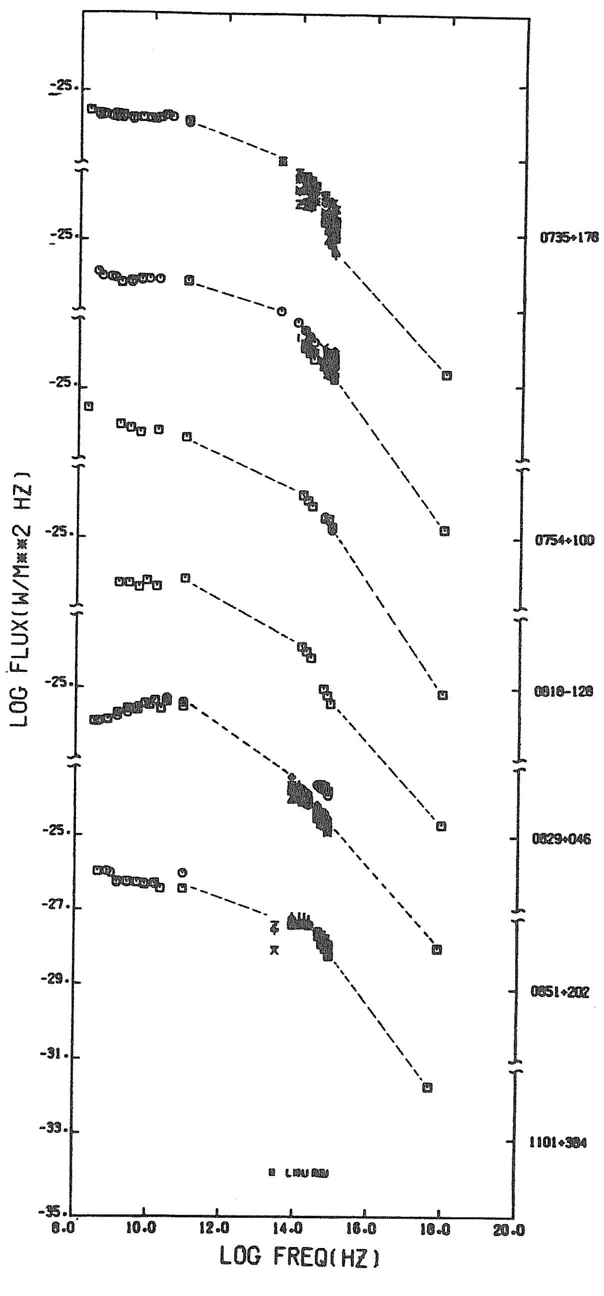


Fig. 13



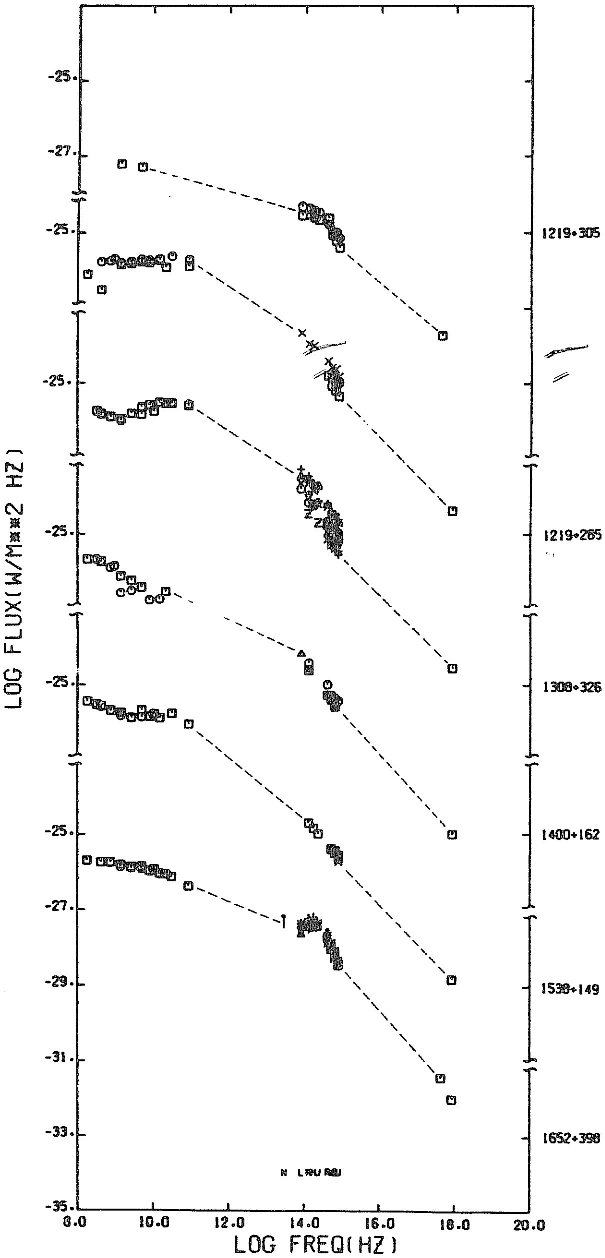
LOG FLUX(W/M**2 HZ)
LOG FREQ(HZ)
0048-097
0219+428
0235+164
0521-365
0537-441
0548-322

