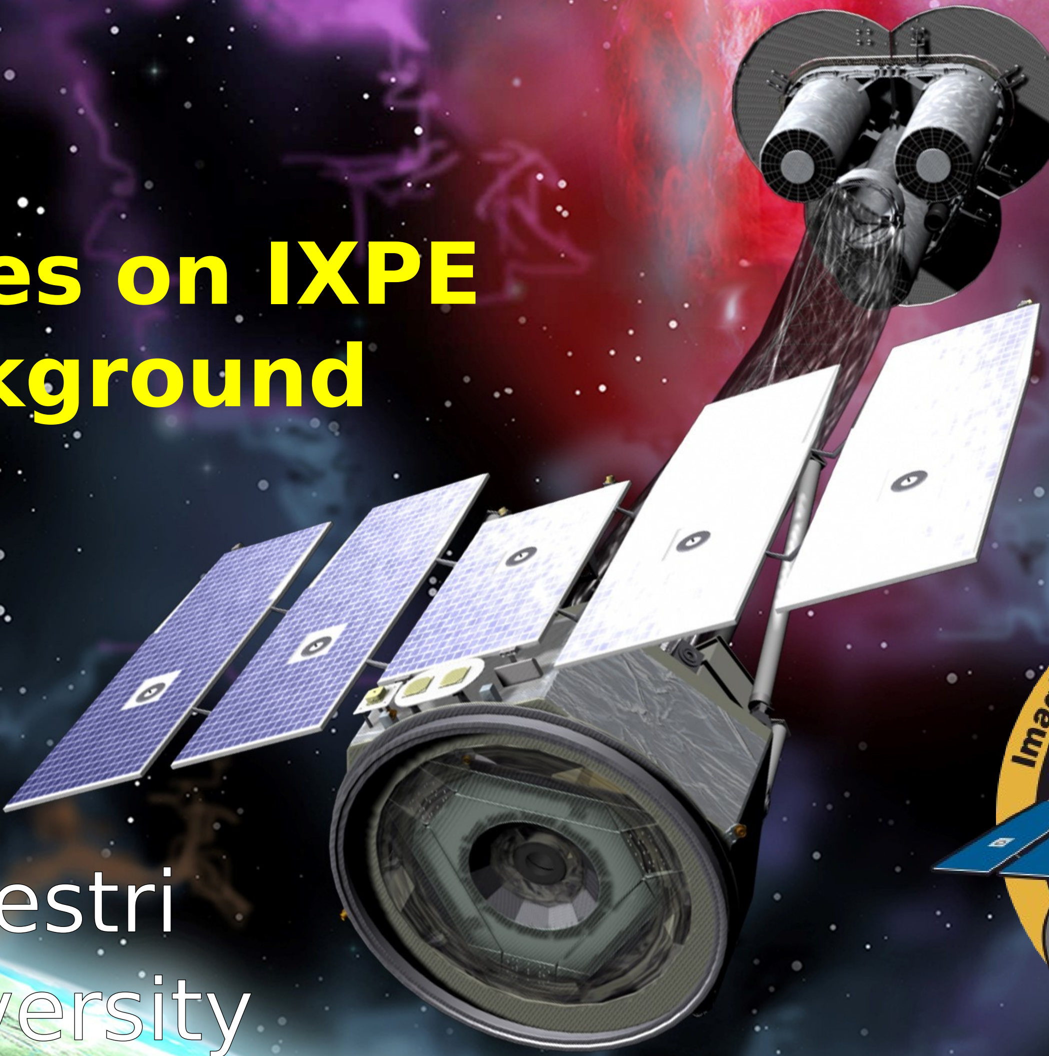
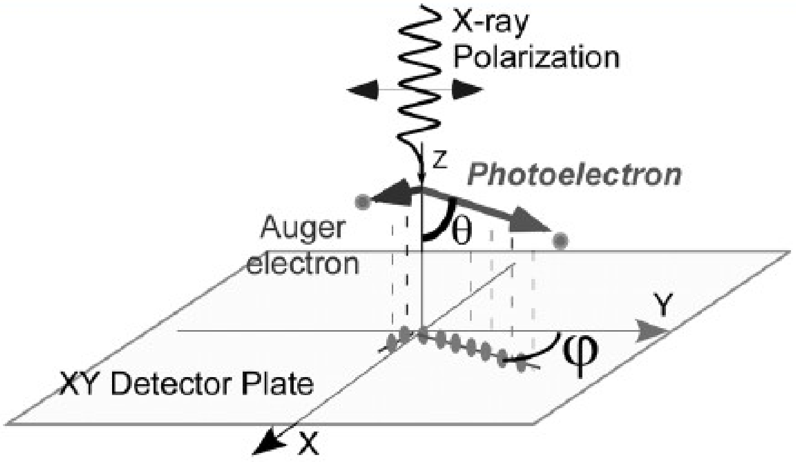
Updates on IXPE background



Stefano Silvestri
INFN and University (Pisa)

How we measure polarization

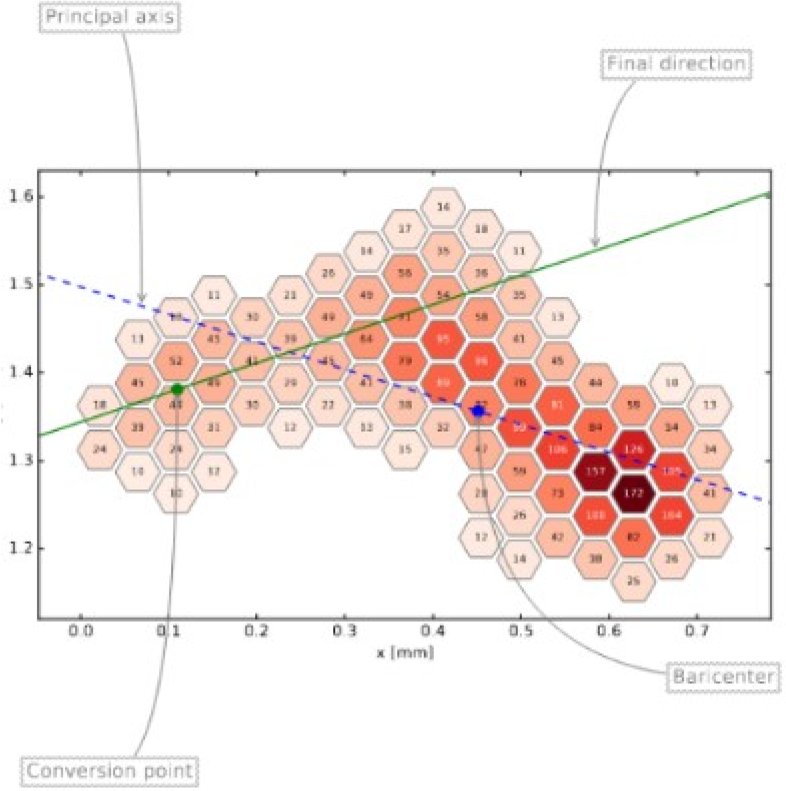
Photoionization is polarization-sensitive



$$\frac{d\sigma}{d\Omega} \sim Z^5 E^{\frac{7}{2}} \frac{\sin^2\beta \boxed{\cos^2\phi}}{(1+\beta\cos\theta)^4}$$

And then we call phi the polarization angle

This is done in a gas (longer tracks)
Reconstruction algorithm event by event



How we measure polarization

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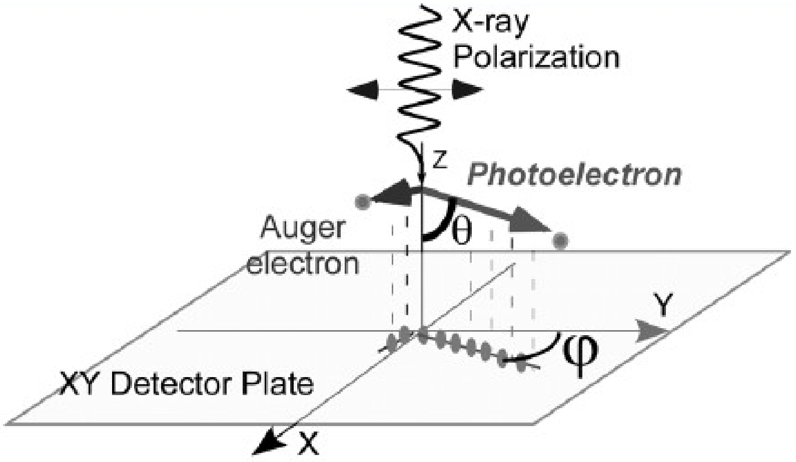

