The Athena X-ray Integral Field Unit

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on behalf of Didier Barret, Thien Lam Trong, Jan-Willem den Herder, Luigi Piro, Massimo Cappi and the X-IFU team

Athena in a nutshell

- Advanced Telescope for High Energy Astrophysics, for the study of the hot and energetic universe
- Second Large (L) mission of the ESA Cosmic Vision 2015-2035
- Launch year: end of 2028
  - with the newly developed Ariane 6 (64)
- A 7 ton spacecraft to be placed in a L2 (L1) orbit
- Unprecedented collecting area in X-rays:
  - 2 m^2 goal at 1 keV and 0.17 m^2 at 7 keV
  - 5'' angular resolution
- Two focal plane instruments with a movable mirror assembly
  - The Wide Field Imager (WFI) optimized for surveys
  - The X-ray Integral Field Unit (X-IFU) optimized for spatially resolved spectroscopy

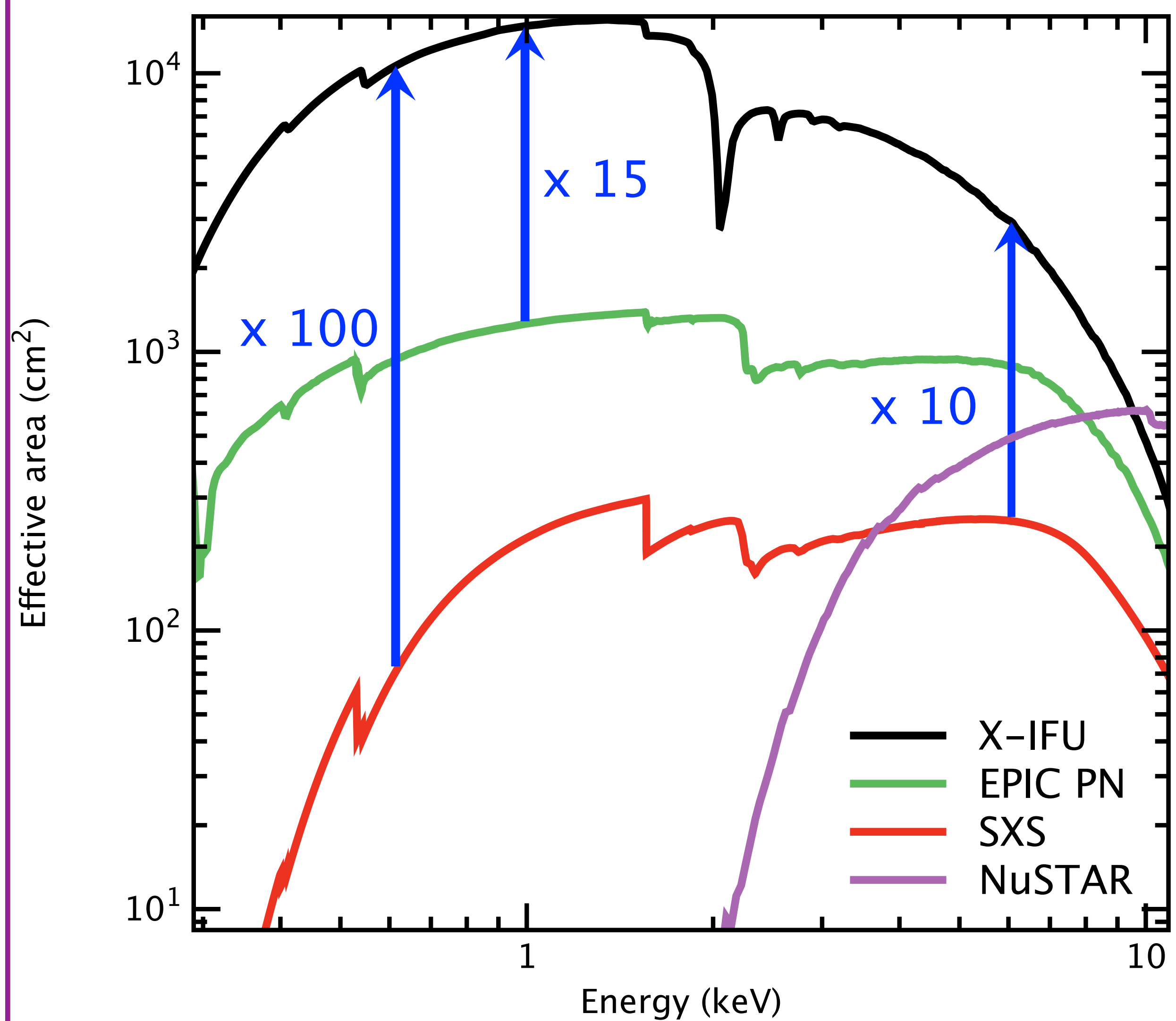
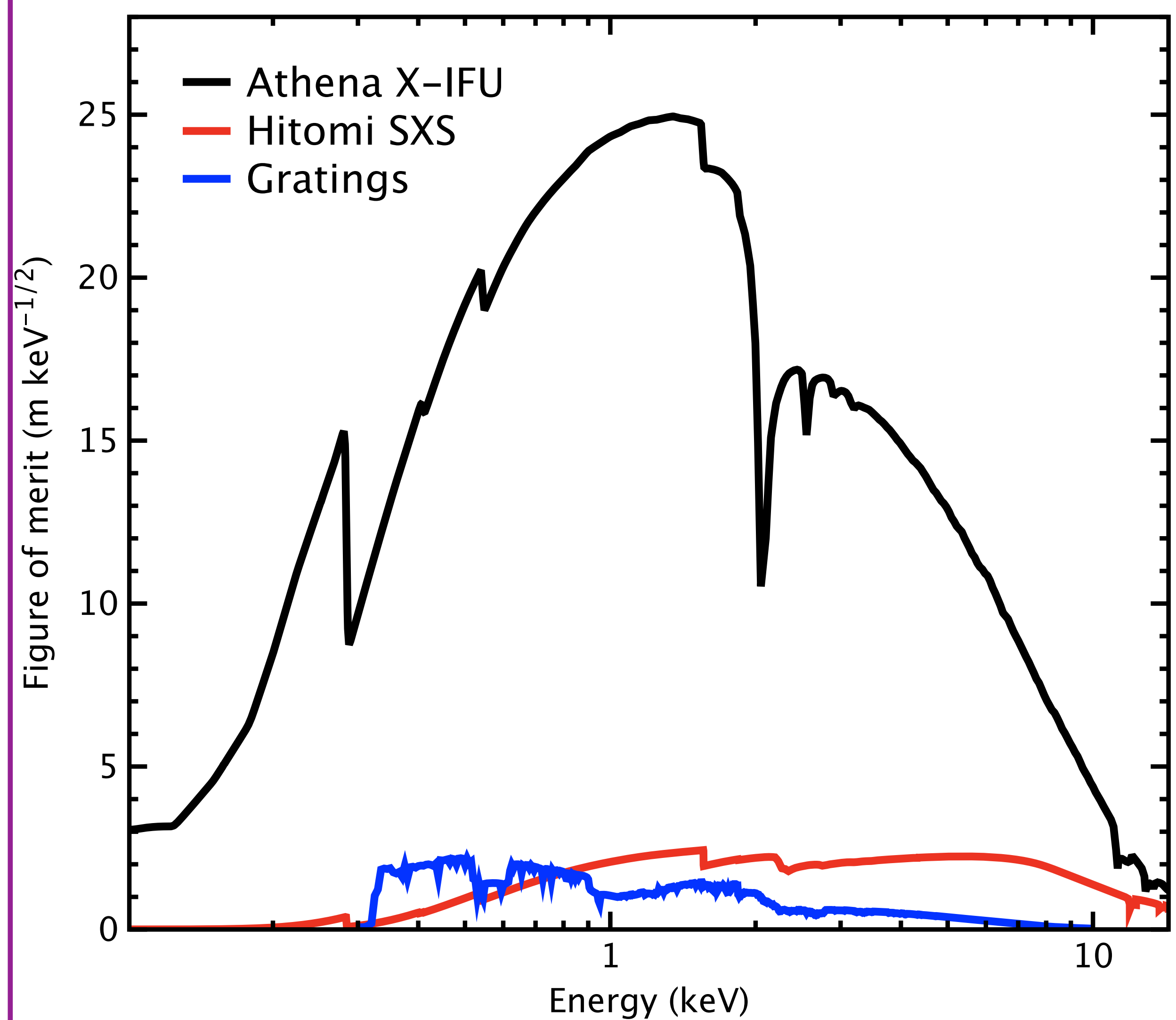
The X-ray Integral Field Unit

