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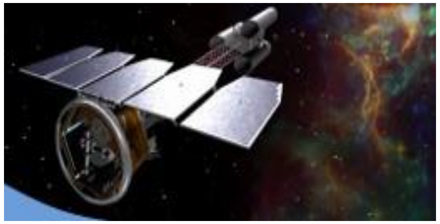
IXPE
Imaging
X-Ray
Polarimetry
Explorer



The Imaging X-ray Polarimetry Explorer

Giorgio Matt (Univ. Roma Tre, Italy)
on behalf of the IXPE team

IXPE's TIMELINE

- Proposed to NASA as a SMall EXplorer (SMEX) mission in December 2014
- One of the three proposals selected for an Assessment Study in August 2015
- Final down-selection in January 2017
- Launch on early 2021
- Baseline duration: 2 years

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IXPE WILL:

- **(Re)Open the X-ray polarimetry window**
  - Only one positive measurement so far: 19% polarization of the Crab Nebula (OSO-8)

- **Address key scientific questions**
  - What is the spin of a black hole?
  - What are the geometry and magnetic-field strength in magnetars?
  - Was our Galactic Center an Active Galactic Nucleus in the recent past?
  - What is the magnetic field structure in synchrotron X-ray sources?
  - What are the geometries and origins of X-rays from pulsars (isolated and accreting)?
  - ……

- **Provide powerful and unique capabilities**
  - Integration time reduced by a factor of 100 over OSO-8 experiment
  - Simultaneous imaging, spectroscopic, timing, and polarization data
  - Instrument systematic effects at less than a fraction of a percent
  - Meaningful polarization measurements for a large number of sources of different classes

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IXPE IN A NUTSHELL

Principal Investigator: **M. C. Weisskopf (MSFC)**

Co-Investigators: *Brian D. Ramsey, Paolo Soffitta, Ronaldo Bellazzini, Enrico Costa, Stephen L. O'Dell, Allyn Tennant, Herman Marshall, Fabio Muleri, Jeffery Kolodziejczak, Roger W. Romani, Giorgio Matt, Victoria Kaspi, Ronald Elsner, L. Baldini, L. Latronico*

- **Pegasus XL launch from Kwajalein**
- **540-km circular orbit at 0° inclination**
- **2 year baseline mission, 1 year SEO**
- **Point-and-stare at known targets**
- **Science Operations Center at MSFC**
- **Mission Operations Center at CU/LASP**
- **Malindi ground station (Singapore Backup)**

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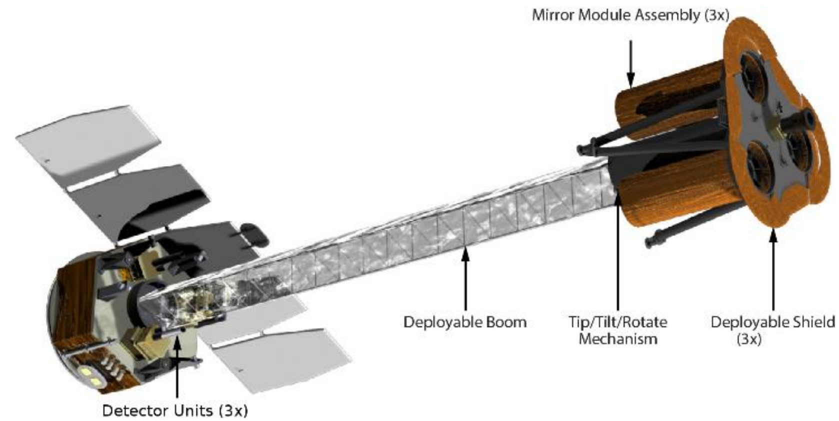
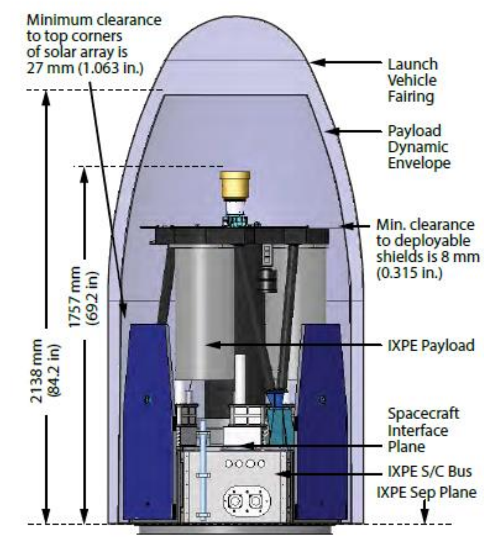
IXPE IN A NUTSHELL

