MATΦ
University of Belgrade
Faculty of Mathematics

Polarization in broad emission lines of active galactic nuclei

In honor of V.L.Afanasiev

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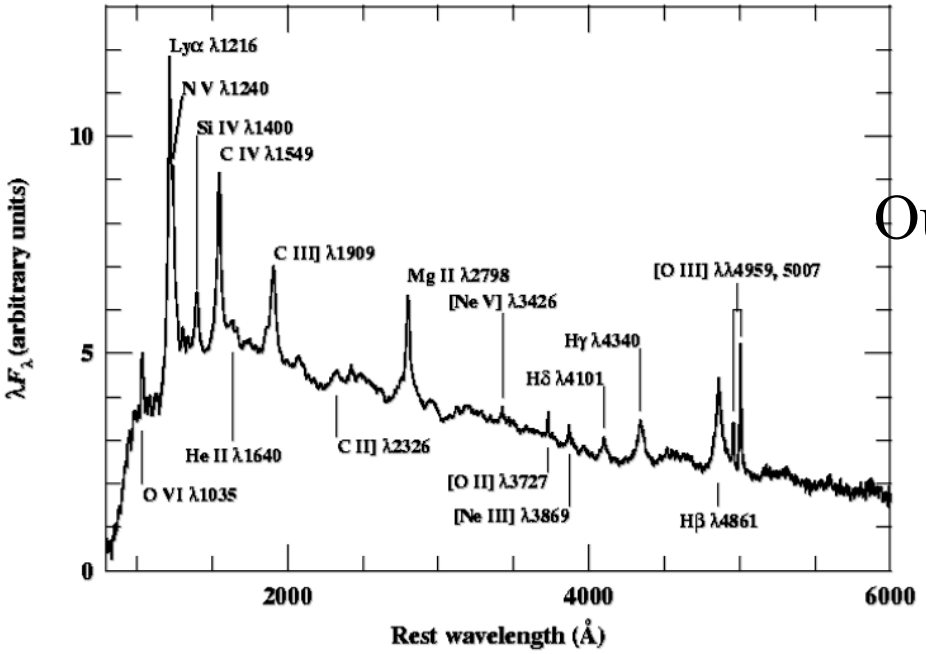
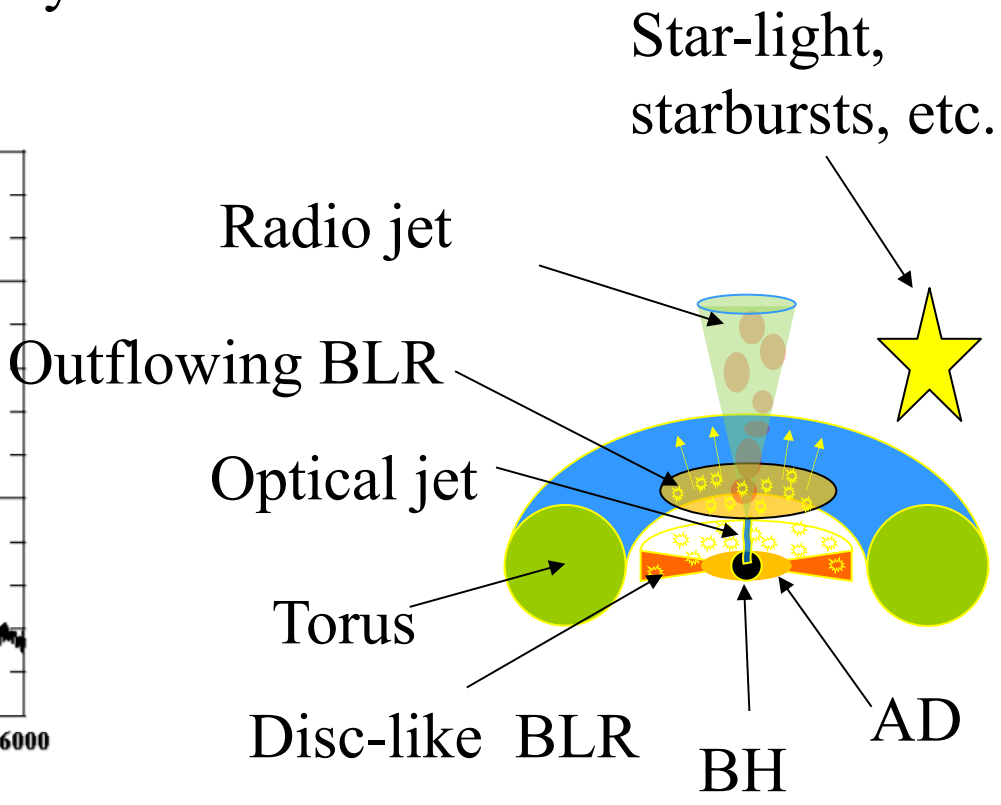
Optical emission of AGNs – different emission regions!

The structure can be more complex.
Emission in the optical is coming from different AGN regions + host galaxy





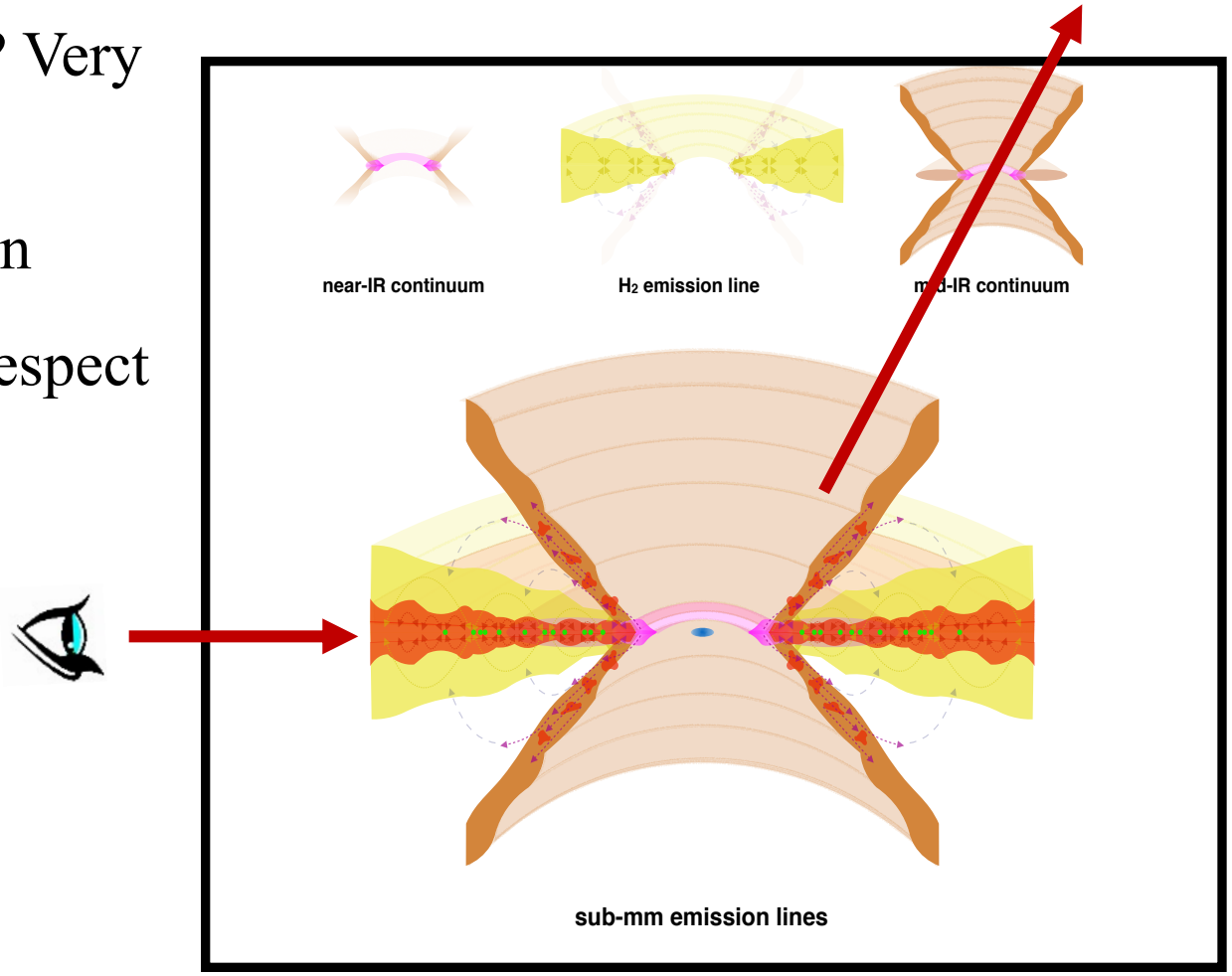
Optical emission of AGNs – different emission regions!

Type 1 or Type 2 AGNs? Very important:

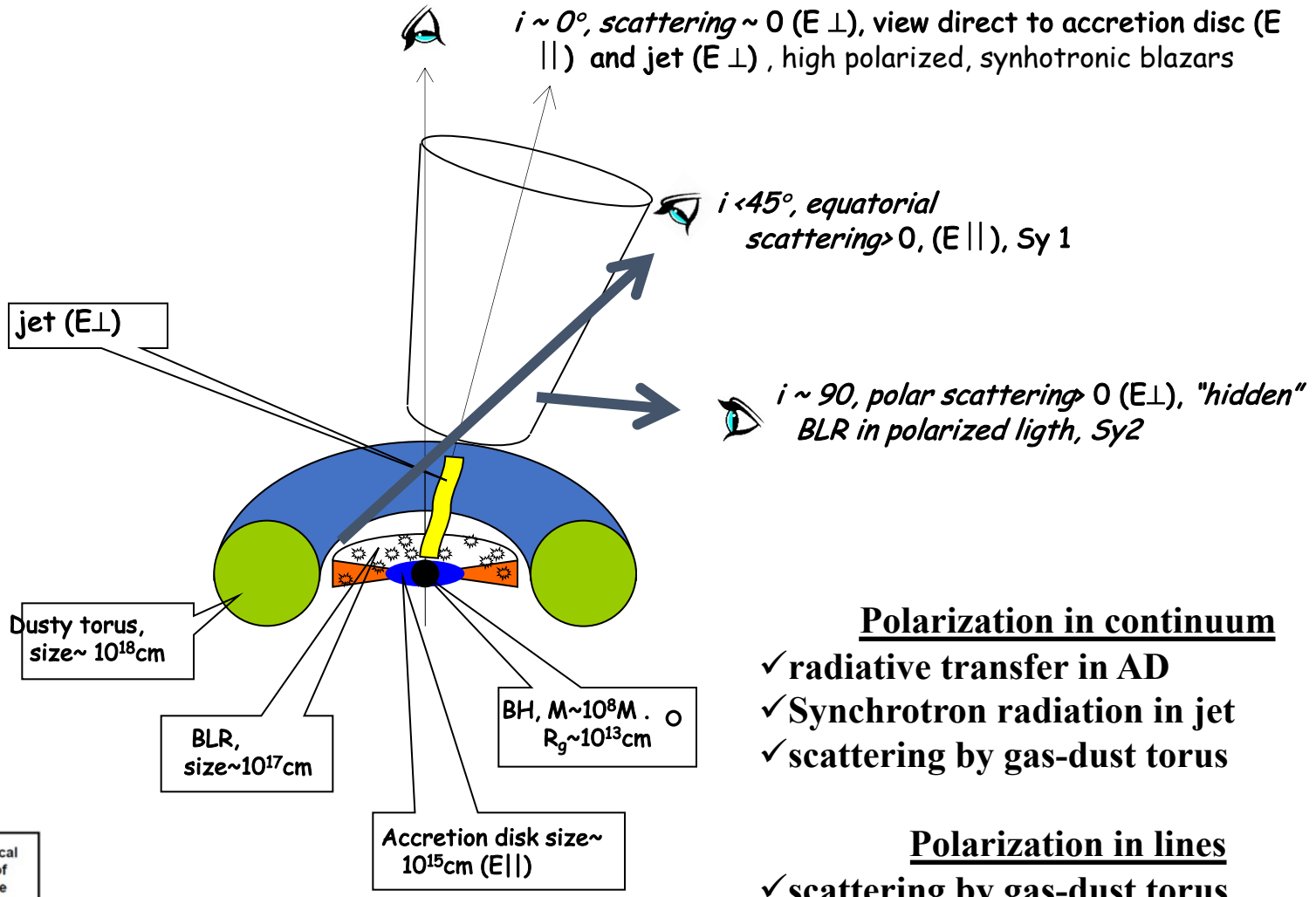
- dust => rate of accretion

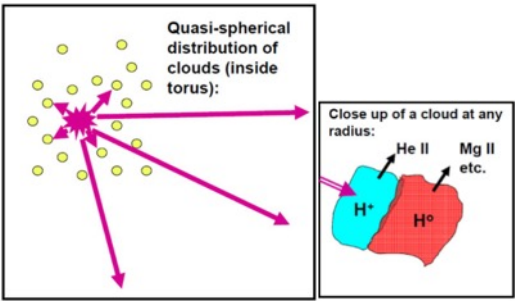
- dust distribution with respect to an observer

