The first X-ray polarimetry of GRS 1739–278 reveals its rapidly spinning black hole

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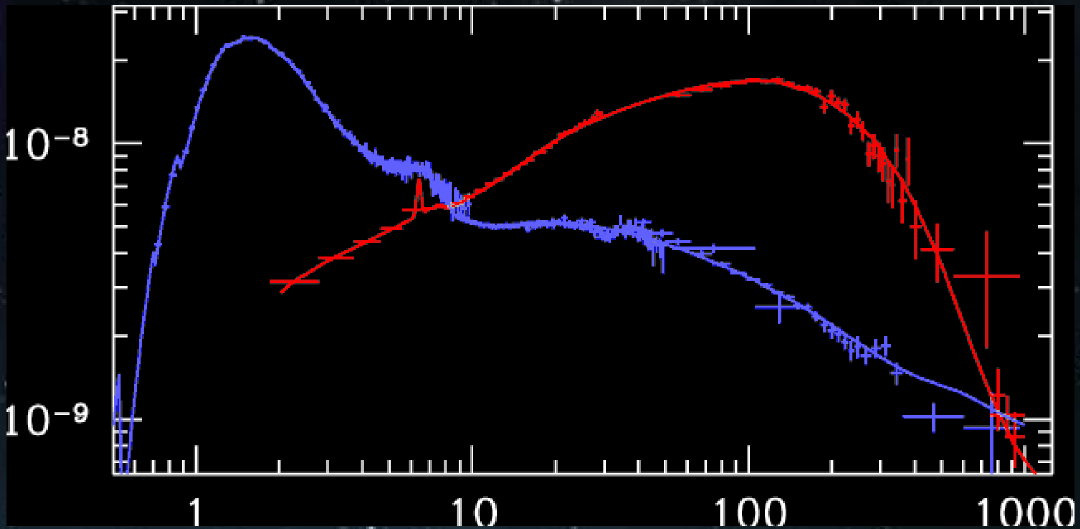
Done, Gierliński & Kubota (2007)



Components:

- **black hole**
- **star companion**
- **accretion disc**
- **bulge**
- **corona**
- **winds (LM vs. HM XRBs)**
- **jets**

Spectral states:

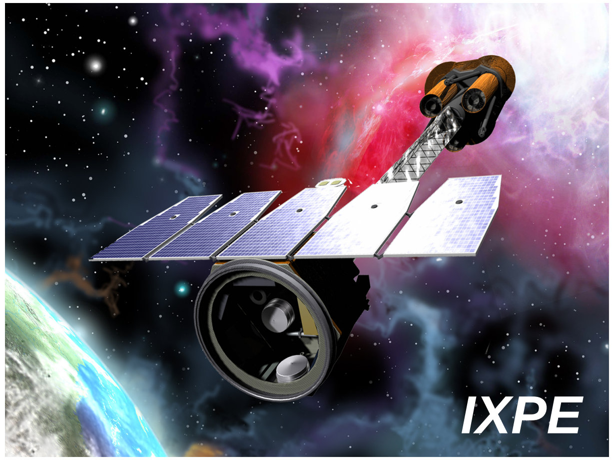
- high/soft
- low/hard
- very high/steep power-law
- intermediate

Credit: G Pérez Díaz (IAC)

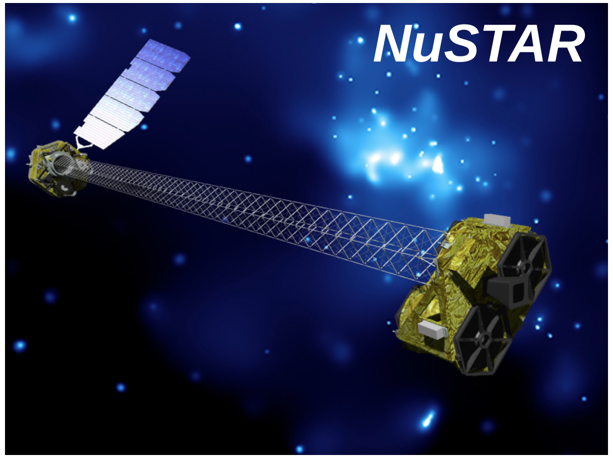
GRS 1739-278

- discovered in 1996 (Paul et al, 1996)
- further major outbursts in 2014, 2016
- distance: ~ **6–8.5 kpc** (Greiner et al, 1996)
- inclination: ~ **43°** (Miller et al, 2015)
  ~ **70°** (Draghis et al, 2024)
- BH mass: ≲ **18.3** $M_\odot$ (Wang et al, 2018)
- BH spin: ≳ **0.6** (Miller et al, 2015)
  ~ **0.90–0.99** (Draghis et al, 2024)
- **QPOs** detected (Mereminskiy et al, 2019)
- **no radio jet**
- on **8 September 2025** outburst reported by **Einstein Probe**

