



X-ray polarimetry explorers: **IXPE & eXTP**

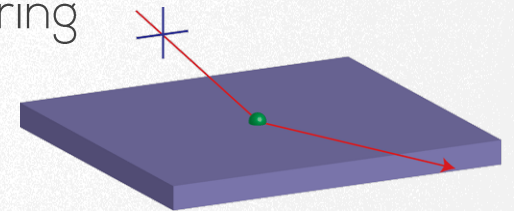
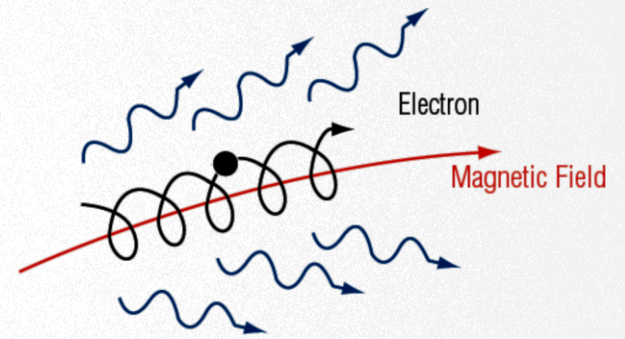
Xiaochen SUN (THCA & IASTU)

Supervised by Prof. H. Feng

2018.11.9

Why we need polarimetry?

- Information about the magnetic field
 - ◆ Synchrotron radiation
 - ◆ Plasma polarization
 - ◆ Vacuum polarization/ birefringence
- Information about the scattering medium
 - ◆ Thomson/Compton/Inverse Compton scattering
 - ◆ Geometric symmetry
- No Faraday effect (proportional to λ^2)



History of polarimetry observatory?

- First attempt: **Aerobee 150**
 - ◆ 1968
 - ◆ Scattering polarimeter
 - ◆ Target: the brightest X-ray source ScoX-1
 - ◆ Because of sensitivity, nothing found

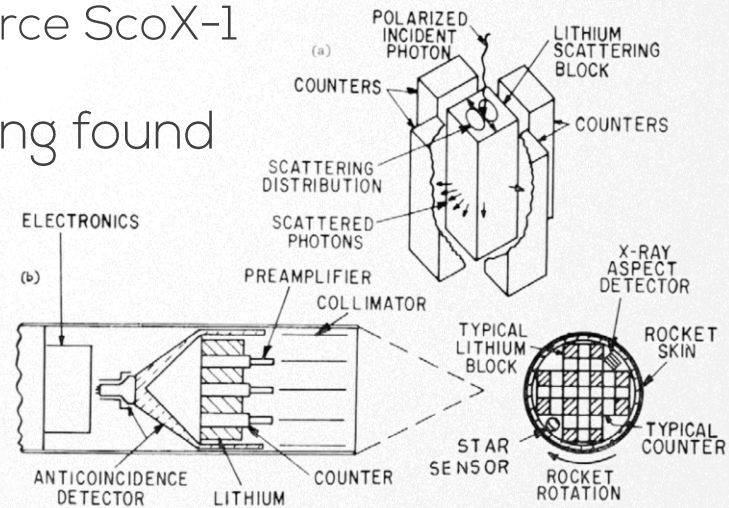
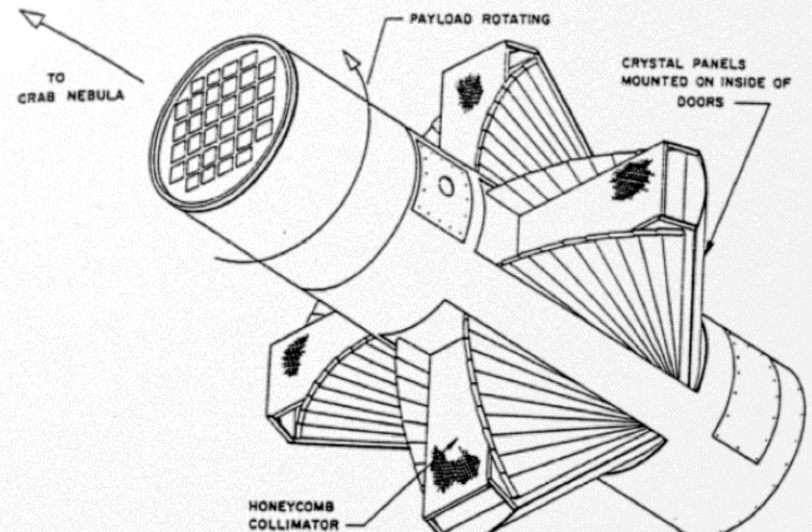


Fig. 1. (a) Schematic representation of the polarimeter concept. (b) Mounting of the polarimeter and ancillary equipment in the rocket.



History of polarimetry observatory?

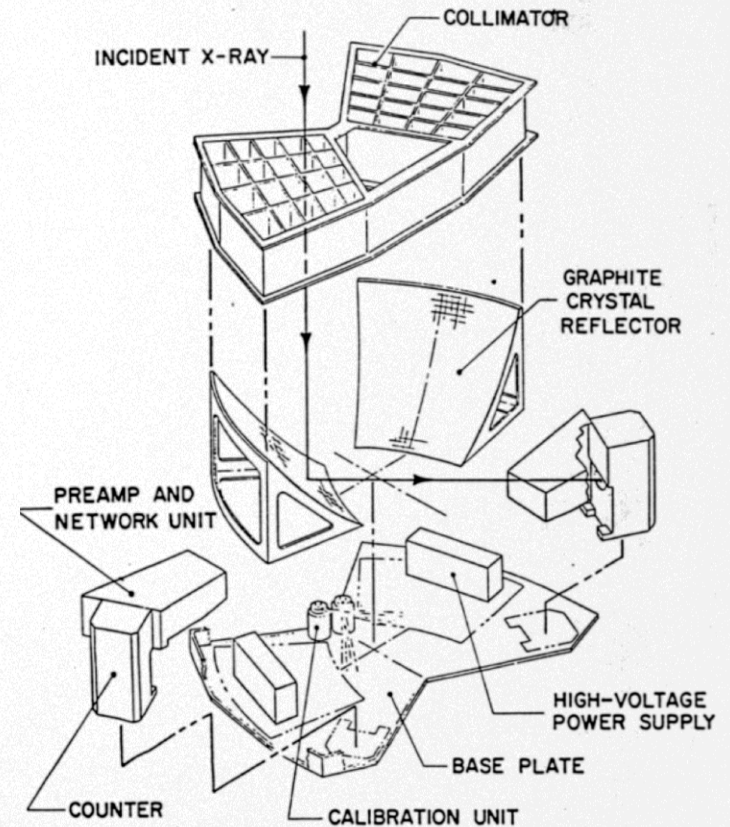
- First success: **Aerobee 350**
 - ◆ 1971
 - ◆ Bragg polarimeter
 - ◆ Crab nebula: $P = 15\% \pm 5\%$, $\phi = 156 \pm 10^\circ$



History of polarimetry observatory?

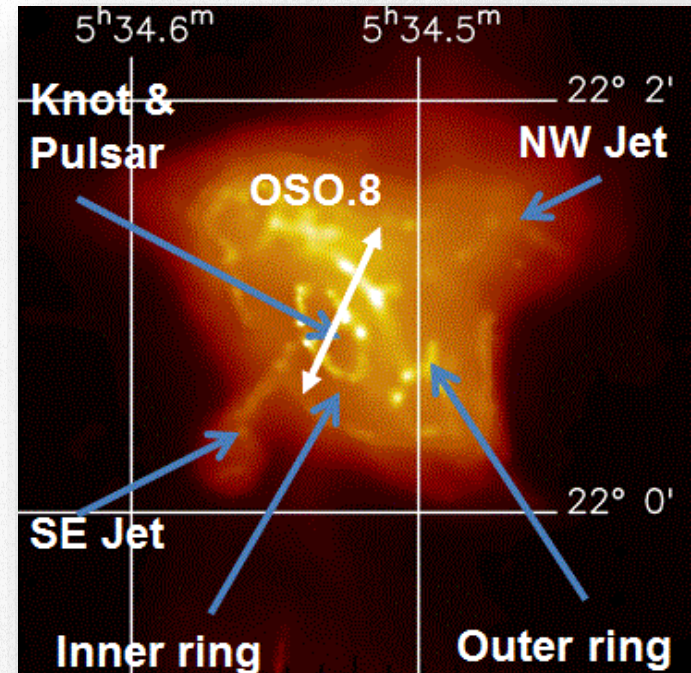
- First precise measurement: **OSO-8**

- ◆ 1975
- ◆ Bragg polarimeter
- ◆ Crab nebula: $P = 19.2\% \pm 1.0\%$,
 $\varphi = 156.4^\circ \pm 1.4^\circ$



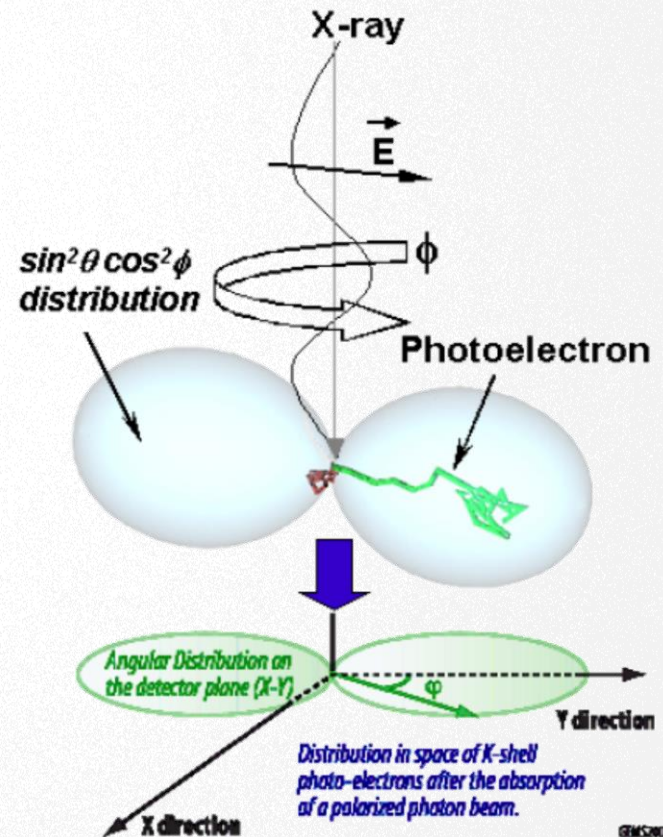
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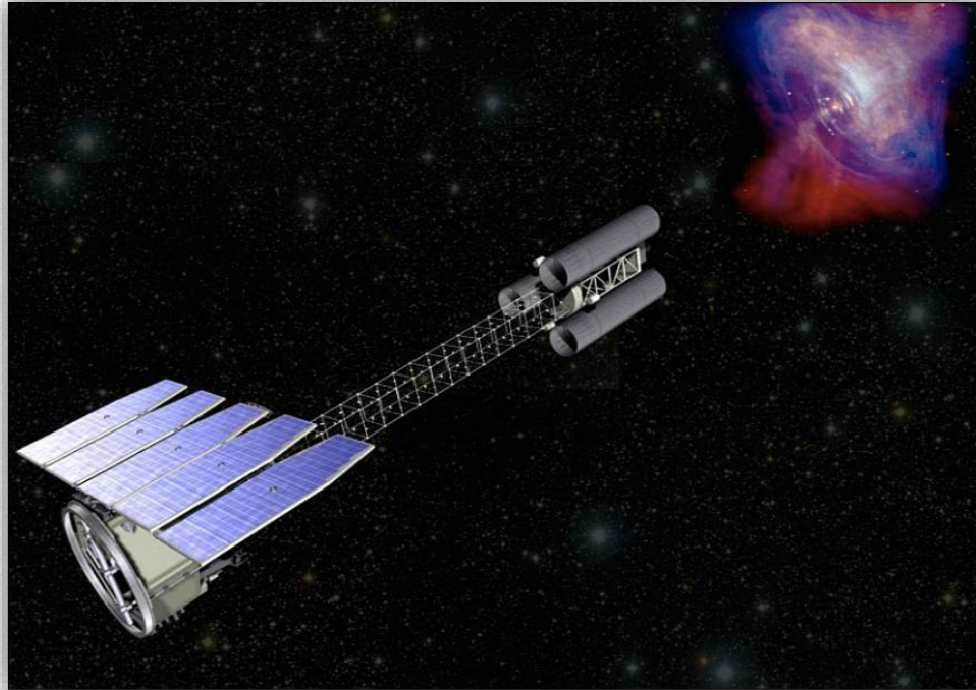
New era of polarimetry observatory

