IACHEC

International Astronomical Consortium for High Energy Calibration

Scientific satellites cross-calibration: the *IACHEC* activity

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and

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Special thanks to: Matteo Guainazzi and Jukka Nevalainen

http://web.mit.edu/iachec

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Talk Overview

- IACHEC presentation
- Overview of flying High Energy Astronomy Observatories and Instruments
- Introduction to Spectral Analysis
- The approach of cross-calibration: standard candles
- Group structure and organization
- Main results and impact of cross-calibration on Astrophysics and… Cosmology
- Summary and Prospects

What is IACHEC?

- The IACHEC is the *International Astronomical Consortium for High-Energy Calibration*
- Founded in 2006 on impulse by Marcus Kirsch (ESA) and Steve Sembay (University of Leicester). Chaired by Matteo Guainazzi (ESA)
- It is a shared undertaking among high-energy calibrators to coordinate (and therefore strengthen) our work
- It acts as a forum where astronomers involved in calibration of past, present (operational) and future missions work together to improve the cross-calibration among their instruments
  - Past missions: ASCA, BeppoSAX, ROSAT, RXTE
  - Operational missions: Chandra, Fermi, Integral, MAXI, Suzaku, Swift, XMM-Newton, NuSTAR
  - Future missions: Astro-H, eRosita, HXMT, Athena+, LOFT
- Not directly funded by any Agencies or institutions. Individual projects/missions contribute through the work and mission budget of their calibration teams
- Strongly endorsed by *XMM-Newton* and *Chandra* User's Group

The IACHEC Team

2006
Nesbud, Iceland

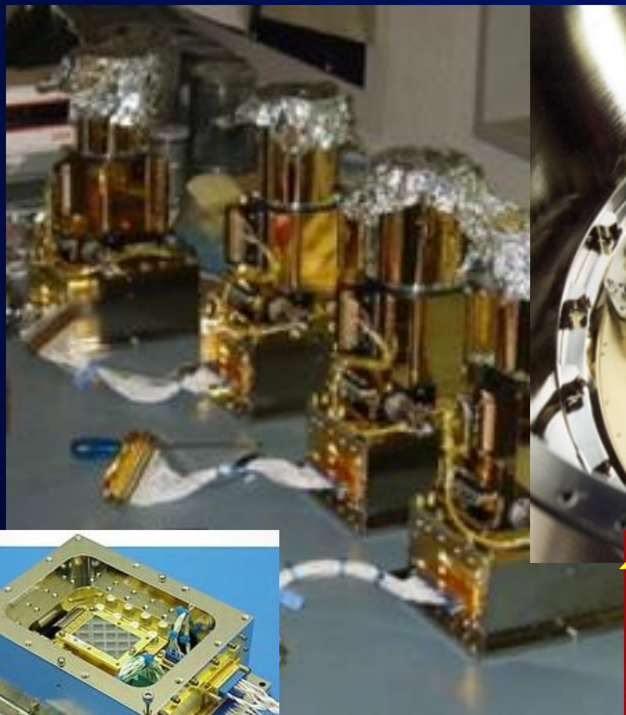
2013
Leicestershire, UK

Instrumentation on flying satellites

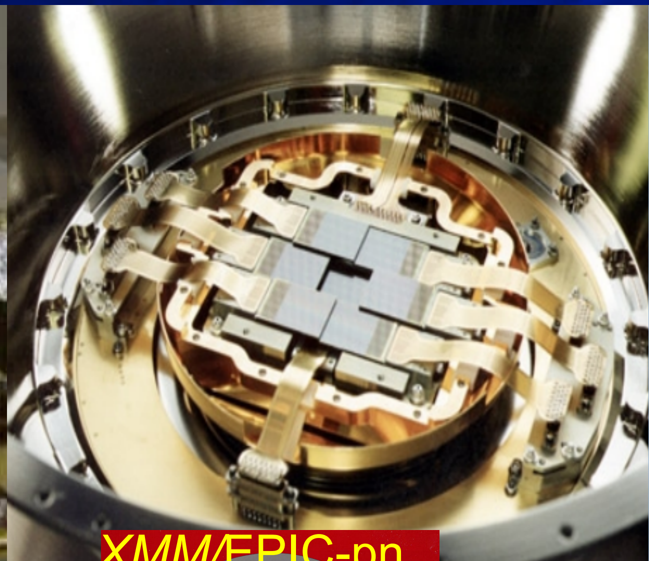
- CCD based detectors (~0.1-10 keV): *XMM-Newton, Chandra, Suzaku, Swift*
- Diffraction Grating Spectrometers (~0.2-2 keV): *XMM-Newton, Chandra*
- Gas filled detectors (~3-30 keV): *MAXI, INTEGRAL*
- Scintillators (~8-40 MeV) & Pair Conversion (>20 MeV) detectors: *Suzaku, Fermi, INTEGRAL*
- Hard X-ray/Soft γ-ray semiconductor detectors (~0.003 to 10 MeV): *INTEGRAL, Suzaku, Swift, NuSTAR*

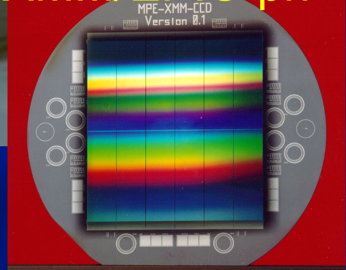
Calibrating…CCD detectors

- Cooled devices, moderate to good spectral resolution.
- Effects impacting on perfomance: contamination, pileup for high count rates, Charge Transfer Inefficiency (CTI)

