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CCD surface photometry of galaxies in the cluster Shapley 1346-30

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Summary. — Multicolour CCD surface photometry has been obtained for seven galaxies in the cluster Shapley 1346-30, *viz.* IC 4329, IC 4329A, NGC 5291, NGC 5291B, NGC 5298, NGC 5298A and NGC 5302. The data have been reduced *via* ellipse fitting routines. Intensity profiles are used to clarify some discrepancies in previous morphological classifications. We also present colour profiles and variations of position angle, eccentricity and centre with isophotal radius.

Key words: clusters : of galaxies — galaxies : general — photometry.

1. Introduction.

Shapley (1936) was the first to describe a cluster in the Centaurus region situated near 13^h46^m, $-30°$. It is sometimes referred to as the IC 4329 cluster or group after its brightest member (e.g. de Vaucouleurs and de Vaucouleurs, 1964 ; RC1) or alternatively as Klemola 27 (Klemola, 1969). It is the easternmost and most distant $\left(v = 4300 \text{ km s}^{-1}\right)$ member of the chainlike Hydra-Centaurus Supercluster (Chincarini and Rood, 1979). The cluster is centrally placed in ESO Southern Sky Survey field No. 445 (Richter, 1984 ; Holmberg *et al.*, 1978 ; ESO). No surface photometry has previously been published for any member galaxy (see the bibliography of Davoust and Pence, 1982 ; Pence and Davoust, 1985) apart from an uncalibrated equidensity map of IC 4329A (Feitzinger *et al.*, 1981).

In this paper we present multicolour (generally *BVR*) CCD surface photometry of seven galaxies in the cluster ; IC 4329, IC 4329A, NGC 5291, NGC 5291B, NGC 5298, NGC 5298A = ESO 445-G35 ([1]) and NGC 5302. The only uncertain case as regards cluster membership is NGC 5302 which has a redshift 1000 km s^{-1} less than the cluster mean and may be a foreground object (Buta and de Vaucouleurs, 1983).

2. Data and data reduction.

The observations were made during the week 1983 May 3-10 (by MJD and SP) shortly after the commissioning of the UCL RCA CCD on the 1 m telescope at the South African Astronomical Observatory (SAAO). Details of the CCD and its *BVRI* bands are given in Walker *et al.* (1984) and Walker (1984). Galaxy exposures were 1000-2000 s in *B*, *V* and *R*, except that no *R* frame was obtained for NGC 5298A and only a short *R* exposure (120 s) for IC 4329A. An additional *I* frame (also 120 s) was taken for the latter object.

Standard CCD reduction procedures were applied to the raw data frames (e.g. Carter *et al.*, 1983) and the reduced frames were analysed using packages available on STARLINK. Calibration from pixel counts to standard *BVRI* system magnitudes was *via* standard stars of Cousins (1976, 1980) and Landolt (1973, 1983) as in Walker (1984). Full details are given in Daly (1986). Standard deviations are $\simeq 0^m.01$ per observation in each band for the observed stars. The galaxy frames were analysed using an extended version of the GASP (Galaxy Surface Photometry) package (Cawson 1983a ; see also Cawson *et al.*, 1986 ; Davis *et al.*, 1985 ; Phillipps *et al.*, 1986 for further details of its use).

3. Magnitude comparisons.

As noted above there exists no quantitative surface photometry on any cluster member. We have therefore derived pseudo-aperture photometry and compared this with previously published *V* magnitudes from Sandage *et al.* (Sandage, 1978 ; Sandage and Visvanathan, 1978 ; S), the Oxford group (Bucknell and Peach, 1976 ; Godwin *et al.*, 1977 ; O), Dottori (1979 ; D), Wegner (1979 ; W), Griersmith (1980 ; G), McAlary *et al.* (1983 ; M) and Veron-Cetty (1984 ; V) ([2]).

