Instrumental limits to our knowledge in X-ray Astronomy

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Calibration (as any truly scientific endeavors) is a collective effort

Discussions with and contributions by A.Beardmore (Leicester University), C,Grant (SAO), L.David (SAO), K.Madsen (CALTECH), R.Mushotzky (Un. Maryland), J.Nevalainen (Tartu University), G.Schnellenberger (Bonn University), and S.Sembay (Leicester University) are acknowledged

Outline

observational

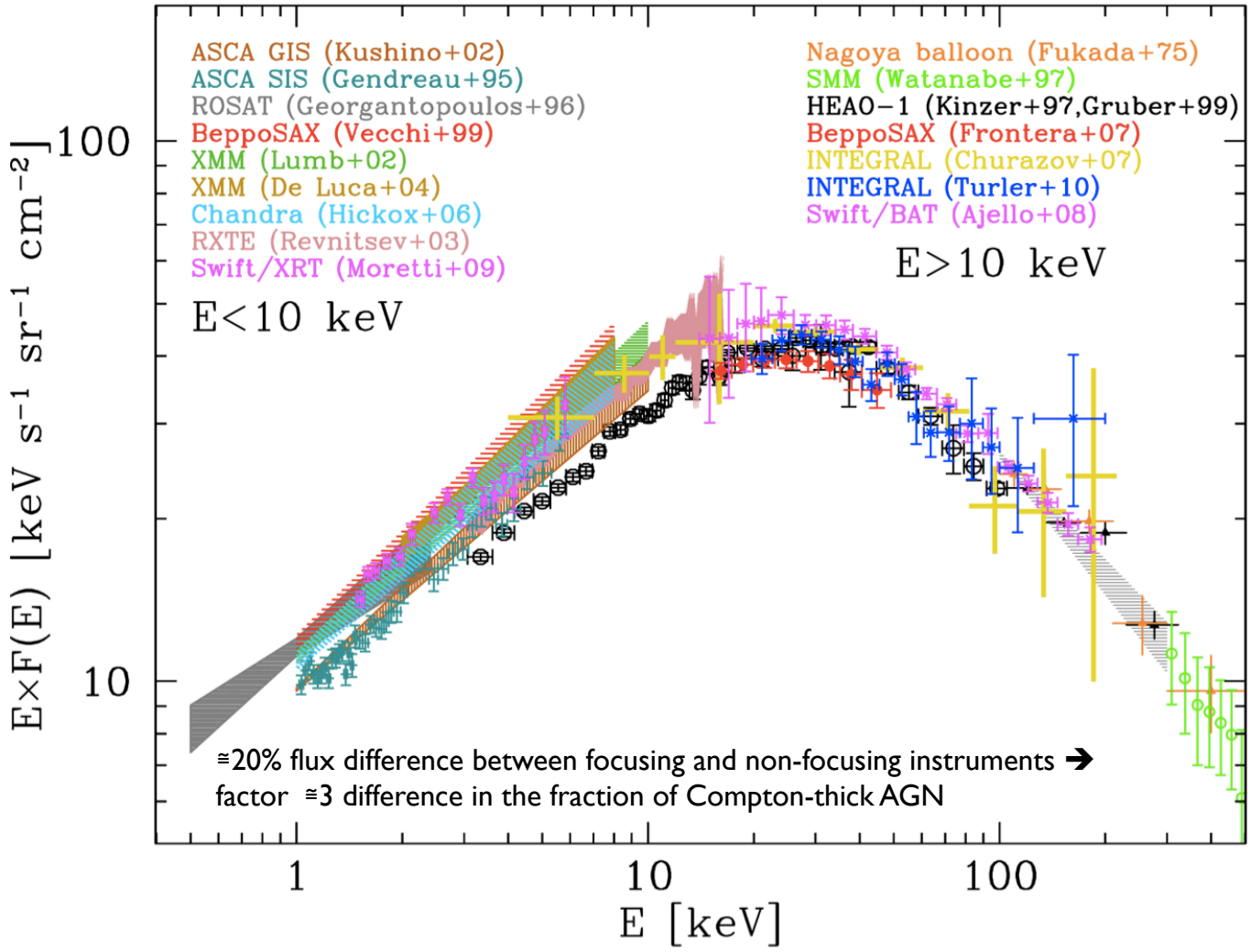
How good is our science?

