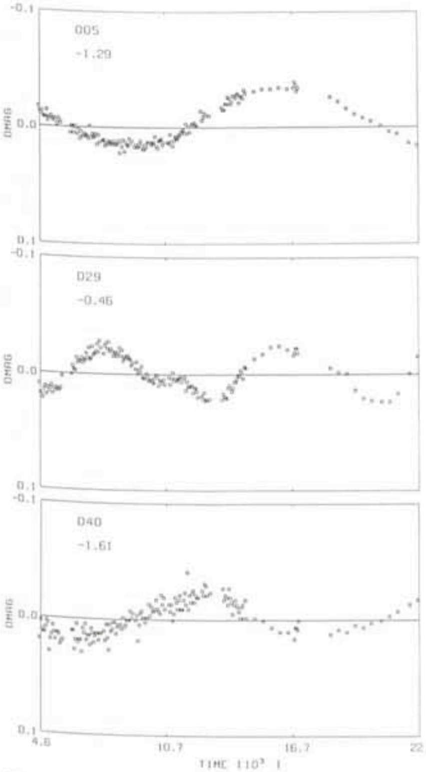

Figure 2: *Light curves for three stars in NGC 6134. Time is given in units of thousand seconds. The curves are labeled by a running number and the same relative magnitude as used in Figure 1.*

TABLE 1: *Properties of the δ-Scutii stars in NGC 6134*

#	B(mag)	$(B-V)_o$	M_B	A	P(hours)
5	12.73		1.11	0.0252	4.161
29	13.04	0.275	2.10	0.0176 0.00785	2.329 1.089
40	12.50		0.89	0.00838	3.358

line, mainly determined by the photon statistics. The brightest star is overexposed. A noise level of 0.0001 mag is reached for the brighter stars. One of the high points for the lower frequency band corresponds to a variable, the others are caused by the influence of close neighbours. Other time series give similar diagrams, and under reasonable weather conditions the noise limit reached does not seem to contain any instrumental effect. We do not seem yet to have reached a lower limit, where the instrumental noise starts to dominate. Gilliland and Brown (Ref. 1) reached the same conclusion using a Tektronix 512 × 512 chip.

Variables in NGC 6134

In NGC 6192 only one variable star of unknown type was found (Ref. 2). In the older cluster NGC 6134 ($t \approx 10^9$ y), three δ-Scuti stars have been located. The light curves from one night are plotted in Figure 2. An additional short time string was obtained 8 days later and helps to define the periods better. Two of the stars pulsate in only one mode, whereas the third has at least two modes. The periods and amplitudes are given in Table 1.

Star number 40 is the brightest and slightly overexposed which is reflected in the increased noise compared to the fainter star number 5.

The result of our search for δ-Scuti stars so far indicates that these stars are common only in fairly old clusters like NGC 6134 or NGC 2660 (Ref. 3). They seem to be nearly missing in young clusters. We still need to verify the suspected high number of δ-Scuti stars in NGC 2660, which could not be observed during our last expedition in May-June 1988.

The reason, why some stars in the instability strip near the main sequence pulsate and others do not, is still unknown, but the studies of clusters will be able to tell more precisely under which conditions pulsation is favoured.

References

(1) Gilliland, R.L. and Brown, T.M., 1988, *Publ. Astr. Soc. Pac.*, **100,** 754.
(2) Frandsen, S. and Kjeldsen, H., 1988, *Proceedings Symp. on Seismology of the Sun and Sun-like Stars,* Puerto de la Cruz, Tenerife, 26–30 Sept. 1988, 575.
(3) Frandsen, S., Dreyer, P. and Kjeldsen, H., 1989, *Astron. Astrophys.*, in press.

Imaging Polarimetry of High Redshift Radio Galaxies with EFOSC

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Most of our visual perceptions of the world around us, particularly in daylight, are derived from radiation which has been reflected or scattered. Consequently, we are continually bathed in linearly polarized light, even if only the loyal followers of M. Minnaert (1954) use the phenomenon of "Haidinger's Brush" to make themselves aware of it. At night, by contrast and with the exception of the Moon and planets, most of the astronomical sources we see are both self-luminous and highly spherically symmetric. Polarized light in astronomy is therefore the exception rather than the rule but, when it is observed, it can prove a valuable diagnostic either of exotic radiation mechanisms or of anisotropic scattering geometries.

