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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With a lot of input by my collaborators

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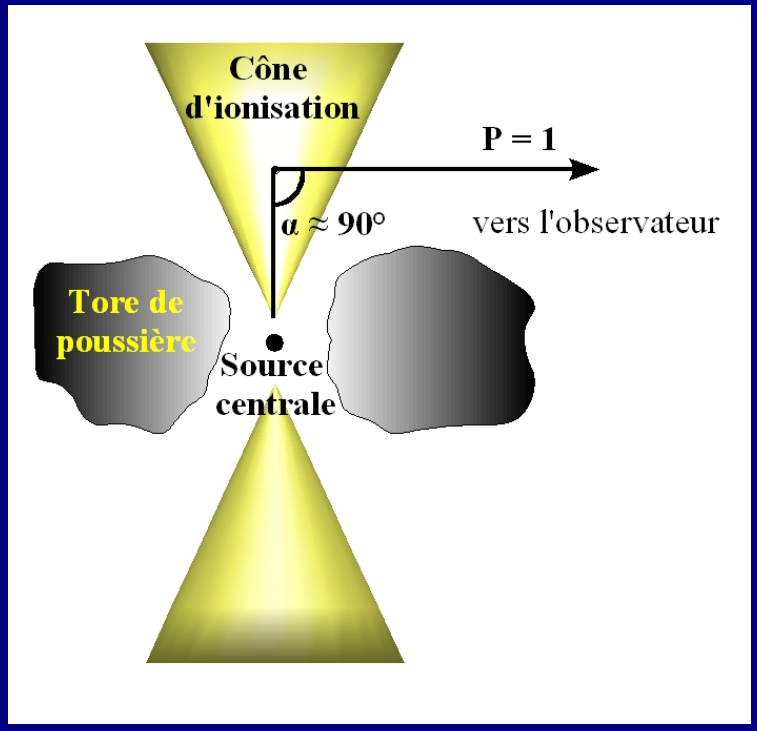
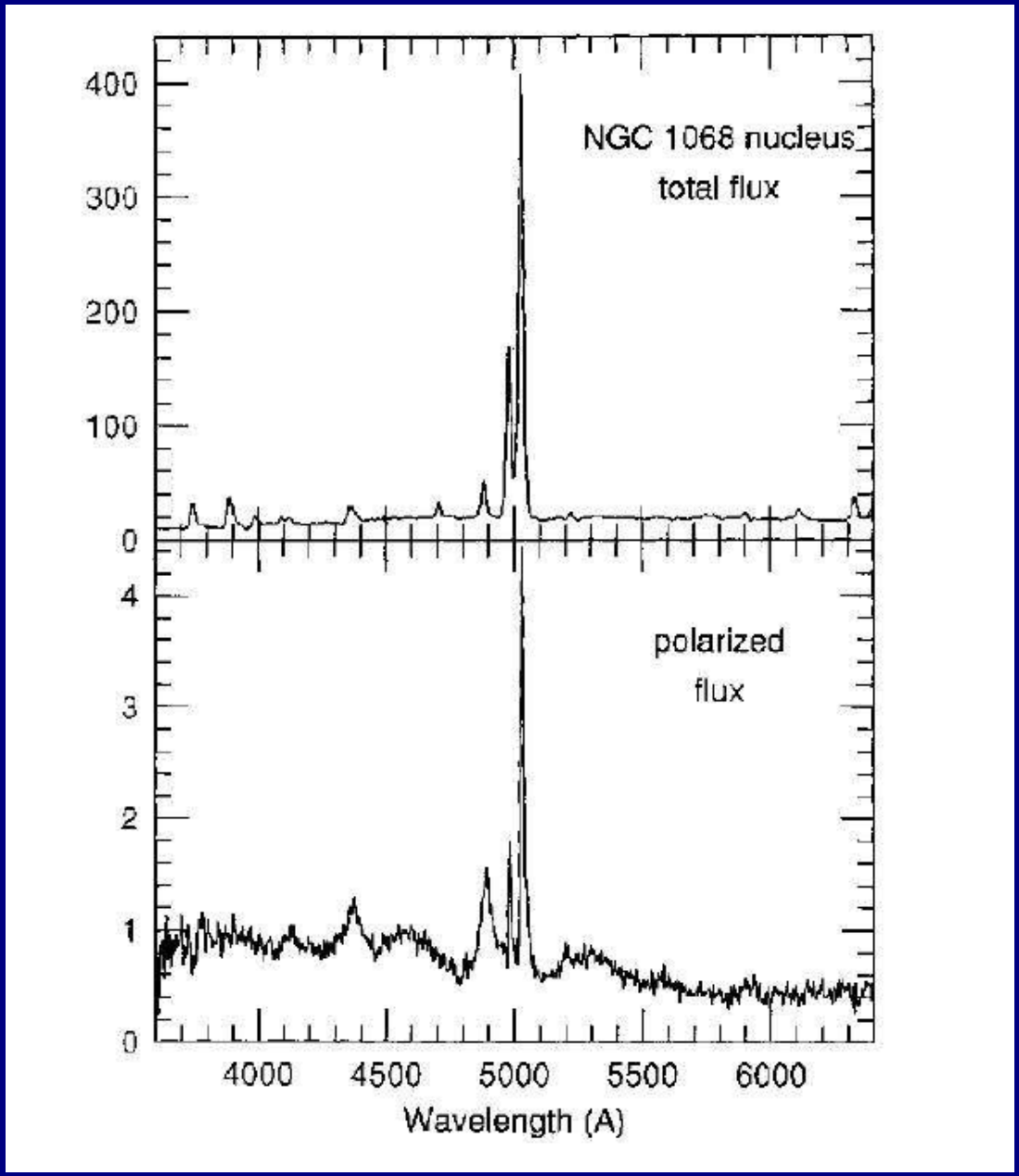
Radio-quiet objects Hidden type-1 AGN

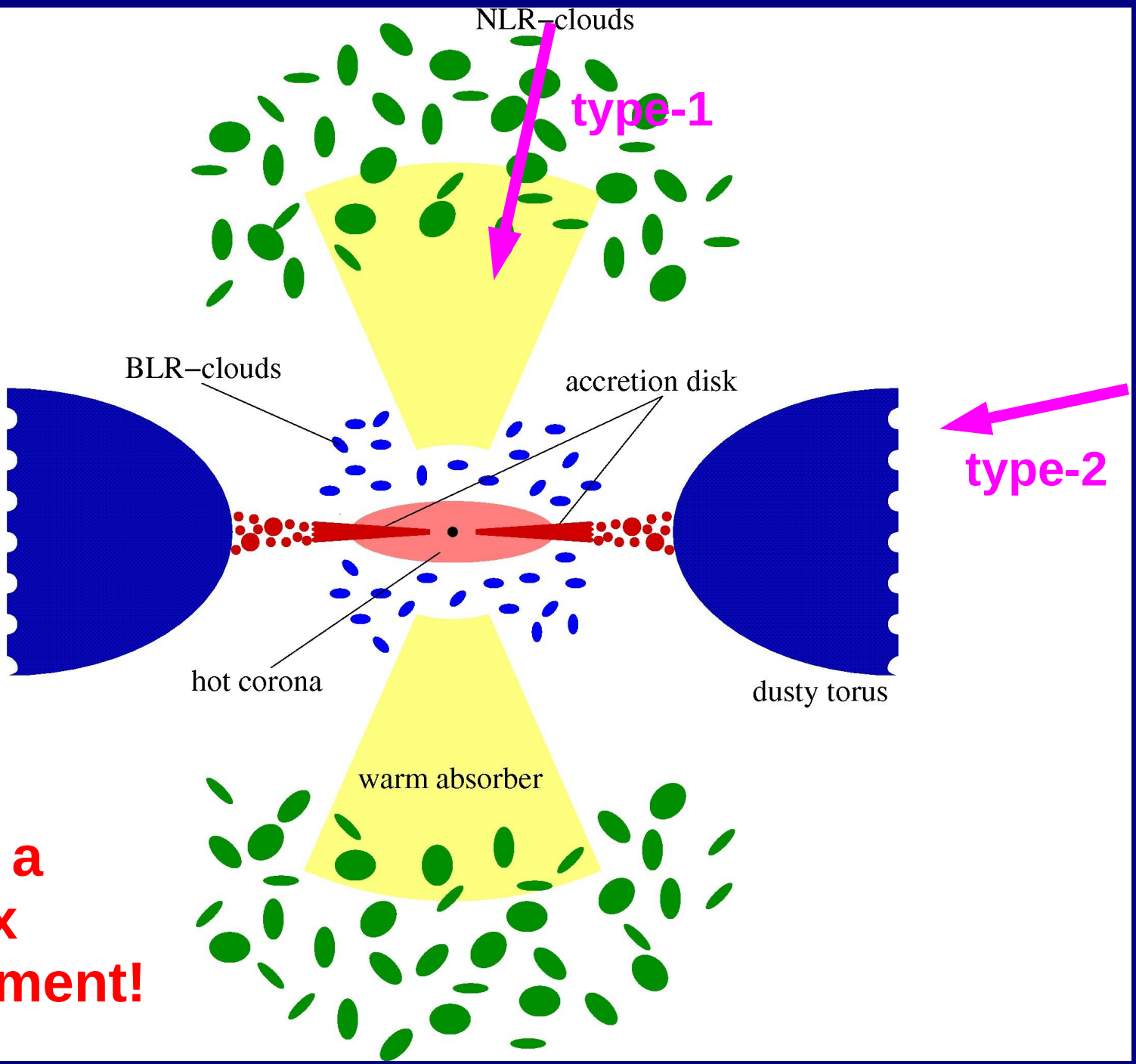
A major break-through for the unified model with NGC 1068 (Antonucci & Miller 1985)

