Modeling the broad emission line polarization in active galactic nuclei

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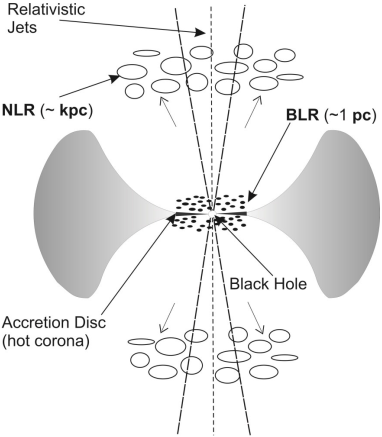
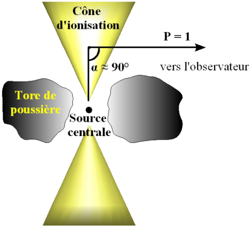
Unified model

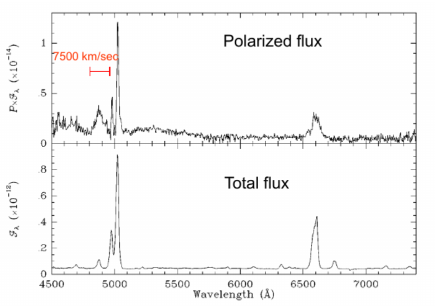


- BLR is not obscured - type 1 objects, broad + narrow emission lines
- BLR is obscured - type 2 objects, only narrow emission lines

Observations in polarization

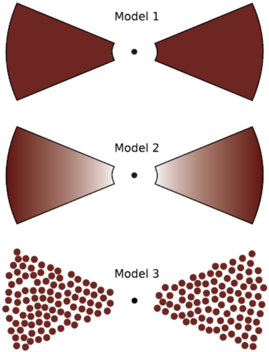
- A major break-through for the unified model for NGC 1068 (Antonucci & Miller 1985)
- A periscope view of AGN in polarized flux





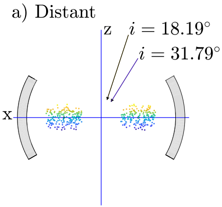
The importance of polarization

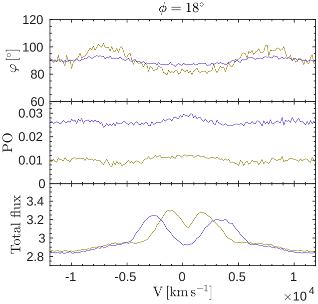
- Insight to the innermost parts of the central engine
- Sensitive to geometry and kinematics (Marin et al. 2012,2015,2018)
- Time lag studies (Rojas et al. 2018)



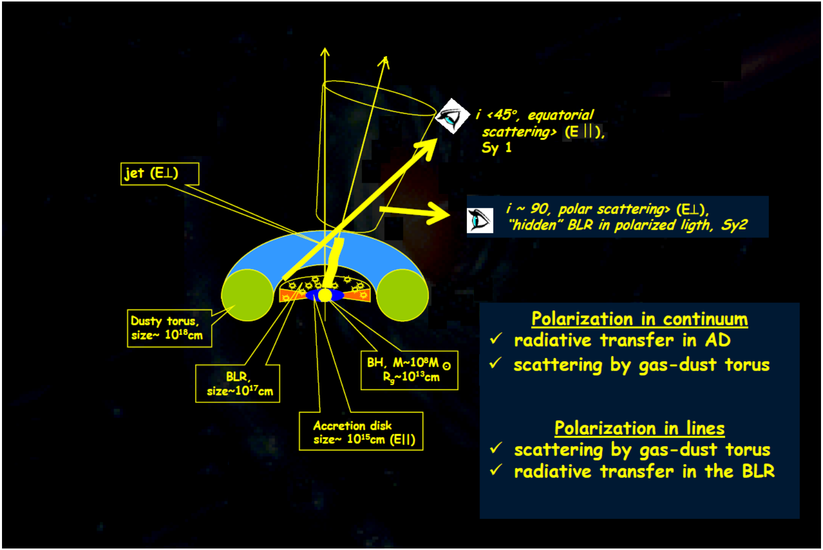
The importance of polarization

- Supermassive binary black holes signiture (Savic et al. 2018)
- Unique polarization angle profiles





