Scientific Justification

Since the discovery of the first (Walsh et al., 1979), strong i.e. multiply-imaged, gravitational lenses have been exploited for their long-understood potential (Refsdal, 1964) for measuring the Hubble constant, H_0. The requirements for this include, at a minimum, knowing the redshift of the lens and lensed object, sufficient observational constraints that allow a good model for the gravitational potential of the lensing mass to be constructed and the measurement of the light travel time difference between the lensed images. Additionally, it greatly helps if the lensing mass is simple i.e. a single galaxy without significant substructure lying in a single plane. A number of lens systems have been investigated for their potential in this regard, but pre-eminent amongst them is JVAS B0218+357 (Patnaik et al., 1993). One of its strengths is that the background quasar is reliably and significantly variable, not only in total flux density, but also in polarisation percentage and position angle. This has allowed the time delay between the two lensed images to be determined (Biggs et al., 1999) to reasonably high accuracy (10.5 ± 0.4 days; 95 per cent confidence). Fig. 1 in the PDF attachment shows a MERLIN/VLA 5-GHz map that shows the two flat-spectrum cores and the Einstein ring.

Since the last monitoring campaign with the VLA in 1996/97, no further observations to refine the time delay have been undertaken, despite the uncertainties in the model of the lensing potential falling significantly, in no small part due to the measurement of the position of the lensing galaxy relative to the lensed images (York et al., 2005). Innovative approaches such as that of Wucknitz et al. (2004), who used the structure in the Einstein ring as constraints on the model measured $H_0 = 71$ km s^{-1} Mpc^{-1}. Most recently, an e-MERLIN Legacy Survey of gravitational lenses has been awarded time to search for the central (greatly demagnified) images in a number of lens systems, including 0218+357 (PI: N.Jackson). This will also produce an impressively detailed map of the system at the highest signal to noise to date (and in polarisation) which will certainly aid future modelling efforts. In order to match this ressurgence of interest in this system, we propose to return to the issue of the time delay in this system, with a view to improving its accuracy further.

Monitoring at higher frequencies than has been done to date offers a number of advantages, some unique to this system. Firstly, flat-spectrum radio sources are often observed to vary more at shorter wavelengths and this has been confirmed in 0218+357 from simultaneous observations with the VLA at 5, 8.4 and 15 GHz (Fig. 2). Also, due to the rich instellar medium of the lensing galaxy, polarisation observations of the flat-spectrum lensed cores depolarise at frequencies as high as 8.4 GHz. Finally, although extremely useful for constraining lens models, the Einstein ring is a hindrance for determining time delays as it surrounds the weaker image B. This makes it more difficult to measure the flux density of image B, more so because the inevitable differences in (u, v) coverage of each monitoring epoch may produce systematic offsets in the flux density of this component. As the ring is produced from the lensed steep-spectrum emission of a radio jet, it gets progressively weaker at higher frequencies and has yet to be detected at 43 GHz with the VLA.

Our proposal is to monitor this lens system with ALMA at a frequency of 95 GHz over a period of 3 months with an observations every 1–2 days. ALMA's exceptional sensitivity in this band is such that only very short observations (1 min) will produce a signal to noise ratio of about 1000:1 on the *weaker* of the two components (in total flux density; 100:1 will still be achieved in polarised flux). At the same time, ALMA's carefully-constructed configurations also ensure that excellent (u, v) coverage is delivered with such a short exposure (although, giving that we will only be mapping two point sources, the details of the (u, v) coverage are not critical).

Flux calibration at these frequencies is of course difficult, but the great advantage of 0218+357 is that the lensed cores are polarised. Therefore, so long as the instrumental polarisation can be calibrated, there is no requirement to set the flux scale at all as a light curve can be constructed from measurements of the percentage polarisation at each epoch. This fact makes 0218+357 a particularly good target for time delay determination. We further note that the unpolarised calibrator 3C 84 lies only 20 degrees from 0218+357 and can be used to set the instrumental polarisation with a single short observation per epoch, a strategy that has proved extremely successful with the VLA.

References

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