THE CENTRAL REGIONS OF ACTIVE GALAXIES AND QUASARS

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There is a growing body of evidence that the non-thermal extragalactic sources in the Universe--the Radio Galaxies, Seyfert nuclei, QSO's, BL Lacertae objects and the X-ray galaxies--are all powered ultimately by collapsed objects at the centers of galaxies. Moreover, there is no reason at this stage to doubt that the central energy source is probably the same in all cases. At this point, five years before the Space Telescope is to be launched, the fundamental problem is to identify the nature of the central engine and then to understand in detail the variety of observed phenomena.

The main properties of the central source may be listed as follow

a) It must be able to produce an amount of energy up to 10^{63} erg (corresponding to a rest mass of 3×10^{8} $M_{\odot}$).

b) It must be able to achieve rates of energy production as high as 10^{47-48} ergs s^{-1}.

c) The size of the energy production region must not exceed a few light days (or $\sim 10^{16}$ cm).

d) The recent studies of radio jets on vastly different scales show that the source must be able to remember the direction of ejection over periods of at least 10^{6} years.

1. THEORIES

The main theories that have been proposed for the central engine in active galaxies and QSO's are

a) The collapse of a dense stellar system.
b) The supermassive star using nuclear energy.
c) The spinar.
d) Accretion of stars or gas onto a black hole.

It is widely, but not universally, believed that the fourth possibility is the most plausible. Rees (1977), in a recent review of the situation, described the black hole as the "best buy" amongst the current theories, in part because as far is known, the other entities must eventually evolve into black holes, anyway.

The history of the study of active galaxies and QSO's has been marked by an enormous gap between theory and observation. It is one of the prime tasks of the Space Telescope to close this gap. Therefore, in the rest of this paper, I shall adopt the view that the notion of accretion onto a black hole is basically right. I shall then discuss how observations with the Space Telescope might be aimed to prove or disprove the notion.

2. ACCRETION ONTO A BLACK HOLE

If the black hole idea is right then the rate of fueling required is

$$\dot{M} = 0.1\ \varepsilon^{-1}\ L_{46}\ M_{\odot}\ \mathrm{year}^{-1}\ , \tag{1}$$

where ε is the efficiency conversion of mass into energy and L_{46} is the luminosity of the object in units of 10^{46} ergs s^{-1}. Efficiency factors in the range $0.01 \lesssim \varepsilon \lesssim 0.1$ are commonly discussed; therefore, the accretion rate required to produce a typical QSO luminosity is $\dot{M} \sim 0.1$ to 1 $M_{\odot}$ per year.

It is now becoming apparent that the great variety of observed phenomena associated with active galaxies and QSO's may result, at least in part, from a variety in the mechanisms by which the black hole is fueled. Possible fueling mechanisms which come immediately to mind are:

a) General infall of the products of normal stellar mass loss into the center of a galaxy. (This is estimated to be $\sim 10^{-11}$ $M_{\odot}$ per year per solar mass in the Galaxy.)

b) Stellar disruption through either tidal forces produced by the black hole or through stellar collisions in the dense cusp of stars around it. For black holes of reasonable mass, stellar collisions are more important than tidal disruptions.

c) Infall of interstellar gas around the nucleus of a galaxy.

d) Tidal interactions with other galaxies. (A surprising fraction of Seyfert galaxies are in interacting systems--e.g., VV 150.)

e) The capture of intergalactic clouds. (This possibility is suggested by the existence of elliptical galaxies such as NGC 5128 and NGC 4278 which contain rotating disks of gas with the rotation axis inclined to the principal axes of the elliptical. Such a state of affairs is unstable on a time scale of $\sim 10^8$ years.

f) Galactic mergers. (NGC 5128 has also been discussed in this context as a possible merger between an elliptical and a Magellanic irregular galaxy.)

g) "Freezing out" of hot gas in the gravitational potential well at the centers of certain X-ray clusters--e.g., NGC 1275 at the center of the Perseus cluster (Fabian and Nulsen 1977).

In order to account for the energies observed, black holes with masses in the range $M_H = 10^6 - 10^9\ M_\odot$ are required. The Schwarzschild radius $R_s = 2GM_H/c^2 = 3 \times 10^5 (M_H/M_\odot)$ cm thus lies in the range 10^{-7} to 10^{-4} pc. The normal angular resolution quoted for the Space Telescope is $0''.1$; this corresponds to a linear resolution of 10 pc at the distance (20 Mpc) of M87, which is one of the closest active galaxies. Thus it is evident that the Space Telescope will not achieve direct imaging on a scale anywhere near that of the Schwarzschild radius even fo black holes at the upper end of the expected range. However, as we sha see the ST should lead to less direct observations of great interest, particularly if imaging close to the diffraction limit ($0''.02$ at λ2500) can be achieved by the use of suitable sophisticated deconvolution techniques.

