

X-ray Polarimetric Observations of Stellar Mass Black Holes with *IXPE* and *XL-Calibur*

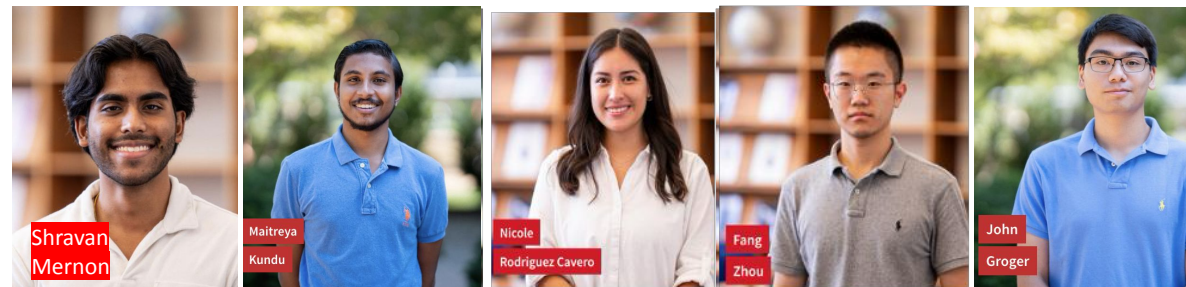
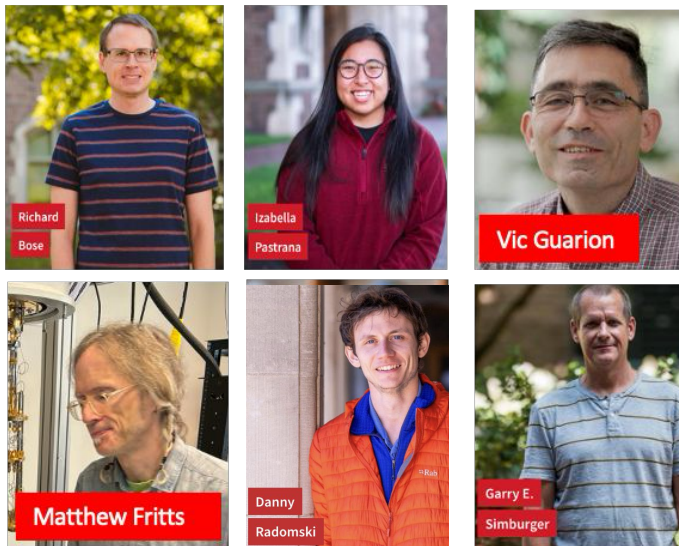
Henric Krawczynski, 05/07/2025

Plan of talk:

- (1) Two space borne X-ray polarimeter missions: *IXPE* and *XL-Calibur*.
- (2) *IXPE* results for Stellar Mass Black Holes & Implications:
 - (a) Overview.
 - (b) A deeper look.
- (3) Results from the the 2024 *XL-Calibur* balloon flight.
- (4) Summary.



3 Engineers, 1 Senior
Researcher, 2 Technicians



1 post-doc,
8 grad. students,
2 master students

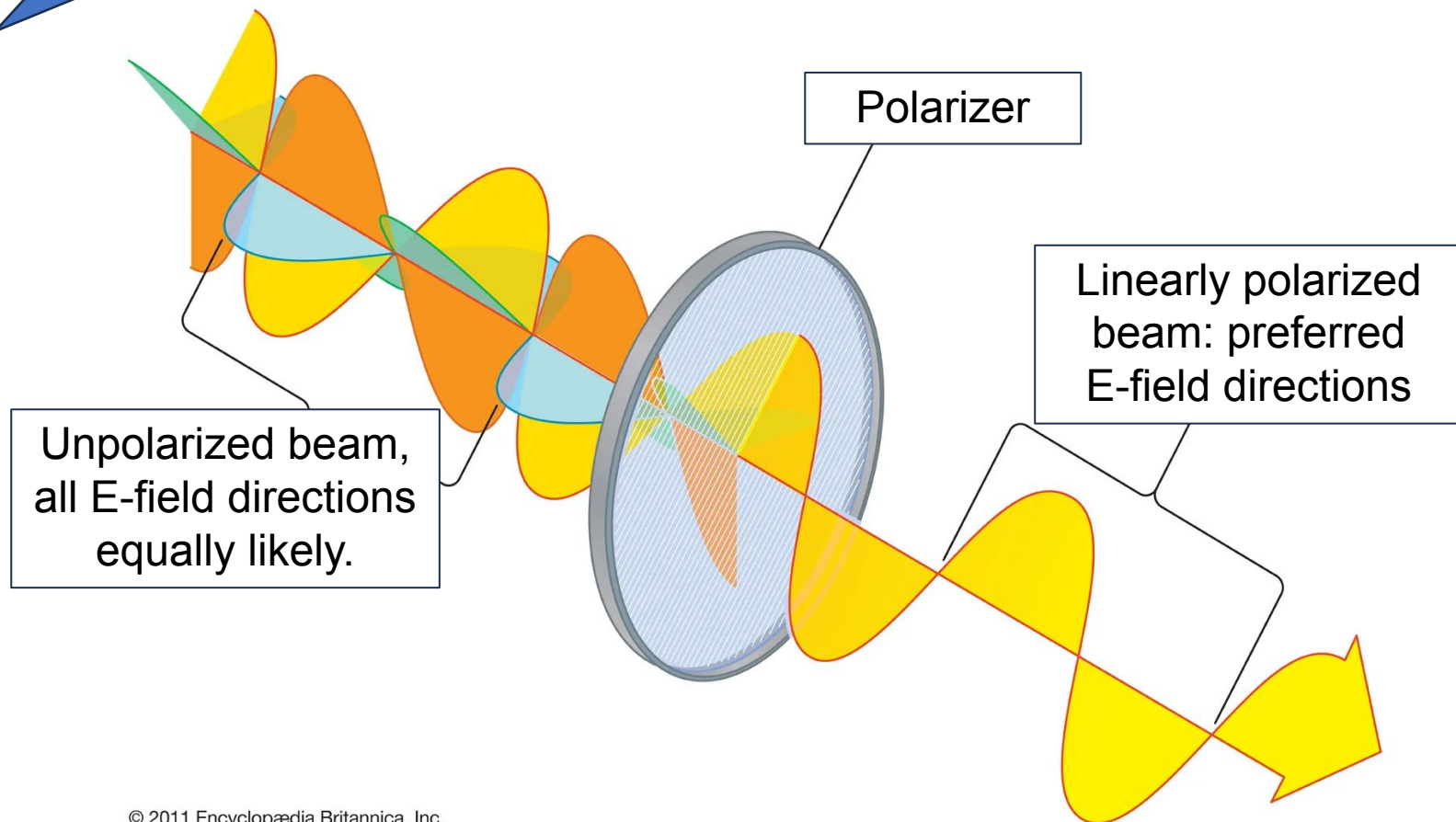




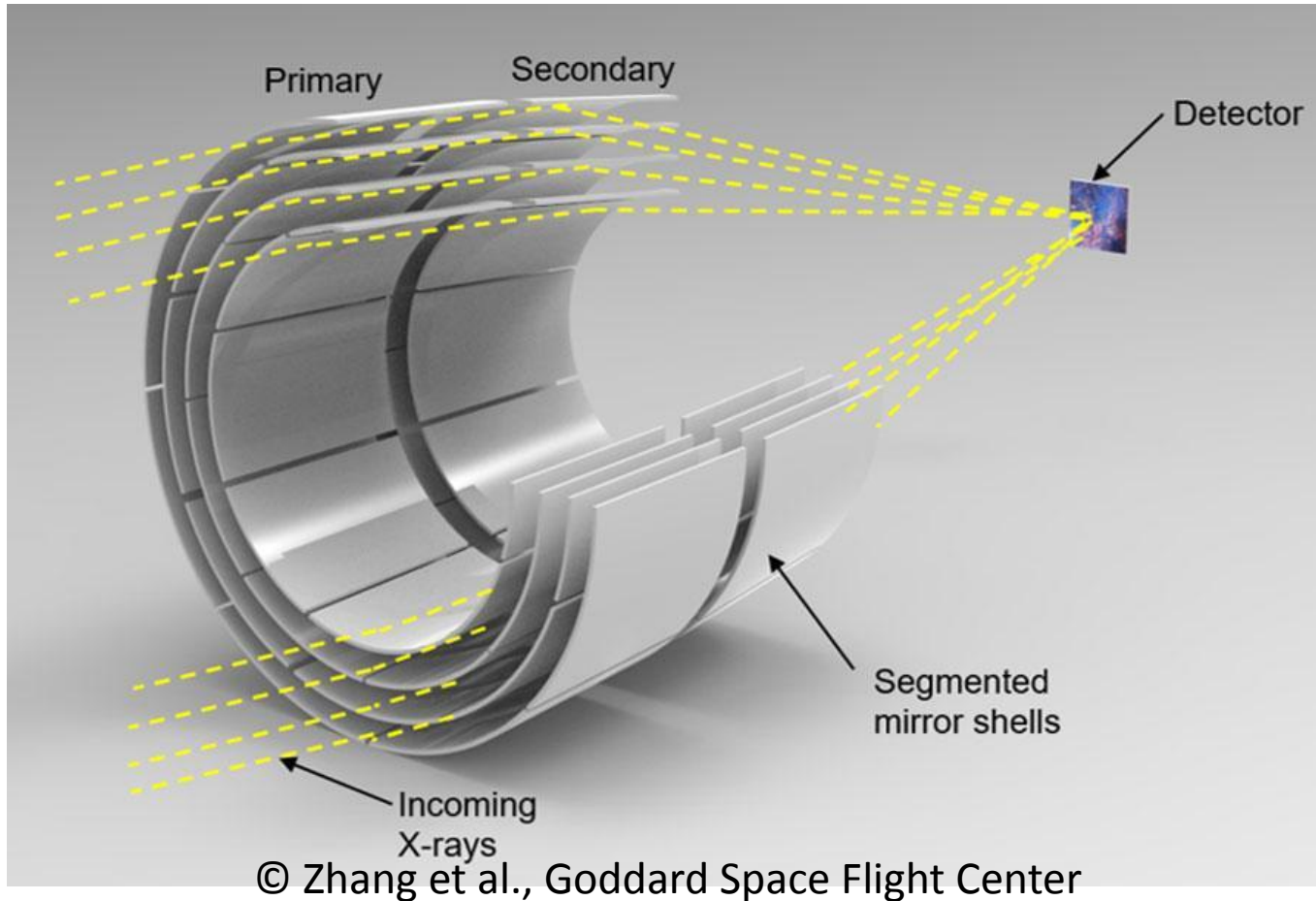
George Gabriel Stokes(1852)

You shall measure
 I , Q , U and V !

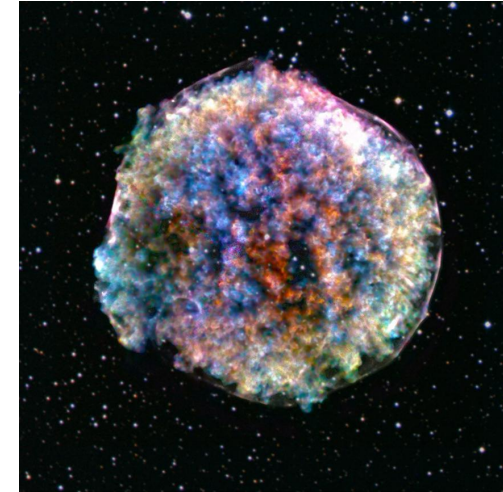
Why is this difficult?
5% Pol. Degree (99% CL)
requires 40,000 photons.



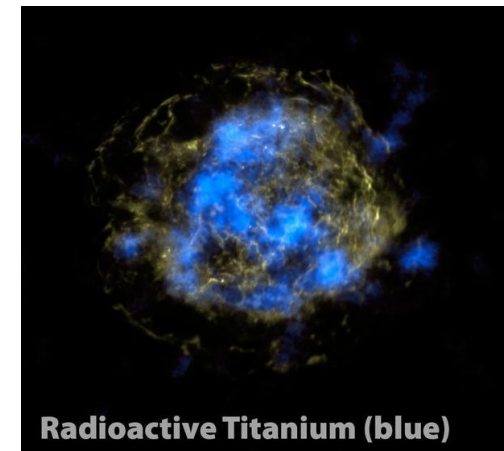
X-ray Polarimetry - Key Technologies



Chandra (Ir-mirror) image of
Tycho's SNR (0.3-6.1 keV)
(X-ray: NASA/CXC/RIKEN & GSFC/T. Sato et
al; Optical: DSS)

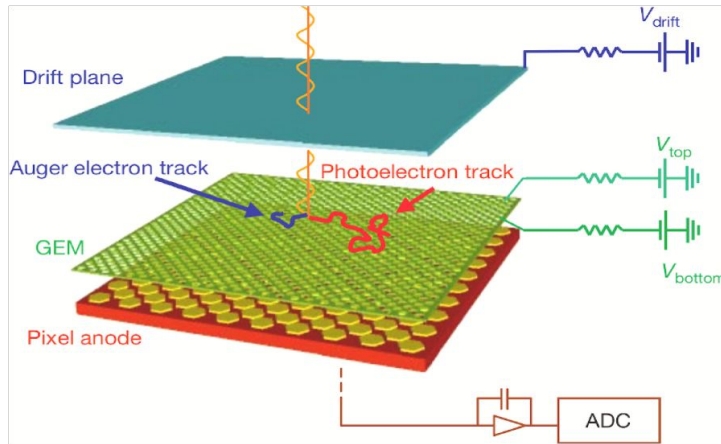


NuSTAR (Si-W) image of Cas
A SNR (67 & 78 keV)
NASA/JPL-Caltech/CXC/SAO



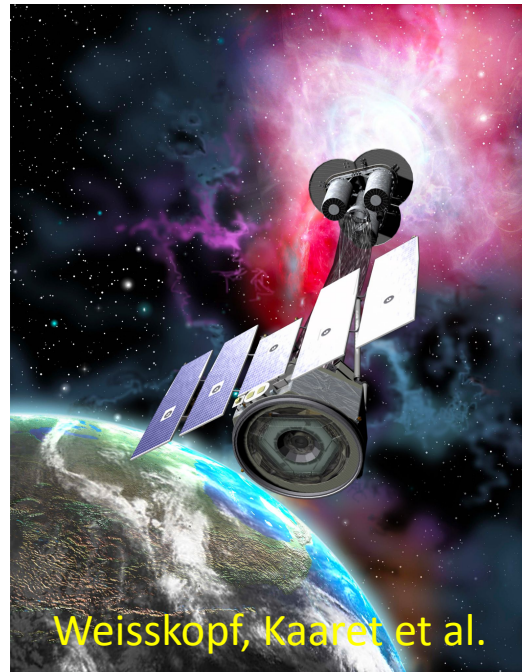
X-ray Polarimeters

Photoelectric
effect
polarimeter:



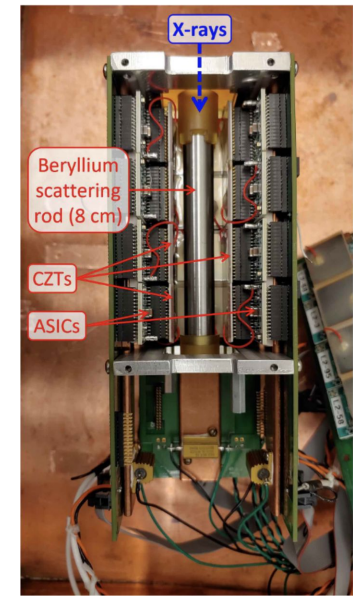
IXPE: 2-8 keV:
minimum detectable
polarizations of a few %
for ~ 1 mCrab sources.

Launch:
12/9/2021!



Weisskopf, Kaaret et al.

Scattering
Polarimeter:



XL-Calibur: 15-80 keV.
minimum detectable
polarizations of $\sim 5\%$ for
500 mCrab sources

Balloon flight:
July 2024!



Primary Science Objectives

(1) Black Holes:

Stellar Mass Black Holes

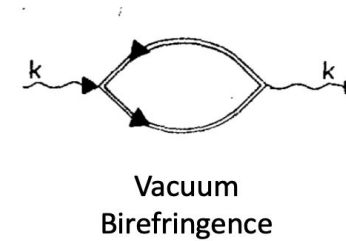
Supermassive Black Holes

(1b) Accreting neutron stars.

(2) Magnetars/Pulsars:

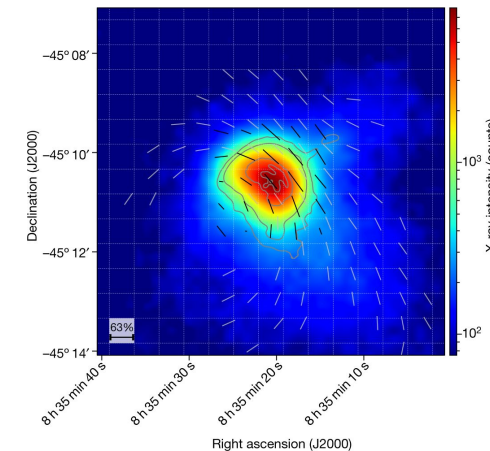
⇒ Neutron star surfaces & magnetospheres.

Strong-field QED, i.e. 4U 0142+61 (Lai 2023)



(3) Pulsar Wind Nebulae, Blazars, Supernova-Remnants:

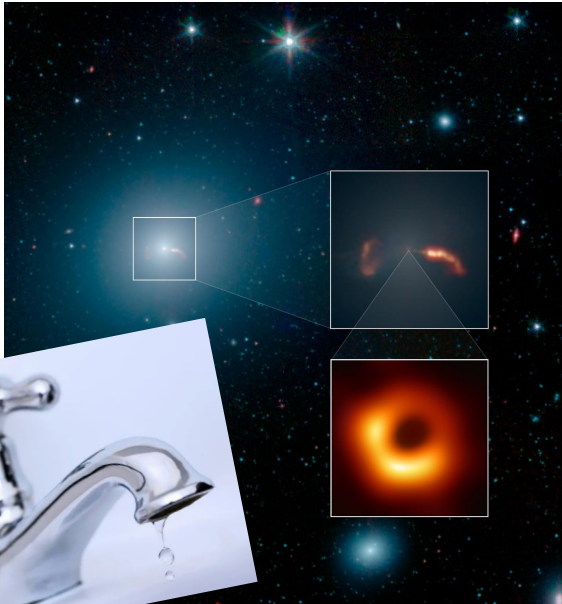
Particle
acceleration



Xie et al.,
[*Nature*](#) (2022)

Black Hole Accretion

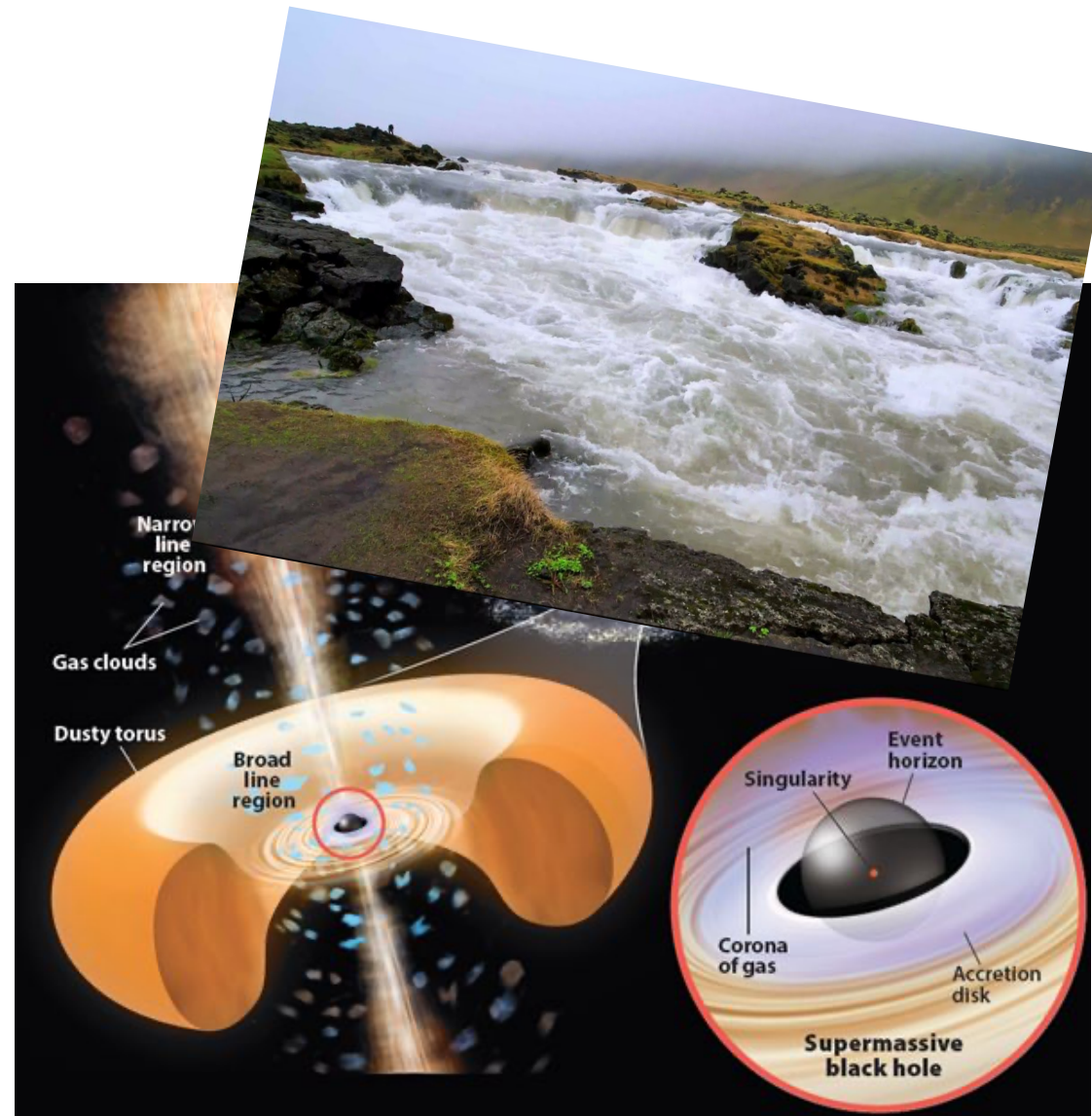
NASA/JPL-Caltech/IPAC/Event
Horizon Telescope Collaboration



M87, SGR A*



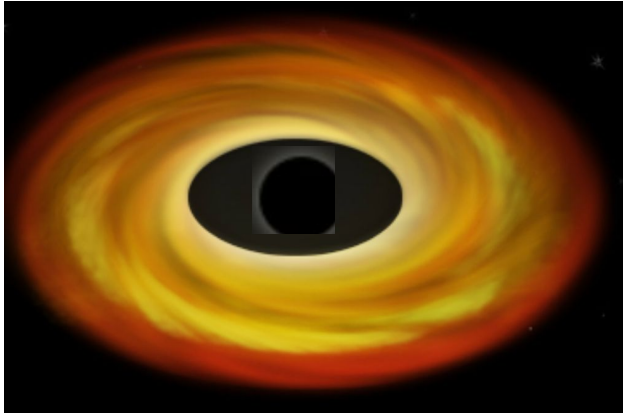
Black Hole X-ray
Binaries



Active Galactic Nuclei

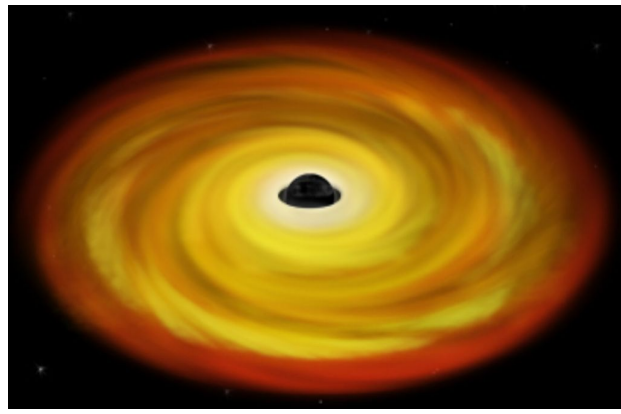
Some Terminology

$$r_g = \frac{GM}{c^2} \approx 1.48 \text{ km} \frac{M}{M_\odot}$$



non-spinning:

$$R_H = R_s = 2 r_g$$

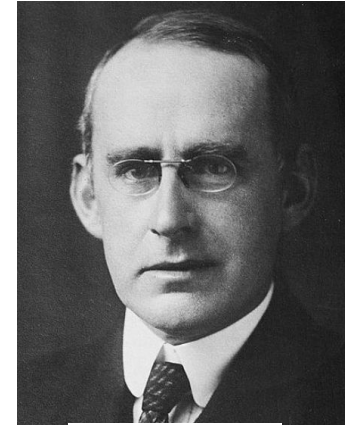


max-spinning:

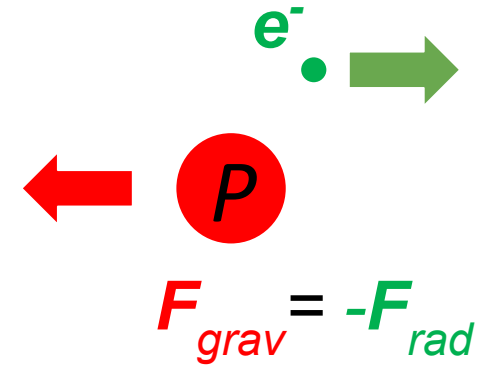
$$R_H = r_g$$

$$a = J/Mc$$

$$|a| = 0 \dots 1$$



A.S. Eddington
1882 – 1944



Max. Luminosity for
spherical accretion:

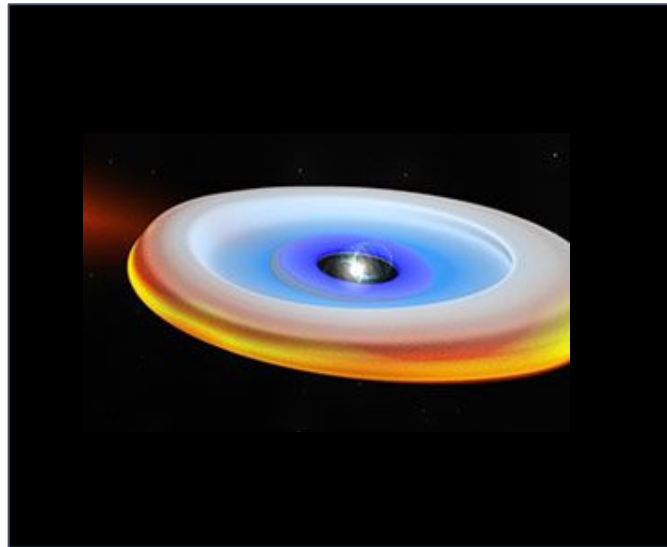
$$L_{\text{Edd}} = \frac{4\pi GMm_p c}{\sigma_T}$$

BHXRBs in Different Emission States



<https://screenrant.com/hulk-best-worst-mcu-moments-phase-1-2-problem/>

BH spins &
inclinations,
strong gravity.



