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Roma Tre

The X-ray Polarimetry Explorer (IXPE) view of RQ AGN

Giorgio Matt (Univ. Roma Tre)
on behalf of the IXPE team

Plan of the talk

- **A brief introduction to the Imaging X-ray Polarimetry Explorer (IXPE)**

- **IXPE results on RQ AGN:**

Unobscured AGN: the geometry of the hot corona

Compton-Thick AGN: the structure of the "torus"

Plan of the talk

- **A brief introduction to the Imaging X-ray Polarimetry Explorer (IXPE)**

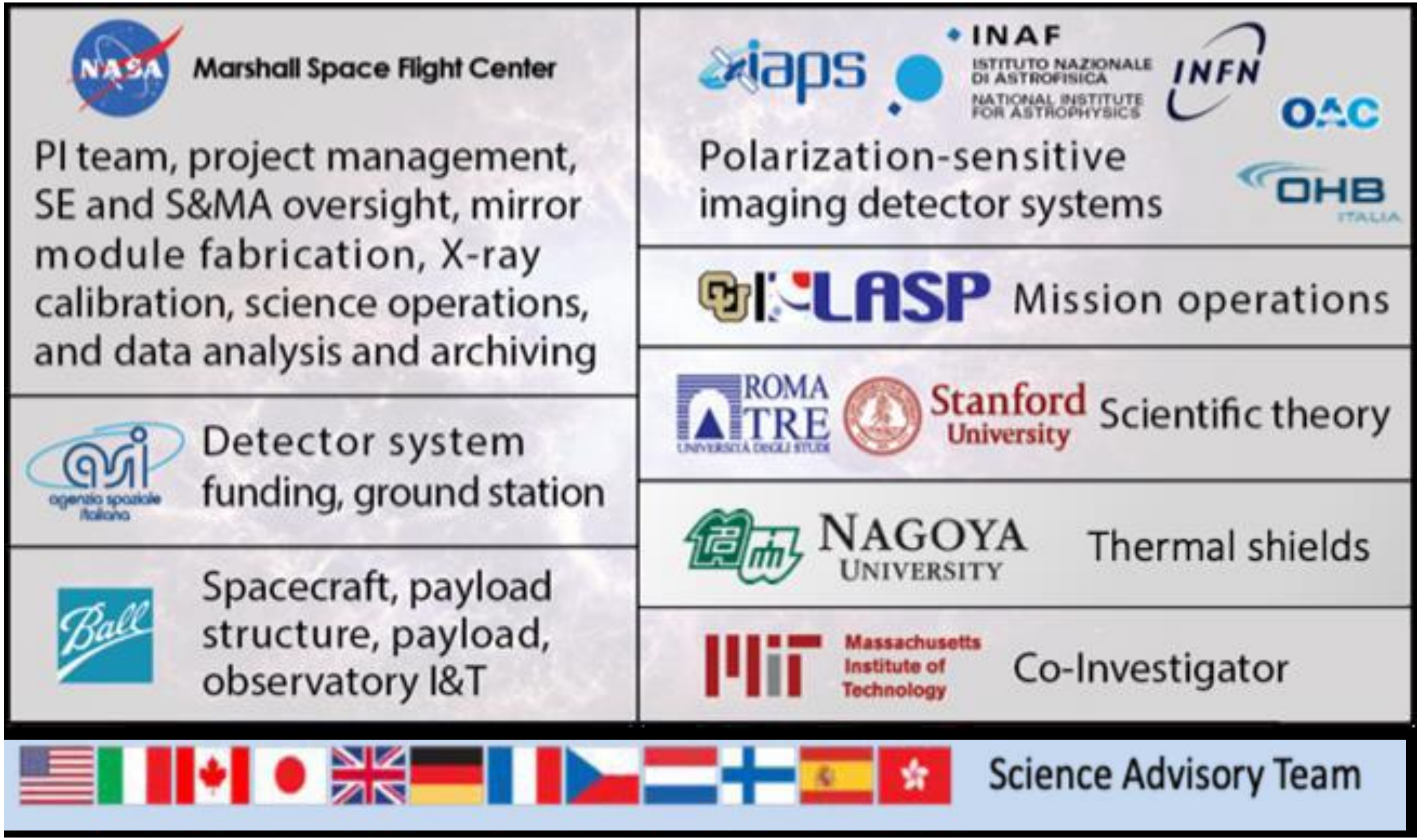
X-ray polarimetry

- **Before IXPE, only one positive measurement (Crab Nebula: 19%) in the classic X-ray band, dating back to the 70s (OSO-8)**
- **No X-ray polarimeters onboard X-ray satellites after OSO-8, due to lack of sensitive enough detectors**
- **Now such detectors do exist, based on the photoelectric effect**
- **The Imaging X-ray Polarimetry Explorer (IXPE) was selected by NASA in 2017 in the framework of the SMEX program, and launched in December 2021**
- **IXPE is providing a wealth of diverse and often surprising results**

IXPE mission description

- A NASA/ASI mission within the NASA's Small Explorer Program (SMEX)
- Launched December 9, 2021 on a Falcon 9 from KSC
- 600-km circular orbit at a nominal 0° inclination
- 2-year baseline mission, now extended with GO program
- Point and stare (with dither) at pre-selected targets
- Malindi ground station - primary (Singapore - secondary)
- Mission Operations Center (MOC) at the University of Colorado, Laboratory for Atmospheric and Space Physics (LASP)
- Sciences Operations Center (SOC) at MSFC
- Data archiving at NASA's HEASARC – No proprietary rights, neither in the baseline phase nor in the present GO phase

IXPE Team



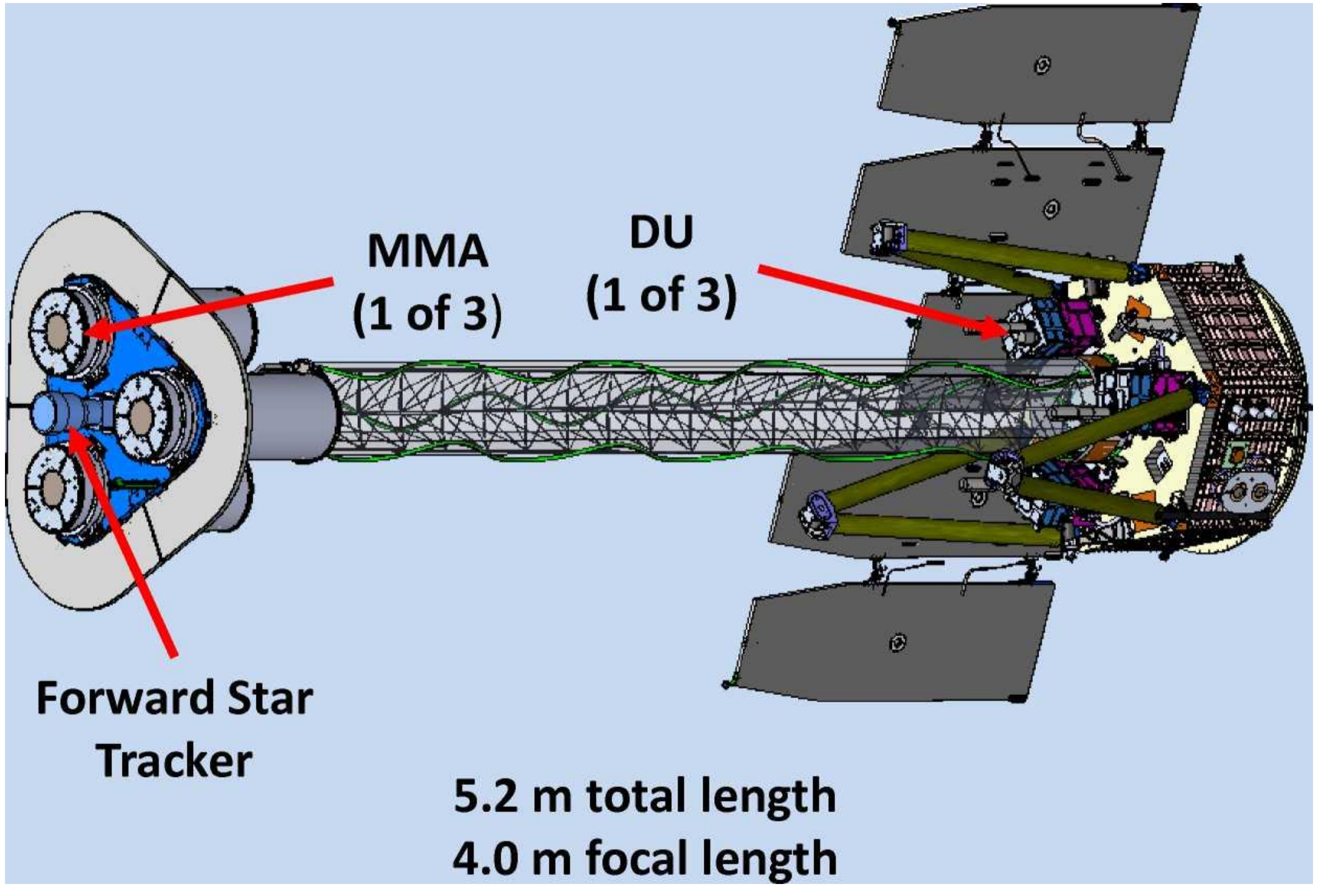
SAT currently comprises > 100 scientists from 12 countries

PI: Phil Kaaret, MSFC

(formerly Martin Weisskopf)

