The PoGO+ Mission

OKC Day Seminar

by Mette Friis and Victor Mikhalev

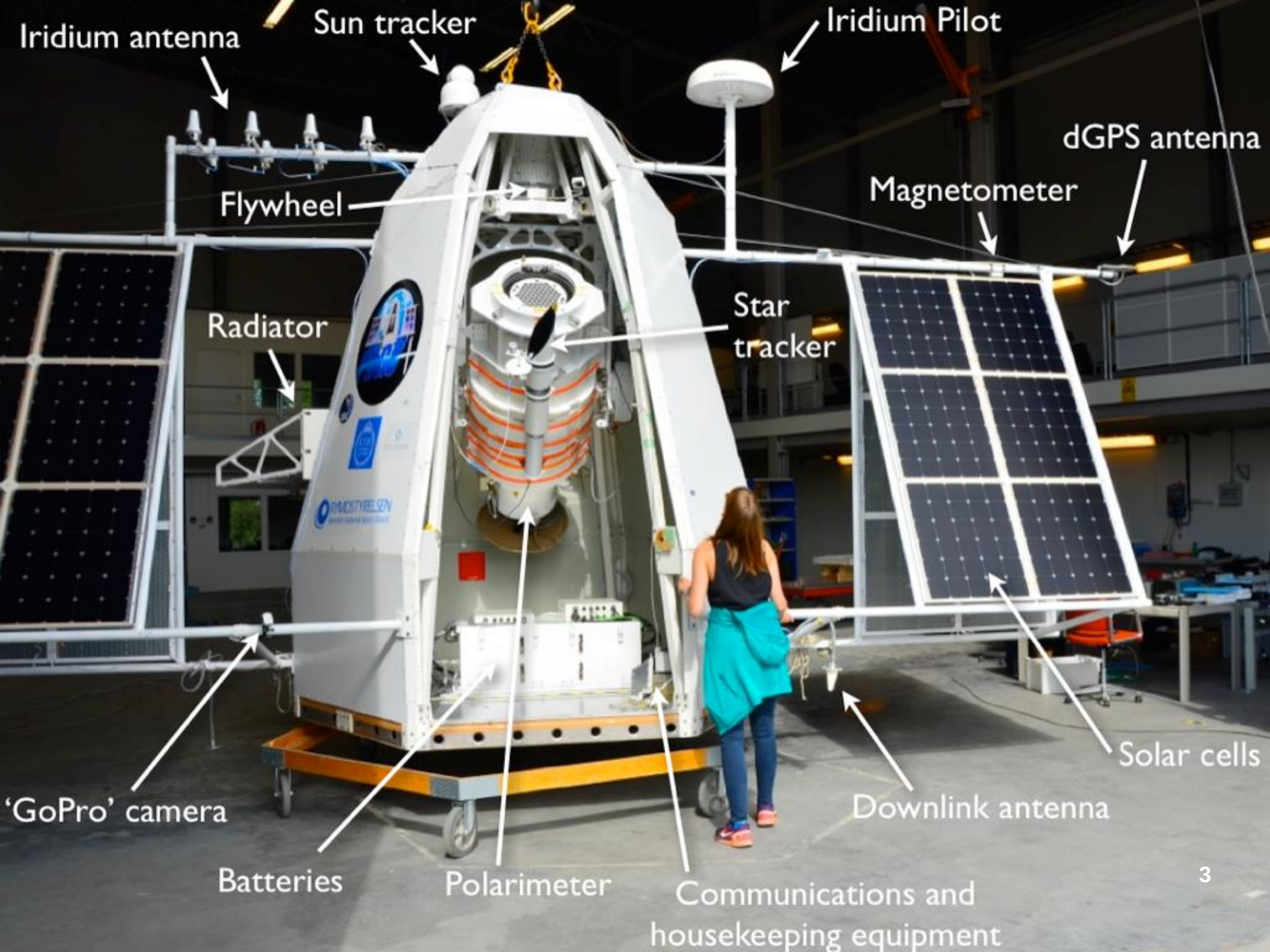
2017-04-19

POLARISATION

- Electric field vector is perpendicular to the magnetic field lines and hence a polarisation measurement determines the direction of magnetic field.

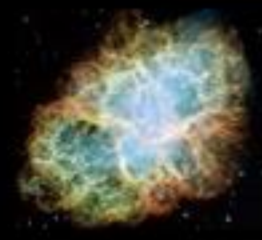
- Magnitude of polarisation depends on the energy of photons. Photons with electric vector perpendicular to the magnetic field are highly absorbed and hence a polarisation measurement determines the direction and magnitude of the magnetic field.

- Electric vector is perpendicular to the plane of scattering and hence polarisation measurement determines the geometrical relation between the photon source and the scatterer.



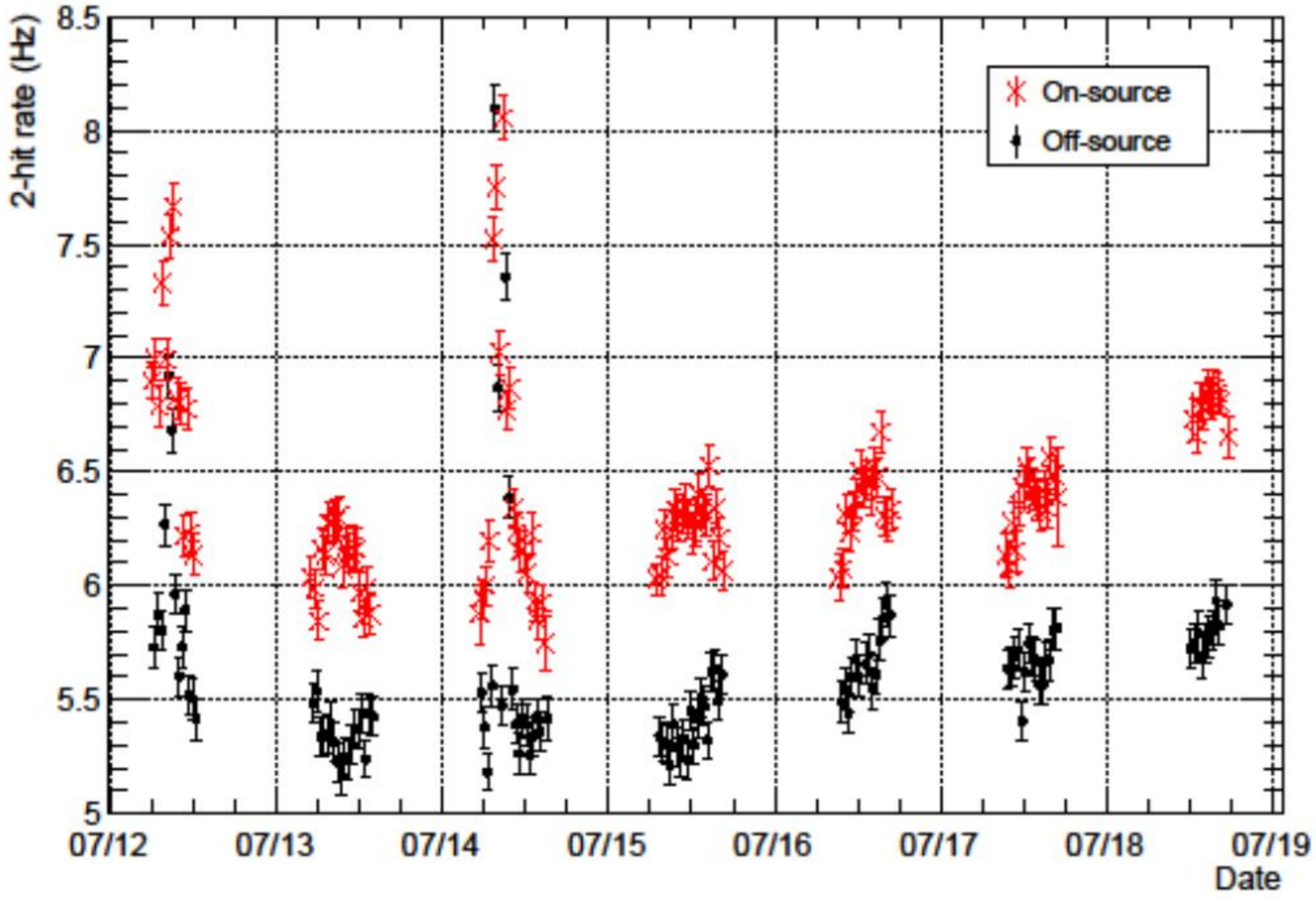
Iridium antenna
Sun tracker
Iridium Pilot
dGPS antenna
Flywheel
Magnetometer
Star tracker
Radiator
Solar cells
'GoPro' camera
Downlink antenna
Batteries
Polarimeter
Communications and housekeeping equipment