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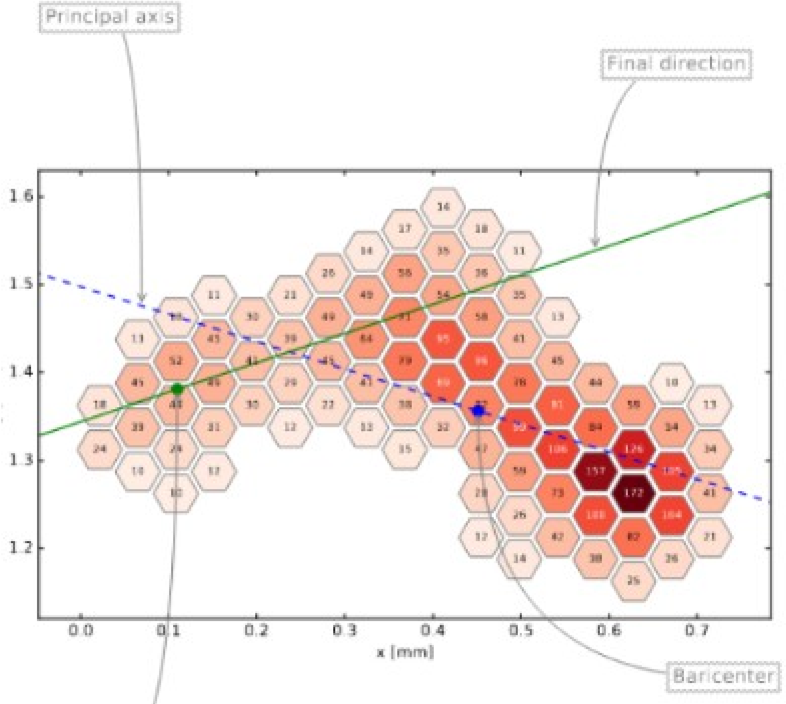
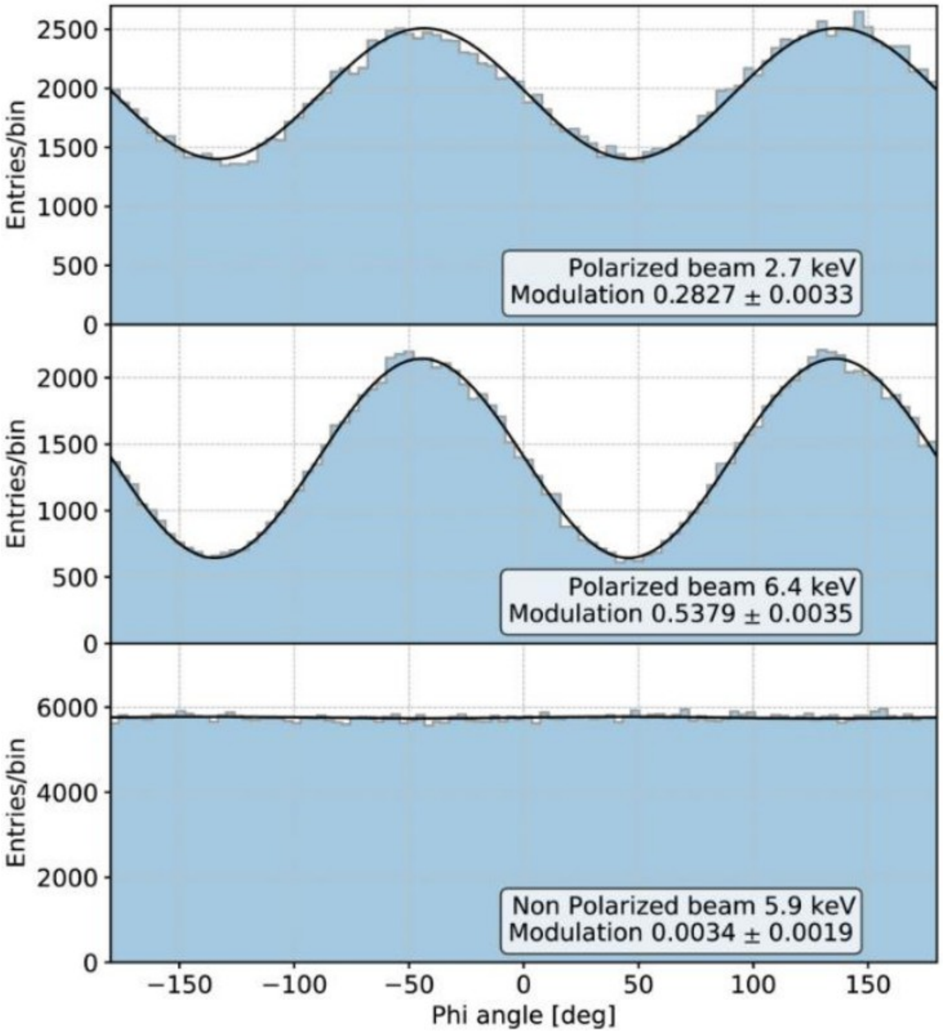


And then we call phi the polarization angle **(It's okay for on-axis X-rays)**

The modulation factor



- A fully polarized beam produces a partly modulated output

$$M(\phi) = A + B\cos^2(\phi - \phi_0)$$

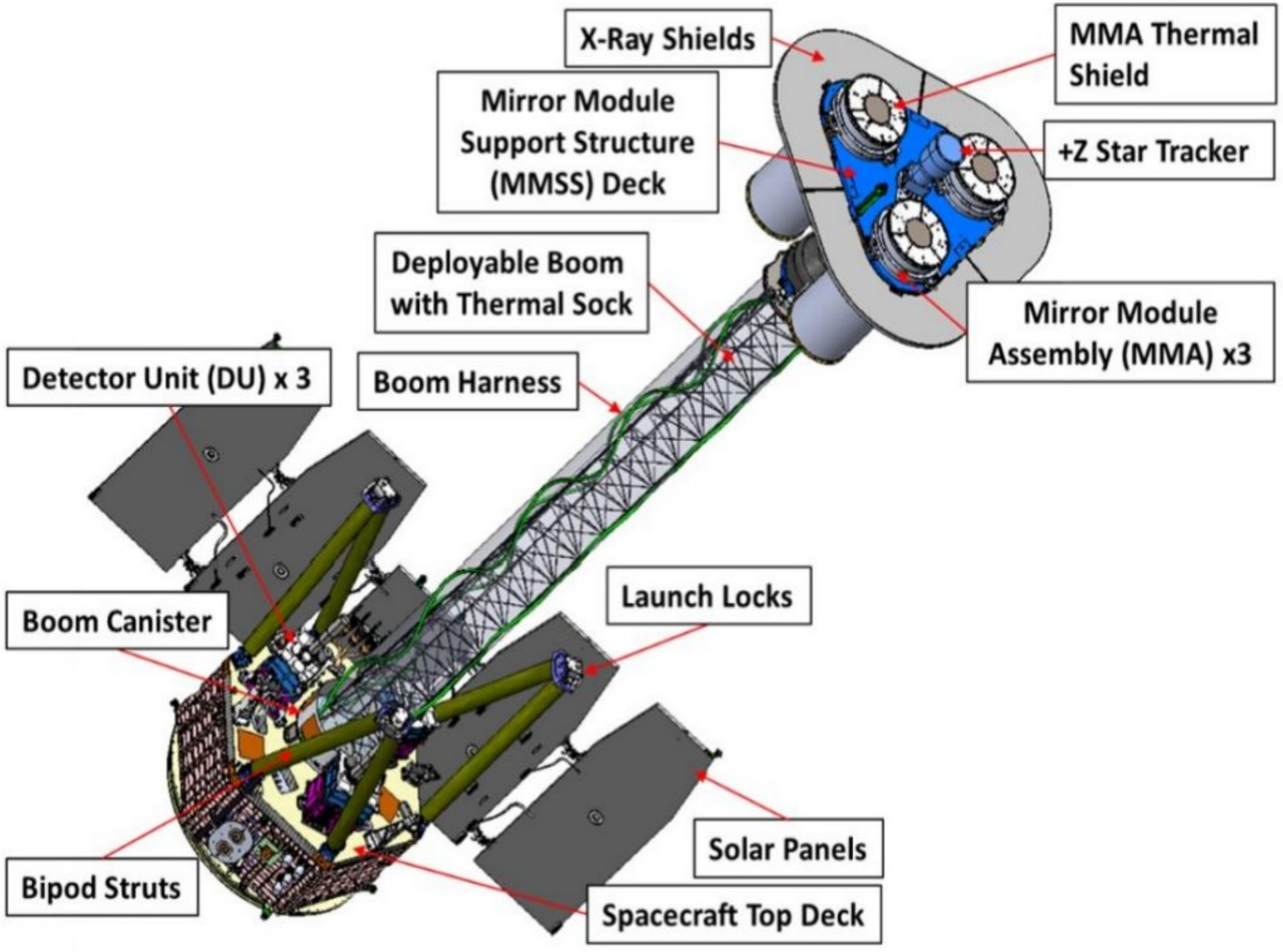
- We can recover the polarization degree

$$\mathrm{PD} = \frac{M}{\mu} = \frac{1}{\mu}\frac{B}{B+2A}$$

- The modulation factor characterizes the response to on-axis photons of different energies.