In the study of active galactic nuclei and quasars, the measurement of optical polarization, both from synchrotron sources in nuclei, jets and "hot-spots" and from scattering around obscured sources, is a fruitful field of interest which is producing some remarkable new results. "Hidden" Seyfert 1 nuclei are being found in Seyfert 2 galaxies by looking at the polarized flux produced by the scattering of nuclear light from either dust particles or electrons which have a more direct line of sight to the activity than do we (Schmidt and Miller 1985).

At radio wavelengths, radio galaxies are known to be highly anisotropic ob-

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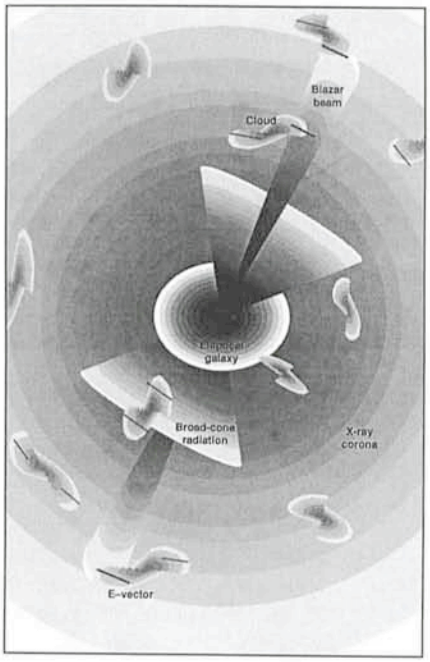

Figure 1: *An illustration of what may be producing the apparent optical elongation of high redshift radio galaxies. Beamed radiation from the active nucleus – either a broad cone due to equatorial obscuration and/or a narrow cone due to relativistic beaming – is scattered by dusty clouds which may be a common feature of young galaxies. In some cases, particularly massive clusters, there may be sufficient Thomson optical depth from electrons in the hot intracluster medium to produce wavelength independent scattering. In either case, the scattered radiation will be polarized with an E-vector perpendicular to the line joining the cloud to the nucleus.*

jects with narrow jets powering extended double-lobed sources. Much effort has been expended in trying to relate the axis of this radio structure to optical properties such as the apparent axes of the elliptical galaxy counterpart and to the extended emission line regions (EELR) which are often found associated with this type of activity. Although there are relationships, they are not strikingly obvious at low redshifts.

It was a surprise then when the discovery was made (McCarthy et al. 1987, Chambers et al. 1987) that the very distant, powerful radio galaxies at redshifts greater than about 0.6 had optical (rest-frame ultraviolet) images that are strikingly extended, in both emission lines and continuum, along the radio axis and look quite unlike their closer counterparts in the rest-frame optical band. Until we get ultraviolet images, with the Hubble Space Telescope, of a good sample of low redshift radio galaxies, we will not really know if we are seeing a qualitatively new phenomenon in the distant objects or whether it is just something which is being revealed by the different spectral balance of components at these wavelengths. The suggestion that the phenomenon really is new may be supported by the observation that at least some of the same objects are also elongated in K-band images around 2.2 μm – emitted in the rest frame at around 1 μm (Chambers et al. 1988, Rawlings and Eales 1989).

The solution to the problem is particularly important because these objects occupy such a prominent position in studies of the formation and early evolution of galaxies. Although probably very closely related to quasars, these high redshift sources are seen as galaxies and the most distant ones we can find. The fact that they are tracked down and identified by virtue of their activity may, in this case, be a hindrance and certainly demands caution in interpreting their observed properties solely in terms of stellar evolutionary processes.

