The X-ray Imaging Polarimetry Explorer

Fabio Muleri *INAF-IAPS (Italy)*

on behalf of

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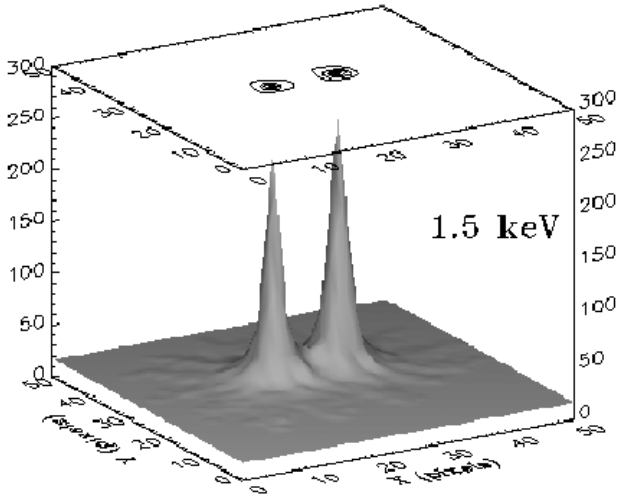
A little bit of history...

A small mission of X-ray polarimetry is an old idea in Italy:

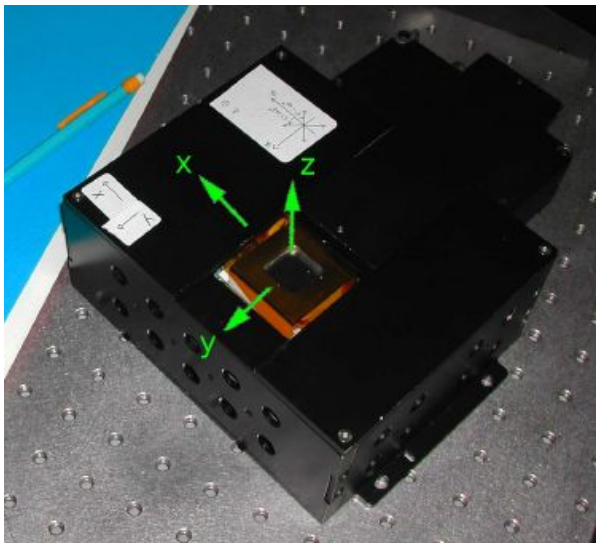
Jet-X optics (3 mirror modules)

- ~ 150 cm^2 each
- 15 arcsec angular resolution
- calibrated and tested: TRL 9

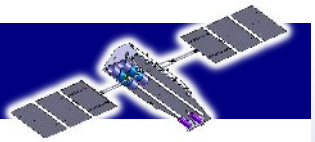


Gas Pixel Detector

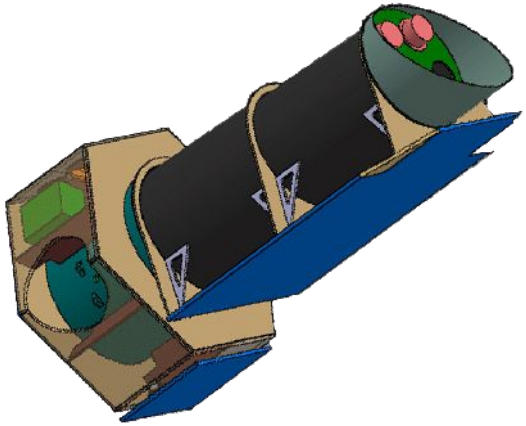
- polarimetric, imaging e spectral capability
- no need of rotation
- studied for a number of missions: XPOL on-board XEUS/IXO, NHXM, POLARIX



The story of POLARIX



POLARIX: 3 Jet-X optics with 3 GPDs working in 2-10 keV energy range



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2008 02 One out of five missions selected for a Phase A study
2008 12 End of Phase A study
2009 02 Expected selection of the two missions to be implemented

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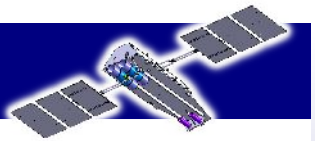

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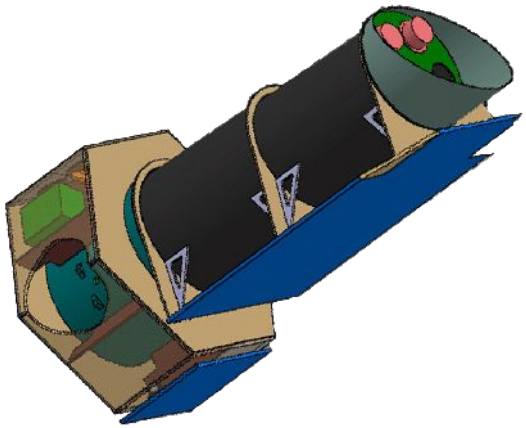

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GEMS: 3 Suzaku-like concentrators with 3 TPCs working in 2-10 keV energy range

2008 02 Proposed to NASA as small mission (in competition with IXPE based on GPDs)
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2009 06 Selected for a launch by 2014
2009 10 Start of the GEMS phase B

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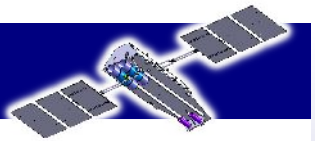

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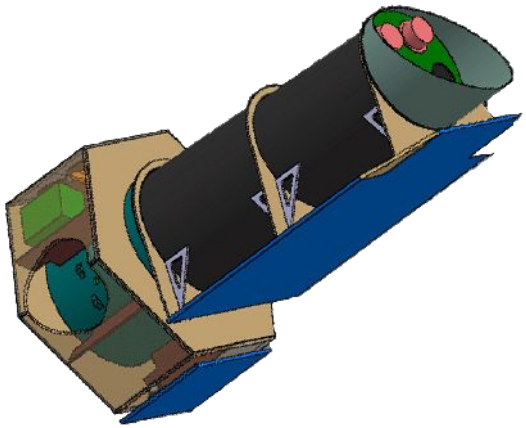