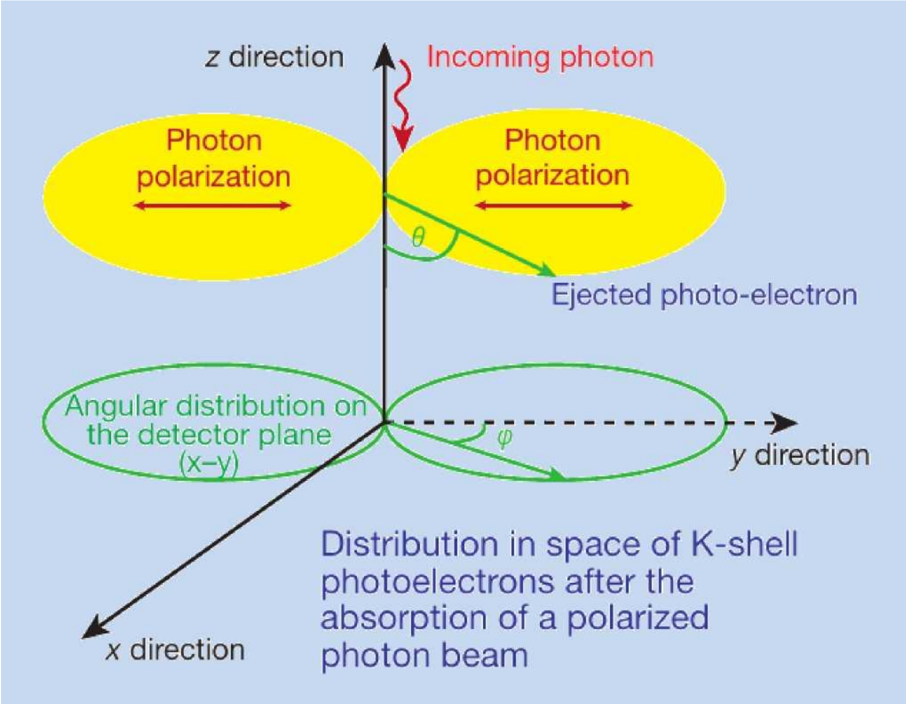
IXPE in a nutshell

- *Energy range: 2-8 keV*
- *Spatial resolution: 30'' (FWHM)*
- *FOV=13'*
- *Energy resolution: 0.57 keV @ 2 keV (FWHM)*

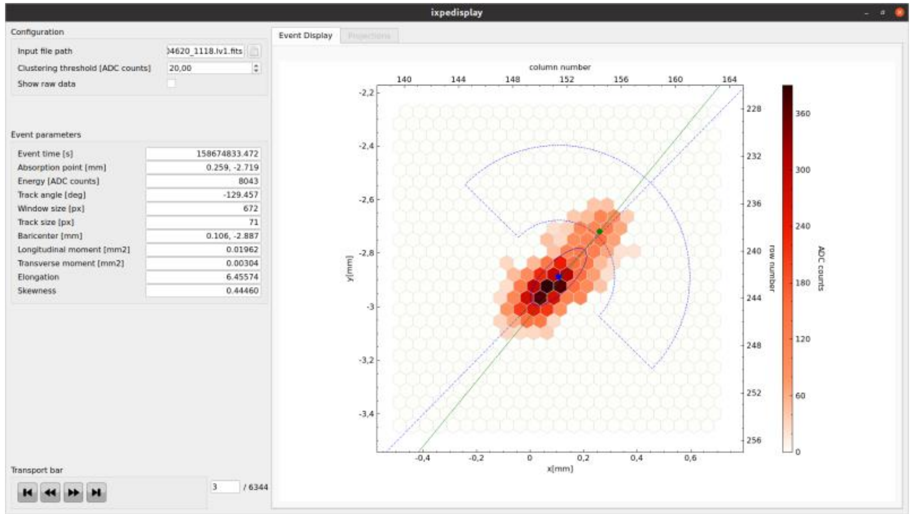


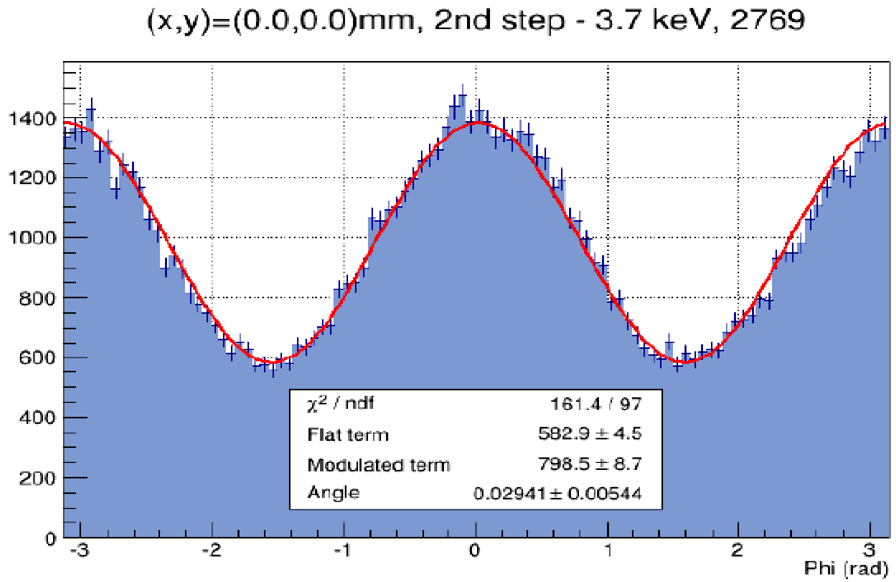
Polarization Detection Principle

The detection principle is based on the photoelectric effect



$$\frac{\partial\sigma}{\partial\Omega} = r_0^2 \frac{Z^5}{137^4} \left(\frac{mc^2}{h\nu}\right)^{7/2} \frac{4\sqrt{2}\sin^2(\theta)\cos^2(\varphi)}{(1-\beta\cos(\theta))^4}$$





Observing Program

The IXPE baseline mission was funded for two years, and finished on January 31, 2024. Observation program defined by the IXPE team

A “bridge” extension till September 2025 granted by NASA, waiting for the standard call for mission extensions in 2025

A General Observer Program issued in 2023. GO1 started February 1, 2024. Oversubscription larger than 6

Deadline for GO2 proposals was August 29, 2024. Joint programs with NICER, NuSTAR and Swift

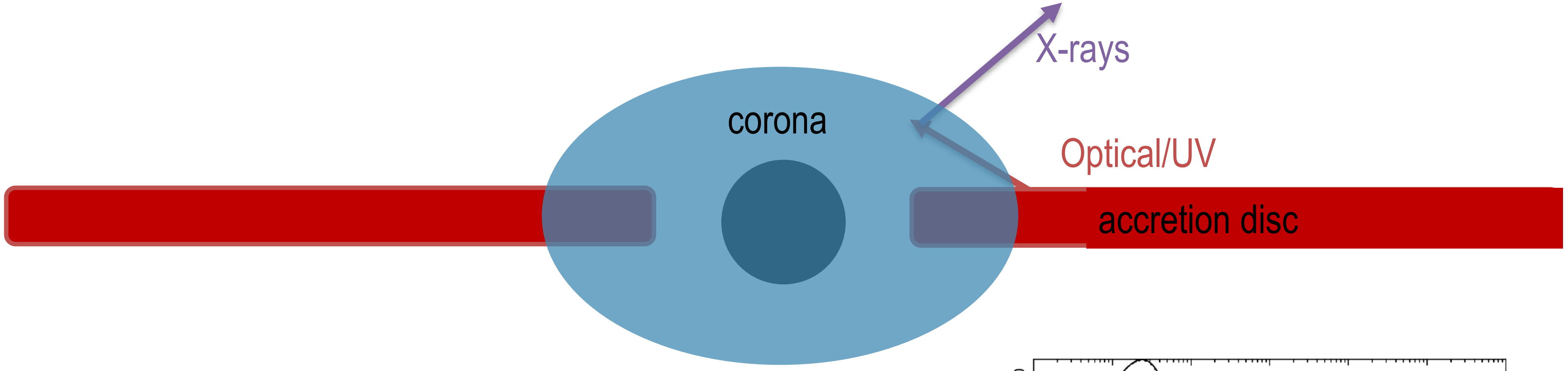
Plan of the talk

- **IXPE results on RQ AGN:**

Unobscured AGN: the geometry of the hot corona

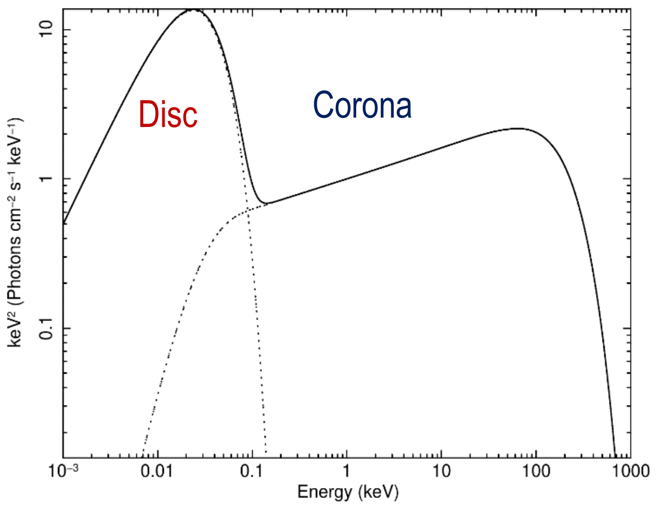
Unobscured Radio Quiet AGN

In AGN the primary X-ray emission is due to Comptonization by electrons in a hot corona of the UV/soft X-ray disc photons (Shapiro et al. 1976; Sunyaev & Titarchuk 1980; Haardt & Maraschi 1991)



