Light on dark lenses

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We present an update of the status of the Cosmic Lens All-Sky Survey (CLASS). Twelve lenses have been found to date in CLASS together with the earlier Jodrell Bank-VLA Astrometric Survey (JVAS). Six other sources are under investigation as possible lenses. To date, all lens systems studied optically have been shown to have associated lensing galaxies to a limiting I magnitude of 23–24. These observations place severe constraints on published claims that dark ($M/L > 100$) galaxies form a significant fraction of the general population of galaxies.

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The importance of gravitational lenses as probes of mass independent of the light emitted by the mass has long been recognised. On the small scale, microlensing studies represent the best way of determining the contributions of MACHO objects to the halo of our galaxy (see elsewhere in these proceedings). On a larger scale, lensing of background quasars is the only reasonable way to determine the contribution of extremely underluminous galaxies to the total population. In principle, all that is required is an unbiased lens sample, selected only on the properties of the background quasars, for the prevalence of dark galaxies, and their masses, to be determined.

Radio surveys are very useful for obtaining such unbiased samples. There are two reasons for this. First, they are unaffected by the dust obscuration that can plague optical surveys. Second, large surveys at high (0.2 arcsec) resolution are much easier to carry out at radio wavebands: at such high resolution, optical surveys need large amounts of time on the Hubble Space Telescope.

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Accordingly we are carrying out a survey (JVAS/CLASS) of 11000 flat-spectrum radio sources in order to identify the $\simeq$20 that are likely to be lensed by foreground galaxies. The final observations are scheduled for March-April 1998. So far, twelve definite and six probable lenses have been identified. Initial observations are done in 30-second snapshots with the VLA, which rejects $\simeq$97% of objects as having pointlike structure. Remaining objects are followed up by higher-resolution radio interferometers, namely MERLIN and the VLBA, to separate the genuine lens systems (multiple point components) from the sources which have core-jet radio structure. Only at this stage do we attempt to find the lensing galaxy. In all cases (12/12) of lens candidates which pass the radio tests, we find the lensing galaxy. Six others await NICMOS observations with the HST.

In Fig. 1 we present a selection of the lens systems so far discovered. The pictures are a mixture of radio (MERLIN), optical (HST/WFPC2) and infrared (NICMOS) images. In all cases the lensing galaxy is detected, although in a few cases it is only visible in the optical I-band and infra-red bands. The magnitudes of the lensing galaxies range from I=19 down to I=24 (see Jackson et al. 1998 for a full list). Simple (singular isothermal sphere) models have been fitted to determine the mass of the lens within the Einstein radius. The resulting mass-to-light ratios can then be calculated and corrected for evolution and spectral K-correction.

Hawkins (1997) has studied the cases in which optical surveys reveal pairs of quasars with very similar optical spectra (e.g. Hawkins et al. 1997). The extreme similarity of the spectra argue for an interpretation as lens systems. However, the lens systems are not found. Kochanek et al. (1997) argue, based on statistics of known lenses, that the coincidences are chance, or genuine pairs of quasars. Indeed Muñoz et al. (1998) report the discovery of a close pair of quasars, one radio-loud and one radio-quiet, which therefore cannot be lensed images of a single quasar despite their similar optical spectra.

Our results create additional difficulty for the dark lens hypothesis, as none of our lensing galaxies has $M/L > 40$ and most have $M/L < 10$. The only possible escape lies in the difference between the two samples. The first difference is that the Hawkins (1997) sample contains pairs of typically much greater separation than those found in our survey. One might therefore postulate that only massive lenses are dark. A second problem, however, is that a few of our lenses do have large separations, and these also have detected lensing galaxies. They are, however, mostly 4-image rather than 2-image lens systems, and a further ad hoc modification could be made to the effect that galaxies with very elliptical mass distributions, which tend to produce 4-image systems, are generally not dark (Kochanek et al. 1997). The alternative to such ad hoc modifications is to accept that there exist genuinely separate, close quasar pairs, of separation $\sim$10kpc and with extremely similar broad line regions on

1-pc scales. Theoretical models of how quasars evolve are hereby challenged to reproduce this – at first sight extraordinary – observation.