([1]) This galaxy is incorrectly identified as NGC 5298 in the RC1 and RC2 (de Vaucouleurs *et al.*, 1976). The real NGC 5298 (=ESO 445-G39) is the « anon. companion » in the RC1 notes (Corwin, private communication).

([2]) Several cases of « mistaken identity » occur and have been carried over into the catalogue of Lauberts and Sadler (1985) ; Sandage's table I and notes to table II and Sandage and Visvanathan's table II refer to IC 4329A as IC 4329 and IC 4329 as IC 4327 ; Griersmith and Wegner used RC2 data so presumably observed NGC 5298A not NGC 5298 ; Dottori's magnitudes clearly refer to IC 4329 not IC 4329A as claimed.

The comparison is shown in figure 1. In almost all cases the agreement is excellent. Neglecting the very smallest aperture of both O and D, since small differences in centring or in « seeing » can lead to significant variations, and also that part of his data which Griersmith flagged as « unreliable », we find a mean difference

$$V - V(\mathrm{O} + \mathrm{D} + \mathrm{W} + \mathrm{G} + \mathrm{V}) = -0.01 .$$

Comparison with the individual observers shows systematic (zero point) errors $\lesssim 0^{\mathrm{m}}.05$ and random errors $\lesssim 0^{\mathrm{m}}.03$ in agreement with those expected. Exceptions are the values for IC 4329A by McAlary *et al.* (as transformed from the published values in mJy by Lauberts and Sadler) which are about $0^{\mathrm{m}}2$ too faint, and the data of Sandage which has a consistent zero point shift, $V - V_s = -0.11 \pm 0.03$, as found previously by Capaccioli *et al.* (1984) and Currie (1983).

4. Analysis and results.

Our CCD frames were obtained with a bright sky background $\sim 21.5\ B\mu$. Determination of the sky background from the borders or corners of the frames is accurate to 0.5-1.0 % so that precise photometry is not possible below $\sim 24.5\ B\mu$ (6 % of sky). In addition of course the physical size of the CCD frames limits us to fairly small radial distance $\lesssim 90''$. For these reasons we concentrate on the details of the intensity profiles, colour profiles and ellipse fits at fairly bright isophotes.

Contour plots of our galaxies in the B-band are given in figure 2. Figure 3 gives the corresponding radial profiles. Differential colour profiles are given in figure 4. Note that the profiles are obtained from an ellipse fitting routine which allows the position angle, eccentricity and centre of the ellipse to vary with radius (Cawson, 1983b ; Davis *et al.*, 1985) so that they are identical with major axis profiles only in the case of confocal elliptical isophotes (cf. Kent, 1984). Figure 5 shows the radial variations of these ellipse parameters.

4.1 IC 4329. — IC 4329 has conventionally been classified SO or SO/E but Malin and Carter (1983) have claimed that it is clearly a first-ranked elliptical. The isophotes are closely fitted by confocal ellipses with no twisting of isophotes. The radial profile however shows clear departures from a de Vaucouleurs (1959) $r^{1/4}$ law in the sense expected for an SO galaxy. Indeed, a simple trial and error superposition of an exponential disc and an $r^{1/4}$ bulge gives an excellent fit to the profile.

Additionally there is a very noticeable increase in ellipticity with radius, from about E2 at $\cong 10''$ to E4 by $r \cong 30''$ followed by a probable decrease in eccentricity beyond $\cong 60''$. Michard (1984, 1985) has shown that this is characteristic of SO galaxies.

The galaxy shows a significant and reasonably smooth colour gradient in $(B\text{-}V)$ and $(B\text{-}R)$, becoming $\cong 0^{\mathrm{m}}.2$ bluer in $(B\text{-}R)$ from the centre to $r \gtrsim 50''$. It appears that the gradient decreases when the disc begins to dominate over the bulge at around 20″. A more complete discussion of the colour data will be given in a separate paper. In general the point-to-point scatter is a good indication of the random errors in the colour plots. The main systematic error, as with the rest of the photometry, will be in the determination of the sky levels. However, this error will not be as large as might be supposed from the accuracy of the separate B and V photometry, say, since the colour of the background is observed to be more uniform than the background itself. At the $24\ B\mu$ isophote ($\sim 10\ \%$ of the sky brightness) the uncertainty in $(B\text{-}V)$ or $(B\text{-}R)$ should be $\sim 0^{\mathrm{m}}.03$.

