KIAA-WAP II



Sensitive X-ray Polarimetry

progress and future perspective

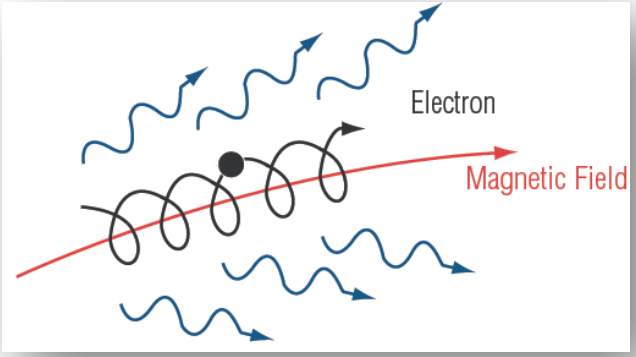
Hua Feng
Tsinghua University

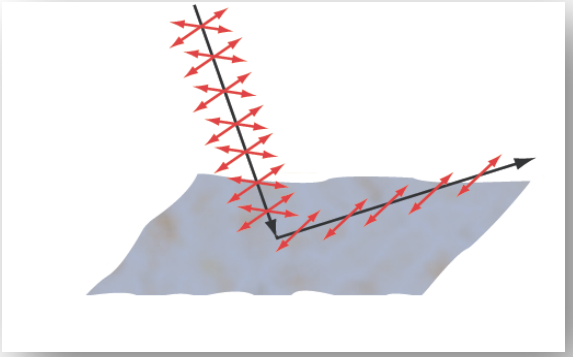
Outline

- Science with X-ray polarimetry
- A Very Brief History
- Today and the Future

What can we learn with X-ray polarimetry?

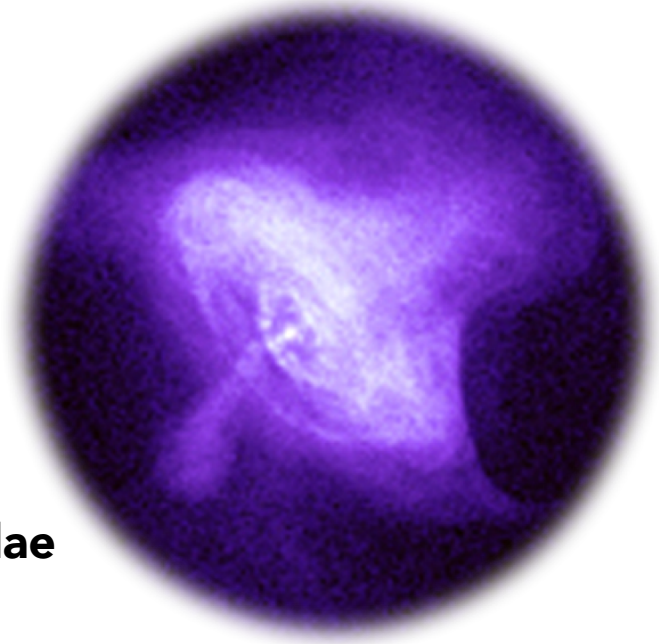
- **Information about the magnetic field**
  - Synchrotron radiation (PWNe, SNRs, Jets)
  - Plasma polarization (Magnetized plasma)
  - Vacuum polarization (Neutron Stars)
- **Information about the scattering medium**
  - Thomson/Compton/InverseCompton scattering
  - Geometric Symmetry (accretion flow, BH spin, Sgr B2, etc.)





Unique science cases

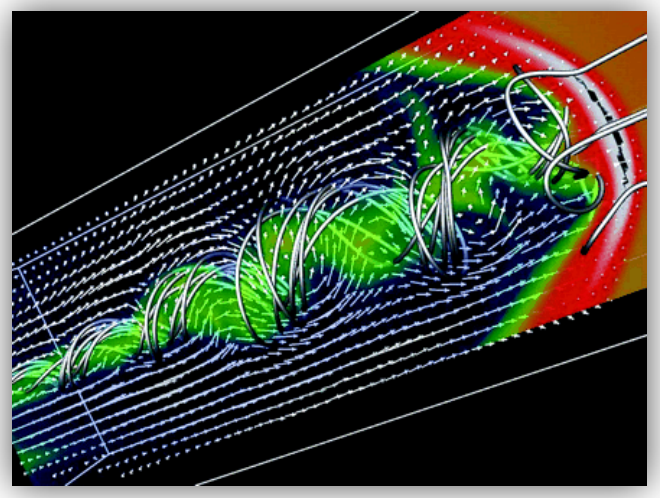
- Particle acceleration
  - Probe the magnetic fields and place constraints on the acceleration mechanism
  - Imaging polarimetry



Pulsar wind nebulae

Unique science cases

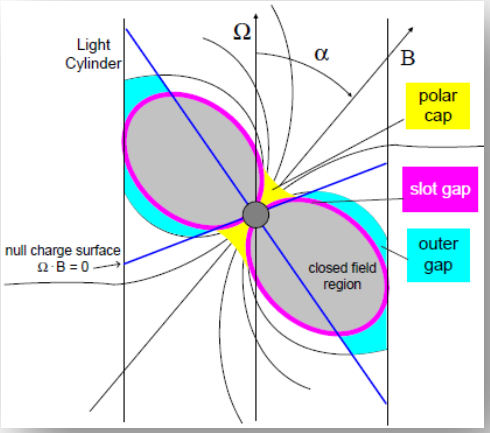
- Relativistic X-ray jets
  - Role of magnetic fields in jet formation (Marscher 2014)
  - Leptonic or hadronic? (Zhang & Bottcher 2013)
  - Emission mechanism for the blazar high energy peak

