Mem. S.A.It. Vol. 79, 1213

**Memorie** della

# AGN disks and winds: a new understanding from spectropolarimetry

D. J. Axon[1,2], A. Robinson[1,2], S. Young[1,2], J. E. Smith[2], and J. H. Hough[2]

[1] Department of Physics, Rochester Institute of Technology, Rochester, NY 14623, USA
[2] Centre for Astrophysics Research, Science & Technology Research Institute, University of Hertfordshire, Hatfield AL10 9AB, UK, e-mail: djasps@rit.edu

**Abstract.** Spectropolarimetry of the broad emission lines provides a direct means of probing the kinematics of the circumnuclear material within the unresolved central parsec of AGN. We describe two key results that have been obtained using this method which are direct evidence for a disk-like component to the broad line region of type 1 Seyfert galaxies and the observational confirmation of the existence of accretion disk winds in Broad Absorption Lines QSO.

**Key words.** Spectropolarimety – Active Galaxies: Broad Line Region– Active Galaxies: Broad Absorption Line Quasars–Active Galaxies: Accretion Disk Winds

## 1. Introduction

Spectropolarimetry played a pivotal role in one of the most important advances in our understanding of Active Galactic Nuclei in the last 20 years, the rise of the *Unification Scheme* (Antonucci 1993; Urry & Padovani 1995). The Basic Hypothesis being that Type 1 (S1) and Type 2 (S2) Seyfert nuclei are the same type of object seen at different orientations. In S2 our direct line-of-sight to the nuclear continuum source and broad-line region (BLR) is blocked by a circumnuclear torus of dusty molecular gas on the $\leq$ 100 pc scale (e.g.Antonucci (1993); Axon (2001) and references therein). However, the broad lines can be seen in the polarized flux spectrum of S2 due to scattering by material above the poles of the torus e.g., (Antonucci & Miller 1985; Gu & Huang 2000). Assuming that the radio source axis, the torus, and the scattering cone are coaligned, the scattered light will then always be polarized with its E-vector perpendicular to the axis of the radio source in both S1 and S2. However in S1, it is often, but not always, found that the position angle of polarization ($\theta$) is parallel to the radio axis rather than perpendicular (e.g., Antonucci (1983); Brindle et al. (1990); Goodrich & Miller (1994)). This implies that the simplest unification geometry, including only a single, polar scatteringmirroris incomplete and that the scattered light emerging from S1s follows a different path to that in S2s.

*Send offprint requests to*: D. J. Axon

## 2. The polarization properties of Seyfert type 1 galaxies

S1 as a class exhibit a much wider range of optical polarization properties than S2 (Smith et al. 2002). The optical polarization in

