

# The PoGO+ Mission: The hunt for two numbers

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on behalf of the PoGO+ collaboration

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# What is PoGO?

Build an instrument



Fly it on a balloon



Reduce data



Get two numbers

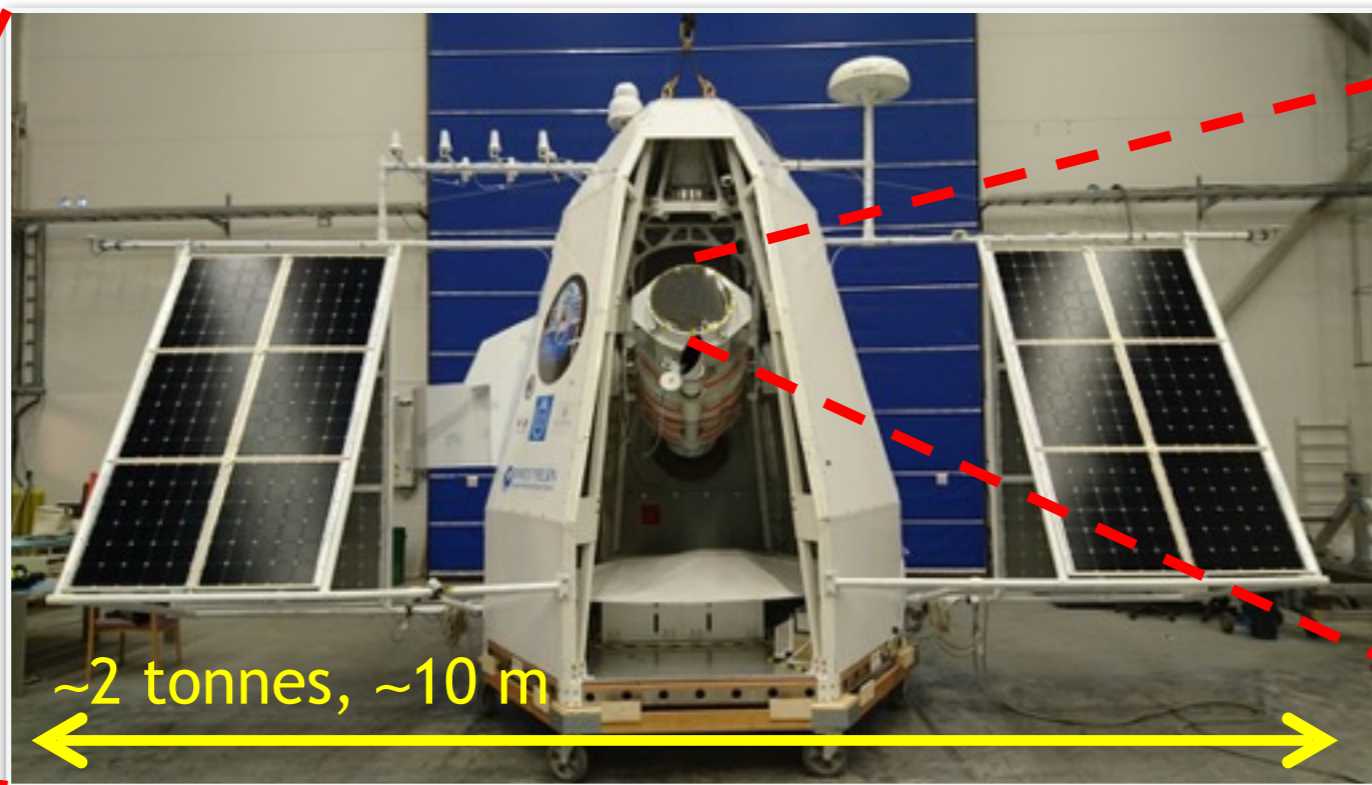
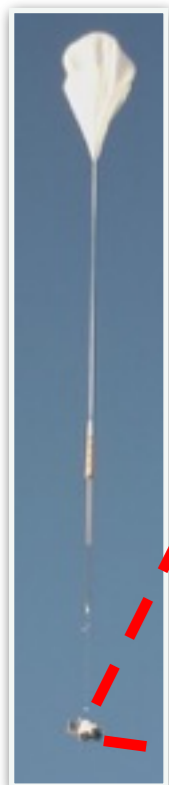
**Goal:**

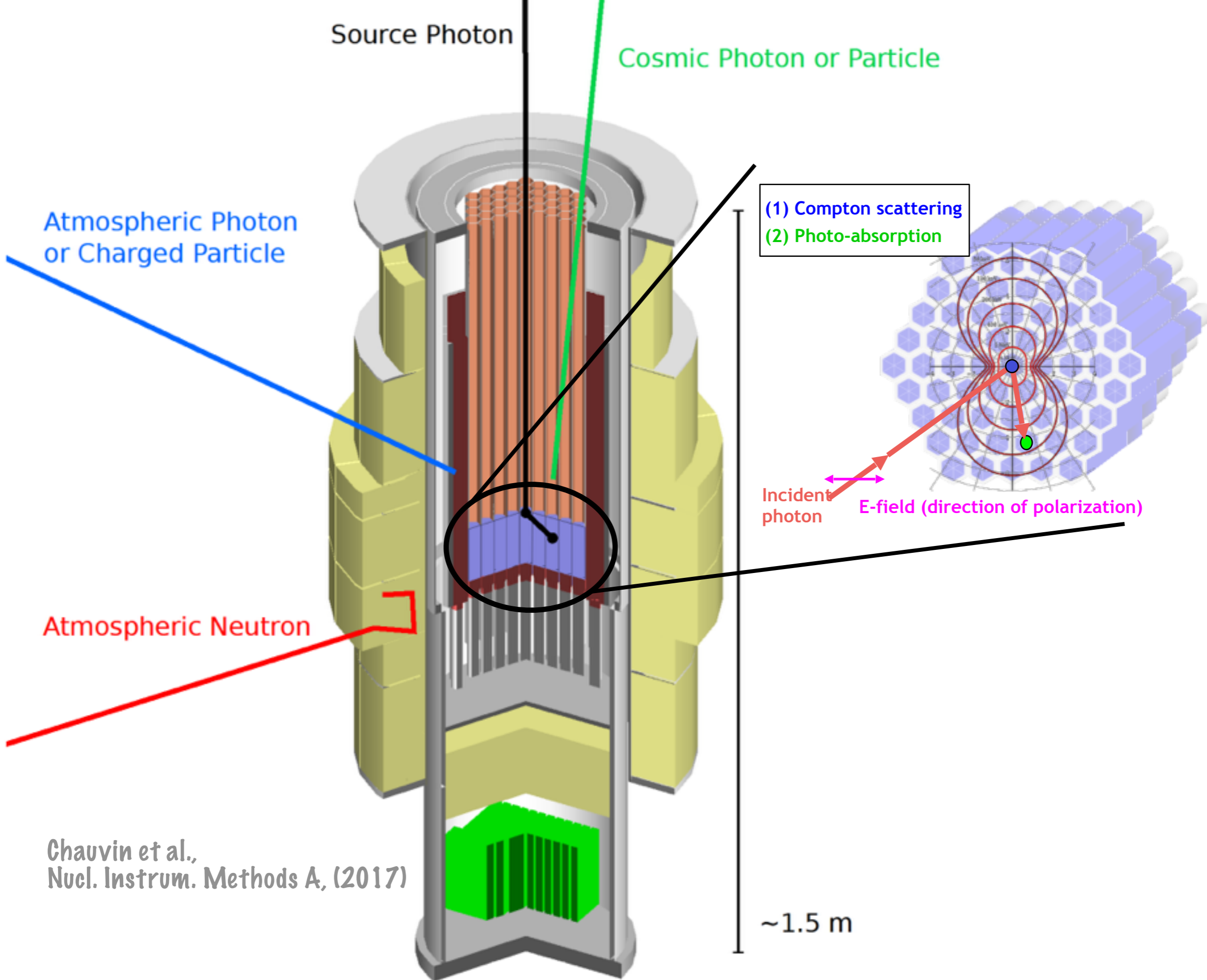
**Two numbers → Interesting physics**

**Build an instrument**

# Polarised Gamma-ray Observer

- Balloon-borne telescope for polarised X-rays (20-180 keV)
- Compton telescope (no imaging but two new observational parameters: polarisation fraction, angle)
- Collaboration between Sweden, Japan
- Attitude control system: DST Control, Sweden
- Gondola, launch services: SSC Esrange
- Launch from Esrange Space Center (July 2016), Sweden
- Successor to the PoGOLite “Pathfinder” (flight in 2013)





