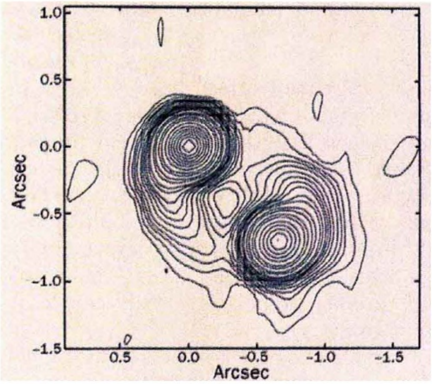
GRAVITATIONAL LENSES

The optics of cosmology

C. S. Kochanek

GRAVITATIONAL lenses promise to answer many of the most important questions in cosmology and in galactic structure and evolution. Or so astronomers have claimed for the past fifteen years. There has been progress. Lenses provide the strongest constraints on the cosmological constant (a measure of the self-repulsion of space), agree with other estimates of the Hubble constant and strongly suggest the existence of dark matter in the inner regions of elliptical galaxies. Yet, all in all, they have failed to fulfil their early promise. It is not, I think, a failure in our lenses, but in the psychology of the field. To paraphrase one prominent astronomer, most observers are more interested in the numerator (finding new lenses) than in the denominator (accurate, quantitative studies of existing lenses and their source populations). Fortunately, not all observers have adopted this view; a good example is the clever approach of Wiklind and Combes — reported on page 139 of this issue[1] — who determine the redshift of the lens responsible for the PKS1830–211 radio ring[2,3] (see figure) by searching for molecular absorption lines.



An 8.4-GHz VLA map[3] of the lensed radio source PKS1830–211, showing the two main components of the ring-like image.

The gravity of an intervening galaxy can magnify and produce multiple images of distant objects. Twenty-three convincing examples of these lenses have been found, where the sources are quasars, radio sources or distant galaxies[4]. Only six have measurements of both source and lens redshift, which are needed to determine the distances to the lens and the source, as well as physical parameters such as galaxy masses and the Hubble constant, and to test cosmological models. Two promising new approaches to finding them are infrared[5] and radio spectroscopy. Although the lens redshift of B0218+357 was confirmed by detection of 21-cm absorption[6], that of PKS1830–211 is the first to be determined by radio spectroscopy.

Detailed photometry of lensed systems is largely confined to projects that monitor the variability of lensed images. In particular, source fluctuations appear in the images at different times due to differences in path length, and these delays can be used to determine the Hubble constant geometrically, with few of the interminable calibration problems of local estimates. A delay is measured[7,8] in the first lens to be discovered, 0957+561, but this system is a compound lens consisting of a galaxy and a cluster, complicating the interpretation. Most lenses avoid the difficulties of 0957+561, but it has been impossible to obtain the necessary radio or optical telescope time to systematically monitor the better candidates. PKS1830–211 and B0218+357 show strong radio variability, and several quasar lenses show low-level optical variability. A small fraction of the observational resources devoted to traditional means of measuring the Hubble constant would allow this field to explode.

The precise redshift of $z=0.886$ measured by Wiklind and Combes might allow us to determine the Hubble constant at an intermediate cosmological scale. They used a 15-m radio telescope to look for absorption in the 2- and 3-mm wavebands caused by the rotational lines of a few simple molecules such as CS and HCN. Because the line of sight to the source passes within a few thousand parsecs of the centre of the inferred lensing galaxy, there was some chance of finding a molecular cloud there. If, as the authors suggest, only one of the two main images is covered by a cloud, their signals can be distinguished by the presence of absorption lines, and it is possible to determine the relative fluxes of the two images using a single-dish telescope instead of an interferometer. In this way one could measure the time delay and, if the source redshift can be measured, the Hubble constant.

