X-ray Polarimetry: what next?

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What so far

At beginning of X-ray Astronomy it was proposed that Polarimetry could be a powerful diagnostic tool and measurement techniques based on diffraction or scattering were proposed. After the first detection of polarization of the Crab, no stellar X-ray polarimeter has been flown any more.

More recently new data have arrived from balloons or from small polarimeters devoted to the sun or to GRBs. Also some polarimetry data have come out as a byproduct of instruments designed for other purposes.

But polarimetry is not a topic it is a window, of potential interest for many astrophysical subjects including most of soirces studied with X-ray Astronomy. You add two physical parameters, i.e. amount and angle.

It is very difficult to single out a specific thematics to be the backbone of a succesful proposal.

But it is also difficult to propose polarimetry as part of an observatory because a large public of observers is not aware of the potentialites.

NO design is good for all

Since there is already a wealth of well identified scientific objects there is also a large menu of possible instrumental configurations

Solar	-	Stellar

Soft X - Medium X - Hard X - Soft γ

Dispersive	-	Non dispersive

Diffraction Photoelectric Scattering Pairs

One phase	-	Two phases
Imaging	-	Non imaging

Which is better?

There is no obvious choice but in some case there is no need for any choice: We must play on different tables and select the solution more suited to win on each table. If we concentrate on one specific game we have good chances to go ahead without any polarimeter.

On the contrary the risk to have two approved is almost null. And in any case our community is relatively strong from the hardware point of view and could be capale to manage.

Sun or stars?

A first rule, which is the lesson from the last ESA S1 selection is to play different games for stellar and solar polarimetry. The probability that both communities converge on a polarimeter is very low even if in some cases like GRBs/Solar Flares the technical compatibility is not a problem.

A solar polarimeter, in this preliminary phase, does not require a telescope and can be built in a low mass, low power version, that can fit within a multi instrument solar mission.

The path to have a solar polarimeter should be easier. Actually according to our calculation also a polarimeter aboard a cubesat could be competitive.

We are following this approach with SEEPE (PIs Paolo Soffitta and Siming Liu).

In the L2/L3 theme selection the Solar Eruptive Events (SEE) 2020 Mission Concept was proposed that included X-ray polarimetry in the core science but not in the model payload.

For stellar polarimetry is it better a dedicated mission or a polarimeter aboard a multi-instrument observatory?

In early times of X-ray astronomy the measurement philosophy was to have a detector with a window and a slat collimator in front, usually offset with respect to the rotation axis of the space-craft. A source was an increase of counts following the trangular profile of the area exposed at a certain phase of the rotation to a certain direction in the sky.
Also polarimetry was performed with bragg crystals at 45° from the spinning axis diffracting photons toward counters again at 45°.

Therefore the concept of the two measurements were not much different. They could cohabit wthin the same satellite. It was only a matter of sharing the resources (mass, room, observing time, bits, …).

Out of observatories

After HEAO-2/Einstein a source is a cluster of detected photons in an imaging detector in the focus of an optics. Rotation is no more needed and is a nasty complication. X-ray astronomy images extended sources,resolves complex fields. The sensitivity increases enormously allowing for large samples of extragalactic sources.

The technical mismatching and the sensitivity mismatching conjure against keeping polarimeters in observatory missions.

Polarimeters are removed at a certain development stage (Einstein, AXAF) or from the very beginning (XMM, ATHENA) or share the fate of hosting missions (SRG, XEUS, IXO).

The new photoelectric devices have reduced both technical and sensitivity mismatching but the management of agencies hates complexity. «The polarimeter is low mass, low power, weak thermal requirements but complexity by itself converts into money»

Future observatories

From the experience there are good reasons to expect that also any future observatory will find good arguments not to embark a polarimeter.
We can console ourselves by thinking that:

1) It is not clear whether any other X-ray observatory will arrive. If something arrives at NASA level we can expect that imaging would be the clue.
2) An observatory out of the mainstream, like XTP, incuding polarimetry in the core science, has concrete probability to be done
3) A telescope of 1000 cm^2 doing polarimetry 100% of time can do the same or even better than a telescope of 2 m^2 doing polarimetry for 5% of its time. We mainly miss high angular resolution with GPD and some short life transient source requiring many photons in a short time, because you cannot compensate the lack of photons with longer observation.