3. THE AIM OF THE RESEARCH

In decreasing order of importance, the main aims of work on activ galaxies and QSO's, both with the ST and with ground-based telescopes, will be seen to be

a) To identify with certainty the nature of the central energy source.

b) To understand the fueling mechanisms.

c) To understand the detailed phenomena which result from different fuels and circumstances. This includes the problem of the generati of the relativistic particle beams which are responsible for the radio emission from many of these objects.

4. THE ADVANTAGES OF THE SPACE TELESCOPE

As everyone knows, the main advantages are

a) The ultraviolet response for imaging and for spectroscopy.

b) The high angular resolution of $0''.1$. (Moreover, the expected high stability of the image profile should enable the diffraction limit to be reached even on very faint objects. In this respect the ST will have an overwhelming superiority over the largest ground-based telescopes using speckle techniques.)

c) The stability for photometry through small apertures or on small angular scales in the optical and at UV wavelengths.

As a spectroscopist, I am surprised to find that I regard the last two items as the major advantages of the ST. Point (c) has not been sufficiently stressed in discussions of the ST; it will have enormous advantages over ground-based techniques for such observations as the light variations of the active nucleus seen against the surrounding galactic background.

5. OUTLINE OF RESEARCH PROGRAMS WITH THE ST

These can be divided into two main categories. The first is those observations that deal with (mostly phenomenalogical) questions regarding the general environment of the central engine. The second category comprises those observations that directly attack the question of the nature and structure of the engine itself. Let us first consider the environmental observations.

a) It will be possible with the ST to determine morphological types of galaxies out to a redshift of $z \sim 0.3$ to 0.5. Moreover, a typical galaxy with a linear extent of around 10 kpc (corresponding to ~ 10 arcseconds at these redshifts) will always be much larger than the bright active nucleus. It will thus be possible to find our whether QSO's are giant Seyfert nuclei in the centers of galaxies as we commonly suppose and, if so, we shall be able to determine what kinds of galaxies are associated with QSO's. Such observations may reveal new correlations between the kind of activity and galaxy type. However, the most important possibility is that the identification of the type of galaxy associated with QSO's would enable time-scale arguments to be made. As an example, we know that the classical Seyfert nuclei are found in roughly 1 percent of spiral galaxies. Accordingly, we can estimate that the Seyfert phenomenon must last at least 1 percent of the Hubble time, or 10^8 years. This type of argument, if it could be applied to QSO's would lead to an estimate of the total energy released by a QSO during its lifetime and hence to an estimate of the minimum mass of the central engine.

b) A search for faint Seyfert nuclei. The least luminous Seyfert nucleus known is NGC 4051 whose nucleus has $M_B = -17$; this galaxy is also one of the nearest Seyferts. Work by Huchra and Sargent (1973), recently improved on by Veron (1979) showed that the luminosity function of Seyfert nuclei rises rapidly as one goes from $M_B = -23$ to $M_B = -17$ and is not observed to turn over. This must clearly be an effect of observational selection; from the ground it is difficult to separate a faint Seyfert nucleus from the light of the surrounding galactic bulge. Thus, at present we do not know whether or not there is a lower limit to the luminosity of the QSO-Seyfert phenomenon. It would clearly be important to undertake a search for faint Seyfert nuclei in nearby galaxies with the ST. This could be done either spectroscopically or by first looking for galaxies with point UV nuclei.

c) Observations of the fueling mechanism in more distant systems (for example, in Markarian 78 which has two sets of emission lines), and at higher spatial resolution in nearby objects such as NGC 1275.

d) Observations of optical jets: it is now becoming clear that the jets are the means whereby the non-thermal energy is directed from the central engine to the outer regions. A prime object for study is obviously the optical jet of M87 which contains discrete, bright knots, at least one of which appears to be unresolved at the diffraction limit ($0''.02$) of the 200-inch telescope (Arnold, Boksenberg, and Sargent, unpublished). If the knots are moving at the speed of light, then in 10 years they should move through a distance of 3 pc or $0''.03$; this should be detectable with the ST.

The second category of observations deals with direct attacks on the problem of the mass, size, and structure of the central engine, the main question being whether or not it is in fact a black hole. There seem to be two lines of investigation:

a) Studies of the continuum and the broad emission line region in nearby Seyfert nuclei.

b) The search for central mass concentrations in nearby elliptic galaxies.

