PROCEEDINGS OF SCIENCE

X-Ray Polarimetry and IXPE mission

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In the past X-Ray Polarimetry was not able to follow the same development of other subtopics of X-Ray Astronomy. This occurred because the conventional instruments, based on Bragg diffraction or on Compton scattering, were not suited to benefit of the great step forward due to the introduction of Optics. With the development of polarimeters based on photoelectric effect, the focal plane, imaging polarimetry became feasible.
IXPE satellite includes three X-Ray telescopes with three photoelectric detectors the focus. Launched at the end of 2021 it has opened again the window of X-Ray Polarimetry on tens of sources belonging to most of the classes, frequently with unpredicted results. I present some data on Pulsar Wind Nebulae and the only observation of a Gamma-Ray Burst Afterglow. The observation of a group of molecular clouds at the center of our Galaxy gives the evidence of a strong flare of the central Black Hole occurred around 200 years ago.

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Figure 1: Roentgen discovered X-Rays in 1986. 11 years later Barkla through polarimetry demonstrated that they are electromagnetic radiation

Figure 2: Riccardo Giacconi and Bruno Rossi discovered the first extrasolar source of X-Rays in 1962. 9 years later Robert Novick launched the first rocket to measure polarization

1. Polarimetry in X-Ray Astronomy

X-rays were discovered in 1895 by Wilhelm Konrad Röntgen. He was immediately aware of the practical applications, but had fancy ideas about what those rays could be. In 1906 Charles Glover Barkla demonstrated that X-rays are scattered according to the rules of polarization and this demonstrated that X-rays are electromagnetic radiation (Figure1). So we can state that Physics and Polarimetry of X-Rays are borne almost together. Also the Astrophysics and the Polarimetry of X-Rays are borne almost together. Extrasolar X-Ray Astronomy was started by Bruno Rossi and Riccardo Giacconi in 1962 with the first sounding rocket. The first experiment of X-Ray Polarimetry was performed on 1971 by Robert Novick (Figure 2). Soon after the first discovery Giacconi sketched a strategy, based on the development of optics, to bring X-Ray Astronomy to the same level of other bands. This strategy was in practice adopted by NASA

- A satellite based on the same techniques of sounding rockets to have a first comprehensive view of X-Ray Sky that would be UHURU launched on 1970
- A satellite with a first implementation of X.ray optics that would be Einstein launched on 1978
- A satellite with a full exploitation of X-Ray optics (area and angular resolution) that would be Chandra launched on 1999)

Polarimetry, started at the beginning with rockets (1971), matched the first step with Ariel-5(1974) and OSO-8 (1975) satellites, but missed the passage from the first to the second step.

A polarimeter was foreseen in the original design of Einstein but was removed. A polarimeter was foreseen in the original design of Chandra but was also removed. The equivalent of Einstein was IXPE launched 43 years later![1] The third step is still to come. How could this occur? I think it was determined from the evolution of instruments at the passage from collimated detectors, (with all the variants as modulation collimators or coded masks), to imaging detectors in the focus of a grazing incidence telescope. An X-Ray telescope with an imaging detector can:

1. Image extended sources, localize and associate a source with a known astrophysical object
2. Detect very weak sources because compares their flux with fluctuations of the background in the point spread function and not on the whole detector or ½ of that (as in experiments with collimators, modulation collimators or coded masks)

Conventional polarimeters, based on Bragg Diffraction were massive, and could not determine the impact point of the photon. In the focus of an X-Ray telescope they would not benefit of a relevant reduction of the backgrounds. Scattering polarimeters were active only at higher energies (>15 keV) and would not detect the interaction point as well. Moreover, with the introduction of optics, the rotation was no more needed for imaging and spectra, while both Bragg and Thomson needed a rotation resulting in complications on the aspect and power subsystems.

In conclusion in face of the tremendous improvement of imaging and spectroscopy in the focus of telescopes, the classic polarimeters would require consistent resources (mass, room, power, observing time) for the observation of a few bright sources, while X-ray astronomy was moving toward the extragalactic sky and the study of hundreds of weak sources. The total mismatching of the expected throughput was the real cause of the exclusion of polarimetry, until a new generation of detectors arrived, capable to exploit the use of telescopes for both imaging and background demolition.

2. Measuring X-Ray Polarization

But, in order to understand how various features and technicalities impact on sensitivity, and why photoelectric could do what the conventional polarimeters could not, I need to make a digression to introduce the basic statistics. All polarimeters are based on a physical process, whose probability depends on the angle between the polarization of photons and a reference axis of the instrument. In practice the outcome of the measurement is the so called modulation curve, namely an histogram of photons detected at various angles. In Figure 3 we show a schematic modulation curve and what is expected for a polarized and an unpolarized