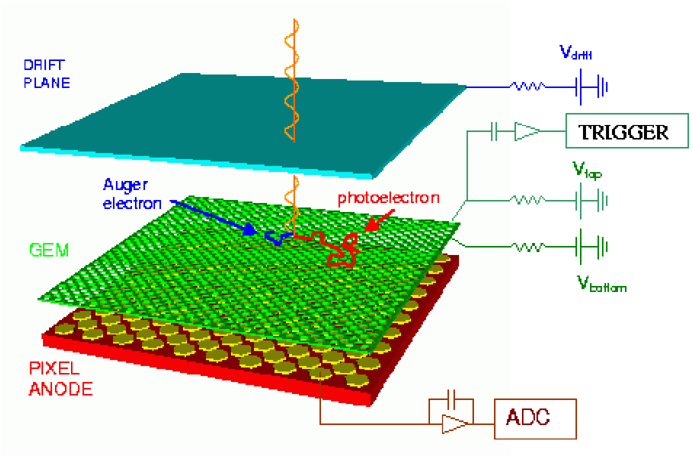
- **3x Telescopes**
  - 3x Mirror Units (MUs) + 3x Detector Units (Dus)
  - A Detectors Service Unit (DSU) with built-in redundancy
  - 4 m focal length, deployable boom and X-ray shield
- **Performance**
  - Polarization sensitivity: $MDP_{99\%}$<5.5% in 1 day for flux of 10^{-10} ergs/cm^2/sec
  - Energy range: 2-8 keV
  - Limit polarization: 0.5% (degree), 1 degree (angle)
  - Angular resolution: better than 30 arcsec, field of view larger than 9 arcmin
  - UTC synchronization: better than 250 µs
  - Energy resolution: better than 25%

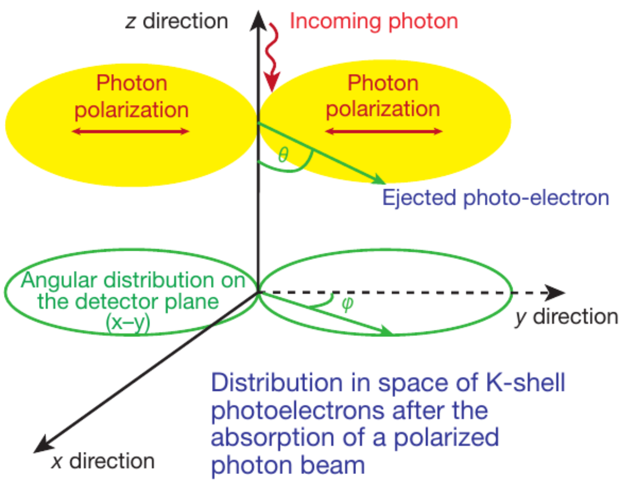




IXPE PAYLOAD

- **Mirror based on grazing incidence reflection**
  - Total collecting area: >700 cm^2 at 3 keV
- **Photoelectric polarimeter based on GPD design**
  - Include a Filter & Calibration wheel with
    - Filters for specific observations (very bright sources, background)
    - Calibrations sources (polarized and unpolarized, gain)





$$\frac{\partial\sigma}{\partial\Omega} = r_0^2 \frac{Z^5}{137^4}\left(\frac{mc^2}{h\nu}\right)^{7/2} \frac{4\sqrt{2}\sin^2(\theta)\cos^2(\varphi)}{(1-\beta\cos(\theta))^4}$$

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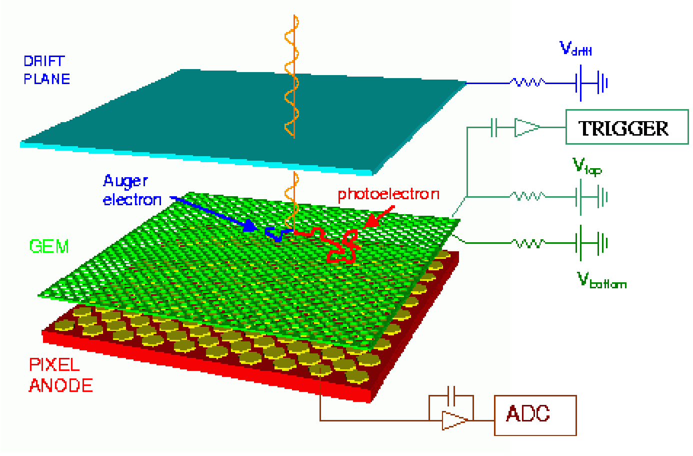