What could cause these optical elongations? The most favoured interpretation has been that the directional forms of activity – the radio jets – have somehow induced star formation processes along their tracks which would show up as blue coloured extensions. Although theoretical studies show that this process may be feasible (De Young 1989, Rees 1989), there are few, if any, known examples of it occurring in powerful low redshift galaxies, suggesting that the circumgalactic environment would have to have evolved significantly. In addition, it has proved difficult to reconcile the observed colours from the infrared to the ultraviolet with a single burst of star formation although this may not be an insurmountable difficulty if more complex evolutionary models are used. The association of the extended images with non-thermal emission appears unpromising because, although the radio and optical major axes are aligned, there is no detailed correspondence be-

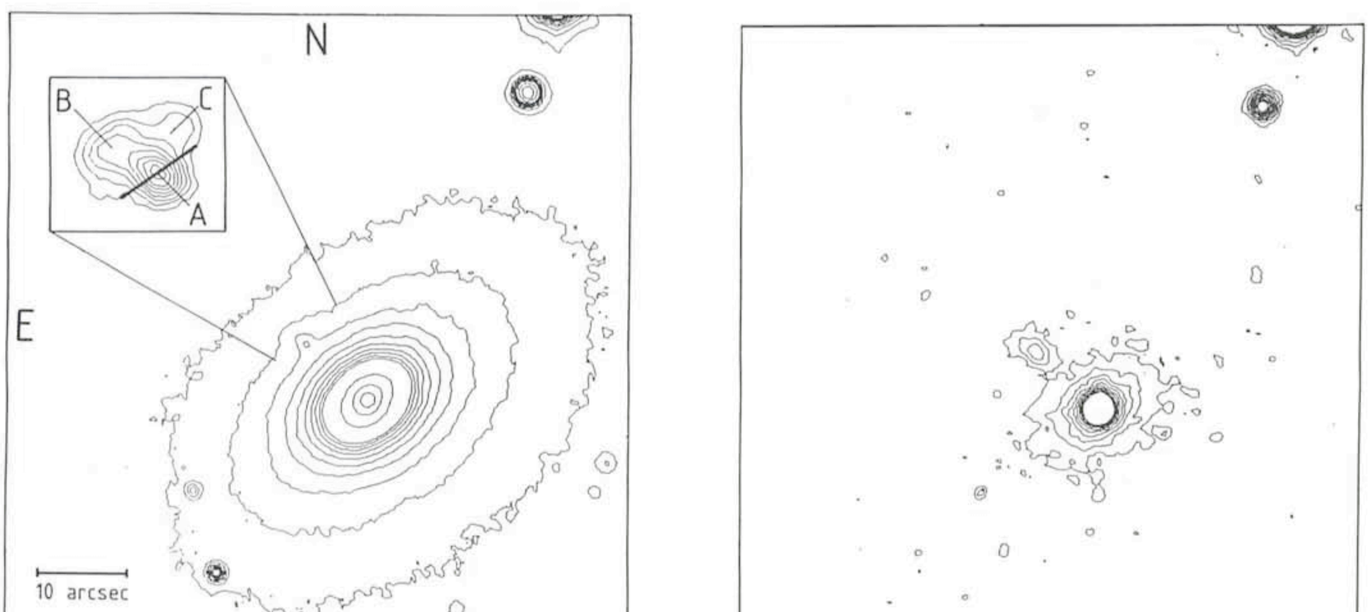

Figure 2: *Two continuum images of the nearby (z = 0.0282) radio galaxy PKS 2152-69, around 5500 Å on the left and around 3500 Å on the right. The insert shows an enlargement of the cloud along the radio axis after subtraction of the galaxy. The line through it shows the direction of the E-vector for the polarization which has been measured in the cloud. A comparison of the two images clearly illustrates how different radio galaxies can be in the UV and might explain the elongation along the radio axis observed at high redshift, where these objects are observed in their rest frame UV.*