- **This works for on-axis photons.**

The instrument



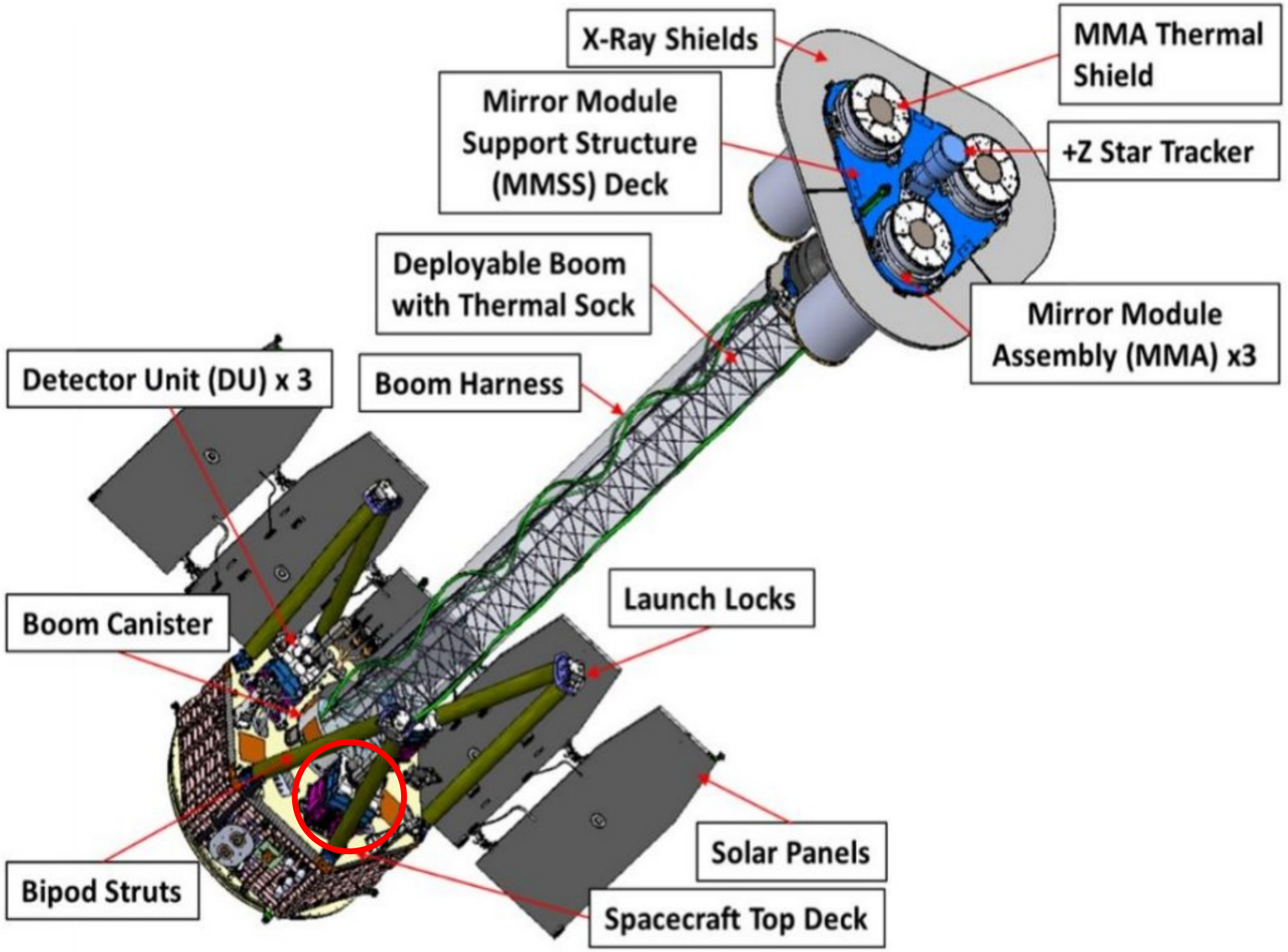
IXPE DESIGN

- Optics — Wolter (Ni-Cb)
  3x 24 nested
- Detector — 3x DME GPD
  Low Q.E. (0.1)

IXPE STATS

- Energy range — 2 - 8 keV
- Field of view — 12’
- Angular resolution — 25’’-30’’
- Peak effective area — 78 cm^2

The instrument



IXPE DESIGN

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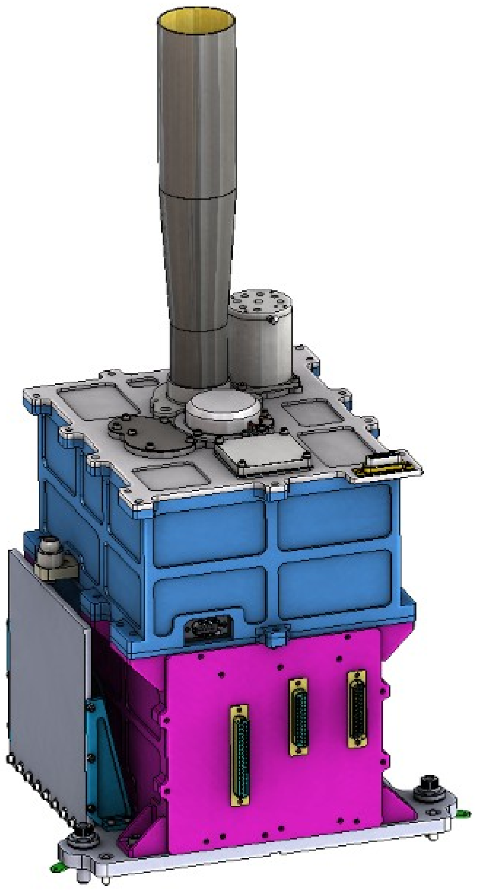
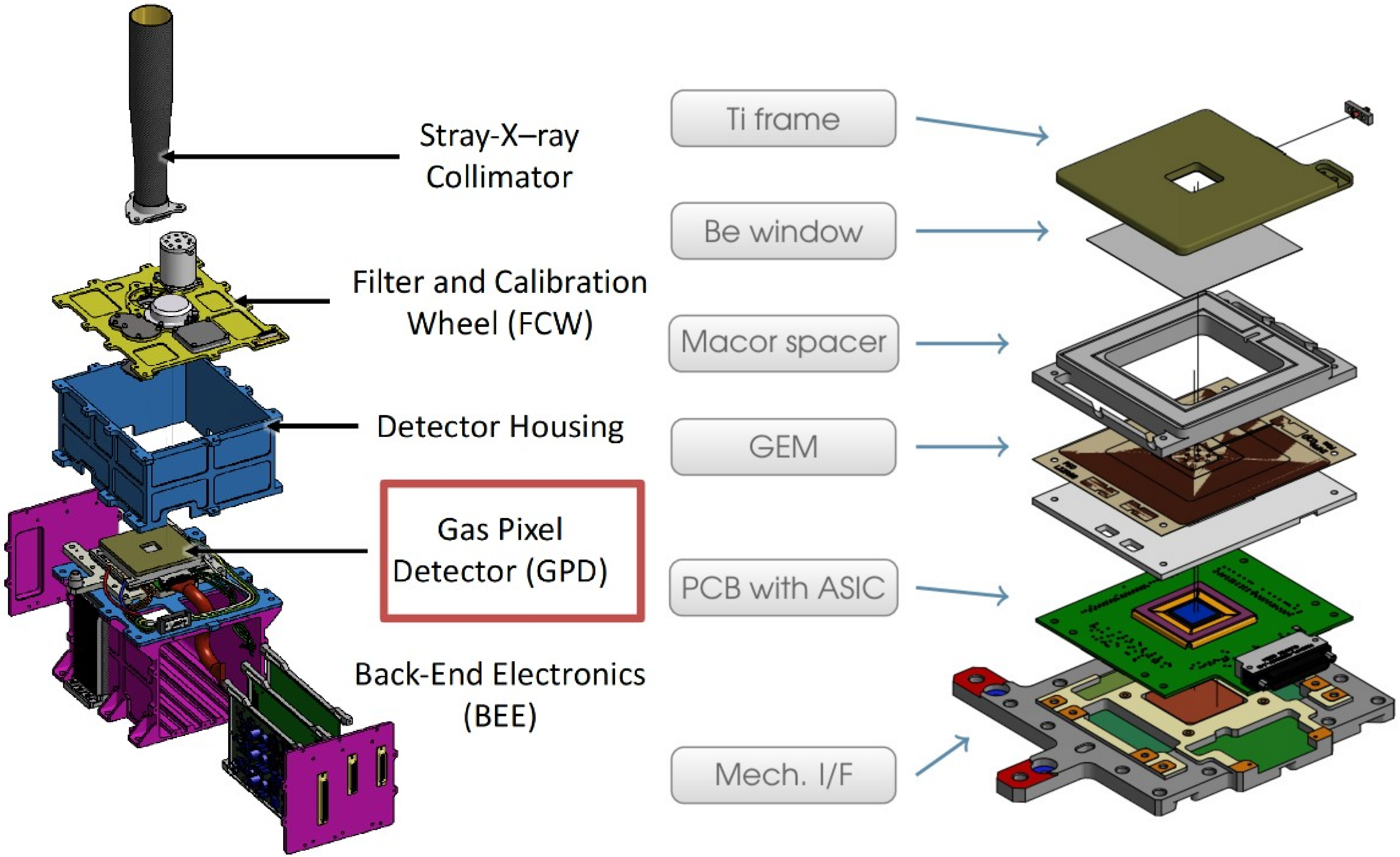
The GPD




Stray-X–ray Collimator
Filter and Calibration Wheel (FCW)
Detector Housing
Gas Pixel Detector (GPD)
Back-End Electronics (BEE)
Ti frame
Be window
Macor spacer
GEM
PCB with ASIC
Mech. I/F

IXPE Imaging X-Ray Polarimetry Explorer

Background

Preliminar knowledge

Our background is a mix of particles and photons, both on-axis and off-axis

- Response functions, analysis software, treat them like on-axis photons.

Component	Rate in total [s^{-1}]	Rate in 2–8 keV [s^{-1}]
Cosmic X-ray	3.19E-03	1.73E-03
Albedo Gamma	3.39E-03	1.24E-03
Albedo Neutron	1.14E-03	2.97E-04
Primary Proton	9.77E-02	3.16E-02
Primary Electron	8.67E-04	2.39E-04
Primary Positron	7.45E-05	1.91E-05
Primary Alpha	3.03E-02	1.09E-02
Secondary Proton	4.50E-02	1.41E-02
Secondary Electron	4.16E-02	1.11E-02
Secondary Positron	1.32E-01	3.36E-02
Total	3.56E-01	1.05E-01

A Study of background for IXPE

F. Xie[a,*], R. Ferrazzoli[a], P. Soffitta[a], S. Fabiani[a], E. Costa[a], F. Muleri[a], A. Di Marco[a]

[a]*INAF-IAPS, via del Fosso del Cavaliere 100, I-00133 Roma, Italy*

Xie+, 2021

Early knowledge

Our background is a mix of particles and photons, both on-axis and off-axis

- Response functions, analysis software, treat them like on-axis photons.
- We have means of identifying particles by the shape of the track and we've been doing it from the beginning. I am talking about the *residual* background

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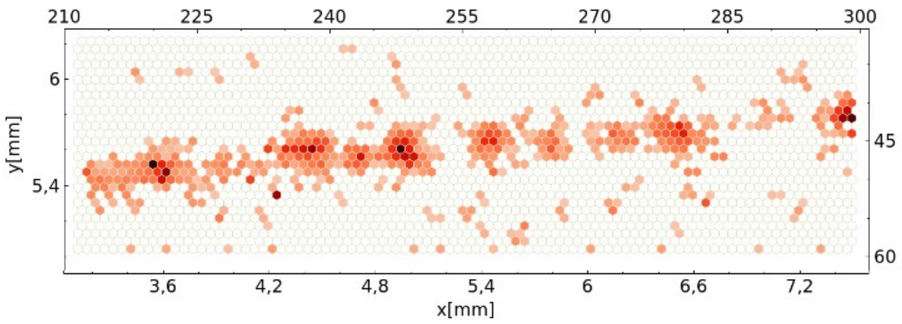
Typeset using LaTeX **preprint** style in AASTeX63

