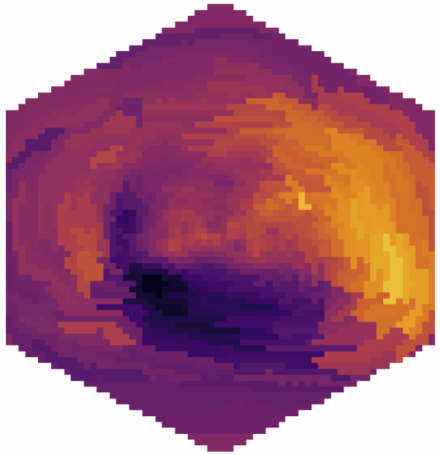
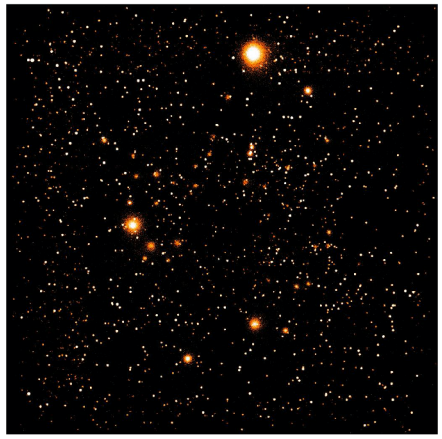
ATHENA



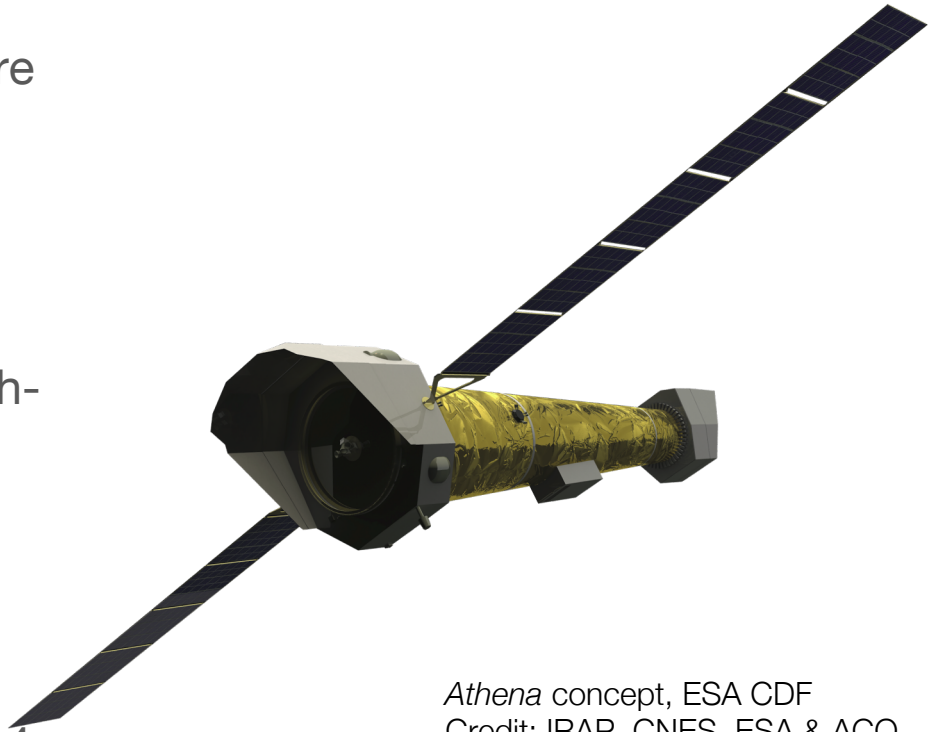
Athena: The Advanced Telescope for High Energy Astrophysics



Rob Petre
NASA Athena Project Scientist
NASA / GSFC

Athena mission concept

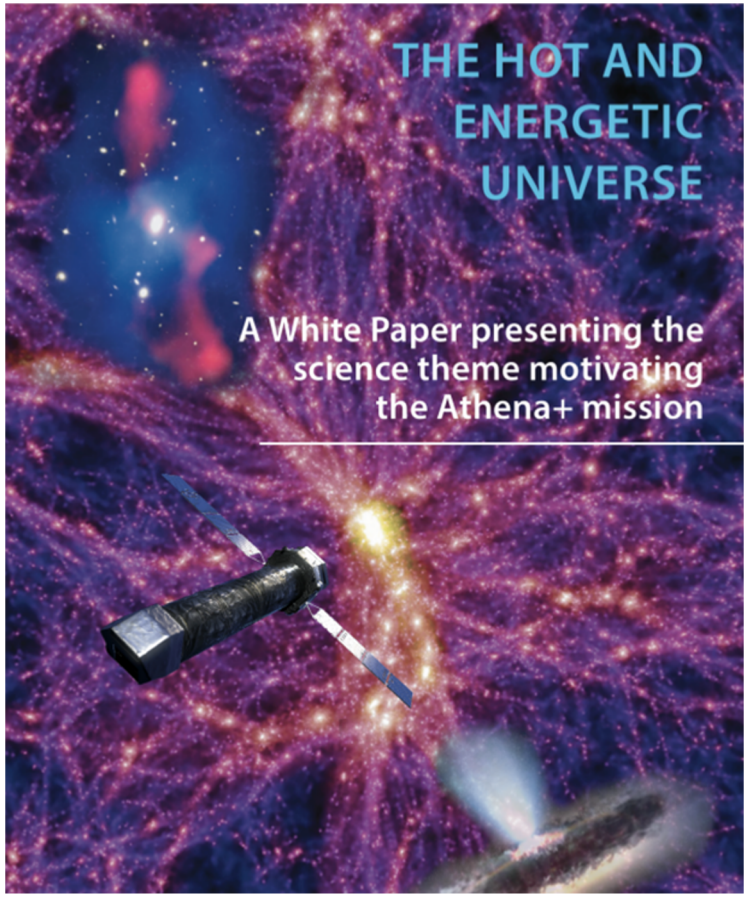
- Second large ESA Cosmic Visions mission
- Single telescope, using Si pore optics. 12m focal length
  - Wide Field Imager (WFI): sensitive imaging & timing
  - X-ray Integral Field Unit (X-IFU): spatially resolved high-resolution spectroscopy
- Movable mirror assembly to switch between the two instruments
- Launch early 2030s, Ariane 6.4
- L1 halo orbit
- Lifetime: 4 yr + possible extensions (designed for 10 yr)