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





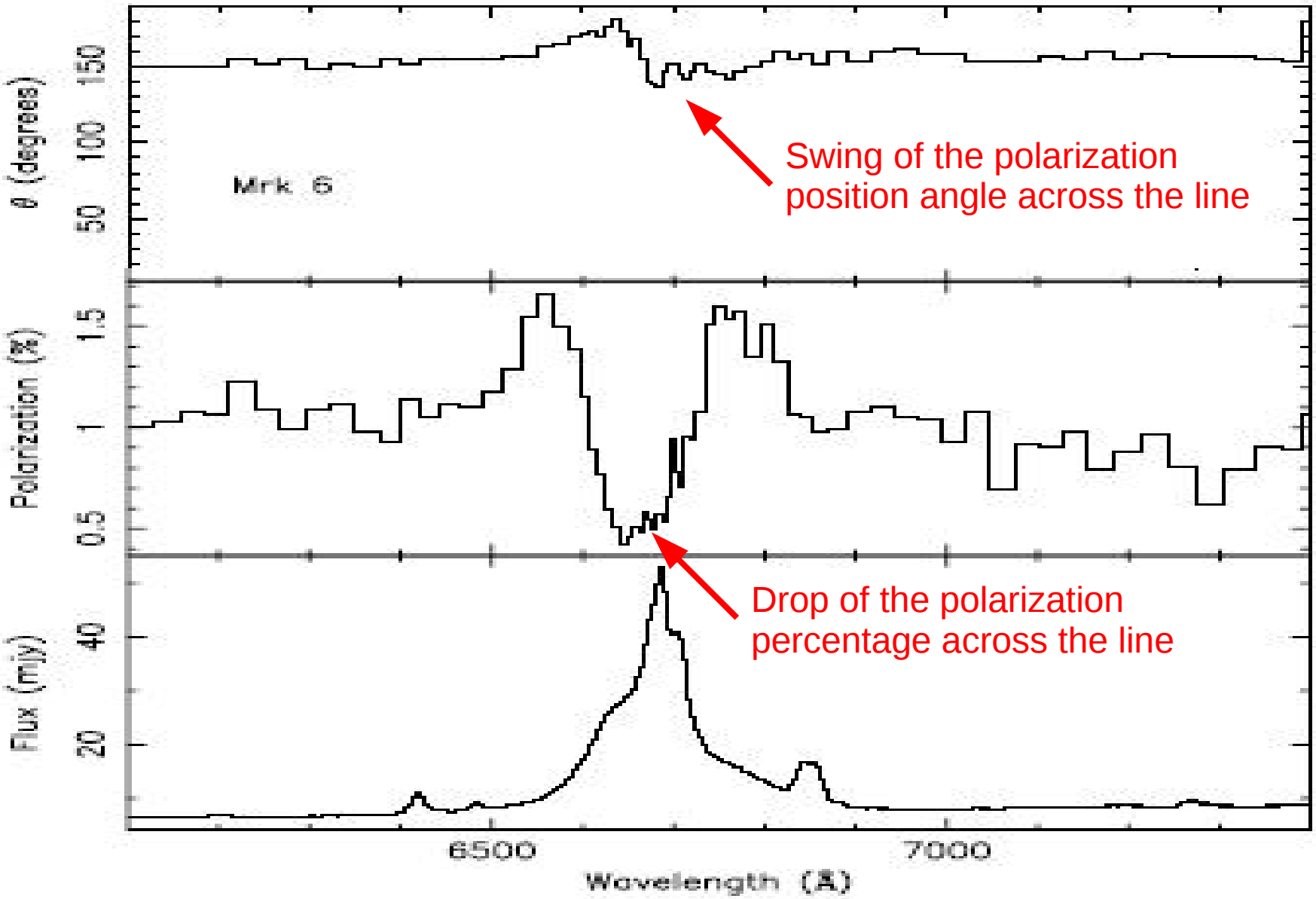
Accreting supermassive black holes...



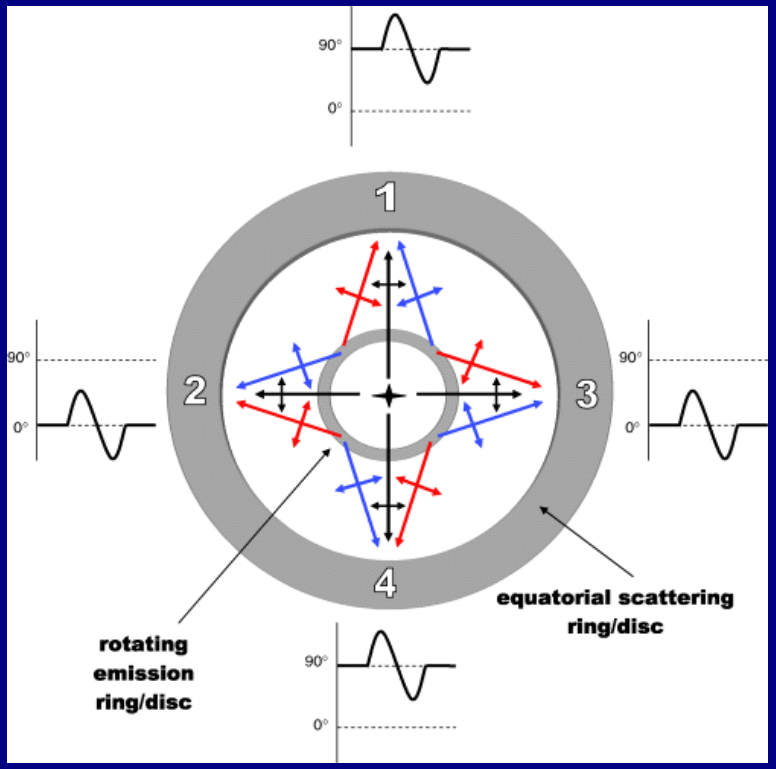
...live in a complex environment!

