Constraining sub-orbital structures in AGN Accretion disks from polarized broad emission lines

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on Spectroscopic Line Shapes in Astrophysics (SCSLSA)

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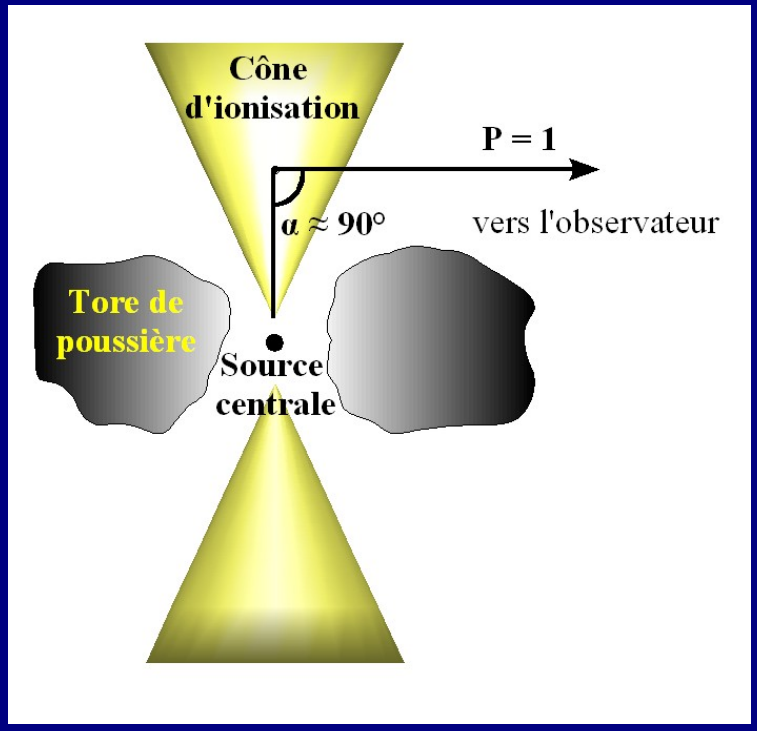
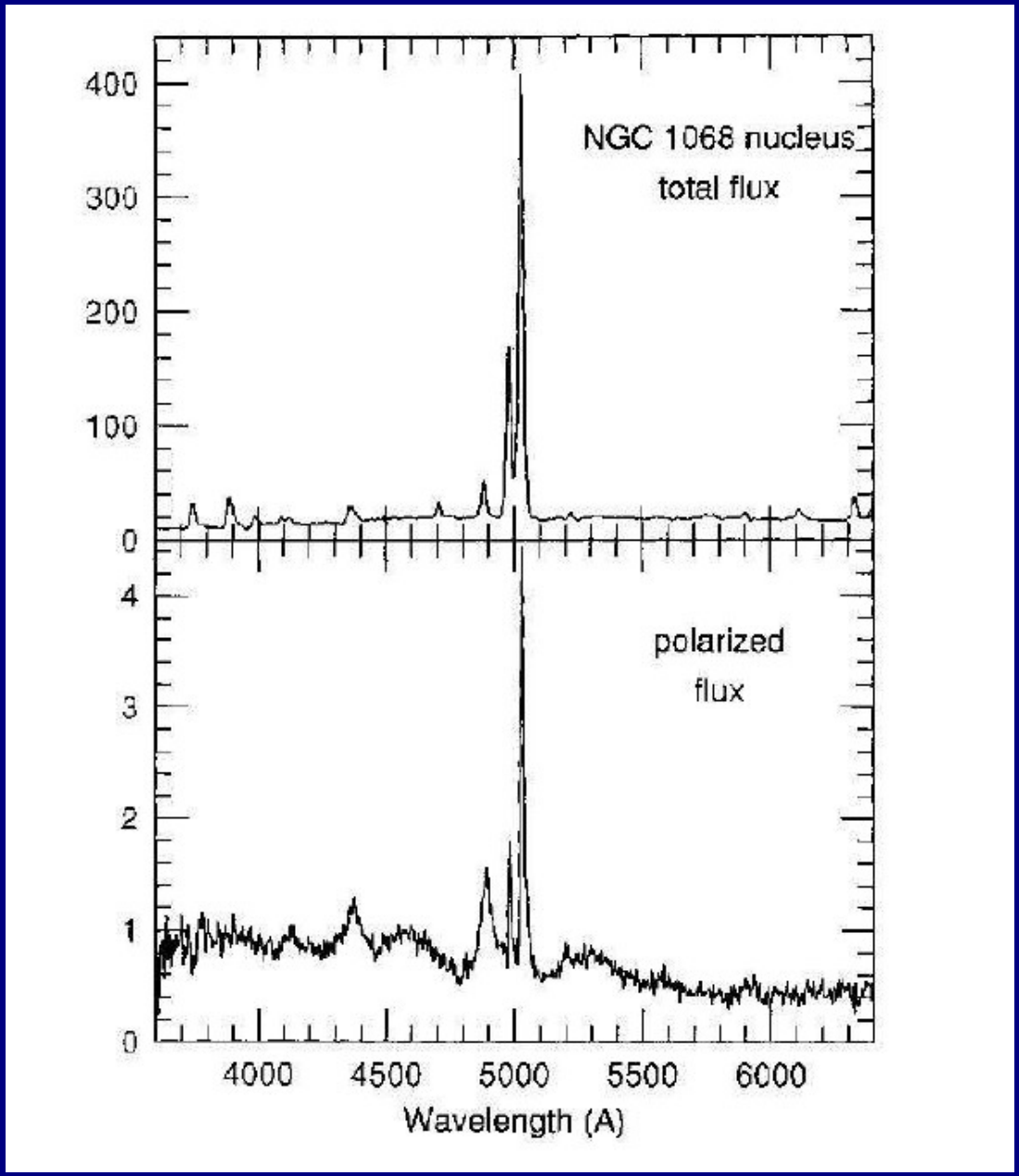
Banja Koviljaca, Serbia

Radio-quiet objects Hidden type-1 AGN

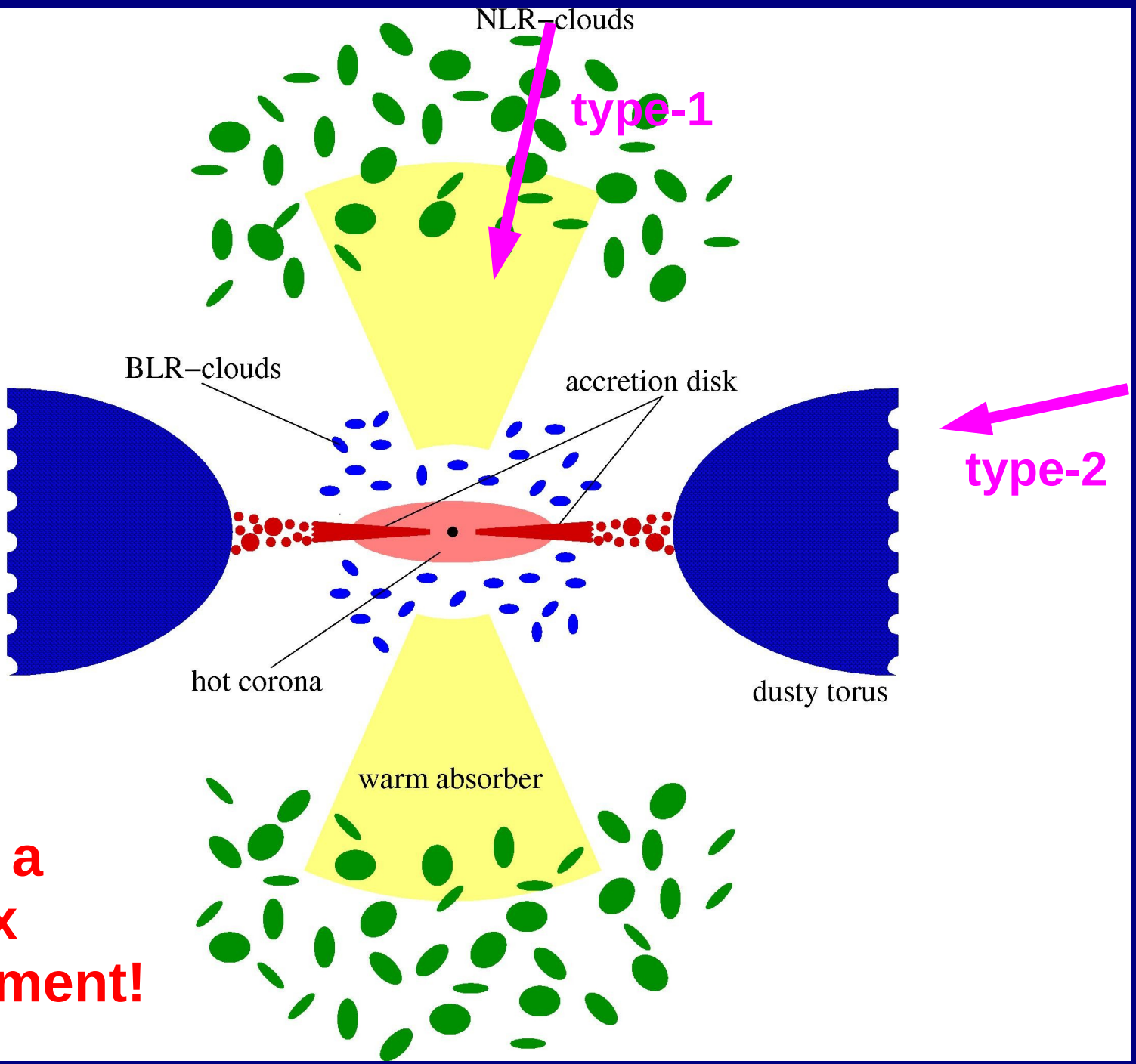
A major break-through for the unified model for NGC 1068 (Antonucci & Miller 1985)

