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

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**Abstract.** In quasi-stellar objects the redshifts of spectral lines are generally different in absorption and emission. The possibility that the redshift difference in most cases is gravitational is not ruled out. The effect can be seen in a Fowler–Hoyle type model. There exists the possibility that most (but not all) of lines with $z_{ab} < z_{em}$ might be associated with quasi-stellar objects.

## 1. Introduction

Quasi-stellar objects (QSO) show a large redshift in their spectra and the $z_{max}$ so far observed is about 3·5. The redshift is attributed to cosmological expansion because the maximum gravitational redshift obtained from the surface of a spherical configuration of uniform density is $z_s = 2$ when the central pressure tends to infinity. Burbidge and Burbidge (1971) consider the observed redshift $z_o$ as

$$1+z_o = (1+z_c)(1+z_g)(1+z_r) \tag{1}$$

where $z_c$, $z_g$ and $z_r$ correspond to cosmological, gravitational and Doppler redshifts respectively. Further, they have given a very good account of absorption lines in spectra of QSO.

To explain the $z_{ab} < z_{em}$ it is assumed at present that the absorption takes place in clouds of gases moving with large velocities (as much as $10^4$ km s$^{-1}$) (Lawrence *et al* 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. In order to explain multiple absorption redshifts one has to assume that gaseous clouds are ejected from the surface of QSO with very large and very different speeds.

As an alternative, it is suggested that the emission region and the cloud of ions which absorb radiation are at different gravitational potentials. This will avoid the necessity of assuming the absorbing medium to be moving with large speeds when $z_{ab} < z_{em}$. To explain the $z_{ab} < z_{em}$ we can construct two types of model based upon the ingenious device of Hoyle and Fowler (1967) (a cluster model).

However, in the present model one cannot account for the lines with $z_{ab} > z_{em}$. Also, no explanation has been provided for the narrow width of the absorption lines.

## 2. Gravitational model

For gravitational models of QSO, we know that

$$1+z_g = e^{-\nu/2} \tag{2}$$

where $e^\nu$ corresponds to the metric coefficient in the line element

$$ds^2 = e^{\nu(r)}\,dt^2 - e^{\lambda(r)}\,dr^2 - r^2\,d\theta^2 - r^2 \sin^2\theta\,d\phi^2, \tag{3}$$

(where $\nu$ and $\lambda$ are functions of $r$ alone) for a spherically symmetric and static system. From equation (1) neglecting $z_r$ we have

$$f = \frac{1+z_{gem}}{1+z_{gab}} = \frac{1+z_{oem}}{1+z_{oab}} = \frac{e_{ab}^{\nu/2}}{e_{em}^{\nu/2}}. \tag{4}$$

The factor $f$ is the same whether the redshifts are purely gravitational or partly cosmological and partly gravitational, hence we drop the suffixes o and g and use $z_{em}$ and $z_{ab}$ only.

In the Fowler–Hoyle model the main mass belongs to a low density gas, composed of subunits in the form of burnt-out stars. (For example a density of $\sim 10^{-11}$ g cm$^{-3}$ may be considered as a cluster of about $3\times10^{10}$ neutron stars in a sphere of radius $\sim 10^{18}$ cm. Thus only $\sim 10^{-25}$ of the total volume is occupied and the rest of it is empty.) The radiation originates in a cloud of gas at the centre of the cluster and absorption takes place in ionic clouds surrounding the core. Ipser (1969) has shown that when $z_{central} \lesssim 0{\cdot}5$ the collapse sets in. Hence the maximum gravitational redshift from such a cluster is only 0·5.

### 2.1. *Uniform density outside the core*

For a better understanding we will solve Einstein's field equations for a model in which a spherical configuration (core) is surrounded by a medium of low density (the cluster of burnt-out stars). The general assumptions made here are similar to those made by Bondi (1964). In addition we must have continuity at all the boundaries, ie at $r = a$ (radius of the core) and $r = b$ (radius of the cluster).

In the region of low density $\rho(a \leqslant r \leqslant b)$ the solutions are (Wyman 1949)

$$\begin{aligned} e^{-\lambda} &= 1 - \tfrac{8}{3}\pi\rho r^2 + S/r \\ e^{\nu} &= e^{-\lambda}(d+\alpha I_b^r) \\ p &= -\rho + \alpha\, e^{-\nu/2}/4\pi \end{aligned} \tag{5}$$

where

$$I_b^r = \int_b^r e^{3\lambda/2} r\,dr. \tag{6}$$

From the continuity at $r = b$

$$d = 1, \qquad \alpha = 4\pi\rho(1-2M/b)^{1/2}, \qquad S = \tfrac{8}{3}\pi\rho a^3 - 2m$$

where $m$ is the core mass and $M$ is the mass of the whole configuration.

