Testing the Unified Model of AGN with broadband polarimetry

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Akademie věd České republiky

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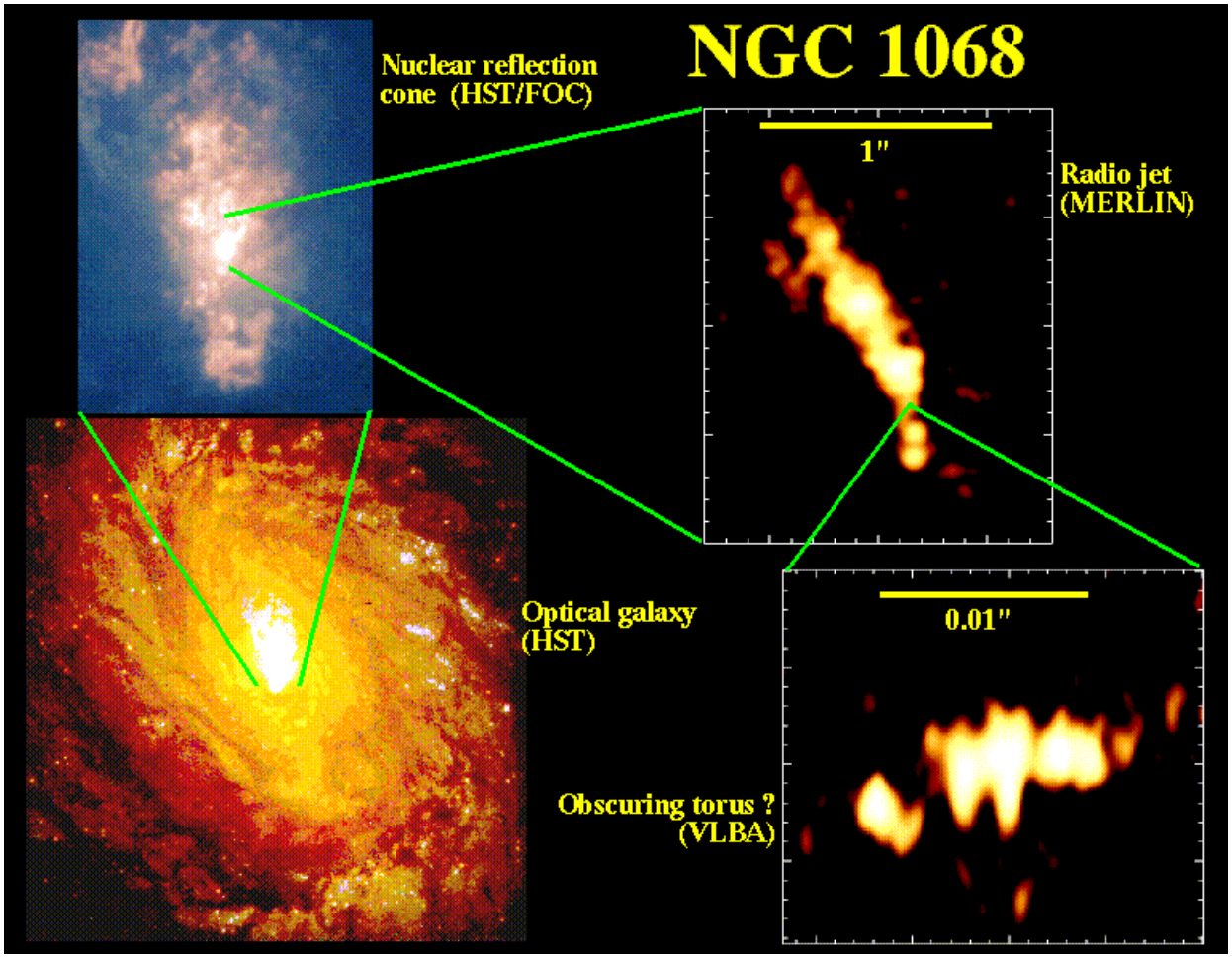
How to resolve the unresolvable?



Active Galactic Nuclei (AGN)

- Situated at Mpc from Earth
  (Centaurus A ~ 3 – 5 Mpc)
- Size of few kpc
  (including extended NLR)
- Used as probes to measure cosmological distances
  (Watson et al. 2011)

To examine the physics and morphology of the innermost AGN regions, a resolution below 10^{-7} arcsec would be needed
(accretion disk mapping, McKernan & Yaqoob 1998)

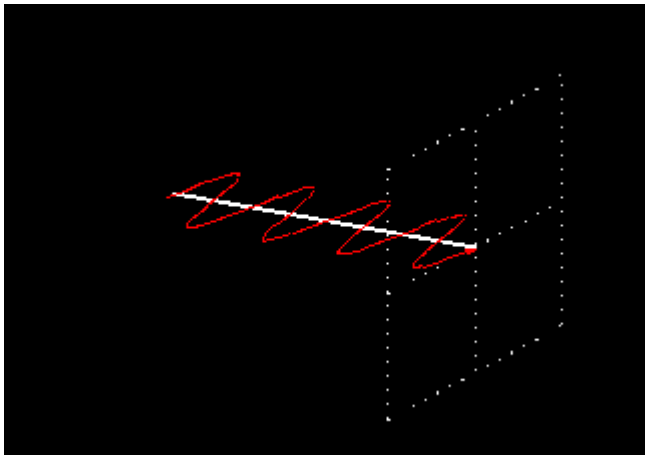
Credit: William C. Keel

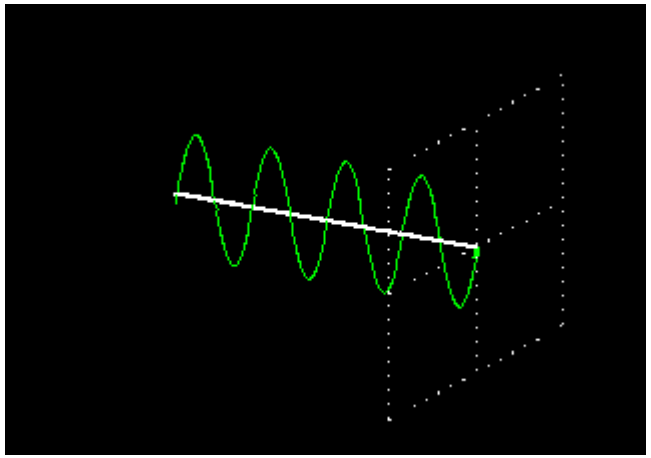
How to resolve the unresolvable?

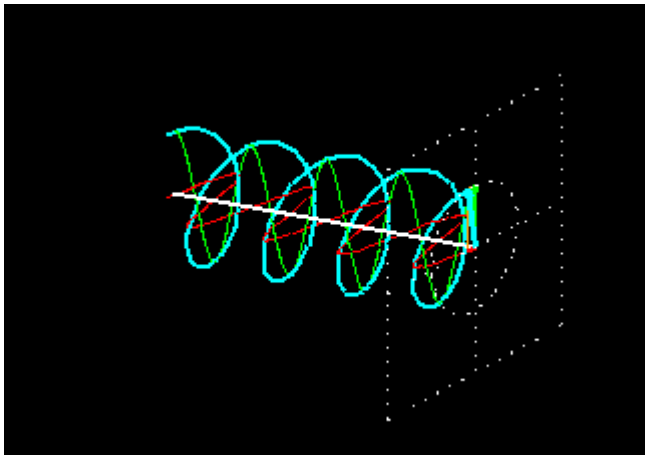
We don't have the technology (yet) to reach 10^{-7} arcsec
But we have another information, encoded in electromagnetic waves: polarization !

By definition, the electric (and magnetic) vector of light oscillates randomly;
the light is said to be unpolarized

But ! An event can fix the plane in which this electric vector oscillates through time;
the light is said to be (partially) polarized







Polarization

An electromagnetic wave is said to be polarized if the tip of its transverse (electric) vector is found not to vary during the measurement time

(vectorial nature of light, Young 1801, Fresnel 1821)

(De)polarization can arise from

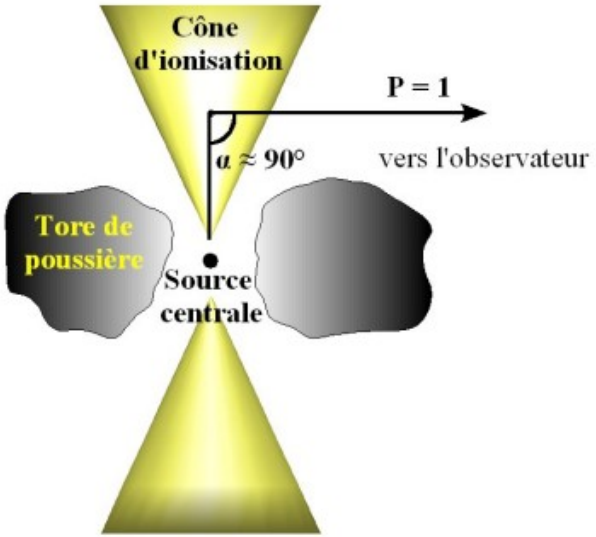
- synchrotron emission
- dust (Mie) scattering
- dichroic absorption
- dilution
- Thomson and Rayleigh scattering
- resonant line scattering
- Faraday rotation
- general relativity.

