INVESTIGATION OF SUB-PC AGN REGIONS AND GRAVITATIONAL LENSES WITH OPTICAL SPECTROPOLARIMETRIC METHOD

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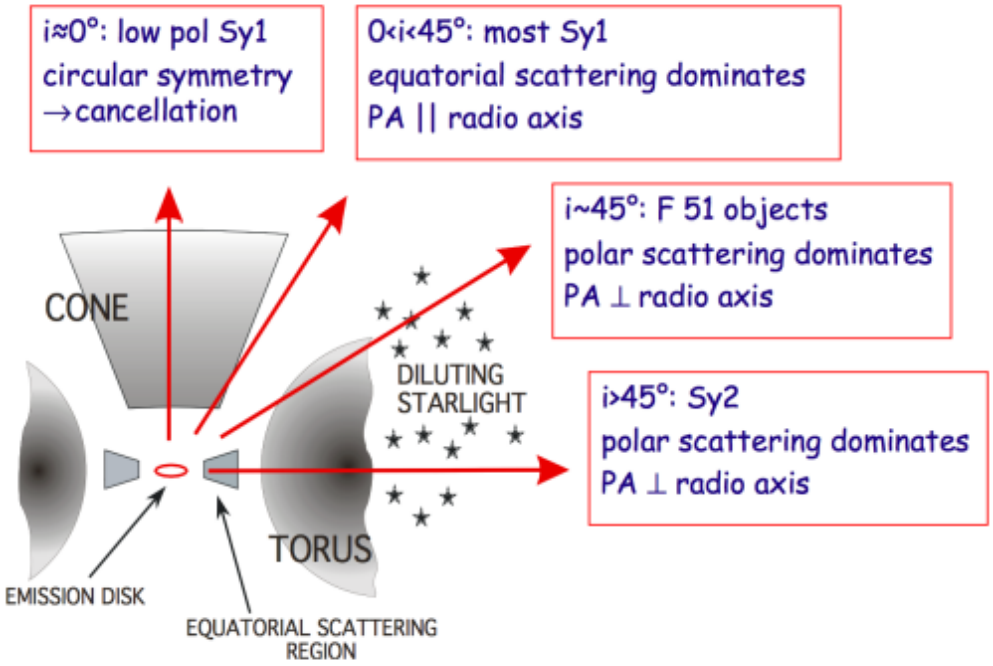
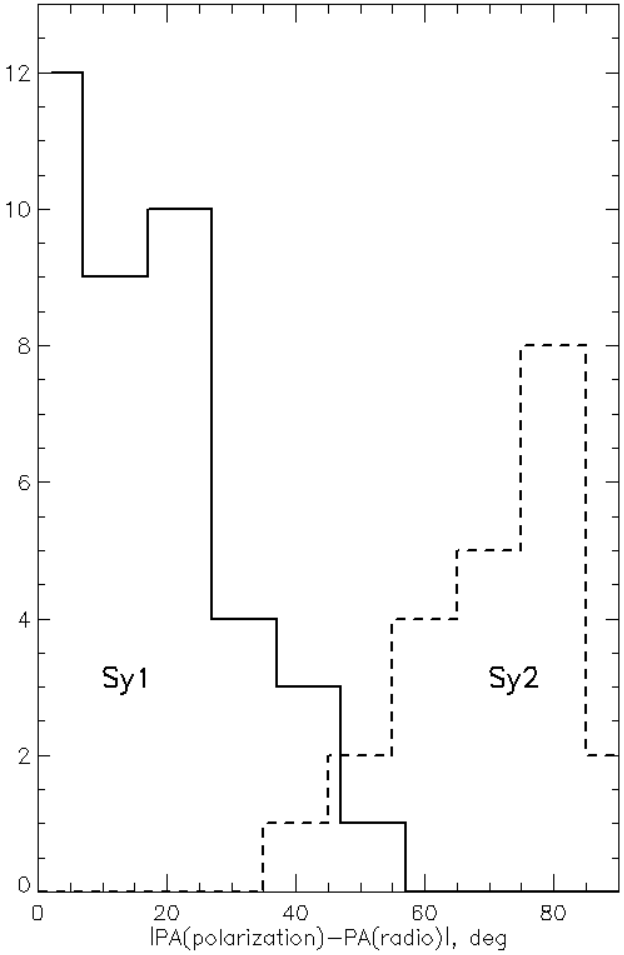
X SBAC, Beograd
30. 05-03.06.2016

Polarization of AGNs - a simple (UNIFIED) model

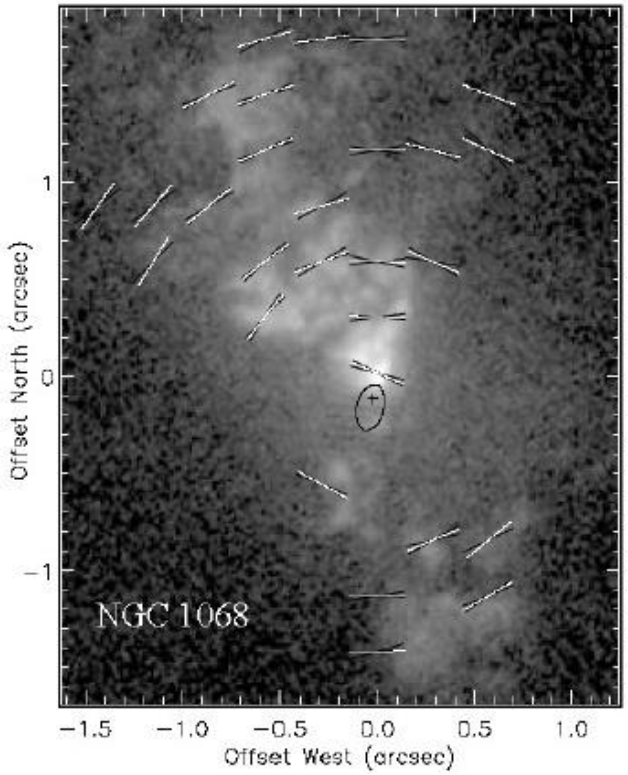


Relation between polarization class and orientation in the generic scattering geometry that broadly explains the optical polarization spectra of Seyfert galaxies Smith et al. (2004)

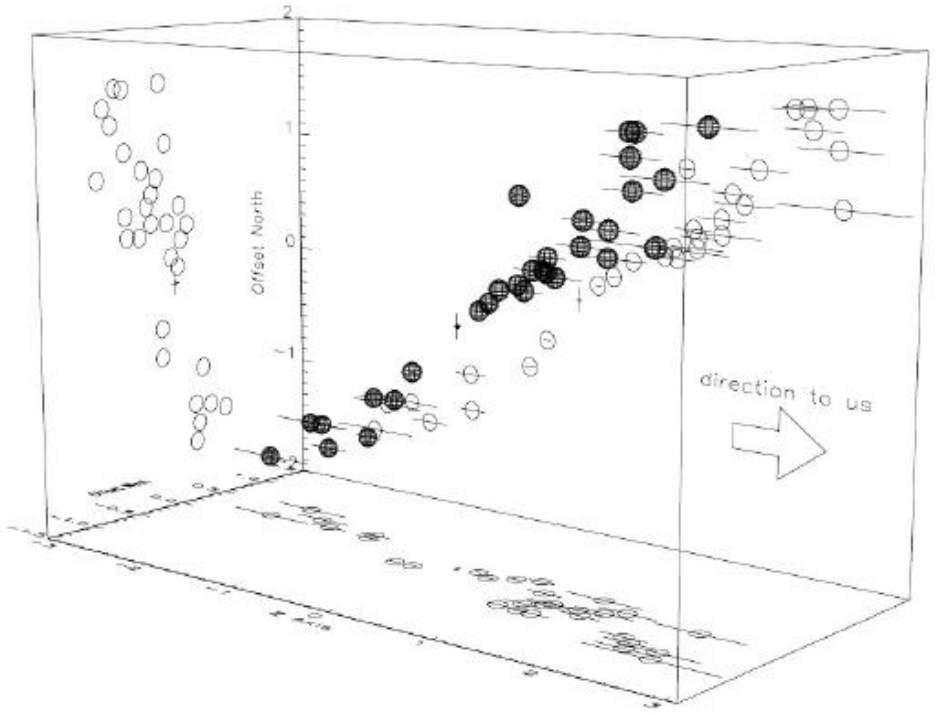


Orientation is important !

Scattering clouds in NGC 1068 (Sy2)



Capetti et al. 1995



Kishimoto et al. 1999

- **Phase function of Thomson scattering**
- **Spatial distribution of polarized flux**
- **Assuming optically thin matter**

3D image of the scattering clouds

In polarized light is visible broad Hα: Sy2 =>Sy1 !

Polarization AGN – INSIDE OR OUTSIDE ?

INSIDE (scale < 1pc)

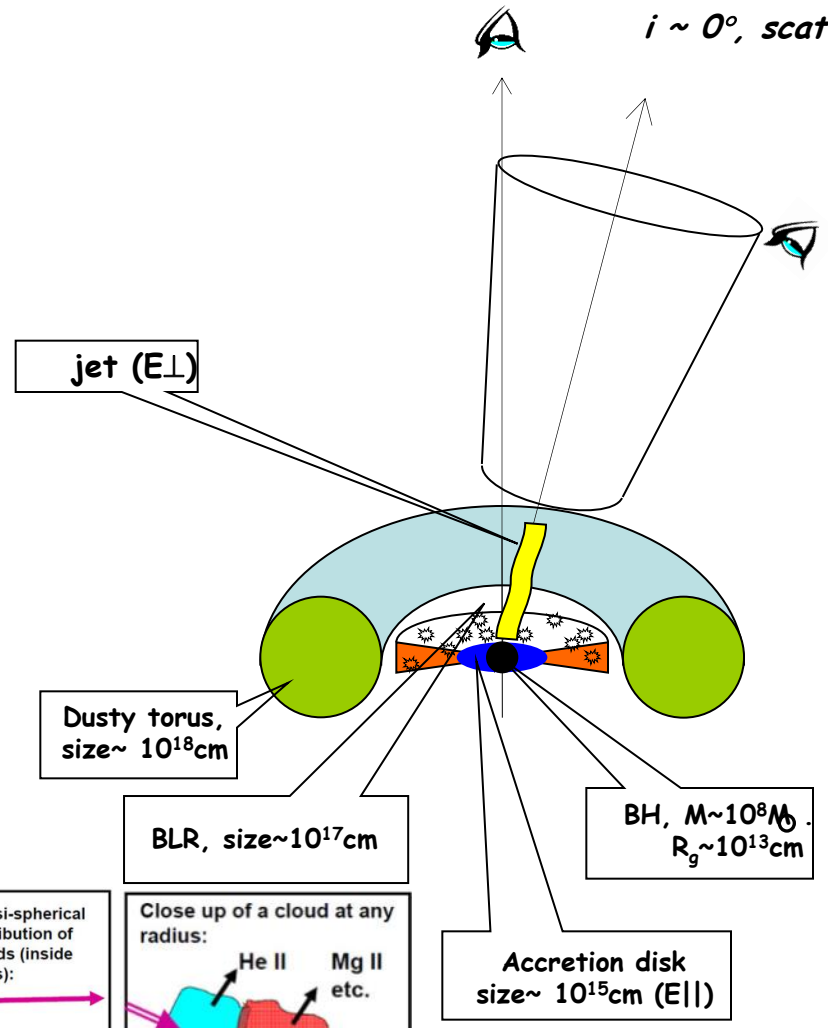
- *polarization of radiation in the field of a rotating black hole*
- *radiation transfer in* optically thick *accretion disk (electron scattering)*
- *synchrotron radiation of the jet*

OUTSIDE (scale> 1pc)

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

SCALE IS IMPORTANT !