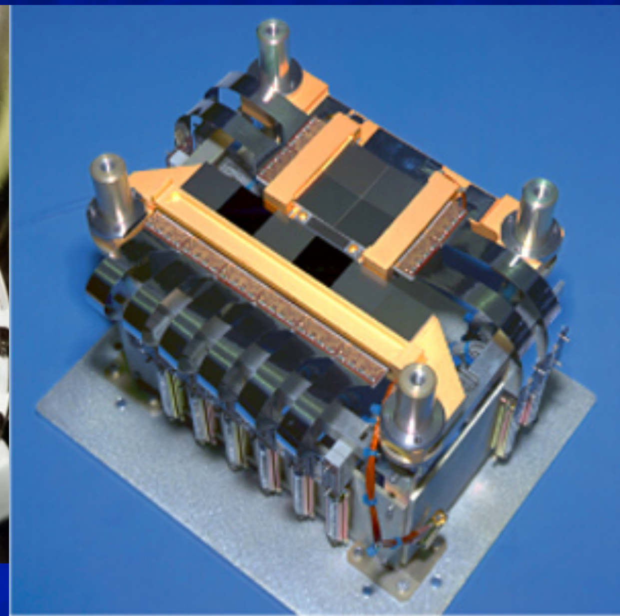


Suzaku/XIS





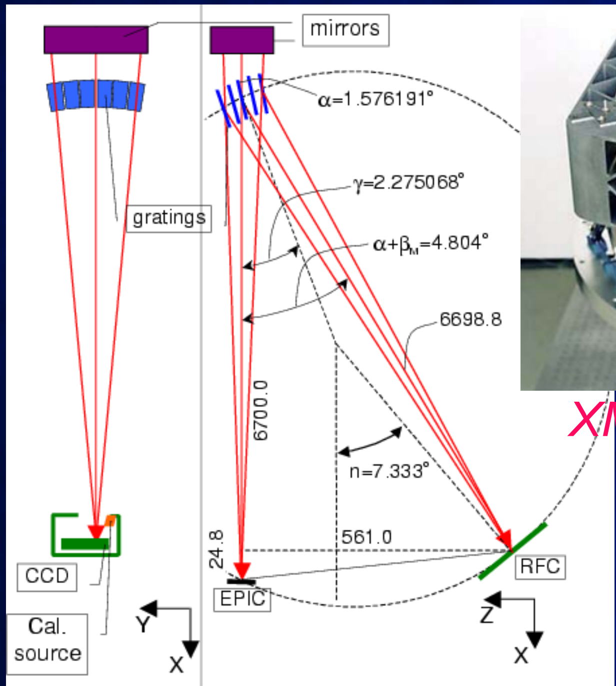
XMM/EPIC-pn

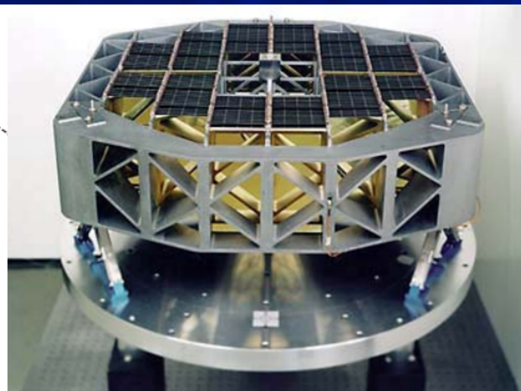


Chandra/ACIS focal plane assembly

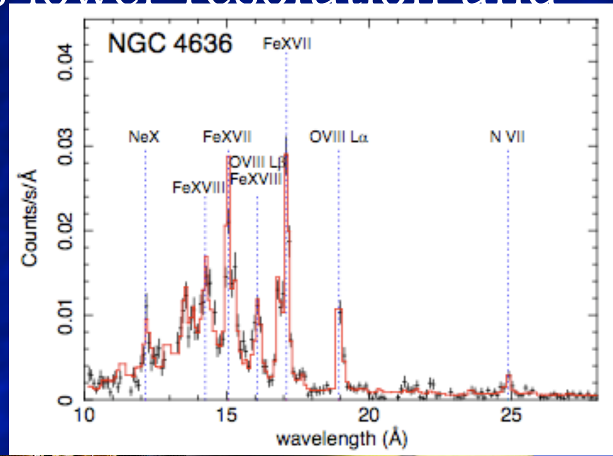
Calibrating…Diffraction grating spectrometers

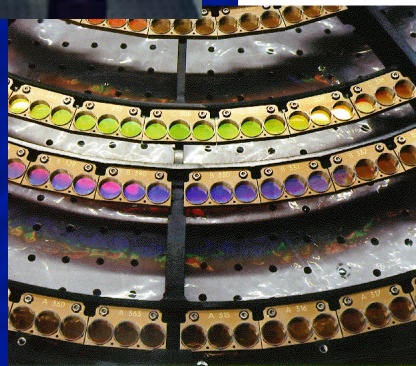
- Assemblies swinged into position behind the mirrors. Readout by CCD devices
- Compared to Chandra, XMM/RGS has lower resolution and much higher effective area

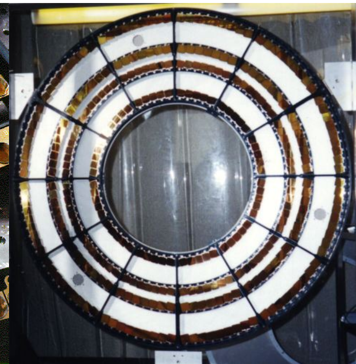




XMM/RGS





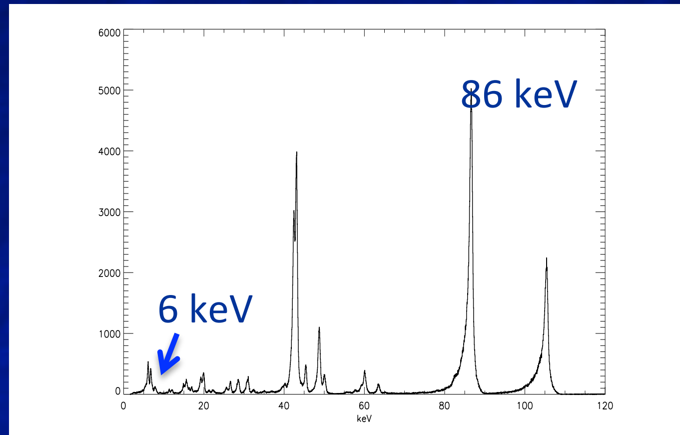


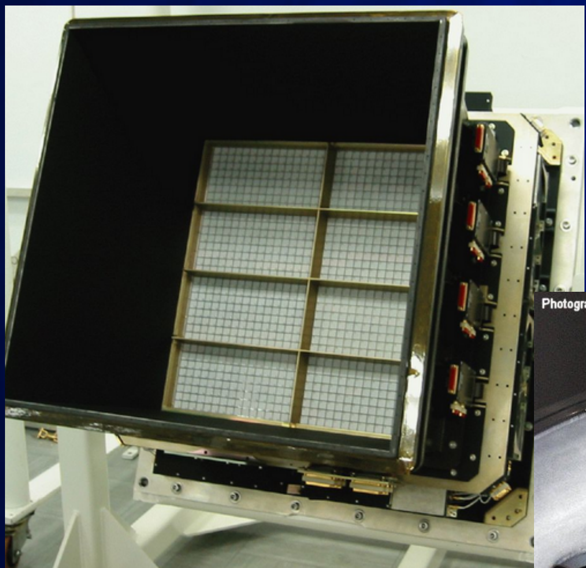
Chandra/LETGS HETGS

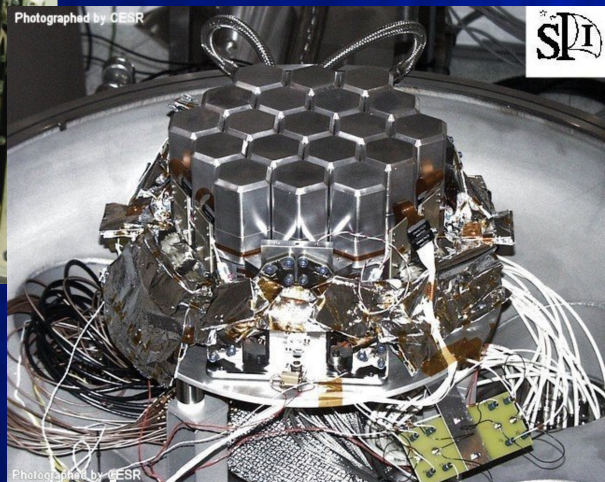
Calibrating…Hard X-ray/soft γ-ray spectrometers

- Room temperature devices: Silicon diodes (HXD-PIN), Cdte (IBIS-ISGRI) and CZT detectors (BAT, NuSTAR FPMs): radiation hard, suffer charge loss and/or charge splitting

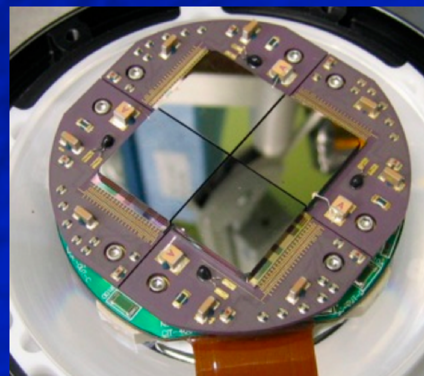
- Ge cooled detectors (SPI) provide high resolution spectra up to ~10 MeV