Let the pressure at $r = a$ be given by $\chi\rho$. Then equation (5) gives

$$p_{r=a} = \chi\rho = \rho[(1-2M/b)^{1/2}\, e^{-\nu/2}_{r=a} - 1], \tag{7}$$

or

$$e^{\nu/2}_{r=a} = \frac{(1-2M/b)^{1/2}}{\chi+1}. \tag{8}$$

From equations (5) and (8) we obtain

$$e^{-\lambda/2}_{r=a}[1 + 4\pi\rho(1-2M/b)^{1/2} I^a_b] = \frac{(1-2M/b)^{1/2}}{\chi+1}. \tag{9}$$

We take $b \gg a$ and $\rho \ll \rho_c$ (core density). For very large values of $b$ and small values of $\rho$ we get

$$2M/b \simeq 8\pi\rho b^3/3 \qquad \text{and} \qquad I^a_b \simeq (3/8\pi\rho)[1-(1-2M/b)^{-1/2}]. \tag{10}$$

From equations (9) and (10) and the relation $e^{-\lambda(a)} = 1 - 2m/a$ (for the core), we get

$$(1-2M/b)^{-1/2} = 3 - 2/(\chi+1)(1-2m/a)^{1/2}.$$

If we take $2m/a \ll 1$, we get

$$(1-2M/b)^{-1/2} = 3 - 2/(\chi+1). \tag{11}$$

From equations (8) and (11), we have

$$z_{\text{gem}} = 3\chi. \tag{12}$$

For the maximum difference between $z_{\text{ab}}$ and $z_{\text{em}}$ we can consider the absorption gas cloud to be at $r = b$. We get

$$f_{\max} = e^{\nu/2}_{r=b}/e^{\nu/2}_{r=a} = 1 + \chi. \tag{13}$$

For $z_{\text{gem}} = 0{\cdot}5$. $\chi = \frac{1}{6}$ giving $f_{\max} = 1{\cdot}167$. This limit of $f$ covers all the QSO listed by Burbidge and Burbidge except PHL 938 (where $f = 1{\cdot}832$ for the absorption line 0·6128) and PKS 0237-23 (where $f = 1{\cdot}365$).

### 2.2. *Varying density outside the core*

In a cluster surrounding a core and having a deep potential well at the centre, it may not be proper to consider a uniform density throughout from $r = a$ to $r = b$. It is more appropriate to consider the density to be more at $r = a$ and less at $r = b$. By choosing various density distributions in the region $a \leqslant r \leqslant b$, one can solve the field equations. Let us choose a density distribution which varies approximately as $1/r^2$ (Durgapal and Gehlot 1969) which then gives $f = (r/a)^n$. Then the distance of the absorption region from the centre is

$$r = af^{1/n}. \tag{14}$$

The value of $n$ depends upon the ratio $a/b$ and the value of $\chi$ in the equation of state $p = \chi\rho$. Since here $a/b$ is very small, we shall see later that $n$ and hence $\chi$ is very small when we apply this model to QSO. This model covers $z_{ab} < z_{\text{em}}$ for all QSO except PHL 938 ($z_{\text{ab}} = 0{\cdot}6128$).

## 3. Discussion

### *3.1. Uniform density cluster*

QSO with $z_{em} < 2{\cdot}0$ and having only one $z_{ab} < z_{em}$ have the value of $f$ ranging from 1·008 to 1·016, the average value of $\chi = 0{\cdot}012$. These QSO may be classified together as the physical conditions prevailing in their core is represented by $p = 0{\cdot}012\rho c^2$ when the absorption spectrum originates at $r = b$.

Next, we have QSO with multiple $z_{ab} < z_{em}$. The value of $\chi$ is associated with the larger $f$ value, because then only other $z_{ab}$ lines will arise within the cluster. If we assume that the lowest $z_{ab}$ takes place at $r = b$, then by using equations (5) to (9) we can find regions of other absorption lines. In PKS 0812+02, we take $\chi = 0{\cdot}043$ so that $z_{ab} = 0{\cdot}384$ takes place at $r = 0{\cdot}57b$. For PHL5200, $\chi = 0{\cdot}031$ and region of absorption for $z_{ab} = 1{\cdot}90/1{\cdot}98$ and 1·9502 are $r = 0{\cdot}96b/a$ and $0{\cdot}57b$ respectively. For Ton1530, $\chi = 0{\cdot}038$ and $z_{ab} = 1{\cdot}9798$ takes place at $r = 0{\cdot}75b$.