(Hoenig 2019) =>



Possible sources of AGN polarization





Polarization in continuum

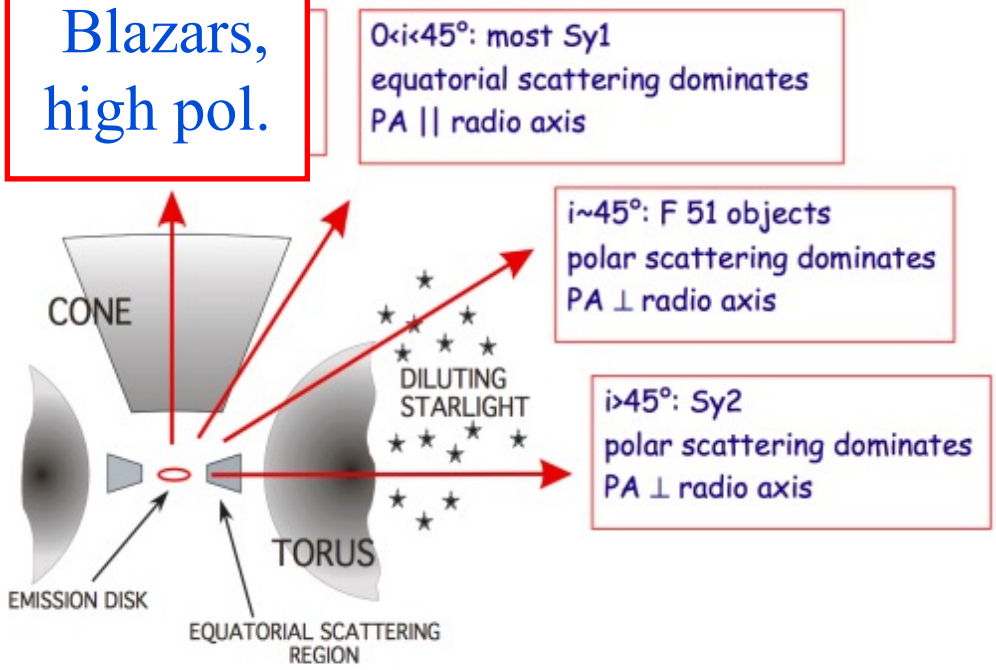
- ✓radiative transfer in AD
- ✓Synchrotron radiation in jet
- ✓scattering by gas-dust torus

Polarization in lines

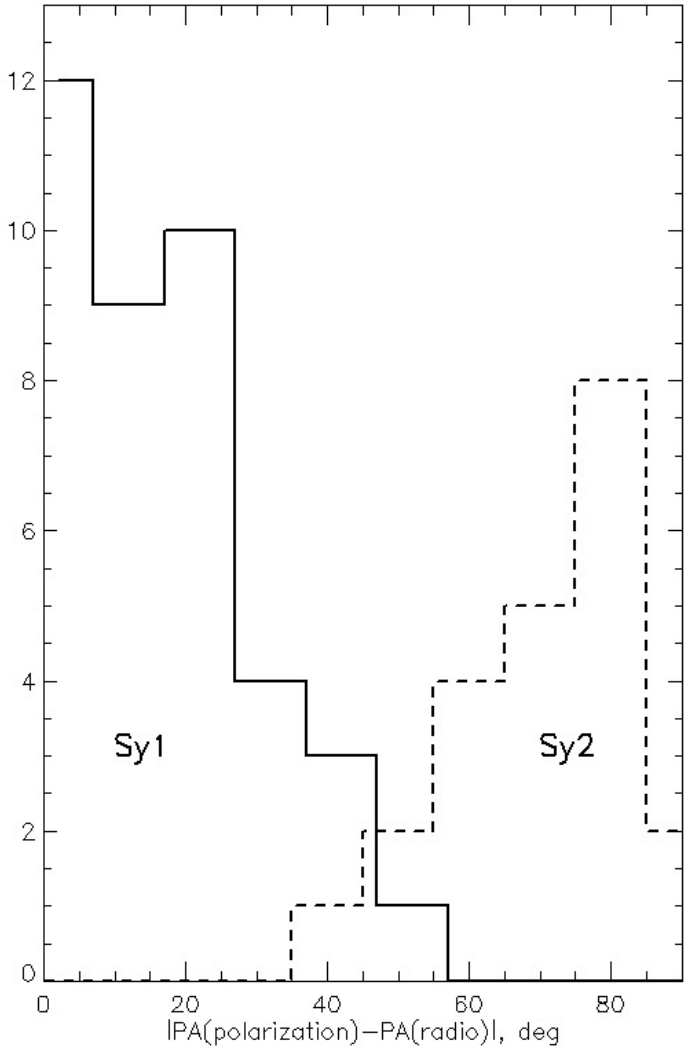
- ✓scattering by gas-dust torus
- ✓radiative transfer in the BLR

Polarization of AGNs - a simple (UNIFIED) model (e.g. NLS1, see Popovic et al. 2018)

Blazars, high pol.



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 !

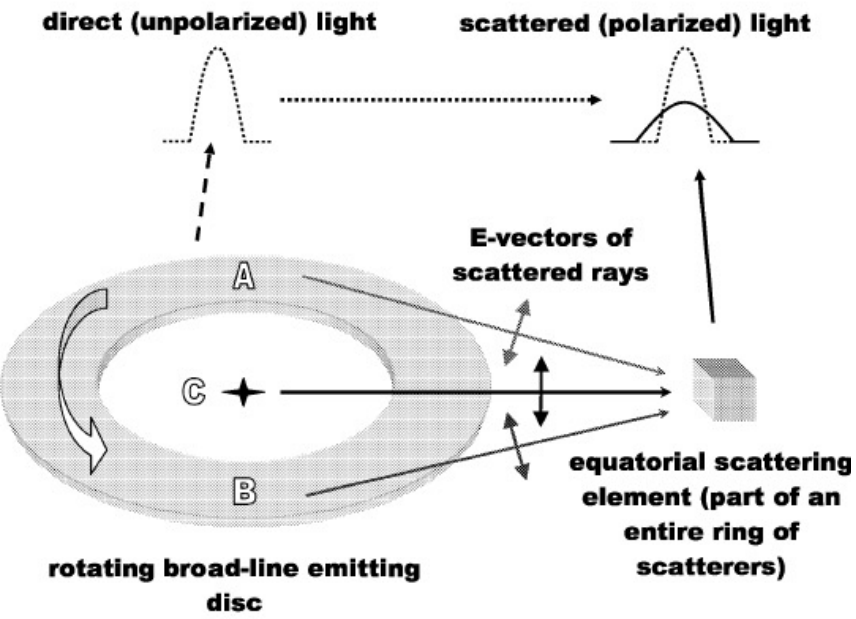
Resolving the BLR of AGNs using polarization!

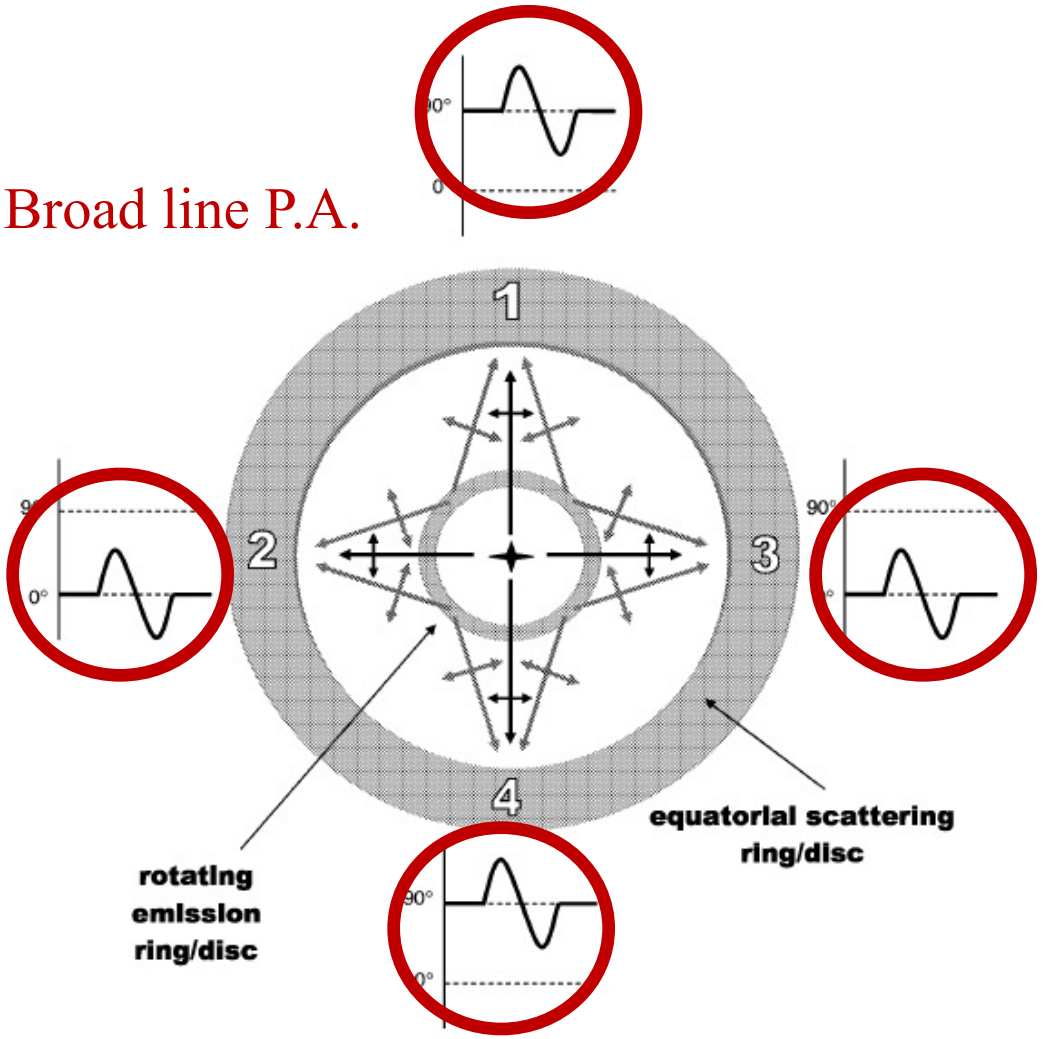
- BLR characteristics
- measuring SMBH masses in AGNs (Afanasiev & Popovic 2015)

Type 1 AGN: Equatorial polarization in broad lines (Smith et al. 2004,2005) - BLR gas motion – specific PA shapes!

Broad line P.A.

