

# Probing the geometry of black hole binaries with X-ray polarimetry

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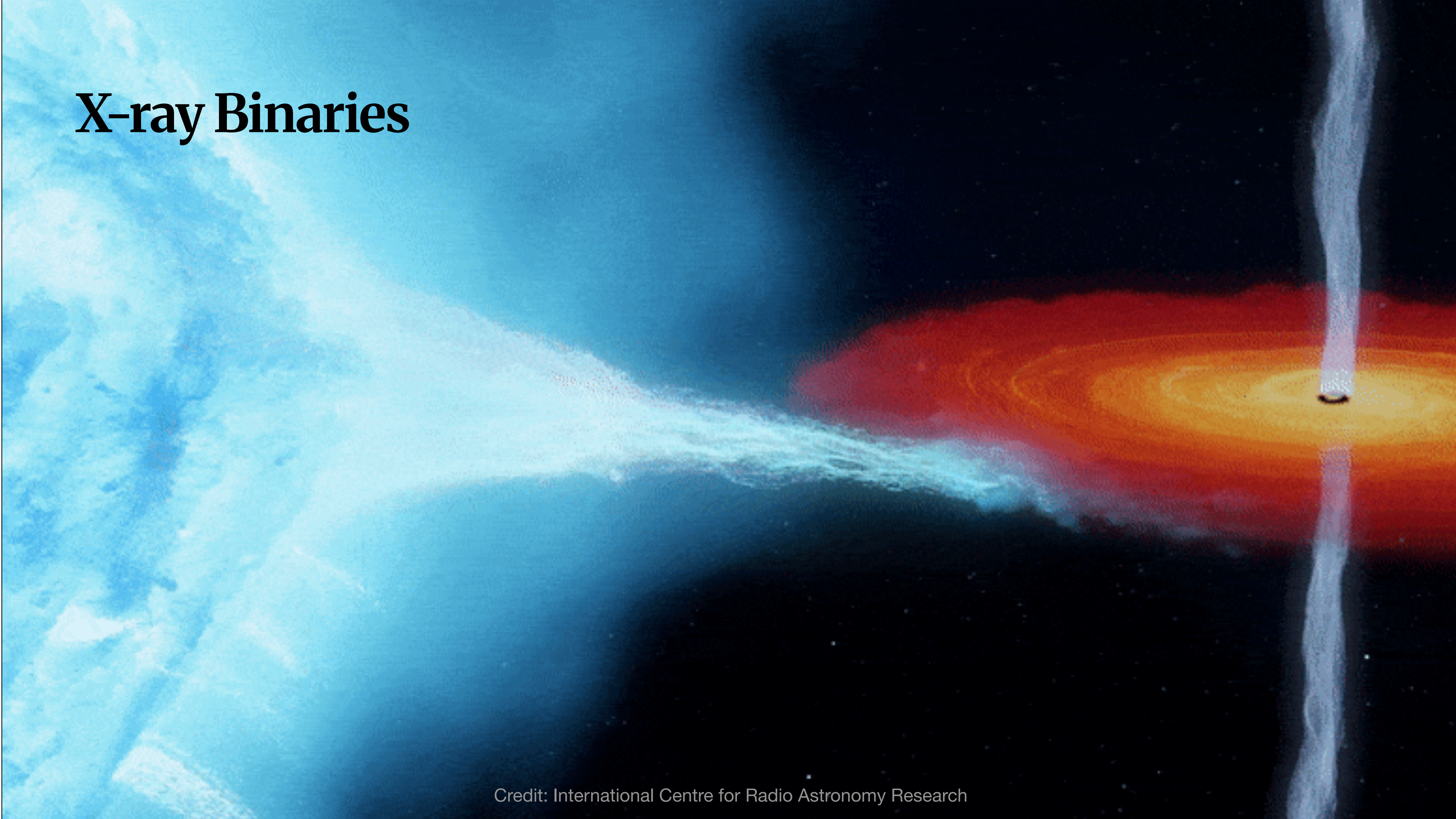
**Nordic-Baltic Astronomy Days**

Radisson Blu Marina Palace Hotel

Turku, Finland

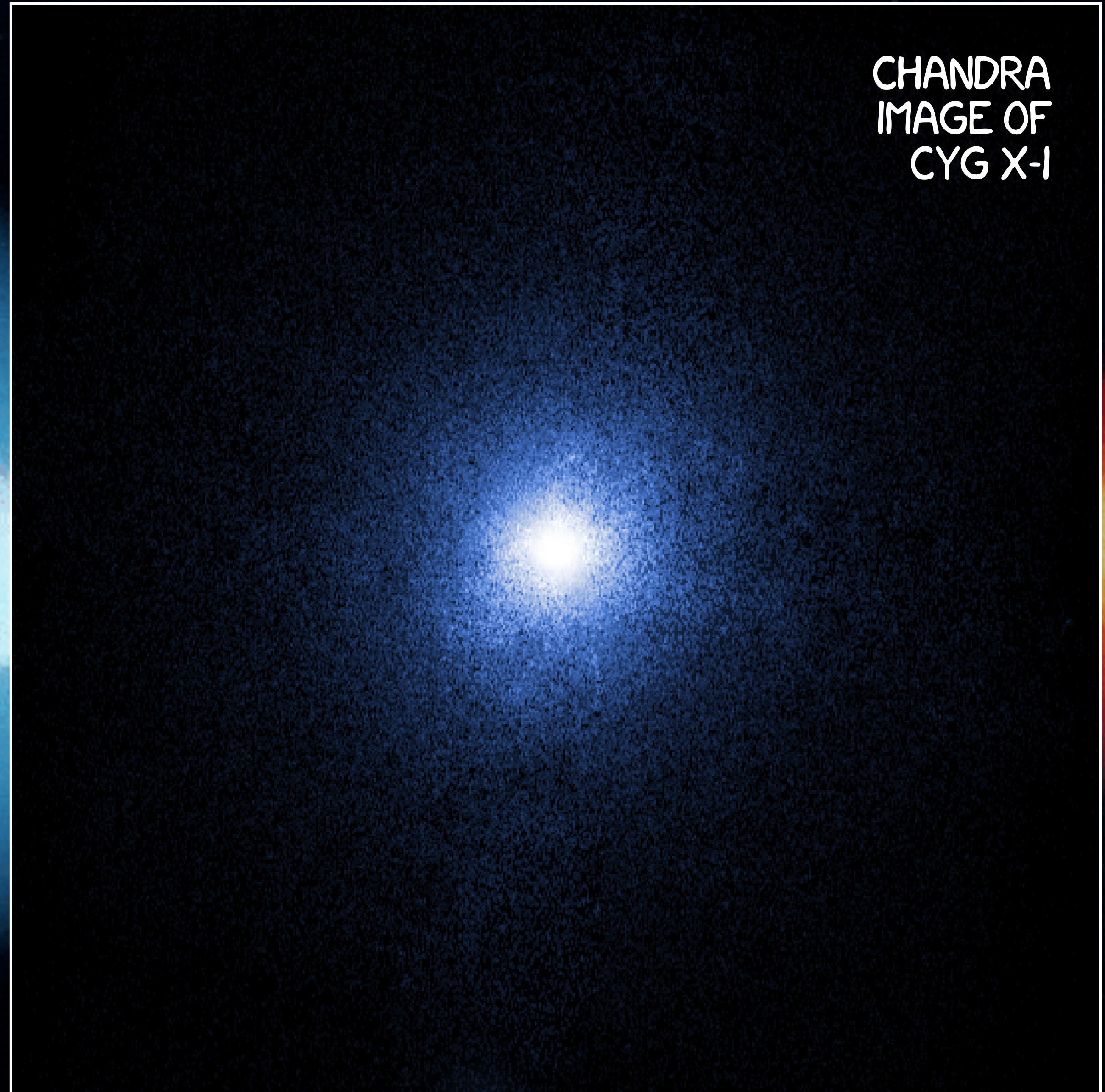
27 May 2026

# X-ray Binaries



# X-ray Binaries

CHANDRA  
IMAGE OF  
CYG X-1



# Polarized Radiation

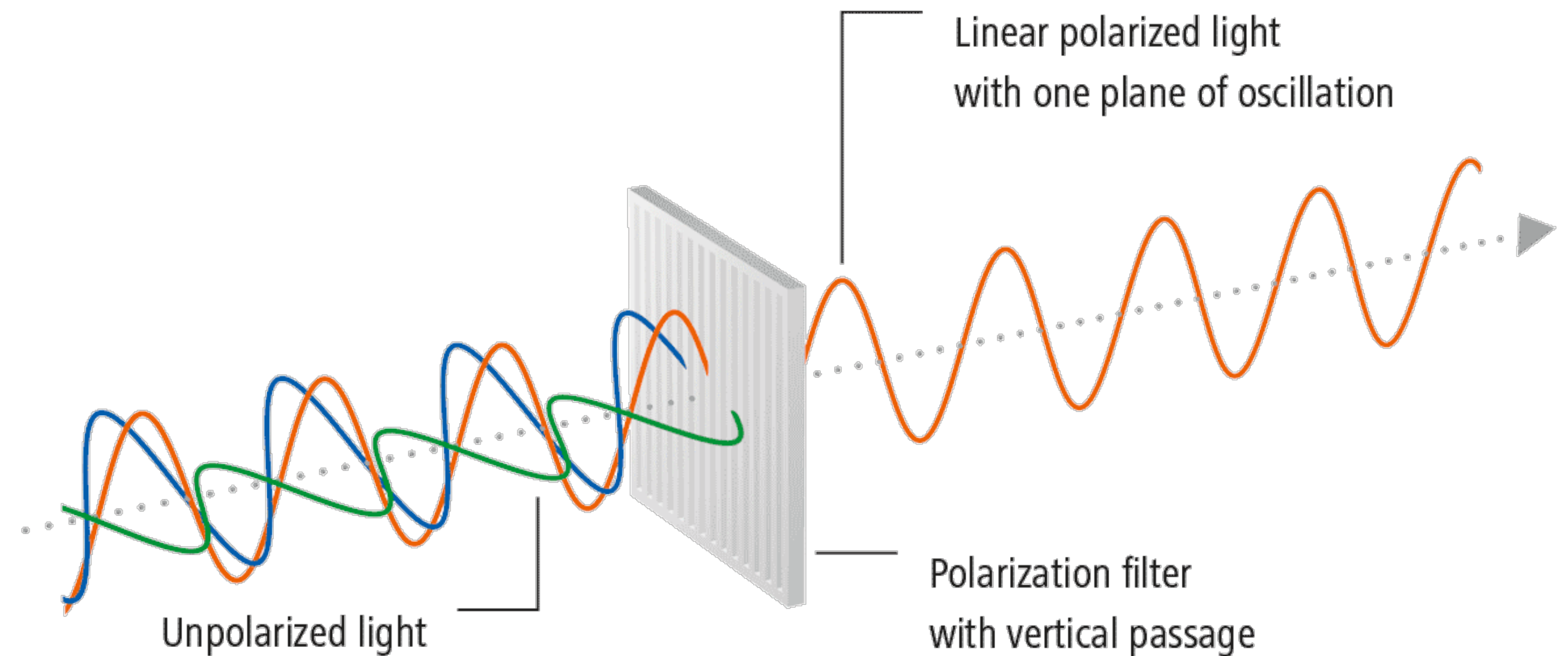
# Polarization

## Definition and description

The polarization of electromagnetic waves describes the preferred direction of the electric field oscillations.

If there is no preferred direction of oscillations, the **light is unpolarized**.

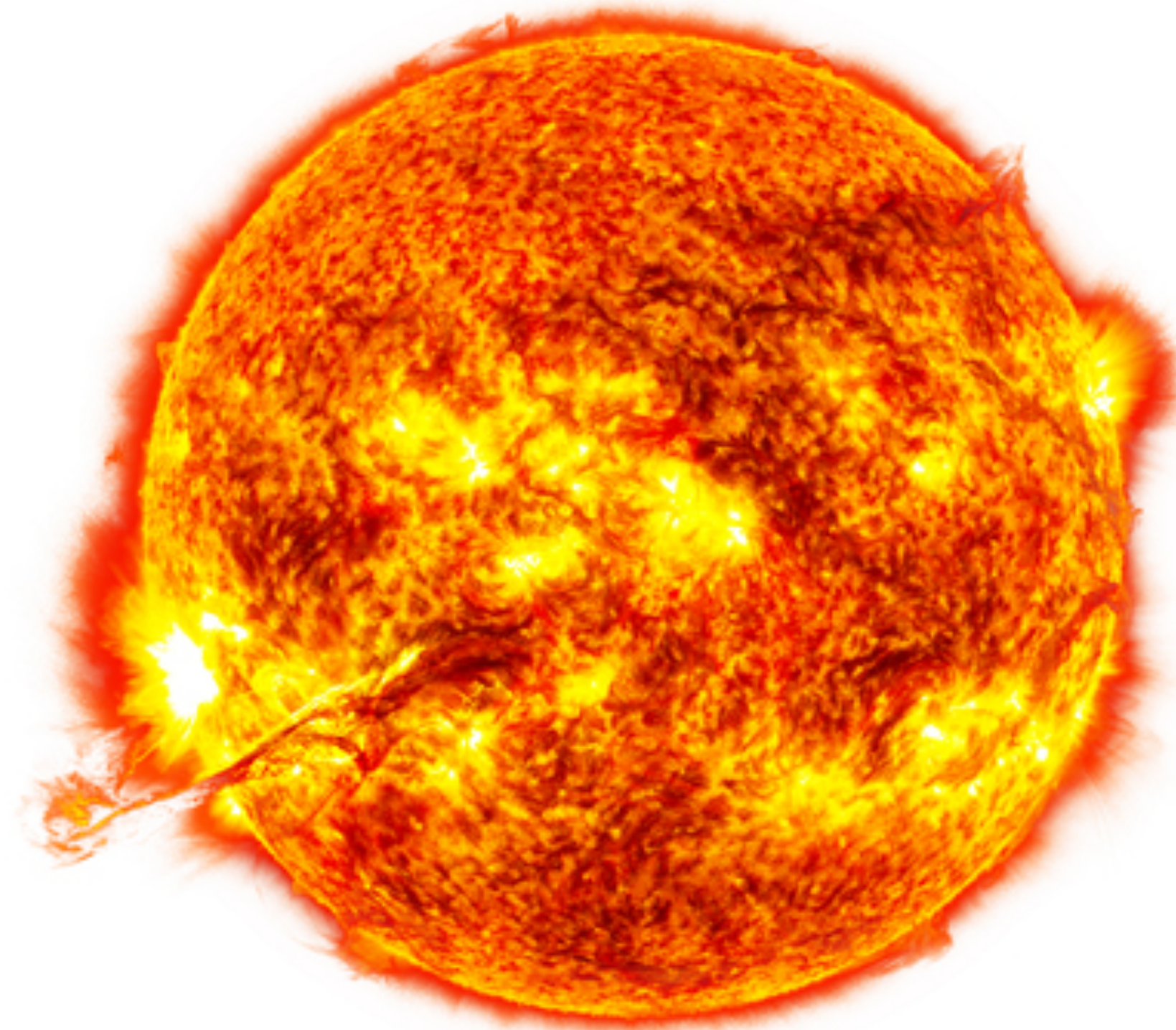
If the electric vector oscillates within one plane, the light is **linearly polarized**.



# Polarization

Definition and description

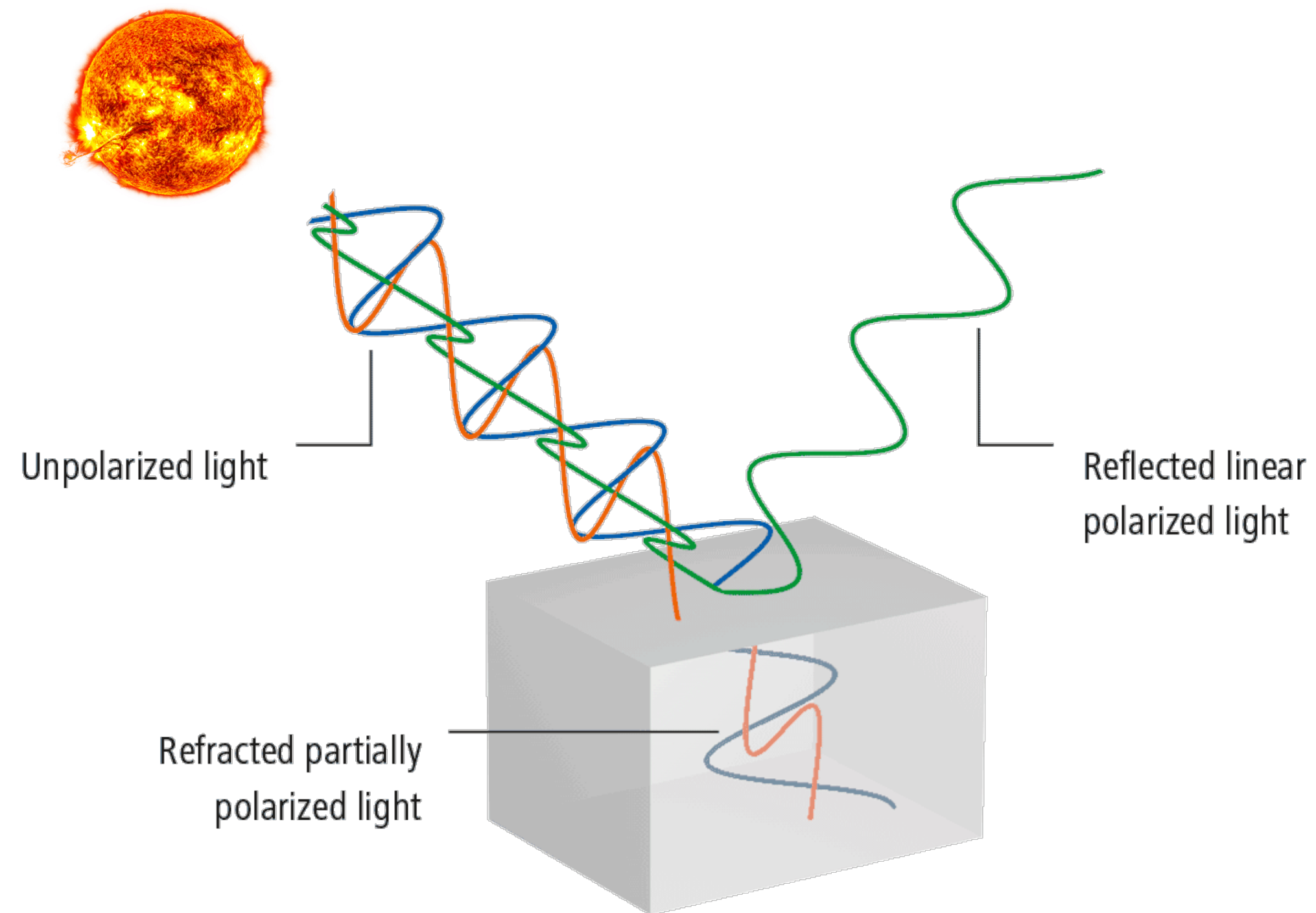
Real life example of **unpolarized light** – sunlight.