Soft (Thermal) State



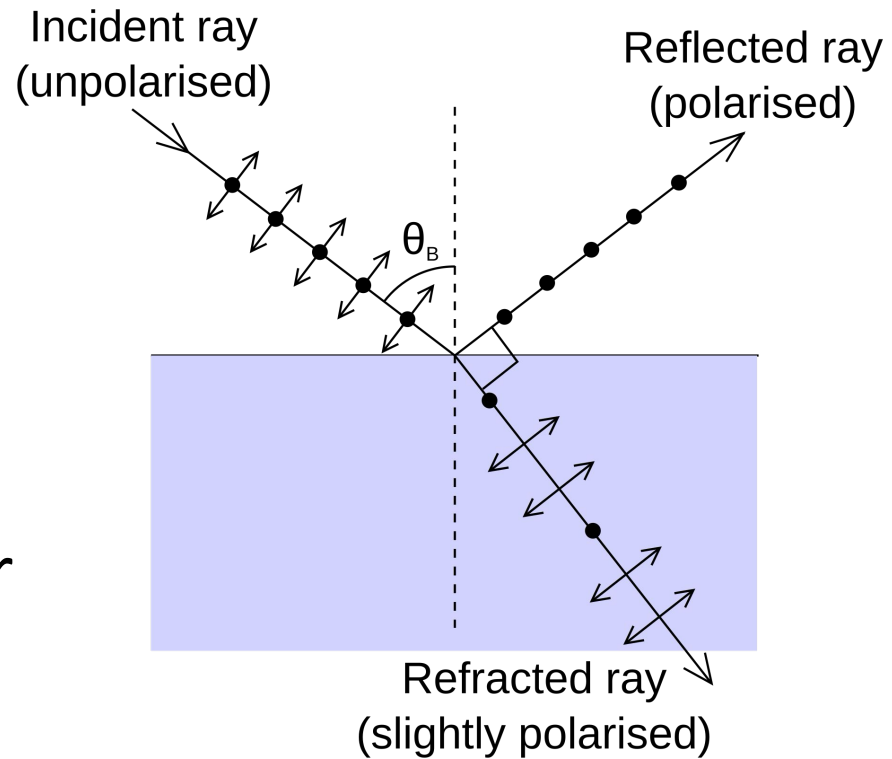
Hard State

BH accretion.

What polarizes X-rays from mass accreting black holes?

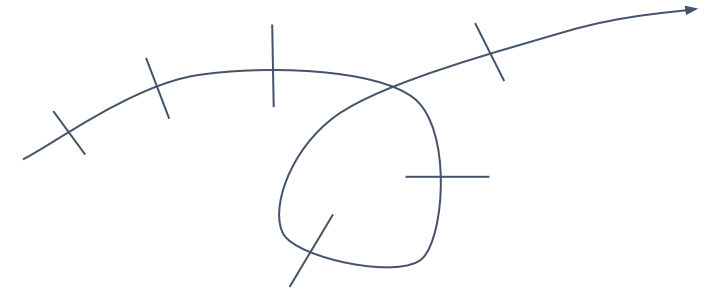
Scattering

(or reflection)
polarize light perpendicular
to scattering
(reflection) plane.



Chandrasekhar:
emission from scattering
atmosphere: $\leq 11.7\%$ PD

Faraday rotation $\sim \lambda^2$
is negligible.



Spacetime curvature
affects PA.

Overview of IXPE Results

Review
IXPE View of BH XRBs during the First 2.5 Years of the Mission

Michal Dovčiak ^{1,*}, Jakub Podgorný ¹, Jiří Svoboda ¹, James F. Steiner ², Philip Kaaret ³,
Henric Krawczynski ⁴, Adam Ingram ⁵, Vadim Kravtsov ⁶, Lorenzo Marra ^{7,8}, Fabio Muleri ⁹,
Javier A. García ^{10,11}, Guglielmo Mastroserio ¹², Romana Mikušincová ⁹, Ajay Ratheesh ⁹
and Nicole Rodriguez Cavero ⁴

Galaxies **2024**, *12*(5), 54; <https://doi.org/10.3390/galaxies12050054>



X-ray Polarization of Accreting Stellar-Mass Black Holes
through Accretion States
by
Nicole Rodriguez Cavero



multistate

single state

Source	IXPE Polarization	Interpretation	Publications
Cyg X-1, 21.2 M $\odot$	Hard: $\sim$ 3-4%	Corona & Jet	Krawczynski+2022
	Soft: $>$ 2%	Outflow, slim disk, ionization	Steiner+2024
GX 339-4, 5.8-10 M $\odot$	SIMS: $1.3\pm 0.4\%$	PD from coronal emission	Mastroserio+2024
	Soft: $<$ 1.4%		
Swift J1727.8	Hard: $4.1\pm 0.2\%$	Corona & Jet	Veledina+2023
	IMS: $\sim$ 3%	Soft lags	Ingram+2023
	Soft: $<$ 1%	PD sensitive to state	Svoboda+2024
	Low hard: $3.1\pm 0.6\%$	PD independent of luminosity	
4U1630-47	Soft: 8.3%	Obscured ULX, geometry, ionization	Ratheesh+2024
	SPL: 6.8%	Same PA as in the soft state.	Rodriguez Cavero+2023
LMC X-1	Soft: $<$ 2.5%	Consistent with low inclination	Podgorný+2023
LMC X-3, 7 M $\odot$	Soft: $3.2\pm 0.5\%$	Consistent with low spin	Svoboda+2024
LMC X-1, 11 M $\odot$	Soft: $<$ 1.1%	Consistent with low inclination, spin constraints	Podgorný+2023
		Constrain on spin and returning radiation	Marra+2024
4U 1957+115, 3-6.2 M $\odot$	Soft: $1.9\pm 0.4\%$	Consistent with low inclination	Ling+2024
Swift J151857.0-572147	Soft: $<$ 0.2%	Implications for Cyg X-1 and Swift J1727	Parra+2025, Debnath+2025
IGR J17091-3624	Hard: $8\pm 1\%$		
Cyg X-3	Hard: $20.6\pm 0.3\%$, $21.4\pm 0.4\%$		Veledina+2024, 2025
	IMS: $10.4\pm 0.3\%$		Mikusincova+2024
	Soft: $11.9\pm 0.3\%$		Rodriguez Cavero+2025

Cygnus X-1 in the Hard State ($\sim 1\% L_{\text{Edd}}$)

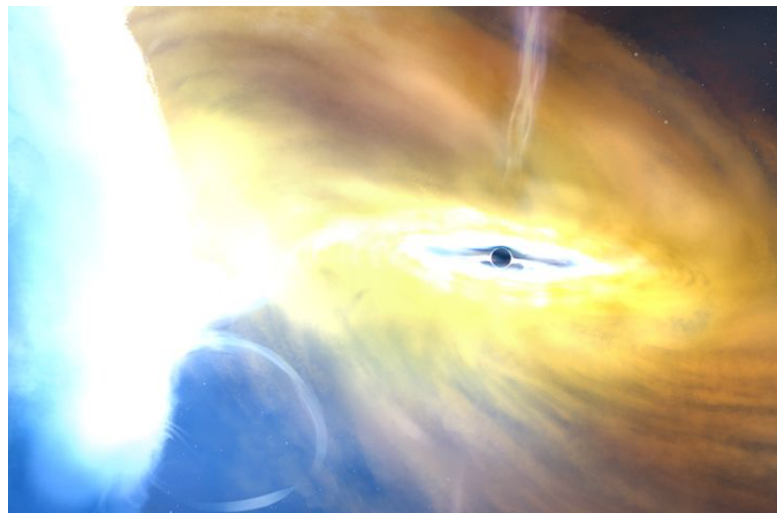
$$M_{\text{BH}} = 21.2 \pm 2.2 M_{\odot}$$
$$M_2 = 40.6^{+7.7}_{-7.1} M_{\odot}$$

$$P = 5.6 \text{ days}$$
$$d = 2.22^{+0.18}_{-0.17} \text{ kpc}$$

Orbital inclination:

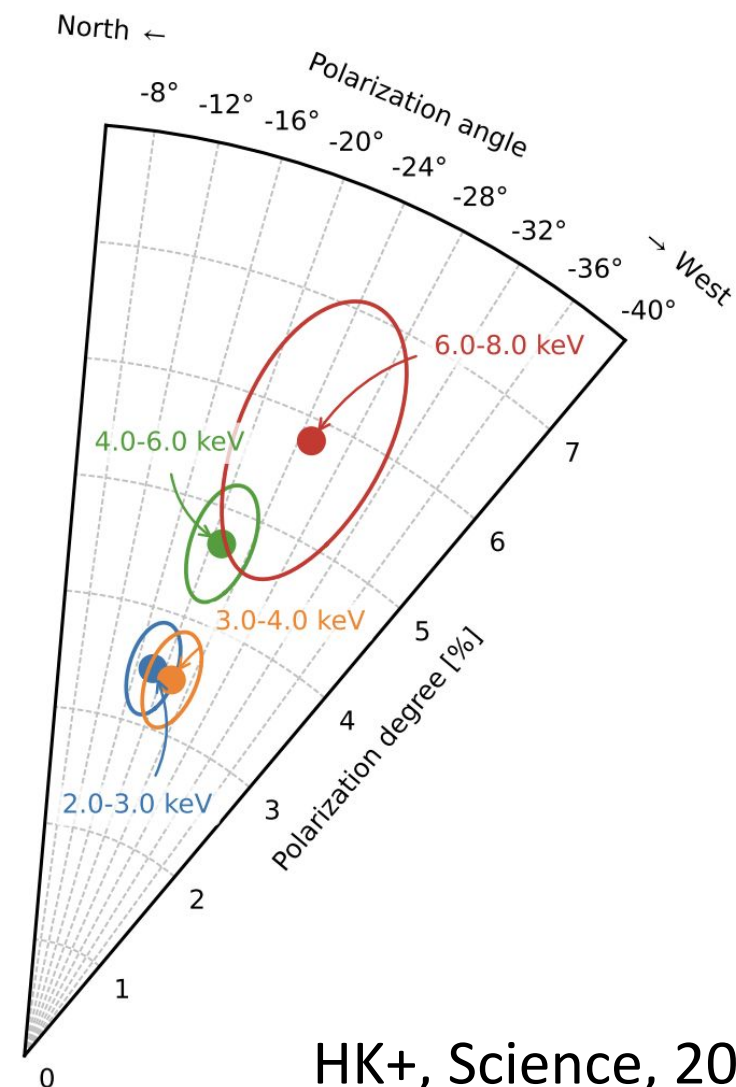
$$i = 27.51^{+0.8^\circ}_{-0.7^\circ}$$

Miller-Jones et al. 2021

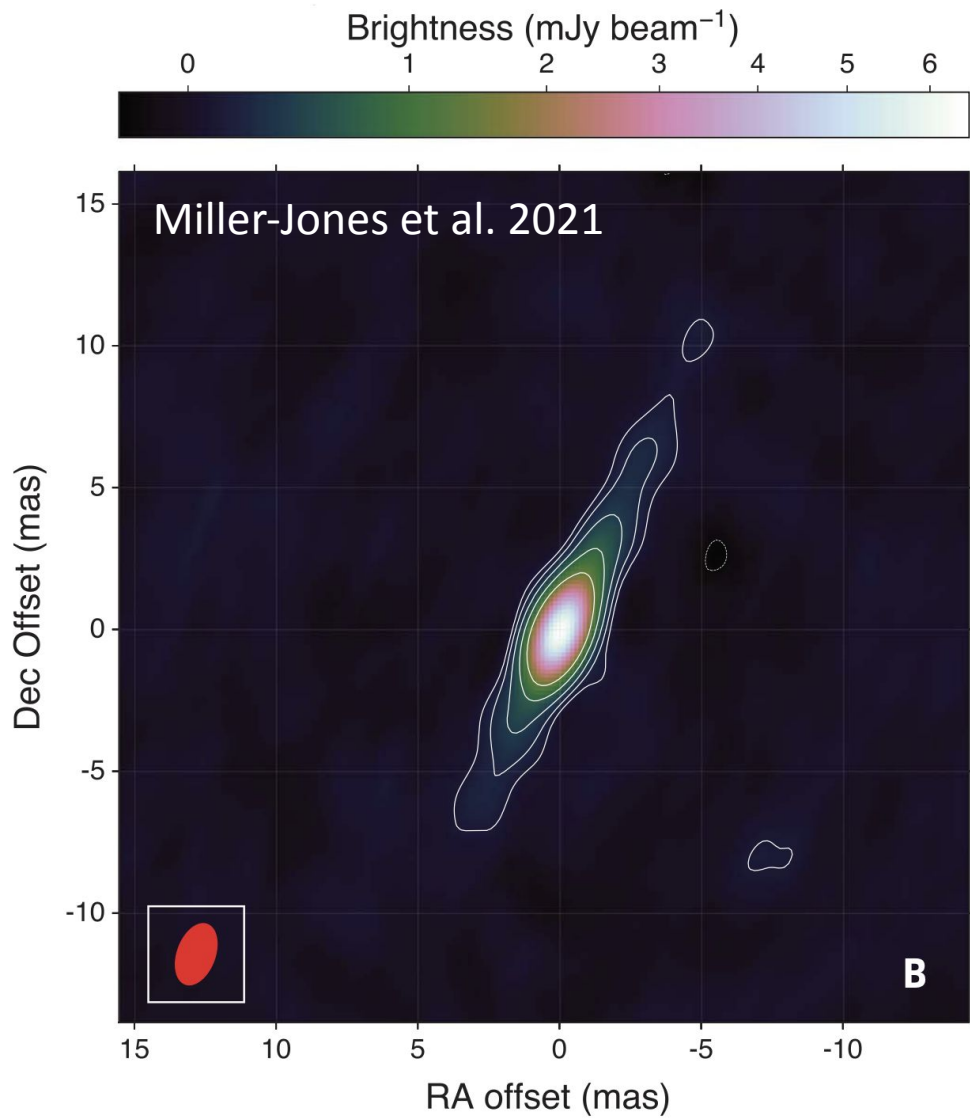


Hard state: emission is dominated by hot coronal plasma.

5/15-5/22, 2022,
242 ksec

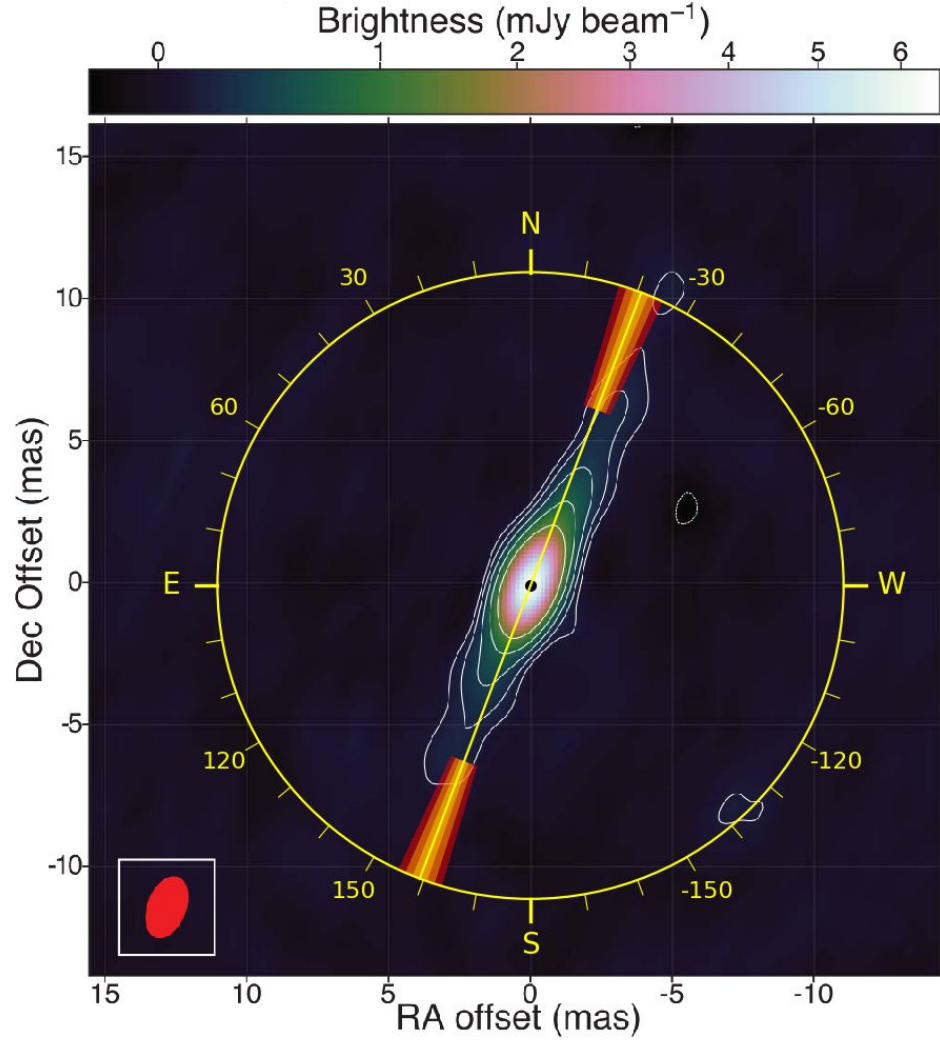


HK+, Science, 2022

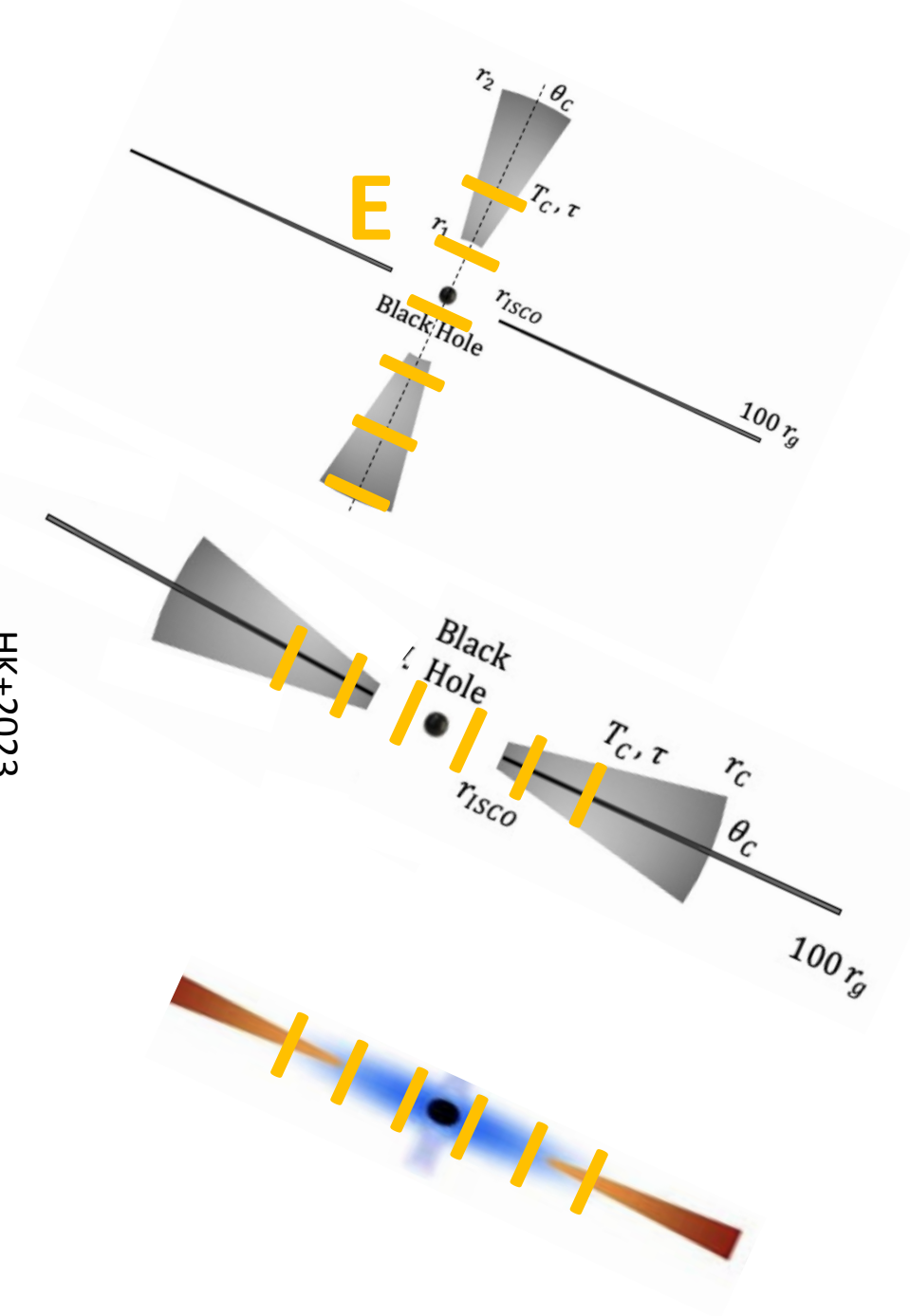


10 billion km

IXPE emission
probes $70 r_g \sim$
2,000 km $\varnothing$ region!



HK+2023

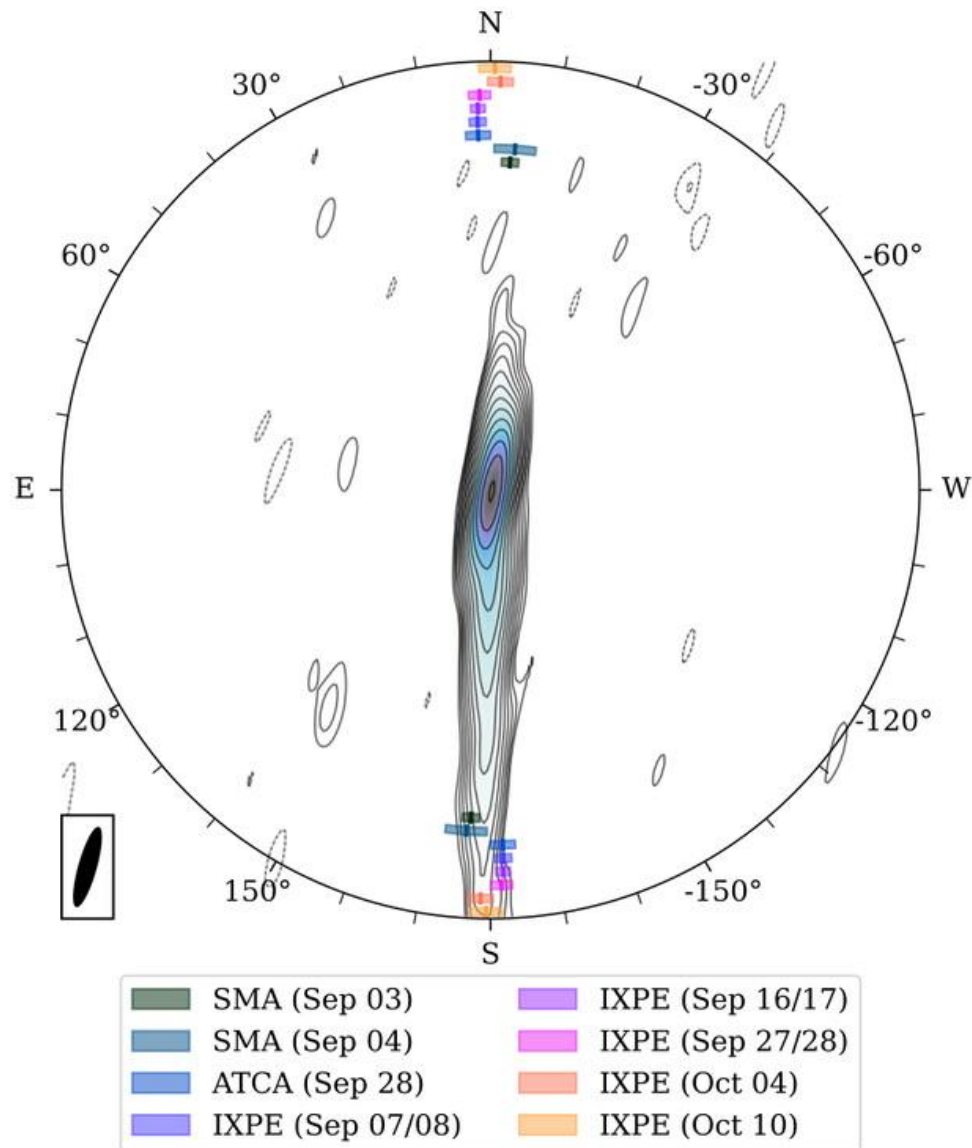


~~Lamppost~~

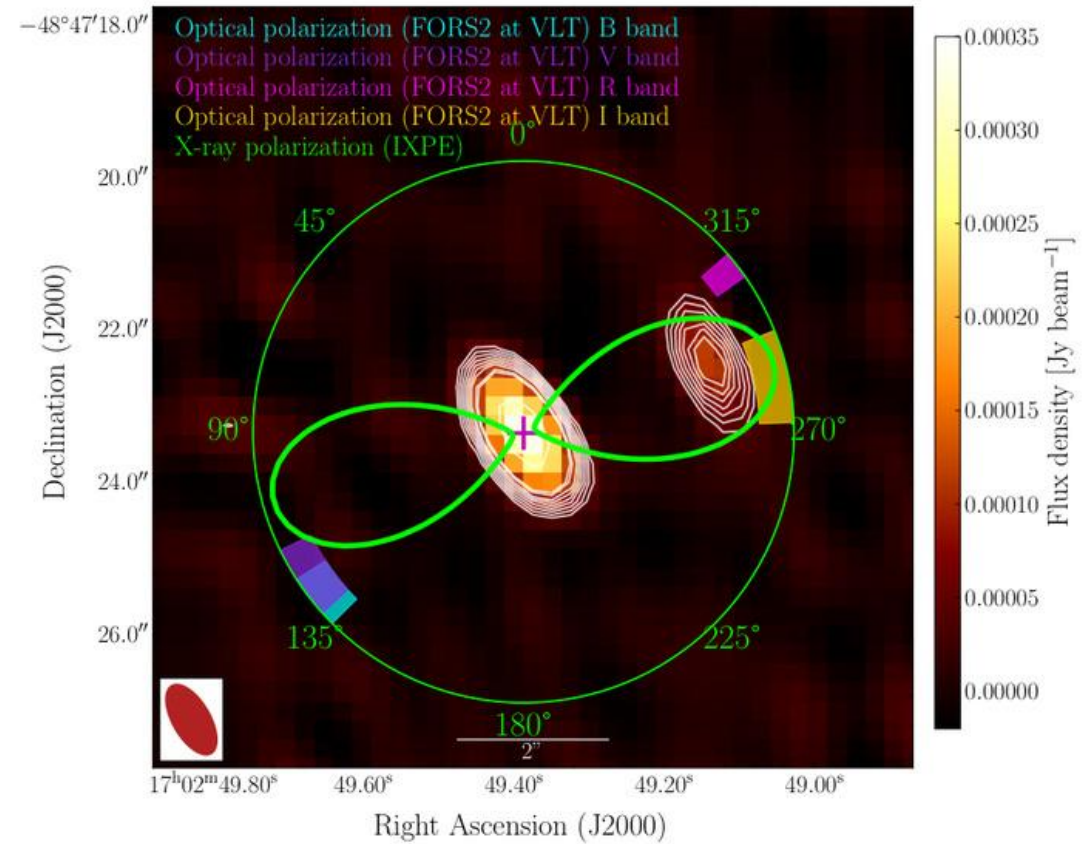
Sandwich

Hot inner
flow

Swift J1727.8-1613.