- scattering/Bragg diffraction → photoelectric effect
 - ◆ cross section: $d\sigma/d\Omega \propto \cos^2 \phi$
 - ◆ more efficient
 - ◆ IXPE, eXTP, XIPE etc.





IXPE



Imaging **X**-ray **P**olarimetry **E**xplorer

Special Topics in Observational Astrophysics














IXPE



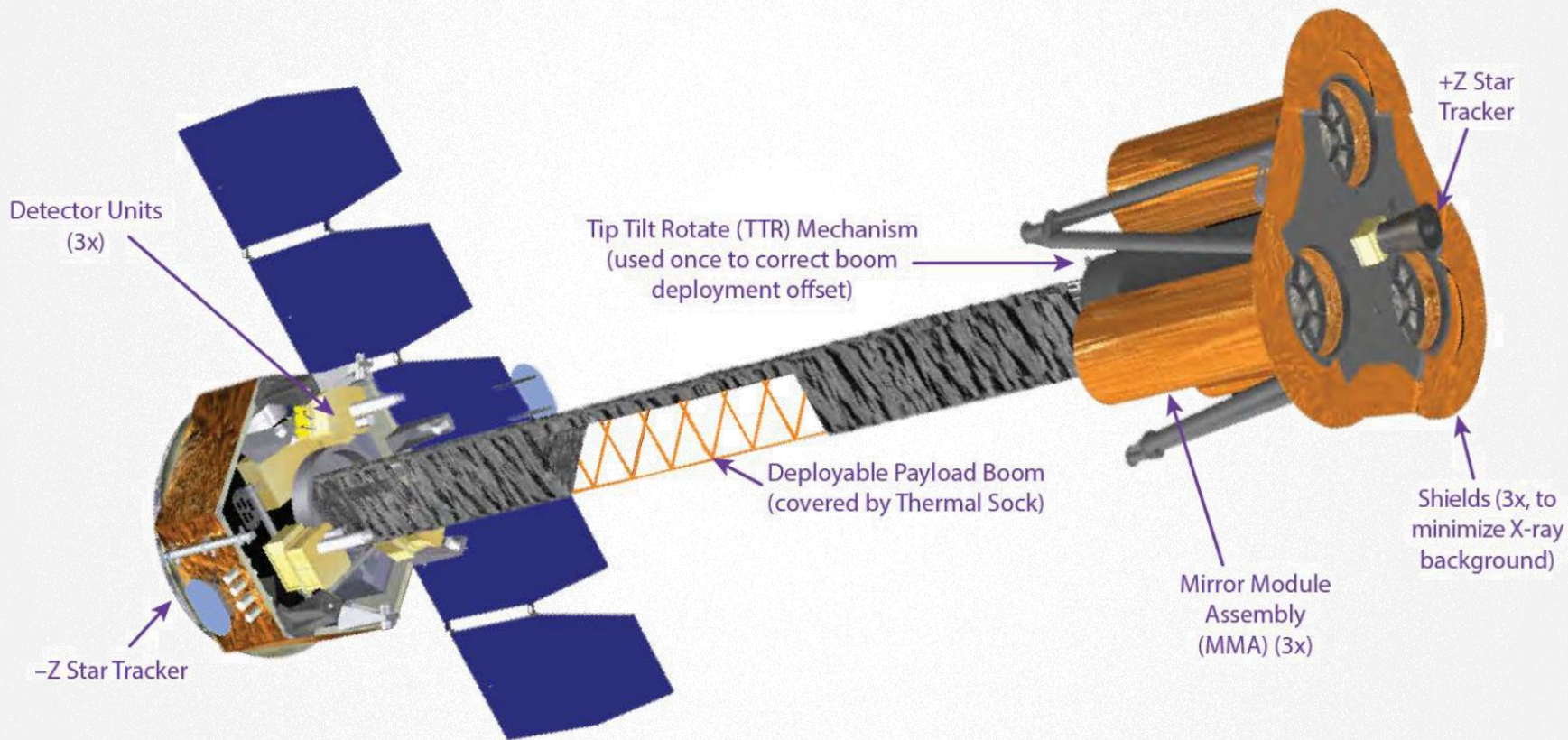
An estimated price tag of \$188 million

PI: **Martin Weisskopf**
(Marshall Space Flight Center)

Launch around **2021**

 Marshall Space Flight Center PI team, project management, SE and S&MA oversight, mirror module fabrication, X-ray calibration, science operations, and data analysis and archiving	   INAF ISTITUTO NAZIONALE DI ASTRONOMIA NATIONAL INSTITUTE FOR ASTRONOMY Polarization-sensitive imaging detector systems
 ASI Agenzia Spaziale Italiana Detector system funding, ground station	 LASP Mission operations
 Ball Spacecraft, payload structure, payload, observatory I&T	  Stanford University Scientific theory  McGill Science Working Group Co-Chair
	 MIT Massachusetts Institute of Technology Co-Investigator <small>A12567_151</small>

The scientific payload of IXTP





eXTP



enhanced **X**-ray **T**iming and **P**olarimetry mission



eXTP



An estimated price tag of \$**473** million

More than **200** scientists

From **20** countries

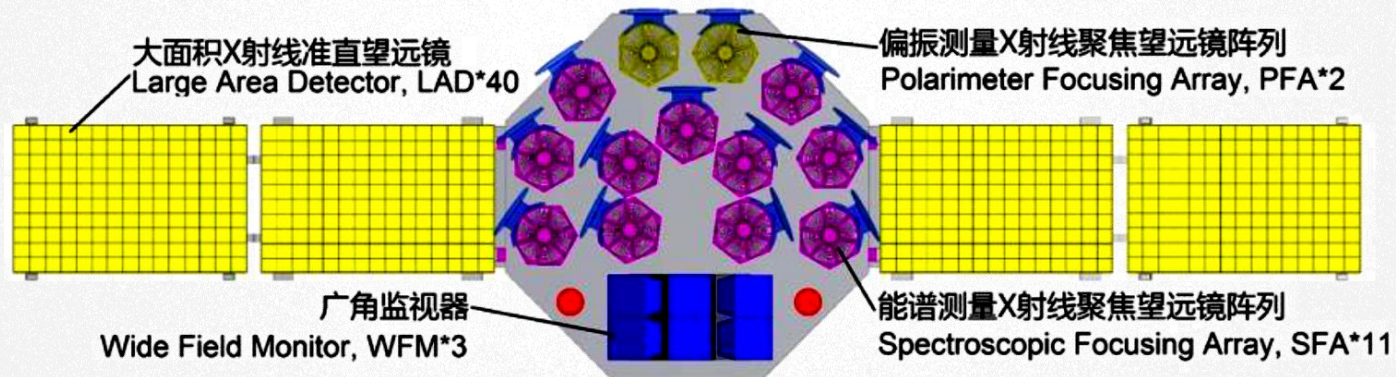
Launch around **2025**





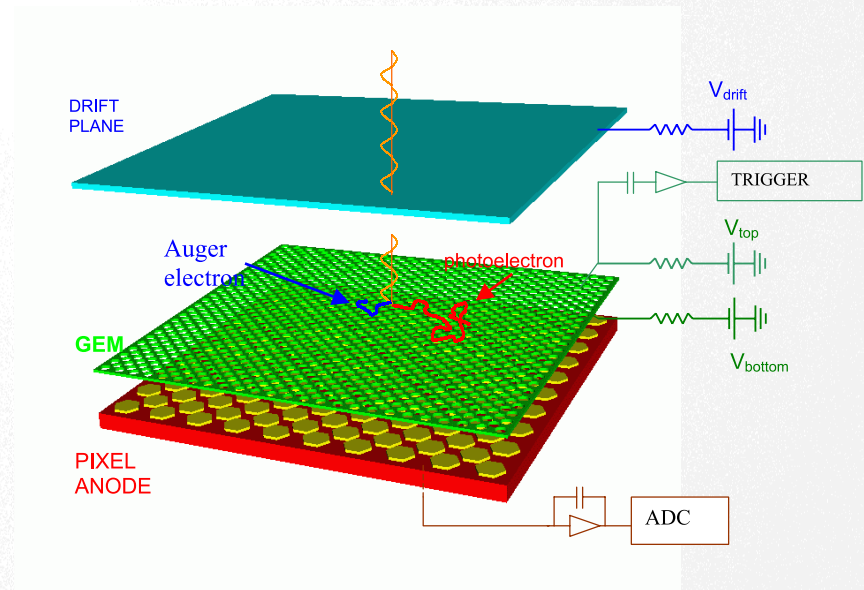
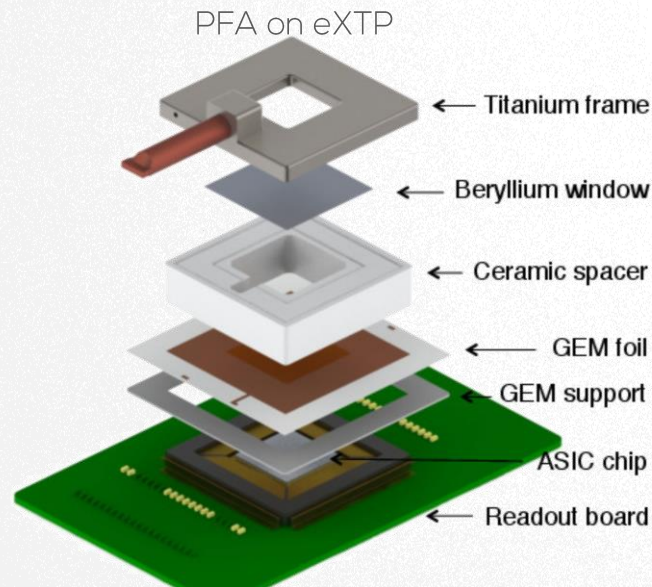
The scientific payload of eXTP