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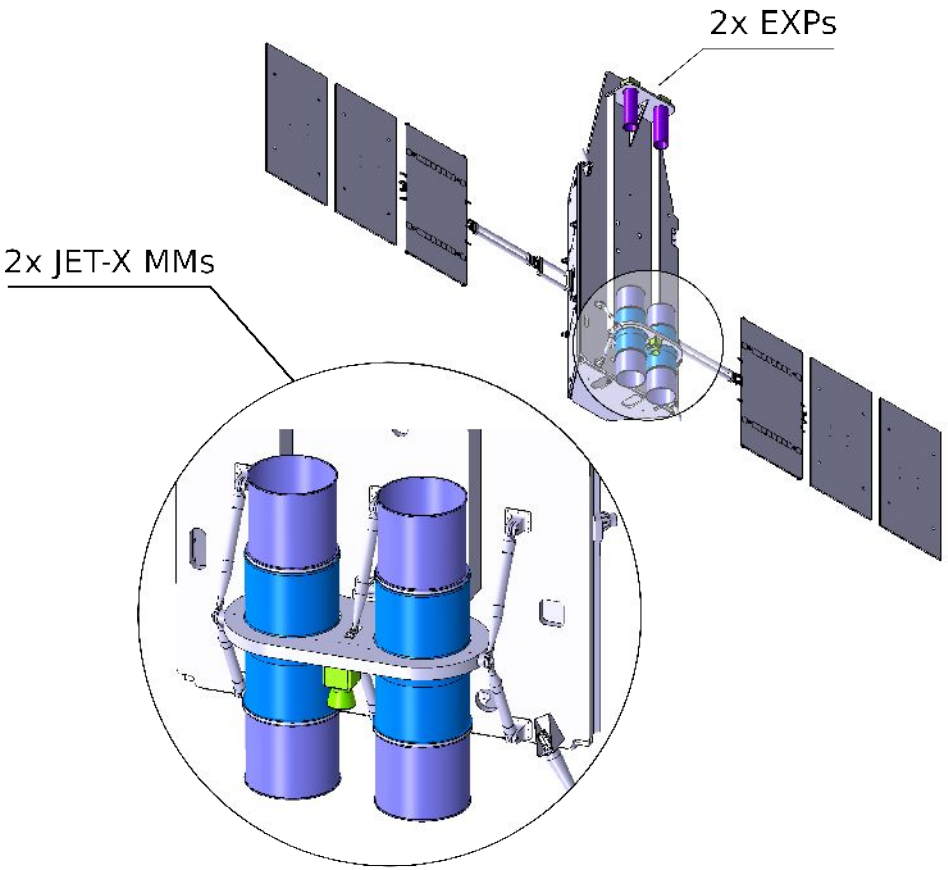
2012 05 Cancellation of the program

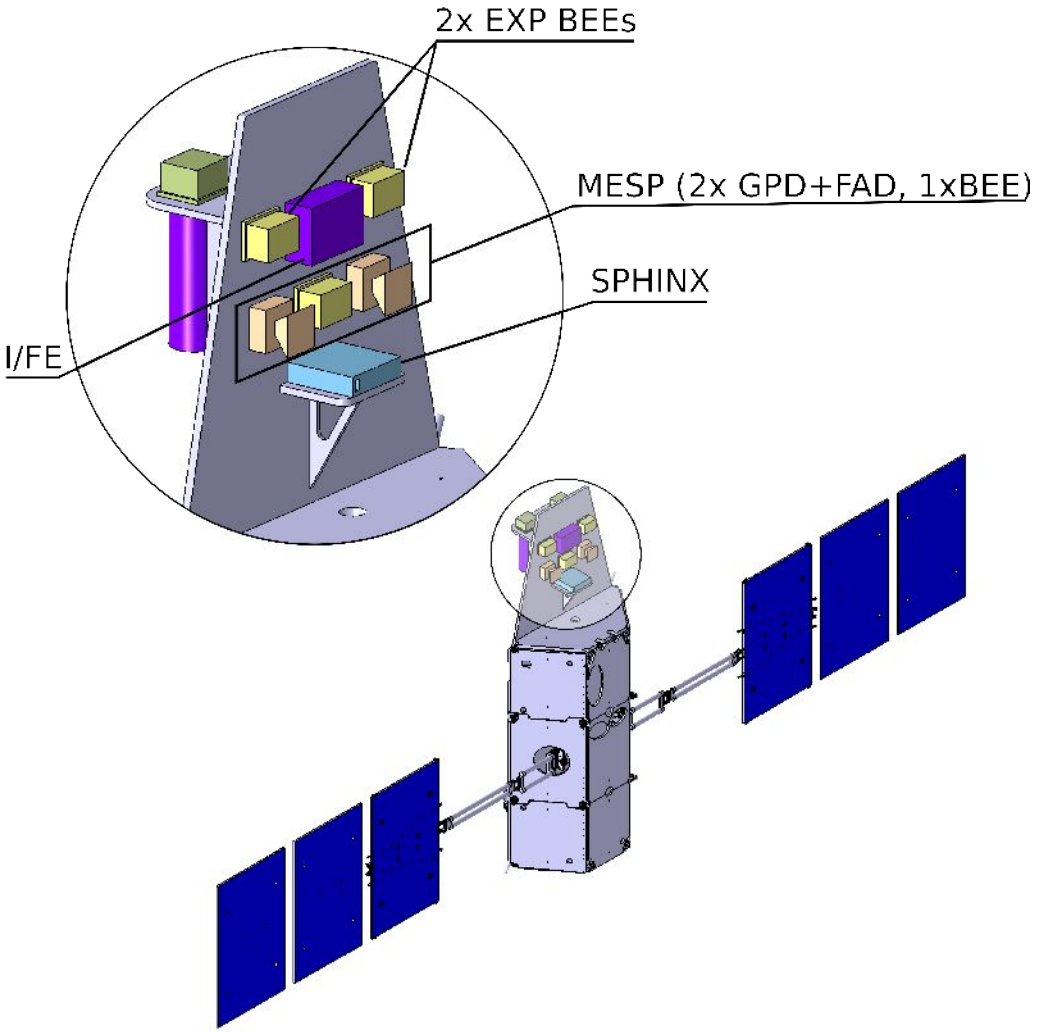
… three weeks before ESA small mission call deadline...

