CO molecules in the shells of quasars 1556+3517 and 0840+3633

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Abstract

New class of low-ionization BAL quasars (Becker et al. 1997), represented by QSO 1556+3517, 0840+3633 and 0059-2735, is considered. Their optical spectra are completely dominated by absorption features, whereas emission lines are weak or absent. Possibility to explain these exclusive features of their spectra by existence of molecular shells, responsible for the absorption is discussed. In particular, it is suggested to identify line at $\lambda = 2063$ Å, attributed to CrII, as a line of Cameron band $a^3\Pi_i \leftarrow X^1\Sigma^+$ of CO molecule. Estimation of the expected optical depth value in rotational radio lines of this molecule is made. It is suggested to carry out radio observations of quasars 1556+3517 and 0840+3633 to check the molecular hypotheses.

1 Introduction

Investigation of absorption features in spectra of remote quasars is the most effective method to explore the physical conditions in absorbers. In this way one can obtain data not only on the galaxies at line of sight quasar-observer, but also on shell of the quasar.

Last time the high activity take place in the field of searching and identification of molecular lines in spectra of quasars. Possible existence of this lines, created in distant molecular clouds, was first suggested by Carlson (1974) for quasar 4C05.34, in spectrum of which he was trying to identify lines of $H_2$ molecule. However these lines was certainly detected by Levshakov and Varshalovich (1985) in absorption spectrum of the quasar PKS 0528-250 at $Z = 2.811$. This identification was confirmed later by higher-resolution observations independently by Foltz, Chaffee and Black (1988) and by Cowie and Songaila (1995).

First possible detection of CO UV- lines in a quasar spectrum was made by Varshalovich and Levshakov (1979) in spectrum of source PHL957 ($z_c = 2.69$), but identification of these lines was not confirmed up to now. Only the upper
limits were estimated by Levshakov, Folts, Chaffee, Black (1989), Levshakov, Folts, Chaffee, Black (1992), and Lu, Sargent, Barlow (1997).

Possible radio observations of molecular clouds at cosmological distances was discussed by Khersonsky, Varshalovich, Levshakov (1981). From year to year, more and more distant radio absorption system of CO molecules in spectra of quasars are observed. The most remote CO- absorber, recently discovered, is located at $Z = 4.6$.

The observations of the radio lines of CO molecule in galaxies located at line of sight, became usual events, whereas existence of this molecule in the quasar shell is not believed to be probable due to strong ionized radiation of the quasar core. However recently Guilloteau et al. (1997) observed rotational transition $J'J = 5-4$ of the CO molecule at $z_a = 4.407$ in spectrum of radioquiet quasar BRI 1335-0415. This result is of particular interest because, as it was mentioned by the authors, this line can originate in the gas of the QSO host galaxy (red shift of the quasar, determined with the number of lines of atoms and ions is estimated to be from 4.407 to 4.41).

Recently we have discussed possible existence of molecular ion $HeH^+$ in the hot quasar shell (Dubrovich and Lipovka 1995). To form $HeH^+$, the ionized hydrogen (and hence strong ionized radiation) is required, but in spite of rather small ionization potential of this molecule, even under this circumstances the optical depth in rotational lines of this molecule can be sufficiently large to be detected. In relation to this topic the new class of iron- lowionized BAL quasars, suggested by Becker et al. (1997) is of particular interest, because in their shells the molecules like CO could possibly survive.

This population, referred to as "iron Lo BAL QSO", is represented by three objects: 1556+3517, 0840+3633 and 0059-2735 with redshifts $z = 1.48$, 1.22 and 1.62 respectively. Spectra of these quasars are heavily attenuated at optical wavelength in region less than 2800 A in the quasar restframe. The number of ions and nutrals were found in their spectra (in particular $FeI$ and $MnI$ characterized by ionization potentials 7.9 and 7.4 eV). Large optical depths of nutral $Fe$ and $Mn$ in spectrum of 1556+3517 on the one hand, and unusually strong absorption in lines and continuum as well, on the other hand, lead to conclusion on low degree of ionization in their shells. It mean that strong ionized radiation of their cores is shielded by dense internal part of the shell. It suggest on the possible existence of steady molecules with high (about 10 eV) dissociation energies in the shells.