Athena concept, ESA CDF
Credit: IRAP, CNES, ESA & ACO

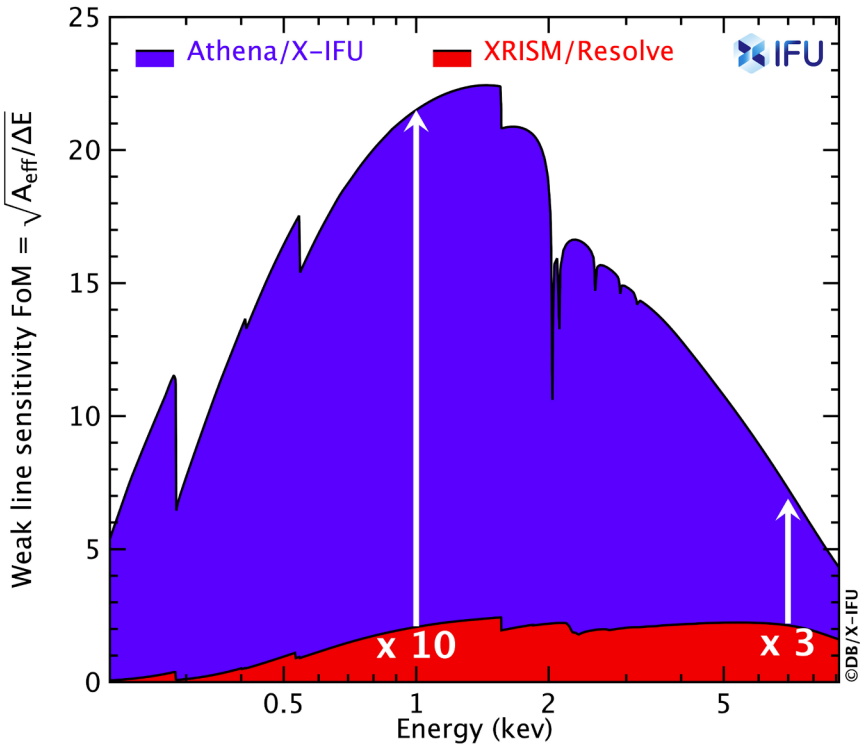
The Hot and Energetic Universe

- The Hot Universe: How does ordinary matter assemble into the large-scale structures that we see today?
  - >50% of the baryons today are in a hot (>10^6 K) phase
  - There are as many hot (> 10^7 K) baryons in clusters as in stars over the entire Universe
- The Energetic Universe: How do black holes grow and influence the Universe?
  - Building a SMBH releases 30× the binding energy of a galaxy
  - 15% of the energy output in the Universe is in X-rays

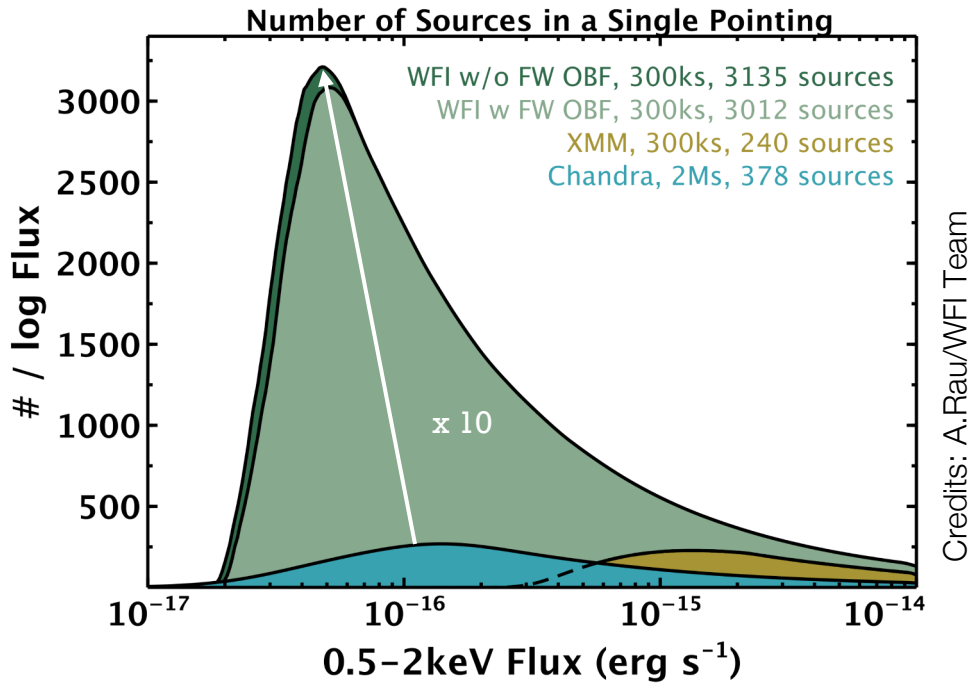


Nandra, Barret, Barcons et al. arXiv:1306.2307

Athena: a transformational observatory



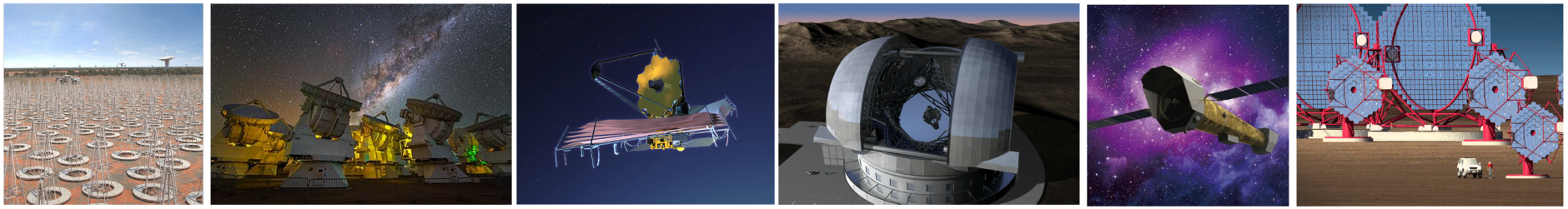
Weak line sensitivity comparison between X-IFU and XRISM