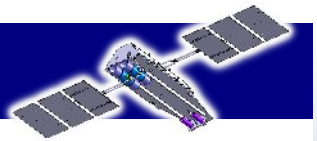
The XIPE mission

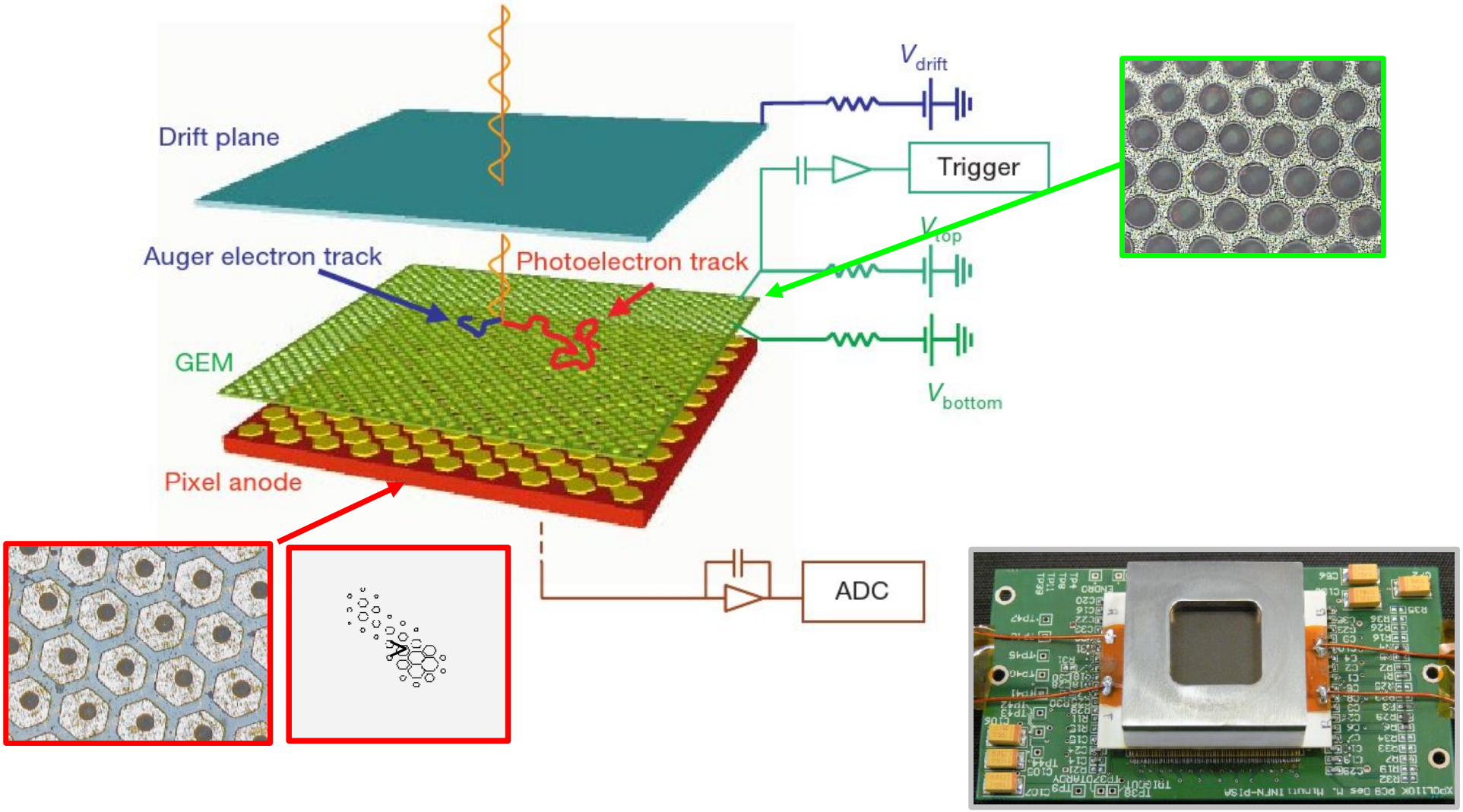
Proposed to ESA small mission call for a launch in 2017.

- commercial bus
- 2 Jet-X optics
- 2 + 2 GPDs
- Solar photometer





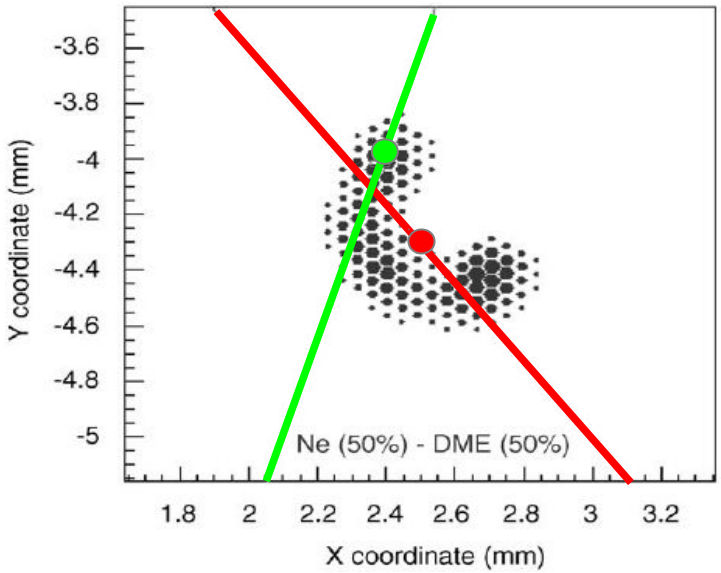




Costa et al. 2001

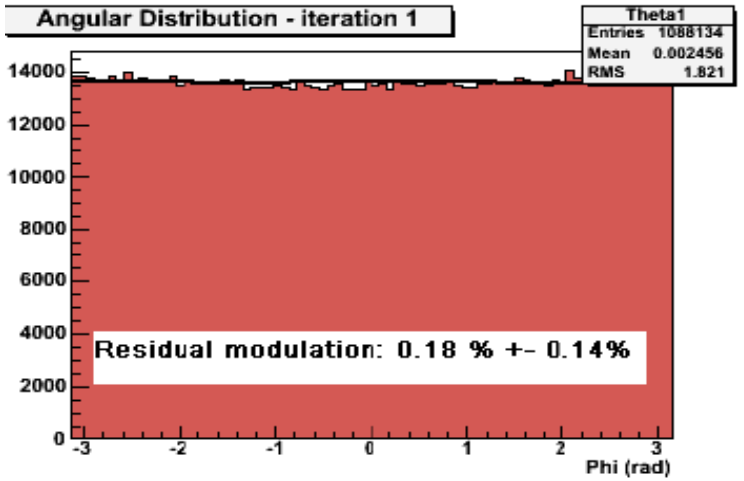
The GPD as a X-ray polarimeter

$$\frac{d\sigma}{d\Omega} \propto \cos^2\phi \ \sin^2\theta \ \frac{1}{(1+\beta\cos\theta)^4}$$

