Athena and Beyond: TES detectors for future X-ray missions

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Setting the stage

- Science drivers for a **Integral Field Spectrometer** in X-rays
- Driving Requirements and mapping into detector
- Scenarios for L2 stage
- Technological roadmap

Topical Science Drivers for X-ray IFS

- Formation and evolution of large scale structures
- First objects in the Universe
- Formation and evolution of metals in the Universe
- …

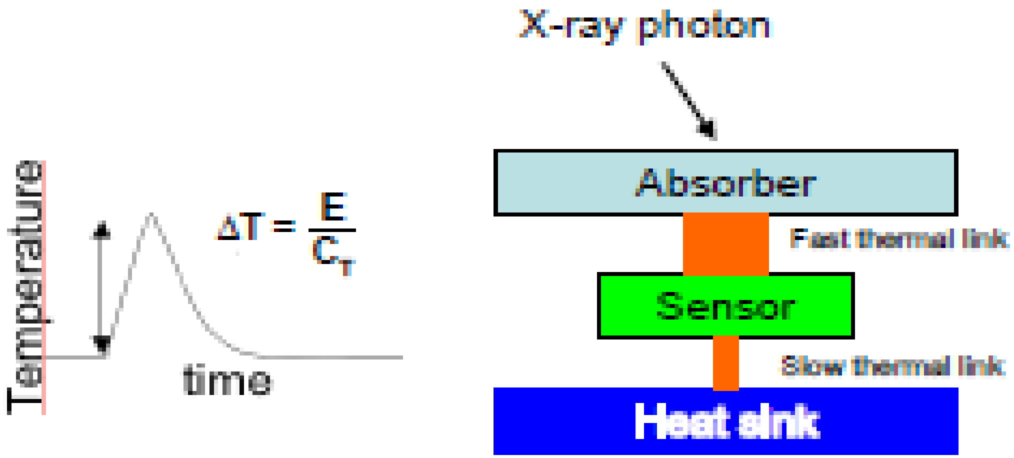
Requirements

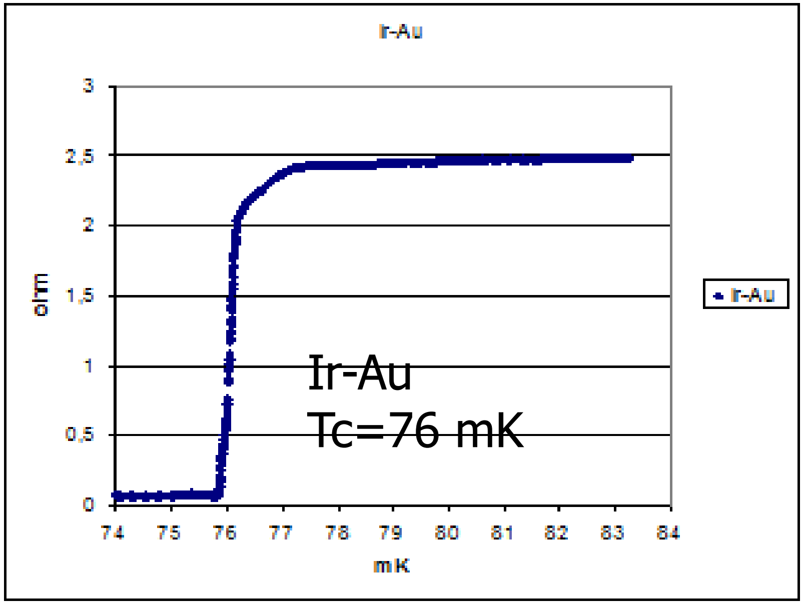
$$S/N \approx \sqrt{\frac{A \cdot T_{\exp}}{\Delta E \cdot B}}$$

- Main driver: energy resolution
- Faint/Diffuse sources: (WHIM, Proto-clusters, cluster outskirts): area, background, FOV
- Bright sources/ diffuse(Cluster cores, SNR,.): area, FOV, angular resolution
- Bright sources/ point like (Compact Gal and Extr., GRBs, stellar coronae): area, c/r capability, TOO mode (at mission level)

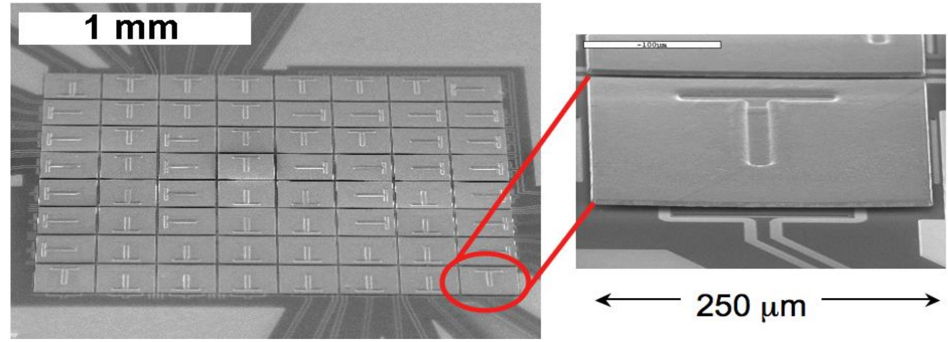
TES cryogenic microcalorimeters

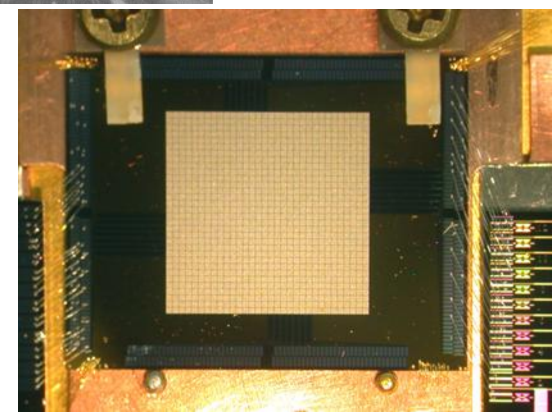
- eV resolution, kpixel imaging and high count rate: the first X-ray Integral Field Spectrometer
- International TES consortium: IAPS with SRON, GSFC/NASA, ISAS/JAXA founding members
- Consortium in Italy: IAPS + INFN-Genova, INAF: Oss & IASF Palermo, IASF/Bologna, IASF/Mi, IFN/CNR-Rome & Thales Alenia Milano