### *3.2. Varying density cluster*

In the second type of cluster model the value of $\chi$ in the equation $p = \chi\rho$ at $r = a$ is given by $\chi = n/(2-n)$ when $a/b$ is negligible. Also, the contribution of the gravitational field to the redshift in emission spectra $z_{gem}$ depends upon the value of $n$ according to the equation

$$1 + z_{gem} = (2n+1)^{1/2}(b/a)^n. \tag{15}$$

In our model we have assumed $a/b$ to be very small. Now, let $b/a = 10^x$. Then

$$xn + \tfrac{1}{2}\lg(2n+1) = \lg(1+z_{gem}). \tag{16}$$

Values of $n$ for different values of $x$ are given in table 1 for various values of $z_{gem}$. We see that the value of $n$ is smaller for smaller values of $a/b$ and it further reduces as $z_{gem}$ decreases. Hence in this model $\chi = n/(2-n)$ remains small.

**Table 1.** Value of $n$ for various values of $x$ and $z_{gem}$.

| $x$ \ $z_{gem}$ | 0·5 | 0·4 | 0·3 | 0·2 | 0·1 | 0·05 | 0·025 |
|---|---|---|---|---|---|---|---|
| 2 | 0·073 | 0·053 | 0·046 | 0·032 | 0·017 | 0·008 | 0·005 |
| 3 | 0·053 | 0·045 | 0·032 | 0·024 | 0·012 | 0·007 | 0·003 |
| 4 | 0·040 | 0·037 | 0·025 | 0·018 | 0·009 | 0·006 | 0·002 |
| 5 | 0·032 | 0·026 | 0·021 | 0·014 | 0·008 | 0·005 | 0·002 |
| 6 | 0·028 | 0·021 | 0·017 | 0·012 | 0·007 | 0·003 | 0·001 |
| 7 | 0·025 | 0·017 | 0·016 | 0·011 | 0·006 | 0·003 | 0·001 |

Choosing some value of $z_{gem}$ and $x$ one can find the value of $n$ and hence the region of absorption $r = af^{1/n}$. On the other hand if the absorption takes place at $r = b$, we have

$$xn = \lg f. \tag{17}$$

Choosing $x$ we can find $n$ from equation (17). For multiple $z_{ab}$ the value of $n$ is found by supposing that the lowest $z_{ab}$ takes place at $r = b$. Then we can calculate the region of absorption for other values of $z_{ab}$. As an example if $x = 2$ for Ton1530 the value of $n$ is 0·081 giving us $r = 0{\cdot}13b$ for $z_{ab} = 1{\cdot}9798$.

### *3.3. PKS 0237-23.*

The cluster model of uniform density was unable to explain the multiple redshifts of PKS 0237-23. The second model can account for these absorption lines. Let us take $z_{gem} = 0{\cdot}5$. Then

$$(b/a)^n = 1{\cdot}5/(2n+1)^{1/2}. \tag{18}$$

If we assume that the emission region is at $r = a$ and the least redshifted line $z_{ab} = 1{\cdot}3646$ arises at $r = b$, then $f_{max} = (b/a)^n = 1{\cdot}366$. From equations (17) and (19), $(2n+1)^{1/2} = 1{\cdot}082$ giving $n = 0{\cdot}085$ and $b = 87a$. The other absorption lines $z_{ab} = 2{\cdot}2017$, 1·9556, 1·6744, 1·6715, 1·6564, 1·5958 and 1·5132 originate in the regions given by $r = 1{\cdot}11a$, $2{\cdot}82a$, $9{\cdot}15a$, $9{\cdot}32a$, $11{\cdot}77a$, $13{\cdot}06a$ and $39{\cdot}17a$ respectively. The equation of state at $r = a$ is $p = 0{\cdot}045\rho$.

## References

Bondi H 1964 *Proc. R. Soc.* A **282** 303–17

Burbidge G R and Burbidge E M 1971 *General Relativity and Cosmology* ed R K Sachs (London: Academic Press) pp 284–305

Durgapal M C and Gehlot G L 1969 *Phys. Rev.* **183** 1102–4

Hoyle F and Fowler W A 1967 *Nature, Lond.* **213** 373–4

Ipser J R 1969 *Astrophys. J.* **158** 17–43

Lawrence J L, Morton D C, Zuchino P, Oke J B and Schmidt M 1972 *Astrophys. J.* **171** 233–51

Wyman M 1949 *Phys. Rev.* **75** 1930–6