Spectropolarimetry of broad lines

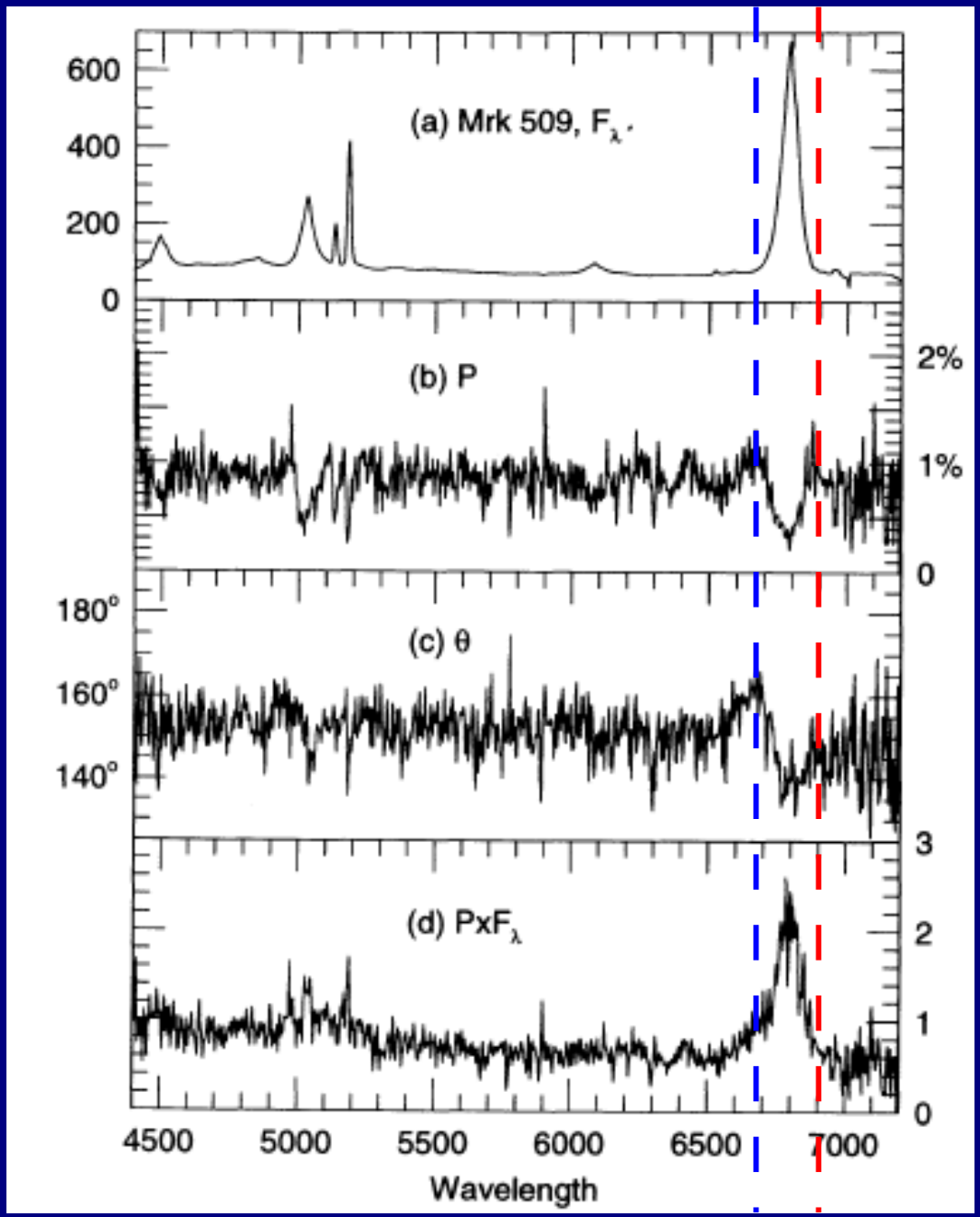
Smith et al. (2002)



Rotation of polarization angle across emission line



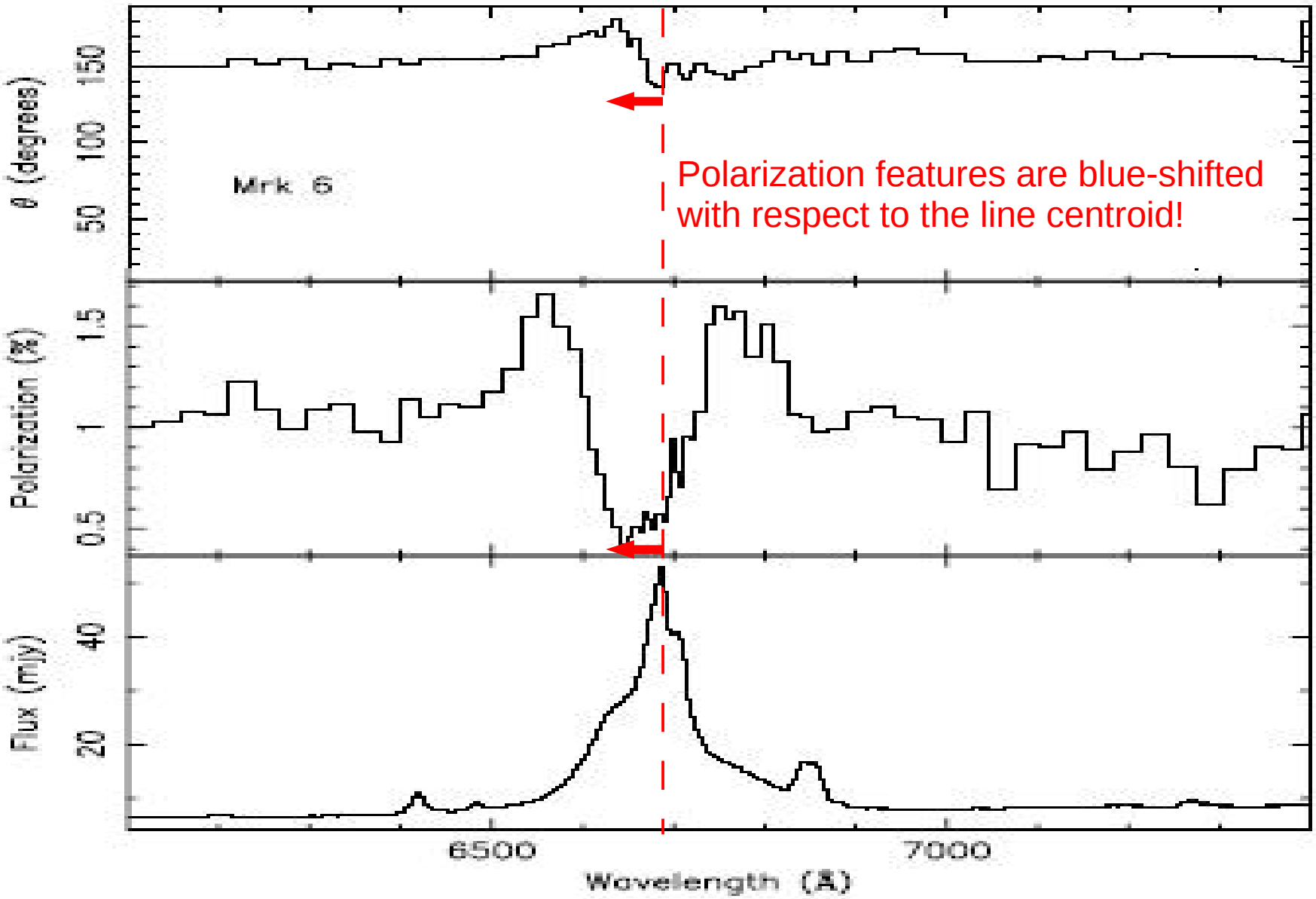
Interpretation and modeling
by Smith et al. (2005)



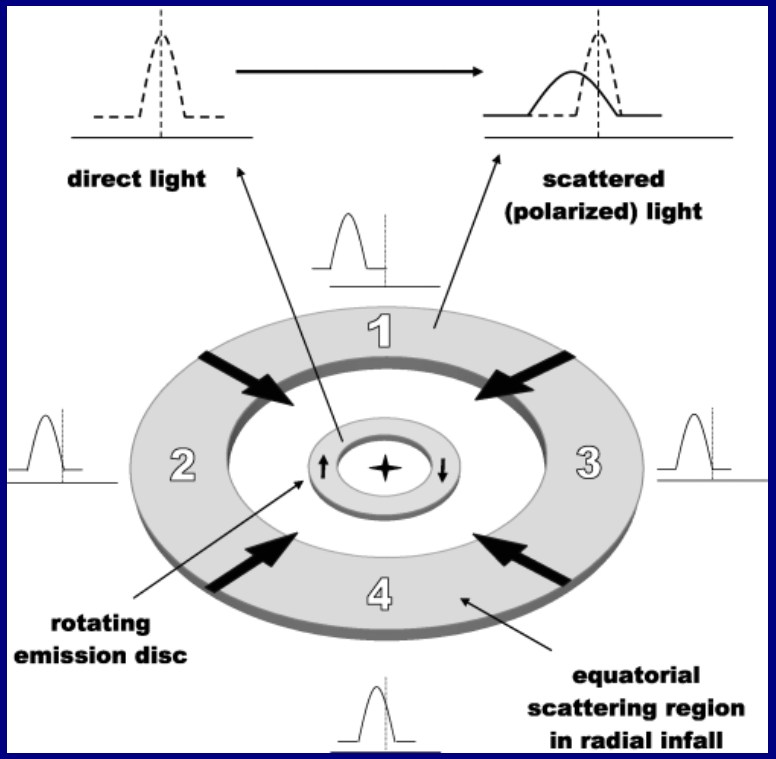
Spectropolarimetric data for Mrk 509
from Goodrich & Miller (1994)