Source Photon

Cosmic Photon or Particle

Atmospheric Photon or Charged Particle

(1) Compton scattering  
(2) Photo-absorption

Atmospheric Neutron

Incident photon

E-field (direction of polarization)

Chauvin et al.,  
Nucl. Instrum. Methods A, (2017)

~1.5 m

Copper-Tin-Lead Collimator

Plastic scintillator

BGO

PMT

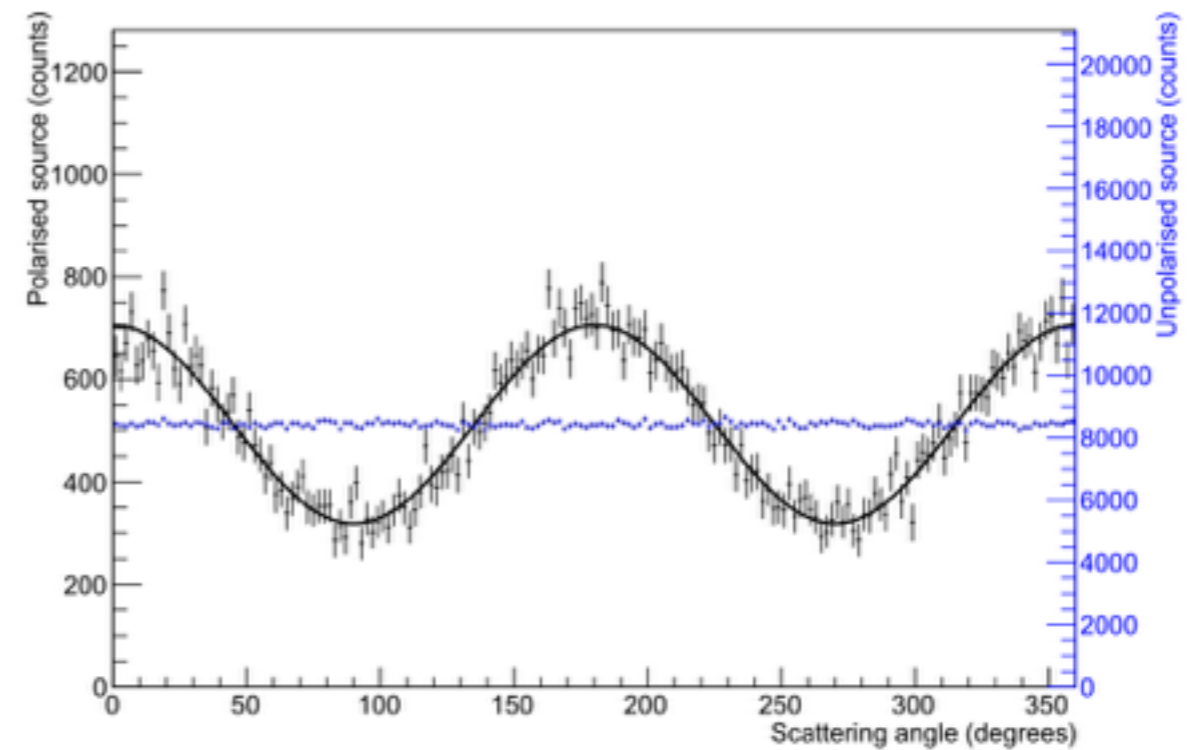
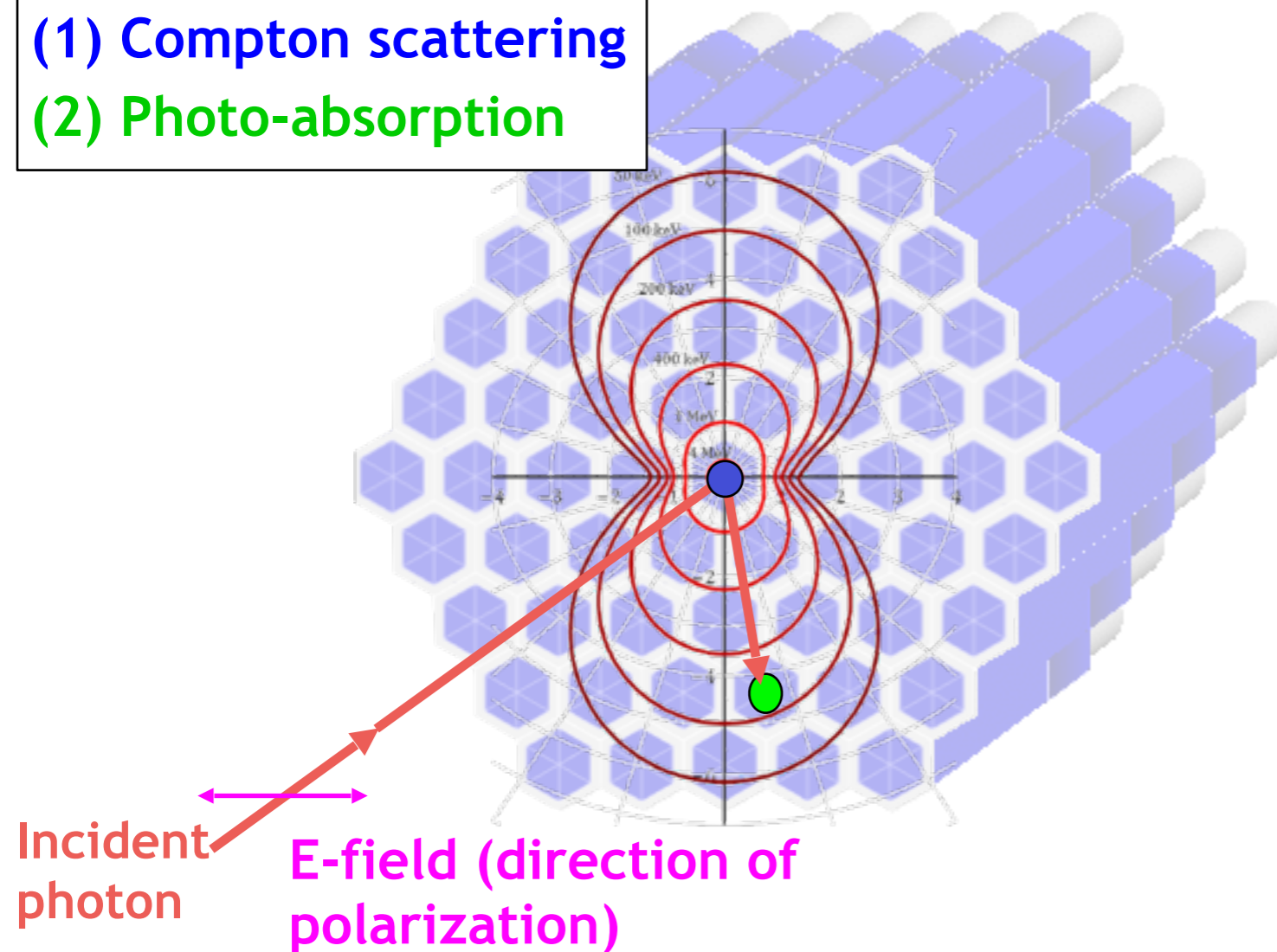
# Measuring Polarisation

Compton scattering polarimeter:

$$\frac{d\sigma}{d\Omega} = \frac{1}{2} r_e^2 \frac{E'^2}{E^2} \left( \frac{E'}{E} + \frac{E}{E'} - 2 \sin^2 \theta \cos^2 \phi \right)$$

Measure the azimuthal scattering angle  $\phi$  between **Compton scattering** and **Photo-absorption**