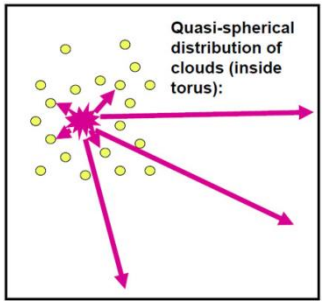
Polarization in BLR & continuum

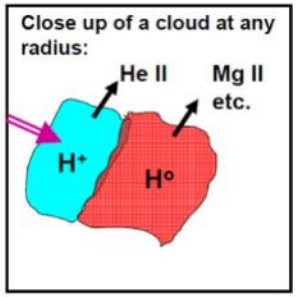


i ~ 0°, scattering ~ 0 (E ⊥), view direct to accretion disc (E ||) and jet (E ⊥)

i <45°, equatorial scattering> 0, (E ||)

i ~ 90, polar scattering> 0 (E⊥), *"hidden" BLR in polarized ligth*





Polarization in continuum

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

Polarization in lines

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

Spectropolarimetric observations:

Motivations

- To study variability in polarized spectra (continuum and broad lines) of Type 1 AGNs
- To measure the dimension and clarify the nature of the polarization region (e.g. is the continuum polarized in the BLR)

Methods

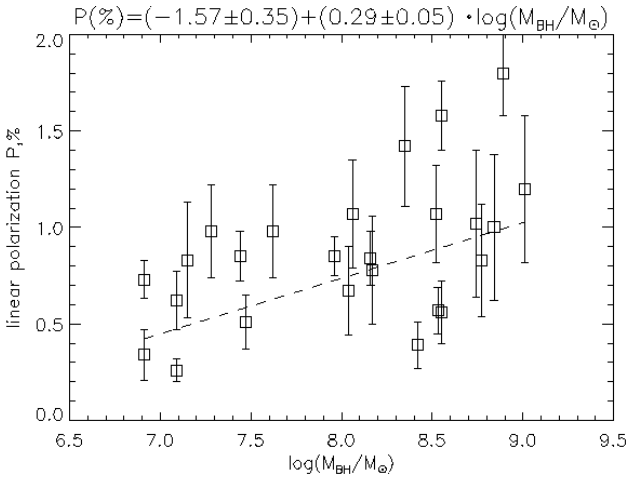
- To observe and measure the linear polarization (Stokes parameters) in spectra of radio quiet AGN with low spectral resolution covering a wide spectral range in several epochs
- To performe echo-mapping (reverberation) in order to find the dimensions of polarization region and compare it with the BLR dimension

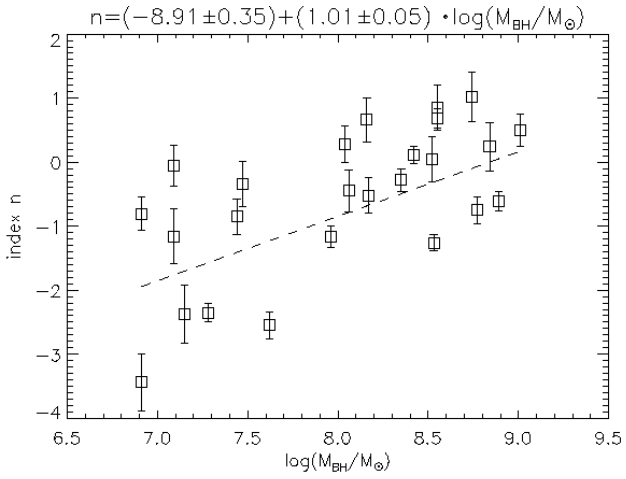
Instrument

- 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%

Polarization in continuum. Observation

(Afanasiev et all., Astronomy Letters., 2011, v.37,p.307

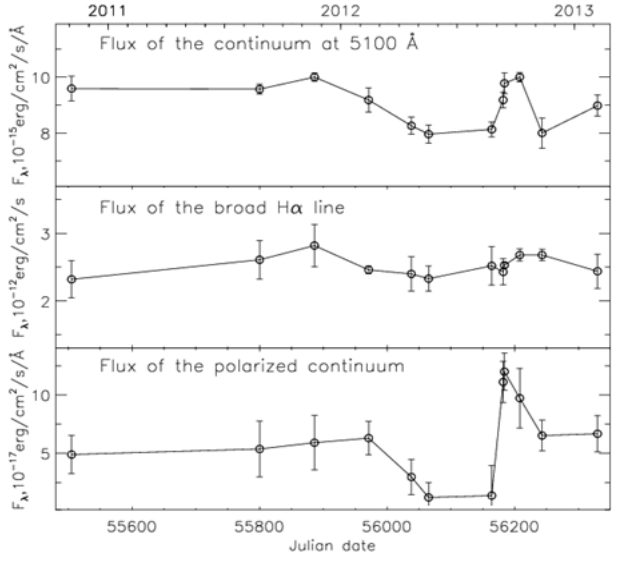


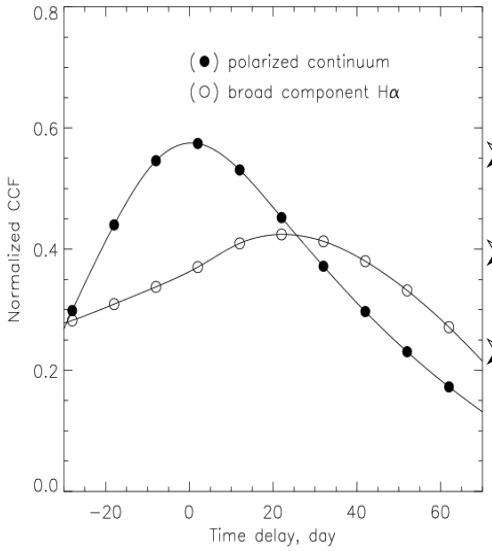


Observed in the continuum polarization is formed on a small scale

- *The polarization caused by the Thomson scattering does not depend on the wavelength*
- *Observed wavelength dependent polarization as* $P \propto \lambda^n$
- *The reason - Faraday rotation in the magnetic field AD on the photon mean free path (Gnedin & Silant'ev, 1997)*
- *Extrapolation of the magnetic field in the disc gives an estimate of the magnetic field on the event horizon of about one thousand gauss*

Polarization in continuum. Variability

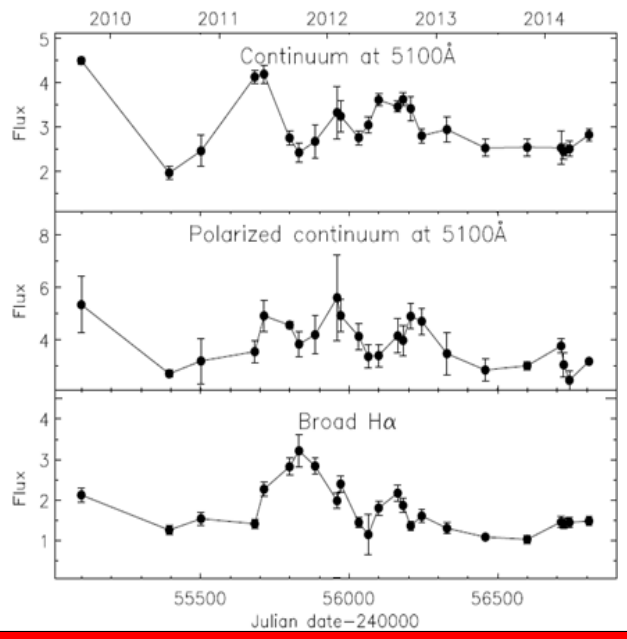


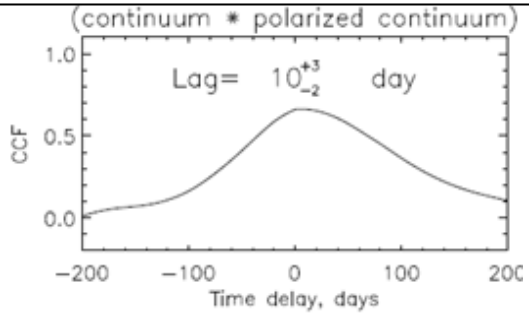


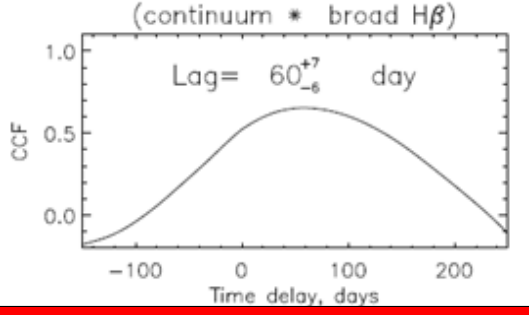
Seyfert galaxy Mkn 6 (Sy1.5)

- spectropolarimetric monitoring (12 epoch) in 2010-2014
- size of the polarized continuum about 2 light days (0.002 pc)
- BLR size from reverberation broad Hα about 22 light days (~0.02 pc)

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







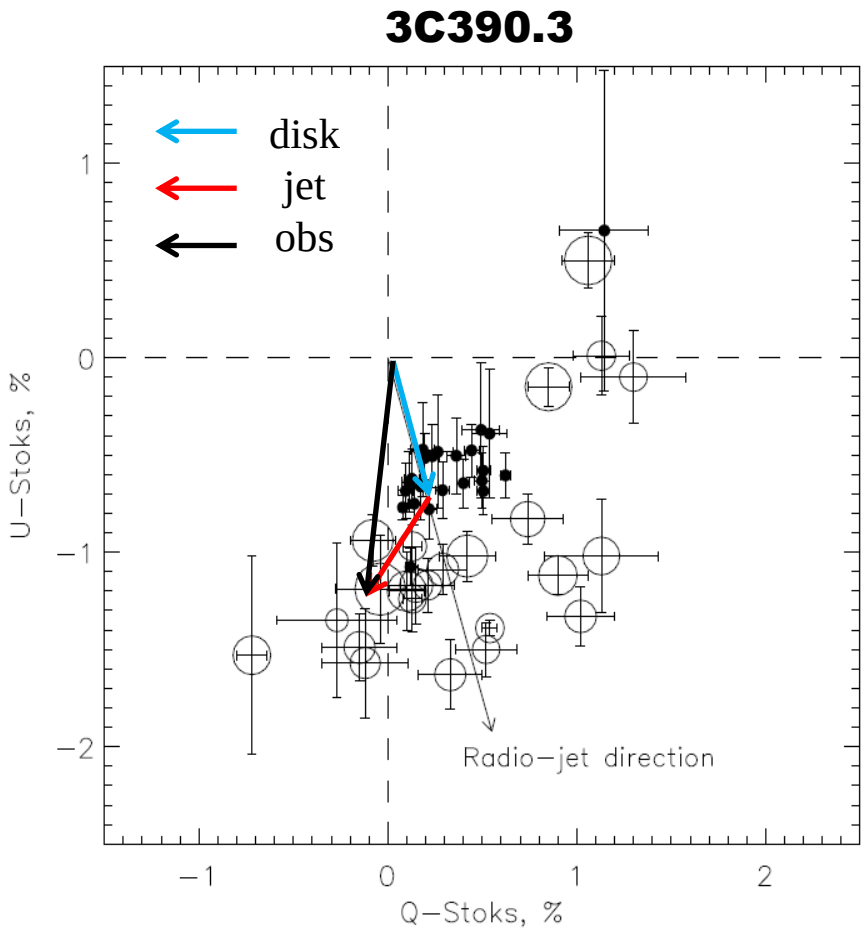
Radio-galaxy 3C390.3 (Sy1)

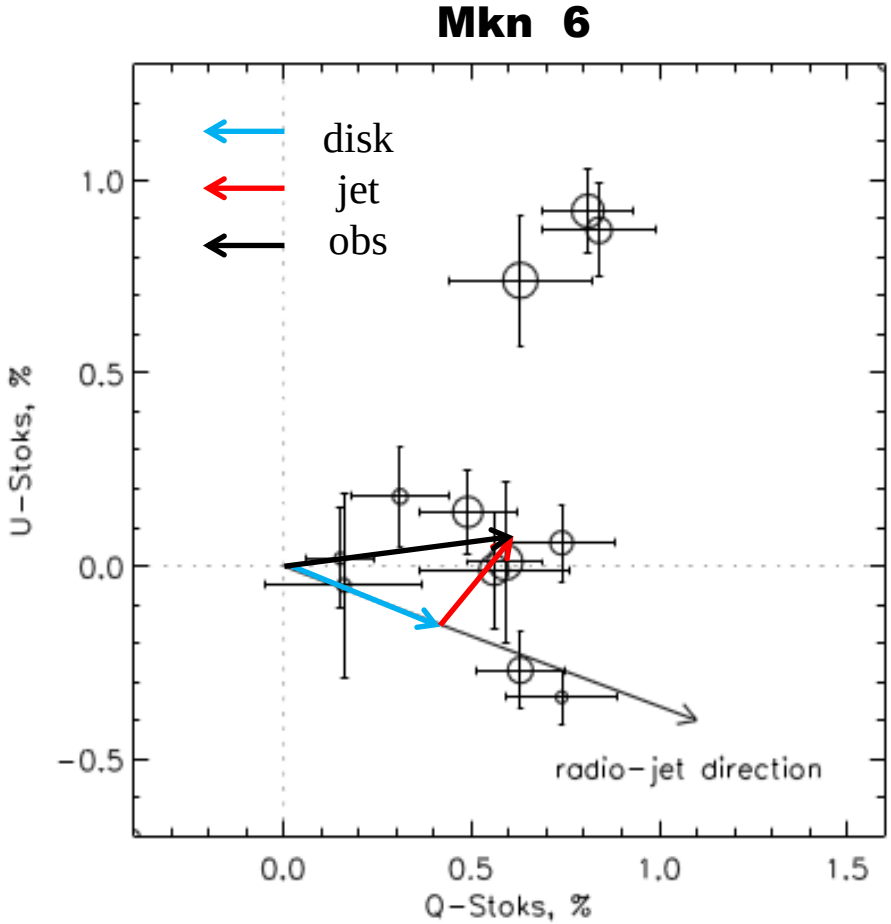
- spectropolarimetric monitoring (23 epoch) in 2009-2015
- size of the polarized continuum about 10 light days (0.01 pc)
- BLR size from reverberation on broad Hβ about 60 light(~0.06 pc), and about 140 days on broad Hα (~0.06 pc)

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

Region of polarized continuum less on order BLR !

