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Possibility of a gravitational effect in the spectra of quasi-stellar objects II

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Abstract. In quasi-stellar objects the redshifts of the spectral lines are generally different in emission and absorption. It has been proposed that quasi-stellar objects which are at cosmological distances have a small contribution to their emission redshift due to their gravitational field (gravitational emission redshift = 0·01 to 0·04). The absorption takes place in clouds of gases moving under the influence of this gravitational field. Different possible types of motions have been considered for these clouds. Both $z_{ab} < z_{em}$ and $z_{ab} > z_{em}$ have been discussed. In order to explain the sharpness of absorption lines it has been assumed that the clouds of gases were ejected with a speed less than the escape velocity and at the time of absorption the velocity of a cloud is comparable to the velocity required for the Doppler width of the absorption lines. For illustration the quasi-stellar objects 3C191, Ton1530 and PHL1522 have been discussed.

1. Introduction

In quasi-stellar objects (QSO) the redshifts of the spectral lines are generally different in absorption and emission (Burbidge and Burbidge 1971). To explain (absorption redshift) $z_{ab} < z_{em}$ (emission redshift) it is assumed at present that the absorption takes place in the clouds of gases moving with large speeds (as much as 10^4 km s^{-1}, Morton and Morton 1972) towards the sun relative to the emission line source. Unfortunately, there is still no way to decide whether these clouds actually have been ejected from QSO or just happen to lie along the line of sight. The QSO absorption lines are usually very narrow (the narrowest lines have Doppler widths of 30 km s^{-1} or less). To explain $z_{ab} > z_{em}$ one has to assume that the absorption takes place in a cloud falling with large speed towards the QSO along the line of sight. In some QSO both $z_{ab} < z_{em}$ and $z_{ab} > z_{em}$ are observed. This means that the gaseous clouds are ejected from the surface of QSO with very large and very different speeds and also that some clouds are falling towards the QSO with large velocities.

In paper I (Durgapal 1974) I have discussed the possibility of a gravitational effect in the spectra of QSO by considering a Hoyle–Fowler type of model. In the present paper an alternative solution of the problem is given. It is assumed that the absorption lines are produced in clouds of gases moving in the gravitational field of QSO. Existence of both $z_{ab} < z_{em}$ and $z_{ab} > z_{em}$ may be accounted for. The scope of this paper is limited to showing that the difference in redshift is due to a gravitational effect. Though $|z_{ab} - z_{em}|$ is considered to be due to gravitation, it is possible to have sharp absorption lines.

One possibility is that the quasar at some earlier time ejected material with speed nearly equal to the escape velocity. The material cooled down as time passed; in the process of cooling it might have been split into various clouds. These clouds are still moving in the gravitational field of QSO. These clouds which now have very small internal motions within themselves, can cross the line of sight in various ways: (i) the clouds might be falling radially towards QSO along the line of sight; (ii) the clouds are moving in parabolic orbits, thus crossing the line of sight transversely. If such a case exists one might observe changes in the intensity of absorption lines (inconclusive evidence by Morton and Morton 1972). (iii) The clouds form a ring about QSO.

Another possibility is that some stray clouds (which have not originated from QSO), are trapped in the QSO gravitational field and move in the manner (i), (ii) or (iii).

Further, the existence of fine structure in absorption spectra indicates that the distance of the absorbing medium from the source is $10^{2\pm1}$ pc (Bahcall 1967, Bahcall *et al* 1967). If the absorption lines from metastable states are observed the distance of the absorbing medium must be less than 10 pc from the source. Since several of the lines reach zero central intensities, these clouds must be large enough to completely cover the whole region producing the continuum. Hence, any model used to explain the absorption features of quasars must take into account these facts.

Lastly, it has been shown that the presence of a gravitational field may avoid the difficulty in explaining the sharpness of absorption lines. In the possible explanation of the sharpness of lines, it is assumed that the absorption clouds were necessarily ejected with a speed less than the escape velocity.

Models have been proposed for 3C191, Ton1530 and PHL5200(4C5.93).

2. Objects in a centrally symmetric field

Let a test particle be moving in the exterior field of a spherically symmetric source given by the metric

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

where

$$\begin{aligned} m &= \text{mass of the source,} \\ r &= \text{distance of the test particle from the centre of the source.} \end{aligned} \tag{2}$$

Three types of motions are considered.