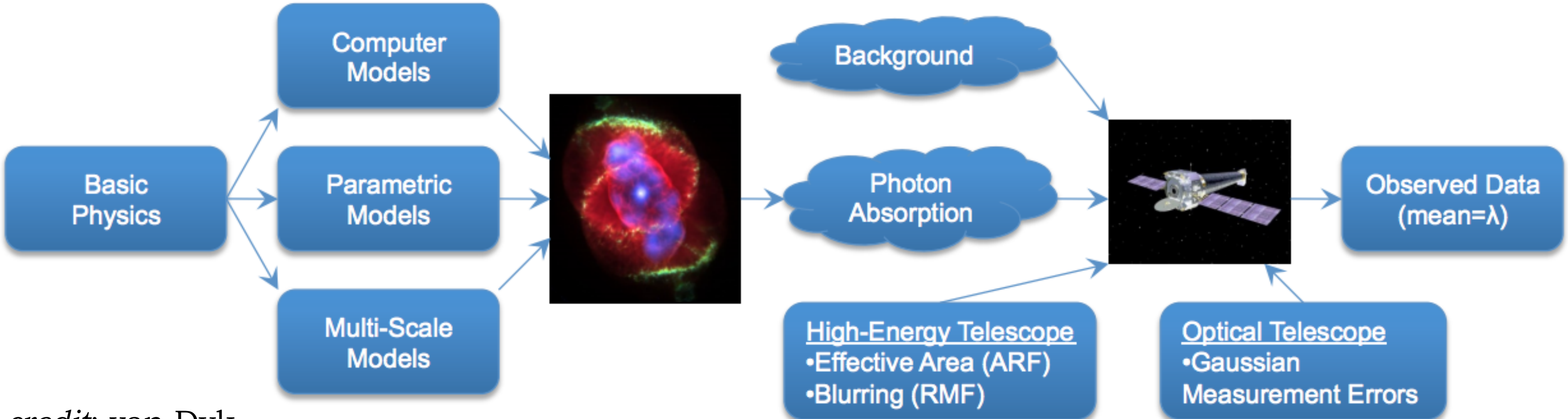


ISGRI (CdTe) and SPI (Ge) detectors, on board *INTEGRAL*



NuSTAR CZT Focal Plane Assembly

Spectral Analysis [1/4]



credit: van Dyk

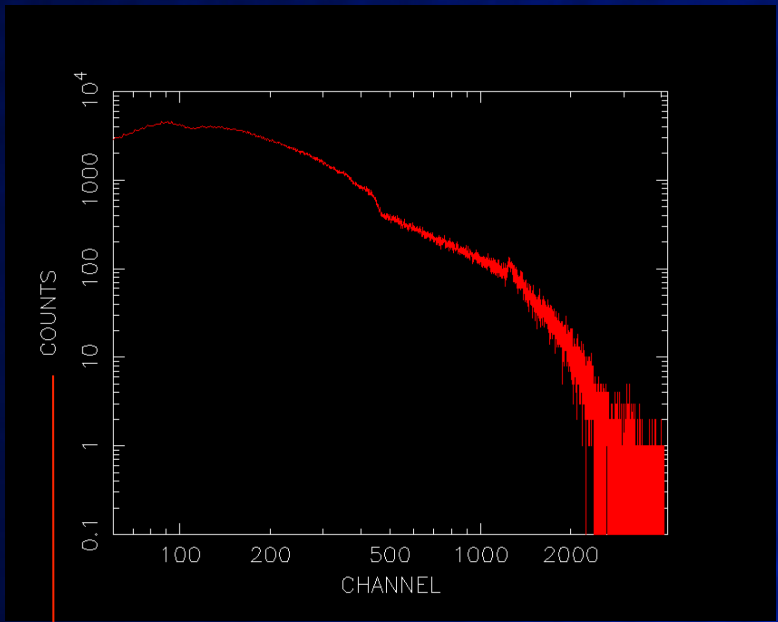
- In High Energy astronomy, the impact of effective area (ARF) and blurring (or redistribution, RMF) is very strong
- Need for decoding

$$C(h) = (N\tau)\int dE\, R(h,\, E)A(E)s(E)$$

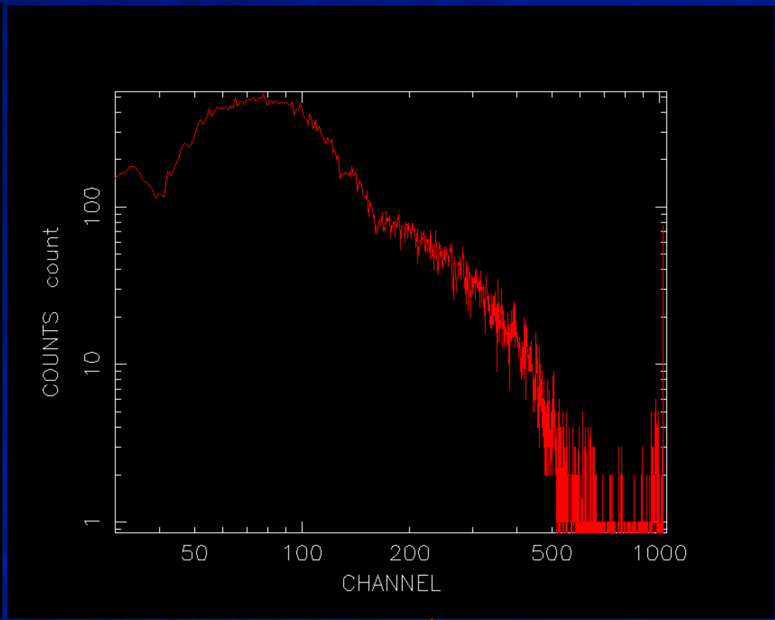
Spectral analysis [2/4]

- Use of spectral extractors to retrieve flux vs. energy information. Most popular tools: XSPEC, ISIS, SHERPA, SPEX
- Spectral extractors produce spectra in instrumental quantities

Ark120, EPIC-pn



Ark 120, *ASCA*/SIS



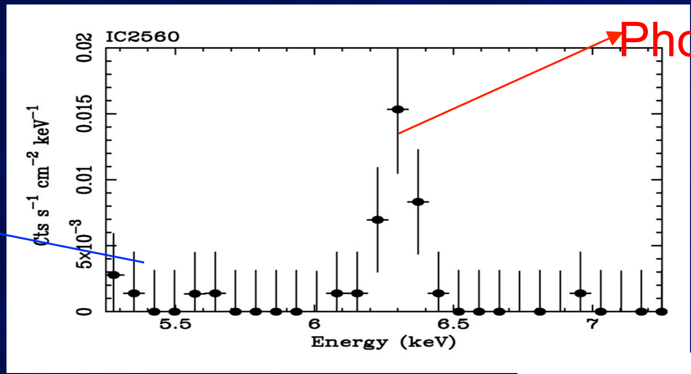
These are "COUNTS per bin", not flux!

These are "CHANNELs", not energy!

Spectral analysis [3/4]

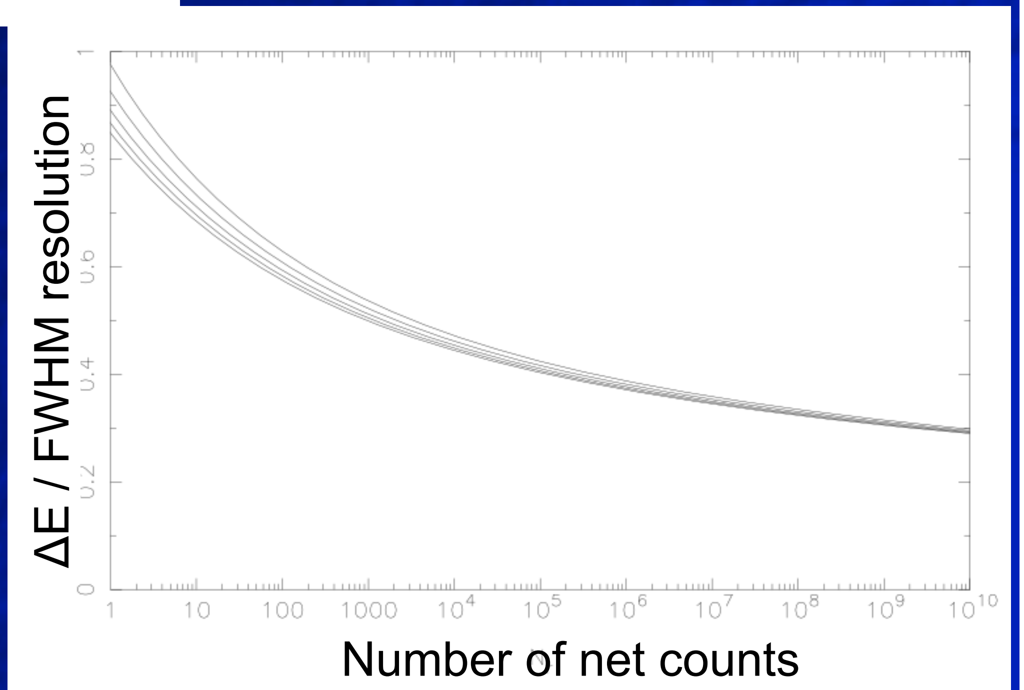
- Data binning against energy resolution. Avoid loss of scientific information

