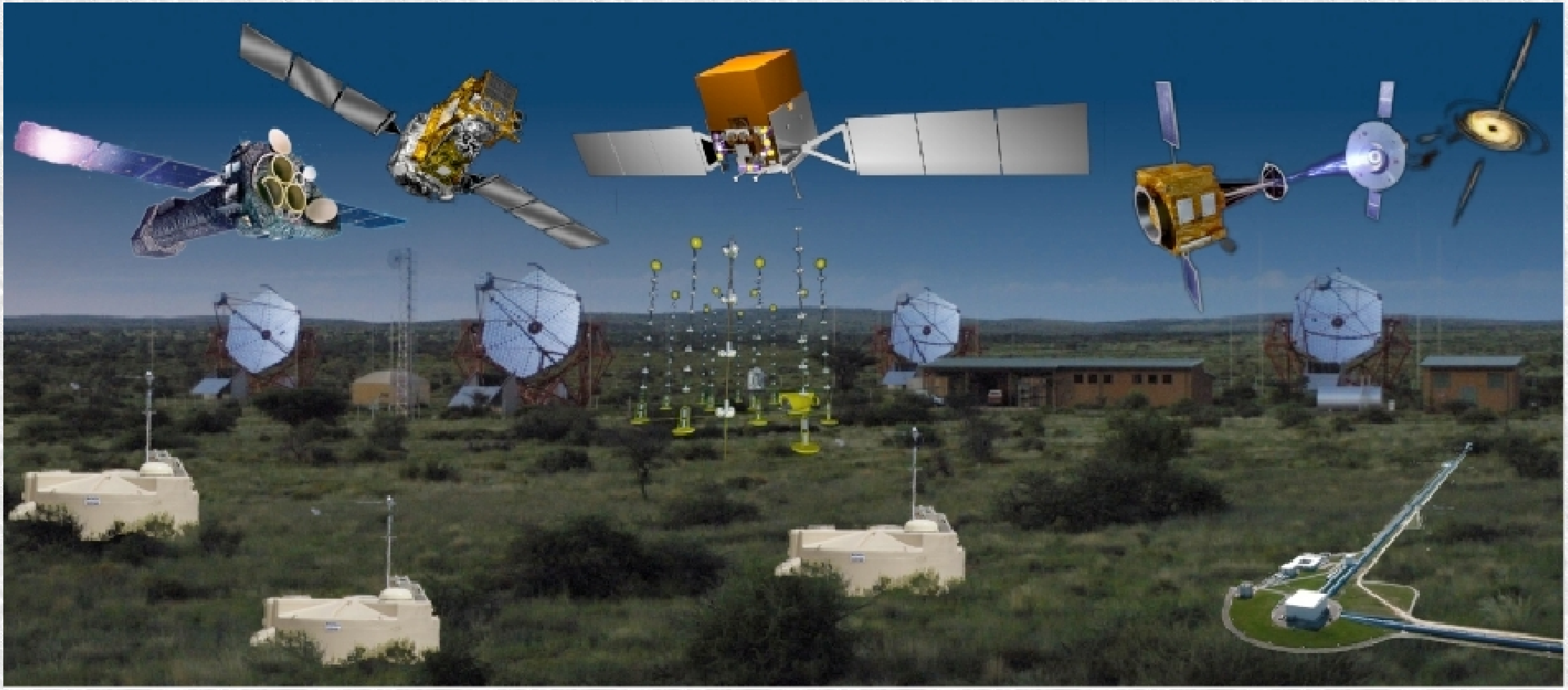
Prospects for X-ray Astronomy in the High Energy Domain



René W. Goosmann
Jean Ballet, Pierre Brun, Guillaume Dubus
on behalf of the PNHE

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Programme national hautes énergies

Prospects for X-ray Astronomy in the High Energy Domain

Prospects for 2010-2015

Identifying five main research areas:

- The Universe as a laboratory
- Compact objects and their environments
- Explosive phenomena
- Cosmic Rays
- New messengers


Prospective du GdR PCHE 2010 – 2015

Version finale (20 mai 2010)

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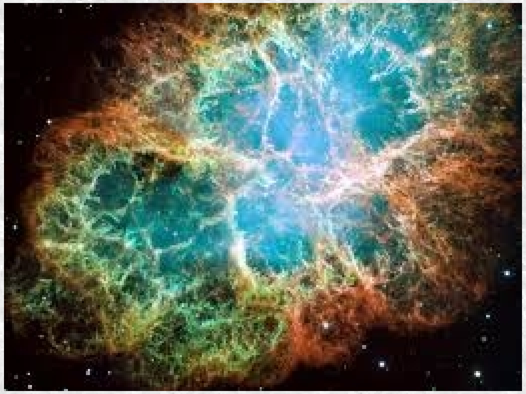
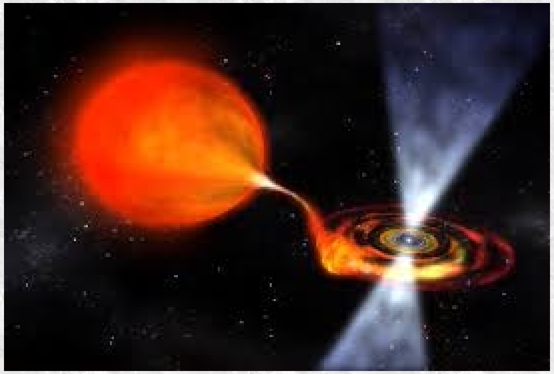
Prospects for X-ray Astronomy in the High Energy Domain

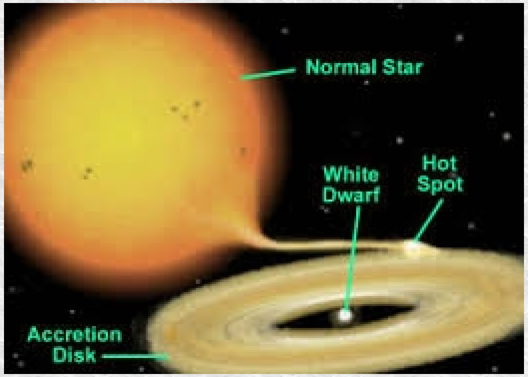
Our favorite objects:





- Supernovae
- Gamma-ray bursts
- Neutron stars
  - Pulsars
  - Magnetars

- Black holes
  - Galactic X-ray binaries
  - Active Galactic Nuclei
  - Ultraluminous X-ray sources



White dwarfs
  Cataclysmic variables

Prospects for X-ray Astronomy in the High Energy Domain

The Universe as a laboratory

Fundamental questions related to X-ray astronomy

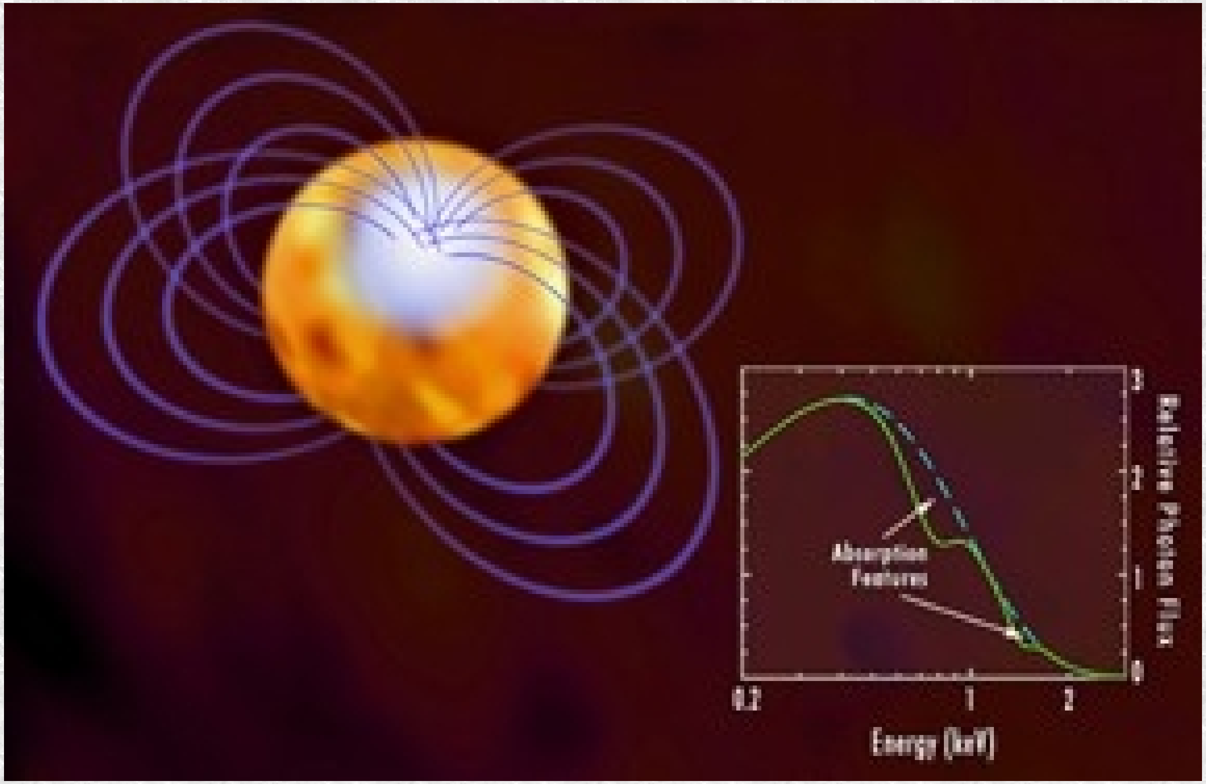
- What is the equation of state of ultra-dense matter?
- Does General Relativity hold in the strong field limit?

The Universe as a laboratory - Ultra-dense matter

• Equation of state for the interior of neutron stars?

• P(*n*) puts precise constraints on M/R

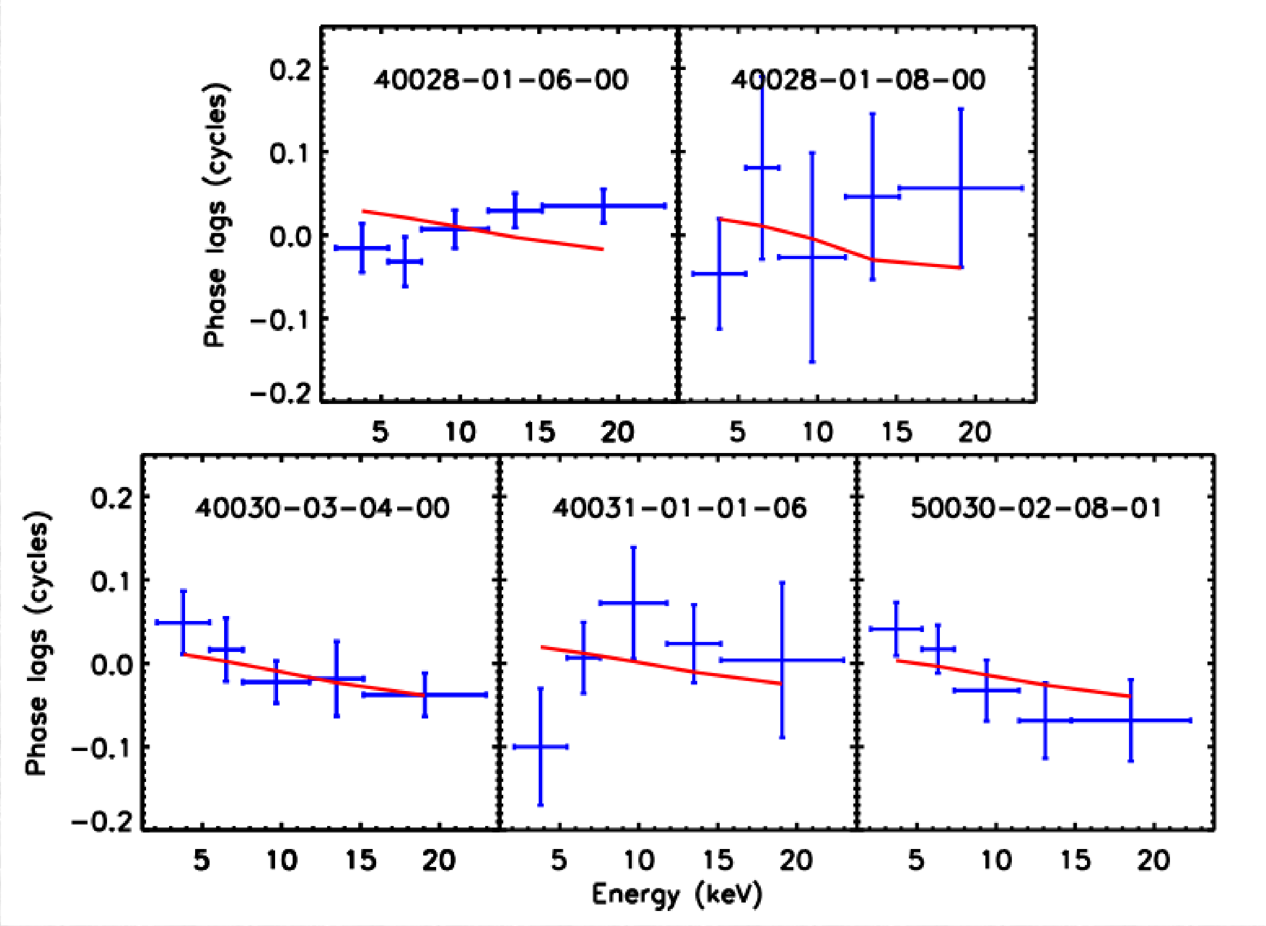
• Measure M/R from relativistic shift of absorption features for slowly rotating neutron stars



