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ABSORPTION LINES PRODUCED BY GALACTIC HALOS

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ABSTRACT

We propose that most of the absorption lines observed in quasi-stellar sources with multiple absorption redshifts are caused by gas in extended halos of normal galaxies.

Recent work has established that some quasi-stellar sources have multiple redshift systems in absorption (Bahcall 1968; Bahcall, Greenstein, and Sargent 1968; Burbidge, Lynds, and Stockton 1968; Burbidge 1969; Bahcall, Osmer, and Schmidt 1969). A number of possible explanations have been suggested for this phenomenon (Bahcall *et al.* 1968; Burbidge *et al.* 1968; Peebles 1968), but none of the suggestions seem especially plausible when considered in the light of the observed features of the absorption systems. We propose that most of the absorption lines are caused by tenuous gas in extended halos of normal galaxies (see Spitzer 1956 for a review of some earlier work on galactic halos and for a preliminary discussion of the possibility of observing ultraviolet absorption lines formed in such halos).

Our proposal for explaining the observed absorption lines differs from previous suggestions involving galaxies (Wagoner 1967; Shklovsky 1967; Peebles 1968) in that we assume a much larger cross-sectional area for individual galaxies than is indicated by their optical or radio appearance and present a more detailed interpretation of the principal observational features. The probability of intercepting a galaxy along the line of sight is sufficiently large, if galaxies have extended halos, to explain the observations with normal galaxies in standard ($\Lambda = 0$) cosmologies. We first review the observed features of the absorption systems and then show how these features could be caused by galactic halos. We then indicate a possible test of our ideas that could be carried out by means of a satellite-based telescope.

The principal characteristics of the observed absorption systems in PKS 0237−23 and Ton 1530 (see Bahcall 1968; Bahcall *et al.* 1969) are: (1) for absorption redshifts in the detectable range $z_{\rm abs} \sim 3$ to $z_{\rm abs} \sim 1$ about five absorption systems are found; (2) $z_{\rm em} > z_{\rm abs}$; (3) the special-relativistic velocities $v_{\rm rel}$ between emitter and absorbers range from 0.01 to 0.3; (4) the dispersion in velocities for an individual absorption line is $v_{\rm disp} \sim 10^{-4\pm0.5}\, c$; (5) a wide variety of ionization stages of the most abundant elements occurs (they include H I, C II, C IV, Si II, Si III, Si IV, N II, N V, Al II, Al III, and Fe II), but the resonance lines of O I and N I, characteristic of H I regions, are not found; and (6) no lines from metastable levels (e.g., He II λ1640.4 or C III λ1175.5) or from excited fine-structure states are definitely identified. In obtaining characteristic 4, we have made use of the fact that even completely dark lines less than about 0.3 Å in width could not have been detected.

The observed large values for the dimensionless ratio $v_{\rm rel}/v_{\rm disp}$, which sometimes are

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greater than 10^3, lead us to believe that most of the narrow absorption lines are produced in material not associated with the quasi-stellar sources in whose spectra they are detected. A few lines, which correspond to $v_{\rm rel}/c \lesssim 10^{-2}$, may plausibly be attributed to material associated with the emitting object.

The number P of galaxies intercepted between $z_{\rm em}$ and z_c (see Bahcall and Peebles 1969; we assume for simplicity $q_0 = \frac{1}{2}$ and $\Lambda = 0$) is

$$P = 2\left[\frac{R_0}{100\ \rm kpc}\right]^2 \left[\frac{N_0}{0.03\ \text{galaxy Mpc}^{-3}}\right][(1 + z_{\rm em})^{3/2} - (1 + z_c)^{3/2}] . \quad (1)$$