Spectropolarimetry of broad lines

Smith et al. (2002)



Blue polarization wing of the emission line



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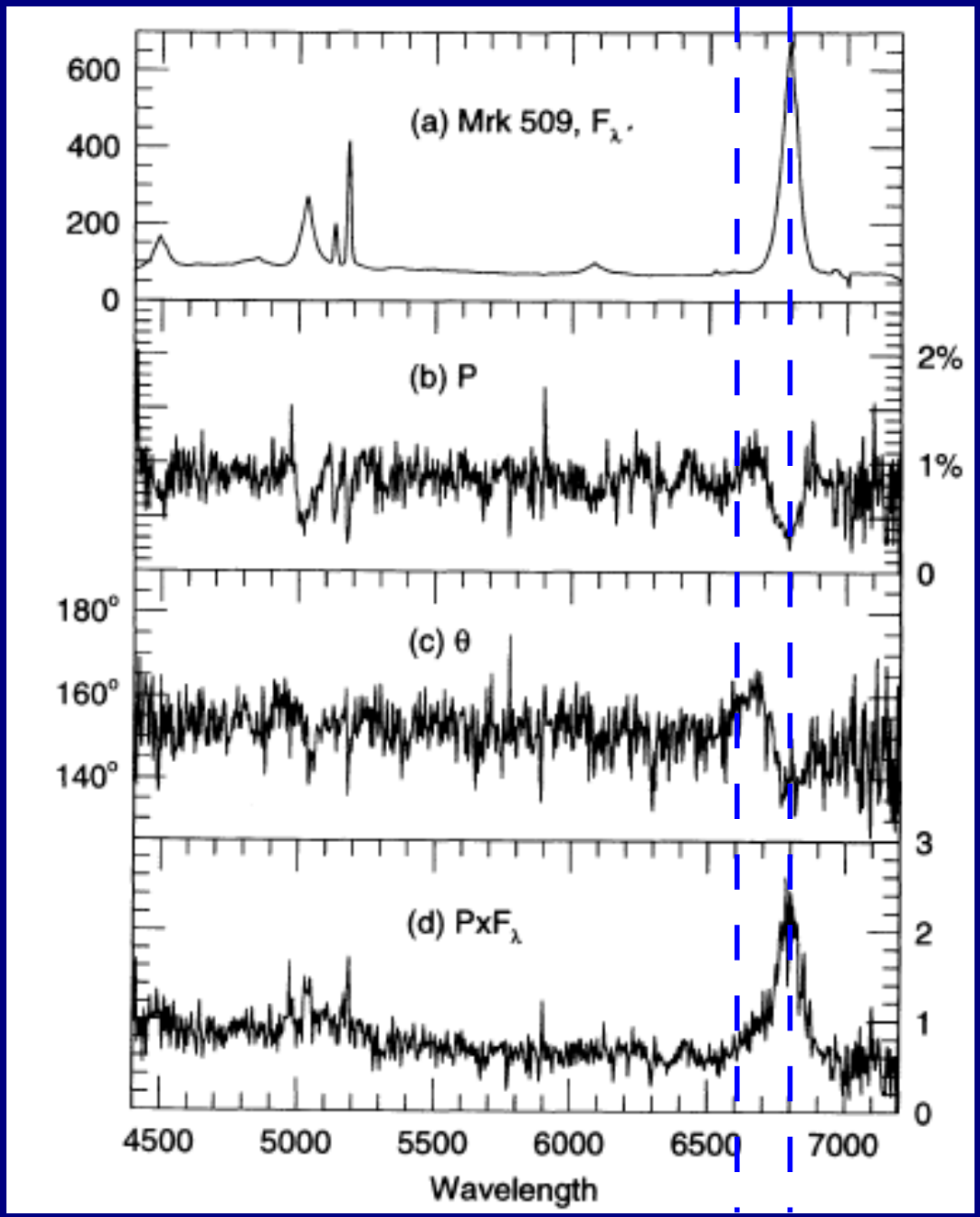
Similar work on NGC 3783 (Lira et al. 2007)



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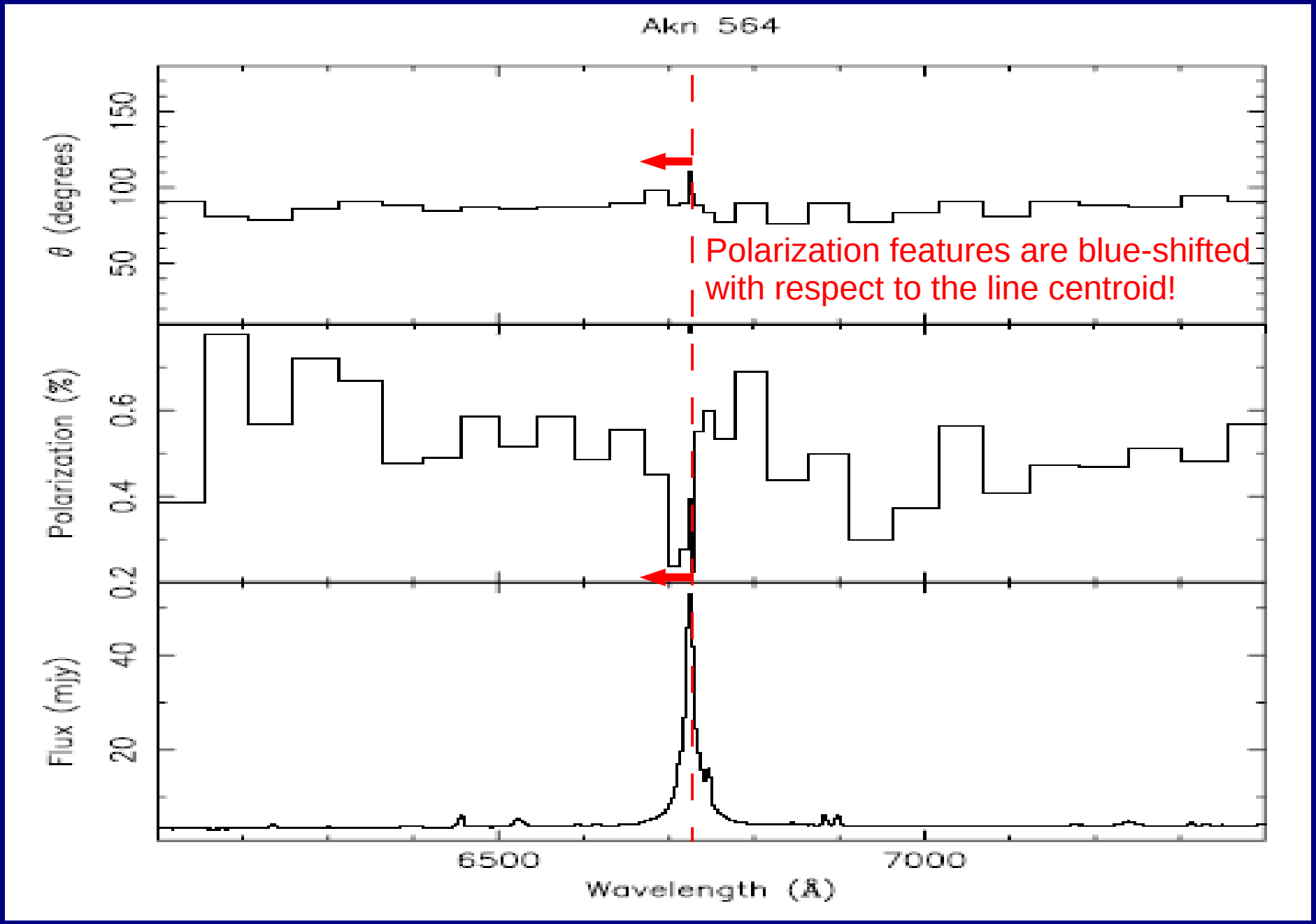

Smith et al. (2002)

