Chin. J. Astron. Astrophys. Vol. 1, No. 2, (2001) 133–143
(*http://www.chjaa.org* or *http://chjaa.bao.ac.cn*)

Chinese Journal of
Astronomy and
Astrophysics

Annual Modulation in Intraday Variability Timescales of Extragalactic Radio Sources

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Received 2000 November 30; accepted 2000 December 28

Abstract Annual modulations in timescales of intraday variability (IDV hereafter) are discussed for six extragalactic sources: 0716+714, 0917+624, 0954+65, 1749+70, 1803+78 and 2007+77. The timescales calculated from scintillation theory are compared with the observational data. It is emphasized that systematic observations are required to identify the phenomenon and to determine the motion of the interstellar medium with respect to the Local Standard of Rest. In addition, significant deviations from the annual modulation could be due to intrinsic variations.

Key words: scattering – ISM: kinematics – BL Lacertae objects: individual: 0716+71 – quasars: individual: 0917+62 – radiation mechanisms: non-thermal

1 INTRODUCTION

IDV is a general phenomenon of extragalactic radio sources (Heeschen et al. 1987). The origin and nature of this phenomenon have been investigated intensively in recent years. Most of the studies were aimed to show the role played by two mechanisms (Wagner & Witzel 1995; Witzel 1990; Qian 1994a): intrinsic mechanism (relativistic shocks, Qian et al. 1991; Marscher et al. 1992; Marscher 1996; Kochanev & Gabuzda 1998) and refractive interstellar scintillation (Hjellming & Narayan 1986; Heeschen et al. 1987; Fiedler et al. 1987; Wambsganss et al. 1989; Rickett et al. 1995; Qian 1994a, 1994b; Qian et al. 1995; Qian & Zhang 1996). One firm phenomenon in favour of an intrinsic origin was the IDV event with a radio-optical correlation observed in the BL Lac object 0716+71 (Quirrenbach et al. 1991). This event has an apparent brightness temperature of $\sim 10^{17}$ K, exceeding the inverse-Compton limit by a factor of $\sim 10^5$. A detailed model was proposed by Spada et al. (1999) to explain this high apparent brightness temperature by invoking electron-sheets propagating through an oblique standing shock with a Lorentz factor of ∼10.

A few extremely rapid intraday variations with timescale of one or two hours were recently observed in the compact sources J1819+385 (Dennett-Thorpe & de Bruyn 2000a) and 0405–385

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(Kedziora-Chudczer et al. 1997). If they are intrinsic to the sources, the apparent temperatures derived from causality will reach $\sim 10^{21}$K, exceeding the inverse-Compton limit by a factor of $\sim 10^{9}$. It seems difficult to interpret these extremely short timescale variations in the framework of intrinsic mechanisms. Therefore, refractive interstellar scintillation is accepted as a plausible explanation, because the observed wavelength dependence of the modulation index and timescale are consistent with the scintillation theory. But even applying to scintillation, the apparent temperatures are still derived to be in the range of $\sim 10^{14}$– 10^{15} K, if the scattering screen is situated at distances larger than ∼0.2 kpc. This implies that some intrinsic mechanisms may be partly involved. They could be the relativistic motion of the scintillating components with Lorentz factors of ∼100 or some coherent radiation mechanism. Similarly, for the quasar 0917+62, Qian et al. (2001) indicate that, in addition to refractive scintillation, Doppler beaming with a Doppler factor of ∼7 may also be required to explain the observed high brightness temperatures ($\sim 10^{18}$ K).

A significant progress made recently is the annual variation of the IDV timescale in J 1819 + 385 found by Dennet-Thorpe & de Bruyn (2000b). Its IDV timescale was observed to vary during a year by a factor of ∼10 (timescales from ∼1 to 10 hours). This phenomenon was interpreted in terms of the annual modulation of interstellar scintillation by the Earth motion relative to the scattering medium. However, this relative motion is not only due to the Earth's motion with respect to the Local Standard of Rest (LSR), but a motion of the scattering medium of $\sim 25\,\mathrm{km\,s^{-1}}$ is also required.

Previously, Bondi et al. (1994) made a statistical study of the structure functions of more than 40 extragalactic low frequency variables (408 MHz) and found a flattening of the structure function at a lag value of ∼0.5 years. They interpreted this flattening as due to the annual modulation of the refractive scintillation by the Earth's motion. In that study they could not find any motion of the scattering medium. (See also Spangler et al. 1989; 1993).