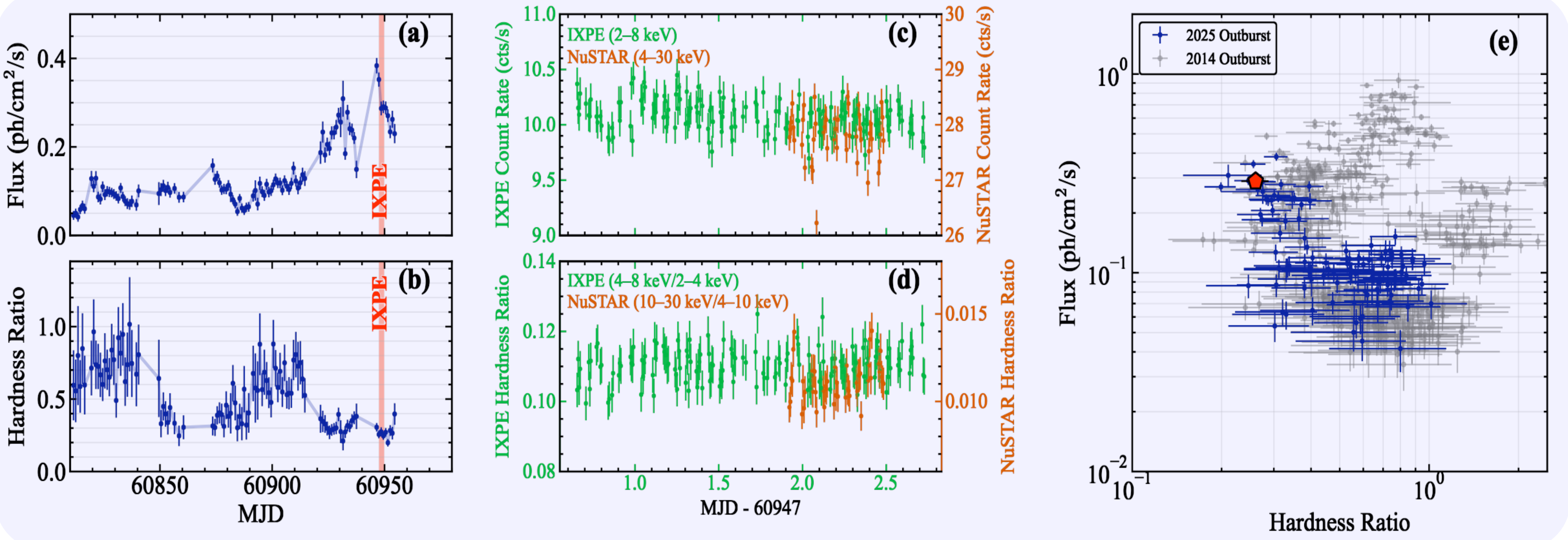
IXPE
29/9–1/10/2025
~100 ks



NuSTAR
30/9/2025
~22 ks

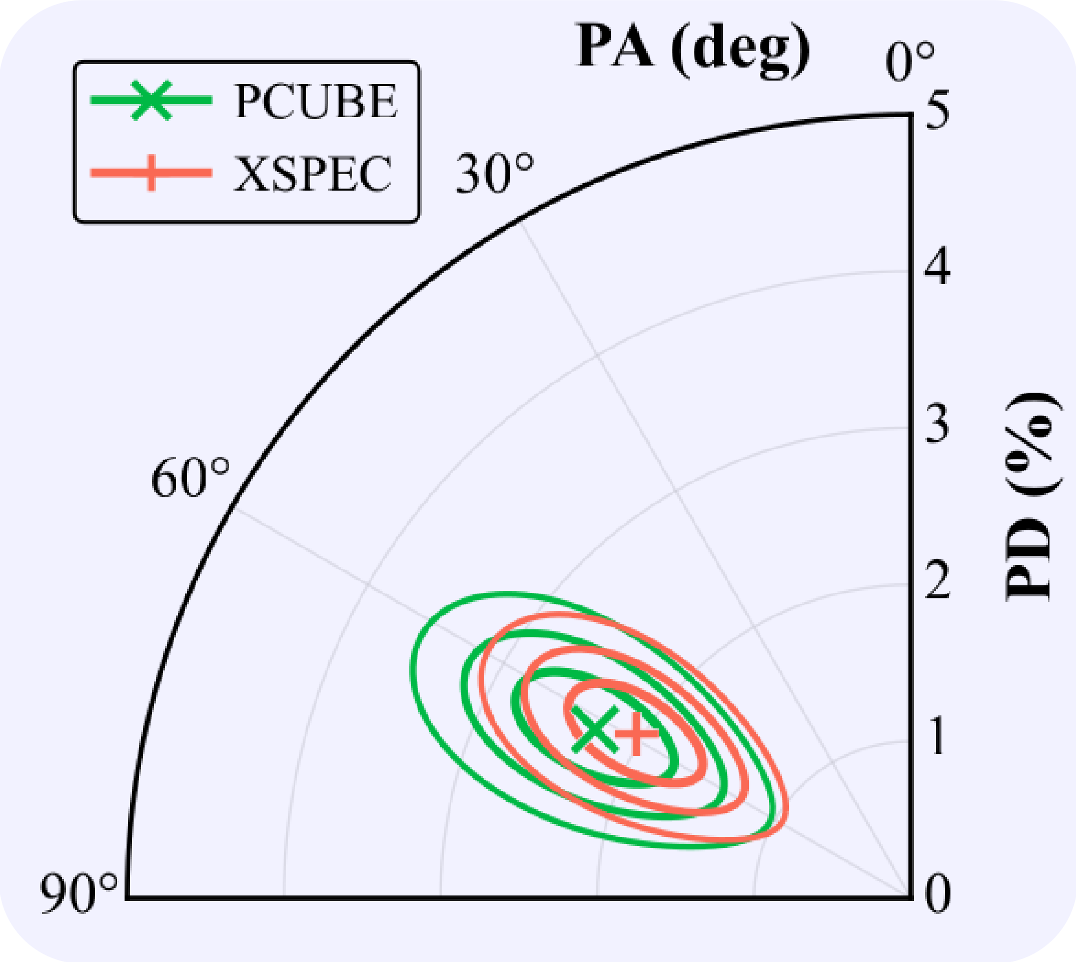


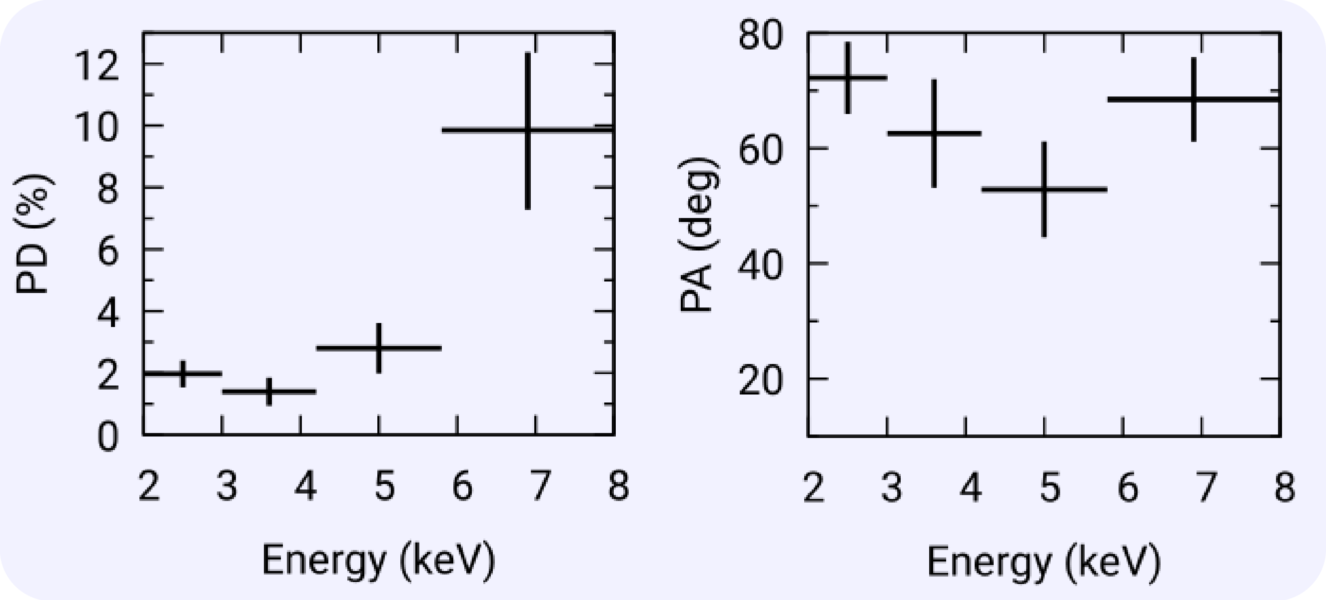
Light Curves, Hardness Ratios, Position in HID



