1993BASI...21..433N

Bull. Astr. Soc. India (1993) **21**, 433-435

Straight arcs in gravitational lens systems

D. Narasimha and S. M. Chitre
Theoretical Astrophysics Group, Tata Institute of Fundamental Research, Homi Bhabha Road, Bombay 400 005

Abstract. Faint straight arcs extending over ten to twenty arcseconds have been observed behind rich clusters of galaxies elongated by the lensing action of the foreground cluster. When a cluster of galaxies has its projected surface mass density barely above the minimum mass density required for multiple imaging of a background source, it is called a marginal lens for the specified redshifts of the lens and the source. A marginal lens produces images of large magnification and consequently, in a flux limited sample we expect ample number of such cases in spite of the rarity of such events. Rich clusters at redshift greater than around 0.2 are capable of multiple imaging of objects along their line of sight situated at redshift larger than about 1. The marginal lensing action of these clusters producing straight arcs will provide valuable diagnostic of the cluster as well as the large scale geometry of the Universe. Spectroscopy of the straight arcs is a valuable probe of the rotation curve and other characteristics of galaxies at high redshifts. Further, presence of mirror images of these galaxies provide observational constraints which would not be available for nearby galaxies.

Over the past several years, a number of galaxy-clusters have revealed the presence of giant luminous arcs and arclets. Amongst these an unusual configuration of a nearly straight arc was reported by Pello *et al.* (1991) in the rich cluster of galaxies, Abell 2390 with a redshift of $z = 0.23$. There has been so far a sample of four straight arc-like configurations detected in rich clusters (Giraud 1988; Pello *et al.* 1991; Mathez *et al.* 1992). Recently, Melnick *et al.* (1993) have reported the detection of another extremely luminous blue linear feature with a V magnitude of 20.4 in a galaxy-cluster at redshift $z = 0.56$, associated with the Ooty radio source $Cl2236 - 04$.

We expect that in a flux-limited sample of rich clusters of galaxies, there should be present a good many highly magnified background galaxies; some of these are likely to have a morphology of linear arcs of $\gtrsim$ 10 arcsec extent. Equally, in these clusters we should be able to identify multiply imaged background galaxies which will manifest as arclets at redshifts larger than that of the straight arc; these arclets would be typically 4-5 magnitudes fainter than the straight arc.

Giant, tangentially amplified luminous arcs are formed when the background galaxy lies on the caustic of the intervening deflector. Thus, the giant luminous arc in Abell 370 was simulated by Grossman & Narayan (1988) and Narasimha & Chitre (1988) as arising from the situation where the source galaxy is located on a fold caustic. But while a general fold caustic invariably produces curved images, we need to appeal to lip catastrophes in order to produce linear arc-like features. Kassiola, Kovner & Blandford (1992) have given an extensive and illuminating analysis of the lip and beak-to-beak configurations.

In the present work we outline a theoretical lens model for largely amplified straight arcs by simulating the observed morphology of the linear structure in the arc *Cl*2236 – 04. For this purpose we adopt a scenario wherein an extended background source galaxy is being marginally lensed by a galaxy cluster (Kovner 1987). This involves the gravitational lens parameters to be such that the projected surface mass density is close too but just a little higher than the critical value of the surface density for multiple imaging,

$$\Sigma_c = \frac{c^2}{4\pi G D_{\mathrm{eff}}}, \qquad \ldots (1)$$

where

$$D_{\mathrm{eff}} = \frac{(D_{\mathrm{observer-lens}})(D_{\mathrm{lens-source}})}{D_{\mathrm{observer-source}}}. \qquad \ldots (2)$$

It is possible to reproduce the straight arc morphology observed, for example, in the rich clusters *Cl*2236 – 04 and Abell 2390 with the assistance of reasonable set of parameters for the cluster lens, assuming a King-type density distribution. The model gives a transversely amplified linear structure of over 10 arcsecond in length, with a radial extent of about an arcsecond; there also appears break in the form of a neck in the contour plot. Note that we need only one source-galaxy and we find that the most natural model to account for straight arcs observed in rich clusters should involve the lensing of this single high redshift galaxy by foreground galaxy-cluster, with surface mass density just exceeding the critical value. The highly amplified linear structure would invariably result from such a marginal lensing phenomenon with the formation of a line-like cusp caustic intersecting the source galaxy. These straight arcs would all be oriented approximately perpendicular to the major axis of the cluster. There will naturally be other galaxies behind the cluster at redshifts in the vicinity of the one that is producing the straight arc configuration and which are located within a core-radius from the centre of the cluster. These should manifest as arclets which will be largely aligned with the straight arc, but lying at progressively larger radial distances and some 4-5 magnitudes fainter than the dominantly luminous straight feature.

A spectroscopic analysis of the straight arc in Abell 2390 by Pello *et al.* (1991) and Soucail & Fort (1991) indicates a velocity gradient along the arc, reflecting the intrinsic rotation velocity field in the background source. By invoking the Tully-Fisher relation, it then becomes possible to deduce the intrinsic luminosity of the source to within an accuracy of better than half a magnitude. A comparison with the observed magnitude then provides an idea of the magnification due to the lensing action.

In conclusion, a study of straight arcs in clusters is likely to be a powerful diagnostic probe of the gravitating matter on the cluster scale. The location, morphology and amplification of the arcs on the critical curves in the image plane should assist in constraining the surface mass distribution and gravitational potential of the lensing cluster. Equally, a reliable estimate of Σ, the surface mass density of the cluster-lens will be immensely helpful in making a reasonable determination of the Hubble constant, if one were to equate Σ with Σ_c.

References

Giraud E., 1988, ApJ, 334, L69.

Grossman S. A., Narayan R., 1988, ApJ, 344, L37.

Kassiola A., Kovner I., Blandford R. D., 1992, ApJ, 396, 10.

Kovner I., 1987, ApJ, 321, 686.

Mathez G., Fort B., Mellier Y., Picat J.-P., Soucail G., 1992, A&A, 256, 343.

Melnick J. Altieri B., Gopal Krishna, Giraud E., 1993, A&A, 271, L5.

Narasimha D., Chitre S. M., 1988, ApJ, 332, 75.

Pello R., Le Borgne J. F., Soucail G., Mellier Y., Sanahuja B., 1991, ApJ, 366, 405.

Soucail G., Fort B., 1991, A&A, 243, 23.