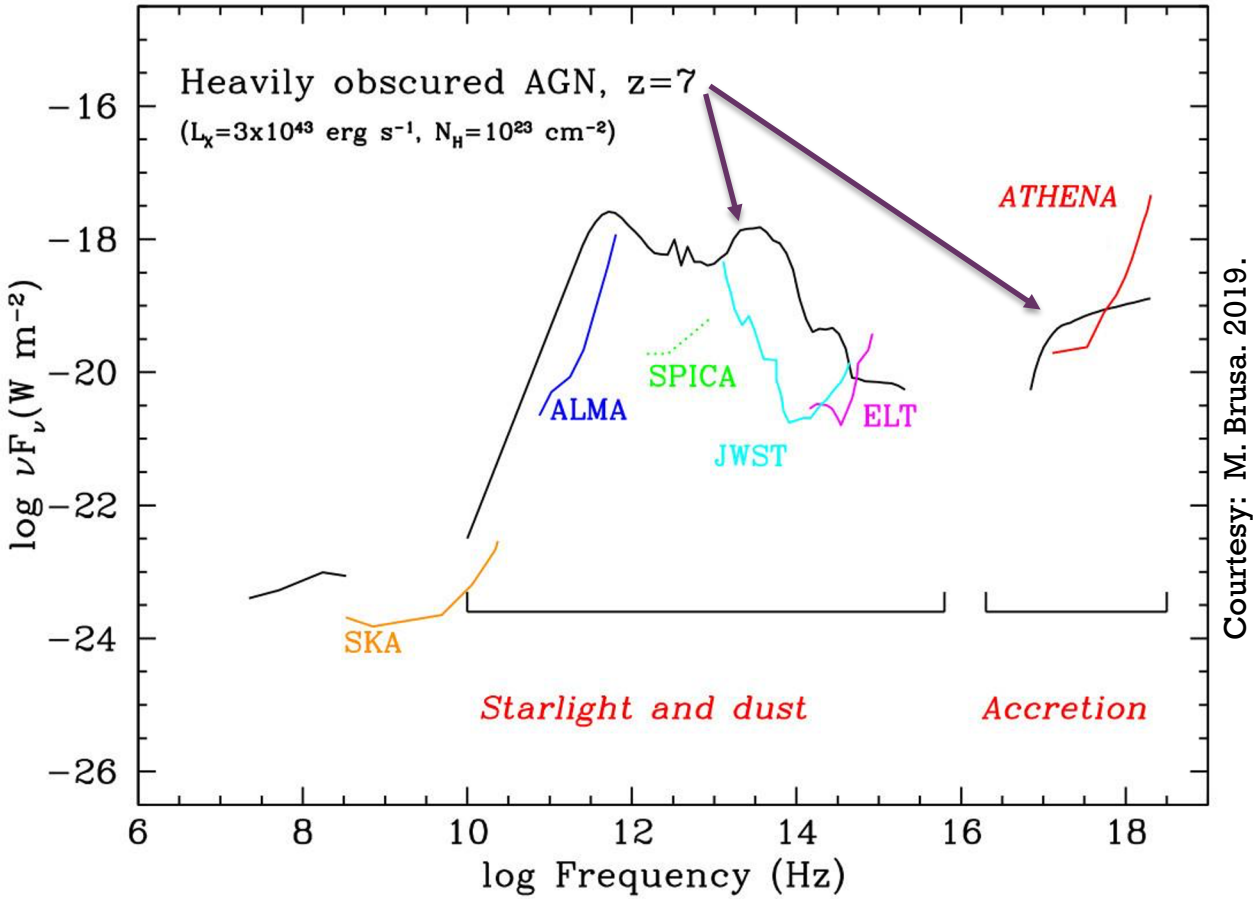


Number of sources per log flux that can be detected in a single pointing with WFI compared to XMM-*Newton* & Chandra

Athena in the framework of the early 2030s

SKA ALMA *JWST* ELT *Athena* CTA





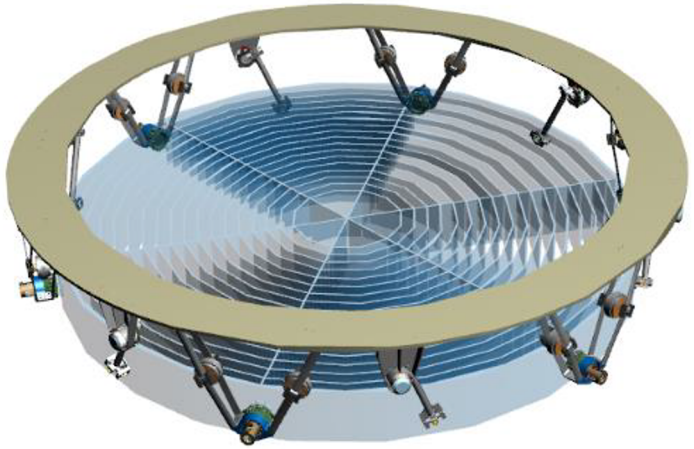
Courtesy: M. Brusa. 2019.

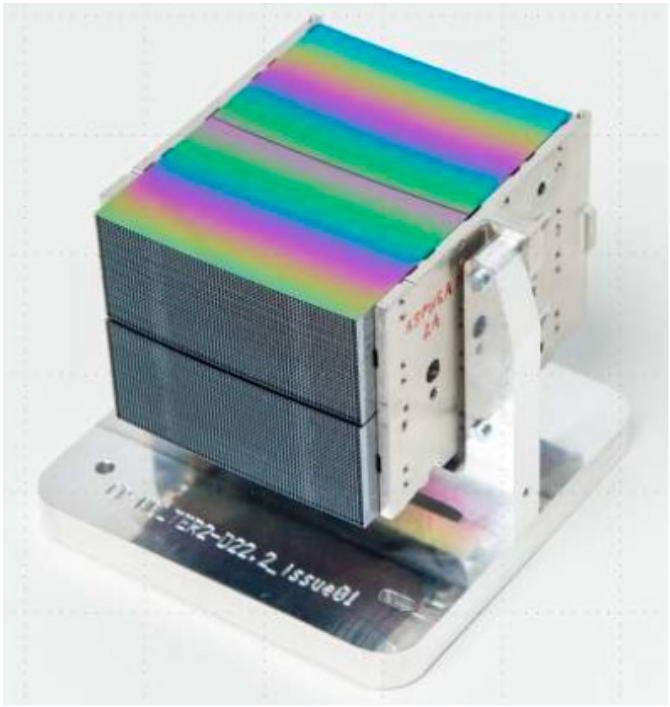
Athena will fill a gaping hole in the multi-wavelength and multi-messenger parameter space in the early 2030's and reveals otherwise unobservable aspects of cosmic sources.