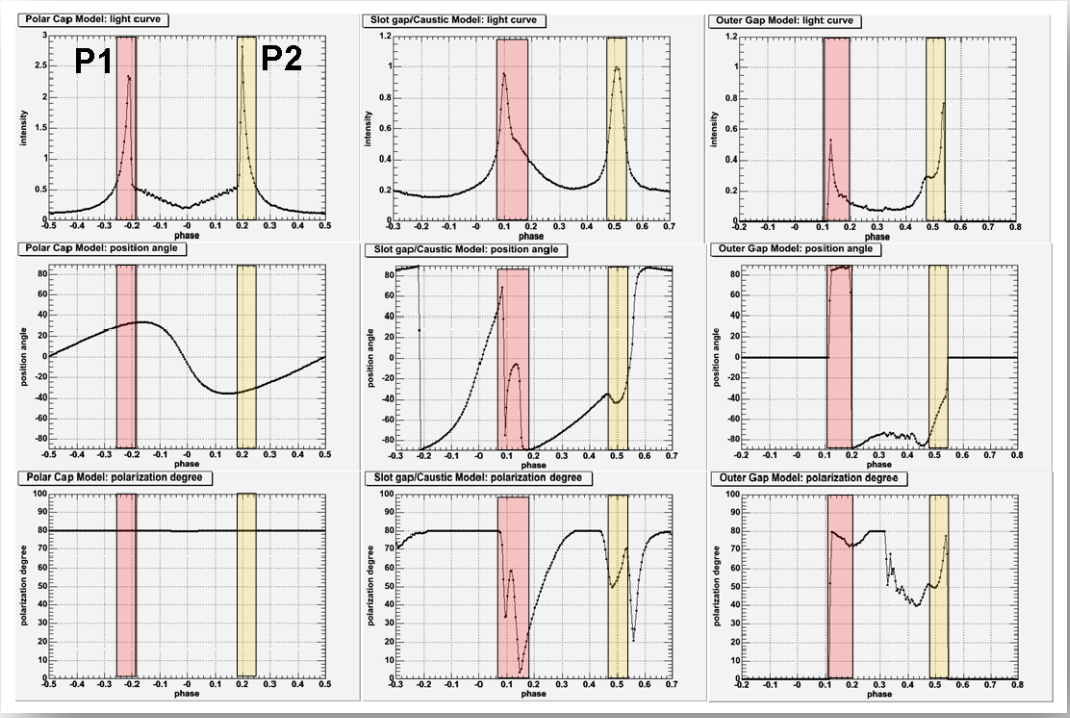


Blazars **GRB afterglows** **Jetted TDEs**

Unique science cases

- Pulsars
  - Rotation-powered
    - test the emission geometry

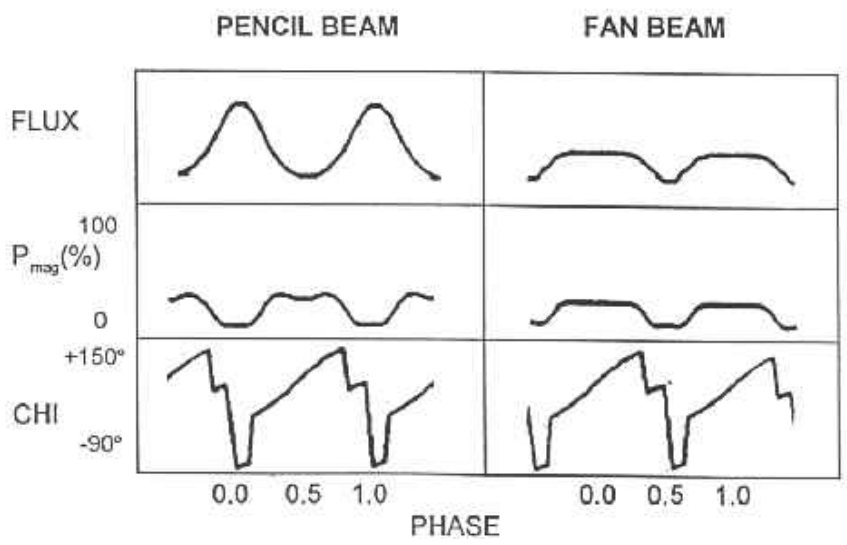




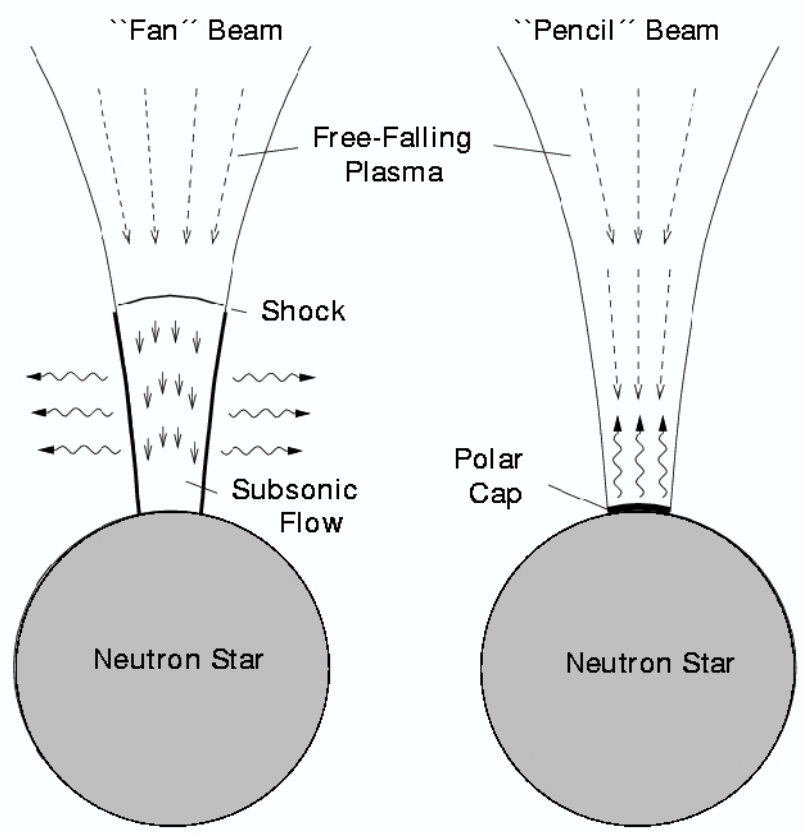
Polar cap (Daugherty & Harding 1996)
Slot gap (Muslimov & Harding 2004)
Outer gap (Romani 1996; Takana 2007)

Unique science cases

- Pulsars
  - Accretion-powered
    - fan beam vs. pencil beam

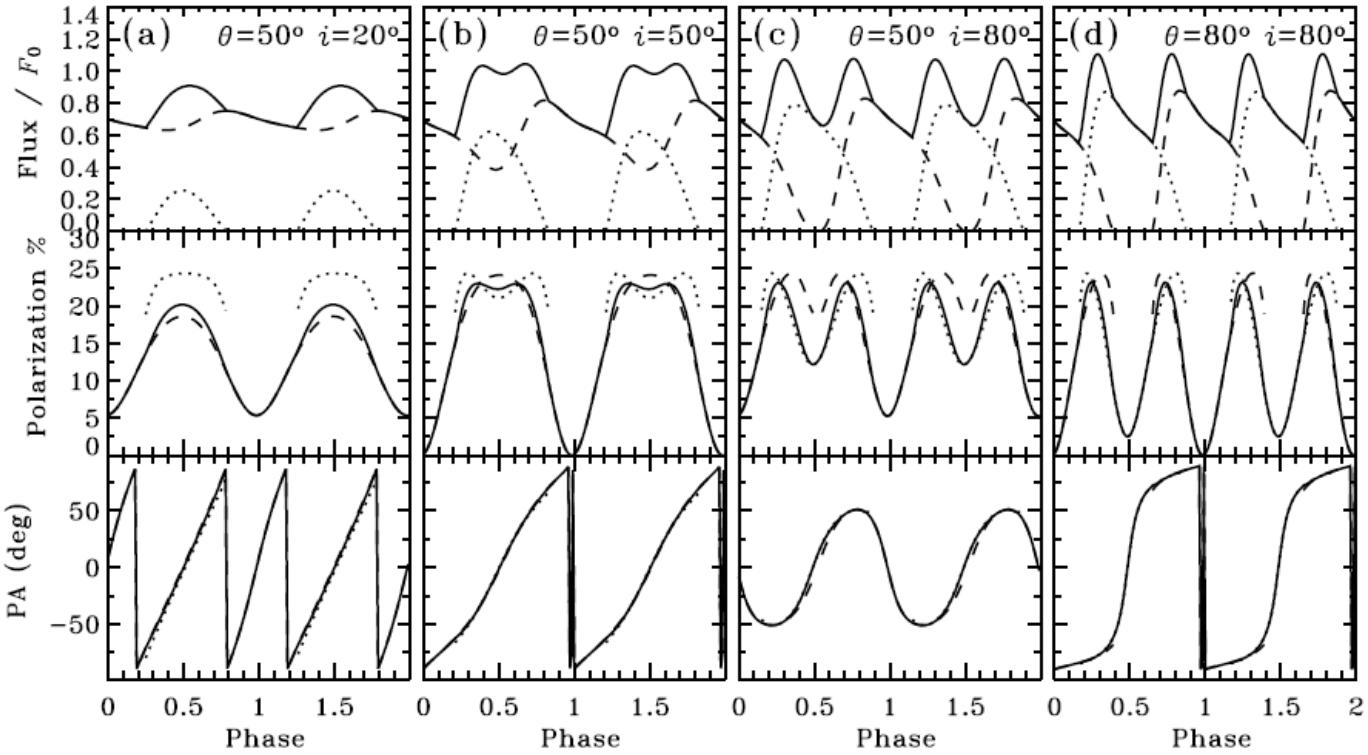


(Meszaros et al. 1988)