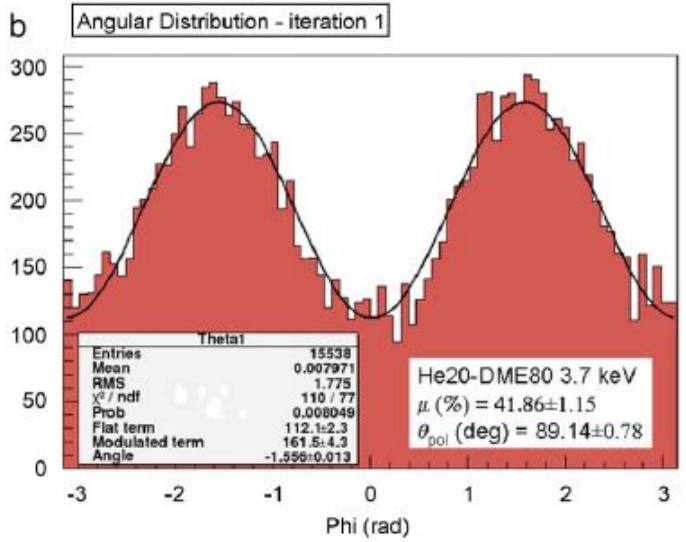


Real photoelectron track @ 5.4 keV

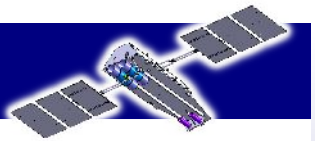
unpolarized



polarized



Fundamental parameters

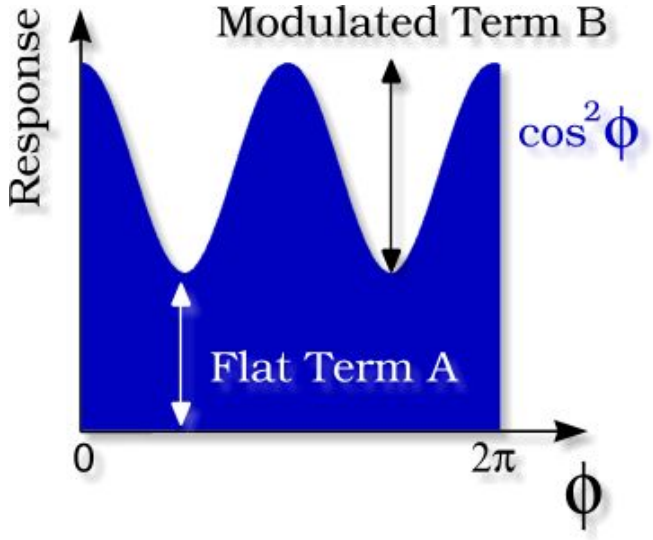


Fit function: $\mathcal{M}(\phi) = A + B\cos^2(\phi - \phi_0)$

Modulation: $\dfrac{\mathcal{M}_{\max} - \mathcal{M}_{\min}}{\mathcal{M}_{\max} + \mathcal{M}_{\min}} = \dfrac{B}{B + 2A}$

Polarization: $\dfrac{1}{\mu}\dfrac{B}{B + 2A}$

μ is the modulation factor



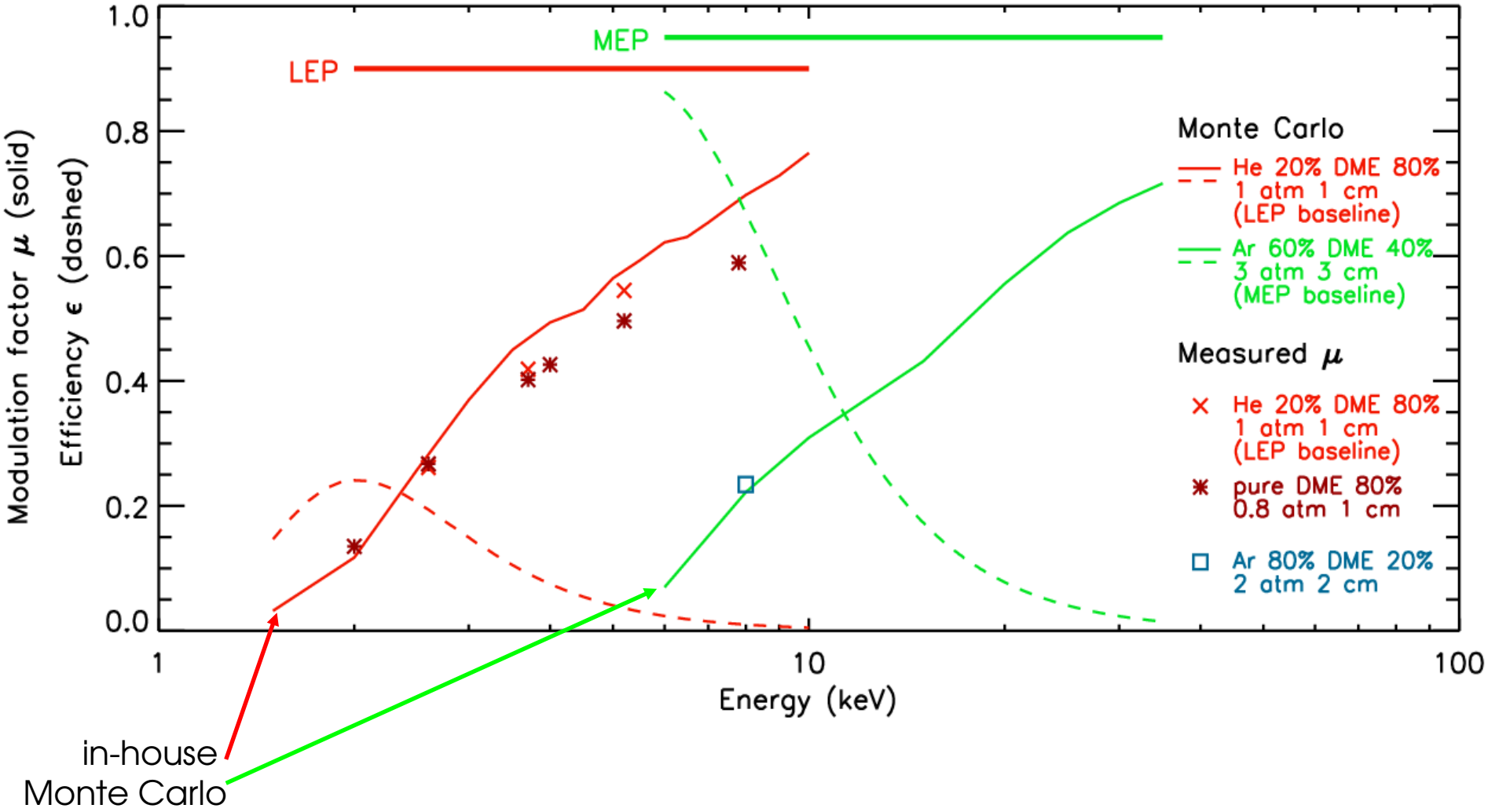
Minimum Detectable Polarization (99%): $$\mathrm{MDP} = \frac{4.29}{\epsilon\mu F}\sqrt{\frac{B + \epsilon F}{ST}}$$

To reach MDP=1% with μ=0.5 and negligible background: $N_{ph} = \left(\dfrac{4.29}{\mu\ \mathrm{MDP}}\right)^2$ = 736 10^3 ph

Source **detection**: >10 ph
Source **spectra**: >100 ph
Source **polarimetry**: >100,000 ph

