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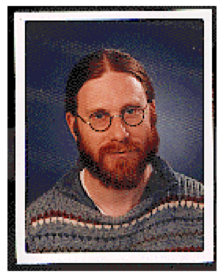

I give a brief overview of the current status of some aspects of the Cosmic Lens All-Sky Survey, CLASS.

1 Who and What?

CLASS, the Cosmic Lens All-Sky Survey, is a collaboration between groups at the Jodrell Bank Observatory (UK), ASTRON (NL), the Kapteyn Astronomical Institute at the University of Groningen (NL), Caltech (USA), the University of Pennsylvania (USA) and NRAO (USA). It is a survey for flat-spectrum radio sources ($\alpha \geq -0.5$ for $S_f \sim f^\alpha$ between L-band (Condon et al.[1] (NVSS)) and C-band (Gregory et al.[2] (GB6))) with the selection criteria $0 \leq \delta \leq 75^\circ$ (due to the area covered by GB6), $|b| > 10^\circ$ and $S_{\mathrm{C-band}} > 30\,\mathrm{mJy}$: 11685 objects. The objects thus selected were then observed with the VLA in A-configuration at X-band. CLASS has many goals, many of which are lens-related (measuring λ_0 and Ω_0 with lensing statistics and H_0 with time delays, studying the properties of lensing galaxies). (The definition of CLASS has evolved, mainly due to improvements in the input catalogues used. The above definition is the current, final one. However, objects were observed which are not part of the currently definied 'statistically complete CLASS' and, if they happened to be lens systems, were of course followed up.)

2 Why and How?

Radio surveys can be particularly good gravitational-lens surveys, for a number of reasons:

- Using interferometry, the beam size is much smaller than the image separation.
- Flat-spectrum objects are compact (i.e. (almost) point sources), allowing typical lensing morphologies to be recognised easily.

- Somewhat related to the previous point, the lensing probability depends on the cross section determined by the lens population; for extended sources, the source geometry partially determines what is recognised as a lens system.
- Most sources are quasars at high redshift, which leads to a high lensing rate.
- Since flat-spectrum objects are compact, they can be variable on relatively short timescales, which aids in determining time delays.
- There is no bias from lens galaxies due to extinction by the lens or comparable brightness of source and lens, as can be the case with optical surveys.
- High-resolution followup is possible with interferometers such as MERLIN, the VLBA, VLBI. . . .

But there is one disadvantage:

- Additional work is required to get redshifts.

From our own CLASS VLA observations (i.e. A-configuration at X-band), objects with multiple compact (<170 mas) are marked as lens candidates if the separation is between 300 mas and 6 arcsec, the flux ratio <10:1 and the total flux at X-band in the compact components is >20 mJy. These constraints are chosen so that sufficient followup is possible for all such candidates. Candidates are then observed at progressively higher resolution, first at C-band with MERLIN (50 mas resolution) and then, if necessary, the VLBA (3 mas resolution) and finally if needed with VLBI, at additional frequencies if needed. About 80% of the candidates are rejected after the MERLIN 'filter' due to different surface brightnesses in the components (gravitational lensing, of course, conserves surface brightness). Other reasons for rejection include obvious non-lens structure (such as a core-jet morphology) and different spectral indices or polarisation. It is interesting to note that, with one possible exception, every candidate which has passed these tests and thus been deemed to be a lens system on the basis of radio data alone has yielded a lens galaxy when observed optically (usually with HST). Since the source and lens redshifts are needed for various purposes, these are also checked to be consistent with lensing ($z_{\rm l} < z_{\rm s}$, the same $z_{\rm s}$ for all components of the source), though in practice no candidates which have passed the above-mentioned tests have been ruled out on this basis.

Table 1 shows the current CLASS and JVAS lens systems. It should be noted that missing redshifts are mostly from relatively new systems (though in the case of B1938+666, a redshift might could have been measured if UKIRT were able look this far north). It thus appears to be a realistic goal to have the survey complete with respect to both source and lens redshifts within the next several months. Note also the relatively narrow range of image separations, which is definitively *not* due to any sort of bias or incompleteness but reflects a real fact about the universe (more precisely, the mass spectrum of lens galaxies).