Polarization in continuum : disk+jet?



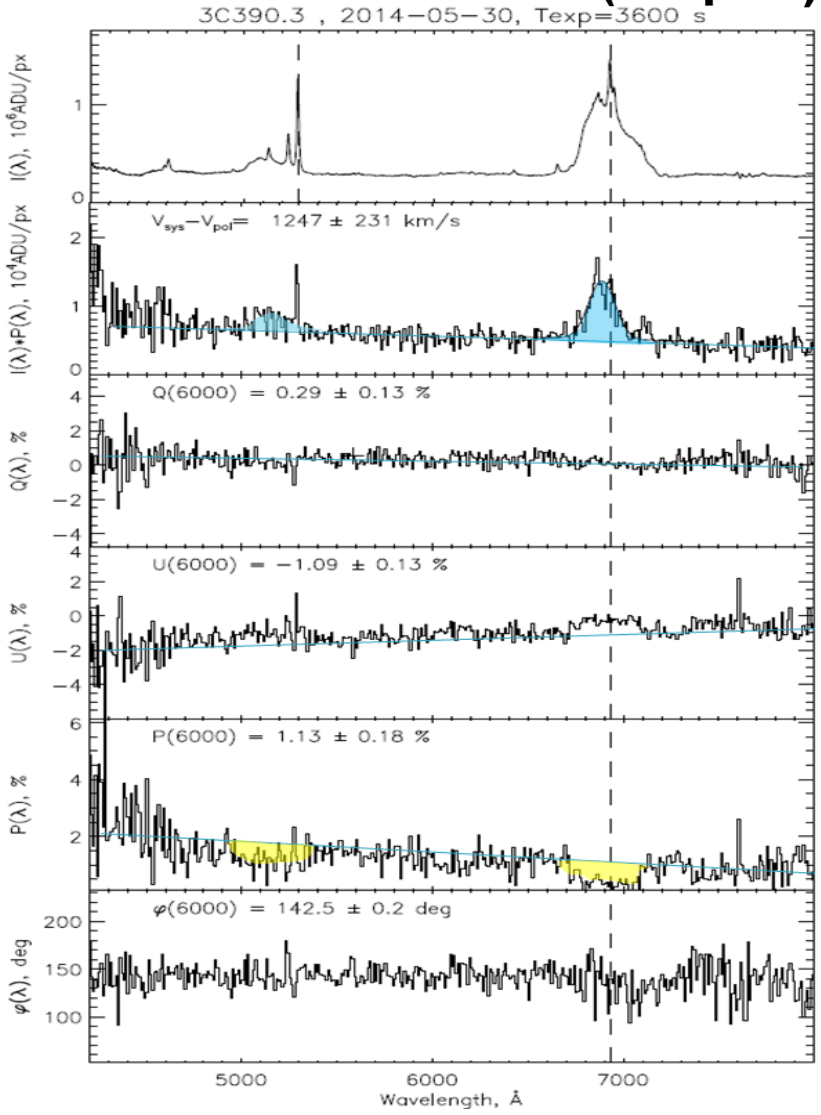


- Polarization in the disk ⇒ radiative transfer in the AD ($\vec{E}$ || axis)
- Polarization in the jet ⇒ synchrotron radiation in the variable Jet ($\vec{E} \perp$ axis)

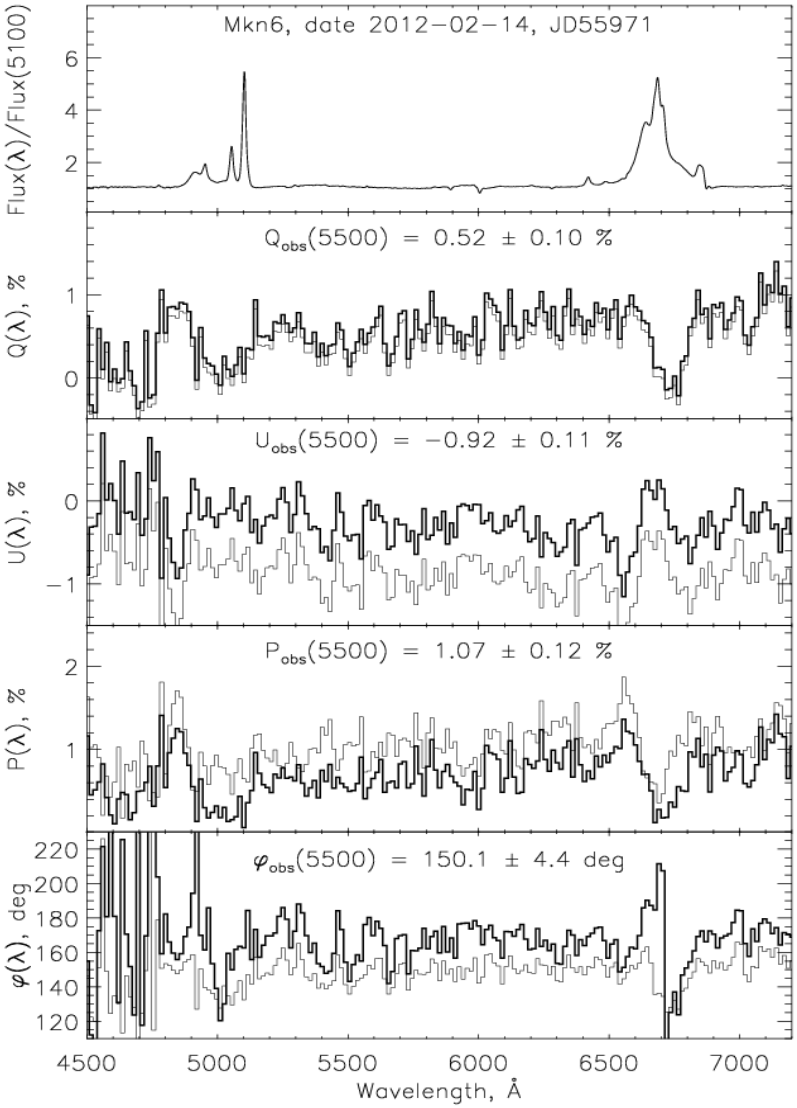
The observed polarization in the continuum – the result of the vector addition disk and jet polarization

Spectropolarimetry Mkn6 и 3C390.3

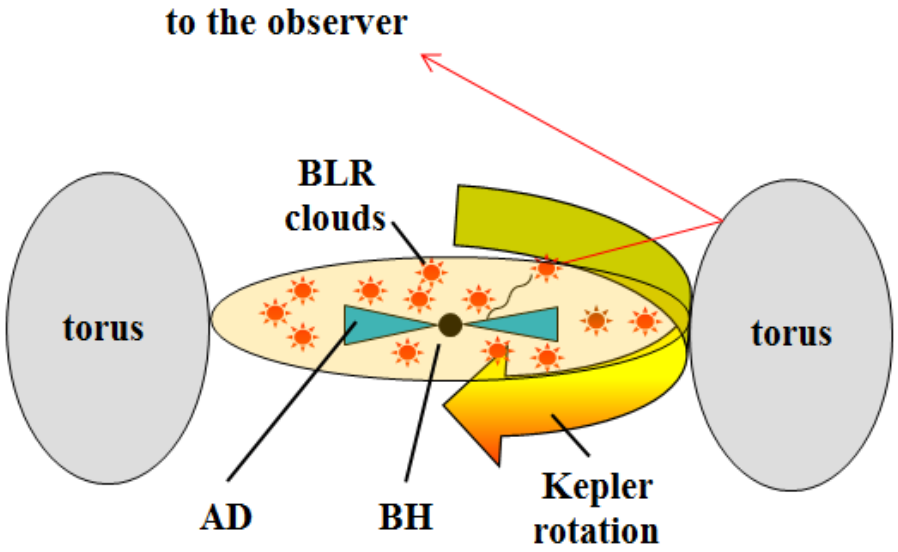
3C390.3 2009-2015 (23 epoch)



Mkn 6 2009-2015 (12 epoch)

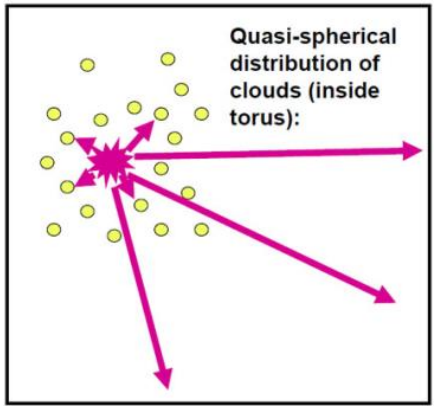


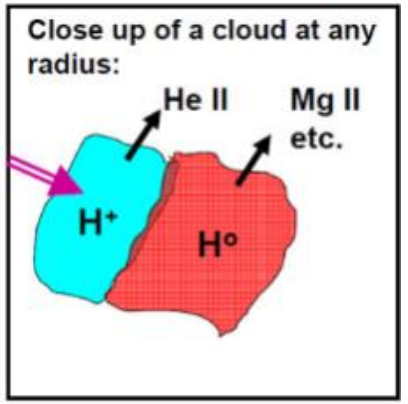
Polarization in broad lines



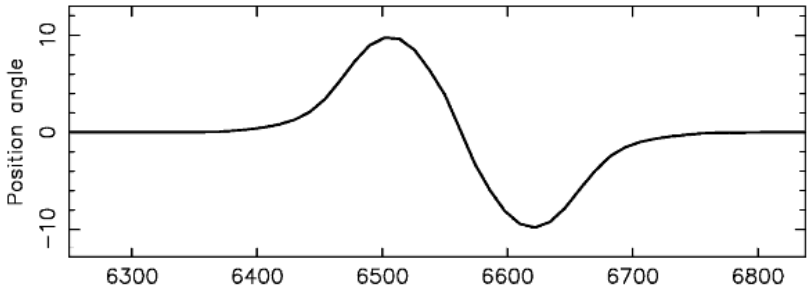
Broad lines region BLR:

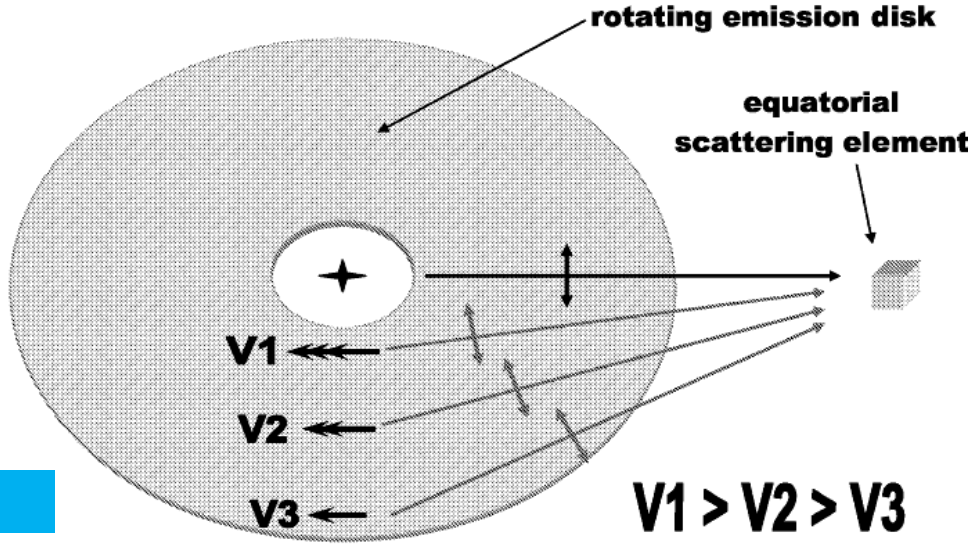
- **Mist of clouds with N~10^{8}÷10^{12} cm^{-3}**
- **Size BLR ~ 0.1-1 pc , ε~0.001**





