X-ray [γ-ray] Astrophysics in the next years and possible contribution to Fundamental Physics

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On 2012:

100years of CR - 50years of XRA

On september 1949 a NRL team lead by Herbert Friedman, performed a rockett (V2) borne experiment searching for extreme UV and X-rays from outside the atmosphere. This was the first detection of astronomic X-rays.

In 1962 a rockett experiment built by R.Giacconi (America Science & Engineering), actuating an idea of Bruno Rossi, discovered the intense diffuse background of X-rays and a very bright source, later named Sco X-1. This was the first detection of non solar Astronomic X-rays.

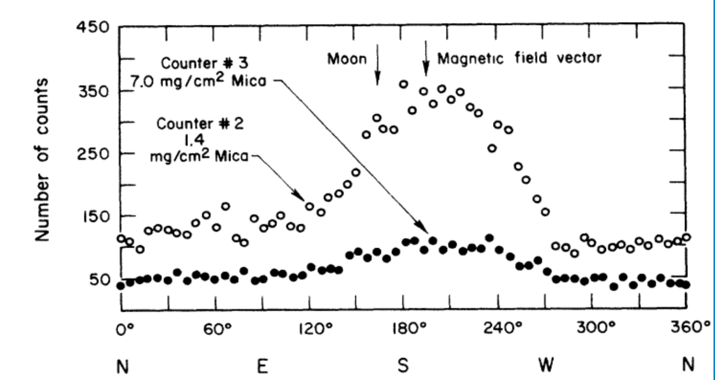
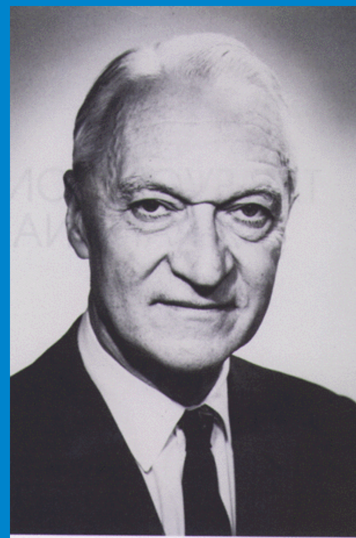


FIG. 1. Number of counts versus azimuth angle. The numbers represent counts accumulated in 350 seconds in each 6° angular interval.



50 years after the discovery of CR

A result from CR scientists.

PHYSICAL REVIEW LETTERS

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EVIDENCE FOR X RAYS FROM SOURCES OUTSIDE THE SOLAR SYSTEM*

Riccardo Giacconi, Herbert Gursky, and Frank R. Paolini
American Science and Engineering, Inc., Cambridge, Massachusetts

and

Bruno B. Rossi
Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received October 12, 1962)

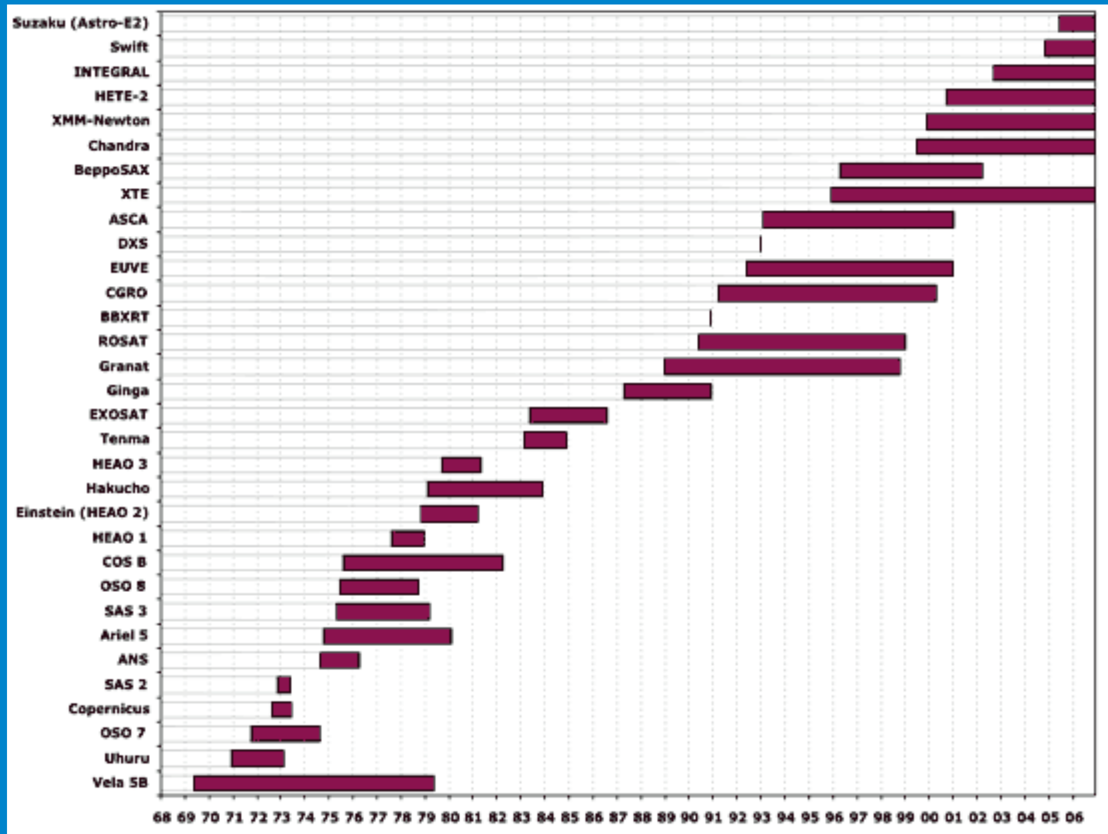
Nobody believed that any non solar X ray could be detected (at least without telescopes). Rossi stated that we must give the Nature the chance to surprize us.
The main lesson from this is: leave a room for discovery. This is also true for costly science.

In 50 years: 27 past missions

ANS - Lifetime: Aug 1974 - June 1977, Energy Range: 0.1 - 30 keV and 1500-3300 Angstoms
Ariel V - Lifetime: Oct 1974 - Mar 1980, Energy Range: 0.3 - 40 keV
ASCA - First X-ray mission to combine imaging capability with broad pass band, good spectral resolution, and a large effective area. (1993 - 2001)
BBXRT - Lifetime: Dec 1990, Energy Range: 0.3 - 12 keV, Shuttle-borne instrument
BeppoSAX - Broad band energy. X-ray imaging the sources associated with Gamma-ray bursts and determining their positions with an unprecedented precision. (1996 - 2002)
CGRO - Compton Gamma Ray Observatory. First Great Gamma-Ray observatory. Discovery of an isotropic distribution of the Gamma-ray bursts. (1991 - 2000)
Copernicus - Lifetime: Aug 1972 - late 1980, Energy Range: 0.5 - 10 keV
COS-B - Lifetime: Aug 1975 - Apr 1982, Energy Range: 2 keV - 5 GeV«
DXS - Lifetime: Jan 1993, Energy Range: 0.15 - 0.28 keV, Shuttle-borne instrument
Einstein - Lifetime: Nov 1978 - Apr 1981, Energy Range: 0.2 - 20 keV
EUVE - Extreme Ultraviolet Explorer. First dedicated extreme ultraviolet mission. (1992 - 2001)
EXOSAT - Lifetime: May 1983 - Apr 1986, Energy Range: 0.05 - 20 keV, 90-hour highly eccentric Earth orbit
Ginga - Lifetime: Feb 1987 - Nov 1991, Energy Range: 1 - 400 keV
Granat - Lifetime: Dec 1989 - Nov 1998, Energy Range: 2 keV - 100 MeV
Hakucho - Lifetime: Feb 1979 - Apr 1985, Energy Range: 0.1 - 100 keV
HEAO-1 - Lifetime: Aug 1977 - Jan 1979, Energy Range: 0.2 - 10 keV
HEAO-3 - Lifetime: Sep 1979 - May 1981, Energy Range: 50 keV - 10 MeV
HETE-2 - Lifetime: Oct 2000 - Oct 2006, Energy Range: 0.5 - 400 keV, designed to detect and localize gamma-ray bursts
OSO-7 - Lifetime: Sep 1971 - Jul 1974, Energy Range: 1 keV - 10 MeV
OSO-8 - Lifetime: Jun 1975 - Sep 1978, Energy Range: 0.15 keV - 1 MeV
ROSAT - Roentgen Satellite. All-sky survey in the soft X-ray band with catalog containing more than 150000 objects. (1990 - 1999)
RXTE - Rossi X-ray Timing Explorer. Lifetime: Dec 1995 - Jan 2012, Energy Range: 1.5 - 240 keV, very large collecting area and all-sky soft X-ray monitor, precision timing with 1 microsecond resolution
SAS-2 - Lifetime: Nov 1972 - Jun 1973, Energy Range: 20 Mev - 1 GeV
SAS-3 - Lifetime: May 1975 - 1979, Energy Range: 0.1 - 60 keV
Tenma - Lifetime: Feb 1983 - late 1984, Energy Range: 0.1 - 60 keV
Uhuru - Lifetime: Dec 1970 - Mar 1973, Energy Range: 2 - 20 keV
Vela 5B - Lifetime: May 1969 - Jun 1979, Energy Range: 3 - 750 keV

http://heasarc.nasa.gov/docs/heasarc/missions/past.html

A large coverage



(From HEASARC site)

7 operative missions with X-ray capabilities

AGILE,	(2007 - present)
Chandra	(1999 - present)
Fermi	(2008 - present)
INTEGRAL	(2002 - present)
MAXI (ISS)	(2009 - present)
NuSTAR	(2012 - present)
Suzaku	(2005 - present)
Swift	(2004 - present)
XMM-Newton	(1999 - present)

All these missions are observatories open to the community worldwide. Observations may be request on the basis of competitive AOO. At least data are publicaly distributed. Also missions conceived as «experiments» after succesful peformance are converted into observatories.
This is a major difference between High energy Astrophysics and High Energy Physics

Also IKAROS-GAP of Solar Flare/GRB Polarimetry

The cost to mantain a mission is much lower than that to make a new one. Specially for telescopes there is a large room for new ideas and for serendipitous disoveries.

Conversely for this reason every time a hot topic is singled out the first check is whether it can be solved by pointing an existing mission.

Existing

- FERMI and AGILE are γ-ray missions with some limited X-ray capabilitiesmainly oriented to complement the γ-ray measurements
- MAXI, aboard the ISS is an all-sky monitor. It detects transient and burst sources and monitors all sources including a good number of extragalactic. After the switch-off of XTE it is the only all-sky monitor in soft/medium X-rays. Around 400 sources.
- Chandra is the best X-ray imager ever made (0.5 arcesec). Excepional images. Good spectroscopy (CCDs and gratings). Maximum sensitivity for deep fields.
- XMM is the Workhorse of X-Ray Astronomy. Good but not exceptional imaging capabilities (15 arcseconds) but large area and good energy resolution (CCDs and gratings).
- INTEGRAL is the only missions studying soft gamma rays with imaging and spectroscopic capabilities. It has also surveying the sky in Hard X-Rays with a sensitivity increasing with time.
- SWIFT is devoted to study GRBs but is also producing a survey of Hard X-ray Sky and acting as an X-ray telescope with CCD open to the community.
- Suzaku includes an X-ray telescope with a CCD open to the community and collimated HardX-ray detectors.
- NUSTAR with a Hard X-Ray telescope and CZT pixel detector mainly devoted to hard X-ray spectra

Large Discovery Space

In advanced stage

National/bilateral programs:
SPECTRUM-X-G (E-ROSITA + ART XC) (Germany, Russia) 2015
ASTRO-H (mainly Japan) 2015
HXMT (China) 2015-2016
ASTROSAT (India) 2015

Under selection process

Many missions proposed for ESA M4 selection :
LOFT (timing), XIPE(polarimetry), Phenix (Hard X), a GRB mission.
A AOO for a NASA SMEX about to close: 4 missions of X-ray Polarimetry (IXPE, GEMS, STARPOLAR, a mission of GRB/Solar Flare Polarimetry).
In ESA: ESA-CAS (Small Mission with China), Future M5/M6 AOO.

Approved for the future

ATHENA (ESA) 2028

X-ray Astronomy covers almost all fields of Astronomy

The first discoveres were the binaries including White Dwarfes , Nutron Stars, Black Holes. With UHURU satellite 350 sources including a few extragalactic (mainly AGNs). In galaxy clusters there is a large amount of hot gas: the mass of the universe is 3 times what previously known. Einstein satellite was the first to use the X-ray optics allowing for imaging extended sorces and increasing the sensitivity of many orders of mgnitude. Einstein took images and spectra of SuperNova Remnants and of Clusters, found coronal emission of stars, sources in other galaxies and enormously increased the sample of galactic sources and especially of extragalactic ones. ROSAT satellite, also based on an X-ray telescope, made the first deep survey of all the sky. Moreover discovered the emission from the moon and from comets and measured the flux of brighter sorces for around15 years.. XTE disvered quasi pulsations from neutron stars up to 1 kHz frequency. Beppo SAX made the first broad band sectra from 0.1 to 300 keV and discvered and localized the afterglow of GammaRay Burst. SWIFT discovered the fuzzy behavior of early GRBs and continuously maps the Hard X-ray sky. INTEGRAL mapped the 511 keV line i the galaxy and surveys hard X-ray sky.
But far the largest amount of data have been collected in the last 10 years with the two big telescopes Chandra and XMM.

But what about Physics?

Many or most of proposed X-Ray Missions intend or pretend to face and solve problems of fundamental Physics.

Historically the contribution of Astrophysics to Physics has been very important but limited to some specfic cases:
e.g. Kepler Laws, Speed of Light, Series in Solar Spectrum, Solar Neutrinos, Gravitational Radiation in binary pulsars ……
In General Relativity Cosmology and beyond Physics and Astrophysics merge and the distinction is no more meaningful

Historically the major contribution of X-ray Astrophysics to Physics were:
•the existence of stellar Black Holes
•a strong contribution to the existence of Super Massive Black Holes.
•Doubling the mass of baryonic matter

X-Ray Astronomy also discovered scenarios where laws of Physics can be probed:
•Extreme Magnetic Fields (pulsars and magnetars)
•Extreme Gravitational Fields (BH and NS)
•Extreme Variabilty
•Long Distances GRBs up to Z ~ 10

Physics and Astrophysics

In some cases Astrophysics is the core/guaranteed science and Physics the «just in case» science. Feeding the community with data is the basis of a succesful mission.

But in some cases Physics is the core science: e.g. LOFT

Which Discovery Space? What is on the table in terms of new missions and new instrumental solutions?

- High Resolution Spectroscopy: approved ATHENA (ESA 2028)
- Timing: LOFT advaned Study in ESA M3 not selected – candidate M4: with less area (ASTROSAT, XTP)
- Polarimetry: 3 mission competing for NASA SMEX, 1 for ESA M4 (2025), 1 proposal ESA-CAS
- Wide Field/all Sky/GRB : candidate missions at every AOO

High Resolution Specroscopy

ATHENA a Large Mission approved by ESAfor 2028
SCIENCE THEME: THE HOT AND ENERGETIC UNIVERSE

Table 4: Key parameters and requirements of the *Athena*+ mission. The enabling technology is indicated.