The GPD performance

The GPD can work between <2 – 35 keV choosing a proper mixture/pressure

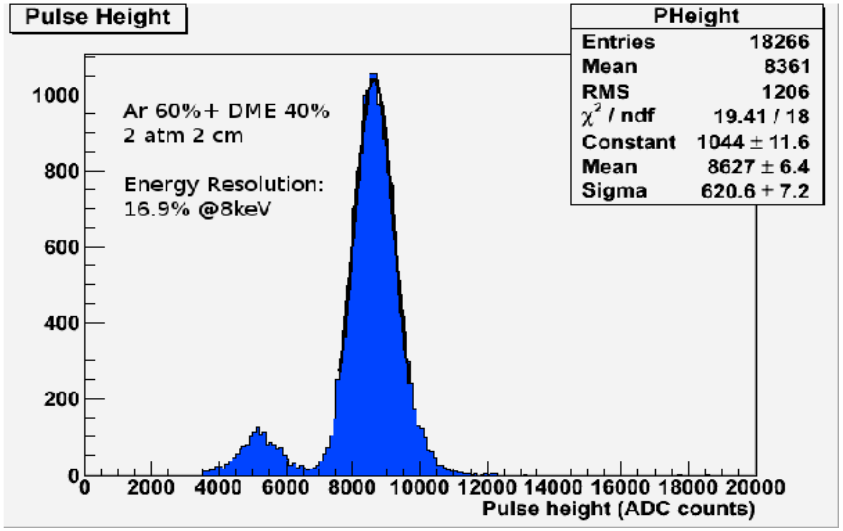


Systematics <1%, still not statistically detected

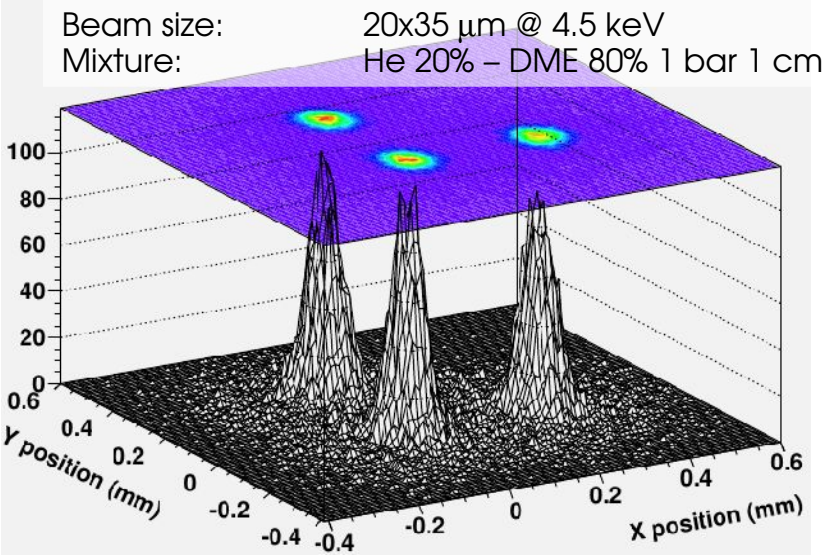
The GPD performance

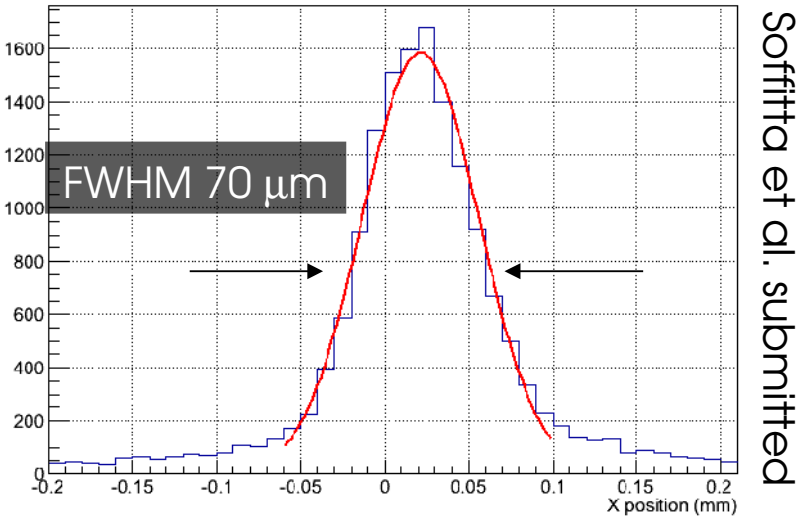
Timing resolution: ~8 μs

Spectroscopy: <20% @ 6 keV



Spatial resolution: 82 μm FWHM + blurring due to inclined penetration in the gas cell