Energy-dependent / species-dependent / spacetime-dependent / magnetically-dependent

AGN investigation from radio to γ-rays	composition of matter + morphology	new physics research	magnetic structures + morphology

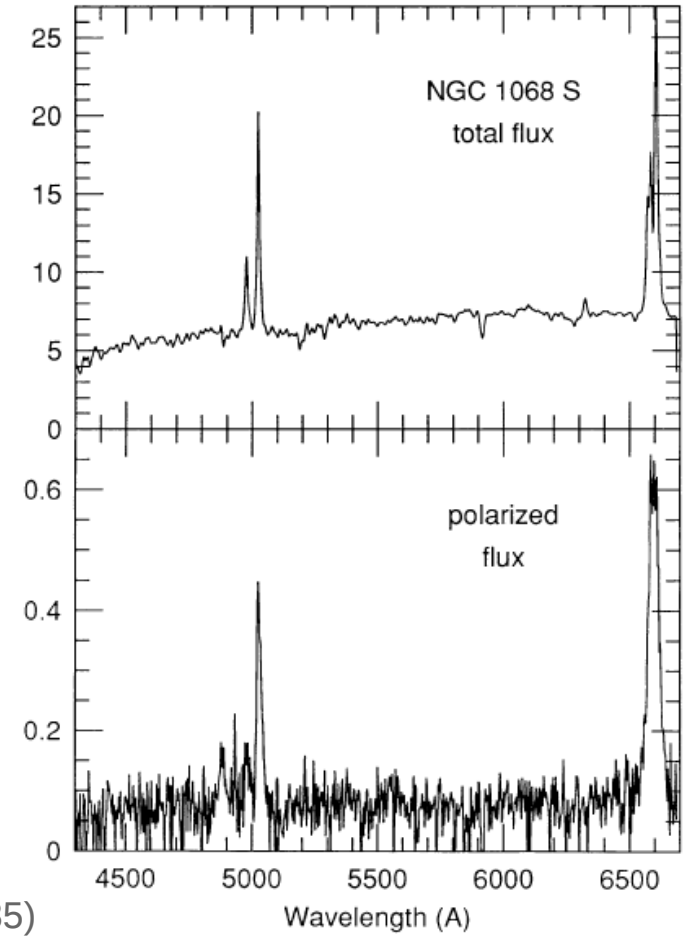
Polarization: a pillar of the Unified Model

A perfect example
the nucleus of NGC 1068 seen through
a periscopic view thanks to polarization



Credit : René Goosmann

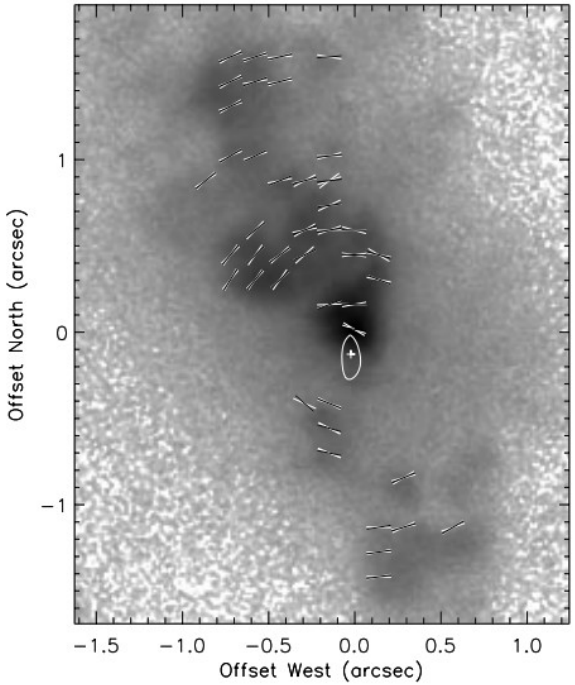
$$P = \frac{1-\cos^2\theta}{1+\cos^2\theta}$$

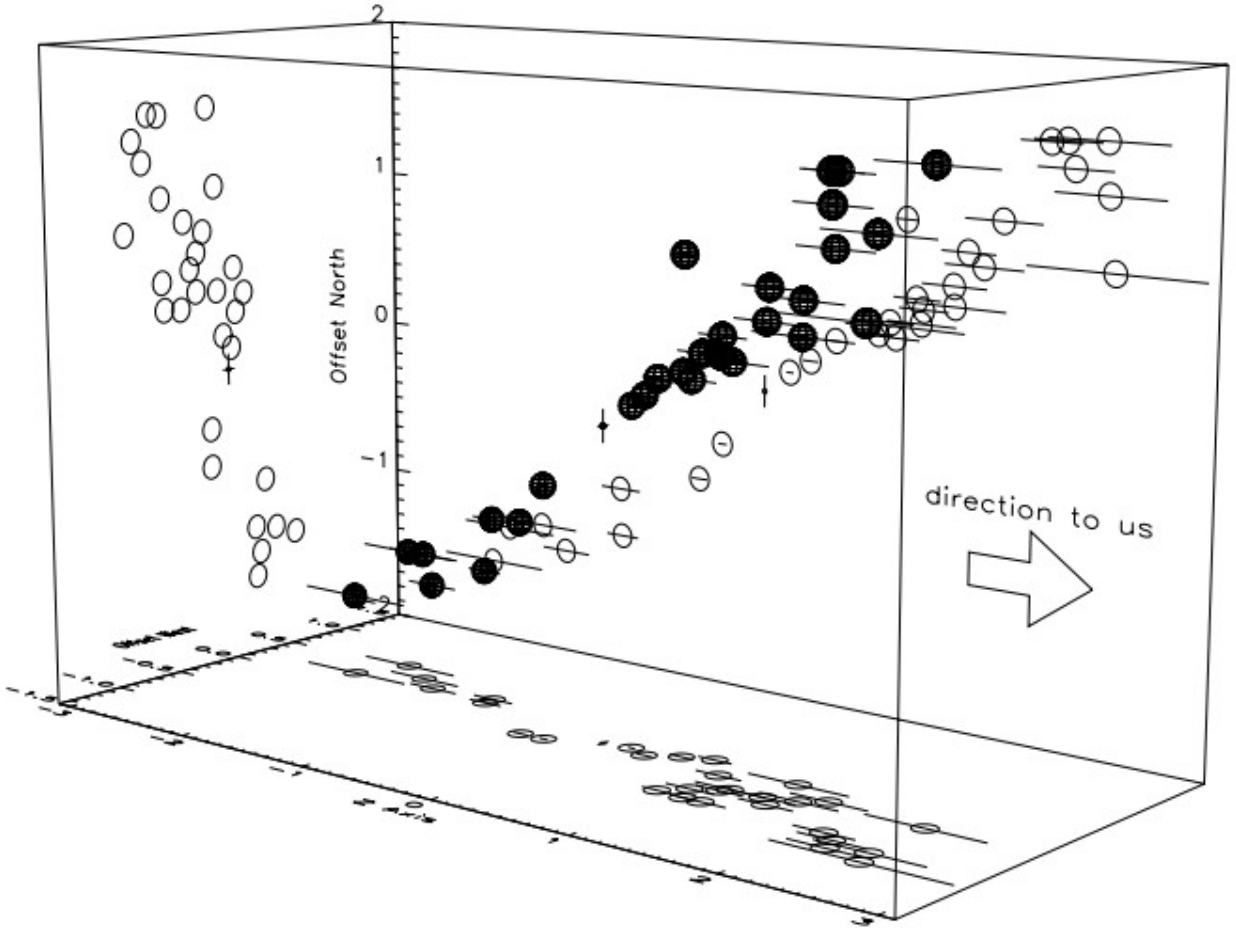


Antonucci & Miller (1985)

3D geometry

A perfect example
the ionization cone / NLR
of NGC 1068 reconstructed
thanks to polarization





Kishimoto (1999)

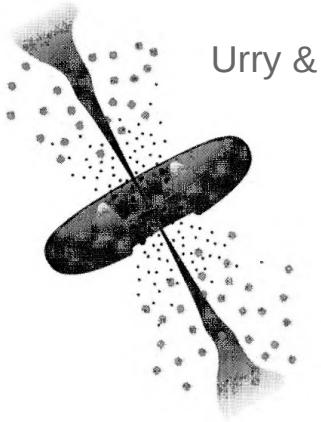
What can be tested next?

A lot of unknowns: composition, morphology, orientation …

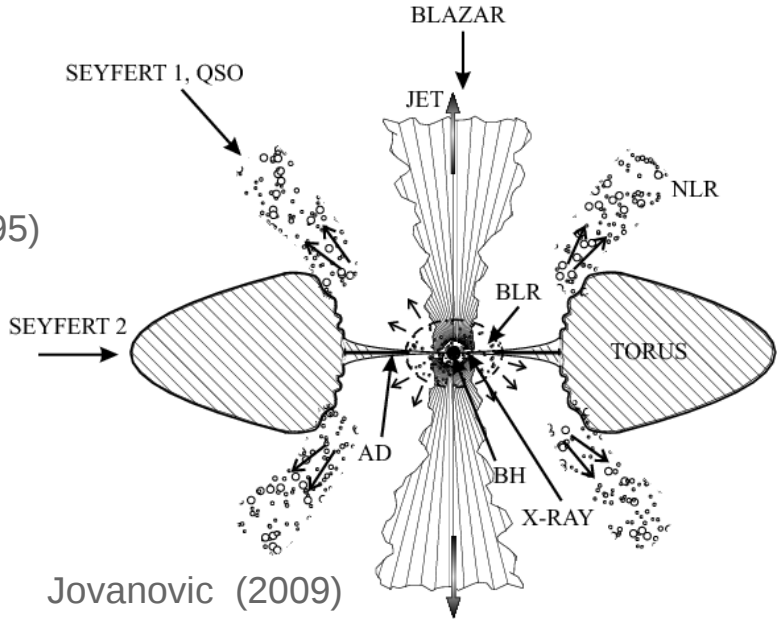
Radiative transfer as a solution to:

- reproduce polarization signatures
- predict polarimetric results
- distinguish between different models

Test of the Unified Scheme

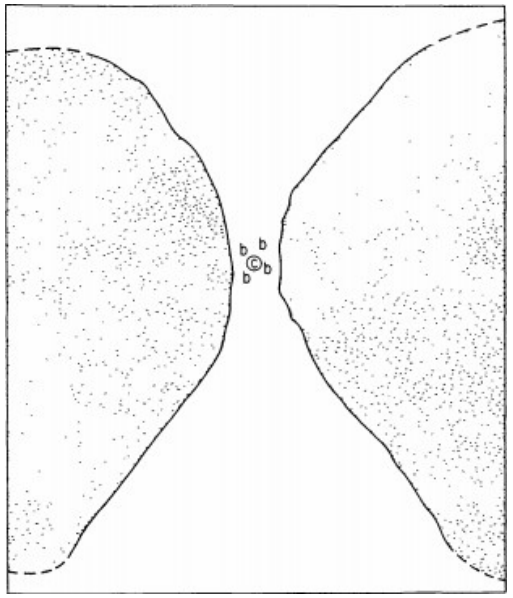


Urry & Padovani (1995)



