



IXPE
Imaging
X-Ray
Polarimetry
Explorer



The Imaging X-ray Polarimetry Explorer (IXPE): a new window for Astrophysics

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**Astronomy, Astrophysics and Space Science PhD - Cycle XXXIV -
PhD students seminar series
The Internet, 2021 April 21**

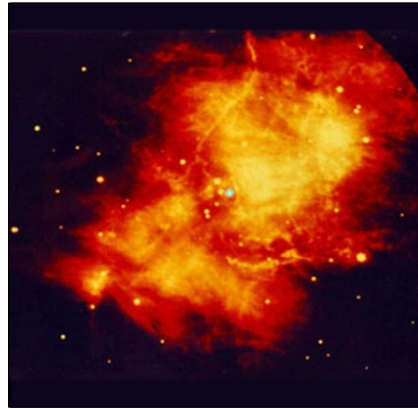
INTRODUCTION

THE MISSING PIECE OF THE PUZZLE...

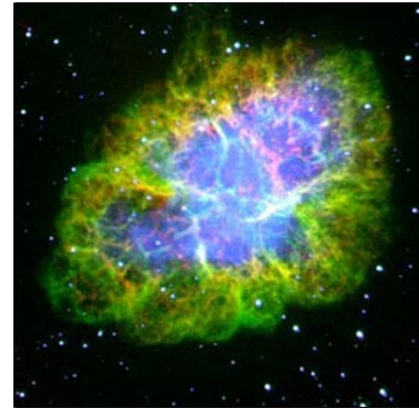
"Astrophysics has two areas of study: the Crab Nebula, and everything else."
- Anonymous astrophysicist



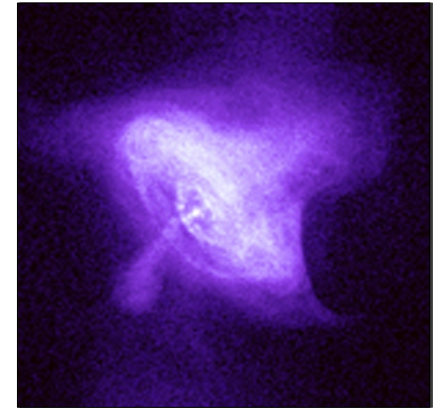
Radio (VLA)



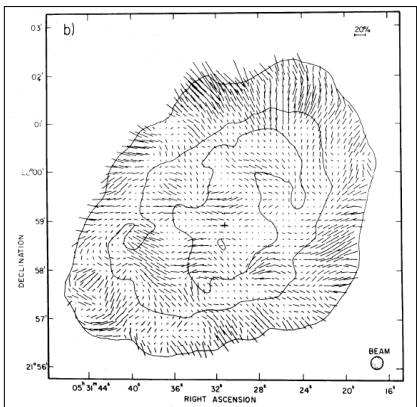
Infrared (Keck)



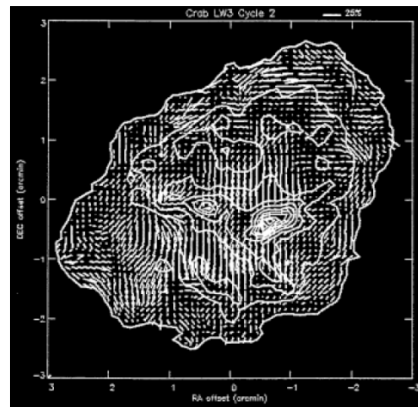
Optical (Palomar)



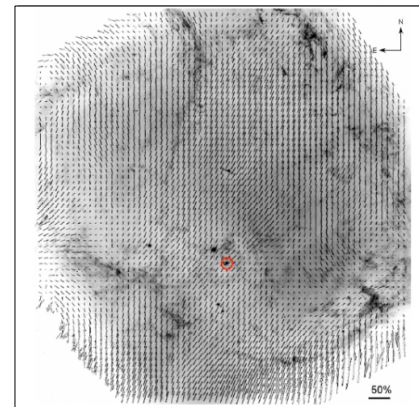
X-rays (Chandra)



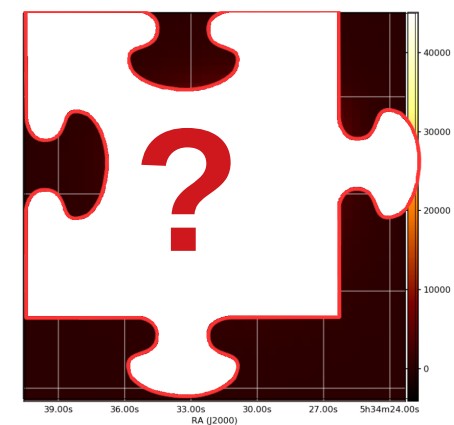
Radio polarization



IR polarization

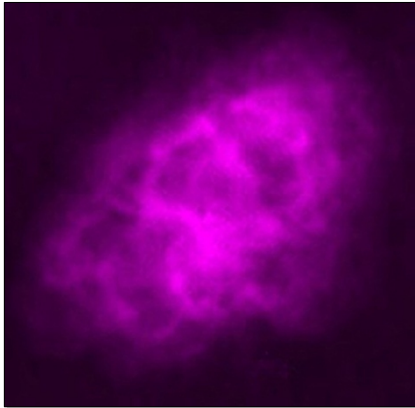


Optical
polarization

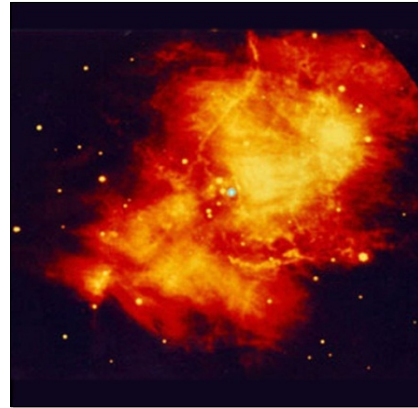


X-ray polarization

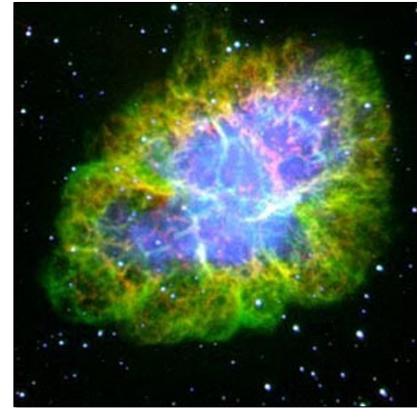
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 - Anonymous astrophysicist



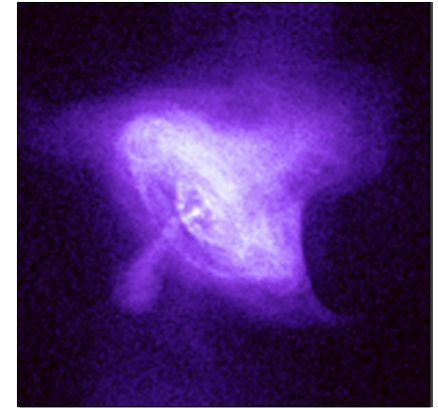
Radio (VLA)



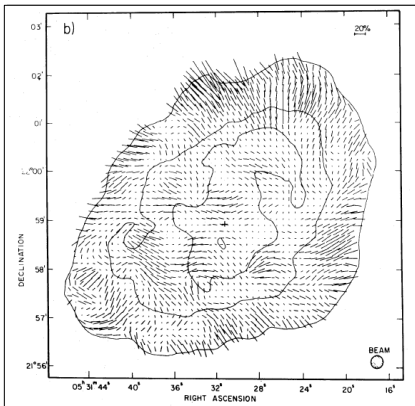
Infrared (Keck)



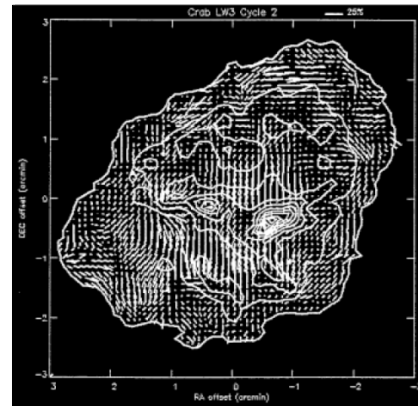
Optical (Palomar)



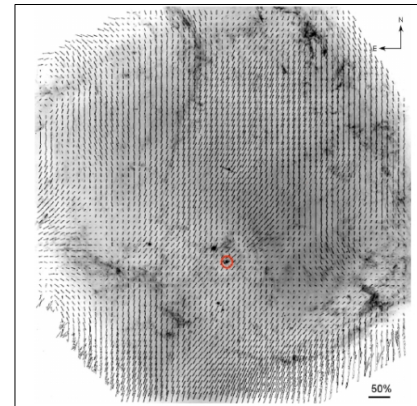
X-rays (Chandra)



