USES OF VERY LARGE TELESCOPES FOR GALAXY RESEARCH

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SUMMARY

Many areas of extragalactic research will greatly benefit from observations with a very large telescope. We concentrate, here, on four of them as illustrative examples:

First we briefly discuss the study of the absorption lines in quasar spectra.

In the second section we suggest the possibility of doing serendipity large field imaging during high spectral resolution exposures on point sources.

In sections 3 and 4 we discuss two topics which have long been recognized as important drivers for the construction of very large telescopes, the determination of the nature of the missing mass, and the study of elliptical galaxies.

1. ABSORPTION LINES IN QUASAR SPECTRA

The spectra of distant quasars show narrow absorption lines at different redshifts which are caused by gas clouds located along the line-of-sight to the quasar. Some of these gas clouds belong to the halo or the disk of intervening galaxies, while the others appear to be intergalactic hydrogen clouds since, at present, they have been detected only from Lyman lines in absorption. These gas clouds pose different astrophysical problems:

(a) Halos and disks of galaxies produce absorption lines in H and heavier elements (C, N, O, Ca, Na, Mg, etc.). The halo gas and the disk gas represent different physical conditions and are excited by different mechanisms. The question here is to find out how the properties of the halo gas and the disk gas change with cosmic epoch. For example, the state of the halo material is expected to change with cosmic time as the density of X-ray and UV photons susceptible to ionizing this material increases with z following the increase with z of the volume density and luminosity of quasars.

The ground based studies of the absorption lines with $z \gtrsim 2$, soon to be supplemented by observations of lines at $z < 2$ with the Space Telescope, should tell us how the state of the gas varies with cosmic epoch.

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(b) Perhaps even more interesting is the problem raised by the "Lyman α clouds" and in particular whether these clouds are made of unprocessed material. The upper limit to the metal abundances Z/H obtained in a few well studied systems is at present 100 times less than solar (Chaffee et al., 1984). Significantly lower limits require that the observations be made at much higher S/N than has been done so far.

(c) A small number of quasars appear in pairs either because they lie on very close lines of sight or because they are two images of the same quasar caused by a galaxy forming a gravitational lens. The observation of whether the same absorption lines appear in both quasars or only in one is the only way to get direct information on the dimension of the intervening gas clouds causing the absorptions. The limit on the size of the cloud d is particularly stringent in the case of gravitational pairs ($d \lesssim 20$ kpc in the case recently studied by Foltz et al. 1984) but unfortunately such systems are rare and only a handful are observable now with the adequate S/N ratio.

(d) Finally an important observation is the search for deuterium Lyα at 1216.555 Å. Current cosmological models predict D/H < 10^{-4} and thus Dα is expected to be extremely faint (Carswell et al., 1984). Clearly this can be attempted only with spectra having extremely high S/N.

Further progress in most of these astrophysical problems requires the knowledge of the intrinsic width of the absorption lines which means that the observations must be made with a wavelength resolution similar to the thermal width of the absorbing gas clouds. This corresponds to approximately 0.1 Å or R ~ 50000 depending on the element, the temperature of the gas, and the redshift. Table 1 gives the integration time in hours to obtain spectra at this resolution, and S/N = 50.

Moreover it is essential to be able to observe quasars 2 or 3 magnitudes fainter than observable now in order to have a large number of quasars at one's disposal for statistical studies. For example, quasars at $z > 3$, or gravitational pairs of quasars, give extremely valuable information. However, they are very rare and only by going to $m > 19$ can one study enough cases to reach conclusive results.

Finally, as in all domains of astrophysics there are difficulties which complicate the interpretation of even the most excellent and numerous data. In the case of the determination of Z/H in halos and in intergalactic clouds, where the gas is completely ionized, neutral hydrogen is only a trace element and the determination of Z/H depends heavily on the model for the clouds (temperature and

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density). There is also an ambiguity in the measurement of deuterium Lyα because at the expected equivalent width of this line one also expects a number of Lyα lines of the "Lyα forest" which will coincide or blend with the Dα line, making its measurement very difficult.

2. DIRECT IMAGING IN SERENDIPITY MODE

One of the main drivers for a very large telescope is to do high resolution spectroscopy on faint ($m \sim 20$) objects. These observations will require long exposures, will take place in the grey or dark moon and many will consist in observing one object at a time (e.g. distant halo stars, absorption lines in quasars).

A small area, ~2 arc minutes in diameter, will be used to send the on-axis beam to the Nasmyth or the Coudé focus, and the rest of the field will remain unused for these observations. It is therefore worthwhile to consider doing large field imaging in a serendipity mode during these long-on-axis spectroscopic observations.

With a very large telescope, the sky will be registered in a few minutes and thus only imaging through narrow band filters and/or aperture holes will be worthwhile. These observations can be tailored to search for emission line objects, or objects of peculiar colours (for example, red giants with white dwarf companions). Most promising are objective prism observations through an aperture plate where the holes have been drilled at the positions of objects previously selected according to their magnitudes, colours and positions from a short direct exposure obtained ahead of time. (For details on this particular objective prism observations through an aperture plate see B. Fort, this volume). Objects up to $m_V \sim 25$ should be observable with this technique.