Jovanovic (2009)

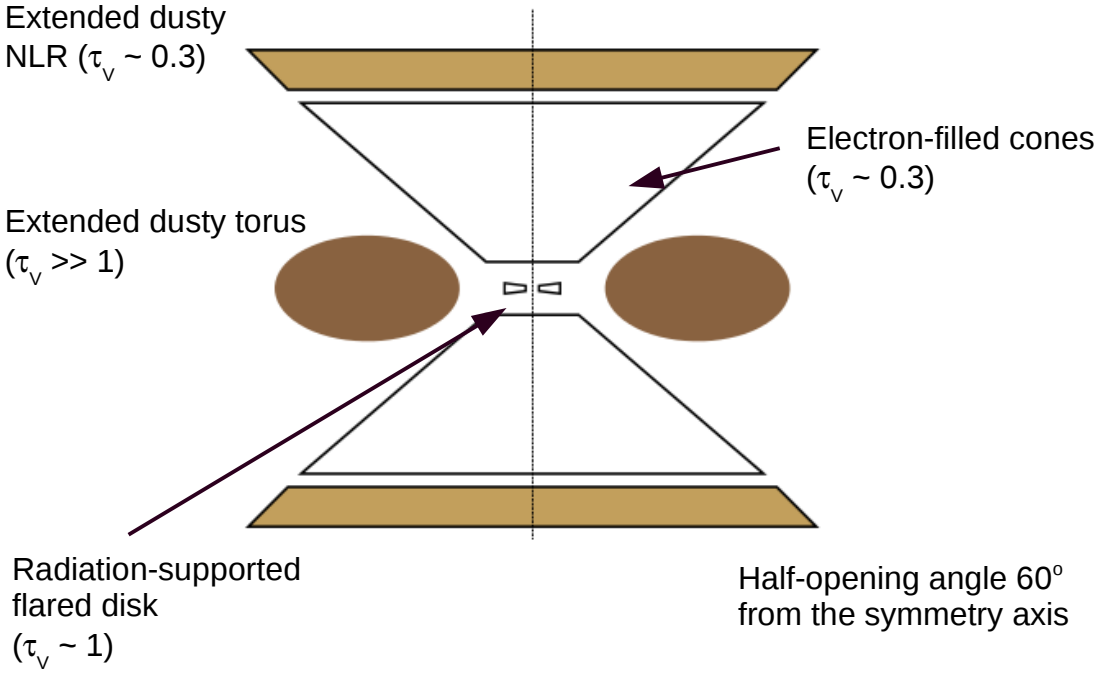
Antonucci (1993)



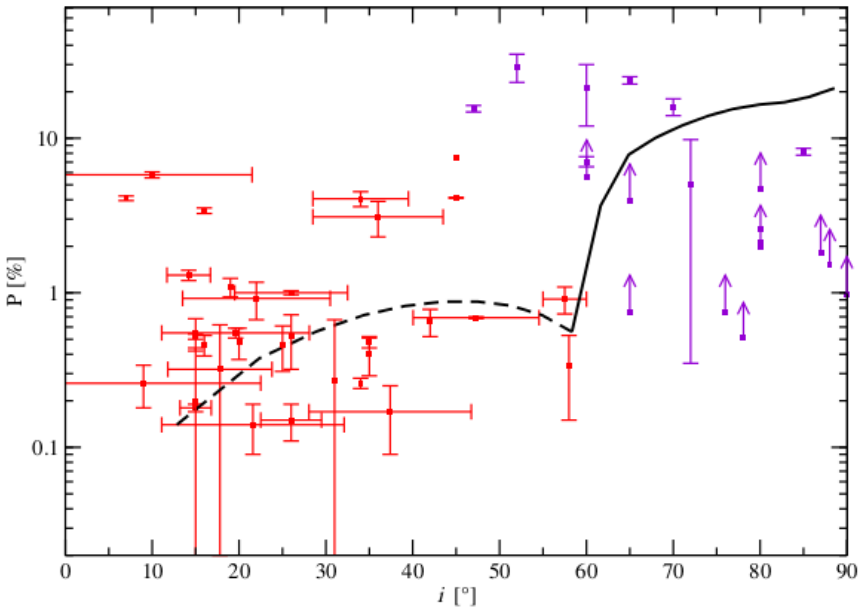
The Unified Model

The Unified Scheme

With uniform-density regions



Inflow + torus + wind + NLR



Type-1 / **Type-2s**

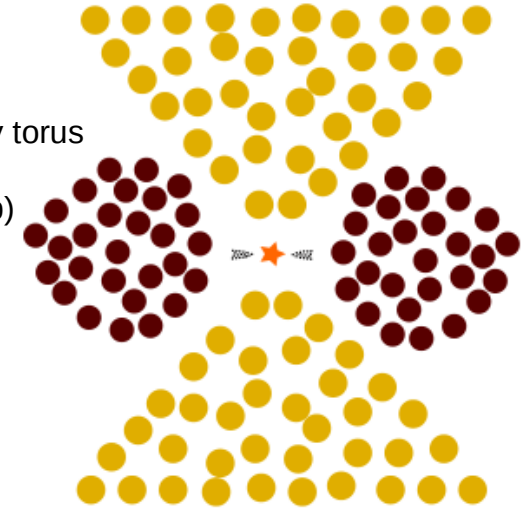
Marin et al. (2012) + Marin (2014)

The Unified Model

The Unified Scheme

With clumpy regions

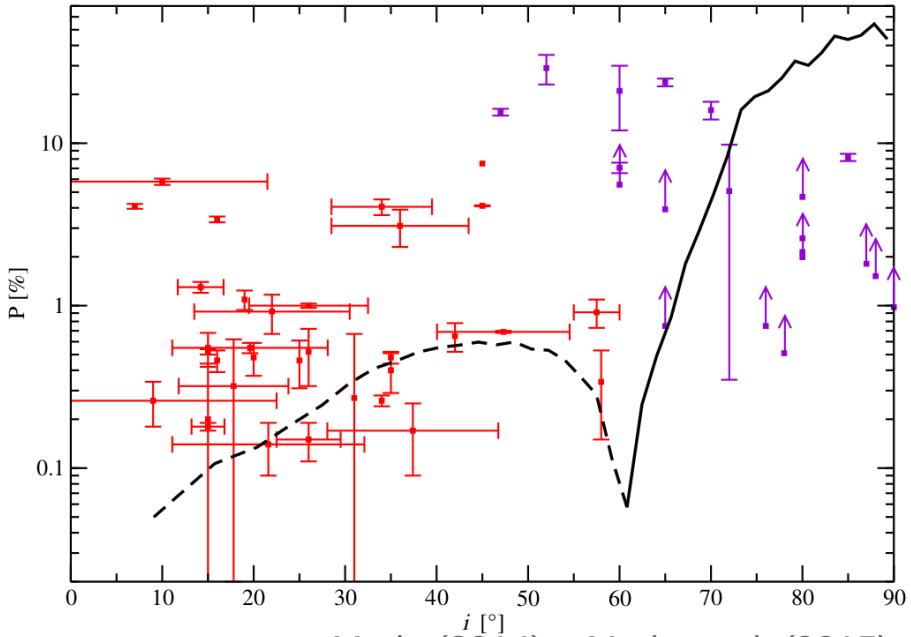
Fragmented dusty torus
Filling factor 25 %
(τ_V ~ 60 per clump)



Fragmented radiation-supported flared disk
Filling factor 25 %
(τ_V ~ 0.3 per clump)

Fragmented electron-filled cones
Filling factor 6 %
(τ_V ~ 0.3)

Inflow + torus + wind (all clumpy)

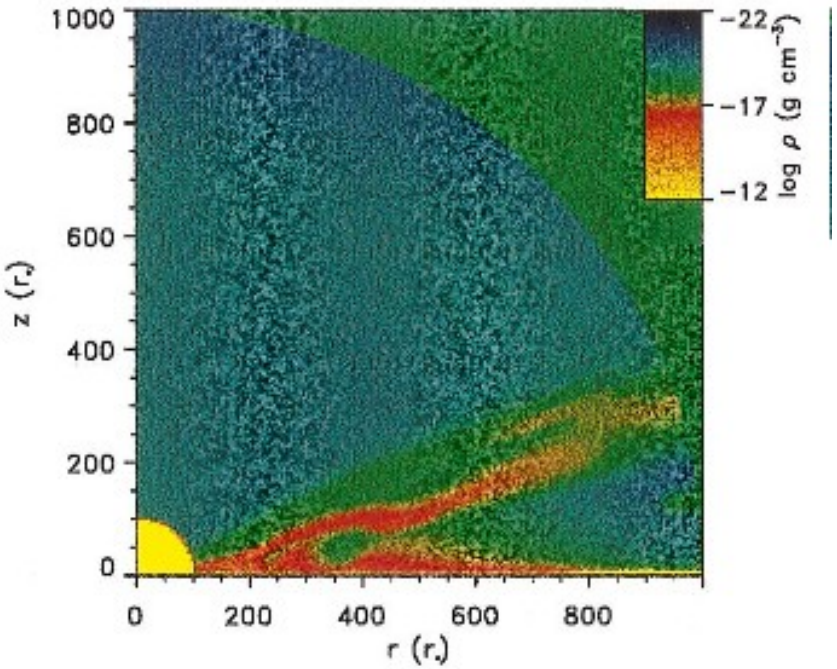


Marin (2014) + Marin et al. (2015)