6. THE CENTERS OF SEYFERT GALAXIES

As is well known, the spectra of Seyfert nuclei lead to a fairly sharp division into two kinds of objects. The Type I Seyfert galaxies have spectra in which the Balmer emission lines have broad wings while the forbidden lines of such ions as O III are much sharper; the Balmer lines have sharp cores like the forbidden lines. On the other hand, in the Seyfert galaxies of Type II Balmer lines do not have broad wings. In general terms, the spectra of QSO's resemble those of Type I Seyfert galaxies.

Considerable work over the past few years, particularly on NGC 41 the archetype of Seyfert I galaxies, and on NGC 1068, the archetype of Seyfert II's, has led to the following picture of the structure of a Seyfert nucleus. There is a central source of non-thermal radiation which, from its variability at optical and X-ray wavelengths, is thought to be a few light days (10^{16} cm) in extent. This is surrounded by relatively dense gas clouds ($10^9 < n_e < 10^{11}$ cm^{-3}) which produce the broad components of the permitted lines. This region, which we shall discuss in more detail later, has a size of order 0.1 pc ($\sim 3 \times 10^{17}$ cm) and contains about 10^2 $M_\odot$ of gas. The wide wings on the emission lines are due to mass motions, perhaps in part by rotation around the central energy source which serves to photoionize the surrounding clouds. Outside the broad emission line region there are more tenuous clouds which produce the forbidden emission lines and the sharp cores of the Balmer lines. This region is a few hundred pc ($\sim 10^{21}$ cm) in radius and, with a density $n_e \sim 10^4$ cm^{-3}, the gas has a mass of about 10^5 $M_\odot$. The velocities in this gas are in the range 300 to 1000 km s^{-1}. The Type II Seyfert galaxies have nuclei in which the broad-lined region is absent or weak and in which the central non-thermal source does not dominate the light from the central parts of the galaxy at optical wavelengths.

Osterbrock (1978) has deduced from his extensive spectroscopic studies a model for Seyfert nuclei which is along the lines sketched above, but which is able to account for such refinements as the detailed differences between the emission spectra of radio galaxies and those of Type II Seyfert galaxies. The essential additional feature of Osterbrock's model is that the broad emission line region is supposed to be in the form of a thick disk which is optically thick in the equatorial direction to Lyman continuum from the central source. However, the disk, which is envisaged to have a filamentary structure, is optically thin to such radiation in the vertical direction. According to Osterbrock the broad components of the Balmer emission lines are produced partly by rotation of the disk and partly by turbulent motions in it.

7. EVENTS CLOSEST TO THE CENTRAL ENGINE

If the energy emitted by Seyfert galaxies and QSO's is due to accretion onto a black hole, then the non-thermal parts of the optical, ultraviolet and X-ray continua come from about a radius of about 10 R_s. This is 3×10^{14} cm (corresponding to a light travel time of hours) for $M_H = 10^8\ M_\odot$. In Seyfert galaxies and QSO's there are several components to the continuum radiation:

a) A non-thermal (power law) component with $f_\nu \sim \nu^{-1}$.

b) Stars near the center of the system (this component being very important in the optical spectra of Seyfert II galaxies).

c) Hydrogen recombination radiation from the broad and sharp emission line regions.

d) The "blue bump" observed in the near UV region of Seyfert galaxies and in 3C 273. This is possibly thermal radiation from the dense gas in the broad line region where the temperature is $T \sim 10^4$°K.

An important goal of the Space Telescope will be to sort out these components on the smallest angular scales both in the optical and in the ultraviolet.

The broad emission lines also arise close to the central engine. There are several empirical indications that the broad-line region is small:

a) The ionization equilibrium in the broad-line region is such that

$$y \sim \frac{L_{UV} e^{-\tau}}{r^2 \rho c^2} \sim \frac{\text{radiation energy density}}{\text{mass energy density}} \sim 10^{-11} ,$$

and so the electron density comes out to be

$$n_e \sim 10^{11}\ L_{46}\ r_{pc}^{-2}\ e^{-\tau}\ \text{cm}^{-3} ,$$

where L_{UV} is the flux in ergs s^{-1} beyond the Lyman limit and r_{pc} is the radius of the region in parsecs. The total flux in the hydrogen emissi lines is such that

$$n_e^2 V = 10^{69} L_{46} ,$$

which leads to a small filling factor $f = V/\frac{4}{3}\pi r_{pc}^3$.

b) The broad emission lines have been observed to vary on time scales of months both in their shape (e.g., 3C 390.3) and intensity.

c) In NGC 4151 there are absorption components in the blue wings of the Balmer lines and the He I line λ3889 whose lower level is metastable. These absorption lines have been observed to vary on time scales as short as 2 weeks.

d) The relative strengths of the broad hydrogen emission lines (e.g., the Lα : Hβ ratios) are anomalous in Seyfert galaxies and QSO's. This indicates that the region has a high electron density and hence, via the ionization equilibrium, a small radius.

e) There are time variations in the wavelength of the low energy cutoff produced by the broad-line region in the X-ray emission from the central source.