The annual modulation of the IDV timescale observed in J1819+385 provides quite strong support for scintillation mechanism, but VLBI observations also show that the jet-flow in this source is very fast (de Bruyn, private communication). Similarly, Qian et al. (2001) have found that, for the IDV source 0917+62, the scintillating components may be in highly superluminal motion with a bulk Lorentz factor of ∼7. Therefore, on the basis of the available observations, we would come to the conclusion that IDV sources contain very compact components which are scintillating and, at the same time, they are Doppler boosted. The reduction of the apparent brightness temperatures below the inverse-Compton limit in the comoving frame may be due to two factors: the angular size of the scintillating components is larger than that derived from the observed timescale by causality, and the intrinsic intensity is reduced by correcting the Doppler beaming.

In this paper we will calculate the annual variations of the timescale of refractive scintillation for six IDV sources (0716+71, 0917+62, 0954+65, 1749+70, 1803+78 and 2007+77). The relative motion between the Earth and the scattering medium is investigated, taking into account the Earth's motion around the Sun, the solar motion and the motion of the scattering medium with respect to the Local Standard of Rest (LSR). It will be shown that the Earth velocity projected onto the scintillation pattern in the direction of these sources can vary by a factor of $\sim 2-7$ during a year. Therefore, the IDV timescale of these sources should correspondingly vary by a similar factor, if their intraday variations are due to refractive scintillation and if their intrinsic compact structures do not change much during a year.

2 RELATIVE VELOCITY BETWEEN EARTH AND SCATTERING MEDIUM

As we pointed out above, in order to explain the annual variation of the IDV timescale observed in some extragalactic radio sources in terms of interstellar scintillation, the relative motion of the Earth with respect to the scattering medium is an important parameter. This relative motion consists of three parts: (1) the Earth's orbital motion around the Sun; (2) the motion of the Sun towards the solar apex; (3) the motion of the scattering medium with respect to the Local Standard of Rest. And the timescale due to scintillation is defined by the Earth's moving across the scintillation pattern.

2.1 Earth's Orbital Motion

Construct an equatorial coordinate system with its origin fixed at the center of the Sun (or on the solar system barycenter): the X-axis is directed towards the equinox, the Y-axis towards the point on the terrestrial equator at right ascension 6^{h}, and the Z-axis towards the north pole. We can then calculate the annual variation of the right ascension ($\alpha_\oplus$) and declination ($\delta_\oplus$) of the Earth in this frame as follows. Obviously we have

$$\begin{aligned} \alpha_\oplus &= \alpha_\odot + 180^\circ\,, && (1)\\ \delta_\oplus &= -\delta_\odot\,. && (2) \end{aligned}$$

Here ($\alpha_\odot$, $\delta_\odot$) represent the right ascension and declination of the Sun in the usual geocentric equatorial coordinate system. They can be calculated in the following way (see The Astronomical Almanac 1999)

$$\begin{aligned} n &= \text{day of year} - 1.5\,, && (3)\\ L &= 280.460^\circ + 0.985647\cdot n\,, && (4)\\ g &= 357.528^\circ + 0.9856003\cdot n\,, && (5)\\ \lambda &= L + 1.915^\circ\,\sin g + 0.020^\circ\,\sin 2g\,, && (6)\\ \epsilon &= 23.439^\circ\,. && (7) \end{aligned}$$

In the above L–mean longitude of the Sun, g–mean anomaly, λ–ecliptic longitude, ϵ–obliquity of ecliptic. Defining

$$\begin{aligned} f &= 180^\circ/\pi\,, && (8)\\ t &= \tan^2(\epsilon/2)\,, && (9) \end{aligned}$$

we obtain

$$\begin{aligned} \alpha_\odot &= \lambda - f\,t\,\mathrm{sin}2\lambda + 0.5\,f\,t^2\,\mathrm{sin}4\lambda\,, && (10)\\ \delta_\odot &= \arcsin(\mathrm{sin}\epsilon\,\mathrm{sin}\lambda)\,. && (11) \end{aligned}$$

And we obtain the spatial velocity of the Earth's orbital motion around the Sun:

$$\begin{aligned} \boldsymbol{V}_\oplus &= -V_\oplus\frac{\mathrm{sin}\delta_\oplus}{\mathrm{sin}\epsilon}\cdot\boldsymbol{X}_0 + V_\oplus\mathrm{cos}\alpha_\oplus\mathrm{cos}\delta_\oplus\mathrm{cos}\epsilon\cdot\boldsymbol{Y}_0\\ &\quad + V_\oplus\mathrm{cos}\alpha_\oplus\mathrm{cos}\delta_\oplus\mathrm{sin}\epsilon\cdot\boldsymbol{Z}_0\,, && (12) \end{aligned}$$

Here $V_\oplus = 29.8\,\mathrm{km\ s^{-1}}$. $\boldsymbol{X}_0$, $\boldsymbol{Y}_0$ and $\boldsymbol{Z}_0$ are the unit vectors along the coordinates (X, Y, Z) respectively.

