Variability in AGN polarized spectra - a view to the BLR and torus structure

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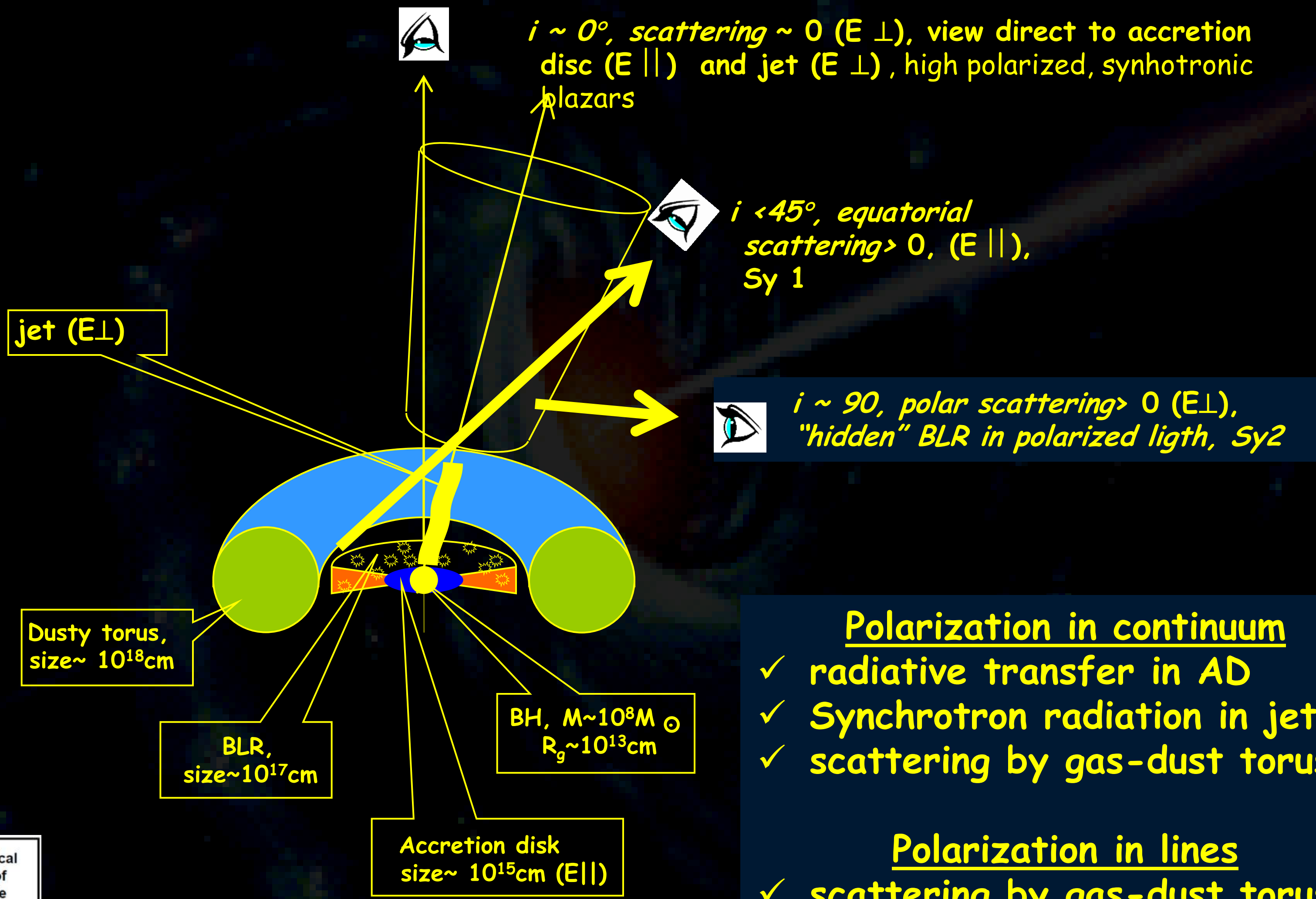
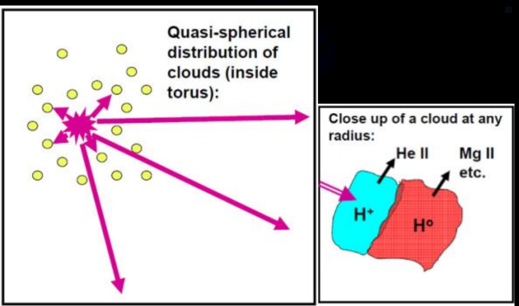
AGN Reverberation Mapping , Lijiang, Oct. 24-26

Polarization in AGNs





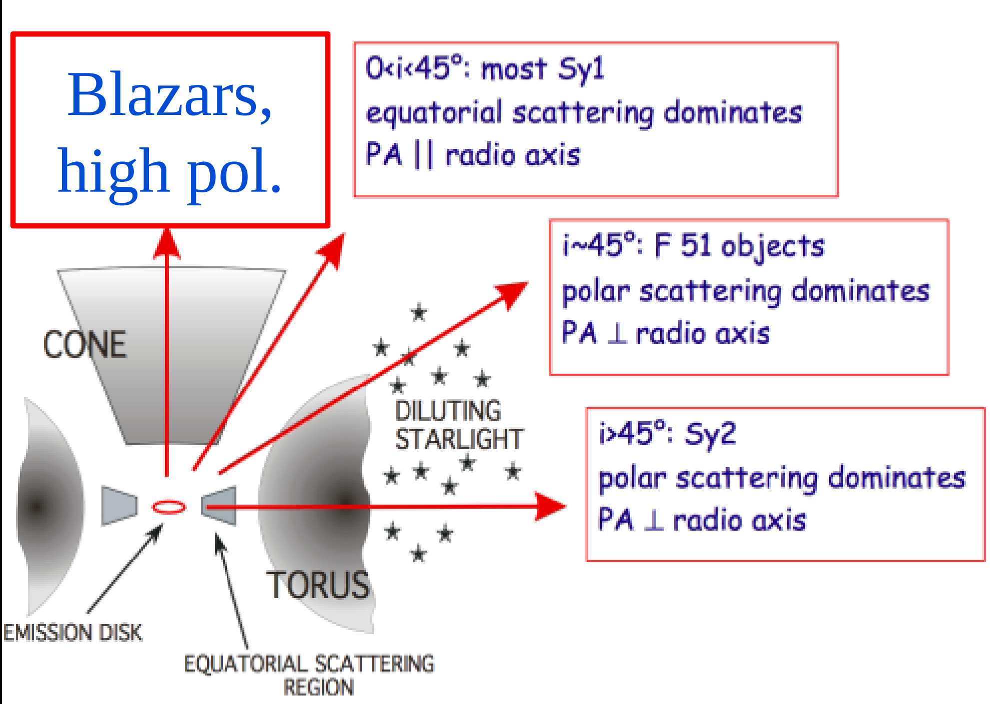
Polarization in continuum

- ✓ radiative transfer in AD
- ✓ Synchrotron radiation in jet
- ✓ scattering by gas-dust torus

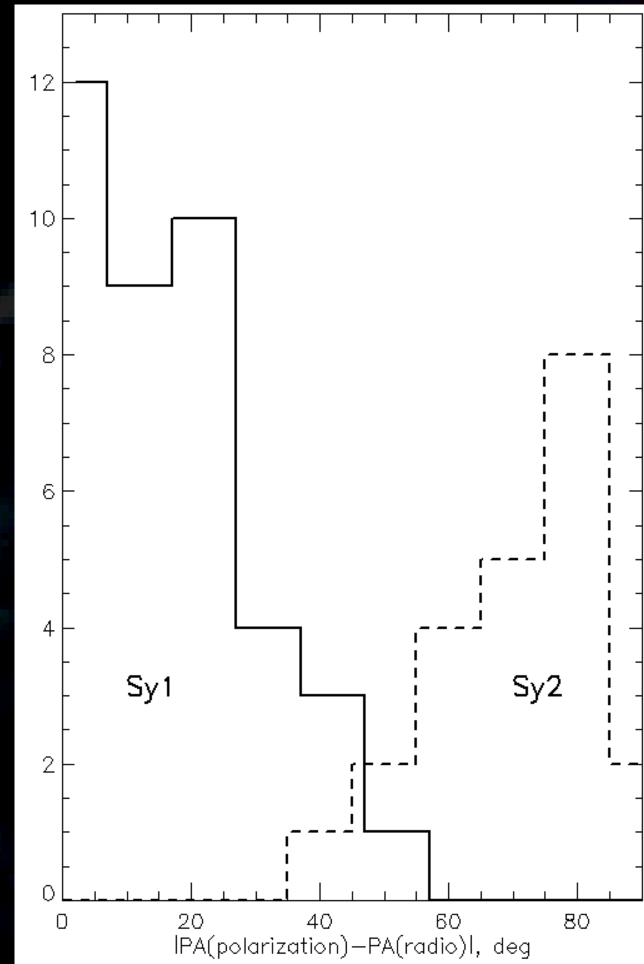
Polarization in lines

- ✓ scattering by gas-dust torus
- ✓ radiative transfer in the BLR

Polarization of AGNs - a simple (UNIFIED) model



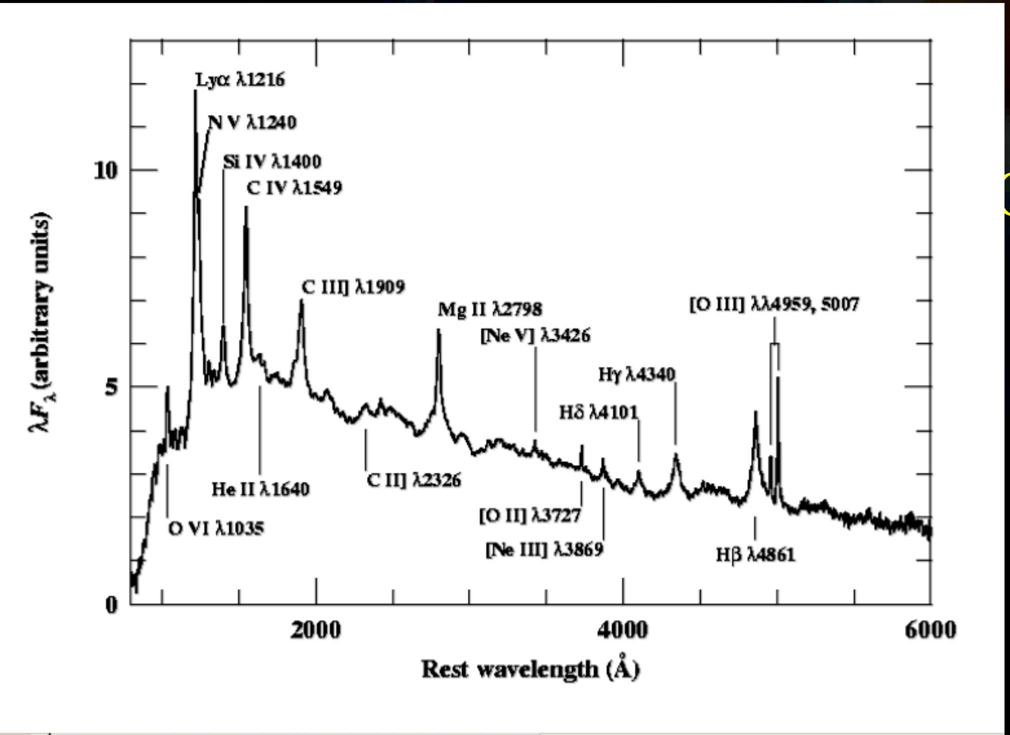
Relation between polarization class and orientation in the generic scattering geometry that broadly explains the optical polarization spectra of Seyfert galaxies Smith et al. (2004)

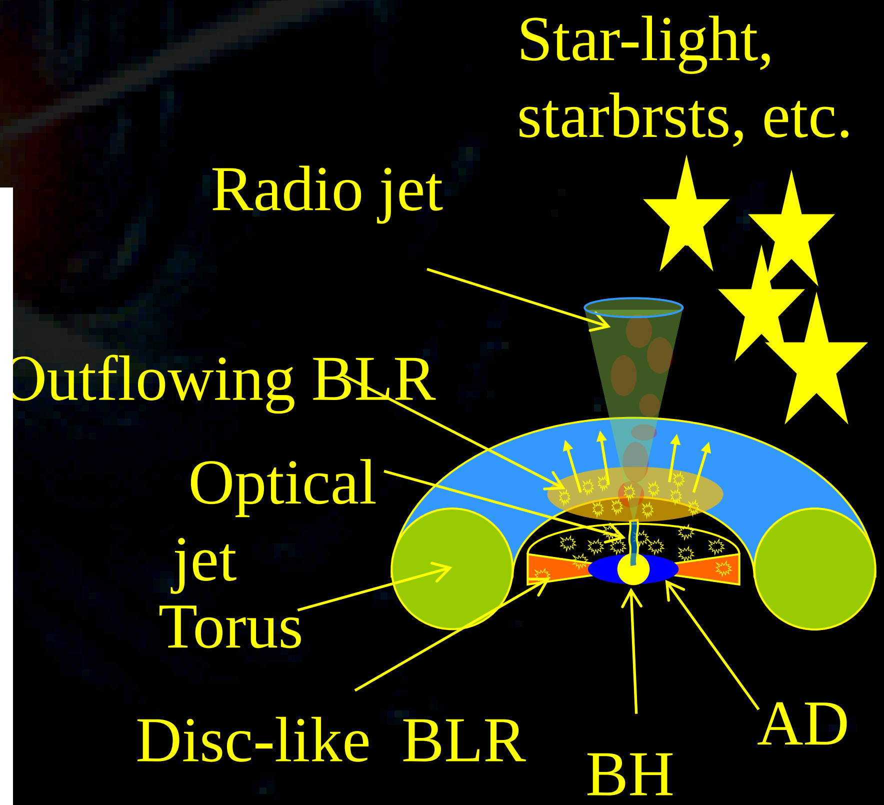


Orientation is important !

Optical emission of AGNs

The structure can be more complex. Emission in the optical is commig from differet regions





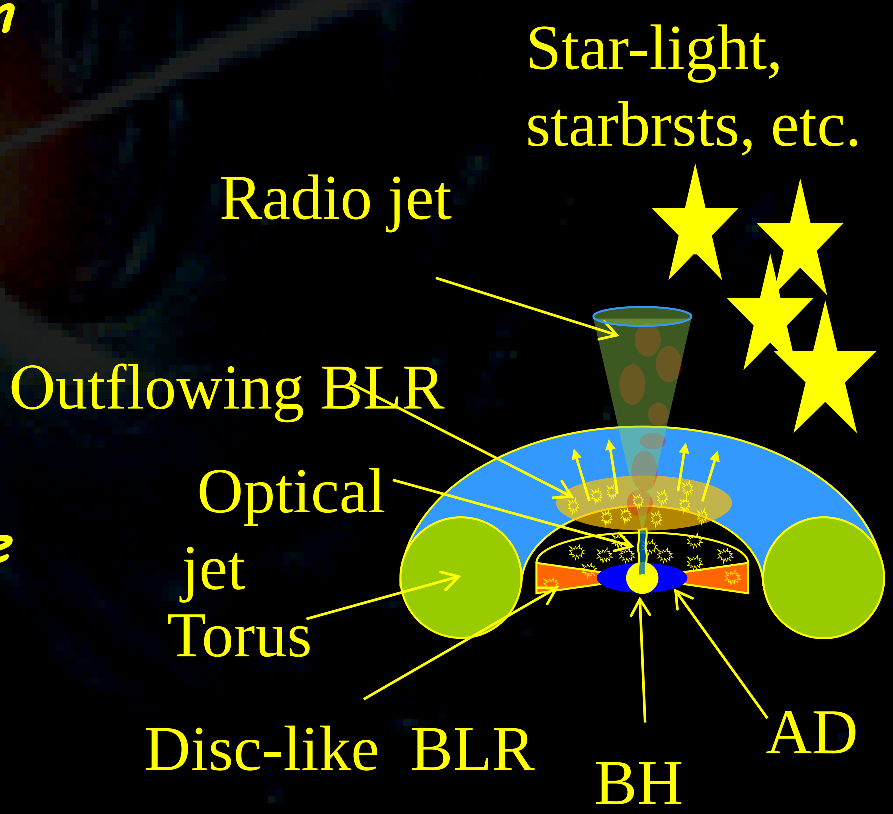
Exspected variability of polarization parameters in AGN spectra – scales?

Small scales (order of the BLR)

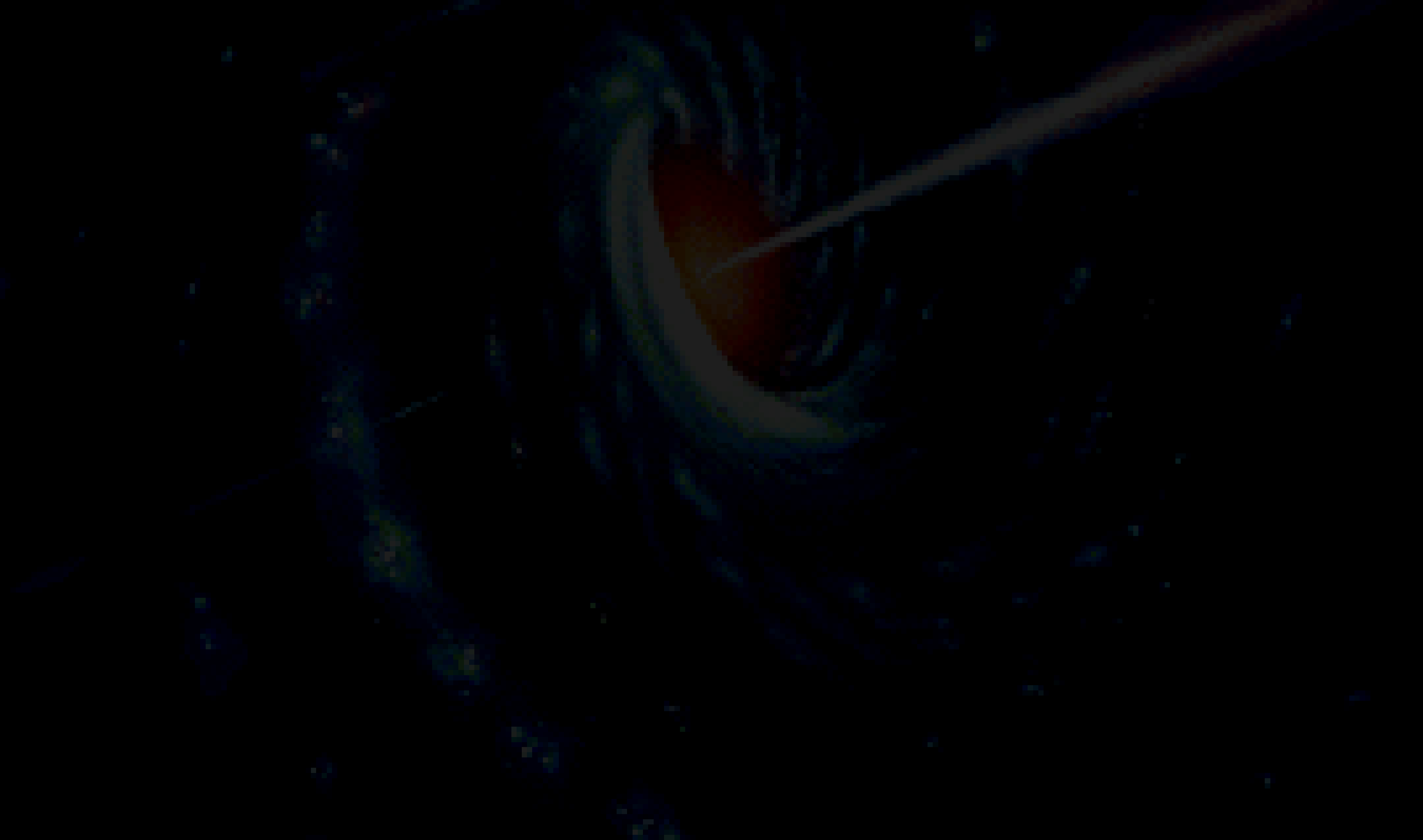
- *Radiatiove transfer in the accretion disk (electron scattering)*
- *synchrotron radiation of the jet*

Larger scales (> tha BLR)

- *scattering in optically thick gas-dust torus*
- *scattering in optically thin gas cone ionization*



Spectropolarization of the broad line AGNs – our observatios



Spectropolarimetric observations:

Motivations

- To study variability in polarized spectra (continuum and broad lines) of Type 1 AGNs
- To measure the dimension and investigate the nature of the polarization regions in Ty1 AGNs