The *Athena* X-ray mirror

- *Athena* optics development:
  - Light-weight Si-pore optics
  - Grazing incidence optics with modified Wolter-Schwarzschild type I geometry optimized to provide wide flat field imaging
  - Vigorous development program on-going

- Performance Goals:
  - 5″ HEW on-axis
  - Graceful degradation off-axis
    HEW <10″ @ 30′
  - ≥1.4 m^2 effective area @ 1 keV
    0.25 m^2 effective area @ 6 keV (TBR)





Cosine/ESA

ATHENA – Study Status (from ESA) - 1

Mission & SC

- Mission Adoption Review in February 2023
- Spacecraft ITT (= RFP) expected to be released in late 2023. Meanwhile, carrying parallel study contracts with Airbus and Thales-Alenia
- Both candidate SC designs are stable – some design optimization to lower overall mass (to relieve SIM mass NC – see below)
- SC Primes are currently focusing on Mirror Assembly Module (MAM), in support of the MAM<>SC interface and the MAM Demonstrator (MAMD) activities, as well as answering outstanding issues from the SC Interface Review
- ATHENA custom adaptor design concept by Arianespace/CASA ~completed, geometry confirmed (I/F plane height) and mass estimate received (slightly above internal estimate used to-date)
- Ariane-64 performance estimate increased significantly, but no final decision on mass allocation to the SC

SIM (Science Instrument Module) & Payloads

- SIM-IR completed in May, main problem identified was a non-compliance against the NTE mass (2,500 kg) - mass reduction exercise (also payloads); increased A-64 performance estimate seems to have solved this.
- The X-IFU Detector Cooling System (DCS) activity first cool-down expected Q3_2022, in addition to a significant number of subsystem and component-level demonstration activities already ongoing and continuing through adoption
- For the WFI, demonstration activities under national funding are underway to demonstrate TRL 5-6
- The new SIM definition activities and the X-IFU key technology demonstrations are currently driving the mission adoption date (closely followed by the optics developments)

ATHENA – Study Status (from ESA) - 2

Optics Technology Development

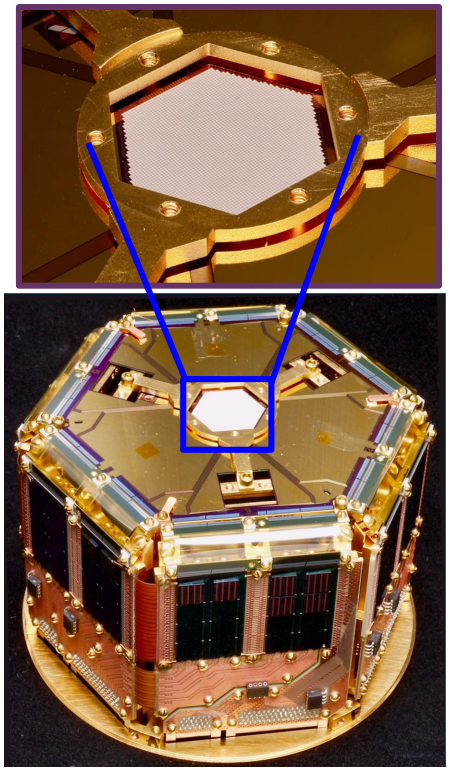
- SPO technology development continues; 2022 will be essential to understand what performance can actually be reached (IBF machine procurement delayed, arrives Q2 '22), and the Red Book preparation has been delayed to allow 2022 results to be factored into the assumed performance
- Mirror demonstrator activities with each candidate SC Prime are at CDR-stage, SC Primes shortly to manufacture a pocket demonstrator (one 60° segment) to provide pre-demonstration prior to manufacturing the full-size demonstrator for mechanical testing in 2024
- The reference mirror layout is stable, with some micron-level updates underway as a consequence of additional specification to define the plate curvatures – these small adjustments do not affect the MM<>SC interface

International Contributions

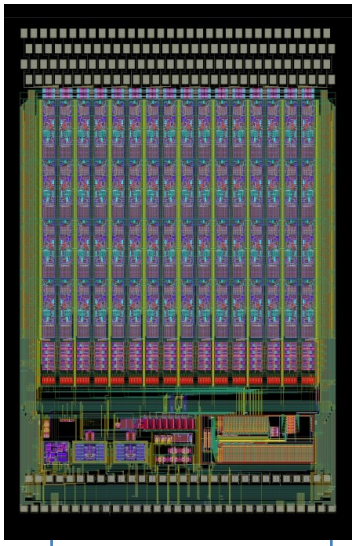
- NASA existing international contributions are stable
- Preparation of the XRCF facility (for X-ray testing of the selected mirror) is ramping up; 3 month feasibility study by Moog for the hexapod and position/metrology completed with the result that it is feasible
    - MPE adaptor ring study passed PDR in August, CDR planned in December then proceed to manufacture in '22
    - NASA shall initiate procurement for up-righting jig before end '22
- JAXA contribution now only 2K JT stage – Study Team initiating planned activity with RAL/Hymatic for industrialization preparation to manufacture 4K JT RAL coolers

NASA contributions to ATHENA

- **NASA's hardware contributions are in the $100M-$150M range**
- **Contributions consist of various enabling technologies:**
  - X-IFU Focal Plane Array (GSFC) components
  - Use of NASA Testing Facilities (MSFC-XRCF) and involvement in mirror calibration
  - WFI VERITAS ASIC Design (Stanford, BNL)
  - WFI Background Analysis Model (BAM) Development (PSU, SAO, MIT, Stanford
  - Vibration Isolation System (Moog SoftRide)
- **Additional contributions will include:**
  - Science Ground Segment support
  - US Guest Observer Facility
  - Preparatory Science and Guest Observer programs



