ATHENA

The X-ray Integral Field Unit calibration plan

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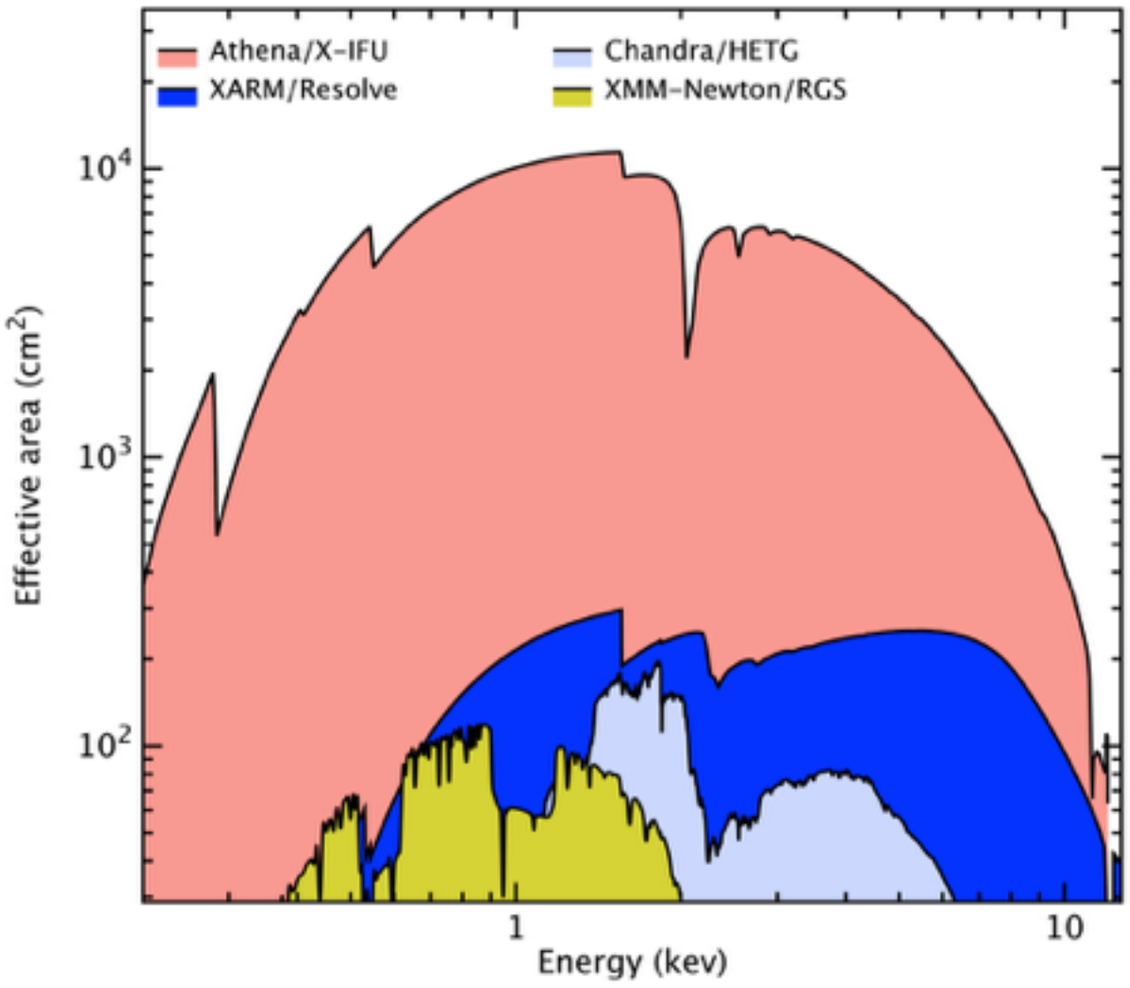
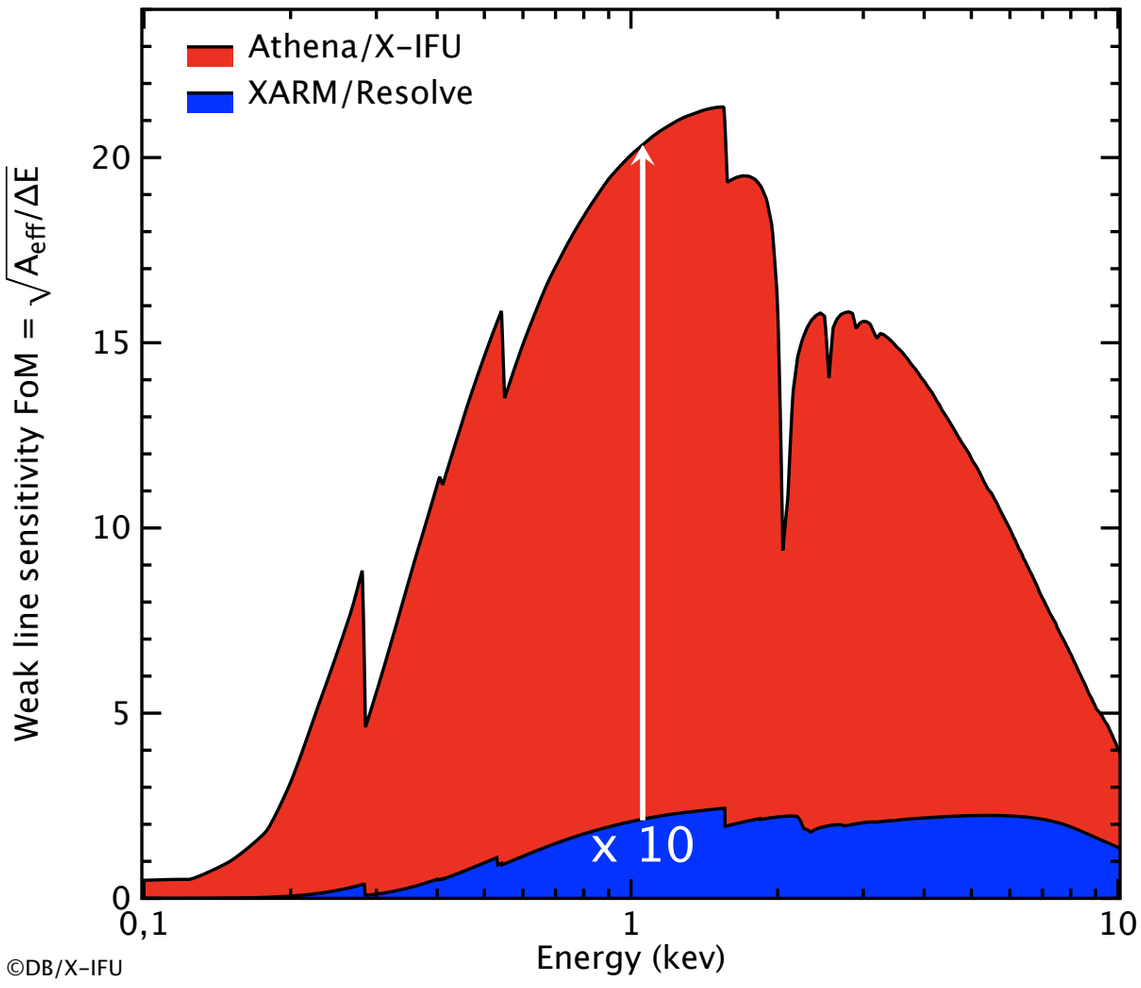
A jump in high sensitivity high resolution spectroscopy



