Goonhilly Sparklers

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Abstract. Flux monitoring of compact radio quasars has revealed dramatic radio-wave lensing events which challenge our understanding of the interstellar medium. However, the data on these events remain very sparse. Here we consider how the Goonhilly radio astronomical facility can make an impact on this problem by dedicating one or more dishes to flux monitoring for a period of one year. Such an experiment would be able to identify ~ 6 new events and study them in detail.

1. Introduction

Extreme Scattering Events (ESEs) are a type of transience in which the flux variations are not intrinsic to the source but are caused by radio-wave refraction in ionised gas along the line-of-sight (Fiedler et al 1987; Romani, Blandford and Cordes 1987). To generate these events the ionised gas must have a pressure which is a thousand times higher than the general Interstellar Medium (ISM), in a region of dimensions ~ 1 AU. Thus the ESE phenomenon poses a serious challenge to our understanding of the most basic physics of the ISM.

Because of the difficulty in understanding ESEs within a conventional picture of the ISM, we have previously proposed that they are caused by baryonic dark matter (Walker 2007; Walker and Wardle 1998): cold, dense, AU-sized molecular clouds ramming their way through the ISM at high speeds.

ESEs merit further study. Unfortunately there has been no substantial new dataset since the original work of Fiedler et al (1987,1994) using the Green Bank Interferometer. Within the next five years that situation will change drastically as SKA-pathfinder instruments are brought into service. In particular the Variables And Slow Transients (VAST) project, which utilises the Australian Square Kilometre Array Pathfinder (ASKAP: Johnston, Feain and Gupta 2009), will survey a large fraction of the sky on a daily basis. But ASKAP only operates efficiently up to 1.5 GHz, whereas the data we have on ESEs are at 2.7 GHz and above, making it difficult to plan for ESE science with VAST. With Goonhilly we will change that, by discovering a number of new events using 5 GHz data and then studying them at lower frequencies. In the process we will gain some powerful new insights into the physics of ESEs.

2. The Goonhilly facilities

The Goonhilly Earth Station, in Cornwall, UK, was formerly a telecommunications facility. On site are three 30m dishes and some smaller (15m) antennas. The Consortium of Universities for Goonhilly Astronomy plans to instrument two of the 30m dishes for radio astronomy, potentially including various frequency bands within the 1 to 10 GHz range.

In this paper we outline the possibilities for ESE science which may be opened up by operating Goonhilly as an astronomical facility. We consider two hypothetical instruments:
$\mathbf{C_1}$: a single 30m dish equipped with a 5 GHz receiver having 1 GHz bandwidth
$\mathbf{C_2}$: a pair of 15m dishes operating as an interferometer and receiving across the full 4 to 8 GHz band simultaneously.

3. ESE science with the C_1 system

To find ESEs we need to monitor the fluxes of a large number of compact radio sources. The combined probability of the two most striking ESEs (those in Q0954+658 and Q1749+096) is $\sim 5 \times 10^{-4}$, so that in a sample of 2,000 extragalactic sources there will typically be one ESE in progress at any given moment. And the event durations are ~ 2 months, so the event rate in a sample of 2,000 sources is $\sim 6 \ \text{year}^{-1}$.

For daily, year-round monitoring we need to choose sources which are away from the ecliptic. Restricting ourselves to the region with ecliptic latitude greater than $30°$ means that we have π steradians available, in principle. But the reality of an alt-az mount is that it can take a long time to slew between sources which are North of the zenith, and those to the South, whereas we need to minimise overheads associated with slewing. The latitude of Goonhilly is approximately $50°$ and we therefore restrict
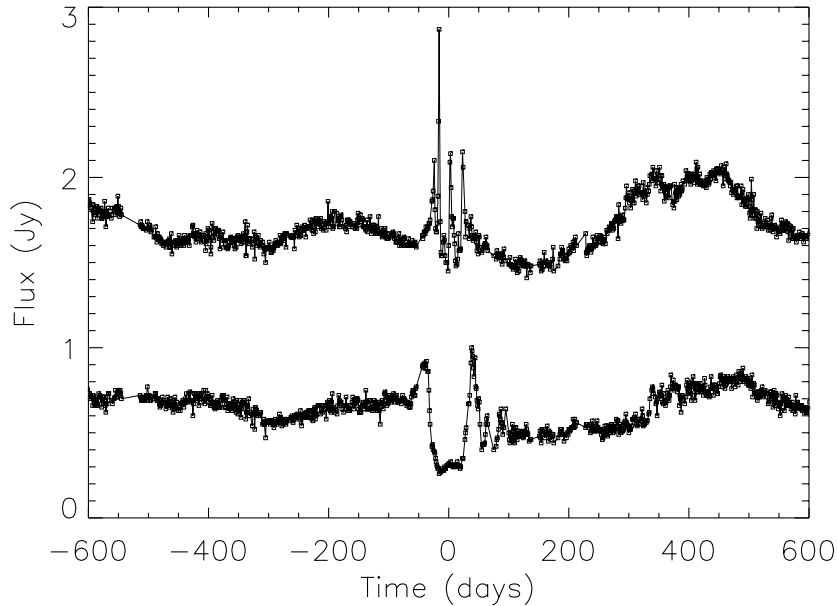
Fig. 1. The best example of an Extreme Scattering Event: that detected in the source Q0954+658, at 8.1 GHz (top curve) and 2.7 GHz (lower curve), from Fiedler et al (1987). An offset of $+1$ Jy has been added to the high-frequency data for clarity of presentation. These data taken from `http://ese.nrl.navy.mil/`.