Sanval, Pavlov et al. (2002)

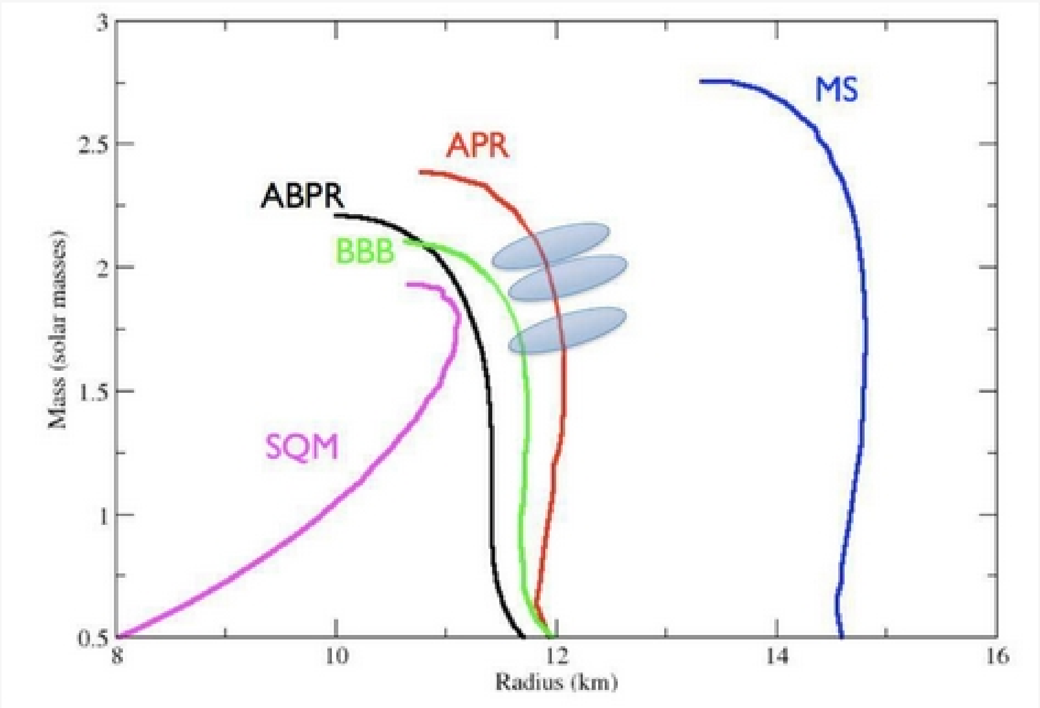
The Universe as a laboratory - Ultra-dense matter

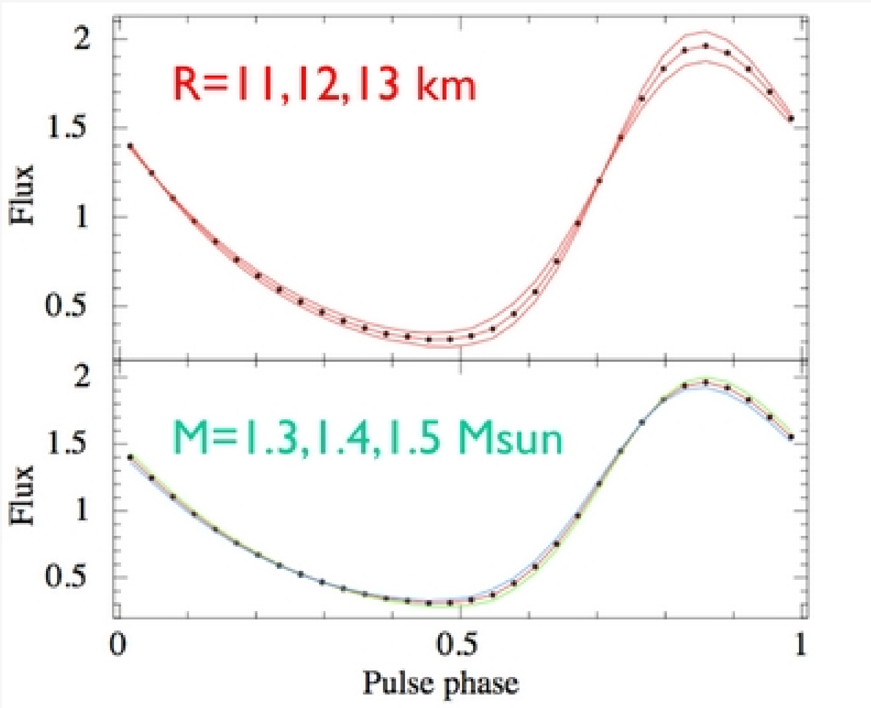
- For faster rotation, M/R is constrained from timing analysis of the pulsed emission
- Confrontation to (relativistic) model of rotating hot-spots
- Better constraints on M/R for more objects requires high-resolution timing



Artige et al. (2013)

The Universe as a laboratory - Ultra-dense matter





→ Measuring the mass and radius of a neutron star to decide about the equation of state

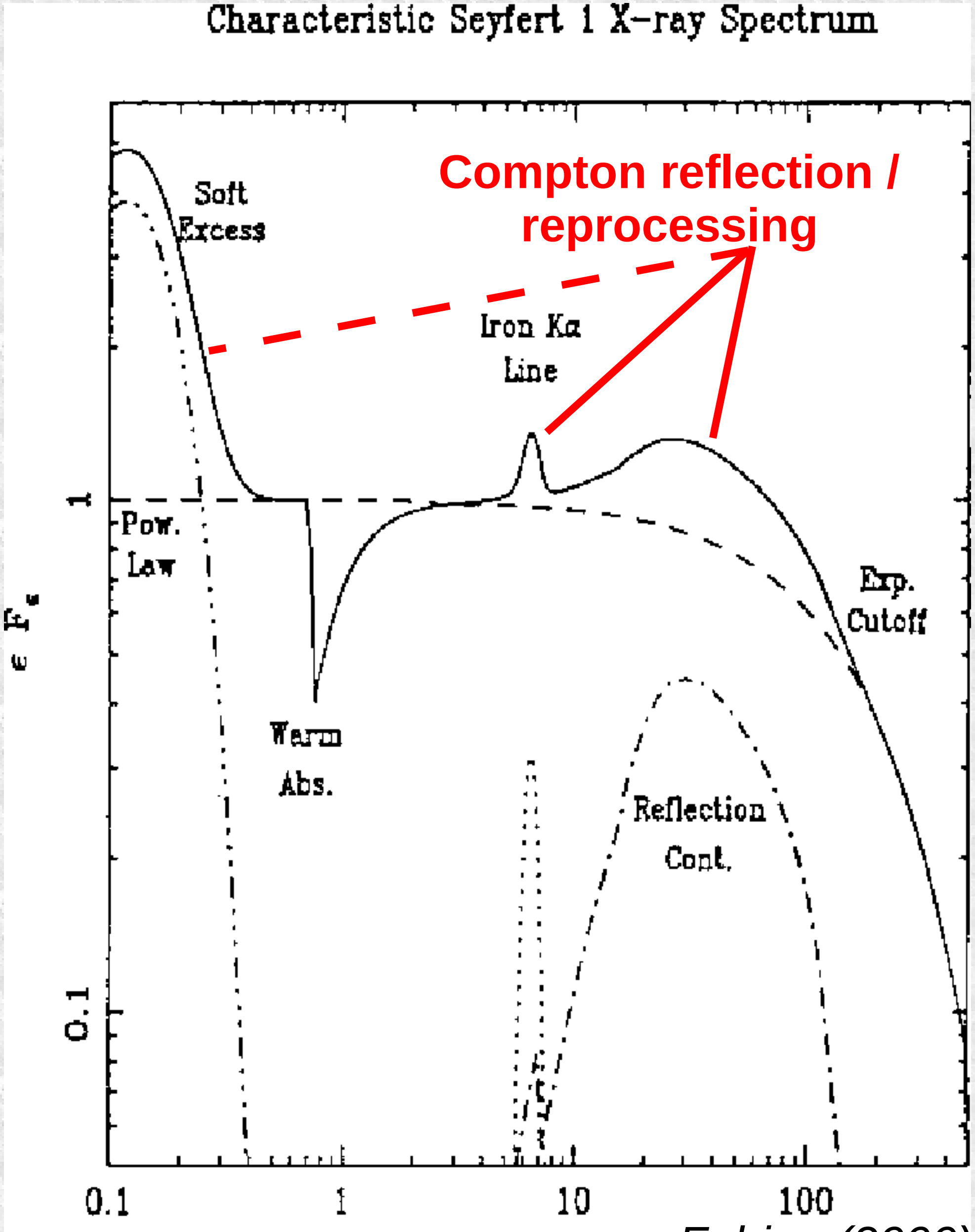
→ Accurate constraints on the pulse shape

(Simulations for LOFT)

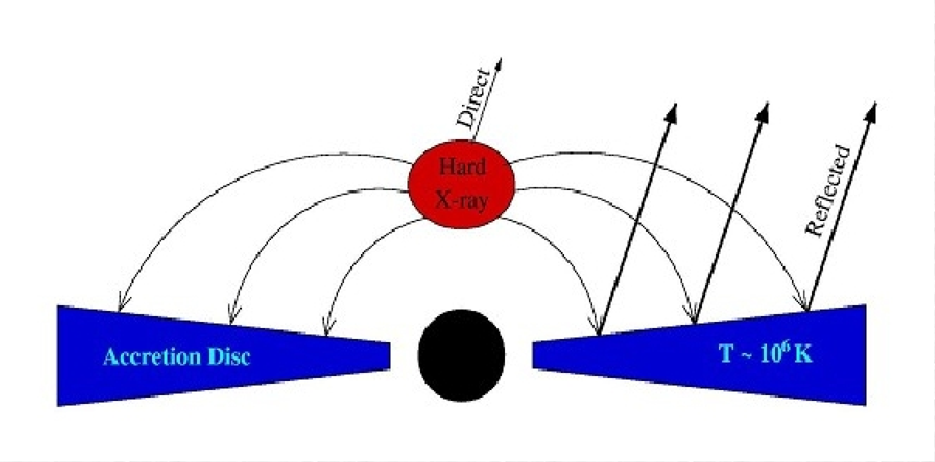
The Universe as a laboratory - GR in strong fields

X-rays from the close vicinity of compact objects

- Quasi-thermal emission from the accretion flow
- Non-thermal emission from the corona

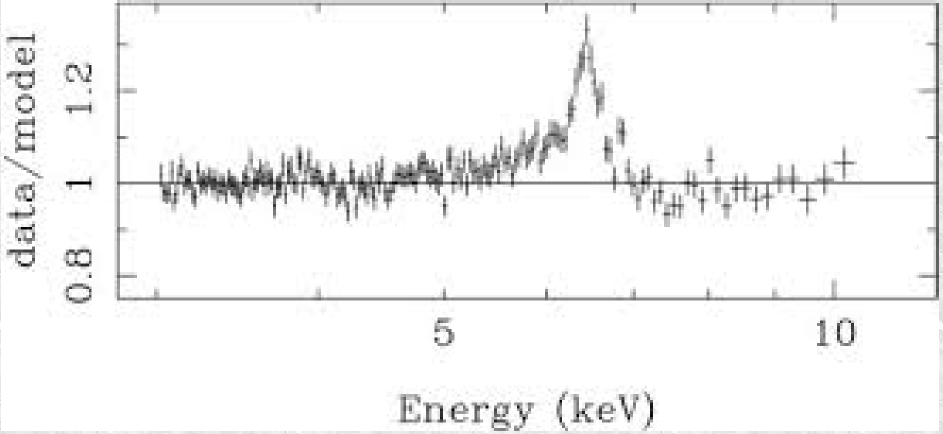


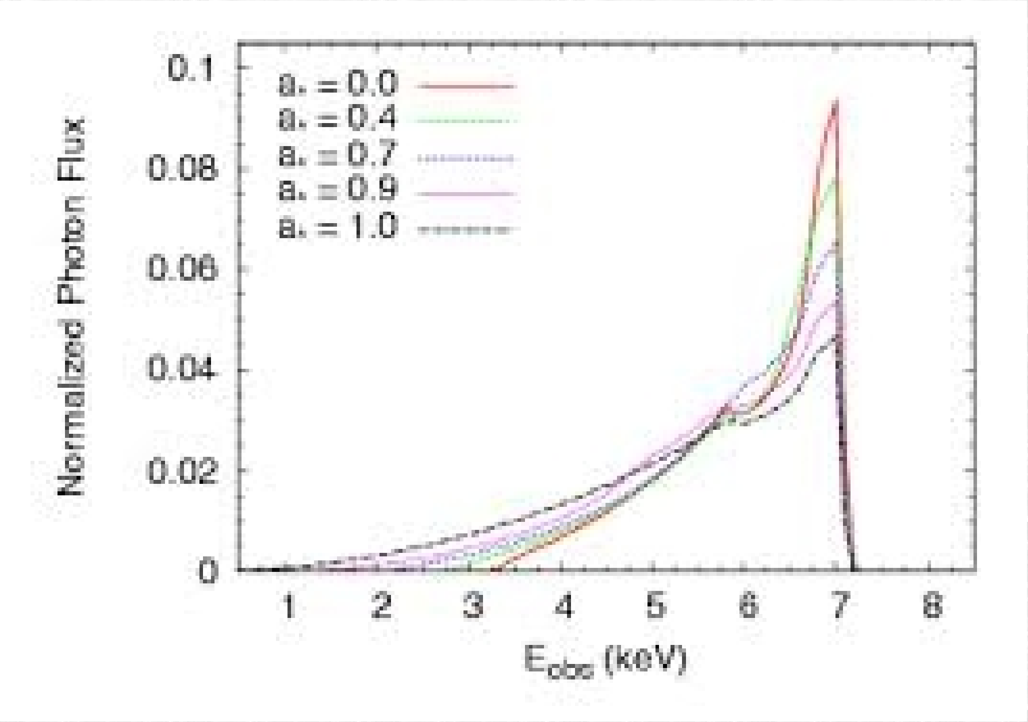
Fabian (2000)