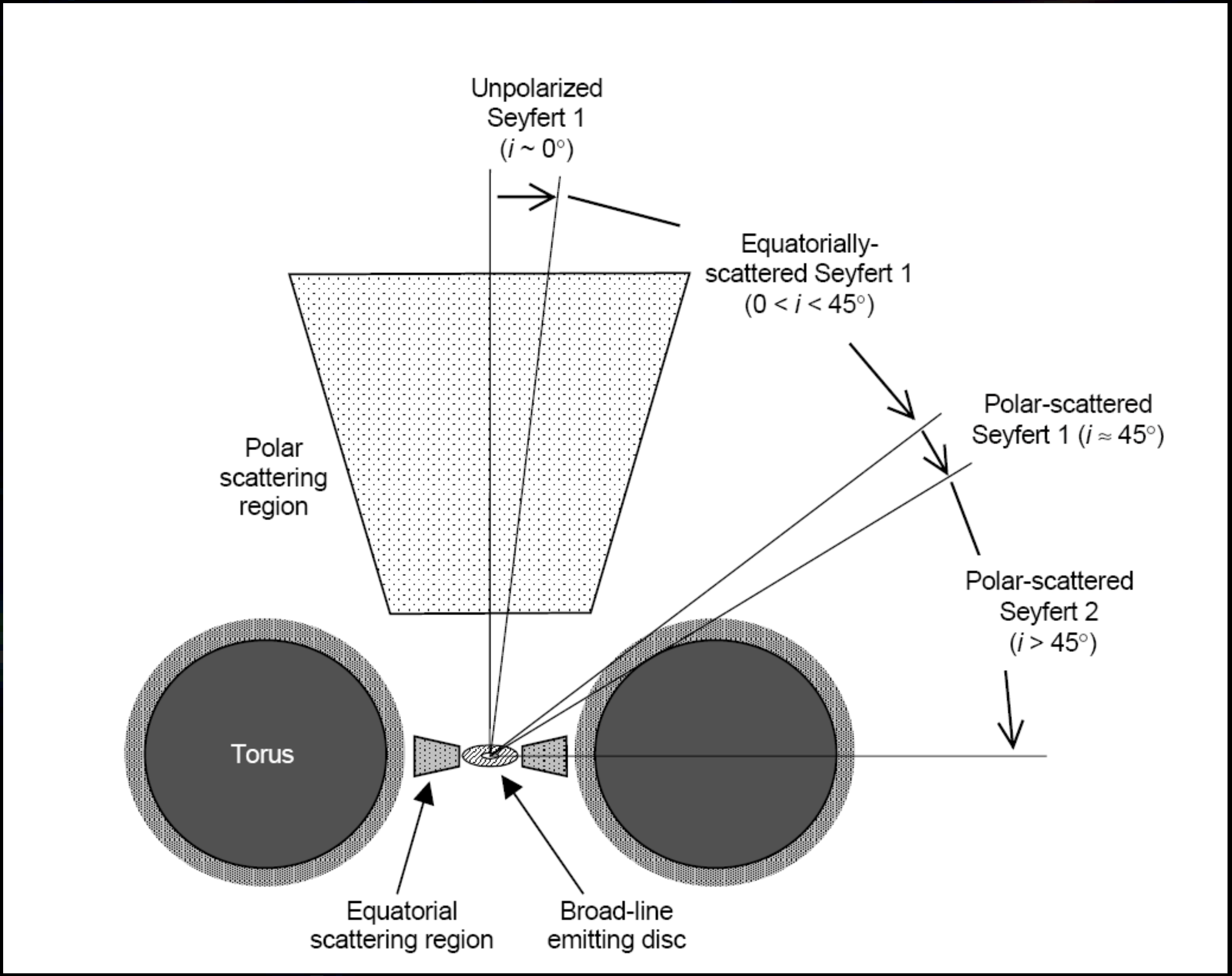
Methods

- To observe and measure the linear polarization (Stokes parameters) thype 1, radio quiet AGNs. Low spectral resolution covering a wide spectral range in several epochs
- Reverberation - to find the dimensions of polarization region and compare it with the BLR dimension
- To model observatios using STOKES code (also variability of PP)

Instrument

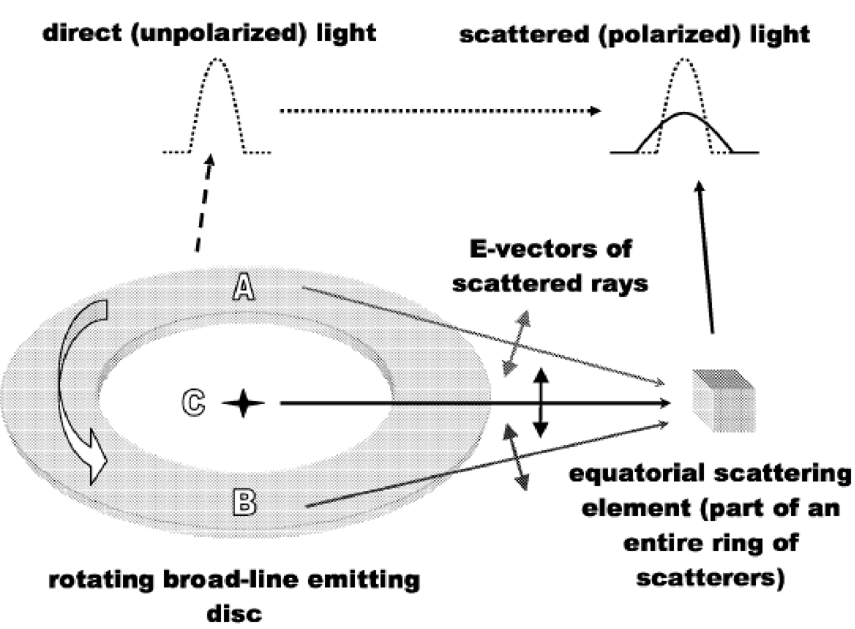
- 6-m telescope + SCORPIO, spectral coverage 4000-8000 AA
- Different type analyzer – Savart plate, Single and Double Wollaston prisms
- Spectral resolution 5-40AA,
- Precision measurement of the polarization 0.1-0.3%

Broad line AGNs (Sy 1) – Smith et al. 2004, polar vs equatiorial pol.

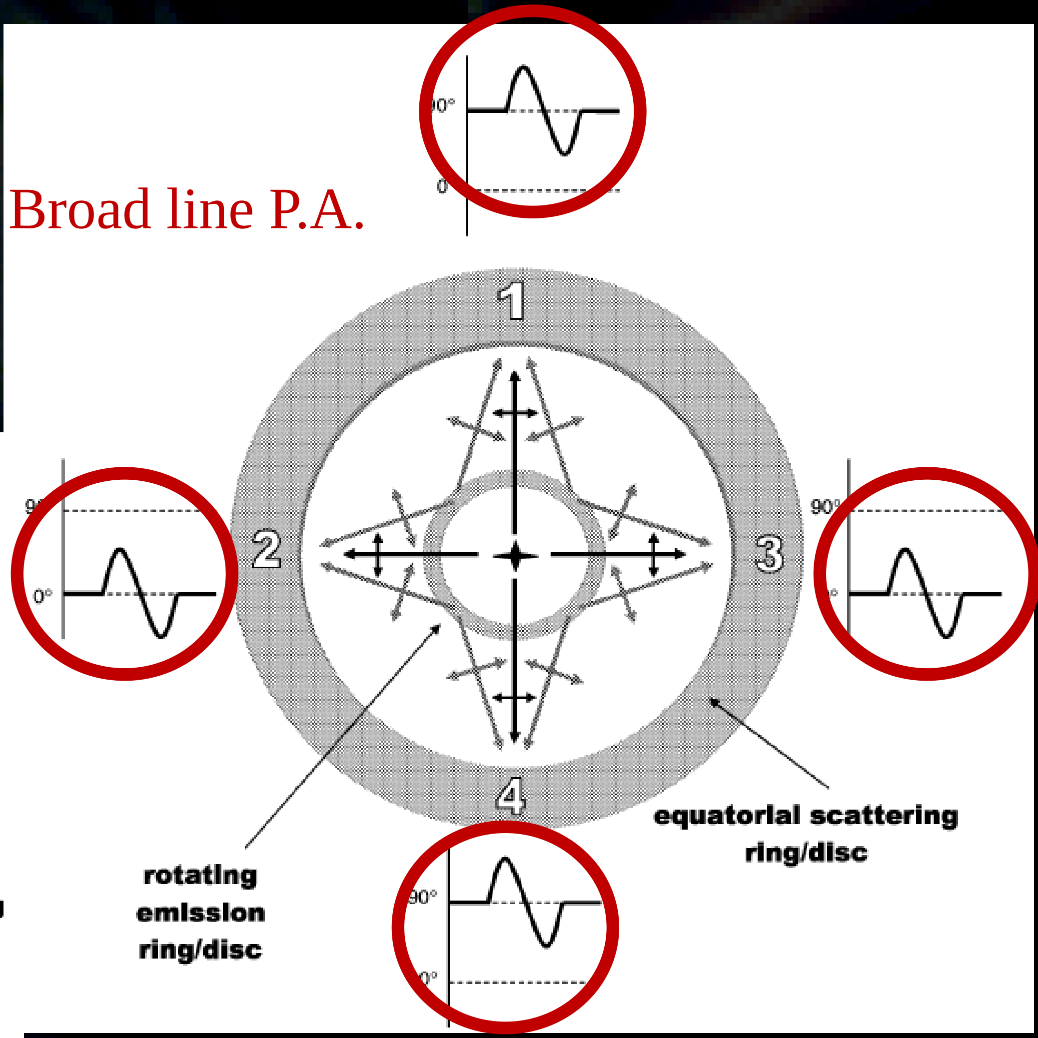


Type 1 AGN: Equatorial polarization in broad lines: (Smith et al. 2004,2005)

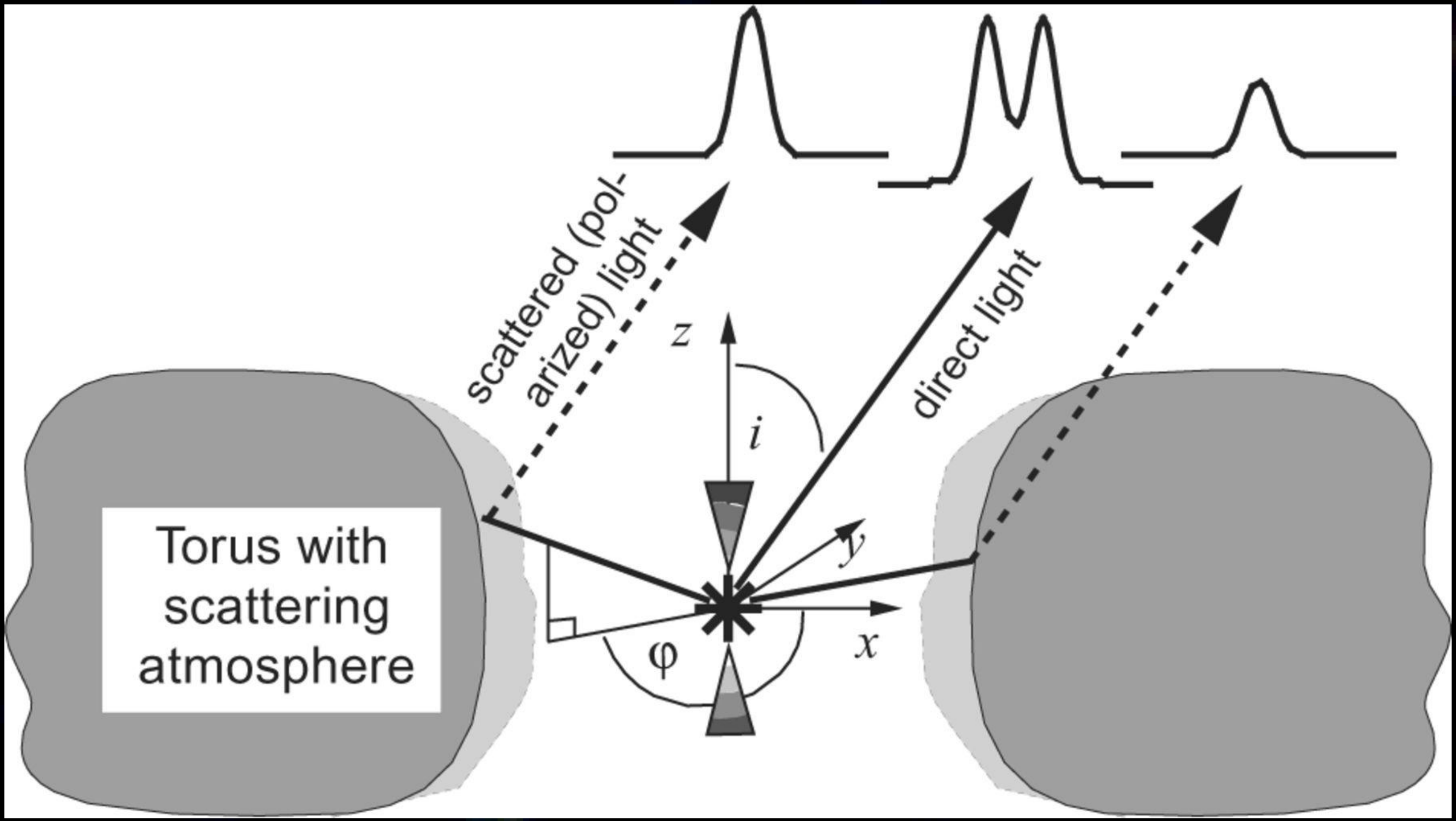
Broad line shapes



Broad line P.A.



Equatorial polarization – Keplerian disk – polarization in the broad line



Sketch showing a possible far-field scattering geometry in which Hα photons from BLR clouds undergoing bi-polar outflow are scattered by dust or free electrons in the inner wall of a surrounding torus.

Corbett E A et al. MNRAS 2000;319:685-699

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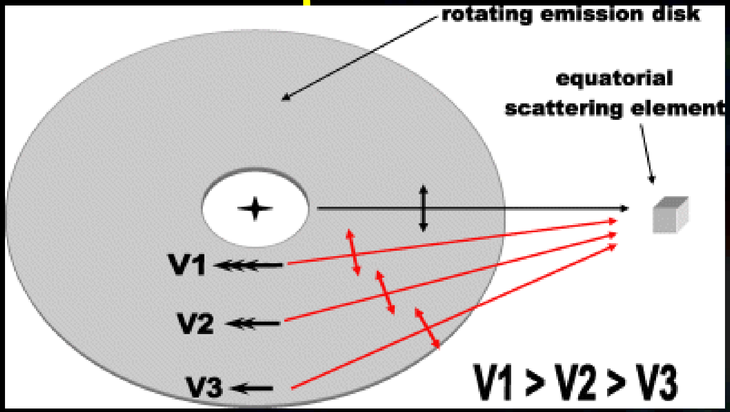
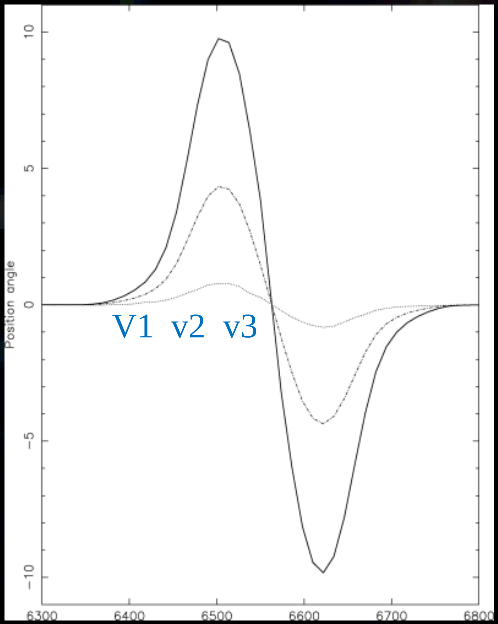
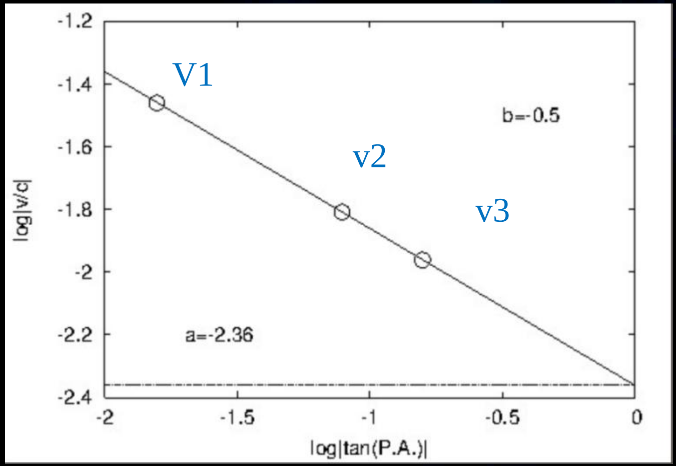
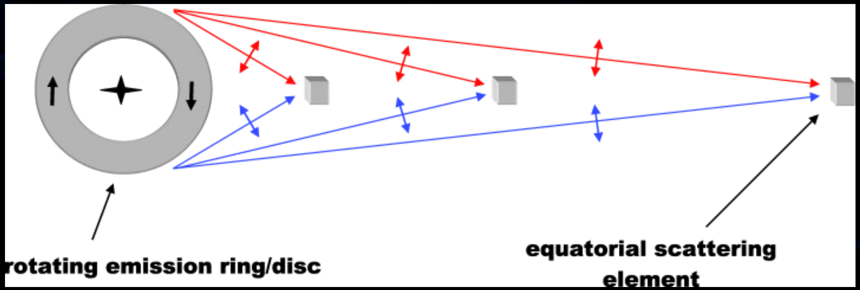
Equatorial polarization – Keplerian disk – polarization in the broad line



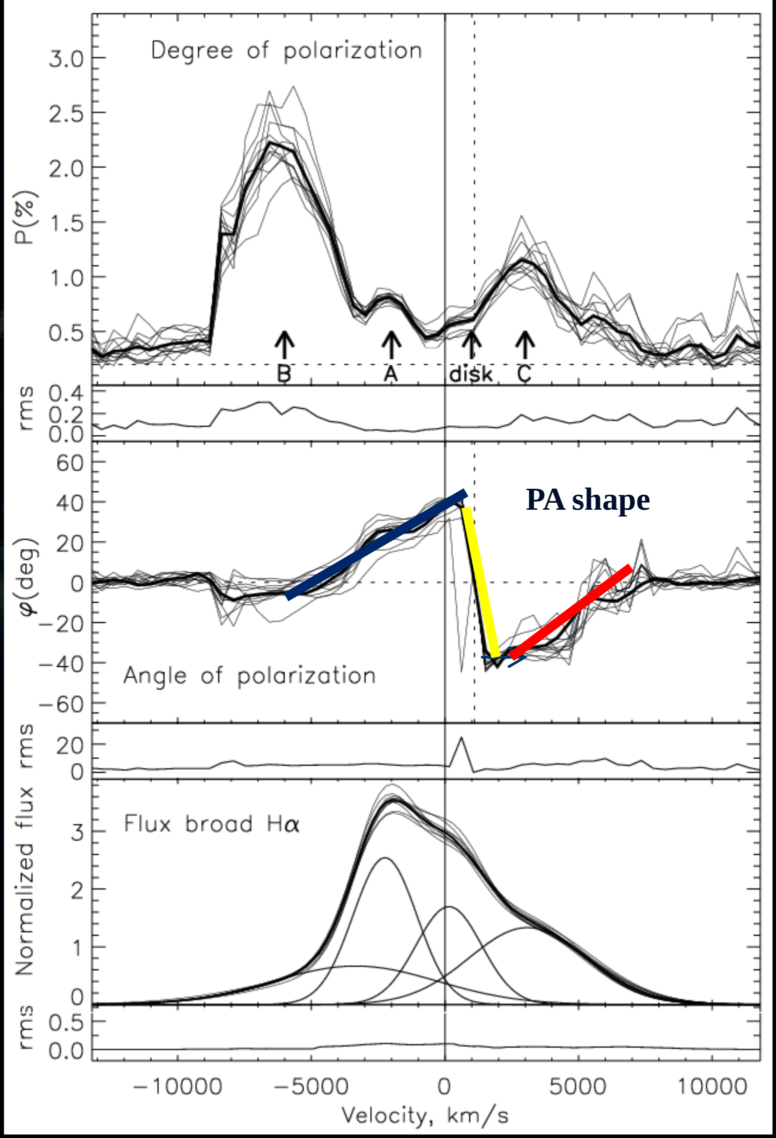


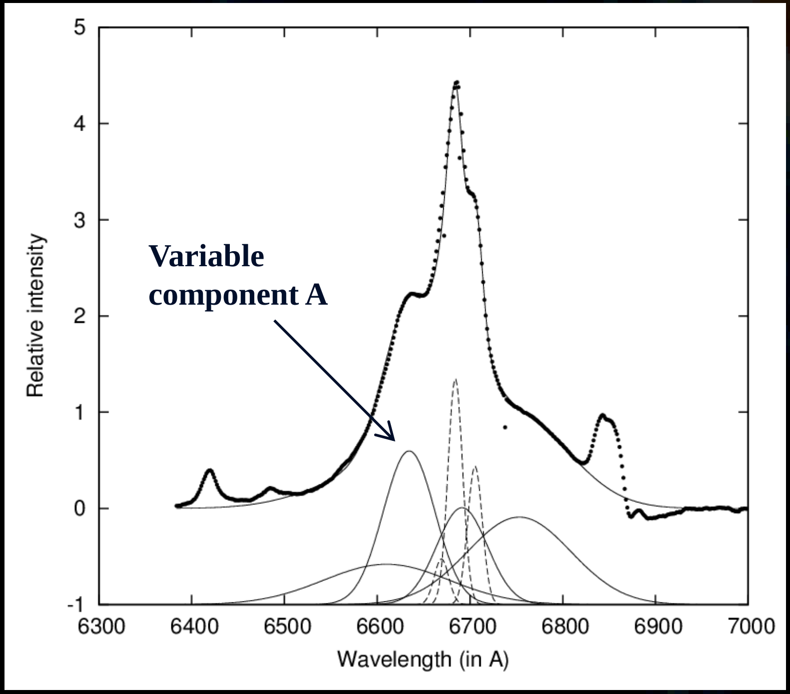




Polarization in the broad Hα of Mrk6. Observation

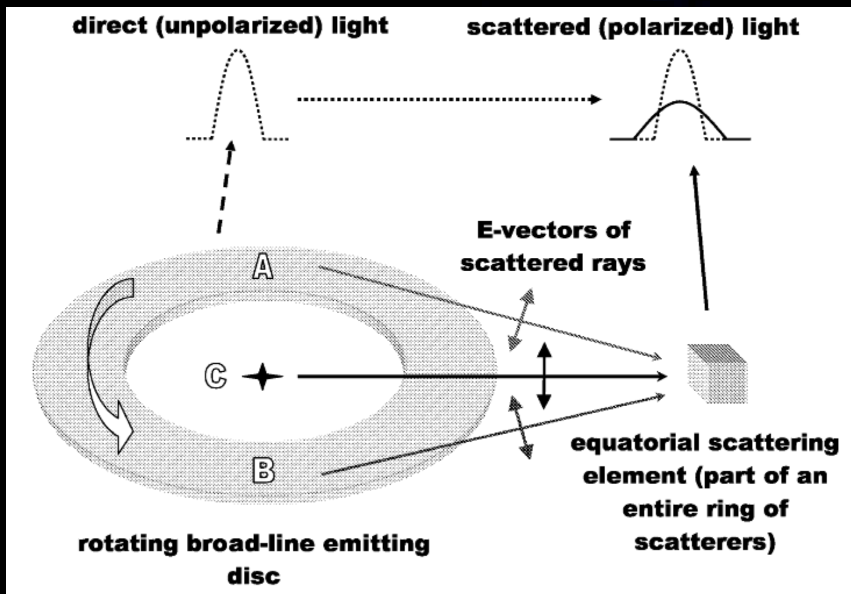
- *The polarization from the disk emission and additional three components A, B and C of the BLR polarized emission at speeds -2000, -6000 and 3000 km / s, respectively*
- *Within experimental error (~ 0.2%) in the polarization of the line has not been changed in a period of two years*
- *There is an expansion scattering region inside of the torus at a rate of ~ 1000 km/s*
- *The shape of polarization angle (PA)*