→ **periscope view of AGN in polarized flux**





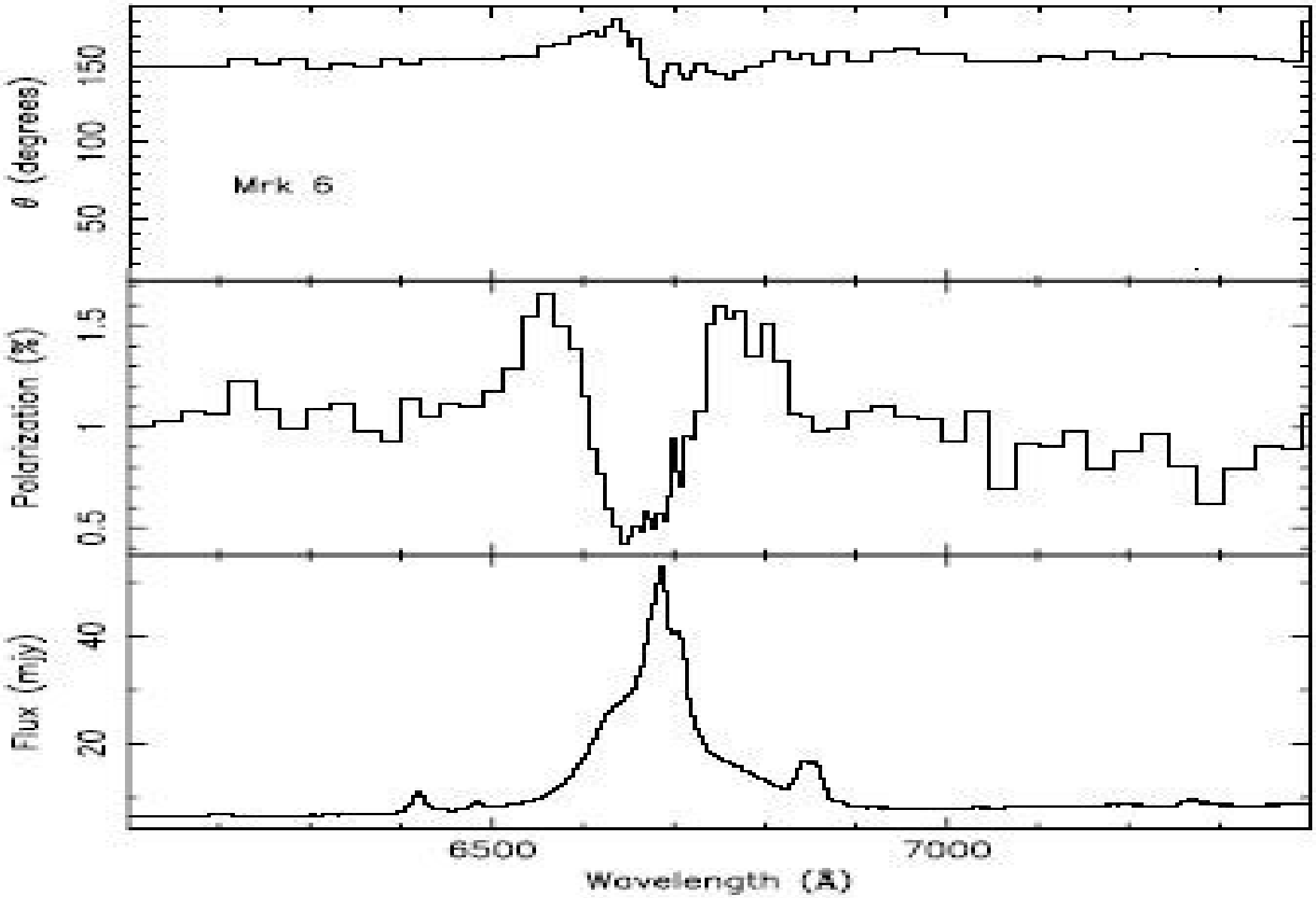
Accreting supermassive black holes...



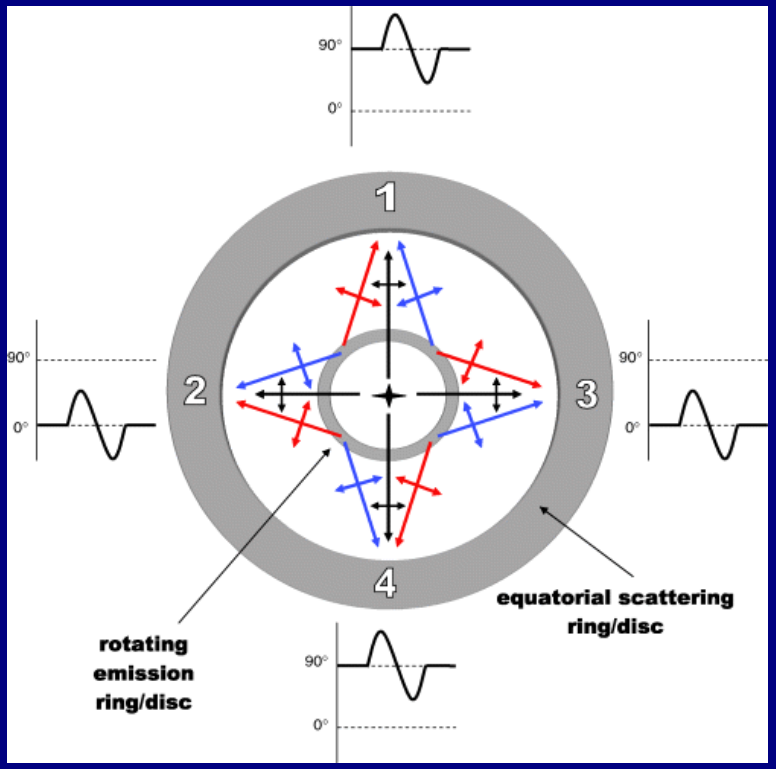
...live in a complex environment!

Spectropolarimetry of broad lines

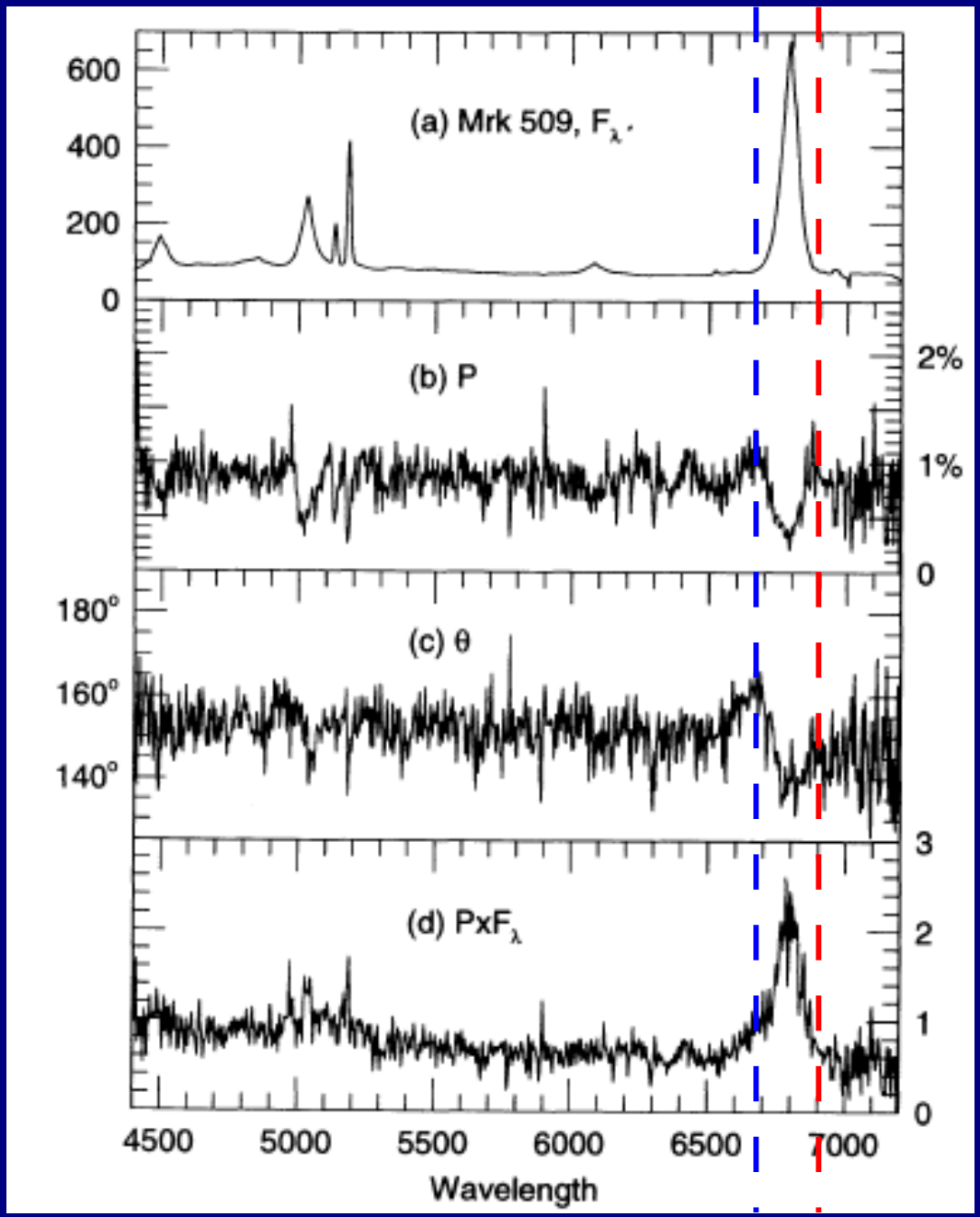
Smith et al. (2002)