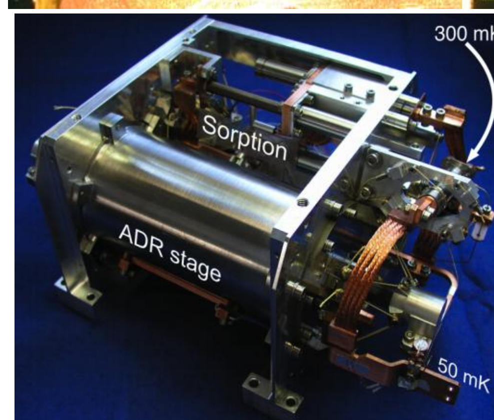




Instrument implementation





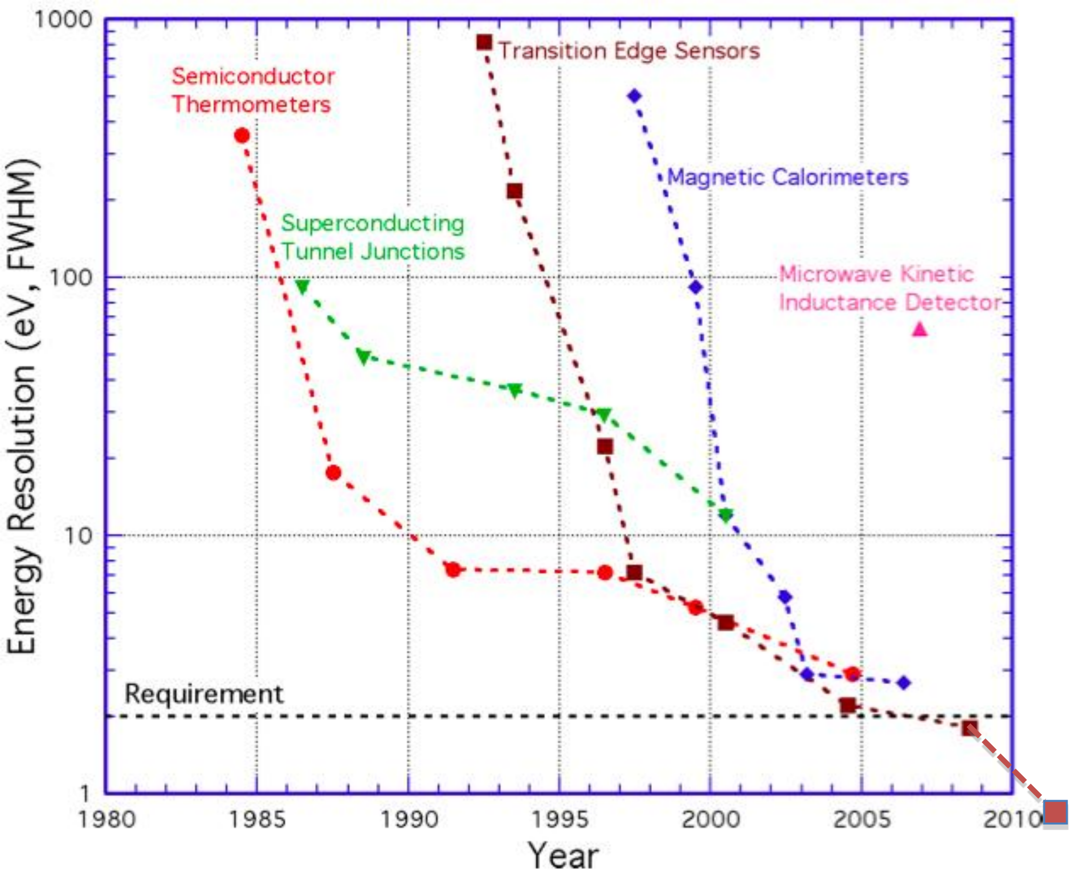


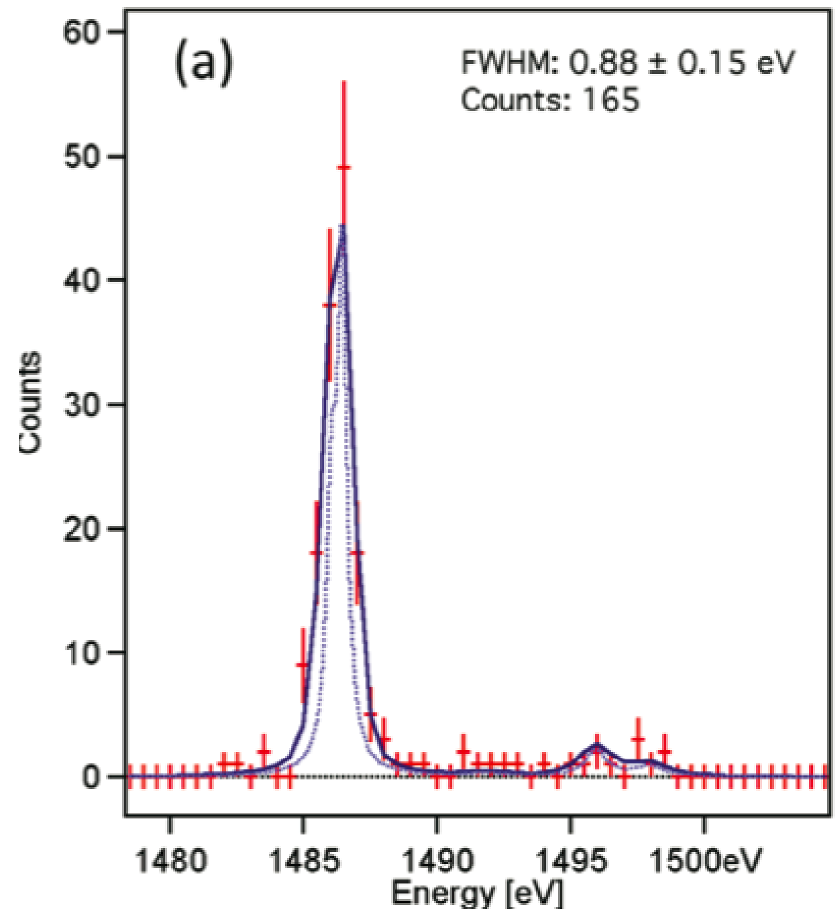
- Read-out: demonstrated performance on 2 x 8 array with $\Delta E < 3$ eV, potential for significantly better resolution;
- Detector with 32 x 32 array size build
- Cooling system various options: JAXA, European based on Herschel/Planck heritage + ADR
- ASTRO-H
- MICRO-X rocket: First TES-based instrument flight in 2014: 128 pixel array, 13’ FOV, PuppisA