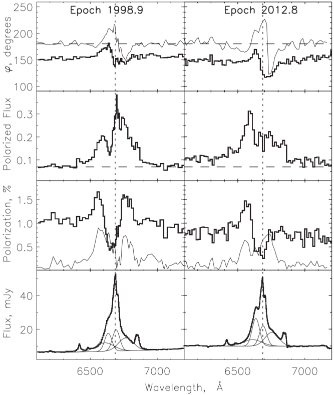
Parallel and orthogonal polarization

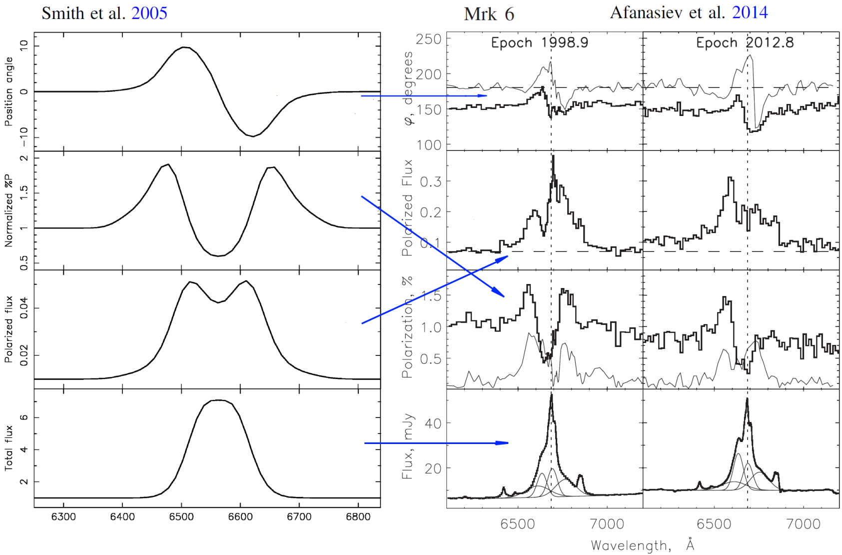


Polarization in type 1s

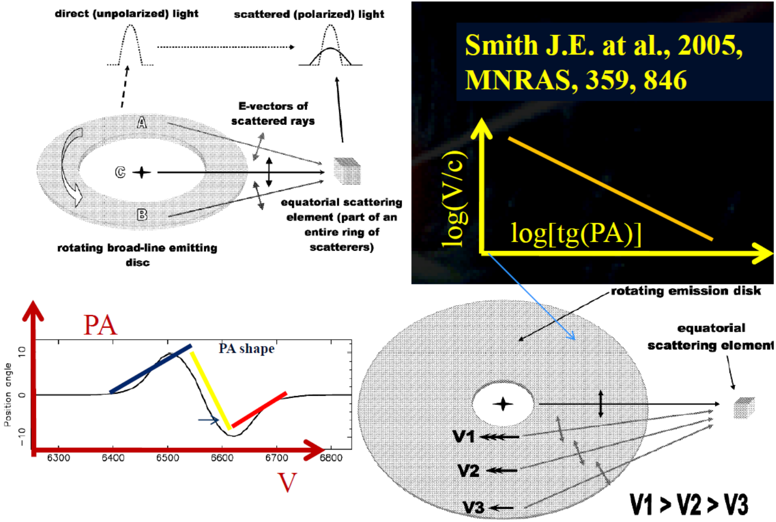
- Polarization position angle (PA) rotation as evidence for equatorial scattering in type 1s
- Disk-like BLR with Keplerian motion
- Co-planar scattering region
- Weak polarization, typically few percents

Mrk 6 (Afanasiev et al. 2014)



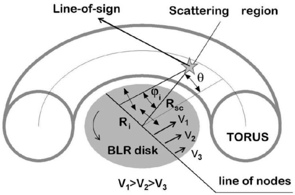

Smith et al. 2005
Mrk 6
Afanasiev et al. 2014
Epoch 1998.9
Epoch 2012.8
Position angle
Normalized %P
Polarized flux
Total flux
φ, degrees
Polarized Flux
Polarization, %
Flux, mJy
Wavelength, Å

Polarization of broad lines in type 1s



Method for determining SMBH masses

- Afanasiev & Popovic (2015).

