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SOLAR VLBI

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1. Introduction

The use of data recording systems having milli-second time resolution for solar radio observations has revealed the presence, at both decimeter and centimeter wavelengths, of spikes and intensity fluctuations having durations of tens of ms. If the associated mechanical disturbances propagate at the Alfvén speed then such time-scales imply spatial dimensions of the order of 100 km. Indications of bright radio sources having such compact dimensions are of considerable interest in the study of solar plasma processes, so there would be great value in being able to determine the properties of the sources directly, rather than by inference.

The required angular resolution is beyond the reach of single antenna radio telescopes or of connected-element interferometers. The only observing technique currently available which will yield the required angular resolution is that of Very Long Baseline Interferometry (VLBI). Since this technique was developed primarily for the observation of extra-galactic and other sources having intensities varying slowly with time, it does not lend itself well to the study of transient, solar phenomena. Subject to certain restrictions however, it can be used for solar studies. A general discussion of (non-solar) VLBI is given in Meeks (1976).

There are two areas of particular applicability, namely the study of the initial plasma instabilities in solar flares, and of the sources of the milli-second spikes observed at decimeter wavelengths. The work so far has been mainly with respect to the former application.

2. Current Work

In April, 1981, radio telescopes at Dwingeloo (The Netherlands) and Onsala (Sweden) were used as a long-baseline interferometer at a wavelength of 18 cm. The baseline of 619 km gave a spatial resolution on the sun of about 45 km. The experiment and results are described by Tapping et al. (1983). Strong suggestions were obtained of the occurrence of multiple sources of short duration (≤ 0.2 s) during a small solar burst. If the maximum size of the sources was 45 km, the inferred brightness temperature was at least 10^{12} K at 18cm wavelength. In 1984 a

further experiment was made by the same workers, this time using one of the antennas of the Westerbork Synthesis Radio Telescope (The Netherlands) in conjunction with a radio telescope at Onsala. Several bursts were observed, some strong and at least two showing transient, spike structures, so therefore good candidates for compact sources. The results are still being analyzed.

3. The Technique

A detailed discussion of the major problems of Solar VLBI and its associated problems is given by Tapping (1985); only a few notes will be given here. There are four major difficulties to be encountered in Solar VLBI which are not encountered in non-solar VLBI:

- (a) The position of the source cannot be predicted to within arc-minutes. The experiment must be designed to accommodate the expected values of the positional errors.
- (b) The source is moving. Besides the annual motion of the sun against the celestial sphere, and the solar rotation, the source may have an intrinsic velocity. This is a consequence of the flare event itself and cannot be predicted.
- (c) On the basis of the 1981 results and the inferred sizes of spike events, the lifetime of the sources is likely to be less than the cycle time of the processor.
- (d) The source has to be observed against the bright background made up by the solar disc emission and the contributions from resolved sources in the parent flare.

In order to process the data, an estimate of the position and motion of the source is required. The receiver bandwidth used must be sufficiently small that the error in the estimate of the source position lies within the acceptance range of the processor. Since the processor operates on the assumption that the source is fixed to the celestial sphere, a compensating "incremental fringe rate" must be used to correct for the motion of the source against the sky. The annual solar motion and the solar rotation are easily calculable, but the intrinsic source velocity is usually unknown. The processors now in use can accommodate the contribution to the fringe rate for the velocities observed for Type II events. Consequently this component can be ignored with reasonable safety.

Since the sources can have a duration shorter than a processor cycle time, the correlated amplitudes may be considerably degraded even within the correlator cycle. No integration of multiple cycles can be carried out. Also, the rate of change of fringe phase cannot be determined. Thus, only the correlator delay can be used to estimate the position of the source. With only one antenna baseline, only one source coordinate can be measured accurately.

The sources studied in non-solar VLBI are usually observed against a cold sky; the system sensitivity is determined by the receiver and signal processing hardware. In the solar case the source appears against the bright solar disc, and against a background of emission components from resolved sources in the flare. Accordingly, the system sensitivity is quite poor (in the 1981 experiment, a source brightness of the order of 10^{12} K yielded a signal to noise ratio of about unity). The bandwidth must therefore be as large as possible in order to maximize the system sensitivity. In the experiments carried out so far, only single interferometer baselines were used. In the 1981 experiment, the Westerbork Synthesis Radio Telescope was used at 6cm wavelength, simultaneously with the VLBI observations. It was intended that positional information may be obtained which would facilitate the analysis of data. One of the major difficulties in the analysis of the 1984 experiment has been the absence of collaborative data from which estimates of source position within the active region can be obtained.

4. Further Observations

There is a real need for further observations. However, unlike the experiments done so far, multiple baselines should be used. These will provide confirmation of the occurrence of sources. If the baselines are at an angle to each other, estimates of the position and spatial size in more than one dimension of the sources will be available. The sources detected in the 1981 experiment had durations small compared with the processor cycle time, there can be no reliable estimates of the difference between the estimated and actual fringe rate. This residual fringe rate component can be used to estimate one of the components of the source position. However, even if the residual fringe rate can be determined, in the case of single baseline measurements it is not possible to separate the contribution due to the source position and that due to source motion. The use of multiple baselines would make it possible to determine the source positions from measurements of delay alone. Any estimates of the residual fringe rate can then be used to estimate the source velocity and direction.

The more accurate the estimate of the source position that can be used for the data correlation and processing, the more it is possible to design the experiment for maximum sensitivity. The use of a high resolution, real-time synthesis instrument such as the Very Large Array in parallel with the Solar VLBI observations would provide high quality observations of the burst position. It would also give information concerning the relationship of the compact sources to the larger components of the burst emission. Solar VLBI has considerable potential in the study of solar plasma processes, so despite its limitations and the difficulty in its application, further experiments will be highly worthwhile.

References

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