Parameter	Requirements	Enabling technology/comments
Effective Area	2 m^2 @ 1 keV (goal 2.5 m^2) 0.25 m^2 @ 6 keV (goal 0.3 m^2)	Silicon Pore Optics developed by ESA. Single telescope: 3 m outer diameter, 12 m fixed focal length.
Angular Resolution	5" (goal 3") on-axis 10" at 25' radius	*Detailed analysis of error budget confirms that a performance of 5" HEW is feasible.*
Energy Range	0.3-12 keV	Grazing incidence optics & detectors.
Instrument Field of View	*Wide-Field Imager:* (WFI): 40' (goal 50')	Large area DEPFET Active Pixel Sensors.
	X-ray Integral Field Unit: (X-IFU): 5' (goal 7')	Large array of multiplexed Transition Edge Sensors (TES) with 250 micron pixels.
Spectral Resolution	WFI: <150 eV @ 6 keV	Large area DEPFET Active Pixel Sensors.
	X-IFU: 2.5 eV @ 6 keV (goal 1.5 eV @ 1 keV)	*Inner array (10"x10") optimized for goal resolution at low energy (50 micron pixels).*
Count Rate Capability	> 1 Crab[3] (WFI)	*Central chip for high count rates without pile-up and with micro-second time resolution.*
	10 mCrab, point source (X-IFU) 1 Crab (30% throughput)	*Filters and beam diffuser enable higher count rate capability with reduced spectral resolution.*
TOO Response	4 hours (goal 2 hours) for 50% of time	*Slew times <2 hours feasible; total response time dependent on ground system issues.*

The instruments

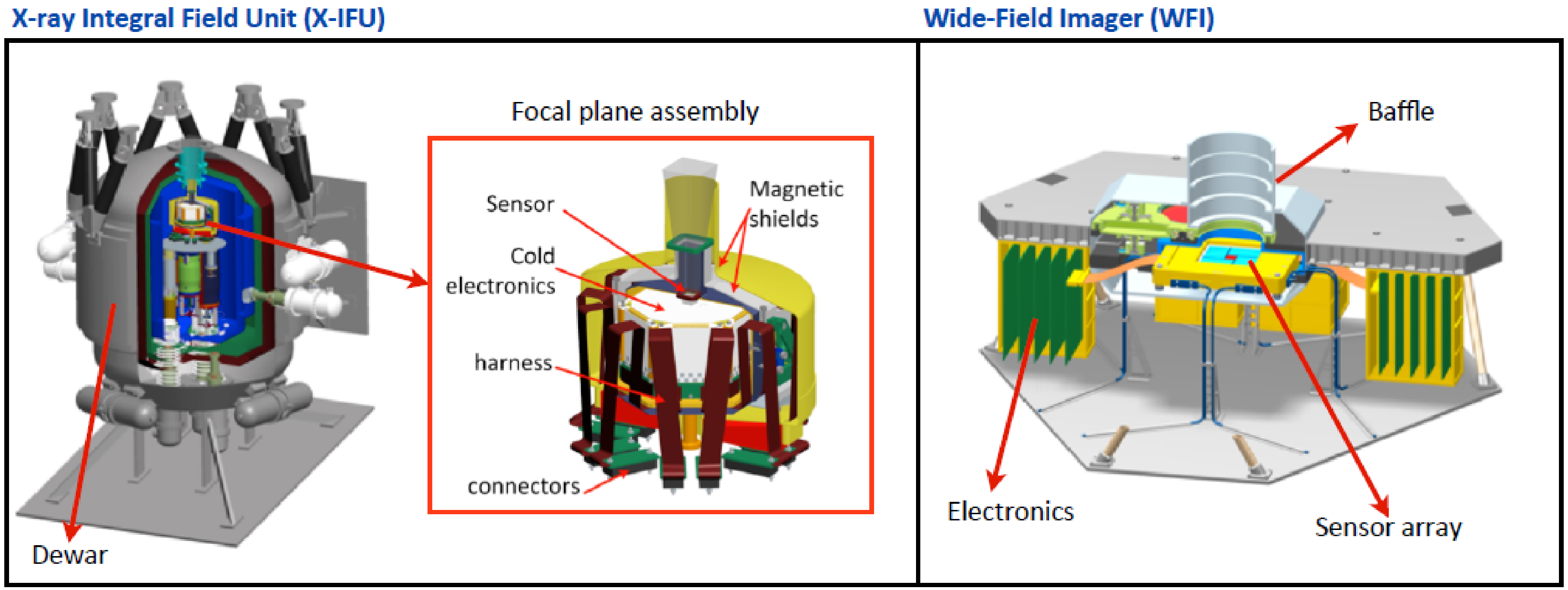
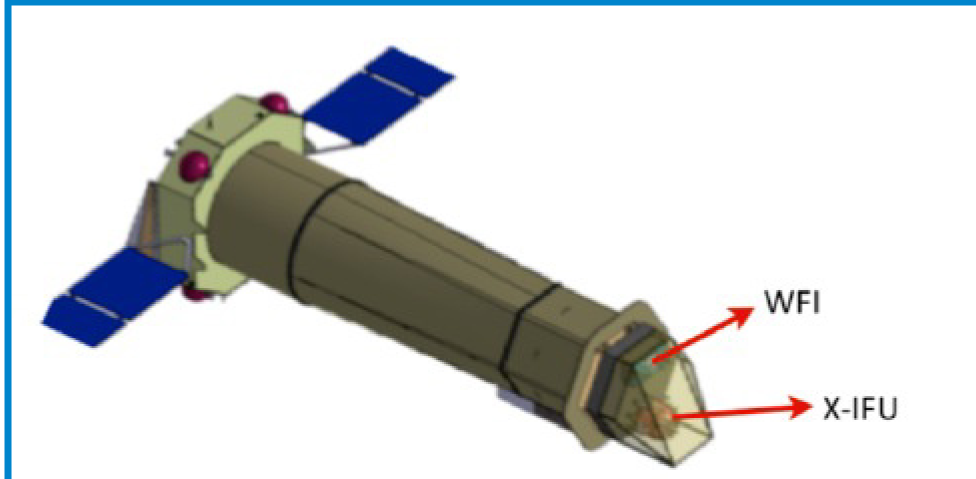


Figure 10: The *Athena+* science instruments. *Left:* Design drawing of the X-IFU showing the Dewar and a zoom on the focal plane assembly. *Right*: Design drawing of the WFI.

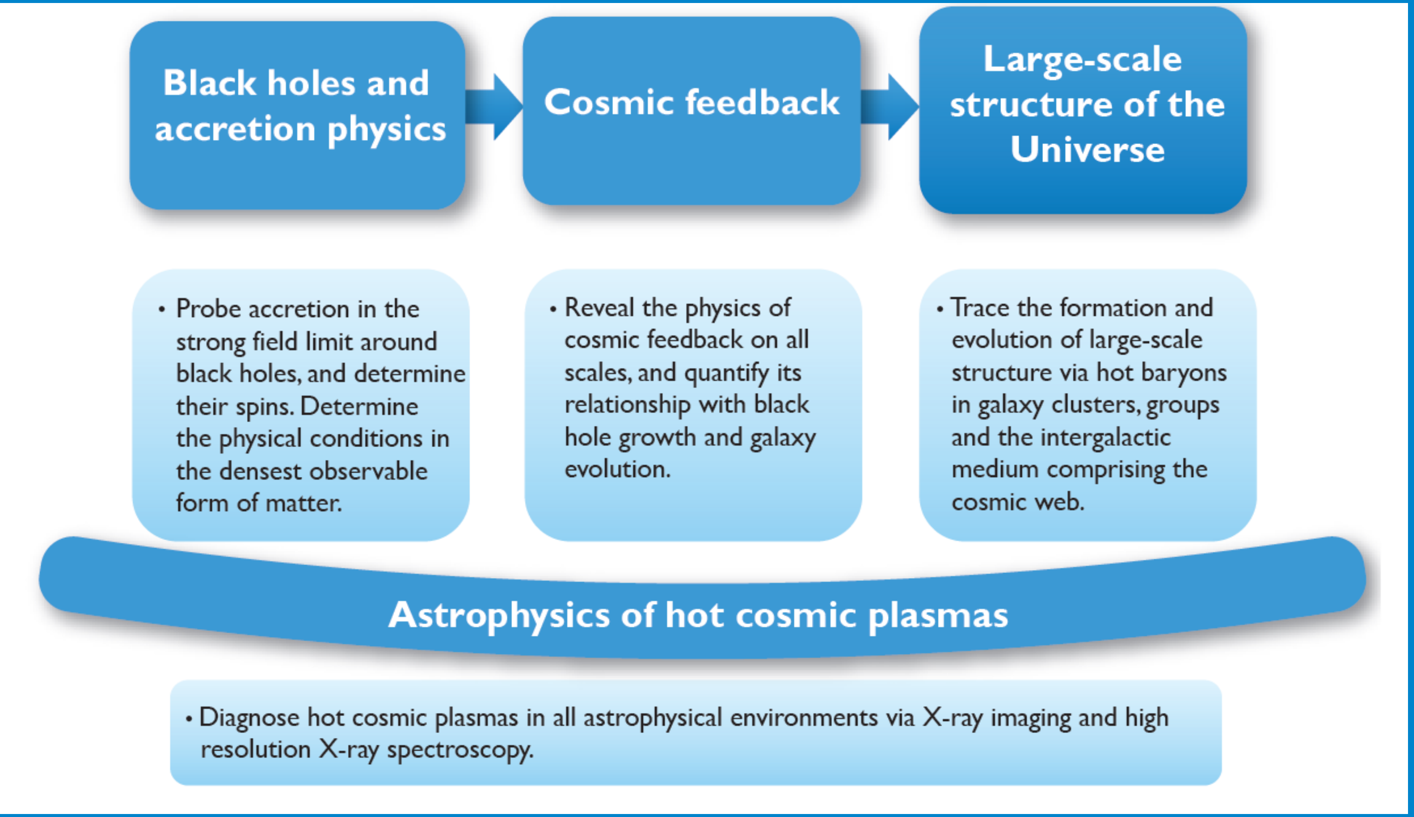


A telescope of 2 m^2 (→1.4 m^2) of Silicon Pore Optics
A microcalorimeter
An imager (APS)
ATHENA will cover with unprecedented sensitivity almost all fields of Astronomy
(from ATHENA Whie Paper)

X-ray Cosmology

In the objectives of ATHENA

- Reveal the physics underpinning cosmic feedback, and show how it relates the growth of super-massive black holes to the evolution of galaxies.
- Trace the formation and evolution of large-scale structure via the properties of hot baryons in clusters of galaxies and the cosmic web.



ATHENA for Physics

ATHENA will be a large observatory covering all issues of Astrophysics (from planets to GRBs).
But the Core Science of ATHENA is contributing to Cosmology by studying the Large Scale Structures of the Universe in X-rays.
Two key questions in astrophysics:
1)How does ordinary matter assemble into the large scale structures that we see today?
2)How do black holes grow and shape the Universe (feed back)?

ATHENA will map the large scale distribution of the baryonic matter. But in fact the structures are gravitationally bound by dark matter so that the Hot Universe is the tracer of DM and play on a large scale the same role of rotation in galaxies.

Dark Energy. Presently studied with Supernovae. In the future with weak gravitational lensing and Baryonic Acoustic Oscillations (EUCLID). Thanks to high resolution spectroscopy ATHENA will study clusters and derive density and metal content to derive the correct density and disentangle the gravitational heathing from the heathing due to other sources.

The power of spectroscopy

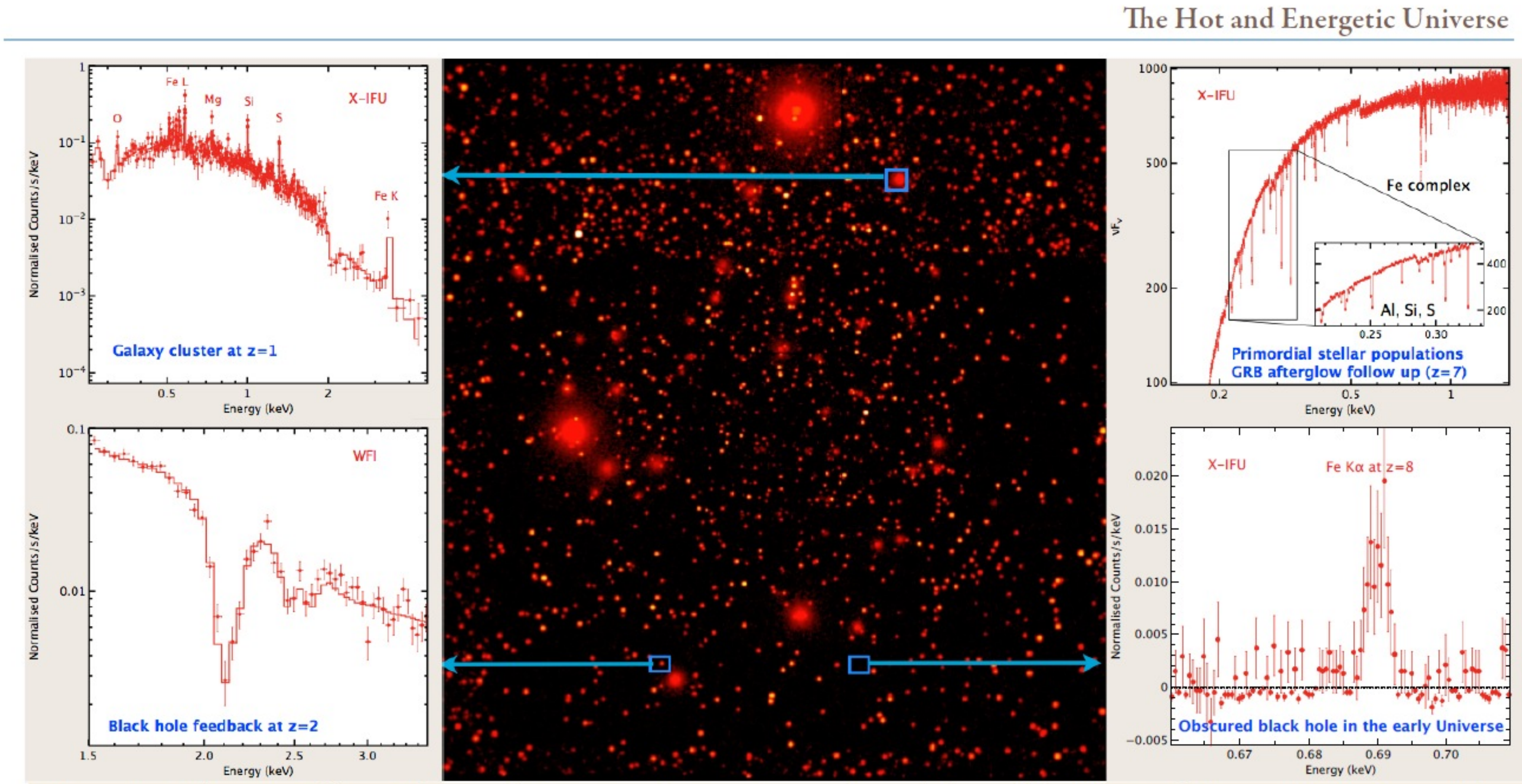


Figure 1: *Athena+* **will provide revolutionary advances in our knowledge of the Hot and Energetic Universe.** The central panel is a simulated deep WFI observation, while the four surrounding spectra illustrate advances in different science areas, none of which are possible with current facilities.

PHYSICS OF COMPACT OBJECTS

X-ray Astronomy is the domain of fast variability.
Pulsars (discovered in Radio) gave evidence of the existence of Neutron Stars. X-ray Pulsars are powered by accretion of matter from a companion.
X-Ray Astronomy also provided the evidence for the existence of binary systems with a Black Hole.
Soft Gamma Repeaters and Anomalous X-Ray Pulsars provided the evidence for the existence of isolated NSs with very high magnetic fields (up to 1015 gauss)., the so called Magnetars.
The emission from neutron stars with high manetic field is dominated by the pulsation with the period of the rotation of the neutron star.
Both NSs and BHs also show Quasi Periodic Oscillations.

