Resolving the Broad Line Region Characteristics using Spectropolarimetry of Type 1 Active Galactic Nuclei

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Polarization in AGNs

Antonucci & Miller 1985

- Sy2=>hidden Sy1

(very important)

- Mechanism of polarization

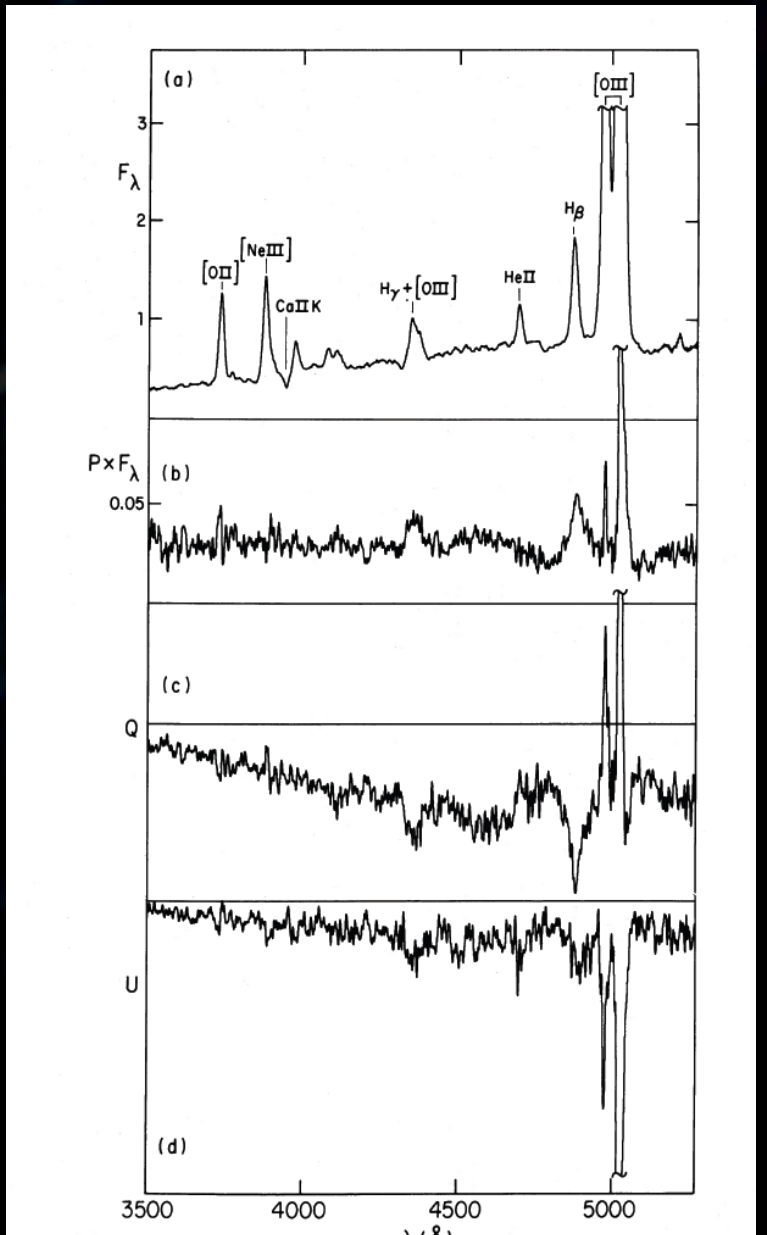
in AGNs

Smith et al. 2004, 2005;

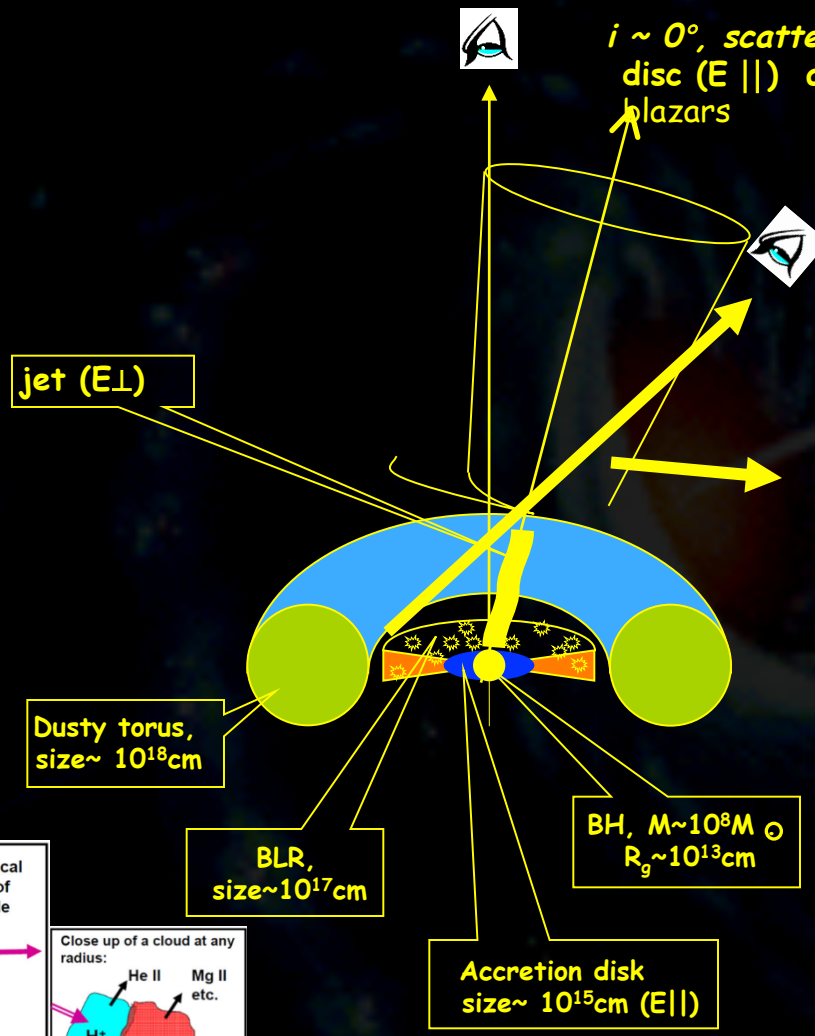
Afanasiev et al. 2014, 2019

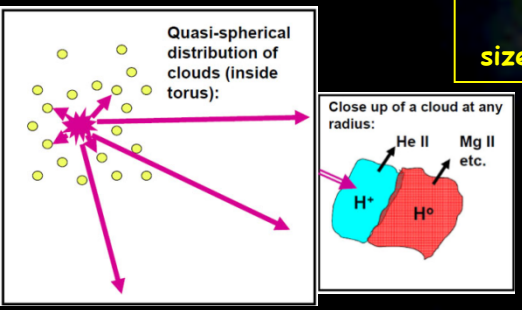
Goosmann & Gaskell 2007;

Savic et al. 2019, etc.



Polarization in AGNs





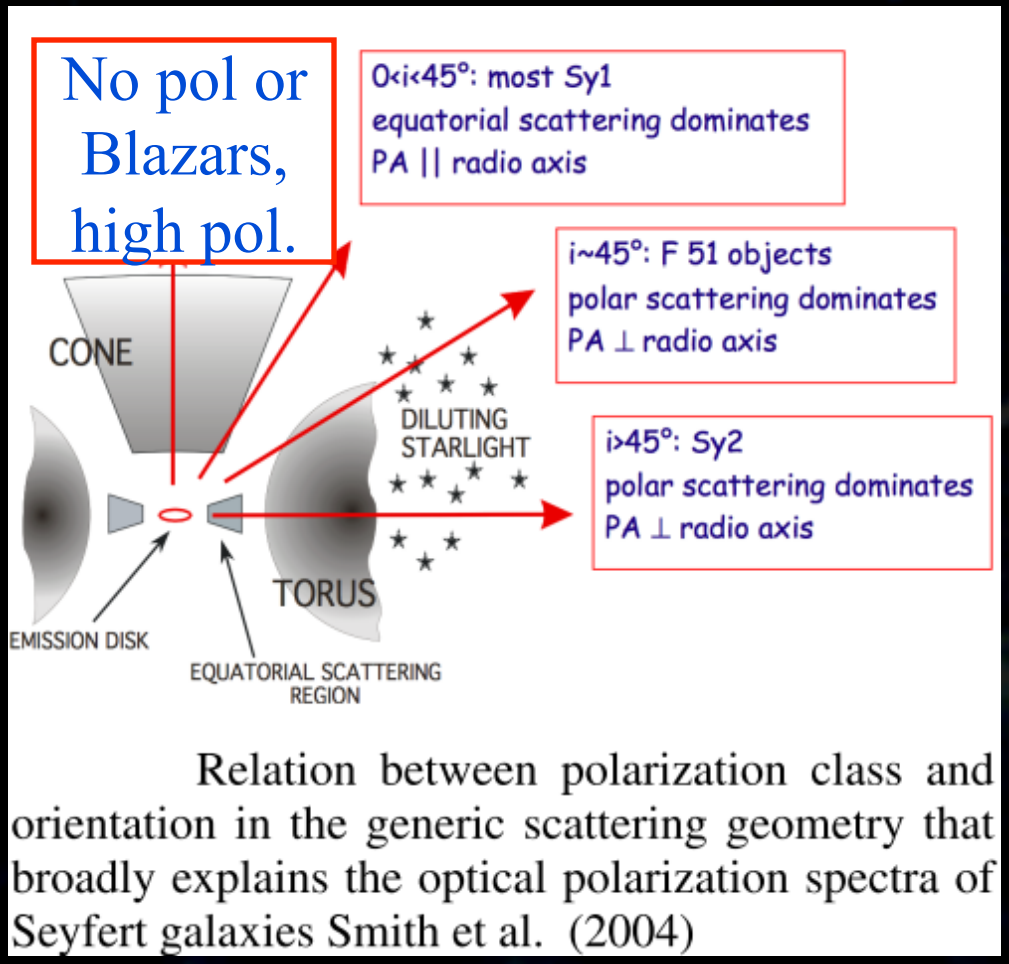
Polarization in continuum

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

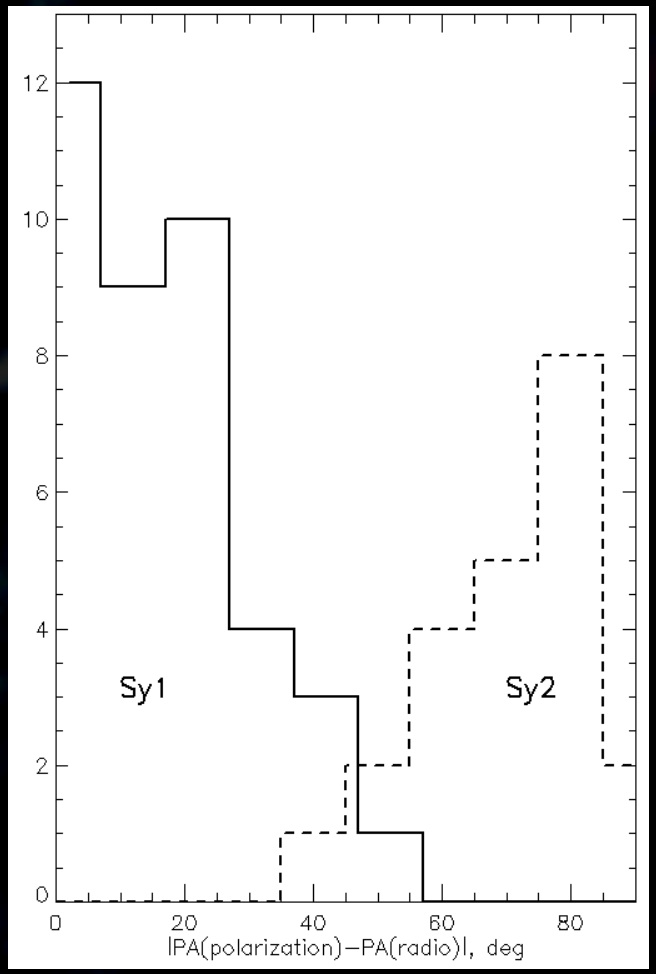
Polarization in lines

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

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



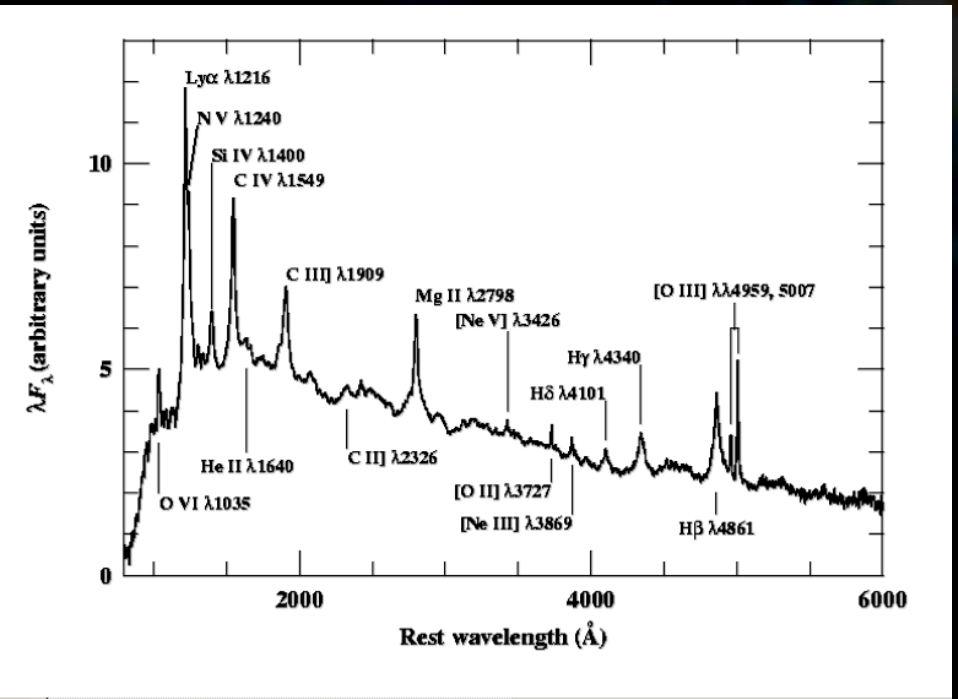
Relation between polarization class and orientation in the generic scattering geometry that broadly explains the optical polarization spectra of Seyfert galaxies Smith et al. (2004)

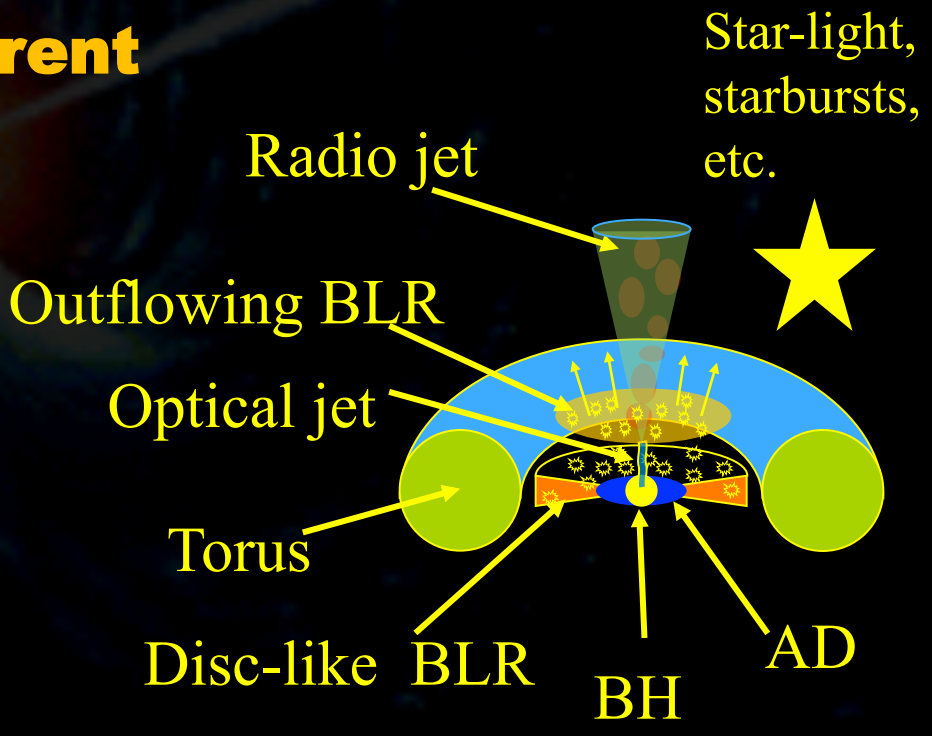


Orientation is very important!