Finally, a lower limit to the size of the broad emission region comes from the requirement that the maximum emissivity in the lines has to be less than that of a blackbody with $T = T_e$. This condition leads to a limit

$$r_{em} \gtrsim r_{min} = 3 \times 10^{16} L_{46}^{1/2} \left(\frac{T_e}{10^4}\right)^{-2} \text{ cm} .$$

The evidence summarized above leads to the conclusion that the actual radius of the broad-line region is close to this limit. Accordingly, the region may more resemble the outer parts of the photosphere of a hot star than an H II region--thus giving rise to the thermal "blue bump" observed in the near-ultraviolet continuum radiation.

8. PROJECTS FOR THE ST ON THE CENTERS OF SEYFERT GALAXIES AND QSO'S

The foregoing considerations suggest the following observations which would help to pin down the nature and structure of the central source:

a) It should not be possible to resolve the broad emission line region or the non-thermal continuum source.

b) On small angular scales is there evidence from the velocity field in the sharp emission lines for rotation around the central sourc If so, what is the central mass?

c) It is important to follow the time variations in the continuu (optical and UV), the broad emission lines and associated absorption features and in the low-energy X-ray cutoff in order to further elucida the structure of the broad-line region.

d) The broad emission lines have bumpy profiles when observed at high spectral resolution; they also change with time. It is important to search for any evidence for rotation in the time variations of the profiles. If found, this would lead to an estimate of the central mass.

e) As will be discussed later, estimates of the central mass could also be obtained from studies of the radial distributions of the luminosity and velocity dispersion of the stars in Seyfert nuclei. Here the high spatial resolution afforded by the ST would enable the stellar radiation to be distinguished from the other components much closer in towards the center than is possible from the ground.

9. THE SEARCH FOR SUPERMASSIVE OBJECTS IN ACTIVE E GALAXIES

The velocity fields revealed by the emission lines from the centers of active galaxies are so chaotic that no estimates of the masses of the central sources have been obtained so far. Therefore, one is lead to the idea of examining the effect of a central black hole on the stars near the center.

Normal elliptical galaxies appear to have distributions of light and velocity dispersion σ_v that are well fitted by King's (1966) models. These models are characterized by an isotropic distribution function $f(E)$ with a cutoff in the energy E so that the star density ρ reaches zero at a finite radius $r = r_t$, the tidal radius. Thus

$$E = \frac{1}{2} m^* v^2 - \frac{GM(r)m^*}{r} \tag{2}$$

where m^* is the mass of a star, and where

$$M(r) = \int_0^r 4\pi v^2 \rho(r) dr \tag{3}$$

is the mass inside radius r. The distribution function is

$$f(E) = A \exp(-\beta E) - A \exp(-\beta E_{esc}) \tag{4}$$

so that $f = 0$ for $E > E_{esc}$, the escape velocity from the system. As $E_{esc} \rightarrow \infty$ the models tend towards isothermal spheres; near the center the models are nearly isothermal so that $\rho(r) \sim r^{-2}$.

The effect of a central black hole (or other effectively "point" mass) on the star distribution near the center of a galaxy which otherwise obeys a King model has been considered by several authors. Some analytical solutions exist for the case in which the gravitational potential of the black hole

$$\phi = -\frac{GM_H}{r} \tag{5}$$

is dominant.

Following a suggestion by Peebles (1972), several authors have explored the consequences of assuming a self-similar power law

$$f(E) = K|E|^P \quad , \quad E < 0 \tag{6}$$

for the distribution function. In this case

$$\rho(r) = \rho_a\left(\frac{r}{r_a}\right)^{\left(-\frac{3}{2} + p\right)} \tag{7}$$

where $\rho = \rho_a$ at some scale length $r = r_a$, and

$$\sigma_v(r) = \frac{2}{5+2p} \frac{GM_H}{r} \quad . \tag{8}$$

Three solutions of interest have been discussed, They are

a) Relaxed models, in which the system of stars has had time to completely relax under the gravitational influence of the black hole. In this case

$$p = 1/4, \quad \rho(r) \sim r^{-7/4} \quad . \tag{9}$$

b) Adiabatic, unrelaxed models, in which the black hole mass grows slowly as compared with the orbital revolution of time of a star. In this case the stellar orbits are slowly pulled in and

