SUMMARY : FUTURE PROSPECTS

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Before this meeting, it occurred to me that the simplest thing to do would be just to read the summary I gave at Liège two and a half years ago. Fortunately, it turned out that this is not possible, because in some areas substantial progress has been made. With 137 papers presented at this meeting, however, it is impossible to review them all; so I shall just make some general comments.

Much has been said about the basic framework in which the observations are to be discussed. Just two comments about this. First, if one wishes to show that the majority view of cosmological redshifts is incorrect, a few specific cases will carry much more weight than many a posteriori statistics. Second, the very high confidence levels of 10^{-4}-10^{-8} are misleading: a systematic error can easily be equal to a number of r.m.s. statistical errors and the "confidence" levels become so large only in the case of gaussian error distributions. With regard to the first point, close pairs of objects with very unequal redshifts and with absorption features in the spectrum of one at the redshift of the other may be particularly telling. If there were several cases with absorption at the higher redshift in the spectrum of the lower z object, a powerful case could be made for redshifts not related to distance; one case might not suffice, however, since then there would be endless arguments about the correct redshift of the absorption system. The results discussed by Shaver and also the interesting quasar-galaxy superposition reported by Jacqueline Bergeron, however, all seem to give further support to the cosmological interpretation.

Let us now come to some basic statistics, numbers, etc. Relatively little has changed, but the data have become better. To a B magnitude of 21 there appear to be about 40 quasars per square degree. This corresponds to somewhat over a million over the whole sky, and there is therefore an ample supply of objects for more detailed study. Beyond B = 21 the N(>B) curve flattens. The X-ray picture does not seem to be very different. There seems to be agreement that L_x/L_{opt} varies about like $L_{opt}^{-1/4}$ and that it decreases perhaps modestly with z. As a result of all of this, the estimates for

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the contribution of quasars to the X-ray background are still within the range 40 ± 25 per cent. Probably, it will remain difficult with the kind of data likely to become available in the coming years to do much better than this. However, there is a fundamental problem with a large part of the X-ray background consisting of unresolved quasars, and that is that the incompatibility of the spectra seems to become better established. Various papers at this meeting have reported spectral indices of 0.5 - 1.0 for quasars and around 0.9 for Seyferts, all steeper than the probable value for the background. The cheap way out is to say that the fainter quasars which account for most of the background may have different spectra, but this seems somewhat artificial. I suppose that it is more likely that this means that the contribution of quasars is not large enough to be fully dominant, and this raises the more interesting question of the origin of the remainder.

Quasars have a very steep luminosity function. Evidence was presented that the density of the very bright quasars has a maximum around z = 2, followed by some decrease towards z = 3.8 at which point the distribution abruptly stops. But, of course, there are serious problems remaining in all of this. There are the effects of variability and of photometric errors, and in particular uncertainties of the variation of the equivalent widths of the emission lines with z and L. A few objects at large z appear to have relatively faint lines, and this may reduce the discovery probability for high z objects. Wampler and Ponz made the claim that if all these effects are taken into account, it is even possible that there is no evolution. While most of us might feel that this is a rather extreme point of view, their analysis certainly shows that one should not take too seriously the disagreements about the details of the evolutionary picture. What is needed are samples of high photometric accuracy at the time of discovery - to eliminate variability effects, obtained with sufficient spectroscopic resolution to observe lines of small equivalent width.

There seems to be some evidence that the luminosity function narrows at large redshifts. Schmidt and others have been unable to find significant numbers of large redshifts at magnitudes fainter than about B = 20. If this is confirmed - and the accidental discovery of a very faint quasar with z = 3.2 reported by D'Odorico should perhaps still serve as a warning - it would tell one that there are relatively fewer low luminosity objects at high z, with interesting implications for quasar evolution.

Turning now to the more physical aspects of quasars, let me begin with the question of anisotropies which has been extensively discussed here. Are the observed anisotropies due to Doppler boosting or are they intrinsic ? On the positive side for Doppler boosting are the superluminal velocities that seem to be difficult to get in other ways. Also the relation between the width of Hβ and the relative core luminosity discussed by Beverley Wills seems to point in the same direction. On the other hand, as Porcas and others discussed, the lack of a correlation between the extended radio structures and some of these phenomena seems difficult to understand on this basis. And

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then there are the extremely interesting observations by Davis of the jet in 3C 273 which show an eventual counterjet to be at least 5500 times fainter than the jet - something which would be hard to achieve with the Doppler models. The not very surprising conclusion of all of this seems to be that both Doppler boosting and intrinsic ansisotropies probably play a role, but that their relative importance still needs to be clarified. Larger samples of VLBI data on superluminal expansion in different radio sources with different structures are needed, as are more extensive studies of the relationship between radio characteristics and the detailed optical emission line profiles of lines with different ionization stages.

Relatively little has changed in our knowledge of the relationship between galaxies and quasars. Fuzz has been detected around most quasars with $z < 0.5$, and its characteristics are not incompatible with what would be expected for underlying galaxies. Of particular interest are the images obtained in [O III] which show much excited gas in irregular distributions around some quasars. While there seems to be a general belief that elliptical galaxies are related to radio galaxies and radio quasars, and spirals to Seyferts and optical quasars, the situation is still not very clear for the higher luminosity objects. The issue is important also in connection with quasar evolution. As Green showed, many evolutionary scenarios are possible, with perhaps luminosity dependent luminosity evolution providing the best fit to the data. If there were important differences in the types of galaxies associated with different kinds of quasars, further constraints on the possible evolutionary tracks might become available. In the same context, there are the clustering effects which indicate connections between quasars, galaxies and the environment; again, very carefully selected (by luminosity, etc.) samples of quasars are needed before meaningful conclusions can be drawn in particular about the redshift dependence.