Rotation of polarization angle across emission line



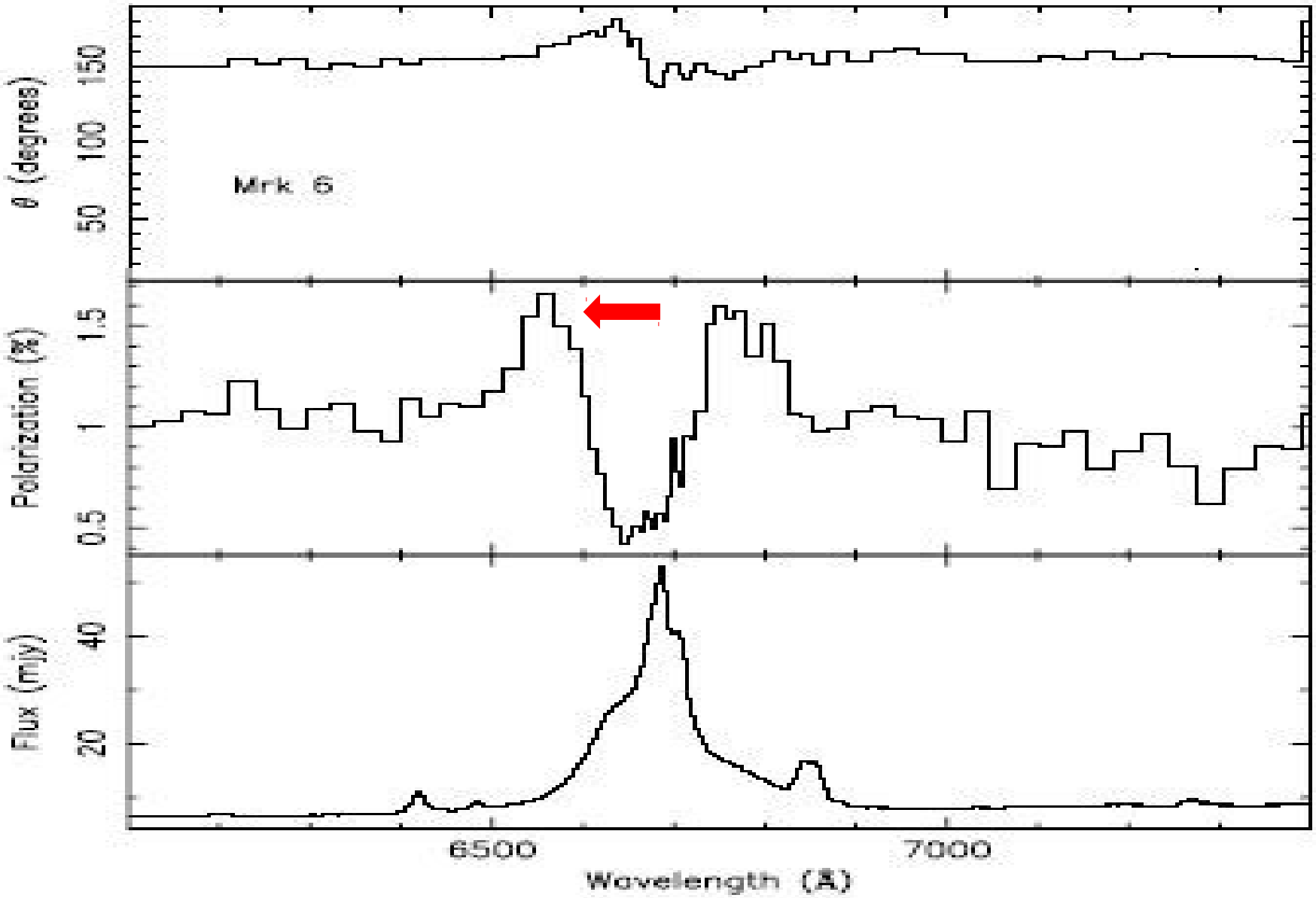
Interpretation and modeling
by Smith et al. (2005)



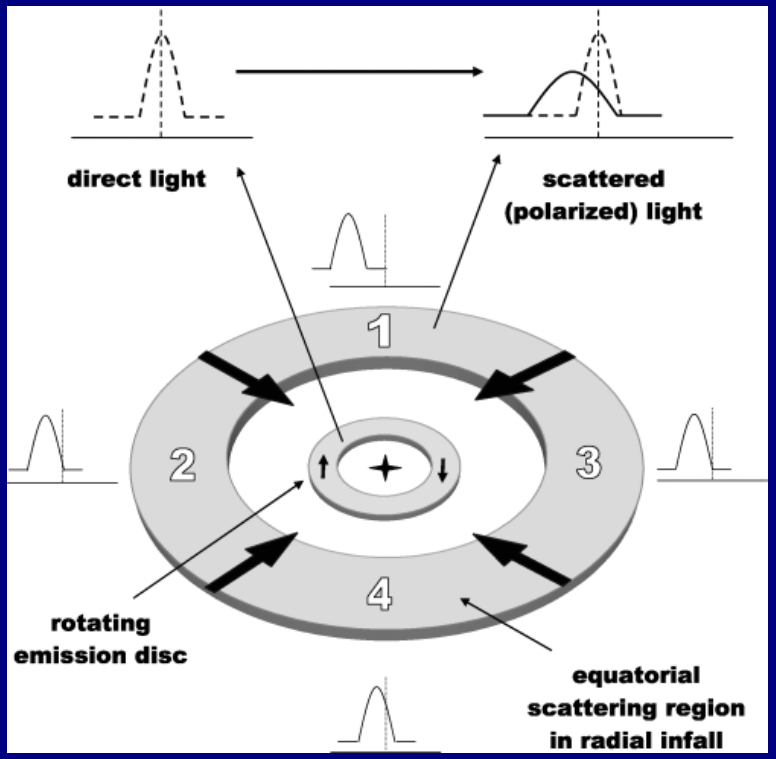
Spectropolarimetric data for Mrk 509
from Goodrich & Miller (1994)

Spectropolarimetry of broad lines

Smith et al. (2002)