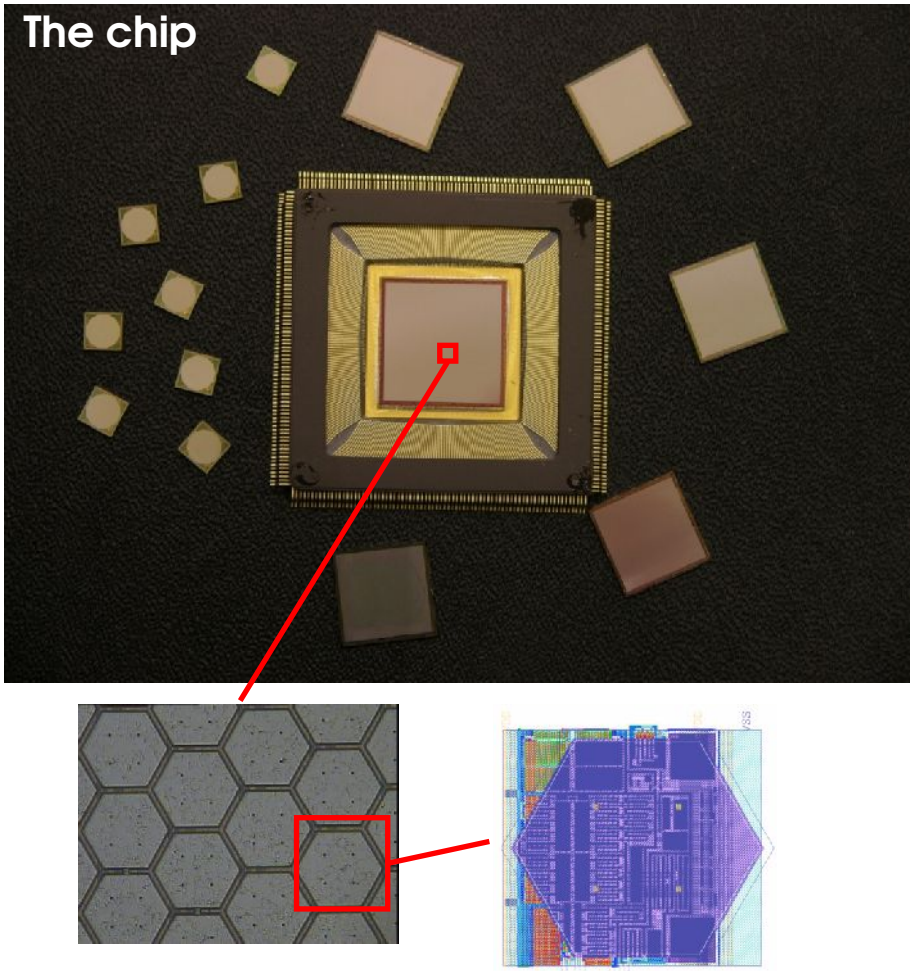


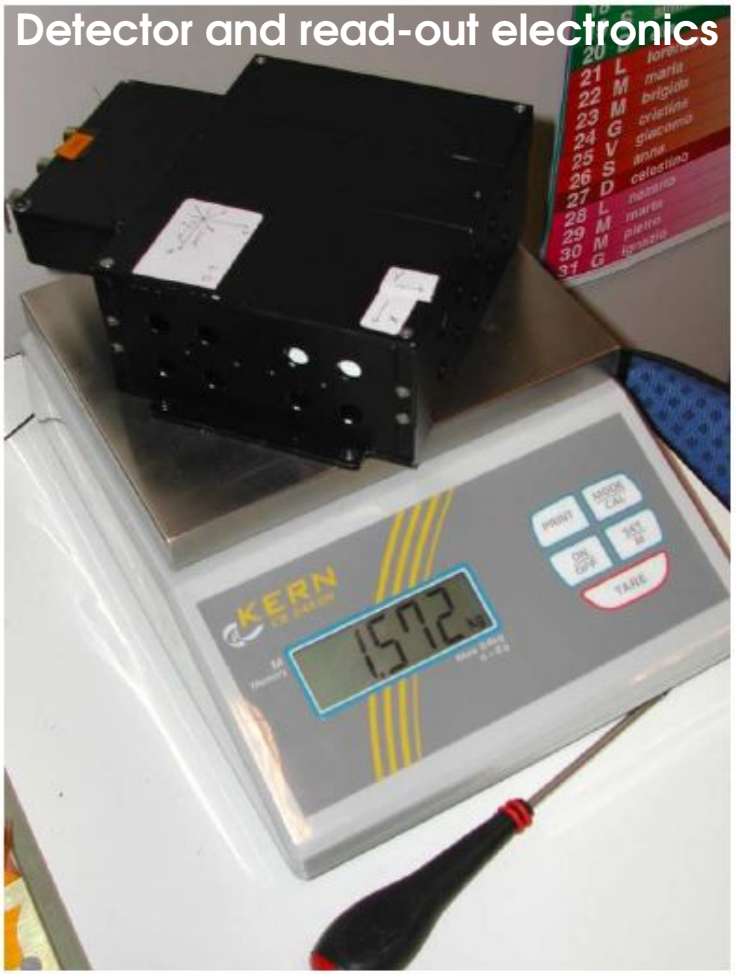
Soffitta et al. submitted

Angular resolution mainly driver by optics quality

The Gas Pixel Detector

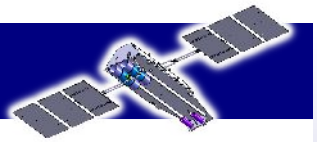
The chip integrates more than 16.5 million transistors and has a 15 mm x 15 mm active area. It is composed of 105600 pixels organized in a honeycomb matrix with 50 μm pitch.





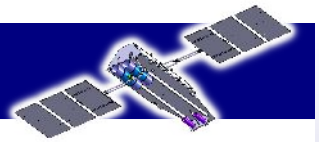
Bellazzini et al. 2006, 2007 NIMA

XIPE Science requirements



	2x EXP units	**MESP**
Polarization sensitivity	MDP = 14% in 100ks for 1 mCrab	MDP = 5% for X1.2 flare
Imaging capability	20'', 15x15 arcmin^2 FoV	+/- 30 degrees
Spectral resolution	20% @ 5.9 keV	<20% @ 5.9 keV
Timing	Resolution 8 μs, 10 μs dead time, negligible for all observations	Resolution 8 μs, 30 μs, deadtime, 5% for X10 flare
Mixture	20%He-80%DME 1 atm 1 cm	60%Ar-40%DME 3 atm 3 cm
Energy range	2-10 keV	15-35 keV
Background	1.3 10^{-7} c/s or 1 μCrab	Negligible for all observations

XIPE Science requirements



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3.1 Astrophysics

- **3.1.1 Acceleration phenomena**
  - 3.1.1.1 Pulsar wind nebulae
  - 3.1.1.2 Jets
  - 3.1.1.3 Magnetic reconnection
- **3.1.2 Emission in strong magnetic fields**
  - 3.1.2.1 Magnetic cataclysmic variables
  - 3.1.2.2 Accreting millisecond pulsars
  - 3.1.2.3 Accreting X-ray pulsars
- **3.1.3 Scattering in aspherical situations**
  - 3.1.3.1 X-ray binaries
  - 3.1.3.2 Radio-quiet AGN
  - 3.1.3.3 X-ray reflection nebulae

3.2 Fundamental Physics

- **3.2.1 Matter in Extreme Magnetic Fields: QED effects**
- **3.2.2 Matter in Extreme Gravitational Fields: GR effects**
- **3.2.3 Quantum Gravity**
- **3.2.4 Search for axion-like particles**

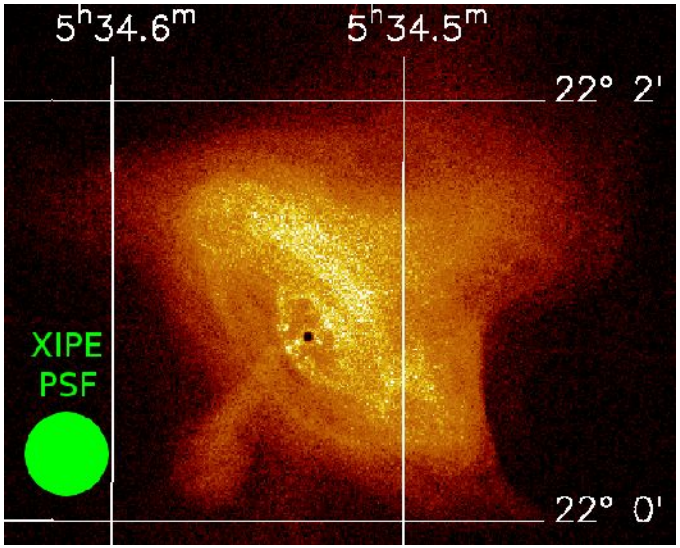
Cosmic Vision themes:

1. Explore the Limits of Contemporary Physics
2. Matter Under Extreme Conditions
3. The Evolving Violent Universe
4. From the Sun to the Edge of the Solar System

Acceleration processes in PWNe and SNRs
- pinpoint acceleration sites
- trace the magnetic field

Crab Nebula: 5x5 regions, MDP~2% in 100ks
Few other sources accessible.