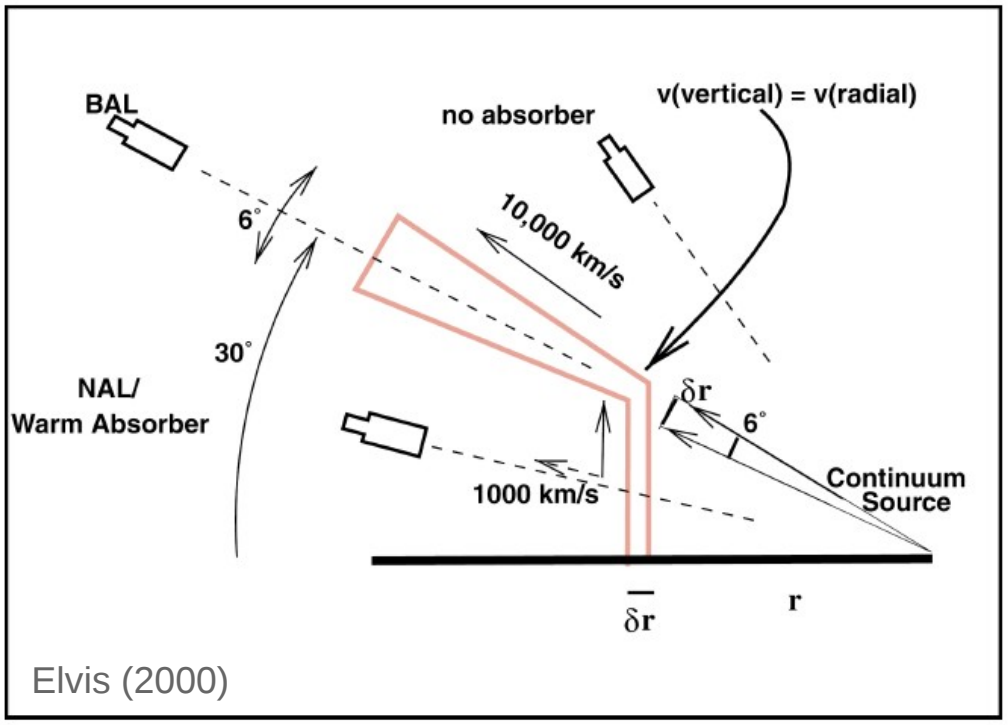
An alternative model

Towards dynamical, outflowing structures

More realistic structures from MHD simulations and phenomenological reasoning



Proga et al. (2000, 2002, 2004)



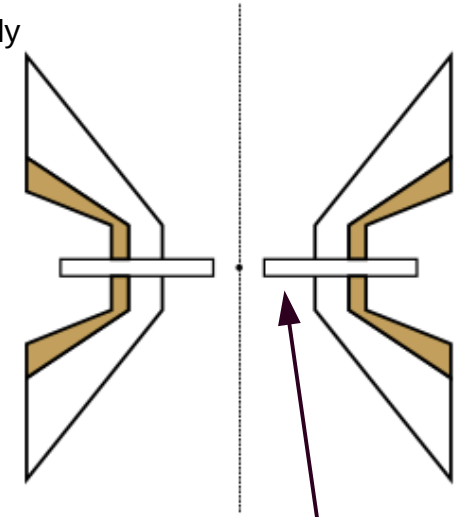
Elvis (2000)

An alternative model

A new scheme: a dynamical outflowing structure

Disk-born winds (Elvis 2000)

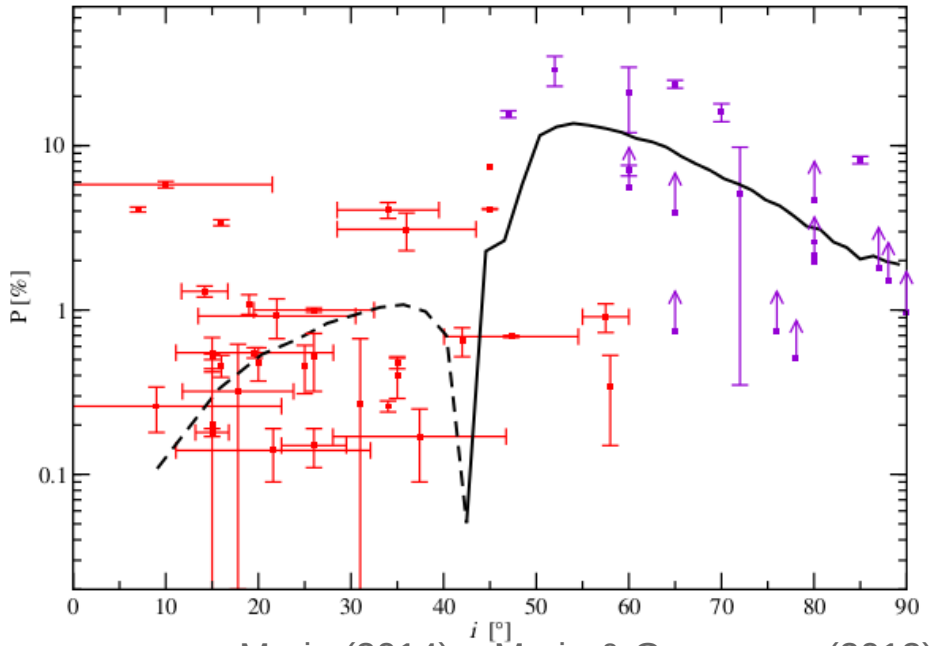
Flow of warm, highly ionized matter
Bending angle 60º
($0.02 < \tau_V < 20$)



Failed dusty wind
Bending angle 66º
($40 < \tau_V < 4000$)

Fully ionized accretion disk ($\tau_V \sim 1$)

Inflow + torus + wind (all clumpy)

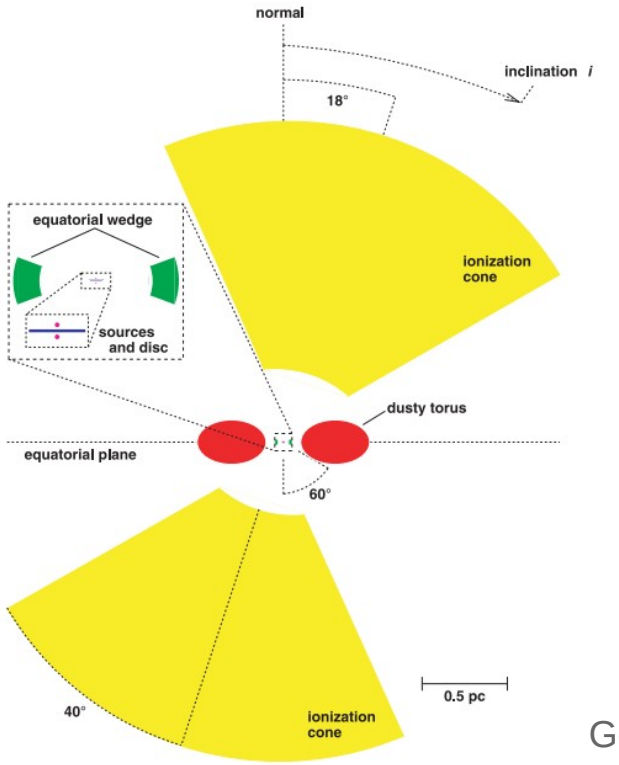


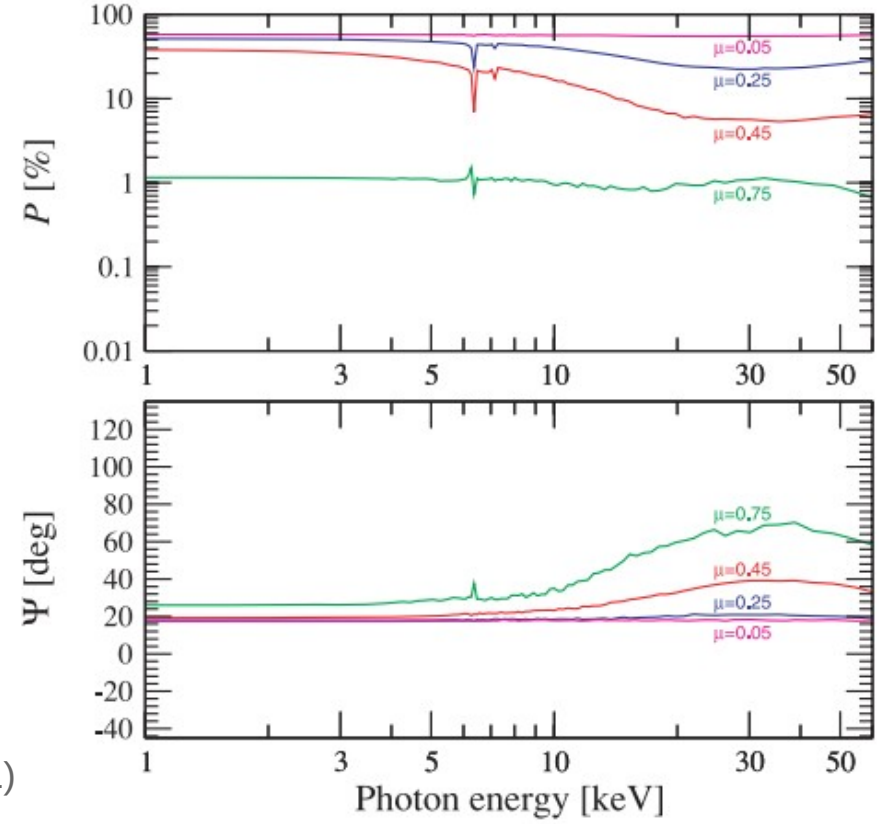
Marin (2014) + Marin & Goosmann (2013)

Paving the way for X-ray polarimetry

Extending the simulations to the X-ray domain

NGC 1068





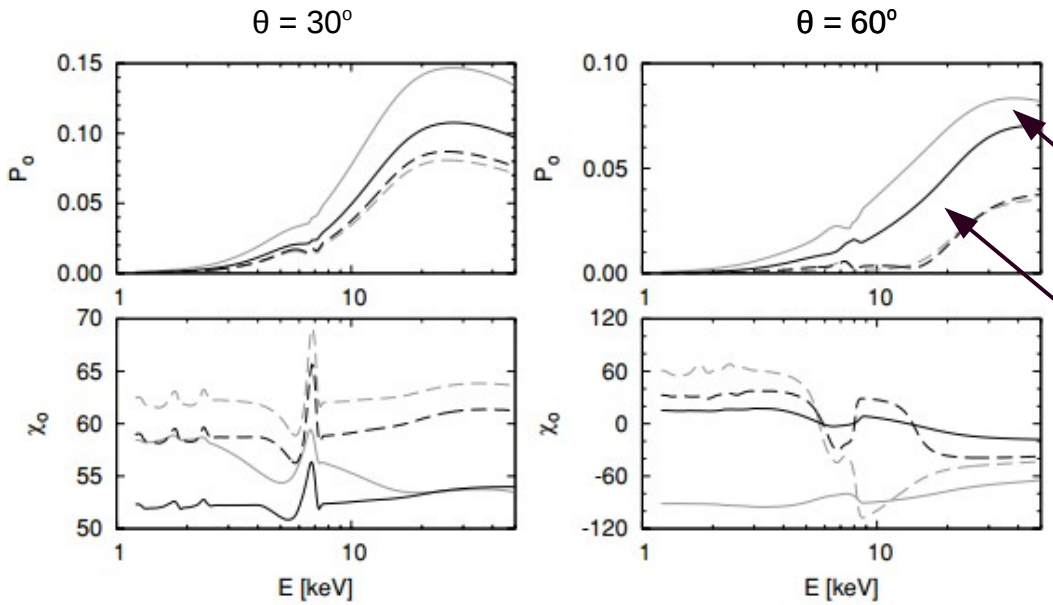
Goosmann & Matt (2011)