Good photometry of the lensing galaxies is less common, even though it can be used to test cosmological models (for example, how much matter is in the Universe, and whether there is a cosmological constant). We measure the apparent magnitude of the lens galaxy and the separation of the lensed images, which is related to the mass of the lens and therefore to its absolute luminosity. For a given absolute luminosity, the apparent magnitude depends on the cosmological model. At a redshift of 0.8, a lens galaxy in a Universe dominated by self-gravitation of space (with the cosmological constant $\Lambda_0=1$) is 2.0 magnitudes fainter than in a flat, matter dominated model (with matter density $\Omega_0=1$). Corrections must be made for evolution, and the relation between luminosity and image separation must be calibrated, but these uncertainties are smaller than the cosmological differences. The dominant uncertainty is the extraordinarily mundane problem that most measurements of lens galaxy magnitudes do not report on the aperture through which the flux was measured! This single missing number can lead to uncertainties larger than the effects of cosmology.

In theory, the strongest cosmological constraints from gravitational lenses should come from surveys for radio lenses — these surveys have found many more lensed systems[9–11], and are immune to some systematic problems in the quasar surveys, such as dust. In practice, there is a crippling uncertainty about the redshift distribution of faint (< 100 mJy) radio sources. Radio source redshifts were popular until 1990, but interest waned rapidly as cosmology became the hot topic of the day. Yet the mean redshift of 50-mJy sources must be about 0.5 if the cosmological constant is large, and about 1.5 if it is small — a simple and clean way of attacking a fundamental cosmological problem through the neglected 'denominator'.

The promises made fifteen years ago still hold — gravitational lenses are powerful constraints on cosmology and galactic structure. The fact remains, however, that a fundamental bottleneck in using gravitational lenses as tools in astrophysics is the focus on finding new ones, rather than making precise measurements on the known lenses. Any progress, such as the PKS1830–211 lens redshift, is a step in the right direction, and with enough such steps we can fulfil the earlier promises. ☐

C. S. Kochanek is at the Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts 02138, USA.

---

1. Wiklind, T. & Combes, F. *Nature* **379**, 139–141 (1996).
2. Rao, A. P. & Subrahmanyan, R. *Mon. Not. R. astr. Soc.* **231**, 229–236 (1988).
3. Jauncey, D. L. *et al. Nature* **352**, 132–134 (1991).
4. Keeton, C. R. & Kochanek, C. S. in *Astrophysical Applications of Gravitational Lensing, Proc. 173 Symp. of the IAU* (eds Kochanek, C. S. & Hewitt, J. N.) 419–439 (Kluwer, Dordrecht, in the press).*
5. Lawrence, C. R. in *Astrophysical Applications of Gravitational Lensing, Proc. 173 Symp. of the IAU* (eds Kochanek, C. S. & Hewitt, J. N.) 299–304 (Kluwer, Dordrecht, in the press).*
6. Carilli, C. L., Rupen, M. P. & Yanny, B. *Astrophys. J.* **412**, L59–L62 (1993).
7. Haarsma, D. B., Hewitt, J. N., Burke, B. F. & Lehár, J. in *Astrophysical Applications of Gravitational Lensing, Proc. 173 Symp. of the IAU* (eds Kochanek, C. S. & Hewitt, J. N.) 43–44 (Kluwer, Dordrecht, in the press).*
8. Schild, R. E. & Thomson, D. J. in *Astrophysical Applications of Gravitational Lensing, Proc. 173 Symp. of the IAU* (eds Kochanek, C. S. & Hewitt, J. N.) 51–52 (Kluwer, Dordrecht, in the press).*
9. Burke, B. F., Lehár, J. & Connor, S.R. in *Gravitational Lenses* (eds Kayser, R., Schramm, T. & Nieser, L. 237–244 (Springer, Berlin, 1992).
10. Patnaik, A. R. in *Gravitational Lenses in the Universe* (eds Surdej, J., Fraipont-Caro, D., Gosset, E., Refsdal, S. & Remy M.) 311–321 (Univ. Liège, 1994).
11. Meyers, S. T. in *Astrophysical Applications of Gravitational Lensing, Proc. 173 Symp. of the IAU* (eds Kochanek, C. S. & Hewitt, J. N.) 317–322 (Kluwer, Dordrecht, in the press).*

---

*Conference proceedings are available at http://cfata2.harvard.edu/iau173/book.html