2.1. *Cloud (test particle) falling radially inward along the line of sight*

The quantity which remains conserved during the motion of a test particle is given by (Landau and Lifshitz 1971)

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

where v is the speed of the particle at a distance r and v_∞ is the speed of the particle at spatial infinity.

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

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

The signal from this test particle has a non-cosmological redshift z' given by

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

where z_{gr} is the gravitational redshift and z_D is the Doppler redshift.

The observed redshift z of QSO is given by

$$1+z = (1+z')(1+z_c) \tag{6}$$

where z_c and z' are respectively the cosmological and non-cosmological redshifts. Then

$$1+z_{em} = (1+z'_{em})(1+z_c)$$

and (7)

$$1+z_{ab} = (1+z'_{ab})(1+z_c).$$

Since, in the present work, the absorption lines are assumed to be 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

$$1+z'_{em} = (1-2m/a)^{-1/2} \tag{8}$$

where a is the radius of the emission region of QSO. The absorption takes place in an in-falling cloud at a distance r from the centre of QSO. Then from equation (5)

$$1+z'_{ab} = [1-(2m/r)^{1/2}]^{-1}. \tag{9}$$

(i) If $z'_{ab} = z'_{em} = z'$ (say), we have from equations (8) and (9)

$$r/a = (2+z')/z' = D_A(z'). \tag{10}$$

It is very easy to see that:

(*a*) for $r/a > D_A(z')$ one gets $z_{ab} < z_{em}$

(*b*) for $r/a < D_A(z')$ one gets $z_{ab} > z_{em}$.

(ii) When $z_{ab} \neq z_{em}$, one can find the position of the cloud where absorption takes place. From equations (8) and (9)

$$r/a = z'_{em}(2+z'_{em})/z'^2_{ab}f^2 \tag{11}$$

where

$$f = (1+z'_{em})/(1+z'_{ab}) = (1+z_{em})/(1+z_{ab}).$$

(iii) *Width w of absorption lines.* Let the thickness of the cloud be d. The absorption redshift differs at the lower (l) and the upper (u) surface of the cloud as

$$\lambda_l/\lambda_0 = (1+z_c)/[1-(2m/r)^{1/2}] \qquad \text{and} \qquad \lambda_u/\lambda_0 = (1+z_c)/[1-(2m/r+d)^{1/2}]$$

$$(\lambda_l-\lambda_u)/\lambda_0(1+z_c)(1+z'_{ab}) = (2m/r)^{1/2}(d/2r)(1+z'_{ab}) = w/\lambda$$

or

$$w/\lambda = (2m/a)^{1/2}(a/r)^{1/2}(d/2r)(1+z'_{ab}) \tag{12}$$

where w is the width of the line due to the gravitational effect and λ is the total redshifted wavelength of the absorption line.

Since $d/r < 10^{-3}$, $a/r \sim 10^{-2}$ and $2m/a = 0{\cdot}04$, one gets $w/\lambda \sim 10^{-5}$ corresponding to a width of about 3 km s^{-1} which is very small compared to the width of the narrowest absorption line.

2.2. Cloud trapped in a parabolic orbit

The geodesic equation for a test particle yields (Tolman 1934)

$$dt/ds = K\,e^{-\nu} = e^{-\nu}(1-v_\infty^2)^{-1/2} \tag{13}$$

where

dt = an element of coordinate time

ds = an element of proper time as measured by a local clock moving with the particle

v_∞ = speed of the particle at spatial infinity.

If $v_\infty \ll 1$,

$$dt/ds = e^{-\nu}. \tag{14}$$

This means that a signal emitted from a object which is moving in a centrally symmetric field will have a non-cosmological redshift z' given by

$$1+z' = (1-2m/r)^{-1}. \tag{15}$$

Let the absorption cloud be crossing the line of sight at a distance r from the source. Then as in § 2.1, we have

$$1+z'_{em} = (1-2m/a)^{-1/2} \quad \text{and} \quad 1+z'_{ab} = (1-2m/r)^{-1}. \tag{16}$$

(i) If $z'_{em} = z'_{ab} = z'$, we have from equation (16)

$$r/a = (2+z')/(1+z') = D_B(z'). \tag{17}$$

It is easy to see that:

(*a*) for $r/a > D_B(z')$ one gets $z_{ab} < z_{em}$

(*b*) for $r/a < D_B(z')$ one gets $z_{ab} > z_{em}$.

