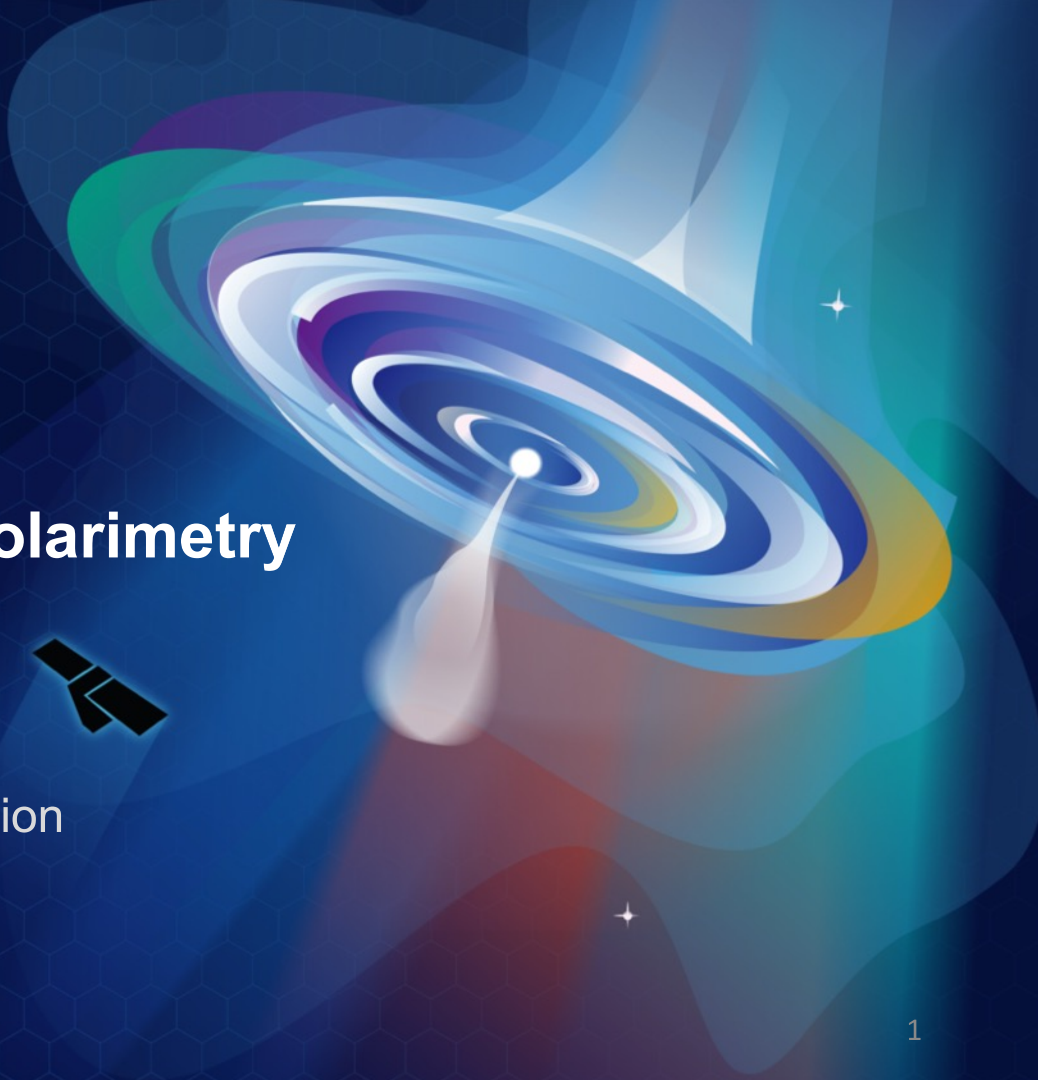
Reopening the window of astronomical soft X-ray polarimetry



Hua Feng 冯骅 (Tsinghua University)
on behalf of the PolarLight collaboration

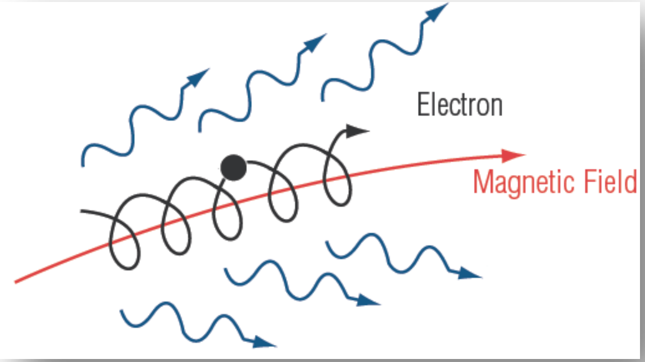
目录
CONTENTS

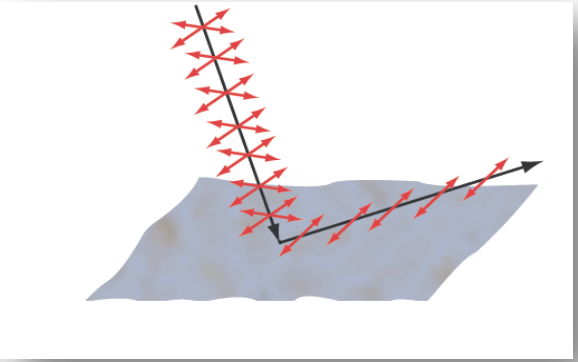
PART ONE

Science with X-ray Polarimetry

What can we learn from X-ray polarimetry?

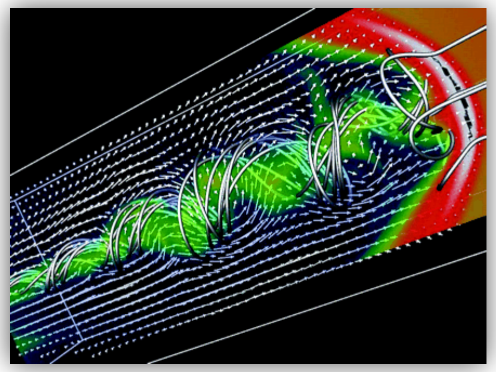
- **Information about the magnetic field**
  - Synchrotron radiation (PWNe, Jets)
  - Plasma polarization (Magnetized plasma)
  - QED vacuum birefringence (Neutron Stars)
- **Information about the scattering medium**
  - Thomson/Compton/InverseCompton scattering
  - Geometric symmetry (accretion flow,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



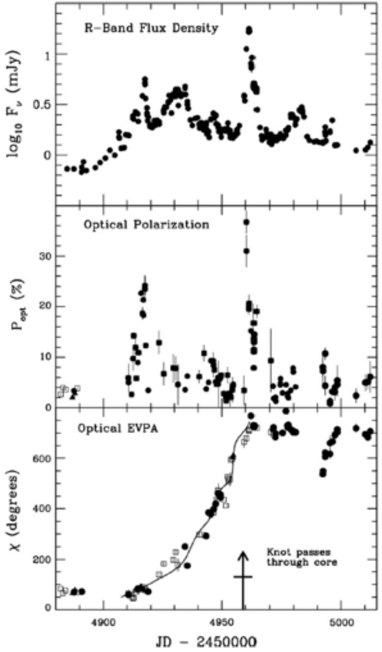


Science cases

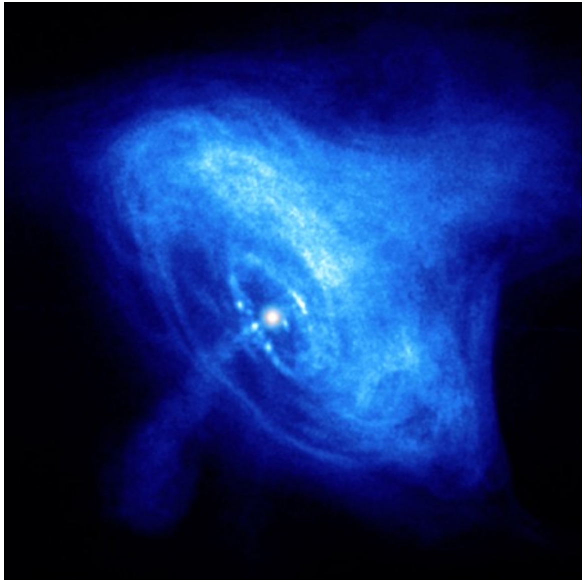
- Synchrotron radiation and B-fields



Blazars GRB Jetted TDEs



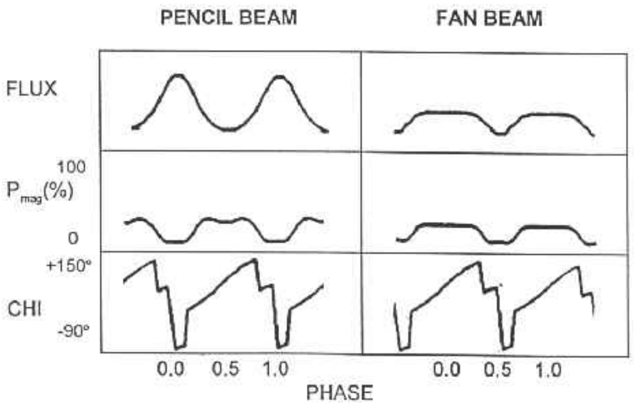
(Marscher et al. 2010)