Cutoff power law $F_E \sim E^{-\Gamma} \exp(-Ec/kT)$
$\Gamma = \Gamma(kT,\tau)$, while Ec depends on kT

Temperature kT ~ 10-100 keV
Thomson optical depth ~ 1



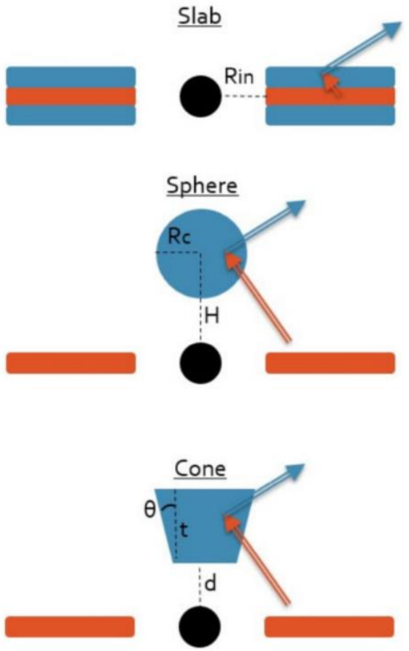
Unobscured Radio Quiet AGN

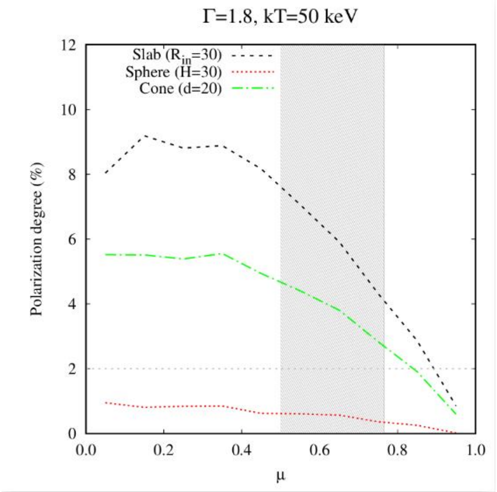
X-ray spectroscopy can constrain the physical parameters of the corona.

However, it is almost insensitive to its shape and location.

Polarimetry, on the contrary, is very sensitive to the geometry of the corona, and can measure deviations from a spherical symmetry.

The coronal geometry is related to its physical origin.



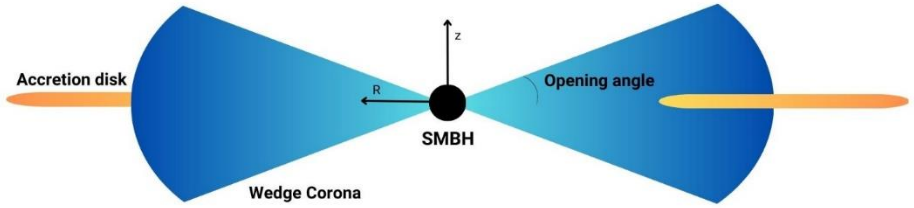


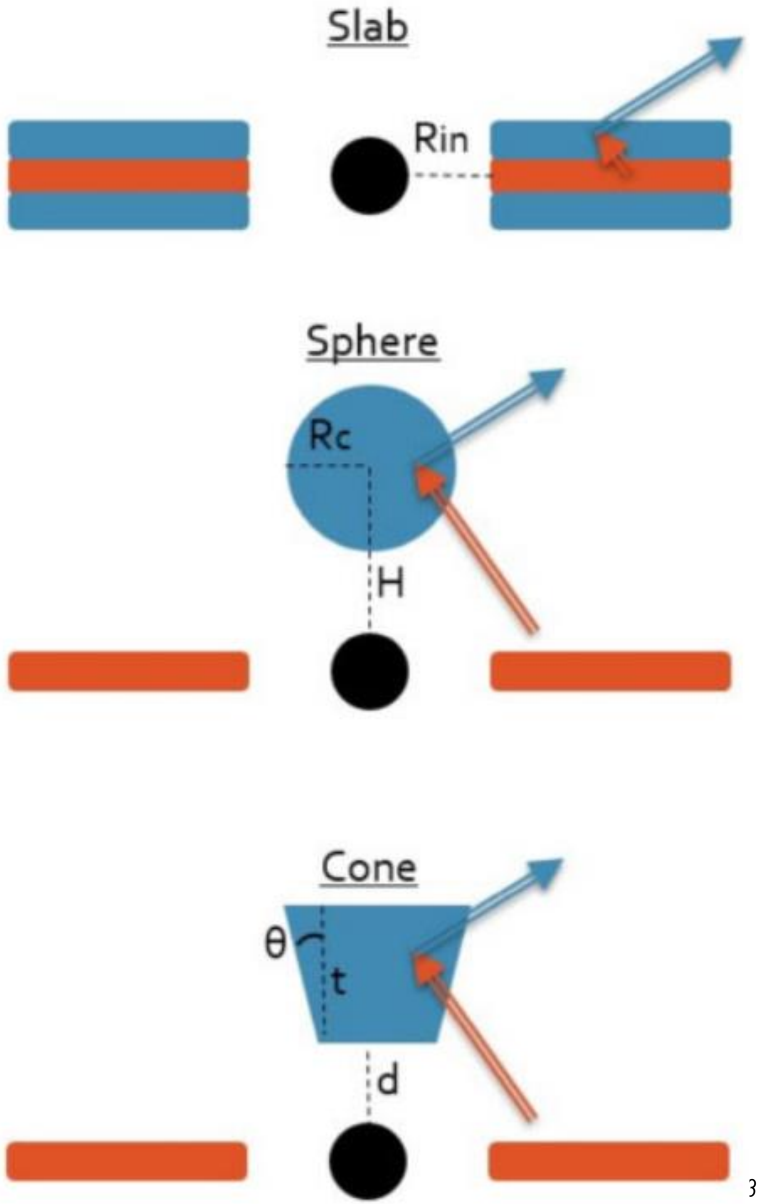
Unobscured Radio Quiet AGN

MonteCarlo simulations normally used to predict the polarization properties. Many codes available.

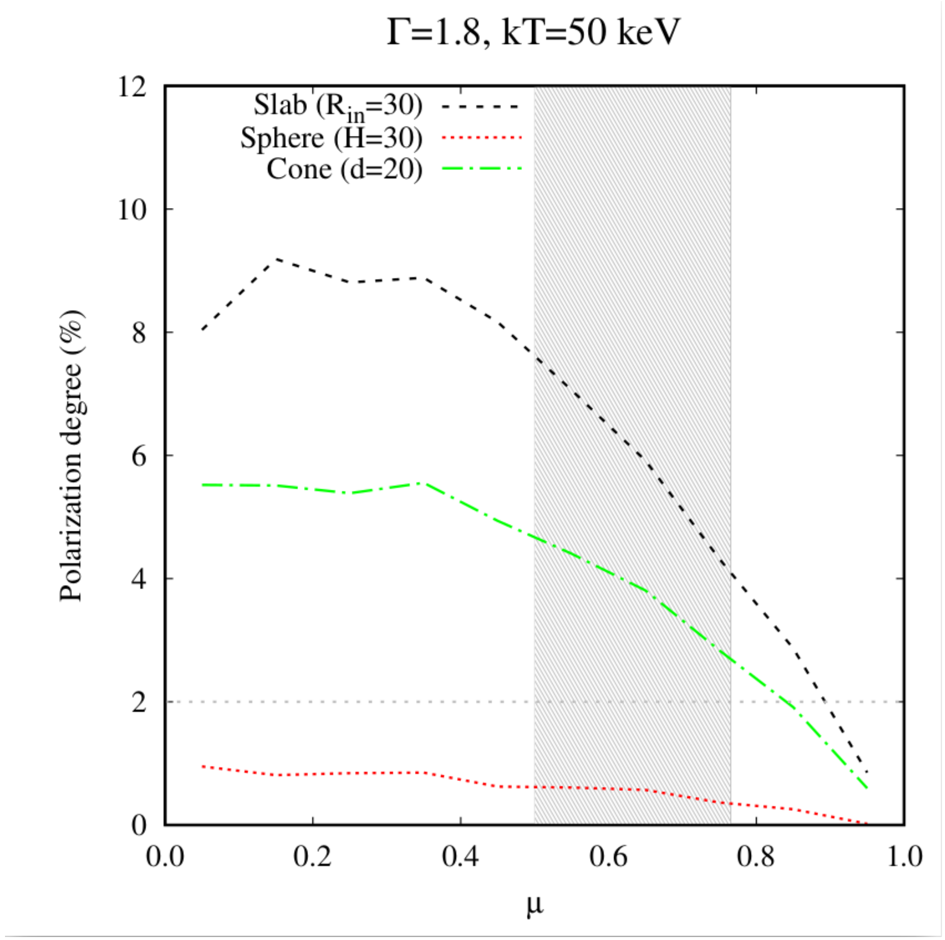
We performed numerical simulations of the expected coronal polarization with the Monte-Carlo radiative transfer code MONK (Zhang et al. 2019), which includes also special and general relativistic effects. Pure thermal plasma assumed (Maxwell-Jüttner distribution)

We explored different configurations and physical parameters of the disc/corona/BH system: e.g. a slab, a wedge, a spherical lamppost, an outflowing (v=0.3 c) cone (Ursini et al. 2022, Tagliacozzo et al. 2023)

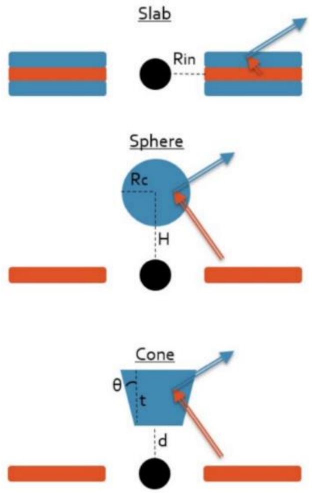




Unobscured Radio Quiet AGN



MCG-5-23-16



Polarization from slab and wedge geometries much higher than for spherical lamppost geometries.