Optical emission of AGNs – different emission regions!

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





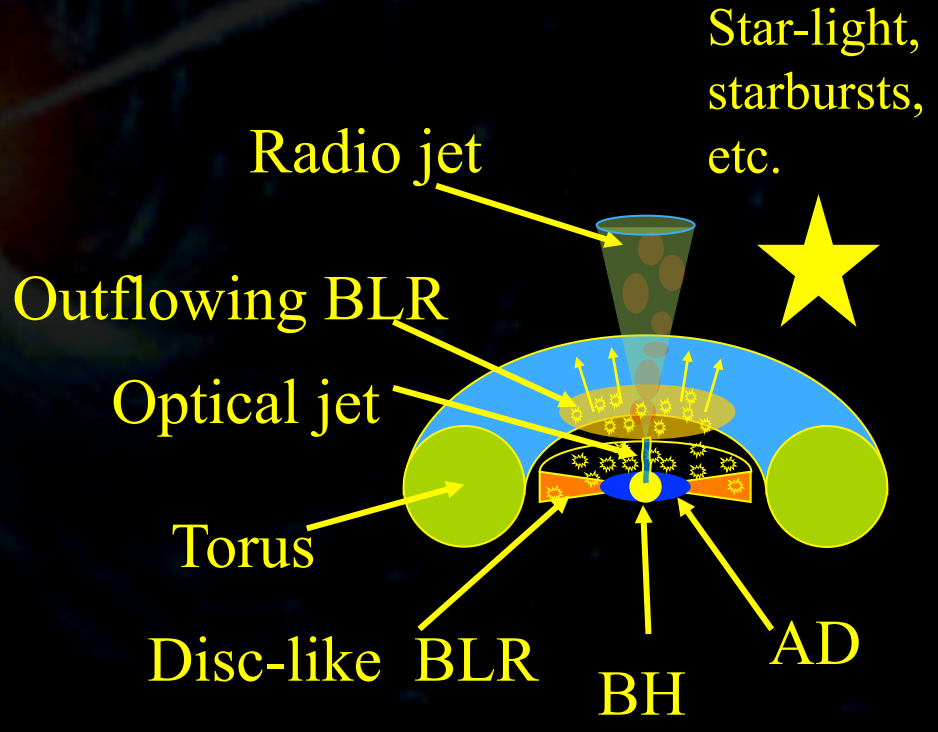
Expected variability of polarization parameters in AGN spectra – scales?

Small scales (order of the BLR)

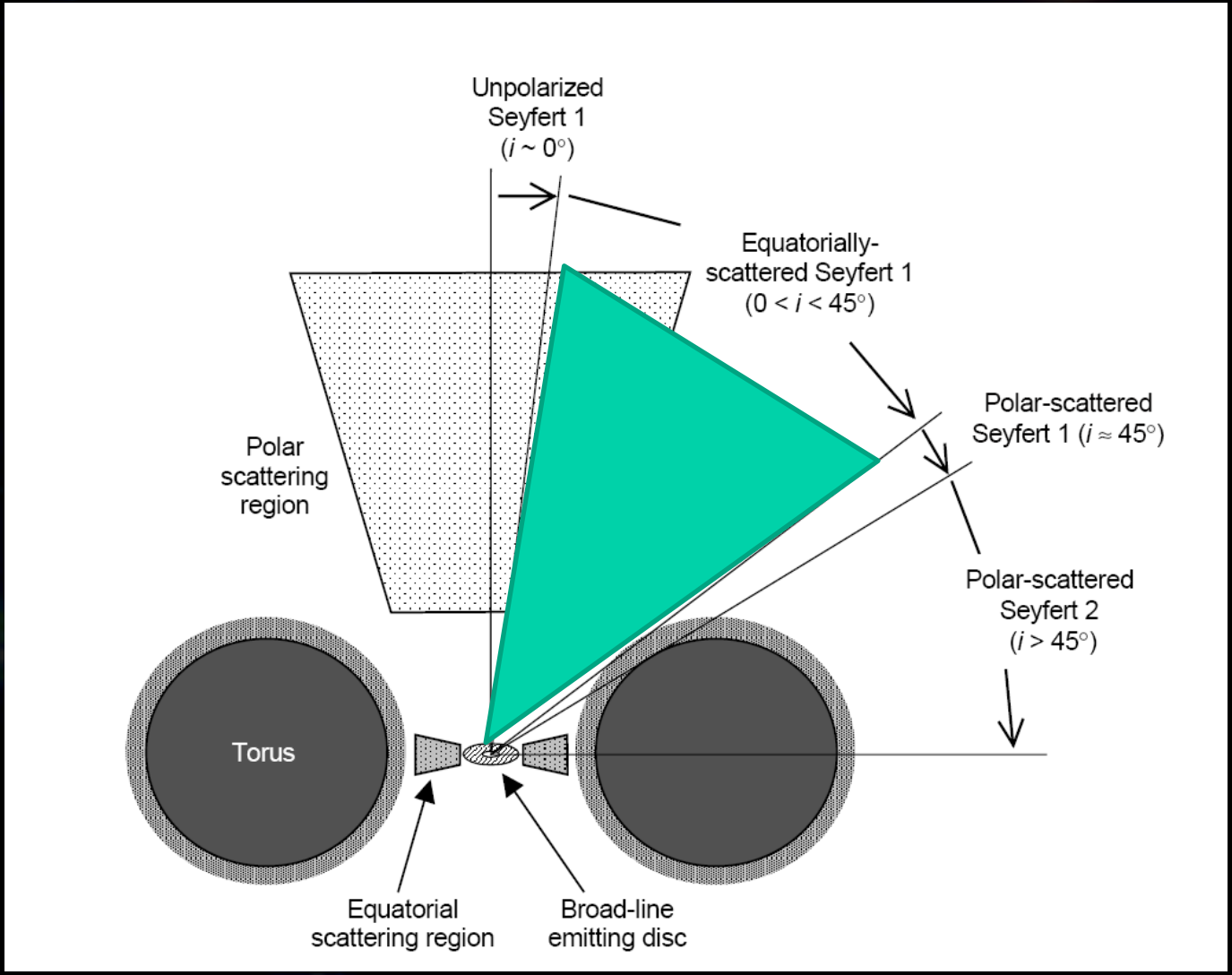
- Radiative transfer in the accretion disk (electron scattering)
- synchrotron radiation of the jet

Large scales (> BLR)

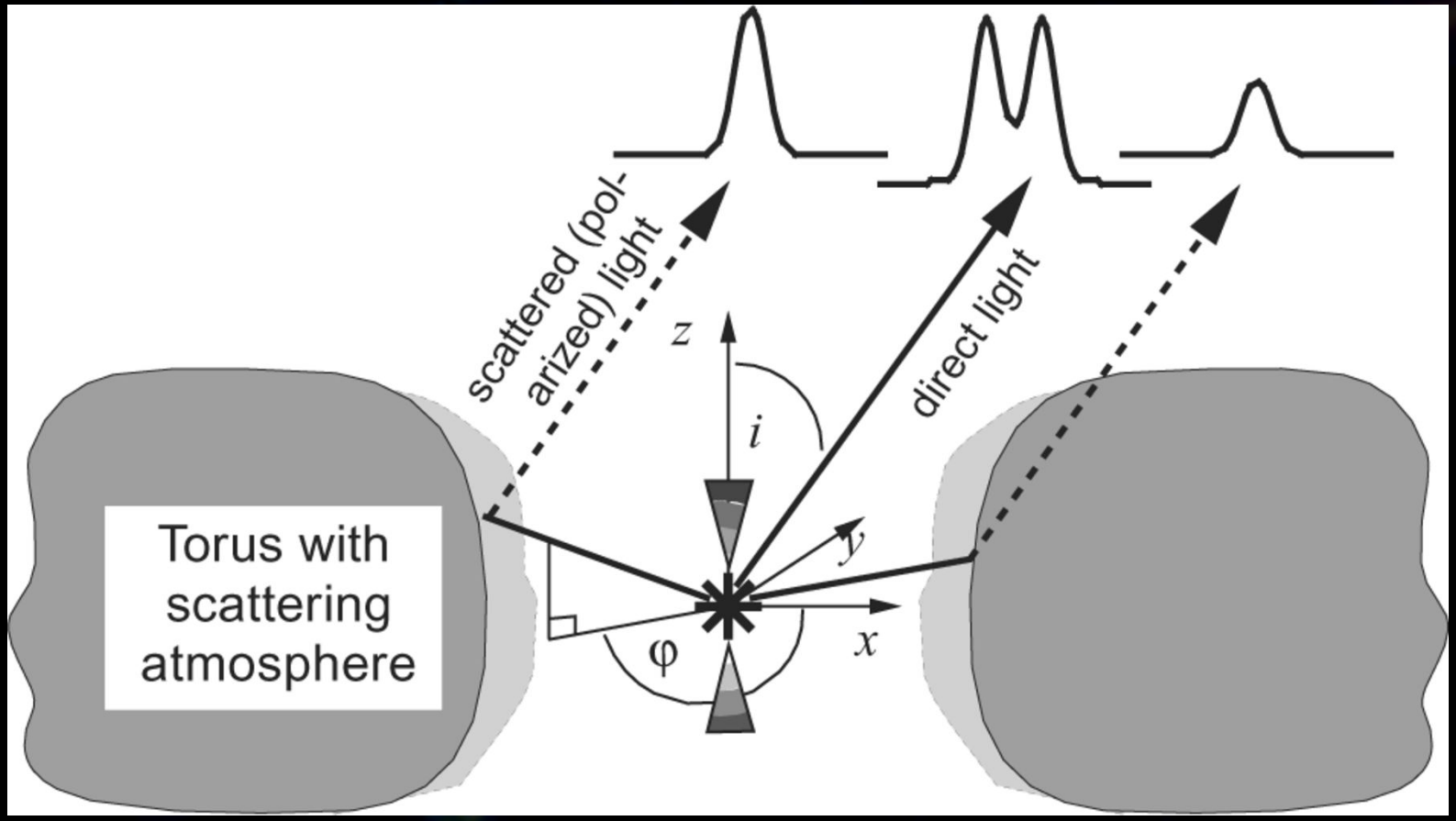
- scattering in optically thick gas-dust torus
- scattering in the optically thin gas cone



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



Equatorial polarization – Keplerian disk – polarization in the broad line



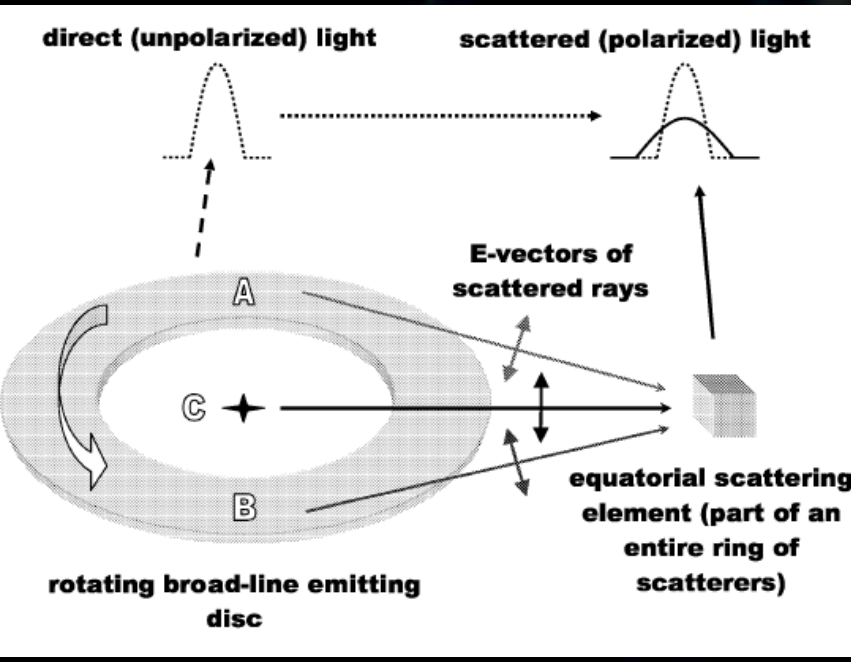
Sketch showing a possible far-field scattering geometry in which Hα photons from BLR clouds undergoing bi-polar outflow are scattered by dust or free electrons in the inner wall of a surrounding torus.

