Both the observed flux densities and rates of increase (about 10 per cent per year) in the emission of NGC 1275 and the quasi-stellar source 3C 273B at 8000 Mc/s are comparable, while the redshift of 3C 273B is about ten times that of NGC 1275. The similarity in the rates of increase of NGC 1275 and 3C 273 could suggest that their radio luminosities may also be comparable, in which case the distance of 3C 273 would be much less than the cosmological distance inferred from its redshift. If, however, quasi-stellar sources are at cosmological distances, then the variable component of NGC 1275 is about 100 times less luminous than the variable component of 3C 273B and the observed radio variability of NGC 1275 provides further evidence that the nuclei of Seyfert galaxies are a related but less energetic phenomena than quasi-stellar sources.

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ABSORPTION LINES IN THE SPECTRA OF DISTANT SOURCES

We discuss the properties of absorption lines that might appear in the continuum spectra of distant quasi-stellar sources (henceforth abbreviated "QSS") and outline what can be learned from a search for such lines. We consider first absorption by intergalactic gas in clusters of galaxies that are in the line of sight. We extend our previous discussion (Bahcall and Salpeter 1965)[1] of absorption lines caused by neutral hydrogen

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[1] Eq. (6) of our paper should contain the factor $(\nu/100\text{ Mc/s})^{-4}$ instead of $(\nu/100\text{ Mc/s})^{4}$ Observations of the ultraviolet spectra of 3C 9 (down to 3100 A by Wampler [1965]) and of 0106+01 (Burbidge 1966) enable one to conclude that the cosmological number density of molecular hydrogen is less than 10^{-10} cm^{-3} if it is uniformly distributed.

to resonant absorption lines in other elements and use a variety of cosmologies to estimate some of the uncertainties. If the intergalactic gas in clusters has relative abundances comparable to those inside our Galaxy, densities above 10^{-5} cm^{-3}, and temperatures below 5×10^5 ° K, a number of different ion species could cause pronounced absorption lines; we present a table of the spectral lines expected to be prominent in absorption for various temperatures. The detection of more than one absorption feature in the same spectrum corresponding to the same redshift for the absorber would help to eliminate the possibility that an apparent absorption feature was really a valley between two emission peaks. In particularly favorable cases identification of the absorber with an optically detectable cluster might be possible. A number of QSS's are known with sufficiently large redshifts so that an interposed cluster might contribute several absorption features redshifted into the visible. The characteristics (such as wavelengths, depth, and width) of absorption lines formed in clusters of galaxies could provide otherwise unobtainable information about distant clusters (such as the temperatures, chemical composition, and velocity dispersion of the absorbing gas).

We show in what follows that the identification of absorption lines with a common redshift appreciably different from that of the emitting QSS's would provide strong evidence for the hypothesis that the redshifts of QSS's are of cosmological origin. We also discuss absorption features which could be formed by gas clouds in the neighborhood of a QSS and which might lead (under special circumstances) to apparent variations in the observed wavelengths of some QSS emission lines.

A program is under way at the California Institute of Technology (J. N. Bahcall, B. A. Peterson, and M. Schmidt) to search for absorption lines in spectra (taken by Schmidt) of QSS's.

I. ABSORPTION LINES CAUSED BY SOURCES AT COSMOLOGICAL DISTANCES

We express the cosmological "distance" of any object relative to us in terms of its redshift parameter, Z ($Z \equiv \Delta\lambda/\lambda_0$) and consider, besides the steady-state model, evolving cosmologies with positive deceleration parameters q_0 and zero cosmological constants. As a prescription for the variation of cluster parameters with cluster distance, Z_{cl}, we assume (for evolving cosmologies) that (i) the number density of cluster of galaxies is proportional to $(1 + Z_{\text{cl}})^3$, and (ii) (from ignorance rather than conviction) the radius of a typical cluster is independent of Z_{cl}. A different set of assumptions for the variation of cluster parameters would probably lead to predictions that differ from the ones given here by not much more than the spread between the predictions of typical cosmologies.

