

# 极光计划及科学结果

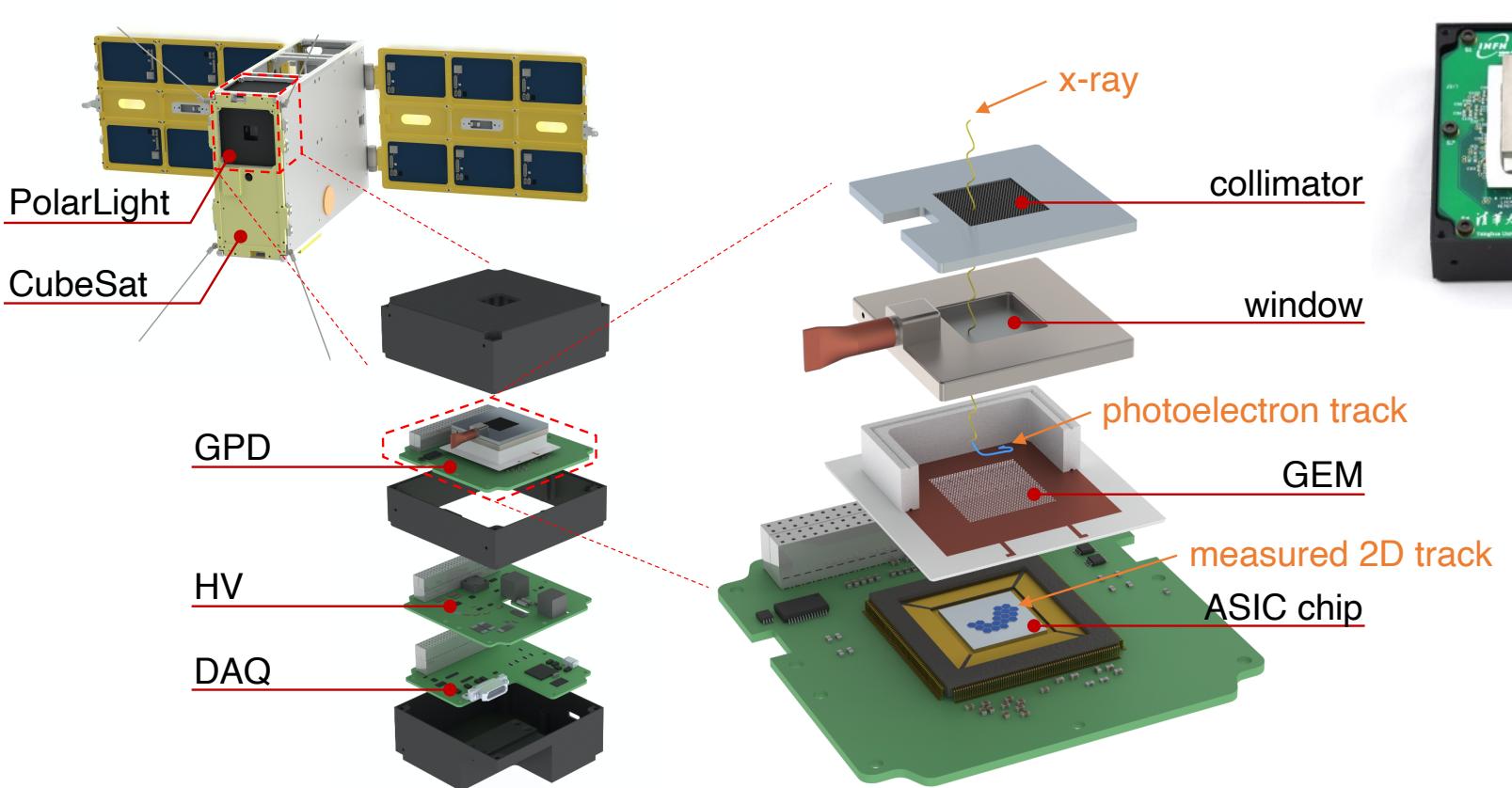
## PolarLight and Science results

Hua Feng 冯骅 (清华大学)  
on behalf of the PolarLight collaboration

Tsinghua Univ., IHEP,  
INFN-Pisa, IAPS/INAF-Rome,  
Ningbo Univ. of Tech., North Night Vision Tech., Spacety