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

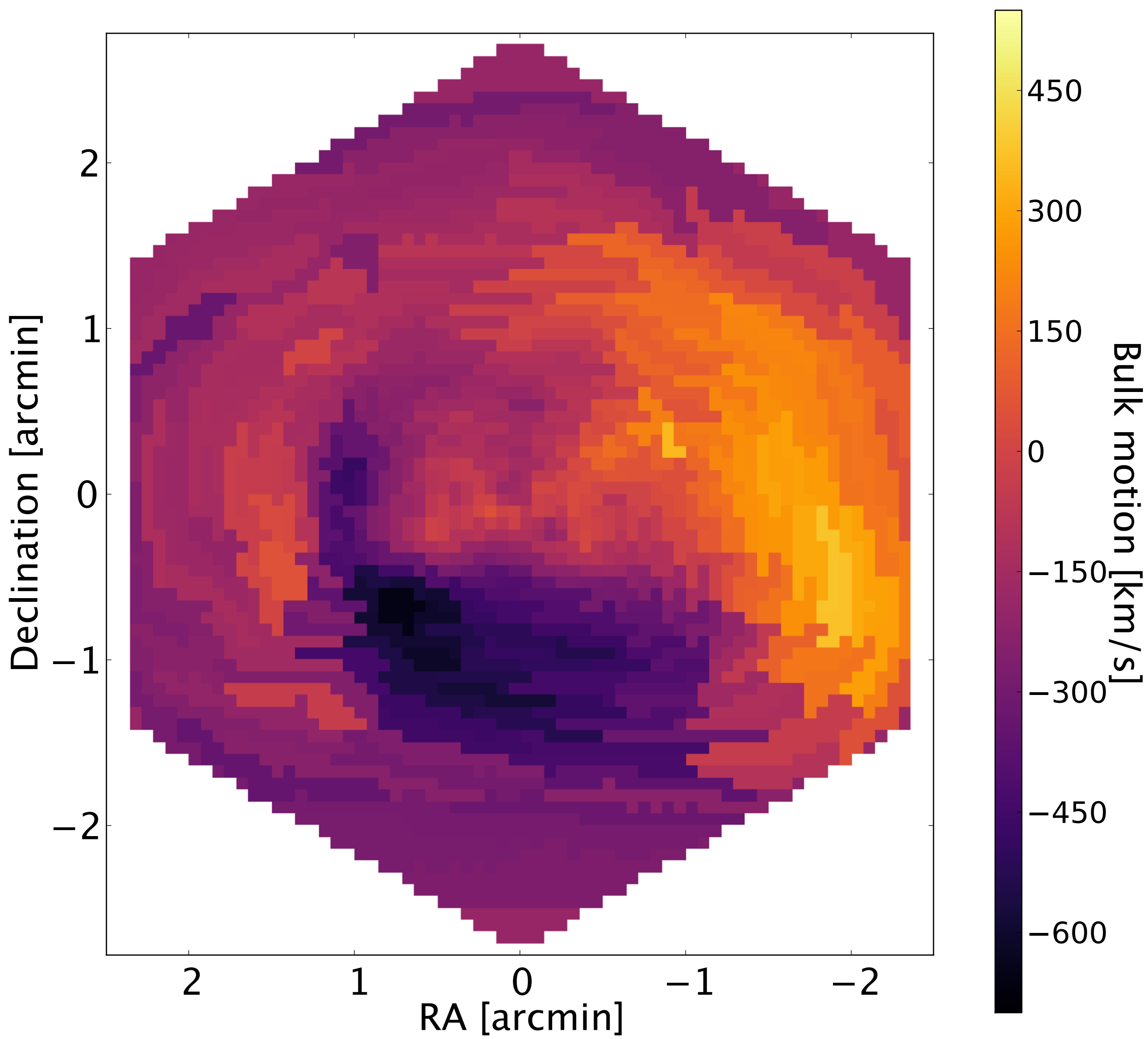
- Consortium led by CNES/IRAP-F, with SRON-NL, INAF-IT and other European partners, NASA and JAXA.

