Mon. Not. R. Astron. Soc. **000**, 000–000 (1994) Printed 1 December 1997 (MN plain TEX macros v1.6)

# A search for optical polarization from the narrow-line Seyfert I galaxy RE J1034+396

A. A. Breeveld and E. M. Puchnarewicz

*Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Dorking, Surrey, RH5 6NT*

**ABSTRACT**

We present spectropolarimetry data on RE J1034+396, an ultra soft X-ray narrow line Seyfert 1 galaxy, and find an upper limit of ∼0.4 to the linear polarization in the optical band. This suggests that there is no synchrotron emission in this AGN, thus it is unlikely that RE J1034+396 is related to BL Lac objects. Furthermore, any other polarization due to transmission through dust, or reflection from dust and electrons, must be cancelled out by geometrical effects or diluted to a high degree by unpolarized radiation.

**Key words:** Polarization – Galaxies: Seyfert – Galaxies: active – Galaxies: individual: RE J1034+396

## 1 INTRODUCTION

The AGN RE J1034+396 (also known as Zw 212.025), at redshift z=0.042, has been classified as a narrow line Seyfert 1 galaxy (NLS1; Osterbrock & Pogge 1985). In common with other NLS1 galaxies it has Balmer lines with full widths at half maximum (FWHM) of $\lesssim$2000 km s$^{-1}$ (Puchnarewicz et al. 1995), which are nevertheless broader than the forbidden lines. The optical spectrum rises towards the red, with a spectral index $\alpha$ ∼1.4 (defined as $f_\nu \propto \nu^{-\alpha}$) and it has an unusual multiwavelength spectrum overall, with a very hot soft X-ray excess (a blackbody temperature of ∼80 eV) and no significant 'big blue bump' (BBB) in the UV/optical (Puchnarewicz et al. 1995; Pounds, Done & Osborne 1995).

The optical continua of a number of other NLS1s also rise towards the red (Goodrich 1989) rather than to the blue as is normally seen in type 1 AGN. One is IRAS13349+2438 where the steep, red spectrum has been attributed to reddening of the flat continuum produced by the central engine (black hole and accretion disk) by transmission through dust (Wills et al. 1992). IRAS13349+2438 also has a very high, wavelength dependent, level of polarized optical light (8 per cent at 3600 Å, rising towards the blue) which Wills et al. (1992) attributed to reflection from hot electrons above the poles of the system. Other NLS1s have also shown evidence for relatively high levels of polarization (Goodrich 1989), e.g. Mrk766, which has 2 per cent optical polarization with a position angle perpendicular to its radio axis (Ulvestad, Antonucci & Goodrich 1995; its optical continuum is also red).

A steep, red optical continuum has been identified in RE J1034+396, but there is little evidence for absorption. The object's detection in the ROSAT WFC survey (Pounds et al. 1993) limits the column density of cold gas along the line of sight to $\lesssim 2 \times 10^{20}$ cm$^{-2}$, and thus, with a Galactic column of $1.52 \times 10^{20}$ (Stark et al. 1992) in the direction of the source, there must be little intrinsic absorption of soft X-rays. In the absence of absorption, the red spectrum might be explained by a strong contribution from the host galaxy, or thermal dust emission, but there are no features indicating the presence of the host galaxy in the optical continuum and, since dust grains sublime at T>1800 K, thermal emission components from dust are not expected at wavelengths below ∼1$\mu$m (Chini, Kreysa & Beirmann 1989; Barvainis, Antonucci & Coleman 1992). The lack of absorption does not rule out the possibility of the presence of dust embedded in ionized gas (Brandt, Fabian & Pounds 1996), however, in the optical the Balmer decrement is consistent with little or no reddening. Thus the origin of the red optical continuum remains unclear. It may be dominated by the emission of a soft underlying power law ($\alpha$=1.4), reminiscent of those seen from BL Lac objects and Puchnarewicz et al. (1995) speculated that there may be some low level BL Lac-type activity in this object.

In this paper we present optical spectropolarimetry data on RE J1034+396 and use these to test the hypotheses that the red optical continuum is caused by:

*(1)* transmission through dust as in the case of IRAS13349+2438, where the polarization is believed to be caused by electron and dust scattering

*(2)* synchrotron radiation as in the case of a BL Lac object.