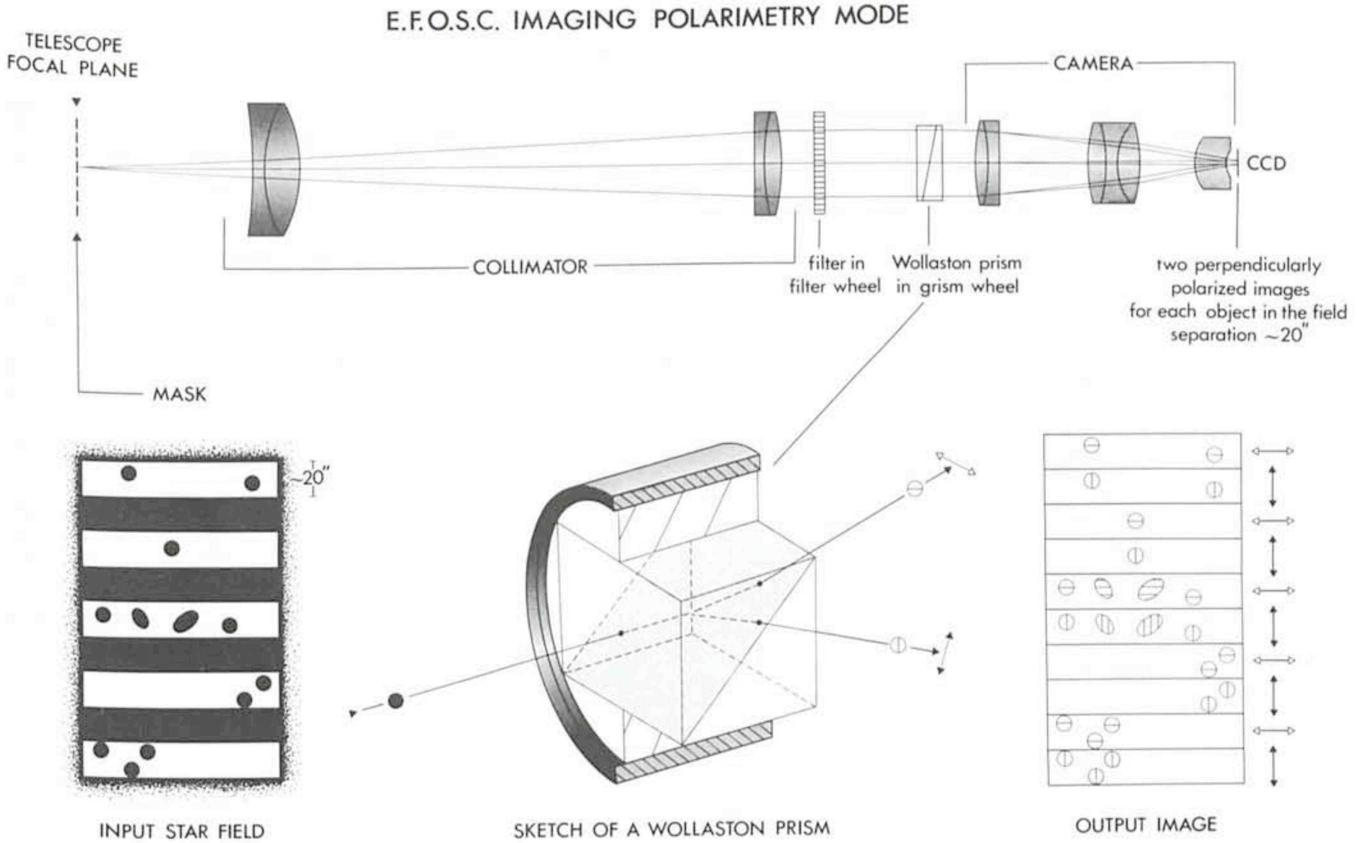

Figure 3: *An illustration of how the Wollaston prism in the collimated beam of EFOSC produces on the CCD two images with perpendicular polarization for each object in the field.*

tween their structures as there is with the radio-optical jets and hot-spots known at low redshift.

The third explanation, involving the scattering from matter – either dust or electrons – in an anisotropic radiation field, is in retrospect perhaps a natural choice given what is known now about the intrinsic and extrinsic mechanisms which can cause such anisotropy. We were, in fact, led to this suggestion by a series of detailed studies of a bright southern hemisphere radio galaxy known as PKS 2152-69 which is notable for its extreme extranuclear activity. This bright, 13th magnitude, galaxy shows a detached cloud at a projected distance of about 8 kpc along its radio axis which radiates emission lines from species up to and including Fe^{9+} (Tadhunter et al. 1988). Associated with it is a continuum source remarkable for its blue colour ($f_\nu \propto \nu^{+3 \pm 1}$) which, incidentally, is quite unlike known synchrotron sources which are rather red.