As good as the quality of the instrument calibration!

Questions I wish to address in this talk:

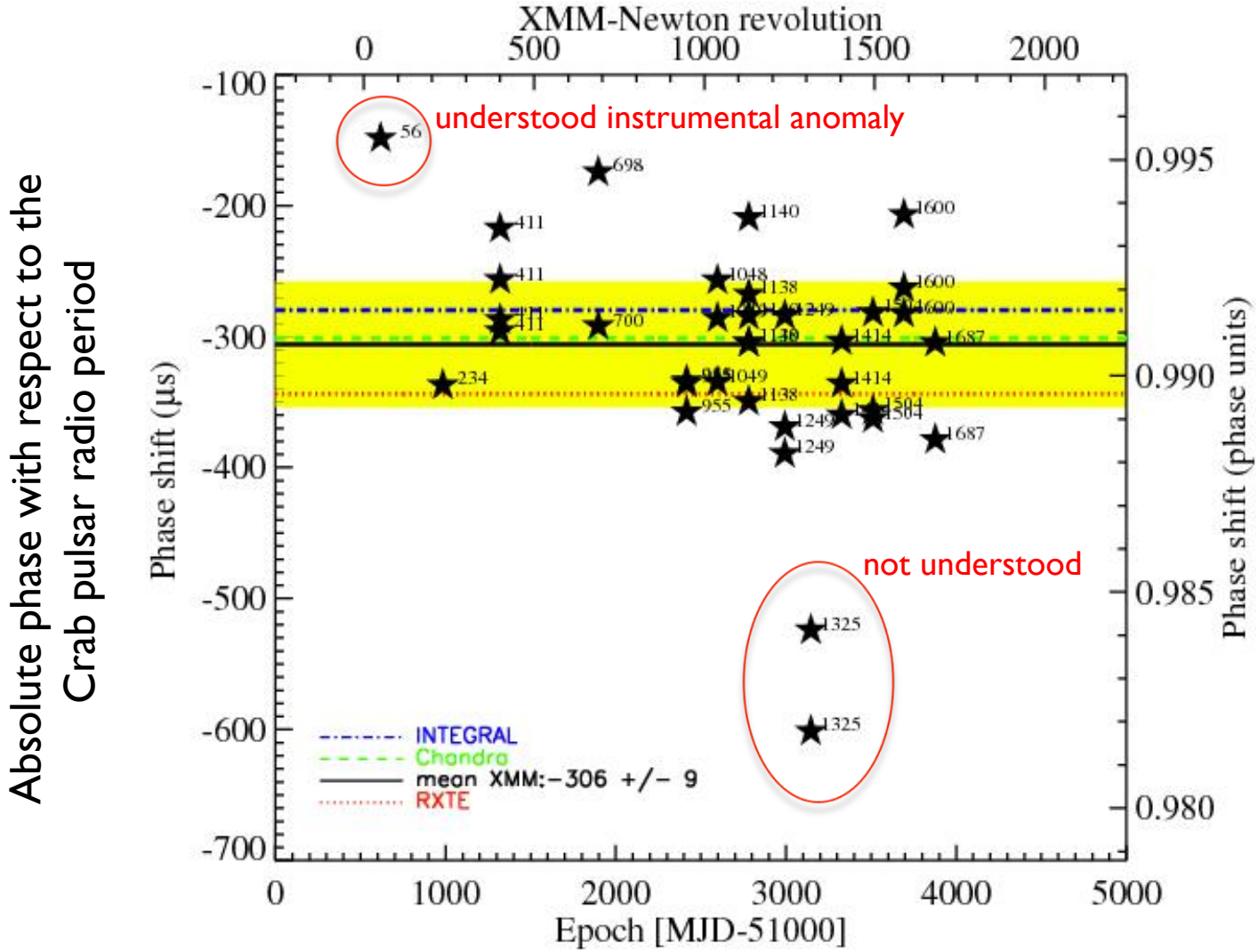
1. How good is our science?
2. Why is our science as good as it is?
3. What are we doing to make our science even better?