# 极光计划 (PolarLight)

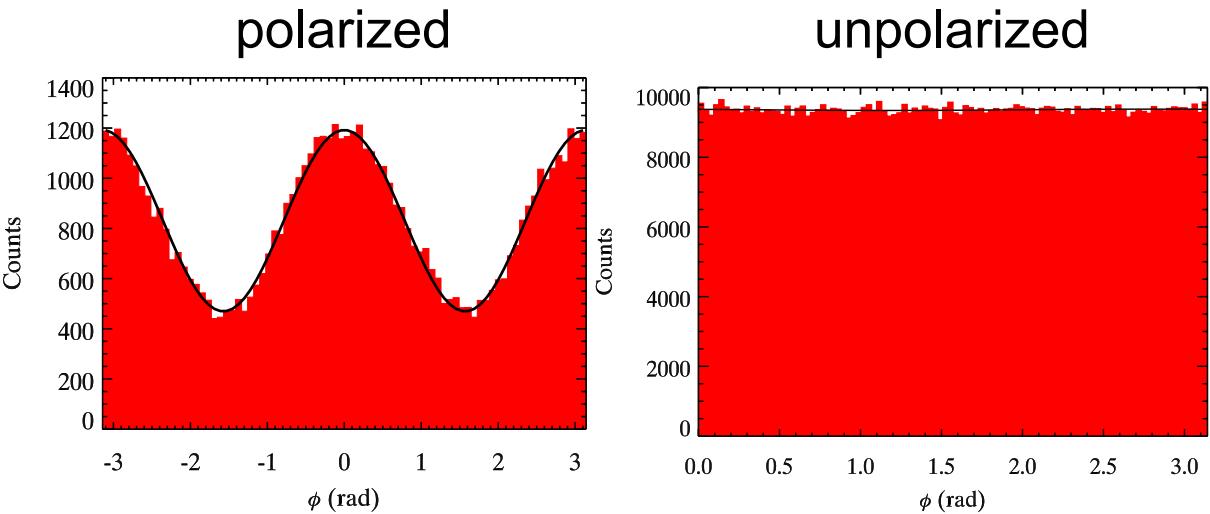
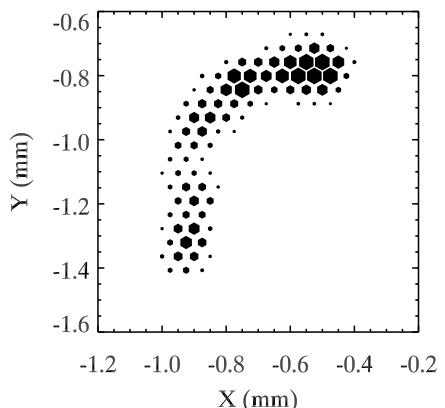
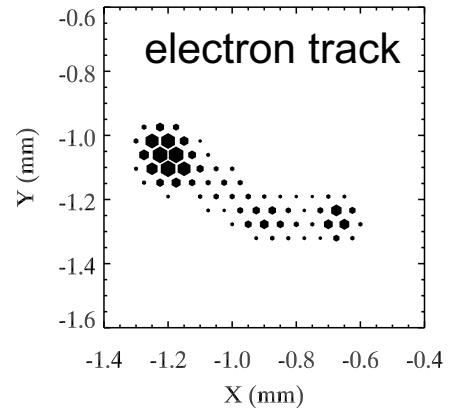




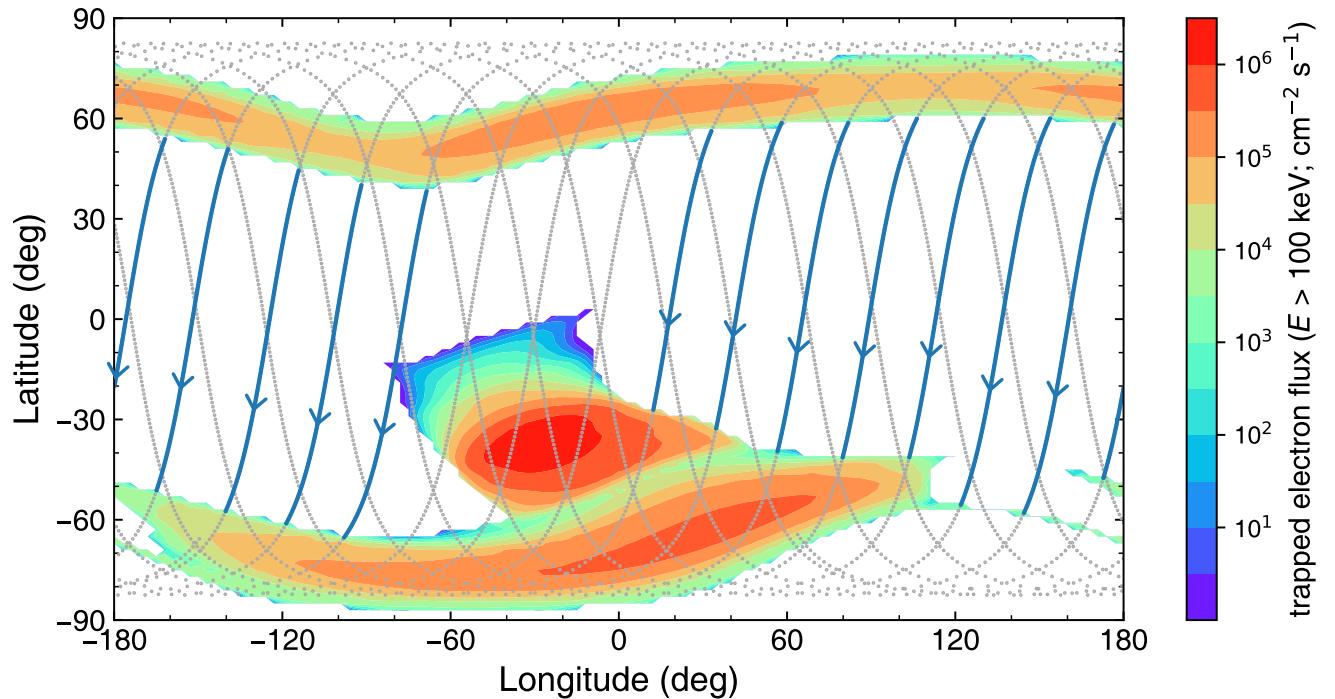
# X-ray polarimetry

## Photoelectric cross-section

$$\frac{\partial\sigma}{\partial\Omega} = r_0^2 \frac{Z^5}{137^4} \left(\frac{mc^2}{h\nu}\right)^{7/2} \frac{4\sqrt{2}\sin^2(\theta)\cos^2(\varphi)}{(1-\beta\cos(\theta))^4}$$



