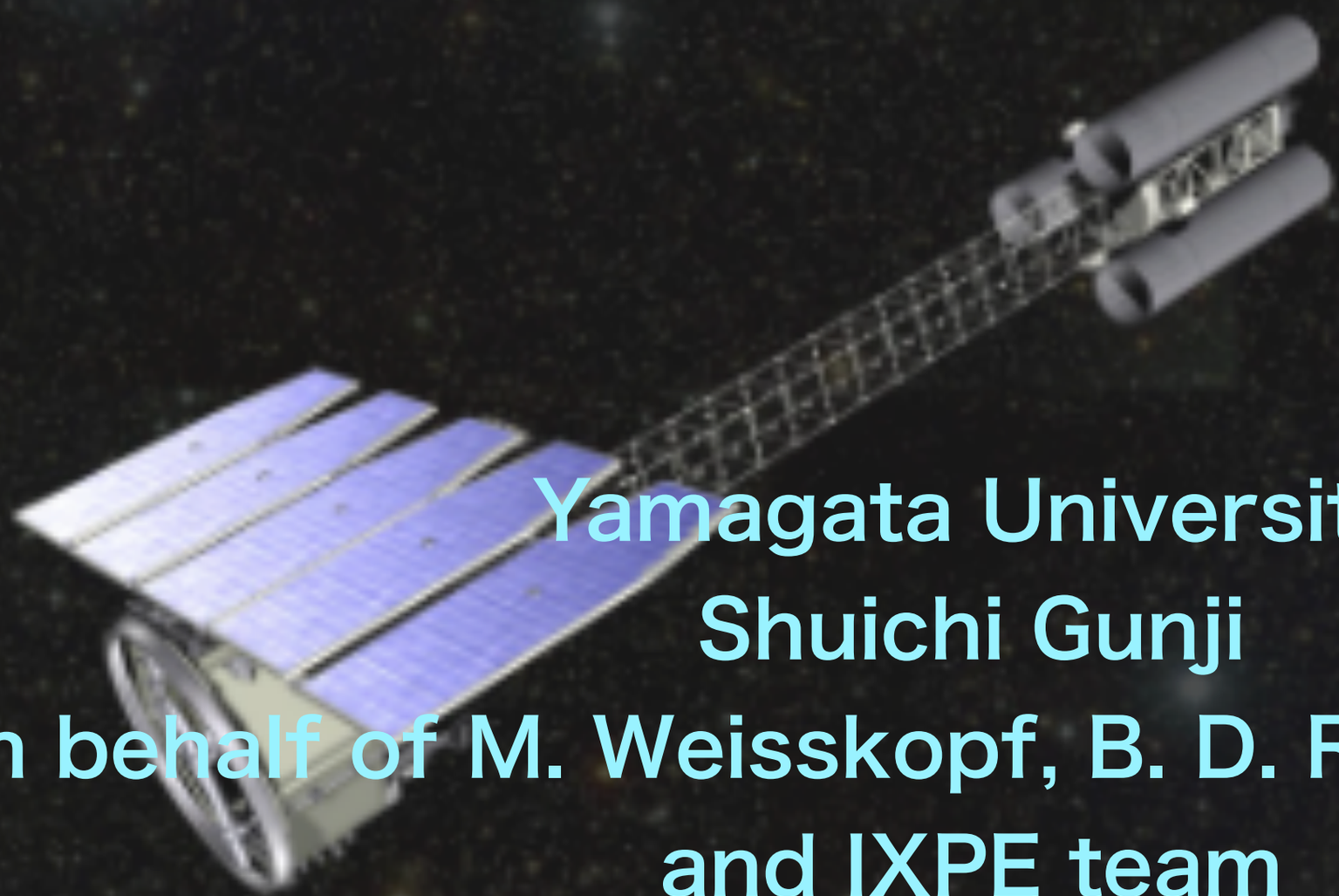
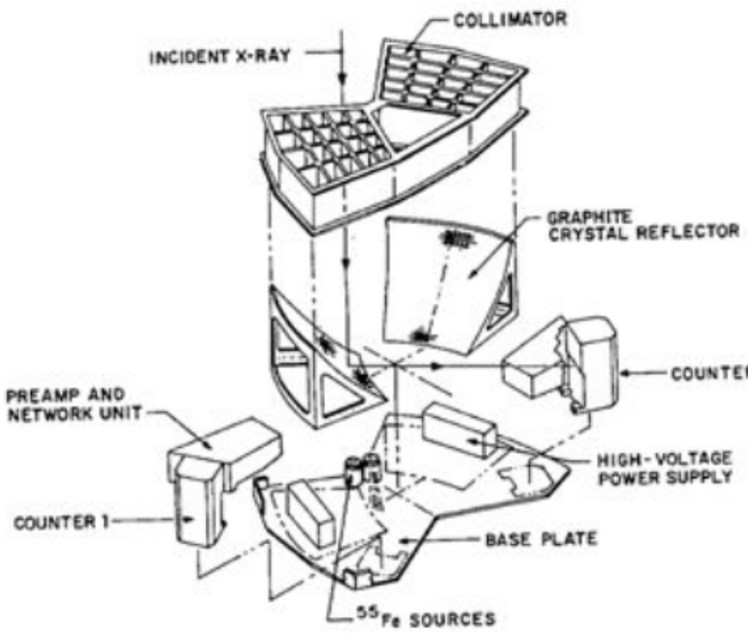
Imaging X-Ray Polarimetry Explorer

