# Nuove missioni di polarimetria - la scienza con XIPE e IXPE

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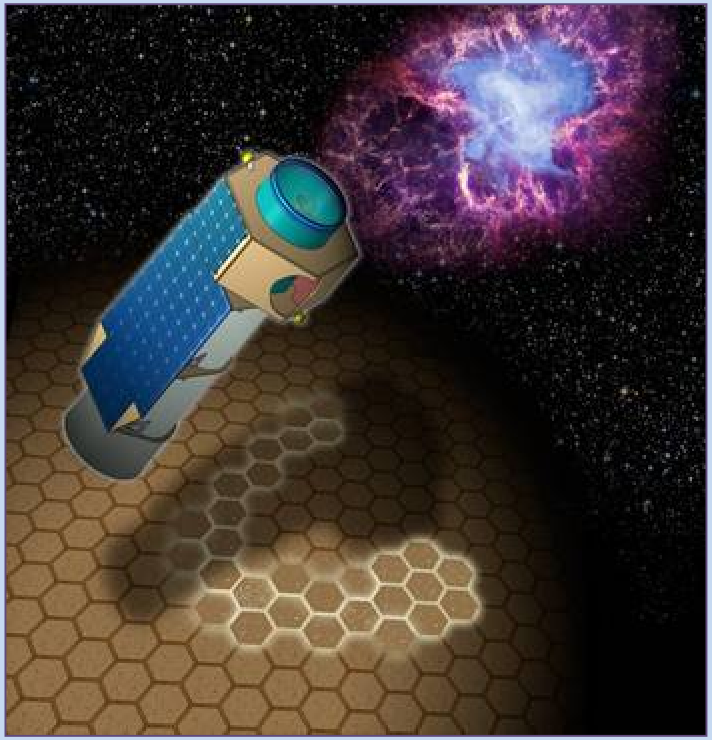
IAPS/INAF, Italy

Torino 4 Maggio 2016

Picking the right direction



www.isdc.unige.ch/xipe

Polarization from celestial sources may derive from:

- **Emission processes themselves: cyclotron, synchrotron, non-thermal bremsstrahlung**

(Westfold, 1959; Gnedin & Sunyaev, 1974; Rees, 1975)

- **Scattering on aspherical accreting plasmas: disks, blobs, columns.**

(1975; Sunyaev & Titarchuk, 1985; Mészáros, P. et al. 1988)

- **Vacuum polarization and birefringence through extreme magnetic fields**

(Gnedin et al., 1978; Ventura, 1979; Mészáros & Ventura, 1979) usual techniques in X-ray astronomy are: imaging, spectroscopy and timing

**Opening an 'almost' new window in the X-ray sky**

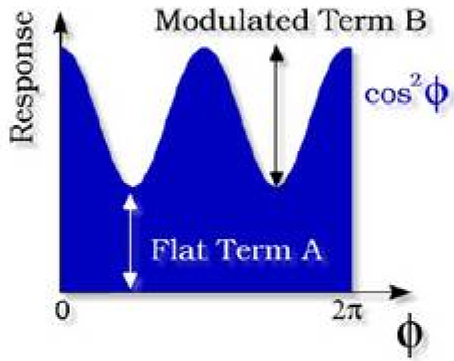
# Two new observables

- Polarization degree.
- Polarization angle.

# The conventional formalism

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

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




Modulation curve

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**

$$S(\phi) = I + Q\sin(2\phi) + U\cos(2\phi)\,,$$

$$I = (A + B/2),\ Q = (B/2)\sin(2\phi_0),\ \text{and}\ U = (B/2)\cos(2\phi_0),$$

P= $\dfrac{\sqrt{QQQQQ}}{Q}$ Φ = $\dfrac{1}{2} QQQQ \dfrac{Q}{Q}$

No V → no circular polarization with present techniques

# Minimum Detectable Polarization (MDP)

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

$R_S$ is the Source rate, $R_B$ is the Background rate, T is the observing time
μ is the modulation factor: the response of the polarimeter to a 100% polarized beam (spanning from 0 or no sensitivity, to 1 or maximum sensitivity)

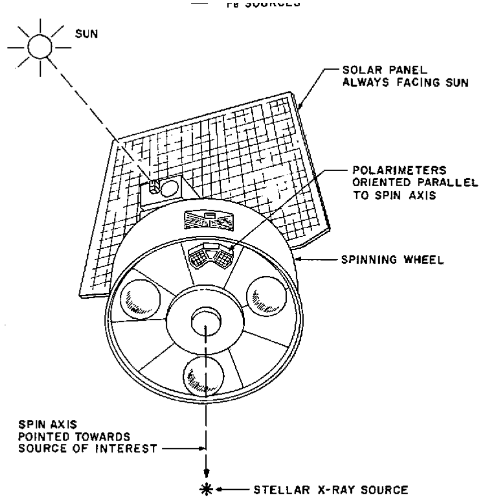
If background is negligible: $$\mathrm{MDP} = \frac{4.29}{\mu\sqrt{N_{ph}}}$$

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

Source detection > 10 counts
Source spectral slope > 100 counts
Source polarization > 100.000 counts

Caution: the MDP describes the capability of rejecting the null hypothesis (no polarization) at 99% confidence. For a 3-sigma meaurement an observing time 2.2 times longer is needed while the 1-sigma error scales like : $28^o.5$/S/N

# OSO-8

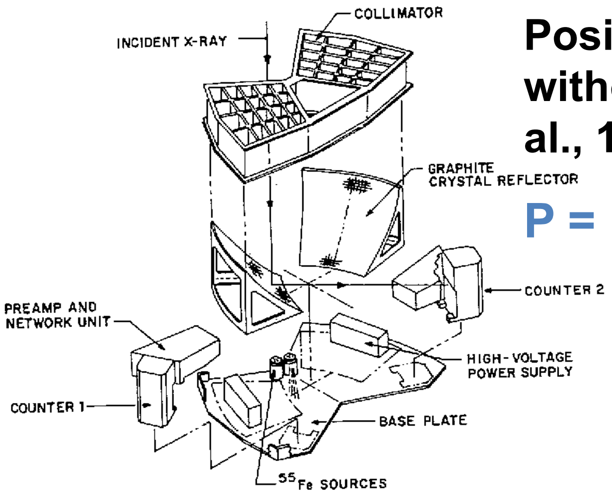



468 mosaic graphite mosaic crystals mounted to a sector of parabolic surface of revolution.

Mosaic spread of 0.8° Bandpass = 40 eV (2.62 keV)

Bragg angles allowed between 40° and 50°
Overall band-pass 400 eV (2.62 keV)
$\mu$ = 0.94

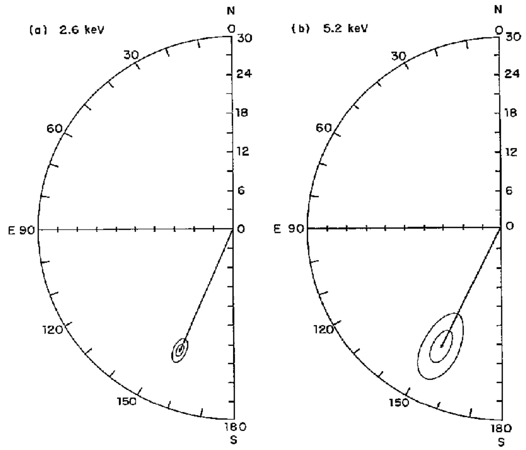
Projected crystal Area = 2 x 140 cm$^2$ ; Detector area = 2 x 5 cm$^2$; FOV = 2°
B = 2 x 3 10$^{-2}$ counts/s in each order (pulse shape analysis + antincoincidence)




**Positive measurement: of X-ray polarization of the Crab Nebula without pulsar contamination (by lunar occultation, Weisskopf et al., 1978).**

**P = 19.2 ± 1.0 %; $\theta$ = 156.4° ± 1.4° (2.6 keV)**

**Polarization vector for the Crab Nebula. Surrounding the vectors in order of increasing size are 67 % and 99 % confidence contour. The radial scale is the polarization in percent**




OSO-8 satellite (top) and polarimeter (bottom)

# Other OSO-8 results.

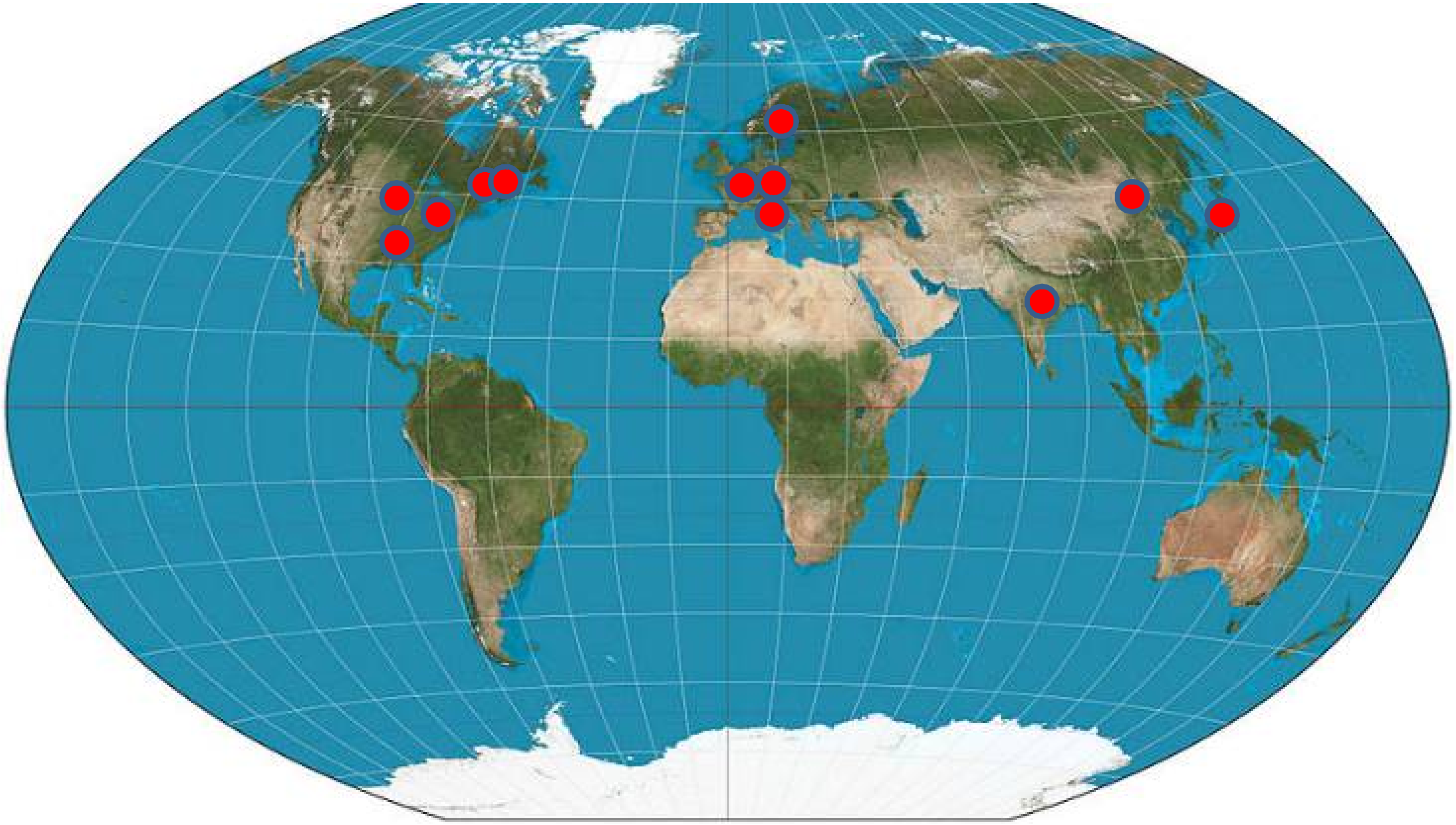
- Upper Limit (20% 99 % confidence level) on Crab Pulsar X-ray emission (Silver et al., 1978).
- Precision 'zero' X-ray polarization determination from Sco X-1 (0.39 % ±0.20% at 2.6 keV and 1.31 % ±0.40% at 5.2 keV, Long et al. 1979).
- Low significance polarization measurement on Cyg X-1 2.4 % ± 1.1 % at 2.6 keV and 5.3 % ± 2.5 % at 5.2 keV.
- Other upper limits (99% level) on a number of sources (Hughes et al., 1984) :