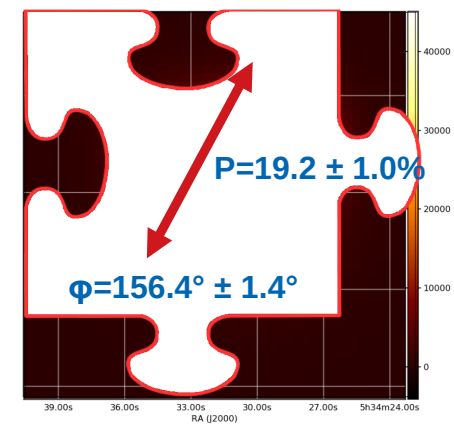
Radio polarization



IR polarization



Optical polarization



X-ray polarization
Weisskopf et al. 1976

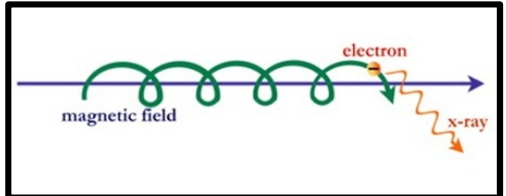
INTRODUCTION

X-RAY POLARIMETRY

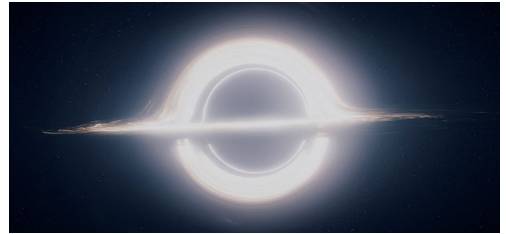
TECHNIQUE	OBSERVABLE	INFORMATION
• Imaging:	Position	Morphology
• Spectroscopy:	Energy	Composition, processes
• Timing:	Arrival time	Variability
• POLARIMETRY:	1) Polarization Degree 2) Polarization Angle	Processes / asymmetry Geometry / B Field

Polarization arises when there is a preferred direction

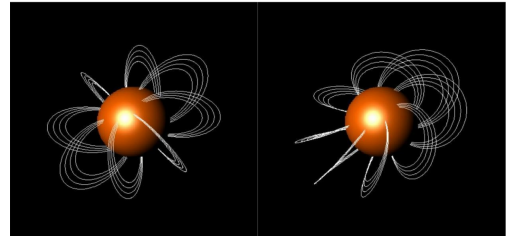
Non-Thermal emission: e.g. synchrotron



Geometrical Asymmetry e.g. accretion disk, jets, columns, blobs, etc...



Radiative transfer in strong gravitational / magnetic field

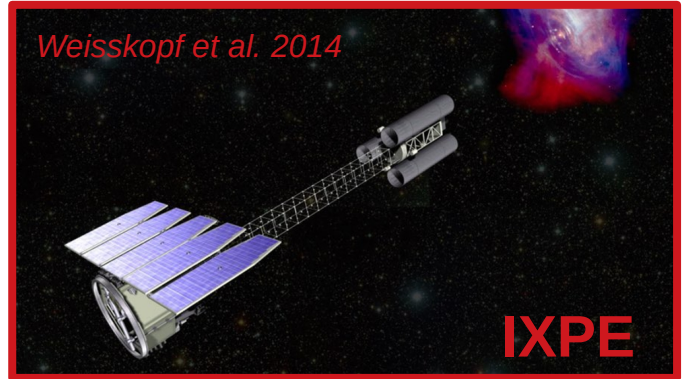




First X-ray polarimeters flown on sounding rockets.

Angel et al. 1969
Wolff et al. 1970
Novick 1970
Tindo et al. 1970
Novick et al. 1972

Dark age:
many X-ray polarimeters developed, none flown...
e.g. Kaaret et al. 1989



Weisskopf et al. 2014

IXPE

1969 - 1972

1976

...

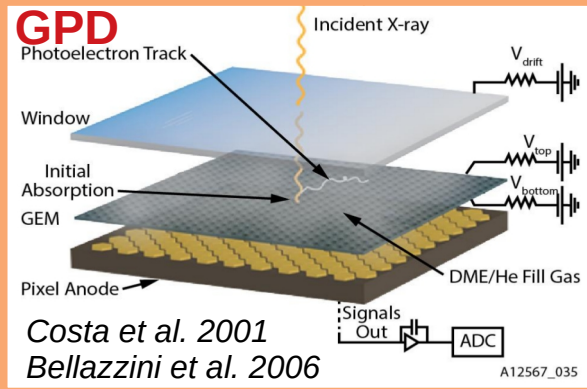
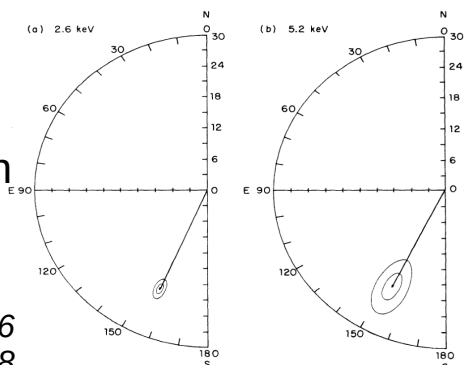
2000'

2017

2021

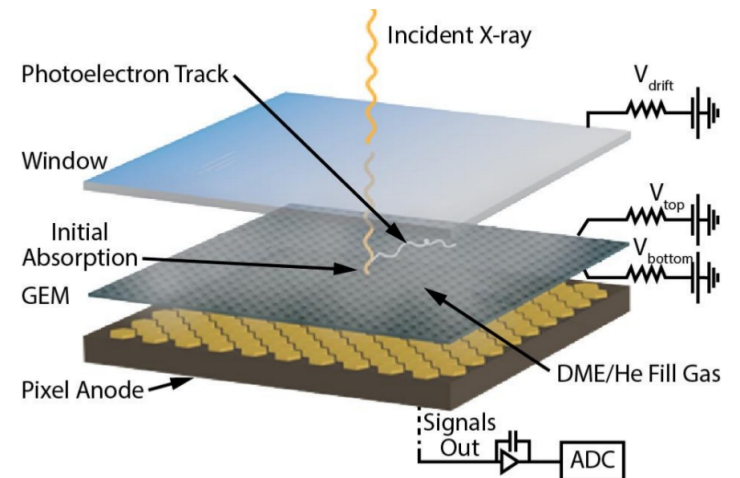
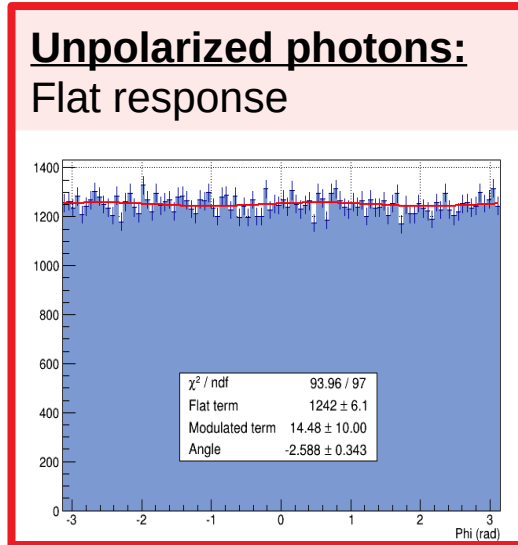
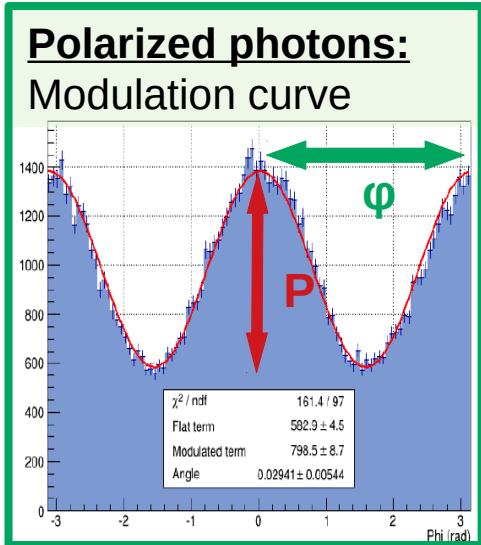
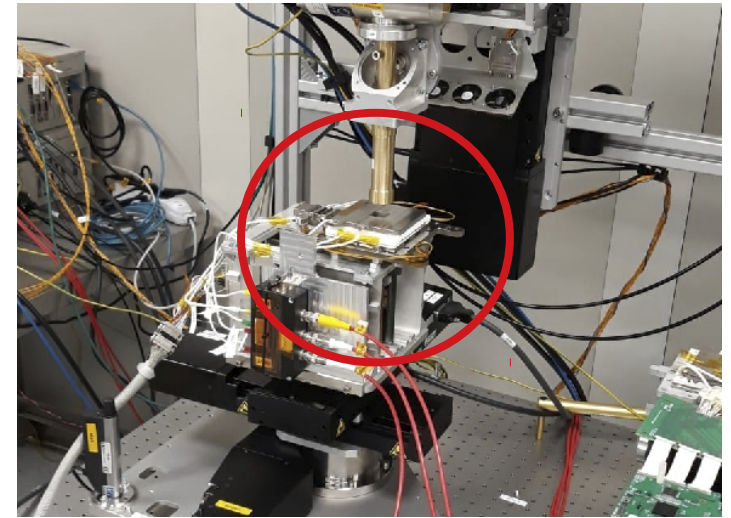
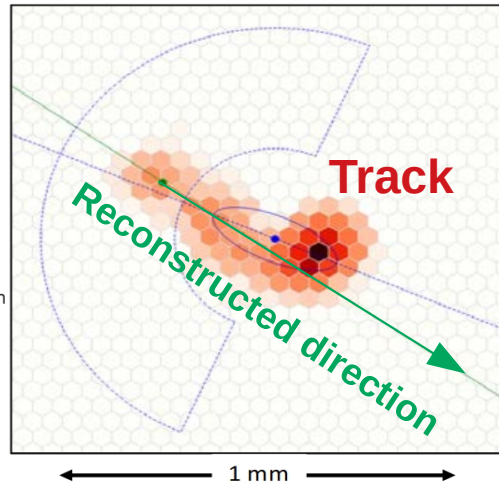
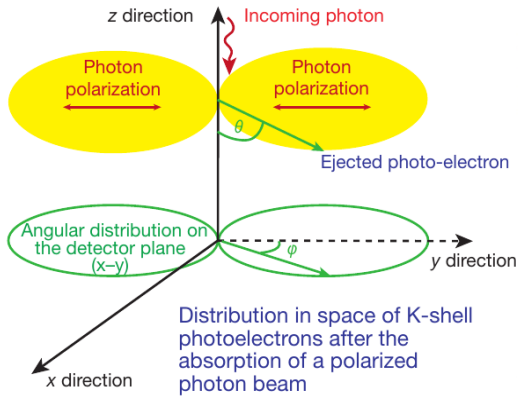
OSO-8: First significant detection of X-ray polarization from the **Crab Nebula.**

