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Polarization properties of direct radiation in stellar-mass black hole accretion disks

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IAPS - INAF Rome

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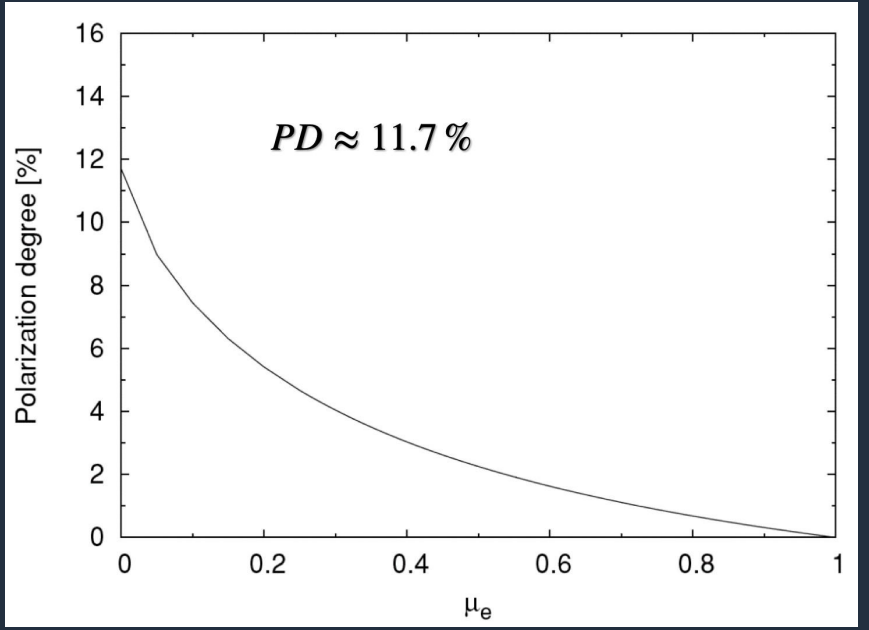
11th FERO meeting - 25-27 November 2025

Introduction - Accretion disk emission polarization properties

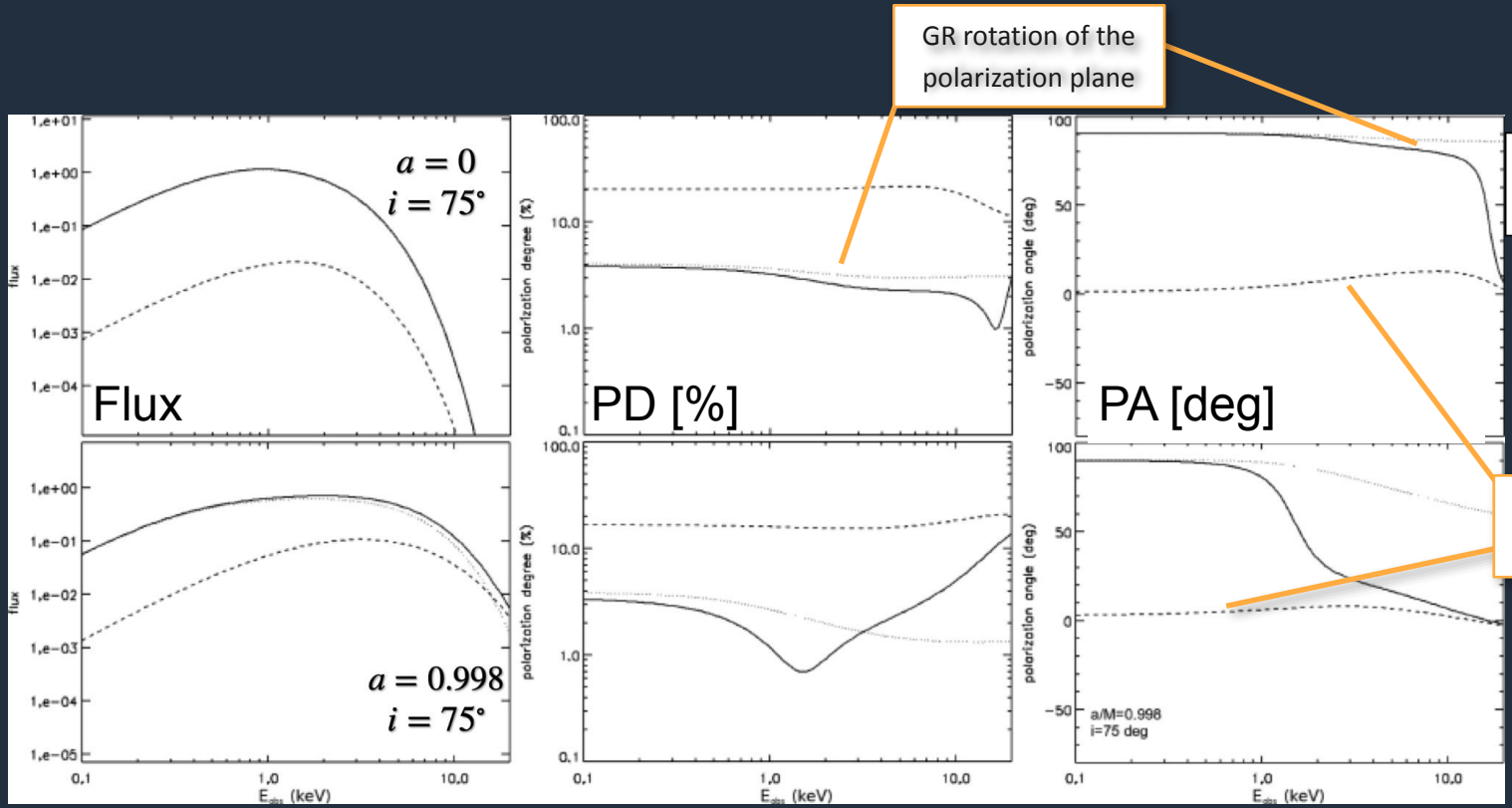
- Accretion disk emission is polarized because of the **scattering processes** occurring within the disk atmosphere

- **Symmetry**: polarization vector can be either parallel or perpendicular to the disk symmetry axis
- **Chandrasekar (1960)** and **Sobolev (1963)** computations for radiation emerging from **a plane-parallel, semi-infinite, pure electron-scattering atmophere (τ >>1).**



