Cosmic telescopes: witnessing the radio quiet quasar emission mechanism

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A small fraction – around 10 percent – of quasars produce large amounts of radio emission resulting from the acceleration of plasma particles in galactic-scale jets, which are thought to result from the violent accretion and collimation of matter close to the central supermassive black hole. In the remaining 90 percent of the population, however, large jets are absent, and little radio emission is observed. This stark difference leads some authors to suggest that so-called radio quiet quasars (RQQ) constitute a different population of objects from their radio loud counterparts: a population where star-formation is ongoing in the host galaxy [1, 2, 3]. On the other hand, some authors use evidence of excess radio emission from the radio–far-infrared (radio–FIR) correlation obeyed by star-forming galaxies [4], or of a continuous distribution between radio quiet and radio loud sources [5] to point to the existence of AGN-related radio emission in RQQ, perhaps occurring at different power scales [6]. The problem is crucial for the understanding of galaxy evolution; only by determining what is happening in these puzzling objects can we fully describe the role played by AGN feedback processes in the quenching of star-formation, responsible ultimately for the large numbers of 'red and dead' elliptical galaxies observed at late times in the local Universe.

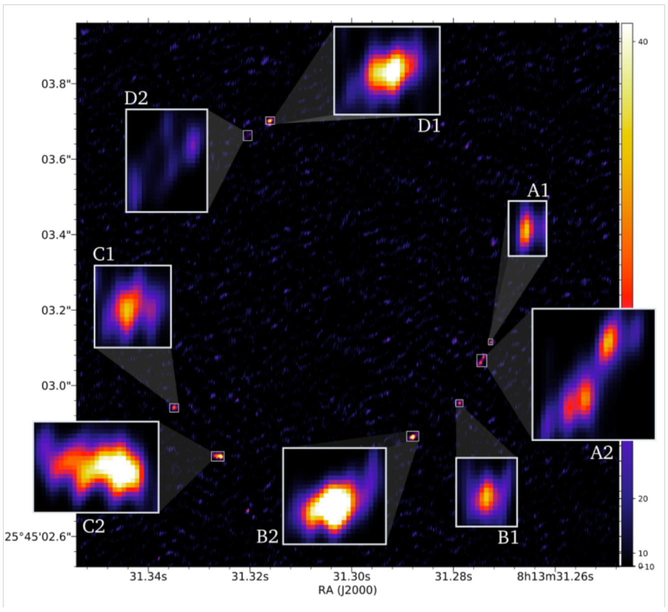

Figure 1: Radio emission from strongly lensed RQQ HS 0810+2554 using the EVN at 1.4 GHz. The very high resolution of the EVN combined with the magnification of lensing reveals that the background source consists of two highly compact components, each of which has been lensed into four images (see [10]).

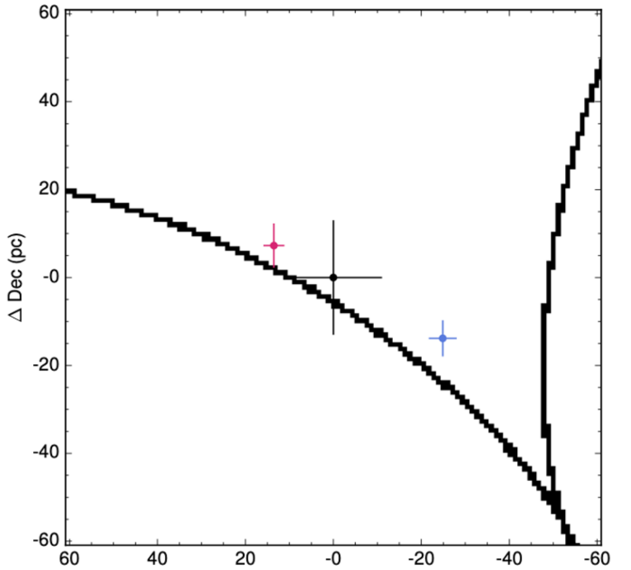

Figure 2: Reconstruction of the unlensed RQQ of HS 0810+2554. The model comprises radio components 1 (blue marker) and 2 (red marker) located either side of an optical component (black marker). All three components are located on the inner side of the tangential lensing caustic (black curve), along which lensing magnification theoretically reaches infinity. The morphology and brightness temperatures of the radio components provide strong evidence that this RQQ features two mini radio jets either side of the optical quasar core (see [10]).

Strong gravitational lensing

Strong gravitational lensing, predicted by Einstein‖, is produced when the light from a background object is strongly deflected by a large intervening mass, such as a galaxy or cluster of galaxies. The resulting pattern we observe – featuring multiple images and sometimes dramatic arcs – is dependent on the distribution of the lensing mass. Strong lensing is therefore a powerful tool for the study of mass structures – both baryonic and dark – allowing us to probe the dark matter power spectrum down to the 10 $M_\odot$ scale [7]. The magnification afforded by lensing also increases the effective resolution and sensitivity of our observing instruments, such that a magnification factor of 10 provides ten-fold the instrumental resolution and a one hundred-fold effective integration time. Strong lenses therefore serve as 'cosmic telescopes', giving us access to the very faintest galaxy populations and resolving their structure into unprecedented detail. We use strong lenses to directly address the RQQ radio emission problem.

