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The minimum size and mass of some quasi-stellar objects

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Abstract. The minimum sizes of four quasi-stellar objects, each of which exhibits an absorption redshift greater than its emission redshift, have been calculated by assuming that the absorption lines originate in clouds which are falling radially towards the quasi-stellar objects along the line of sight, and that the quasi-stellar objects are at a distance inferred from the cosmological interpretation of their redshifts. It has been found that the radii are greater than 10 pc and that the masses are of the order of $10^{12}\,M_\odot$.

1. Introduction

The size of quasi-stellar objects (QSO) has been a matter of great interest. Greenstein and Schmidt (1964) estimated the dimension of the emitting region to be 1–10 pc by considering electron densities and the strengths of forbidden lines, but luminosity variation requires the size of the QSO continuum source to be of the order of 10^{-2} pc. Morrison and Sartori (1968) have discussed the luminosity variation and place an upper limit to the dimension of the emission region in the range 10^3–10^4 pc. Bahcall and Kozlovsky (1969) have discussed a possible model for 3C273 with a small continuum core and an emission region with a dimension of several parsecs.

A number of QSO show an absorption line system having a redshift greater than the redshift of the emission lines ($z_{ab} > z_{em}$). The explanation of this anomaly is given by assuming that the absorption clouds are falling radially towards the QSO along the line of sight (Burbidge and Burbidge 1971). Obviously, the most plausible cause of in-fall can be the gravitational attraction of the cloud by the QSO (Williams 1970). If the speed of the cloud is attributed to gravitational attraction, it can be shown that possibly the minimum size of the emitting region of the QSO discussed in this communication ranges between 10 pc and 20 pc. A general discussion of gas clouds cutting the line of sight has been given by the author in an earlier paper (Durgapal 1974).

2. A cloud falling radially towards a QSO

Let a cloud be falling radially towards a spherically symmetric source (QSO) given by the metric

$$ds^2 = e^{\nu}\, dt^2 - e^{\lambda}\, dr^2 - r^2\, d\theta^2 - r^2 \sin^2\theta\, d\phi^2 \qquad (1)$$

where

$$e^{\nu} = e^{-\lambda} = 1 - 2m/r, \qquad (c = G = 1) \qquad (2)$$

m is the mass of the QSO and r is the distance of the cloud from the centre of the QSO.

The quantity which remains invariant during the motion of the cloud is given by (Landau and Lifshitz 1971)

$$e^{\frac{1}{2}\nu}/(1-v^2)^{1/2} = \text{constant} = (1-v_\infty^2)^{-1/2} \tag{3}$$

where

v = speed of the cloud at a distance r,
v_∞ = speed of the cloud at spatial infinity.

Taking $v_\infty \ll 1$, one obtains

$$1-v^2 = e^{\nu} = 1-2m/r \qquad \text{or} \qquad v = (2m/r)^{1/2}. \tag{4}$$

The signal absorbed in this cloud has a non-cosmological redshift z' given by

$$\begin{aligned} 1+z'_{\mathrm{ab}} &= (1+z_{\mathrm{gr}})(1+z_{\mathrm{D}}) \\ &= (1-2m/r)^{-1/2}[1+(2m/r)^{1/2}]/(1-2m/r)^{1/2} \\ &= [1-(2m/r)^{1/2}]^{-1} \end{aligned} \tag{5}$$

where z_{gr} and z_{D} are the gravitational and Doppler redshifts respectively.

The observed redshift of the absorption lines is given by

$$1+z_{\mathrm{ab}} = (1+z_{\mathrm{c}})(1+z'_{\mathrm{ab}}) = (1+z_{\mathrm{c}})[1-(2m/r)^{1/2}]^{-1} \tag{6}$$

where z_{c} is the cosmological redshift of the QSO.

Since it is assumed that for $z_{\mathrm{ab}} > z_{\mathrm{em}}$ the absorption lines are associated with QSO, z_{c} is the same for both emission and absorption. Let us assume that the emission lines originate at the surface $r = a$, ie

$$1+z_{\mathrm{em}} = (1+z_{\mathrm{c}})(1-2m/a)^{-1/2} \tag{7}$$

where a is the radius of the emission region.

3. The distance of the absorbing cloud from the QSO

Bahcall (1967) and Bahcall and Wolf (1968) showed that an analysis of the absorption lines in QSO can be used to obtain estimates of either (i) the electron density in the absorbing region or (ii) the distance between the QSO continuum and the absorbing region. If the absorption spectra show lines originating in the ground state fine structure, one can establish that:

(i) the electron density $\geqslant$ a certain critical value;

(ii) the distance of the absorbing cloud from the QSO continuum source, $r \leqslant \epsilon \times 10^3$ pc where ϵ is the ratio of the actual luminosity distance of the QSO to the distance computed assuming the cosmological interpretation of redshift and a world model with $q_0 = +1$.

Hence, if the fine structure in the ground state is absent from absorption spectra and QSO are assumed to be at cosmological distances, then the absorption clouds may possibly be at a distance $r \gtrsim 1$ kpc from the QSO continuum (Bahcall and Goldsmith 1971). In arriving at the 1 kpc lower limit for this distance, it has been assumed that the absolute emitted flux in these quasars in the UV range ($\sim$ 1600 Å) is similar to that of QSO 3C9. For 3C9 Oke (1966) obtained the absolute emitted flux by assuming a Hubble constant of 100 km s^{-1} Mpc^{-1} and a world model with $q_0 = +1$. For other world models the estimation of absolute emitted flux will be different. For an accurate estimation of r one must scan the continuum of these quasars in the observed range around $1600(1+z_{\mathrm{em}})$ Å and then calculate the emitted UV flux. If the estimation of UV flux turns out to be considerably different from that of 3C9, the lower limit of r will change and the results obtained in this paper will be modified accordingly.

