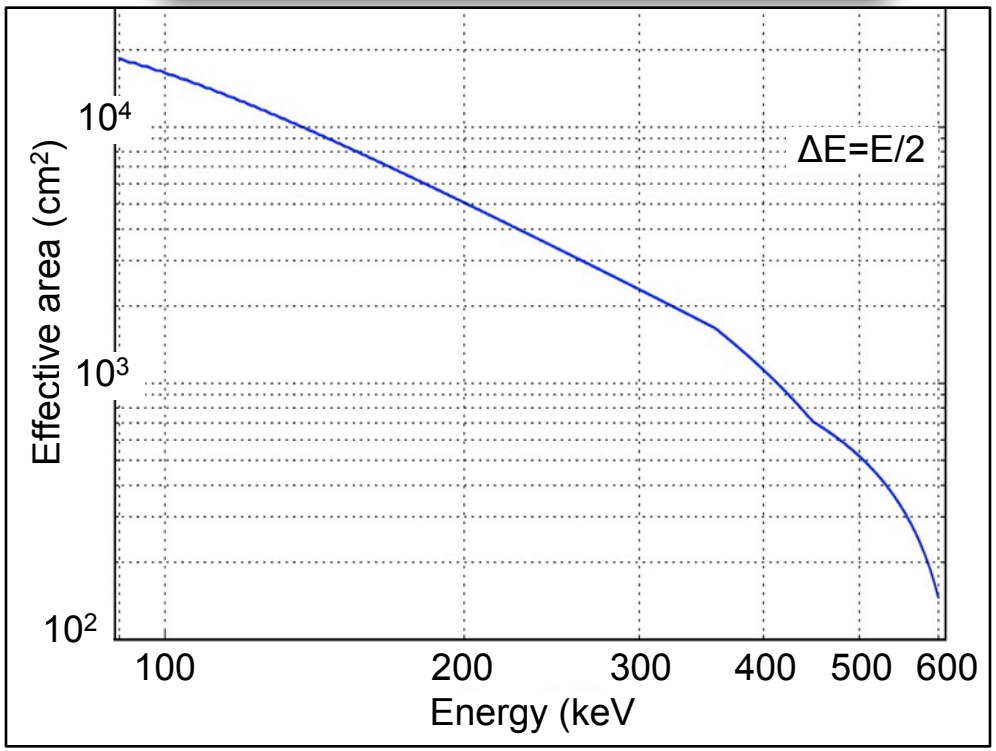
Science applications of the LAUE telescope

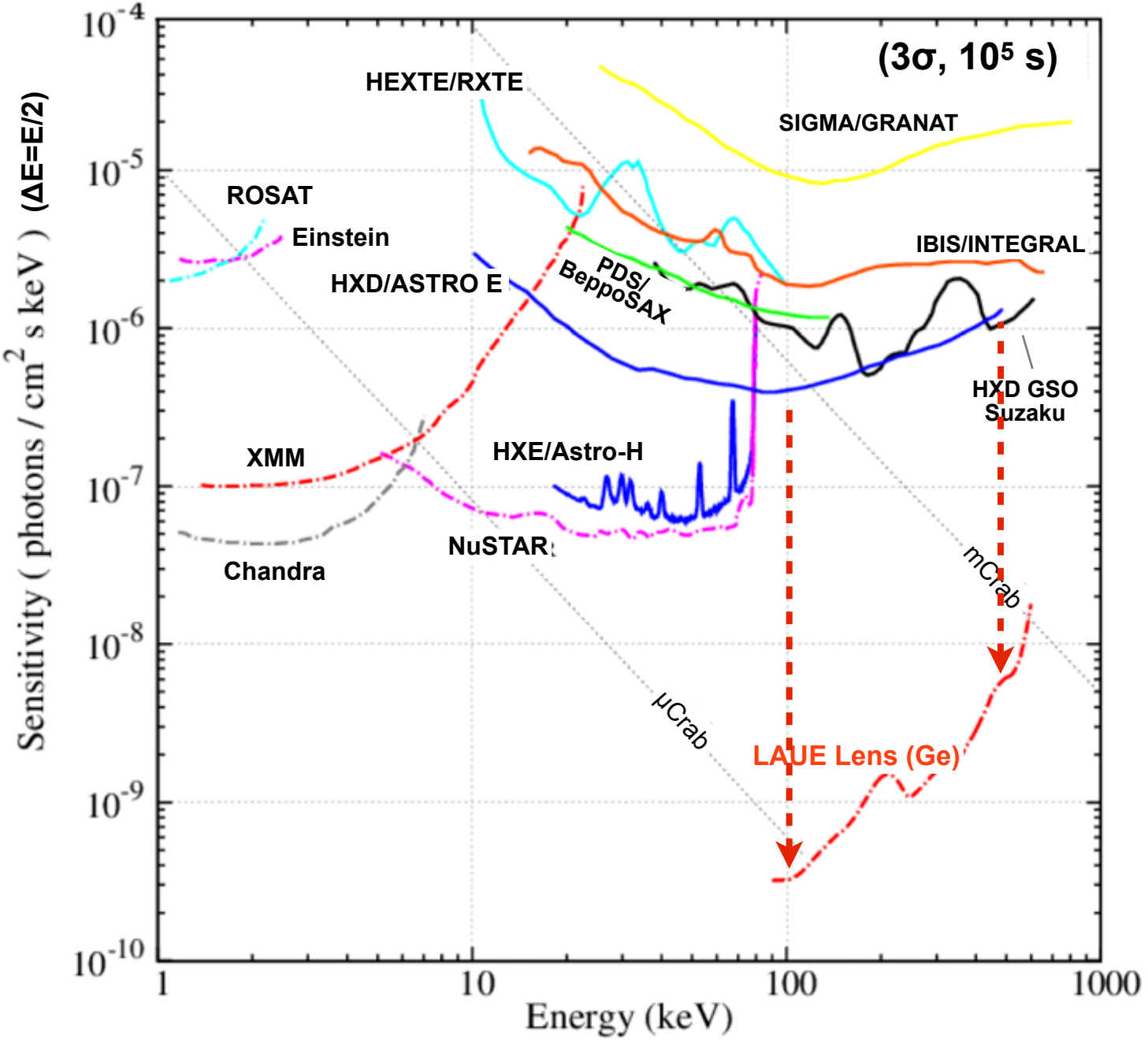
Piero Rosati, Filippo Frontera (University of Ferrara) **and the LAUE Collaboration**