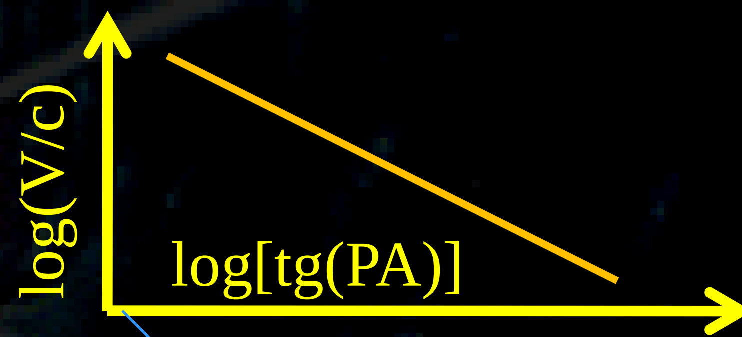


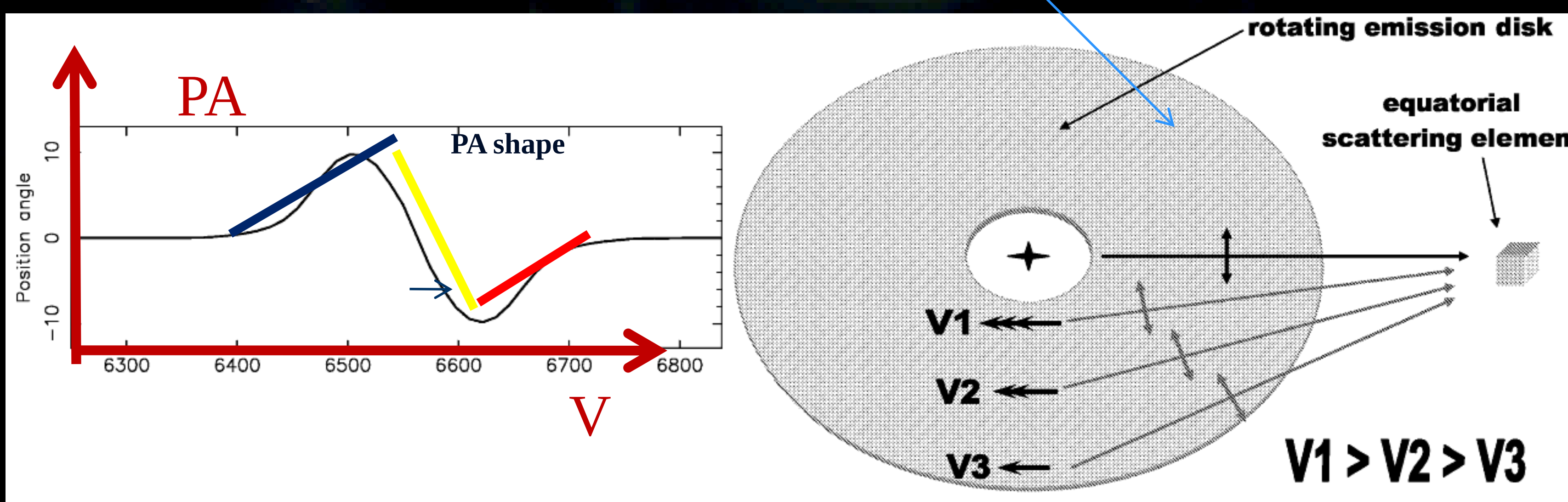


Polarizarion in the broad Hα (BLR). Equatorial scattering - idea

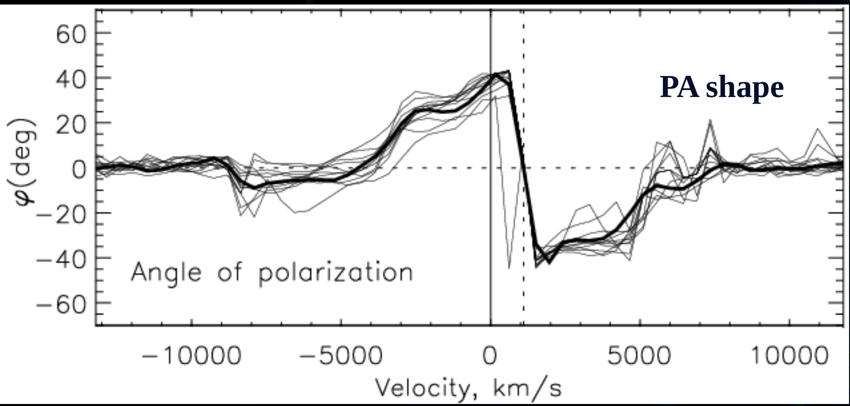
Smith J.E. at al., 2005, MNRAS, 359, 846



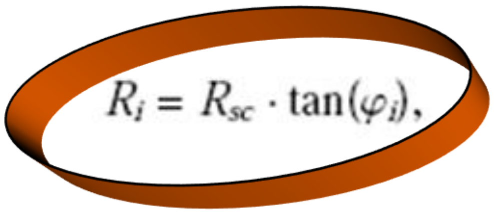




Afanasiev et al. 2014 (Mrk 6); Afanasiev & Popovic 2015, ApJL, 800, L35



$$V_i = V_i^{rot}\cos(\theta) = \sqrt{\frac{GM_{BH}}{R_i}}\cos(\theta),$$

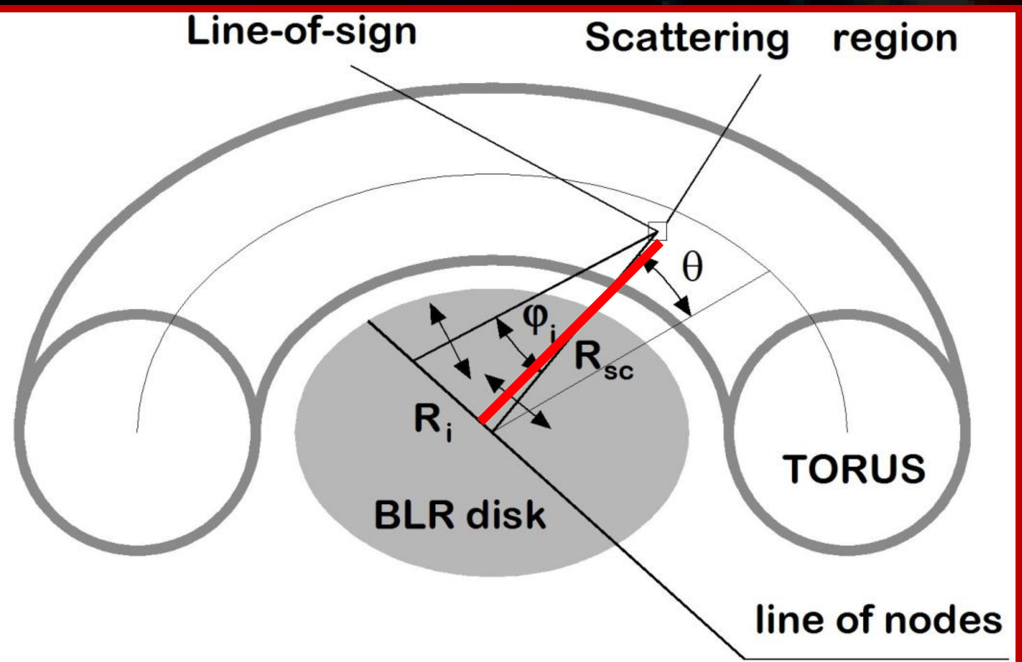


$$R_i = R_{sc}\cdot\tan(\varphi_i),$$

$$\log(\frac{V_i}{c}) = a - b\cdot log(\tan(\varphi_i)),$$

$$a = 0.5\log(\frac{GM_{BH}\cos^2(\theta)}{c^2 R_{sc}}).$$

$$\log(\frac{V_i}{c}) = a - b\cdot log(\tan(\varphi_i)),$$



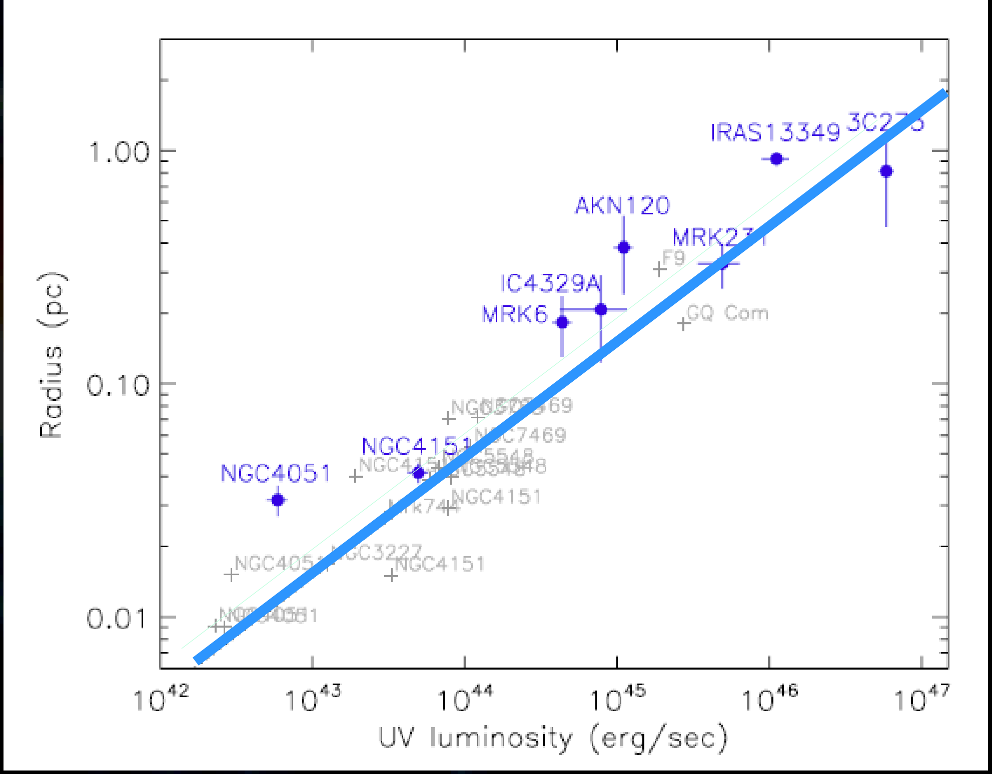
Estimating of the inner radius of the torus

M. Kishimoto et al., A&A 527, A121 (2011)

Direct measurements of the size by interferometry in the near-IR (2-3 mkm)

Estimation by delay variability radiation in K with respect to V

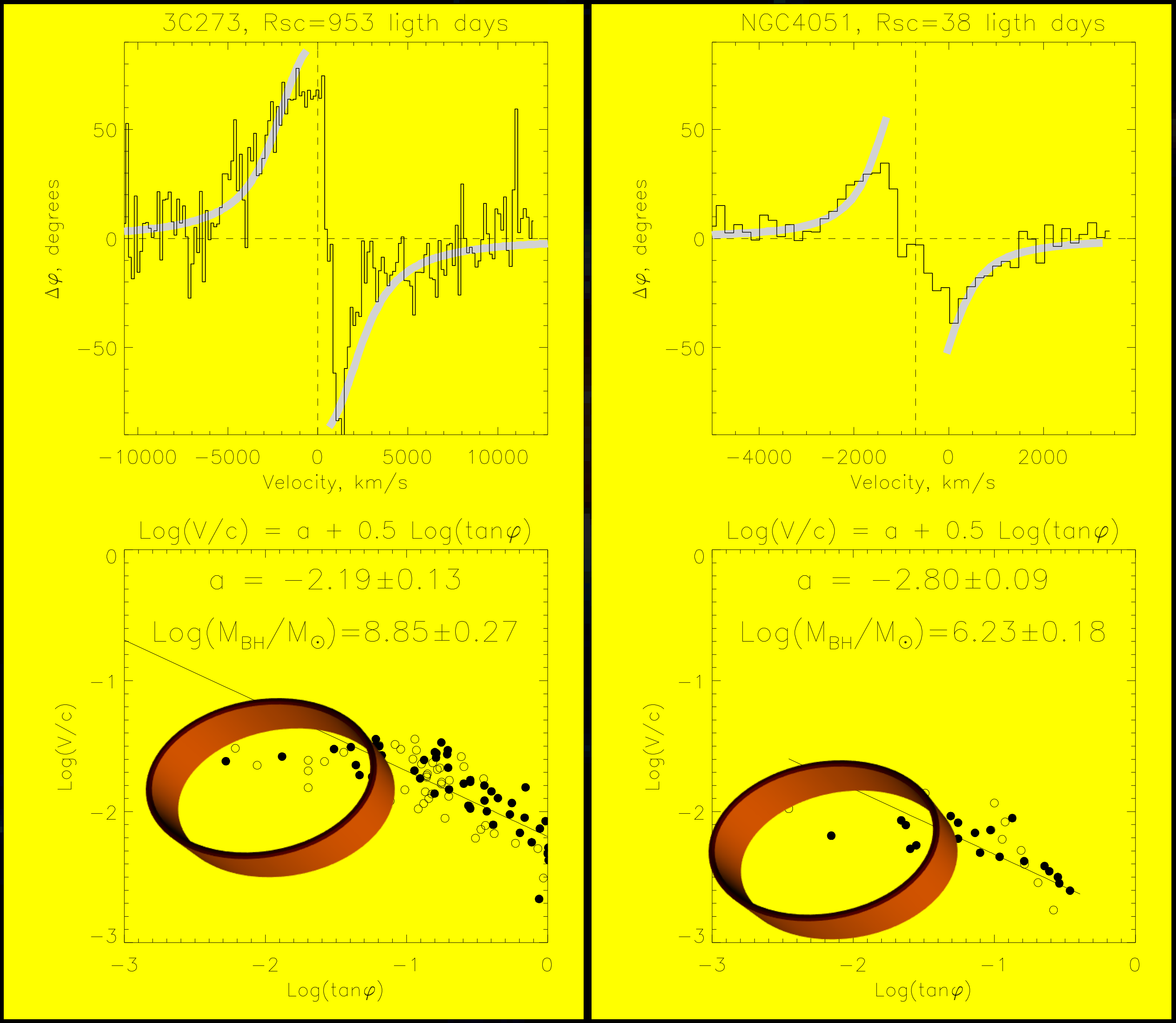
Estimating the size of the calibration by relation {size - UV luminosity}



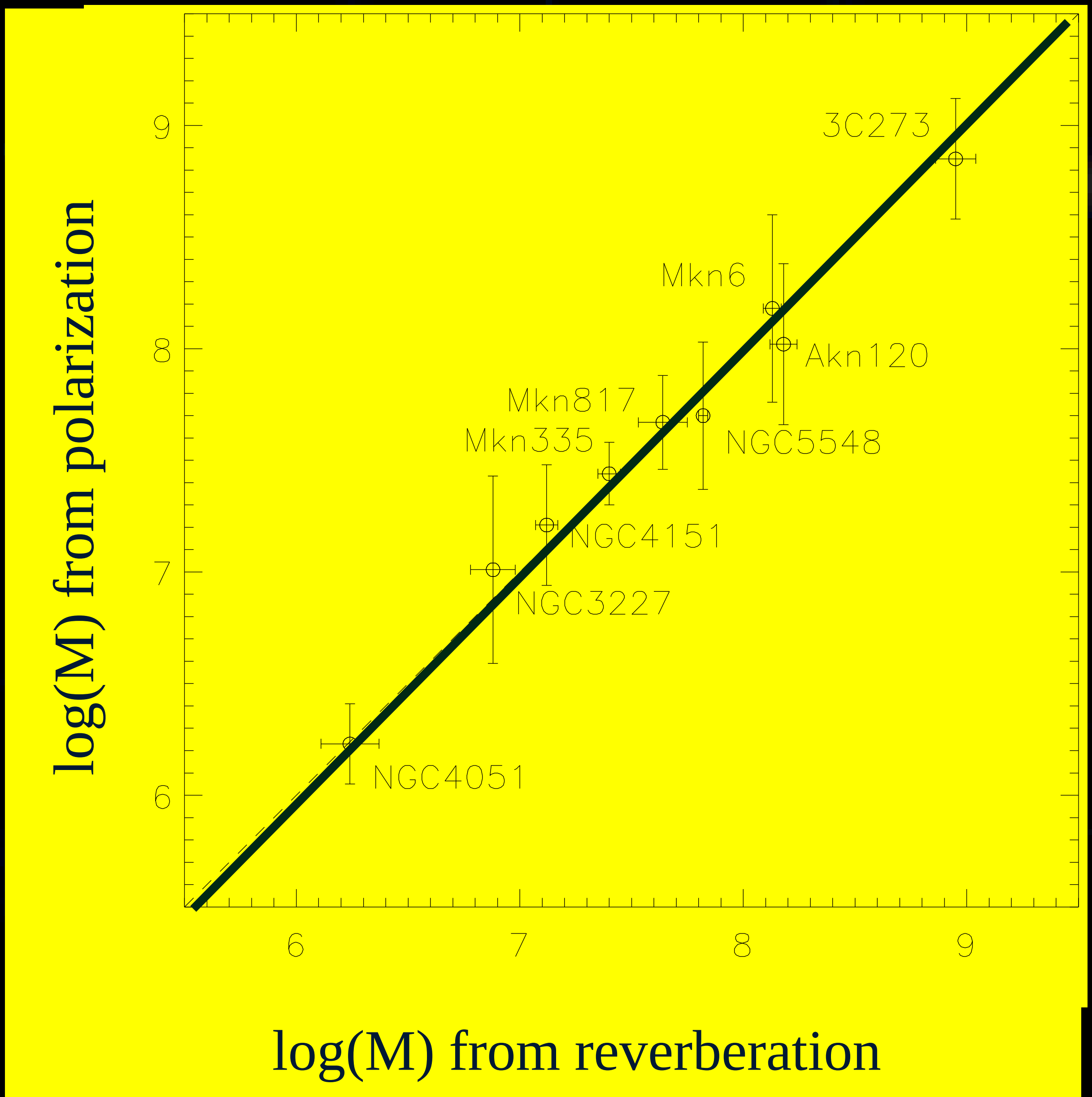
$$R_{\rm in} \simeq 1.3 \cdot \sqrt{L_{46}^{AGN}} \cdot T_{1500}^{-2.8} \quad [\rm pc]$$

Estimated size by interferometry is about two times larger than by variability

Results:Observed 9 AGNs, Popovic & Afanasiev 2015

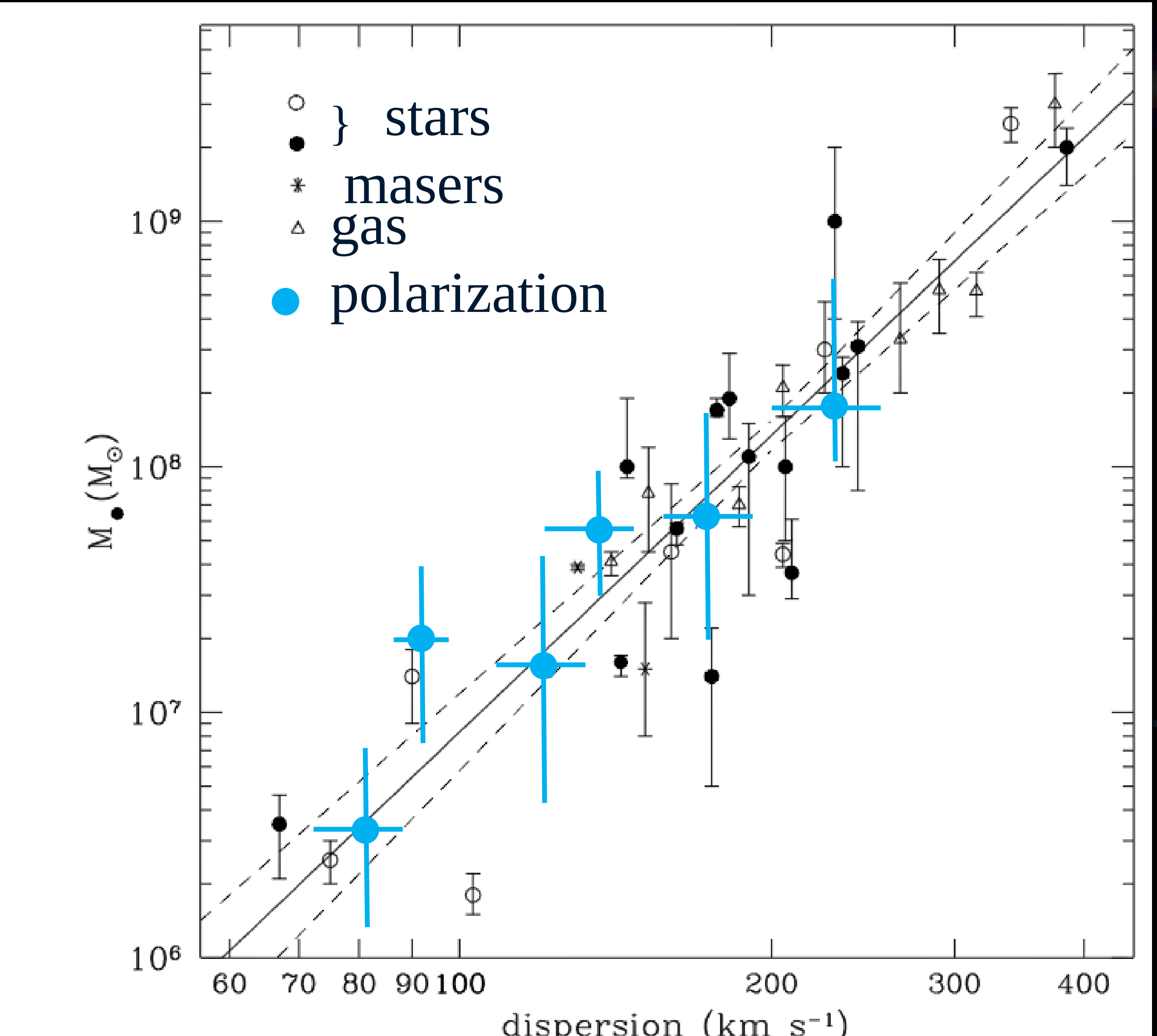


Comparison polarization and reverberation



BH mass vs. central velocity dispersion

Tremaine et al., ApJ, 2002, **574**, 740 (our data blue full circles)