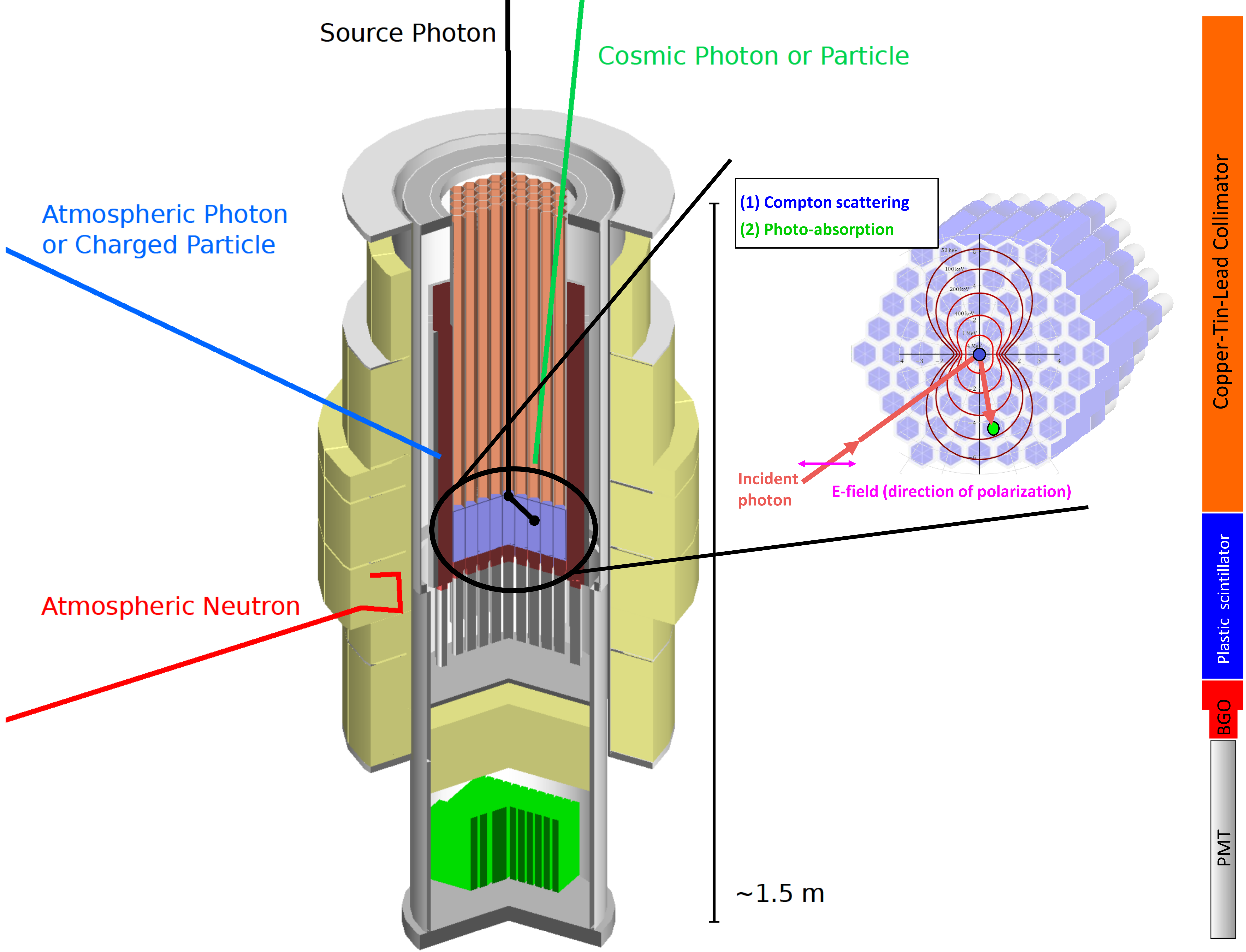

Landing
July 18th 2226 UT
Launch
July 12th 0317 UT
SSC



DEDICATED POLARIMETER

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





Source Photon
Cosmic Photon or Particle
Atmospheric Photon
or Charged Particle
Atmospheric Neutron
(1) Compton scattering
(2) Photo-absorption
Incident
photon
E-field (direction of polarization)
~1.5 m
Copper-Tin-Lead Collimator
Plastic scintillator
BGO
PMT

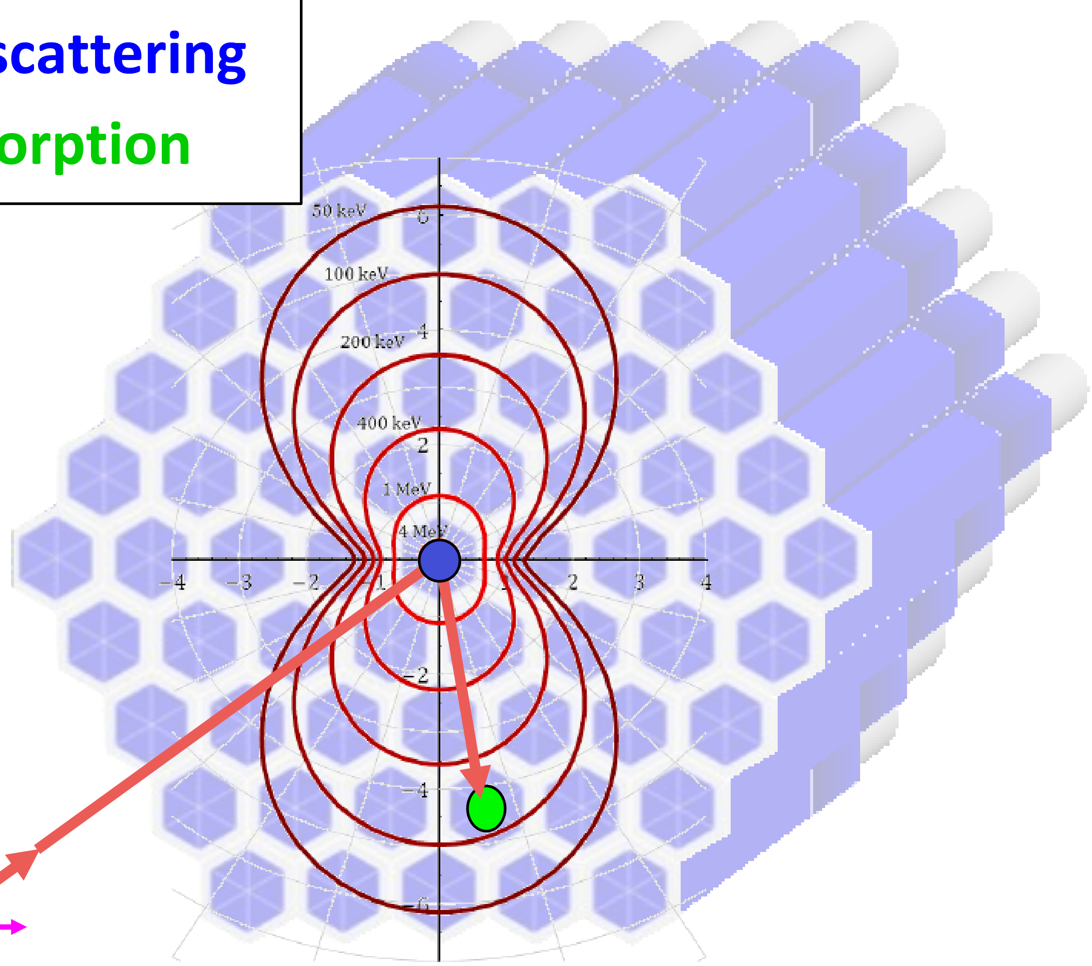
Measuring Polarisation

Compton scattering polarimeter:

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

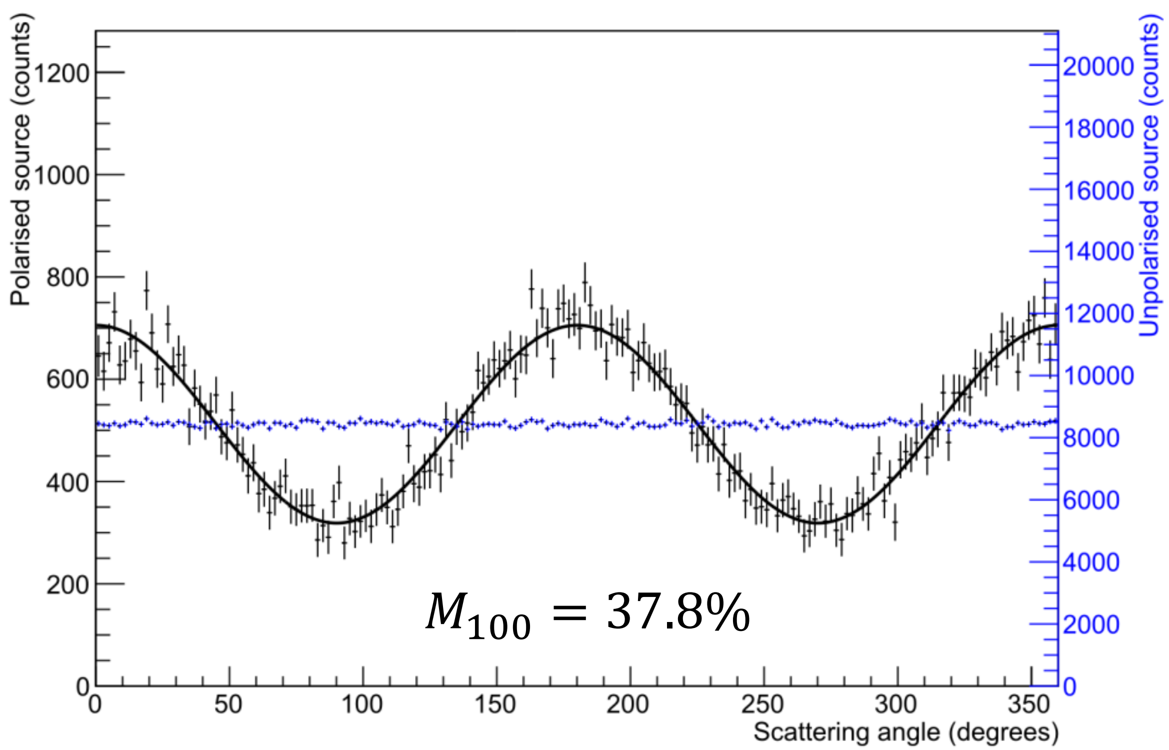
Measure the azimuthal scattering angle ϕ between **Compton scattering** and **Photo-absorption**

(1) Compton scattering
(2) Photo-absorption



Incident photon

E-field (direction of polarization)