Weisskopf et al. 1976
Weisskopf et al. 1978



INTRODUCTION

THE GAS PIXEL DETECTOR (GPD)

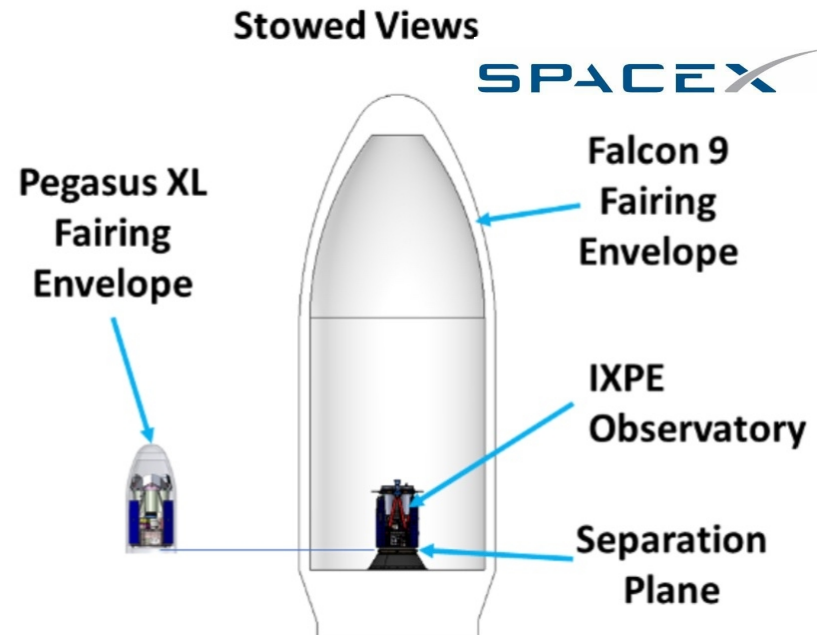
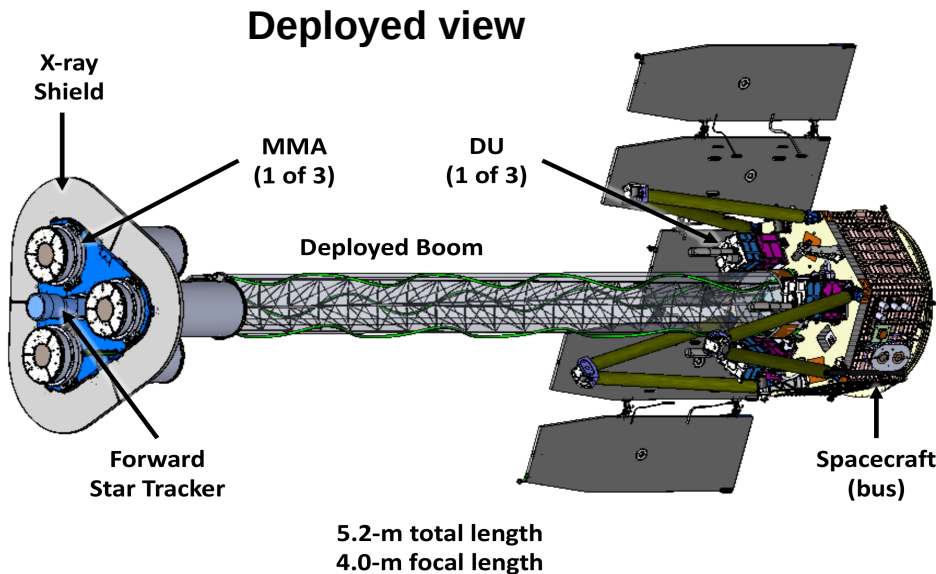


INTRODUCTION

THE IMAGING X-RAY POLARIMETRY EXPLORER (IXPE)

- **Imaging X-ray Polarimetry Explorer (IXPE)**
- **Launch:** on **Falcon 9** in **April May September NOVEMBER 2021**.
- **Orbit:** circular, **600 km**, **0.2°** inclination.
- **Capabilities:** **30''** PSF, **12.8'x12.8'** FOV, **2 – 8 keV** energy band.

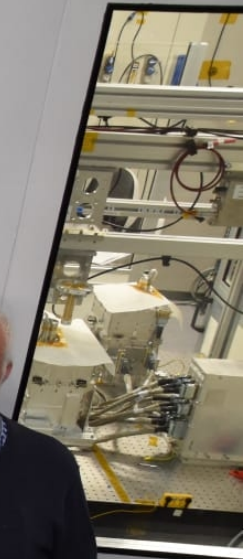
 Marshall Space Flight Center PI team, project management, SE and S&MA oversight, mirror module fabrication, X-ray calibration, science operations, and data analysis and archiving	 INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS Polarization-sensitive imaging detector systems   
 QMI sistema spaziale italiano Detector system funding, ground station	 LASP Mission operations
 Ball Spacecraft, payload structure, payload, observatory I&T	 ROMA TRE UNIVERSITA' DEGLI STUDI  Stanford University Scientific theory
	 McGill Co-Investigator
	 MIT Massachusetts Institute of Technology Co-Investigator



INTRODUCTION

STATUS OF THE IXPE MISSION

Delivery of Flight
Detector Unit (DU)2
in December 2019



Me :)