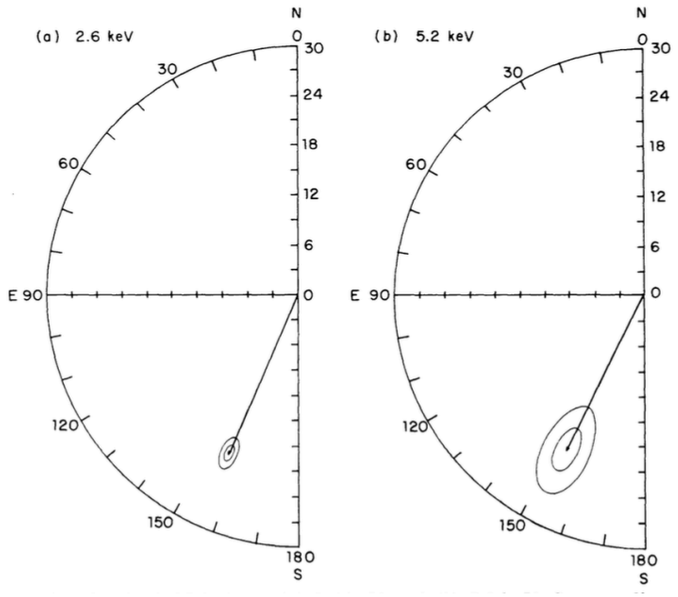


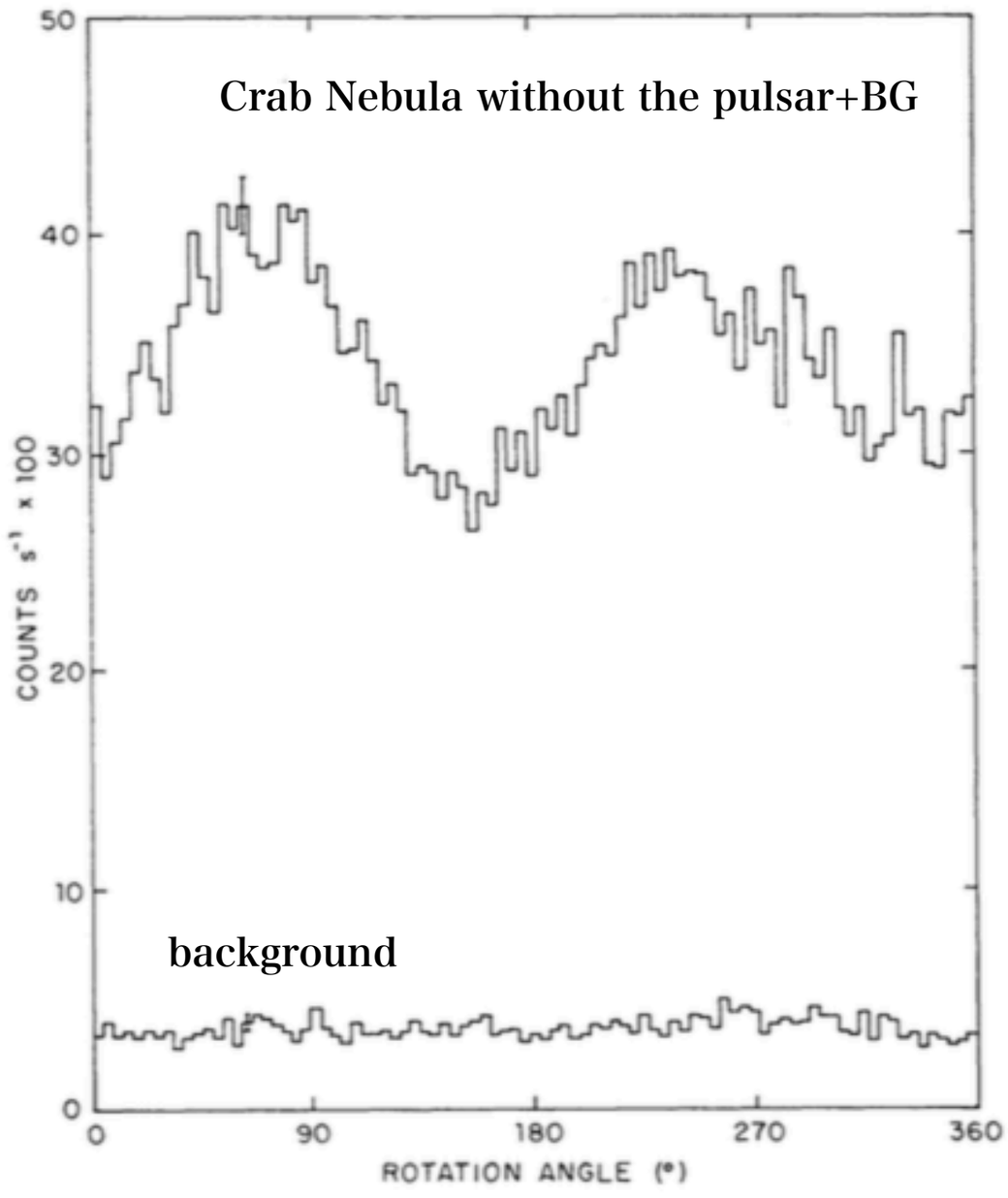
Yamagata University
Shuichi Gunji
On behalf of M. Weisskopf, B. D. Ramsey, S. O'Dell
and IXPE team

1. Introduction

From the measurement of polarization for Crab Nebula by OSO 8,
the history of the X-ray polarimetry had started.







Weisskopf et al. Ap.J. 220 (1978)

It also told us the lessons learned to the next step.

Below 10 keV, the expected degree of polarization will be at most several percents for black holes, pulsar, AGN, SNR, magnetar, and so on.

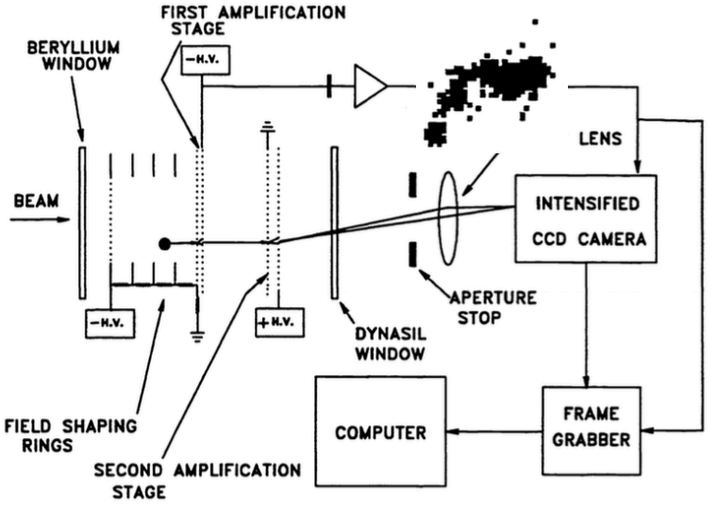
↓

1)We must improve the ratio of the signal to the background.