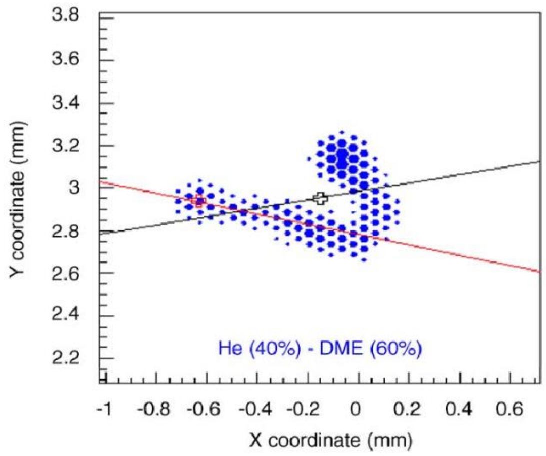

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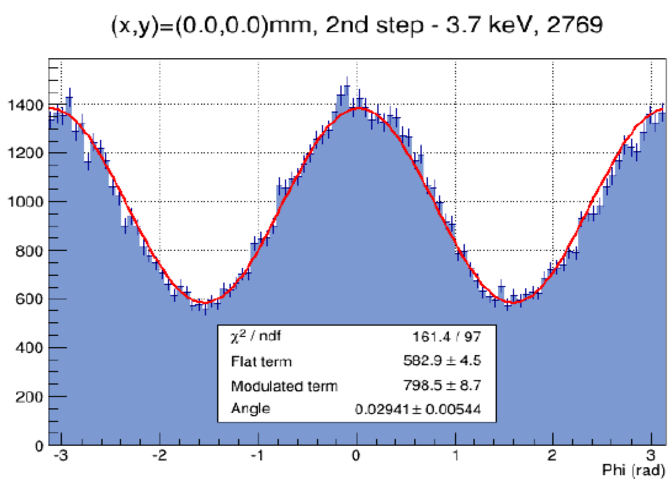
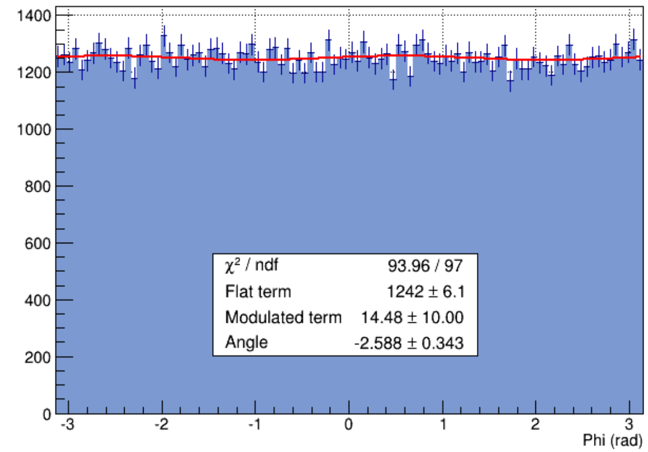


Real modulation curve derived from the measurement of the emission direction of the photoelectron.



Residual modulation for unpolarized photons.

Bellazzini et al. 2012

SCIENTIFIC GOALS (a few examples)

- Acceleration processes in PWN
- The spin of the black hole in microquasars
- QED effects in magnetars
- Blazars and radiogalaxies
- Astroarcheology of the Galactic Centre

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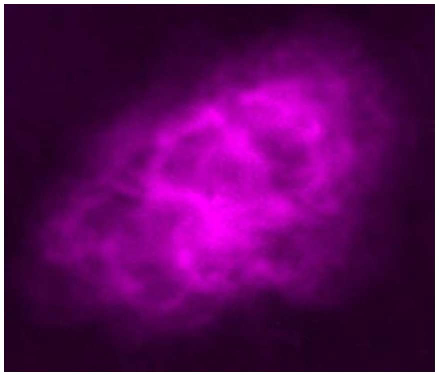
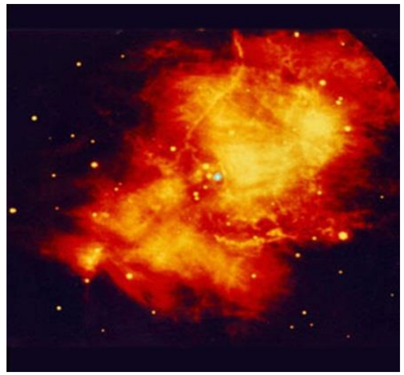
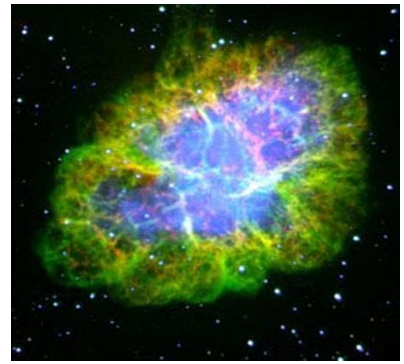
THE CRAB NEBULA OR THE IMPORTANCE OF IMAGING X-RAY POLARIMETRY



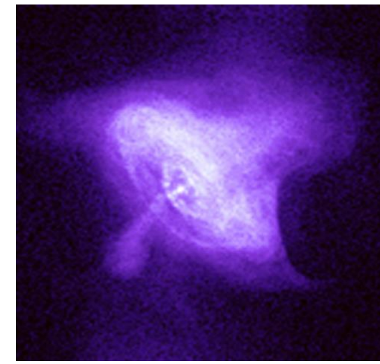
Radio (VLA)