Nakamura e Shibata 2007; Volpi et al. 2008
Bykov et al 2009



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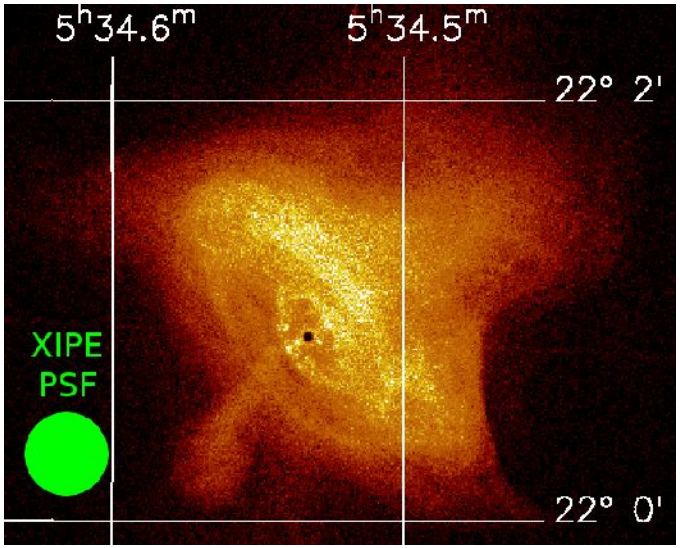
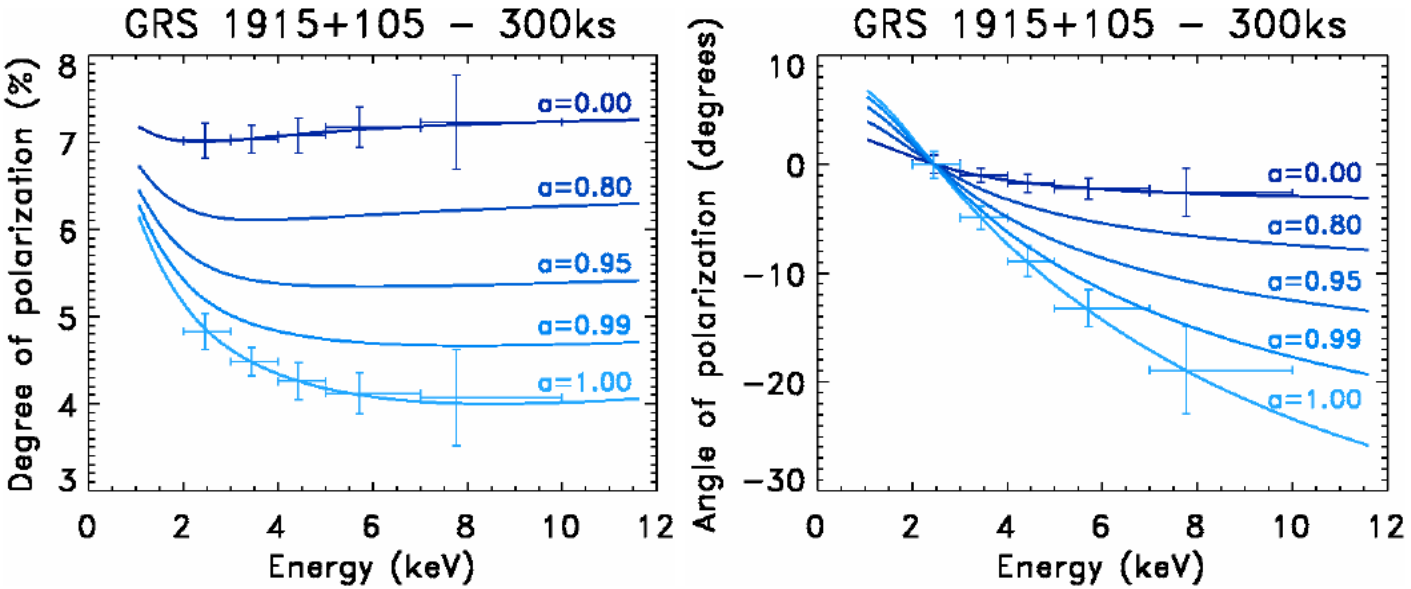


Independent estimates of Galactic BHs spin



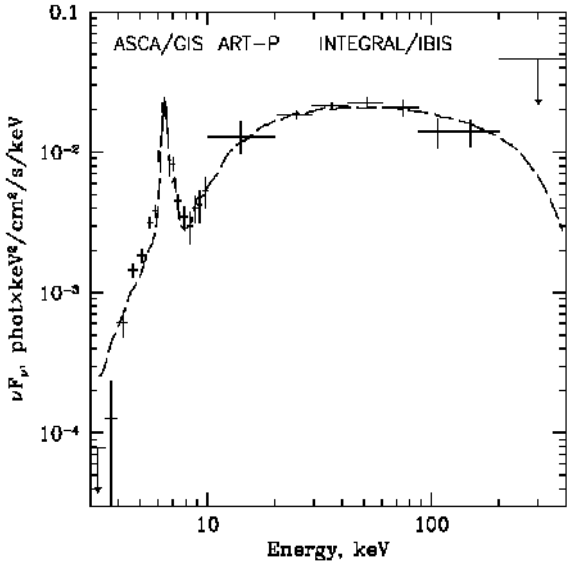
Stark and Connors (1977), Connors et al. (1980), Dovciak, et al. (2008), Li et al. 2009; Schnittman & Krolik (2009)

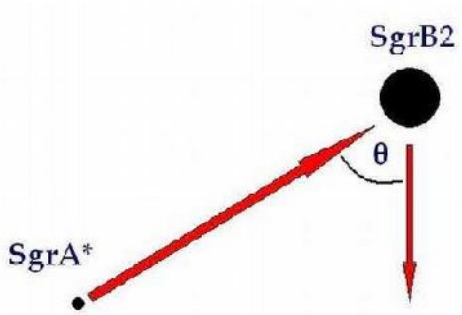
Science with XIPE: Molecular clouds in the GC

- Fe Kα line;
- Hard emission;

Reflection nebula: **outburst** from Sgr A*?