Fig. 14



LOG FLUX(W/M**2 HZ)
LOG FREQ(HZ)
0735+178
0754+100
0818-128
0829+046
0851+202
1101+384

Fig. 15


LOG FLUX(W/M**2 HZ)
LOG FREQ(HZ)
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1219+285
1308+326
1400+162
1538+149
1652+398
8.0
10.0
12.0
14.0
16.0
18.0
20.0
-25.
-27.
-29.
-31.
-33.
-35.

Fig. 16

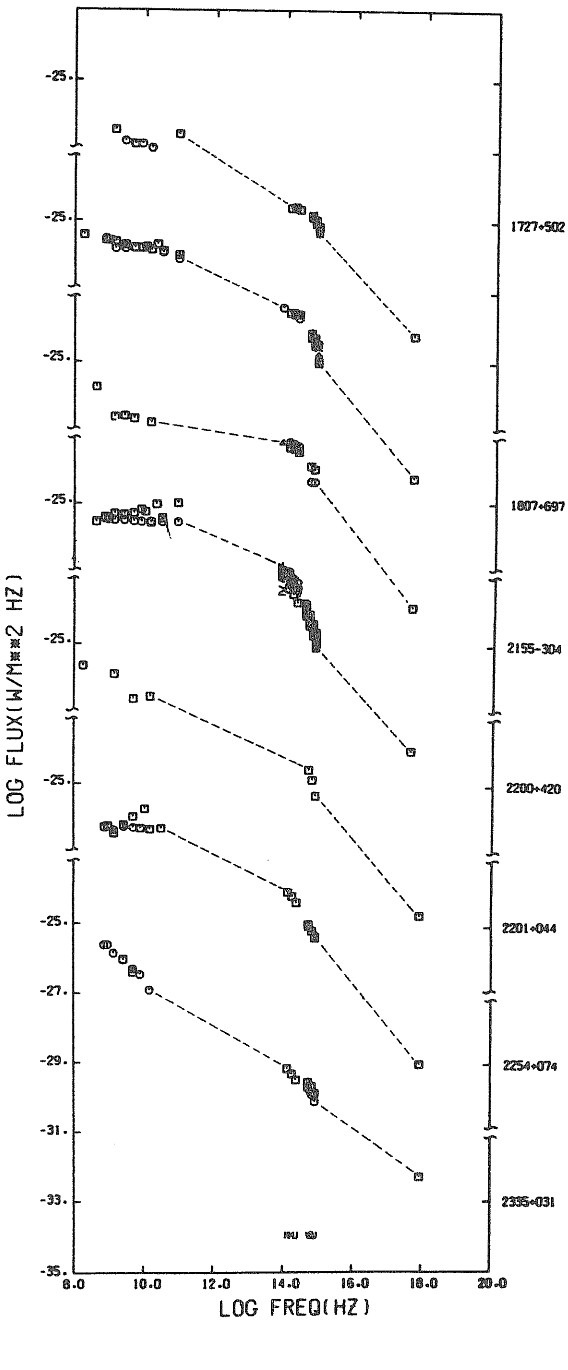
LOG FLUX(W/M**2 HZ)
LOG FREQ(HZ)
1727+502
1807+697
2155-304
2200+420
2201+044
2254+074
2335+031
8.0
10.0
12.0
14.0
16.0
18.0
20.0
-25.
-27.
-29.
-31.
-33.
-35.