Photons in the continuum: 9



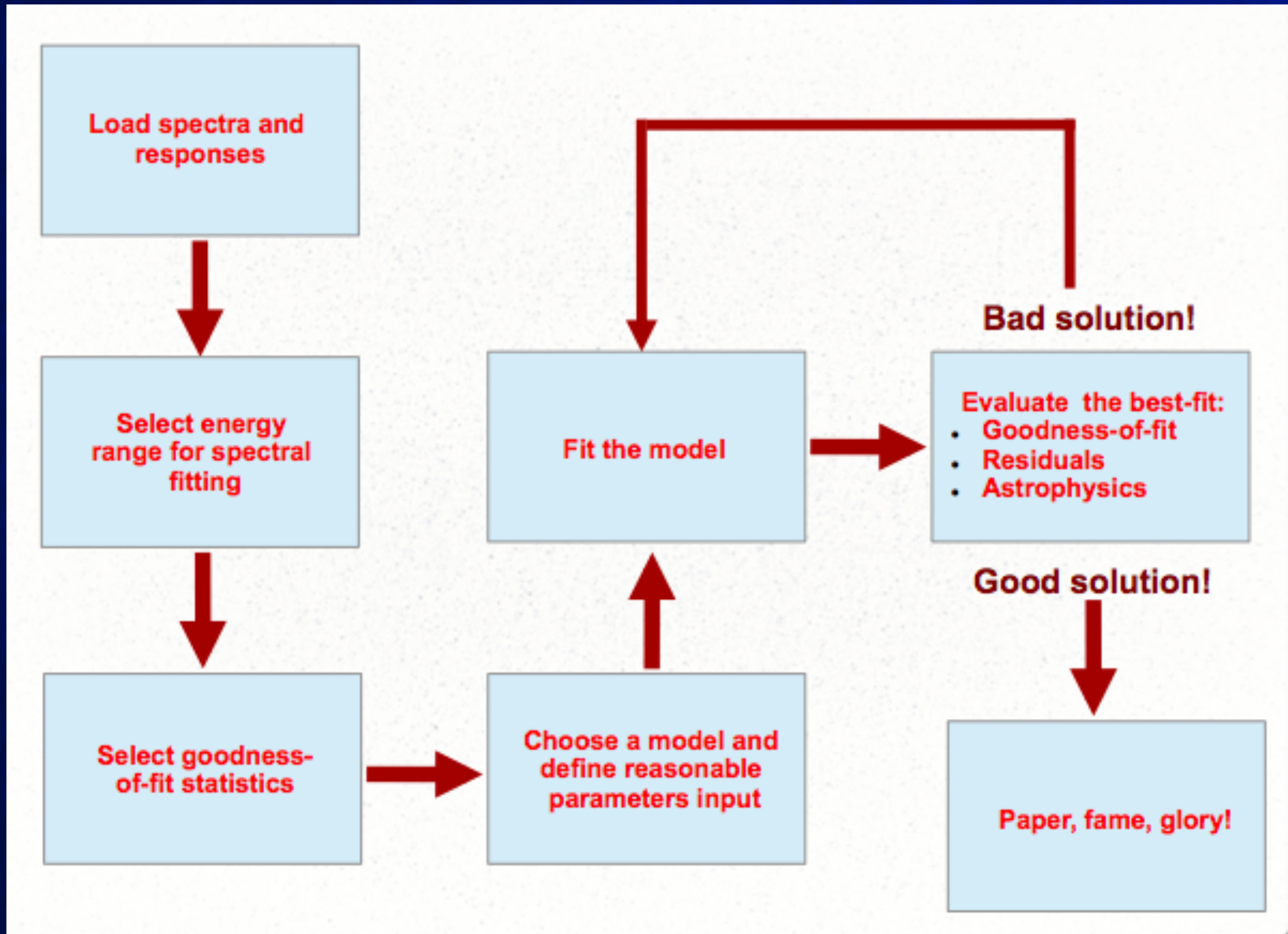
Photons in the line: 21

- Optimal binning can be evaluated by extension of the *Shannon theorem* to the energy domain
- Alternatively, un-binned data can be fitted using *Cash statistics*, if the counts distribution is Poissonian



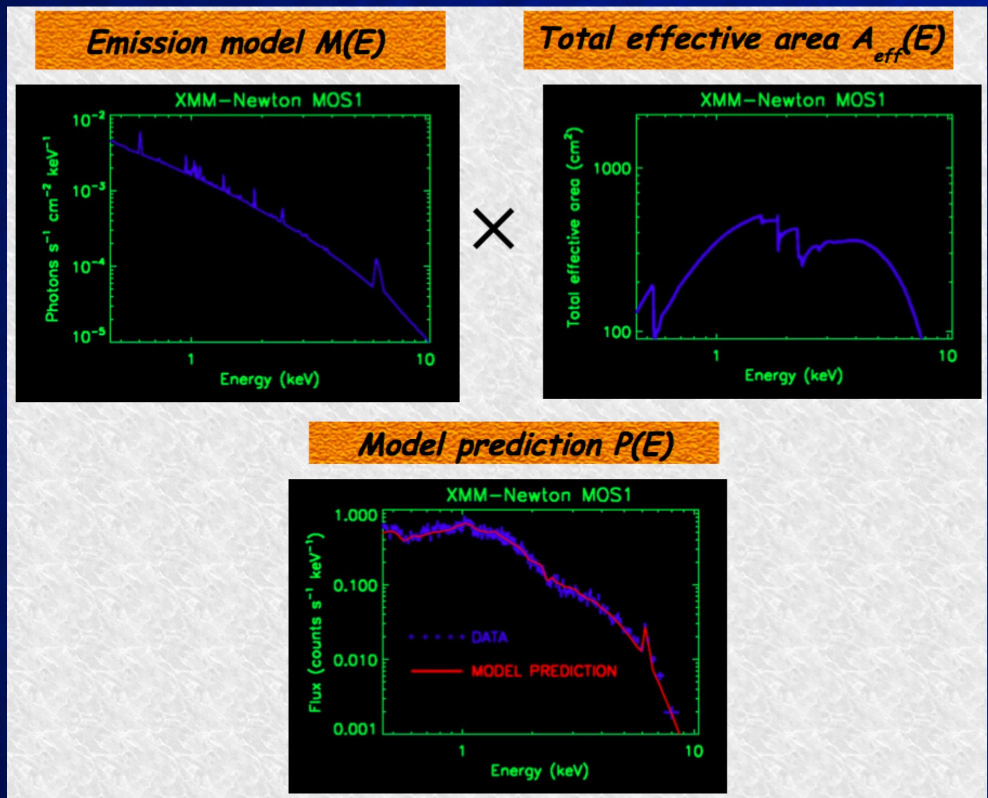
Spectral analysis [4/4]

- Final step. Decoding spectra: Iterative approach based on source and instrument models



In reality…

- If the instrument models (ARF,RMF) have significant systematic uncertainties, the model prediction will be not correct
- Combination of an uncorrect emission model and uncorrect instrument response can give rise to a good fit result
- Instrument models *always* contain systematic errors



How to build an instrument model?

