

Constraints on the Corona Geometry of Cyg X-1 in the hard state with Spectrum and Polarimetric Observations in X-rays in 2022

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Outline

Introduction

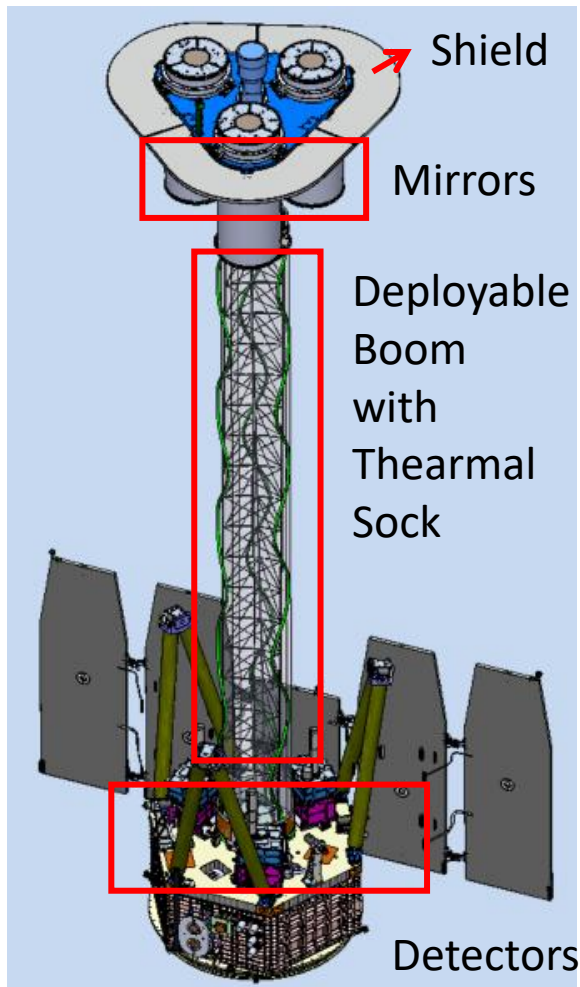
Observation Data

Data Analysis

Polarimetric Simulation

Conclusion & Prospect

Introduction--- The IXPE Mission



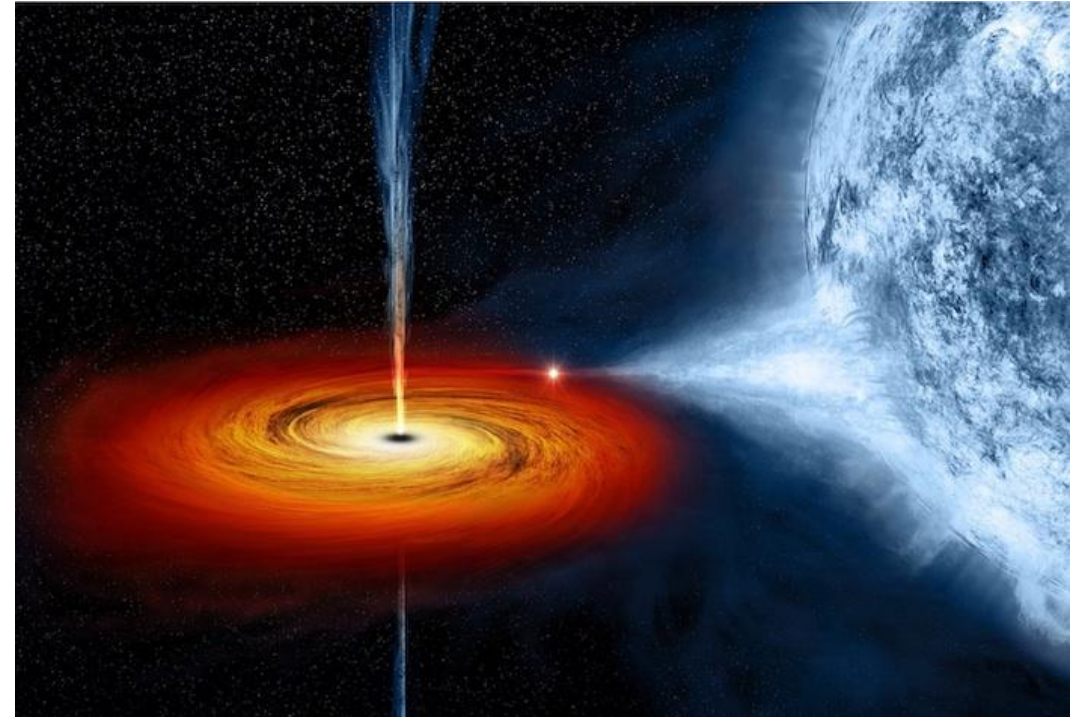
IXPE Imaging X-ray Polarimetry Explorer

- IXPE was launched in Dec, 2021;
- IXPE employs three sets of **mirror modules** and **imaging detectors**;
 - Energy range ----- 2-8 keV;
 - Field of view $\sim 11'$;
 - Angular resolution $\leq 30''$;
 - 100 times more efficient than OSO-8;
- Modulation factor characterize sensitivity to polarization (~ 0.45)

$$\text{MDP}_{99} \approx 4.5\% / \sqrt{\left[\frac{F_{2-8}}{10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}} \right] \left[\frac{\Delta t}{10 \text{ day}} \right]}$$