(ii) $z_{ab} \neq z_{em}$. The position of the absorption cloud is given by

$$r/a = z'_{em}(2+z'_{em})/\,z'_{ab}(1+z'_{em})f. \tag{18}$$

(iii) The width of the absorption lines is given by

$$w/\lambda = (2m/a)(a/r)(d/r)(1+z'_{ab}). \tag{19}$$

Since $m/a \simeq 0{\cdot}02$, $a/r \sim 10^{-1}$ and $d/r \lesssim 10^{-3}$, one gets $w/\lambda \sim 10^{-6}$ which corresponds to a width of less than a kilometre per second.

2.3. Circular orbit about the QSO

Tolman (1934) writes: 'In accordance with the form of line element, the relation between increment in proper time ds as measured on the planet and in the coordinate time dt

would be given by

$$\frac{ds^2}{dt^2} = 1 - \left(\frac{1}{1-2m/r} \frac{dr^2}{dt^2} + r^2 \frac{d\theta^2}{dt^2} + r^2 \sin^2\theta \frac{d\phi^2}{dt^2} + \frac{2m}{r} \right). \tag{20}$$

For a circular orbit (r = constant) let the plane of the orbit be fixed by taking $\theta = \pi/2$. Then

$$ds^2 = (1-2m/r)\,dt^2 - r^2\,d\phi^2 \tag{21}$$

$$dt/ds = [(1+h^2/r^2)/(1-2m/r)]^{1/2} \tag{22}$$

where

$$r^2\,d\phi/ds = h\,(\text{constant}). \tag{23}$$

In the non-relativistic case, a signal emitted from such an orbiting object will be redshifted by

$$z' \simeq m/r + h^2/2r^2 \simeq 3m/2r \qquad (\text{since } h^2 = mr). \tag{24}$$

Let us assume that the absorption takes place in a ring of radius r. For values of $m/a \lesssim 0{\cdot}02$, the approximate result (24) may be used without much error. We have then $z'_{em} = m/a$ and $z'_{ab} = 3m/2r$ giving

$$r/a = 3z'_{em}/2z'_{ab}. \tag{25}$$

The width of the absorption lines is given by

$$w/\lambda = (3m/2a)(a/r)(d/r) \tag{26}$$

which corresponds to a width of less than 1 km s^{-1}, for the values of $m/a \lesssim 0{\cdot}02$.

3. Gravitational redshift in objects at cosmological distances

The presence of absorption lines with $z_{ab} > z_{em}$ suggests that the absorption lines originate in clouds of gases falling towards QSO with speeds of about $0{\cdot}01\,c$. This in-falling motion may be due to the gravitational attraction by QSO. The absorption features require the cloud to be at $10^{2\pm1}$ pc. Since the speed of free fall $v = (2m/r)^{1/2}$, one gets

$$2m/a = (2m/r)(r/a) = 10^{-4}(r/a). \tag{27}$$

Now if,

$a = 1$ pc,	$r = 10^2$ to 10^3 pc:	$2m/a = 0{\cdot}01$ to $0{\cdot}1$
$a = 10$ pc,	$r = 10^2$ to 10^3 pc:	$2m/a = 10^{-2}$ to 10^{-3}
$a = 10^{16}$ cm,	$r = 10^2$ to 10^3 pc:	$2m/a = 3$ to 30 (absurd).

The value of $a = 10^{16}$ cm has been chosen from the luminosity variation in QSO of the order of a few weeks (or even days). The above chart suggests that the dimension of the emission region is of the order of 1 to 10 pc.

Greenstein and Schmidt (1964) have shown by considering the intensity of spectral lines and electron density that QSO showing gravitational redshift can neither exist near the galaxy nor in the nearby galactic sphere. They conclude that 3C273 and 3C48 are at cosmological distances and the dimensions of the emission regions are 1 pc and 11 pc respectively. This is also the order of dimension inferred from equation (27).