Intermediate values for the conical geometry

Polarization either parallel or perpendicuar to the accretion disc

The exact values depends on the temperature and optical depth → need for good spectroscopic simultaneous observations

IXPE Imaging X-Ray Polarimetry Explorer

IXPE results on Unobscured Radio Quiet AGN

To study the geometry of the hot corona in AGN three bright Compton-thin Seyfert galaxies have been observed by IXPE

MCG-05-23-16 May/November 2022 (Marinucci et al. 2022, Tagliacozzo et al. 2023)
$M_{BH}=2\times10^7\ M_{sun}$ (Ponti et al. 2012)

IXPE: 486 ks+642 ks

XMM-Newton: 58 ks/none -- NuSTAR: 83 ks/85ks

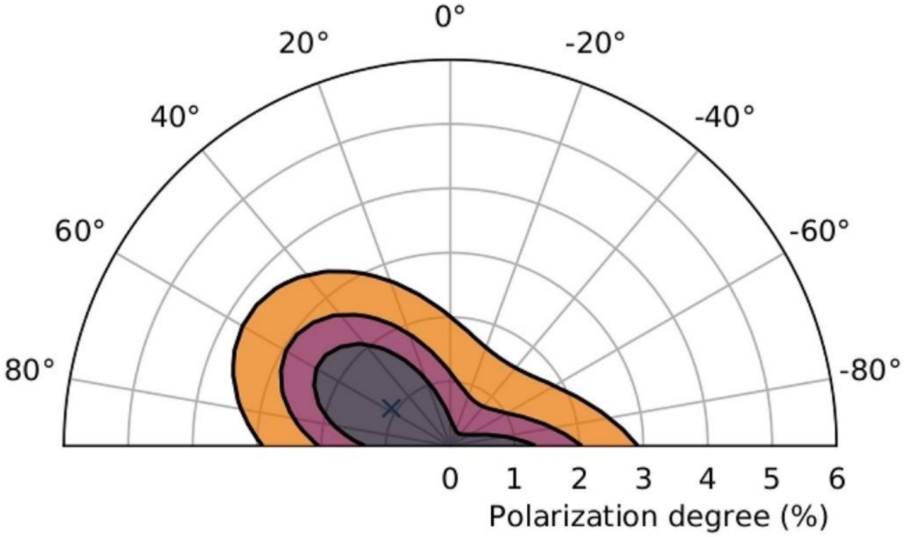
NGC 4151 December 2022 (Gianolli et al. 2023)
$M_{BH}=4.6\times10^7\ M_{sun}$ (Bentz et al. 2006)
IXPE: 632 ks

XMM-Newton: 33 ks -- NuSTAR: 97 ks

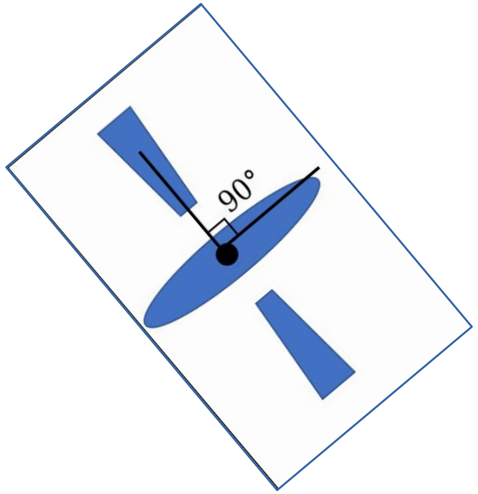
IC 4329A January 2023 (Ingram et al. 2023)
$M_{BH}=7\times10^7\ M_{sun}$ (Bentz et al. 2023)
IXPE: 458 ks

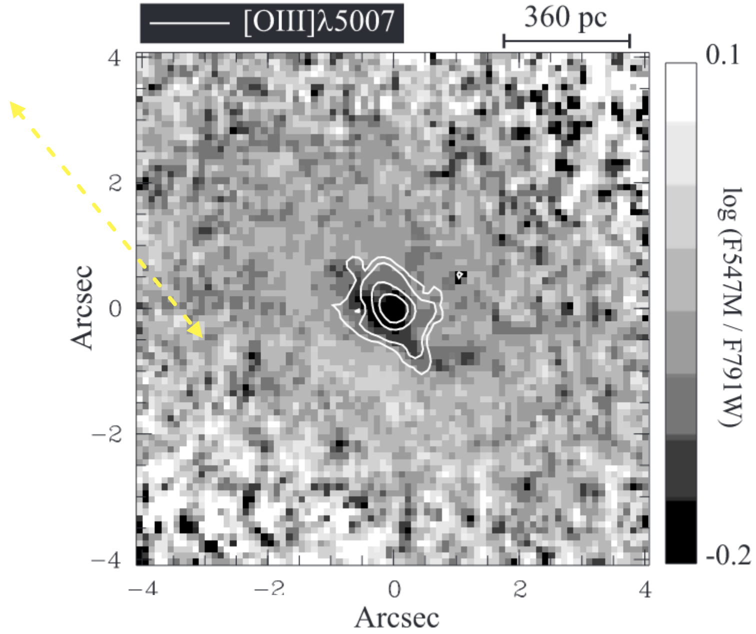
XMM-Newton: 62 ks -- NuSTAR: 82 ks

MCG-5-23-16

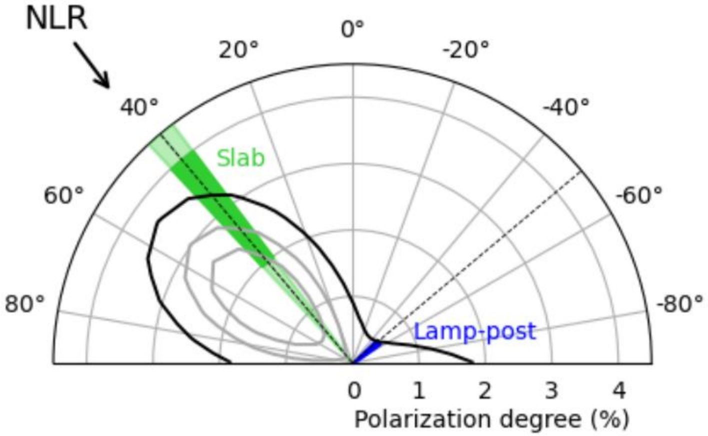


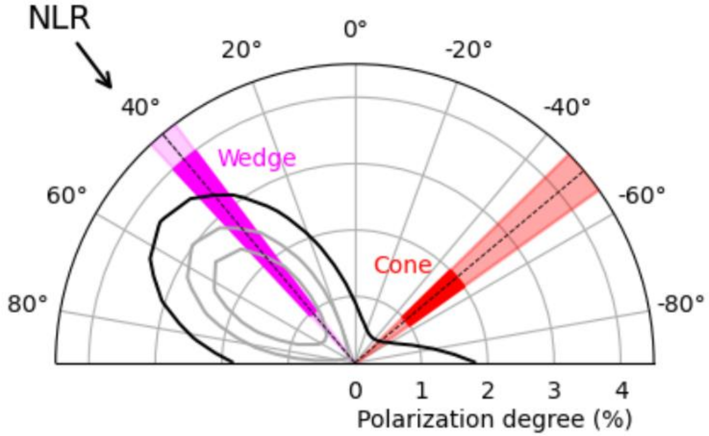
Tagliacozzo et al. 2023





Ferruitt et al. 2000





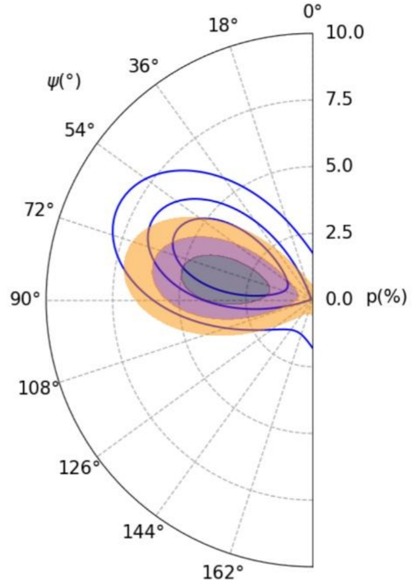
P < 3.2 %

IC 4329A

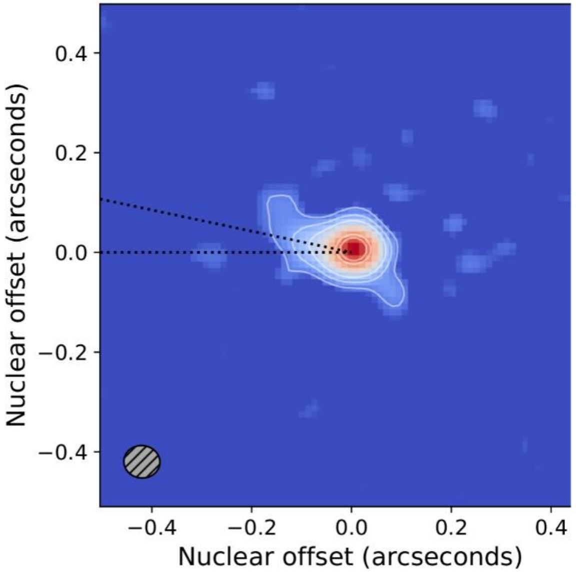
Strictly speaking, an upper limit.