INTRODUCTION

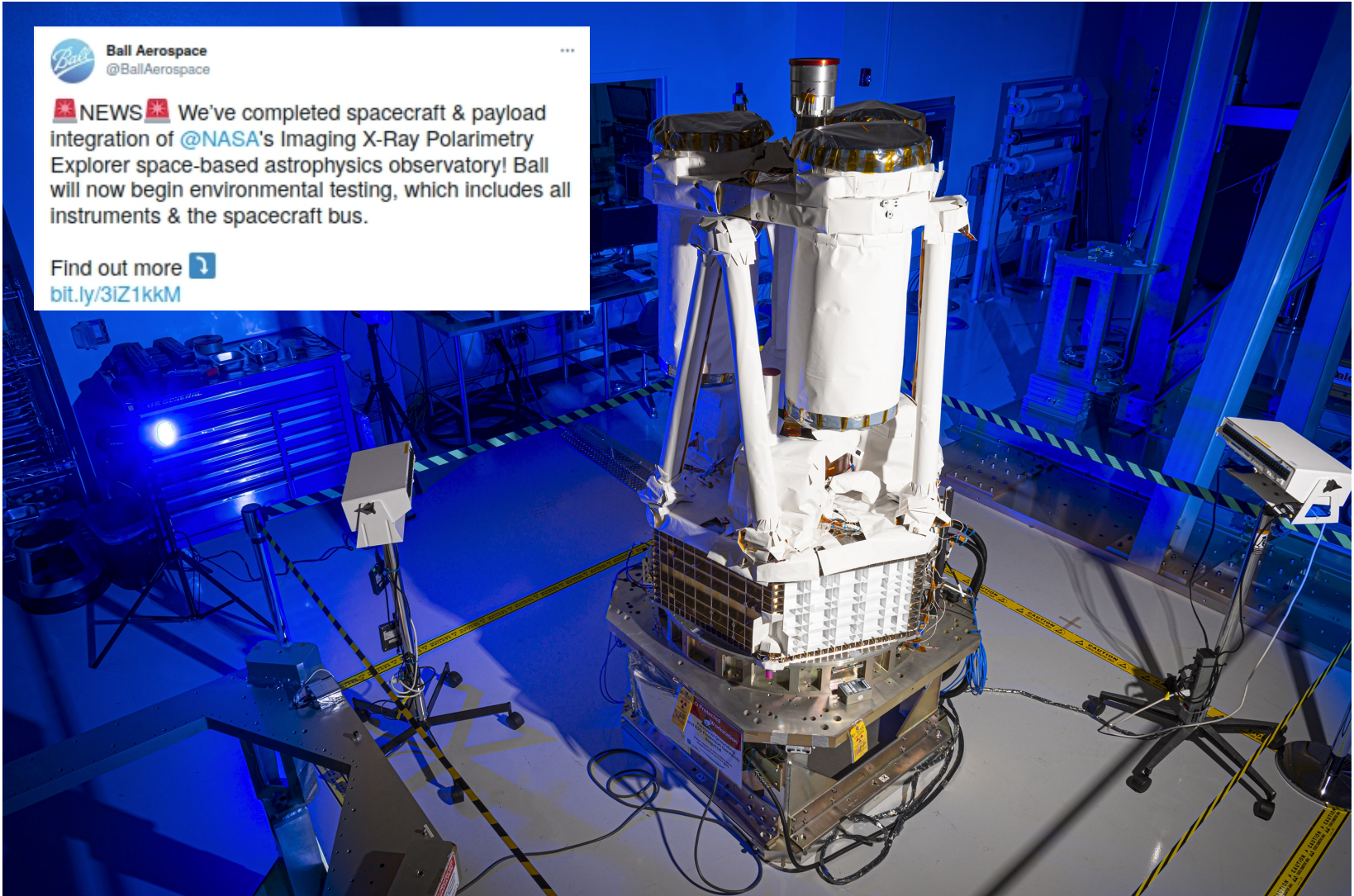
STATUS OF THE IXPE MISSION



Ball Aerospace
@BallAerospace

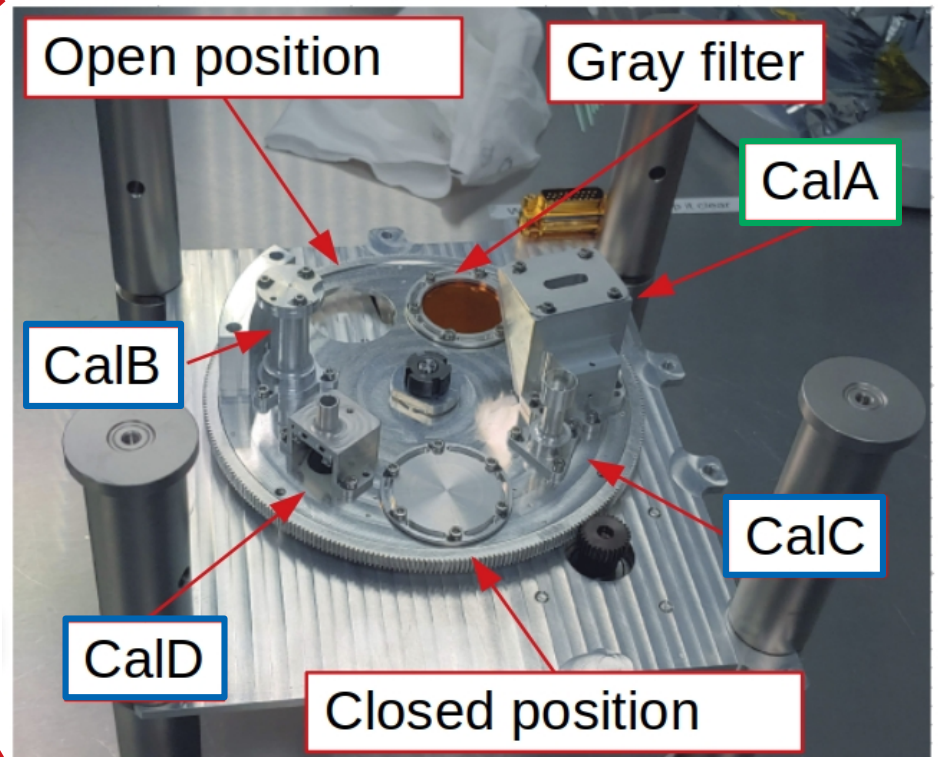
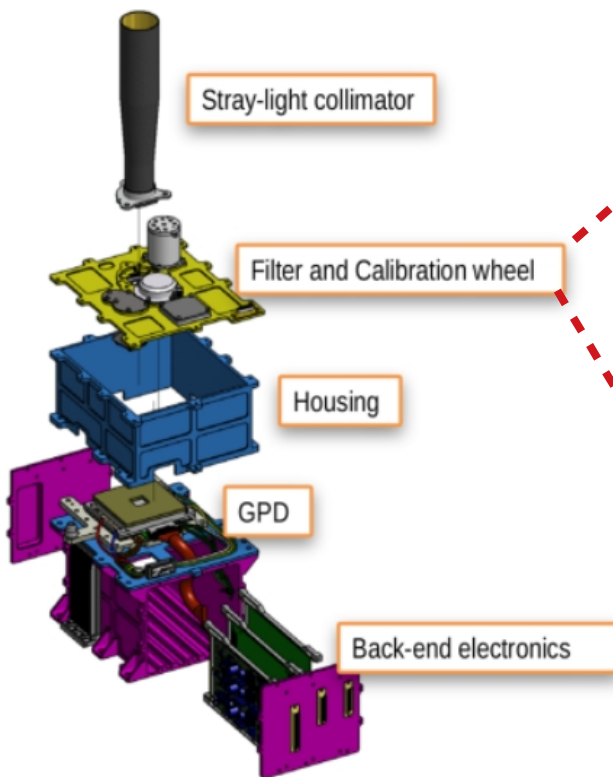
📰 NEWS 📰 We've completed spacecraft & payload integration of @NASA's Imaging X-Ray Polarimetry Explorer space-based astrophysics observatory! Ball will now begin environmental testing, which includes all instruments & the spacecraft bus.

Find out more bit.ly/3IZ1kkM



CALIBRABILITY IN SPACE THE FILTER AND CALIBRATION SET

- No Celestial polarized X-Ray source is available: **we have to bring our own calibration sources!**
- **Filter and Calibration Set (FCS)** with **1 polarized** and **3 unpolarized** sources;
- Each source powered by a ^{55}Fe radioactive nuclide.



CALIBRABILITY IN SPACE

TESTING SETUP



SDD: calibration source spectrum

CCD camera: calibration source image



DU with
GPD and
FCS in
Thermal
Vacuum:
polarization
properties
and counting
rate of
calibration
sources
in vacuum



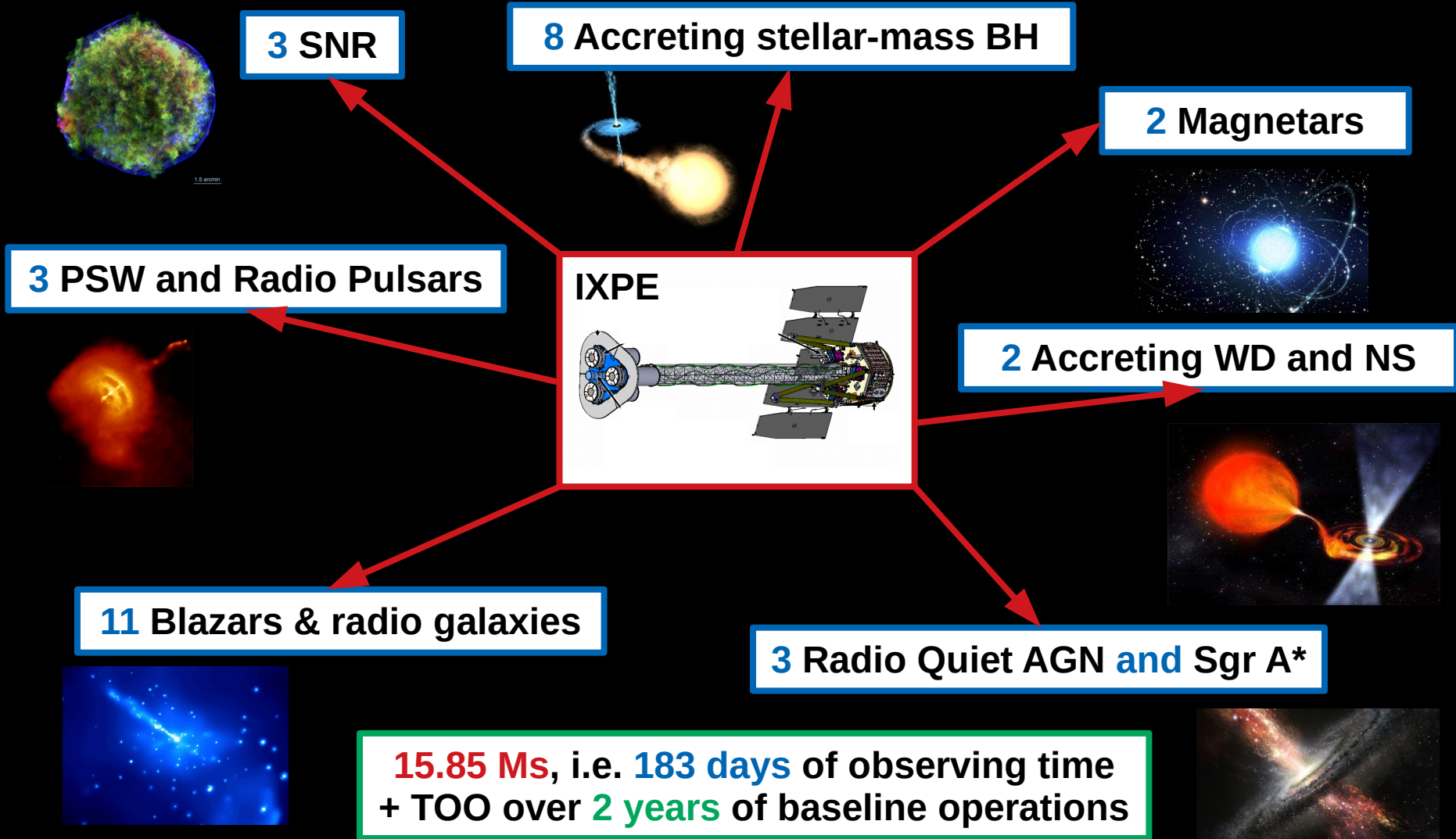
In-flight calibration system of Imaging X-ray Polarimetry Explorer