Pajot et al. JLTP 2018



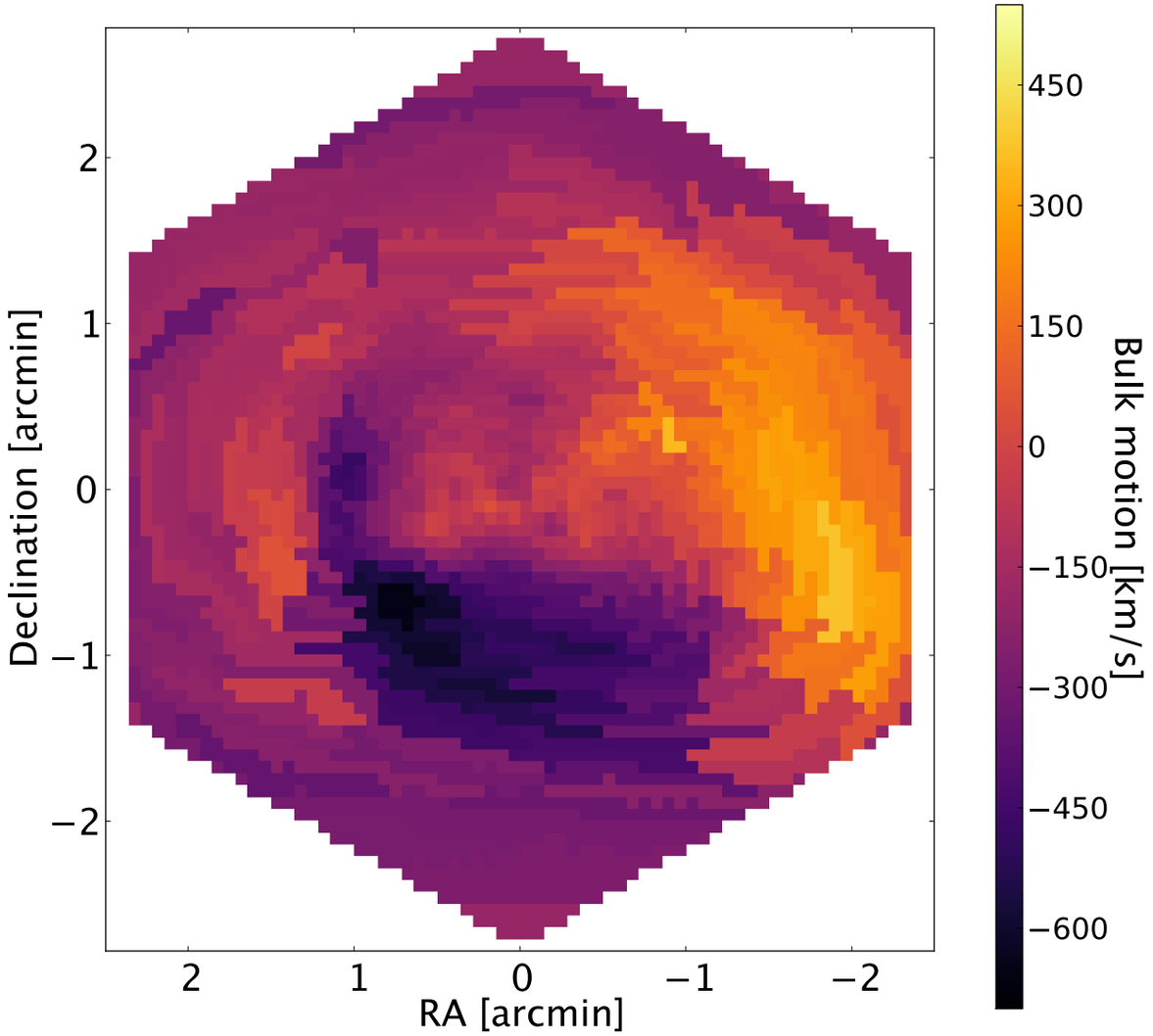
©DB/X-IFU

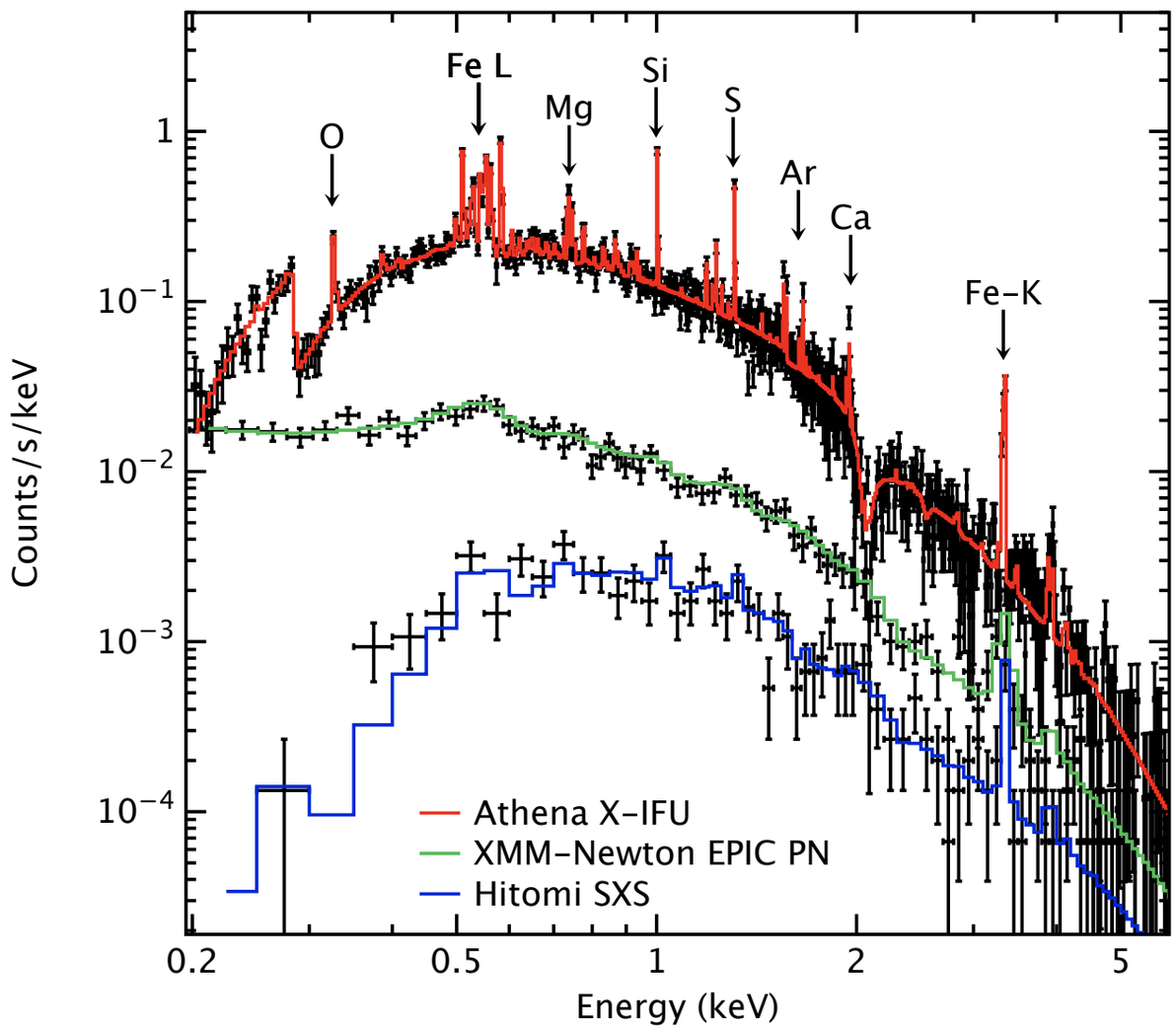
- Effective area of the Athena/X-IFU instrument compared to current (Chandra/HEGT, XMMNewton/ RGS) or near future (XARM/Resolve, assuming the same response as Hitomi/SXS) X-ray imaging spectrometers in the 0.2—12 keV energy range.

- Weak line sensitivity factor of merit of the Athena/X-IFU instrument compared to the next and only high resolution imaging spectrometer XARM/Resolve. High resolution spectrometry refers to instruments achieving a better than 10 eV energy resolution, a capability now enabled in space by micro-calorimeter arrays

X-IFU spectroscopy on clusters simulations

Barret et al. SPIE 2016





- Reconstructed bulk motion velocity field of the hot intra-cluster gas for a 50 ks X-IFU observation of the central parts of a Perseus like cluster considered at a redshift of 0.1

- Simulated X-IFU spectrum of a z = 1 galaxy group with kT = 3 keV and L_X = 1 x 10^{44} erg/s for 50 ks. Emission lines from elements which are key to understand chemical evolution can be clearly seen.