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

Measuring Polarisation

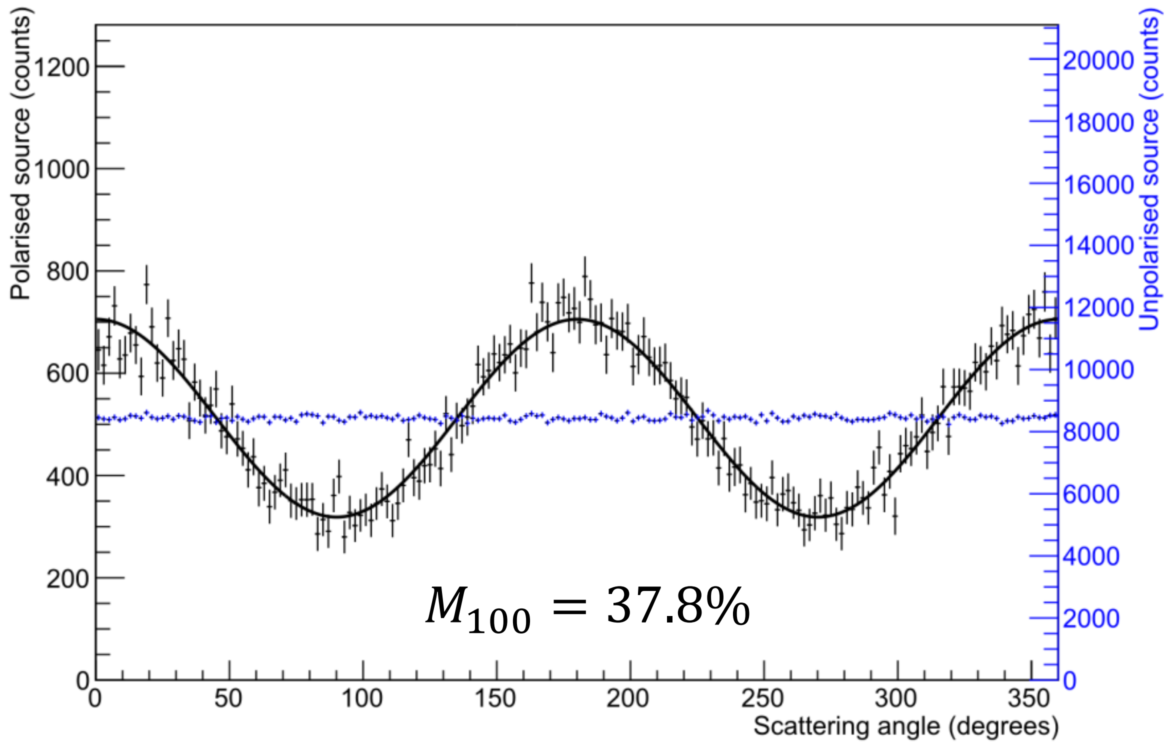
Detector array is rotated 1° s^{-1} (unlike other non-dedicated instruments)

⇒ All scattering angles possible

⇒ Remove differences in detector efficiency

Systematics are well understood

⇒ For high statistics: unpolarised source produces **flat modulation curve**

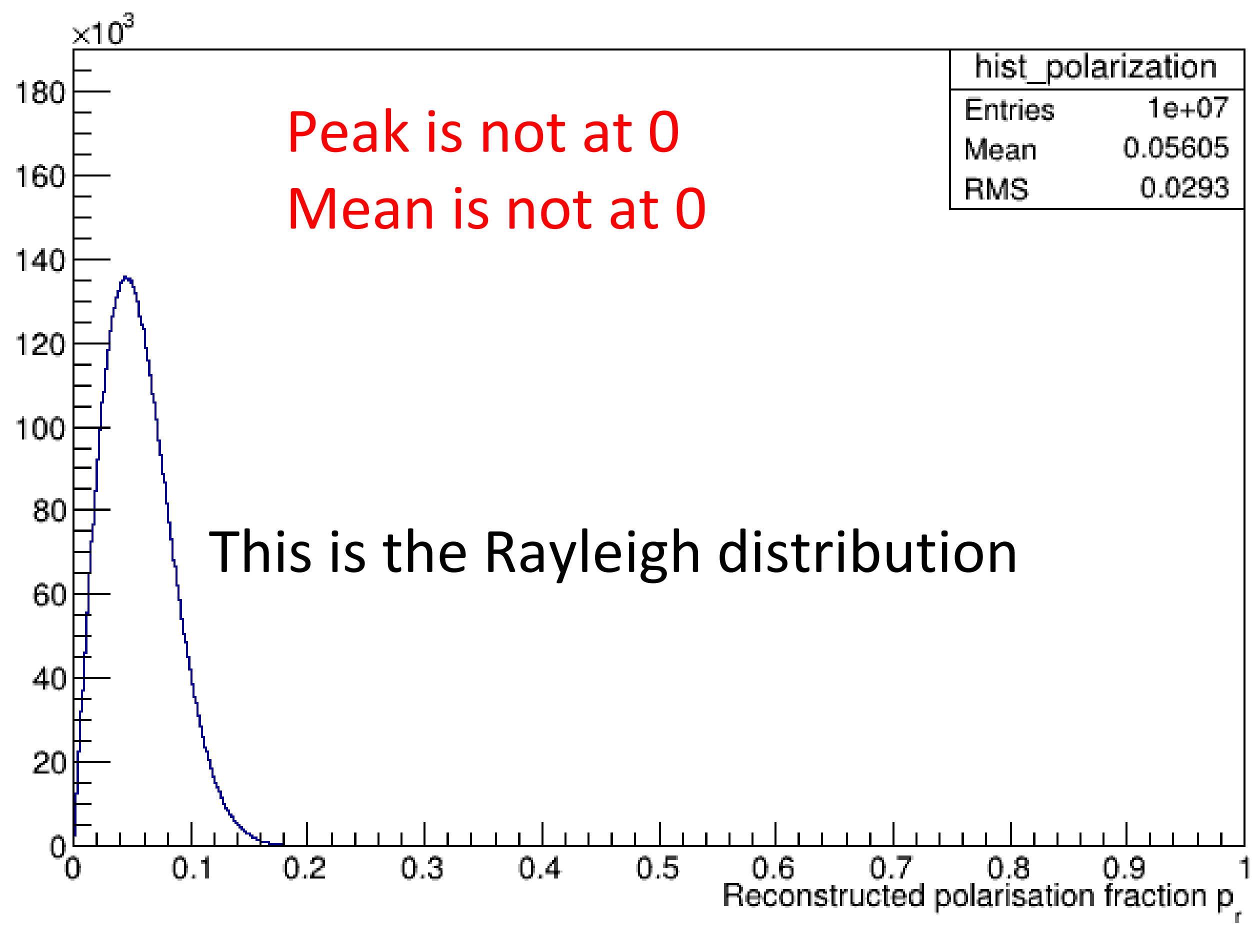


M. Chauvin, et al., Nucl. Instrum. Methods A, (2017)

Measuring Polarisation

Example:

- Suppose we have 1000 photons from an unpolarised source (low statistics).



Polarisation is a positive definite quantity!

- Understanding of instrument systematics and statistics is very important

Measuring Polarisation

Example:

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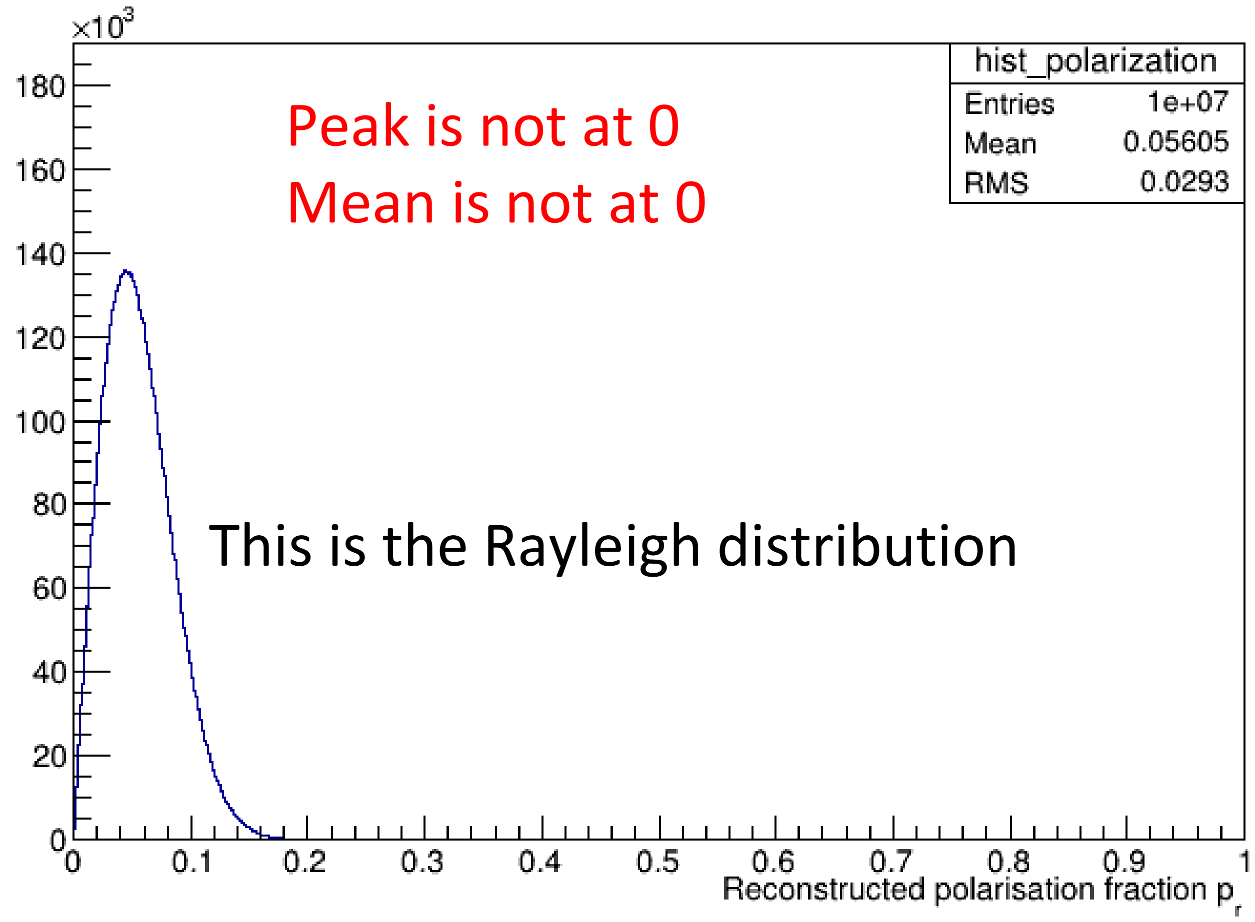


Polarisation is a positive definite quantity!