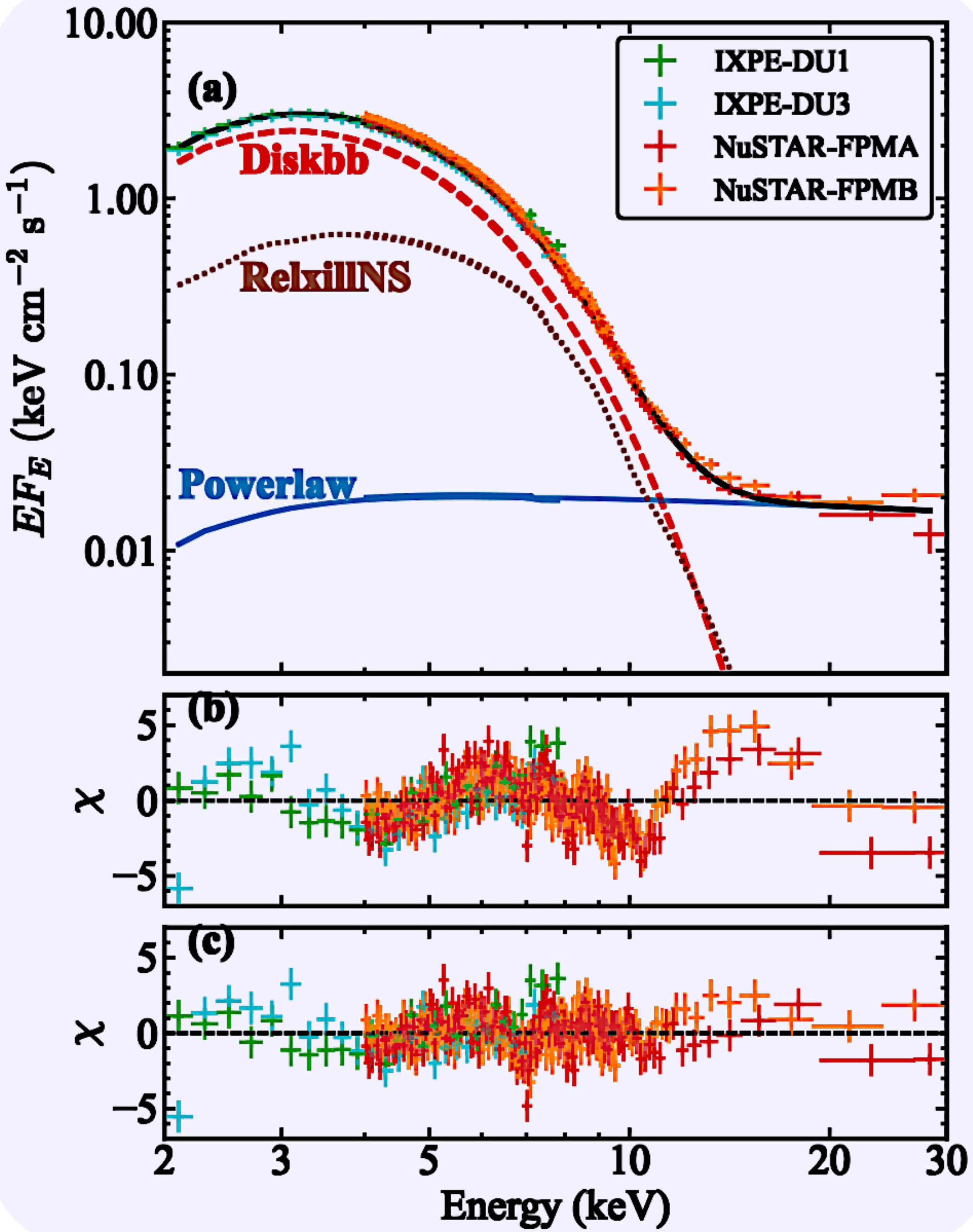
- we were lucky, *IXPE* observed in the **softest** and **brightest** state of this outburst!
- light curves and hardness ratio were stable during the observation