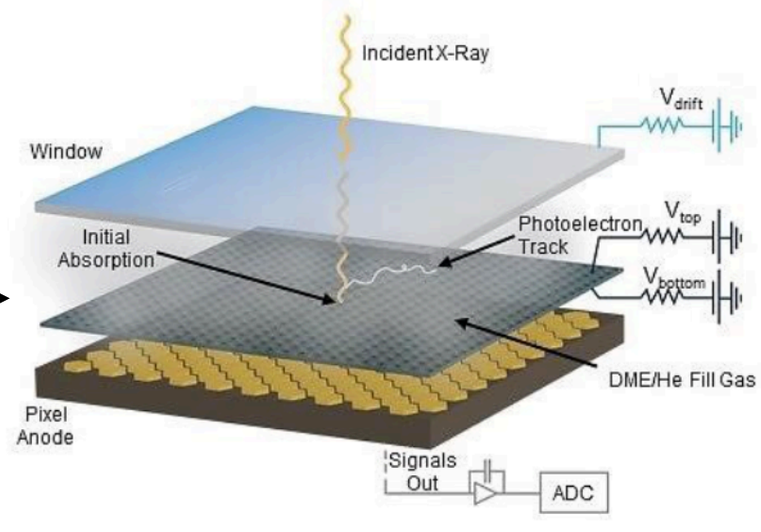
- An x-ray mirror should be used.
- The Bragg polarimeter is sensitive only in certain discrete energies.
  Required is the polarimeter with wide energy band, better detection efficiency and moderate modulation factor. The new type of polarimeter is necessary.

2) The systematic error should be reduced less than ~1%.

- The design of the polarimeter should be symmetrical.
- The imaging capability can be very useful to investigate the systematic error.



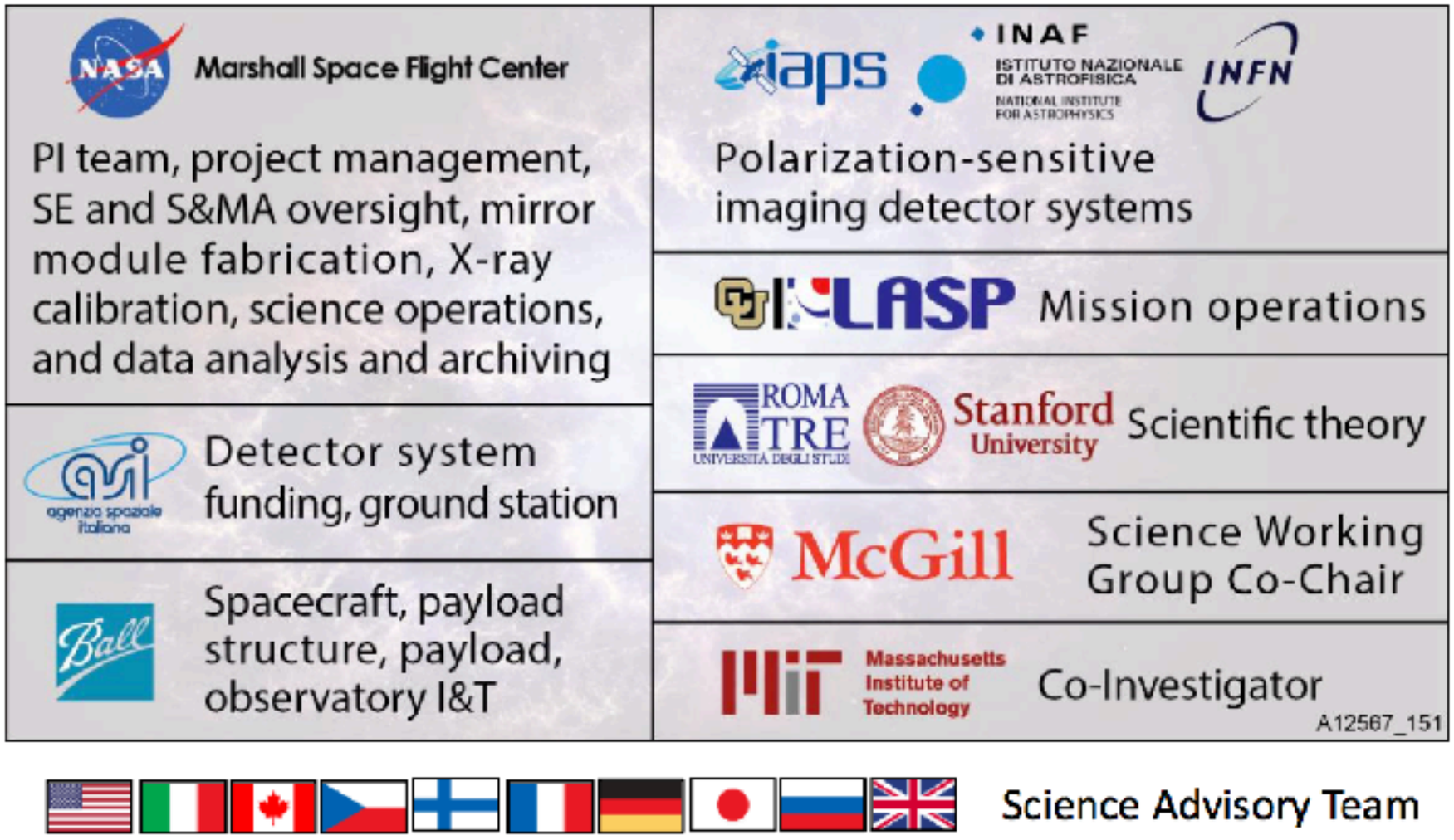
R.A. Austin, T. Minamitani, and B. D. Ramsey SPIE 2010 (1993)