Matter accreting (or ejected) on the NS and the BH is exposed to very high gravitational fields. It is a laboratory o test gravitation in this regime. The phenomelogy associated cn be studied in:

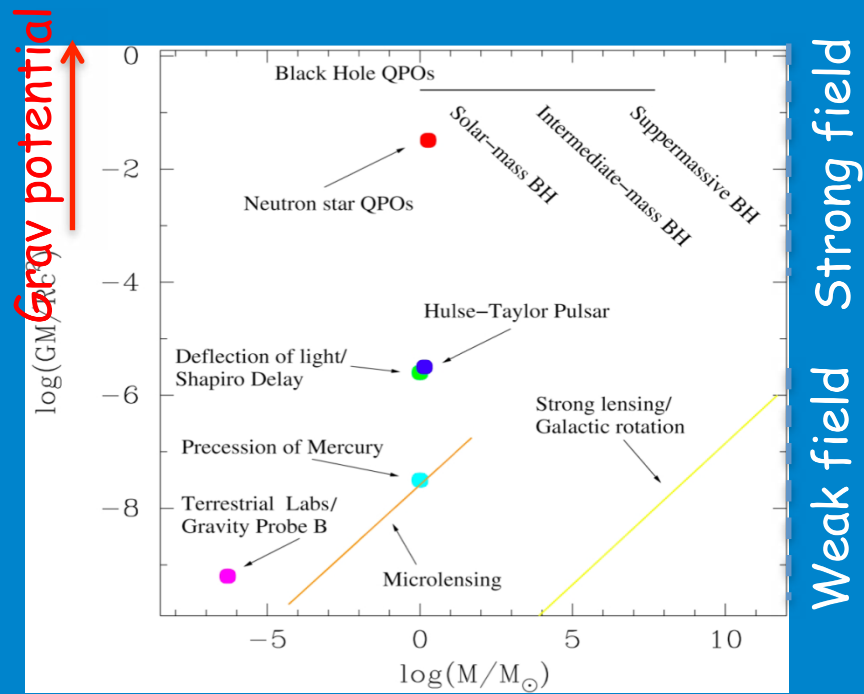
- Spectroscopy (Lines and continuum)
- Timing (Periodic, Aperiodic, Quasi-Periodic)
- Polarimetry

Most of these measurements are model dependent but from different measurements the model can be overdetermined

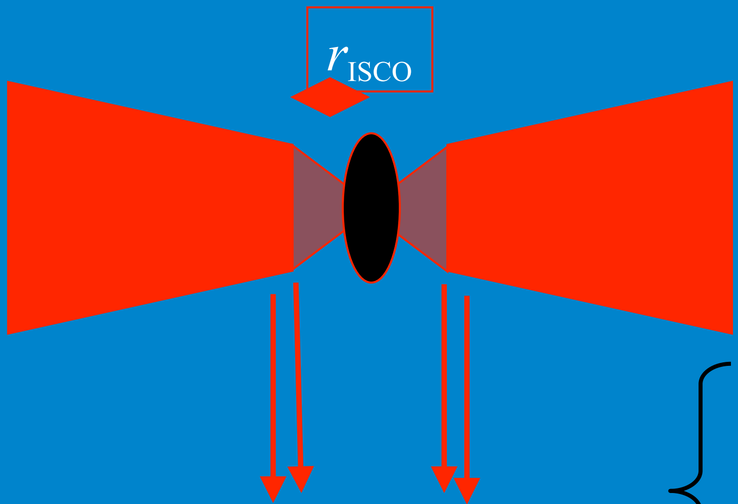
Strong Field Gravity: What are the laws of physics in extreme conditions?

General Relativity (GR) has been probed in the so-called weak-field regime at scales of the order of 10^5-10^6 R_g (R_g=GM/c^2)

Regions at the scales of few R_g need to be probed to detect GR in its most extreme conditions: matter accretion into black holes and neutron stars provide the best tools.



Psaltis 2004



Photons (mainly EUV + X-rays)

- Spatial (x,y) – unresolved (interferometry)
- Timing (t)
- Spectroscopy (E)
- Polarization (PA) – unresolved (polarimetry)

Timing and Spectroscopy: feasible can be improved

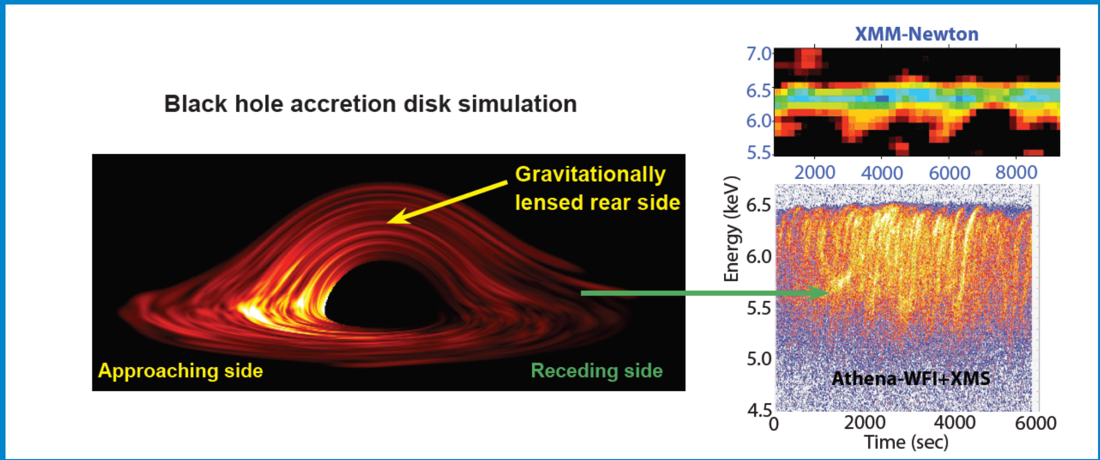
The main diagnostic tools

So far two major tools:

- Spectroscopy of Fe lines broadened by gravitational gradient and distorted by kinematics
- Quasi-periodic oscillations of the flux.

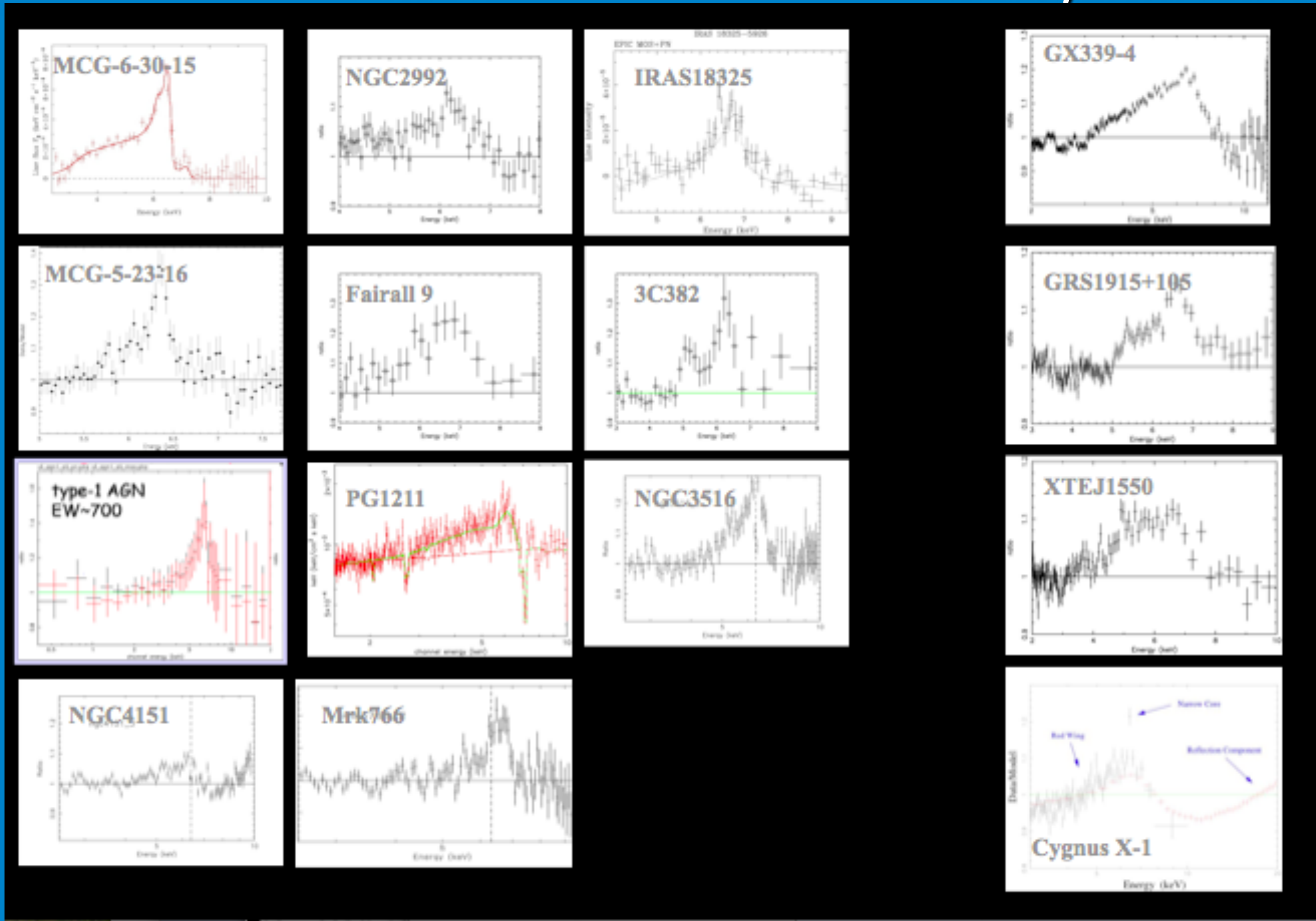
To be potentially integrated in the future with

- polarimetry

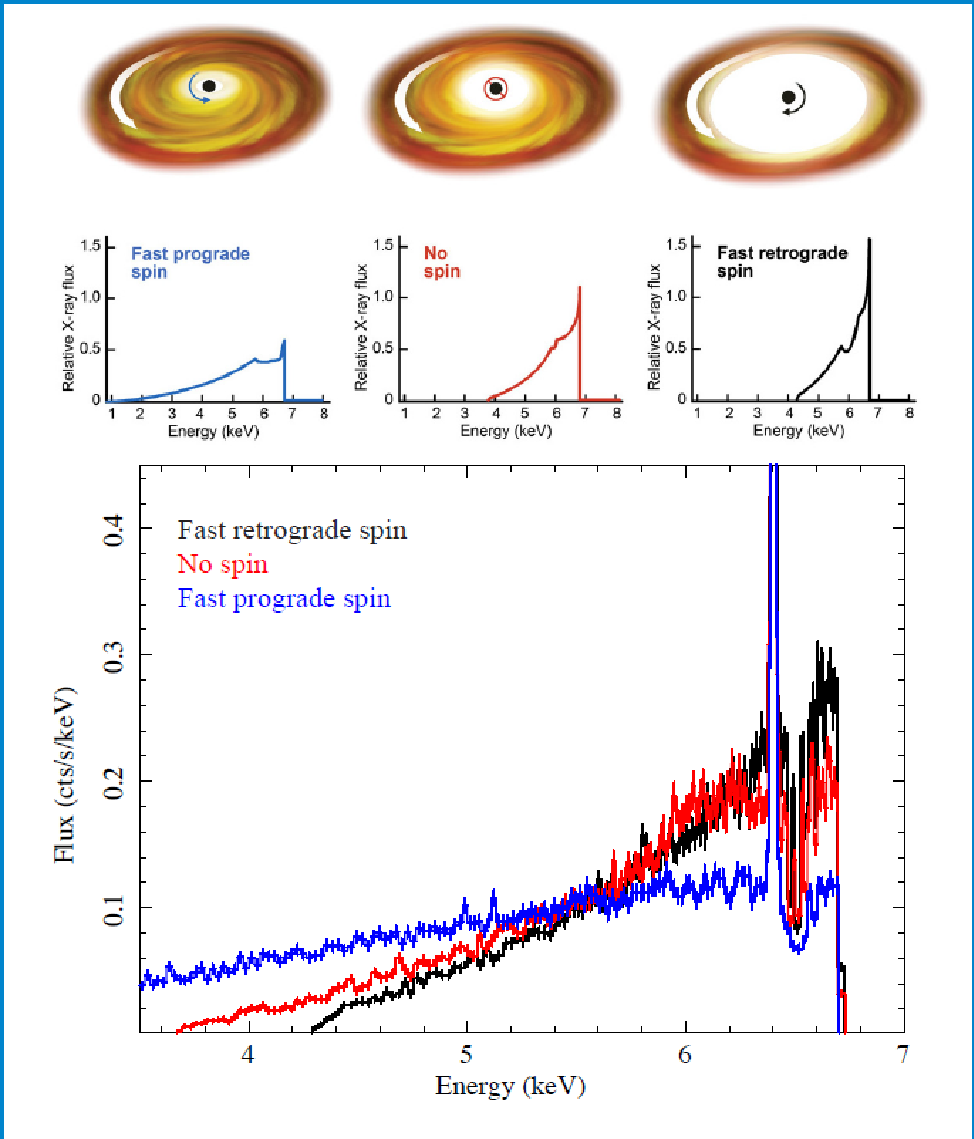


Investigating the turbulent accretion flow on a BH by time resolved spectroscopy. Needs Area and Spectral Resolution. ATHENA v/s XMM

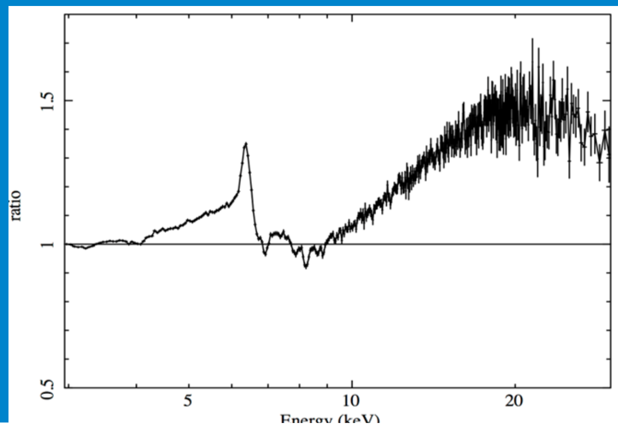
Very Broad Fe-K line profiles in :
AGNs X-ray Binaries



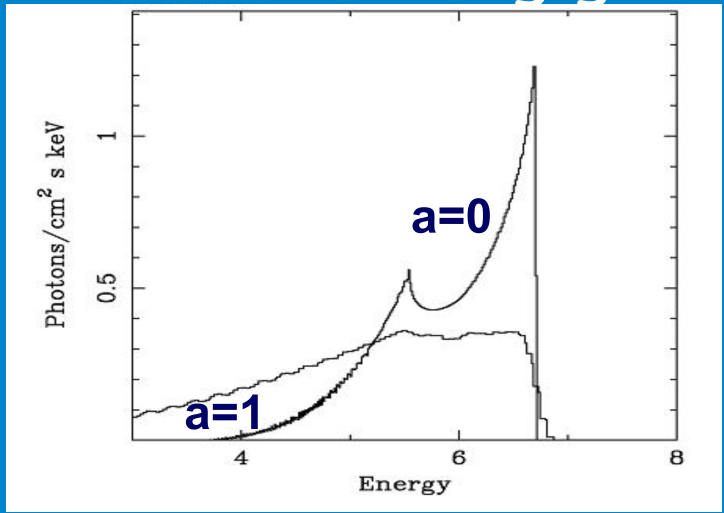
Relativistic lines with ATHENA and LOFT



The relativistic lines have been discovered by ASCA thanks to the good resolution of CCDs, and deeply studied with XMM and Chandra.
A Large telescope like ATHENA can extend the sample of extragalactic sources and search for the predicted evolution of BH spin.
Moreover the high spectral resolution is useful to disentingle the unmodified core of the Fe line.
A large area collimated instrument like LOFT can do the the same work on brightest (near) sources.