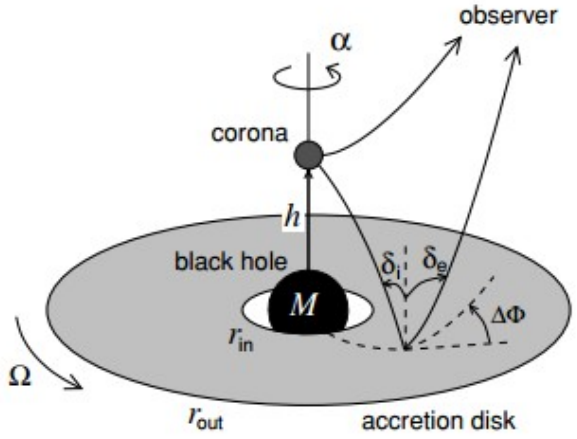
Paving the way for X-ray polarimetry

Extending the simulations to the X-ray domain

Disk reprocessing

Properties of the radiation at infinity
(height of the primary source 3 GM/c2 (solid) and 15 GM/c^2 (dashed))





Kerr

Schwarzschild

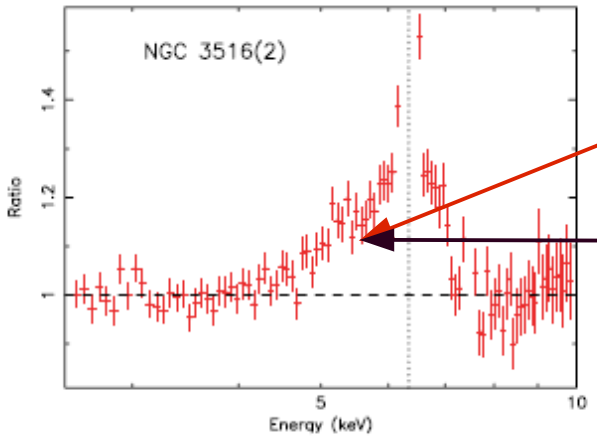
Dovciak et al. (2011)

Paving the way for X-ray polarimetry

Extending the simulations to the X-ray domain

Investigating the asymmetric broadening of the Fe Kα line

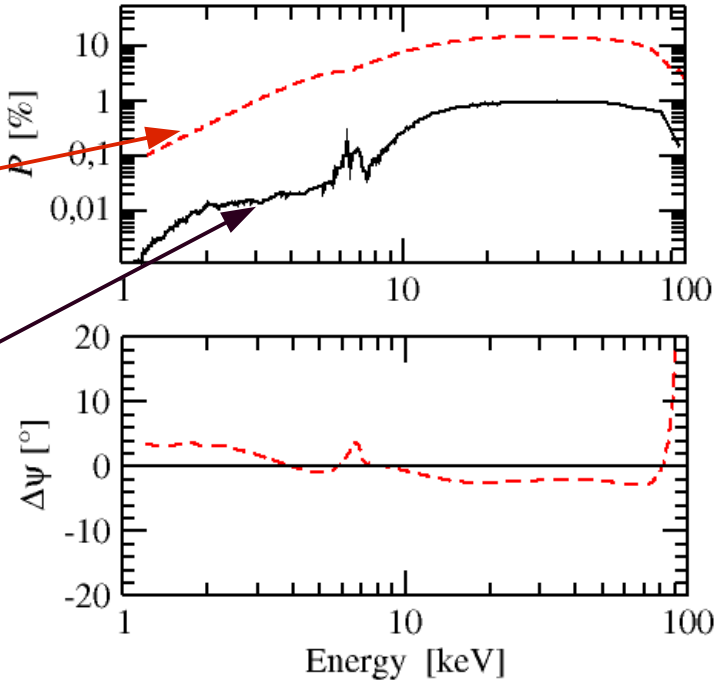
Nandra et al. (2007)



GR effect ?

Pure absorption ?

Marin et al. (2012,2013)

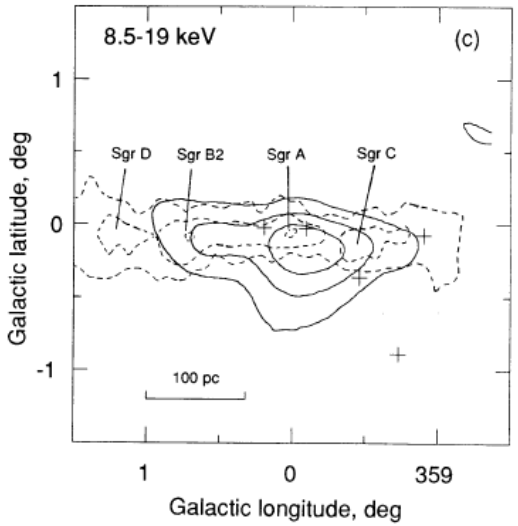


Paving the way for X-ray polarimetry

Finding evidence for a past AGN phase of our own Galactic center !

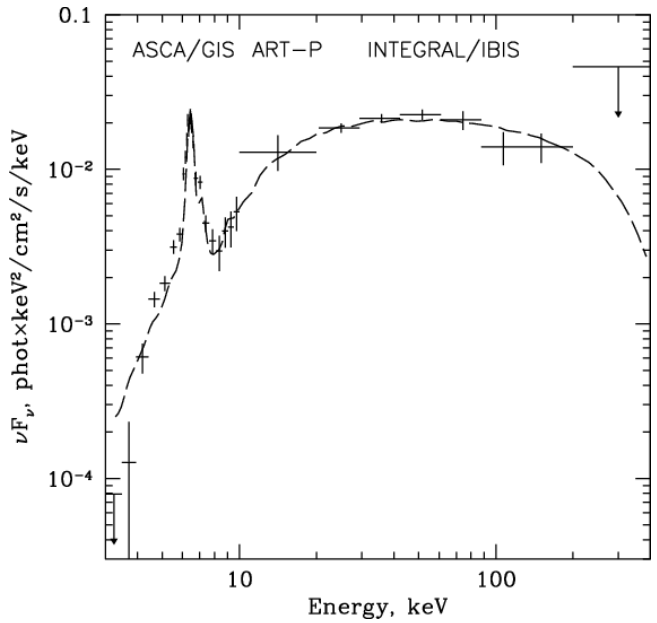
Was Sgr A* a low-luminosity AGN in the past ?

Accretion rate: 10^{-8} $M_{sol}.y^{-1}$ near the event horizon ($L_X \sim 2 \times 10^{33}$ erg.s^{-1})



Sunyaev et al. (1993)

Sgr B2



Pure reflection spectrum ($L_X \sim 10^{35}$ erg.s^{-1})

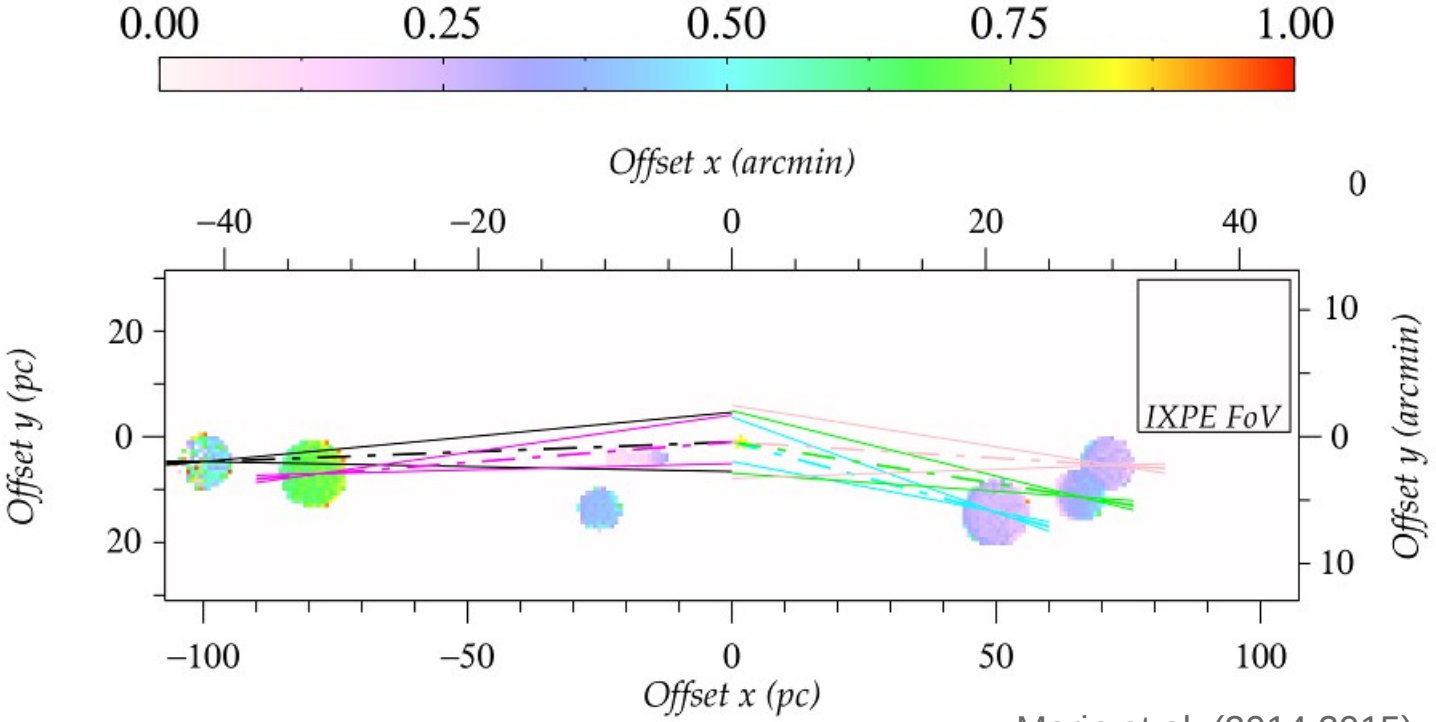
But no nearby sources bright enough!