Polarimetry as a byproduct of instruments dedicated to other I

Every instrument capable to detect an angular dependence correlated with the polarization can be the basis of an instrument. This does not mean that this polarimeter is worth to be done.

In some instrument, designed for othe purposes, some phenomenology occurs dependent on polarization.
The most typical case is that of arrays of pixels, as most of imagers are. Either by photoelectric effect or by compton scattering, depending on the energy and on the material there is usually a certain number of contiguous pixels hit starting from the same event.

Perodically somebody comes out with the idea that an array can be used as a polarimeter. E.g. CCD or CdTe imagers. Starting from simulations data a sensitivity can be computed but some of these ideas (I would say most of them) can be discarded without even wasting time for simulations.

Polarimetry as a byproduct of instruments dedicated to other II

1) Is the range of the interaction larger than the pixels? If not the probability to have double events depends more on the position of the interaction within the pixel than on the polarization. For a focal plane polarimeter this will be a source of very heavy systematics. The situation for a non foca plane instrument (e.g. EXIST or ASTROSAT) is considerably better in terms of control of systematics.
2) In any case, since most of arrays are square if the range is not very long with respect to pixels your double interactions will be mainly on contiguous pixels and with a square array you will not measure the polarization with contiguous pixels only . Rotation is needed but usually imagers do not like to rotate. i.e. the histhorical problem of having a
3) The sensitivity of a polarimeter designed to exploit in an optimal way a certain physical process is (helas!) heavily mismatched with that other instruments (imagers, spectrometers). The sensitivity of a byproduct polarimeter is typically two orders of magnitude below the sensitivity of a properly designed instrumet. The mismatching is letal. You may ask months to detect the polarization of the Crab, while in the same time.

Polarimetry as a byproduct of instruments dedicated to other?

All the conflicts in terms of mission design and of mismatching of observing time are still there. The only advantage is that since they are solved a priori in favor of the other instrument the polarimeter cannot be kicked off. But also the design is driven by the main application and many of the cautions or of the tricks needed to perform the polarimetry in effective and reliable way cannot be applied.

In any case science can be opportunistic. A measurement of polarization derived from an instrument designed for other applications is, of course, welcome, but it cannot deviate from the general need to extend to polarization the ordinary tools of X-ray Astronomy.