# Launched on Oct 29, 2018



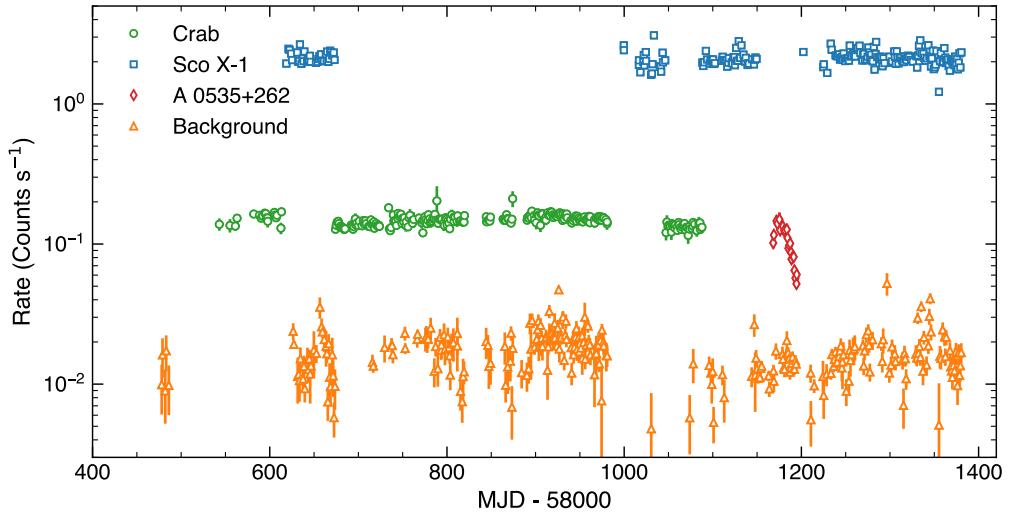
Altitude: 520 km

Inclination: 97.5°

Period: 95 minutes



# Targets

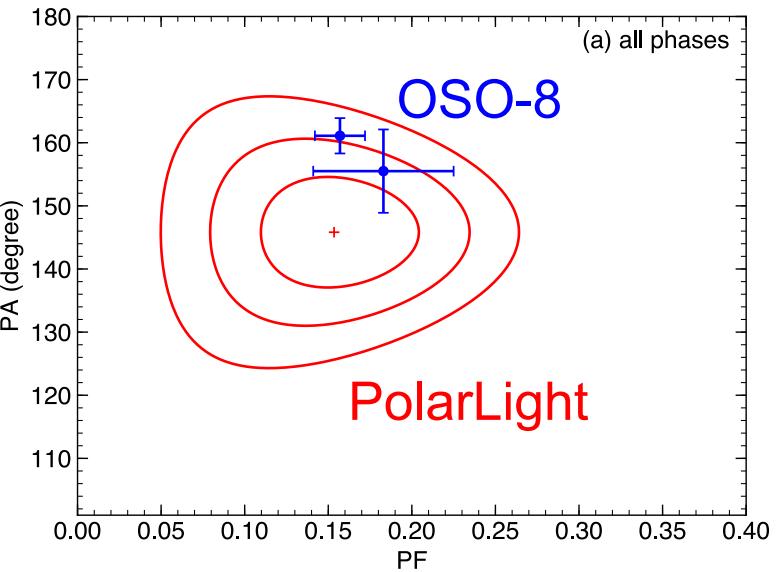
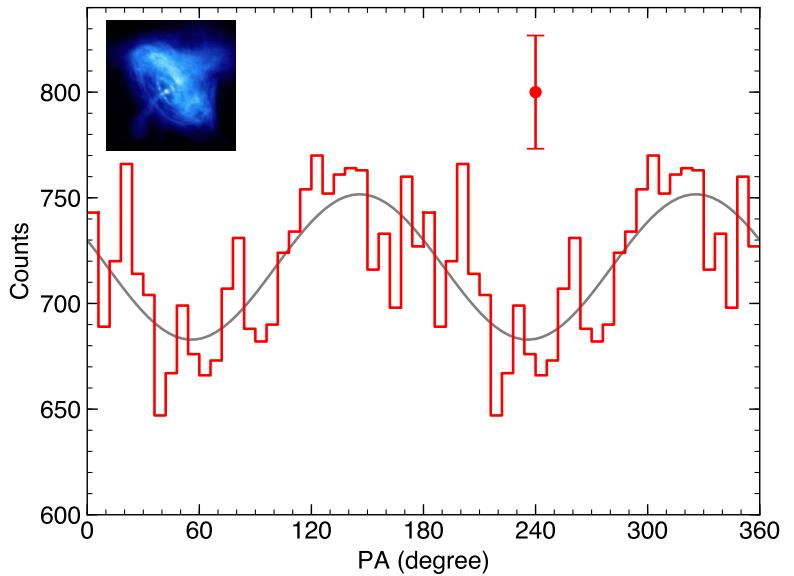


