Optical polarization from AGN

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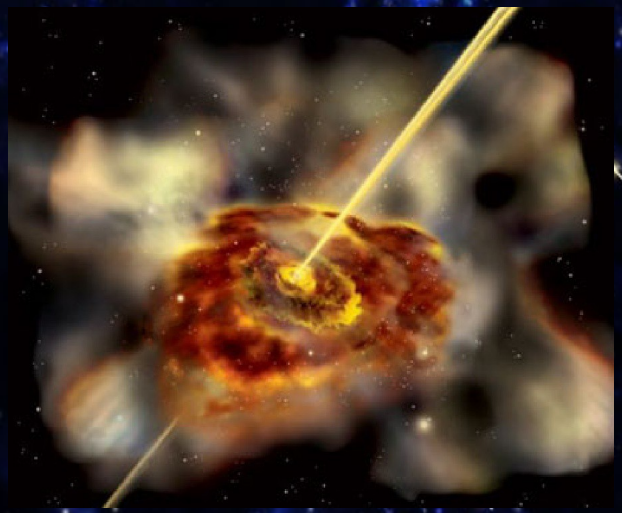

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Outline

Polarization properties of radio-quiet AGN including some low-polarization radio-loud objects (excluding blazars), with focus on the origin of the polarization

➔Seyfert 2

➔Seyfert 1

➔Quasars type 1

➔Quasars type 2

➔Broad Absorption Line QSOs

➔A coherent view of AGN polarization ?

➔Quasar polarization and large-scale structures

Outline

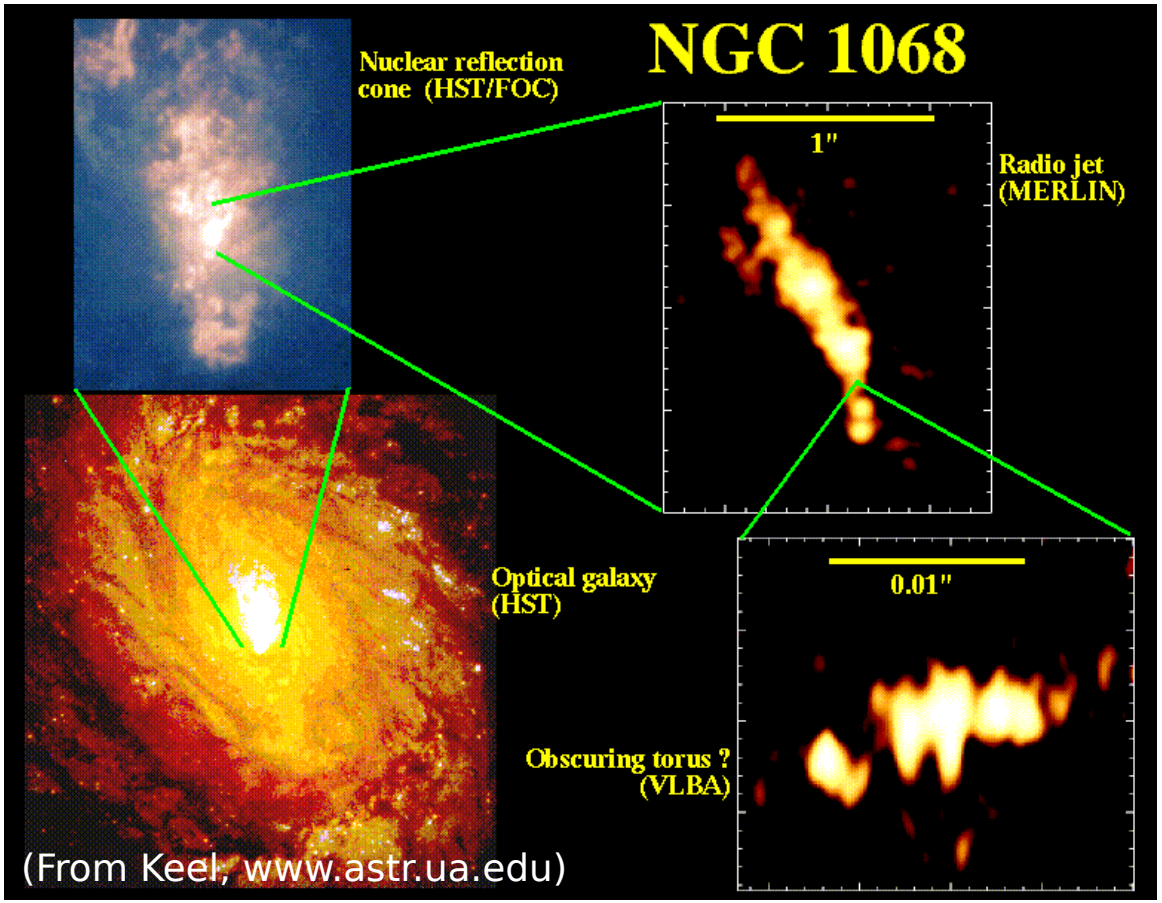
"*Never underestimate the pleasure we feel from hearing something we already know*."

