# Search for axions and ALPs with X-ray Polarimetry

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# The rationale

In the path from a source of X-rays to the observer and in the presence of ordered magnetic fields axion/photon coupling can introduce a linear polarization in a beam originally unpolarized or, alternatively, de-polarize an originally polarized beam (see the talk by M.Roncadelli). This suggests that X-ray Polarimetry can be a tool to search astrophysical evidences for the existence of Axions or Axion Like Particles

Polarimetry is a branch of X-Ray Astronomy almost completely neglect for more than 40 years.

Recently both NASA and ESA have approved advanced studies on three missions aimed to this subtopics, so that the probability that a mission of Polarimetry will fly within the next 10 years is relatively high. The most performing of the proposed mission is the X-ray Imaging Polarimetry Explorer (XIPE) one of the 3 missions candidate for ESA M4 slot.

By using XIPE as a reference I try to figure how X.ray polarimetry could contribute to the quest for axions and ALP.

# Measurements in 53 years of X-ray Astronomy

Timing: (Geiger, Proportional Counters, MCA, in the future Silicon Drift Chambers)
Rockets, UHURU, Einstein, EXOSAT, ASCA, SAX, XMM, Chandra, …, LOFT(?).

Imaging: Pseudo-imaging (modulation collimators, grazing incidence optics + Proportional Counters, MCA, CCD in the future DepFET)
Rockets, SAS-3, Einstein, EXOSAT, ROSAT, ASCA, SAX, Chandra, XMM, INTEGRAL, SWIFT, Suzaku, NUSTAR, ……., ATHENA.

Spectroscopy: Non dispersive (Proportional Counters, Si/Ge and CCD, Bolometers in the future Tranition Edge Spectrometers)
Dispersive: Bragg, Gratings.
Rockets, Einstein, EXOSAT, HEAO-3, ASCA, SAX, XMM, Chandra, XMM, INTEGRAL, Suzaku, ……., ATHENA.

Polarimetry: (Bragg, Thomson/Compton, in the future photoelectric and subdivided compton)
Rockets, Ariel-5, OSO-8, ……., XIPE(?) or other (IXPE, Praxys, XTP)

# The status

A vast theoretical literature, started from the very beginning of X-ry Astronomy, predicts a wealth of results from Polarimetry

In 43 years only one positive detection of X-ray Polarization: the Crab (Novick et al. 1972, Weisskopf et al.1976, Weisskopf et al. 1978) $P = 19.2 \pm 1.0$ %; $\theta = 156.4^{o} \pm 1.4^{o}$

Plus a fistful of upper limits, most of marginal significance

# A window not yet disclosed in 2015

**THE TECHNIQUES HAVE BEEN THE LIMIT!**

**Conventional X-ray polarimeters are cumbersome and have low sensitivity, completely mismatchedwith sensitivity in other topics**

# The window is still undisclosed in 2015

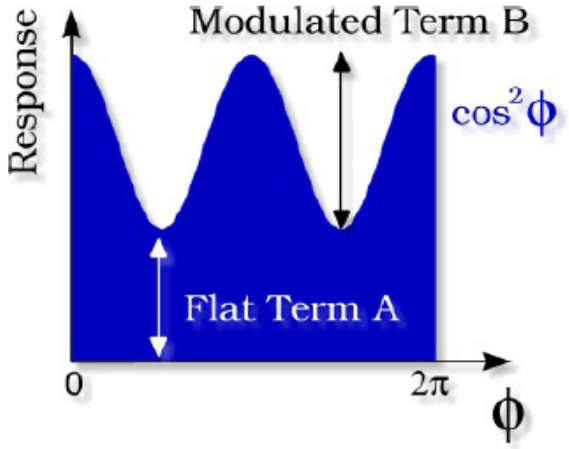
**But New technical solutions are now ready**

**The attitude of Agencies is cleary changed**

**A new Era for X-ray Polarimetry is about to come (maybe….)**

# The conventional formalism

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

$\mu$ is the modulation factor, i.e. the modulation for 100% polarized radiation

Or by Using Stokes Parameters

$$I = A + \frac{B}{2} \qquad I = A + \frac{B}{2} \qquad U = \frac{A}{2}\sin(2\varphi_0)$$

No V → no circular polarization with present techniques

# The first limit: In polarimetry the sensitivity is a matter of photons

MDP is the Minimum Detectable Polarization

$$MDP = \frac{4.29}{\mu R_S}\sqrt{\frac{R_S + R_B}{T}}$$

$R_S$ is the Source rate, $R_B$ is the Background rate, T is the observing time

μ is the modulation factor: the modulation of the response of the polarimeter to a 100% polarized beam

If background is negligible: $$\mathrm{MDP} = \frac{4.29}{\mu\sqrt{N_{ph}}}$$

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

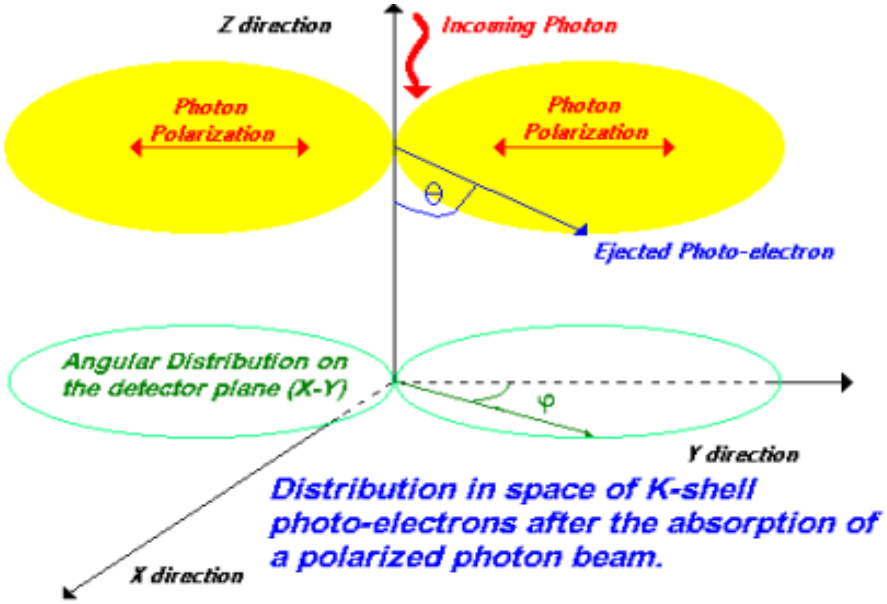
Source detection > 10 photons

Source spectral slope > 100 photons

Source polarization > 100.000 photons

Caution: the MDP describes the capability of rejecting the null hypothesis (no polarization) at 99% confidence. For a significant meaurement a longer observation is needed. For a confidence equivalent to the gaussian 5σ the constant is higher $4.29 \rightarrow 7.58$

Modern polarimeters dedicated to X-ray Astronomy exploit the photoelectric effect resolving most of the problems connected with Thomson/Bragg polarimeter.




By measuring the angular distribution of the ejected photelectrons (the modulation curve) it is possible to derive the X-ray polarization.

Costa, Bellazzini
Nature, 2001

$\beta = v/c$

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

Heitler W., The Quantum Theory of Radiation

# What next? A mission of polarimetry? And with which concept?

ESA

In 2014 **ESA** issued an AOO for the 4th Scientific Mission of Medium Size (M4) with a budget of 450 M€ (+ national contributions).

**3 missions have been selected on 2015 for phase A study**:

1) XIPE: and X-ray Imaging Polarimeter based on GPD
2) ARIEL: a mission for the spectroscopy of Exoplanets
3) Thor: a mission to study turbolence on Solar Wind

On 2017 one of these 3 missions will be selected for flight

NASA

In 2014 **NASA** issued an AOO for a Small Explorer Mission (budget of ~ 150 M$)

On july 30 **NASA selected 3 missions for phase A study**

1) IXPE: a Mission of X-ray Polarimetry based on GPD
2) Praxys: a Mission of X-ray Polarimetry based on TPC
3) SPHEREx: a Mission of All Sky Survey of NearIR spectroscopy

On end of 2016 NASA will select one of the 3 missions to flight

CNSA

**CNSA** is defining its planning and **XTP**, a very large mission of X-ray astronomy, including some polarimeters, is one of the candidates. The time horizon should be after XIPE.

# Let us focus on XIPE

XIPE is by far the most performing of the 3 missions under study.

I use it as a reference of what X-Ray Polarimetry can do in the next future.

# X-ray Imaging Polarimetry Explorer

## Proposed by

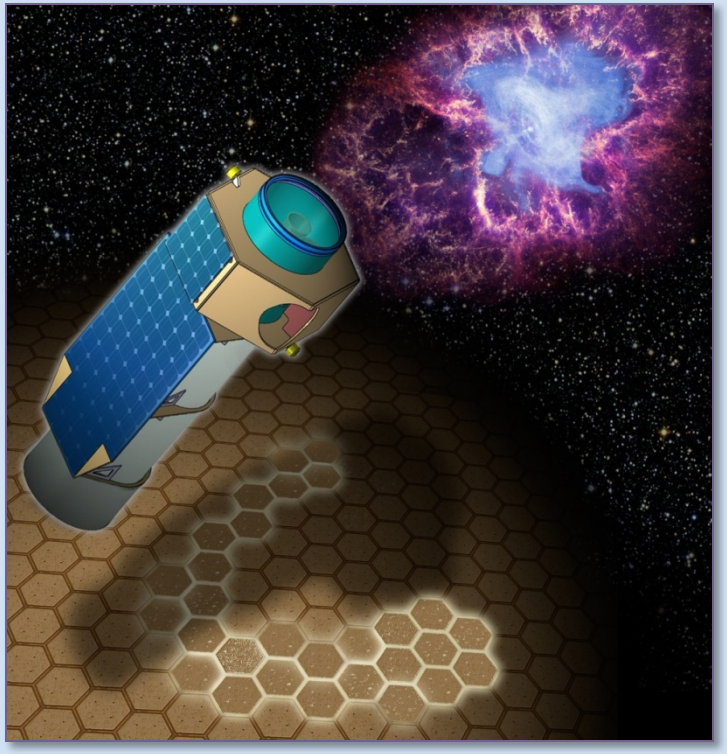
**Paolo Soffitta, Ronaldo Bellazzini, Enrico Bozzo, Vadim Burwitz, Alberto J. Castro-Tirado, Enrico Costa, Thierry J-L. Courvoisier, Hua Feng, Szymon Gburek, René Goosmann, Vladimir Karas, Giorgio Matt, Fabio Muleri, Kirpal Nandra, Mark Pearce, Juri Poutanen, Victor Reglero, Maria Dolores Sabau, Andrea Santangelo, Gianpiero Tagliaferri, Christoph Tenzer, Martin C. Weisskopf, Silvia Zane**

### XIPE Science Team

Agudo, Ivan; Aloisio, Roberto; Amato, Elena; Antonelli, Angelo; Atteia, Jean-Luc; Axelsson, Magnus; Bandiera, Rino; Barcons, Xavier; Bianchi, Stefano; Blasi, Pasquale; Boër, Michel; Bozzo, Enrico; Braga, Joao; Bucciantini, Niccolo'; Burderi, Luciano; Bykov, Andrey; Campana, Sergio; Campana, Riccardo; Cappi, Massimo; Cardillo, Martina; Casella, Piergiorgio; Castro-Tirado, Alberto J.; Chen, Yang; Churazov, Eugene; Connell, Paul; Courvoisier, Thierry; Covino, Stefano; Cui, Wei; Cusumano, Giancarlo; Dadina, Mauro; De Rosa, Alessandra; Del Zanna, Luca; Di Salvo, Tiziana; Donnarumma, Immacolata; Dovciak, Michal; Elsner, Ronald; Eyles, Chris; Fabiani, Sergio; Fan, Yizhong; Feng, Hua; Ghisellini, Gabriele; Goosmann, René W.; Gou, Lijun; Grandi, Paola; Grosso, Nicolas; Hernanz, Margarita; Ho, Luis; Hu, Jian; Huovelin, Juhani; Iaria, Rosario; Jackson, Miranda; Ji, Li; Jorstad, Svetlana; Kaaret, Philip; Karas, Vladimir; Lai, Dong; Larsson, Josefin; Li, Li-Xin; Li, Tipei; Malzac, Julien; Marin, Frédéric; Marscher, Alan; Massaro, Francesco; Matt, Giorgio; Mineo, Teresa; Miniutti, Giovanni; Morlino, Giovanni; Mundell, Carole; Nandra, Kirpal; O'Dell, Steve; Olmi, Barbara; Pacciani, Luigi; Paul, Biswajit; Perna, Rosalba; Petrucci, Pierre-Olivier; Pili, Antonio Graziano; Porquet, Delphine; Poutanen, Juri; Ramsey, Brian; Razzano, Massimiliano; Rea, Nanda; Reglero, Victor; Rosswog, Stephan; Rozanska, Agata; Ryde, Felix; Sabau, Maria Dolores; Salvati, Marco; Silver, Eric; Sunyaev, Rashid; Tamborra, Francesco; Tavecchio, Fabrizio; Taverna, Roberto; Tong, Hao; Turolla, Roberto; Vink, Jacco; Wang, Chen; Weisskopf, Martin C.; Wu, Kinwah; Wu, Xuefeng; Xu, Renxin; Yu, Wenfei; Yuan, Feng; Zane, Silvia; Zdziarski, Andrzej A.; Zhang, Shuangnan; Zhang, Shu.