R. Ferazzoli et al., JATIS, 6(4), 048002 (2020)



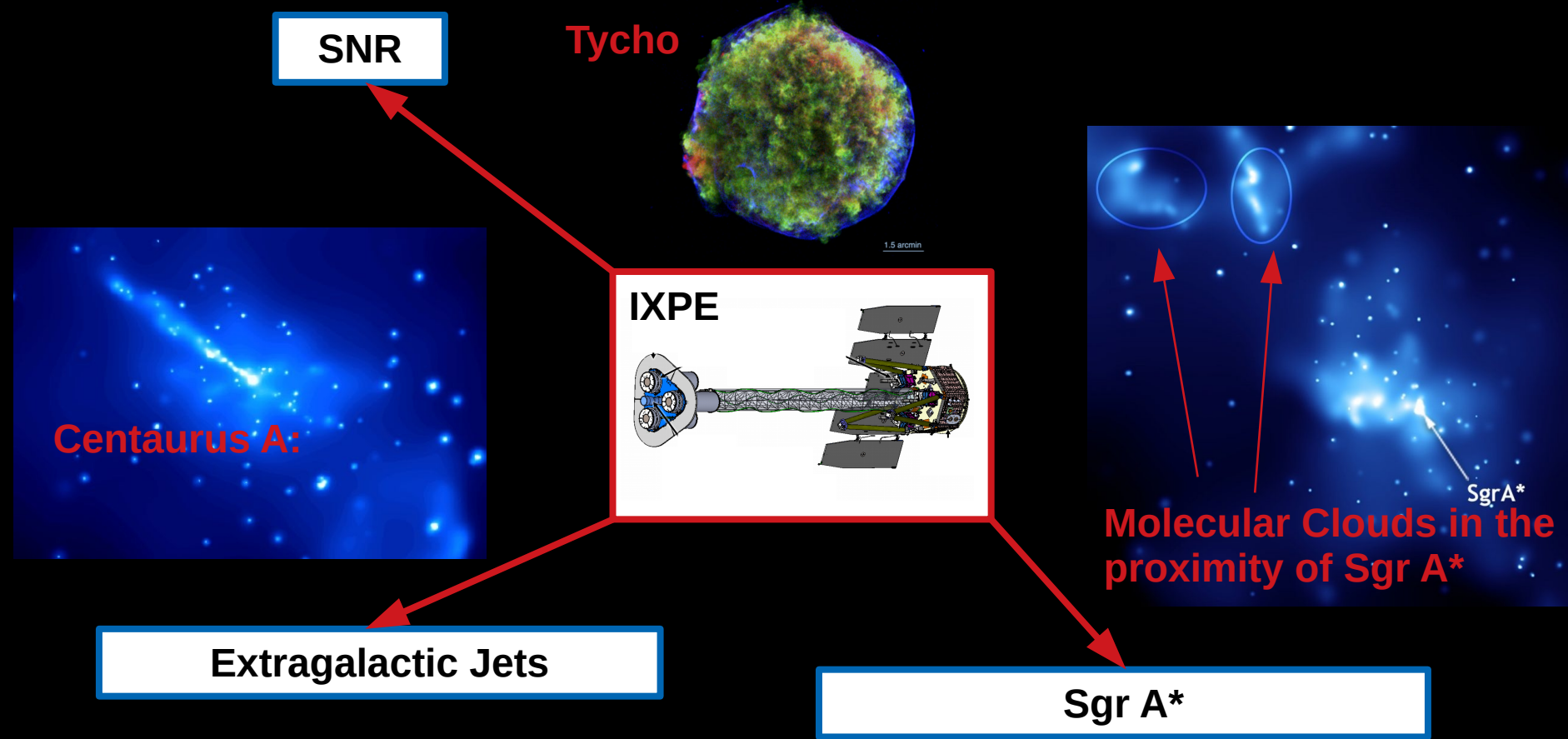
X-RAY POLARIMETRY OF EXTENDED SOURCES

IXPE TARGET LIST

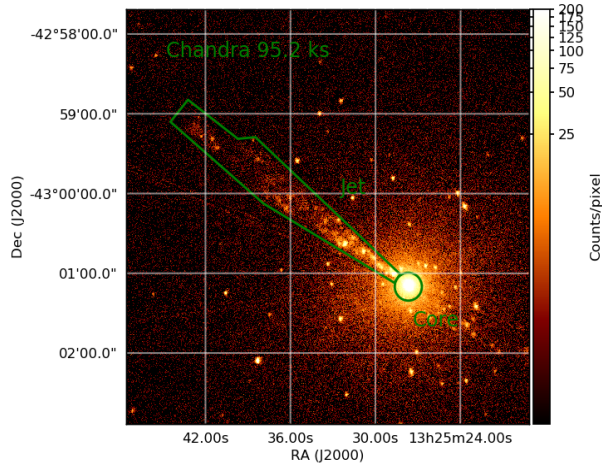


X-RAY POLARIMETRY OF EXTENDED SOURCES

IXPE TARGET LIST

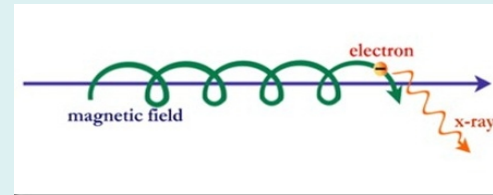


X-RAY POLARIMETRY OF EXTENDED SOURCES EMISSION PROCESSES IN EXTRAGALACTIC JETS



Synchrotron:

P similar to radio/optical if same seed photons involved

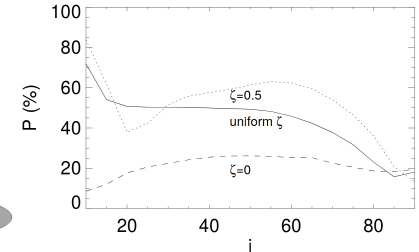
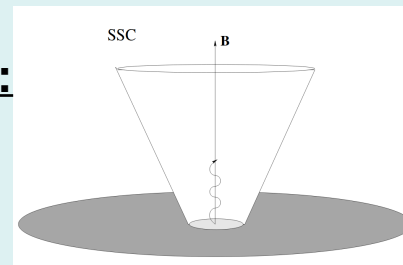


$$P_{max} = \frac{p}{p + \frac{7}{3}}$$

$$p = 2\alpha + 1$$

Synchrotron Self-Compton:

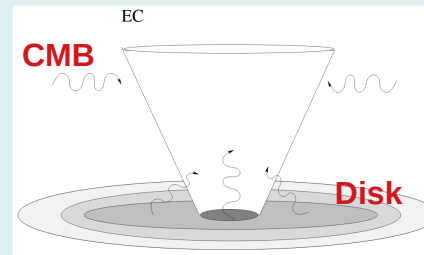
P depends on inclination **i** and seed photon distribution



Radio/optical Jet emission consistent with Synchrotron but X-ray emission mechanism not yet constrained!

External Compton:

seed photons may come from the **Disk** and/or the **CMB**

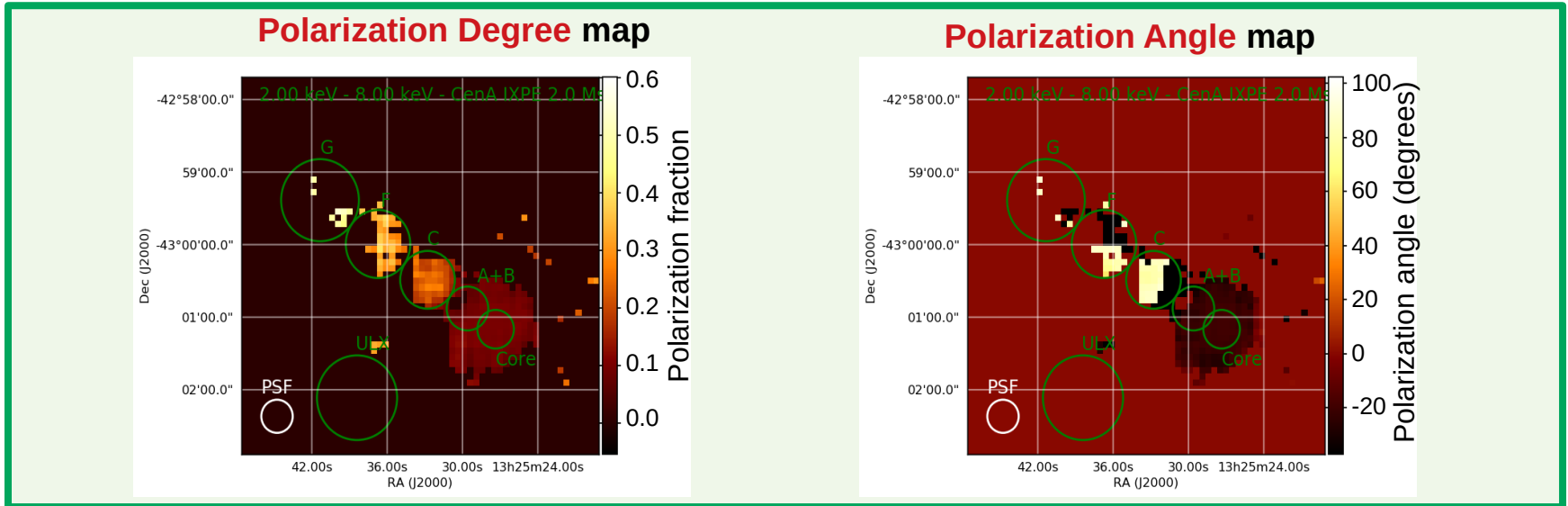
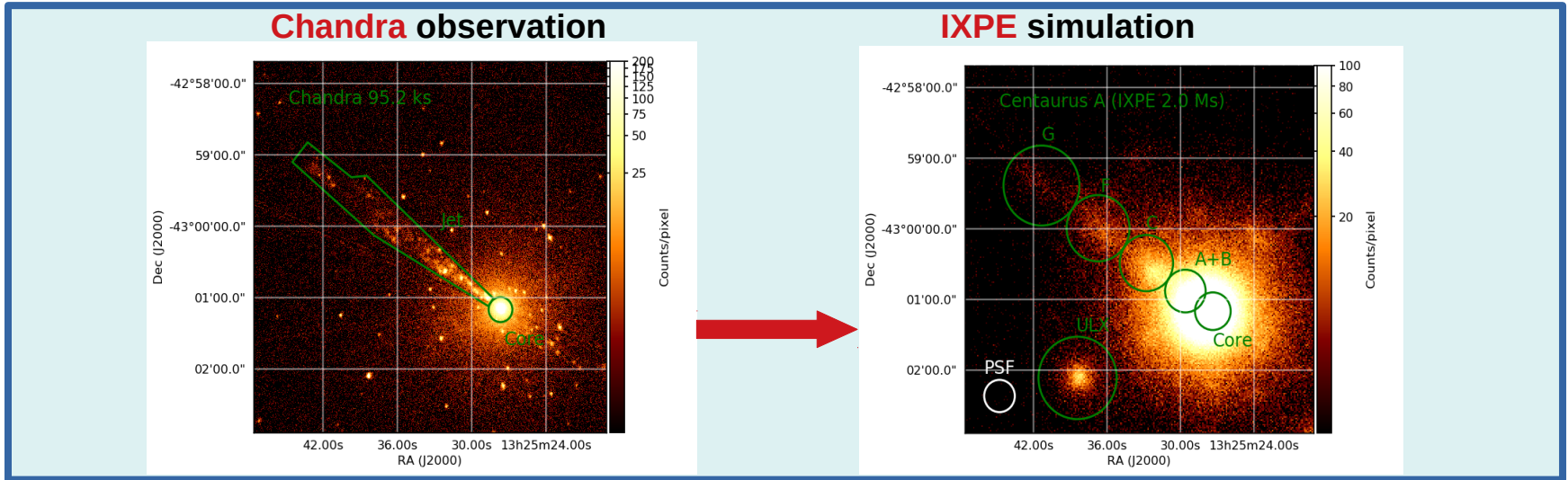