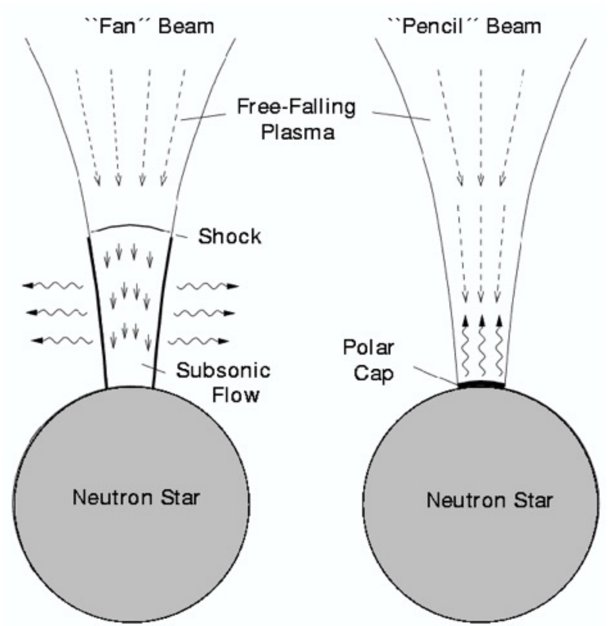
Pulsar wind nebulae

Science cases

- Accreting Pulsars

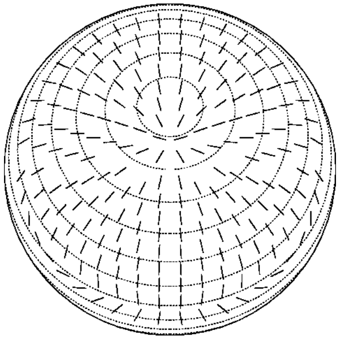


(Meszaros et al. 1988)

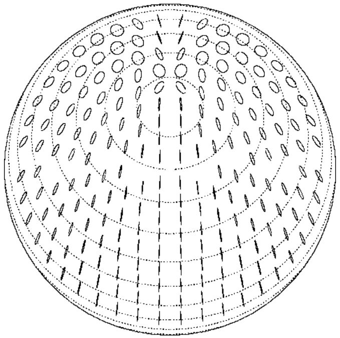


Science cases

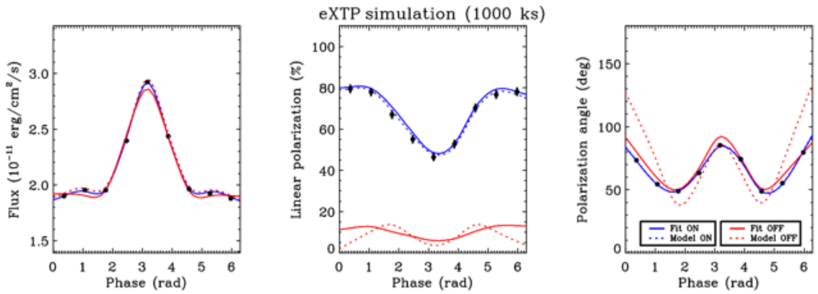
- Surface thermal emission from NSs
  - QED effects (vacuum birefringence) & B-field geometry
  - Tested in optical (RX J1856.5-3754; Mignani et al. 2017)
- – SGRs & AXPs



~10%



~70-80%



Simulations by R. Taverna and R. Turolla

Science cases

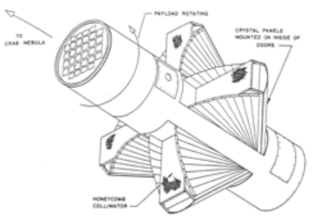
PART TWO

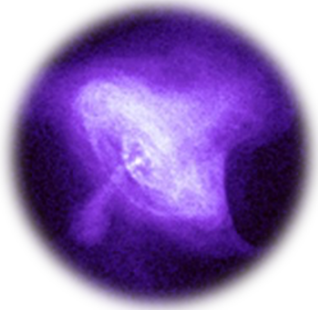
Technique for X-ray Polarimetry

Exploration of the new window since the 1960s

X-ray astronomy started in 1962

First attempt: 1968
Scattering polarimeter
Aerobee 150





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

First detection: 1971
Bragg polarimeter
Aerobee 350
Crab nebula $P = 15.4\% \pm 5.2\%$

First satellite: 1974
Flat Bragg crystal
Ariel 5

450 R. E. Griffiths et al. Vol. 175

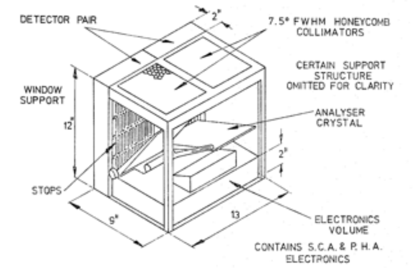
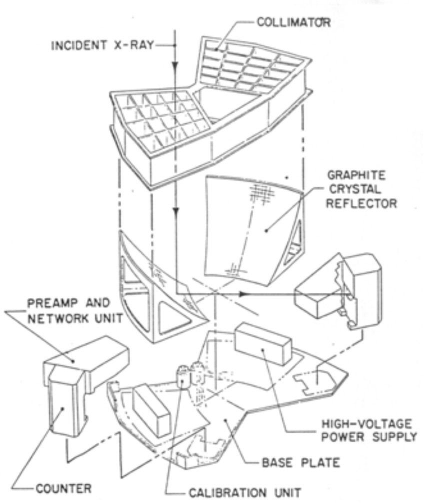


Fig. 1. *A schematic representation of the Leicester crystal spectrometer/polarimeter on Ariel V.*

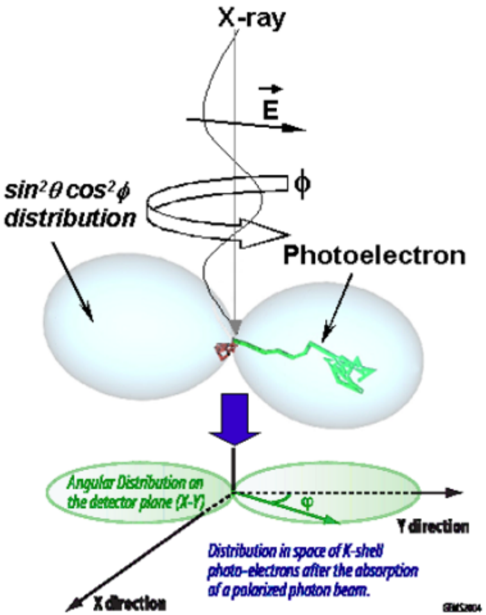


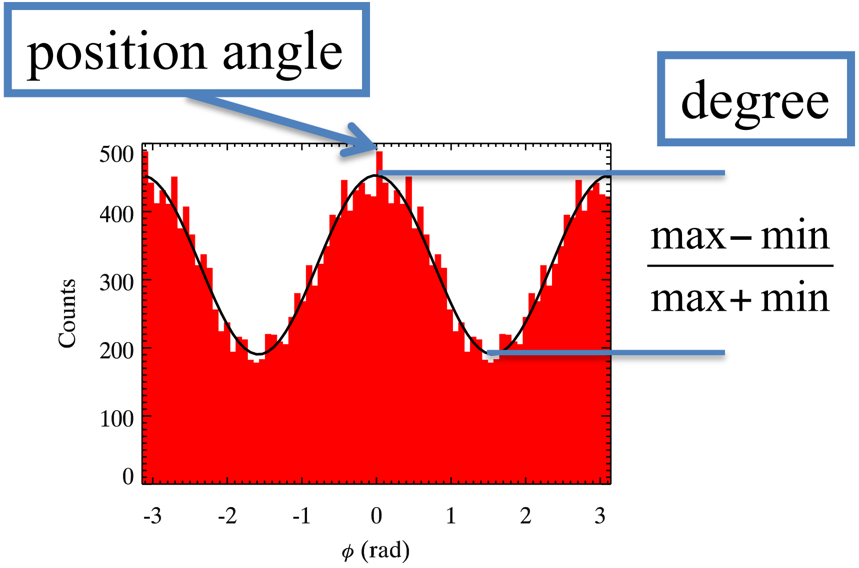
X-ray polarimetry based on the photoelectric effect