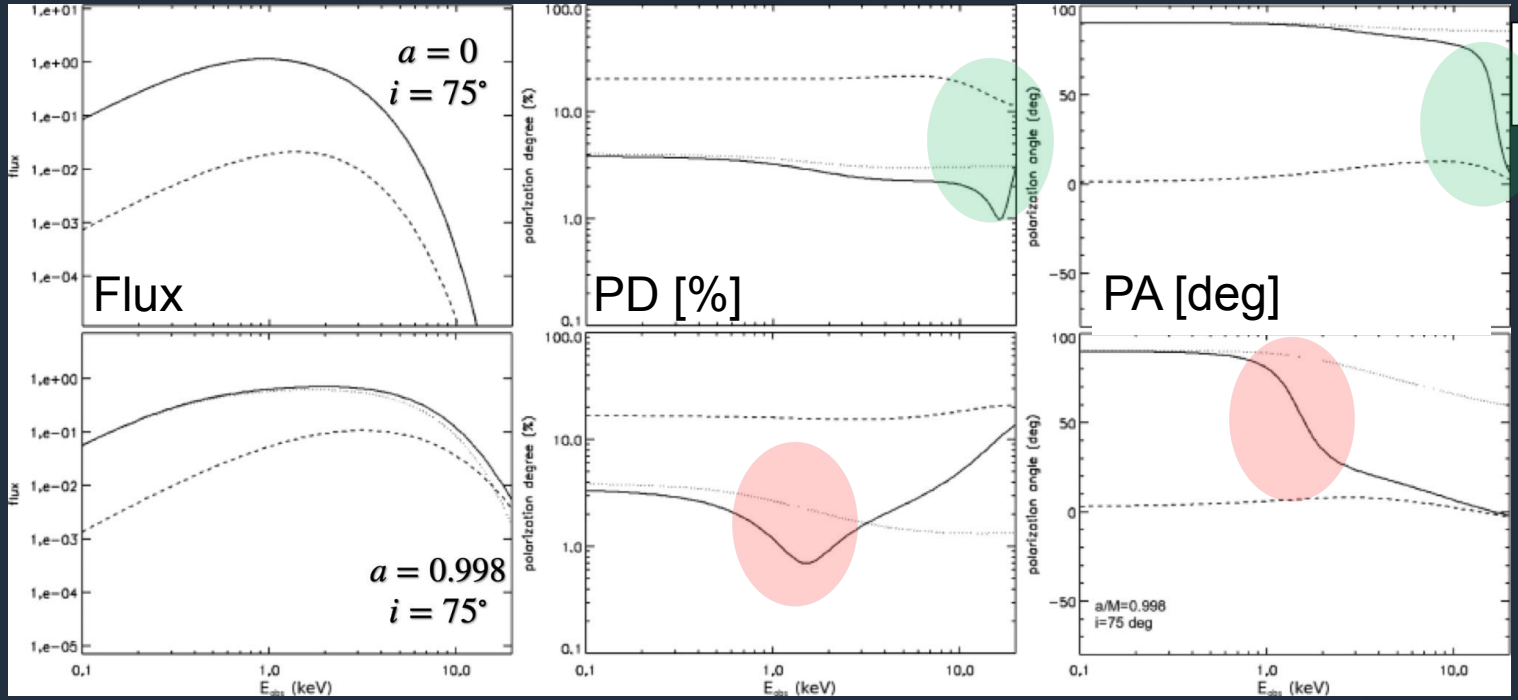
Data from Table XXIV in Chandrasekhar (1960)

Introduction - GR effects



Taverna et al. (2020)

Introduction - GR effects



Taverna et al. (2020)

IXPE observations of BHB in soft state

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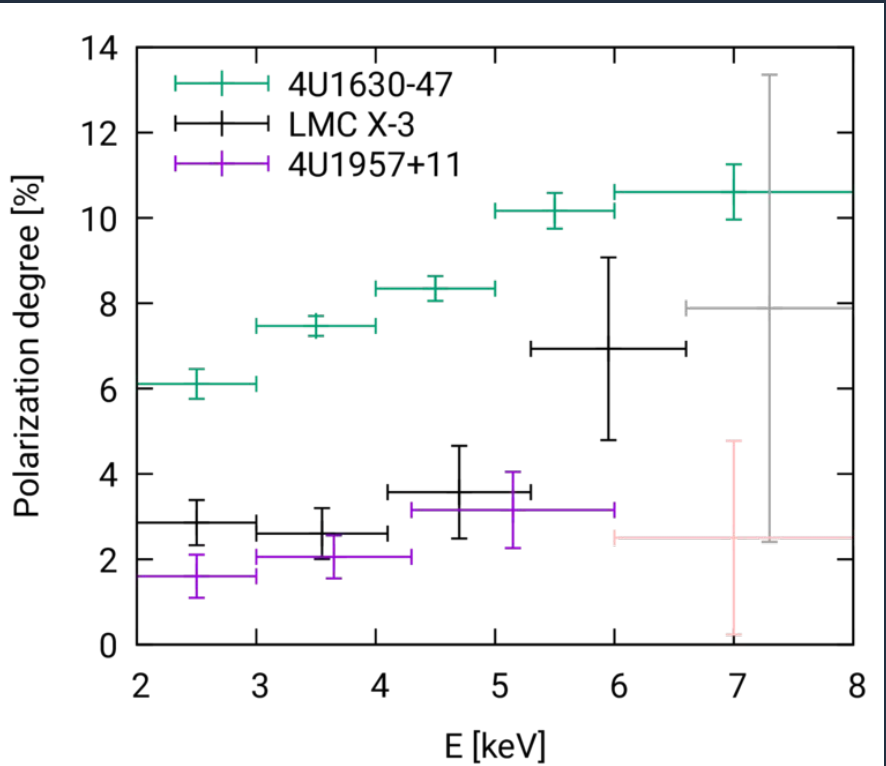
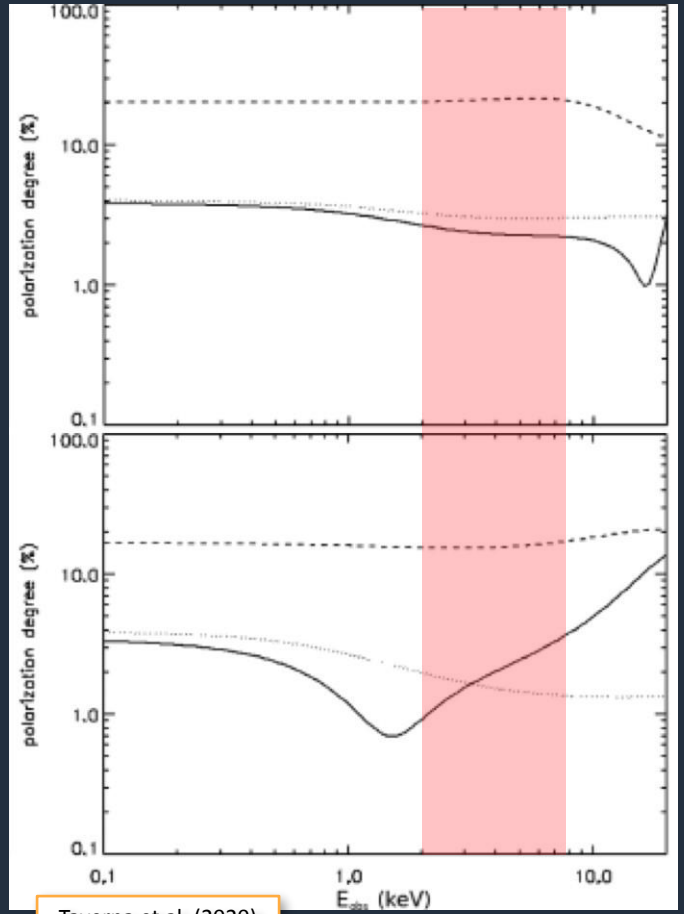


Svoboda et al. (2023)



Taverna et al. (2020)