- The Spectroscopic Focusing Array (**SFA**)
- The Large Area Detector (**LAD**)
- The Polarimetry Focusing array (**PFA**)
- The Wide Field Monitor (**WFM**)



Gas Pixel Detector (GPD)

- photoelectric effect
- first demonstrated by INFN-Pisa & IAPS-Rome in 2001
- Initial photoelectron direction correlated to electric field



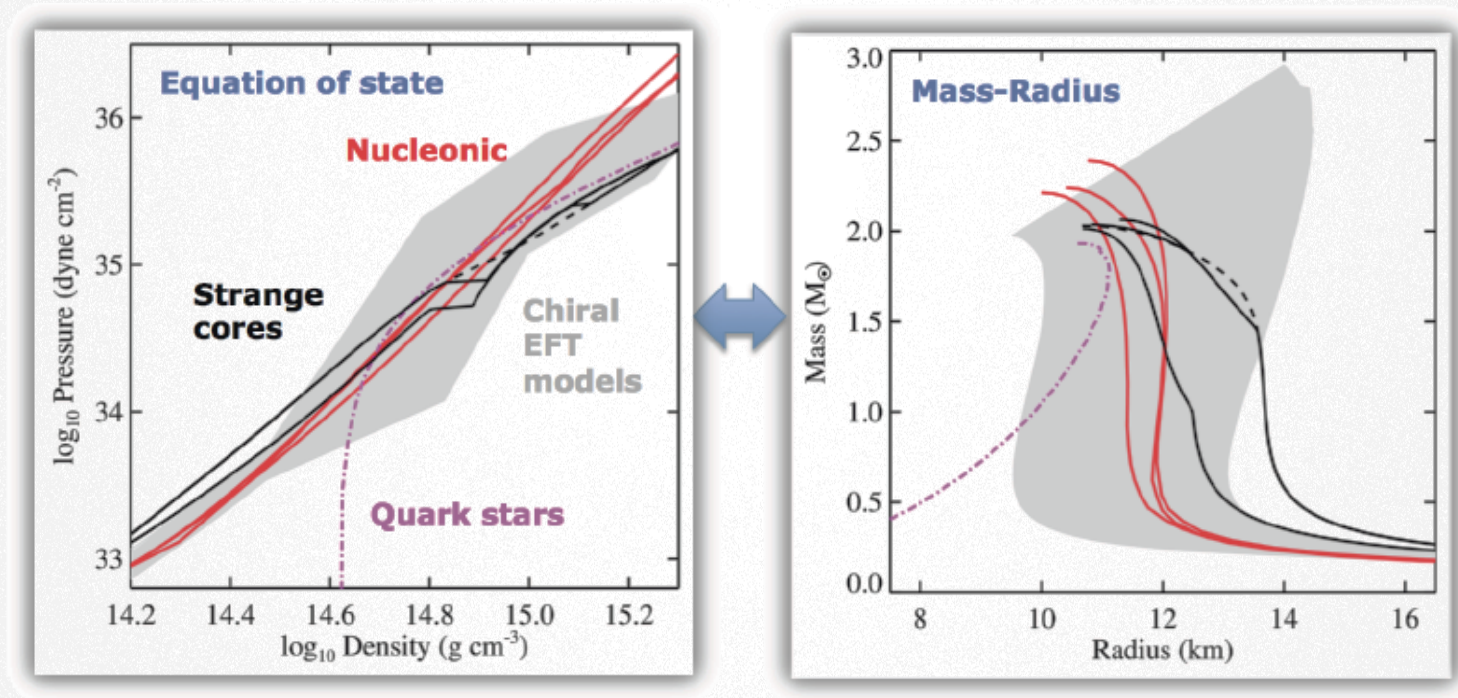


Scientific cases with polarization

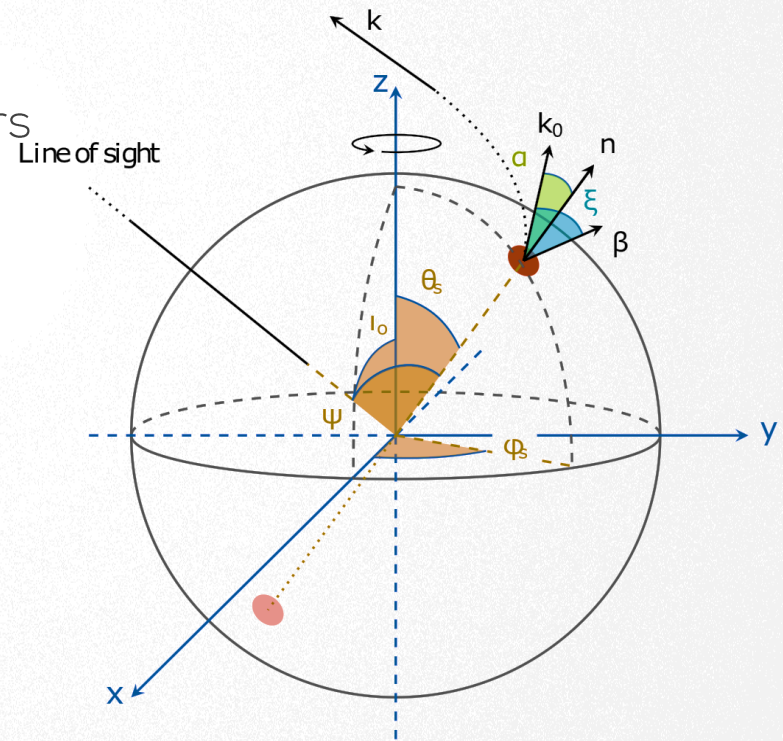
- Dense matter with neutron star
- Physics & astrophysics of strong magnetic fields
- Accretion in strong field gravity
- Map magnetic field of extended sources
- Test reflection-nebula hypothesis for X rays

- Dense matter with neutron star

- strong interaction \leftrightarrow mass vs. radius diagram



- Dense matter with neutron star
- **pulse profile modeling** & spin measurements
 - ◆ accretion-powered millisecond pulsars, rotation-powered pulsars & burst oscillation sources
 - ◆ polarimetry

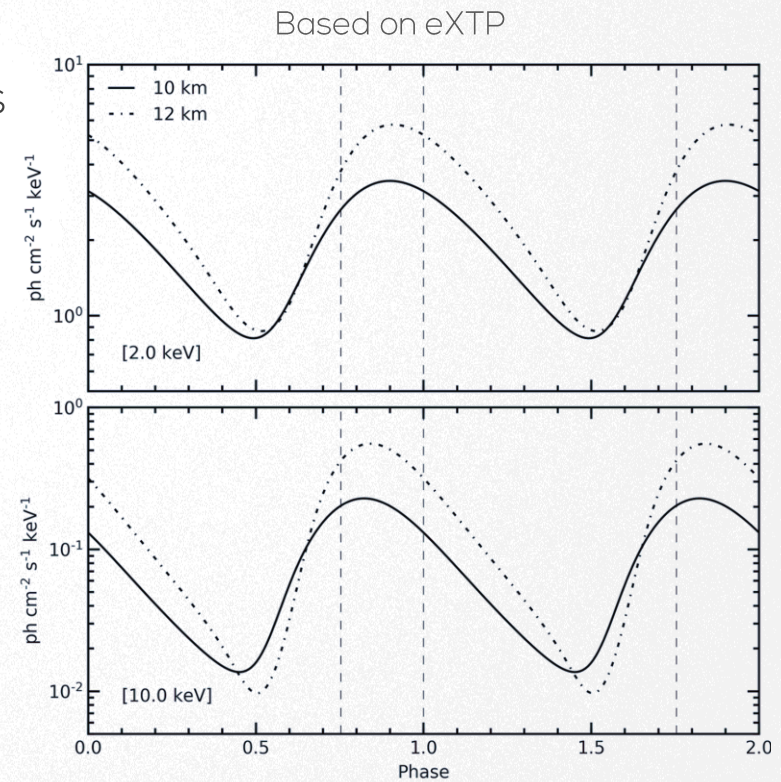




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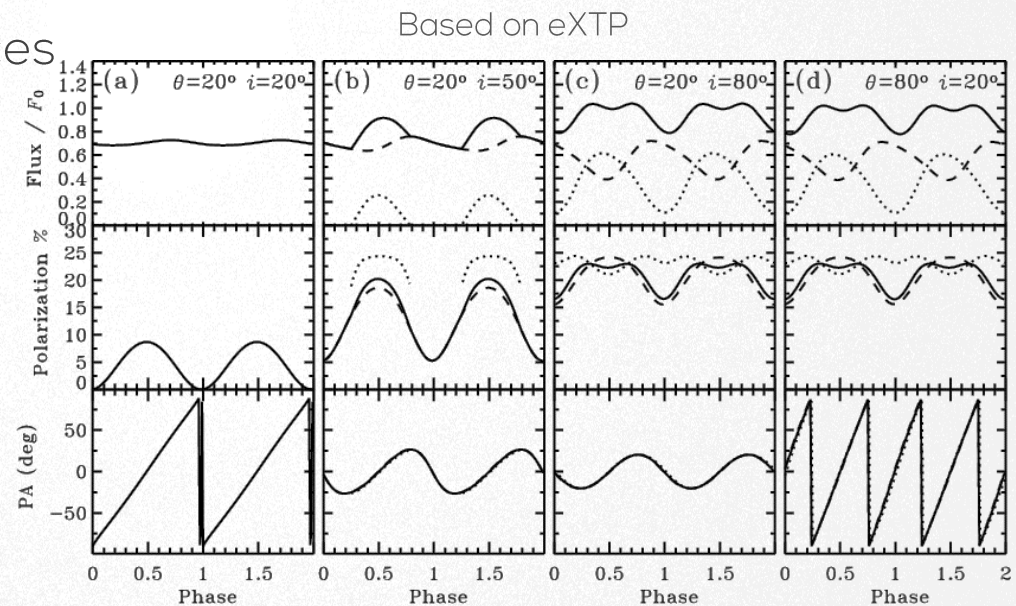
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Viironen K, Poutanen J. 2004.