During a 4-hour, high resolution spectroscopic observation one could either take 4 objective prism spectra of the same faint objects to increase the S/N or take 1 hour exposure spectra through 4 different aperture plates to increase the number of faint objects observed. If one assumes that the large field serendipity observations are carried out 3 nights a month, with 2 fields of ~ 30' x 30' area observed for 4 hours per night, the total area covered per year is 18 square degrees.

3. THE NATURE OF THE MISSING MASS

It has been known for several years that there is a discrepancy between the mass of galaxies in a cluster calculated from the virial theorem and the mass deduced from the known stellar content. There are other pieces of evidence pointing to the existence of non-luminous material in galaxies and groups of galaxies, but it is in the case of large clusters of galaxies that the non-luminous material appears to be most abundant in proportion, amounting to 10 times the mass of the luminous material. The determination of the nature of this "missing mass" is therefore one of the most important current problems in astrophysics. The first step towards solving this problem consists in mapping the distribution of matter in large clusters.

The total mass of an individual galaxy can be obtained by measuring the velocities and the trajectories of subcomponents assumed to be gravitationally bound to the galaxies: individual stars in nearby galaxies (e.g. Aaronson, 1983), globular clusters (e.g. Huchra, Stauffer and Van Speybroeck, 1982), dwarf companions, and hot gas (M87). These observations are demanding. For example, the velocity dispersion of the stars in the Draco dwarf galaxy relies on the measurements with 1 km s^{-1} accuracy of the velocities of stars which are fainter than 17th magnitude (Aaronson, 1983).

It is also very important to determine how the mass is distributed in a galaxy and how the mass distribution merges with the mass spread throughout the cluster. This, in principle, can be done by observing the variation of the projected velocity dispersion of the stars, σ, as a function of the distance to the center of the galaxy. For a constant M/L ratio, σ is expected to decrease from the center to the outskirts of the galaxy. However, in the two galaxies in clusters where σ has been measured at 50 to 100 kpc from the center, it increases with radius and is still increasing at the last measured point. This is interpreted by an increase of M/L and thus of the fraction of non-luminous material with radius (Carter et al. 1981; Dressler, 1979). This is particularly interesting in view of the fact that if all the unseen matter were attached to individual galaxies, dynamical friction would produce mass segregation contrary to observational evidence (White, 1976). On the other hand Tonry (1983) is able to build models of galaxies with constant M/L where the velocity dispersion is largely tangential. In his models, the projected velocity dispersion increases with radius and fits the raise of σ with radius seen in the cD galaxy in A2029 (Dressler, 1979) up to the last point observed. This shows that even observations of σ extending to 100 kpc from the galaxy center, where the surface brightness is less than 10% of the sky, do not extend far enough out to provide a discriminant