Accretion disk emission - Numerical implementation

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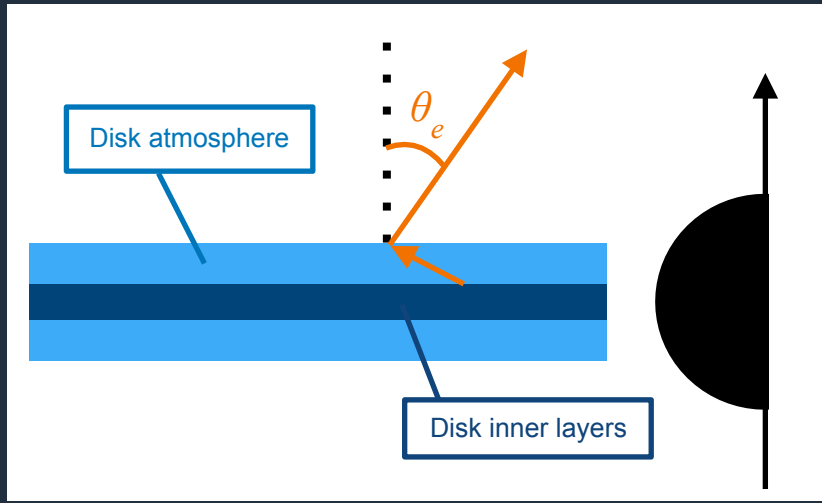
- Study the **radiative transfer within the disk atmosphere** (Absorption and Compton scattering effects) [Taverna et al. (2021), Marra et al. Accepted A&A]

  - CLOUDY
    - Temperature, density (constant) and optical depth
    - **Two ionization regimes: Collisional Ionization Equilibrium (CIE) and Photo Ionization Equilibrium (PIE).**

  - STOKES
    - **Includes Line emission, photoelectric absorption, Compton down-scattering (No up-scattering in v 2.33)**



Accretion disk emission - Scattering and absorption

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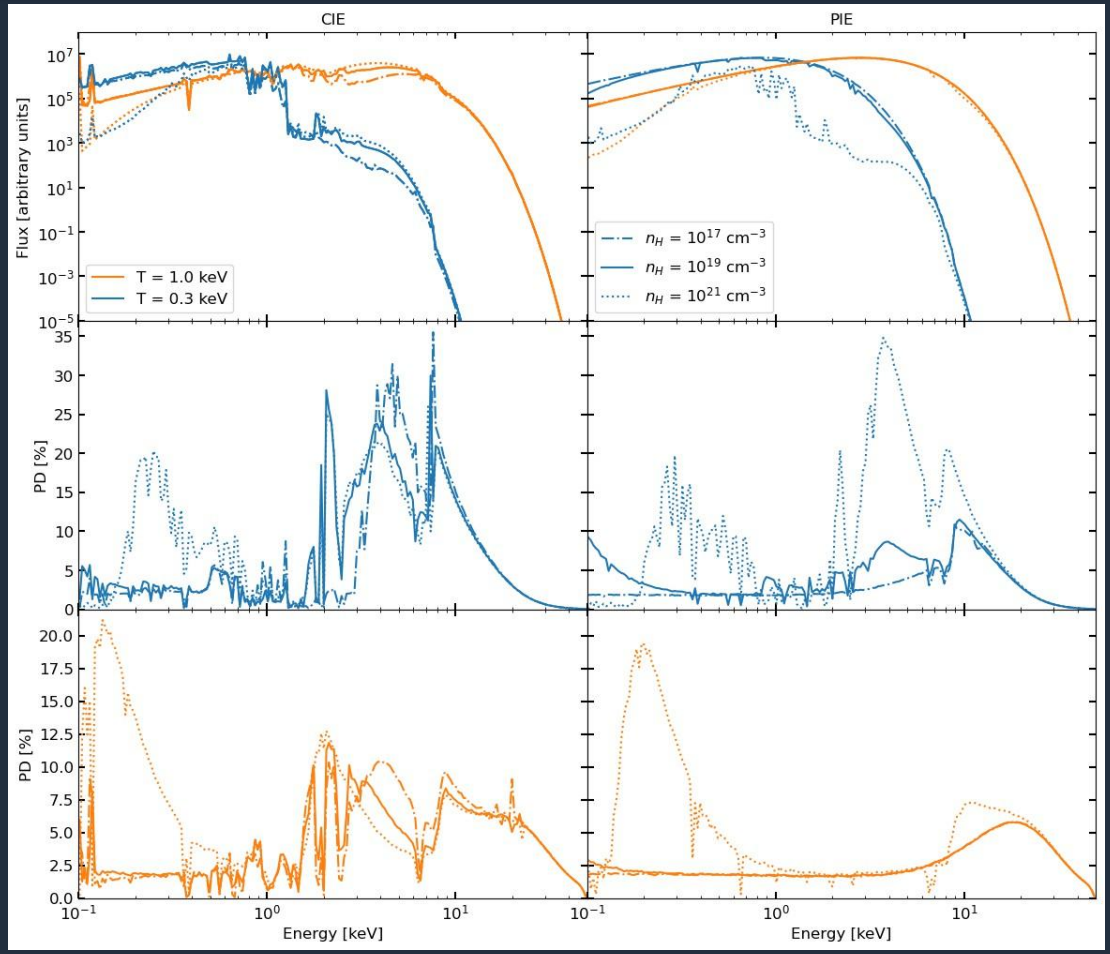
- Slab with $= 75^{\circ}$; $\tau \sim 1$
- **PA perpendicular** to the slab normal
- **Low ionization**: Strong absorption features
- **High ionization**: PD increase observed at high energies
- An highly ionized state is more easily achieved when photoionization is included