Polarization Upper Limits

| | | Energy: 2.6 keV | | | Energy: 5.2 keV | | |
|---|---|---|---|---|---|---|---|
| Source (1) | Year (2) | I (cts per 1000 s) (3) | π (4) | Upper Limit (5) | I (cts per 1000 s) (6) | π (7) | Upper Limit (8) |
| 4U 0316+41 | 1976 | 24.62 ± 5.13 | 0.58 | 25.4% | Not detected | ... | ... |
| | 1977 | 21.34 ± 0.63 | 0.62 | 15.9% | 7.14 ± 0.50 | 0.40 | 34.5% |
| | Comb | 21.39 ± 0.63 | 0.88 | 12.6% | ... | ... | ... |
| 4U 1118−60[a] | 1975 | 44.69 ± 0.93 | 0.55 | 14.1% | 21.25 ± 0.74 | 0.87 | 19.8% |
| | 1978 | 11.75 ± 1.06 | 0.16 | 71.6% | 3.85 ± 0.89 | 0.43 | 100.0% |
| | Comb | 30.36 ± 0.70 | 0.18 | 18.2% | 14.14 ± 0.57 | 0.49 | 27.0% |
| 4U 1636−53 | 1976 | 36.25 ± 1.00 | 0.83 | 15.3% | 7.82 ± 0.72 | 0.33 | 60.1% |
| 4U 1656+35[a] | 1975 | 10.76 ± 1.26 | 0.96 | 62.1% | 3.27 ± 1.13 | 0.20 | 100.0% |
| 4U 1658−48 | 1978 | 48.19 ± 1.09 | 0.95 | 10.4% | 2.17 ± 0.70 | 0.17 | 100.0% |
| 4U 1702−36 | 1975 | 194.25 ± 3.45 | 0.92 | 9.2% | 58.67 ± 2.17 | 0.55 | 22.0% |
| 4U 1758−25[b] | 1975 | 254.97 ± 2.96 | ... | ... | 80.99 ± 1.92 | ... | ... |
| 4U 1820−30 | 1976 | 66.87 ± 0.96 | 0.64 | 6.0% | 18.11 ± 0.77 | 0.48 | 14.4% |
| | 1978 | 85.18 ± 1.15 | 0.40 | 8.0% | 23.05 ± 0.76 | 0.72 | 15.7% |
| | Comb | 74.39 ± 0.74 | 0.50 | 4.7% | 20.61 ± 0.54 | 0.42 | 10.8% |
| 4U 1837+04 | 1975 | 73.35 ± 2.19 | 0.62 | 17.9% | 17.21 ± 1.44 | 0.04 | 64.8% |
| 4U 2321+58 | 1976 | 30.88 ± 3.24 | 0.66 | 26.4% | 2.40 ± 2.42 | 0.26 | 100.0% |

[a] Binary eclipse background data subtracted from $I$, $Q$, and $U$.
[b] Contaminated by off-axis source 4U 1744−26.

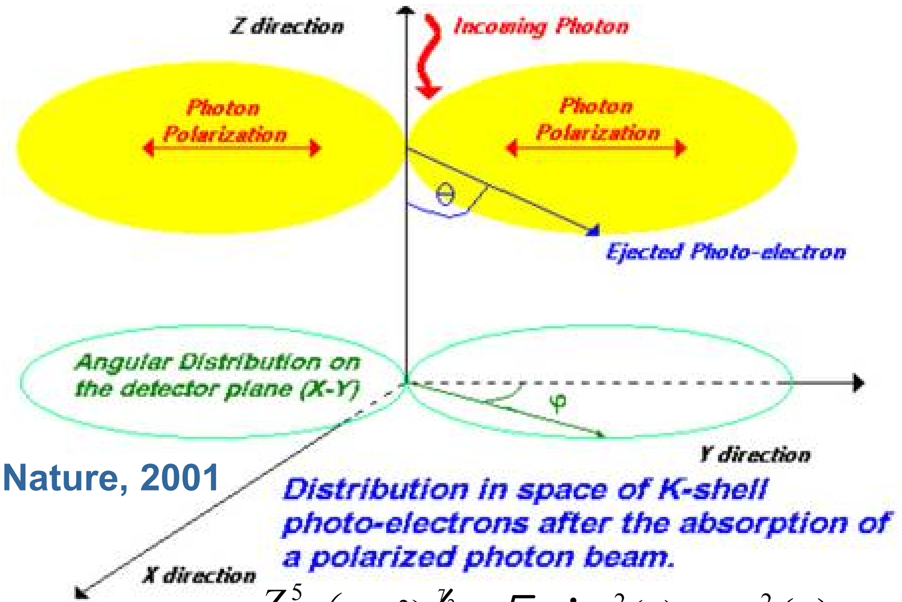
# Today’s X-ray polarimetry in the world.



**Photoelectric** : GPD (Italy, China) ; TPC (USA, China).
**Scattering** : (France, Italy, Germany, Sweden, Switzerland, India, USA, Japan)
**Bragg diffraction** : (China, USA)

Polarimetry based on photoelectric effect was tempted very long ago but it is now a mature technology.

Heitler W.,The Quantum Theory of Radiation




Costa, Nature, 2001

$\beta = v/c$

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

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

**An X-ray photon directed along the Z axis with the electric vector along the Y axis, is absorbed by an atom.**

**The photoelectron is ejected at an angle θ (the polar angle) with respect the incident photon direction and at an azimuthal angle φ with respect to the electric vector.**

**If the ejected electron is in 's' state (as for the K–shell) the differential cross section depends on $\cos^2(\varphi)$, therefore it is preferentially emitted in the direction of the electric field.**

**Being the cross section always null for φ = 90° the modulation factor μ equals 1 for any polar angle.**

# Many proposed X-ray polarimetry missions

## From 2002 to 2008 missions proposed to NASA, ESA, ASI, JAXA and CNSA

A polarimeter was supposed to fly on XEUS/IXO. -> Athena without a polarimeter was selected for L2

**POLARIX** was one of the two missions selected as italian small mission, but the whole program was later dropped.

**GEMS was selected by NASA on May 2008** to fly on 2014 but stopped in 2012 for *programmatic* reasons.

# What's next ?

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 May/June 2017 one of these 3 missions will be selected for flight

Launch in 2026

NASA

In 2014 **NASA** issued an AOO for a Small Explorer Mission (budget of ~ 175 M$)

On july 30 2015 **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 January 2017 NASA will select one of the 3 missions to flight

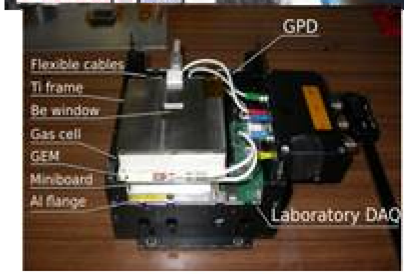
Launch in 2020

**Three out of 6 missions under study are of X-ray Polarimetry**

XIPE is the most sensitive of the 3 missions under study.

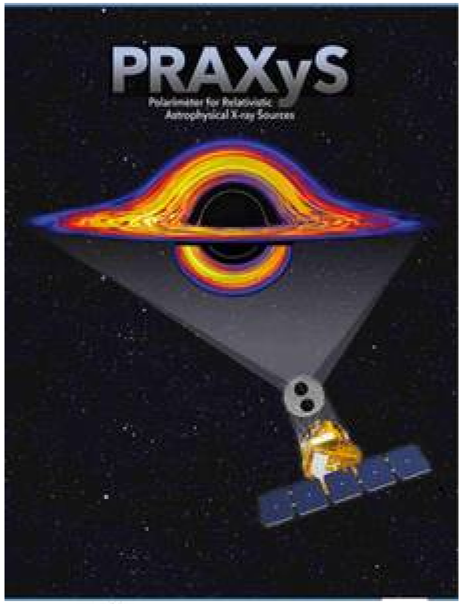
# IXPE e PRAXyS

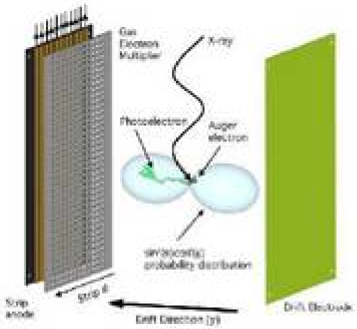
**Two X-ray polarimeters in competition**


Gas Pixel Detector
Costa et al. 2001
Bellazzini et al. 2006, 2007

- **3 GPDs**
- **3 X-ray optics MSFC**
- **About 350 kg limit (Pegasus)**




**GSFC/NASA**

Time Projection Chamber
Black et al. 2007

**2 TPCs, 2 Optics**
**About 350 kg limit (Pegasus)**

# IXPE SMEX Timeline

| Activity | Date |
|---|---|
| PHASE A REPORT DUE | 19/07/2016 |
| Site-visit NASA | 21 Nov. 2016 |
| NASA DOWN SELECTION | Jan 2017 |
| Bridge Phase | Feb-Jun 2017 |
| Phase B | July 2017-Feb 2018 |
| Delivery Italian Payload | Dec 2018 |
| Phase C/D | Feb 2018-Dec 2020 |
| Launch | End 2020 |

# Italian Contribution to IXPE:

| What | | Quantities |
|---|---|---|
| Detector Unit | Gas Pixel Detectors | 3 Proto-flight, 1 Spare |
| | Back end electronics | 1 EM, 3 Proto-flight, 1 Spare |
| | Filter Wheels | 1 EM, 3 Proto-flight, 1 Spare |
| | Housing & Straylight collimator | 1STM, 3 Proto-flight, 1 Spare |
| Computer | P/L Computer | 1EM, 1 Protoflight |
| Test equipments | | One TE |

# X-ray Imaging Polarimetry Explorer

## Proposed by

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### XIPE Instrument Team

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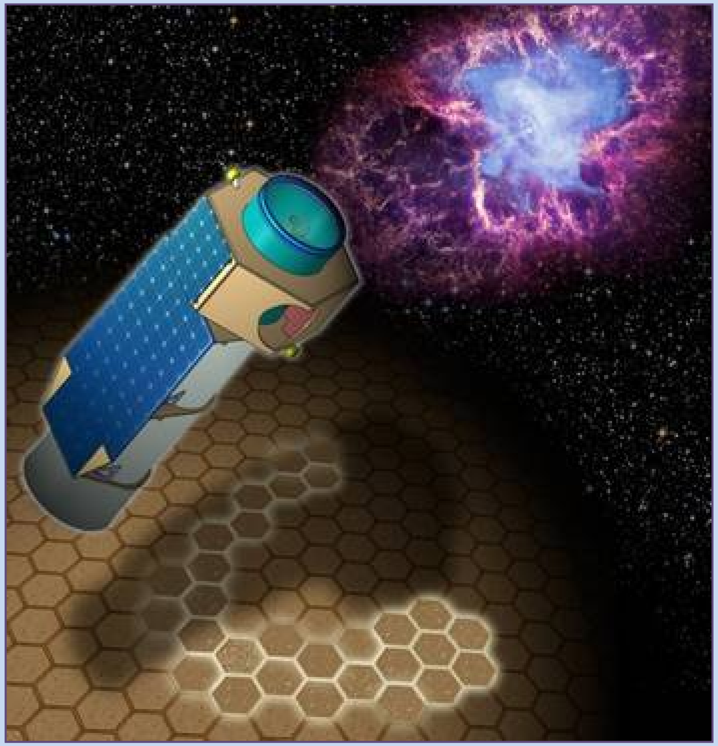


### XIPE participating Institutions

**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.

<u>XIPE uniqueness</u>: Time-, spectrally-, spatially-resolved **X-ray polarimetry** as a breakthrough in high energy astrophysics and fundamental physics

# The X-ray Imaging Polarimetry Explorer

A **large** number of scientific topics and observable sources:

**Astrophysics**

**Acceleration phenomena**

Pulsar wind nebulae

SNRs

Jets Blazars

**Emission in strong magnetic fields**

Magnetic cataclysmic variables

Accreting millisecond pulsars

Accreting X-ray pulsars

Magnetar

**Scattering in aspherical situations**

X-ray binaries

Radio-quiet AGN

X-ray reflection nebulae

**Fundamental Physics**

**Matter in Extreme Magnetic Fields: QED effects**

Magnetars

**Matter in Extreme Gravitational Fields: GR effects**

Galactic black hole system & AGNs

**Quantum Gravity**

**Search for axion-like particles**

Basically, XIPE will observe **almost all classes of X-ray sources**.

