6.1 Introduction

High resolution interferometry at 38 MHz (Hewish and Okoye, 1964) and lunar occultation observations at 26 MHz (Andrew et al. 1964) of the region of Crab Nebula showed the presence of a pulsed radio source (0531+21). Later, IPS observations (Hewish and Okoye, 1965; Bell and Hewish, 1967; and Antonova et al. 1971) showed the presence of a scintillating radio source, called 3C 144, at the same position as the pulsar (0531+21). Based on the observations of its angular size, pulse broadening, spectra and scintillation, Kenneth (1971) also concluded that the compact source is the pulsar NP 0532.
Armstrong et al. (1973), on the basis of 74 MHz observations, concluded that the scintillating flux of the compact continuum source was about 14% of that of the Crab Nebula. It had a gaussian shape of size of about $0.18 \pm 0.01$ arcsec. with the flux twice that of the extrapolated flux from the VLBI observations of the pulsed emission (Erickson et al., 1972 and Vandenberg et al. 1973). Armstrong and Coles (1978) pointed out that this discrepancy in the scintillating flux values (values estimated from IPS and VLBI observations) is due to the models used. Armstrong et al. (1973) estimated the flux by comparing the observed scintillation with the predictions of Readhead (1971). Scintillation index is defined observationally as

$$\frac{\text{r.m.s. flux}}{\text{Flux of the entire Nebula}}$$

(Armstrong and Coles, 1978)

and in the Readhead's model as

$$\frac{\text{r.m.s. flux}}{\text{total compact source flux}}$$

Hence the estimation of the scintillating flux has been made with respect to the entire Nebula, which gives the larger value of the former (Armstrong and Coles, 1978). Readhead's model assumes the gaussian shaped solar wind turbulence. Power-law model for the same (Rumsey, 1975; Marians, 1975) predicts a scintillation index about twice
Fig. 6.1 R.M.S. fluctuation of the compact source flux plotted against its solar elongation. Solid line is a third degree polynomial fit to the data at 103 MHz.
the Readhead value for a given source. Hence this removes the previous disagreement with the VLBI estimated flux.

Therefore, it was interesting to make observations of IPS of 3C 144 over a wide range of elongation at 103 MHz in an attempt to find out whether or not these two sources (scintillating source 3C 144 and the pulsar (0531+21) are identical. An estimation of its angular size and scintillating flux was made using gaussian and power-law models for the IPM.

6.2 Observations

The present IPS observations of 3C 144 were made regularly from May through September 1984 by using the Thaltej radio telescope. During these observations the antenna beam widths to half power at the local zenith were 1.8° and 3.6° in dec. and R.A. planes respectively. The solar elongation range covered during the observations, was about 10°-80°. Analog as well as digital data recording systems were used. The data were corrected for undesirable noise and interference. Beyond about 70° solar elongation, the data points affected by ionospheric effects were excluded for the fitting of the polynomial to the IPS data.

6.3 Analysis and Results

Fig.6.1 shows the r.m.s. fluctuation of the scintillating flux of the compact source plotted against its
Fig. 6.2  R.M.S. fluctuation of compact source flux normalized by nebular flux plotted against its solar elongation. Solid line is third degree polynomial fit to the data at 103 MHz.
solar elongation. A polynomial of third degree is fitted to these data. The flux of the nebula was estimated to be 1623 Jy at 103 MHz from its value at 81.5 MHz (Readhead and Hewish, 1974) using the relation $S(f) \propto f^{-0.75}$ (where $f$ is the operating frequency). Fig.6.2 shows the r.m.s. fluctuation of the scintillating flux of the source normalized by the flux of the nebula plotted against the solar elongation. A third degree polynomial is fitted to these data also. The uncertainties, on either side of the maximum r.m.s. fluctuations, could be 20%, while at the maximum it is about 10%. The maximum scintillation index occurs at about $30^\circ$ solar elongation. Due to the well-known effect of broadening of the source due to strong scattering, there is a turnover in scintillation index for lower values of solar elongation. According to scintillation theory (Readhead, 1971), the r.m.s. flux at $30^\circ$ depends on the flux of the scintillating component, its size and the shape of the density irregularity spectrum.

The scintillating flux values of the compact source for the gaussian and power-law models (Readhead, 1971; Rumsey, 1975; Marians, 1975) turn out to be about 112 Jy and 95 Jy at 103 MHz respectively. These values have been calculated by assuming its size to be 0.2 arcsec. (Readhead and Hewish, 1974; Armstrong 1975). These values are about 7 and 6 percent of the Nebular flux. Fig.6.3 (Fig.3 of Armstrong et al. 1973) shows the scintillating flux values of the compact continuum source at various frequencies estimated from IPS observations (Bell and
Fig. 6.3 Radio spectrum of compact source (Fig. 3 of Armstrong et al. 1973). The line is a power law fit to the VLBI and pulsating flux measurements. Scintillating flux at 103 MHz from IPS observations is shown by +.
Fig. 6.4 Flux density as a function of frequency. Flux densities at frequencies 40-86 MHz are taken from Armstrong et al. (1973) and that at 103 MHz is from the present work. The plot has a slope of about -1.88, indication that $S(f) \propto f^{-1.88}$. 