4.2 NGC 5302. — The next brightest of the galaxies in the core of the cluster is NGC 5302. As with IC 4329 its morphological type is disputed, ranging from elliptical (Sandage, 1975), through SO (RC2), to Sa (ESO, Buta and de Vaucouleurs, 1983 ; Richter, 1984). The distinction is not merely academic as Tonry and Davis (1981) included it in their list of elliptical and lenticular galaxies with measured central velocity dispersions.

The intensity profile is evidently not a pure $r^{1/4}$ law and furthermore there exists structure in the profile which clearly cannot be accounted for by merely the superposition of smooth bulge and disc profiles. Non-axisymmetric structure is also visible in a false colour display of the image, although it is not readily apparent in the contour plot. Our data thus confirms the more recent classifications as an early-type spiral. The bulge component is quite large, dominating the profile out to $\cong 15''$.

Given this classification it is not surprising that we see a colour gradient from a red bulge to a bluer disc. The feature in the intensity profile at $\cong 35''$ is somewhat bluer still, supporting its interpretation as spiral structure. We see also the expected increase in ellipticity with radius due to the decreasing effect of the bulge, and also a « wandering » of the position angle due to the spiral arms (cf. Kent, 1984).

4.3 NGC 5298. — Another spiral, NGC 5298 has similar properties to NGC 5302. The bulge component is less prominent, dominating only inside $\approx 5''$. Even allowing for the smaller overall size of NGC 5298, this supports its later classification of Sb (RC2, ESO). One interesting feature is that the position angle in the B frame is shifted relative to that in the V and R frames (circles in the Fig.) at radii $\sim 5''$-15″. There is a slight difference in eccentricity too. This presumably is due to the greater contrast of the arms in the B band.

NGC 5298 also has a dwarf neighbour at a projected separation of only $\cong 60''$, comparable to the distance between NGC 5291 and NGC 5291B (see below). However in this case there is no sign of tidal interaction, such as miscentred or distorted isophotes, so we conclude that the projected neighbour is probably not a physically close companion.

4.4 NGC 5298A. — A very similar galaxy to NGC 5298, with which it is transposed in the RC2, NGC 5298A has a marginally larger bulge ($r \cong 7''$) suggesting perhaps a Sab classification (cf. Sb in RC2, Sa in ESO). The difference in position angle between the B and V frames is also less than for NGC 5298, which would be consistent with less prominent spiral arms. There is, though, a sharp change in colour when the disc starts to dominate over the bulge.

4.5 IC 4329A. — An extreme Seyfert I (Disney, 1973), IC 4329A is an edge-on lenticular or early-type spiral (RC2, ESO). It has a very prominent dust lane (e.g. Feitzinger *et al.*, 1981) easily seen in the *B*-contour plot. Note that due to the non-elliptical (boxy or even concave) contour shapes in the *B*-band near the centre, the profile generated by the ellipse fitting routine (for $r \gtrsim 5''$) does not join up with the direct cross-section (shown for the inner 6″). The dust lane complicates classification too, but the generally red colour, even away from the dust lane in the outer disc $(B\text{-}V)^\circ \sim 0.9$, suggests that the usual lenticular appellation is correct. The nuclear region is very red at radii ≈ 3″5, as expected from the strong dust absorption, but inward of ~ 2″ the nucleus is so bright that the observed colour is relatively blue despite the dust. A more detailed study of the dust lane and the nucleus using colour difference plots (cf. Sparks *et al.*, 1985) will be presented in a subsequent paper.