Handling the background in IXPE polarimetric data

Alessandro Di Marco,[1] Paolo Soffitta,[1] Enrico Costa,[1] Riccardo Ferrazzoli,[1] Fabio La Monaca,[1] John Rankin,[1] Ajay Ratheesh,[1] Fei Xie,[2,1] Luca Baldini,[3,4] Ettore Del Monte,[1] Steven R. Ehlert,[5] Sergio Fabiani,[1] Dawoon E. Kim,[1,6,7] Fabio Muleri,[1] Stephen L. O'Dell,[5] Brian D. Ramsey,[5] Alda Rubini,[1] Carmelo Sgrò Stefano Silvestri,[3,4] Allyn F. Tennant,[5] and Martin C. Weisskopf[5]



Residual background

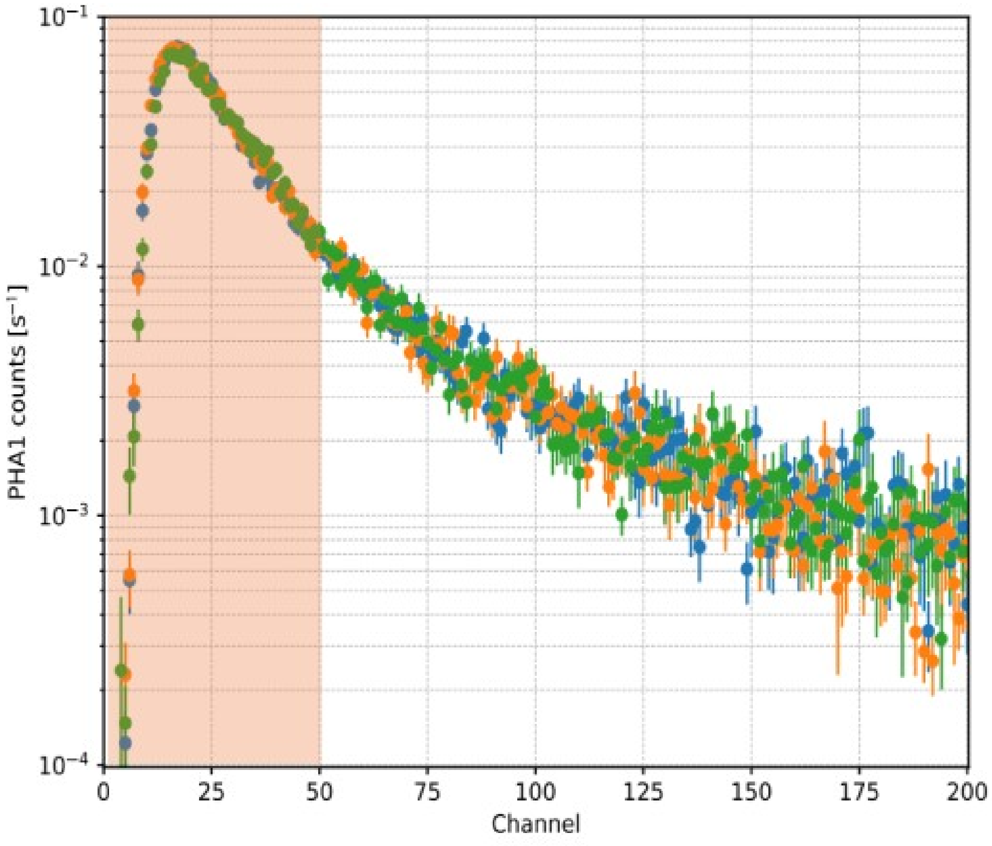
Our background is a mix of particles and photons, both on-axis and off-axis

- Response functions, analysis software, treat them like on-axis photons.
- We have means of identifying particles by the shape of the track and we've been doing it from the beginning. I am talking about the *residual* background

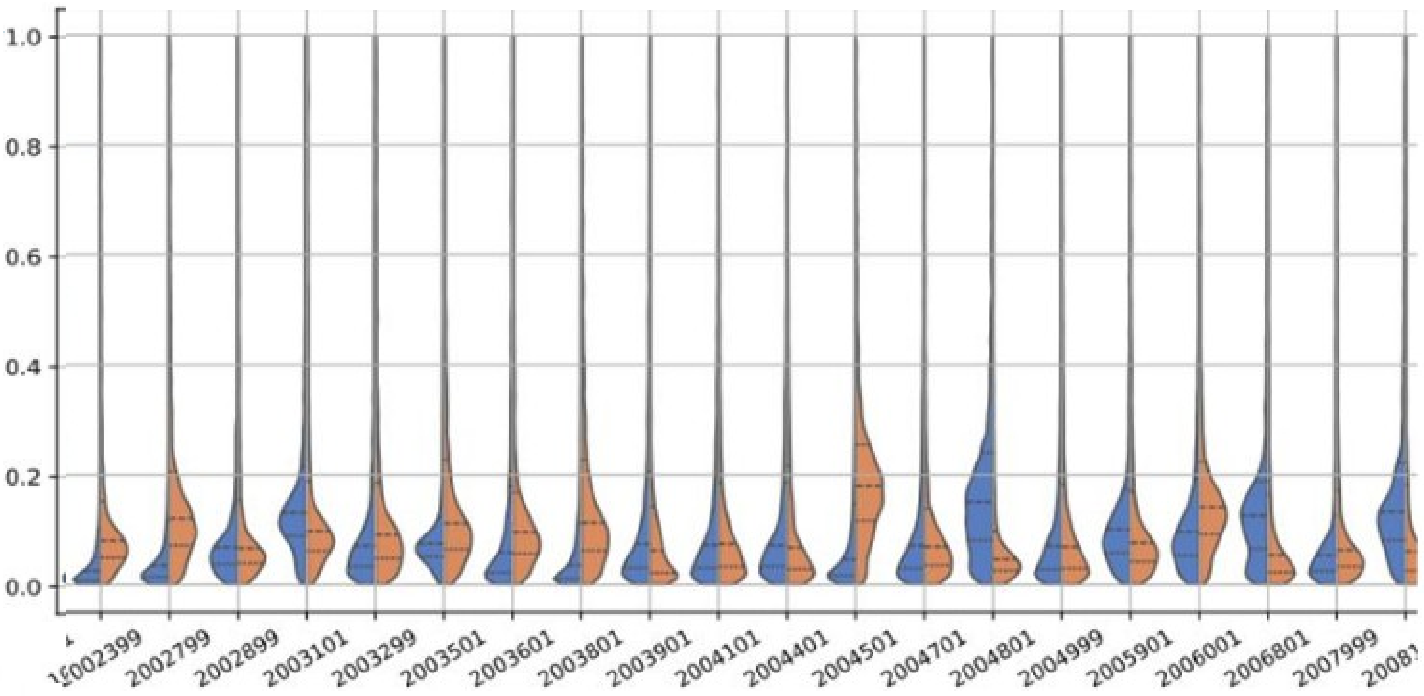
- The **residual background** has multiple components
  - A hard power law component, identical for different times and detector units (static component)

Static component

The static spectrum is identical for all three detector units and all observaitions



Also, no evidence of polarization



Residual background components

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- The **residual background** has multiple components
  - ➔ A hard power law component, identical for different times and detector units (static component)
  - ➔ A line-like feature at ~1.5 keV which varies across times and DUs

Variability?

Our background is a mix of particles and photons, both on-axis and off-axis

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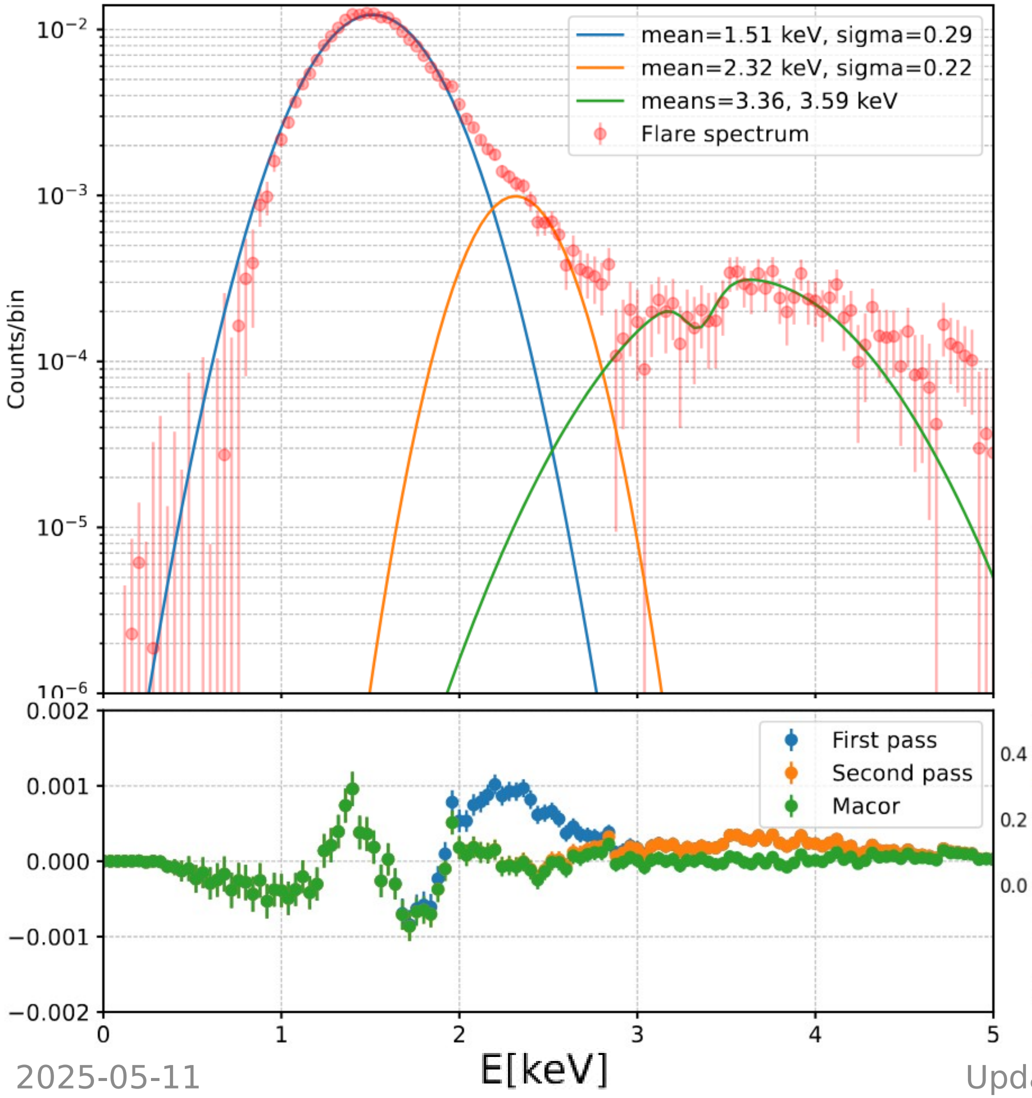
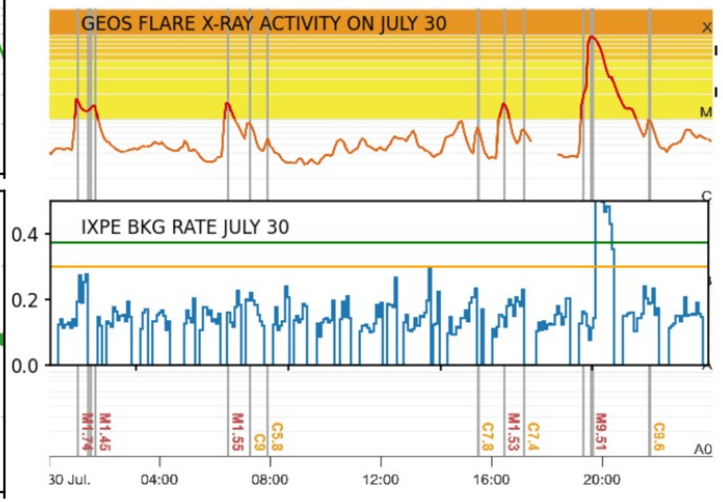
  - ➔ A line-like feature at ~1.5 keV which varies across times and DUs
  - ➔ A line-like feature at ~3.3 keV appearing only at times on DU2 and DU3
  - ➔ A line-like feature at ~3.6 keV appearing only at times on DU2 and DU3