$$p = 0, \quad \rho(r) \sim r^{-3/2} \quad . \tag{10}$$

c) Unbound stars; the stellar system is not relaxed and the stellar orbits are merely deflected as they pass close to the black hole. In this case

$$p = 1, \quad \rho(r) \sim r^{-1/2} \quad . \tag{11}$$

In all of these cases, the outer edge of the sphere of influence of the black hole will be at a radius r_a such that

$$\frac{3}{2}\sigma_v^{\ 2} = \frac{GM_H}{r_a} \tag{12}$$

where σ_v is the velocity dispersion near the center of the galaxy in the absence of the black hole. Inside this radius we expect the stellar distribution to assume the form of a cusp with one of the three radial density distributions described above. In suitable units we find

$$r_a = 70\left(\frac{M_H}{10^9 M_\odot}\right)\left(\frac{\sigma_v}{200 \text{ km s}^{-1}}\right)^{-2} \text{ parsecs} \quad . \tag{13}$$

We note that at the distance of the nearest active elliptical galaxies (for example, M87) 1 arcsecond ~ 70 pc, so that a central black hole of order 10^9 $M_\odot$ is required before its effect on the light distribution could be detected from the ground.

The inner edge of the cusp around the black hole occurs at some critical radius r_c at which either

a) Stars are tidally disrupted by the black hole (r_D),

or b) Stars have to physically collide during the relaxation process (r_{coll}).

In suitable units, we find that for main-sequence stars

$$r_D = 2.1 \times 10^{-5} \left(\frac{M_H}{10^9 M_\odot} \right)^{1/3} \text{pc} \quad , \qquad (14)$$

which is to be compared with the Schwarzschild radius

$$R_S = 10^{-4} \left(\frac{M_H}{10^9 M_\odot} \right) \text{parsecs} \quad , \qquad (15)$$

(We note that stars are swallowed whole for $M_H \gtrsim 10^9 M_\odot$.)

The collision radius occurs at the point where the velocity dispersion of the stellar system equals the velocity of escape from an average star. We find

$$r_{coll} \sim r^* \left(\frac{M_H}{m_*} \right) [\ln \Lambda]^{-1/2}; \quad \Lambda = \frac{\text{radius of system}}{\text{radius of a star}} \qquad (16)$$

We find for main-sequence stars of one solar mass that

$$r_{coll} = 5 \left(\frac{M_H}{10^9 M_\odot} \right) \text{parsecs} \quad , \qquad (17)$$

so the inner edge of the cusp is always determined by collisions.

For the star-star relaxation time we may take Spitzer's reference time

$$t_R = \frac{8 \times 10^5 \, N^{1/2} \, R_{pc}^{\;3/2}}{\left(\frac{M^*}{M_\odot} \right)^{1/2} \log_{10} N} \text{ years} \quad , \qquad (18)$$

where N is the number of stars and R_{pc} is the core radius of the system in parsecs. For a typical giant elliptical galaxy $N \sim 10^9$ (inside the core radius) and $R_{pc} \sim 10^3$ so that $t_R \sim 10^{14}$ years.

From these considerations it follows that the most likely cusp around a black hole would have a density distribution $\rho(r) \sim r^{-3/2}$, so that the projected luminosity goes like $\sigma(r) \sim r^{-1/2}$. For a really massive black hole with $M_H \sim 3 \times 10^9 M_\odot$ the cusp would extend from a few hundred parsecs radius in to about 5 pc radius. At this point, inside the collision radius, the star distribution would flatten off.

Young _et al_. (1978) and Sargent _et al_. (1978) have respectively measured the light distribution and the radial distribution of velocity dispersion in M87 and have concluded from their measurements that M87 contains a central mass concentration (which may be a black hole) with a mass of about $5 \times 10^9\ M_\odot$. More recently, Young <u>et al</u>. (1979) have studied the light distributions in the centers of the radio galaxy NGC 6251 and in NGC 4874 and NGC 4889, the two giant central galaxies of the Coma cluster. The latter two galaxies can be fitted to King models while NGC 6251 cannot; again the required central mass for NGC 6251 is about $3 \times 10^9\ M_\odot$.

There are, therefore, preliminary indications that at least some active galaxies contain massive black holes whose effects can even be discovered by ground-based observations. What are the implications for the Space Telescope?