The background is not dominant when observing Crab or Sco X-1

Target	Exposure (ks)	2-8 keV Flux (Crab)
Crab	1403	1
Sco X-1	884	~10
1A 0535 + 262	70	~3 (peak)
Background	393	0.1



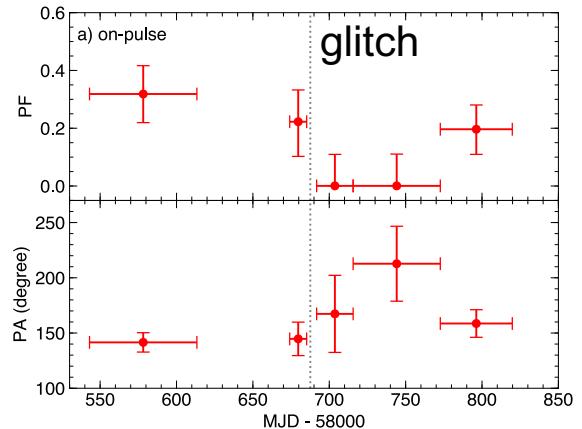
# Re-detection of X-ray polarization from the Crab nebula



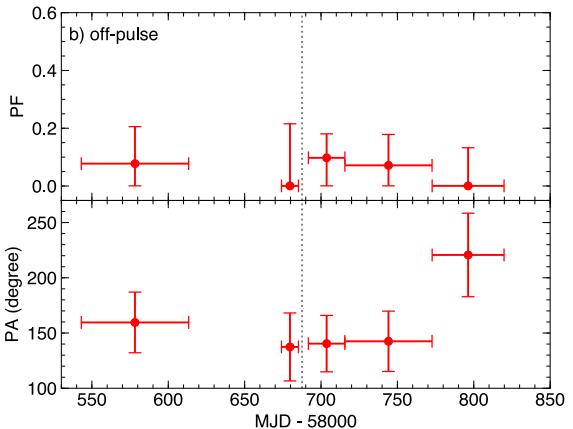


# Time variation of polarization

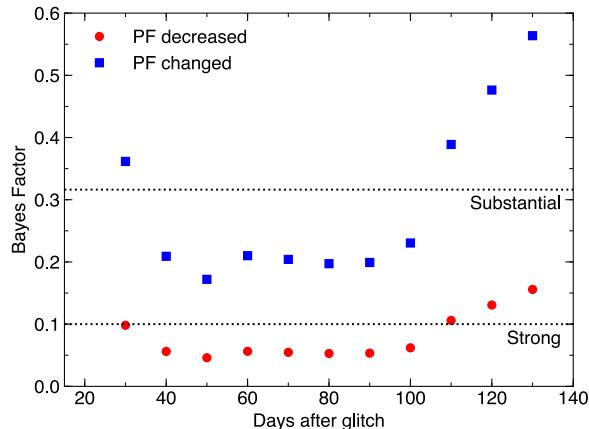
July 23, 2019



With pulsar emission



Without pulsar emission



significance level: 3 $\sigma$

## Magnetosphere altered after the glitch

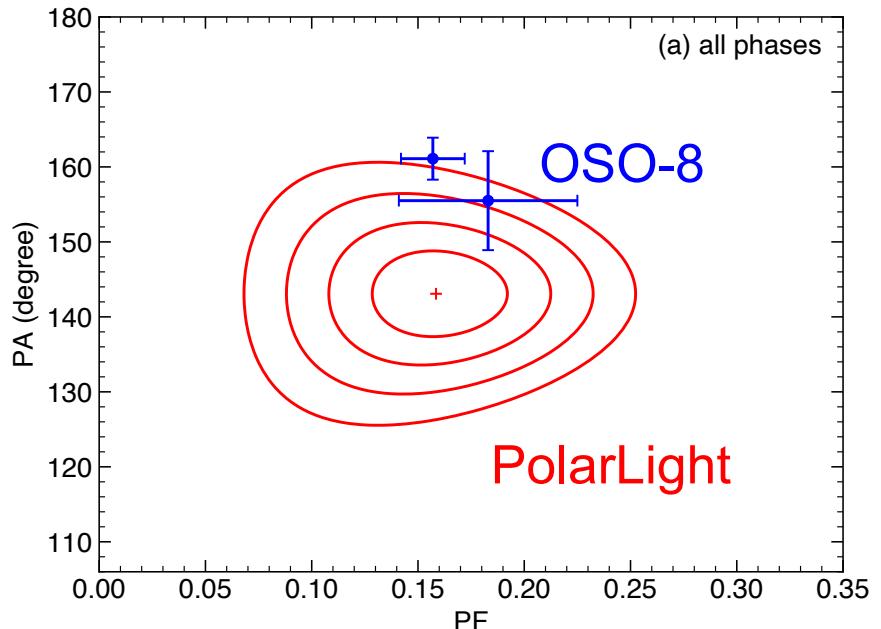
Feng et al. 2020, Nature Astronomy, 4, 511