In addition to its colour, we also measured a linear polarization of $12 \pm 3\%$ with the electric vector perpendicular to the line joining the cloud to the nucleus (di Serego Alighieri et al. 1988). Since we were unable to think of an emission mechanism which would produce such a blue and polarized source, Rayleigh-like scattering of a bright, beamed nuclear source seemed to be the only consistent solution. This would produce polarization in the correct orientation and, like the blue sky, a bluer spectrum than the source. Thomson scattering from electrons, while producing polarization, would not explain the blue colour and so we proposed fine dust particles as the scattering medium. Although such dust could well be destroyed in the intense radiation field of the beam, new material could be supplied by the orbital motion of circumgalactic clouds.

We are led, then, to a picture of a radio galaxy with a Blazar-like "searchlight" beam of radiation shining out through a dusty envelope in the general direction of the radio axis (Fig. 1). Unless the beams impinge upon clouds, they remain essentially invisible. From the sequence of continuum images we have of PKS 2152-69 (Fig. 2) it is clear that scattering from the cloud is almost completely swamped by starlight in the visible part of the optical spectrum. In the near ultraviolet, however, where the stars are faint and the scattering is strong, the cloud becomes comparable in brightness to the rest of the galaxy. Is this then not a natural explanation for the extensions seen at high redshift which we see in the optical at rest wavelengths between 2000 and 3000 Å? The most direct test of the hypothesis is to look for linear polarization which would have to have the correct orientation – perpendicular to the elongation.

We have therefore measured the polarization of two high redshift radio galaxies, 3C277.2 (z = 0.766) and 3C368 (z = 1.132), chosen because they are brighter members of the class and are accessible from La Silla (di

Polarimetry of high redshift radio galaxies.

Object	Filter	$\Delta\lambda_{rest}$ (Å)	Magn.	P %	P_{corr} %	θ Degr.	PA_{rad} Degr.
3C277.2	B	2150–2850	B = 22.0	21 ± 4	21 ± 4	164 ± 6	61
3C277.2B	B		B = 22.5	6 ± 7	0 ± 7		
3C368	V	2250–3000	V = 21.4	7.6 ± 0.9	7.6 ± 0.9	85 ± 4	18
3C368	R	2650–3750	R = 20.5	2.8 ± 1.2	2.5 ± 1.2	92 ± 15	18

These results refer to the integrated light from each source. 3C277.2B is an extended object 7 arcsec to the North East from 3C277.2. $\Delta\lambda_{rest}$ is the rest frame wavelength range covered by the observation and PA_{rad} is the position angle of the radio axis (McCarthy et al., 1987).