Unique science cases

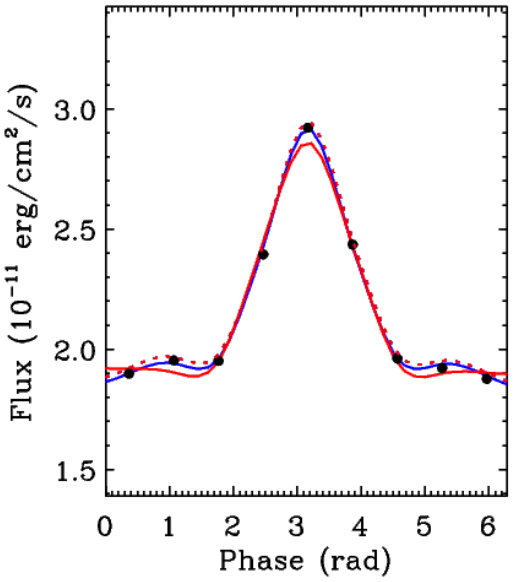
- Pulsars
  - Accreting millisecond pulsars
    - test the geometry; constraints on *M*/*R*
    - Polarimetry can help determine the geometry and orientation of the B fields

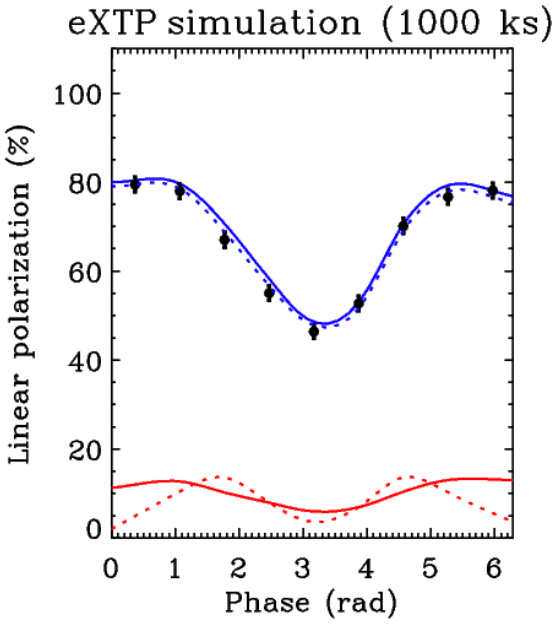


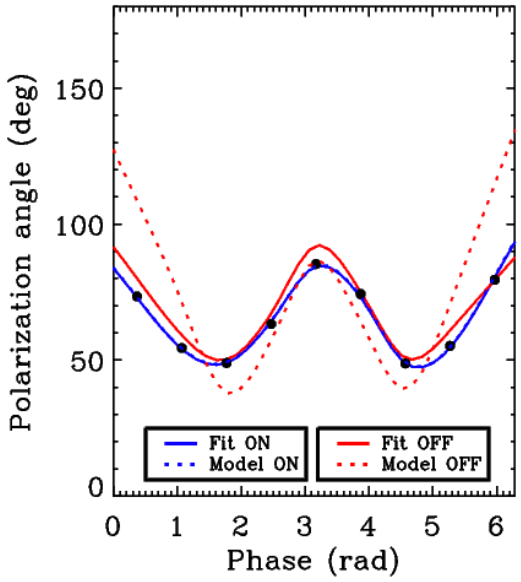
(Viironen & Poutanen 2004)

Unique science cases

- Pulsars
  - Surface thermal emission
    - QED effects (vacuum birefringence) & B-field geometry
    - Tested in optical (RX J1856.5-3754; Mignani et al. 2017)
  - SGRs & AXPs



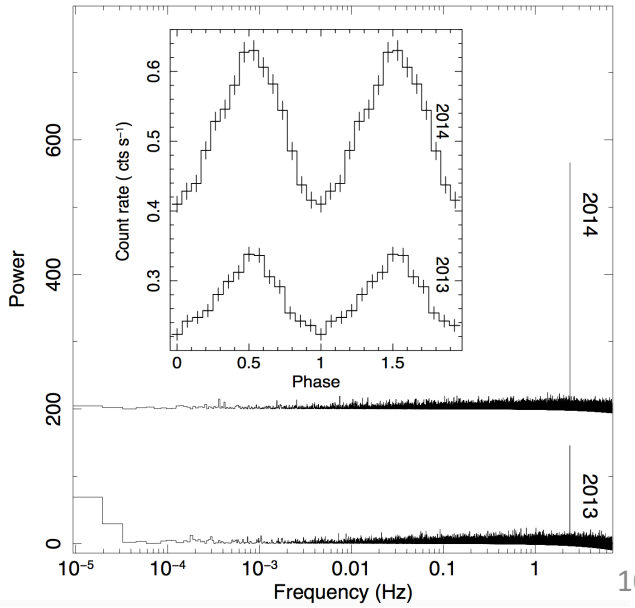




Simulations by R. Taverna and R. Turolla

Unique science cases

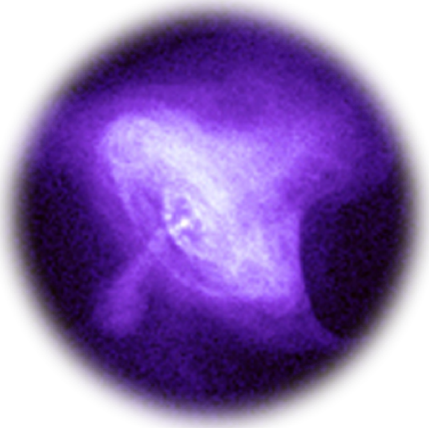
- Pulsars
  - Ultraluminous X-ray pulsars
    - 3 known objects
      - M82 X-2 (Bachetti et al. 2014) – crowded region
      - NGC 7793 P13 (Israel et al. 2016; Furst et al. 2016)
      - NGC 5907 ULX-1 (10^{41} erg s^{-1}; Israel et al. 2016)
    - Why they can break the Eddington limit by a factor of ~500
    - Sinusoidal modulation – no strong beaming
    - Large variability and bimodal luminosity distribution – propeller effect
- highly magnetized neutron stars (e.g., Dall'Osso, Perna & Stella 2015; Eksi et al. 2015; Mushtukov et al. 2015; Tsygankov et al. 2016)
- low magnetic neutron stars (Kluzniak & Lasota 2015)



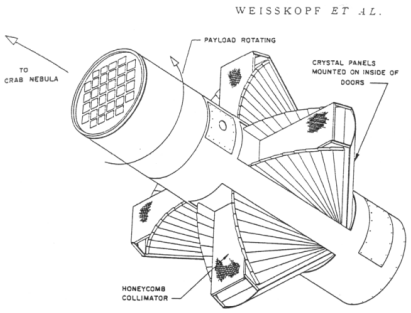
History of X-ray Polarimetry

Exploration of the new window – since 1960s

First attempt: 1968
Scattering polarimeter
Aerobee 150



First precise measurement: 1975
Bragg polarimeter, OSO-8
P = 19.2% ± 1.0%
ψ = 156.4°± 1.4°
Weisskopf et al. 1976, 1978