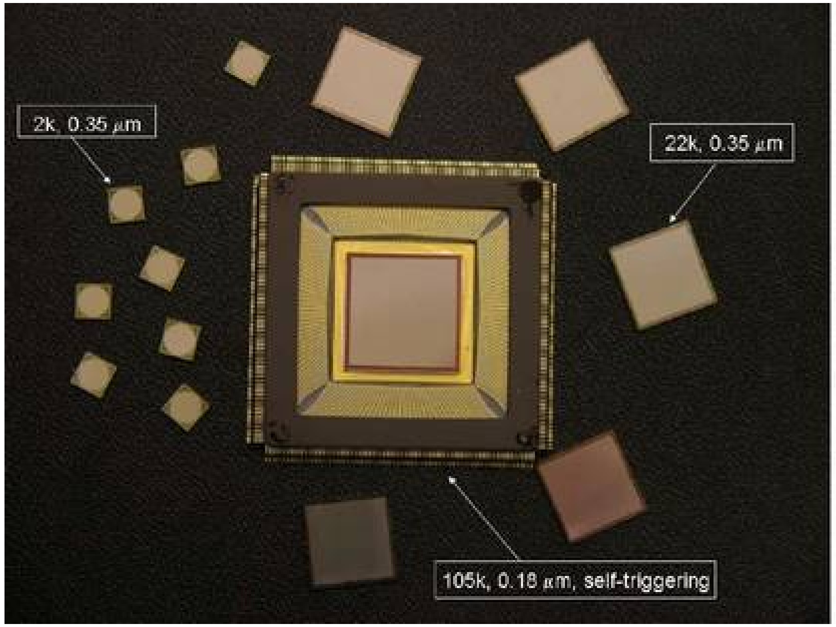
A **large** community involved:

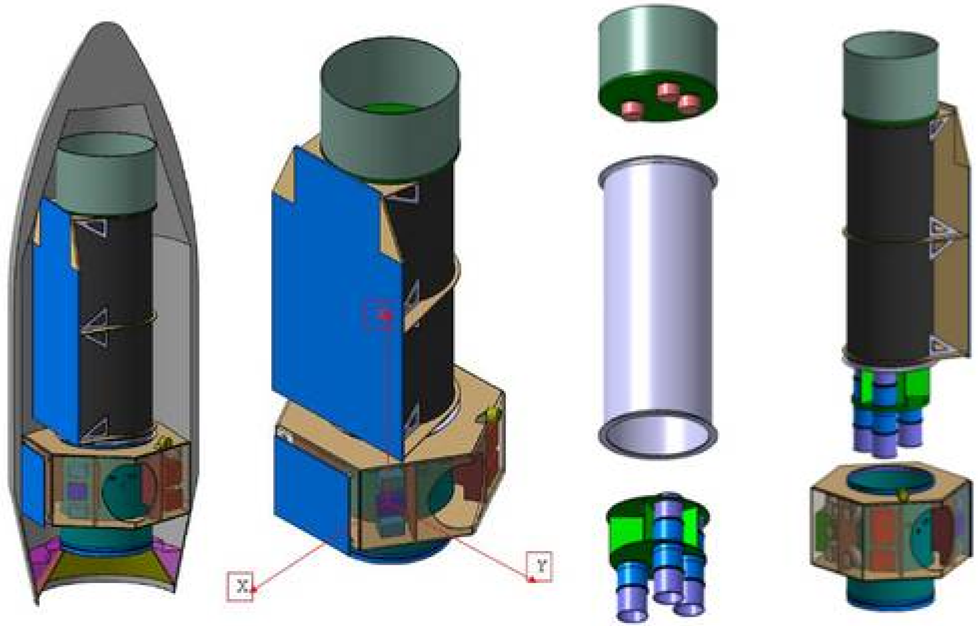
- **17 countries**
- **146 scientists**
- **68 institutes around the world**

# XIPE design guidelines

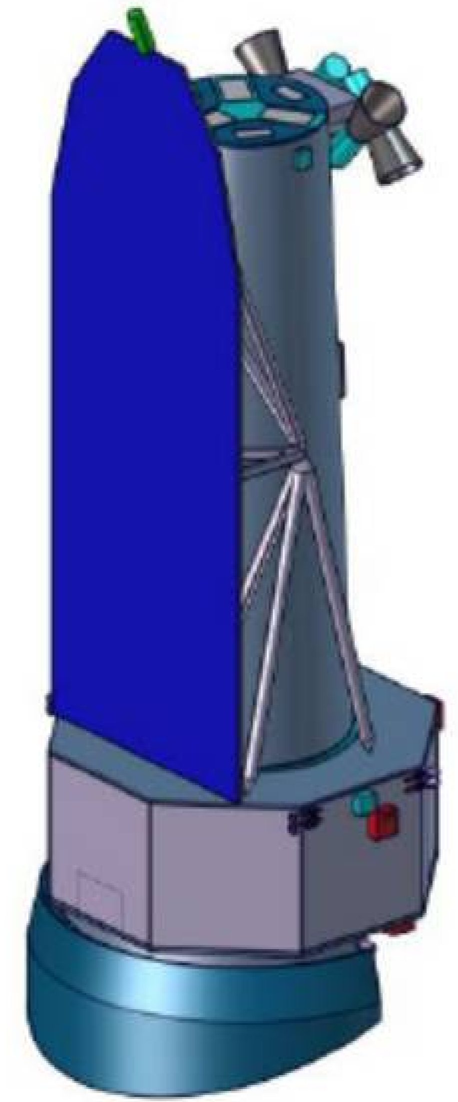
## A light and simple mission

- 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.

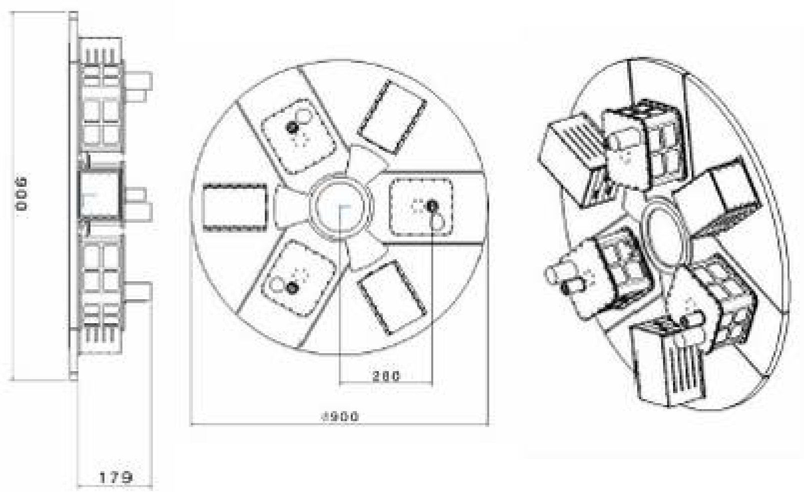


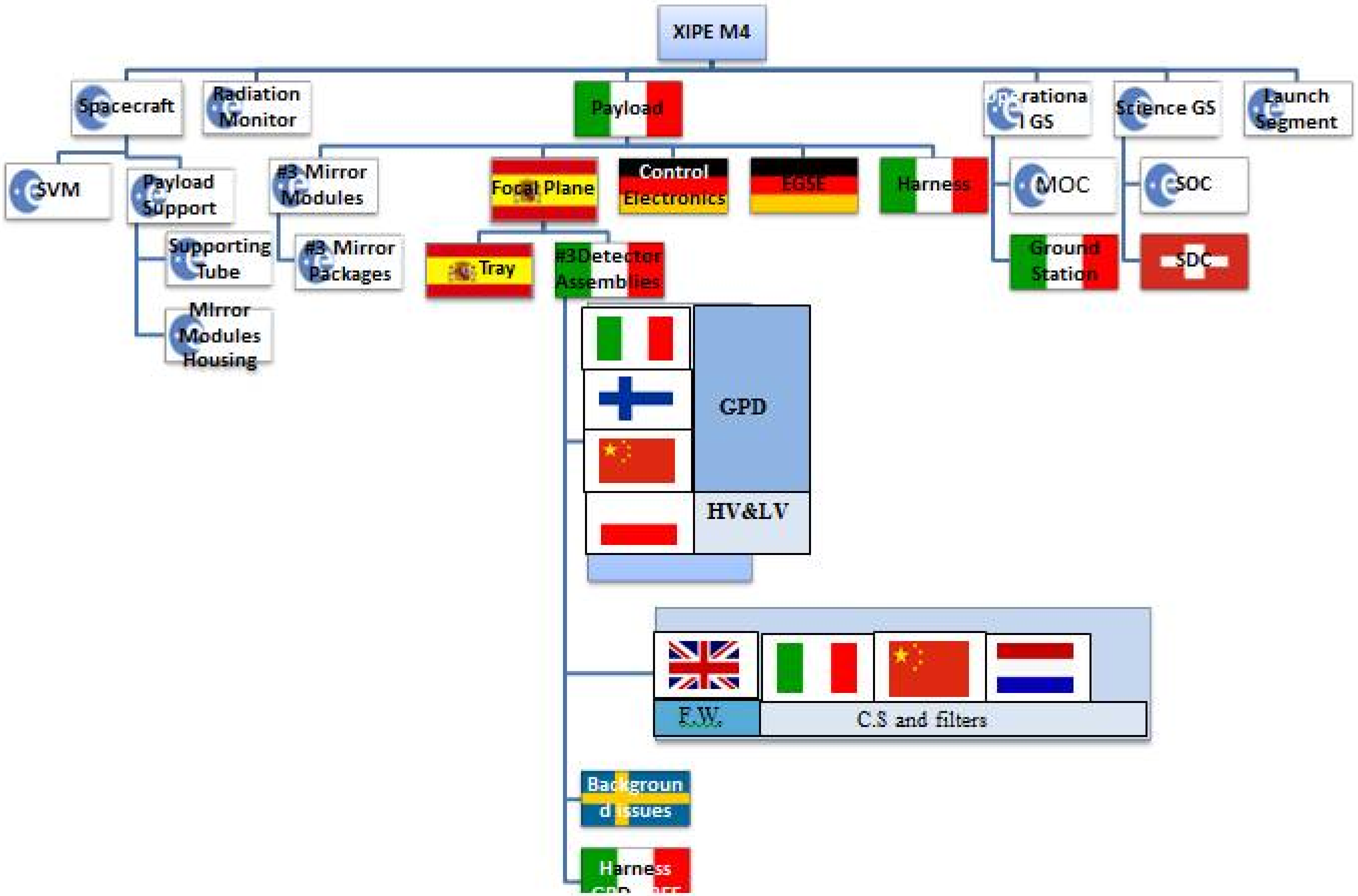
Bellazzini et al. 2006, 2007



- Configuration of the proposal basically confirmed
- Vega Launcher confirmed for 3.5 m focal length. A possible longer focal length will be studied (Goal 4 m)
- Orbit confirmed.
- Efficiency requirement met.
- Power and mass confirmed.
- Estimated cost well within the cap.
- Low risk mission.
- Flight ready f



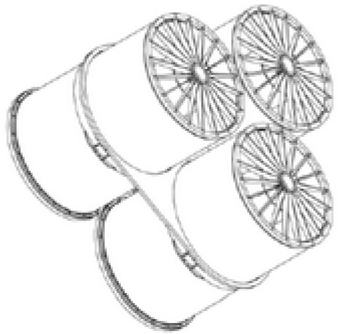
# All Europe and more



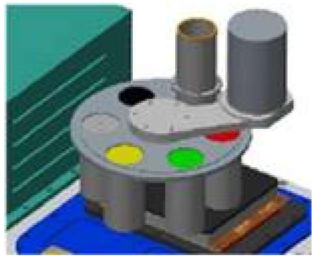

**The distribution of activities**

# The XIPE ingredients

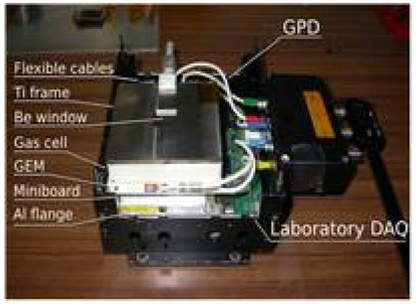
X-RAY OPTICS



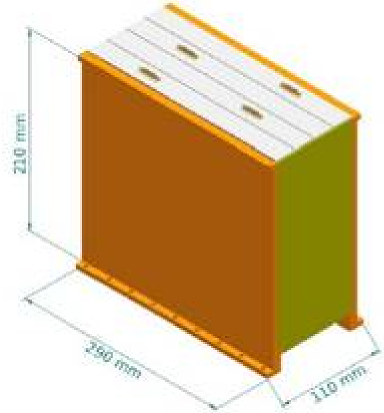
FW



GPD

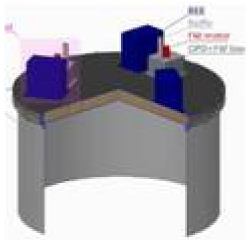



CE

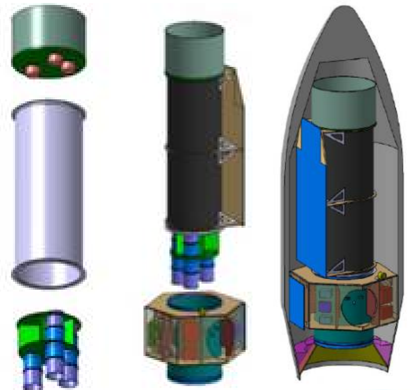




End to End Calibration



FPA

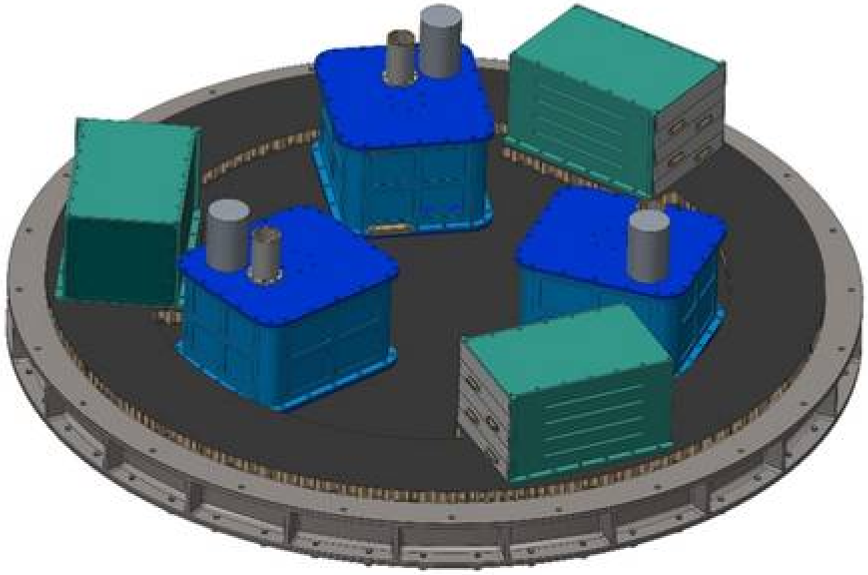


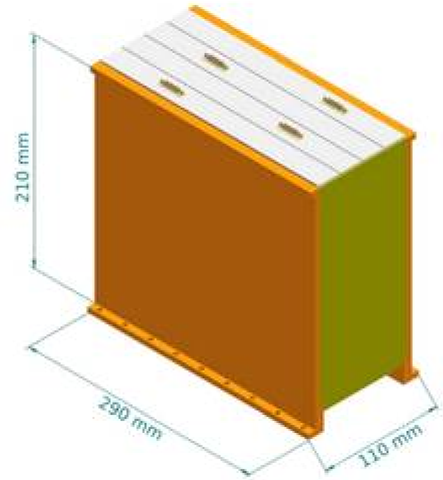
AIV & Launc.