Energy resolution

$$DE_{FWHM} = 2.35 z \sqrt{kT^2 C}$$

- Theoretical limit: 0.3 eV

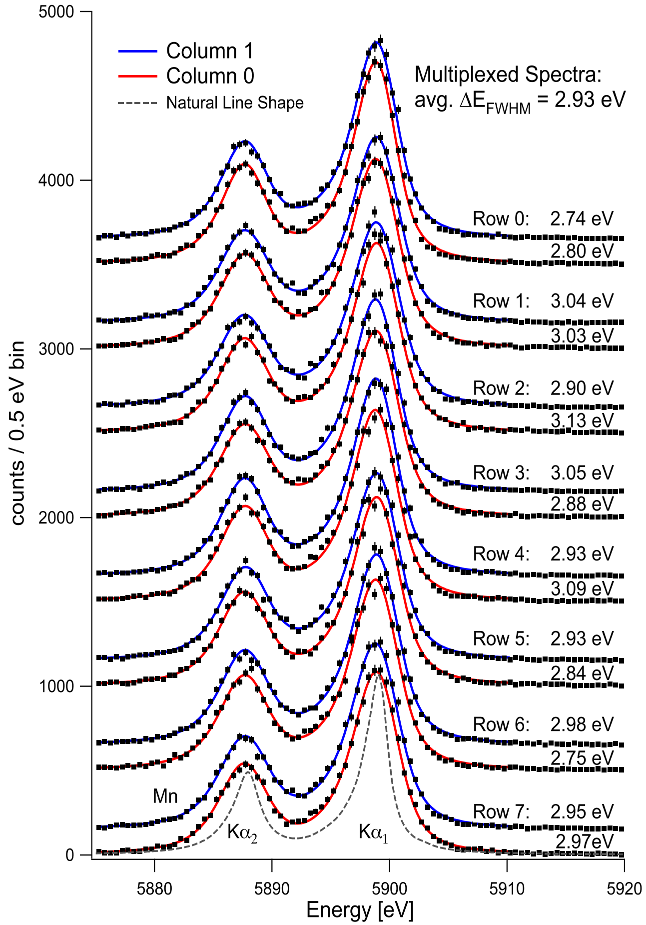




Bandler et al 2012

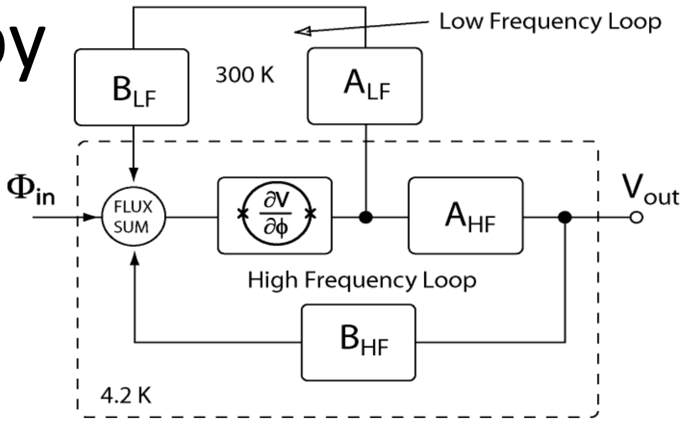
Arrays and Number of Pixels

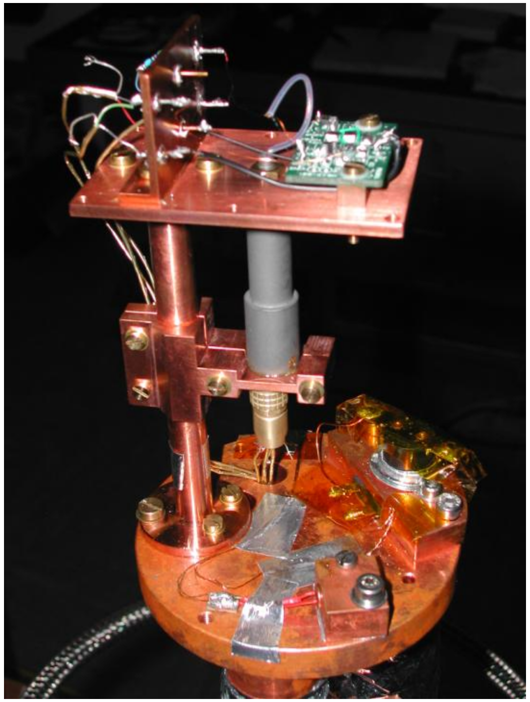
- Bottleneck is readout
- Multiplx is required (Frequency or Time domain)
- FDM: ~ 5 channels/MHz
- SQUID linearity requires feedback => bandwidth limitation due to cable delay
- Demodulation(baseband feedback: SRON, JAXA): 1-4 kpixel