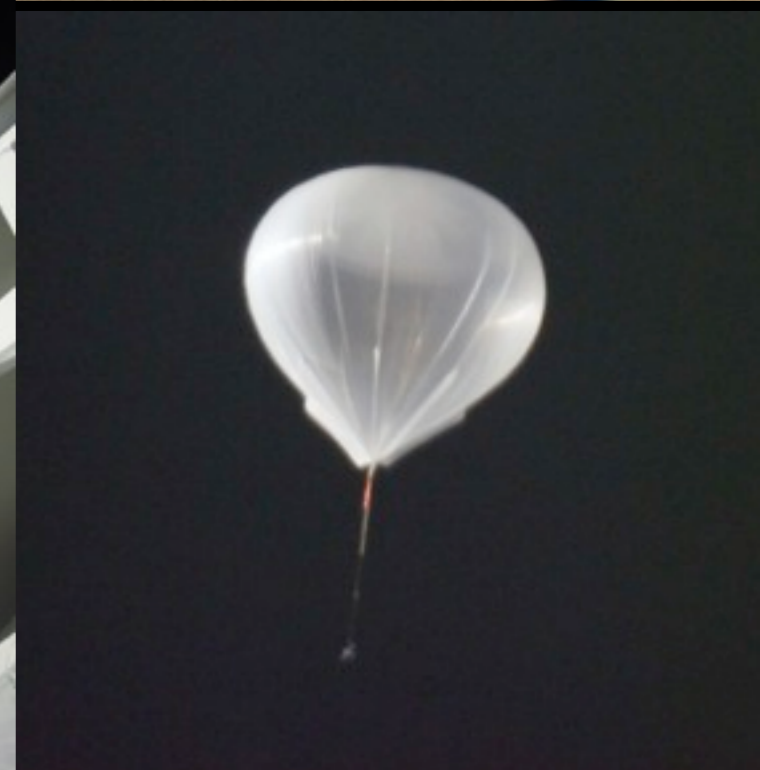
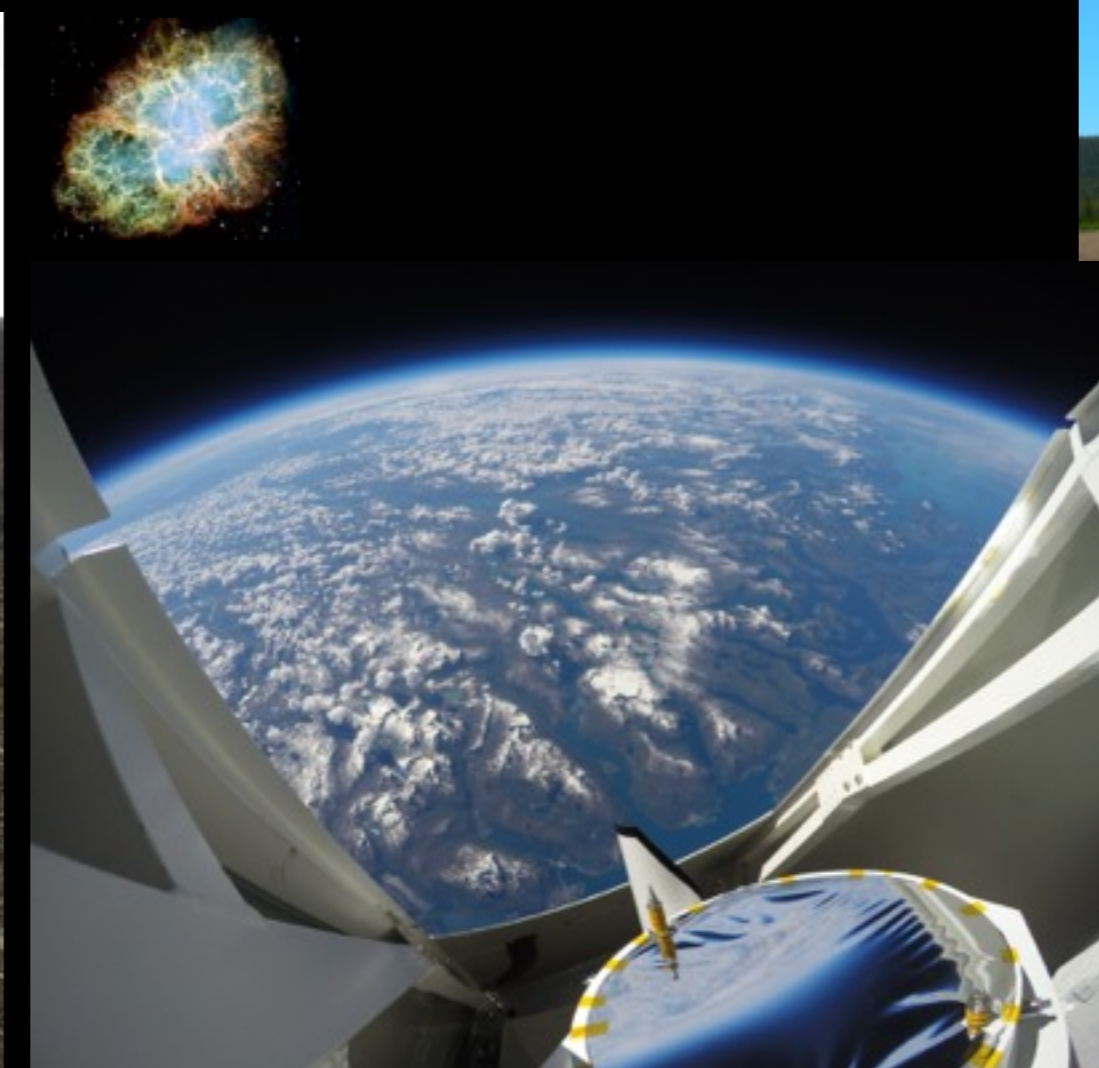
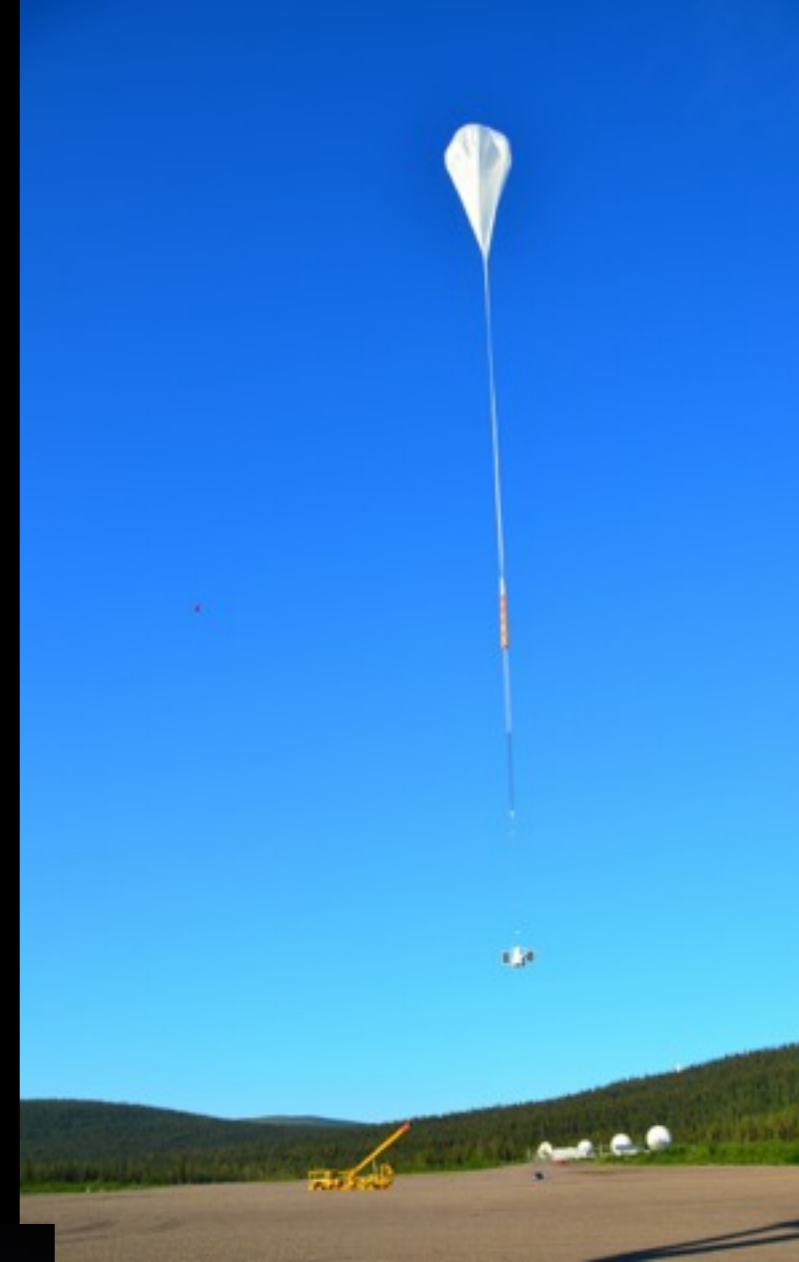
- (1) Compton scattering
- (2) Photo-absorption