### XIPE Instrument Team

Baldini, Luca; Basso, Stefano; Bellazzini, Ronaldo; Bozzo, Enrico; Brez, Alessandro; Burwitz, Vadim; Costa, Enrico; Cui, Wei; de Ruvo, Luca; Del Monte, Ettore; Di Cosimo, Sergio; Di Persio, Giuseppe; Dias, Teresa H. V. T.; Escada, Jose; Evangelista, Yuri; Eyles, Chris; Feng, Hua; Gburek, Szymon; Kiss, Mózsi; Korpela, Seppo; Kowaliski, Miroslaw; Kuss, Michael; Latronico, Luca; Li, Hong; Maia, Jorge; Minuti, Massimo; Muleri, Fabio; Nenonen, Seppo; Omodei, Nicola; Pareschi, Giovanni; Pearce, Mark; Pesce-Rollins, Melissa; Pinchera, Michele; Reglero, Victor; Rubini, Alda; Sabau, Maria Dolores; Santangelo, Andrea; Sgrò, Carmelo; Silva, Rui; Soffitta, Paolo; Spandre, Gloria; Spiga, Daniele; Tagliaferri, Gianpiero; Tenzer, Christoph; Wang, Zhanshan; Winter, Berend; Zane, Silvia.



### XIPE participating Institutions

**BR**: INPE; **CH**: ISDC - Univ. of Geneva; **CN**: IHEP, NAOC, NJU, PKU, PMO, Purdue Univ., SHAO, Tongji Univ, Tsinghua Univ., XAO; **CZ**: Astron. Institute of the CAS; **DE**: IAAT Uni Tübingen, MPA, MPE; **ES**: CSIC, CSIC-IAA, CSIC-IEEC, CSIC-INTA, IFCA (CSIC-UC), INTA, Univ. de Valencia; **FI**: Oxford Instruments Analytical Oy, Univ. of Helsinki, Univ. of Turku; **FR**: CNRS/ARTEMIS, IPAG-Univ. of Grenoble/ CNRS, IRAP, Obs. Astron. de Strasbourg, **IN**: Raman Research Institute, Bangalore; **IT**: Gran Sasso Science Institute, L'Aquila, INAF/IAPS, INAF/IASF-Bo, INAF/IASF-Pa, INAF-OAA, INAF-OABr, INAF-OAR, INFN-Pi, INFN-Torino, INFN-Ts, Univ of Pisa, Univ. Cagliari, Univ. of Florence, Univ. of Padova, Univ. of Palermo, Univ. Roma Tre, Univ. Torino; **NL**: JIVE, Univ. of Amsterdam; **PL**:CopernicusAstr. Ctr., SRC-PAS; **PT**: LIP/Univ. of Beira-Interior, LIP/Univ. of Coimbra; **RU**: Ioffe Institute, St.Petersburg: **SE**: KTH Royal Institute of Technology. Stockholm Univ.: **UK**: Cardiff Univ., UCL-MSSL, Univ. of Bath; **US**: CFA, Cornell Univ., NASA-MSFC, Stony Brook Univ., Univ. of Iowa, Boston Univ., Institute for Astrophysical Research, Boston Univ., Stanford Univ./KIPAC.

XIPE is devoted to **observation of celestial sources in X-rays**

XIPE uniqueness:

- Time-, spectrally-, spatially-resolved **X-ray polarimetry**
  as a breakthrough in high energy astrophysics and fundamental physics

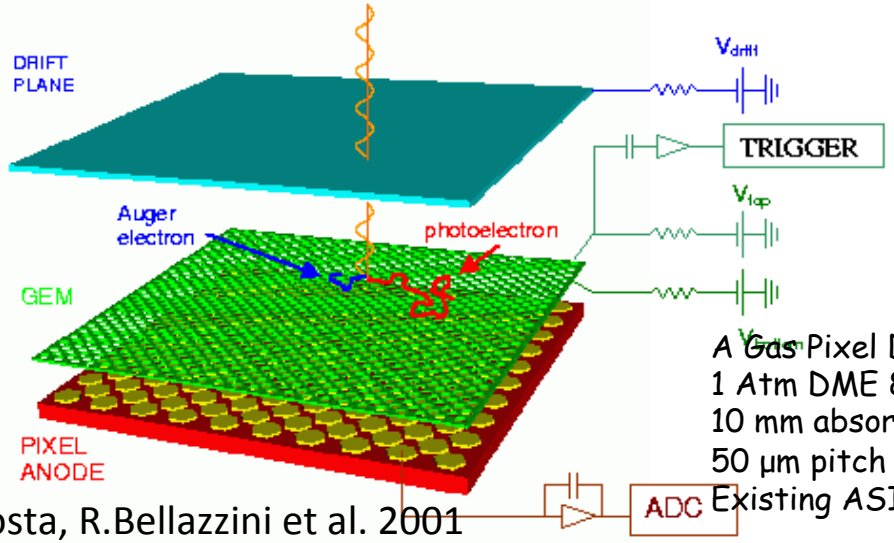
- It will explore this observational window after 40 years from the last positive measurement, with a dramatic improvement in sensitivity: **from one to hundred sources**

In the violent X-ray sky, polarimetry is expected to have a **much greater** impact than in most other wavelengths.

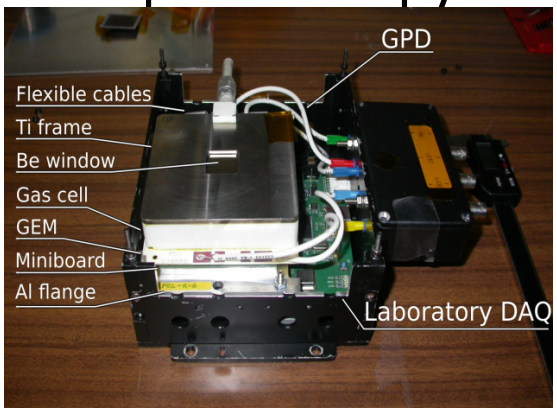
XIPE is going to exploit the complete information contained in X-rays.

## The Gas Pixel Detector

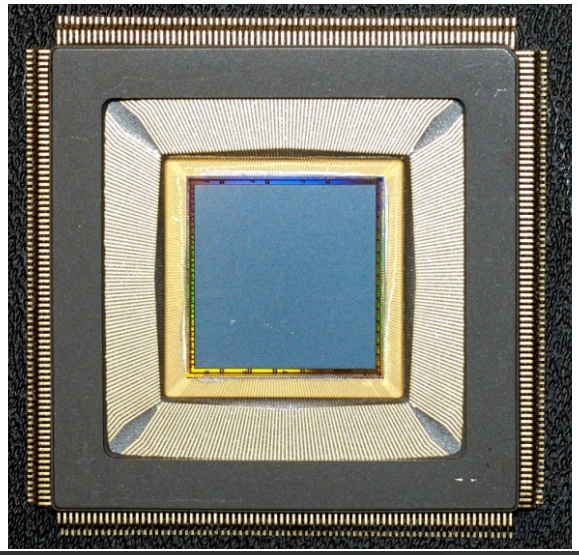
# We developed at this aim The Gas Pixel Detector a polarization-sensitive instrument capable of imaging, timing and spectroscopy




E. Costa, R.Bellazzini et al. 2001




A Gas Pixel Detector with:
1 Atm DME 80% He 20%
10 mm absorption/drift gap
50 μm pitch GEM
Existing ASIC (100000 pixel, 50 μm pitch, auto-trigger, ROI)



- **The core: an asic chip**
- **Peaking time: 3-10 μs, externally adjustable;**
- **Full-scale linear range: 30000 electrons;**
- **Pixel noise: 50 electrons ENC;**
- **Read-out mode: asynchronous or synchronous;**
- **Trigger mode: internal, external or self-trigger;**
- **Read-out clock: up to 10MHz;**
- **Self-trigger threshold: 2200 electrons (10% FS);**
- **Frame rate: up to 10 kHz in self-trigger mode (event window);**
- **Parallel analog output buffers: 1, 8 or 16;**
- **Access to pixel content: direct (single pixel) or serial (8-16 clusters, full matrix, region of interest);**
- **Fill fraction (ratio of metal area to active area): 92%**

# Why this is now possible

## The Gas Pixel Detector

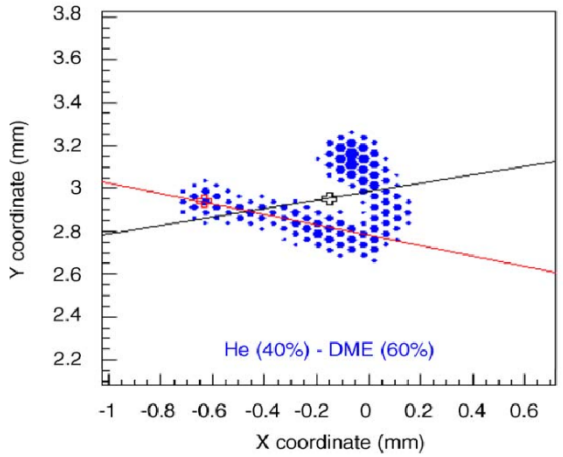
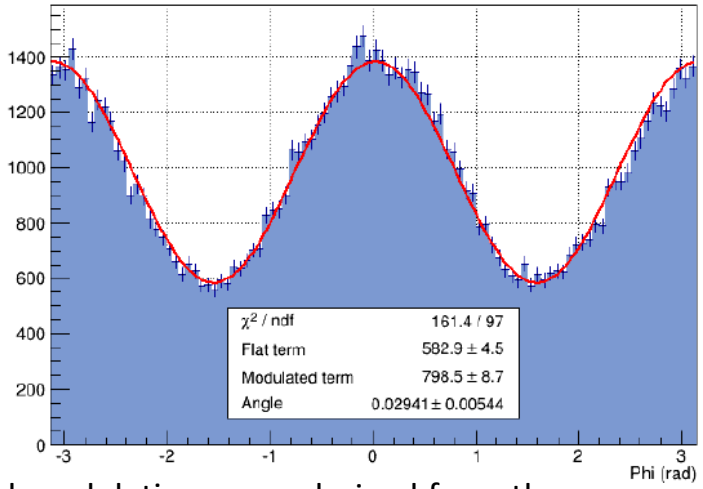
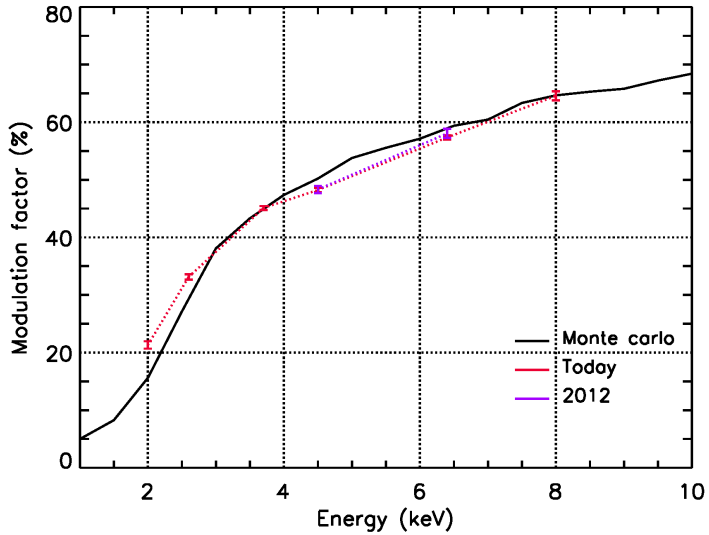



Image of a real photoelectron track. The use of the gas allows to resolve tracks in the X-ray energy band.

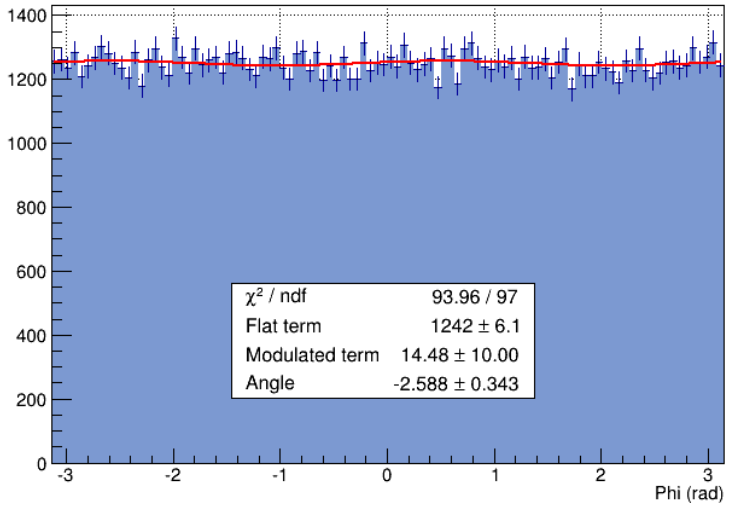



Real modulation curve derived from the measurement of the emission direction of the photoelectron.




Muleri et al. 2008,2010

Modulation factor as a function of energy.