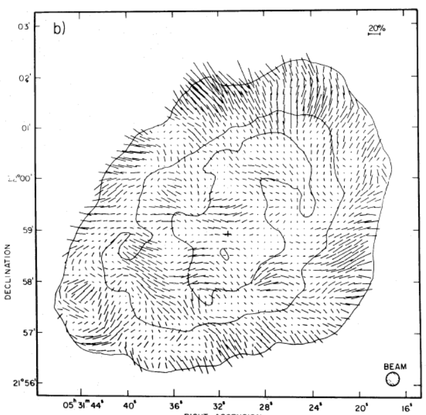
Infrared (Keck)



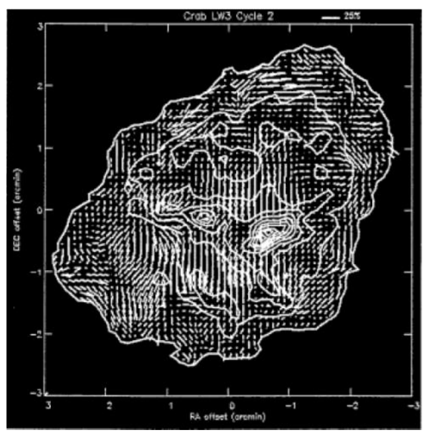
Optical (Palomar)



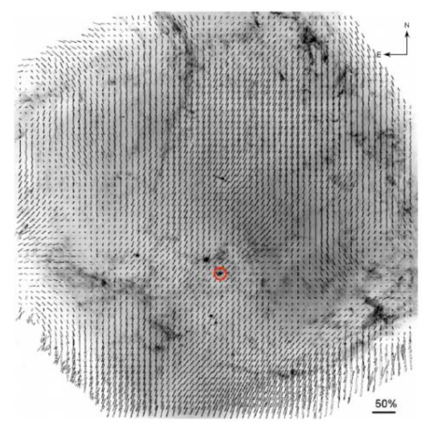
X-rays (Chandra)



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.

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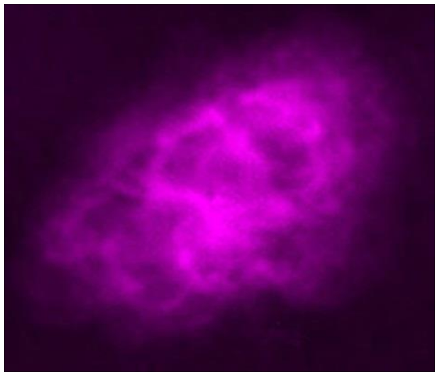
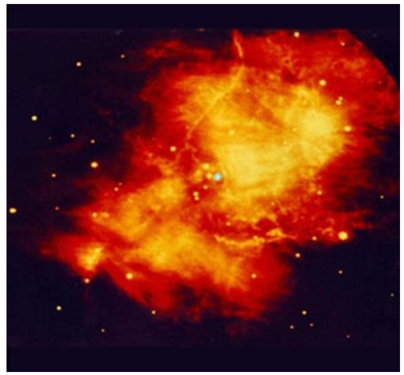
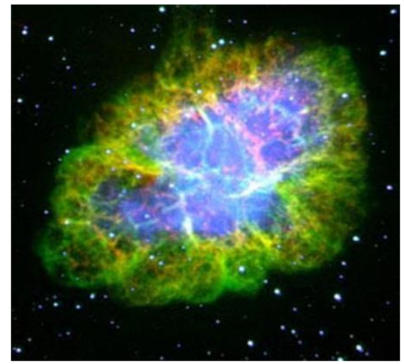
THE CRAB NEBULA OR THE IMPORTANCE OF IMAGING X-RAY POLARIMETRY



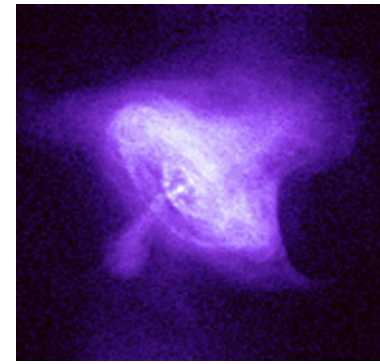
Radio (VLA)



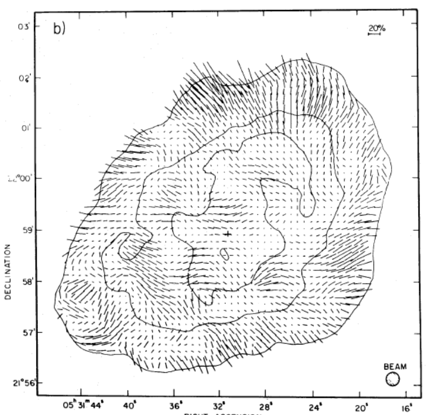
Infrared (Keck)



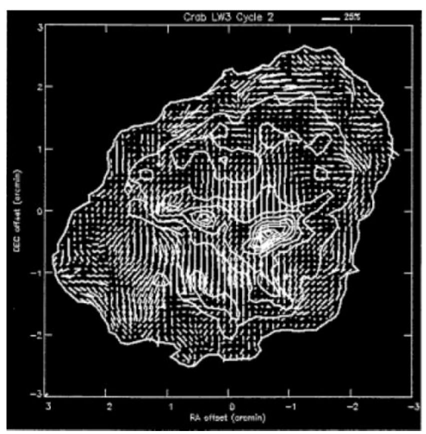
Optical (Palomar)