SDC

## Overview

The instrument is the Payload Module part under the XIPE consortium responsibility.






Conceptual design; under revision for alignment, accessibility and AIV/T aspects

**Focal Plane** (FP):

- 3 Detector Units (3x DUs, blue boxes)
- 3 Back End Electronic Units (3x BEEUs, green boxes)
- 1 Focal Plane Structure (FPS, gray)
- Harness connecting each DU and the corresponding BEEUs (not shown)

Located at the external end of the Structural Tube

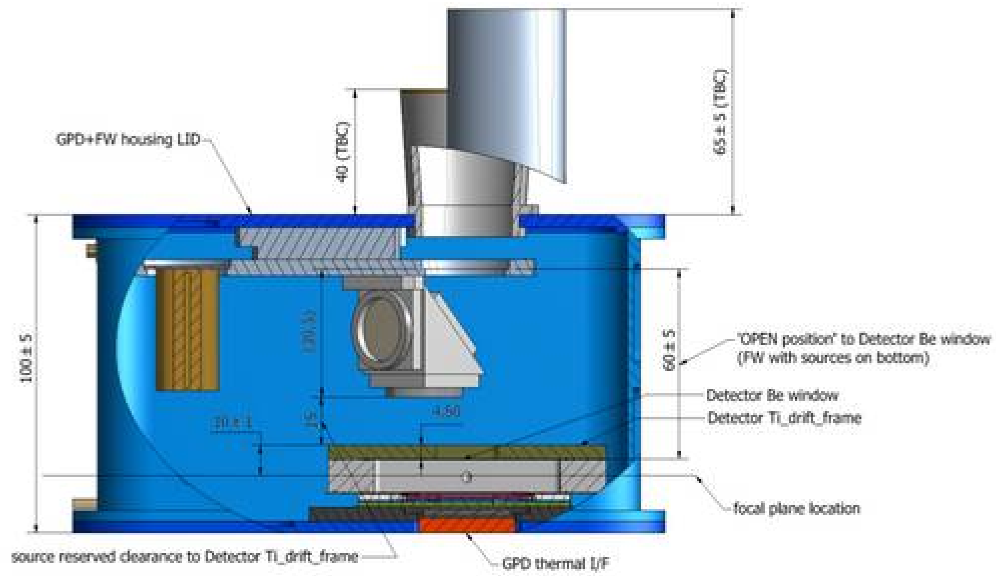
**Instrument Control Unit** (ICU):

- 1 unit interfacing the Service Module (SM) with the 3 BEEUs
- Harness connecting the ICU and the 3 BEEUs

Can be located everywhere on the SM.

## Mass and Power budget

Detector Unit
- 1 Gas Pixel Detector (GPD)
  - ASIC
  - Gas cell
  - Peltier
- 1 Filter Wheel (FW) with 8 positions
  - 4 calibration sources, 3 filters, 1 open position
- 1 Stray-Light Collimator (SLC)
- 1 Housing




FW: MSSL/UCL

| Item | Mass (with margins) | Power (maximum) |
|---|---|---|
| GPD | 0.7 kg | 3.0 W |
| FW | 1.9 kg | 6.0 W occasionally |
| SLC | | --- |
| Housing | 2.2 kg | --- |
| **Total** | **4.8 kg** | **(3.0 + 6.0) W** |

# Instrument mass and power budget

## Summary

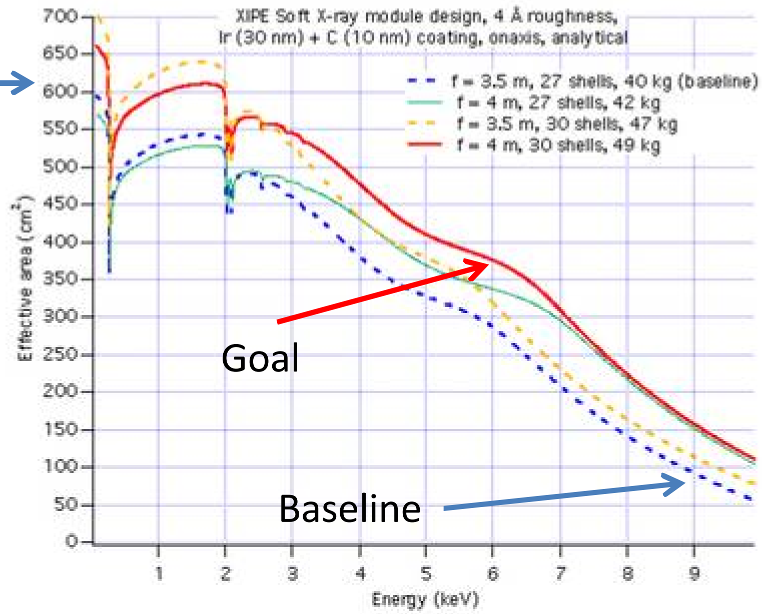
| Item | | Mass (kg) | Total mass of the FP (kg) | Total mass (kg) |
|---|---|---|---|---|
| FP | | | | |
| | DU | 4.8 | 14.4 | |
| | BEEU | 1.9 | 5.7 | |
| | FPS | 25.2 | 25.2 | |
| | | Total | 45.3 | 45.3 |
| ICU | | | | 7.8 |
| **Total** | | | | **53.1 kg** |

| Item | | Power (W) | Total power of the FP (W) | Total power (W) |
|---|---|---|---|---|
| FP | | | | |
| | DU | 9.0 | 27.0 | |
| | BEEU | 6.8 | 20.4 | |
| | | Total | 47.4 | 47.4 |
| ICU | | | | 31.2 |
| **Total** | | | | **78.6 W** |

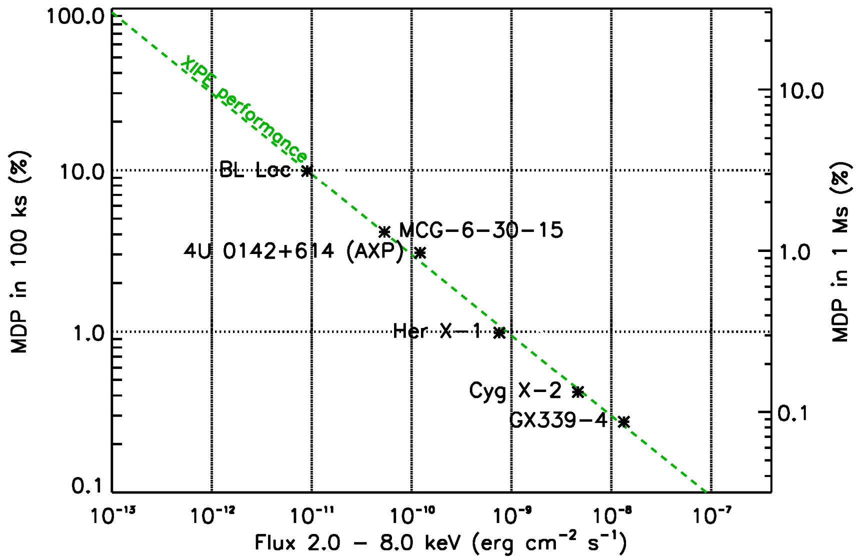
Budget substantially confirmed during CDF

# XIPE facts

3 of these optics




| | |
|---|---|
| Polarisation sensitivity | 1.2% MDP for 2x10$^{-10}$ erg/s cm$^2$ (10 mCrab) in 300 ks |
| *Spurious polarization* | <0.5 % (goal: <0.1%) |
| *Angular resolution* | <26 arcsec |
| *Field of View* | 15x15 arcmin$^2$ |
| *Spectral resolution* | 16% @ 5.9 keV |
| *Timing* | Resolution <8 μs |
| | Dead time 180 μs |
| *Stability* | >3 yr |
| *Energy range* | 2-8 keV |
| *Background* | 2x10$^{-6}$ c/s or 4 nCrab |



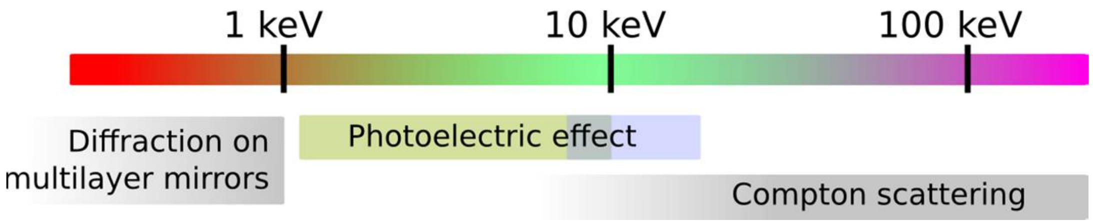
# M4 Timeline

| Activity | Date |
|---|---|
| Phase 0 kick-off | Jun-2015 |
| Phase 0 completed (ARIEL, THOR, XIPE) | Oct-Nov 2015 |
| ITT for Phase A industrial studies | Nov-2015 |
| Phase A kick-off | Mar-2016 |
| Preliminary Requirement Review completed | Apr-2017 |
| Down-selection recommendation for M4 mission | May-2017 |
| SPC selection of M4 mission | Jun-2017 |
| Phase B1 kick-off for the selected M4 mission | Jul-2017 |
| Phase B1 completed | Sep-2018 |
| SPC adoption of M4 mission | Nov-2018 |
| Phase B2/C/D kick-off | 2019 |
| Launch | 2026 |

Table 1: Tentative timeline for M4 activities

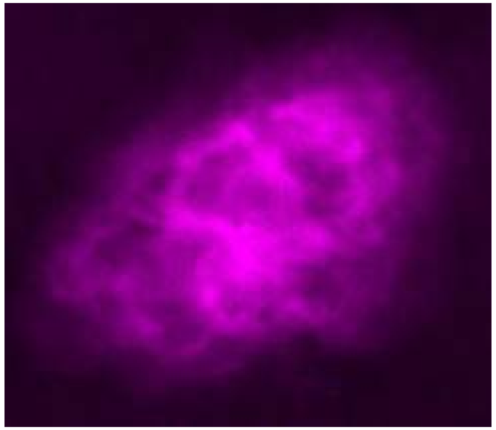
# The XIPE energy band

| Scientific goal | Sources | < 1keV | 1-10 | > 10 keV |
|---|---|---|---|---|
| Acceleration phenomena | PWN | yes (but absorption) | yes | yes |
| | SNR | no | yes | yes |
| | Jet (Microquasars) | yes (but absorption) | yes | yes |
| | Jet (Blazars) | yes | yes | yes |
| Emission in strong magnetic fields | WD | yes (but absorption) | yes | difficult |
| | AMS | no | yes | yes |
| | X-ray pulsator | difficult | yes (no cyclotron ?) | yes |
| | Magnetar | yes (better) | yes | no |
| Scattering in aspherical geometries | Corona in XRB & AGNs | difficult | yes | yes (difficult) |
| | X-ray reflection nebulae | no | yes (long exposure) | yes |
| Fundamental Physics | QED (magnetar) | yes (better) | yes | no |
| | GR (BH) | no | yes | no |
| | QG (Blazars) | difficult | yes | yes |
| | Axions (Blazars, Clusters) | yes ? | yes | difficult |