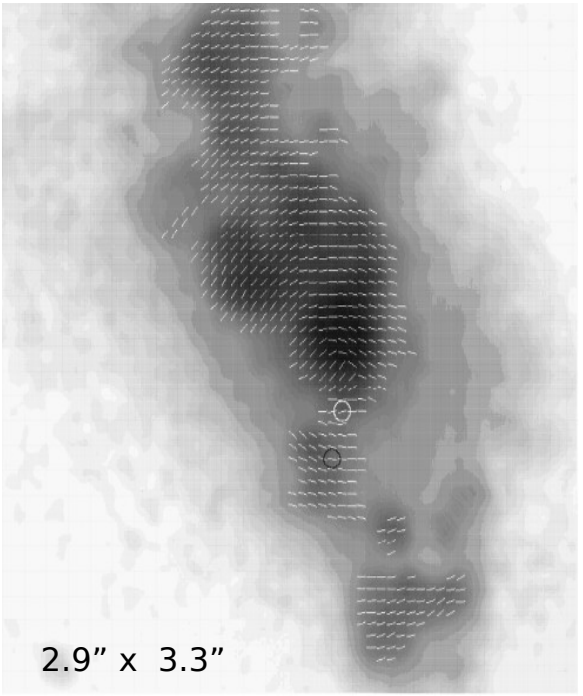
— Enrico Fermi (c.1935)

NGC 1068

- NGC 1068 : one of the nearest and brighest type 2 Seyfert galaxy (narrow-line Seyfert)
- Optical spectropolarimetry (Angel et al. 1976, Antonucci & Miller 1985):
  - p_{cont} ~ 16% wavelength independent but diluted by stellar light
  - broad Balmer lines typical of Seyfert 1 are observed and polarized as the continuum (in p and θ)
  - polarization angle θ perpendicular to the radio jet axis
  - narrow lines have low polarization (~1%) and different θ
- Lines and continuum polarization → not synchrotron but scattering in a region outside the BLR
- Wavelength-independent scattering over the X-ray / optical range → not dust but electron scattering
- Seyfert 2 = Seyfert 1 obscured by a dusty torus : unification models

NGC 1068





Centrosymmetric polarization due to dust scattering
(HST UV observations, Capetti et al. 1995)

Scattering of nuclear light occurs at different scales :
electrons inside the NLR and dust in external conical regions.
Electron and dust produce different line broadening (Miller et al. 1991)

Seyfert 2 galactic nuclei

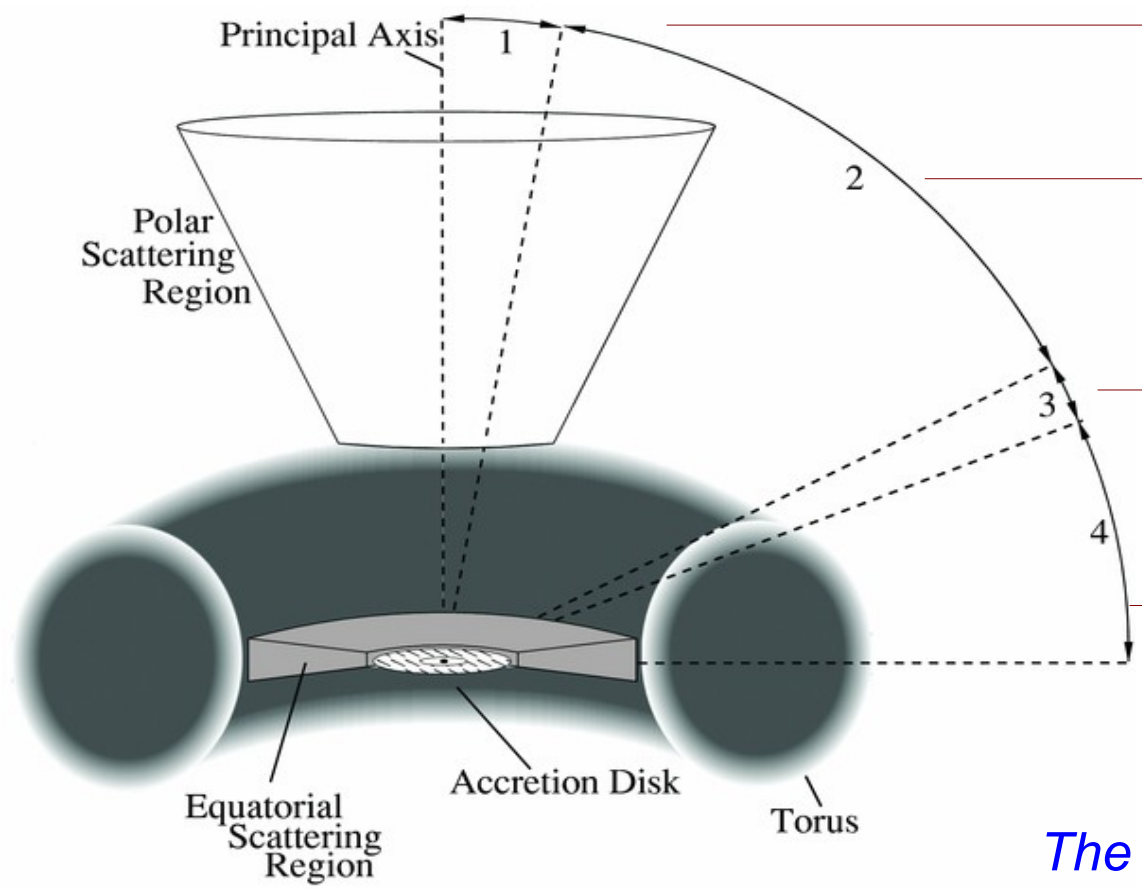
- Observations of other highly polarized Seyfert 2 confirm the scenario proposed for NGC 1068, revealing other hidden Seyfert 1 nuclei
- Electron scattering is likely the main polarization mechanism in the nucleus, although a firm conclusion requires proper disentangling of various contributions to the continuum light
- In most objects, the polarization is perpendicular to the radio axis and/or to the ionization cones
- However, most Seyfert 2 galaxies have little polarization and high polarization objects are rare → dilution by an additional continuum source is needed (partly unobscured continuum ? emission from the scattering region itself ? starburst)