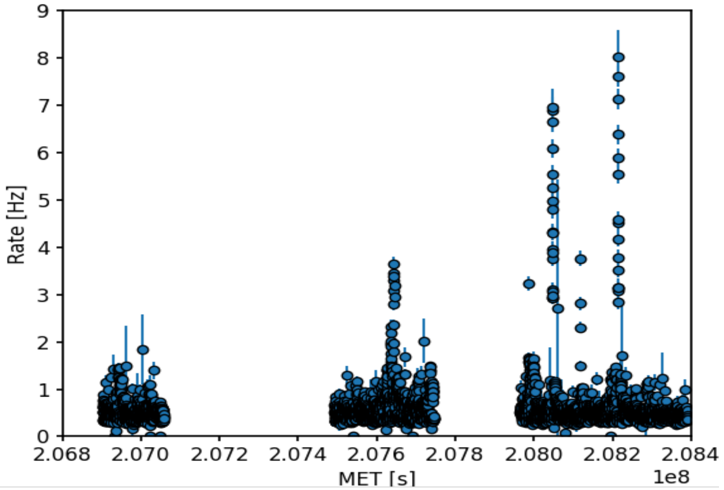
Flare component



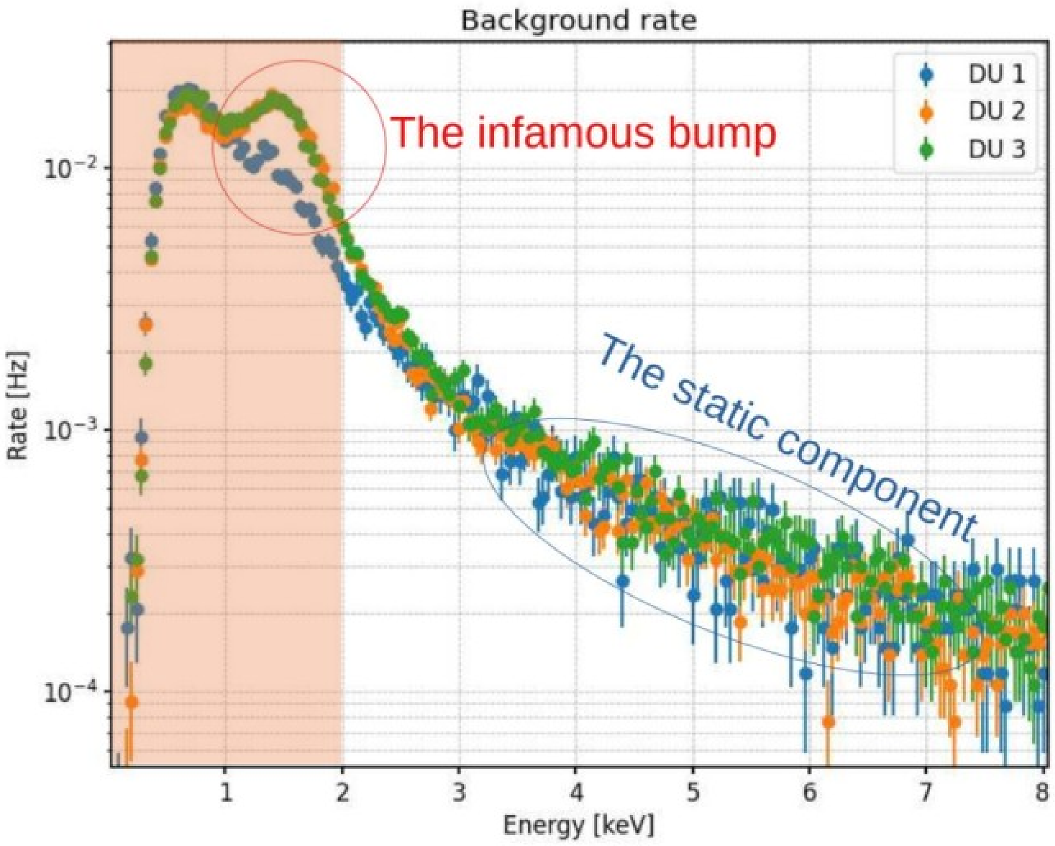
Took us forever and a while but we now have a means to extract the variable component only (more on this later)

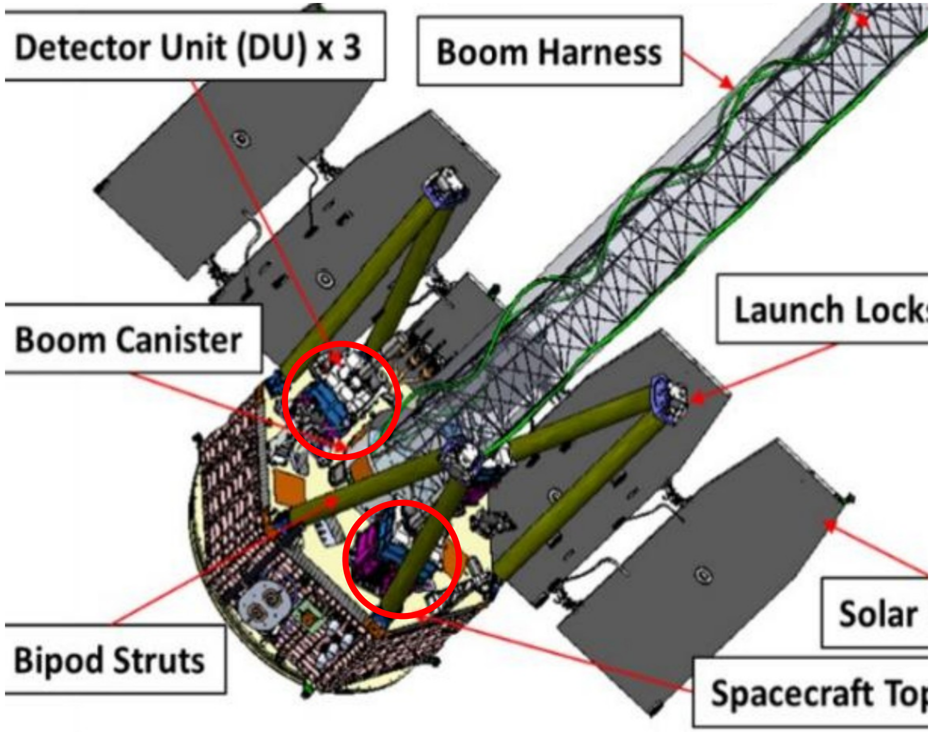
- The spectrum reveals a few lines. Aluminum, Potassium… Argon?
- Lines appear especially when the sun is active
- Rate somewhat correlates with solar flares
- Flared data appears to be polarized





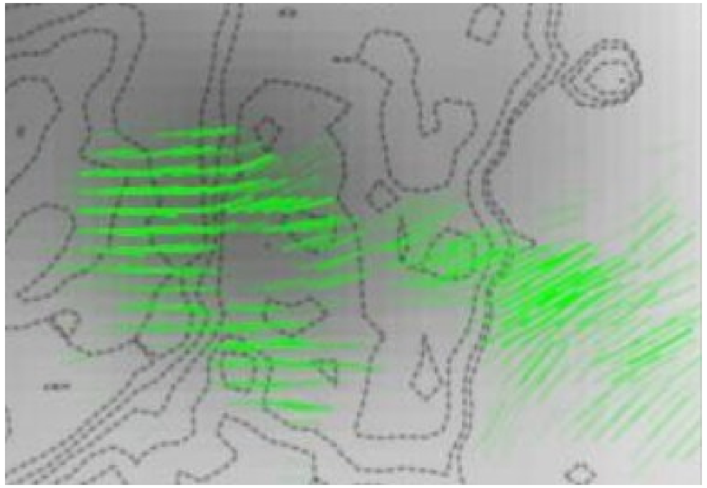
DU-wise variability





Oh, the flares are polarized (?)