Numerous papers have been presented about the optical emission lines and about the flow patterns they indicate. The "Broad Line Region" in the inner few parsec and the "Narrow Line Region" further out (kpc scale) have been recognized long ago. The location of the "Broad Absorption Line Region" seen in some quasars is less certain, but it may be related to the Broad Emission Line Region. The electron densities in the Broad Line Region vary over a large range (10^6 - 10^{11} cm^{-3}) indicating that a simple pressure confinement model is probably inadequate and that a dynamic model is needed. Judith Perry discussed the various winds and flows that occur and their connection to stellar mass loss, supernova explosions, etc. The variability of the emission lines gives detailed information about the location of some of the emitting regions, and one begins to get an impression of a certain continuity between them. I think that once one has realized that all of this takes place in a very dynamic situation, one also begins to wonder whether pure photoionization models are reasonable or if energy input from hydrodynamical processes or from high energy particles also plays a role.

Of particular interest, of course, is the physics of the interior of the quasar. There seems to be agreement about the ingredients that are necessary. First, there is in most pictures a black hole. While the characteristic signature of a black hole has certainly not been seen, it seems clear that - unless conventional physics is wrong - any very massive object or set of objects in the center of a galaxy ultimately will have little choice but to become a black hole. In addition to this, in most models there is an accretion disk, there are magnetic fields which facilitate the transfer of angular momentum and which may cause much flaring activity, and there are in the compact sources the electron-positron plasmas which, as Novikov showed, may in a relatively model-independent way explain the spectral properties of these sources.

The basic power in quasars would come from the rotational energy of the black hole and/or from gravitational energy released in the accretion disk. Jets are seen in many cases and while their origin is still not entirely clear, there appears to be agreement that a magnetic field is needed to confine the jet and also a confining medium to keep the magnetic field in place. As was noted by Barthel, at larger redshifts the medium may become so confining that the jets do not make it out of the galaxy anymore. In a way, this is unfortunate, because it may make it more difficult to probe the intergalactic medium at those redshifts.

The accretion rate, and thereby the luminosity, can be limited either by the supply of matter to the black hole or by the Eddington luminosity. In the former case, much irregular variability could be expected, in the latter more systematic oscillations would also become possible. An interesting example of such an oscillation in an accretion disk was given by Abramovicz and applied to the observations of Alloin and Pelat on the Seyfert galaxy NGC 1566 which seems to show quasi-periodic behavior. The combination of such results with the general evolutionary picture of quasars could have far reaching consequences. Taking the example of this Seyfert galaxy and the fact that such oscillations require the luminosity to be near the Eddington luminosity, we would conclude that the central mass would be around 10^6 solar masses, which with an accretion rate of $0.01\ M_{\odot}$/year gives a time scale of 10^8 years. This could give difficulties for some evolutionary scenarios, since as Rees pointed out at the beginning in the case of pure luminosity evolution central masses of the order of $10^9\ M_{\odot}$ are required, because the objects were much brighter in the past. Hence, if in Seyfert galaxies such oscillations do, in fact, occur, it might favor a picture in which many galaxies host a quasar or Seyfert nucleus during a relatively small part of their life. Perhaps also the very high dynamic range maps in the radio domain from Westerbork and elsewhere can give further information on these issues. In models of pure luminosity evolution, quasars would be more or less eternal, and one could perhaps expect to find faint residues of past activity around them, especially at lower frequencies.

Finally, with regard to cosmology, it follows from Burke's presentation that we have been very lucky: the number of gravitational lenses does not seem to be so large as to obscure the overall evolutionary picture, but at the same time, it is large enough to have many cases in which significant inferences about the distribution of (dark) matter in the universe may be made. Results about clustering of quasars are just beginning to come in, but their interpretation is unclear owing to possible effects of intergalactic absorption on the apparent distribution and of environmental effects on the real distribution. The latter may make the clustering properties of galaxies and quasars rather different. Lastly, the quasars are, of course, useful probes of the intergalactic medium (Ly α clouds) and also of intervening galaxies. As an example, the report by Hunstead of an absorption line due to zinc shows how much may be learned from studies of absorption lines in quasars about nucleogenesis in high redshift galaxies.

To make significant further progress, a new generation of instrumentation will be required. For the absorption line studies just mentioned, observations of faint objects at high spectroscopic resolutions will be needed which will require a new generation of optical telescopes as currently planned in various parts of the world. Optical interferometers will be needed in order to resolve the various emission or absorption line regions; they will almost certainly ultimately have to be located in space to overcome the effects of the earth's atmosphere. To qualitatively improve the imaging of the radio structures in which the superluminal motions are observed, new VLBI techniques are required involving also instrumentation like the proposed Quasat satellite. And, of course, further IR and X-ray satellites are needed, the latter also to study rapid time variations. While EXOSAT, ROSAT and perhaps other satellites will make important contributions, still larger facilities will be required thereafter. It is clear that the study of quasars can provide an important chapter in the scientific justification of most of the observational facilities, both space- and ground-based, currently under consideration. And once these facilities will be available ten or fifteen years from now, an entirely new picture of the nature and evolution of quasars may well emerge.