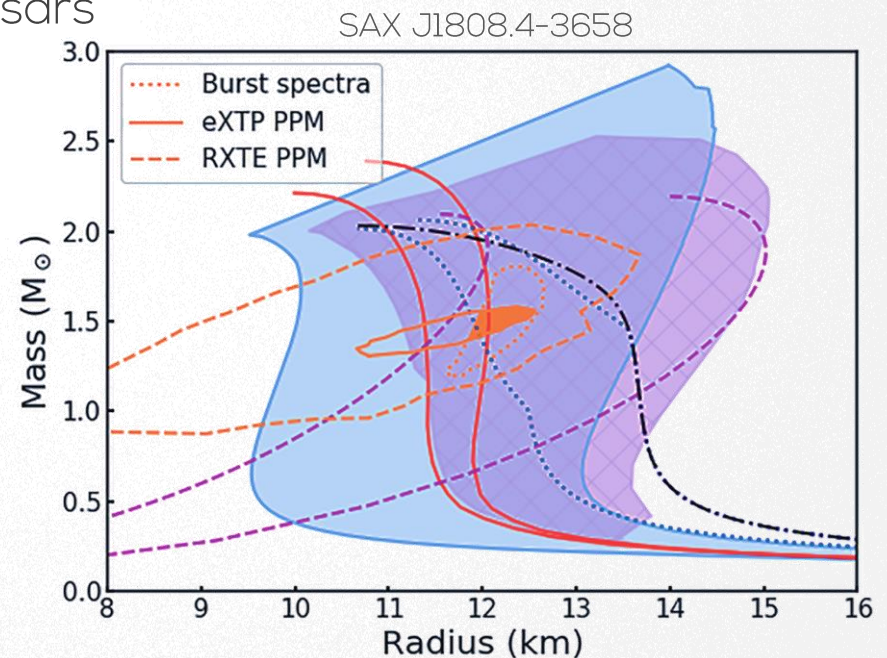


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- Physics & astrophysics of strong magnetic fields
 - rotation-powered pulsar, accreting X-ray pulsar & magnetar
 - QED effects: vacuum birefringence



- Physics & astrophysics of strong magnetic fields
 - rotation-powered pulsar, accreting X-ray pulsar & magnetar
 - ◆ cyclotron resonance scattering feature
 - ◆ polarization

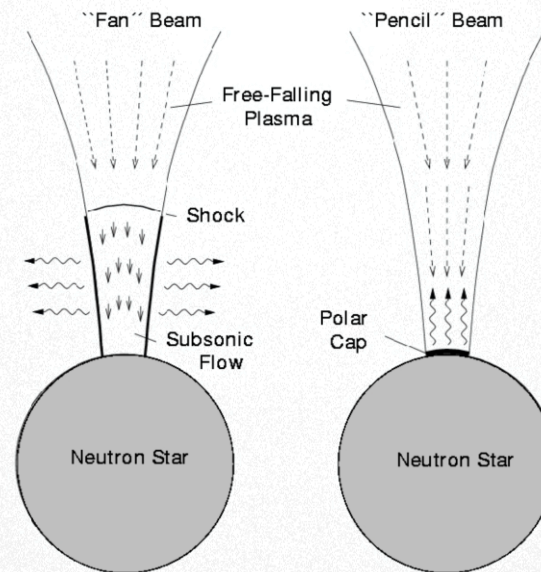




- Physics & astrophysics of strong magnetic fields

- rotation-powered pulsar, accreting X-ray pulsar & magnetar

- **polarization** → geometry of the emission region & radiation formation

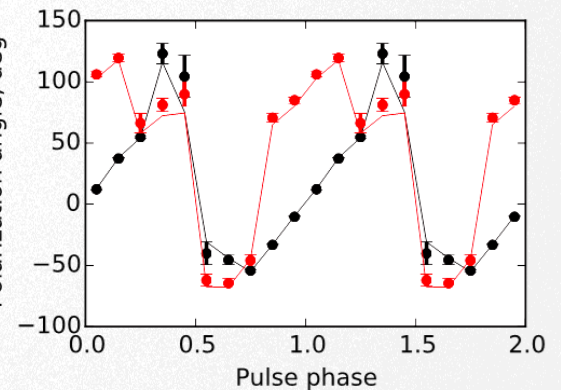
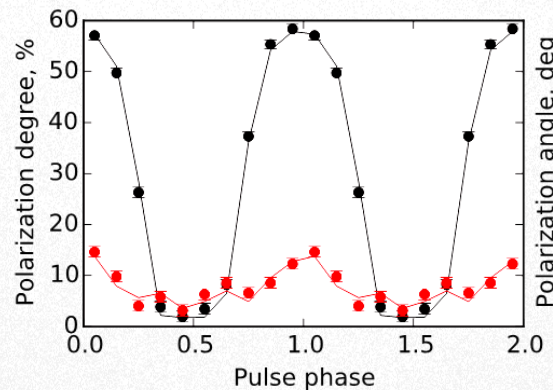
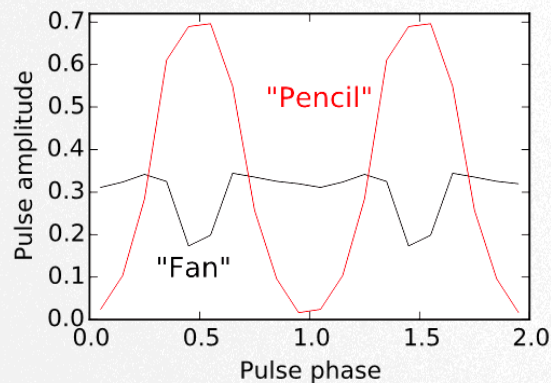




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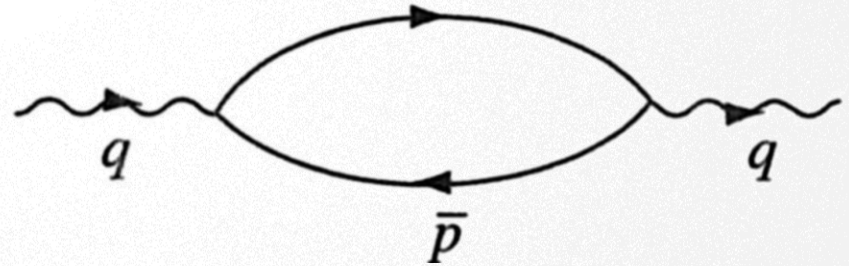
Vela X-1 based on eXTP





• Physics & astrophysics of strong magnetic fields

- QED effects: vacuum birefringence
 - ◆ “vacuum” is not real vacuum, with a Dirac field where $F_{\mu\nu} \neq 0$
 - ◆ $\Delta n \sim \alpha (B/B_k)^2$, $B_k = (m^2 c^3)/e\hbar \approx 4.4 \times 10^{13} \text{ G}$
 - ◆ $\Delta\phi = \Delta n l/\lambda$



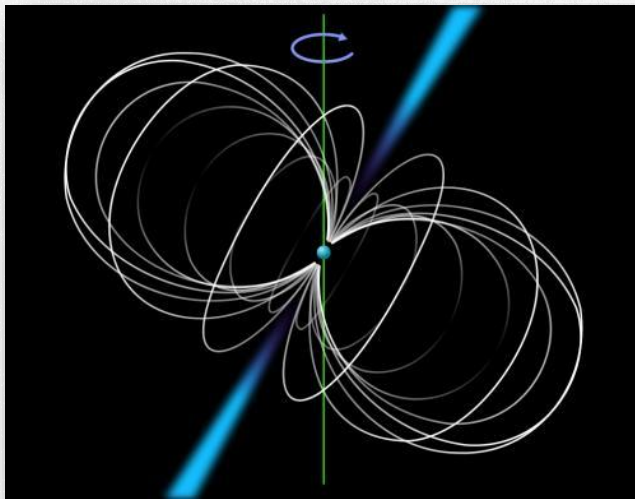


- Physics & astrophysics of strong magnetic fields
 - QED effects: vacuum birefringence
 - ◆ neutron stars
 - ◆ black holes & white dwarfs

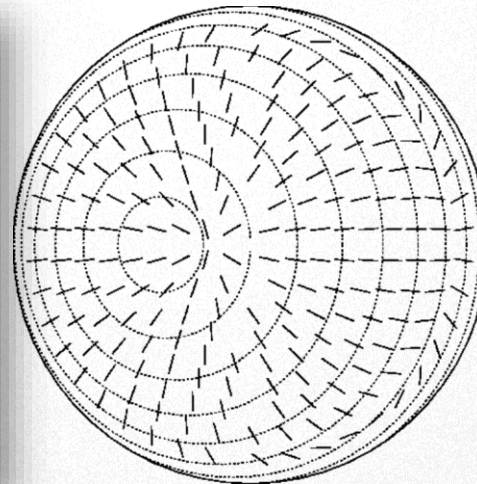


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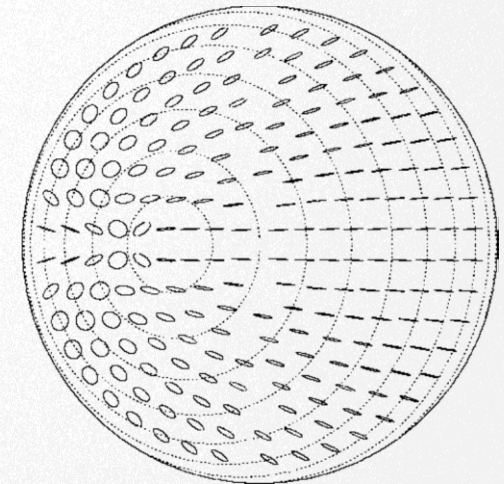
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QED off



QED on

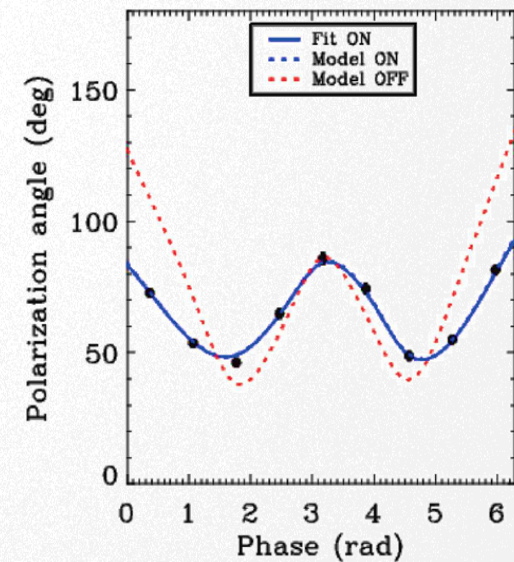
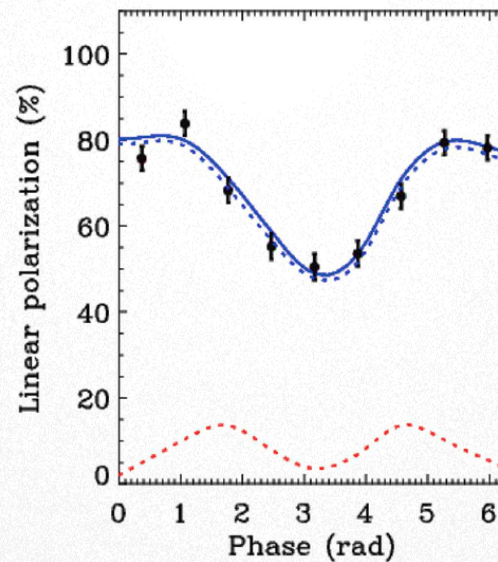
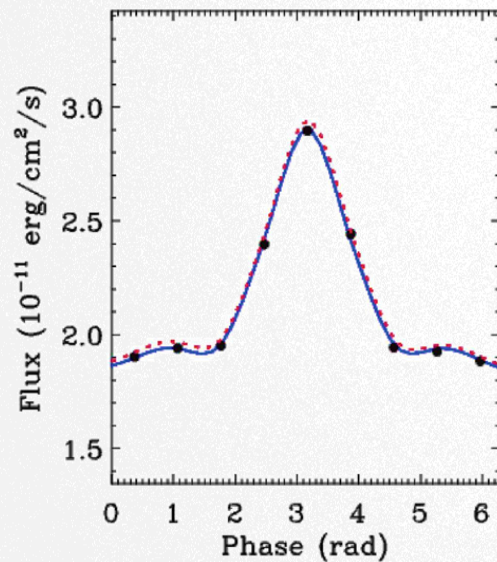