E.Costa et. al, Nature 411 (2001)

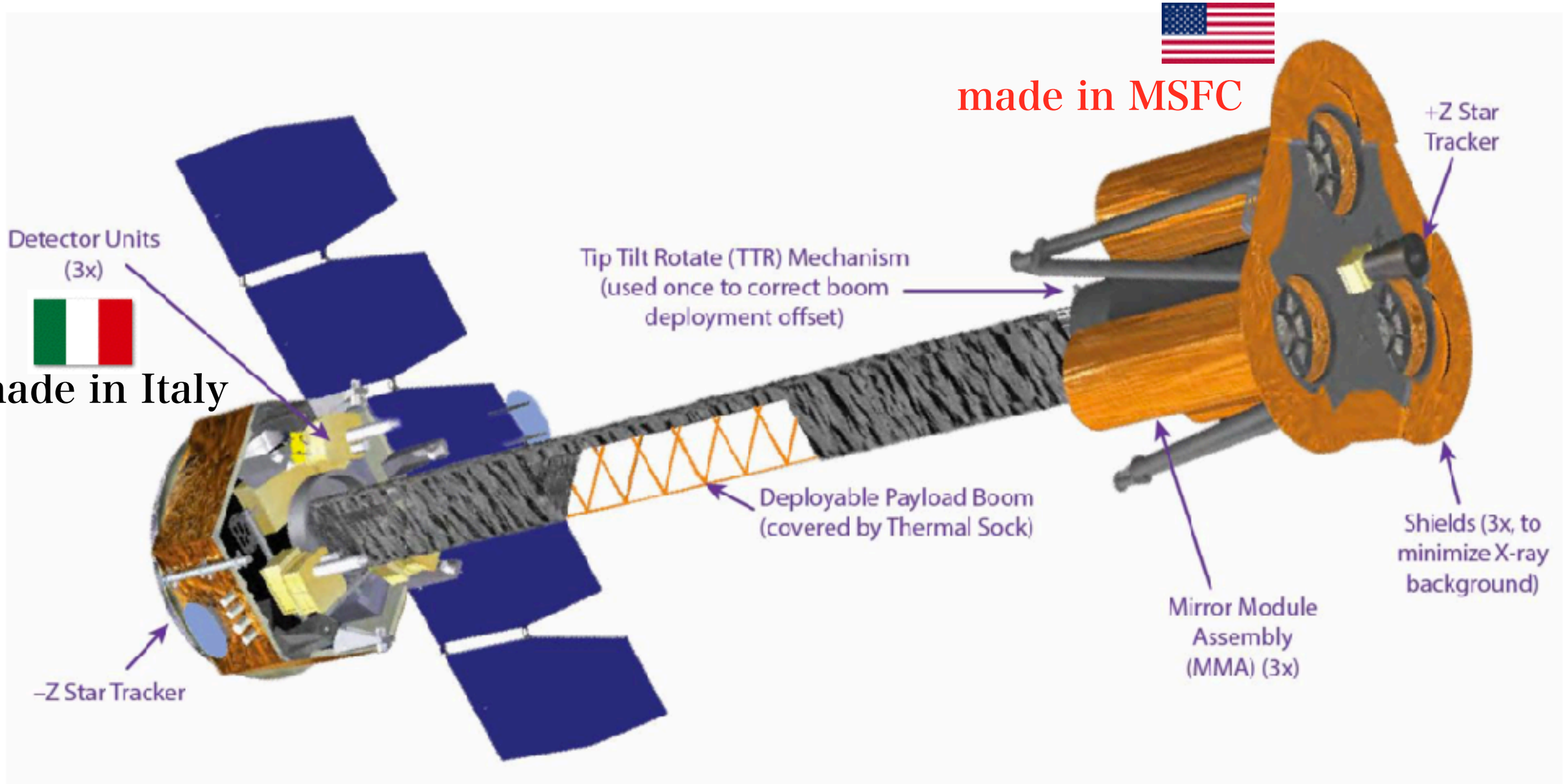
2. IXPE

P.I. : Martin Weisskopf.



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

Collaborators: L. Baldini, A. Brez, N. Bucciantini, E. Churazov, S. Citrano, E. Del Monte, N. Di Lalla, I. Donnarumma, M. Dovčiak, Y. Evangelista, S. Fabiani, R. Goosmann, S. Gunji, V. Karas, M. Kuss, L. Latronico, A. Manfredo, F. Marin, M. Minuti, N. Omedei, L. Pacciani, G. Pavlov, M. Pesce-Rollins, P.-O. Petrucci, M. Pinchera, J. Poutanen, M. Razzano, A. Rubini, M. Salvati, C. Sgrò, F. Spada, G. Spandre, L. Stella, R. Sunyaev, R. Taverna, R. Turolla, K. Wu, S. Zane, D. Zanetti