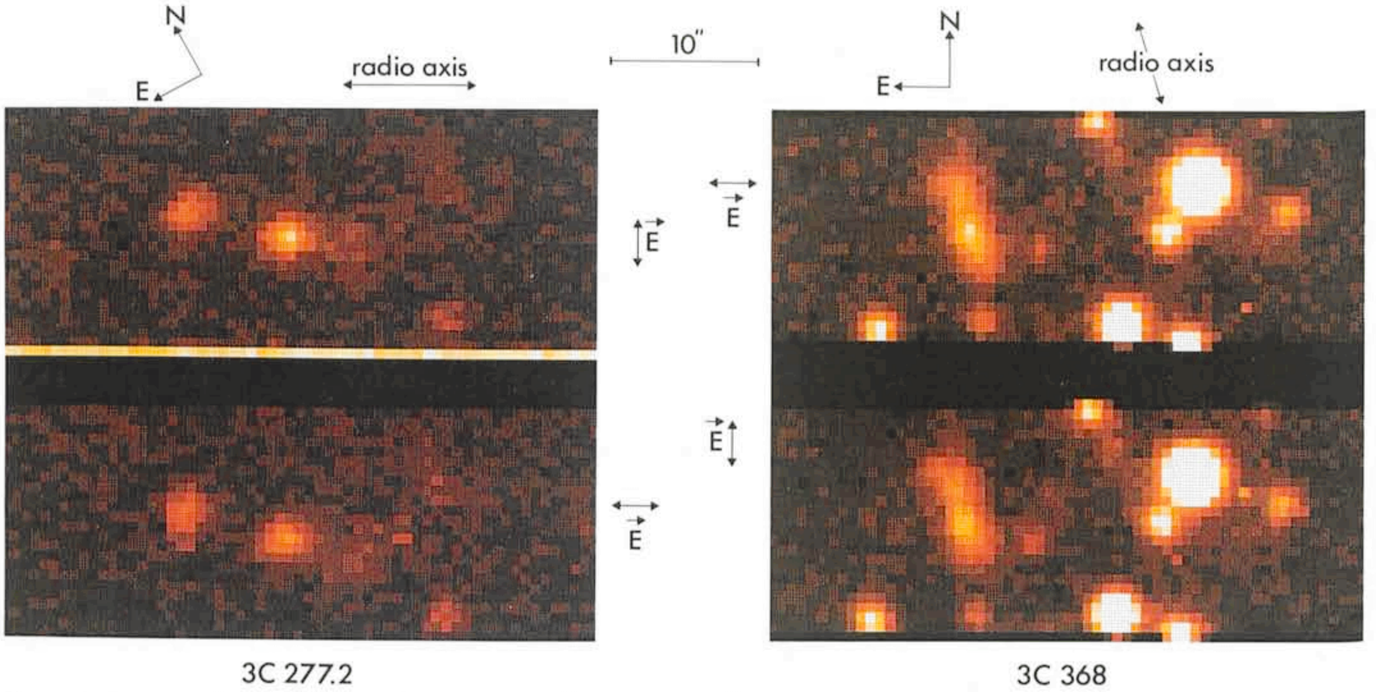

Figure 4: *EFOSC frames of 3C277.2 (left, B filter + Wollaston prism) and of 3C368 (right, V filter + Wollaston). 3C277.2 is clearly brighter on the top strip, where the E-vector is vertical while the radio axis is horizontal. The object on the left is 3C277.2B. 3C368 is clearly elongated and is brighter in the top strip which has a horizontal E-vector, while the radio axis is approximately vertical (along the elongation).*

Serego Alighieri et al. 1989). Observations were made in two runs in July 1988 and April 1989 with EFOSC on the 3.6-m telescope. The results are shown in the table.

The EFOSC polarimeter mode (Dekker and D'Odorico 1986, di Serego Alighieri 1989), with its focal plane masks of 20 arcsec which are sufficiently large to accept the entire image of these distant objects, is uniquely suited for this type of observation (Fig. 3). It is not easy however, since the galaxies are faint ($V \geq 21$) and the most critical part of the process is undoubtedly the precision with which the sky signal can be estimated and subtracted. The principle of the instrument is to image an object, simultaneously, in orthogonal linear polarizations; the simultaneity ensuring that the method is insensitive to seeing and transparency changes. Although the problem can be solved with just two exposures at different position angles – and indeed the polarization of 3C277.2 is so strong that it is obvious from the raw images (Fig. 4) – better error estimates can be made by obtaining a sequence of measurements at different angles and plotting a function $S(\varphi)$ of the brightness ratio of the two images versus position angle, φ.

The curve obtained for 3C368 is shown in Figure 5 and the fitted $P\cos2(\theta-\varphi)$ curve gives the degree of linear polarization P and the position angle of the E-vector θ. Instrumental polarization, which is small, generally less than 1%, is measured from bright stars in the field which are assumed to be unpolarized. The whole process is checked by making measurements of a set of faint stars, bracketing the galaxy in brightness; although these could be polarized by interstellar extinction effects, particularly at low Galactic latitudes, it does give a rather direct check on the error estimates. The measurements for some faint stars are also shown in Figure 5. Since the sky subtraction is so critical, we devoted considerable effort to selecting the best method and we obtained the best results with the MIDAS command MODIFY/PIXEL, improved with the help of Richard Hook at the ST-ECF. This command replaces a subsection of the image selected with the cursor by an interpolation on the surroundings. The difference between the original image and the replaced one is then integrated (e.g. with INTEGRATE/APERTURE) to obtain the sky-subtracted intensity of the object in the subsection.