# Polarization

## Definition and description

Real life example of **unpolarized light** – sunlight.



NO GLASSES



POLARIZED GLASSES

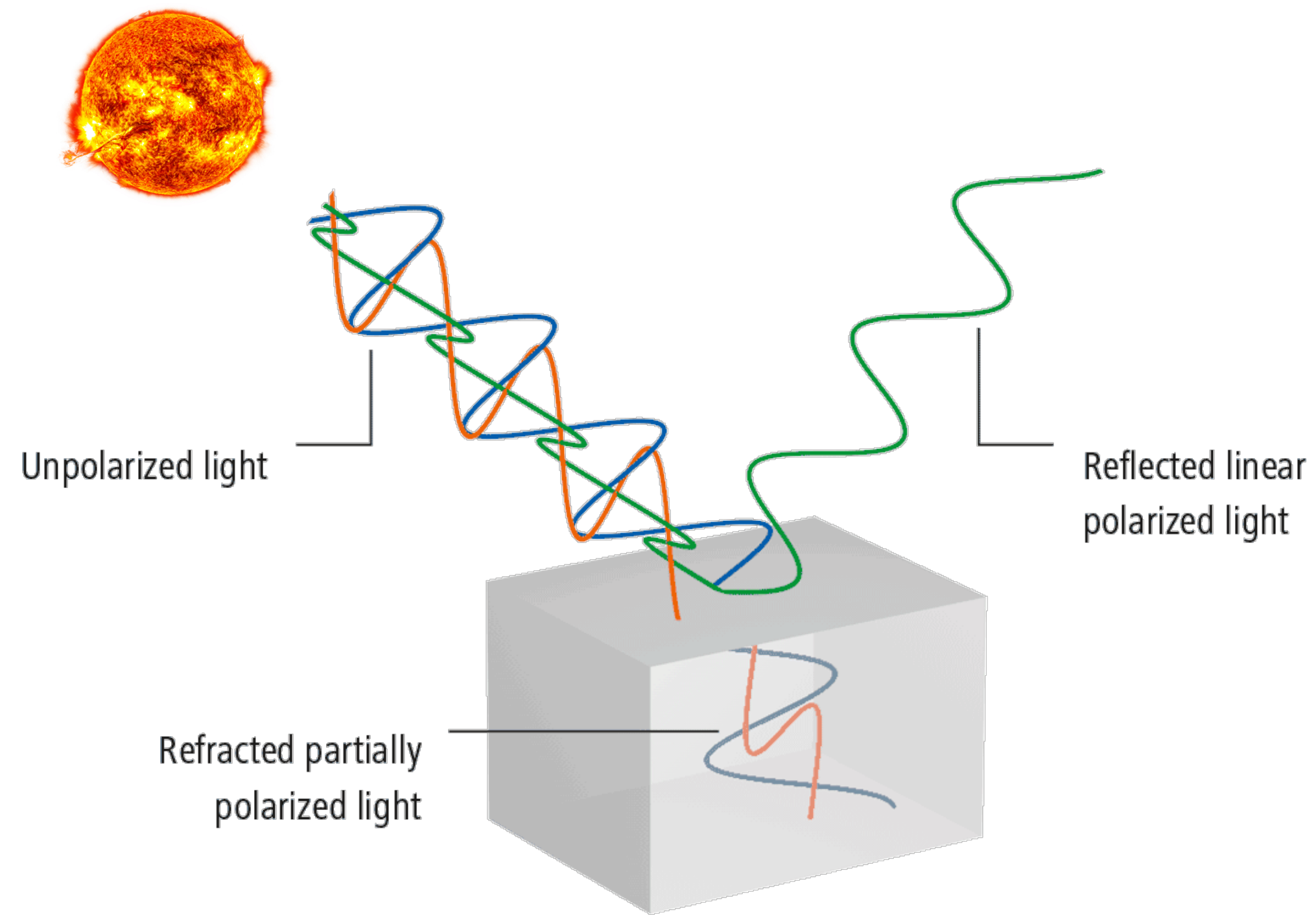


Reflection from the window, as seen without (left) and with (right) polarized glasses

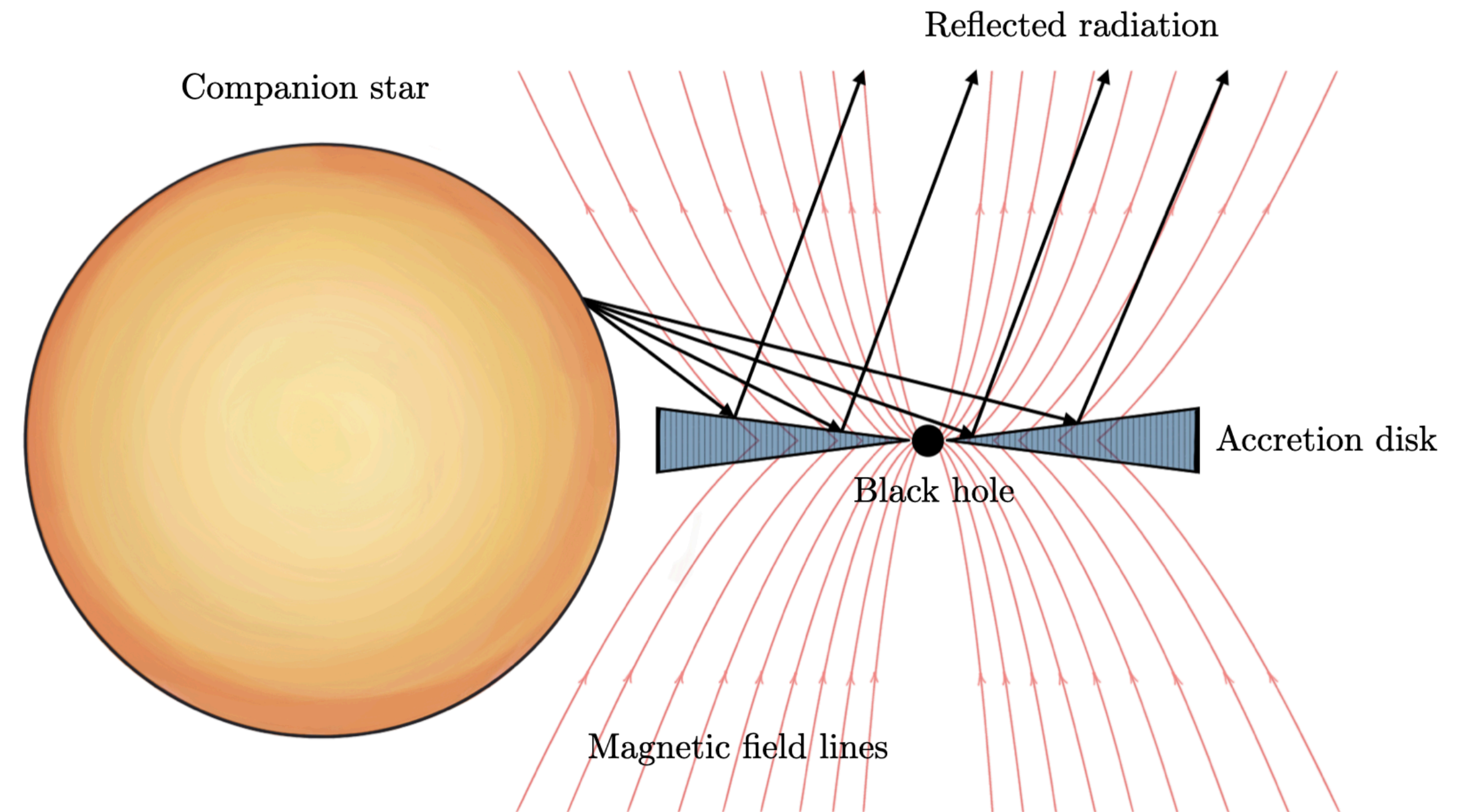
# Polarization

Definition and description

Real life example of unpolarized light – sunlight.



## SCATTERINGS ARE COMMON IN X-RAY BINARIES

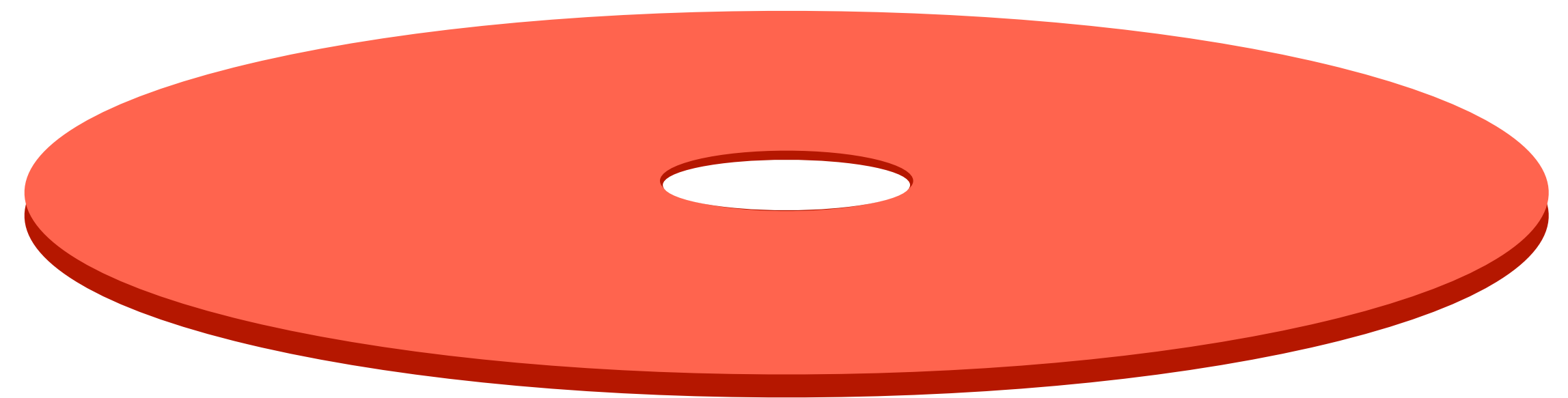


# What contributes to the polarization?

1. **Disk:** plane-parallel, electron scattering-dominated atmosphere (Shakura & Sunyaev 1973; Novikov & Thorne 1973).

$$\text{PD} = 11.7\% \frac{1 - \cos i}{1 + 3.58 \cos i}$$

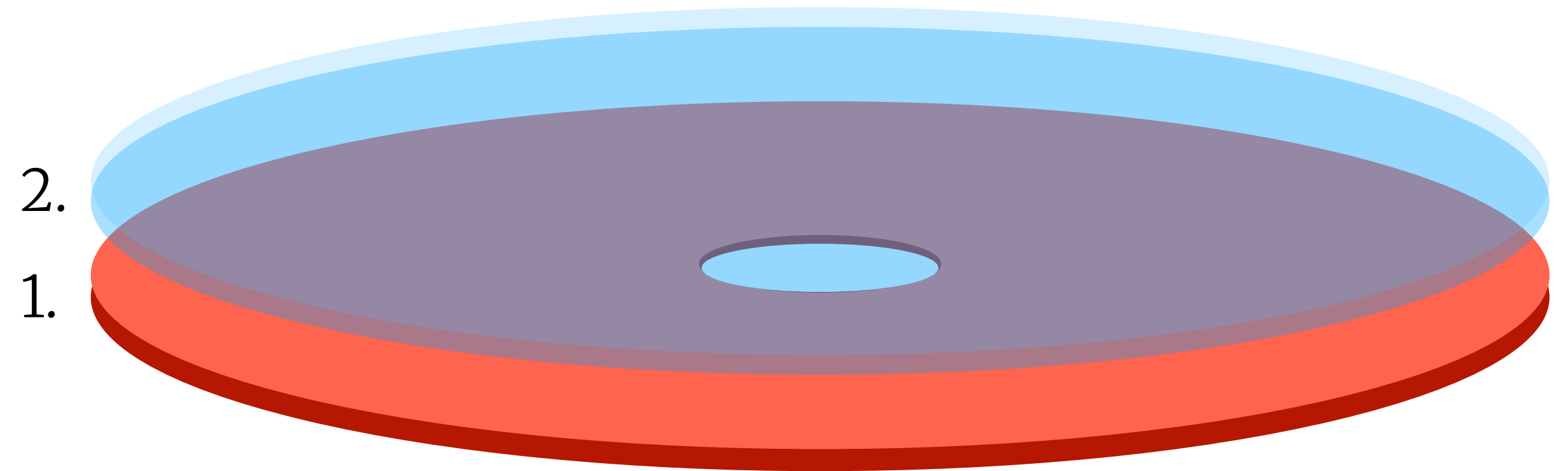
1.



# What contributes to the polarization?

1. **Disk:** plane-parallel, electron scattering-dominated atmosphere (Shakura & Sunyaev 1973; Novikov & Thorne 1973).
2. **Corona:** hot, optically thin plasma in the vicinity of black hole. Inverse Compton scattering. Different geometries were proposed: **slab**, **lamppost**, **sphere**, **conical**, **wedge**, etc. (see e.g. Poutanen & Svensson 1996; Dovčiak et al. 2004, 2008; Kara et al. 2019; Krawczynski & Beheshtipour 2022).

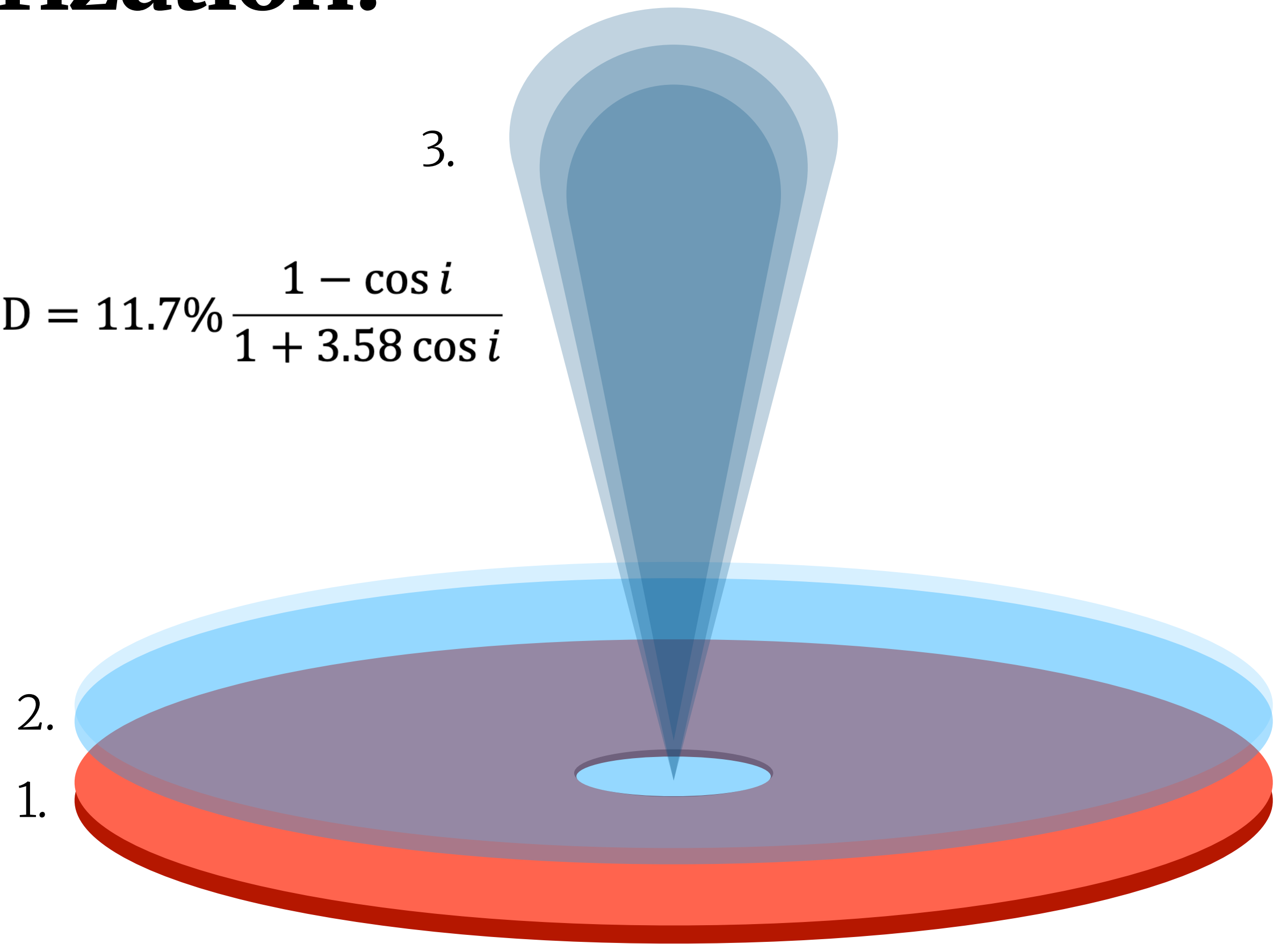
$$\text{PD} = 11.7\% \frac{1 - \cos i}{1 + 3.58 \cos i}$$