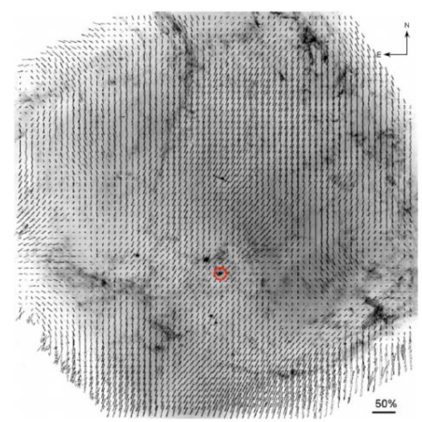
X-rays (Chandra)



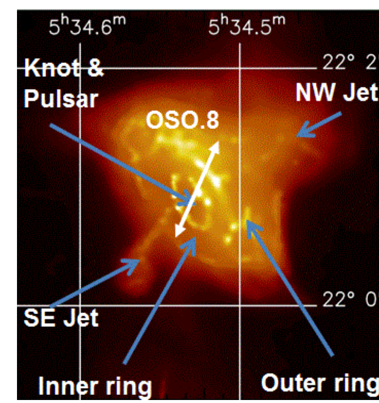
Radio polarisation



IR polarisation



Optical polarisation



X-ray polarisation

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

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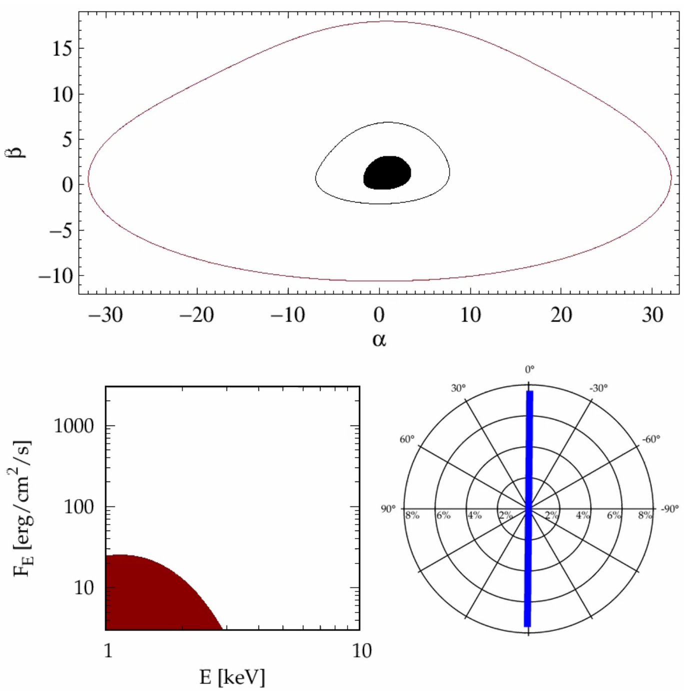
THE SPIN OF THE BLACK HOLE

- **For an accreting Galactic BH in the soft state**
  - Scattering polarizes the thermal disk emission
  - Polarization angle rotates due to GR effects
    - Polarization rotation is greatest for emission from inner disk
    - Inner disk is hotter, producing higher energy X-rays



Rotation of the polarization angle with energy

Courtesy: Michal Dovciak

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Why another method, besides the three ones already in use?

J1655-40:

QPO a = J/Jmax= 0.290±0.003

Continuum: a = J/Jmax 0.7±0.1

Iron line a = J/Jmax 0.95

Rotation of the polarization angle with energy

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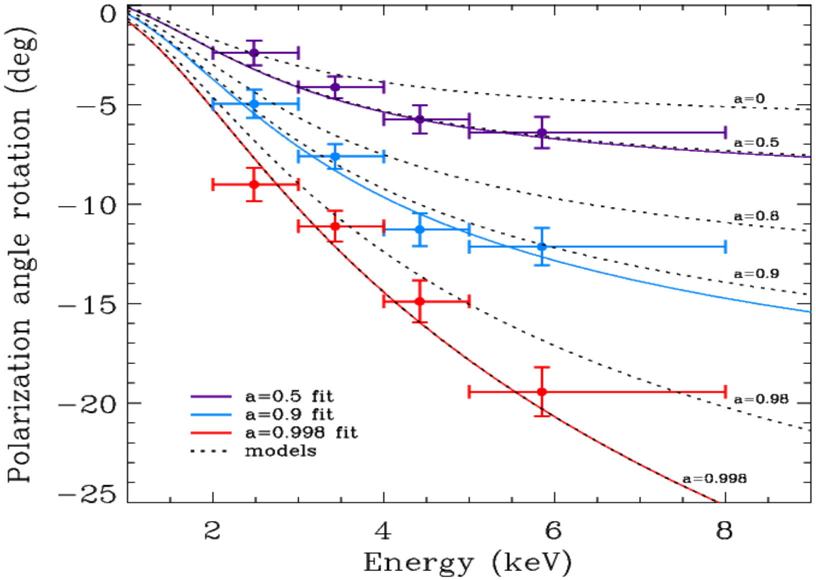