Spectropolarimetry of broad lines

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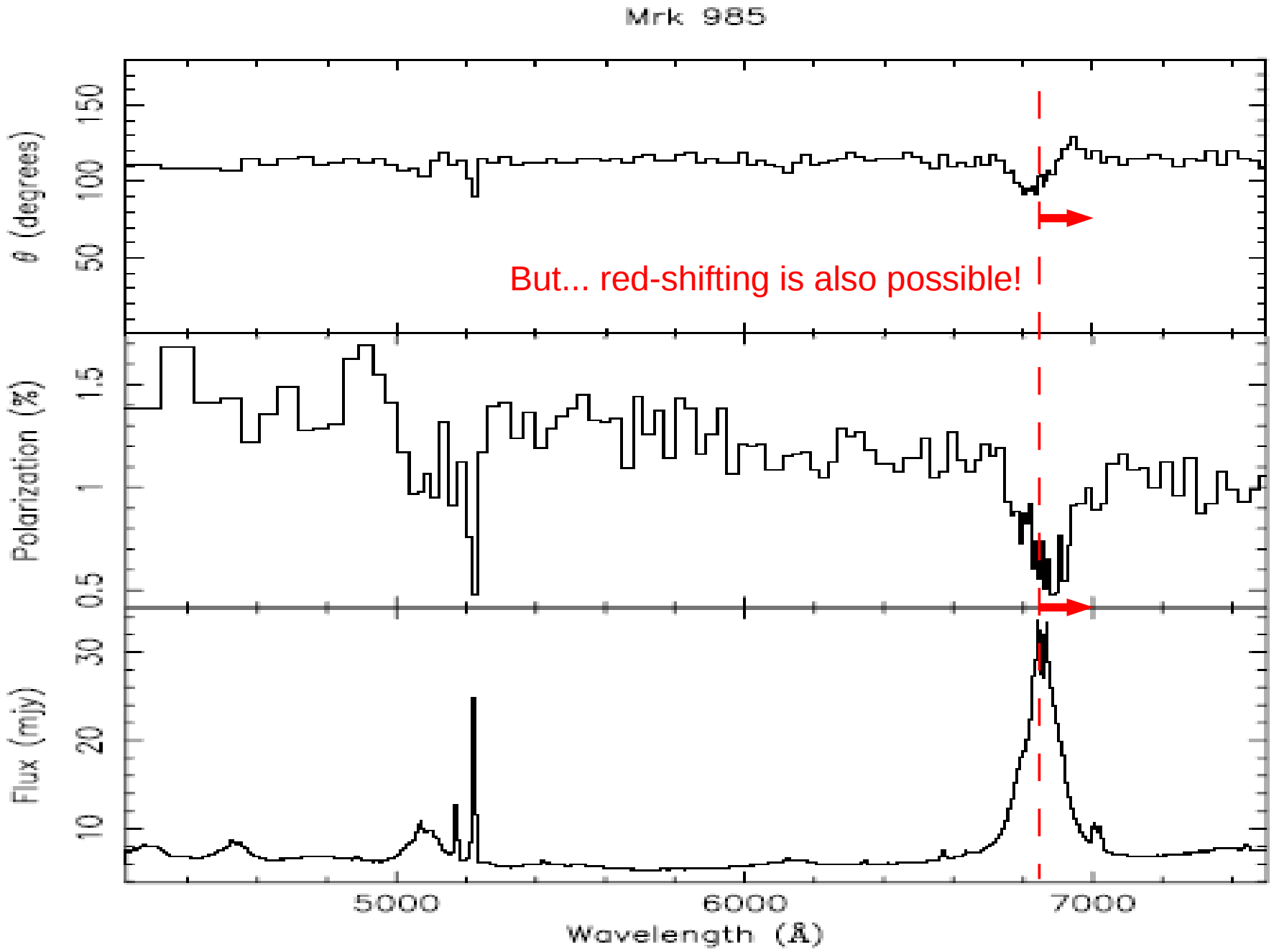
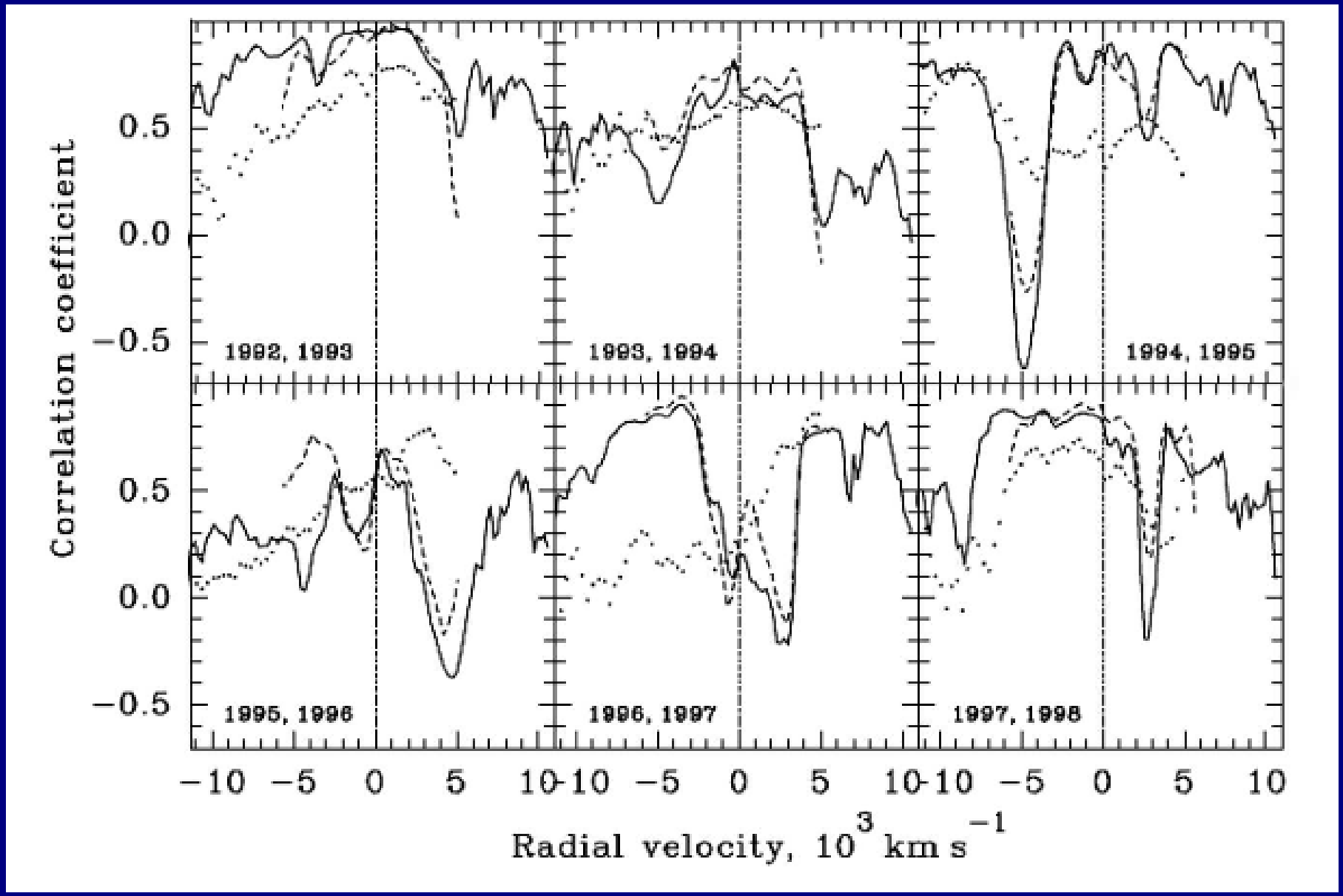
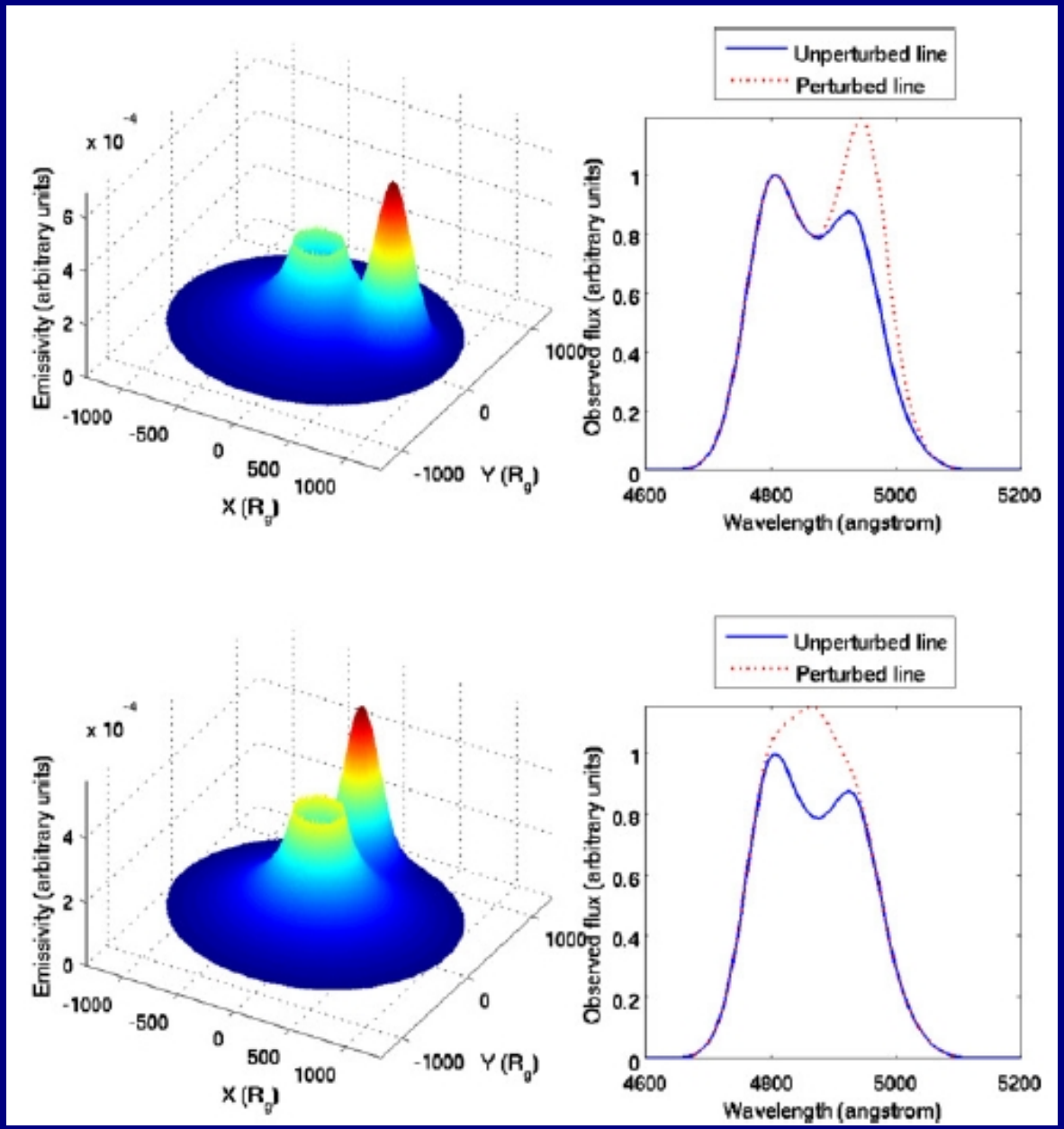