Black hole mass estimates – polarization in the broad line profiles vs. reverberation

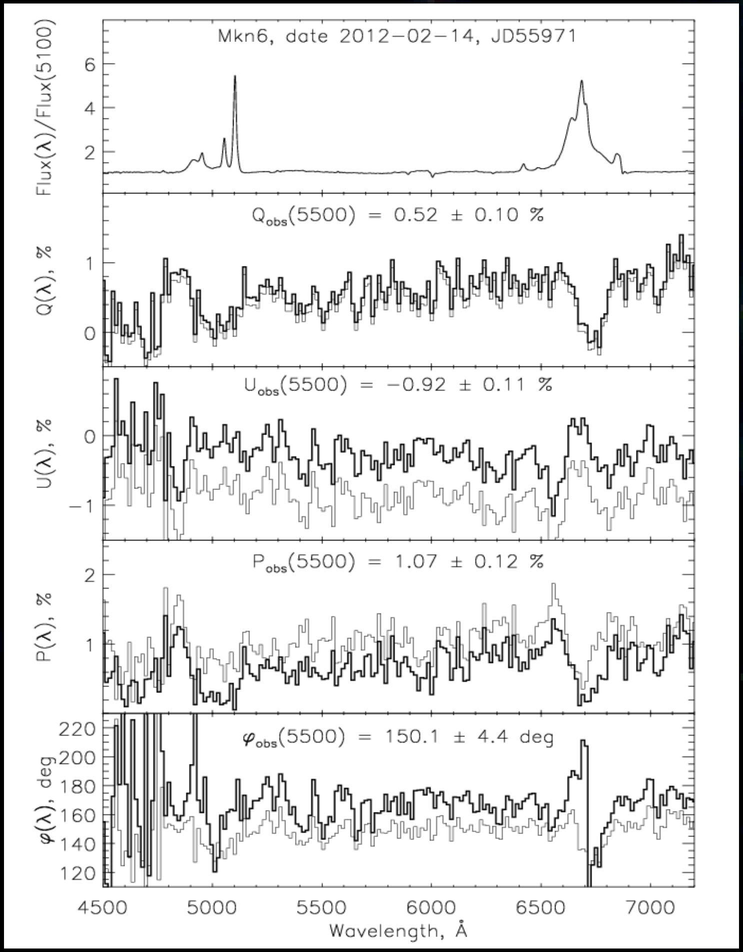
$$M_{BH} = f\,\frac{R_{BLR}v^2}{G}$$

calculated from broad line widths

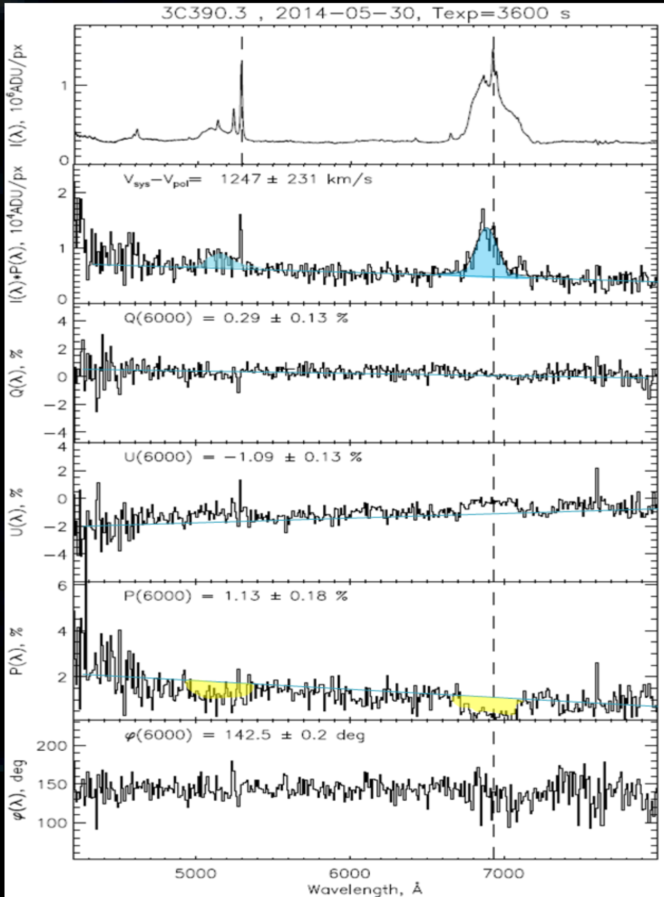
- Reverberation → $R_{BLR}=c\tau$ -time delay between continuum and broad line
- PROBLEMS:
- *f* - depends on the BLR geometry (may be very complex – disc, outflows, inflows -combination of these)
- <u>This assumption of virialization cannot be directly verified because the BLRs are spatially unresolved</u>

Variability in the continuum and broad lines – Mrk 6 and 3C390.3

Afanasiev et al., 2014, MNRAS, v.440, p.519



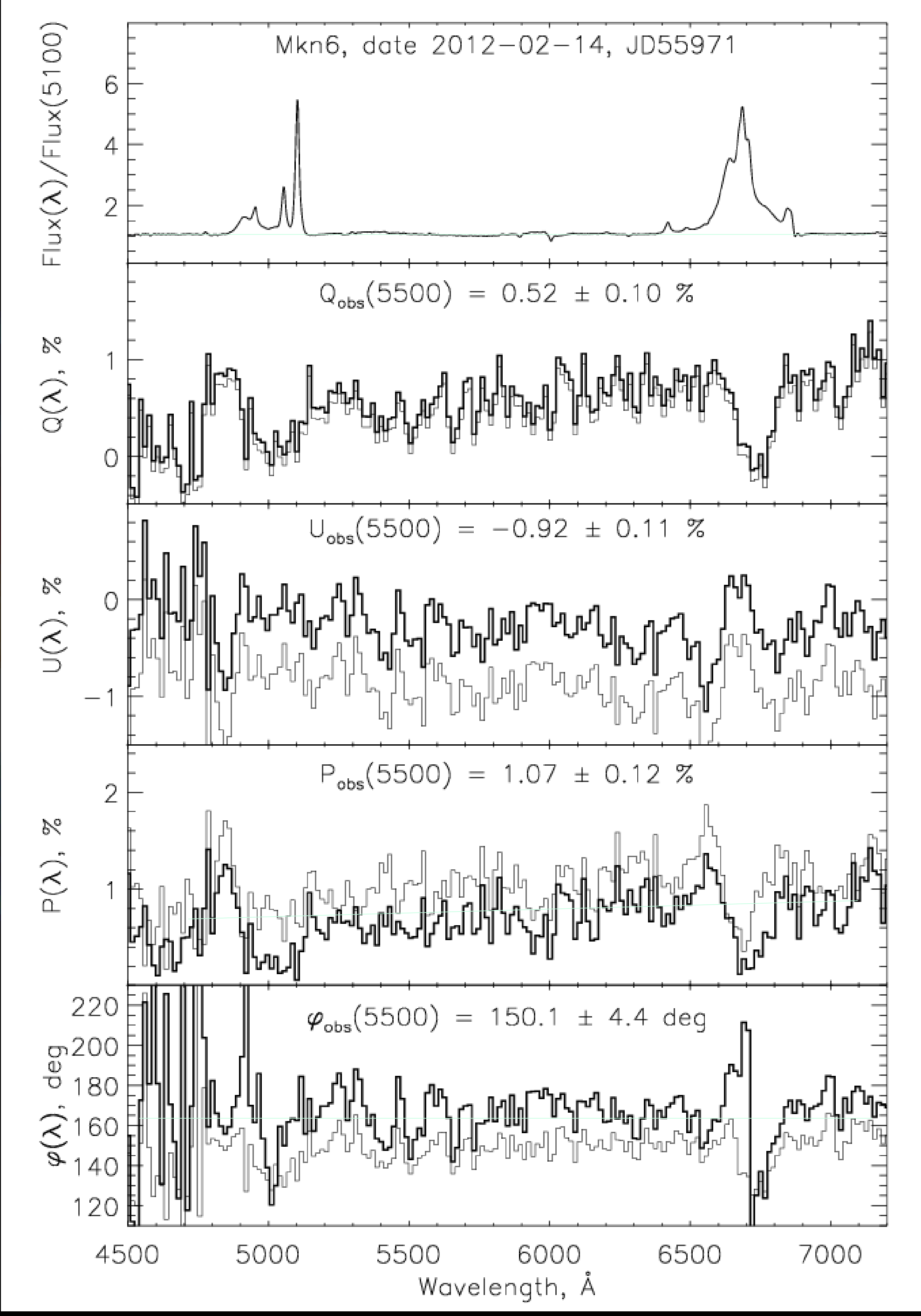
Afanasiev et al., 2015, MNRAS, v.448, p.276



Spectropolarimetry Mrk 6 (IC 450)

Sy 1.5 galaxy, z=0.0185,
m(B)=14.29, M(B)=-20.41

- Observations with 6 -m telescope of SAO RAS in 2010-2013;
- Obtained spectra for 12 epochs in the spectral range from Hβ to Ha with resolution 7-8 A ;
- The interstellar polarization is taken into account
- The resulting accuracy of the measurement of the Stokes parameters is about 0.2% per resolution element

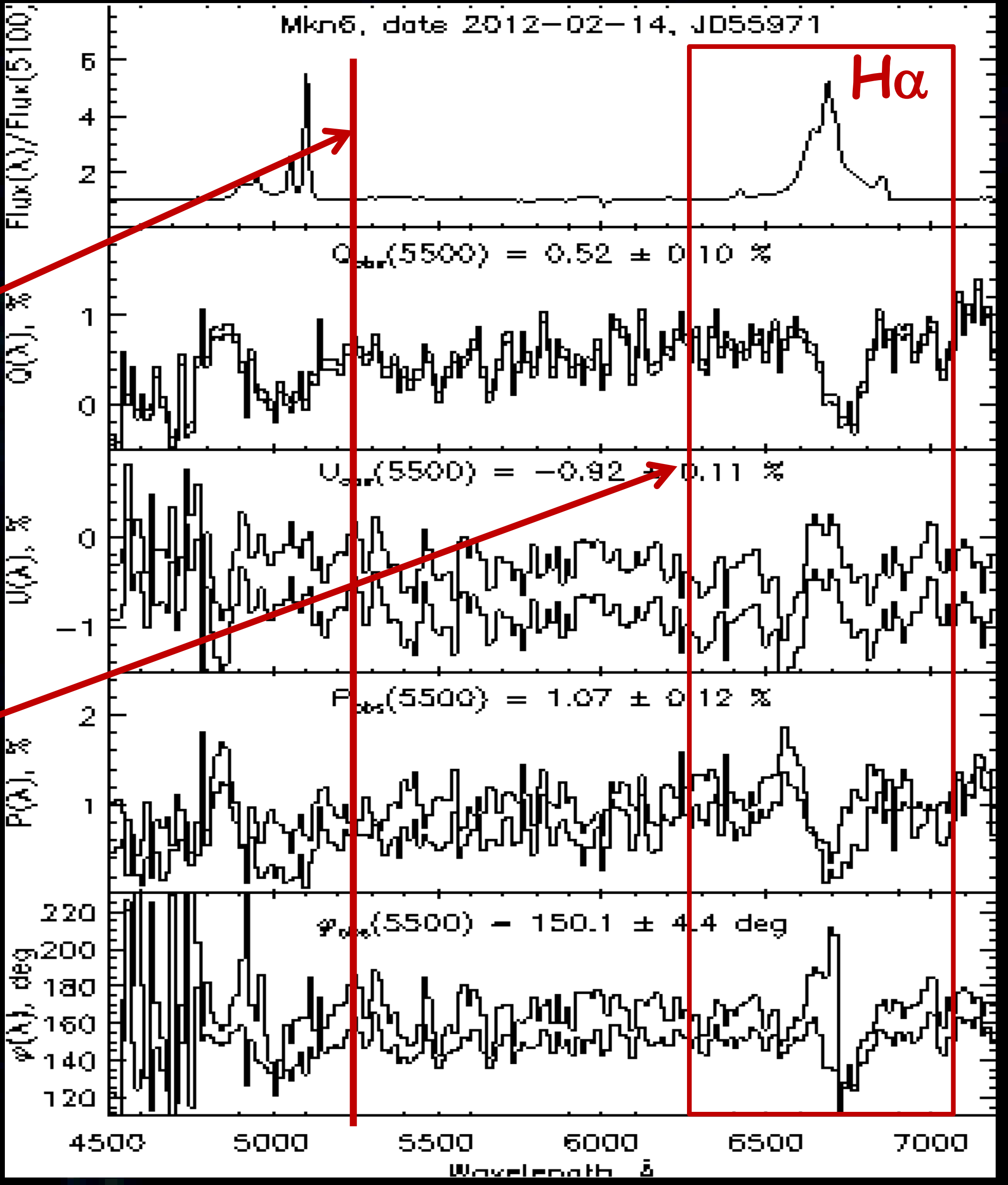


Afanasiev, V. L., Popovic, L. C., Shapovalova, A. I. et al., 2014, MNRAS, 440, 519

Observations

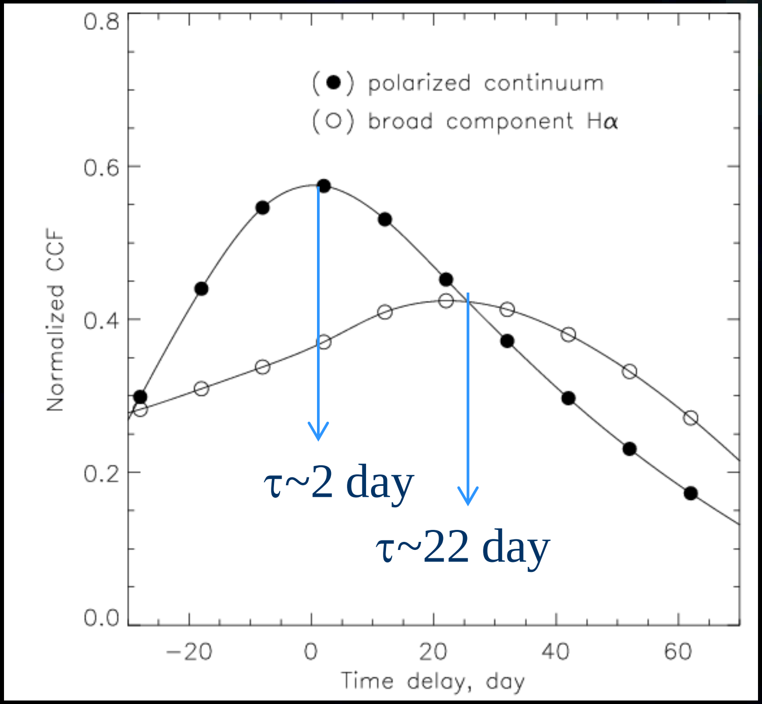
continuum

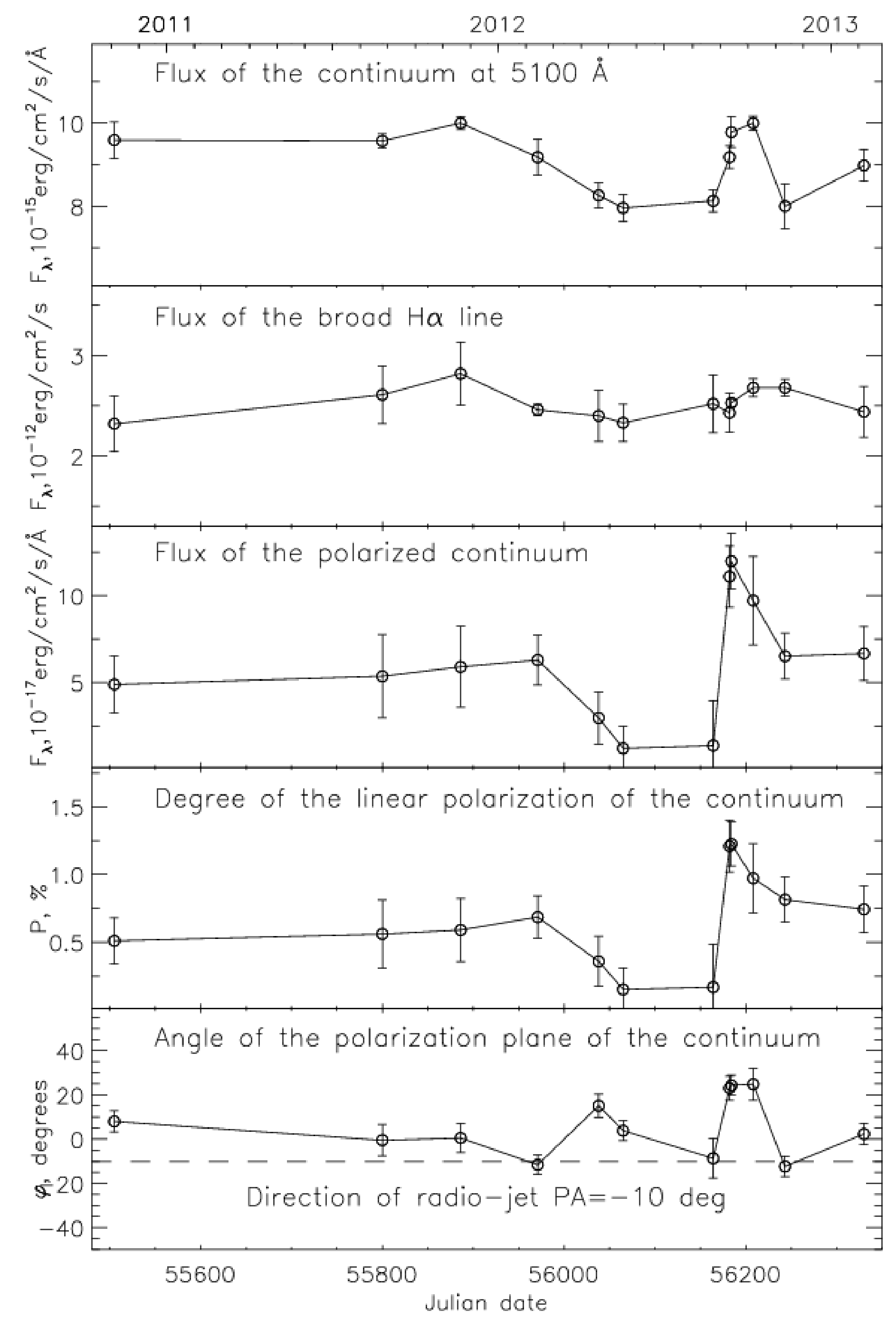
continuum and line



Variability

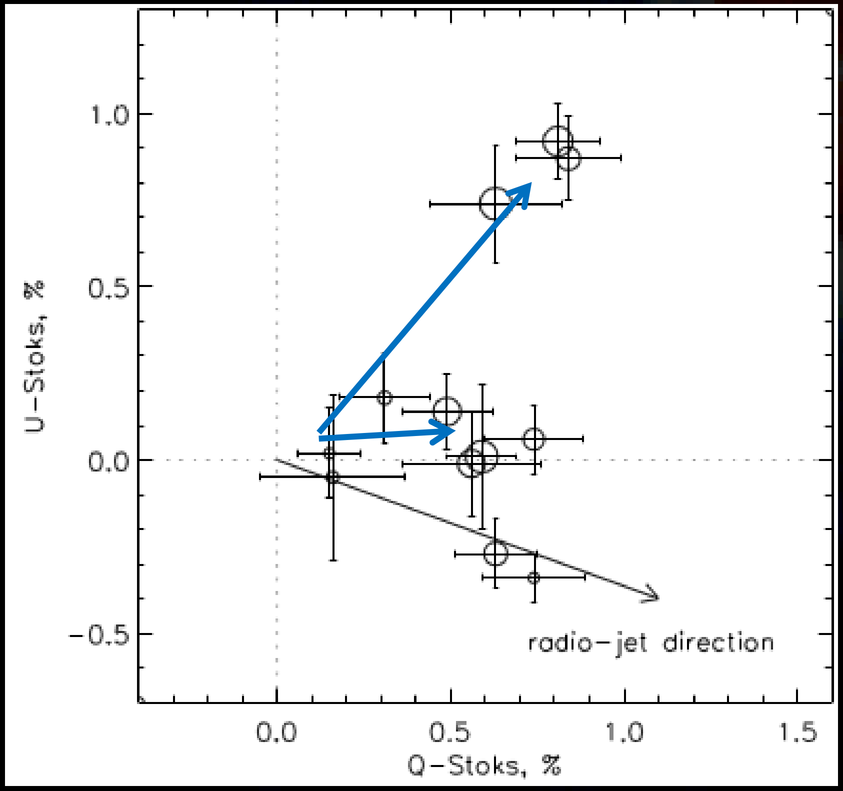
the characteristic size of the polarized continuum ~ 0.002 pc, which is much smaller than the BLR (~ 0.2 pc)