Configuration being developed at
Ferrara Univ. + Thales-Alenia Space-(Turin, IT)
Sponsored by ASI

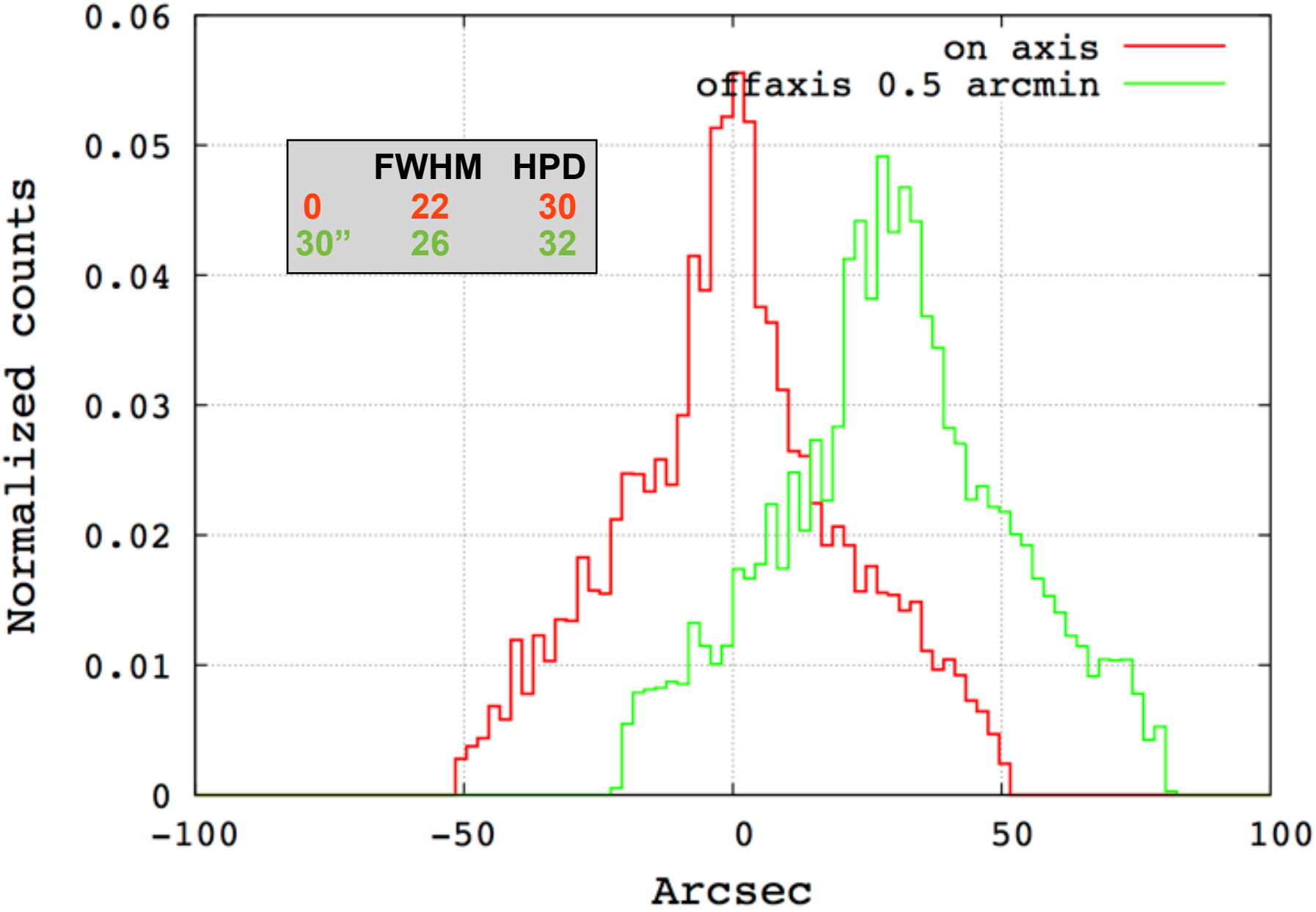
- Material: Ge (111)
- Bent crystal tiles 2mm thick, 30x10 mm^2
- Inter-distance between crystal tiles: 0.1 mm (assembling petal)
- 28 rings, 9341 crystals
- Total diameter: 190 cm
- Weight: 19 kg (+ frame ~10 kg)
- Passband: 90-600 keV
- Focal length: 20 m
- Resolution~30 arcsec (over 1' FoV)
- Could be extended down to 60 keV (with Ge) with 240 cm diameter