A textbook example: the XRB



(Courtesy A.Comastri, Un. Bologna)

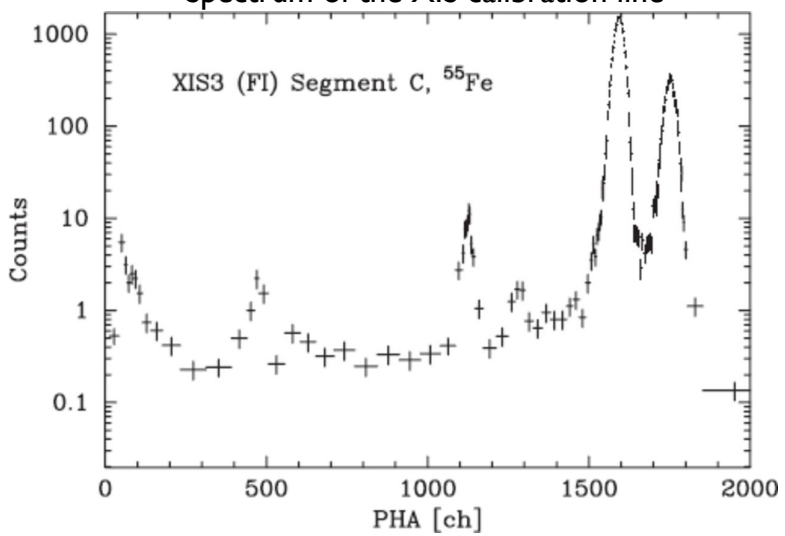
Not always so hard … Timing

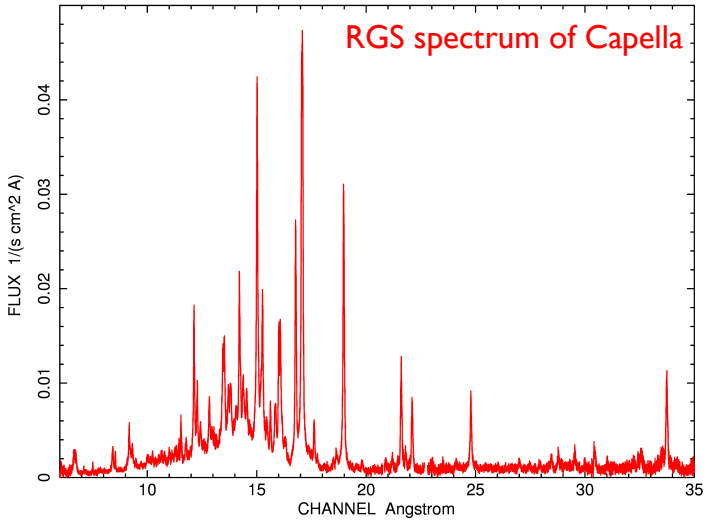


(Martin-Carrillo et al., 2012, A&A, 545, 126 – continuous updates available in the EPIC Calibration Status Document)