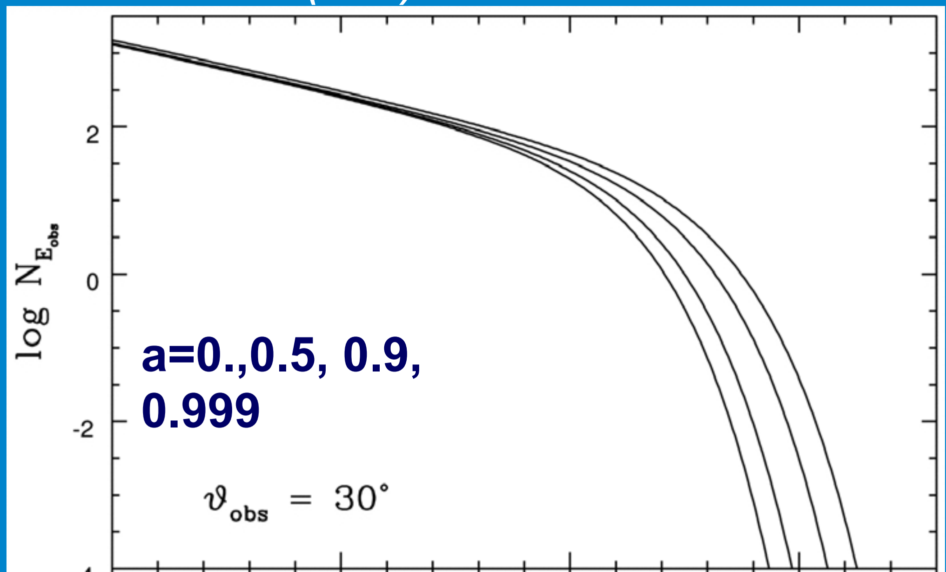


Strong gravity and black hole spin



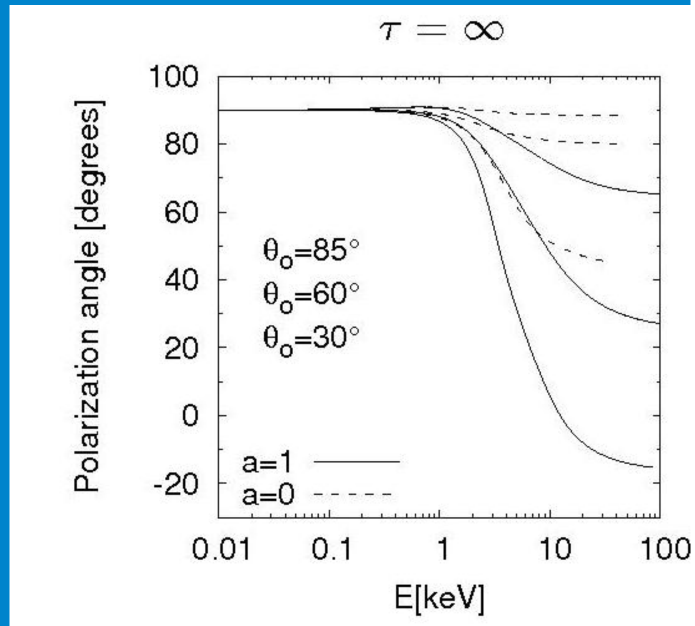
Fabian et al. (2000)

Different, independent methods (line profile, continuum shape, rotation of the polarization angle) can be applied simultaneously to estimate the black hole spin ("concordance model"). A broad band measurement and simultaneous spectroscopy and polarimetry (such as NHXM).

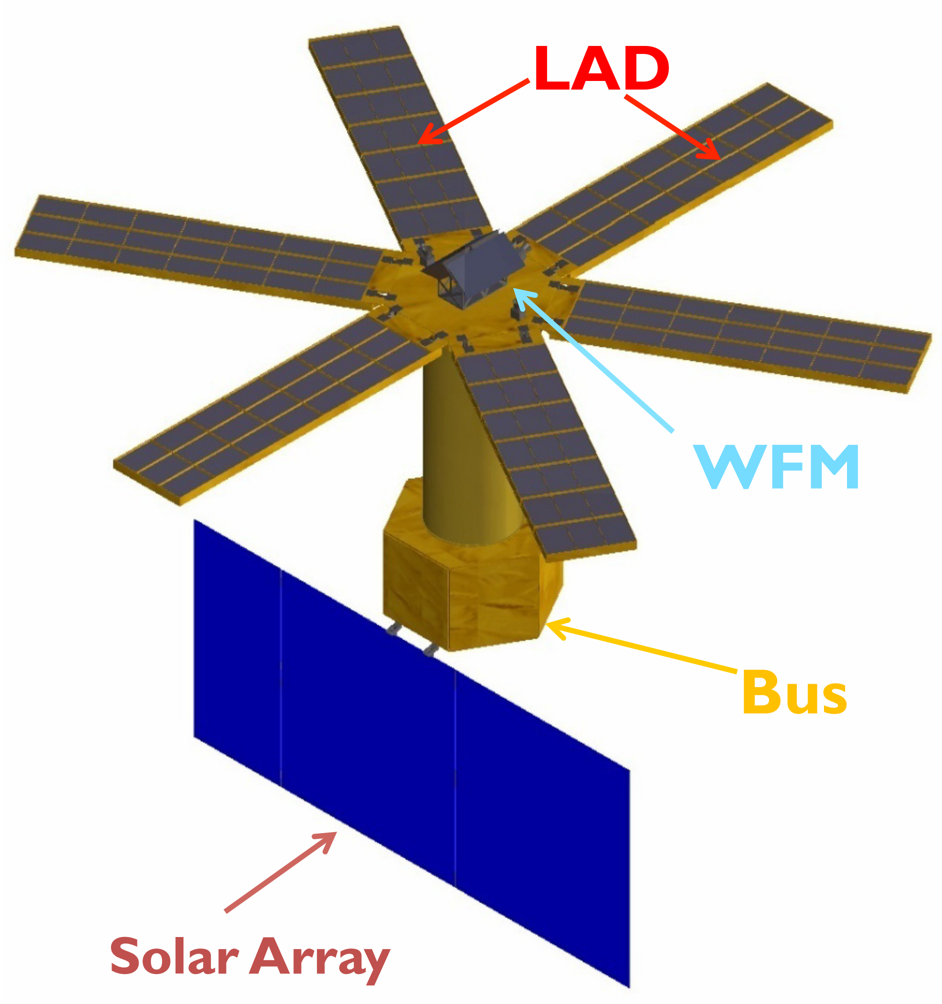


Li et al. (2005)

Dovciak et al. (2008)



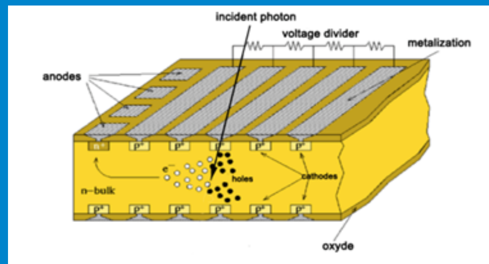
Medium size mission (LOFT)

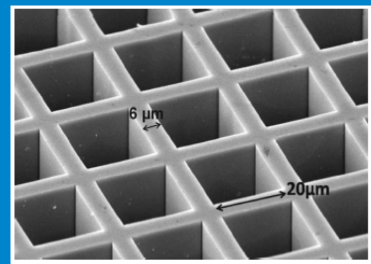


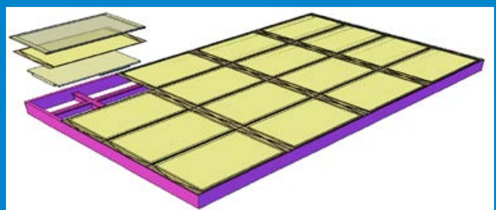
Fully modular/redundant by design
(126 independent modules)

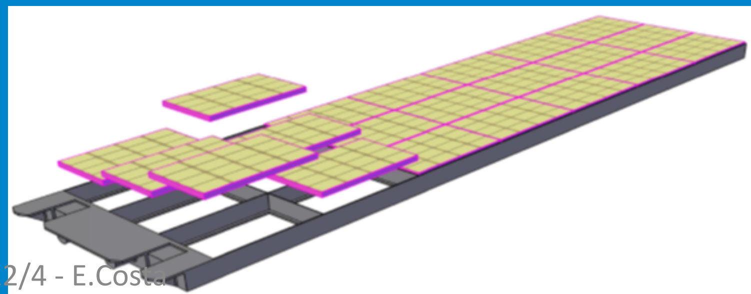
Fine detector segmentation
($5x10^5$ read-out channels, 0.3 cm^2 each, deadtime and the pile-up minor issues).

Driving Technology:
large-area Silicon Drift Detectors and capillary plate collimators.





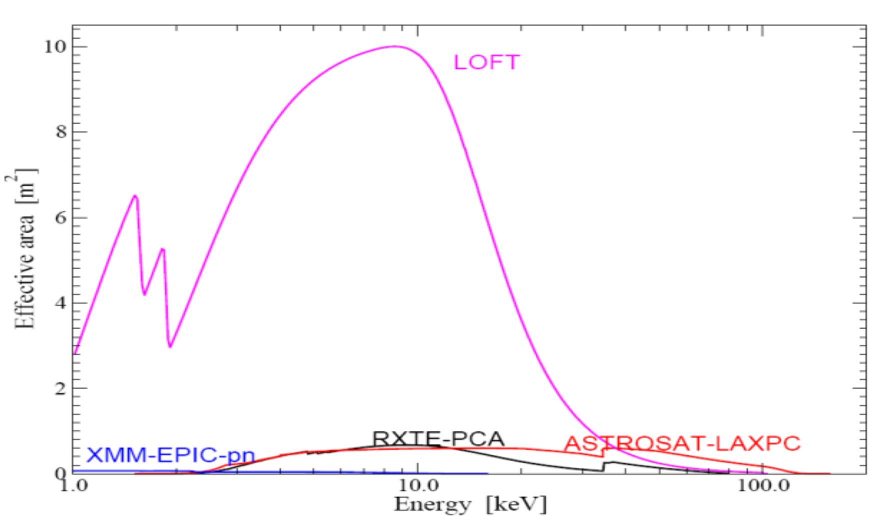




TIMING

Large Observatory for Fast Timing (LOFT) is one of the four missions performing assessment study for the selection of the M3 ESA mission. LOFT was not selected as is running now for M4 (2025).

LOFT has a very clear driver: to make fast timing you need Area.



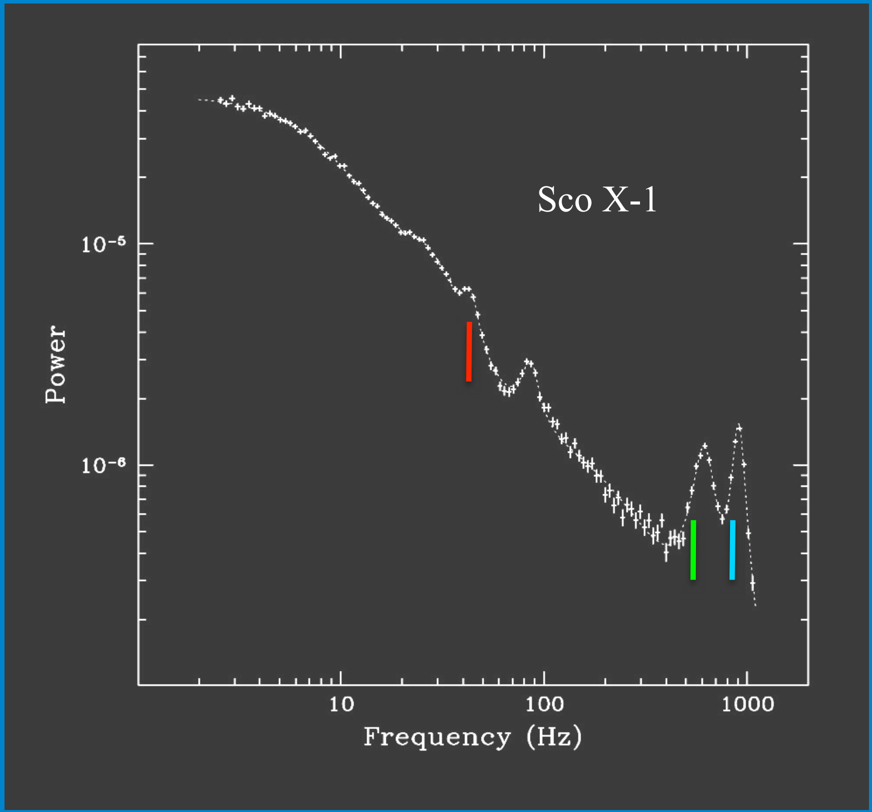
LAD – Large Area Detector	
Effective Area	4 m² @ 2 keV 8 m² @ 5 keV 10 m² @ 8 keV 1 m² @ 30 keV
Energy range	2-30 keV primary 30-80 keV extended
Energy resolution FWHM	260 eV @ 6 keV 200 eV @ 6 keV (45% of area)
Collimated FoV	1 degree FWHM
Time Resolution	10 μs
Absolute time accuracy	1 μs
Dead Time	<1% at 1 Crab
Background	<10 mCrab (<1% syst)
Max Flux	500 mCrab full event info 15 Crab binned mode

Far the best measurements of timing were performed by XTE PCA, that served for 15 years til 2010.
LOFT Large Area Deector is 20 times PCA.

