The High Energy Astrophysics Group and the Athena mission

Scientific Council of APC

A. Lemière, A. Goldwurm
for the **AHE group**

Paris, 19-20 march 2020

The AHE group

33 Group Members : larger group at APC !

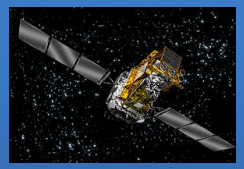
- 21 permanent researchers :
  - 10 CNRS
  - 7 EC *(6 Paris Diderot, 1 Paris Sud)*
  - 2 CEA
- 1 EMERITE, 1 scientific associate (CEA)
- 5 Post-docs
- 6 PhDs

- 14 APC members as secondary group
- 9 associated researchers *(CNRS,CEA, Observatoire,…)*

AHE Projects

10^3eV 10^6eV 10^9 eV 10^{12} eV 10^{15} eV 10^{18} eV 10^{21}eV

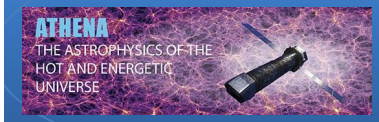
INTEGRAL



TARANIS microsat

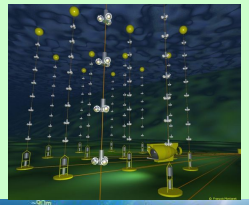
IGOSAT

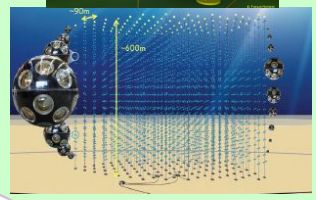
SVOM Eclairs GRB trigger



ATHENA

HESS & CTA



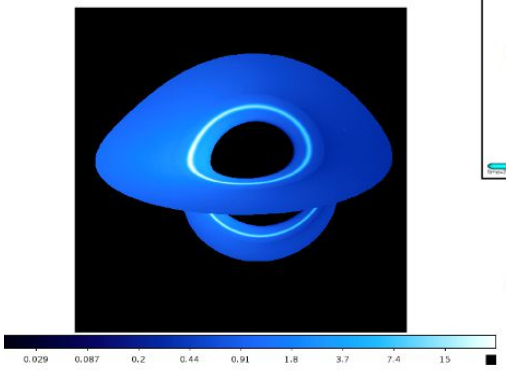


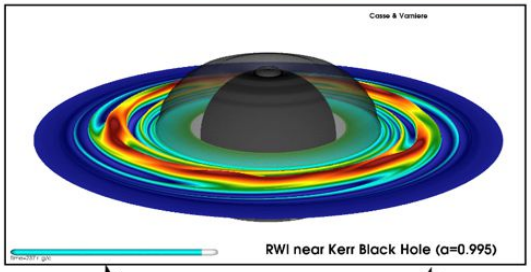
Antares & km3Net

EUSO-SPB/ Mini-EUSO
JEM-EUSO

Numerical Simulation

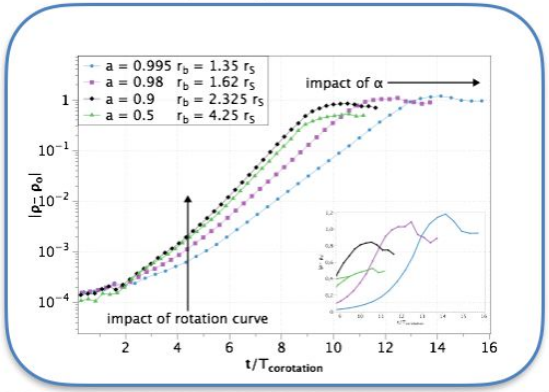
Temporal variability of compact objects: towards multi-messengers predictions