(Martin et al. 1983, Miller & Goodrich 1990, Tran 1995, Heckman et al. 1995)

Seyfert 1 galactic nuclei

- Like Seyfert 2 galaxies, most Seyfert 1 have little polarization, some rare objects showing p ~ 5% (Martin et al. 1983, Goodrich & Miller 1994)
- Optical spectropolarimetry of Seyfert 1 nuclei reveals diversity (Goodrich & Miller 1994, Smith et al. 2002)
  - polarization is more often parallel to the radio axis / ionization cones but perpendicular polarization is also observed (~1/5)
    → equatorial and polar scattering regions are needed
  - broad line polarization shows structure in p and θ across the line profile
    → the BLR is resolved in velocity by the scattering region subject to two distinct scattering regions
  - diversity of wavelength dependence of p and line broadening
    → both electron and dust scattering contribute

Polarization in Seyfert galaxies : a unified view



S1 with null-polarization

S1 with polarization dominated by equatorial scattering

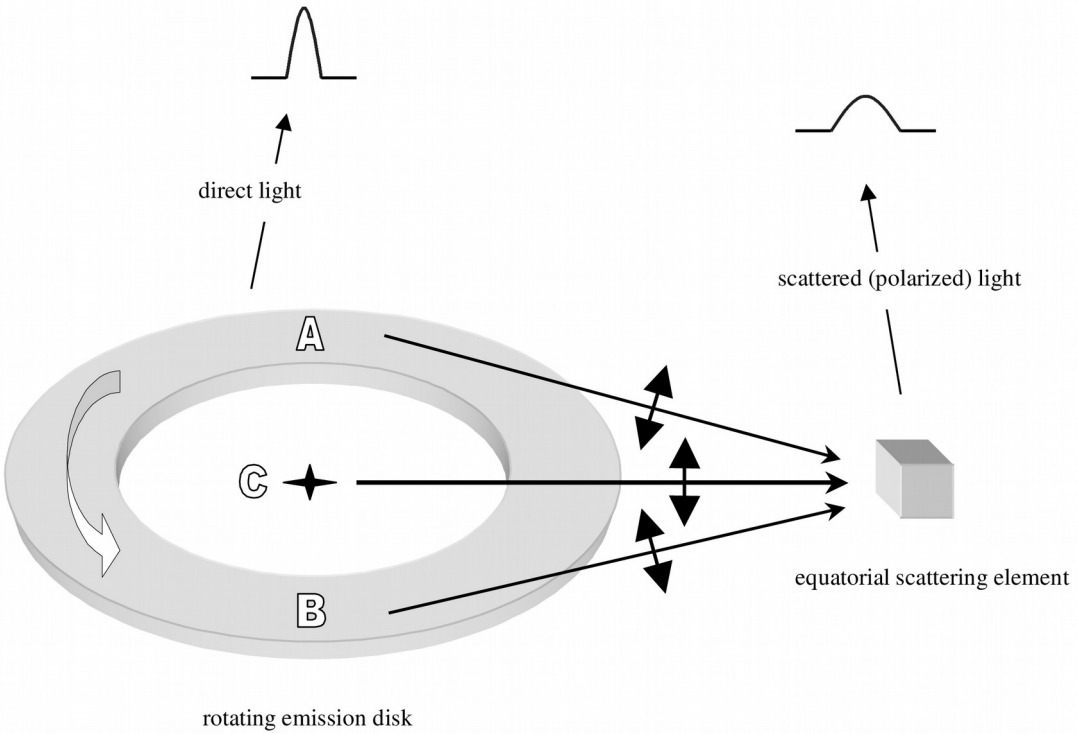
S1 with polarization dominated by polar scattering