## 2 OBSERVATION

The spectra of RE J1034+396 were taken on the 4.2 m William Herschel Telescope at La Palma on 1996 February 27 as part of the Isaac Newton Group (ING) Service Programme. The ISIS triple spectrograph was used, with a 1024x1024, Tek2 CCD detector and a R158B grating in the blue arm and R158R in the red arm. There is one series of polarization measurements with exposures of 2100 s in the blue on RE J1034+396, and one series of 1200 s in red.

With ISIS one can achieve spectropolarimetry of good resolution (8.4 Å) and nominally 0.1 per cent precision. It allows measurement of the two orthogonally-polarized intensities (the o- and e- beams) with the same detector within a very short time interval. A set of four exposures were taken, one for each setting of the halfwave plate, and these allow the fractional amplitude of the sine modulation (degree of polarization; P) and its phase (polarization angle; $\theta$) to be determined. Exposures 1 and 2 (halfwave plate 0° and 45°) yield the Stokes Q parameter, and exposures 3 and 4 (halfwave plate 22.5° and 67.5°) the Stokes U, relative to the instrument coordinate system.

Two standard stars, the polarized HD 25443, and unpolarized HD 21447 were observed also, in order to calibrate the magnitude and zero offset of the polarization. Observations of the sky, for background subtraction, and CuAr and Ne arcs for wavelength calibration, completed the measurements.

## 3 DATA ANALYSIS AND RESULTS

The data analysis followed the procedure outlined in Tinbergen & Rutten 1992. In this section the various components of the data and error analysis are explained and the results given.

All binning and calculation of means and errors were based on Q and U. The photon counting uncertainties on each pixel of each spectrum were propagated to Q and U and thence to errors on P and $\theta$. The systematic errors were added to Q and U after binning and propagated through to the final P and $\theta$. Weighted means for Q and U were used to give final weighted means for P and $\theta$ across the red and blue wavelength ranges. The errors are quoted as percentages of the value of P.

A CCD bias value was found by averaging the data in the overscan region at the edge of the chip. This was subtracted from the data before scaling by exposure time.

Cosmic ray spikes in the data were removed by using a median filter 4 pixels wide. For the standard stars this affected a negligible number of pixels; for the source 0.01 per cent of the pixels, because of the longer exposure time. Filtering data where there are no cosmic rays, reduces P, but neglecting to filter out a cosmic ray, increases P falsely. Getting the right balance required a degree of judgement. We kept a check on the number of discrepancies found: two cosmic rays was the average in the short 2 s exposures and therefore, approximately 1200 were expected in the long 1200 s exposures. We obtained an estimate of the error introduced (16 per cent of the value of P for RE J1034+396), by adjusting the filtering parameters used and noting the effect on the final value. The filter was not used on the standard star data, because the number of spikes was very small and the number of counts in each spike negligible compared with the high count rate from the stars. An error for filtering has therefore not been applied to the standard star results.

One particularly energetic cosmic ray is not completely removed by the filtering and affects the red spectrum of RE J1034+396 at 7589 Å. This part of the spectrum was not included in the weighted mean of the polarization.

Having subtracted the bias value from the frames and removed the cosmic rays, the spatially resolved spectra were summed along the dispersion direction to obtain spatial profiles of the source. From the profile, an extraction region was selected maximising the point source contribution and excluding the wings of the host galaxy. For the polarized star, the error incurred in the extraction region selection was relatively small, giving 3 per cent error on P, because of its high count rate and well defined profile. For the unpolarized star and the AGN, the errors on P were 30 per cent.

For faint objects sky polarization must be corrected for and this is taken care of by the background subtraction. The background spectra we used in the subtraction were extracted from the same sized areas on the CCD, and in the same position relative to the dekker window, as the object spectra. The background subtraction was also performed on the separate sky observation in order to check the accuracy of this procedure (1 per cent error).

The extracted spectra were averaged and wavelength calibration was performed by comparison with CuAr and Ne arcs taken during the observation.

Extinction variations, scintillation, image motion and other seeing variations are removed by taking the ratios of the spectra corresponding to the o- and the e-beams, because all these effects are independent of their projection onto the o and e vectors whereas the polarization is not.

Pixel to pixel variations in gain could lead to a false polarization measurement of the object, however, since we selected the same extraction regions, the same pixels are used for all four source exposures. Taking ratios of the spectra taken with the polarization vector 90° apart should remove variations in gain. In addition, the integration over about 20 pixels in the spatial direction reduces the error. It is therefore unnecessary to use a flat field.

Scattered light between the e and o spectra would falsely reduce the degree of polarization. However, the scattering may be assumed to be negligible (Tinbergen & Rutten 1992). Scattering between different wavelengths may be more of a problem, but will be negligible with respect to general trends.