- Bayes factor
- Bayesian posterior
- Bootstrap



# Follow-up observations of the Crab nebula

## Secular variation of the PA



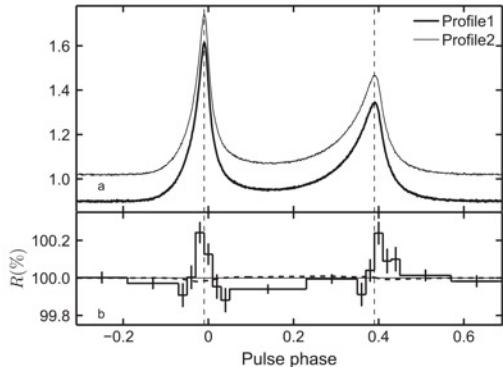
$$\Delta PA = 18^\circ.3 \pm 4^\circ.6$$

over 42 years

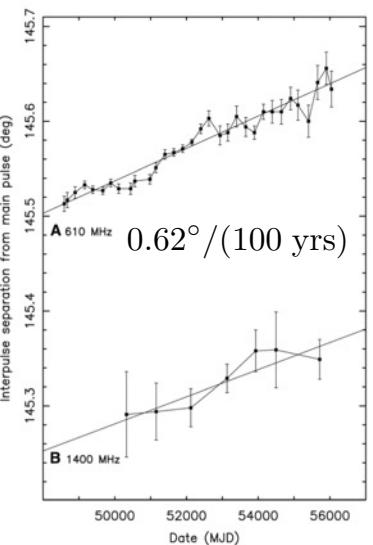
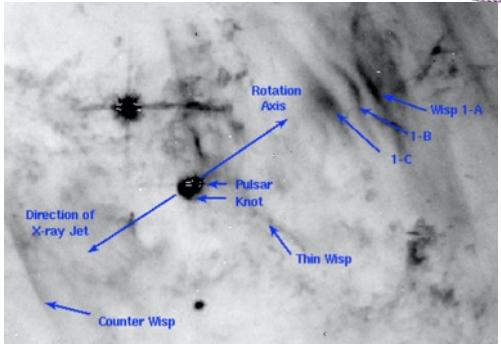
Long, Feng, et al. 2021 ApJ, 912, L28

# PA variations in the Crab nebula

- 26 glitches in between (Espinoza et al. 2011)
- PA variations revealed in other bands (Moran et al. 2016)
  - Optical:  $109.5^\circ \pm 0.7^\circ$  (2005) →  $85.3^\circ \pm 1.4^\circ$  (2012)
  - Gamma-ray:  $115^\circ \pm 11^\circ$  (2003-2007) →  $80^\circ \pm 12^\circ$  (2012-2014)
  - **Magnetic reconnection?**
- Secular evolution of the pulse profile
  - radio (Lyne et al. 2013) and X-ray (Ge et al. 2016)
  - **Evolution of pulsar magnetic geometry?**



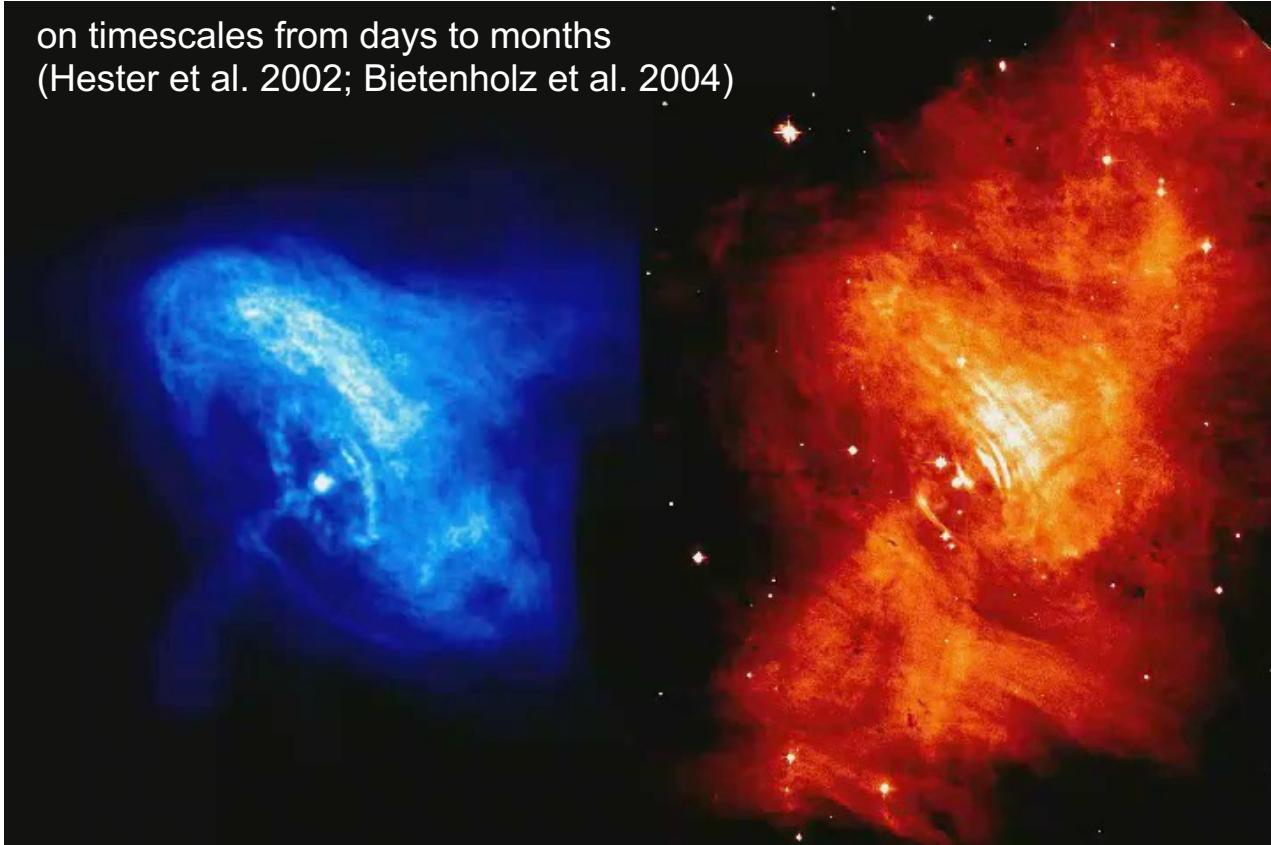
Hua Feng - Tsinghua Univ.