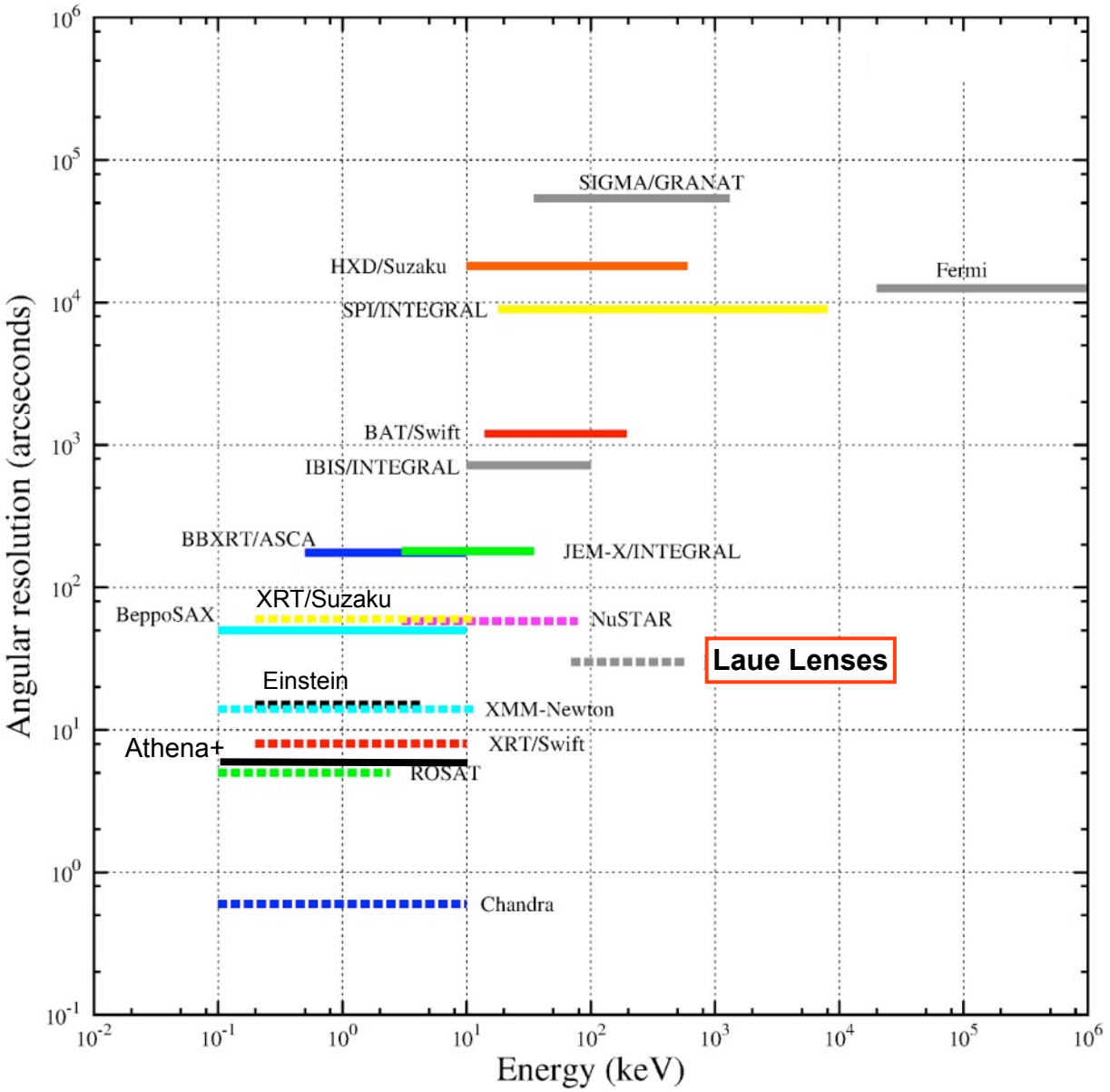
Sensitivity of soft/hard X-ray missions



Angular resolution



Angular resolution

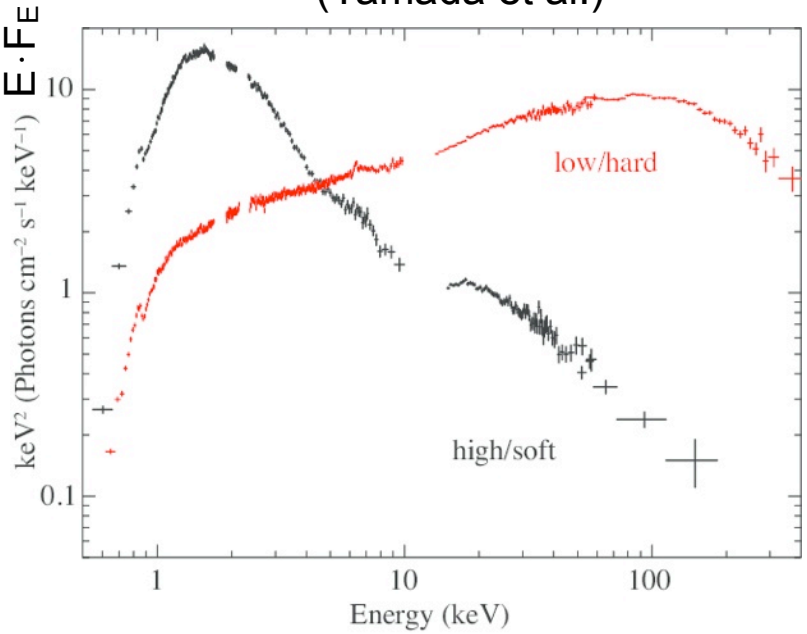


Physics of accretion onto Galactic compact objects in binary systems

(See J. Rodriguez's talk)

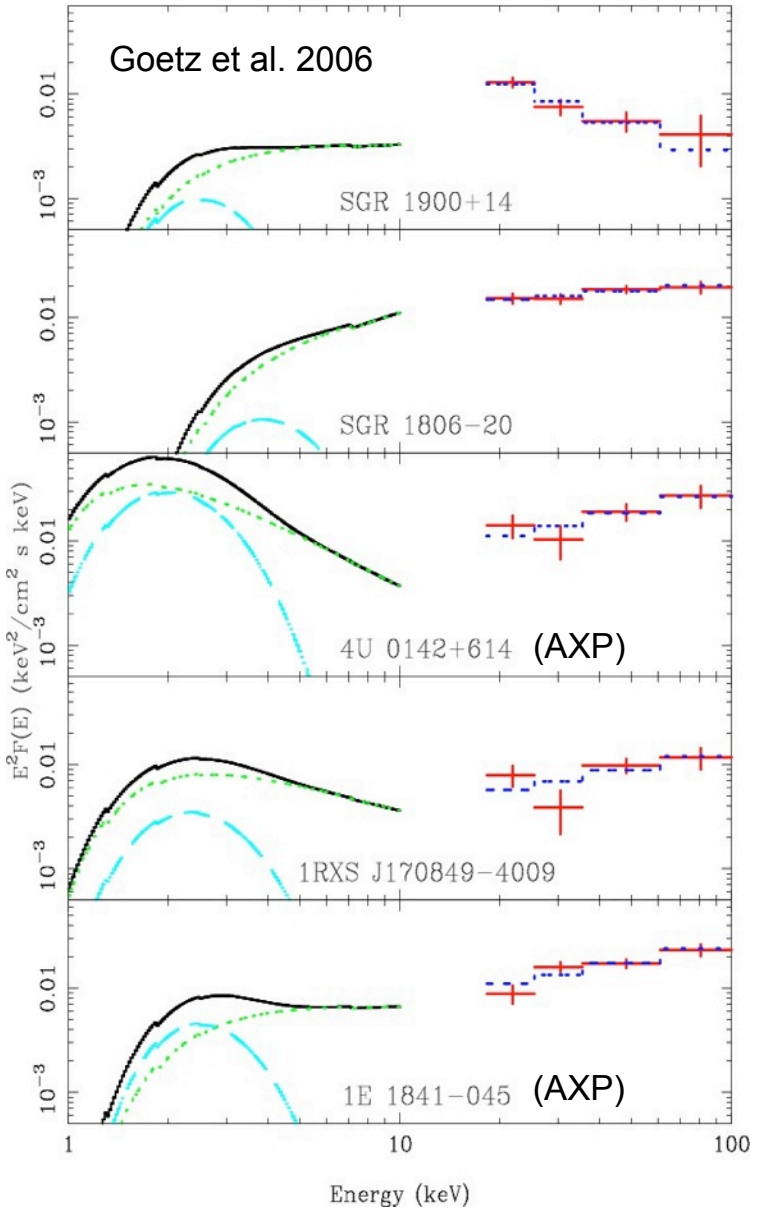
- Spectra of compact objects extend beyond 100 keV
- High energy dependent variability: high/soft state, low/hard state (probe physics of accretion, different comptonization regimes, geometry)
- Correlations between E_{cutoff} and photon index to be compared with models (Titarchuk+ 10, Laurent+ 12)
- **Laue lens sensitivity (2-3 order of mag better) can probe the hard state of a large sample of systems**