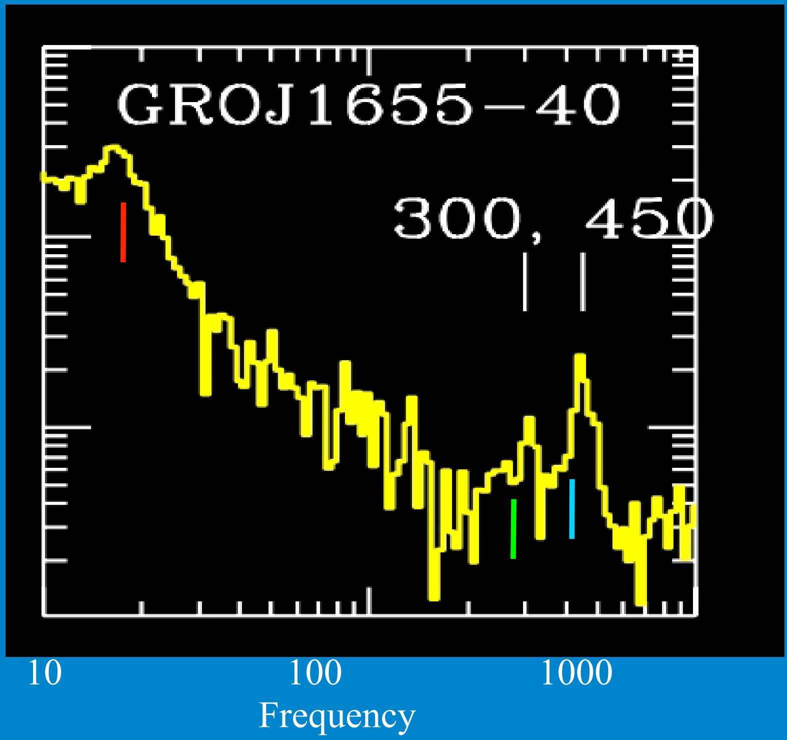
Feroci et al. 2012

Strong Field Diagnostic: Quasi Periodic Oscillations

Accreting Neutron Stars



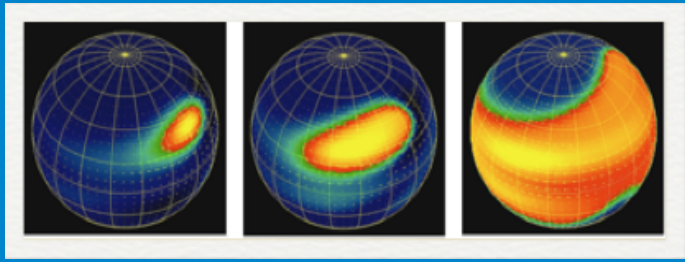
Accreting Black Holes



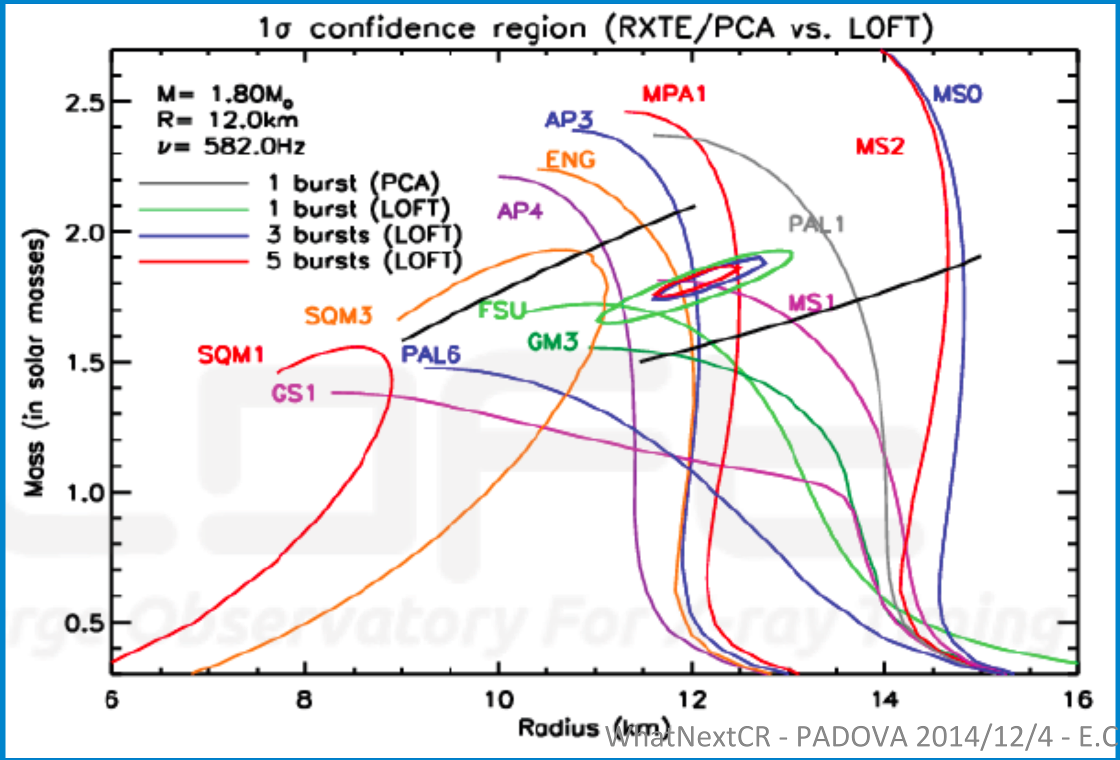
Quasi because the frequency changes. You cannot accumulate data in phase on a long term (as was the case of Gamma Ray Pulsars)

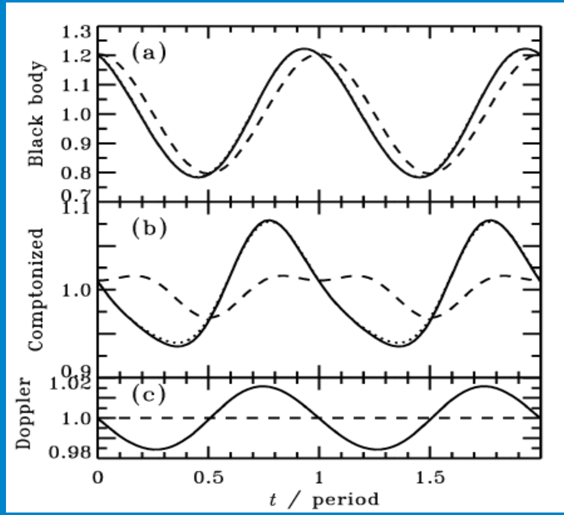
Dense matter:
Neutron Star Structure and Equation of State of ultradense matter

X-ray oscillations are produced by hot spots rotating at the NS surface.
Modeling of the pulses (shape, energy dependence) taking into account Doppler boosting, time dilation, gravitational light bending and frame dragging will constrain the M/R of the NS.

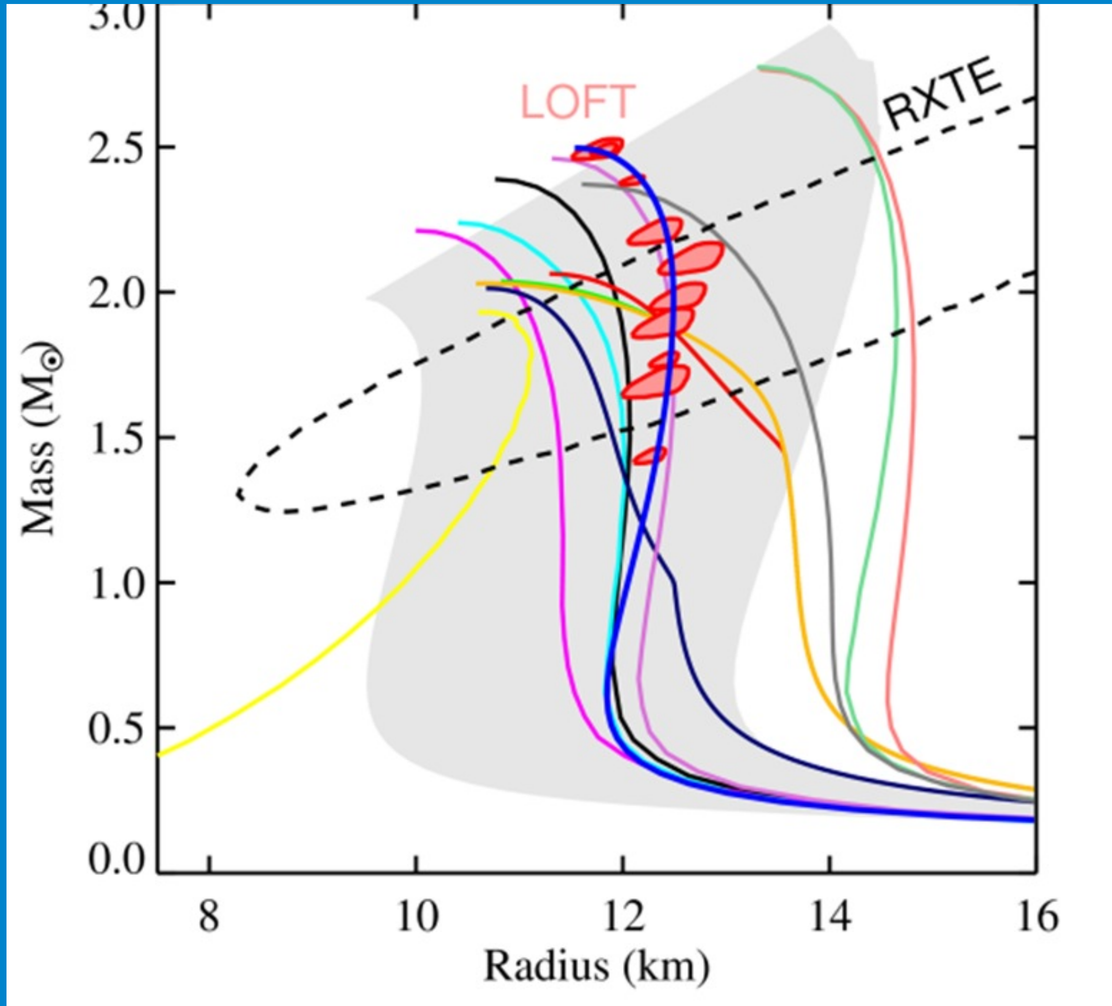


Poutanen and Gierlinski 2003



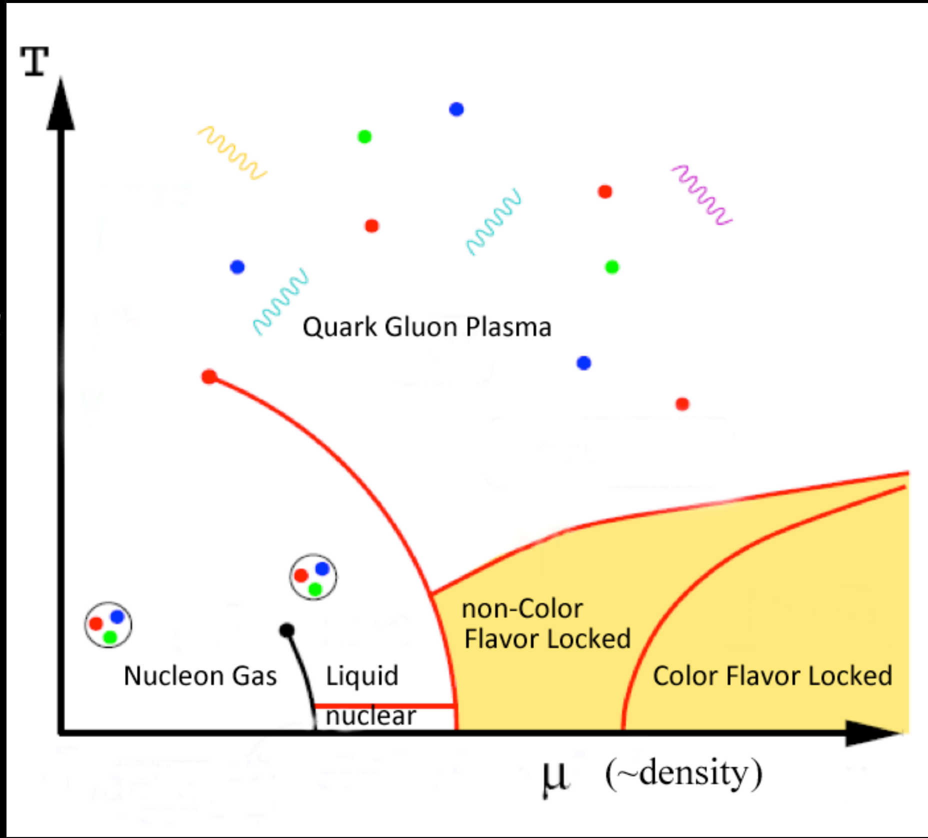


One point is not enough for EOS



QCD Phase Diagram

- Little known on the properties of bulk matter at supernuclear densities
- Color Flavor Locked (CFL) phase expected asymptotically (high mu)
- Quark Gluon Phase at high T and mu
- Gas and liquid phases of nuclei at low mu
- Normal Quark phase or other exotic Phases in between (e.g. two-flavor color superconducting phase(2SC), gapless 2SC phase)



Heavy ion collision experiment sample the high-energy regime (> 100 GeV/nucleon, i.e. high T in the diagram)

Low energy regime can only be studied through compact stars

Courtesy of L.Stella

QCD Phase Diagram

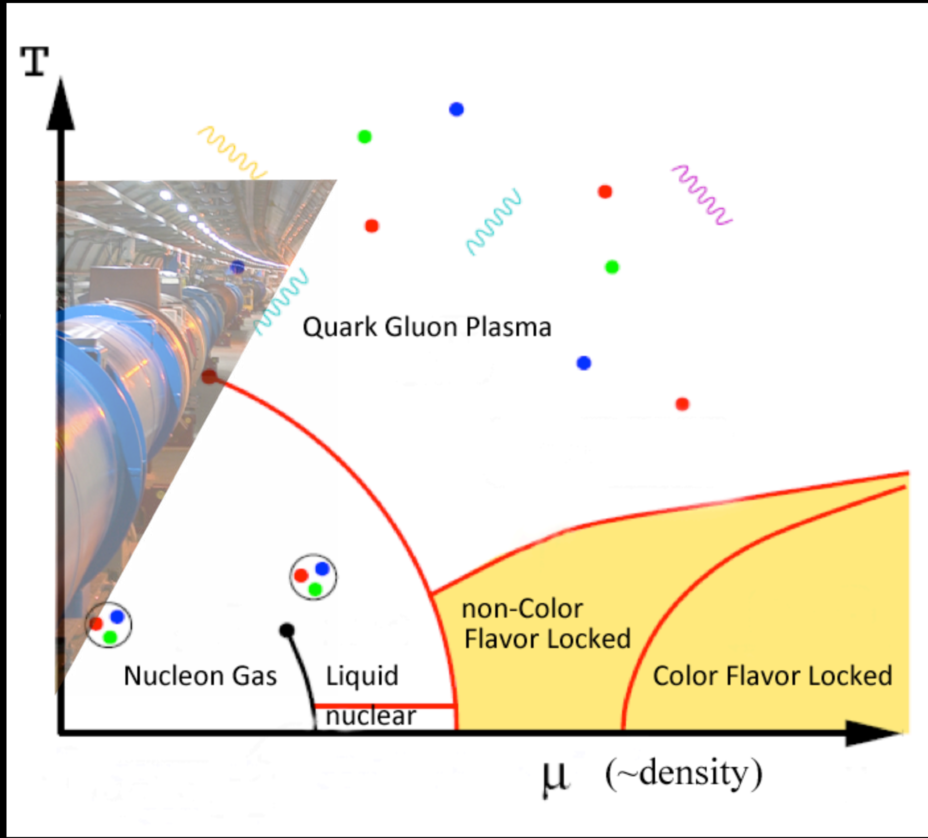
- Little known on the properties of bulk matter at supernuclear densities

- Color Flavor Locked (CFL) phase expected asymptotically (high mu)

- Quark Gluon Phase at high T and mu

- Gas and liquid phases of nuclei at low mu

- Normal Quark phase or other exotic Phases in between (e.g. two-flavor color superconducting phase(2SC), gapless 2SC phase)



Heavy ion collision experiment sample the high-energy regime (> 100 GeV/nucleon, i.e. high T in the diagram)

Low energy regime can only be studied through compact stars

Courtesy of L.Stella

QCD Phase Diagram

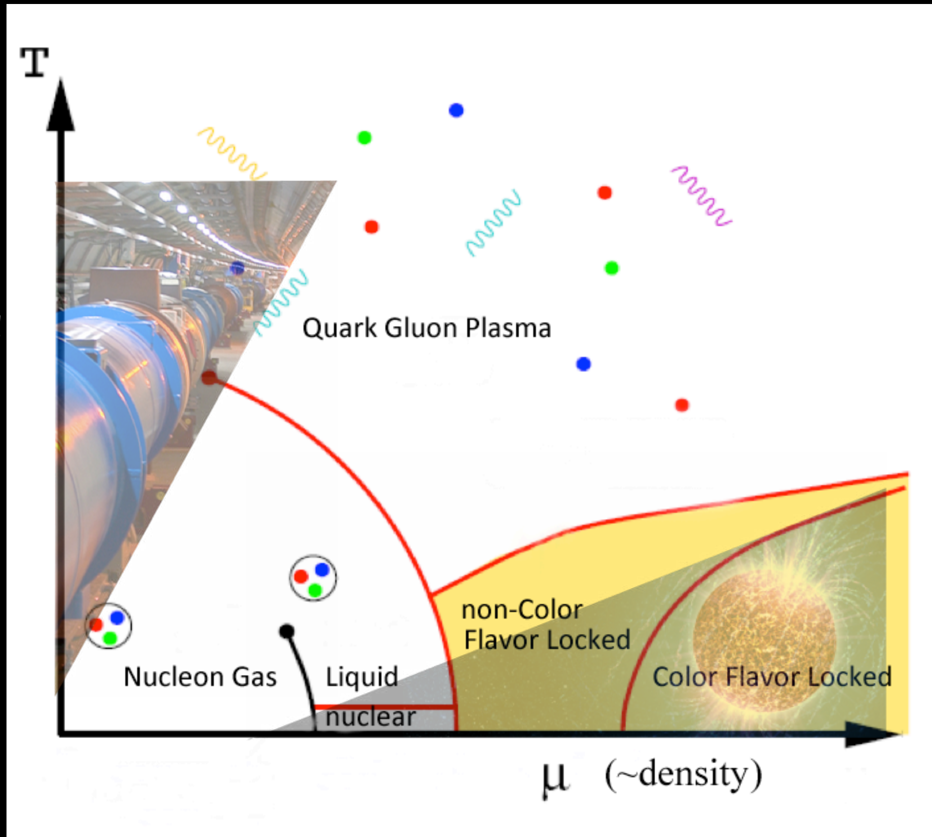
- Little known on the properties of bulk matter at supernuclear densities