# A dynamic Crab nebula

on timescales from days to months  
(Hester et al. 2002; Bietenholz et al. 2004)





# Scorpius X-1

THE ASTROPHYSICAL JOURNAL, 232:L107-L110, 1979 September 1  
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## THE LINEAR X-RAY POLARIZATION OF SCORPIUS X-1

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Columbia Astrophysics Laboratory, Columbia University

*Received 1979 April 23; accepted 1979 May 31*

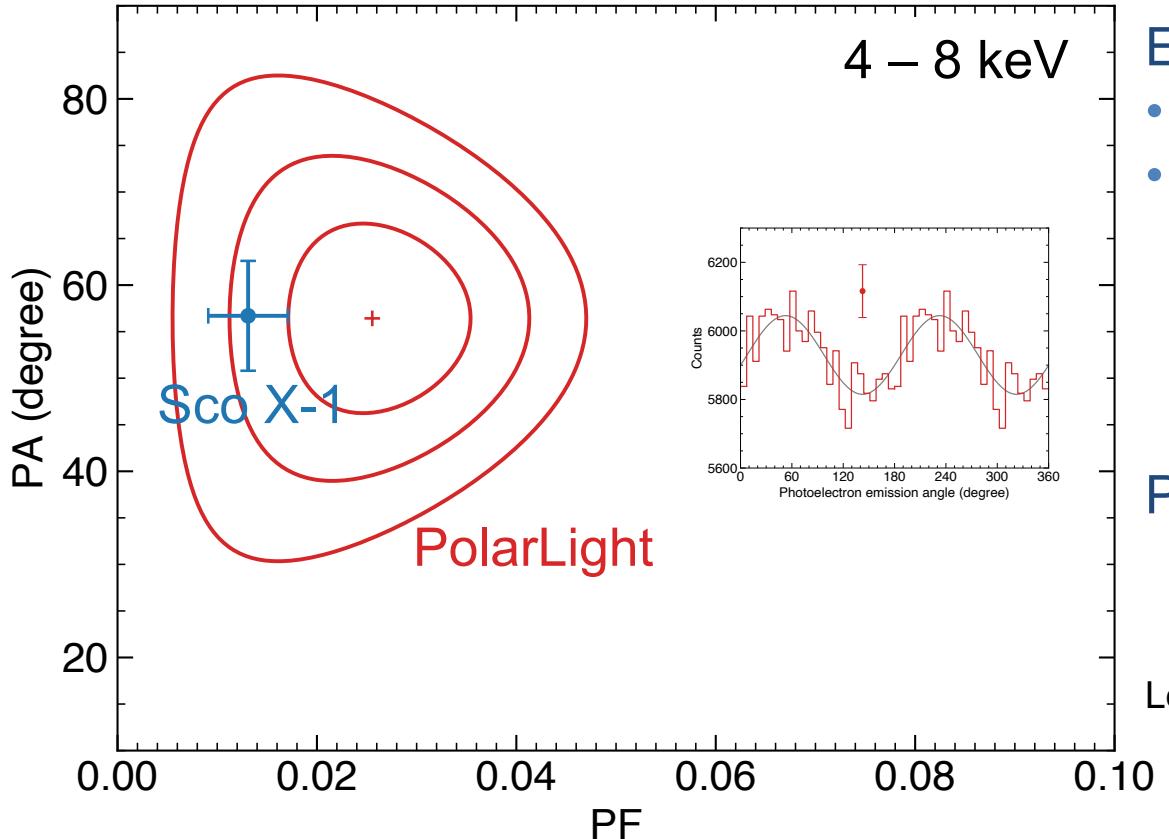
### ABSTRACT

Scorpius X-1 was observed with the Bragg crystal polarimeters aboard *OSO 8* in 1977 August and again in 1978 August. An analysis of these observations reveals a time-averaged polarization of  $0.39\% \pm 0.20\%$  at 2.6 keV and  $1.31\% \pm 0.40\%$  at 5.2 keV. The corresponding position angles are  $29^\circ \pm 10^\circ$  and  $57^\circ \pm 6^\circ$ , respectively. Binary phase-dependent polarization was searched for but not observed.