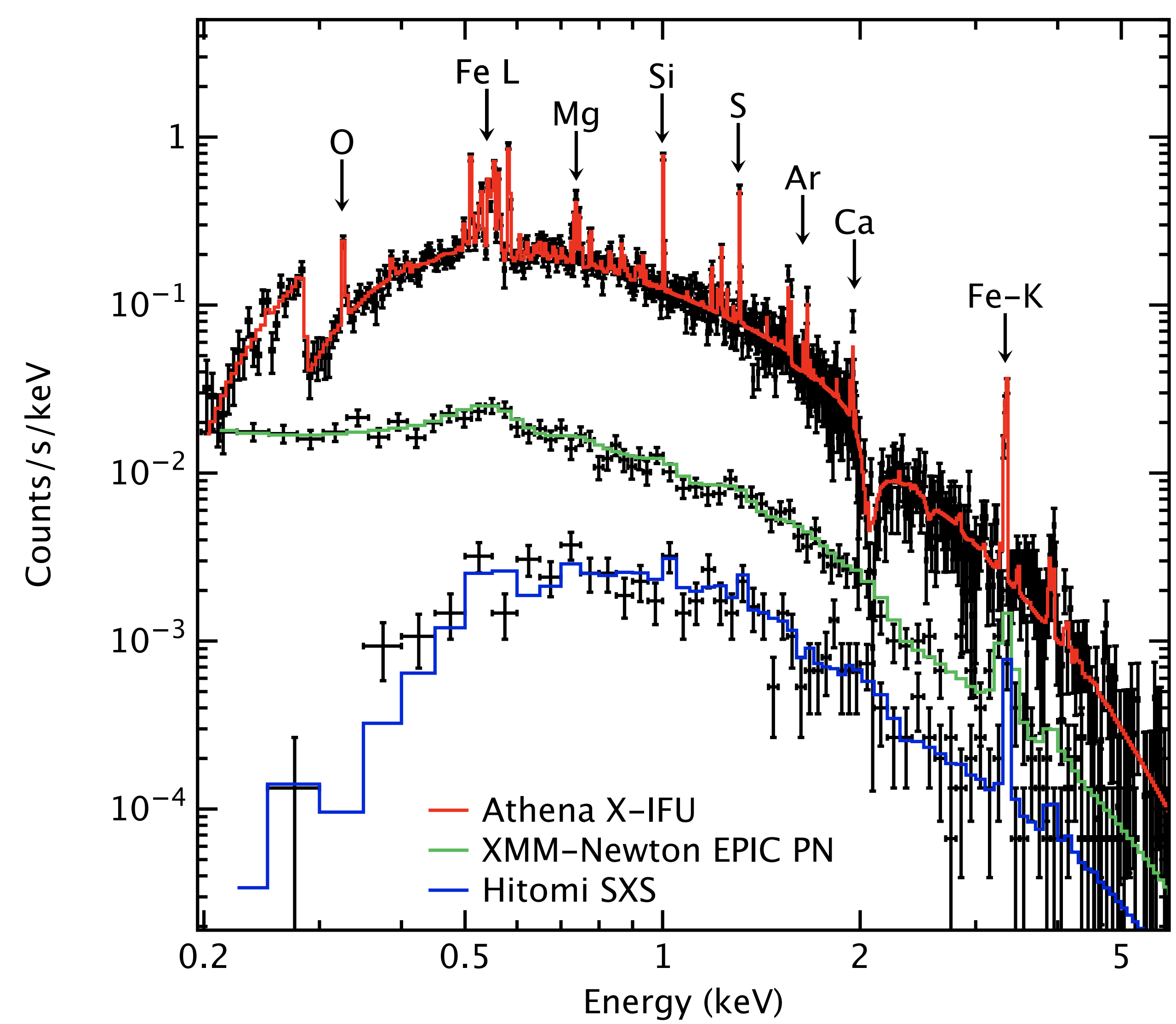
Spectroscopic capabilities

Effective area comparison between X-IFU and other facilities	Figure of merit for spectroscopy measurements
	

X-IFU simulations: spectroscopy on clusters

Barret+ SPIE 2016



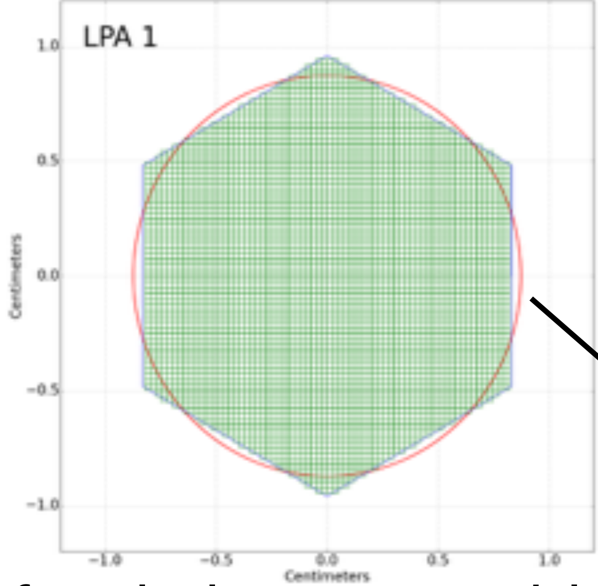


- Reconstructed bulk motion velocity field of the hot intra-cluster gas for a 50 ks X-IFU observation of the central parts of a Perseus like cluster considered at a redshift of 0.1

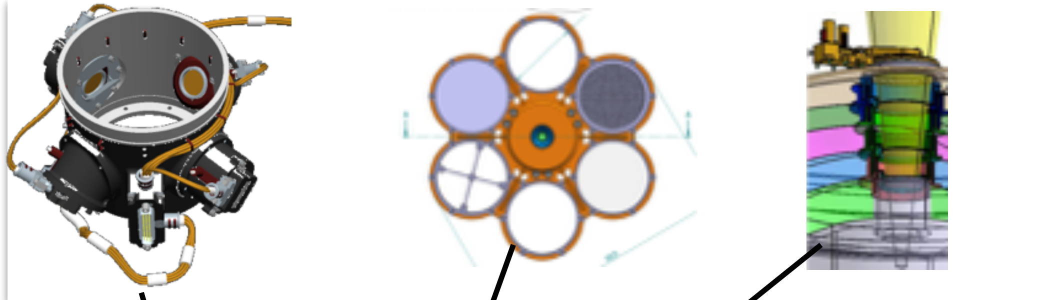
- Simulated X-IFU spectrum of a z = 1 galaxy group with kT = 3 keV and L_X = 1 x 10^{44} erg/s for 50 ks. Emission lines from elements which are key to understand chemical evolution can be clearly seen.