S2 with polarization from polar scattering

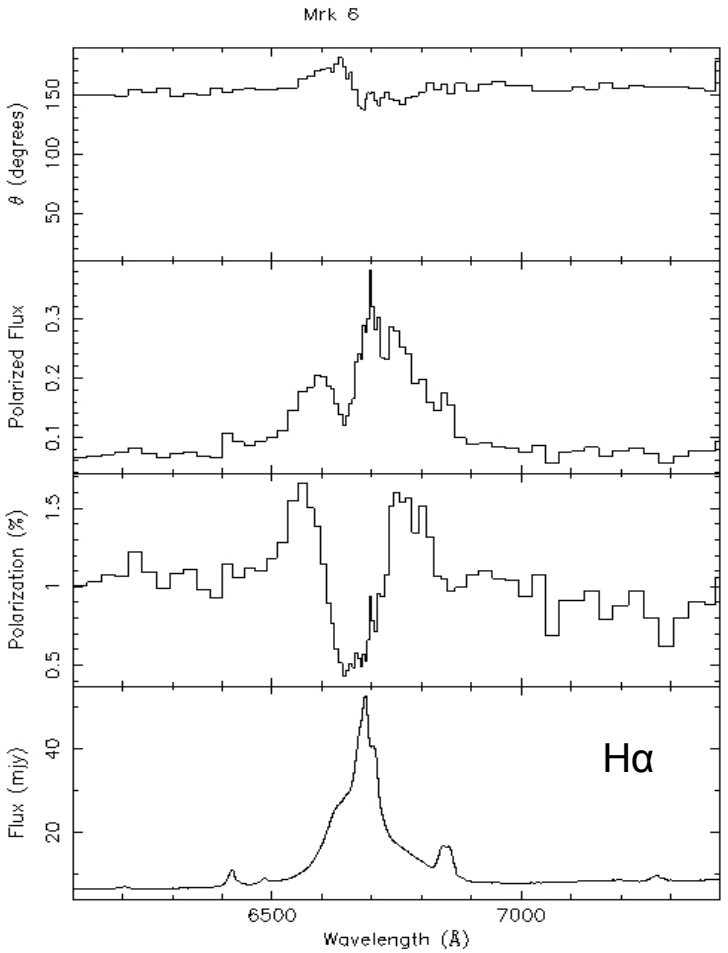
The relative importance of extended polar scattering and compact equatorial scattering is determined by inclination

(Smith et al. 2004, Batcheldor et al. 2011)

Polarization across the Hα line profile



(Smith et . 2002, 2005)



Polarization dilution in the core + rotation across the profile symmetric around the continuum PA. Additional polarization by the polar region can break the PA rotation symmetry if this region is outflowing.

State-of-the-art modeling vs data

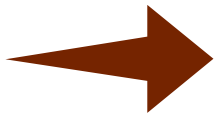
- Monte-carlo radiative transfer models allow to consider various geometries, scatterer species, and multiple scattering, further extending previous models (e.g., Goosmann & Gaskell 2007)
  - dust scattering off the torus is important for Seyfert 2 polarization in addition to the resolved electron/dust polar scattering, and negligible for Seyfert 1 orientations
  - the accretion disk itself cannot produce the Seyfert 1 polarization: an equatorial electron scattering region is definitely needed
- Time-dependent polarization modeling of NGC 4151 (Seyfert 1) explains the 8-day time lag between total and polarized flux by polarization from an electron-scattering disk, ruling out dust scattering in the torus (Gaskell et al. 2012)
- Confrontation of models with observations on a statistical basis is necessary (cf. Marin 2014). More observables and high quality measurements are needed

Radio-quiet quasars : type 1

- High-redshift objects :
  - rest-frame ultraviolet continuum and high-ionization lines
  - barely resolved host galaxies
- Broad-band polarization surveys found p_{mean} ~ 0.6%, a small minority (~ 1/100) showing p > 3% (Stockman et al. 1984, Berriman et al. 1990)
- As for radio-loud quasars (Stockman et al. 1979, Rusk and Seaquist 1985), the optical polarization PA of radio-quiet objects is also apparently aligned with the radio structure suggesting equatorial scattering (Berriman et al. 1990)
- Spectropolarimetry of 2MASS QSOs reveals unpolarized narrow lines and polarized broad Balmer lines with sometimes structure in p and θ (Smith et al. 2003), while some low-polarization *radio-loud* type 1 quasars show polarization only in the continuum, the broad lines being essentially unpolarized (Kishimoto et al. 2004). This suggests that the scattering region can be located outside or inside the BLR

Radio-quiet quasars : type 2

- About 150 type 2 quasars in the redshift range $0.3 < z < 0.8$ were found in the SDSS by selecting narrow-line AGN with high [OIII] luminosities (out of ~10^5 objects) (Zakamska et al. 2003)
- Spectropolarimetry reveals (Zakamska et al. 2005)
  - high polarization often > 3% and up to 17%
  - type 1 broad lines are detected in the polarized flux