- Color Flavor Locked (CFL) phase expected asymptotically (high mu)

- Quark Gluon Phase at high T and mu

- Gas and liquid phases of nuclei at low mu

- Normal Quark phase or other exotic Phases in between (e.g. two-flavor color superconducting phase(2SC), gapless 2SC phase)

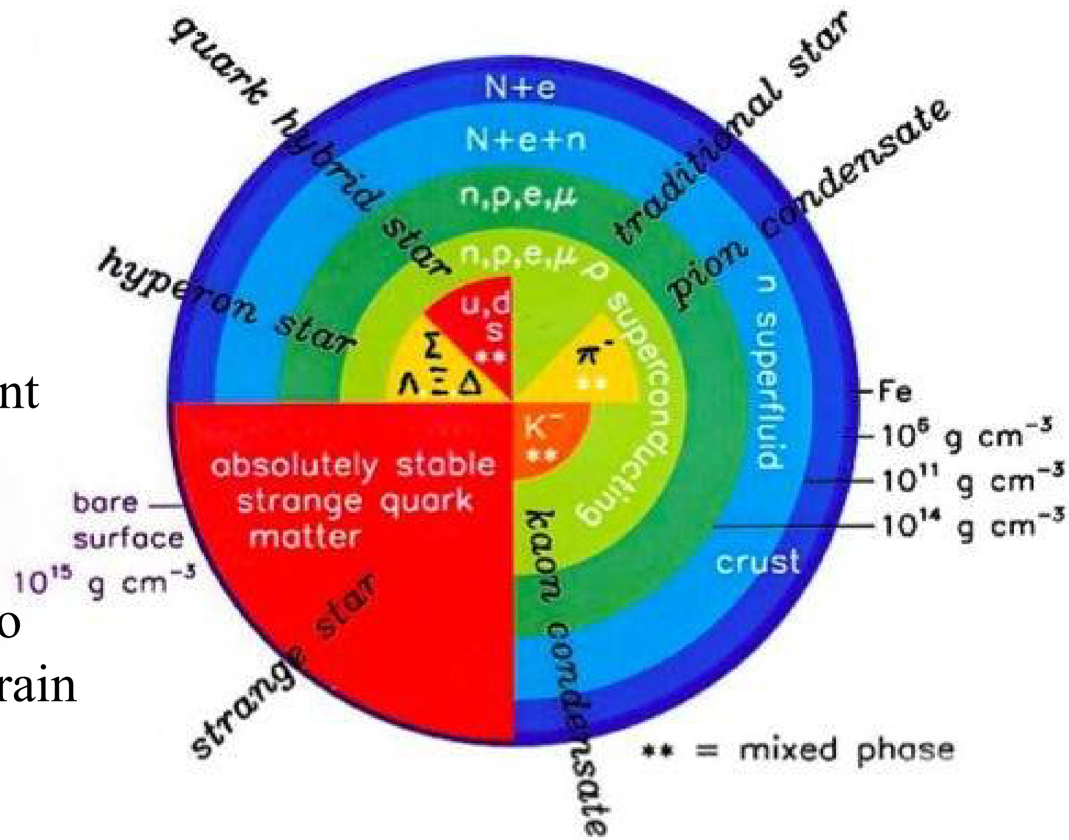


Heavy ion collision experiment sample the high-energy regime (> 100 GeV/nucleon, i.e. high T in the diagram)

Low energy regime can only be studied through compact stars

Dense Matter Diagnostic:
Neutron star structure and equation of state (EOS)

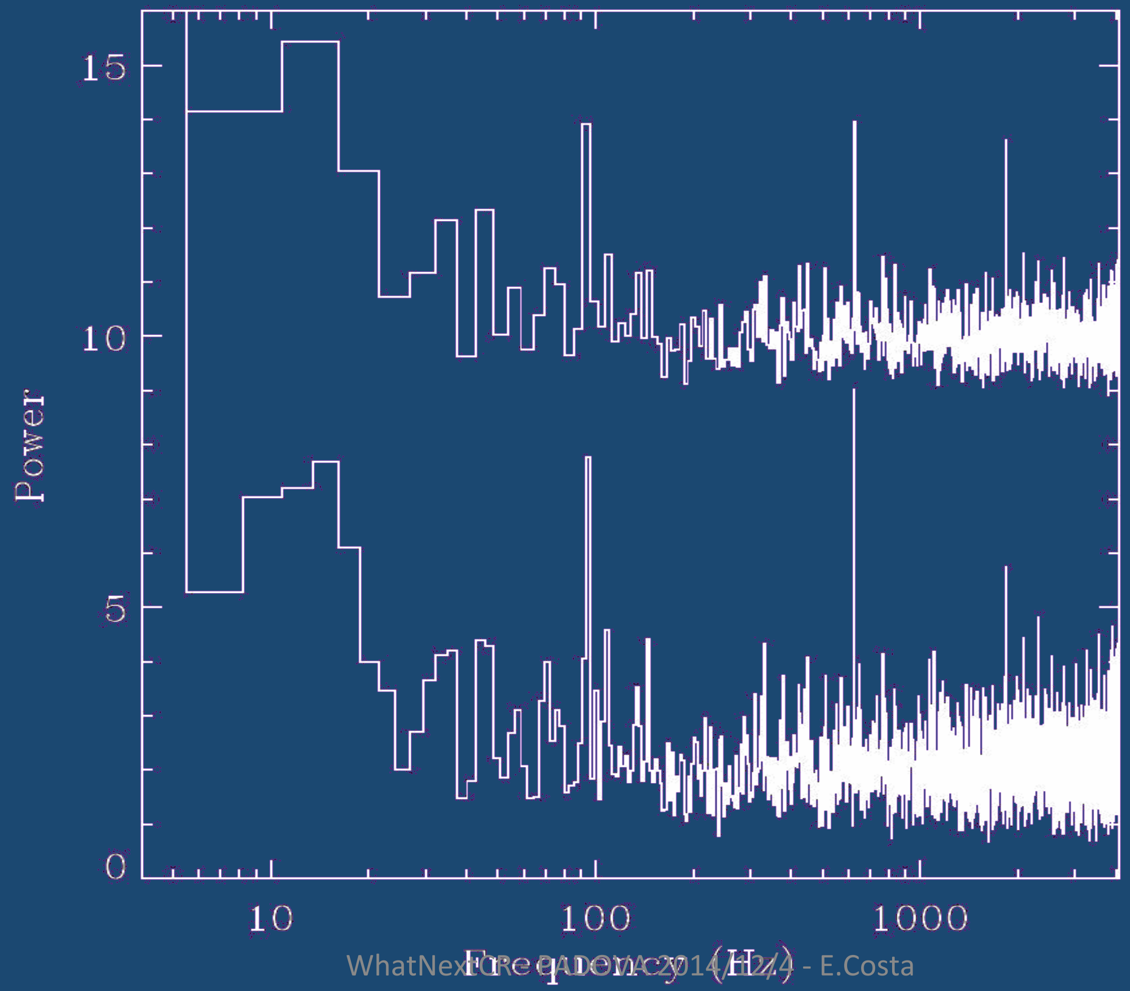
- Different hypotheses include different particle species and phases of matter in the core
- Each of the possible equations of state (EOS) provides different predictions about the possible masses and radii of NS.
- Major goal of studying NS is to make measurements that constrain the EOS of dense matter.



Courtesy Lattimer/Morsink

Transient Quasi Periodic Oscillations also in Magnetars

QPOs detection confirmed by RHESSI obs.
Additionally... transient QPOs at 720 and 976 Hz.
Moreover 625 and 1840 Hz were detected.

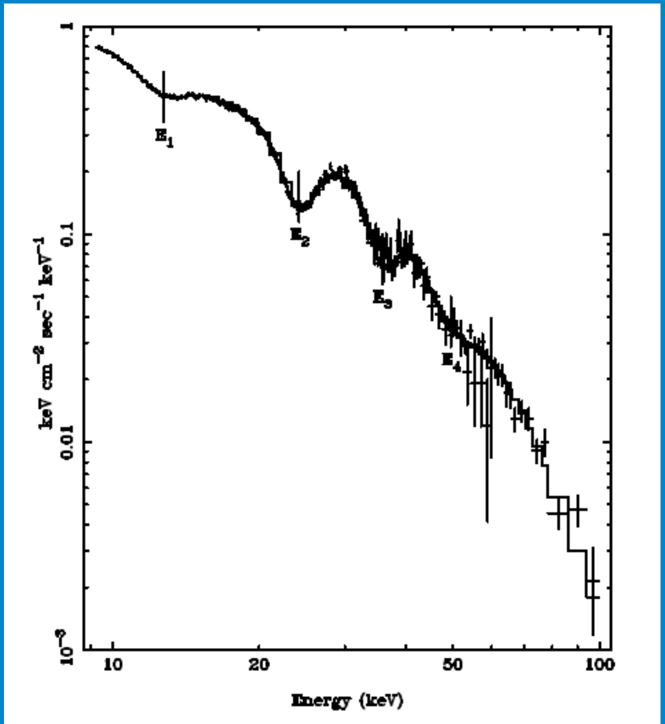


SGR1806-20

Courtesy G.L. Isreal

Outside a neutron star

Cyclotron lines in accreting pulsars. A direct probe of th magnetic field but a complex fenomenology: requires hard X-ray sensitivity (>10 keV). Most discovered by BeppoSAX, XTE INTEGRAL and Suzaku . Important progresses expected from hard X-ray optics (NUSTAR, ASTRO-H, ...). Polarimetry could disentingle the geometric parameters (angle between the magnetic and the mechanic axis) from those describing the accretion. In any case does not seem the driver to design new missions.



Santangelo 1999

More interesting the accretion on low magnetic field neutron stars

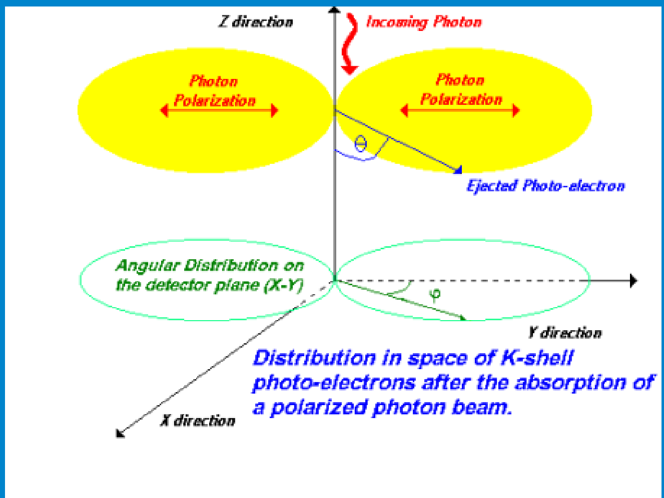
Matter organized in an accretion disk comes very close to the NS surface.

Small missions: polarimetry

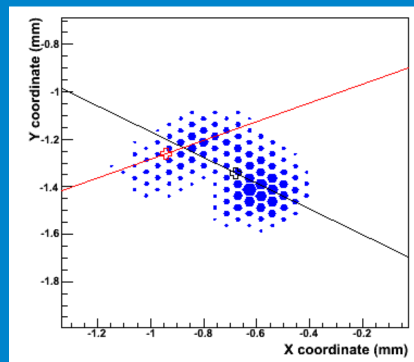
In 50 years of X-ray astronomy impressive progresses have been performed in X-ray imaging, spectroscopy and timing. Polarimetry is still in a very early stage. The only positive detection is that of the Crab Nebula (Novick et al. 1972, Weisskopf et al.1976, Weisskopf et al. 1978) with OSO-8 satellite P = 19.2 ± 1.0 %; $\theta = 156.4^{o} \pm 1.4^{o}$

The main reason is that the traditional techniques of Bragg Diffraction at 45° and compton scattering arond 90° are cumbersome and low efficent in the X-ray band (<20 keV).

In the last 10 years new detectors have been developed capable to measure the linear polarization of X-rays in the band 2-10 keV. They are based on the photoelectric effect and suited to be used in the focal plane of telescopes.

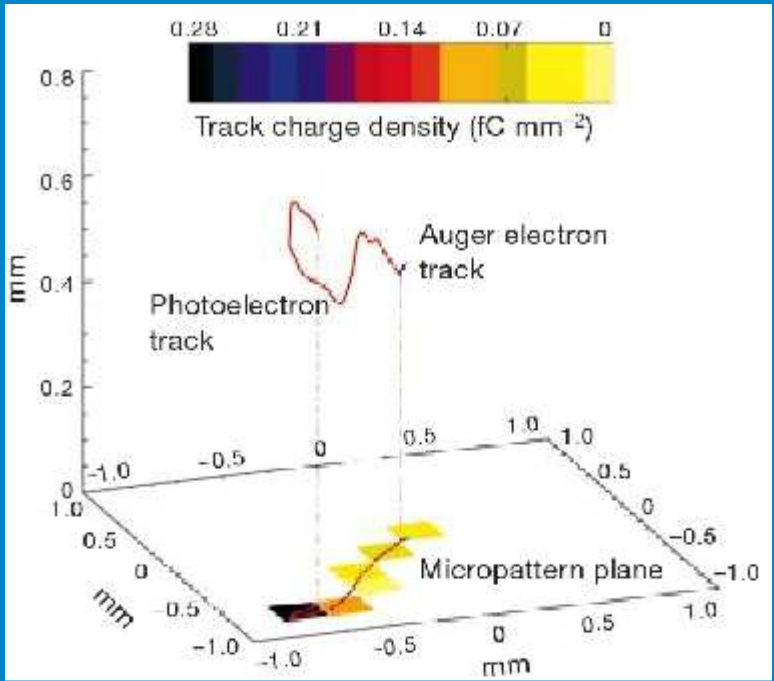


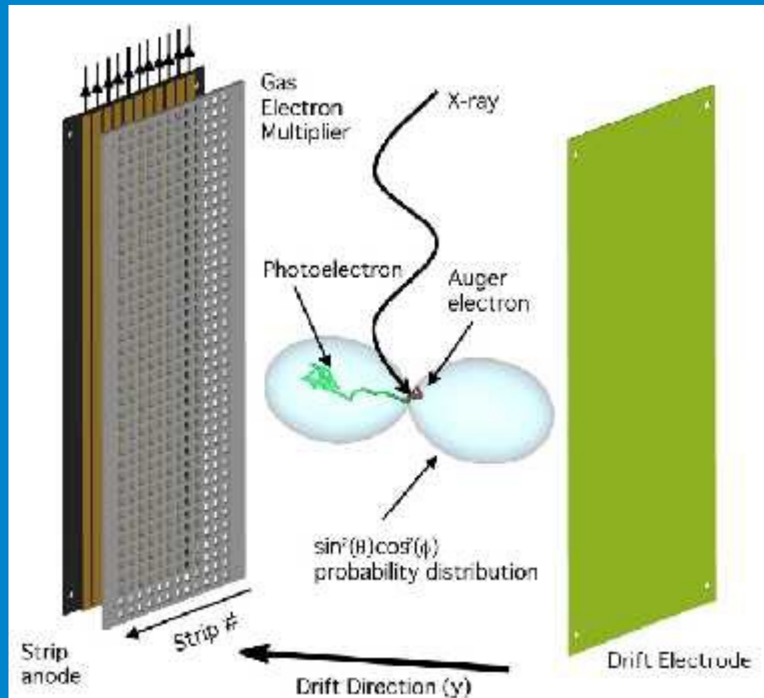
$$\frac{\partial\sigma}{\partial\Omega} = r_o^2 \frac{Z^5}{137^4}\left(\frac{mc^2}{h\nu}\right)^{7/2} \frac{4\sqrt{2}\sin^2(\theta)\cos^2(\varphi)}{\left(1-\beta\cos(\theta)\right)^4}$$

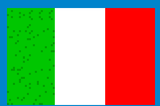


Two implementations of this idea

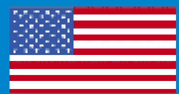
If the photon is absorbed in a gas detector with very fine subdivision the photoelectron scatters and ionizes producing a track. From the analysis of the track the original ejection angle can be reconstructed.