3 λ_0 and Ω_0 from Lensing Statistics

We have done an analysis of JVAS (essentially the brightest 2308 sources in CLASS). Lensing statistics, at least in the interesting part of parameter space, essentially measures $\lambda_0 - \Omega_0$. As discussed in Helbig[3], we obtain

$$-2.69 < \lambda_0 - \Omega_0 < +0.68 \tag{1}$$

at 95% confidence; for a flat universe, this corresponds to

$$-0.85 < \lambda_0 - \Omega_0 < +0.84 \tag{2}$$

Table 1: The JVAS and CLASS gravitational lenses

Survey	Name	# images	$\Delta\theta''$	z_l	z_s	lens galaxy
			confirmed lenses			
CLASS	B0128+437	4	0.542	?	?	?
JVAS	B0218+357	2 + ring	0.334	0.6847	0.96	spiral
JVAS	MG0414+054	4	2.09	0.9584	2.639	elliptical
CLASS	B0712+472	4	1.27	0.406	1.34	spiral
CLASS	B0739+366	2	0.540	?	?	?
JVAS	B1030+074	2	1.56	0.599	1.535	spiral
CLASS	B1127+385	2	0.701	?	?	?
CLASS	B1152+119	2	1.56	0.439	1.019	?
CLASS	B1359+154	4	1.65	?	3.212	?
JVAS	B1422+231	4	1.28	0.337	3.62	?
CLASS	B1555+375	4	0.43	?	?	?
CLASS	B1600+434	2	1.39	0.414	1.589	spiral
CLASS	B1608+656	4	2.08	0.63	1.39	spiral
CLASS	B1933+507	4 + 4 + 2	1.17	0.755	2.62	?
JVAS	B1938+666	4 + 2	0.93	0.878	?	?
CLASS	B2045+265	4	1.86	0.867	1.28	?
CLASS	B2319+051	2	1.365	0.624	?	?
			puzzling probable lenses			
JVAS	B2114+022	2 or 4	2.57	0.32 & 0.59	?	?

It should be noted that the probability distribution in the λ_0-Ω_0 plane is not Gaussian; in particular, the above numbers were obtained from 'real contours' (cf. Helbig[4] and references therein) and not by plotting contours at some fraction of the peak likelihood, and of course they depend on the region of parameter space examined as long as there is a non-negligible likelihood outside of it. These caveats should be kept in mind when comparing these constraints to others in the literature.

Of course, not only an analysis of CLASS but a better analysis of CLASS is in the works. However, first the survey and lens followup have to be finished and the S-z plane of the parent population (i.e. non-lenses in the survey and objects 'amplified in' to the survey by lensing) must be determined. This information is needed in two quite distinct contexts, even though they are really two sides of the same coin:

- The number–flux-density relation at the redshifts of the sources in the lens systems is needed for the calculation of the amplification bias.
- The flux-density–dependent redshift distribution is needed as a proxy for the redshifts of the non-lenses in the survey.

Even without this information, however, there is the interesting possibility of using CLASS for the lens-redshift test; see Helbig[5] for discussion.

4 H_0 from Time Delays

Since all observables in a gravitational lens system are dimensionless except for the time delay between the images, this can be used to scale the model of the system and thus, if the redshifts are known, measure H_0 (with a higher-order dependency on λ_0 and Ω_0). A radio survey offers the advantages that microlensing is less of a worry and that the sources are 'pre-selected' to be variable (due to their flat-spectrum nature, as mentioned above). The angular separation probed by CLASS corresponds to galaxy-mass lenses and thus time delays of weeks, which is convenient. To date, there are 6 measured gravitational-lens time delays, 3 from CLASS, of which 5 agree quite well (see, e.g., Koopmans & Fassnacht[6] for discussion). In principle, as first pointed out by Refsdal[7], one can use time delays from several systems to measure λ_0 and Ω_0. Although it is too early to make a definitive statement, it is interesting to note that the derived values for H_0 agree better if currently favoured values for λ_0 and Ω_0 are assumed. To quote a number for posterity, $H_0 = 68$. More CLASS systems are being monitored, so statistics should improve in the future.

5 Dark Lenses?

As mentioned above, there is only one possible lens system which has passed all the radio tests but in which no lens galaxy has been detected, and could thus be a 'dark lens' (cf. Jackson et al.[8] and references therein). However, statistical arguments favour the alternative explanation of this system, B0827+525, being the first binary radio-loud QSO. On the other hand, the case is not clear-cut. If the latter explanation is true, it will have the smallest separation of all known QSO pairs. On the other hand, if it is a lens system, it will have the largest separation of all CLASS lenses. See Koopmans et al.[9] for further discussion.

6 Wide-Separation Lenses

Although CLASS originally examined the range between 300 mas and 6 arcsec, this has been extended up to an arc-minute in two new surveys. First, CLASS has been extended to search up to 15 arcsec in a manner identical to the original survey, made possible by the increase in computing power since CLASS began. Second, a new survey, the Arc-Minute Radio Cluster-Lens Search (ARCS), has looked for lensing of extended sources on the 15 to 60 arcsec scale (due to the longer time delays, many of the arguments used to rule out candidates at smaller separation will not work at larger separation and the number of chance coincidences on the sky of course increases with the separation, so a different strategy is called for). To date, *no* lens systems have been found in this range of angular separation, though one candidate remains. More details can be found in Phillips et al.[10].

Acknowledgments

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