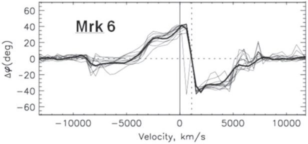


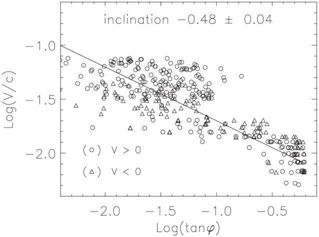
$$V_i = V_i^{rot}\cos(\theta) = \sqrt{\frac{GM_{BH}}{R_i}}\cos(\theta), \quad R_i = R_{sc}\tan(\varphi_i),$$

$$M_{BH-kep} = 10^{2a}\frac{c^2 R_{sc}}{G\cos^2(\theta)} = 1.78\times 10^{2a+10}\frac{R_{sc}}{\cos^2(\theta)} M_\odot,$$

$$\log\frac{V_i}{c} = a - 0.5\log(\tan(\varphi_i))$$

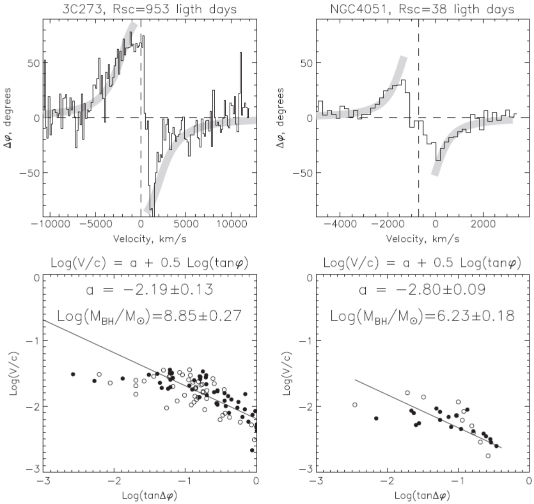
$$a = 0.5\log\frac{GM_{BH}\cos^2\theta}{c^2 R_{sc}}$$





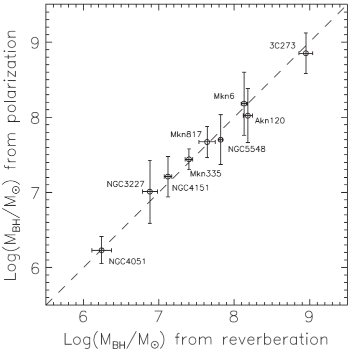
$$M_{BH-kep} = 1.53\times 10^8 M_\odot$$

Method for determining SMBH masses



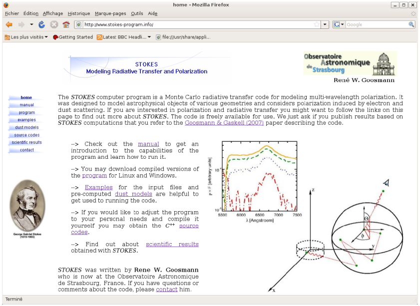
Method for determining SMBH masses

- Single epoch method.
- Good agreement with reverberation mapping method
- Single scattering approximation is well justified (Savic et al. 2018)
- BLR characteristics (Afanasiev et al. 2018)
- **Can be applied for lines in different spectral range**



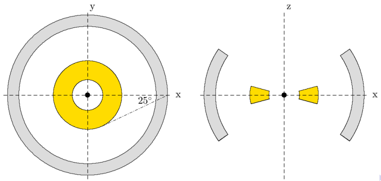
Modeling (scattering-induced) polarization with STOKES

- Full 3D MonteCarlo radiative transfer.
- Various geometries for the emission/scattering regions.
- Polarization due to (multi) electron scattering and dust (Mie) scattering.
- Goosmann & Gaskell (2007); Marin et al. (2012, 2015); Rojas et al. (2018)