X-IFU-FPA

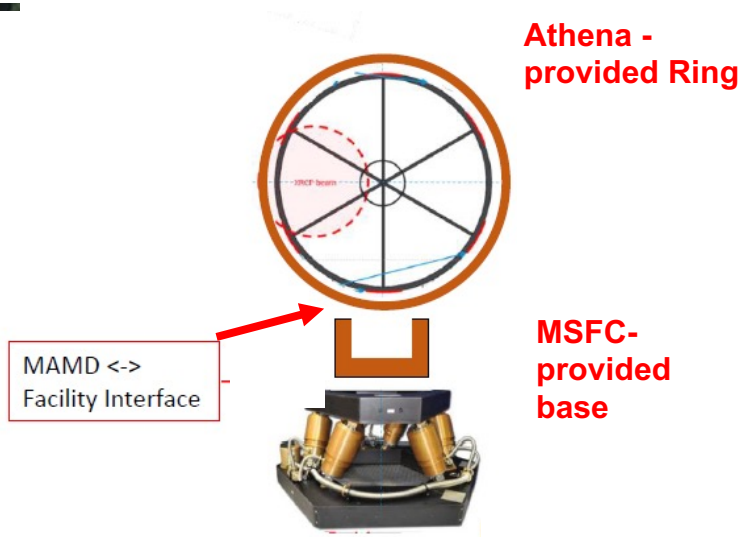


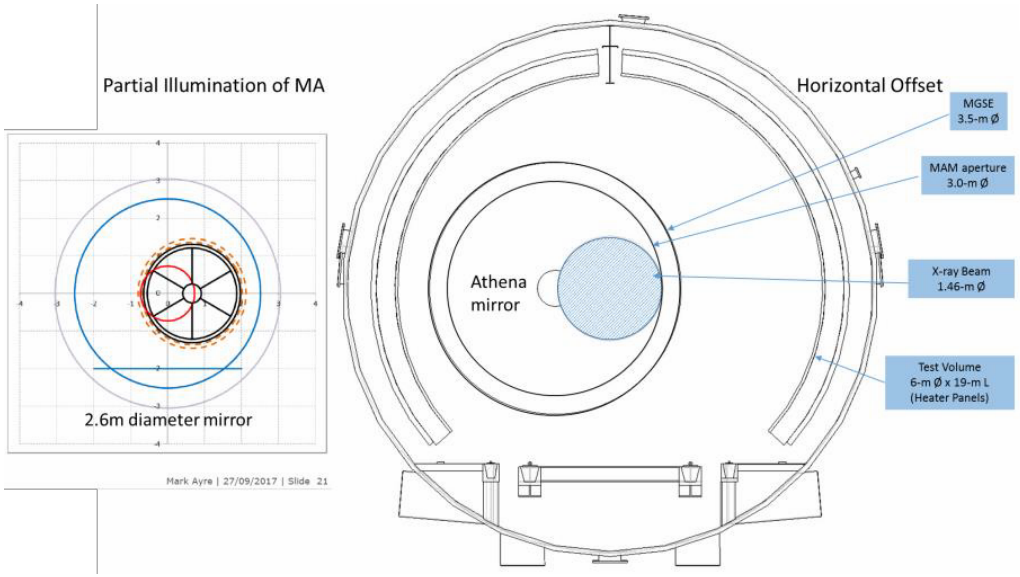
VERITAS ASIC Design

x 120

VIS
(Moog SoftRide Uniflex)

X-Ray and Cryogenic Facility for ATHENA Mirror Calibration



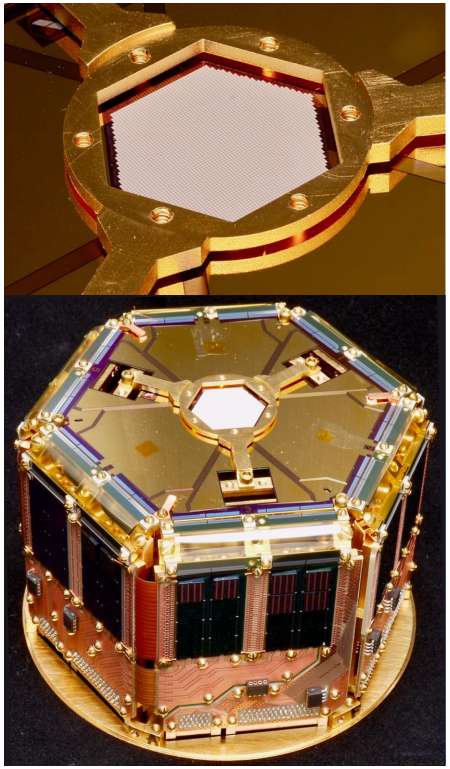


Currently planning MAMD verification (early 2024)

Primary interface between Athena MAMD assembly and XRCF MGSE defined

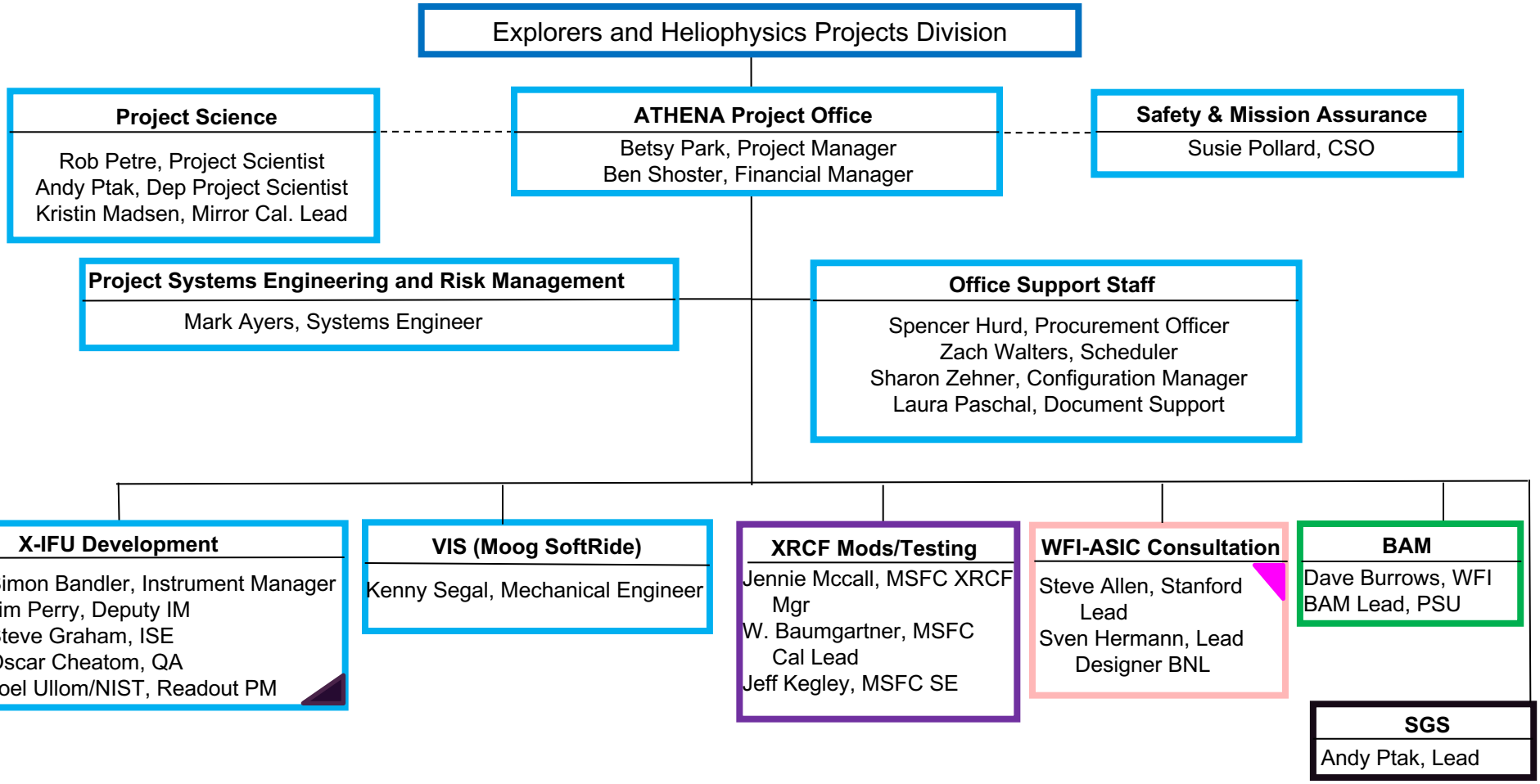
NASA Contributions - Status (1)