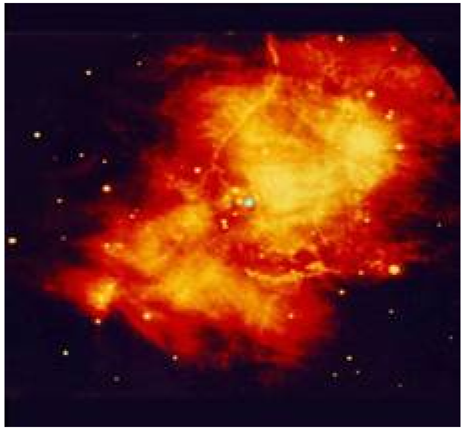


## XIPE scientific goals

### Astrophysics: Acceleration: PWN



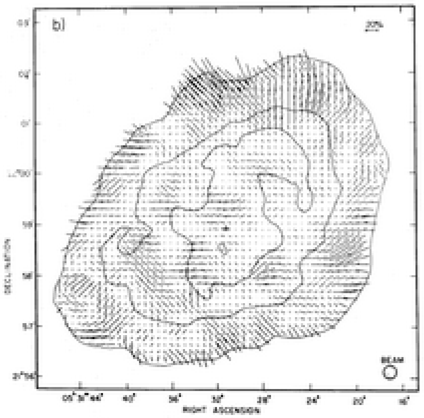
Radio (VLA)



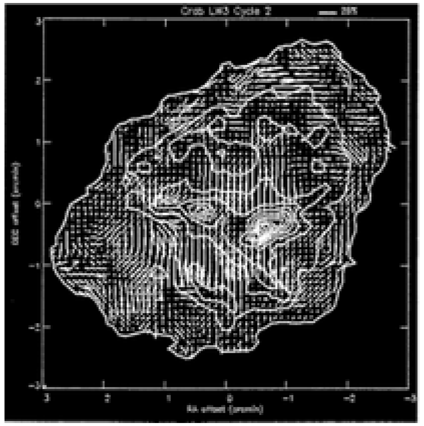
Infrared (Keck)

Optical (Palomar)

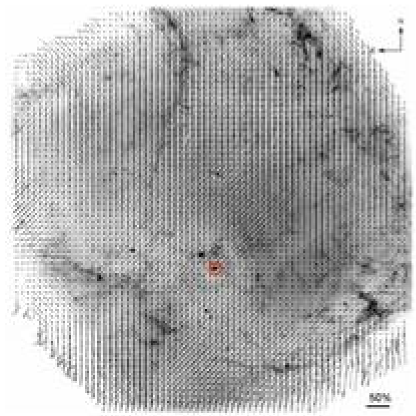
X-rays (Chandra)



Radio polarisation



IR polarisation



Optical polarisation

?

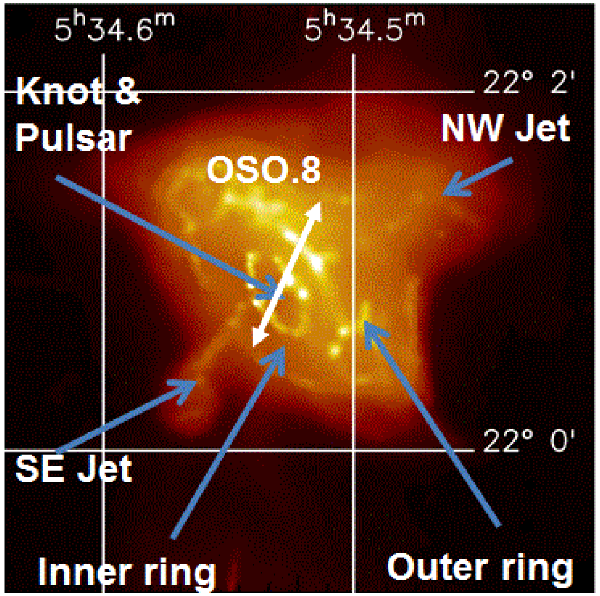
**P=19% integrated over the entire nebula (Weisskopf et al. 1978)**

X-ray polarisation

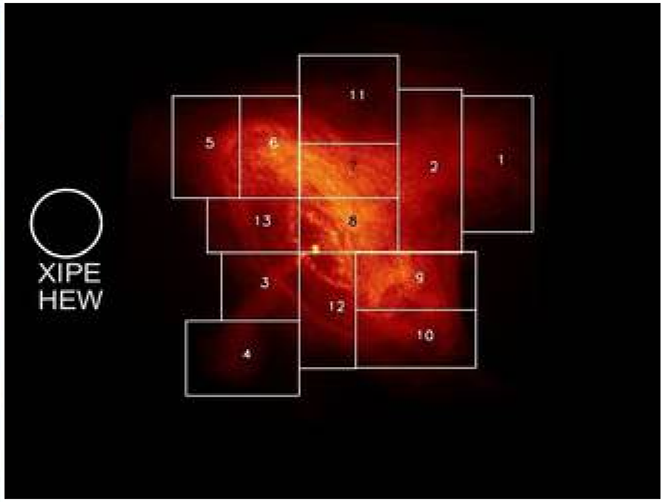
X-rays probe **freshly accelerated** electrons and their acceleration site.

# XIPE scientific goals

## Astrophysics: Acceleration: PWN




| Region | σdegree (%) | σangle (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 over the entire nebula, measured a position angle that is tilted with respect to the jets and torus axes.

- What is the role of the magnetic field (turbulent or not?) in accelerating particles and forming structures?

- XIPE imaging capabilities will allow us to measure the pulsar polarisation by separating it from the much brighter nebula emission.

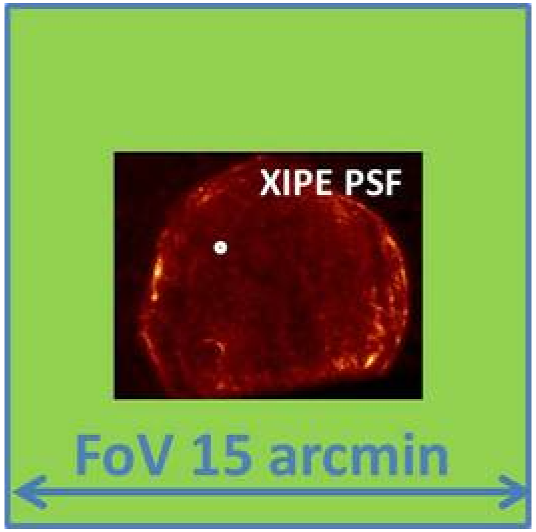
- Other PWN, up to 5 or 6, are accessible for larger exposure times (e.g. Vela or the "Hand of God").

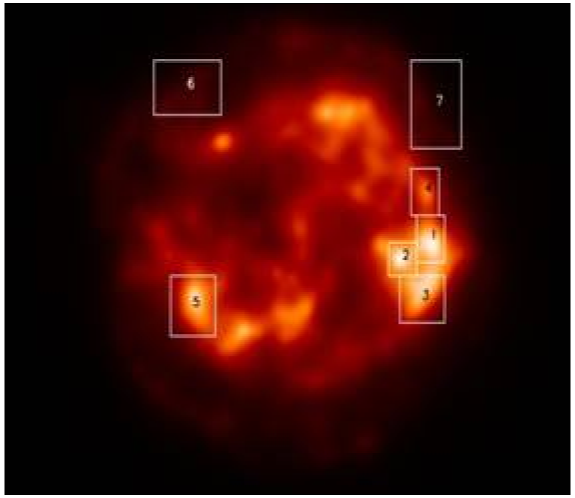
## Astrophysics: Acceleration: SNR

***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

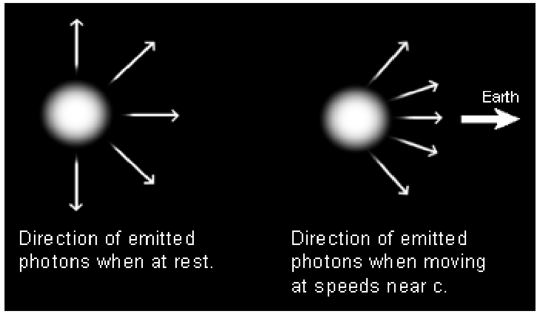
# XIPE scientific goals

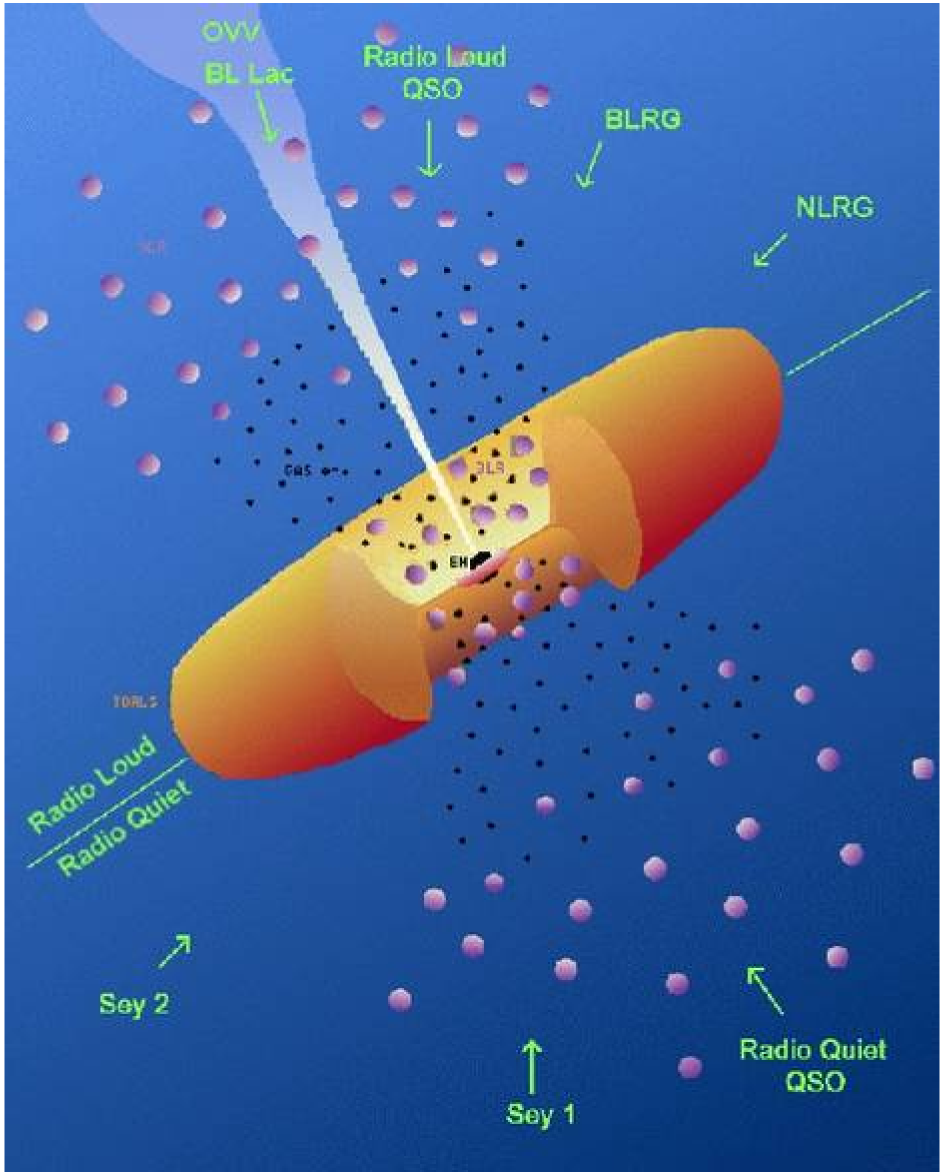
## Astrophysics: Acceleration: Unresolved Jets in Blazars

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

## Astrophysics: Acceleration: Unresolved Jets in Blazars

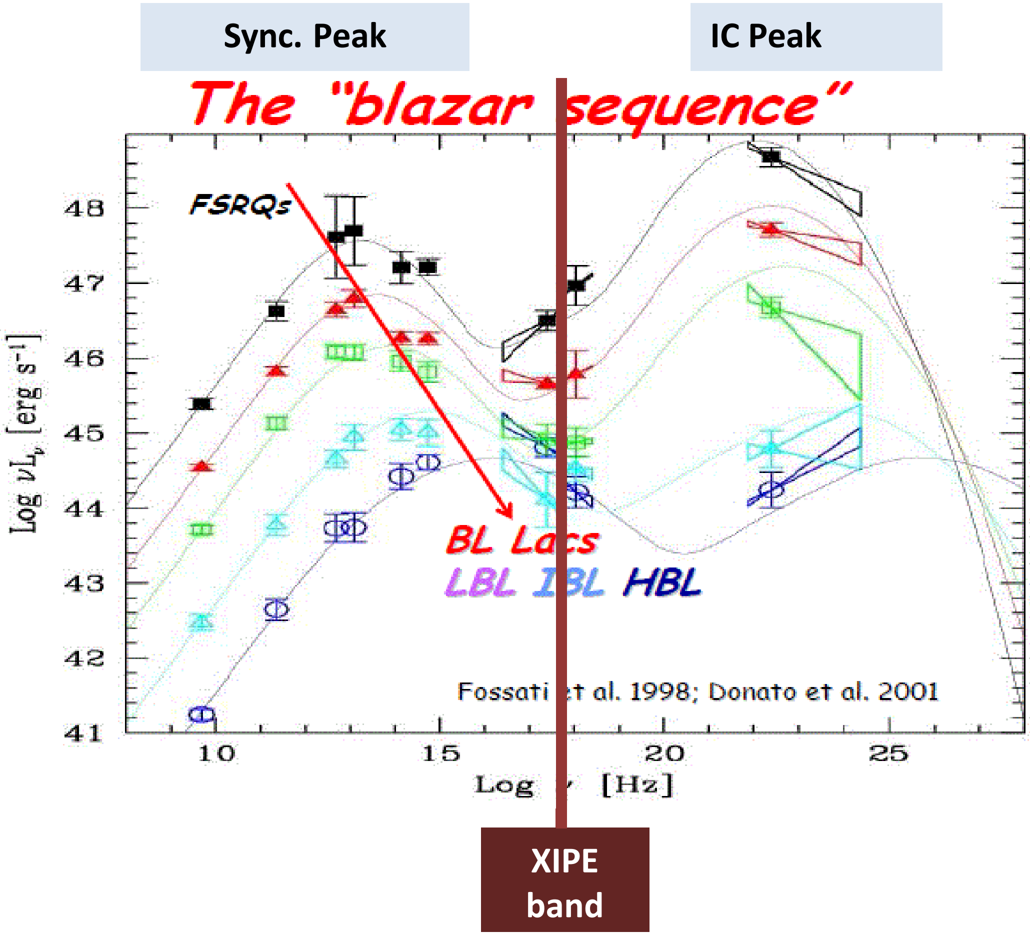
Blazars are extreme accelerators in the Universe, but the emission mechanism is far from being understood.

