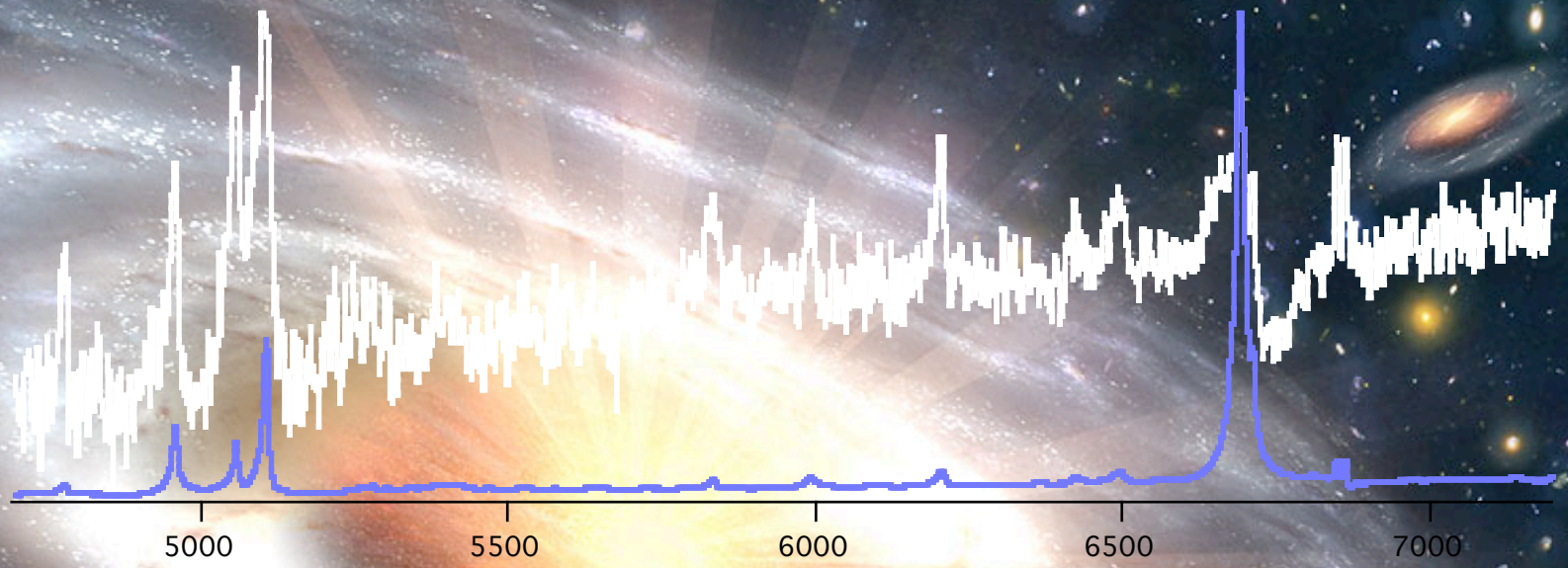
Probing gas flows around supermassive black holes with Spectropolarimetry



Andy Robinson (RIT/Univ Hertfordshire
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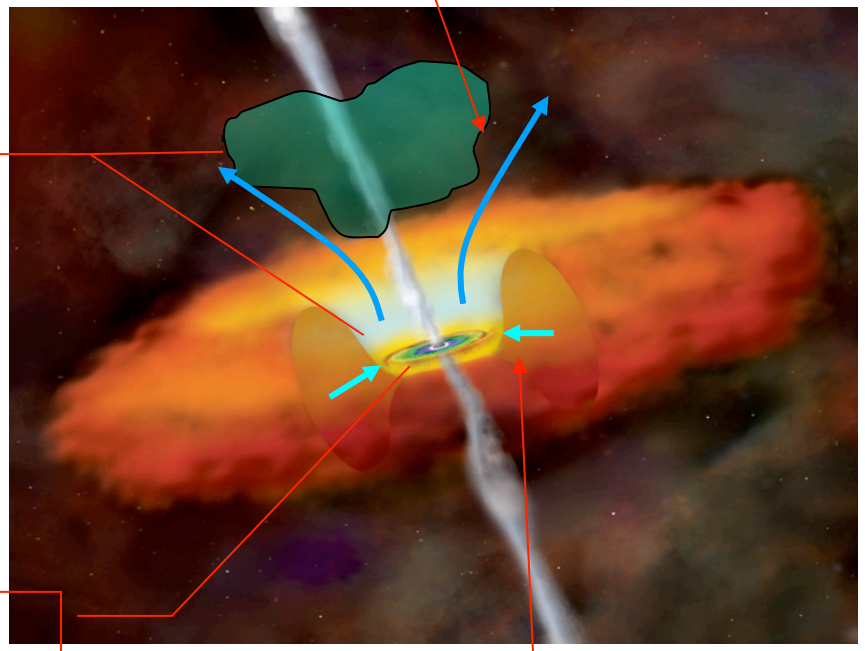
Goals: new insights into the structure of AGN

- Geometry and kinematics of source + scattering regions are imprinted on the polarization spectrum

Are there gas outflows from the disk, or torus?

Establish general structure of the scattering regions, inside and outside torus



What is the structure of the broad emission line region? Is it part of the accretion disk?

Map accretion flows on sub-torus (sub-pc) scales?

R·I·T

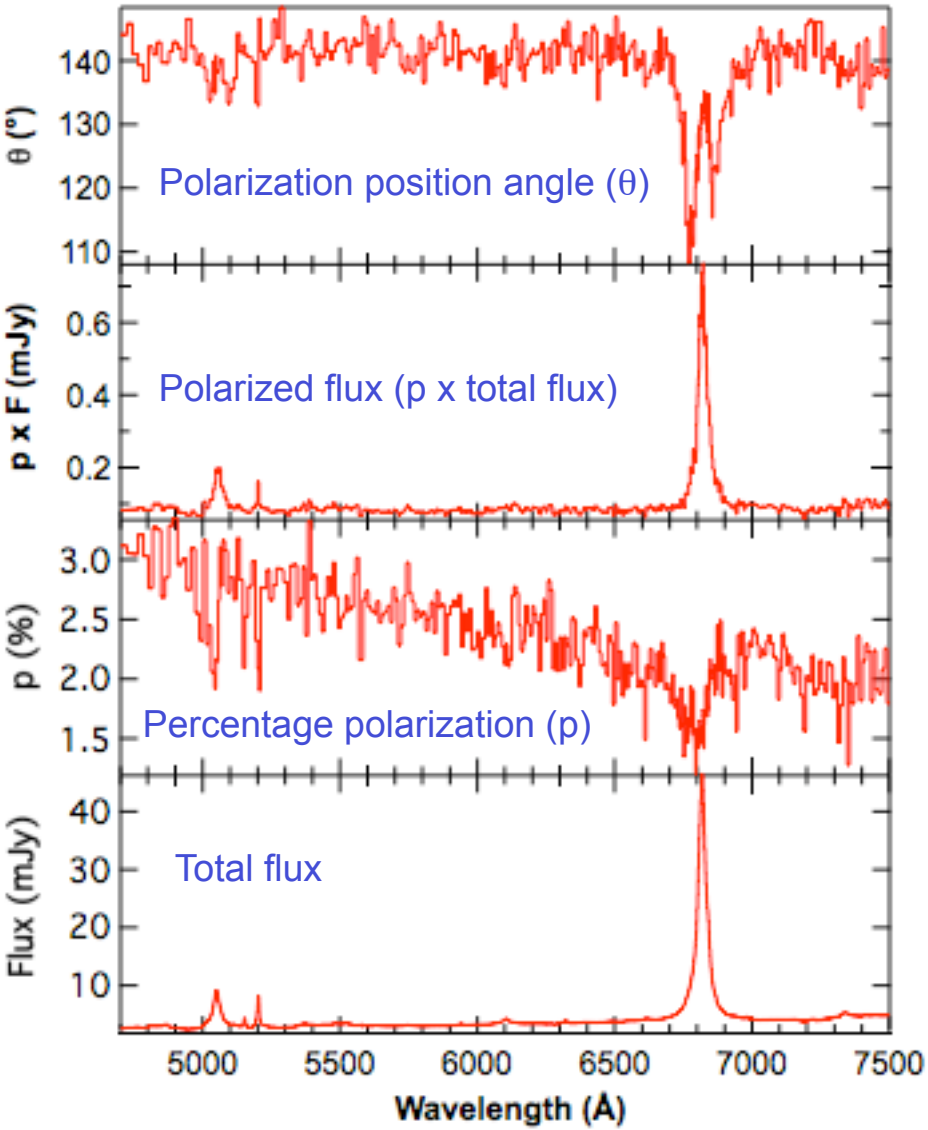
Outline

- A refined AGN scattering geometry
- Evidence for sub-pc accretion flows
  - Mrk509; NGC4151
- Evidence for high velocity outflows
  - Rotating outflow – PG1700+583
- The nature of Narrow Line Seyfert 1's
  - No preferred orientation
- Gravitational recoil observed in scattered light?
  - E1821+643

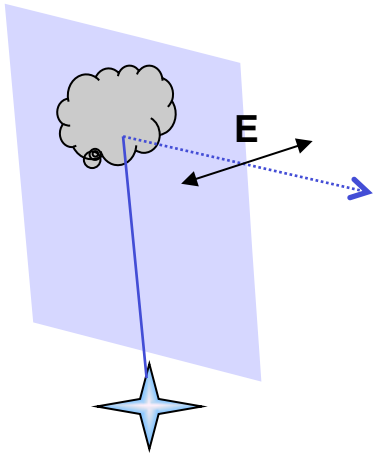
Spectropolarimetry of broad-line AGN

- Optical spectropolarimetry of ≈90 BL AGN to date
- Mostly z < 0.3
- Mostly radio quiet
- Seyfert types 1 → 1.9; NLS1
- Weak Seyferts to luminous QSOs
  - ~4 orders of magnitude in luminosity

Interstellar polarization (dichroic absorption by aligned dust grains) arising in our ISM or host galaxy dominates in many objects…
But here we are concerned only with polarization by scattering



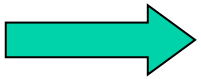
Seyfert scattering geometries



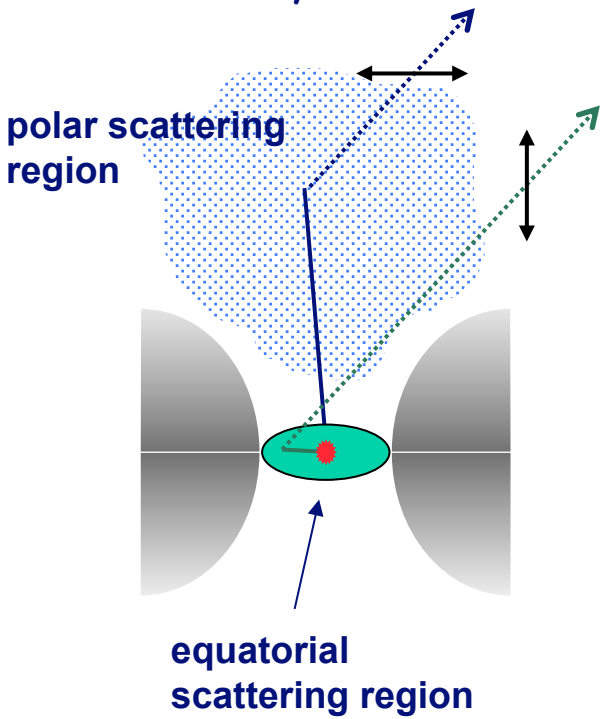
- The E-vector is perpendicular to scattering plane
  - an important clue to the scattering geometry
- For polar scattering, expect polarization PA to be perpendicular to system axis (traced by radio jet, sometimes…)
  - Usually the case in polarized BL Sy2's

- But Sy1's tend to have pol PA parallel to radio axis ⇒ scattering in equatorial plane of torus