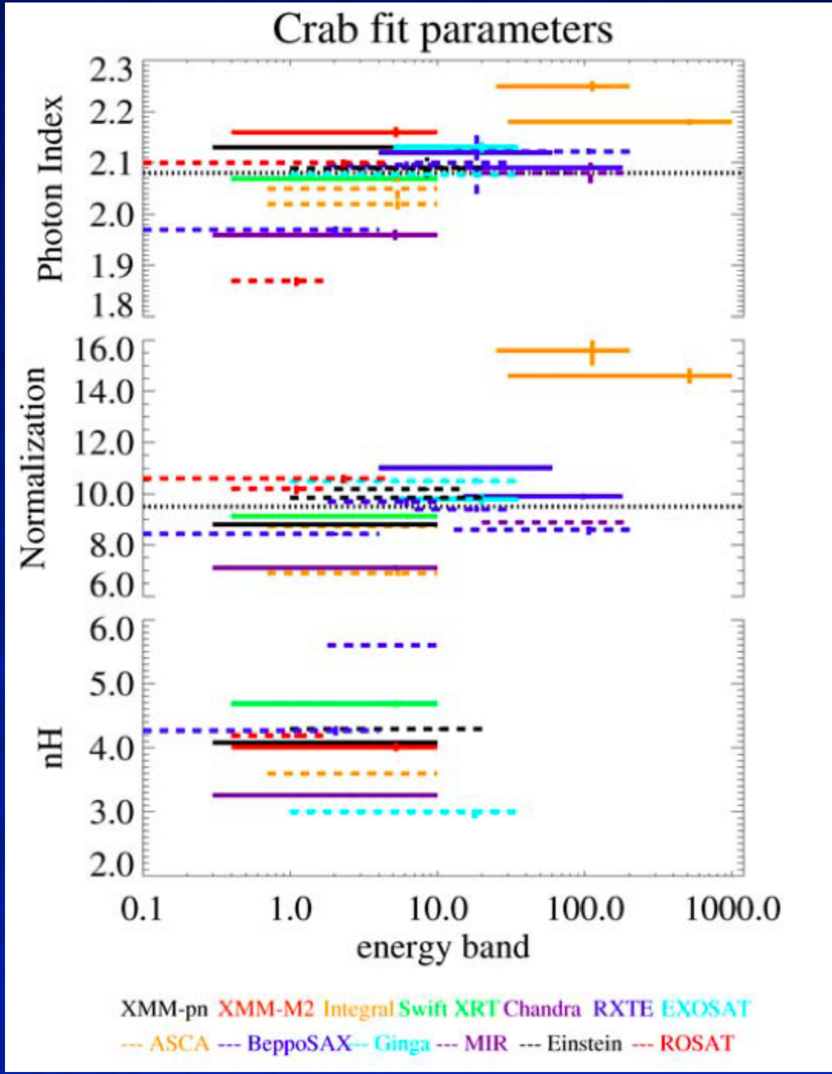
- Computation of instrument models is started during pre-flight calibrations. In operational phase, in-flight corrections and new response files are computed.
- Most approaches use astronomical sources known as *standard candles* (SC)
- SC are a natural tool for on-orbit instrument calibration and are suitable for *cross-calibration* among instruments
- SC are typically sources of continuum and line fluxes in a broad band, or provide thermal soft X-ray spectra. They must have *non-variable* spectra and fluxes.
- They are (*can be?*) often described by a "reference" physical model In high energy astronomy, the choice of a standard candle is mostly driven by the wavelenght band, the energy resolution of the instrument, and the source size as compared to the angular resolution
- In the X-ray band, standard candles cannot rely on a solid knowledge of intrinsic source spectra

The historical Standard Candle: the Crab

- For observations before 2005, a reference summary is in the M. Kirsch paper:

ENERGY RANGE IN KEV	N_H(H)	Γ	N
0.2-2	4.07	2.02	8.95
2-10	4.5 (f)	2.07	8.26
10-50	4.5 (f)	2.12	9.42
50-1000	4.5 (f)	2.17	10.74
0.1-1000	4.5	2.08	8.97

- Results seem largely inconsistent among different instruments, but this is partly due by the use of a single power law to fit different ranges

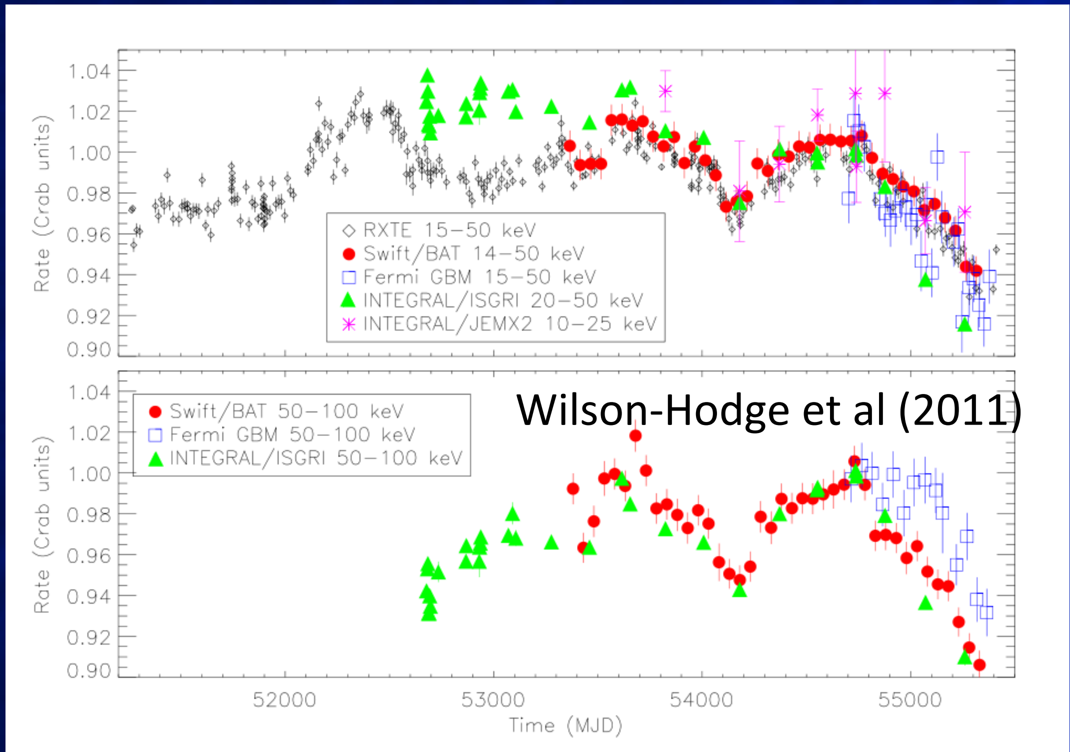


(Kirsch et al, SPIE 2005)

Standard Candles and IACHEC

- Within the IACHEC, a number of activities is focused on standard candles. The following ones are into focus:
- White Dwarfs: HZ43, Sirius B, GD153
- Clusters of galaxies (comparison of temperature and fluxes): HIFLUGCS sample
- Isolated NS: RX J1856
- thermal Supernova Remnants: Cas-A, N132D, 1E0102 (strong X-ray lines)
- non-thermal SNRs: G21.5-0.9, Crab (flux & energy dep. of effective area)
- A standard candle is not necessarily a perfectly constant source: if not, it should be regularly monitored