First detection: 1971
Bragg polarimeter
Aerobee 350
Crab nebula P = 15.4% ± 5.2%

First satellite: 1974
Flat Bragg crystal
Ariel 5

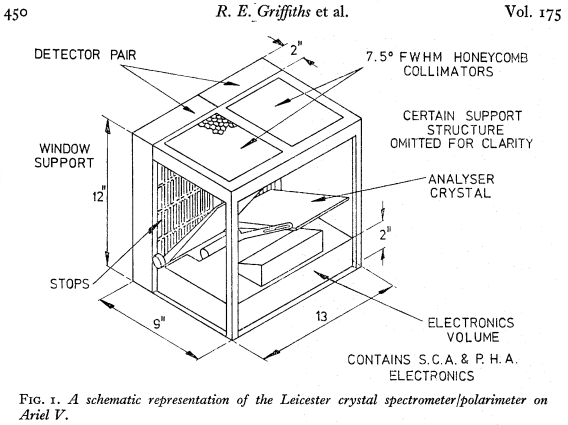
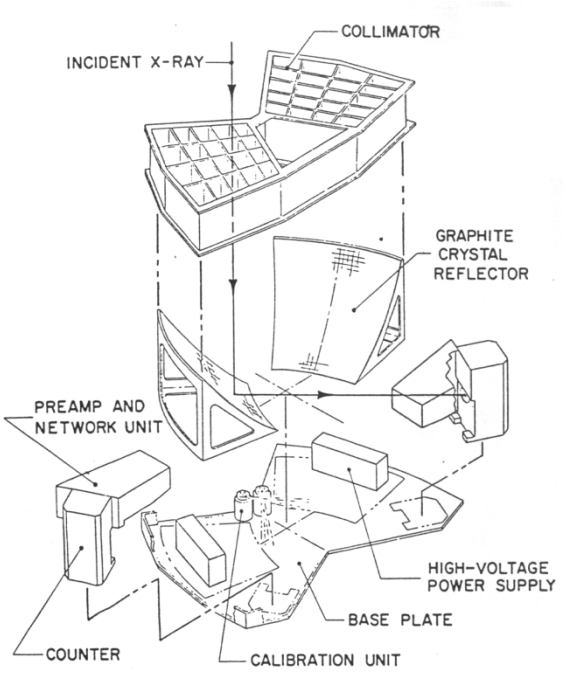
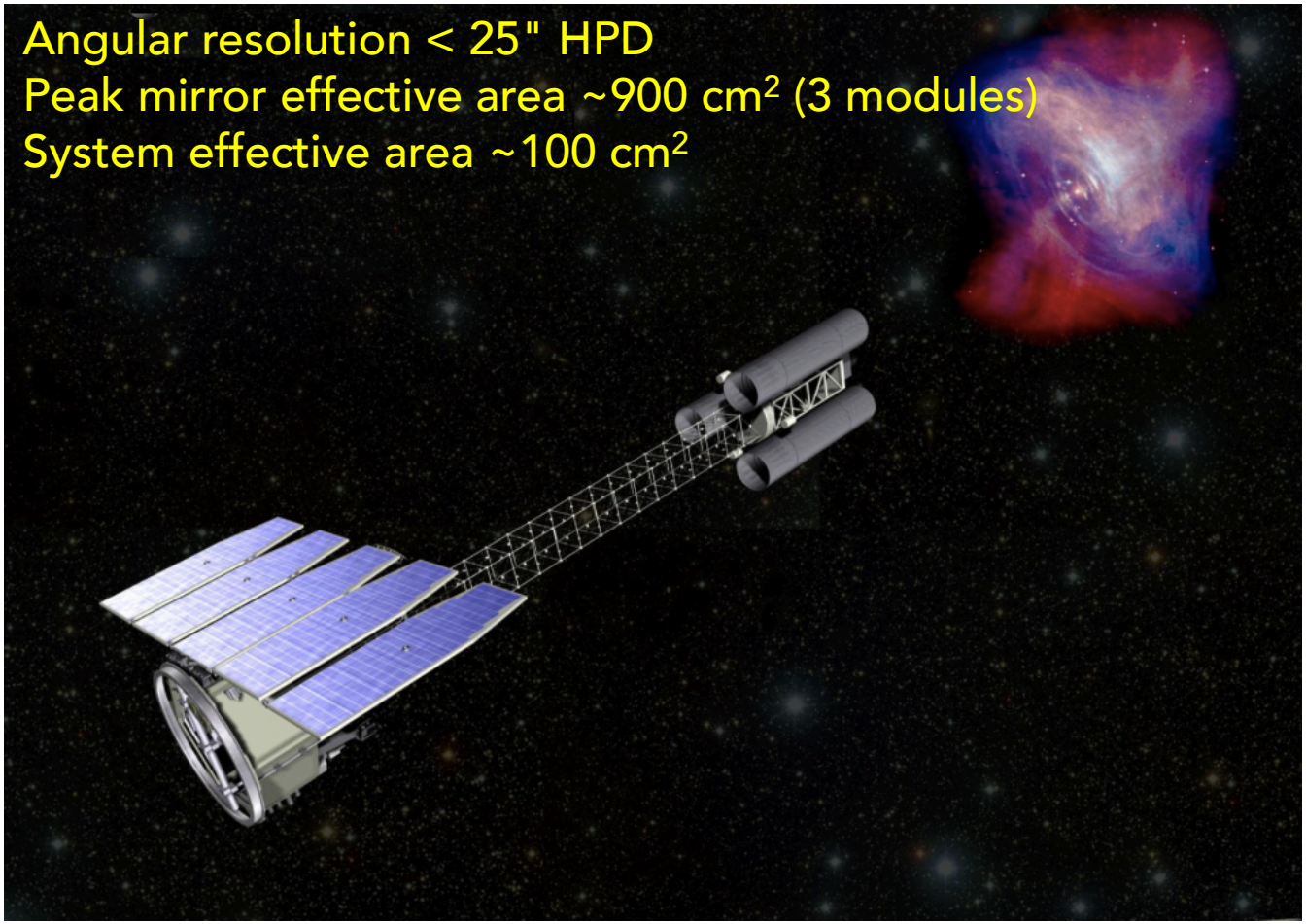


FIG. 1. *A schematic representation of the Leicester crystal spectrometer/polarimeter on Ariel V.*



NASA SMEX – IXPE

- selected in 2015, to be launched in November 2020



100 times more sensitive than the polarimeter on OSO-8

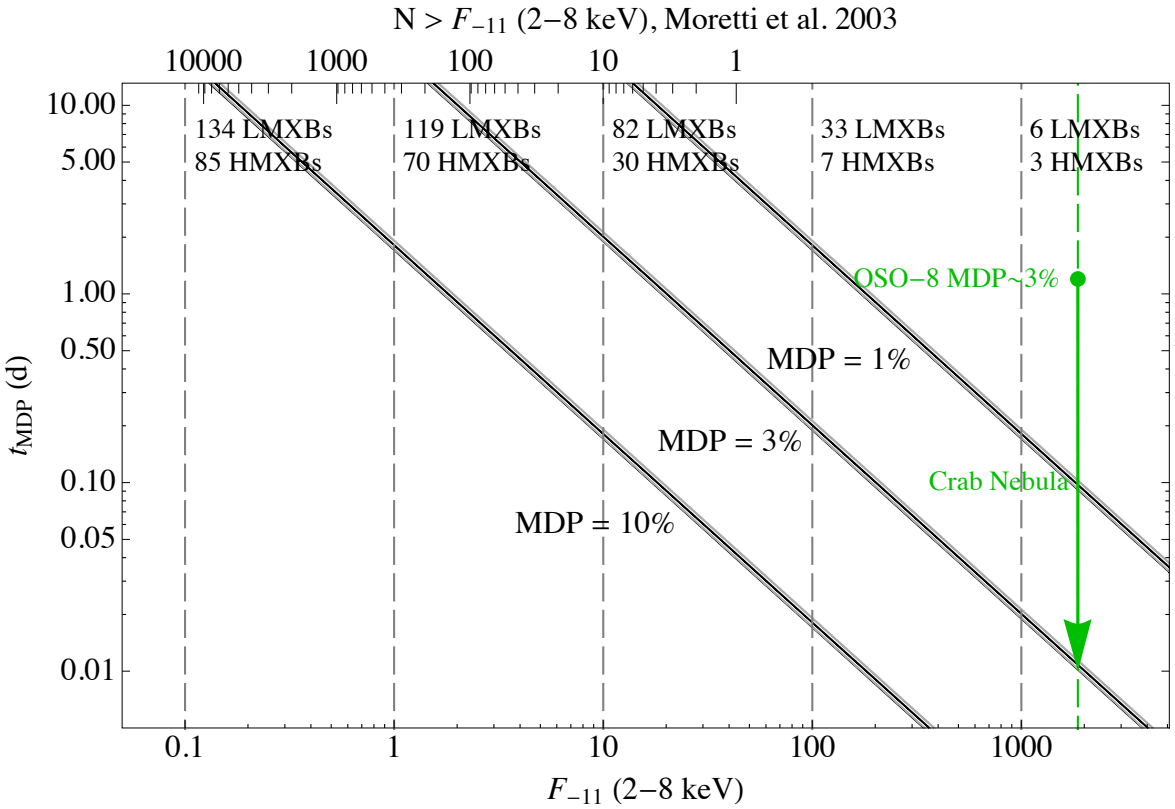


Figure 10—IXPE polarization sensitivity. The plot displays the integration time (in days) to reach a given $MDP_{99\%}$, as a function of 2–8-keV source flux (in 10^{-11} ergs cm^{-2} s^{-1}). See text for details.

