The legacy of IXPE: Directions towards a new generation of 3D photo-electric X-ray polarimetry mission

Ajay Ratheesh[1], Paolo Soffitta [1], Enrico Costa [1], Ettore Del Monte [1], Alessandro Di Marco [1], Giuseppe Di Persio [1], Klaus Desch [2], Nicolas De Angelis[1], Dawoon E. Kim [1,3,4], Sergio Fabiani [1], Riccardo Ferrazzoli [1], Markus Gruber [2], Jochen Kaminski [2], Alessandro Lacerenza[1], Saba Imtiaz [1], Fabio La Monaca [1,3,4], Carlo Lefevre [1], Hemanth Manikantan [1], Alfredo Morbidini [1], Romana Mikusincova [1], Fabio Muleri [1], Vladilavs Plesanovs [2], Alda Rubini [1]

1 Istituto di Astrofisica e Planetologia Spaziali. Via del Fosso del Cavaliere 100, 00133, Rome, Italy
2 Physikalisches Institut der Universität Bonn, 53115 Bonn, Nussallee 12, Germany
3 Dipartimento di Fisica, Università degli Studi di Roma "La Sapienza", Piazzale Aldo Moro 5, 00185 Roma, Italy
4 Dipartimento di Fisica, Università degli Studi di Roma "Tor Vergata", Via della Ricerca Scientifica 1, 00133 Roma, Italy
Email: ajay.ratheesh@inaf.it ; paolo.soffitta@iaps.inaf.it

INAF ISTITUTO NAZIONALE DI ASTROFISICA

UNIVERSITÄT BONN

Abstract:
IXPE has been a highly successful mission, opening a new window in X-ray astronomy. IXPE observations have highlighted the importance of polarimetry along with spectroscopy in determining the geometry and physics behind many high-energy emissions from black hole X-ray binaries (BHBs), Pulsar Wind Nebulae (PWN), Active Galactic Nuclei (AGN) etc. However, IXPE is just the first step towards future wide band (0.1 to 100 keV) X-ray polarimetry. The future of this field demands larger effective areas, better energy resolution, and broader energy bands. IXPE is barely capable to address key scientific cases such as reflection features in X-ray binaries, molecular clouds around the Galactic Center, radio-quiet AGNs, non-thermal emission regions in supernova remnants etc. To take advantage of the recent advances in X-ray optics, gas detectors with different thickness, pressures and gas mixtures would be required. Using next-generation ASICs, like Timepix3, it is possible to have parallel fast readout, providing simultaneous time and charge information for each pixel, enabling 3D imaging of photoelectron tracks. In this poster we explore such a possiblity using GridPix detectors.

Limitations of IXPE and future requirements

- **Low energy resolution (around 20% at 6 keV)** → Better energy resolution is required for detecting polarization changes in narrow spectral features like absorption/emission lines.
- **Low efficiency and large exposure times** → To improve polarization sensitivity and reduce long exposure times, detectors with larger effective areas and higher modulation factors are needed.
- **Large dead-time** and hence has limitations for high count-rate sources → Requires faster readout ASIC.
- **2D-imaging of the photo-electron track** → Photo-electron can be emitted at non-orthogonal angles to the emission direction, so 3D imaging of the track is required to effectively increase the track length compared to 2D imaging.
- **Narrow energy band (2-8 keV)** : The coexistence of thermal and non-thermal components in the spectra creates an intricate overlap, posing challenges in untangling the sources of measured polarization. . For example, in the case of supernova remnant Cas A, NuStar has detected knots in hard X-ray images [1] that are not visible in the soft X-ray images from Chandra (see Fig 1). Hard X-ray polarimetry could help distinguish between different models for the origin of these knots.