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L. Williams: Two comments. (i) The observed properties of strongly lensed optically vs. radio selected QSO samples could be different because of the different source population properties, like luminosity function and its evolution, and source redshift distribution. (ii) From my model, it is expected that wider separation QSO cases are statistically less magnified, therefore you would expect these cases to have statistically smaller multiplicities, i.e. to be double rather than quads, as observed.

N. Jackson: The luminosity function indeed has an effect on the statistics (see e.g. Falco et al. 1998). We are currently trying to obtain complete redshift information on samples of flat-spectrum radio sources at ∼25mJy and ∼5mJy to tie down the currently poorly-constrained luminosity function at these levels (Marlow et al. 1998, in preparation). If doubles were at generally higher separation, this would help to explain the finding of large numbers of 4-image lenses at small separations in our survey. Nevertheless I would still worry about any case where the lensing galaxy could not be detected.

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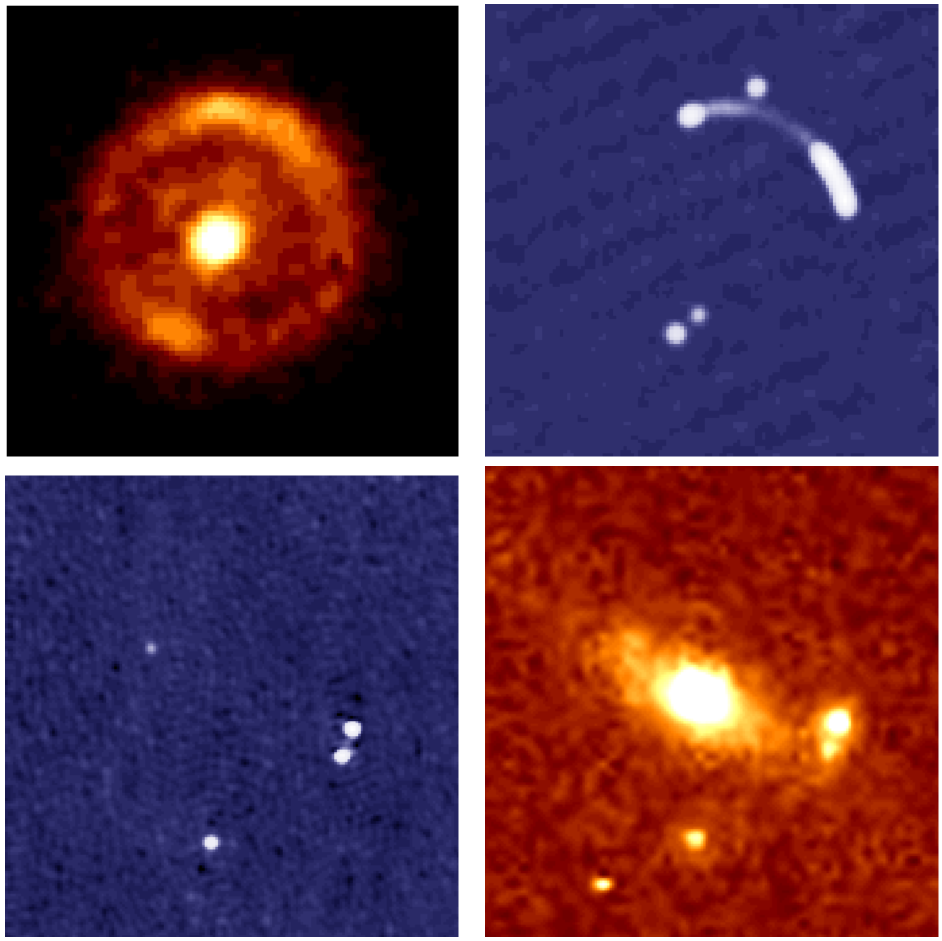

Figure 1. JVAS/CLASS gravitational lenses. Top: B1938+666. This object shows an Einstein ring in the NICMOS picture on the left (King et al. 1998); the lensing galaxy is visible in the centre. The MERLIN image (top right) shows the images of two radio components which are probably arranged symmetrically around the centre of the lensed object. Bottom: B0712+472. The four images are clearly visible both in the MERLIN image (bottom left) and the HST/WFPC2 image (bottom right). An elongated lensing galaxy is seen in the optical picture.