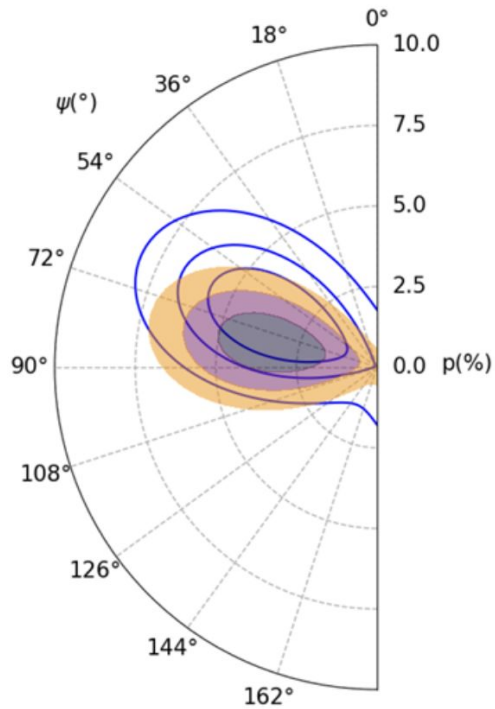


GX 339-4

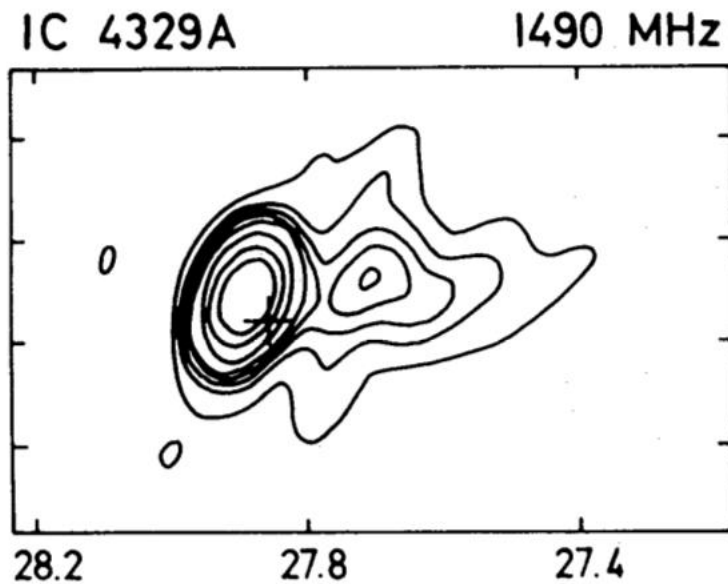


Polarization is parallel to jet.
Corona is perpendicular to jet.

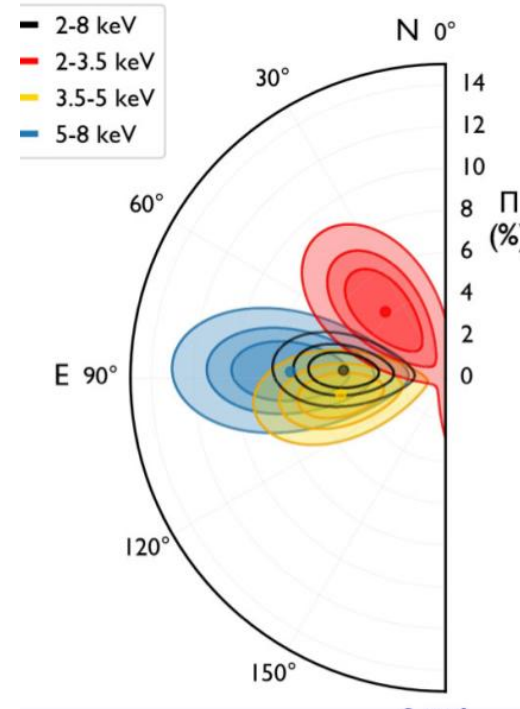
Orientation of X-ray Polarization (and the corona) in Radio Quiet AGNs



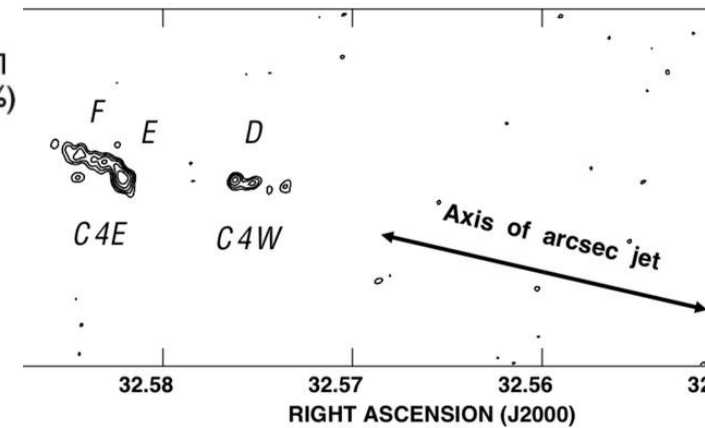
Ingram+2023



Unger+ 1987



Gianolli+2023

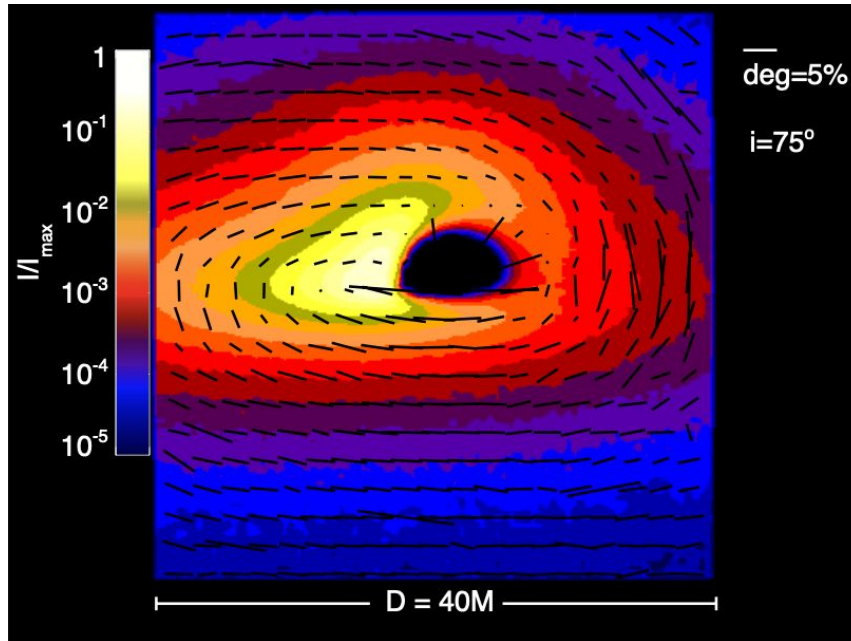


Ulvestad+1998

Polarization is parallel to jet; Corona is perpendicular to jet.

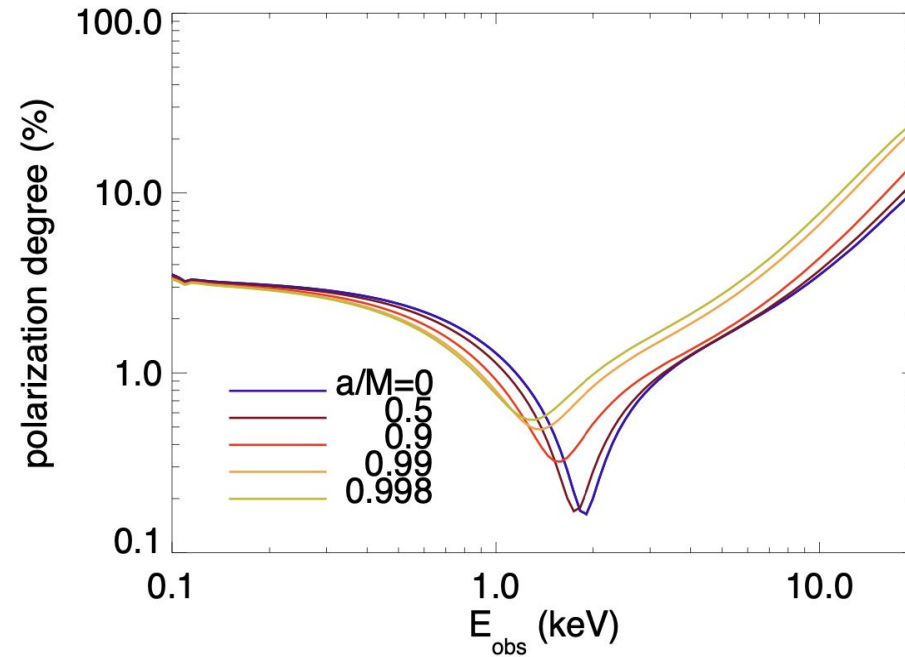
Polarization of Thermal Thin Disk Emission

Schnittman & Krolik 2009



- (i) highest energies from small r .
- (ii) high $a \Rightarrow$ strong gravitational lensing
 $\Rightarrow$ more returning emission reflected

Schnittman & Krolik 2009



Polarimetry gives new constraints on
BH spins.

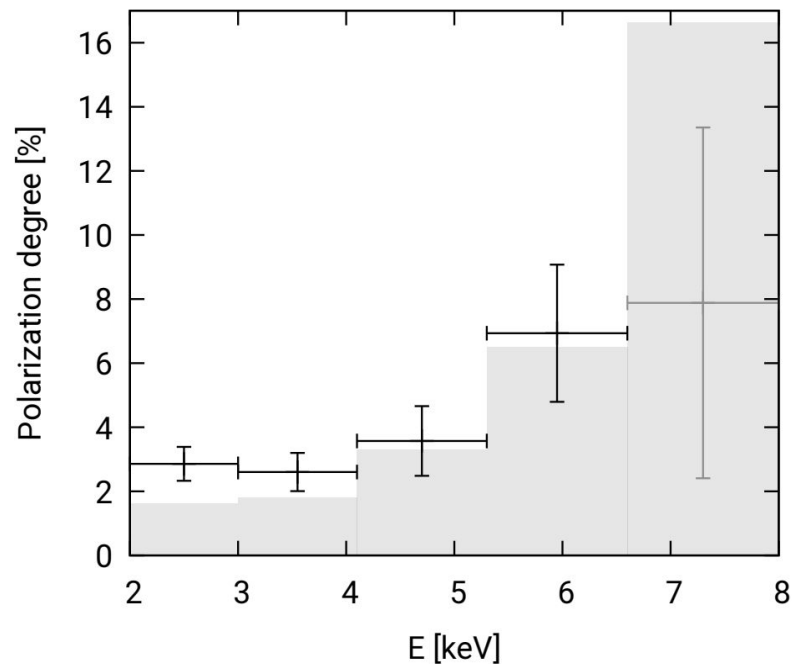
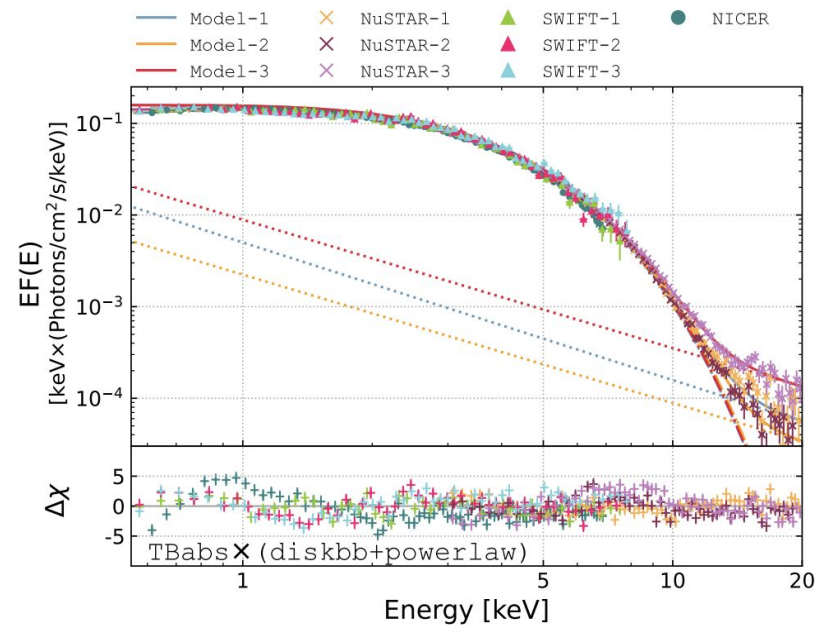
LMC X-3

$D = 49.59 \pm 0.09 \pm 0.54$ kpc (Pietrzyński et al. 2019)

$M_{\text{BH}} = 6.98 \pm 0.56 M_{\odot}$,

$M_{\text{star}} = 3.63 \pm 0.57 M_{\odot}$,

$i = 69.2^{\circ}$ (Orosz et al. 2014)



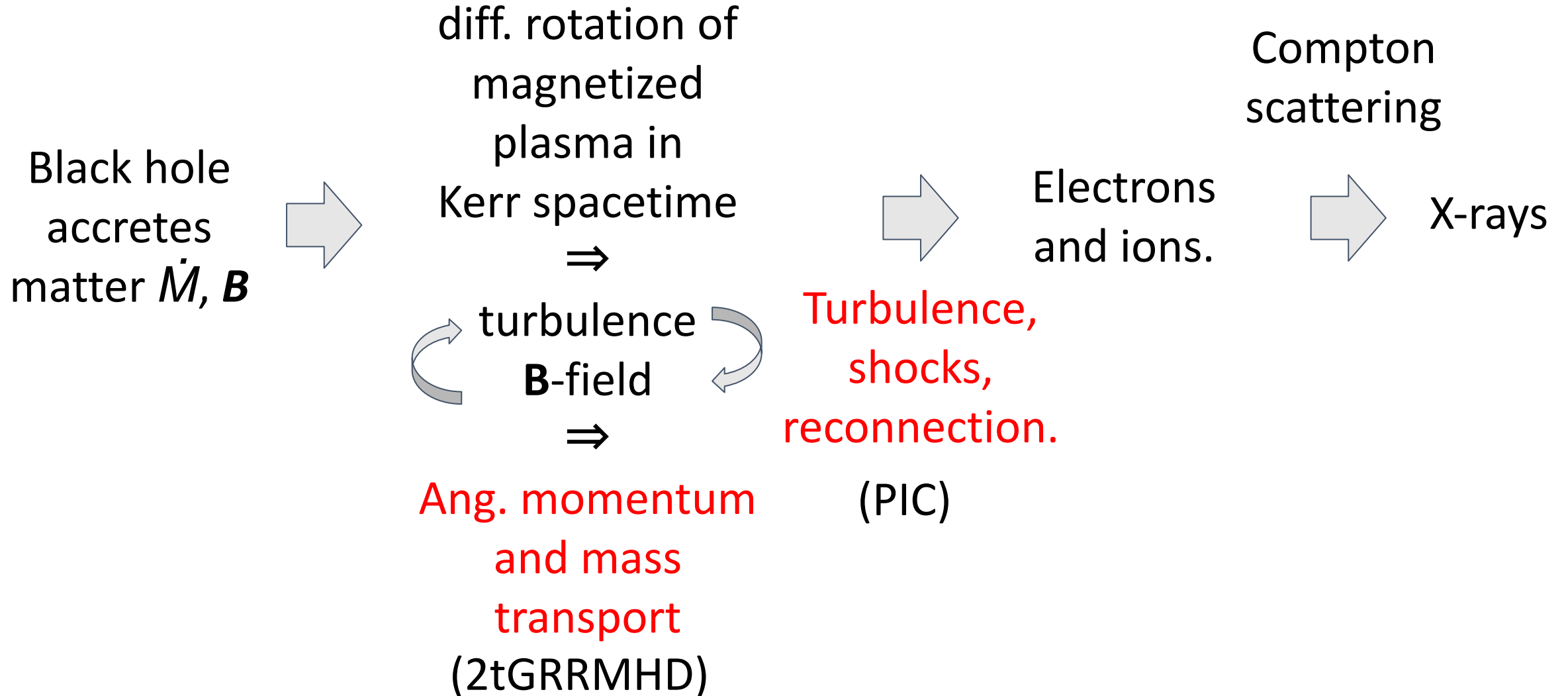
Svoboda et al. 2023

$a \sim 0.2$

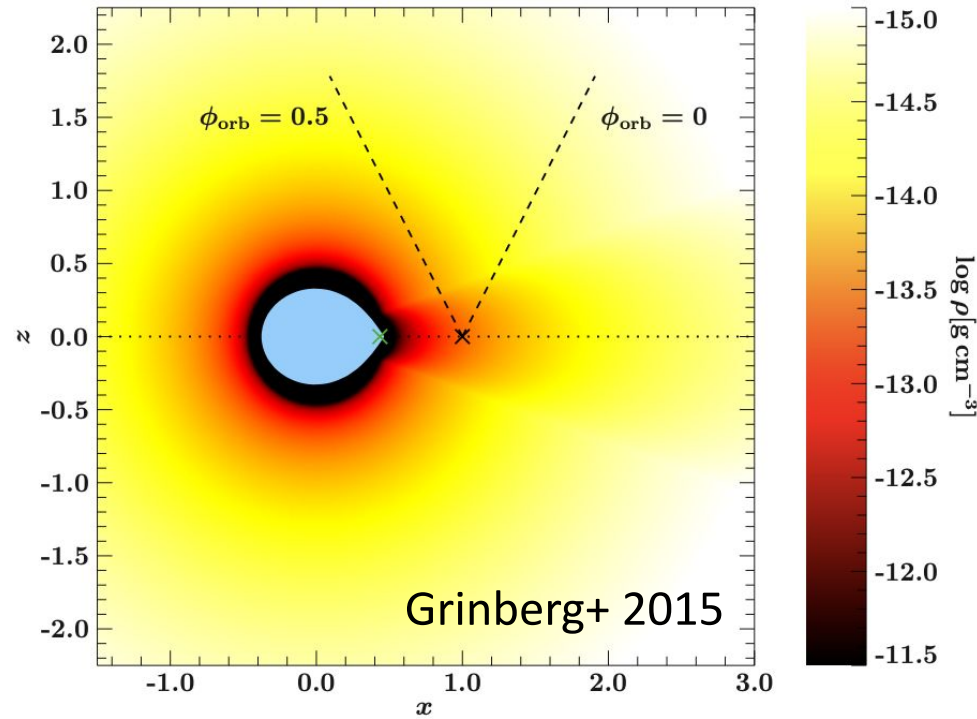
$a < 0.7$

A Deeper Look

What do we learn from these measurements?



Accretion through capture from focussed wind



Modeling of orbital phase dependent
hardness ratios by Lai+ 2024:

$$\dot{M}_{wind} = 7 \times 10^{-6} M_{\odot} \text{yr}^{-1}$$

$$v_{\infty} = 2100 \text{ km s}^{-1}, \beta = 1.5.$$

$$v_{cygx1} = 900 \text{ km s}^{-1}$$

$$f_{capt} = 9 \times 10^{-3}$$

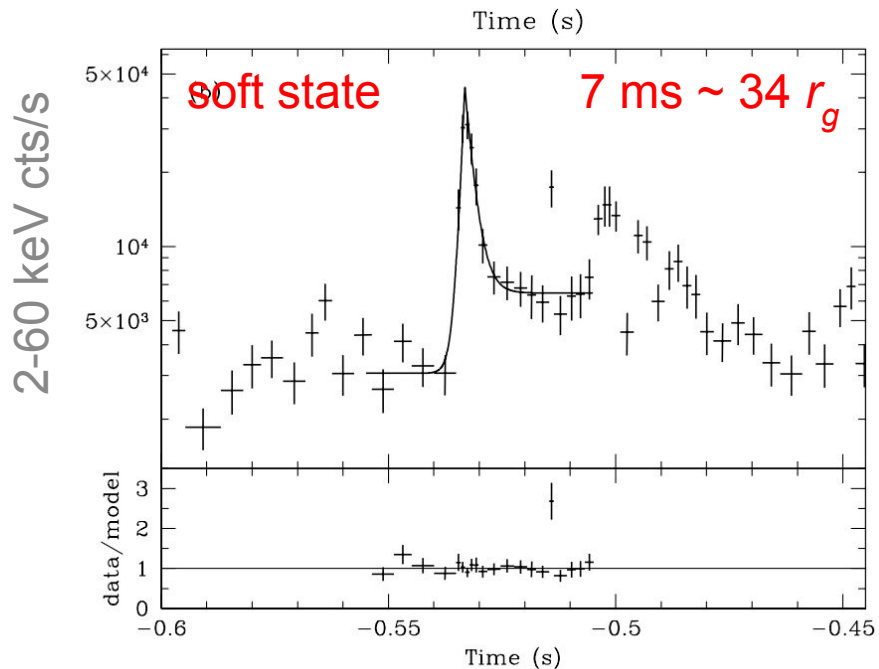
$$\dot{M}_{Cyg X-1} = 4 \times 10^{18} \text{ g s}^{-1}$$

$$L_{Edd}/c^2 = 3 \times 10^{18} \text{ g s}^{-1}$$

Focussed wind amplification: 3 x

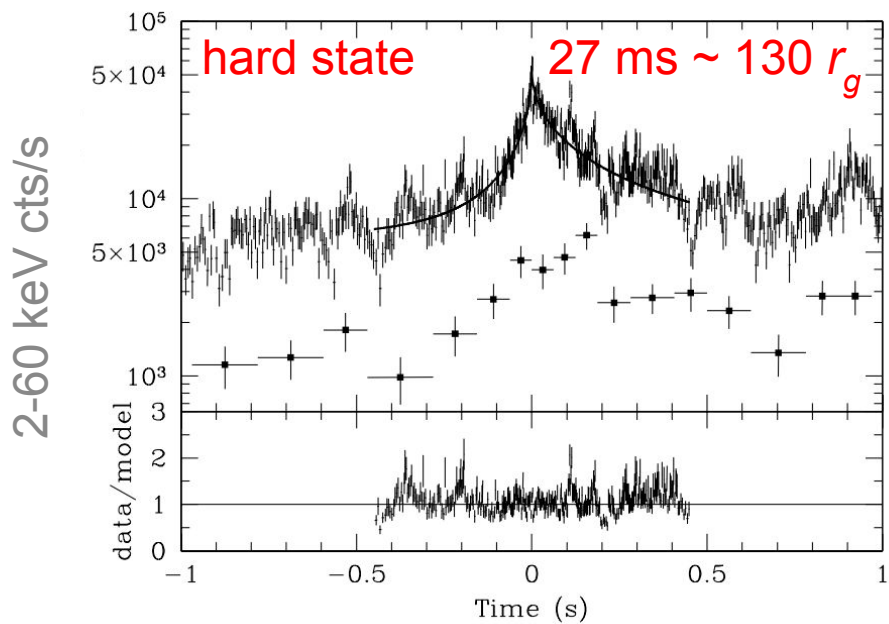
BH can capture:

$$\dot{M}_{cap} \approx 3.5 L_{Edd}/c^2.$$



$$r \leq \Delta t c$$

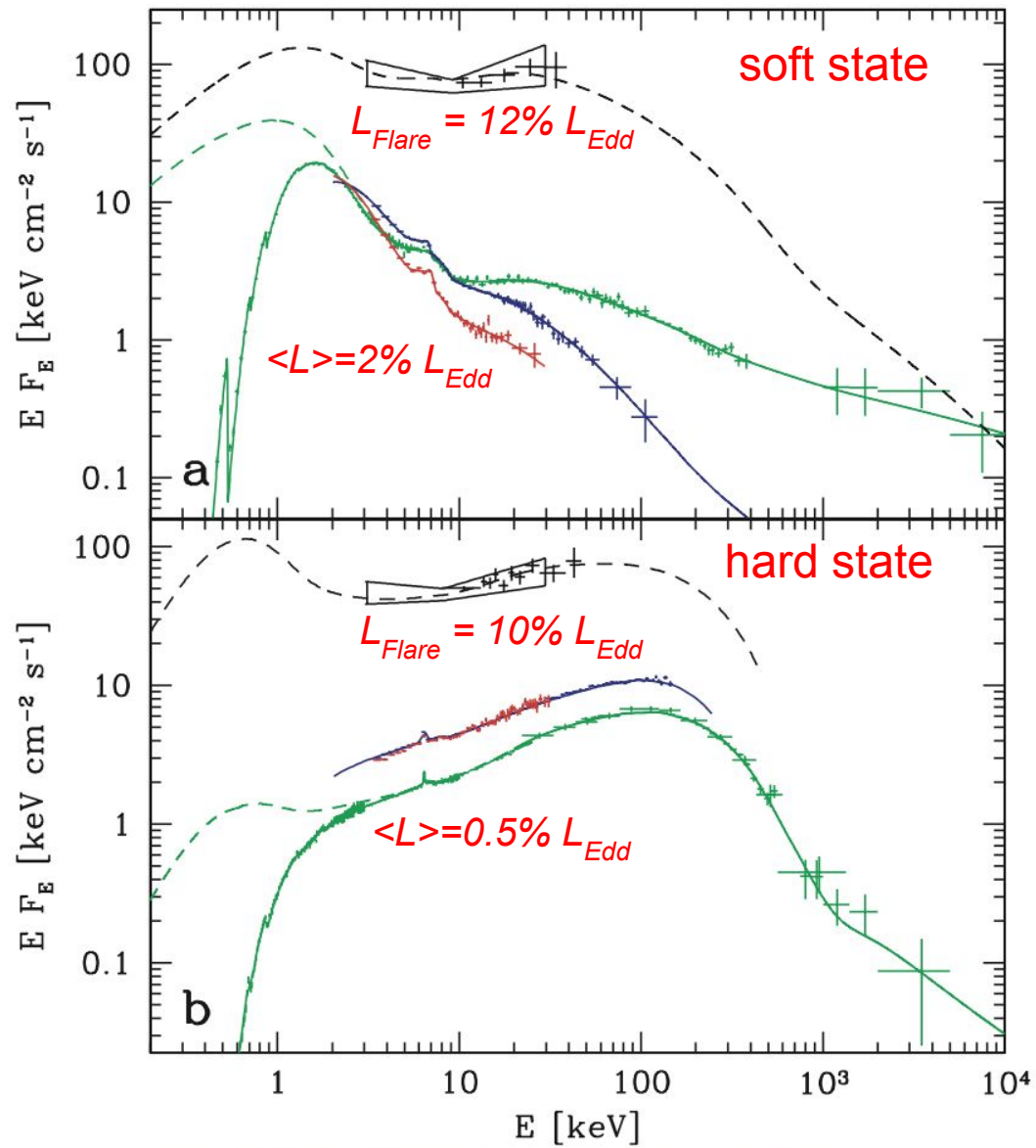
$$r \leq \Gamma \Delta t c$$

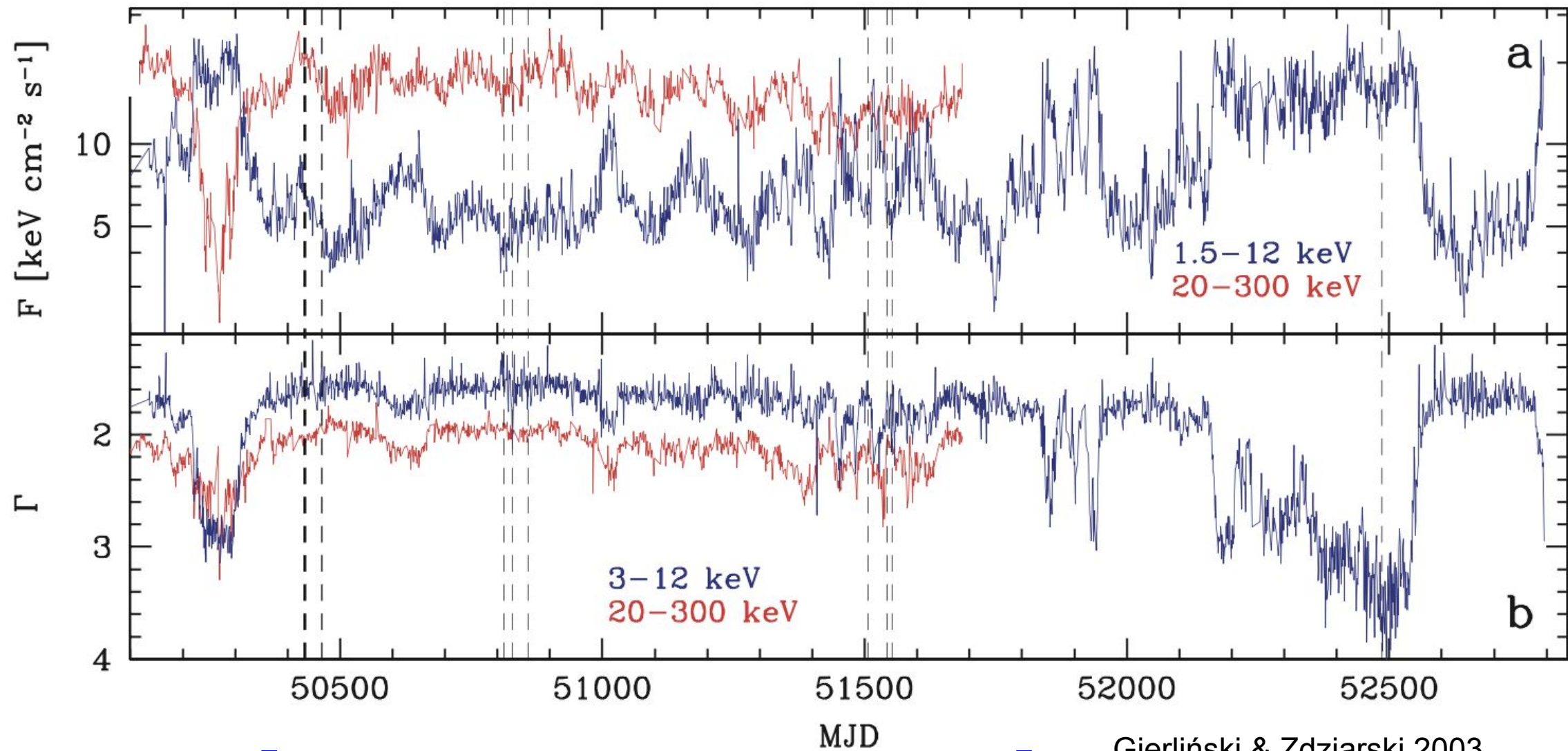


Gierliński & Zdziarski 2003

Time lag: Gilfanov
2010, 6.4 keV-3-20
keV lag [s]
15 ms ~ 72 r_g

Tomsick+2018,
Lamppost height for
Fe K α : $h = 19...36 r_g$

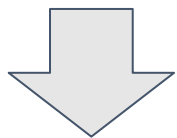
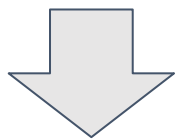




Gierliński & Zdziarski 2003

$\Gamma (dN/dE \propto E^{-\Gamma})$ is stable over ~ 4 years!

$$\dot{M}c^2$$



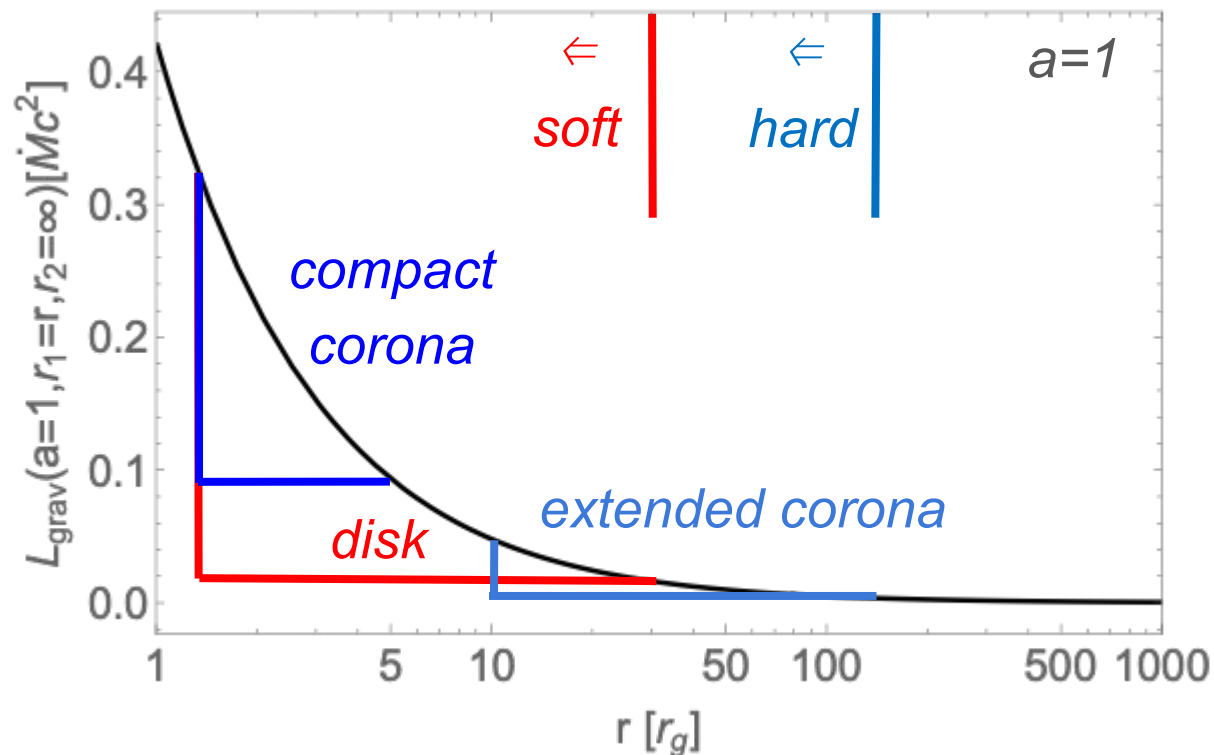
$$L_{\text{grav}} =$$

$$L_{\text{rad}} + L_{\text{jet+wind}} + L_{\text{othe}}$$

r

$$= \eta \dot{M}c^2$$

Efficiency as a function of how close to the BH the matter sinks



Soft state:

Matter accretes to

$$r_{\text{isco}} \sim 1.2 r_g (a=0.998)$$

$$\eta \sim 30\%$$

$$\dot{M} \sim 3\text{-}40\% L_{\text{Edd}}/c^2$$

Hard state:

(i) compact corona,

$$\text{e.g. } 1.2 r_g \dots 5 r_g$$

$$\eta \sim 23\%$$

$$\dot{M} \sim 4\text{-}50\% L_{\text{Edd}}/c^2$$

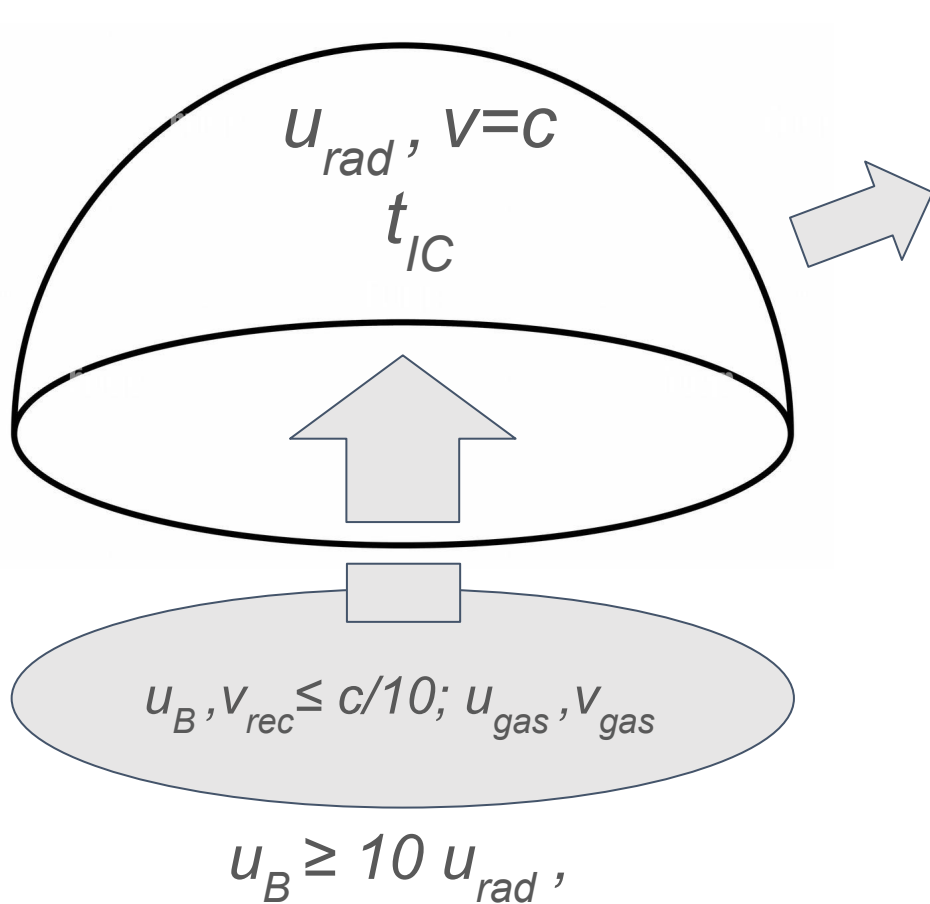
(ii) extended corona,

$$\text{e.g. } 10 \dots 130 r_g$$

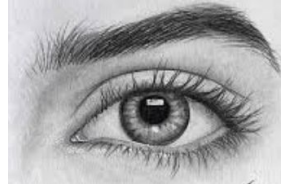
$$\eta \sim 4.4\%$$

$$\dot{M} \sim 20\text{-}250\% L_{\text{Edd}}/c^2$$

Following: Galeev+1979, Belodorodov 2017



synchrotron emission
is self-absorbed.
reconnection can
create pairs.



(i) compact corona,

$3 r_g$ radius volume

$$u_{\text{rad}} = 10^{12} \text{ erg cm}^{-3}$$

$$t_{\text{IC}} = 0.06 R/c$$

$$B = 4 \times 10^7 \text{ G}, n_{e+/-} (\tau=1) = 1.6 \times 10^{17} \text{ cm}^{-3}$$

$$\sigma_i = (2u_B/n m_p c^2) = 0.53, \sigma_{\text{pair}} = 980$$

Energy
carrier:

B

(2) large corona,

e.g. $10 \dots 130 r_g$

$$u_{\text{rad}} = 8 \times 10^8 \text{ erg cm}^{-3}$$

$$t_{\text{IC}} = 2.65 R/c$$

$$B = 10^6 \text{ G}, n_{e+/-} = 4 \times 10^{15} \text{ cm}^{-3}$$

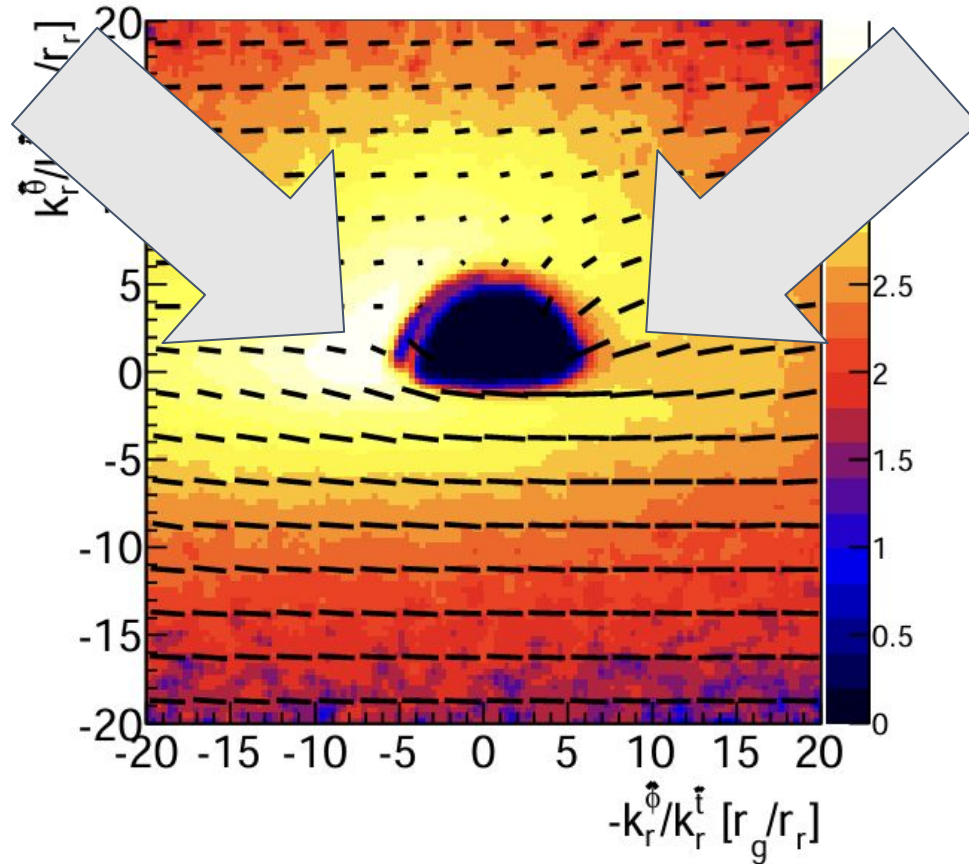
$$\sigma_i = 0.01, \sigma_{\text{pair}} = 30$$

Energy carrier:

**B or hot
plasma**

Where is the plasma energized?

(1) Soft State

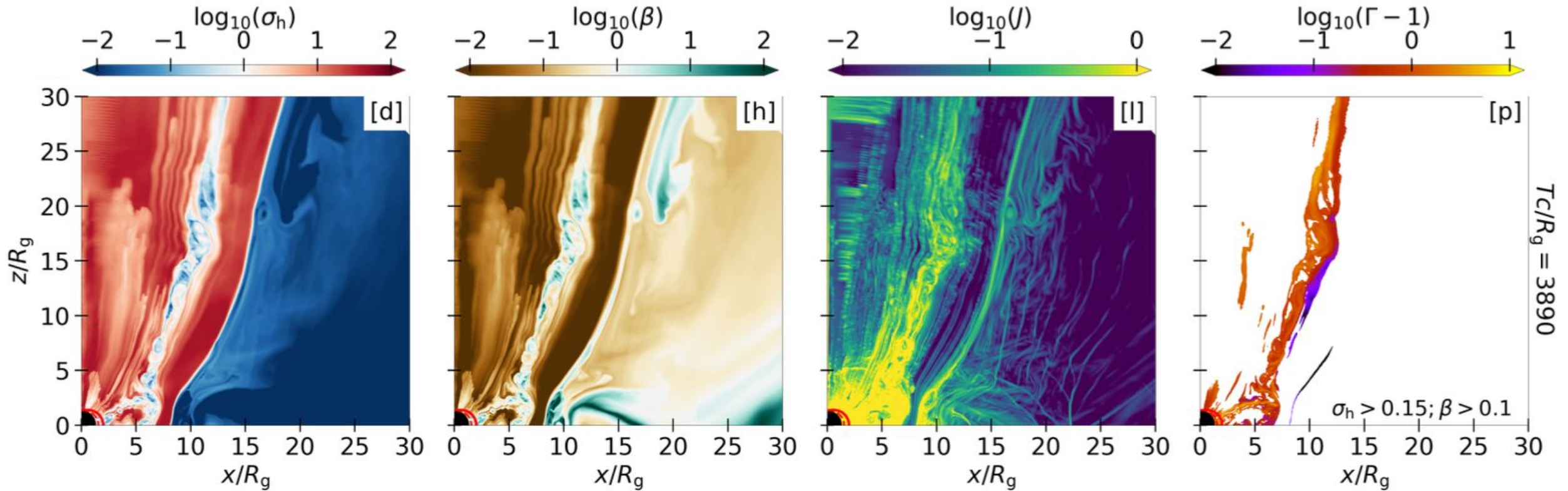


Reconnection may occur on the surface of the disk and create an e^+e^- layer, with non-thermal tail.



Where is the plasma energized?

(2a) Hard State - Compact Corona

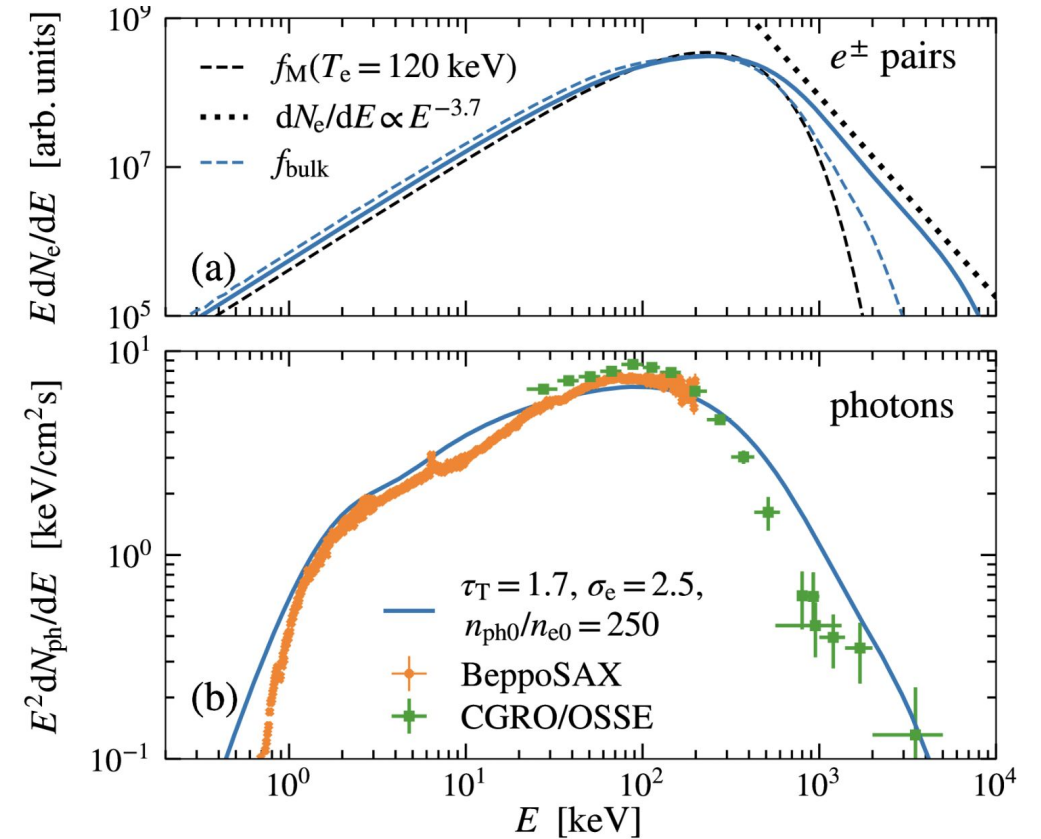
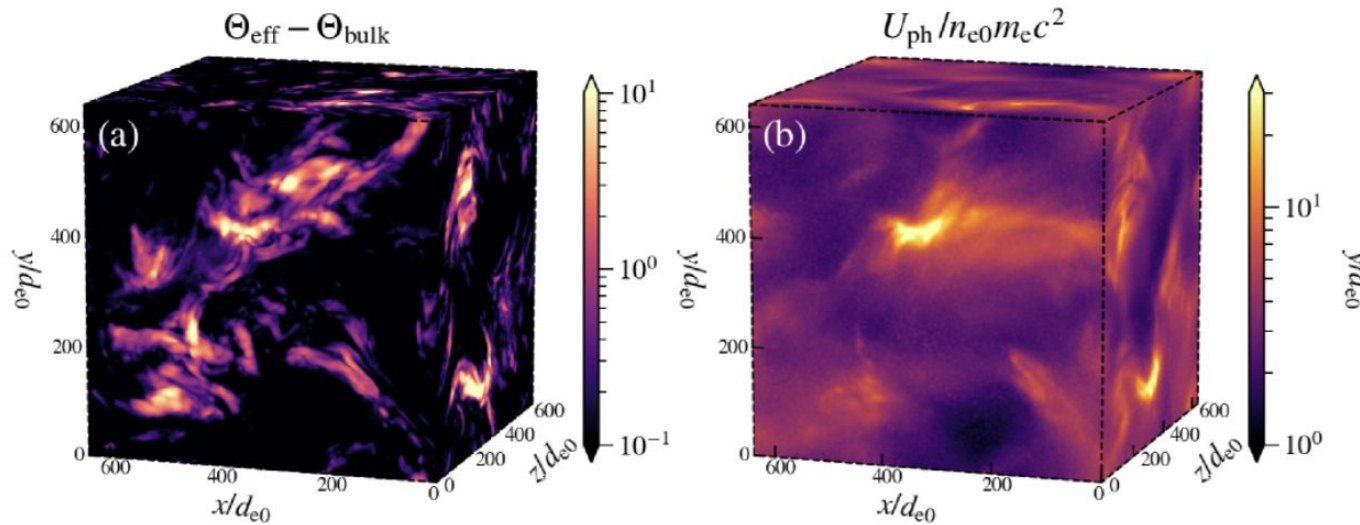


Beloborodov, 2017: comptonization by plasmons moving with bulk velocities $\sim 0.5c$. Anisotropy impacts PD and PA.