Broad line shapes

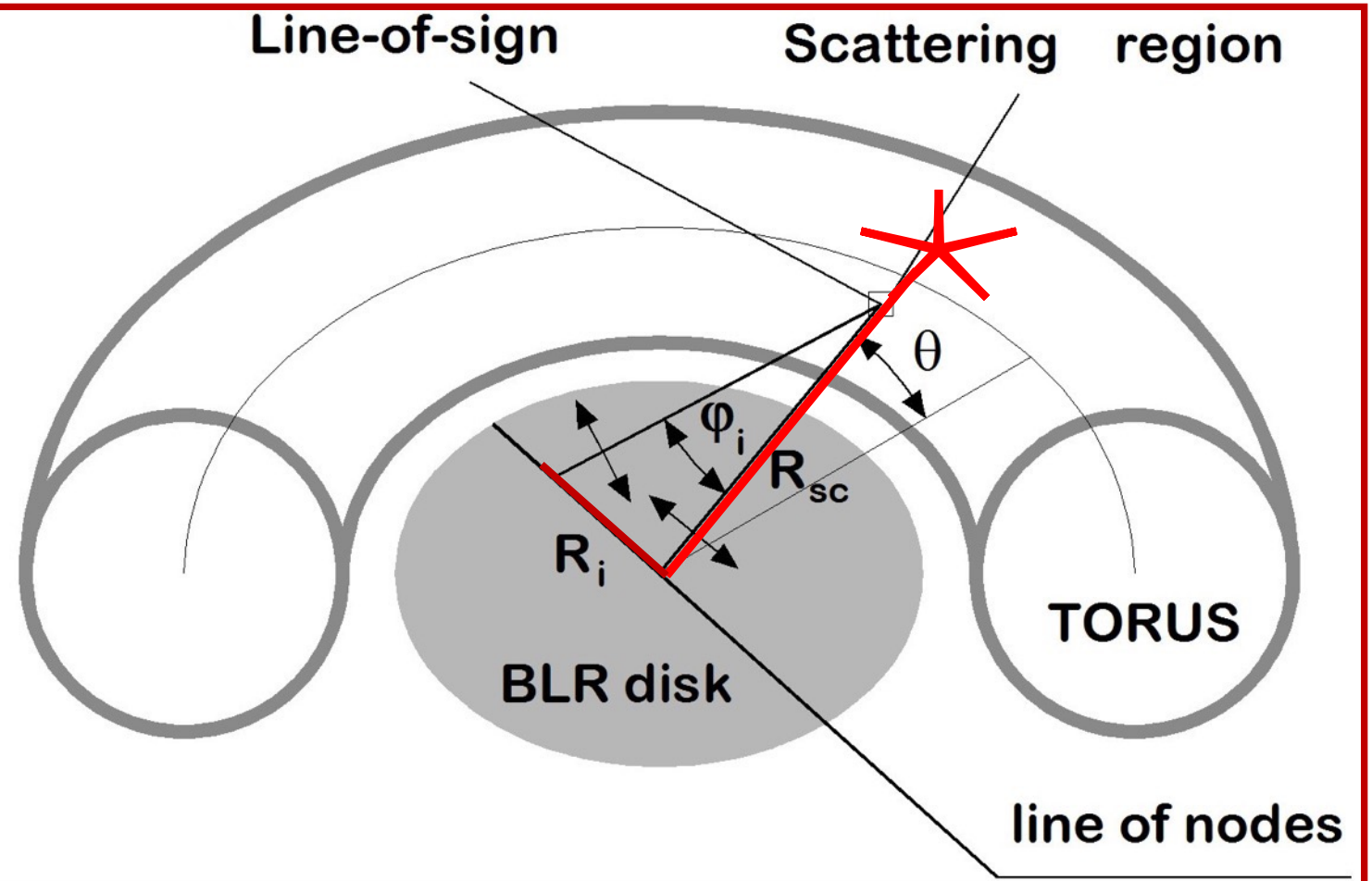




$$v_i = \sqrt{\frac{GM_{BH}}{R_i}}$$

$$R_i / Rsc = \tan(\varphi)$$

$$Rsc = const.$$



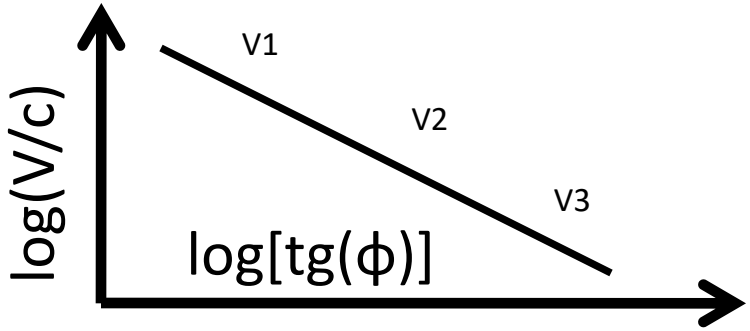
Polarization in the broad Hα (BLR). Equatorial scattering - idea

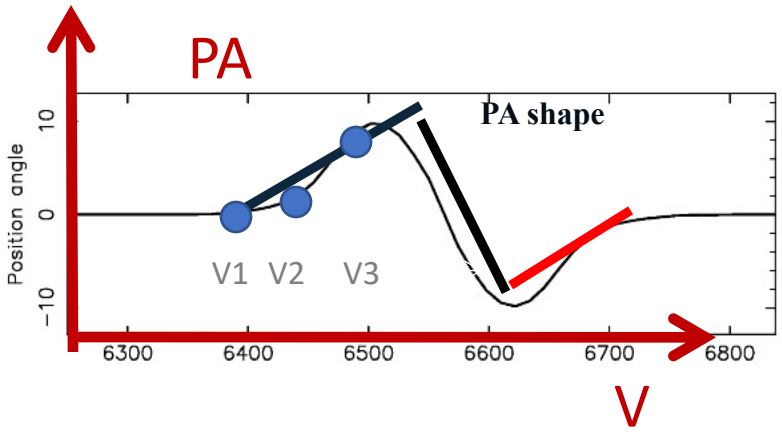
$$v_i = \sqrt{\frac{GM_{BH}}{R_{SC}\tan(\varphi_i)}},$$

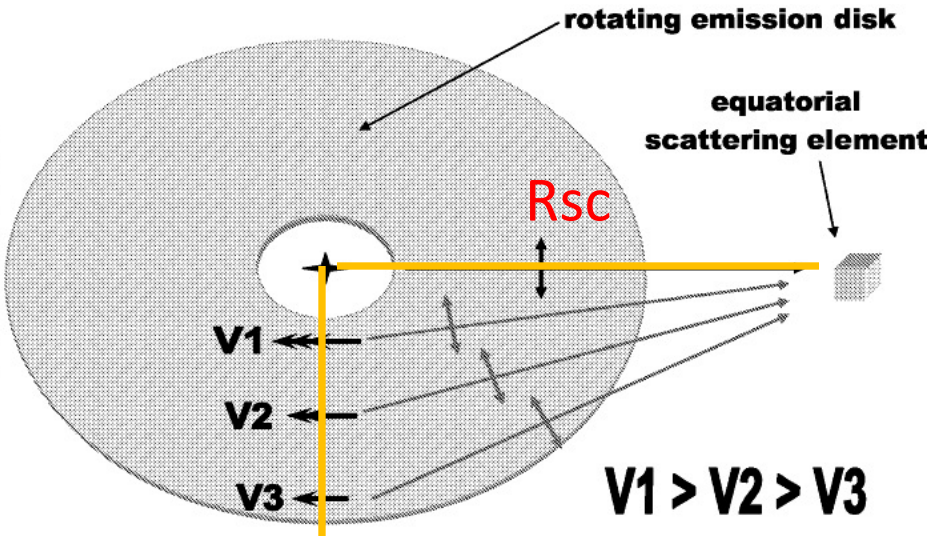
$$\log(v_i) = a - b\log(\tan(\varphi_i)),$$

$$b = 0.5$$

$$a = f\left(\frac{M_{BH}}{R_{SC}}\right)$$

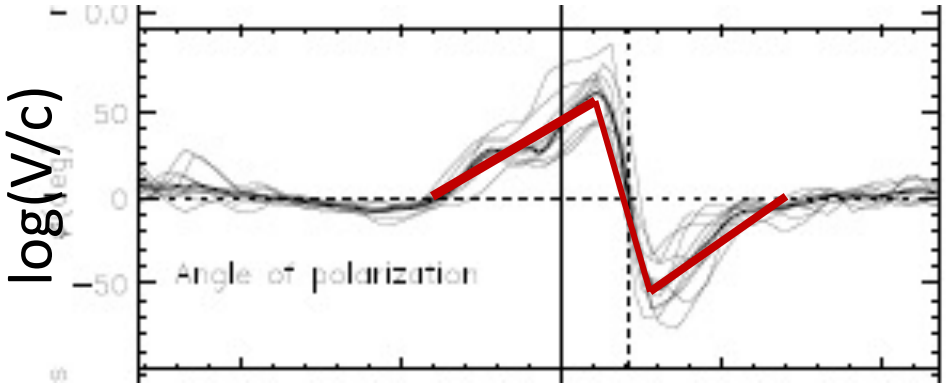


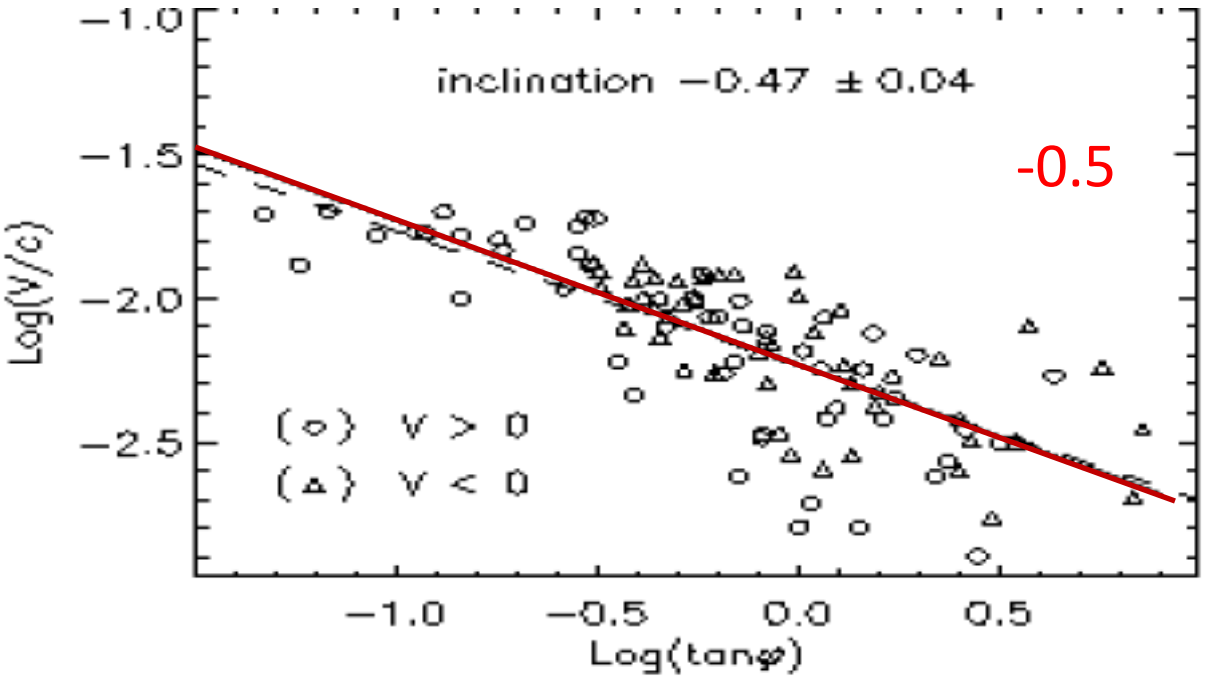




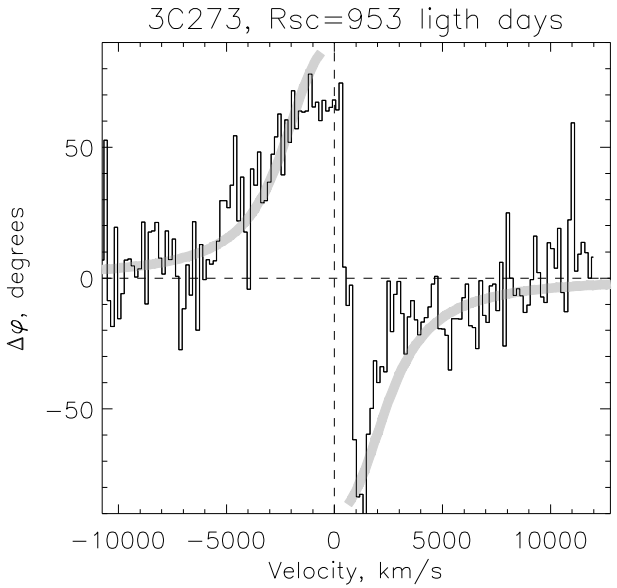
V vs. tan(ϕ) – direct evidence of Keplerian motion in the BLR of Mrk 6, Afanasiev et al. 2014