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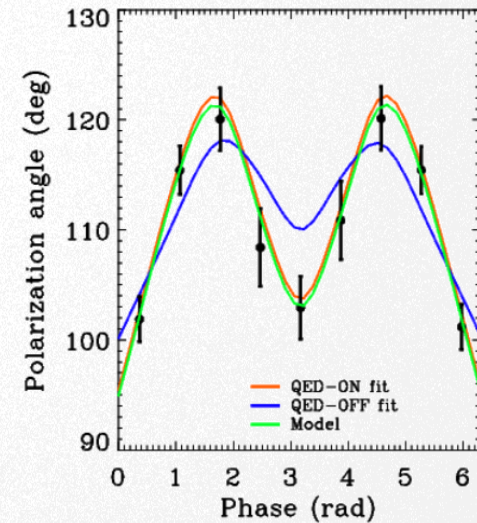
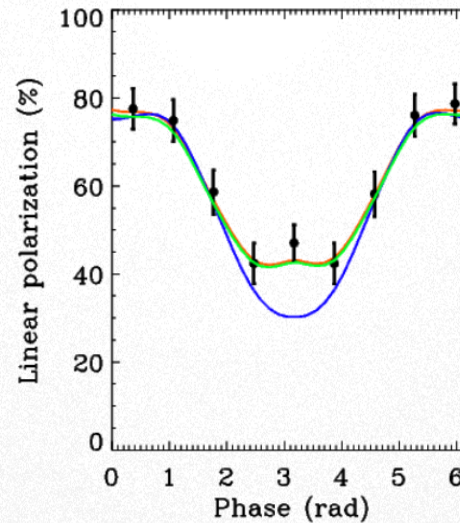
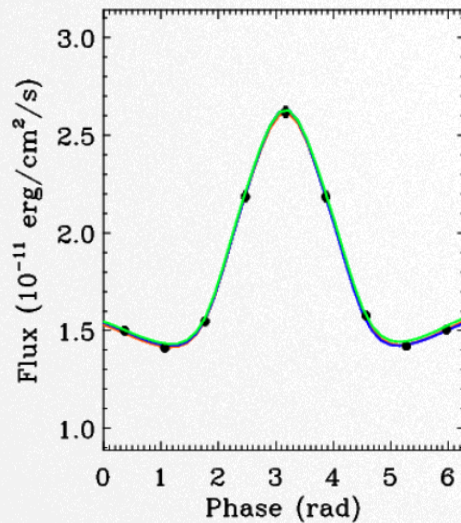




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1RXS J170849.0-400910 based on IXPE

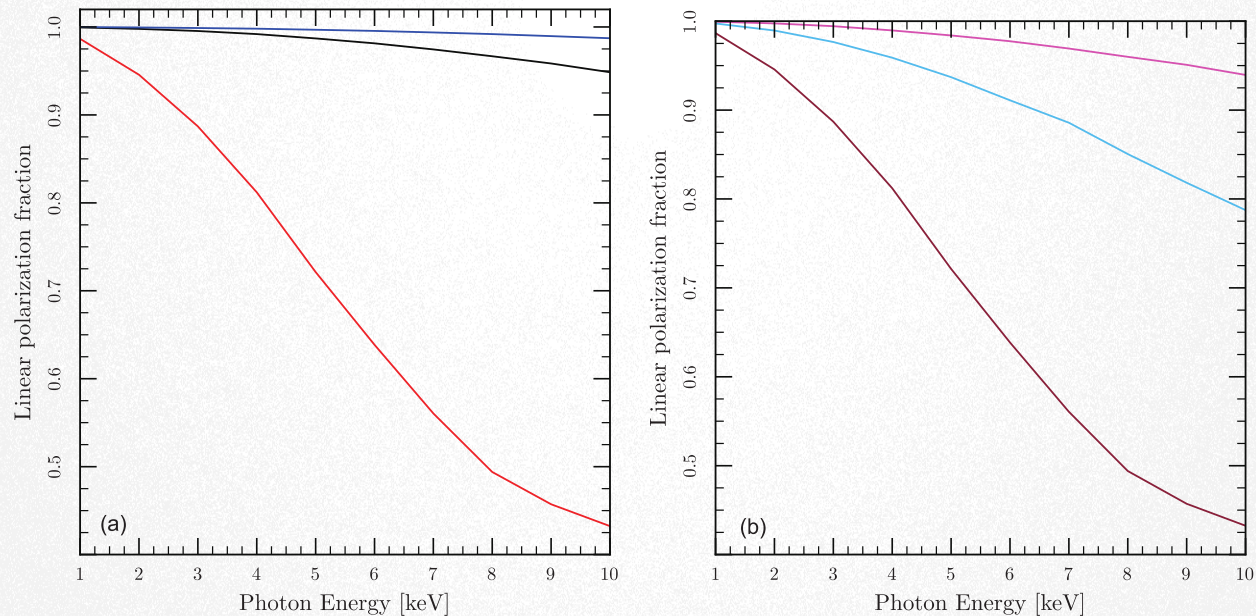




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 - ◆ **black holes & white dwarfs**

Based on eXTP

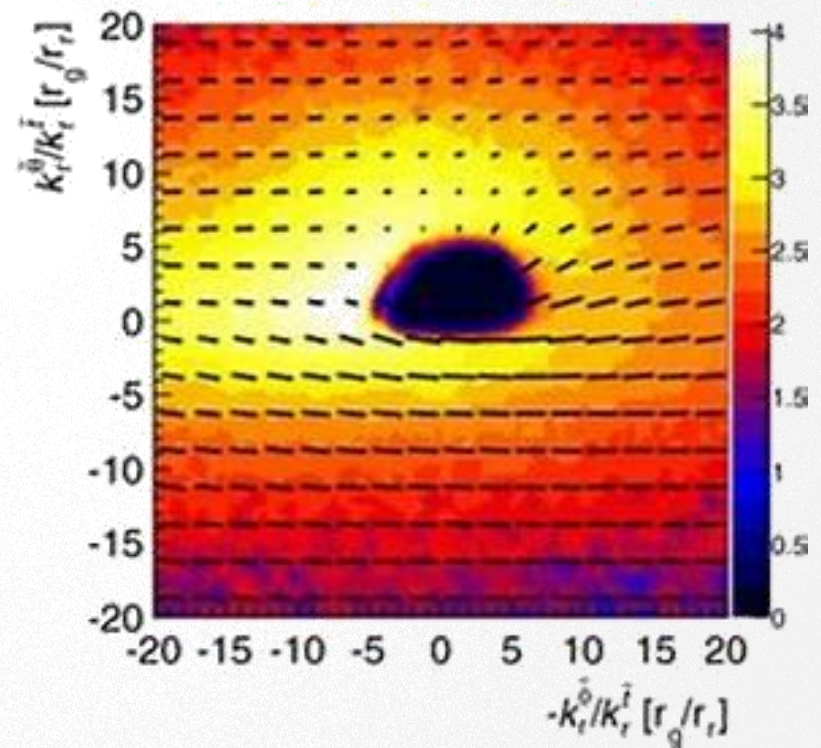
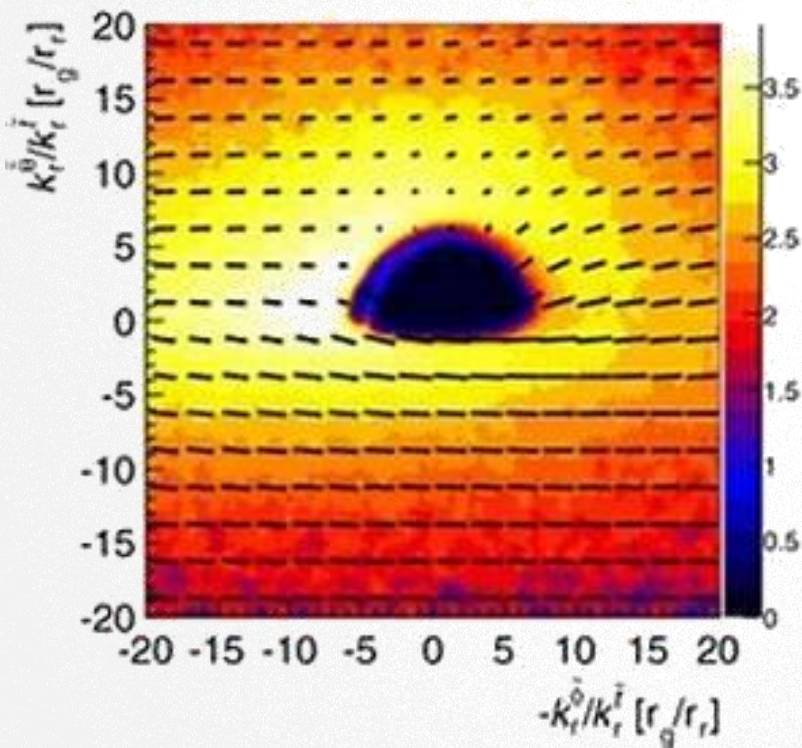




- Accretion in strong field gravity
 - measure black-hole spin from polarization
 - constrain the geometry of the innermost flow & outflow
 - ◆ QPO
 - ◆ jets
 - ◆ shocks
 - ...