2.2 Motion of Sun

The Sun (or solar system) moves towards the solar apex, the right ascension and declination of which are

$$\alpha_a(1950) = 267.0^\circ\,, \tag{13}$$

$$\delta_a(1950) = 28^\circ\,. \tag{14}$$

Thus, the velocity of the Sun in the LSR frame is

$$\boldsymbol{V}_\odot = V_\odot\cos\alpha_a\cos\delta_a\cdot\boldsymbol{X}_0 + V_\odot\sin\alpha_a\cos\delta_a\cdot\boldsymbol{Y}_0 + V_\odot\sin\delta_a\cdot\boldsymbol{Z}_0\,. \tag{15}$$

Here $V_\odot$=16.6 km s^{-1} (Gilmore & Zeilik 2000).

2.3 Motion of Interstellar Medium

Let the velocity components of the interstellar medium along the right ascension and declination of the source be (V_{α_*}, V_{δ_*}). We do not consider its motion along the line of sight, because in the scintillation theory only the transverse velocity of the Earth across the scintillation pattern is involved. Thus, the velocity of the scattering medium can be represented as

$$\boldsymbol{V}_m = \boldsymbol{V}_{\alpha_*} + \boldsymbol{V}_{\delta_*}\,. \tag{16}$$

Here $\boldsymbol{V}_{\alpha_*}$ and $\boldsymbol{V}_{\delta_*}$ are

$$\boldsymbol{V}_{\alpha_*} = -V_{\alpha_*}\sin\alpha_*\cdot X_0 + V_{\alpha_*}\cos\alpha_*\cdot\boldsymbol{Y}_0\,, \tag{17}$$

$$\boldsymbol{V}_{\delta_*} = -V_{\delta_*}\cos\alpha_*\sin\delta_*\cdot\boldsymbol{X}_0 - V_{\delta_*}\sin\alpha_*\sin\delta_*\cdot\boldsymbol{Y}_0 + V_{\delta_*}\cos\delta_*\boldsymbol{Z}_0\,. \tag{18}$$

2.4 Transverse Velocity of Earth Across Scintillation Pattern

The velocity of the Earth with respect to the scattering medium can be represented as

$$V_\perp = V\sin\theta\,. \tag{19}$$

Here θ is the angle between the total velocity $\boldsymbol{V}$ and the line-of-sight towards the source.

$$\boldsymbol{V} = \boldsymbol{V}_\odot + \boldsymbol{V}_\oplus - \boldsymbol{V}_m\,. \tag{20}$$

Its components are

$$V_x = -V_\oplus\frac{\sin\delta_\oplus}{\sin\epsilon} + V_a\cos\alpha_a\cos\delta_a + V_{\alpha_*}\sin\alpha_* + V_{\delta_*}\cos\alpha_*\sin\delta_*\,, \tag{21}$$

$$V_y = V_\oplus\cos\alpha_\oplus\cos\delta_\oplus\cos\epsilon + V_a\sin\alpha_a\cos\delta_a - V_{\alpha_*}\cos\alpha_* + V_{\delta_*}\sin\alpha_*\sin\delta_*\,, \tag{22}$$

$$V_z = V_\oplus\cos\alpha_\oplus\cos\delta_\oplus\sin\epsilon + V_a\sin\delta_a - V_{\delta_*}\cos\delta_*\,. \tag{23}$$

And

$$\sin\theta = (1-\cos^2\theta)^{\frac{1}{2}}\,, \tag{24}$$

$$\cos\theta = \frac{V_x}{V}\cos\alpha_*\cos\delta_* + \frac{V_y}{V}\sin\alpha_*\cos\delta_* + \frac{V_z}{V}\sin\delta_*\,. \tag{25}$$