Let $N_0 Z$ be the fraction of the sky covered by clusters of galaxies out to a redshift Z that is much less than unity. The observations of Zwicky and his associates (Zwicky and Rudnicki 1963; Zwicky and Berger 1965; Zwicky and Karpowicz 1965) give values in the range of $N_0 \approx 4$ (a factor of 5 less than our previous crude estimate). The expected number of clusters along the line of sight between us and a distant object with redshift Z_s is then $N(Z_s)$, where

$$N_{\text{ss}}(Z) = N_0 \ln (1 + Z) \quad (1)$$

for the steady-state cosmology and

$$N_{q_0}(Z) = N_0 q_0^{-1}[(1 + 2q_0 Z)^{1/2}(1 + Z) - (3q_0)^{-1}(1 + 2q_0 Z)^{3/2} + (3q_0)^{-1} - 1] \quad (2)$$

for the evolving cosmological models.

The expected number of absorption lines (with rest wavelengths λ_{res}) in the continuum spectrum of a source with redshift Z_s is $N(Z_s) - N(Z_{\text{min}})$, where $1 + Z_{\text{min}} = (\lambda_{\text{min}}/\lambda_{\text{res}})$ and λ_{min} is the minimum observed wavelength (3200 Å for terrestrial observations) at which photons from the source can be detected. In an observed wavelength region $\Delta\lambda(\ll \lambda_{\text{min}})$, one expects $N_0(\Delta\lambda/\lambda_{\text{min}})$ lines on the steady-state model and $[(1 + Z_s)^2/(1 + 2q_0 Z_s)^{1/2}]N_0(\Delta\lambda/\lambda_{\text{min}})$ lines on the evolving models. The expected number of

Lyman-α absorption lines ($\lambda_{\mathrm{res}} = 1216$ Å) formed by clusters of galaxies in the spectrum of a source with $Z_s = 2.0$ (exceeded by 3C 9 and 0106+01) is about 0.5 for the steady-state model and about 2 for the $q_0 = +1$ model. The corresponding numbers for the C IV line ($\lambda_{\mathrm{res}} = 1549$ Å) are about 1.5 and 5, respectively. The expected number of absorption lines due to individual galaxies is about two orders of magnitude less than the expected number for the gas supposed distributed between the galaxies in a cluster.

An absorption line caused by the gas inside a given cluster of galaxies is Doppler-broadened by the motion of the gas. The observed total width at half-maximum of any line satisfies

$$(\Delta\lambda/\lambda)_{\mathrm{obs}} \approx 2v_{\mathrm{gas}}/c\,, \tag{3}$$

where v_{gas} is a measure of the random velocities of gas in the cluster. The observed velocity dispersion, v_{disp}, among the galaxies in a given cluster is of the order of 10^3 km/sec. The speed, v^H, required to cross a cluster diameter ($\sim$1.5 Mpc) in a Hubble time is $v_0{}^H \sim 150$ km/sec on the steady-state model and $\sim(1 + 2q_0Z_{\mathrm{cl}})^{1/2}(1 + Z_{\mathrm{cl}})v_0{}^H(> v_0{}^H)$ for evolving models. We conjecture that v_{gas} is of the same order of magnitude as v_{disp} or v^H, i.e., $v_{\mathrm{gas}}/c \sim 10^{-2.5\pm0.5}$ (the cosmological differential expansion velocity across a cluster diameter is also of this order of magnitude).