- Accretion in strong field gravity

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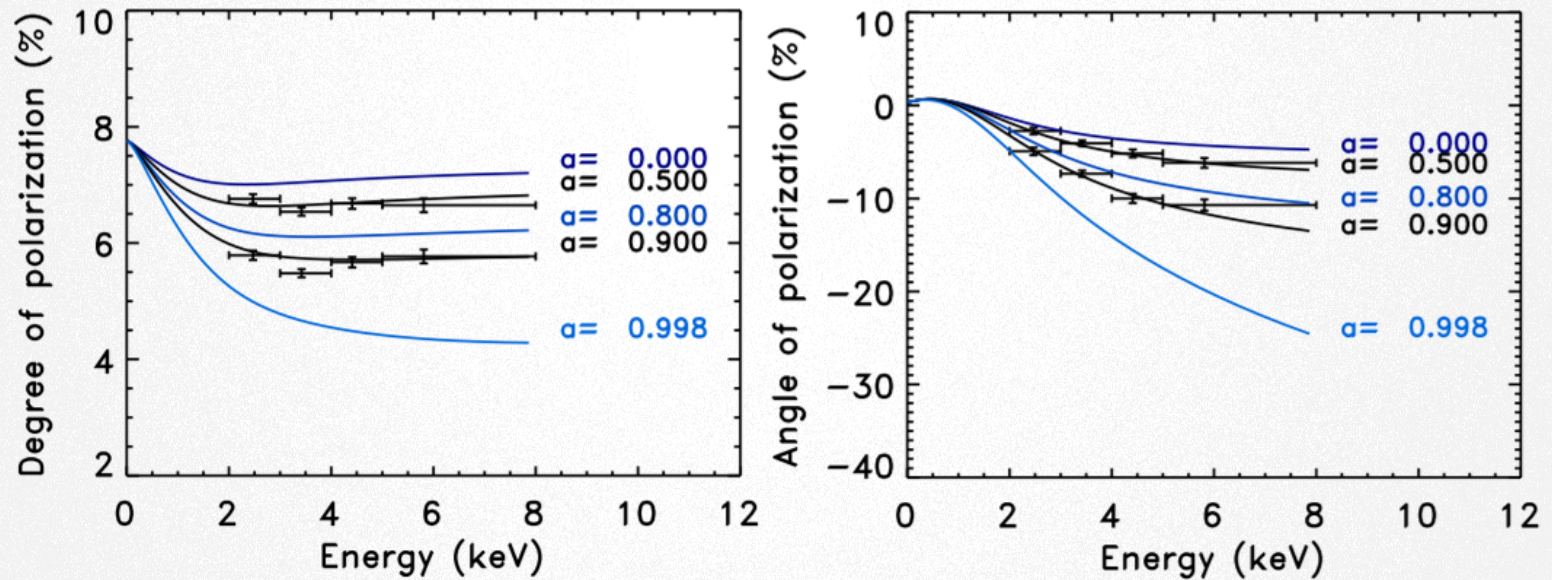




• Accretion in strong field gravity

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GRS 1915+105 based on eXTP

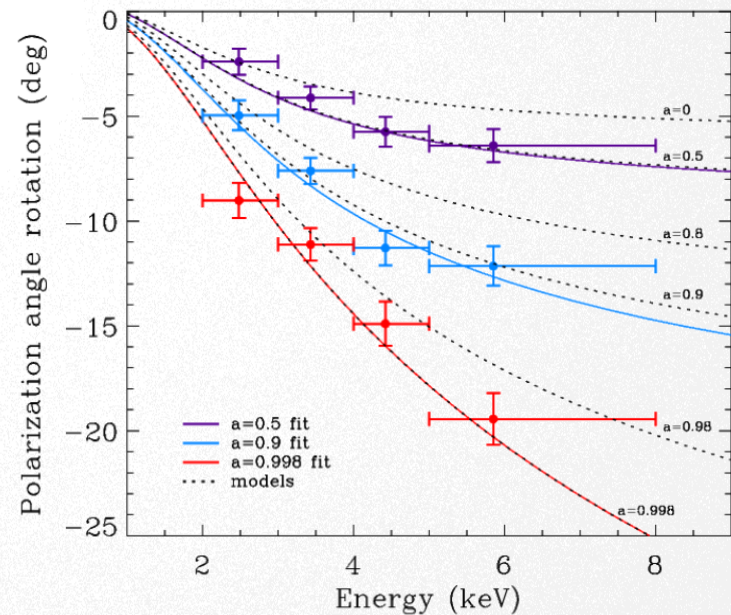
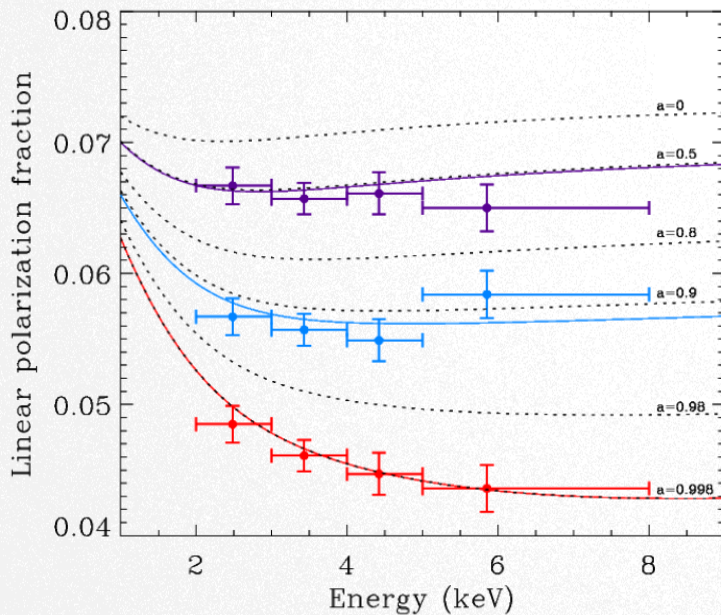




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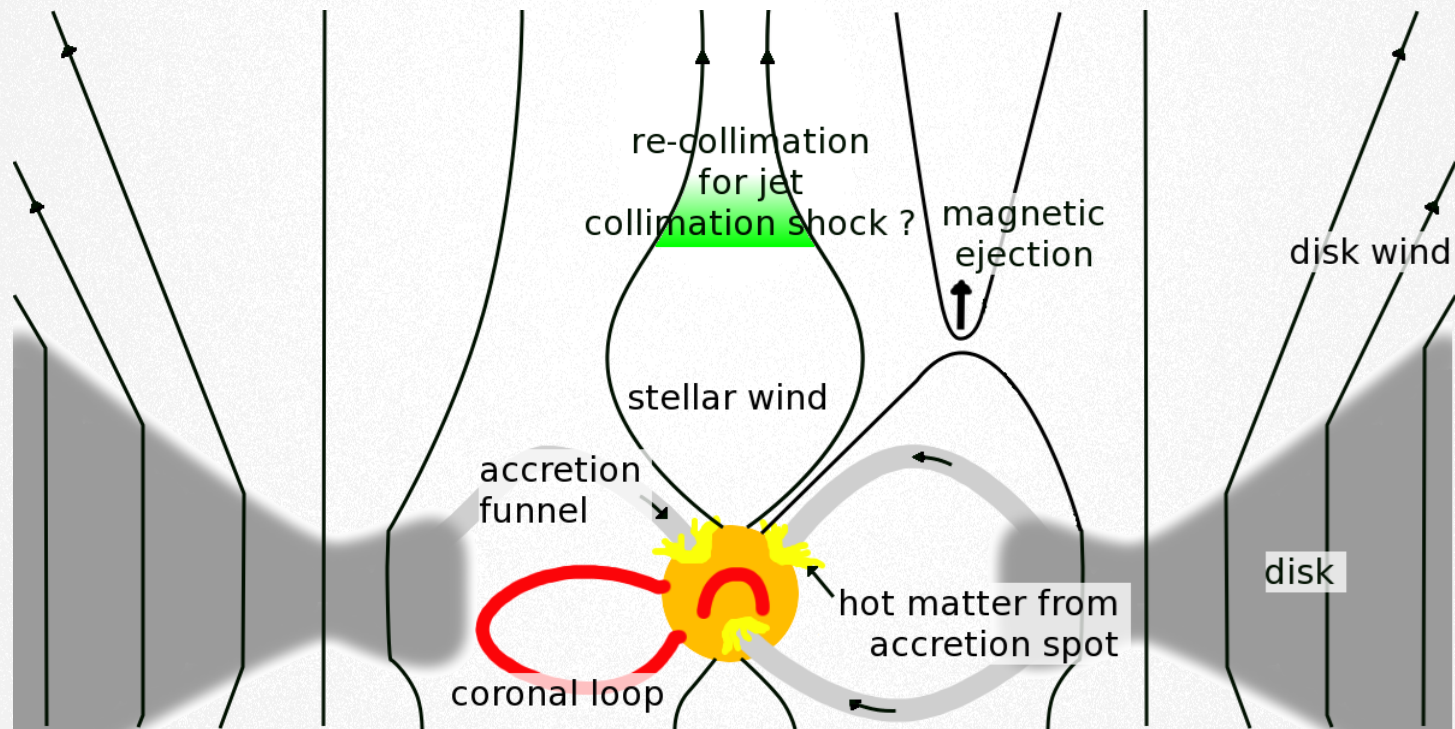
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GRS 1915+105 based on IXPE



- Accretion in strong field gravity

- constrain the geometry of the innermost flow & outflow
 - ◆ symmetry of accretion flow

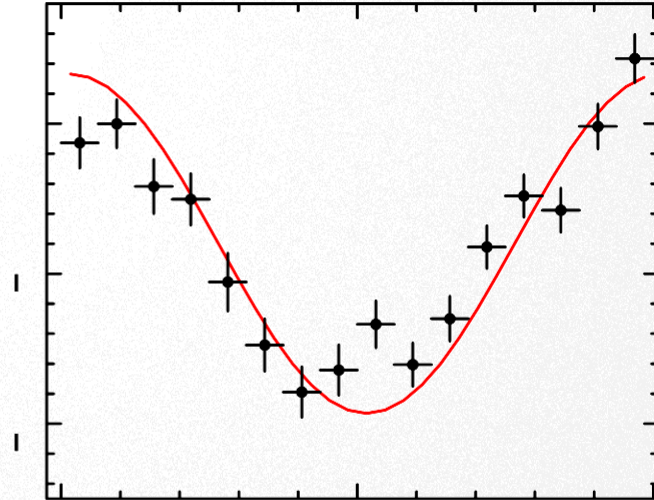
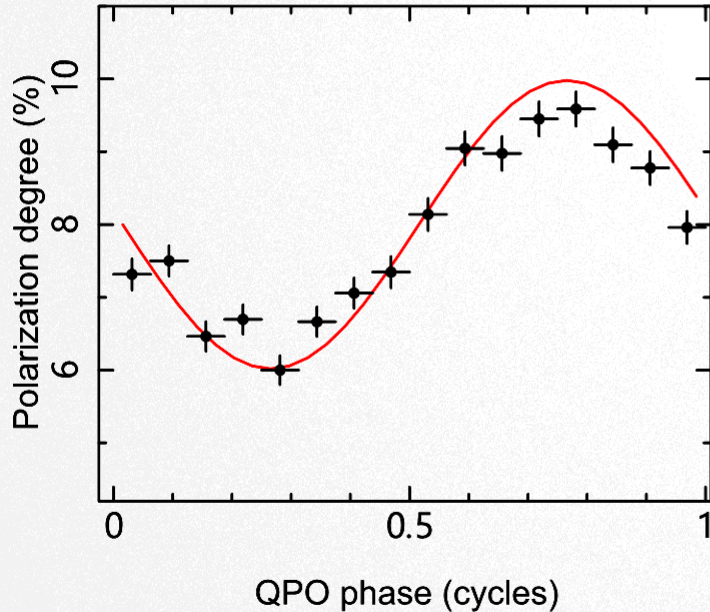