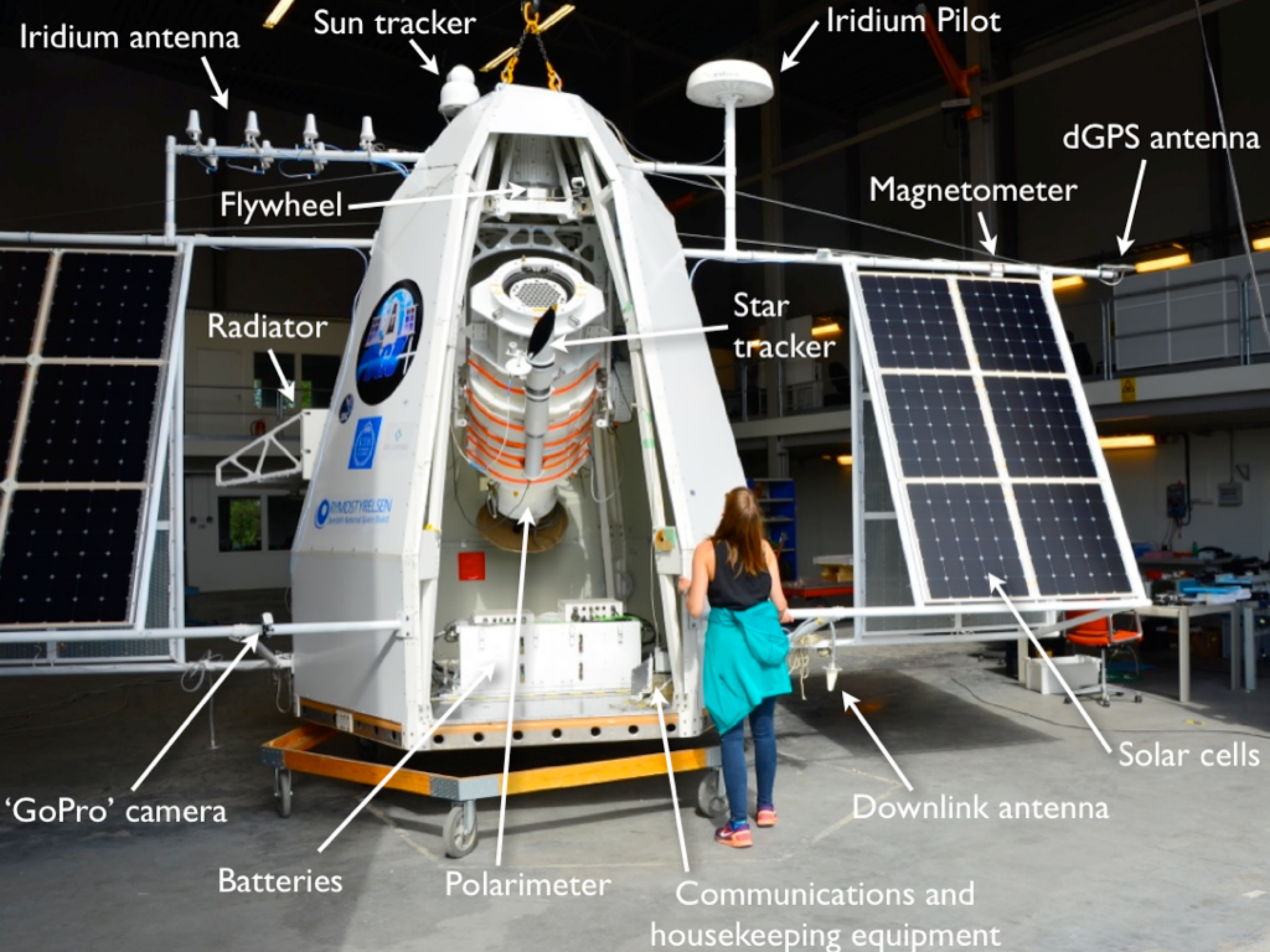


Chauvin et al., Nucl. Instrum. Methods A (2017)

**Fly it on a balloon**







Iridium antenna

Sun tracker

Iridium Pilot

dGPS antenna

Flywheel

Magnetometer

Radiator

Star tracker

'GoPro' camera

Batteries

Polarimeter

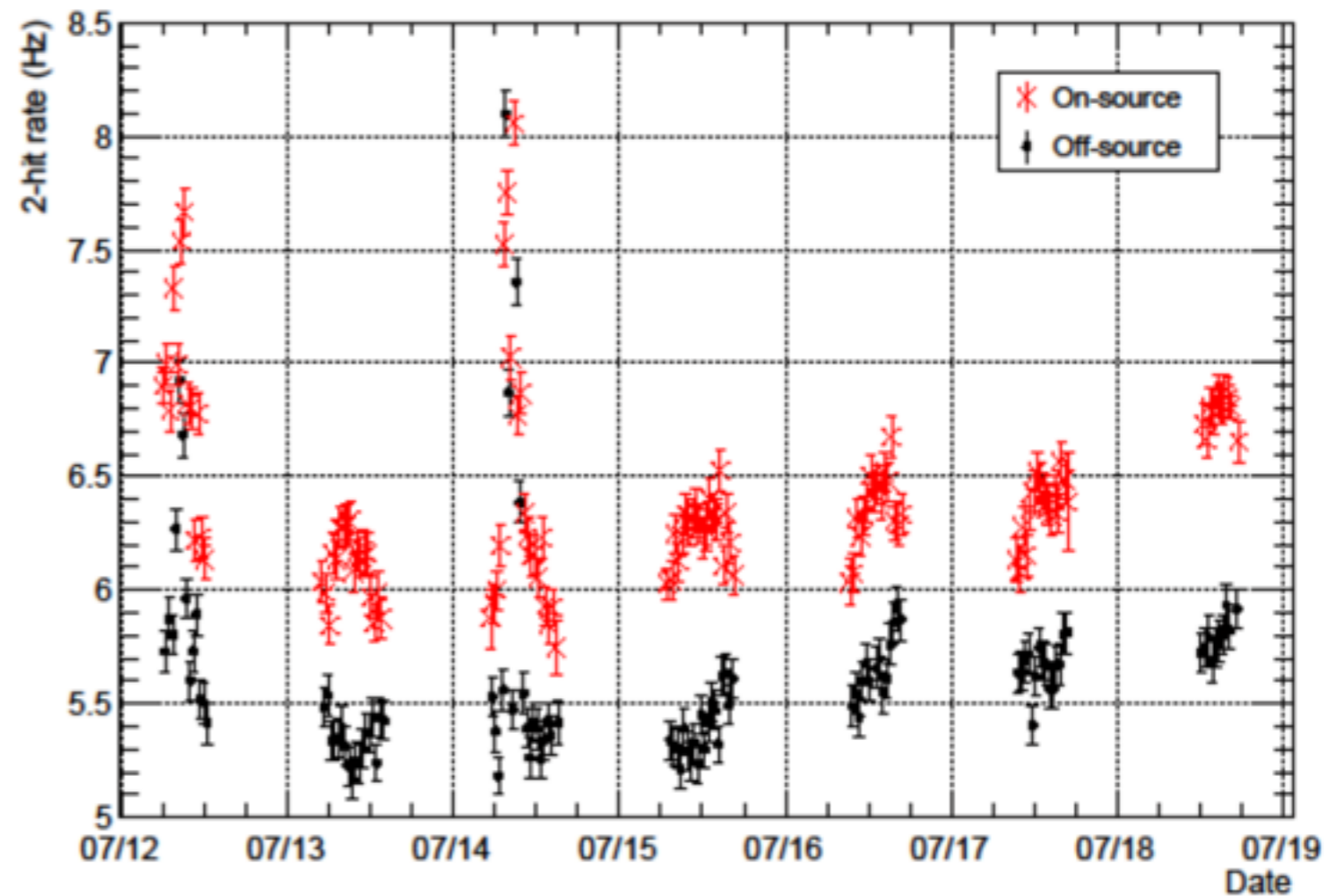
Communications and housekeeping equipment