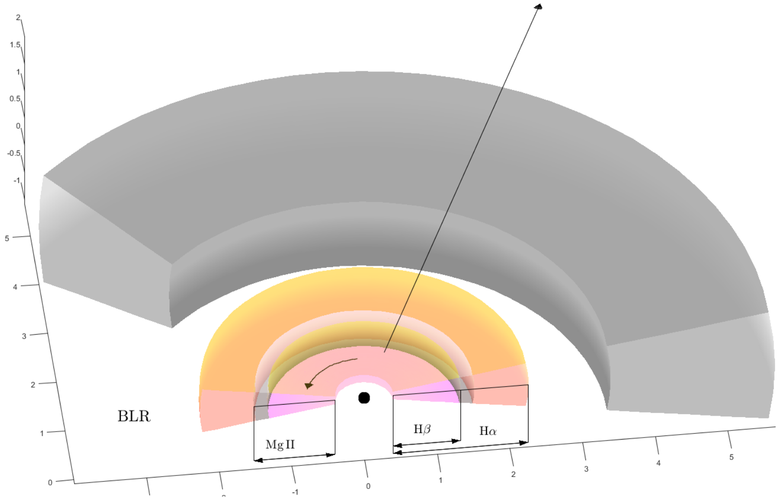


Modeling (scattering-induced) polarization with STOKES

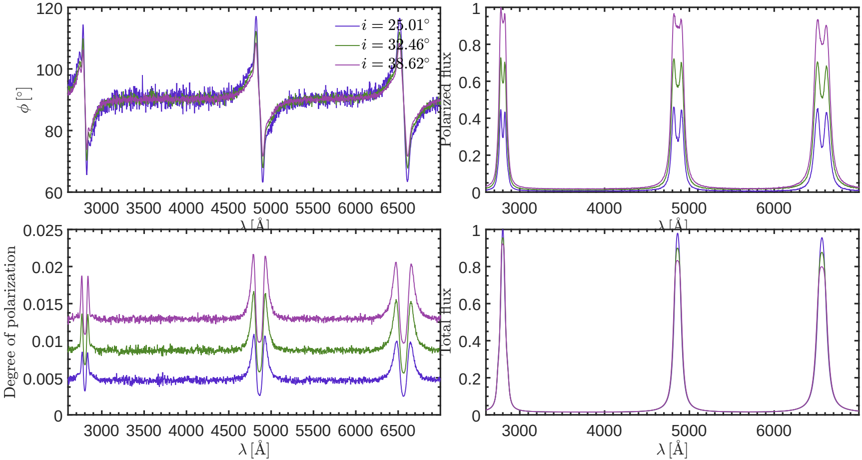
- Point-like source of isotropic continuum radiation, $F_\nu \propto \nu^{-2}$.
- Half opening angle of the BLR and SR are 15° and 35° respectively.
- Inner radius of the BLR from reverberation (Peterson et al. 2004, Kaspi et al. 2005, Bentz et al. 2006).
- Outer radius of the BLR-a due to dust sublimation $R_{\mathrm{out}}^{\mathrm{BLR}} = 0.2 L_{\mathrm{bol},46}^{0.5}$. Bolometric correction from Runnoe et al. (2012).
- Inner radius of the SR from dust reverberation (Kishimoto et al. 2011, Koshida et al. 2014).
- Simultaneous Hα, Hβ and Mg II emission
- **Fountain-like emission of Mg II (Popovic et al. 2019)**