- Understanding of instrument systematics and statistics is very important

$\mathrm{MDP} = \frac{4.292}{M_{100}} \times \frac{\sqrt{S+B}}{S}$, where **S** and **B** are the **Signal** and **Background** counts.

Minimum Detectable Polarisation (MDP) the figure of merit for all polarimeters

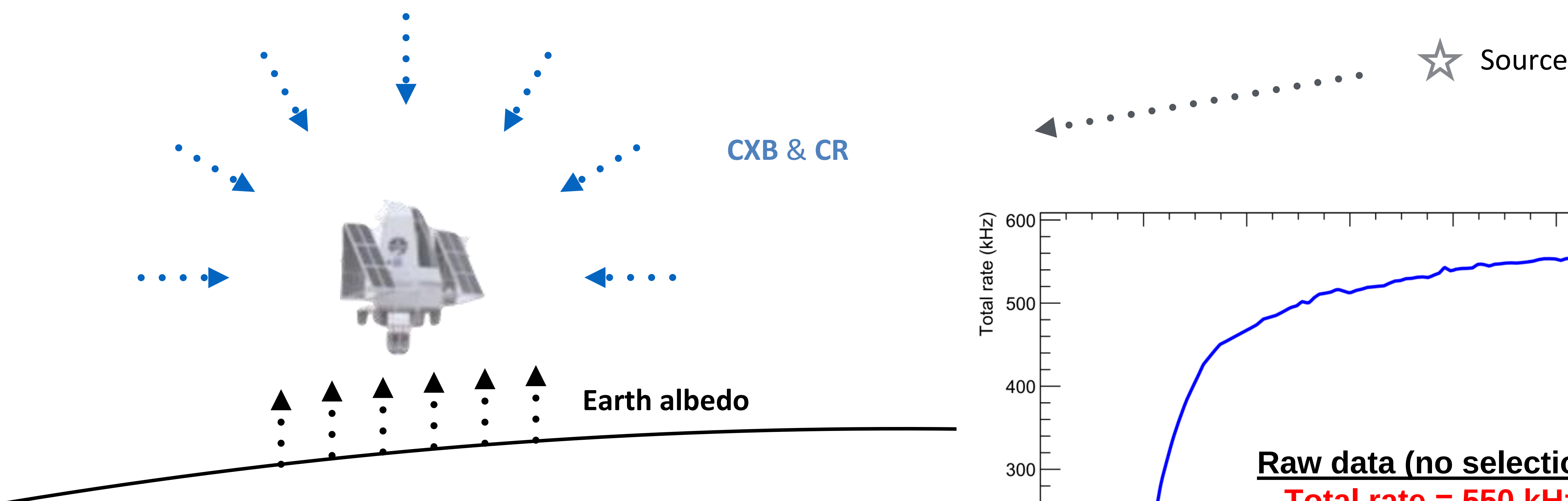
The probability of measuring a polarisation higher than the MDP for an **unpolarised** source is 1%.

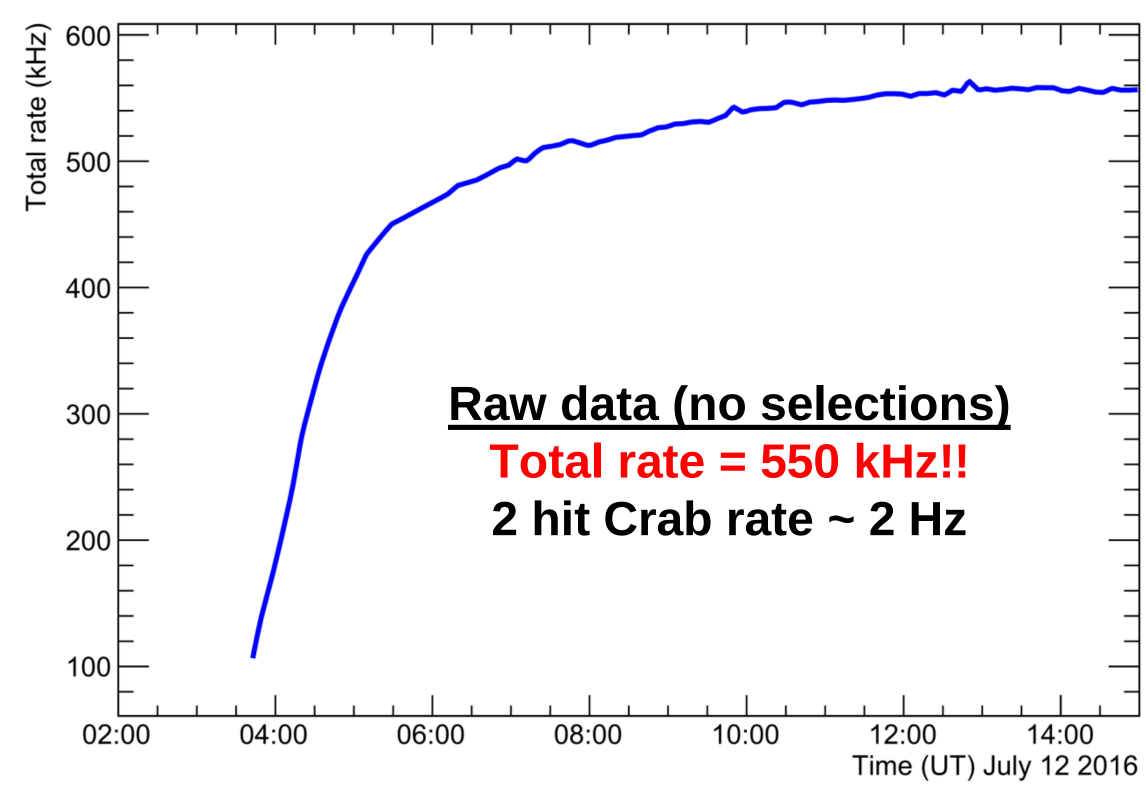
Challenges of High Latitudes

Disadvantage ➡ **high background rate** (low geomagnetic cut-off)

Advantage ➡ **long duration** (circumpolar)

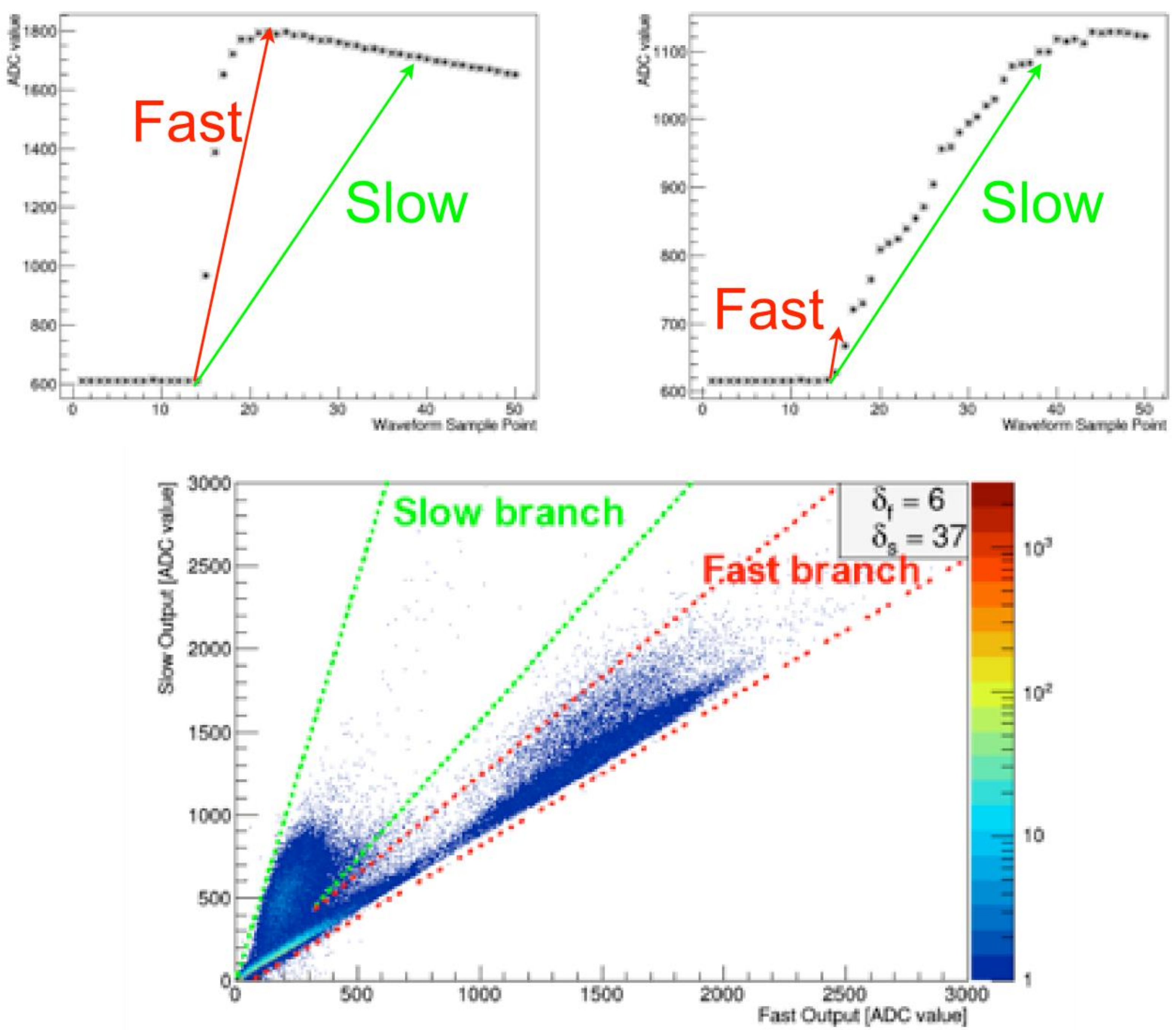
- **CXB** = Cosmic X-ray Background – isotropic photons
- **CR** = Cosmic Rays – isotropic charged particles
- **Earth albedo** – coming from Earth: photons, **neutrons**, charged particles





Rejecting Background (Waveform Discrimination)