Downlink antenna

Solar cells

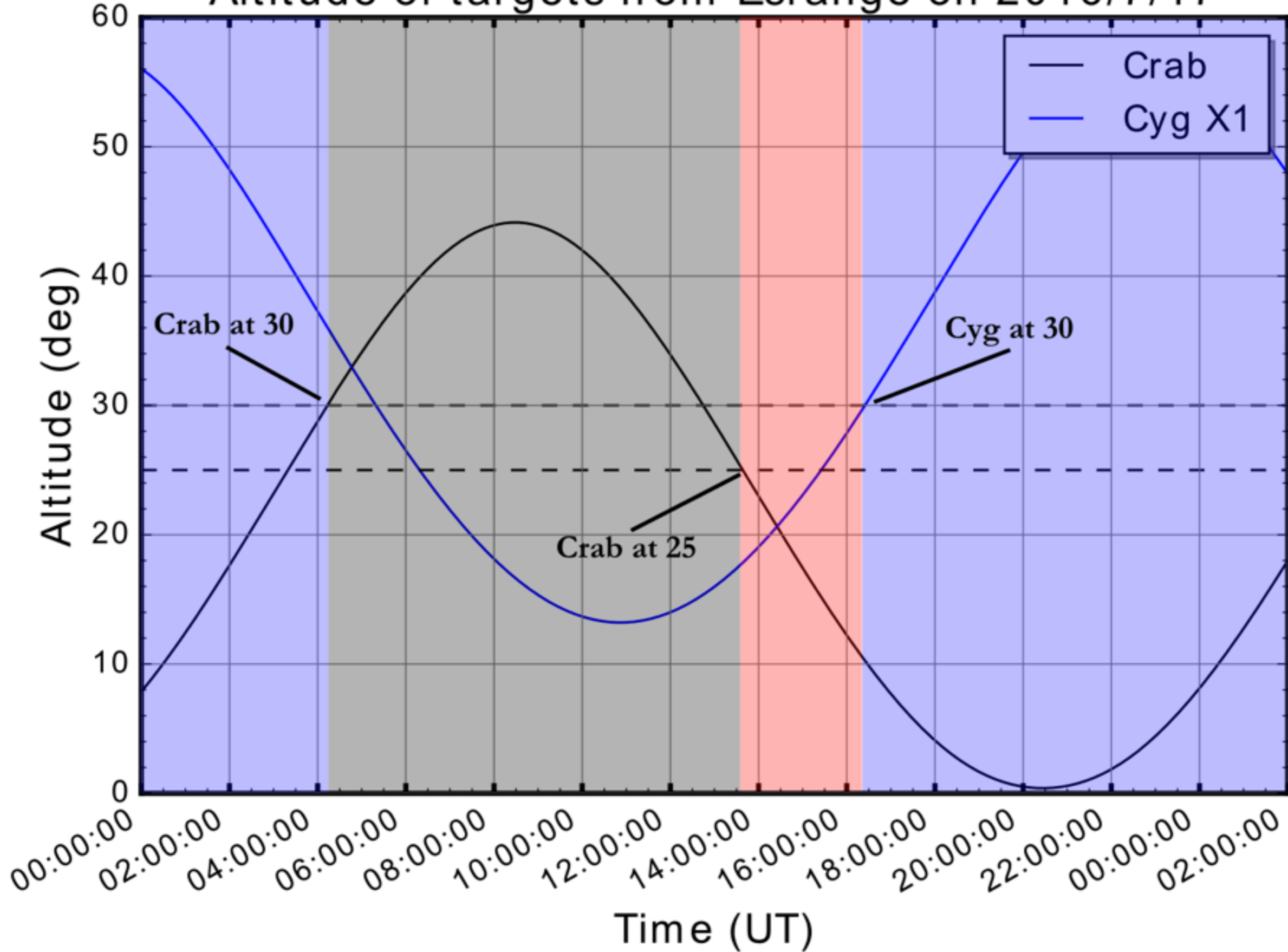
# Dedicated Polarimeter

- The whole instrument is rotated.
- Interspersed source - background obs.
- Response to polarised source calibrated on ground.



Chauvin et al., Scientific Reports (2017)

# Altitude of targets from Esrange on 2016/7/17

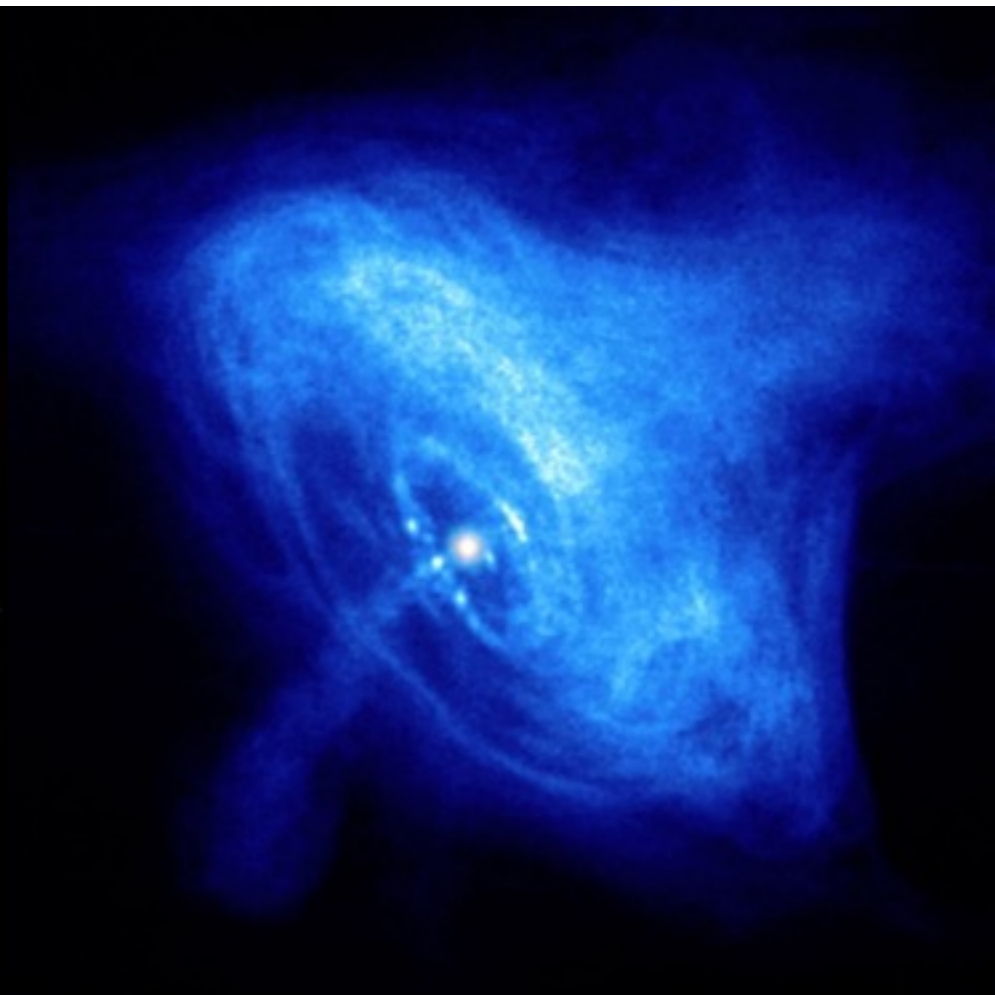


Reduce data (and interpret  
the two numbers)