Cross-section of photoelectric effect

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

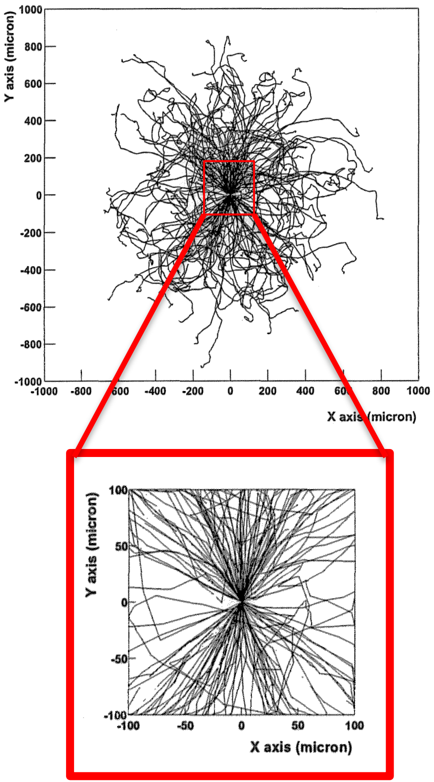
$$\frac{d\sigma}{d\Omega} \propto \cos^2\varphi$$





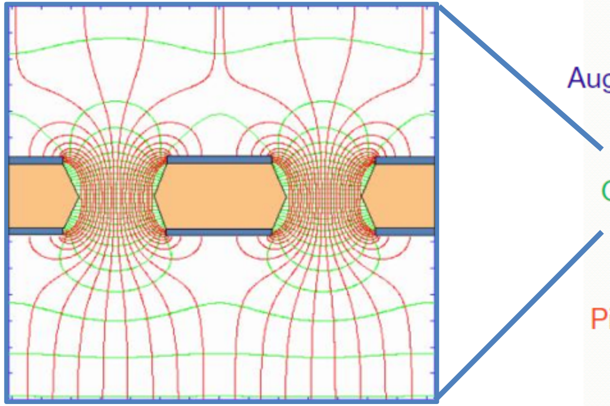
Technical difficulties

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

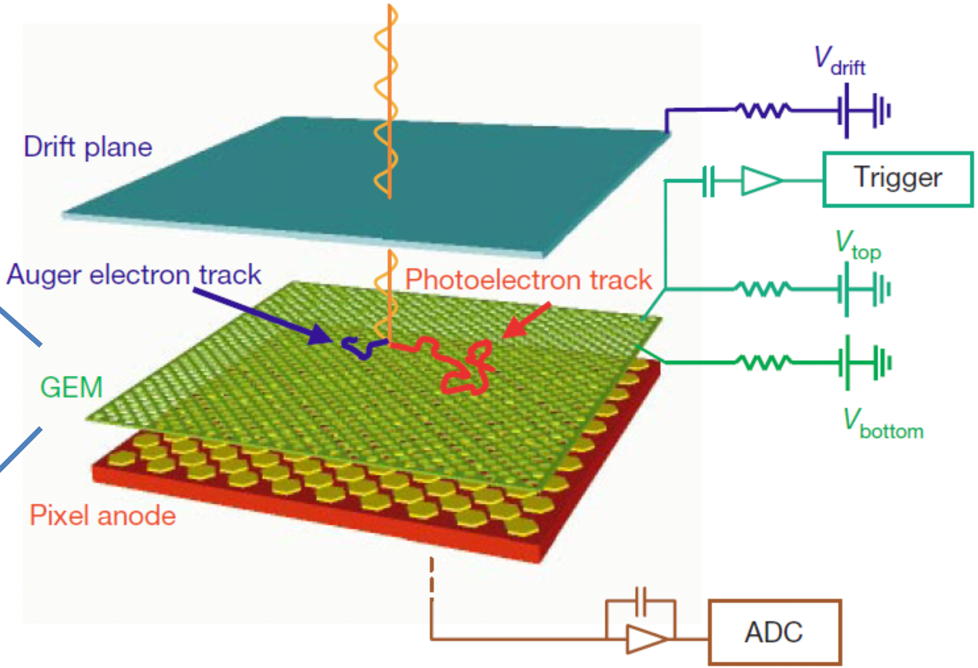


Gas Pixel Detector (GPD)

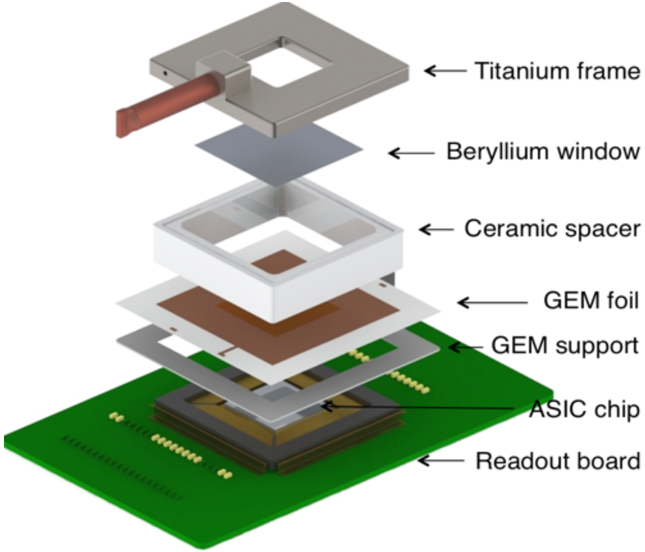
- First demonstrated by INFN-Pisa & IAPS-Rome (Bellazzini et al.; Costa et al. 2001)

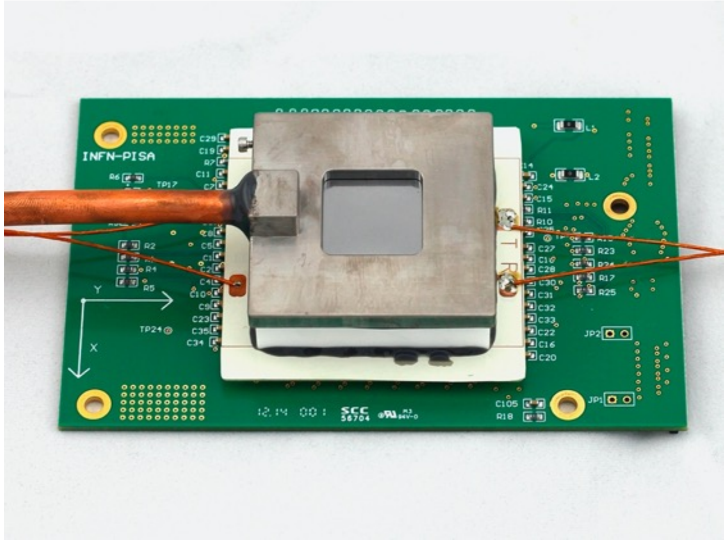


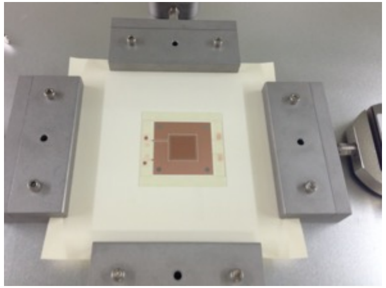
Gas Electron Multiplier (GEM)