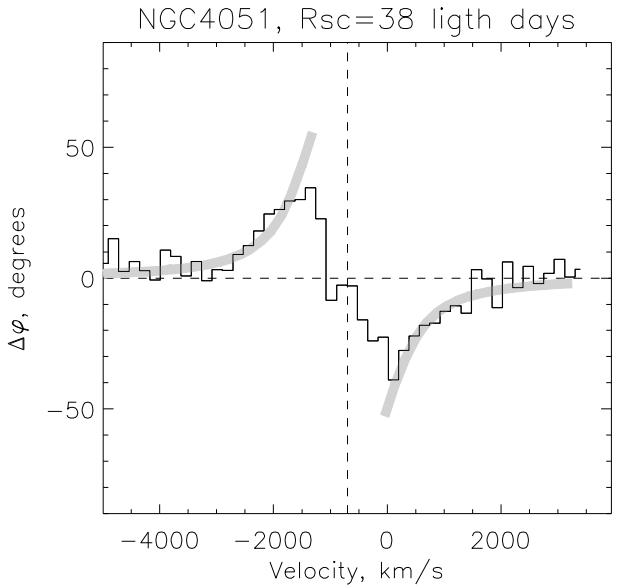
$$\log\left(\frac{V_i}{c}\right) = a - b \cdot log(\tan(\varphi_i))$$

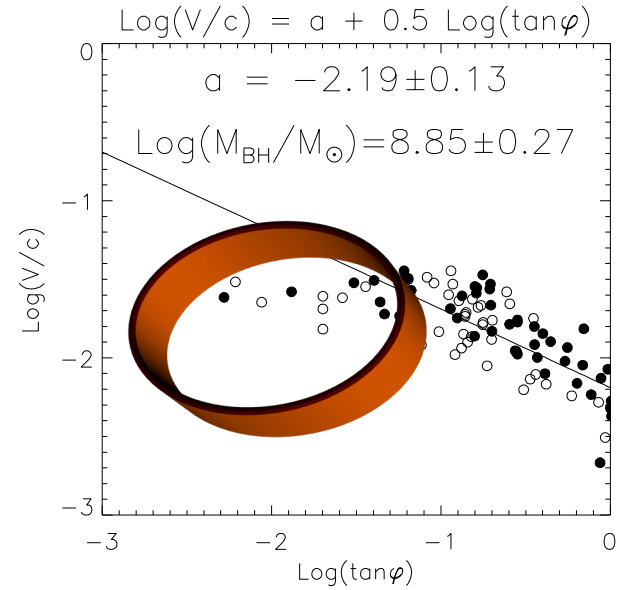


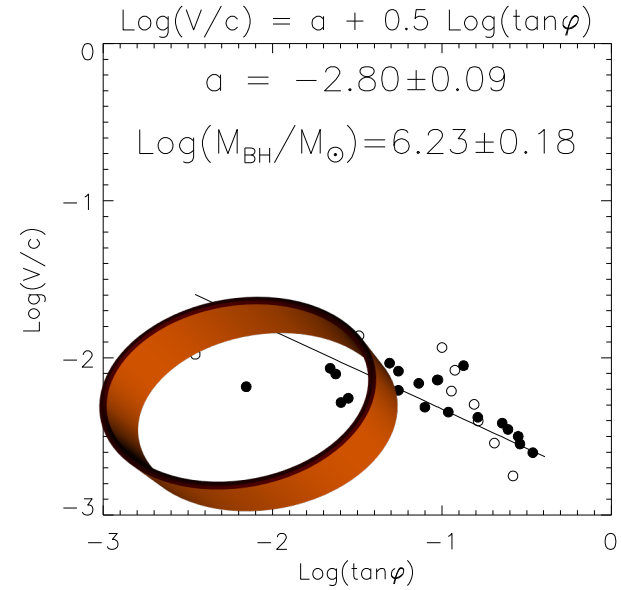


Observed P.A, Afanasiev & Popovic 2015





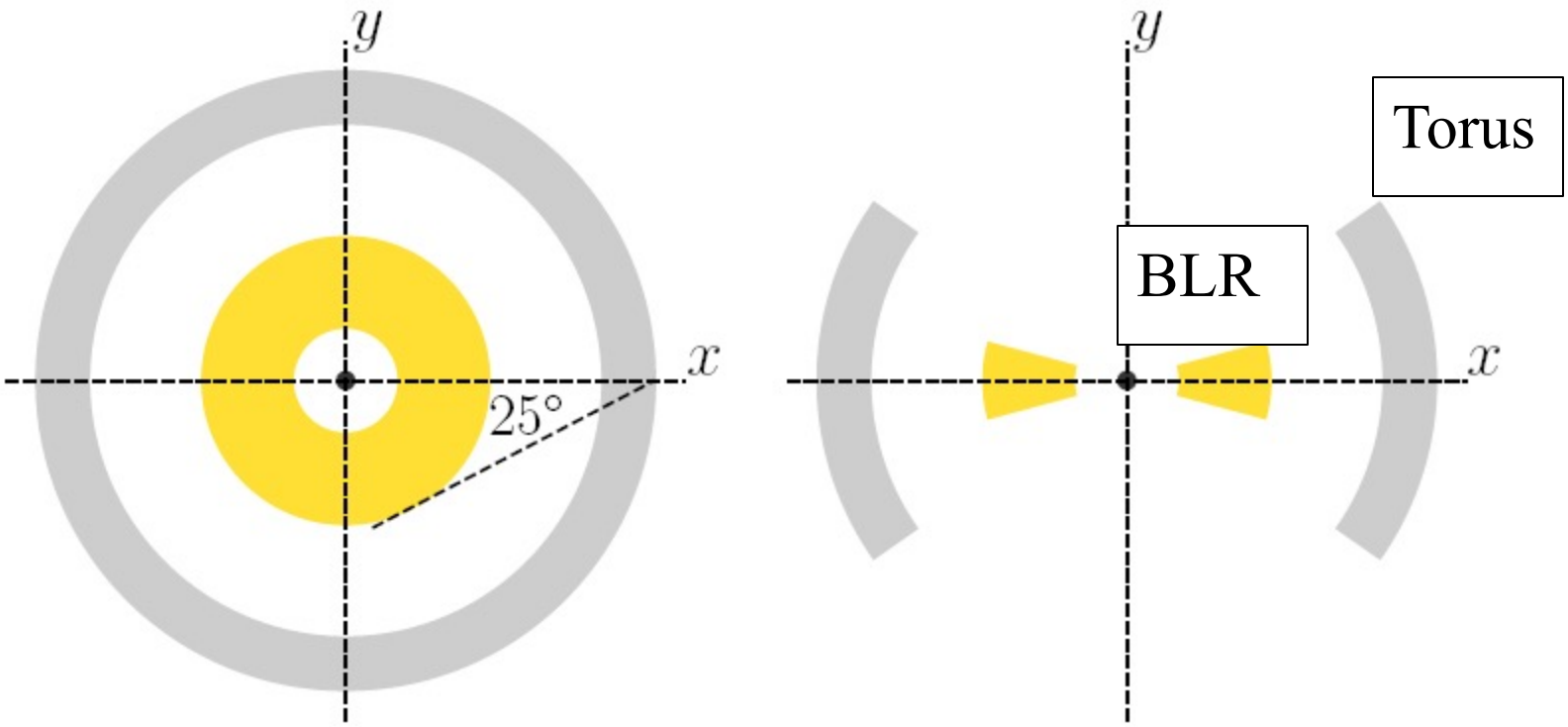




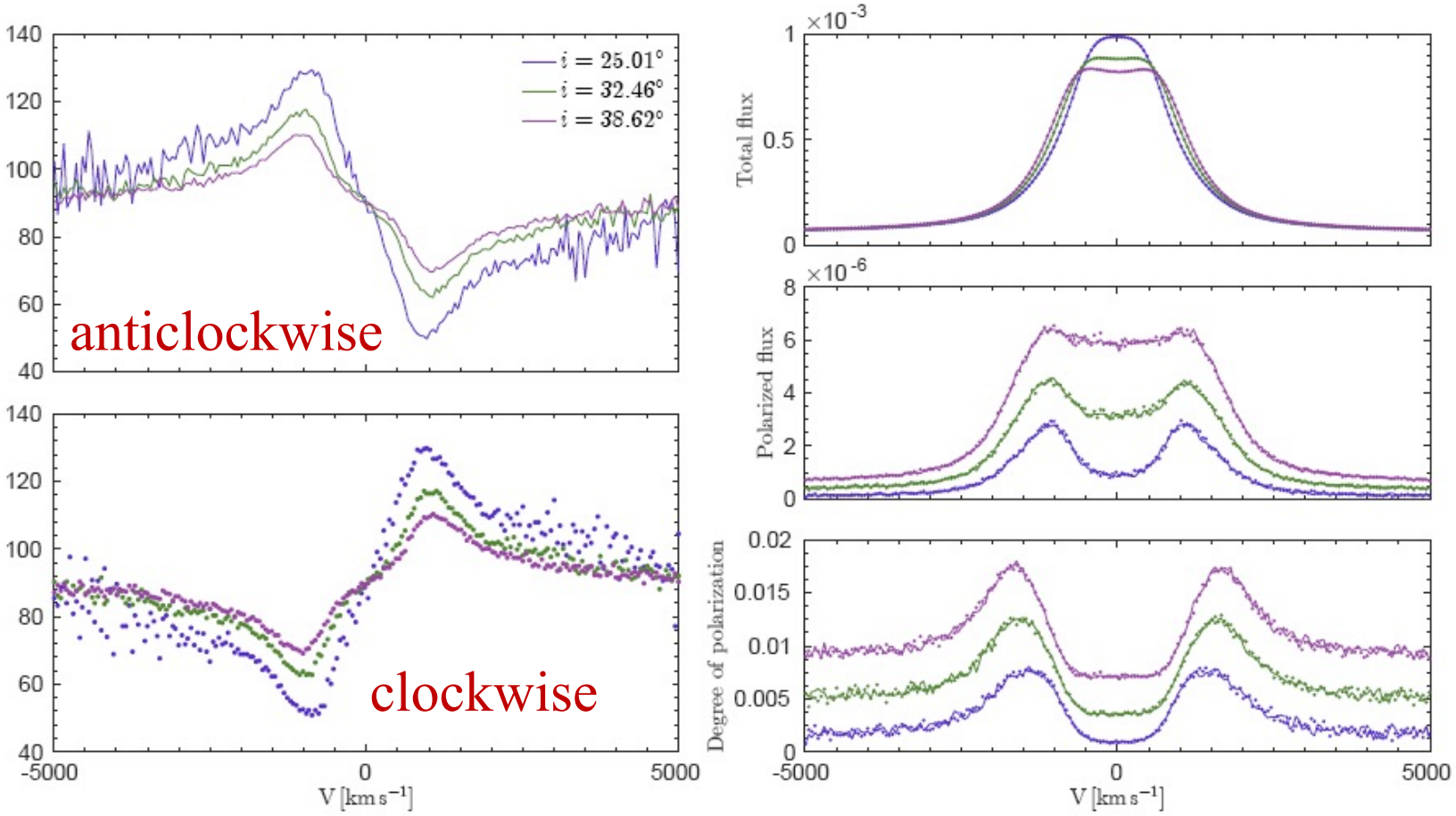
Theory vs. observations (equatorial scattering)

- Model with STOKES code (Goosmann & Gaskell 2007, Marin et al. 2012, etc)