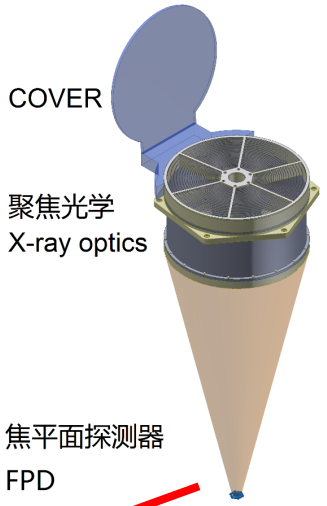
40 targets within 6-month discovery phase:

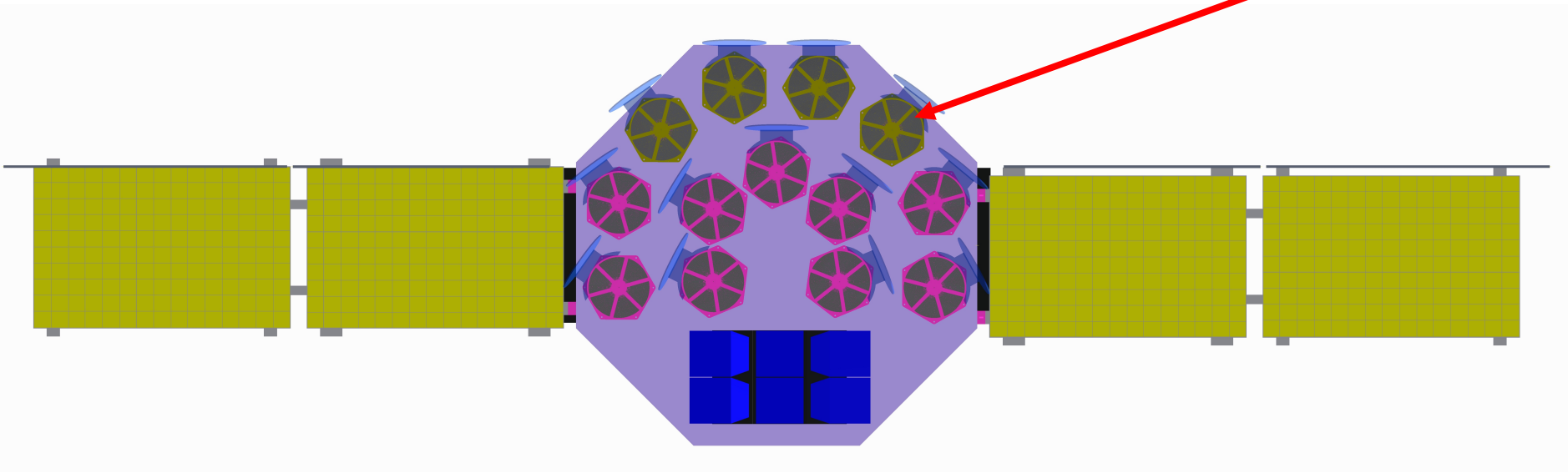
4 PWNe, 4 other pulsars, 12 LMXBs, 6 HMXBs, 8 blazars, and 6 other AGNs.

(Weisskopf et al. 2008)

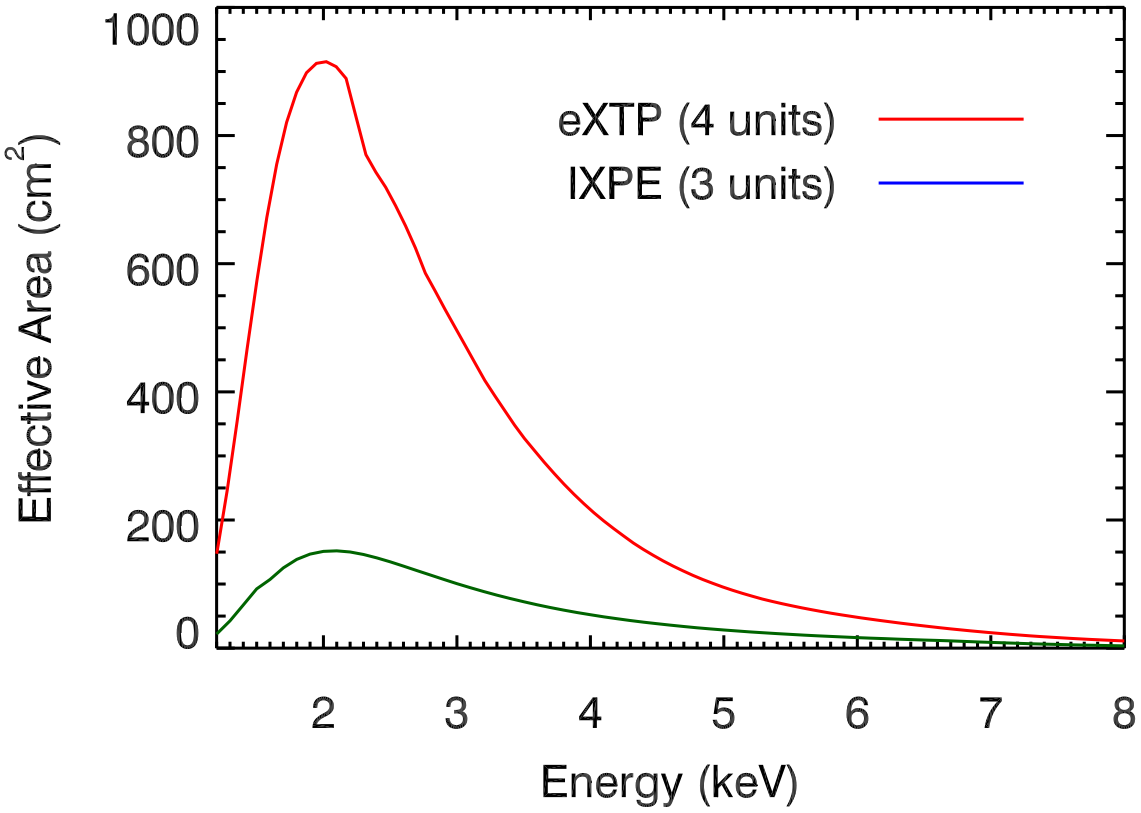
enhanced X-ray Timing & Polarization (eXTP)

Payload	Configuration
Spectroscopic Focusing Array	9 sets/SGO/SDD element
Polarimetric Focusing Array	4 sets/Nickel based optics/GPD
Large Area Detector	40 modules/Pb glass/SDD
Wide Field Monitor	3 units/1.5D coded mask/SDD





eXTP vs. IXPE


1000
800
600
400
200
0
Effective Area (cm^2)
2
3
4
5
6
7
8
Energy (keV)
eXTP (4 units)
IXPE (3 units)