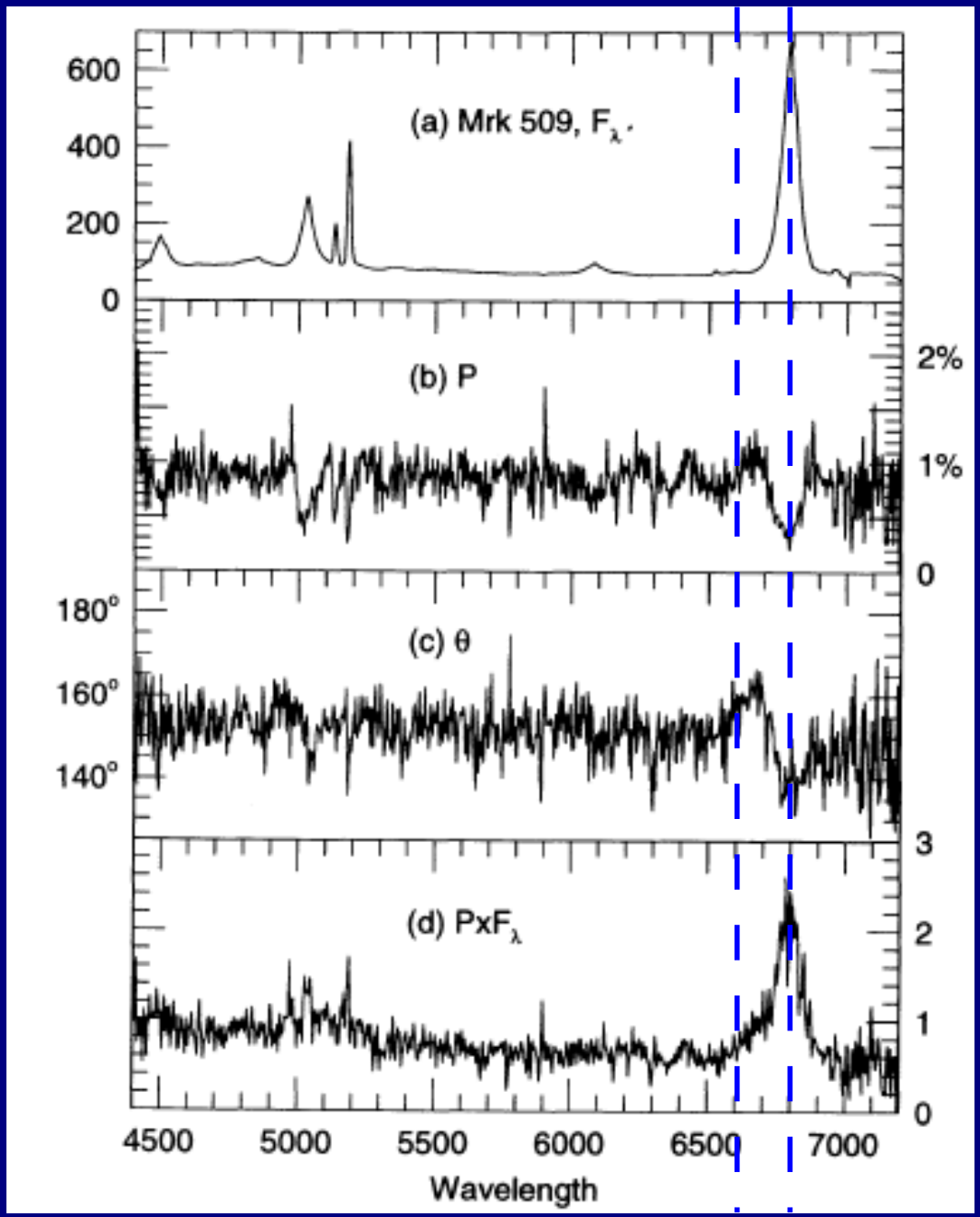


Blue polarization wing of the emission line



Interpretation and modeling
by Smith et al. (2005)

Similar work on NGC 3783 (Lira et al. 2007)



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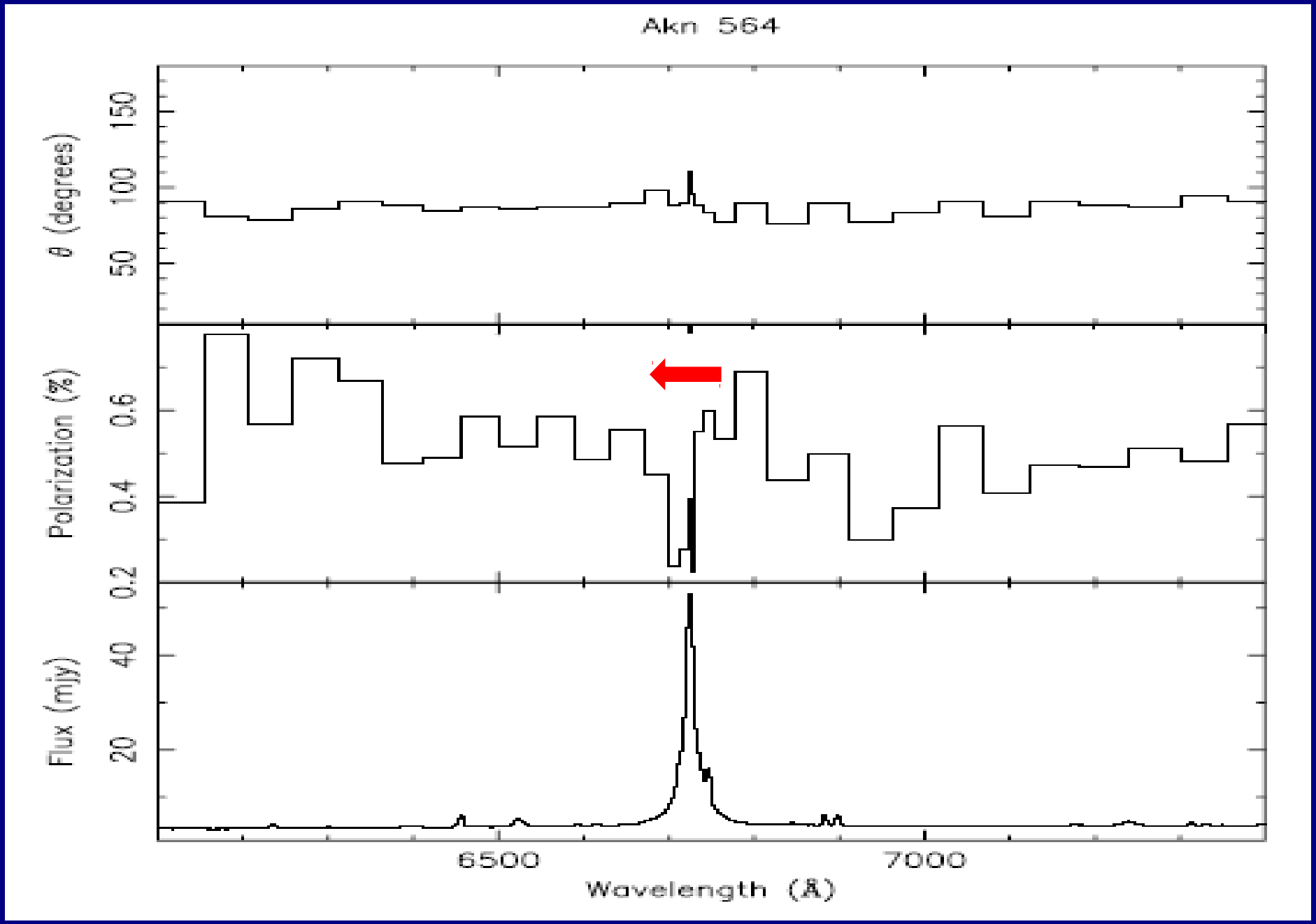
Spectropolarimetry of broad lines

(NLS1)



Smith et al. (2002)

Spectropolarimetry of broad lines

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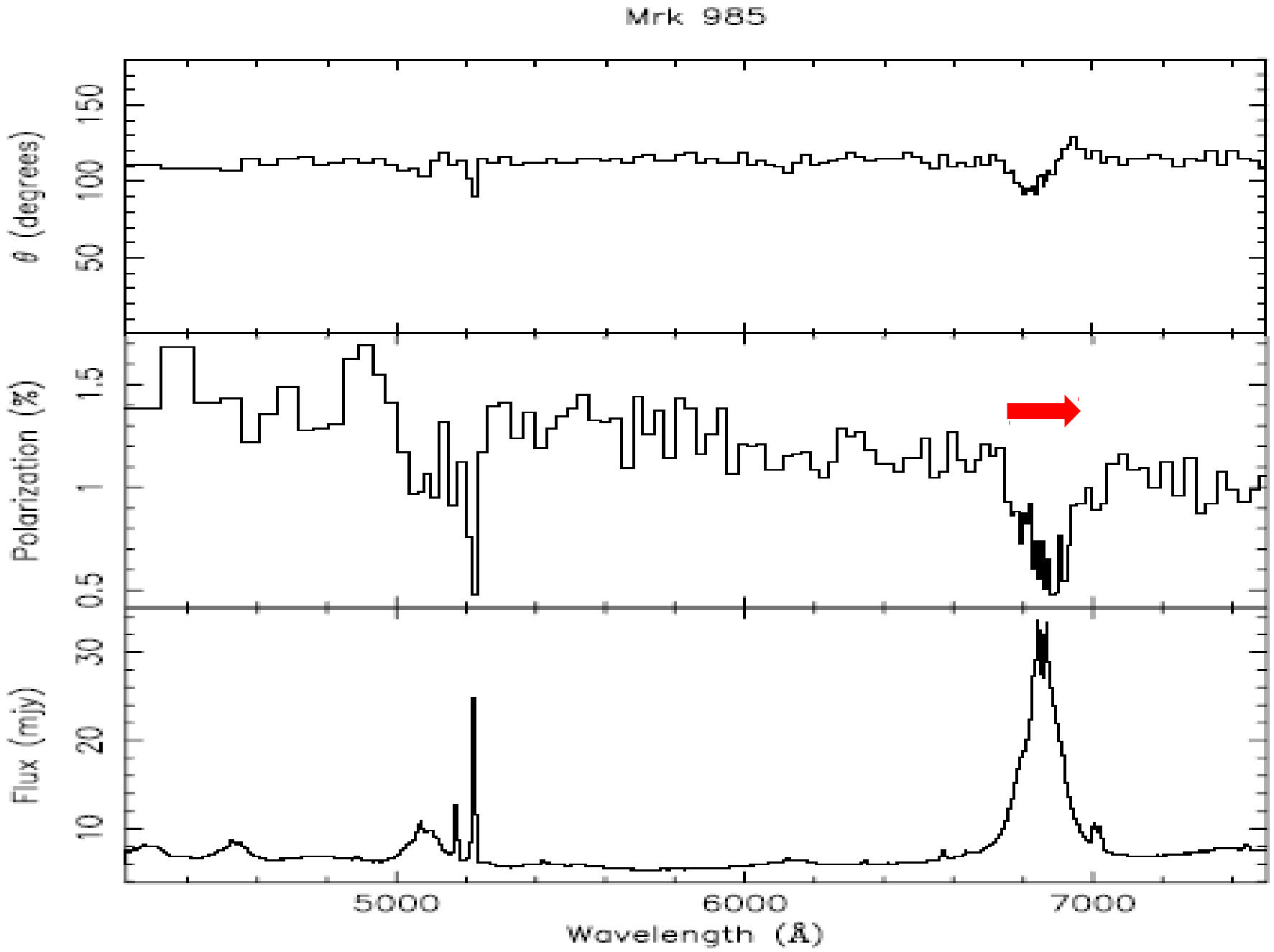
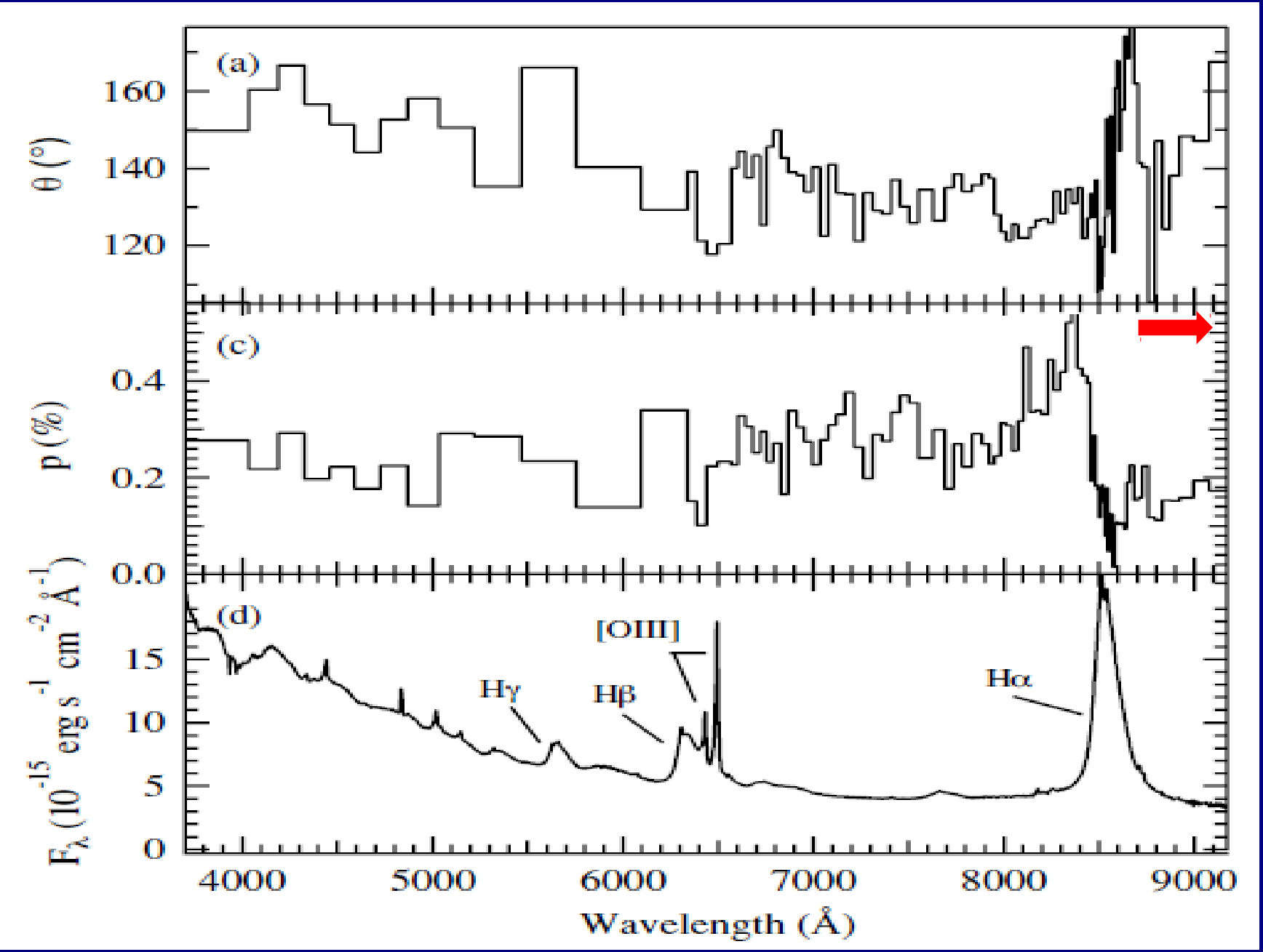