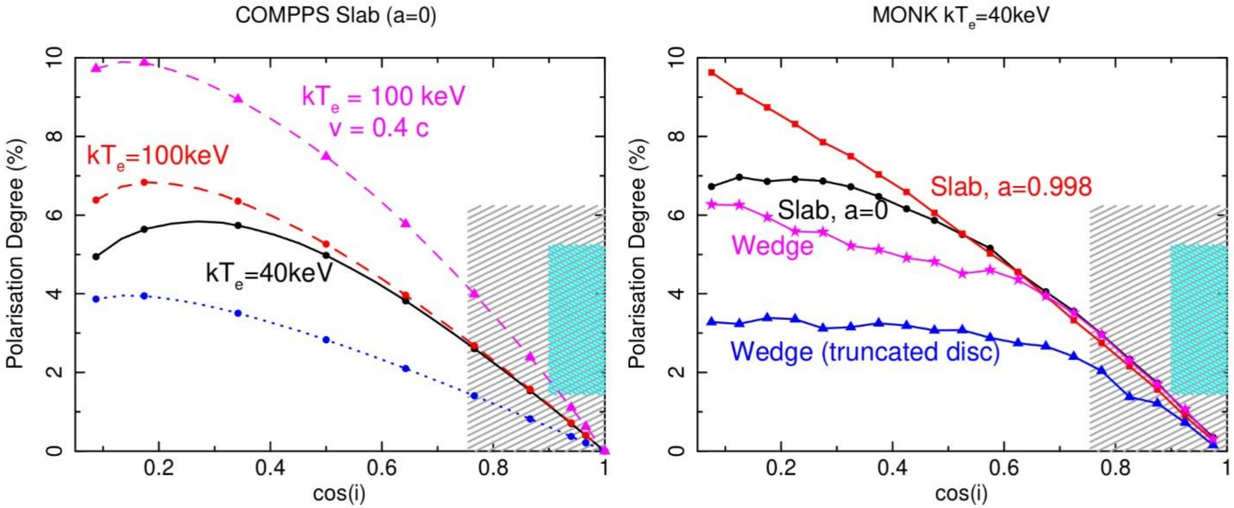
However, a 2.97σ result with P=3.3%

Ingram et al. 2023

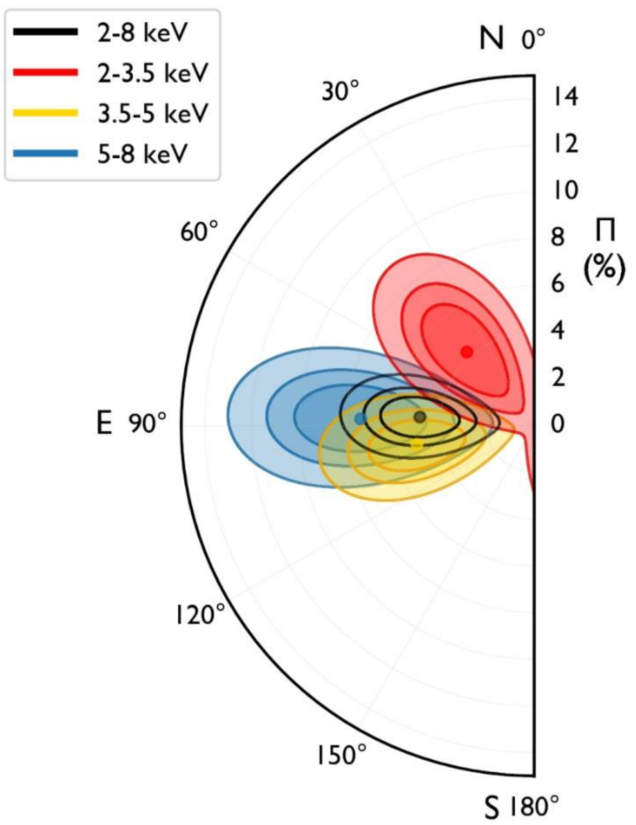


ALMA image at 100 GHz



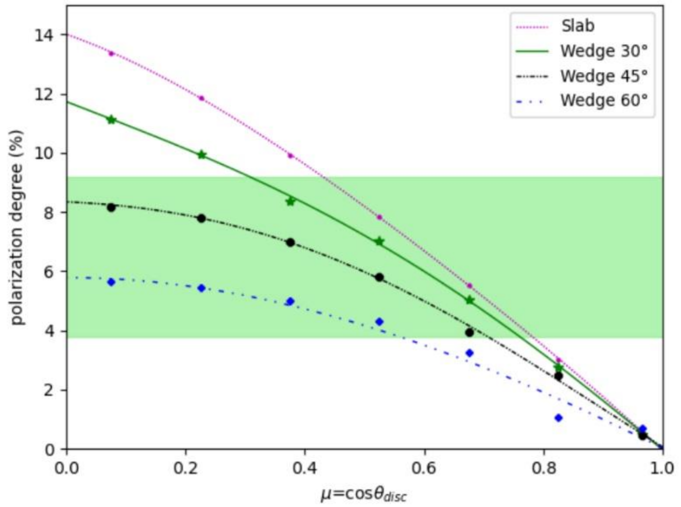


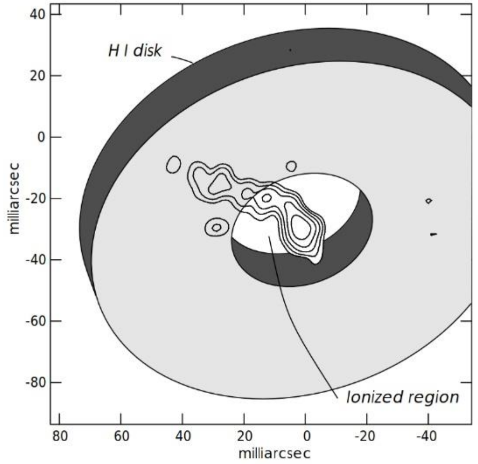
NGC 4151



2023

P=4.9±1.1% in the 2-8 keV range





Ulvestad et al. 1998

The measured Ψ is in the direction of the radio emission (P.A.~83°: Wilson & Ulvestad 1982, Harrison et al. 1986, Pedlar et al. 1993)

The polarization degree and angle disfavours the lamppost geometry for the hot corona.

Re-observed in GO1.
See next talk by Vittoria Gianolli

Plan of the talk

- **IXPE results on RQ AGN:**

Compton-Thick AGN: the structure of the "torus"

Compton-thick AGN

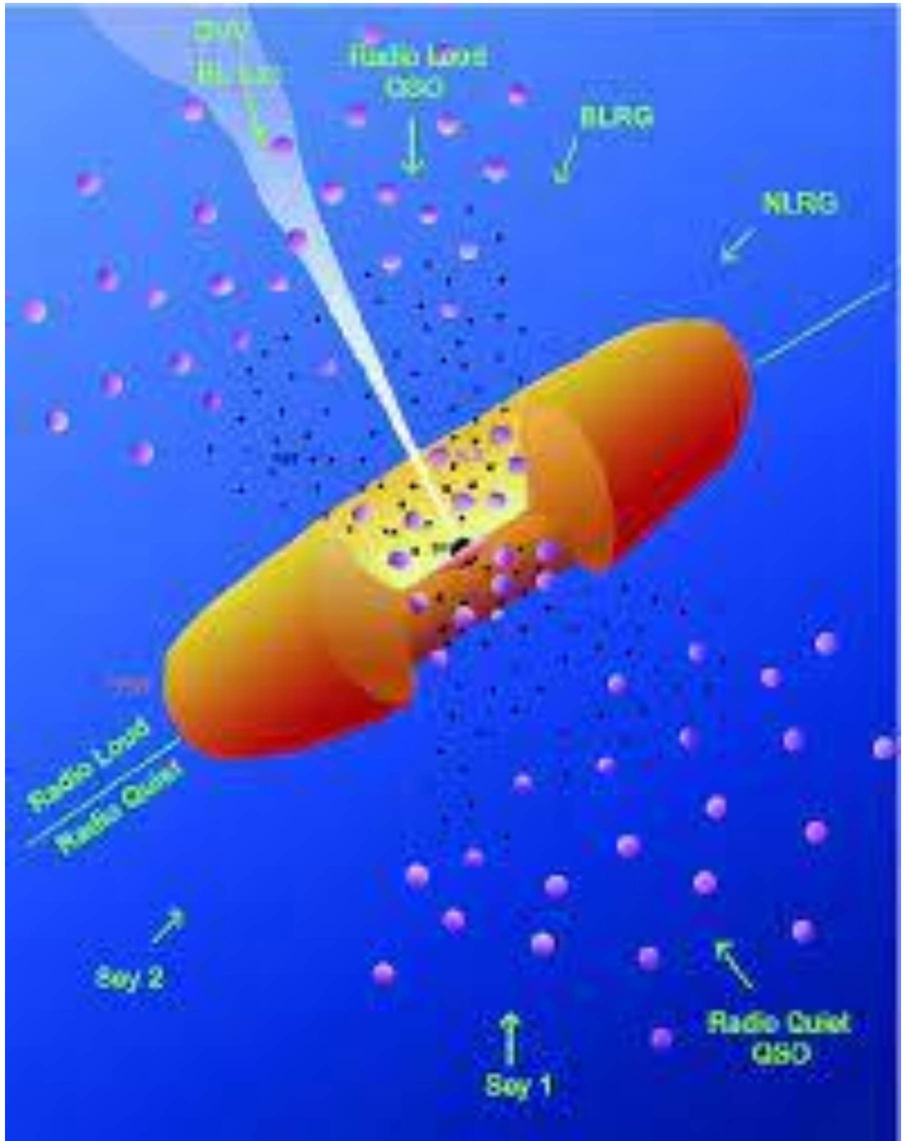
X-ray emission is dominated by reflection, so it should be highly polarized.