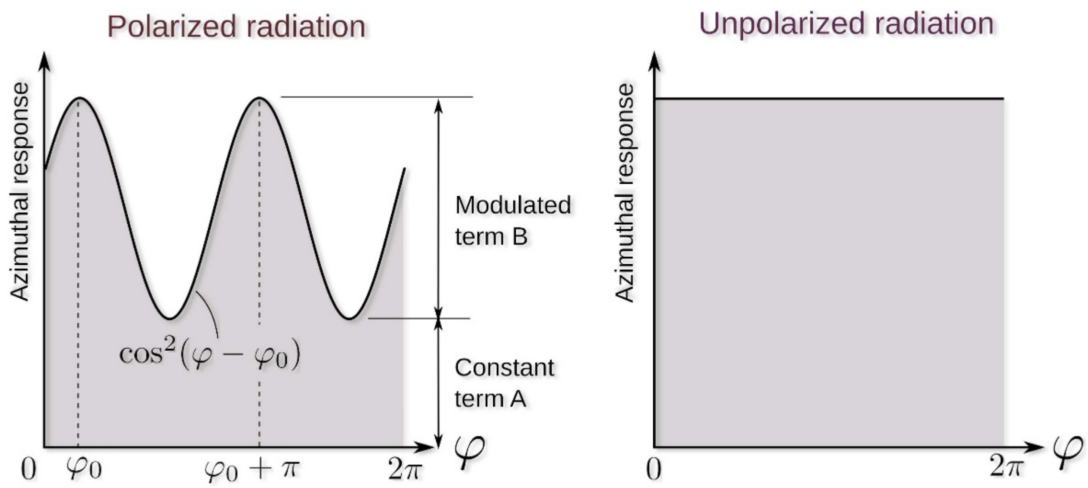


Figure 3: Modulation curve for a polarized and an unpolarized source from Muleri 2022[3]

source[2]. The modulation curve, namely the counts in the histogram, can be fitted with the function:

$$N(\varphi) = A + B \times cos(\varphi - \varphi_0)^2 \tag{1}$$

$$M = \frac{N_(max) - N_(min)}{N_(max) + N_(min)} = \frac{B}{B + 2A} \tag{2}$$

$$PD = \frac{1}{\mu}\frac{B}{B + 2A} \tag{3}$$

M is defined Modulation. μ is the Modulation Factor, namely the Modulation for a 100% polarized beam. The Polarization Degree (PD) is derived by dividing the Modulation by μ. This is an intrinsic property of the instrument and, usually, depends on energy. The Polarization Angle (PA) is derived from the phase of the modulation ϕ_0 (the maximum of the curve) and the aspect of the satellite to the sky. The Polarization Degree and the Polarization Angle are covariant. Usually the results of the fit are displayed as a 2-dimension confidence interval. When the PD is an upper limit the angle is totally unconstrained. A detection at 3σ level corresponds to around an error on the angle of 11°. In the Figure 4 [3] we show the relative dependence of the two parameters.

Alternatively we can follow the formalism of the Stokes Parameters, not forgetting that no polarimeter suited for space is so far sensitive to circular polarization and V parameter is not used:

$$S(\phi) = I + Qsin(2\phi) + Ucos(2\phi) \tag{4}$$

Where $I = (A + \frac{B}{2})$, $U = (\frac{B}{2}) \times sin(2\phi_0)$, $Q = (\frac{B}{2}) \times cos(2\phi_0)$

In IXPE analysis tool , following the approach of Kislat[4], we compute Stokes Parameters for each photon. The outcome is:

$$PD = \frac{\sqrt{Q^2 + U^2}}{I} \tag{5}$$

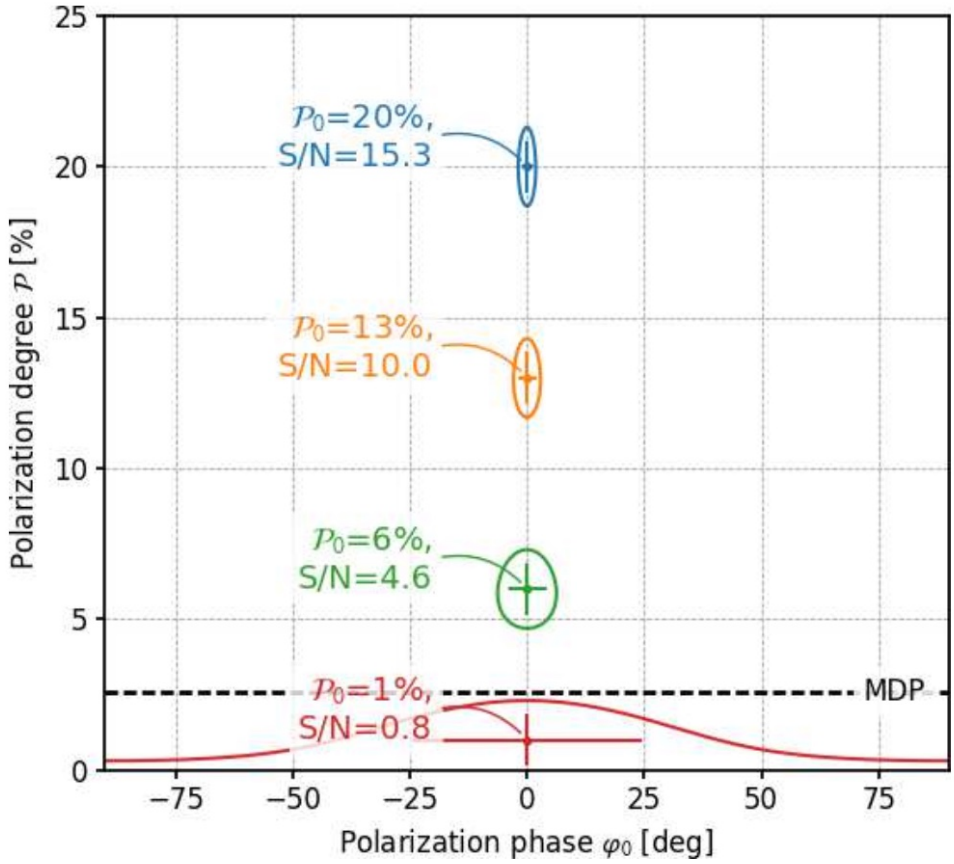


Figure 4: Typical confidence intervals for Polarization Degree and Angle, for different values of Signal to Noise ratio[3]