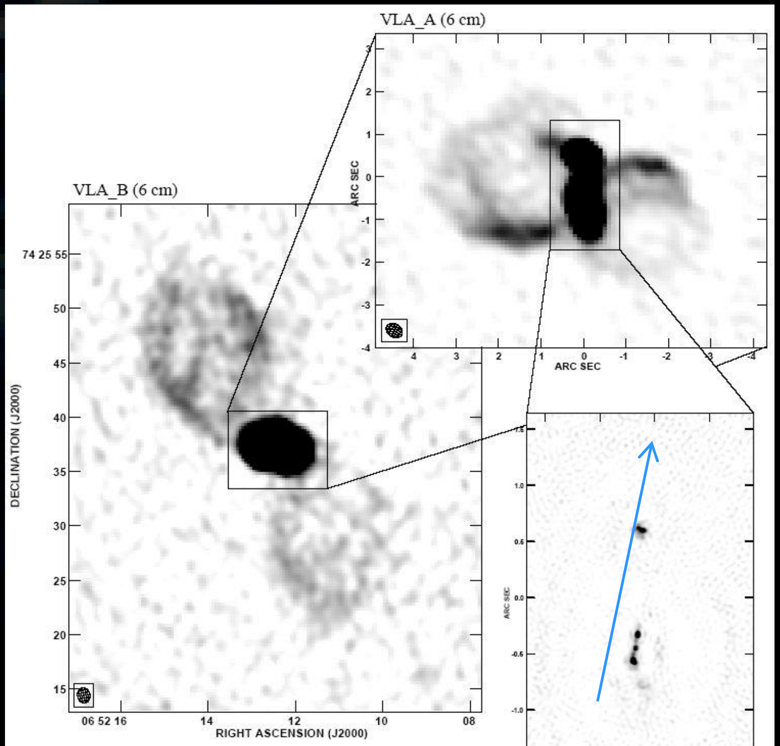




Polarization in continuum : disk+jet

- Vector addition of the disk and jet polarization
- Polarization in the disk => radiation transfer (electric vector is parallel to the axis of the disc)
- Polarization in the jet => synchrotron radiation - variable (precessing?) Jet (~ electric vector perpendicular to the axis)

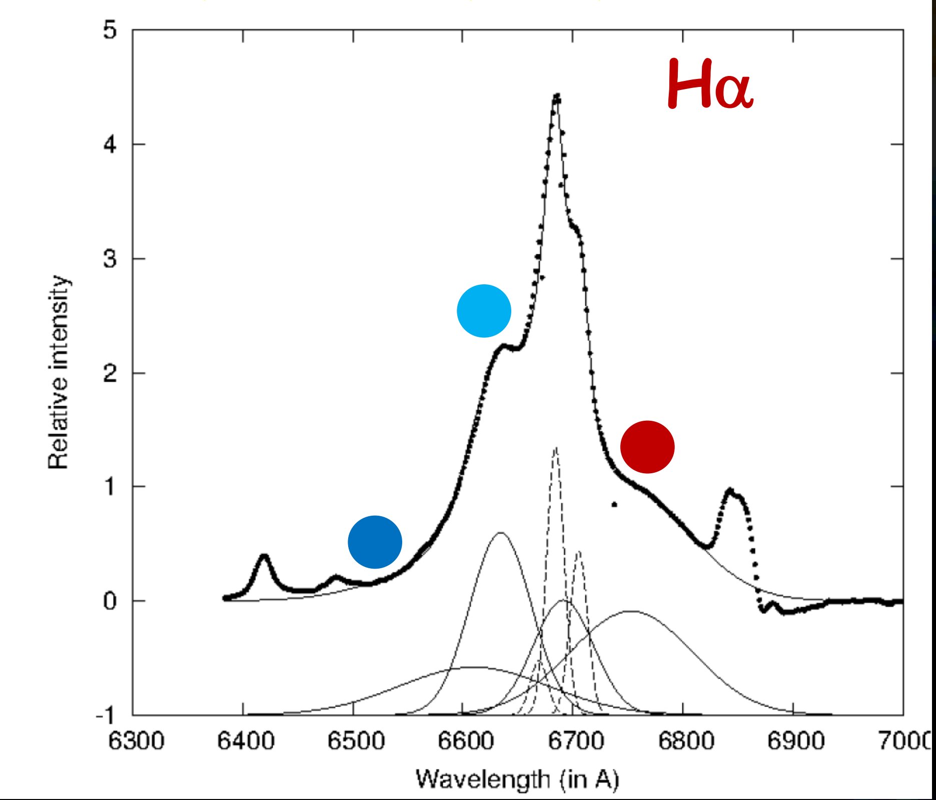


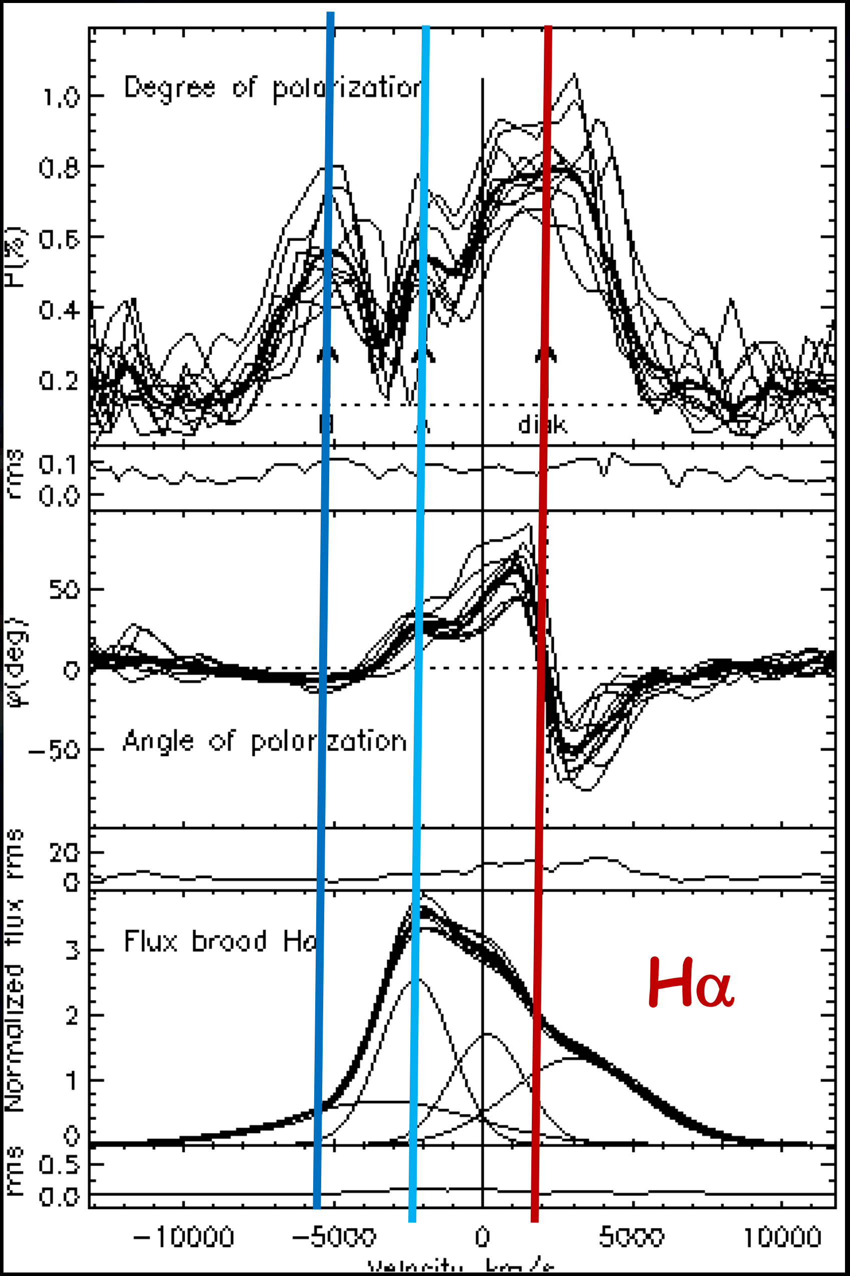


Kharb et al., 2006, ApJ, v.652, 177

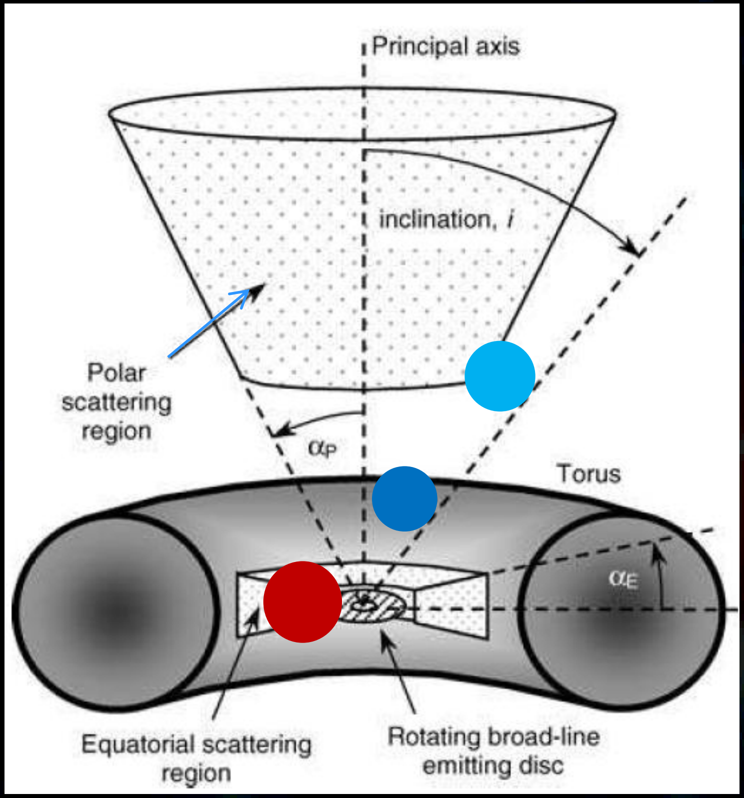
Polarization in broad lines

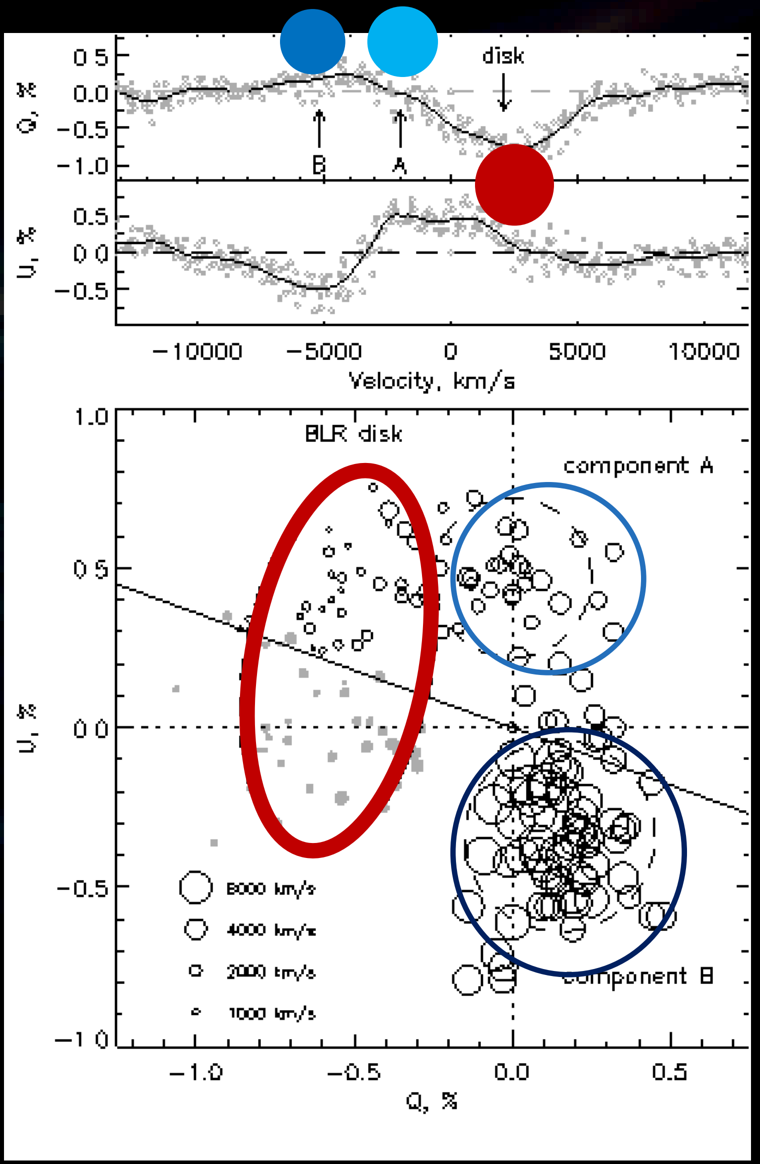
Afanasiev, V. L., Popovic, L. C., Shapovalova, A. I. Ilic, D, , 2014, MNRAS, 440, 519





Three regions of polarization

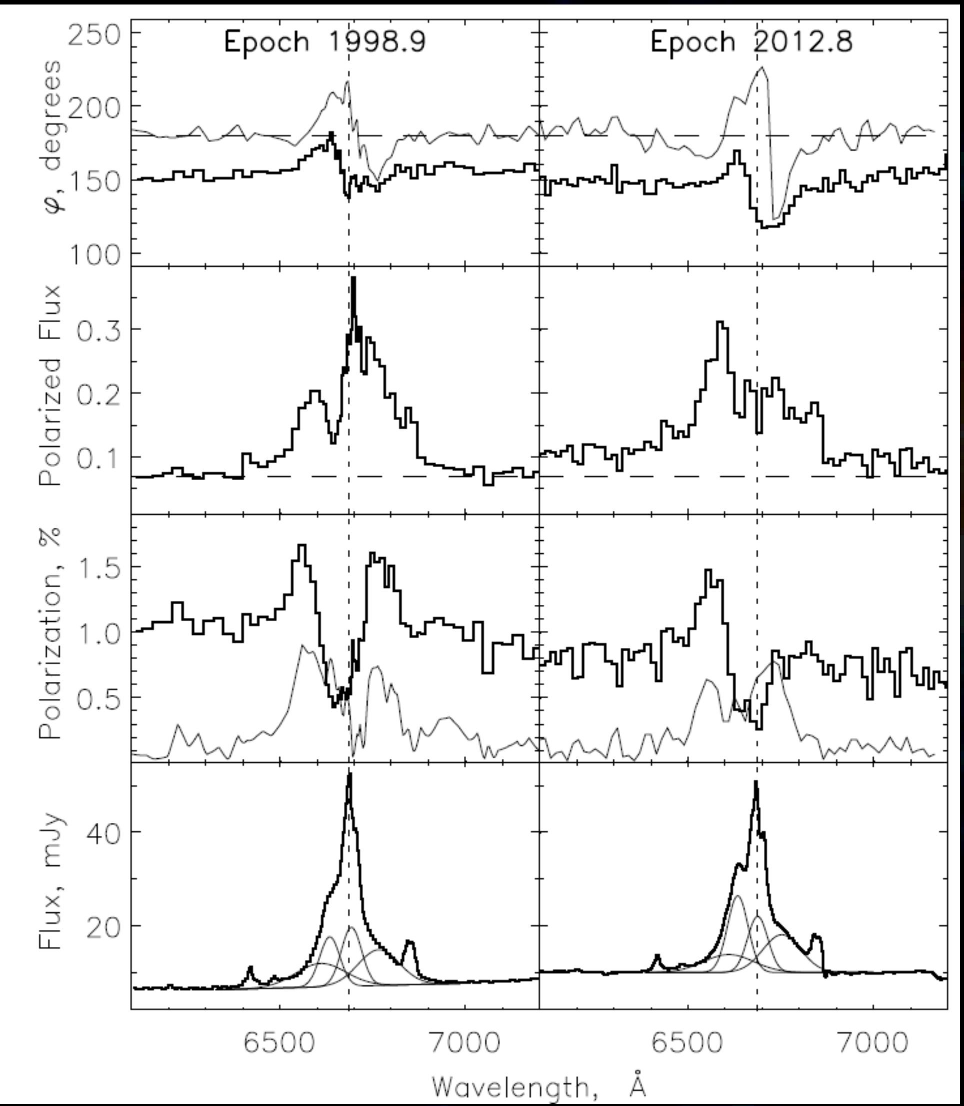


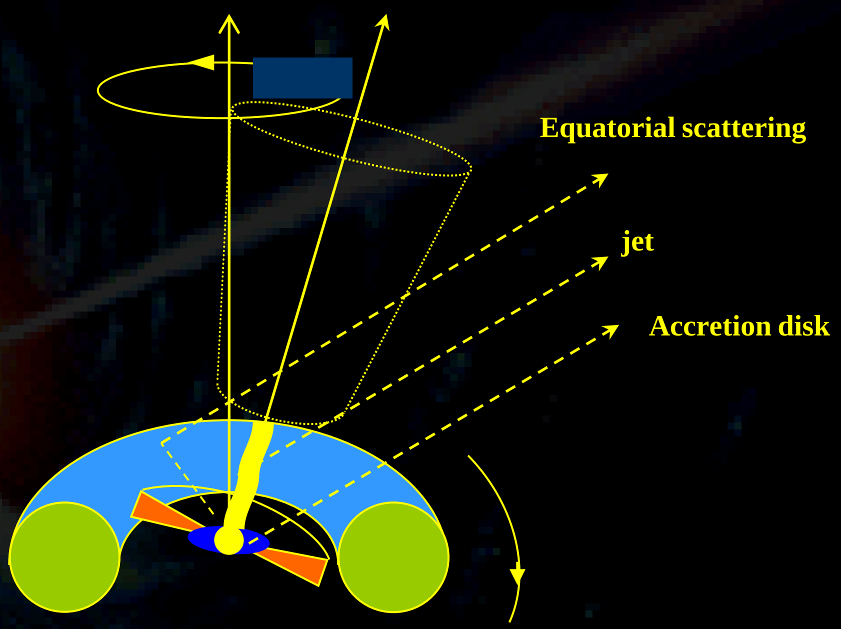


-Torus – equatorial polarization

- two aditonal polarization components probably polar polarization (outflows).

Variability of broad Hα on the scale of 10 years



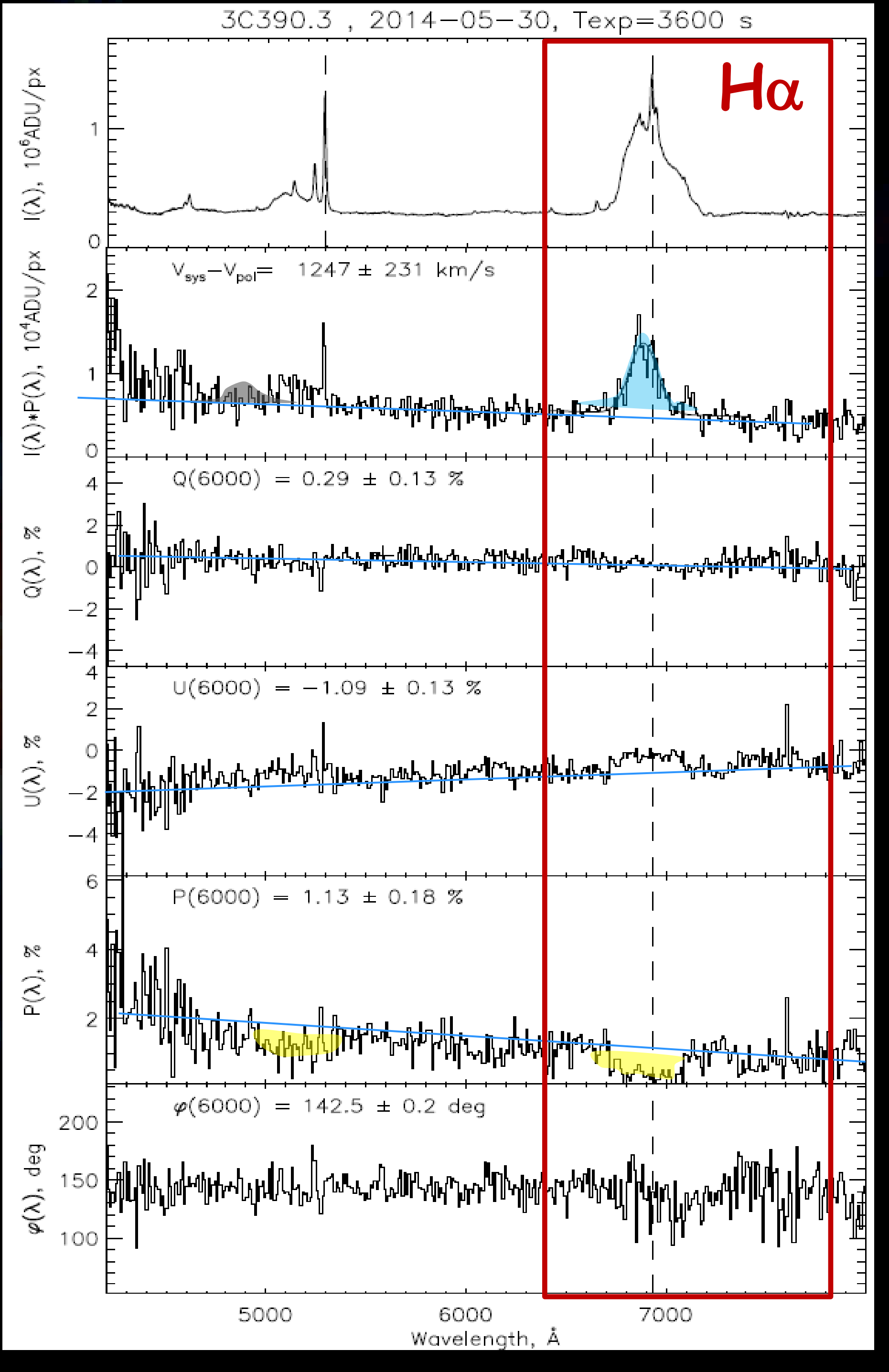


BLR size, optical depth of SR, precesion of jet-like motion (outflow)?