X-IFU design

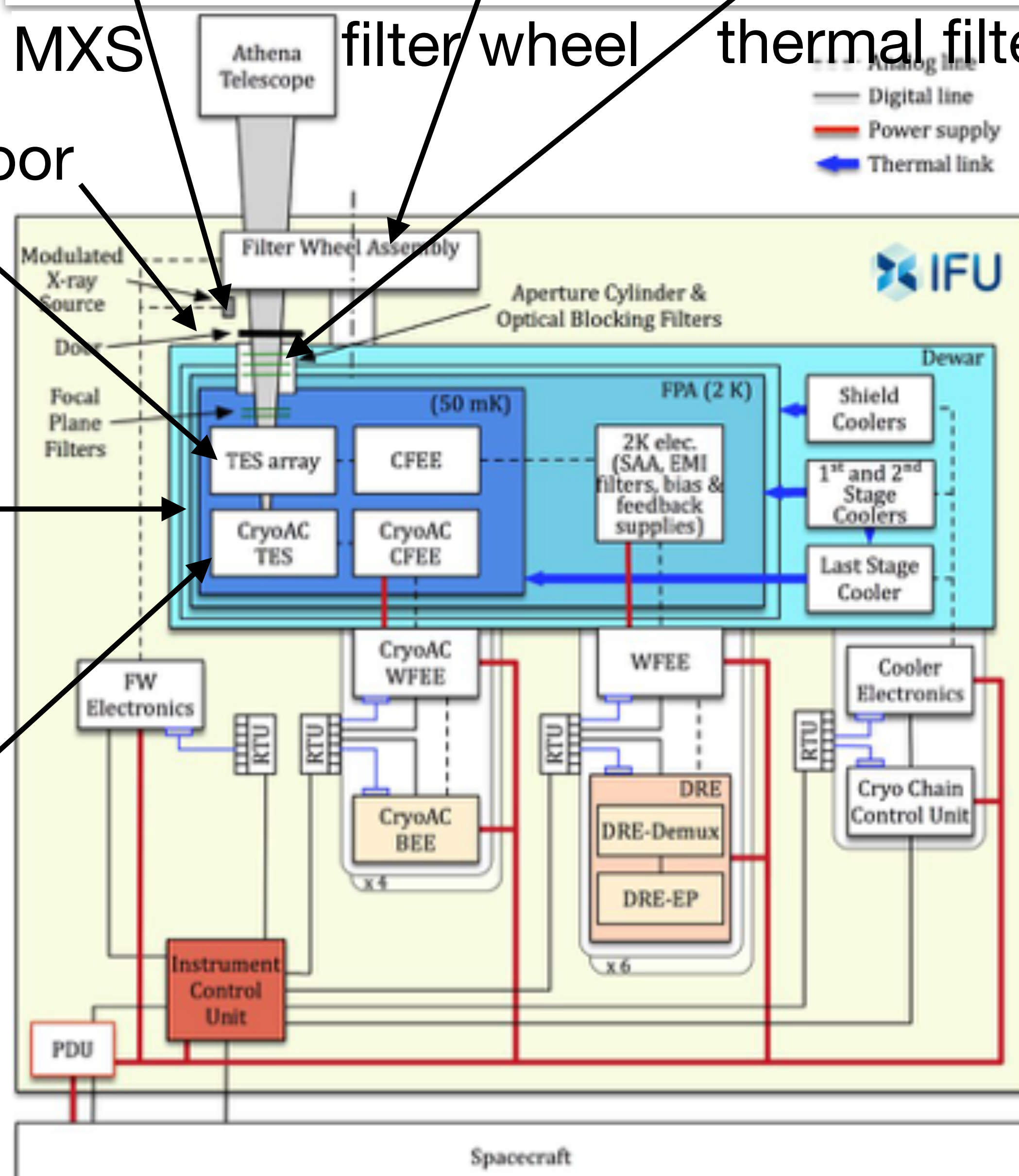
microcalorimeter array



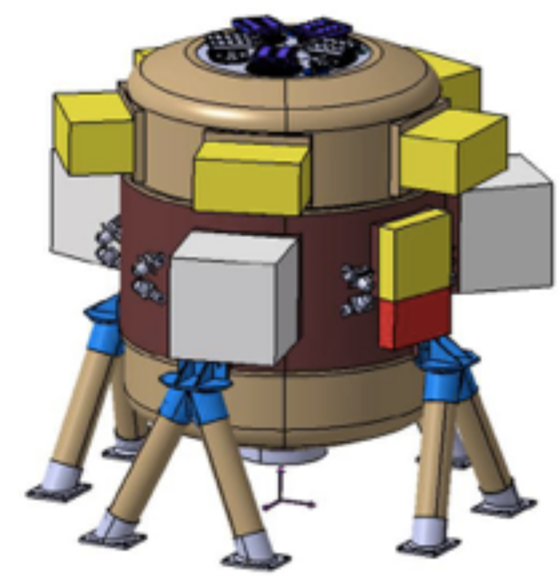
MXS filter wheel thermal filters



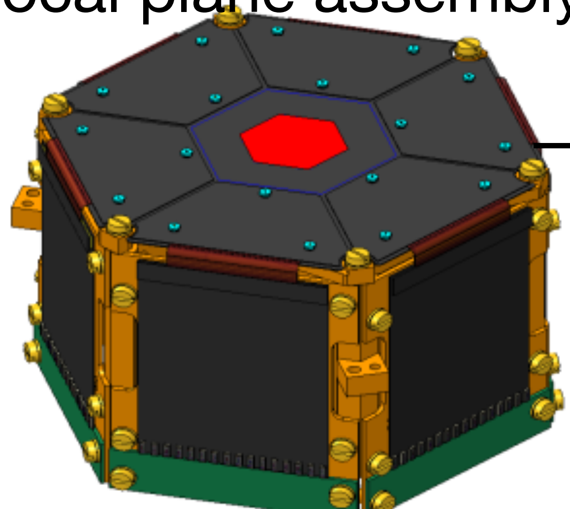
door



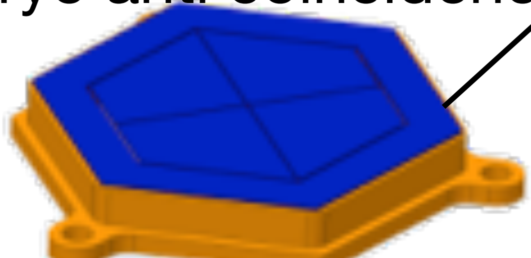
dewar



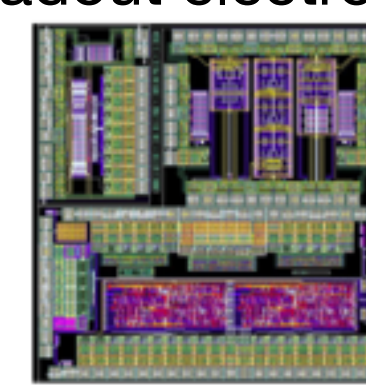
focal plane assembly



cryo anti coincidence



readout electronics



X-IFU key design driving items (1)

- Detectors
  - Allocation 2.1 eV -> X-IFU energy resolution budget
  - Detector speed /event record -> X-IFU count rate capability
  - 3840 microcalorimeter array with Mo/Au TES from NASA-Goddard (SRON backup) under AC bias
  - Intrinsic energy resolution
  - Operation of TES under AC bias
  - Extreme sensitivity to EMI/EMC, magnetic field, microphonics

(Goodwin Pappas+ O-23, Gottardi+ O-24, Wakeham+ O-27, Sakai+ PA-40, Khosropanah+ PA-41, Nagayoshi+ PA-47, Miniussi+ PA-50, Ridder+ PC-22)

X-IFU key design driving items (2)

- Readout chain
  - Allocation 1.2 eV -> X-IFU energy resolution budget