- **Programmatics**
  - Formulation Authorization Document signed Mar 16, 2021
  - Transition the APD ATHENA study to the EHPD ATHENA Project Office Oct 1, 2021
  - Preparations for Phase A Review leading to KDP A/B (August 2022)
- **X-IFU Focal Plane Assembly (GSFC)**
  - Demonstrated several TRL-5 milestones using brass-board detector
  - Engaged in CNES mass reduction exercise requested by ESA, looking at both readout and detector redesign options
  - NIST yielded the next generation of SQUID multiplexer chips with newer more symmetrized and differential designs
  - NIST generated and provided to GSFC updated side panel designs to match the recently updated NIST large-chip (4x34) readout designs
  - Completed extensive radiation testing campaign at UC Davis
- **Mirror Assembly Test and Calibration at XRCF**
  - Completed Moog short study; concluded existing Hexapod hardware can be used for ATHENA
  - Provided draft facility Contamination Control Plan to ESA for review



X-IFU-FPA

NASA ATHENA Project Organization



LEGEND

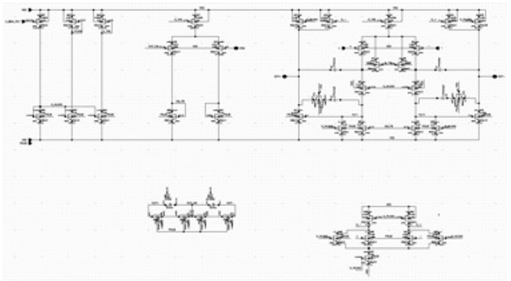
EHPD GSFC MSFC NIST PSU Stanford BNL

NASA Contributions - Status (2)

- **Vibration Isolation System**
  - Held joint NASA/Moog PSR with ESA Acceptance Review
  - Moog delivered Demonstrator Model isolators to GSFC for storage until shipment to ESA ~April 2022

Vibration Isolation System (Moog)

- **WFI ASIC Consultation**
  - Ported VERITAS 2.2 filter design to XFAB technology and performed optimization

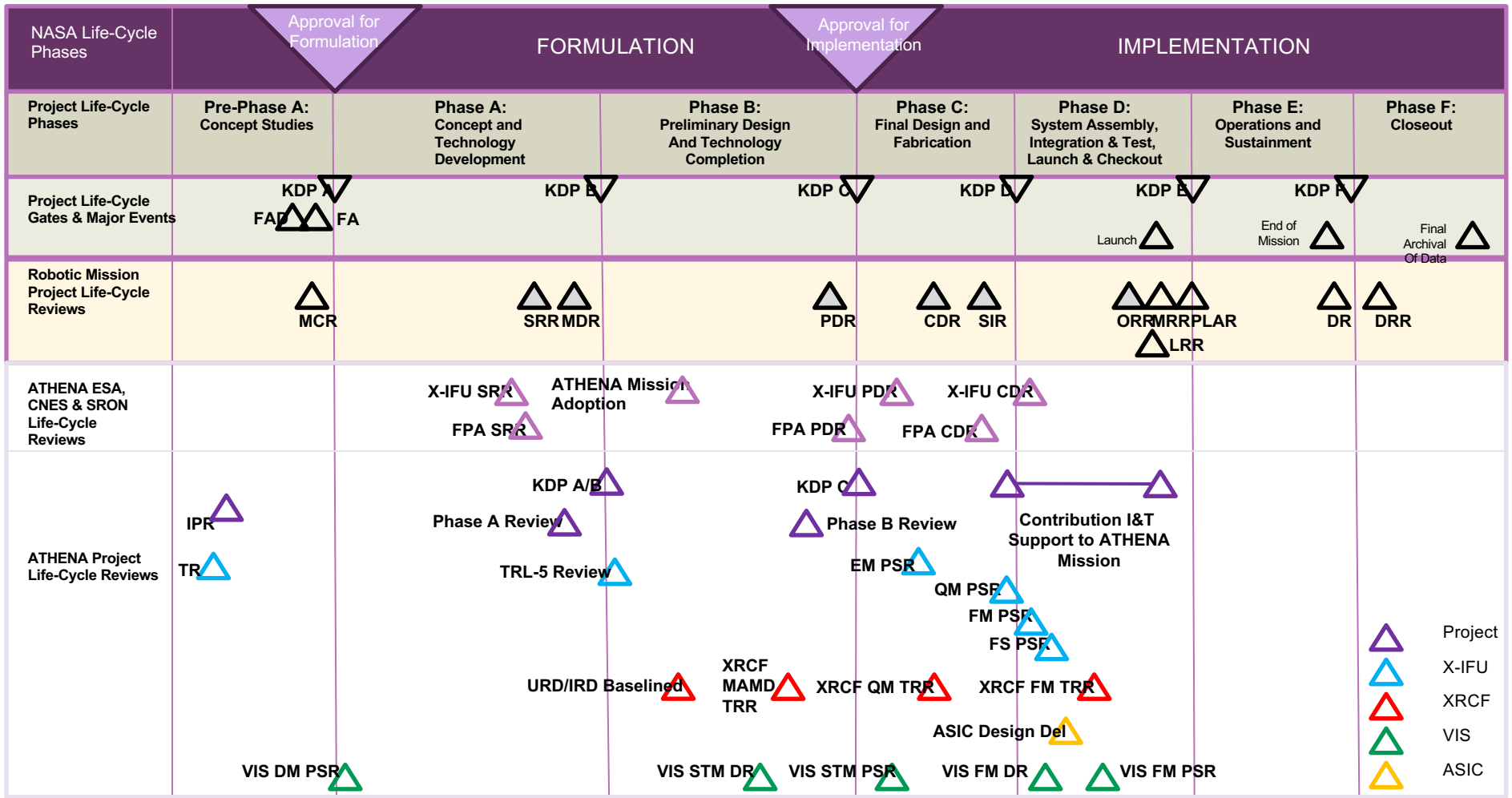


VERITAS ASIC Design (Stanford)