Variable(!) correlation of BL profiles with continuum



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):

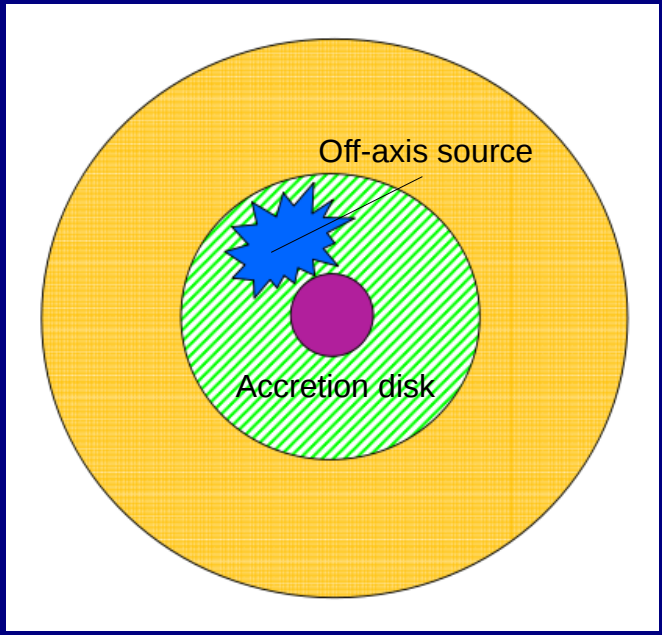
The line profile is a superposition of

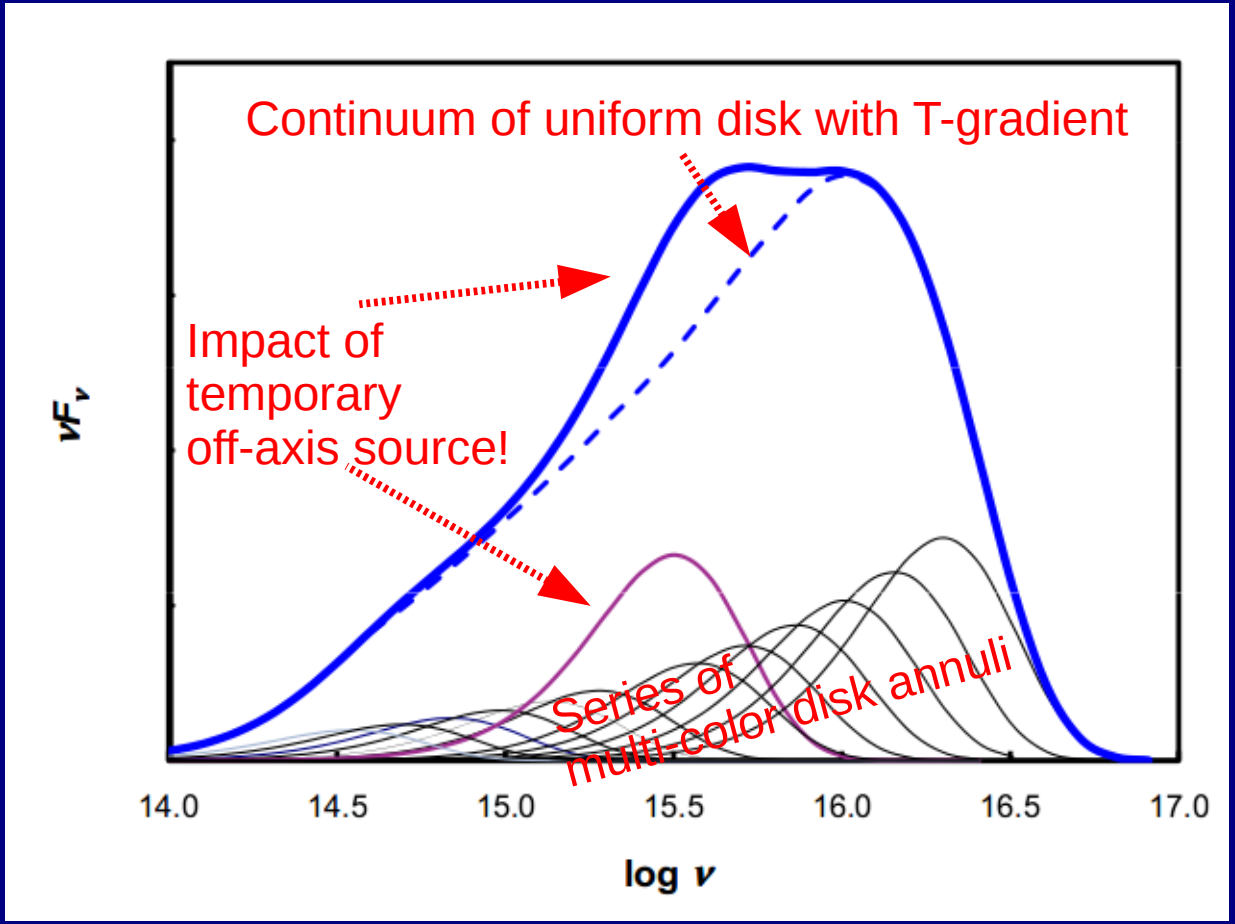
→ emission from a compact, off-axis source rotating with a Keplerian Doppler velocity

→ underlying disk emission due to a radial tempertaure gradient

Continuum variability requires emission to be off-axis!

Continuum emission of a uniform disk with temperature gradient + a local off-axis source Gaskell (2008).