Here, we are not interested in a purely gravitational model. What is being sought is a possible gravitational contribution to the redshift from the objects which are at cosmological distances greater than 10^3 Mpc. The main contribution to the redshift is due to cosmological expansion. Greenstein and Schmidt did not discuss such objects.

A stringent condition on z'_{em} (the gravitational redshift) can be imposed by considering the emission from $r = 0$ to $r = a$ (though it may not be proper). The gravitational redshifts originating at the centre $r = 0$ (ie z'_0) and at the surface $r = a$ (ie z'_s) are different. The spread of redshift $z'_0 - z'_s$ will broaden the emission lines. In a sphere of uniform density

$$(1+z'_0)/(1+z'_s) = 2/(2-z'_s) \tag{28}$$

or

$$(1+z'_0)-(1+z'_s) = z'_0 - z'_s = z'_s(1+z'_s)/(2-z'_s)$$

or

$$(\lambda_c - \lambda_s)/\lambda_0 = (1+z_c)z'_s(1+z'_s)/(2-z'_s) \tag{29}$$

where λ_c is the total redshifted wavelength from the centre and λ_s is the total redshifted wavelength from the surface. Thus, the width w of the emission lines is given by

$$w/\lambda = z'_s/(2-z'_s). \tag{30}$$

Quasar emission lines are 30–60 Å wide and even very wide lines ($\sim$ 150 Å) have been observed. We may thus possibly choose w/λ = 0·01 to 0·03 and hence the maximum limit of z'_s = 0·06.

In the present paper only $z'_{em} \leqslant 0{\cdot}04$ has been considered and in most of the cases under discussion, $z'_{em} \leqslant 0{\cdot}02$. This is a negligible contribution to the total redshift of the QSO which exhibit absorption lines in their spectra.

An objection raised by critics concerning the cosmological distance of quasars is that objects with such small dimensions (the optical variation puts the size at about 10^{16} cm) cannot be detected if they are at cosmological distances. Hoyle *et al* (1966) pointed out that if variable radio and optical emissions originate within the same volume and if they are attributed to synchrotron radiation, the relativistic electrons loose all their energy by inverse Compton scattering producing x rays rather than optical emission. Also for dimensions as small as 10^{16}–10^{17} cm it is hard to obtain sufficient line emission without requiring the electron density to be so high that the cloud is opaque to the continuum. They conclude that either QSO are at a distance of 10 Mpc or less, or the physical model associated with these objects must be different from theories at present in vogue.

The above mentioned difficulty does not arise if the dimension of the emission region is of the order of 1 to 10 pc. Actually, the problem is twofold: (i) How should one explain the luminosity variation, if the cosmological interpretation is accepted? (ii) How should one explain the redshift if QSO are nearby objects?

In the present discussion it is considered that the QSO are cosmological objects and hence the dimension of the emission region is taken as 1 to 10 pc, as given by Greenstein and Schmidt.

However, the dimension of the region producing the continuum may be small enough to account for the luminosity variations. Morrison and Sartori (1968) have discussed the luminosity variation and they put the upper limit for dimension of emission region as 10^3–10^4 lt-yrs. Rees and Simon (1968) have also discussed the luminosity variation, by assuming that the variable components expand with relativistic speeds. Bachall and

Kozlovsky (1969) have discussed a possible model of 3C273 with a small continuum core and an emission region with a dimension of several parsecs.

For $z'_{em} \leqslant 0.02$ one can infer from equation (8) that the mass associated with QSO is about $10^{11} M_{\odot}$. Such large masses may not be stable (Fowler 1964) and a spherical collapse may take place in about 10^6 yr giving out gravitational energy of the order of 10^{61} erg, consistent with the requirements for QSO at cosmological distances. How the enormous gravitational energy gets converted into other form is not yet known. Can this large energy output provide stability to the configuration? However, one may have stable gaseous spheres for certain limiting values of m/a: $m/a \leqslant 0.319$ for adiabatically stable configurations (Bondi 1964), $m/a \leqslant 0.276$ for polytropic index $n = 1.0$ and $m/a \leqslant 0.0729$ for $n = 3.0$ (Tooper 1964). More recently, Kogan and Throne (1970) have shown that gas spheres with very large masses can be stable. Other possibilities are that: (i) they are structures of the Hoyle–Fowler (1967) type; or (ii) there are about 10^{11} stars pc^{-3} (similar to those discussed by Spitzer and Saslaw 1966), with collisional velocities of about 10^4 km s^{-1}, and the kinetic energy available is some 10^{51} erg/$M_{\odot}$ (Burbidge 1967).