Spectropolarimetry of broad lines



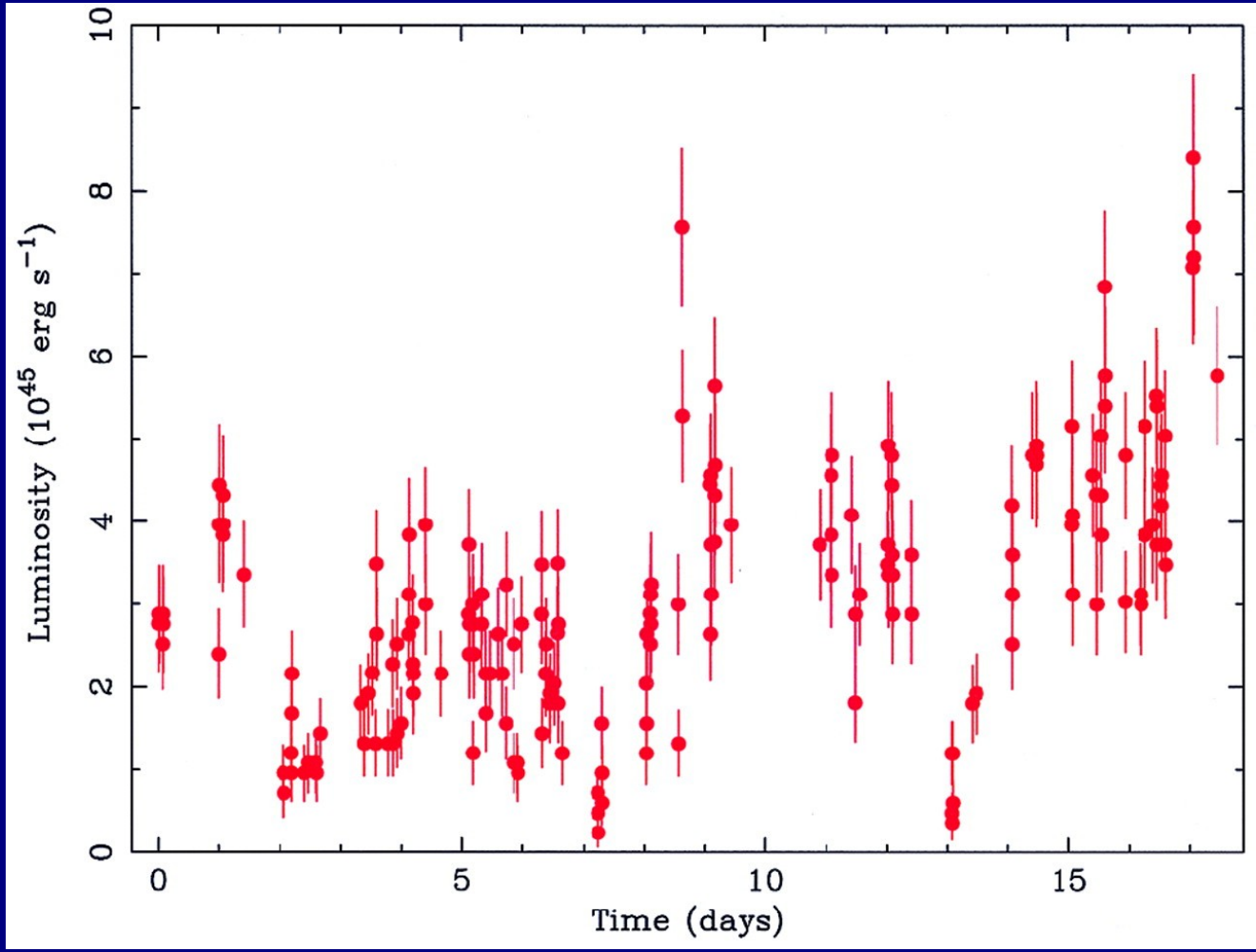
Robinson et al. (2010)

X-ray variability of PHL 1092

Active galactic nuclei vary strongly and rapidly in X-ray brightness.

This constrains the size of the emission site to a very compact region.