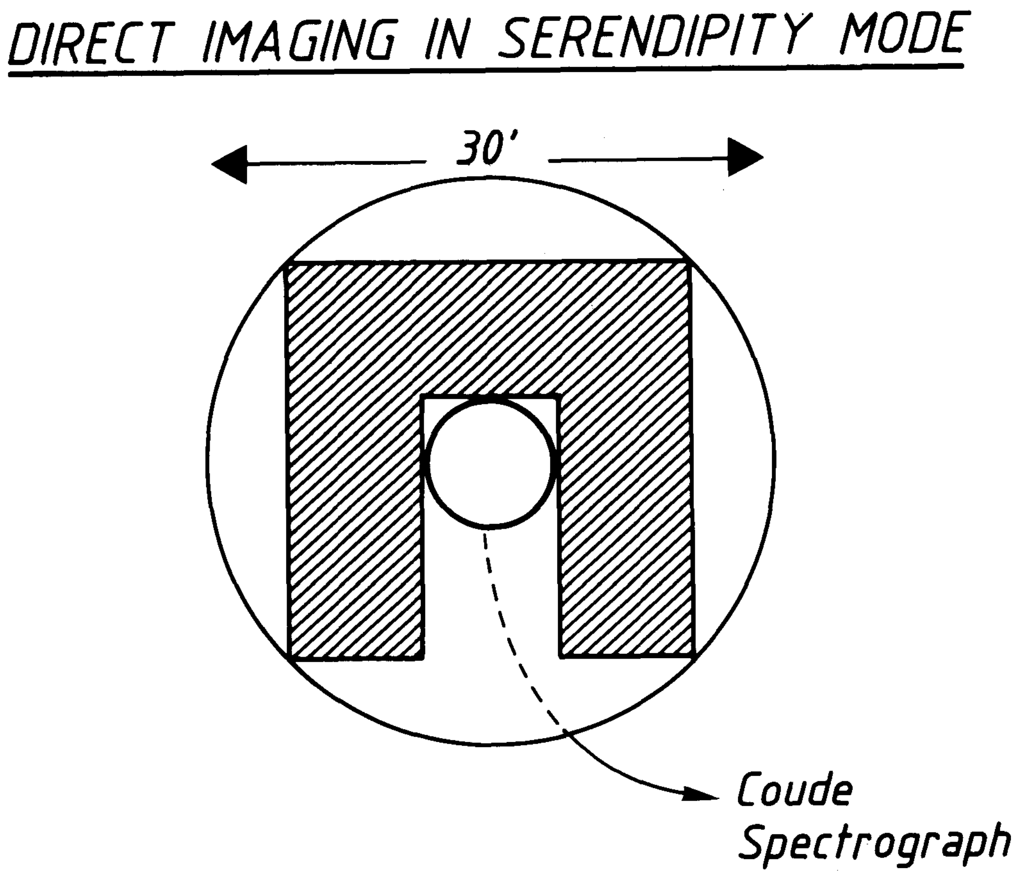

Fig. 1 A number of observations performed with a very large telescope will consist in long on-axis integrations on a single object. During this time the large field will be unused. It is of interest to evaluate the usefulness of serendipity direct imaging, in particular imaging through narrow band filters and objective prism observations through an aperture plate.

between models of galaxies. The determination of the mass distribution requires therefore observations of σ extending to even fainter surface brightness than has been done up to now. Table 1 shows that decisive observations are prohibitively long with a 4 to 5 m telescope and can be carried out successfully only with a very large telescope.

4. ELLIPTICAL GALAXIES

The impetus for this study is to obtain an accurate description of the structure, the velocity field and the stellar population of ellipticals as a necessary step torwards understanding their formation process. There the hope - possibly the dream - is to obtain some information on the gas before collapse if a significant memory of pregalactic conditions is retained.

There are three sets of data that one would wish to acquire (i) the light distribution which is related to the triaxial structure. This requires very high S/N two dimensional photometry and is not discussed here. (ii) the chemical gradient which suggests a process of enrichment during collapse (Eggen, Lynden-Bell and Sandage 1962; Larson 1975; Carlsberg 1984) and (iii) the velocity and velocity dispersion in function of the distance from center which is related to the topic of the previous section.

These parameters characterizing galaxies depend on the total mass, the ellipticity and the environment and thus numerous galaxies must be observed in order to separate these effects.

In the case of large nearby galaxies (up to the distance of the Virgo cluster) significant variations of the parameter values take place on scales of several arc seconds, and thus larger than the seeing disk (except near the center where the surface brightness is rather high), and in principle a large entrance aperture could be used. In contrast, for more distant galaxies such as galaxies in rich clusters, cD, radio galaxies, decisive progress requires the use of a very large telescope because significant gradients in σ or in metal abundances occur on the scale of the seeing disk. For example for a galaxy in Coma at ~ 100 Mpc, the effective radius, $r_e \sim 5$ kpc, corresponds to only 10 arc sec and one cannot increase the entrance aperture of the spectrograph much above the size of the seeing disk without losing precious spatial information.

Information on the chemical gradient comes from observations of line strength in the optical range. The gradient of some lines is well established in particular the strengthening of Mg2, CN and NaD toward the center (Faber, 1977).

TABLE 1

Integration Time (hours)

Resolution 0.1 Å		Read out noise 100
Efficiency 0.03		loss at slit 0.25
S/N = 50		
m_V	8m	4×8m
16	1.4	-
18	11	2.2
19	33	6.3
20	120	18

Resolution 1.0 Å		Read out noise 100
Efficiency 0.12		loss at slit 0
S/N = 20		
m_V	8m	4×8m
21	<2	<2
22	2.2	<2
23	10	2.5
24	50	12
25		34

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The interpretation of this variation in terms of metal enrichment is not clear because the variations in iron-peak spectral features which have recently been detected are much smaller than expected from the gradients in the other lines (Faber, 1983). This suggests that one should go back to K-giant stars and globular clusters to improve the calibration of the relation between line strength and metallicity, and observe the gradient in line strengths in galaxies in as many lines as possible, and in particular faint unsaturated lines.

The data quality must be exquisite as the velocity dispersion must be determined simultaneously with the line strength. Table 1 gives examples of the exposure times to obtain spectra with a resolution $R \sim 5 \times 10^3$ and $S/N = 20$ at radial distances equal or larger than the effective radius.

Observations in the near IR constitute another promising way to study the gradient in metallicity and stellar mix. The CO index (2-3μ) is a sensitive indicator of the number of giants to dwarfs, the H_2O index (2.0μ) indicates the contribution of very late M stars and the U-K colour appears to be an indicator of metallicity. So far these indices have been measured only in the central regions of different galaxies (Frogel et al. 1978) but the construction of very large telescopes and progress in infrared detectors will make it possible to measure them as a function of radius. This is extremely desirable in view of the complexity of the interpretation of chemical gradients measured in the optical range as mentioned above.

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