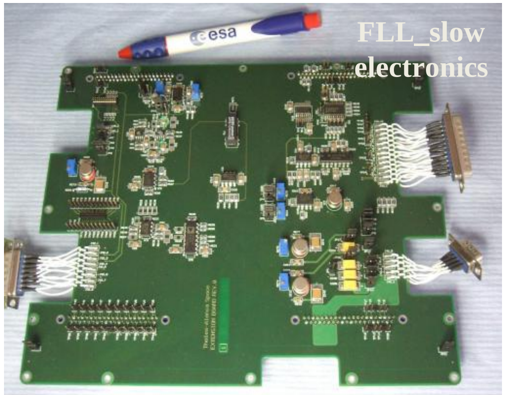


Double loop cryo feedback

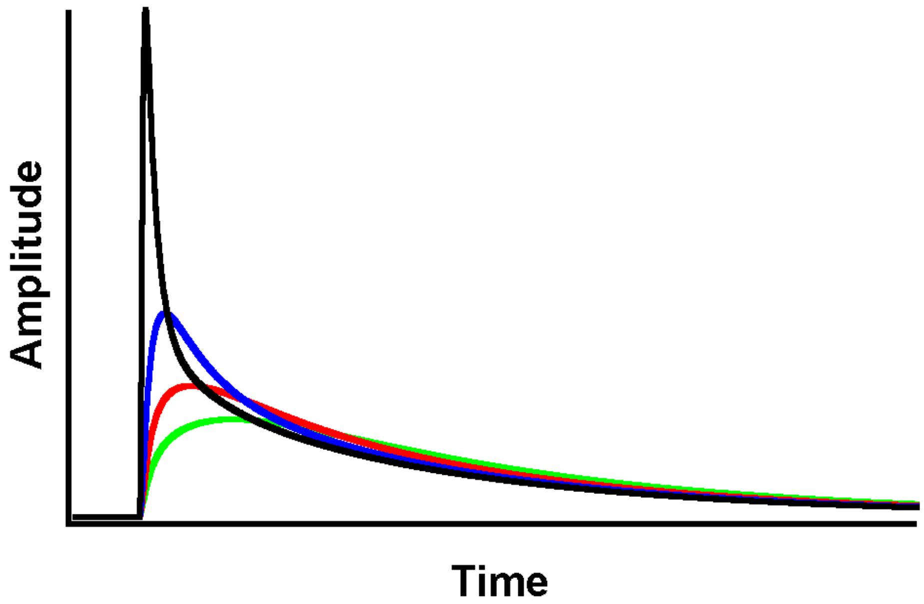
- Devised and under development by Italian consortium
- Short loop in cryo environment
- First prototype: badwidth (8MHz) consistent with kpix array
- **Potential bandwith: 200 MHz**
- **Megapixel array**