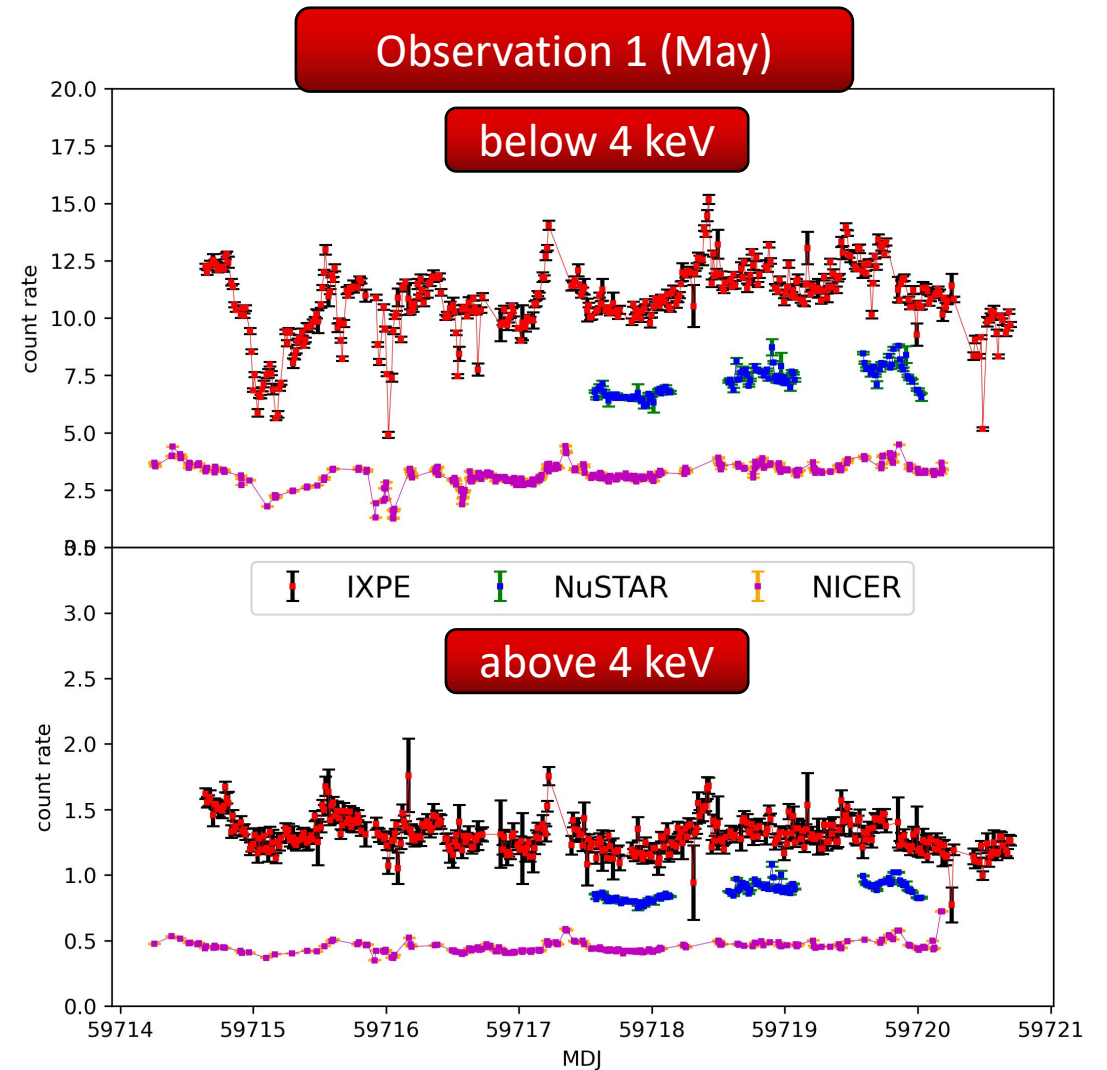
Introduction--- Cyg X-1

- Cyg X-1 is the first known BH system and one of the **brightest** X-ray sources in the sky;
 - HMXB;
 - BH 21.2 ± 2.2 solar masses and an O I_{ab} companion of 41.6 solar masses;
 - The orbit period is 5.6 days;
 - The inclination of the system $i = 27.5^\circ \pm 0.8^\circ$ inferred from optical observations (J.C.A.Miller-Jones et al);
 - **Jet was found in radio band at an angle around -20°** (A. M. Stirling, et al. 2001).

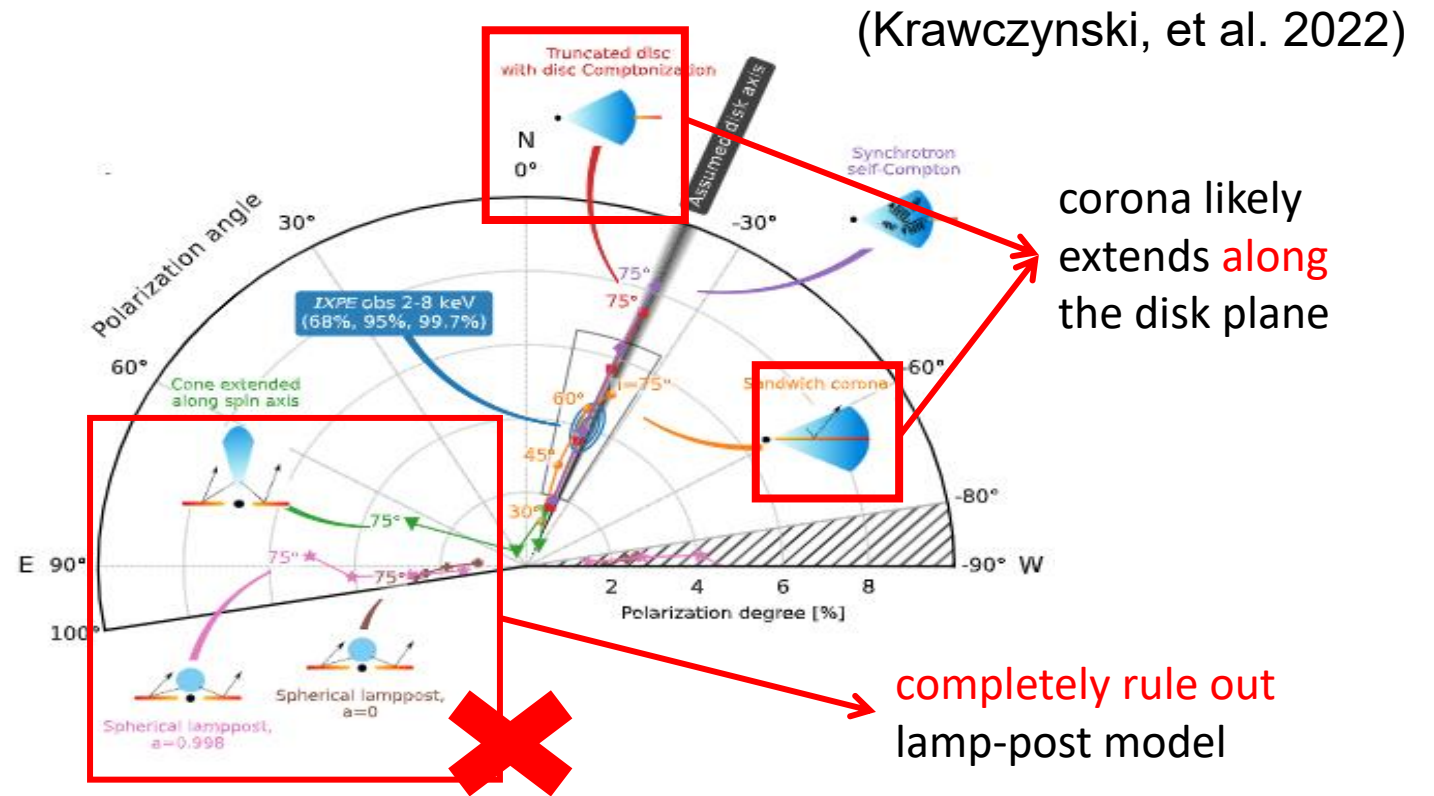
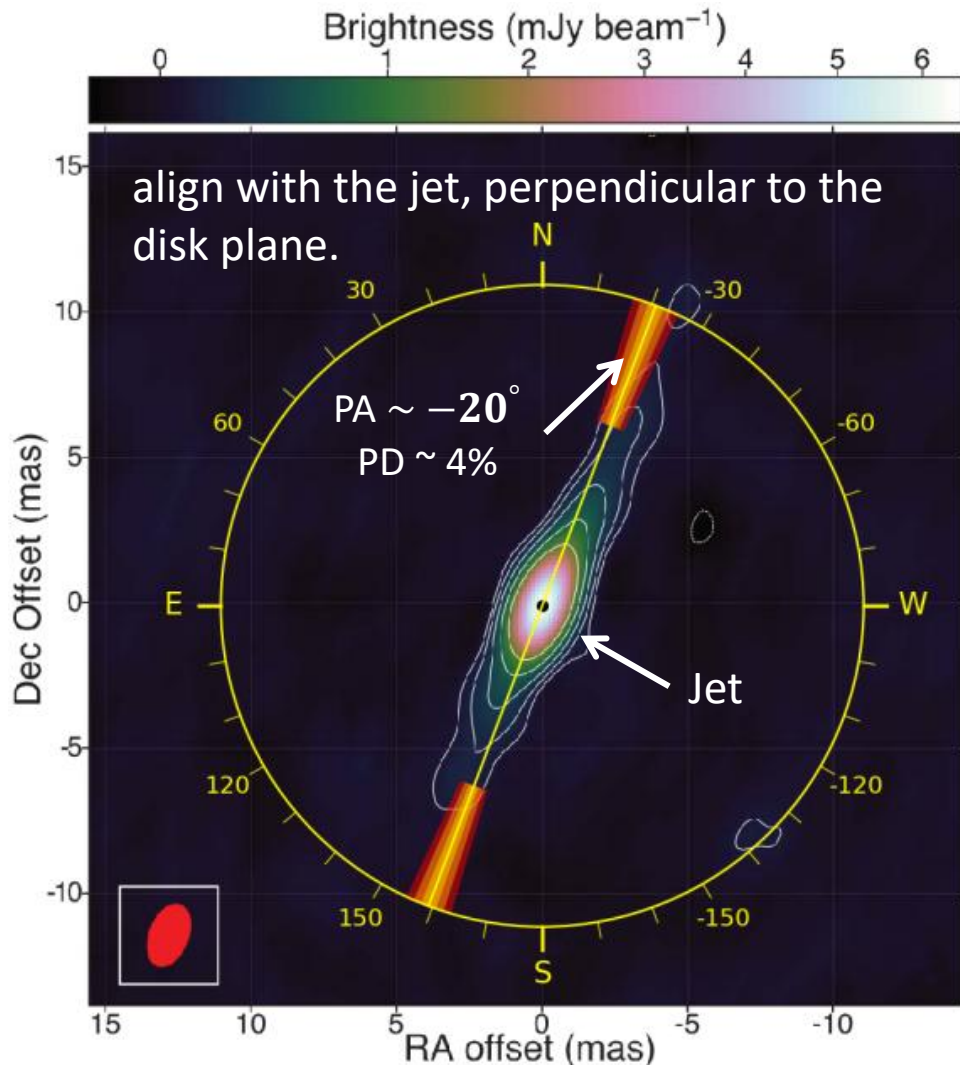