- Polarized is probably not the right term but this is what the analysis suggests
- Flared observations have a (strong!) observed background modulation
- In one case, this is so strong that the flared background is depolarised by the less bright orthogonally polarized source
- This is messed up: **you don't get polarization for free!**



Old RCW86 analysis

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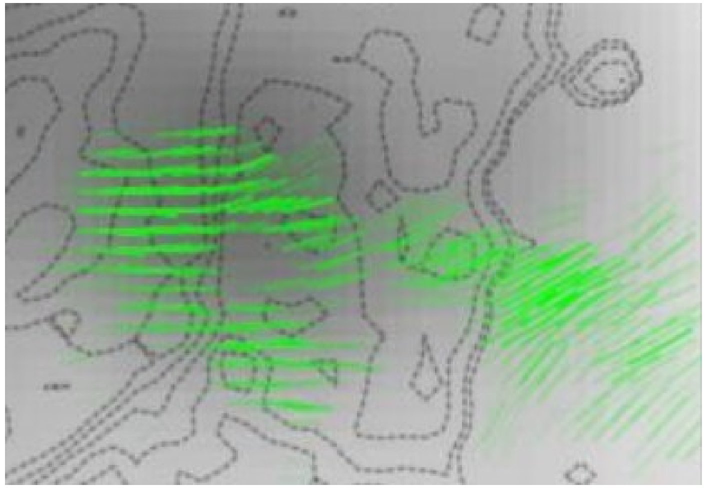
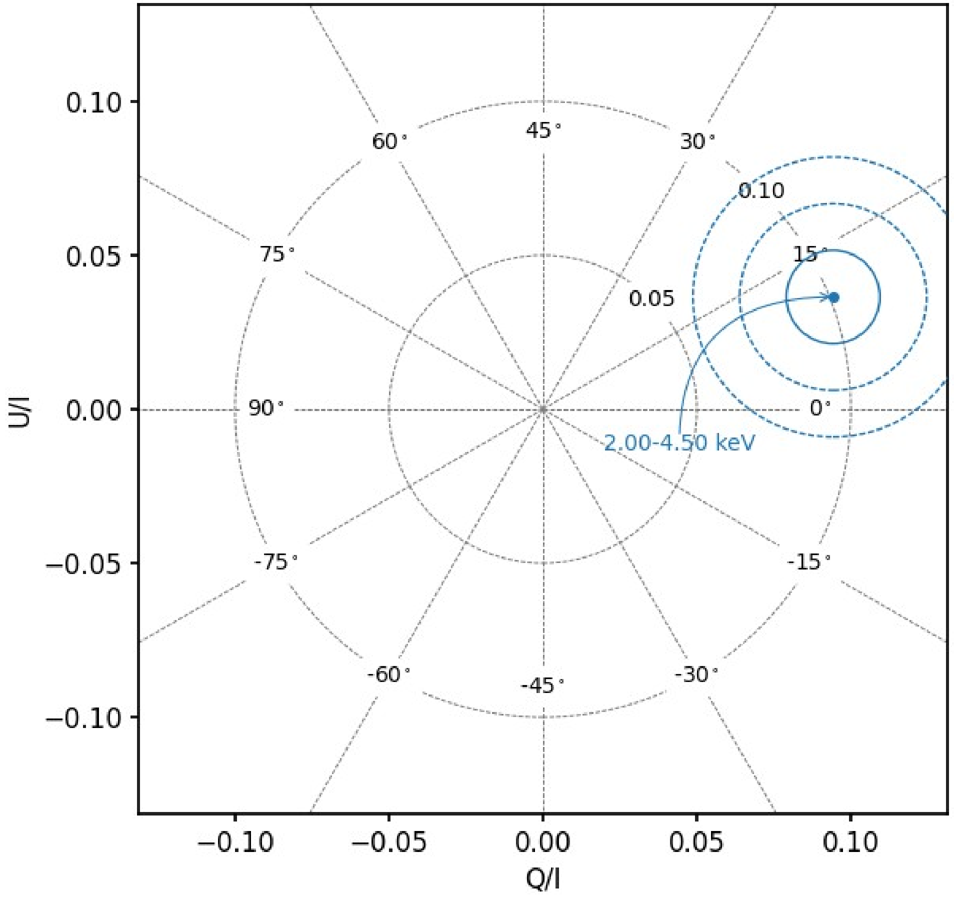


Old RCW86 analysis



RCW86 background

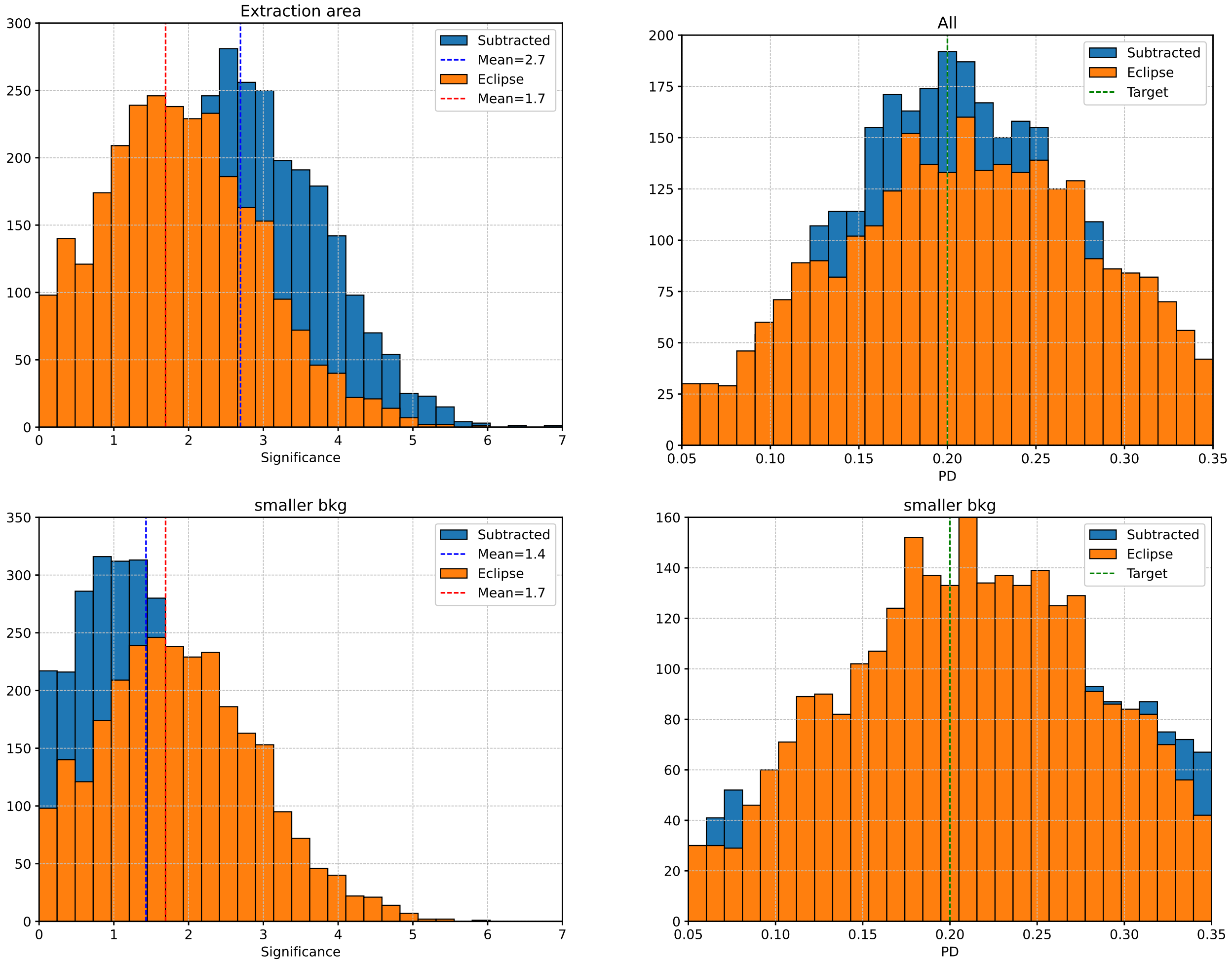
Subtracting the flares

- Split The dataset: insun and in eclipse
- Extract the flares data from insun – ineclipse
- Non flared background is static and non polarised so you can get it from our history
- Both insun and ineclipse contain the source which is removed automatcally
- Eventually subtract both the estimated static and the extracted flaring

Caveats

- Insun, ineclipse, and source REGIONS must not be identical or the process loses effectiveness
- Seems to work better when bkg region is much wider than source region
- Needs binned data

It’s a bit barbaric… but it works!