We leave the discussion of the size and the mass of QSO, since it will be a digression from the main topic.

4. Absorption spectra of QSO

The distance r of absorption cloud can be calculated for given z_{ab} value. The minimum gravitational redshift z'_{em} is chosen by considering the cosmological redshift z_c to be slightly less than z_{ab} (for the least redshifted line). In other words z'_{em} must be larger than $(f-1)$. The smaller the value of $1+z'_{em}-f$, the farther away will be the cloud (r/a can be made as large as 10^4 or more by a suitable choice of z'_{em}) for $z_{ab} < z_{em}$.

Table 1 lists the r/a values for $z'_{em} = 0.02$ and 0.03 for clouds falling radially towards the QSO and r/a values for $z'_{em} = 0.01$ and 0.02 for clouds in parabolic orbits.

Table 1. Values of r/a

				For radially falling clouds z'_{em}		For clouds in parabolic orbits z'_{em}	
QSO	z_{em}	z_{ab}	f	0·02	0·03	0·01	0·02
PHL1194	0·299	0·283	1·0125	712·6	198·2	—	5·26
PKS1510–08	0·361	0·351	1·0074	254·5	119·2	7·65	3·14
PKS1229–02	0·388	0·395	0·9950	64·5	49·7	1·32	1·58
BSO 1	1·241	1·241	1·0000	101·0	67·7	1·99	1·98
3C298	1·439	1·419	1·0083	293·5	128·9	11·48	3·37
3C270·1	1·519	1·498	1·0084	300·3	130·5	12·44	3·41
PKS2146–13	1·800	1·775	1·0090	334·5	138·2	20·10	3·60
B194	1·864	1·837	1·0095	374·9	145·2	41·46	3·81
		1·895	0·9893	41·9	36·7	×	1·28
PHL1222	1·910	1·934	0·9918	50·9	41·8	1·09	1·41
PHL938	1·950	1·906	1·0151	1710·4	275·8	×	8·15
		0·613	1·8291	Interstellar region			
3C191	1·956	1·947	1·003	140·6	84·4	2·86	2·34
PHL1127	1·990	1·950	1·0136	974·1	225·3	×	6·15

Let us discuss the individual methods separately

(i) *The cloud is falling radially.* The path traversed by light through the cloud remains the same throughout the fall and also the area covering the continuum remains the same. The intensity of the line thus remains unchanged. In these cool gas clouds internal motions can be very small and hence one may observe sharp absorption lines. The contribution of a gravitational effect to the linewidth is only of the order of 3 km s^{-1}.

Does the value of z_{ab} change? $2m/a \sim 0{\cdot}04$ and $a/r \sim 10^{-2}$ give $v = (2m/r)^{1/2} \sim 0{\cdot}02$. Suppose $r = 1000$ pc, the time of fall through a distance of 1 pc is about 150 yr. During this time the redshift in absorption line changes by a factor of about 10^{-5}. Thus the redshift changes by a factor of 10^{-7} in one year. If $r = 100$ pc the change is about 10^{-6} in one year. Such small changes in redshift cannot be detected.

(ii) In this case the absorption cloud is supposed to cut the line of sight transversely. Since several of the lines reach zero central intensities, the cloud must be wide enough to cover the entire continuum. Taking the dimension of the cloud to be about 1 pc and the speed about 0·02 the entire cloud will cross the line of sight in about 150 yr. If a change in intensity is observed (Burbidge 1969), it may possibly be due to such clouds. Further, some of the weak features observed earlier may entirely vanish after some time or may become stronger, depending upon whether the cloud is receding or approaching the line of sight. Bahcall *et al* (1969) showed that a weak system ($z_{ab} = 2{\cdot}055$ in Ton1530) reported earlier by Burbidge *et al* (1968) was missing. Also an entirely new system was reported by Burbidge (1969) in the spectra of PHL5200 which was absent on the plate taken by Lynds (1967). However, these examples cannot be considered as conclusive evidence, but they suggest that the possibility of such an occurrence cannot be ruled out.