Among suggested by Becker et al. (1997) identification, there is rather strong line at $\lambda \approx 2063$ A, attributed to $CrII$. This identification is not apparent due to uncertainty on the $Cr$ abundance in the shell (which need not to be Solar one). In addition, it should be noted the main depth in the $CrII$ line must grow in thin internal region because of low ionization degree in the shell.

At the same time the transition from the ground state $X^1\Sigma^+$ of CO molecule to the first exited one $a^3\Pi_2$, has wavelength $\lambda = 2062.9$ A, and next transition $a^3\Sigma \leftarrow X^1\Sigma^+$ has $\lambda = 1806.5$ A (the line at this wavelength in the spectra of
the quasars is attributed to \( Si II : \lambda = 1808 \text{ A} \). CO molecule has dissociation energy \( E_D = 11 \text{ eV} \) (it is more than value of ionization potential of many atoms), and for this reason the possible existence of CO in the quasars shells, discussed in this paper, become very attractive. In this case one can identify the line at 2063 A, as a line of Cameron band \( a^3\Pi_i \leftarrow X^1\Sigma^+ \) of CO molecule.

If this molecular hypothesis is supported by observations of CO molecule in the QSO shell, it will become a corner-stone in the model of atmosphere of this objects. Besides that, it will be necessary to reidentify the number of absorption lines in their spectra.

2 Optical spectrum

Two most prominent members of this population are quasars 1556 +3517 and 0840 +3633, distinguished by their strong absorption. Both objects are redder than typical quasars at these redshifts. So, their magnitudes taken from APM POSS I are \( O=21.2, E=18.7 \) for 1556 +3517 and \( O=17.3, E=15.9 \) for 0840 +3633, whereas typical values for intermediate- redshift quasars are \( O-E \approx 0.5 \) (Becker et al. 1997). As a rule a reddening is connected with existence of dust, but the spectra character does not support this assumption.

There are three \( \epsilon \)-vibronic bands of CO molecule in the region of wavelengths from \( \lambda = 1400 \) to \( \lambda = 3500 \) A in which the spectra of quasars are shown in the paper of Backer et al (1997). The most strong absorption band, should be mentioned first, is \( A^1\Pi \leftarrow X^1\Sigma^+ \). It is allowed transition characterized by oscillator strengths \( \approx 10^{-2} \). It cover the wavelength region shorter than 1544 A. Spectra of quasars 1556+3517 and 0840+3633 are totally absorbed in this region, and this fact is an argument to support the molecular hypothesis.

The next term of our interest is lower triplet state \( a^3\Pi_i \) of CO molecule. Cameron band \( a^3\Pi_i \leftarrow X^1\Sigma^+ \) is forbidden by the spin selection rule, however this transition can be observed due to strong spin- orbital interaction of \( a^3\Pi_i \) and \( A^1\Pi \) states (James 1971). The first observation of this band was made by Barth et al. (1969) in emission from upper atmosphere of Mars, but the oscillator strengths (need for correct identification) was obtained by James (1971). In consequence to these data, the values \( f(v', v) \) for transitions \( a^3\Pi_i(v') \leftarrow X^1\Sigma^+(v) \) are \( f(1,0) = 2 \times 10^{-7} \) ( \( \lambda_{10} = 1993\text{A} \)), and \( f(0,0) \approx f(0,1) = 1.6 \times 10^{-7} \) ( \( \lambda_{00} = 2064\text{A}, \lambda_{01} = 2159\text{A} \)). It should be stressed, in spectra of quasars under consideration, there are absorption lines at wavelengths \( \lambda_{10}, \lambda_{01} \) and \( \lambda_{00} \). This fact justify our suppose on molecular nature of these lines. Recently Minaev, Plachkevytch and Agren (1995) recalculated the oscillator strengths, but their values does not change significantly. For transition of our interest \( (v', v) = (0,0) \) they suggest the value \( f(0,0) = 1.4 \times 10^{-7} \), which will be used farther.

