Summer Student Lecture Notes -- 1974

QUASARS

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I. How Will I Recognize a QSO* if I See One?

Since the physical nature of quasars is still somewhat mysterious, the class of objects so named is defined observationally, and as follows:

1) Star-like objects, often identified with radio sources.
2) Variable light (and often radio) output.
3) Large UV flux.
4) Broad emission lines; sometimes absorption lines.
5) Large redshifts.

Although first isolated because of their radio emission, most QSO's are relatively radio-quiet; only about 1 in 300 is more intense than 9 f.u. at 178 MHz (the 3CR Catalogue limit). Common method of finding QSO's is to utilize their blue-ness (point 3 above; also see color-color plot next page) which is easily discerned by comparing red and blue Palomar prints. Only conclusive test is spectroscopy, particularly to verify point 5). Wisps were seen in several of the

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*Since the term "quasar" has been severely deprecated by many astronomers, we use the more genteel term "quasi-stellar object," or QSO.

earliest identified QSO's (3C48, 3C273, 3C196), but this feature has not proved to be common.

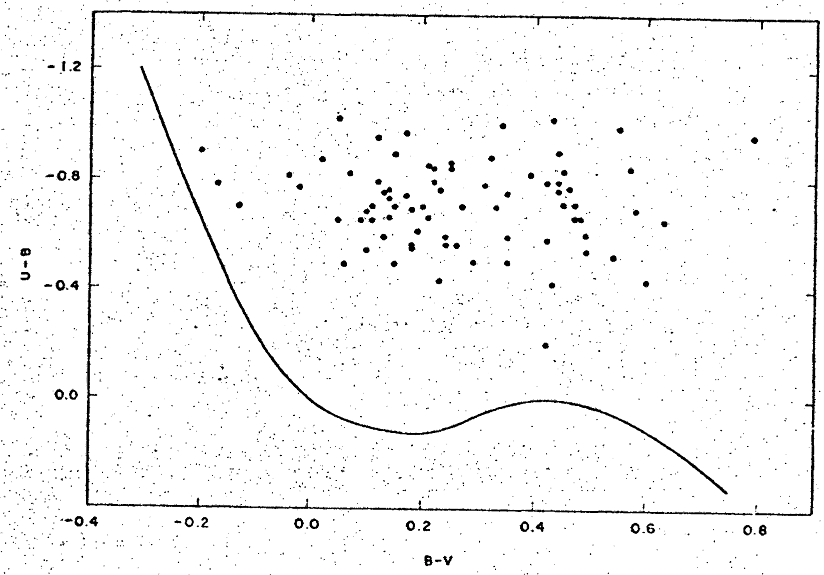

FIG. 2.1 *Two-color plot for all QSO's with measured colors in Table 1.2. The curve is the locus of normal unreddened galactic stars (highest temperature at upper left). The points are QSO's.*

II. Why Should I Care?

The QSO's are, firstly, interesting in and of themselves. If cosmological (i.e., if one may correctly interpret the large observed redshifts as being due to the general expansion of the universe, and consequently infer that the QSO's are at great distances), these objects possess the following properties for confounding theoreticians:

1. Optical luminosities up to 100 times that of the brightest known galaxies. Except for the occasional wisps, QSO's are unresolved optically.

2. Radio luminosities comparable to the strongest radio galaxies -- 10^{43} to 10^{45} ergs s^{-1}. Radio structure often includes a double source component with implied separations of ∿100 kpc. VLB interferometry has revealed radio cores with dimensions less than 10^{-3} arcsec (5 - 10 pc). In any given case, QSO's are indistinguishable from the radio galaxies except by

their optical properties. Statistically, they have generally more compact radio sizes.

3. Strong, broad (up to $\sim$1000km s^{-1} wide) emission lines, similar to those found in Seyfert nuclei and planetaries.

4. Narrow absorption lines sometimes present, with redshifts z^*_{abs} slightly less than the emission lines. Suggestive of a thin (hence non-broadening) shell of cooler gas blown off from the QSO. However, in at least one case the redshift of the absorption line system is <u>greater</u> than z_{em}. Collapsing shells? Absorption line systems are also occasionally multiple. Multiple shells?

5. Non-thermal radio and optical continuum, with a maximum in the infra-red. Usually ascribed to synchrotron mechanism -- note that the resulting energy requirements are $\sim 10^{61}$ ergs.

6. Optical and radio variability on time scales of days to years. The emission lines do not vary, suggesting that they arise in a physically larger region than the continuum.

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*Redshift z is defined as $z = \Delta\lambda/\lambda$. Thus, classically, the radial velocity is $v = cz$. When special relativity is invoked,

$$v = c \frac{(1+z)^2 - 1}{(1+z)^2 + 1},$$

e.g. $v = 0.8c$ for $z = 2$.

