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IPS observations of the solar wind at 327 MHz - A comparison with Ulysses observations

P. Janardhan[1], V. Balasubramanian[2], S. Ananthakrishnan[3], R. Srivatsan[2]

[1] *Physical Research Laboratory, Ahmedabad 380 009, India*

[2] *Radio Astronomy Centre, TIFR, PO Box 8, Udhagamandalam (Ooty) 643 001, India*

[3] *National Centre for Radio Astrophysics, TIFR, PO Box 3, Ganeshkhind, Pune 411 007, India*

Abstract. Extensive IPS observations at 327 MHz using the Ooty Radio Telescope (ORT) are presented. The observations spanning two and a half years starting in September 1992 covered two important periods during the Ulysses south polar pass in early February 1995 and its subsequent north polar pass in August 1995. The comparison of these ground based IPS single station velocity measurements and Ulysses spacecraft measurements are shown to be in good agreement.

1. Introduction

Interplanetary scintillation (IPS) is a diffraction phenomenon in which coherent electromagnetic radiation from a distant radio source passes through the solar wind, which is a turbulent refracting medium, and suffers scattering. This results in random temporal variations of the signal intensity (scintillation) at the earth. The intensity fluctuation of the radio waves from the source are quantified by scintillation index (m), where m is the ratio of the root mean square deviation of signal intensity to the mean signal intensity. Scintillation index depends upon solar elongation ϵ for the source, where ϵ is the angle between the earth-sun line and the line of sight (LOS) from the earth to the source. The m of a source increases with decreasing solar elongation upto a certain ϵ. After this point, it shows a turnover and then falls off sharply with further decrease in ϵ. The value of ϵ at which it turns over is dependent upon the frequency, and at 327 *MHz* it is about 10°. $\epsilon = 10°$ corresponds to a distance of about 40 solar radius from the sun to LOS. The region of ϵ larger than the turnover defines the region of weak scattering where the approximation of scattering by a thin screen is valid (Salpeter 1967).

The agreement between predictions of theoretical models of the scattering of radio waves by the interplanetary plasma under the assumptions of weak scattering by a thin, diffracting screen and the results from observations of IPS of compact extragalactic radio sources is excellent. The models have been developed to such an extent that by observing IPS with a single antenna of large collecting area it is possible to obtain precise estimates of the velocity of solar wind across the LOS to the radio source by fitting the theoretically modelled power spectra to the observed IPS spectra, providing that the signal to noise ratio (*S/N*) of the observed spectra are larger than about 15 *db*. (Manoharan & Ananthakrishnan 1990; Gothoskar 1995). The technique enable reliable determination of the angular sizes of the compact scintillating components of the radio sources also (Balasubramanian *et al.* 1996). These techniques were successfully tested and proven with the IPS observations of a large number of compact radio sources with Ooty Radio Telescope (ORT) which operates at 327 *MHz*, both under conditions of steady and transient solar wind (Janardhan *et al.* 1996).

The above results relate to solar wind from low heliographic latitudes. In this paper we present results from IPS observations of radio sources which probe solar wind at high heliographic latitudes. These observations clearly show the presence of solar wind at high speeds emanating from the north and the south polar regions of the sun. These observations were possible because of the recent improvement to the ORT which extend its coverage in declination to ± 60°, beyond the earlier limit of $-35° \leq \delta \leq 35°$. The results of the determination of the solar wind velocity by using the IPS technique presented here pertain to two periods – February – March 1995 and July – August 1995 – during which the Ulysses spacecraft was flying over the south and north polar regions respectively, of the sun.