### 3.1 Standard stars

The same data reduction procedure was applied to data on the two standard stars. The zero polarization standard star is used to set the zero offset, while the polarization standard gives a clear indication of the systematic errors. The polarization standard star, HD 25443, is a B0.5III star of V magnitude 6.78, and $P_V = 5.13 \pm 0.061$ per cent and $\theta_V = 134^\circ.2$ (Schmidt, Elston & Lupie 1992) (see table 1). The unpolarized star, HD 21447, is an A1V variable star, of V magnitude 5.097 (Oja 1996), with $P_B = 0.017 \pm 0.03$ per cent (Schmidt, Elston & Lupie 1992). The zero-point for $\theta$ was determined from the polarization standard.

The values we obtain for P from the polarized and unpolarized standard stars are consistent, within the uncertainties, with previous results (see table 1). (The fact that in the unpolarized standard there is a discrepancy in $\theta$ is likely to be due to the low level of polarization.) Thus we find that there are no further major systematic errors.

### 3.2 Results

For RE J1034+396, in the blue band (3900–5600 Å), we find P=0.36±0.13 per cent, $\theta$=78±9°, and for the red band

(5800–9200 Å), P=0.40±0.13 per cent, $\theta$=71±9°. These measurements are given in table 1 together with those for the comparison stars. Figures 1 and 2 show the RE J1034+396 spectra together with the P and $\theta$ measurements across the wavelength ranges. The Q and U data were binned to reduce the errors, until the errors on P were approximately 50 per cent of the value per bin.

The values of P in the blue and red for RE J1034+396 are consistent. However, no account has been taken of polarization due to the interstellar dust in our galaxy, which can be expected to polarize by up to 0.5 per cent (Goodrich 1989). The interstellar medium could also affect the position angle of the incoming polarized light. Other effects, for which no corrections have been made, include a contribution to the polarization by dust in the host galaxy and contamination by host galaxy starlight. It is unlikely that all these effects are contriving to oppose any intrinsic polarization from the source and therefore the resulting measurement of the polarization has to be considered an upper limit.

## 4 DISCUSSION

We have measured the optical polarization of the NLS1 RE J1034+396 and found the fraction of polarized light to be less than 0.4 per cent. The lack of a significant polarized component in this object has several implications for our interpretation of the inner regions of the AGN.

### 4.1 Synchrotron

Many NLS1s are abnormally variable and highly polarized, which might indicate a general similarity to BL Lac objects. In the NLS1 RE J1034+396 Puchnarewicz et al. (1995) suggest that the apparent underlying power law (with a slope of $\alpha$=1.4), from the infrared through to X-rays, bears some similarity to the BL Lac spectrum produced by synchrotron radiation. RE J1034+396 has also been detected at 21cm, as a core dominated radio source with a flux of 26mJy (Condon et al. 1996). Depending on the definition (e.g. Jang & Miller 1997; Zamorani et al. 1981) this makes it borderline between radio loud and quiet, supporting a low level BL Lac-type activity. However, we have shown here that, unlike other NLS1s, there is no significant polarization in this object, and it appears to have been stable over the five years of observation, which argues against the analogy. Nevertheless the idea that RE J1034+396 could be a mini-BL Lac cannot be ruled out. For example, Jannuzi, Green & French (1994) indicate that X-ray selected BL Lacs spend roughly half of their time with a polarization magnitude of less than 4 per cent. Thus it remains possible that a mini-BL Lac may exist in the centre of RE J1034+396 but that the polarization level and activity are currently in a low state.

### 4.2 Scattering by dust or electrons

Scattering by electrons in the photoionized region of the inner torus, or by dust in the outer regions, can cause polarization. The absence of polarization could indicate the absence of any dust or highly ionized gas surrounding the central continuum source, but this is physically unlikely. It is more likely that we are unable to see polarization due to geometrical or dilution effects.

One example of a geometrical effect is if the dust and gas lies in a symmetrical distribution around the nucleus, relative to our line of sight such that the polarization vectors would cancel out (Wolstencroft et al. 1995). For example this would be the case if the object is consistent with the unified theory of active galaxies, (Antonucci 1993), and if we are looking at a torus pole-on . This is the expected orientation for a Type I object, although Brandt et al. (1996) have suggested that the NLS1 IRAS13349+2438 is viewed edge on.

