Great Expectations

J. H. Oort

Professor Jan H. Oort from the Leiden Observatory in the Netherlands is one of the founders of ESO and one of the most ardent supporters of collaboration in European astronomy. We are extremely pleased to bring his comprehensive views on the utilization of the VLT. During many decades of active front-line research in astronomy, Professor Oort has inspired numerous programmes and astronomers. We trust that the readers will share his enthousiasm for what the VLT can contribute to cosmology!

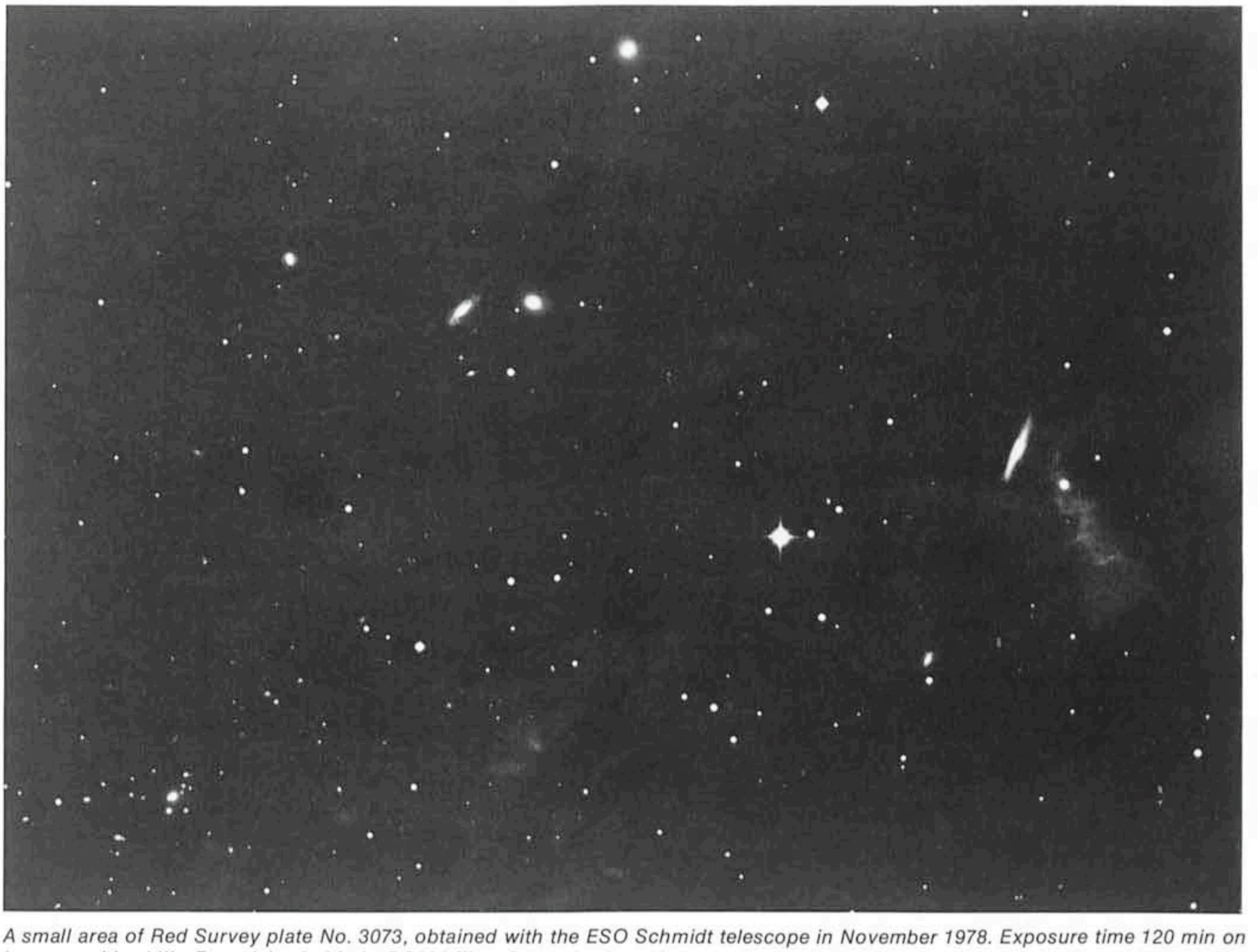
The Very Large Telescope of the future raises great expectations for cosmologists. For might it not provide answers to two fundamental questions:

I. In which era of the Universe were the majority of the galaxies formed, and in which era the majority of galaxy clusters? Were the galaxies there prior to the clusters, or did they condense as a consequence of the cluster formation? And what place have the quasars in this?