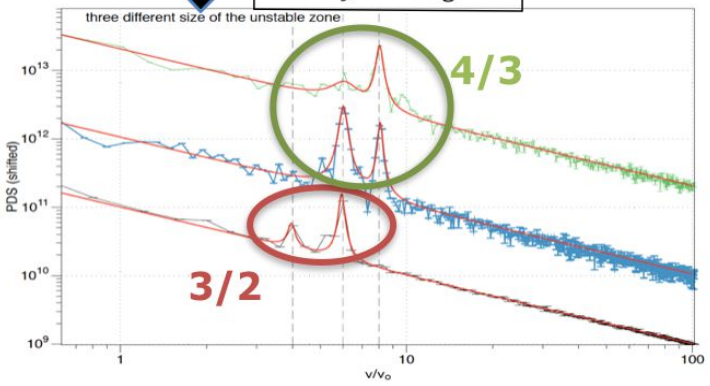
General Relativistic HD simulation

Casse & Varniere (2018)



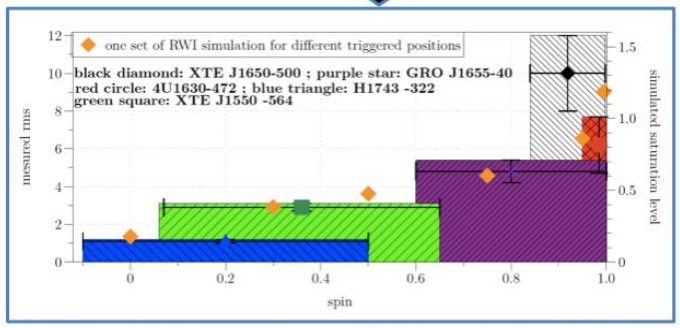
NOVAs prediction:
RWI = X-ray binary HFQPOs rms level increases with the spin of BH.

General Relativistic ray tracing



RWI can explain HFQPOs integer frequency ratios !

Varniere et al. (2019)

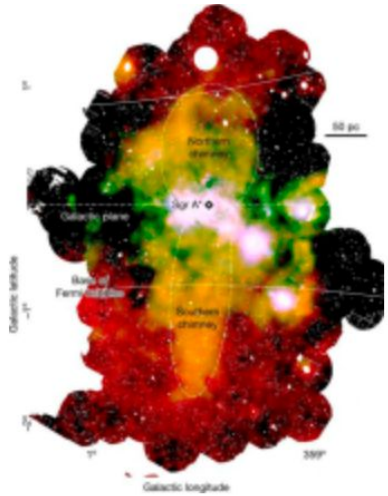


RXTE data support that prediction !

Theory

PeV Cosmic-rays (ANR Percora)

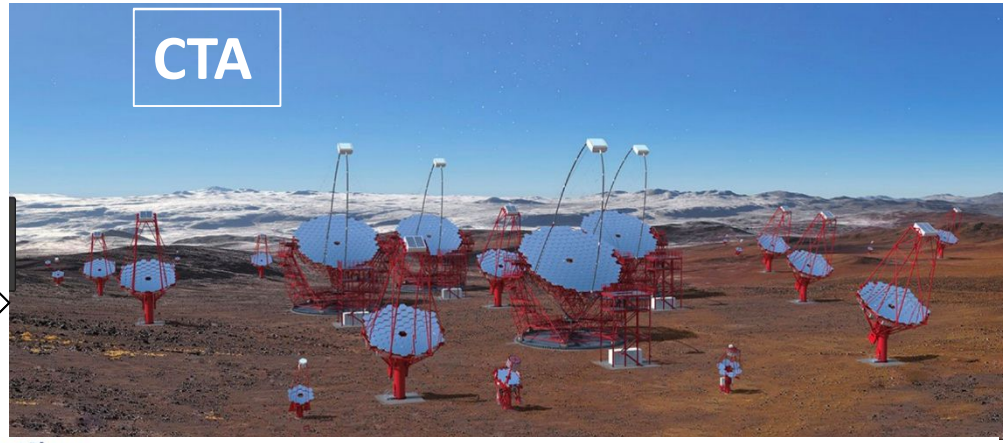
- Ponti, G. et al., *An X-ray chimney extending hundreds of parsecs above and below the Galactic Centre*, Nature, 567, 347 (2019)