Polarization degree from the torus depends on the geometry of the system (inclination angle, torus opening angle)

The polarization vector is expected to be orthogonal to the torus axis.

The ionization cone/NLR may also scatter (and polarize) the primary emission.

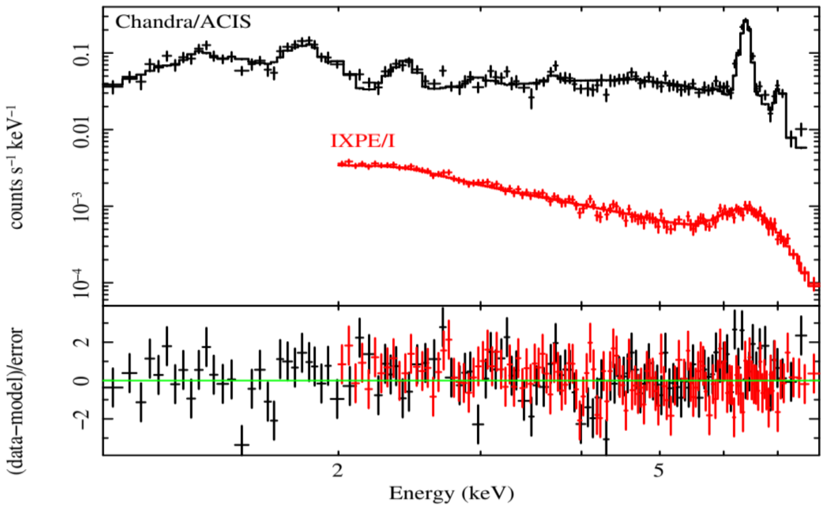
Polarization vectors from ionization cone and torus are the same, if coaligned.

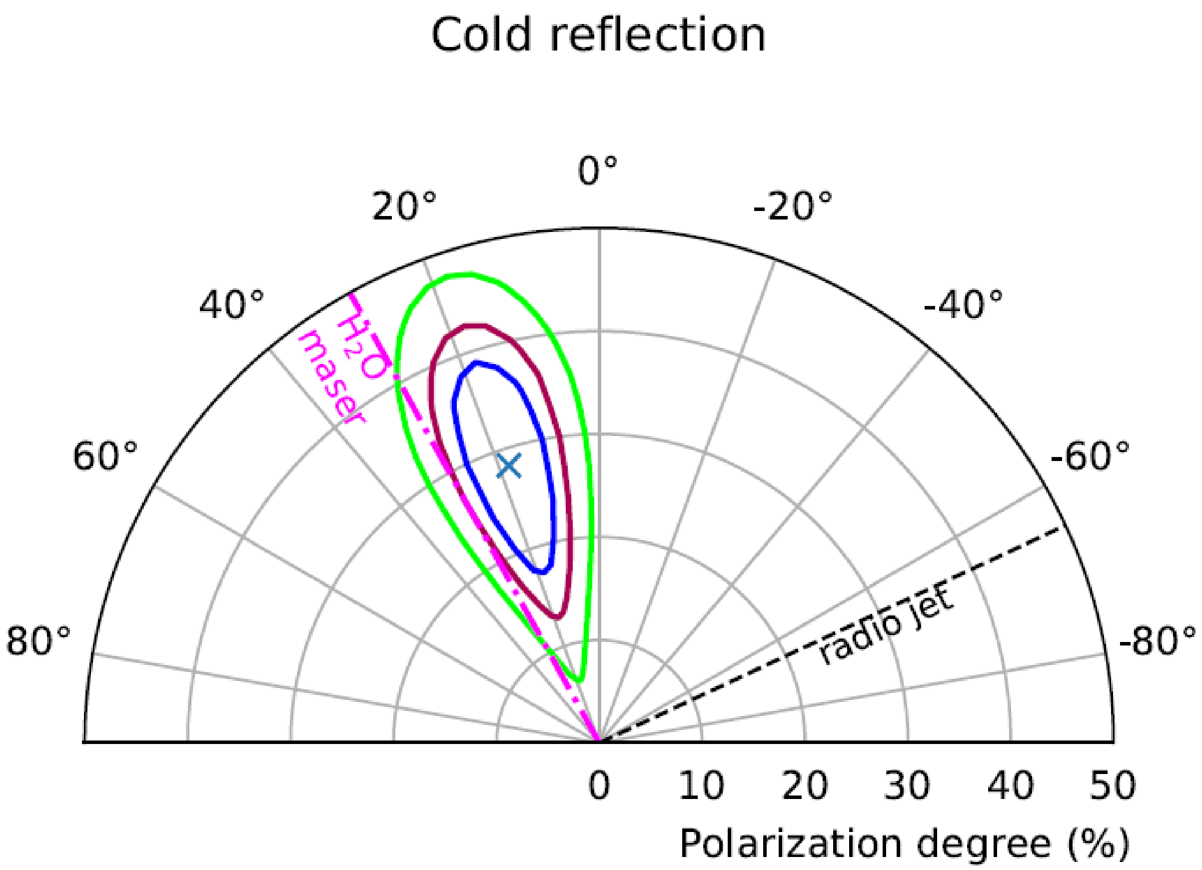


The Circinus Galaxy

IXPE observed the Circinus Galaxy for about 800 ks, along with two Chandra snapshots to monitor the ULXs in Circinus.

A high polarization degree (about 30%) is found, perpendicular to the radio jet (and the ionization cone)





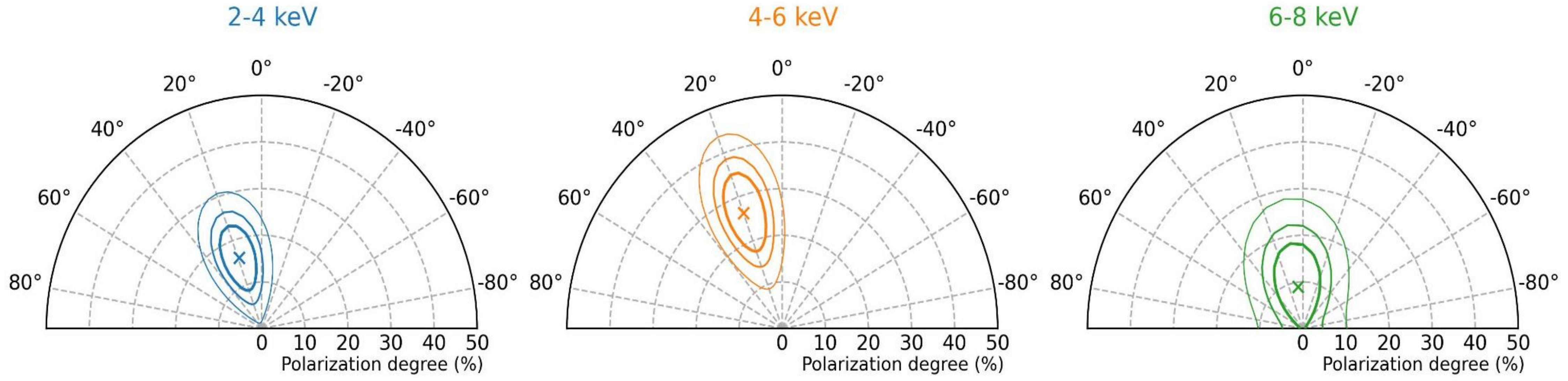
Ursini et al. 2023

The Circinus Galaxy

The spectro-polarimetric analysis shows for the cold reflector:

- PD = 28% ± 7%
- PA = 18° ± 5°, perpendicular to radio jet

Energy	P.D. (%)	P.A. (deg)
2–8 keV	17.6 ± 3.2	16.9 ± 5.3
2–4 keV	16.0 ± 4.9	19.1 ± 8.9
4–6 keV	26.3 ± 5.7	20.2 ± 7.5
2–6 keV	20.0 ± 3.8	19.1 ± 5.5
6–8 keV	< 24.5	-