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 the synchrotron peak.

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

The polarization degree determines th electron temperature in the jet.



# XIPE scientific goals

## Astrophysics: Acceleration: Unresolved Jets in Blazars

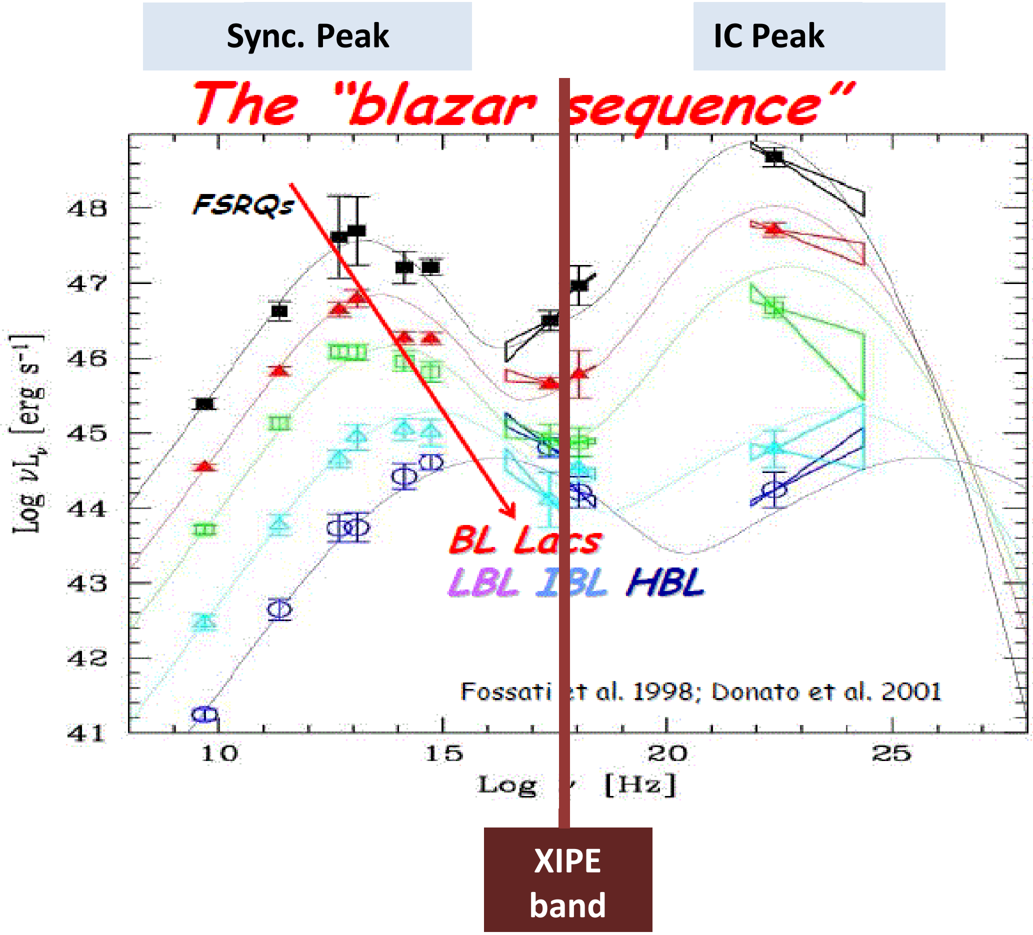
Blazars are extreme accelerators in the Universe, but the emission mechanism is far from being understood.

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

Models predict a larger and more variable polarisation in X-rays than in the optical.

Coordinated multi-wavelength campaigns are crucial for blazars.

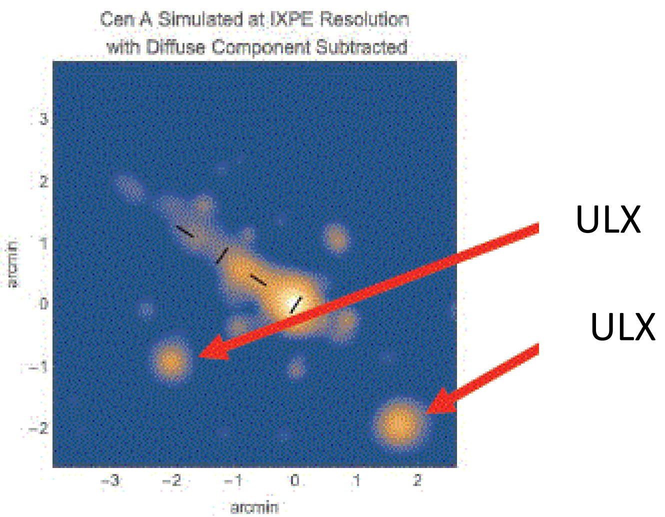
Such campaigns (including polarimetry) are routinely organised and it will be easy for XIPE to join them.

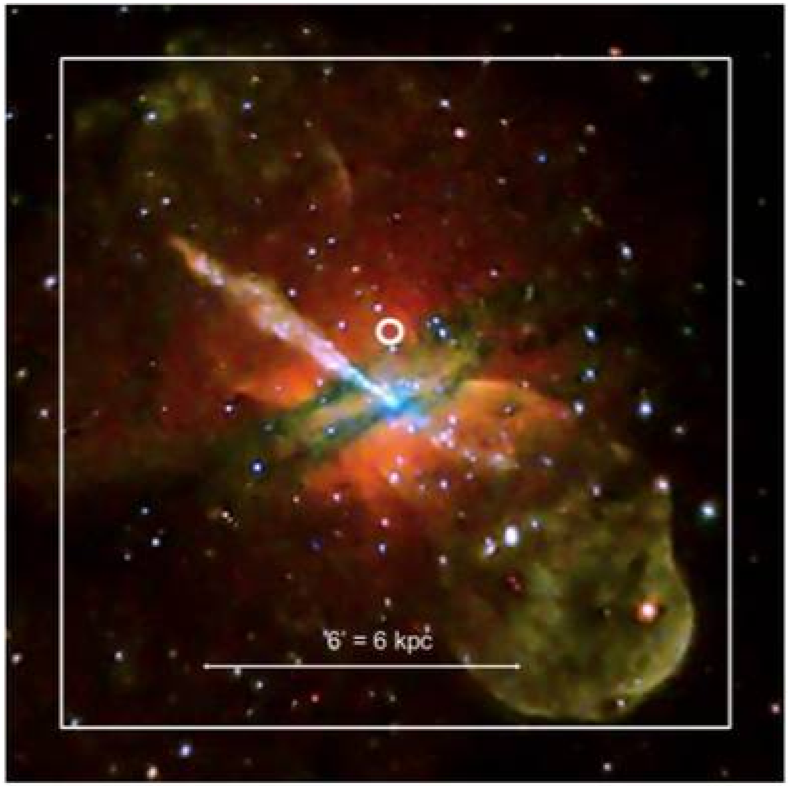


XIPE can, map the X-ray polarisation and thus the magnetic field of resolved X-ray emitting jets.

MDP for the jet is 5% in 1 Ms of observation in 5 regions.

Blurred Chandra image




The extended (4’) radio jet in Cen A.

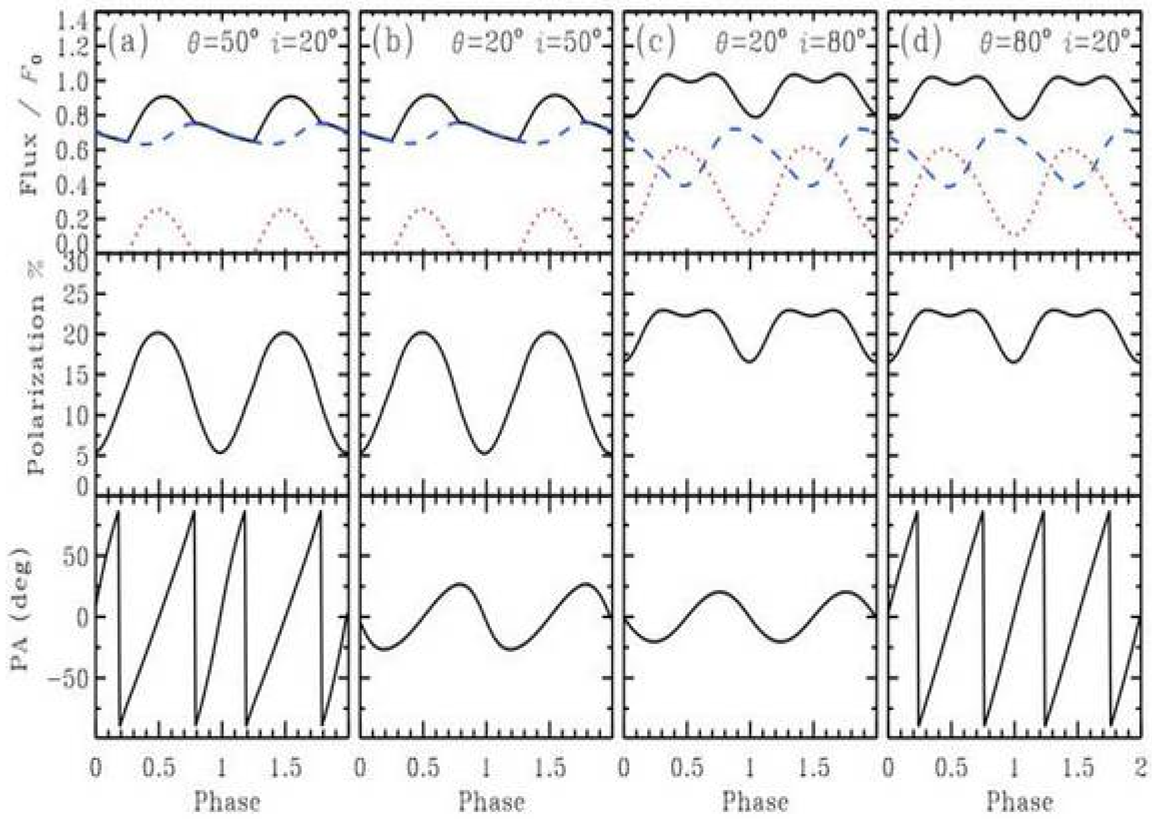
# XIPE scientific goals

## Astrophysics: Strong Magnetic Fields: Accreting Millisecond Pulsars

Emission due to scattering in hot spots

⇒

Phase-dependent linear polarization




Viironen & Poutanen 2004

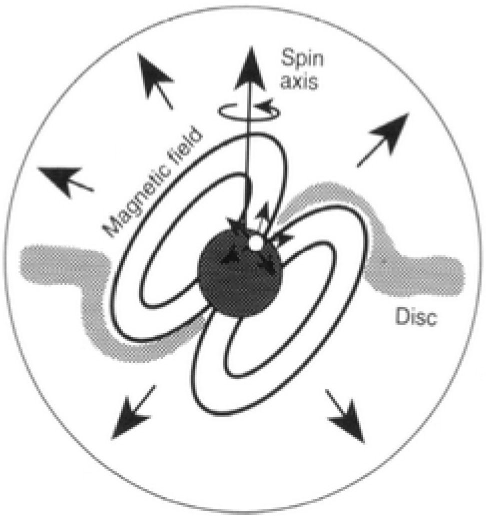
## Disentangling geometric parameters from physical ones