- Jaupart, E., **Parizot, E.**, Allard, D., *Contribution of the Galactic centre to the local cosmic-ray flux,* A&A, 619, A12 (2018)
- **Recchia, S.**, Phan, V. H. M., Biswas, S., **Gabici, S.**, *Can a cosmic ray carrot explain the ionization level in diffuse molecular clouds?*, MNRAS, 485, 2276 (2019)
- Nava, L., **Recchia, S.**, **Gabici, S.**, Marcowith, A., Brahimi, L., Ptuskin, V., *Non-linear diffusion of cosmic rays escaping from supernova remnants - II. Hot ionized media*, MNRAS, 484, 2684 (2019)
- **Tatischeff, V.**, **Gabici, S.**, *Particle Acceleration by Supernova Shocks and Spallogenic Nucleosynthesis of Light Elements*, Ann. Rev. Nucl. Part. Sci., 68, 377 (2018)
- Cristofari, P., **Gabici, S.**, **Terrier, R.**, Humensky, T.B., *On the search for Galactic supernova remnant PeVatrons with current TeV instruments*, MNRAS, 479, 3415 (2018)

Gamma-ray Astronomy: HESS & CTA

Array of Tcherenkov telescopes



4 MSTsince 2003+ CT5 since 2012
Prolongement +3 years : up to 2022
Change CT5 camera (flashCam) summer 2019

High energy gamma-rays (30 GeV – 100 TeV)

NORTH

4 LST + 15 MST
1 LST on site taking data since oct 2019

High energy gamma-rays 20 GeV-20 TeV

SOUTH

4 LST + 25 MST + 70 SST
Site agreement finalized
SST harmonisation ongoing

High energy gamma-rays (20 GeV-300 TeV)

Gamma-ray astronomy at APC

High level tools

A Python package for gamma-ray astronomy

A prototype for the CTA science tools:DL3 data level. Spectrum, timing, 3D Fit, morphology, multi-instruments fit, multi-messenger fit.

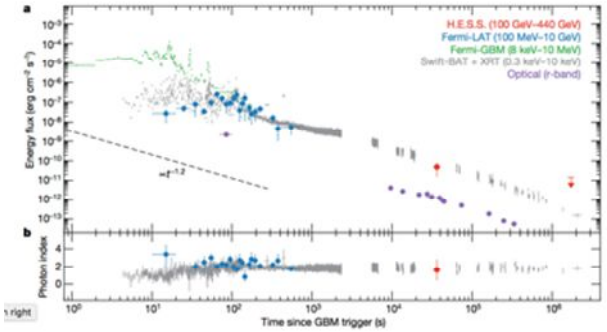
CTA PHP

Product aiming to manage the Guest Observer proposals

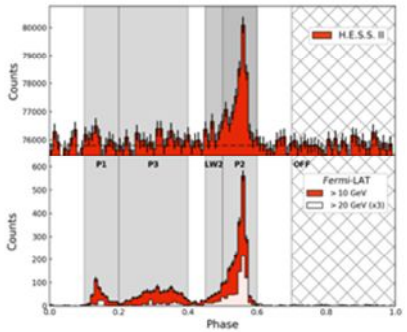
CTA Trigger

Central Trigger
Clock distribution (TDC)
Quality

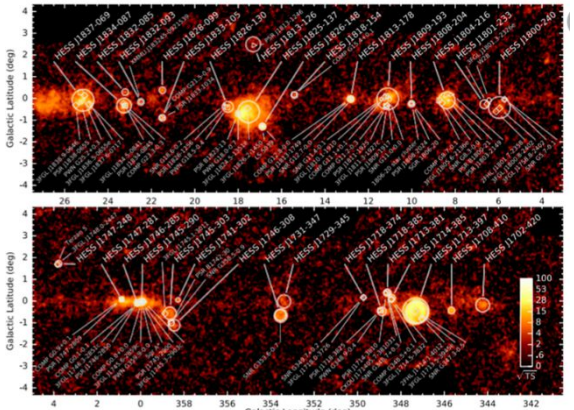
HESS data analysis and CTA PHYS



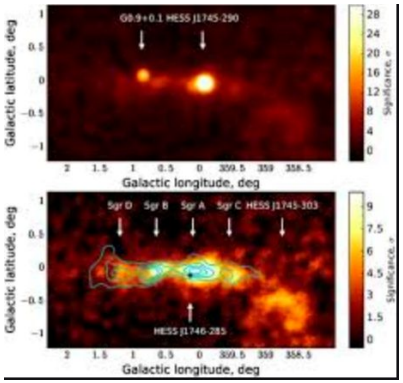
First VHE GRB detection !