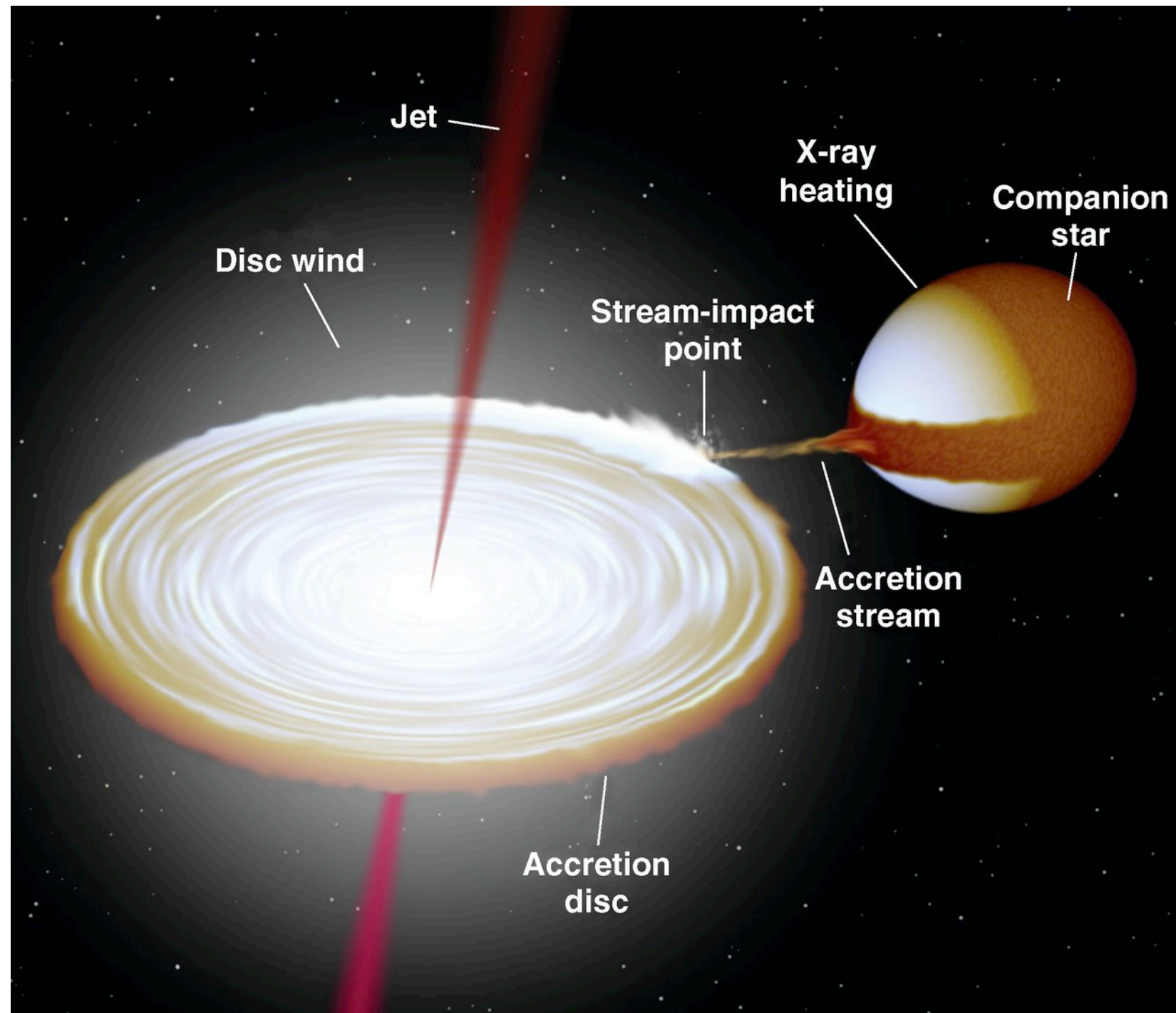
# What contributes to the polarization?

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3. **Jet? Outflow?** Synchrotron emission is highly polarized, however, even in radio the PD is quite small (Faraday rotation).

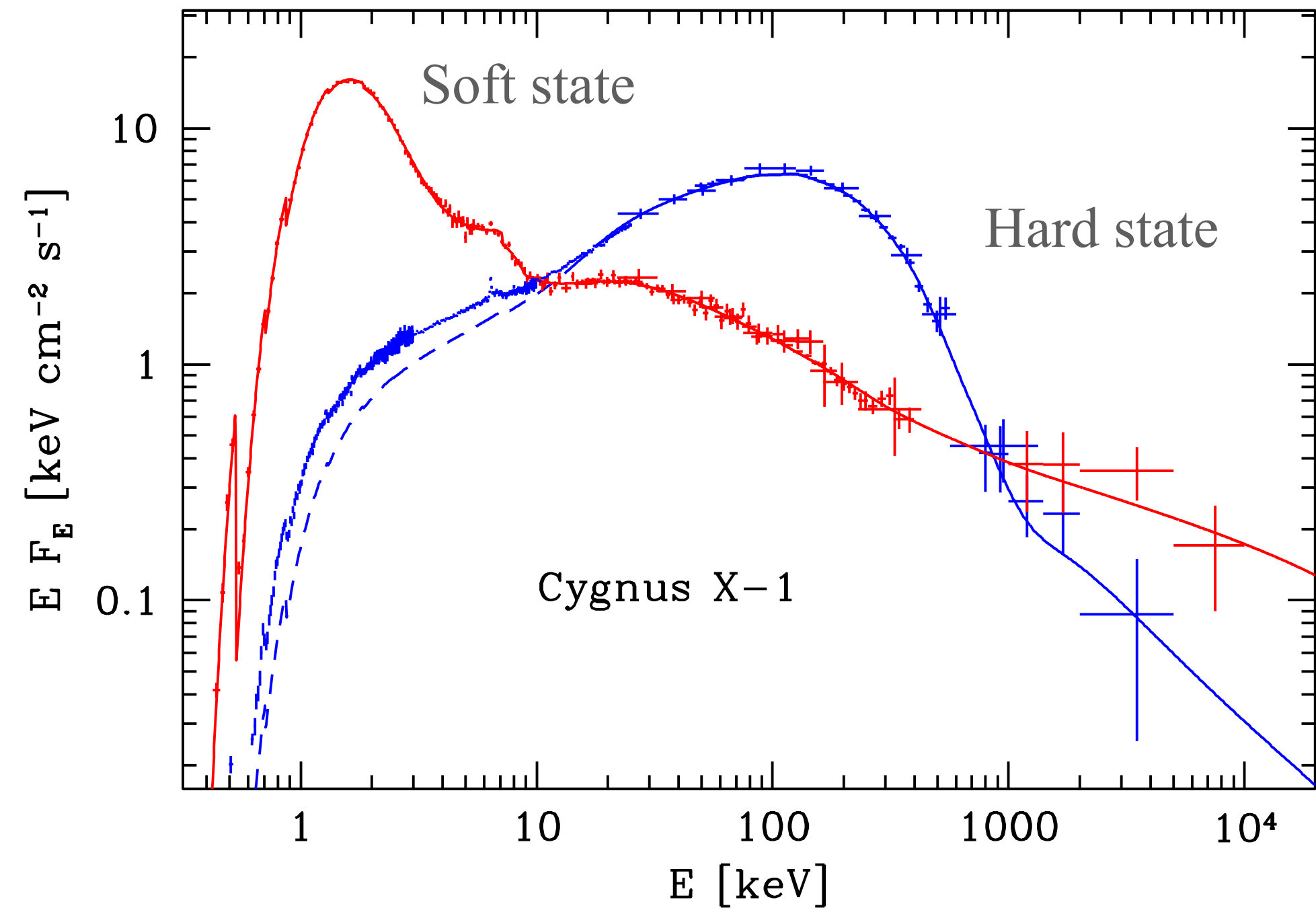
$$\text{PD} = 11.7\% \frac{1 - \cos i}{1 + 3.58 \cos i}$$



# Background on Cyg X-1

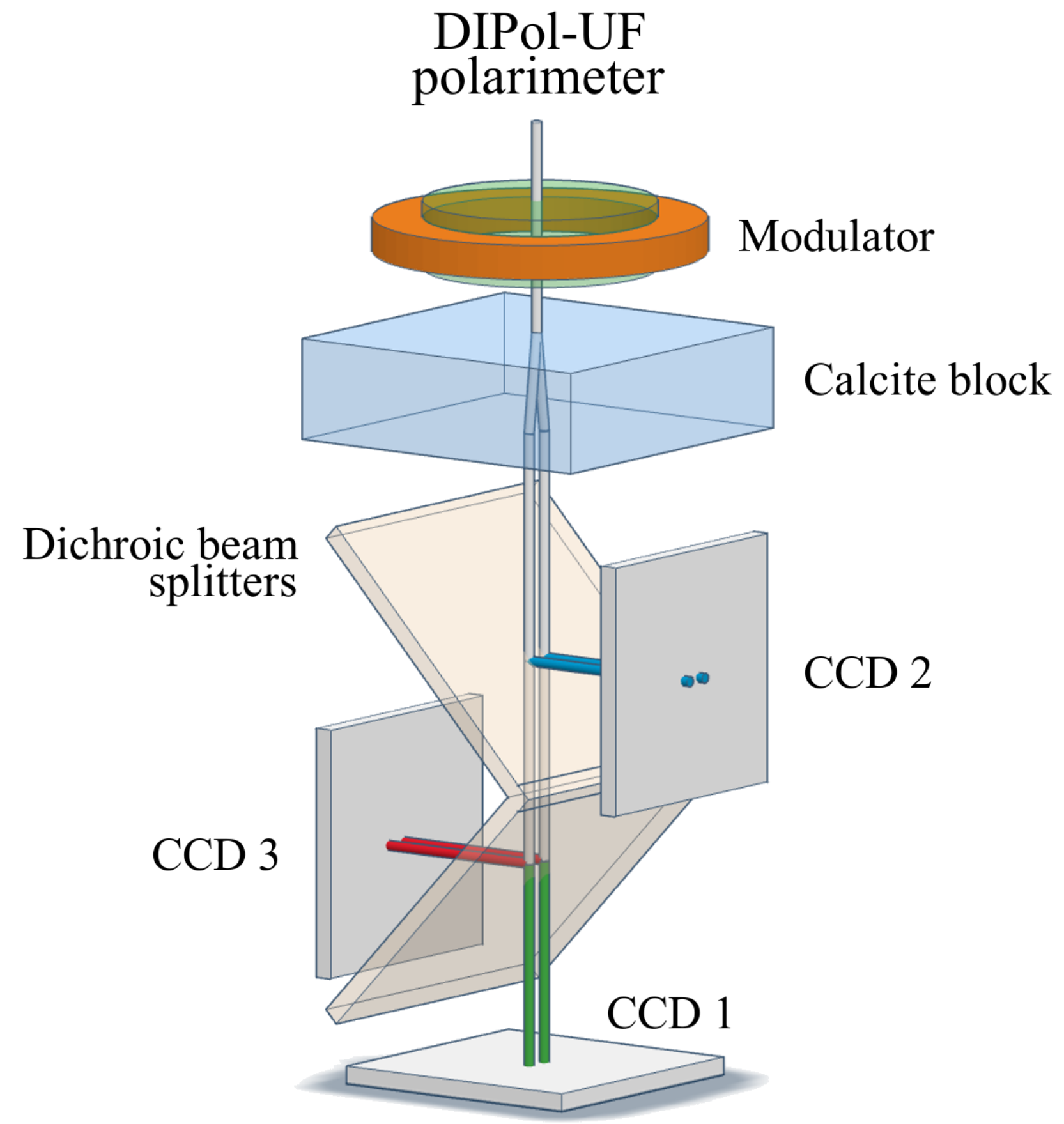


[Image produced with BinSim by Rob Hynes]