Not always so bad … Energy scale

Spectrum of the XIS calibration line



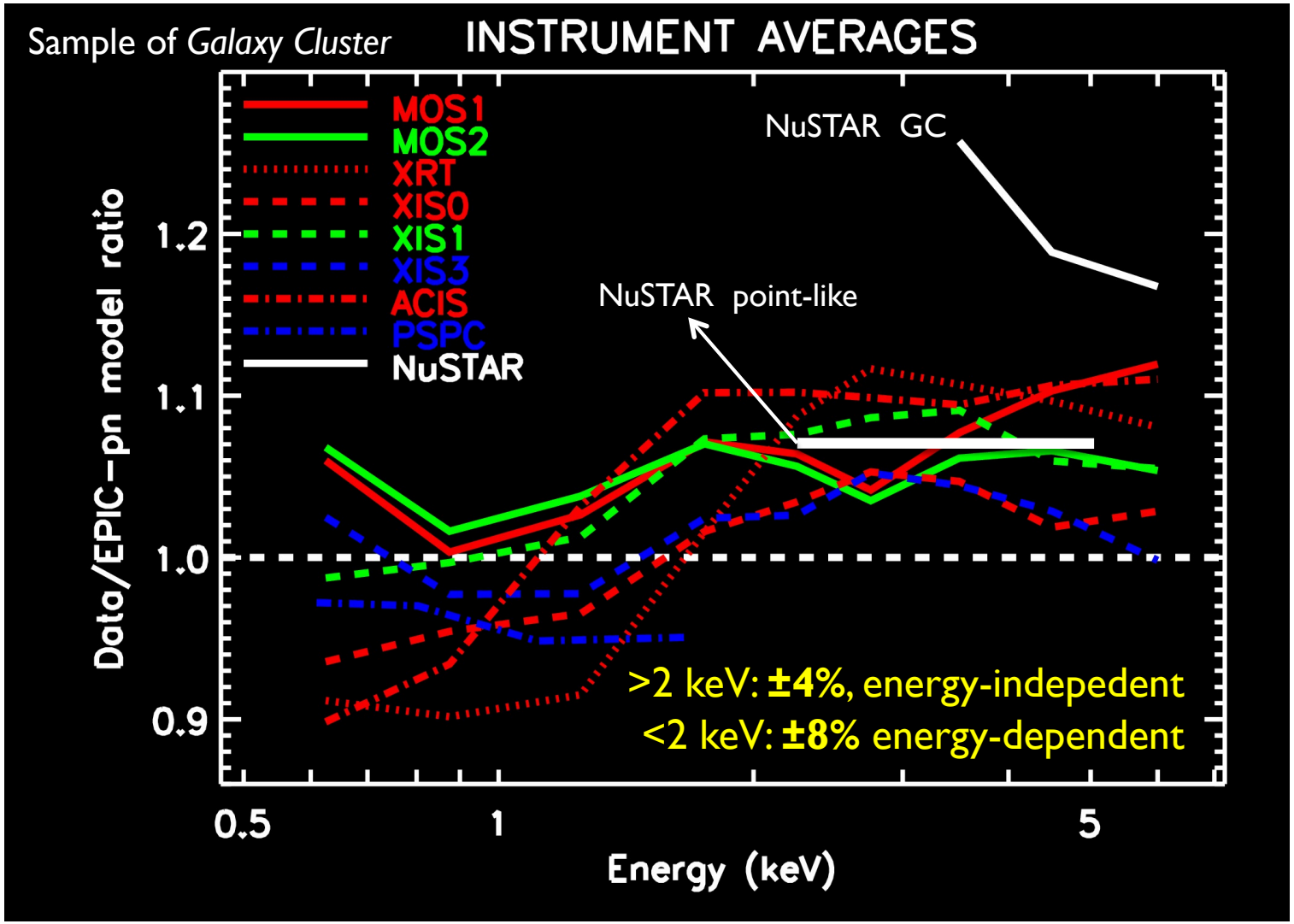


Instrument	Energy scale accuracy
LETG	4 (15) mÅ for λ < (>) 20 Å
HETG	6 (3) mÅ MEG(HEG)
RGS	6 (5) mÅ 1st (2nd) order
ACIS-I	0.2-1% (Fe/O)
EPIC-MOS	5 eV*
EPIC-pn	12 eV** (Fast: 20)
XIS	0.5%
XRT	20 eV

(XIS: Tamura et al., 2007, PASJ, 57, 23)