Equatorial scattering

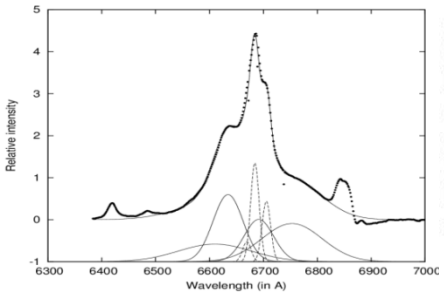


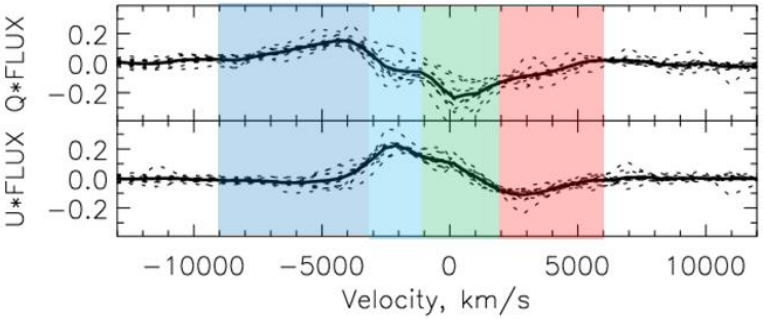


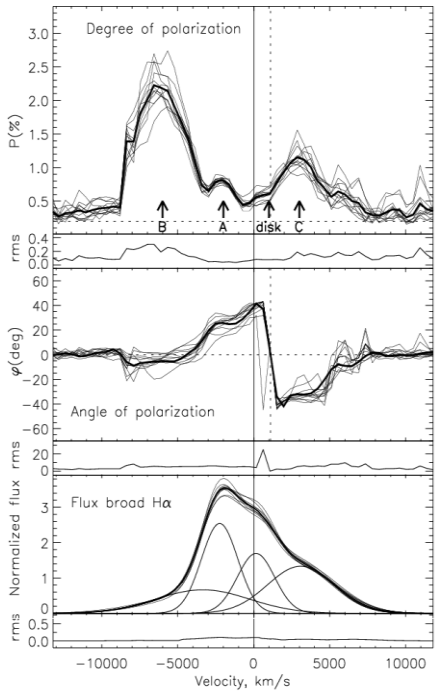
Smith J.E. at al., 2005, MNRAS, 359, 846

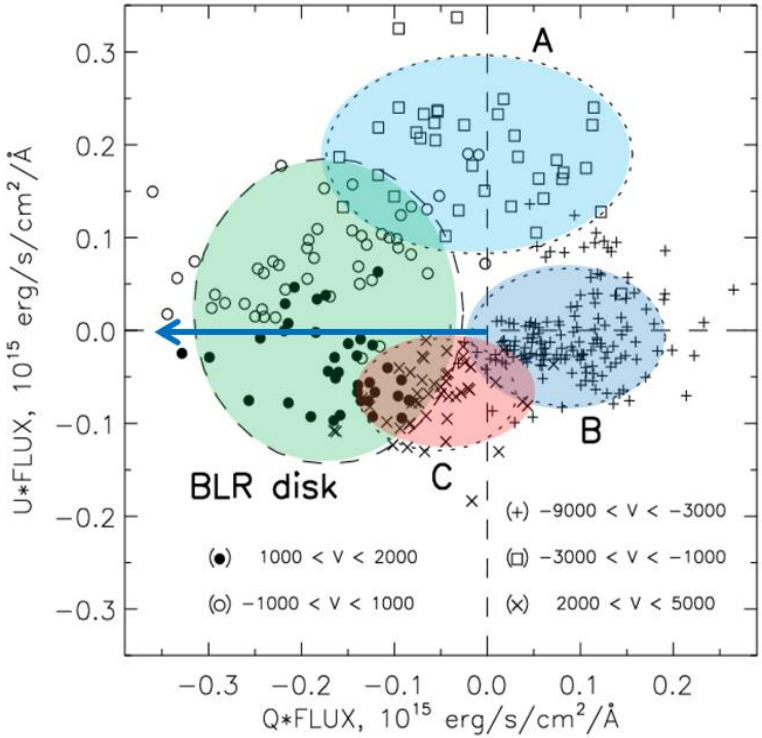
Scattering region in broad Hα Mkn6

- *rotating BLR disk has an average degree of polarization of ~ 0.5% and shows the change in the angle of the plane of polarization within ± 40° relative to the direction of the disk axis (PA~170°)*
- *Component A, apparently, is probably the outflow at the velocity of -2000 km/s with a polarization ~ 0.6% and the angle of the plane of polarization ~ 45°; This component is clearly visible in the profile of the broad lines and changes with time*
- *For the first time in polarized light detected by the outflow (jet?) of the velocity - 6000 km / s with the degree of polarization > 2% and the angle of the plane of polarization about 90°*









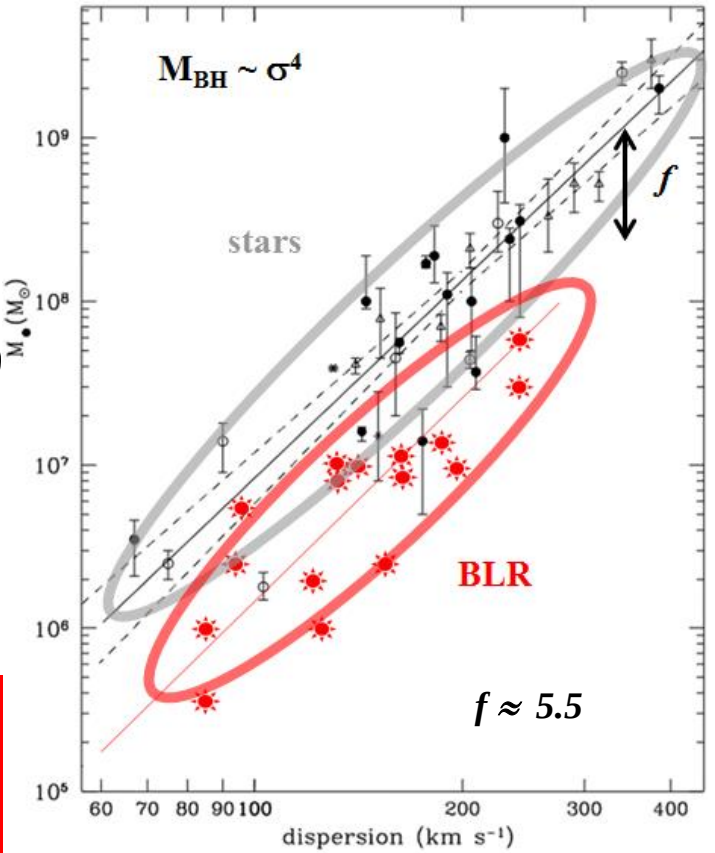
Afanasiev, Popović, Shapovalova et al., 2014, MNRAS, v.440, p.519

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=Vobs/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.

virial relation

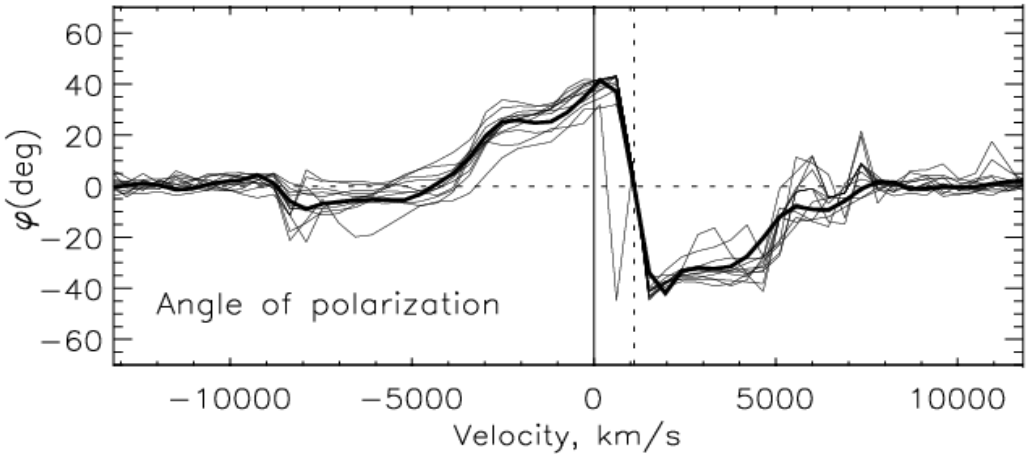
$$M_{BH} = f\frac{c\tau V^2}{G}$$



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

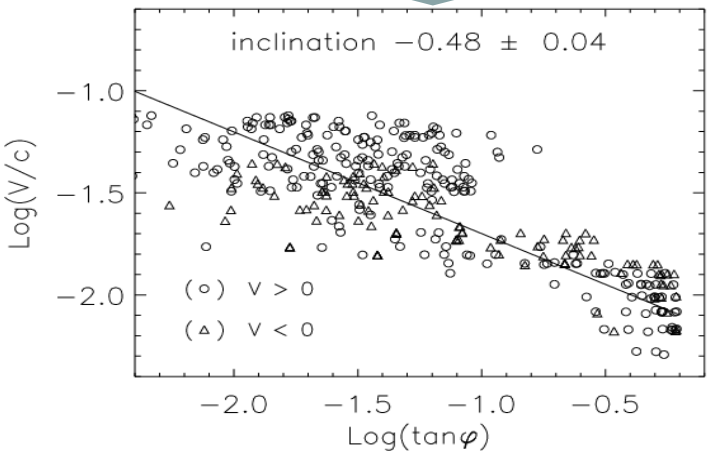
This assumption cannot be directly verified because the BLRs are spatially unresolved

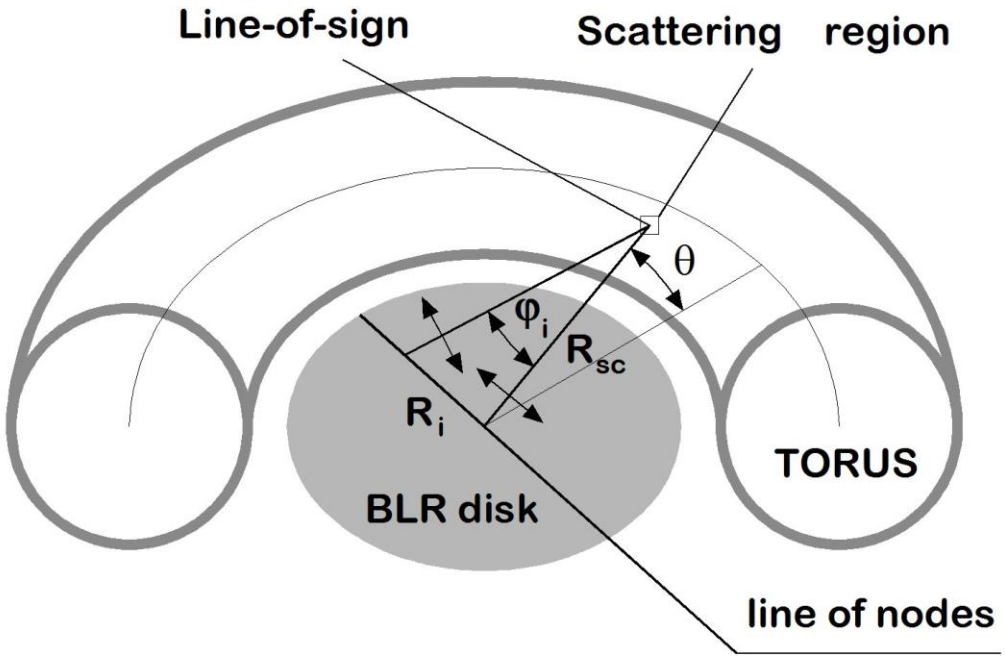
Rotation of the plane of polarization in the BLR

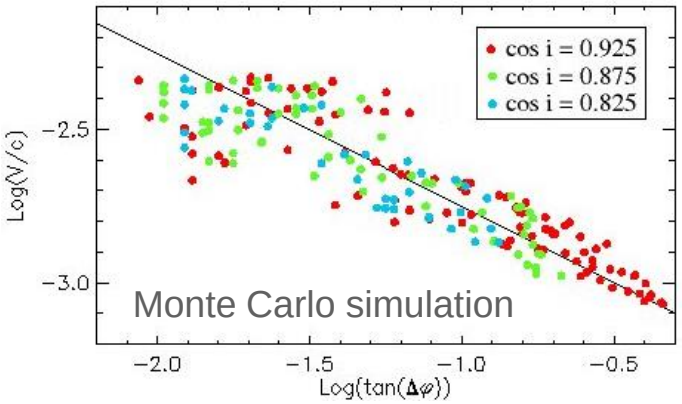


$$V_i = V_i^{rot}\cos(\theta) = \sqrt{\frac{GM_{BH}}{R_i}}\cos(\theta), \qquad R_i = R_{sc}\cdot\tan(\varphi_i)$$

$$\log\left(\frac{V_i}{c}\right) = a - b\cdot log(\tan(\varphi_i)), \qquad a = 0.5\log\left(\frac{GM_{BH}\cos^2(\theta)}{c^2 R_{sc}}\right)$$