- **WFI Background Analysis Modeling**
  - Submitted papers and gave talks on WFI background
  - Comparing eROSITA (filter wheel closed) background with XMM pnCCD Small Window Mode (SWM) and XMM pnCCD Full Frame

ATHENA Project Lifecycle

Life-Cycle reviews that require SRB.



10/13/21

Peer Reviews, Subsystems PDFs, Subsystem CDRs, and Systems Reviews

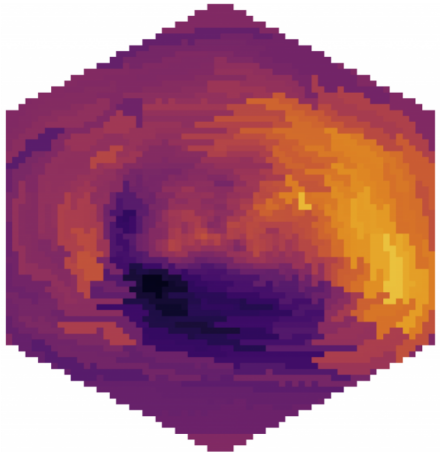
Note: Flexibility is allowed as long as the equivalent information is provided at each KDP and the approach is fully documented in the Project Plan.

Outlook

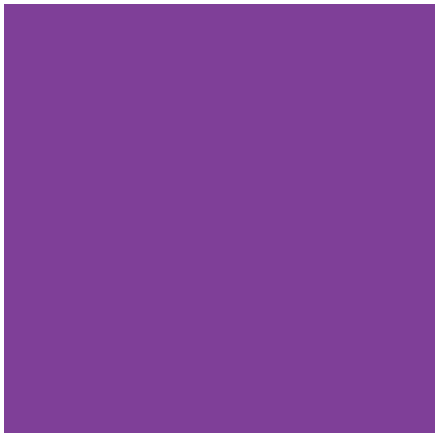
- *ATHENA* will be a transformational X-ray observatory
  - Designed to address the Hot and Energetic Universe science theme
  - Will impact virtually every corner of astronomy
- Progress continues on spacecraft, instruments, NASA contributions
- In US, ATHENA is now an official project, managed out of GSFC
- Key milestones: NASA KDP A/B (August 2022), Mission Adoption (Q1/2023) & launch early 2030s
- Current major concerns: 5 arcsec angular resolution is unlikely to be demonstrated by Adoption (and possibly ever); mirror design also does not meet effective area requirement. ASST is assessing revised science case in case only 10" is achieved.

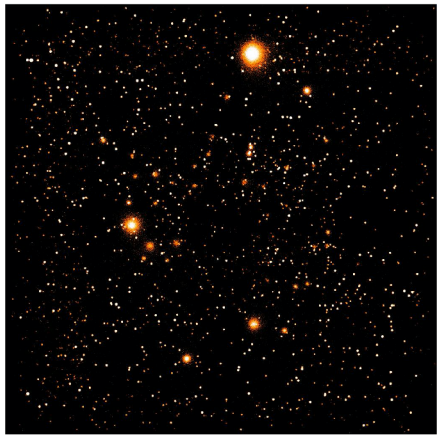
- Follow *Athena* on
  - Web: www.the-athena-x-ray-observatory.eu
  - Twitter: @AthenaXobs
  - Facebook: The Athena X-ray Observatory
  - *Athena* Community Office email: aco@ifca.unican.es

ATHENA



Backup





Athena Science Requirements

Parameter	value	enables (driving science goals)
Effective area at 1 keV	≥1.4 m^2	Early groups, cluster entropy and metal evolution, WHIM, high redshift AGN, census AGN, first generation of stars
Effective area at 6 keV	0.25 m^2 (TBR)	Cluster energetics (gas bulk motions and turbulence), AGN winds & outflows, SMBH & GBH spins
PSF HEW (≤ 7 keV)	5'' on axis (TBR), 10'' off axis	High z AGN, census of AGN, early groups, AGN feedback on cluster scales
X-IFU spectral resolution	2.5 eV 0.2-12 keV	WHIM, cluster hot gas energetics and AGN feedback on cluster scales, energetics of AGN outflows at z~1-4
X-IFU FoV	5' effective diameter	Metal production & dispersal, cluster energetics, WHIM
X-IFU background	< 5 10^{-3} counts/s/cm^2/keV 2-10keV	Cluster energetics & AGN feedback on cluster scales, metal production & dispersal
WFI spectral resolution	<80eV (1keV) & <170eV (7keV)	GBH spin, reverberation mapping
WFI FoV	40' x 40'	High-z AGN, census AGN, early groups, cluster entropy evolution, jet-induced cluster ripples
WFI count rate	1 Crab > 80%	GBH spin, reverberation mapping, accretion physics
WFI background	< 5 10^{-3} counts/s/cm^2/keV 2-7keV	Cluster entropy, cluster feedback, census AGN at z~1-4
Recons. astrometric error	1'' (3s)	High z AGNs
GRB trigger efficiency	50%	WHIM
ToO reaction time	≤ 4 hours	WHIM, first generation of stars

X-ray Integral Field Unit (X-IFU)