*10 eV during eclipses **only for *single events* and *before 2012*

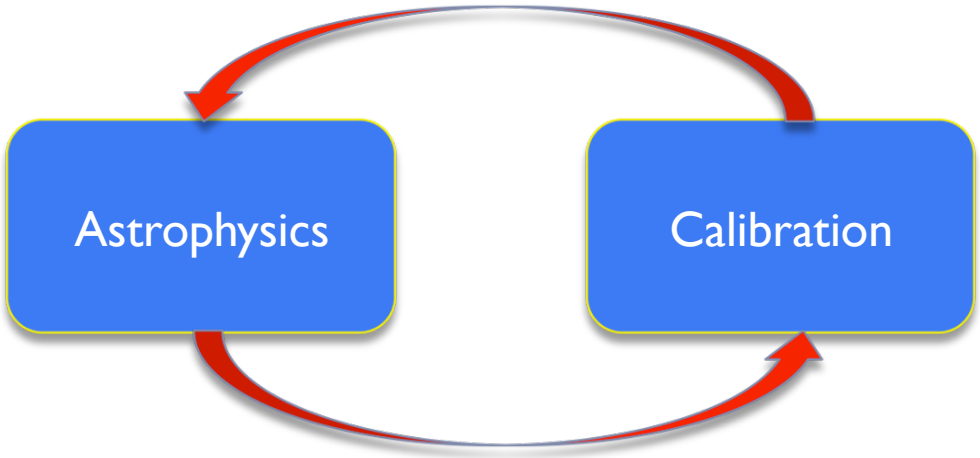
The difficult bit is the area



(Nevalainen at el, in prep.; for a similar analysis above 10 keV: Tsujimoto et al., A&A, 2011, 525, 25)

Why so difficult?

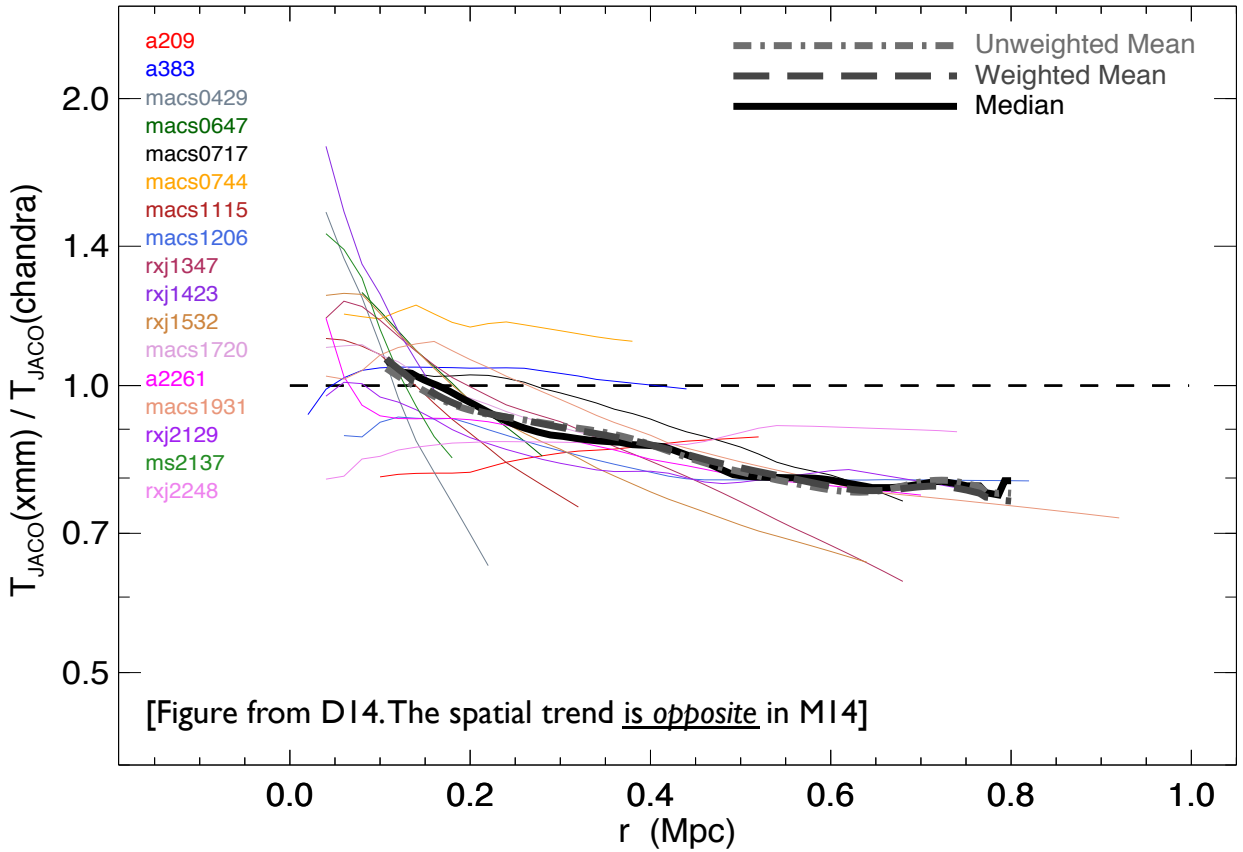
- Theory: full ground-calibration ➔ complete instrument physical model
- Practice: there is hardly enough time for full ground-based calibrations, and to properly maintain know-how and data
- Reality: instrument on-flight performances change
- X-ray astronomy cannot rely on standard candles *strictu sensu*