The Universe as a laboratory - GR in strong fields

Determining black hole spin from iron line fitting





Simulated iron line profile for an irradiated accretion disk around a black hole with different spin parameters

Caveats and spoilers:

- Broadening obtained is possibly biased by the observational analysis

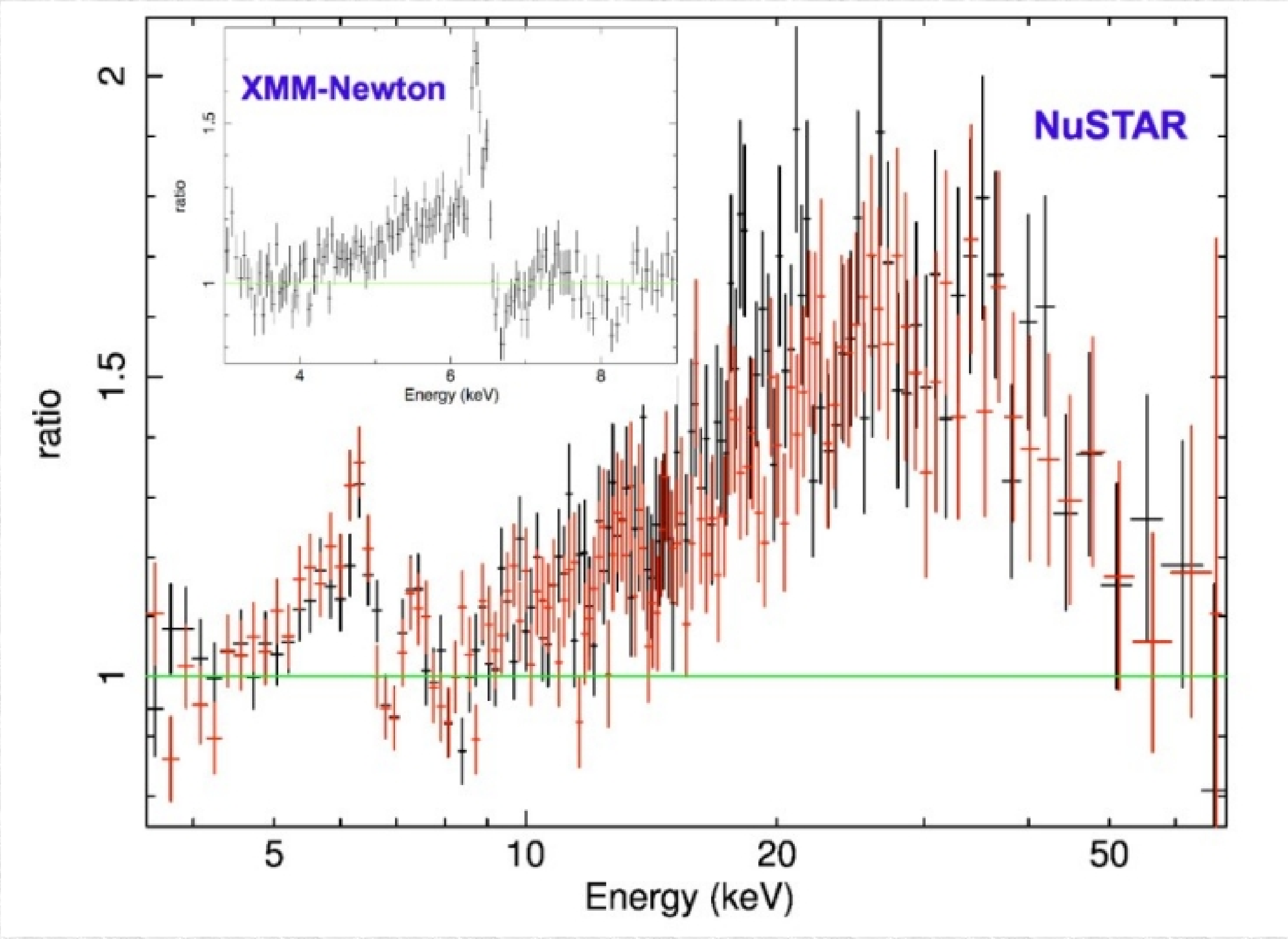
- Alternative interpretation as an absorption feature is still in play

The Universe as a laboratory - GR in strong fields

New constraints from the hard X-ray range

• Broad band spectroscopy may discriminate to some extend

• However, independent methods need to be found ; X-ray polarimetry is one of them



Risaliti et al. (2013)

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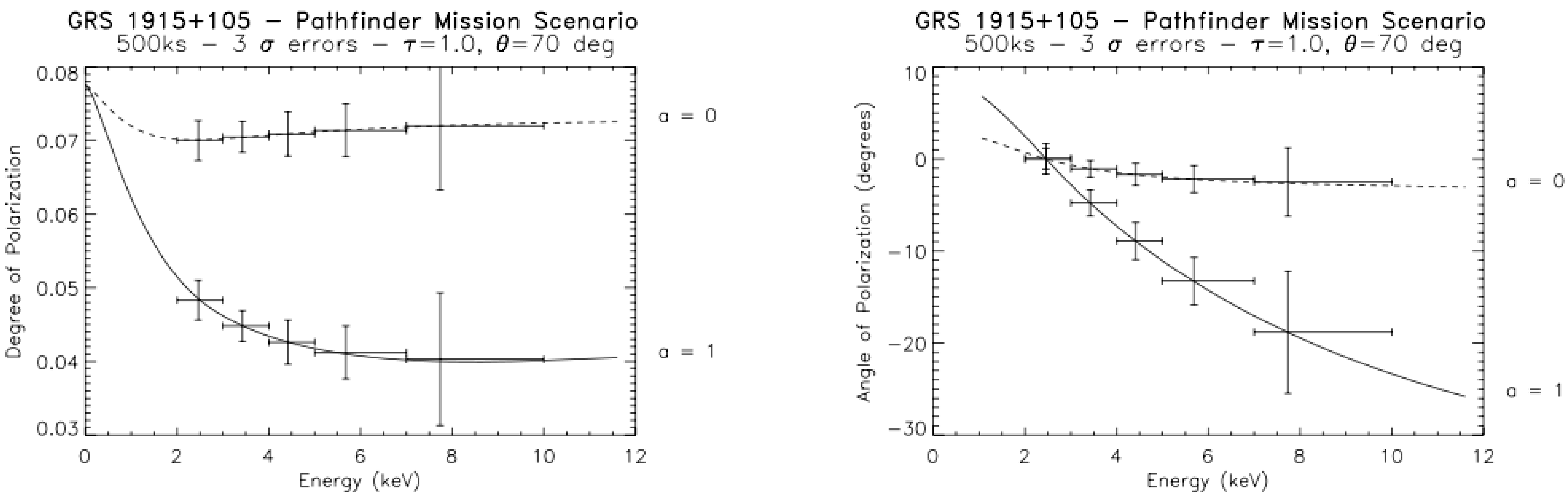
The Universe as a laboratory - GR in strong fields

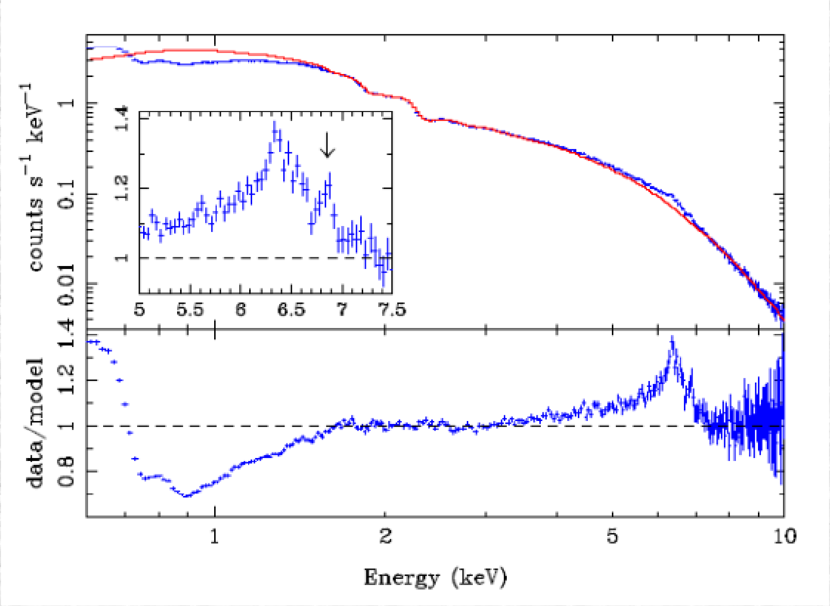
GRS 1915+105 — Pathfinder Mission Scenario, T = 500 ksec, *i* = 70°

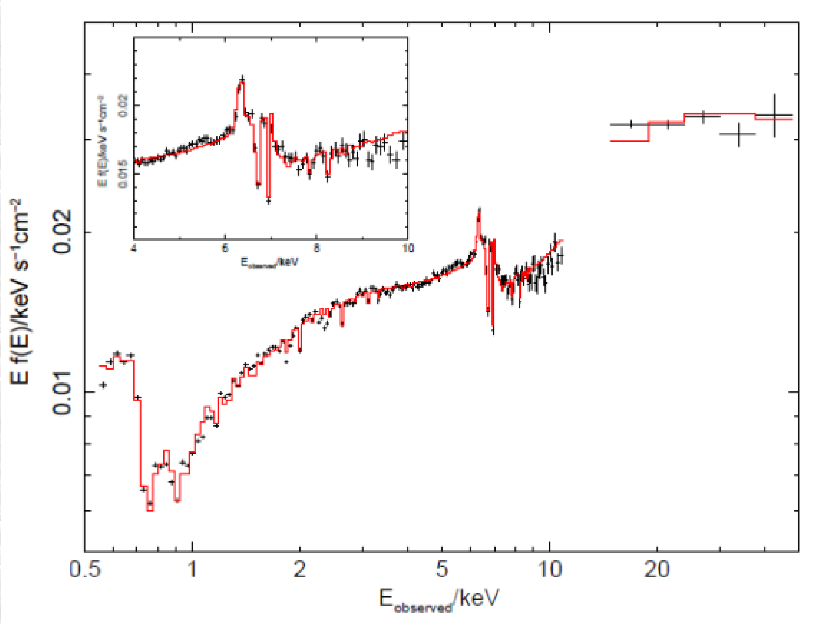


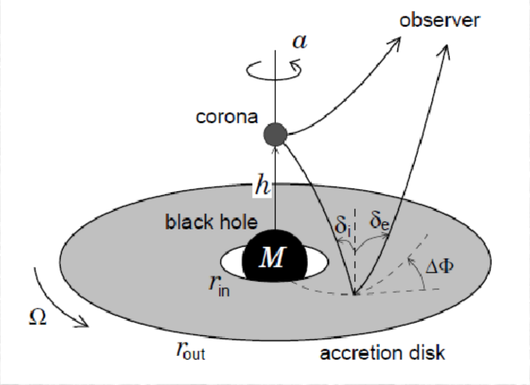
Dovčiak et al. (2008)

- X-ray polarimetry can be applied to measure black hole spin
- Independent from iron line or continuum fitting method

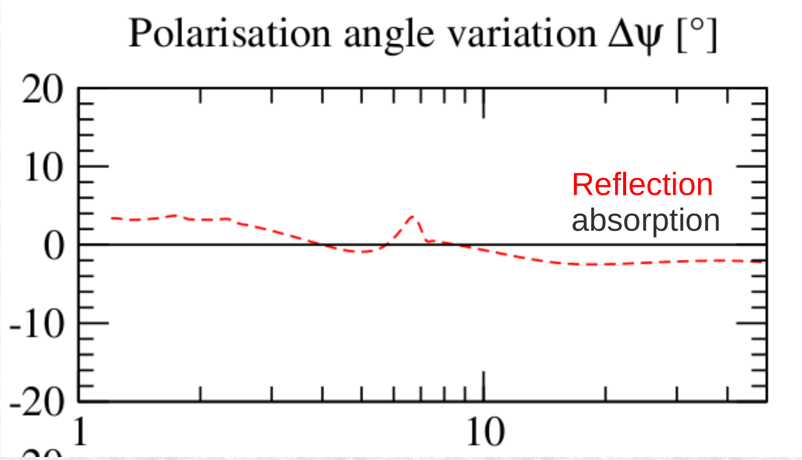
The Universe as a laboratory - GR in strong fields

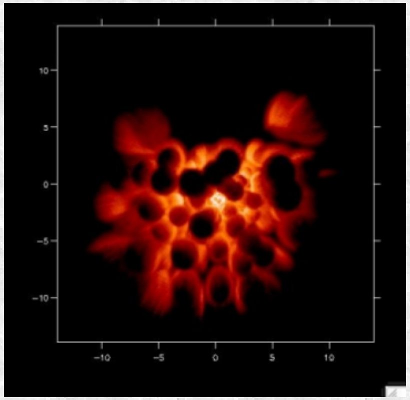






Dovčiak et al. (2011)





Miller et al. (2009)

Marin et al. (2012)

Prospects for X-ray Astronomy in the High Energy Domain

Compact objects and their environment

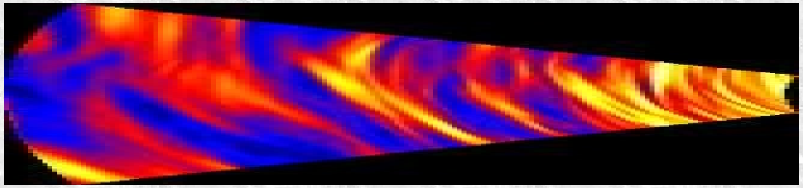
Fundamental questions related to X-ray astronomy

- What is the physics of the accretion flow?
- What is the link between accretion and ejection and how does it relate to the spin of the compact object?
- What builds and collimates relativistic jets?
- What fraction of the accretion flow returns to the ambient medium?