Rotation of the polarization angle with energy

Adapted from Dovciak et al. 2009

200 ks IXPE observation of GRS1915+105

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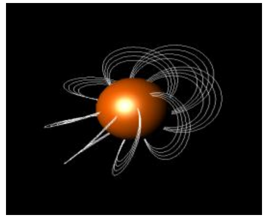
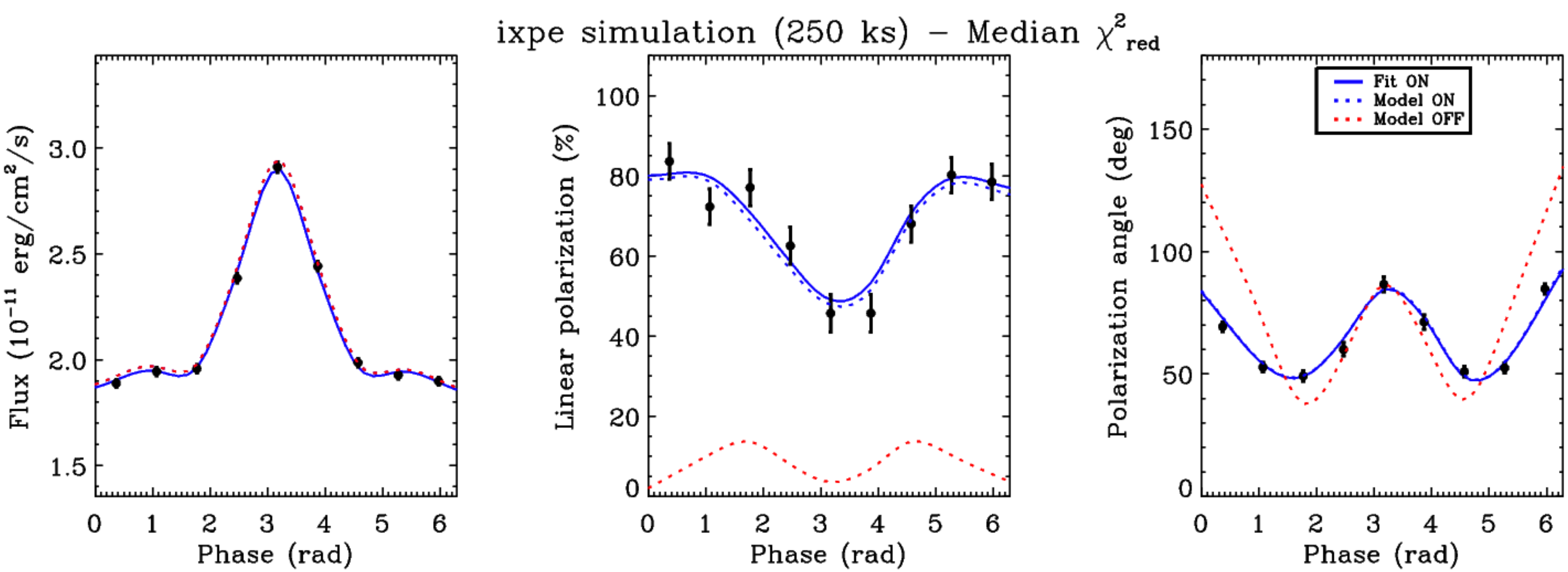


QED EFFECTS IN MAGNETARS

- **Magnetar is a neutron star with magnetic field up to 10^{15} Gauss**
  - Billion times the strongest laboratory field
  - Non-linear QED predicts magnetized-vacuum birefringence
    - Refractive indices different for the two polarization modes
    - Impacts polarization and position angle as function of pulse phase
    - Can exclude QED-off at better than 99.9% confidence