(McNamara et al. 2009)

i [deg]	P (%) (E=1-10 keV)
10	4.2
45	16.5
80	23.9

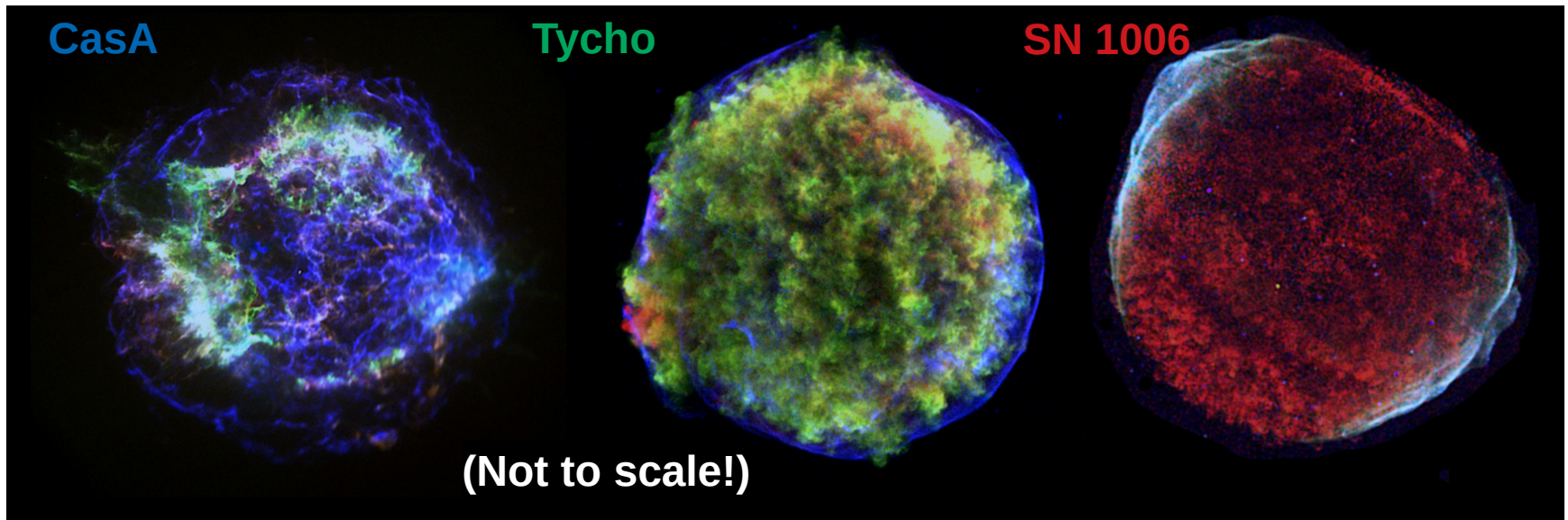
X-RAY POLARIMETRY OF EXTENDED SOURCES

EMISSION PROCESSES IN EXTRAGALACTIC JETS: CENTAURUS A



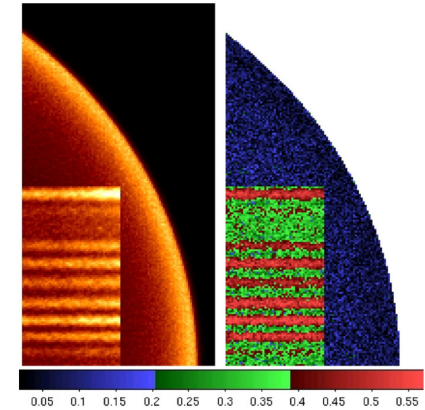
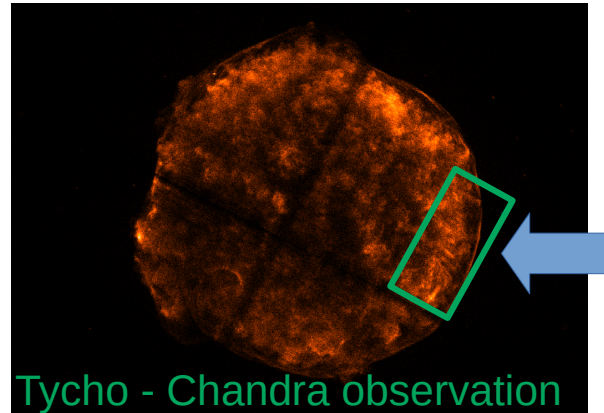
X-RAY POLARIMETRY OF EXTENDED SOURCES SUPERNOVA REMNANTS

CasA, **Tycho**, and **SN 1006** will be part of the IXPE 1st year observation plan.

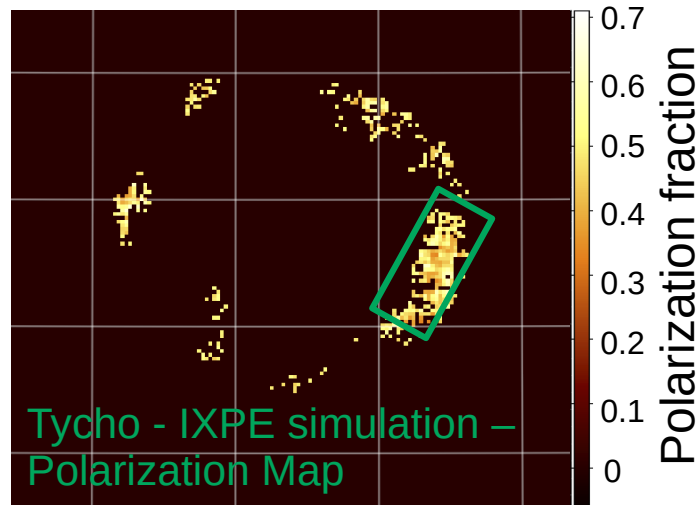


X-RAY POLARIMETRY OF EXTENDED SOURCES SUPERNOVA REMNANTS

- Young SNR are thought to be the source of **Galactic Cosmic Rays**
- Lines and thermal continuum (unpolarized) dominates **1 - 4 keV**
- Non-thermal emission (polarized) dominates **4 - 6 keV**
- **Imaging** allows to separate the thermalized plasma from the regions where particles are accelerated.
- What is the **orientation** of the magnetic field?
- How **ordered / turbulent** is it?




Bykov et al. 2009




**Diffusive
Shock
Acceleration:**

- **Synchrotron emission** in region of active particle acceleration (i.e. **Shock fronts**)


X-RAY POLARIMETRY OF EXTENDED SOURCES EFFECT OF INSTRUMENTAL BACKGROUND IN SNR






Astroparticle Physics
Available online 6 February 2021, 102566
In Press, Journal Pre-proof



A Study of Background for IXPE

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

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<https://doi.org/10.1016/j.astropartphys.2021.102566>  [Get rights and content](#)

Abstract

Focal plane X-ray polarimetry is intended for relatively bright sources with a negligible impact of background. However this might not be always possible for IXPE (Imaging X-ray Polarimetry Explorer) when observing faint extended sources like supernova remnants. We present for the first time the expected background of IXPE by Monte Carlo simulation and its impact on real observations of point and extended X-ray sources. The simulation of background has been performed by Monte Carlo based on GEANT4 framework. The spacecraft and the detector units have been modeled, and the expected background components in IXPE orbital environment have been evaluated. We studied different background rejection techniques based on the analysis of the tracks collected by the Gas Pixel Detectors on board IXPE. The estimated background is about 2.9 times larger than the requirement, yet it is still negligible when observing point like sources. Albeit small, the impact on supernova remnants indicates the need for a background subtraction for the observation of the extended sources.

Expected IXPE instrumental background counting rate:

1.16×10^{-2} counts/s¹/cm²/DU (2 – 8 keV)

Value consistent with the one measured by the GPD on Polarlight cubesat (*Huang et al. 2021*).

Still negligible for point-sources, what about extended sources (e.g. SNR)?

- | | Bkg effect | P dilution |
|------------------|-----------------------|-------------|
| • <u>CasA:</u> | negligible | <<1% |
| • <u>Tycho:</u> | almost negligible | ~1.5% |
| • <u>SN1006:</u> | NOT negligible | ~18% |

X-RAY POLARIMETRY OF EXTENDED SOURCES GALACTIC ARCHAEOLOGY

Today Sgr A* is “X-ray dim”: $L_x \sim 2 \times 10^{33} \text{ erg s}^{-1}$.

However, **signs of active past:**

- Fermi-LAT: gamma-ray bubbles (*Su et al. 2010; Zubovas et al. 2011*);
- Gas distribution in CMZ reminiscent of AGN torus (*Ramos Almeida & Ricci 2017*);
- **X-ray reflection features in Molecular Clouds but no (persistent) source strong enough to have produced them!** (*Sunyaev et al. 1993*)

Was Sgr A* X-ray luminosity 10^6 larger “JUST” ≈ 300 years ago?