→ suggests occurrence of spatially very compact flares



Fabian 1999

Modeling of black hole accretion disks

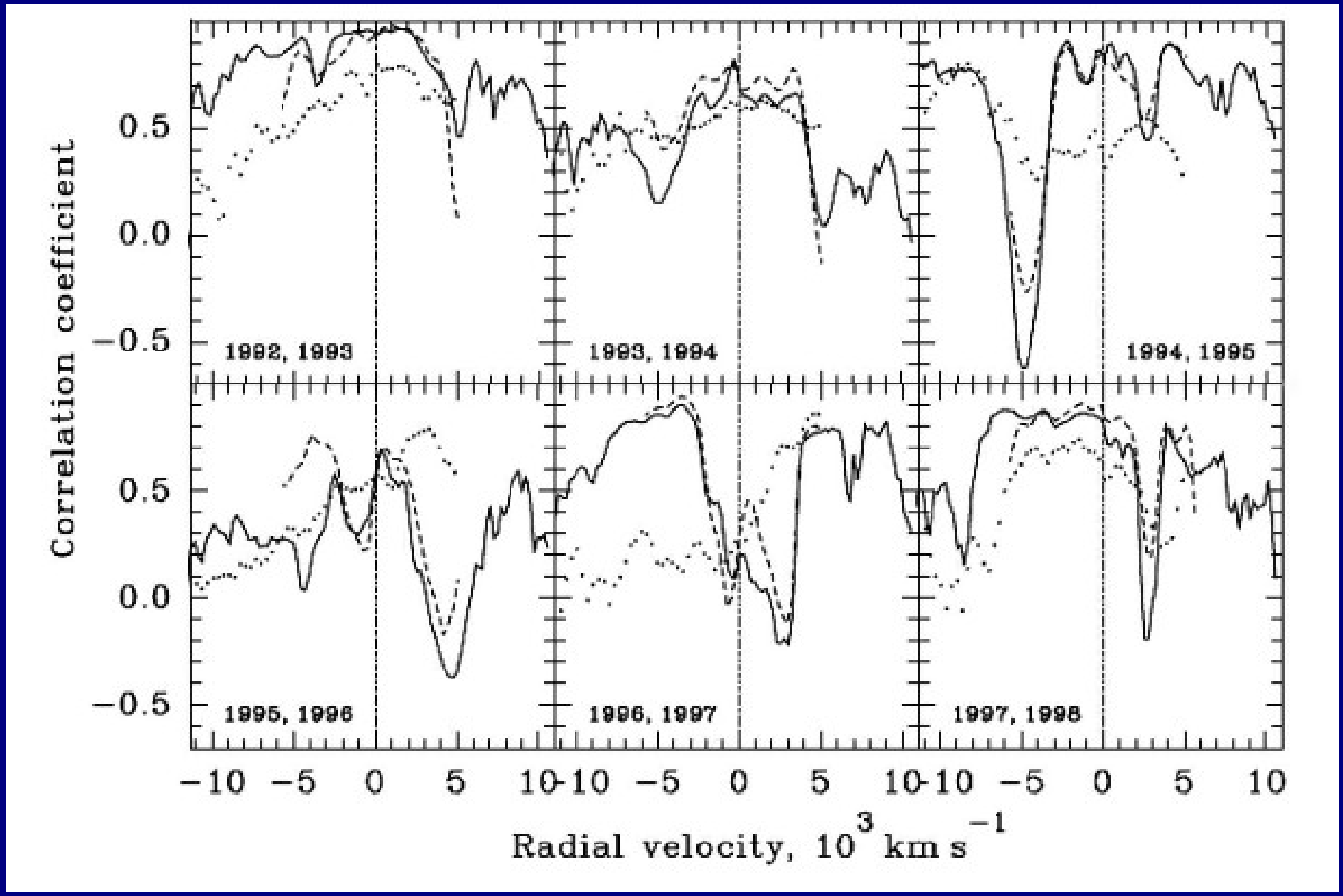
Face-on

Edge-on

The modeling reveals a fragmented (clumpy) emission structure!

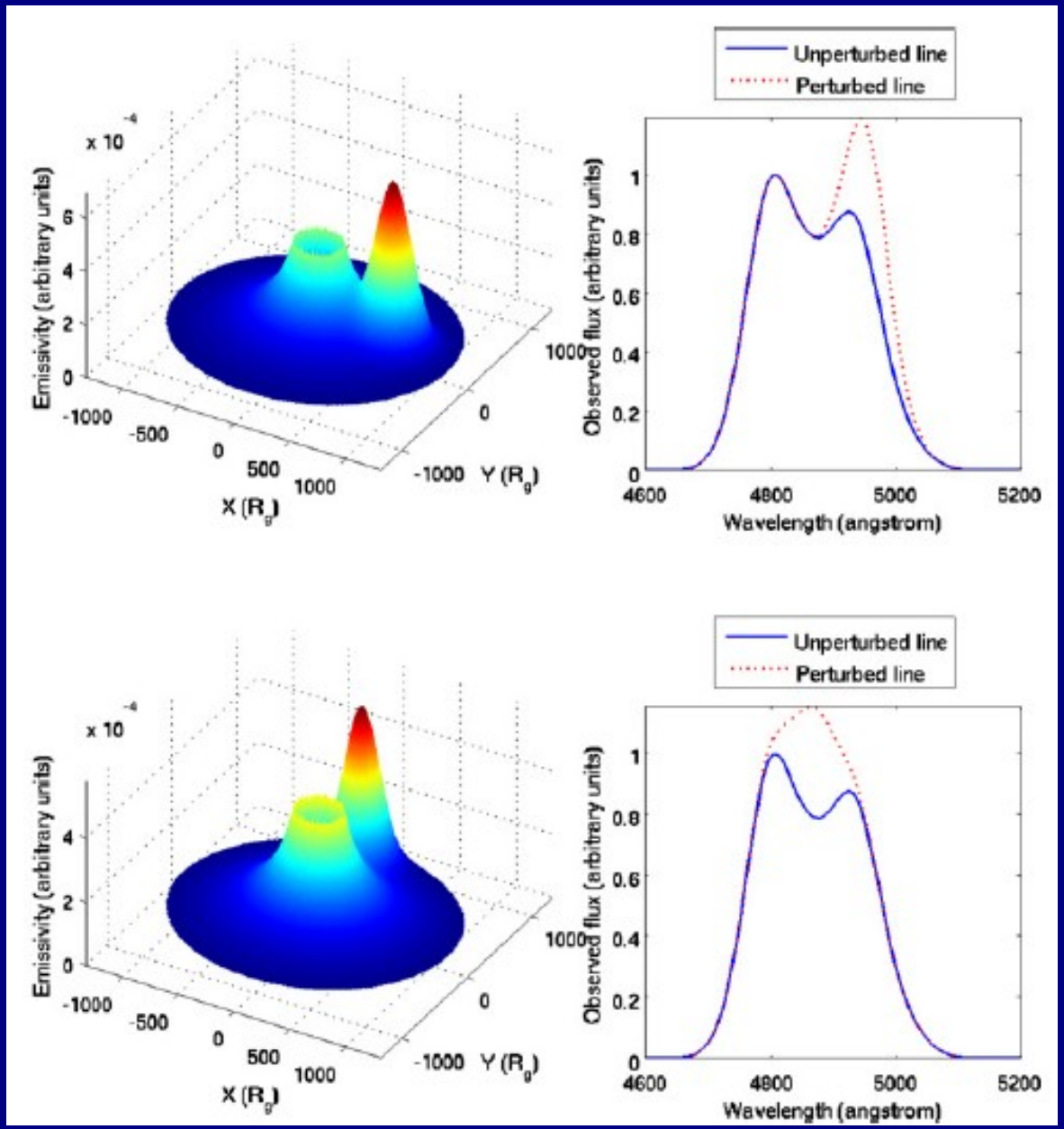
Armitage et al.

Variable(!) correlation of BL profiles with continuum



Gaskell (2011), adapted from Sergeev et al. (2001)