- Savić et al. 2018, A&A, 614, 120

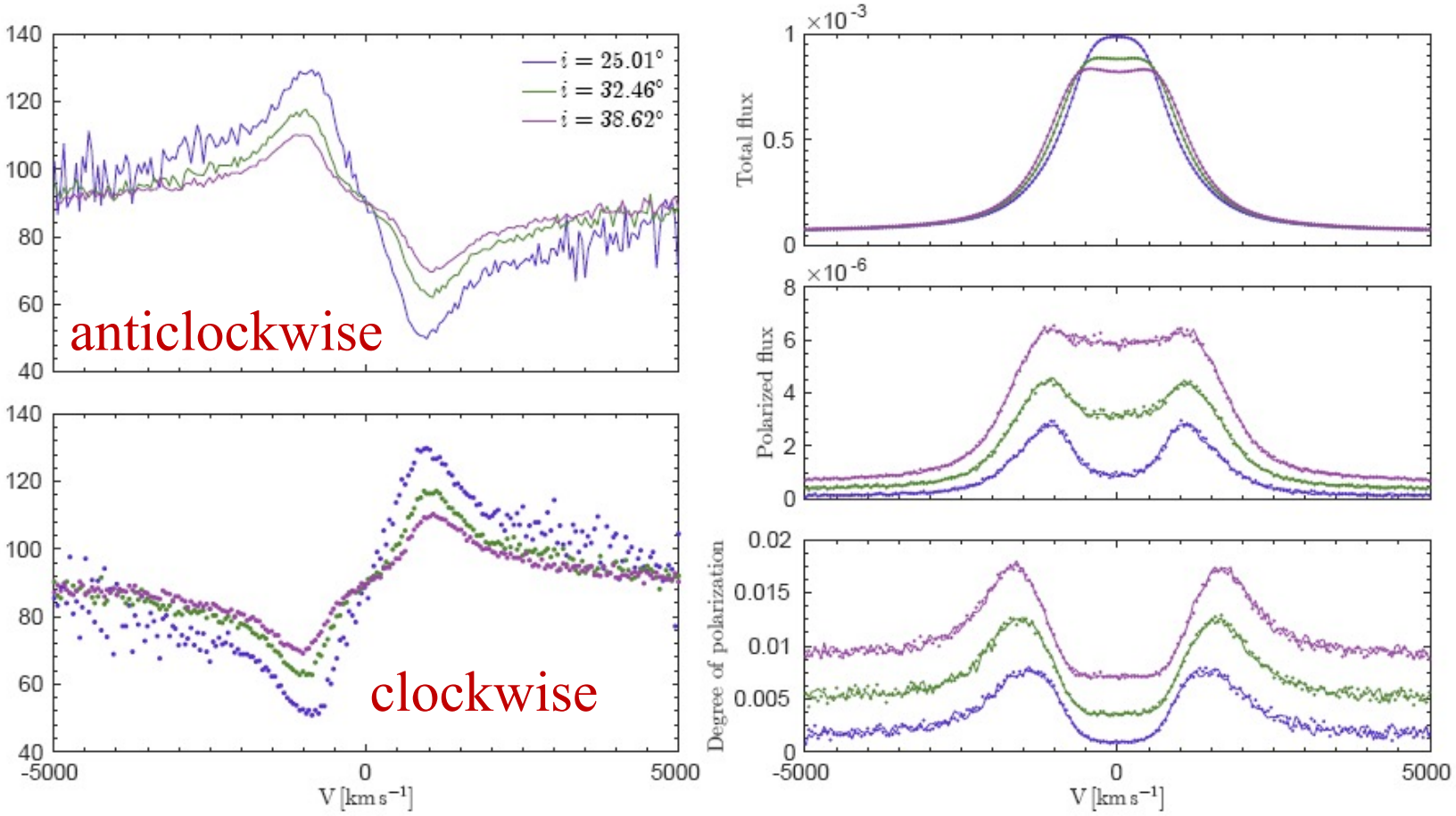


Theory vs. Observations
Savić et al. 2018



Pure Keplerian motion

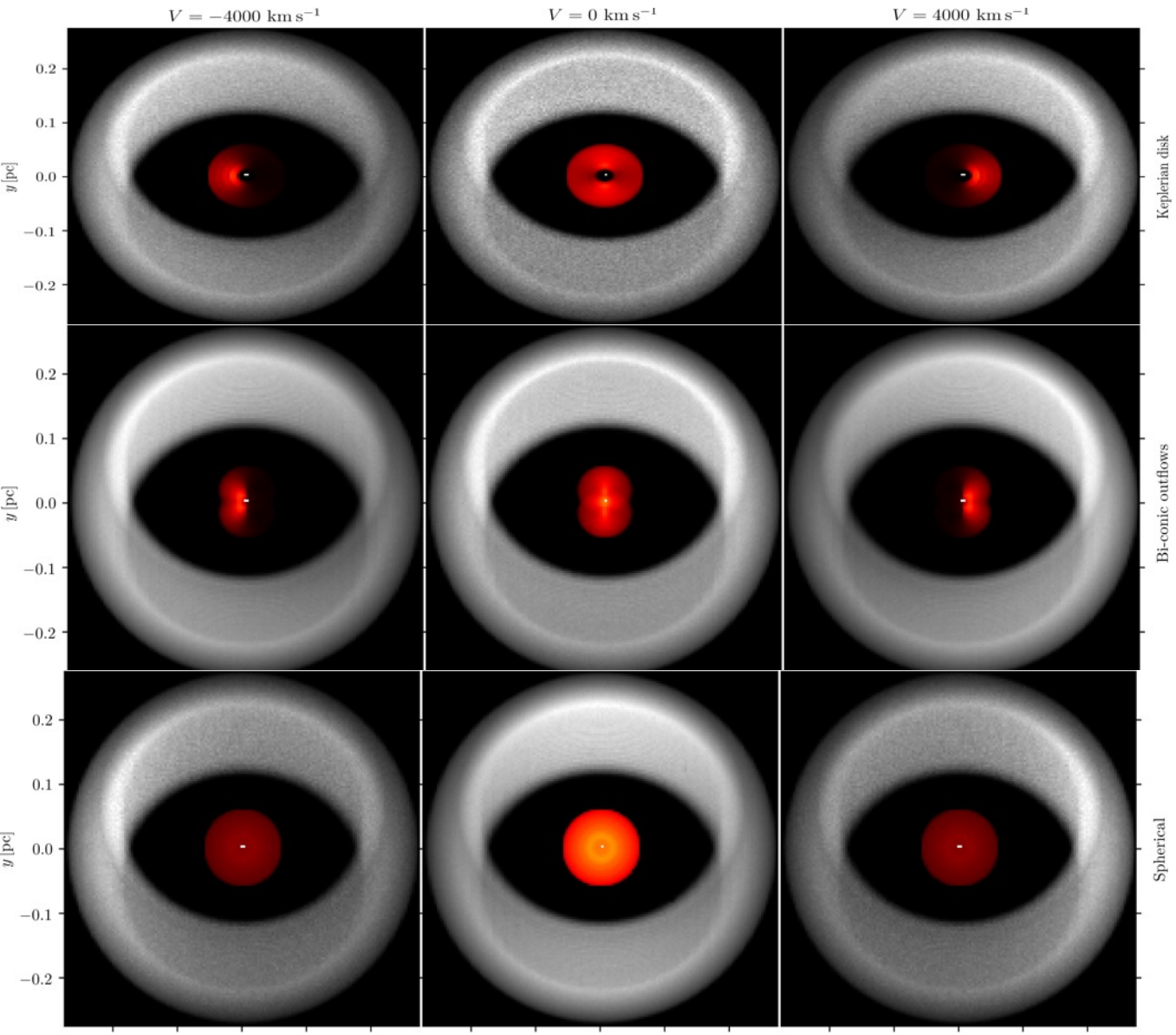
Theory vs. Observations
Savić et al. 2018



Pure Keplerian motion

Equatorial scattering for different BLR geometries (Bo et al. 2021, accepted in MNRAS)