Koyama et al. (1996)
Terrier et al. (2010)

Paving the way for X-ray polarimetry

Finding evidence for a past AGN phase of our own Galactic center !

Was Sgr A* a low-luminosity AGN in the past ?



Marin et al. (2014,2015)

Conclusions

Broadband polarimetric investigation of AGN

→ constrain the morphology and composition of the dusty circumnuclear region
→ constrain the size and opening angle of the system
→ retrieve the nuclear orientation (spectral and timing analyzes required for reliability)
→ test the different models

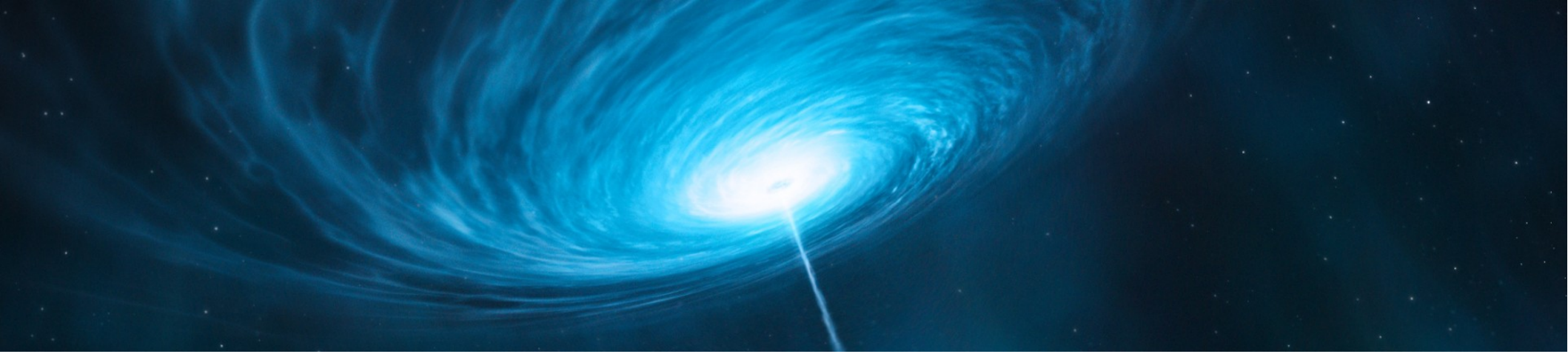
Outflowing structures seems to be favored

→ launch mechanism of the disk-born wind ?
→ collimation / bending angle ?

Future of X-ray polarimetry

→ NASA: 2 X-ray polarimeters in competition (2018)
→ ESA: 1 X-ray polarimeter in competition (2025)

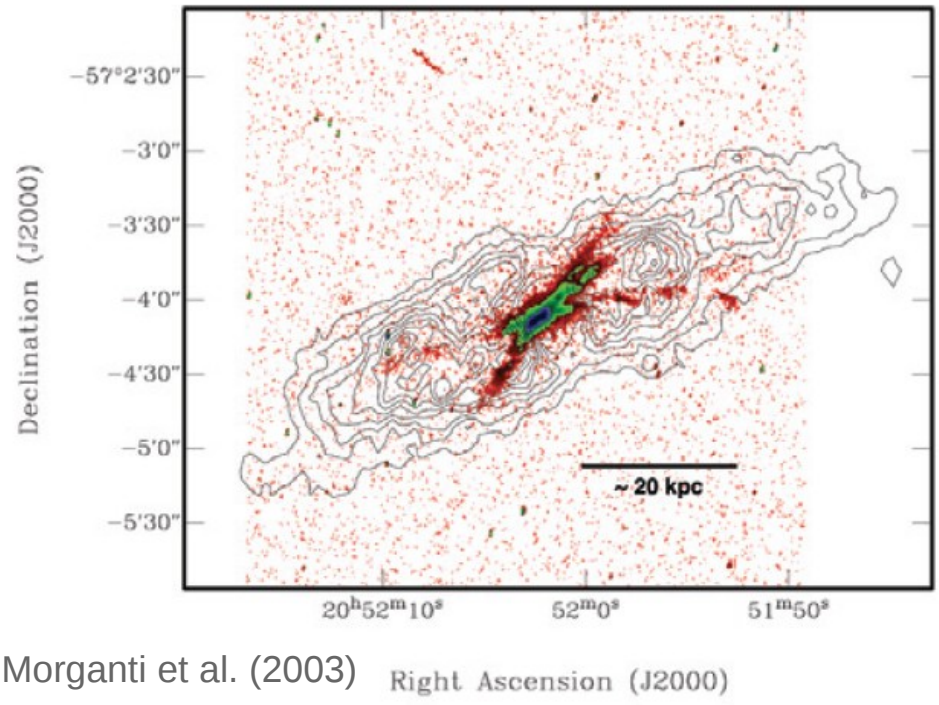
Supplementary material



Disk-born winds

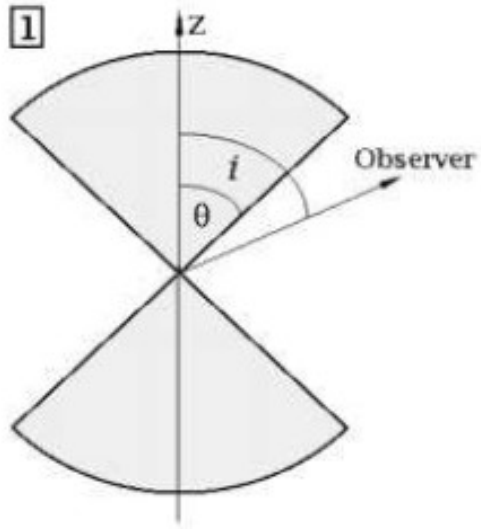
Towards dynamical, outflowing structures

Hollow geometry highlighted by spectroscopy in IC 5063



Morganti et al. (2003)

Wolf & Hennig (1999)

