The Long Wavelength Array (LWA) and Interplanetary Scintillation (IPS)

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1. Introduction

The current state-of-the-art in observations of the phenomenon of interplanetary scintillations is well described in the following paragraph from the introduction of Zhang (2007):

Interplanetary scintillation (IPS) is the random fluctuation in the intensity and phase of electromagnetic waves passing through the interplanetary space. The fluctuation is caused by refraction and deflection from the inhomogeneous plasma (solar wind) in the interplanetary space. Observing the IPS using ground based telescopes has given many useful results. Several important IPS stations, such as Cambridge (UK) (Hewish et al. 1964; Purvis et al. 1987), Ooty (India) (Swarup et al. 1971; Manoharan et al. 1990), Puschino (Russia) (Vitkevich et al. 1976) adopted single station-single frequency observations (SSSF) and used the power-spectrum fit method to obtain the solar wind speed and scintillation index, while the STEL (Japan) (Asai et al. 1995) is a multi-station system which can measure the projected solar wind speed directly. The phased array of the Miyun telescope, NAOC, is also an SSSF system operating at 232 MHz (Zhang et al. 2001; Wu et al. 2001). The SSSF mode of IPS observation needs high sensitivity, for example, better than 25 dB, to obtain reasonable spectrum fitting, and the fitting accuracy is somehow easily affected by variations in the solar wind parameters (Ye & Qui 1996). Another technique of IPS observation using [a] single telescope is the single station dual-frequency method (SSDF) (Scott et al. 1983). This method adopts simultaneous dual-frequency **[sic]** ***when observing an IPS source and then calculates the normalized cross-spectrum (NCS) with the power spectra of two different frequencies. Comparing to the SSSF mode, the SSDF technique has the following advantages: (1) Higher sensitivity; (2) Higher accuracy on the measurement of solar wind speed; (3) Higher stability against the wide variations in solar wind parameters.***

While several facilities (including the Cambridge array) have closed, at least two new IPS facilities are currently under construction – the Mexican Array Radio Telescope (MEXART) (González-Esparza *et al.* 2004) and the Murchison Widefield Array (MWA). And momentum has been building for the organization of an IPS World Network and Common Database (including efforts led by the MWA to define a common data format). The frequencies in use today tend to be higher than in the early days - >100 MHz, 327 MHz, 1420 MHz, and as high as 8 GHz. Baselines greater than 2000 km have been used for some observations at higher frequencies (with MERLIN and EISCAT).

Sporadic efforts have been made to combine IPS data with other observations by the Solar Mass Ejection Imager (SMEI) and STEREO spacecraft and with *in situ* measurements by the Ulysses spacecraft (now defunct) to study space-weather phenomena such as coronal mass ejections (CMEs) (Breen *et al.* 2008) and comet tails (Buffington *et al.* 2008). Modern three-dimensional tomographic reconstructions have been used sometimes to analyze the masses of data available (Breen *et al.* 2008). The group at UCSD provides fairly current reconstructions (http://ips.ucsd.edu/index_ss.html). Except for the MEXART, which seems to be coming online very slowly, there appear to be no operating IPS observatories in the Western Hemisphere. Elsewhere, the only regular IPS observations are from the Solar-Terrestrial Environment Laboratory (STELAB) in Japan (Coles 2008). The MWA website discusses its capability to study IPS (http://www.haystack.mit.edu/ast/arrays/mwa/) but that is only one of its scientific goals.

2. The LWA and IPS

The LWA should be able to make significant contributions to the study of IPS at all stages of its construction. The LWA-1 can do standard single-station, single-frequency studies but also can take advantage of its multiple-frequency capability. And its capability as digital spectrometer means it can use the method of Coles *et al.* (2003) which promises to be robust and insensitive to anisotropic structure or strong scattering.

In the future, as stations are added to the Central Core, the Central Core itself can be operated as a phased array with its sensitivity increasing as stations are added. Furthermore, as more distant stations are added for the LWIA and eventually for the full LWA, the multiple-station capability can be utilized.

The combination of multiple stations, multiple frequencies, and digital spectrometer promises to make the LWA a very capable IPS observatory. Other IPS observatories operate at higher frequencies than the LWA. The lower operating frequency of the LWA should allow it to observe IPS at greater solar elongations and to better complement the Heliospheric Imager on the STEREO spacecraft. A program to observe IPS at large solar elongations (90^{o} or greater) properly may require observations around the clock although the necessary cadence may be low.

There is no list of IPS sources comparable to the VLA Calibrator List for completeness or frequency coverage. But Purvis *et al.* (1987) have published a catalogue of 1789 sources which exhibit IPS at 81.5 MHz, which fortunately is available as an ASCII file (http://radio.astro.gla.ac.uk/ips/purvis.txt). I suggest that the source coordinates be converted to J2000 and the catalogue compared to the VLSS to identify those sources in Aaron's list of ionospheric calibrators that exhibit IPS.

3. The LWA and Faraday Rotation

Coles (2008) also recommends serious consideration of observations of Faraday rotation because

…potentially they give you a handle on the magnetic field and the magnetic field is a far more important quantity energetically than the electron density. It controls the topology near the sun, and controls the turbulence further from the sun. In any case energy in Alfven waves is equipartioned between fluctuations in B and fluctuations in V.

The feasibility of such observations with the LWA is presently unknown – because of uncertainties about its instrumental characteristics and about the number of polarized sources available at its operating frequencies. Pulsars may be the only numerous polarized sources but I have not been able to find a compilation of pulsar polarizations at 81.5 MHz, for example.

The MWA is planning to do observations of both IPS and Faraday rotation.

4. The LWA and Ionospheric Scintillation

The method of Coles *et al.* (2003) should also be applicable to the study of ionospheric scintillation of radio sources – to obtain two-dimensional spatial information. Fortunately, for low-frequency radio astronomers this phenomenon occurs infrequently. Bill Coles and I look forward to using LWA-1 to do such studies; one hopes that the occurrence of such episodes can be identified using real-time diagnostics.

5. References

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