McConnell et al. 2002

# Methods and instruments



**Nordic Optical Telescope (NOT)**



La Palma, Canary Islands, Spain

**Haleakala Observatory**



Haleakala, Hawaii, US

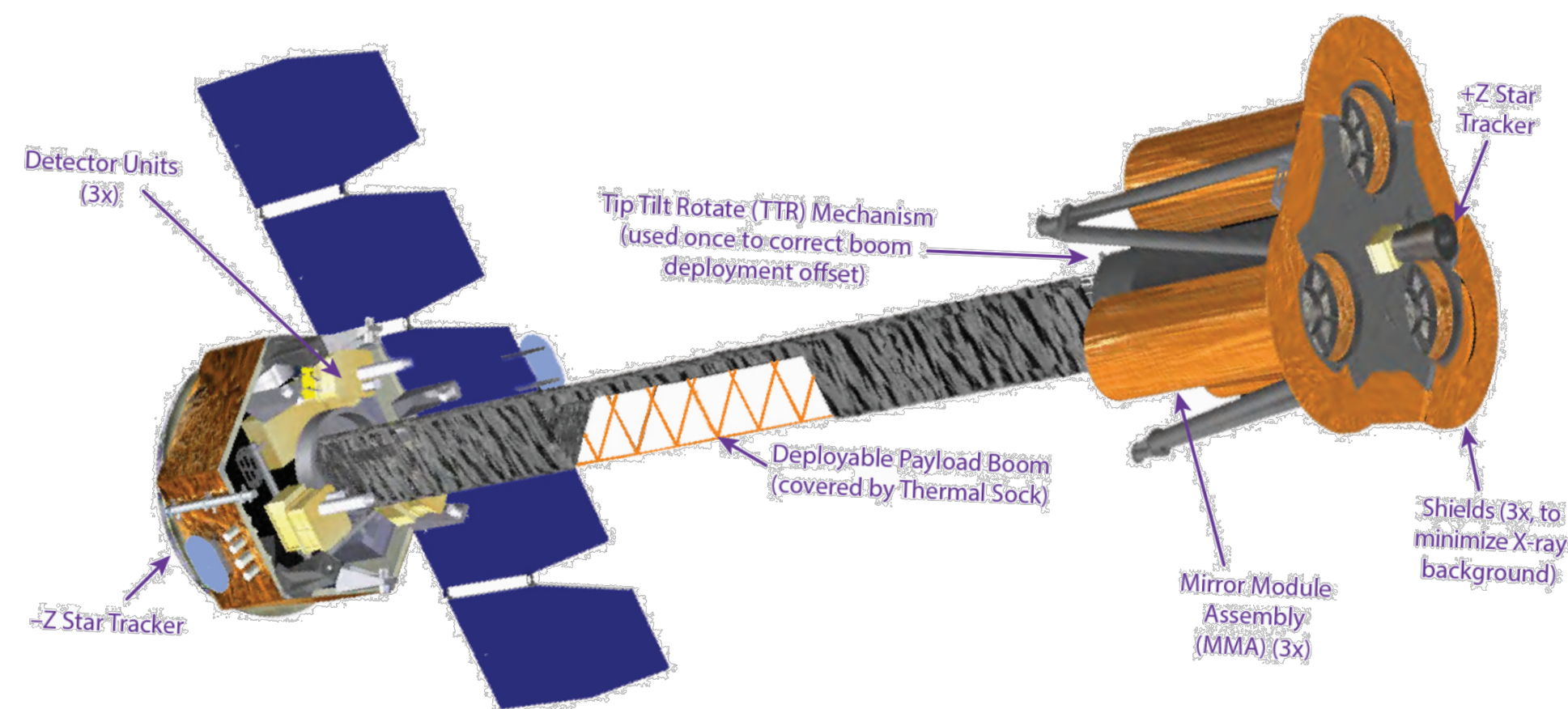
**Very Large Array (N.Mex, US)**



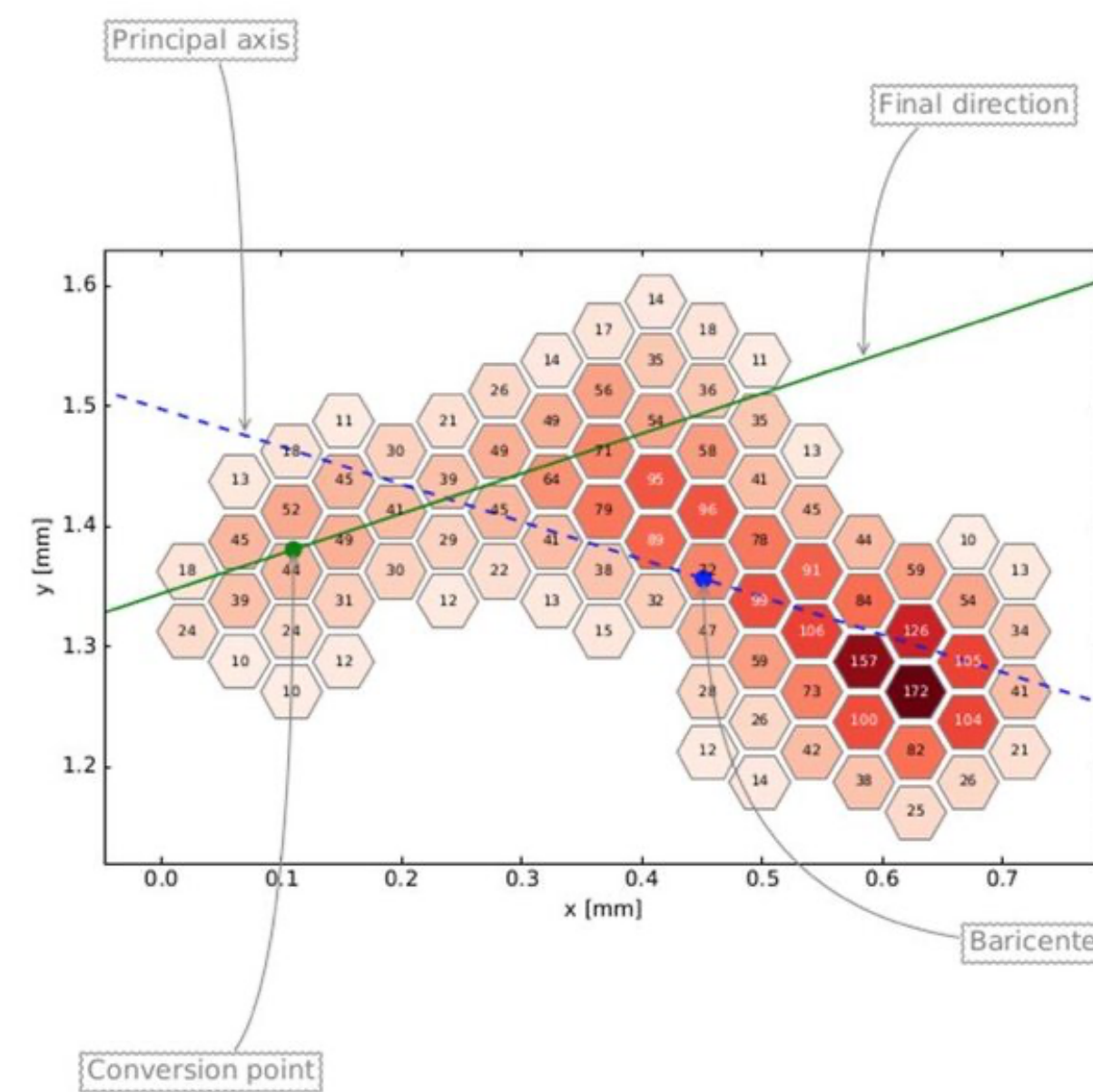
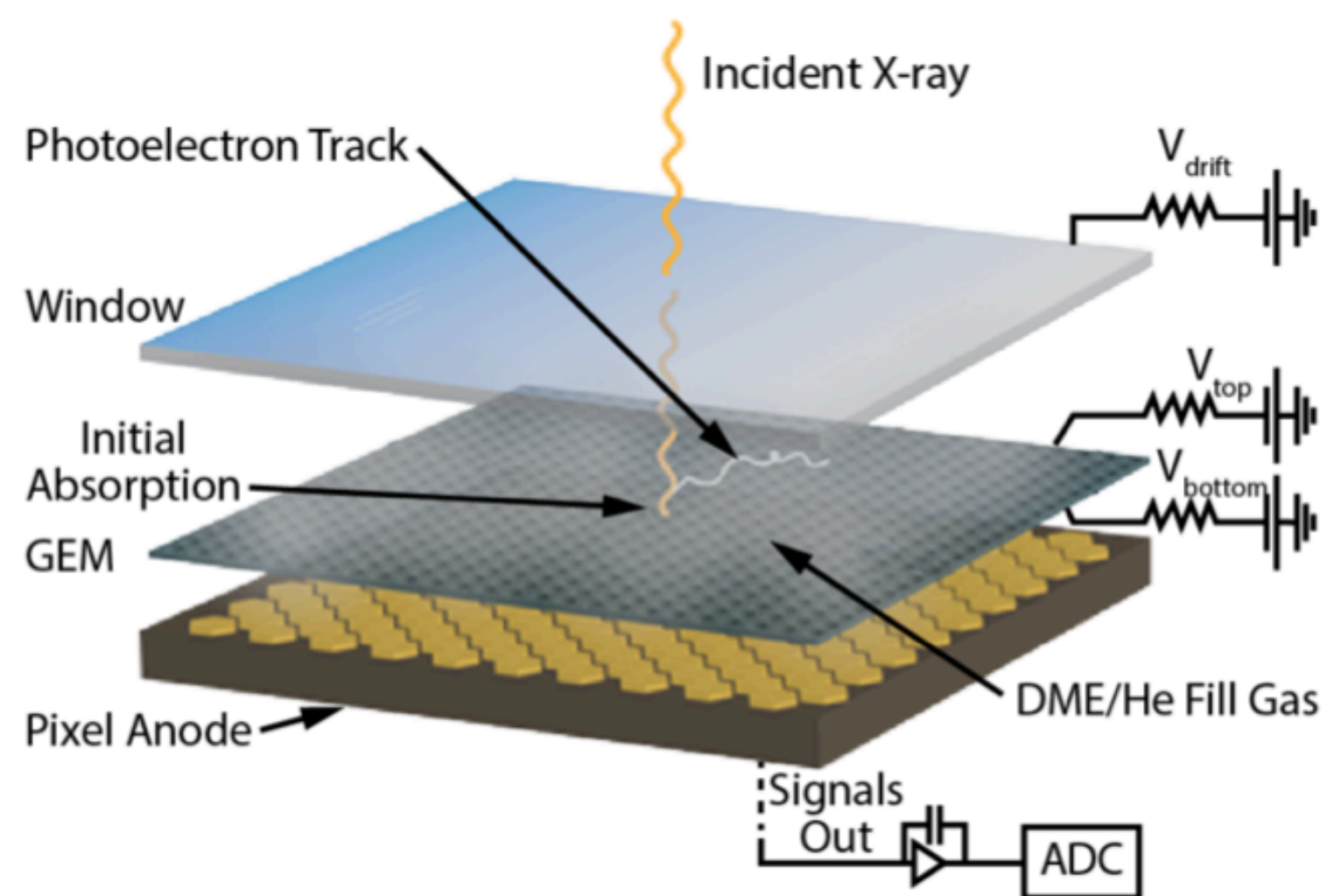
# Methods and instruments

IXPE - THE FIRST SATELLITE CAPABLE OF MEASURING THE X-RAY POLARIZATION!  
(LAUNCHED IN 2021)