- ✓ 2.6 keV: PF =  $0.39\% \pm 0.20\%$ , PA =  $28.6^\circ \pm 10.1^\circ$
- ✓ 5.2 keV: PF =  $1.31\% \pm 0.40\%$ , PA =  $56.7^\circ \pm 5.9^\circ$



# PolarLight measurements



4 – 8 keV

- Energy dependent
  - 3-4 keV: non-detection
  - 4-8 keV: 4  $\sigma$

Flux dependent

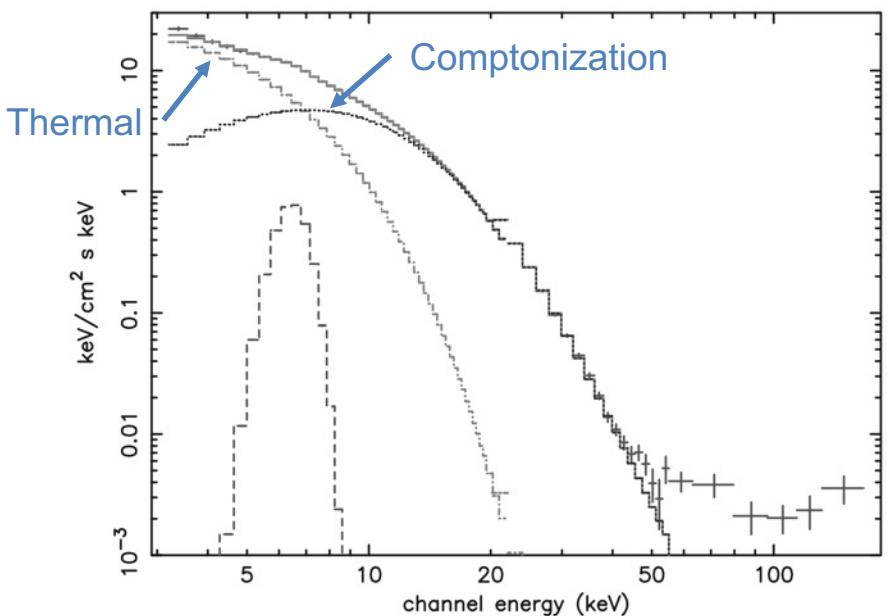
- Low flux: non-detection
- High flux: 5  $\sigma$

PA: consistent with OSO-8

Long et al. 2022, ApJ, 924, L13

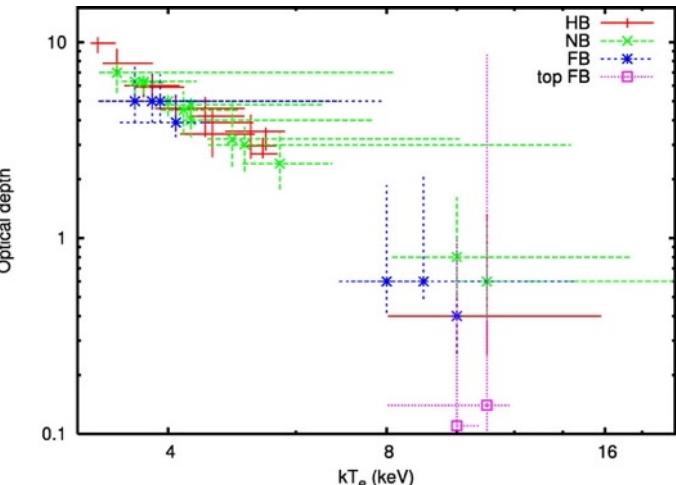
# Spectral models for Sco X-1

- Four spectral components (D'Aí et al. 2007)
  - Thermal + Compton + Fe line + hard tail