Smith et al. 2002
Brindle et al. 1990
Antonnuci 1983



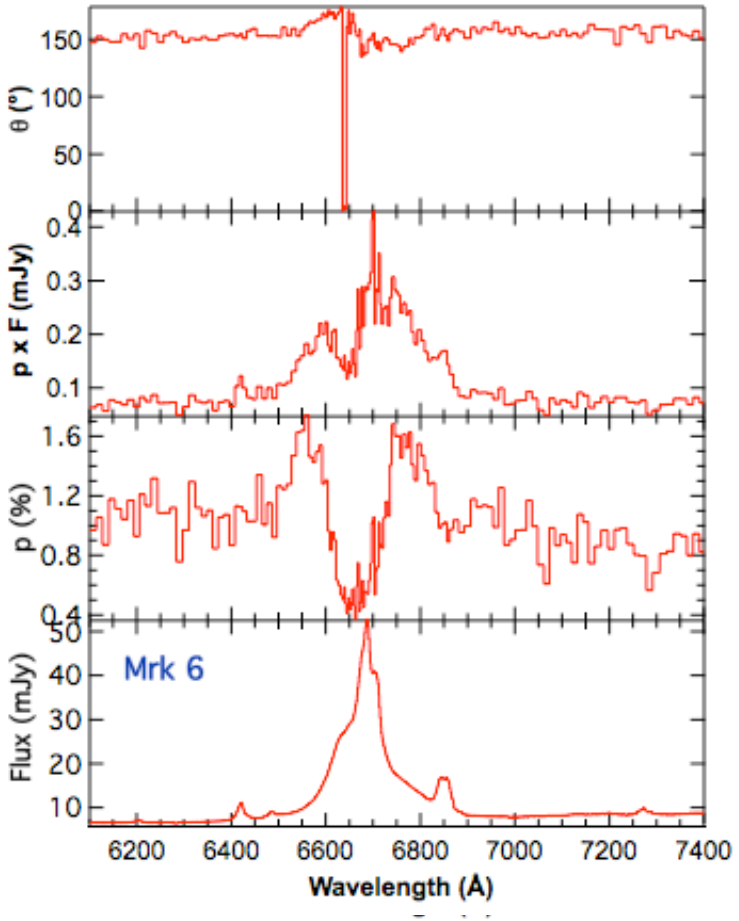
Two scattering routes: compact equatorial scattering region also present



Seyfert 1 polarization properties

Three broad categories

- Null polarization
  - p < 0.3% (detection limit)
- Equatorial scattering
  - p ~ 0.5–1 %
  - Distinctive variations in p, θ across broad Hα line
- Polar scattering (~30% of S1)
  - p ~1–5%
  - Exhibit "Seyfert 2-like" polarization spectra



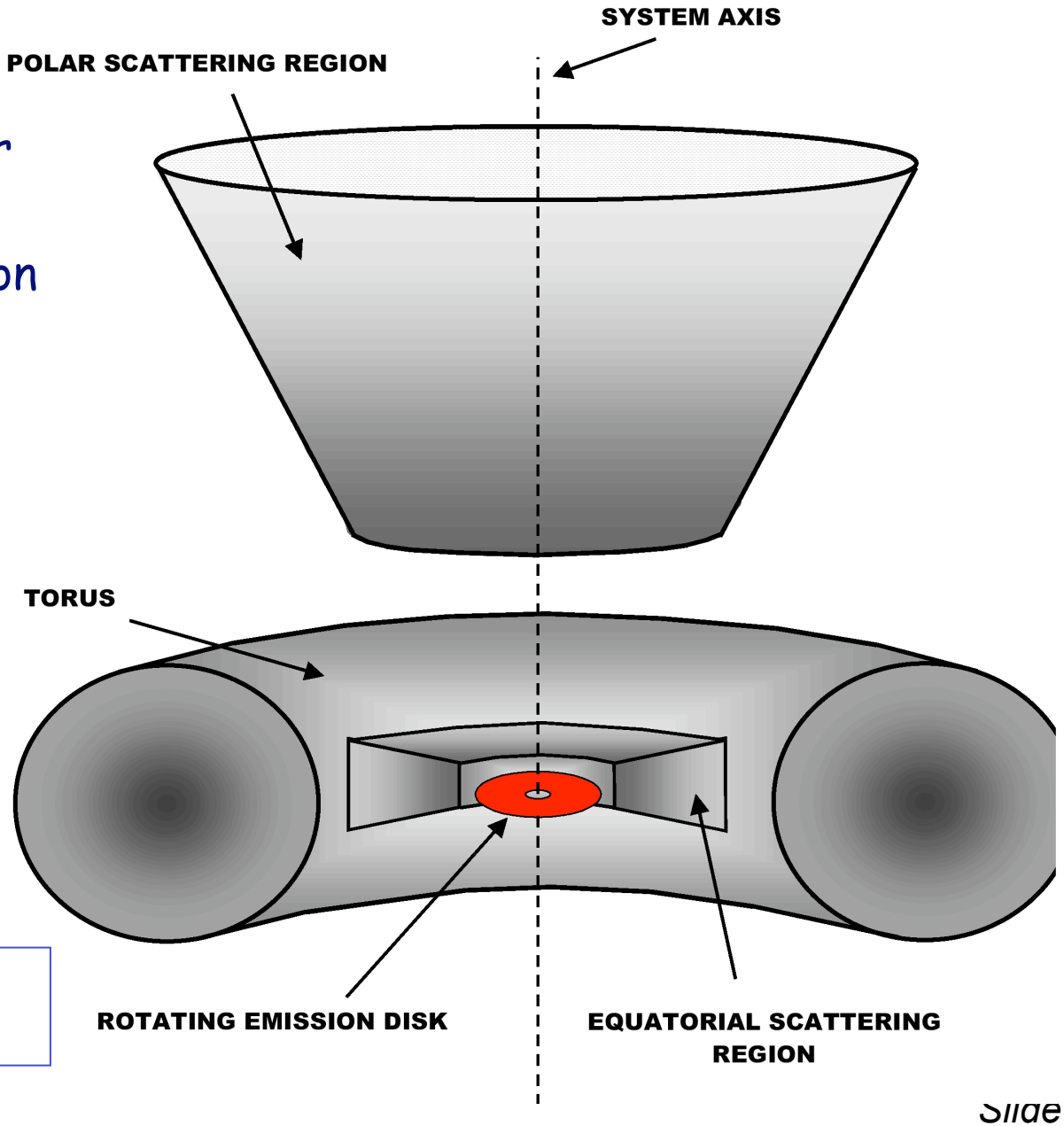
Smith et al. 2002; 2004; 2005 & refs therein

Generic scattering model for Seyferts

All Seyferts (non-Blazar AGN?) contain

- Polar scattering region (outside torus)
- Compact equatorial scattering region (within torus)

observed polarization properties determined by orientation



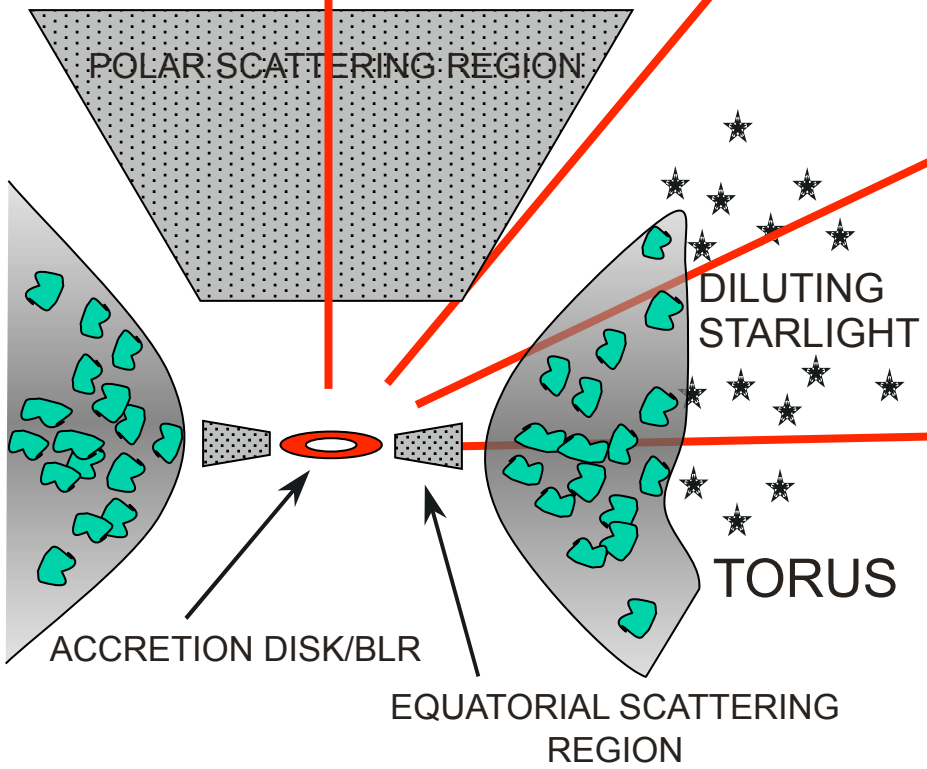
Young 2000, MNRAS 312, 567

Smith et al 2005, MNRAS, 359, 846

Unification of Seyfert Polarization Properties

i≈0°: null pol Sy1
circular symmetry
→ cancellation

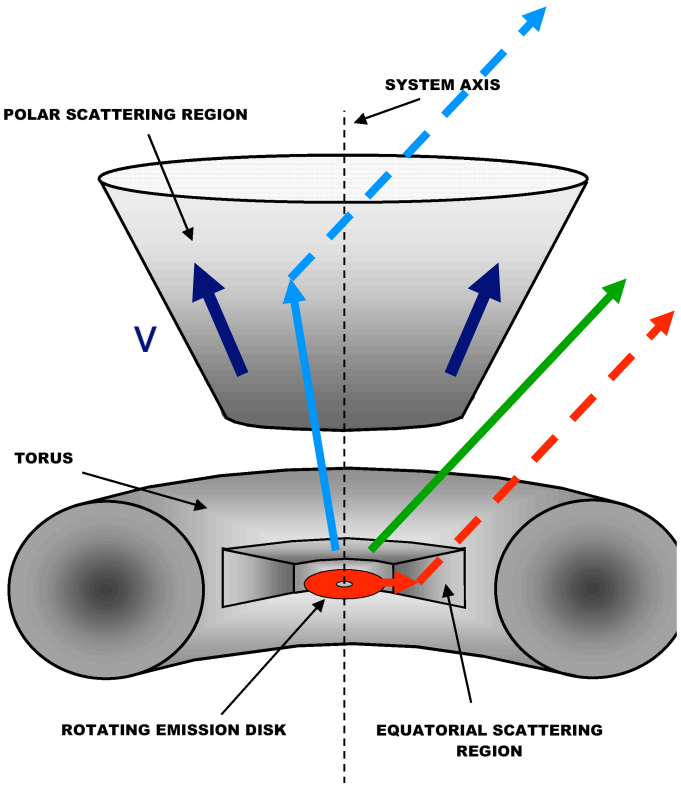
0<i<45°: most Sy1
equatorial scattering dominates
PA || radio axis



i~45°: 30% of Sy 1
polar scattering dominates
PA ⊥ radio axis; direct l-o-s subject to A_V~1