Blue wing Line center Red wing

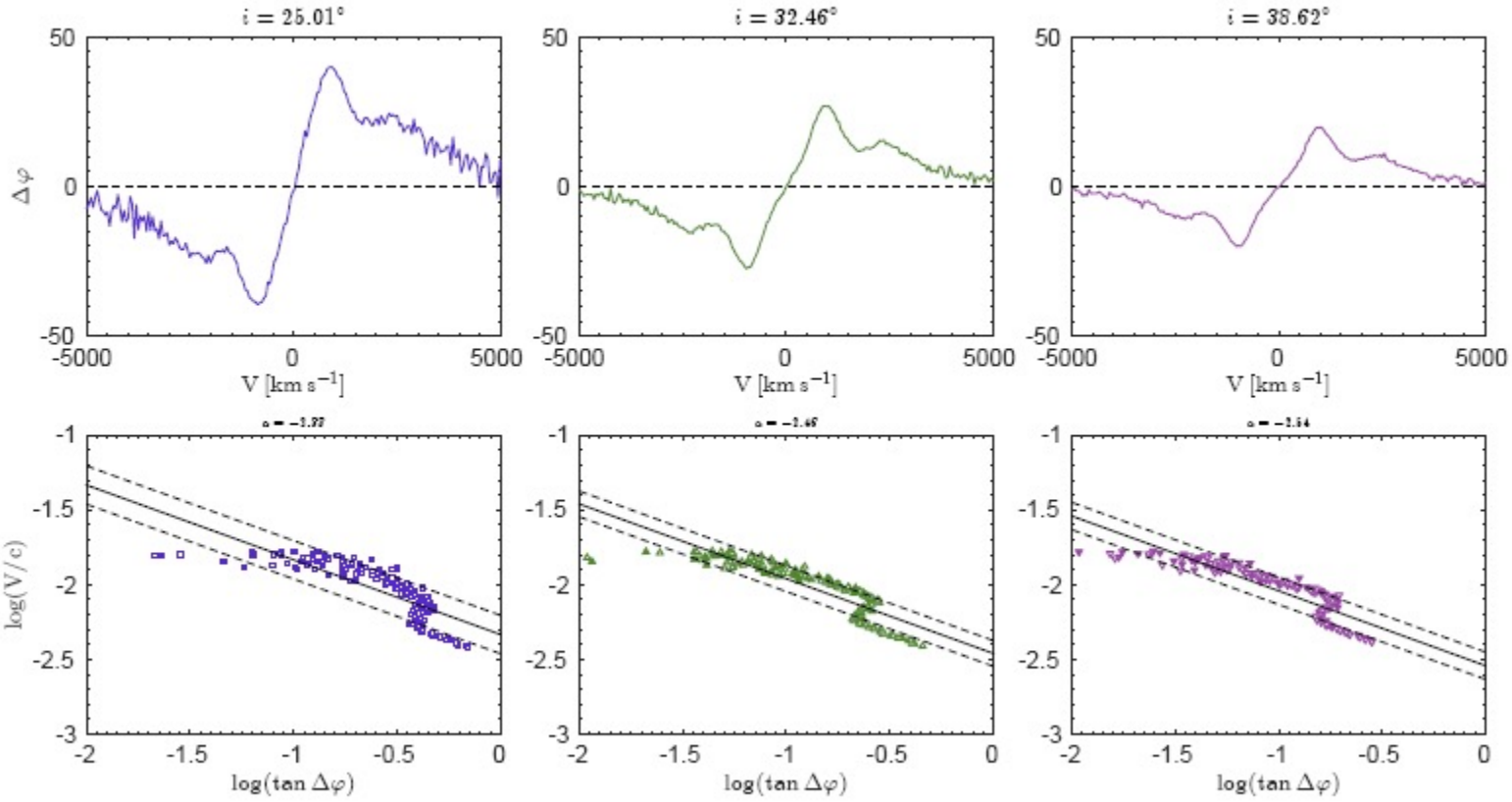


Disc - like

Otuflow

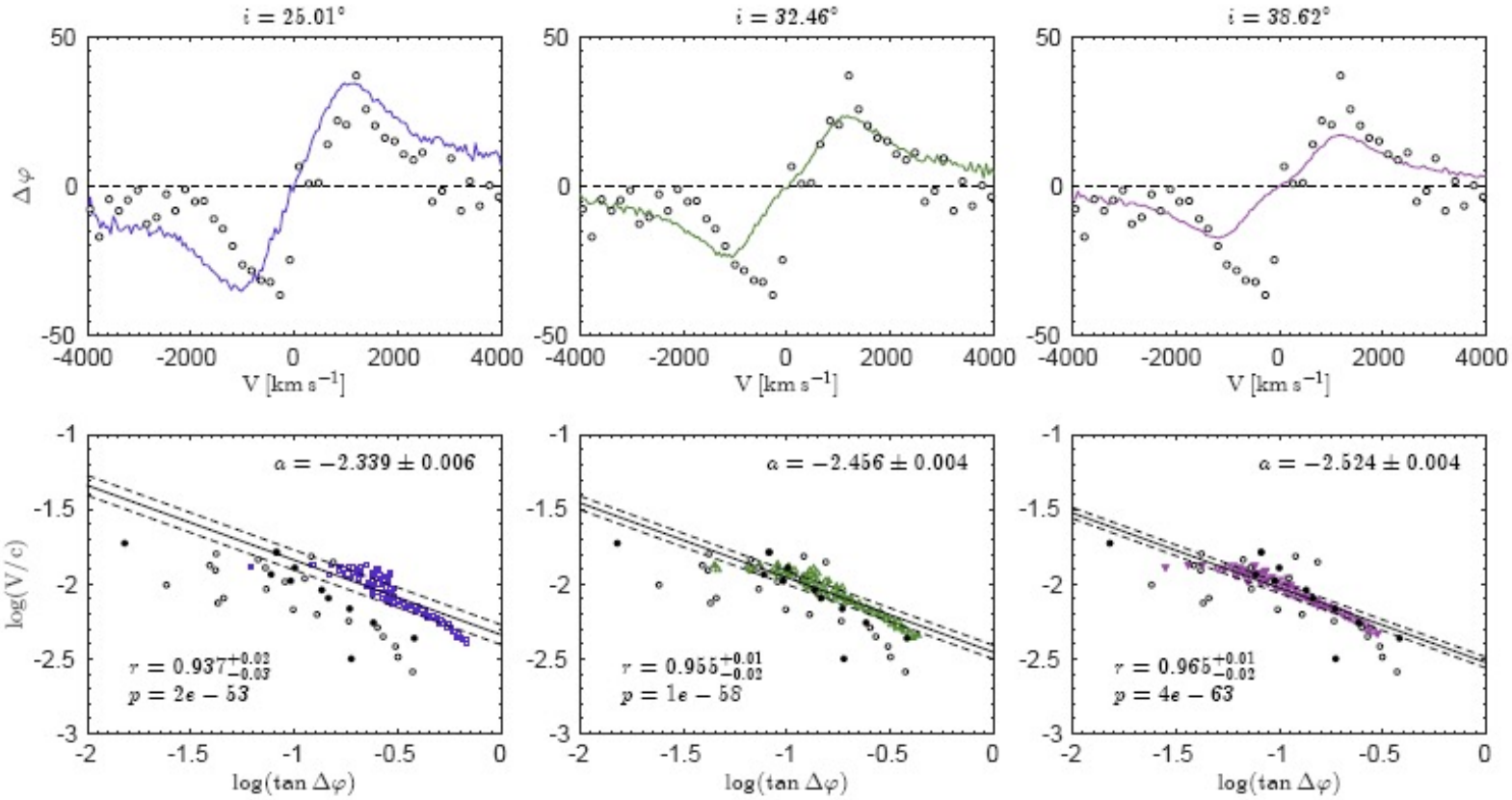
Spherical

Theory vs. Observations
Savić et al. 2018



Keplerian motion + outflow -2000 km/s

Theory vs. Observations
Savic et al. 2018



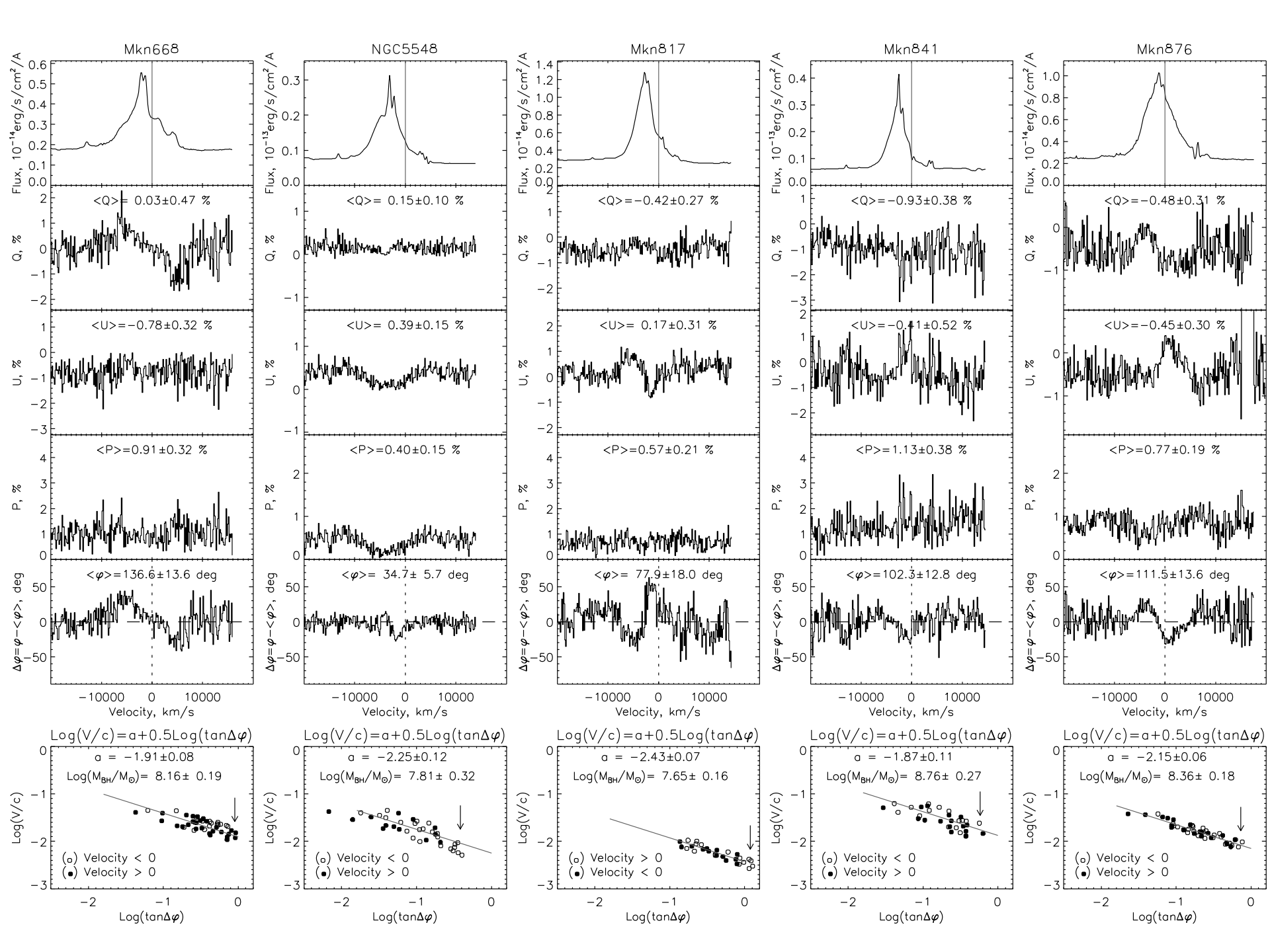
Fitted observations for NGC 4051

Black hole masses for 30 Type 1 AGNs

Afanasiev, Popović, Shapovalova 2019, MNRAS, 482, 4985

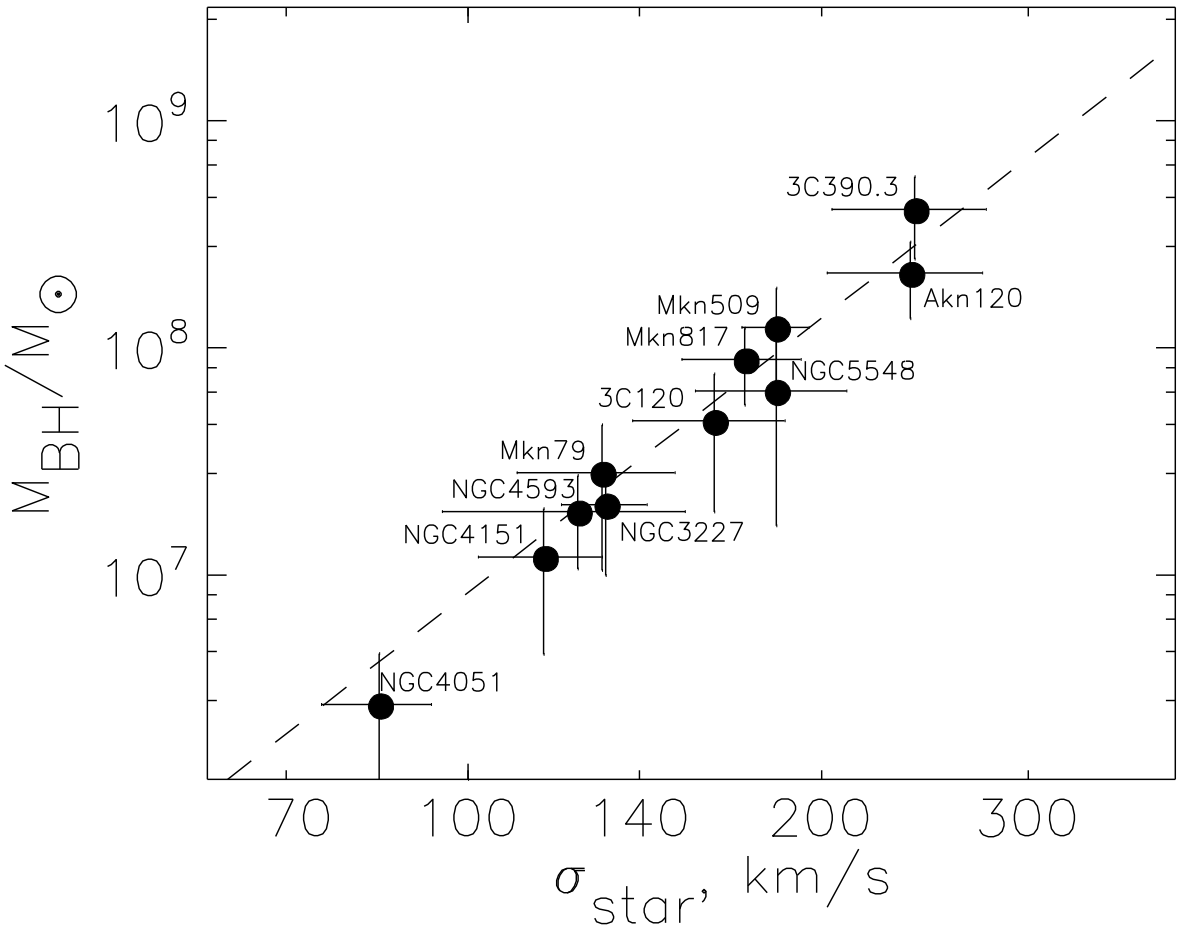
Observations with 6m telescope SAO RAS

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


Mkn668
NGC5548
Mkn817
Mkn841
Mkn876
Flux, 10^-14 erg/s/cm^2/A
Flux, 10^-13 erg/s/cm^2/A
<Q>= 0.03±0.47 %
<Q>= 0.15±0.10 %
<Q>=-0.42±0.27 %
<Q>=-0.93±0.38 %
<Q>=-0.48±0.31 %
Q, %
<U>=-0.78±0.32 %
<U>= 0.39±0.15 %
<U>= 0.17±0.31 %
<U>=-0.41±0.52 %
<U>=-0.45±0.30 %
U, %
<P>=0.91±0.32 %
<P>=0.40±0.15 %
<P>=0.57±0.21 %
<P>=1.13±0.38 %
<P>=0.77±0.19 %
P, %
<φ>=136.6±13.6 deg
<φ>= 34.7± 5.7 deg
<φ>= 77.9±18.0 deg
<φ>=102.3±12.8 deg
<φ>=111.5±13.6 deg
Δφ=φ−<φ>, deg
Velocity, km/s
Log(V/c)=a+0.5Log(tanΔφ)
a = −1.91±0.08
Log(M_BH/M_⊙)= 8.16± 0.19
a = −2.25±0.12
Log(M_BH/M_⊙)= 7.81± 0.32
a = −2.43±0.07
Log(M_BH/M_⊙)= 7.65± 0.16
a = −1.87±0.11
Log(M_BH/M_⊙)= 8.76± 0.27
a = −2.15±0.06
Log(M_BH/M_⊙)= 8.36± 0.18
Log(V/c)
Log(tanΔφ)
(o) Velocity < 0
(•) Velocity > 0

Black hole masses for 30 Type 1 AGNs

Afanasiev et al. 2019



Our measurements of BH masses as a function of host galaxy bulge stellar velocity dispersion *(taken from Onken et* al. 2004). The dashed line shows the dependence of M-σ taken from Tremaine et al (2002).

BLR inclination for 30 Type 1 AGNs

Afanasiev et al. 2019

$$f = \frac{1}{\sin^2 i}$$

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

$$\frac{1}{f} = \frac{VP}{M_{BH}}$$

Our measurements of SMBH masses do not depend on inclination (see Afanasiev & Popovic 2015), Keplerian motion=>assumption that f depends only from BLR inclinatin!