Third transition fall within the region under consideration \( (a^3\Sigma^+(v) \leftarrow X^1\Sigma^+(v)) \) is forbidden too. To our knowledge, its oscillator strengths was not
calculated to the moment, because of strong perturbations of $a^3\Sigma^+$ term by other ones. In this case the correct estimation of equivalent width of lines become impossible.

3 Optical depth and expected flux in radio continuum

The value of optical depth in line $\lambda = 2063$ Å is known. For this reason we can exclude the column density of CO molecules from consideration, and calculate the ratio of the radio line depth to the optical one: $\tau_r/\tau_o = \alpha_r/\alpha_o$, where

$$\alpha_\nu = \frac{A_{nn}c^2}{8\pi\nu_{nm}^2} \frac{g_m}{g_n} \frac{N_n}{\Delta \nu_D} \{1 - e^{-h\nu_{nm}/kT_{nm}}\},$$

and for optical wavelengths:

$$\alpha_o = \frac{\pi e^2}{mc} \frac{N_0}{\Delta \nu_D} f_{00}.$$

In this expressions $N_n$ - is the molecule density at level $n$, $A_{mn}$ - is the Einstein coefficients, $N_0$ - is the molecule density at the zeros vibrational level, $f_{00}$ - is the oscillator strength for the transition $a^3_i(v' = 0) \leftrightarrow X^1\Sigma^+(v = 0)$, $\Delta \nu_D$ - is the Doppler width of line. By substituting these expressions, we obtain:

$$\frac{\tau_r}{\tau_o} = \frac{mc^3\nu_{opt}}{8\pi^2e^2\nu_{J'J}} \frac{g_J}{g_J} \frac{n_J A_{J'J}}{n_0 f_{00}} \{1 - e^{-h\nu_{J'J}/kT_CMBR}\}.$$

Under reasonable assumption $n_0 \approx 1$ and $T_{J'J} = T_{CMBR}$, one can obtain $\tau_r/\tau_o \approx 1.1 \times 10^3 n_J$ for lower rotational levels, listed in table 1. In the table their wavelengths recalculated for quasar 1556+3517 are given.

| $J'J$ | $\nu_0[GHz]$ | $\nu_{opt}$ | $A_{nn}[s^{-1}]$ | $\lambda(1+z)[mm]$ |
|-------|---------------|-------------|------------------|------------------|
| 0 1   | 115.271204    | 7.166(-8)   | 6.4498259        |
| 1 2   | 230.537974    | 7.874(-7)   | 3.2249749        |
| 2 3   | 345.79598     | 2.483(-6)   | 1.2901624        |
| 3 4   | 461.04081     | 6.094(-6)   | 1.6126104        |
| 4 5   | 576.26793     | 1.215(-5)   | 1.2901624        |
| 5 6   | 691.47298     | 2.126(-5)   | 1.0752108        |
The fluxes from quasar 1556+3517 at frequencies 1.4 and 5 GHz are 30.6 and 27.0 mJy respectively (Becker, et al. 1997). Spectral index in this case is $\alpha = -0.1$, that lead to expected flux $F = 20$ mJy at the frequency of line $(J'J) = (21)$ shifted at $(1 + z)$: $\nu = 92.9$ GHz. For quasar 0840+3633, the flux at 1.4 GHz is 1.3 mJy. If we take $\alpha = -0.1$, we will obtain the expected flux $F = 0.8$ mJy at frequency of observation $\nu = 103.8$ GHz. Such fluxes can be observed with modern radiotelescopes. For observations with IRAM 3mm receiver, for example, the time of observation should be approximately 1 minute for QSO 1556+3517 and 10 hours for 0840+3633 (note that $\tau_r > 1$).

4 Conclusion

In the paper, the assumption on the presence of CO molecules in low-ionized shells of quasars of new population was considered. The possibility is connected with the fact that on the one hand, there are very large optical depth of the shell in the region of allowed band $\Delta^1\Pi ← \Delta^1\Sigma^+$, on the other hand, in their spectra there are number of absorption lines can be attributed to band $a^3\Pi_i ← \Delta^1\Sigma^+$.

The values of calculated fluxes in radio continuum from QSO 1556+3517, and optical depth in radiolines CO molecule, are sufficiently large to detect predicted lines.

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6 References

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