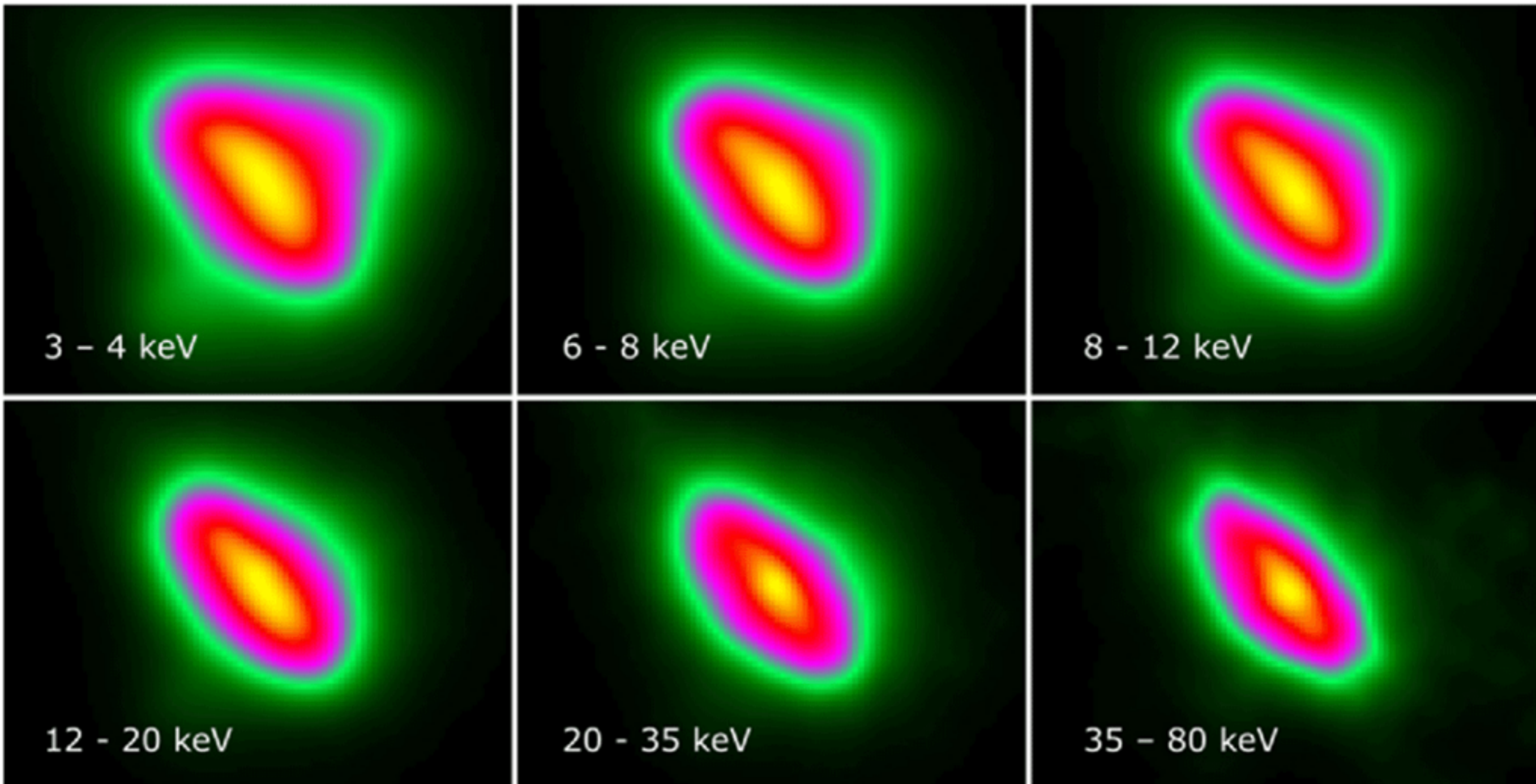
# The Crab system

- Supernova observed by Chinese astronomers in 1054.
- Observed over the entire observable spectrum in incredibly details.
- Observed by PoGO+, measuring polarised X-rays.