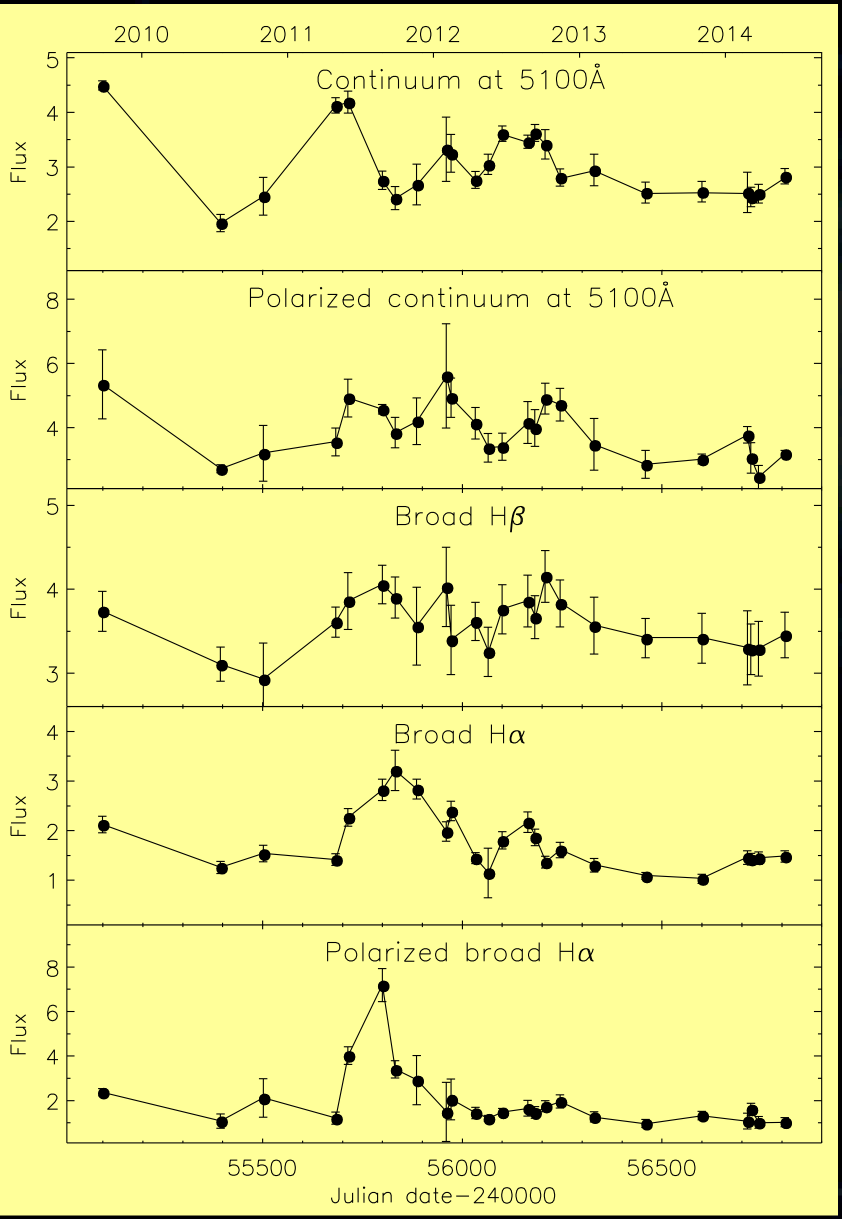
Spectropolarimetry AGN 3C390.3

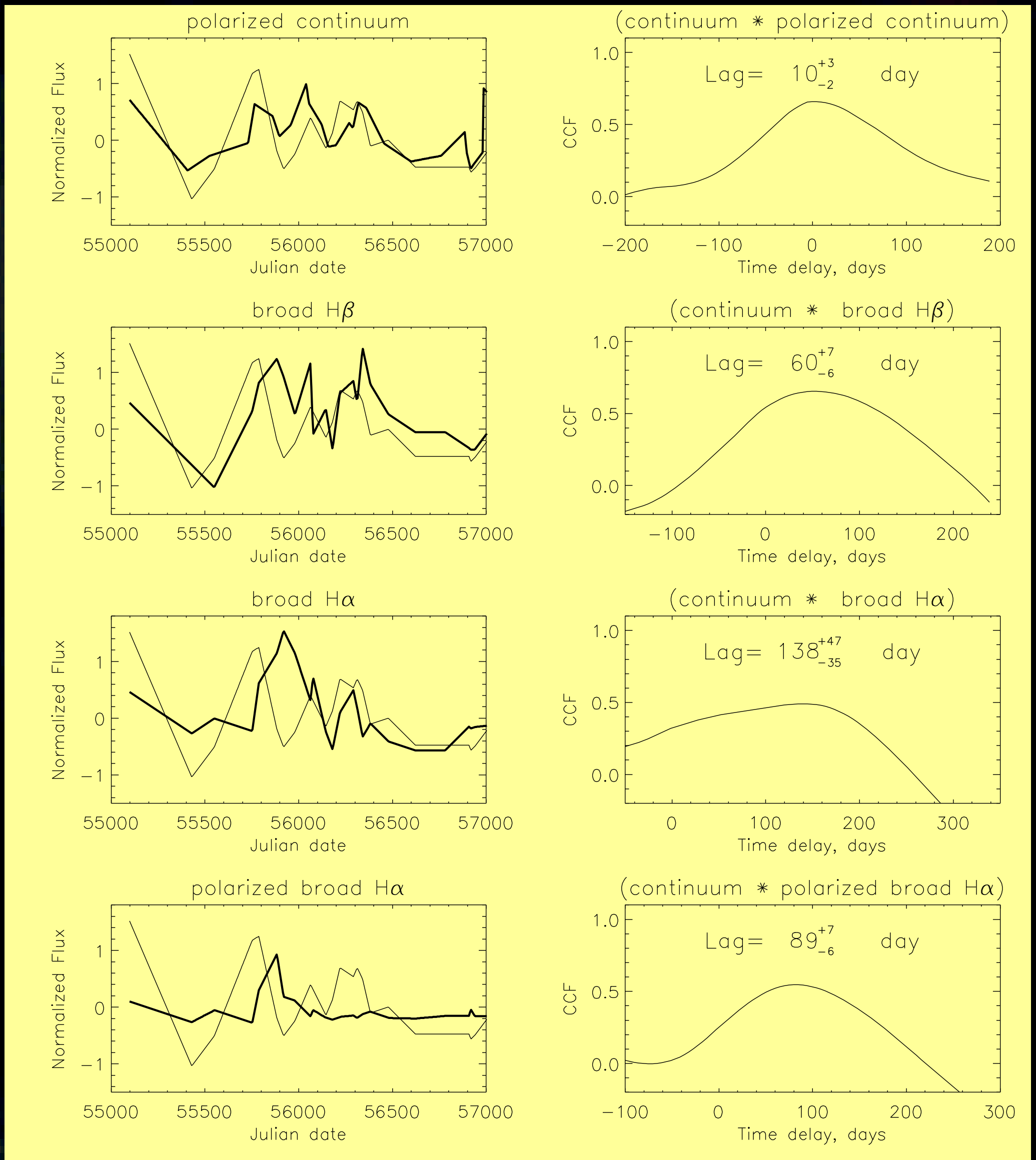
24 epochs observation at 2010-2014 years

- *decrease of the degree of polarization with the wavelength ("flat spectrum")*
- *depolarization in the broad lines Hβ and Hα (like a "suitcase")*
- *blue shift of the broad lines in polarized light (-1200 km/s)*
- *Variability polarization and spectral properties :*
  - *small delay (~10 ligth days) between the unpolarized and polarized continuum*
  - *the delay for the broad emission lines (lag(Hα) ~138 and lag(Hβ) ~60 ligth days)*
  - *The delay of the polarized light in the line, lag(Hα)~ 89 ligth days*



Variability



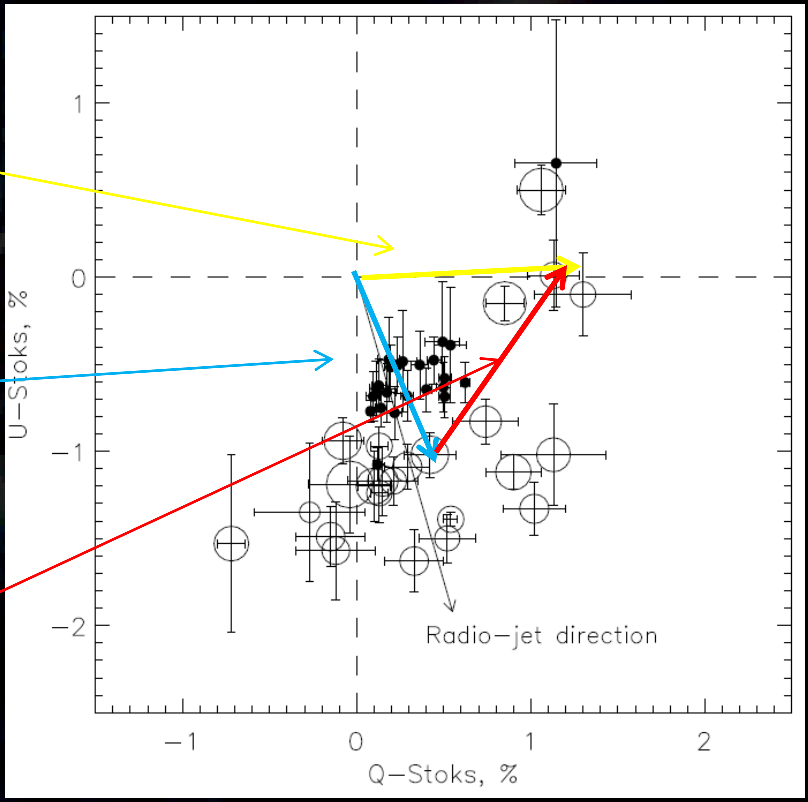


Variability polarized continuum: disk+jet

- the polarization disk and jet

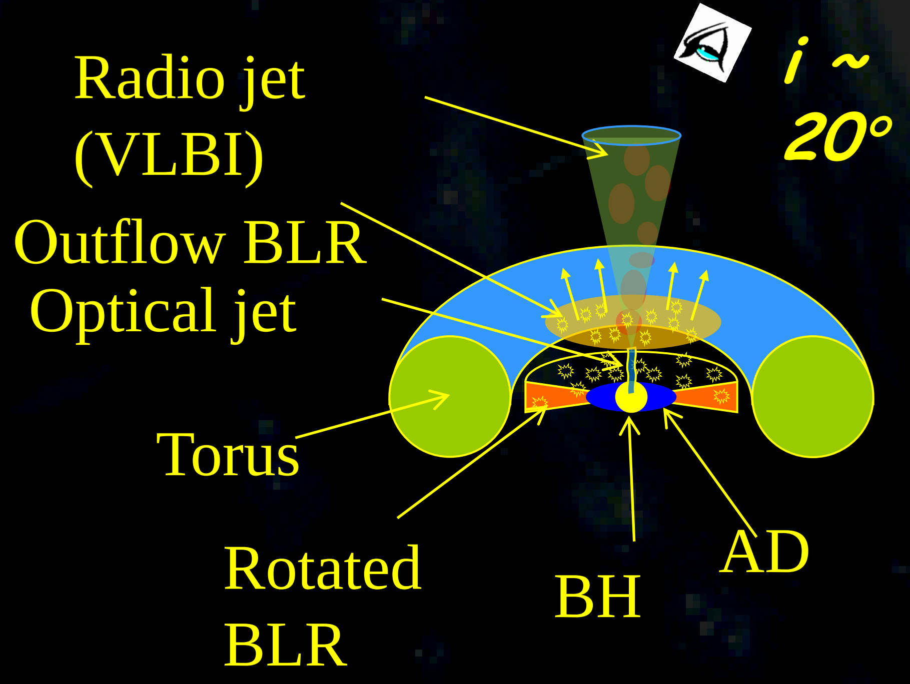
- Polarization in the disk =>
  Electric vector parallel to the disk axis

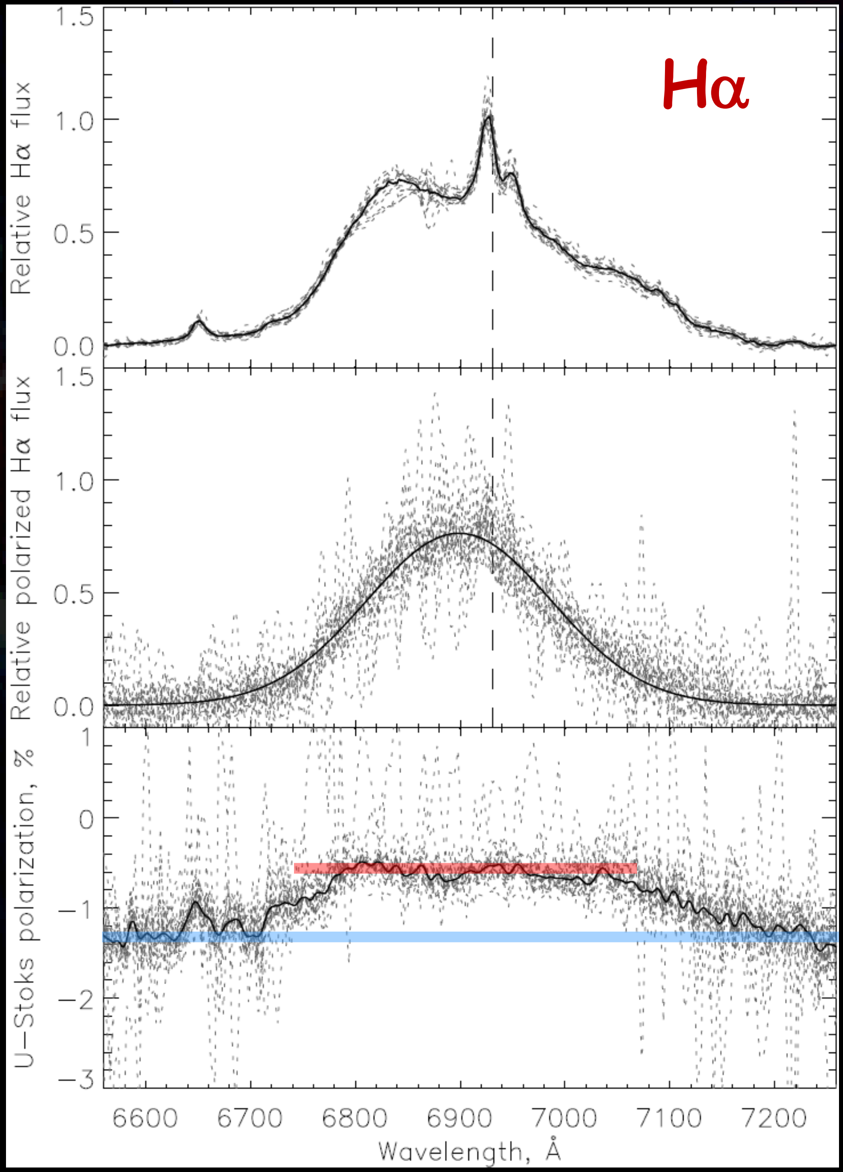
- Polarization in the jet => synchrotron from the jet . Electric vector ~ perpendicular to the disk axis with accuracy up to pitch angle



Polarization in broad Hα 3C390.3

- *Depolarization in broad lines => depolarization in the hot material above thick disk BLR in the direction of the disk axis*
- *Shift broad Hα -1200 km/s and FWHM ~ 6000 km/s*

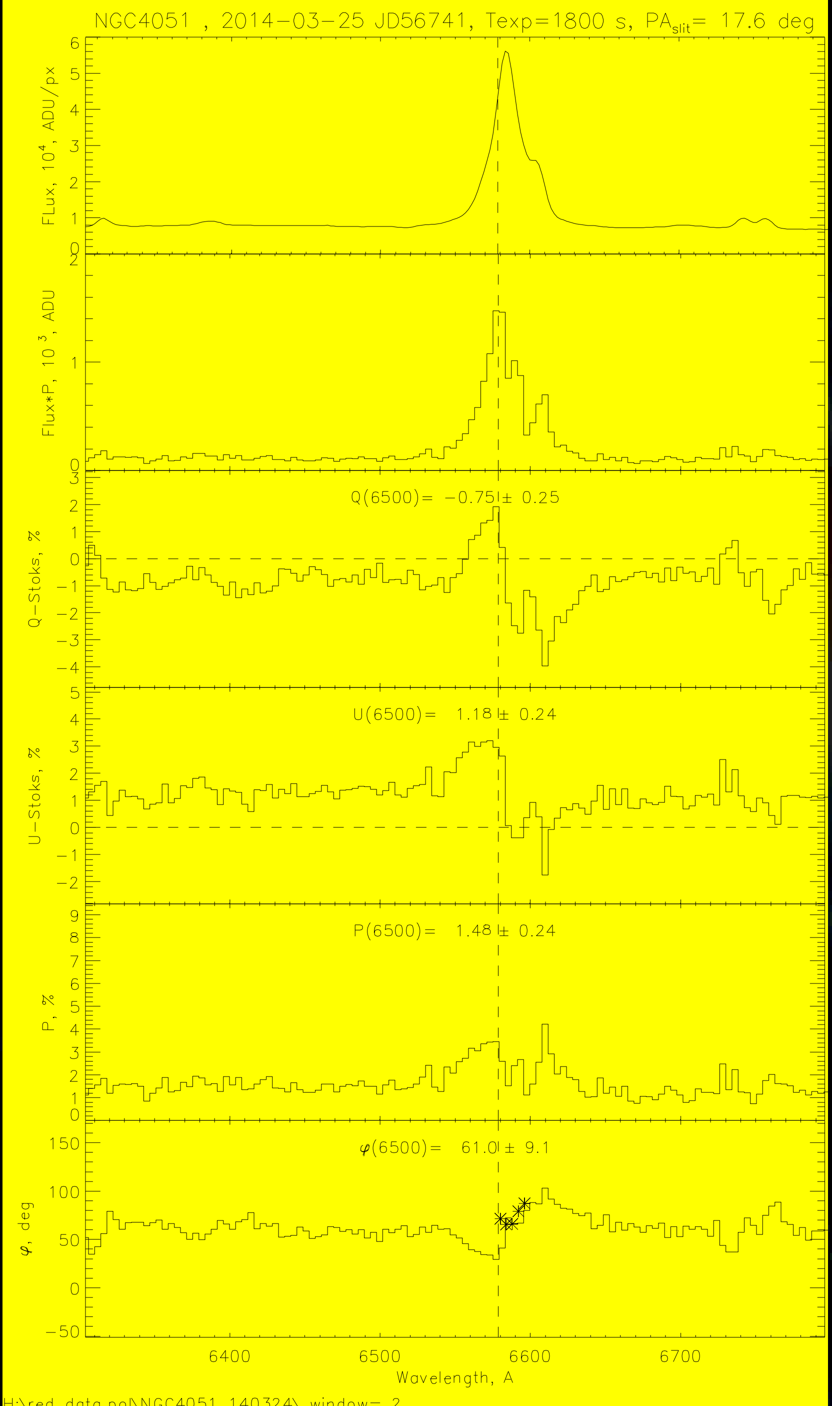


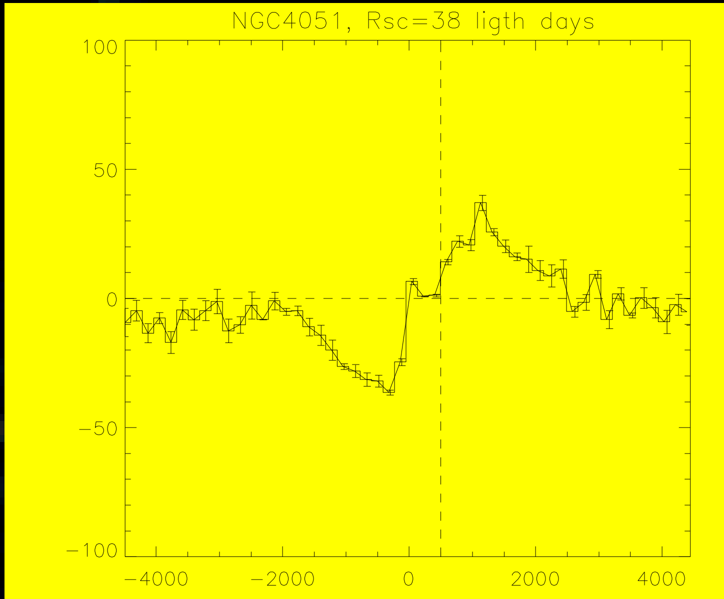


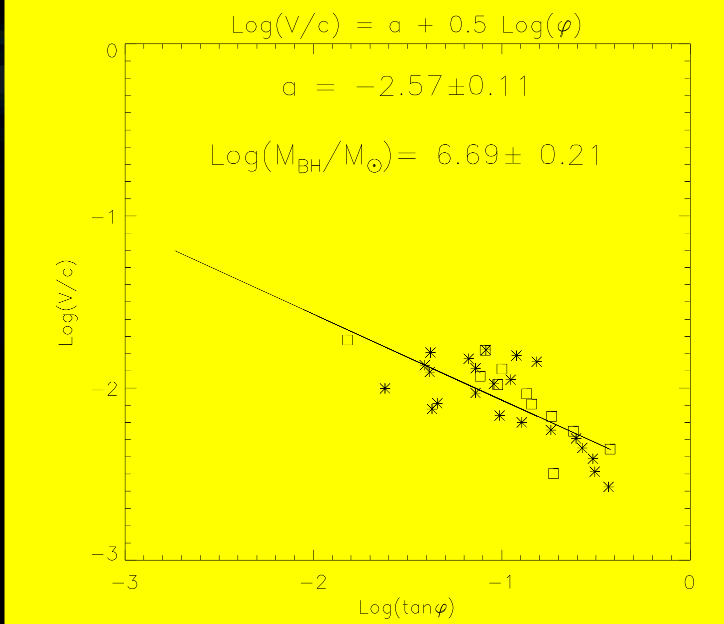
Future work

- ✓ **Observation of a numbero of Sy 1 AGNs (we still observed aroud 40 broad line AGNs)**
- ✓ **Model the AGN polarization (R. Goosmann, PhD studet Dj. Savic)**
- ✓ **Some first results for NGC 4051**
- ✓ BLR (ld) 4.3 – 15 ld, torus 38 – 54 ld, V =400 km/s, tau 0.5 and 0.8 and theta 30 degrees