2. Ulysses solar wind observations at high southernly latitudes

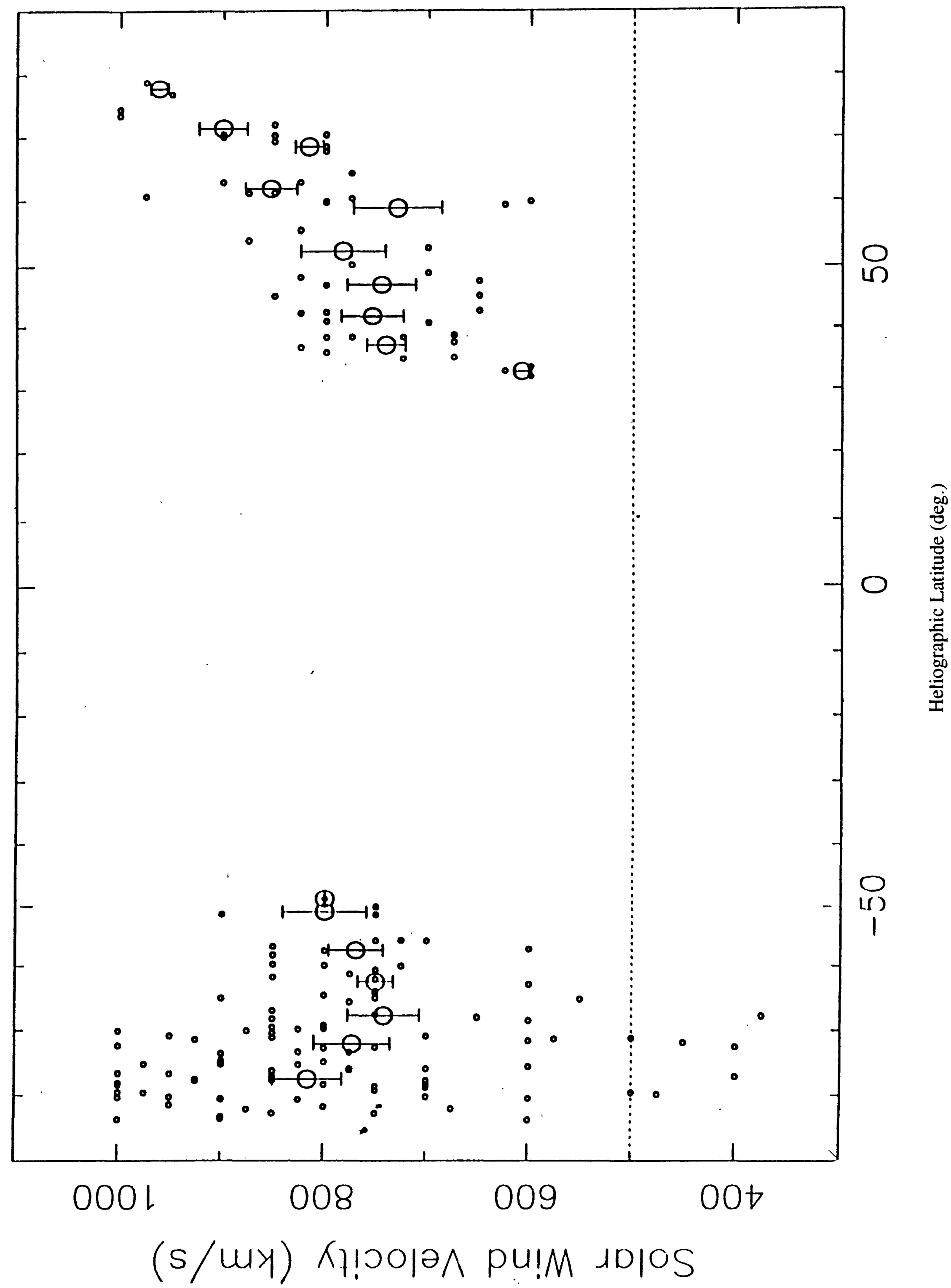
Ulysses is the first spacecraft to explore the field and particle environment of the sun's polar region. It was launched on 6 October 1990 from the space shuttle and used three upper stages to escape the earth's gravity en route to Jupiter. Its encounter with Jupiter on 11 February 1992 had a sling shot effect and rotated the orbit 80° relative to the solar equator. The resulting flight path passed under the south pole of the sun (June to October 1994) and then passed over the north pole (June to September 1995).

The solar wind observations by Ulysses from – 10° to – 80° latitude during the period February 1992 to January 1995 are summarised by Phillips *et al.* (1995). It was seen that recurrent high speed streams and corotating interaction regimes dominated at the middle latitudes. At more southerly latitudes than – 35° the solar wind speed was high, being 700 – 800 km/s typically.

3. The IPS observations

For the IPS observations from mid February to mid March 1995 a set of spatially well-distributed compact extragalactic sources were chosen such that their radio signals probe the solar wind at southern heliographic latitudes close to the latitudes sampled by Ulysses on the day of the observation. i.e., the LOS to these sources had their points of closest approach to the sun at almost the same heliographic latitude as the spacecraft. Such a geometry ensured that the IPS data will be sensitive to the solar wind from the southern polar coronal hole. Observation were made during July – August 1995 also of a different set of compact radio sources. These were such that the LOS were over the north polar regions of the sun.

Fig.1 High Latitude IPS Velocities — Feb. & Aug. 1995



4. Results

The main result from these IPS observations is that the solar wind velocities at high latitudes were found to be much higher than the velocities over low heliographic latitudes. This is seen from Figure 1 where the abscissae represent the heliographic latitude of the point of closest approach of the LOS to the sun. The ordinates represent the solar wind velocity determined from the IPS observations. The small open circles represent individual measurements, whereas the large open circles represent the mean of the velocities averaged over a 5° bin of heliographic latitudes. The vertical bars indicate $\pm 1\sigma$ level. The data points at negative latitudes are the measurements during February – March 1995 and those at positive latitudes correspond to the July – August 1995 observations.

The trend of these results from IPS observations at negative latitudes is in good agreement with the Ulysses data reported by Phillips *et al.* (1995) for the period November 1993 – September 1994 when the spacecraft was sampling the solar wind at high southerly latitudes. The high solar wind velocities from the south polar coronal hole are clearly seen in the IPS measurements. Some of the lower values at the negative latitudes are owing to the part of the LOS being over mid latitudes. In contrast to these, the measurements for the northern latitudes do not have any low values, because the LOS to the selected IPS sources were such that they were probing the wind from the north polar regions only. The intrefrence is that the solar wind velocities measured by the IPS method were dominated by the wind emanating from the north polar coronal hole.

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