‖ *"Of course, we have no hope of observing this phenomenon directly"*, Einstein (1936)

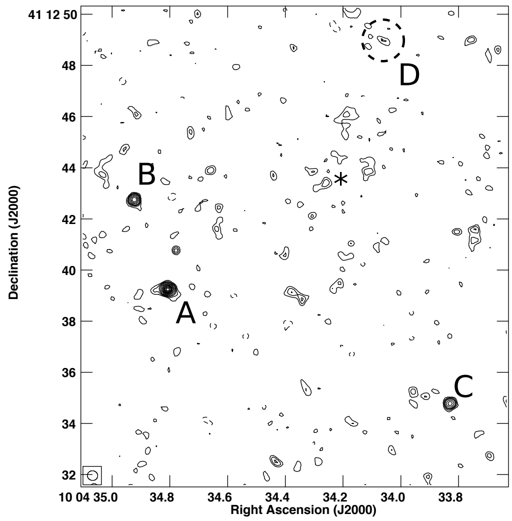

Figure 3: VLA 5 GHz map of strongly lensed RQQ SDSS J1004+4112. The RQQ radio emission is lensed into four images by an intervening galaxy cluster. Image D, which traverses the greatest distance of the four images, and is therefore the last to arrive, has more than halved in brightness in six years. Such rapid variability is strong evidence for the highly compact radio emission associated with the central AGN engine (see [8]).

The cosmic telescopes programme

Setting out to study all quadruply-lensed RQQ located above -30° declination, the cosmic telescopes programme [9] has used high sensitivity radio observations combined with the magnification power of lensing to directly probe the RQQ radio emission mechanism. We find, in this very faint population, that AGN-related activity can be responsible for the bulk of radio emission even in sources that reside in the faint end upturn of the radio quasar luminosity function typically modelled using a star-forming population. For example, very long baseline interferometry (VLBI) observations using the European VLBI Network (EVN) have demonstrated the presence of two mini-jets aligned in a linear configuration either side of the optical core in HS 0810+2554, a RQQ at redshift $z = 1.51$ (Figure 1 and 2). In this case, a lensing magnification factor of at least 50 provided an effective resolution of just 0.1 milli- arcseconds, or 0.27 parsec at the redshift of the source which, with a peak flux density of 890 nJy, is the faintest source ever imaged [10]. Jansky Very Large Array (VLA) observations of two $z = 1.7$ RQQ, SDSS J1004+4112 and PG 1115+080, has also found evidence of AGN-related radio emission, in the variability of the source (see Figure 3) and in the excess radio emission with respect to FIR emission associated with star-formation (see Figure 4), respectively [8]. Both HS 0810+2554 and SDSS J1004+4112 have been found to contain ultrafast outflows [11, 12], and both are found to lie on the radio-FIR correlation. Evidence of AGN-related radio emission in these sources therefore hints at a connection between small and large scale AGN feedback process, and calls into question the use of the radio–FIR correlation to distinguish between AGN and star-forming activity in RQQ.

The RQQ picture is mixed, however, with some RQQ showing strong evidence for ongoing star-forming activity. For example, [13] have used the Atacama Large (sub)Millimeter Array (ALMA) and VLA observations to demonstrate a radio emission region that is co-spatial with a rotating molecular disk. Further, in a source that was not detected using VLBI observations [14], [15] used ALMA observations to find evidence for turbulent star-forming activity in the quasar host . The result leads the authors to suggest that RQQ star-formation efficiency is dependent on the host galaxy morphology as opposed to the nature of the AGN. Our programme continues with new and upcoming observations to help us determine once and for all the feedback mechanisms at play in RQQ and their role in galaxy evolution.

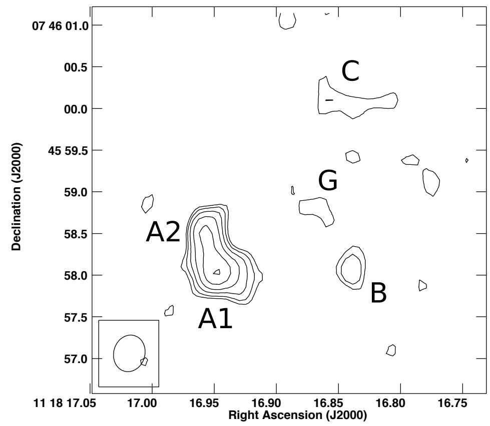

Figure 4: VLA 5 GHz map of strongly lensed RQQ PG 1115+080. Comparing the imaged radio emission with the FIR luminosity associated with star-formation finds an excess of radio emission with respect to the radio–FIR correlation obeyed by star-forming galaxies. Star-formation alone does not appear to explain the radio emission in this RQQ (see [8]).

References

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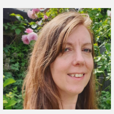

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