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Detection of large scale electron density irregularities during IPS observations at 103 MHz

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Abstract. Angular displacements in the positions of the quasar 3C 298 were observed during its interplanetary scintillation (IPS) observations made using a correlation interferometer at 103 MHz at Thaltej near Ahmedabad. These changes in the apparent positions of the source could be seen as variations in the declination of 3C 298. Two possibilities which might cause such effects are considered; refraction of the radio waves either in the earth's ionosphere or in the interplanetary medium (IPM) by large scale plasma density inhomogeneities. Order of magnitude calculations for both are presented. Further studies using two-site observations are suggested to decide between the two mechanisms.

Keywords. Compact radio source; correlation interferometer; interplanetary scintillation; ionospheric refraction; gravity waves.

1. Introduction

It is well known that the apparent positions of radio sources as well as artificial satellites undergo quasi-periodic variations. These have been attributed to refraction of radio waves by inhomogeneities of electron density in the ionosphere. This effect has been reported mainly in the case of strong extended radio sources, such as Cassiopea and Cygnus A (Okoye and Hewish 1968), and solar noise storm (Bougeret 1981).

In this paper, we report observations made using a sensitive correlation interferometer with receiver fringes having high resolution in declination. This enables accurate determination of shift in the declination of a radio source. The radio source under observation, 3C 298, is a compact (0·4 arc sec) scintillating source.

2. Observations

Observations of angular displacements of the position of the compact radio source 3C 298 have been made while recording its IPS using a correlation interferometer at a frequency of 103 MHz (Alurkar *et al* 1982) at Thaltej (72° 36′E, 23° 02′N) Ahmedabad. The interferometer operation is effected by multiplying the response of the southern half of the antenna aperture with its northern half, the separation between their phase centers being 93 m, corresponding to 32 wavelengths. The resulting antenna response in declination, together with the SIN and COS fringes of the correlation type receiver, are displayed in figure 1. The half power beam width (HPBW) of this declination aerial response is 1·87°. The HPBW in right ascension near zenith is 7·5°. This interferometer has an advantage that the source stays on the same SIN and/or COS fringes at a fixed position during its transit.

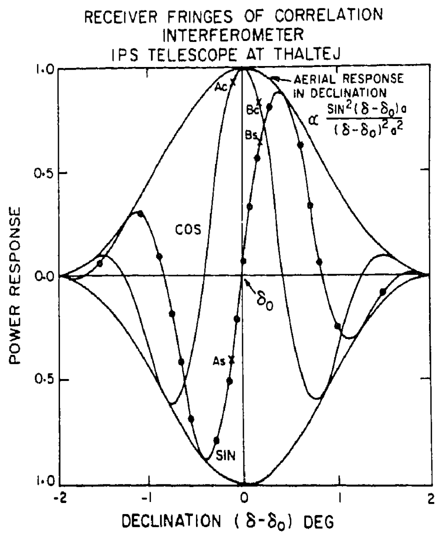

Figure 1. Receiver fringes of correlation interferometer of IPS telescope at Thaltej. A_c, A_s and B_c, B_s are two assumed positions of 3C 298 on COS and SIN fringes.

Regular observations of 3C 298 were made over the solar elongation range of about 20°–80° at Thaltej. There were 70 observations in this solar elongation range, of which 35 were in the elongation range of 20° to 33°. These latter observations can be grouped into five types and one each of these types is shown in figure 2. Beyond 33° all the records are as in figure 2(a). The record (a) on 13–10–83 indicates strong d.c. as well as scintillating flux on the COS channel, while very small flux increase is seen on the SIN channel. Note that this increase is on the same side as that on the COS channel. The corresponding positions of 3C 298 on the COS and SIN fringes in figure 1 can be thought of as near the peak of the COS fringe and near the zero-crossing of the SIN fringe respectively. The recordings (b) and (c) on 15–10–83 and 20–10–83 indicate good enhancements on the SIN channel also, with the latter showing reversed deflection. The record in (c) will result if the source positions were at A_c and A_s on the COS and SIN fringes in figure 1 and the record (b) will result if they were at B_c and B_s.

The events in figure 2(d, e) on 14–11–83 and 21–11–83 correspond to solar elongations of 28° and 33°. The wavy pattern of the SIN channel between 1118 and 1136 hrs is a result of the change in declination of 3C 298 from a position such as at B_s to very near zero-crossing and back to B_s within about 18 min time. A comparable time interval is taken by the event on 21–11–83.