Standard Candles and IACHEC

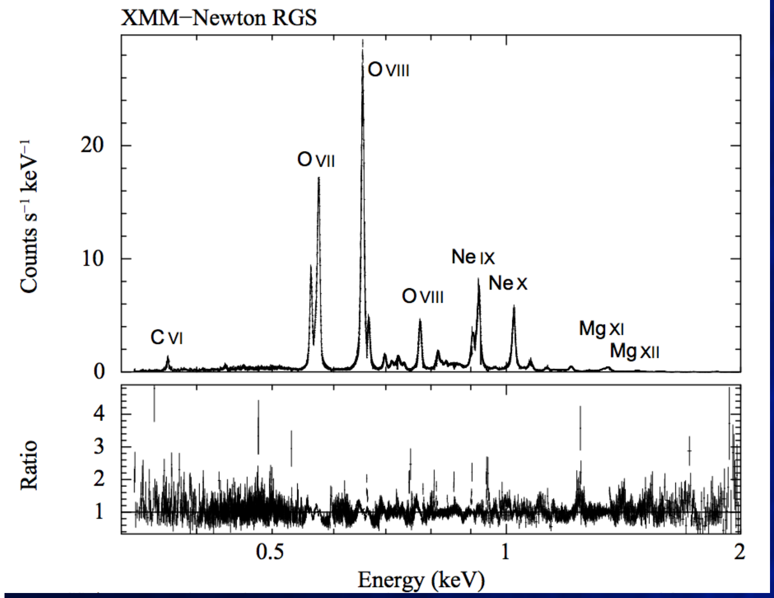


Working Group activities

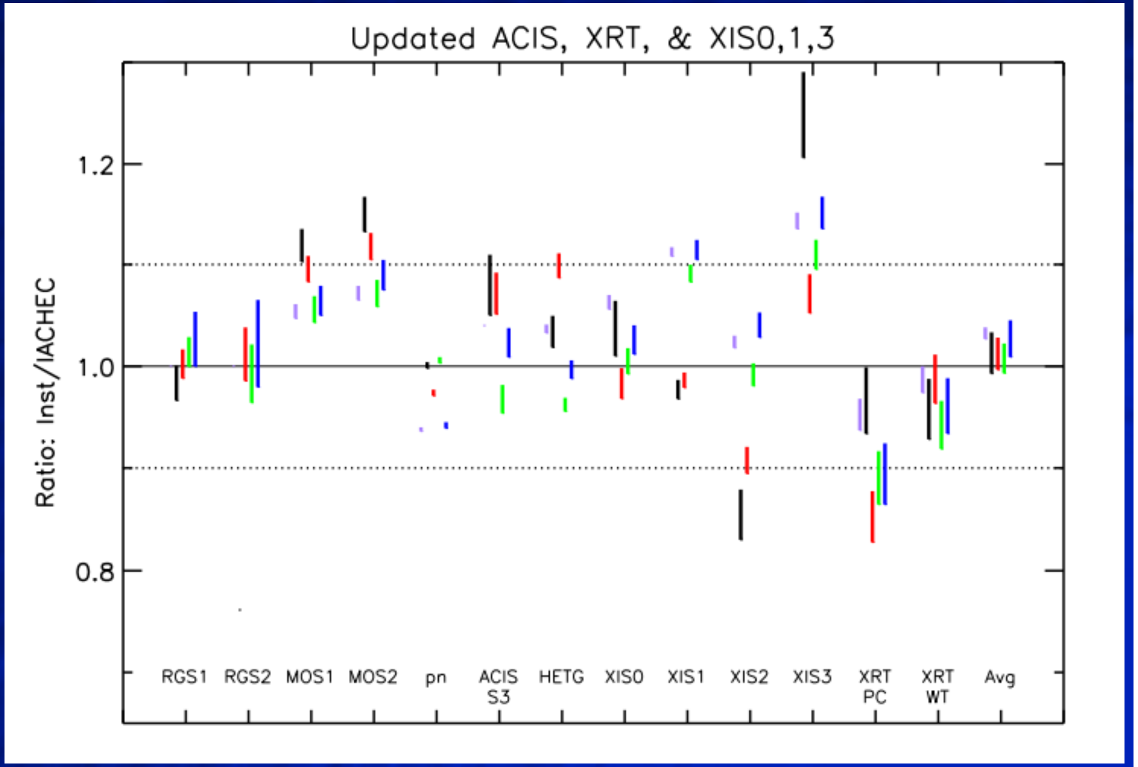
- **CCD issues** (*Chair:* *Catherine Grant*). It aims to provide a forum for cross-mission discussion and comparison of CCD-specific modeling and calibration issues, lessons learned, and best practices.
- **Clusters** (*Chair:* *Jukka Nevalainen*). It aims at a systematic comparison of cluster temperatures measured by Chandra and XMM-Newton, with a possible extension of this comparison to Suzaku in the nearby future.
- **Effective area** (*Chairs:* *Manabu Ishida* and *Hermann Marshall*). It aims at the analysis of the Chandra, Suzaku and XMM-Newton cross-calibration campaign data on PKS2155-304 collected so far.
- **High Resolution** (*Chair:* *Andy Pollock*). It aims at a complete census of emission lines in the RGS and LETG spectrum of Capella.
- **Isolated Neutron Stars** (*Chair:* *Frank Haberl*). It aims at the cross-calibration analysis of the RXJ1854.5-3754 spectra
- **Non-Thermal SNR** (*Chairs:* *Lorenzo Natalucci* and *Masahiro Tsujimoto*). It aims at the cross-calibration analysis of G21.5-0.9 (mainly below 10 keV) and of the Crab (mainly above 10 keV) spectra.
- **Thermal SNR** (*Chair:* *Paul Plucinsky*): analysis of 1E0102.2-7219
- **White Dwarfs** (*Chair:* *Vadim Burwitz*). It aims at comparing atmospheric models in conjunction with analysis of high-resolution data.

Defining astrophysical models for Standard Candles

- Cross-calibrating *Chandra*/ACIS, *XMM-Newton*/EPIC, *Suzaku*/XIS and *Swift*/XRT using 1E0102.2-7219 (the brightest SNR in the SMC)
- Model built by XMM-Newton/RGS spectrum



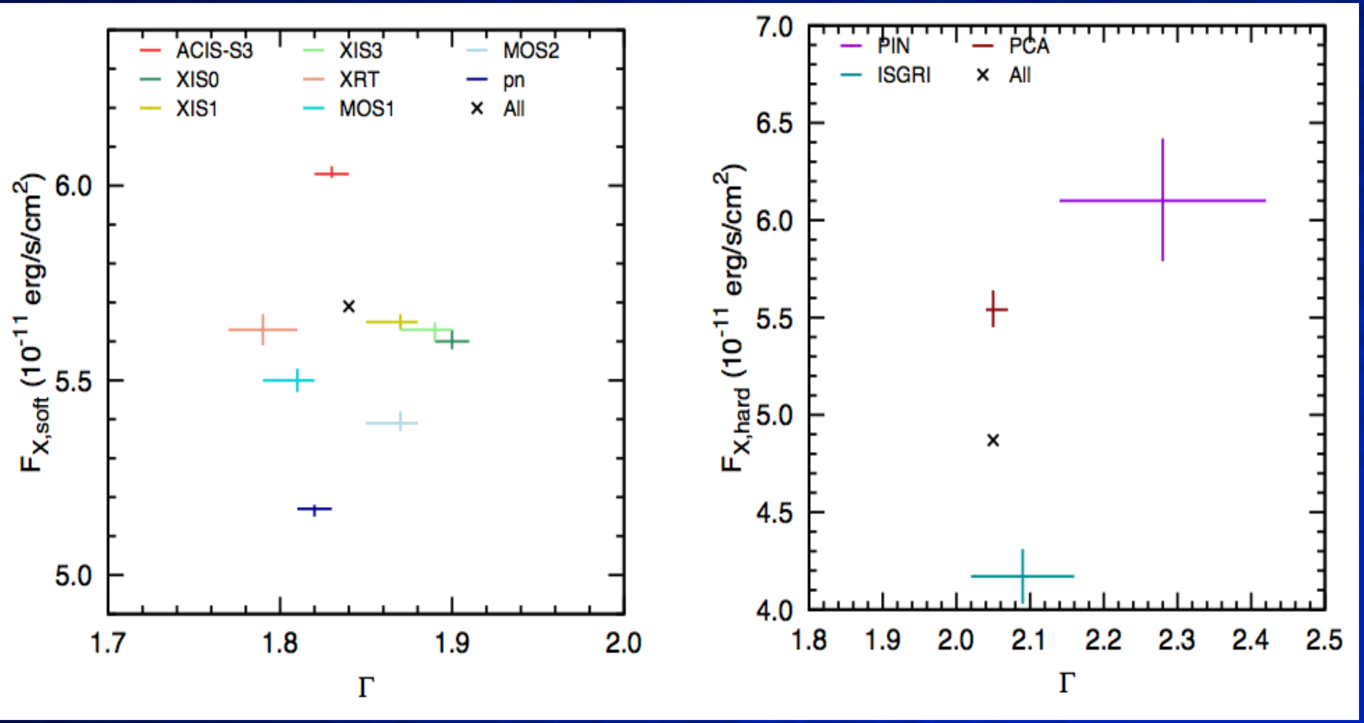
Defining astrophysical models for Standard Candles