2.5 Time Scale of Scintillation

The timescale of scintillation depends on the motion of the Earth across the scintillation pattern and is determined by the angular size of the source and the characteristic parameters of the scattering medium. In the general case this time scale can be calculated as follows. Let $d_{\rm scr}$ be the distance of the equivalent scattering screen, and $\theta_{\rm eff}$, the effective angular size of the compact source. The timescale due to interstellar scintillation is then (Goodmann 1997):

$$T_r = 0.58\,\theta_{\rm eff}\,d_{\rm scr}\,{V_\perp}^{-1}\,. \tag{26}$$

The units are : T_r – day, $d_{\rm scr}$ – kpc, $\theta_{\rm eff}$ – 10μas, $V_\perp$ – $30\,{\rm km\ s^{-1}}$. The effective angular size can be calculated as follows

$$\theta_{\rm eff} = [{\theta_{\rm s}}^2 + (0.71\theta_{\rm d})^2 + (0.85\theta_{\rm f})^2]^{\frac{1}{2}}\,, \tag{27}$$

$$\theta_{\rm d} = 0.293\,\nu^{-2.2}{\rm SM}^{0.6}\,, \tag{28}$$

$$\theta_{\rm f} = 0.257\,\nu^{-0.5}{{\rm d}_{\rm scr}}^{-0.5}\,, \tag{29}$$

$$\mathrm{SM} = \int_0^l {C_n}^2(l){\rm d}l \approx \langle {C_n}^2\rangle \cdot l \tag{30}$$

$$d_{\rm scr} = 0.5\cdot l \tag{31}$$

In the above formulae $\theta_{\rm d}$ represents the scattering angle, which is determined by the scattering measure SM and frequency ν. $\theta_{\rm f}$ denotes the Fresnel angular size, and $\theta_{\rm s}$ the intrinsic angular size of the scintillating component. $\langle {C_n}^2\rangle$ is a parameter to describe the strength of scattering.

2.6 Correction of Coordinates for Precession

The equatorial coordinates of the radio sources are corrected to epoch 2000.0 according to the following formulae. Taking $(\alpha,\,\delta)$ as the coordinates of the source for epoch 1950.0, then the coordinates $(\alpha_*,\,\delta_*)$ for epoch 2000.0 are

$$\alpha_* = \alpha - M - N\,{\rm sin}\alpha_m {\rm tan}\delta_m\,, \tag{32}$$

$$\delta_* = \delta - N\,{\rm cos}\alpha_m\,, \tag{33}$$

$$\alpha_m = \alpha - \frac{1}{2}(M + N\,{\rm sin}\alpha\,{\rm tan}\delta)\,, \tag{34}$$

$$\delta_m = \delta - \frac{1}{2}N\,{\rm cos}\alpha_m\,. \tag{35}$$

The precession constants M and N are: $M = -0.6405^\circ$, $N = -0.2785^\circ$.

Table 1 Source List and the Parameters for the Interstellar Medium in the Source Direction

Source name	α (h m s)	δ (° ′ ″)	d (kpc)	$\langle {C_n}^2\rangle$ ($10^{-3.5}m^{-20/3}$ kpc)	θ_s (μas)
0716+71	07 16 12.98	71 26 15.0	0.56	0.5	70
0917+62	09 17 40.30	62 28 38.7	0.20	0.5	70
0954+65	09 54 57.86	65 48 15.5	0.20	0.5	35
1749+70	17 49 03.38	70 06 39.5	1.0	0.5	84
1803+78	18 03 39.18	78 27 54.2	1.0	0.5	100
2007+77	20 07 20.42	77 43 58.0	1.0	0.5	84

3 COMPARISON OF THEORETICAL PREDICTION WITH OBSERVATION

In the following we will use the formulae given in the last section to calculate the Earth velocity projected onto the scintillation pattern for six sources (0716+71, 0917+62, 0954+65, 1749+70, 1803+78 and 2007+77). The motion of the scattering medium (or equivalent screen) is taken into account for three sources. For each source, we will assume some appropriate values for the parameters (θ_s, $d_{\rm scr}$, $\langle C_n{}^2\rangle$) when calculating the theoretical timescales predicted by the scintillation theory. These parameters are summarized in Table 1. The coordinates of the sources are taken from Kühr et al. (1981). For a comparison with the observations we take the observational data (at 6 cm) from Quirrenbach (2000), Kraus (1999), Riesse (1996) and Wegner (1994).