4.6 NGC 5291 AND NGC 5291B. — NGC 5291 is noteworthy for its close interacting neighbour, called NGC 5291B by Richter (1984) and the « Seashell » by Longmore *et al.* (1979). Its morphology, or more precisely its underlying morphology is a matter of debate. It is classified E by Sandage (1975), Ep (i.e. peculiar elliptical) in the RC2, and SO/a in the ESO Atlas. In a detailed study, Longmore *et al.* on the evidence of *U* and *B* band UKSTU plates, classify it as SO^+. Our data does not resolve the difficulty except inasmuch as the galaxy is definitely peculiar ! It can be seen from figure 2 that the inner profile (to ≅ 6″) is fairly well represented by an $r^{1/4}$ law ; this could be evidence for an underlying elliptical morphology or merely an SO bulge. However the galaxy profile then breaks downwards, the reverse of the expected behaviour for a lenticular. This is well seen in both the blue, where star formation induced by the interaction may be important and in the red (open circles in the Fig.), where presumably the underlying old stellar population is predominant. (The « normal », i.e. blueward, colour gradient is also seen to reverse temporarily at the breakpoint). It is not clear whether this may represent tidal truncation of a former $r^{1/4}$ law galaxy (e.g. Kormendy, 1977). An alternative explanation would be that in fact the inner $r^{1/4}$ law is illusory, the profile actually being dominated for the most part by a (somewhat irregular) SO disc, the bulge only dominating at very small ($\lesssim 3''5$) and possibly, in the red, at very large radii ($\gtrsim 25''$).

At still larger radii ($\gtrsim 40''$) there is seen in the blue profile a « plateau » which presumably corresponds to the diffuse emission noted by Longmore *et al.* on their blue and ultraviolet plates. The colours in this region are extremely blue, $(B\text{-}V)^\circ \sim 0.4$, typical of an irregular galaxy (allowing for a reddening ≈ 0^m1 as in Longmore *et al.*). This suggests the presence of widespread star formation as exemplified by Longmore *et al.*'s observations of blue knots with spectra like HII regions at very large radii from NGC 5291.

NGC 5291B has clearly been seriously effected by its close passage by NGC 5291 (the projected separation is only ~ 8 h^{-1} kpc). However, Longmore *et al.* suggested from their *U* plate that the galaxy is inherently an edge-on SO or early-type spiral. This suggestion is borne out by our CCD data. Beyond the central bulge the galaxy is highly flattened with $b/a \sim 0.3$. The bulge itself is quite large, following an $r^{1/4}$ law out to 4″-5″. To the east, i.e. towards NGC 5921 the isophotes are clearly more extended and indeed there is a subsidiary maximum.

Because of this asymmetric behaviour both halves of the cross-section are shown in figure 2 for $r \lesssim 7''$. Note that the eastward extension and the « hump » in the profile are not significantly bluer than the interior of the galaxy, suggesting that this is a tidal distortion *per se* and not primarily an effect of induced star formation. The actual colour, $(B\text{-}V)^\circ \sim 0.75$, is characteristic of early-type spirals.