  - Frequency domain multiplexing 1-5 MHz range with 40 pixels for each 96 chains
  - Cryogenic two stage SQUID amplification and low noise amplifier at ambiant temperature
  - Base Band Feedback implementation to linearize SQUID operation
  - Event processor based on optimal filtering and pulse templates
  - Digital to Analog Converter
  - Crosstalk
  - Gain/thermal stability and monitoring with Modulated X-ray Source -> X-IFU energy scale

(Prêle+ O-59, Akamatsu+ O-60, Bruijn+ O-75, den Hartog +PB-3, van der Kuur+ PB-13, DeNigris+ PC-14, Cucchetti+ PE-49)

X-IFU key design driving items (3)

- Cryogenic chain and aperture cylinder
  - Allocation 0.6 eV -> X-IFU energy resolution budget
  - Rejection of IR-visible-UV photons and EMI
  - 50 mK base temperature with 0.9µK rms thermal stability
  - Thermal filters including mesh insuring EMI immunity
  - Impact of Cosmic Ray on thermal stability of the detector
  - Preserving the X-ray Quantum Efficiency

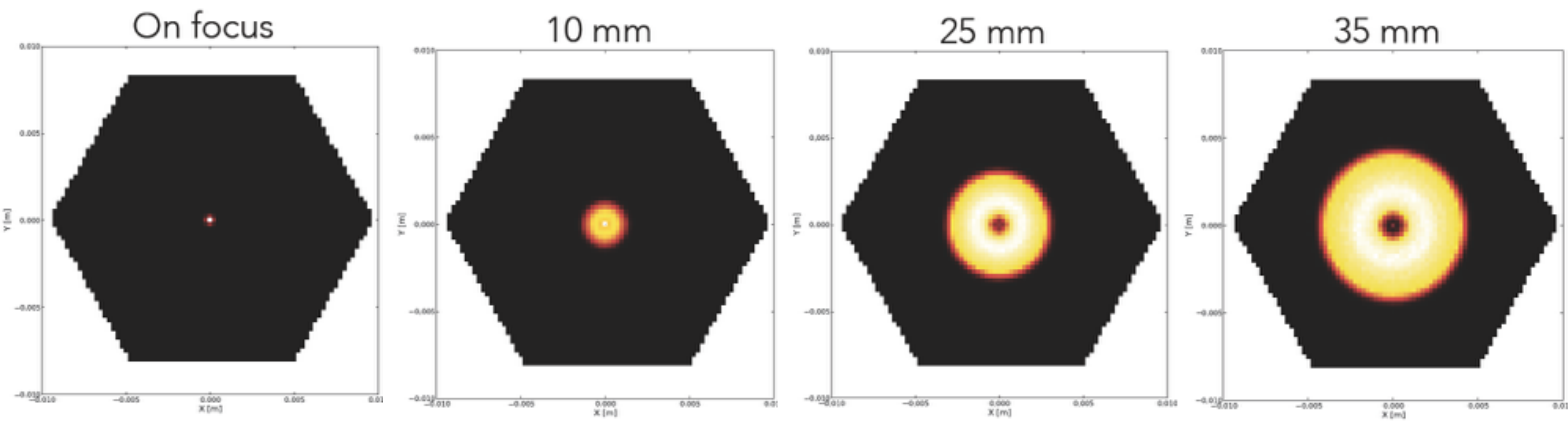
  (Yamasaki+ PD-17, Sciortino+ O-82, Barbera+ PE-62)