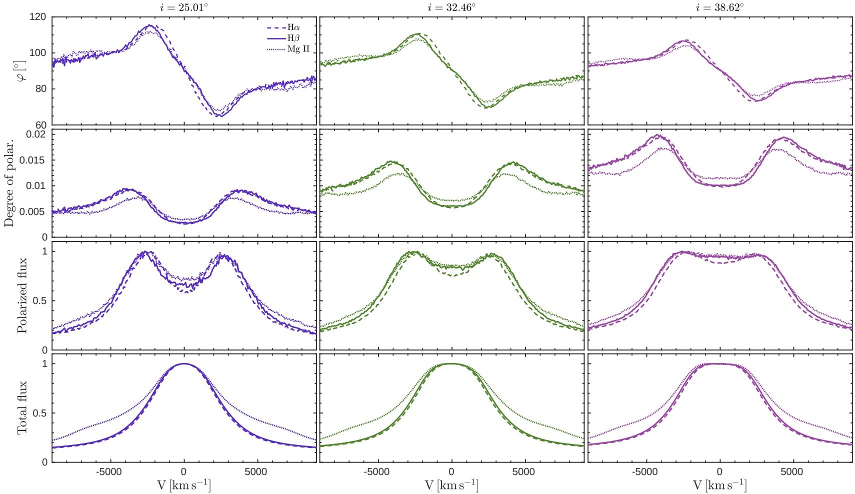
Modeling (scattering-induced) polarization with STOKES



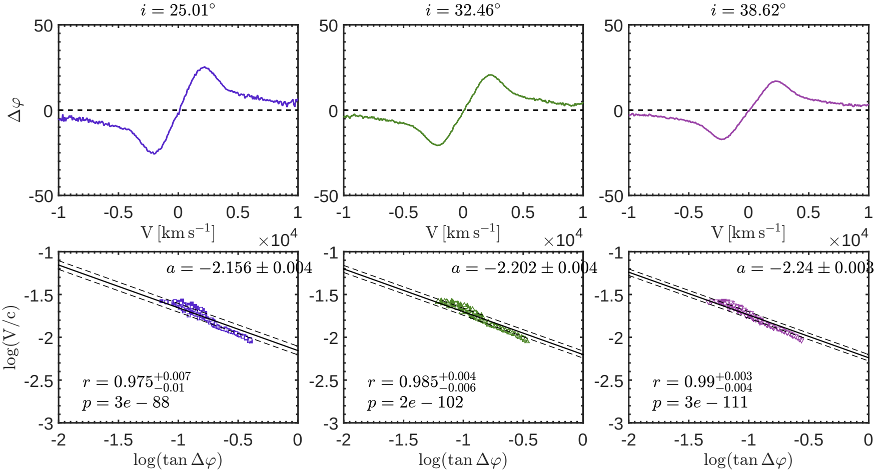
Modeling (scattering-induced) polarization with STOKES



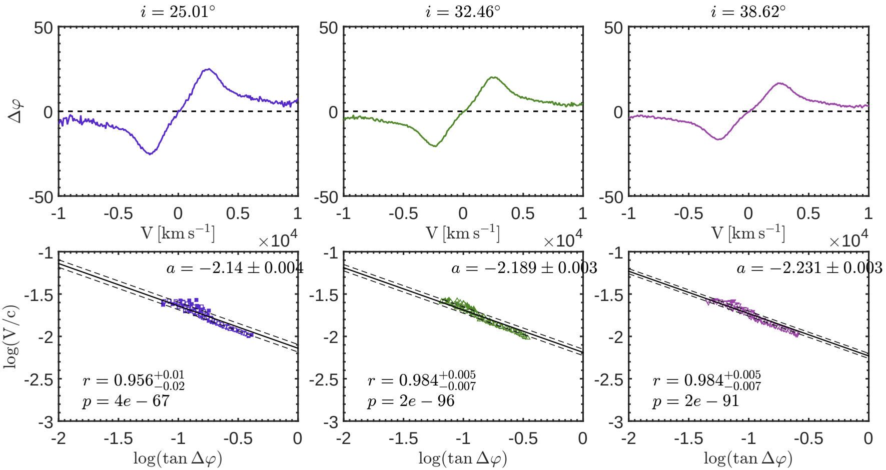
Modeling (scattering-induced) polarization with STOKES