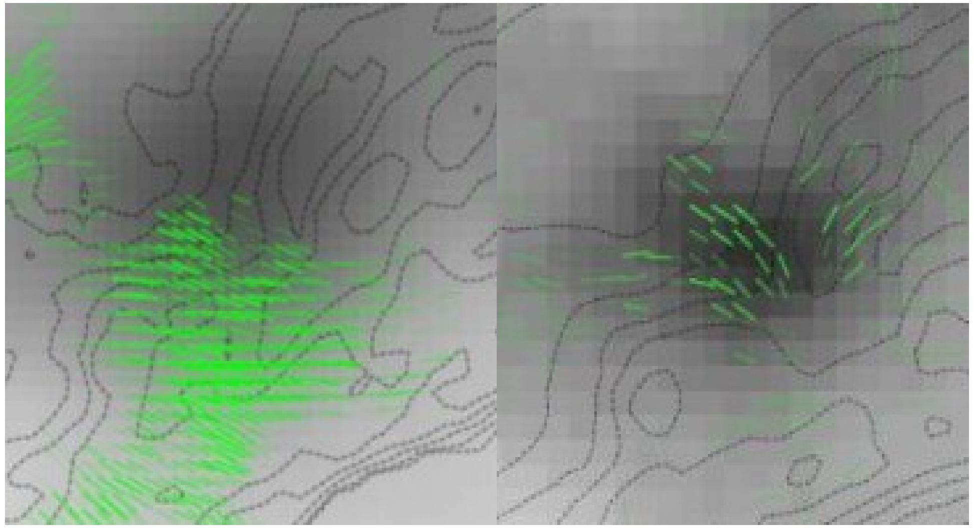


Effectiveness depends on source

Case study: **RCW86**, faint SNR map

Left: First segment with typical background handling
Right: After flare subtraction

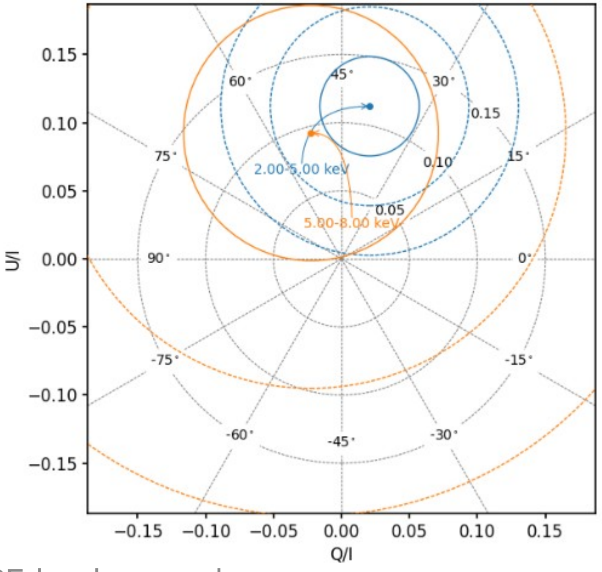
Vectors are orthogonal to polarization angle
Results are **completely** different!

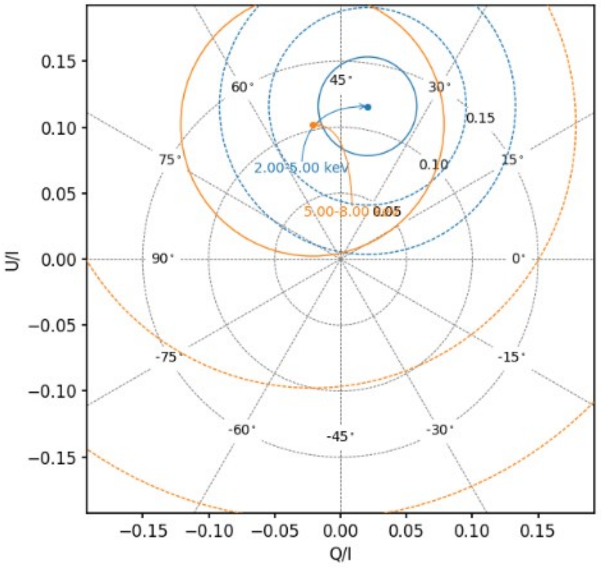


Case study: **Kes75**, brighter PWN integrated

Left: No background subtraction
Right: Background-subtracted data

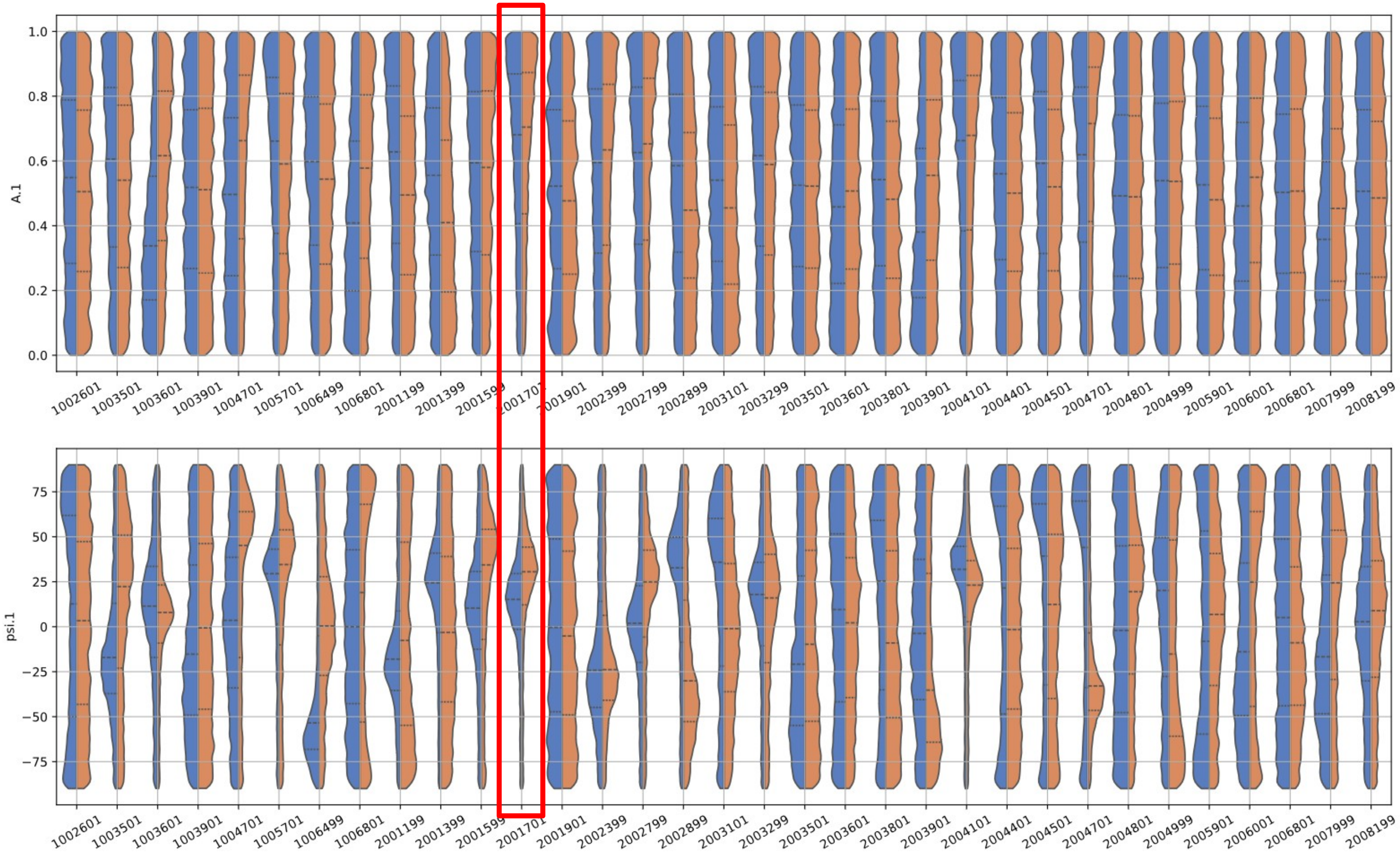
Results are pretty consistent (Significance increases to 2.69 from the initial 2.66)





Unsolved flares issues

In some cases we get polarization >100%



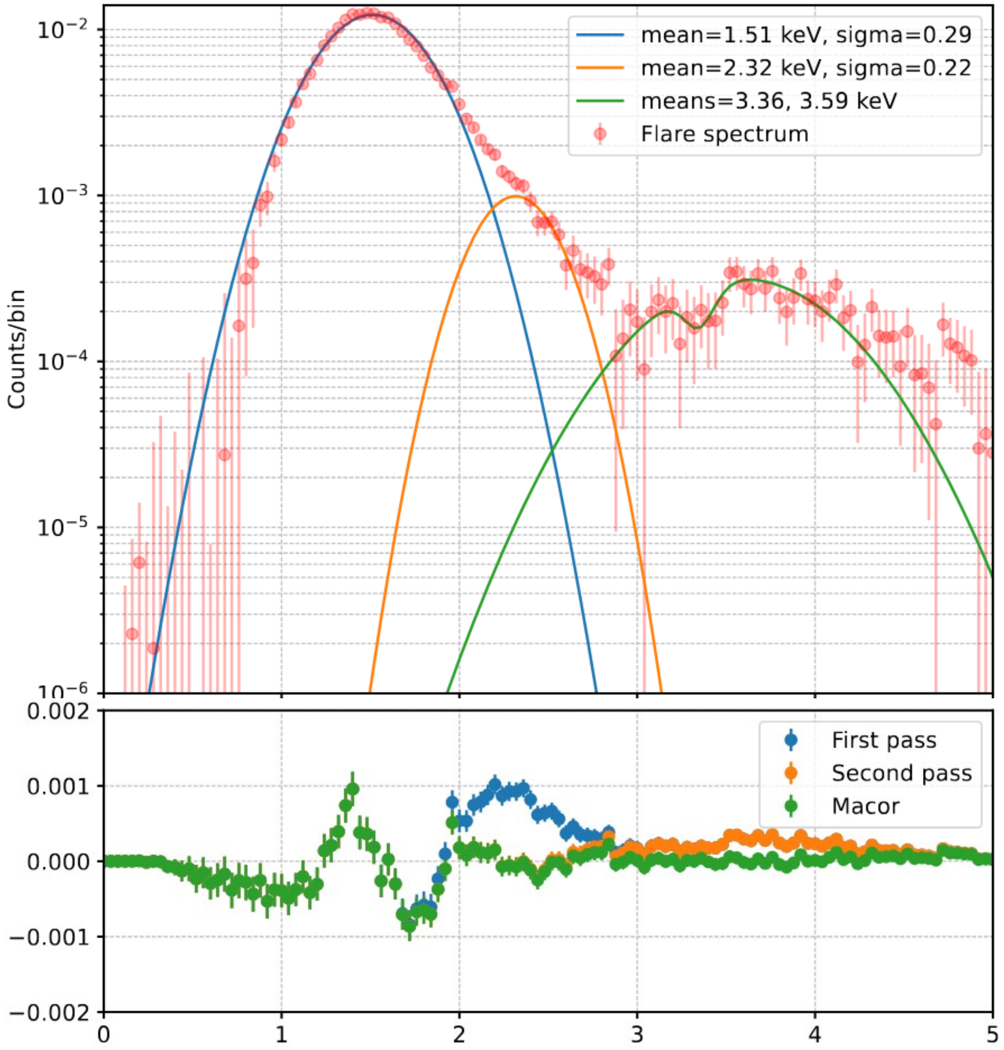
Fluorescence should not even be polarized.