1RXS J170849 - Courtesy: Roberto Taverna

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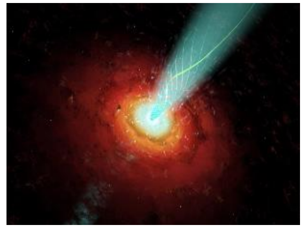
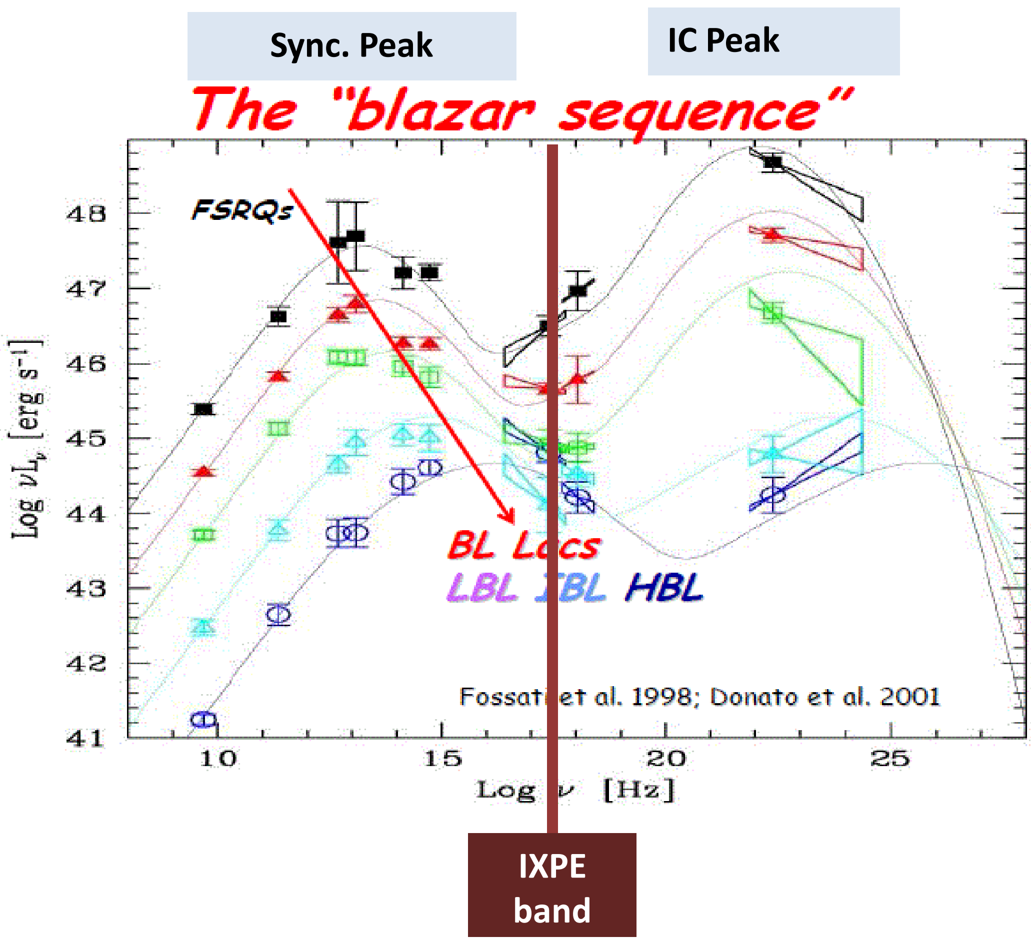


BLAZARS ...

In synchrotron-dominated X-ray Blazars, multi-λ polarimetry probes **the structure** of the jet and of its **magnetic field**

In inverse Compton dominated Blazars, multi-λ polarimetry observations can determine:

- **the composition of the jet** (hadronic vs. leptonic)
- **the origin of the seed photons** Synchrotron-Self Compton (SSC) or External Compton (EC)



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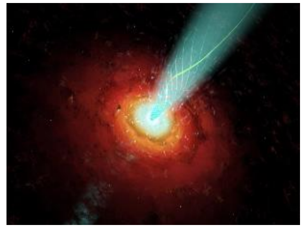
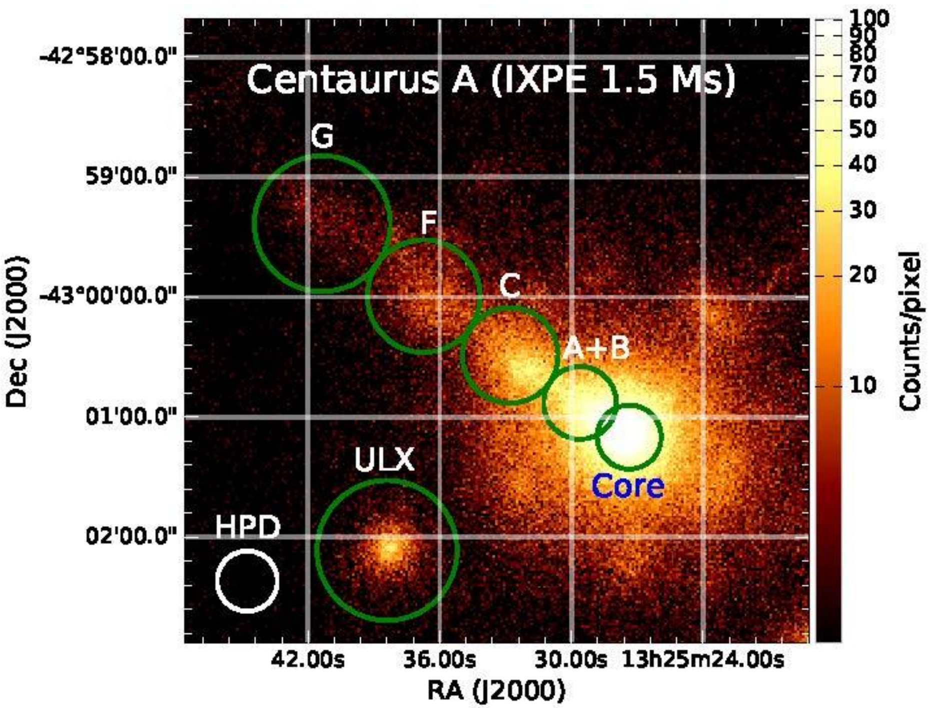


… AND RADIOGALAXIES



Region	MDP_{99}
Core	**0.4%**
Jet	**10.9%**
Knot A+B	17.6%
Knot C	16.5%
Knot F	23.5%
Knot G	30.9%
ULX	**14.8%**

Includes effects of dilution by unpolarized diffuse emission

WAS THE GC ACTIVE A FEW CENTURIES AGO?