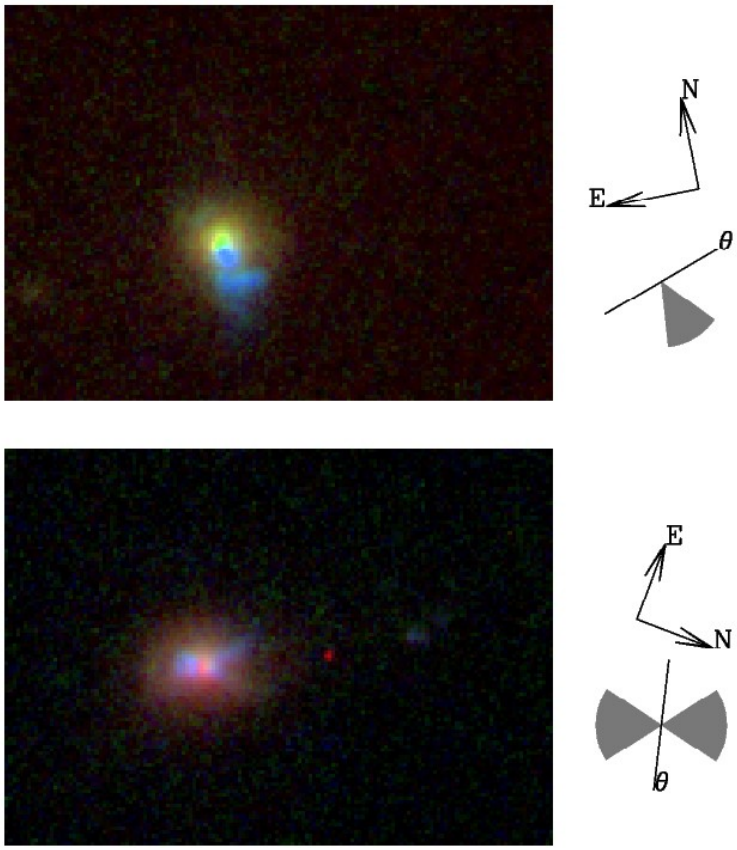


Support the extension of the type 1 / type 2 unification by orientation model to at least some high-luminosity AGN

Polarization angles : a type 1 / type 2 dichotomy

- The polarization of type 2 quasars is perpendicular to the extended UV continuum (Zakamska et al. 2005)
- After image deconvolution, the polarization of type 1 quasars appears mostly parallel to the extended UV continuum (Borguet et al. 2008)

The two-component polar + equatorial scattering may also prevail in high luminosity AGN

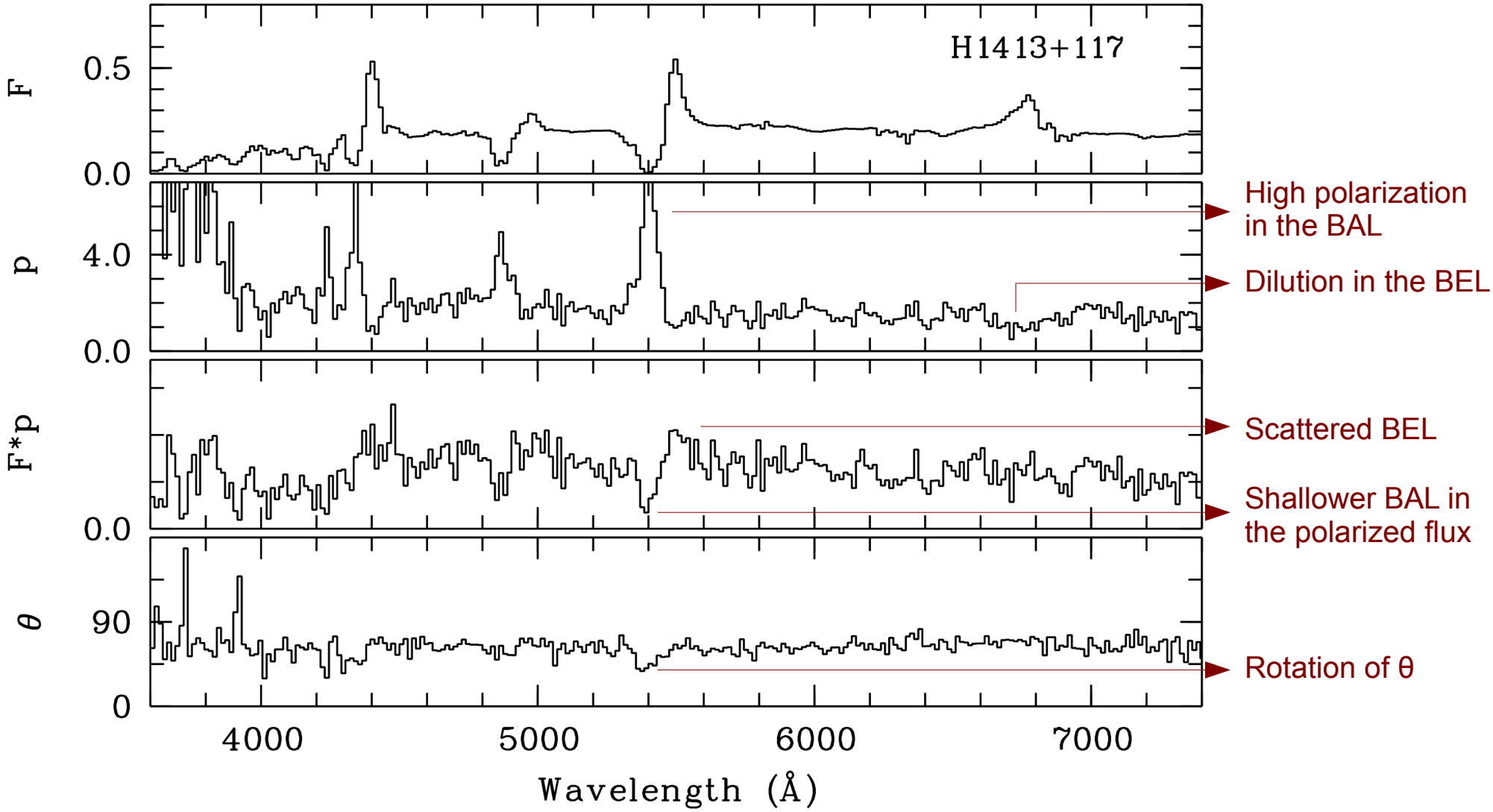


Three-band HST color-composite images of type 2 quasars. The irregularly shaped blue spot is identified as a one-sided scattering region (top) or as a fairly symmetric bi-conical region (bottom).
(From Zakamska et al. 2005)