SLOPE = -1.88

The scintillating flux of the compact source at 103 MHz extrapolated from the pulsar flux values is about 48 Jy (Fig.6.3). Therefore our estimated scintillating flux values of the compact source (3C 144) for gaussian and power-law models are about 2.4 and 2 times this extrapolated flux. At 74 MHz the flux (256 Jy) of the compact source for a gaussian model is 14% of the Nebular flux (Armstrong et al. 1973). Fig.6.4 shows the flux values, $S$, at different frequencies (40-86 MHz) given by Armstrong et al. (1973) together with our value at 103 MHz, plotted against the operating frequencies. It has a slope of about $-1.88$, indicating that $S(f) \propto f^{-1.88}$.

The data are fitted with the gaussian model for 0.2 arcsec. source, computed by using the method of Kemp (1976). This is shown in Fig.6.5 where the scintillating flux of the compact source at 103 MHz normalized by the compact source flux is plotted against solar elongation, $e$. This fit is rather unsatisfactory for elongations less than about 15°. This may be due to contamination by the solar radiation closer to the Sun.

An attempt has also been made to fit to the present IPS data of 103 MHz, the power-law model (Rumsey, 1975).
Fig. 6.5 R.M.S. fluctuation of the compact source flux at 103 MHz normalized by the compact source flux is plotted against its solar elongation. Continuous curve is for gaussian model of 0.2 arcsec source. The model computations were made using the method of Kemp. (1976).
Fig. 6.6 Curves of scintillation index vs. solar elongation after scaling the computations of Marians (1975) to 103 MHz.
This model is appropriate for a thin plasma layer of strong scattering with a spatial wave-number spectrum for the refractive medium given by

\[ P(q) \propto q^{-\alpha} \]  \hspace{1cm} \text{(6.a)}

where \( q \) is a 3-dimensional spatial wave-number.

Taking \( \alpha = 3 \),

the turbulence in the solar wind plasma as

\[ c \cdot q^{-3} \cdot r^{-\beta} \]  \hspace{1cm} \text{(6.b)}

(where \( C \) is a constant, \( r \) is the Heliocentric distance and \( \beta = 4 \), (Armstrong and Coles, 1978)), computations of Marians (1975) were scaled to the present conditions. Curves of scintillation index, \( m \) vs solar elongation, \( \epsilon \) for various source sizes at 103 MHz are plotted (Fig.6.6). The power-law curve for 0.2 arcsec. source size is a best-fit to these IPS data (Fig. 6.7). Comparison of Figs.6.5 and 6.6 shows that the power-law model is a better fit to the 3C 144 IPS data of 103 MHz.

To estimate the angular size of 3C 144, theoretical curves of scintillation index vs. solar elongation for various source sizes and for a gaussian irregularity spectrum have been used (Readhead, Kemp and Hewish, 1978) (Fig. 6.8). From these curves another theoretical curve for various of \( m(28^\circ)/m(70^\circ) \) source sizes has been plotted (Fig.6.9).
Fig. 6.7  R.M.S. fluctuation of the compact source flux at 103 MHz normalized by the compact source flux is plotted against solar elongation. The continuous curve is for power law model for 0.2 arcsec source. The model computations were made using the method of Marians (1975).
Now from our observational curve (m vs. $\varepsilon$) of Fig. 6.2, $m(28^\circ)/m(70^\circ)$ was calculated to be about 3. Using Fig. 6.9 the angular size of the scintillating source was estimated to be about 0.16 arcsec.

6.4 Discussion and Conclusion

There is a discrepancy in the flux values of the compact source in the Crab Nebula obtained from the IPS observations and those obtained from the extrapolation of the VLBI and lunar occultation observations of the pulsed emission. This suggests that either the pulsed radiation is getting smeared due to multipath scattering in the interstellar medium, resulting at low frequencies into a source of continuum radiation, or else, there is another compact source near the pulsar.

In the latter case, the scintillations would add incoherently. The IPS observations at 103 MHz would then imply that the square-root of the sum of the squares of their fluxes must equal 100 Jy. This means that the compact continuum source would have to be stronger than the pulsar i.e. $[S_1^2 + S_2^2]^{1/2} = 100$ Jy. The value of $S_1$, the pulsar flux extrapolated from the spectrum, is about 45 Jy. Therefore, $S_2$, the compact continuum flux = 89 Jy which is larger than the pulsar flux. But high frequency VLBI observations do not indicate a double source (Vandenberg et al. 1973). For frequencies $\leq$ 300 MHz, the pulsar (0531+21) pulse appears as a sharp rise followed by an
Fig. 6.8 103 MHz theoretical curves of scintillation index vs. solar elongation for various source sizes for a gaussian model. After Readhead et al. 1978.
Fig. 6.9 Theoretical curve of ratios of scintillation indices \( \frac{m(28^\circ)}{m(70^\circ)} \) vs. source size, using fig. 6.8.
exponential decay. As the time constant of the exponential decay is about 13 ms at 115 MHz with the pulsar period of 33 ms, the pulse is smoothed out due to interstellar scattering (ISS). This results into a continuous signal. Assuming a uniform irregularity structure of the interstellar medium between the pulsar and the observer (scattering screen half-way in between), the apparent angular diameter of the pulsar has been estimated using intensity scintillation analysis (Ratcliffe, 1956; Salpeter, 1967). At 115 MHz, the angular size of the compact source was estimated to be about 0.12 arcsec. (Sutton, 1969). Using $\theta_d \propto \lambda^2$, (Cronyn, 1970) where $\lambda$ is the operating wavelength, this size $\theta_d$ at 103 MHz turns out to be about 0.134 arcsec. This is the expected value of the angular size of the compact source, whereas observationally at 103 MHz it is calculated to be about 0.16 ± 0.02 arcsec. Thus our observations at 103 MHz indicate that there is a 23% rise in the angular diameter of the compact source compared to its expected value.