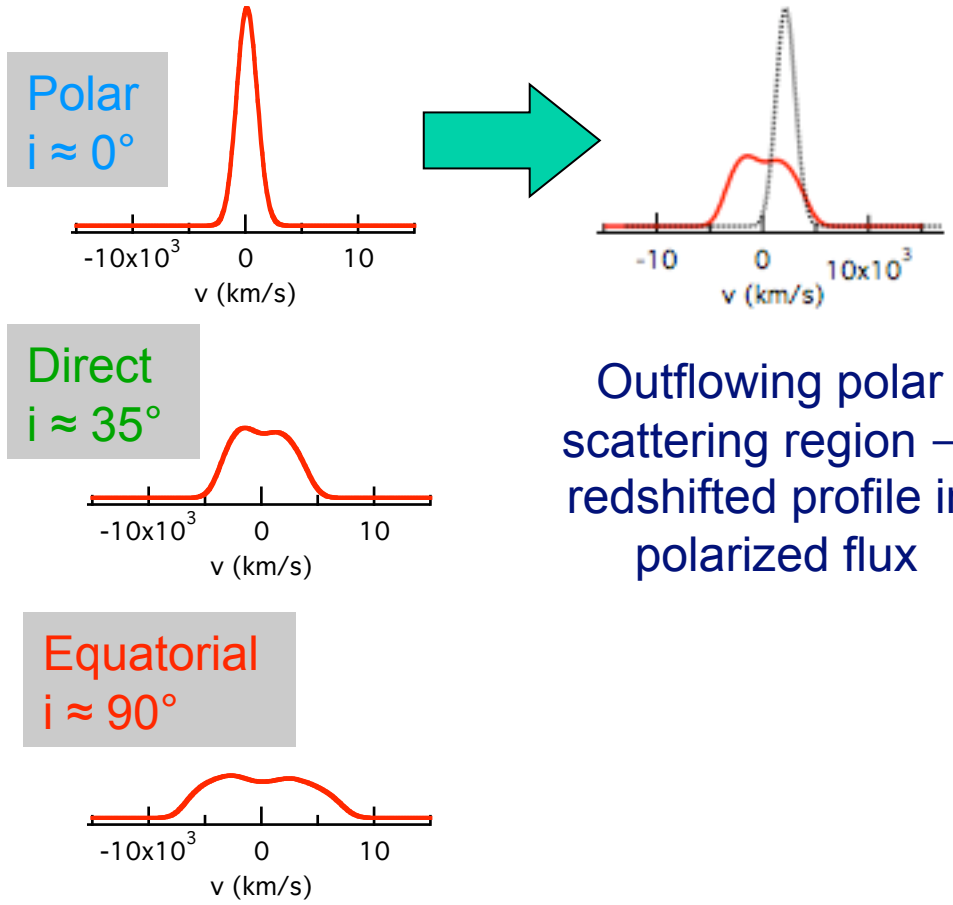
i>45°: Sy2
polar scattering dominates
PA ⊥ radio axis

What can we learn from spectropolarimetry?



Two-component (equatorial + polar) scattering geometry

Disk line profiles at different inclinations

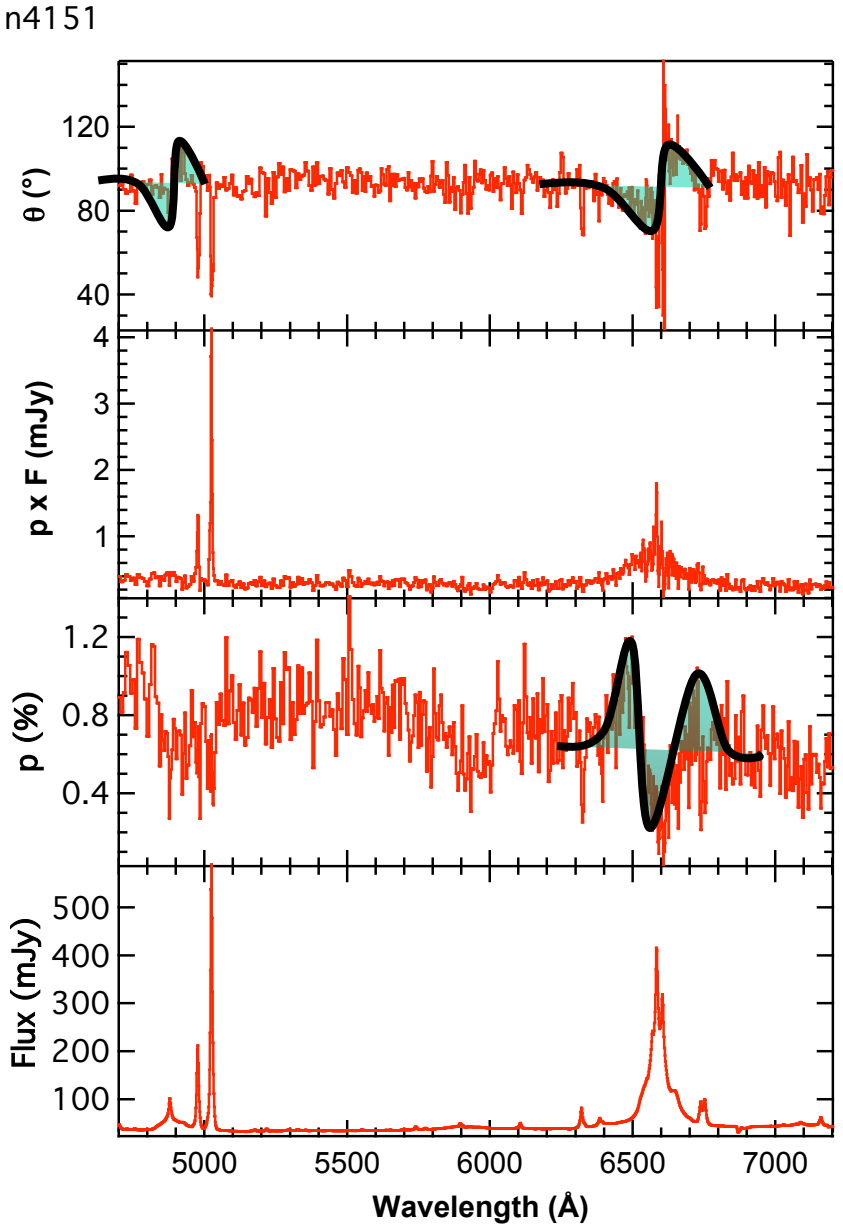


Outflowing polar scattering region → redshifted profile in polarized flux

Signatures of equatorial scattering + rotation

Double PA rotation across broad Hα, Hβ

Peak-trough-peak variation in p



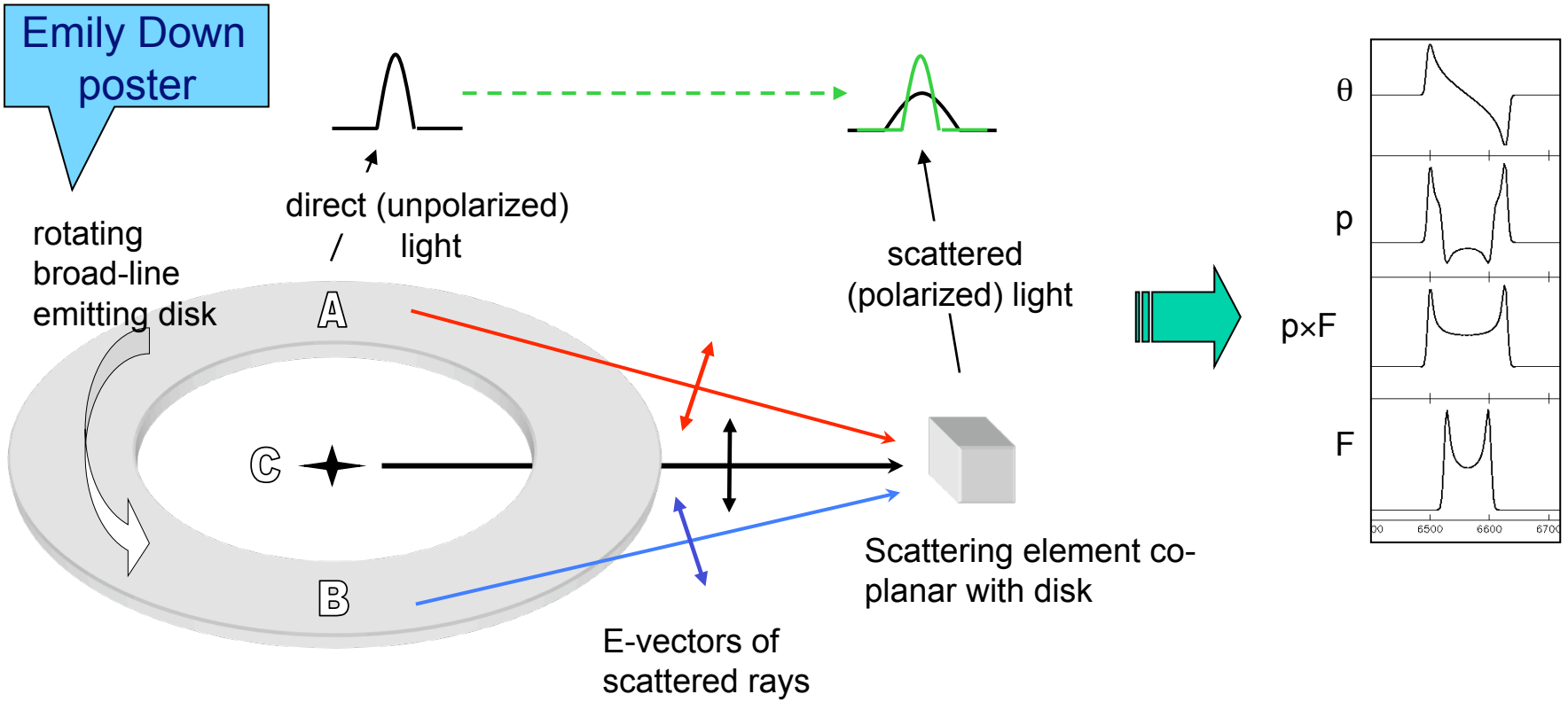
NGC4151

Young et al 2010, in prep

Emission Disk with near-field Equatorial Scattering

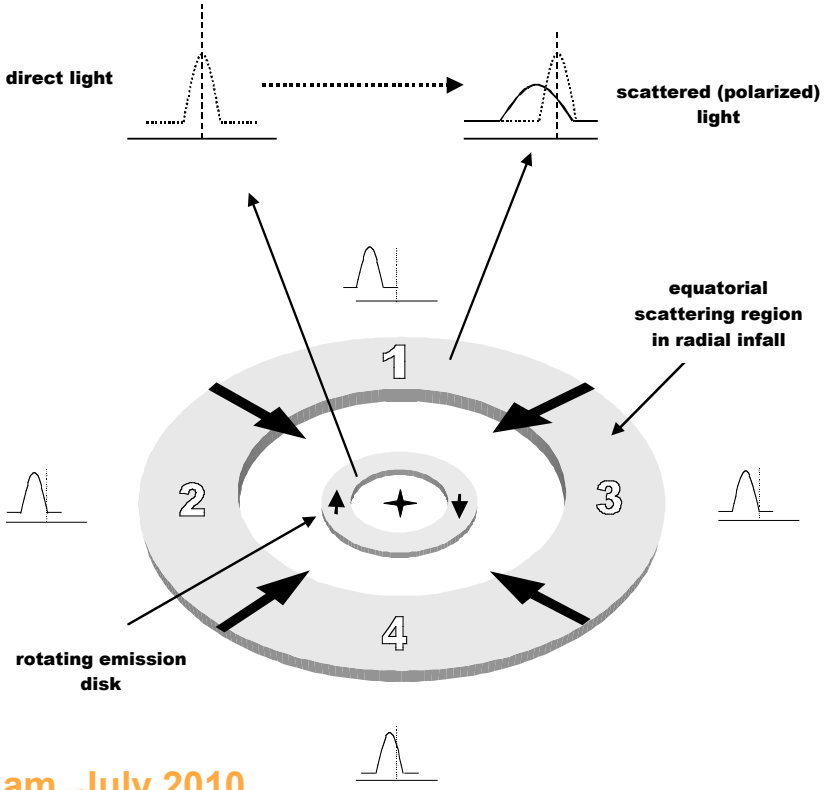
Explains variations in both p & θ

- Narrower directly viewed profile dilutes polarized profile
- Redshifted & blueshifted rays subtend different angles at scattering element