This method is not suitable for $z_{ab} > z_{em}$ since $r/a < 2$. At such close distances from QSO, the dimension of the cloud will have to be less than 10^{-3} pc in order to account for the sharpness of absorption lines. Such a small cloud will cross the line of sight in a few months.

(iii) In this case the absorption takes place in a ring of clouds. This model is not suitable for $z_{ab} > z_{em}$ provided the fine structure is present in absorption spectra, because $r/a < 1{\cdot}5$. If the fine structure is absent this model may account for $z_{ab} > z_{em}$ provided the thickness of the ring is less than 10^{15} cm. This model can account for the absorption from metastable states, because for excitation of absorption lines from metastable states one must have $r < 10$ pc.

Methods (i), (ii) and (iii), discussed above, have their advantages and disadvantages. (i) is good for both $z_{ab} < z_{em}$ and $z_{ab} > z_{em}$, but it is not suitable to account for the absorption from metastable states because, for $r < 10$ pc the gravitational width of absorption lines greater than 30 km s^{-1} and the redshift will change by 0·005 in one year (which is easily detectable). Model (ii) is suitable when the strength of absorption line changes with time. With a suitable combination of (i), (ii) and (iii) one may possibly account for most of the properties of absorption spectra for a number of QSO (except PKS0237–23, 4C05.34 and PHL957).

(iv) *Cloud ejected with a speed less than the escape velocity.* If the cloud is ejected from the surface of the QSO with a speed u less than the escape velocity, it will come to rest at a distance r_0 given by (from equation (3))

$$1-2m/r_0 = (1-2m/a)/(1-u^2). \tag{31}$$

Let the absorption take place in a cloud which has negligible motion ($v \simeq 30\ \mathrm{km\ s^{-1}}$, ie v^2 can be neglected). Then

$$1+z'_{\mathrm{em}} = (1-2m/a)^{-1/2} \qquad \text{and} \qquad 1+z'_{\mathrm{ab}} = (1-2m/r_0)^{-1/2}$$

or

$$r_0/a = z'_{\mathrm{em}}(2+z'_{\mathrm{em}})/z'_{\mathrm{ab}}(2+z'_{\mathrm{ab}})f^2 \tag{32}$$

and ejection speed

$$u = (f^2-1)^{1/2}/f. \tag{33}$$

If $r_0/a = 100$, $z'_{\mathrm{em}} \simeq 100\, z'_{\mathrm{ab}} \simeq m/a$ (when m/a is small). For $m/a = 0{\cdot}01$,

$$z'_{\mathrm{ab}} \simeq m/r_0 = 10^{-4}.$$

At r_0, one can make use of Newtonian mechanics also. Thus, the acceleration due to gravity at r_0 is

$$g = m/r_0^2 = (m/a^2)(a/r_0)^2. \tag{34}$$

If the cloud falls under gravity its speed will become v after a time

$$t = va(r/_0/a)^2/(m/a). \tag{35}$$

Taking $v = 10^{-4}$, $m/a = 0{\cdot}01$, $r_0/a = 100$ and $a = 1$ pc one gets, $t = 300$ yr and the distance traversed in this time is 0·01 pc. Hence, no change in gravitational redshift is observed. The speed changes by 0·1 km s^{-1} in one year. Hence, in one year the redshift changes by an amount $(1+z_c)\times 10^{-6}/3$. If $z_c = 2$, the redshift changes by 10^{-6} in one year. Hence, the observed redshift remains constant and also the Doppler width is very small.

5. Discussion

The method developed in previous articles is applied to some specific examples. QSO have been chosen so that most of the features of absorption spectra are covered.

5.1. 3C191

3C191 is the most thoroughly discussed QSO for its absorption spectra (Burbidge *et al* 1966, Bahcall 1967, Bahcall *et al* 1967 and others). The main features are $z_{\mathrm{em}} = 1{\cdot}956$, $z_{\mathrm{ab}} = 1{\cdot}947$, halfwidth of emission lines is 65 Å and halfwidth of absorption lines at source is less than 3 Å.