Observation Data--- Light Curves

- IXPE observed Cyg X-1 twice in 2022
 - May, 242 ks \rightarrow **Hard State**
 - June, 86 ks \rightarrow **Hard State**
- Observation 2 has higher count rate and slightly harder;
- **Significant variations in low energy LC;**
 - Change of absorption \rightarrow **One or Both?**
 - Change of soft component \rightarrow **One or Both?**
- Co-observation time is longer in observation 1;
- **We will analysis observation 1 only since simutaneous in observation 2 is low.**

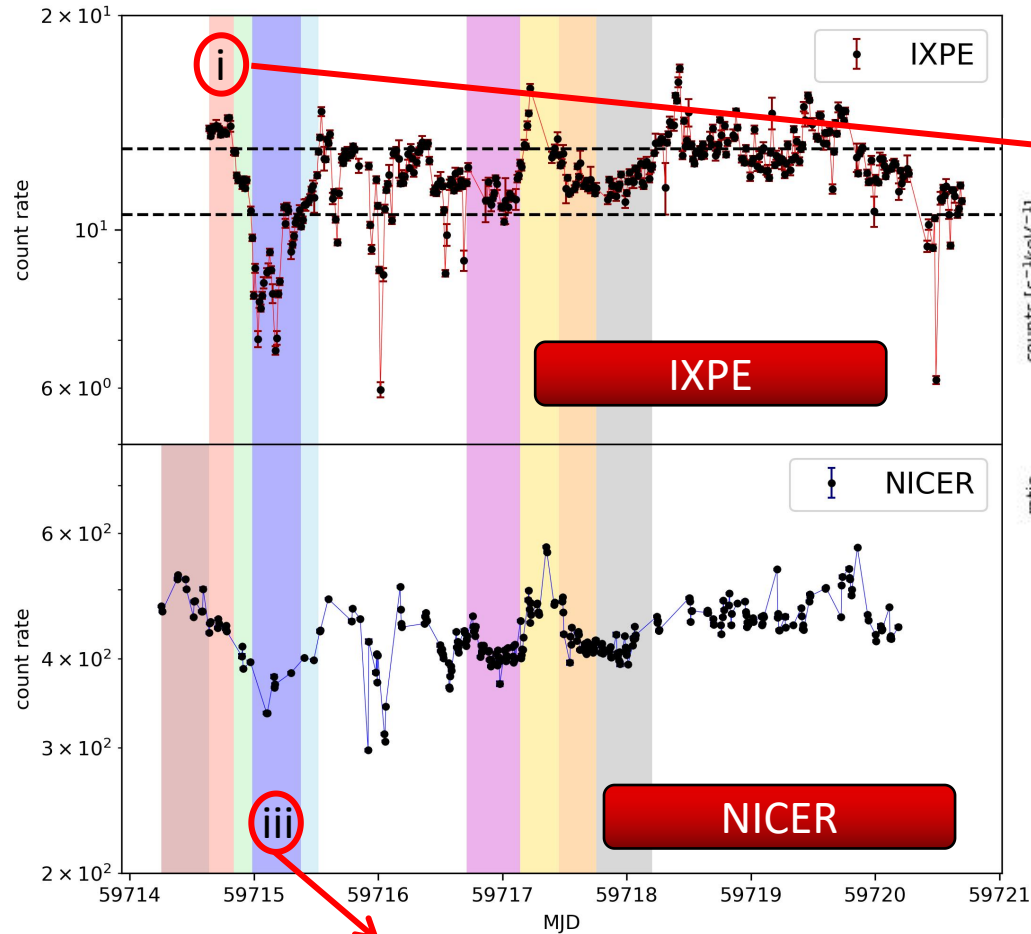


Time-integrated Analysis--- Summary of discovery paper

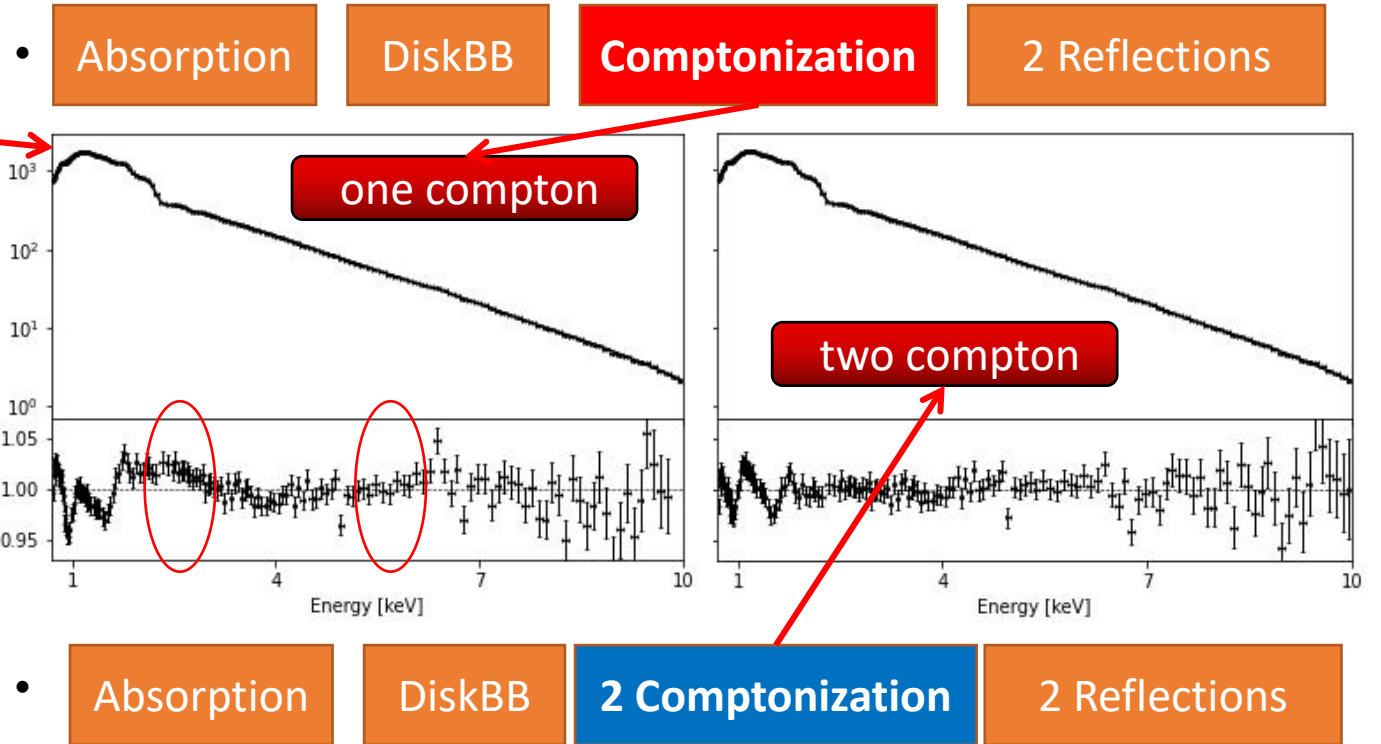


- The detected PD (4%) is too high (expected PD is 1%);
- The model adopted in the discovery paper is too simple.