If the phase bins of the modulation curve are counts and follow the Poisson Statistics the Modulation follow a χ^2 distribution with two degrees of freedom. By this distribution we can compute the probability of chance occurrence of a certain level of modulation and, thence, the confidence of a detected modulation. Historically the threshold was fixed to 99% (instead than 3σ that, in my opinion, proves that since the beginning it was evident that polarimetry would be a tough task).

By integrating the distribution we can derive (the computations in [5]) the number of counts needed to detect a modulation with a given instrument at 99% confidence. This is the Minimum Detectable Modulation (MDM). By dividing the MDM by the Modulation Factor of the instrument we derive the Minimum Detectable Polarization.

$$MDP = \frac{4.29}{\mu \varepsilon S} \times \sqrt{\frac{\varepsilon S + B}{T}} \tag{6}$$

From the equation of the MDP we see that, the high sensitivity is arrived when the counts from the source exceed those from the background. This is achieved with the optics and with an imaging detector. As mentioned above, a Compton polarimeter in this energy band is not suited to localize the interaction point. In the focus of a telescope the background is collected on a surface orders of magnitude larger than the point spread function. A Bragg flat crystal can be set near the focus of the telescope in a sort of newtonian mounting. Such a configuration was included in the Stella X-Ray Polarimeter, built for the Spectrum X-Gamma Mission[6]. The interaction point in this case is preserved but the efficiency is reduced of orders of magnitude. In other terms in the focus of a telescope the traditional polarimeters have some advantages but much less than those for imaging or spectra. The introduction of the optics made this mismatching lethal for a combination of the various techniques aboard the same mission.

3. Photoelectric is the way

In the range of interest the main interaction of photons with matter is the photoelectric effect. Unfortunately a photoelectric absorption depending on polarization only exist in very narrow bands, of no practical interest. So in this range we haven't a viable polarization filter. But a process sensitive to polarization is there.

When a photon is absorbed an electron is ejected, with a kinetic energy equal to T=hν - E$_k$. When the electron is an s electron the angular distribution of the ejection direction follows the differential cross section:

$$\frac{d\sigma}{d\Omega} \propto \cos^2(\varphi)\frac{sin^2(\theta)}{(1-\beta cos\theta)^4} \tag{7}$$

where φ and θ represent the azimuth and polar angles of the photoelectron direction, respectively, and β is the photoelectron velocity in units of the speed of light. The emission direction is preferential on the plane normal to the photon direction and in the direction of the electric field. The term at denominator represents a small forward bending of the distribution, that for the energies of interest is almost negligible. The electron ionizes the gas, is scattered and eventually stopped, leaving a cluster of ion-electron pairs, usually named the *track*. In low atomic number gases an Auger electron is also ejected with isotropic distribution. A photoelectric polarimeter collects the electrons of the track, amplifies them, while preserving the shape, and collects the charge on a pixellated sense plane[7]. The analysis of the track image allows to derive the impact point, the original direction of the photoelectron and the total charge, proportional to the energy of the photoelectron. In practice at the low energies organic gases or Ne and, at high energies, Argon are the only viable solution because the tracks are extended enough to allow for the analysis. The practical implementation for IXPE is the Gas Pixel Detector (GPD)[8, 9], with a drift field parallel to the axis of the telescope, a Gas Electron Multiplier as amplifier stage and an ASIC chip of 10^4 pixels as final stage[10]. A GPD filled with 0.8 atm of Dimethylether is in the focus of each Telescope of IXPE. From this discussion we can state that:

- If the track is well imaged the point of the first interaction ca be easily derived from a clever analysis

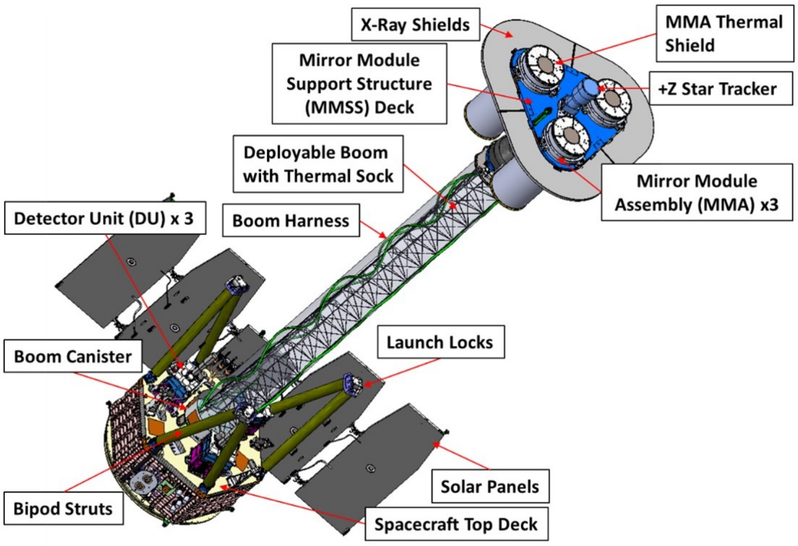


Figure 5: IXPE Observatory after the deployment in space

– The system can be built axis-symmetric not needing rotation at the first approximation