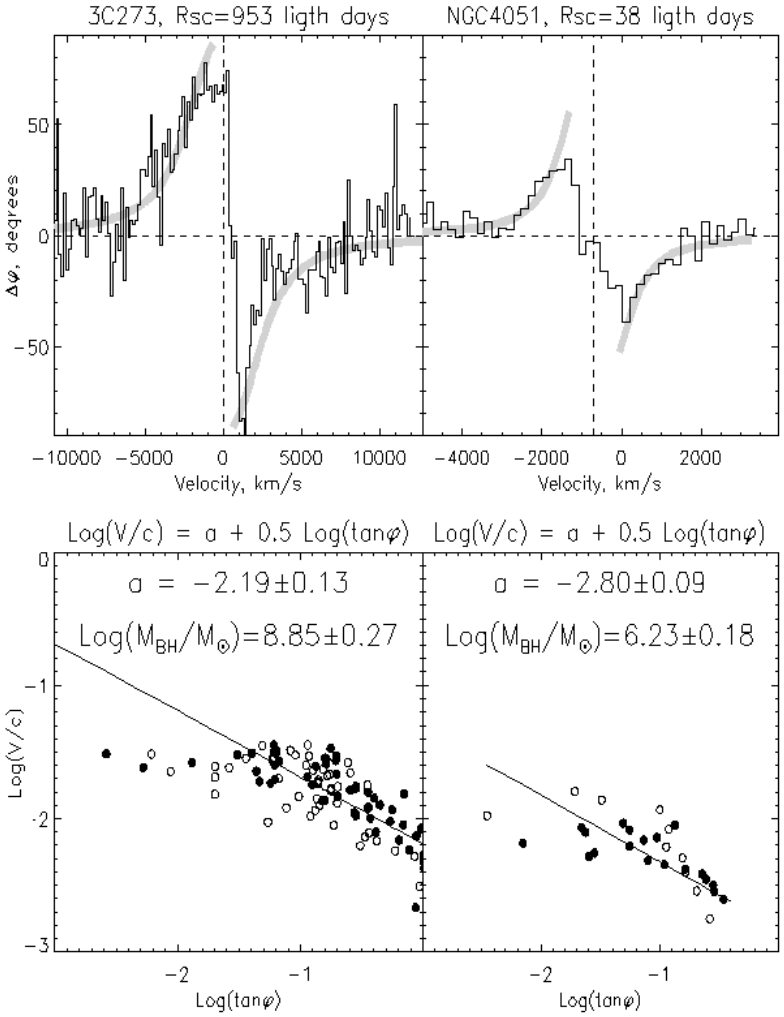


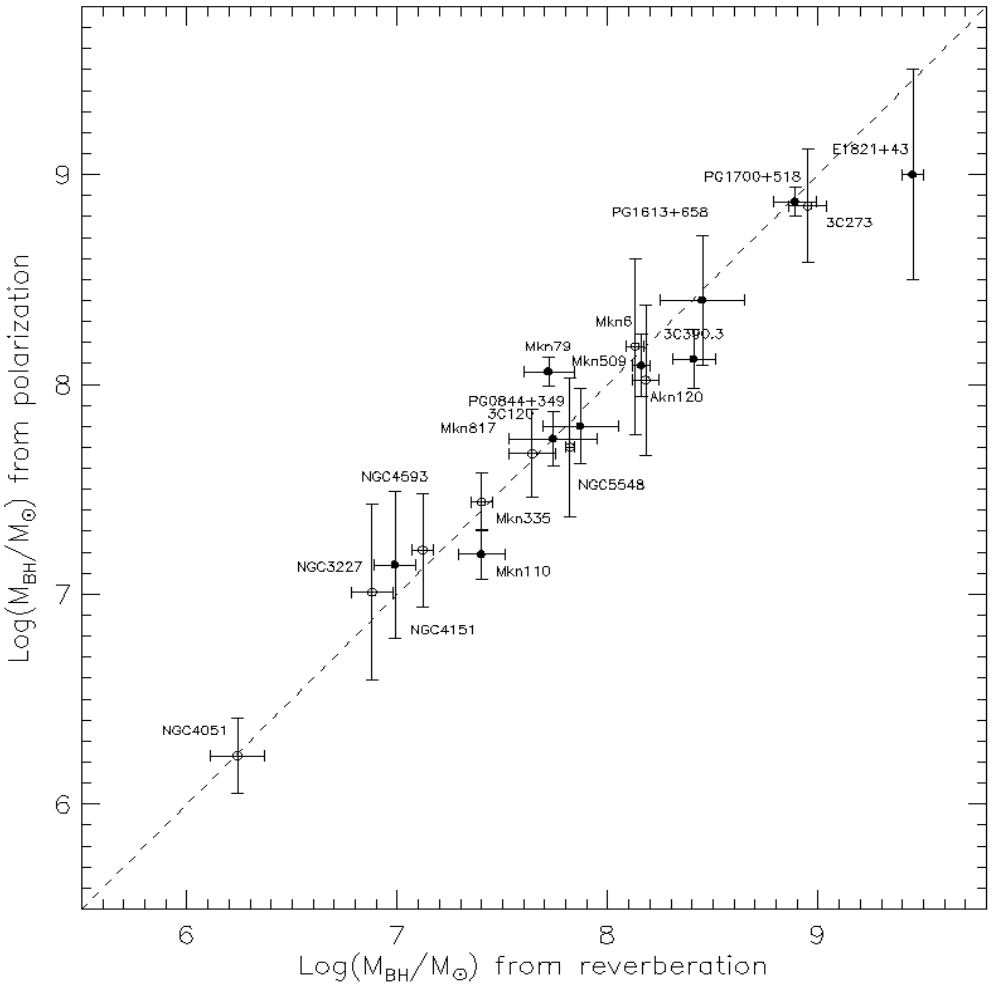


Estimation M_{BH} does not depend of the inclination BLR

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

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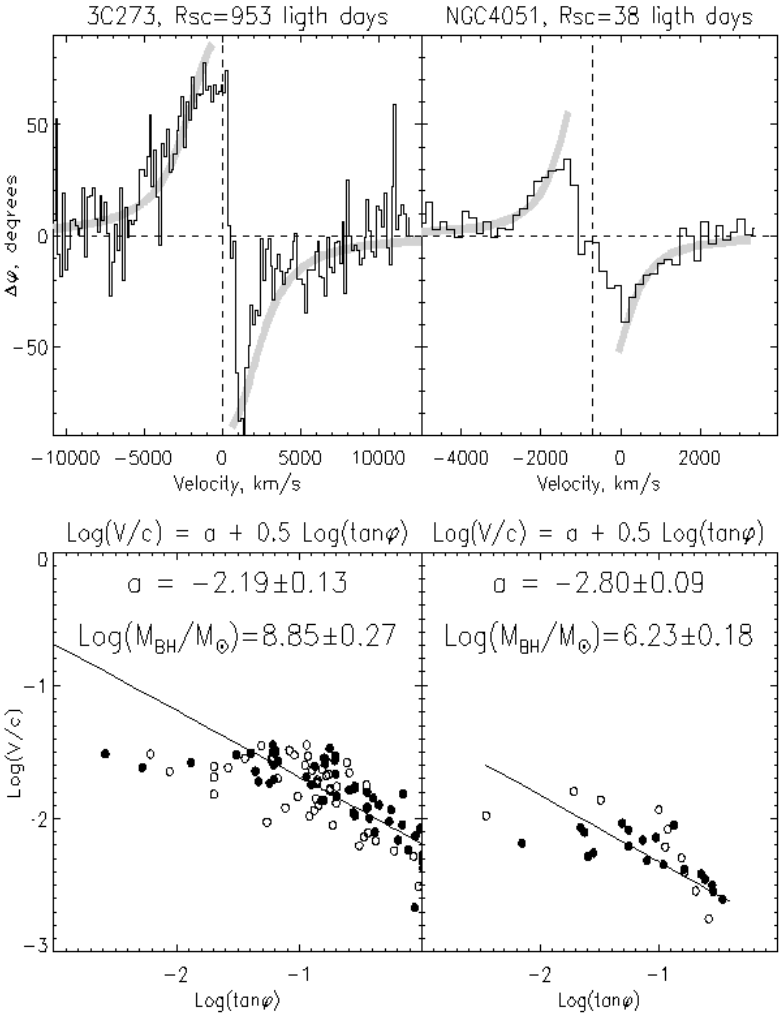