Alternatively, the polarized radiation could be diluted by other unpolarized continuum components, for instance if we have a direct view of an unpolarized continuum source. Kartje (1995) has modelled AGN with opaque cylindrical tori, and with stratified winds driven centrifugally from the accretion disk. He finds zero polarization in the case of the opaque torus, provided the viewing angle is less than the half opening angle of the torus. In the case of winds, the swamping is less severe, but polarization is still low. There are many other geometries which can be imagined where the direct view swamps the scattered radiation.

It is also possible for more than one scattering surface, or multiple scattering plus dichroic extinction (see section 4.3) to combine destructively to give a zero resultant polarization vector.

### 4.3 Dichroism by a dusty medium

The Balmer decrement in RE J1034+396 was found by Mason, Puchnarewicz & Jones (1996) to be ~5, although Puchnarewicz et al. (1995) measured a value closer to 3, i.e. consistent with case B recombination (see e.g. Gaskell & Ferland 1984). However, photoionization model predictions of the H$\alpha$/$H\beta$ flux ratio of RE J1034+396, which included the very high soft X-ray component as observed, show that the Balmer decrement can be as high as ~10 without any need for reddening (Puchnarewicz et al. 1995). Similar results for AGN in general have also been reported (e.g. Gaskell & Ferland 1984; Kwan & Krolik 1981; Canfield & Puetter 1981; Goodrich 1990). Thus, evidence from the Balmer decrement for dust absorption in RE J1034+396 along the line of sight is inconclusive.

Evidence for dust absorption from the multiwavelength continuum spectrum is also uncertain. The optical spectrum is red, which may suggest some dust absorption, but there is no evidence of warm or cold gas absorption in the X-ray spectra.

However, if dust *is* present along the line of sight, it could give rise to polarization by dichroic extinction, provided the dust grains are aligned in the local magnetic field, as would be expected for AGN (Kartje 1995). The lack of polarization could indicate that there is no dust in the line of sight or that the grains are not aligned. Grain alignment would be caused by paramagnetic relaxation, but the degree of alignment depends on the dust-to-gas temperature ratio as well as on the damping parameter. Thus, a weak magnetic field and/or a high gas temperature might result in a random orientation of the grains. While no magnetic field has been measured in RE J1034+396, the presence of hot gas in RE J1034+396 is indicated by observations of highly ionised iron (e.g. [FeXI]$\lambda$7892). Hot gas along the line of sight should not give rise to polarization by the electrons,

**Table 1.** Polarization magnitude and angle for the two standard stars and the AGN.

| Object | Colour | Measured P (per cent) | Measured $\theta$ (°) | Previous measurements P (per cent) | Previous measurements $\theta$ (°) |
|---|---|---|---|---|---|
| RE J1034+396 | blue (4650) | 0.36±0.13 | 78±9 | | |
| | red (7350) | 0.40±0.13 | 71±9 | | |
| HD 25443 | U (3500) | | | 4.930±0.062 | 134.55±0.36 |
| | B (4300) | | | 5.232±0.092 | 134.28±0.51 |
| | * | | | 5.25 ±0.07 | 132 |
| | blue(4506) | 5.18±0.11 | 128.9±0.3 | | |
| | V (5500) | | | 5.127±0.061 | 134.23±0.34 |
| | R (6500) | | | 4.734±0.045 | 133.65±0.28 |
| | red (6998) | 4.61±0.11 | 133.4±0.2 | | |
| | I (8000) | | | 4.249±0.041 | 134.21±0.28 |
| HD 21447 | N | | | 0.07 ±0.035 | 92.85 |
| | U | | | 0.042±0.039 | 122.94 |
| | B | | | 0.017±0.03 | 28.63 |
| | blue | 0.07±0.03 | 117±13 | | |
| | V | | | 0.051±0.02 | 171.49 |
| | red | 0.06±0.03 | 110±17 | | |

The first two columns of P and $\theta$ are the results obtained from this work. The second two columns are from Schmidt, Elston & Lupie (1992) and * from Bastien et al. (1988).

