

SUPER-MASSIVE BINARY BLACK HOLE AND POLARIZATION IN THE BROAD LINES

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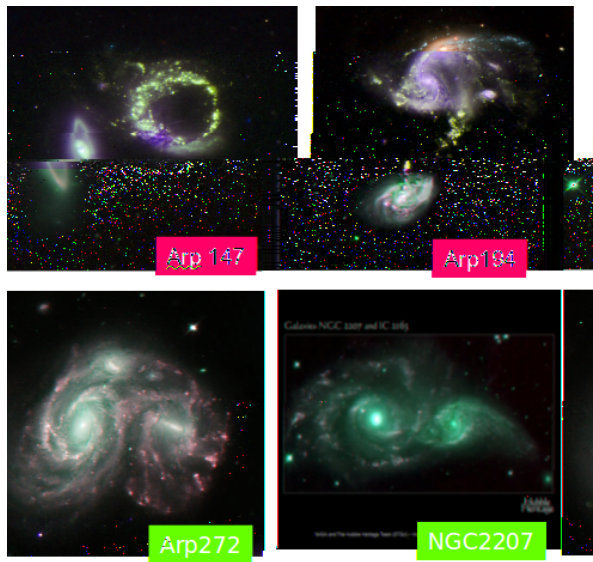


The search for SMBBHs

- Supermassive black holes (SMBH) at the center of massive galaxies
- Mass range $10^6 \{ 10^9 M_{\odot}$ (Kormendy & Richstone 1995)
- SMBHs play an important role in the co-evolution of the host galaxy (Kormendy & Ho 2013)
- Growth by accretion { slow process and cannot explain the most massive cases (Mayer et al. 2010)



Galaxy mergers

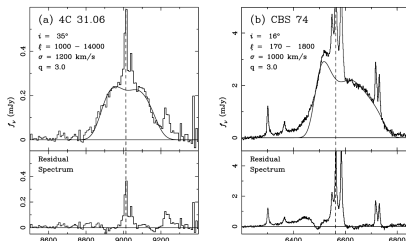


- Evolution of SMBH via mergers with other SMBHs (Volonteri et al. 2003a,b)
- Dynamical friction as a main process for bringing two SMBHs together (Begelman et al. 1980)
- The final parsec problem once the merging of the galaxies completes (Milosavljevic & Merritt)
- Growth by accretion { slow process and cannot explain the most massive cases (Mayer et al. 2010)
- Emission of gravitational waves



The search for SMBBHs

- It is hard to spatially resolve at pc-scale the central part of the nearest galaxies
- Double-peaked Balmer lines may be associated with binary systems (Eracleous & Halpern 2003)
- Significant number of AGNs show broad line profiles that could not be explained by "disk-like" profiles
- Strong asymmetric broad line peaks
- The broad line profiles and their variability may indicate the SMBBH presence (Popovic 2012)



The search for SMBBHs

- Indications for SMBBH presence in the center of some active galaxies (see e.g. Bon et al. 2012; Li et al. 2016).
- Low probability of finding amongst quasars
- Only two candidates from SDSS catalog (Boroson and Lauer 2009)
- From simulations 5 – 10 per 10000 sources (Volonteri 2009)



Unified model

Antonucci (1993)

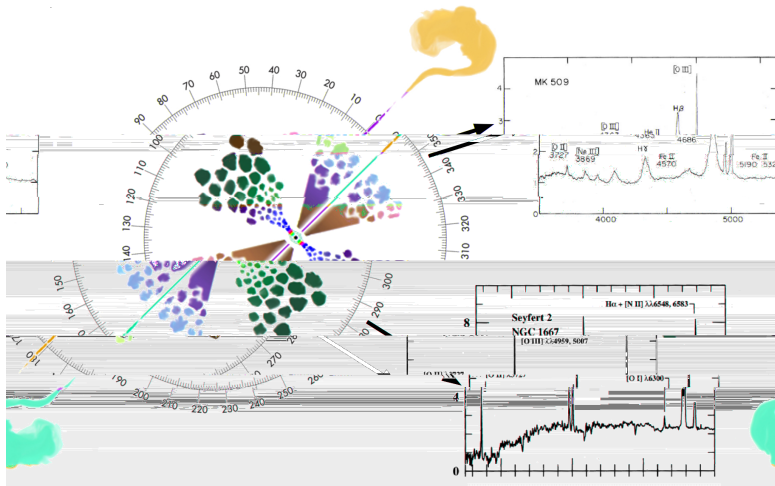
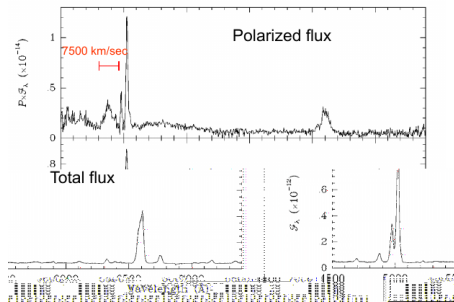
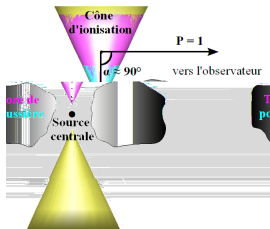