A different approach: off-axis emission

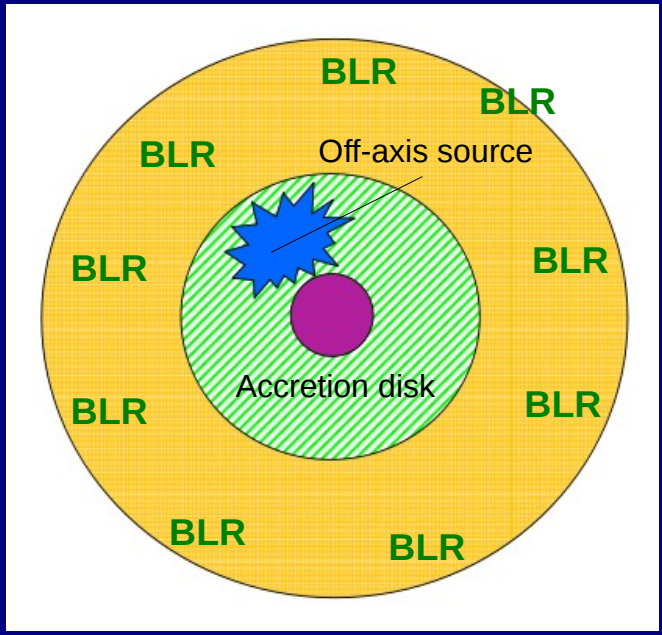


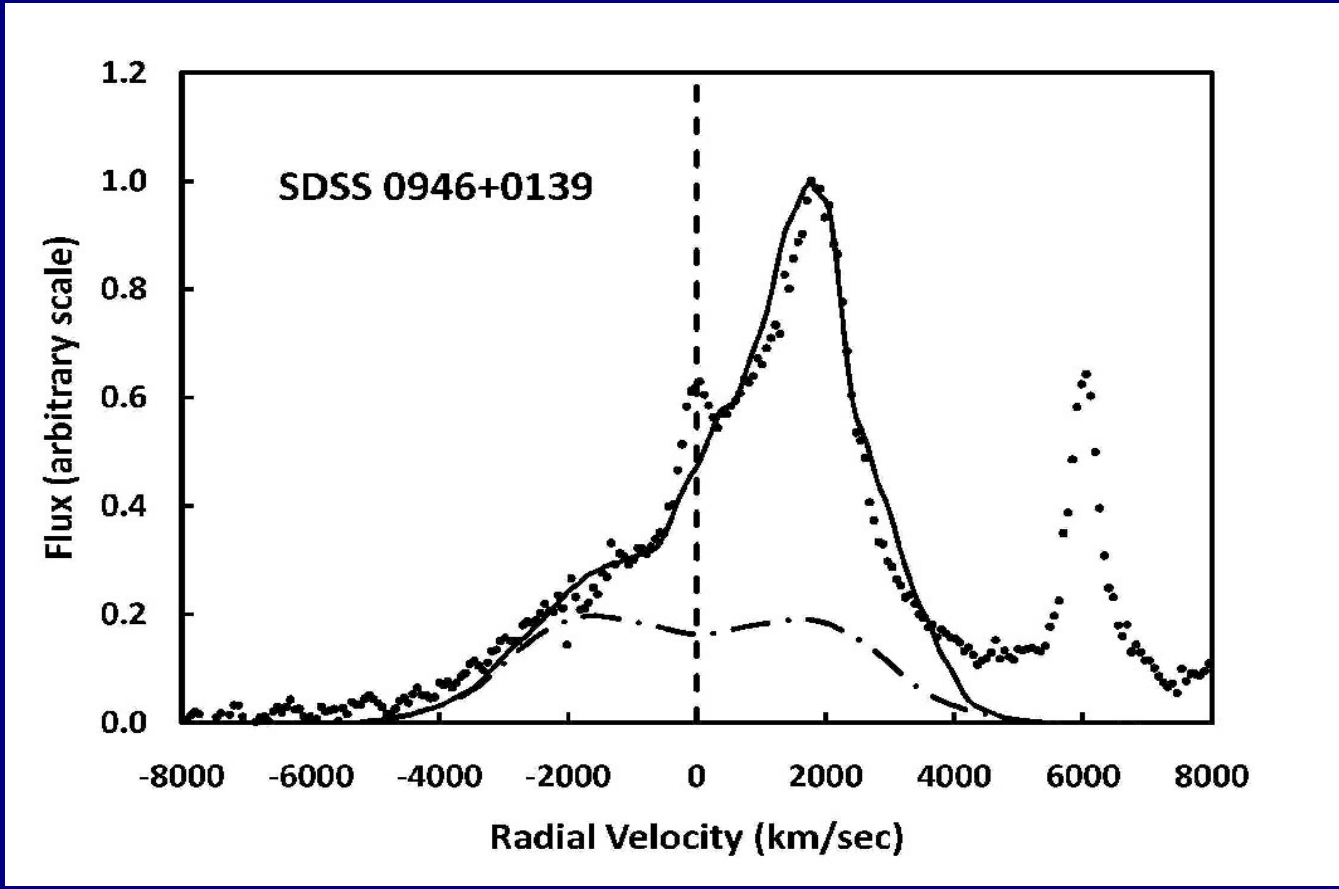
The off-axis irradiation interpretation as worked out by Jovanovic, Popovic, Stalevski, & Shapavalova (2010)

A different approach: off-axis emission

The off-axis scattering model as it is worked out by Gaskell (2011)

RESEARCH IN PROGRESS !



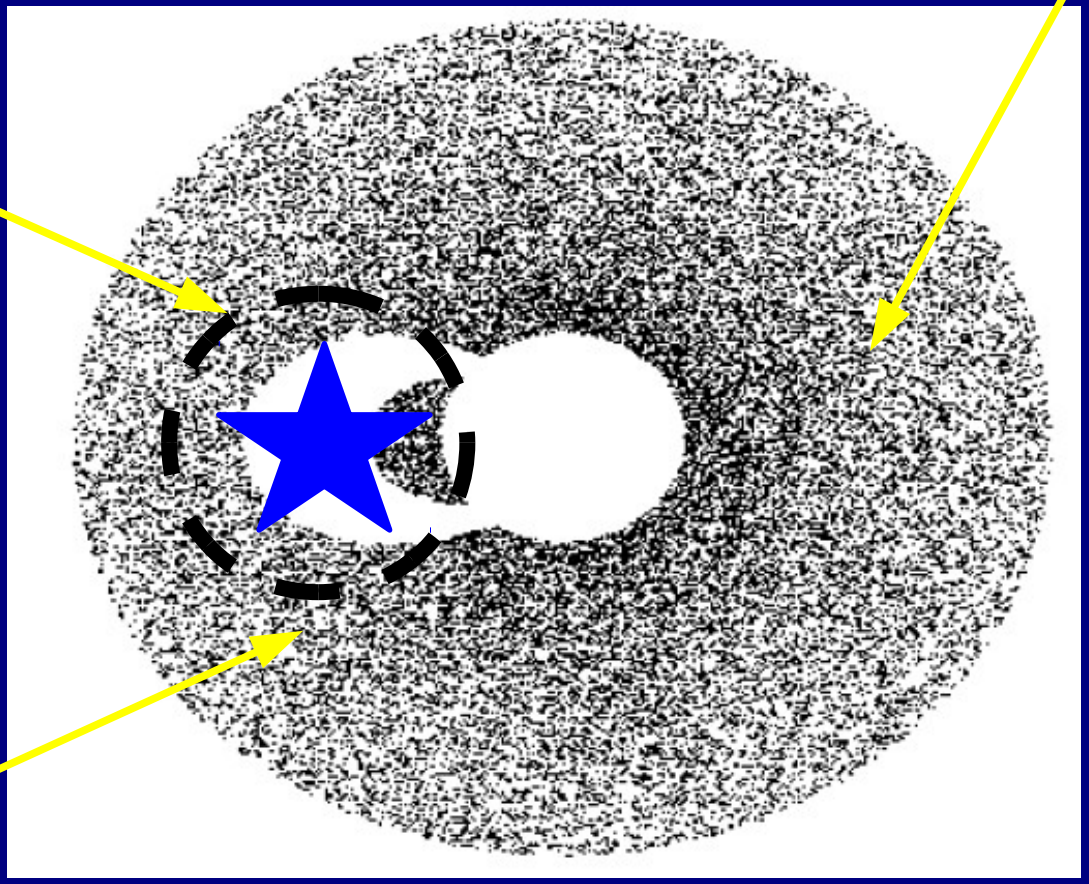


The off-axis model focuses rather on the source than on the scattering regions. The asymmetry lies more in the irradiation pattern and less in the geometry of the different media.

Key element: the $1/r^2$ fall-off in intensity

Maximum polarization on this side

Region corresponding to a narrow range of velocity



Minimum polarization near flaring region (more symmetric)

Modeling of polarized broad emission lines as a function of the source's azimuth has been carried out.

How to implement resonant line scattering

An incoming photon with polarization ***n*** is resonantly scattered with the outgoing polarization ***J***. The change in polarization is governed by a scattering matrix ***S :***

$$\begin{pmatrix} J_{\parallel} \\ J_{\perp} \end{pmatrix} = S \begin{pmatrix} n_{\parallel} \\ n_{\perp} \end{pmatrix},$$

The 4x4 scattering matrix elements are related to the atomic transition between the two atomic levels with degenerate angular momentum M_e state

Lee & Blandford (1997)

$$S_{\parallel\parallel} = \sum_e \left\{ \frac{1}{2} \cos^2\theta_o [(R^{-1}_{ee+1})^2 + (R^{1}_{ee-1})^2] + \sin^2\theta_o (R^{0}_{ee})^2 \right\}$$

$$\times [\cos^2\theta_i C_{e+1} (R^{-1}_{ee+1})^2 + \sin^2\theta_i C_e (R^{0}_{ee})^2]$$

$$S_{\parallel\perp} = \sum_e \left\{ \frac{1}{2} \cos^2\theta_o [(R^{-1}_{ee+1})^2 + (R^{1}_{ee-1})^2] + \sin^2\theta_o (R^{0}_{ee})^2 \right\}$$

$$\times C_{e+1} (R^{-1}_{ee+1})^2$$

$$S_{\perp\parallel} = \sum_e \frac{1}{2} [(R^{-1}_{ee+1})^2 + (R^{1}_{ee-1})^2]$$

$$\times [\cos^2\theta_i C_{e+1} (R^{-1}_{ee+1})^2 + \sin^2\theta_i C_e (R^{0}_{ee})^2]$$

$$S_{\perp\perp} = \sum_e \frac{1}{2} [(R^{-1}_{ee+1})^2 + (R^{1}_{ee-1})^2] \times C_{e+1} (R^{-1}_{ee+1})^2$$

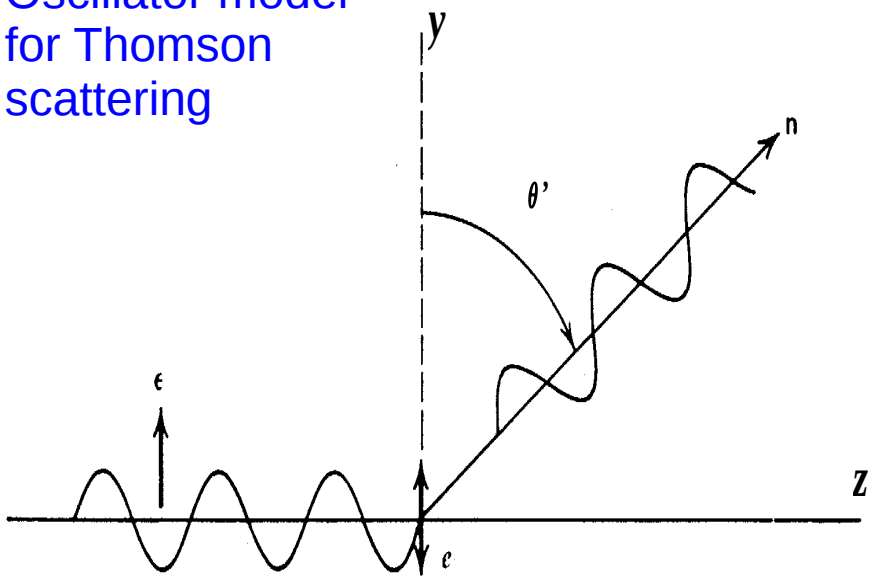
Processes producing (de-)polarization

- Synchrotron emission
- Electron scattering
- Dust (Mie) scattering
- Resonant line scattering
- Dichroic absorption
- Faraday rotation
- Zeeman lilne splitting
- Dilution (by unpolarized radiation)
- General Relativity