The derivation of the degree of polarization and its angle from a set of brightness measurements involves the forming of a ratio, close to unity, of CCD counts which are subject to photon statistical and readout noise and an error resulting from the sky subtraction, followed by a fitting process. The analytical propagation of error estimates through this procedure in not straightforward and so we chose to do it using Monte-Carlo techniques. The starting points of this were sets of repeated measurements of the sky signal made using an aperture identical in size with that used for the galaxies. The results are shown as 1σ errors on the values given in the table.

Another worry in the interpretation of the measurements, particularly for 3C 368 which is at low latitude, is the estimate of Galactic interstellar polarization. We have used first the relationship between the maximum interstellar polarization P_{ISM} and the Galactic extinction derived by Hiltner (1956). Using computer readable extinction maps (Burstein 1988, priv. comm.) we find that $P_{ISM} \leq 0.05\%$ for 3C277.2 ($b = 79°$) and $P_{ISM} \leq 1.2\%$ for 3C368 ($b = 15°$). In the case of 3C368 the position angle of the E-vector of the polarization induced by the interstellar medium of the Galaxy (Mathewson and Ford 1970) would be close to the one measured for the object. A better check would then be to measure the polarization of another (hopefully normal) galaxy in the same field whose light, unlike faint field stars, would be subject to propagation along the whole pathlength through the Galaxy. Such an object was found in the field of 3C368 and its polarization in V was found to be less than 0.5% in the position of the radio galaxy E-vector. A similar check could be performed on 3C277.2 – which is at high latitude and therefore unlikely to show interstellar effects – by measuring a faint companion galaxy, 3C277.2B. This also turned

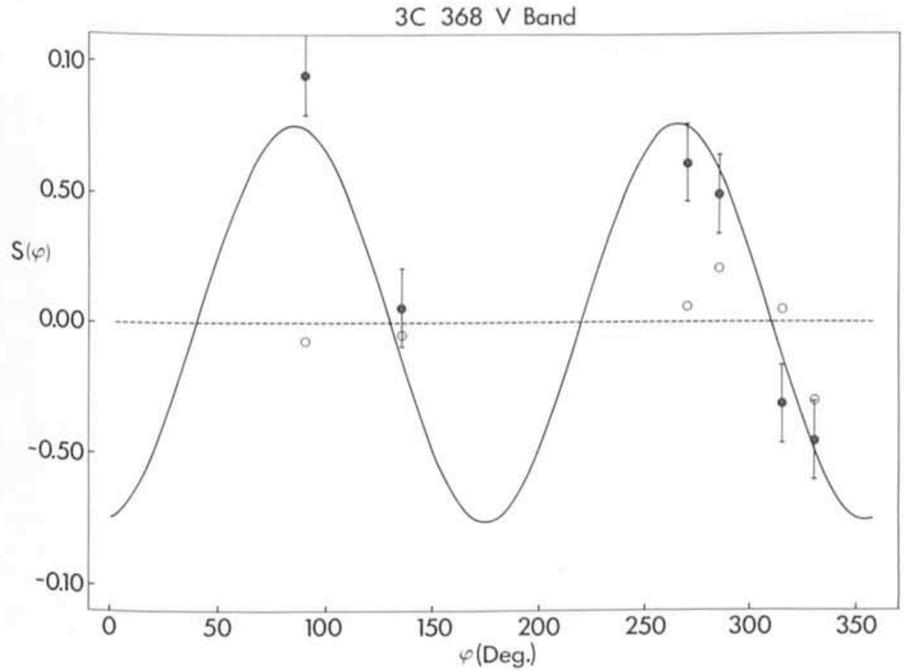

Figure 5: *The measurements (•) of S(φ), the component of the normalized Stoke parameters for linear polarization, for the V images of 3C368 and the fitted cosine curve. Also shown (○) is the average S(φ) for faint stars in the same frames.*

out to be unpolarized as shown in the table.