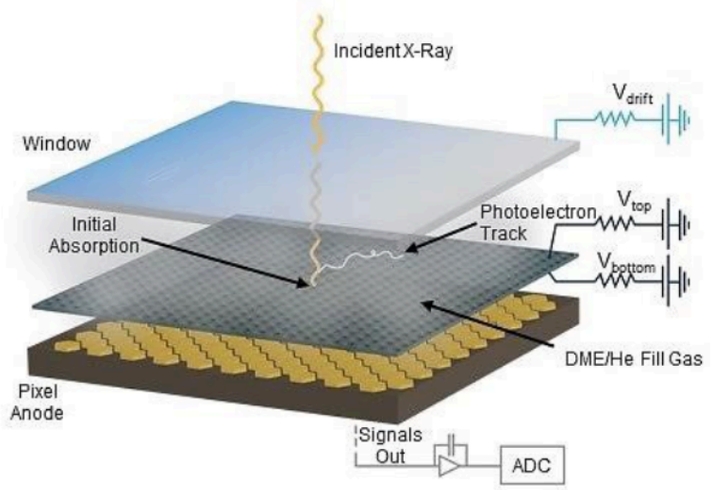


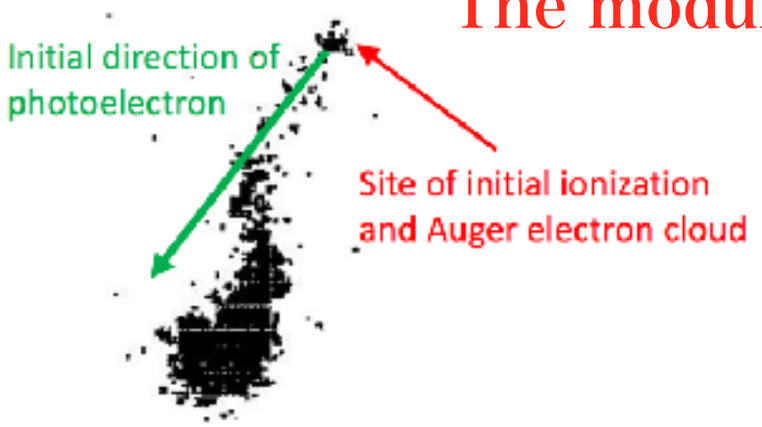
1) The X-ray mirror has been developed by NASA/MSFC group including B.D. Ramsey. They has also developed the mirrors such as ART-XC, HEROES, FOXSI, and Micro X.
2) The micro pattern gas detector has been developed by Italian group including E. Costa. It has high Technical Readiness Level (TRL).

3. The X-ray Mirror Modules

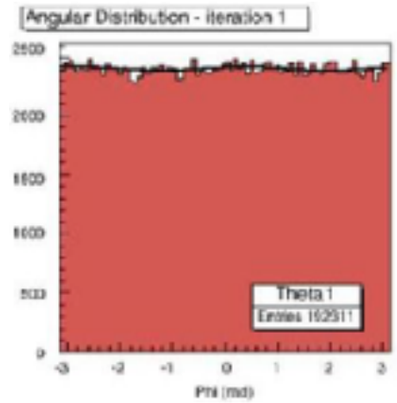
Parameter	Value
Number of mirror modules	3
Number of shells per mirror module	24
Focal length	4000 mm
Total shell length	600 mm
Range of shell diameters	162–272 mm
Range of shell thicknesses	0.16–0.26 mm
Shell material	Electroformed nickel–cobalt alloy
Effective area per mirror module	230 cm^2 (@ 2.3 keV); >240 cm^2 (3–6 keV)
Angular resolution (HPD)	≤ 25 arcsec
Field of view (detector limited)	12.9 arcmin square

4. The micro pattern gas detector





The modulation factor is~ 50% @4keV.



Any systematic effects are very low.

Parameter	Value
Sensitive area	15 mm × 15 mm
Fill gas and composition	He/DME (20/80) @ 1 atm
Detector window	50-µm thick beryllium
Absorption and drift region depth	10 mm
GEM (gas electron multiplier)	copper-plated 50-µm liquid-crystal polymer
GEM hole pitch	50 µm triangular lattice
Number ASIC readout pixels	300 × 352
ASIC pixelated anode	Hexagonal @ 50-µm pitch
Spatial resolution (FWHM)	≤ 123 µm (6.4 arcsec) @ 2 keV
Energy resolution (FWHM)	0.54 keV @ 2 keV ($\propto \sqrt{E}$)

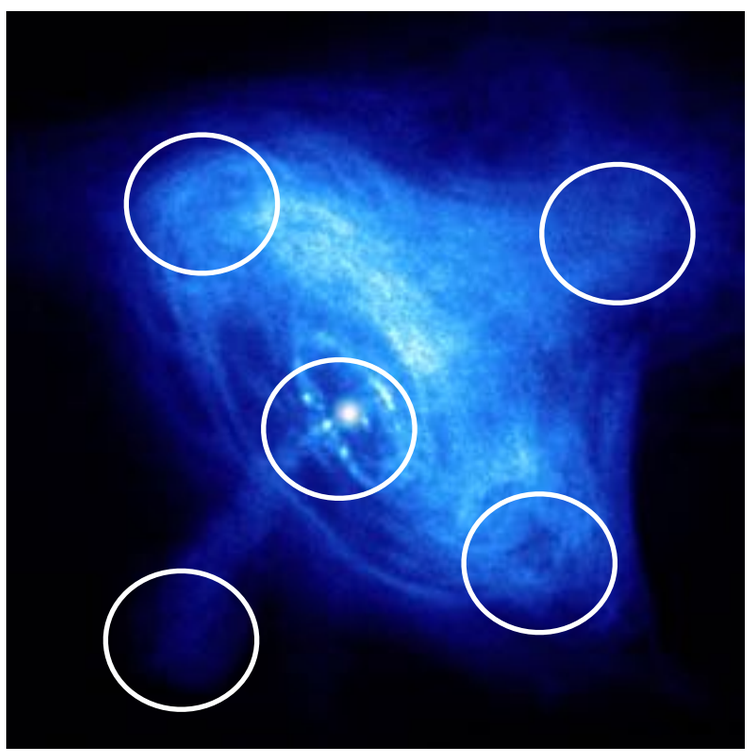
5. Physics

We will observe about 50 stellar objects. For the observations of stellar objects such as PWN, SNR, and AGN, the imaging capability is very useful.

This is a part of the full list and preliminary.