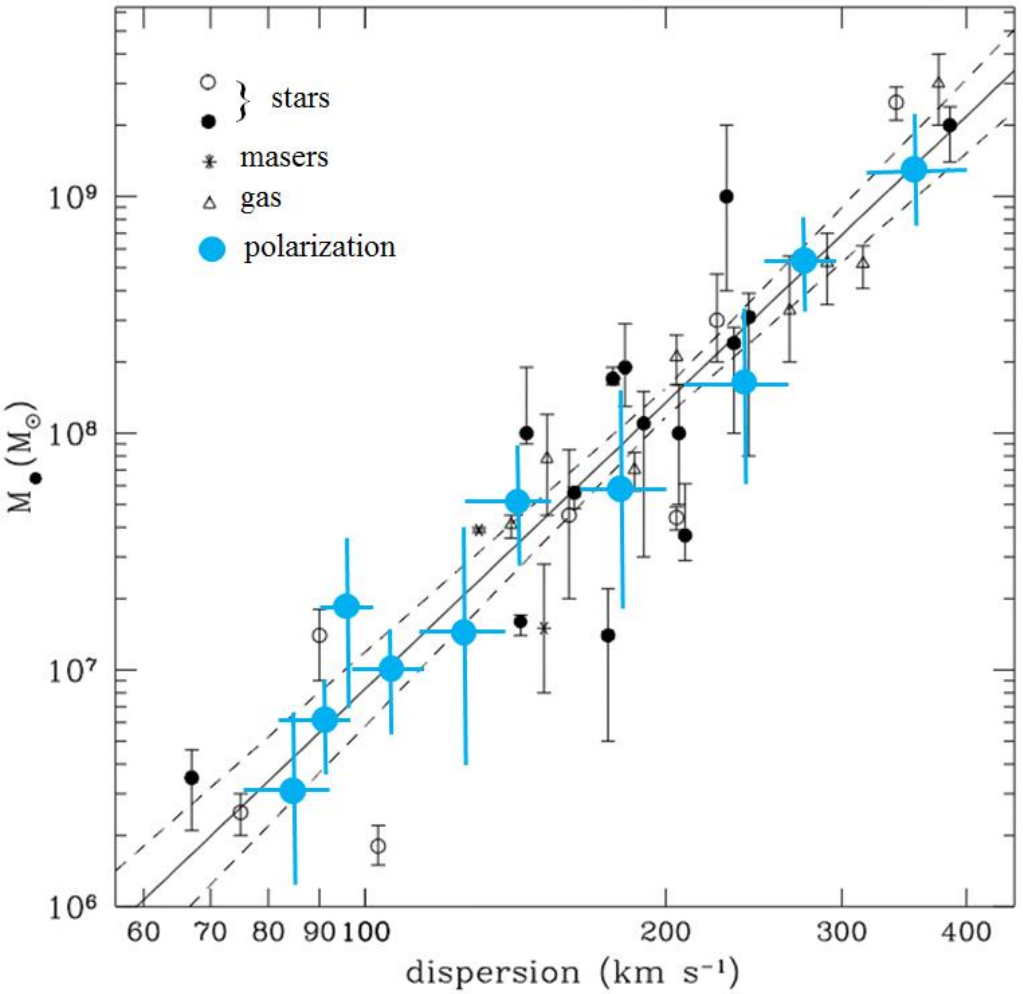

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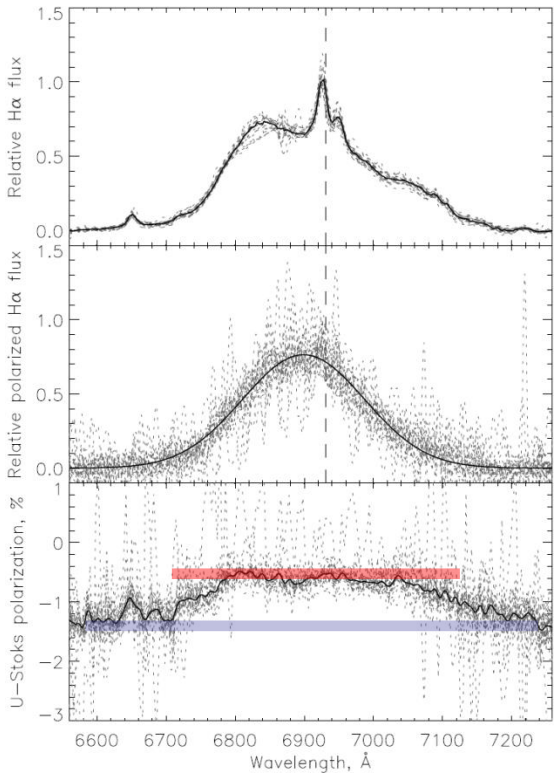
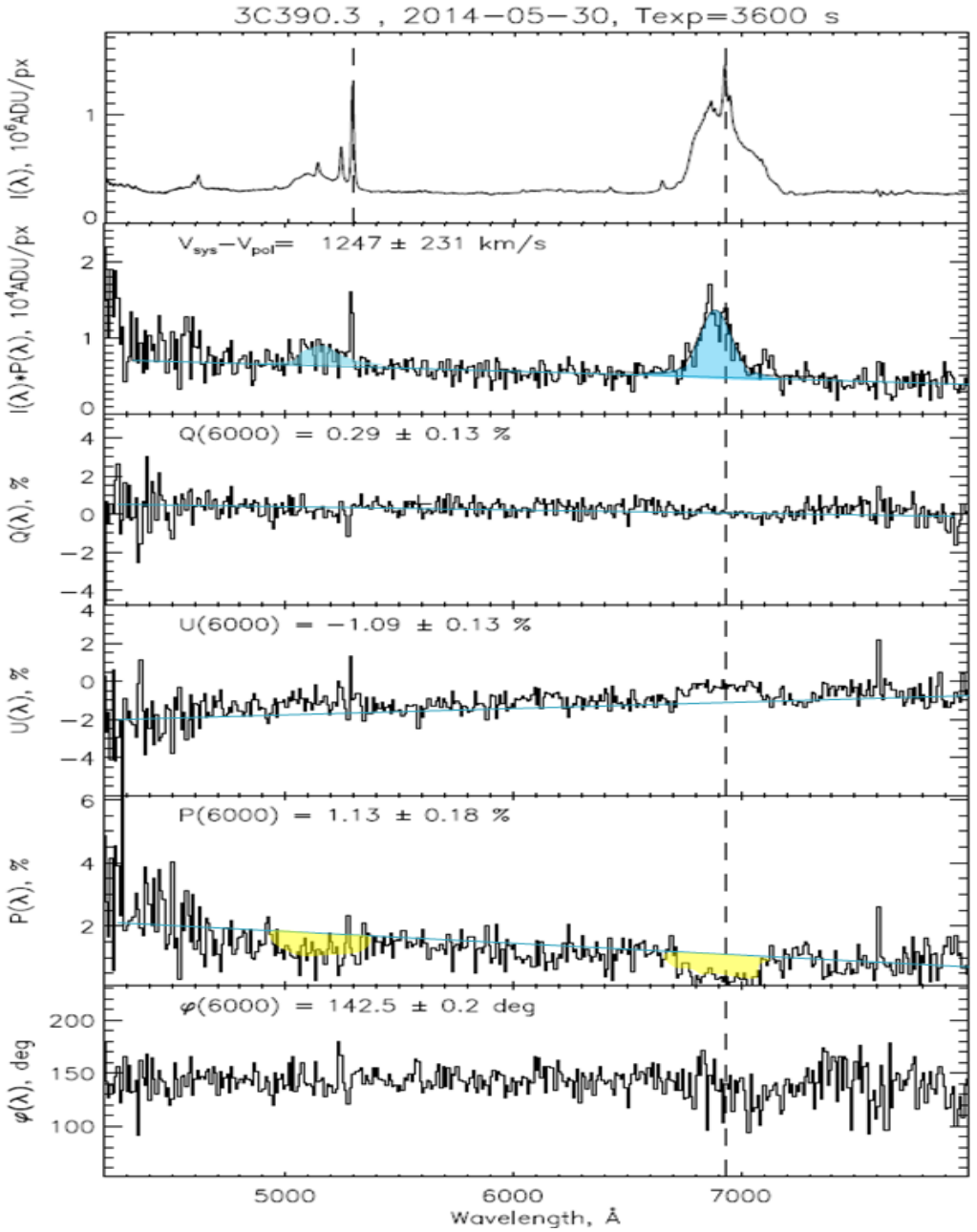
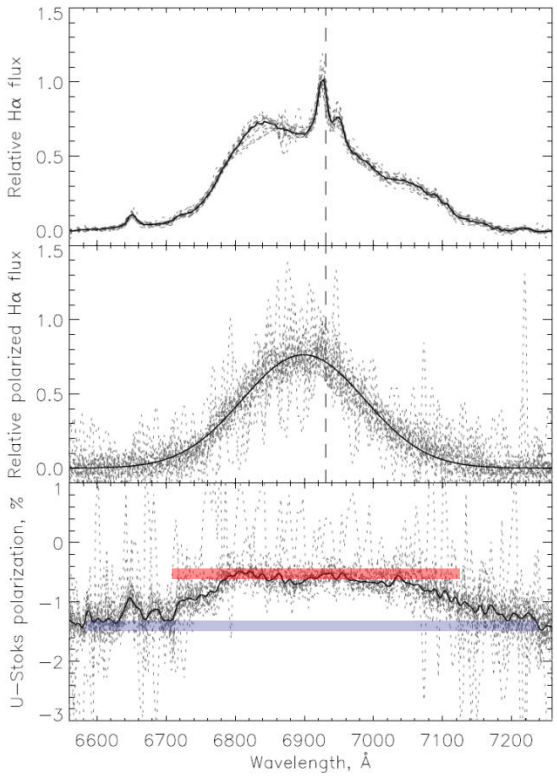
Depolarization in broad line Hα в 3C390.3

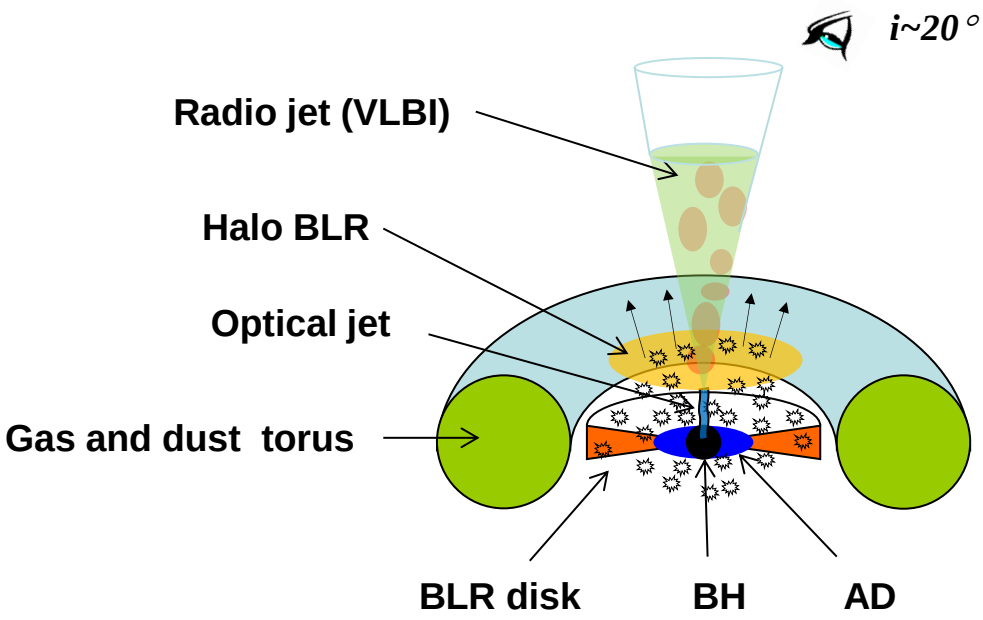




- **Depolarization polarized flux of accretion disk because of the “mist” halo BLR clouds in the direction of the disk axis with PA~152° => -U (PA=135°)**
- **The halo of clouds in Hα, extends along an axis at velocity -1200 км/с**

Depolarization in broad line Hα в 3C390.3





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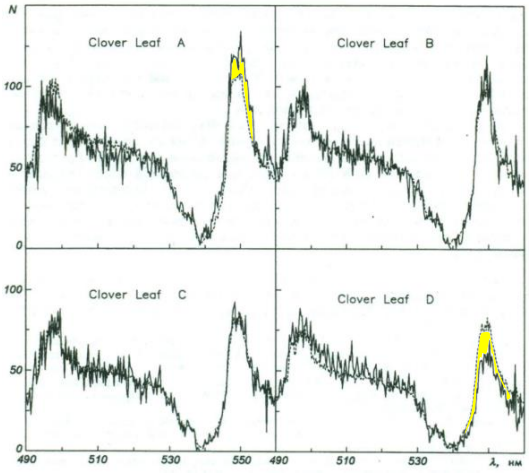
The observed properties of an 3C390.3

- ✓ Size of torus (from UV-calibration)
- ✓ Radio-jet (VLBI) 1-10 pc
- ✓ Size of BLR (Hα) ~ 0.12 pc
- ✓ Outflow in halo of BLR -1200 km/s, size ~ 0.08 pc
- ✓ Variable optical jet, size <0.01 pc
- ✓ Size of accretion disk <0.01 pc
- ✓ $M_{BH} \sim 3 \cdot 10^8$ M

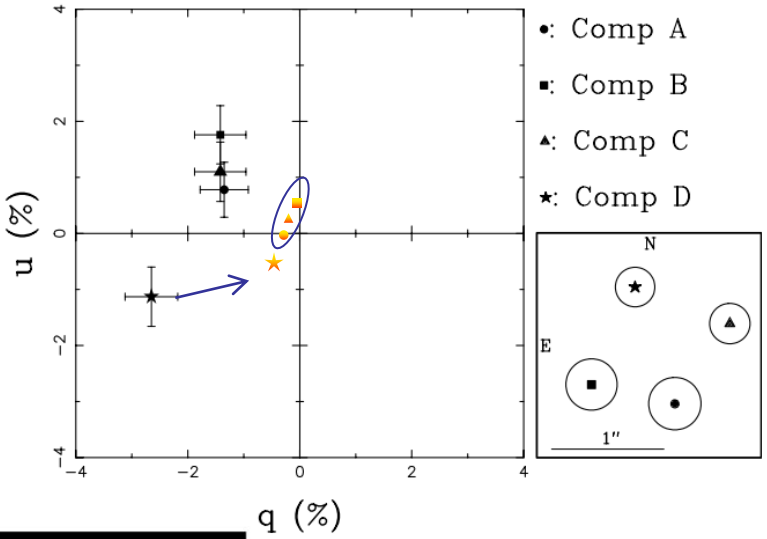
The polarization of gravitational lenses

Polarization and microlensing in the lensed quasar H1413+117(Clover Leaf):

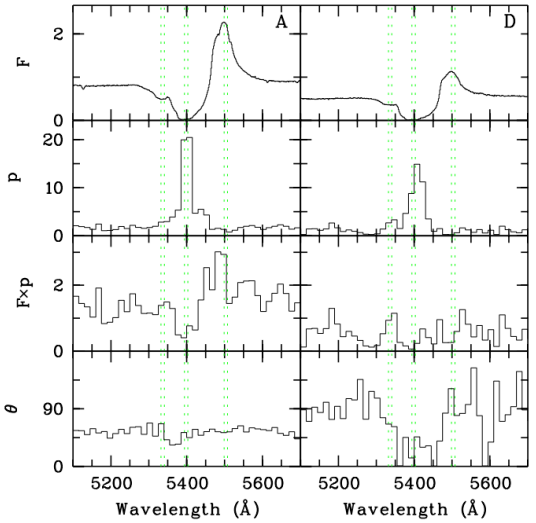
6-m + IFU MPFS (Afanasiev et al., 1993)

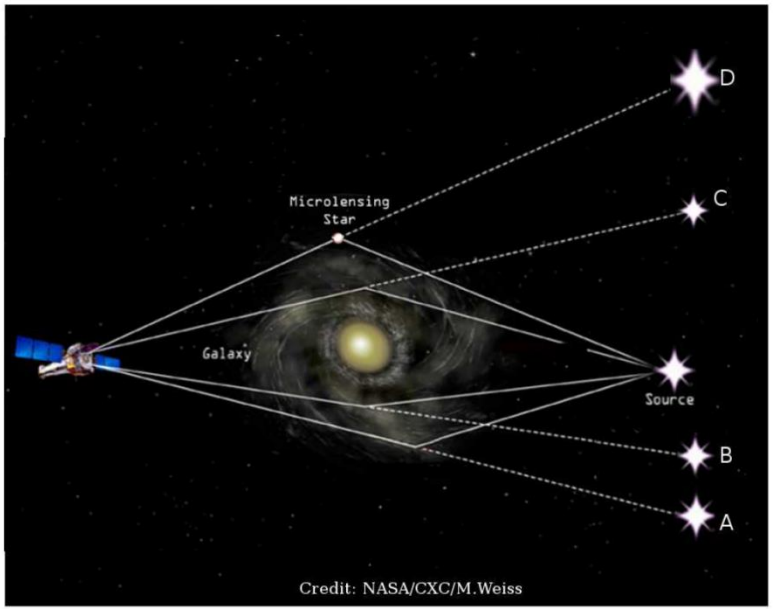


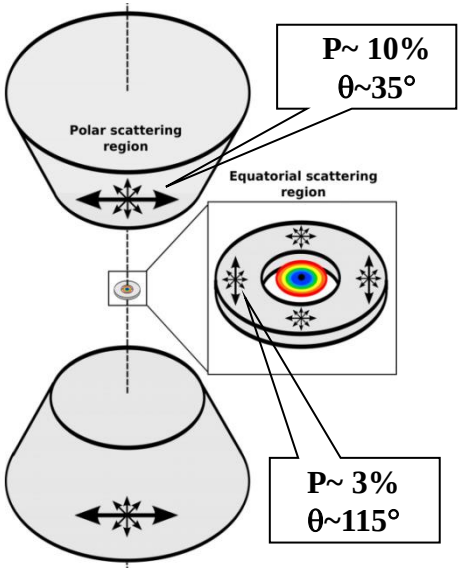
HST+F555W (Chae et al., 2001)