6-7 keV X-rays

30 pc

G.11-0.11 Central Molecular Zone (CMZ)

cloud

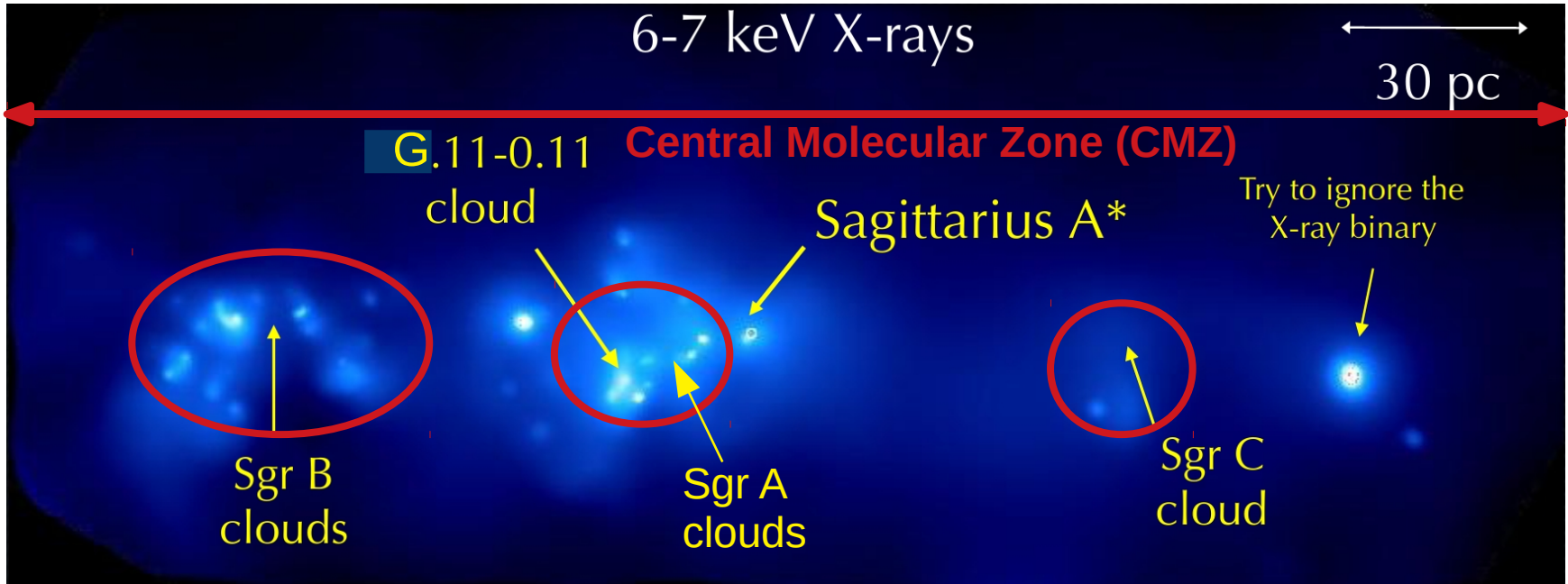
Sagittarius A*

Try to ignore the
X-ray binary

Sgr B
clouds

Sgr A
clouds

Sgr C
cloud



X-RAY POLARIMETRY OF EXTENDED SOURCES GALACTIC ARCHAEOLOGY

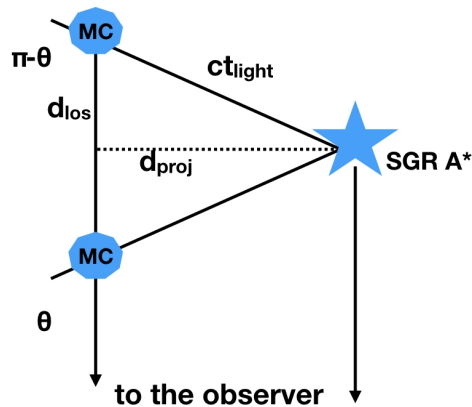
An X-ray polarimetric observation could solve this mystery!

Direction of external illumination source from **polarization angle**

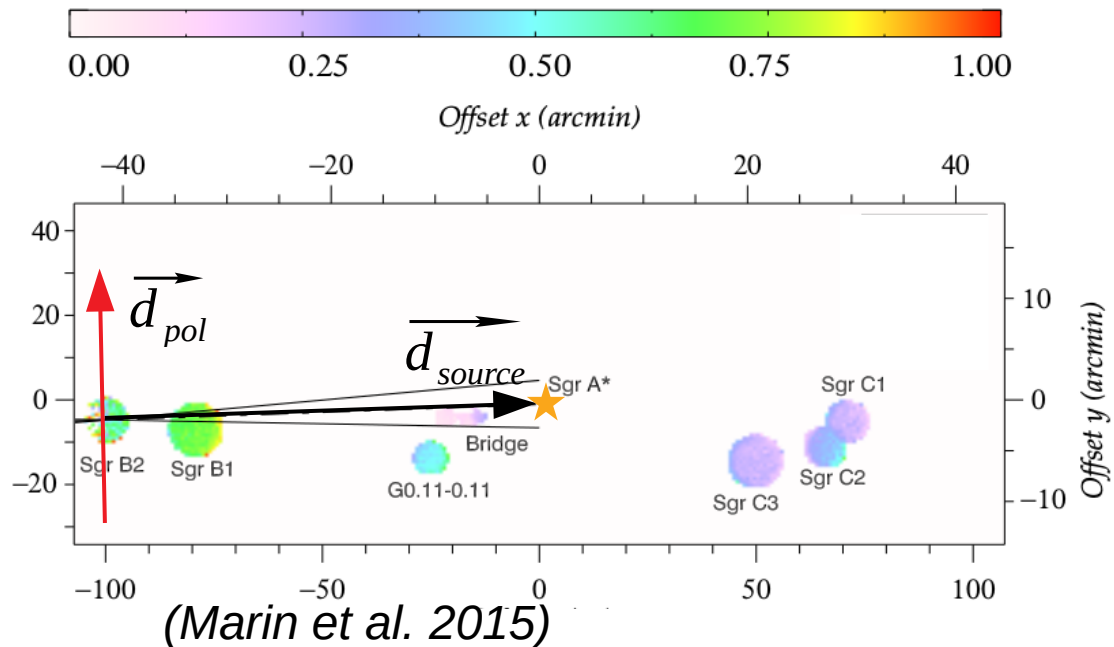
$$\vec{d}_{pol} \perp \vec{d}_{source}$$

Scattering angle θ → cloud distance along l.o.s → **polarization degree**

$$P = \frac{1 - \cos(\theta)}{1 + \cos(\theta)} \rightarrow d_{los} = d_{proj} \cot(\theta)$$



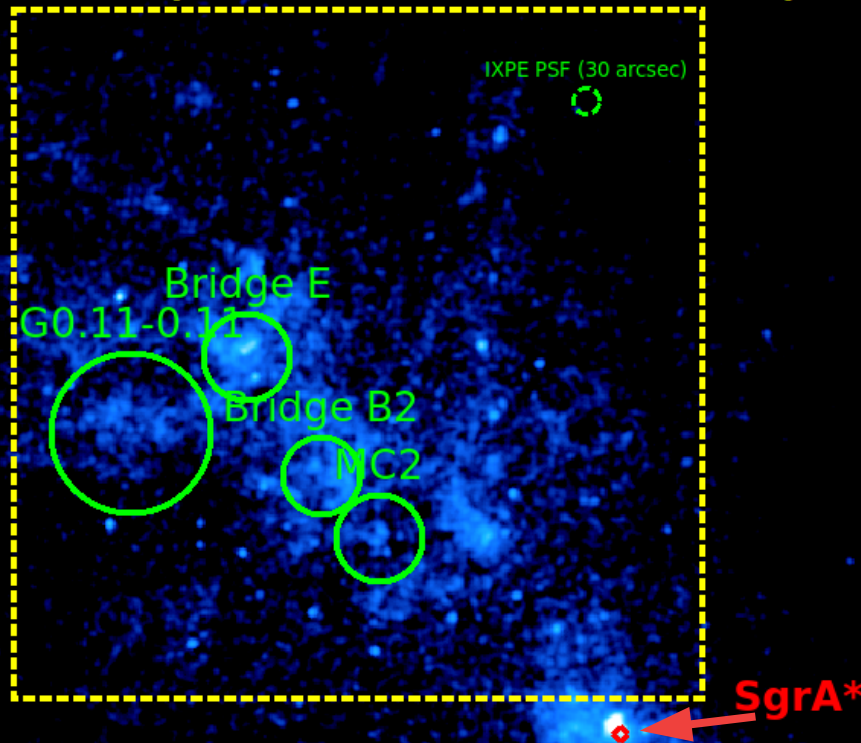
Polarization fraction



X-RAY POLARIMETRY OF EXTENDED SOURCES GALACTIC ARCHAEOLOGY

IXPE will observe this region for at least **1 Ms** during its first year of operations

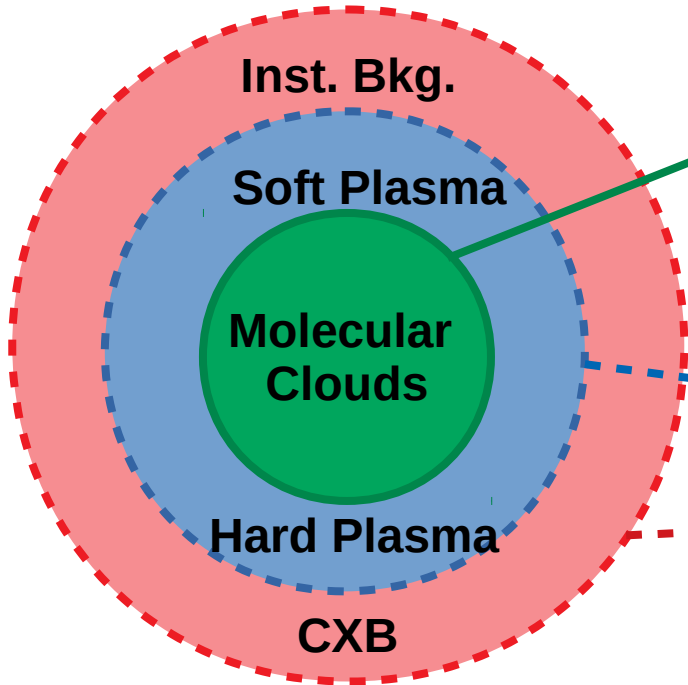
IXPE f.o.v. (12.8 arcmin x 12.8 arcmin)



(Chandra 6.4 keV map of Sgr A complex)

X-RAY POLARIMETRY OF EXTENDED SOURCES

GALACTIC ARCHAEOLOGY

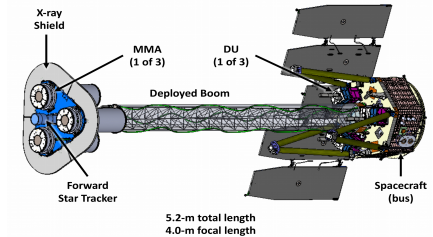


Theoretical Polarization degree

$$P = \frac{1 - \cos(\theta)}{1 + \cos(\theta)}$$

Diluted by:

- Diffuse emission
- Background
- PSF



Another problem:
 morphology and brightness of Molecular Clouds changes with time!