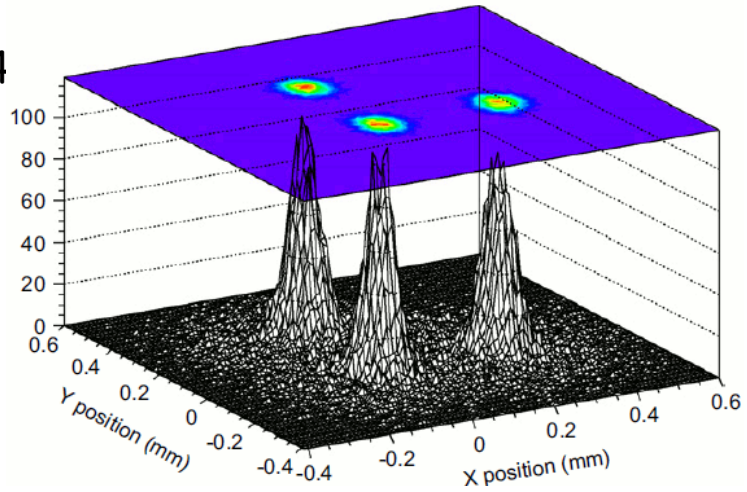



Bellazzini et al. 2012

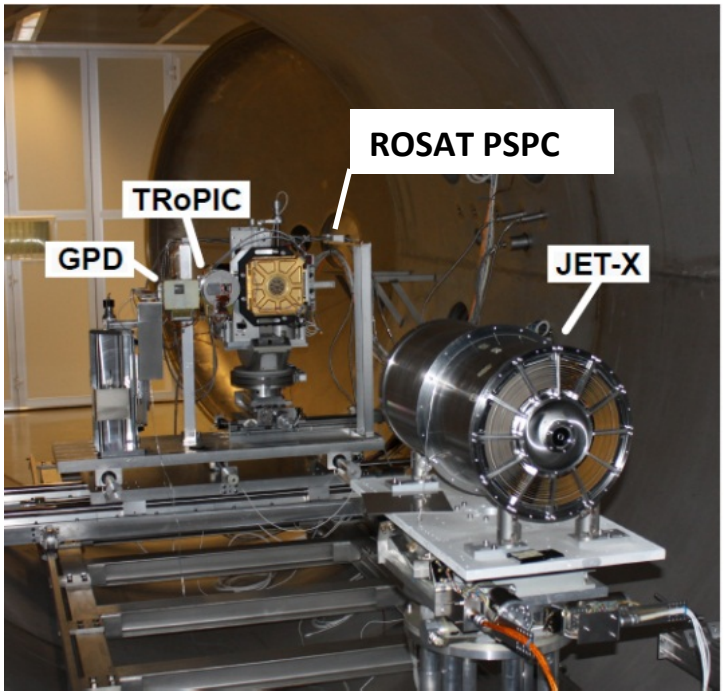
Residual modulation for unpolarised photons.

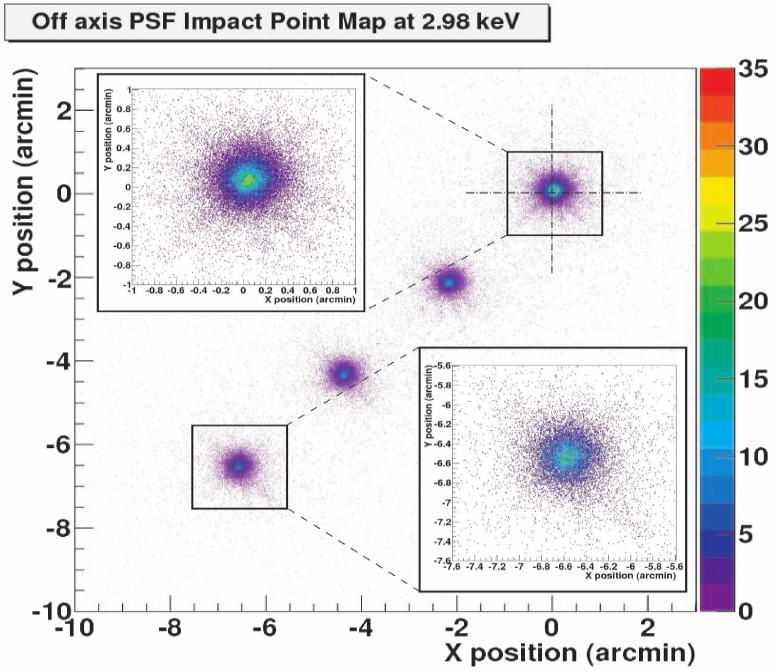
# Imaging capabilities of GPD tested at PANTER

STSM acknowledged in the paper by Fabiani et al.2014

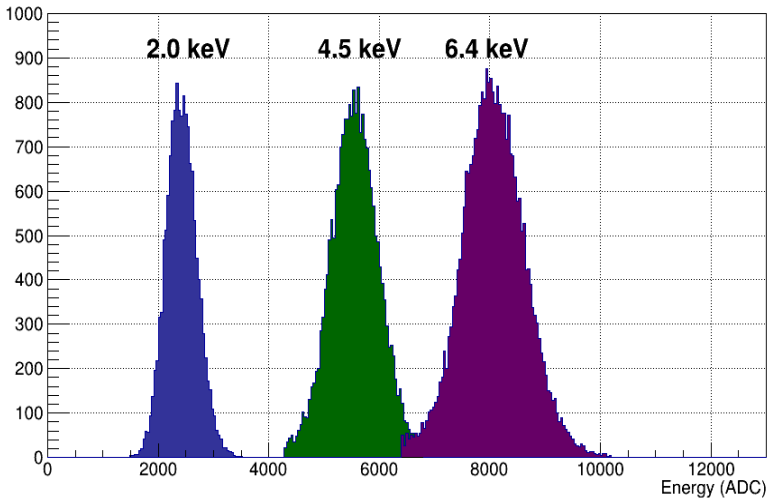


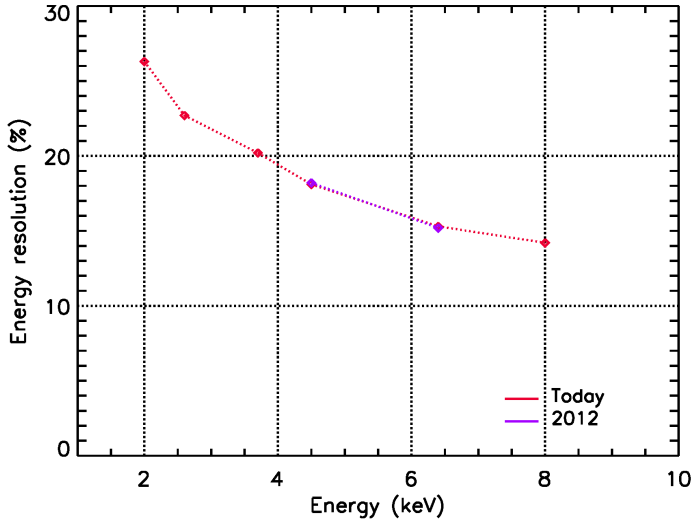

- Good spatial resolution: 90 μm Half Energy Width
- Imaging capabilities on- and off-axis measured at PANTER with a JET-X telescope (Fabiani et al. 2014)
- Angular resolution for XIPE: <26 arcsec



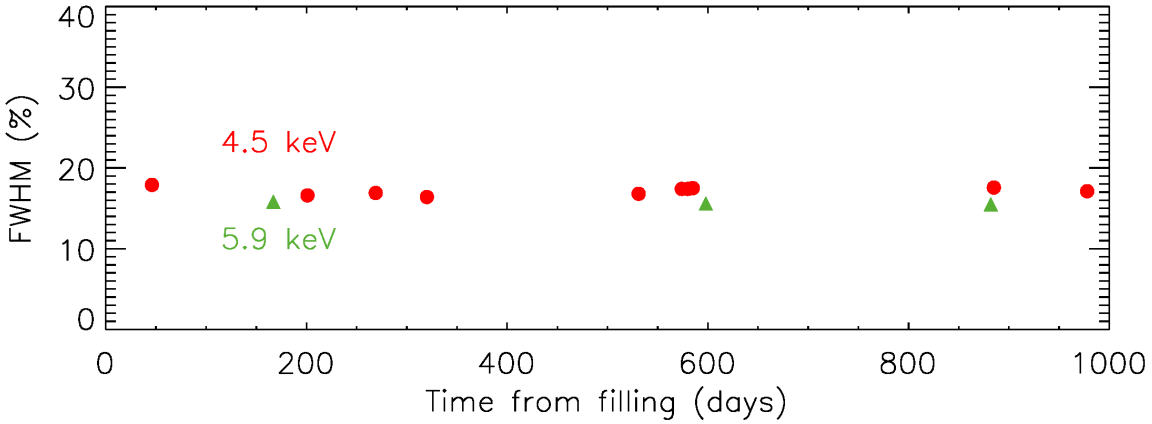



## Spectroscopic capabilities



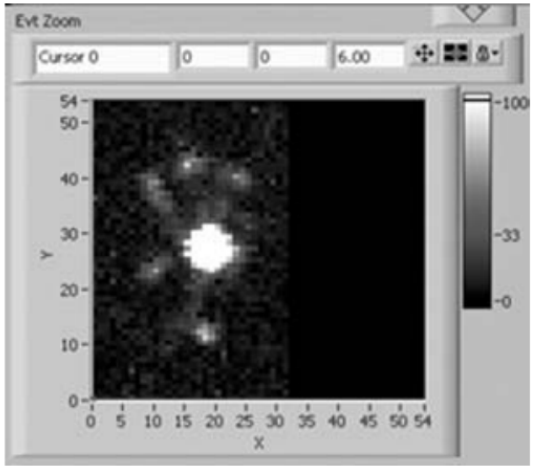




- Adequate spectrometer for continuum emission (16 % at 6 keV, Muleri et al. 2010).
- Stable operation over 3 years



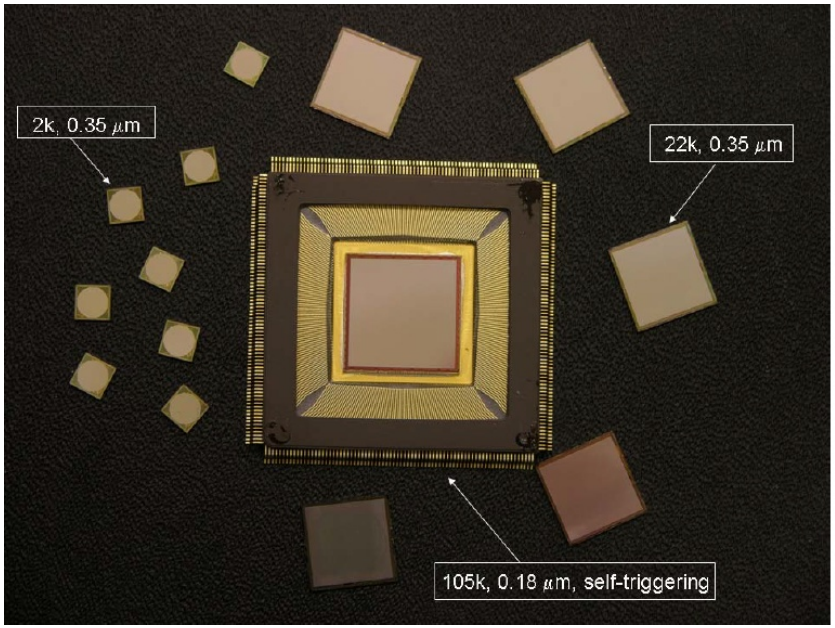
# No sparks even with Ions

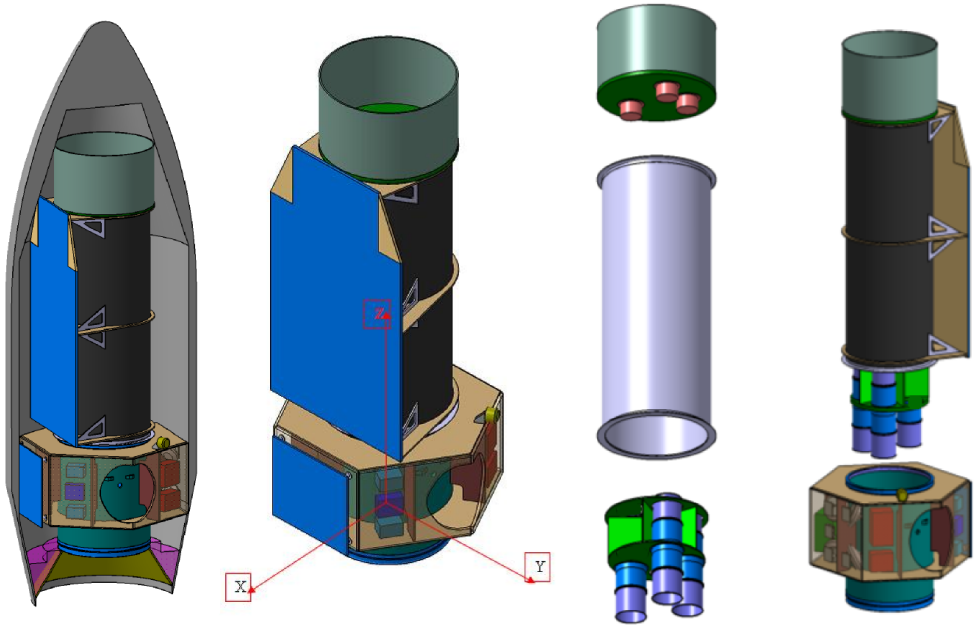
In order to test the sensitivity of the GPD to the radiation environment in Space, we irradiated the GPD with heavy ions in the 500-MeV/nucleon Fe beam at the Heavy Ions Medical Accelerator in Chiba (HIMAC), Japan (Bellazzini etal. 2010). The total exposure was 1.7x104 Fe ions, which corresponds to 42 years in space in a LEO orbit. During the irradiation the GPD was powered on, at the nominal voltage levels. A single event acquired during the test by the online monitor is shown in Figure 30. The event saturates the electronics and several secondary delta rays are also visible. We did not register any damage or performance loss in the detector (Bellazzini et al. 2010).