The X-ray Integral Field Unit

Parameters	Requirements
Energy range	0.2 — 12 keV
Energy resolution [1]: E < 7 keV	2.5 eV
Energy resolution: E > 7 keV	E/ΔE = 2800
Field of View	5′ (equivalent diameter)
Effective area @ 0.3 keV	> 1500 cm^2
Effective area @ 1.0 keV	> 15000 cm^2
Effective area @ 7.0 keV	> 1600 cm^2
Gain calibration error (peak, 7 keV)	0.4 eV
Count rate capability nominally bright point sources [2]	1 mCrab (> 80% high-resolution events)
Count rate capability brightest point sources	1 Crab (> 30% throughput)
Time resolution	10 µs
Non X-ray background (2 — 10 keV)	< 5 10^{-3} counts/s/cm2/keV (80% of the time)

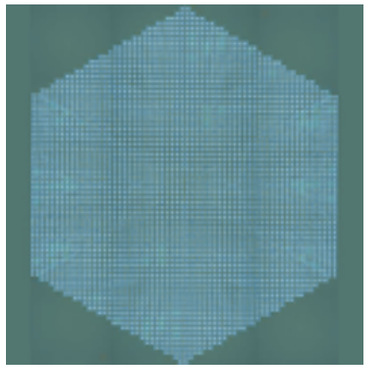
[1] goal 1.5 eV, [2] goal 10 mCrab (> 80% high-resolution events) events

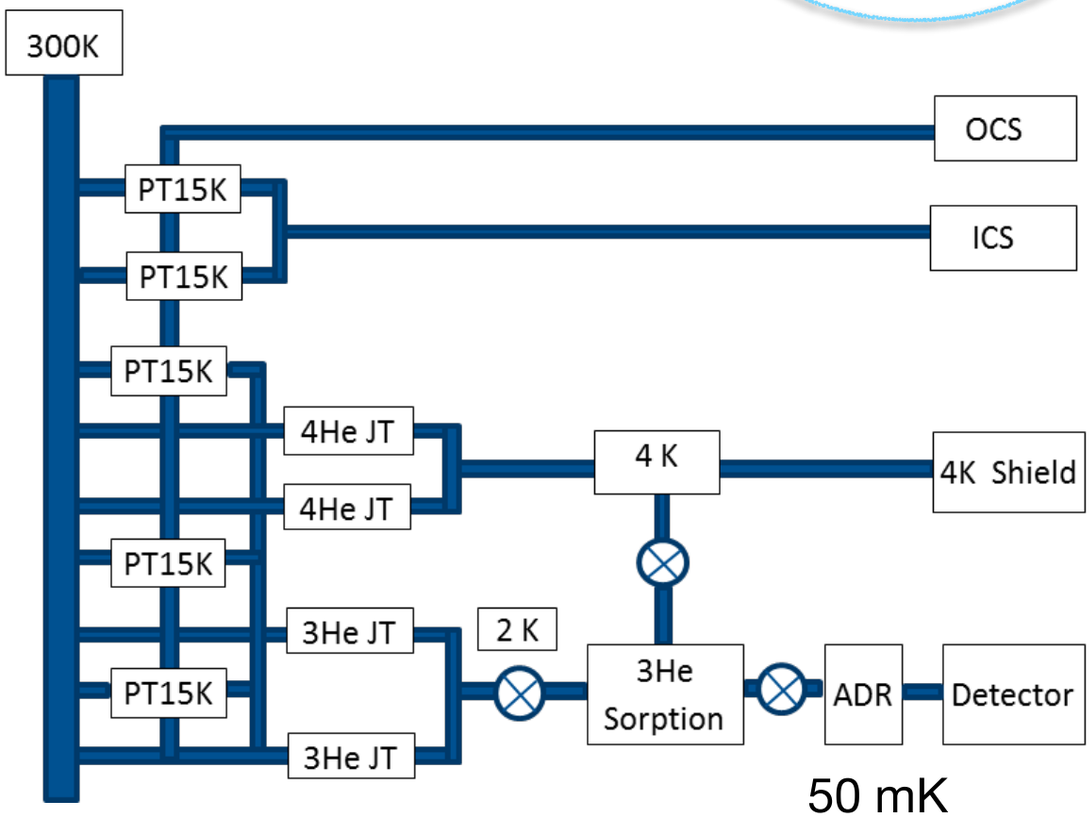
- Consortium led by CNES/IRAP-F, with SRON-NL, INAF-IT and other European partners, NASA and JAXA.