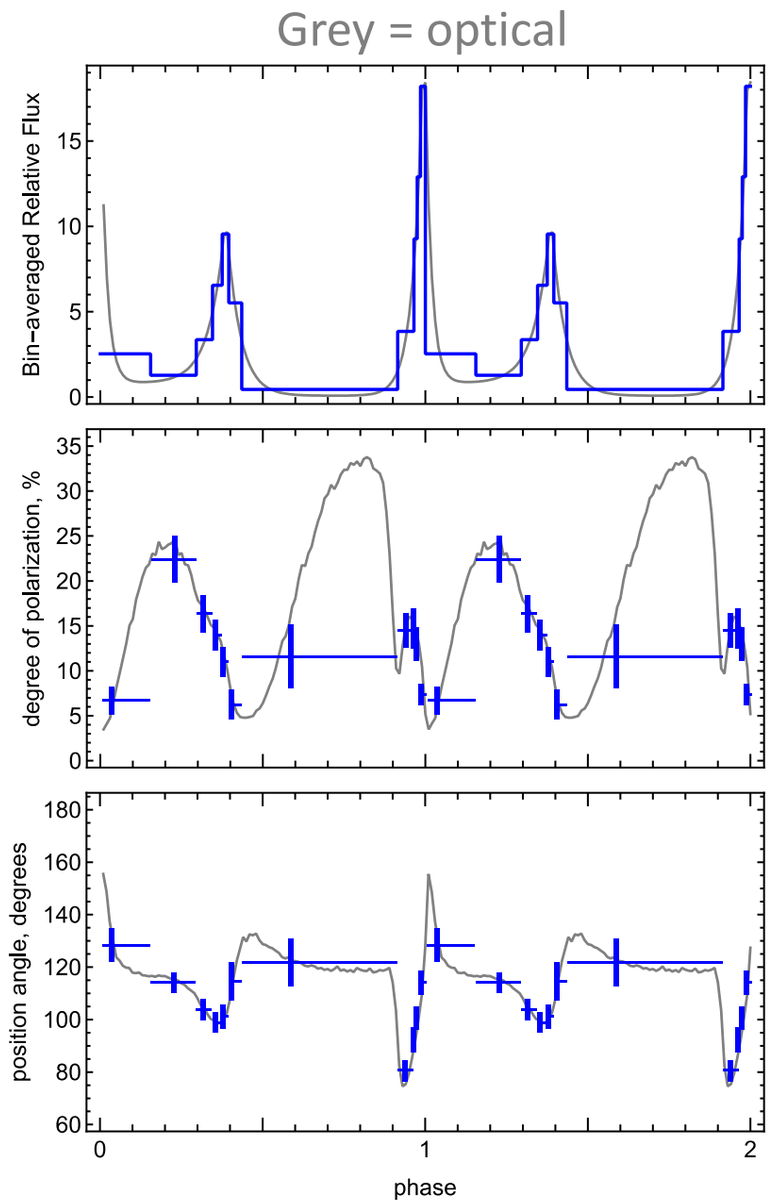
Source name	F_{2-8} 10^{-11} cgs	MDP_{99} %	Δt day	Uncertainty σ_Π and σ_ψ for representative polarization measurements for indicated number of energy × time or pulse phase × spatial bins
Active Galactic Nuclei (AGN)				
Cen A radio galaxy	33.5	0.7	10.9	Core (4 bins) Π±0.5%, ψ±2.8° (if Π≈5%) & Jet (4 bins) Π±1.5%, ψ±4.2° (if Π≈10%)
Mkn 421 blazar	27.2	2.0	1.6	(3 bins) Π±1.1%, ψ±3.3° (if Π≈10%)
Galactic Center				
Sgr B2	0.30	7.5	11.6	(3 bins) Π±4.3%, ψ±2.5° (if Π≈50%), test hypothesis of Sgr A* reflection
Microquasars				
GRS 1915+105	1300.	0.25	2.3	(4 bins) Π±0.2%, ψ±1.0° (if Π≈5%),with energy, measure black-hole spin
Cyg X-3 average	580.	0.4	2.8	(4 bins) Π±0.3%, ψ±1.5° (if Π≈5%); MDP = 0.7% in low state
Cyg X-1 average	1000.	0.4	0.7	(4 bins) Π±0.3%, ψ±1.5° (if Π≈5%); MDP = 0.6% in low state
Pulsar-Wind Nebulae (PWNe) + Pulsars (PSR)				
Crab PWNe + pulsar	1950.	0.24	1.6	PWNe (25 bins) Π±0.4%, ψ±0.3° (if Π≈20%), image magnetic structure Pulsar (9 bins) Π±2.6%, ψ±3.7° (if Π≈20%), 34-ms pulse period, PWNe subtracted
Vela PWNe + pulsar	5.2	1.8	11.7	PWNe (18 bins) Π±2.6%, ψ±3.7° (if Π≈20%), image magnetic structure Pulsar (2 bins) MDP = 19.9%, 89-ms pulse period, PWNe subtracted
MSH 15-52 + B1509-58	7.2	1.5	12.3	PWNe (18 bins) Π±2.6%, ψ±3.7° (if Π≈20%), image magnetic structure Pulsar (9 bins) Π±3.1%, ψ±4.4° (if Π≈20%), 151-ms pulse period, PWNe subtracted
Supernova Remnants (SNR)				
Cas A	116.0	0.35	11.6	(48 bins) Π±0.8%, ψ±4.6° (if Π≈5%), image magnetic structure
Magnetars				
4U 0142+61	5.9	2.0	5.4	(9 bins) Π±2.0%, ψ±1.1° (if Π≈50%), 8.7-s pulse period, test vacuum birefringence
Classical Accreting X-ray Pulsars (High-B X-ray Binaries)				
Cen X-3	341.	0.5	2.6	(27 bins) Π±0.9%, ψ±1.2° (if Π≈20%), 4.84-s pulse period
4U 0900-40	574.	0.5	1.5	(27 bins) Π±0.9%, ψ±1.2° (if Π≈20%), 283-s pulse period
Accreting Millisecond X-ray Pulsars & other Low-B X-ray Binaries				
Sco X-1 *0.1 transmission	2250.	0.4	0.34	(5 bins) Π±0.3%, ψ±1.7° (if Π≈5%), with bright-source attenuating filter
Cyg X-2	987.	0.4	1.1	(5 bins) Π±0.3%, ψ±1.7° (if Π≈5%)

The Crab Nebula and the angular resolution



Probe emitting regions of pulsars through phase-resolved polarimetry: Crab Pulsar