Many theoreticians have addressed themselves to the problem of modeling the QSO's. To date, none has been successful in finding acceptance beyond wife and family. The biggest problem, again assuming cosmological distances, is that of producing the huge amounts of energy observed in the radiation field in a compact volume. The most popular energy source is gravitational collapse, either involving multiple supernovae or massive stars or stellar systems. Some have suggested that new physics is required.

Beyond deciphering the QSO's themselves, their great distances promised to make them the answer to the cosmologist's prayers. In particular, with redshifts z ∿2, we see back about four-fifths of the way to the "big bang." That is,

1. If QSO's all have approximately the same intrinsic luminosity (i.e., if they are "standard candles"), we can compare luminosity distances with redshift distances, find deviations from the Hubble law and establish reasonable cosmological models. Unfortunately, as can be seen from the accompanying graph, QSO's are hardly "standard candles."

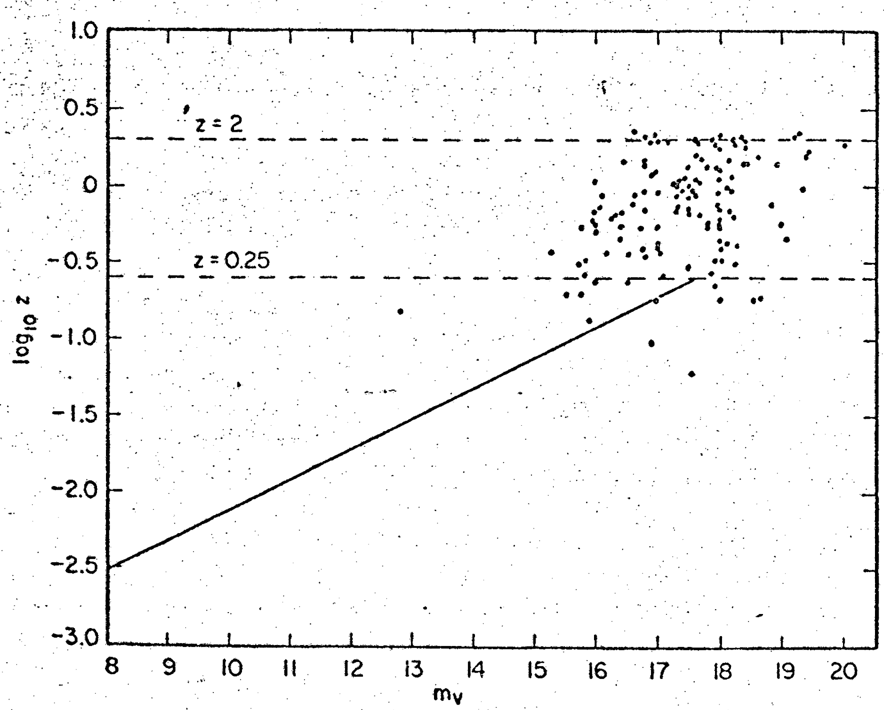

Fig. 5. The redshift-apparent magnitude relation for 136 QSOs. The full line is the Hubble relation for brightest cluster member galaxies (reproduced from Burbidge and Burbidge (1969)).

A similar scatter diagram obtains if one uses radio luminosity.

2. One might hope to study the homogeneity of the universe over a scale larger than the superclusters of galaxies. We could even expect that QSO's might be sensitive indicators of matter density. To date, claims of anisotropy in the distribution of QSO's over the sky have involved heterogeneous material, and are consequently uncertain (but, see discussion of Arp's claims below). There is substantial evidence for an overabundance of faint QSO's (or a local deficit of bright ones). The implication is that the volume density of QSO's increases approximately as $(1+z)^6$. The local density of QSO's is $\sim 10^{-8}$ Mpc^3, and this increases by a factor of 100 at z=1.

3. We should be able to deduce chemical abundancies from line strengths. Curiously, fairly good agreement with observations is obtained using solar abundancies. (An exception is He, which seems underabundant in QSO's.)

4. One would hope to learn of the distribution of gas and galaxies along the line-of-sight to the QSO's. So far, no absorption, either optical or radio, has been detected.

III. Can They Shift For Themselves?

Currently the number one problem with regard to the QSO's, and a matter of no little controversy, is the meaning of the redshifts. In this tract we have assumed the redshifts are cosmological and can be interpreted in the same way as for ordinary galaxies. This view has long been the most popular one, but has recently been subject to increasing challenge. Causes of the redshifts can be separated into four catagories:

1. Cosmological
2. Gravitational (photons are "tired" after escaping a very massive object.
3. Local Doppler (QSO's have been blown out of our own or nearby galaxies.)
4. Metaphysical.