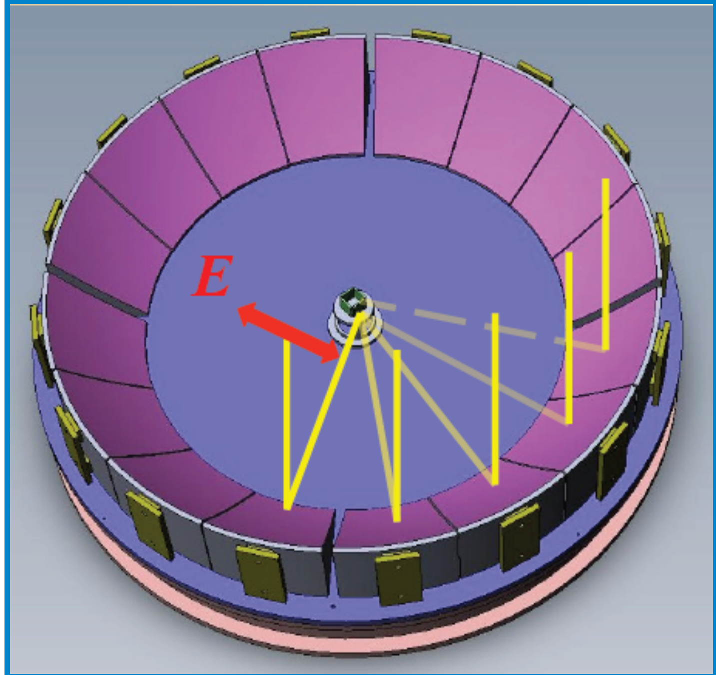
Moving to scattering

Do these thoughts apply to scattering polarimetry? No in my opinion.
If a detector is based on compton and if the energy range is not that high to exclude 90° scattering angles (as COMPTEL unfortunately was) the instrument is also a polarimeter. Of course this would imply to include polarimetry in the design philosophy and in the calibration procedures.
Actually in the early times it was frequently declared that INTEGRAL would be also a polarimeter. At least the use of IBIS as a polarimeter should not be, strictly speaking, an unexpected application. But the fact that no calibration was performed with that pourpose is a problem. SPI, to my memory, was never declared as a polarimeter, because of the dimensions of the pixels, but in this case the hexagonal geometry helps. ASTRO-H was always conceved also as a polarimeter, so that what we see about calibrations is very encouraging.
For future gamma ray instruments to be used as polarimeters I recommend to think from the beginning to the problems that will be faced by the future analyzer of the data.
e.g. a scattering instrument with a square geometry starts with a good 20% of systematic effects. Everybody should seriously consider to adopt an hexagonal geometry, even though it is clear that this is not easy, especially with solid state detectors. Butcompromises are possible. E.g. arrays of square detetors disposed in an hexagonal pattern.

Decreasing the energy:Polarimetry by Diffraction at ~ 45°

Traditionally (35 years ago!) only polarimeters based on Bragg diffraction aroud 45°. Rocketts, OSO-8

Bragg Diffraction at > 2 keV is nowadays overruled by photoelectric polarimeters. At energies < 1 keV is still the only viable technique. Due to thre need of rotation and of long dedicated pointing is a typical application for a (very) small dedicated satellite.



Lightweight Asymmetry and Magnetism Probe (~250eV)
(Tsinghua, Tongji, INAF, INFN)

A good news: ultrathin windows are now available based on AlN. They can provide sensitivity below 500 eV to gas counters. Do not need cooling and should be leak tight (tbv).

Also H.Marshall at MIT is working on proposals based on bragg diffraction

Increasing the energy: γ-rays

The new development of technology allow to expand the present technology of detection to lower energies.

Compton telescopes could go down to 10 – 200 keV and improve significantly the angular resolution strarting with smaller pixels. The holy Gral is to track the compton electron: Si >500keV but less with Xe (SMILE >200 keV).

Pair production telescopes can go far below 100 MeV by thinning or removing the converter. The Holy Gral is to use the same material both as converter and as detector (what I name «one phase polarimeter) with TPCs.

GRBs?

Big news from the Est: Ikaros-GAP, Polaris, POLAR

But also at the SMEX proposal something will arrive

For the future every good Compton Telescope is good also for GRBs

What next?: 3 AOO almost simultaneous!

1) A SMEX AOO from NASA

At least 3 proposals of polarimetry (the names are not necessarily the actual ones):

1) GEMS: X-ray telescope + TPC
2) IXPE: X-ray telescope + GPD
3) X-Calibur: Hard X-ray (ML) telescope with scattering polarimeter

+

4) A wide field polarimeter for solar flares and GRBs
5) ……….

Please notice that the future Japan programs depend also on the result of the NASA SMEX selection. The Chinese mission XTP and the Indian Mission with Thomson polarimeter are completely independent.

What next?: 3 AOO almost simultaneous!

2) ESA-CAS AOO

1)XIPE light: a simplified version of XIPE to meet the very tight constraints put by ESA and CAS to the missions (60kg payload mass).
2)…………….

3)ESA M4

1) Any idea? Maybe 2 telescopes, one with a conventional optics and a low energy (2-8 keV) polarimeter, one with multi-layer optics and a Medium Energy (6 – 35 keV) polarimeter.

Competition and/or Collaboration

Are we decreasing our chances by competition? Would we have more chances by combining different proposals?
I do not think that we can skip competition. And every proposal already includes a certain level of aggregation.

Every team has strong opinions about how an instrument should be designed and built. It is clear that competition is helping to find and solve weakness in different proposals.

Theoreticians can still help by proposing observables that will be the benchmark to compare the different solutions.

Maybe future application on large observatories might require a major flexibility and capability to trade-off, but small missions are the realm of competition and we cannot change this fact.

WHAT NEXT?