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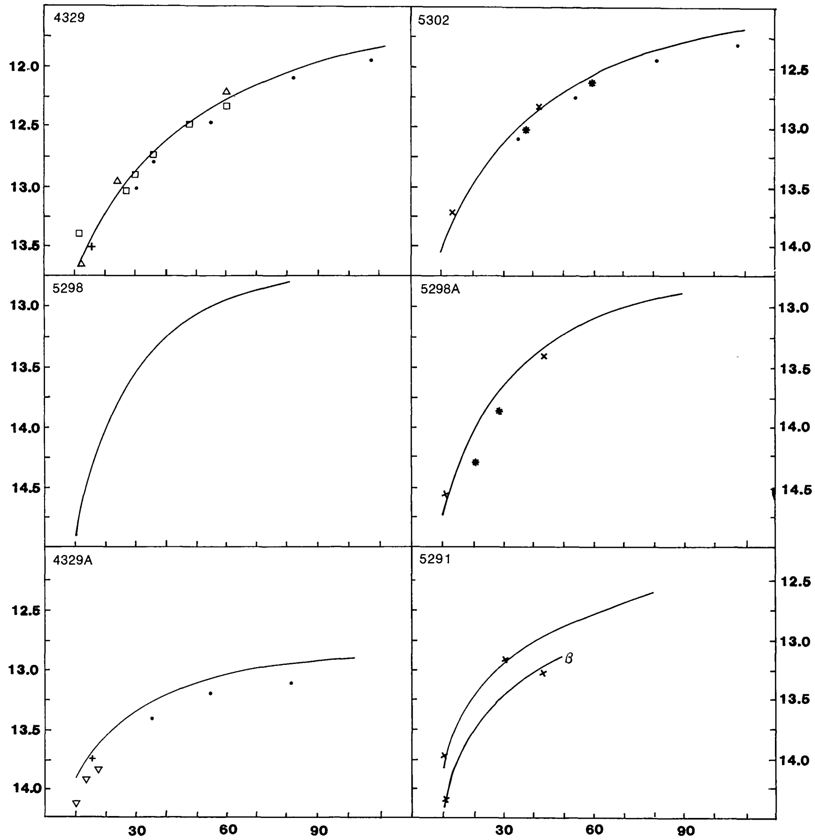

FIGURE 1. — V band curves of growth from the CCD data. The radial scale is aperture diameter in arcseconds. Note that the curve for NGC 5291B has been raised by 0.75 magnitudes in order to fit on the panel with NGC 5291. Symbols represent other observations as follows : ● S, □ O, △ D,* G, × W, ▽ M, + V (see text for Ref.).

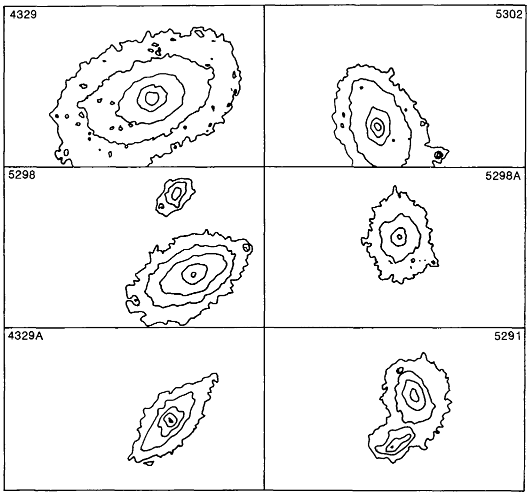

FIGURE 2. — Contour plots in the B band. Contour levels are : 4329 - 20.5, 21.5, 22.4, 23.2, 24.0 $B\mu$, 5302 - 20.0, 21.0, 22.0, 23.0, 24.0 $B\mu$, 5298 - 20.5, 21.5, 22.5, 23.4, 24.2 $B\mu$, 5298A - 20.5, 21.5, 22.5, 23.5 $B\mu$, 4329A - 20.0, 21.0, 22.0, 23.0, 24.1 $B\mu$, 5291 - 20.5, 21.5, 22.5, 23.5 $B\mu$. North is up, East to the right.