OBSERVED POLARIZATION PROPERTIES





- **PD = (2.3 ± 0.4) %**
  and increases with energy
- **PA = 62° ± 5°**
  and consistent to be constant



RETURNING RADIATION REVEALED BY *NUSTAR*

- **thermal disc** dominates the spectra
- **reflection features** fitted with `relxillNS` (Garcia et al, 2022) with incident thermal radiation
- very weak contribution of **hard Comptonization** which does not affect polarization in *IXPE* band
- simple `polconst` modelling shows the **polarization is dominated by reflection** with **PD ~ 17% !**
- this is due to high PD at 6–8 keV
- ***Is this due to reflected returning radiation?***

…ALMOST 50 YEARS AGO…

RETURNING RADIATION IN ACCRETION DISKS AROUND BLACK HOLES*

CHRIS CUNNINGHAM
California Institute of Technology
Received 1975 November 17

ABSTRACT

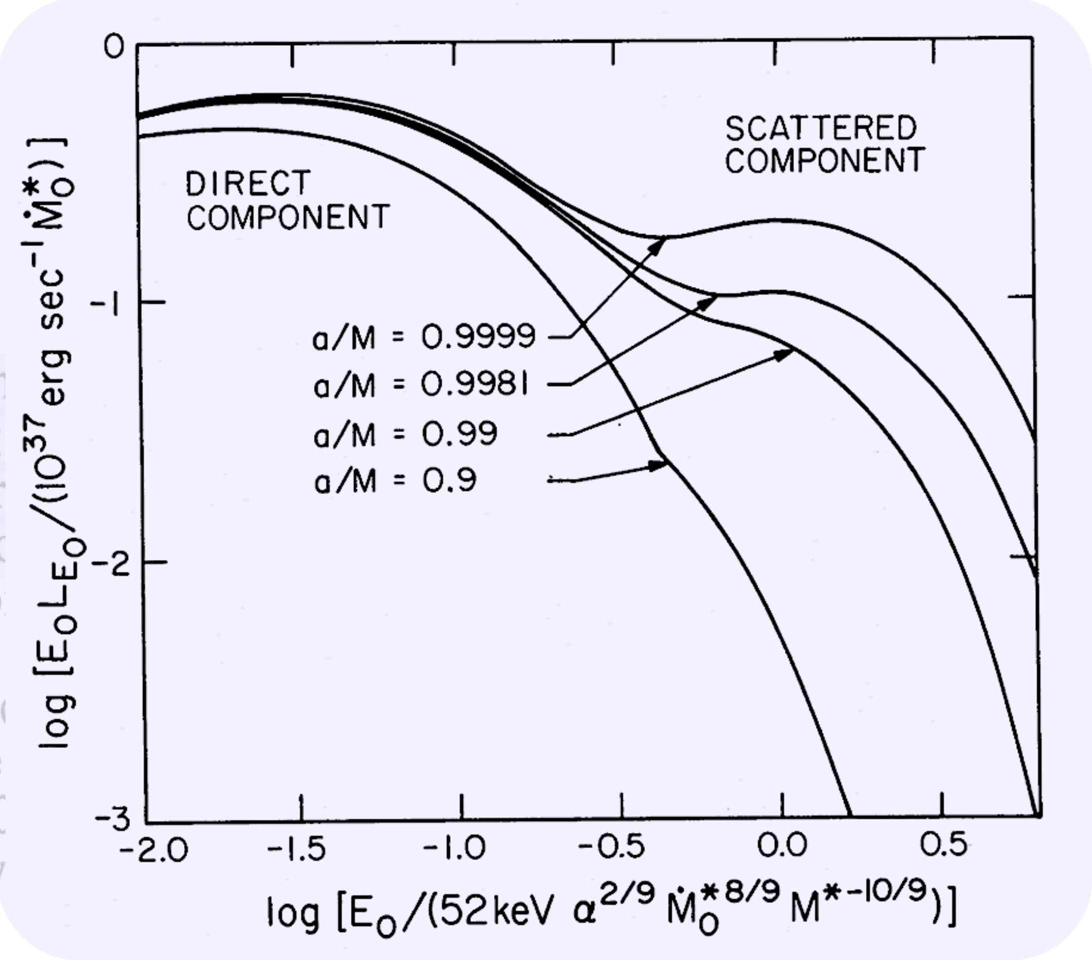
Returning radiation is radiation emitted by an accretion disk which returns to its surface due to gravitational focusing or the shape of the disk. While it is unimportant for thin disks around non-rotating black holes, returning radiation will have significant effects on the structure and appearance of thin disks around rotating holes with $a/M \approx 1$. We calculate the flux of the returning radiation as a function of radius for $a/M = 0.9, 0.99, 0.9981$, and 0.9999, treating the propagation of the radiation by general-relativistic geometric optics and treating the disk as thin. We also consider the effects of returning radiation on the spectrum of an accretion disk seen by a distant observer. The spectrum will be modified by the returning radiation at photon energies greater than about 10 keV and less than about 10 eV. The notch at 10 keV in the "pre-transition" spectrum of Cyg X-1 might be a "signature" of returning radiation.