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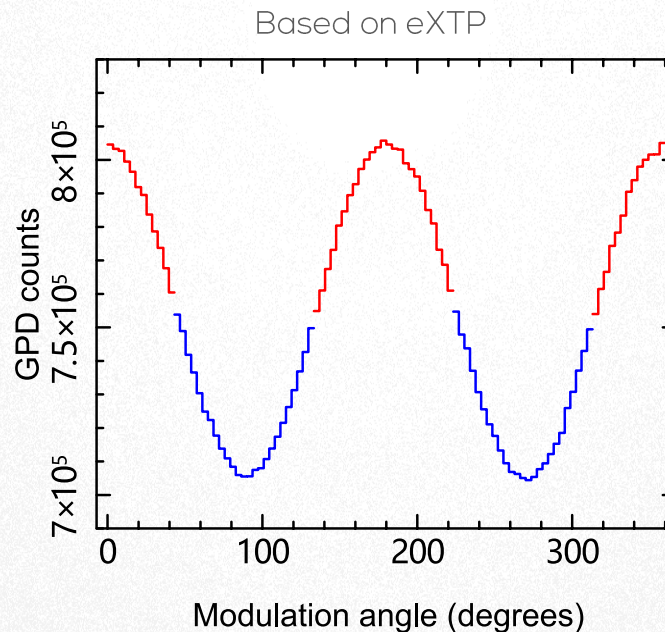
GRS 1915+105 based on eXTP





- Accretion in strong field gravity

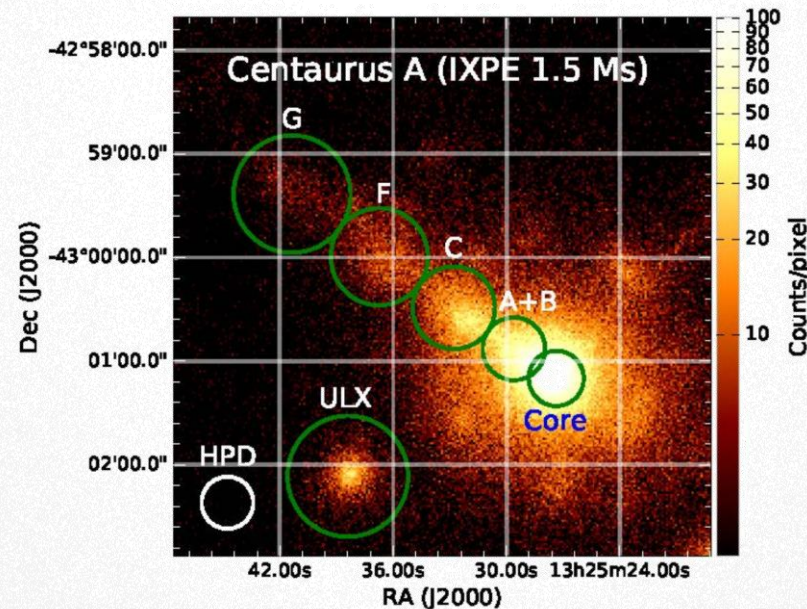
- constrain the geometry of the innermost flow & outflow
 - ◆ a weakly polarized component from the corona
 - ◆ a strongly polarized component from the jet



- Accretion in strong field gravity

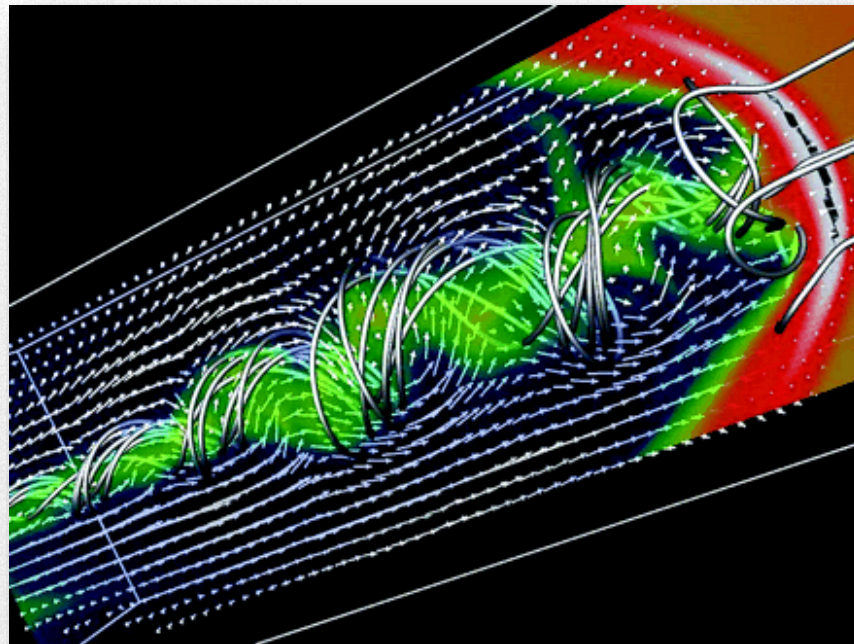
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Based on IXPE



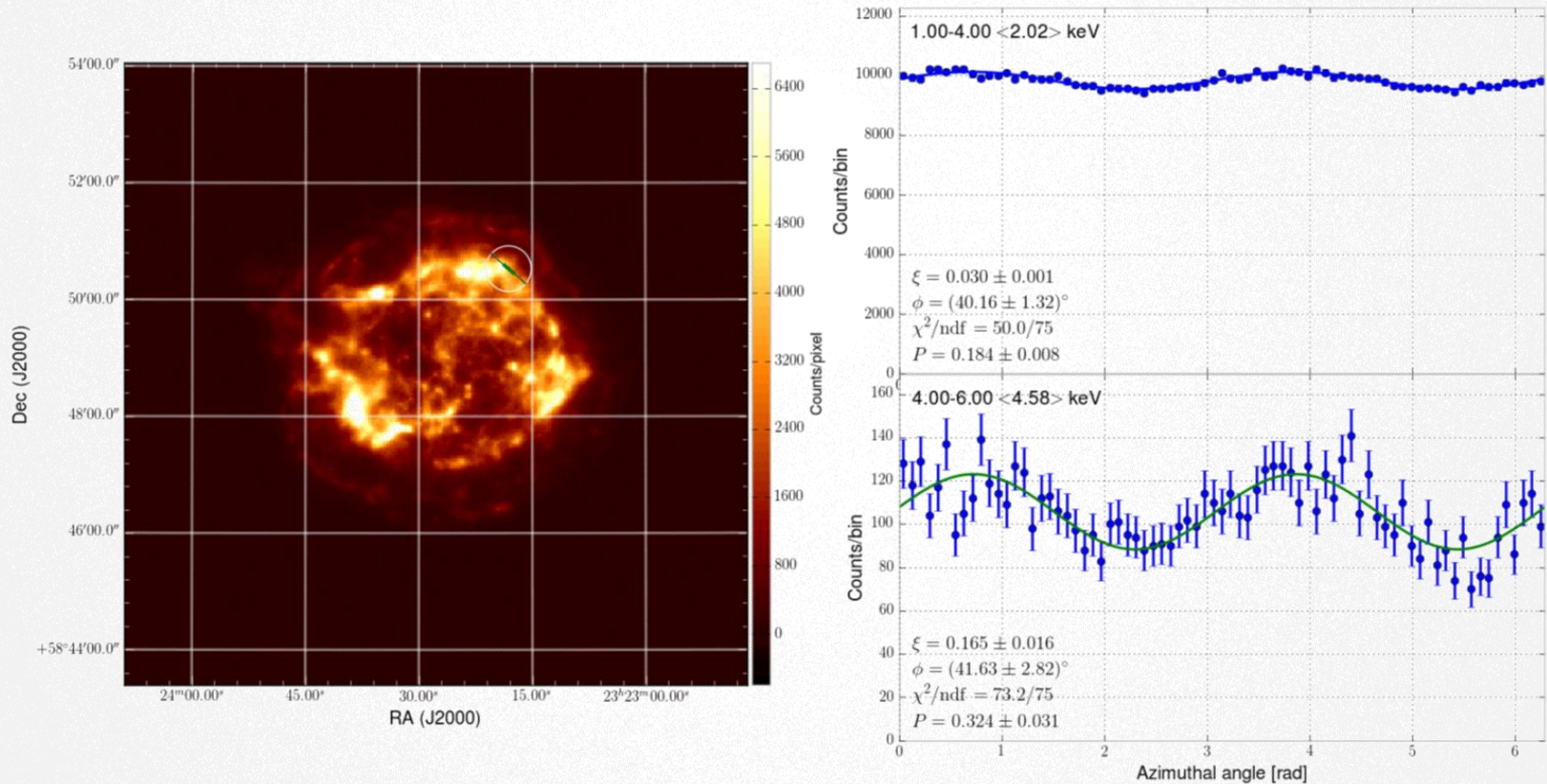
- Accretion in strong field gravity

- constrain the geometry of the innermost flow & outflow
 - ◆ quasi-perpendicular shocks
 - ◆ quasi-parallel shocks



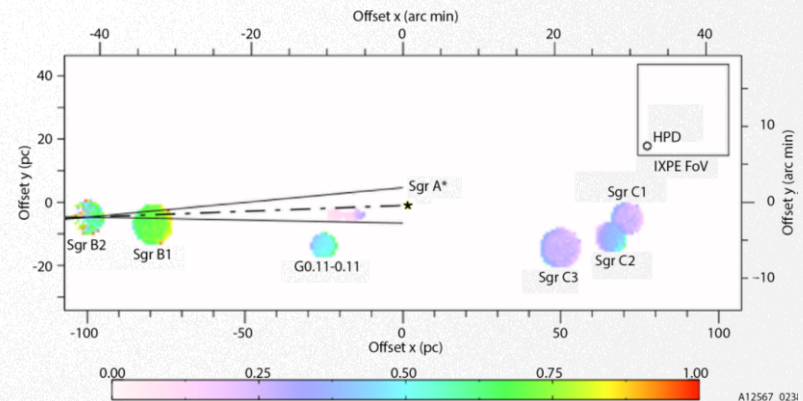
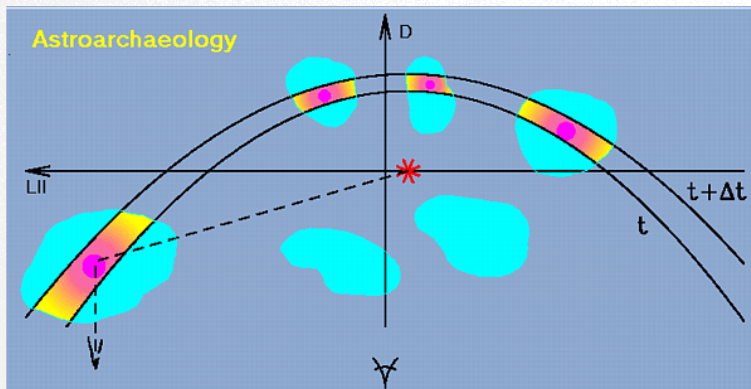
• Map magnetic field of extended sources