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

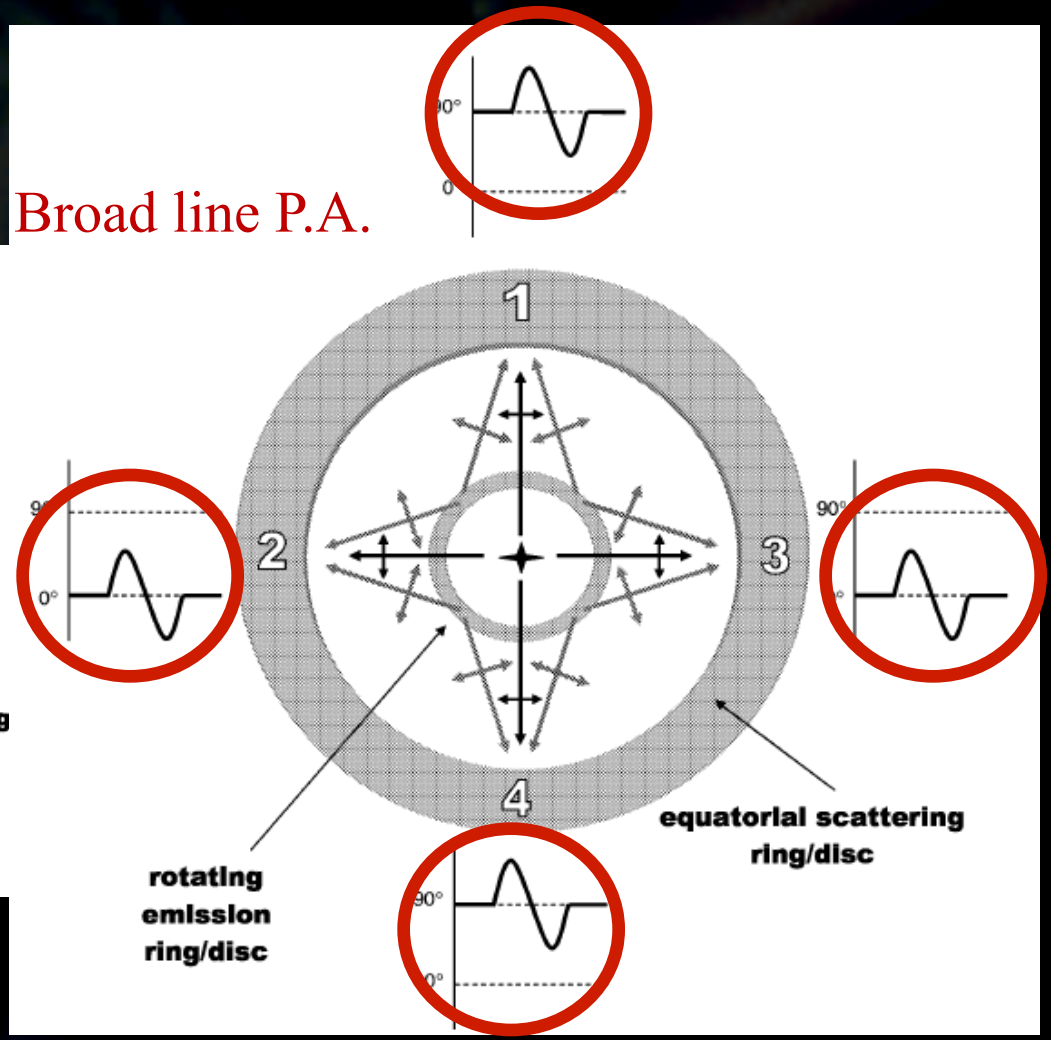
MONTHLY NOTICES
of the Royal Astronomical Society

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

Broad line shapes



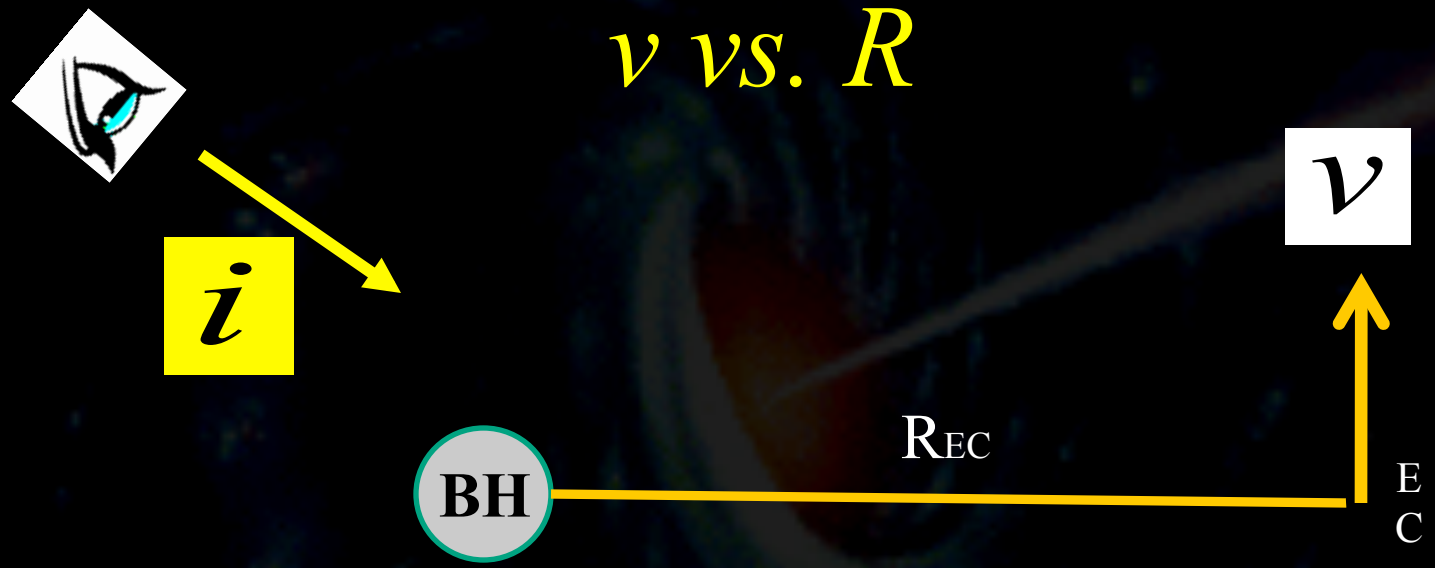
Broad line P.A.



Resolving the central part AGNs using polarization!

1. Measuring the mass of SMBH in AGNs
2. BLR characteristics
3. The radius of the innerpart of torus

To measure the black hole mass – *v vs. R*



$$v = \sqrt{\frac{GM_{BH}}{R_{EC}}}$$

$$M_{BH} = \frac{R_{EC} v^2}{G}$$

To measure the black hole mass – *v vs. R*

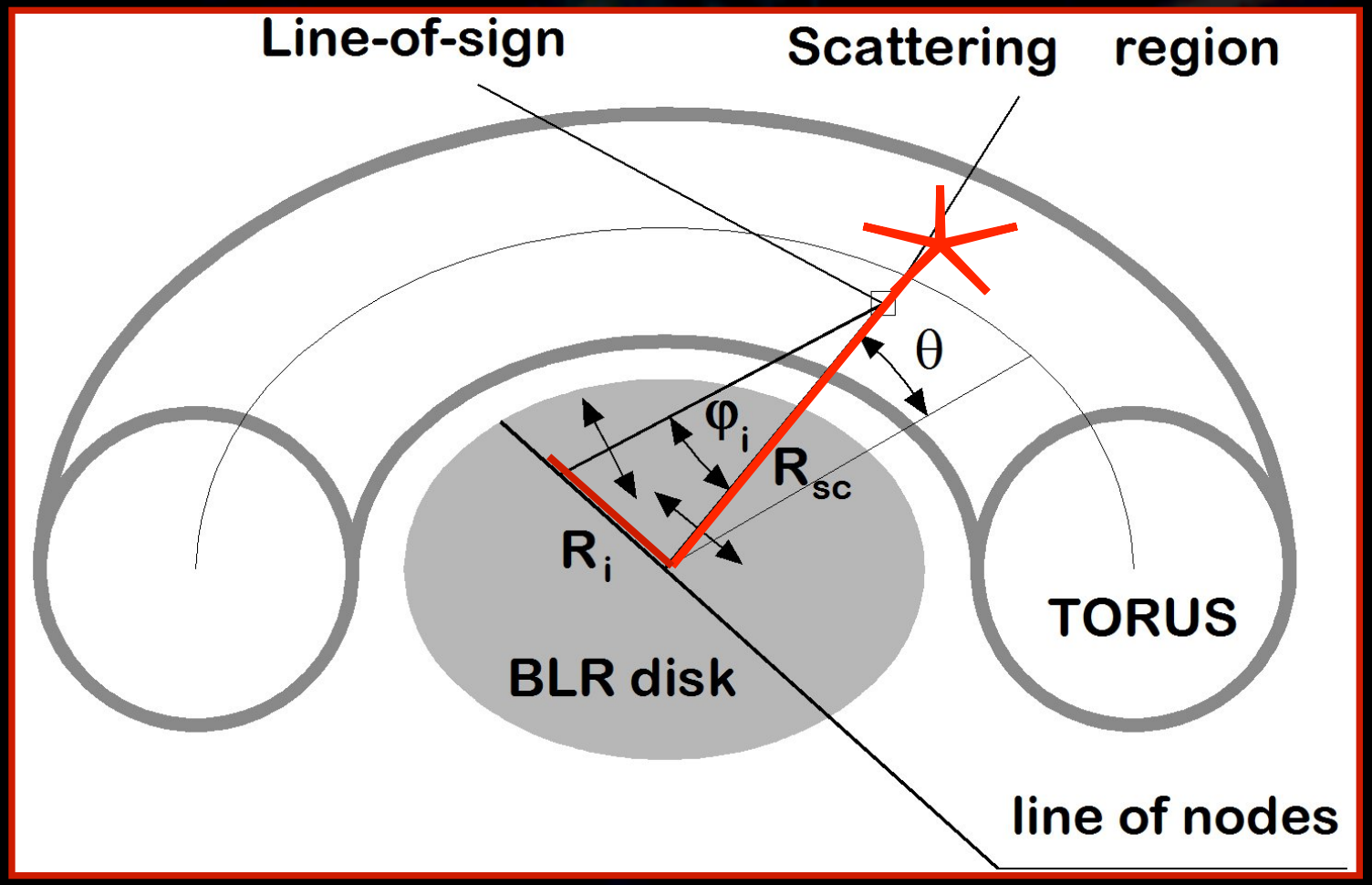
$$v = \sqrt{\frac{GM_{BH}}{R_{EC}}}$$

$$M_{BH} = \frac{R_{EC} v^2}{G}$$

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

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

$$Rsc = const.$$



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

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

$$b = 0.5, \text{ Keplerian motion}$$

$$a = 0.5\log\left(\frac{G}{c^2}\frac{M_{BH}}{R_{SC}}\right), \; BLR \parallel torus$$

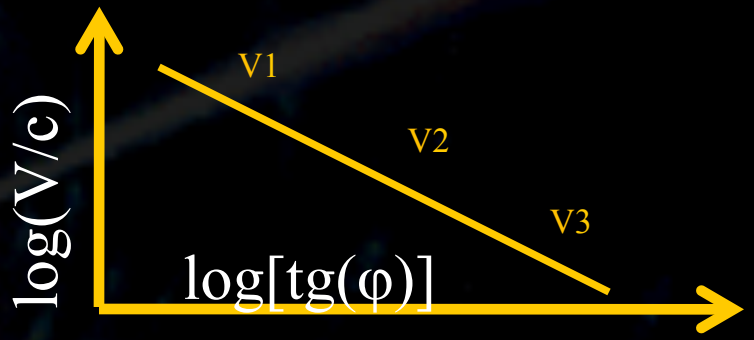
Polarizarion in the broad Hα (BLR). Equatorial scattering - idea

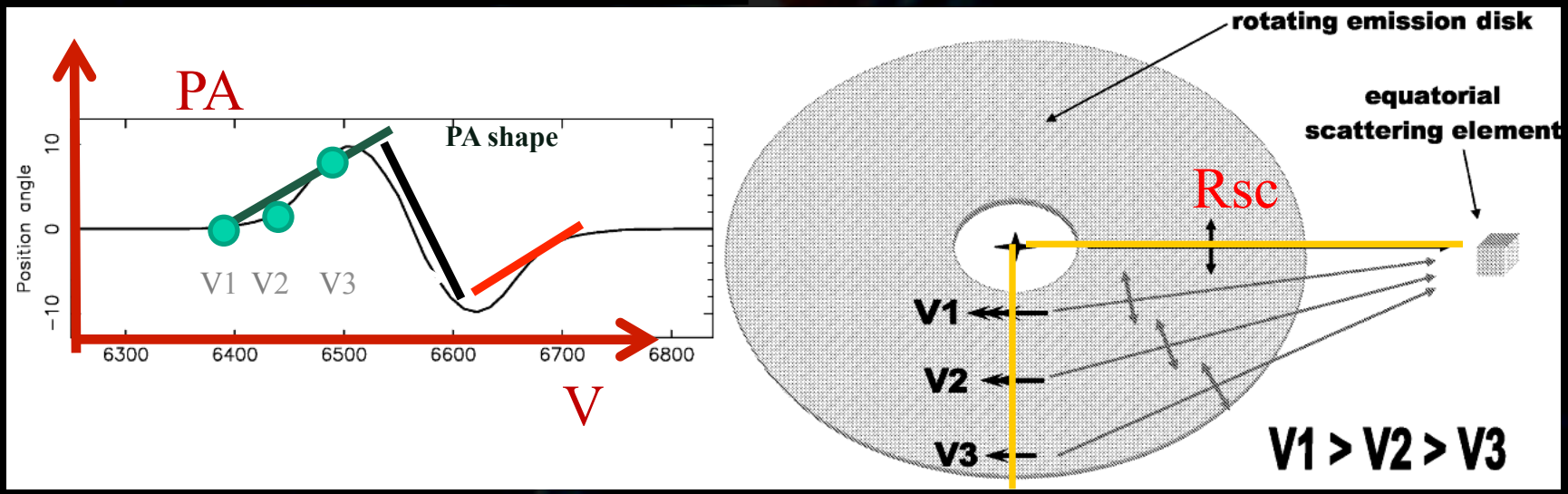
$$v_i = \sqrt{\frac{GM_{BH}}{R_{SC}\tan(\phi_i)}},$$

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

$$b = 0.5$$

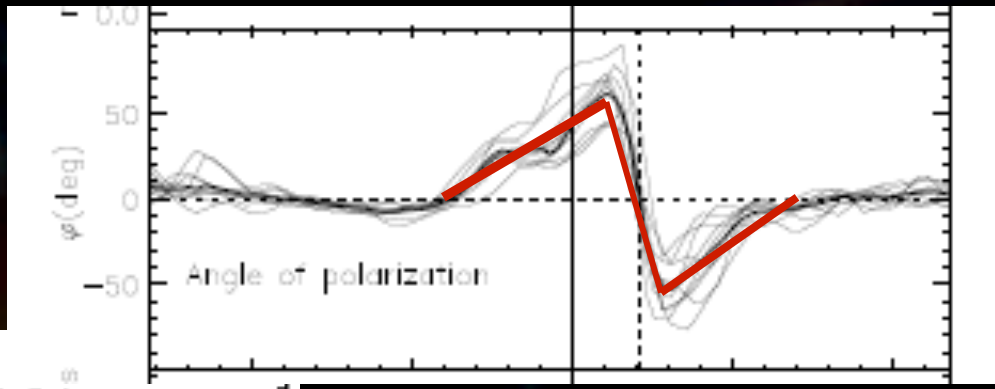
$$a = o.5\log(\frac{GM_{BH}}{c^2 R_{SC}})$$