The ground state of Si II is a fine structure doublet separated by 0·04 eV. Absorption lines originate on both the ground and excited states. If the population of the higher fine structure state is a result of photon excitation, Bahcall *et al* (1967) put the limit on the distance of the absorbing cloud at $10^{2\pm1}$ pc. Stockton and Lynds (1966) identified two absorption lines, arising from relatively low-lying metastable states, namely,

$$\mathrm{S\,II}\ \lambda = 1231{\cdot}8\ \text{Å}.$$

The S II lines were also identified by Burbidge *et al* (1966). This puts the distance $r < 10$ pc. But Bahcall *et al* (1967) do not confirm the existence of S II lines.

Since the width of emission lines is 65 Å, the maximum value of z'_{em} can be greater than 0·03. Taking $z'_{em} = 0{\cdot}02$, the radially falling cloud is at $r = 156a$. If $a = 6$ pc, $r \simeq 10^3$ pc the gravitational width of absorption lines is 15 km s^{-1} which is much less than the observed width of about 300 km s^{-1}.

If S II lines are present, they may possibly originate in a ring at $r = 9$ pc with a thickness of less than 10^{15} cm. If one takes $z'_{em} = 0{\cdot}0031$, $a = 1$ pc the fine structure lines originate in an in-falling cloud at 900 pc. The speed of the in-falling cloud is about $1{\cdot}7 \times 10^{-3}c = 500$ km s^{-1} which is comparable with internal motions.

5.2. Ton 1530

Ton1530 has $z_{em} = 2{\cdot}047$ with two absorption clouds at $z_{ab} = 1{\cdot}9803$ and 1·93702, Earlier, Burbidge *et al* (1968) mentioned a third possible redshift at $z_{ab} = 2{\cdot}0553$, which is not confirmed by later observations (Bahcall *et al* 1969, Morton and Morton 1972). Morton and Morton (1972) found: 'Each of the shorter wavelength pair of C IV lines was found to be split into three components with the two weaker separated from a stronger central one by ± 130 km s^{-1} ($z^+ = 1{\cdot}9358$, $z^0 = 1{\cdot}9371$ and $z^- = 1{\cdot}9384$). These lines cannot be due to Zeeman splitting and originate in different clouds having a relative velocity of ± 130 km s^{-1}. Weak lines reported by earlier workers were absent. Further, there was some difference in two spectra (taken almost a year apart) such as the strength of all C IV lines, but the evidence is not strong enough to show any definite change.'

The important feature is the splitting of the C IV lines into three components. These components originate in different clouds. Let us take $z'_{em} = 0{\cdot}04$ (or $2m/a = 0{\cdot}075$) and $a = 10$ pc. If the cloud (for $z_{ab} = 1{\cdot}937$) was ejected with a speed of 0·27c, less than the escape velocity (0·2739), it would come to rest at $r \simeq 20a$ in a time of about 3×10^3 yr. During this time the cloud shed its mass somehow. Out of all the fragments shed out by it two are lying along the line of sight, one on each side of the main cloud. The relative velocity of these fragments with respect to the main cloud is 130 km s^{-1}. This picture may probably explain the strong central line with two weaker lines on either side at a separation of ± 130 km s^{-1}. If the fragmentation of the cloud took place about 10^3 yr ago, the separation of fragments from the main cloud would be about 0·15 pc, thus the gravitational field is the same for all three clouds. At $r = 200$ pc, the speed of the central cloud is negligible and hence the absorption lines are sharp, though of course the fragments have a speed of 130 km s^{-1}, which is not very large. Thus, both the sharpness of the absorption lines and the splitting of the C IV lines can be understood.

Another feature is the disappearance of the possible system at $z_{ab} = 2{\cdot}0553$ (if earlier observations can be taken as valid). Could this system originate in a cloud moving in a parabolic orbit, cutting the line of sight at $r = 19$ pc? This is purely a conjecture.