IXPE
Imaging X-Ray Polarimetry Explorer

…ALMOST 50 YEARS AGO…

RETURNING RA ... BLACK HOLES*

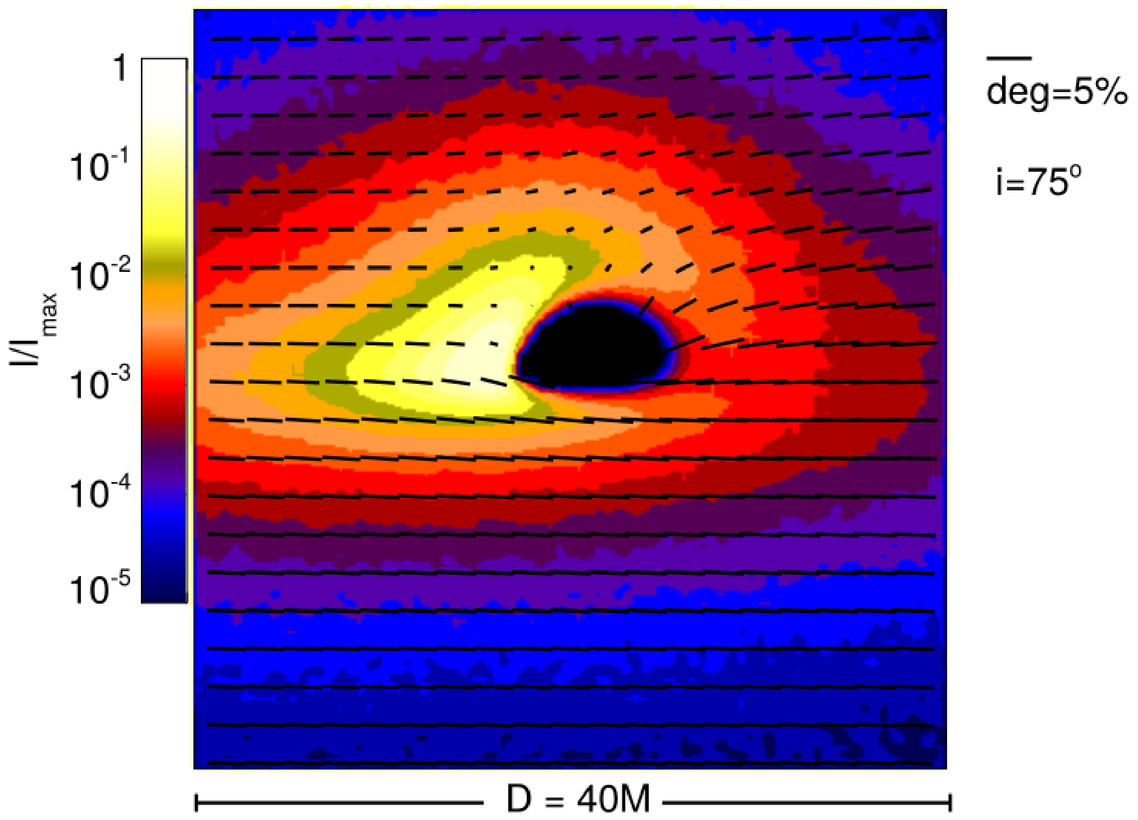
CUNNINGHAM (1976)



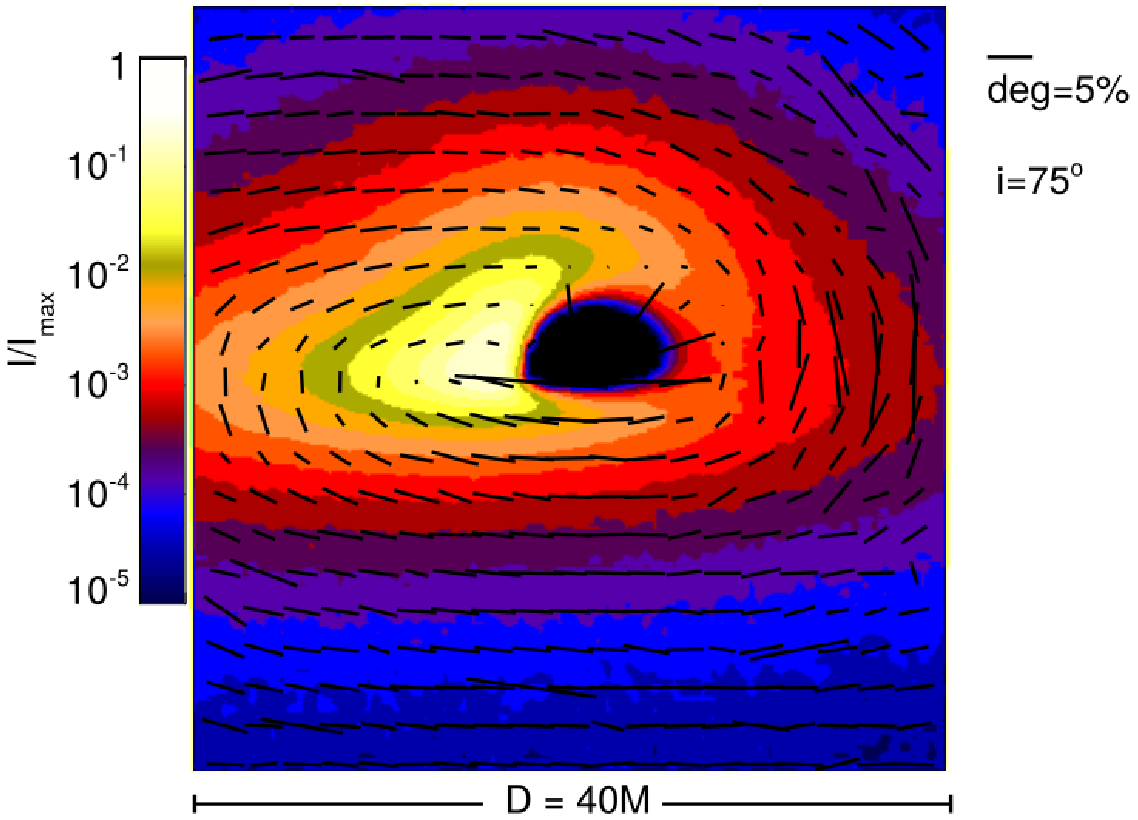
Returning radiation ... ns to its surface due to gravitational focusing ... hin disks around non-rotating black holes, ... structure and appearance of thin disks ar ... flux of the returning radiation as a functio ... treating the propagation of the radiation ... the disk as thin. We also consider the effe ... retion disk seen by a distant observer. The ... n at photon energies greater than about 1(... V in the "pre-transition" spectrum of Cy