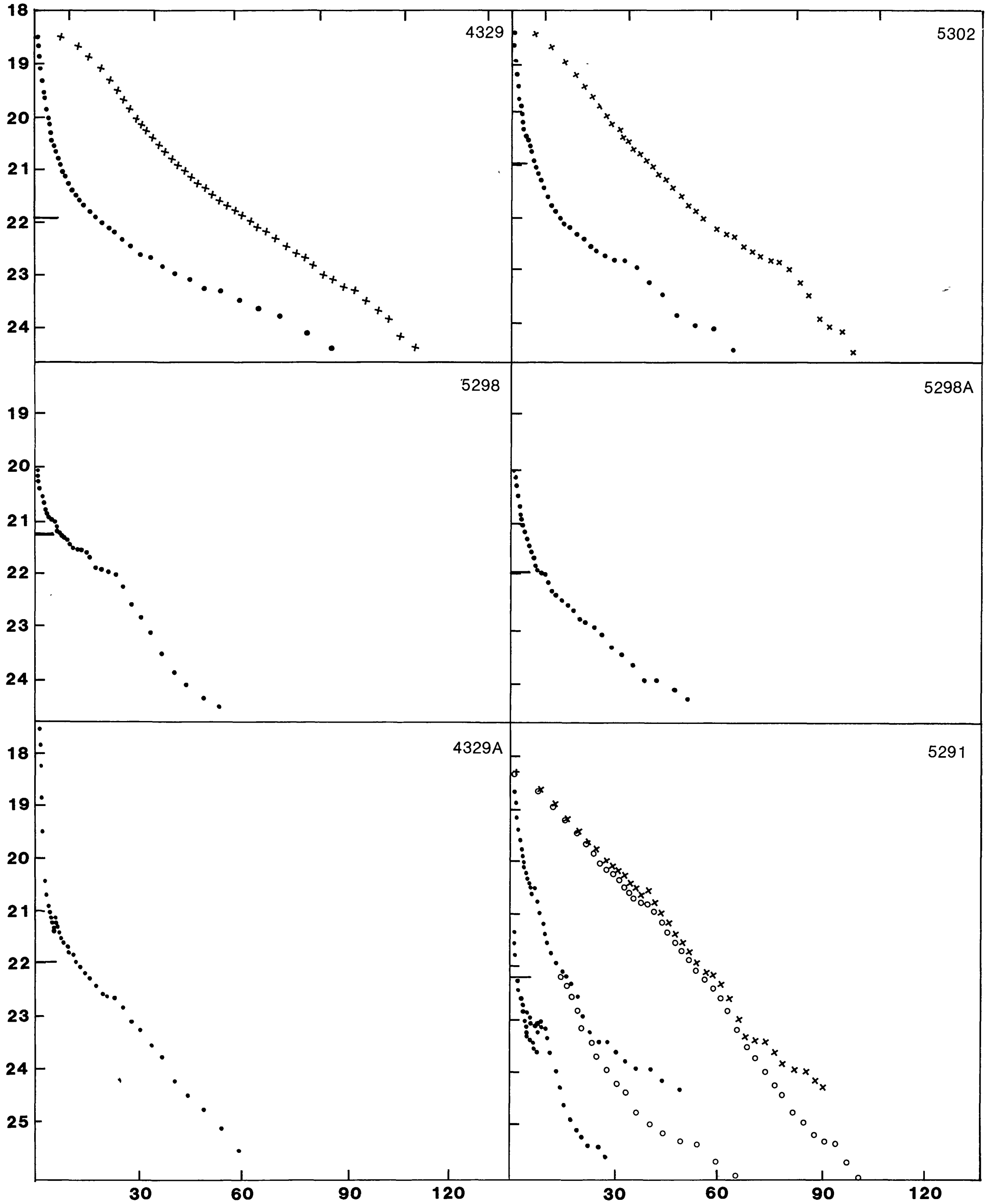

FIGURE 3. — Intensity profiles in the B band (in $B\mu$). Radial scales are radius in arcseconds (lower) and (radius in arcsecond)$^{1/4}$ (upper). Points plotted as crosses correspond to the upper scale. For clarity the profile of NGC 5291B has been shifted down by 2 $B\mu$ relative to NGC 5291. The form of the R band profile (scaled by the mean B-R for the inner parts) is also shown for NGC 5291 (circles). The longer tick marks on the vertical scales indicate the sky brightness for each frame.