Cyg X-1 Suzaku campaign (Yamada et al.)

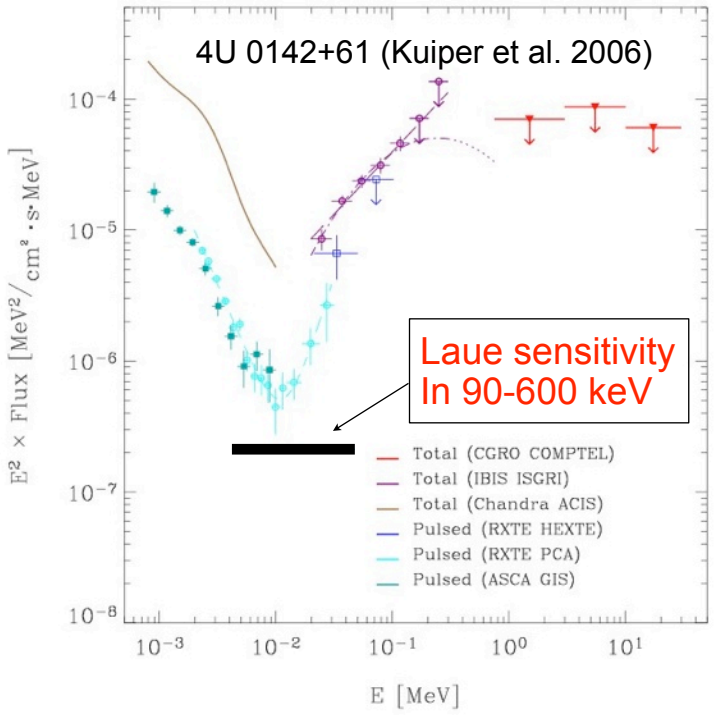


- **Also, in case of X-ray pulsars**, new discoveries of high energy cyclotron features and/or harmonics of lower energy features, thus higher magnetic field strengths and its properties investigated

Case of Magnetars



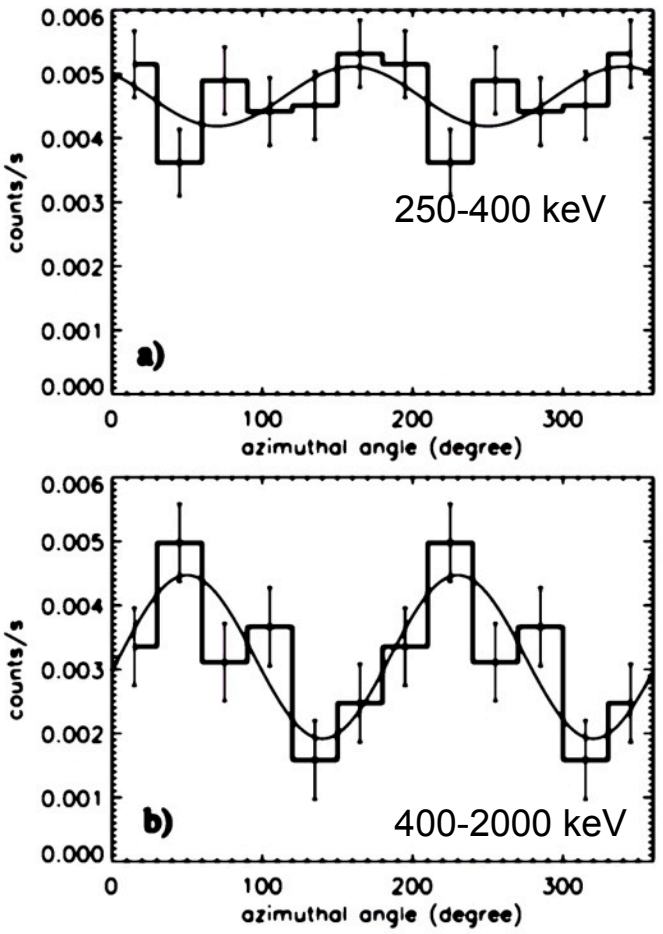
- Origin of the high energy component in anomalous X-ray pulsars and soft gamma-ray repeaters (SGR) for which a magnetar models has been invoked?
- Several mechanisms proposed (e.g. synchrotron originated by pair production (Thompson & Beloborodov, 2005)



Hard X-ray polarization

- Strong polarization signal found from Cygnus X-1 with INTEGRAL above 400 keV
- Polarization in Hard X-ray critical to separate the different emission components (C, S, R)
- The Laue lens (high angular resolution/sensitivity/low bckgrd) is particularly suited for polarization studies in the Hard X-ray:
  - can extend BH candidate studies to many more weaker sources
  - monitor early stages of outbursts
  - GRB follow-up observations