Time-sorted Analysis----Physical Model

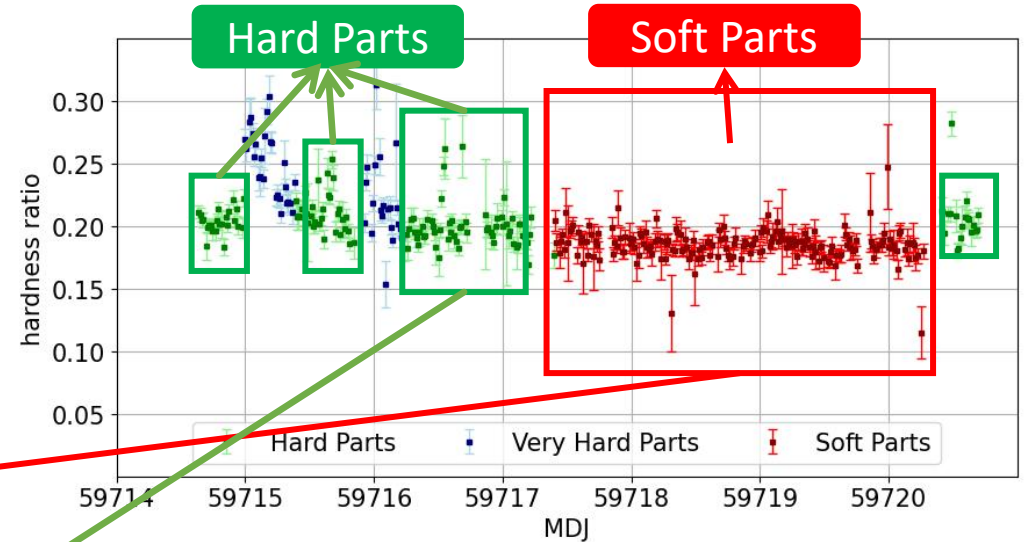
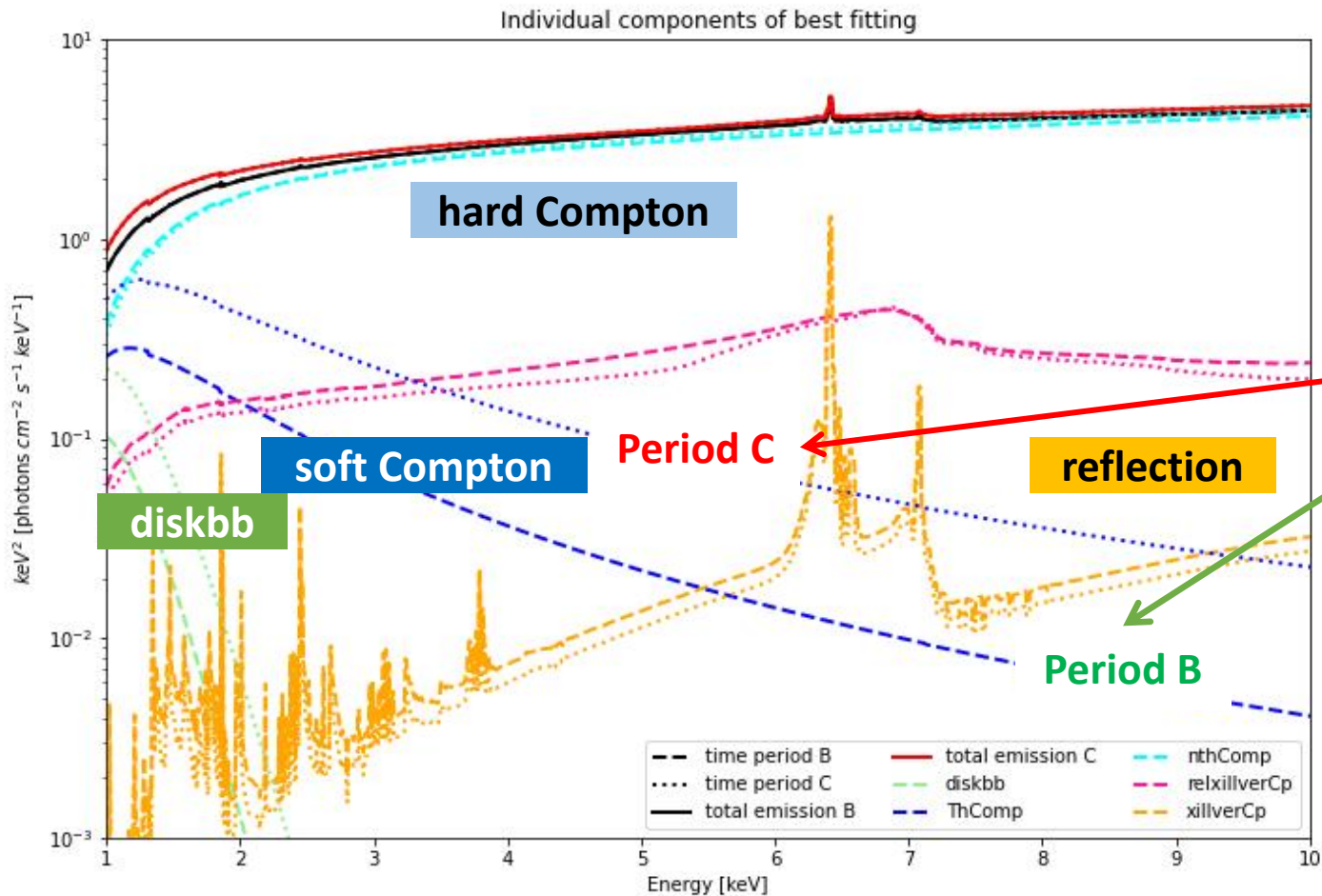


ignore time period iii due to the large absorption



We suggest that **two Comptonization component model** is better and will use in latter spectral-polziation anaysis. Other time periods show the **same** result.