Cas A SNR based on IXPE



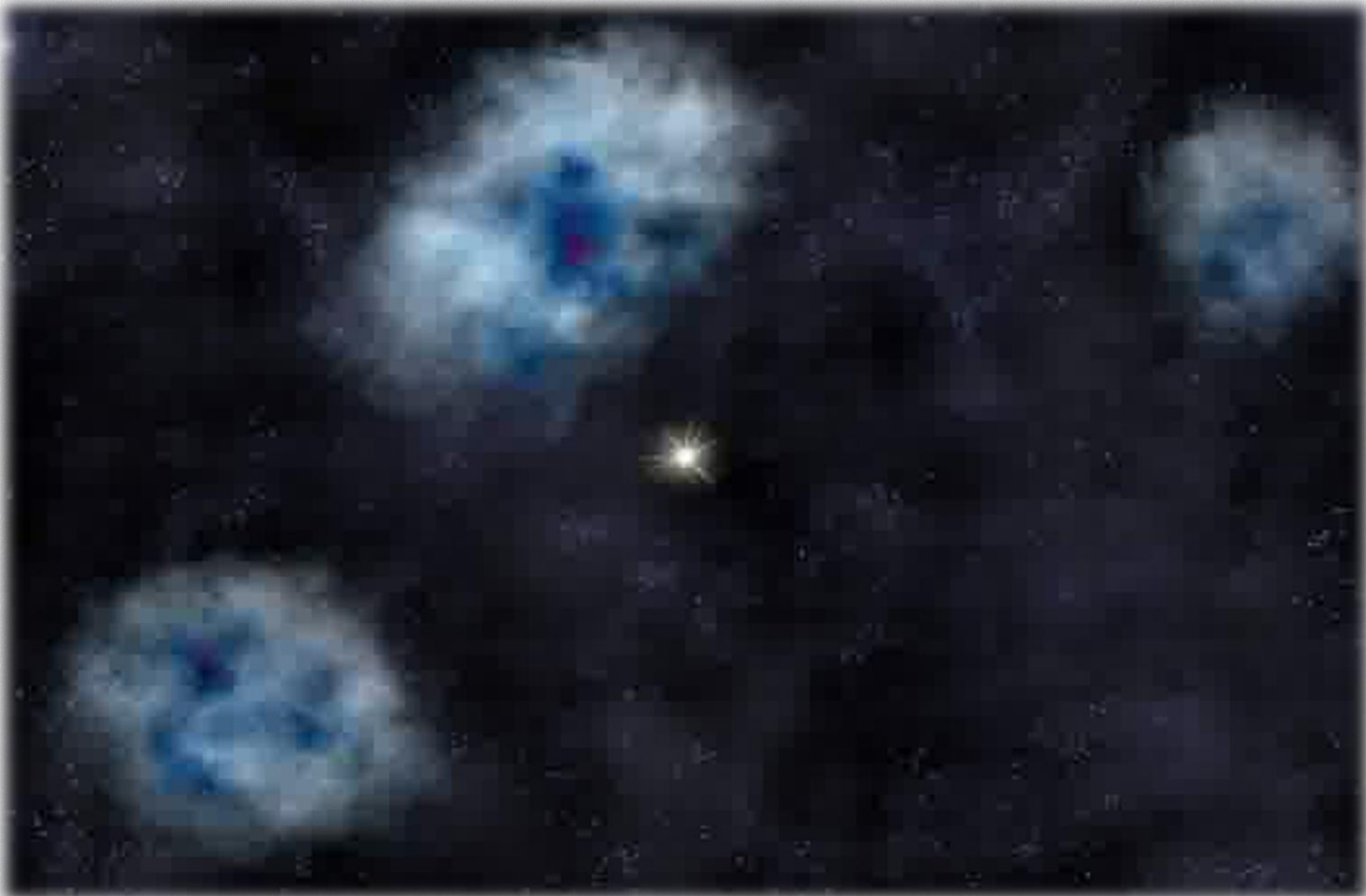
• Test reflection-nebula hypothesis for X rays

- Galactic Center molecular clouds are known X-ray sources
- If MCs reflect X-rays from Sgr A* (Thomson scattered)
 - ◆ X-radiation would be highly polarized perpendicular to plane of reflection & indicates the direction back to Sgr A*
 - ◆ Sgr A* X-ray luminosity was 10^6 larger \approx 300 years ago



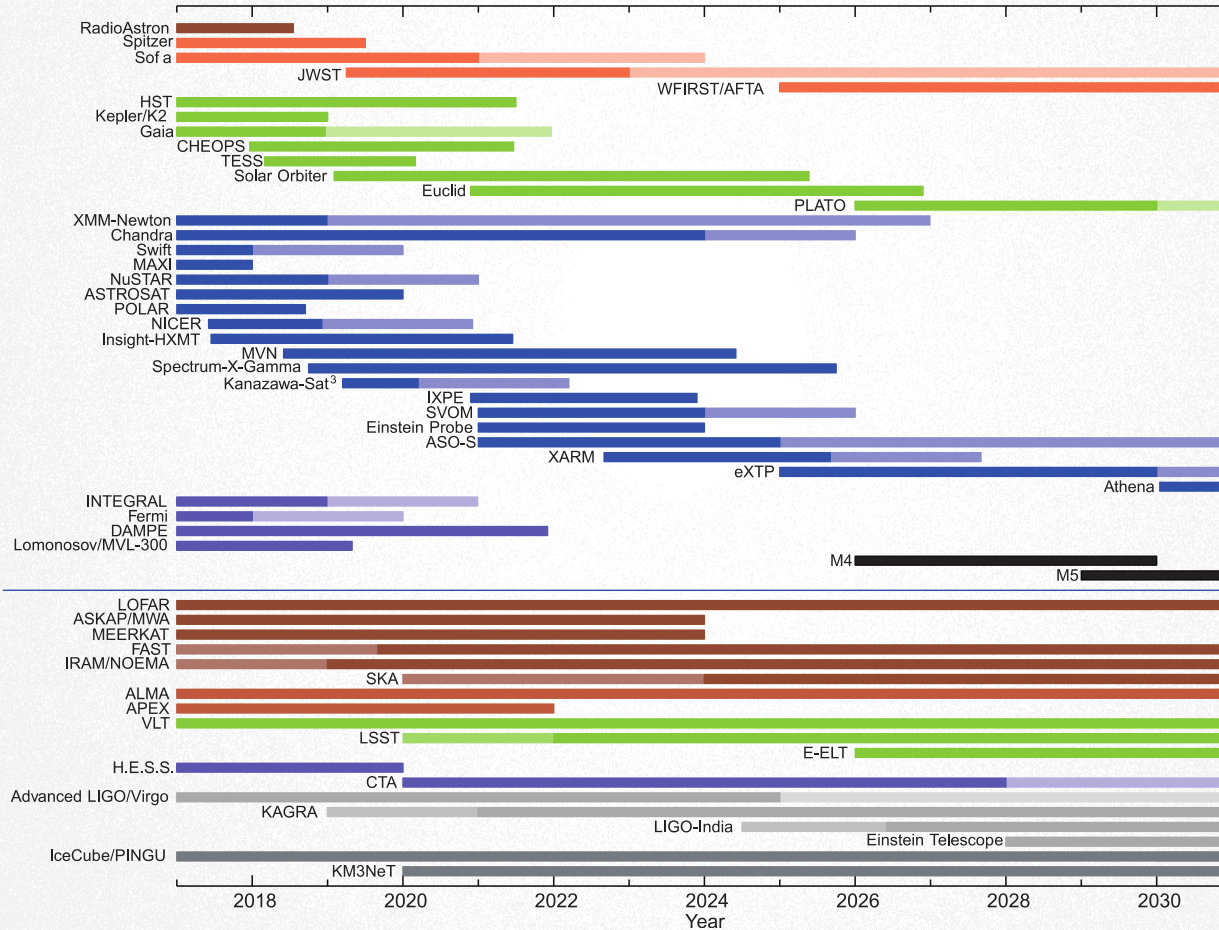


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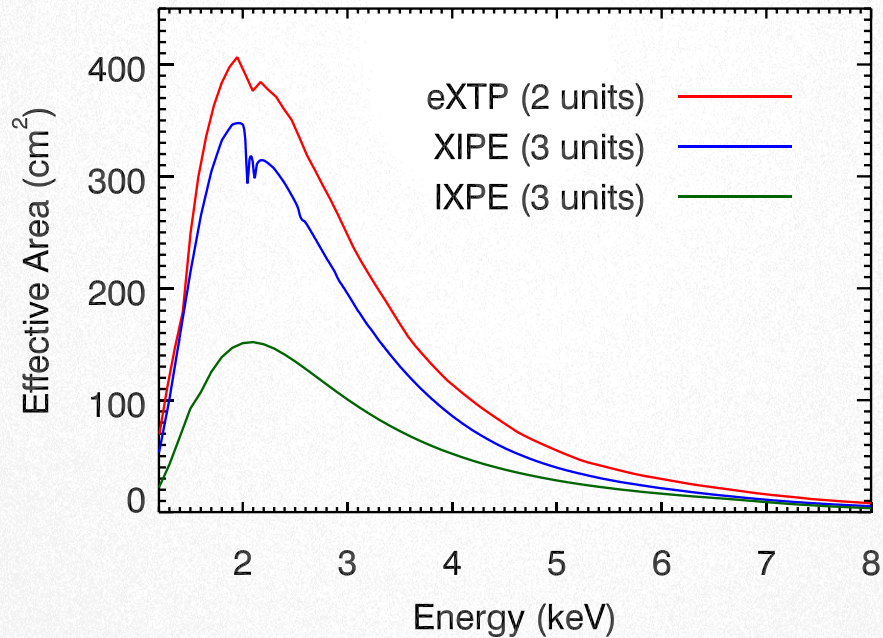
eXTP vs. XIPE vs. IXPE





eXTP vs. XIPE vs. IXPE

3 keV		4 keV
248	eXTP	114
195	XIPE	86
101	IXPE	52





Summery

- Polarimetry is a new window of astrophysics
- Current discussions of the science cases are mostly about the discovery sciences; we need to discuss sciences that requires deeper polarimetric observations
- At least 100 times more sensitive than polarimeters of last century
- A milestone of the multi-messenger exploration of the universe in the next decade.