Calibration of X-ray instruments is always "with respect to ..."

Impact on cosmology with clusters

Comparison between cluster temperatures (0.5-7 keV) measured by EPIC and ACIS



Why?

- Effective area? (S14)
- PSF? (D14)
- Background? (M14)

Hydrostatic bias @r_{500} ACIS/EPIC [$f=1-(M_X/M_{WL})$]

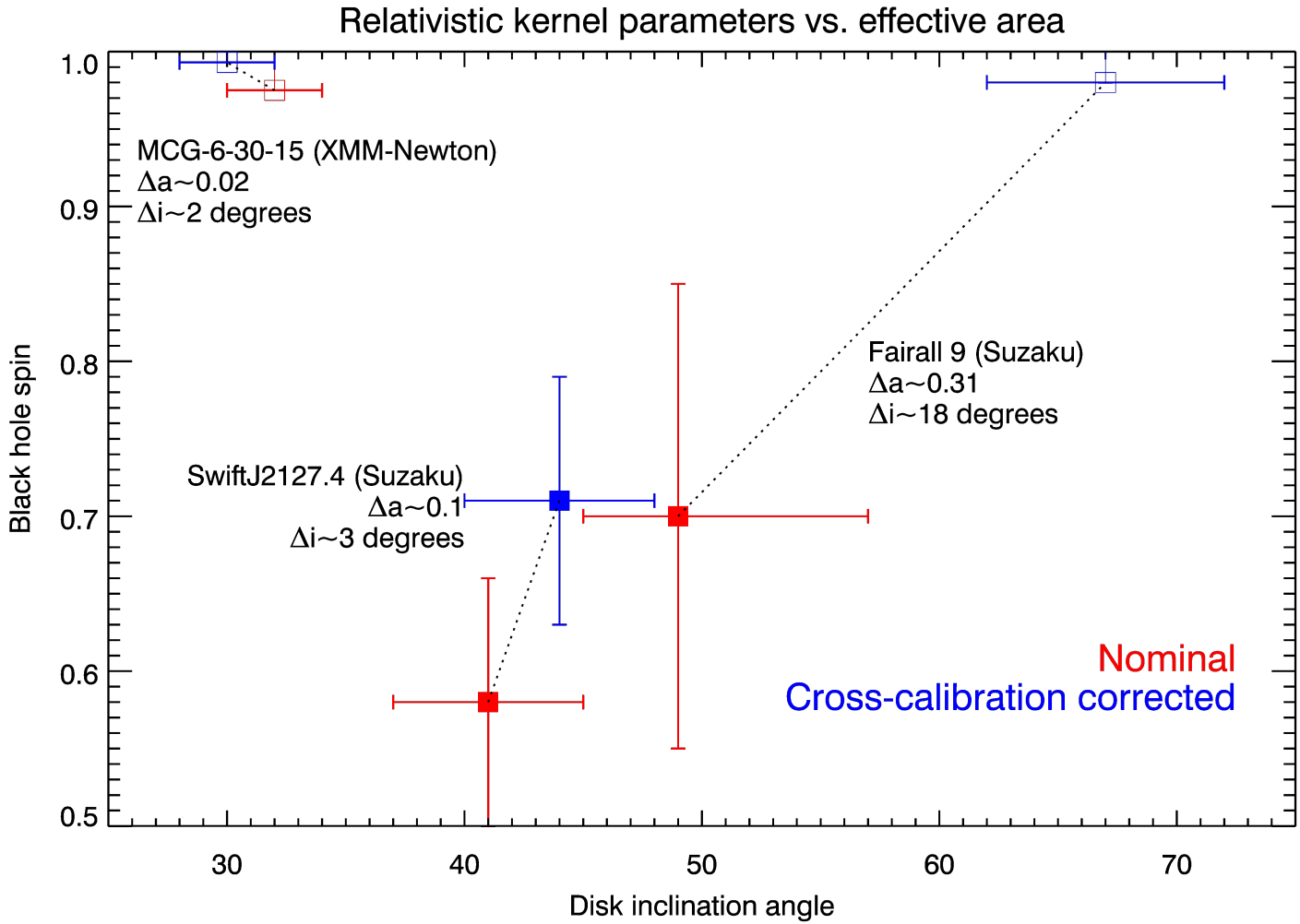
M13: 0.88/1.00
M14: 0.94/0.93
D14: 0.78/0.56