rGRMHD,
Sridhar et al. 2025

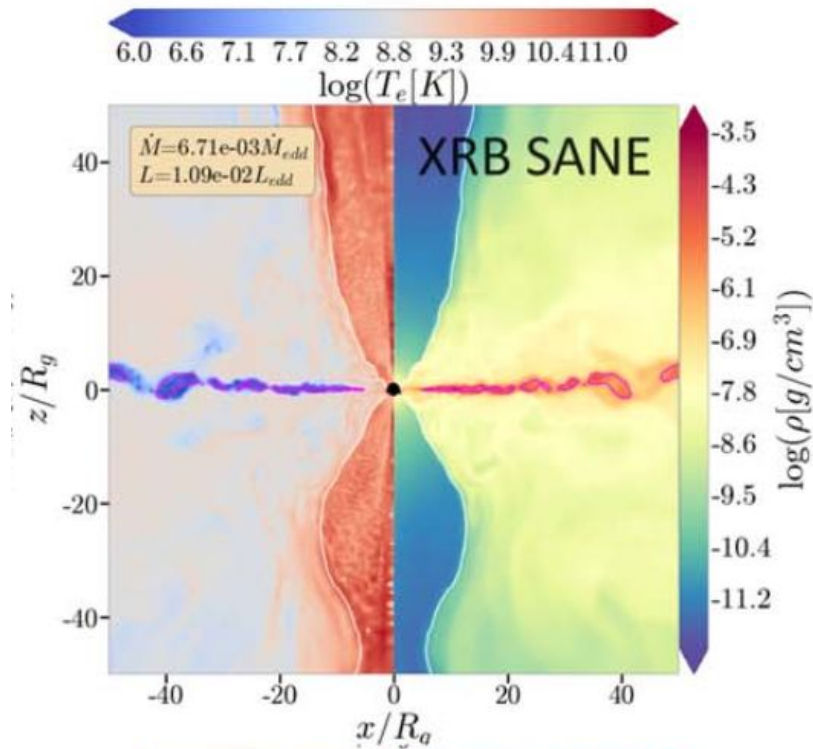
Radiative Particle-in-Cell Simulations of Turbulent Comptonization in Magnetized Black-Hole Coronae

Daniel Grošelj ^{1,2}, Hayk Hakobyan ^{3,4}, Andrei M. Beloborodov ^{4,5}, Lorenzo Sironi ²,
and Alexander Philippov ⁶

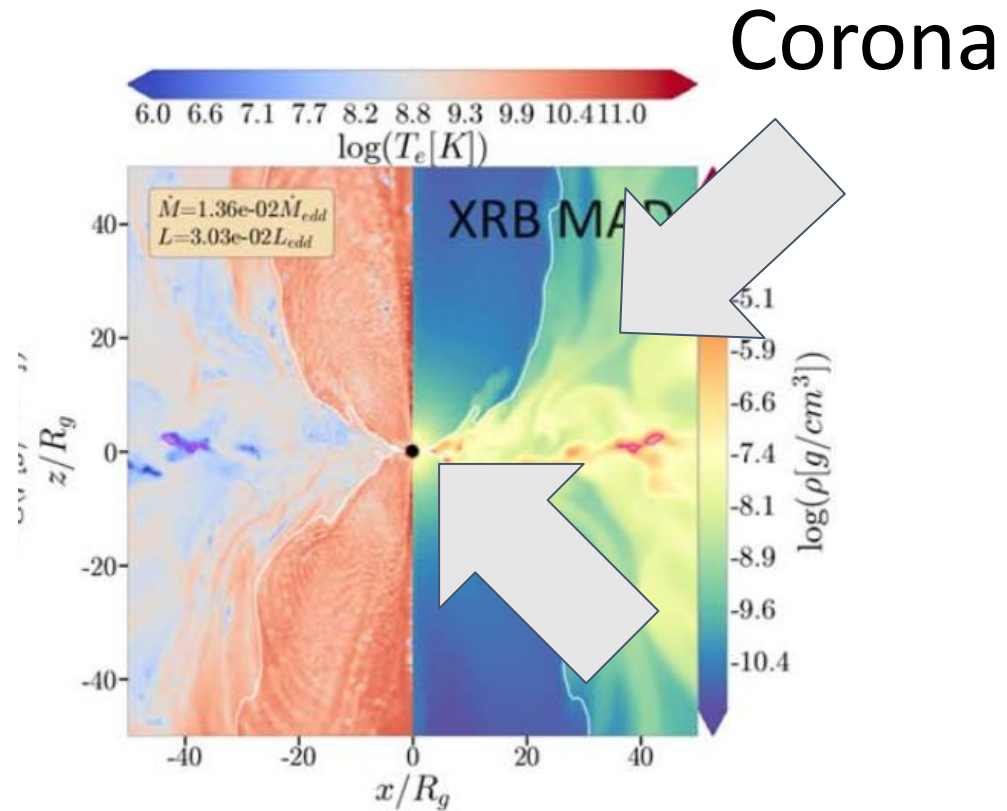


Anisotropy increases PDs!

(2b) Hard State - extended corona



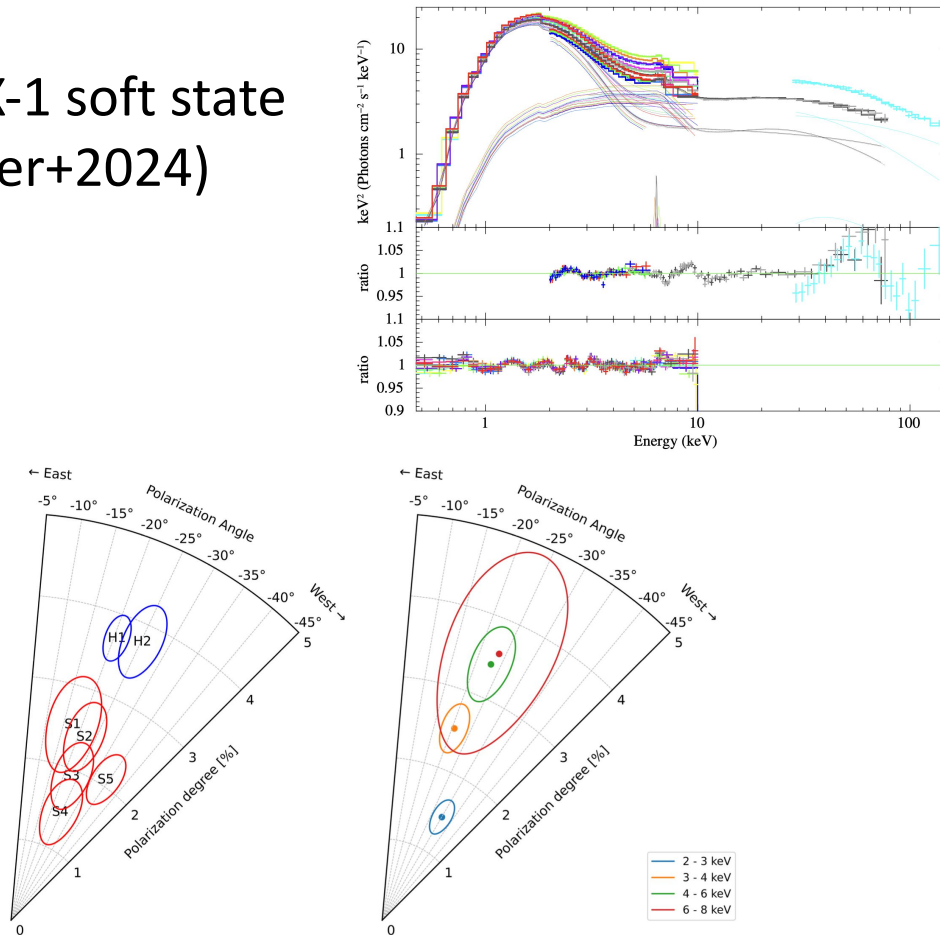
Liska et al. 2023



Current sheet?
Cold clumps $\Rightarrow$ Fe K- α .

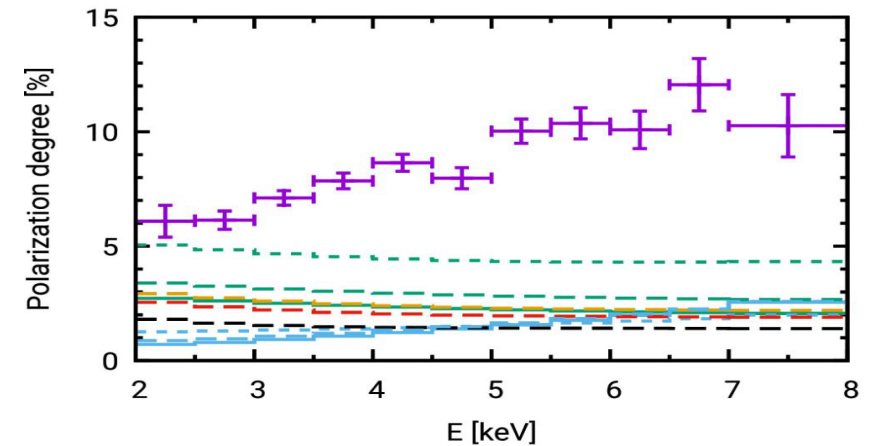
Unexpected *IXPE* Findings

(1) Cyg X-1 soft state (Steiner+2024)



Rather high PD in soft state as well,
and same PA in soft and hard state!
Kun Hu & HK: kerrC explanation.

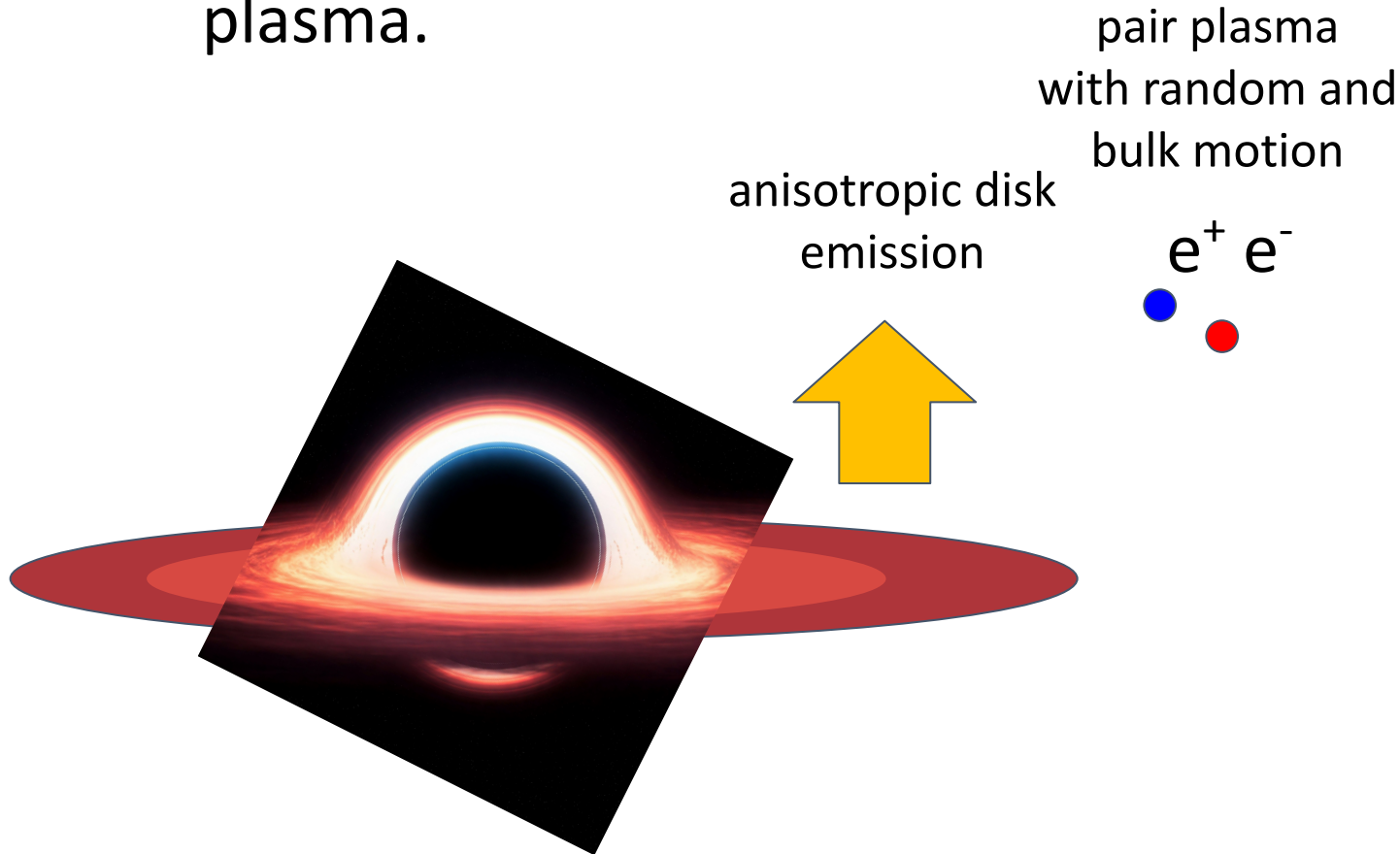
(2) 4U 1630-47 (Ratheesh+2024, Rodriguez Caverro+2023)



Very high PD in soft state!

(3) IGR J17091-3624 (Parra+2025, Debnath+2025): PD~8% in hard state.

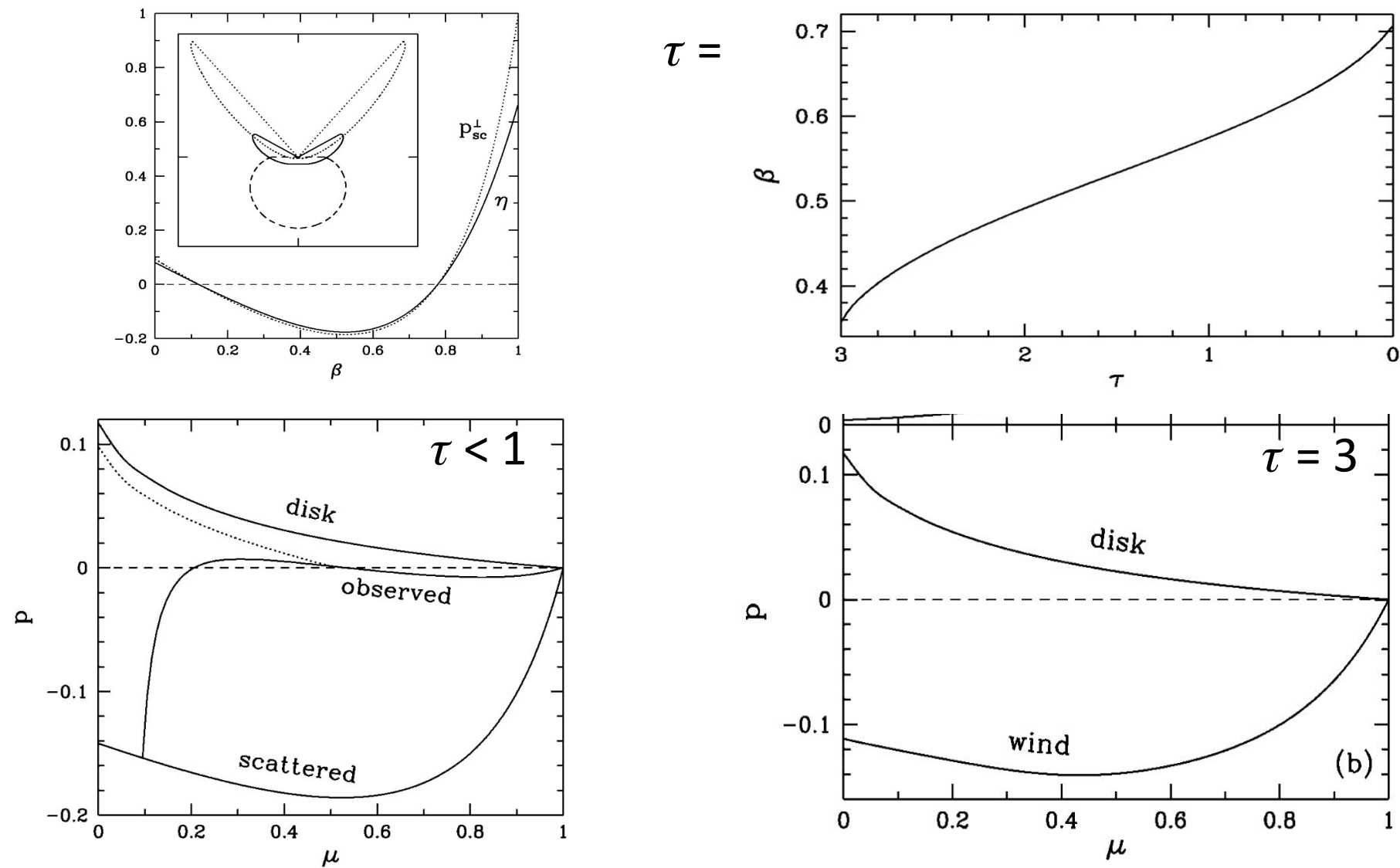
Explanation #1: Bulk motion of pair plasma.



- (1) conversion of internal energy into bulk outflow energy (**Compton Rocket**, O'Dell 1981, Phinney 1981, Cheng, 1981).
- (2) acceleration of “cold” pair plasma by radiation pressure (**Beloborodov 1998, 1999**).

Complex situation:
pair plasma continues to be heated
through reconnection
while accelerating.

Beloborodov 1998 & 1999:



THE ASTROPHYSICAL JOURNAL

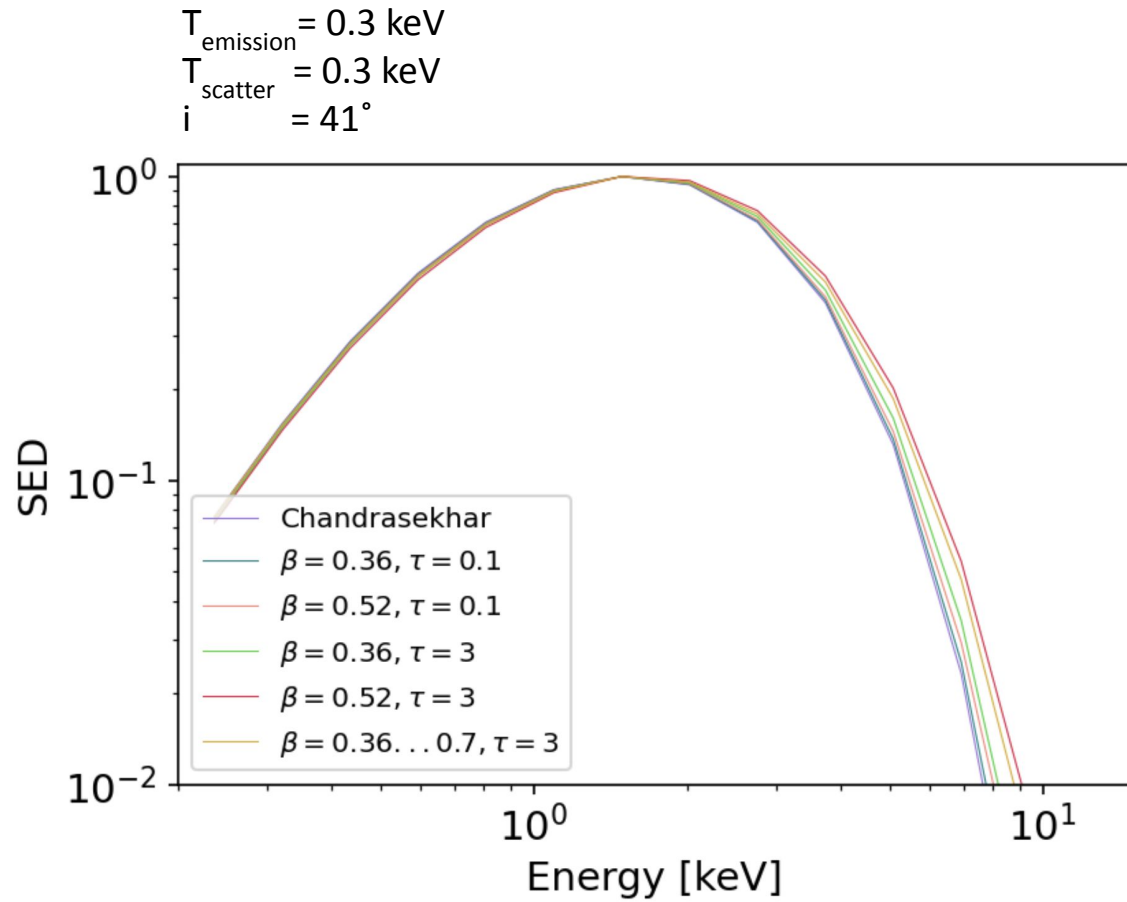
FREE ARTICLE
Spectral Hardening in Black Hole Accretion: Giving Spectral Modelers an f
Shane W. Davis and Samer El-Abd
Published 2019 March 18 • © 2019, The American Astronomical Society. All rights reserved.
[The Astrophysical Journal, Volume 874, Number 1](#)
Citation Shane W. Davis and Samer El-Abd 2019 ApJ 874 23
DOI 10.3847/1538-4357/ab05c5

see also Zdziarsky+ 2024

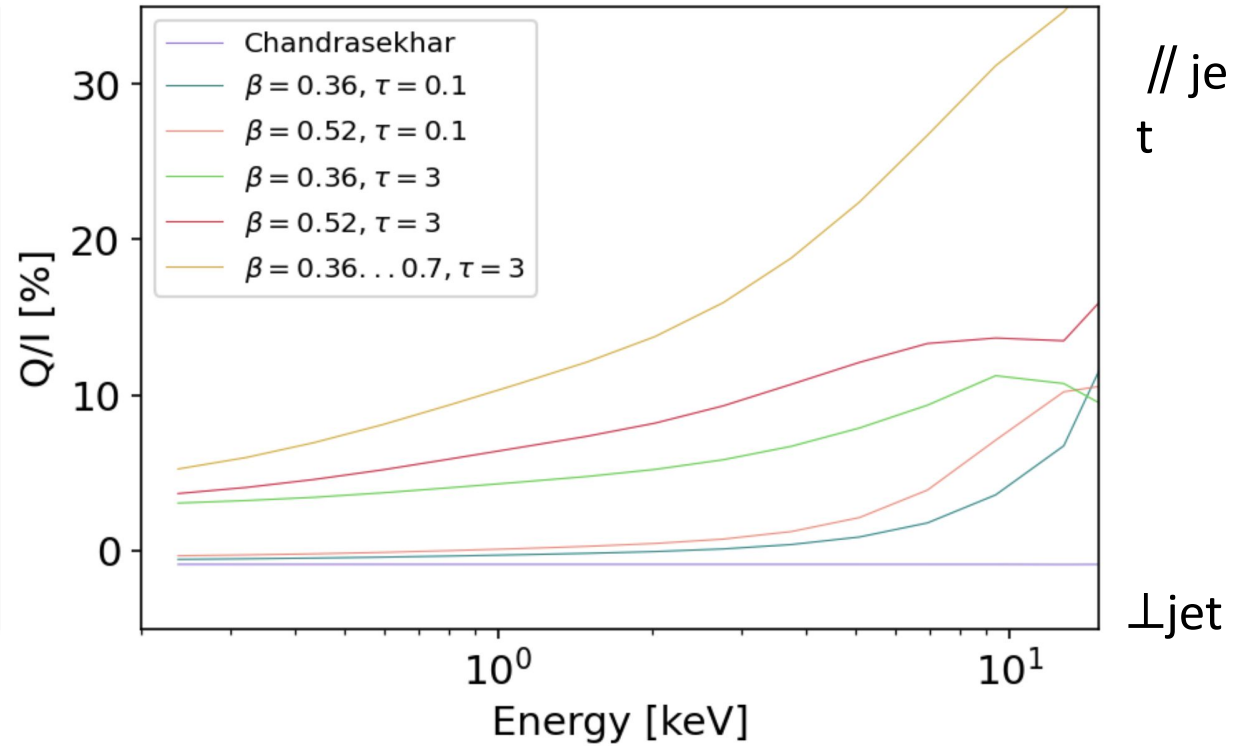
Hard state (also: Poutanen+2024)

Soft state

Soft State - Results from Plain-Parallel Atmosphere MC Rad. Transport

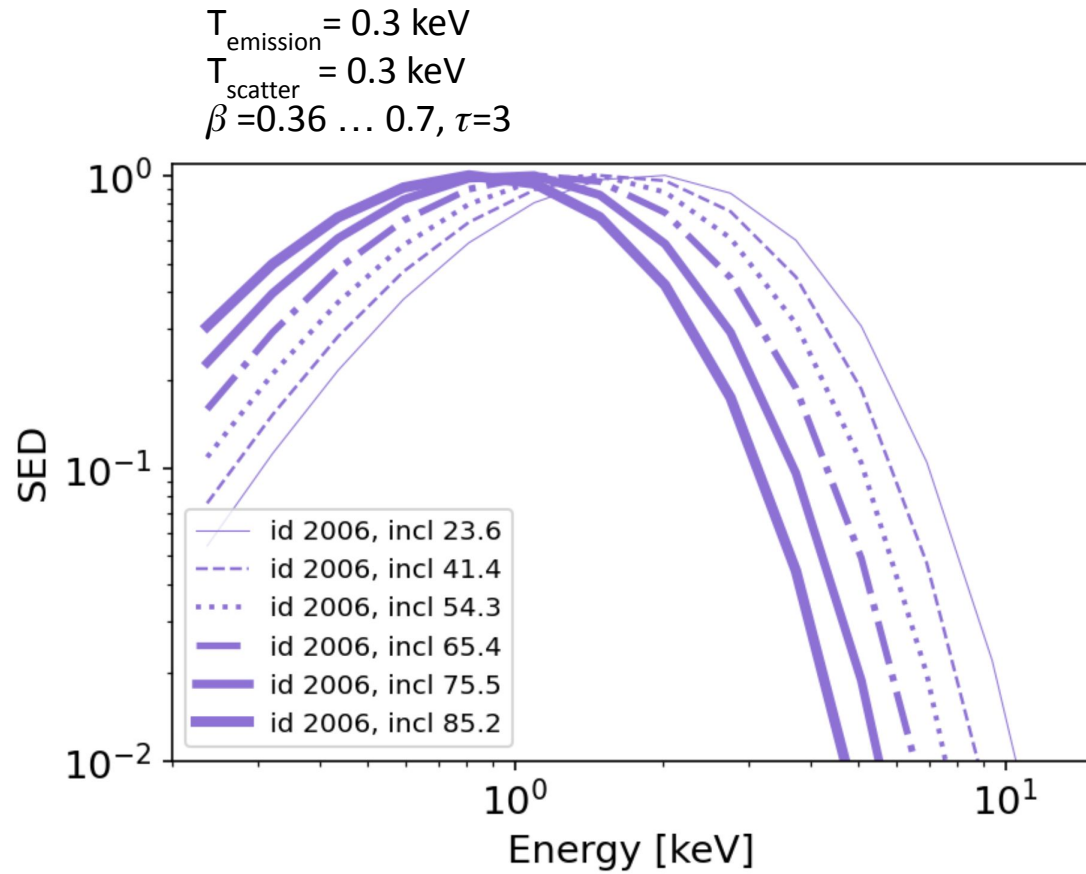


Passing X-rays through $\beta \sim 0.5$ pairs impacts PD and PA - but impact depends on μ .