Finally, there is a statistical bias in the measurement of polarizations close to zero simply because, being the length of a vector, it is a positive definite quantity. This can be corrected using a standard technique (Wardle and Kronberg 1974) and the results are shown as P_{corr} in the table.

The single most important conclusion that can be drawn from these results is that a significant fraction of the light that we see in the optical band cannot be coming directly from stars and this means that the colours cannot be interpreted simply in terms of stellar populations. This has profound and unfortunate consequences for the method of using distant radio galaxies as tracers of normal galaxy evolution. On the positive side, however, it does – if interpreted as light scattering of beams of radiation emanating from active nuclei – lend considerable support to the ideas which are seeking to unify the properties of radio galaxies, quasars and BL Lac objects or Blazars by supposing that their different apparent properties are simply a result of their particular orientation with respect to us, the observer.

In the case of 3C 368, we were able to show that not all of the polarized flux was coming from the nucleus and so the extended structure must also be polarized. 3C277.2 is really too faint to investigate the extension separately using current techniques but clearly a task for the future is to test carefully that the extended structures really are polarized and see if the E-vector is accurately perpendicular to the radius-vector from the nucleus. This is a strong prediction of the scattering model. In addition, the wavelength dependence of the polarized flux can, in principle, distinguish between scattering by electrons and by dust. In 3C368, our two measurements, in V and R, already favour the dust hypothesis in this object although there is no reason why Thomson scattering could not play a role, particularly in massive clusters where there could be a large column density of coronal gas (Syunyaev 1982).

References

Chambers, K.C., Miley, G.K. and van Breugel, W., 1987, *Nature* **329,** 604.
Chambers, K.C., Miley, G.K. and Joyce, R.R., 1988, *Astrophys. J.* **329,** L75.
Dekker, H. and D'Odorico, S., 1986, *The Messenger* **46,** 21.
De Young, D.S., 1989, *Astrophys. J.* **342,** L59.
di Serego Alighieri, S., Binette, L., Courvoisier, T.J.-L., Fosbury, R.A.E. and Tadhunter, C.N., 1988, *Nature* **334,** 591.
di Serego Alighieri, Fosbury, R.A.E., Quinn, P.J. and Tadhunter, C.N., 1989, *Nature*, in press.
di Serego Alighieri, S., 1989, in *Proceedings of the 1st ESO/ST-ECF Data Analysis Workshop* (eds. P. Grosbøl et al.), in press.
Hiltner, W.A., 1956, *Astrophys. J. Suppl. Series* **2,** 389.
Mathewson, D.S. and Ford, V.L., 1970, *Mon. Not. R. Astr. Soc.* **74,** 139.
McCarthy, P.J., van Breugel, W., Spinrad, H. and Djorgovski, S., 1987, *Astrophys. J.* **321,** L29.
Minnaert, M., 1954, "The nature of light and colour in the open air", Dover Publications Inc.
Rawlings, S. and Eales, S.A., 1989, in *Proceedings of the Second Wyoming Conference on "The Interstellar Medium in External Galaxies"*, in press.
Rees, M.J., 1989, *Mon. Not. R. Astr. Soc.* **239,** 1p.
Schmidt, G.D. and Miller, J.S., 1985, *Astrophys. J.* **290,** 517.
Syunyaev, R.A., 1982, *Sov. Astron. Lett.* **8,** 175.
Tadhunter, C.N., Fosbury, R.A.E., di Serego Alighieri, S., Bland, J., Danziger, I.J., Goss, W.M., McAdam, W.B. and Snijders, M.A.J., 1988, *Mon. Not. R. Astr. Soc.* **235,** 405.
Wardle, J.F.C. and Kronberg, P.P., 1974, *Astrophys. J.* **194,** 249.

SN 1987 A: Two Years of Six-colour Photometry with the Danish 0.5-m Telescope

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For several years, a Brazilian-Danish-Spanish group has collaborated on studies of a particular type of variable stars, the so-called eclipsing binaries. Part of the work has consisted of observing the binaries with the Danish 0.5-m telescope in order to obtain accurate light curves in the Strömgren four-colour *uvby* system. In early 1987 we began yet another two-month observing run. Jens Viggo Clausen (Copenhagen) started in late January, one of us