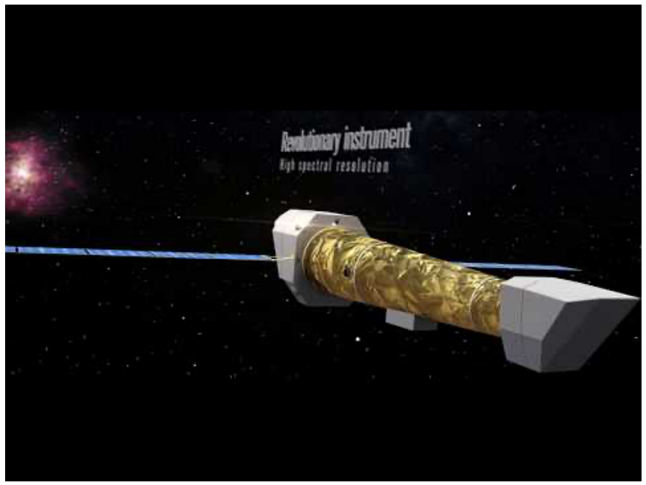
- Cryogenic imaging spectrometer, based on Transition Edge Sensors, operated at 50 mK featuring an active cryogenic background rejection subsystem

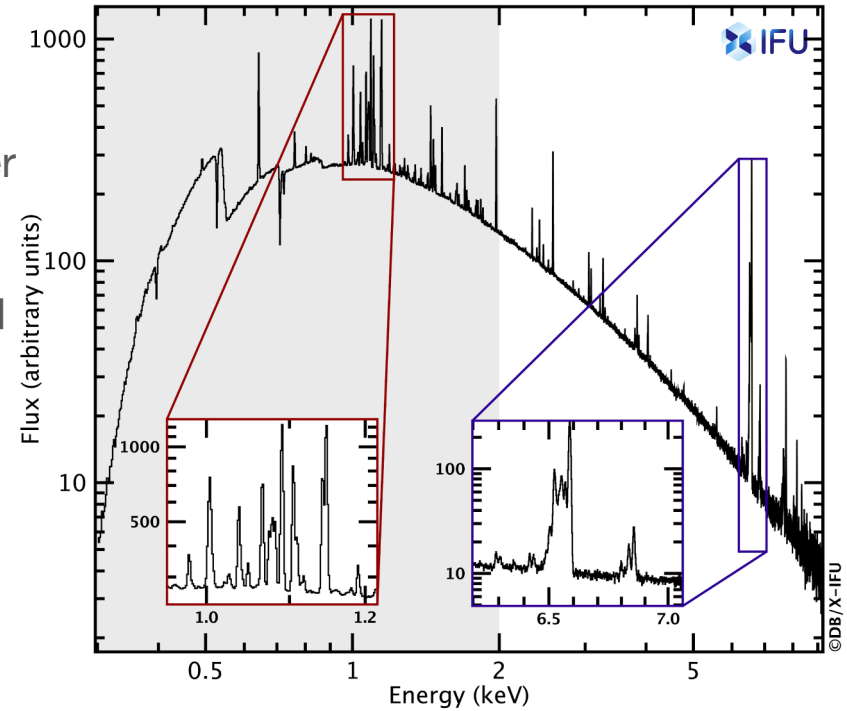
- Key performance parameters:
  - 2.5 eV energy resolution <7 keV
  - FoV 5´ diameter
  - Pixel size <5´´

- Consortium led by IRAP/CNES-F, with Netherlands and Italy and further ESA member state contributions from Belgium, Czech Republic, Finland, Germany, Ireland, Poland, Switzerland and contributions from Japan and the United States

- Providing both spatially-resolved high spectral resolution and high count rate capability

http://x-ifu.irap.omp.eu/

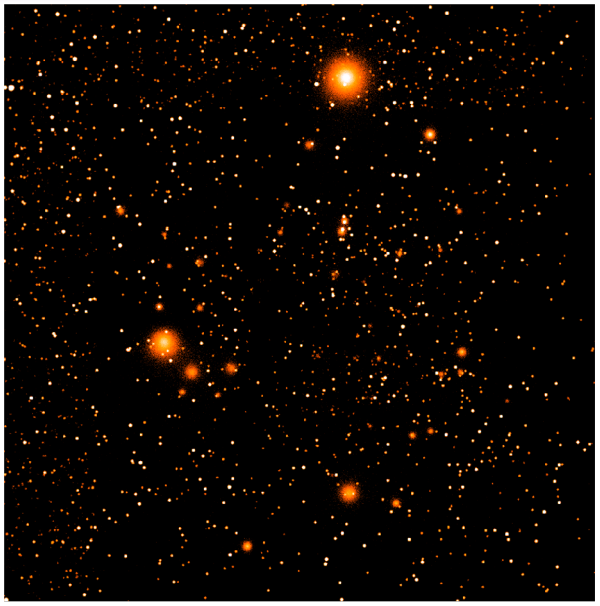




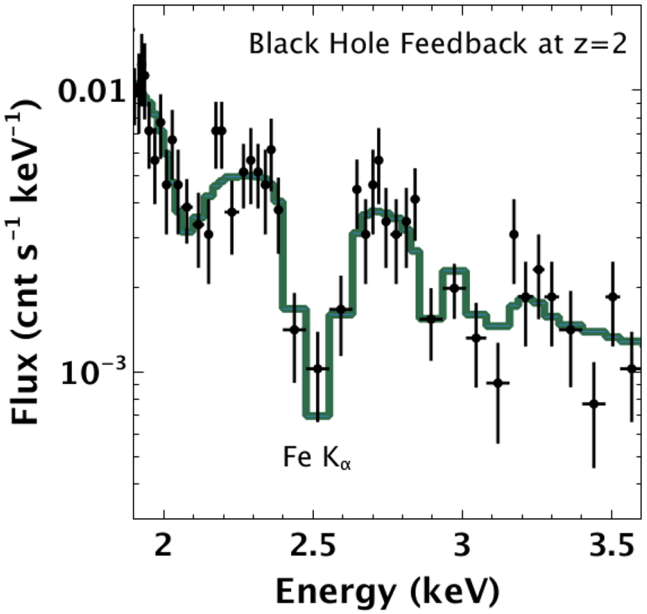
Credits: X-IFU Consortium

Wide Field Imager (WFI)

- Silicon Active Pixel Detector based on DEPFET technology
- Key performance parameters:
  - <80 (<170) eV spectral resol. @ 1 (7) keV
  - 2.2″ pixel size (PSF oversample)
  - Field of view: 40′×40′ square
  - Separate chip for fast readout of brightest sources
  - Readout speed up to ~30 MHz
- Consortium led by MPE, with other European partners (DE, AT, DK, FR, IT, PL, UK, CH, P & GR) and NASA
- Optimized for sensitive wide-field imaging and intermediate resolution spectroscopy, up to very bright sources



Credit: A.Rau/WFI team.



Credit: WFI team.

http://www.mpe.mpg.de/*ATHENA*-WFI/