3.1 0716+71

The Earth's velocity projected on the scintillation pattern and the theoretical timescales are shown in Figure 1. The parameters are: $d_{\rm scr}$=0.56 kpc, θ_s=70 μas and $\langle C_n{}^2\rangle = 0.5\ 10^{-3.5}$ $m^{-\frac{20}{3}}$ kpc. The three curves corresponds to different motions of the scattering medium: ($V_{\alpha*}$, $V_{\delta*}$)=(0, 0), (10, −10) and (−10, 10) km s^{-1}. It can be seen that, for ($V_{\alpha*}$, $V_{\delta*}$) = $(0,0)$ km s^{-1}, (i.e. assuming the scattering medium to be at rest in the LSR frame), the projected velocity and the IDV timescale can vary by a factor of ∼7 during a year. (The projected velocity varies in the range of ∼ 6–40 km s^{-1}). The slowest intraday variations are predicted to occur during September-October. Only one observational data point is available within this period, but it is not consistent with the prediction. This might imply that the motion of the scattering medium should be taken into account. As is well known, 0716+71 is one of the most variable BL Lac objects, and its compact structure could not keep stable over any length of time. Moreover, in this source correlated radio-optical intraday variations were observed (Quirrenbach et al. 1991; Qian et al. 1995). Therefore monitoring the possible annual modulation of its IDV timescale is important to distinguish intrinsic variations and scintillation. Simultaneous VLBI observations are desirable for monitoring any changes in its compact structure.

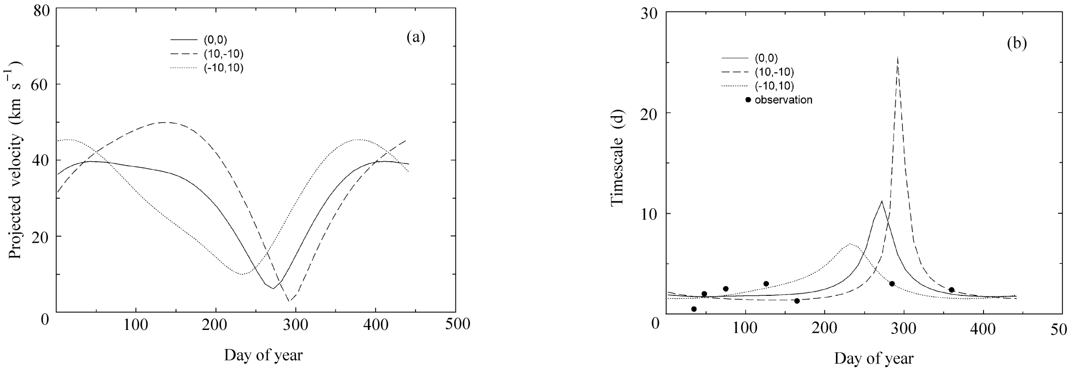

Fig. 1 0716+71: the projected velocity of Earth (a) and the timescale (b) predicted by scintillation theory. $d_{\rm scr}$=0.56 kpc, θ_s=70 μas, $\langle C_n{}^2\rangle = 0.5{\times}10^{-3.5}m^{-\frac{20}{3}}$ kpc. The motion of the scattering medium is taken into account: ($V_{\alpha*}$, $V_{\delta*}$) = $(0,0)$, $(10,-10)$ and $(-10,10)$ km s^{-1}.

3.2 0917+62

The projected Earth velocity and the IDV timescale predicted by the scintillation theory are shown in Figure 2. The parameters adopted for the scattering medium and the source are: θ_s=70 μas, $d_{\rm scr}$=0.2 kpc and $\langle {C_n}^2 \rangle = 0.5{\times}10^{-3.5}m^{-\frac{20}{3}}$. Four curves are given for considering the effect of the motion of the scattering medium: $(V_{\alpha *},\ V_{\delta *}) = (0,0)$, $(-10,0)$, $(-10,4)$ and $(-10,10)$ km s^{-1}. It can be seen that, for the scattering medium at rest in the LSR frame, the projected velocity of the Earth and the predicted IDV timescale can vary by a factor of ~ 7 ($\sim$ 6–40 km s^{-1}), similar to 0716+71. The slowest IDV variations are predicted to occur during October-November.