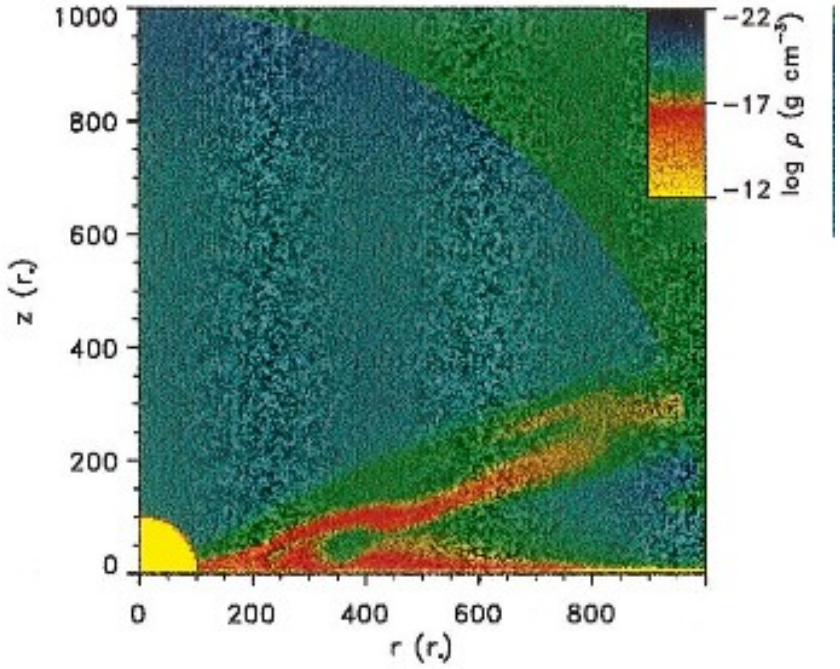


Simple, double-cone model used in most of AGN simulation

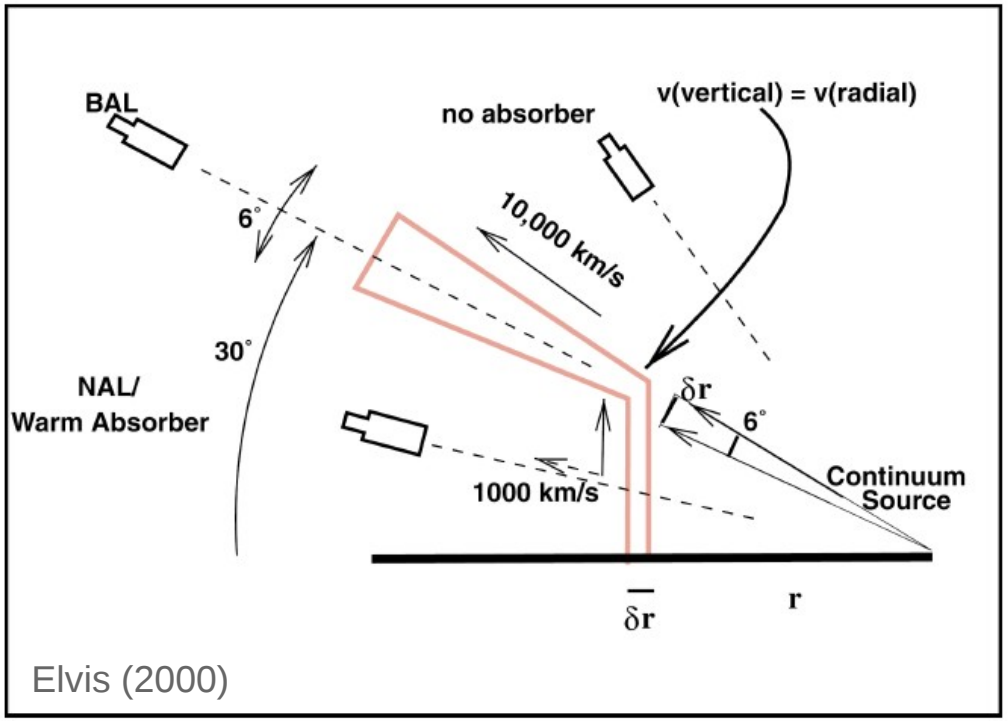
Disk-born winds

Towards dynamical, outflowing structures

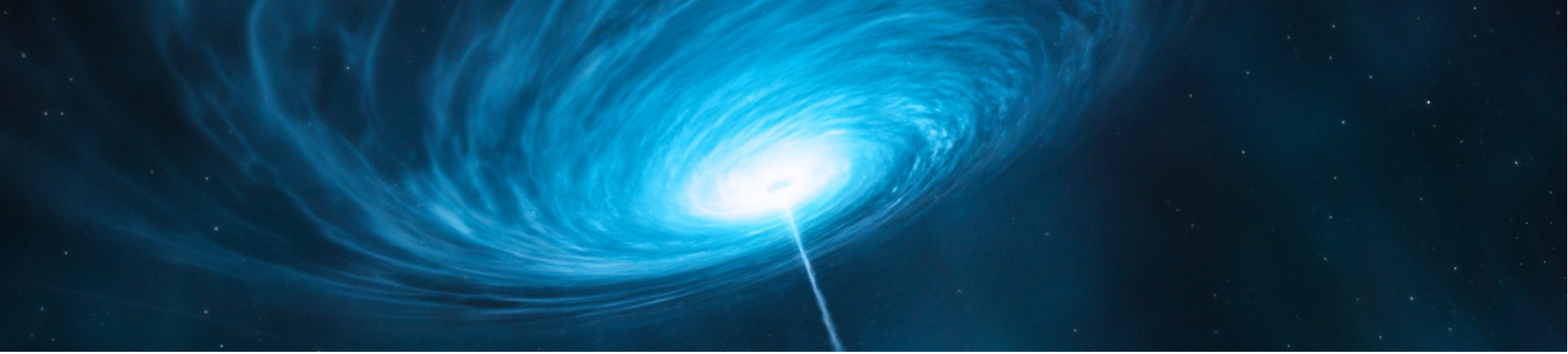
More realistic structures from MHD simulations and phenomenological reasoning



Proga et al. (2000, 2002, 2004)



Elvis (2000)

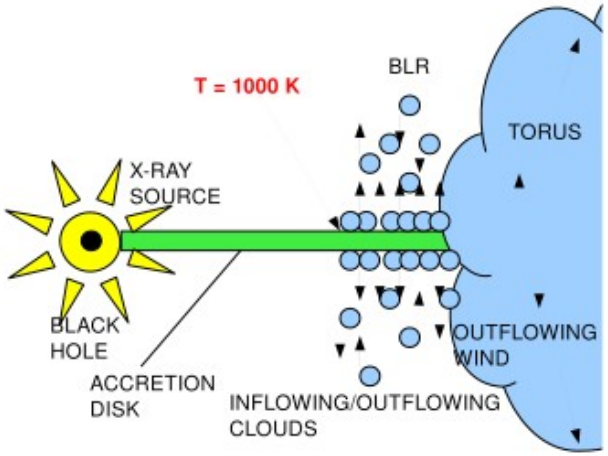


Disk-born winds

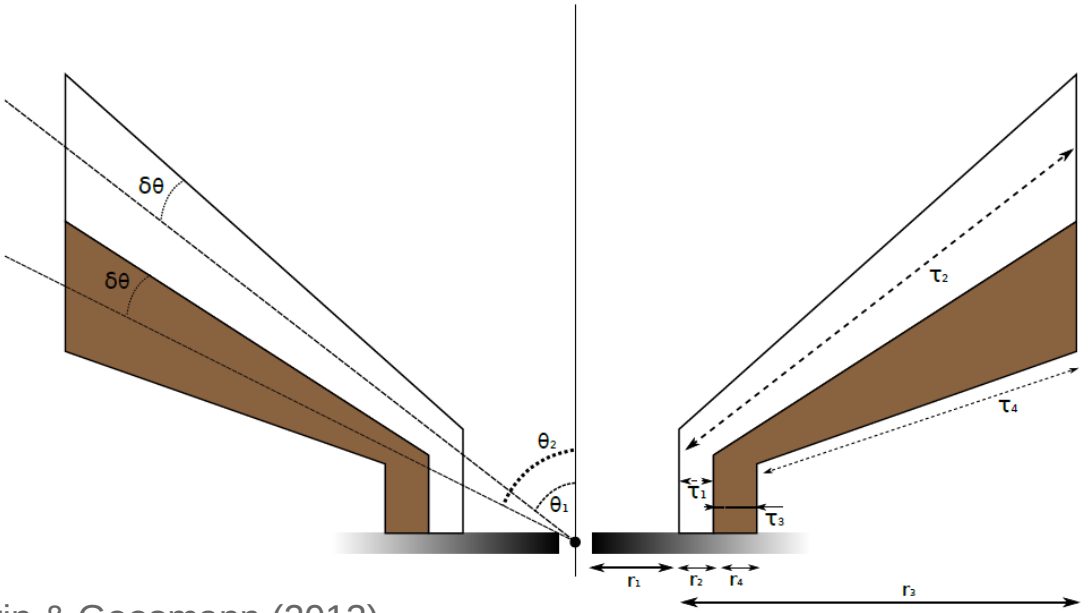
Towards dynamical, outflowing structures

Disk-born wind modeling

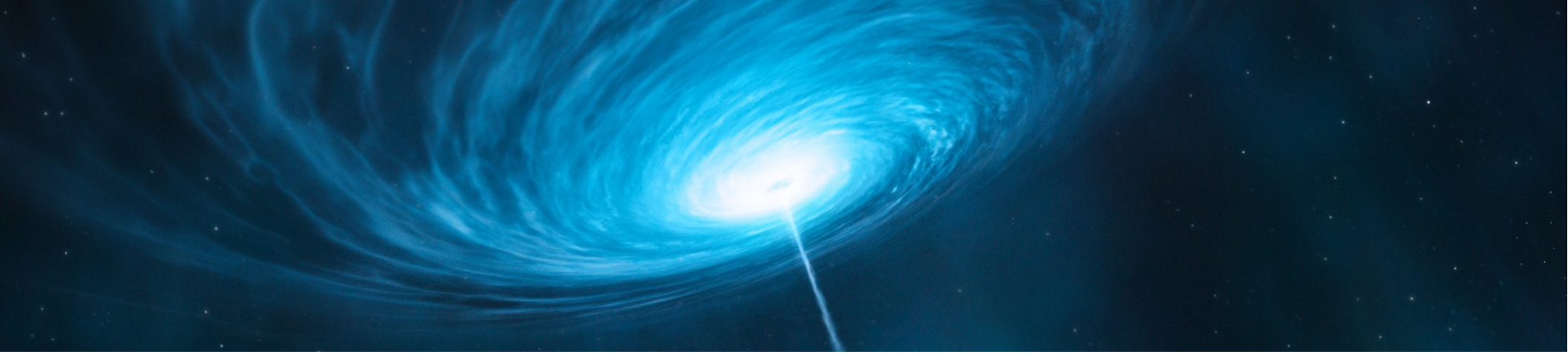
→ Dust may originate close to the accretion disk, shielded from the full continuum by the WHIM



Czerny & Hryniewicz (2012)



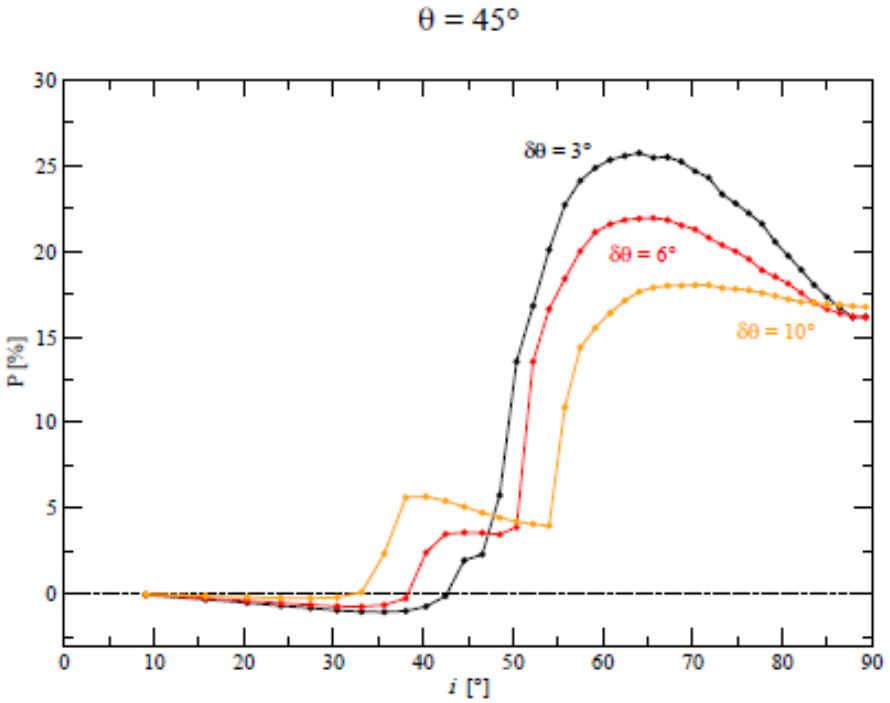
Marin & Goosmann (2013)