Figure : Marin 2015

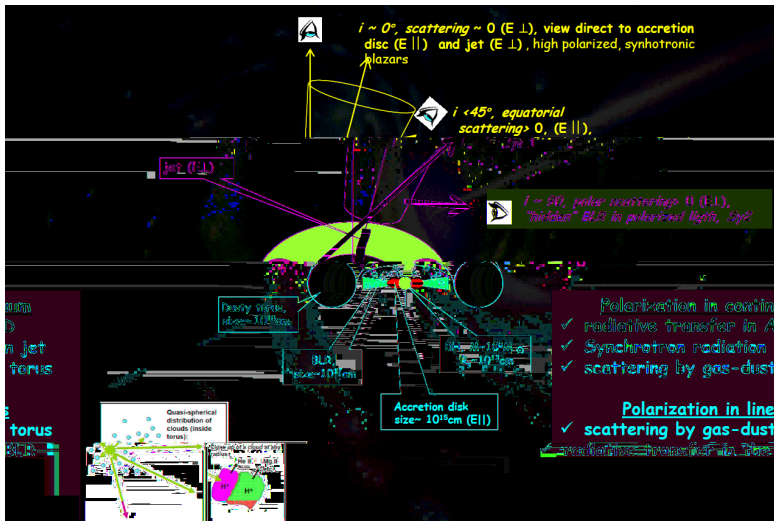


Polarization observations

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



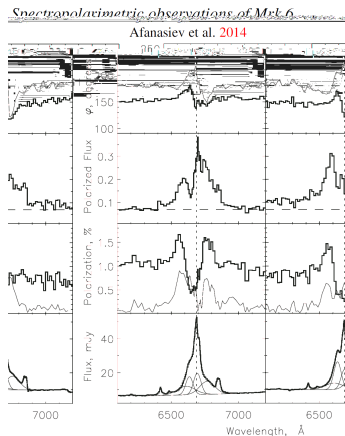
The origin of polarization



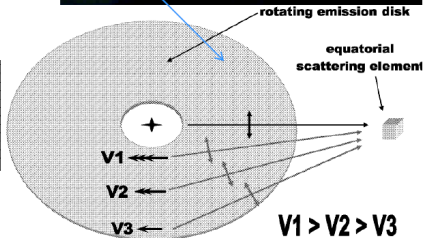
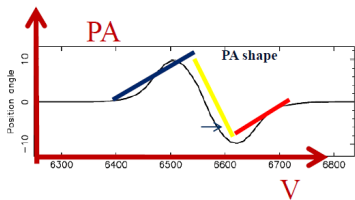
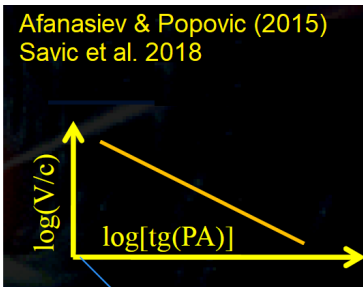
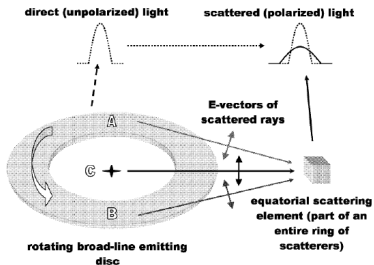
Polarization in Sy 1s

- Polarization position angle (PA) rotation as evidence for equatorial scattering in Sy 1s.
- Weak polarization, typically few percents.

Smith et al. 2002



Polarization of broad lines in Sy 1s



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.
- Resonant line scattering included.
- Goosmann & Gaskell (2007); Marin et al. (2012, 2015).

The screenshot shows a web browser window displaying the STOKES website. The page title is "STOKES Modeling Radiative Transfer and Polarization". The website is from the Observatoire Astronomique de Strasbourg, France, and is authored by René W. Goosmann. The page contains a navigation menu on the left with links like "home", "about", "usage", "download", "contact", "scientific results", "license", and "faq". The main content area includes a description of the STOKES code as a Monte Carlo radiative transfer code for handling multi-wavelength polarization. It also features a plot showing polarization percentage versus wavelength (Angstroms) with several curves in different colors. A diagram of a sphere with coordinate axes and a vector is also visible.