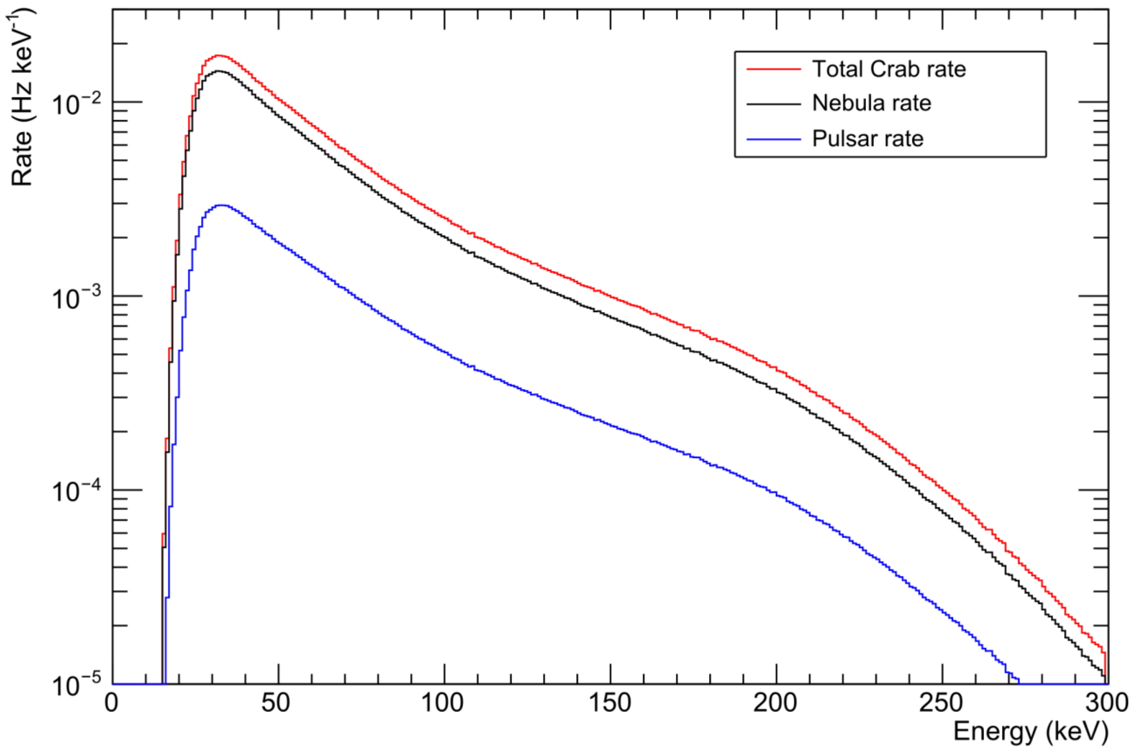
Plastic / 'fast waveform'   BGO / 'slow waveform'



- PMT waveforms sampled at **100 MHz**
- Pulse-shape discrimination to separate **plastic** and **BGO** components
- **Online veto system:** upper discriminator, waveform discrimination (anticoincidence), hit multiplicity > 1.

In-Flight Performance

- Energy range and M_{100} derived from simulations validated during ground calibration.

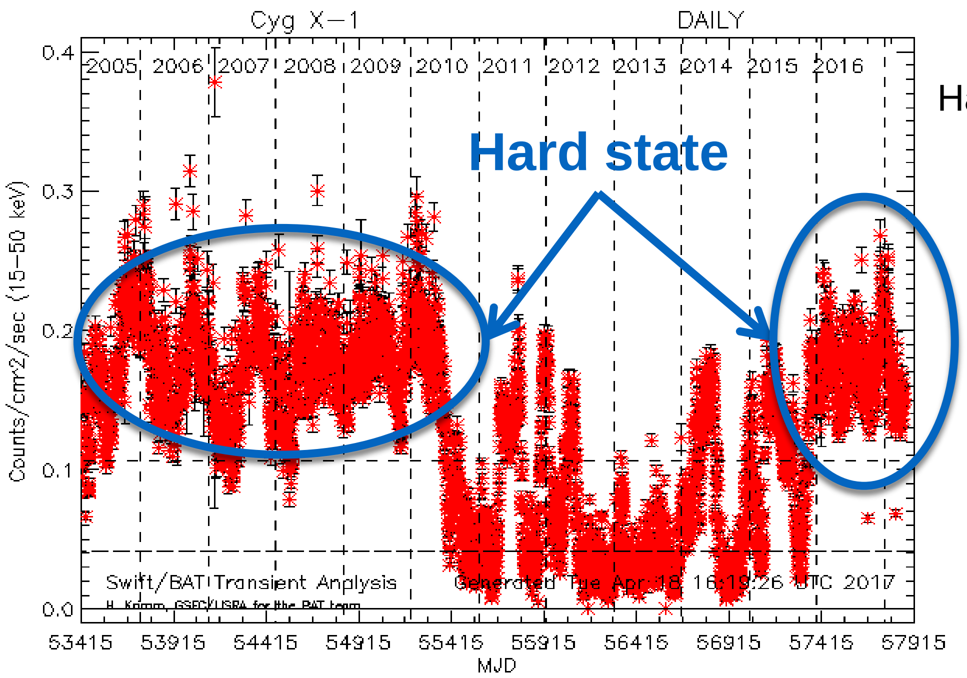


Crab energy range:
18 – 160 keV
$M_{100} = 42.9\%$

MDP=15% (after BG subtraction)

Cygnus X-1 energy range (hard state):
19 – 180 keV
$M_{100} = 44.1\%$

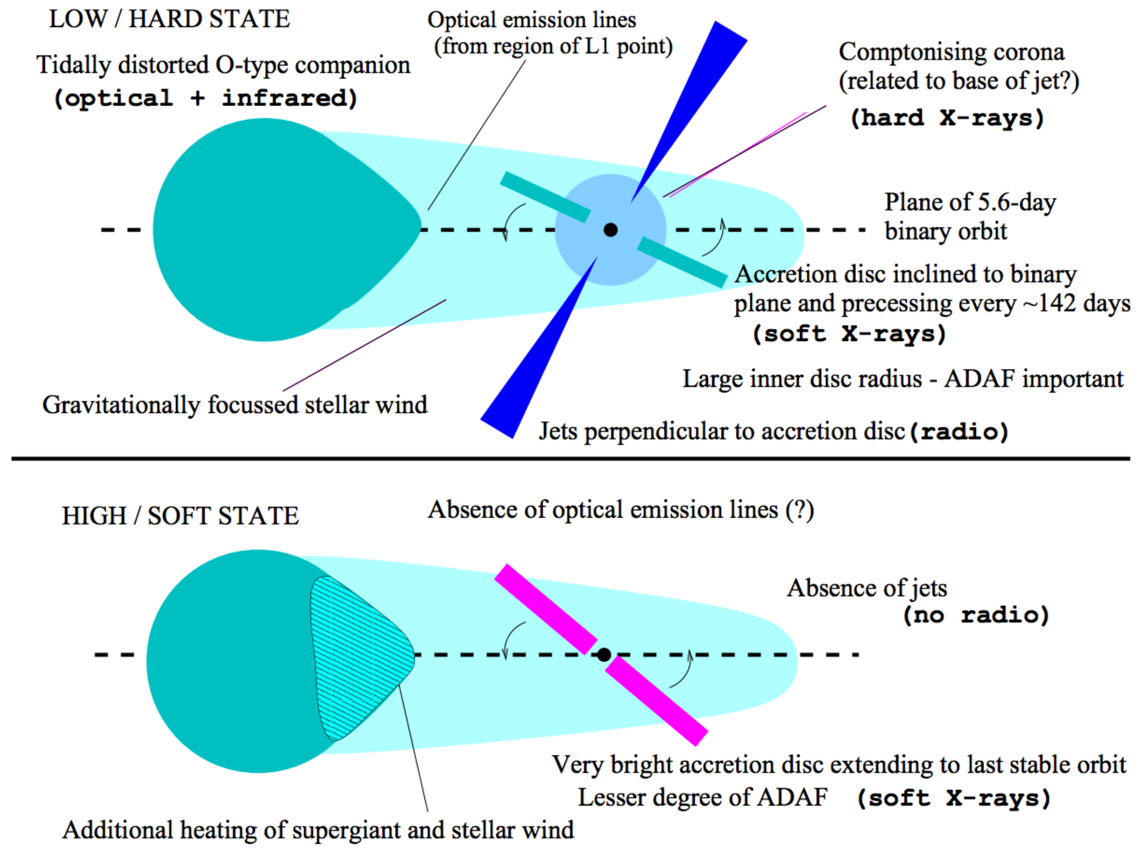
MDP=11% (after BG subtraction)