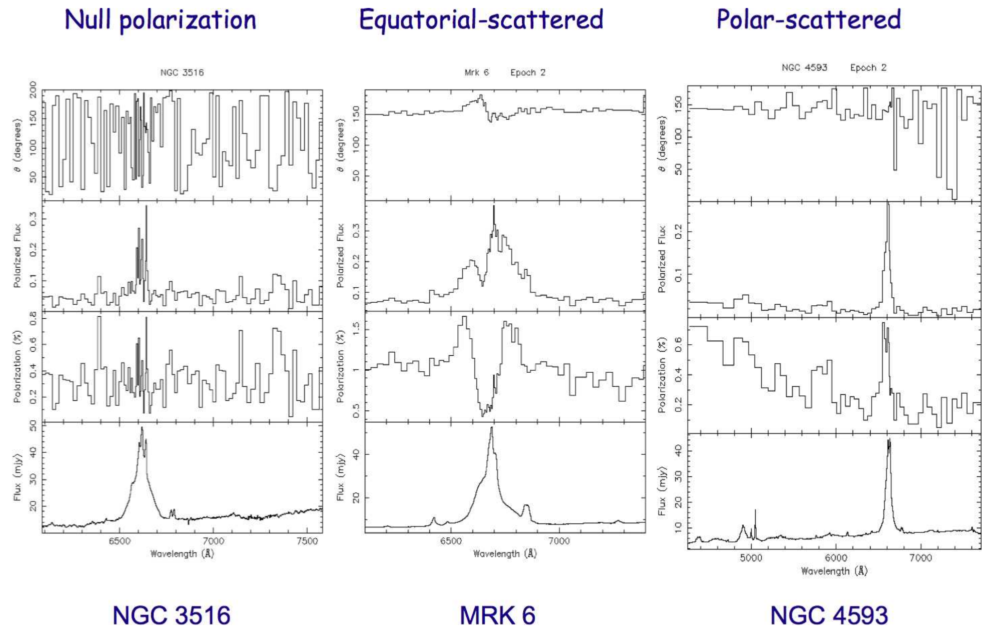


**Fig. 1.** The Three Seyfert 1 Polarization Classes (Smith et al. 2002). From Left to right: NGC 315 a Null Polarized object ; MrK 6: a galaxy in which equatorial scattering dominates the observed polarization and NGC 4593, an example of a Seyfert 1 galaxy in which polar scattering dominates the observed polarization. In each case the panel contains four plots which show from top to bottom, the position angle of polarization ($\theta$), the polarized flux density ($p \times F_\lambda$), the percentage polarization (p), and the total flux density ($F_\lambda$). The polarization data are binned to an error of 0.1%.

most S1 is dominated by scattering in a compact region that lies in the equatorial plane of the circumnuclear torus (and is thus obscured in S2). In addition to the equatorially scattered objects, about 20% of S1 exhibit null polarization while a significant minority ($5-5\%$) show characteristics of S2-like polar scattering (Fig. 1). The distinctive polarization characteristics of the first class of S1 take the form of variations of $\theta$ and p across the broad H$\alpha$ emission-line profile (Fig. 1). This observed polarization structure is naturally produced only if some of the line emission originates in a rotating disk and is scattered in a compact region, which itself must closely surround the disk so that it sees a spatially resolved BLR Smith et al. (2005). In general in total flux the lines do not exhibit double-peaked profiles. To account for this one requires in addition to the disk a second more spheroidal H$\alpha$-emitting component to the BLR region. If the system axis is close to pole-on ($\leq 20^o$) geometrical cancellation leads to a null polarization. As the inclination is increased the symmetry is broken, resulting in the observed S-shaped variation of $\theta$ across the BLR lines, until eventually at high inclinations the differing lines of sight of the scatters become increasingly degenerate, and no $\theta$ swing is seen. Occultation by the torus hides this latter group of S1 from our view.

Where do the S2-like polar scattered objects fit into this picture? The answer is that a polar scattering region is also present, and the combination of far-field polar plus near-field equatorial scattering can account for Seyfert polarization properties (Smith et al. 2004). Polar scattering can dominate if the line-of-sight to BLR & equatorial scattering suffers moderate extinction ($A_{\rm V} \sim 1-4$ mag.) attenuates the polarized flux from equatorial region enough that polar scattering dominates Smith et al. (2004). Physically, likely scenar-

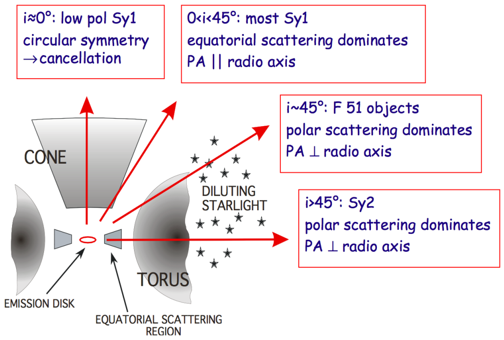


**Fig. 2.** Relation between polarization class and orientation in the generic scattering geometry that broadly explains the optical polarization spectra of Seyfert galaxies Smith et al. (2004)