Fig. 17

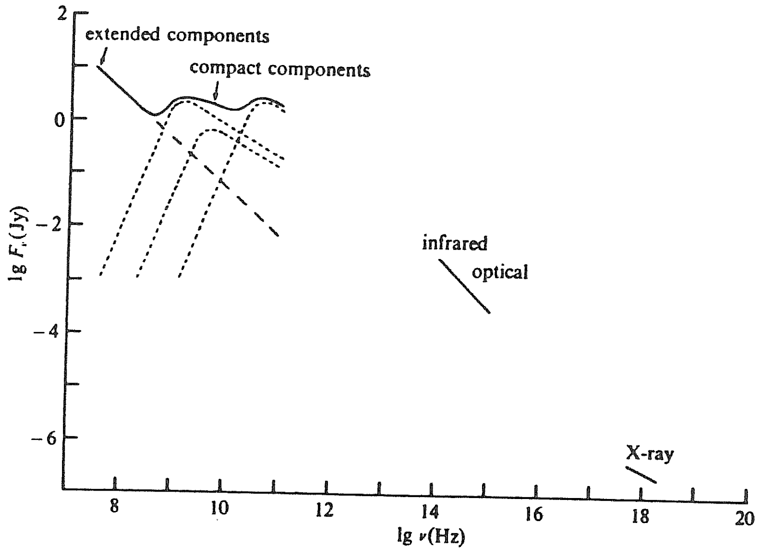

Fig. 18. Schematic representation of spectral-flux distribution of the continuum radiation from a hypothetical quasar or BL Lac object. The radio spectrum is the superposition of a number of inhomogeneous components