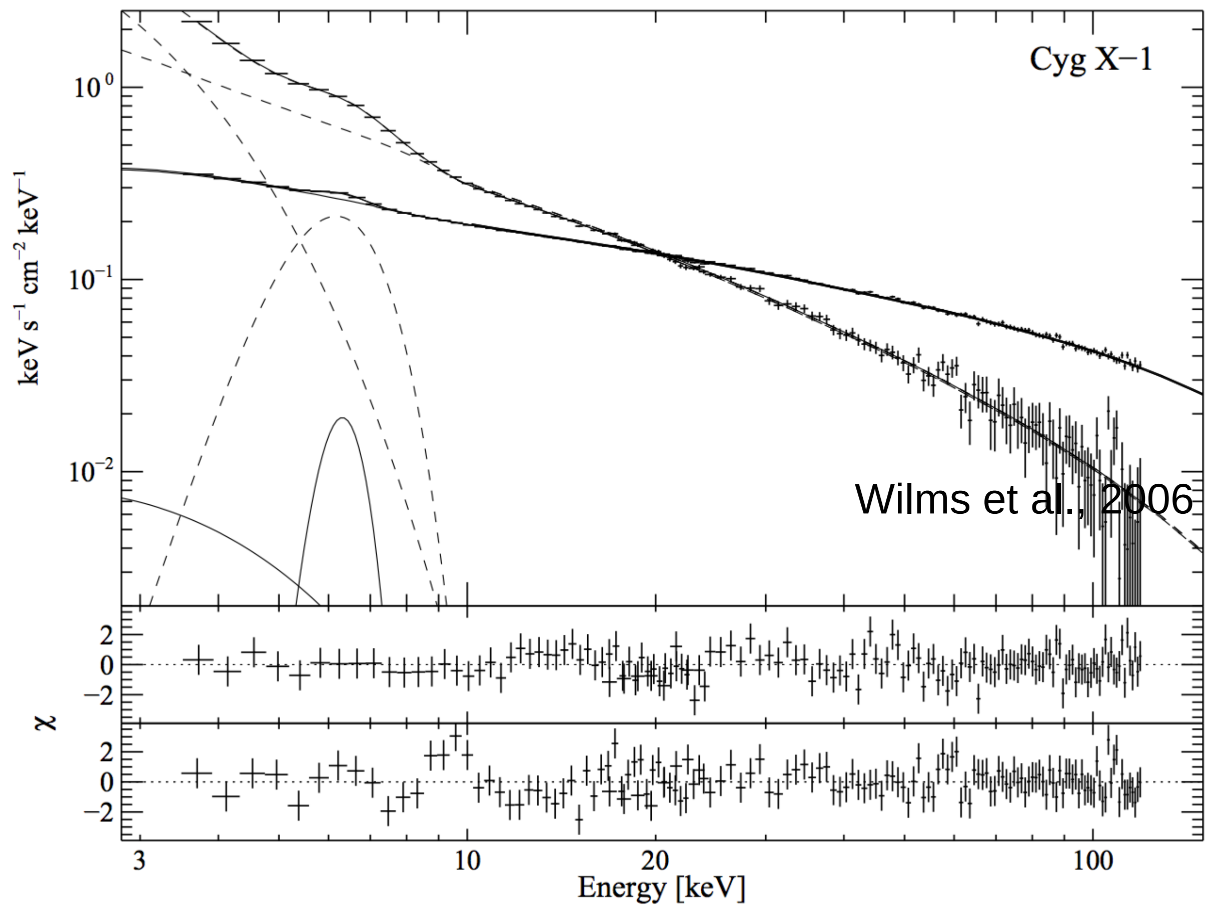


from Swift/BAT
Hard X-ray Transient Monitor
15 – 50 keV

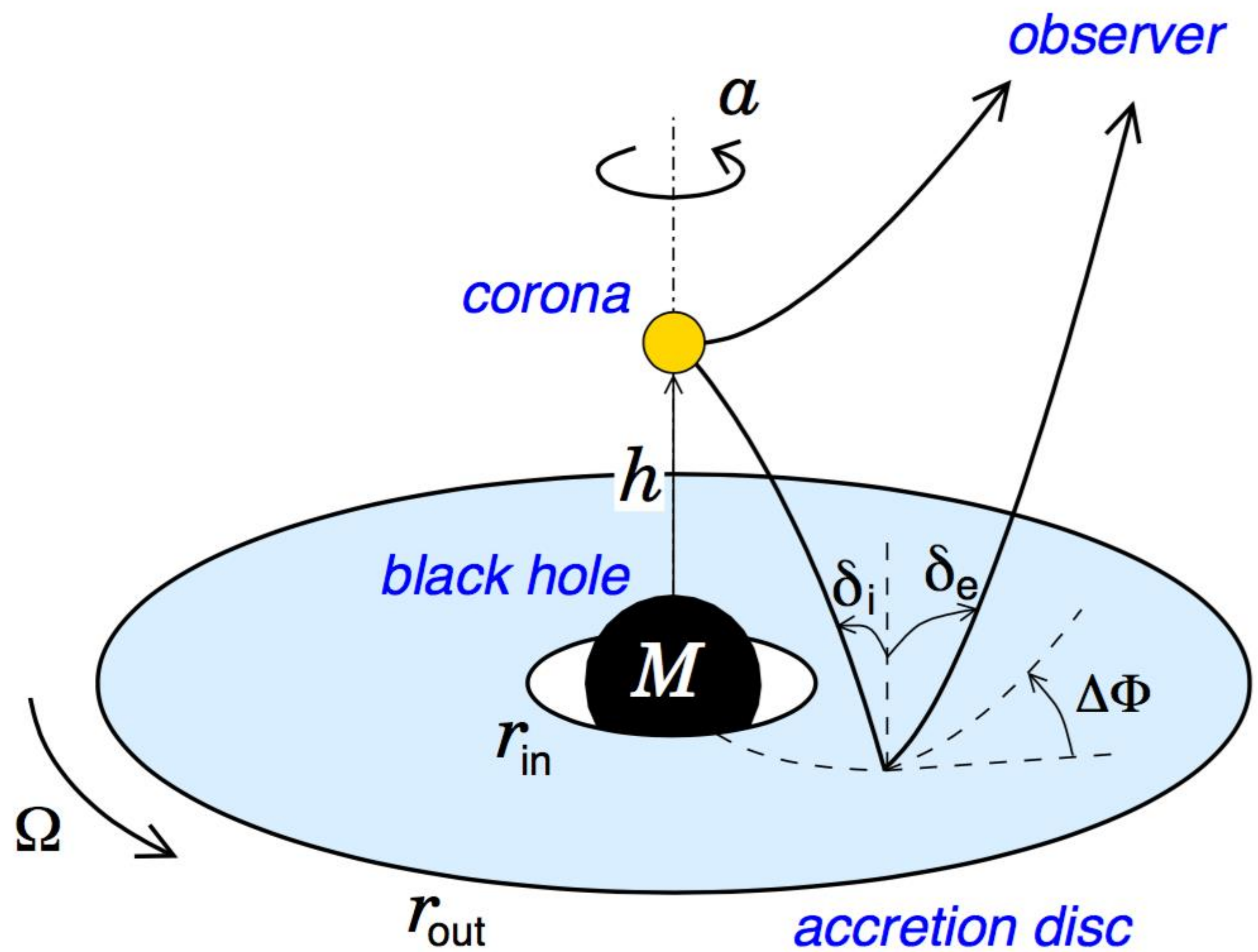
CYGNUS-X1

- Accreting black hole in high-mass X-ray binary.
- Two states: high/soft and low/hard
- Popular models:
(1) Comptonization by accretion disc corona,
(2) Lamp post model