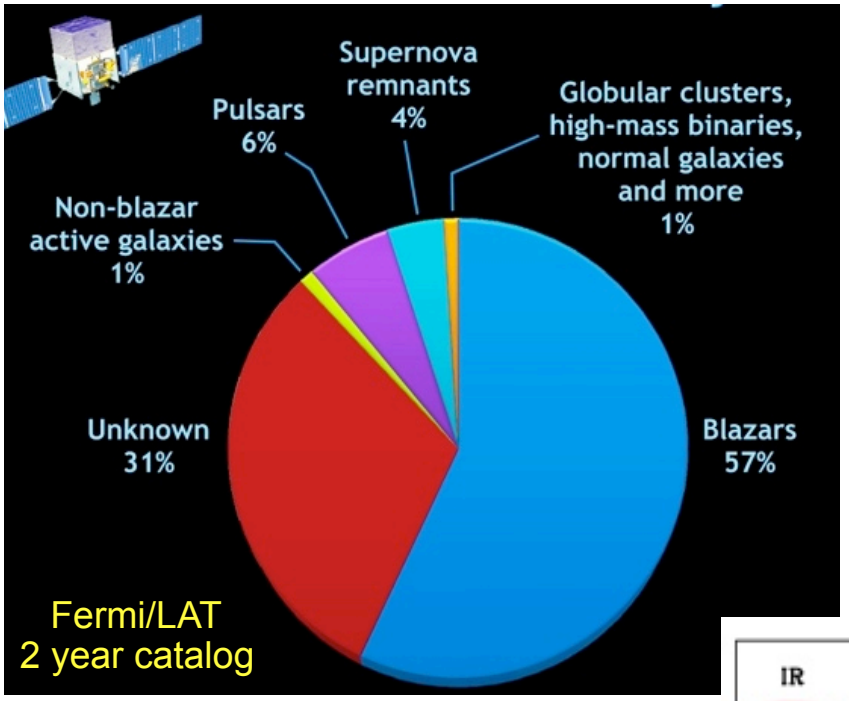
Laurent at al. 2011



- **Sensitivity**: <1% MDP at 10^{-9} ph/cm^2/s/keV with 10^5 ksec

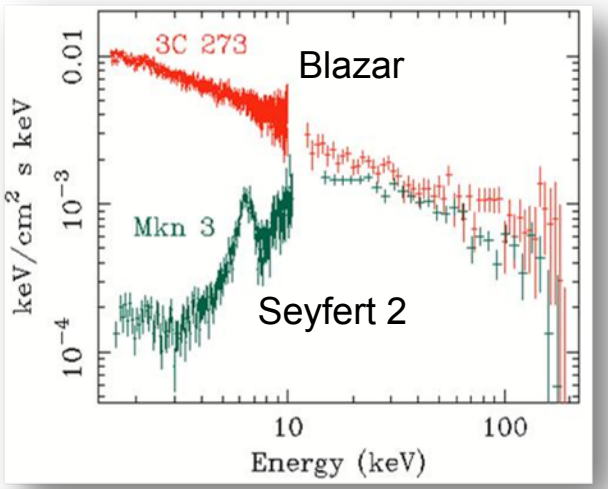
Emission physics and nature of Blazars

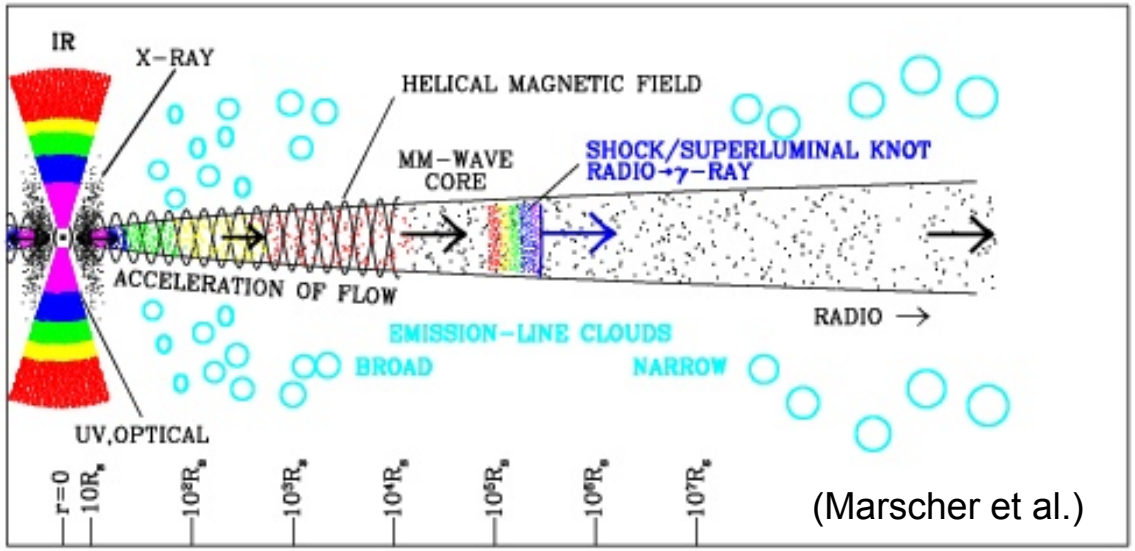
Blazars are found in increasingly large numbers at γ-ray and μ-wave energies



Classification and interpretation of Blazars is complex to to the combination of jet, accretion disk and host galaxy emission

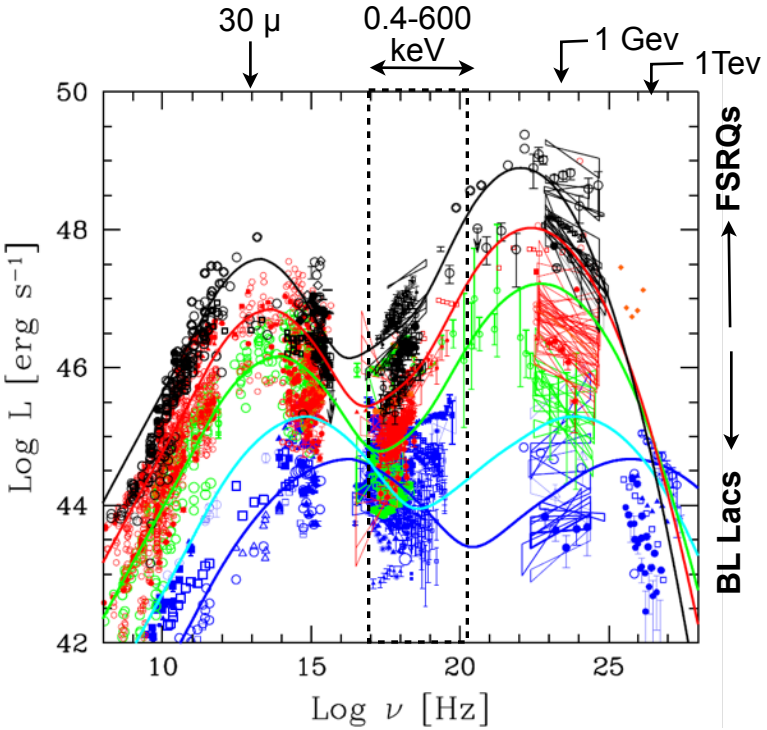
Extreme properties: large/rapid variability, strong emission over entire e.m spectrum, superluminal motion.
Hard X-ray emission due to Compton up scattering (IC) of synchrotron and external seeds photons