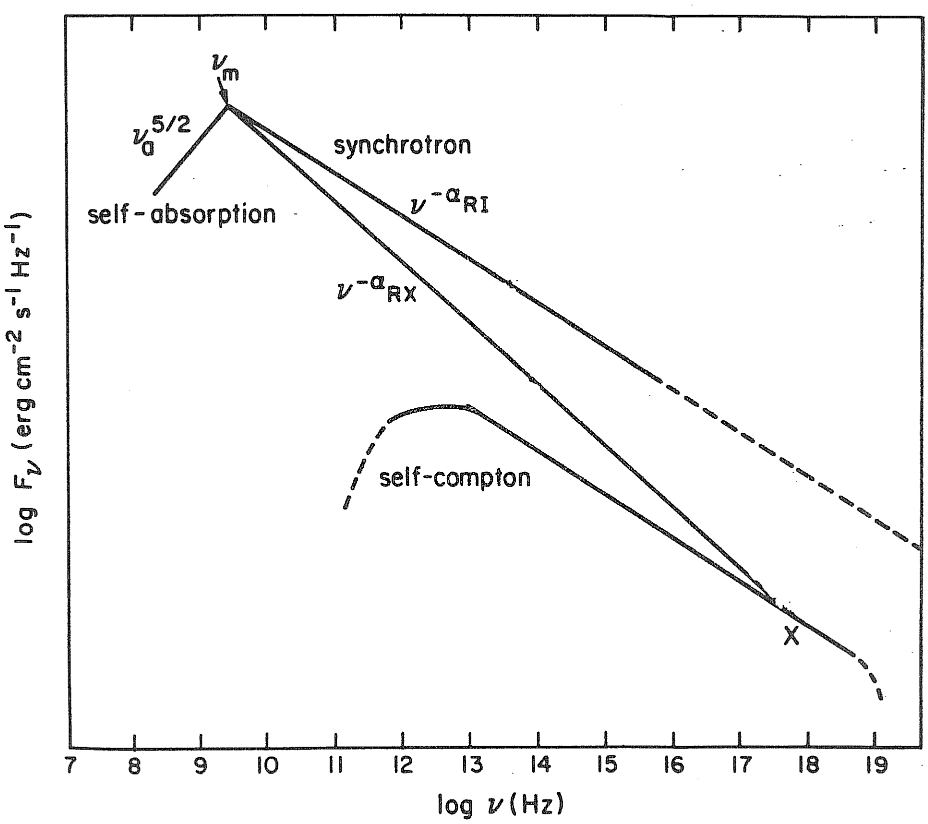

Fig. 19

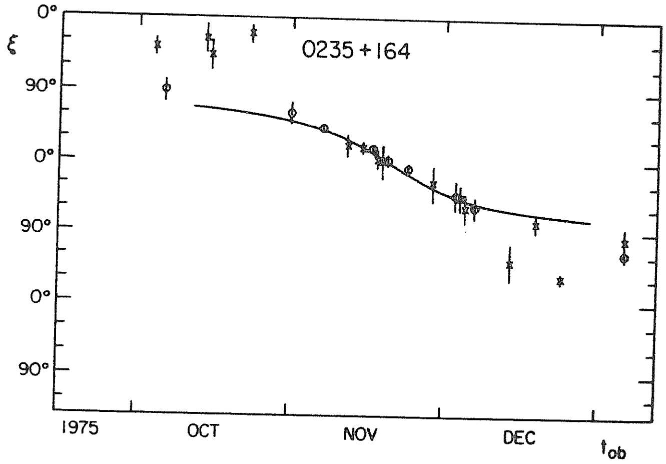
ξ
0°
90°
0°
90°
0°
90°
0235+164
1975
OCT
NOV
DEC
t_{ob}

Fig. 20

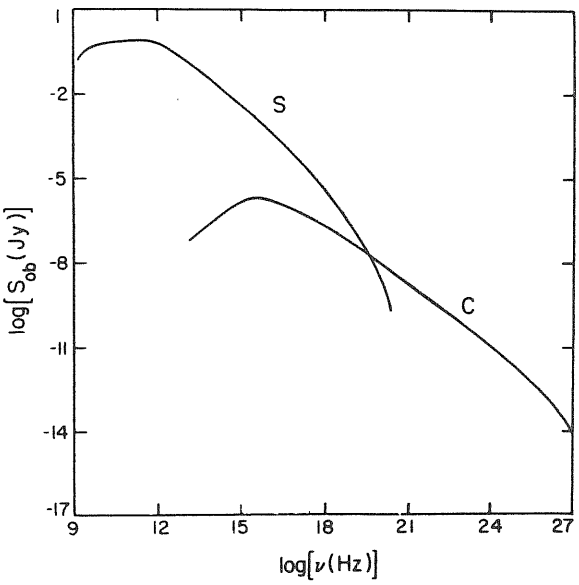
1
-2
-5
-8
-11
-14
-17
S
C
log[S_{ob}(Jy)]
9
12
15
18
21
24
27
log[ν(Hz)]

Fig. 21

A p p e n d i x

DETERMINATION OF FOUR NEW REDSHIFTS OF BL LACS

Abstract.

We present tentative identifications of emission lines in the spectra of the four BL Lac objects 0754+100, 0829+046, 1514+197, 2254+074, as given in the atlas of spectra of QSOs and related objects by Wilkes et al. (1983). Some of them, if confirmed, would be -to our knowledge- the first of that type reported for BL Lacs.

Introduction.

One of the main problems which affect the study of BL Lac objects is the lack of published redshifts for most of them. Out of the nearly one hundred objects which are classified as BL Lacs, less than forty have published redshifts. This relatively small number is still reduced if we take into account that some of them are based on absorption lines that may be due to intervening clouds not physically connected with the BL Lac sources themselves. Of course this situation seriously hinders the study of some important topics such as evolutionary and population properties.

An additional important reason to strive to identify emission lines is to gain a better understanding of the still poorly known properties of the regions where they are emitted.

The Spectra.

Keeping these issues in mind we think that the atlas of spectra of QSOs and related objects published by Wilkes et al.(1983) deserves special attention. It contains 295 spectra (for technical remarks see the atlas), out of which 15 belong to BL Lac objects or to BL Lac candidates. Of these, 6 have no published redshifts. For the present work we selected (on grounds of estimated photometric quality and well-ascertained membership of the objects to the BL Lac class [cf. Angel and Stockman, 1980]) four spectra among the six with unknown redshifts.

Discussion.

The tentative identifications and redshifts for each spectrum are reported in Table 1. The names of the sources are indicated in the first column, the observed wavelengths of the recognized spectral features and their identifications with lab wavelengths are listed in the second and third columns respectively, while the values of redshift for each identification appear in the fourth column. Let us examine the reliability of the identifications for each object in turn.

0754+100. The emission feature centred at λ4685 has a broad profile similar to the one found in the spectrum of the BL Lac object 1308+326, which was identified as MgII λ2800 as well (Miller et al., 1978). We argue that the not perfect agreement between the redshift of this fea_ ture and the redshifts of the others is due possibly to the uncertain_ ty in the former's measurement because of the very broad profile of the feature (FWZI is 300 Å). All the other identifications are quite com_ mon in BL Lac spectra (Danziger et al., 1978; Smith, 1978; Miller et al., 1978; Miller and French, 1978). The quality of the spectrum is good.