Accretion disk emission - Scattering and absorption

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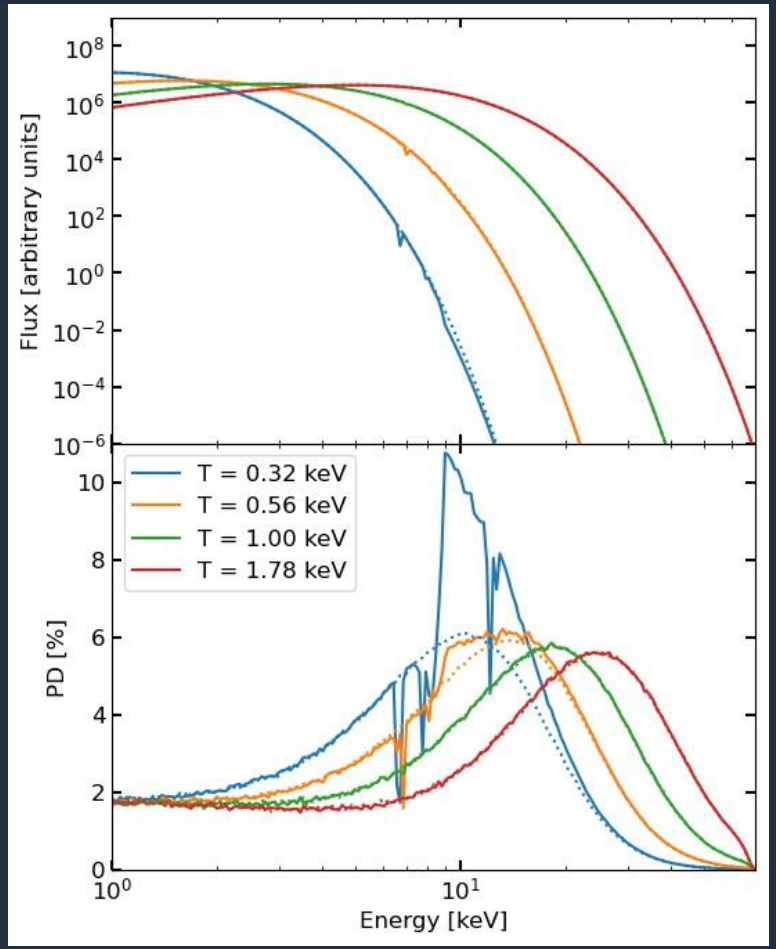
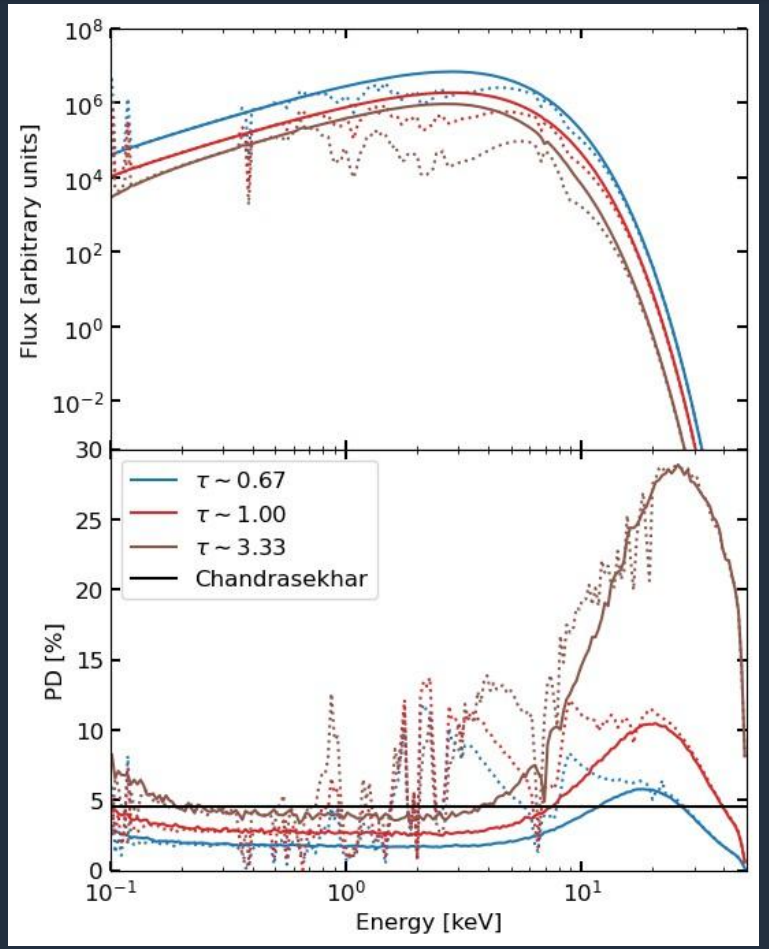
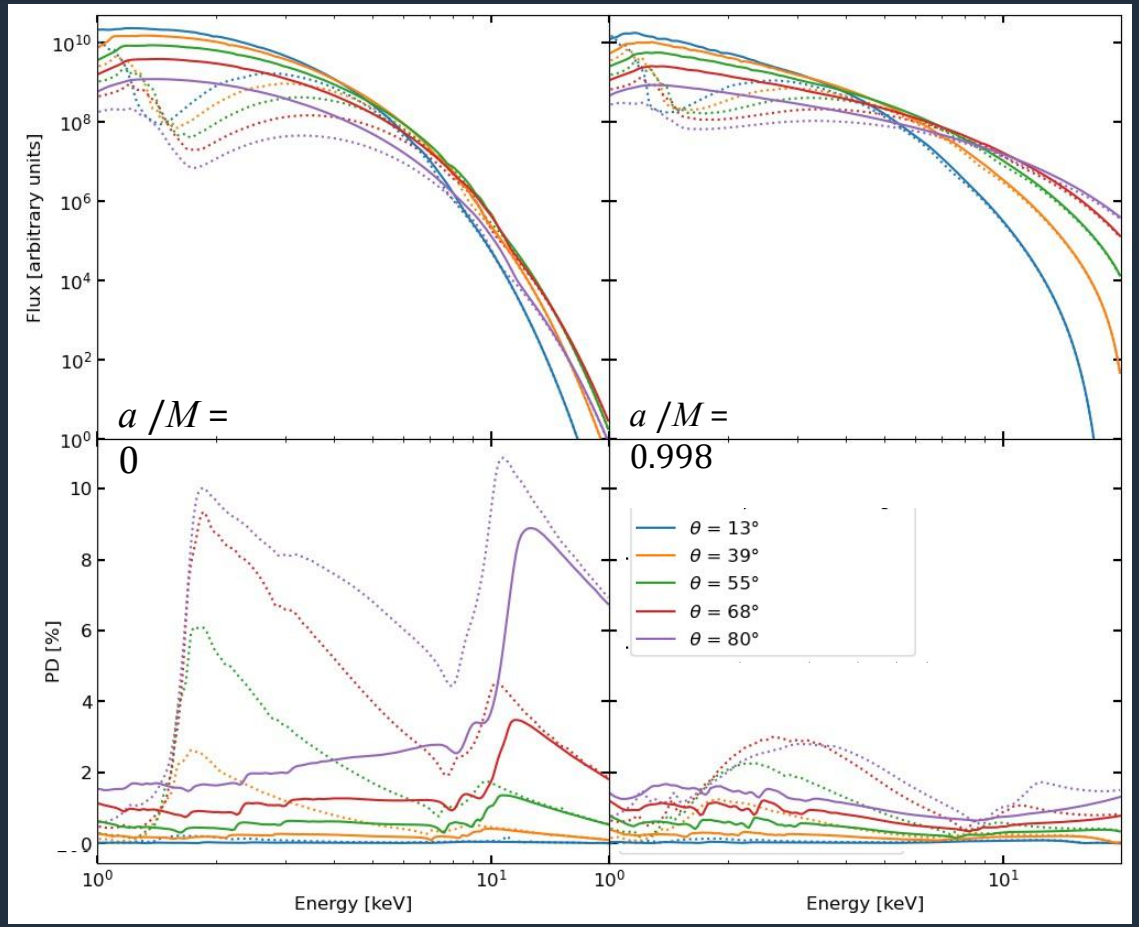




Accretion disk emission - Accretion disk emission

- Include GR effects using the fully relativistic ray tracing package KYN [Dovciak et al. (2008)]
  - $M = 10\ M_{\odot}$
  - $a = 0 - 0.998$
  - Only **direct radiation**