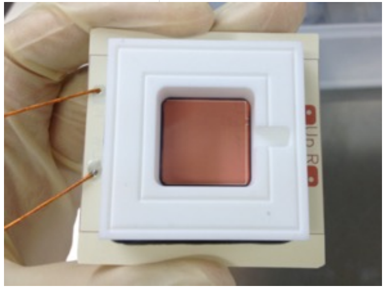


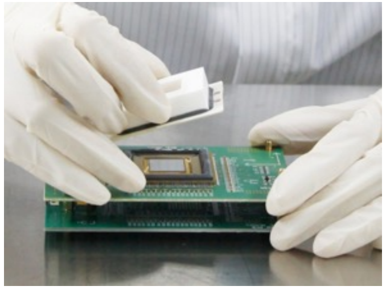
Detector assembly



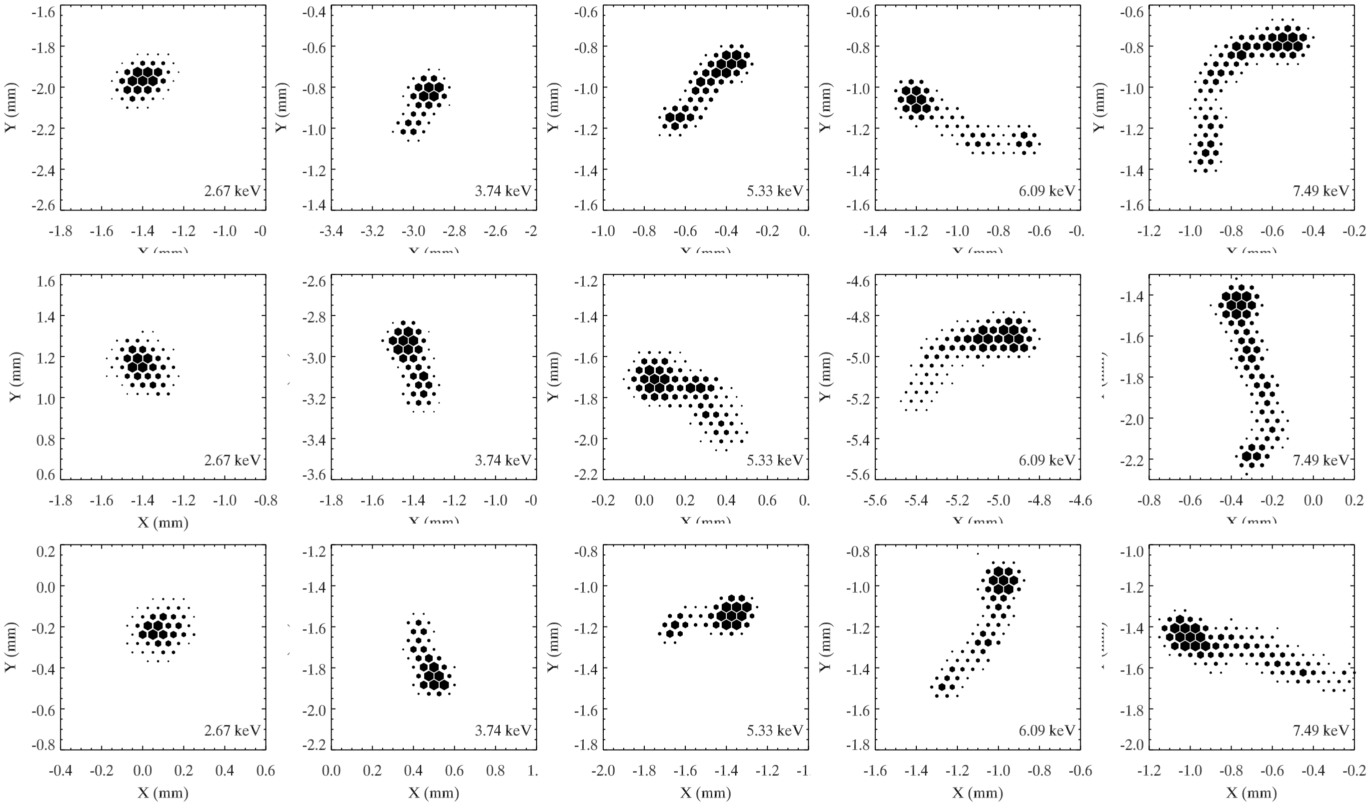




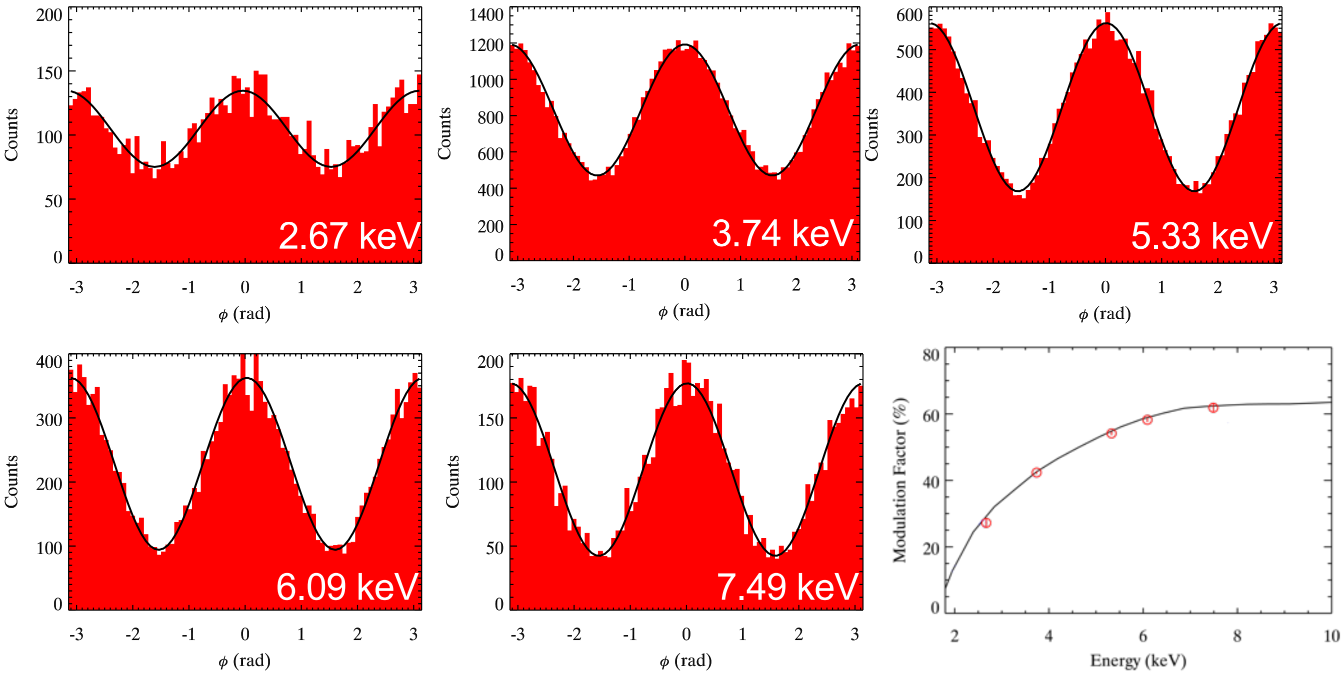




Measured electron tracks