## IXPE - IMAGING X-RAY POLARIMETRY EXPLORER

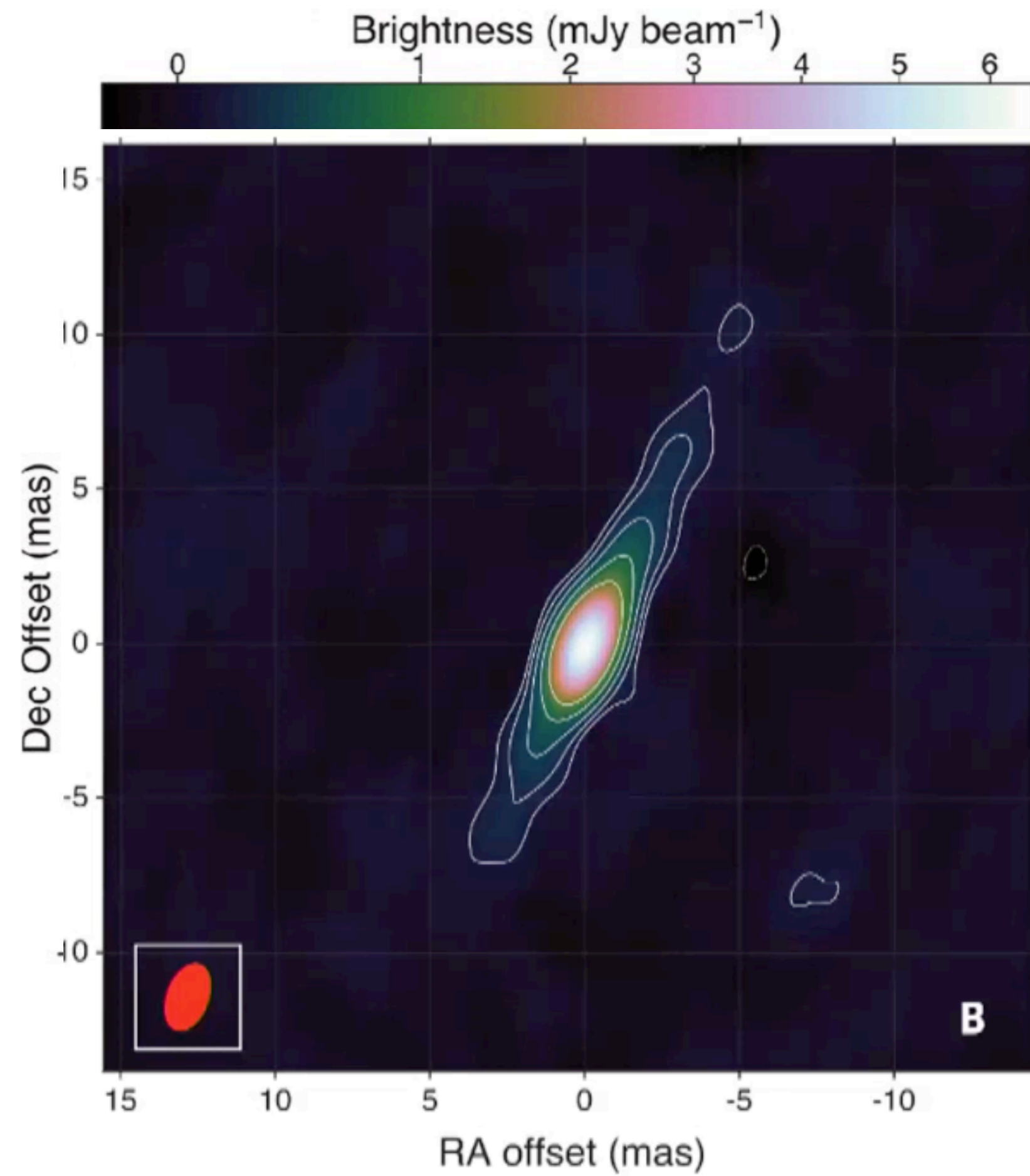


## GAS PIXEL DETECTOR

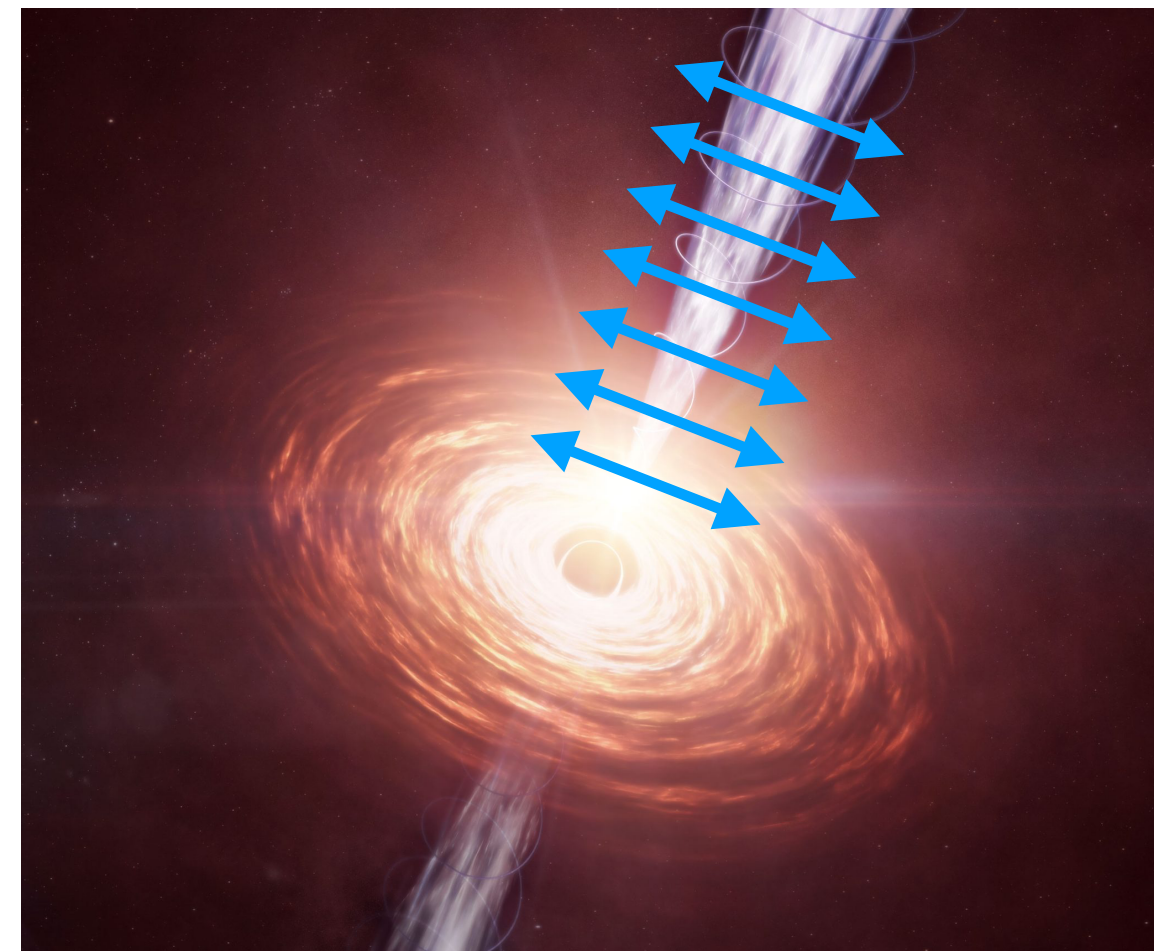


PHOTOELECTRON TRACK

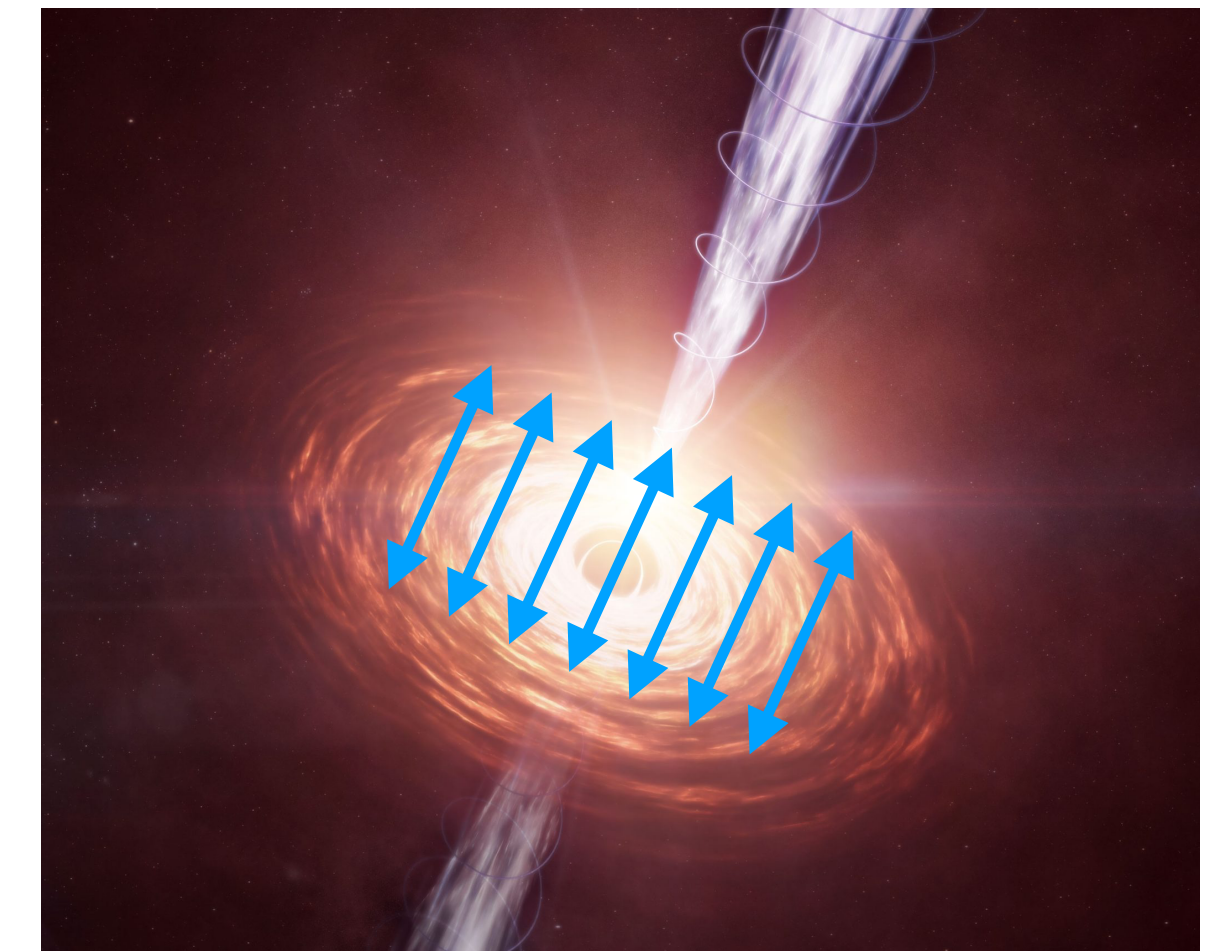
# Background on Cyg X-1



## X-RAY POLARIZATION PREDICTIONS

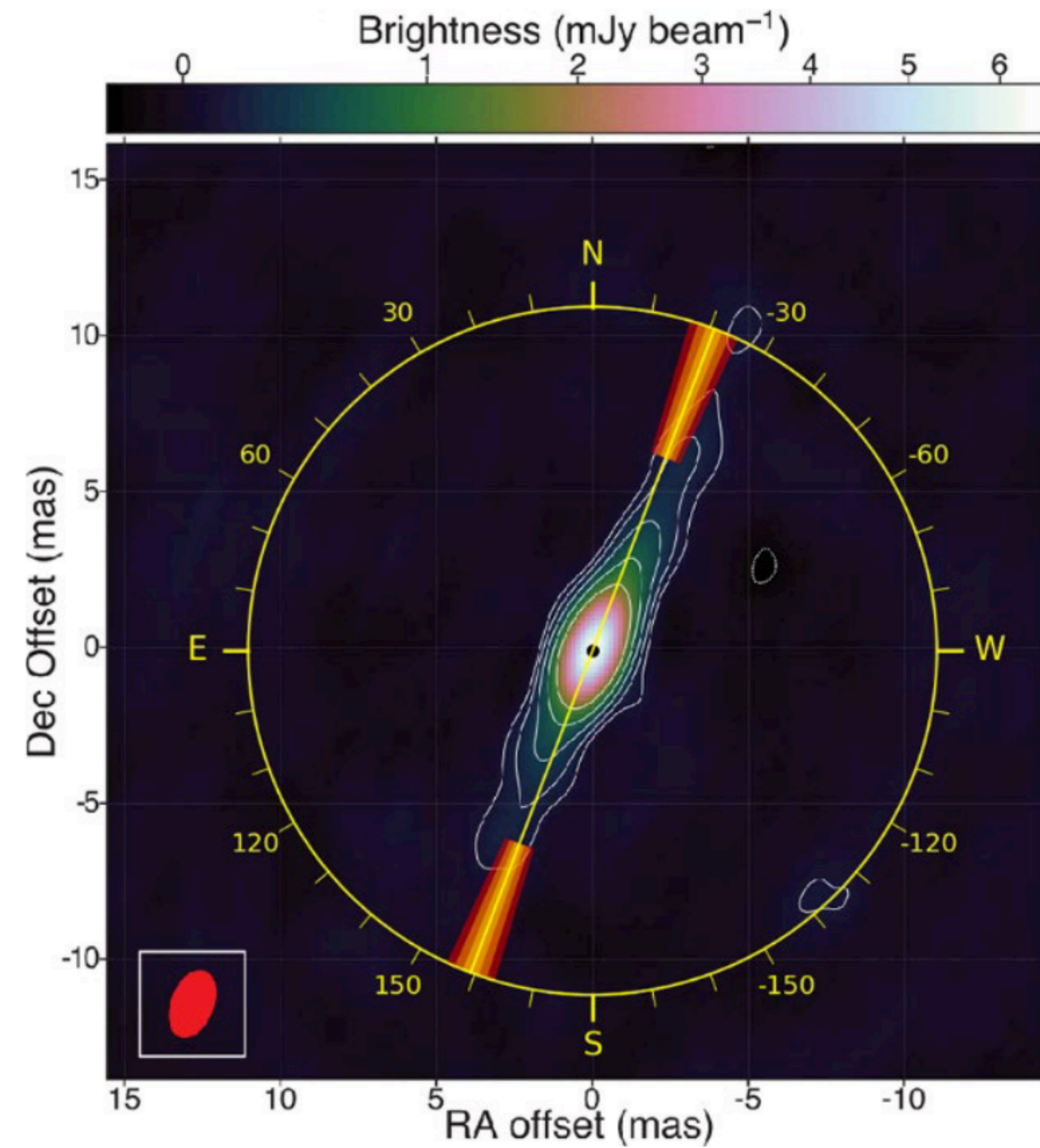


NASA/CXC/SAO/M. Weiss



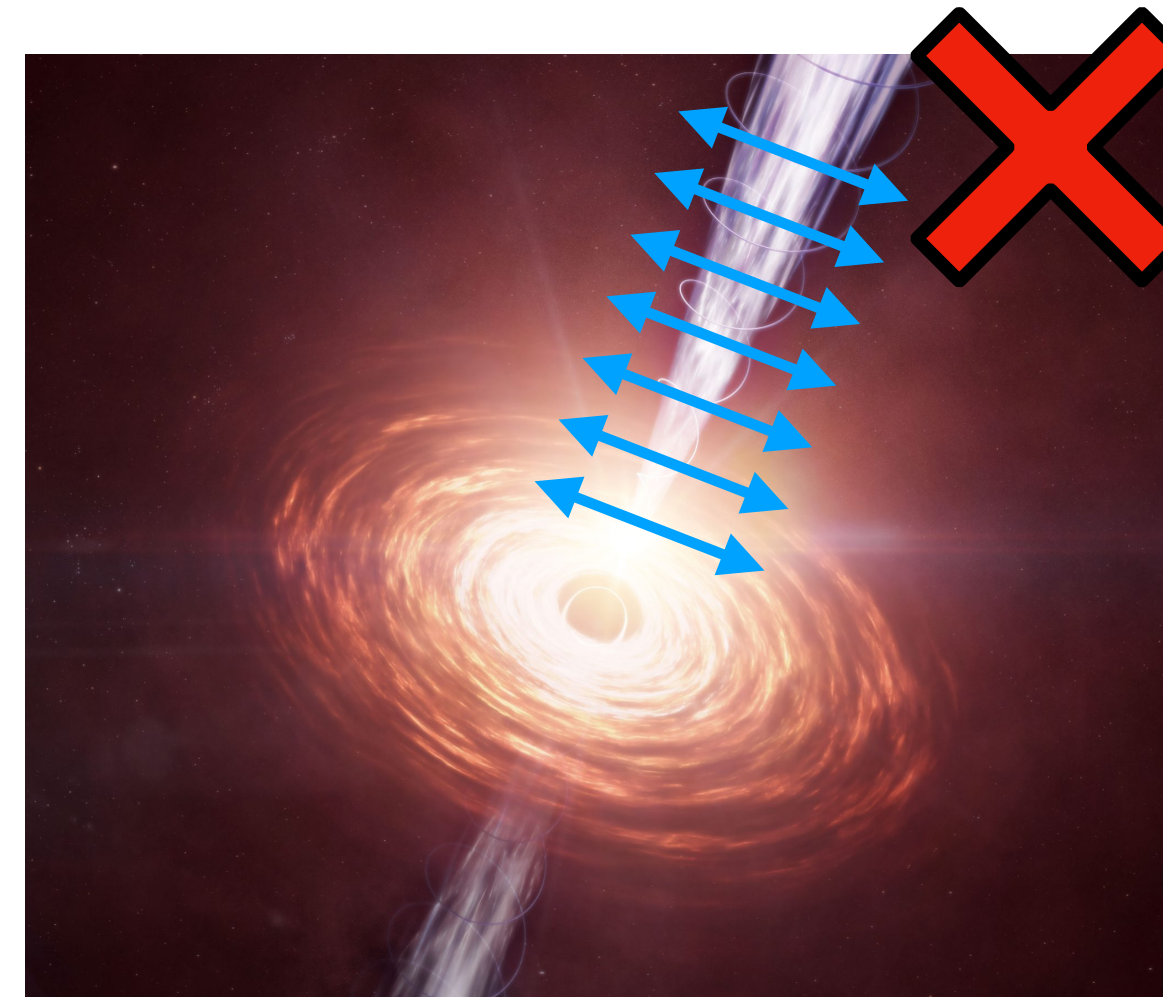
NASA/CXC/SAO/M. Weiss

# Background on Cyg X-1

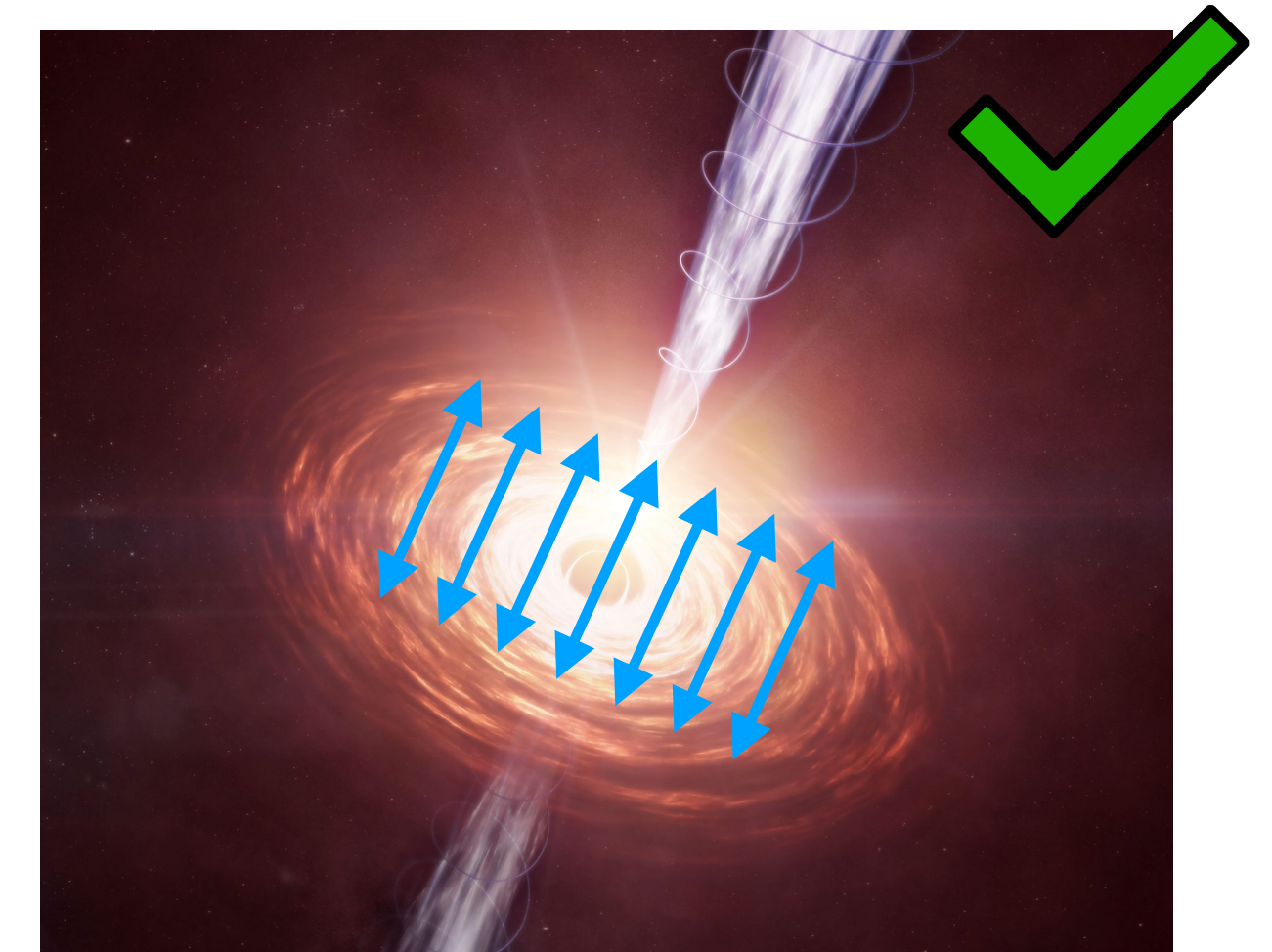


Krawczynski ... VK et al. 2022, Science

## X-RAY POLARIZATION PREDICTIONS



NASA/CXC/SAO/M. Weiss

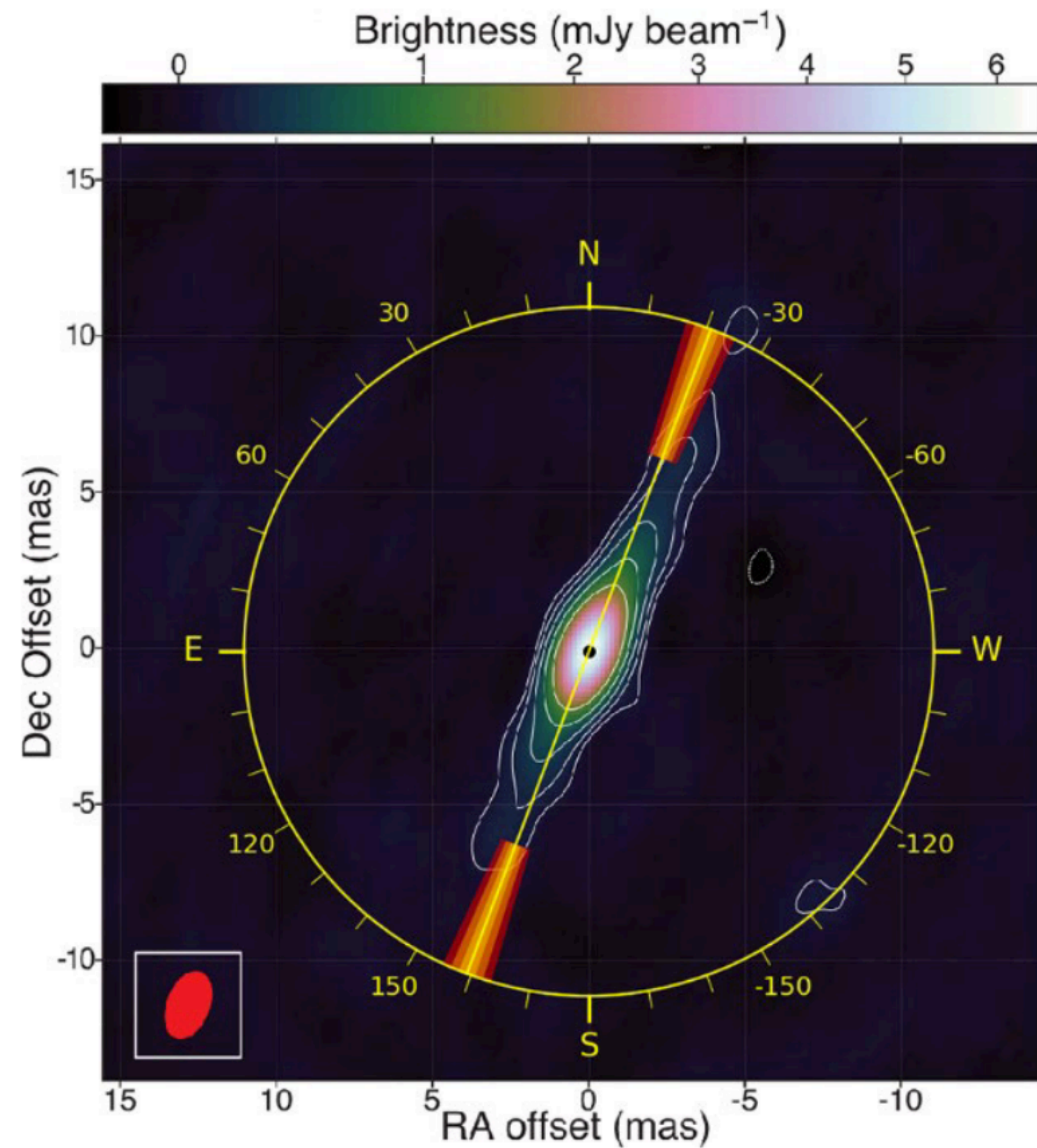


NASA/CXC/SAO/M. Weiss

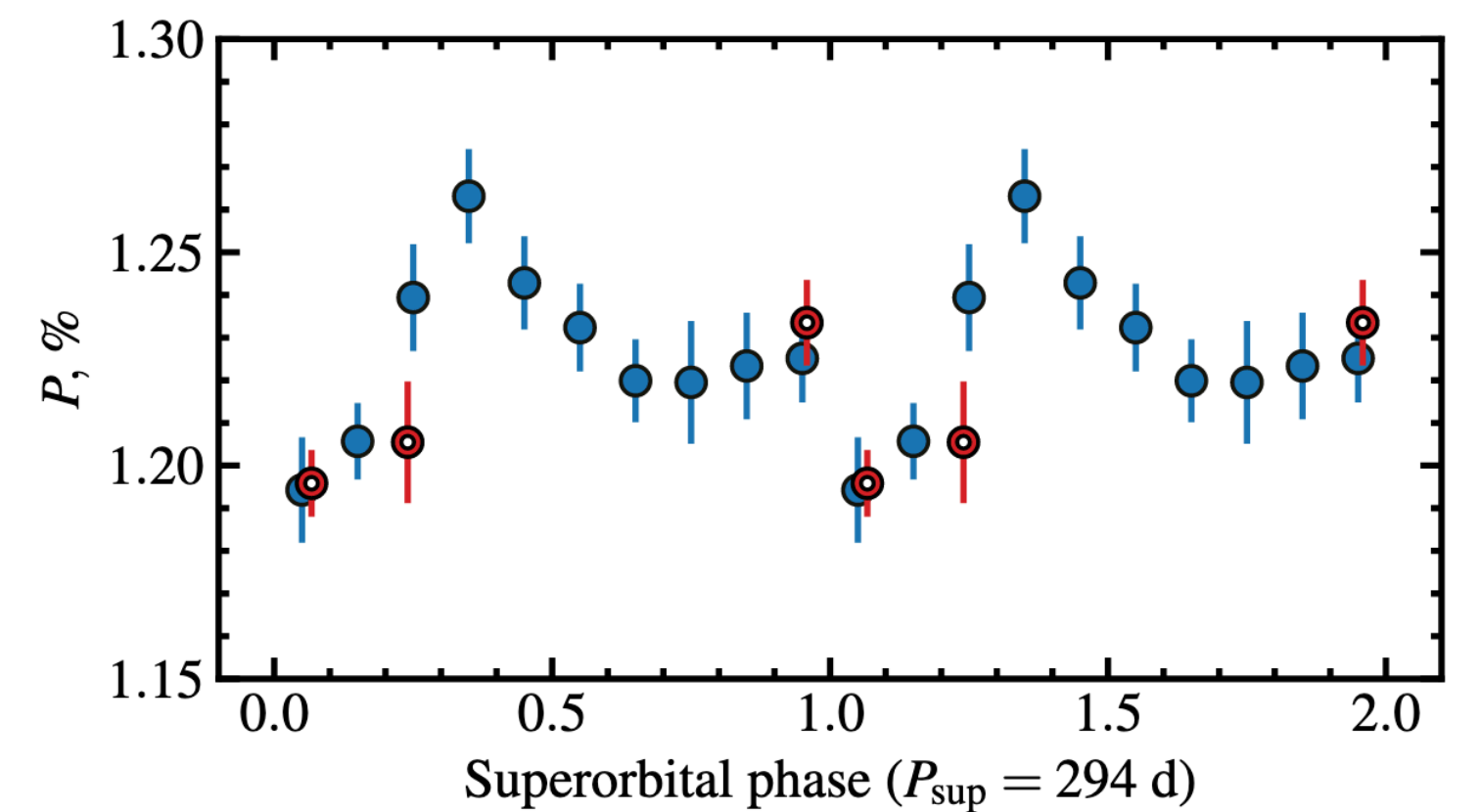
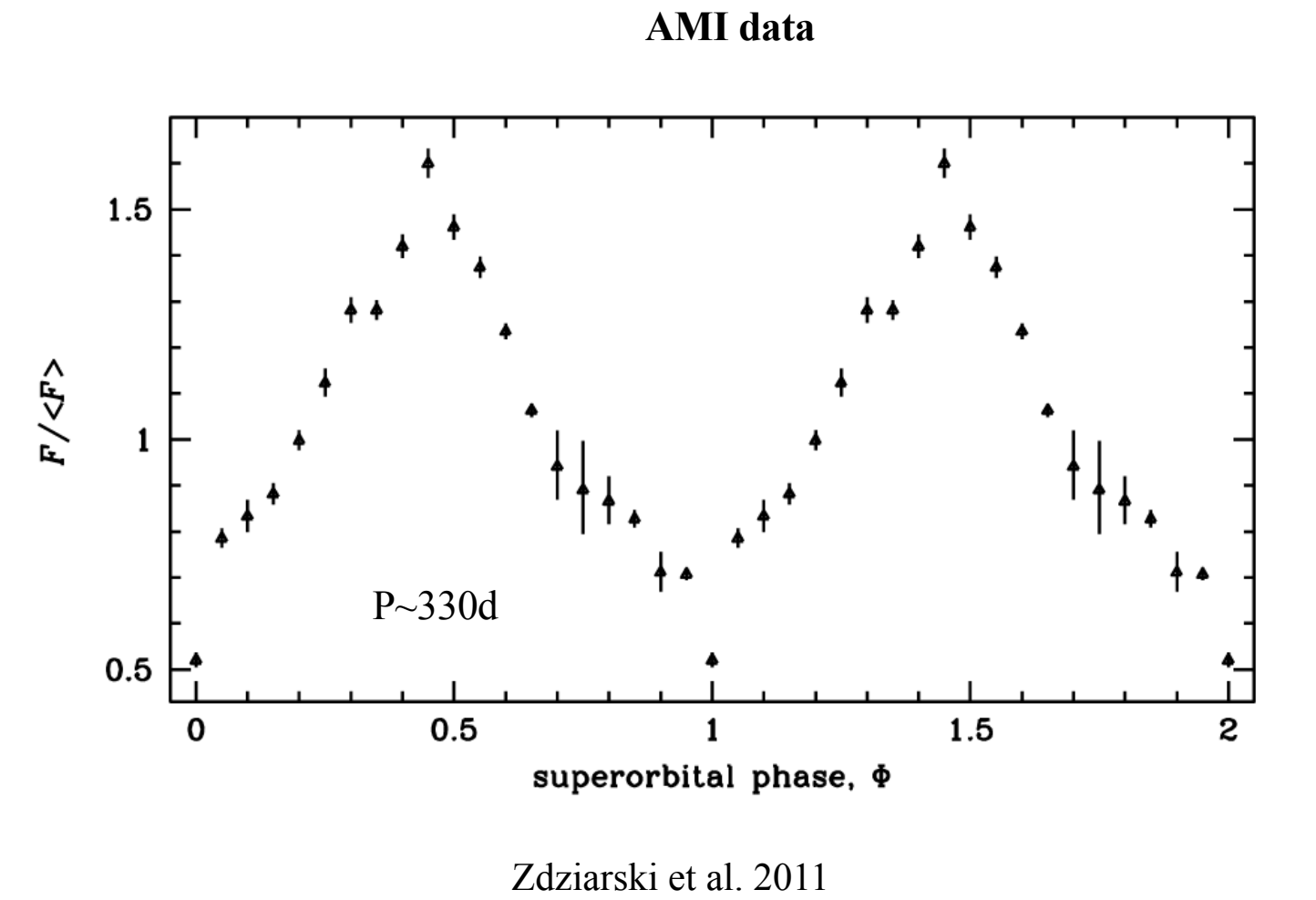
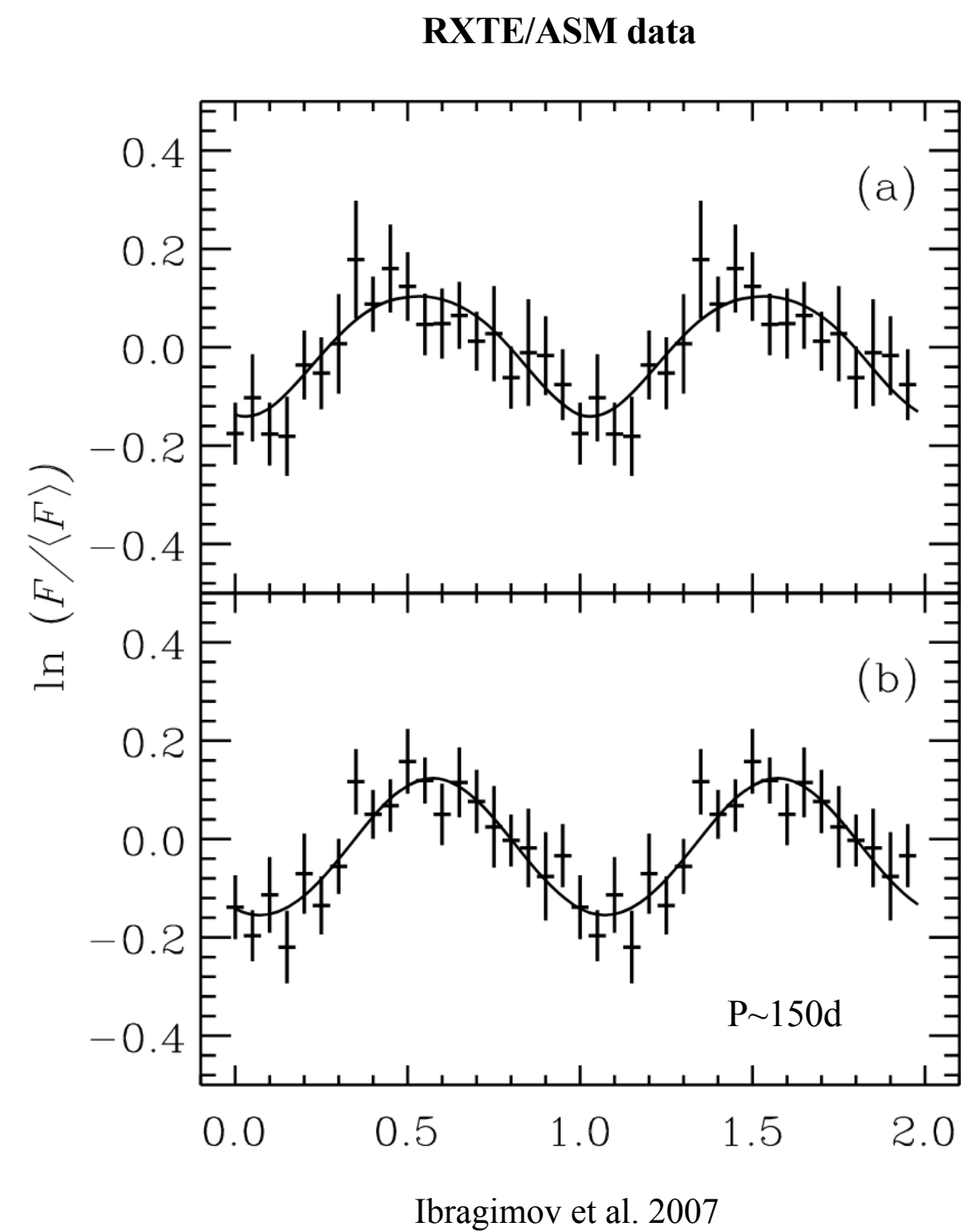
PD > 4% required high ( $i > 45^\circ$ )  
inclination of the X-ray bright region

# Background on Cyg X-1

## Superorbital precession of the disk?



Krawczynski ... VK et al. 2022, Science