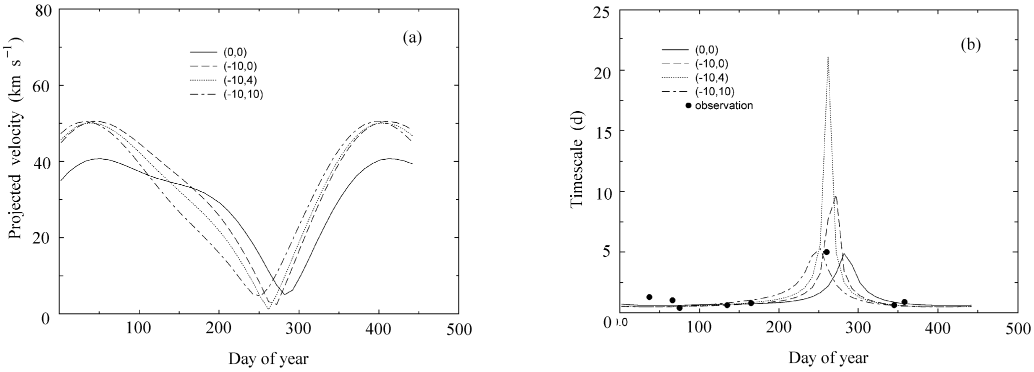

Fig. 2 0917+62: the projected velocity of Earth (a) and the timescale (b) predicted by scintillation theory. $d_{\rm scr}$=0.2 kpc, $\theta_s = 70\,\mu$as, $\langle {C_n}^2 \rangle = 0.5{\times}10^{-3.5}m^{-\frac{20}{3}}$ kpc. The motion of the scattering medium is taken into account: $(V_{\alpha *},\ V_{\delta *}) = (0,0)$, $(-10,0)$, $(-10,4)$ and $(-10,10)$ km s^{-1}.

One observation made by Kraus et al. (1999) in September 1998 showed a much longer timescale of >5 days as compared with the usual timescales of $\sim$ 1 day. So the annual modulation of IDV timescale by scintillation seems to be really present in this source. But as shown in Fig. 2, the available observational data cannot provide a detailed comparison with the theoretical predictions. More monitoring observations are needed to get the precise pattern of annual modulaton and to determine the motion of the scattering medium. We should point out that 0917+62 is behind the Galactic SN remnant Loop-III (Berkhuijsen et al. 1971), so a motion of the scattering screen is possible.

Standke et al. (1996) have shown that superluminal motion was observed in 0917+62. The relationship between the intraday variations and the superluminal motion is thus a topic worth investigating further.

3.3 0954+65

The projected Earth velocity and the IDV timescale predicted by the scintillation theory are shown in Figure 3. The adopted parameters are: $\theta_s = 35\,\mu$as, $d_{\rm scr} = 0.2$ kpc and $\langle {C_n}^2 \rangle = 0.5{\times}10^{-3.5}m^{-\frac{20}{3}}$ kpc. Only one curve is shown in Fig. 3, which corresponds to the scattering medium being at rest in the LSR frame. It can be seen that one observational data point having a much longer timescale was observed in February, deviating greatly from the time interval predicted by the scintillation theory. It is not clear whether this event was due to intrinsic variations. Since in 0954+65, as in 0716+71, correlated optical and radio intraday variations were observed (Wanger et al. 1995), investigation of the annual modulation of its IDV timescale due to scintillation would be very meaningful.

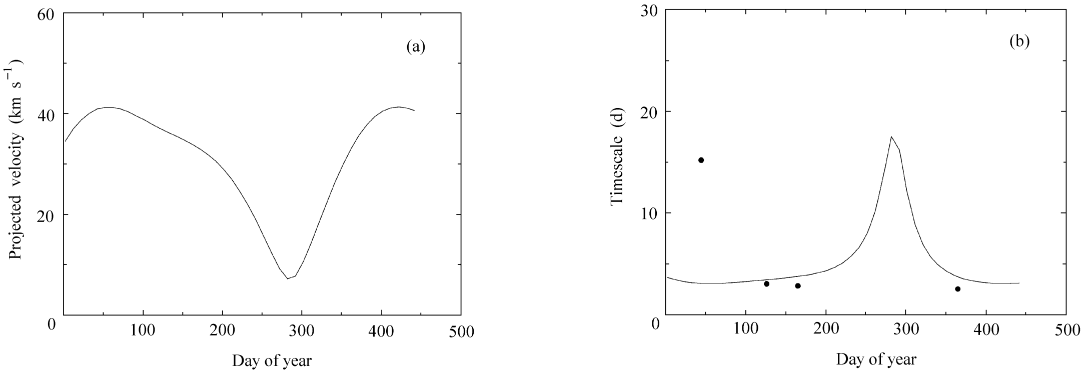

Fig. 3 0954+65: the projected velocity of the Earth (a) and the timescale (b) predicted by scintillation theory. $d_{\rm scr}$=0.2 kpc, θ_s=35 μas, $\langle {C_n}^2 \rangle = 0.5\times10^{-3.5}\ m^{-\frac{20}{3}}$ kpc.

3.4 1749+70

The projected Earth velocity and the IDV timescale predicted by the scintillation theory are shown in Figure 4. The adopted values for the parameters are: θ_s=84 μas, $d_{\rm scr}$=1 kpc and $\langle {C_n}^2 \rangle = 0.5\times10^{-3.5} m^{-\frac{20}{3}}$ kpc. One theoretical curve is shown for the scattering medium at rest in the LSR frame. It can be seen that the theoretical timescale and the projected velocity predicted by the scintillation theory can vary by a factor of ~2 during a year. One observational data point seems to show a longer timescale than is predicted by the theory.