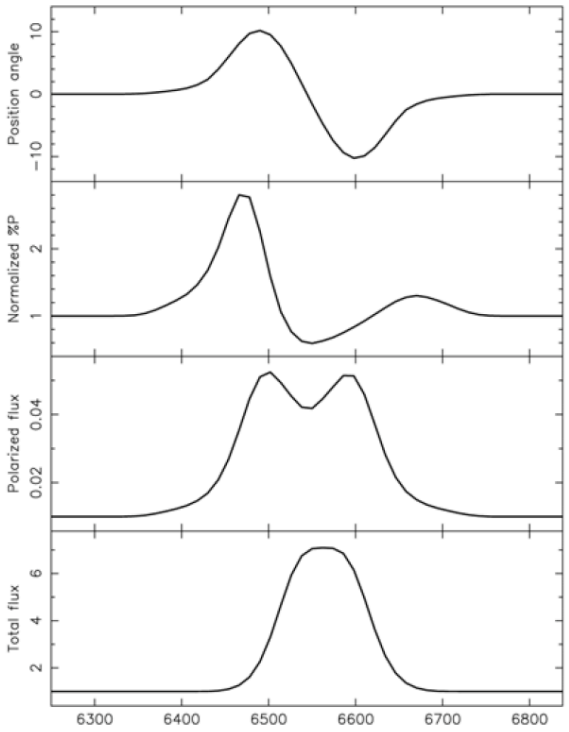


Kinematics of the Equatorial Scattering zone

- Bulk radial motions appear as asymmetries in polarization spectrum
  - E.g., inflow produces blue asymmetry

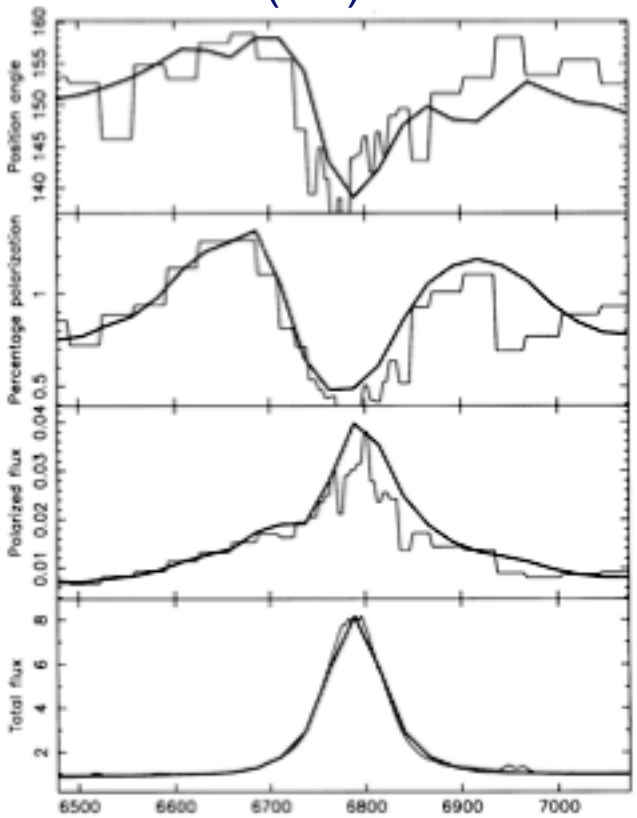


- Blue asymmetries are common in objects with equatorial scattering signatures

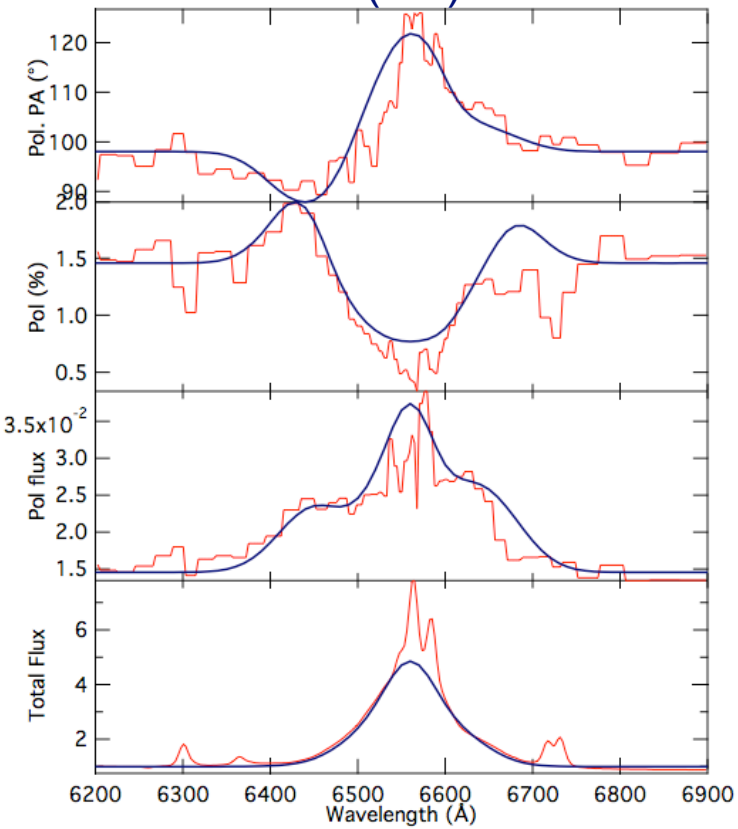


Accretion flows in Mrk 509 & NGC4151?

Mrk 509 (Hα)



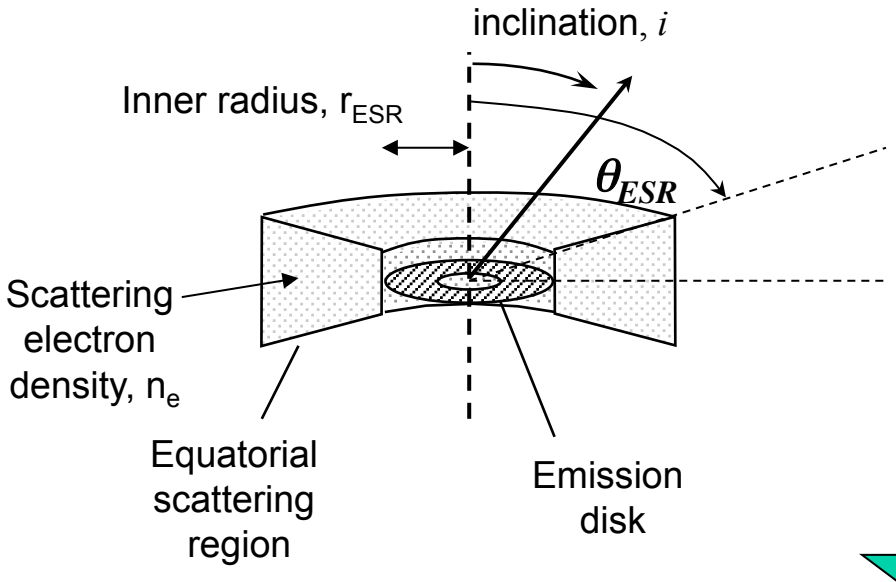
NGC 4151 (Hα)



Scattering models → equatorial scattering region has bulk inward radial velocity ~ 900 km s^{-1}

Scattering electrons part of accretion flow?

Estimating mass inflow rates



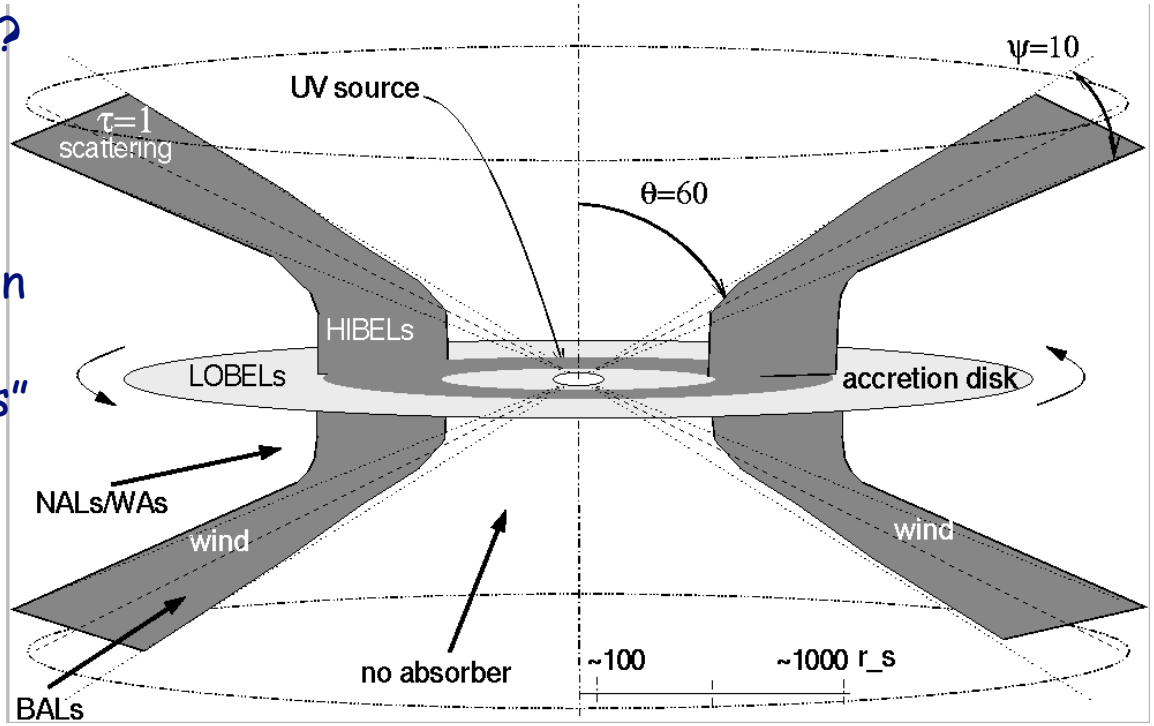
Observed pol spectrum also constrains scatterer density, geometrical parameters

mass inflow rates	~ 0.7 $M_\odot$ yr^{-1} for Mrk 509
(ionized gas)	~ 0.2 $M_\odot$ yr^{-1} for NGC 4151

- Mass inflow through ESR exceeds accretion rate $\dot{m}_{acc} \sim \frac{L_{Bol}}{\eta c^2}$ in both objects
  - Most of mass accreted through ESR gets "blown out" again by disk wind
  - NGC4151: mass outflow rate through NLR ~ 0.2 $M_\odot$ yr^{-1} (Crenshaw & Kraemer 2007)

Quasar disk winds

- ***Winds*** launched from accretion disk thought to be key components of AGN
- Physics
  - Carry away disk angular momentum?
  - Significant mechanical luminosity?
  - Feedback to host ISM?
- Phenomenology
  - Broad absorption lines (BAL's)
  - Narrow (UV) absorption lines
  - X-ray "warm absorbers"
  - High ionization broad emission lines?
  - Torus?