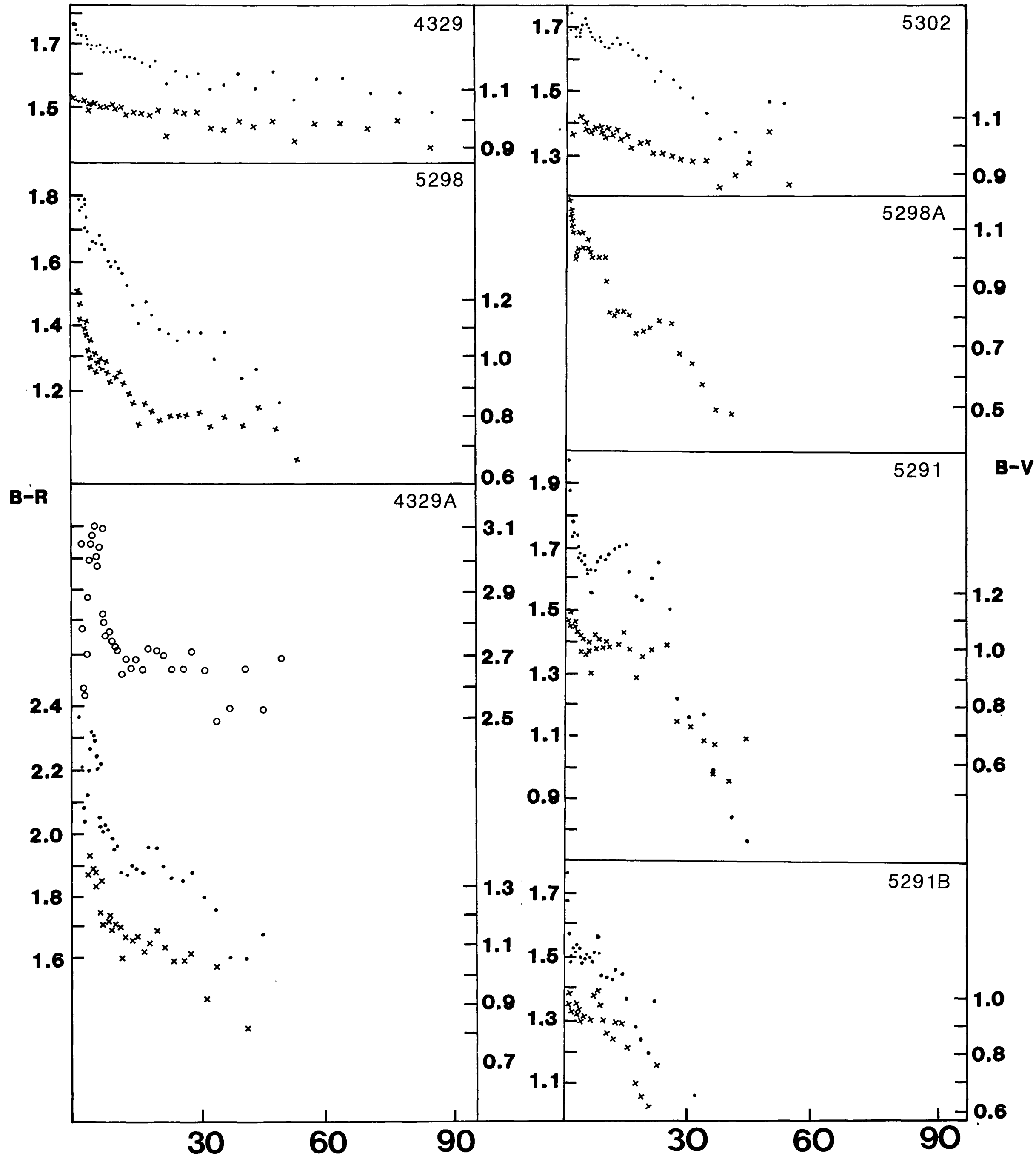

FIGURE 4. — Colour profiles in *B-R* (dots ; left-hand scale) and *B-V* (crosses ; right-hand scale). For IC 4329A *B-I* is also shown (circles ; right-hand scale). Radial scale is radius in arcseconds.