STOKES Modeling Radiative Transfer and Polarization

Observatoire Astronomique de Strasbourg
René W. Goosmann

The STOKES computer program is a Monte Carlo radiative transfer code for handling multi-wavelength polarization. It was designed to model astronomical objects of various geometries and compute polarizations induced by electron and dust scattering. If you are interested in polarization and radiative transfer you might want to follow the links on this page to find out more about STOKES. The code is freely available for use. We just ask if you publish results based on STOKES computations that you refer to the [Goosmann & Gaskell \(2007\)](#) paper describing the code.

→ Check out the [manual](#) to get an introduction to the capabilities of the program and learn how to run it.

→ You may download compiled versions of the program for Linux and Windows.

→ [Examples](#) for the input files and pre-computed [shell models](#) are helpful to get used to running the code.

→ If you would like to adjust the program to your personal needs and create it yourself you may obtain the [C++ source codes](#).

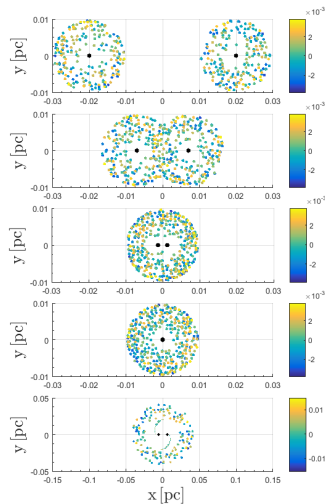
→ Find out about [scientific results](#) obtained with STOKES.

STOKES was written by René W. Goosmann who is now at the Observatoire Astronomique de Strasbourg, France. If you have questions or comments about the code, please [contact](#) him.



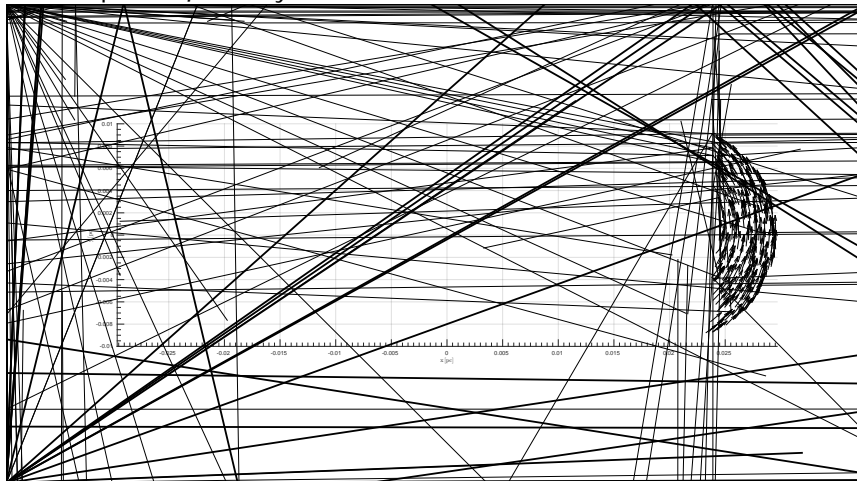
Polarization in Sy 1s

- Two SMBHs with mass $5 \cdot 10^7 M_{\odot}$
- Two point-like source of isotropic continuum radiation, $F_{\nu} \propto \nu^{-2}$.
- Clumpy BLR, filling factor $f = 0.25$
- Four different cases of BLR configuration.
- Half opening angle of the BLR is 20°



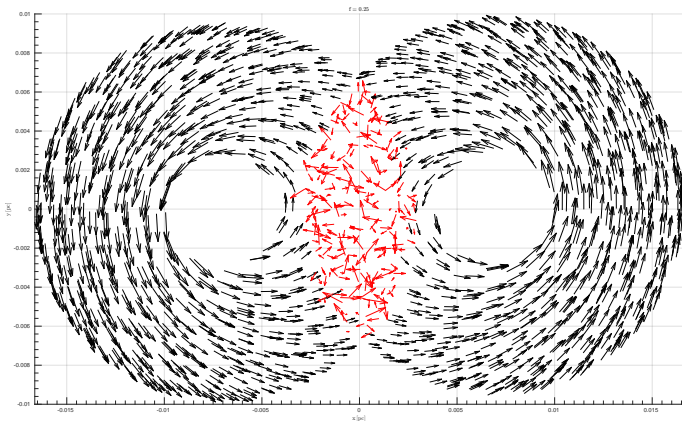
Distant BLR

- Orbital separation $a = 47.6 \text{ ld}$
- Orbital period $p = 75 \text{ years}$