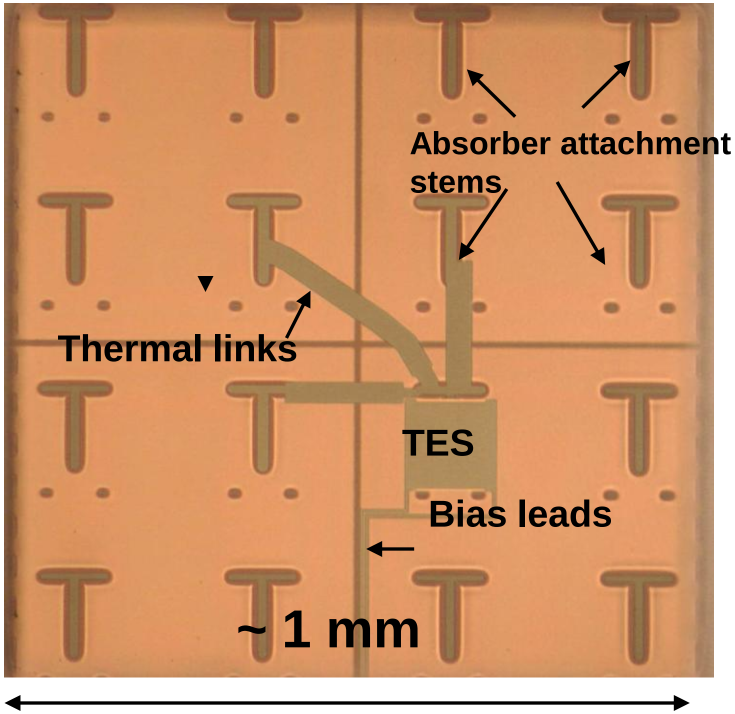






Hydra Pixels

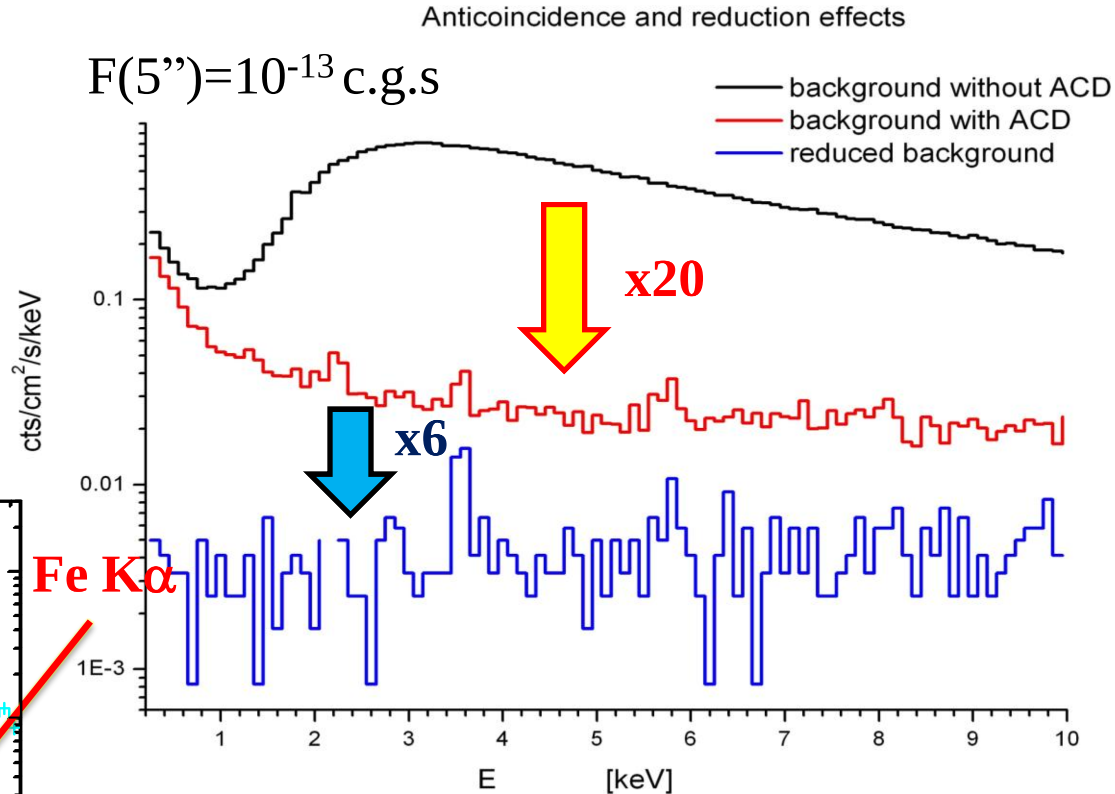


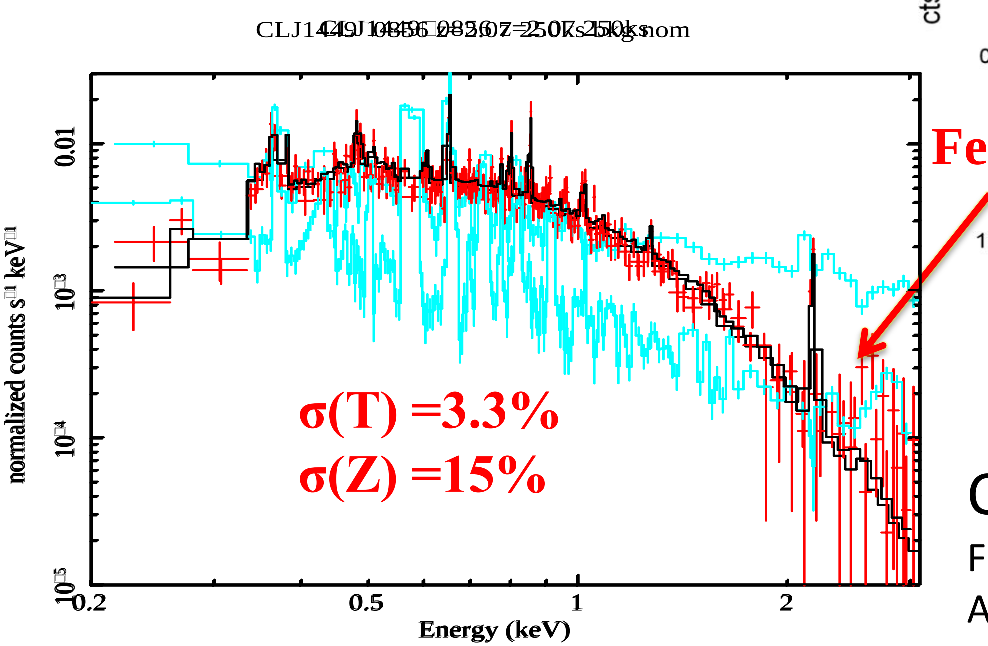


Kelley et al

Background reduction

- Extensive simulations/design and TES AC detector by Italian consortium



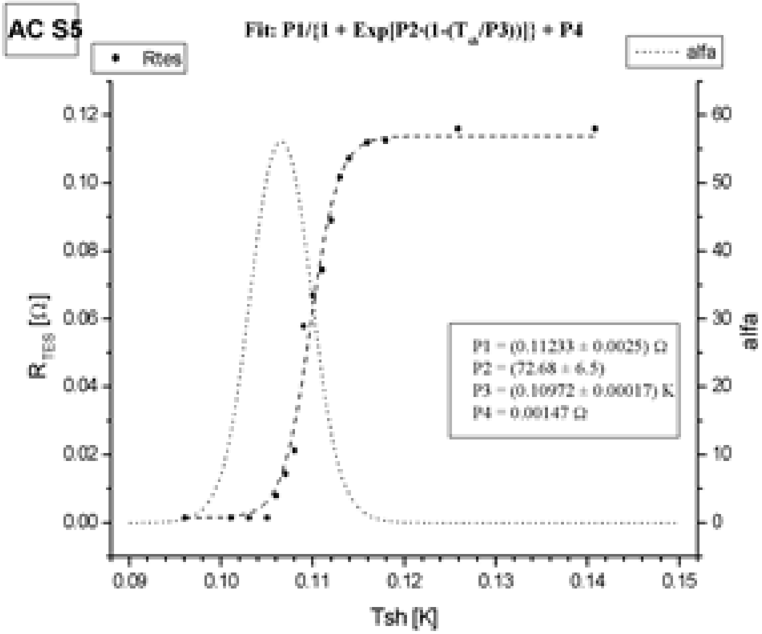


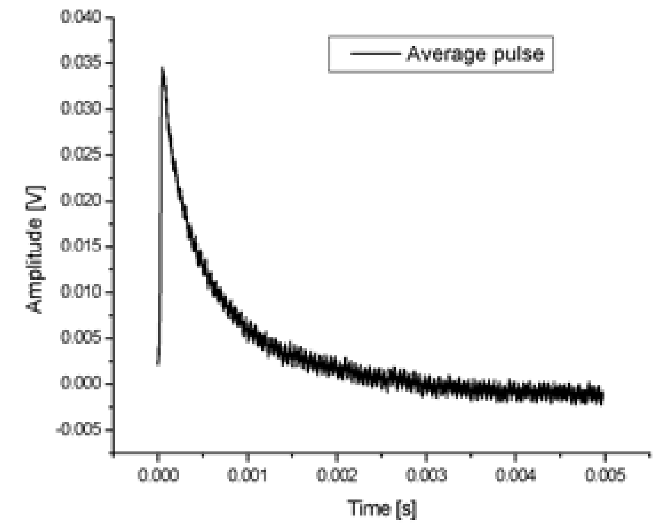
Cluster at the formation epoch (z=2)