Ratio of the OVII triplet, OVIII Lyα, NeIX triplet, and NeX Lyα line normalisations, as well as a global normalisation factor, when the IACHEC models is applied to the E0102 spectra of different missions (Plucinsky et al., SPIE 2012)

Cross calibration in the soft X-ray using G21.5-0.9

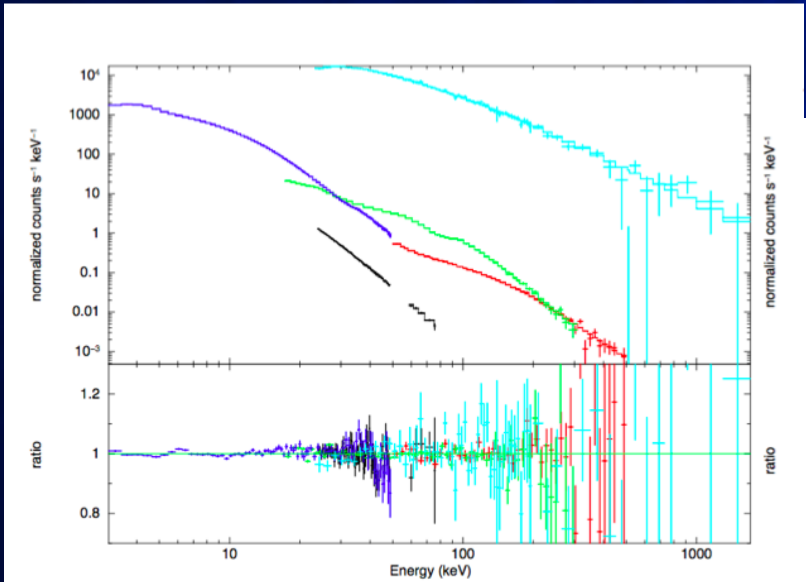
- The Crab Nebula is both too bright and extended to be an ideal calibration standard in the soft band.
- the Pulsar Wind Nebula in G21.5-0.9 is used to cross-calibrate both soft and hard band instruments.



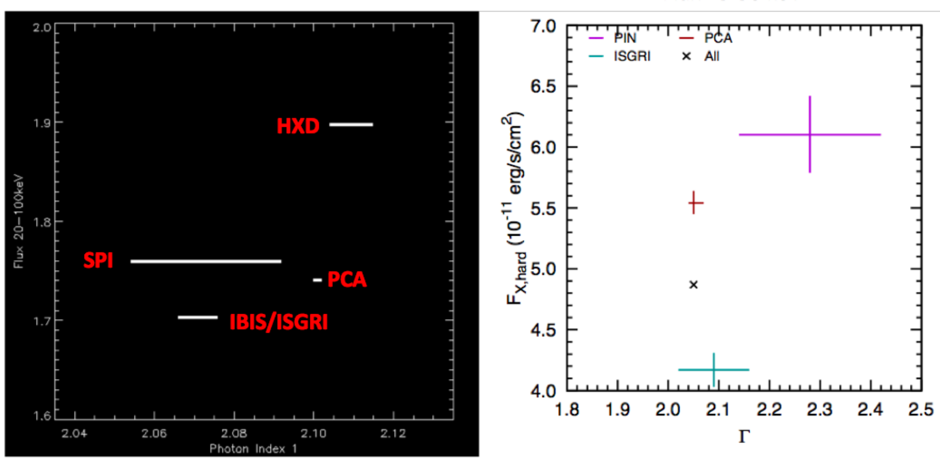
Scatter plot of PL fit parameters for *soft-band* and *hard-band* instruments.
(Tsujimoto et al., A&A 2010)

Hard X-ray cross-calibration

- Eploiting a dataset of nearly simultaneous observations (2005-2011) of the *Crab Nebula*
- For *INTEGRAL*/IBIS, *RXTE*/PCA and *Suzaku*/HXD-PIN, the results are roughly consistent with Tsujimoto et al. (2010).



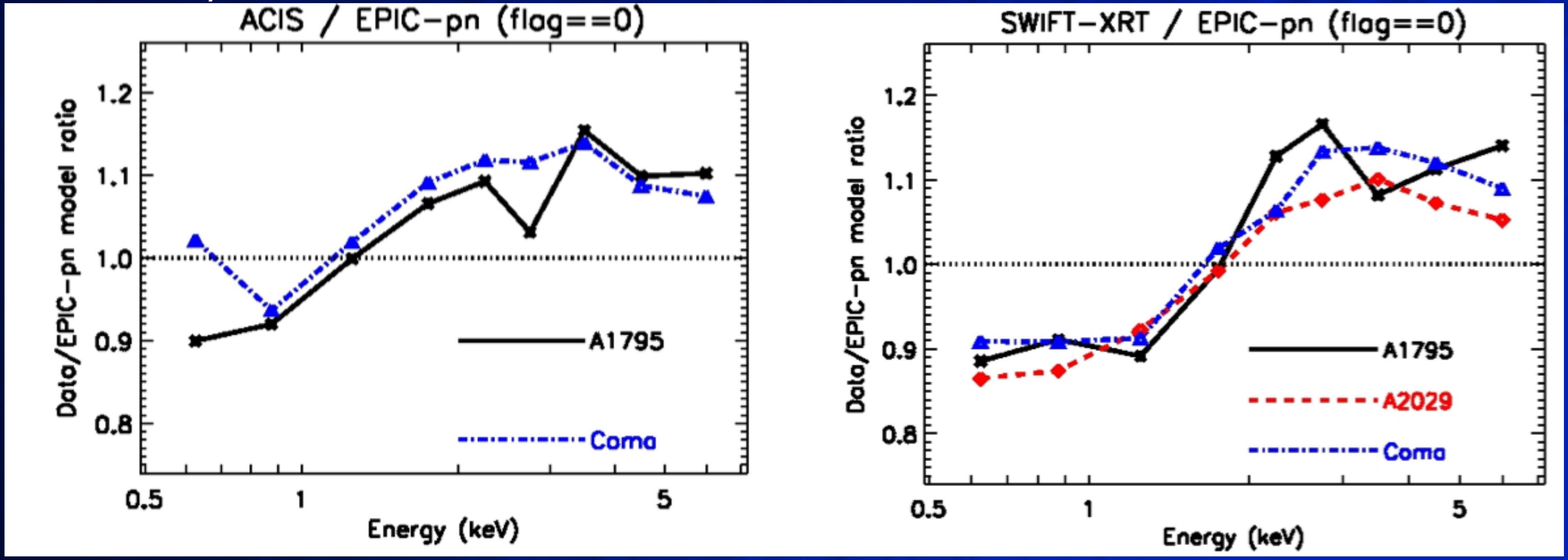
Epoch A (Fall 2005)