9. PROJECTS ON ACTIVE ELLIPTICAL GALAXIES WITH THE ST

There are several obvious observations:

a) To study the light distribution in the "cusp" in the center of M87 down to the diffraction limit of the telescope ($0''.02$ or ~ 2 pc). Note that, according to the considerations made earlier, the whole of the cusp down to the collision radius should be observable if there is indeed a black hole of $M_H \sim 5 \times 10^9\ M_\odot$ present.

b) Does the light distribution obey a law similar to $\rho(r) \sim r^{-3/}$

c) By spectroscopic of color measurements show whether or not th light is dominated by ordinary stars down to the diffraction limit.

d) Measure the velocity dispersion σ_v as near as possible to the center of M87. It should be $\sigma_v \sim 1000$ km s^{-1} at $r_o \sim 0''.1$. Such a measurement could be done at low resolution (~ 10 Å) but the integratio time would be tens of hours.

e) Make similar observations of other, nearby ellipticals and of the nuclei of spirals, including Seyfert galaxies.

10. CONCLUDING REMARKS

As I remarked at the beginning, there has been a gap between theory and observation in the study of QSO's and active galaxies which the Space Telescope could do much to fill. I am convinced that the maximum scientific benefits will be obtained by pushing the capabilitie of the telescope to their limits on nearby objects--particularly M87 an NGC 4151. In my view, in our present state of knowledge, it would be better to devote observation time to the study of time-variable phenomena in a few well-chosen objects rather than give fleeting attention to many.

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DISCUSSION

J.N. Bahcall: In the calculations of Wolf and myself, we find that the velocity distribution of stars in the central cusp is very far from Maxwellian. Most of the light is due to stars with small velocities but the velocity dispersion is much larger because of a few stars with high velocities.

Sargent: I agree. The velocity distribution has a central cusp and a long tail. I would avoid this problem by ignoring the very centre of the galaxy. At somewhat larger radii, the increase of velocity dispersion with decreasing radius should be definable in some sense and it should be a big effect.

Weymann: It is striking that the densities in the broad-line regions are always about 10^9-10^{10} cm^{-3}. This may be due to the fact that our diagnostic tools are only sensitive to densities in this range but one would like to know how this scales with luminosity. Do these regions get bigger and denser with luminosity ? One would have to study more than a few objects to find this out.

Sargent: I am struck by the fact that there are very few empirical correlations, especially with luminosity, between the properties of active nuclei. This is despite the fact that their luminosities range over a factor of 10^4.

Illingworth: I have measured the velocity dispersion as a function of radius for several galaxies, including two normal galaxies, and in these cases the velocity dispersion increases with decreasing radius within the core radius, as has been found for M87. This suggests either that we are making errors in measuring $\sigma(v)$ or that these normal galaxies also have mass concentrations in their centres.

Gunn: I would make a cautionary remark about the way in which the velocity dispersions $\sigma(v)$ are measured. Using the Fourier technique, there turns out to be a disturbing correlation between line strength γ and $\sigma(v)$. These are highly correlated statistically so that large $\sigma(v)$ goes with large γ. If γ is constrained to be constant, then so is $\sigma(v)$. Probably this is not the whole of the observed effect. It is likely to be most important in the outer regions where the S/N ratio is low.

Illingworth: We have tested this possibility using data of high S/N ratio in the region where the velocity dispersions vary with radius and altering the metallicities makes a very small change to the velocity dispersion.

Tinsley: I would like to mention the recent preprint by Faber and French, finding a possible excess of M dwarfs right at the centre of M31. Is it still possible, on the basis of present data, that the mass concentrations at the centers of E galaxies are due to low-mass dwarfs?

Sargent: I think the data are consistent with that now but you could push things in such a way with ST that it would not be.

Weymann (Discussion leader): I propose we discuss the paper in two parts. First, the environment, ranging from the region immediately around the central engine, to the surrounding galaxy, to the group and cluster environment. Second, we should look at the physics of the emission line regions. All contributors said they would make remarks provided Wal did not cover the topic adequately and thoroughly so it is not clear what there is to be added.

Osterbrock: Let me re-emphasise what Sargent has said about the importance of direct pictures, with the best possible angular resolution, of the central regions of Seyfert galaxies. I think that the "best bargain" would be to look at approximately 10 of the nearest to try to see their morphology right at the centre - as close to the central source as possible. There is a very strong correlation between the featureless continuum and the presence of broad emission-lines, yet the broad lines have a variety of widths. This strongly suggests a non-spherical velocity distribution -- perhaps ejection more or less in a plane of broad line gas that has interacted with a central rotating disc. Direct pictures in the continuum and in one or two strong emission lines would be very helpful in revealing structure near the centre.