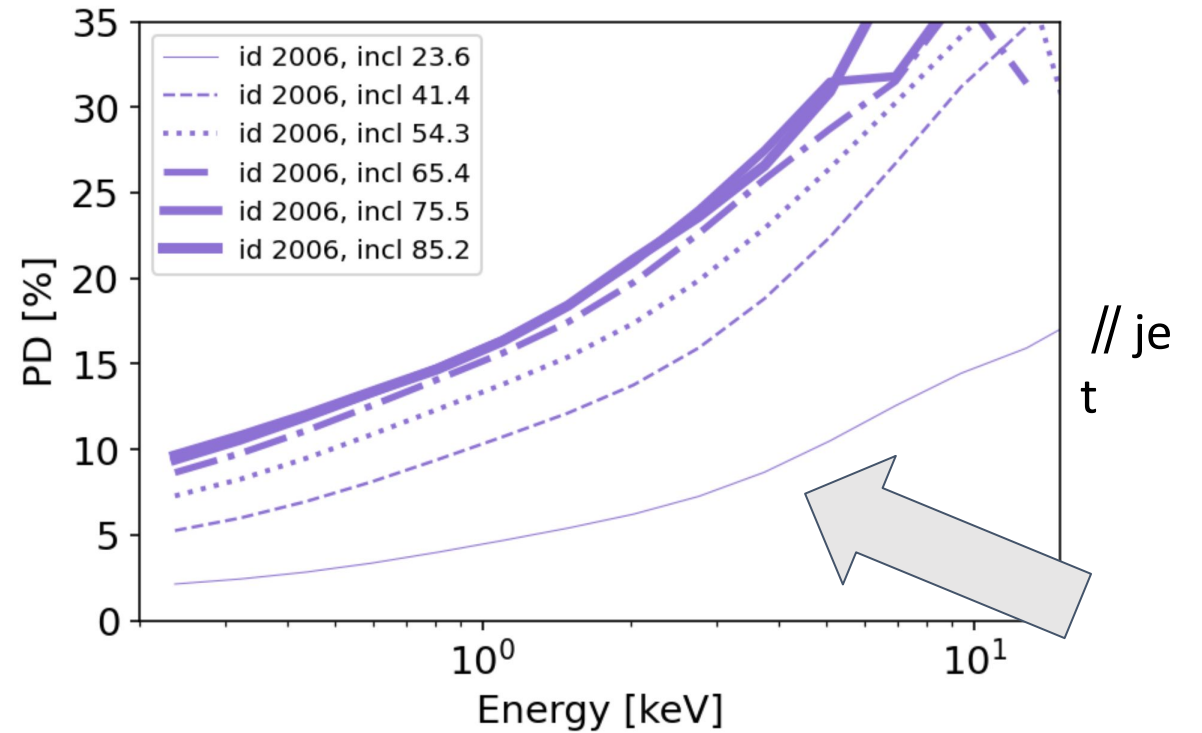


Passing X-rays through $\beta \sim 0.5$ pairs has major impact on PD and PA (impact depends on μ).

Soft State - Results from Plain-Parallel Atmosphere MC Rad. Transport



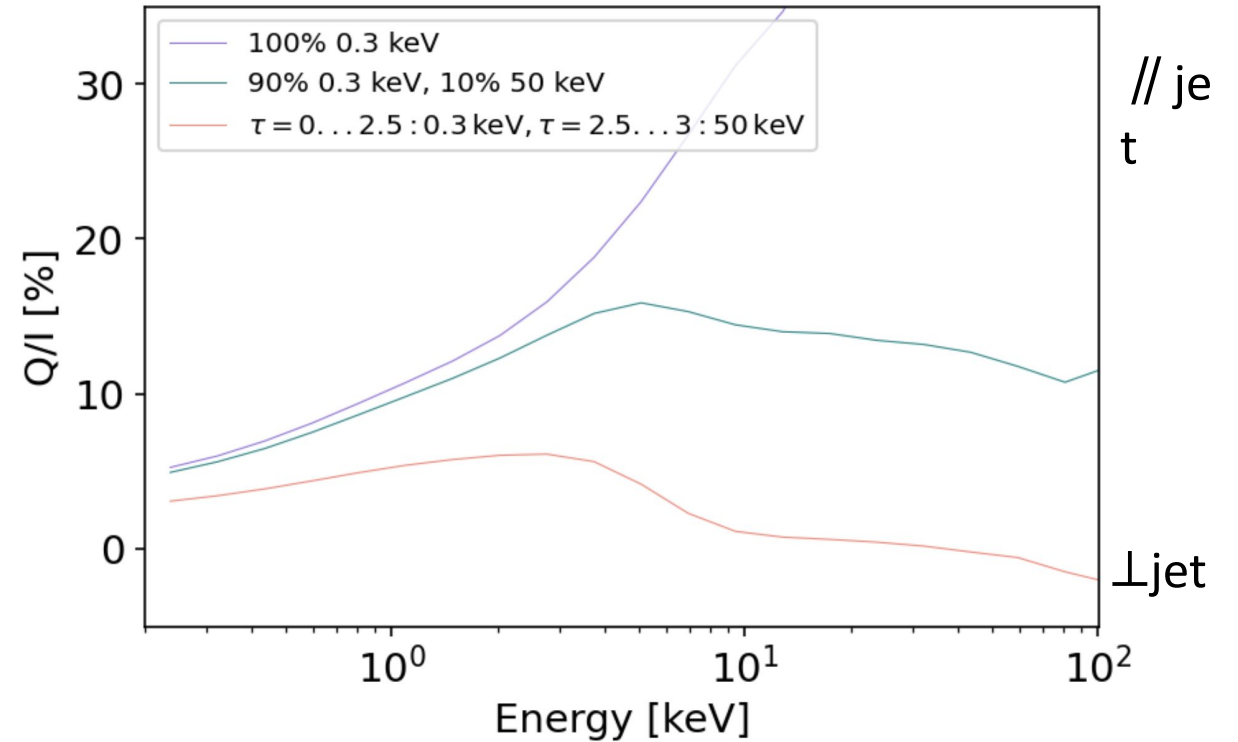
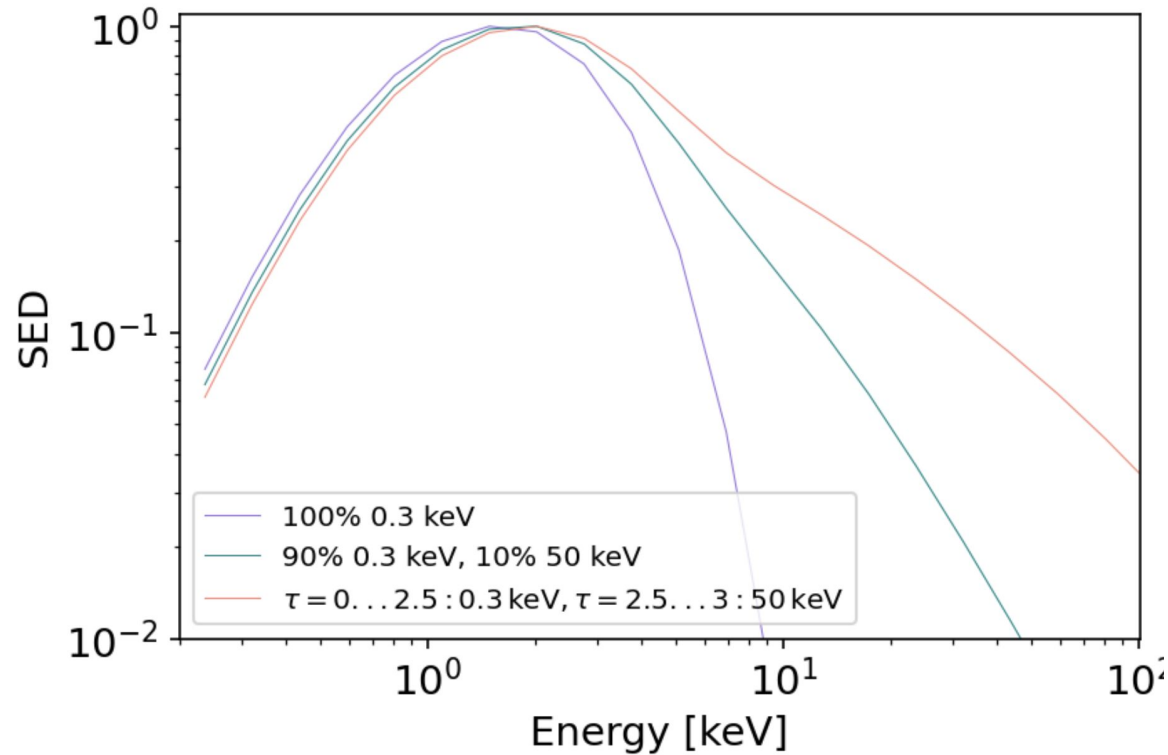
Passing X-rays through $\beta \sim 0.5$ pairs impacts PD and PA - but impact depends on μ .



Passing X-rays through $\beta \sim 0.5$ pairs has major impact on PD and PA (impact depends on μ).

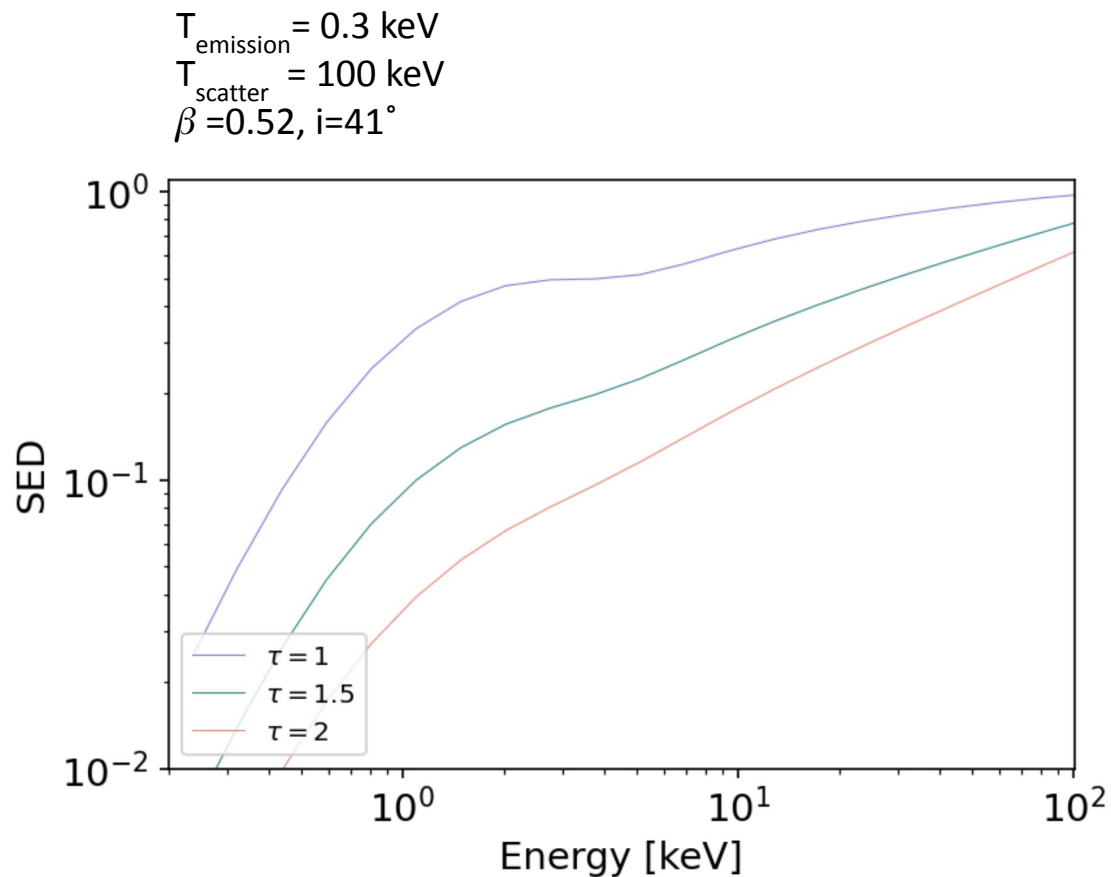
Intermediate State - Results from Plain-Parallel Atmosphere MC Rad. Transport

$T_{\text{emission}} = 0.3 \text{ keV}$
 $T_{\text{scatter}} = 0.3 \text{ keV and } 50 \text{ keV}$
 $\beta = 0.52 \text{ and } 0.36 \dots 0.7, \tau = 3 \text{ and } , i = 41^\circ$

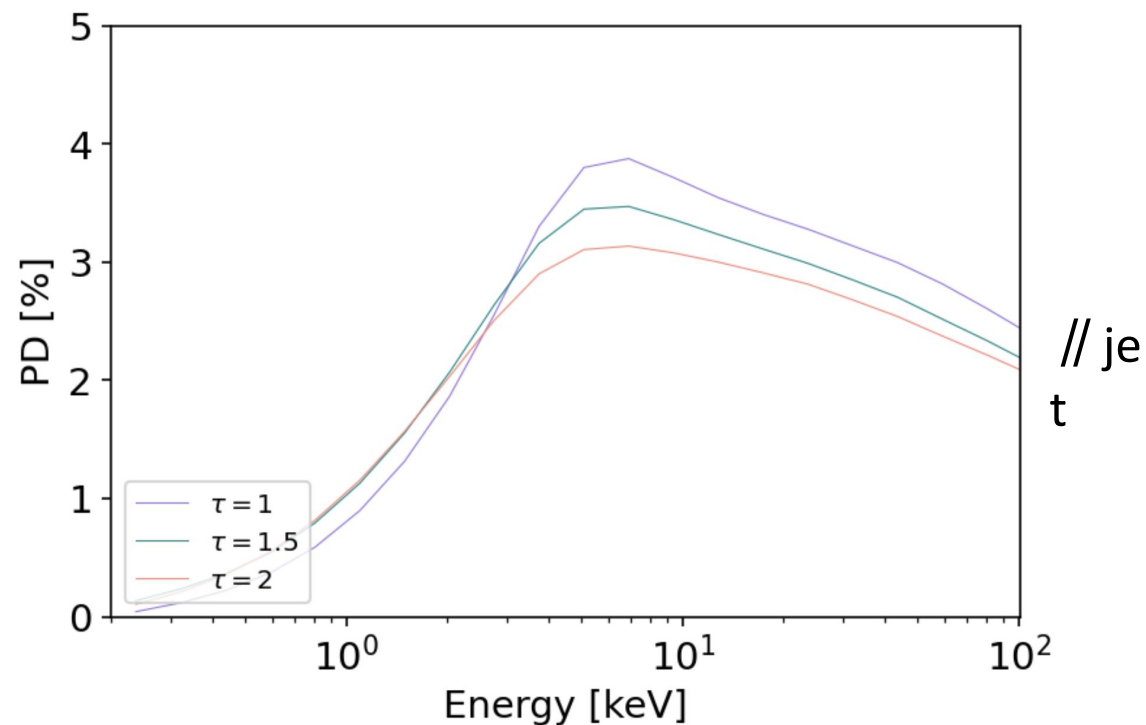


Two temperatures can produce high PDs at high energies.

Intermediate State - Results from Plain-Parallel Atmosphere MC Rad. Transport

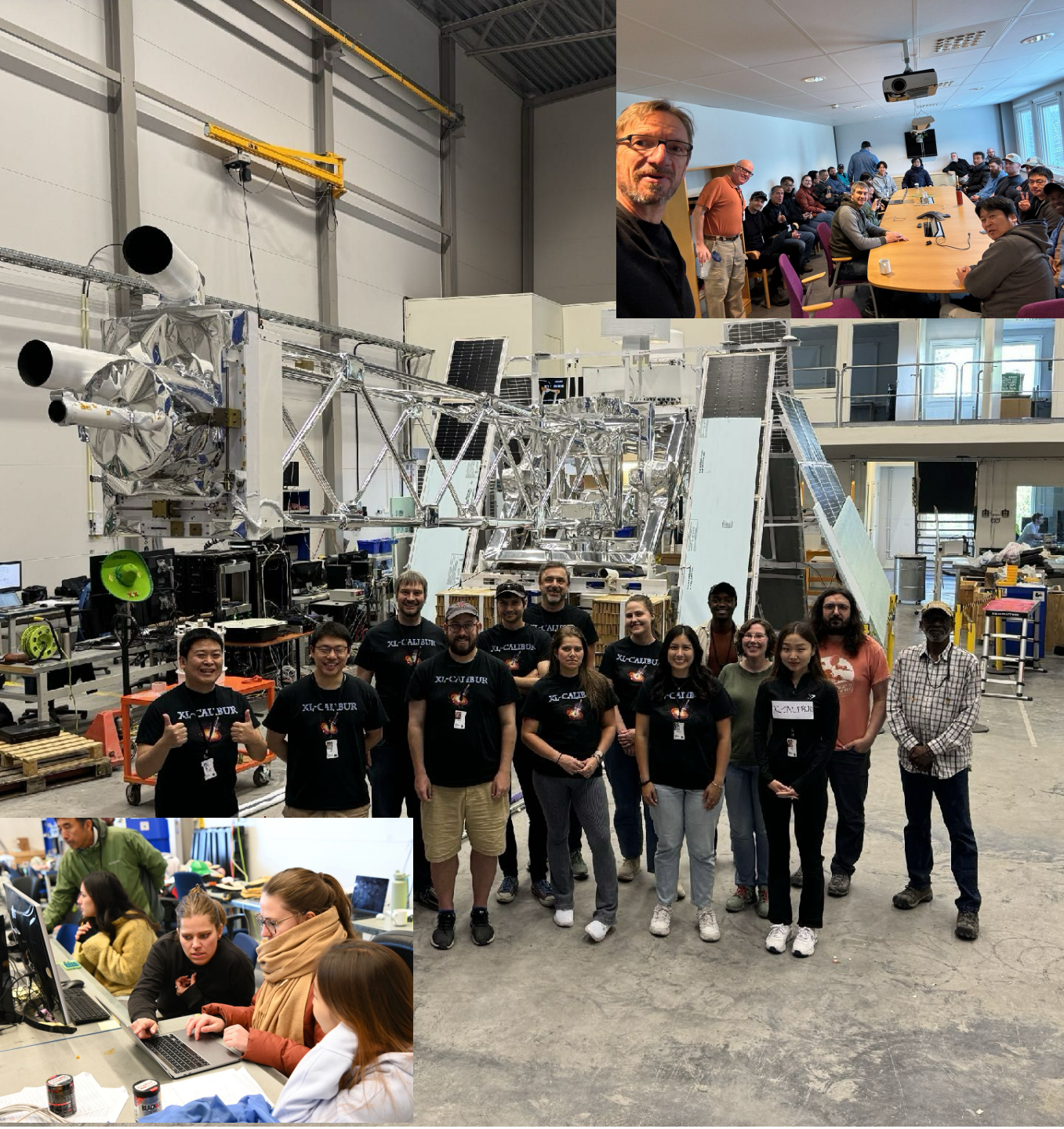


Explanation #2:
Scattering off anisotropic plasmons
from reconnection or turbulence.



Competition of disk and corona polarization
cancel at low energies.

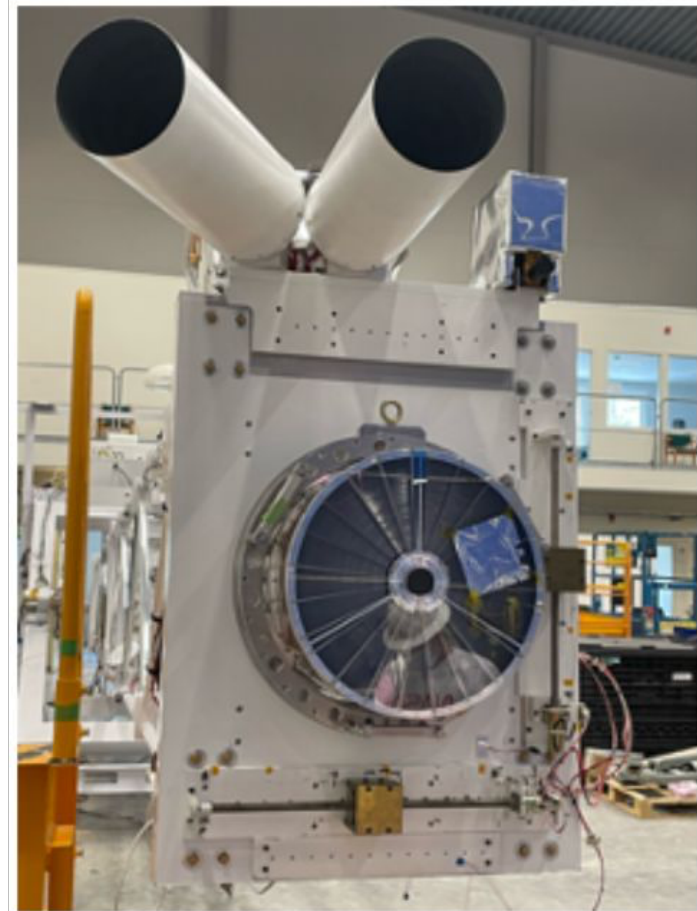
XL-Calibur



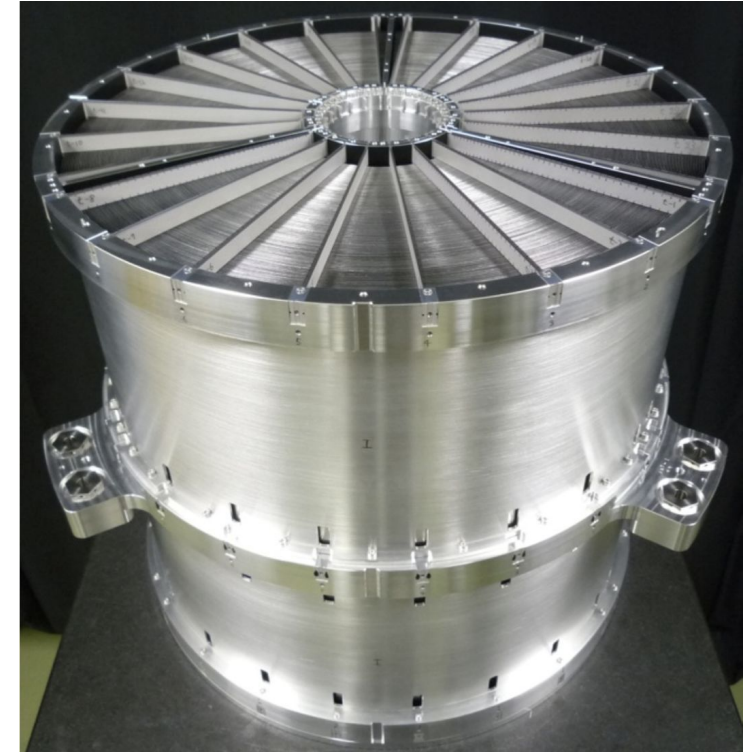
Filip	af Malmborg	Henric	Krawczynski
Mio	Aoyagi	Haruki	Kuramoto
Hisamitsu	Awaki	James	Lanzi
Richard	Bose	Lindsey	Lisalda
Dana	Braun	Yoshitomo	Maeda
Jacob	Casey	Hiroto	Matake
Sohee	Chun	Hironori	Matsumoto
Gianluigi	de Geronimo	Gakuto	Matsumoto
Teruaki	Enoto	Asuka	Miyamoto
Manel	Errando	Takuya	Miyazawa
Yasushi	Fukazawa	Tsunefumi	Mizuno
Akihiro	Furusawa	Takashi	Okajima
Thomas	Gadson	Mark	Pearce
Ephraim	Gau	Zachary	Peterson
Victor	Guarino	Mehrnoosh	Rahbardar Mojaver
Shuichi	Gunji	Brian	Rauch
Tomohiro	Hakamata	Nicole	Rodriguez Cavero
Scott	Heatwole	Felix	Ryde
Arman	Hossen	Yoshitaka	Saito
Kun	Hu	Natsuki	Sakamoto
Ryuta	Imamura	Kohei	Shima
Ryo	Imazawa	Kentaro	Shirahama
Kazunori	Ishibashi	Garry	Simburger
Manabu	Ishida	Sean	Spooner
Kota	Ishiwata	Theodor-Adrian	Stana
Nirmal Kumar	Iyer	David	Stuchlik
Keon	Harmon	Hiromitsu	Takahashi
Wataru	Kamogawa	Mai	Takeo
Fabian	Kislat	Toru	Tamagawa
Mózsi	Kiss	Hiroshi	Tsunemi
Takao	Kitaguchi	Nagomi	Uchida
Kassi	Klepper	Yuusuke	Uchida
Merlin	Kole	Andrew	West
		Wulf	Eric A.
		Marina	Yoshimoto