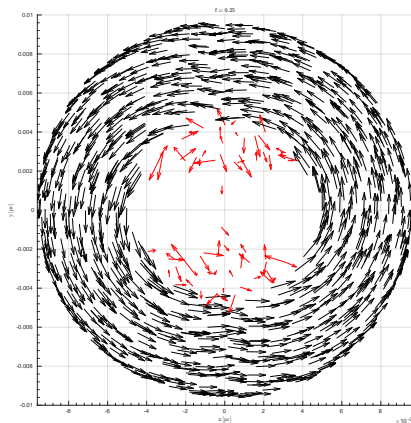
Contact BLR

- Orbital separation $a = 16.7 \text{ ld}$
- Orbital period $p = 15.5 \text{ years}$



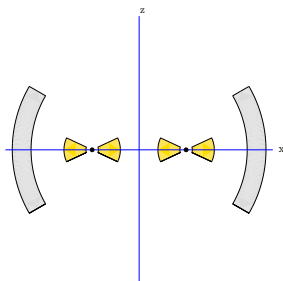
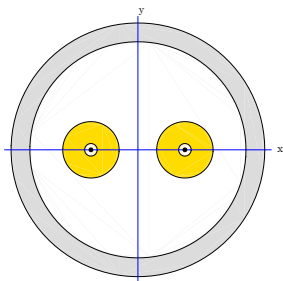
Mixed BLR

- Orbital separation $a = 2.97 \text{ ld}$
- Orbital period $p = 1.17 \text{ years}$

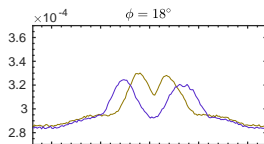
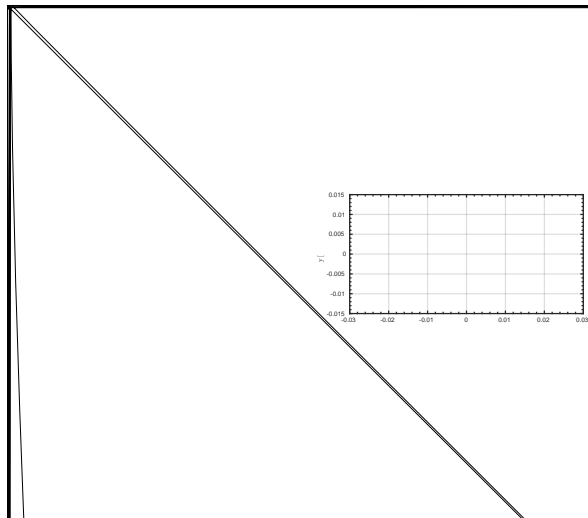


Scattering region

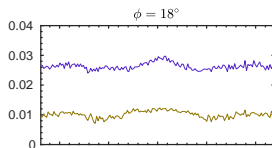
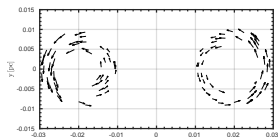
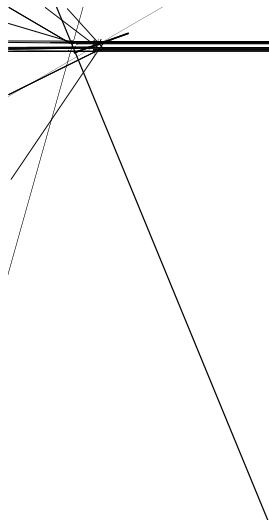
- From 0.1 { 0.5 pc
- Half opening angle 30°
- Radial optical depth is 3
- Thomson scattering