Accretion disk emission - Application to 4U 1630-47

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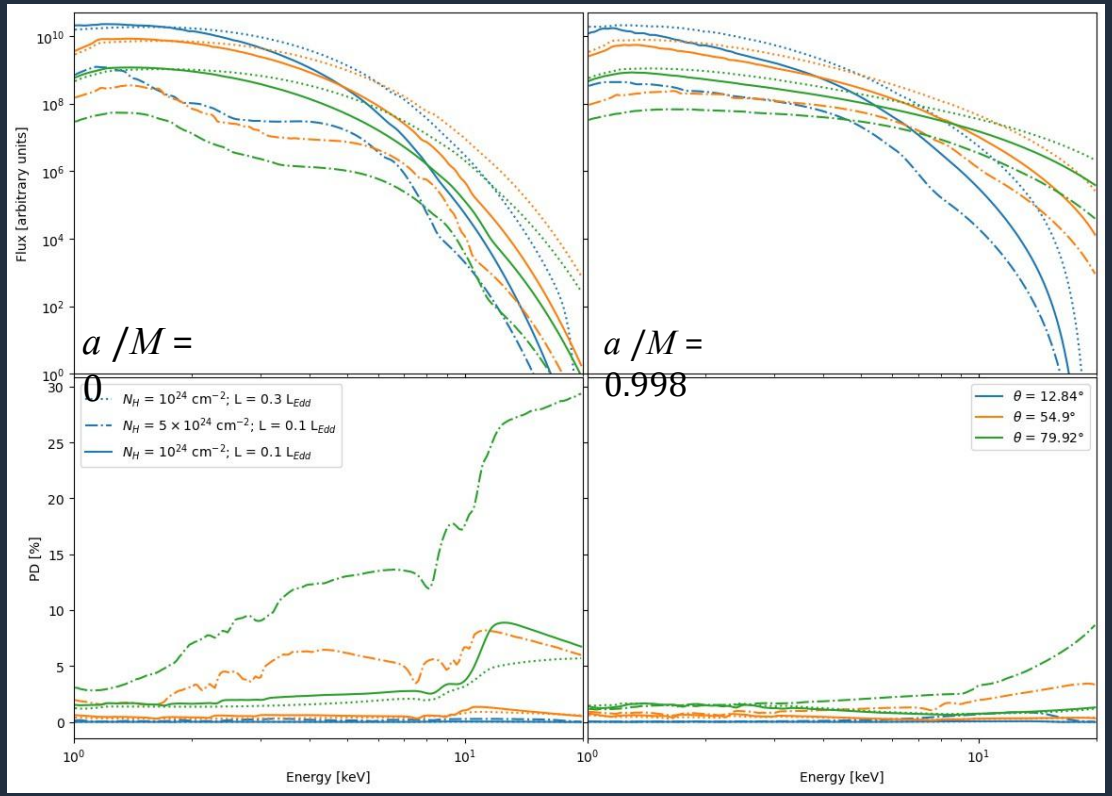
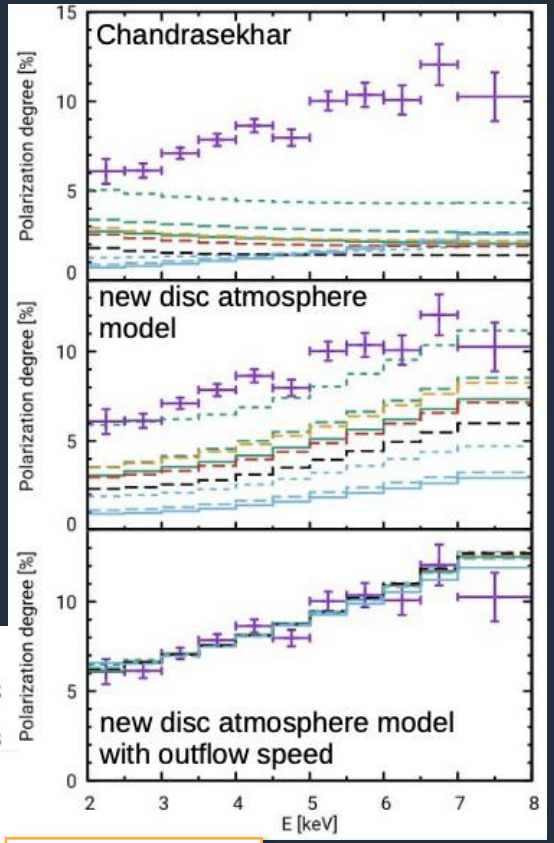
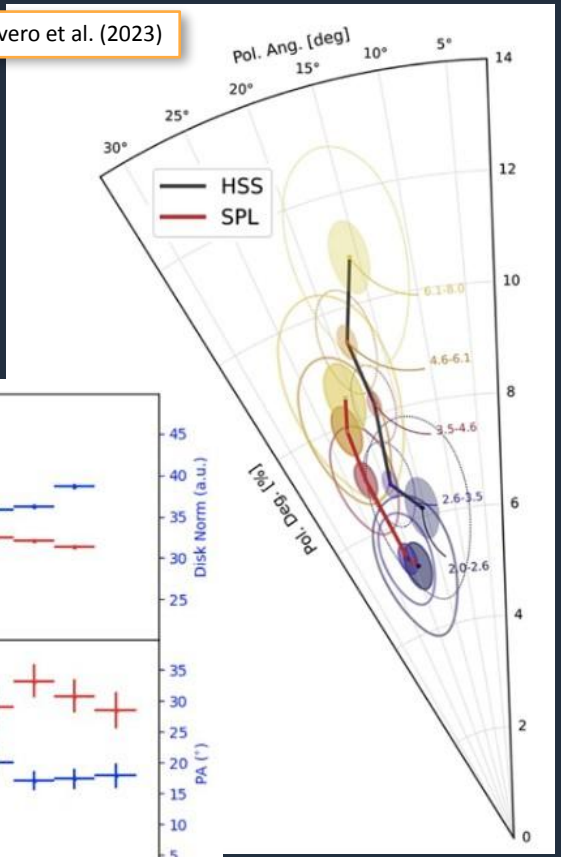




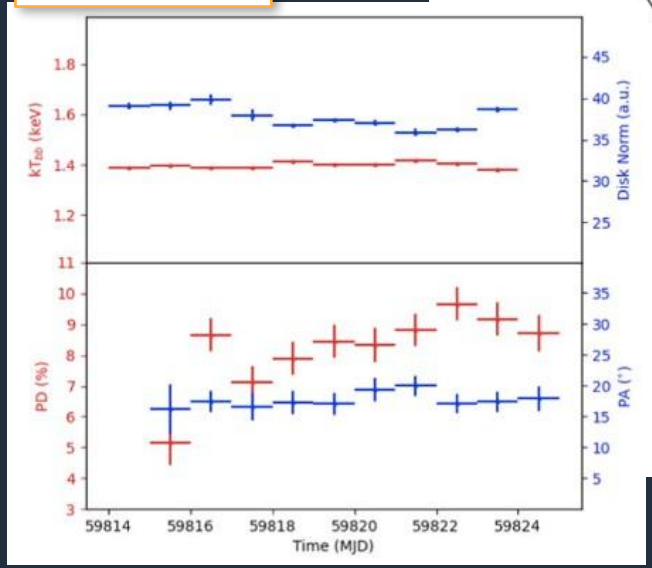
Ratheesh et al. (2024)