66 scientists,
21 institutions





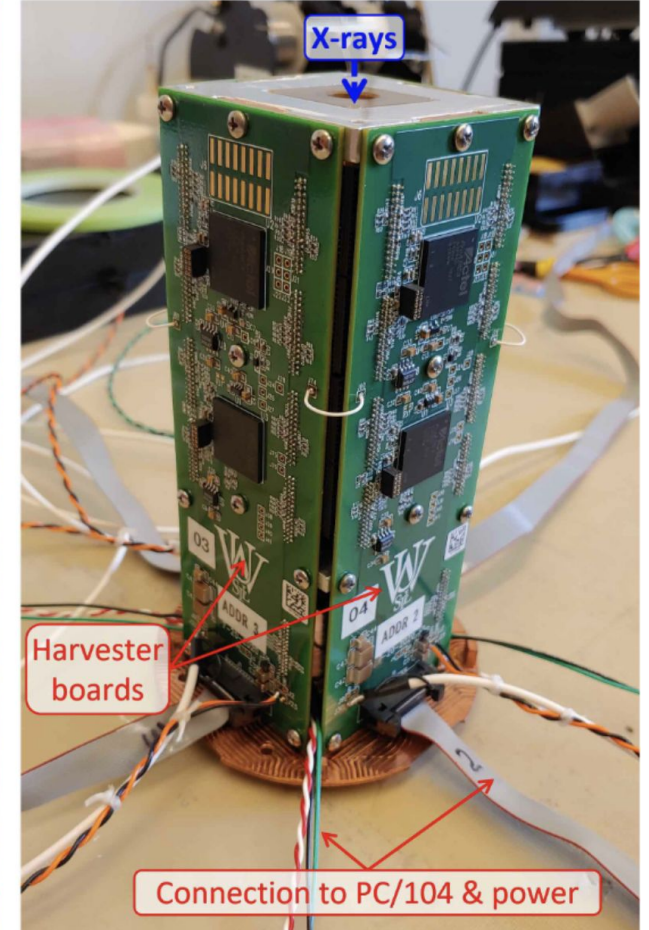
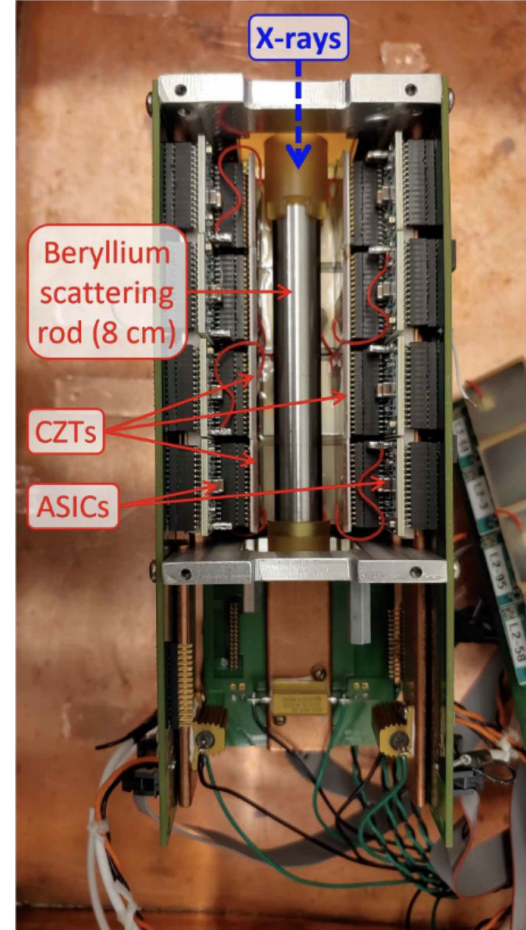
CARDS
(WASP/WFF)



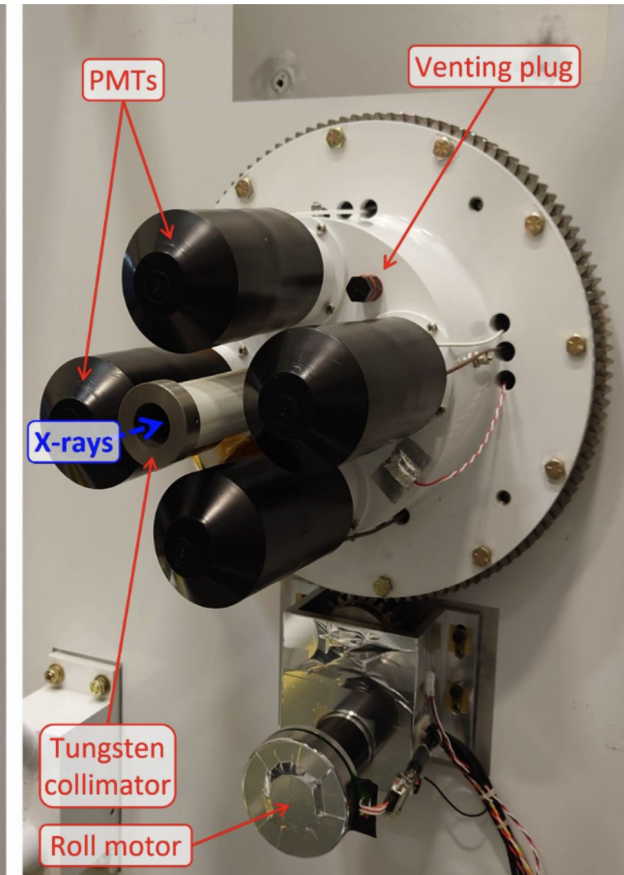
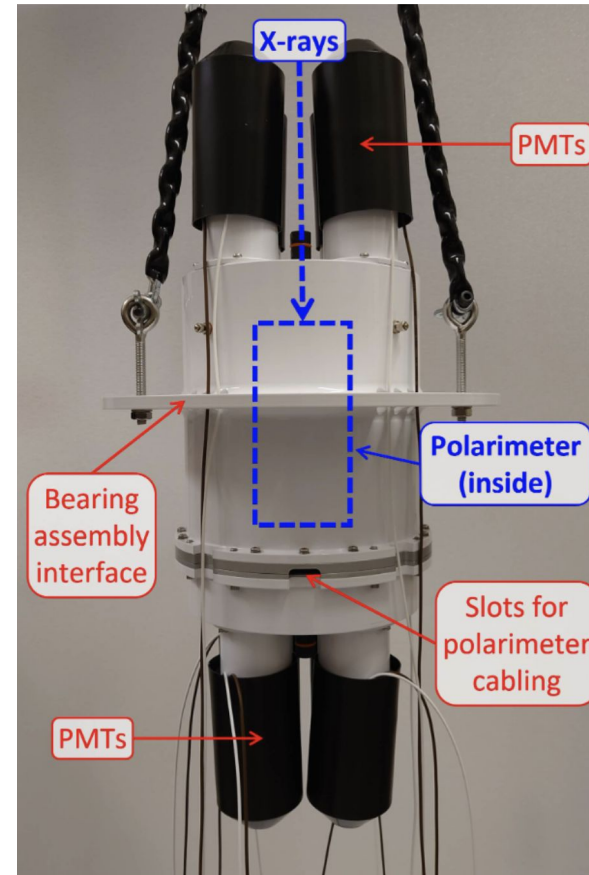
213 shells with Pt-C multilayers.
Hitomi (FFAST) Spare Mirror, Awaki
et al. 2014, Awaki et al. 2016, Maeda
et al. 2017, Tamura et al. 2018, Mori
et al. 2018.

X-ray Mirror

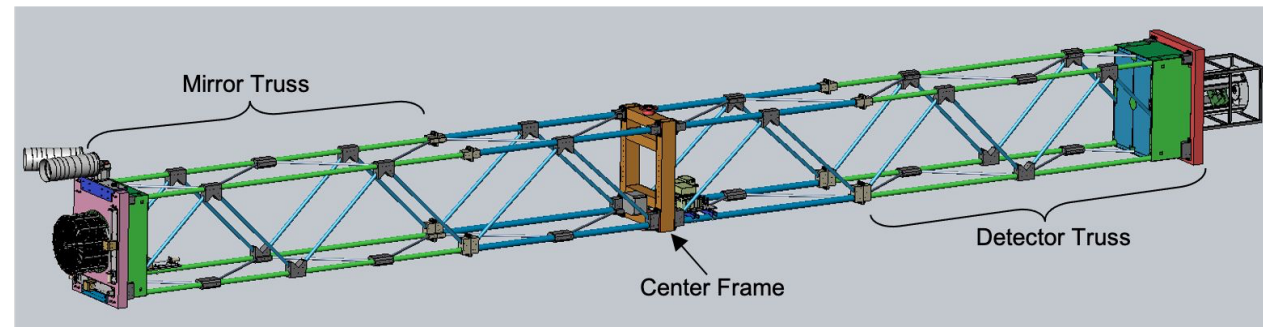
(Osaka Univ., ISAS/JAXA)



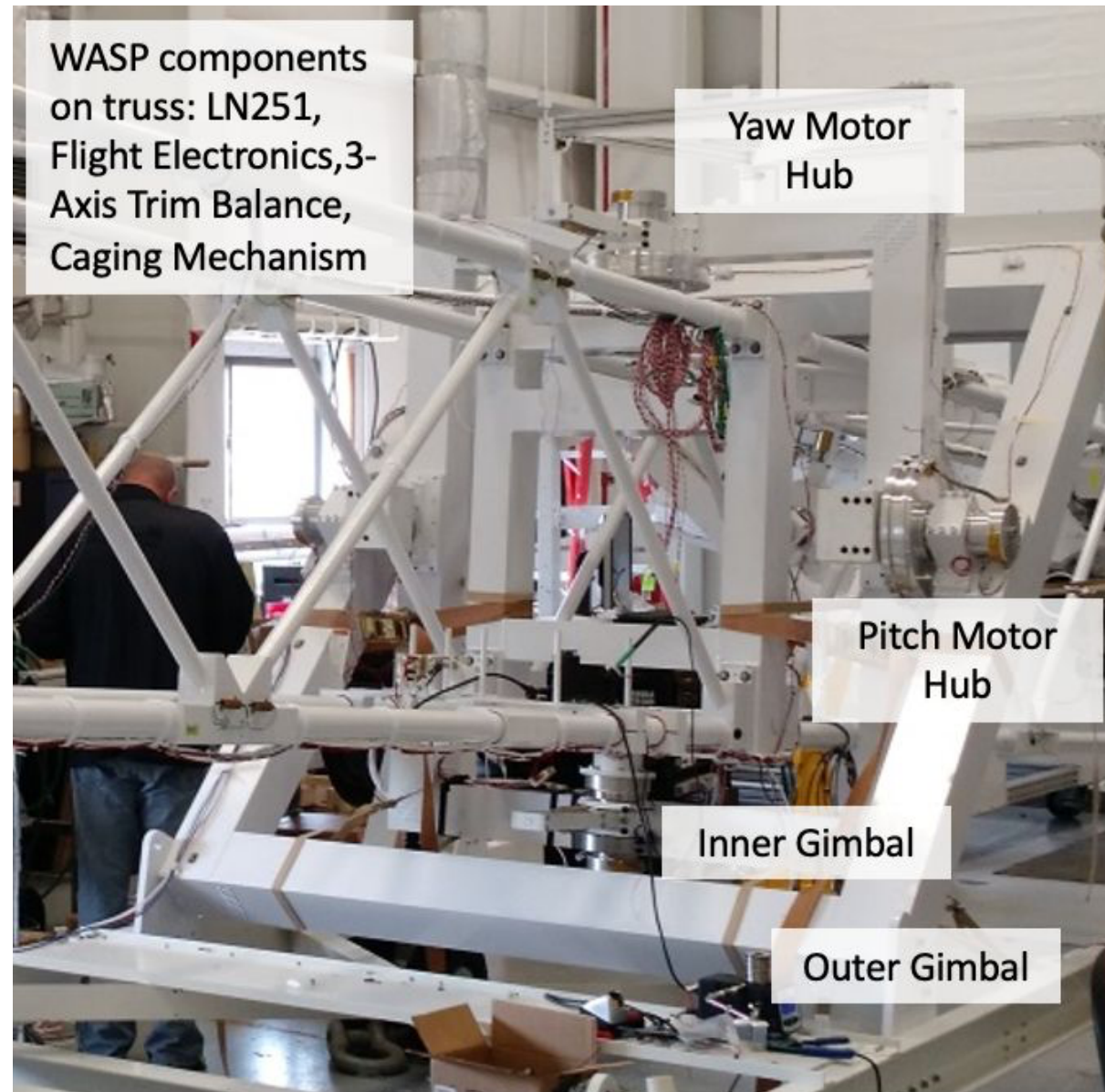
Scattering Polarimeter (WashU, NRL),
0.8 mm thick $2 \times 2 \text{ cm}^2$ CZT detectors
(~100% QE $\leq 50 \text{ keV}$, 95% QE @60 keV).



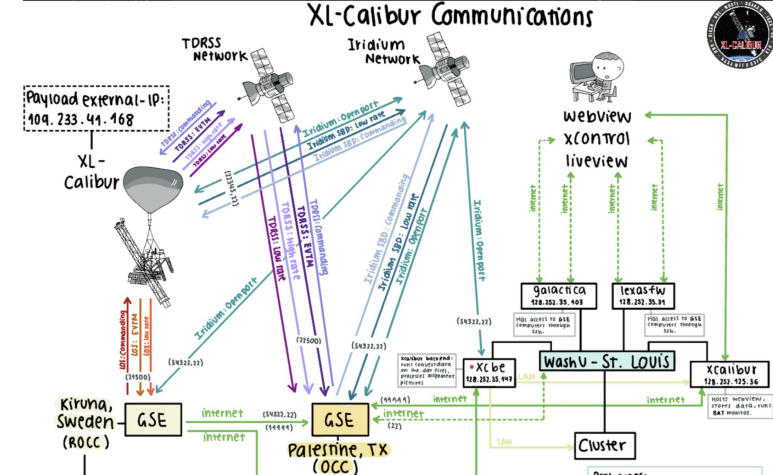
Active BGO shield (KTH)
BGO wall thickness: 3cm.



12m Carbon Fiber tube +
Al joint truss (WashU), 322 kg



WASP Pointing System (WFF)



X-Calibur WebView

Home Data runs Sources Live data » Detector ASICs Housekeeping

Home

View all data runs.

Active Sources

Source	Rate(mC)	Time(UTC)
Cen A	183	2018-12-25 11:44:56
AX J1631.9-4752	213	2018-12-25 11:44:56
Vela X-1	177	2018-12-25 11:44:56
4U 1700-377	0	2018-12-25 11:44:56
GX 301-2	326	2018-12-25 11:44:56

Current pointing

Right ascension: 0h 00' 03.5"
 Declination: 1° 35' 14.2"
 Bank: -0.0°
 Elevation: 0.5°
 Target: —

Current position

Latitude: 77° 51' 16.8" S
 Longitude: 167° 10' 59.1" E

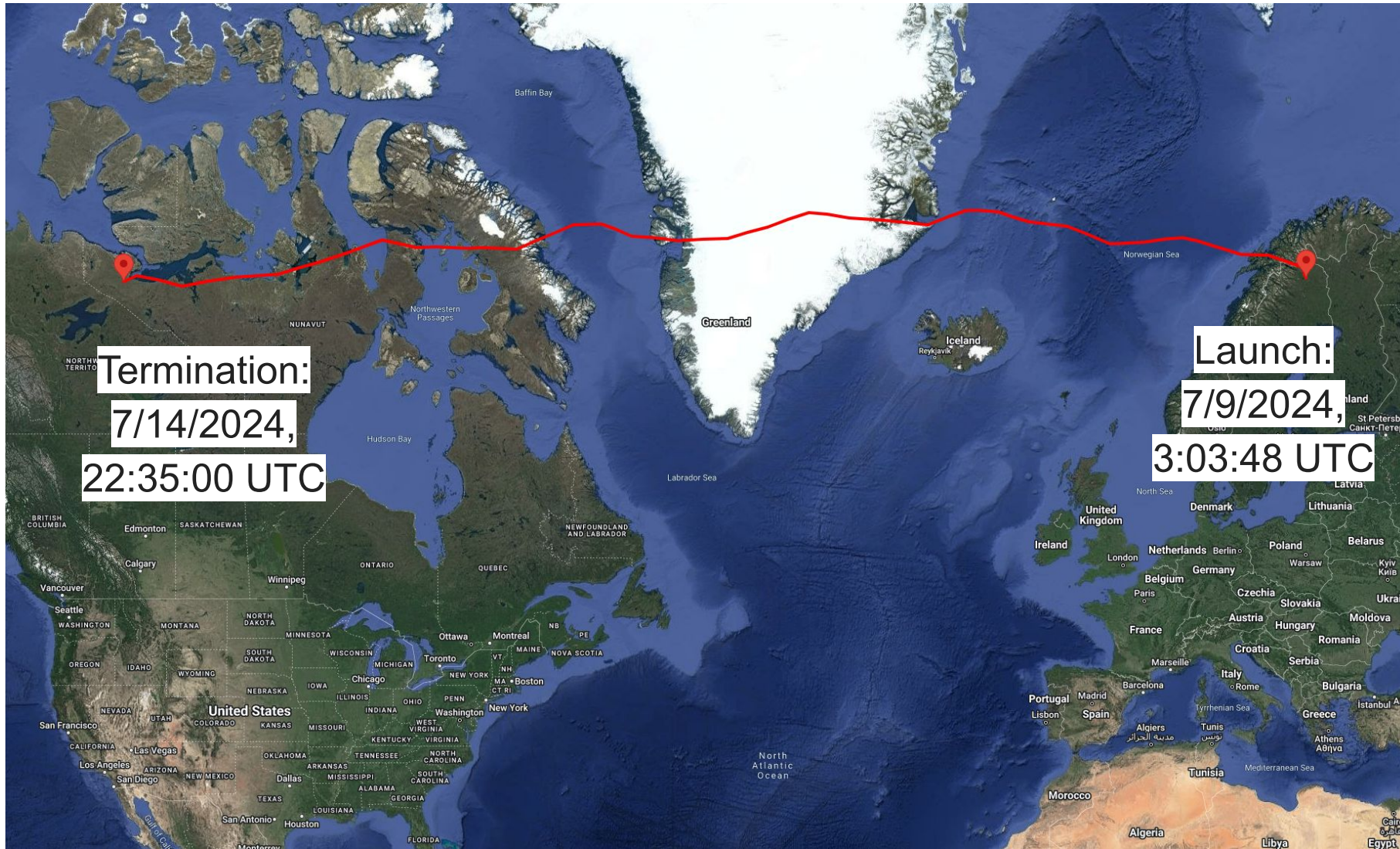
Recent messages

[12/25/2018 at 11:59AM] GSE WARNING: (11:59:52) No ping from Gondola CPU since 60 seconds.
 [12/25/2018 at 11:59AM] GSE WARNING: (11:59:51) No ping from Polarimeter CPU since 60 seconds.
 [12/25/2018 at 11:59AM] GSE WARNING: (11:59:50) No ping from Truss CPU since 60 seconds.
 [12/25/2018 at 11:59AM] GSE WARNING: (11:59:50) Truss CPU is busy.

Last data received

Component	Time
Gondola CPU	2018-Dec-25 11:58:39 UTC
Truss CPU	2018-Dec-25 11:58:42 UTC
Polarimeter CPU	2018-Dec-25 11:58:51 UTC
WASP	2018-Dec-25 11:58:57 UTC

Commanding, Telemetry, and Monitoring software (UNH)



Time at float:
5 days, 15 hours,
49 minutes.

Float time spent
with WASP pointing:
4 days, 16 hours,
51 minutes.

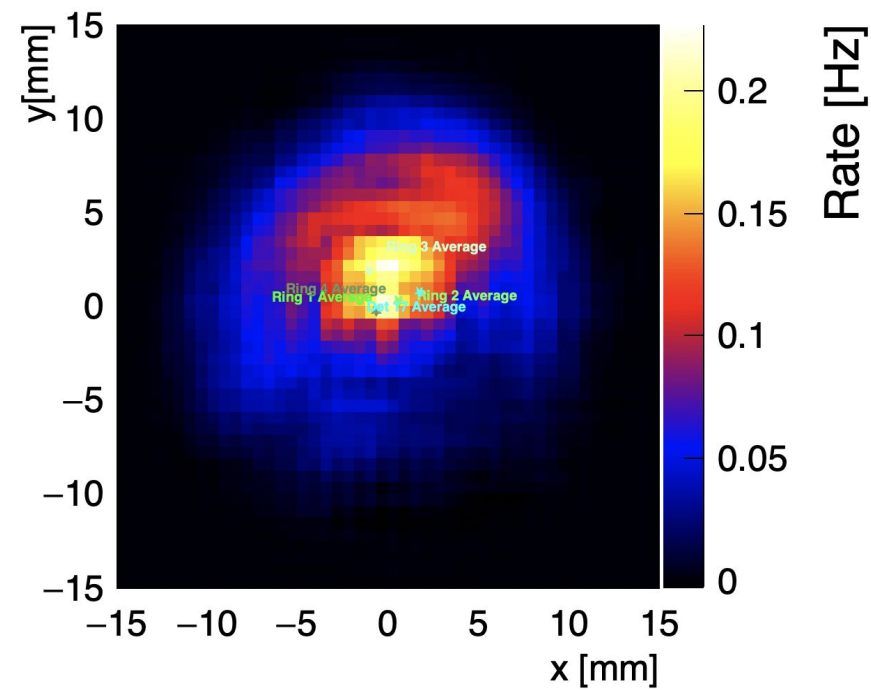
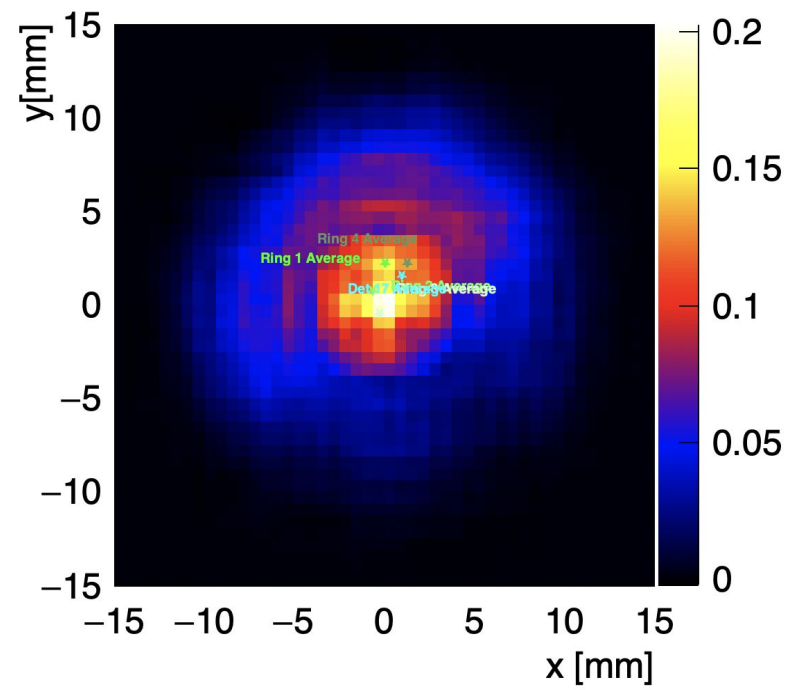
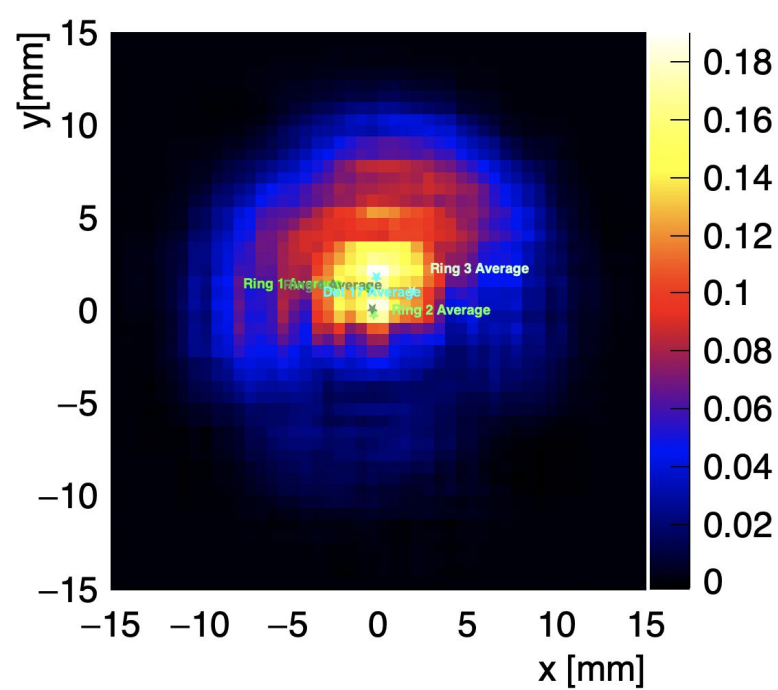
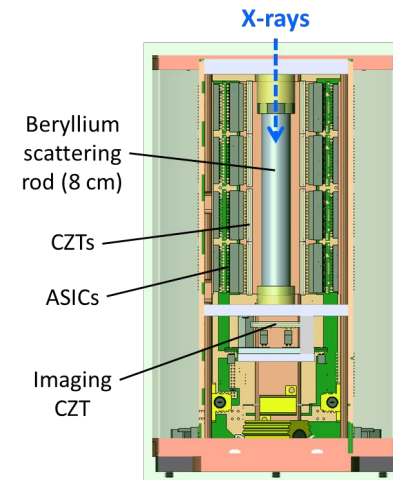


Truss, mirror,
BGO shield,
polarimeter
successfully
recovered.

Results - Crab Nebula and Pulsar

(Mozsi Kiss, Ephraim Gau, Kun Hu, Sean Spooner, Jacob Casey,
Shravan Vengalil Menon et al.)