Broad Absorption Line Quasars

- Broad absorption lines are present in ~20% of high redshift ($z > 1.5$) radio-quiet quasars. BALs are blue-shifted wrt the emission lines, sometimes detached, revealing ionized outflowing material
- Since non-BAL and BAL QSOs have similar emission-line properties, a BAL region may be present in all radio-quiet quasars, BALs being only observed from nearly equatorial views (between type 1 and type 2 views) (Weymann et al. 1991)
- BAL QSOs are essentially radio-quiet but a significant number of radio-loud objects does exist (1/10) (Shankar et al. 2008)
- BAL QSOs as a class are more polarized than non-BAL QSOs (p ~1-2% vs 0.6%) (Moore & Stockman 1984, Hutsemékers et al. 1998)

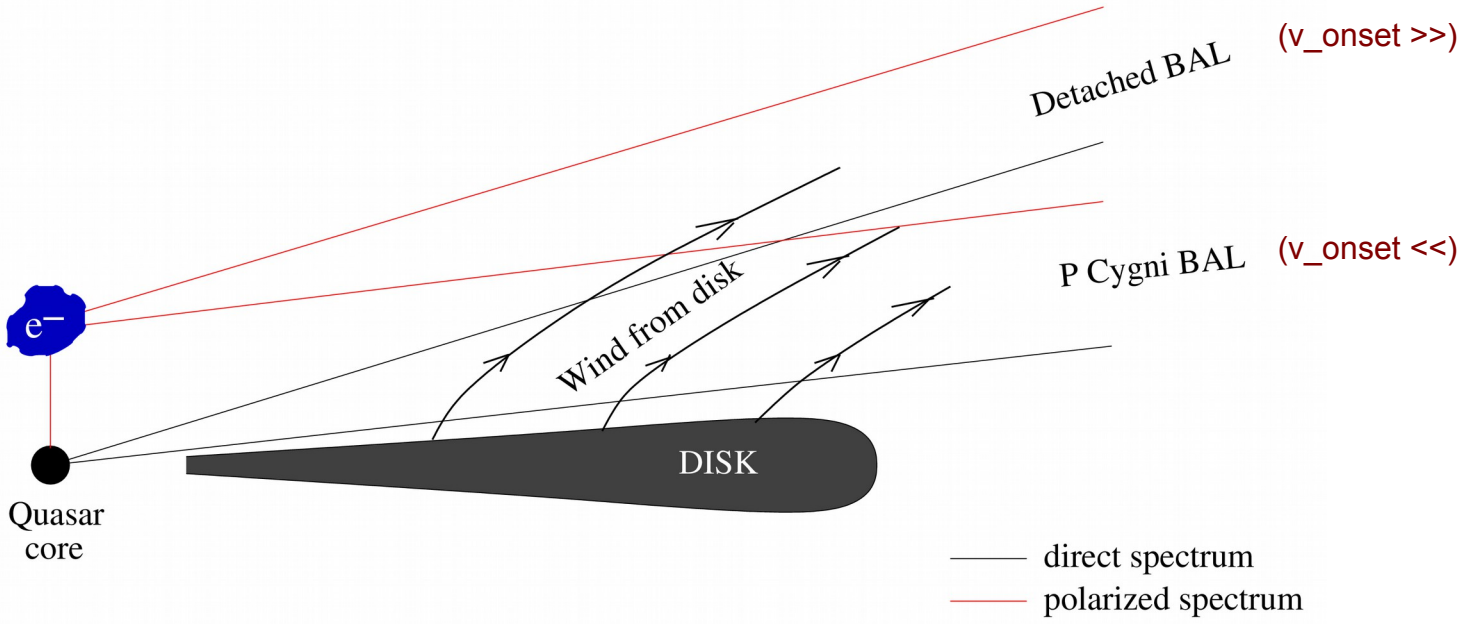
Spectropolarimetry of BAL QSOs



(e.g. Goodrich & Miller 1995, Ogle et al. 1999, Lamy & Hutsemékers 2004, DiPompeo et al. 2013)

Polarization in BAL QSOs

- BELs are usually less polarized than the continuum → the scattering region is (only slightly?) outside the BLR
- The BAL is shallower in the polarized flux → the scattered light passes through the BALR and is less absorbed than the direct light
- Statistical analyses of various observables reveal a correlation between polarization and the BAL onset velocity
  (Lamy & Hutsemékers 2004, DiPompeo et al. 2013)



A two-component BAL wind model?

- Rotation of the polarization in the lines → more than one scattering regions or resonance scattering
- Radio observations of radio-loud BAL QSOs suggests that BAL flows are seen at various inclinations wrt the line of sight and various orientations wrt the jet axis (Zhou et al. 2006, DiPompeo et al. 2013, Bruni et al. 2013) → equatorial and polar outflows do exist (BAL / non-BAL unification by orientation models are incomplete)
- Microlensing suggests the simultaneous presence of two orthogonal scattering regions, a compact one and an extended one

→ A two-component polar + equatorial wind can explain most observations. Continuum polarization can be due to electron scattering in the BEL / BAL wind (Wang et al. 2005, 2007)

A coherent view of polarization from radio-quiet AGN ?