RETURNING RADIATION IN POLARIZATION

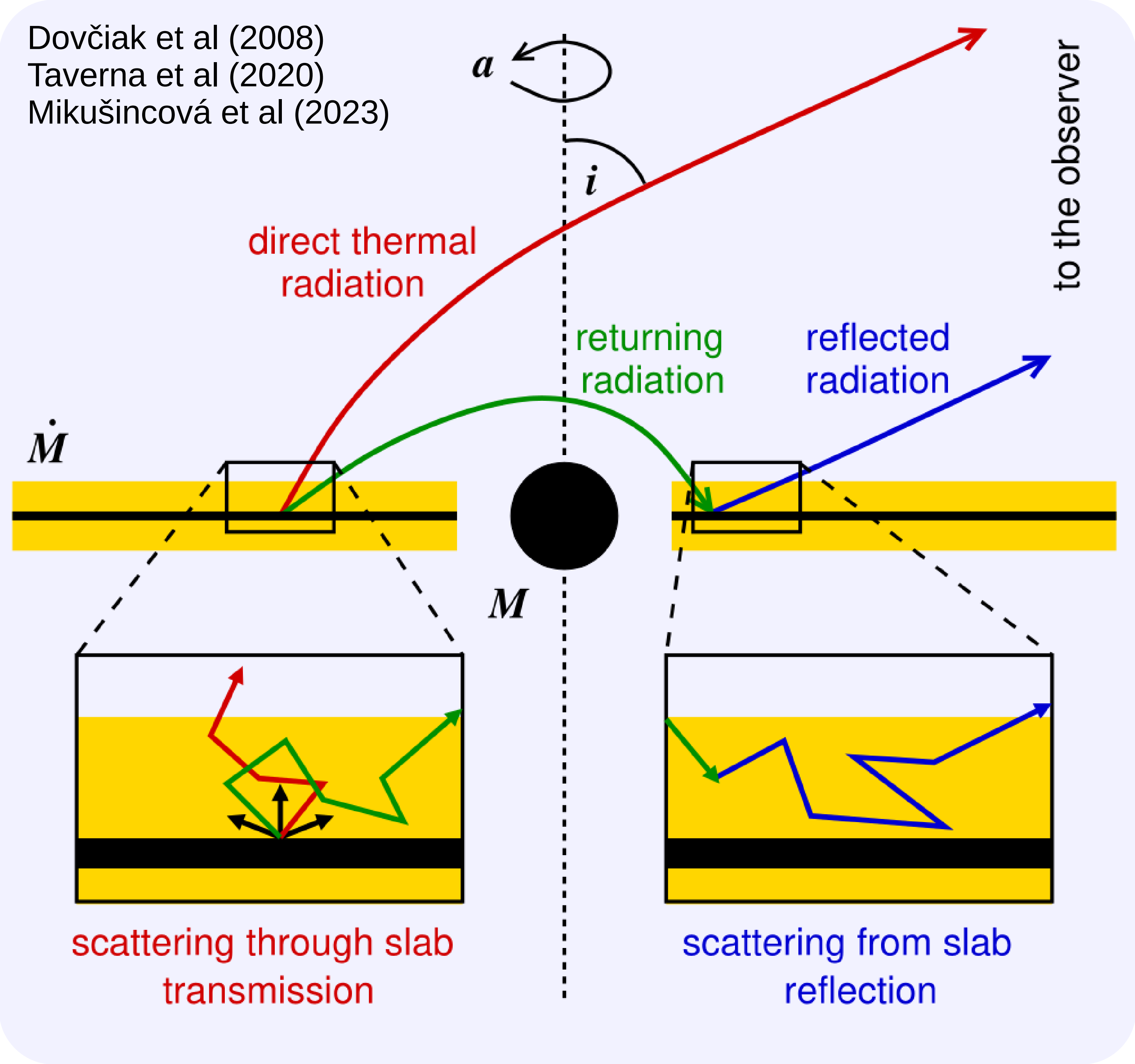
direct radiation



total radiation



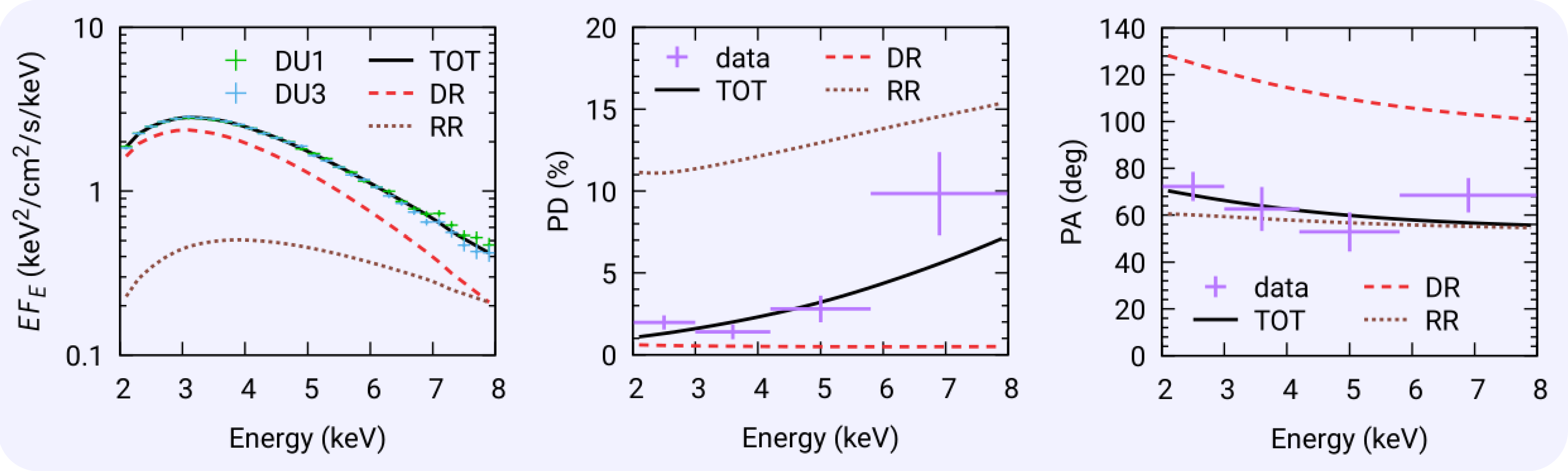
Schnittman & Krolik (2009)