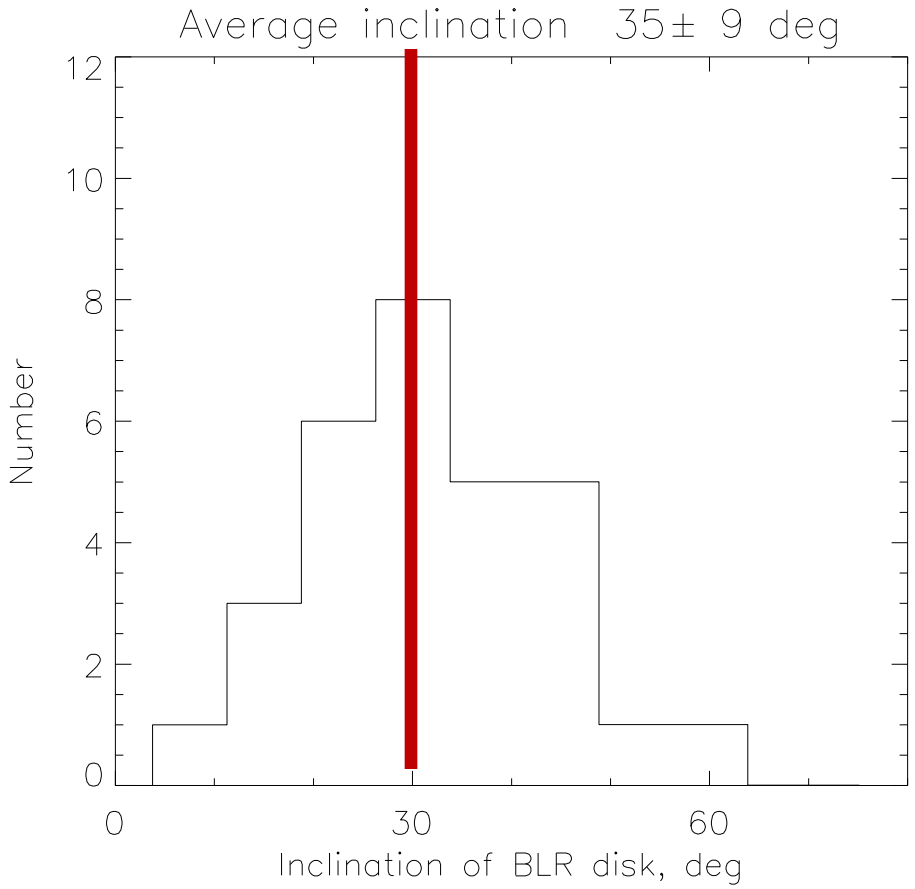
BLR inclination for 30 Type 1 AGNs

Afanasiev et al. 2019

$$f \approx \frac{1}{\sin^2 i}$$

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

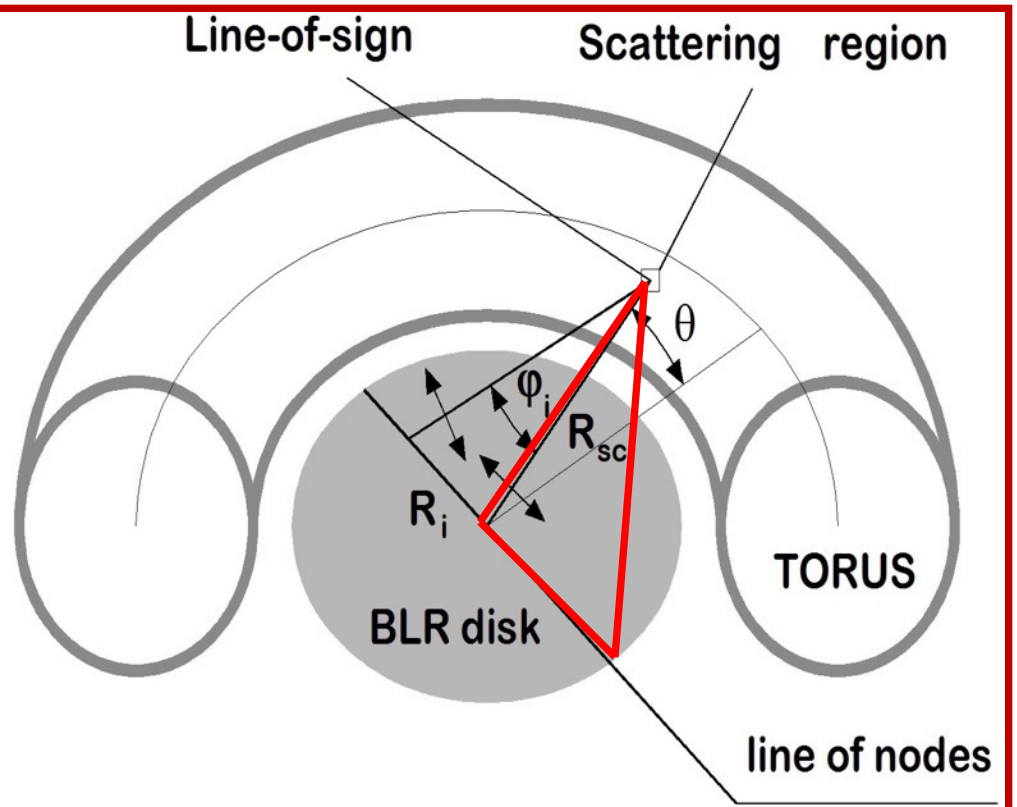
$$\frac{1}{f} = \frac{VP}{M_{BH}} \approx \sin^2 i$$

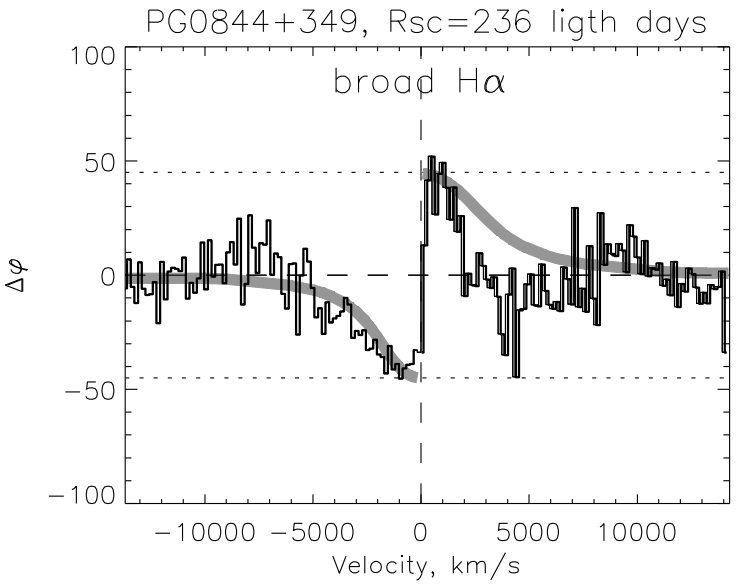


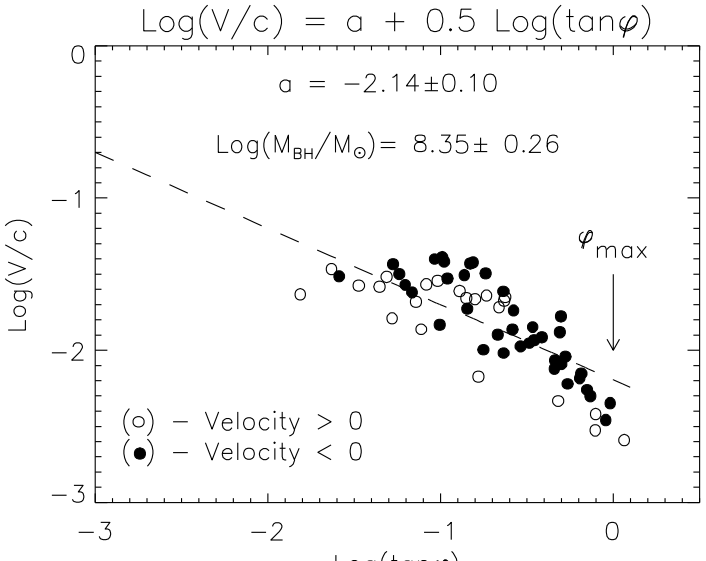
Our measurements of SMBH masses do not depend on inclination (see Afanasiev & Popovic 2015), Keplerian motion=>assumption that f depends only from BLR inclinatin!

Dimensions of the BLR

$$R_{max} = R_{sc} \tan(\varphi_{max})$$







Dimensions of the BLR
Afanasiev et el. 2019

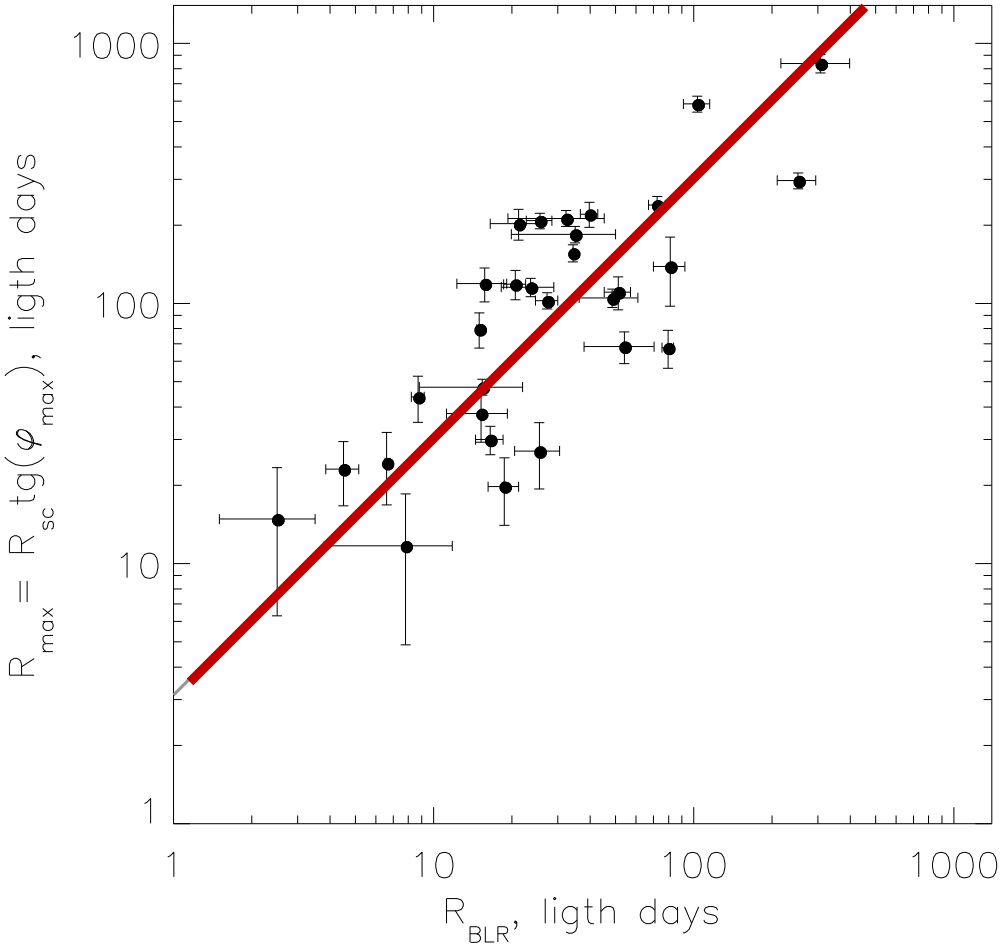
The maximal (*Rmax)* *vs photometric BLR (RBLR)* *r*adius. The solid line represents the best fit