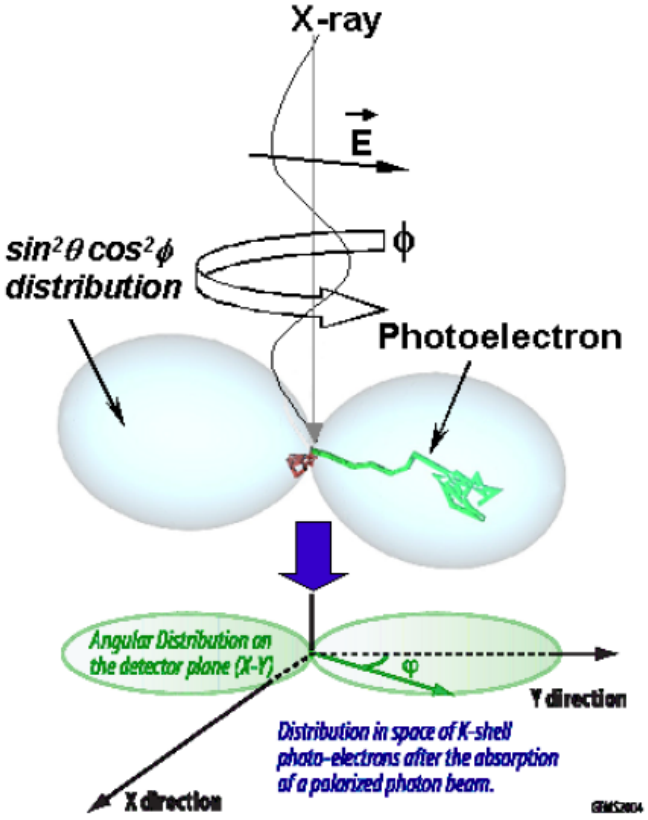
Technical Break & Current Progress

Technical breakthrough

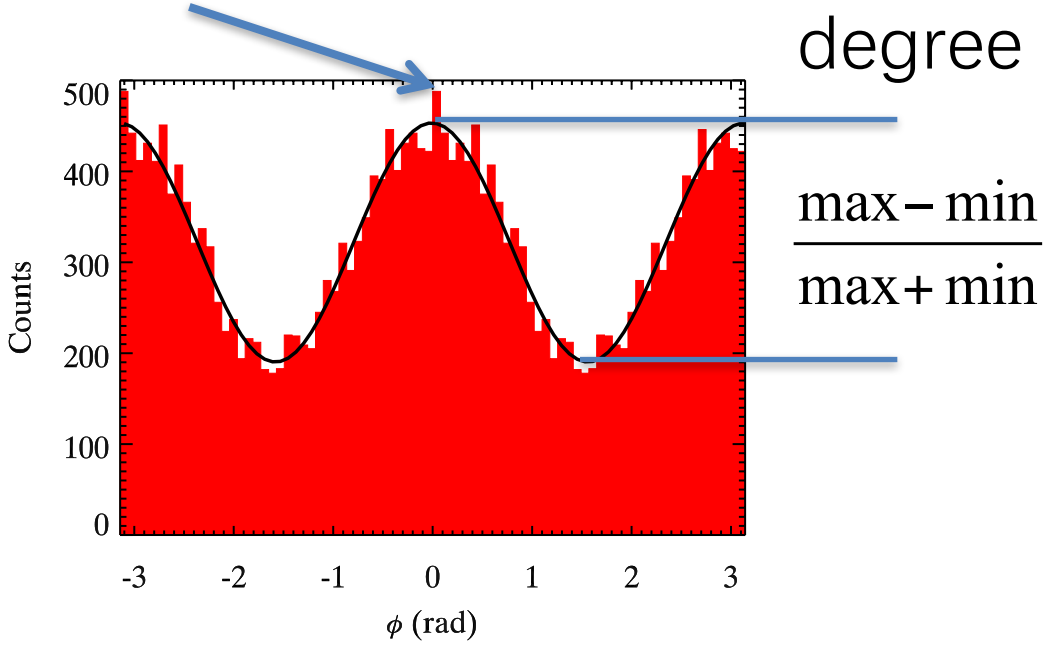
Cross-section of **photoelectric effect**