– All the energy is released in the gas and can be measured

– The background could be adequately understood and efficiently rejected because of rich information

The GPD, a photoelectric polarimeter based on fine subdivision in gas is good for the focal plane and compliant with these capabilities. On the other side the MSFC team had developed low mass optics of good quality. This is the technical basis of IXPE

4. From a concept to a mission

After the development and characterization of GPD, this device was proposed as part of multi-instrument missions, such as XEUS, IXO and NHXM or to missions dedicated to polarimetry proposed to ASI (POLARIX), ESA (mini-XIPE, XIPE), CAS (HXMT), NASA (IXPE). After various complications, described in Costa2022[1], IXPE, proposed in 2014 for the second time as a Small Explorer Mission (SMEX), was approved in 2017 and launched in 2021 in an equatorial Low Earth Orbit[11]. As a SMEX IXPE (Figure 5) is a PI mission based on an agreement of NASA and ASI. The Scientific Payload is composed from the Mirror Units, designed, manufactured and tested at the Marshall Space Flight Center[12] and the focal plane instrument built by italian Institutes (INAF, INFN[13] and industrial contractors (OHB-I). ASI is also providing the Malindi ground station.

The Mirror Module Assembly composed of three units has an effective area of the order of 600 cm^2 and a resolution of the order of 30" Half Power Diameter[12]. In the focal plane to each telescope corresponds a Detector Unit namely a GPD, with read-out electronics, a

Working Groups		**and objects**
TWG -1	3 PWNe and isolated	Crab PWN, Vela PWN, MSH 15-52 PSR b0540
TWG-2	3 SNR	Cas A, Tycho's, NE SN 1006
TWG-3	4 Accreting stellar-BH	Cyg X-1, 4U 1630-472, Cyg X-3, LMC X-1, SS433, 4U 1957-115
TWG-4	13 Accreting NS & WD	Cen X-3, Her X-1, GS1826-67, Vela X-1, Cyg X-2, GX 301-2, Xpersei, GX 9-9, 4U 1820, GRO J1008-57, XTE 1701-46, EXO 2030+375, LS V+44 17, GX 5-1
TWG-5	2 Magnetars	4U 0142+61, 1RXS J170849, SGR 1806
TWG-6	4 Radio-quiet AGN & Sgr A*	MCG 5-23-16, Circinus Galaxy, NGC 4151, IC 4329 A, Sgr A* Complex
TWG-7	13 Blazars & radio galaxies	Cen A, S5-0716-714, 1ES 19-59-650, Mrk 421, BL Lac, 3C 454, 3C 273, 3C 279, Mrk 501,1ES 1959-650, BL-Lac, 1ES 0229-200, PG 1553 -113

Table 1: Sources observed starting from the indications of the various Topical Working Groups

filter wheel harboring polarized and unpolarized calibration sources. a collimator to avoid the huge sky background to arrive to the entrance window and a polyimide filter to reduce the flux of very bright sources to levels compliant with the large dead time (around 1 ms) and the telemetry restrictions[13]. IXPE data telemetered to ground stations in Malindi (primary) and in Singapore (secondary) are transmitted to the Mission Operations Center (MOC), at the Laboratory for Atmospheric and Space Physics, University of Colorado and then to the Science Operations Center (SOC, at the NASA Marshall Space Flight Center). Given the lack of any data but a few observations by the much less sensitive mission OSO-8, a team of international scientists, including the hardware teams that were doing IXPE, and a good number of scientists who, in the past, had done predictions on polarization, has worked out a list of reasonable targets. These scientists were organized in Topical Working Groups (TWG) under the coordination of Mission Scientists and the supervision of a Science Working Group. Proposals by the TWGs were combined by the SOC with pointing constraints and with the total available time. Eventually a planning for the first year was assessed, with some minor adaptations due to a few Target of Opportunity pointing. At the time of this Conference the second year is started since a few months . In Table1 the sources observed on the basis of the proposals of the various Working Groups.

5. Astrophysics with IXPE

Many colleagues are presenting IXPE results in this conference. Here I present some result including a few not belonging to the major observational classes. But I cannot avoid starting

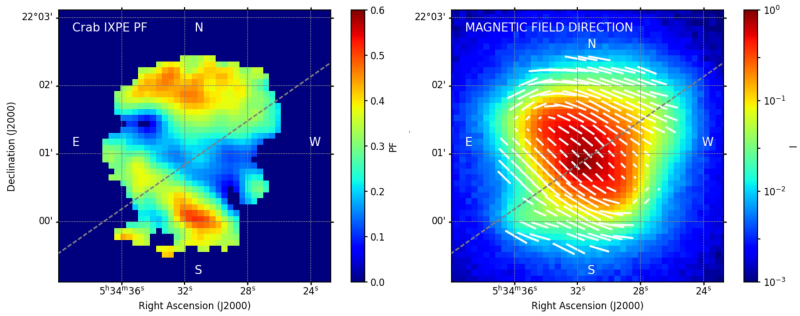


Figure 6: The Polarization map of the Crab (on the left). By comparing with the luminosity (on the right) we see that the torus is the less polarized region. The white lines are the direction of the magnetic field. From[14]

with the sources that are the real benchmark of X-Ray Polarimetry.