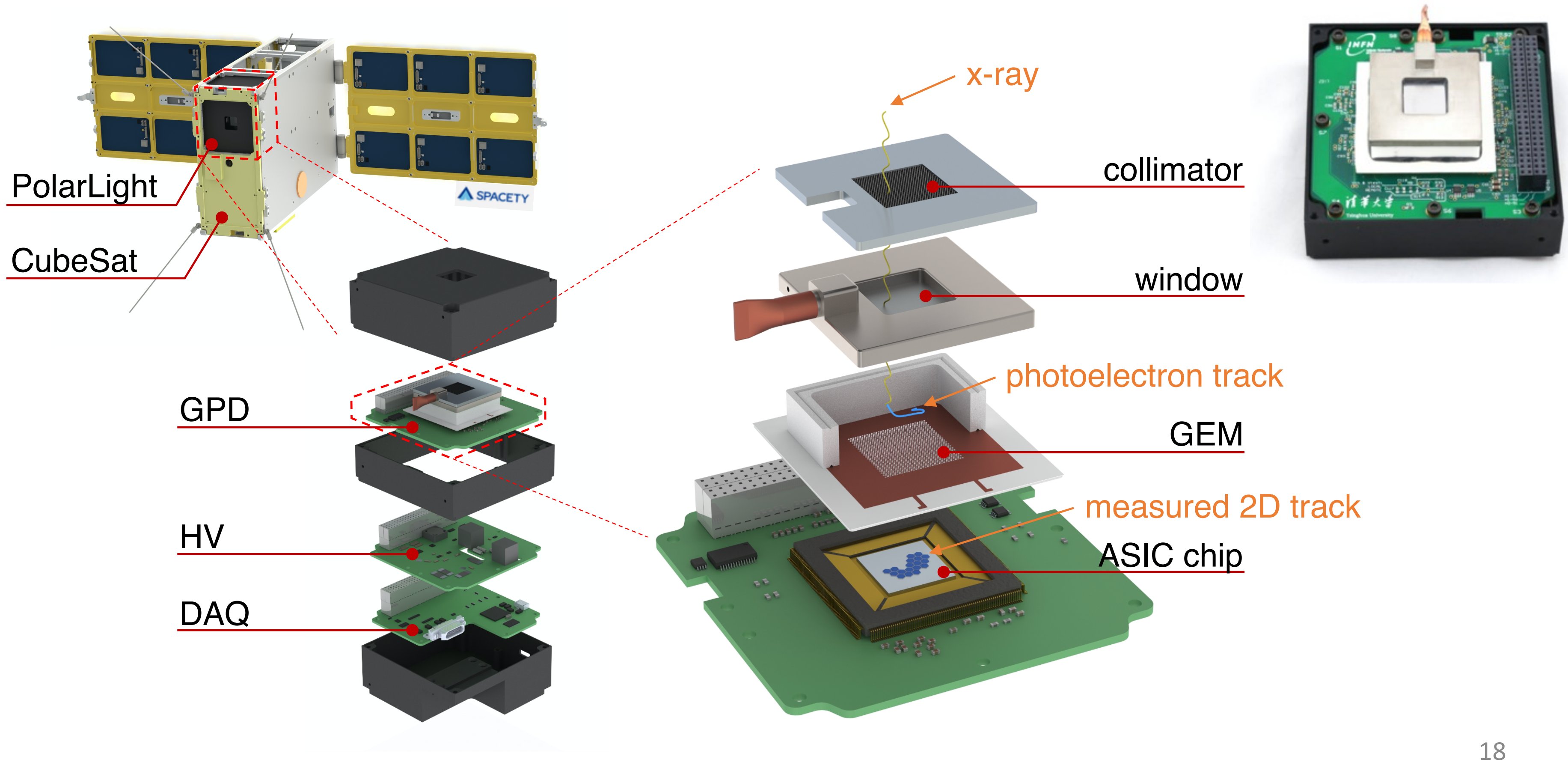
Angular modulation



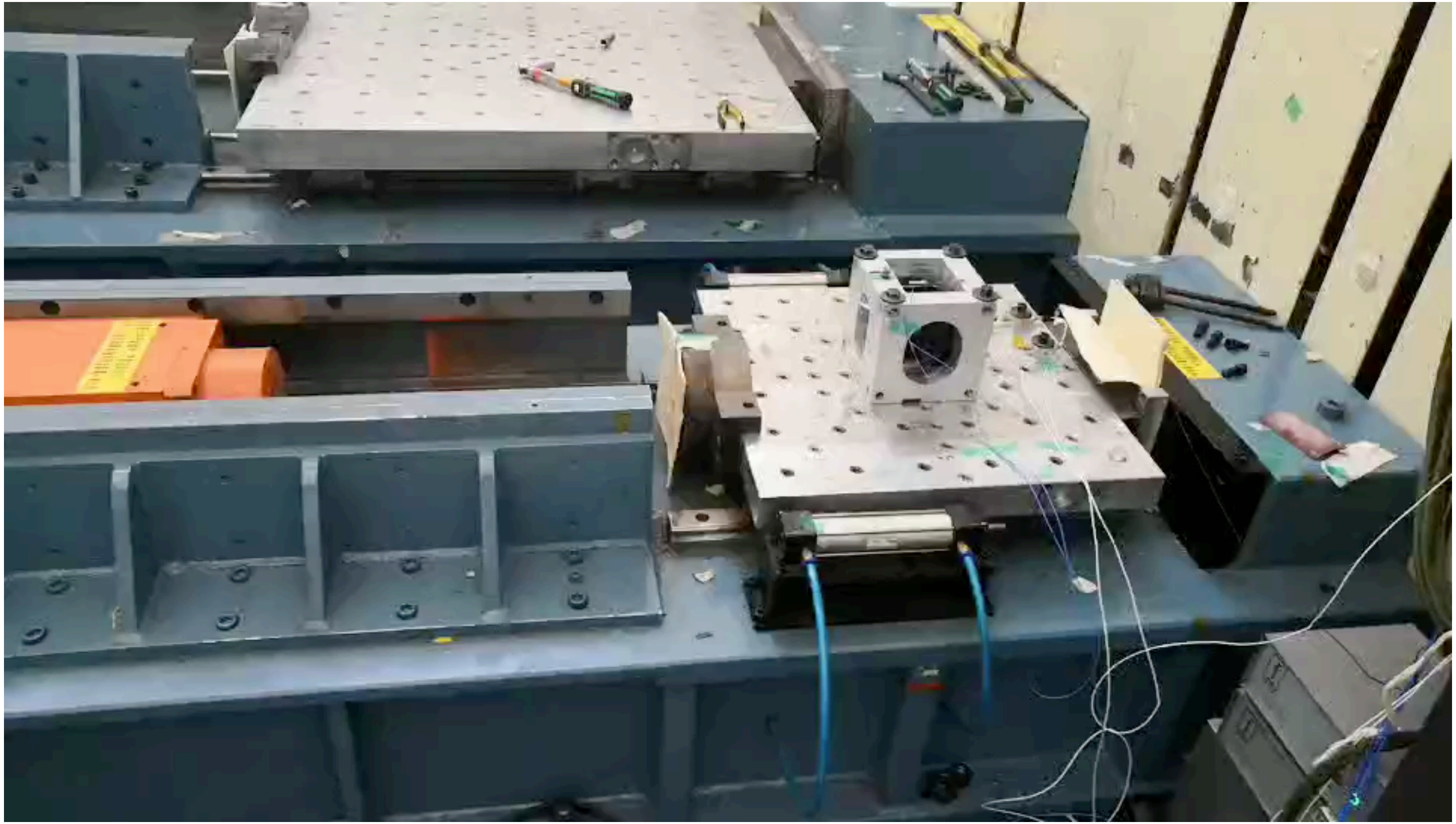
PART THREE

PolarLight

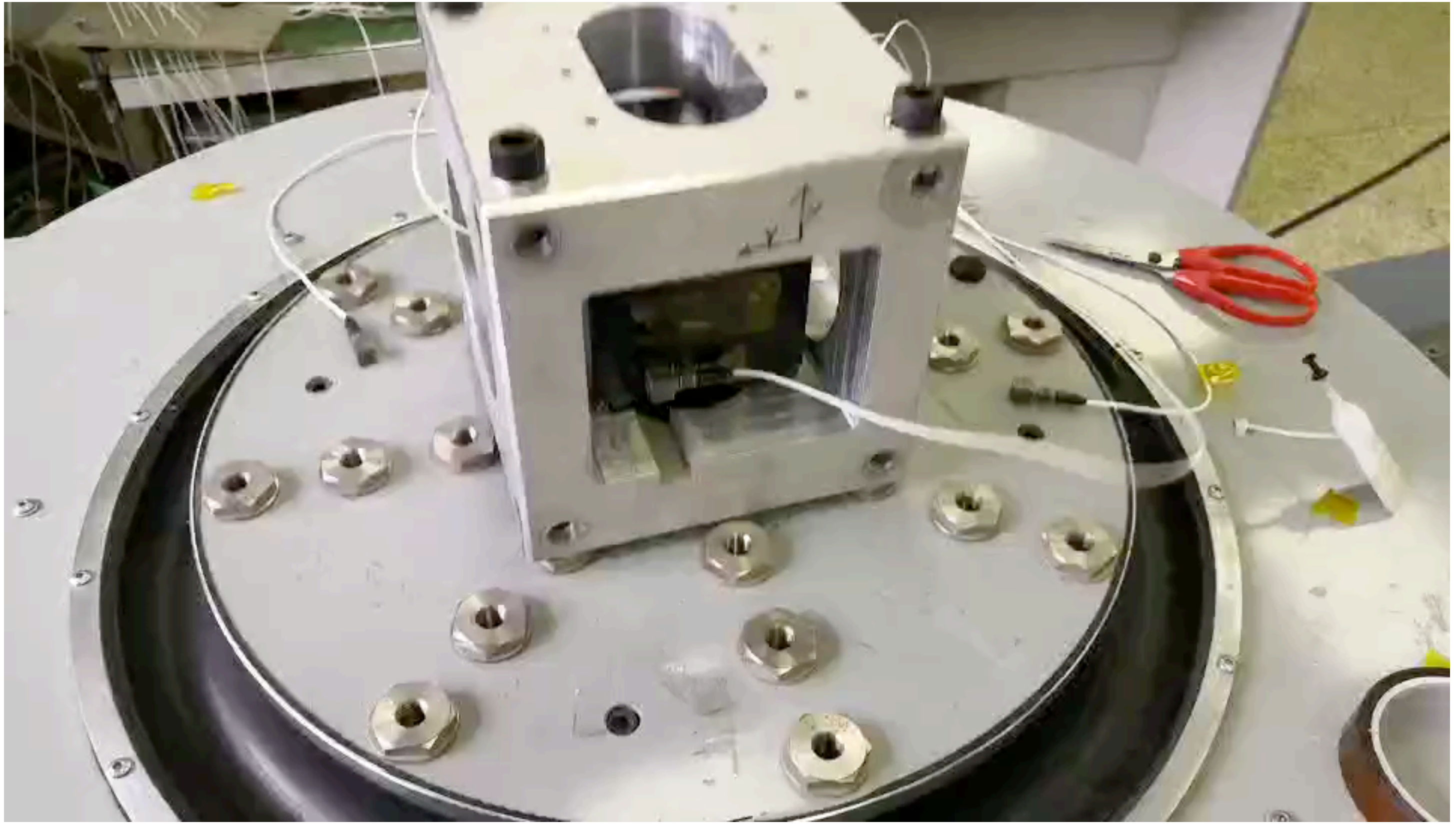
Polarimeter Light (PolarLight；极光计划)