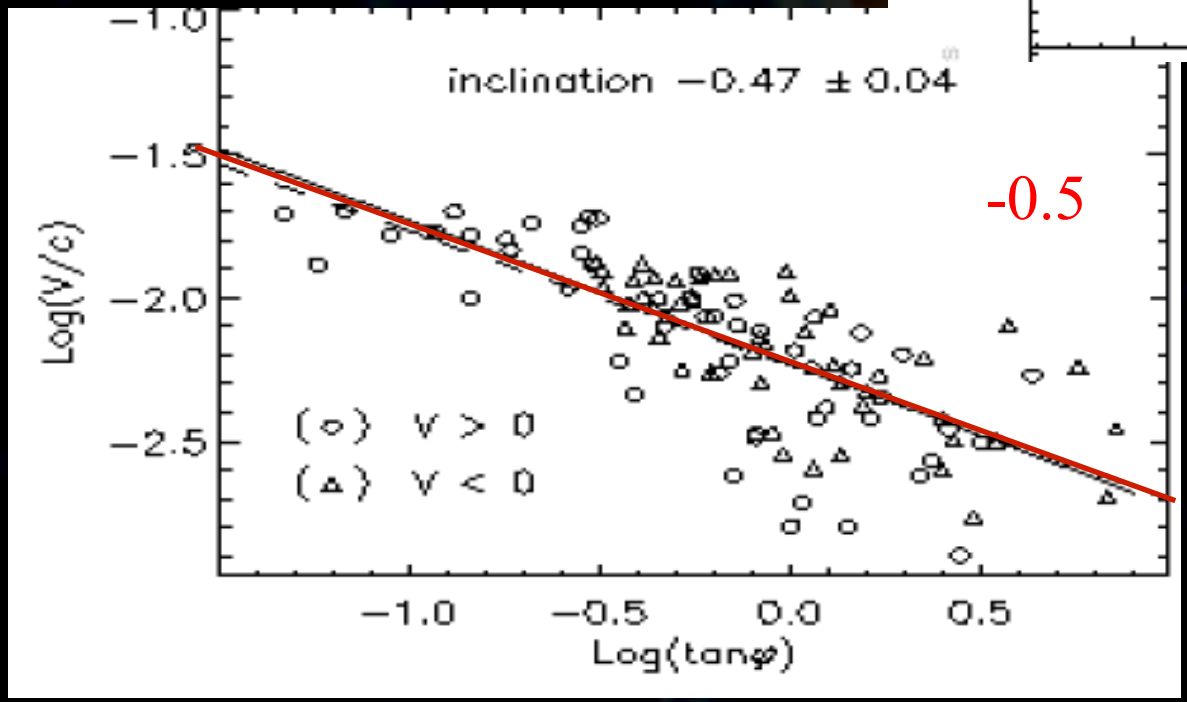




V vs. tan(φ) – direct evidence of Keplerian motion in the BLR of Mrk 6

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

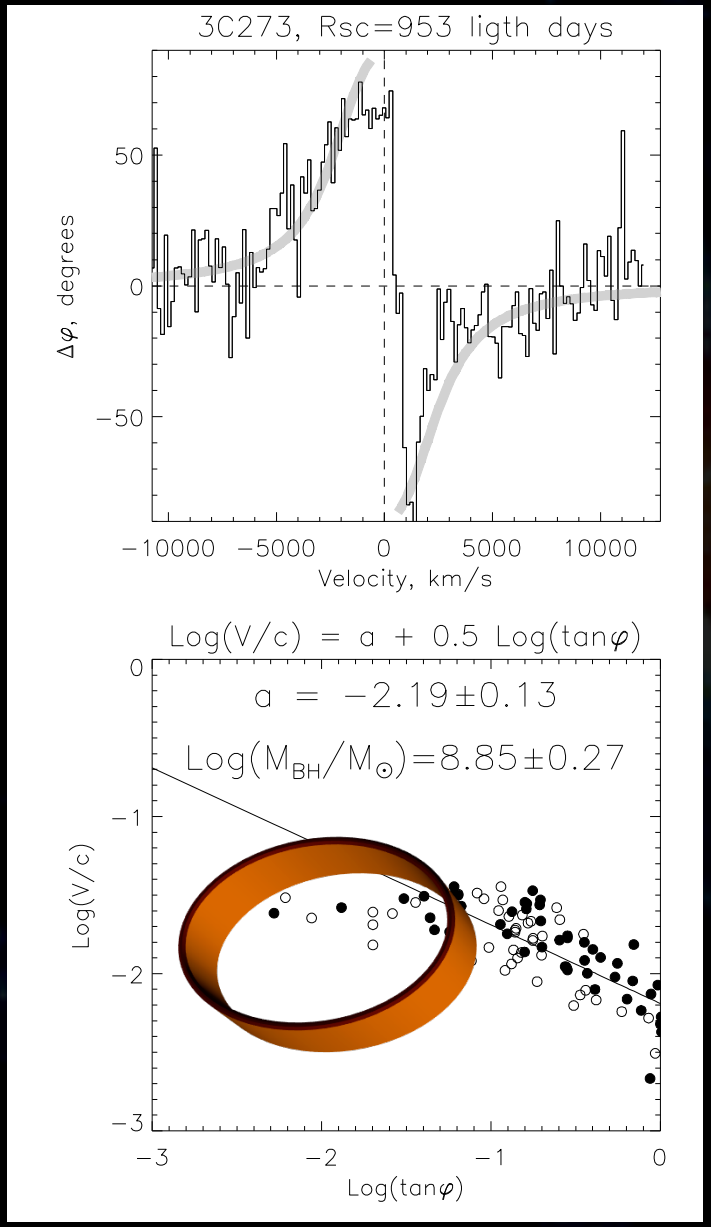


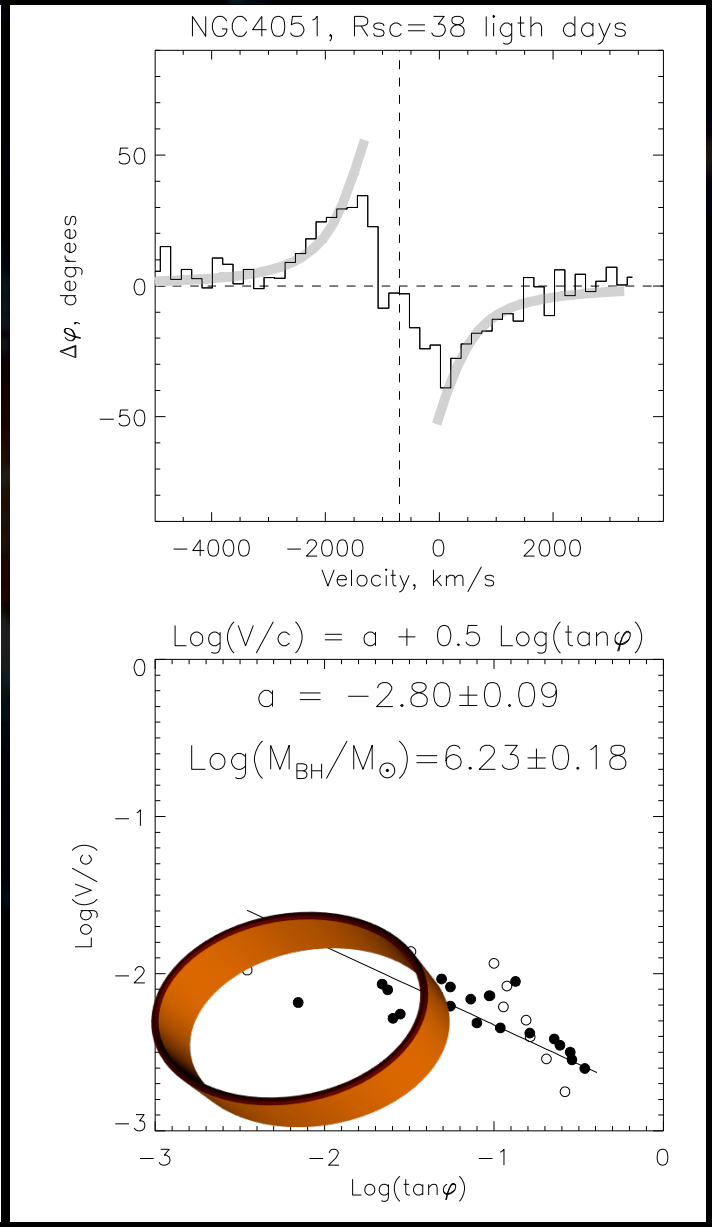


-0.5

Afanasiev et al. 2014
Afanasiev & Popovic 2015

Observed P.A, Afanasiev & Popovic 2015

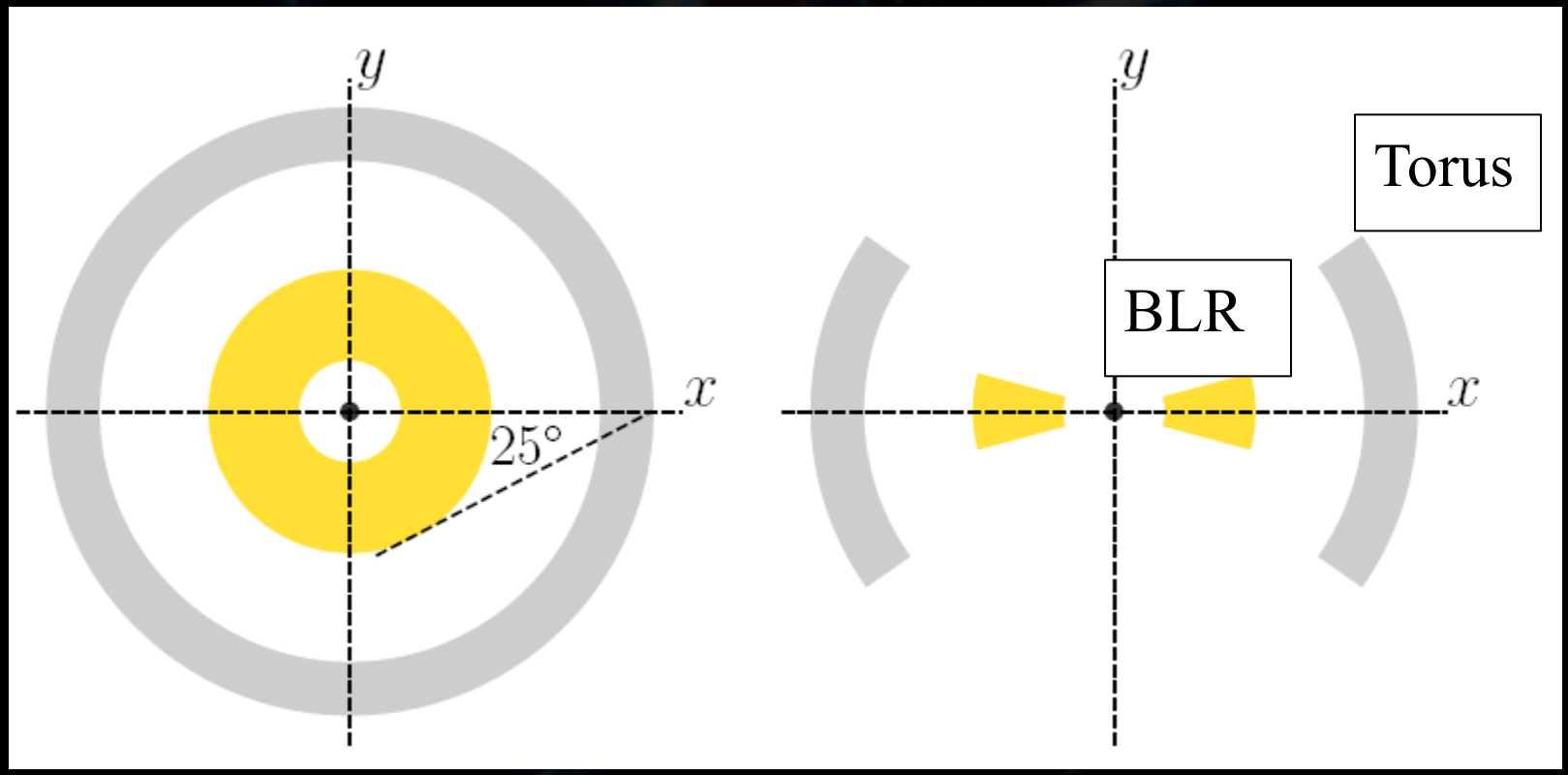




Theory vs. observations

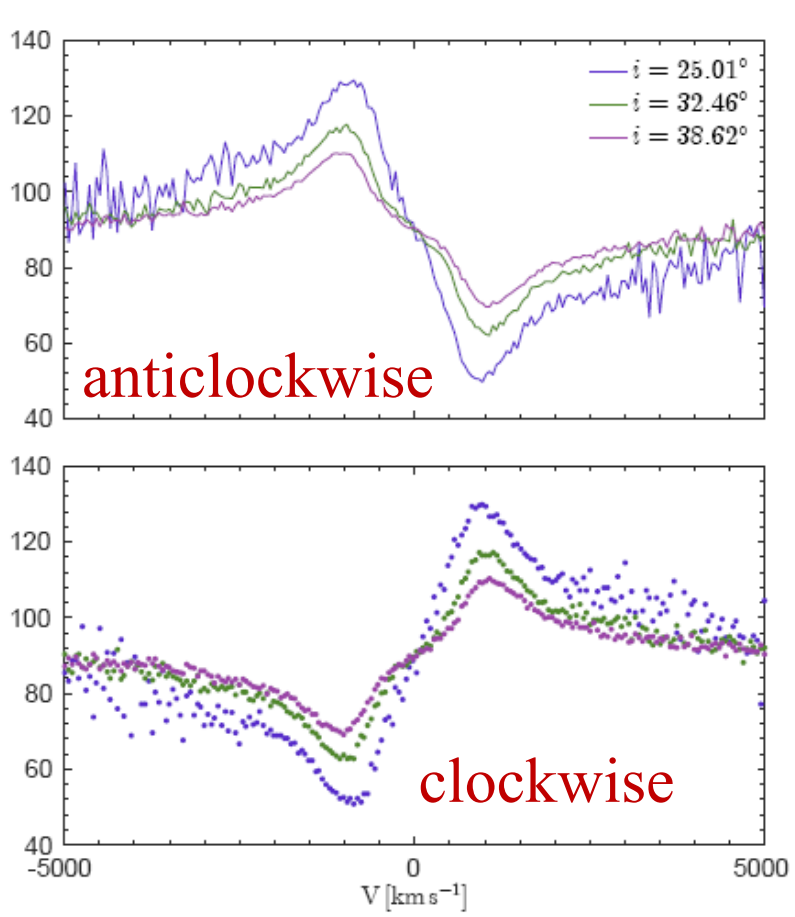
Model with STOKES code

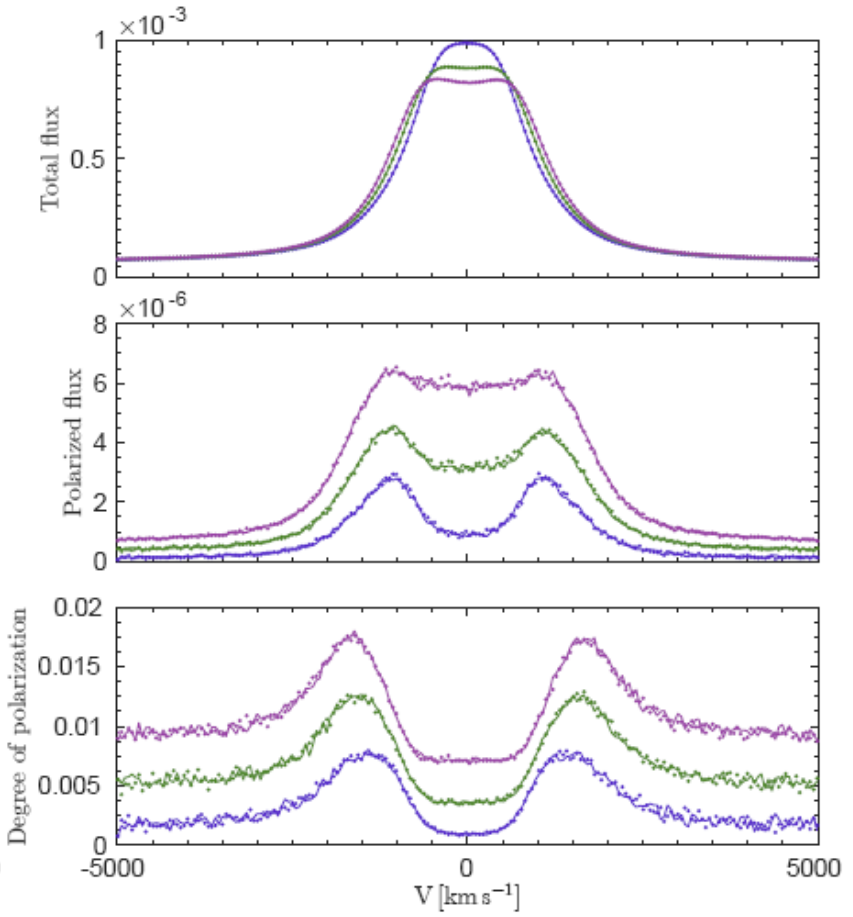
(Goosmann & Gaskell 2007, Marin et al. 2012, etc),
Savic et al. 2018, A&A, 614, 120