X-IFU detectors and dewar

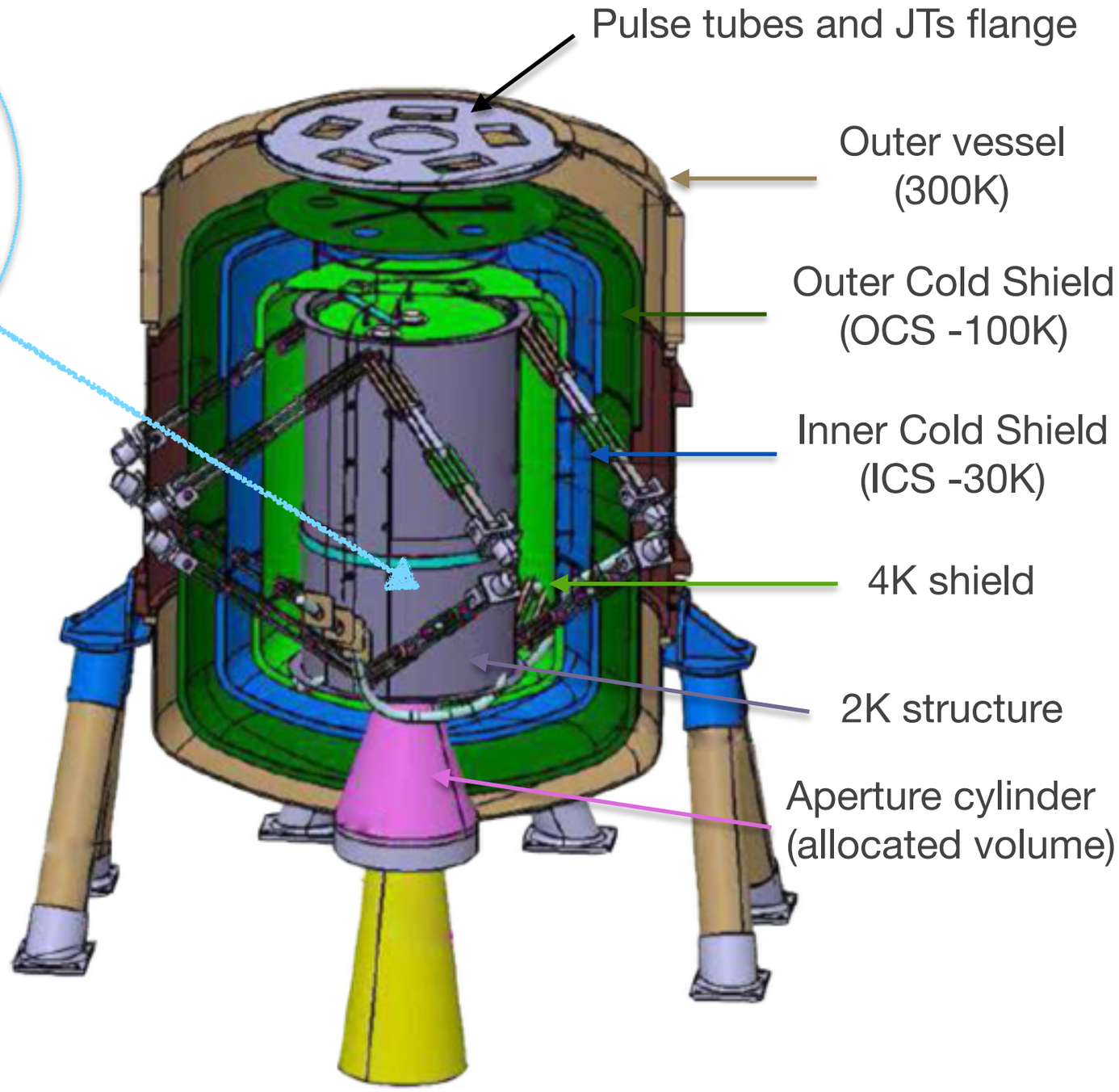
3840 TES microcalorimeters array at 50 mK