3. Data analysis and results

In order to estimate the change in declination of the source from the variations in the mean flux level in the SIN channel, we plotted the magnitude ratios A_c/A_s and B_c/B_s as functions of declination. The observed ratios of average peak fluctuations of the COS and SIN records in the presence of the events in figure 2(d, e) as well as during normal events were determined. For (d) this was done by extrapolating the peak flux on the SIN

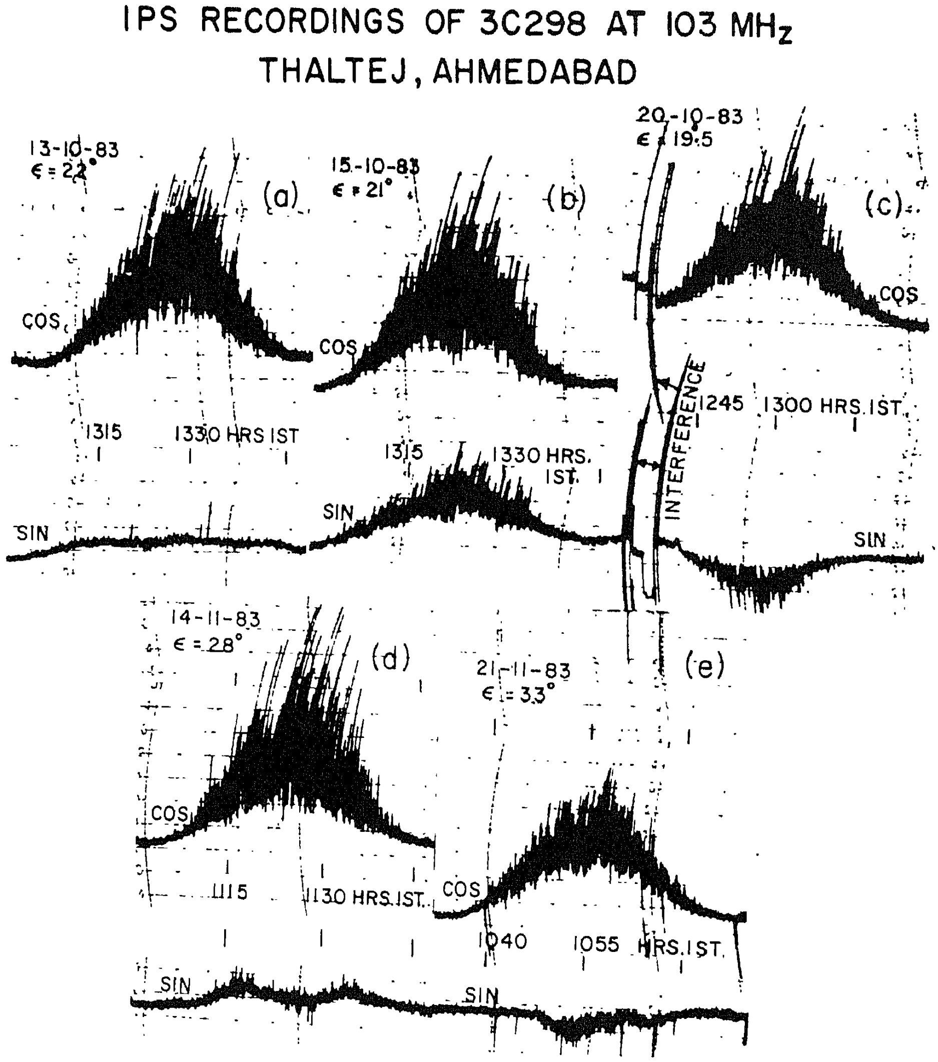

Figure 2. Typical IPS records of 3C 298 showing (a) normal record and (b)–(e) records with the effect of large scale electron density inhomogeneities in the ionosphere or IPM.

record between 1118 and 1136 hrs. The declinations corresponding to these ratios were obtained from the graph of A_c/A_s and B_c/B_s versus declination. The difference between these two values gave the maximum change in the declination of 3C 298. For the event on 14–11–83 this amounted to about 5 arc minutes in the declination plane.

4. Discussion

This effect may be caused due to refraction (a) by either a large scale ionospheric irregularity or a gravity wave propagating in the F-region of the ionosphere or (b) by a large scale plasma density irregularity in the interplanetary medium. In the following we shall discuss both these possibilities.

(a) In the case of gravity waves, these would be of medium scale according to the classification of Georges (1968). The irregularity or gravity wave should be at the point of intersection of the line of sight (source-observer line) with the ionosphere. If we assume the ionospheric drift to be 100 m/sec, (Sardesai *et al* 1983), the scale size L of the irregularity or the wavelength of the gravity wave, corresponding to the time interval of 18 min between 1118 and 1136 hrs in figure 2d, works out to about 100 km. These agree well with periods (12–40 min) and horizontal wavelength (50–300 km) of medium scale gravity waves (Bougeret 1981).