Further, if the gas producing the absorption lines is to be photoionized it must be located at $r \leqslant 1$ Mpc (Cohen 1973).

4. The minimum sizes of four QSO

Combining equations (6) and (7),

$$(1+z_{\mathrm{em}})/(1+z_{\mathrm{ab}}) = [1-(2m/r)^{1/2}](1-2m/a)^{-1/2} = f\,(\mathrm{say}) \tag{8}$$

or

$$a = 2mf^2/\{f^2-[1-(2m/r)^{1/2}]^2\}. \tag{9}$$

The minimum value of a for a fixed value of f and r will be

$$a_{\mathrm{min}} = r(1-f^2), \qquad \text{when} \qquad 2m/a = (2m/r)^{1/2} = 1-f^2. \tag{10}$$

QSO PKS1229-02, B194, PHL1222 and PKS0119-04 are supposed to be at cosmological distances and each has one absorption line system with $z_{\mathrm{ab}} > z_{\mathrm{em}}$. The spectra of these QSO show absorption lines Lyα λ1215·7 and C IV λ1249·1. Besides, there are Si III λ1206·5, N V $\lambda\lambda$1238·8, 1242·8 and Si IV $\lambda\lambda$1393·7, 1402·7 in PKS0119-04 and N V λ1238·8, C II λ1335·3, Si IV λ1393·7 and the C IV doublet in B194, but no absorption lines from ground state fine structure have been confirmed so far in systems with $z_{\mathrm{ab}} > z_{\mathrm{em}}$. The resolution of these earlier experiments might not have been good enough to observe the splitting of C II lines. Also, no later attempt has been made to look for fine structure of the ground state in systems with $z_{\mathrm{ab}} > z_{\mathrm{em}}$. However, without any definite evidence for the presence of fine structure in the ground state, it may be said that the absorption regions are possibly at a minimum distance of 1 kpc from the QSO continuum and that the electron density in the absorption region is less than $10^2\ \mathrm{cm}^{-3}$.

If we take $r = 1$ kpc, the minimum value of a can be found for these QSO (see table 1).

Table 1. Values of a (pc) for different m/a values and a_{min}

QSO	z_{em}	z_{ab}	f	m/a 0·1	 0·01	 0·001	a_{min} (pc)
PKS1299-02	0·388	0·395	0·9950	62·9	11·4	18·0	10·0
B194	1·864	1·895	0·9893	66·4	21·6	68·4	21·3
PHL1222	1·910	1·934	0·9918	63·9	16·8	42·3	16·4
PKS0119-04	1·955	1·966	0·9944	61·2	12·8	20·5	11·2

5. The mass of the QSO

The masses corresponding to the minimum sizes of these QSO (emission regions) are $1\cdot1\times10^{12}M_\odot$(PKS1229-02), $2\cdot2\times10^{12}M_\odot$(B194), $1\cdot7\times10^{12}M_\odot$(PHL1222) and $1\cdot2\times10^{12}M_\odot$(PKS0119-04). These masses are about ten times greater than the mass of a large galaxy. By considering the fall time of the gas clouds, Schmidt (1971) estimated an average mass of $5\times 10^{12}M_\odot$ for these objects.

One can also estimate the minimum masses of these QSO from equation (8), which gives

$$(2m/r)^{1/2} = 1-f(1-2m/a)^{1/2}.$$

For a fixed value of r the value of m will decrease as $2m/a$ decreases. When $2m/a\rightarrow 0$, we have $2m = r(1-f)^2$; but $2m/a$ cannot tend to zero because a must always be less than r, otherwise the phenomenon $z_{\mathrm{ab}} > z_{\mathrm{em}}$ will not occur. The minimum value which may be approached is estimated by taking $a\rightarrow r$. This gives

$$m_{\mathrm{min}} \underset{\text{always}}{>} \tfrac{1}{2}r[(1-f^2)/(1+f^2)]^2. \tag{11}$$

The value of $r[(1-f^2)/(1+f^2)]^2$ is found to be $10^{11\cdot 4}M_\odot$(PKS1229-02), $10^{12\cdot 1}M_\odot$(B194), $10^{11\cdot 8}M_\odot$(PHL1222) and $10^{11\cdot 5}M_\odot$(PKS0119-04). The masses must be much greater than these values so that $z_{\mathrm{ab}} > z_{\mathrm{em}}$ occurs.

Hence, the masses of these QSO are of the order of $10^{12}M_\odot$. Supermassive structures of this mass are highly unstable (Fowler 1964). Possibly they may be (i) Hoyle–Fowler (1967) type structures or (ii) configurations with 10^{10} stars/pc^3 similar to those discussed by Spitzer and Saslaw (1966).

6. Conclusions

Thus if the QSO under discussion are at cosmological distances implied from their redshifts and if absorption takes place in clouds falling towards QSO, it may be concluded that (i) the minimum sizes of the emission regions of these QSO range from 10 pc to 21 pc (ii) their masses are of the order of $10^{12}M_\odot$. Thus if one is able to detect a system of absorption lines with $z_{\mathrm{ab}} > z_{\mathrm{em}}$ and if there is no absorption from the excited levels of the ground state fine structure, the minimum size of the emission region in such a QSO may be computed. The quasars which exhibit this property would tend to be amongst the most massive quasars and the mass values could possibly be upper limits to quasar masses.

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