Kemp et al., 1983 (blue); VK et al. 2023 (red)

# Our observations

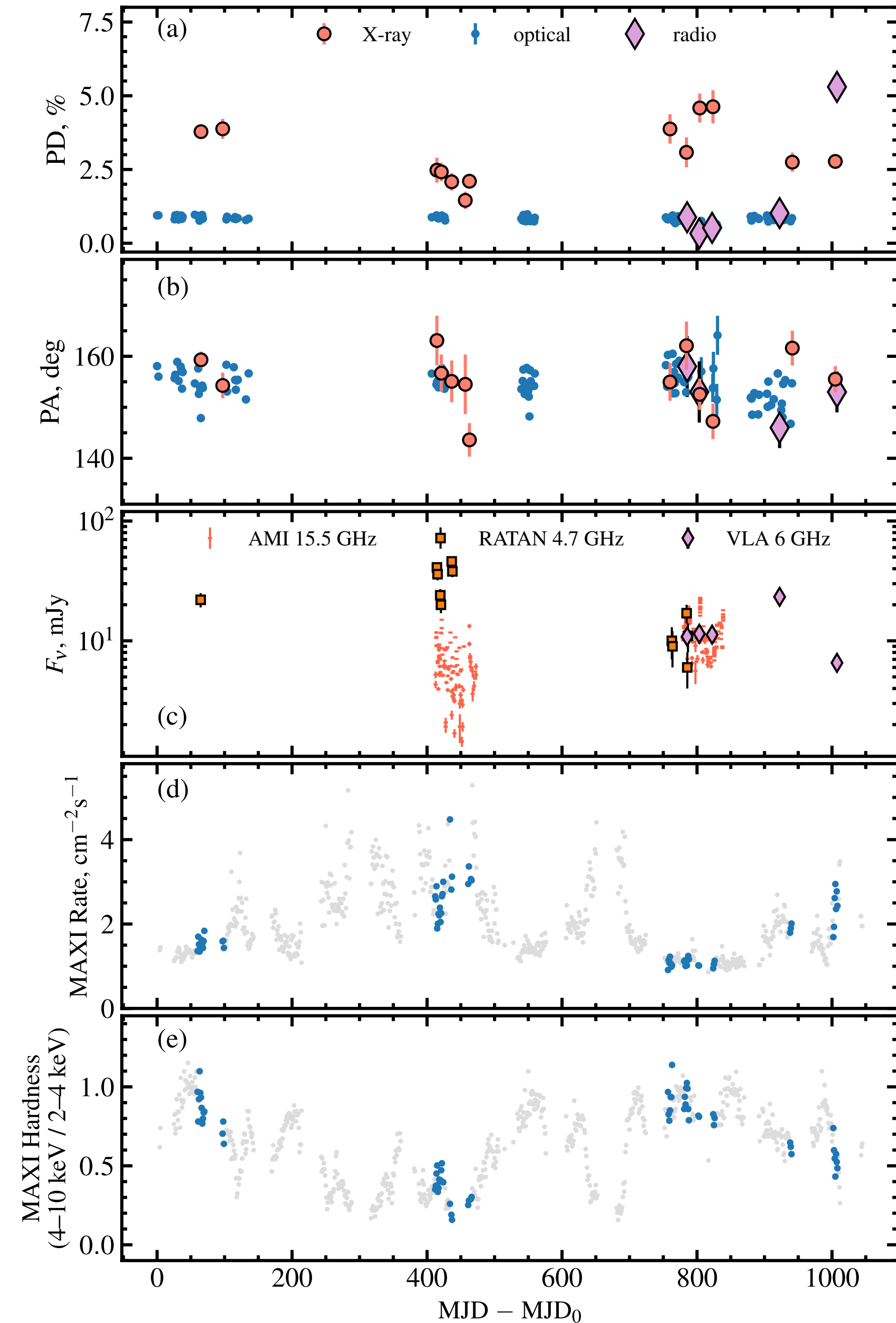
## 13 IXPE pointings during 3 years

Epoch	Date	State	PD (%)	PA (deg)
1	2022 May 15	H	$4.0 \pm 0.2$	$-21 \pm 2$
2	June 18	H	$3.9 \pm 0.3$	$-26 \pm 3$
3	2023 May 2	S	$2.5 \pm 0.4$	$-17 \pm 5$
4	May 9	S	$2.4 \pm 0.3$	$-23 \pm 4$
5	May 24	S	$2.1 \pm 0.3$	$-25 \pm 4$
6	June 13	S	$1.5 \pm 0.3$	$-26 \pm 6$
7	June 20	S	$2.1 \pm 0.2$	$-36 \pm 3$
8	2024 April 12	H	$3.9 \pm 0.5$	$-25 \pm 4$
9	May 6	H	$3.1 \pm 0.5$	$-28 \pm 5$
10	May 26	H	$4.6 \pm 0.5$	$-28 \pm 3$
11	June 14	H	$4.6 \pm 0.6$	$-33 \pm 3$
12	October 10	S	$2.8 \pm 0.3$	$-18 \pm 3$
13	December 12	S	$2.8 \pm 0.2$	$-25 \pm 3$

[1-2] Krawczynski et al. 2022

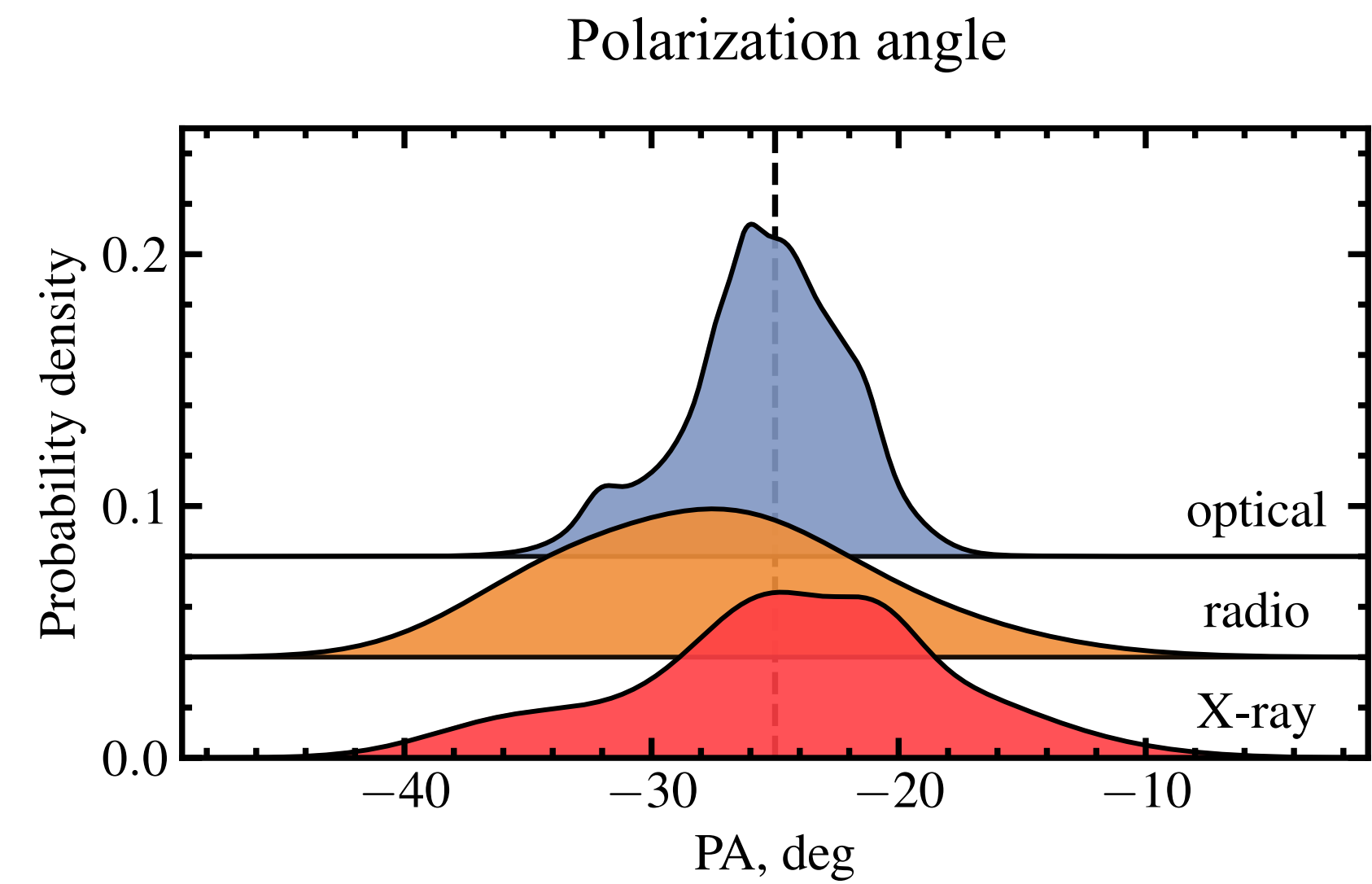
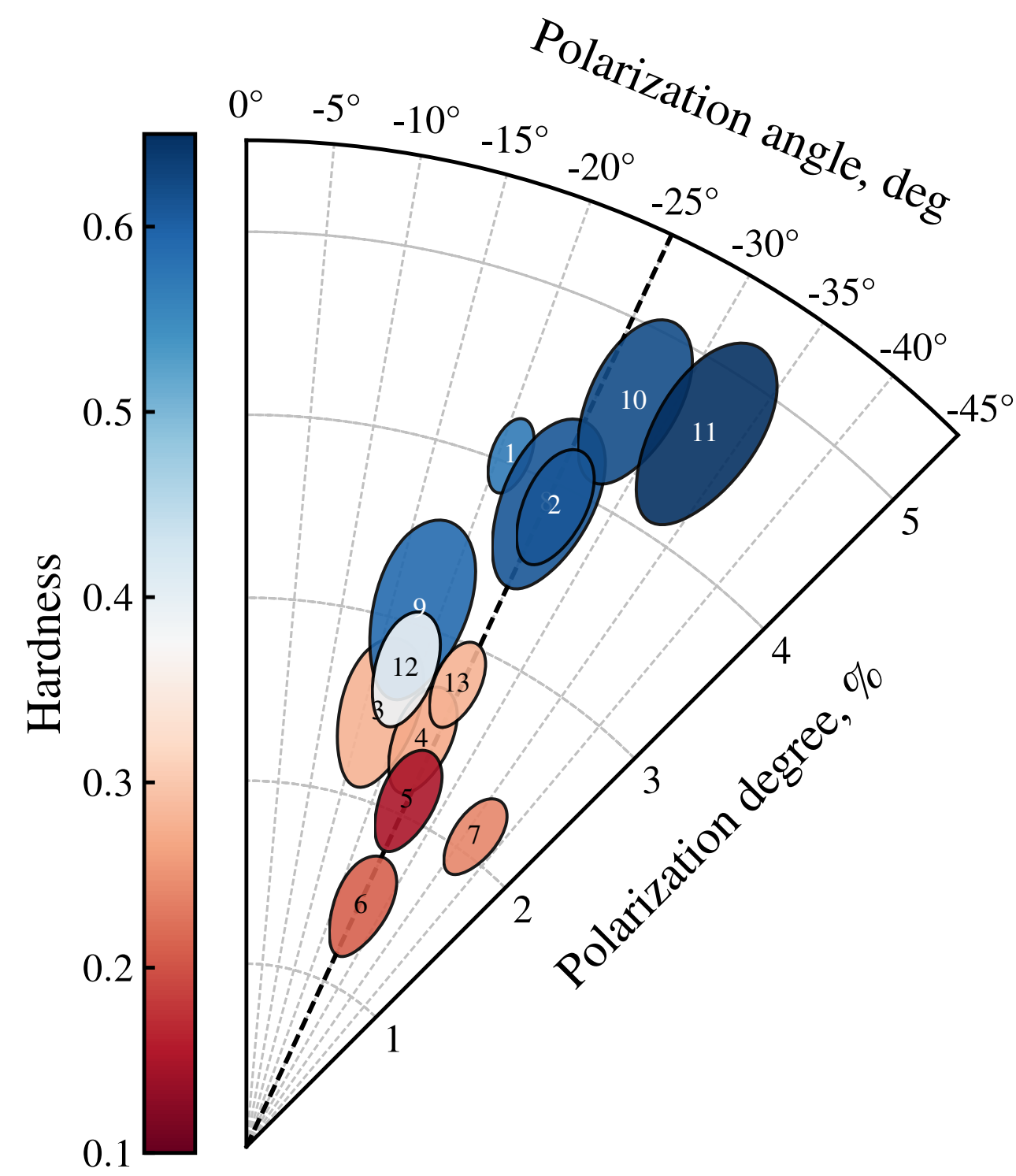
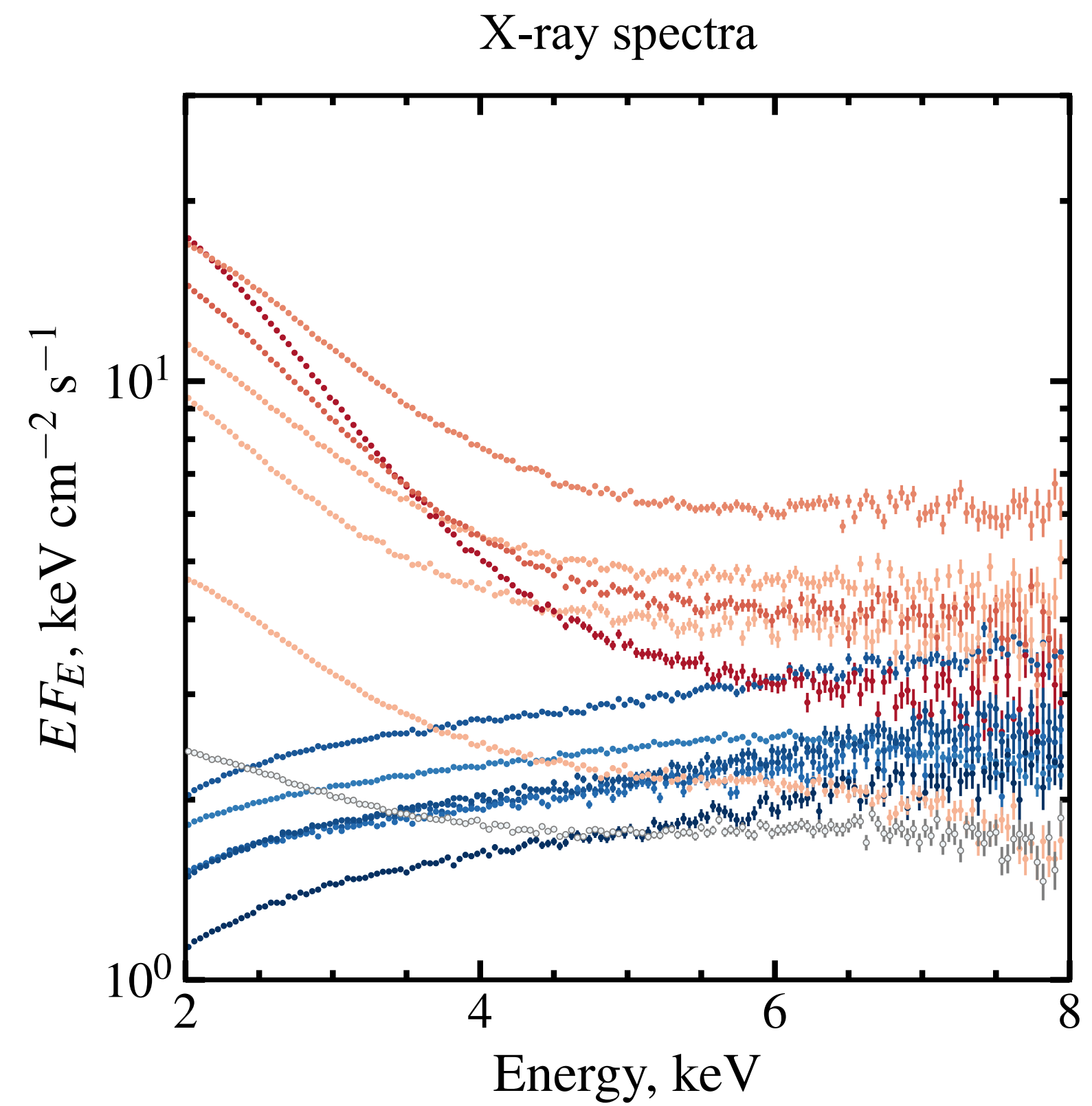
[3-7] Steiner et al. 2024, Jana et al. 2024