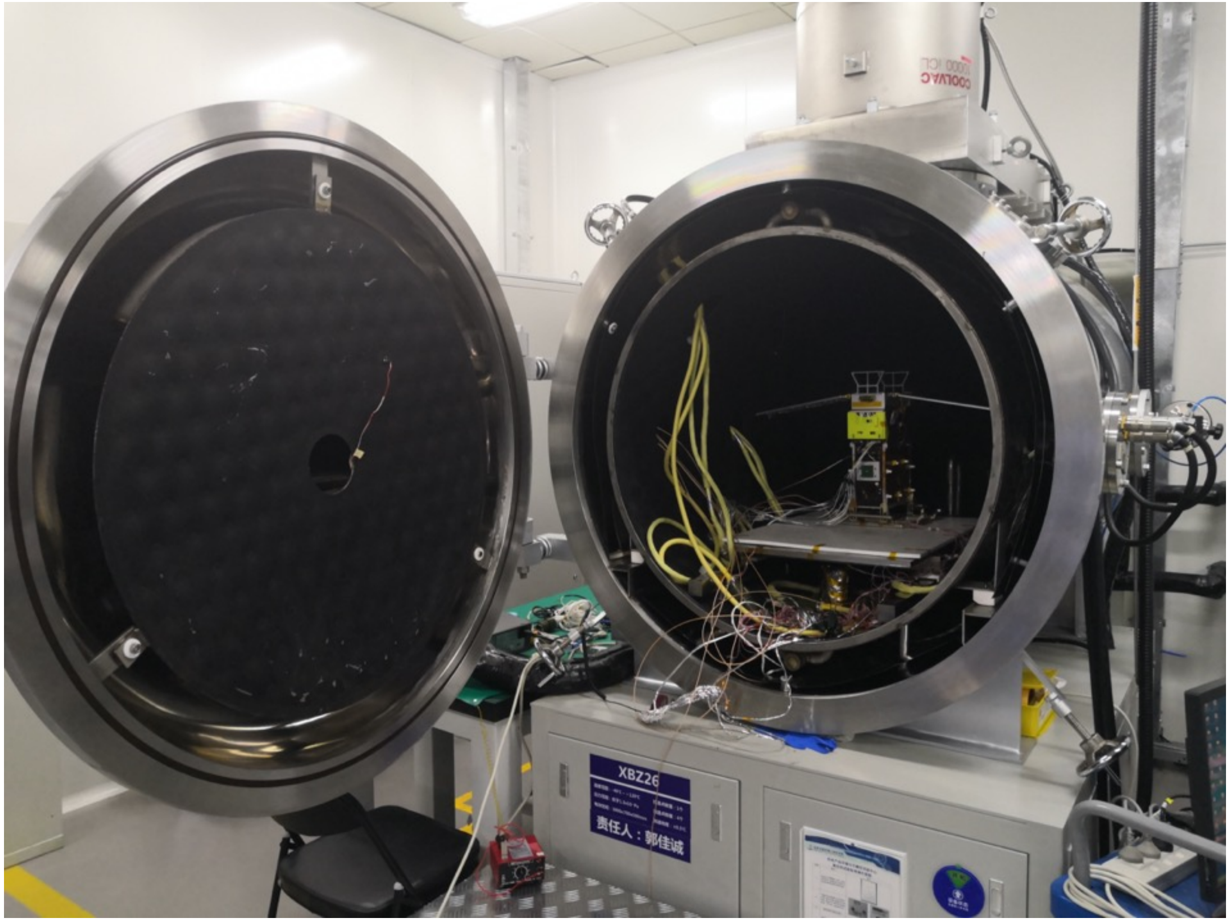
Shocking test



Vibration test

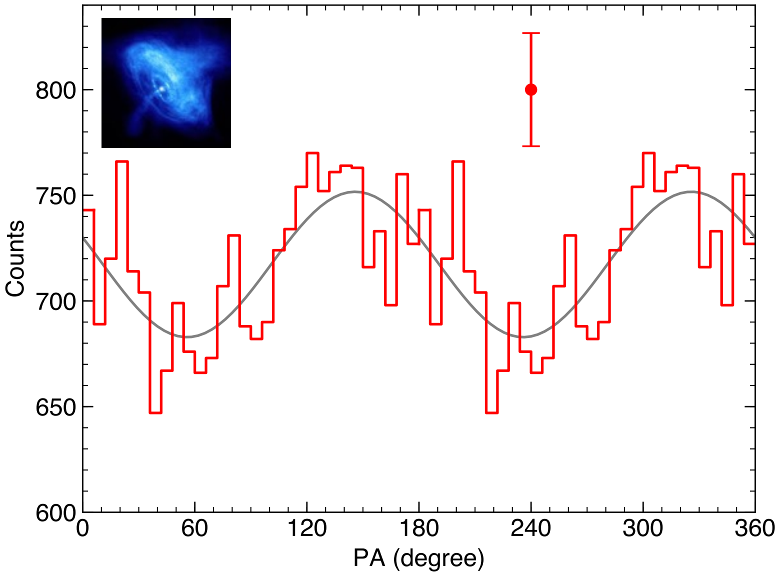


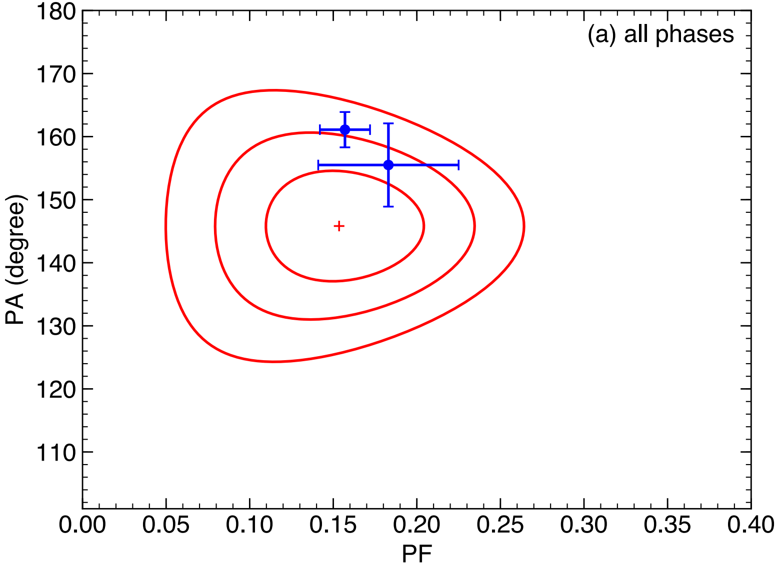
Thermal vacuum



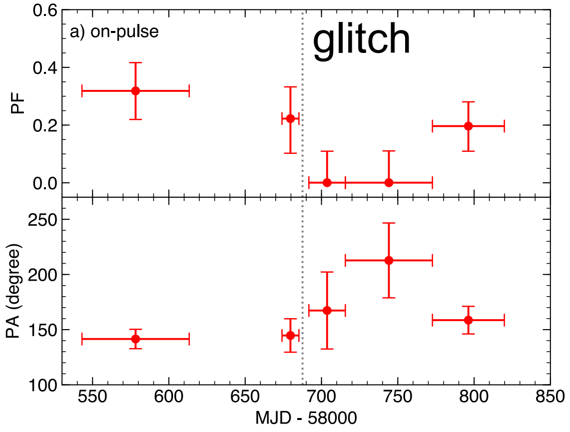
Launched into a low Earth orbit

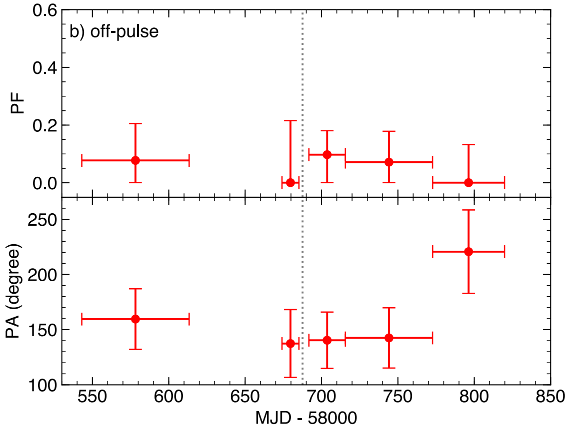
Re-detection of X-ray polarization from the Crab nebula