Sunyaev et al. 1993, Koyama et al (1996)

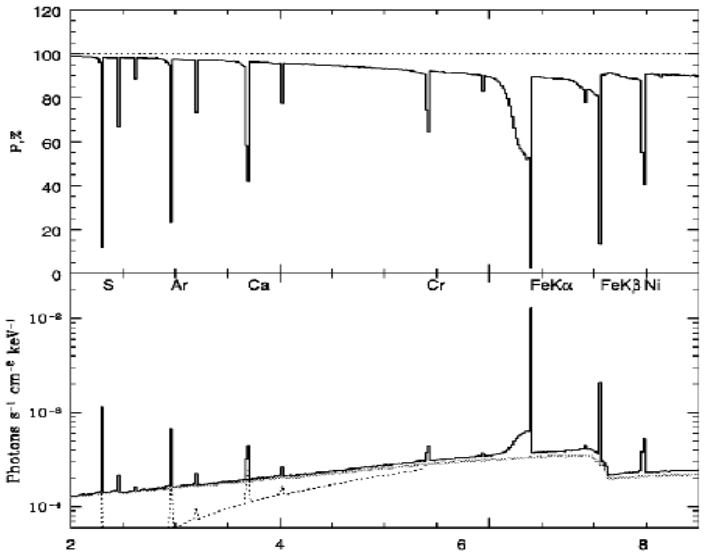


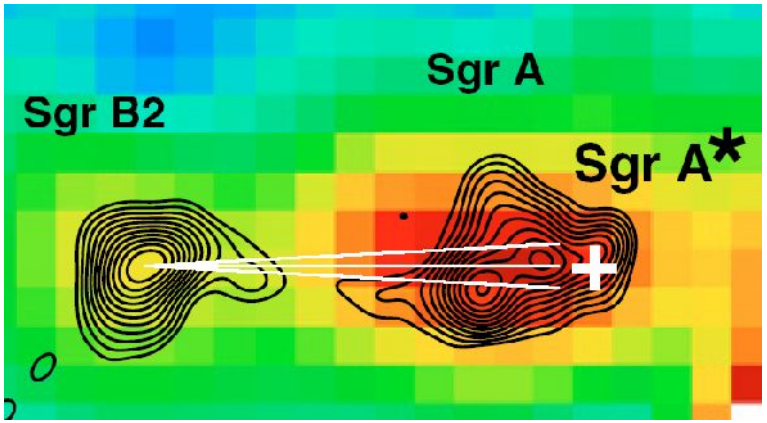


Revnivtsev et al (2004)

- Strongly polarized contiuum emission
- Unpolarized fluorescence lines.

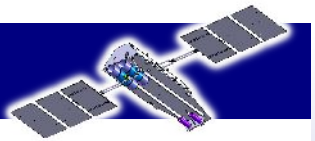
Churazov et al (2002):





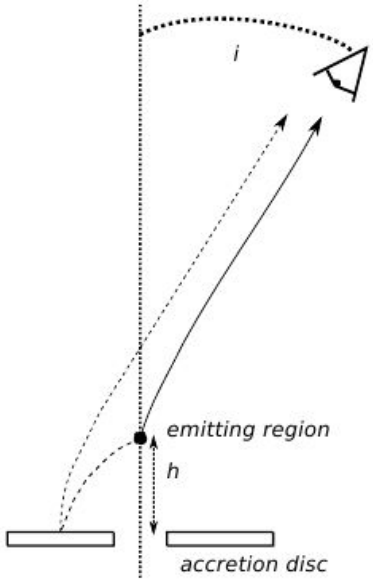
XIPE: 3.5 deg (1-s) in 3 Ms

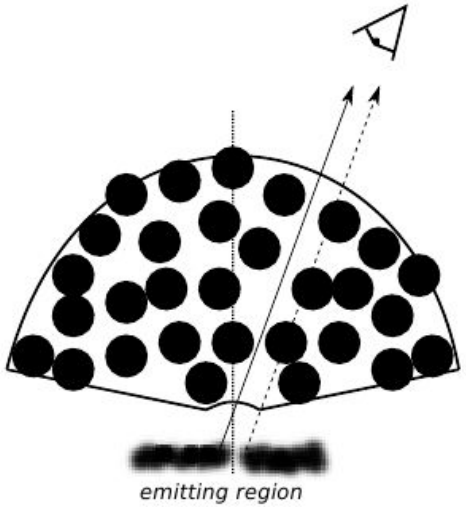
Science with XIPE: Reflection vs Complex absorption scenario

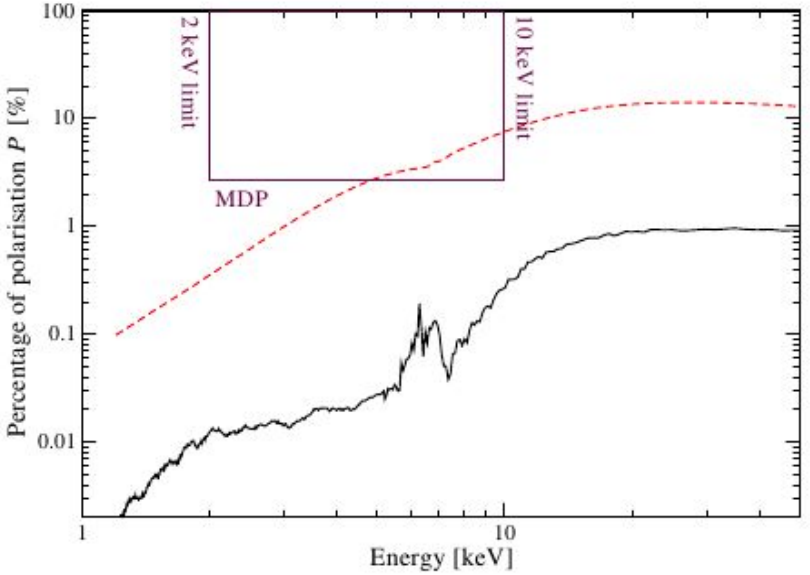


Marin et al. (MNRAS accepted, arXiv:1208.3314v1) compare

- complex absorption with partial covering and clumpy wind
- reflection based on the lamp-post geometry.

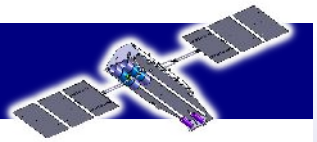






→ within the reach of XIPE in 1 Ms observation of MCG-6-30-15

Conclusions



XIPE is currently the only possibility to perform X-ray polarimetry in the next future in a systematic way.

On paper, it has good chance:

- Outstanding science

- Mature and proven technology
  - Optics already manufactured and tested
  - High TRL (5) for the LEP (already studied for IXO) the MEP requires minor changes

- Low costs
  - Based on a commercial bus
  - Low mass and power budget