5.1 Pulsar Wind Nebulae. A confirmation and much more

Crab was the only source for which a positive detection of the order of 19% was already achieved with rockets and with OSO-8 satellite. Given the extended and complex structure of the nebula, as derived from the Chandra image, with a torus, an inner ring, the pulsar and two jets, it was expected to have, with an imaging instrument, some feature of high polarization degree. This was confirmed by the two observations, lasting one day each, performed at the beginning of the first year[14]. The polarimetric image is shown in the left side of Figure 6.

In astronomical systems dominated by synchrotron radiation from the map of polarization we derive and plot the map of magnetic field, as in the right side of Figure 6. The main feature in the Crab image is the torus. The polarization map shows a toroidal structure of the fields. Given the high inclination the fields at the edges of the torus has a large component toward the observer and the polarization is much lower. Out of the torus, in northern and southern regions, of relatively lower brightness, a higher polarization is present. In general the magnetic field appears ordered to a very high level. This is even more evident in the Vela PWN, observed edge-on. The polarization is close to the limit for synchrotron radiations and the regular magnetic field structure is extended at distances larger than the X-ray torus[15]. From these data it is evident that turbulence is basically absent in these systems. Polarimetry of the pulsars is a much more complicated task. The angular resolution of IXPE is not sufficient to avoid that a large amount of nebular photons is added to those of the pulsar. In the area including the pulsar we find a lower polarization. To disentangle the PSR from the nebula we can use the phase resolved analysis assuming that the off-pulse flux is all nebular and phase independent. By subtraction we find in the main peak (P1) a PD=15.1% ± 2.1%. The second peak (P2) is also polarized with PD=8.8% ± 2.8%. For Vela, the pulsar is too weak to be observable. But we can notice that the region including the pulsar is significantly less polarized than the torus.

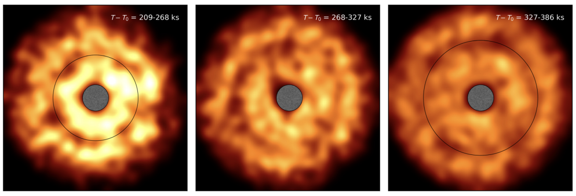


Figure 7: The field of GRB221109a as imaged by IXPE. The three images are around 60000 s each in temporal sequence. We have an inner and an outer ring structure. The much more luminous point like afterglow source has been removed.From[16]

5.2 An unexpected observation

Given the severe operation limits of a small mission, Gamma-Ray Bursts have never been considered a primary target for IXPE. Yet when the extraordinary GRB221109a occurred IXPE was pointed, only 210000 s after[16]. We measure a polarization of 6.1 ± 3.0 %, far from a detection, resulting in an upper limit on the Polarization Degree 13.8% at 99% confidence level. Unfortunately, given the complexity of the field, the optical polarimetry was not very sensitive. With NOT data [17] we have an upper limit of PD of 8.3% at 99% confidence level, which is much worse than many data on less epochal GRBs. The combined optical and X-Ray values can be fitted in the frame of theories of polarization from GRB afterglow. In the frame of the Ghisellini and Lazzati theory[18], under some hypothesis on the jet structure it allow to put constraints on the ratio between the view angle and the opening angle and the direction of the magnetic field with respect to the jet.

Also interesting the afterglow of GRB221109a, at very low galactic latitude, was surrounded by the rings due to the scattering of X-Rays on dust grains, sometime occurring on sources on the galactic plane. The theory of rings around point-like X-Ray sources, due to scattering on interstellar dust, has been adapted for transient sources, and GRB in particular, by Tiengo and Mereghetti[19]. The rings correspond to small angle scattering on dust clouds in our Galaxy. Each group of rings correspond to a group of clouds. Given the time evolution of the GRB, the rings are radiation from the main peak of the GRB, arriving to the observer at the same time of the afterglow, due to the longer path. Thanks to the imaging capability of IXPE, we observe these rings as well, as shown in Figure 7, even though with less sensitivity than XMM. But we are also able to perform polarimetry of these rings. With our resolution we can separate an inner ring and an outer one, whose brightness and dimension evolve in time. We add photons at a radial distance >0.8' and < 6' from the central afterglow source. According to theory of small angle scattering the polarization status in not affected by the scattering at angles <5' (actually the effect is of the order of 10^{-5}). Therefore while the time resolved photometry of the rings is informative about the composition of the dust, the polarimetry is in practice the polarimetry of the prompt event.