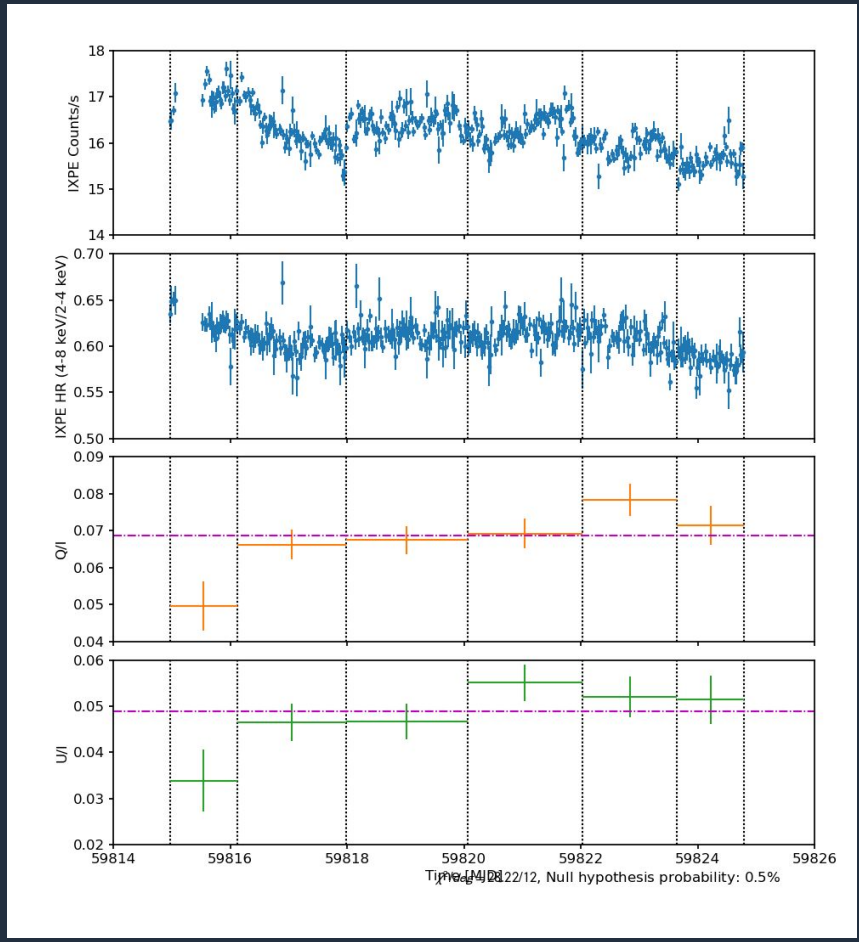
Additional details on 4U 1630-47

Rodriguez Cavero et al. (2023)



Ratheesh et al. (2024)





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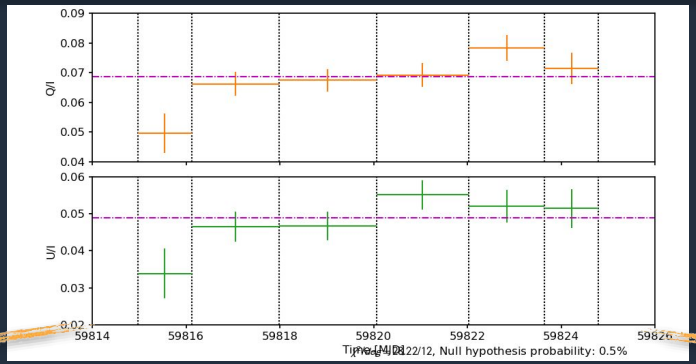
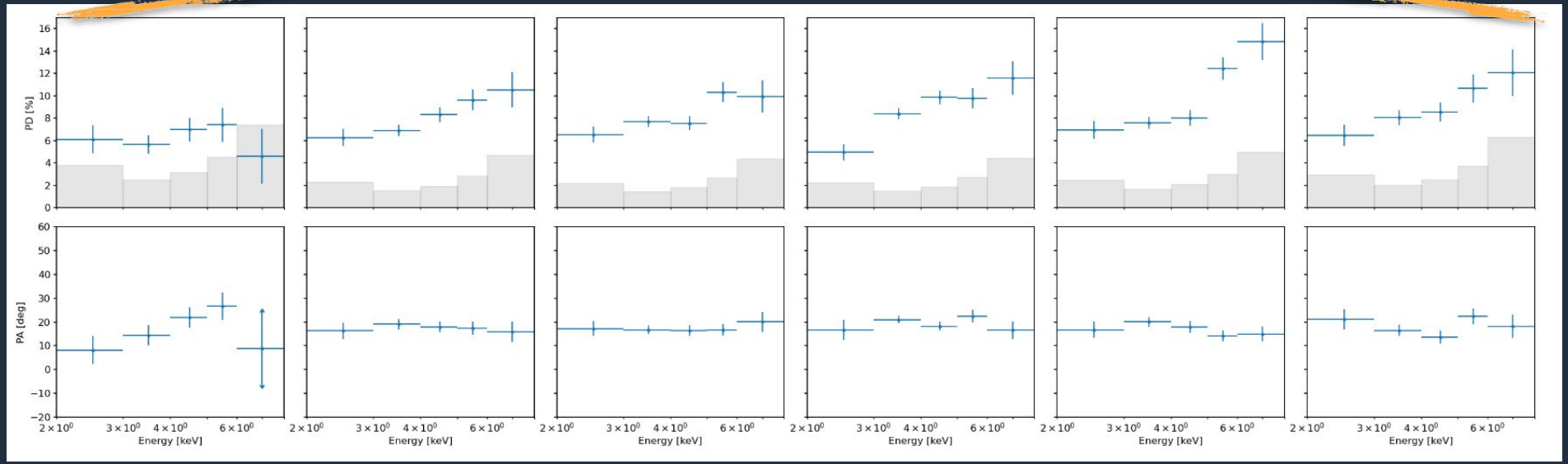
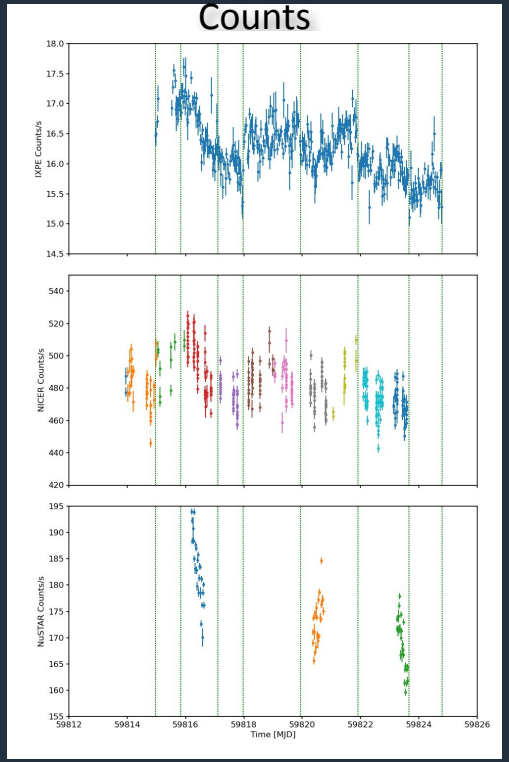
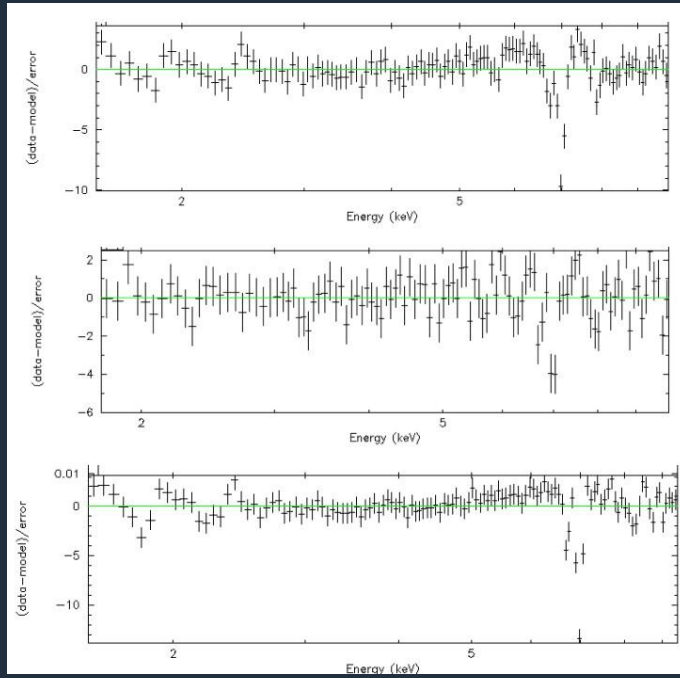