At the latitude region in question ionospheric irregularities are not field-aligned, so the angular displacement in the direction of the drift would be the same as observed in the declination plane i.e. 5′ arc $\sim 1{\cdot}5 \times 10^{-3}$ rad. The r.m.s. phase deviation $\phi_0 = L\theta_r \cdot f/c$ in this case would be ~ 50 rad. The phase deviation is related to integrated mean square deviation of ionization density $\int \overline{(\Delta N)^2}\, dz$ (Booker 1981) as

$$\phi_0 = 4r_e^2 \cdot \sec\chi,\ \lambda^2 \cdot L \int \overline{(\Delta N)^2}\, dz,$$

where r_e = classical electron radius, χ = zenith angle of the source, and λ = wavelength of operation.

From this, $\int \overline{(\Delta N)^2}\, dz$ turns out to be $7{\cdot}5 \times 10^{25}\ m^{-5}$. If we assume the thickness of the irregularity, or of the region in which gravity waves exist, to be equal to the thickness of the F-region (~ 300 kms), we get the r.m.s. deviation of electron density $\sim 1{\cdot}6 \times 10^{10}$ el/m^3. This is around 3% of the average ambient density which is $5{\cdot}8 \times 10^{11}$ el/m^3 (Chandra *et al* 1979). Inference of such irregularities or waves that could cause density perturbations, have been reported through other ionospheric measurements and calculations (Titheridge 1972; Yeh and Liu 1974; Jain 1977; Vats and Deshpande 1980; Bougeret 1981; Vats *et al* 1981). Thus our calculations in the case of a large scale inhomogeneity of electron density in the ionosphere provide a reasonable magnitude.

(b) Alternatively, the same effect can be explained by a large scale plasma density irregularity in the interplanetary medium. In this case, the angular displacement of the source would be caused by a density irregularity being convected in the solar wind across the line of sight. Then assuming a solar wind velocity $V = 400$ kms/sec and referring to the same figure 2d, the scale size L of the irregularity works out to be $\sim 5 \times 10^5$ kms. Now assuming an axial ratio of 1 : 10 for such a large scale field-aligned irregularity (Sawant *et al* 1976), the observed apparent change in the declination of the source could be caused by an irregularity, aligned with the proper Archimedes spiral traced out by the interplanetary magnetic field. The model of such an irregularity is shown in figure 3. Such large scale plasma density irregularities in the solar wind were theoretically predicted by Shishov (1973) and were observed by Cole and Slee (1980). These observations were explained as due to large scale plasma density irregularities in the IPM by Hewish (1980).

It is important to note that the change in the apparent position of 3C 298 is observed in the solar elongation range of 20° to 33° only and not seen even once out of 35 observations beyond 33°. This may happen if it were caused by a large scale plasma density irregularity in the IPM although effects of solar radio transients for low solar elongation observations cannot be ruled out. There is also a possibility that the

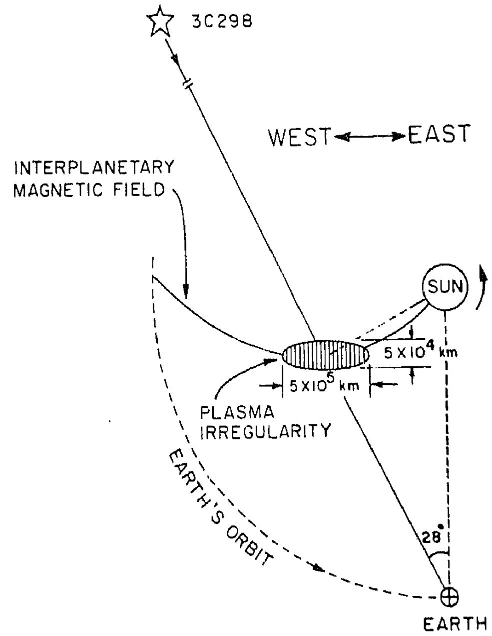

Figure 3. Model of large scale plasma density irregularity in the interplanetary medium for the event on 14-11-1983.

ionosphere was more disturbed on those days when the radio source was at lower solar elongations than for the days of higher elongations. However, from the statistics described above, it seems more likely that the large scale irregularities in the interplanetary medium might have been the cause of the observed refraction. It needs to be verified by making simultaneous observations of a scintillating radio source using two telescopes 200 km or more apart. A large scale density inhomogeneity in the IPM should then produce changes in the apparent position of the source in both the records.

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