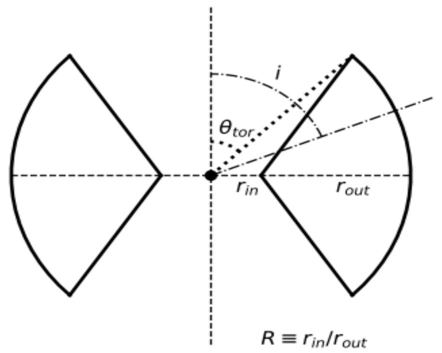
Ursini et al. 2023

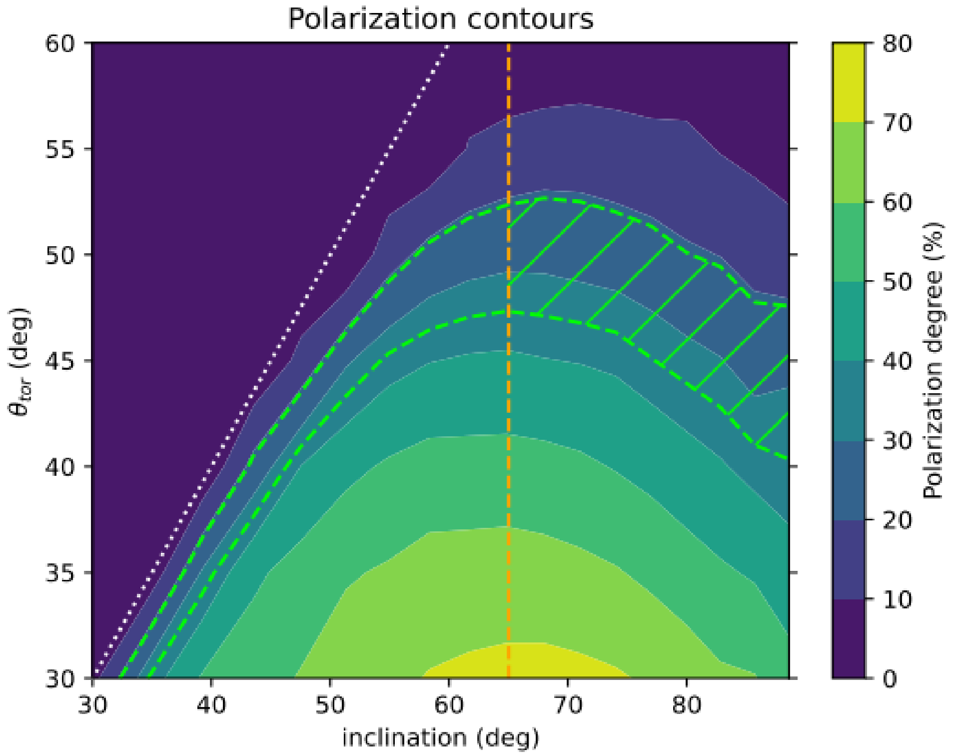
The Circinus Galaxy

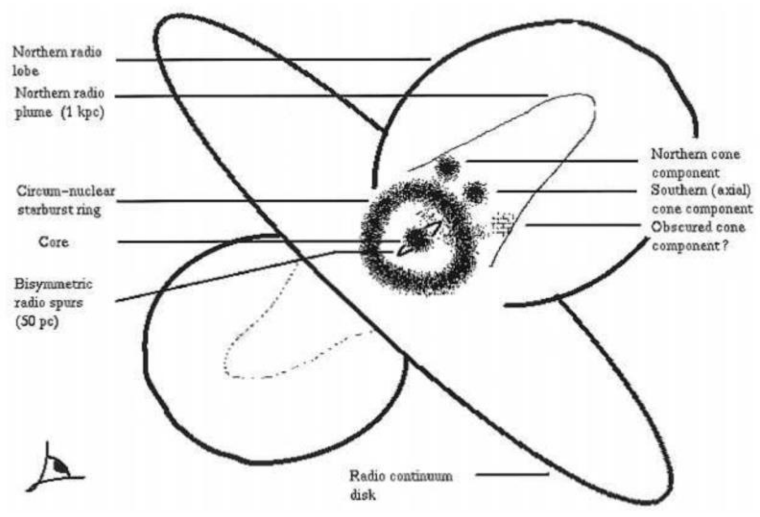
Ursini et al. 2023

Also constrains torus geometry: opening angle likely in the 45-55 deg range, if an inclination of 65 deg is assumed (slightly lower values for higher inclinations).

More sophisticated modeling with the SKIRT code, see talk by Bert Vander Meulen later on







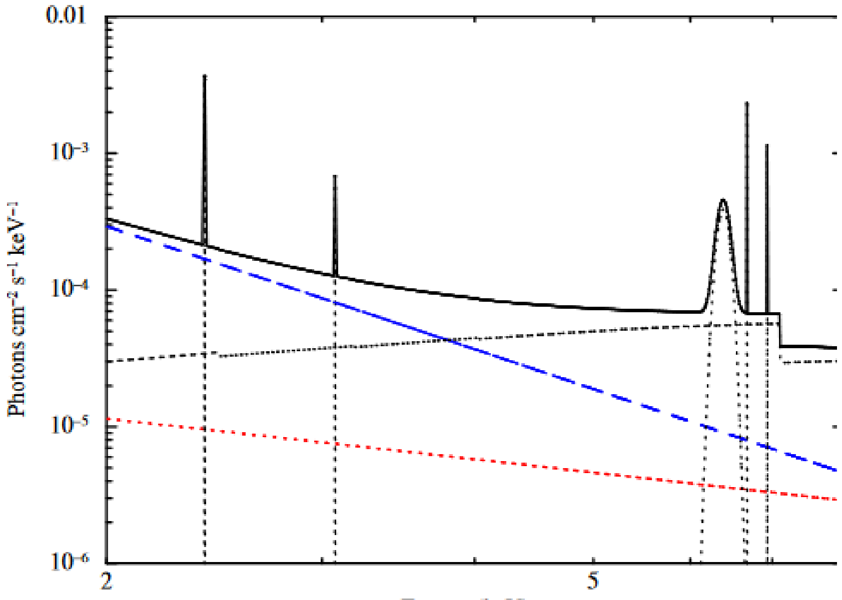
Elmouttie et al. 2008

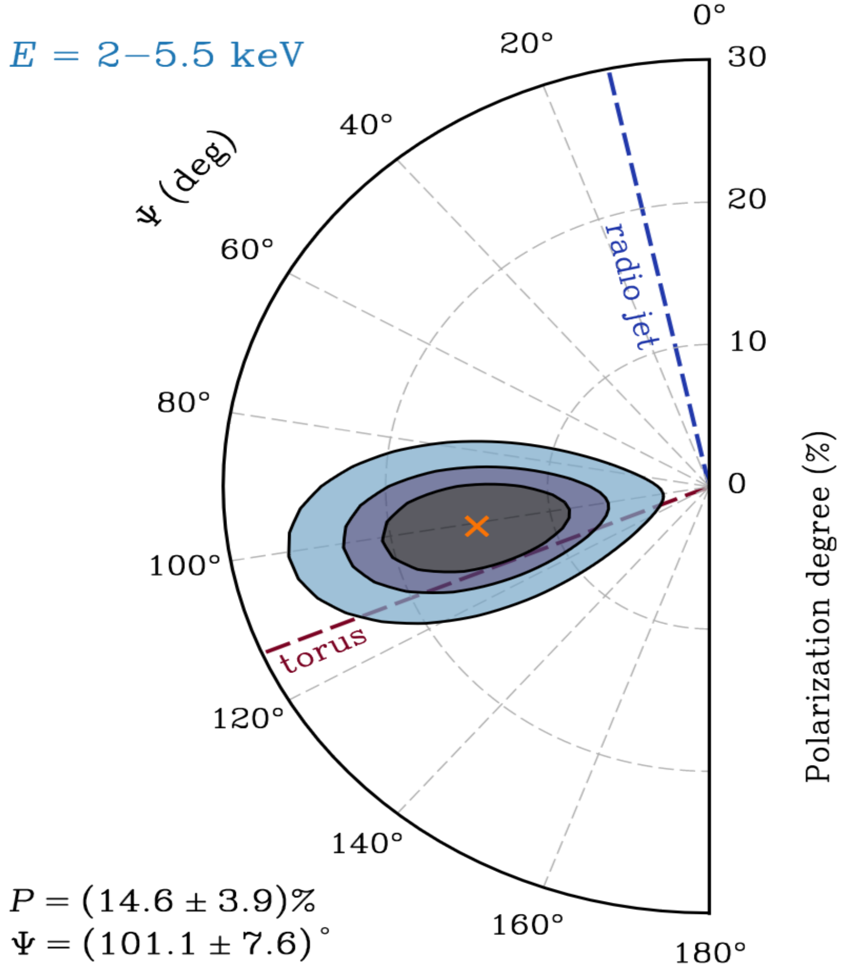
NGC 1068

IXPE observed NGC 1068 for about 1200 ks, along with two Chandra snapshots to monitor the ULXs.

A polarization degree of about 15% is found in the 2-5.5 keV range, again perpendicular to the radio jet.