Crab vs G21.5-0.9 for hard X-ray instruments

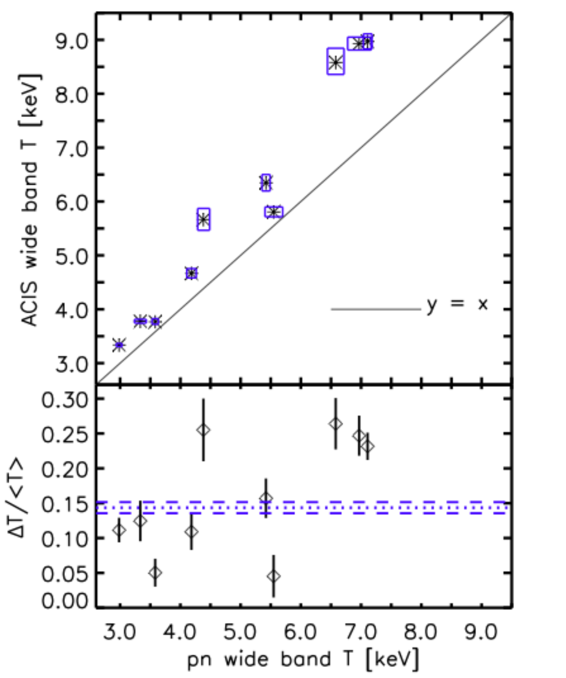
Cross-calibration of X-ray instruments using Clusters of Galaxies [1/2]

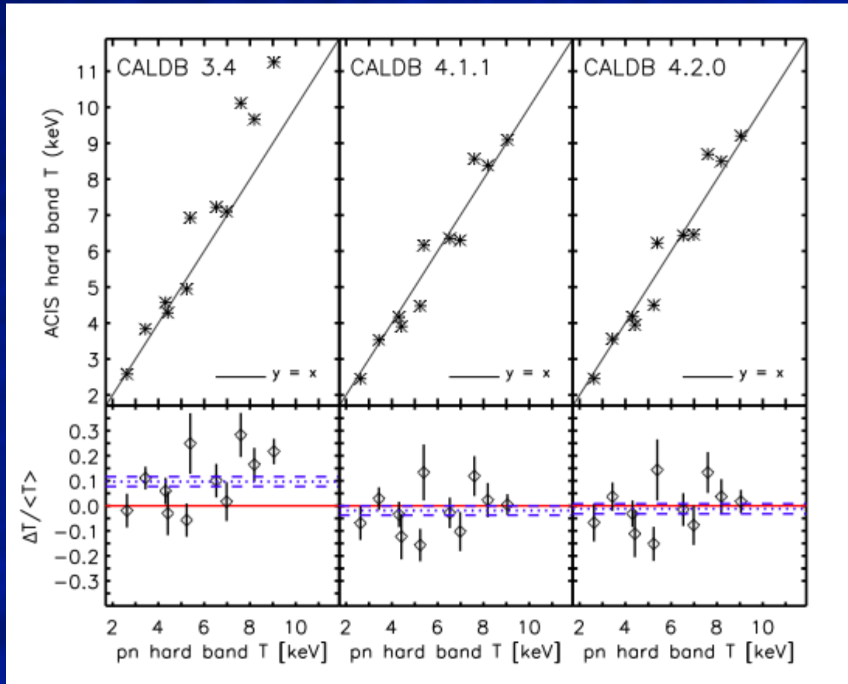
- Cross-calibration of *Chandra*, *XMM*, *Swift* and *Suzaku*
- A first study uses a sample of 11 clusters (Nevalainen et al., A&A 2010)
- Is pn a freak?
- Actually, XMM-Newton/EPIC and Suzaku/XIS are in rough agreement. Together, they disagree with Chandra/ACIS and Swift/XRT



Cross-calibration of X-ray instruments using Clusters of Galaxies [2/2]

- *Chandra* gives ~15-20% higher temperatures than *XMM*.
- A IACHEC study led to an improvement of the *Chandra* calibration after 2007, by more accurate evaluation of the effect of molecular contamination on the mirrors





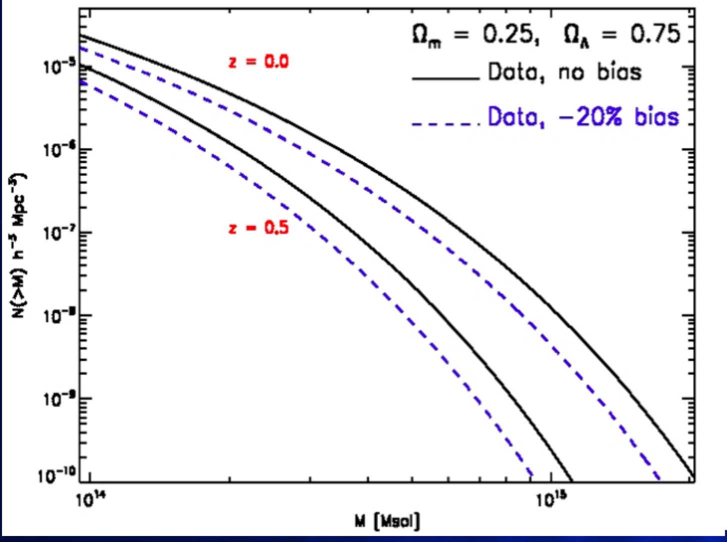
Nevalainen et al. 2010

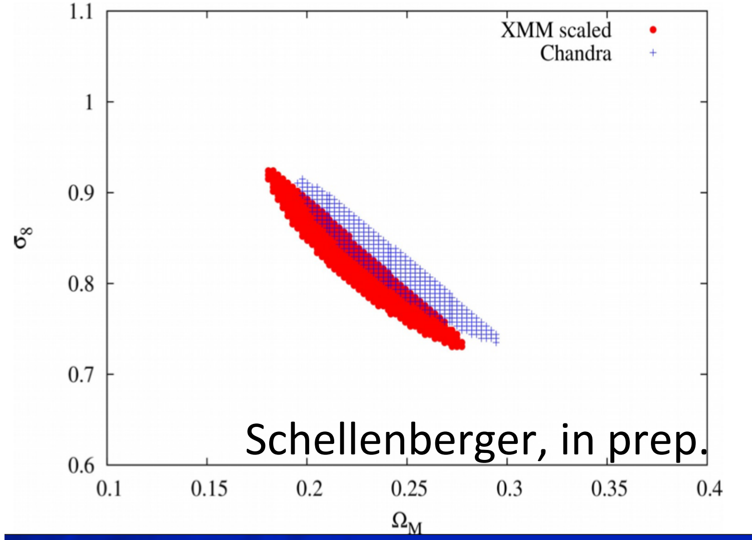
Cluster Masses & Cosmological Parameters [1/2]

- Cluster masses populate the high mass end of the *Press-Scheckter* mass function, that is sensitive to cosmological parameters.
- Hydrostatic X-ray masses of clusters derived from *Chandra* data are ~15-20% bigger than XMM values. If XMM were accurate, this high mass bias would count the clusters in lower mass bins
- So, less power at a given *true* value of the mass.

Cluster Masses & Cosmological Parameters [2/2]

- The effect of a systematic 15% error in the mass function results in a bias in the population of the mass density bins. Effectively, it causes the cosmological mass density parameter Ω_m to vary by 15%.
- A decrease in Ω_m will cause an increase of Ω_Λ. Analogously, the σ_8 parameter is affected.
- Due to the eff.area cross-cal uncertainty of the two satellites, there is about 20% bias in the Ω_m parameter using X-ray determination of cluster masses





Conclusions and future prospects

- A wide community of calibration scientists forms the IACHEC group. They meet each year to run collaborative efforts among different instrument teams in a fully productive framework.
- IACHEC yearly meetings will continue in 2014 and hopefully beyond
- A number of refereed papers have been published and more collaboration papers are expected on individual projects. See

  http://web.mit.edu/iachec/papers/index.html
- We want to further support the high energy community with information on cross-calibration, and encourage consideration of the derived constraints in the data exploitation and in scientific publications
- IACHEC activity emphasizes that no important change in the effective area of an instrument can take place devoid of other instrument's results
- The IACHEC has been a success after years of diverging results on calibrations, and lack of communication among the teams.