F=10^{-15} erg/cm^2/s,
A=0.2 arcmin^2, kT=2.0 keV,
Abundance 0.3, area=1m2,f/l=12m

TES Antico

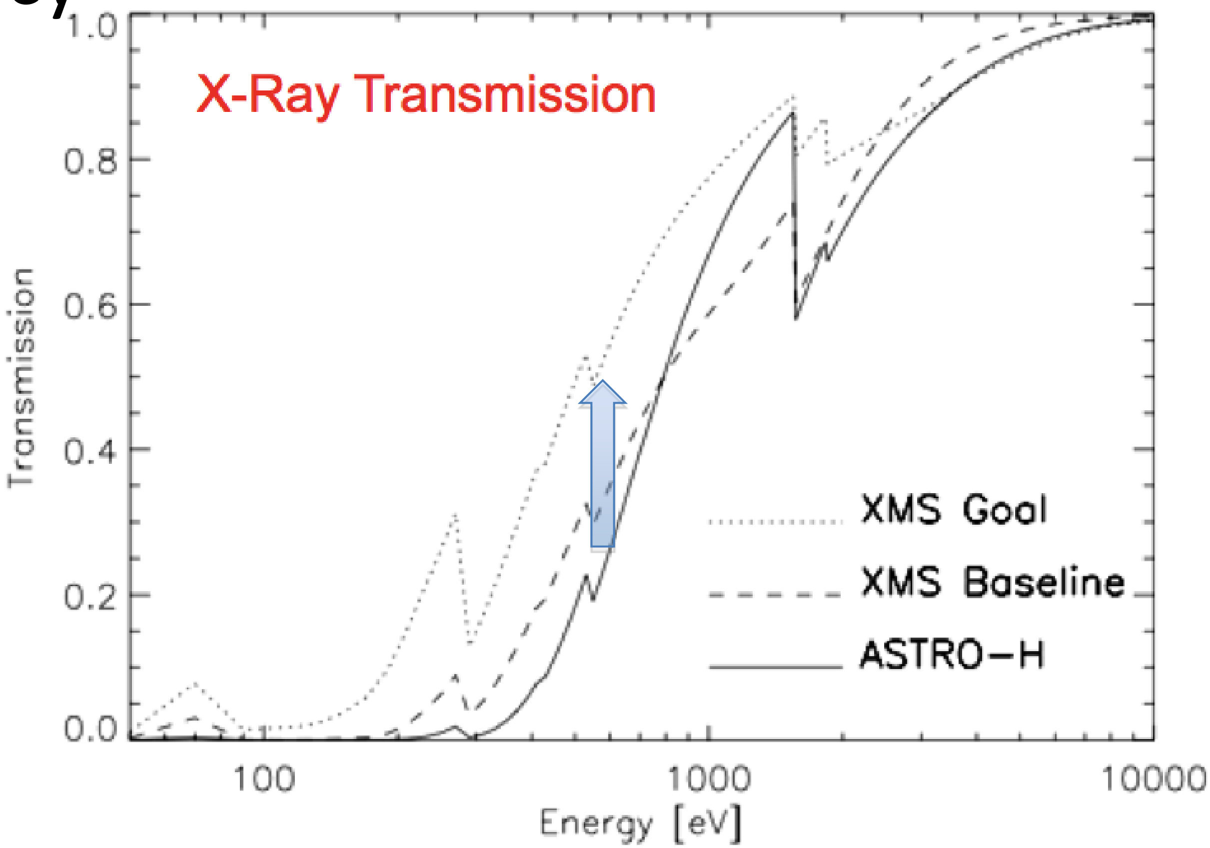
- Based on a large area (4x 0.25 cm2)TES-based detector pixels
- Main requirements: fast (rise time <30 usec) and low energy threshold 20 keV
- Fast response vs large (high C)pixel: a-thermal phonon: large collecting area
- Last (5th gen) prototype already close to req.s (for 1cm2 array)





Effective area

- Quantum efficiency already >90%
- Mirror area: cost limited
- Optical blocking filters