Associated to a 4 pixels anticoincidence TES detector



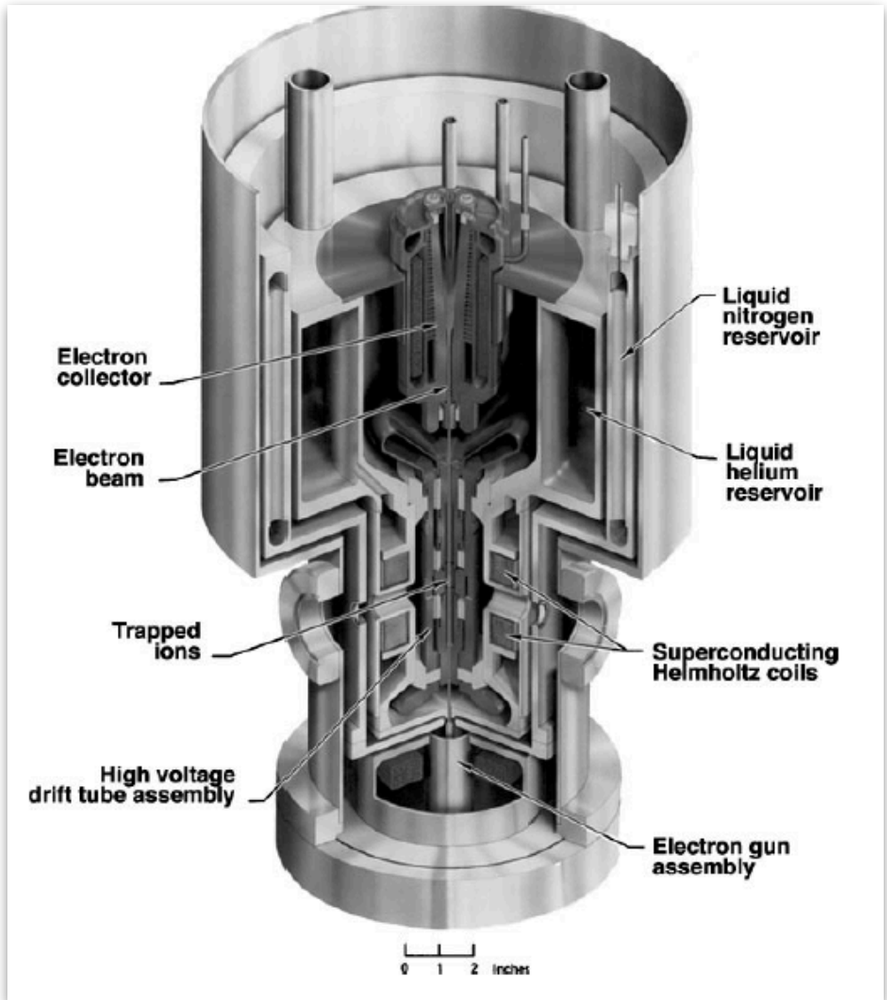


Baseline cryochain



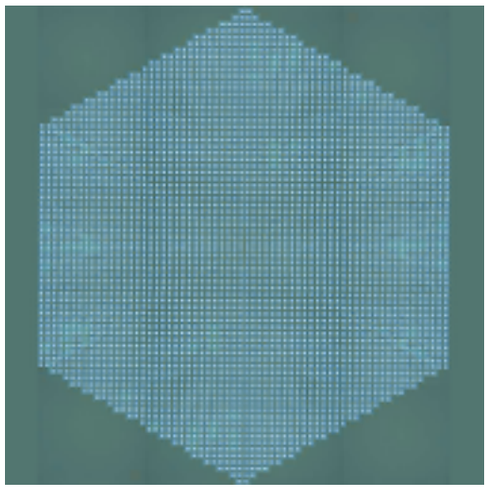
X-IFU calibration

- Most of the X-IFU top-level calibration requirements stem directly from the Athena level
  - all calibrations will be performed at pixel level
  - some additional requirements may be added by the instrument to lower levels (e.g. door calibration)
- Experience from work done for HITOMI/SXS and XARM/Resolve micro-calorimeter arrays is essential
  - definition of requirements
  - calibration methodology specific to microcalorimeters
  - on-ground and instrument calibration sources (grating monochromators, channel-cut crystal monochromators, EBITs,…)
  - in-flight targets definition
- Low energy range will benefit from grating instruments such as ARCUS
  - physics, astrophysical sources



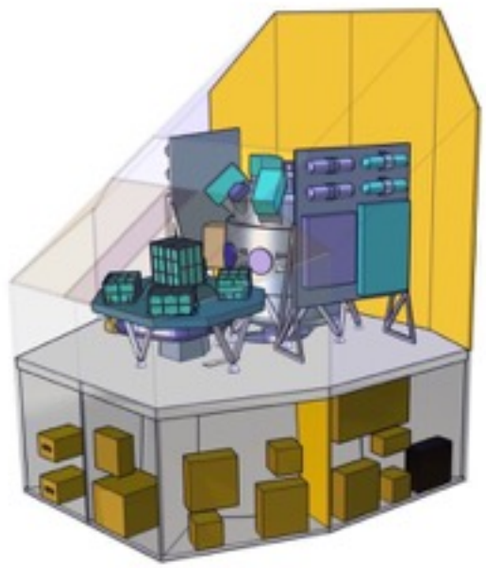
Electron Beam Ion Trap (EBIT)

X-IFU calibration from ground to space

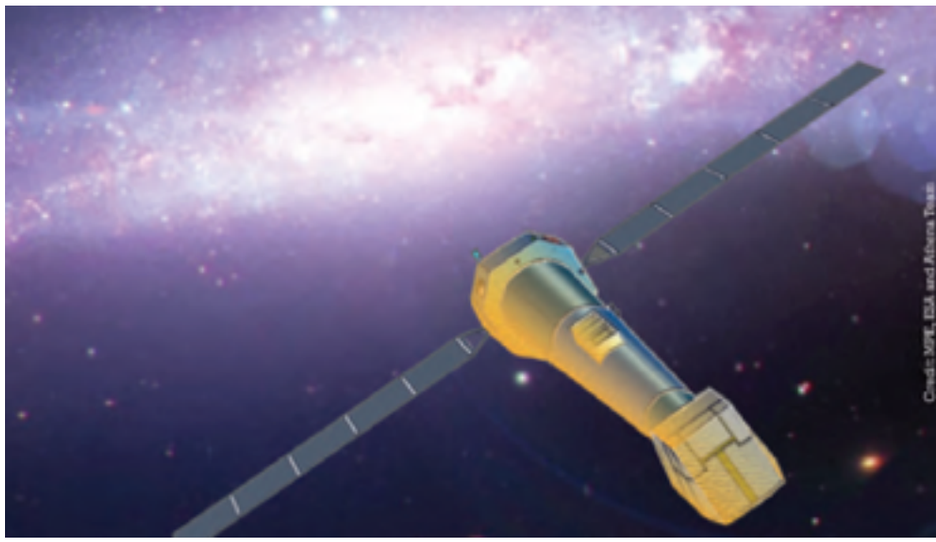


1.6 cm

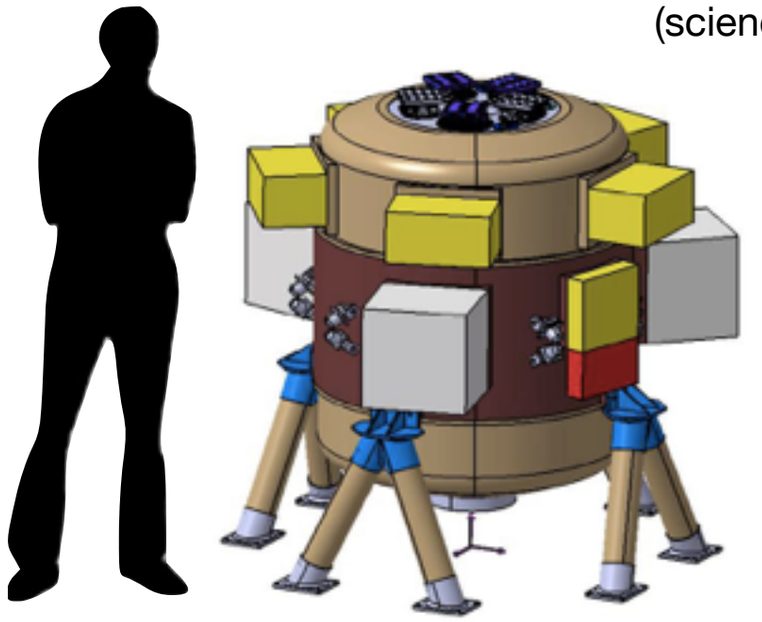
Component
(microcalorimeter array,…)