II. What is the radius of curvature of the Universe?

Evolution in the Universe: Radio Galaxies and Quasars

The discovery by Ryle and his collaborators of the excess density of faint radio sources which revealed that the space density of radio sources increases strongly when looking back in time, and the subsequent confirmation and specification of this density increase by means of quasar redshifts



A small area of Red Survey plate No. 3073, obtained with the ESO Schmidt telescope in November 1978. Exposure time 120 min on hypersensitized IIIa-F emulsion behind a RG630 filter. Several galaxy clusters are seen. Note in particular the very distant cluster in the lower left corner.

by M. Schmidt and others have shown that their population density increases with the redshift z as approximately $(1+z)^6$. At z = 2 the number per co-moving volume (i.e. a volume of which the radius contracts by a factor 1+z) is of the order of 10^3 times that in our vicinity. As quasars are short-lived their birth rate at z = 2 must have been higher by the same factor. The rapid increase seems to come to an end between z = 2 and z = 3. The largest redshifts known today are around z = 3.5. The fact that no larger redshifts have been found may indicate that they are indeed rare, though it is not yet clear how much of this scarcity is caused by observational limitations.

Two important new data have recently appeared on the evolution front. The first is the evidence that ordinary radio galaxies (non-quasars) show a similar increase in number density with z as the quasars, or perhaps an even stronger one. This was found from deep optical identifications of very weak sources. An interesting circumstance is that they show this strong increase already at relatively small distances.

The second interesting observation is that the colours of many parent galaxies of radio sources seem to be considerably bluer than those of other elliptical galaxies. If this is confirmed it may indicate that many of the distant radio galaxies are young systems. Alternatively, they might be old systems showing a burst of star formation. It should be mentioned that similar blue colours have recently been observed in two distant galaxy clusters which are not known to be connected with radio sources.

Quasar and Galaxy Births

The first question which arises is whether the births of quasars and radio galaxies are connected with the births of galaxies.

It is not implausible to assume that quasars form as a result of the collapse of a protogalaxy or of the evolution of a dense stellar core in a young galaxy. As a strong central concentration and a large mass would seem to be necessary conditions, one would expect to find quasars connected with giant elliptical or N galaxies. But it is also conceivable that the production of a quasar could be a repeating process, such as we observe in some radio galaxies; however, the observed rapid decline in quasar frequency below z = 2 is a strong indication that after the era $z \sim 2$ galaxies rapidly lose their ability to make quasars.

We must envisage two possibilities: either the parent galaxies of quasars were largely born around z = 2, or they were formed in an earlier era, and it was only around z = 2 that conditions within them became favourable for the formation of a quasar or the development of strong radio emission. As long as there is no indication why this could have happened at a more or less arbitrary time in the life of a galaxy, the first possibility appears more attractive.

I assume that the life time of a quasar is short compared with the age of the Universe and that therefore the number density at a given z is a measure of their birth rate at that z. The radio *galaxies* will have longer lives, but still rather shorter than the age of the Universe, otherwise they could not show the observed increase in number density. A comparison of the density increase of radio galaxies with that of quasars might give an indication about their life times. For small z their density should rise more steeply than that of the quasars. Indications of such an effect have indeed been found. Because *clusters* of galaxies have very long lives, they would not be expected to show an appreciable change in number density with z. However, *their* history and evolution is likely to be largely determined by other factors beside the birth rate of galaxies.

In this note I adopt as a working hypothesis that the number density of quasars is proportional with the birth rate of giant elliptical galaxies. This is certainly oversimplistic, and the observations will undoubtedly show that the hypothesis is inadequate. But it may nevertheless serve to suggest which observations are crucial, and to give an impression of what they might yield.

Clusters of Galaxies

One way in which we might possibly find out more about the character and the manner of formation of quasars and radio galaxies is to investigate whether they are members of groups or clusters of galaxies. If they are, their relatives in these formations may give new information on their distances and in particular provide data on *ages*.

In the case of the radio *galaxies* we know that a large fraction does lie in clusters. Moreover, for the radio galaxies the age problem can be tackled more directly, because the parent galaxy itself can be observed. As mentioned above, it has recently become possible to do this down to very faint limits, up to $z \sim 0.5$.