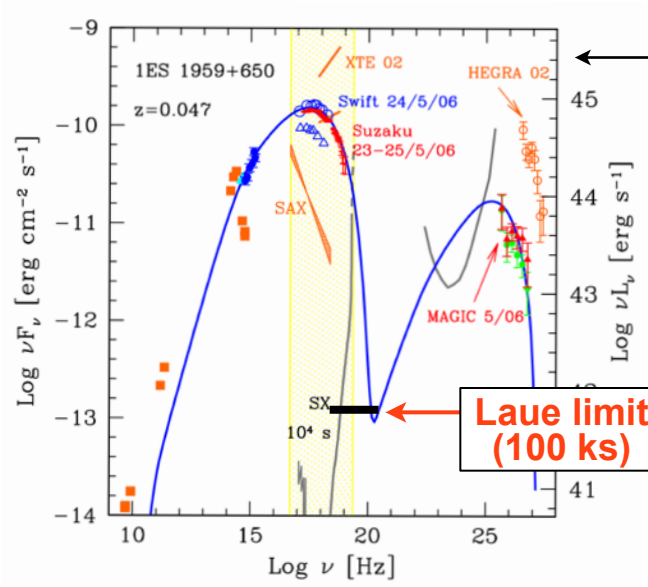




Emission physics and nature of Blazars

- Two humps in the SED:
  - mm-soft X-ray: synchrotron emission
  - 100 keV-TeV: IC (seed photons: disk, jet, BLRs)
- The variation of the overall SED at increasing L_{bol} (decreasing ν_S and ν_P, increasing Compton dominance) is linked to M, $\dot{M}$, with $L_{jet} \sim \dot{M}c^2$
- Observations at 100-600 keV critical for:
  - physics of FSRQs vs BL Lacs
  - contribution of Blazars to XRB at ~>100 keV

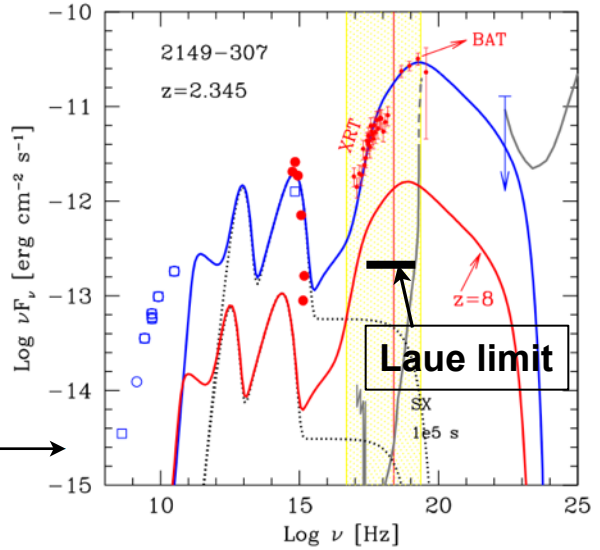




Low power BL Lacs have S peak at keV or higher, thus are best TeV candidates

Laue limit (100 ks)

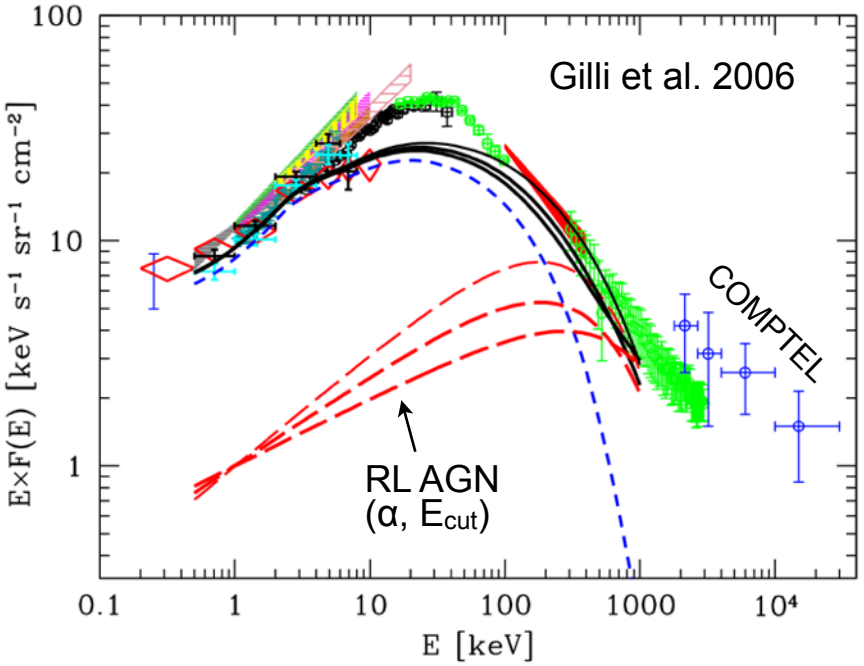
High power Blazars have strong C peak in hard X-ray which can be observed out to z=8