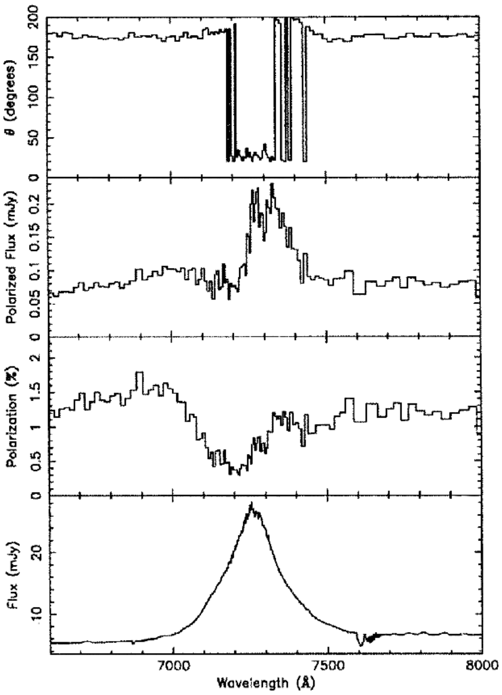


**Fig. 3.** The high velocity wind of 4C74.26 in polarized light Robinson et al. (1999). The layout and notation is the same as used in the individual panels of Fig.1. Notice that in polarized flux the Broad-line appears redshifted

ios are that our line of sight passes through the upper layers of the torus or perhaps through the body of a clumpy torus. Dilution by unpolarized starlight accounts for the polarization peaks across the broad-lines and the increase of p to blue (as in Sy2). Overall this leads to a refinement to the unified model in which the characteristics of Seyfert nuclei vary progressively with orientation Fig. 2. This revision accommodates much of the observed diversity in the optical polarization properties of Seyfert nuclei, including, for the first time, the S1. The inclination of the torus axis to the line-of-sight governs the form of the observed polarization. As inclination increases from pole-on to edge-on we first see null polarization S1; then equatorial scattering dominated S1 with $\theta$ aligned with the radio source axis; with a further increase in inclination we see polar-scattered S1 with $\theta$ perpendicular to the radio axis and finally, S2 like NGC 1068 exhibiting polarized broad-lines (due to polar-scattering).

## 3. Evidence for outflows in AGNs

A wide variety of spectroscopic evidence points to the existence of outflowing gas winds from AGN nuclei. Foremost amongst these are: the strong asymmetries of the high-excitation broad emission lines of CIV$\lambda$1550 e.g. (Espey et al. 1989; Richards et al. 2002) and their large blue-shifts with respect to the low ionization lines (e.g. H$\alpha$ and MgII $\lambda$2800): the widespread detection of blueshifted UV absorption lines (Crenshaw et al. 2003). In the case of Broad Absorption Line(BAL) QSOs for example, the broad absorption lines occur in the blue wings of resonance lines, such as CIV$\lambda$1550 and MgII $\lambda$2800, and can extend to blueshifts $\sim$ 0.1$c$, implying that they arise in high velocity outflows (e.g. Weymann et al. (1991)). If the scattering takes place in a medium outflowing from an emission line source then in broad terms one expects the scattered line to be redshifted, in what we will term a *Doppler ghost*. The broad-line radio galaxy 4C74.26 Robinson et al. (1999) is a good example (Fig. 3), of exactly such a redshifted ( $\sim$ 2000 km s$^{-1}$)Doppler ghost in polarized flux.. The H$\alpha$ polarization can be explained by polar scattering in a high-speed outflow which, if it is directed along the axis of