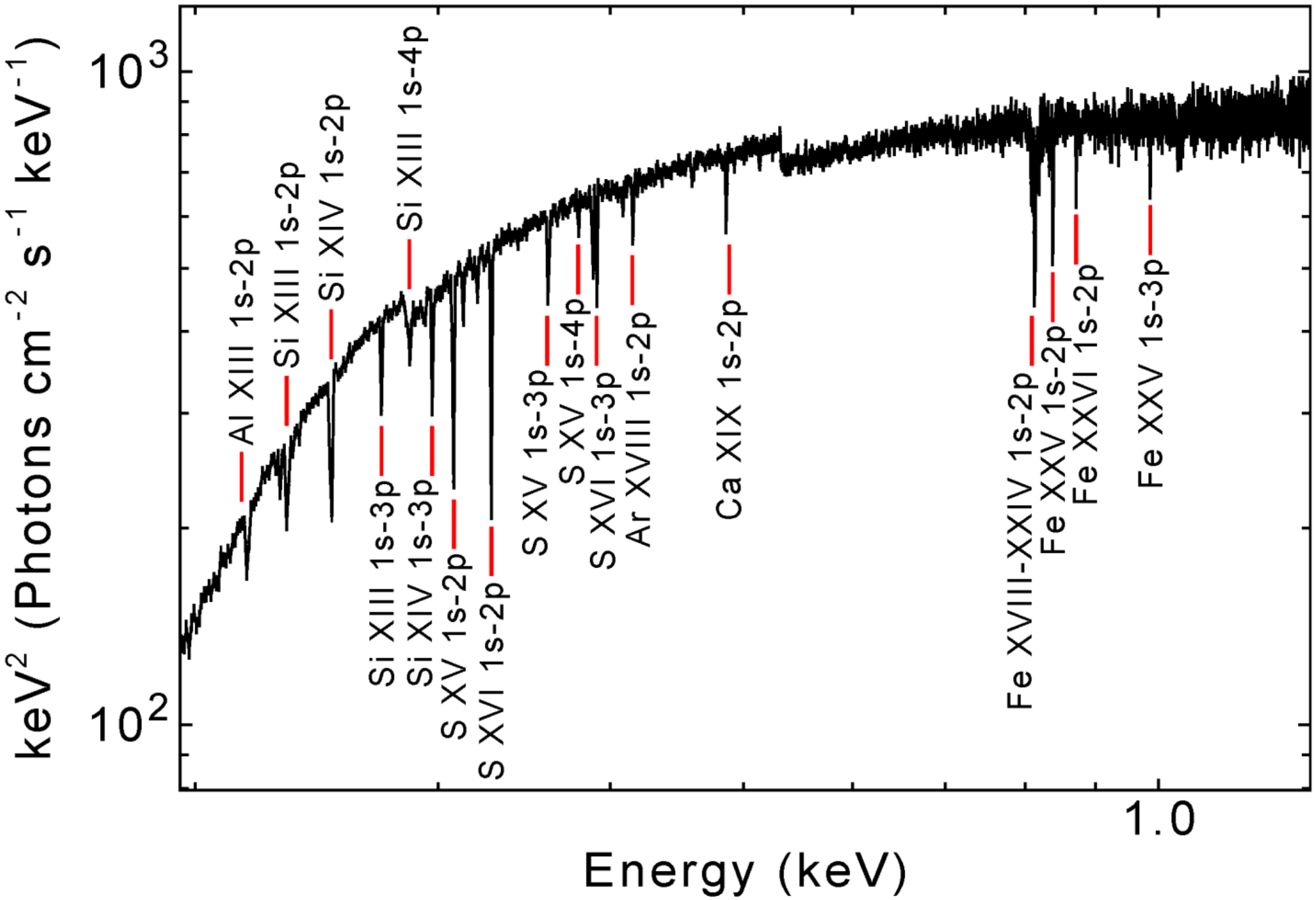


ASTRO-H	5 filters: Polyimide 4600 A + Al 4000 A total, Si mesh on two filters
XMS-Baseline	5 filters: Polyimide 2800 Å + Al 2100 Å total, mesh 93% on the two outer filters
XMS-Goal	5 filters: Polyimide 2250 Å + Al 1000 Å total, mesh 97% on the two outer filters

Count rates and high and bright sources

- Upto 10 Kct/s with customized chip (~ Crab for ~ m^2 mirror)
- At System level, for a TOO reaction time of ~1 hour, High resolution spectroscopy of transients
- Already proved for an Athena-like envelope by TAS-Turin system study

High res. X-ray spectroscopy of high z GRB



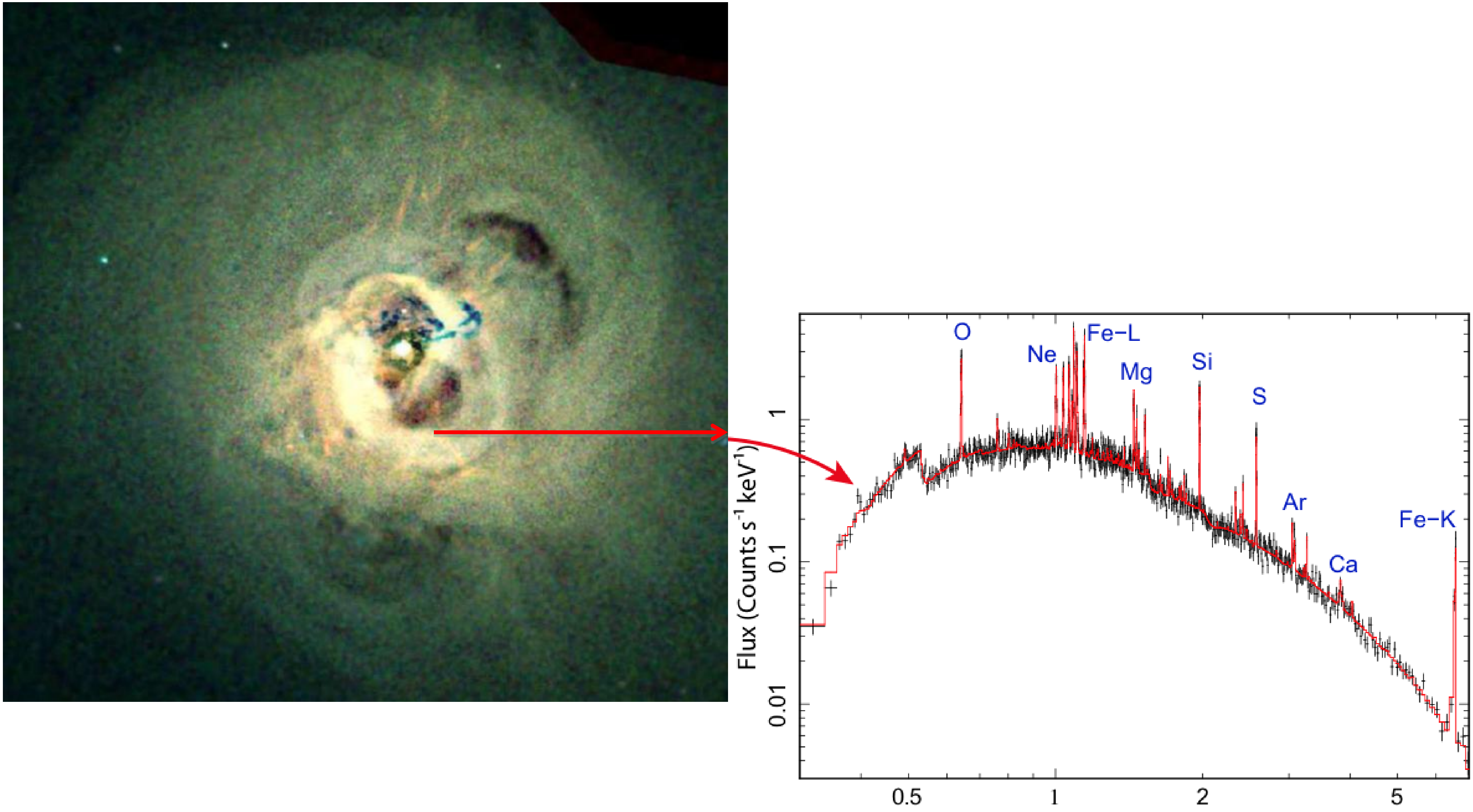
GRB afterglow at z=7

A Technological roadmap

- L mission launch date at X, TRL>5 at X-10 L2: 6-7 years of tech development
- A demonstrator model for end-to-end test with cryo-chain in the ESA tech programme
- Best realistic performances (but need trade-off and €):
- DE<1 eV (small pixels), 2-3 eV
- ~ 4 kpix array (e.g. 10’x10’ for 10”HEW or 5’x5’ for 5”)
- Lower background (<4x)
- High count rate (Crab)
- High throughput mirrors