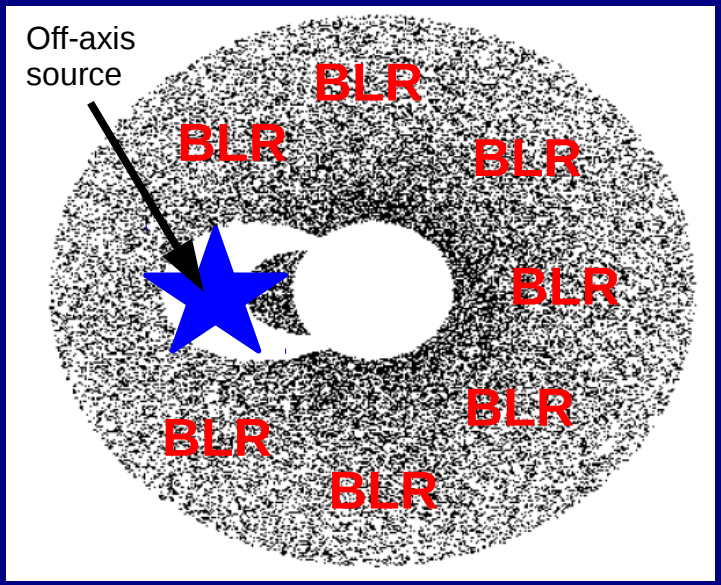
➔ The observed variability across a narrow band in wavelength requires variable emission from a narrow annulus of the disk.

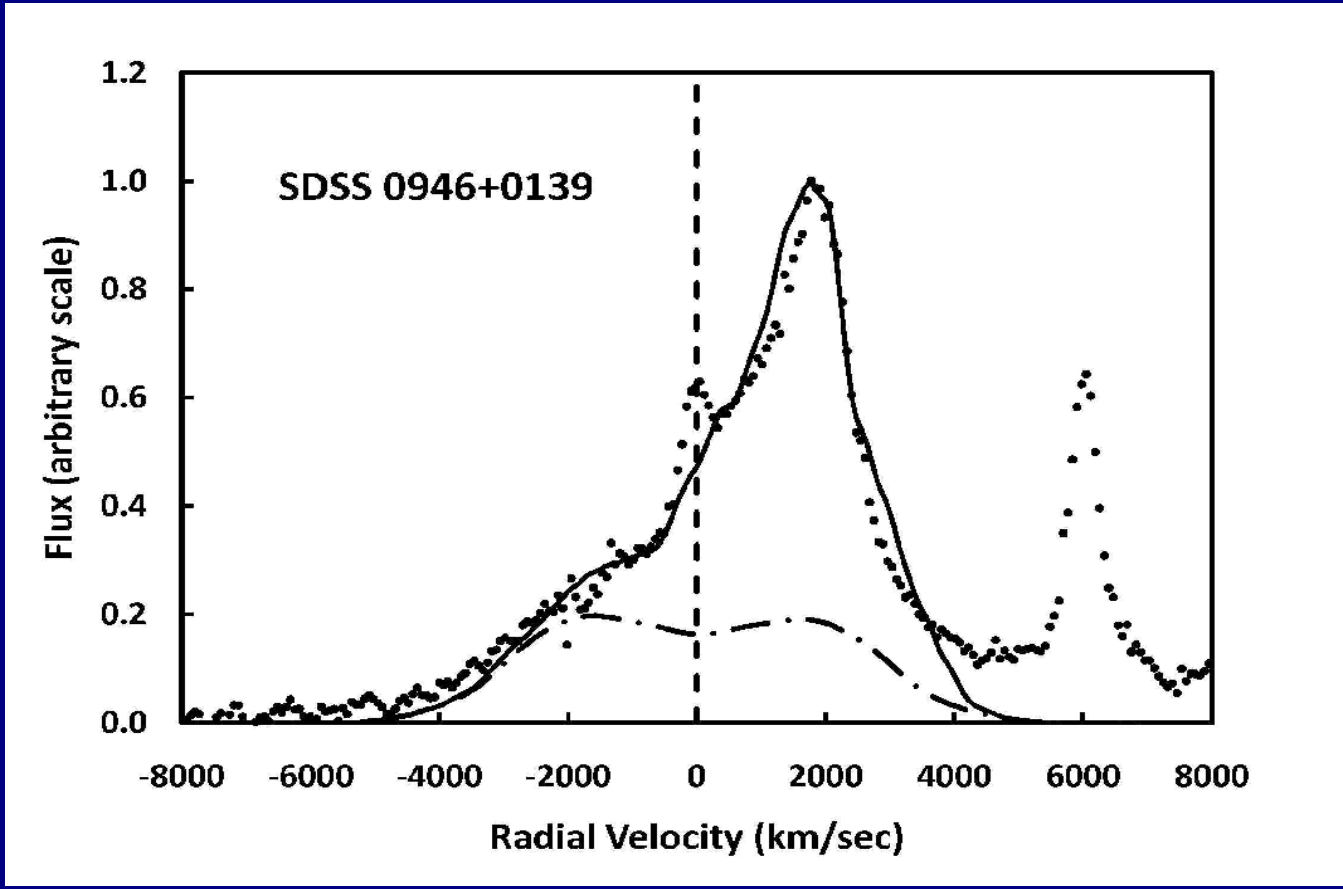
➔ Due to a finite light travel time the annulus cannot vary coherently. The variable source must be compact and off-axis!

Line profiles from off-axis irradiation of the BLR

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

RESEARCH IN PROGRESS !



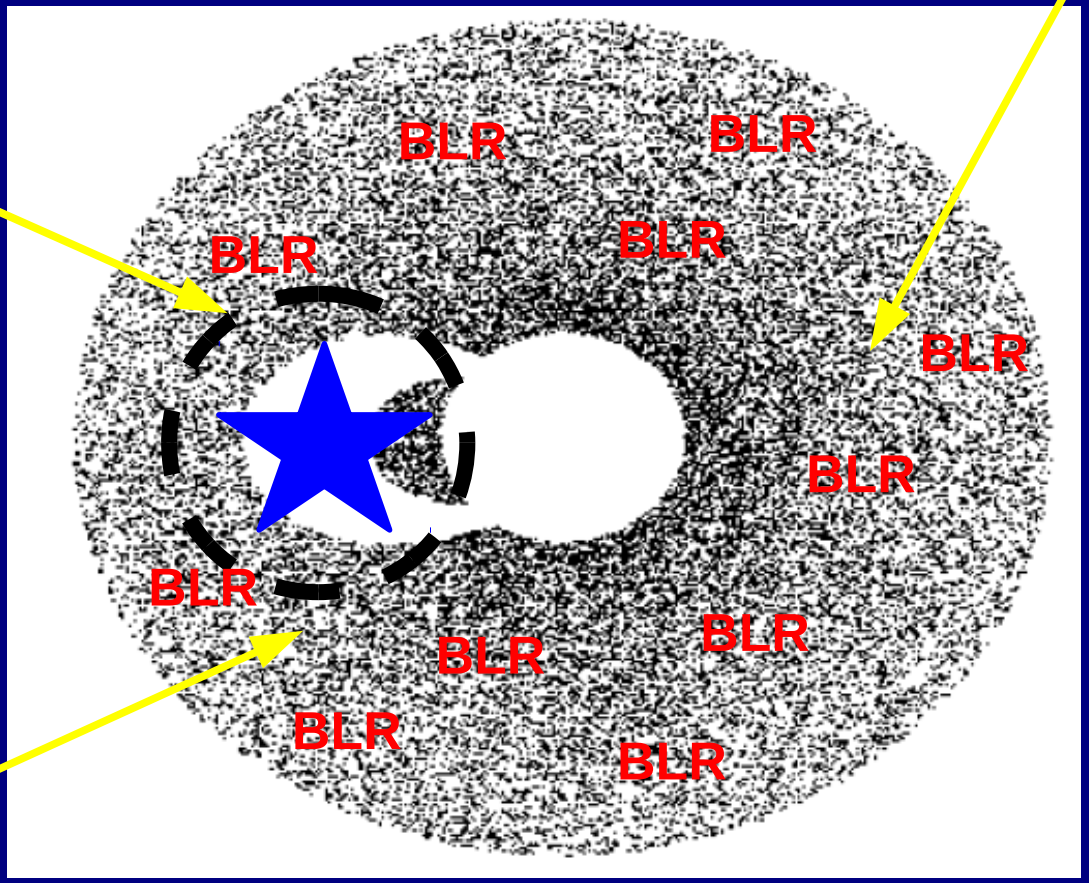


The off-axis model focuses rather on the source than on the scattering regions. The asymmetry lies more in the irradiation pattern and less in the geometry of the different media.