Scattering

Strong polarization: Θ = 90° (Reflection)
Weak polarization: Θ = 0° (Transmission)

Oscillator model for Thomson scattering



$$\frac{\partial\sigma}{\partial\omega}(\alpha)_{tot} = \frac{1}{2} r_0 \left(1+\cos^2\theta\right).$$

$$P = \frac{1-\cos^2\theta}{1+\cos^2\theta}.$$

$$\sigma_T = \frac{8\pi}{3} r_0^2 = \frac{8\pi e^4}{3m^2c^4}.$$

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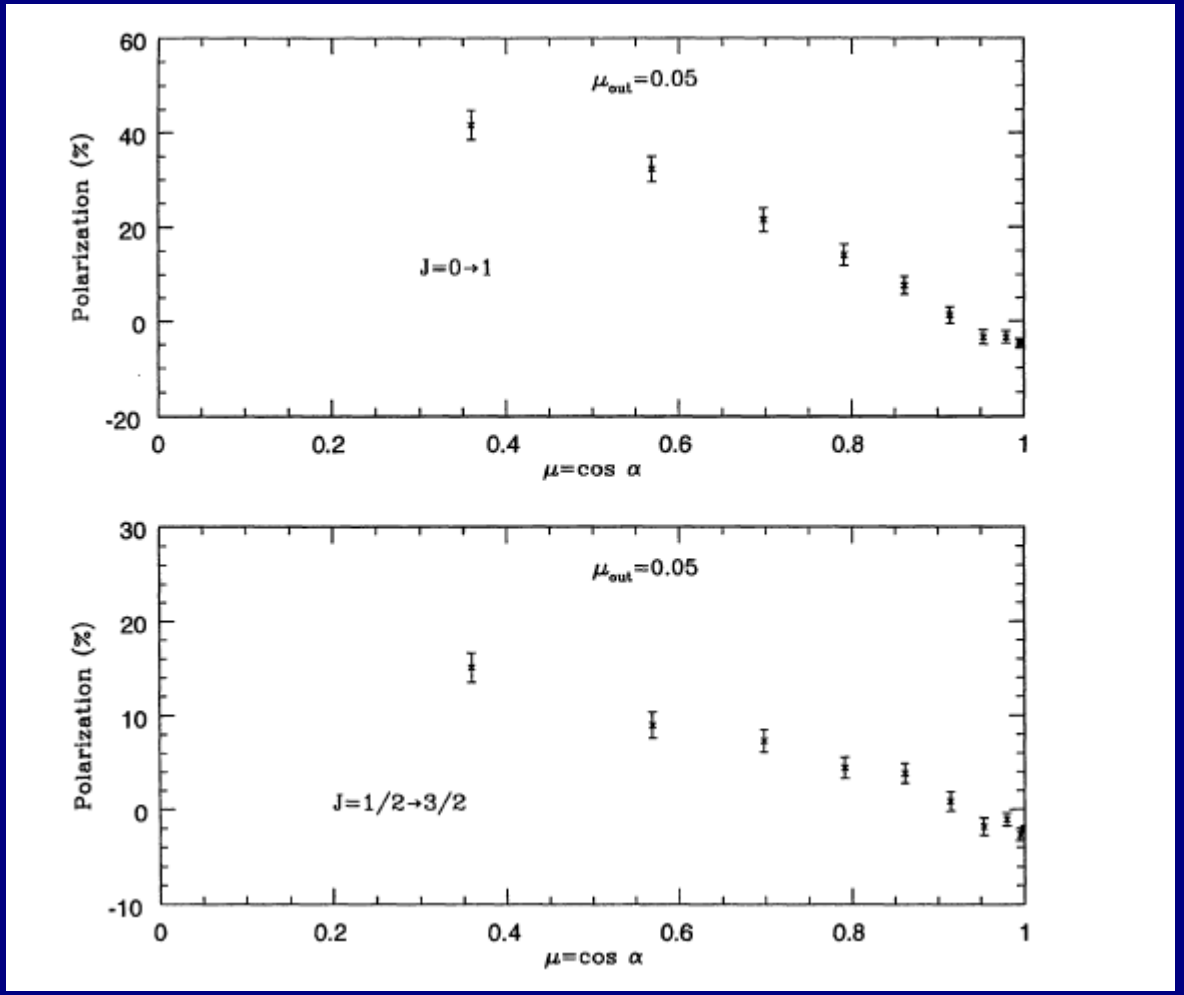
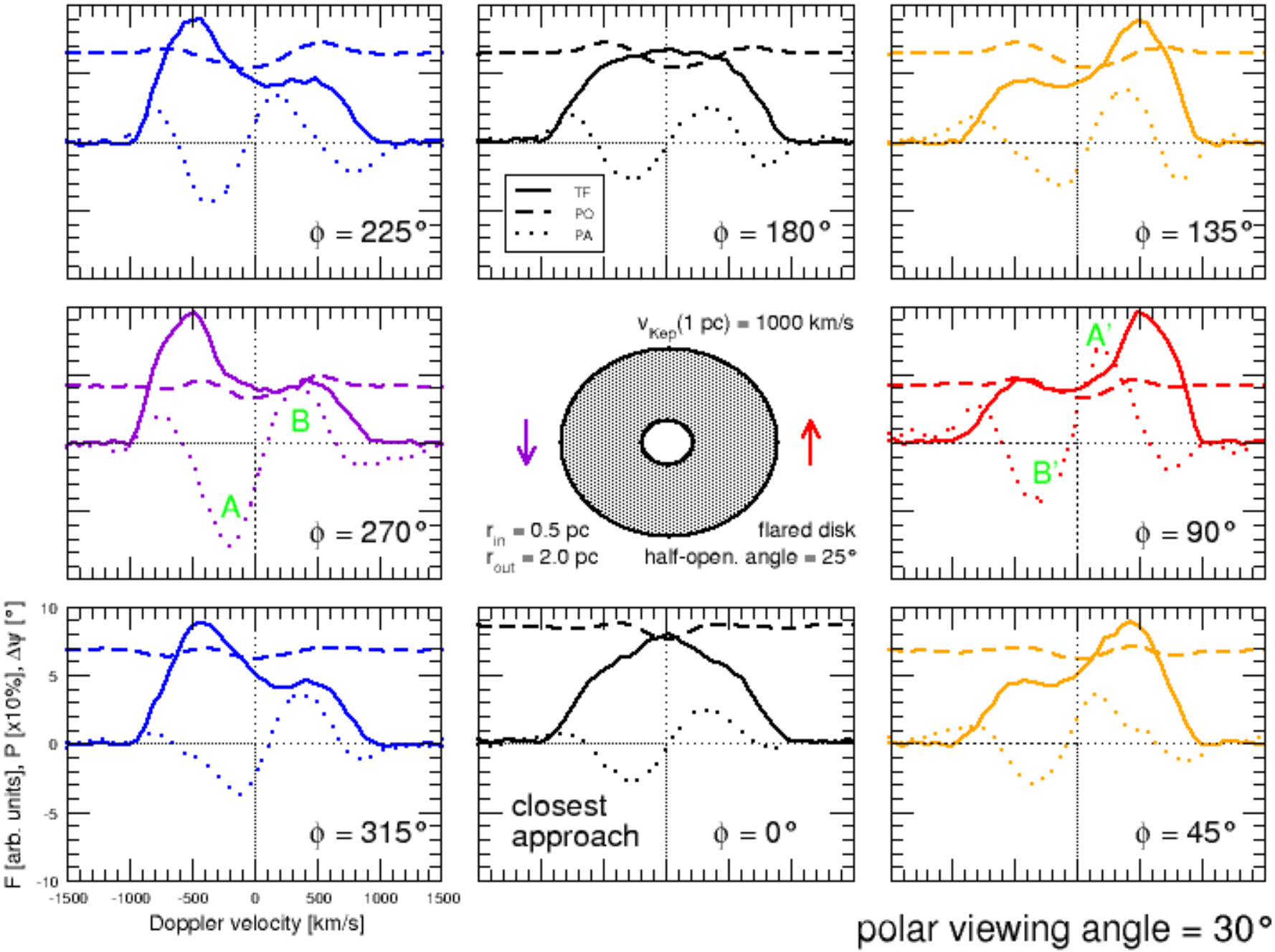


Off-axis irradiation of the BLR as a function of source phase

off-axis source (50% of continuum flux) at inner edge of BLR, Keplerian orbits



polar viewing angle = 30°

The off-axis interpretation also explains...

- changes in reverberation lag
- variability of in very narrow velocity ranges of a line profile
- apparent changes of the direction of motion of the gas as revealed by velocity-resolved reverberation mapping.
- and more … (see Gaskell 2010, 2011)

Off-axis irradition potentially is an alternative interpretation to the presence of binary black holes.

Time-variability of polarized broad emission lines are key to test the off-axis model (monitoring program on the way).

New collaboration with D. Iljic, L. Popovic and collaborators is on the way!