ourselves to the 1.5 sr between declination $50°$ and the North Celestial Pole.

Our program sources must be compact, in order that they can be significantly magnified, so only about one in 5 radio sources will be suitable for our purposes. (Compact sources can be selected on the basis of their radio spectra, which should be inverted or at least flat.) To assemble a sample of 2,000 compact sources we must therefore range down to $S_{min} \simeq 35$ mJy, where the areal density of all radio sources is approximately $6,000\,\mathrm{sr}^{-1}$ at 5 GHz (Wall 1994).

Assuming that the receiver is a clone of the C-BASS system the flux noise for $\mathbf{C_1}$ should be approximately $4\,\mathrm{mJy}\sqrt{\mathrm{s}}$. To detect magnification changes of order 10% with high confidence requires a signal-to-noise ratio of at least 30, which would be achieved in about 12 seconds for a 35 mJy source. (The brightest confusing source in the beam will typically be 0.8 mJy, and this source will normally be steady and will not be detrimental to our study.) Thus the total required on-source time is less than 7 hours per epoch for a sample of 2,000 targets. To this we must add the time required for slewing and settling.

The typical angular separation between targets is less than $2°$. That is not a long slew and it seems reasonable to expect that this can be achieved in under 30 seconds. If so, a sample of 2,000 sources can be monitored on a daily basis using $\mathbf{C_1}$. Daily sampling is desirable, even though the events last for many weeks, in order to clearly distinguish ESEs from other forms of variability and, especially, to do so in real time.

Thus with $\mathbf{C_1}$ operating for one year we can expect to detect 6 ESEs: a significant increase on the current sample of two. But the greatest benefit is not so much the increase in event numbers as the opportunity to identify those events in real time and thus to characterise each one in detail. As well as detailed radio studies (e.g. long baseline imaging), which constrain the ionised gas profiles of the lenses, we aim to test for the presence of underlying neutral gas, e.g. by the associated UV extinction.

4. ESE science with the $\mathbf{C_2}$ system

The $\mathbf{C_2}$ system has four times the bandwidth but only half the collecting area of $\mathbf{C_1}$, so assuming the same system temperature implies that it would take roughly the same integration time to reach the same flux limit (assuming a flat spectrum source).

Confusion noise is potentially larger for $\mathbf{C_2}$, with the brightest confusing source in the beam being typically about 3.5 mJy. However, if each target is observed at the same hour angle (near transit, say), at every epoch then confusing sources make a constant contribution to the measured visibilities and are not detrimental to our study.

On the basis of experience with C-BASS it is anticipated (Mike Jones, personal communication) that $\mathbf{C_1}$ should be photometrically stable (i.e. to within the thermal noise) over periods up to about 100 seconds. It will therefore be necessary to intersperse our target sources with some (steep-spectrum, non-compact so non-variable) sources for calibration. Very few such sources would be

needed for C_2, because of the inherent stability of an interferometer, and C_2 could thus tackle a somewhat larger target sample than C_1.

But the greatest advantage of C_2 lies in the broad bandwidth which it covers. Over an octave in radio frequency the refraction angles introduced by the lens change by a factor of four. In turn this means that the monitoring data themselves would yield tight constraints on the electron column-density of the lenses, even in the absence of any detailed real-time follow-up on other telescopes. Thus the C_2 system is superior to C_1.

Lastly we note that for a long-term experiment, running for many years and discovering large numbers of events, it will not be possible to use facility-class instruments, like the VLA, to study each event in detail. It is here that the C_2 system really comes into its own because as a stand-alone experiment it yields much more powerful constraints on the lenses than C_1.

References

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