## A light and simple mission

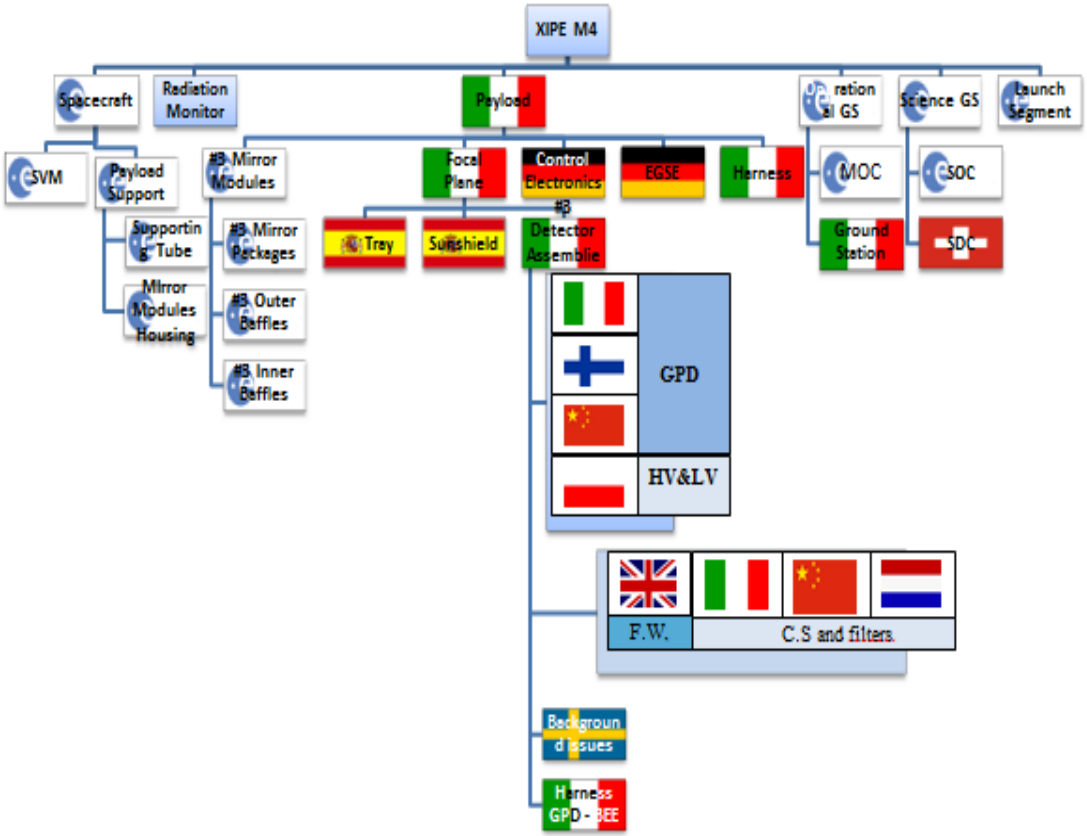
- Three telescopes with 3.5 m (possibly 4m) focal length to fit within the Vega fairing.
  Long heritage: SAX → XMM → Swift → eROSITA → XIPE
- Detectors: conventional proportional counter but with a revolutionary readout.
- Mild mission requirements: 1 mm alignment, 1 arcmin pointing.
- Fixed solar panel. No deployable structure. No cryogenics. No movable part except for the filter wheels.
- Low payload mass: 265 kg with margins. Low power consumption: 129 W with margins.
- Three years nominal operation life. No consumables.
- Low Earth equatorial orbit.




Bellazzini et al. 2006, 2007

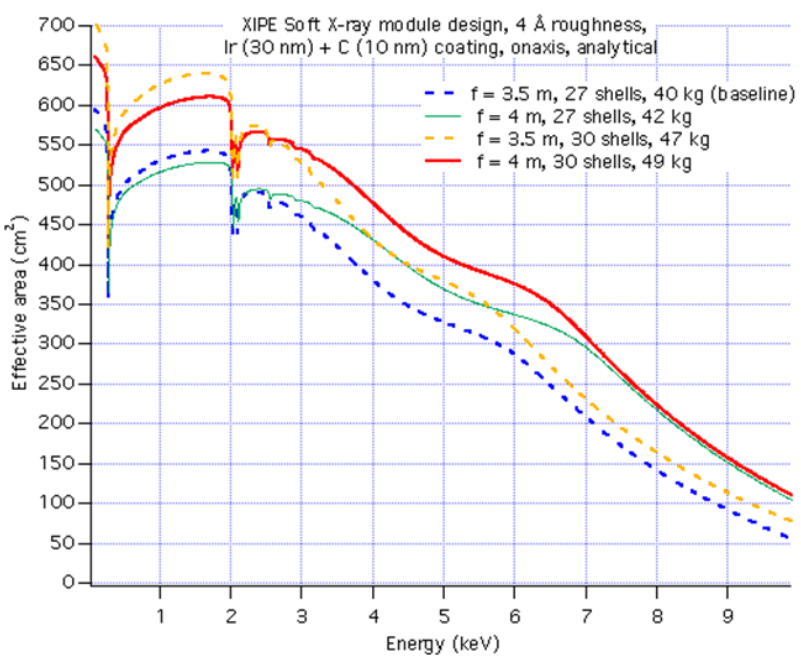
# All Europe and more

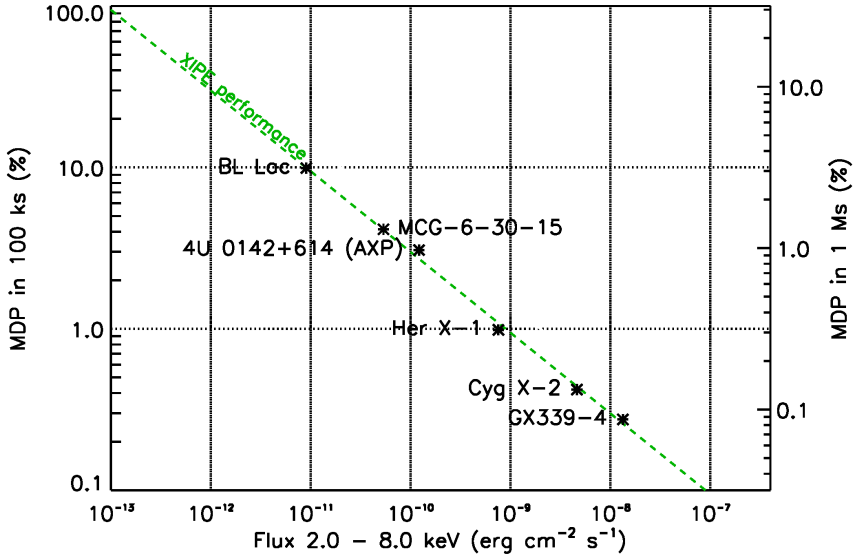



**The distribution of activities**

# XIPE facts

| | |
|---|---|
| Polarisation sensitivity | 1.2% MDP for $2 \times 10^{-10}$ erg/s cm$^2$ (10 mCrab) in 300 ks |
| *Spurious polarization* | <0.5 % (goal: <0.1%) |
| *Angular resolution* | <26 arcsec (goal: <24 arcsec) |
| *Field of View* | 15x15 arcmin$^2$ |
| *Spectral resolution* | 16% @ 5.9 keV |
| *Timing* | Resolution <8 μs |
| | Dead time 60 μs |
| *Stability* | >3 yr |
| *Energy range* | 2-8 keV |
| *Background* | $2 \times 10^{-6}$ c/s or 4 nCrab |



**CP: Core Program (25%)**:

- To ensure that the key scientific goals are reached by observing a set of representative candidates for each class.

**GO: Guest Observer program on competitive base (75%)**:

- To complete the CP with a fair sample of sources for each class;
- To explore the discovery space and allow for new ideas;
- To engage a community as wide as possible.

In organising the GO, a fair time for each class will be assigned. This will ensure “population studies” in the different science topics of X-ray polarimetry.

# Why do we need X-ray polarimetry?

In X-ray sources it is more common that in other wavelengths to find:

- Aspherical emission/scattering geometries (disk, blobs and columns, coronae);
- Non-thermal processes (synchrotron, cyclotron and non-thermal bremsstrahlung).

Furthermore, fundamental physics effects like, e.g., QED birefringence in strong magnetic fields, can be studied by X-ray polarimetry.

Timing & spectroscopy may provide rather ambiguous and model dependent information.

What XIPE can do:

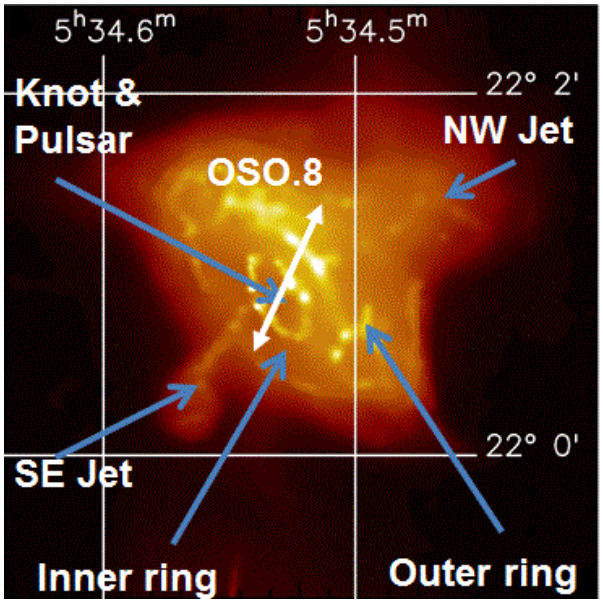
- **Resolved sources**: Emission mechanisms and mapping of the magnetic field: PWNs, SNR and extragalactic jet
- **Unresolved sources**: Geometrical parameter of inner part of compact sources: X-ray pulsars, Coronae in XRB and AGNs.

**Of course let us focus on unresolved galactic sources**

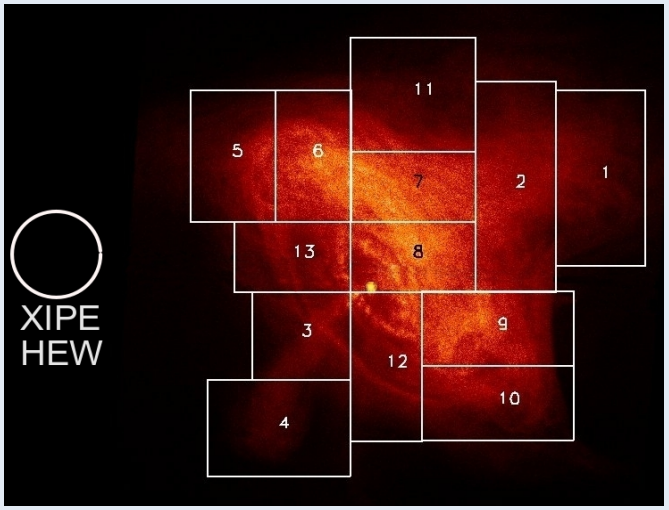
**But is imaging useless for compact sources?**

# Acceleration phenomena: The Crab Nebula

**OSO-8 measured the polarization of the Crab Neula+pulsar as a whole. But after Chandra image ...**




| Region | $\sigma_{degree}$ (%) | $\sigma_{angle}$ (deg) | MDP (%) |
|---|---|---|---|
| 1 | ±0.60 | ±0.96 | 1.90 |
| 2 | ±0.41 | ±0.65 | 1.30 |
| 3 | ±0.68 | ±1.10 | 2.17 |
| 4 | ±0.86 | ±1.39 | 2.76 |
| 5 | ±0.61 | ±0.97 | 1.93 |
| 6 | ±0.46 | ±0.75 | 1.48 |
| 7 | ±0.44 | ±0.70 | 1.40 |
| 8 | ±0.44 | ±0.71 | 1.41 |
| 9 | ±0.46 | ±0.74 | 1.47 |
| 10 | ±0.60 | ±0.97 | 1.92 |
| 11 | ±0.52 | ±0.83 | 1.65 |
| 12 | ±0.53 | ±0.85 | 1.69 |
| 13 | ±0.59 | ±0.95 | 1.89 |




**20 ks with XIPE**

- The OSO-8 observation, integrated on the whole nebula, measured a position angle which is tilted with respect to jets and torus axes. It was not possible to measure the polarization of PSR0531+21 because the contribution to the total counts was around 4% and the nebula was acting as a huge background.

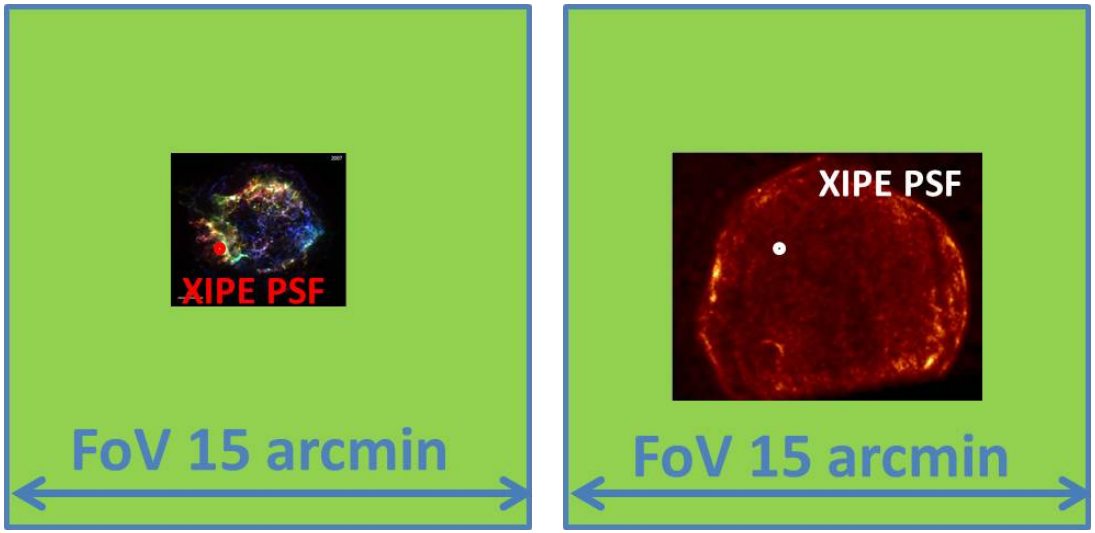
- XIPE has a resolution which is not imaging capabilities will allow to measure the pulsar polarisation by separating from the much brighter nebula emission.