For optical investigations into the still more distant past the quasars are the obvious sign posts. They are at present the only objects which we can observe at the time where on our working hypothesis maximum star formation would have occurred.

Except for the increase in number density with increasing z our knowledge of the evolution of quasars in very scant. It is largely confined to statistics of the redshifts of their absorption spectra. It is conceivable that more detailed optical and radio studies will yield criteria to distinguish quasars of different absolute magnitude. This would evidently be of tremendous value, as it might lead to a direct determination of the radius of the Universe. I return to this in the last section.

It would, of course, be of primary importance to know more about the systems in which quasars are located. Kristian and others have shown that the quasars for which 200" plates could be expected to show the light of the underlying galaxy *did* show such a galaxy. But there are as yet no data that give convincing evidence concerning the type of the galaxy or its age. Especially the latter is important in connection with our working hypothesis. But in view of the difficulty of separating the bright quasar image from that of the surrounding galaxy it seems unlikely that much information could be obtained from ground-based telescopes. I therefore omit this from my list of observing programmes.

Are Quasars in Clusters of Galaxies?

A programme better adapted for the VLT would be the search for galaxies associated with the quasars through their common membership in a cluster or group, and the study of their types and colours.

At present little is known about the connection between quasars and clusters. As the more nearby quasars (with $z < 0.5$) have visual absolute magnitudes between about –24 and –28 (if we assume a Hubble constant $H_0 = 75$ kms^{-1} Mpc^{-1}) while the first-ranked cluster galaxies have –22.1 on the same scale, we should expect to find a few galaxies at magnitudes between 2^m and 6^m fainter than the quasar if the quasar would be situated in a regular cluster. Generally such a cluster would contain some 20 members in an interval of $1^m.5$ below the brightest member, i.e. to a limit roughly 5^m

fainter than a quasar of $M_V = -26$. As quite a number of quasars are known with $m_V \leqq 16.0$, and as searches for clusters must have been made, it is somewhat surprising that only two cases of clusters around quasars have been reported. Stockton (*Astrophys. J.* **223**, 747) has, however, recently reported that in a search around 27 quasars with $z < 0.45$ he has found from 1 to 3 galaxies with a redshift corresponding with that of the quasar in the vicinity of 8 of them.

Further investigations are evidently required before one could conclude that quasars are less commonly associated with clusters than supergiant elliptical galaxies in general. It is an important problem and should well repay a programme with the VLT. I assume, somewhat arbitrarily, that with this telescope it will be possible with special effort to detect galaxies down to $m_V = 24$. The estimate is based on the results of recent optical identification programmes of weak radio sources with the Kitt Peak 4 m reflector, in which galaxies were found down to $m_{pg} = 23$. If a large fraction of the quasars *are* in clusters the VLT should make most of these clusters observable, and should even enable astronomers to make fairly extensive colour measurements. In this way it may well be possible to determine whether the galaxies in these clusters are as young as the quasars are supposed to be on our working hypothesis.

Suggested Programmes

On the basis of the above considerations the following programmes are suggested:

1. Optical identifications in at least two wavelength bands of radio sources down to the faintest attainable radio limits, and search for evolution effects in the galaxies identified with the sources.

1a. Rough determinations of redshifts for a few of the faint galaxies, for verifying the absolute magnitude calibration.

2. Searches for galaxy clusters around the identified galaxies.

3. A search for clusters around quasars (again at at least two wavelengths).

4. A search for distant clusters containing *no* radio sources, in order to investigate how *their* number density varies with z. On our hypothesis it should not vary in a way comparable to that of the quasars.

(1) A recent investigation (H.R. de Ruiter, doctor's thesis Leiden, 1978; cf. also *Astron. Astrophys. Suppl.* **28**, 211) has shown that with special efforts observations with the Kitt Peak 4 m telescope can reveal galaxies as faint as the 23rd photographic magnitude, and that, with this limit, 47 % of all radio sources stronger than about 5 mJy at 1415 MHz could be identified, and that even at the fainter magnitudes galaxies could be distinguished from point sources. The percentage of optical identifications increases rapidly with the limiting magnitude and the scale of the plates. On Palomar 48" Schmidt plates with a limiting magnitude of $22^{m}.5$ it was only 23 %. The VLT should certainly go considerably deeper than the Kitt Peak telescope. If we assume that with special recording techniques it may reach $m_V = 25$ or 26 it will probably make possible the identification and colour measurement of nearly all radio sources found in the deep surveys.