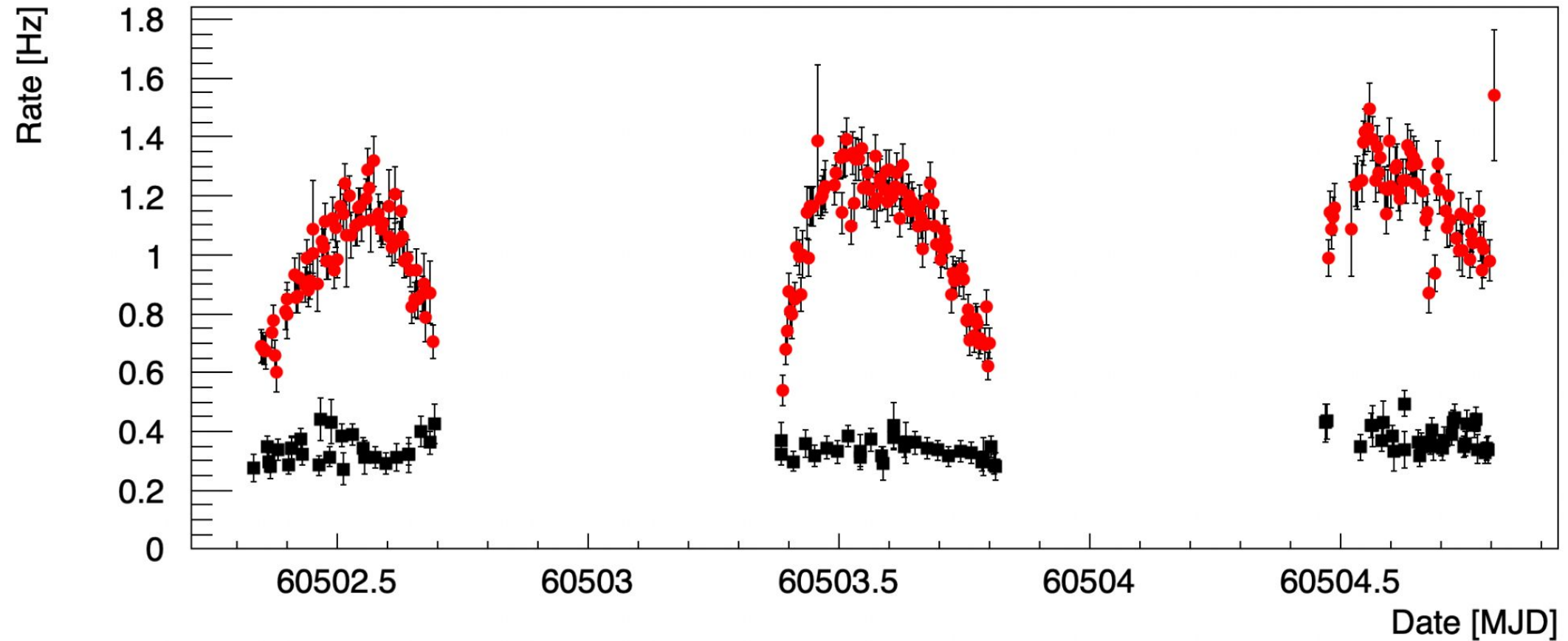
Day-by-day D17 for Crab



Ephraim Gau

Crab Lightcurve (15-60 keV)

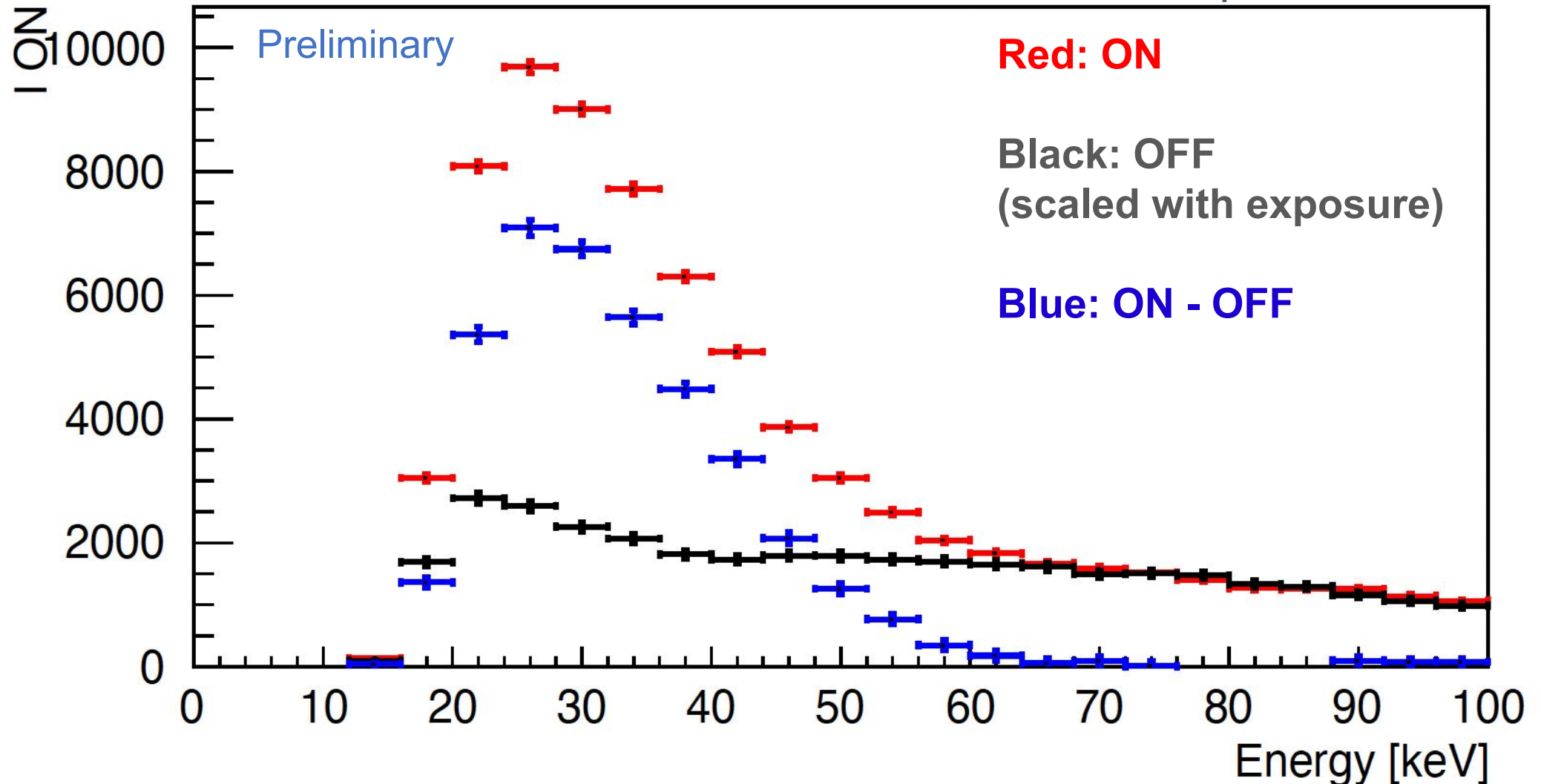
Ephraim Gau



Overall: Polarimeter detected ~60,000 15-60 keV X-rays.

Crab Energy Spectrum

Ephraim Gau

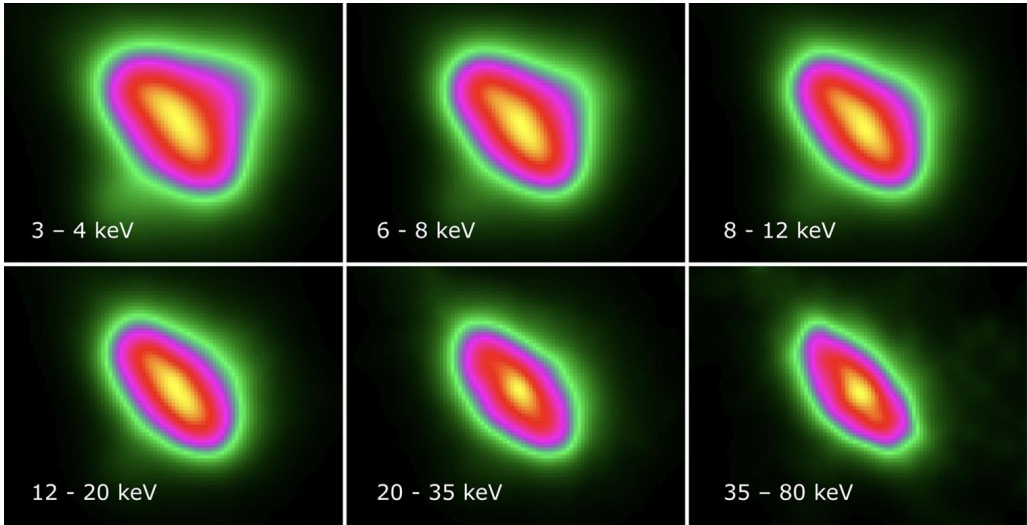
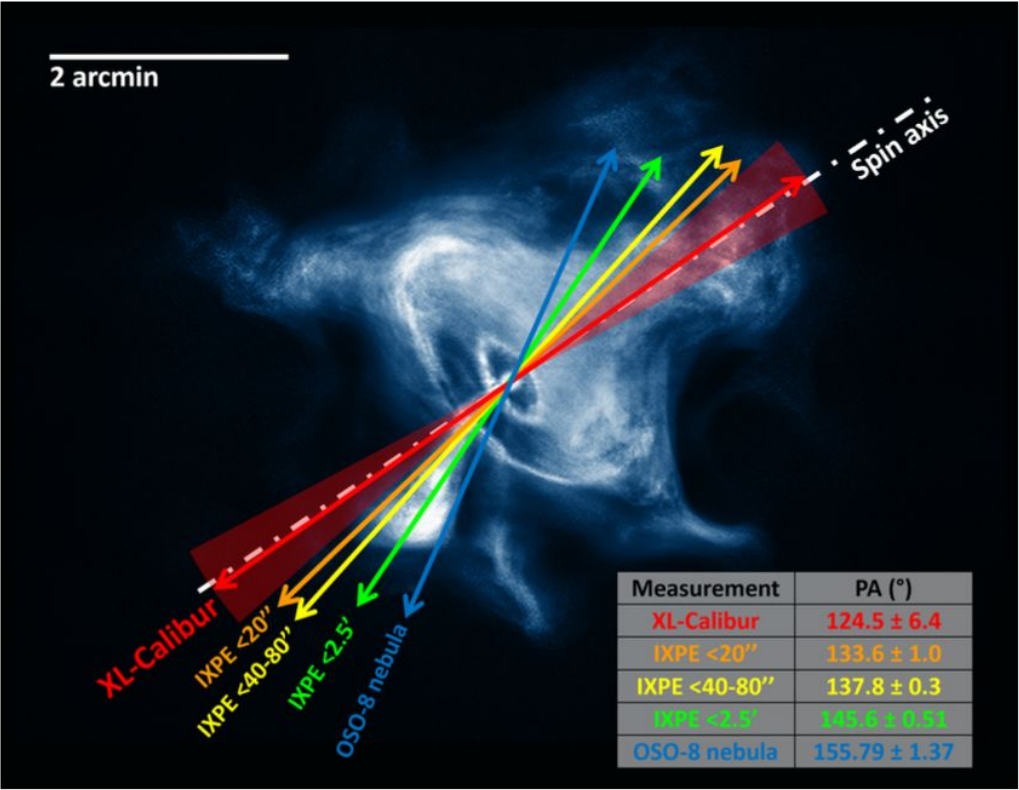
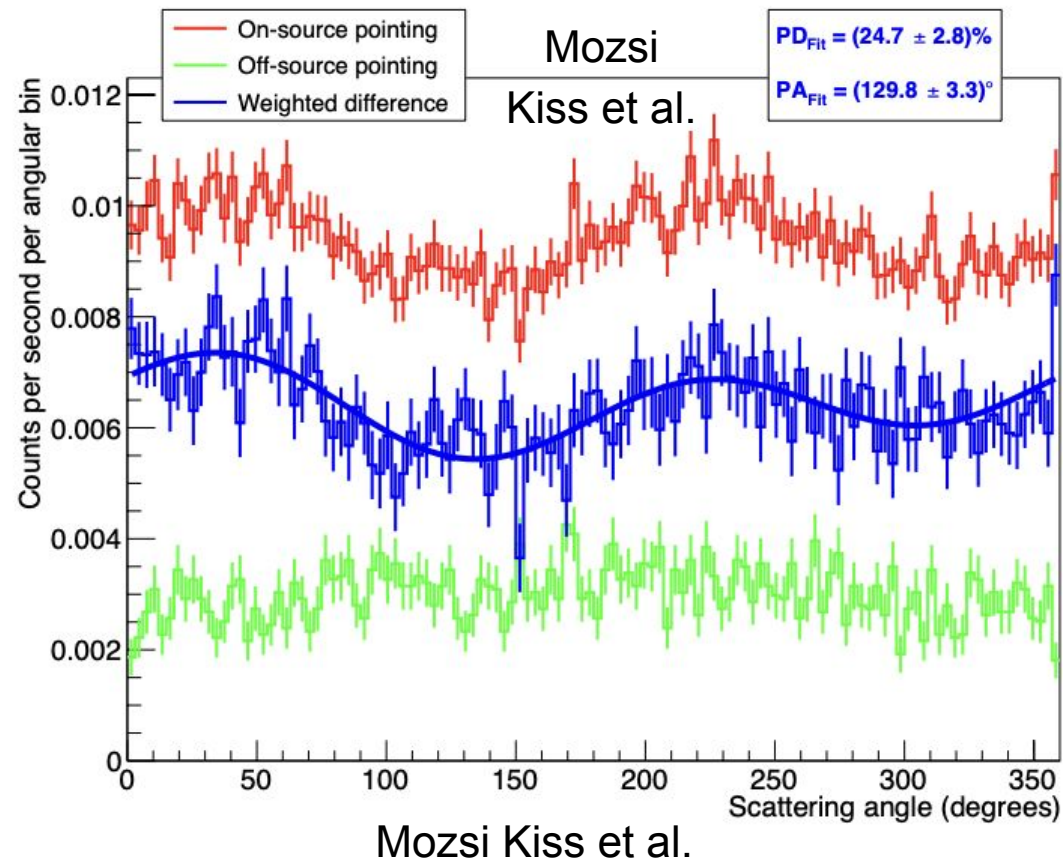


⇒ Strongly detected from 15-60 keV.

XL-Calibur measurements of polarized hard X-ray emission from the Crab

Hisamitsu Awaki , Matthew G Baring , Richard Bose , Dana Braun , Jacob Casey , Sohee Chun , Pavel Galchenko , Ephraim Gau  , Kazuho Goya , Tomohiro Hakamata ...
[Show more](#)

Monthly Notices of the Royal Astronomical Society: Letters, Volume 540, Issue 1, June 2025, Pages L34–L40, <https://doi.org/10.1093/mnrasl/slaf026>

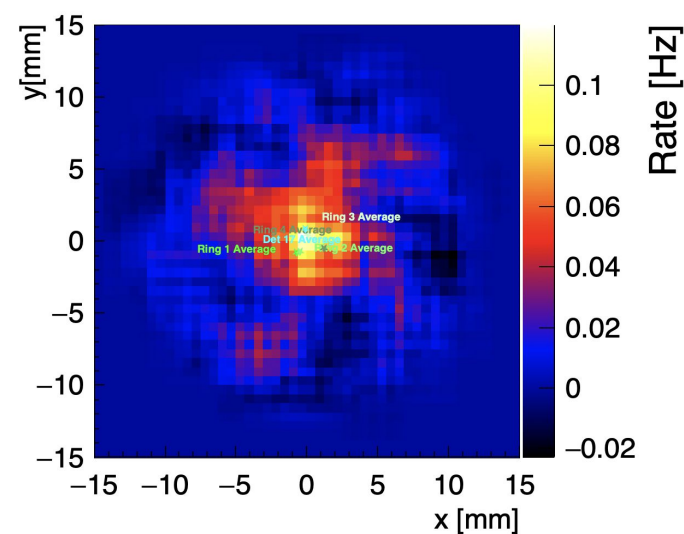
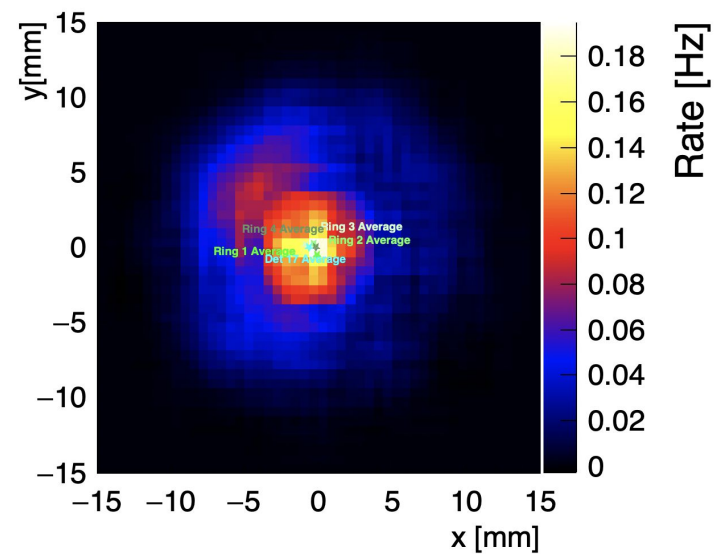
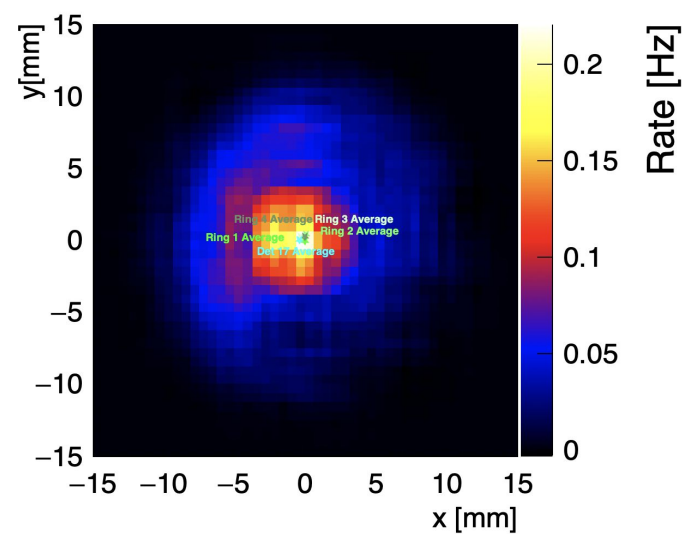
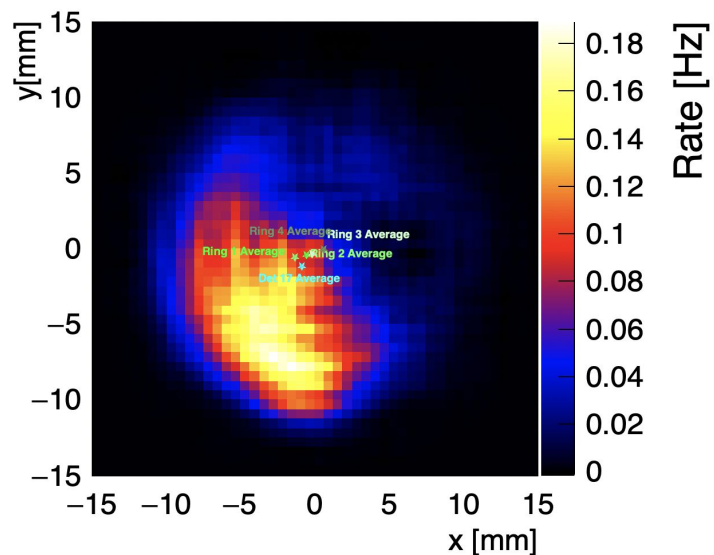


Madsen+
2015
(NuSTAR)

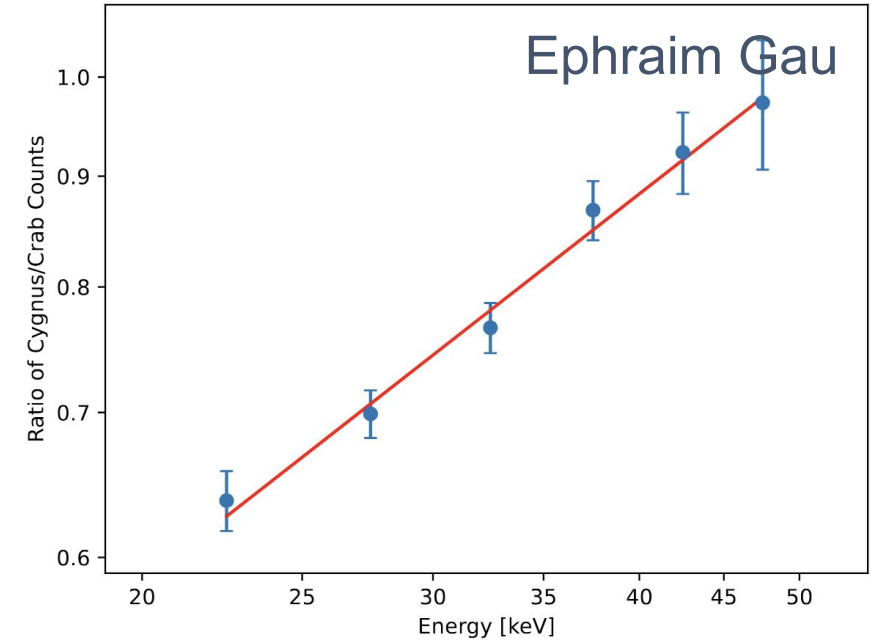
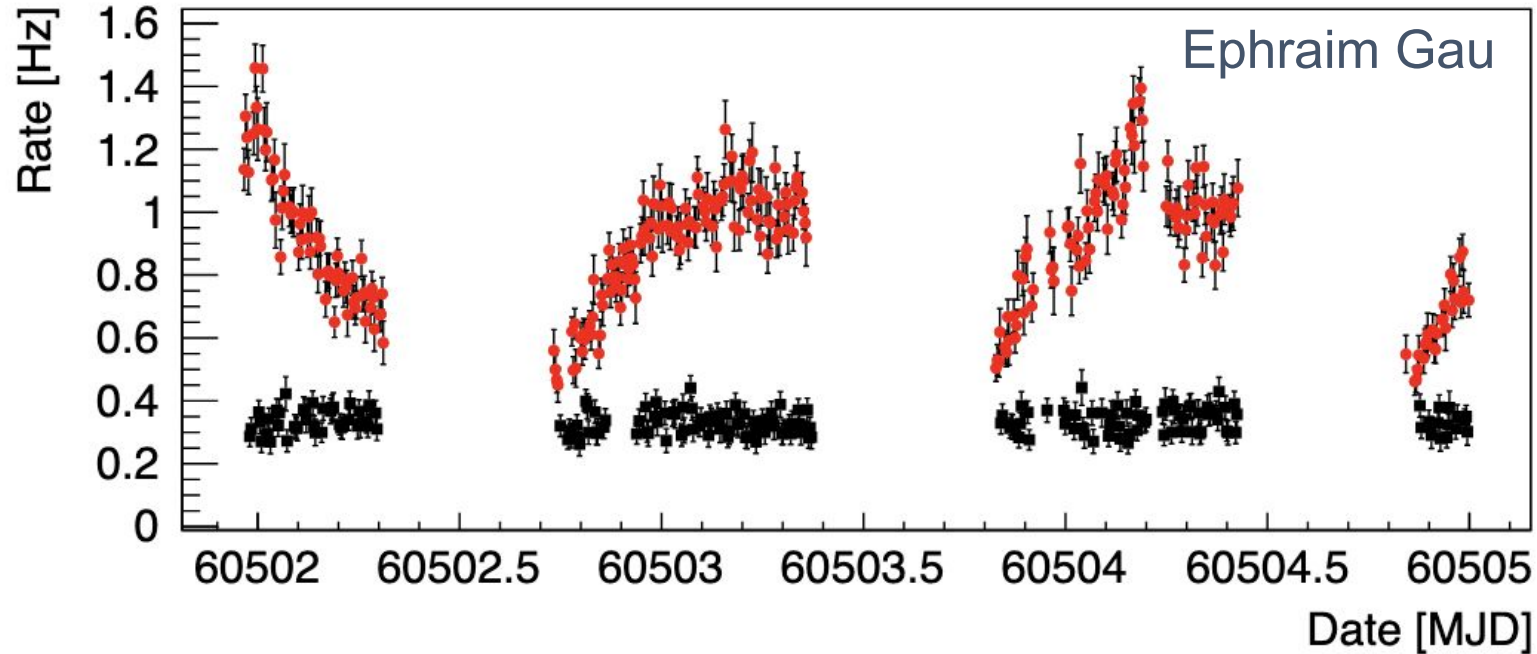
Results - Cyg X-1

(Mozsi Kiss, Ephraim Gau, Kun Hu, Sean Spooner, Jacob Casey,
Shravan Vengalil Menon et al.)

Day-by-day D17



Cygnus X-1 Results (15-60 keV)

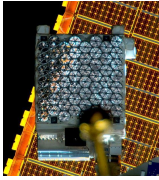


Overall: Polarimeter detected $\sim 60,000$ 15-60 keV X-rays.
Photon index from *XL-Calibur* data: 1.6.

Summary I

- *IXPE, XL-Calibur, NICER, NuSTAR*: are performing tests of inner accretion flow models $\Rightarrow$ energy flows and plasma physics.
- Surprising results: rather high PDs and constant PAs in *soft state* **and** *hard state*:
 - compact emission region preferred: higher σ , rel. broad. Fe K- α line emission;
 - emission may be dominated by fast ($\sim \frac{1}{2} c$) pairs which strongly affect PA & PD.
 - Expect more progress from additional observations and theory.
- *IXPE & XL-Calibur*: similar PDs and PAs.
- *Upcoming: IXPE, Redsox, XL-Calibur, COSI*.

Summary II



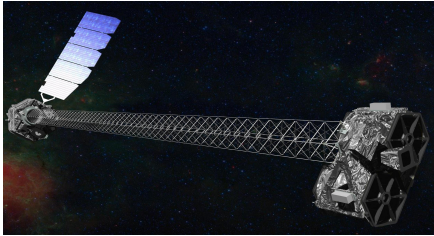
NICER



IXPE



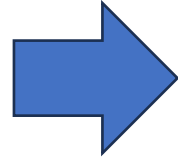
XL-Calibur



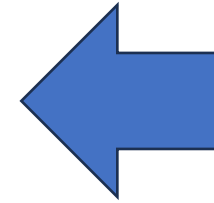
NuSTAR



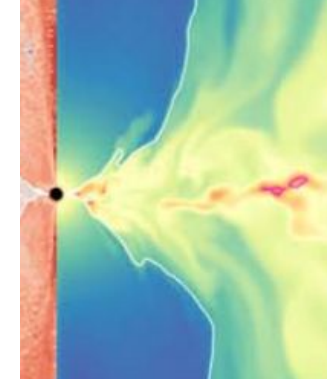
COSI



New opportunities to study effects of extremely curved spacetime and reveal physics of BH accretion (incl. Plasma Physics).

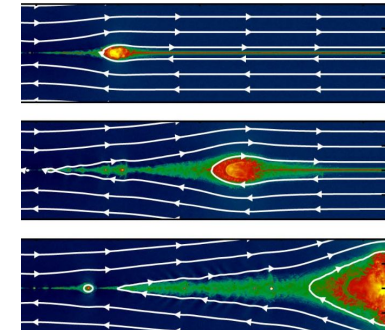


Numerical Simulations



2tGRRMHD

Liska, Dexter, ...



PIC,
GRPIC

*Sironi+, Werner+,
Grošelj+,
Chen+, Yuan+*