Discovery of the pulsed HE emission of the Vela Pulsar



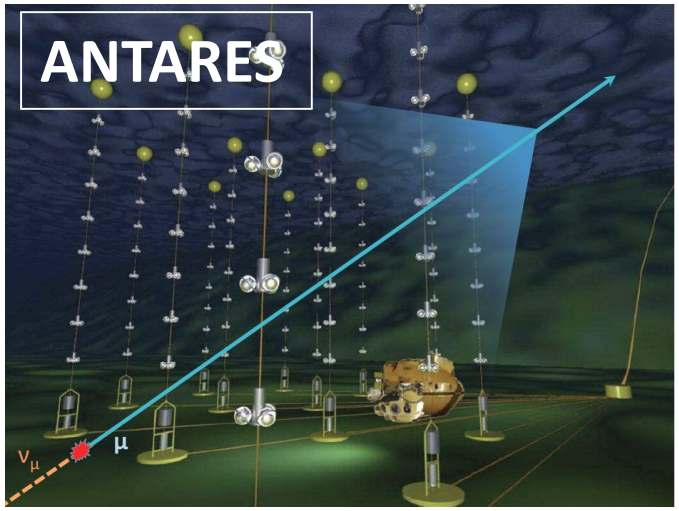
AGN, Blazars redshifts, EBL

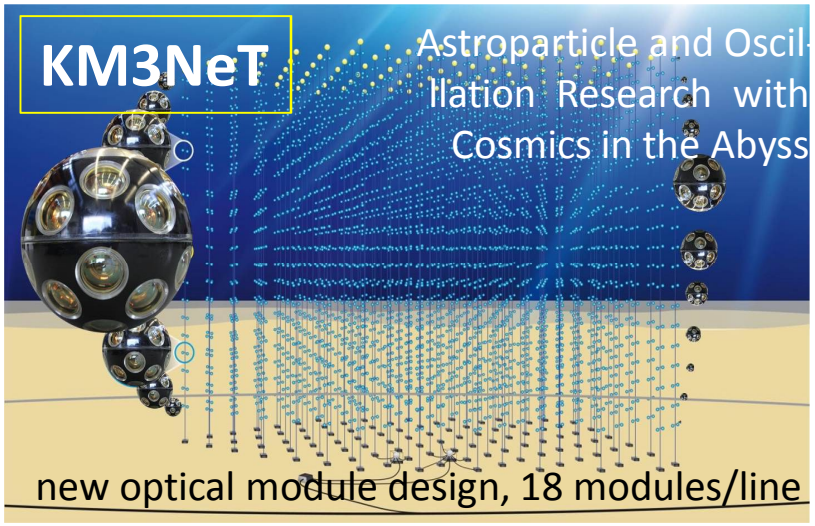


Galactic plane survey analysis, SNRs, PWNe, Galactic Center,Pevatrons search.HESS Legacy (7/14 papers)

Neutrino Astronomy

Neutrino telescopes in the Mediterranean Sea:





2500 m depth, off Toulon
12 lines.Operating since 2008
First undersea neutrino telescope
High energy neutrino astronomy (TeV - PeV)
+ neutrino physics (oscillations)

ARCA
3500 m depth, Sicily
2 x 115 lines, **1 Gton**
1 line operating

High energy neutrino astronomy (TeV-PeV)

ORCA
2500 m depth, Toulon
1 x 115 lines, **5.7 Mton**
6 lines operating since January 2020!