But remember the modulation factor!

Polarization > 100% just means that we get an excess of events reconstructed with an angle phi w.r.t. those we expect for a fully polarized on axis beam of photons!

If the process is different, the IRFs are not adequate and this is not polarization, but just what the softare recognizes as such!

This is not a line



Looking at the residuals one can see that there is no way the bump on the left can be fit by a line (and for what matters even by two lines)

Fits actually work better with a very soft power law, but the index varies among obsids.

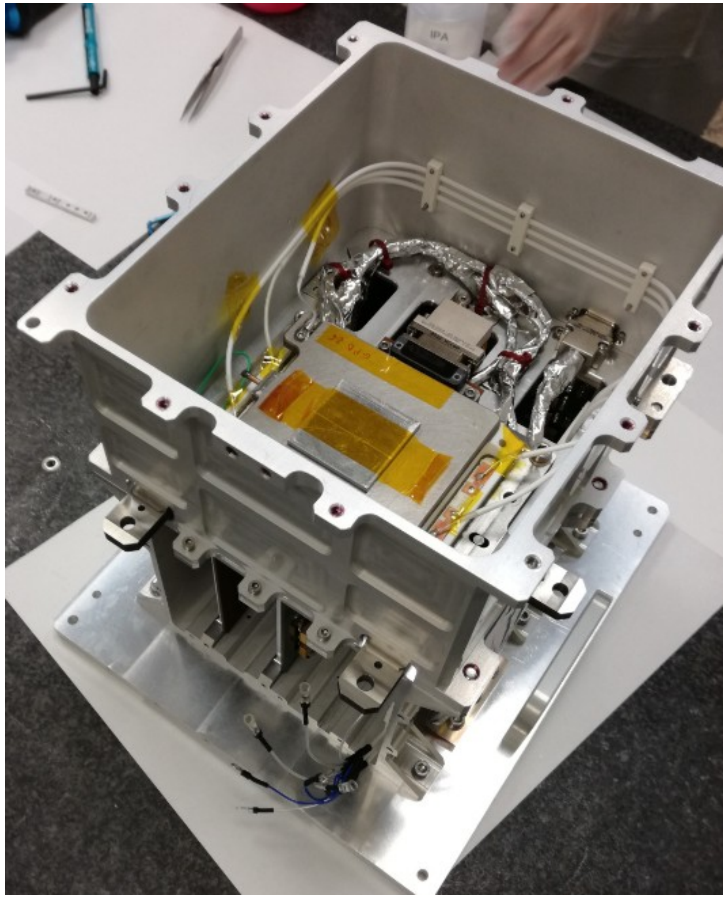
- Spectral charactrization of the background is still lacking!
  - No way we can provide a fitting template at the moment. Only way to do this is bin the data, subtract the flares and analyze the source only data

But there’s an elephant in the room…

- Are we really looking at fluorescence?
  - Asymmetric energy distribution (not a line + energy dispersion)
  - Obsid-dependent track direction (in sky coordinates)
  - Inconsistent with our IRFs

Can we see fluorescence?

Detector unit



GPD housing

Where does the light enter from?

- The detector unit is pretty sealed but not airtight (that's the GPD)
- A few energy features compatible with Macor seem to indicate GPD spacer fluorescence
- Fluorescence is easily self-absorbed (~few microns attenuation in solids)
- Sensitive area of the GPD is 1.5x1.5 cm, gas area is 6x6

Why do we see elongated tracks?

- Entirely spurious off-axis effect?
- Some internal reflection?
- ...Or are they particles?

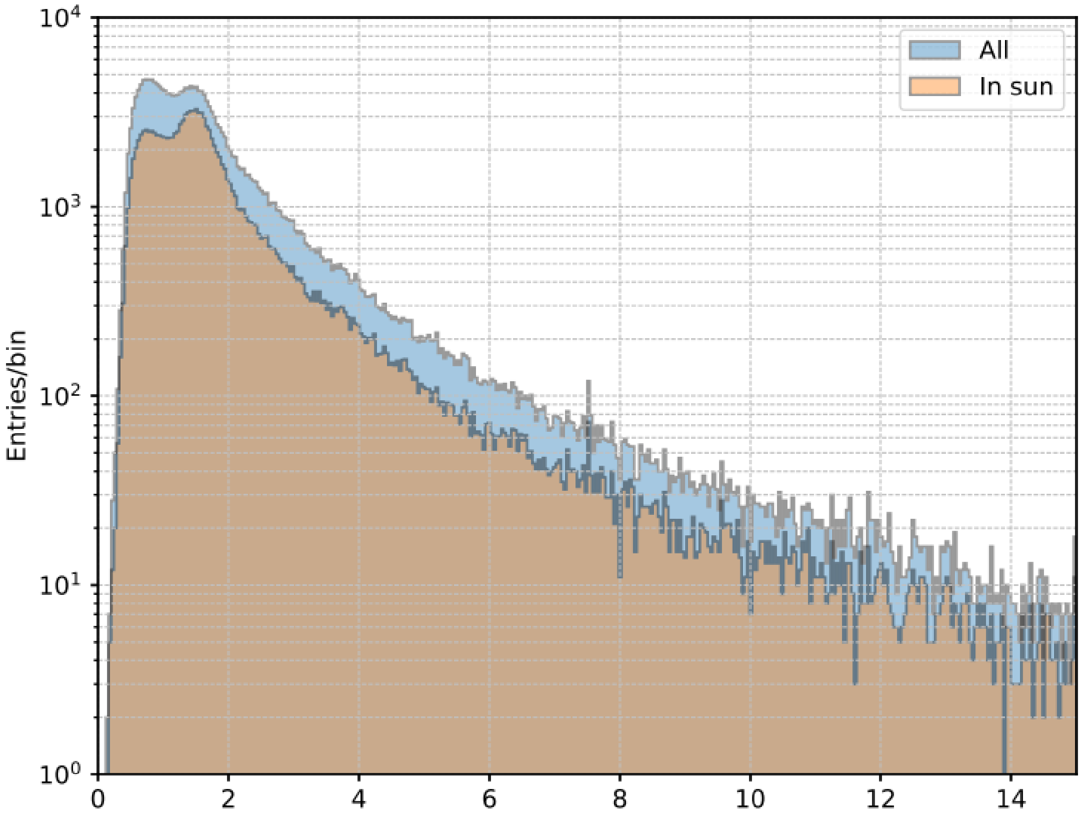
Conclusions

The future is dim

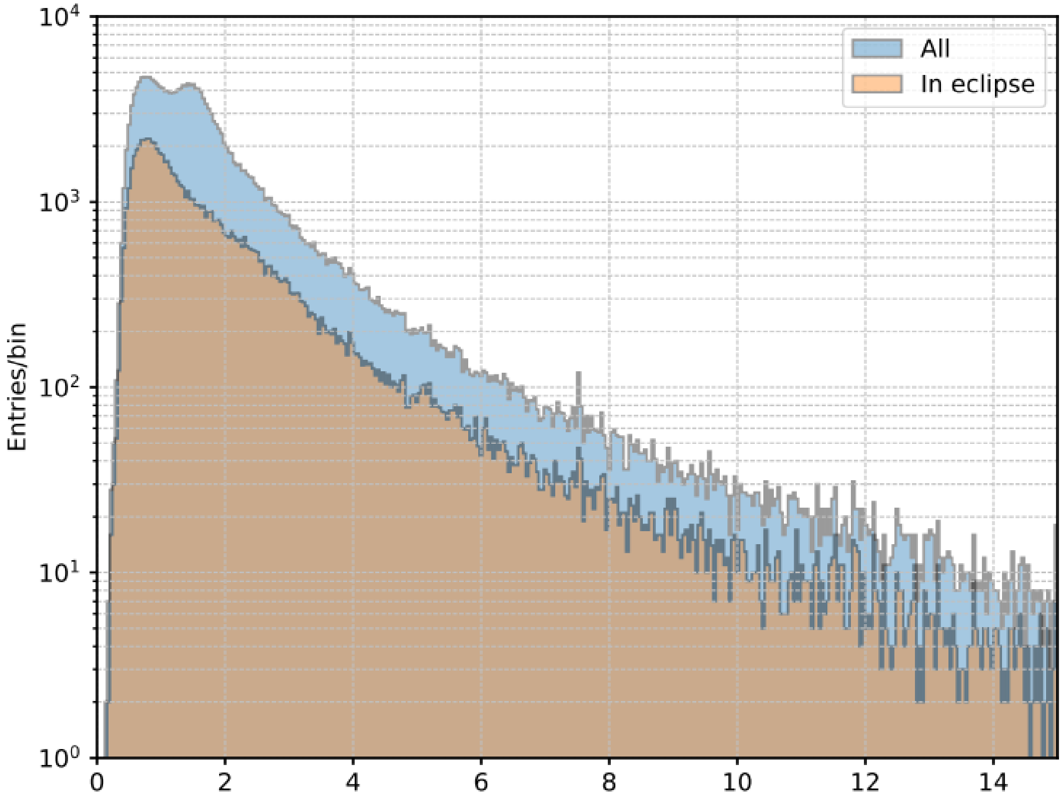
- Faint sources are gonna become the rule, not the exception
  - Background characterization so far has been minor, but it’s likely going to become the next big thing
- Particle background: ok
- Static background: ok
- Variable background: hard to tame, but we’ll get there eventually
  - Subtraction: ok
  - Spectral characterization requires more knowledge, simulations and, why not, your input
- Published work: space for improvement

IXPE
Imaging
X-Ray
Polarimetry
Explorer

Backup



All
In sun
Entries/bin



All
In eclipse
Entries/bin