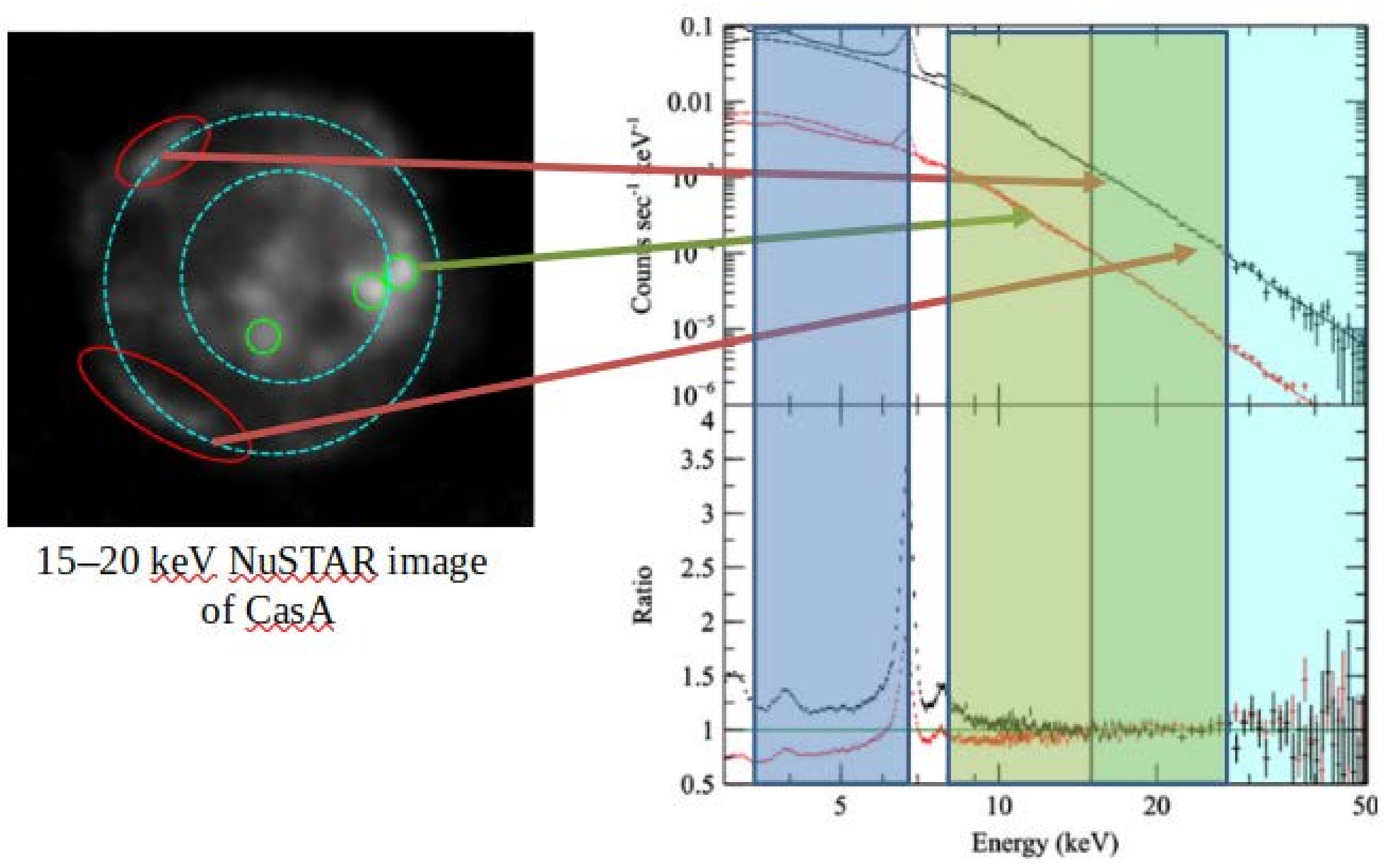

Figure 1: Left : 15-20 keV NuSTAR image of supernova remnant Cas A, Right: Spectra of central filaments and exterior knots

GridPix detectors using Timepix3 ASIC

It has been shown that 3D imaging of photoelectric track could improve the polarization sensitivity (modulation factor) [2]. GridPix detectors [3] using Timepix3 ASIC [4] could be used for this purpose as they offer fast readout.

Properties of Timepix3 ASIC	
No of pixels	256 × 256 pixels
Simultaneous charge and time measurement	Time of Arrival (ToA) and Time over threshold (ToT)
Pixel size	55 × 55 μm^2
ENC	60 e^-
Time resolution	1.56 ns
Pixel deadtime	ToT + 475 ns

Initial testing at INAF/IAPS

A proto-type of the GridPix detectors was tested at the X-ray polarization calibration facility at IAPS using gas mixtures with CO_2, Ne-CO_2, and Ar-CO_2 at various drift gaps.