Theory vs. Observations
(Savic et al. 2018)

Pure Keplerian motion

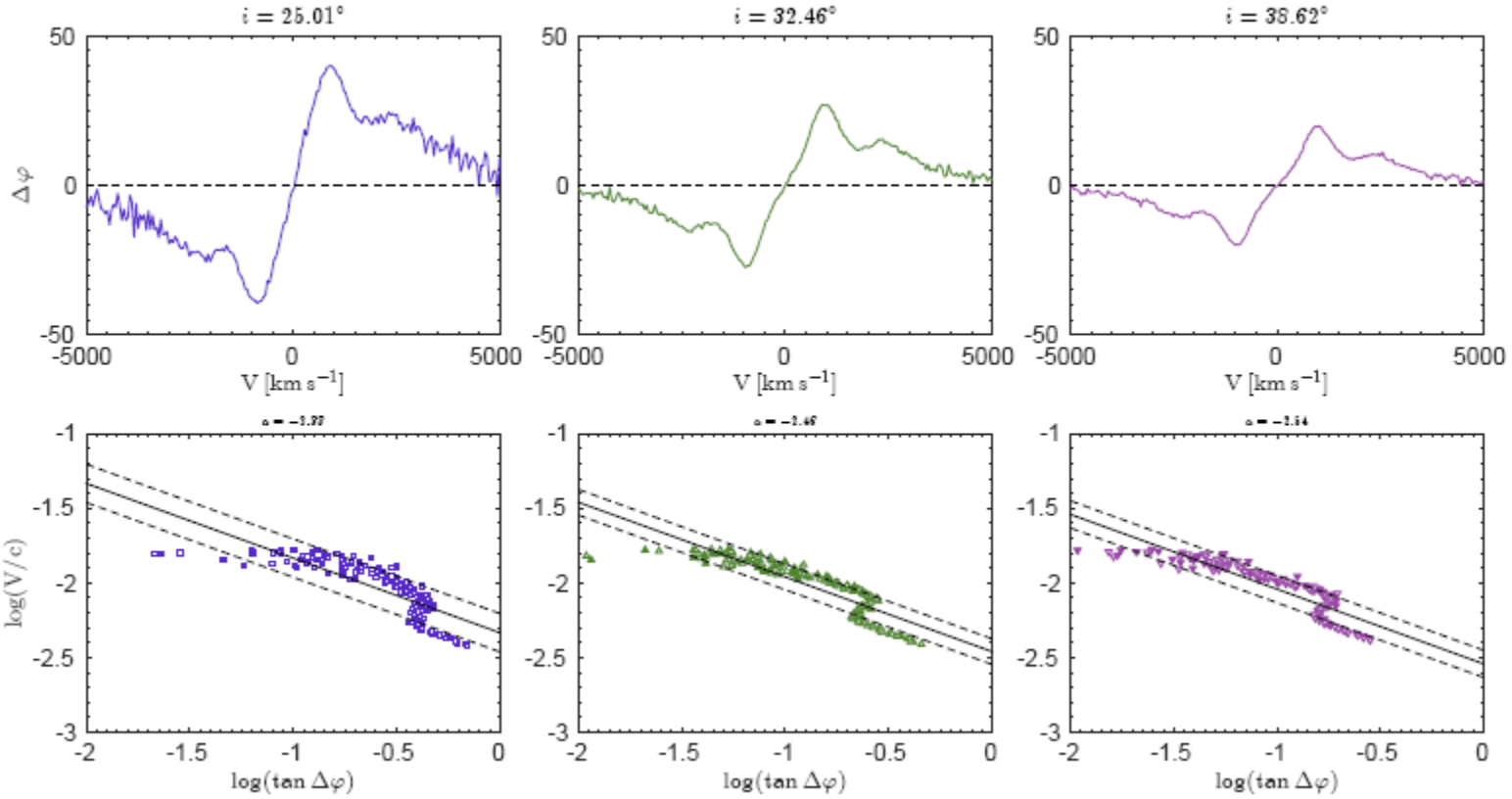




Theory vs. Observations

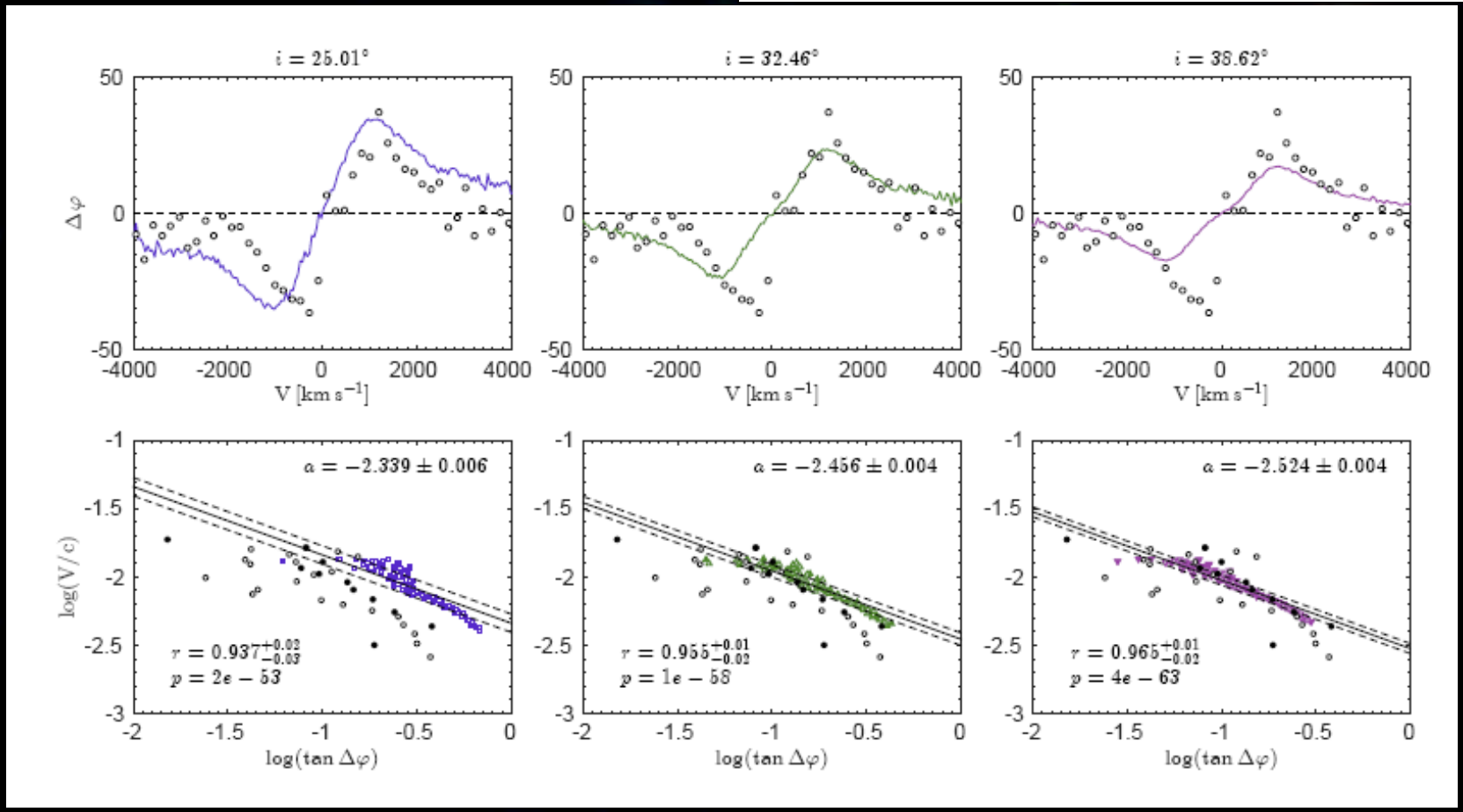
(Savic et al. 2018)

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, Popovic, Shapovalova 2019, MNRAS, 482, 4985