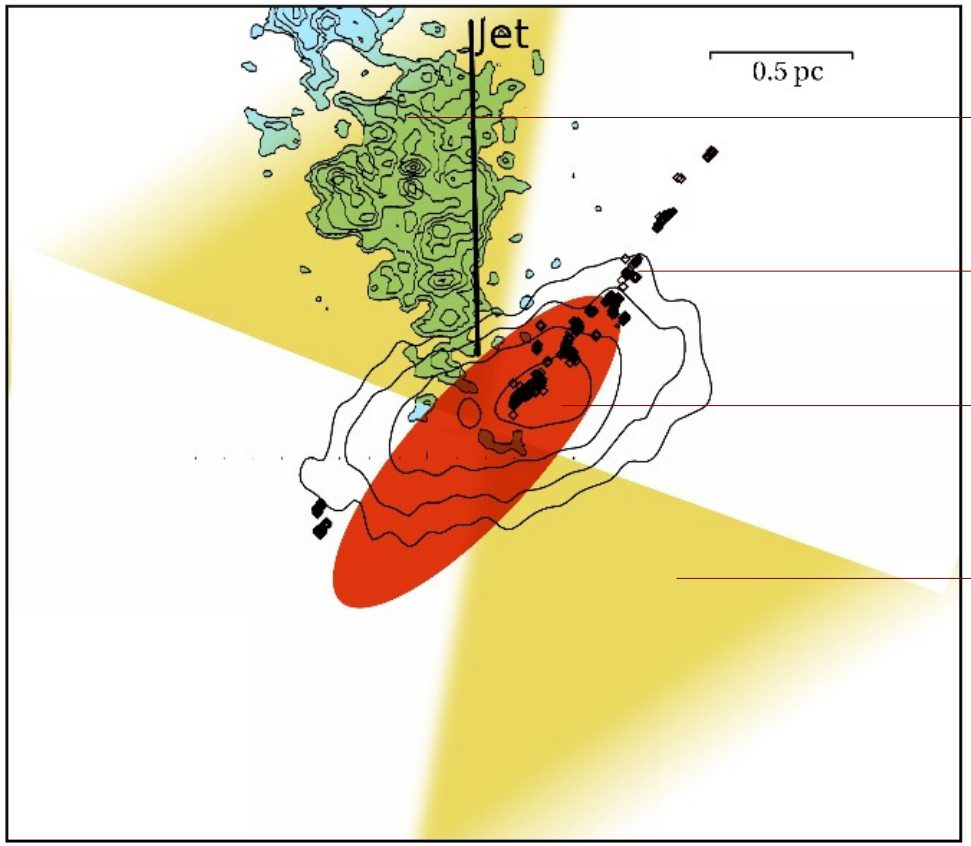
Most observations seem to require two orthogonal scattering regions related to the radio jet / accretion disk axis. In the frame-work of the unification models their relative importance is driven by inclination. The model established for low-luminosity AGN apparently extends to (at least some) higher luminosity quasars

Scattering from compact regions inside the torus requires electrons. The nature / origin of these regions is unknown. In BAL QSOs they could be related to the wind

- What is the nature of the scattering regions ?
- Are all scattering regions simultaneously present in AGN ?
- Polarization in type 2 AGN: mostly due to scattering off the torus ?
- Equatorial scattering region can be inside the BLR for Q1 not for S1 ?
- Do polarization properties evolve with time (redshift) ?

→ *Statistical studies needed*

Infrared interferometry of NGC 1068



[OIII] image

Maser disk

Compact dust emission

Ionization cones (velocity mapping)

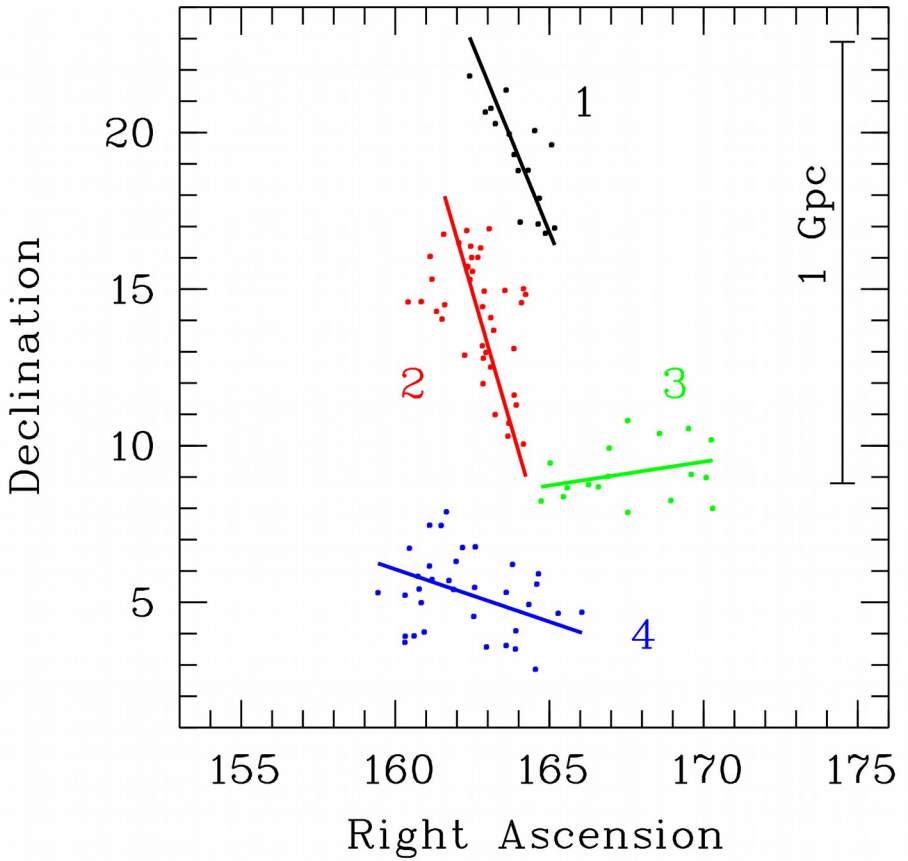
(From Raban et al. 2009)