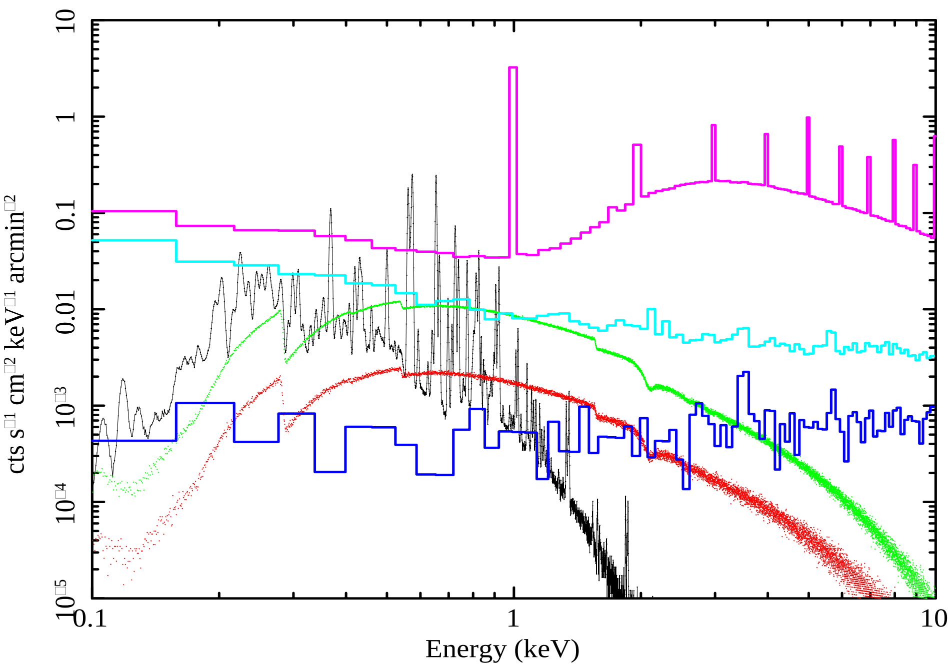
A Technological roadmap II

- Longer time scale (~2020)
- >100 kpixel array (FDM)
- Best candidate: TES (already DE<2eV)
- Non-bolometric detector (KID,MMC) in principle more easily tunable with large b/w FDM
- Effectively a "CCD with 1 eV resolution"
- E.g. for 2" a FOV of ~20'x20'
- Or.. An X-ray IFS with R=3000
- **Better than O-IR instrumentation**

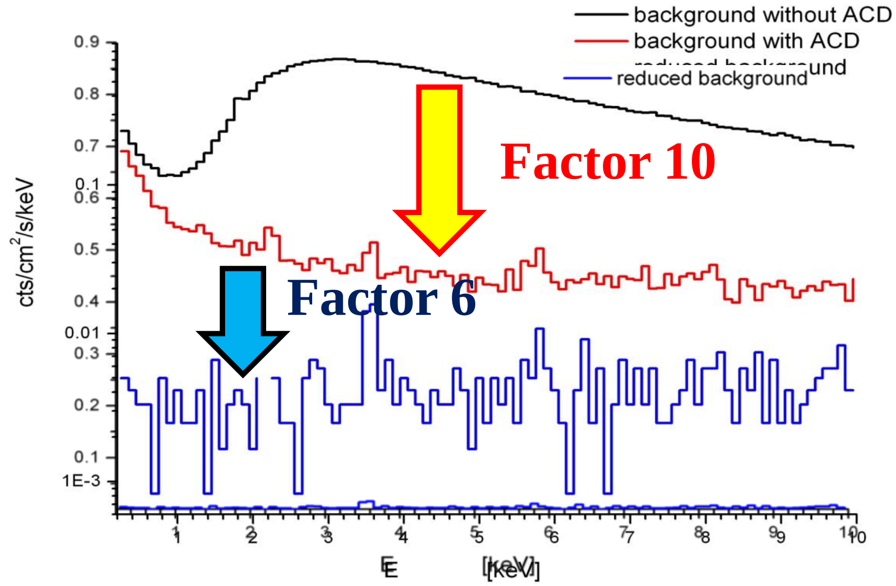

O
Ne
Fe−L
Mg
Si
S
Ar
Ca
Fe−K
Flux (Counts s^{-1} keV^{-1})
1
0.1
0.01
0.5
1
2
5

Background

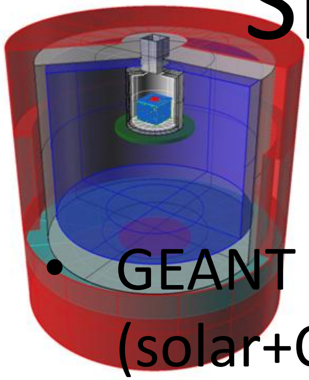
Background components A = 1m² f = 11.5 m



Anticoincidence and reduction effects



Simulations, antico and instrument design



- GEANT simul in L2 environment (solar+CR)
- Without antico bkg x25 larger than requirements.
- With present design + antico compatible with req.s
- Residual background is dominated by secondary e- produced close to detector
- Substantial reduction (x6) by kapton liner and thin filter