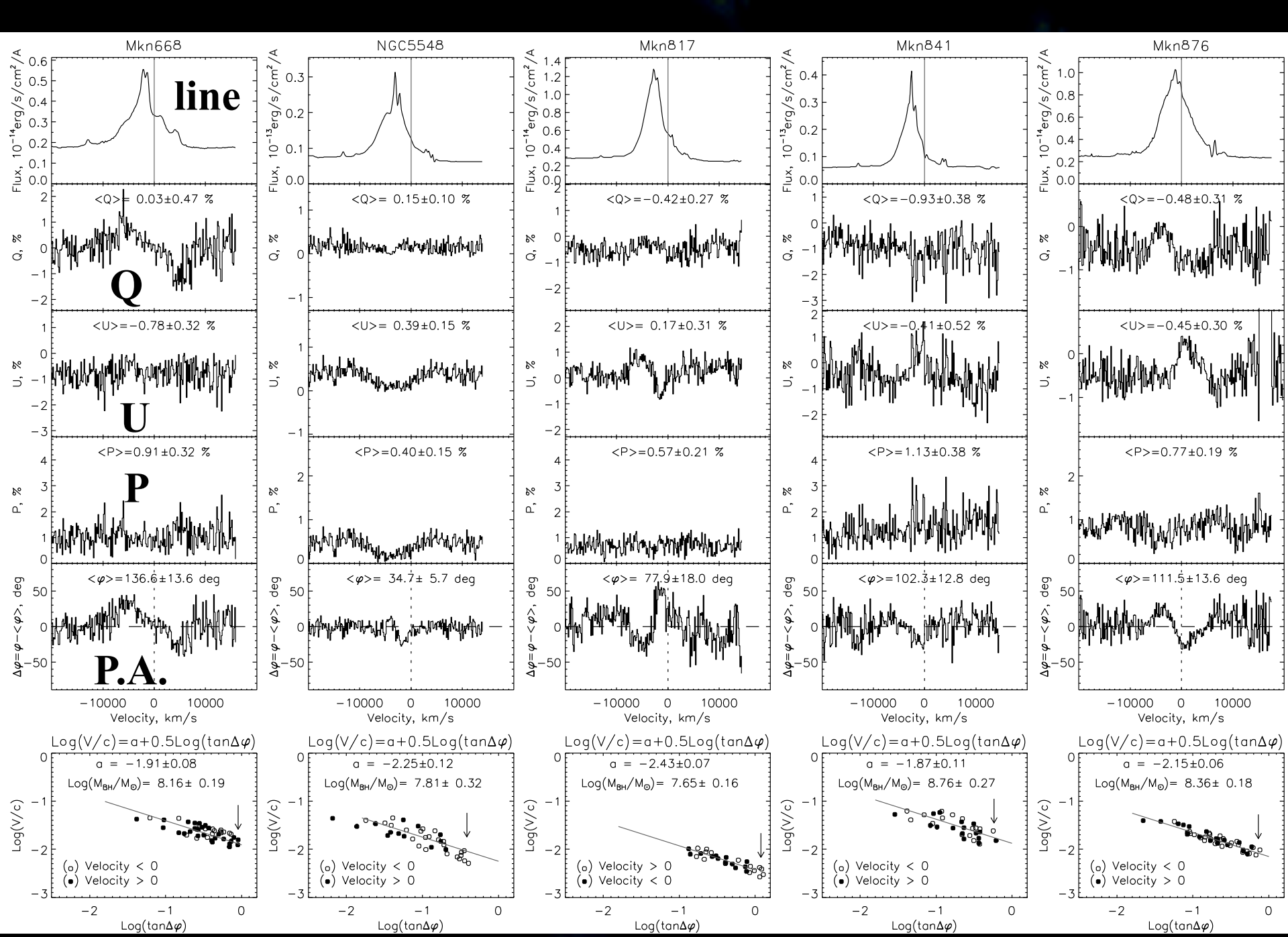
Observations with 6m telescope SAO RAS

6-m telescope + SCORPIO, spectral coverage 4000-8000 AA

Different type analyzer – Savart plate, Single and Double Wollaston prisms

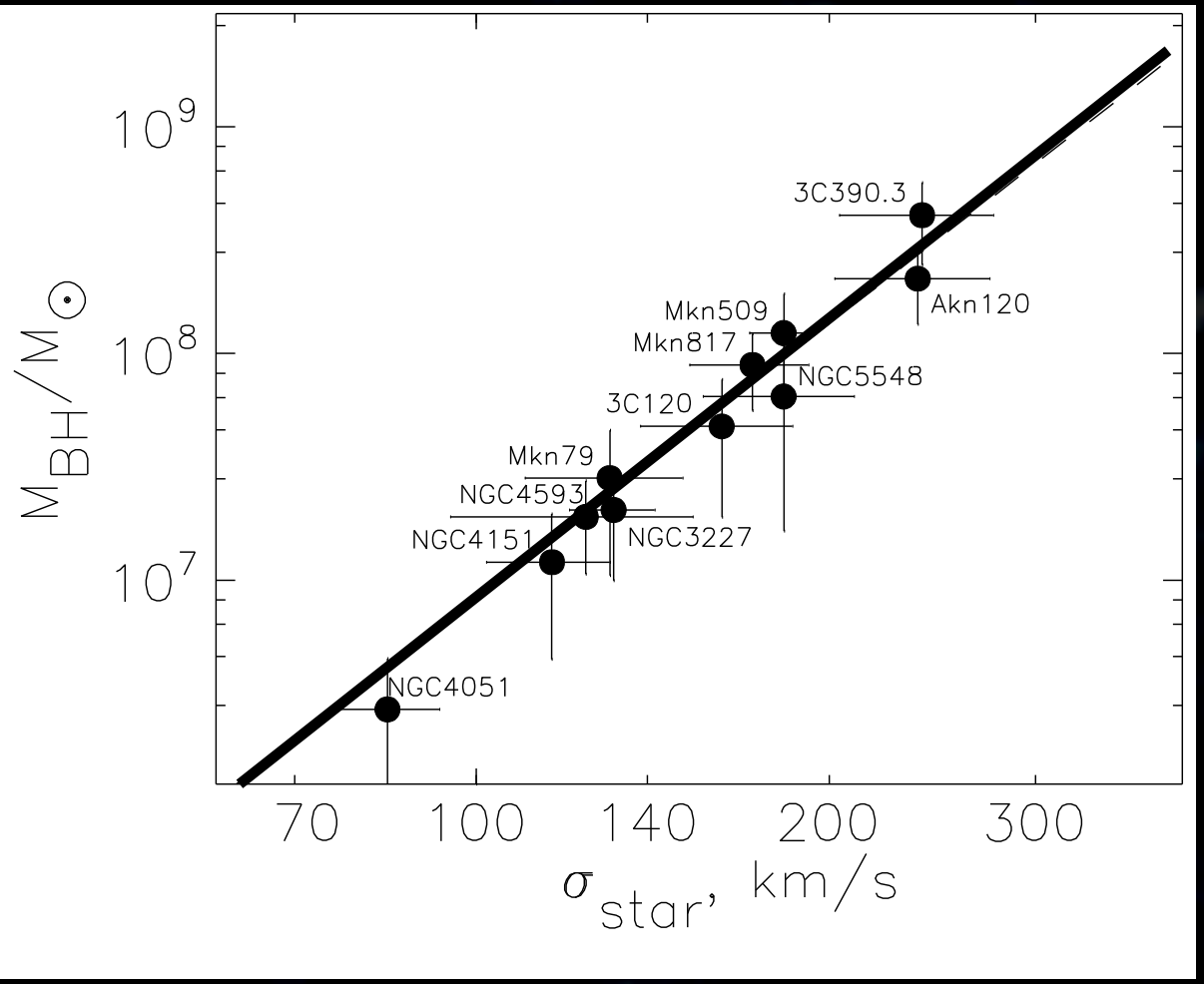
Spectral resolution 5-40AA,

Polarization measurement accuracy ~ 0.1-0.3%


Mkn668
NGC5548
Mkn817
Mkn841
Mkn876
line
Q
U
P
P.A.
Flux, 10^-14erg/s/cm^2/A
Flux, 10^-13erg/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
(o) Velocity < 0
(•) Velocity > 0
(o) Velocity > 0
(•) Velocity < 0
Log(V/c)
Log(tanΔφ)

Black hole masses for 30 Type 1 AGNs

Afanasiev et al. 2019



Our measurements of BH masses for 11 AGNs as a function of host galaxy bulge stellar velocity dispersion *(from Onken et* al. 2004).

Solid line is M-σ from Tremaine et al (2002).

Estimate BLR inclination for 30 Type 1 AGNs

Afanasiev et al. 2019

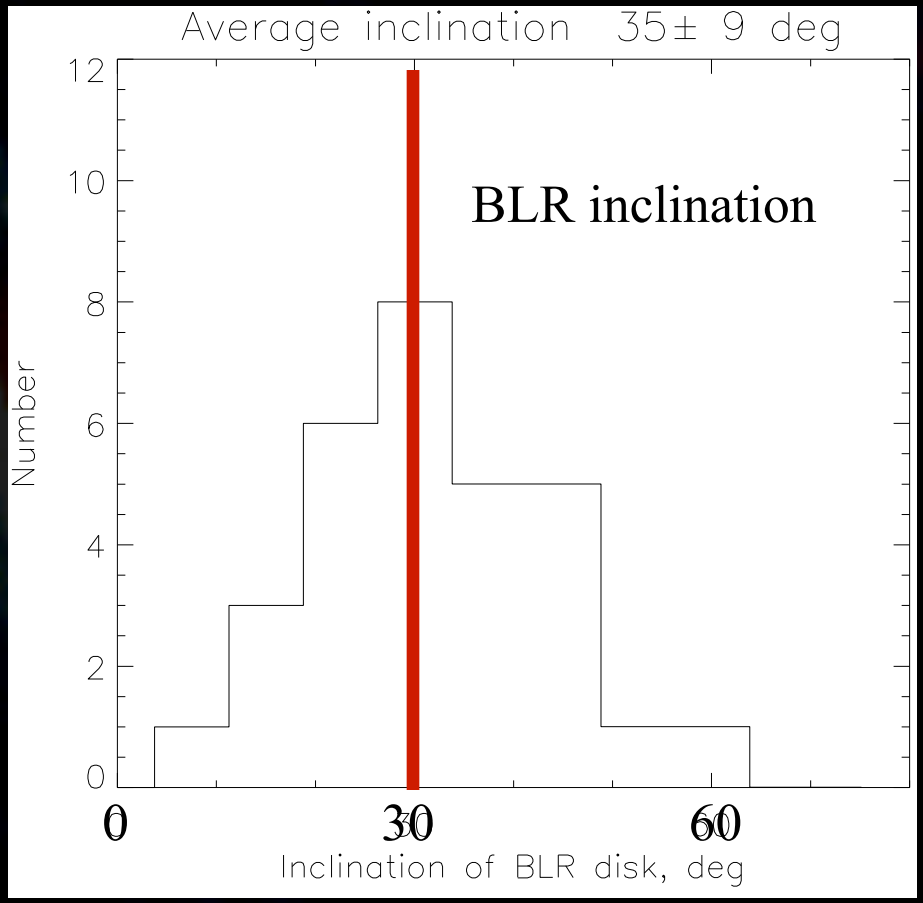
$$M_{BH} = f\frac{R_{BLR}\sigma_V^2}{G} = f * VP$$

$$\sigma_V = \sigma_V^{obs}\sin(i)$$

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

$$Keplerian => f' = 1$$

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

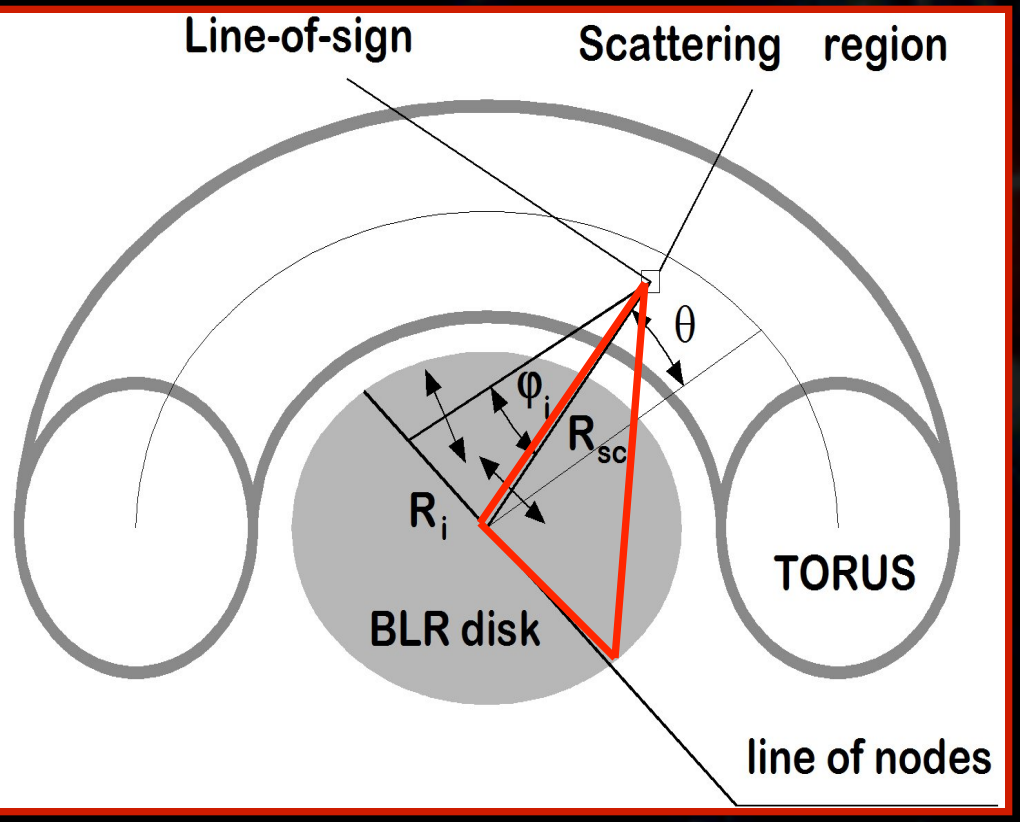


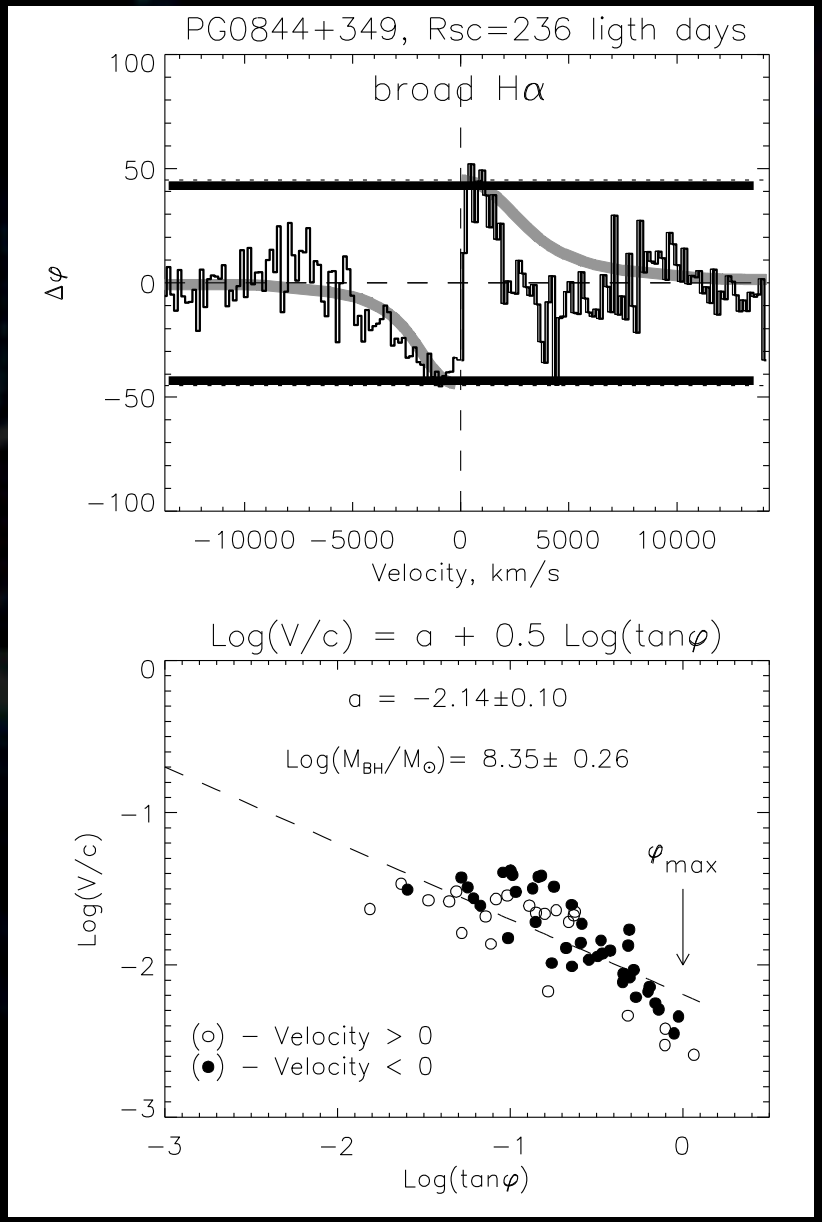
Our measurements of SMBH masses do not depend on inclination (see Afanasiev & Popovic 2015)

Keplerian motion=>assumption that *f* depends only from BLR inclination!

Dimensions of the BLR

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



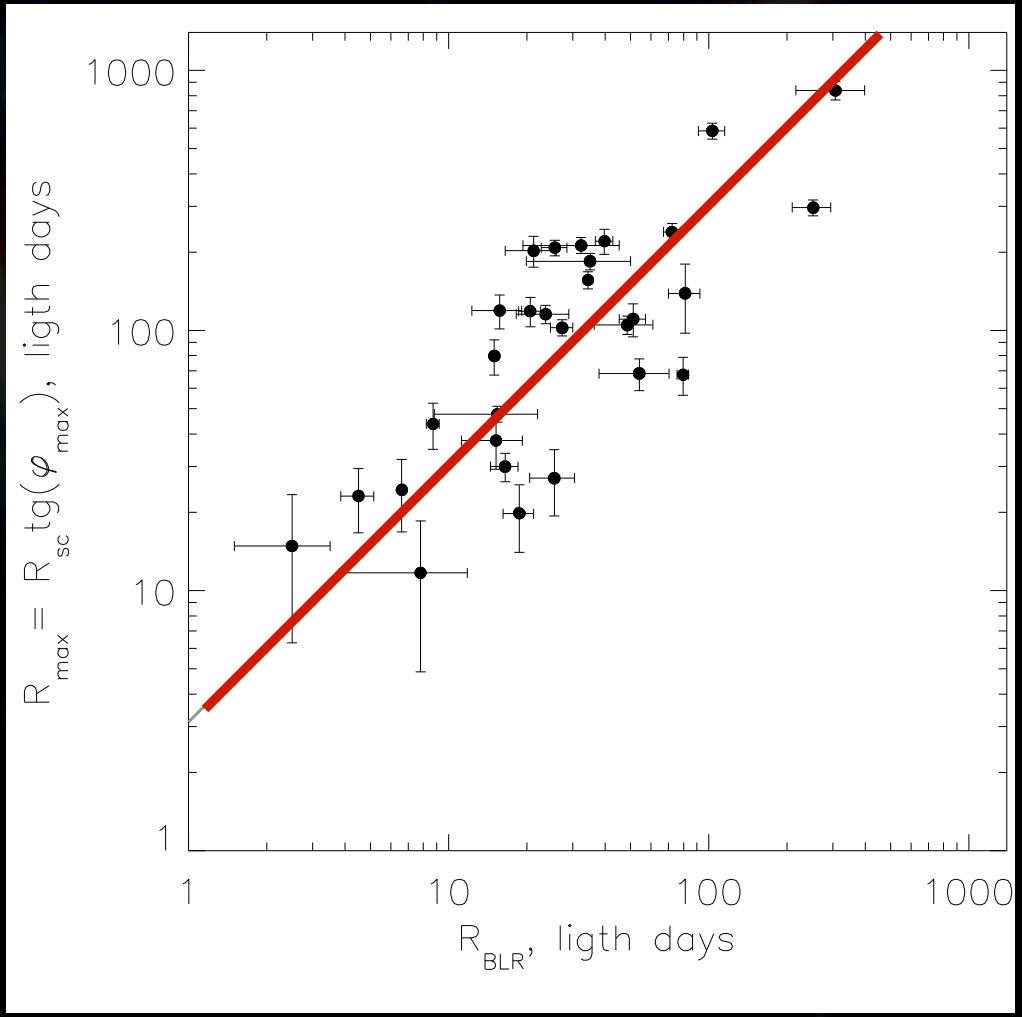


Dimensions of the BLR
Afanasiev et el. 2019

The maximal (Rmax) vs photometric BLR (R_{BLR}) radius. The solid line represents the best fit
$R_{BLR} = (0.31 \pm 0.17)\ Rmax$

Relation between
Rsc and R_{BLR}
$Rsc = (1.72 \pm 0.48)\ R_{max}$

.