e.g. Elvis 2000, 2003

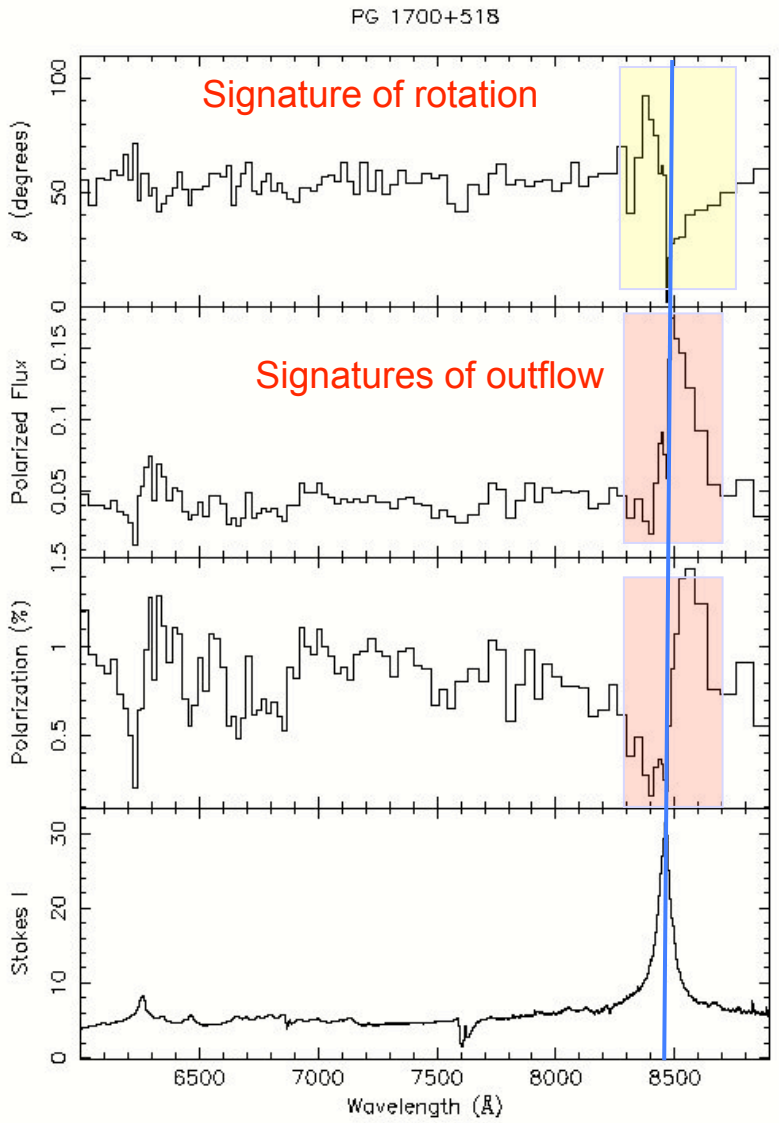
Broad Absorption Line QS0 1700+518

- Low redshift (z=0.292), so Hα accessible in optical

polarization PA exhibits behavior similar to that seen in Seyfert 1 galaxies in which equatorial scattering dominates polarization

however, scattered line profile, seen in polarized flux, redshifted by ~4000 km s^{-1} relative to its total flux counterpart

- Implication: velocity field of scattering medium includes both rotational and outflow components ⇒ outflow from a rotating disk — a disk wind.



First detection of a quasar disk-wind

- Polarization spectrum shows signatures of **both outflow and rotation** at speeds expected for gas orbiting a 10^9 $M_\odot$ black hole at the inferred wind launch radius

$$v_{W,z} \sim v_{W,\phi} \sim v_K \sim 4000 \text{ km s}^{-1}$$

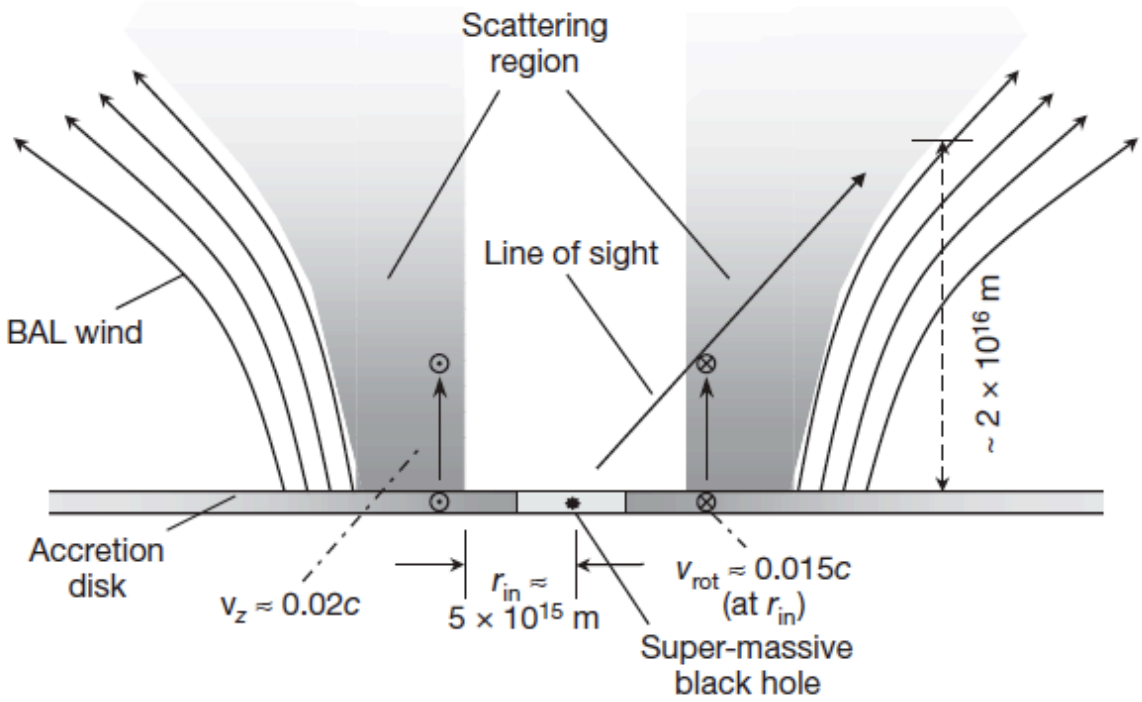
Mass outflow rate (scattering region only)

$$\dot{m}_W \sim 10 \ M_\odot/\text{yr}$$

Accretion rate

$$\dot{m}(L_{Bol}) \sim 7 \ M_\odot/\text{yr}$$

- First **direct observational evidence** that quasar winds are launched from the accretion disk



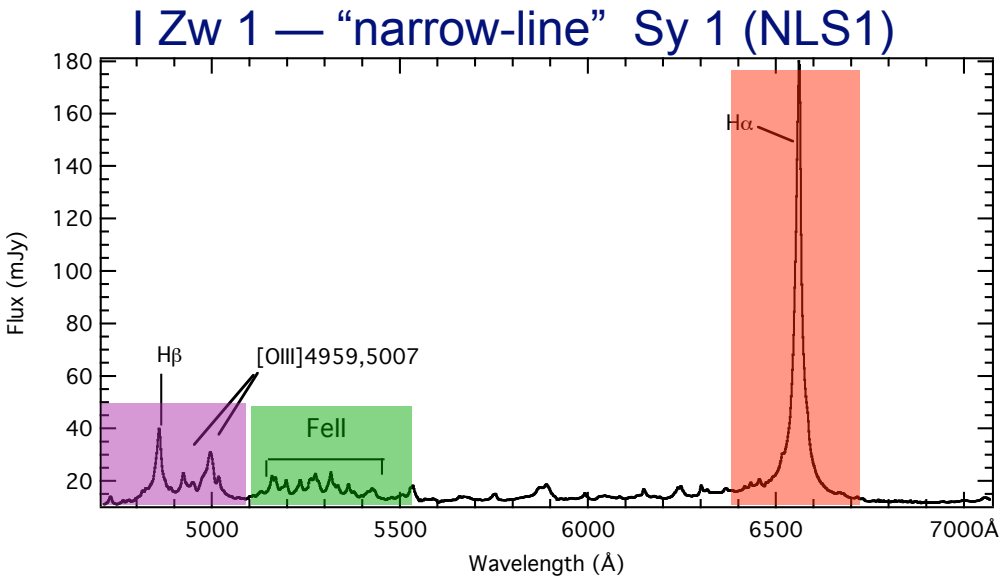
The rotating wind of the quasar PG 1700+518

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

Nature, Sept 2007

Narrow Line Seyfert 1's (NLS1)

- Hα, Hβ FWHM < 2000 km/s
- Strong FeII emission
- Relatively weak narrow lines ([OIII]/Hβ < 5)
- Steep soft X-ray spectra
  - Often with blueshifted "warm absorbers" ⇒ gas outflowing at speeds ~1000 km/s



Small FWHM but "normal" luminosity suggests NLS1 are physically defined by:

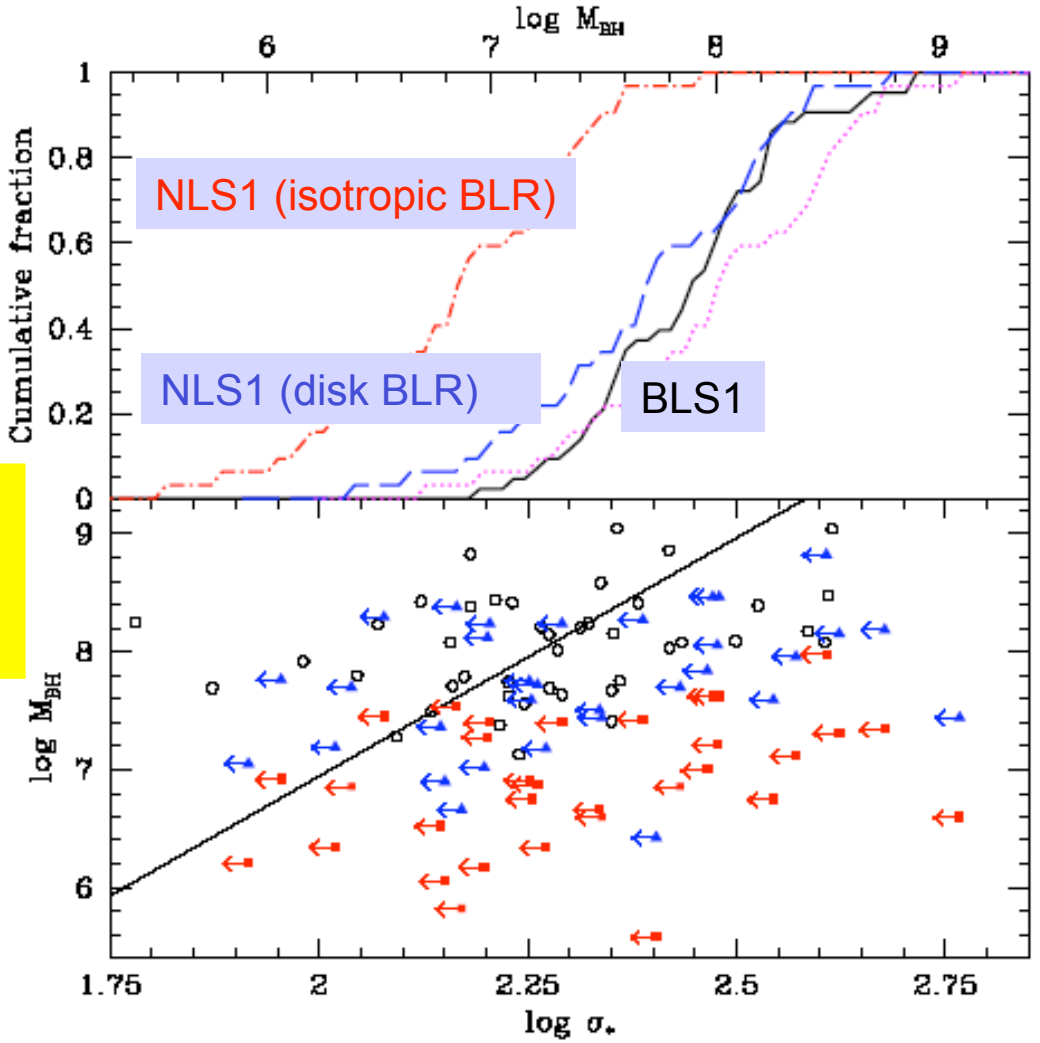
- Low black hole mass (factor ~10 lower than BLS1)
- $L_{AGN}/L_E \rightarrow 1$
  ⇒ rapid SMBH growth & radiation pressure driven winds

Or are NLS1 merely viewed "face on"?