0829+046. In this fairly-good quality spectrum we estimated that the fully exploitable region was the λλ4200-6500 Å band. A rather prominent emission at λ5576 was recognized as due to airglow emission (see Meinel et al., 1968). Three out of the five weak features that were recognized as emission deserve special attention. These features (λλ4970, 5030, 5095) stand out on a rather broad hump that may be attributable to a blend of weaker lines. The identifications of the three features as forbidden lines of FeII would be, if confirmed, the first of this kind for BL Lacs, although [FeII] lines -and these in particular- are quite common in Seyfert galaxies and QSOs. In this view, also the 5000 Å hump underlying the three lines is attributed to a blend of the weaker li_ nes of the multiplets 7F and 21F of FeII to which the individually iden_ tified lines also belong.

A strong contribution of [OIII] λ4363 seems quite possible in the case of the λ5095 feature. In fact we expect the level $2p^2\ ^1D$ of OIII, whi_ ch is the upper level of the transition corresponding to the observed λ 5007 line, to be populated partly by collisional excitation from the ground level $2p^2\ ^3P$ and partly by the cascade from the $2p^2\ ^1S$ level which produces the λ4363 line. We also expect that the $2p^2\ ^1S$ level (about 5 ev above ground) is in turn populated by collisional exci_ tation from the ground level. A support to the identifications of the_ se two [OIII] features would be to also detect the two λλ2332, 2321 li_ nes which represent the other possible decay route from the $2p^2\ ^1S$ le_ vel to the ground level $2p^2\ ^3P$. Unfortunately at this redshift they would fall still outside the wavelength coverage of the spectrum con_ tained in Wilkes et al.'s atlas, in the satellite UV range, therefore we cannot say anything in this respect. However we think that these [OIII] -line identifications are reliable also because of the frequent occurrence of this type of spectroscopic mechanism able to produce the_ se lines in QSOs and AGNs.

The lack of detection of the other nebular line, [OIII] λ4959, is attibuted to the weakness (by a factor of 3) of this line as compared to [OIII] λ5007 which is itself quite faint.

1514+197. The identification of the λ3950 feature as CIII] λ 1908.8 is consistent with the identification of a rather broad (FWZI is 200 Å) hump centred at λ5800 as MgII λ2800 at the same redshift and with the expected lack of easily detectable features at this redshift given the exploitable wavelength coverage (3700 to 5900 Å) of the spectrum and what we know about typical emission-line spectra of AGNs and QSOs. The prominent emission feature at 5890 is a blend of very close together airglow lines (see Meinel et al., 1968).

The quality of the spectrum is fairly good.

2254+074. In this medium-quality spectrum we argue that the exploitable wavelength band is 4200 to 6200 Å, and within this range three spurious emissions fall: the $\lambda\lambda$5570, 5890 airglow lines and the HgI λ4358 city-light line (see Meinel et al., 1968).

The λ3993.3 line of [NiII] is possibly found in Seyfert galaxies (Rafanelli, 1984, private communication) although up to our knowledge it has never been found in a BL Lac spectrum previously.