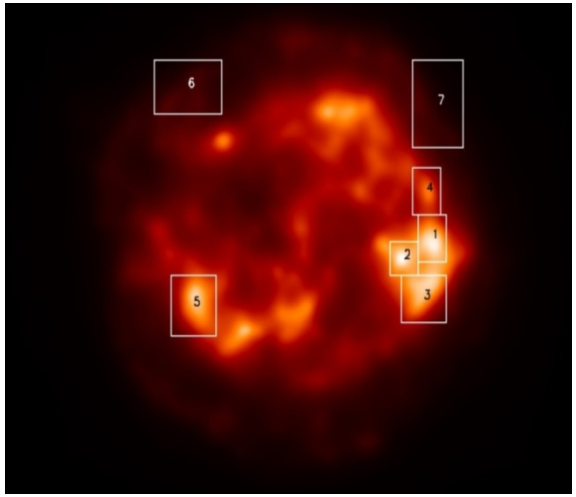
# XIPE scientific goals

***Map of the magnetic field***

Spectral imaging allows to separate the thermalised plasma from the regions where shocks accelerate particles.

What is the orientation of the magnetic field? How ordered is it? The spectrum cannot tell…




4-6 keV image of Cas A blurred with the PSF of XIPE

| Region | MDP (%) | σdegree (%) | σangle (deg) |
|---|---|---|---|
| | | if P=11% | |
| 1 | 3.7 | ±1.2 | ±3.2 |
| 2 | 4.3 | ±1.3 | ±3.7 |
| 3 | 3.2 | ±1.0 | ±2.8 |
| 4 | 4.6 | ±1.4 | ±4.1 |
| 5 | 3.0 | ±0.9 | ±2.6 |
| 6 | 5.3 | ±1.7 | ±4.5 |
| 7 | 5.4 | ±1.7 | ±4.9 |

2 Ms observation with XIPE

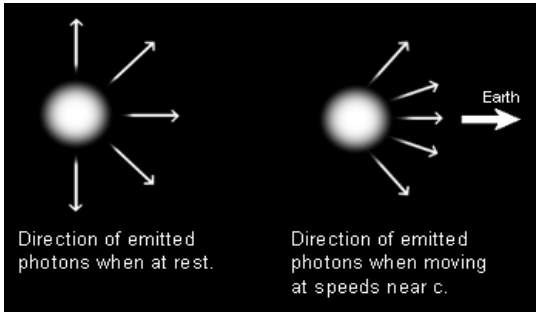
# XIPE scientific goals

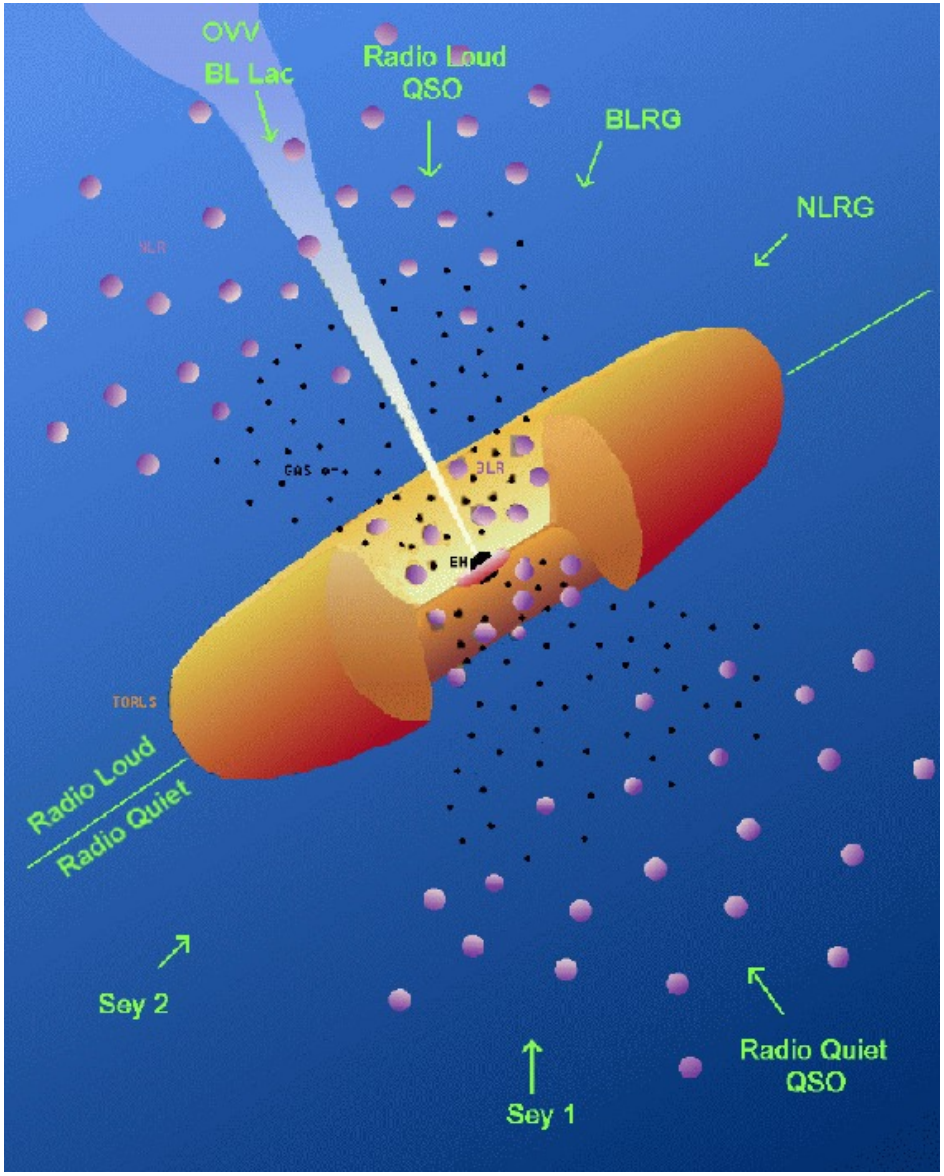
Schematic view of an AGN

➡

Blazars are those AGN which not only have a jet (like all radiogalaxies), but it is directed towards us.

Due to a Special Relativity effect (aberration), the jet emission dominates over other emission components



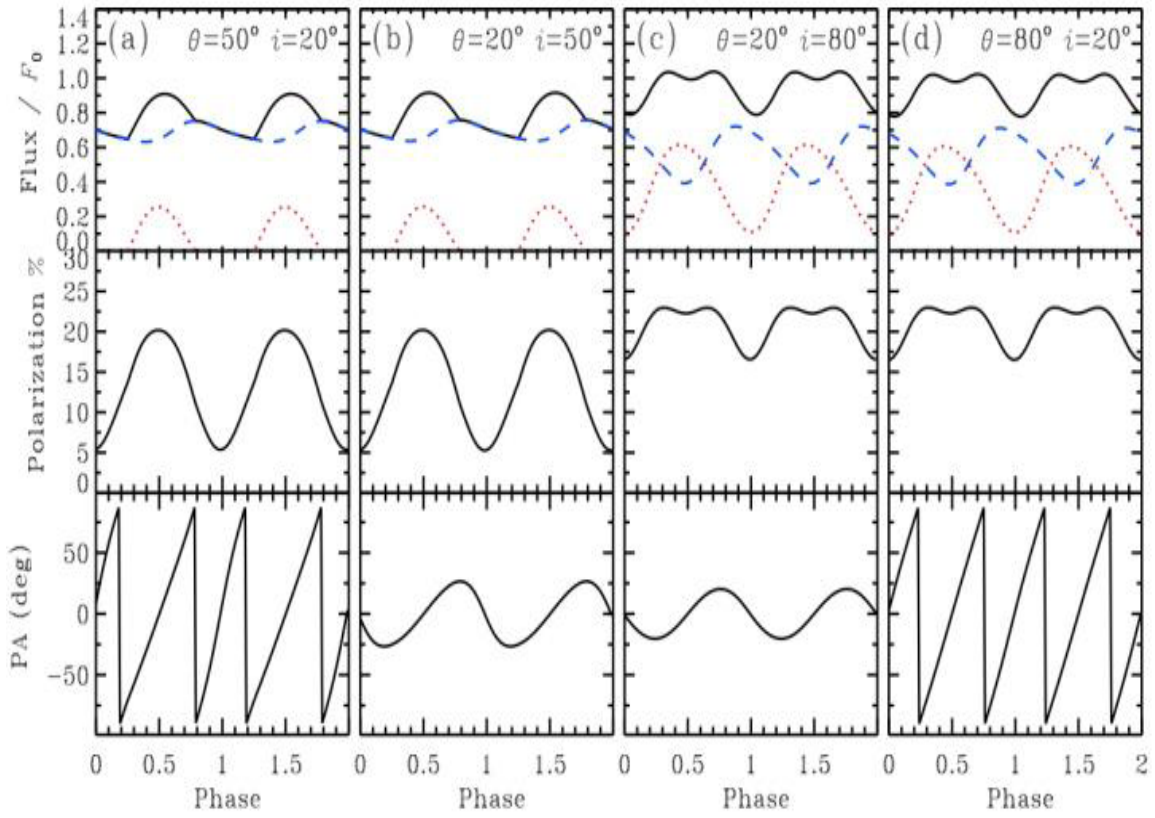



# XIPE scientific goals

Emission due to scattering in hot spots

⇒

Phase-dependent linear polarization

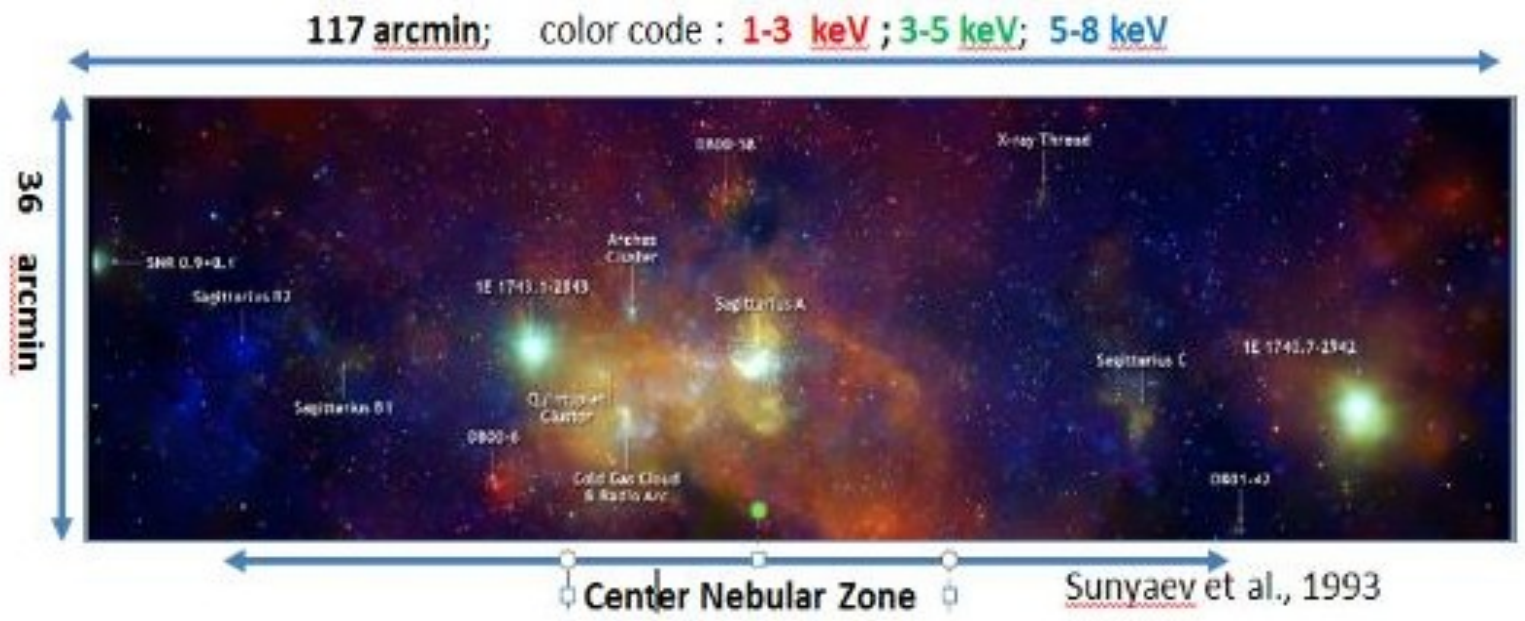



Viironen & Poutanen 2004

# XIPE scientific goals

Cold molecular clouds around Sgr A* (i.e. the supermassive black hole at the centre of our own Galaxy) show a neutral iron line and a Compton bump → Reflection from an external source!?!