- What if BLR has a disk geometry?
- Are NLS1 simply "normal" Sy 1's viewed close to the disk axis?

If so, observed FWHM underestimates BH mass

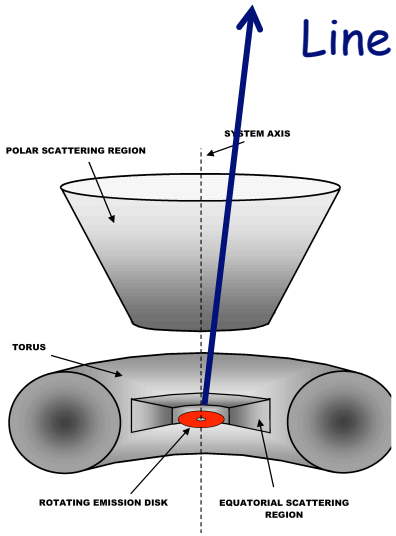
- Anomalous NLS1 SMBH masses & Eddington ratios can be explained if average inclination is ~ 15°
  - Decarli et al. 2008

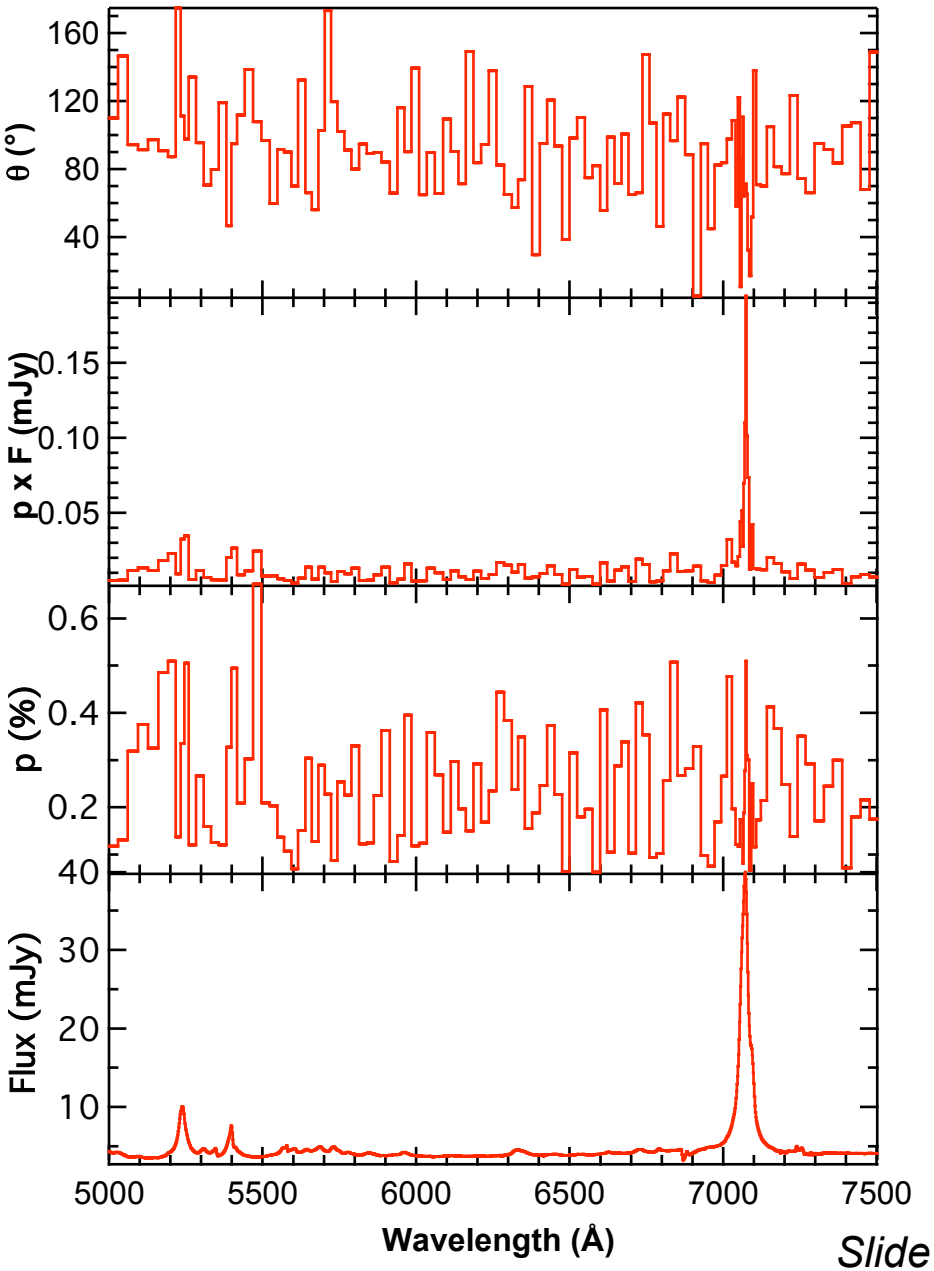


Decarli et al. 2008, MNRAS, 386, L15

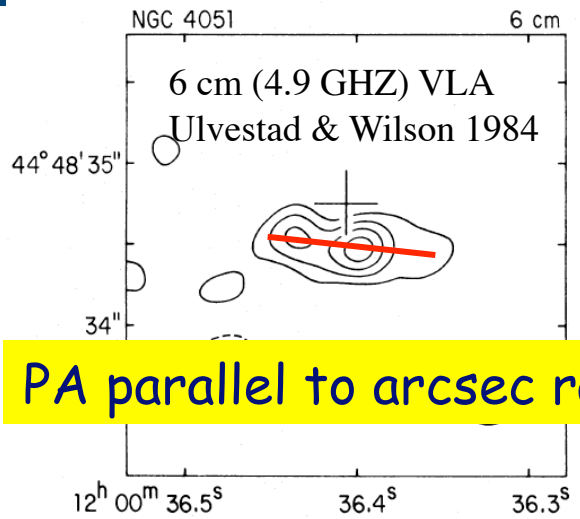
Mrk 478 – intrinsically unpolarized

- Low measured polarization
  Consistent with zero intrinsic polarization
- ⇒ Viewed close to system axis