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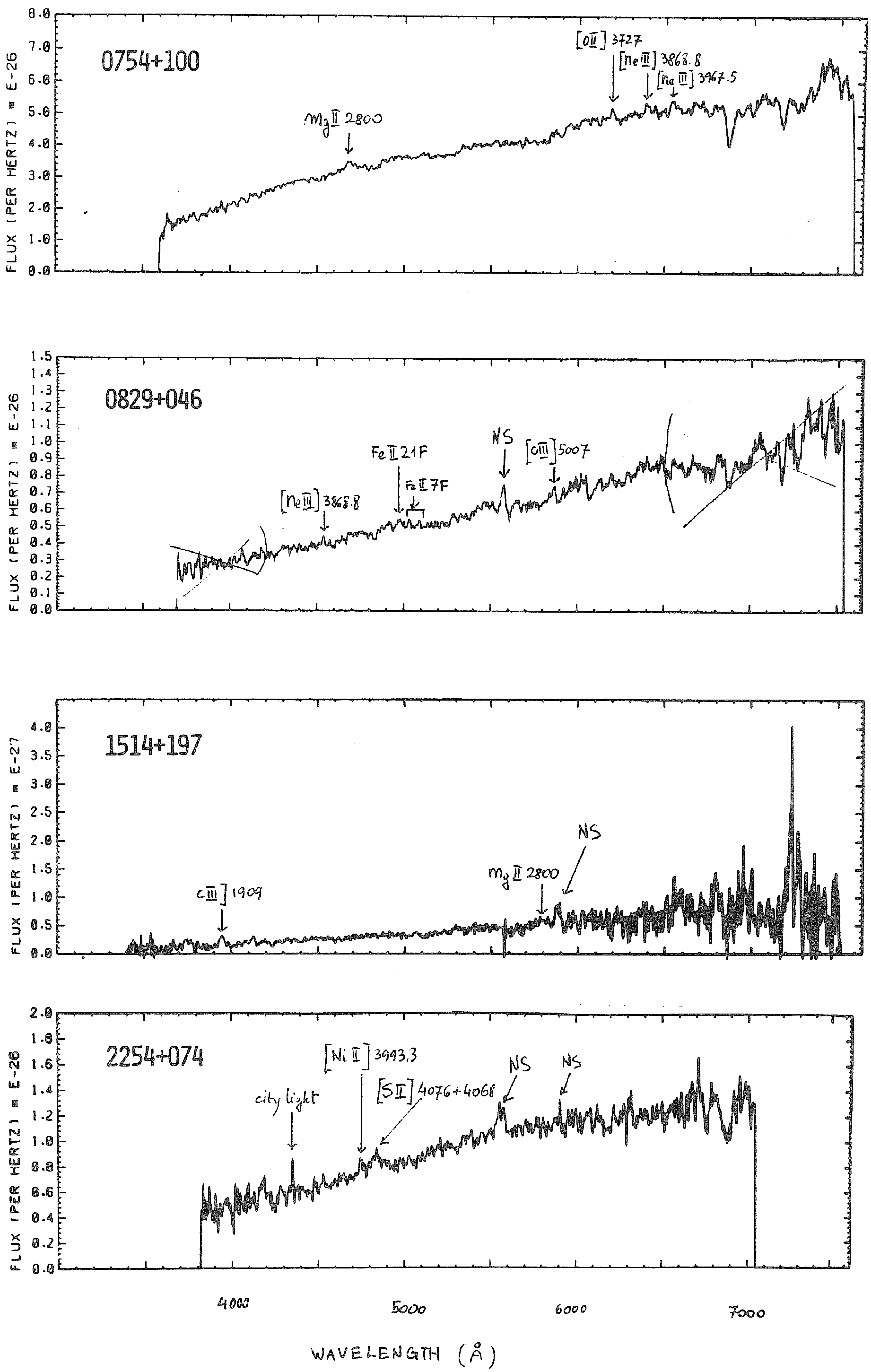
Table 1. The recognized emission features are reported together their identifications and redshifts for the four BL Lacs listed in the first column.

Object	λ_{obs} (A)	Identification	z
0754+100	4685	MgII λ2800	0.67
	6190	[OII] λ3727	0.66
	6400	[NeIII] λ3868.8	0.65
	6550	[NeIII] λ3967.5	0.65
0829+046	4538	[NeIII] λ3868.8	0.17
	4970	[FeII] λ4244 (21F)	0.17
	5030	[FeII] λ4287 (7F)	0.17
	5095	[OIII] λ4363	0.17
		[FeII] λ4359 (7F)	0.17
	5870	[OIII] λ5007	0.17
1514+197	3950	CIII] λ1908.9	1.07
	5800	MgII λ2800	1.07
2254+074	4750	[NiII] λ3993.3 (4F)	0.19
	4840	[SII] λ4068, 4076	0.19


0754+100
[OII] 3727
[Ne III] 3868.8
[Ne III] 3967.5
Mg II 2800
FLUX (PER HERTZ) * E-26
0829+046
Fe II 21F
Fe II 7F
NS
[OIII] 5007
[Ne III] 3868.8
FLUX (PER HERTZ) * E-26
1514+197
NS
Mg II 2800
C III] 1909
FLUX (PER HERTZ) * E-27
2254+074
[Ni II] 3993.3
[S II] 4076+4068
NS
NS
city light
FLUX (PER HERTZ) * E-26
4000
5000
6000
7000
WAVELENGTH (Å)