The optical depth for resonant absorption in a cluster of galaxies is

$$\tau_{\mathrm{cl}} \approx \left[\left(\frac{v_0{}^H}{v_{\mathrm{gas}}}\right)\left(\frac{f_{\mathrm{res}}}{f_{\mathrm{Ly}\text{-}\alpha}}\right)\left(\frac{\lambda_{\mathrm{res}}}{\lambda_{\mathrm{Ly}\text{-}\alpha}}\right)\left(\frac{R_{\mathrm{cl}}}{1\ \mathrm{Mpc}}\right)\right]\frac{n_{\mathrm{cl}}}{3\times10^{-11}\ \mathrm{cm}^{-3}}\,, \tag{4}$$

where λ_{res} and f_{res} are the wavelength and oscillator strength of an absorption line caused by an absorber with average number density n_{cl} in the cluster of radius R_{cl} and $\lambda_{\mathrm{Ly}\text{-}\alpha} = 1216$ Å, $f_{\mathrm{Ly}\text{-}\alpha} = 0.42$. The factor in square brackets in equation (4) is expected to be of order unity.

There is at present no observational evidence concerning the chemical composition of the gas in a cluster of galaxies. If the gas is primordial and contains only hydrogen and helium, then the only expected absorption lines, for sources with $Z_s \leq 4.4$, are those from the hydrogen Lyman series (Ly-α, Ly-β, etc.). The gas density in a cluster is not known, but values in the range of 10^{-5} cm^{-3} to 10^{-2} cm^{-3} are of interest (for the smaller value the gas in a cluster has the same density as the continuous substratum in typical cosmologies, and for the larger value the gas in clusters has a mass roughly equal to the total mass in the universe in typical cosmologies). The electron kinetic temperature is also not known but observations of the isotropic X-ray background give an upper limit of the order of 10^6 ° K and some theoretical arguments suggest (cf. Gould and Ramsey 1966) a lower limit in the vicinity of 10^4 ° K. For most (but not all) of the temperature-density range mentioned above, the lower members of the Lyman series yield values of $\tau_{\mathrm{cl}} \gtrsim 1$ and therefore dark absorption lines.

If there is some interchange of gas between the galaxies and the intergalactic space in a cluster, then the relative heavy-element to hydrogen abundances could be comparable with the abundances usually found in gaseous nebulae in our Galaxy (Osterbrock 1963; Aller, 1958). In Table 1, we give the temperature range T_{min} to T_{max} inside which the number density of any ion species of the most abundant elements (galactic abundance $\gtrsim 10^{-6}$ hydrogen) is $\gtrsim 3 \times 10^{-11}$ cm^{-3} for purely collisional ionization (cf. House 1964). In compiling Table 1, we have assumed (again out of ignorance rather than conviction) that the heavy elements have their typical galactic abundances at the lowest total density discussed above, 10^{-5} cm^{-3}, or, equivalently, 10^{-3} of their galactic abundances at the highest total density, 10^{-2} cm^{-3}; the entry for hydrogen was computed assuming a total density of 10^{-5} cm^{-3}. In the temperature ranges shown, dark absorption lines are expected at the given rest wavelengths (corresponding to ground-state resonance transitions) if other ionization mechanisms are not important and the abundances are at least equal to the values we have assumed. Parts A and B of Table 1 include all lines from ions with the required abundance having wavelengths greater than 1100 Å and ionization potentials in the relevant ranges; Part C includes only a partial list of the strongest lines of the most abundant atoms with ionization potentials less than that of hydrogen (13.6 eV). Note that for ion species with ionization potentials greater than 16.5 eV, which dominate (apart from hydrogen) at $T_e \gtrsim 3 \times 10^4$ ° K for our assumed abundances and conditions, there are only ten resonance lines above 1100 Å and none above 1860 Å. In the temperature range above 10^5 ° K, the most likely strong absorption lines are the Lyman lines of hydrogen and the resonance lines of C IV and N V (and possibly Si IV). The longer-wavelength lines such as $\lambda_{\rm res} = \lambda$ 2799 Å of Mg II and $\lambda_{\rm res} = \lambda$ 2598, λ 2382, and λ 2344 Å and Fe II are only expected to be strong at relatively low temperatures (less than a few times 10^4 ° K). The neutral atoms (except perhaps C I) listed in Part C of Table 1 may be less likely to produce absorption lines since they could be ionized by starlight from the galaxies in a cluster.