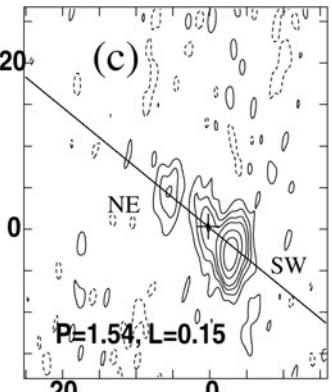
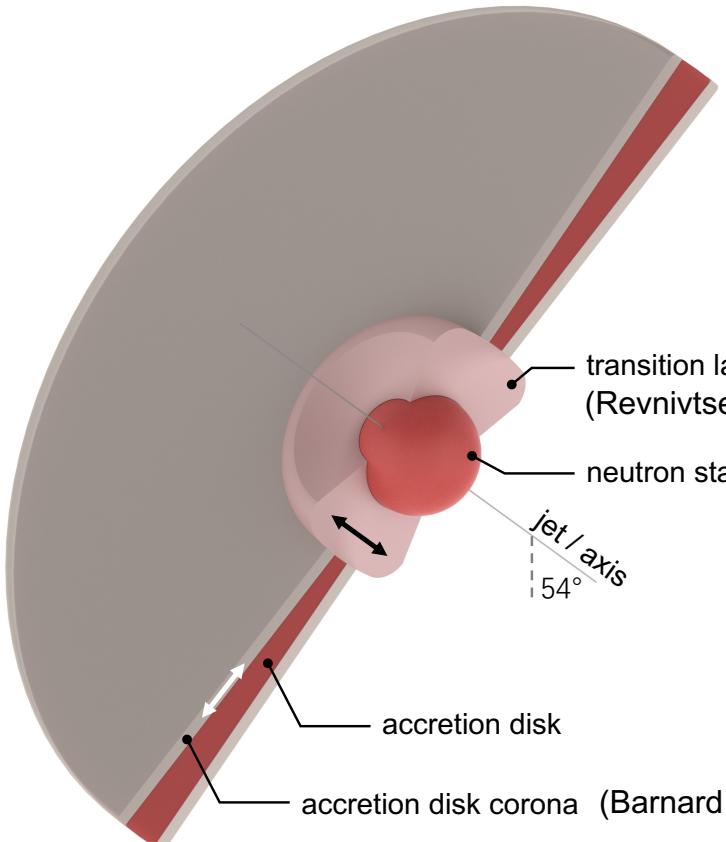


D'Aí et al. (2007)

"for spectra at high accretion rate we obtained low values for the optical depth ( $\leq 1$ )"



# Geometry revealed by X-ray polarimetry



Radio jet with an orientation of  $54^\circ$  (Fomalont et al. 2001)

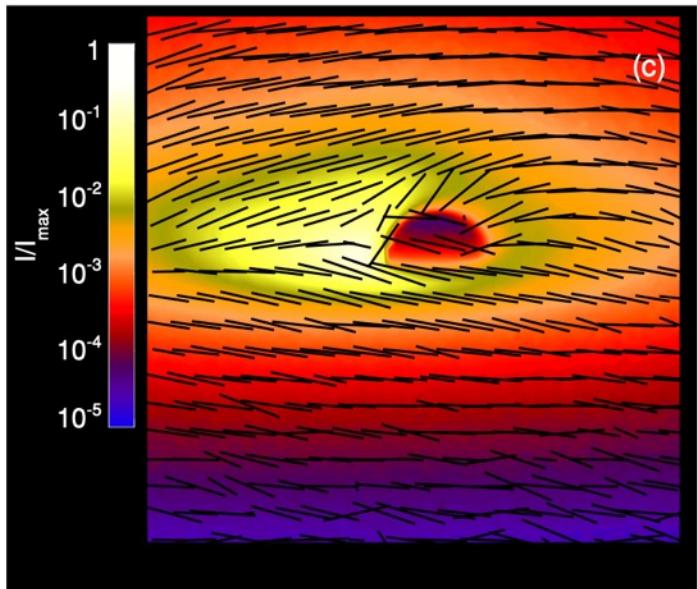
Polarization angle  
 $PA = 52.6^\circ \pm 5.4^\circ$

- PA perpendicular to the inner disk (aligned with the jet orientation)
- An optically thin corona is located in the transition layer at high accretion rates

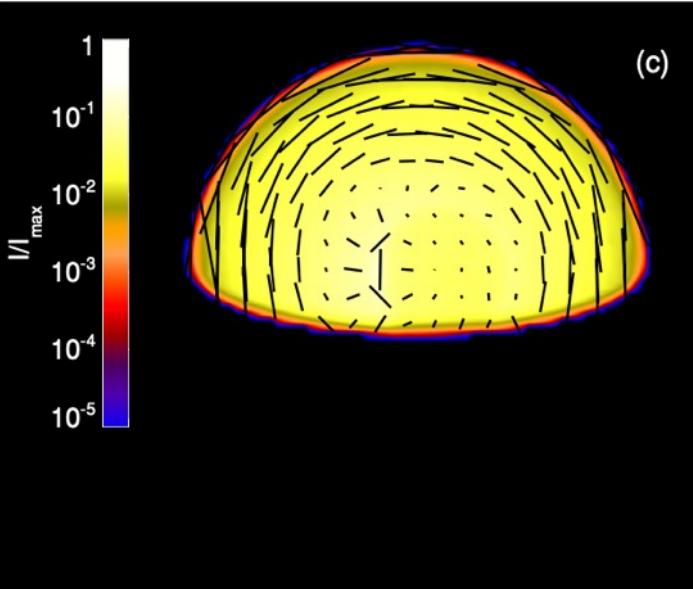


# Numerical simulations

Optically thin, near the thermal peak: scattered once



sandwich corona



spherical corona

(Schnittman and Krolik 2010)



# Discussion

- X-ray polarimetry
  - B-field and geometry
- The need for eXTP
  - Find the phase for periodic or quasi-periodic signals
  - Determine the emission state
    - Large area & wide-band coverage
- Technical demonstration
- Student training

**THANK YOU !**