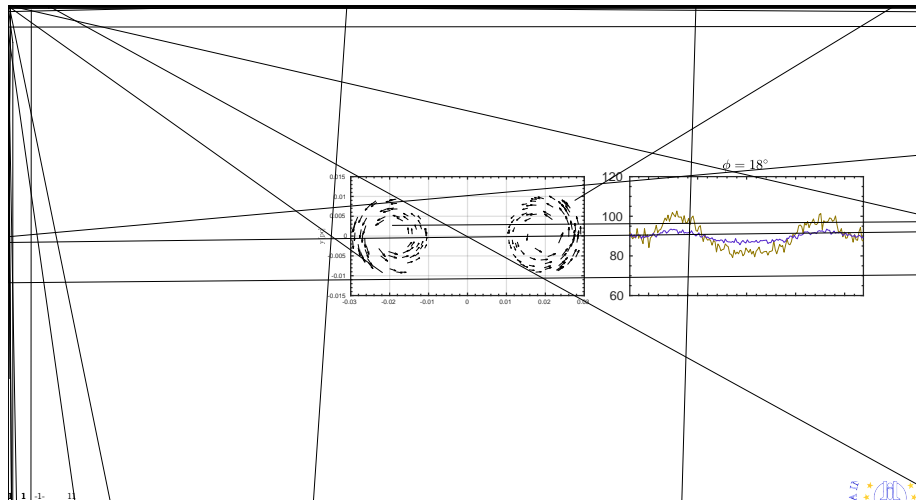
Results: Distant BLRs



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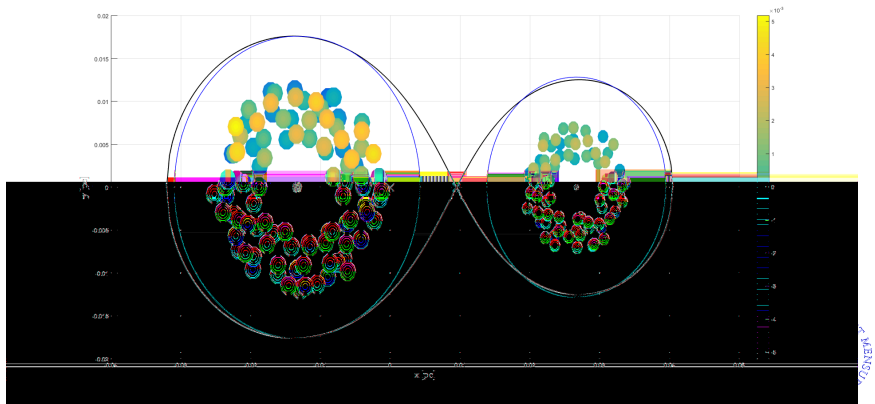


Results: Distant BLRs

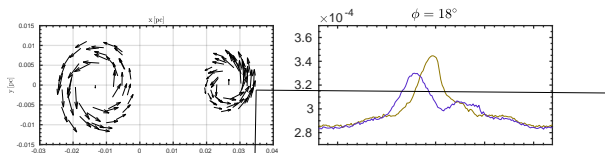


Distant BLR

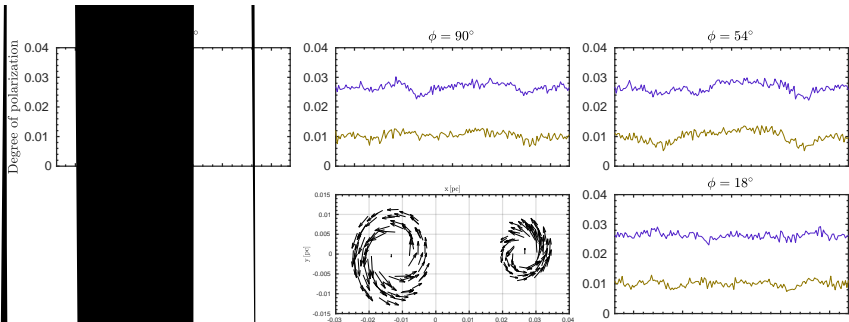
- Orbital separation $a = 47.6 \text{ ld}$
- Orbital period $p = 75 \text{ years}$
- Mass ratio $q = 0.5$