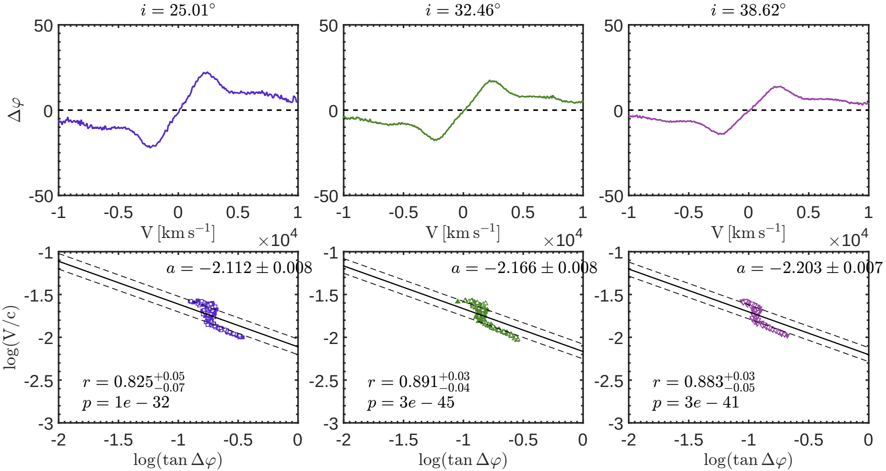


SMBH mass estimates - Hα



SMBH mass estimates - Hβ



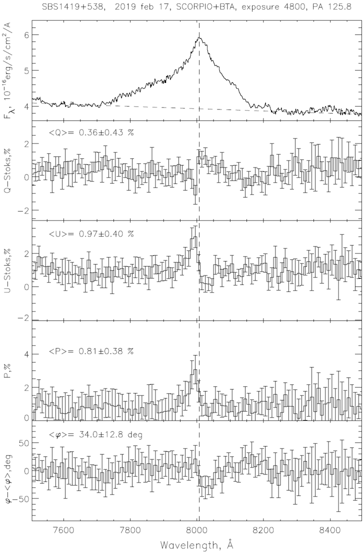


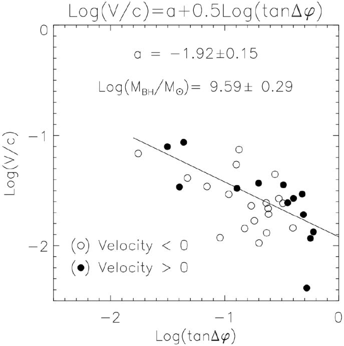
$i = 25.01°$
$i = 32.46°$
$i = 38.62°$
$\Delta\varphi$
V [km s^{-1}]
$\times 10^4$
$a = -2.112 \pm 0.008$
$r = 0.825^{+0.05}_{-0.07}$
$p = 1e - 32$
$a = -2.166 \pm 0.008$
$r = 0.891^{+0.03}_{-0.04}$
$p = 3e - 45$
$a = -2.203 \pm 0.007$
$r = 0.883^{+0.03}_{-0.05}$
$p = 3e - 41$
log(V/c)
log(tan $\Delta\varphi$)

Observations

- SDSS quasar SBS 1419+538 ($z = 1.862$)
- Spectropolarimetry with 6 m telescope of SAO RAS using modified version of the SCORPIO spectrograph (see Afanasiev & Moiseev 2005, 2011).
- Polarization parameters correction for the interstellar polarization Afanasiev & Amirkhanyan (2012)

SBS 1419+538


SBS1419+538, 2019 feb 17, SCORPIO+BTA, exposure 4800, PA 125.8
<Q>= 0.36±0.43 %
<U>= 0.97±0.40 %
<P>= 0.81±0.38 %
<φ>= 34.0±12.8 deg
F_λ, 10^-16 erg/s/cm²/A
Q−Stoks,%
U−Stoks,%
P,%
φ−<φ>,deg
Wavelength, Å


Log(V/c)=a+0.5Log(tanΔφ)
a = −1.92±0.15
Log(M_BH/M_⊙)= 9.59± 0.29
(○) Velocity < 0
(●) Velocity > 0
Log(V/c)
Log(tanΔφ)

Summary

- Simple model for radiative transfer
- Keplerian motion + outflows
- Error bars in observations are higher than those in the model
- Test the method for other broad lines C III] and C IV

Thank you for your attention