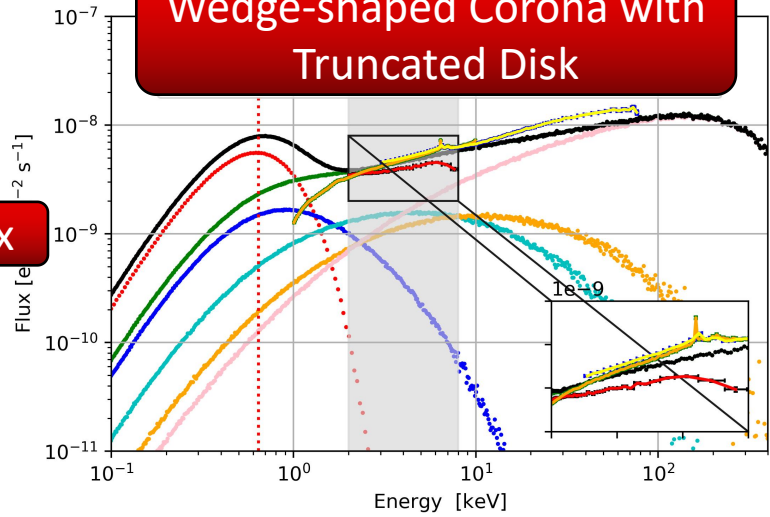
Time-sorted Analysis---Data selection & Spectral fitting



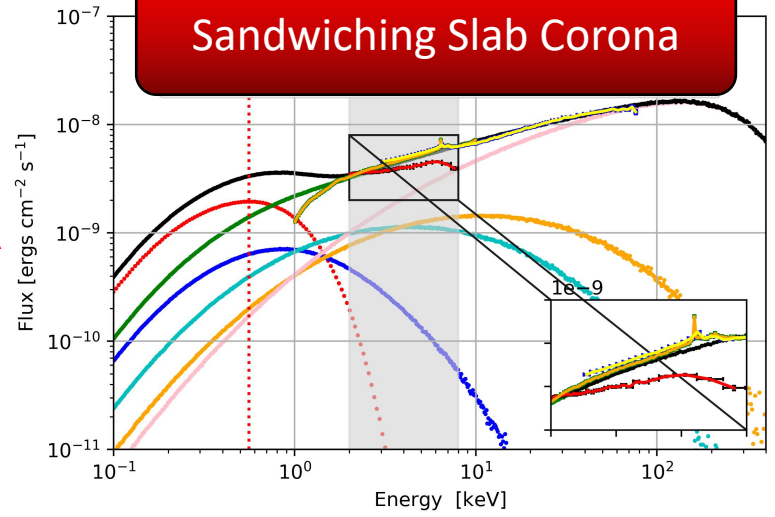
- Disk temperature is 0.15 keV (discovery paper gave 0.3 keV);
- soft component increase by factor 2;
- hard component unchanged.
- Light curves changes is mainly caused by **intrinsic spectrum changes of soft component** rather than absorption.

Polarimetric Simulation--- Spectrum & Polairzation

Wedge-shaped Corona with Truncated Disk



Sandwiching Slab Corona



$kT = 0.15 \text{ keV}$

$\tau = 2 / 0.5$

inner disk = 40 rg / ISCO

inner corona = ISCO

outer corona = 40 rg / 100 rg

open angle = 10 deg (W)

height = 2 rg (S)

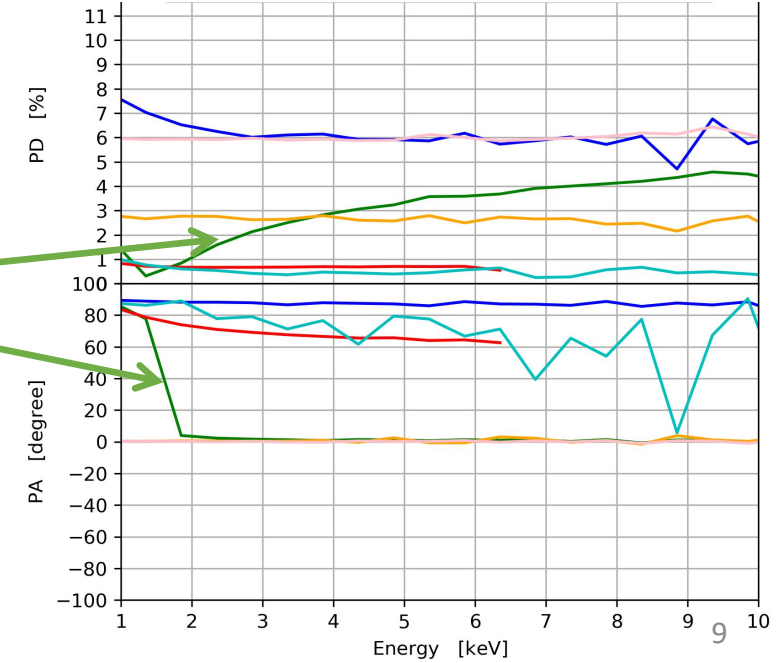
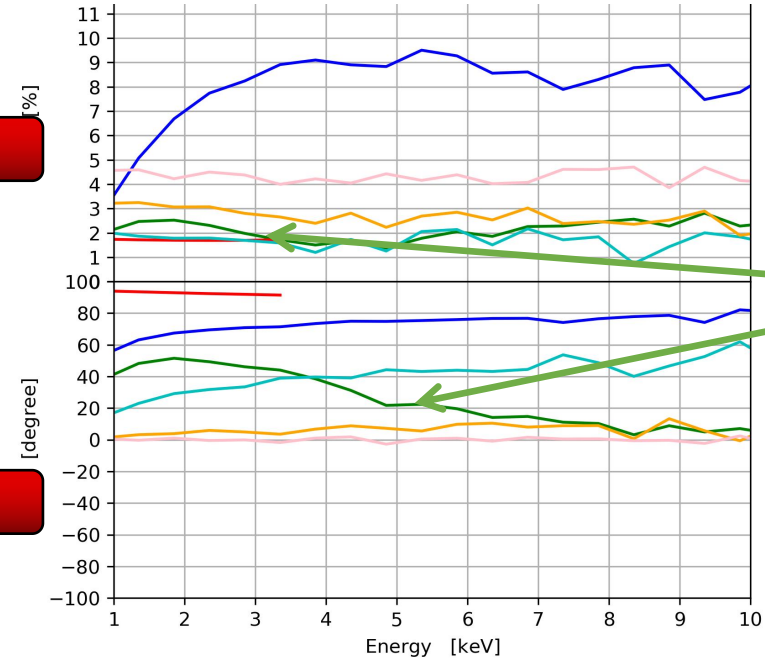
$i = 60 \text{ degree}$