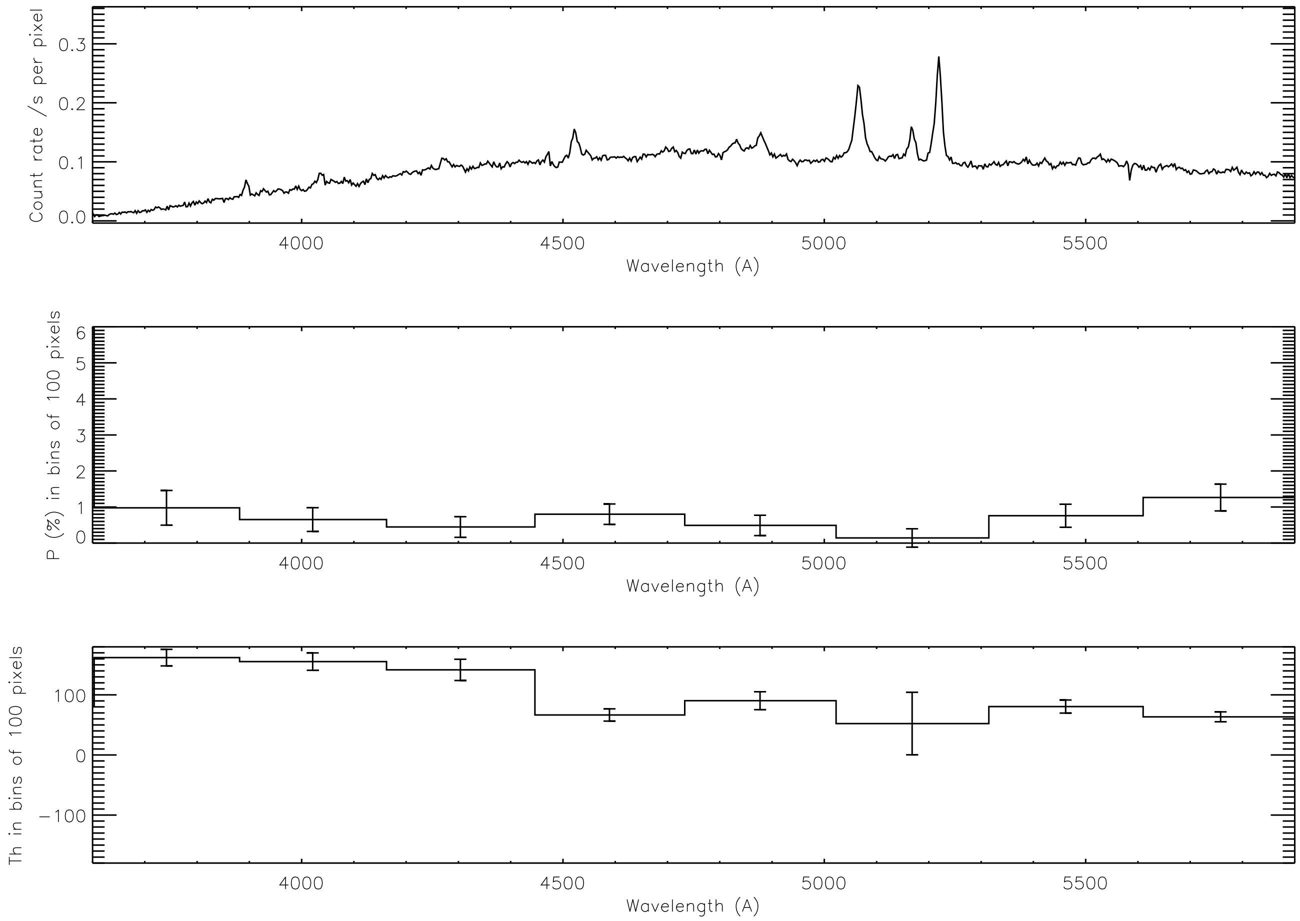


**Figure 1.** The blue spectrum of RE J1034+396 with the measurements of P and $\theta$. $1\sigma$ error bars are shown for each point.

although it could cause a rotation of the position angle by Faraday rotation, if polarization were present.

Thus the polarization measurement supports the conjecture that there is probably a negligible quantity of dust in the line of sight, although there still could be hot gas.