Cosmology (S14)

$\Delta \sigma_8 \leq 0.05$
$\Delta \Omega_M \leq 0.05$
(less than the difference between Planck CMB and SZ)

(Mahdavi et al., 2013, ApJ, 767, 116; Schellenberger et al., arXiv:1404.7130; Donahue et al., 2014, arXiv:1405.7876; Martino et al., 2014, MNRAS, 443, 2342)

Impact on SMBH science



Systematic area calibration uncertainties *can be comparable* to astrophysical uncertainties

- (Guainazzi et al., in preparation; see Reynolds 2013, SSRV, 81 for a discussion on the astrophysical systematics)

IACHEC

IACHEC = International Consortium for High-Energy Calibration

9th IACHEC Meeting picture, May 2014, Airlie Center (Virginia)

(Most of) These astronomers spend (most of their) time to enable your science!

IACHEC duties:

- Define standards for calibration planning and data analysis
- Publish the cross-calibration status (preferentially on refereed journals)
- **Improve the cross-calibration status** (e.g.: Poster#116.08 by Plucinsky et al.)
- Offer expertise to missions in preparation
  - "*In-Flight Calibration Plans for ASTRO-H*": Poster#116.06 by Brenneman et al.

(http://web.mit.edu/iachec/)

Synopsis of recent/ongoing calibration activities

- *Chandra*: ACIS BI gain, CTI temperature-dependence, filter contamination, HETG 0th order efficiency; HRC-S QE; HRMA thermal gradient; LETG 1st order efficiency
- NuSTAR: aspect solution (the whole calibration is "recent", evidently)
- *Suzaku*: XIS contamination; HXD effective area, NXB, timing
- Swift: BAT gain; XRT gain/CTI/trap mapping, RMF
- XMM-Newton: EMOS-MOS contamination; EPIC-pn CTI, gain, Fast Modes energy scale, PSF, timing, RGS contamination, gain/CTI, λ -scale; telescopes' effective area

Caveat: most expected changes at the *few percent level only*

Intrinsic differences in the absolute effective area calibration at the ±*5% level* are likely to remain – **do not ignore them!**

How to *deal* with them?

- CIAO: `pyBLoCXS`: Lee et al., 2011, ApJ, 731, 126
- SASv14: `applymirroradjustement` in `arfgen` (fall 2014; Guainazzi et al. in prep.)

(`http://web.mit.edu/iachec/meetings/2014/index.html`)

10 **Golden Rules** of high-energy calibration

1. **Think of a mission as a single instrument** [credit: S.Sembay]
2. Ground calibration is never sufficient ...
3. ...one might end-up needing recalibrate everything
4. Integrate calibration data in "CALDB" as early as possible
5. Integrate calibration procedures in science analysis s/w
6. Establish *before launch* a cross-calibration working team
7. Facilitate communication among Instrument Teams since $T_{0,ops}$
8. Allow ITs access to all data
9. Do not neglect the potential help of the community
10. Do not hesitate to rely on colleagues from the IACHEC

- 11. There is no golden rule, of course