We did not detect polarization and, due to the poor statistics, the upper limit (at 99% confidence) of 55% is not particularly significant but is anyway the first upper limit to the polarization of a prompt GRB in this energy range. Also the case is interesting from the point of view of methods, because suggests how polarimetry of the prompt event of some

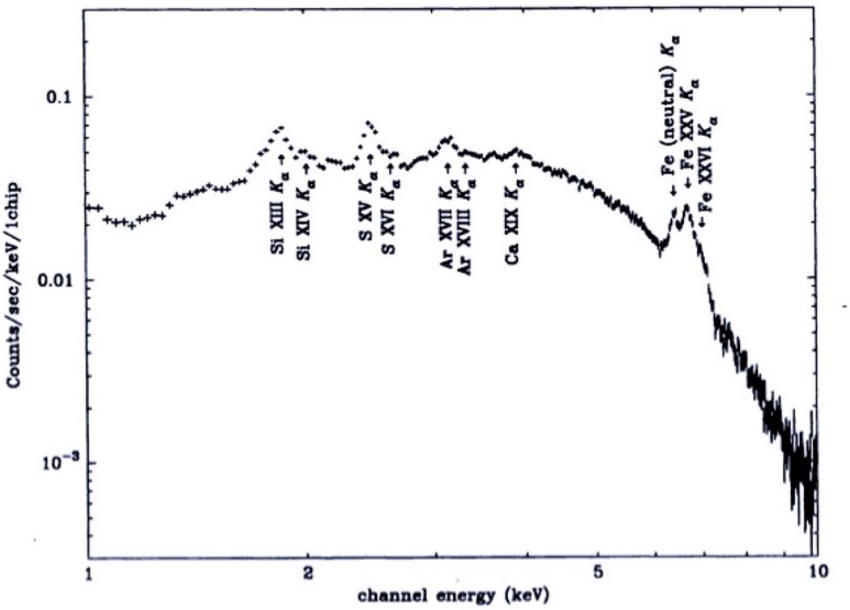


Figure 8: The spectrum by ASCA shows the presence of both thermal lines from the hot plasma regions and fluorescence lines from the reflection on the clouds. From[21]

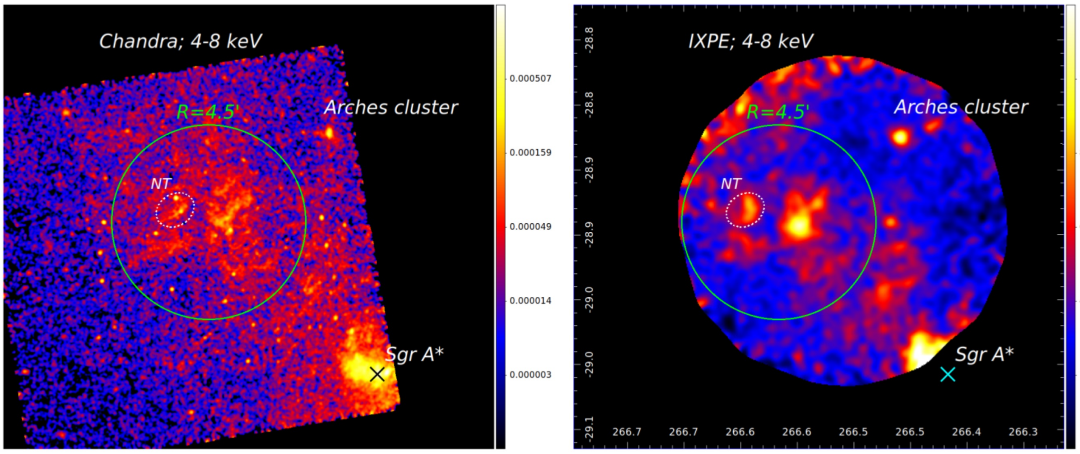
very bright transients (as Soft Gamma Repeaters) could be performed also in absence of an all sky instrument active in that moment and exposed to that part of sky.

5.3 One of the most ambitious targets

In 1993 Sunyaev and his coworkers suggested the idea that features of the extended X-Ray emission at the center of our Galaxy could carry memory of the past activity of the central Black Hole[20]. This intuition was progressively confirmed by the discovery, with ASCA, that , beside some extended regions with the spectral signature of hot plasma, some other extended sources were present with fluorescence lines, pointing to the existence of an extended external source of X-Rays[21] see Figure 8.

These regions were identified with molecular clouds. The second step forward was by Churazov et al. [22]. One of the brightest molecular clouds, named SgrB2, has a pure reflection spectrum, but no object in the field can be the source of the reflected flux. The past activity of another source in the form of a flare, in the neighbours can explain this feature[23]. While the fluorescence lines are by definition unpolarized, the continuum will be polarized of an amount depending on the scattering angle. Therefore polarization degree gives the information on the relative distance of the cloud and the source of the reflected photons, and by default of the time of occurrence of the flare. An adequate set of observations could produce a real three dimension map of the region and an history of the activity of the Black Hole in the last centuries.

After this paper SgrB2 became one of the most ambitious targets of all the proposed missions of X-Ray polarimetry. The most sound alternative model was based on radio and Gamma



(a) (b)

Figure 9: The field of SgrA as seen by Chandra and IXPE. The region selected for the analysis is the yellow circle of 4.5 arcminutes at north east (up-left in the image). From[31]

data (in the GeV range). F. Yusef-Zadeh[24] hypothesized that a source of low energy Cosmic Rays is there. The interaction with clouds produces X-Rays by non-thermal bremsstrahlung, including the production of Fe fluorescence line. The emission could be polarized locally but not ordered in a complex large scale, so that would be canceled. Therefore polarimetry could rule out this model.