[8-10] Dovčiak et al. 2024



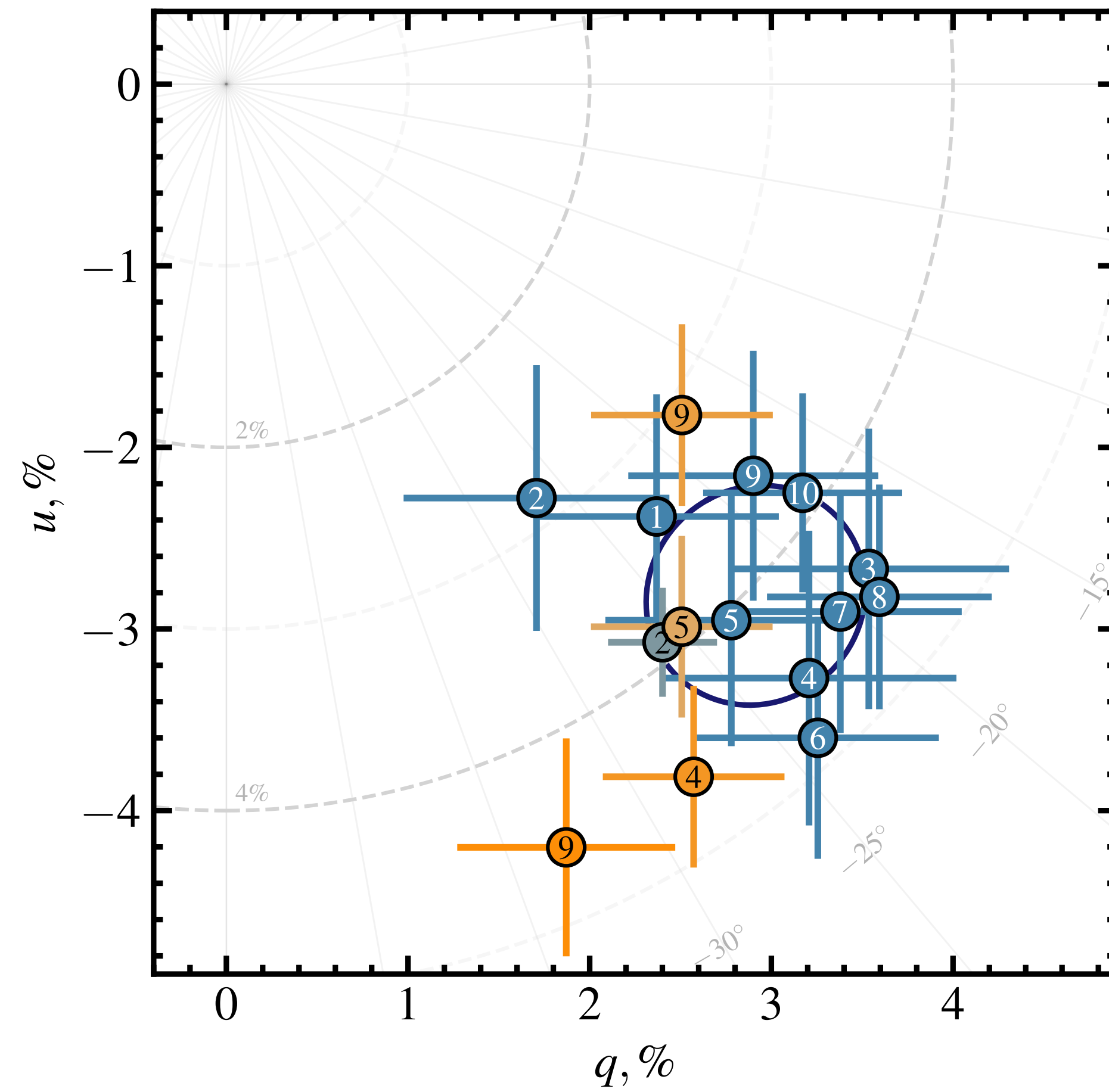
# Results

## X-ray spectra and polarization

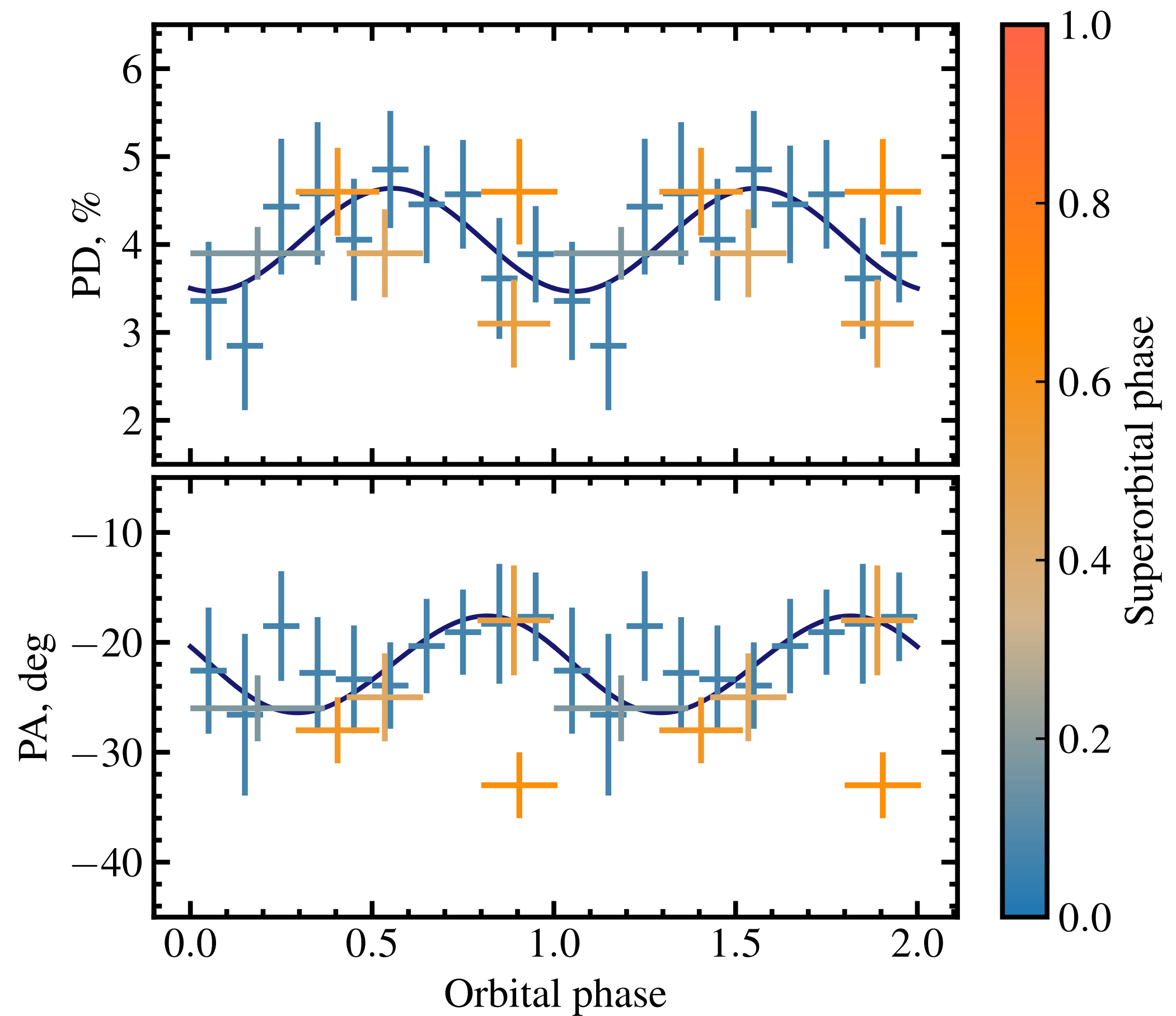


# Results

## Orbital variations of polarization

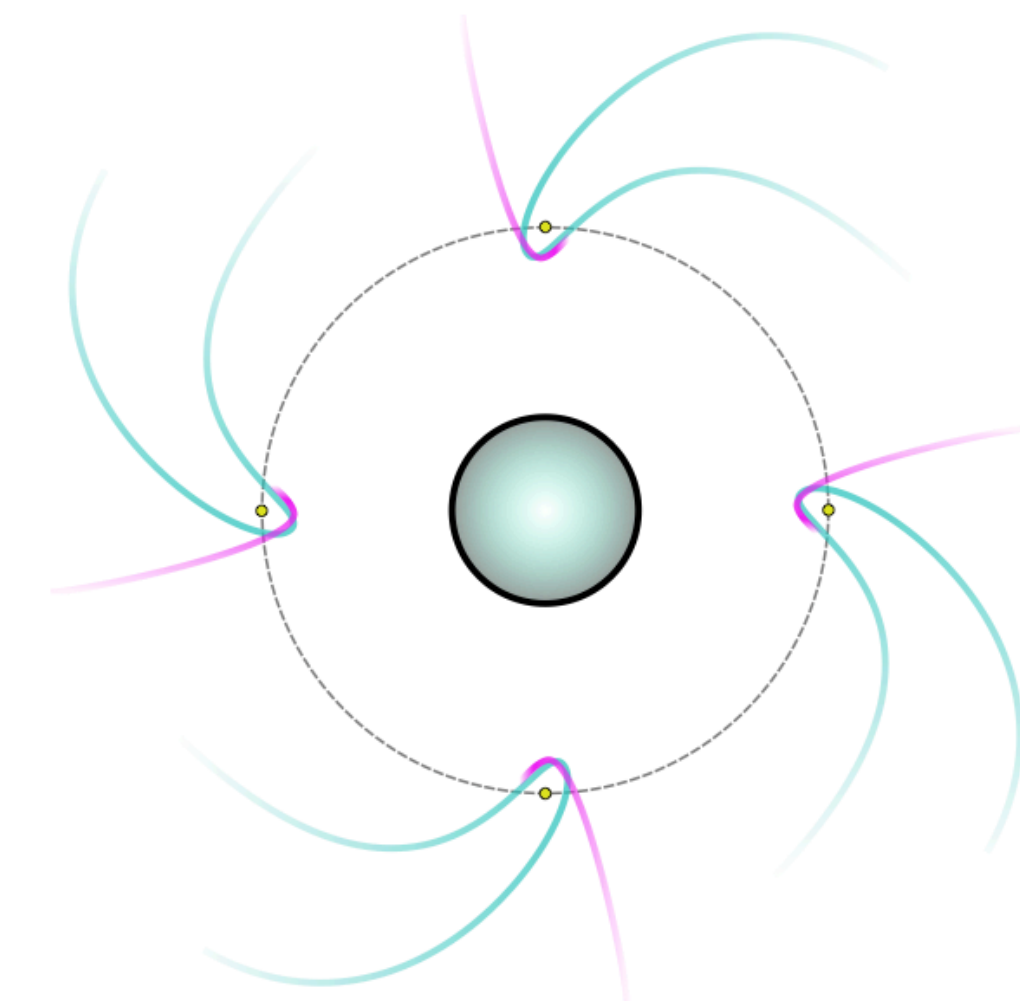
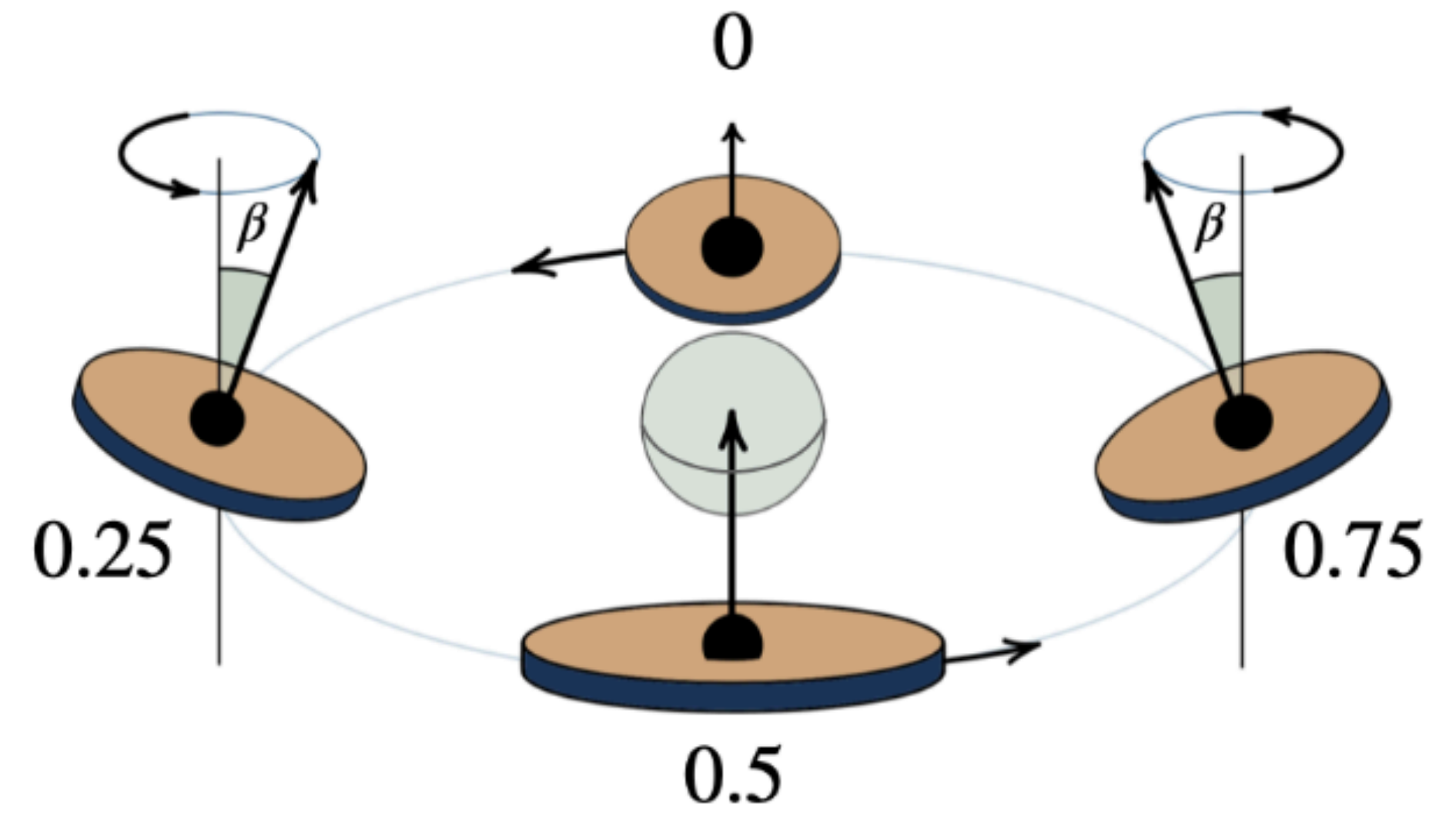
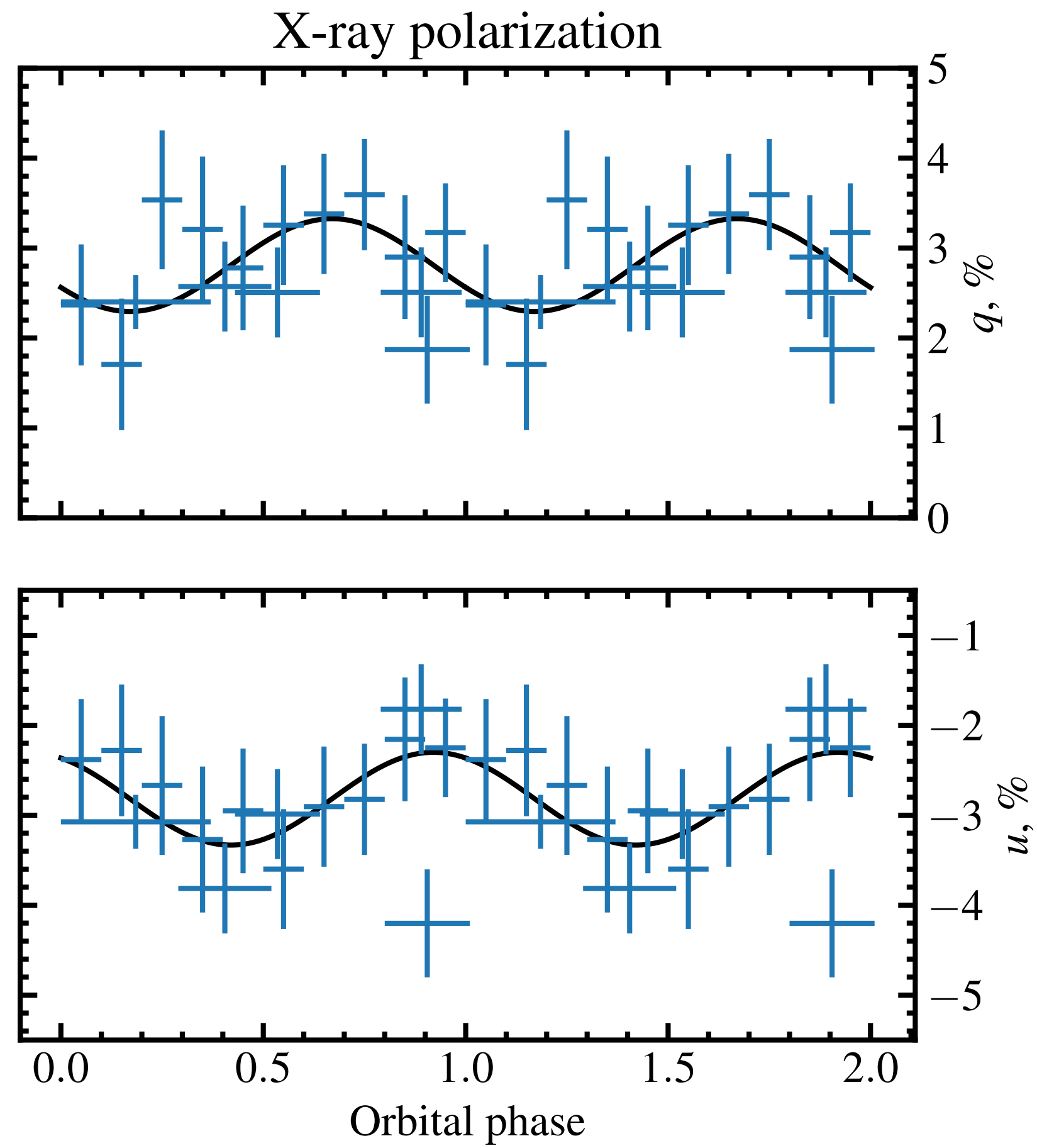