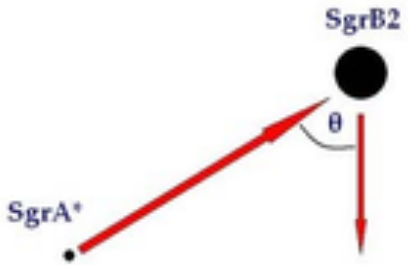
No bright enough sources are in the surroundings. Are they reflecting X-rays from Sgr A*? so, was it one million times brighter a few hundreds years ago? Polarimetry can tell!

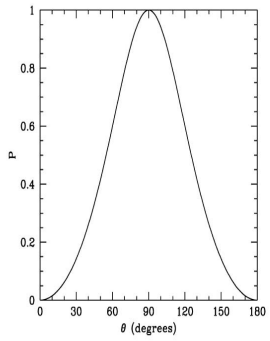


# XIPE scientific goals

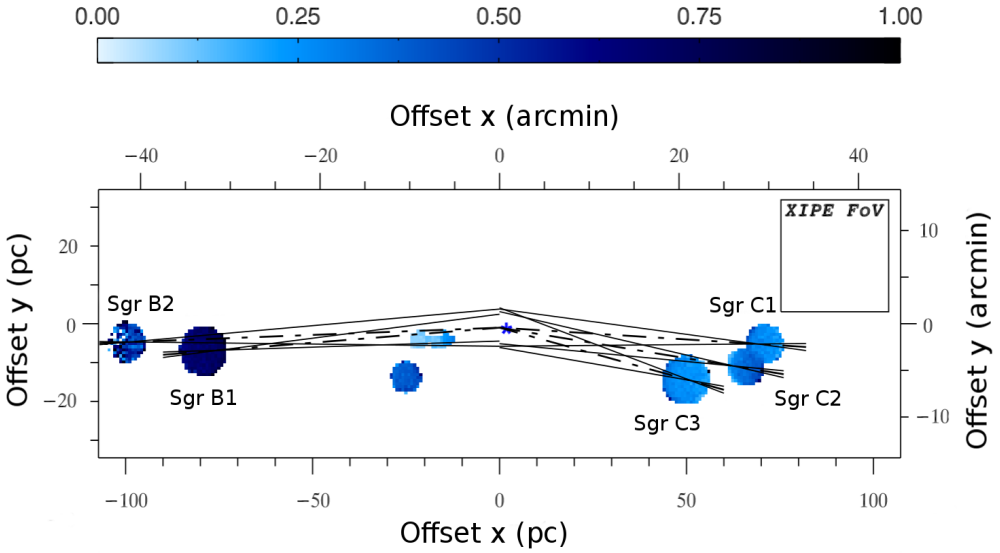
## Polarization by scattering from Sgr B complex, Sgr C complex

- The angle of polarisation pinpoints the source of X-rays
- The degree of polarization measures the scattering angle and determines the true distance of the clouds from Sgr A*.



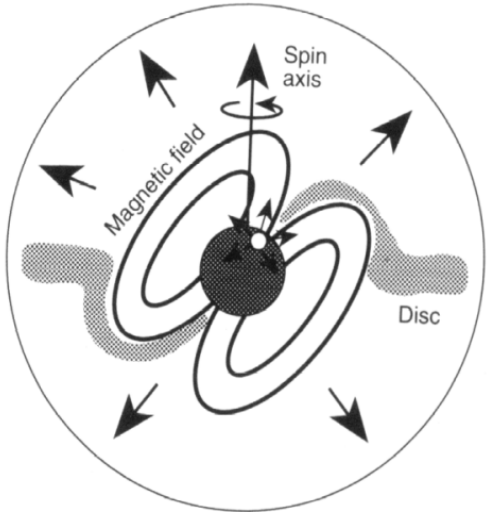

Marin et al. 2014

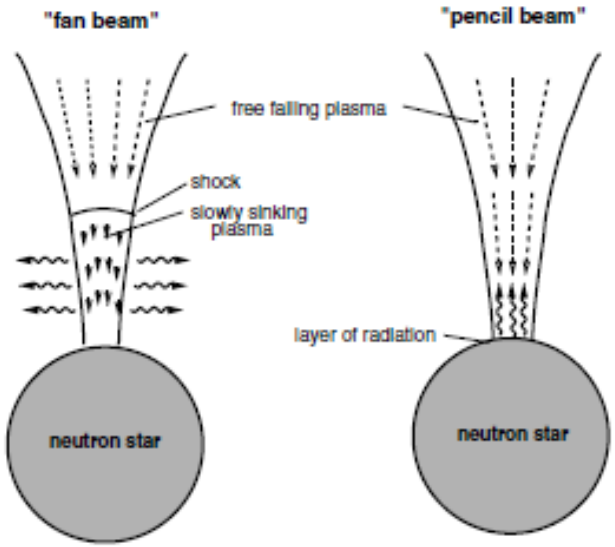


## Disentangling geometric parameters from physical ones

Emission process:
- cyclotron
- opacity on highly magnetised plasma: $k_{\perp} < k_{\parallel}$

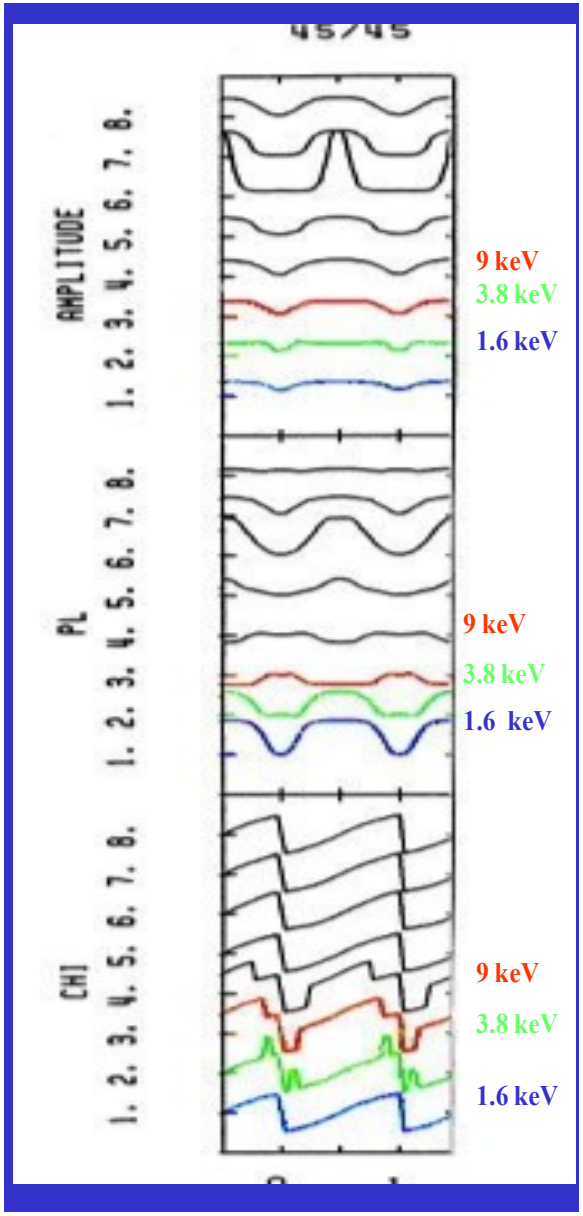
From the swing of the polarisation angle:
- Orientation of the rotation axis
- Inclination of the magnetic field
- Geometry of the accretion column: “fan” beam vs “pencil” beam




For the best class of XIPE candidates we use a paper 27 y old!

Meszaros et al. 1988



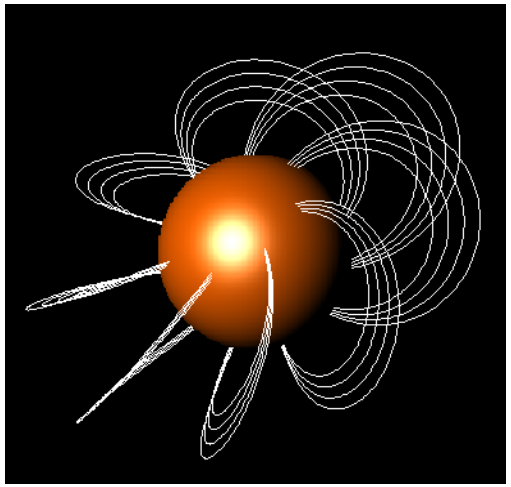
**More papers on isolated neutron stars**

Magnetars are isolated neutron stars with likely a huge magnetic field (B up to $10^{15}$ Gauss).

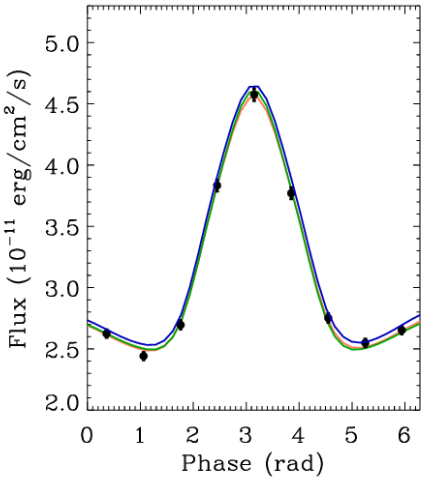
It heats the star crust and explains why the X-ray luminosity largely exceeds the spin down energy loss.

QED foresees vacuum birefringence, an effect predicted 80 years ago, expected in such a strong magnetic field and never detected yet.

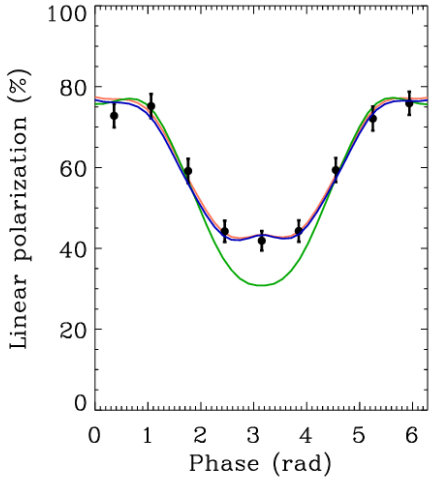
A twisted magnetic field.



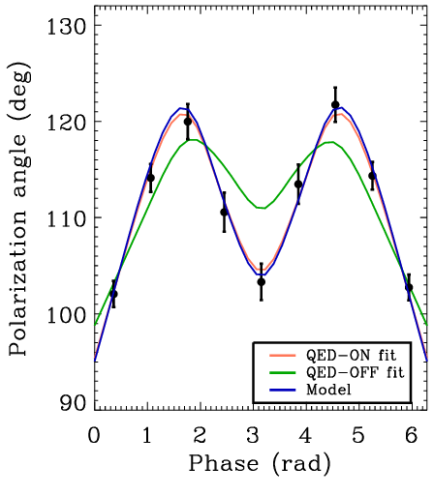
**Light curve**




**Polarisation degree**




**Polarisation angle**




Such an effect is **only** visible in the phase dependent polarization degree and angle.

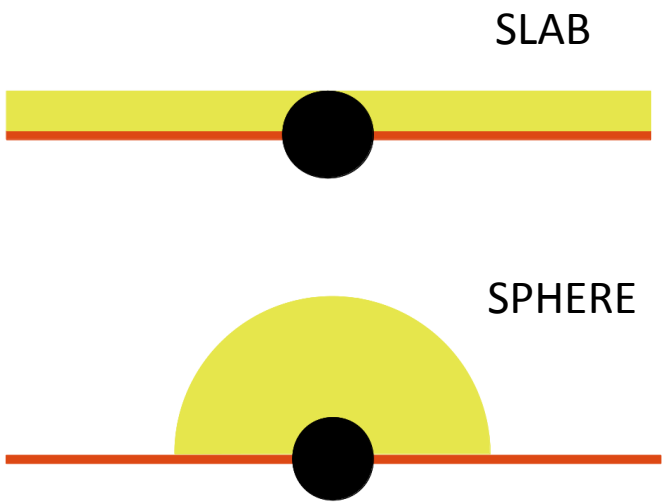
## Constraining components of X-ray emission from AGNs

The geometry of the hot corona of electrons, considered to be responsible for the (non-disc) X-ray emission in binaries and AGN, is largely unconstrained.

The geometry is related to the corona origin:

- Slab – high polarisation (up to more than 10%): disc instabilities?
- Sphere – very low polarisation: aborted jet?

The sensitivity of XIPE will allow to detect the polarisation of the corona in a large sample of binaries and AGN.




Marin & Tamborra 2014

Even larger (more than 20%) polarisation is expected if the X-ray emission of galactic black hole candidates in hard states is due to jet.

## An overdetermined problem: let us increase the confusion

So far, three methods have been used to measure the BH spin in XRBs:

1. Relativistic reflection (still debated, required accurate spectral decomposition);
2. Continuum fitting (required knowledge of the mass, distance and inclination);
3. QPOs (three QPOs needed for completely determining the parameters, so far applied only to two sources).