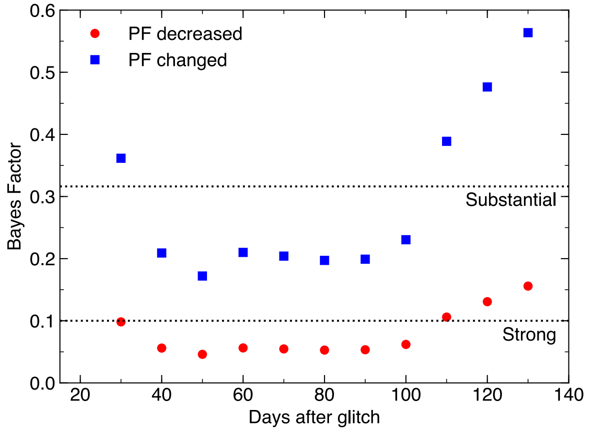




Time variation of polarization







With pulsar emission

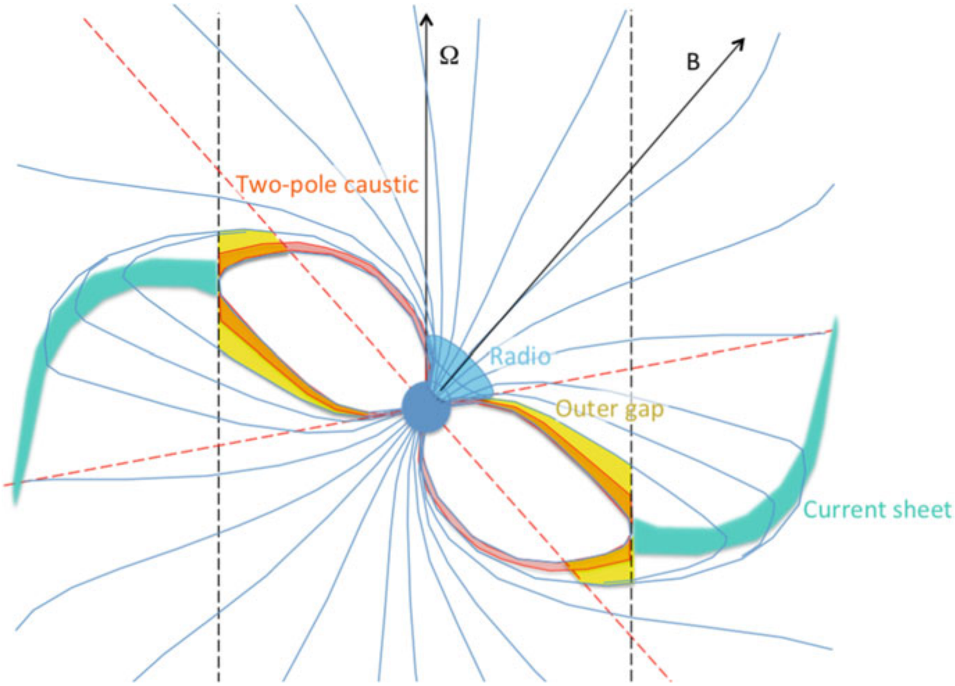
Without pulsar emission

significance level: 3σ

- Bayes factor
- Bayesian posterior
- Bootstrap

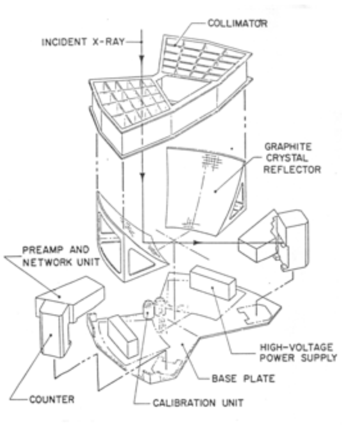
Magnetosphere altered after the glitch

High energy emission from pulsars



Cheng et al. 1986
Muslimov et al. 2004
Kalapotharakos et al. 2012
Harding et al. 2019

Reopening the window



OSO-8 (1975)

PolarLight (2018)

IXPE in 2021
(Weisskopf et al. 2016)

eXTP in 2027
(Zhang et al. 2019)

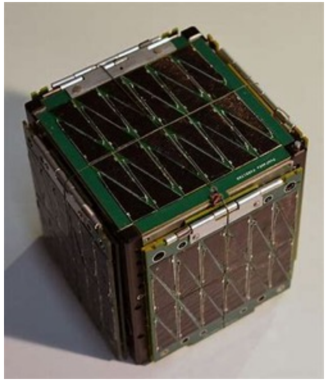
PART FOUR

CubeSats in Astronomy

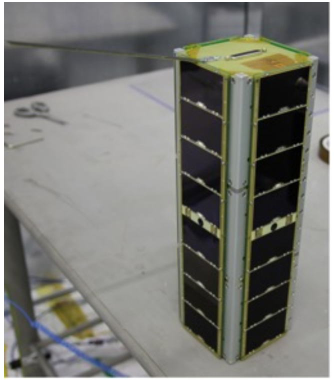
CubeSat 立方星

- The CubeSat standard
  - proposed in 1999 by Jordi Puig-Suari of California Polytechnic State University and Bob Twiggs of Stanford University
  - an educational tool for teaching students about spacecraft hardware, electronics and programming
  - Low cost