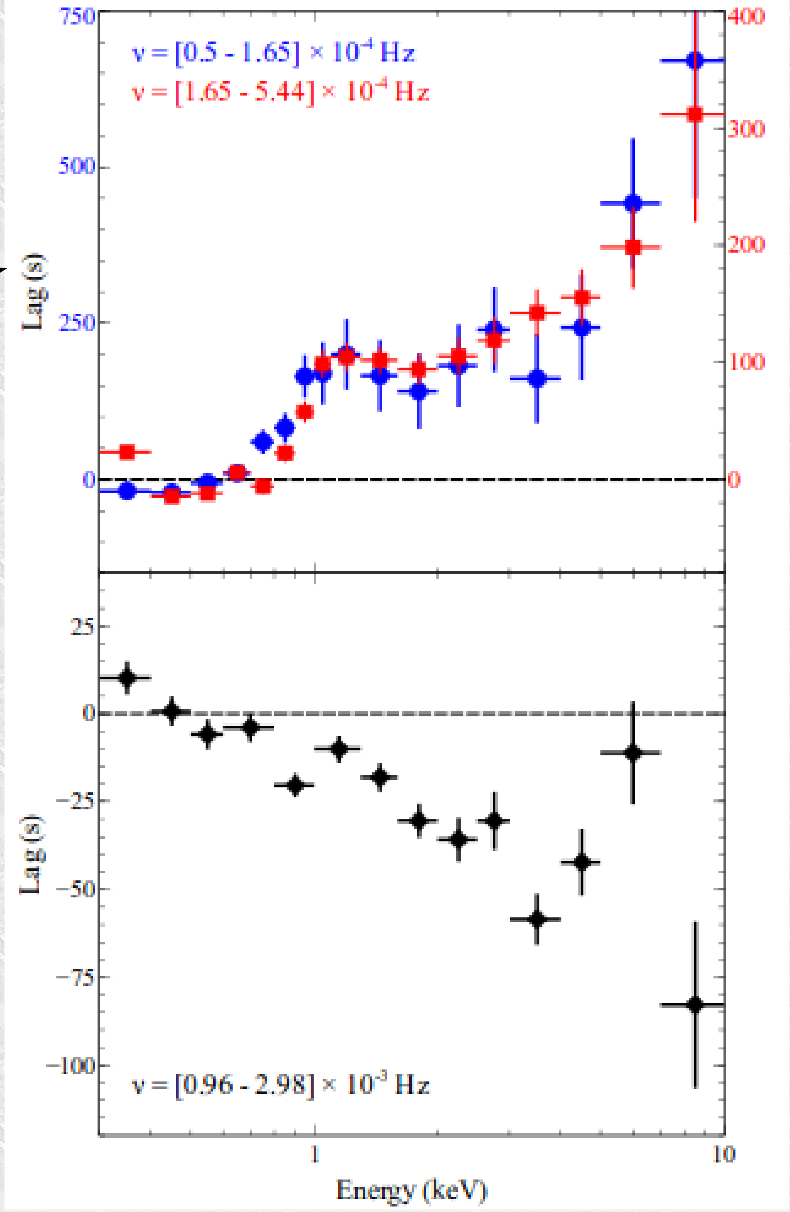
The Universe as a laboratory - Compact objects

X-ray reverberation(!)

Low frequencies
→ positive time lags
→ soft leading hard
→ propagating fluctuations
  in the disk



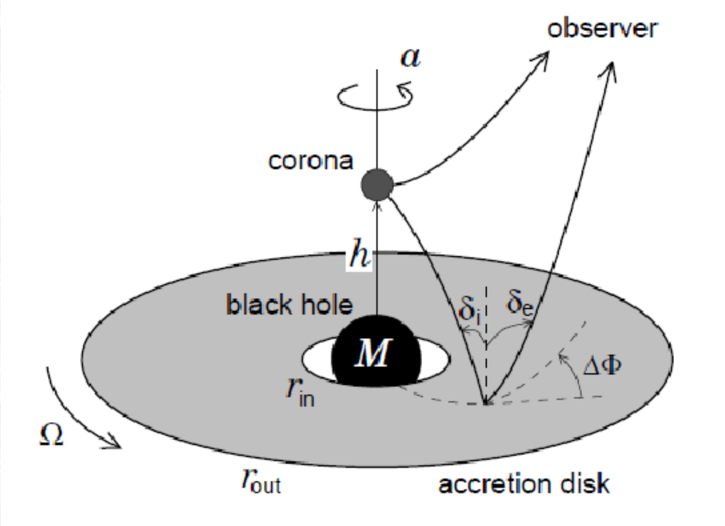
$t_1 > t_2$

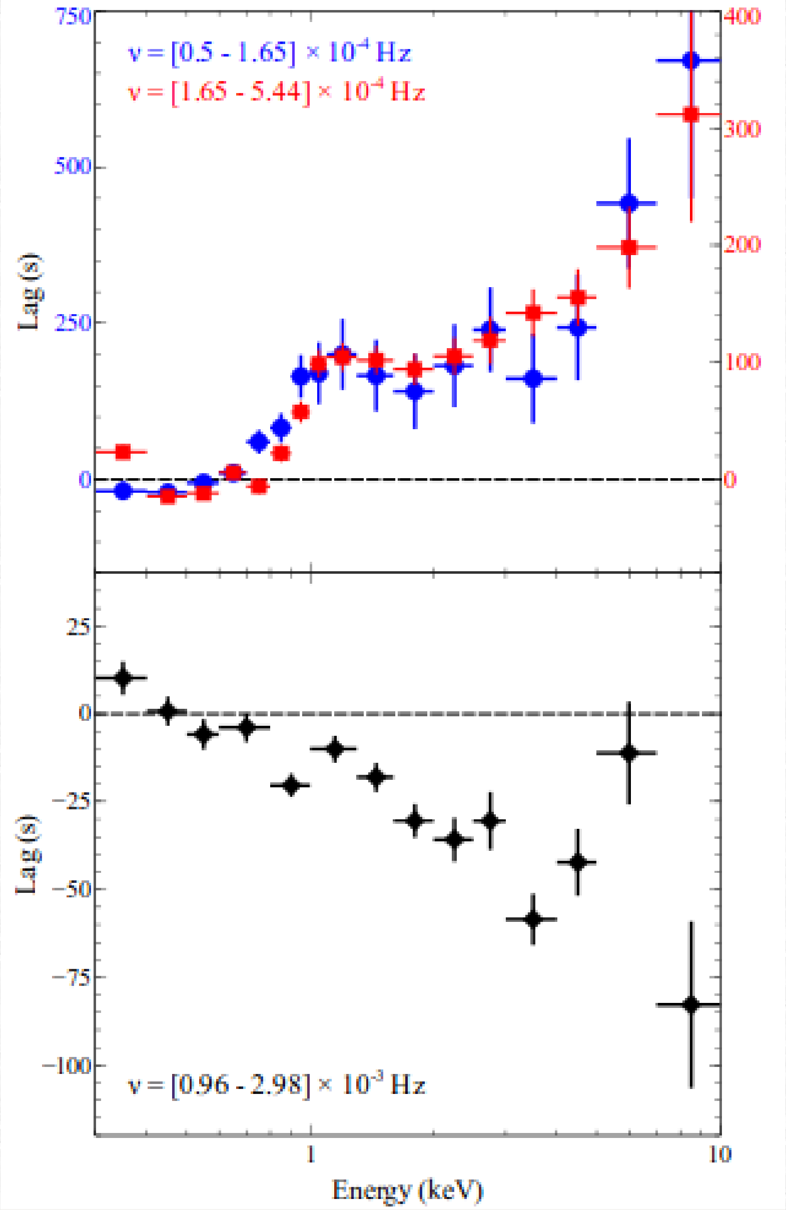


Kara et al. (2012)

The Universe as a laboratory - Compact objects

X-ray reverberation(!)





High frequencies
→ negative time lags
→ hard leading soft
→ propagating fluctuations in the disk

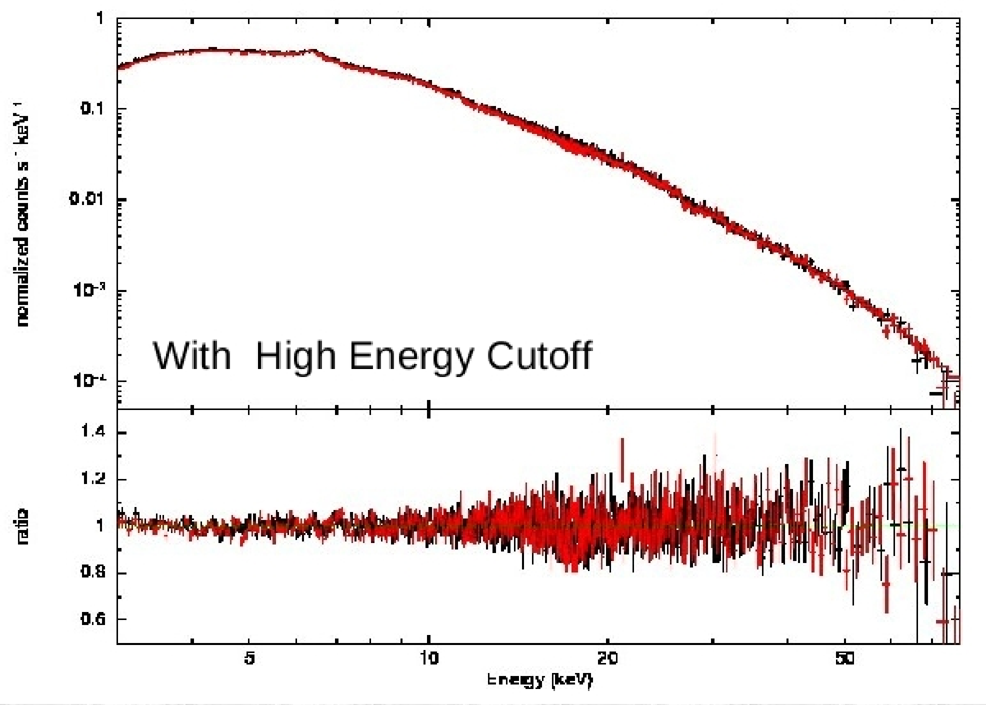
Kara et al. (2012)

The Universe as a laboratory - Compact objects

Constraining the corona temperature from hard X-ray observations

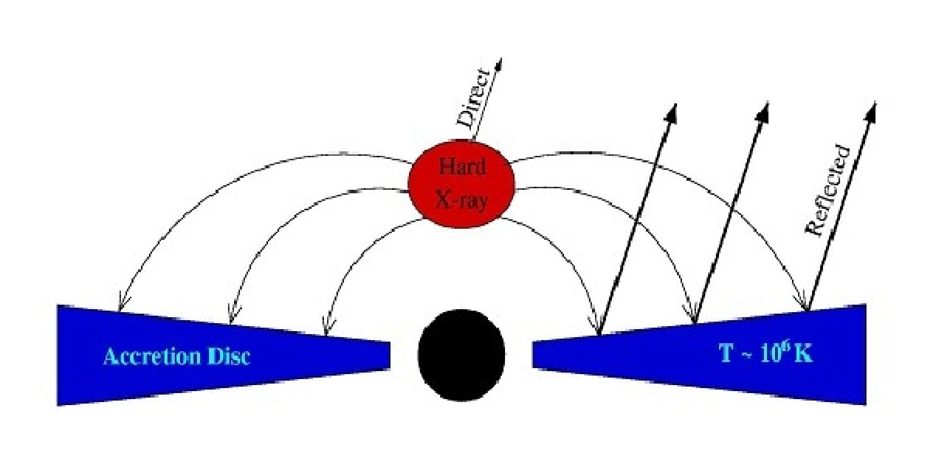
- So far, the cut-off energy of the reprocessed spectra emitted close to compact objects has not been constrained

- For some AGN this became possible with NuSTAR



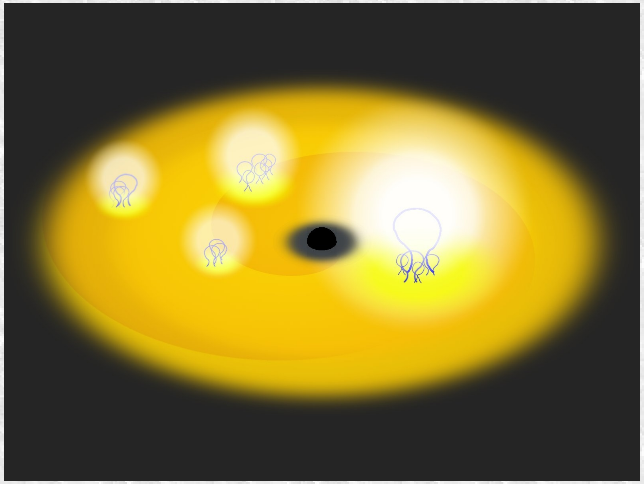
NuSTAR spectrum of MCG-5-23-16
(Baloković et al., in prep.)