VLT+FORS (Hutsemekers et al., 2015)



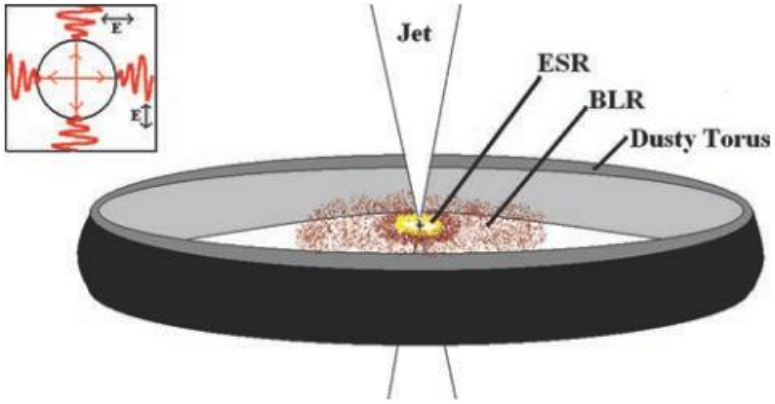




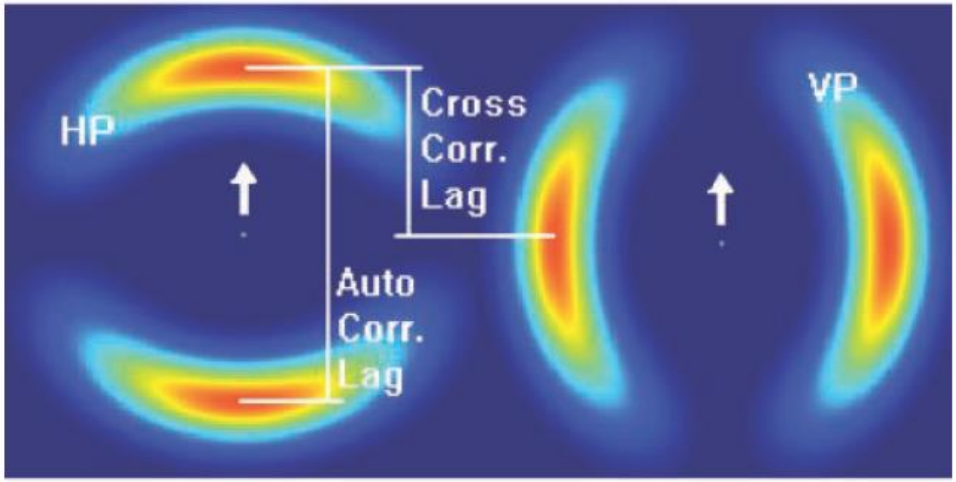
The effect of microlensing on the polarization unveils the presence of two continuum sources polarized roughly perpendicularly

The polarization of gravitational lenses

Prediction polarization in Einstein-Chwolson Ring:

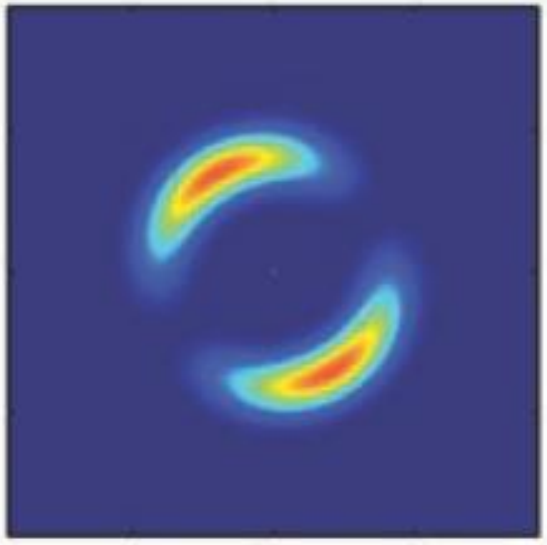


Kedziora at al. 2011,MNRAS, v.415, p.1409

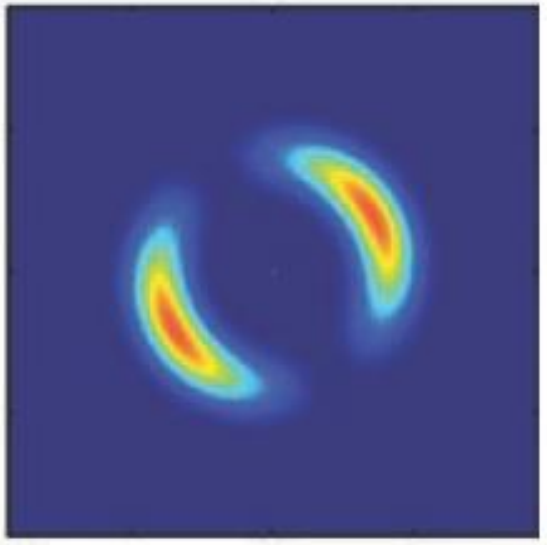


Total Flux

Horizontal Polarisation



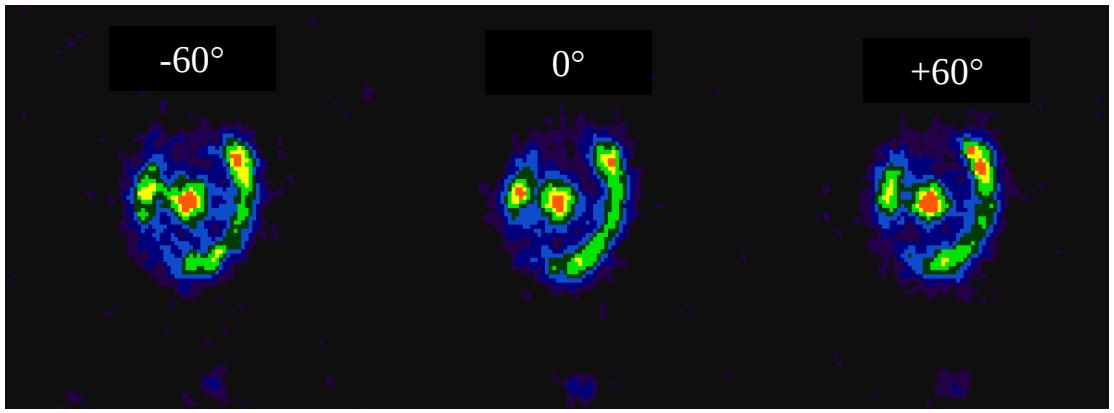
Vertical Polarisation

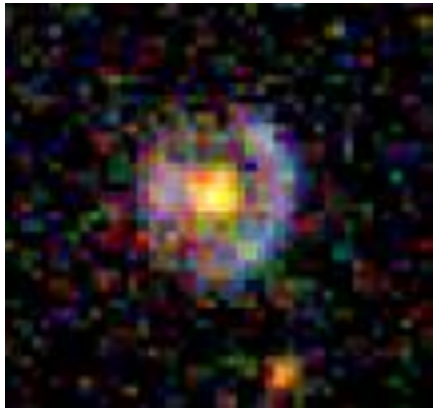


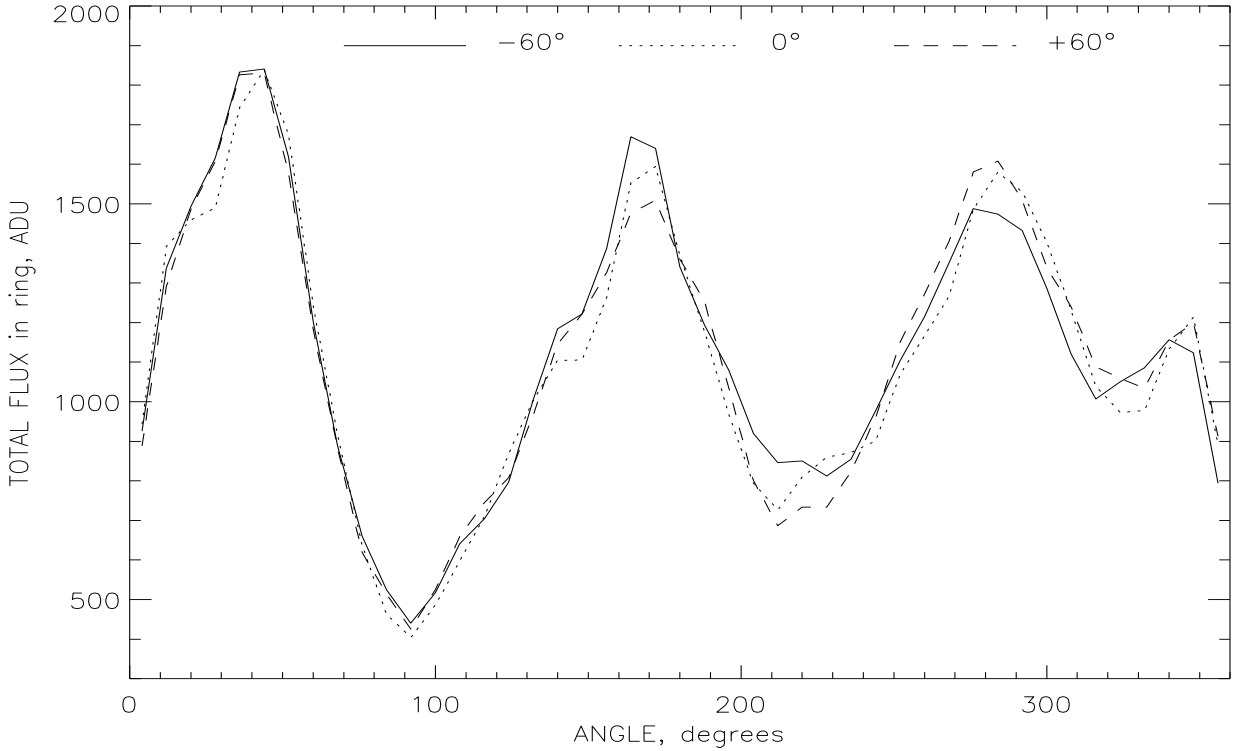
Detection polarization in gravitational lenze J0143+1607

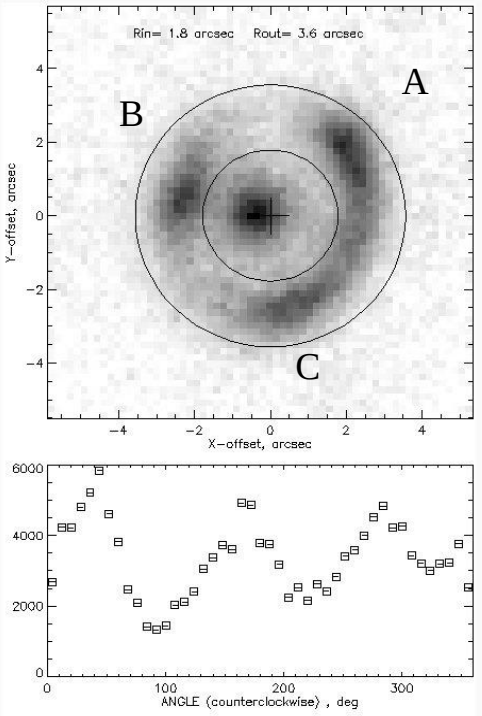
6-m + SCORPIO-2 + polaroid, 3x1800 sec, filter V, θ≈0.9″