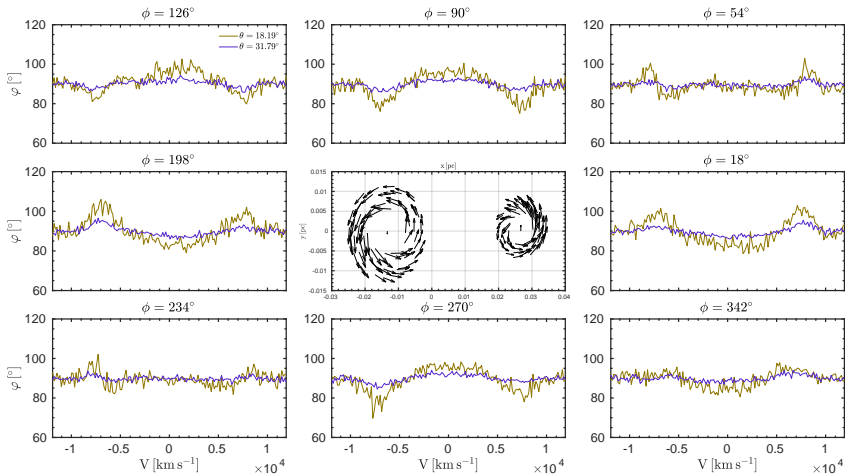
Results: Distant BLRs



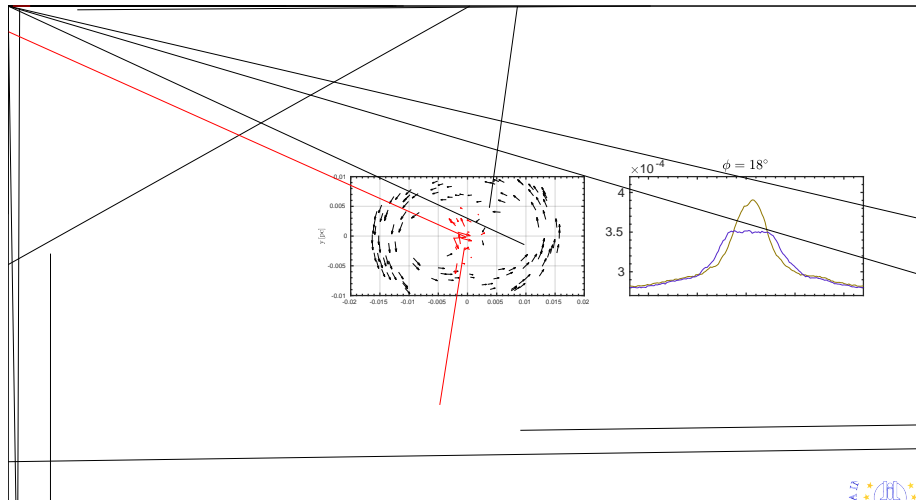
Results: Distant BLRs



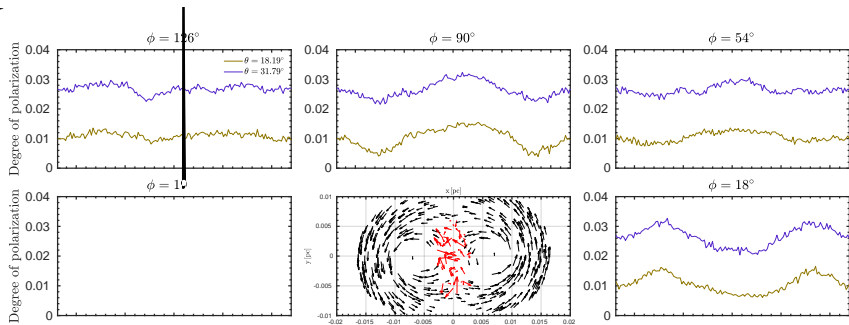
Results: Distant BLRs



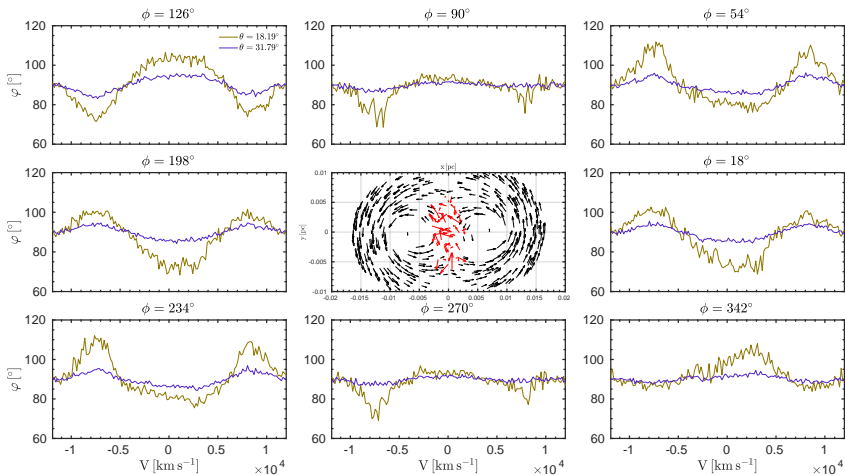
Results: Contact BLRs