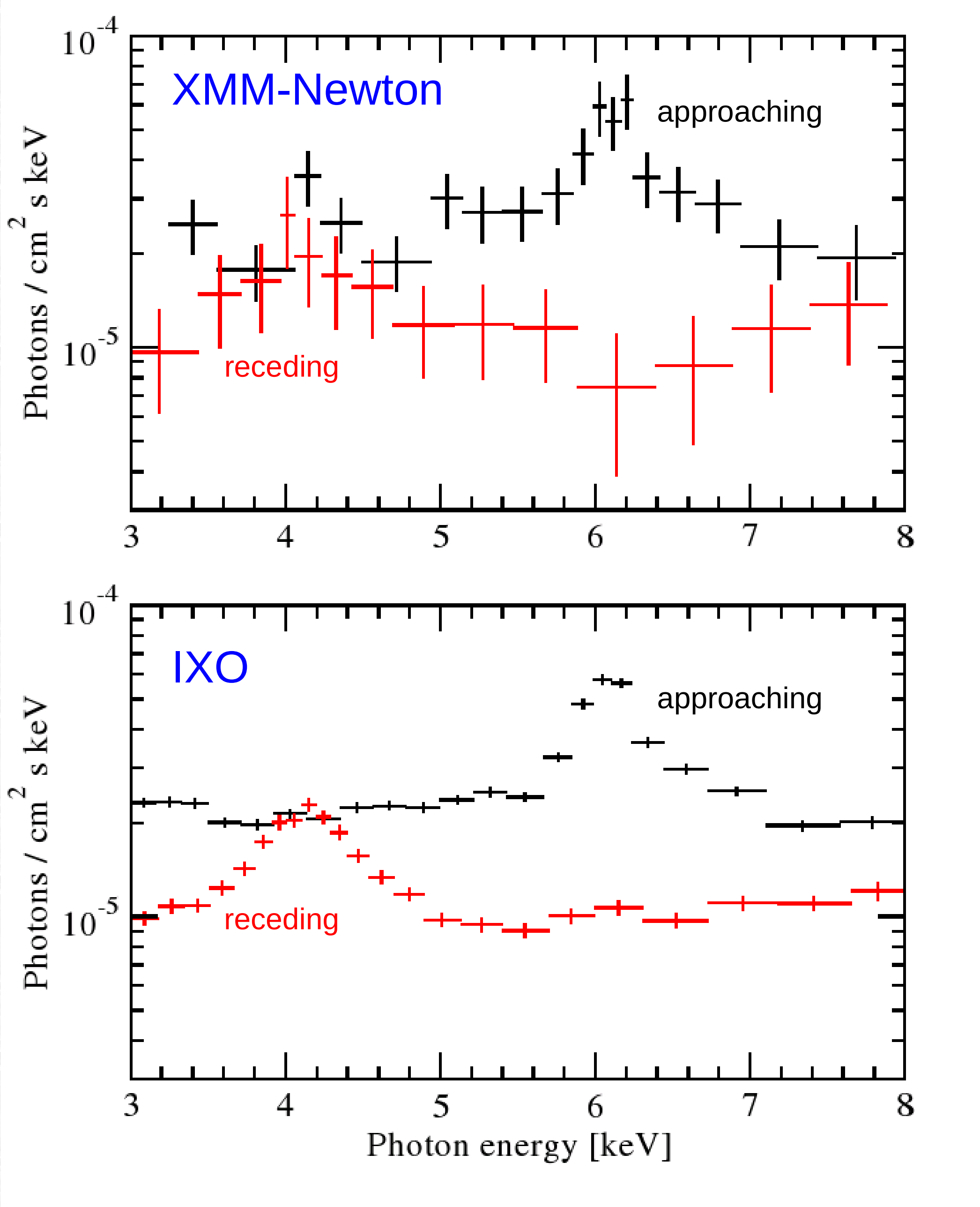
E_{cut} ~ 100 keV



The Universe as a laboratory - Compact objects

- Catching relativistic, sub-orbital structures in the innermost parts of an AGN accretion disk





$M = 3x10^7\ M_{sol}$, $a = 0.998$

$R = 7\ R_g$, T_{obs} = ¼ rot. Kepler

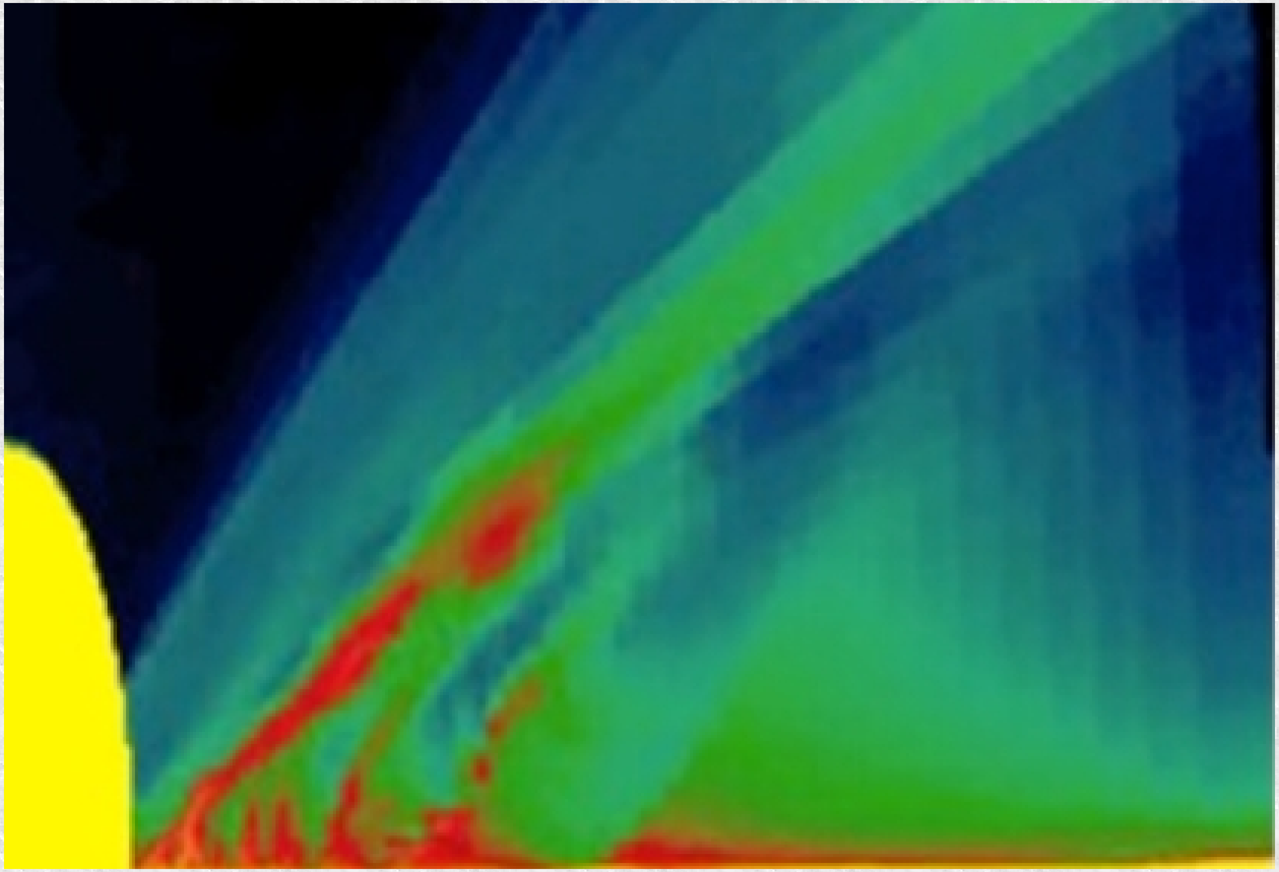
The Universe as a laboratory - Compact objects

- Powerful winds being launched of accretion disks around compact objects

- Enrichment of interstellar matter

- Accretion budget

- Determination of density, outflow velocity, and covering factor gives <u>mass loss rate</u>



Proga et al. (2000)

The Universe as a laboratory - Compact objects

- Powerful winds being launched of accretion disks around compact objects
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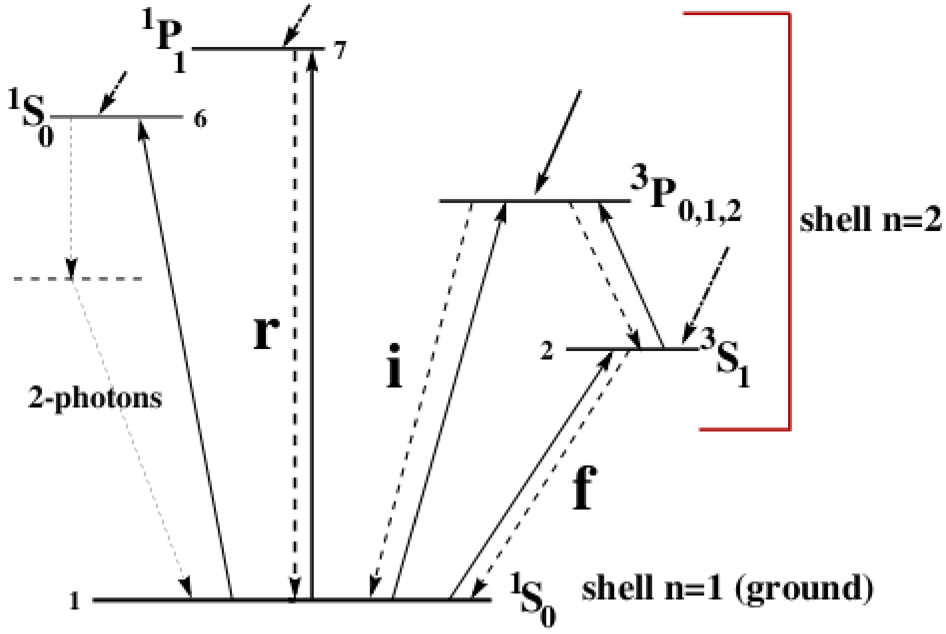


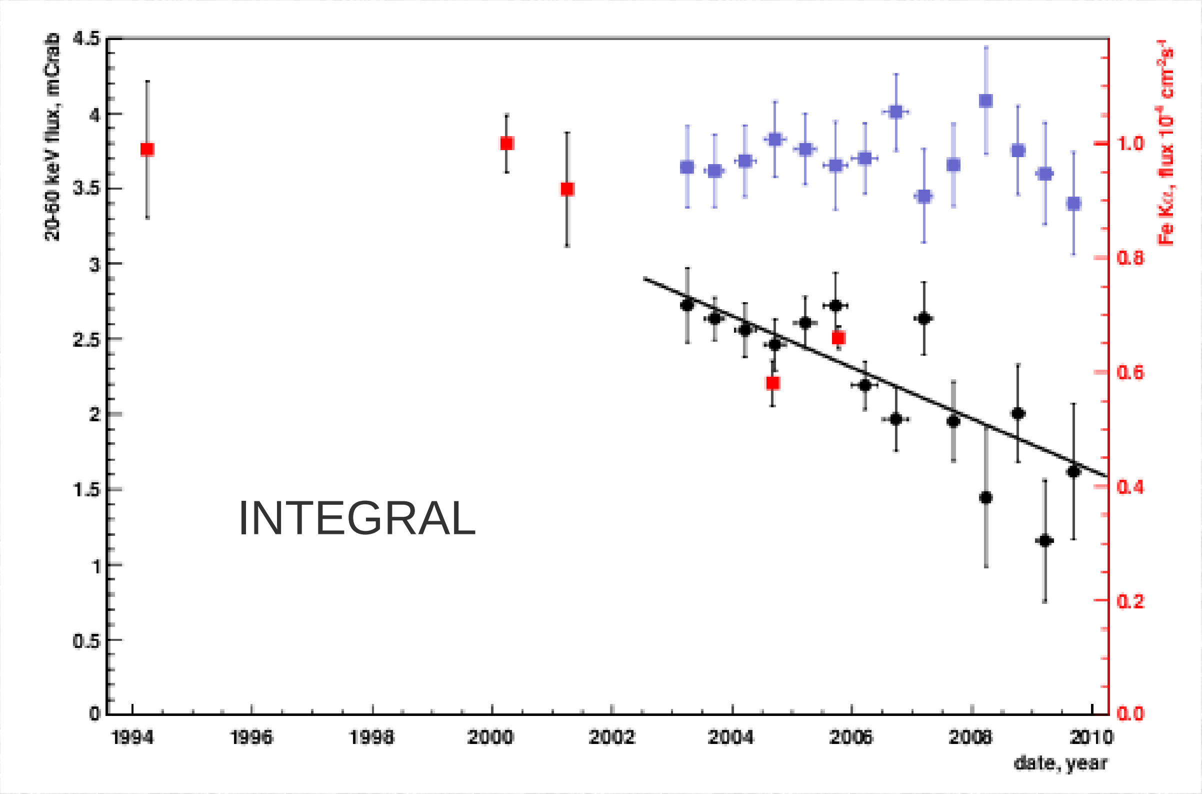
Simplified Gotrian diagram of He-like ions.