Torus is less dominant in the IXPE band than in Circinus



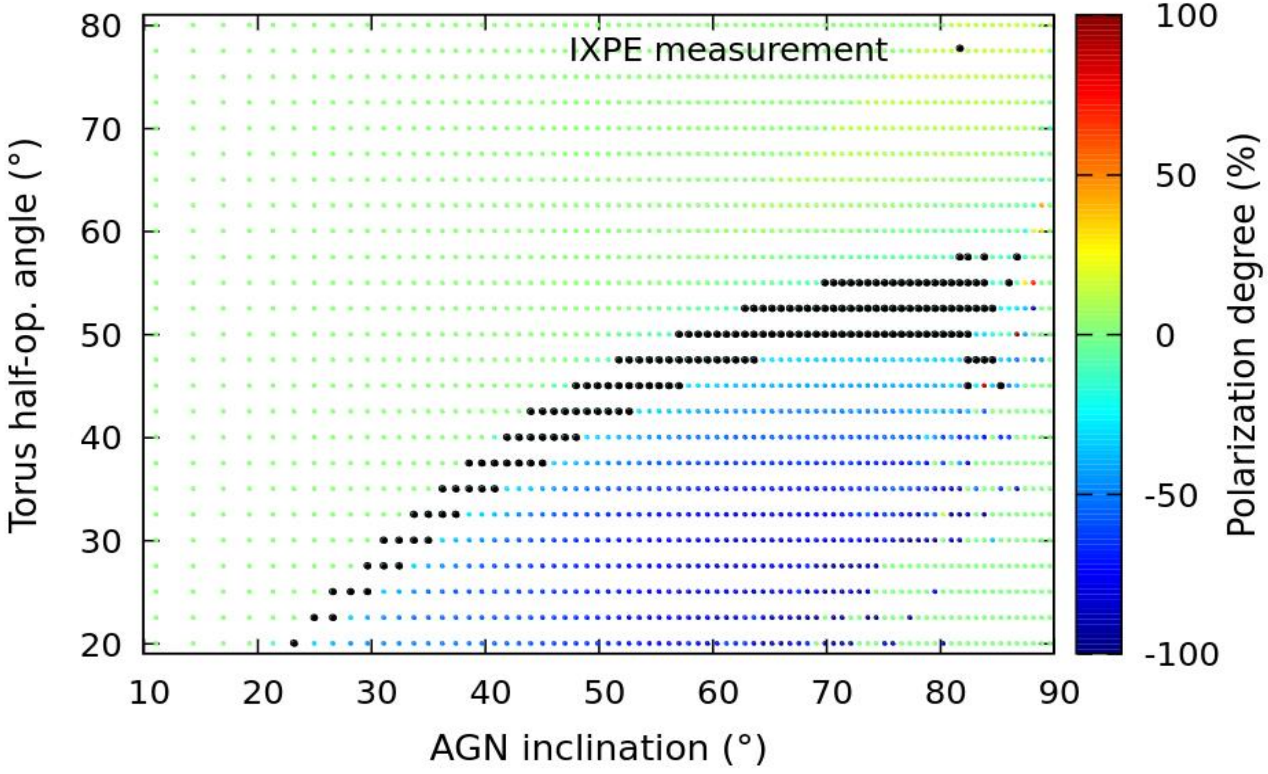


Marin et al. 2024

NGC 1068

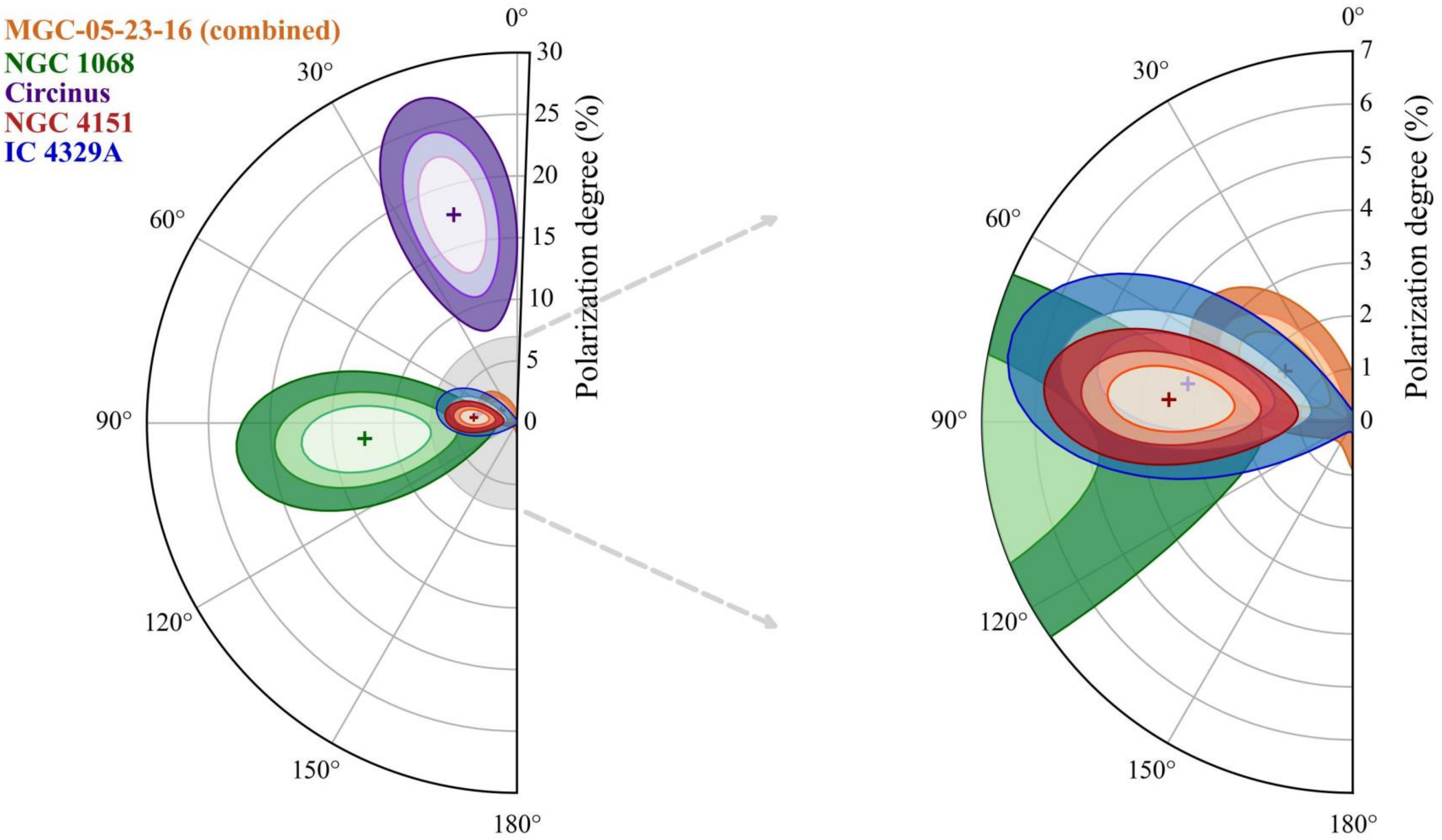
The spectropolarimetric analysis indicates a torus polarization degree of about 20%

Numerical simulations with STOKES suggest a half opening angle of 50-55 deg



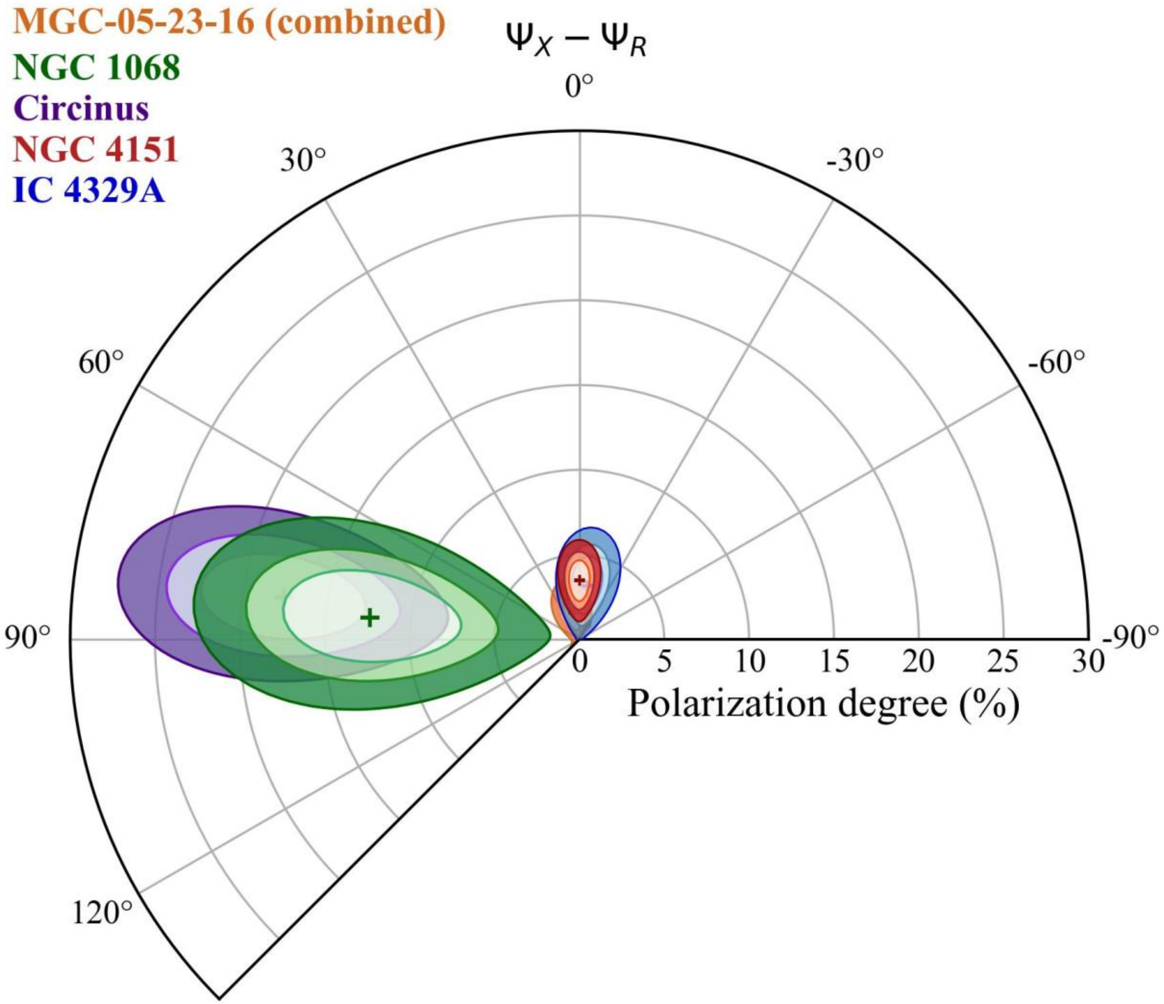
Marin et al. 2024

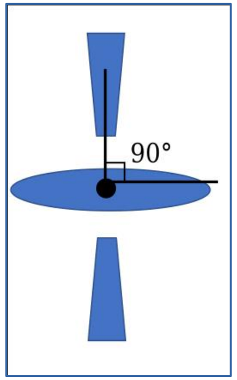
Summary



Marin et al. 2024b

Summary


MGC-05-23-16 (combined)
NGC 1068
Circinus
NGC 4151
IC 4329A
$\Psi_X - \Psi_R$
0°
30°
-30°
60°
-60°
90°
-90°
120°
0
5
10
15
20
25
30
Polarization degree (%)


90°

Thanks for your attention