- Cryogenic anti-coincidence detector
  - Rejecting non X-ray events (cosmic rays, …) to 5 10^{-3} counts/s/cm^2/keV -> low brightness capability
  - Active 4 TES pixels Cryo AC below the X-ray detector array
  - Secondary electrons/back scattering on array

  (Biasotti+ PE-47, D'Andrea+ PE-52, D'Andrea+ PE-53)

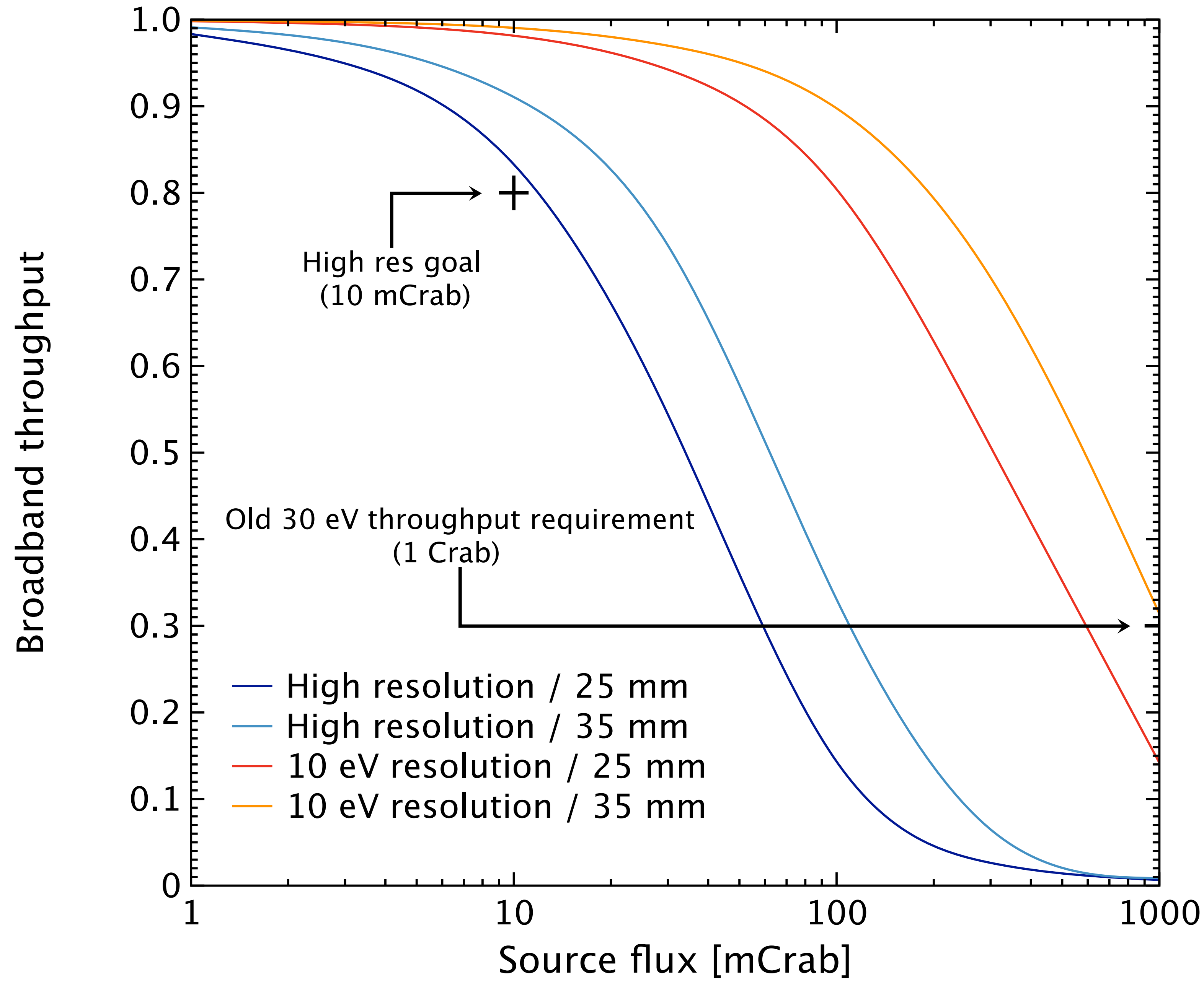
High count rate and defocussing

- Mirror defocus capability up to 35 mm is now in the baseline
- Spreading of the PSF over an increasingly larger number of pixels
  - Allows enhanced throughput on point sources
    (at the cost of a loss of imaging capabilities of these point sources)