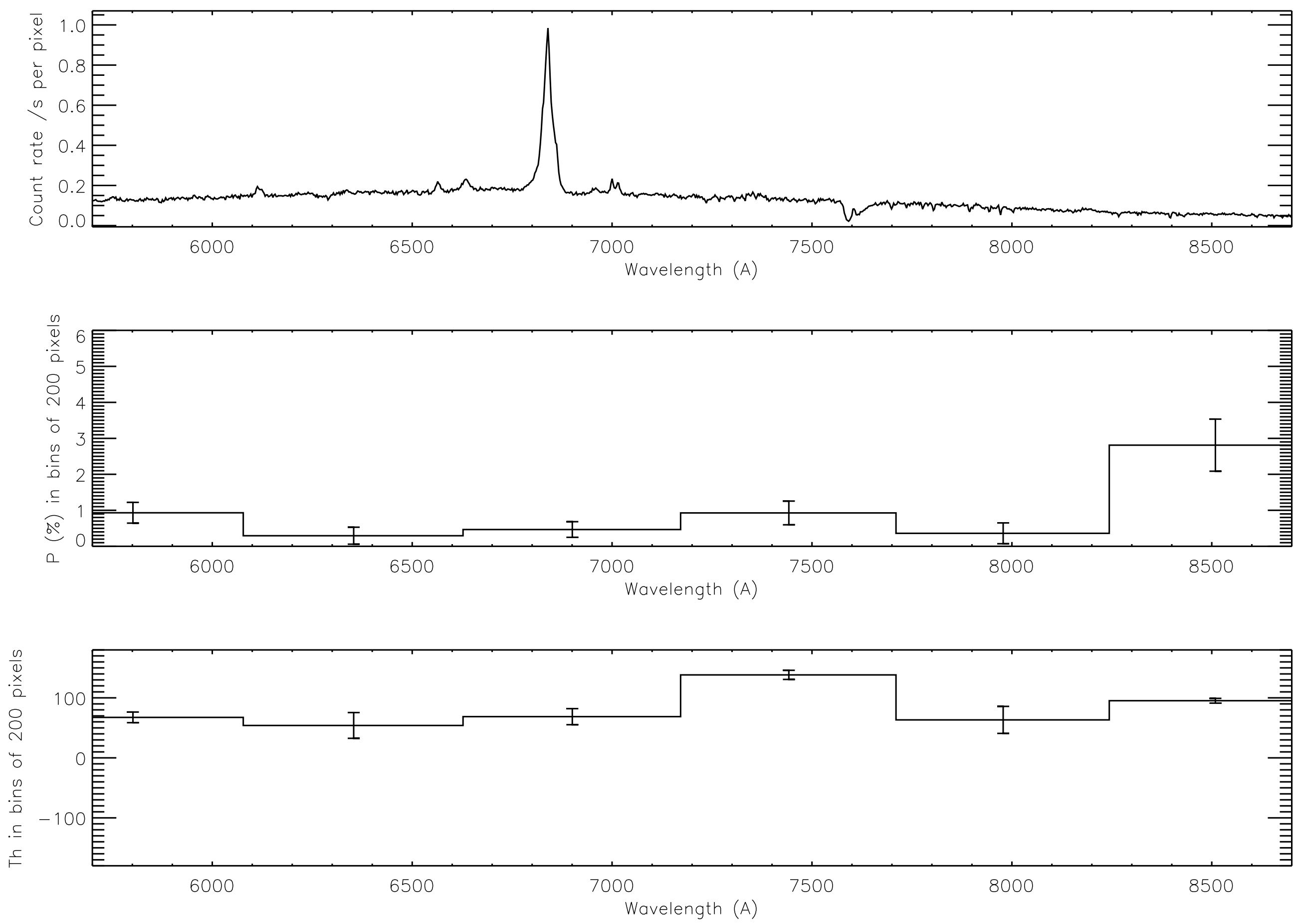


**Figure 2.** The red spectrum of RE J1034+396 with the measurements of P and $\theta$. $1\sigma$ error bars are shown for each point.

## 5 CONCLUSIONS

We have measured the linear polarization of RE J1034+396 and find an upper limit of 0.4 per cent. The lack of observed polarization suggests that directly viewed polarization emission mechanisms, such as synchrotron emission, are weak. However, even if there is some intrinsic polarization, due for example to dichroic absorption or reflection from dust or electrons, this polarization may not be detected for two reasons:

*(1)* Geometrical effects may mean that the polarization vectors cancel out, giving no net polarization along the line of sight. This would be the case if we were looking 'pole-on' at a circularly symmetric system, as expected from a type I object in the unified theory.

*(2)* Dilution of any weak source of polarization by a strong source of unpolarized light, would render the resultant vector too small to measure. This would be the case if, e.g., we had a direct view of an unpolarized nucleus.

Thus, we believe that there is probably no synchrotron emission beamed into the line of sight in RE J1034+396, very little dust in the line of sight, and any dust and electrons are symmetrically distributed around the nucleus relative to our line of sight.

## ACKNOWLEDGMENTS

We thank Keith Mason, Mark Cropper and Ian McHardy for some helpful suggestions.

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