Wind in 4U 1630-47





Nicer obs. **pre ixpe obs;**
Exposure time 2ks

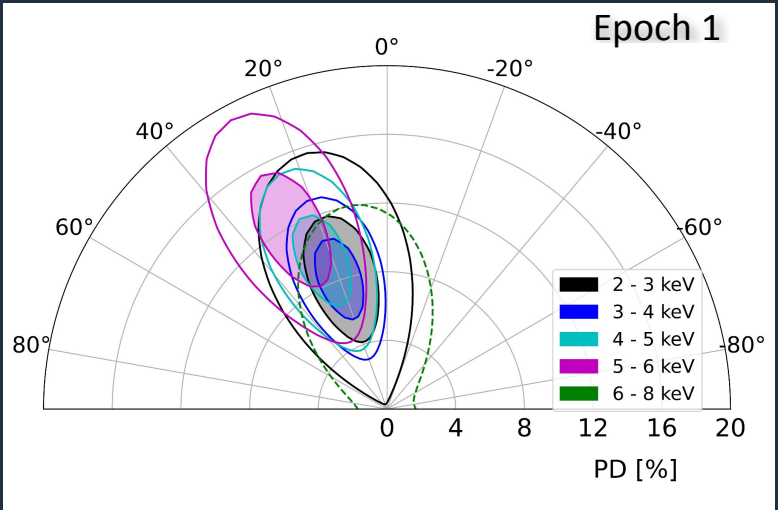
Logxi =5.2(-0.5;+0.3)
Logxh=24.1(-0.5;+0.2)

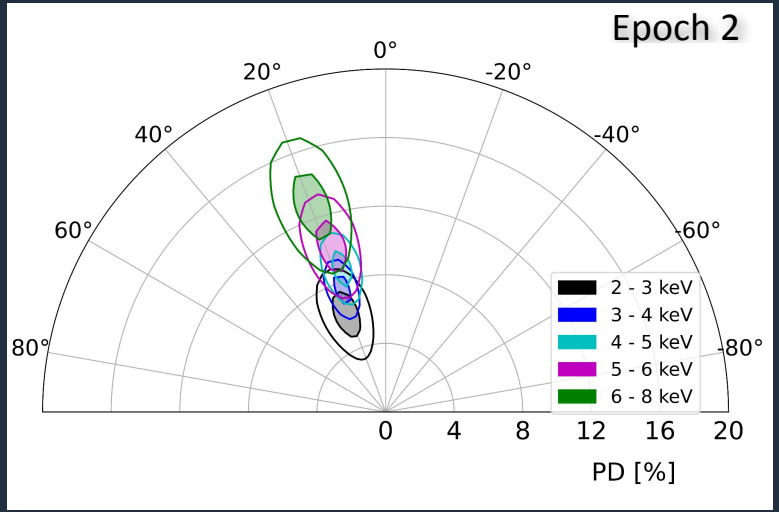
Nicer obs. Simultaneous to **Epoch1** (first IXPE obs)
Exposure time 0.4 ks
Logxi =4.8(-0.5;+0.9)
Logxh=23.5(-0.5;+0.7)

Nicer obs. Simultaneous to **Epoch2** (second IXPE obs.)
Exposure=3.9 ks

Logxi =5.0(-0.1;+0.2)
Logxh=24.0(-0.1;+0.1)