Here R_0 and N_0 are the local radius and number density of the galaxies, and the Hubble constant, H_0, has been set equal to 100 km sec^{-1} Mpc^{-1}. We assume that the galactic number density at z satisfies $N(z) = (1 + z)^3 N_0$ but that the average radius is independent of z (at least in the range $z = 1$–2). The value of 0.03 galaxy Mpc^{-3} used as a standard of reference in equation (1) is somewhat arbitrary and is three times smaller than the density of all galaxies (cf., e.g., van den Bergh 1961) if the mean mass per galaxy is taken to be $10^{11}\ M_\odot$. The reference radius, R_0, of 100 kpc is an order of magnitude greater than the galactic radii normally quoted and even exceeds the radius of 50 kpc suggested for the somewhat controversial halo around M31, observed at 158 and 750 MHz, respectively, by Brown and Hazard (1959) and by de Jong (1965). The maximum radii found for M31 by photoelectric photometry and by 21-cm-emission measurements are even smaller; both methods give about 25 kpc according to de Vaucouleurs (1958) and Roberts (1968). However, all these measures represent not a boundary but rather the radius at which the signal produced by the galaxy becomes indistinguishable from the background. The gas density required to produce absorption lines is so low (see below) that it would not be surprising if the maximum radius for absorption of a measurable line were appreciably greater than the maximum radius detected in other ways.

Applying equation (1), we assume $z_{\rm em} = 2.2$ and a reasonable cutoff in detectable redshifts $z_c \sim 1.2$, caused by the relative paucity of long-wavelength resonance lines (see Table 1 of Bahcall 1968). We then find $P \sim 5$, in agreement with characteristic 1, if $R_0^2 N_0 \approx (100\ \rm kpc)^2\ (0.03\ \text{galaxy Mpc}^{-3})$. Characteristics 2 and 3 are automatically satisfied by any model in which the absorption is caused by objects between us and the emitter but at cosmological distances from the emitter. Assuming that the internal energies and gravitational potential are comparable, we find $v_{\rm disp} \approx (GM/R)^{1/2}c$, or $v_{\rm disp} \sim 10^{-4}c$ for $R = 10^2$ kpc and $M = 10^{11}\ M_\odot$. This result is in agreement with characteristic 4. The wide variety of ionization stages seen suggests that either the halo is not isothermal (and that temperatures in the range 2×10^4 ° to 2×10^5 ° K occur) or else ionization by cosmic rays produces a variety of stages of ionization at any given place. The highly ionized atoms that might be present at temperatures significantly higher than 2×10^5 ° K (e.g., O VI λλ1032.0, 1037.6) could not have been observed because their resonance wavelengths are detectable only for $z > z_{\rm em}$. Any density less than 10^3 particles per cubic centimeter is sufficiently small that characteristic 6 is satisfied (see Bahcall 1967).

For the sake of definiteness we assume that the halo has a radius of 100 kpc at a density of 3×10^{-5} particle cm^{-3}. A typical column of material is then, in agreement with observation, sufficient to produce dark absorption lines for the allowed transitions of the more abundant ions but not for rarer ions such as Sc III, Ti III, Cu II, Mn II, Ge III, and As II. Numerically, for a line of wavelength about 1500 Å,

$$\tau_{\rm abs} \sim 10^{+6} f_{\rm abs}\left[\frac{N_{\rm ion}}{N_{\rm total}}\right]\left[\frac{R_0}{10^2\ \rm kpc}\right]\left[\frac{N_{\rm total}}{3 \times 10^{-5}\ \rm cm^{-3}}\right] . \quad (2)$$

The total mass contained in the halo is $\sim 3 \times 10^9\ M_\odot$. Evidently all these numerical estimates are tentative.

Finally, we remark that the existence of a halo of the kind we have postulated around our own and nearby galaxies could be detected with a satellite telescope, which could measure interstellar absorption lines in the region from 1000 to 3000 Å. The OAO C telescope (Rogerson 1963) should be able to make such measures on a few "runaway B stars," some distance from the galactic plane. To reach the early-type stars in the Magellanic Clouds would require a more powerful instrument, which could obtain spectra with a resolution of 0.3 Å on objects as faint as magnitudes 12–14. Later telescopes in the OAO series (apertures of about 40 inches) could have this capability. The potential usefulness of a 120-inch space telescope for research on galactic halos has been discussed elsewhere (Spitzer 1968). Information obtained from such programs could be of central importance for galactic studies, quite apart from its relevance to quasi-stellar sources.

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