Marginal detection of orbital variations with confidence of  $\sim 4\sigma$



# Results

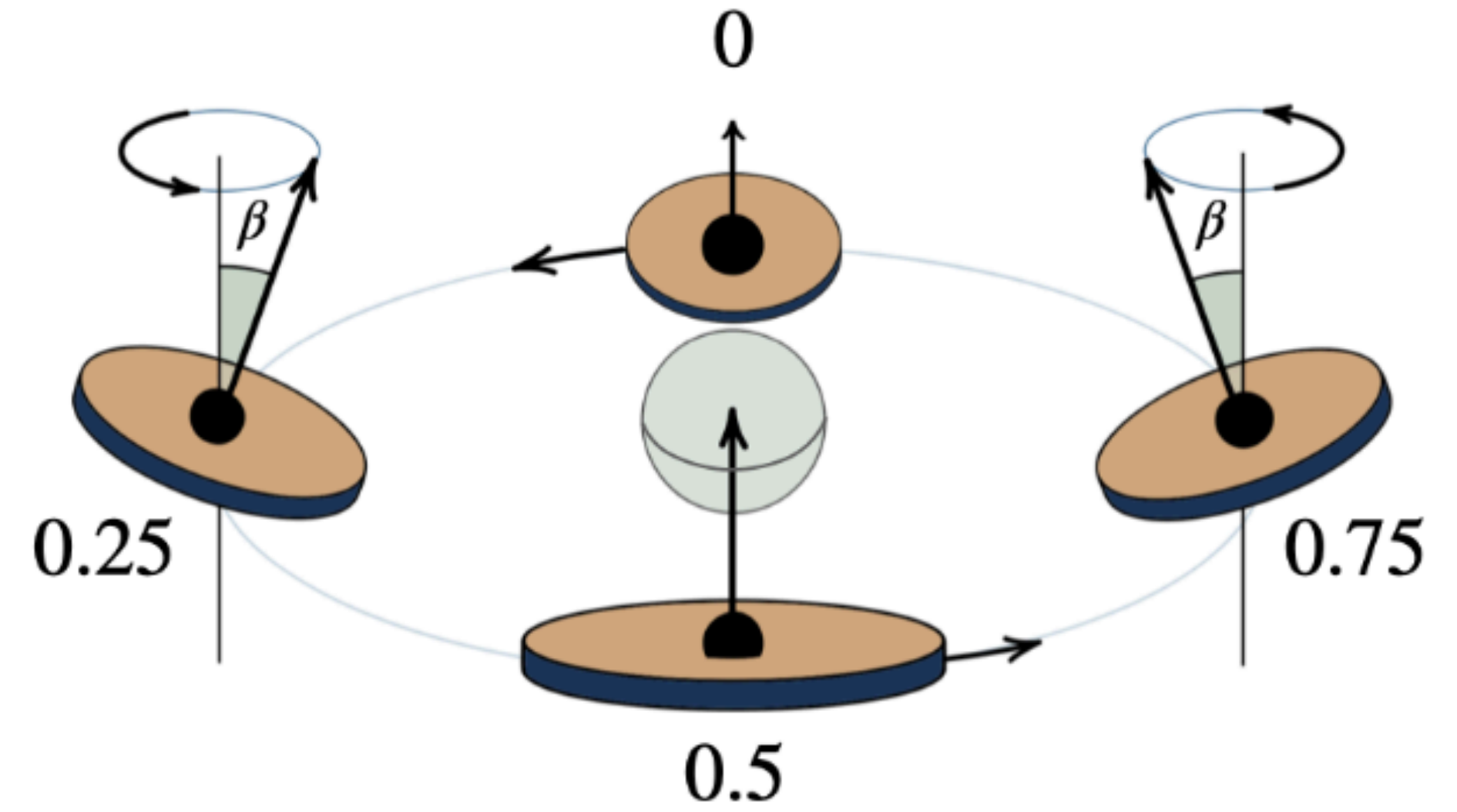
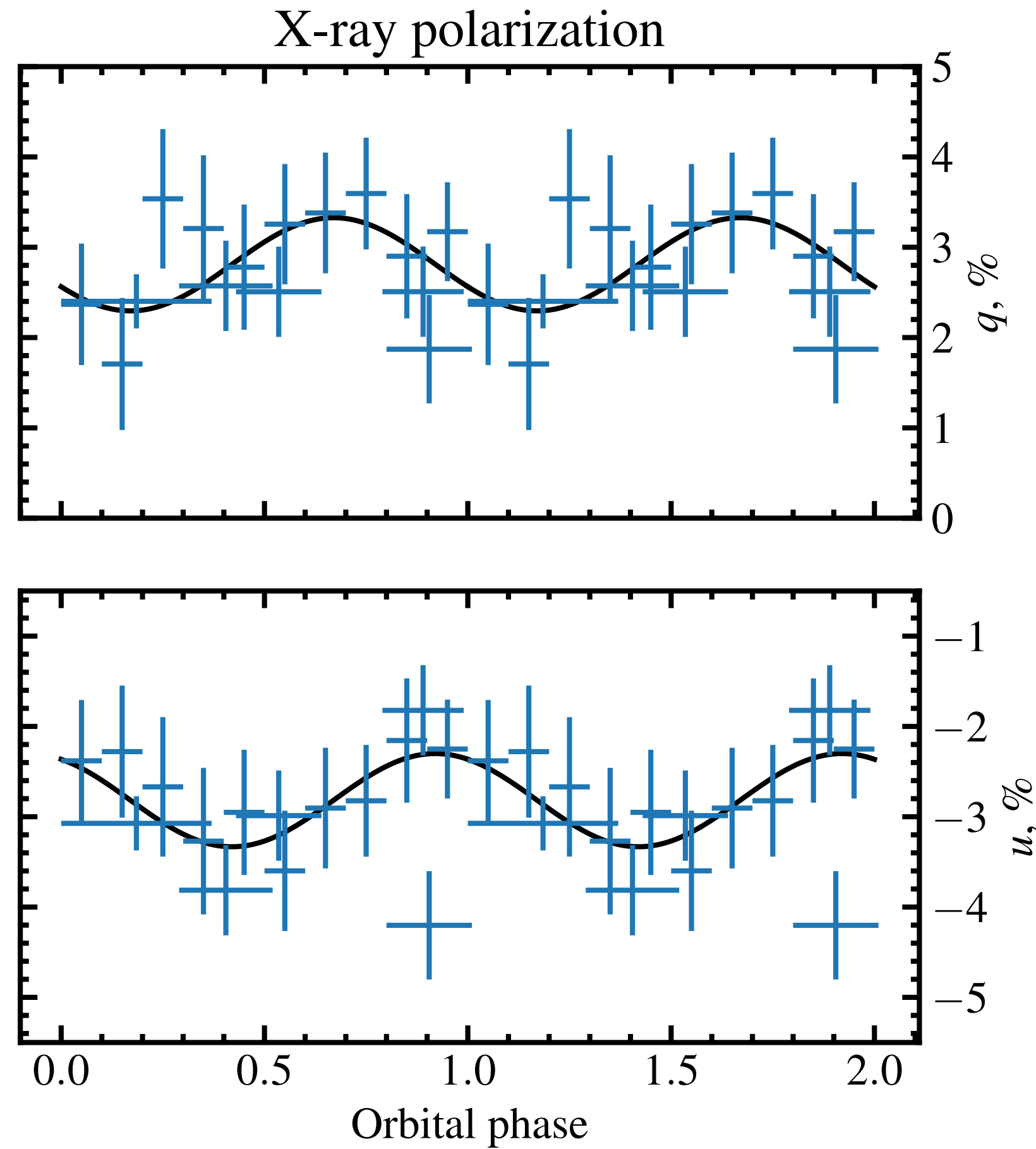
## Orbital variations of polarization



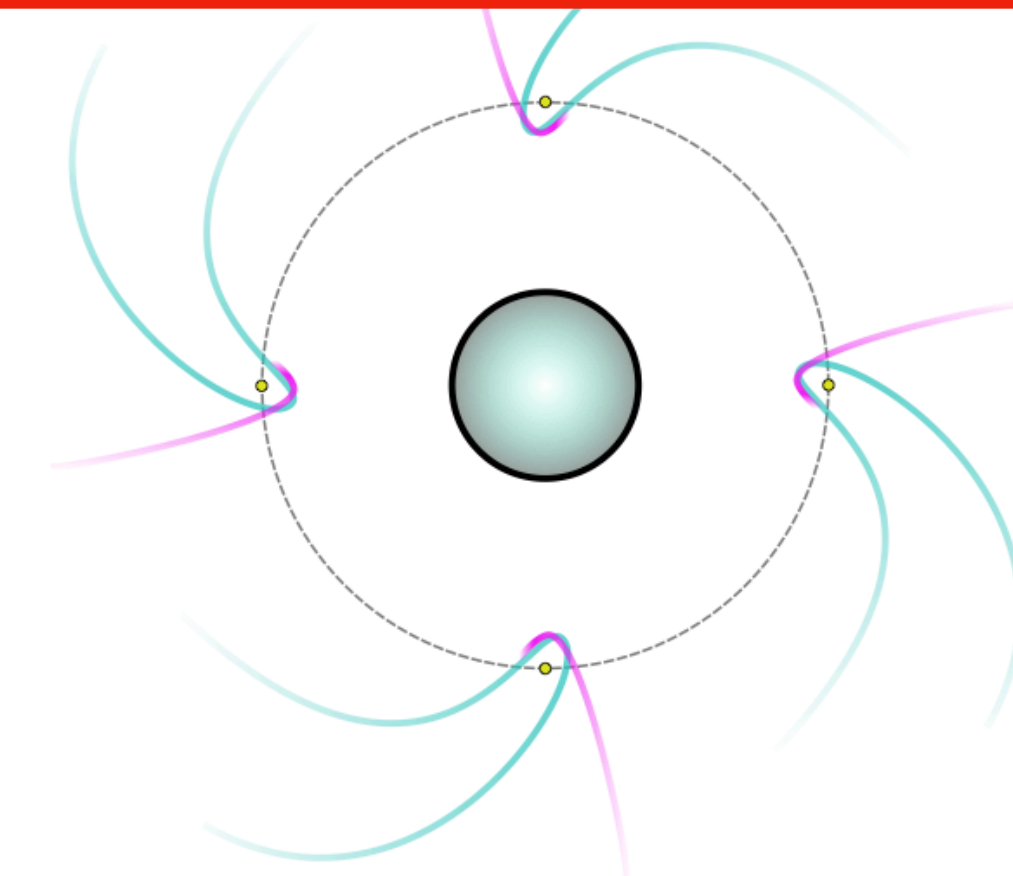
Ahlberg et al. 2025

# Results

## Orbital variations of polarization



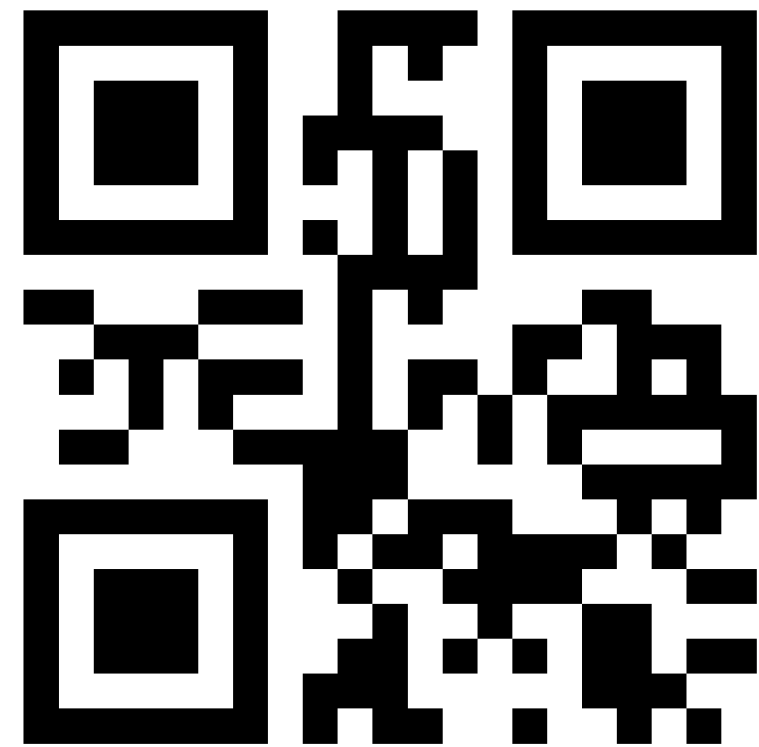
Better data is needed to compare proper models!



Ahlberg et al. 2025

# Summary

- X-ray polarimetry is a promising tool to study the geometry of black hole binary systems
- Combined with the X-ray polarimetry, high precision optical polarimetry put constraints on the accretion mechanisms in X-ray binaries



[www.vakrau.com](http://www.vakrau.com)