Gravitational configurations which can produce the observed redshifts and linewidths are somewhat artificial. Blasting QSO's out of local galaxies (so they will have time to pass us and thereby explain the lack of blueshifts), and at relativistic velocities, requires considerable energies. Furthermore, the ejection of $\sim 10^6$ QSO's (the estimated minimum number) seems improbable. Metaphysical explanations (i.e., requiring unsuspected or even new physics) are suggested by Arp's claims of an association between QSO's and nearby and peculiar galaxies.

IV. So Near, Yet So Far.

Let us, for convenience, divide the protagonists of the redshift debate into two camps: those who maintain that the QSO's are at cosmological distances, and those who don't. We list below arguments used by each side, though it must be said that observations can be (and frequently are) used to support both points of view by use of alternative interpretations.

Evidence That QSO's Are Cosmological

1. No proper motions detected. (Merely constrains QSO's to be $\geq$10 Mpc.)

2. No observed blueshifts.

3. Some recent evidence that, for steep spectrum QSO's, radio angular size decreases with increasing redshift.

4. The association of a few nearby (z <0.2) radio quiet QSO's with galaxy clusters of the same redshift. Gunn, using the 200" telescope, has found a radio QSO (PKS 2251+11) with the same redshift (z=0.32) as a nearby galaxy.

5. The slope of the log N - log S plot is $\sim$ -1.8 for QSO's. (Used to infer source evolution -- excess of weak sources -- as discussed above). Any reasonable grouping of local objects would be expected to have the classical -1.5 slope.

6. Continuum of properties (see figure).

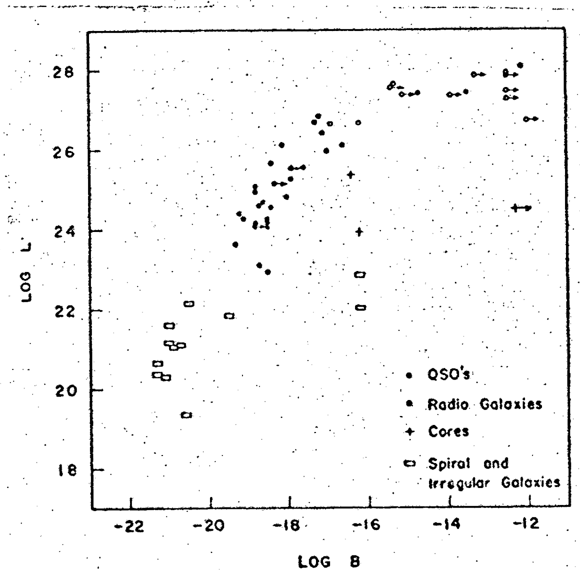

FIG. 16.1 *The absolute radio luminosity L and surface brightness B at 1400 Mc/s for quasi-stellar objects, radio galaxies, and spiral and irregular galaxies.* [*After Heeschen (1966).*]

The QSO's require only an extension of the sequence: normal galaxies, radio gals., Seyfert gals., N gals., QSO's.

7. No new physics required (aesthetic argument).
8. 21-cm absorption at z=0.69 in 3C 286.

Evidence That QSO's Are Local

1. No clear redshift-magnitude relation (see first figure).

2. Evidence of "supra-light" expansions in 3C273, 3C279.

3. Generally (with exceptions noted in point 4, last section) not associated with clusters of galaxies.

4. Absence of detected intergalactic absorption.

5. Existence of a few double radio sources, likely to be QSO's, with 30 arcmin separations.

6. Apparently normal chemical abundancies.

7. Evidence for abnormally large number of QSO's with redshift z = 1.95. Suggests an "intrinsic" redshift mechanism.

8. Lack of QSO's with z >2.5. Could be that all were formed after the time corresponding to z = 2.5. Or, could be UV excess doesn't exist beyond this redshift. Possibly QSO light is cut off by intergalactic HI which existed in greater abundance at earlier epochs.

9. Statistical correlations of QSO's (and radio galaxies) and Arp, Vorontsov-Velyaminov peculiar and interacting galaxies.

10. Arp's position correlations of QSO's and nearby bright galaxies -- distance between QSO and companion galaxy decreases with increasing galaxy redshift.

V. Suppose I Want to Know More?

A good review article, current to 1966, is

E. M. Burbidge, Ann. Rev. (1967), 5, 399.

This material is covered in more detail in the Burbidge's book

Quasi-Stellar Objects (1967, W. H. Freeman and Co.)

An article updating the Burbidge material by two years is

M. Schmidt, Ann. Rev. (1969), 7, 527.

A lot of recent work can be found in

IAU Symp. No. 44 (1972, D. Reidel Pub. Co.)

See M. Rees' article in particular.

Arp has summarized some of his more controversial data in

H. Arp, Science 1971, 174, 1189.

A somewhat different approach to the same problem is given by

G. R. Burbidge, 1973, Nature, 246, 17.