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

$$\frac{d\sigma}{d\Omega} \propto \cos^2\varphi$$



position angle

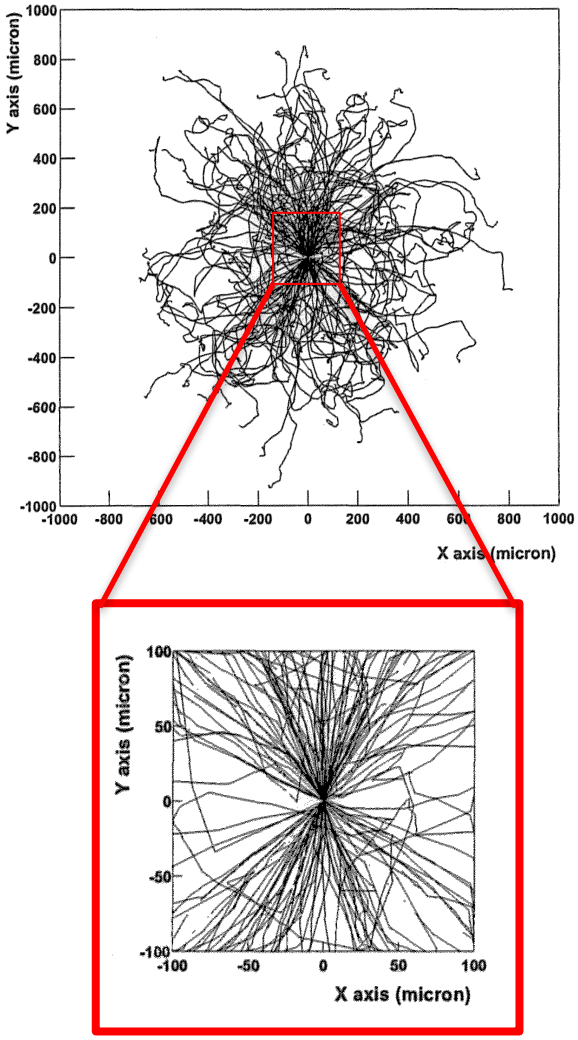


degree

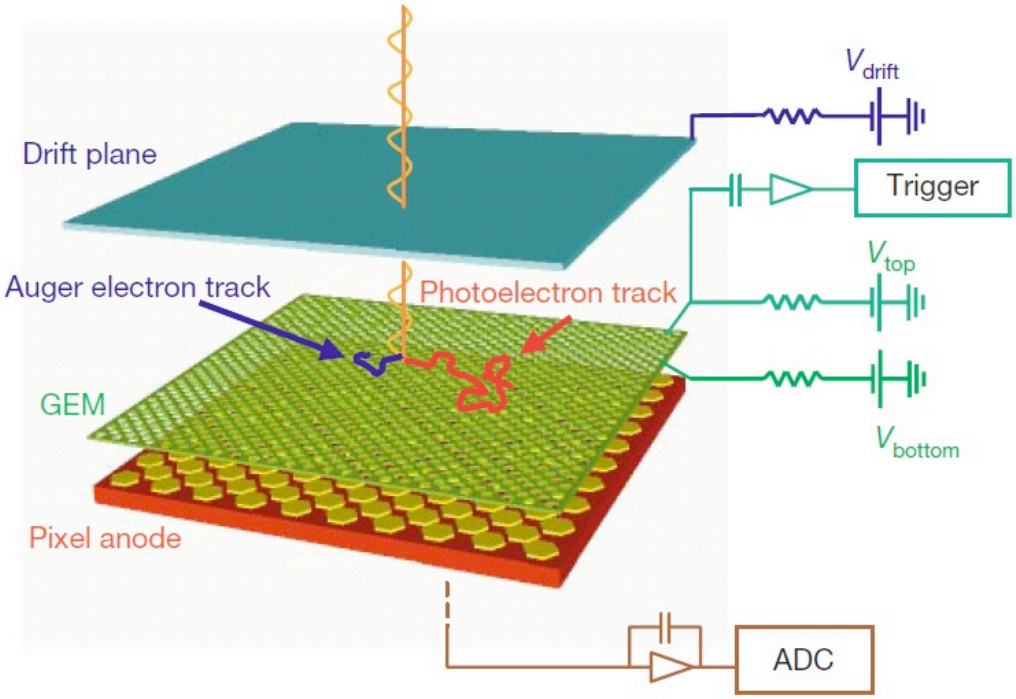
$$\frac{\max - \min}{\max + \min}$$

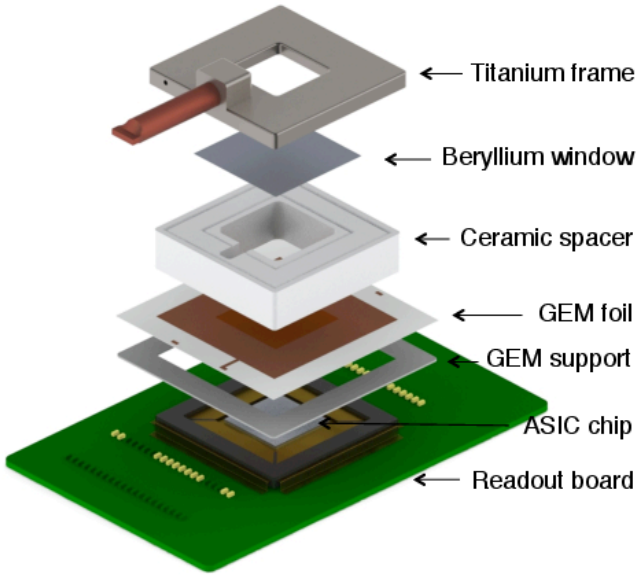
Technical difficulties

- Short range of electrons of a few keV
  - in silicon: ~μm
  - in gas: ~mm
- Electron tracks are not straight during ionization
- Challenge for detector
  - Require 2D imaging device
  - Resolution < 100 μm

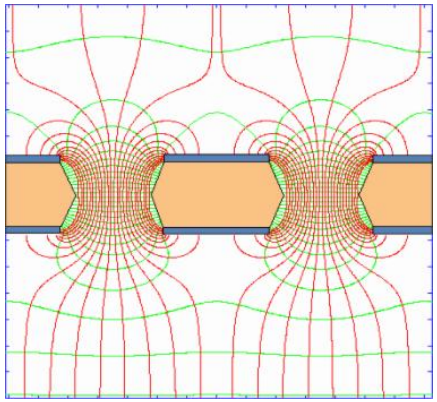


Gas pixel detector (GPD)



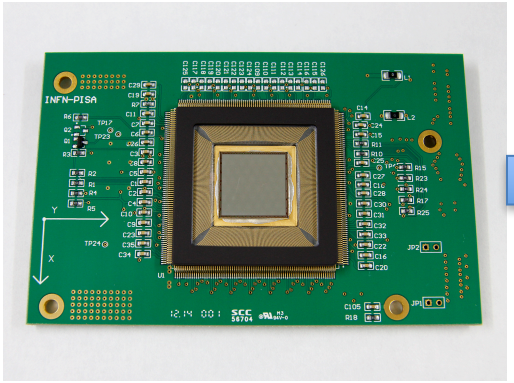


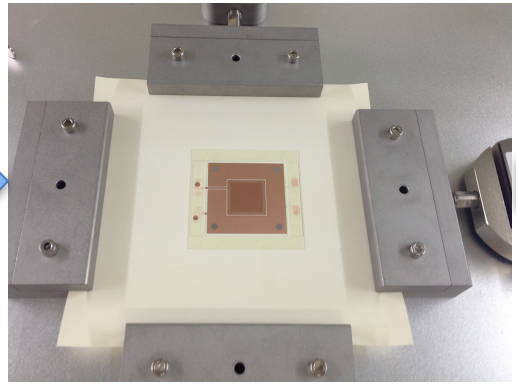
Gas Electron Multiplier (GEM)

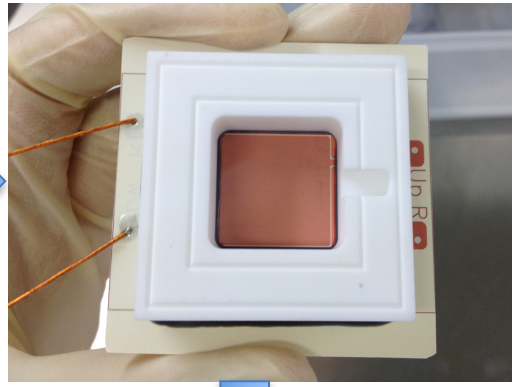


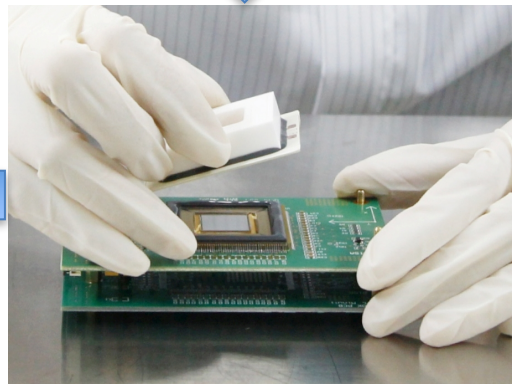
First designed and tested by the INFN-Pisa group (Bellazzini et al.)