5.3. PHL5200 (4C-5.93)

PHL5200 was discovered by Lynds (1967) to have an emission line redshift of $z_{em} = 1{\cdot}981$ and a very strong broad absorption band of C IV, Si IV and N V Ly-α extending from $z = 1{\cdot}88$ to $z = 1{\cdot}98$ with a rather sharp boundary between absorption and emission. Burbidge (1968) observed a real change in her November 1967 plate in the structure of the Si IV band, and later (Burbidge 1969) confirmed the existence of a new band system at $z_{ab} = 1{\cdot}889$. Also, Burbidge (1969) showed that the unidentified line measured by Lynds (1967) at λ 3886 Å, seen weakly earlier (Burbidge 1968) appeared rather clearly. Summarizing, we have

$z_{em} = 1{\cdot}98$

Absorption band $z_{ab} = 1{\cdot}98 - 1{\cdot}88$, $f = 1 - 1{\cdot}035$

Permanent system $z_{ab} = 1{\cdot}95$, $f = 1{\cdot}010$

Newly appearing system $z_{ab} = 1{\cdot}89$, $f = 1{\cdot}031$.

Taking $z'_{em} = 0{\cdot}04$, the absorption bands may possibly arise in a thick atmosphere extending from $r = a$ to $7.3a$. The width of the absorption band is then due to the variation of gravitational potential with distance. The newly appearing system with $f = 1{\cdot}031$ ($z'_{ab} = 0{\cdot}009$), may be originating in a cloud cutting the line of sight at $8{\cdot}45a$. The speed of the cloud is about $0{\cdot}06c$ and if the dimension of the cloud is of the order of 1 pc, the cloud will cross the line of sight in about 50 yr. In this explanation, the line strength may appear to change. The permanent system $z_{ab} = 1.95$ may originate in a radially falling cloud (as in other cases).

5.4. *PKS0237-23, PHL957 and 4C05.34*

The present treatment, as discussed so far, is not suitable for PKS0237-23, PHL957 and 4C05.34, because for these objects one must have z'_{em} greater than 0·366, 0·233 and 0·396 respectively. Bondi (1964) has shown that the gravitational redshift from the surface of an adiabatically stable sphere can be as large as 0·622 which is much larger than the value needed for these objects.

In the emission spectra of these QSO forbidden lines are not present, hence the discussion given by Greenstein and Schmidt (1964) does not hold for them. The restriction on electron number density is not applicable to these objects. The density can be higher and we cannot impose the stringent condition that the emission lines originate from $r = 0$ to $r = a$. We may consider the emission lines to originate at the surface in a layer of hot ionized gases. Since the emission lines from these objects are very broad the emission layer may be very thick. The value of z'_{em}, thus, can be chosen as high as 0·622 for a stable configuration. Again, it is better to remember that though z'_{em} can be chosen high, these QSO are at cosmological distances and the main contribution to their redshift is due to cosmological expansion. The conclusion of Greenstein and Schmidt, that objects with large gravitational redshift cannot be found in the nearby galactic sphere, still holds.

Thus one may discuss the absorption spectra of PKS0237-23 (taking $z'_{em} > 0{\cdot}366$, $z_c \simeq 1{\cdot}36$), PHL957 ($z'_{em} > 0{\cdot}233$, $z_c \simeq 2{\cdot}00$) and 4C05.34 ($z'_{em} > 0{\cdot}396$, $z_c \simeq 1{\cdot}77$) according to the method given in this paper. With the increasing contribution of the gravitational redshift the capture cross section of QSO increases and hence large numbers of clouds may be trapped in QSO field. This is evident from the large number of absorption systems observed in these objects.

6. Conclusion

By assuming a small gravitational redshift, the absorption spectra of QSO (which are at cosmological distances— may be discussed, to account for the difference in the emission and absorption redshifts. The choice of z'_{em} and hence r/a depends upon the features of the absorption lines. For correct analysis, the thickness of the absorption cloud should be estimated from the column densities. The method developed in this paper is just an alternative and it does not, at all, contradict the methods that exist already.

The advantage of this method is that absorption takes place in cool in-falling clouds. The cloud must have come to rest at some earlier time (thus reducing all internal motions to negligible values) and then started its journey back towards the QSO. Alternatively, some stray cool cloud (with negligible internal motion) has been trapped in the field of QSO. The present motion of the cloud is not due to any violent explosion but it is due to a gravitational in-fall. Internal motions, thus, may still remain negligibly small, and hence the observed absorption lines may be sharp.

Moreover, it has been shown (§ 4, iv) that at the time of absorption the speed of the cloud is negligible and hence sharp lines occur in absorption spectra.

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