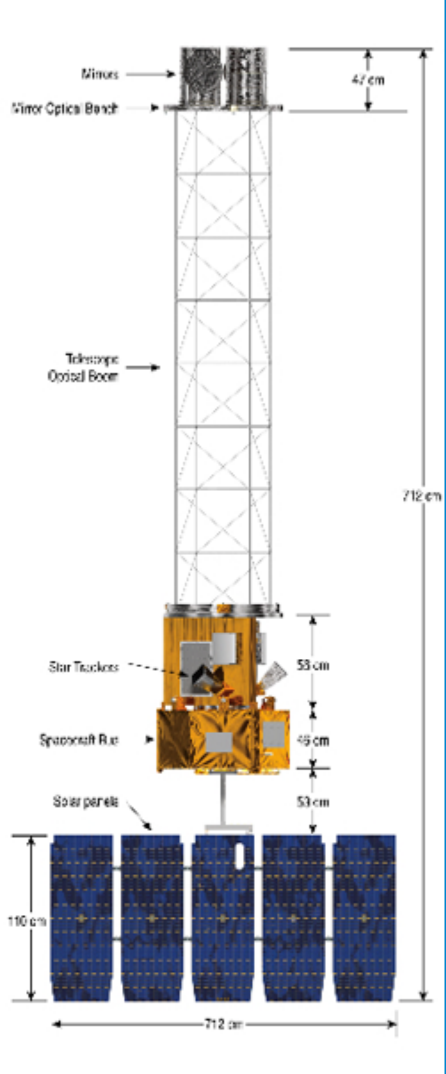


Gas Pixel Detector
Costa et al. 2001
Bellazzini et al. 2006, 2007



Time Projection Chamber
Black et al. 2007

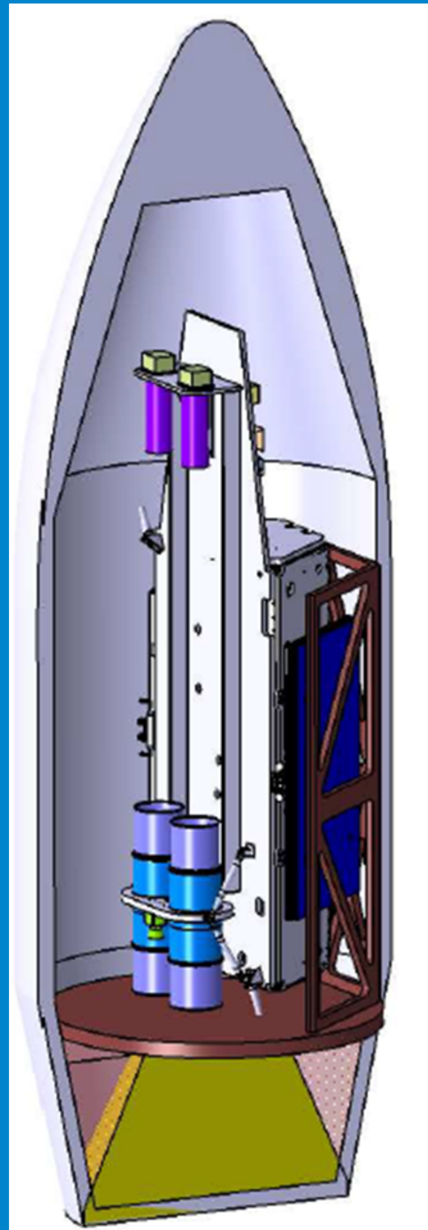
The GPD is imaging, needs no rotation and better controls systematics. The TPC is more efficient. In the focus of a telescope they are 3 orders of magnitude more sensitive than traditional instruments.



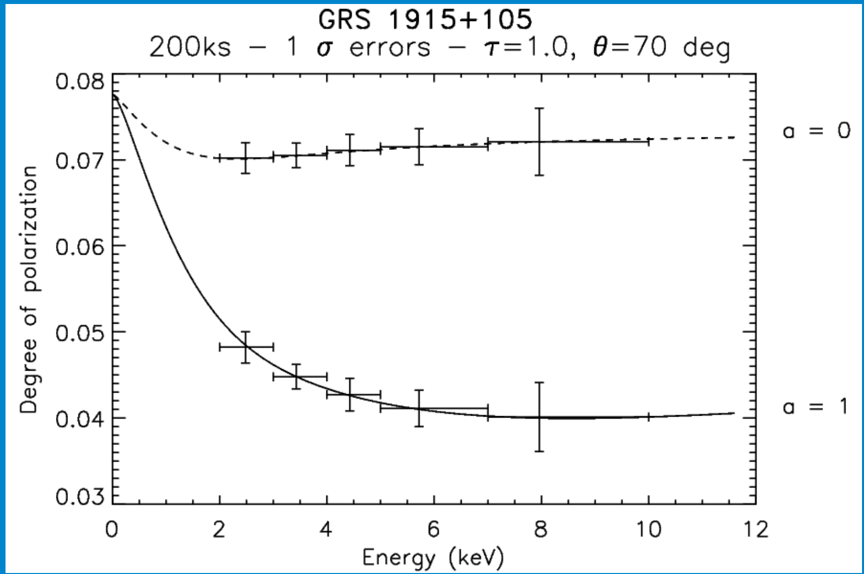
No approved polarimeter

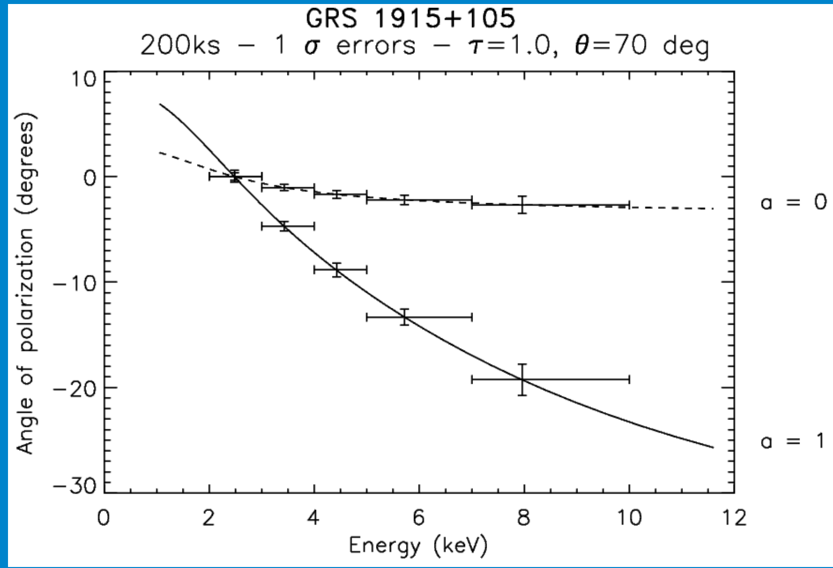
Photoelectric polarimeters can be used with any telescope. A GPD was foreseen aboard XEUS, survived on IXO and was dropped in the passage to ATHENA.
Some proposal of small missions based on a telescope and a focal plane polarimeter have been submitted. The last was XIPE proposed to ESA but not selected.
GEMS was approved by NASA as a SMEX and was cut in May 2012

A polarimetry mission has a good readiness level and could be built in a short time. The sistuation of data is such that even a small mission could contribute significant results.



Spin of BH with Polarimetry





Two days observation with a small satellite.
If the Dovciak, Muleri, Karas, Goosman and Matt model (MNRAS 2008) is correct the observational consequences are impressive. Notice that similar results have been found by Schnittman and Krolik (ApJ 2009) and by Li (ApJ 2005).
Of course GRS1915+105 is a very favourable case because of high inclination of the disk to the observer. But it is known (from radio jets) and this is an excellent constraint.

QED

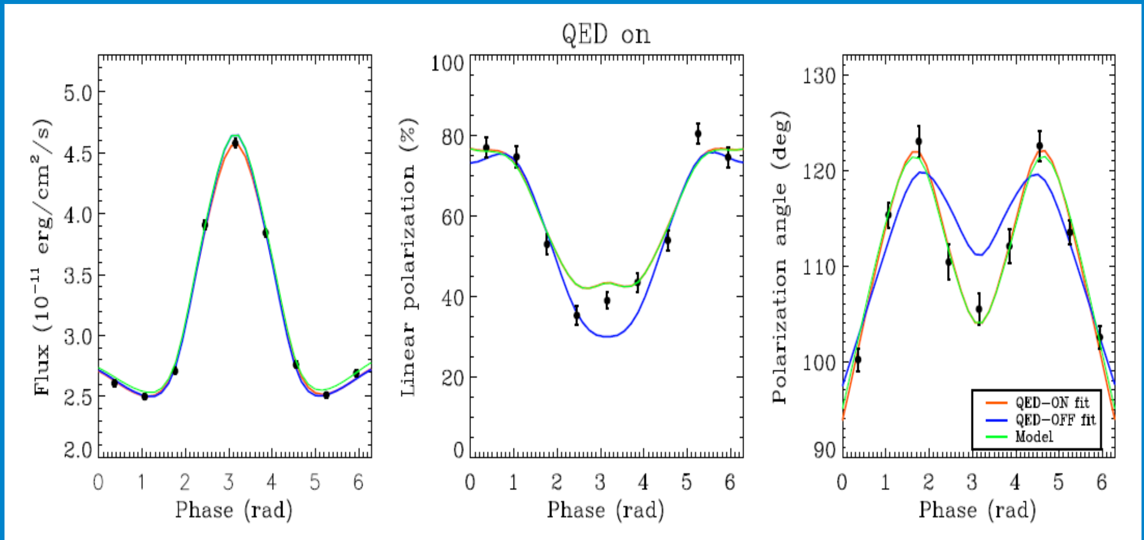


Figure D-7: Simulated 500-ks IXPE observation of a bright AXP (filled circles with error bars) showing (from left to right) unabsorbed 2–6 keV flux, linear polarization fraction, and position angle as functions of spin phase. Green lines denote the model used to generate the data; red/blue lines, best-fit vacuum-polarization on ("QED-on")/vacuum-polarization off ("QED-off") models.

What about magnetars (SGR/AXP)?

- Study of magnetars in quiescent state. Search for redshifted feature as a diagnostic of the surface gravitation: telescopes/spectroscopy
- Search for QED fenomena in extreme manetic fields: polarimetry
- Search for the internal structure and starquakes: timing

Searching for birefringence on medium/long distance

Some theories predict that in the trasfer of radiation on long distances phenomena of birengence can occurr.

But to test these theories we must have a reasonable prediction of how the radiation was in the frame of the source.

Blazars in synchrotron regime (from the brad band SED) can be good candidates

Loop Quantum Gravity

A major challenge in physics is to unify quantum mechanics and gravity. One such theory—Loop Quantum Gravity (QG)—predicts birefringence at the Planck scale that violates Lorentz invariance. This effect results in rotation of the polarization position angle along the photon path that is proportional to distance times energy squared, scaling as a dimensionless factor η. From the (later disproved) detection of polarization of a GRB, a limit on η < 10-14 was derived. The best limit claimed from GRBs is now < 10-16. A more conservative but much more robust limit of η < 10-4 follows from OSO-8 measurements of the Crab. , An upper limit of a few times 10-7 was claimed based on optical/UV measurements of a γ-ray burst afterglow. The challenge for any claimed detection of this effect would be to disentangle the effect from intrinsic source properties. IXPE will address this problem by performing a campaign of systematic polarization measurements. Planned observations of nearby blazars (see the AGN section) will determine the polarization properties of this class. IXPE will then observe more distant objects to search for birefringence effects.

Search for axions or axion-like particles

Axion-like particles (ALPs) are spin-zero bosons predicted by many extensions of the Standard Model of particle physics. Depending on the actual values of their mass and on the *aγγ* photon coupling constant, ALPs can play an important role in cosmology, either as cold dark matter particles responsible for the formation of structures in the Universe or as quintessential dark energy which presumably triggers the present accelerated cosmic expansion (Bassan,Mirizzi,Roncadelli 2010).

So far the search for astrophysical evidence for axions is mainly based on solar mesurements.

Axions are one of the most elusive but of the less exotic candidate for Dark Matter.

If the magnetic field is oriented the photons will be polarized.
Various papers proposed the search of axions on he basis of measurements of X-ray polarimetry (e.g. Bassan 2010). Unpolarazized photons (e.g. from clusters) could be polarized by IG fields. Polarized photons, (e.g. from blazars in the syncrotron regime) could be depolarized. Quantitative computation for realistic missions are missing but the order of magnitude is clearly interesting

Shocks

- A link between X-ray astrophysics and CR astrophysics is the study of shocks as the site of acceleration of CRs.
- Results from Fermi, AGILE and cherenkov telescopes are impressive.
- The X-rays are particularly suited to study the morphology and the physics of the sites of likely acceleration of CRs.
- Large telescopes with fine spectral/angilar resolution can diagnostic the turbolence in plasmas.
- Hard X-ray telescopes (NUSTAR) image the non thermal components.
- Imaging Polarimetry can single out the non thermal components and determine whether the magnetic field is oriented or

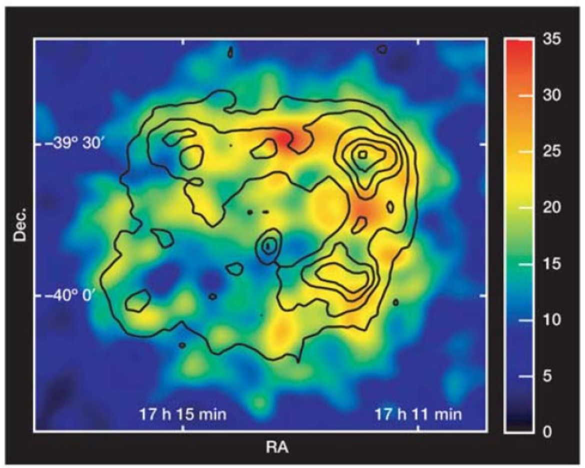


Figure 2 γ-ray image of the SNR RX J1713.7 − 3946 obtained with the HESS

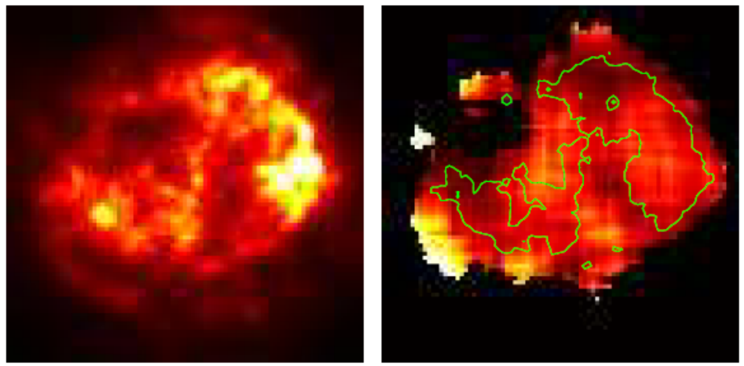
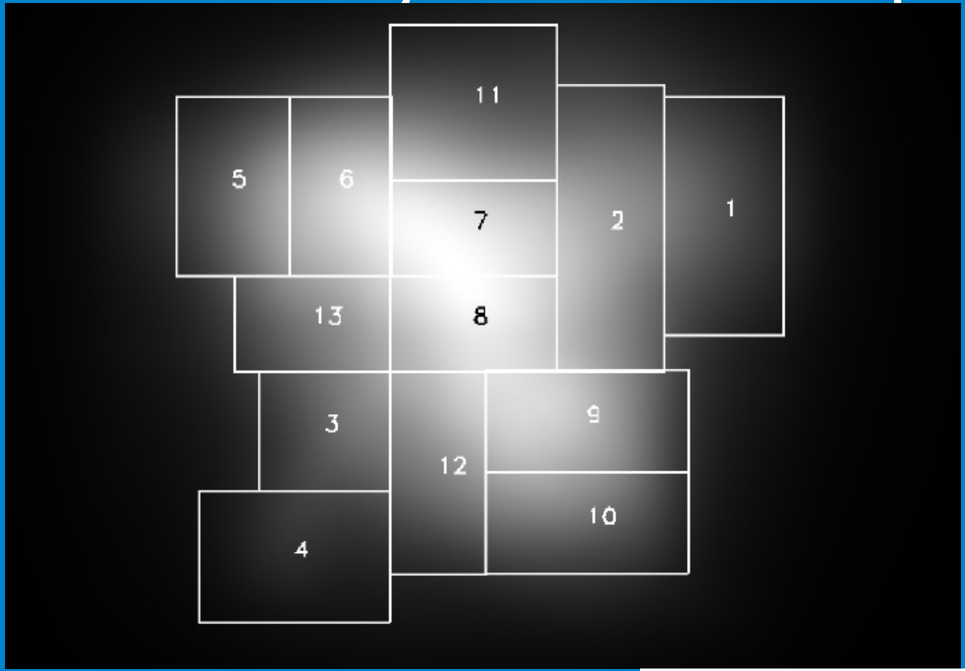


Fig. 3. Continuum 8.10−15.0 keV (left) and hardness ratio (10.0−15.0 MOS+PN)/(8.10−10.0 MOS+PN) 0.15 black to 0.45 white.