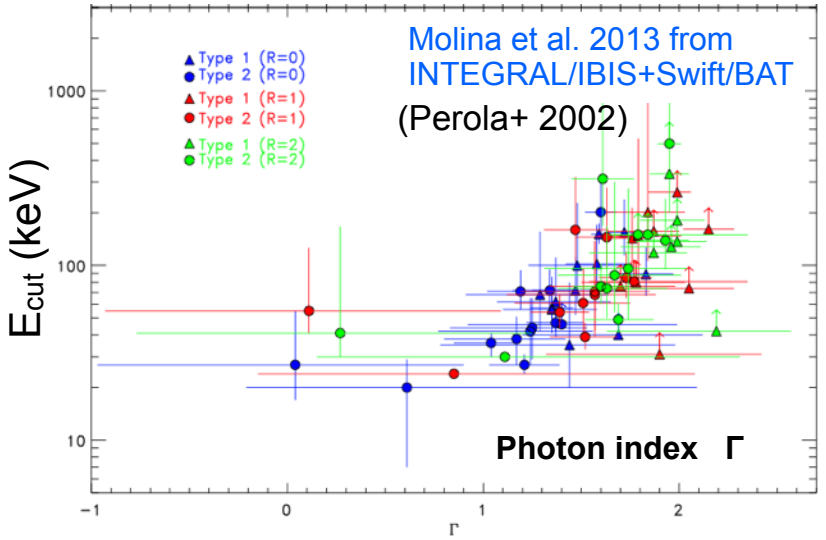
Ghisellini 2009, 2011

X-ray background (E~>100 keV)

- Spectral synthesis models are increasingly degenerate above the XRB peak:
  - unknown CT fraction, evolution, spectral slope, reflection fraction, **E_{cutoff}**
- A single energy cutoff is assumed (found in the range 50-300 keV by Perola et al. 2002 with BeppoSAX)
- Attempts to explain the XRB at E>30 keV with RL AGN (FSRQs, BL Lacs) not successful
- E_{cut} and Γ are linked to the electron temperature and optical depth of Comptonising plasma
- Direct determinations of spectral shapes at 50-500 keV at different L_X (and *z*) essential to complete the cosmic history of accretion power
  ➔ feasible with a *Laue* telescope

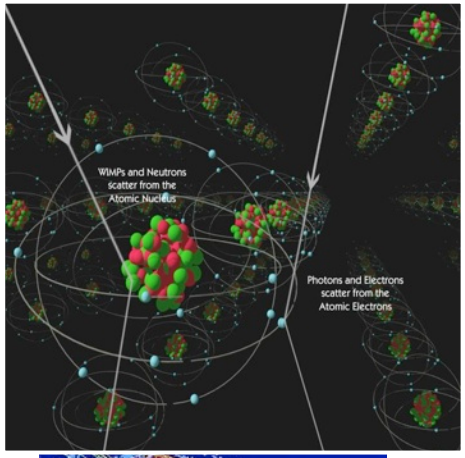


(see also: Akylas+ 2012, Ballantyne 2014)

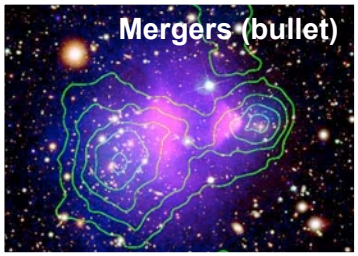


Understanding the nature of Dark Matter

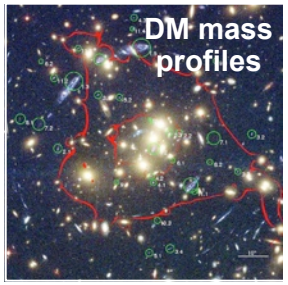
Direct detection of DM
(underground experiments)



Indirect clues on DM properties from Clusters



Constraints on self-interacting DM



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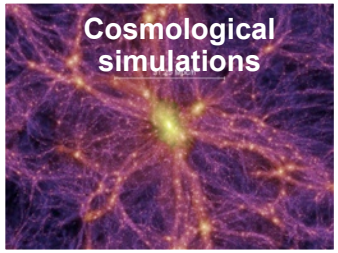

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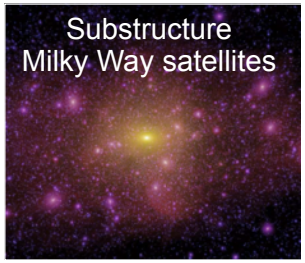
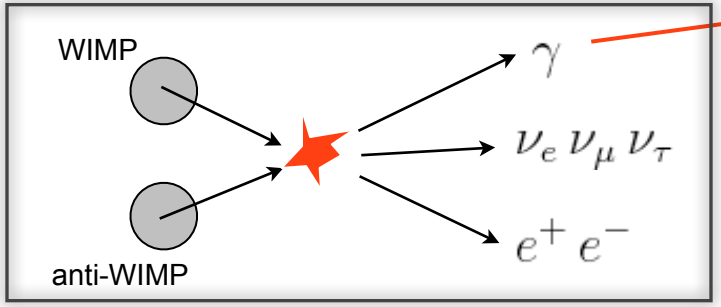
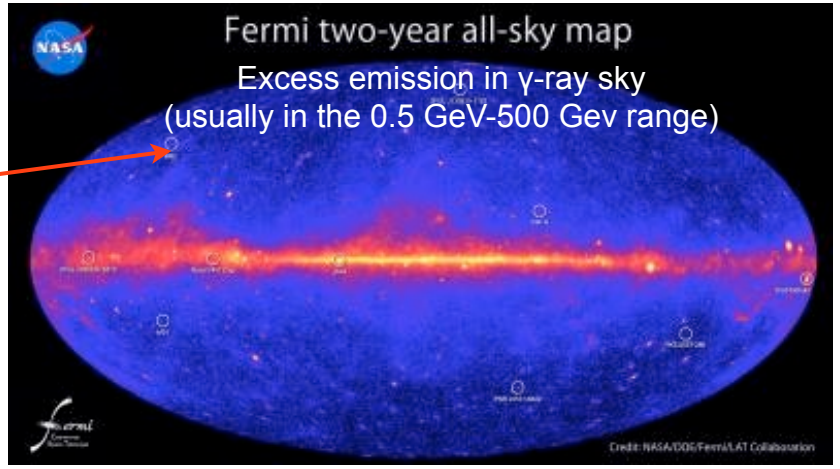
Cold vs Warm DM



Dark Matter particle properties: $M_X, \sigma_X, \sigma_{X\bar{X}}$
+
Beyond Standard Model