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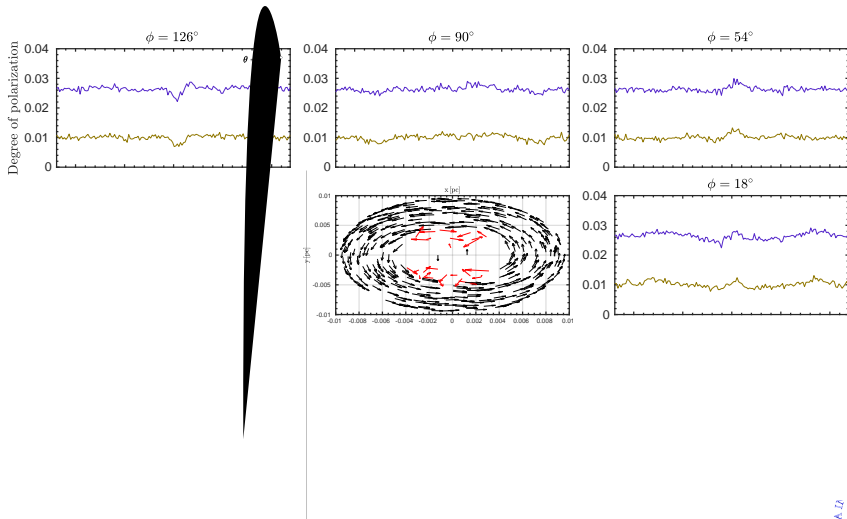
Results: Contact BLRs



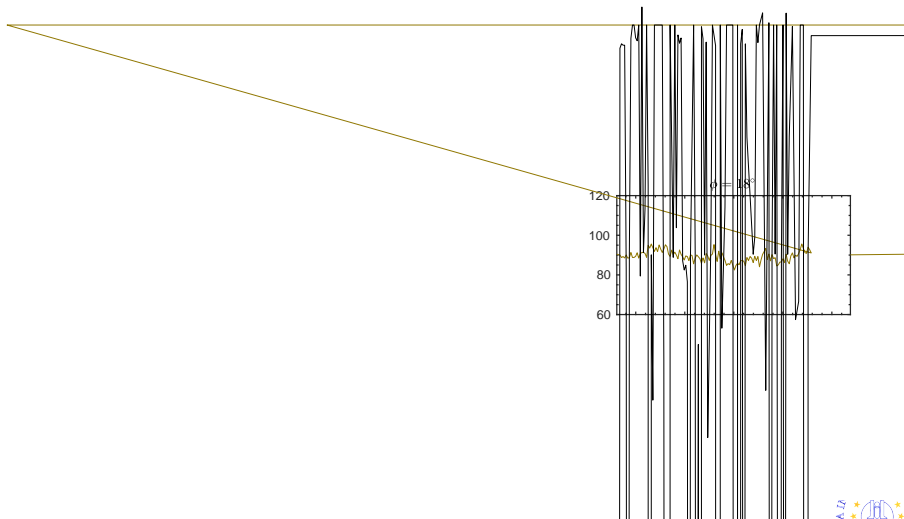
Results: Mixed BLRs



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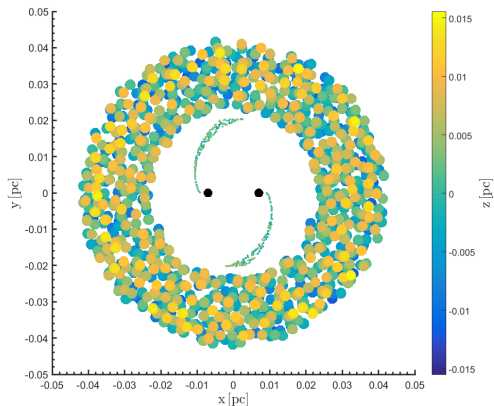