Flux

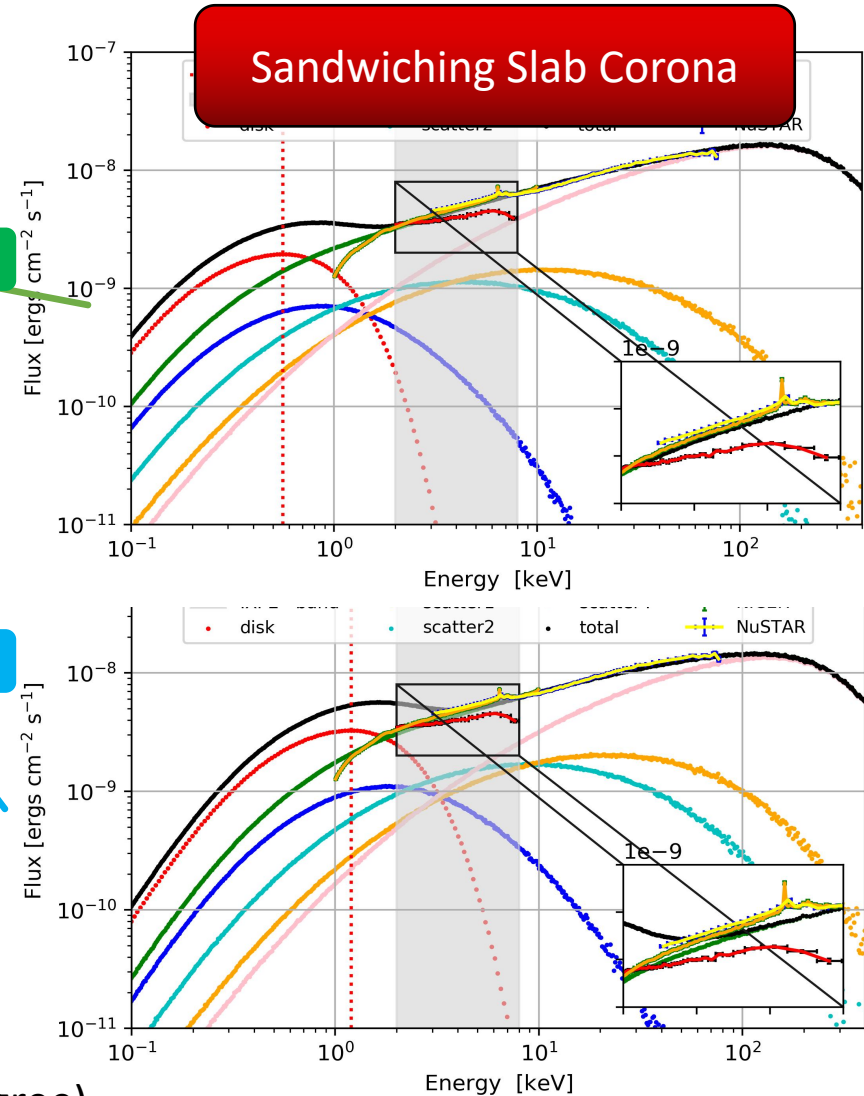
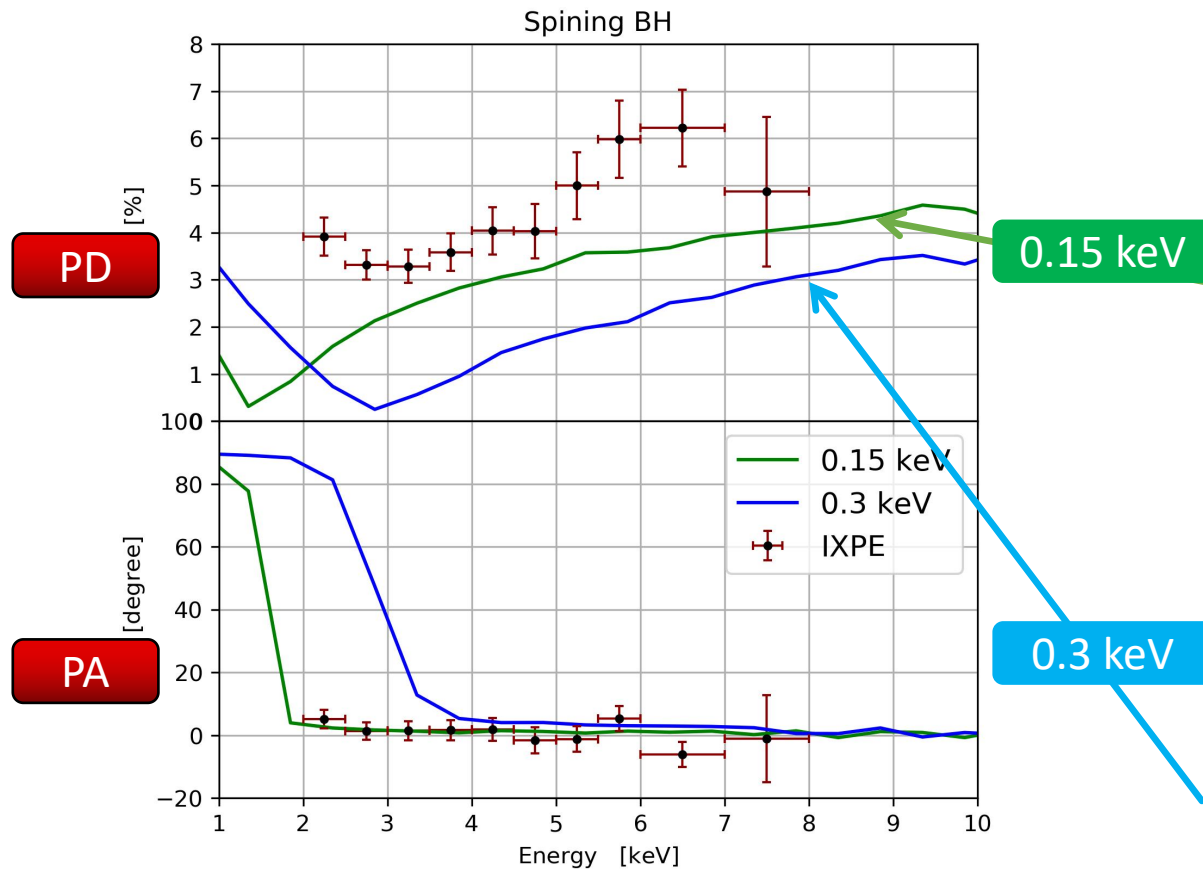
PD

PA

- Total (black)
- Disk (red)
- Compton (green)
- 1 scatter (blue)
- 2 scatters (cyan)
- 3 scatters (orange)
- 4 scatters (pink)



Polarimetric Simulation--- Dependence



- PD increases by 1-2%;
- PA fits the simulation well in 0.15 keV, spinning BH case;
- The discrepancies in PD are partially solved (even with $i=60$ degree).

Conclusion & Prospects

Conclusion

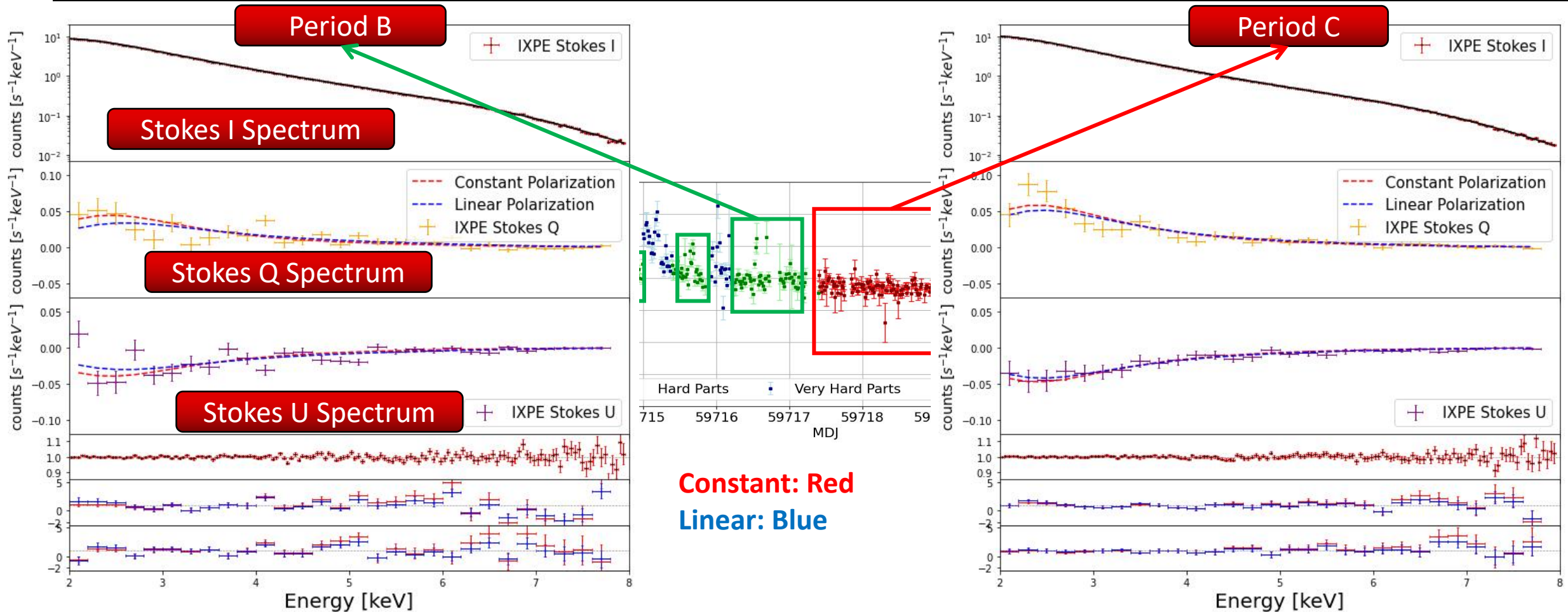
- We fit the spectrum of observation 1 of NICER and IXPE at the same time;
 - we introduced a softer comptonization component to the model
 - two Comptonization components model is better;
 - seed photon temperature is **factor of 2 lower than the discovery paper**;
 - light curves variations mainly caused by changes of soft component;
- We find linear energy dependence of PD and PA remains constant
- **The corona is likely sandwiching slab corona**;
 - disk temperature is lower (0.15 keV, about half in the discovery paper);
 - different optical depth but consistent with previous analysis in hard state;
 - PD will **increase by ~2 percentage points** but still need higher inclinations.