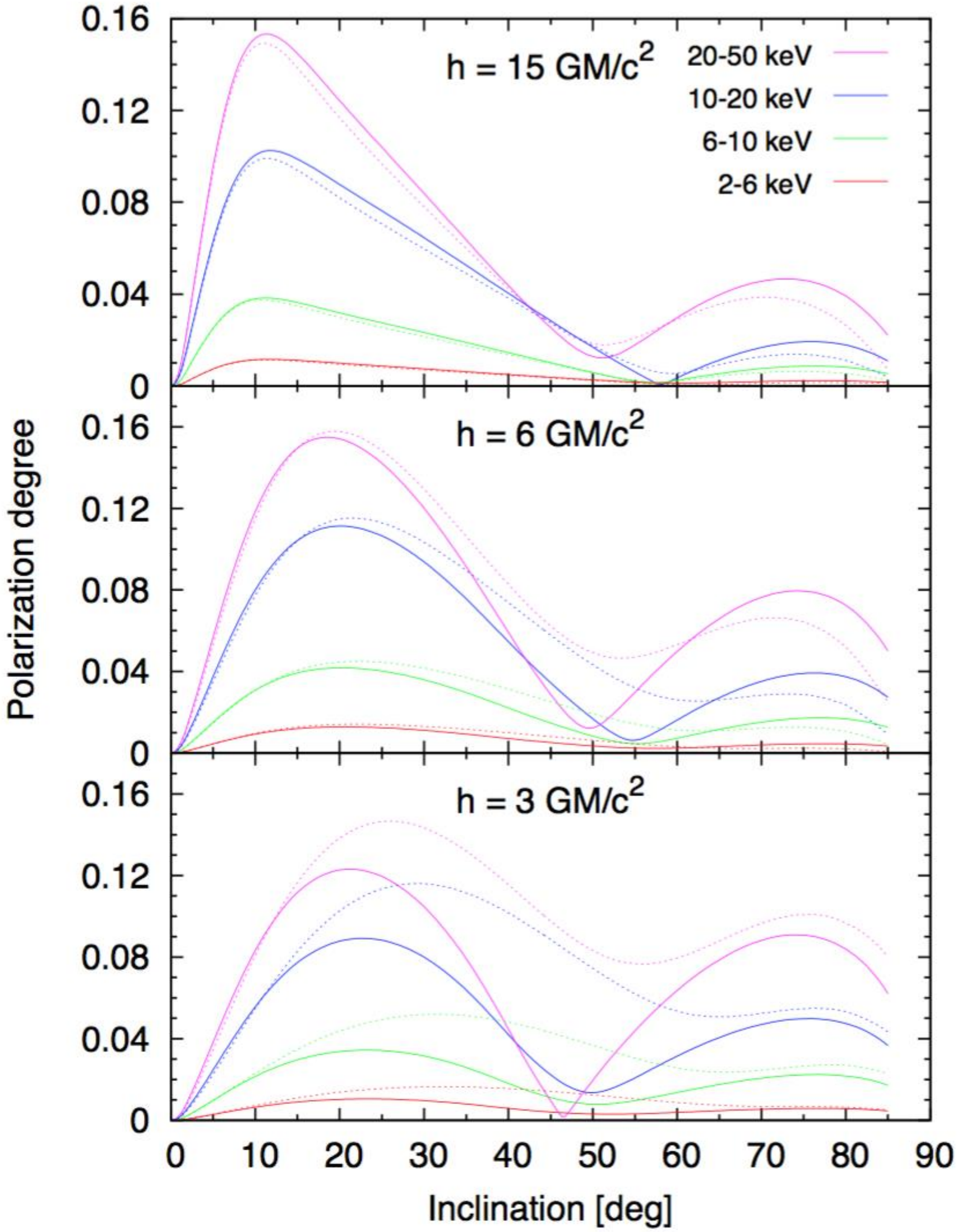


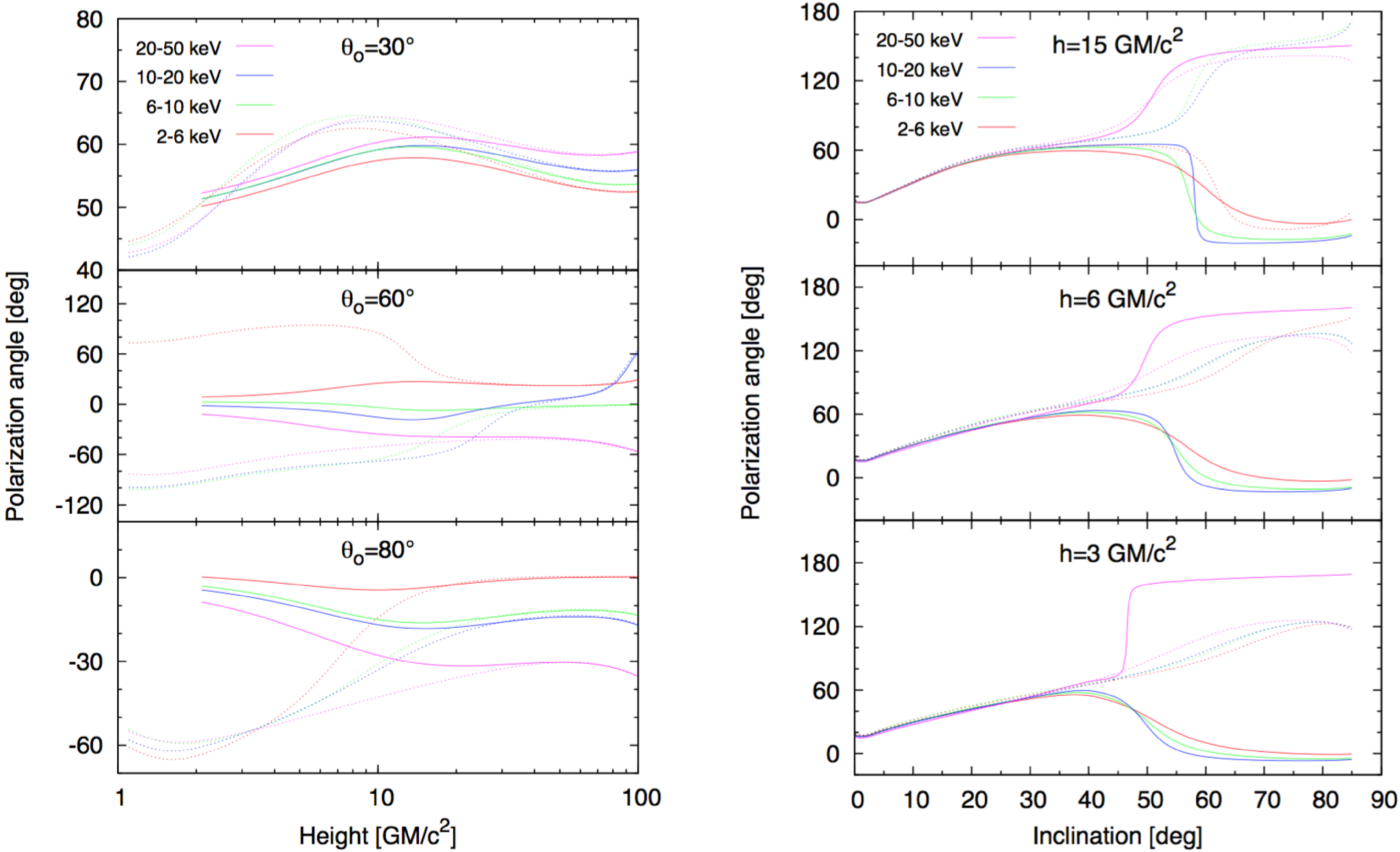


LAMP POST MODEL



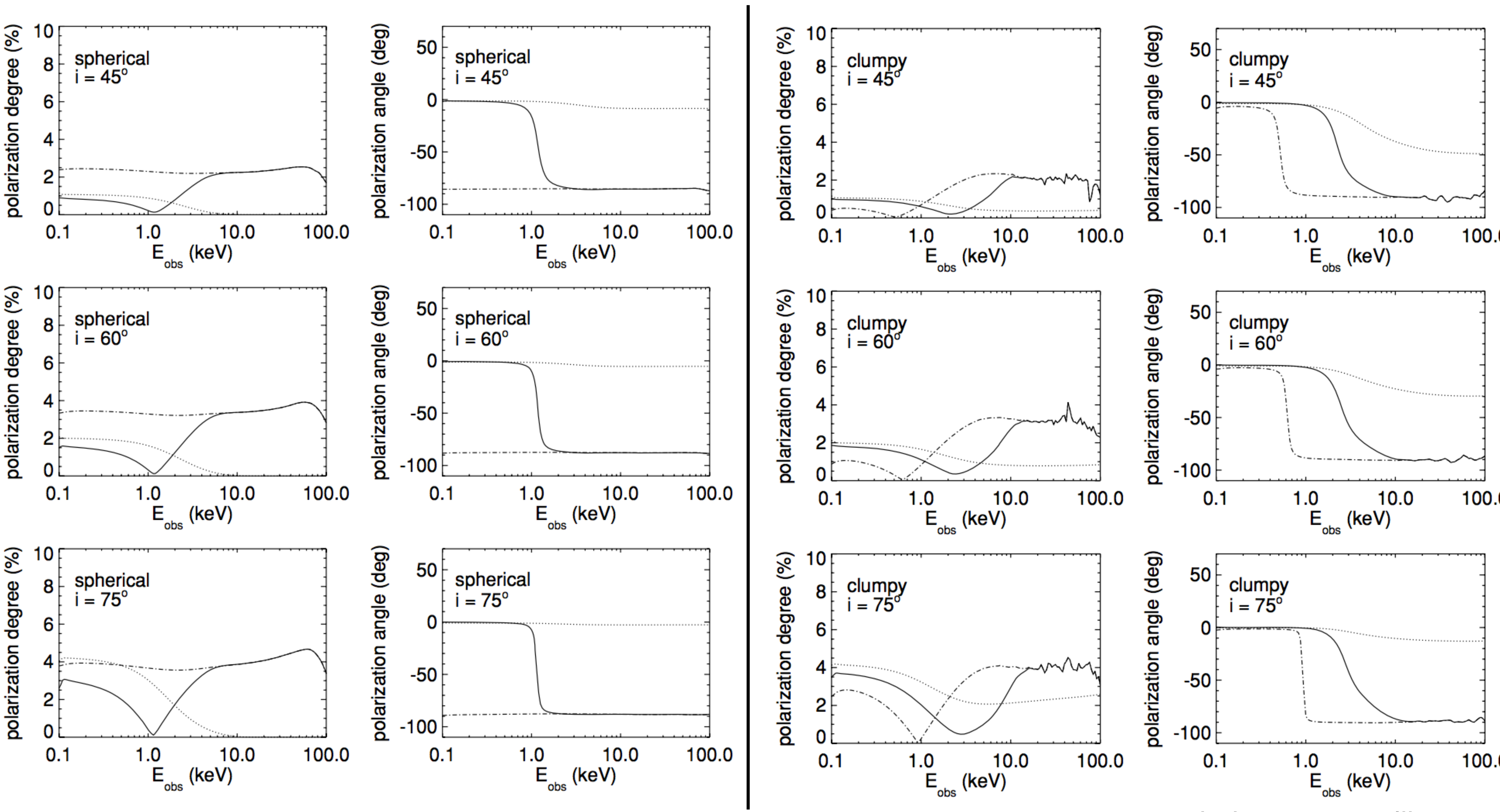
Doviak et al., 2012





20-50 keV
10-20 keV
6-10 keV
2-6 keV
θo=30°
θo=60°
θo=80°
Polarization angle [deg]
Height [GM/c2]
h=15 GM/c2
h=6 GM/c2
h=3 GM/c2
Inclination [deg]