**Problem: for a number of XRBs, the methods do not agree!**

For J1655-40:

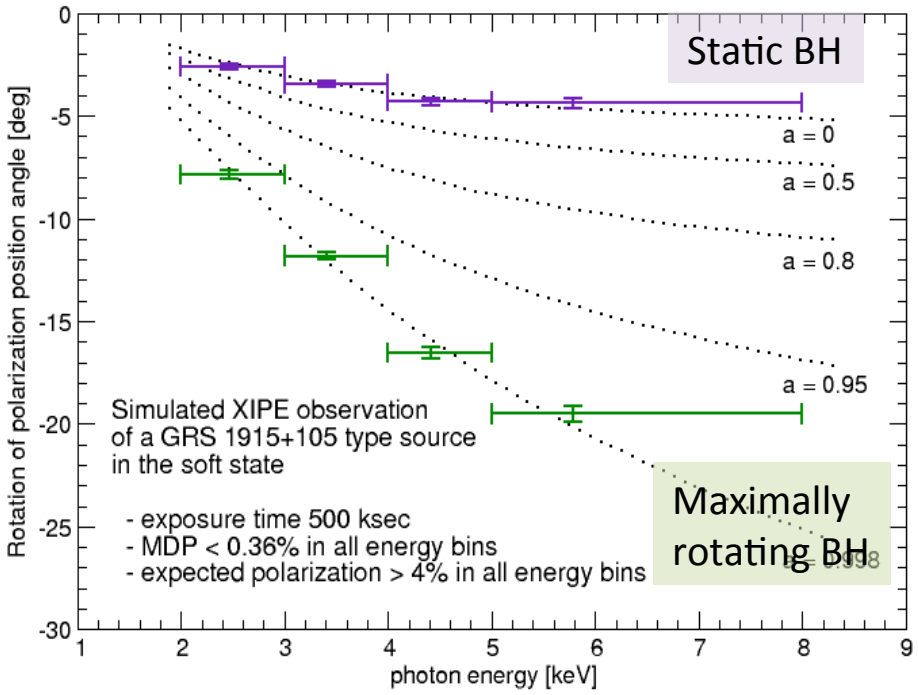
| | |
|---|---|
| QPO: | $a = J/J_{max} = 0.290 \pm 0.003$ |
| Continuum: | $a = J/J_{max} = 0.7 \pm 0.1$ |
| Iron line: | $a = J/J_{max} > 0.95$ |

A fourth method (to increase the mess...!?)

**Energy dependent rotation of the X-ray polarisation plane**

- Two observables: polarisation degree & angle
- Two parameters: disc inclination & black hole spin

*GRO J1655-40, GX 339-4, Cyg X-1, GRS 1915+105, XTE J1550-564, …*



# Many sources in each class available for XIPE

**100 – 150 quoted in the proposal:**

- 500 days of net exposure time in 3 years;
- average observing time of 3 days;
- re-visiting for some of those.

**What number for each class?**

| Target Class | $T_{tot}$ (days) | $T_{obs}$/source (Ms) | MDP (%) | Number in 3 years | Number available |
|---|---|---|---|---|---|
| AGN | 219 | 0.3 | < 5 | 73 | 127 |
| XRBs (low+high mass) | 91 | 0.1 | < 3 | 91 | 160 |
| SNRe | 80 | 1.0 | < 15 % (10 regions) | 8 | 8 |
| PWN | 30 | 0.5 | <10 % (more than 5 regions) | 6 | 6 |
| Magnetars | 50 | 0.5 | < 10 % (in more than 5 bins) | 10 | 10 |
| Molecular clouds | 30 | 1-2 | < 10 % | 2 complexes or 5 clouds | 2 complexes or 5 clouds |
| **Total** | **500** | | | **193** | **316** |

From catalogues: Liu et al. 2006, 2007 for X-ray binaries; and XMM slew survey 1.6 for AGNs.

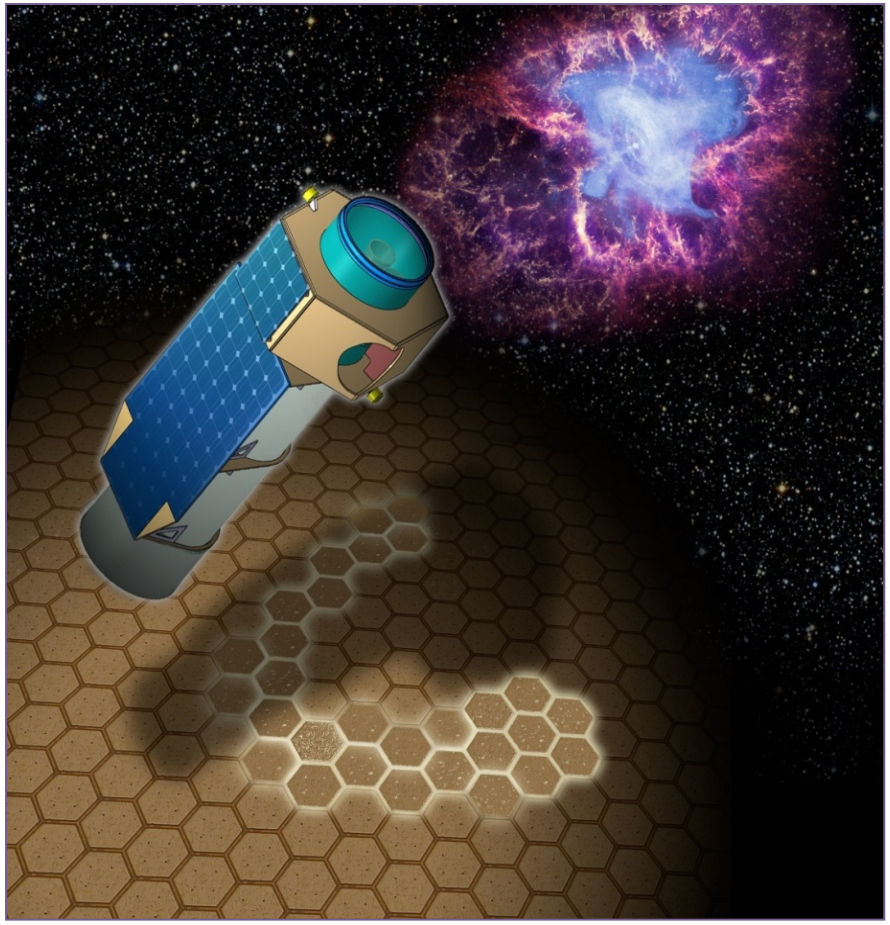
# Summary

**XIPE will open a new observational window, adding the two missing observables in X-rays.**

**Many X-ray sources are aspherical and/or non-thermal emitters, so radiation must be highly polarised.**

**XIPE is simple and ready, using pioneering, yet mature, technology.**

**Coverage of theoretical work on different topics is unevenly covered. This is natural, given the absence of data. But to plan the observations is not very good. Predictions on some of the most straightforward targets for XIPE, such as bright binares with NS are based on a few old papers.**



**Let us try to single out topics that we can figure could provide astrophysical evidences for ALPs.**

# What has X-Ray Polarimetry to do with ALPs?

γALP oscillation can only occurr in presence of an external Magnetic Field.
Only photons γ‖ with polarization parallel to the plane defined from the direction and B mix. If the magnetic field is oriented the oscllation changes the polarization properties of the beam.

The effect should be visible on long distance scale if we assume magnetic fields in intercluster space are ordered within domains of few Mpcs.

# Axions and ALP have two ways to show up through polarization

If the assumption is correct we should detect effects that increase with the distance of the source. .

1) **By introducing an unexpected polarization on sources that we have good reasons to assume to be unpolarized in thir frame**

2) **By decreasing polarization amount and changing polarization angle in the flux of sources for which we can make a reasonable assumption on whic was the polarization in their frame.**

Both cases have been discussed by Nicola Bassan, Alessandro Mirizzi and Marco Roncadelli, Journal of Cosmology and Astroparticle Physics, Volume 2010, May 2010and applied to GRBs.

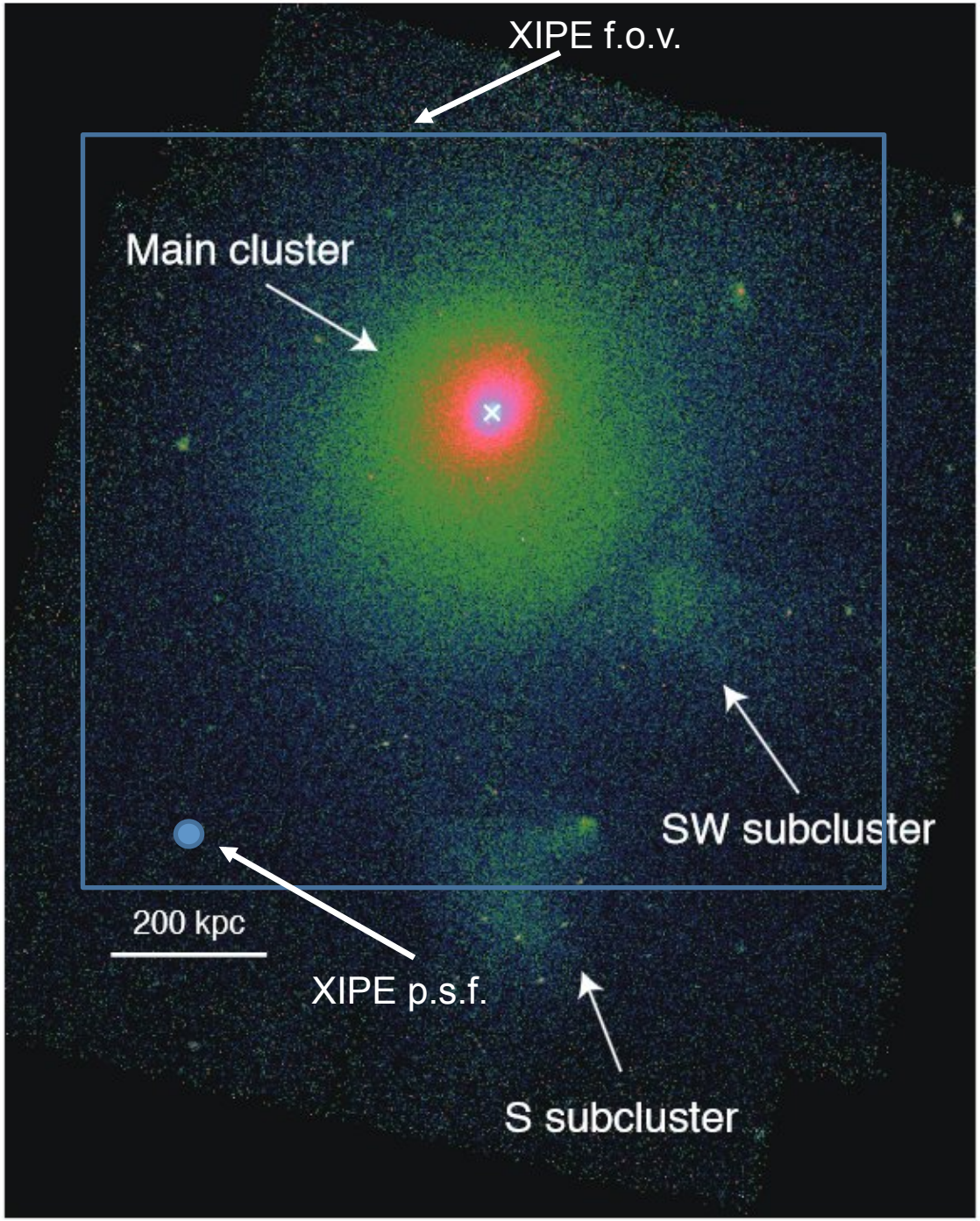
I try to extend the computations to steady sources.

# A totally umpolarized source: the cluster of galaxies

Galaxy clusters have a well studied thermal spectrum with a bremsstrahlung continuum and lines, possibly with different components (temperatures). NUSTAR observations do not confirm the presence of a non-thermal component of Inverse Compton, suggested in the past for a few objects. we can assume that a cluster should be polarized ~0% (≤ 0.2% Komarov et al. Submitted) . With XIPE we can detect possible polarization from a rich sample of clusters.

| HEAO1A2 (Piccinotti et al.1982) | Name | Flux (2-10eV) $10^{-11}$ erg cm$^{-2}$s$^{-1}$ | Z | D (Mpc) | MDP For $10^5$ s |
|---|---|---|---|---|---|
| H0039-0396 | Abell 85 | 6.6 | 0.0499 | 212.6 | 3.9 |
| H0054-015 | Abell 119 | 4.4 | 0.0446 | 190.3 | 4.8 |
| H0256+134 | Abell 401 | 7.3 | 0.0748 | 316.9 | 3.7 |
| H0335+096 | 0335+096 | 3.2 | 0.04 | 170.8 | 5.6 |
| H0411+104 | Abell 478 | 6.5 | 0.09 | 382.2 | 3.9 |
| H0431-134 | Abell 496 | 5.4 | 0.036 | 154.2 | 4.3 |
| H1347+268 | Abell 1795 | 5.9 | 0.0621 | 263.9 | 4.1 |
| H1556+274 | Abell 2142 | 7.6 | 0.0903 | 381.3 | 3.6 |
| H1600+171 | Abell 2147 | 5.0 | 0.0377 | 161.1 | 4.5 |
| H1627+396 | Abell 2199 | 7.5 | 0.0312 | 133.5 | 3.7 |

If we detect a polarization and if it increases in average with the distance we can work on the hypothesis that ALP photon coupling is producinging it. Of course we should disentingle the effects of the same process in our galaxy and within the cluster itself but this is not impossible because the magnetic fields are known.




# Abell 85

Abell85 is a cluster with a hard component. It has been demonstrated that this can be totally explained with thermal components of higher temperature.
Moreover, thanks to the imaging properties of XIPE  B removing possible AGNs and excluding «suspicious» regions such as the two merging subclusters (although they are spectrally yhermal as well).

For a few clusters we can foresee a deep pointing of the order of $1 \times 10^6$ s. With a bright cluster as Abell 85 XIPE can achieve an MDP of 1.2%.