Results: Mixed BLRs

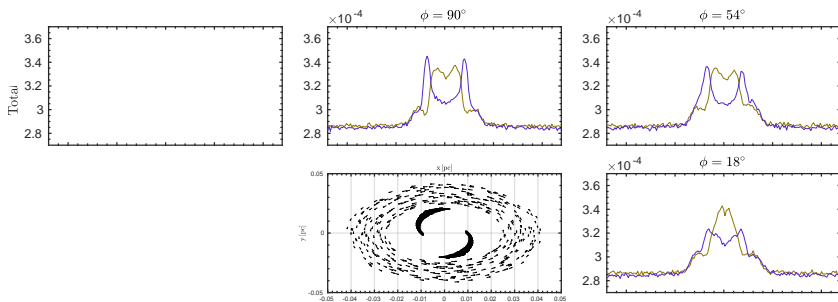


Spiral BLR

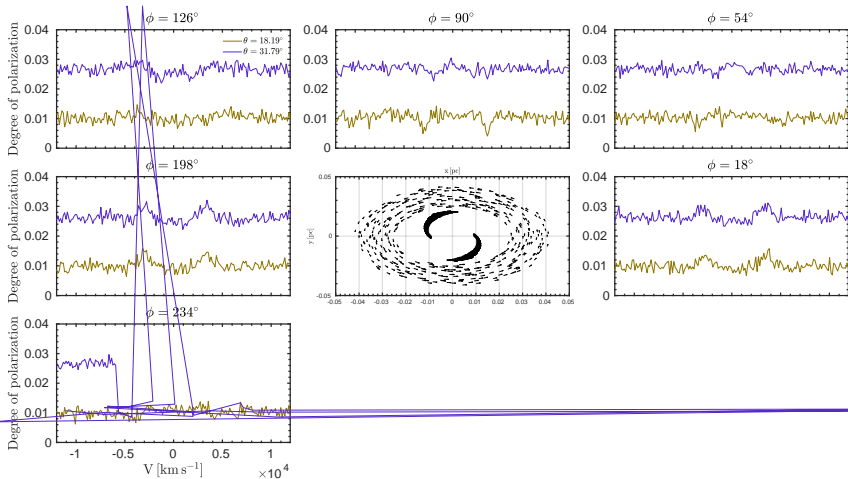
- Orbital separation $a = 16.7 \text{ ld}$
- Orbital period $p = 15.5 \text{ years}$
- Model similar as the one by Smailagic & Bon (2015)



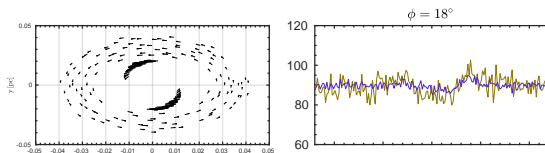
Results: Spiral BLRs



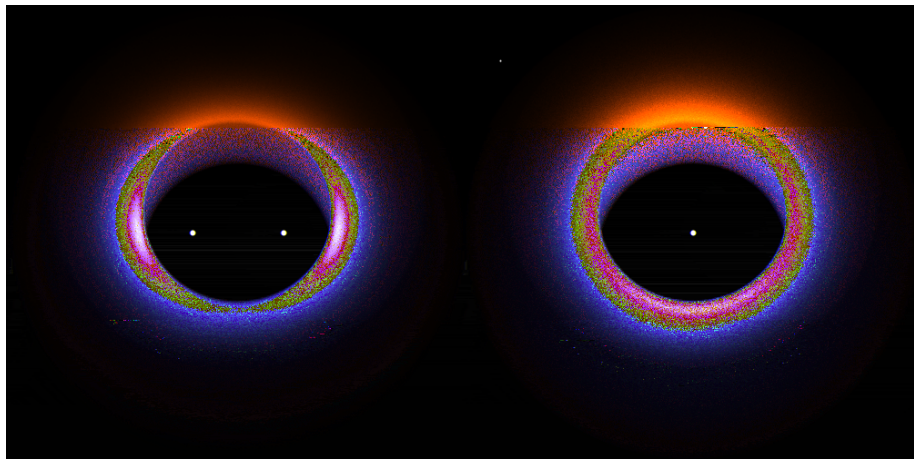
Results: Spiral BLRs



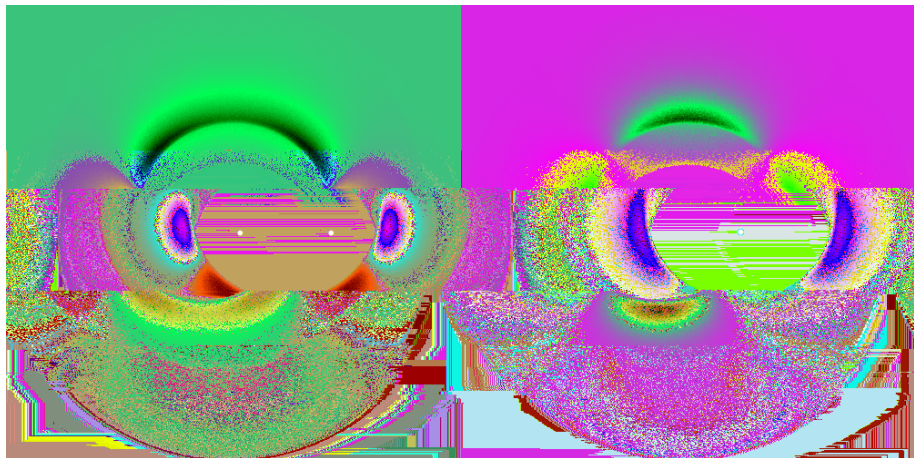
Results: Spiral BLRs



Polarization maps: I



Polarization maps: Q



Polarization maps: U



- Spectropolarimetry is powerful tool for the SMBBHs search
- Position angle profiles show variable *W*- or *M*-like profiles
- Unpolarized lines show periodic variations
- Spatially resolved polarization maps are highly sensitive to the presence of SMBBHs