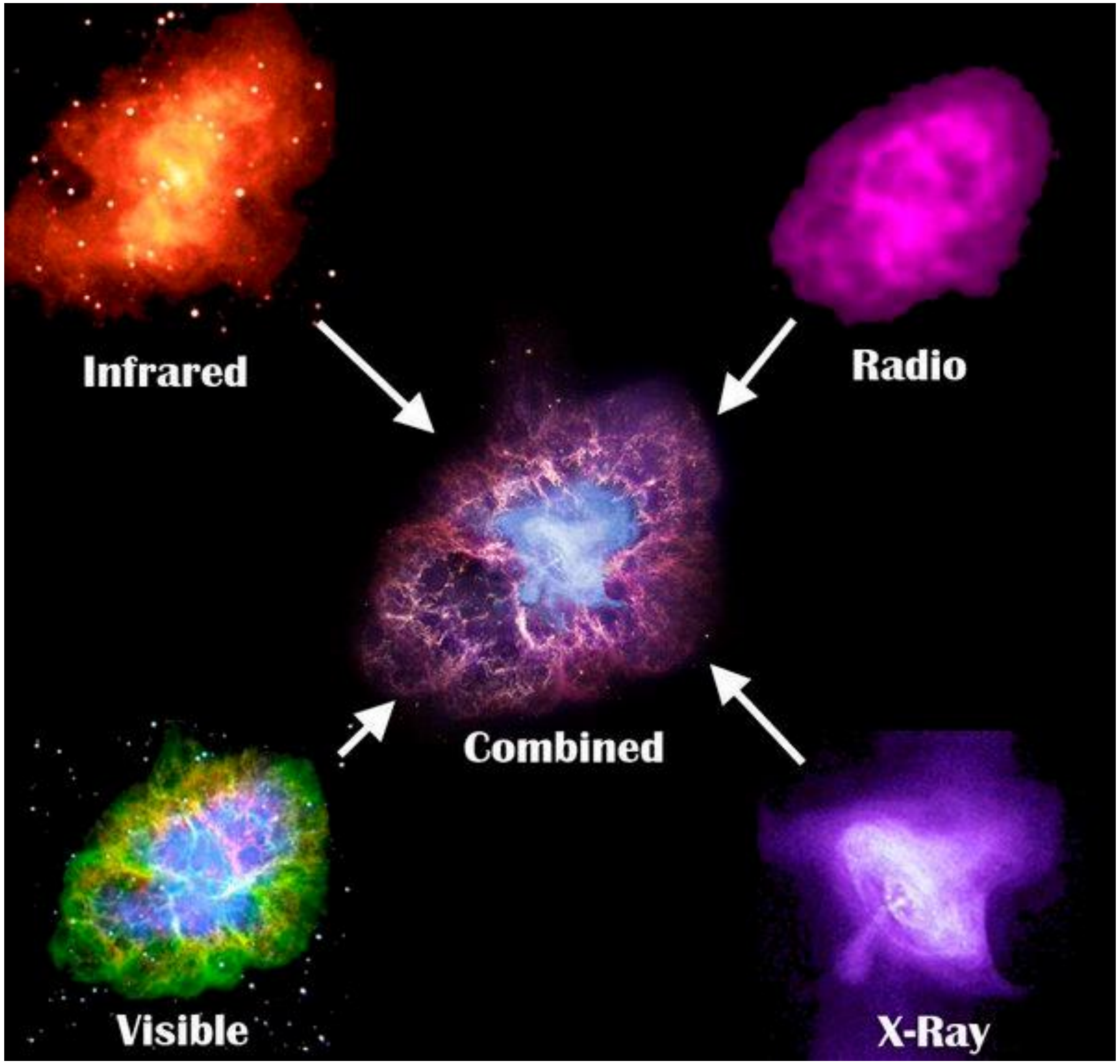
ACCRETION DISC CORONA

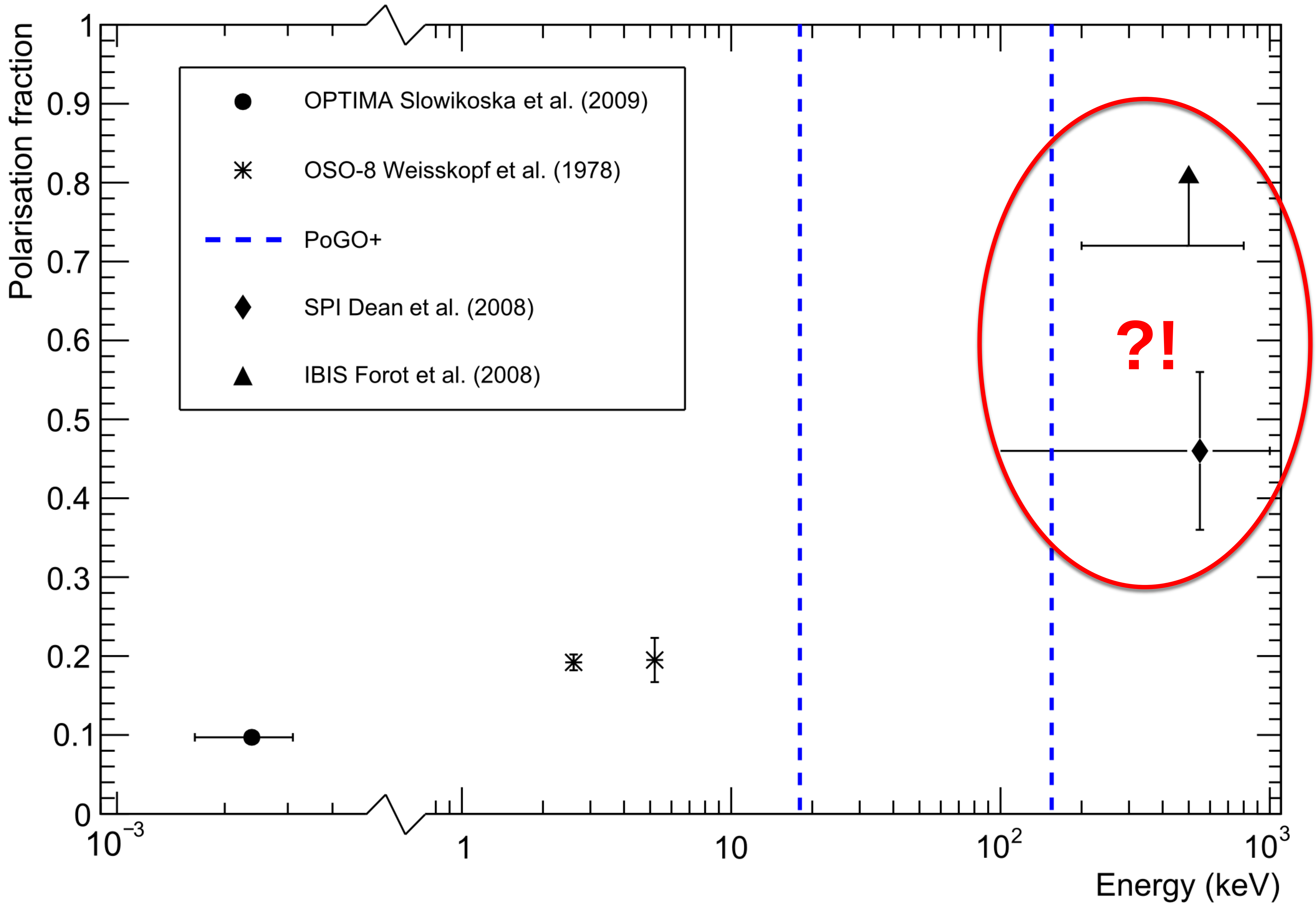


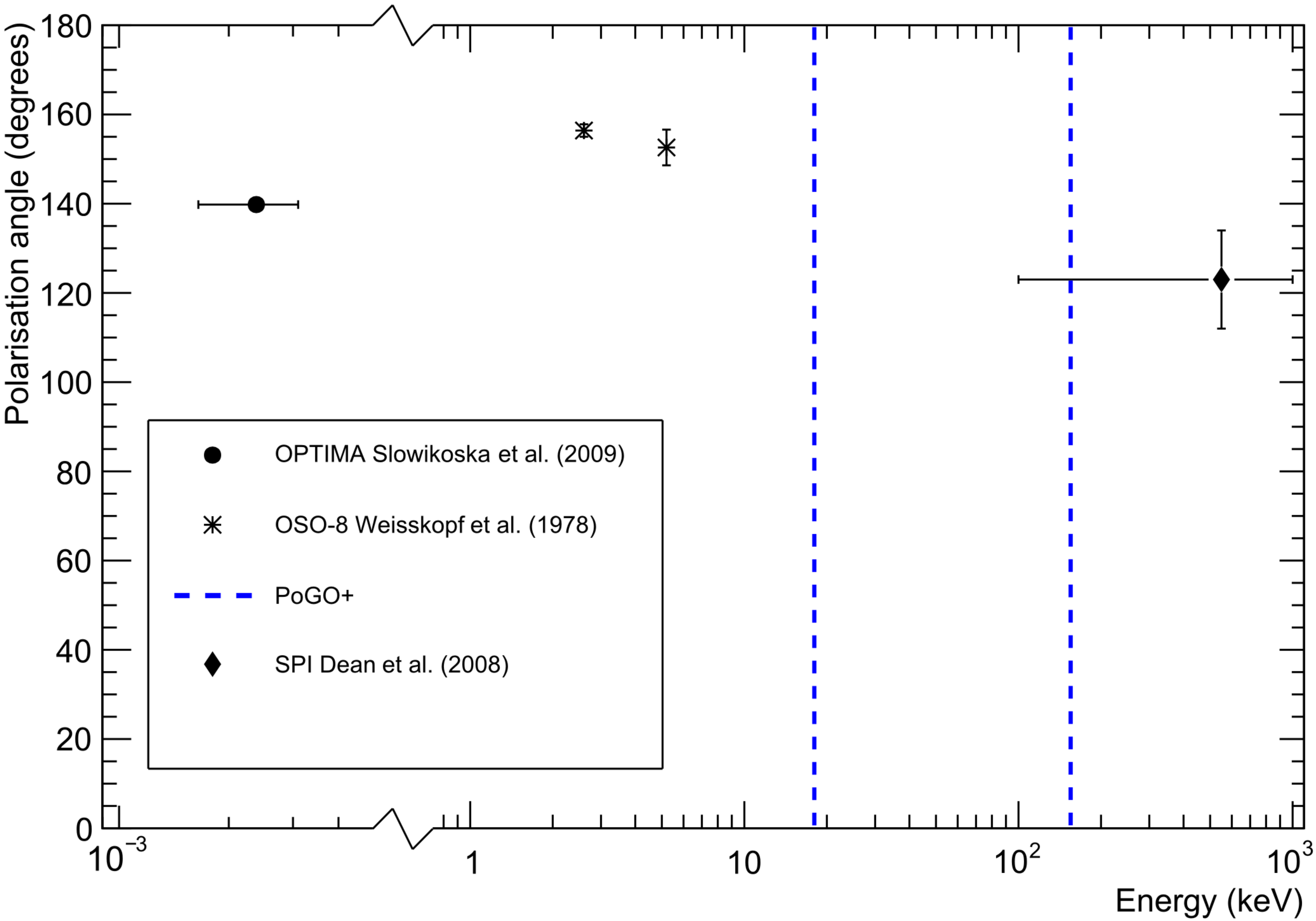
Schnittman & Krolik, 2010

CRAB NEBULA/PULSAR

- Phase cut selections allow us to study both pulsar and nebula contribution.
- Polarisation data exists in optical and soft X-rays (as well as radio).
- Current model predictions do not match optical data.




Polarisation fraction
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
OPTIMA Slowikoska et al. (2009)
OSO-8 Weisskopf et al. (1978)
PoGO+
SPI Dean et al. (2008)
IBIS Forot et al. (2008)
?!
10^{-3}
1
10
10^2
10^3
Energy (keV)



Polarisation angle (degrees)
180
160
140
120
100
80
60
40
20
0
10^{-3}
1
10
10^2
10^3
Energy (keV)
OPTIMA Slowikoska et al. (2009)
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http://web.particle.kth.se/pogo/

KTH VETENSKAP OCH KONST

HIROSHIMA

RYMDSTYRELSEN Swedish National Space Board

SSC

DST CONTROL

OHB SWEDEN

Knut och Alice Wallenbergs Stiftelse

Vetenskapsrådet