Angular resolved polarimetry of Crab



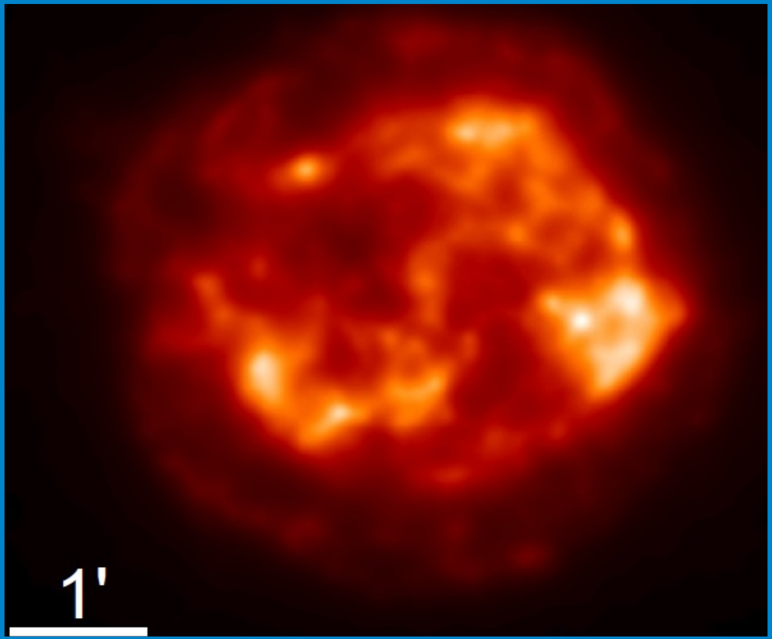
We simulated a long observation of Crab with XIPE. We blurred the Chandra image to account for the limited resolution of XIPE. The major features are still visible. We computed the sensitivity to the amount and angle of polarization for different selected regions of the nebula.

Fabiani et al. ApJ 2014

Table 4. Simulation of a polarization measurement for the Crab. The source is subdivided in 13 regions as shown in Fig. 12. The uncertainties of the degree and angle of polarization are listed, assuming a polarization degree of 19% (Weisskopf et al. 1978) in the energy range 2-10 keV for a 100 ks observation.

Region No.	σ_{degree} (%)	σ_{angle} (deg)	MPD (%)
1	0.7	1.1	2.2
2	0.5	0.8	1.5
3	0.8	1.3	2.5
4	1.0	1.6	3.2
5	0.7	1.1	2.2
6	0.5	0.9	1.7
7	0.5	0.8	1.6
8	0.5	0.8	1.6
9	0.5	0.9	1.7
10	0.7	1.1	2.2
11	0.6	1.0	1.9
12	0.6	1.0	1.9
13	0.7	1.1	2.2

Angular resolved polarimetry of CAS-A



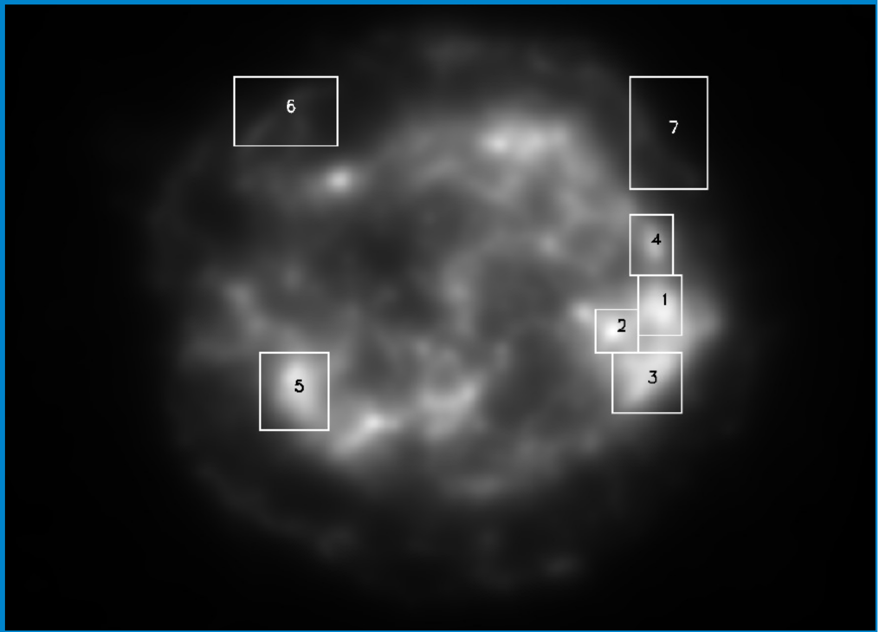
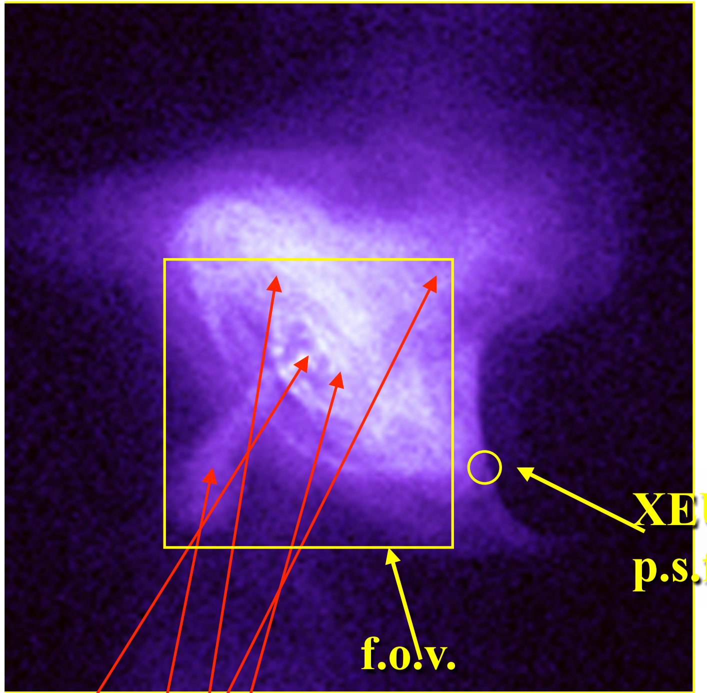


Table 5. Simulation of a polarization measurement for Cas-A. The source is subdivided in 7 regions as shown in Fig. 14. The uncertainties of the degree and angle of polarization are listed assuming a polarization degree of 19% in the energy range 4-6 keV for a 2 Ms observation. Regions 4, 6 and 7 are probably dominated by the non-thermal component, therefore the polarization arising from their emission should be higher with respect to regions 1,2,3 and 5 in which the thermal component is dominant.

Region No.	σ_{degree} (%)	σ_{angle} (deg)	MPD (%)
1	2.4	6.6	7.7
2	2.7	8.3	8.8
3	2.1	5.9	6.7
4	2.9	7.8	9.5
5	1.9	5.3	6.1
6	3.5	11.0	11.1
7	3.6	11.0	11.6

The archetypical accelerator is also only polarized source already known



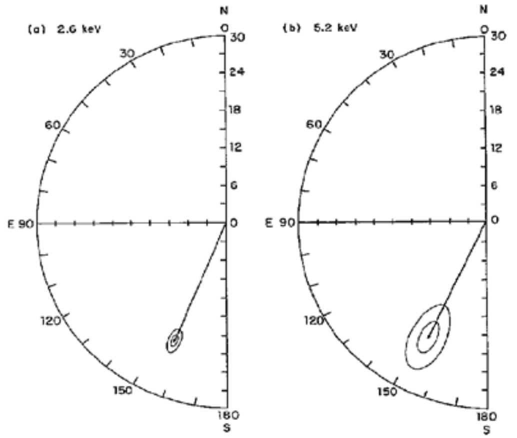
PSR

NW jet

SE jet

Inner torus

Outer torus

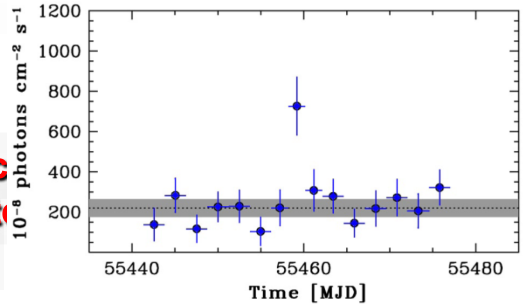


But this is only the average measurement The structure is muc more complex! To perform separat polarimetry of details of the major structures we need imaging!

Positive measurement: of X-ray polarization of the Crab Nebula without pulsar contamination (by lunar occultation, Weisskopf et al., 1978).

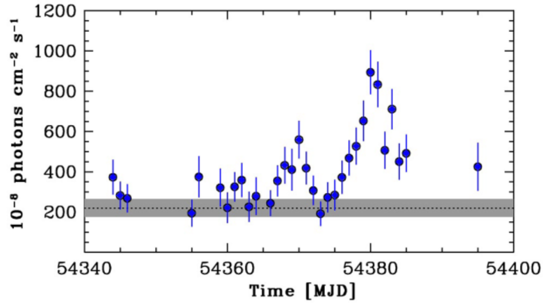
P = 19.2 ± 1.0 %

θ = 156.4° ± 1.4°



How turbulent is the field? How polarized is the PSR?

At much higher energies INTEGRAL finds polarization oriented as the jet axix.
Morover we know from AGILE (confirmed by Fermi) that the Crab (not the PSR) is varying on the scale of days at E>100 MeV. These corresponds to a physical region on the arcsecond timescale!

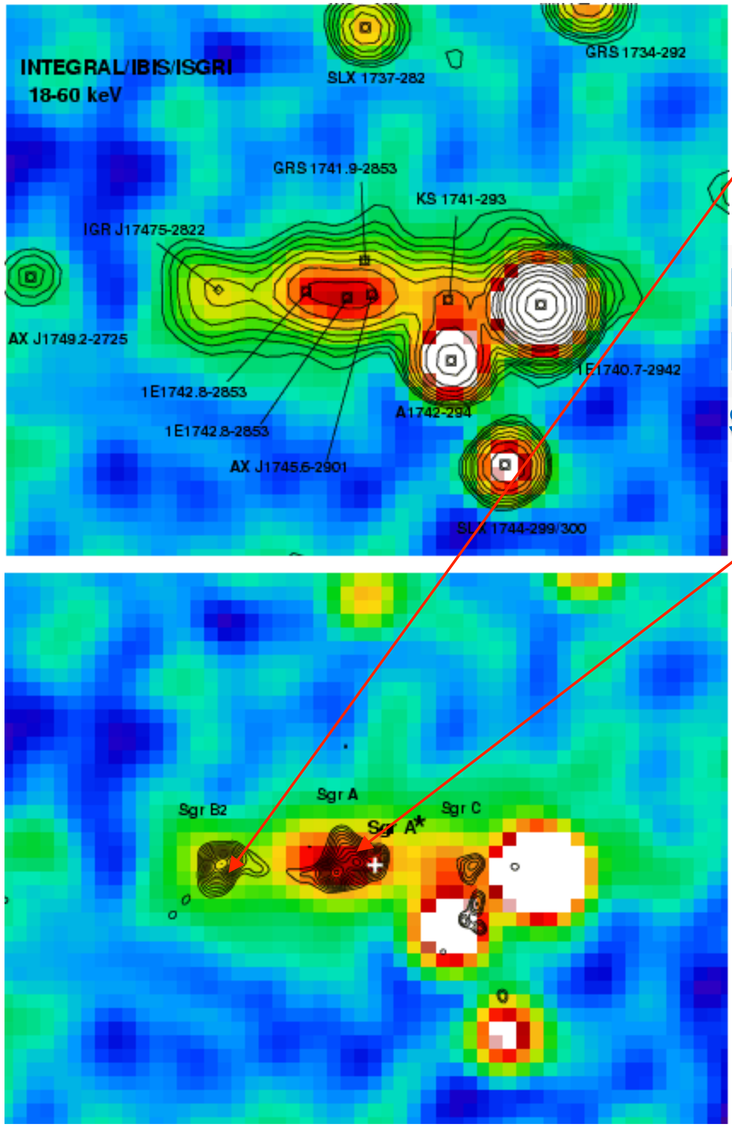


Tavani et al. 2011

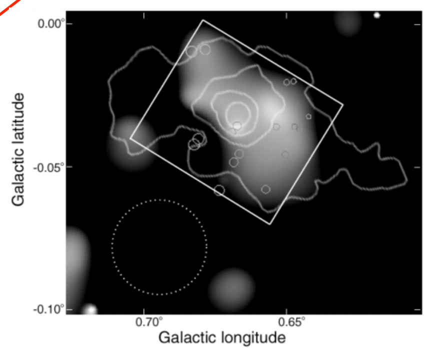
An extreme case of reflection? A local test for feed-back?

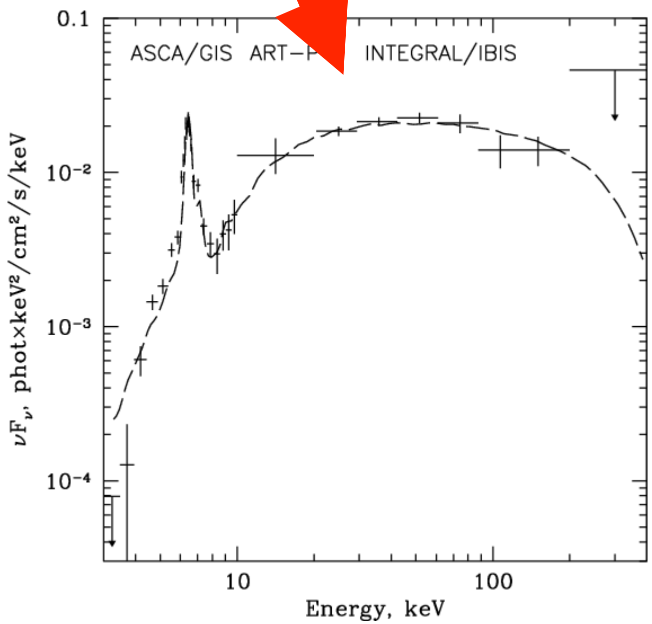
SgrB2 is a giant molecular cloud at 100pc projected distance from SgrA

The spectrumof SgrB2 is pure reflection spectrum



Reflection of what?
No bright enough source is there





The emission from SgrB2 is extended and brighter in the direction of SgrA,Murakami 2001

Rashid Sunyaev suggested that SgrB2 is reflecting the emission from the Black Hole in SgrA as it was a few hundred years ago.

Integral Image of GC, Revnivtsev 2004

When our Galaxy was an AGN (maybe)