But the elegant approach of Churazov et al. was to face several complications: things are relatively less simple. One problem is the simultaneous presence of hot clouds emitting a thermal spectrum. The two components are well separated by Chandra but not by IXPE. The components may be disentangled by the spectrum but in any case will reduce the significance. Another problem was the discovery of changes in the flux of some sources in the field. In particular the flux of SgrB2 decreased significantly.

The flux varies with a rapidity unusual for extended sources as from an external cause. There is evidence that the reflection components moves as for radiation coming from the side of the center [25–27]. Study for alternative targets is performed. It becomes more deep in the proximity of IXPE launch. [28–30]. Eventually a field in the complex Sgr A was selected as the most promising from the point of view of signal to noise ratio. The IXPE team scheduled an observation of around one million of seconds in the early time of the first year program. An observation of Chandra was also performed at a near time. The image of the sky from Chandra and IXPE is shown in Figure 9. Unluckily the GC was one of the first sources observed before important adjustments of the equipment. These include a better equalization of gains and a realignment of telescopes that would equalize the vignetting and thence the effective area for the three detecting units. Anyway we applied the best methods of background rejection based on track shape analysis[32]. Also some data were lost because of an intense solar activity followed by CME episodes with small increases in the background rate that, for a source weak and extended, can be only solved by removing data at the time from the analysis.

Following an optimization based on Chandra and XMM spectra, we avoided all parts of the field potentially affected by systematics. Data around the source G0.130.11 which has a marked non thermal spectrum, were excluded, with a modest loss of data with reflection spectrum. IXPE data within a circle of 4.5 arcminutes were accumulated. Stokes parameters were derived and the polarization degree and angle were derived in the assumption of unpolarized thermal component and background component. The best fit gives $PD = 31\% \pm 11\%$ and $PA = -48° \pm 11°$ with a χ^2 corresponding to 2.8σ, slightly less than what usually accepted for a detection. The Stokes Parameters and the best fit curve are shown in Figure 10. The most striking result is that the direction at 90° from the polarization angle, is only at 6° from the direction of SgrA*. The polarization measurement points to the Black Hole as the source of the scattered photons as shown in Figure 11.

From the degree of polarization we can derive the scattering angle with a degeneracy, implicit in the cross section. A cloud nearer to us than the Black Hole and a cloud farther of the same distance will give the same polarization. This degeneracy should be solved by other data (if any) useful to select one of the two solutions. The scattering angles derived from the fit in the two solutions are 43^{+7}_{-8} and 137^{-7}_{+8} degrees. Assuming a scatterer at the center of the extraction circle we can convert the two angles into two time intervals for the flare. They are 33^{+6}_{-7} and 205^{-30}_{+50} years, respectively.

This is an easy combination. The time interval nearer to us correspond to an epoch when X-Ray Astronomy was already performed with many missions. A source at the center of our Galaxy 5 or 6 orders of magnitude brighter than now would never escape to the surveys. Therefore the *near* solution can be excluded and we can eventually state that around 200 years ago an observer would have observed a flare from SgrA*. Whether this was a status of high activity, at the level of a Seyfert, a Tidal Disruption Event or anything other will be the subject of future investigations. Further observations with IXPE will be performed but for sure a systematic study to understand whether we find evidence of more flares will be more the object of a more sensitive future mission.

6. Two questions for the future

6.1 How multifrequency are we?

So far there has been a good coverage of NICER, NUSTAR, Swift and in some case of Chandra and XMM and a large use of data of missions such as MAXI or Fermi. Some observations were accompanied by optical and radio observations. All the observations, and in particular those of extended sources, could benefit of literature data. My impression is that a multifrequency approach has been in most cases overlooked.

As a matter of fact the IXPE collaboration was based on the Topical Working Groups that had as building ingredient the scientists that in the previous 20 years or more had published papers with predictions about the X-ray polarization. The natural attitude was to put the first effort to

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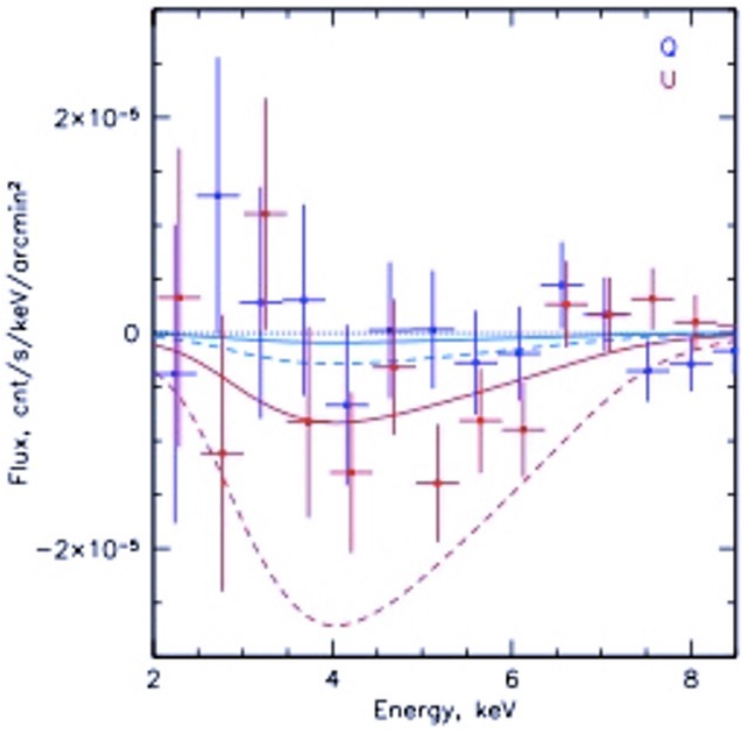