Low energy neutrino astronomy (MeV-GeV)

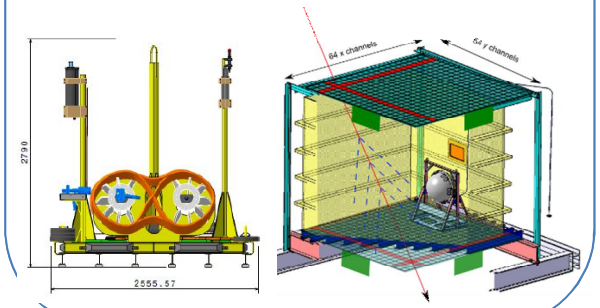
Neutrino astronomy at APC

Detector monitoring

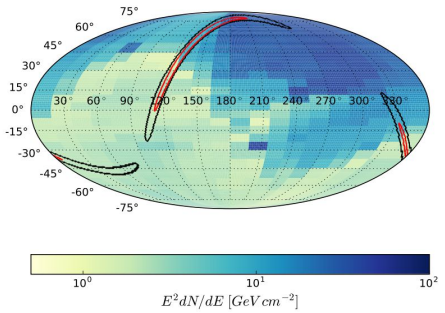
Time/Charge calibration
Data quality

Instrumentation

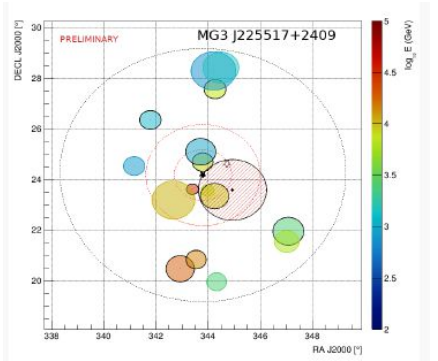
Calibration Units
DOM characterization



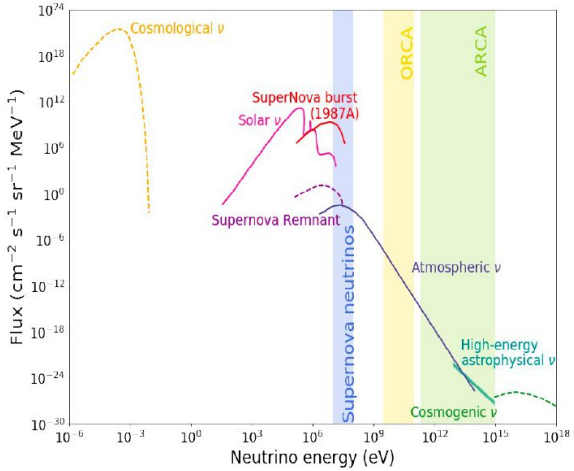
Neutrino astronomy

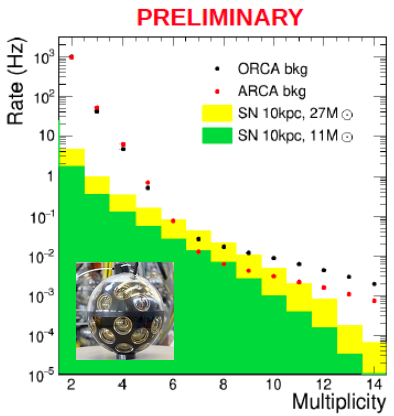


Neutrino-GW correlations



Searches for point sources





Low-energy neutrino astronomy with ORCA/ARCA:
LabEx UnivEarthS project LEAK (APC/AIM/LESIA/LUTh)

The TARANIS/XGRE instrument

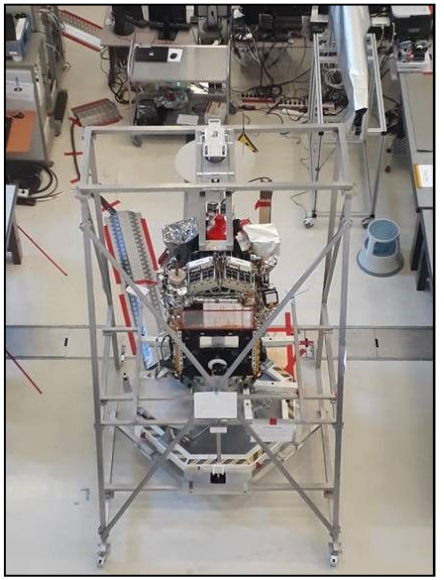
CNES microsatellite is dedicated to the study of transient radio, optical and gamma-ray phenomena observed in association with **thunderstorms**.