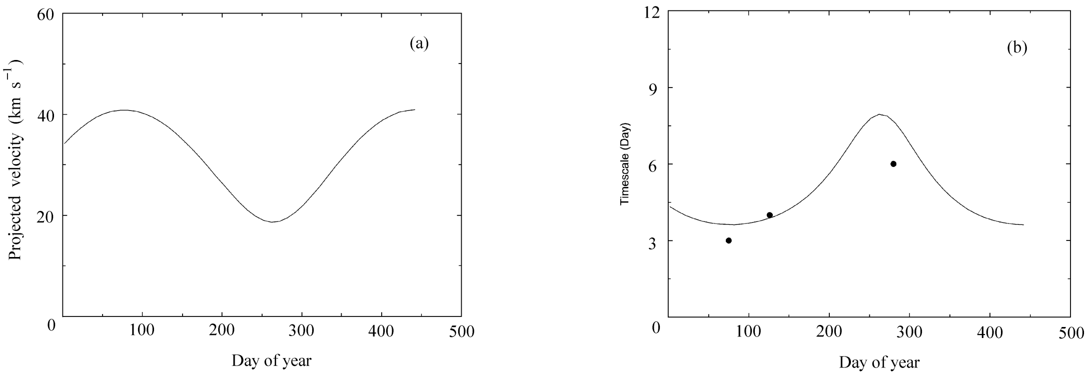

Fig. 4 1749+70: the projected velocity of the Earth (a) and the timescale (b) predicted by scintillation theory. $d_{\rm scr}$=1 kpc, θ_s=84 μas, $\langle {C_n}^2 \rangle = 0.5\times10^{-3.5}\ m^{-\frac{20}{3}}$ kpc.

3.5 1803+78

The projected Earth velocity and the IDV timescale predicted by the scintillation theory are shown in Figure 5. The adopted values for the parameters are: $d_{\rm scr}$=1 kpc, θ_s=100 μas, $\langle {C_n}^2 \rangle = 0.5{\times}10^{-3.5} m^{-\frac{20}{3}}$ kpc. One theoretical curve is shown for the scattering medium being at rest in the LSR. It can be seen from Fig. 5 that the projected velocity and the theoretical timescale can vary by a factor of ∼3 during a year. The longest timescales are predicted to occur during August-October. The available data points fall outside this time interval, so more observations are needed to check whether there is an annual modulation of the IDV timescale.

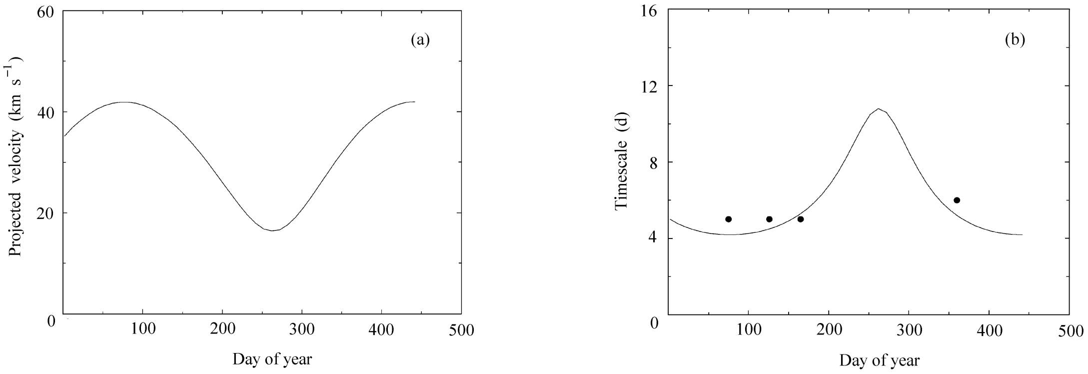

Fig. 5 1803+78: the projected velocity of the Earth (a) and the IDV timescale (b) predicted by scintillation theory. $d_{\rm scr}$=1 kpc, θ_s=100 μas, $\langle {C_n}^2 \rangle = 0.5{\times}10^{-3.5} m^{-\frac{20}{3}}$ kpc.