Porquet et al. (2000)

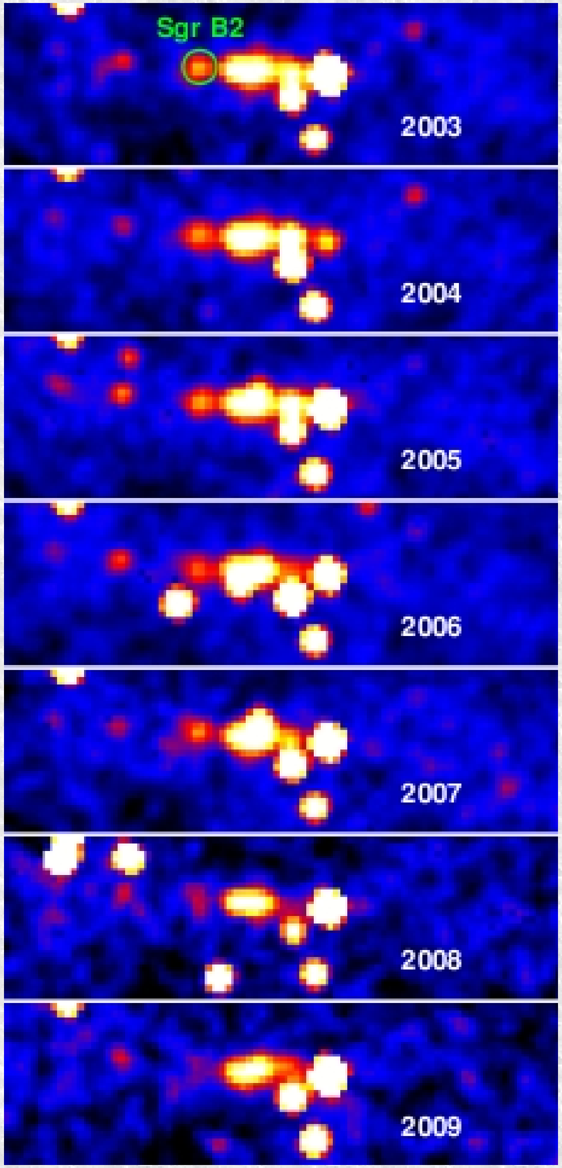
Applicable also for
- Sgr A*
- ULXs
- plasma in astrophysical jets...

The Universe as a laboratory - Compact objects

The echo of the fading Sgr A*
Time-dependent hard X-ray photometry and imaging of the Galactic Center



Terrier et al. (2000)



Explosive phenomena

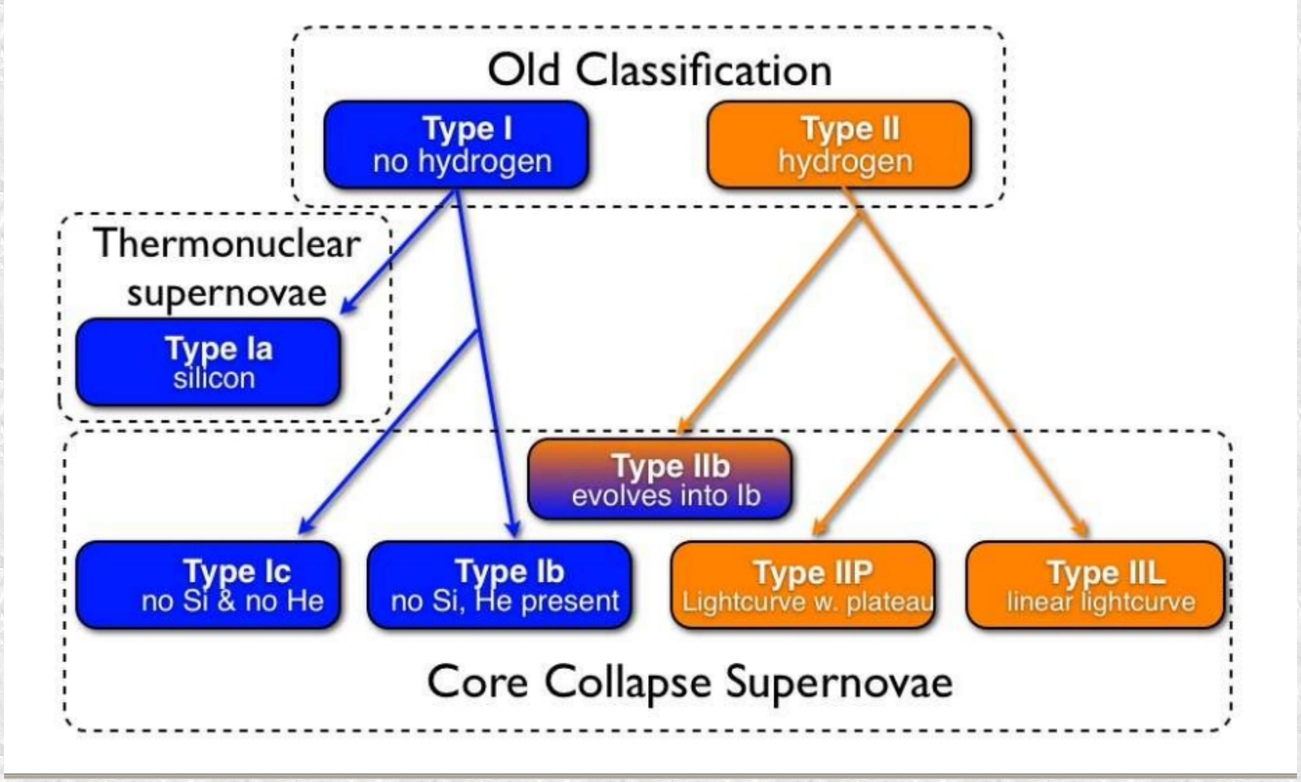
Fundamental questions related to X-ray astronomy

- What is the nature of the progenitor?
- What are the details of the explosion?
- What is the physics of the ejected material?
- What are the products of the explosion?

Explosive phenomena - Supernovae

Open questions:

- Progenitors?
- Details of explosion?
- Ejecta?
- Product of explosion?
- Nucleosynthesis?
- Cosmic ray acceleration?
- Neutrino emission?



Vink et al. (2012)

Young Galactic SNR are key sources!

→ Possibility to study the explosion by imaging-resolved X-ray spectroscopy of the ejecta.

Explosive phenomena - Supernovae

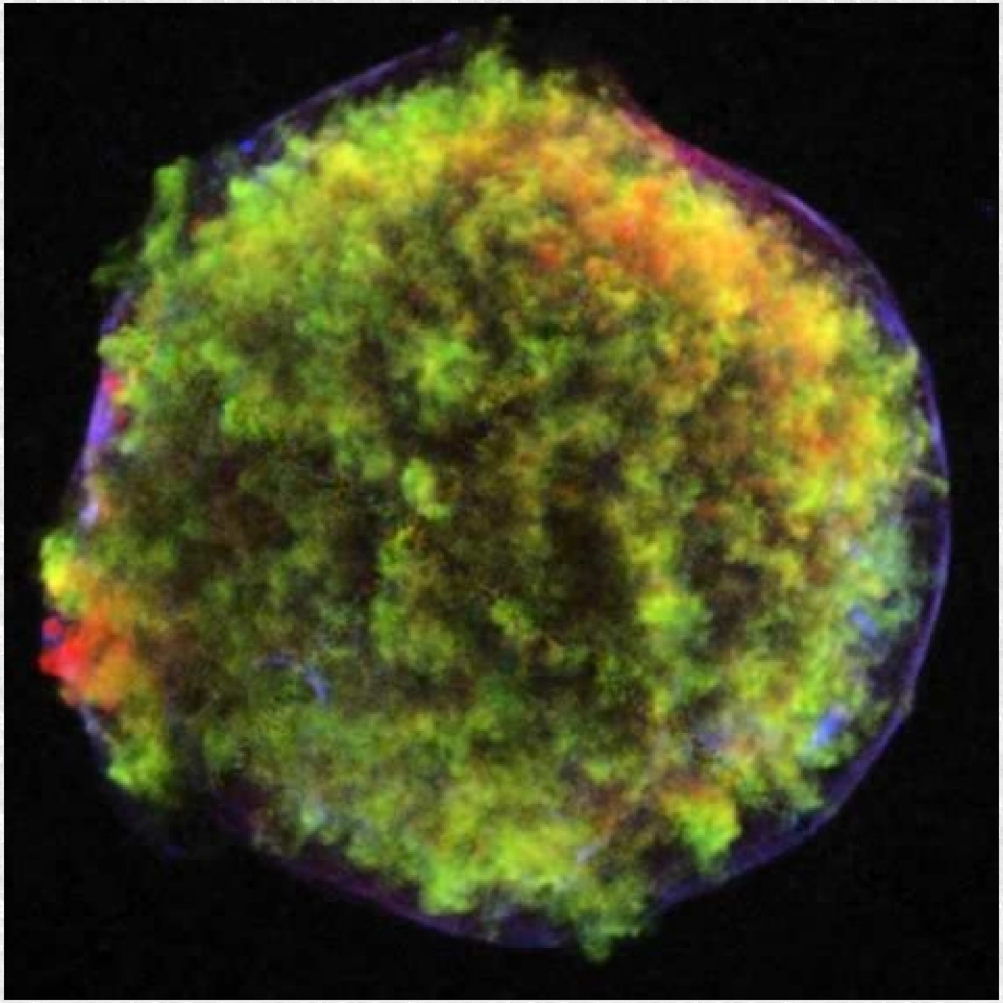
Example of the Tycho SNR (SN 1572)

• Thermonuclear explosion of an accreting white dwarf

• X-ray filaments are shocked regions of particle acceleration

• Need to examine the ejecta emission using X-ray line diagnostics

→ X-ray fine spectroscopy is required (a few eV instead of today's 100 eV)



Three-color Chandra image of Tycho's SNR
Red: Fe-L emission
Green: Si XIII emission
Blue: 4-6 keV continuum

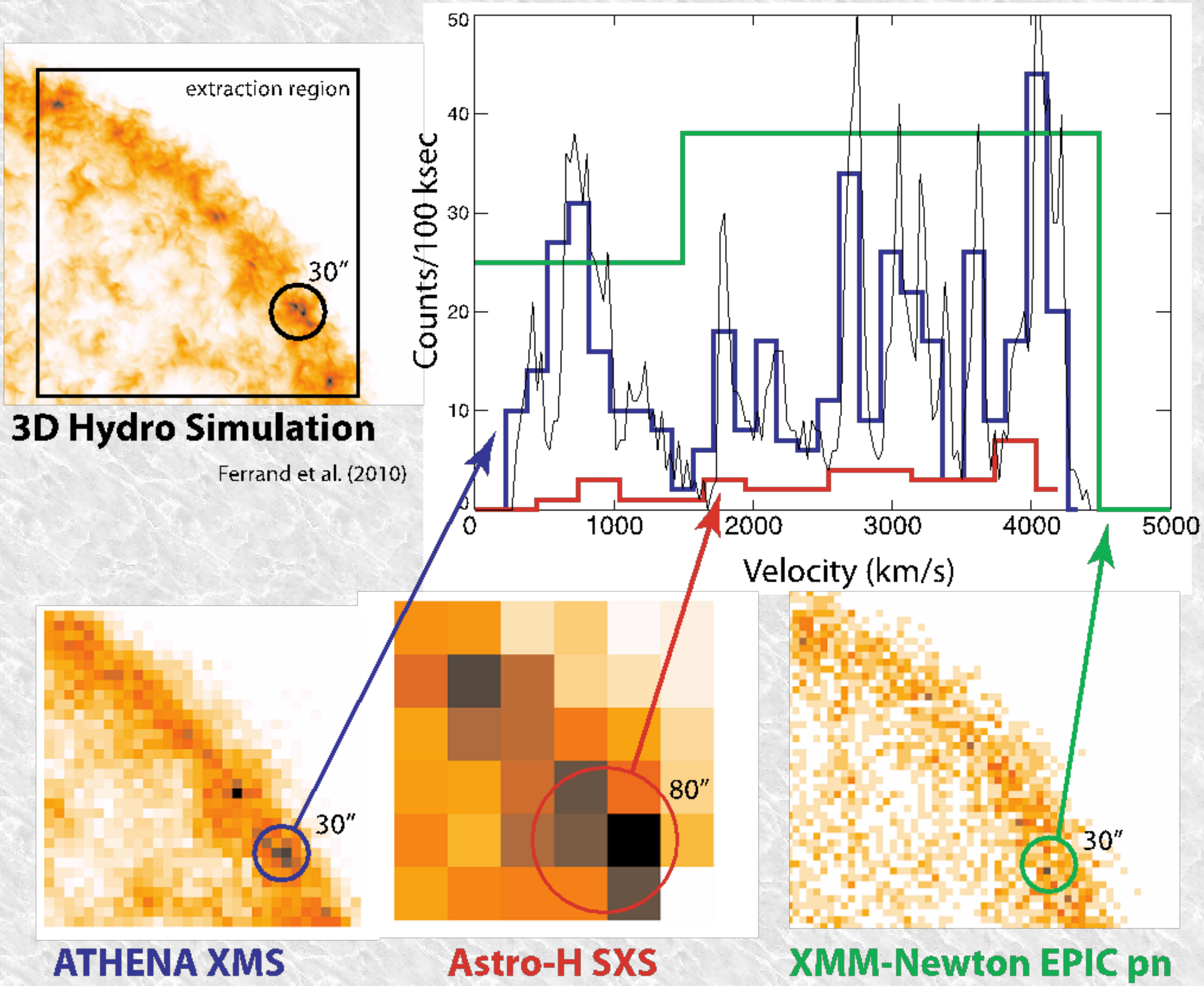
Explosive phenomena - Supernovae

Goals for young SNR

- Resolve the spatial structure of X-ray line velocities

- Distinguish between approaching and receding shocks

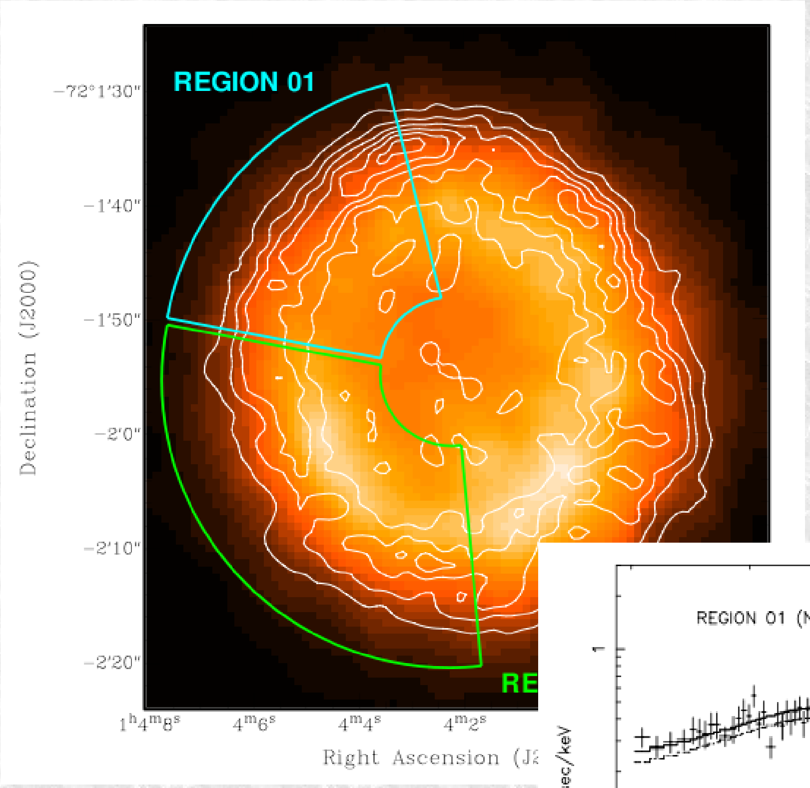
- Find asymmetries in the SNR shell



Explosive phenomena - Supernovae

Goals for older SNR

- Resolve well the soft X-ray emission lines around 1 keV
- Access to detailed line diagnostics to determine *T* and *n*
- Clearly locate the level of the underlying continuum