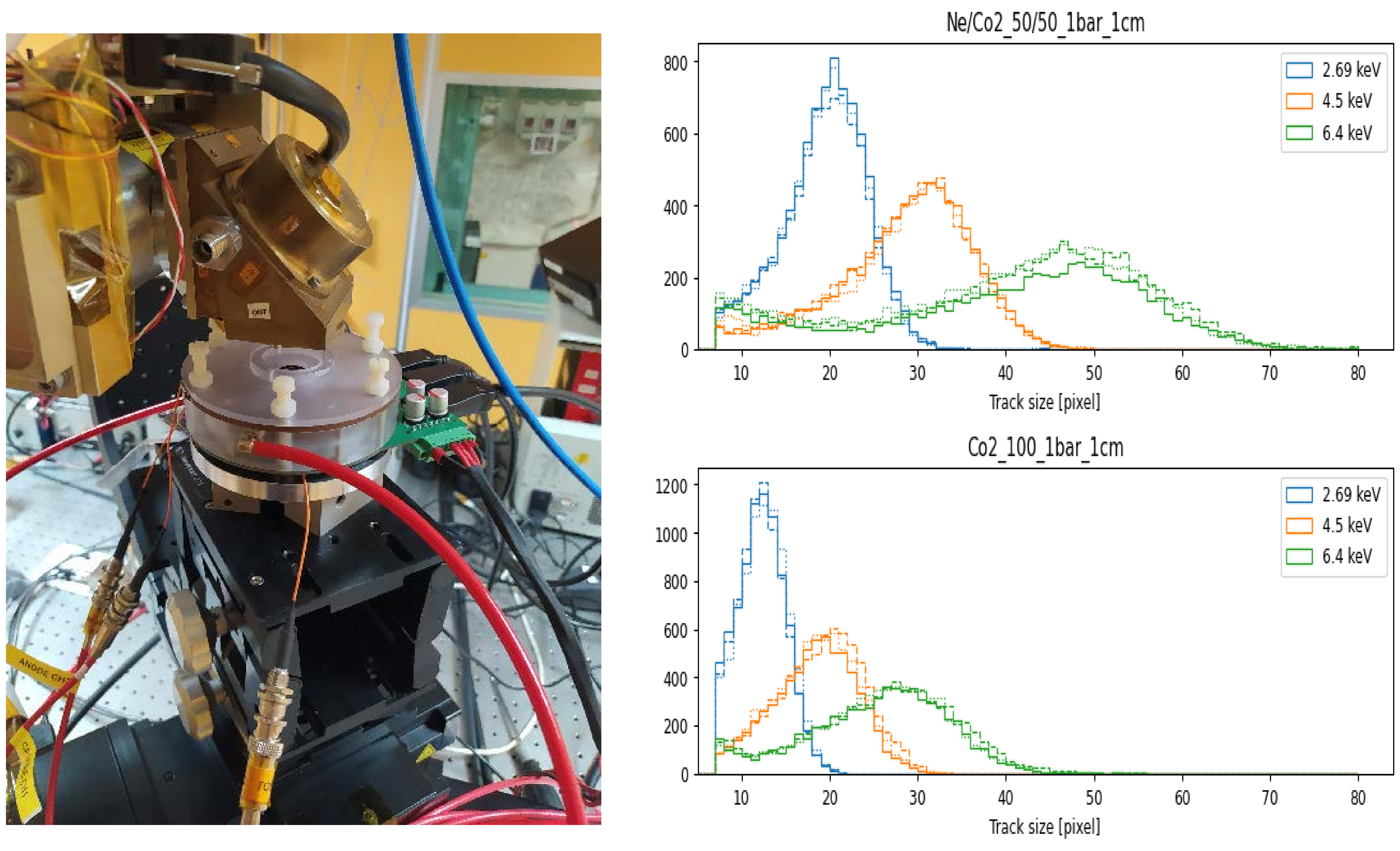

Figure 2. Left : Prototype GridPix detector at the Calibration facility at IAPS. Polarized X-ray source (X-ray tube and crystal scatterer) can be seen on the top to measure the response to fully polarized X-rays, **Right** : The distribution of number of pixels triggered per track in our measurements for 2 different mixtures of Ne-CO_2 and CO_2. These values are as expected.

Conclusions : We anticipate higher modulation factor and energy resolutions and the data analysis is under progress.

References: [1] Grefenstette et al 2015, ApJ 802 15
[2] Dawoon E. Kim et al 2024 JINST 19C02028
[3] Y Bilevych et al 2020 J. Phys.: Conf. Ser. 1498 012012
[4] T Poikela et al 2014 JINST 9 C05013 2024 – SPIE