Burbidge: I'd just like to underscore the need to make velocity measures in the gas around the very active Seyfert nucleus in 3C120, with high spatial resolution. In the regions one can resolve from the ground there is a disordered velocity field, with a sort of line of zero velocities that doesn't agree with the minor axis of light distribution. These velocities have been measured by Baldwin et al. Right in the nucleus is one of the "superluminal" VLBI expanding sources, and the axis agrees with the velocities further out. What happens in between ? Although the ST won't achieve the less than milliarcsec resolution of VLBI measurement capability, it will be able to probe closer into the "active engine" and this is a very important observation.

Now I'd like to follow Ray's invitation to make some further remarks. A discussion of extragalactic research with the ST is surely not complete without a consideration of what observations with ST might best address the problem of "discrepant redshifts". Arp, who could best outline what he would see as the most important observations, is unfortunately not here. Neither is Geoff Burbidge, who always acts as our astronomical conscience, reminding us that it is unscientific to ignore data because it doesn't fit pre-conceived patterns or favorite hypotheses. We should rather examine those data particularly carefully, and look for additional data - i.e. look at what Fred Hoyle calls $\dot{D}$ - the trend of the data. Arp's results would be most exciting if ST observations confirmed his work.

Since he isn't here, I can only suggest that I think of the important tasks here is looking at "connections" between discrepant redshift objects, e.g. the BL Lac object AO 0235+164, with two absorption redshifts 0.524, 0.851 and its companion 3 arc sec away, with emission redshift 0.524. Is this really stellar ? Is the slight connection between them real ? Only the 10 times better imaging of ST can do better than the 4-m plate. Another case is 3C303, with a radio source enveloping and seeming connected with both a radio galaxy, with z = 0.14, and QSO with z = 1.57. The two other UV objects discovered by Wlérick et al. are miserably faint to work on from the ground but should be OK for the FOS; one is noticeably extended on a 4-m plate but has a point-like central condensation. Notice that there seems to be a faint loop of material in an arc between the galaxy and the QSO. Arp is trying to see if this is real. It looks real on this 4-m plate. Does it have knots in it, as looks to be the case ? If so, their spectra might be observable with ST.

Another case is the first "double QSO" - 1548+114, discovered by Wampler. These have very different redshifts, 0.4 and 1.90. Does the lower redshift object produce Ly α absorption in the other ? ST can look at the UV spectrum to see. Also it can image this object and see if the "fuzz" which Butcher et al. have marginally detected round this object is real, and if so what its luminosity gradient is with respect to the central object. Of course, fuzz wherever known around QSOs should be studied with ST (e.g. 3C48 fuzz, which has emission lines but no absorption has been detected).

Finally, we can look at the apparently stellar very faint objects found in radio lobes of e.g. 3C285, by Tyson, Saslaw and Crane. What are these ? Are they like the 3C303 case ?

These are just examples which come to my mind for addressing the "discrepant redshift" problem. There must be many others.

Boksenberg: Wehinger, Wycoff and myself have found evidence for an early-type stellar component in the fuzz around the quasar 0837-12 which has redshift $z \gtrsim 0.2$.

Tarenghi: The problems of observing galaxies in clusters with the Space Telescope are that the galaxies are extended objects and associations of galaxies subtend rather large angles in the sky compared with the field of view of Space Telescope. Because galaxies have typical sizes $\sim$ 1 arcsec at cosmological distances, the photons will be spread over many pixels and the only gain in the optical waveband is the lower background from space which is about 1 magnitude fainter than from the ground.

The precise gain depends upon the profile of the galaxy. The gain in the UV is, of course, very much greater.

The problem with the small field of view may be expressed as follows. With a field of view of 3 arcmin, the core of a rich cluster of galaxies will only be observed in a single WFC frame if its redshift is greater than 0.5. For comparison, a single 4 metre plate can include the whole Abell diameter of a rich cluster in a single exposure if it has $z > 0.5$ and a single Schmidt plate can contain a whole supercluster if $z > 0.5$. However, observations of the cores of distant clusters with the WFC will be important. For example, the stripping of spiral galaxies at redshifts $z \stackrel{\sim}{\sim} 0.5$ can be studied by classifying galaxies on WFC images. Probably these classifications will be possible out to redshift $z \stackrel{\sim}{\sim} 0.7$.

Let me mention two interesting examples of quasars in clusters of galaxies. 3C66A is a BL-Lac object in a rich cluster of galaxies. The quasar 2251-17 is an X-ray quasar with several nearby galaxies at the same redshift. There is evidence that the quasar is exciting the intergalactic gas close to the quasar.