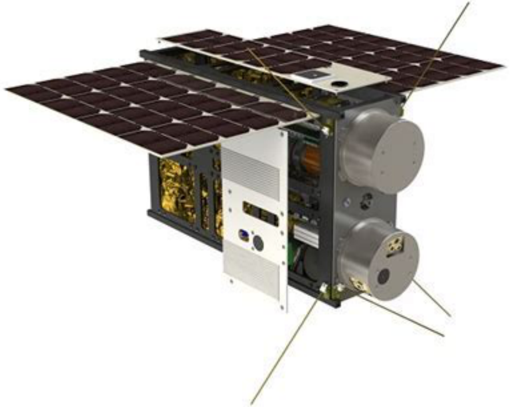
1U



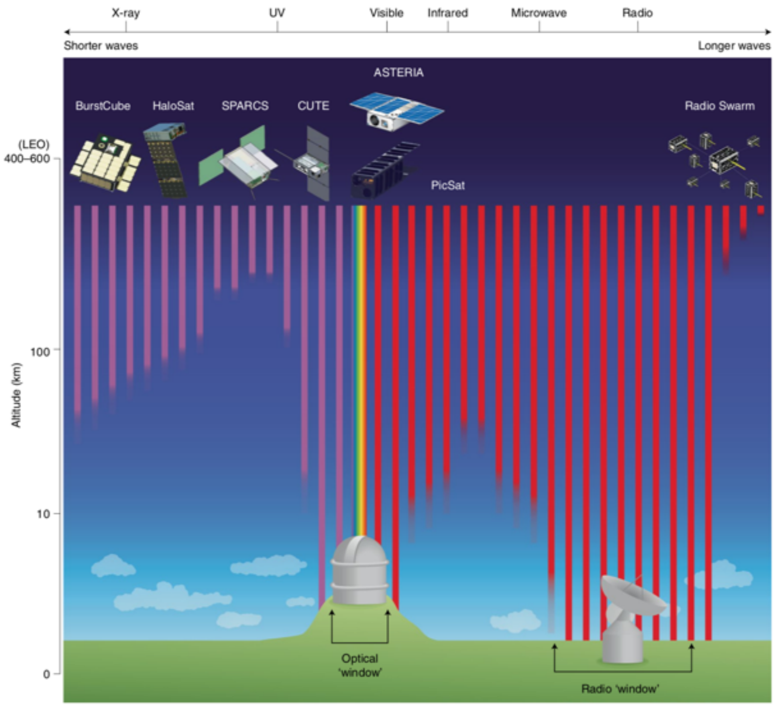
3U



6U

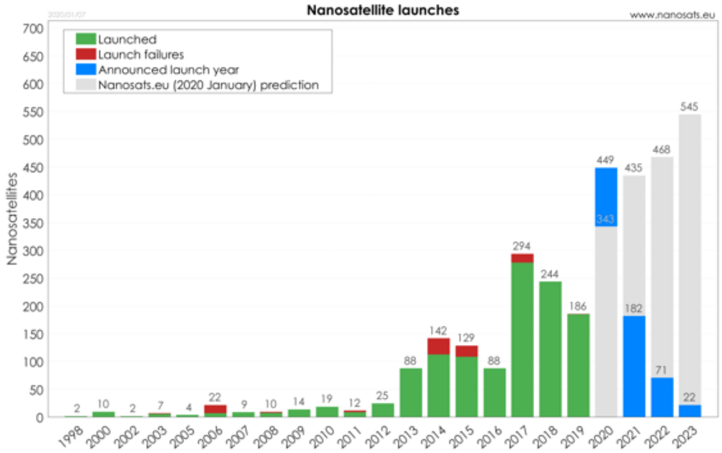


Astronomical CubeSats funded by NASA

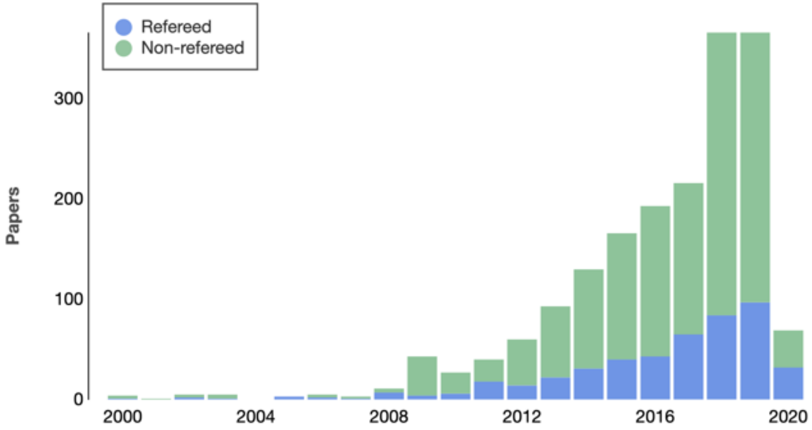


- ASTERIA (Arcsecond Space Telescope Enabling Research in Astrophysics)
  - to measure exoplanetary transits across bright stars with <100 ppm photometry
  - launched in August 2017, one of the first CubeSats enabled for astronomical measurements
- PicSat
  - to observe in visible light the potential transit of the directly-imaged giant planet β Pictoris b
- HaloSat
  - measure the soft X-ray emission from the hot halo of the Milky Way galaxy to resolve the missing baryon problem
- CUTE (Colorado Ultraviolet Transit Experiment)
  - survey of exoplanet transit spectroscopy in the near-UV
- SPARCS (Star–Planet Activity Research CubeSat)
  - the far- and near-UV monitoring of low-mass stars (0.2–0.6 $M_\odot$)
- BurstCube
  - to detect and localize GRBs

A rapid growth

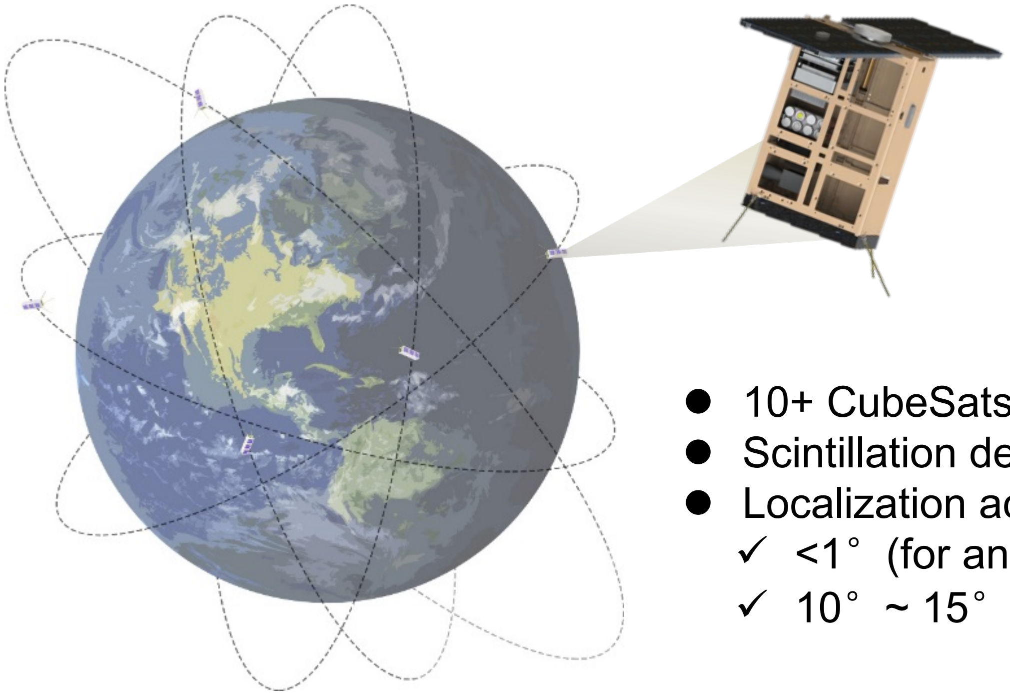


Launches of CubeSats



“CubeSat” on ADS

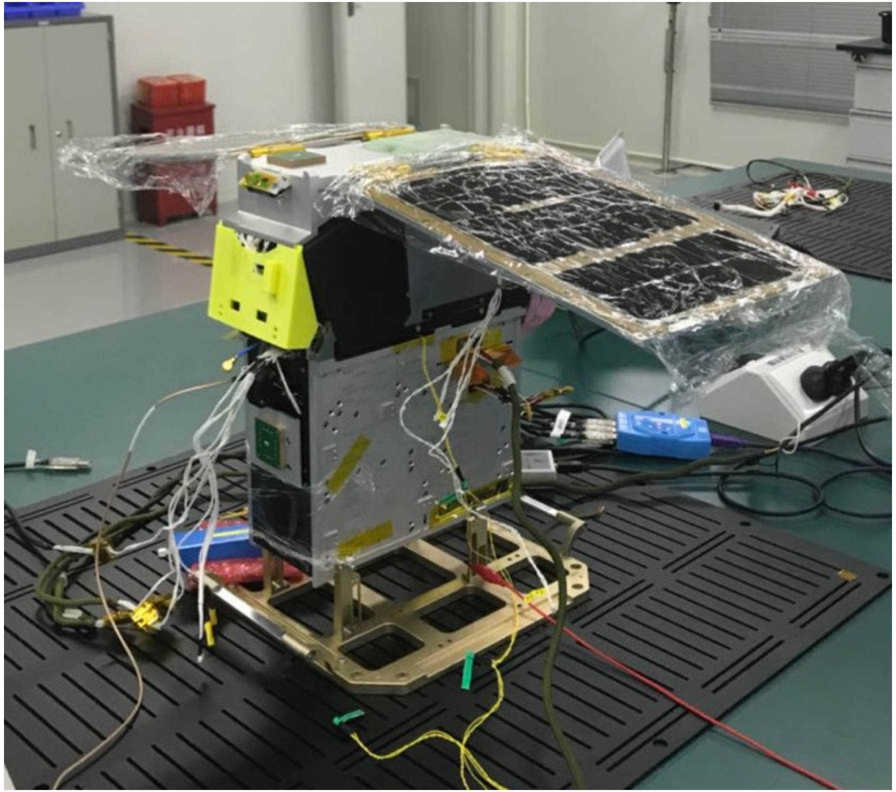
The GRID network



- 10+ CubeSats in LEO
- Scintillation detector, ~60 cm^2 each
- Localization accuracy for GRBs within 200 Mpc
  - ✓ <1° (for an on-axis event, ~0.14 yr^{-1})
  - ✓ 10° ~ 15° (for a GRB 170817A like event, ~5 yr^{-1})

GRID (Gamma Ray Integrated Detectors)

Flight model & satellite



GRID - a student project

The first group

Testing the detector

Talking at COSPAR 2018

- Started in 2016 October
- More than 50 Students from 16 universities
- GRID-1 in orbit
- GRID-2/GRID-3 will be launched this year

CubeSats in Astronomy

- To demonstrate new techniques
  - Sounding rockets vs. Balloons vs. CubeSats
- Highly customized science objective
  - Large missions: observatories
  - Small missions: dedicated
    - Long-term monitoring of a single or a few targets
- Student training
  - Project cycle: ~3 years
  - All-around skills: science + engineering + leadership

THANK YOU!