SMC SNR 0102-72.3
XMM-Newton data
(Sasaki et al. 2001)

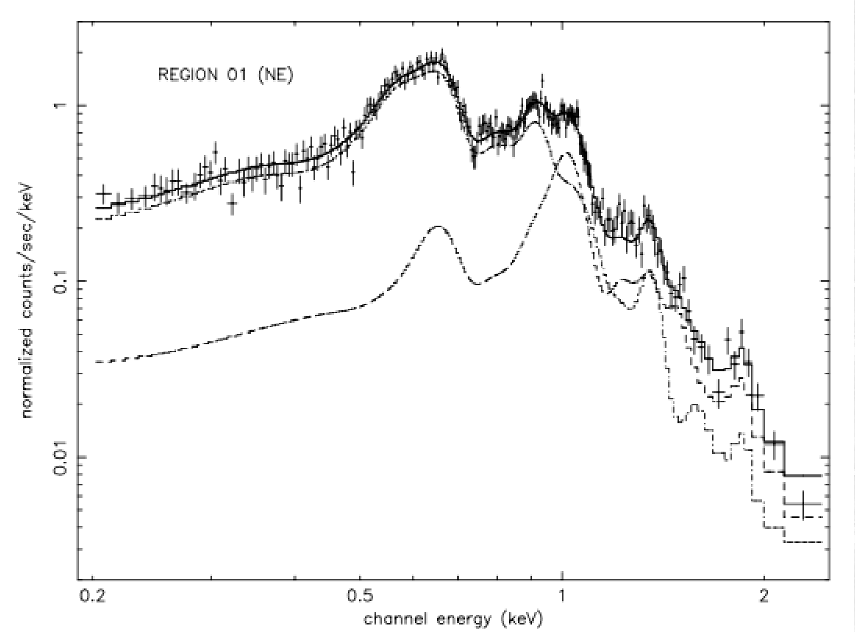


Fig. 3. Spectrum and fitted double VGNEI model of the north-eastern part of the SNR

Prospects for X-ray Astronomy in the High Energy Domain

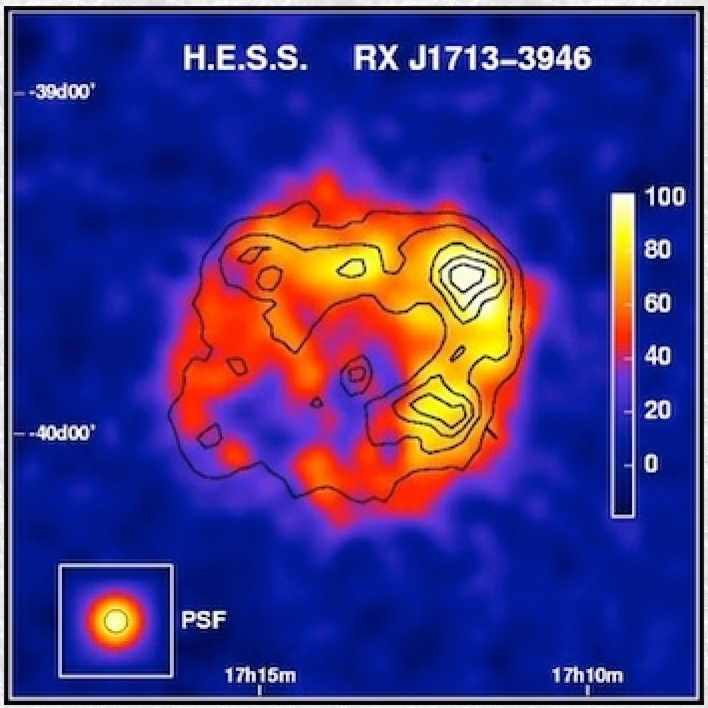
Cosmic rays

Fundamental questions related to X-ray astronomy

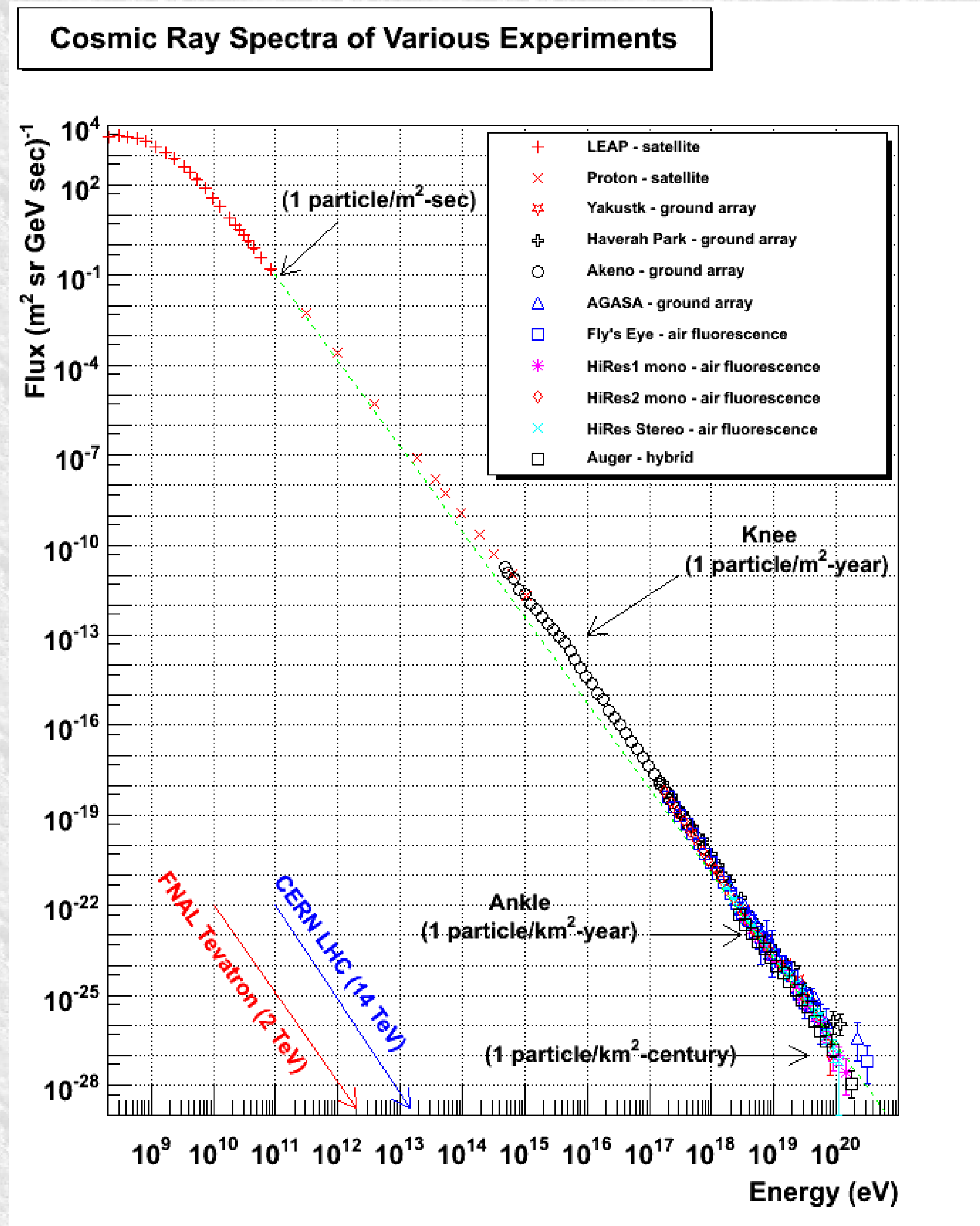
- What is the composition and origin of Galactic cosmic rays with (1017 eV > E > 100 MeV) ?
- How to understand the “knee” of the cosmic ray spectrum at PeV energies?

Prospects for X-ray Astronomy in the High Energy Domain

- Supernova are best candidates to explain Galactic cosmic rays
- Important synergy between X-ray and gamma-ray observations



H.E.S.S. collaboration



Prospects for X-ray Astronomy in the High Energy Domain

New astrophysical messengers

Fundamental questions related to X-ray astronomy

- What can we learn from gravitational wave and neutrino observations?
- What astrophysical particles can be revealed by X-ray emission?

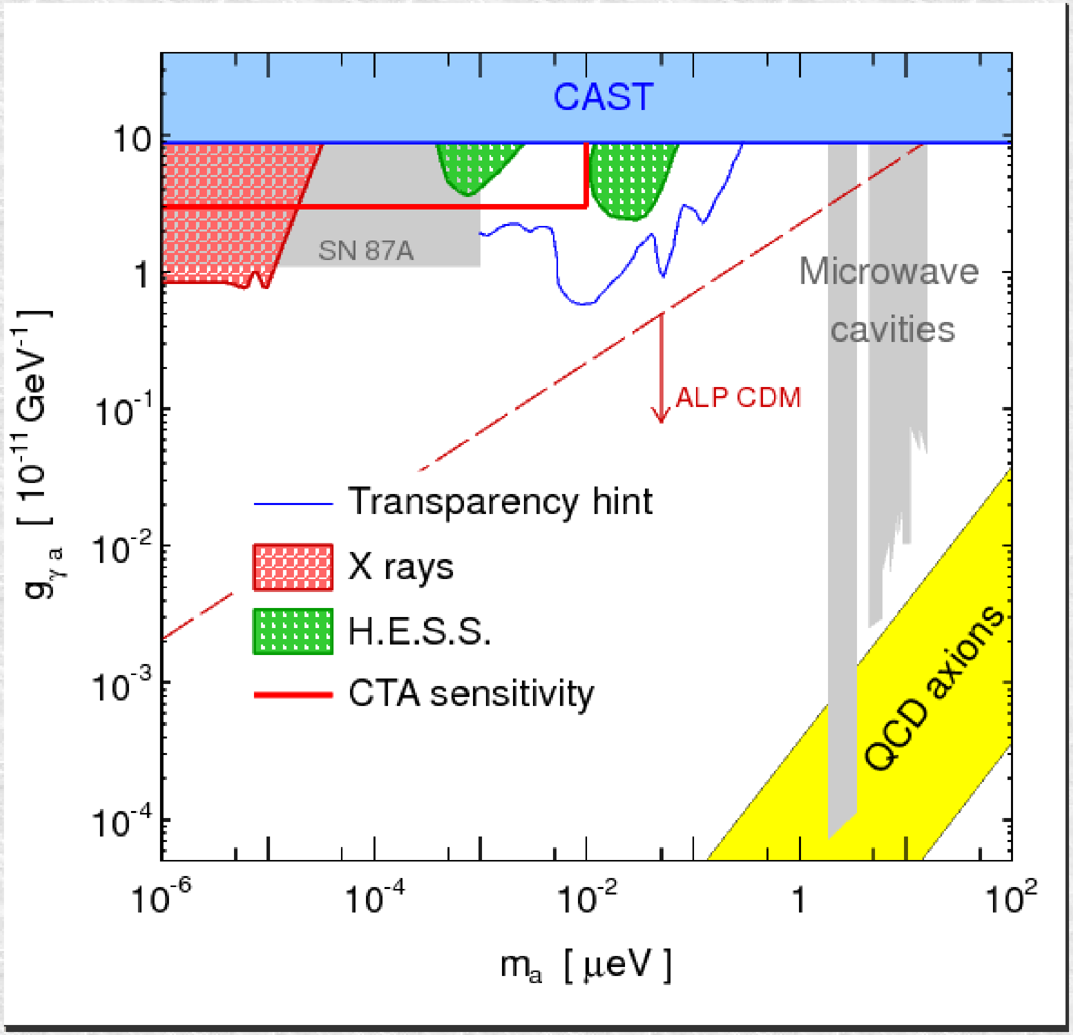
The Universe as a laboratory - Axion-like particles

Quantum Chromo-Dynamics

• Fundamental problem of the broken *CP*-symmetry (charge conjugation and parity switch)