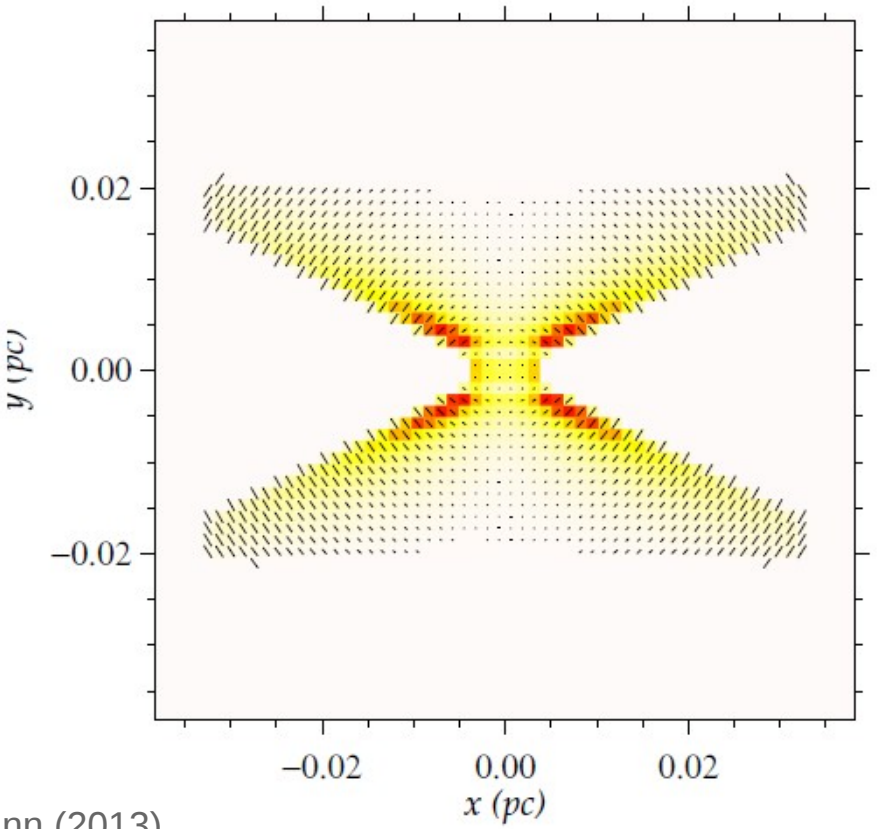


Disk-born winds

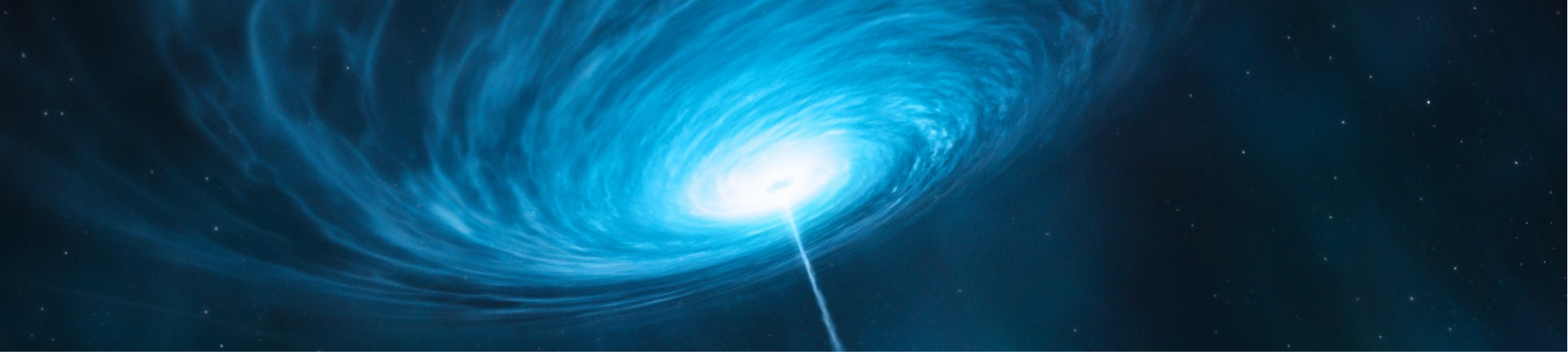
Towards dynamical, outflowing structures

Disk-born wind modeling





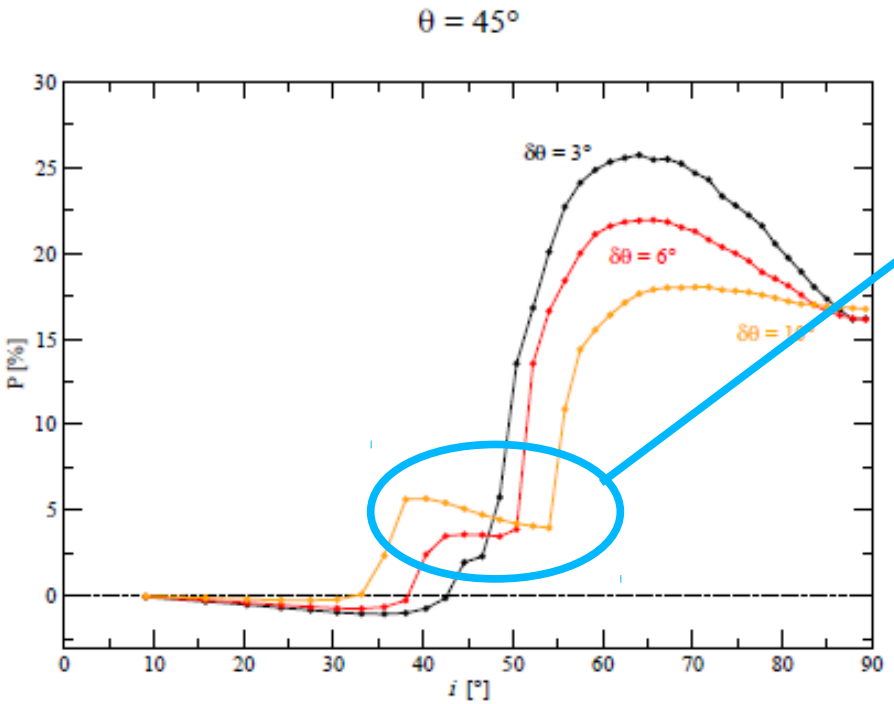
Marin & Goosmann (2013)



Disk-born winds

Towards dynamical, outflowing structures

Disk-born wind modeling



At inclinations 35° – 55°

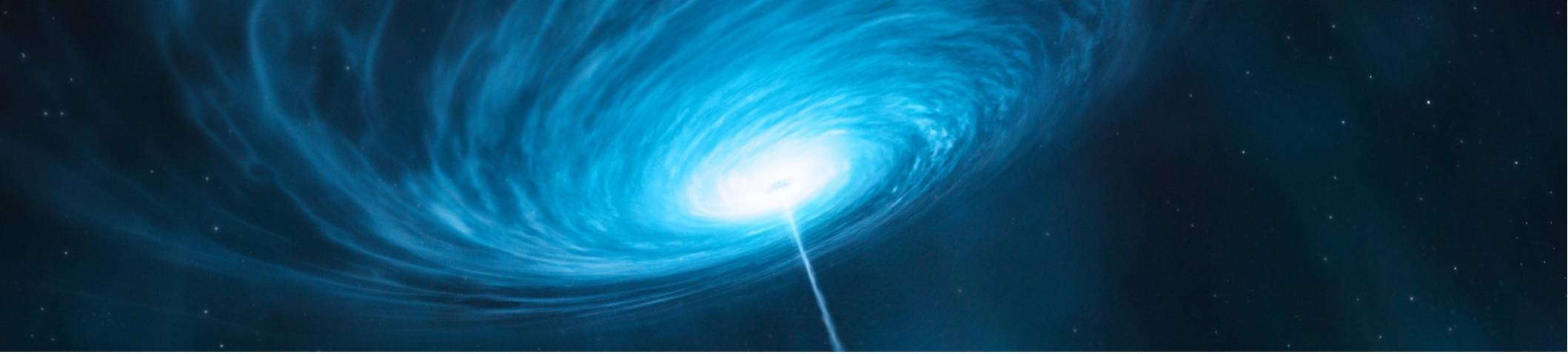
→ polarization plateau

P = 3% – 5%

perpendicular (positive) polarization

Strong prediction that could help to estimate the average δϑ of BAL-quasars

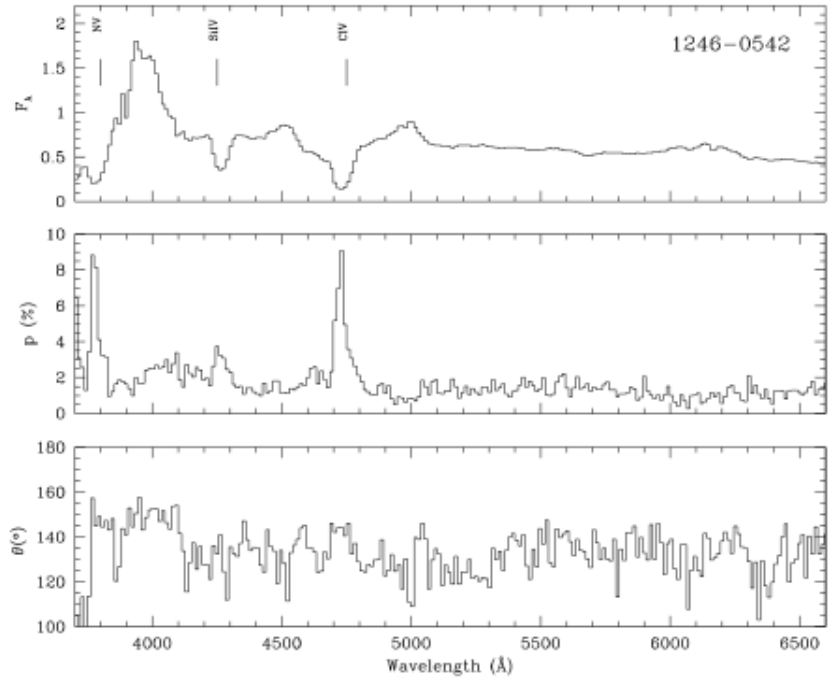
Marin & Goosmann (2013)



Disk-born winds

Towards dynamical, outflowing structures

Prediction supported by the spectropolarimetric observations performed on 6 individual BAL QSO by Lamy & Hutsemekers (2004a,b)



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Lamy & Hutsemekers (2004a)