Courtesy of D. Willingale

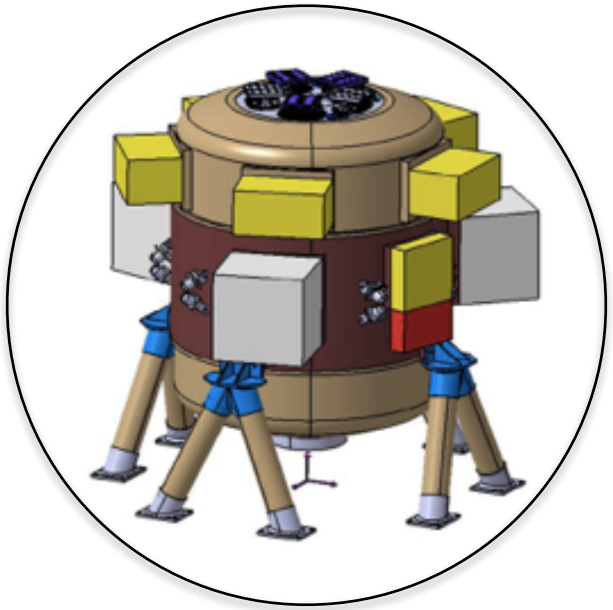
Count rate capability

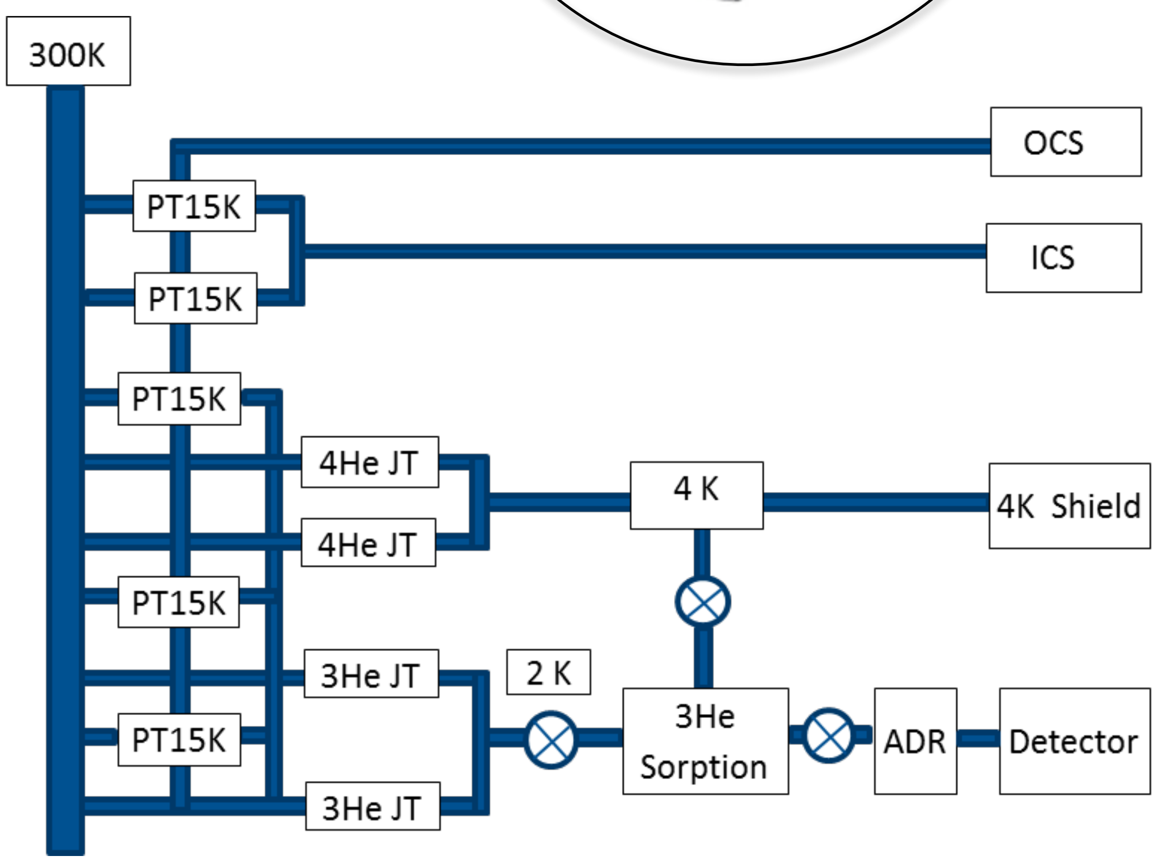


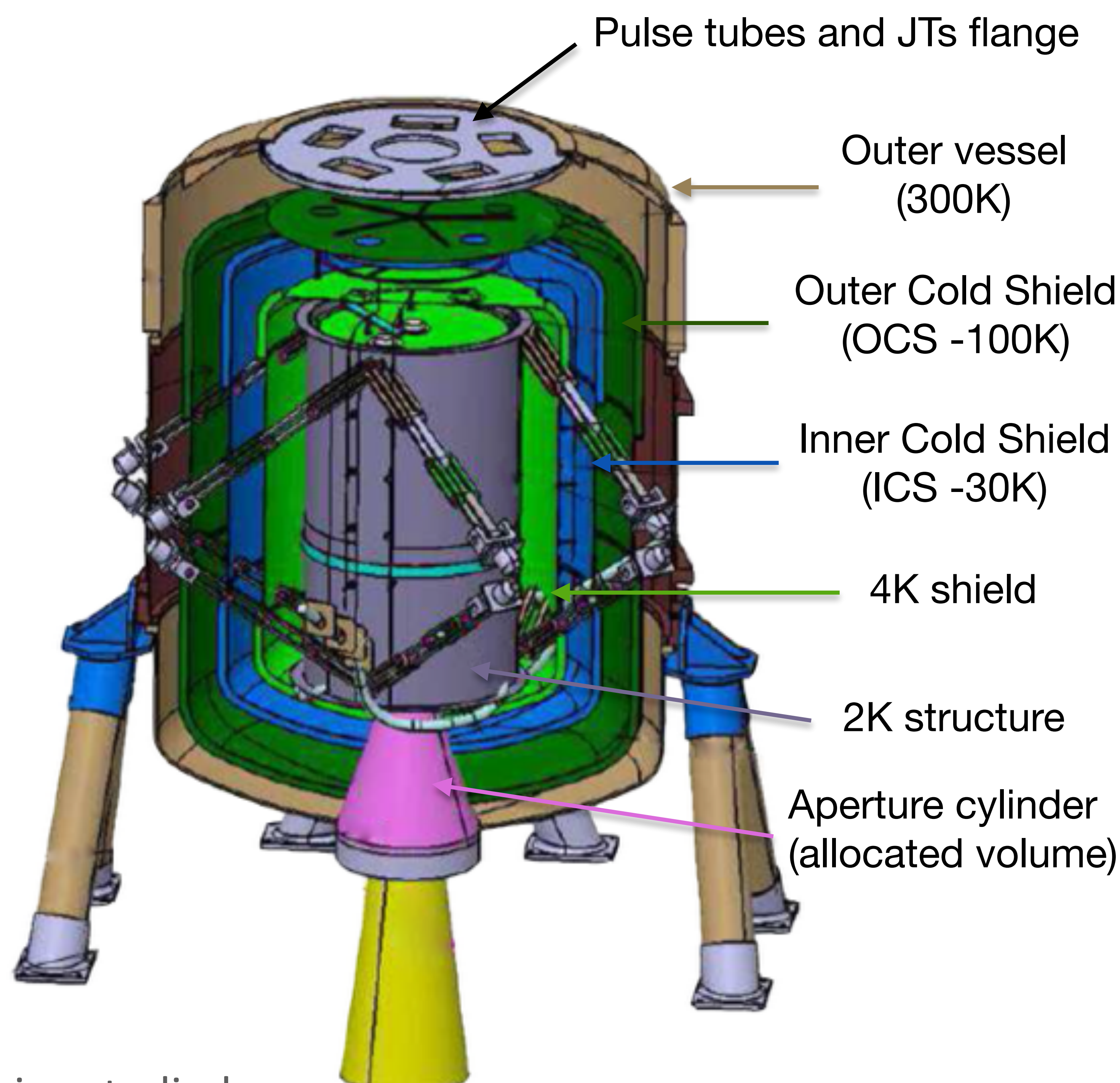
(See Peille+ PE-45)