Future Work

- We use one Comptonization component model in the simulation as an approximation, the true situation is complicated with two Comptonization components;
- MONK assumes a disk emission with a uniform temperature distribution, while the temperature is more likely to decrease as a function of radius;
- Reflection components are ignored in the simulation, and we may also investigate the contribution of them on the polarization properties.

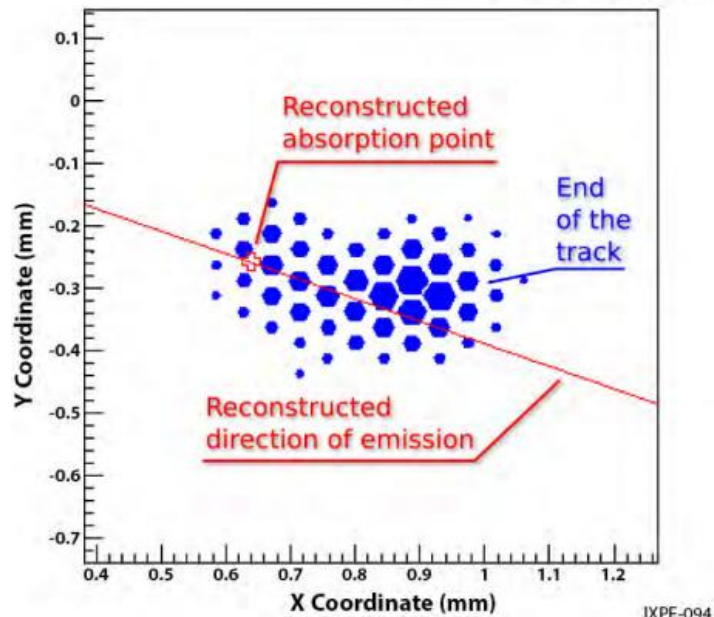
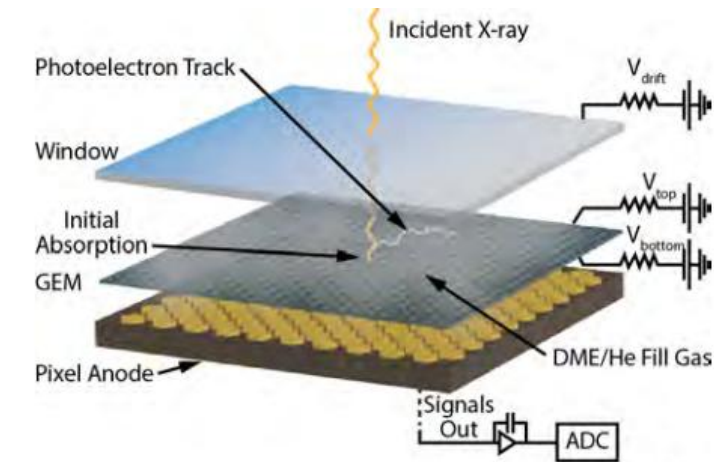
Appendix

Time-sorted Analysis----Data Selection



- **disk temperature is lower (~ 0.15 keV, ~ 0.3 keV by discovery paper)**
- linear polarization model is better

Appendix 1 -----Polarization Measurement



- We use gas detectors to measure polarization;
- The ejected photoelectron has an emission direction peaked around **that of the electric field**;
- The photoelectron interact with the **surrounding gas** and is **slowed** by ionizing collisions;
- The “track” marks the path of the photoelectron from its creation at the original X-ray interaction site to its stopping point.

Appendix 2 ----Stokes Parameters

- Event-by-Event Stock Parameters are introduced in the analysis(kislat et al. & Vink & Zhoug),

$$i_k = 1, q_k = 2\cos 2\theta_k, u_k = 2\sin 2\theta_k$$

- The stokes parameters of the entire data then will be,

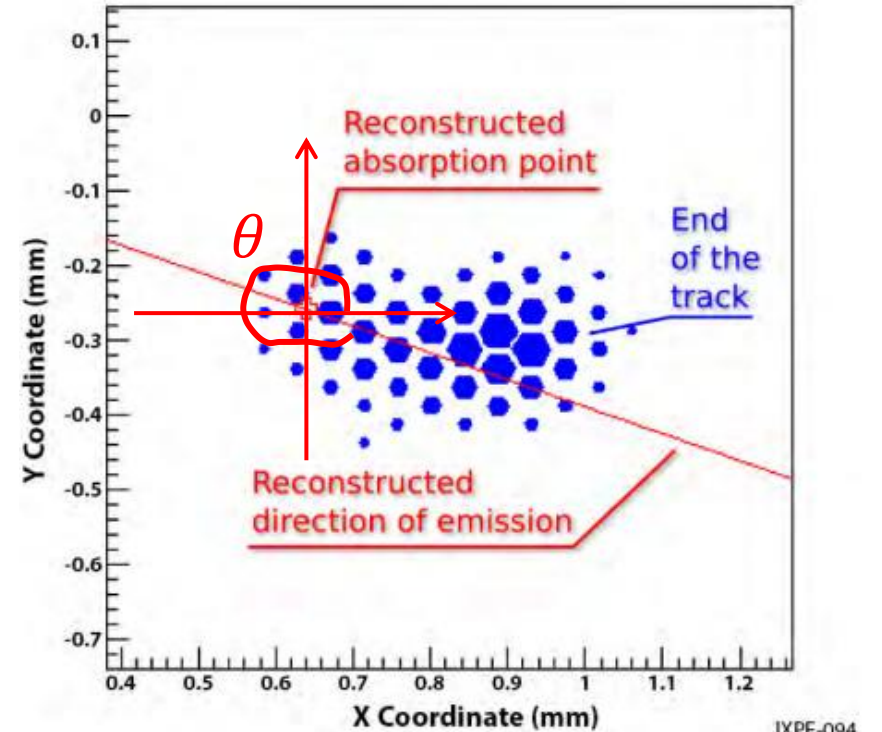
$$I = \sum_i w_i, \quad Q = \sum_i w_i q_i, \quad U = \sum_i w_i u_i.$$

- The normalized stokes parameters are,

$$Q_N = \frac{Q}{I}, \quad U_N = \frac{U}{I}$$

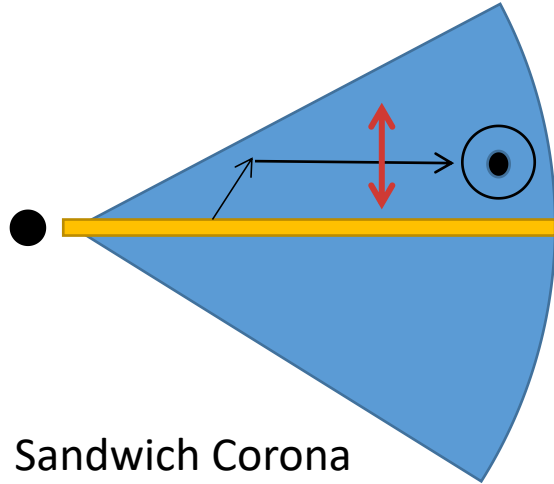
- Then PD and PA will be,

$$p = \frac{\sqrt{Q^2 + U^2}}{I}, \quad \psi = \frac{1}{2} \arctan \left(\frac{U}{Q} \right)$$