Indirect detection of DM

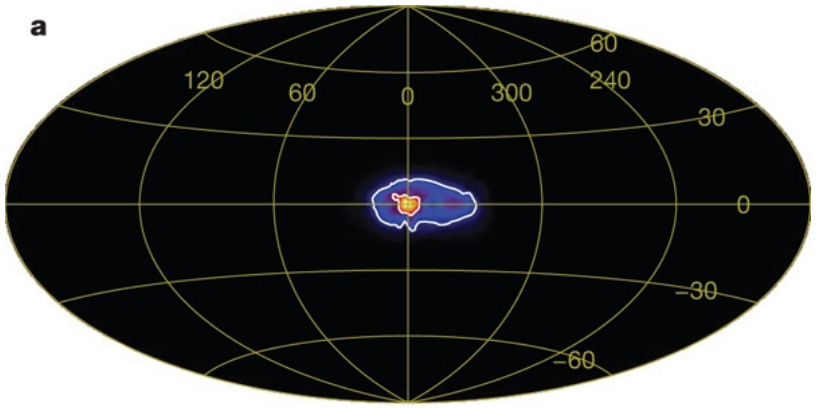




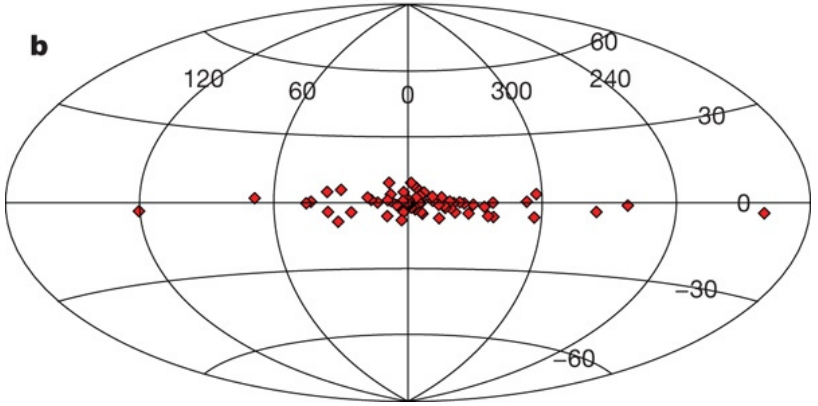
Positron annihilation from GC

- Diffuse annihilation line emission with INTEGRAL (integrated flux: 1.7×10^{-3} ph/cm^2 s).
- Where do the positrons come from ?
- Resemblance with hard LMXBs distribution suggest escaping e^+ from hot inner disk but a more complete census of LMXBs is needed
- Alternative explanations proposed:
  - Dark matter annihilation products
  - Source of radioactive elements like ^{26}Al, ^{56}Co, ^{44}Ti
  - Gamma Source (e.g., Pulsar)
  - BH Binaries

Weidenspointner+2008



511 keV line map from INTEGRAL/SPI



Distribution of Hard LMXBs detected by INTEGRAL/IBIS above 20 keV

- **The sensitivity of the Laue lens is 2 orders of magnitude better than the observed line intensity and the angular resolution is critical to understand the nature of the 511 keV emission**

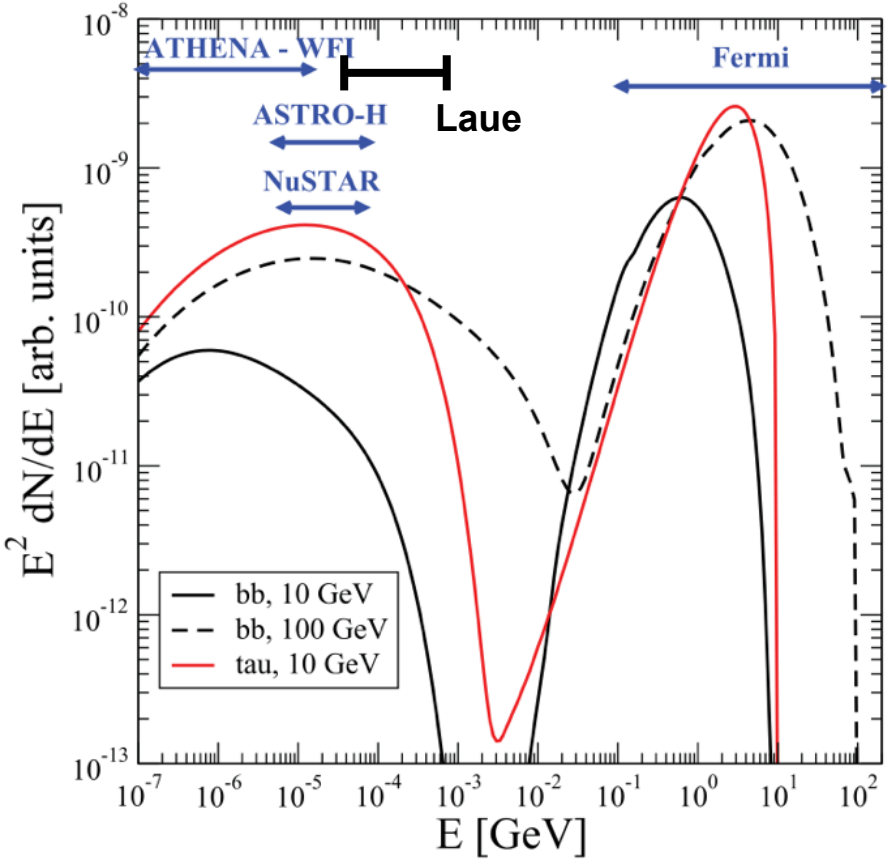
DM indirect detection in hard X-ray

Jeltema and Profumo (2008)

- IC peak at 1-100 keV expected from the upscattering of CMB photons by electrons and positrons ($e^{\pm}$) produced by weak-scale particle dark matter annihilation or decay.

$$\langle \nu \rangle \sim 1\text{–}100 \left(\frac{m_\chi}{10\ \mathrm{GeV}} \right)^2 \mathrm{keV}$$

- Best places to check: groups and clusters
- Interpretation depends on particle physics model (annihilation channels and final states)



Conclusions

- A new apparatus has been developed for building Laue lenses with long focal lengths (20 m)
- For the first time bent crystals have been developed and used for a lens petal
- An industrial study shows the feasibility of a lens made of petals
- The energy band beyond 70-100 keV, past the 511 keV line, can address many key-importance open issues
- The sensitivity and angular resolution provided by the Laue lens is critical to address these outstanding issues and yield a large discovery space
- The passband of Laue lenses can extended down to 30-40 keV with an outer radius of less than 2 m for 20 m FL, and 1.5 m for 15 m FL.
- Concrete prospect for proposing a broad band satellite mission based on Laue lenses plus a multilayer optics