Individual objects can significantly differ from the simplified global view

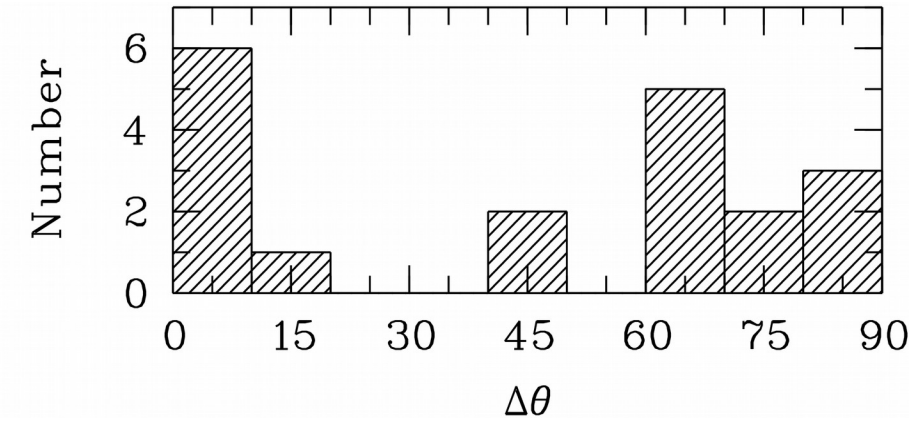
Tracing large-scale structures with quasar polarization

- Models of co-evolution of galaxies with the large-scale structures in which they are embedded predict alignments or anti-alignments of galaxy axes with filaments depending on halo mass, redshift and feedback (e.g., Dubois et al. 2014)
- Observations show that galaxy spin axes align with large-scale structures such as cosmic filaments (e.g., Tempel & Libeskind 2013; Zhang et al. 2013). Till now, such alignments are detected up to redshift $z \sim 0.6$ at scales < 100 Mpc
- Since quasar polarization is related to the accretion disk axis it allows us to test these models at moderate to high redshifts
- We have measured the polarization of quasars belonging to large quasar groups at redhsift $z \sim 1.3$ (Clowes et al. 2013).

Quasar polarization and large-scale structures



The large quasar groups and their orientations. In these groups 19 quasars were found to be significantly polarized (p > 0.6%)



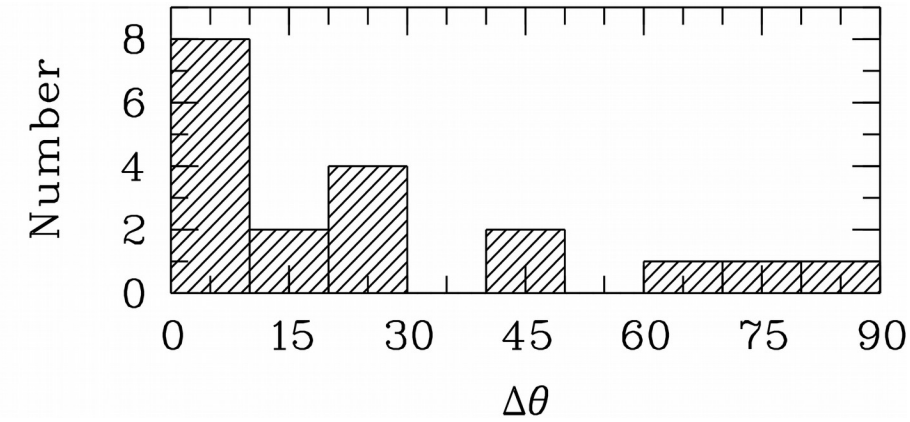
The distribution of the acute angle Δθ between quasar polarizations and the orientation of their host large-scale structure. The bimodal distribution shows that quasar polarization vectors are either parallel or perpendicular to the large-scale structures to which they belong

(From Hutsemékers et al. 2014)

Quasar polarization and large-scale structures

Since polarization is either parallel or perpendicular to the quasar axis depending on inclination

And since quasars seen at high inclinations usually show broader emission lines



Distribution of the angle Δθ after rotating by 90º the polarization angles of objects with very large MgII emission line widths

Polarization of quasars in large groups at z ~ 1.5 apparently shows alignments with the structures in which they are embedded

This kind of observations can constrain models of the co-evolution of AGN, galaxies and large-scale structures

Final conclusions

Although the "standard model" seems successful, AGN polarization still deserves much observations to be fully understood (a dedicated telescope ?)

Polarization is a great tool to probe the physics of AGN as well as their relation to the cosmic evolution