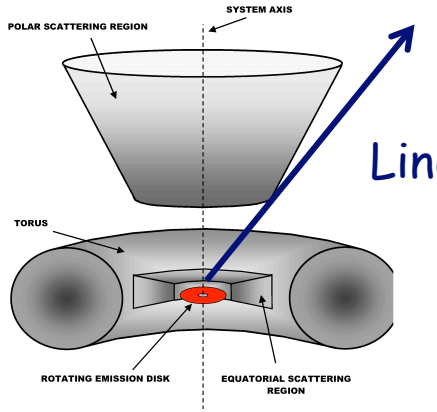
NGC4051 — equatorial scattering



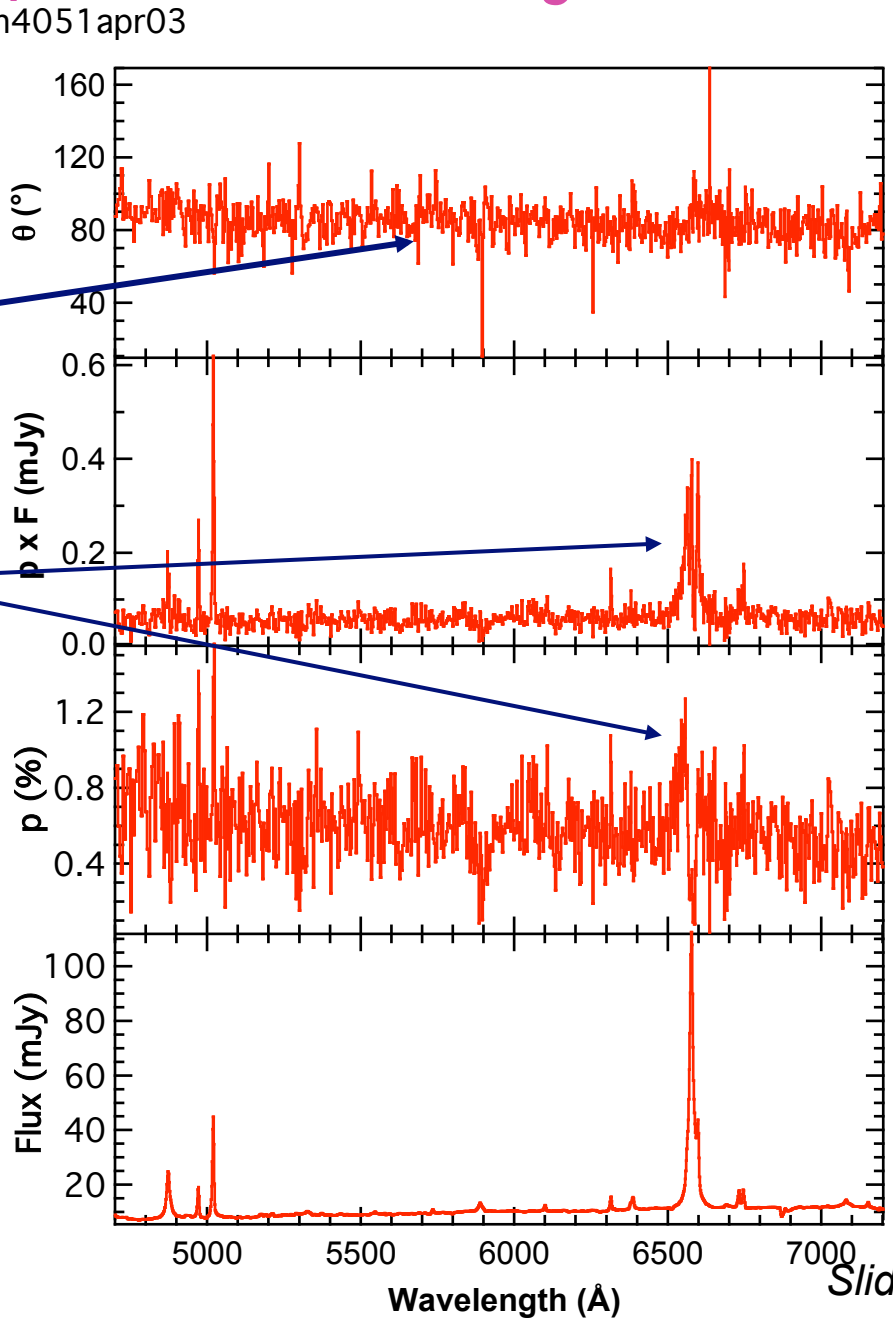
PA parallel to arcsec radio jet

Hα broader in polarized flux

- If equatorial scattering, viewed at intermediate angle



Line of sight

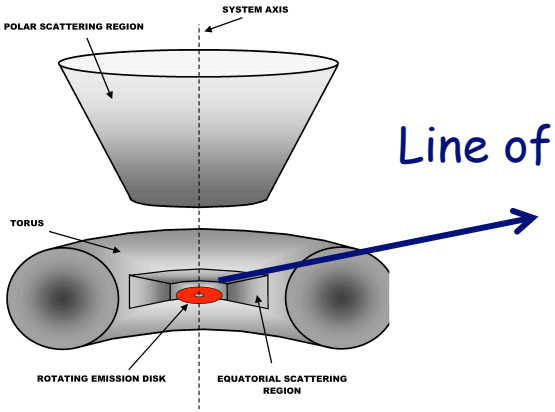


Mrk 766 — polar scattering

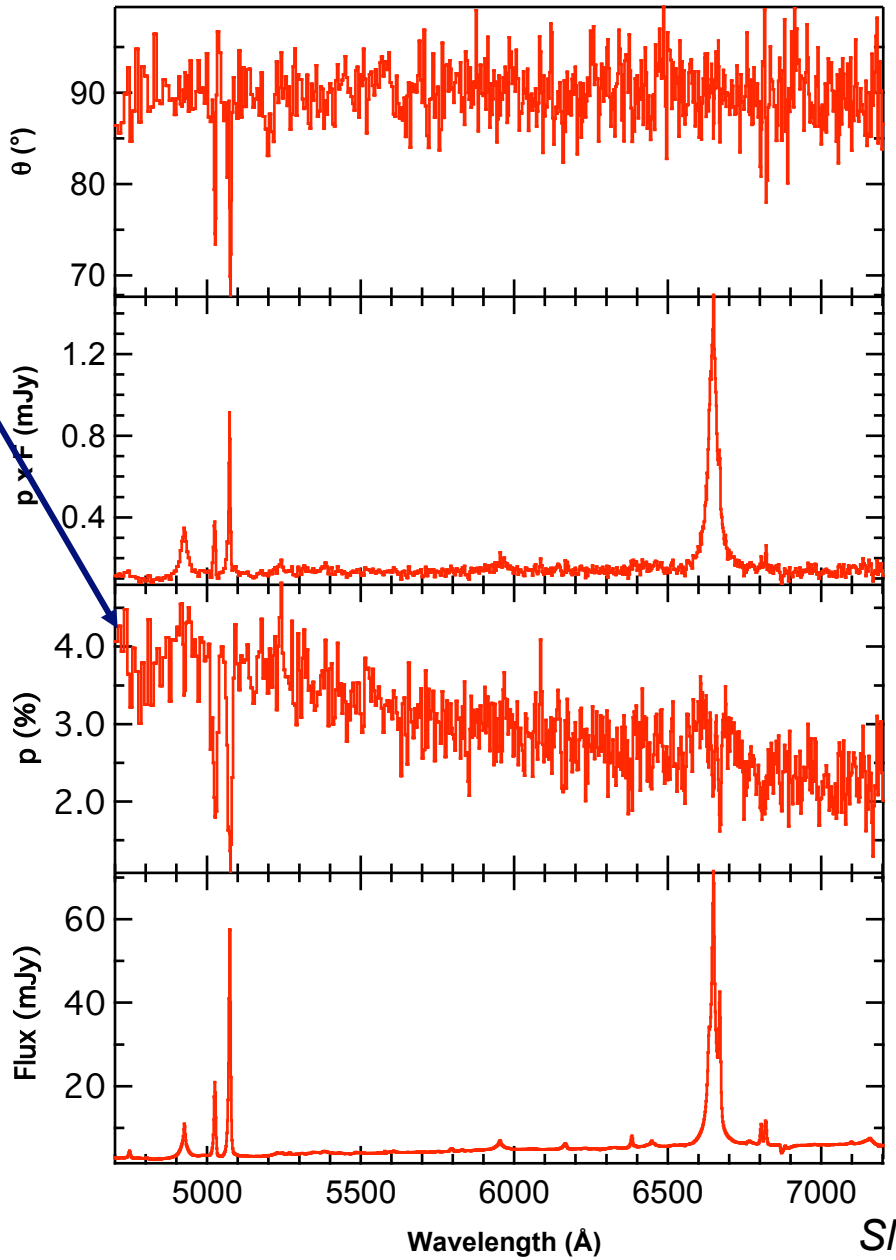
Cont. pol. increases to blue; local peaks at broad lines

4/16 NLS1 show polar scattering characteristics, same fraction as in general Sy 1 sample

Viewed at large inclination to torus axis



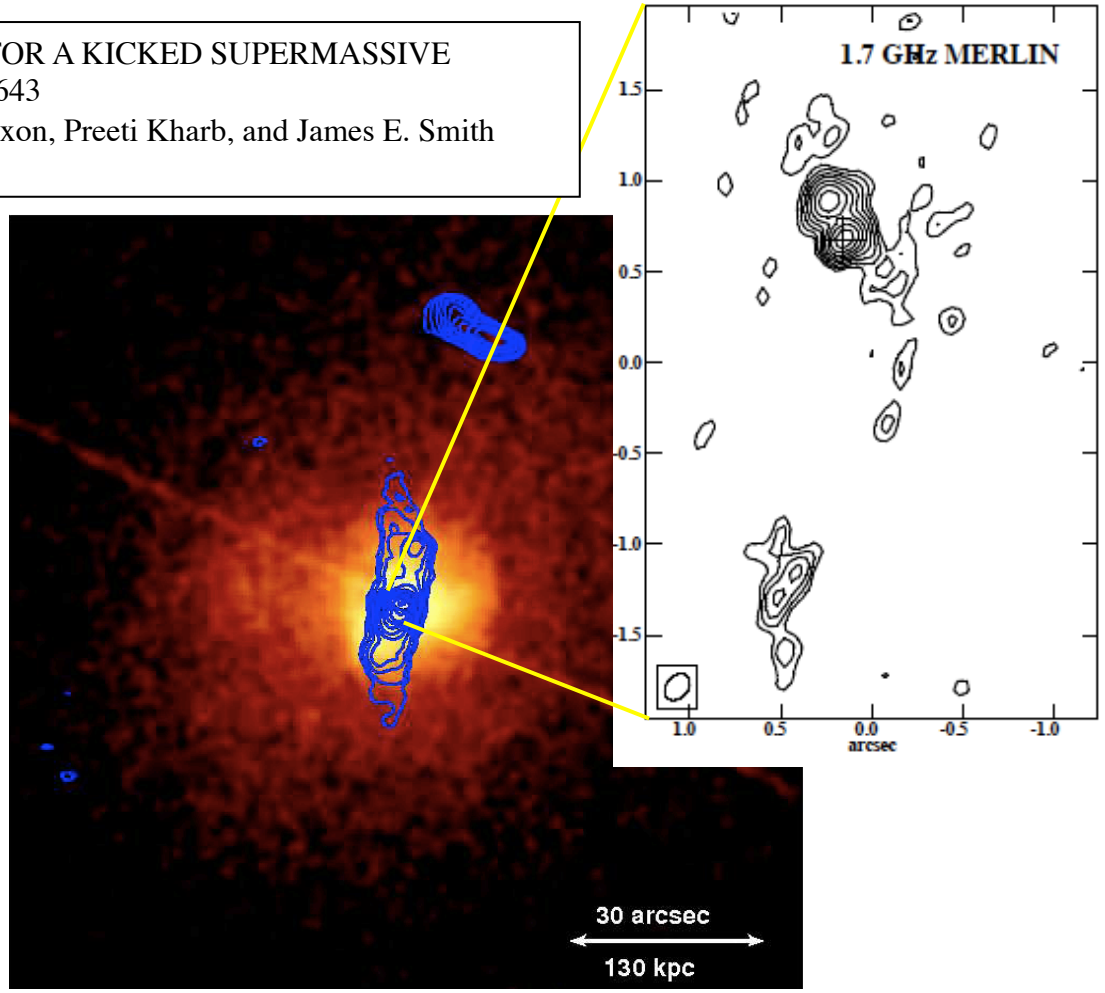
Line of sight



E1821+643: gravitational recoil candidate, SMBH binary or superwind?

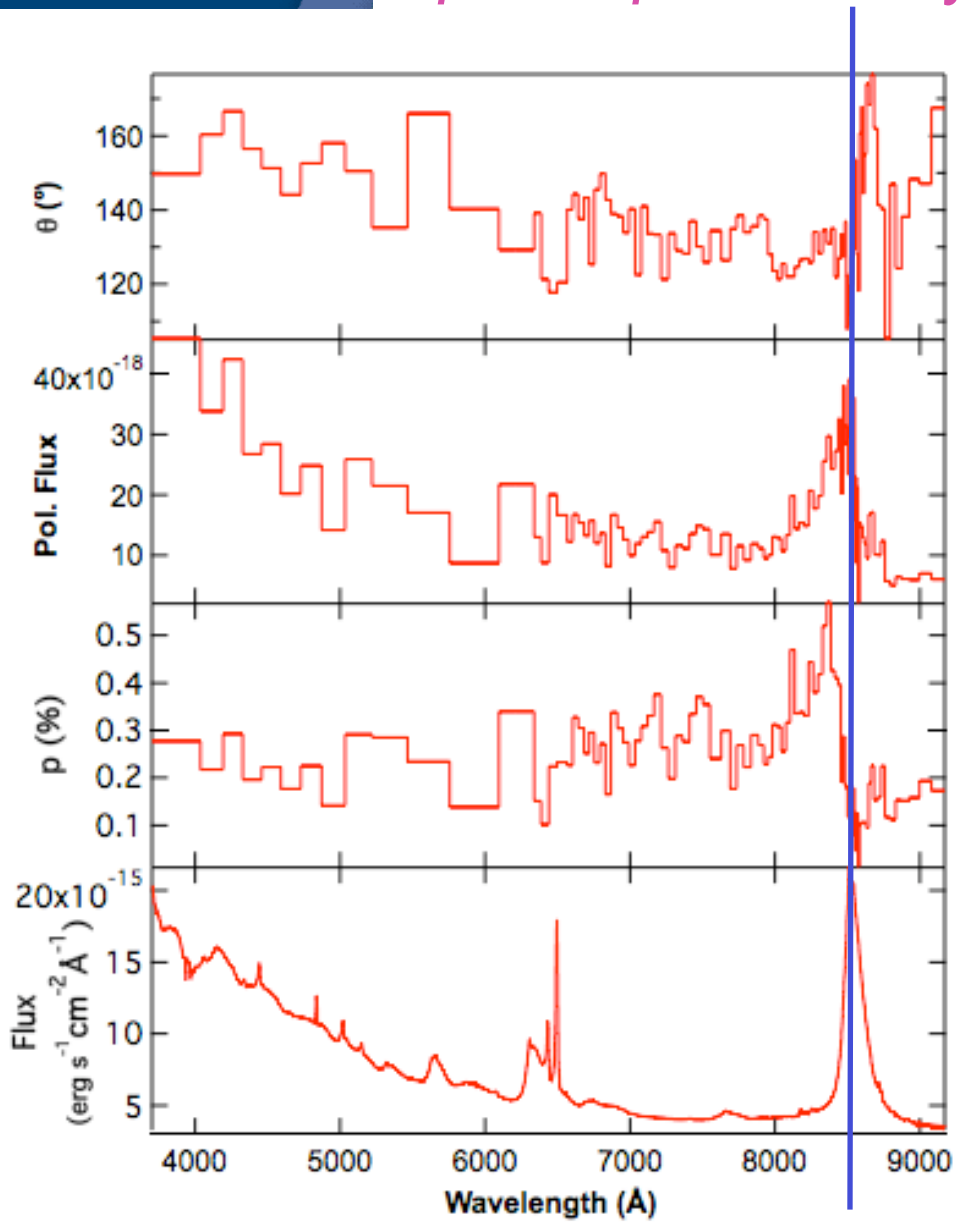
SPECTROPOLARIMETRIC EVIDENCE FOR A KICKED SUPERMASSIVE BLACK HOLE IN THE QUASAR E1821+643
Andrew Robinson, Stuart Young, David J. Axon, Preeti Kharb, and James E. Smith
2010, ApJ 717, L122

- One of most luminous AGN in local universe
- Large CD galaxy at center of large X-ray cluster (Schneider et al 1992, Hall 1997, Russell et al 2010)
- "Radio-Quiet" but with ~250 kpc FR I source (Blundell & Rawlings 2001)
- Jet bends through ~90° on ~ arcsec scales (Blundell et al 1996)
  - Precession in binary SMBH?
  - Re-orientation of spin axis following SMBH coalescence? (Merritt & Ekers 2002)