Figure 10: Stokes Parameters B and Q as a function of the energy, plotted with the best fit curve and compared with the maximum polarization curve from[31]

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compare theoretical predictions with data, moreover that the latter were often divergent from the first. Also the NASA decision to put all data and software in public distribution, without any guaranteed time, pushed the collaboration to analyze first results and publish fast papers . A further analysis of the same data in a multifrequency frame can be done by the same group or by other observers. Data and analysis software tools are available worldwide.

Anyway the starting point of a multimessenger approach is to have messengers. We have just added a new one with a reasonable expectation to go from one source to around 100, belonging to most of classes. Also in view of multifrequency study, in my opinion, the disentanglement of the geometry from the physics will be a contribution of immediate value.

6.2 Which future for X-Ray Polarimetry

Activities of IXPE are planned for 3 years. We can reasonably predict an extension. This mission will arrive to a reasonable scenario of the polarization in almost all classes of X-Ray sources. The observation of extended sources and of extragalactic of luminosity below the brightest observed til now, requires typically a pointing of the order of 20 days. Conversely bright sources cannot be observed for long time (e.g. the Crab for one day including the 50% earth occultation) but then require a certain time to download data. We cannot therefore

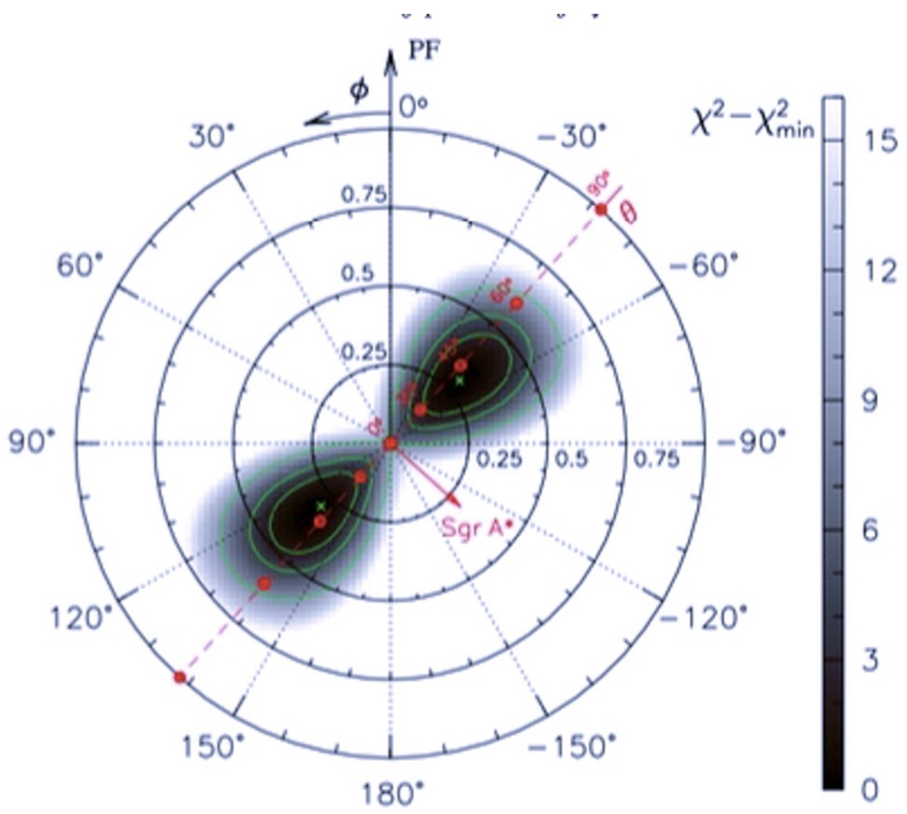

Figure 11: Best fit intervals for Polarization Degree and Angle from[31].The red arrow shows the direction to SgrA*.

expect that IXPE will produce rich catalogues or high statistics studies. The future could be a mission similar to IXPE but with much larger collecting area and/or a mission with extended band combining polarimeters in soft medium and hard X-Ray bands. The former could be the enhanced X-Ray Timing and Polarimetry Mission[33]. The latter a mission deriving from the ideas expressed in the recent past[34, 35] by large collaborations, combining polarimeters sensitive at different energies in a stacked configuration. Moreover it is unlikely that future missions based on multiple X-Ray instruments after IXPE and given the low resources needed for a photoelectric detector, can any more disembark a polarimeter.

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DISCUSSION

BORDAS: B field in PSR does not seem to trace any peculiarity in the jet regions. Why?

ENRICO COSTA Jets are too faint for IXPE. In practice we are only performing polarimetry of the torus.