SDSS g≈19.5



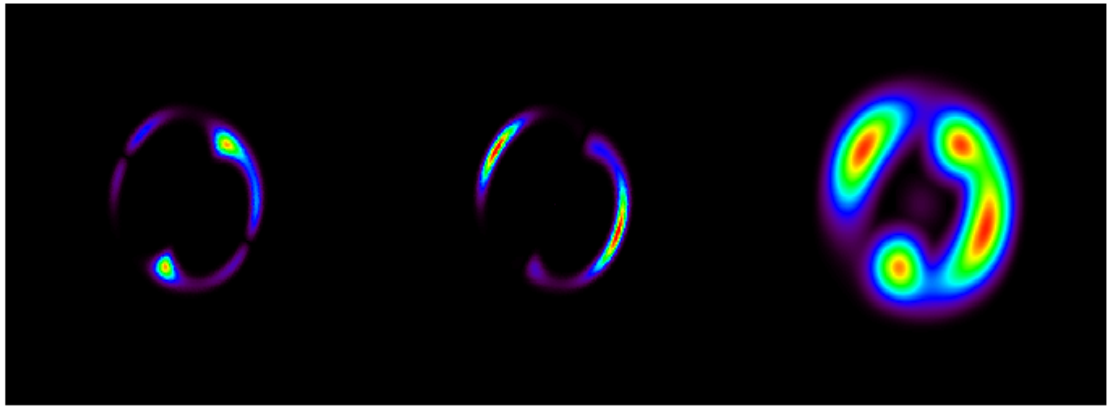


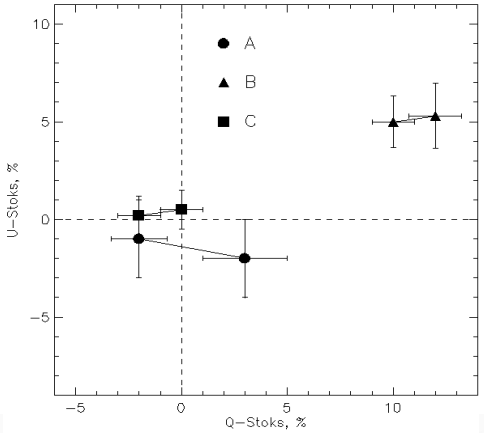


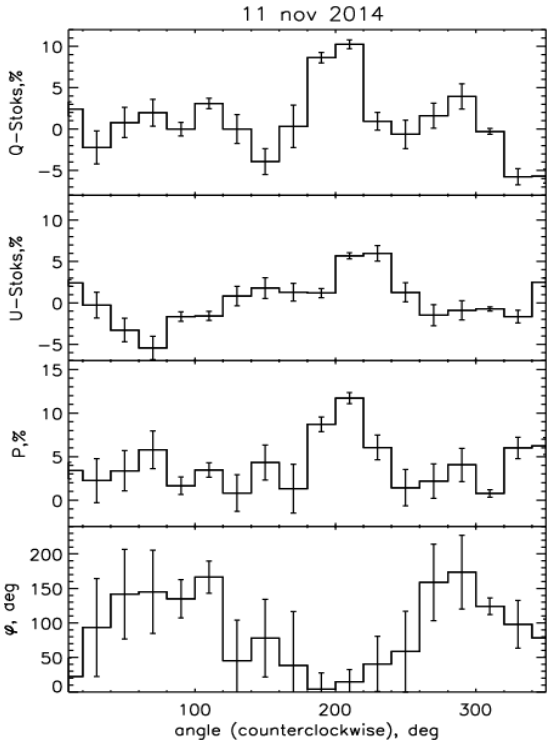


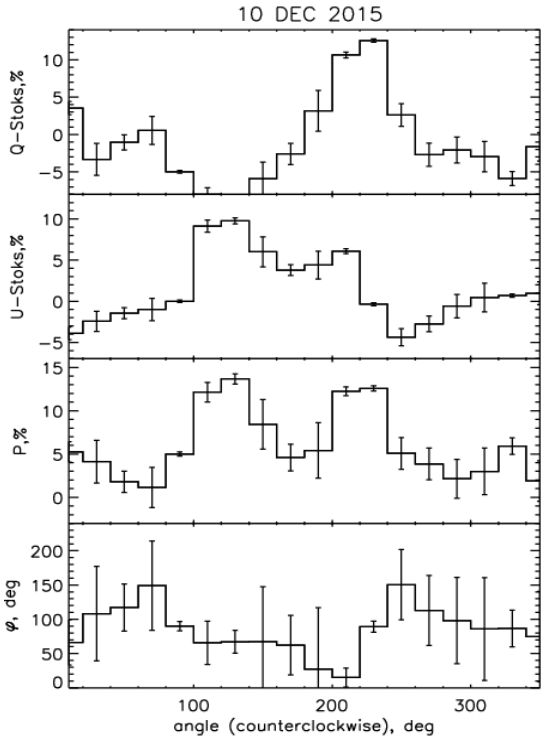
Detection polarization in gravitational lenze J0143+1607

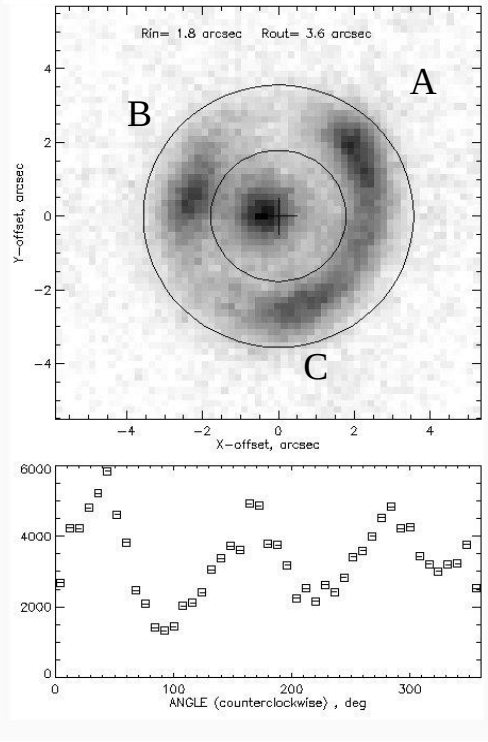
Vertical Horizontal Total





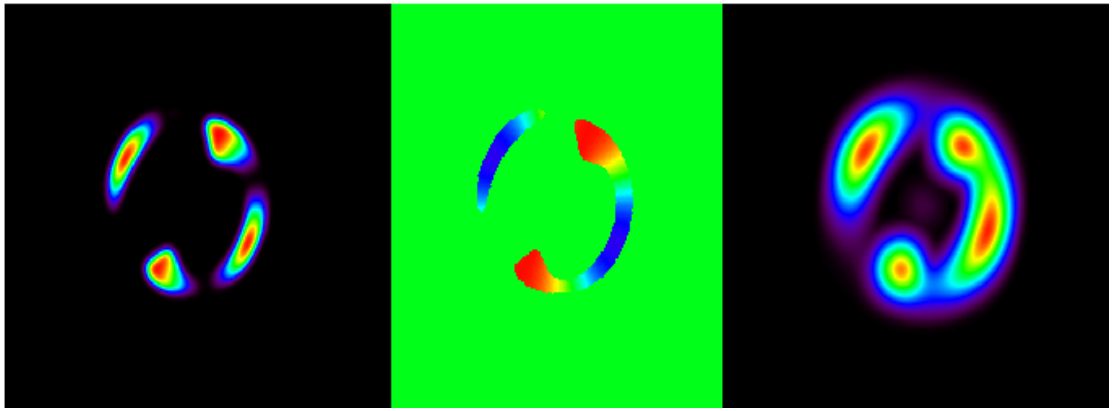


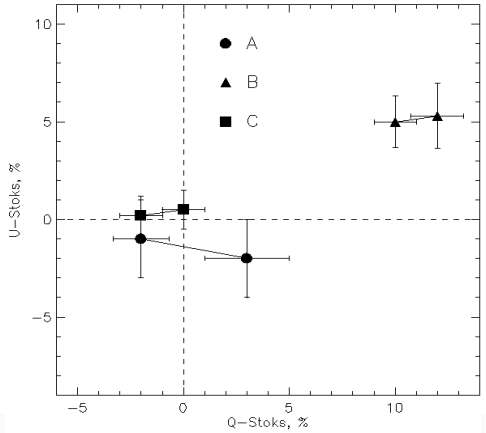


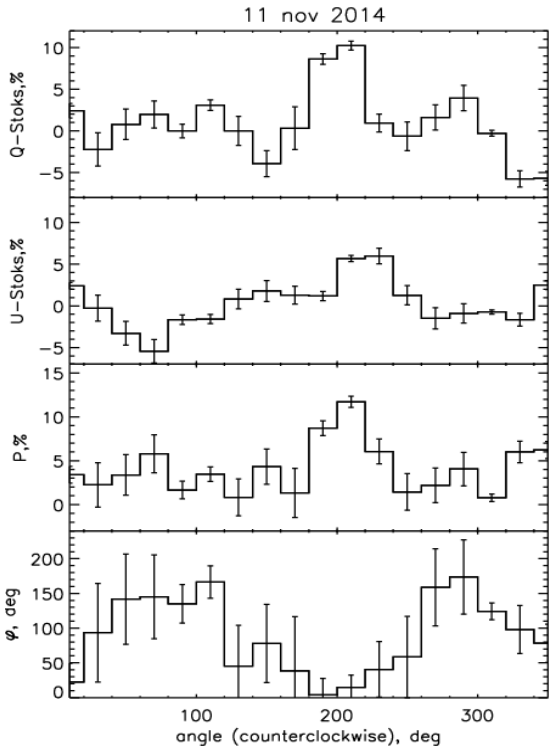


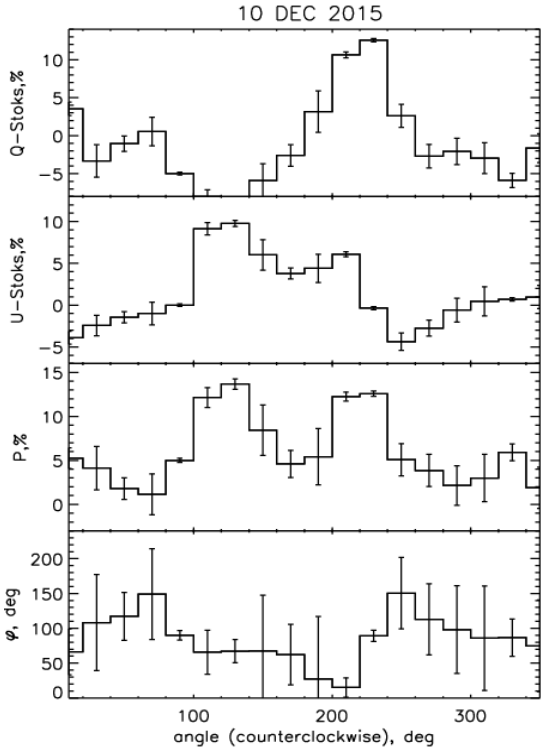
Detection polarization in gravitational lenze J0143+1607

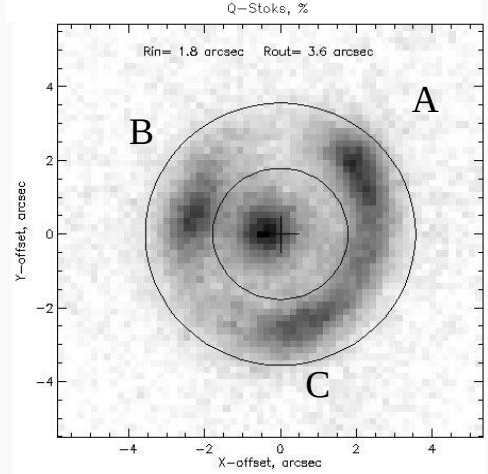
Degree polarization **Anlge polarization** **Total flux**

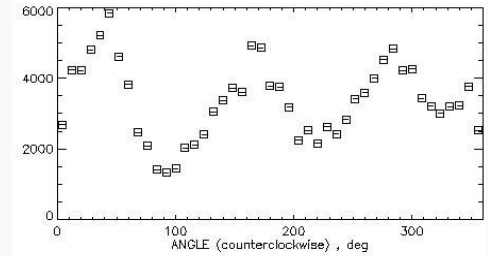












Conclusion

Polarimetry methods allow to share different the field of formation of the polarized radiation:

- ✓ **Polarized continuum indicates the direction of the plane of polarization along the axis of the disk and the size of the field is less than 0.01 parsecs, which is much smaller than the BLR. The observed variable polarization is the result of the vector addition of the accretion disk and jet polarization.**
- ✓ **Polarization in the broad emission lines, probably due to scattering at the inner parts of the torus of gas and dust, and the dependence of the angle of the polarization plane of the BLR clouds velocity allows to determine the nature of the motion at distances less than 0.05-0.1 parsecs that for most objects is less than 10^{-3} seconds of arc.**
- ✓ **An analysis of the Stokes vector components allows you to divide the circular and radial movement along the axis of the disk BLR.**

Thank you for your attention!