- Exceeds goal requirement at 10 mCrab (high resolution) and 1 Crab (10 eV resolution)
- Even higher count rate in the 5-8 keV band with use of a beryllium filter

Cryochain and dewar



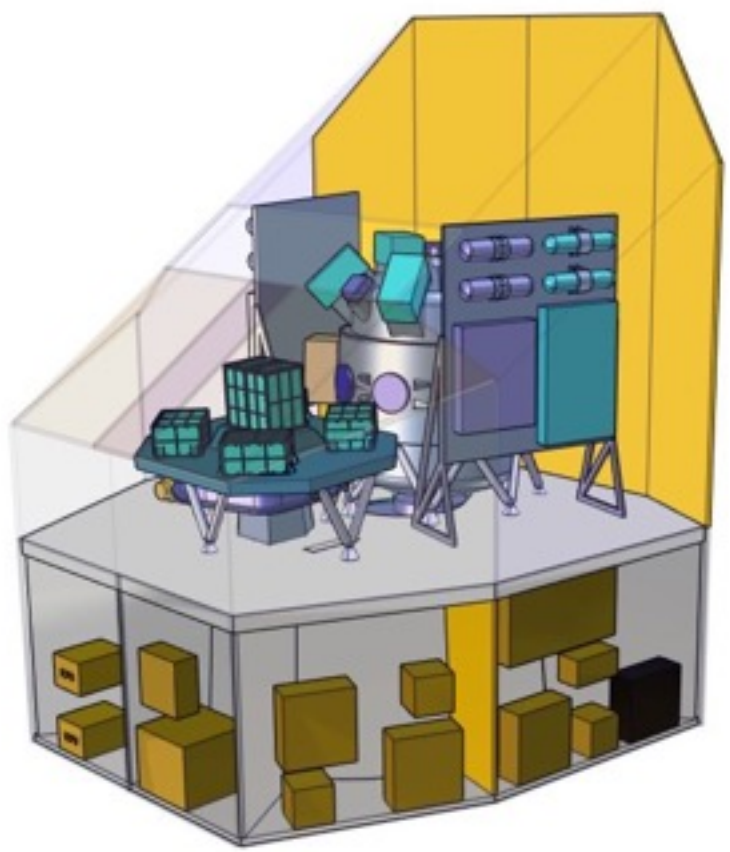




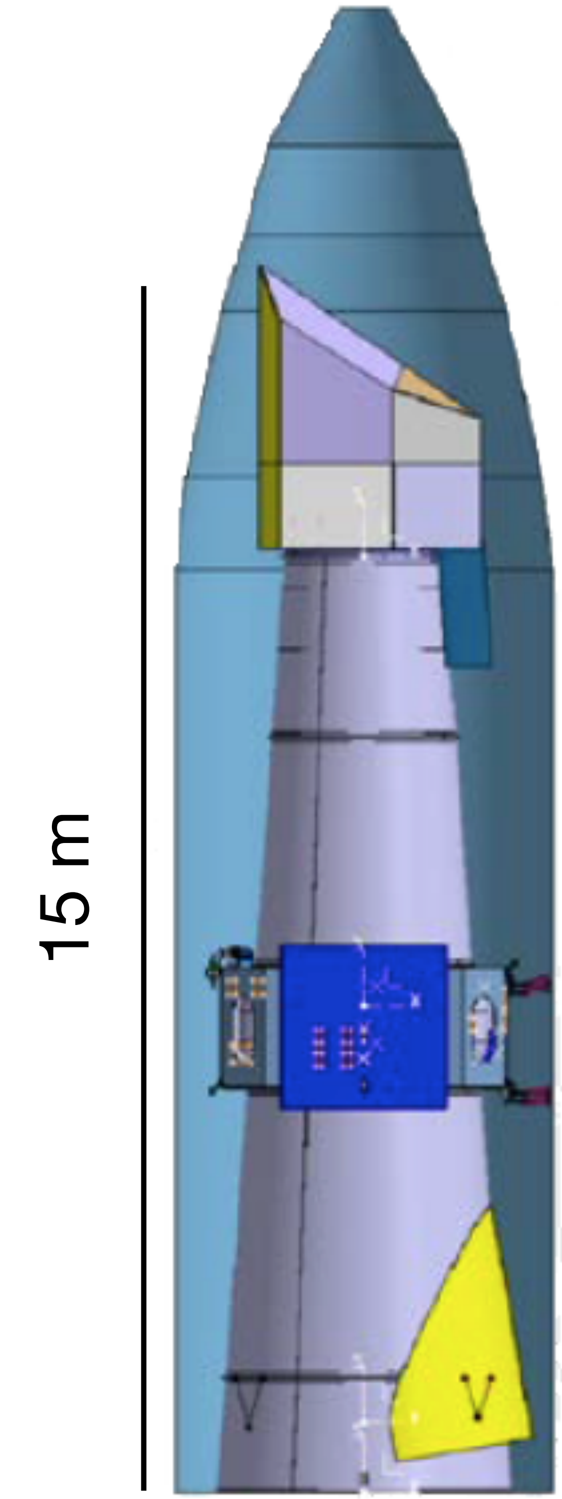
- Present baseline, a simplified cryochain is being studied

X-IFU design status

- Current status: a ~800 kg instrument
  - Optimization in progress (mass, power consumption, margins)
  - Progressing well towards TRL 5 in key technologies
- Phase A until end of 2018 (might evolve)
- Phase B1 up to mission adoption in June 2020



Science Instrument Module



Conclusion

- Thanks to challenging and innovative technologies in microcalorimeters operated at low temperature, X-IFU will provide breakthrough capabilities in high resolution X-ray spectroscopy for the study of the hot and energetic Universe.