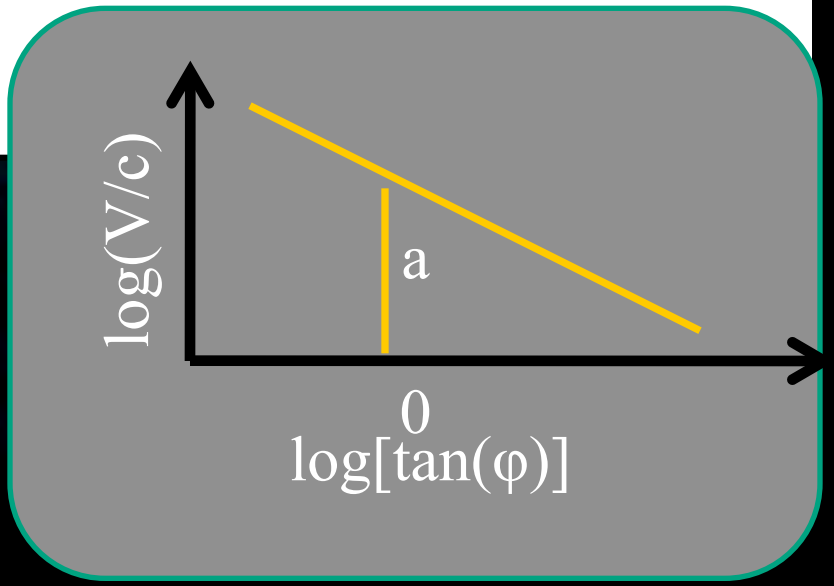


$$\log(v_i) = a - b\log(\tan(\varphi_i)),$$

$$b = 0.5$$

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

PROBLEM No1:
Measuring the radius of scattering region

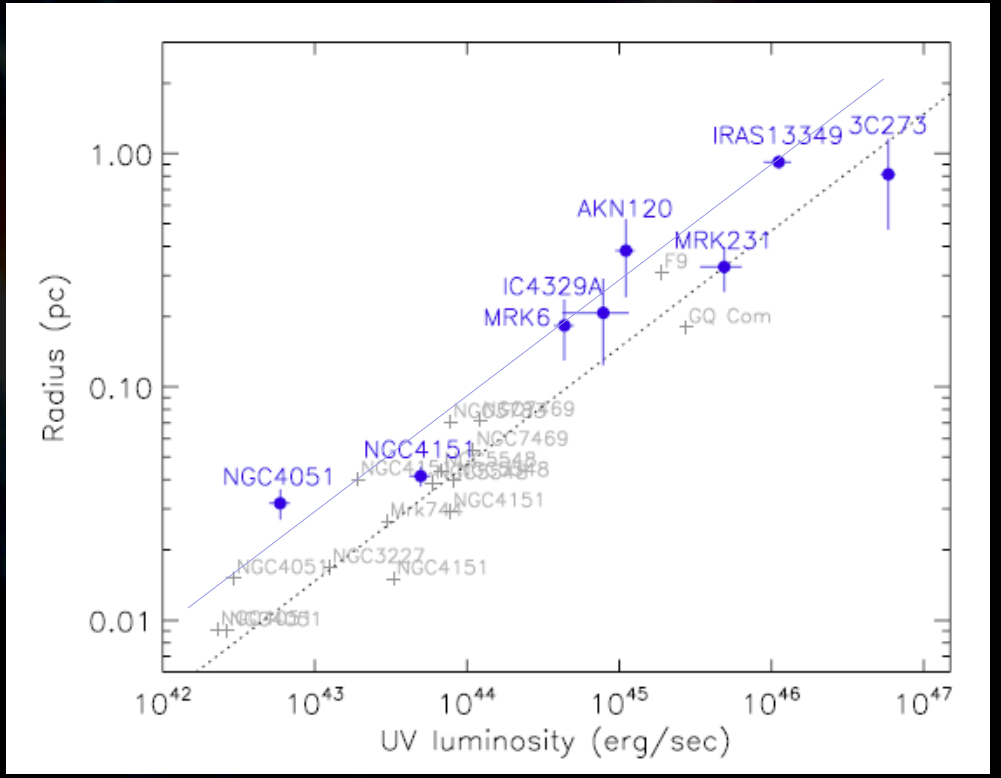


Estimation size Rsc of the dusty torus

Yesterday talks:
Direct measurement from the near IR (2-3 mikrons)
Delay in variability btw. K and V-band.
or
using relations

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

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



Dust sublimation region in AGN => reverberation in broad line polarization

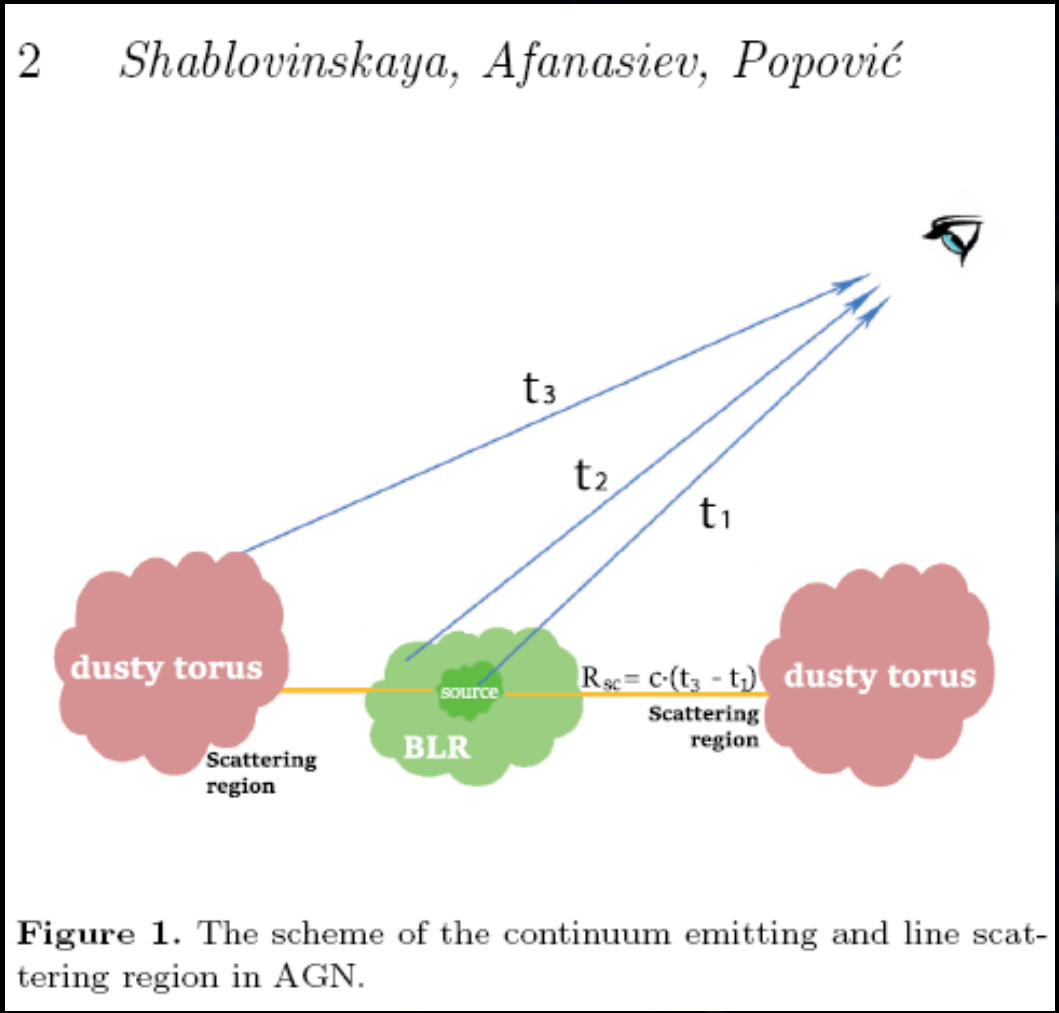


Figure 1. The scheme of the continuum emitting and line scattering region in AGN.

$$R_{\mathrm{BLR}} = c\Delta\tau_{12} = c\cdot(t_2 - t_1)$$

$$R_{\mathrm{SC}} = c\Delta\tau_{13} = c\cdot(t_3 - t_1)$$

Shablovinskaya et al. 2019, will be sent in a couple days

An example of Mrk 6 (Shablovinskaya et al. 2019)

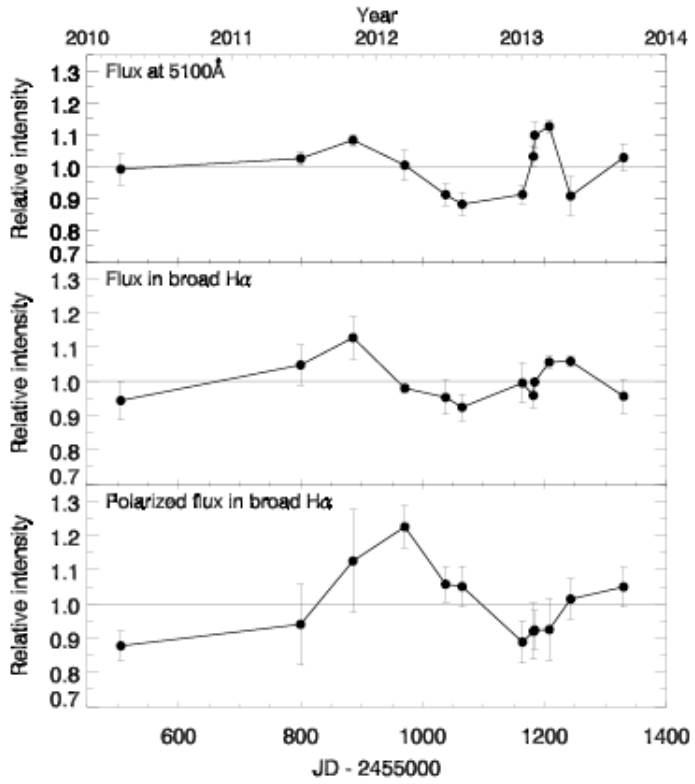
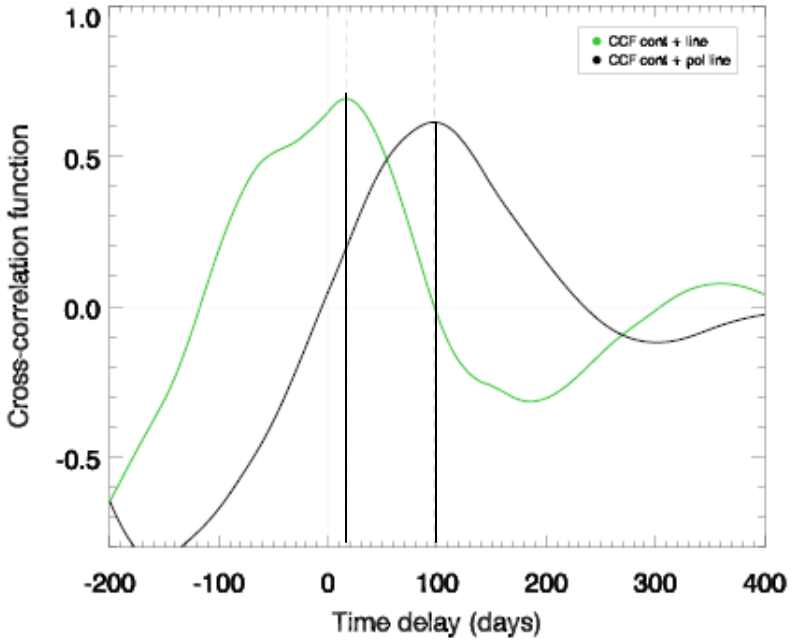


Figure 2. The light curves of Sy 1.5 Mrk 6: The total flux in continuum at 5100Å (upper panel), the total flux in H_α emission line (middle panel) and the polarized flux in H_α emission line (bottom panel).



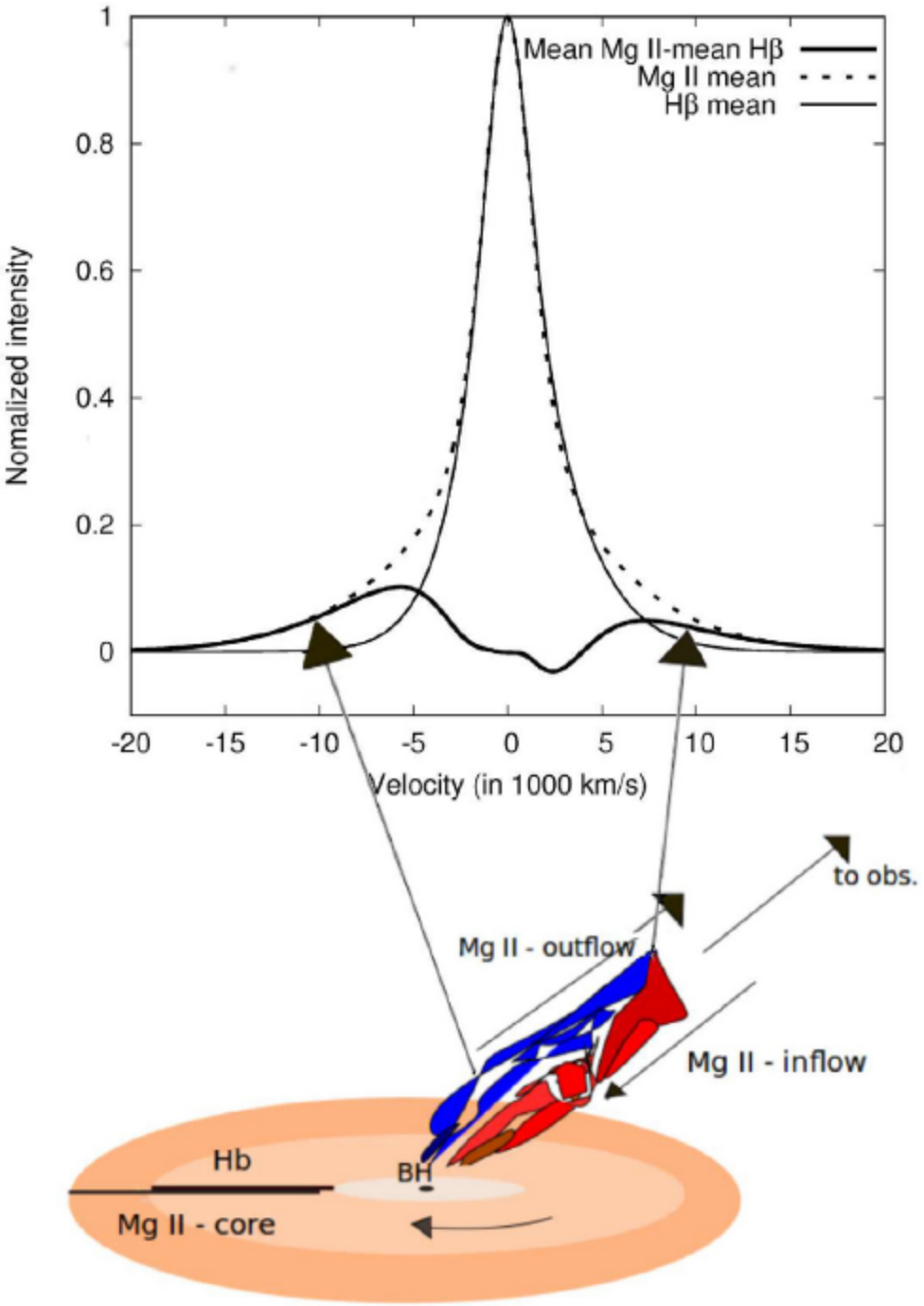
CCF time lags

R_{BLR}= 13.0 ± 6.4 l.d.