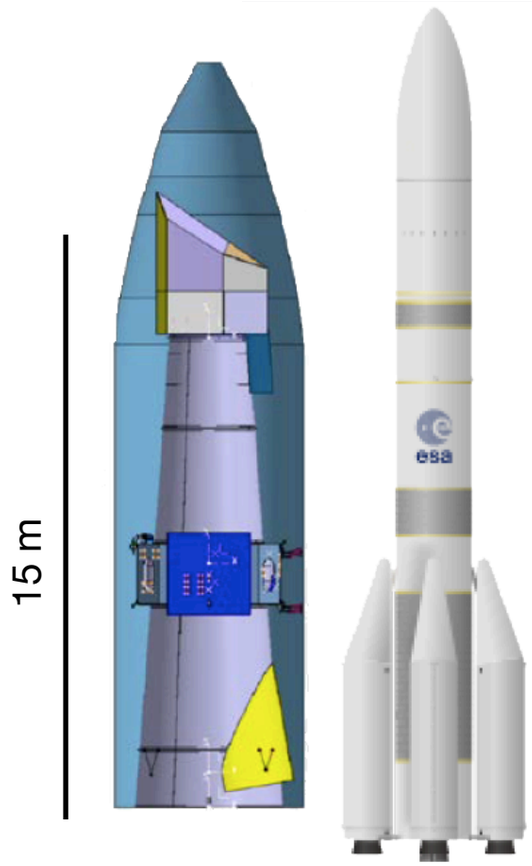
SIM
(science instrument module)



In-orbit



X-IFU dewar



Spacecraft

X-IFU main calibration requirements

Requirement	Name	Athena	Mirror	X-IFU	Comments
Absolute effective area on-axis calibration (%)	CAL-EFF-R-001	10	6	**4**	At the 1σ level Over the [0.5-10 keV] bandpass
Relative effective area, broad-band on-axis (%)	CAL-EFF-R-003	5 (X-IFU), 3 (WFI)	2	**3**	At the 1σ level Over the [0.5-10 keV] bandpass
Relative effective area, fine structure (%)	CAL-EFF-R-005	1 (TBC)	1	**TBD**	At the 1σ level Working from XARM/RESOLVE req.
Knowledge of gain (eV)	CAL-ENR-R-001	0.4 (X-IFU), 10 (WFI)	N/A	**0.4**	r.m.s. variation in [0.3-7 keV] [allows centroiding to 20 km/s at 7 keV]
Energy resolution calibration (%)	CAL-ENR-R-003	6 (X-IFU), TBD (WFI)	N/A	**6**	Over the [0.3-7 keV] bandpass [turbulence to 20 km/s at 7 keV]
Energy redistribution calibration	CAL-ENR-R-004	TBD	N/A	**TBD**	Working from HITOMI/SXS experience and calibration data
Dead time (%)	CAL-TIM-R-001	1	N/A	**1**	All dead time is introduced during processing and known
Photon relative timing (µs)	CAL-TIM-R-003	10 (X-IFU) 5000/80 (WFI)	N/A	**10**	r.m.s. error (absolute requirement is 50 µs at Athena level)
Non-focused background	CAL-BKG-R-001	2	N/A	**2**	Goal 1%. For observations longer than 100 ks over 9'
Focused background reproducibility (%)	CAL-BKG-R-002	10	N/A	**10**	For observations longer than 100 ks over 9 squared arc minutes

High resolution spectroscopy
Atomic Database/Lab Measurement Needs

- Energies / wavelength
  - Athena will measure velocities to 20 km/s at 7 keV (~0.006%) or wavelength accuracy to 3 mÅ at 10 Å (~0.03% at 1.2 keV)
  - Accuracy of wavelength current values is ~1% (Smith+Brickhouse 2014)

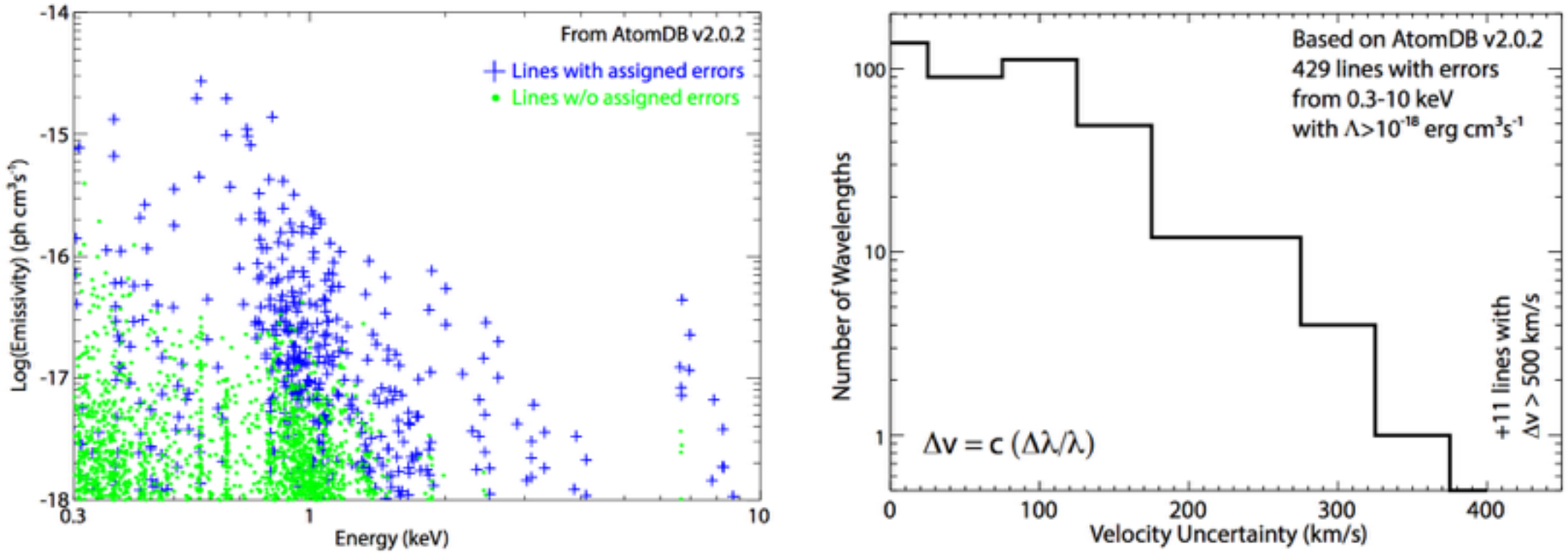


Figure 1.2: *Left*: lines with uncertainties in atomdb; *right*: uncertainties in wavelength translated to Doppler shifts. — From Smith & Brickhouse (2014, Figs. 5 & 6).