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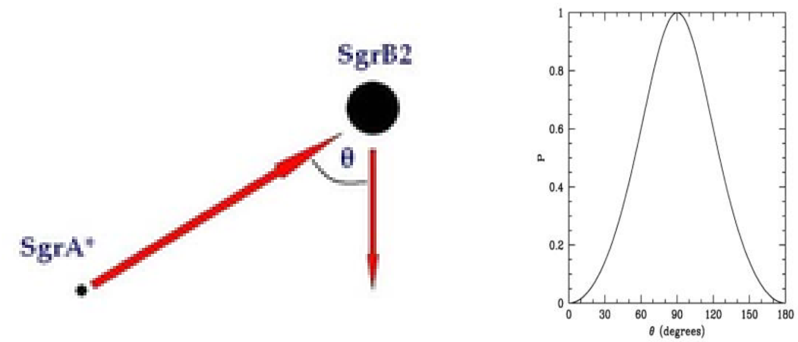
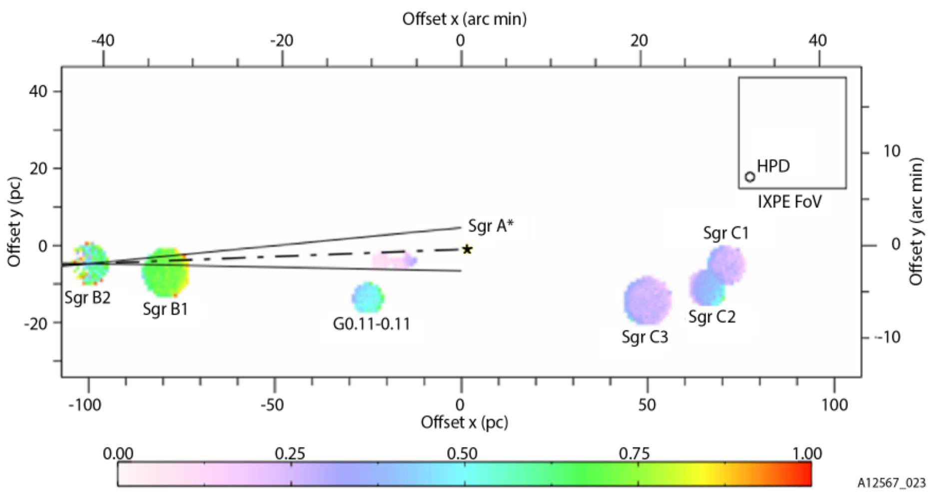
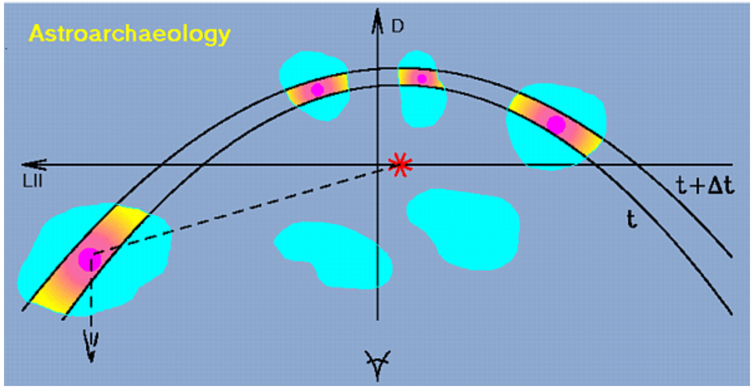
- **Galactic Center molecular clouds (MC) are known X-ray sources**
  - Are MCs reflecting X-rays from Sgr A* ? (supermassive black hole in the GC)
    - X-radiation would be *highly polarized* perpendicular to plane of reflection and indicates the direction back to Sgr A*
    - Sgr A* X-ray luminosity was 10^6 higher ≈ 300 years ago







Marin et al. 2014

AND MANY OTHER SCIENTIFIC GOALS…

- The structure of the magnetic field in SNR
- Accretion in magnetized WD and NS
- Geometry of X-ray coronae in accreting BHs
- The role of jets in microquasars
- + ….. (including fundamental physics: QG, Axion-like particles)

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SUMMARY

IXPE will reopen the X-ray polarimetry window, providing crucial and unique information on the physics and morphology of most classes of X-ray sources