Gunn: In studying galaxies at large redshifts, the K-corrections are much more important than the distance effects. If one looks in the near infrared, the photon rates are large and the gain in going into space is about 3-4 magnitudes compared with the one magnitude gain in the V band. I will show tomorrow that what you can hope to do at 1 μm with the WFC is really quite encouraging.

Groth: You also gain from the high angular resolution. For objects at a given redshift, the faintest galaxies observable have unresolved core radii. It is only at $z \stackrel{\sim}{\sim} 1$ that the faintest galaxies observable have their cores resolved.

Spinrad: I will show two examples of what will be possible with ST on the basis of ground-based observations. Boksenberg has already mentioned the "fuzz" around the quasar 0837-12 which has redshift 0.20. I have surface photometry of this quasar in the red region which shows that the brightness distribution can be decomposed into a point-like object associated with the quasar and a smooth distribution which is identical to that of an elliptical galaxy with $M_V = - 23.3$. The system lies in a cluster which Abell would probably have classified as of richness class 0.

Similarly, the quasar PKS 0405-123 has redshift $z = 0.57$ and is embedded in a cluster of faint galaxies at roughly the same redshift. It is impossible to search for a giant elliptical galaxy underlying this quasar from the ground but from ST with its high angular resolution, this study should be very easy. Clusters around quasars can be studied from the ground out to redshifts $z \lesssim 0.7$.

Thus quasar environments are, at least sometimes, the normal moder tely rich cluster containing elliptical and probably spiral galaxies.

N.A. Bahcall: If quasars with redshifts $z \gtrsim 0.5$ are found in clusters o galaxies, this may indicate an evolutionary change with cosmological epoch because at smaller redshifts, we found very few real associations of quasars with clusters.

Gunn: I wonder if this evolutionary change may not just be statistical. There is a contradiction if you suppose that quasars lie preferentially in clusters. However, if you look at the fraction of galaxies in rich clusters and compare that with the number of quasars which have been carefully studied at small redshifts, I do not believe there is any contradiction.

Oke: I will mention some results to come out of observations with IUE which have implications for observations with Space Telescope. Sargent mentioned the similarity of quasars and Seyfert I galaxies. In the UV, this similarity disappears. In particular the CIV line is very much stronger in Seyfert I galaxies than in quasars by a factor of 2-3. The anomalous Ly $\alpha/H\beta$ ratio is found in Seyfert I galaxies, the value being 15-20 times smaller than the recombination value. There is a hint that interstellar reddening in the object itself may be important becaus a weak 2175 Å absorption feature may be present in some objects. This would alleviate partially the Ly $\alpha/H\beta$ ratio problem. Finally, it is ver important to study time variability in the profiles of Lyman α and other lines in Seyfert galaxies as emphasised by Sargent. This might indicat the origin of the Ly $\alpha/H\beta$ discrepancy.

Collin-Souffrin: I would like to point out the importance of the ST for our knowledge of the broad line region in type I Seyfert galaxies, even if it cannot be observed directly. It is not so clear to me that the broad line region is photoionized by the UV continuum source, and I thin that there are some problems with this interpretation. One of these problems has been mentioned by Dr. Oke, and it is called the $L\alpha/H\beta$ problem. As a matter of fact, all the lines observed in the UV range and not only $L\alpha$, seem to be weaker with respect to the visible lines of the same ions, than the classical photoionization models predict. One example of this is the extreme weakness of the UV lines of Fe II, which, I think, can only be produced by collisional excitations in a very optically thick medium. Such a medium would likely correspond to a kind of thick "atmosphere" activated by some mechanical process of energy dissipation, and we are trying presently to work out such an alternative model, to see if it could explain the $L\alpha/H\beta$ ratio.

However, it has recently been proposed by Netzer and Davidson, on the basis of their detailed computations of photoionization models, that external reddening can explain the Lα/Hβ ratio, and more generally the UV emission spectrum. The implications of this idea are very important: in particular, the intrinsic continuum, corrected for the reddening, will be quite different from a synchrotron spectrum, and should look more or less like that of a black body at ∿ 10^6 K.

On the other hand, the recent UV observations of 3C390.3 and NGC1068 have shown that the narrow line region has a typical "recombination ratio", Lα/Hβ $\gtrsim$ 40; and then, if the reddening explanation is correct, the absorbing dust should be located somewhere between the broad line and the narrow line region.

A way to test this model would be to look in great detail, in nearby Seyfert galaxies, at the ionization structure and to the distribution of dust (obtained through some line intensity ratios and through the 2200 Å feature), in the narrow line region which has typical dimension of a few arc seconds. On the other hand, such an observation could also lead to knowledge of the shape and of the coverage factor of the broad line region, which is optically thick to the ionizing radiation.