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

Maximum polarization on this side

Region corresponding to a narrow range in Doppler velocity



Minimum polarization near flaring region (more symmetric)

We carried out modeling of polarized broad emission lines as a function of the source's azimuth...

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 state M_e.

Lee & Blandford (1997)

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

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

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

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

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

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

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

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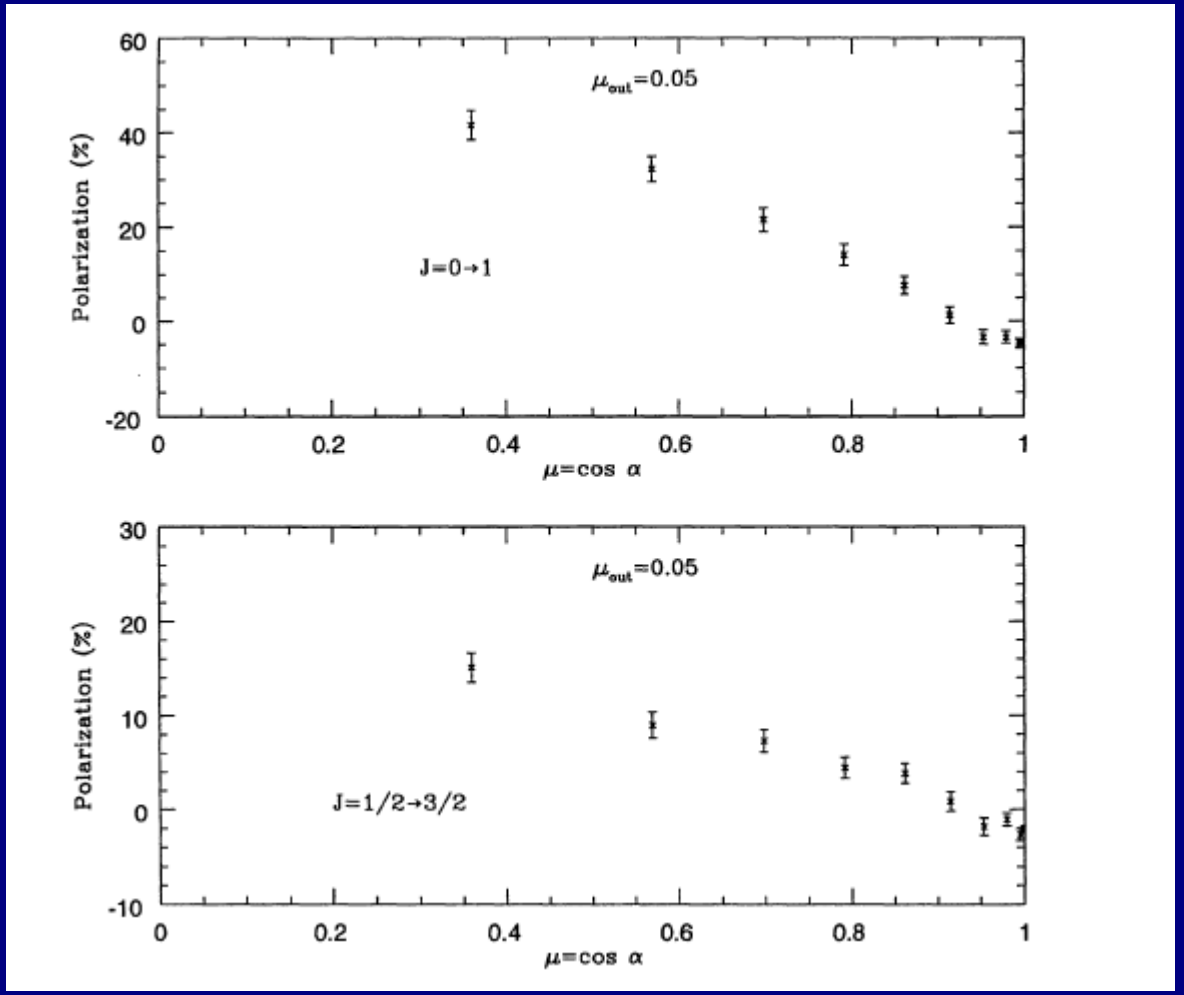
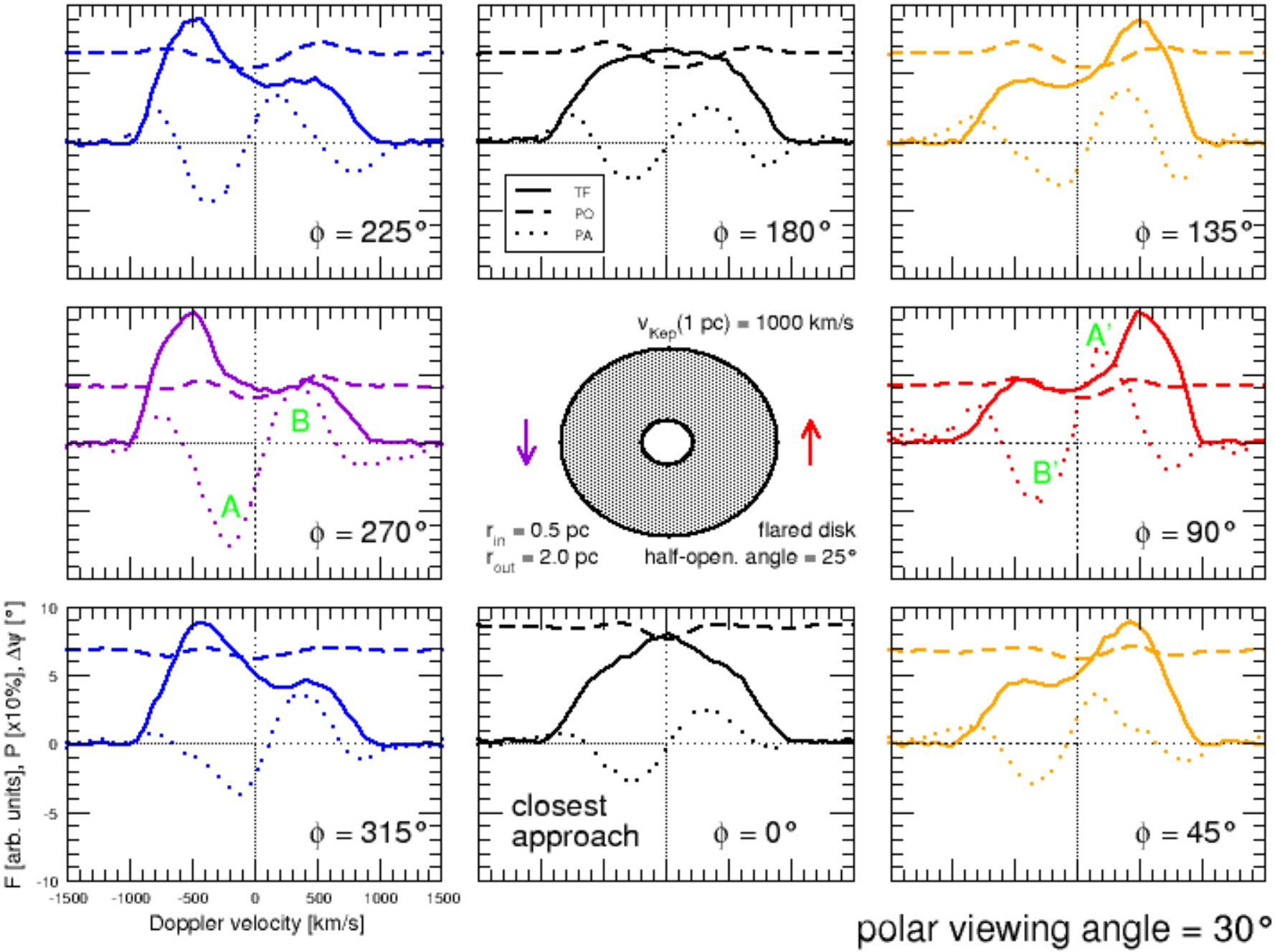


Off-axis irradiation of the BLR as a function of source phase

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 lags with time
- variability 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 2008, 2010, 2011)

Off-axis irradition potentially is an alternative interpretation to the presence of rotating scattering regions or binary supermassive black holes.

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