(2) According to Sandage the average visual absolute magnitude of powerful radio galaxies is $\langle M_V \rangle = -21.6$ with a dispersion of ± 0.44 (for $H_0 = 75$). As a first-ranked cluster galaxy has $\langle M_V \rangle = -22.1$, and a score of the brightest members of a cluster should have M_V brighter than ~ -20.5, it should be possible to discover clusters around at least the brighter half of the identified radio galaxies. The stage of evolution of the cluster could then be studied from measurements at two or three wavelengths.

(3) Should evidently be started with quasars at small redshift. If the quasar it situated in a cluster several dozen members should be observable for redshifts smaller than 0.5. Hopefully, clusters might even be discovered at redshifts as large as 1.0. It is clear that a negative result would also be valuable and intriguing.

(4) A systematic survey down to $m_V = 25$ of, say, 100 square degrees might well yield a sizeable number of clusters to well beyond $z = 1$.

Intrinsic Brightness Criteria for Quasars and the Radius of the Universe

I imagine that at the time the VLT would come into operation this might well be the subject that should have highest priority. Detailed spectroscopic data would be likely to be an important asset, but the few indications that have so far been found give no sufficient basis for outlining a programme at the present time.

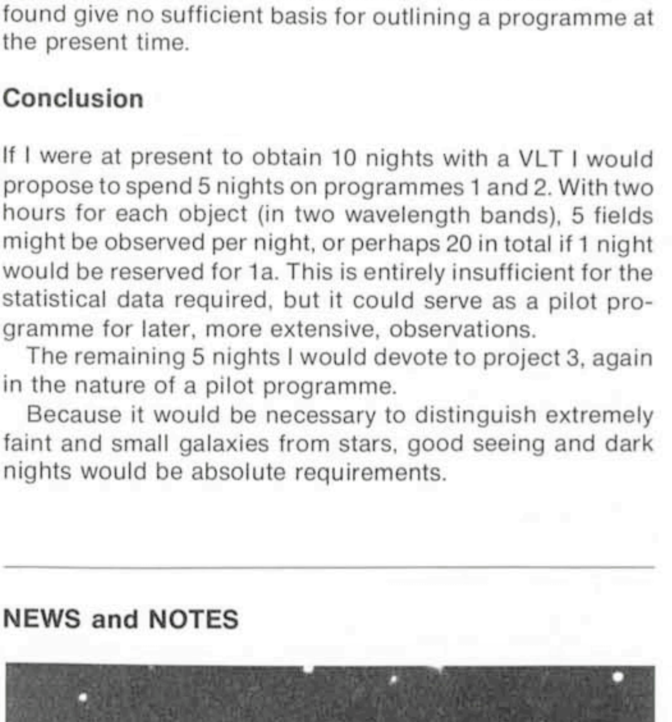
Conclusion

If I were at present to obtain 10 nights with a VLT I would propose to spend 5 nights on programmes 1 and 2. With two hours for each object (in two wavelength bands), 5 fields might be observed per night, or perhaps 20 in total if 1 night would be reserved for 1a. This is entirely insufficient for the statistical data required, but it could serve as a pilot programme for later, more extensive, observations.

The remaining 5 nights I would devote to project 3, again in the nature of a pilot programme.

Because it would be necessary to distinguish extremely faint and small galaxies from stars, good seeing and dark nights would be absolute requirements.

NEWS and NOTES



Was it Really a Comet?

Most comets found by professional astronomers are first seen as a diffuse trail on a photographic plate.

In the middle of December 1978, astronomer Richard West of the ESO Sky Atlas Laboratory in Geneva was checking a lot of deep, red plates from the Schmidt telescope on La Silla when he discovered what appeared to be the trail of an 18th magnitude comet. Since the plate in question was taken a fortnight earlier, control plates were immediately obtained in Chile at the extrapolated positions (the direction of motion was not known from the trail).

To some surprise, no comet was seen on the additional plates. There are only two explanations: either the comet had become too faint to be photographed, or the trail was a "plate fault" in the emulsion. The first possibility cannot be ruled out and the second may be less likely because of the well-defined trail and the attached "tail". We shall probably never know the correct answer.