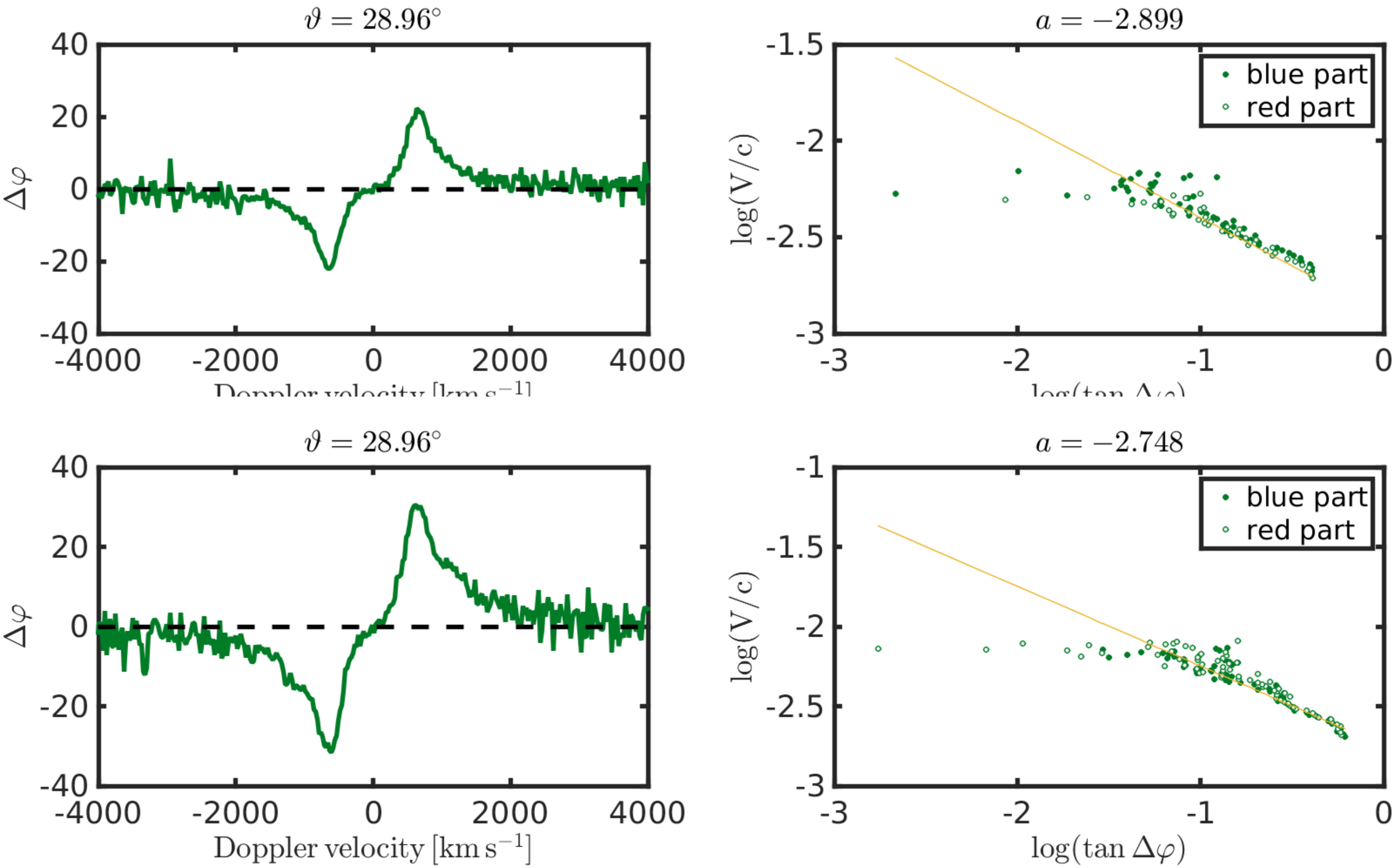
Observatios NGC 4051



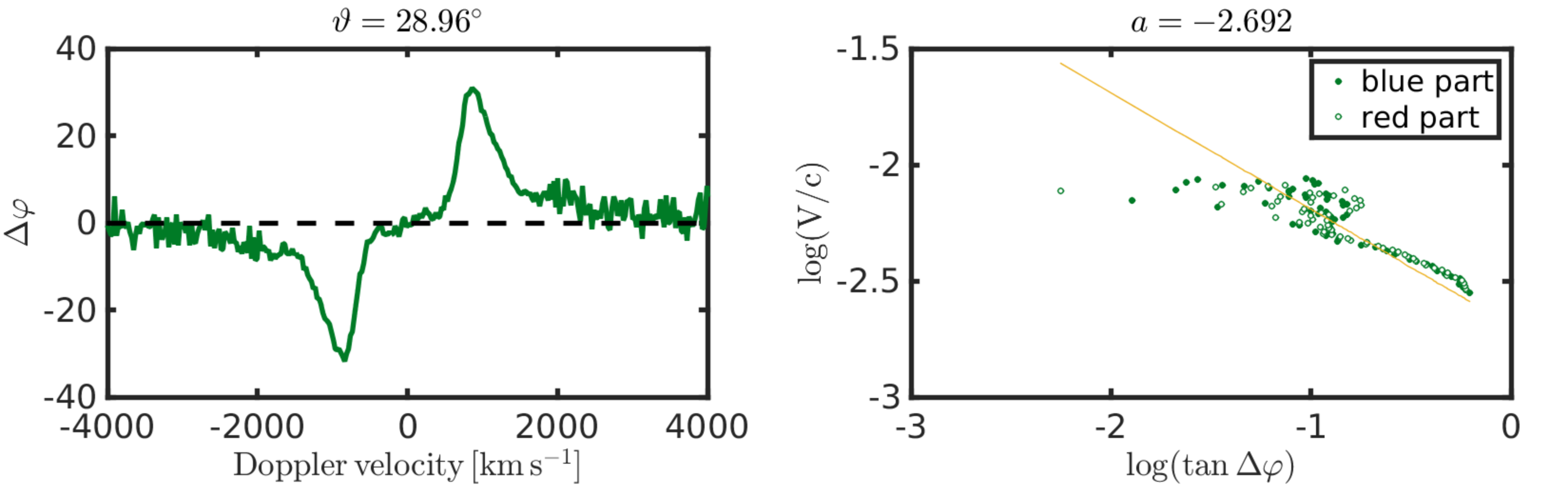




Change in the optical depth from 0.5 to 0.8

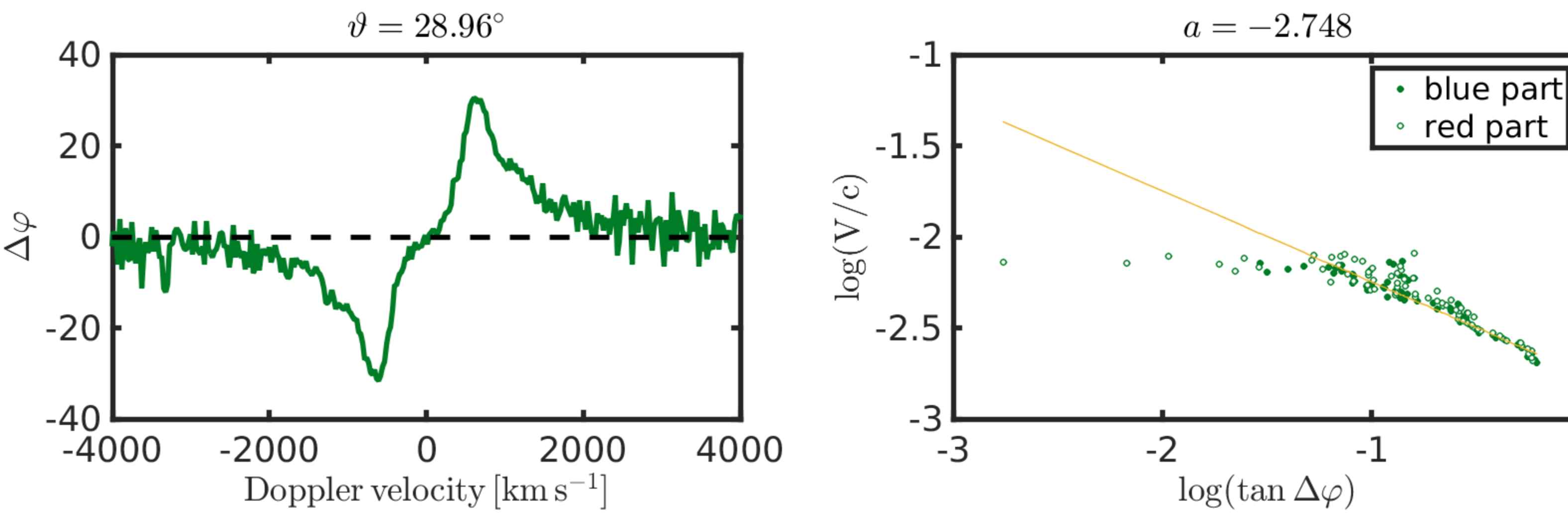


BLR 4.3-10 ld



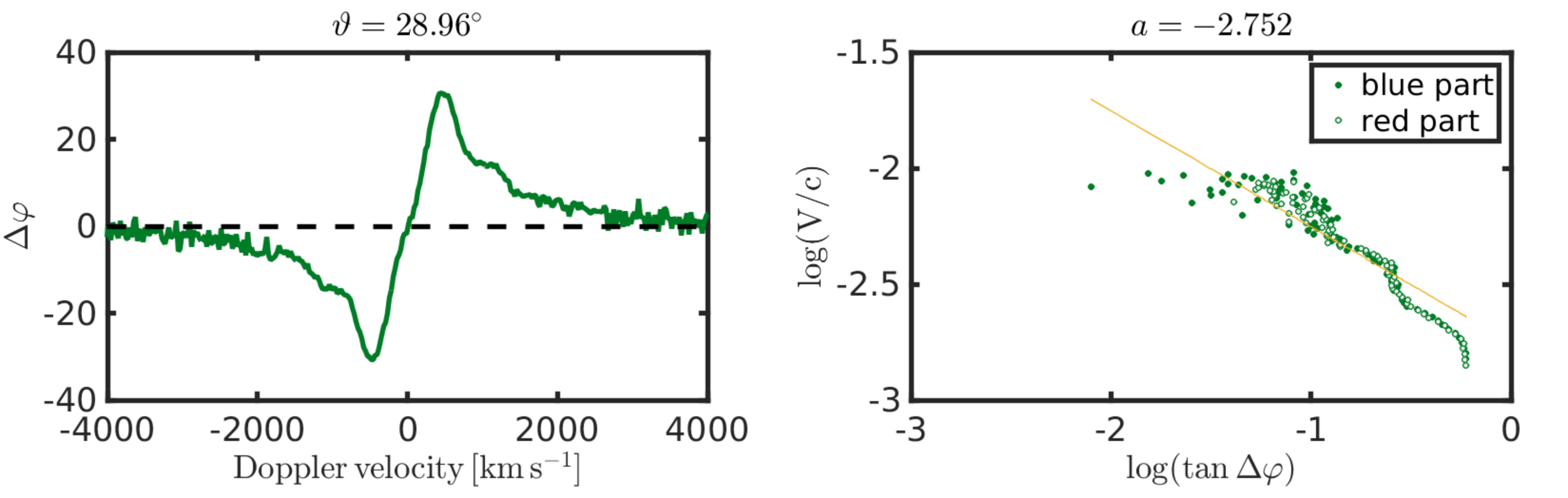
$\vartheta = 28.96^\circ$
40
20
0
-20
-40
$\Delta\varphi$
-4000
-2000
0
2000
4000
Doppler velocity [km s^{-1}]
$a = -2.692$
-1.5
-2
-2.5
-3
log(V/c)
-3
-2
-1
0
log(tan $\Delta\varphi$)
blue part
red part

BLR 4.3-15ld



$\vartheta = 28.96°$
40
20
0
-20
-40
-4000
-2000
0
2000
4000
$\Delta\varphi$
Doppler velocity [km s^{-1}]
$a = -2.748$
-1
-1.5
-2
-2.5
-3
-3
-2
-1
0
blue part
red part
log(V/c)
log(tan $\Delta\varphi$)

BLR 4.3-20ld



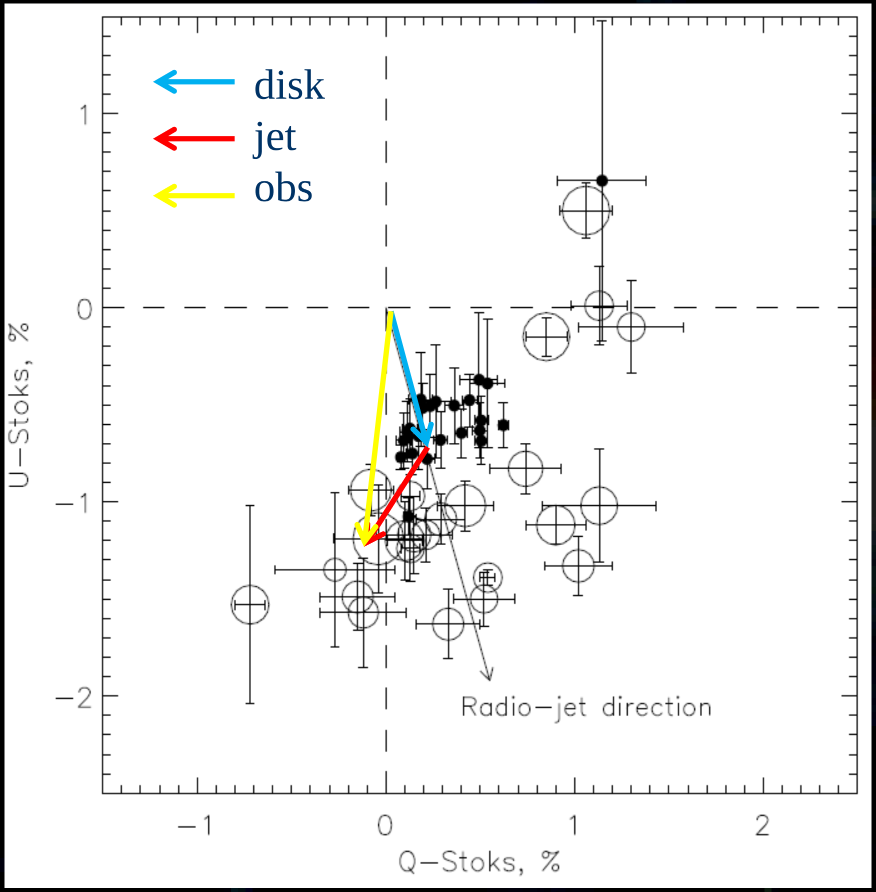
$\vartheta = 28.96°$
40
20
0
-20
-40
$\Delta\varphi$
-4000
-2000
0
2000
4000
Doppler velocity $[\mathrm{km\,s^{-1}}]$
$a = -2.752$
-1.5
-2
-2.5
-3
log(V/c)
-3
-2
-1
0
$\log(\tan \Delta\varphi)$
blue part
red part

CONCLUSION

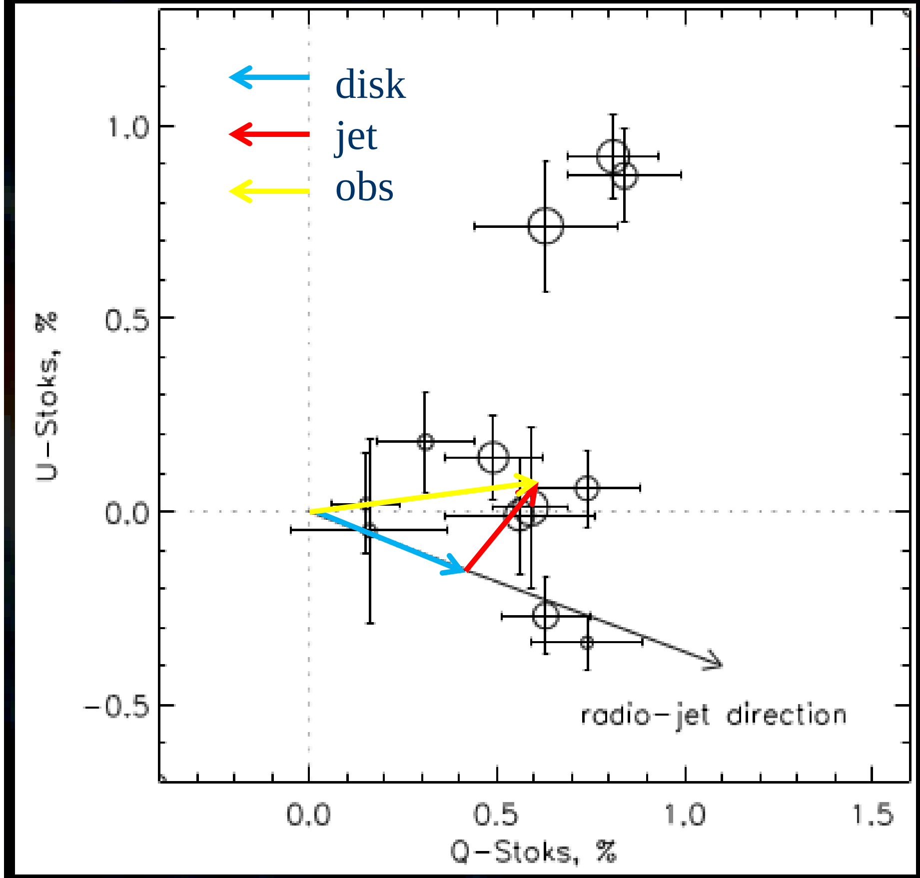
- ✓ Spectropolarimetric monitoring of the AGN allows to resolve regions with different polarization mechanisms and determine their sizes
- ✓ Using the high-resolution spectropolarimetry enables to determine the type of gas clouds kinematics in the BLR (Keplerian motion, outflows)
- ✓ There is a sample of SyG's, with equatorial scattering, which show a Keplerian rotation at <0.2 pc from the center. This can be used for AGN BH mass estimates (a new method).
- ✓ Work is in progress

Polarization in continuum : disk+jet?

3C390.3

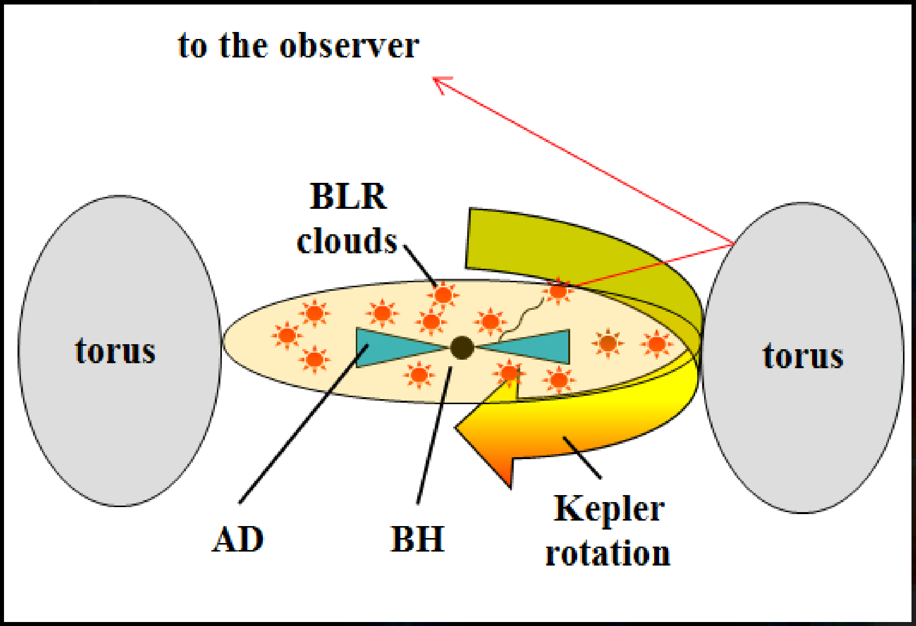


Mkn 6



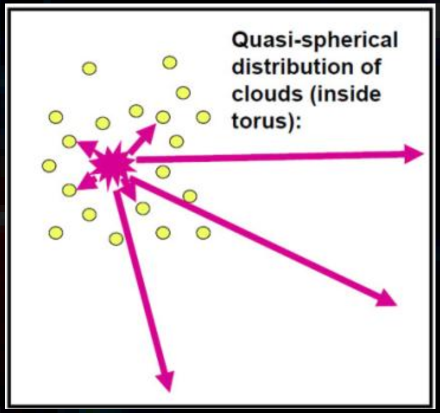
The observed polarization in the continuum – the result of the vector addition disk and jet polarization

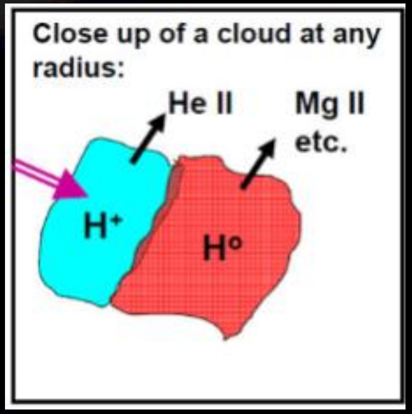
Polarization in broad lines



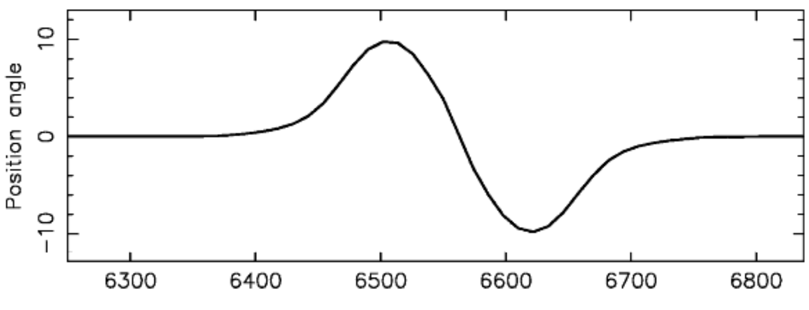
Broad lines region BLR:

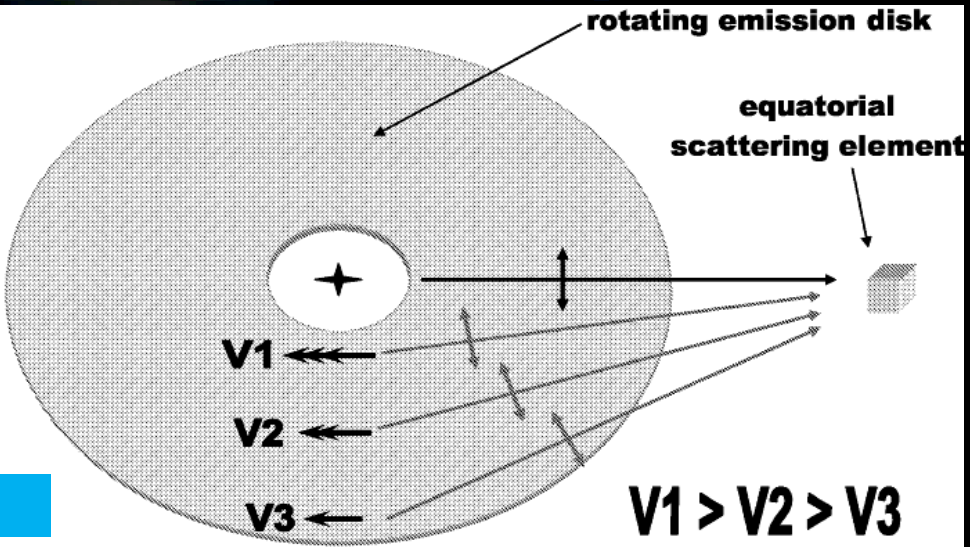
- Mist of clouds with $N \sim 10^{8} \div 10^{12}$ cm^{-3}
- Size BLR ~ 0.1-1 pc , $\varepsilon \sim 0.001$





Equatorial scattering





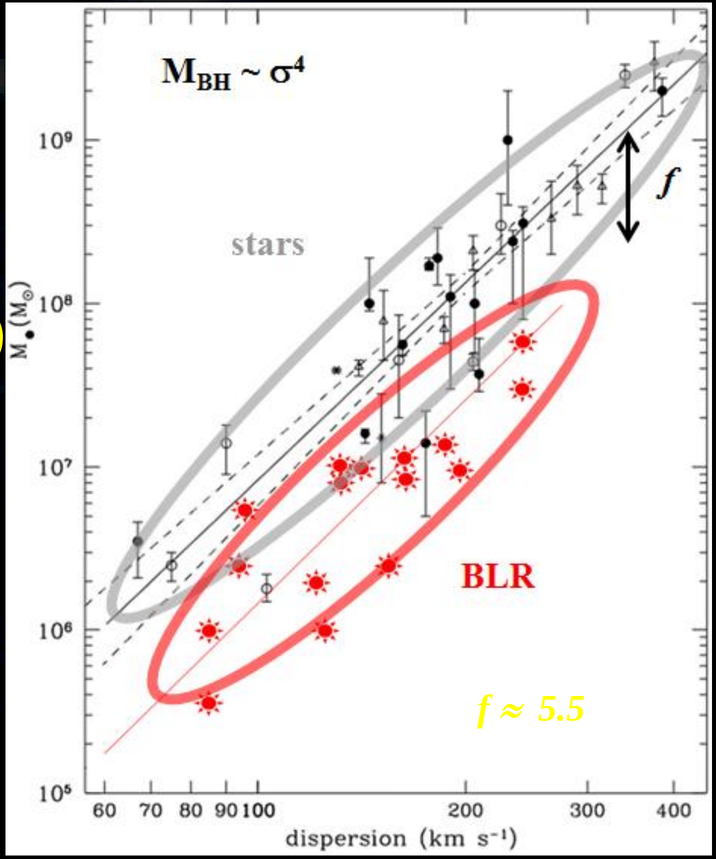
Smith J.E. at al., 2005, MNRAS, 359, 846

BLR - an indication of the BH in AGN

- The size of the BLR is measured at time delay τ of variability flux broad Hα relative to the continuum $R_{BLR} = c\tau$
- Line width V is estimated from the observed width $V = V_{obs}/\sin i$, where *i* - unknown angle of inclination BLR disk to the line of sight
- **PROBLEMS**: *f* - depends on the BLR geometry (may be very complex – disc, outflows, inflows -combination of these) It is believed that the area of broad line (BLR) in active galactic nuclei (AGN) are virialized.

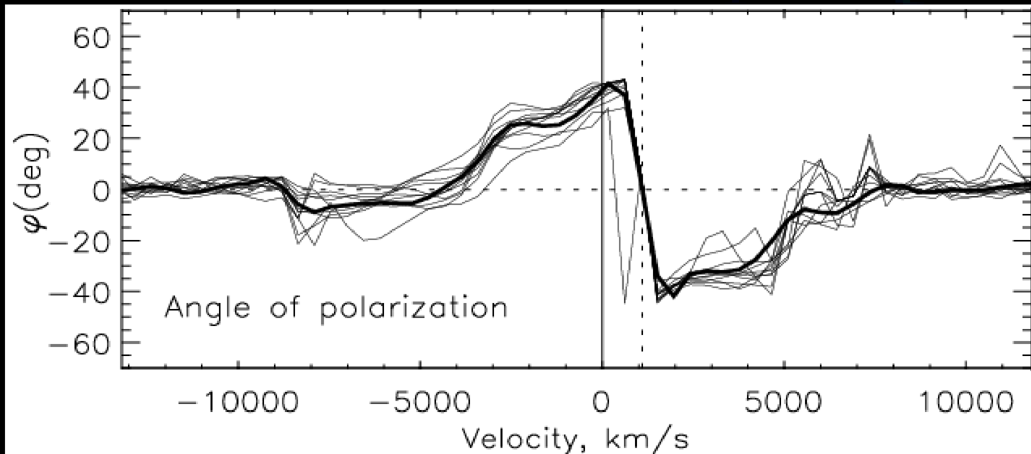
This assumption cannot be directly verified because the BLRs are spatially unresolved

virial relation



Onken at al., 2004, ApJ, 615, 651

Rotation of the plane of polarization in the BLR

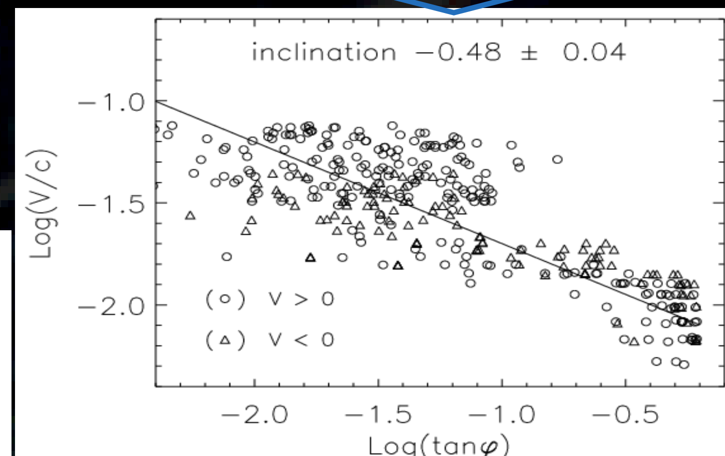


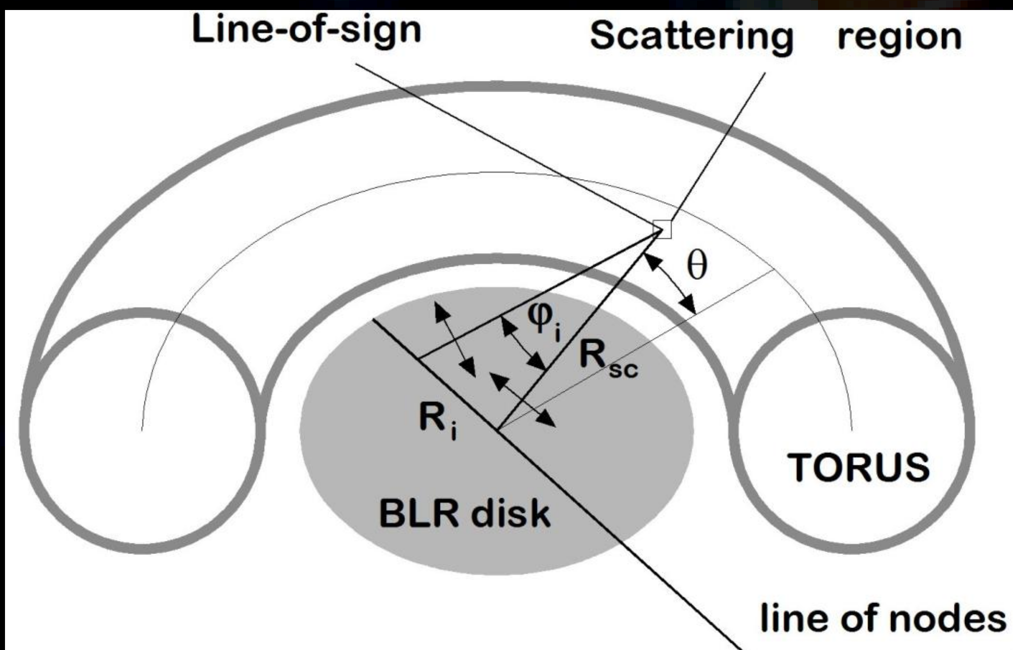
$$V_i = V_i^{rot}\cos(\theta) = \sqrt{\frac{GM_{BH}}{R_i}}\cos(\theta),$$

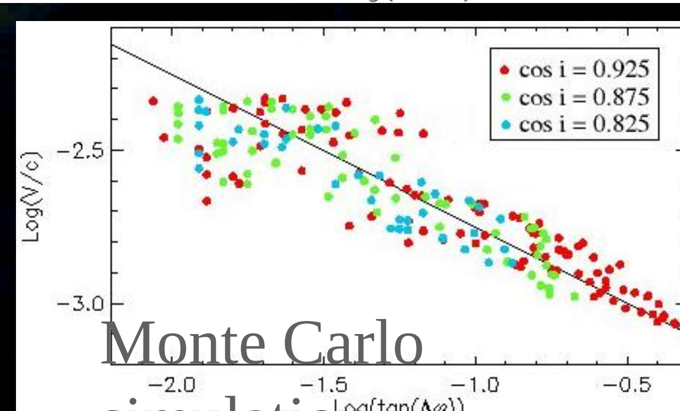
$$R_i = R_{sc}\cdot\tan(\varphi_i)$$

$$\log(\frac{V_i}{c}) = a - b\cdot log(\tan(\varphi_i)),$$

$$a = 0.5\log(\frac{GM_{BH}\cos^2(\theta)}{c^2 R_{sc}})$$





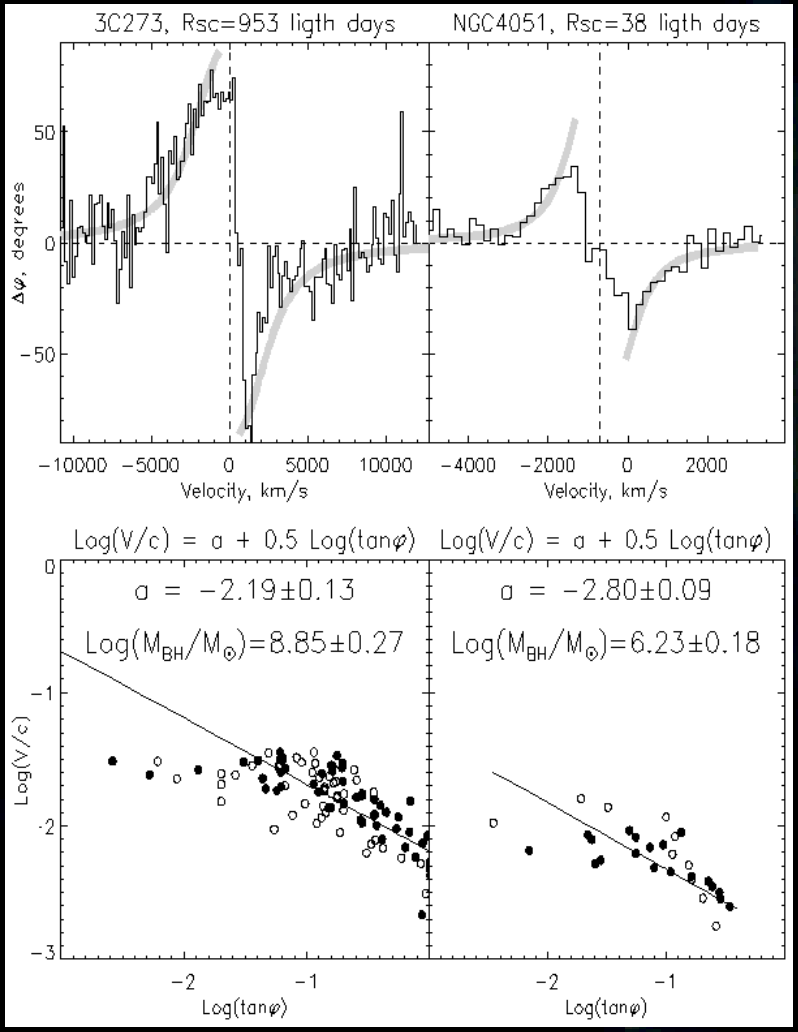


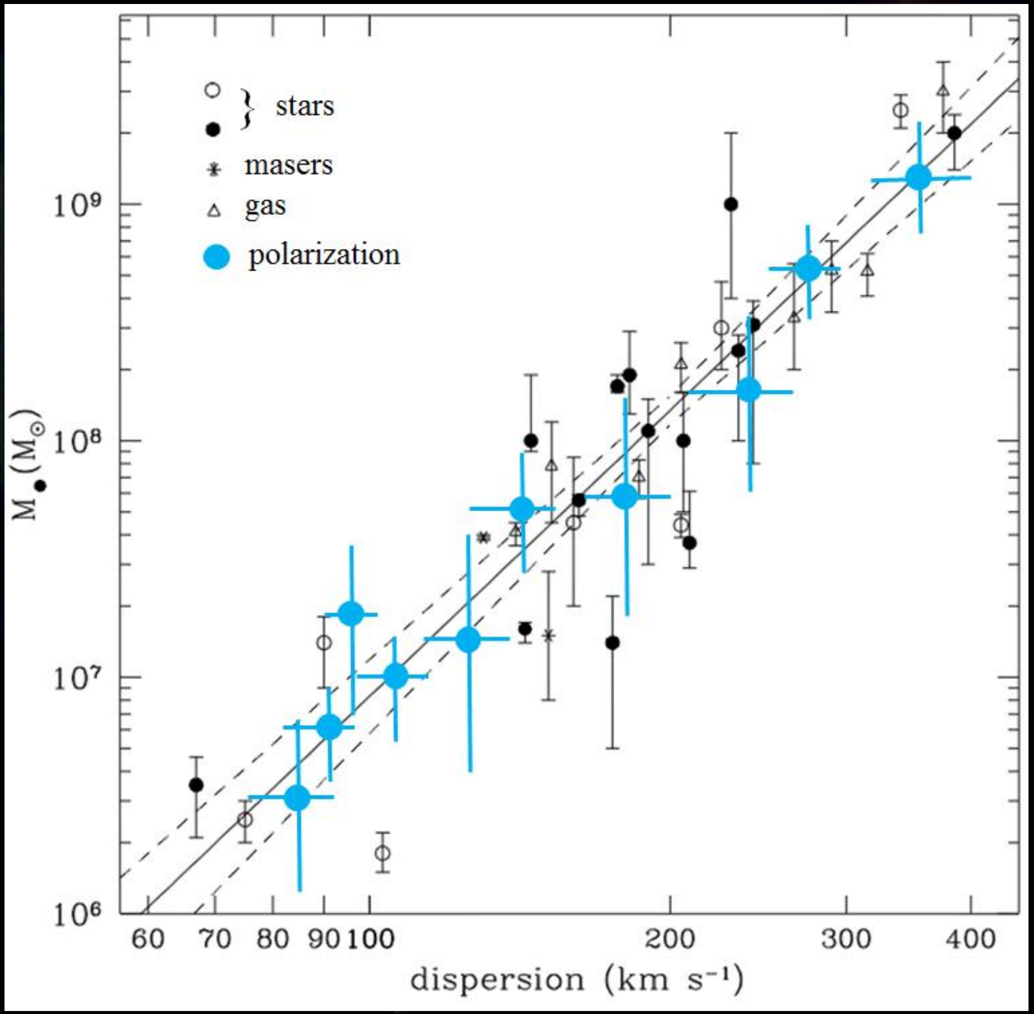
Monte Carlo simulation

Estimation M_{BH} does not depend of the inclination BLR

BH masses by polarization in broad line Hα

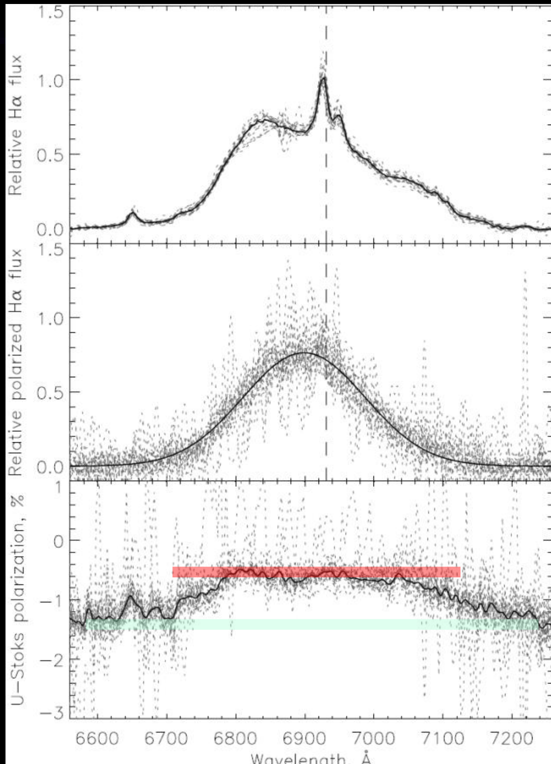
Observation at 6-m telecope sample SyG with equatorial scattering in Hα

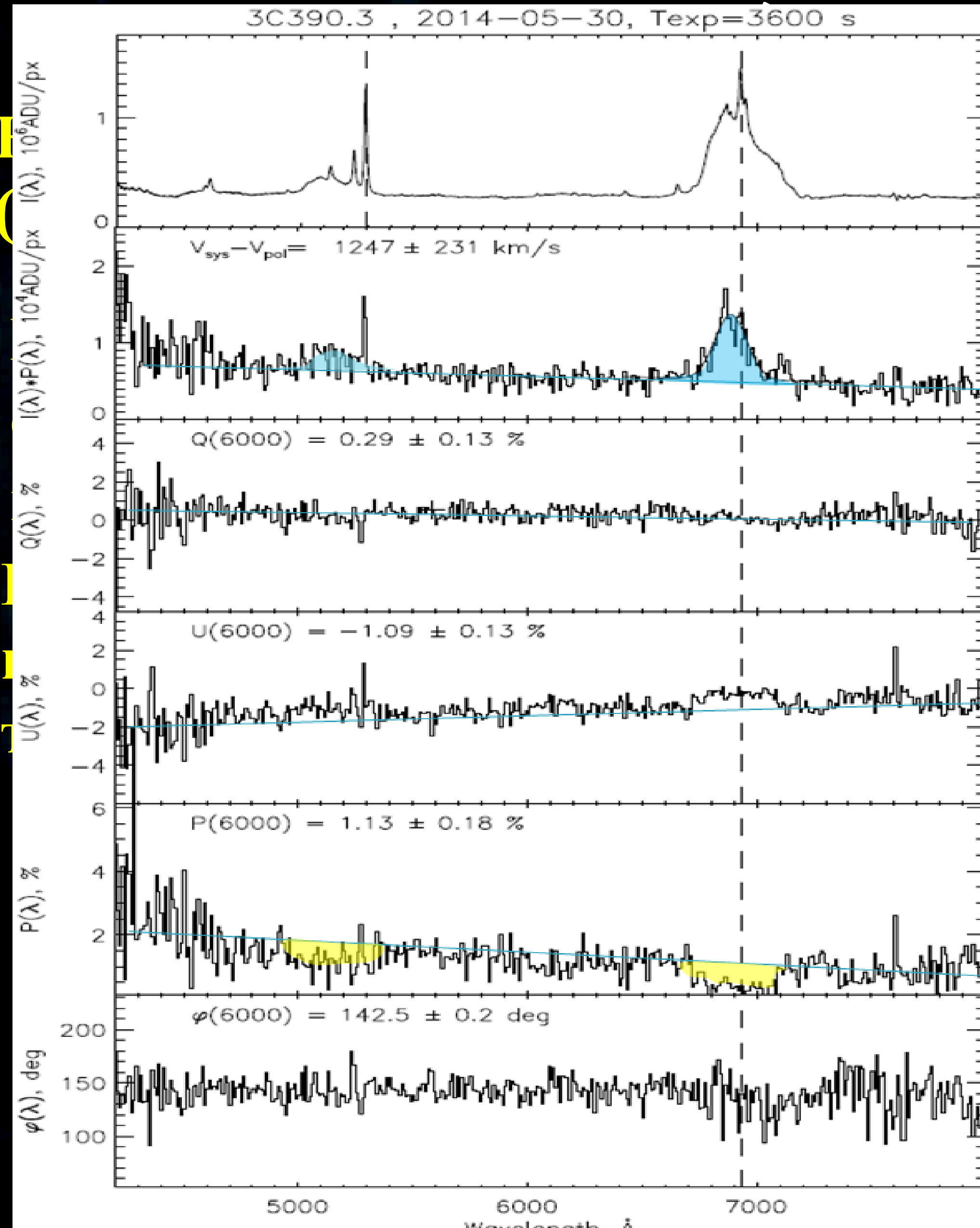




Afanasiev & Popović, 2015, ApJL, v.800, p.L35

Depolarization in broad line Hα в 3C390.3





- **Depolarization polarized flux of accretion disk because of the "mist" halo BLR clouds in the direction of the disk axis with PA~152° => -U (PA=135°)**
- **The halo of clouds in Hα, extends along an axis at velocity -1200 км/с**

E.g. -Polarization in broad Hα 3C390.3 Afanasiev et al. 2015, MNRAS

- ❑ *Depolarization in broad lines => depolarization in the mist of cloudlets thick disk BLR in the direction of the disk axis*
- ❑ *Shift broad Hα -1200 km/s and FWHM ~ 6000 km/s*