3.6 2007+77

The projected Earth velocity and the IDV timescale predicted by the scintillation theory are shown in Figure 6. The adopted values of the parameters are: $d_{\rm scr}$=1 kpc, θ_s=84 μas and $\langle {C_n}^2 \rangle = 0.5{\times}10^{-3.5} m^{-\frac{20}{3}}$. Four theoretical curves are shown to reveal the effect of the motion of the scattering medium: $(V_{\alpha *}, V_{\delta *}) = (0, 0)$, $(-10, 0)$, $(-10, 4)$ and $(-10, 8)$ km s^{-1}. For the case of the scattering medium being at rest with respect to the LSR, the projected velocity and the IDV timescale predicted by the scintillation theory can vary by a factor of ∼3 during a year. One data point obtained in October has a much longer timescale than the others. This seems to imply that an annual modulation of its IDV timescale possibly exists. More monitoring observations are desirable to obtain a more detailed pattern of the timescale variation during a year and to determine the velocity of the scattering medium.

For the last three sources, the IDV timescales of which are usually longer than ∼3 days, we adopted larger values for $d_{\rm scr}$ and θ_s than for the first three sources.

4 DISCUSSION

In the above we calculated the annual modulation of IDV timescale due to refractive scintillation for six extragalactic sources. A comparison with the available observational data indicates that this phenomenon could occur in these sources. For the quasar 0917+62, one observation made in September 1998 showed that the IDV timescale reached ∼5 days, which was longer than the timescales observed in December 1997, Feburary 1999 and other previous epochs by a factor of ∼3–5 (Kraus et al. 1999). Since 0917+62 has been very stable in its flux density during the past decade, the increase of its IDV timescale observed in September 1998 is probably evidence for the annual modulation due to refractive scintillation.

The BL Lac object 2007+77 could be another source, which was observed to have an annual modulation of its IDV timescale, because one observation made in October 1992 showed a much longer timescale than usual by a factor of ∼3 (Riesse 1996).

For the BL Lac object 0716+71 the available observational data does not reveal any annual modulation in its IDV timescale. One observational data point falls into the predicted range of increasing timescale, but the observed timescale is similar to those observed at other epochs.

For the BL Lac object 0954+65, one observation made in February 1990 showed a much longer timescale, and it is outside the predicted range of increasing timescale. In both 0716+71 and 0954+65 correlated optical and radio intraday variations were observed (Quirrenbach et al. 1991; Qian et al. 1996; Wagner & Witzel 1995), so they are the most interesting sources to investigate the question whether there is an annual modulation in their IDV timescale. Because they are highly variable in radio–optical bands, VLBI observations may be useful to find the variations in their compact structures, which could also affect the observed IDV timescales. In addition, monitoring observations for finding out if there is any annual modulation of IDV timescale in 0716+71 and 0954+68 may be also useful to distinguish between intrinsic variations and scintillation.

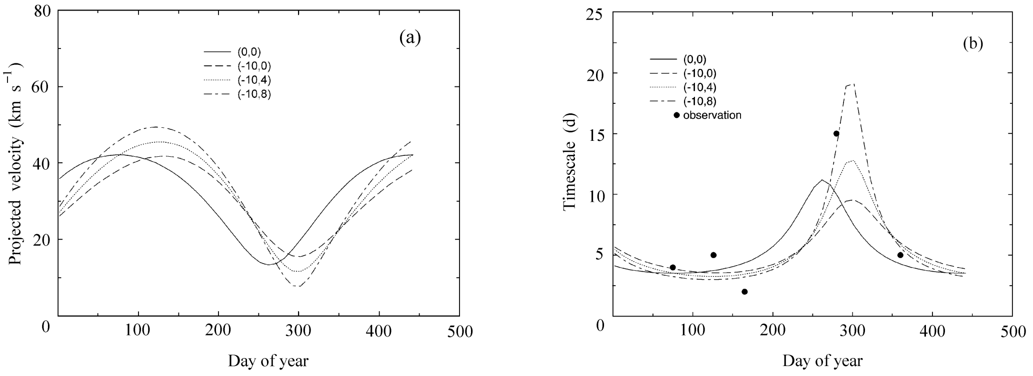

Fig. 6 2007+77: the projected velocity of Earth (a) and the timescale (b) predicted by scintillation theory for 2007+77. $d_{\rm scr}$=1 kpc, θ_s=84 μas,$\langle C_n{}^2\rangle = 0.5\times10^{-3.5} m^{-\frac{20}{3}}$ kpc.

For 1749+70 and 1803+78 the available observational data are too scanty to make any conclusions. Their IDV timescales were observed to be ∼3–4 days. It is not clear whether the longer timescales are due to larger angular sizes of their scintillating components or larger distances of the equivalent scattering screen.

Acknowledgements S. J. Qian acknowledges the support by Max-Planck-Institut für Radioastronomie during his visit.

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