Rsc= 94.7±6.9 l.d.

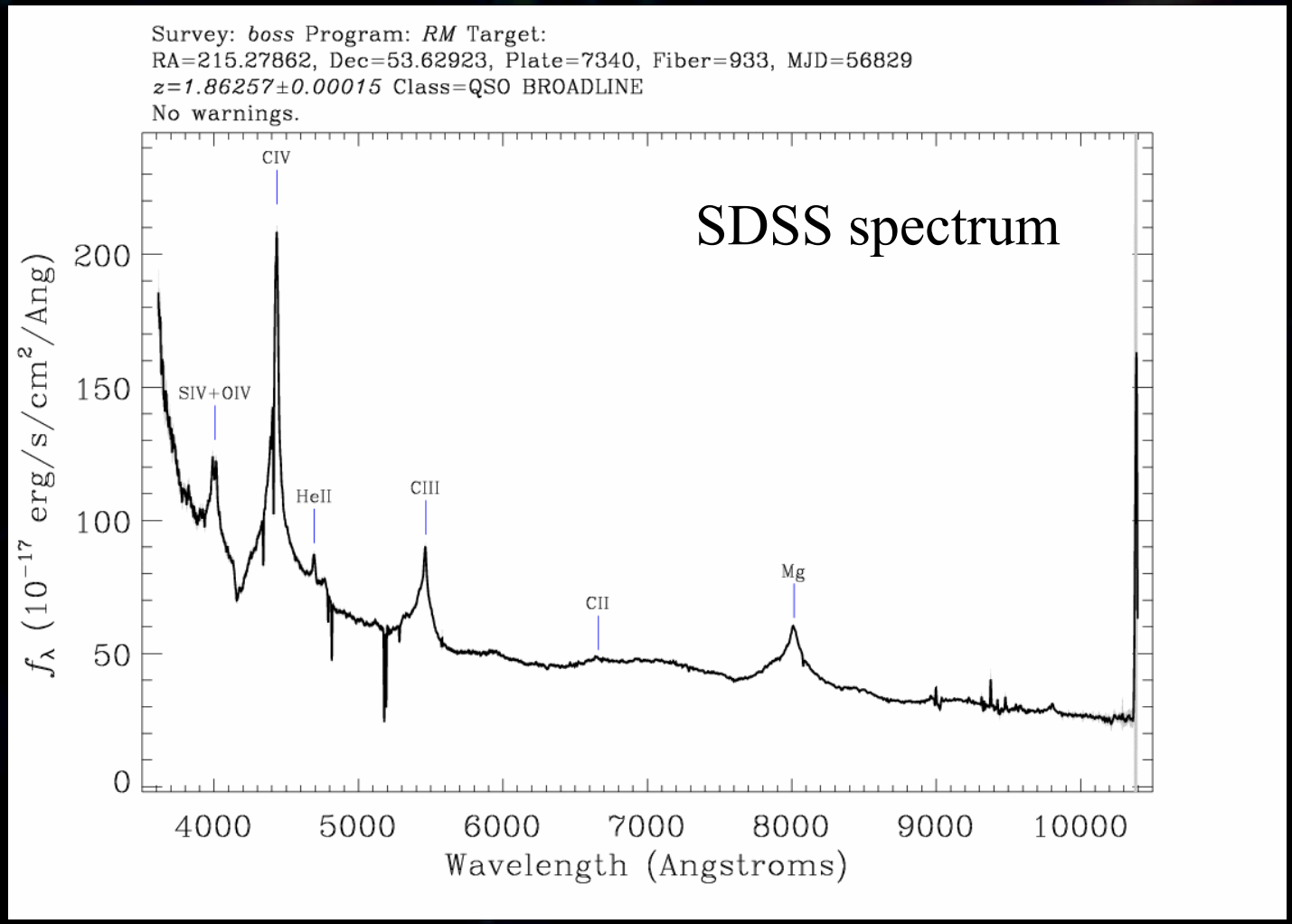
Keplerian motion + outflow/inflow (e.g. Mg II, see Popovic et al. 2019, MNRAS, 484, 3180)

PROBLEM No2: Outflows/inflows



The same method for Mg II line
Savic et al. 2019, in progress

SBS 1419+538 at redshift z = 1.862



The same method for Mg II line

Savic et al. 2019, in progress

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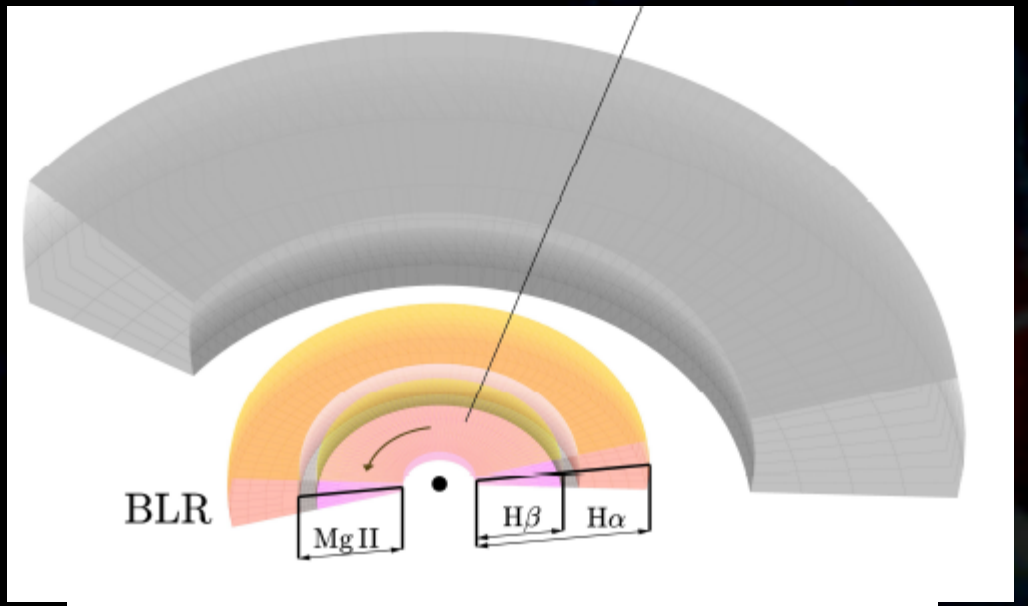
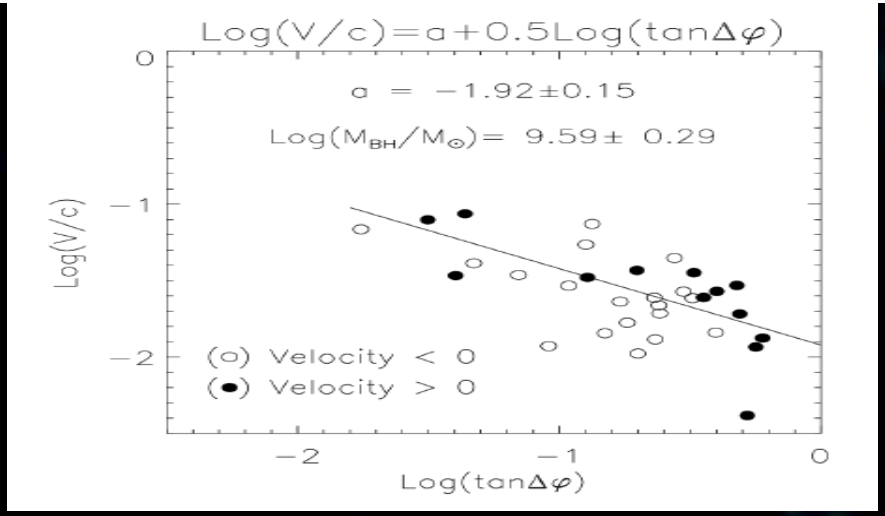
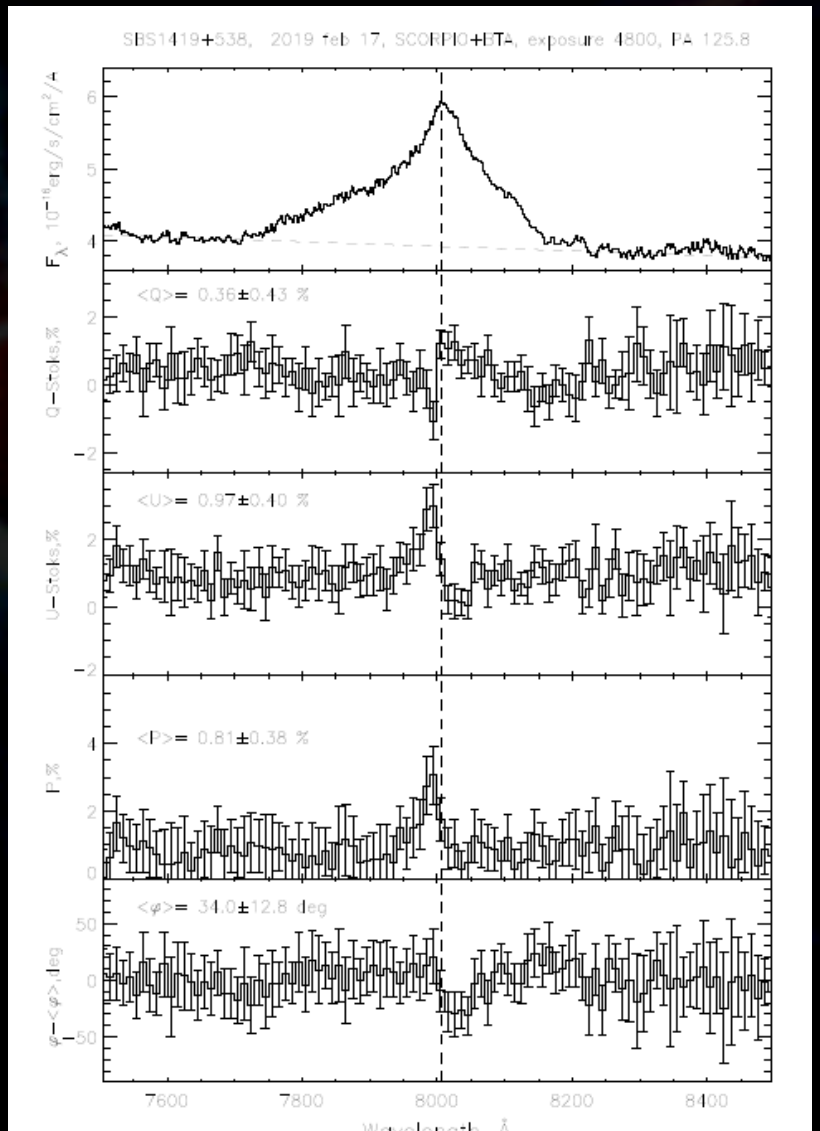
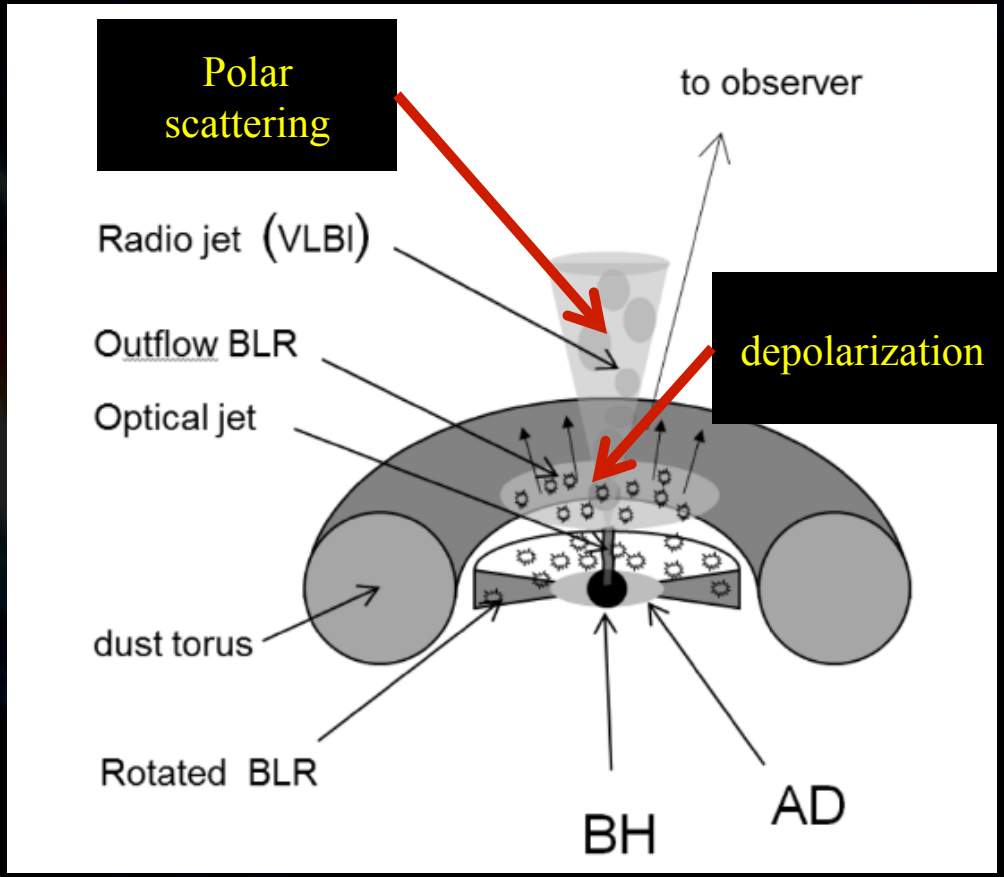






The case of 3C390.3 (Afanasiev et al. 2015)



PROBLEM No3:
Depolarization/polar scattering

Conclusions

- Equatorial polarization in Type 1 AGNs seems to be dominant
- Keplerian motion in BLR is dominant, outflows can affect PA shape, but it still be used for SMBH mass estimates
- Polarization in broad lines => BLR inclination, dimensions, torus dimesions

Thank you for your attention

Observations

continuum

continuum and line