KYNBBRR

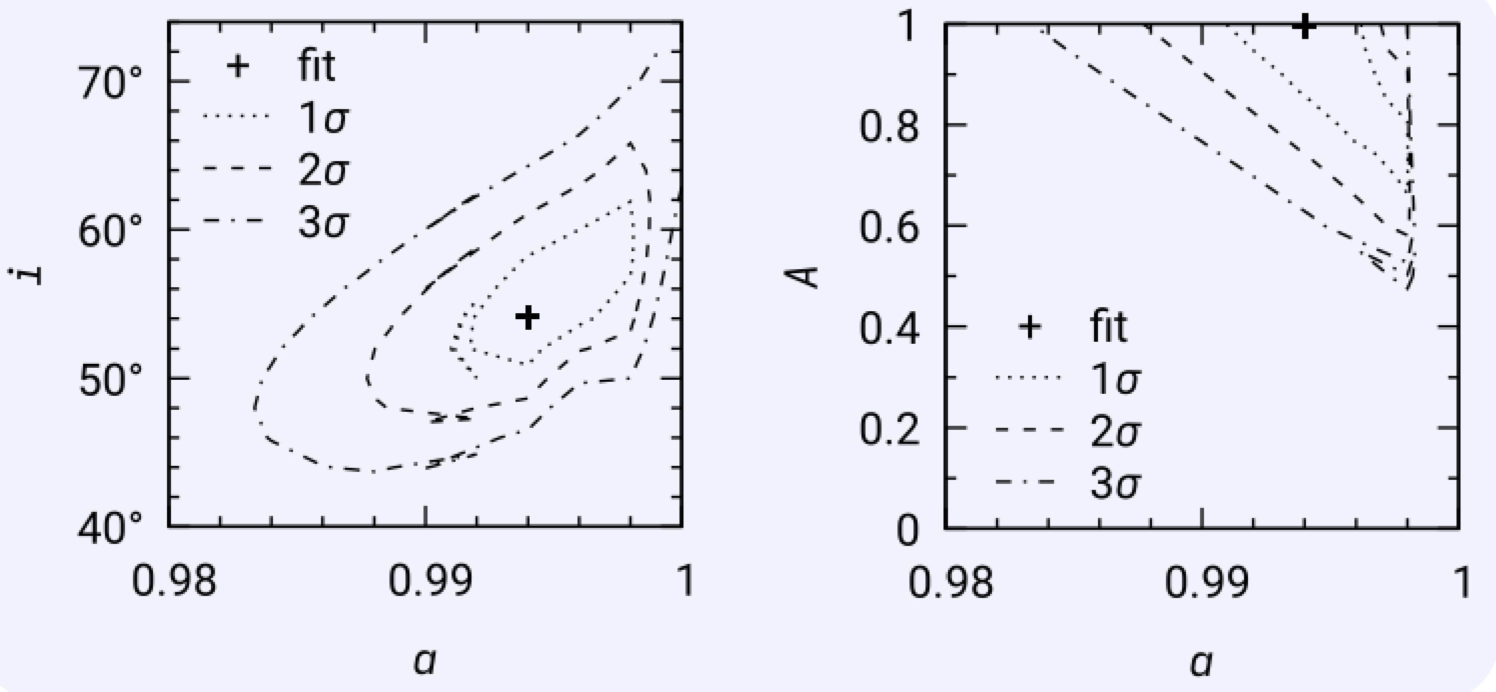
- direct disc thermal radiation
  (Novikov-Thorne disc)
- reflected returning radiation
- Comptonisation in the disc
  - Thomson scattering
  - energy shift simulated by colour correction factor f_{col}
- polarization by Chandrasekhar (1960)
  - *FUTURE*: polarization computed with **STOKES** code (R. Goosmann & F. Marin) `www.stokes-program.info`
  - direct radiation: **Marra et al (2025)**
  - reflected radiation: **Podgorný et al (2025)**
- all relativistic effects included

FIT WITH KYNBBRR



- direct thermal flux ~ **80%** vs. reflection flux ~ **20%** (in 2–8 keV)
- direct thermal PD ~ **0.5%** vs. reflection PD ~ **11% – 15%**
- direct thermal PA differs from reflection PA by **~ 40° – 70°**