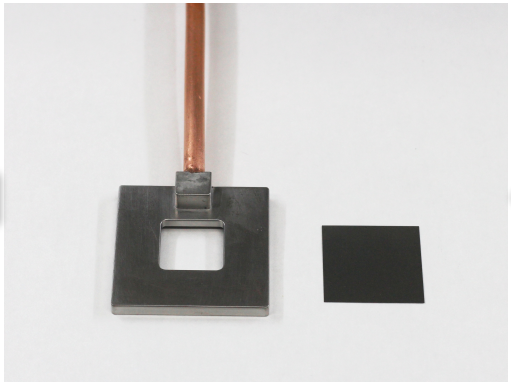
Detector assembly and test at Tsinghua

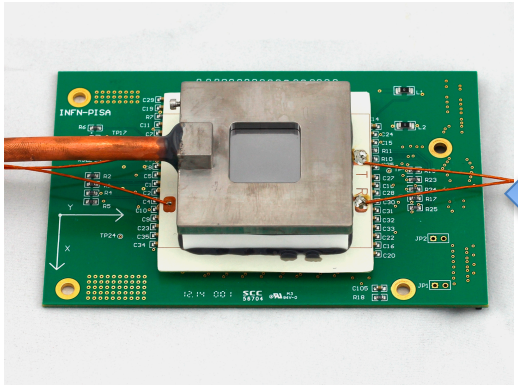




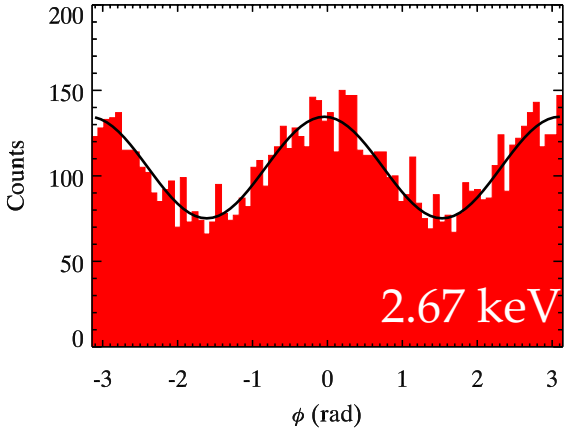


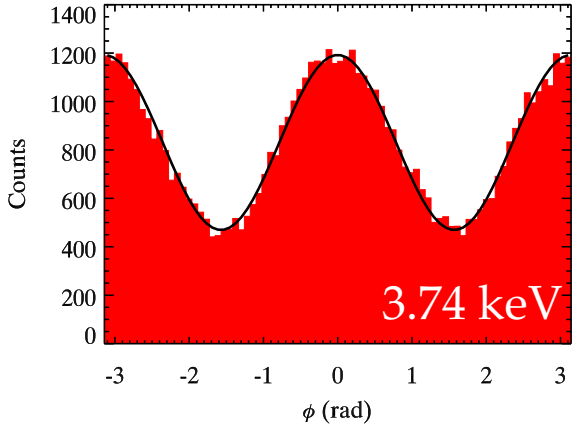


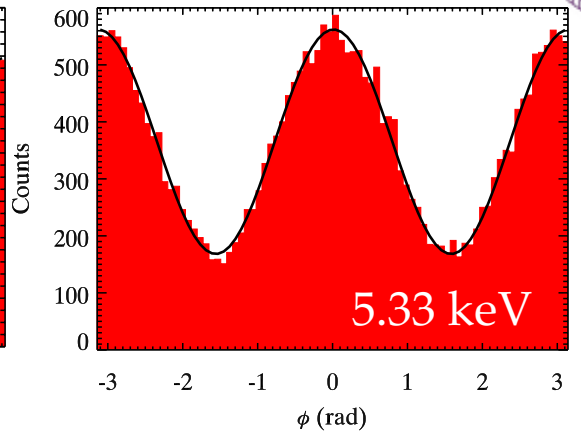


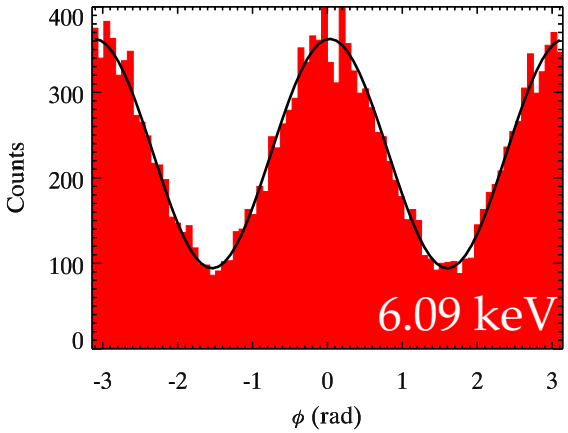


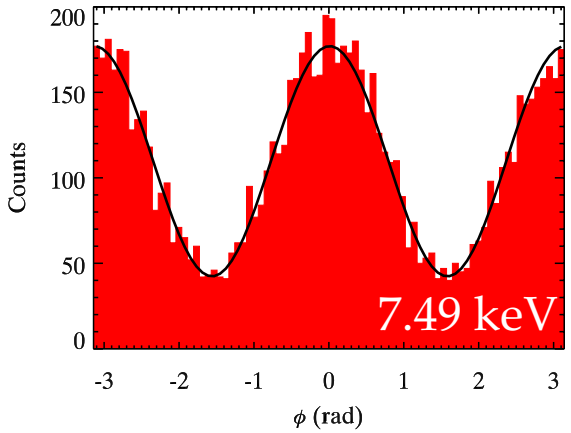
Measurement of fully polarized X-rays

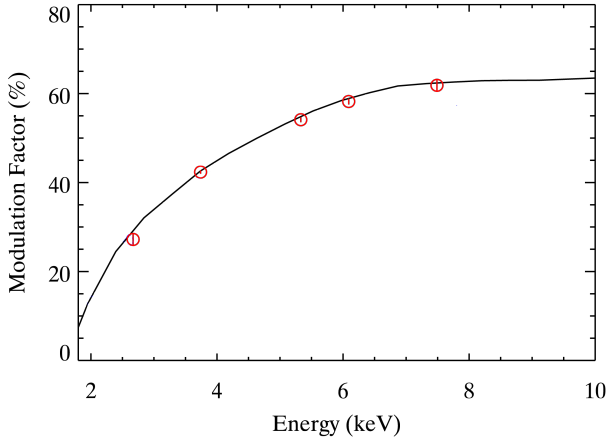


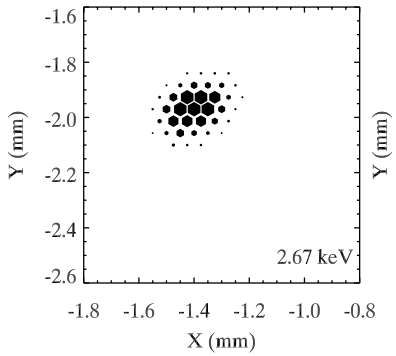


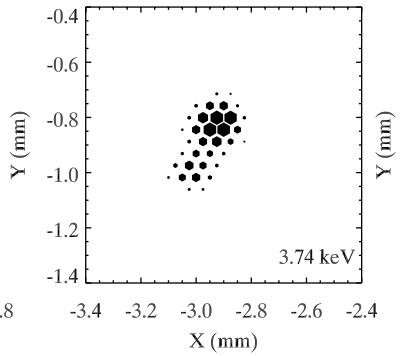


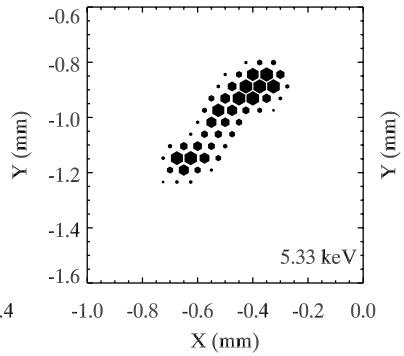


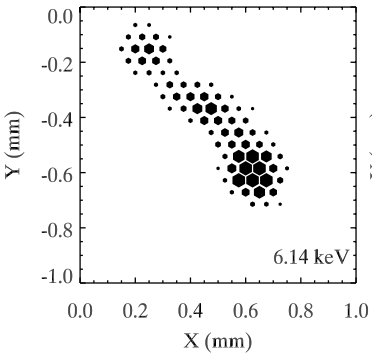


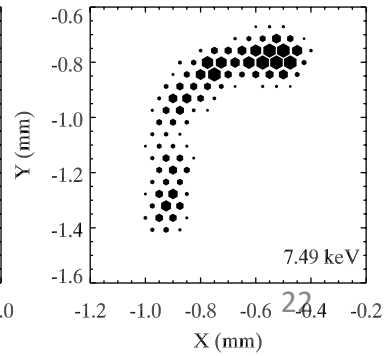






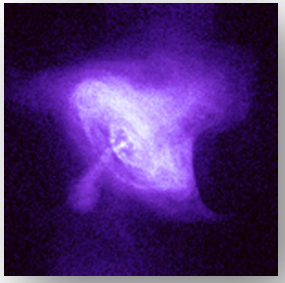






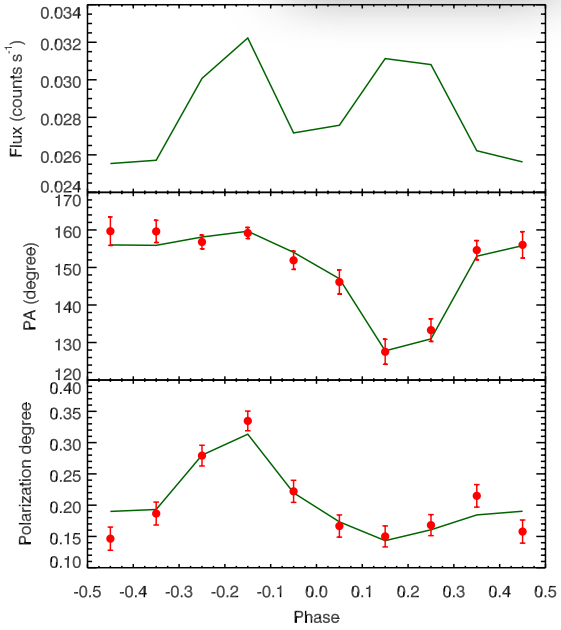
CubeSat flight with GPD

- Science – PWN & pulsar
- Engineering – demonstration









6U CubeSat developed by SpaceTY

Summary

- Science
  - magnetic fields
  - acceleration mechanism



- Technique
  - ready in the lab
  - to be tested in the space soon

Thank You!