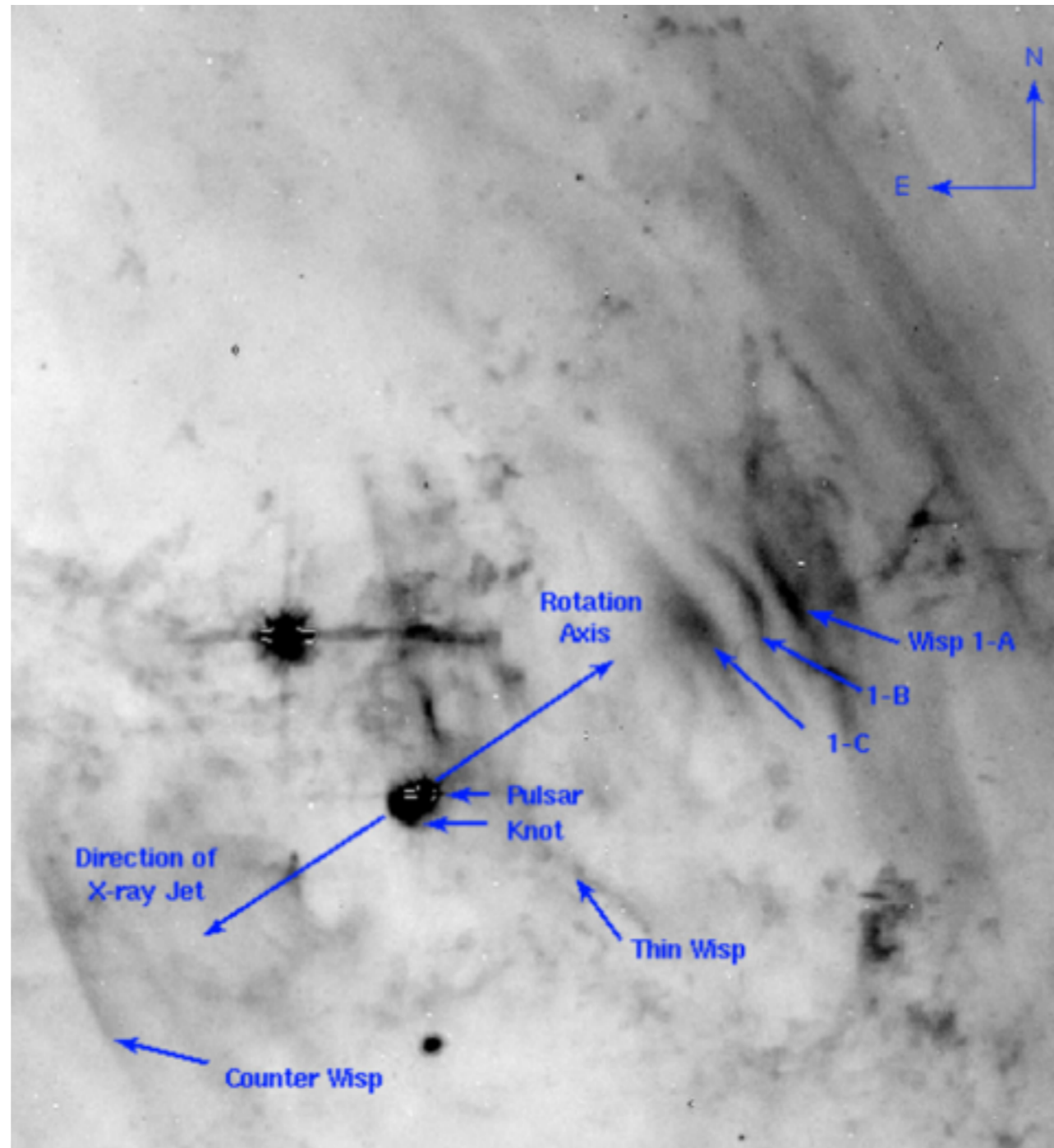


# NuSTAR Imaging



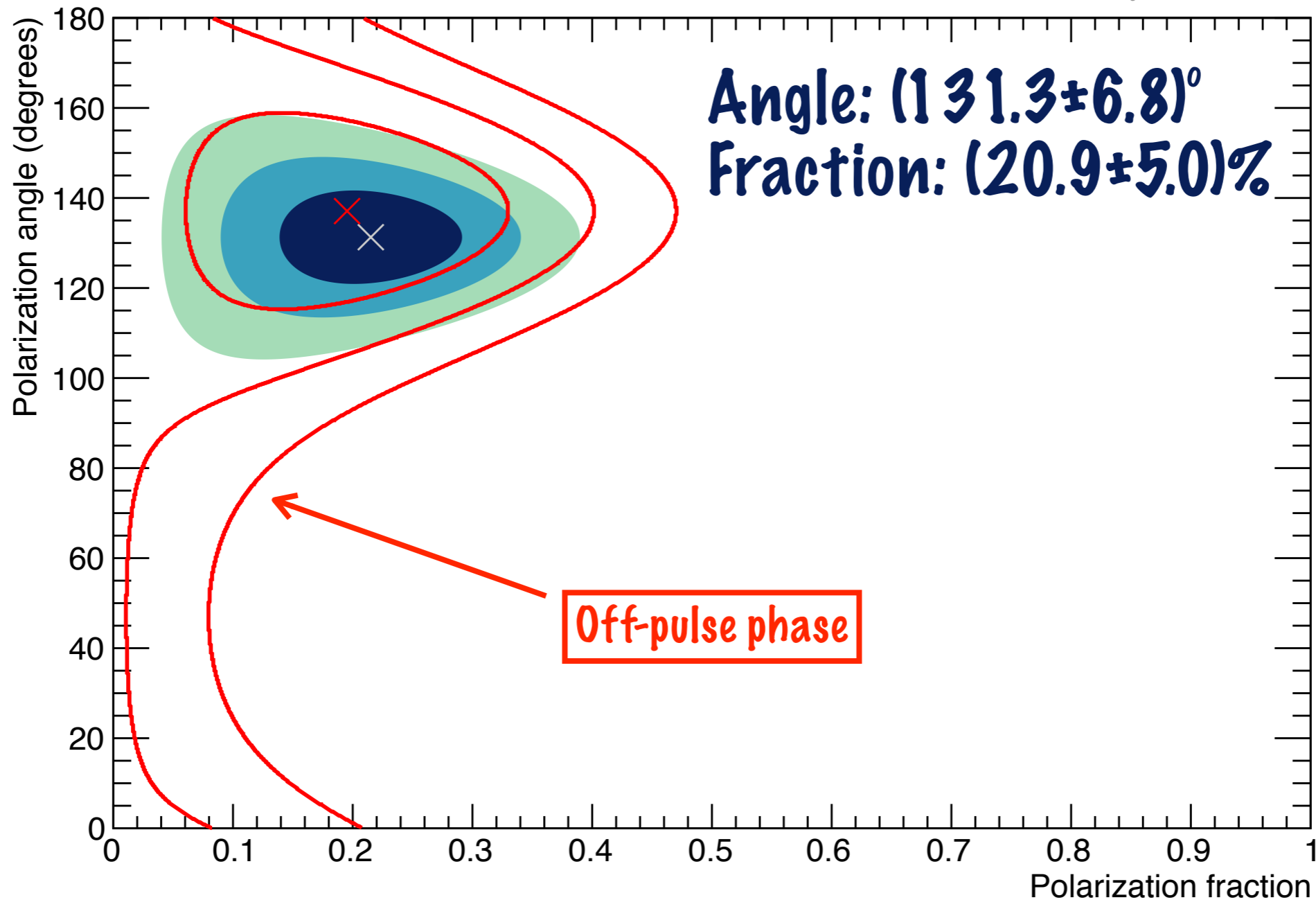


# Optical Imaging (HST)



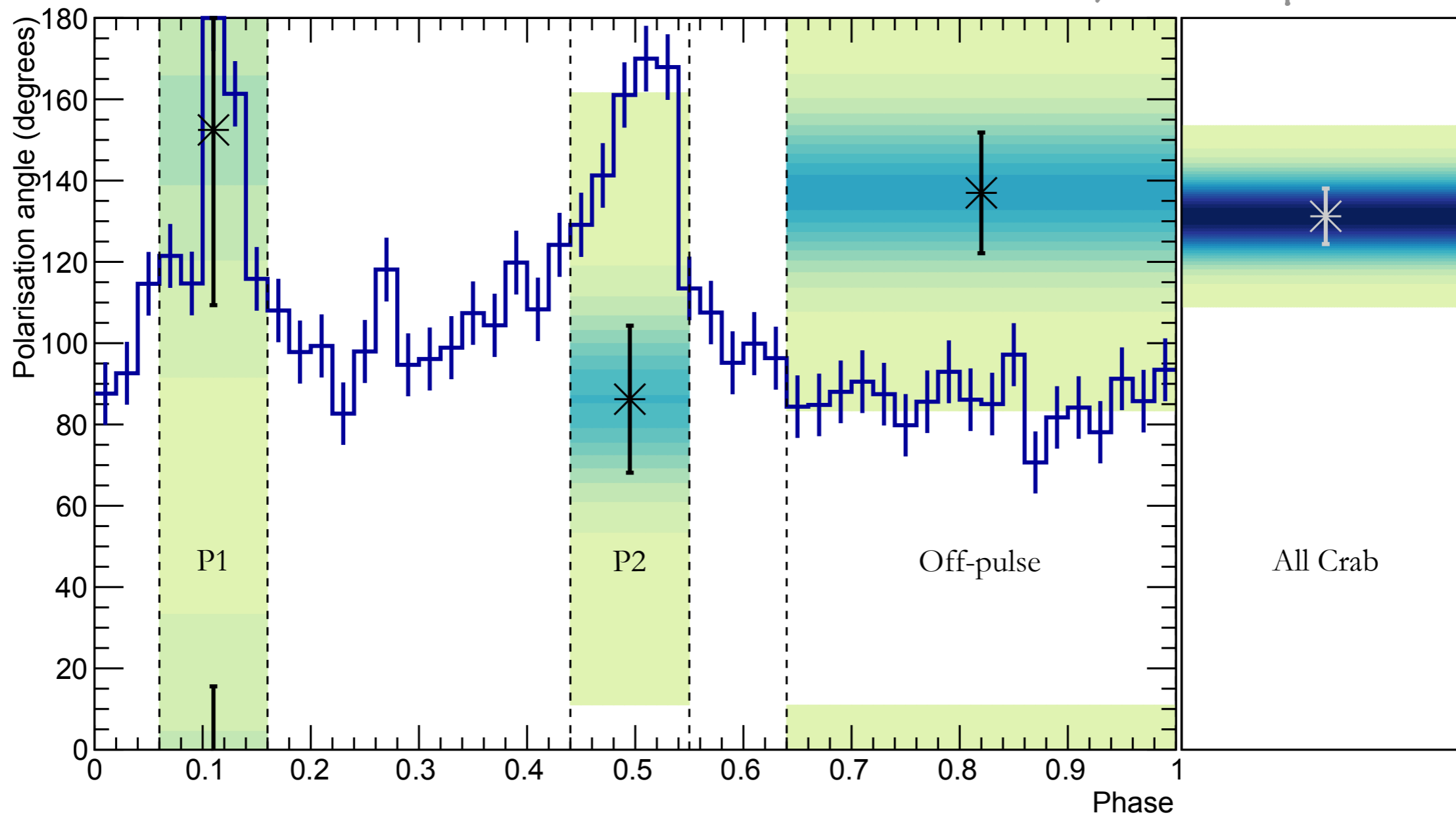
# PoGO+ Crab results

Chauvin et al., Scientific Reports (2017)



# PoGO+ Crab results

Chauvin et al., Scientific Reports (2017)



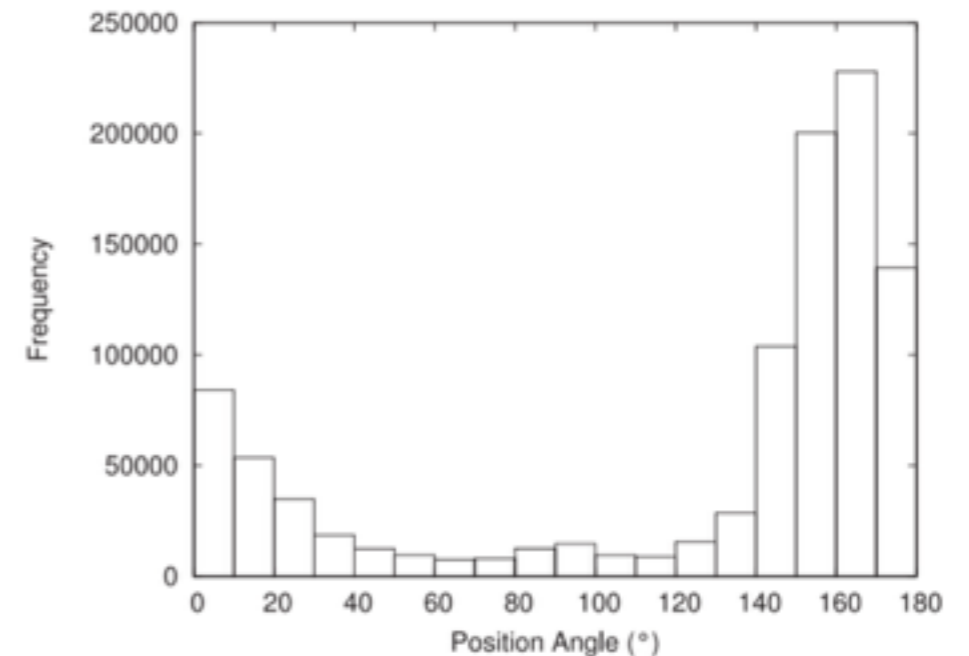
# Polarisation angle coincide with the spin axis+optical structures