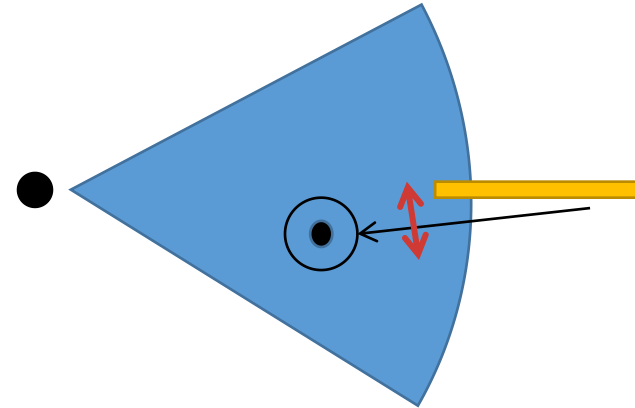


$$\frac{d\sigma}{d\Omega} \propto \sin^2(\theta) \cos^2(\phi)$$

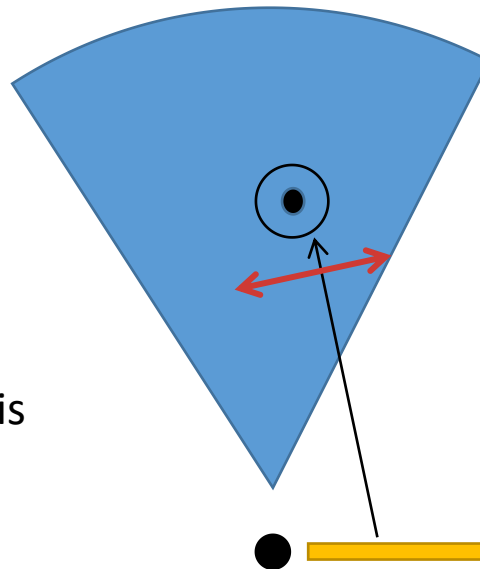
Appendix 3 ----Polarization



(a) Sandwich Corona

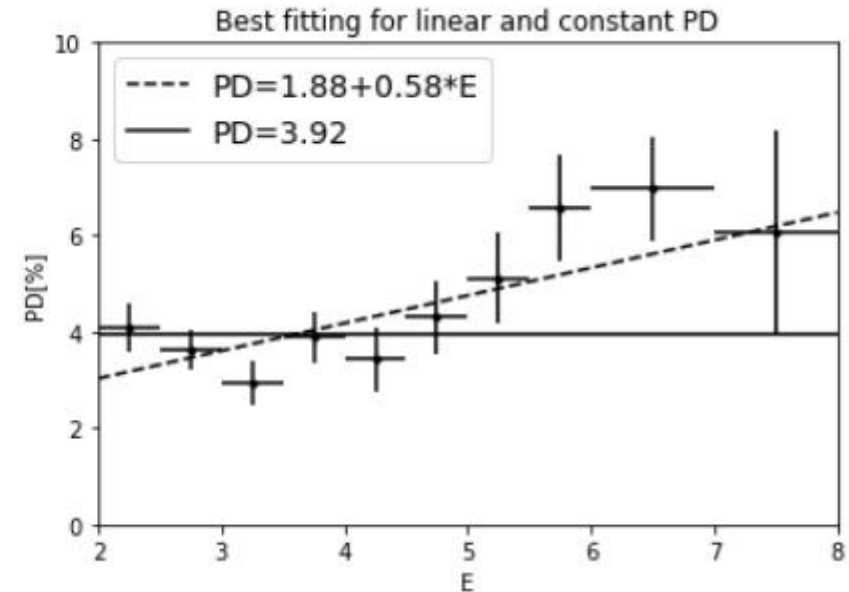
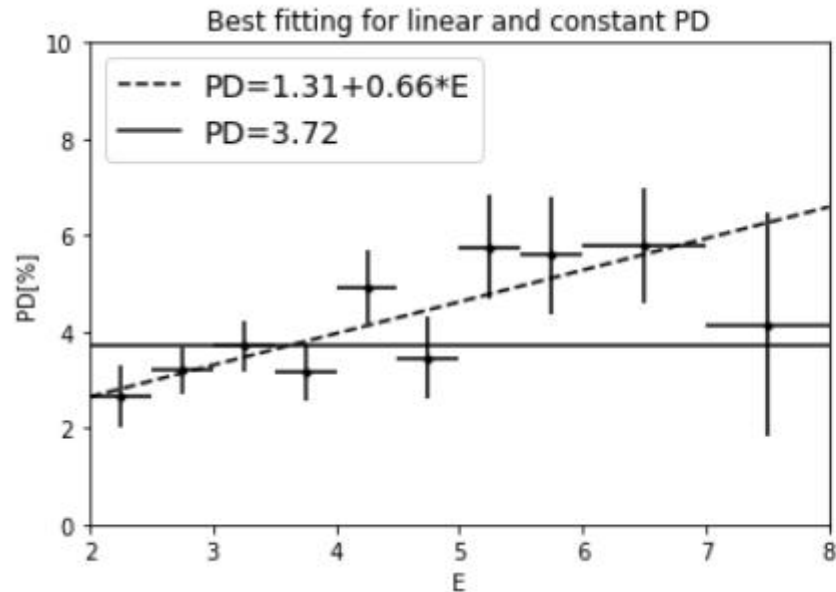


(B) Truncated Disk with Disk Comptonization



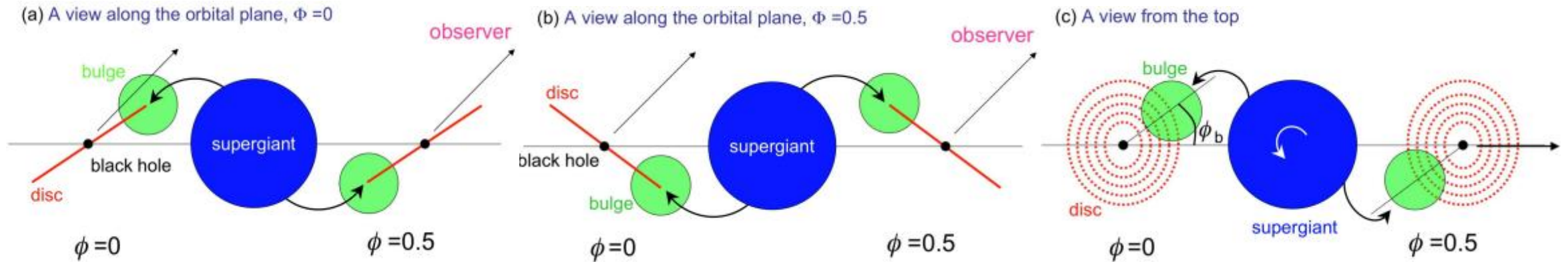
(c) Cone Extended along Spin Axis

Time-sorted Analysis----Independent Polarization



- We find energy dependency of PD in observation 1;
- PD are similar between each other;
- PA remains constant.

Appendix 5----Superorbital Precession



The material in the bulge absorbs some of the X-ray emission originating close to the disc centre. The orbital modulation due to the bulge is seen to strongly depend on the superorbital phase.

- The superorbital phase of zero, when the disc is seen closest to edge-on and the effect of the bulge is strongest;
- The opposite case of the superorbital phase of 0.5.;
- A view from the top, with the arrow showing the direction of the observer.(J. Poutanen, et al. MNRAS 389, 1427, 2008)