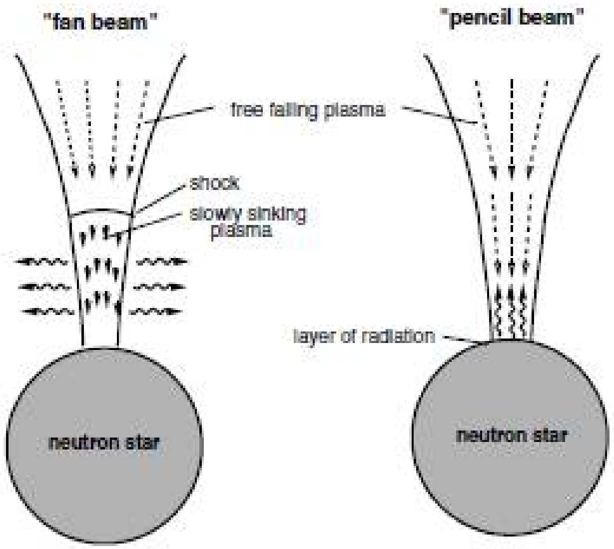
Emission process:

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

From the swing of the polarisation angle:

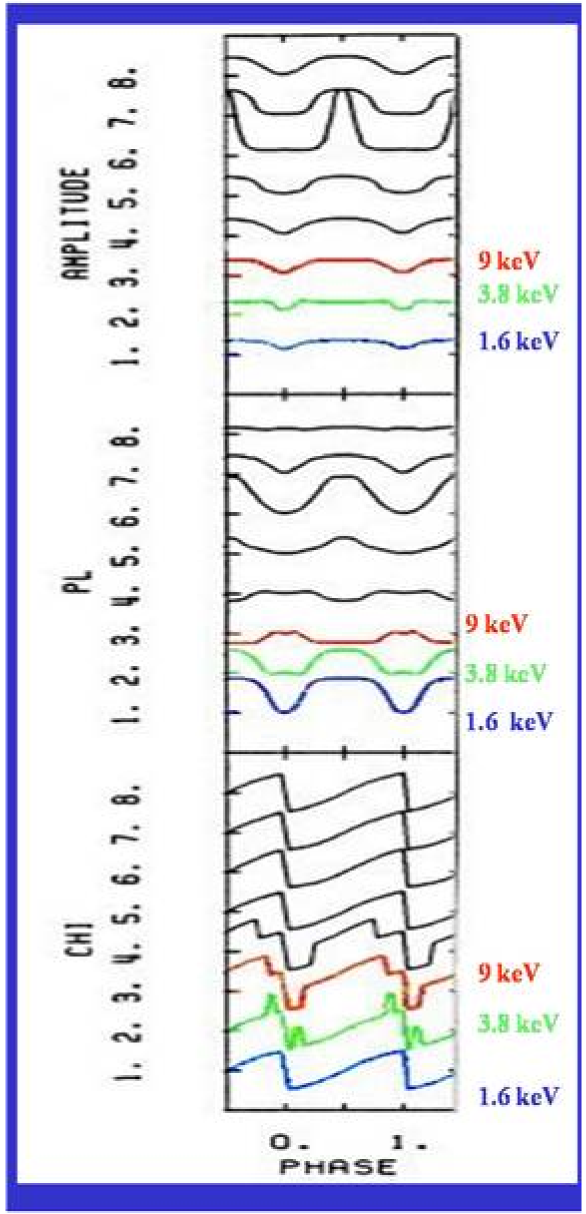
- Orientation of the rotation axis
- Inclination of the magnetic field wrs to the rotation axis
- Geometry of the accretion column: “fan” beam vs “pencil” beam

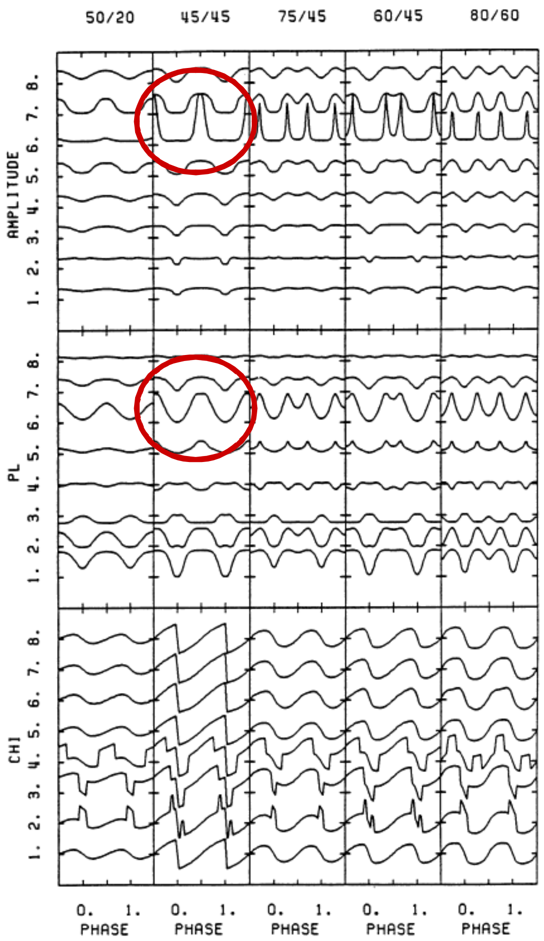


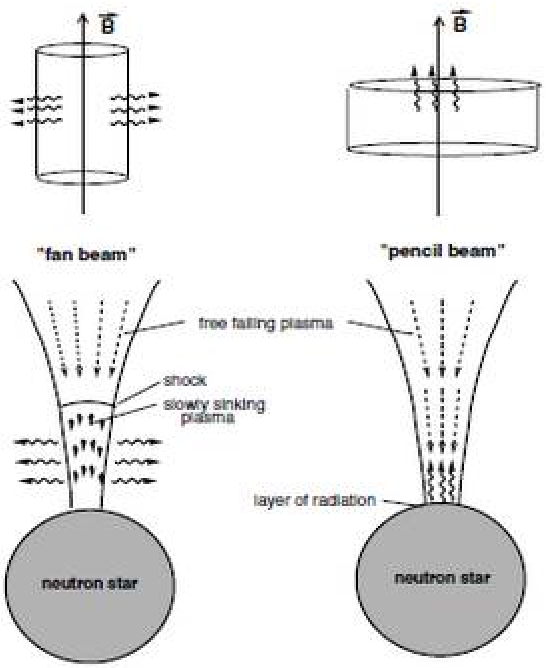

For the best class of XIPE candidates we use a paper 27 y old!

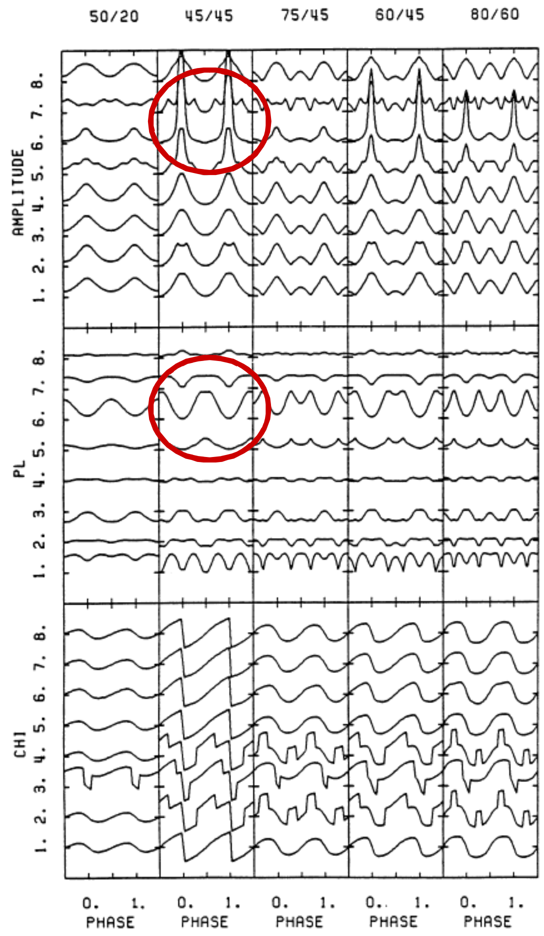
Meszaros et al. 1988






“Fan” vs. “Pencil” beam




Meszaros et al. 1988

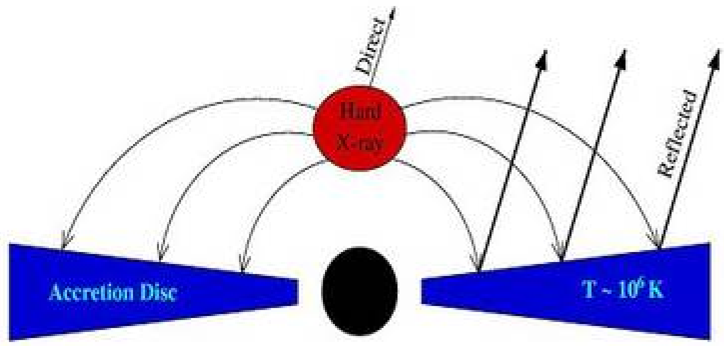
## Astrophysics: Scattering: Coronae in X-ray binaries & AGN

The geometry of the hot corona, considered to be responsible for the 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?

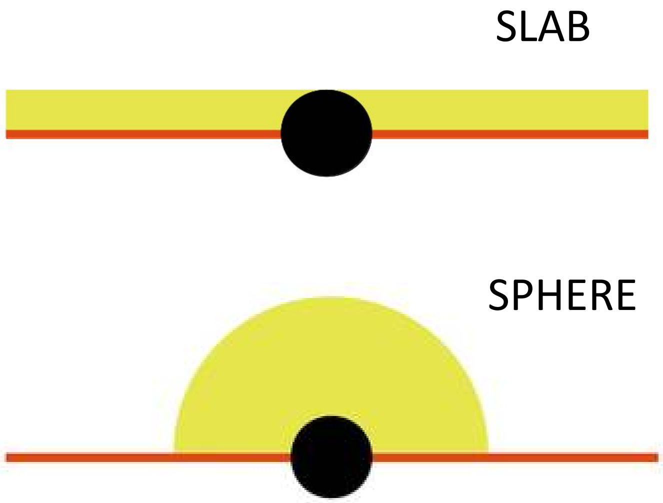
- Sphere – very low polarisation: aborted jet?



# XIPE scientific goals

## Astrophysics: Scattering: Coronae in X-ray binaries & AGN

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




Marin & Tamborra 2014

The geometry is related to the corona origin:

- Slab – high polarisation (up to more than 10%): disc instabilities?

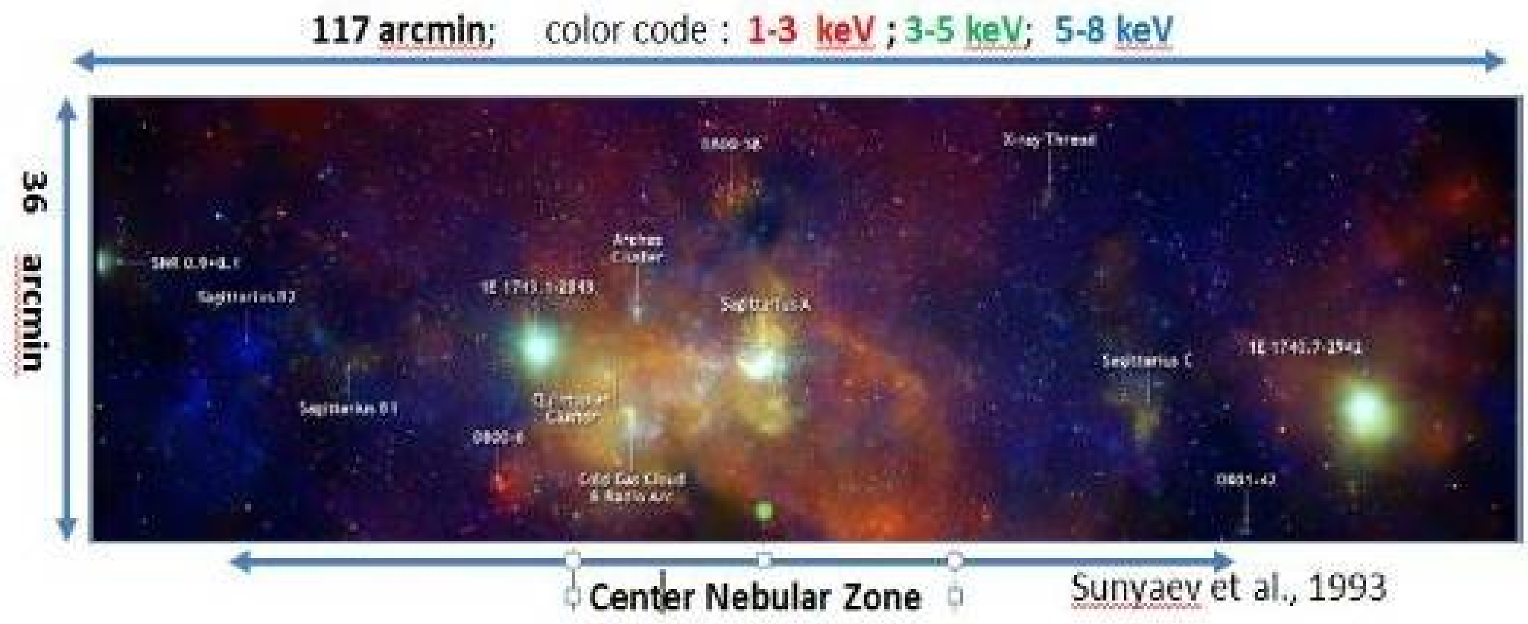
- Sphere – very low polarisation: aborted jet?