Polarisation Angle:  $(131.3 \pm 6.8)^\circ$

Projection of spin axis:  $(124.0 \pm 1.0)^\circ$

Optical inner nebula:  $\sim 160^\circ$

Optical structures:  $\sim 125^\circ$



Moran et al. 2013

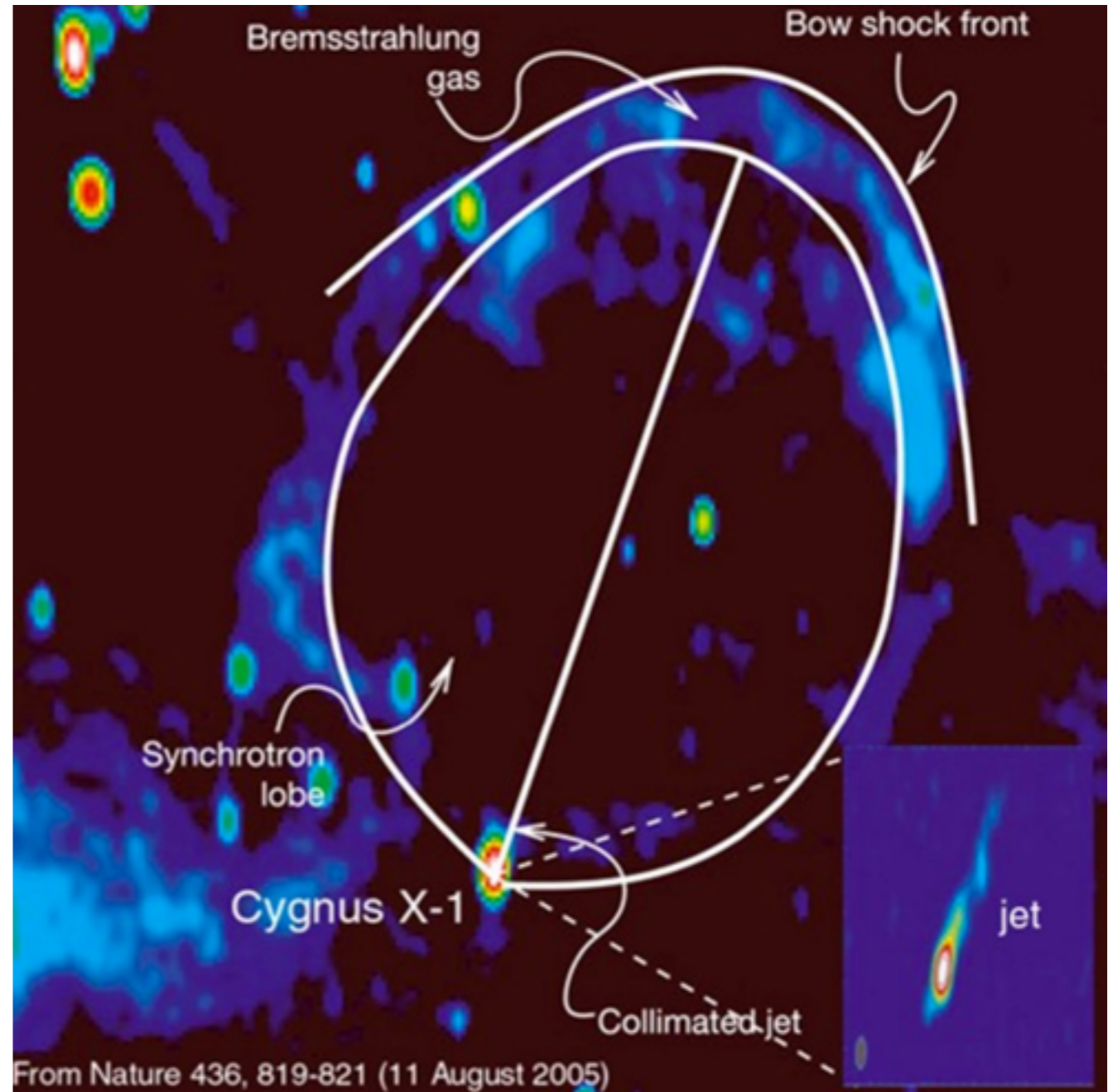


## Summary:

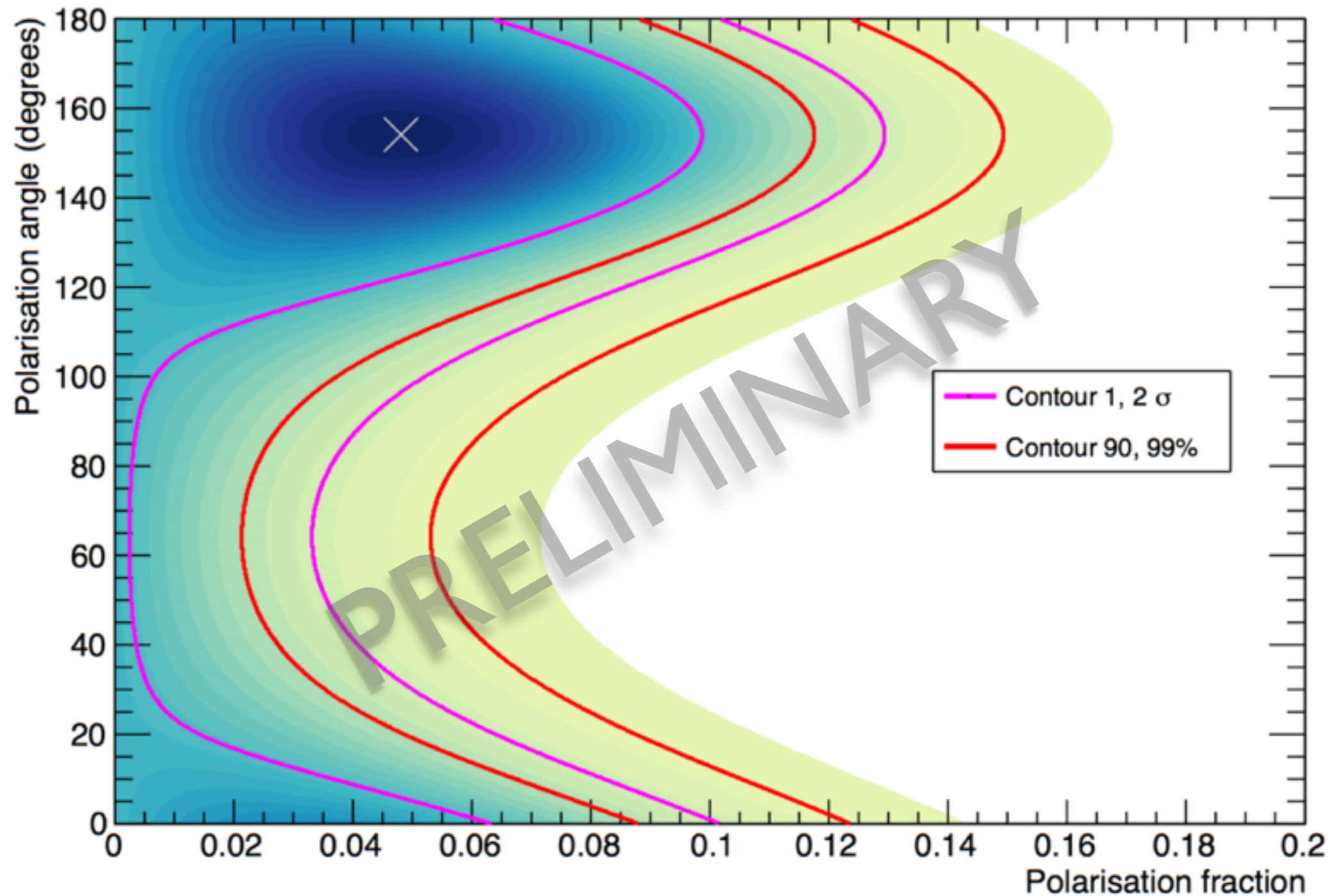
- PoGO+ measurements of the Crab nebula pinpoint origin of hard X-ray emission.

# Cygnus X-1

- First confirmed black hole.  
(mass =  $(15 \pm 1)M_{\odot}$ )
- Observed radio jet  $\rightarrow$  orientation of system.
- Spectral and temporal properties are well studied in broad energy-range.
- Orbital period of  $\sim 5.6$  days.



# PoGO+ results



# Cygnus X-1 polarised

- Polarisation is expected to be **small**, assuming an inclination close to the orbital plane ( $27.1 \pm 0.8^\circ$ , Orosz et al. 2011).
- Results: **PF=( $0.0^{+5.6}/_{-0.0}$ )%** and **PA=154±31°**.
- PA is parallel with radio jet:  $-22 \pm 5^\circ = 158 \pm 5^\circ$  (Stirling et al. 2001; Fender et al. 2006).
- No sign of strong gravity.





## Summary:

- PoGO+ measurements of the Crab nebula pinpoint origin of hard X-ray emission.
- PoGO+ measurements of Cygnus X-1 constrain accretion geometry (important for physical parameters such as BH spin)



**Conclusion:**

**Two numbers → Interesting physics**

# Comparison to existing data

Chauvin et al., Scientific Reports (2017)