TABLE 1

POSSIBLE ABSORPTION LINES

Ion	$\lambda_{\rm res}$ (Å)*	$T_{\rm min}$ (10^4 ° K)	$T_{\rm max}$ (10^4 ° K)
	A. Ionization Potential > 16 5 eV		
C II	1335	0 6	5
C IV	1549	4	20
N V	1240	7	30
Al II	1671	0 6	2
Al III	1857	2	3
Si III	1207	1	4
Si IV	1397	3	5
S II	1259	0 9	2
S III	1190	2	4
Fe III	1123	2	4
	B 13 6 eV $\lesssim$ Ionization Potential $\leq$ 16 5 eV		
H I	1216 (1027 etc)	0	40
N I	1200, 1135	0	3
O I	1302	0	2
Mg II	2799, 1240	0 7	2
Si II	1808, 1527, 1304, 1260, 1192	0 5	2
Fe II	2598, 2382, 2344, 1608, 1261, 1145	0 7	2
	C. Ionization Potential < 13 6 eV		
C I	1657, 1560, 1329, 1280, etc.	0	2
Mg I	2853, 2026, 1828, etc.	0	0 8
Si I	2515, 2209, 2066, 1978, etc.	0	0 8
S I	1807, 1474, 1425	0	1

* For the low densities of interest here, only the ground states (of any of the ions) have appreciable populations. Even the upper components of the ground-state fine-structure multiplets (with energy splittings $\gtrsim 20$ cm^{-1}) decay to the lowest component by magnetic dipole transitions in times short compared to the collisional excitation times The wavelengths listed in Table 1 are average wavelengths from this lowest energy component to the various fine-structure components of the upper state weighted according to the strength of the line.

If the electron temperature, total density, or element abundances are not uniform throughout the thin cylinder through the cluster that the light from a distant source traverses, then absorption features from more than one temperature range of Table 1 may appear. Note also that absorption lines can appear in the continuous spectrum of a distant source even if the corresponding emission line is not present. Close inspection of the continuous spectra of some distant galaxies (as distinct from quasi-stellar sources) might reveal some as yet undetected narrow absorption lines.

II. ABSORPTION BY CLOUDS IN THE VICINITY OF A QUASI-STELLAR SOURCE

Absorption features may also be formed by relatively cool matter outside but near a quasi-stellar source; such absorption lines could, of course, occur even in the absence of the corresponding emission lines (and vice versa). The widths of self-absorption features would probably be narrower than the widths of absorption lines caused by clusters of galaxies and would appear with a redshift essentially equal to the redshift of the emission source. Clouds associated directly with the QSS, moving with comparable speeds to the matter inside, but cooler, could produce a complex shape for the observed emission lines. If the source of a particular emission line is relatively small (as suggested by Bahcall and Wolf [1966] for Mg II), the motion of absorbing clouds in front of the source could lead to apparent changes with time of the shape and center of gravity of the emission line as the absorption line (whose observed wavelength would shift with time) moved relative to the center of the emission line. It is possible that the apparent movement of the observed wavelength of the Mg II emission line in 3C 345 (Burbidge and Burbidge 1966) could be caused by absorption by such clouds.

Any systematic redshift of the self-absorption lines relative to the emission lines would be of special interest. If, as suggested by Bahcall (1966) and Shklovskii (1965), the nebulae of some QSS's are expanding (with speeds $\sim 10^{-2}c$), then the absorption lines would be systematically shifted to the red of their rest wavelengths if the QSS is expanding into a cool medium and to the blue if the absorption is produced by the fastest moving clouds on the periphery of the QSS. In either case, the magnitude of the observed fractional wavelength shift $\Delta\lambda/\lambda$ would be $\sim 10^{-2}\tau/(\tau + 3)$ for a resonance line with an optical thickness τ measured from the surface to the center of the emitting nebula.