Even a polarization ≥ 2% would be hard to explain in terms of physics of the cluster.

# Sources Unpolarized in their frame will look polarized on hundreds Mpc distances

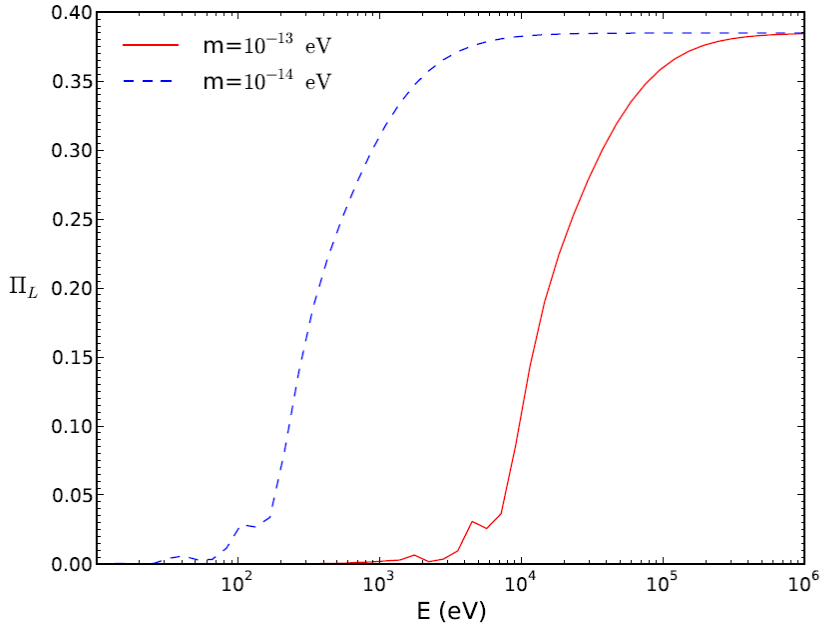



**Figure 1.** Average final linear polarization $\Pi_L$ as a function of the photon energy $E$ after propagation in the extragalactic magnetic field for ALP masses $m = 10^{-13}$ eV (solid line) and $m = 10^{-14}$ eV (dashed line), respectively. The emitting GRB is assumed to be completely unpolarized and at distance $d = 100$ Mpc.

Bassan et al. 2010 computed the linear polarization due to ALP-photon mixing for a set of reasonable parameters: $g_{a\gamma} \leq 8.8 \times 10^{-11}$ GeV$^{-1}$ for m ≤0.02 eV.2 different masses, coherence length for intergalactic B of $10^{-9}$ Gauss ranging from 1 to 10 Mpc. The fig. shows the result of computation for two values of ALP mass for a totally unpolarized source at 100 Mpc distance. If the range of parameters is such that the range of XIPE falls within the strong mixing regime a high and well detectable polarization should be there.

For a correct interpretation the effects of intra-cluster fields and of fieleds in our Galaxy should be disentingled, but for sure a polarization of a few% could not be explained in terms of ordinary plasma physics.

# The other case: sources where polarization is expected

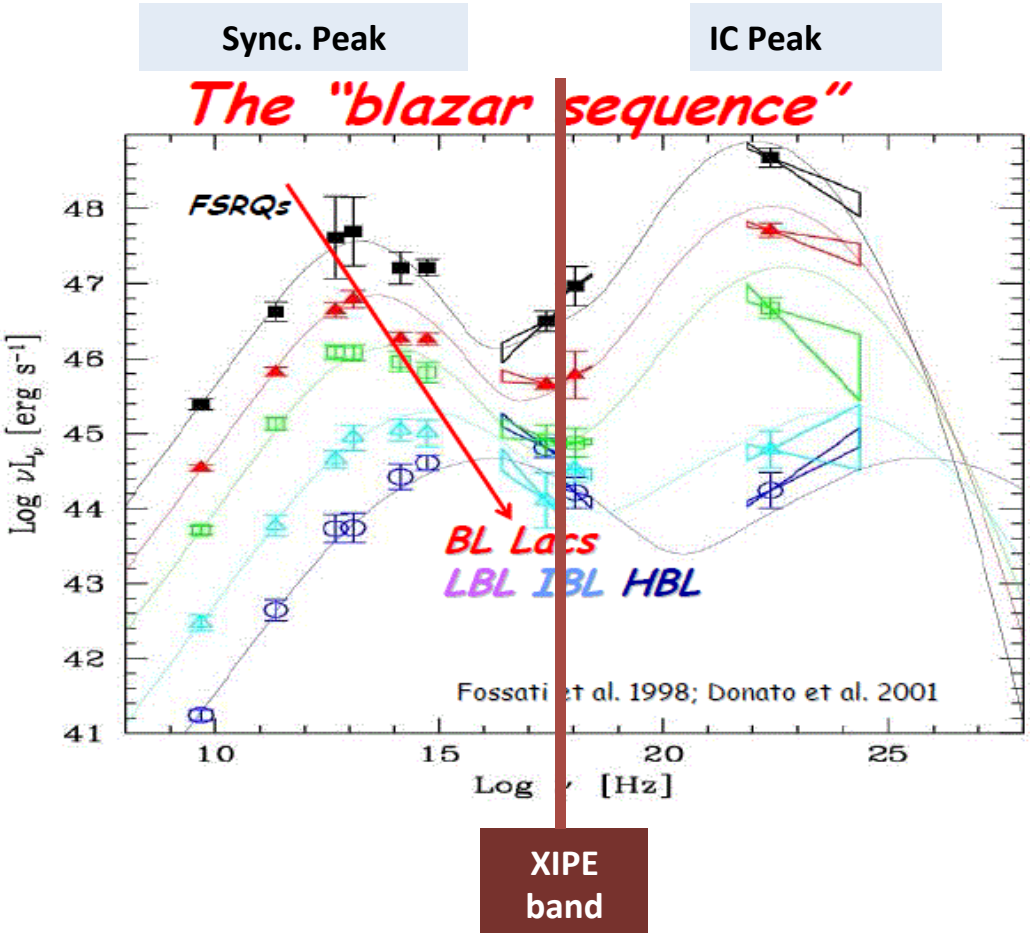
Blazars are extreme accelerators in the Universe, but the emission mechanism is far from being understood.

In inverse Compton dominated Blazars, a XIPE observation can determine the origin of the seed photons:

• Synchrotron-Self Compton (**SSC**) ?
The polarization angle is the same as for th synchrotron peak.

• External Compton (**EC**) ?
The polarization angle may be different.

The polarization degree determines th electron temperature in the jet.



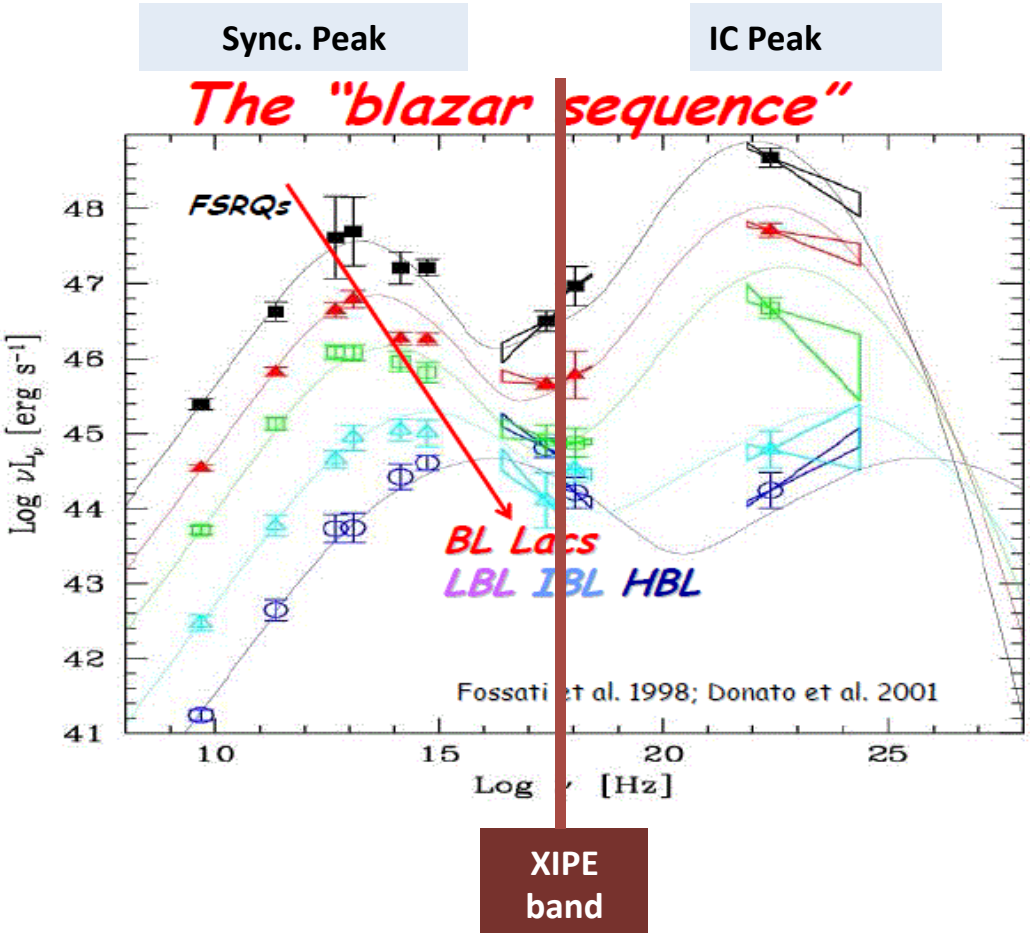
# More on blazars

Blazars are extreme accelerators in the Universe, but the emission mechanism is far from being understood.

In synchrotron-dominated X-ray Blazars, multi-λ polarimetry probes the structure of the magnetic field along the jet.

When XIPE starts operations neraby blazars will be one of the first targets. We can expect on blazars in synchrotron regime a relatively high polarization and a certain correlation (at least during flares) of polarization amount and angle in the optical and X-rray range.

The axion-photon mixing in intergalactic magnetic fields could produce the reverse effect, with respect to clusters. The degree of polarization and the correlation between the angles of optical and x-ray polarization could decrease with increasing distance of the blazars.



# Depolarizatin with distance

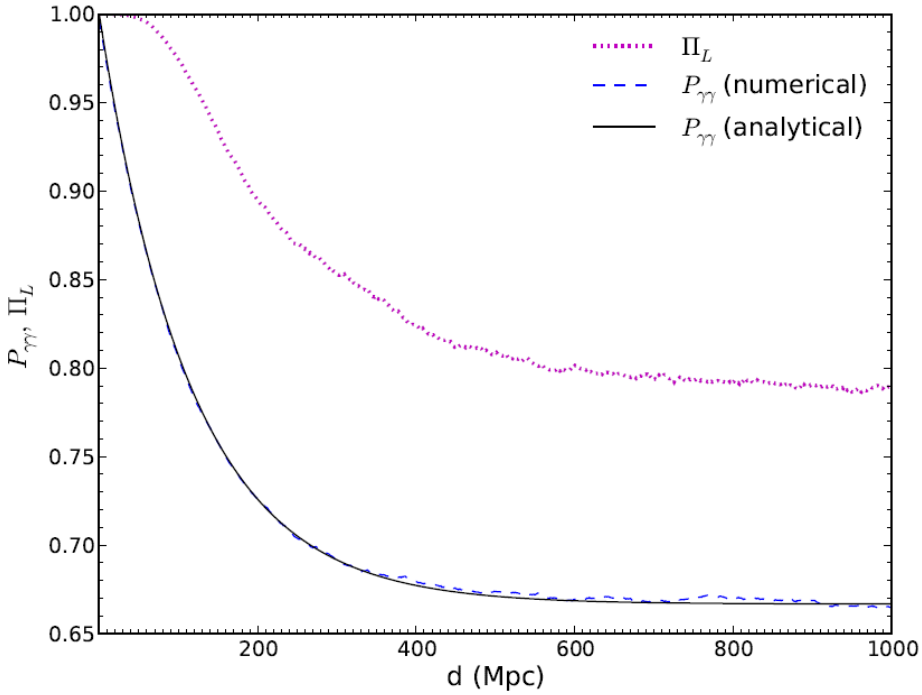



**Figure 2.** Average linear polarization $\Pi_L$ (dotted line) and photon survival probability $P_{\gamma\gamma}$ evaluated numerically (dashed line) and analytically (solid line), as a function of the source distance $d$ for photon-ALP mixing in the extragalactic magnetic field. The source is assumed to be fully polarized along the $x$ direction.

# Less Straightforward Observation

We know almost nothing on X-ay polarization. X-ray polarimetry is an almost totally new topics.
From the first study of Blazars we should verify which is the polarimetric behavior of these objects. E.g. in flares when Optical/IR/and X radiation vary together we could expect a high polarization degree in the different bands. The effect of the ALP – axion coupling should be apparent in X-rays only. Therefore we could expect that the polarization degree in X-rays decreases with the distance in X-rays, while we already know that it does not in IR/O. Also the difference between the polarization angle in X-ray and in IR/O should increase with the distance. Likely the measurement on the angle would be more robust.
With the known Blazar 1ES1101+232, at z=0.186 we can detect variations of the angle don to 2°.

http://www.isdc.unige.ch/xipe/

The site also  includes sciece working groups just set up

The site includes a (very preliminary) calculater of sensitivity of XIPE for a given source and for a given observing time

# Any contribution for IAXO?

Beside the scientific complementarity, the experience on the detector (performance, stability and background reduction) could contribute to IAXO design.