4U 1630-47 polarization

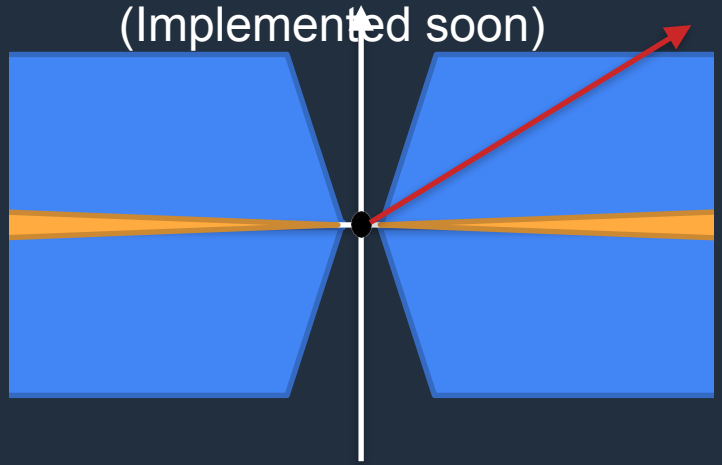


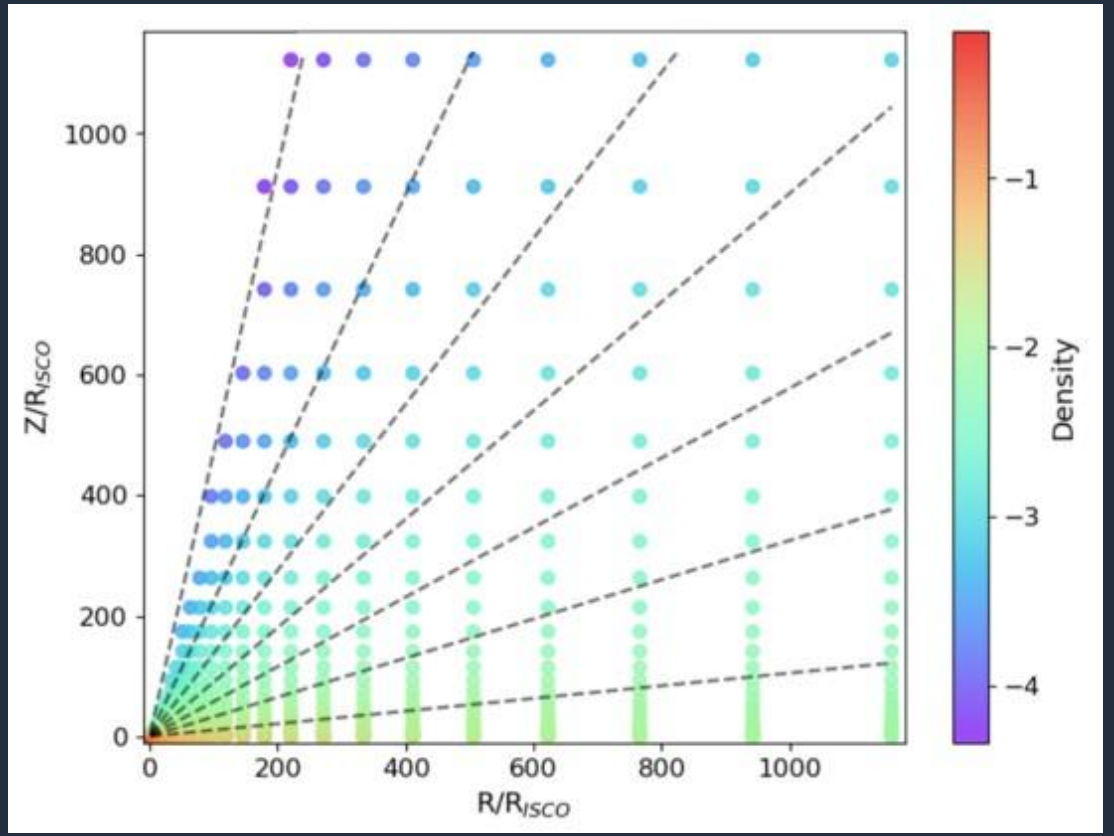


- Epoch 1 is too short (≈ 20 ks) to get any statistically significant information on a variation of the polarization properties
- Two things are certain:
  - A wind is present during the IXPE observation
  - For the time being, **no scenario explains all the details of the polarization behavior in a satisfactory manner**

WORK IN PROGRESS - Disk MHD model

- APPROXIMATIONS
  - Local approach
  - No velocity distribution
  - No reflection (Implemented soon)
  - Disk is illuminated by an unpolarized BB (Implemented soon)





WORK IN PROGRESS - Disk MHD model

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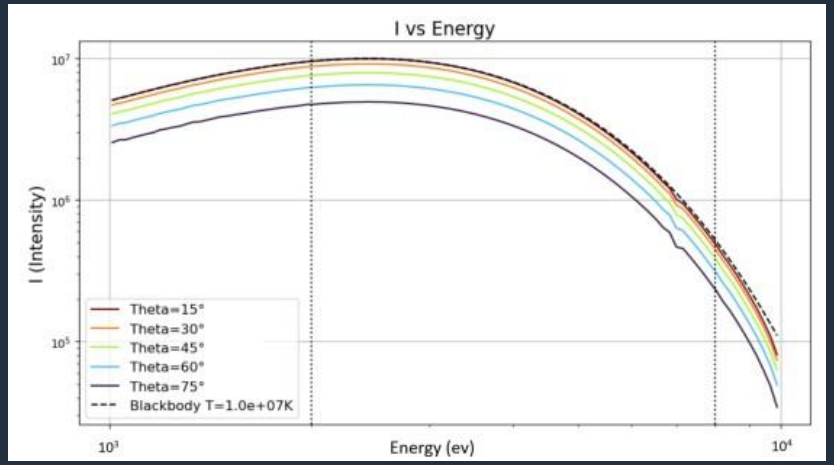
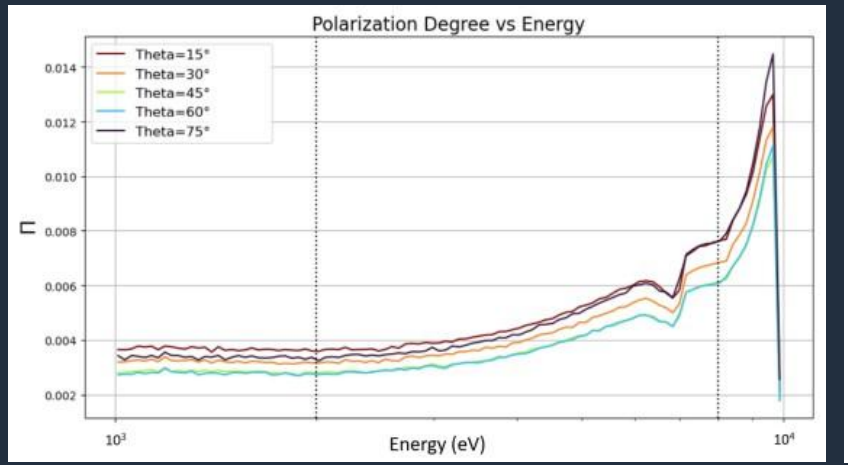
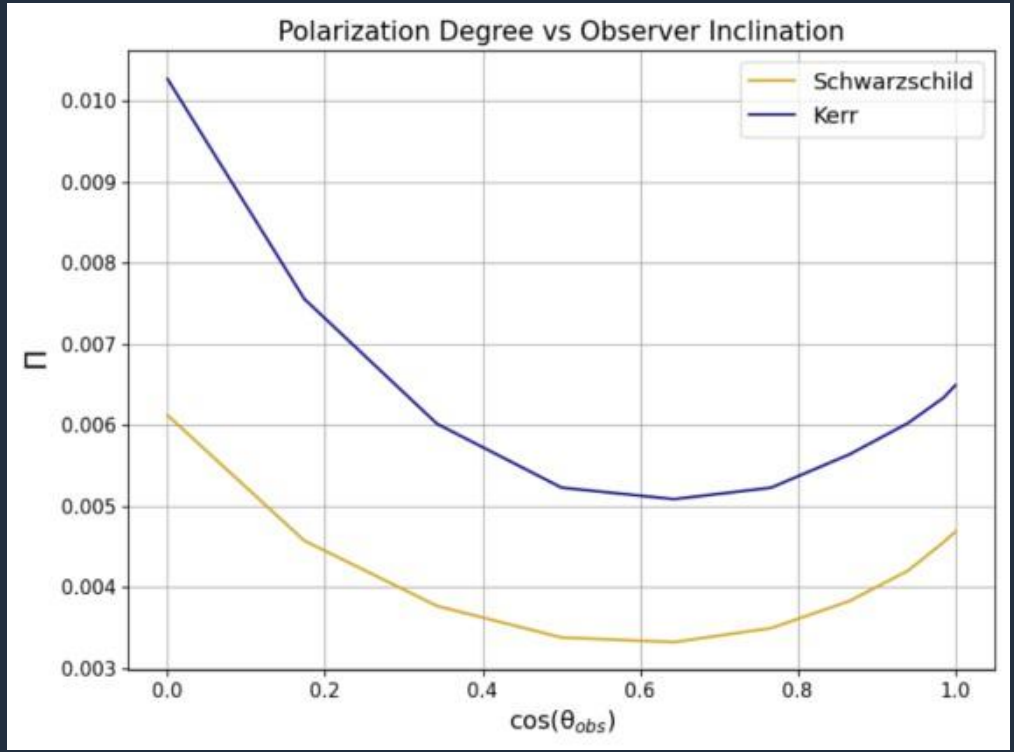




- Polarization vector perpendicular to the disk symmetry axis



Conclusions

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- Including absorption effects and Compton scattering modifies the PD profile of the radiation emerging from an optically thick, plane-parallel atmosphere.
- When absorption effects are prominent (e.g. CIE) a decreasing PD behavior is expected in the IXPE energy range.
- The reprocessing of radiation in an highly ionized atmosphere (e.g. PIE) can give rise to an increasing PD trend with energy.
- 4U 1630-47 polarization properties in soft state are difficult to model
- An MHD disk winds model is under development
  - Low polarization degree $\sim 1\,\%$, polarization vector parallel to the accretion disk
  - An increase with energy can be expected

Conclusions -
THANK YOU FOR YOUR ATTENTION!

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