X-RAY POLARIMETRY OF EXTENDED SOURCES

GALACTIC ARCHAEOLOGY

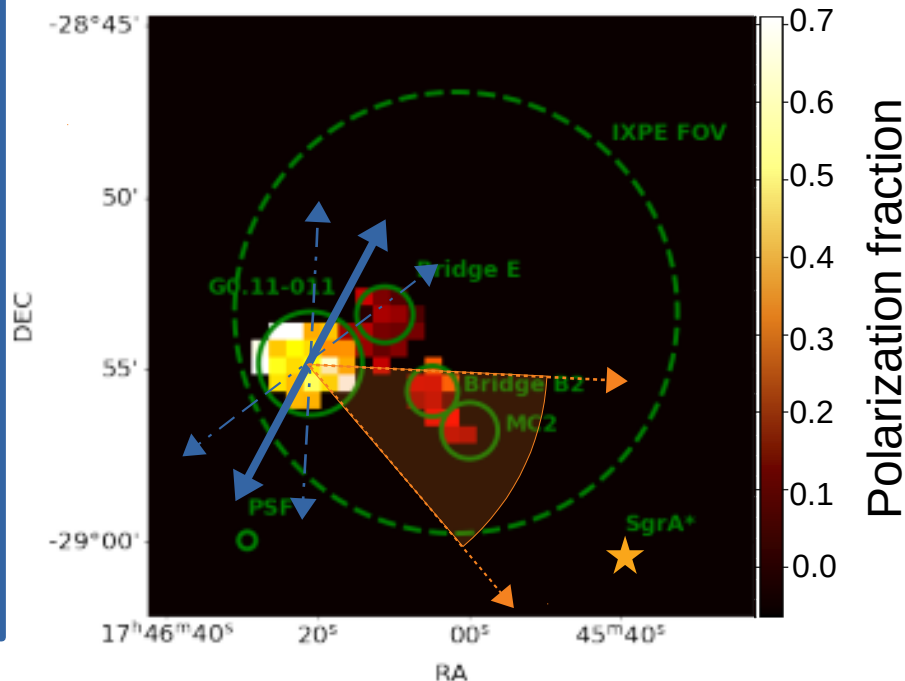
Prospects for IXPE and eXTP polarimetric archaeology of the reflection nebulae in the Galactic center



L. Di Gesu, R. Ferazzoli et al. *A&A*, 643, A52 (2020)

- The **blue arrows** represent the **polarization angle** (with uncertainty)
- The **orange region** the direction of the **external illuminating source** (that includes **Sgr A*!**)

IXPE polarization map of Sgr A complex



Ongoing work:

- Off-axis response.
- Minimum detectable polarization maps.
- Background effects.
- Reconstruction of intrinsic polarization.

X-ray polarimetry can:

Probe strong magnetic and gravitational fields;
Investigate small-scale source geometry through scattering;
Identify emission processes.

Imaging with IXPE:

Maps with magnetic field and source geometry;
Enhances sensitivity in diffuse sources.

In-flight Calibration needed to:

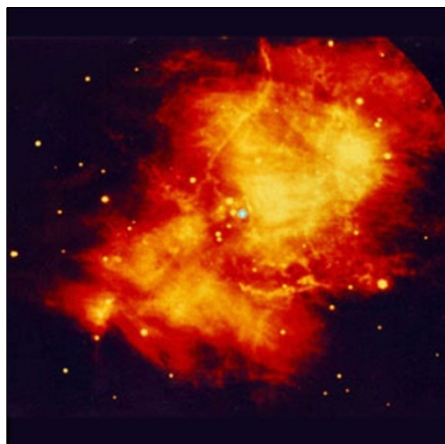
Study the behavior of the GPD in orbit;
Validate the scientific results.

IXPE is launching soon: X-ray polarimetry is coming back!

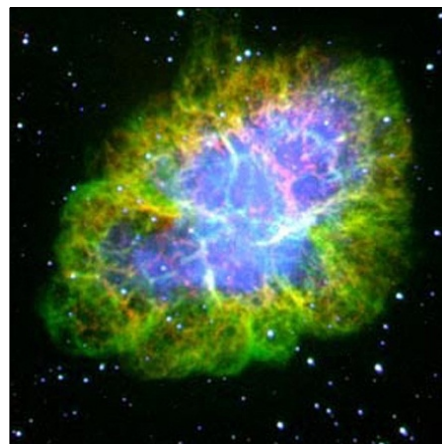
CONCLUSION:
COMPLETE THE PICTURE



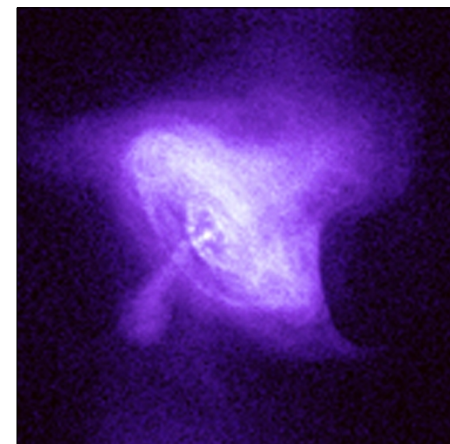
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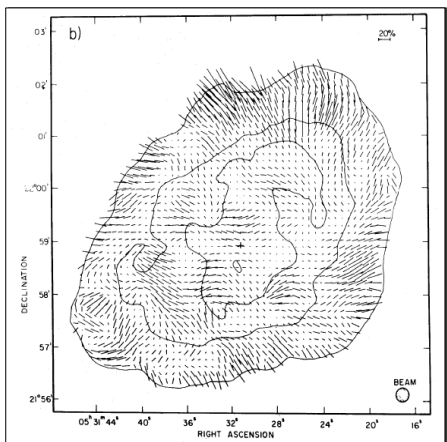
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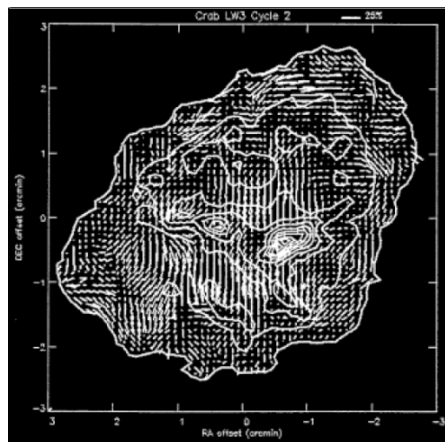
Optical (Palomar)



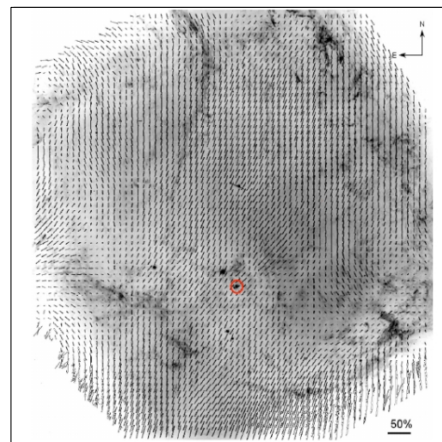
X-rays (Chandra)



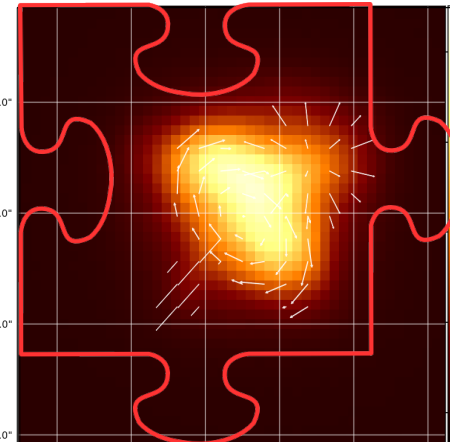
Radio polarization



IR polarization



Optical
polarization



X-ray polarization
(IXPE)



IXPE
Imaging
X-Ray
Polarimetry
Explorer



Thank you for the attention and stay safe!

Prospects for IXPE and eXTP polarimetric archaeology of the reflection nebulae in the Galactic center

L. Di Gesu, R. Ferazzoli et al. *A&A*, 643, A52 (2020)



In-flight calibration system of Imaging X-ray Polarimetry Explorer

R. Ferazzoli et al., *JATIS*, 6(4), 048002 (2020)



A Study of background for IXPE

F. Xie, R. Ferrazzoli et al., *Astroparticle Physics* 128 (2021)