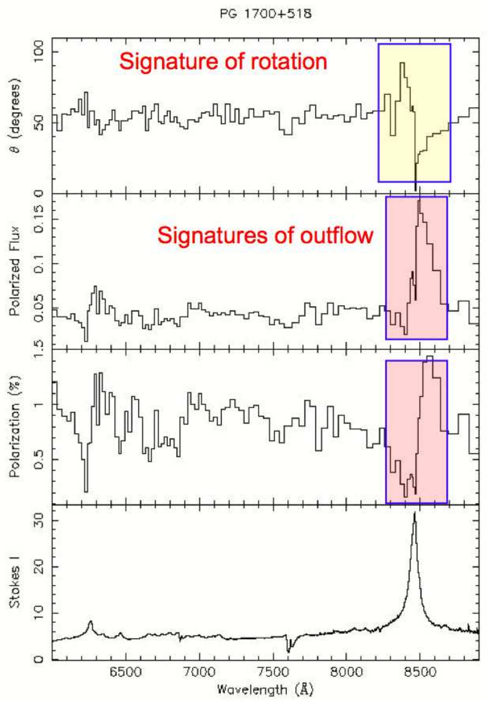


**Fig. 4.** Polarization spectrum of the low-z BALQSO PG 1700+518 (Young et al. 2007). The panels are as in Fig. 1. Note the large rotation in PA across the H$\alpha$ profile. The line profile is redshifted by $\sim$ 4000 km s$^{-1}$ in polarized flux.

the radio jet, must have a deprojected velocity $\sim$ 5000 km s$^{-1}$.

Many authors have argued that the winds are launched from the accretion disk (e.g. (Murray et al. 1995; Proga & Kallman 2004; Emmering et al. 1992). It has also been proposed that disk winds are responsible for part of the BLR emission itself (e.g. (Bottorff et al. 1997). Figure 4 shows the optical polarization spectrum of the low redshift BALQSO PG 1700+518 Young et al. (2007). The position angle of polarization exhibits behavior similar to that seen in S1 in which equatorial scattering dominates the polarization. While the scattered line profile in polarized flux, is also redshifted by $\sim$ 4000 km $s^{-1}$ relative to its total flux counterpart. Thus the polarization spectrum shows signatures of both *outflow* and *rotation* at speeds expected for gas orbiting a supermassive black hole. Crucially, the angle swing does not redshift with the scattered line. Together, these features require that the velocity field of the *scattering medium* itself includes both rotational and outflow components, as would be expected if it is an outflow from a rotating disk – a disk wind.

## 4. Conclusions

Spectropolarimetry provides us with a unique probe of the structure of the BLR and the kinematics of material inside the torus. The results we have described provided arguably the most compelling evidence yet that at least some of the broad-line emission originates in a rotating disc Fig. 1. Moreover, while scattering in the equatorial plane of the accretion disk evidently dominates in some S1, scattering in disk winds may be more important in higher luminosity sources. In the case of PG 1700+518 a key result has been the observational proof that disk winds do exist – they rotate!

## References

Antonucci, R., 1983, Nature, 303, 158.
Antonucci, R., 1993, ARA&A, 31, 473.
Antonucci, R., & Miller, J. 1985 ApJ, 297, 621.
Axon, D. J., 2001. ASP Conf Series 249.
Brindle, C., et al. 1990, MNRAS, 244, 577.
Bottorff, M., et al 1997, ApJ, 479, 200.
Crenshaw et al. 2003 ARA&A..41, 117.
Espey, B., et al ., 1989 ApJ, 342, 666.
Emmering, et al., 1992 ApJ, 385, 460.
Goodrich, R.. & Miller, J., 1994 ApJ, 434, 82.
Gu, Q. & Huang, J., 2002,ApJ579, 205.
Murray, N., et al., 1995, ApJ, 451, 498.
Proga, D., & Kallman, T. 2004 ApJ, 616, 688.
Richards, G., et al., 2002 AJ, 124, 1.
Robinson, A., et al., 1999 MNRAS, 305, 97.
Smith, J. E., et al., 2002 MNRAS, 335, 773.
Smith, J. E., et al., 2004 MNRAS, 350, 140.
Smith, J. E., et al 2005 MNRAS, 359, 846.
Urry, C. & Padovani, P., 1995 PASP, 107, 803.
Weymann, R., et al. 1991 ApJ, 373, 23.
Young, S., et al. 2007 Nature, 450, 74.