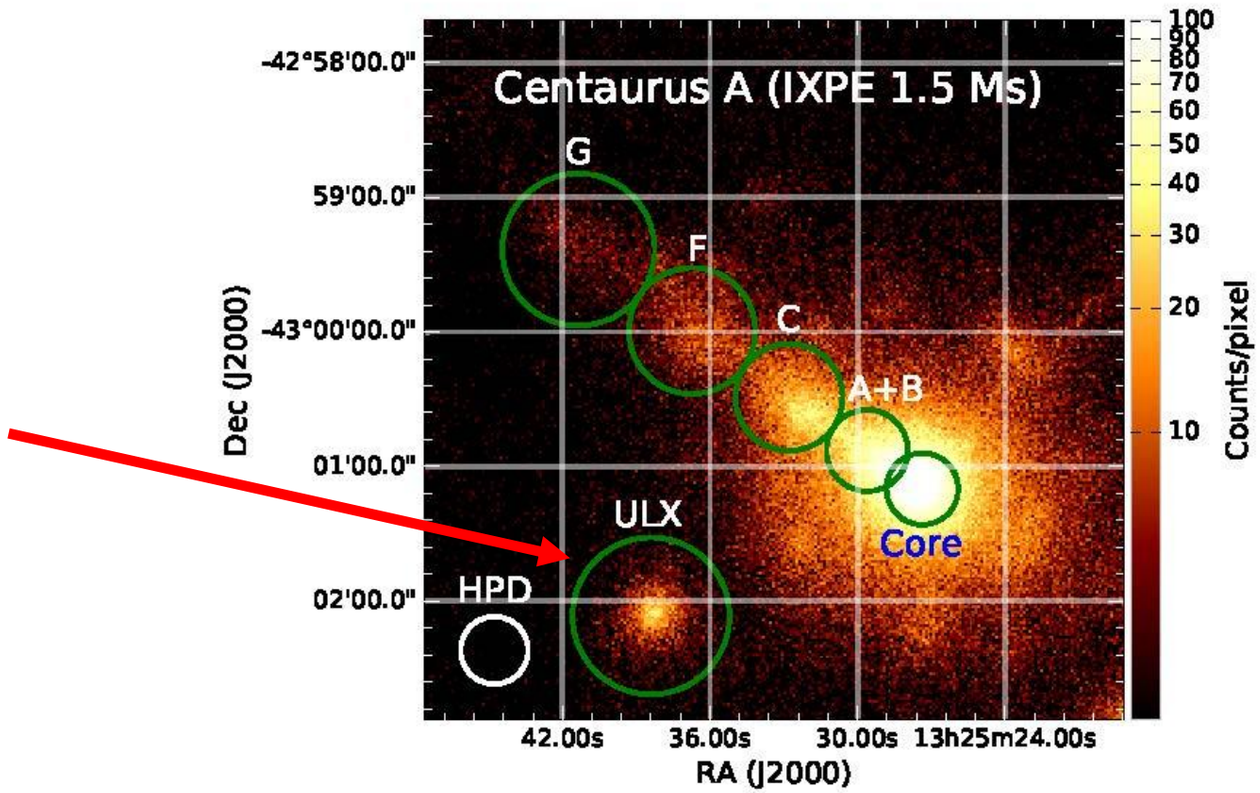
- **Emission geometry and processes are unsettled**
  - Competing models predict differing polarization behavior with pulse phase
- **X-rays provide cleaner probe of geometry**
  - Absorption likely more prevalent in visible band
  - Radiation process entirely different in radio band
    - Recently discovered no pulse phase-dependent variation in polarization degree and position angle @ 1.4 GHz
- **140-ks observation gives ample statistics to track polarization degree and position angle**



IXPE IMAGING ALSO AVOIDS CONFUSION AND PROVIDES SERENDIPITOUS BENEFITS

IXPE
Imaging X-Ray Polarimetry Explorer

- **Active galaxies are powered by supermassive BHs with jets**
  - Radio polarization implies the magnetic field is aligned with jet
  - Different models for electron acceleration predict different dependence in X-rays
- **Imaging Cen A allows isolating other sources in the field**
  - Two Ultra Luminous X-ray sources (one to SW on detector but not visible in 6-arcmin-square displayed region)



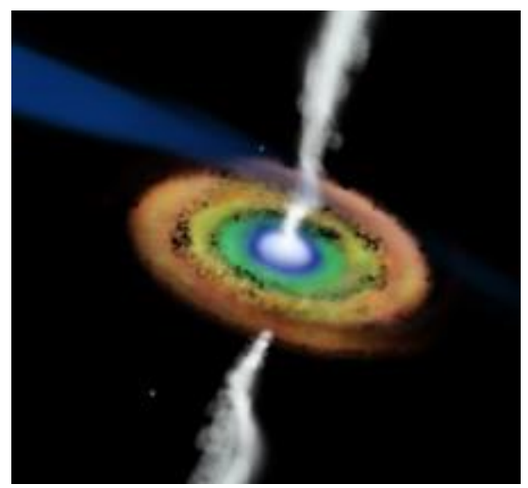
Region	MDP_{99}
Core	**<7.0%**
Jet	**10.9%**
Knot A+B	17.6%
Knot C	16.5%
Knot F	23.5%
Knot G	30.9%
ULX	**14.8%**