III. THE LOCAL HYPOTHESIS

Some authors have suggested that QSS's were ejected at relativistic speeds from a local explosion center, situated in the nucleus of our Galaxy according to Terrell (1964) or in a nearby radio galaxy (such as NGC 5128) according to Hoyle and Burbidge (1966) (see also Hoyle, Burbidge, and Sargent 1966). On both these pictures QSS's are at distances from us of less than 10 Mpc (corresponding to a cosmological redshift $Z < 0.003$), and because of this closeness absorption lines are unlikely to be formed in clusters of galaxies in the intervening intergalactic matter. If one considers absorbers that were formed in the same explosion as the QSS's, one finds that the probability that a QSS of dimension D formed in an explosion a time t ago would exhibit absorption lines displaced from their rest wavelengths by a redshift $\Delta Z(\equiv |Z_{\mathrm{QSS}} - Z_{\mathrm{absorber}}|)$ is $\lesssim (D/c\Delta Z t)$ if the absorber has a linear size $\lesssim D$. This estimate is valid both if the absorber was shot out at the same time as the visible QSS or formed by subdivision of the QSS at a later time. Typical probabilities on a local hypothesis for the appearance of absorption lines with an appreciable $\Delta Z(\gtrsim 0.1)$ are $\lesssim 10^{-6}$. The mass necessary for a large absorber ejected spherically a time Δt ago from the QSS to produce an absorption is $10^{10}\,M_{\odot}$ $(c\Delta t\Delta Z)/1\ \mathrm{Mpc})^{2}$ $(10^{-4}\,\epsilon^{-1})$, where ϵ is the fraction of the total number of particles in the absorber that are in the form of the absorbing ion species. For a large absorber moving in the same direction but lagging behind the QSS, the requisite mass is $\leq 10^{10}\,M_{\odot}$ $(\Delta Z/Z)^{2}$ $(L/1\ \mathrm{Mpc})^{2}$ $(10^{-4}\,\epsilon^{-1})$, where L is the distance of the explosion center from us.

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THE GALACTIC SPURS AS A SINGLE FEATURE

The general radio emission from the galactic system is confined to a band along the galactic equator. This band, roughly between galactic latitude $-15°$ and $+15°$, is undoubtedly connected with the large-scale structure of the system. Outside this band, much weaker emission has been measured by many authors (Blythe 1957; Brown, Davies, and Hazard 1960; Pauliny-Toth and Shakeshaft 1962; Large, Quigley, and Haslam 1962; Turtle and Baldwin 1962; Haslam, Large, and Quigley 1964; Davies 1964; Seeger, Westerhout, Conway, and Hoekema 1965) at various wavelengths. Except for a possible small contribution from a galactic halo, there are several so-called spurs.

In recent years a general belief has arisen that two or three separate spurs can be distinguished and that they are supernova remnants at relatively small distances of the order of 30 pc (Davies 1964). This conclusion is based mainly on the fact that the shape of the spurs can be fitted to small circles (Quigley and Haslam 1965). However, these "arcs" form only part of small circles; the remaining part is thought to be hidden in the general galactic background radiation. Instead of considering the spurs as separate "arcs," one can see if it is possible to connect these various "arcs" in order to get one single feature.

In Figure 1 such a possible single feature has been drawn. One can follow it starting with the north polar spur (*a*) at approximately $l^{\text{II}} = 290°$, $b^{\text{II}} = +40°$. It passes the north galactic pole at a distance of only 15°. From that point on, the brightness increases and it becomes what is generally known as the "galactic spur." At $l^{\text{II}} = 30°$, $b^{\text{II}} = +12°$, it merges with the general galactic radiation. One should note that it is strikingly per-