# Scattering: X-ray reflection nebulae in the GC

## Was in the past the galactic center a faint AGN ?

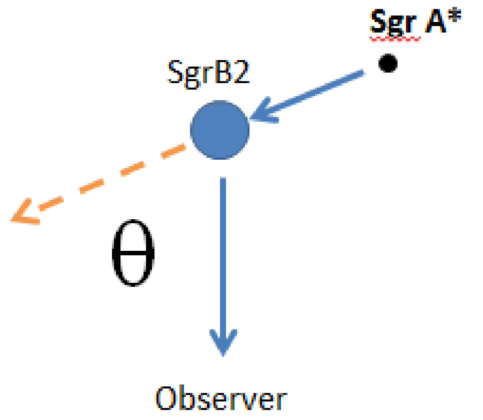
Cold molecular clouds around Sgr A* (i.e. the supermassive black hole at the centre of our own Galaxy) show a neutral iron line and a Compton bump → Reflection from an external source!?!

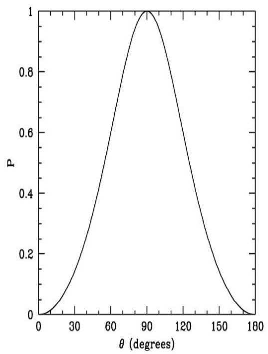
No bright enough sources are in the surroundings. Are they reflecting X-rays from Sgr A*? so, was it one million times brighter a few hundreds years ago? Polarimetry can tell!

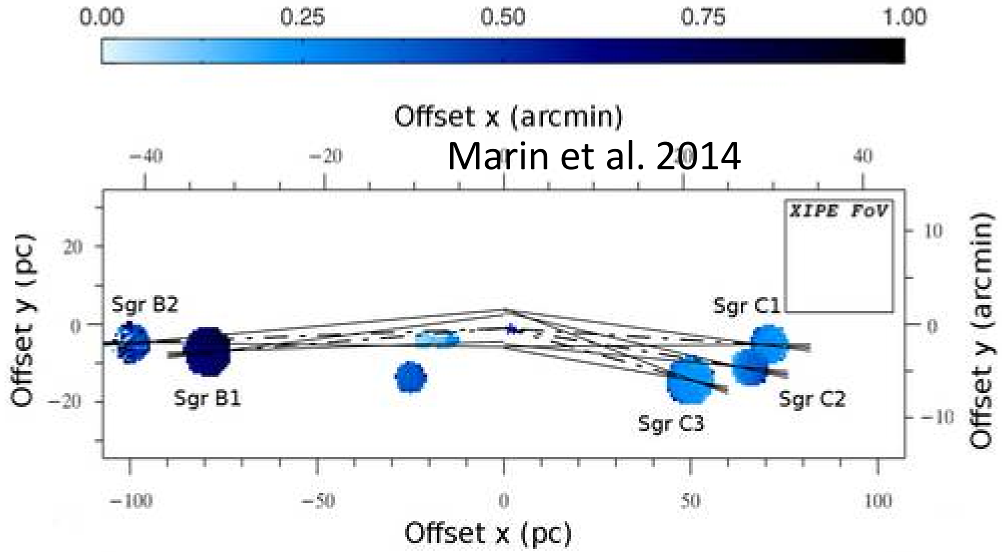


## Polarization by scattering from Sgr B complex, Sgr C complex

- 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*.




| Observation Duration | Value (range seconds) | ID | Condition | Level |
|---|---|---|---|---|
| Definition | The duration of a science observation for any target (exluding monitoring (300 s)) | | | |
| Requirement | 5ks– 1 Ms | SCI-OBS-R-270 | Minimum due to settling and set-up time, and the maximum according to target visibility | 2b |
| | **Justification** A minimum observation duration allows for efficient use of bright targets (e.g. Crab, also for calibration purposes), and a sufficient statistics can be collected for faint sources (e.g. Galactic Centre or supernova remnants) | | | |

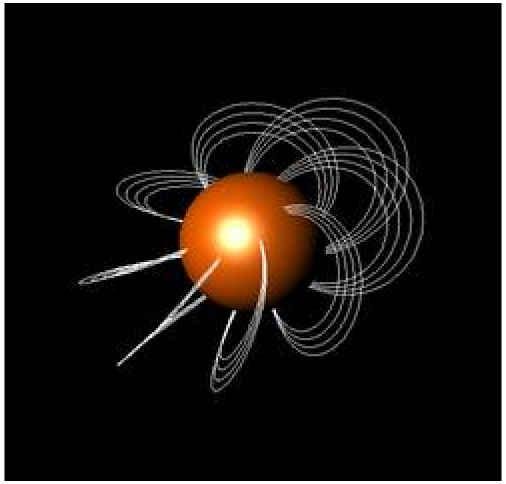
# XIPE scientific goals

## Fundamental Physics: Matter in extreme magnetic fields: QED effects

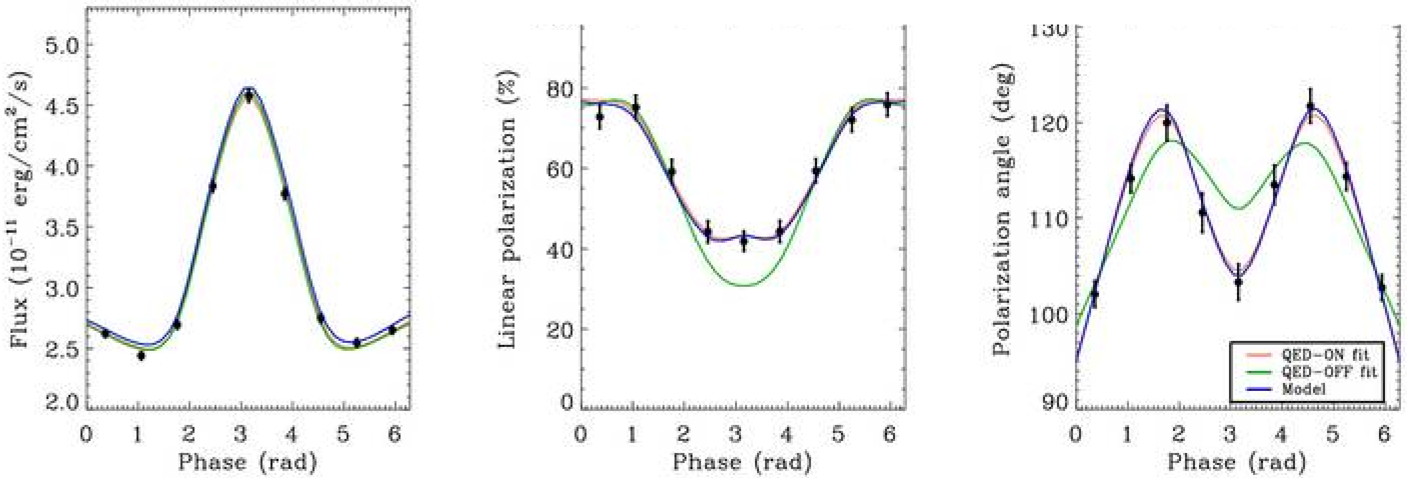
Magnetars
are isolated neutron stars with likely a huge magnetic field (B up to $10^{15}$ Gauss).

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 (Eisenberg & Euler 1936), expected in such a strong magnetic field and never detected yet.



**Light curve** **Polarisation degree** **Polarisation angle**




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

## 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).

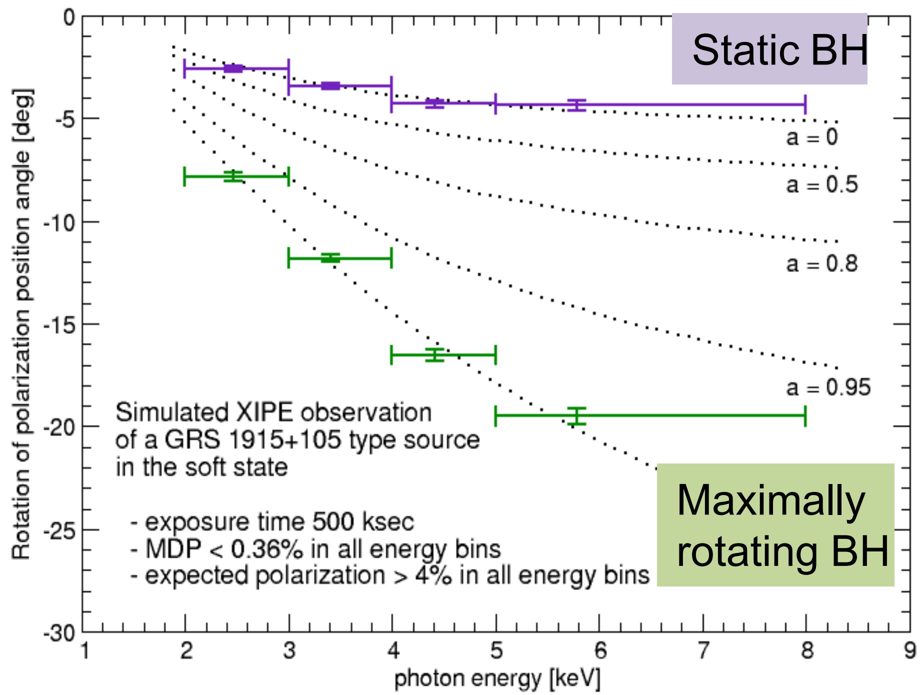
**Problem: for a number of XRBs, the methods do not agree!**

| 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, …*



**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.

# 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.

# Working groups set: about 300 scientists signed for participation.

WG1. Acceleration mechanisms: Giampiero Taglaferri(1), Jacco Vink(2)
(1) Osservatorio Astronomico di Brera INAF, Italy, (2) Astronomical Institute Anton Pannekoek, The Netherlands

WG1.1 **Pulsar Wind Nebulae**: Emma de Ona Wilhelmi , ICE, Spain
WG1.2 **Supernova Remnants**: **Andrei Bykov,** Ioffe Physical-Technical Institute, Russia
WG1.3 **Blazars: Ivan Agudo, Instituto** de Astrofísica de Andalucía, Spain
WG1.4 **Micro-QSO**s: **Elena Gallo**, University of California, Santa Barbara, USA
WG1.5 **Gamma Ray** Bursts: **Carol Mundell**, University of Bath, UK
WG1.6 **Tidal Disruption** Events: **Immacolata Donnarumma**, IAPS/INAF, Italy
WG1.7 **Active Stars**: **Nicholas Grosso**, Astronomical Observatory in Strasbourg, France
WG1.8 **Clusters of Galaxy**: **Sergey Sazonov**, Space Research Institute, Russian Academy of Sciences, Russia

WG2. Magnetic Fields in compact objects: Andrea Santangelo (1), Silvia Zane (2)
(1) Institut für Astronomie und Astrophysik Tuebingen, (2) University College London/MSSL, UK

WG2.1 **Magnetic Cataclismic Variables**: **Domitilla De Martino**, Osservatorio di Capodimonte, taly
WG2.2 **Accreting Millisecond Pulsars**: **Juri Poutanen**, Finland Tuorla Observatory, U. of Turku,Finland
WG2.3 **Accreting X-ray Pulsars**: **Victor Doroshenko**, IAAT, Germany
WG2.4 **Magnetars**: **Roberto Turolla**, University of Padua, Italy

WG3. Scattering in aspherical geometries and accretion Physics: Eugene. Churazov (1), Rene‘ Goosmann(2)
(1)Max-Planck-Institut für Astrophysik, Germany (2) Astronomical Observatory in Strasbourg, France

WG3.1 **X-ray binaries and QPOs**: **Julien Malzac**, CESR/CNRS, France
WG3.2 **AGNs**: **Pierre Olivier Petrucci**, Institut de Planétologie et d'Astrophysique de Grenoble, France
WG3.3 **Molecular Clouds & SgrA***: **Frédéric Marin**, Astronomical Institute of the Academy of Sciences, Czech Republic
WG3.4 **Ultra Luminous X-ray sources**: **Hua Feng**, Tsinghua University, Beijing, China

WG4. Fundamental Physics: Enrico Costa (1), Giorgio Matt (2)
(1) INAF/IAPS, Italy (2) Universita' Roma Tre, Italy

WG4.1 **QED and X-ray polarimetry**: **Rosalba Perna**, Stony Brook University, USA
WG4.2 **Strong Gravity: Jiří Svoboda**, Astronomical Institute of the Academy of Sciences, Czech Republic
WG4.3 **Quantum Gravity**: **Philip E. Kaaret**, Iowa University, USA
WG4.4 **Axion-like particles**: **Marco Roncadelli**, University of Pavia , Italy

# Next meetings, workshop

**First XIPE Science Meeting** 24-26 May 2016, Valencia

**COSPAR E1.15** "X-ray Polarimetry: Experiments and Science Prospects“
30 July 2016 - 7 August 2016, Istanbul

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

We closed the registration to the Working Group but if anybody wants to join, please contact the chair of the WGs of interest.

END