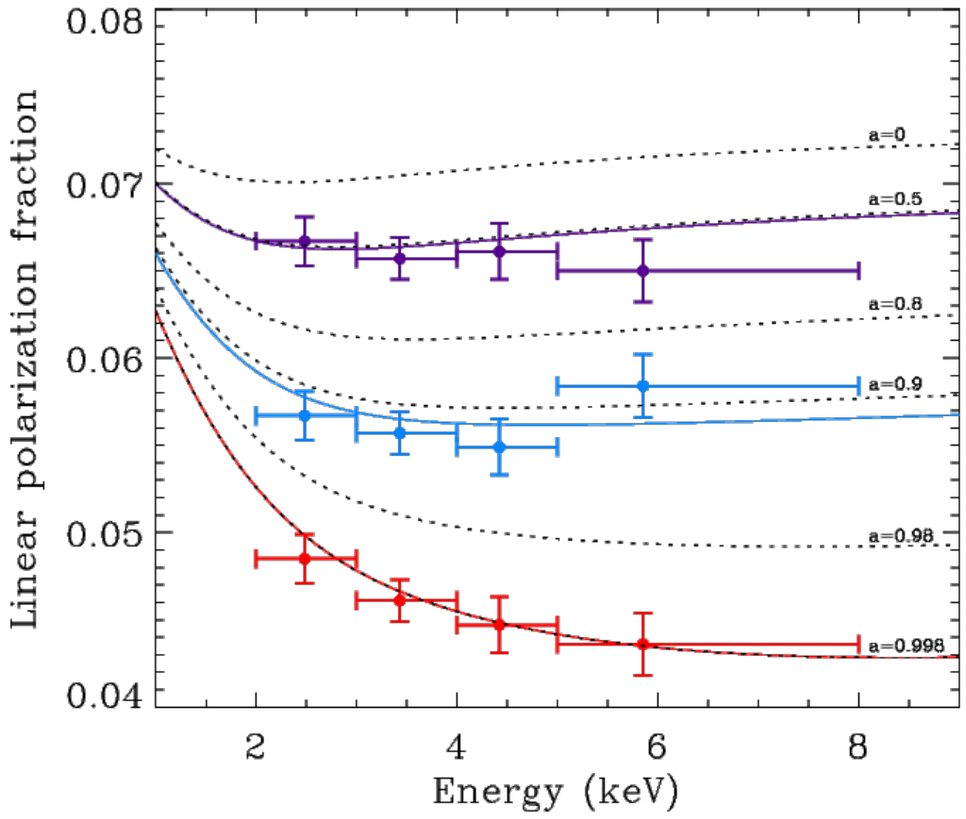
Includes effects of dilution by unpolarized diffuse emission

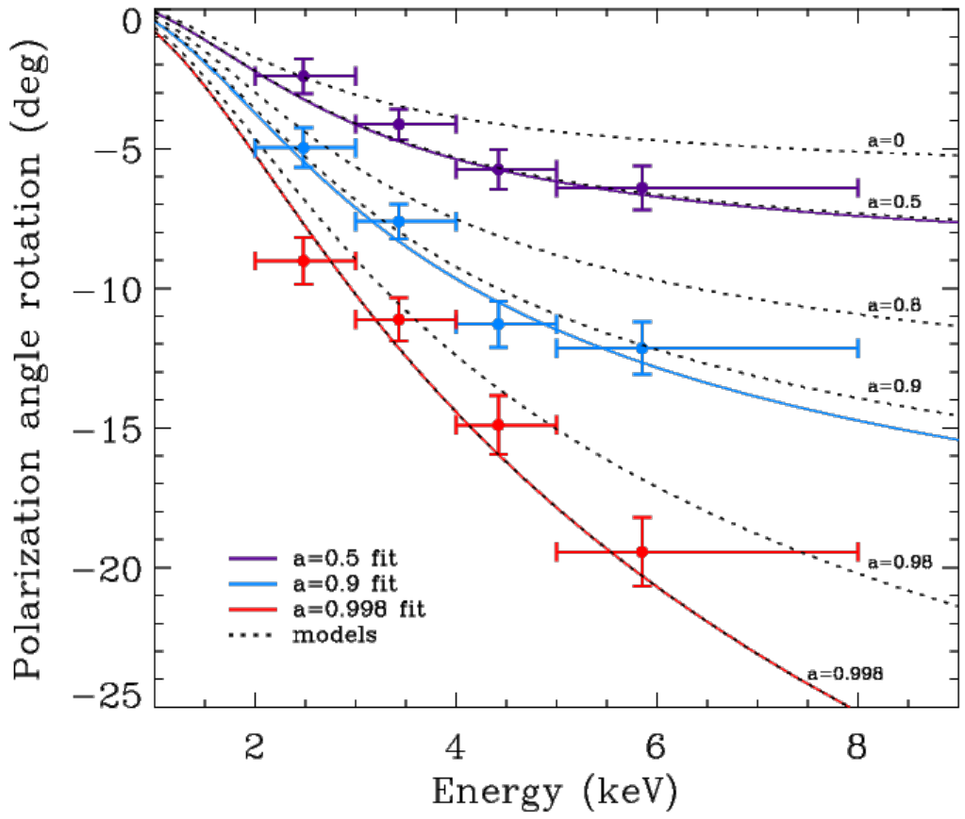
MEASURE BLACK-HOLE SPIN FROM POLARIZATION ROTATION IN TWISTED SPACE-TIME: GRS1915+105

IXPE Imaging X-Ray Polarimetry Explorer

- **For a micro-quasar in an accretion-dominated state**
  - Scattering polarizes the thermal disk emission
  - Polarization rotation is greatest for emission from inner disk
    - Inner disk is hotter, producing higher energy X-rays
  - Priors on disk orientation constrain GRS1915+105 model
    - a = 0.50±0.04; 0.900±0.008; 0.99800±0.00003 (200-ks observation)







6.Summary

1)Since the measurement of polarization for Crab Nebula by OSO-8, about forty years have passed. But the time has come to advance the X-ray polarimetry to the next step. It is Imaging X-ray Polarimetry Explorer.

2)The IXPE is international collaboration including NASA/MSFC and Italian team. The main instruments are three X-ray mirrors and micro pattern gas detectors.
NASA/MSFC and Italian group have much heritage for the development.

3) The energy range is from 2 keV to 8 keV.
The modulation factor is 50 %@4keV.
The angular resolution is 25'' and the field of view is ~ 13' squares.

4)Both diffuse sources and point-like sources are the targets.
In Nov. 2020, it will be launched by Pegasus and their observations of the polarization will be carried out for two years.

The new history of the X-ray polarimetry will be made.