$R_{BLR} = (0{:}31 \pm 0{:}17) Rmax$

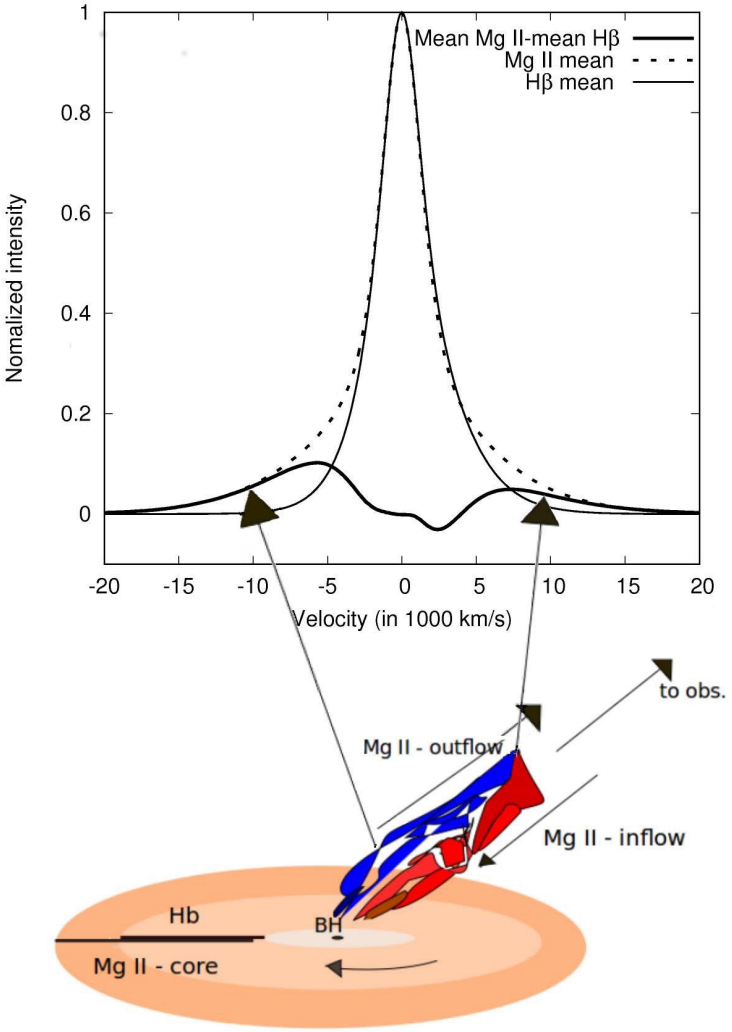
Relation between Rsc and RBLR

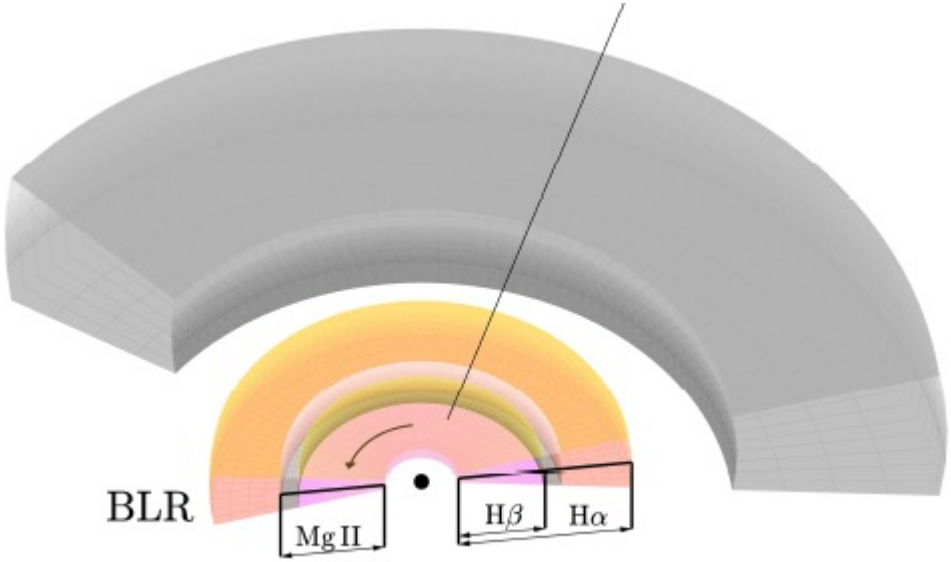
$Rsc = (1.72 \pm 0.48)\ R_{BLR}$

.



What is with other lines, as e.g. Mg II BLR – seems to be complex (Popovic et al. 2020, MNRAS, 484, 3180)





Savic et al. 2020, MNRAS, 497, 3947 – model, BLR with outflows/inflows

Quasar SBS 1419+538, spectroploarometric observations of Mg II (Savic, Popovic, Shablovinskaya -sent to ApJL)

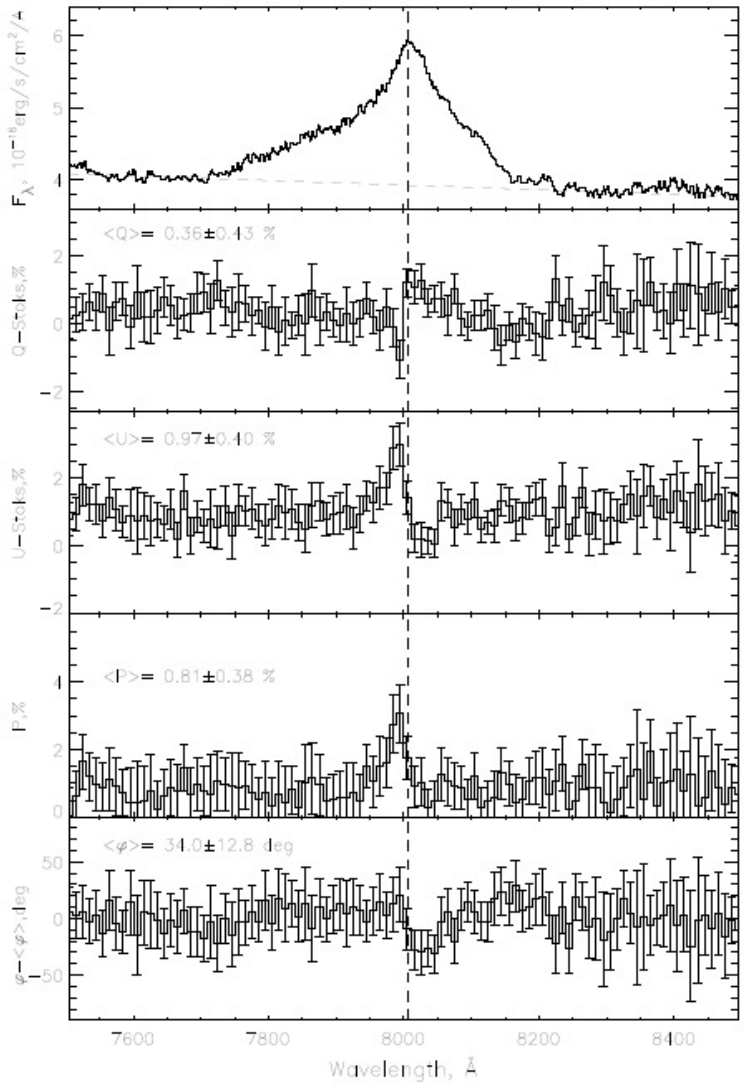
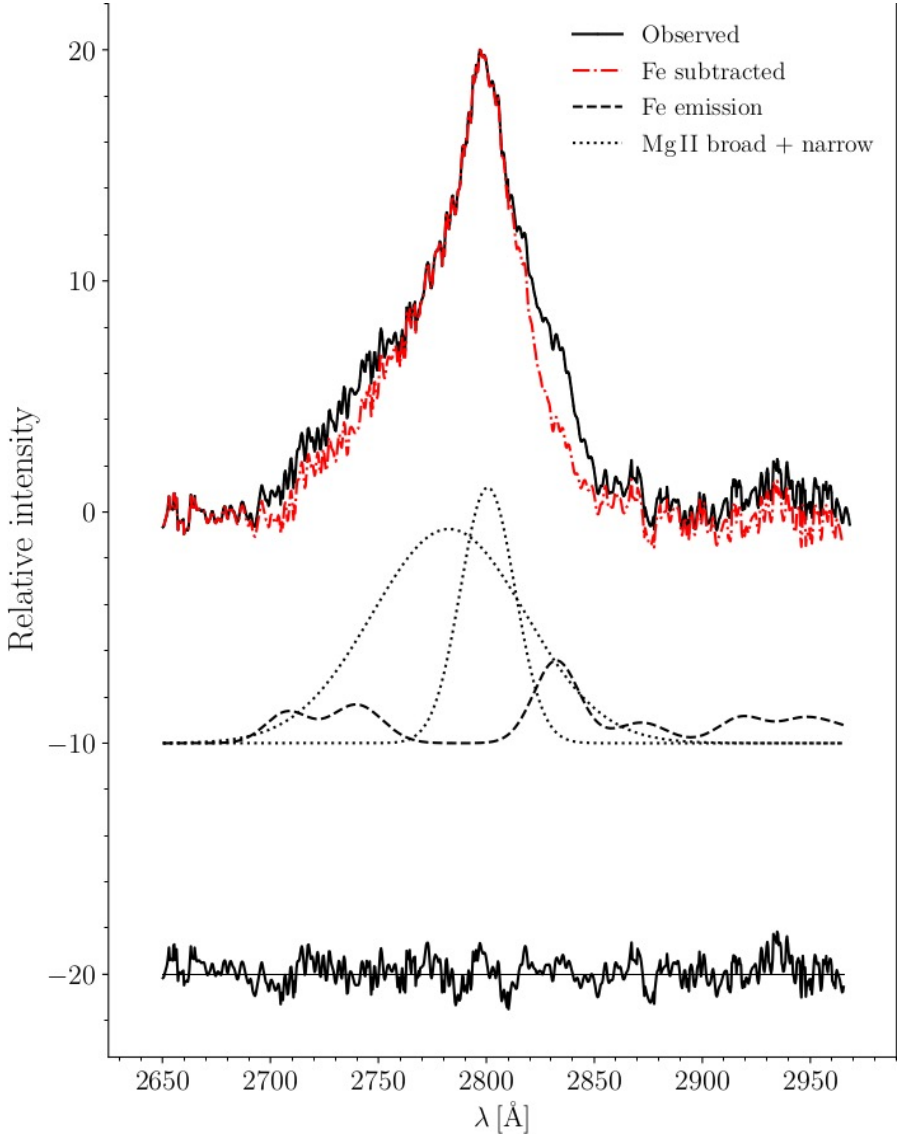
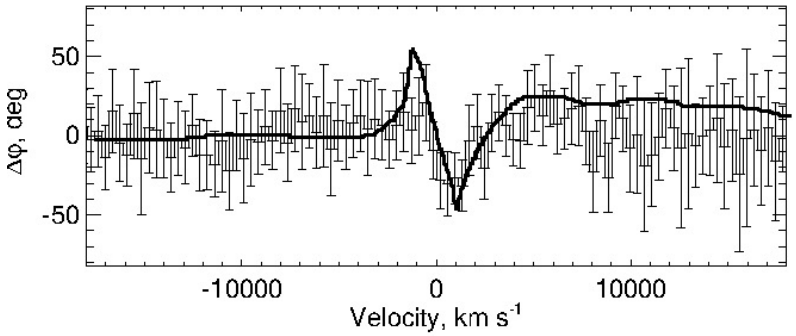


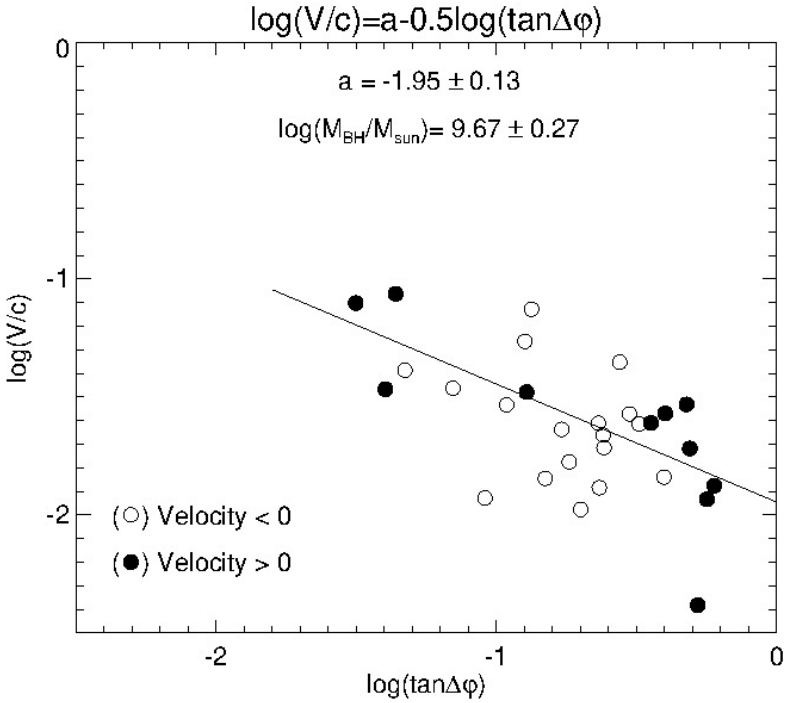
Fig. 5: The Mg II spectral region (1st panel), the Q and U Stokes

SBS1419+538 was observed with the 6-m telescope BTA of SAO RAS with the focal reducer SCORPIO-2 (Afanasiev & Moiseev 2011)

Quasar SBS 1419+538, spectropolarometric observations of Mg II (Savic, Popovic, Shablovinskaya -sent to ApJL)







Conclusions

AGN polarization – BLR characteristics:

- - inclinations
- - BLR dimensions
- - SMBH mass
- Equatorial scattering!
- Problem to find the distance to the scattering region (inner radius of the torus?)

13SCSLSA, Belgrade; August 23-27, 2021

Thank you for your attention


13th SCSLSA
23 - 27 August
Belgrade, Serbia