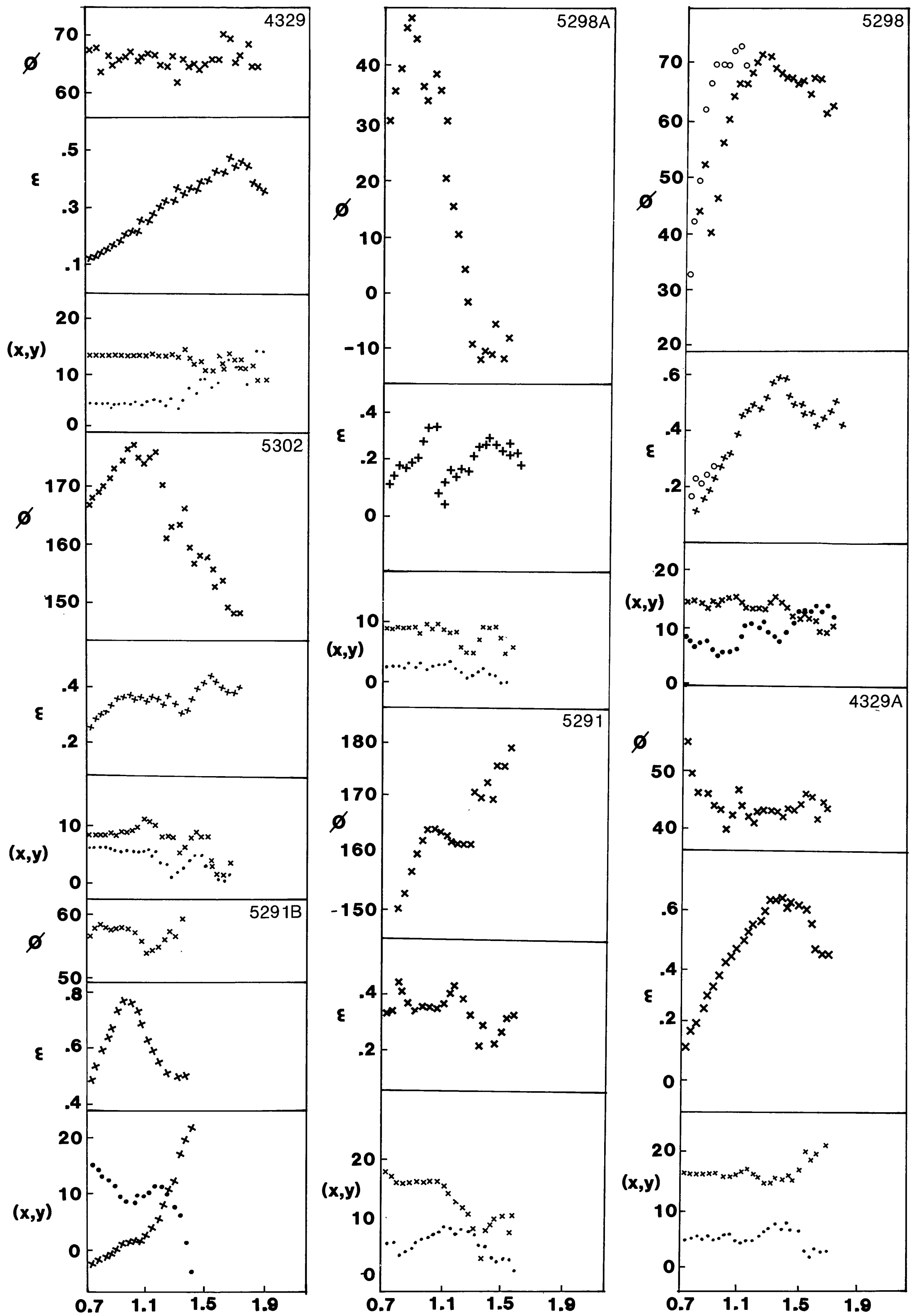

FIGURE 5. — Variation of position angle (ϕ), eccentricity (ε) and centre position (x, y) with semi-major axis of fitted ellipses. The centre position is measured in pixels (0″384) relative to an arbitrary origin. Radial scale is log (radius in arcseconds).