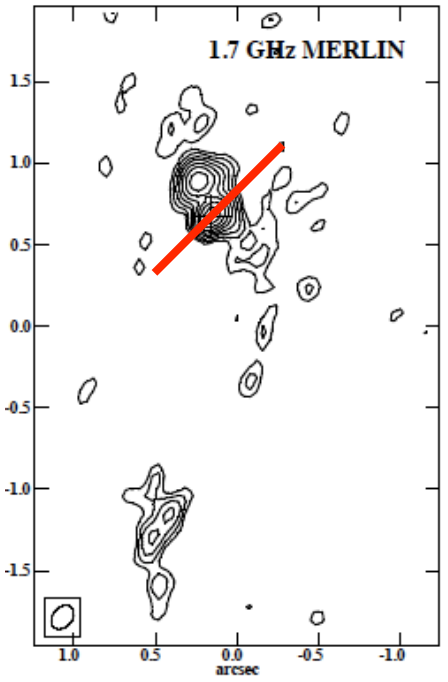


z = 0.297 1 arcsec = 4.3 kpc

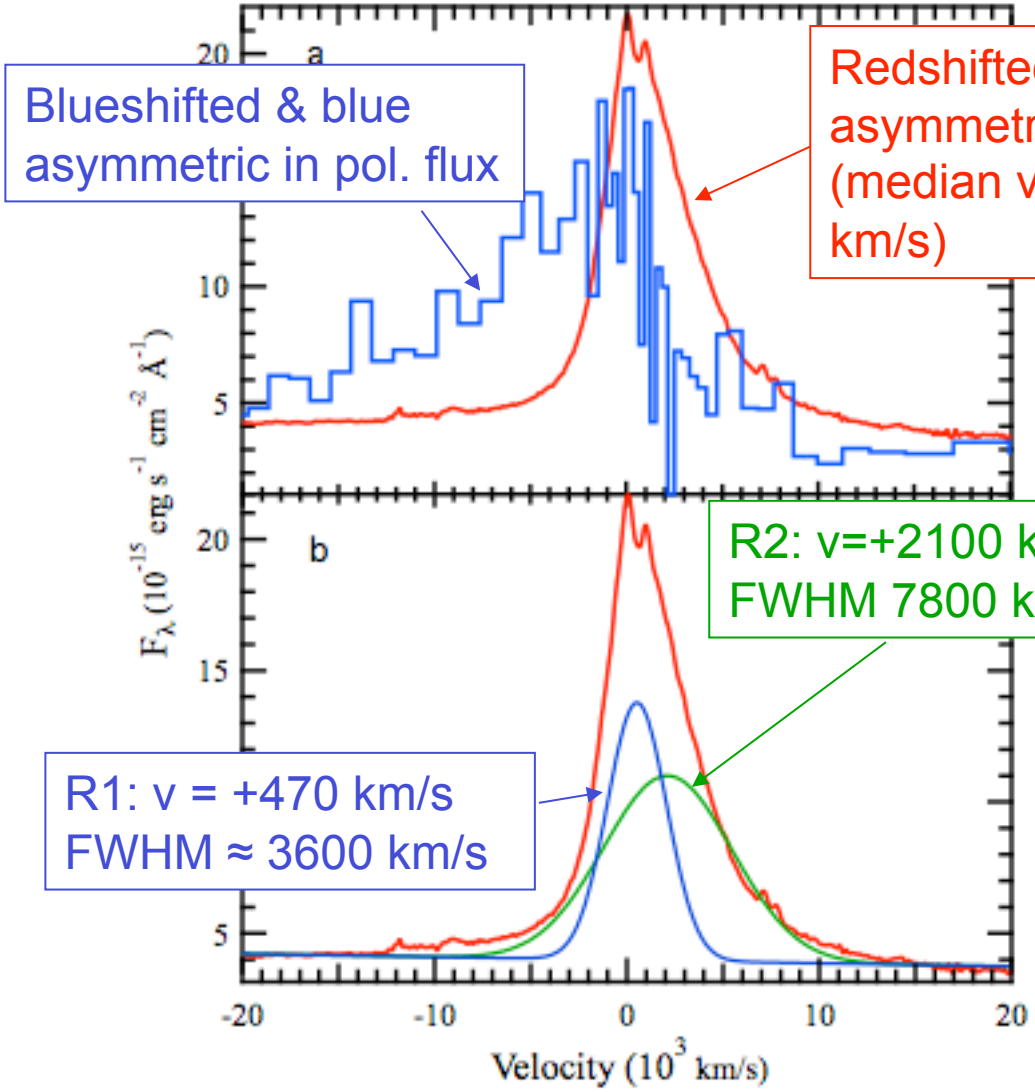
Spectropolarimetry of E1821+643



- Broad Hα, Hβ redshifted & red asymmetric in total flux
- Broad Hα blueshifted & blue asymmetric in polarized flux
- Average pol PA ~ perpendicular to 1" jet

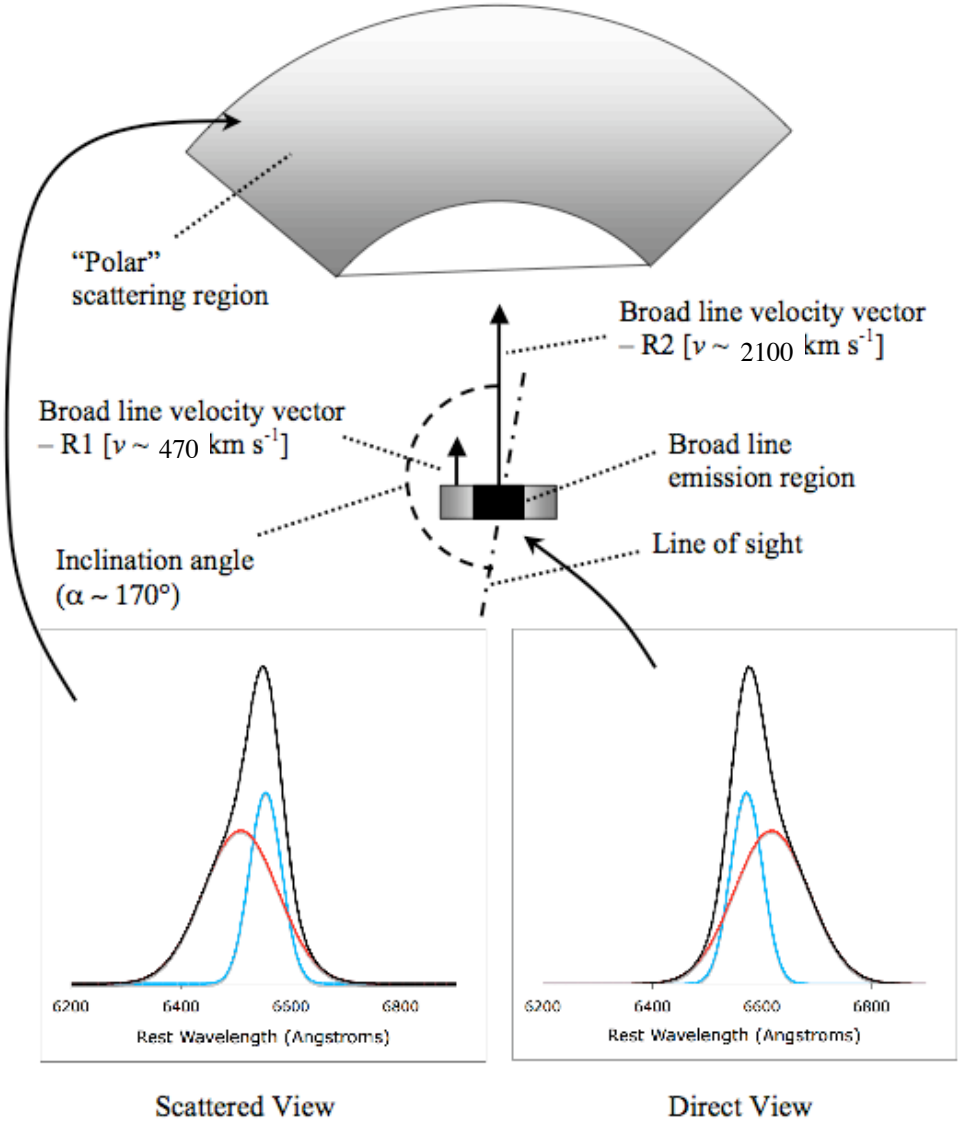


E1821-643: Hα in total & polarized flux



- Total flux profile described by 2 Gaussian components:
  - R1: low velocity, low velocity dispersion
  - R2: high velocity; high velocity dispersion
- "Mirroring" of these components explains polarized flux profile

E1821+643: scattering model



Both BLR components move

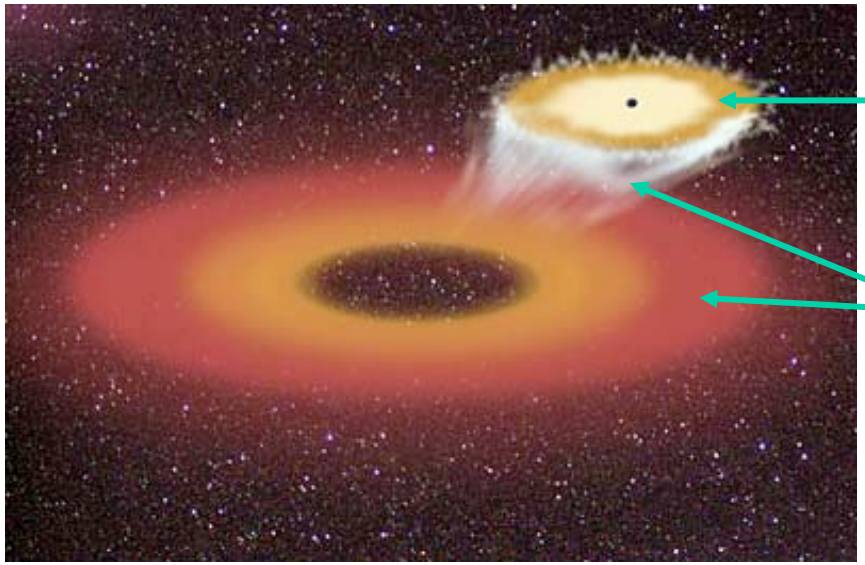
- away from observer
  ⇒redshifts in direct light
- towards scattering region
  ⇒blueshifts in scattered (polarized) light

Shift & asymmetry reversal

- This requires bulk motion of BLR relative to host galaxy
  - R1: 480 – 1400 km/s
  - R2: 2100 – 6100 km/s

  (depending on inclination)

E1821+643: a "kicked" SMBH?



R2: inner BLR retained by recoiling SMBH ($v_{Kepler} > v_{recoil}$)

R1: outer BLR/circumbinary disk left in wake of recoiling SMBH ($v_{Kepler} < v_{recoil}$)

- Coalescence of progenitor binary SMBH → gravitational recoil of merged BH
  - Asymmetric radiation of gravitational waves
- Numerical relativity ⇒ $v_{recoil} > 10^3$ km/s possible

- If change in jet direction due to "spin flip"
  - Time elapsed since coalescence ~ 10^4 – 10^5 yr
  - SMBH has moved 20 – 200 pc (but almost along line of sight)

Francesca Civano poster

[e.g., Baker+ 06,07,08, Campanelli+ 06, 07a,b, Dain+08, Gonzales+ 06, 07a,b, Herrman+ 07a,b, Koppitz+ 07, Pretorius 05, 07,, Schnittman+ 07, 08,Healy+08 ...]

Summary

Spectropolarimetry of broad-line AGN provides a unique probe of the kinematics of circum-nuclear gas flows, even inside the torus

- Observations indicate 2 major scattering regions
  - Extended polar region
  - Compact (within torus) equatorial region
- Direct evidence that BLR has a **rotating disk-like component**
- Blue shifted Doppler ghosts in polarized light yield **direct measure of accretion on sub-pc (torus→BLR) scales**
- NLS1 are **not** viewed at preferred orientation (ie pole-on)
  - favours low BH mass systems radiating near Eddington limit
- Rotating outflow detected in low-z BAL QSO — **direct observational evidence for winds launched from accretion disks**
- Evidence for **gravitational recoil of SMBH** in QSO E1821+643

What polarimetry tells us about AGN