SPIN AND INCLINATION CONSTRAINTS



- extremely high BH spin

$$a = 0.994^{+0.004}_{-0.003}$$

- medium system inclination

$$i = 54°^{+8}_{-4}$$

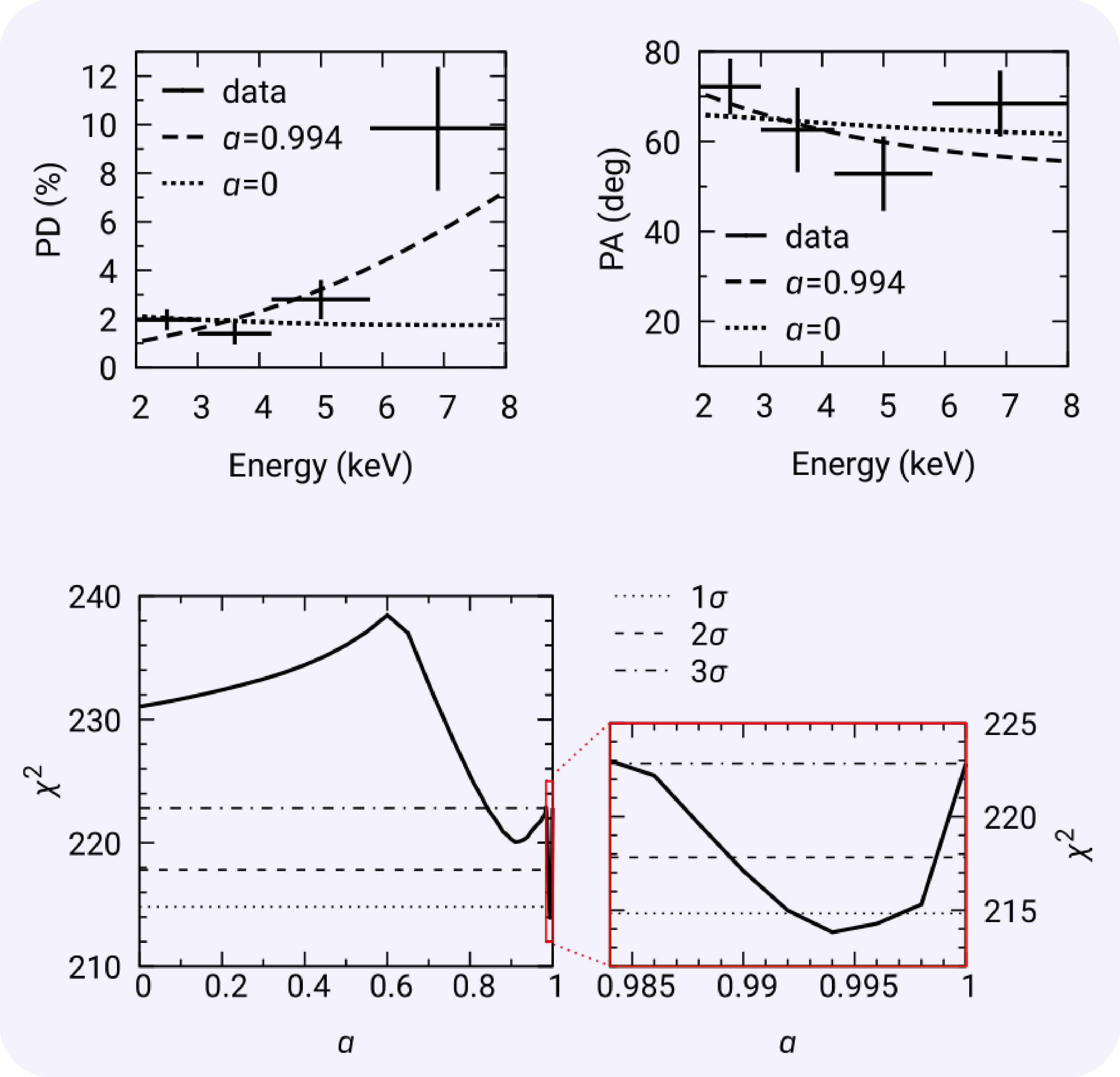
- high disc reflectivity (albedo)

$$A = 1^{+0}_{-0.3}$$

- system axis orientation

$$\psi = 58° \pm 4°$$

- assuming distance of 7 kpc
  - BH mass $M \sim 16\, M_{\odot}$
  - accretion rate $\dot{M} \sim 0.04\, \dot{M}_{\mathrm{Edd}}$



Low vs. High spin

Low spin fit is worse by ~ 4σ and requires

- higher inclination ***i* ~ 65°**
- low albedo ***A* = 0**
- system axis orientation **~ -23°**, i.e. almost perpendicular to the observed polarization direction

Low spin cannot explain the increase in PD at high energies 6–8 keV.

COMPARISON TO OTHER SOFT STATE BH XRBS

- **Cyg X–1** (Steiner et al, 2024)
  - polarimetric observations confirm an extremely high BH spin
  - the soft-state spectrum contains a significant Comptonized component and its reflection from the disc, these dilute the intrinsic polarization of the reflected returning thermal radiation, especially above 5 keV
- **4U 1957+115** (Marra et al, 2024)
  - Comptonized component contributing to the spectrum more than in GRS 1739–278
  - polarimetric observations prefer extremely high BH spin, large disc albedo, inclination above 50°
- **LMC X–3** (Svoboda et al, 2024)
  - mass, inclination, and distance are all well determined
  - polarimetric observations confirm low BH spin

OTHER PHYSICAL SCENARIOS

- high albedo may be achieved in slim or geometrically thick disc (Sadowski et al, 2011)
  - the PD is still too low for H/R $\lesssim$ 0.3 (West & Krawczynski, 2023)
- Comptonization in low-temperature plasma above the accretion disc (Poutanen & Vilhu, 1993; Poutnen & Svensson, 1996)
  - unscattered and once scattered photons polarized paralelly to the disc
  - multiple scattered photons polarized perpendicularly to the disc
  - rather low PD is expected
- accretion disc winds (Veledina et al, 2024; Nitindala, 2025)
  - no spectral signatures of the wind
  - it was not shown yet if it can explain energy dependent PD

→ ***none of these, though, can explain high PD in 6-8 keV***

Zhao, Dovčiak, Li et al, submitted to ApJL

Summary

- *IXPE* has measured X-ray polarization of GRS 1739–278 to be **PD = (2.3 ± 0.4)%** with the direction of **PA = 62° ± 5°**
- *NuSTAR* has revealed the **reflected returning radiation**
- Modelling with `kynbbrr` results in **highly spinning black hole**, **medium system inclination** and **high albedo**

$$a = 0.994^{+0.004}_{-0.003} \qquad i = 54^{\circ}{}^{+8}_{-4} \qquad A = 1^{+0}_{-0.3}$$

- Jet orientation for this source is unknown, we provide the **prediction for the system axis orientation**

$$\psi = 58^{\circ} \pm 4^{\circ}$$

- These findings are in agreement with previous BH spin measurements from reflection modelling in 2014 hard state (Miller et al, 2015; Draghis et al, 2024)

EXPO

(ESA M8 proposal)