Natalie Hell, PhD Thesis 2017

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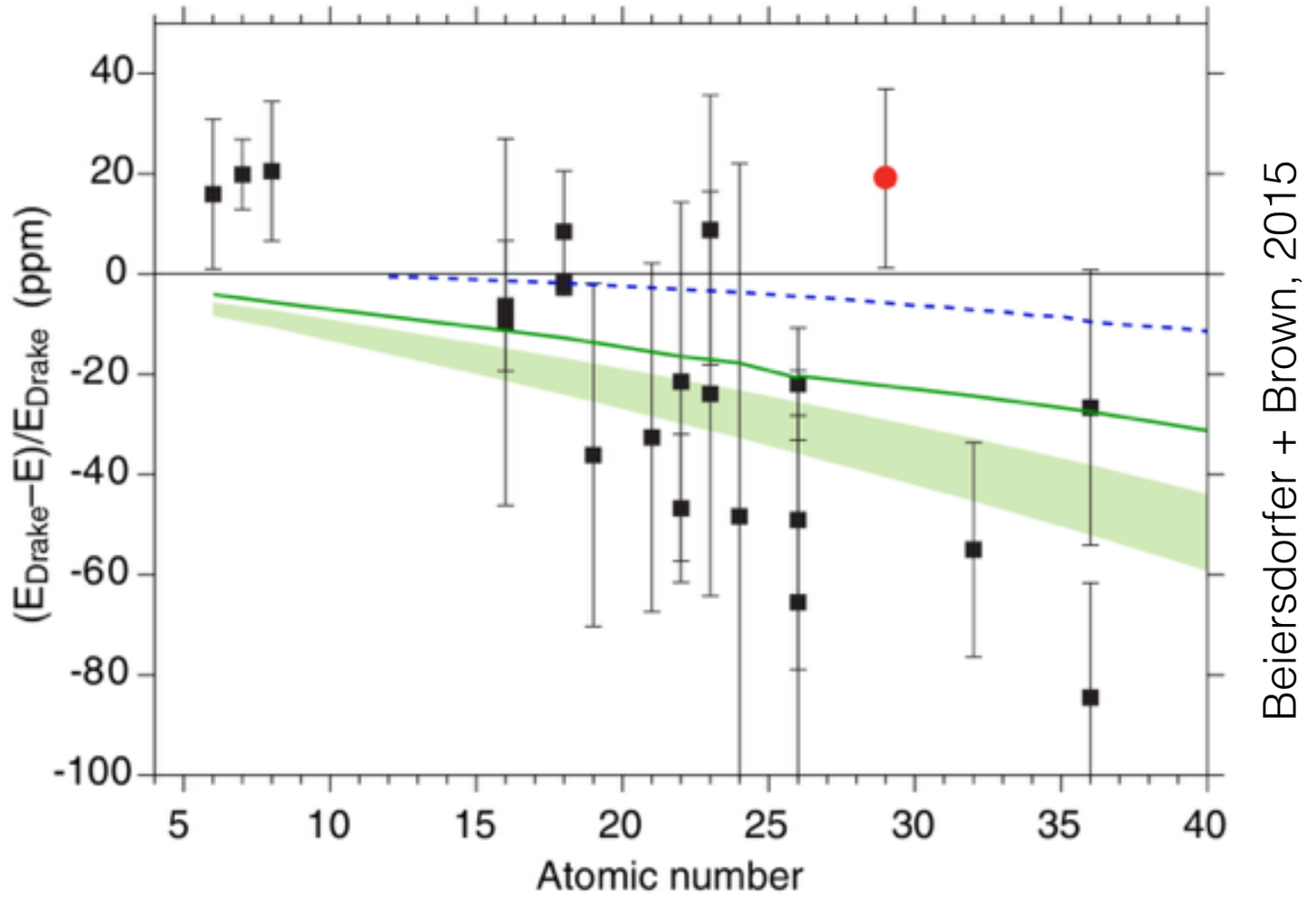
Experiment (various) vs.
Calculation (Drake 1988)

for He-like (w/resonance) lines
($1s2p\ ^1P_1 \rightarrow 1s^2\ ^1S_0$)



High resolution spectroscopy
Atomic Database/Lab Measurement Needs

- Other parameters mostly related to in-flight data analysis
  - Collisional excitation rates → diagnostic line ratios
  - Radiative transition rates → accurate cascades
  - Photoionization/absorption rates → charge state distribution
  - Charge Exchange cross sections → ionization balance, line ratios
  - …

X-IFU Calibration plan

- Prepared by :
  - the X-IFU Calibration Team (XCaT): Marco Barbera, Edoardo Cucchetti, Megan Eckart, Philippe Ferrando, Jean-Michel Mesnager, Lorenzo Natalucci, Philippe Peille, Jelle de Plaa, Etienne Pointecouteau
  - with contribution from: M. Leutenegger, G. Betancourt-Martinez
- First issue December 2018 (for the Instrument Preliminary Requirement Review)

The end / the beginning…