• Adding a new type of scalar particle in the framework of the Peccei-Quinn theory

• Axion-like particles with so far unknown mass and coupling constant



The Universe as a laboratory - Axion-like particles

X-ray measurements from the Hydra Cluster

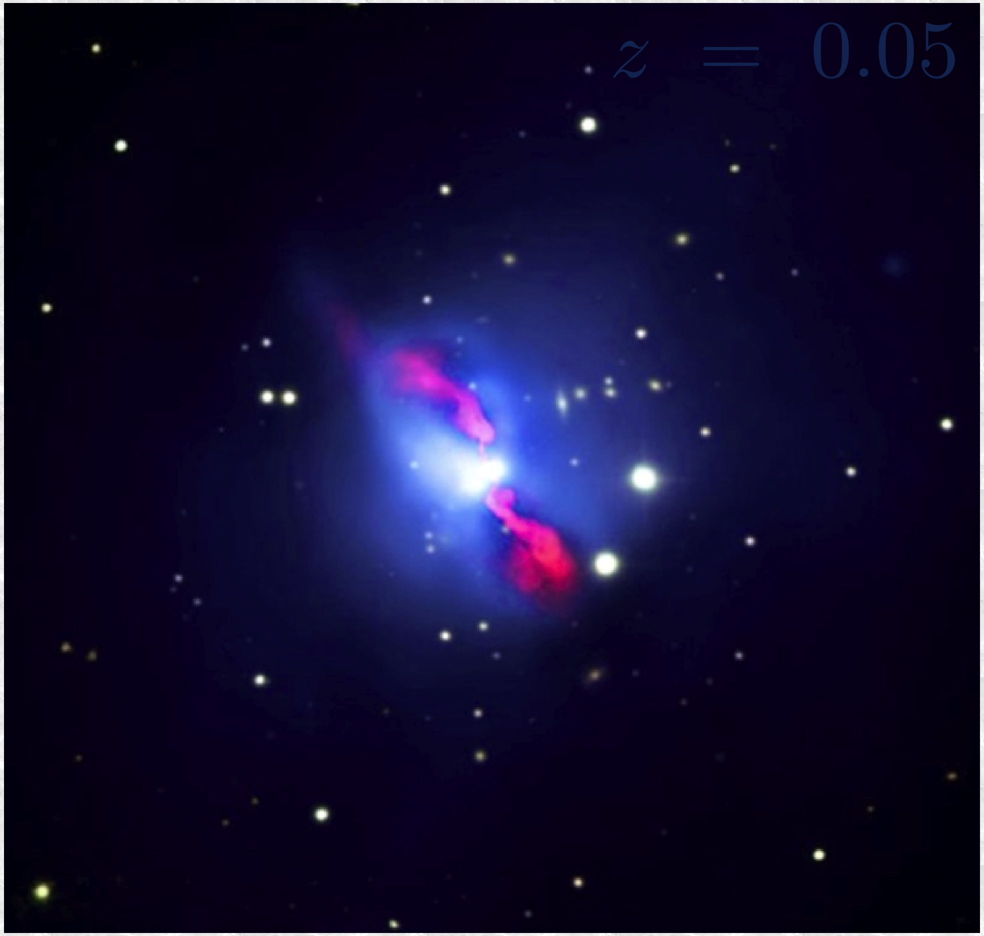
• Axion-like particles can couple to two photons (quantum oscillations)
•One X, one B field

• Coupling is more efficient in strongly magnetized environments

→ Searching for <u>perturbations</u> of the synchrotron spectrum emerging from the <u>turbulent</u> central galaxy of the Hydra A cluster

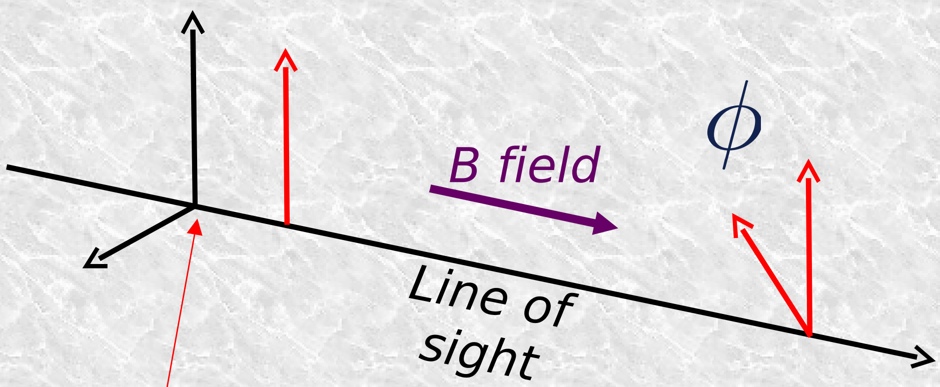
Hydra galaxy cluster

Radio/Optical/X-ray



The Universe as a laboratory - Axion-like particles

Determination of the *B*-field by Faraday radiation of the polarized synchrotron emission



$$\phi = RM \times \lambda^2 + \phi_0$$

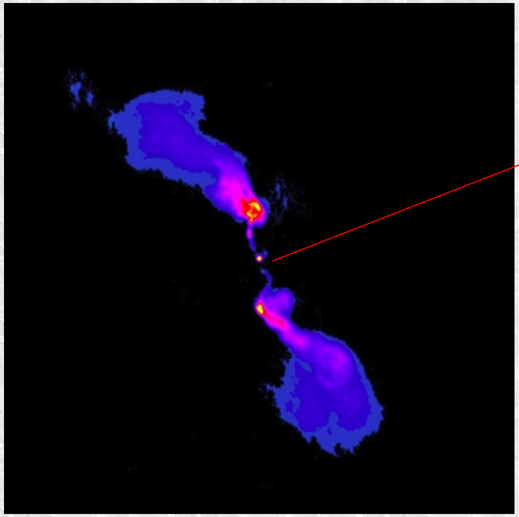
$$RM \propto \int_0^L n_\mathrm{e}(r)\vec{B}\cdot \mathrm{d}\vec{\ell}$$

Polarized emission provided by synchrotron radiation

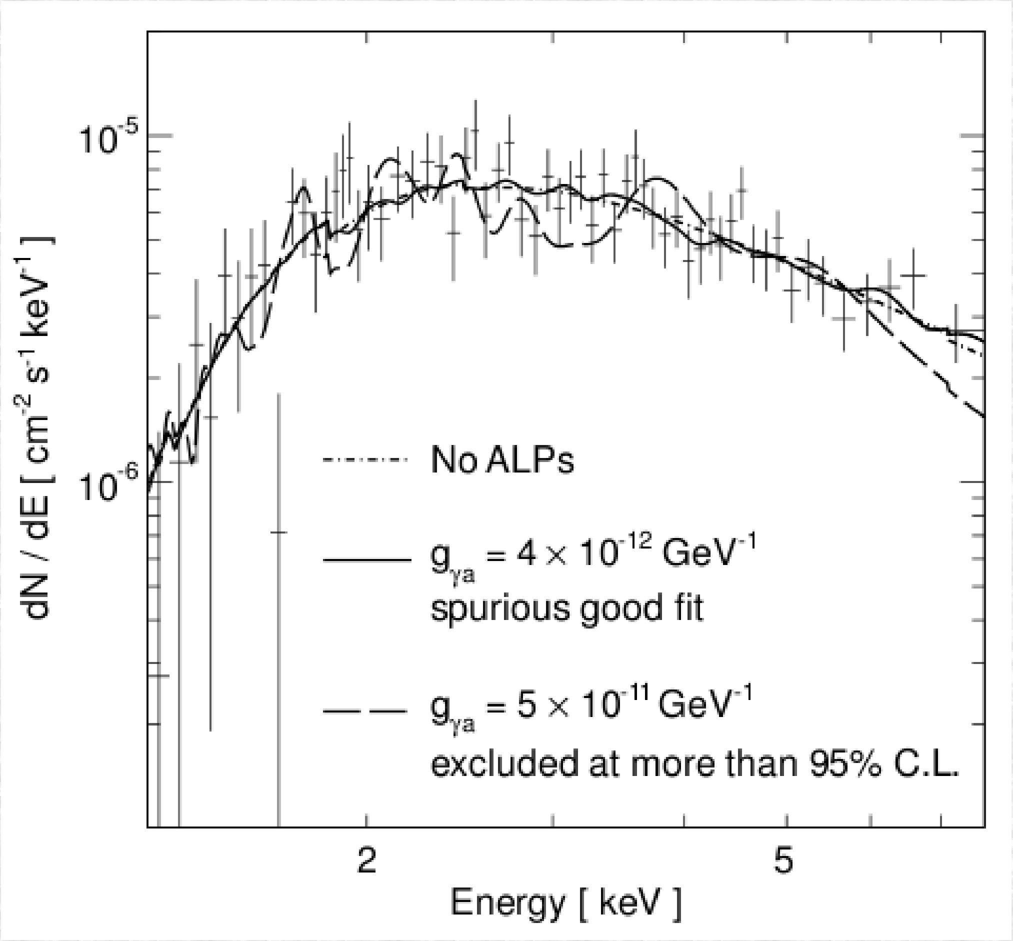
λ^2 behavior probed with radio bands

Electron density from X-ray data

The Universe as a laboratory - Axion-like particles



- Powerful X-ray source
- Non-thermal component extracted with *Chandra*



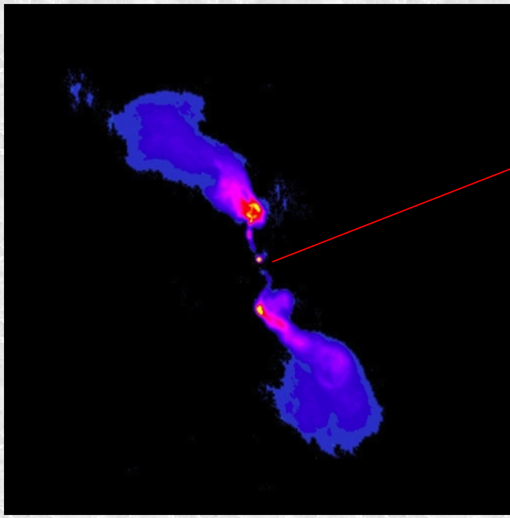
Wouters & Brun (2013)

How much irregularity is allowed ?

⇓

Derive constraints on a statistical basis

The Universe as a laboratory - Axion-like particles



- Powerful X-ray source
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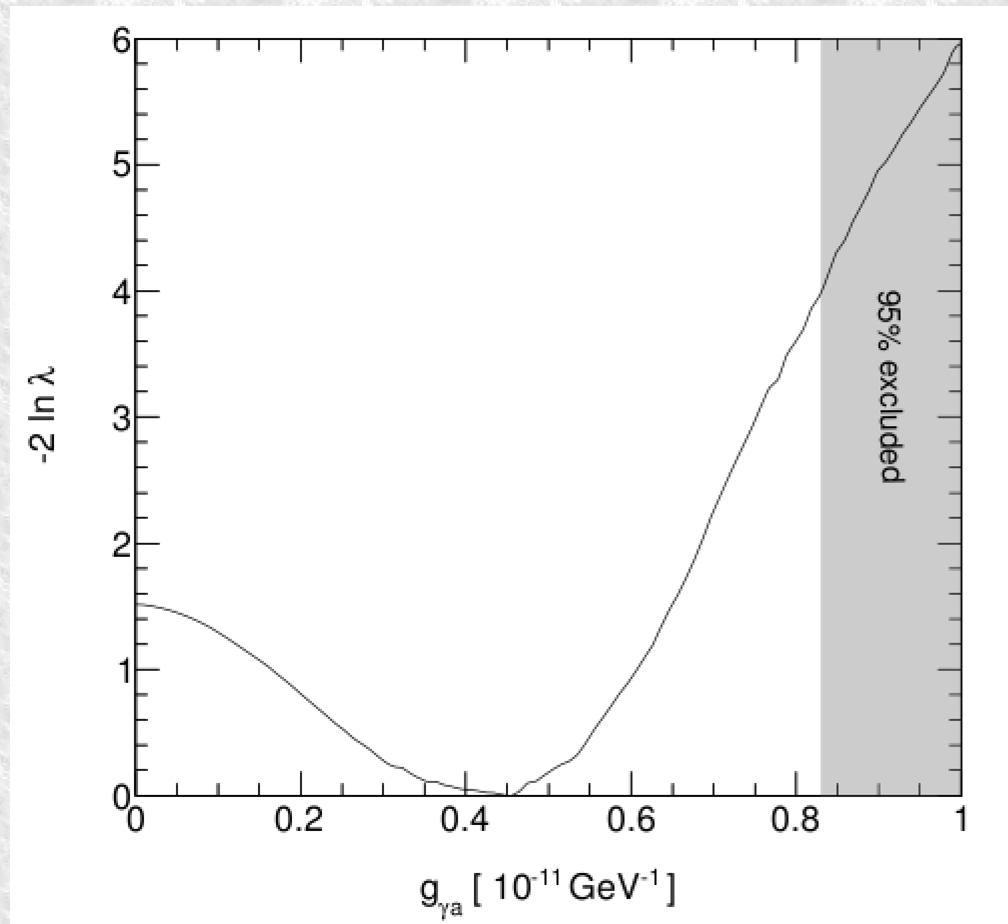

Wouters & Brun (2013)

Prospects for X-ray Astronomy in the High Energy Domain

(preliminary) Conclusions

No – XEUS is no longer in the game.

But, for the sake of the science that we presented here, we still need :

- Large collecting areas -
  We want to see faint sources

- High angular and spectra resolution -
  We want to see spatial details of the sources

- Interchangeable instrumentation -
  We want to look at the object in different ways