Among the payload, the **XGRE** instrument, developed at APC, is optimized to study terrestrial gamma-ray flashes (**TGF**) and terrestrial electrons beams **(TEB)**. With an averaged effective area of **425 cm^2**, XGRE should detect about **200** TGFs per year.

It will also detect **short Gamma-Ray Bursts** and monitor **bright X-ray sources**, such as Crab and Cygnus X-1 on a 3,7 sr field of view with a few degrees position accuracy.

From February 24th to March 3rd 2020, the XGRE FM instrument has been **fully calibrated** on the satellite at CNES Toulouse. These measurement will be cross-checked with GEANT4 Monte Carlo simulations to compute **XGRE sensitive area and energy response**.

Launch expected on **June 19th 2020**

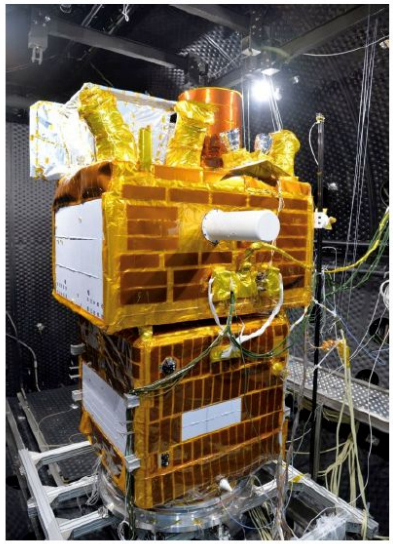


The TARANIS satellite during the FM calibration at CNES: Two XGRE detectors can be seen at the front.

The SVOM Mission

Tests on Satellite Qualification Model (QFM) in Shanghai

Vibrational tests



Thermal tests

GRBs in the distant Universe

Launch date : end 2021

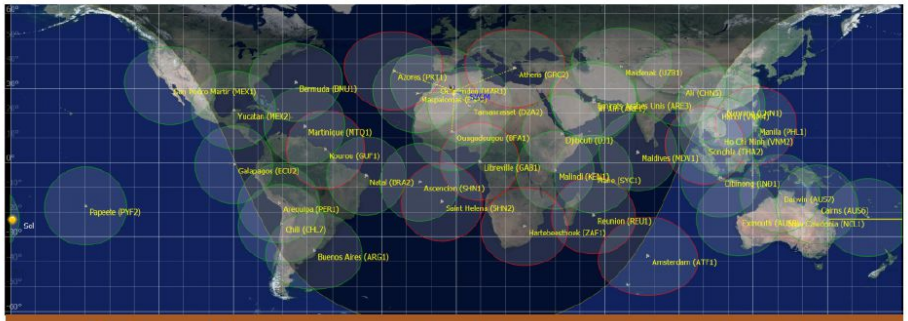
CDR (Concurrent Design Review) ECLAIRs and MXT was successful (feb 2020)

SVOM Burst Advocate school in les Houches in March 2020 canceled.

Network of VHF antennas under deployment

Réunion

Kourou



VHF => 47 antennas : red = deployed, green = planned.
30 january 2020 : 10/47 !

SVOM @ APC : Coded Mask & Pipeline for ECLAIRs

Coded Mask

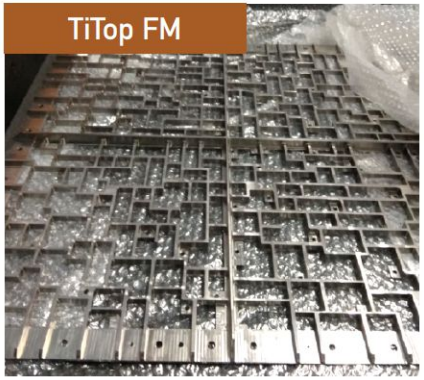
Coded mask ar ECLAIRs CDR was a success

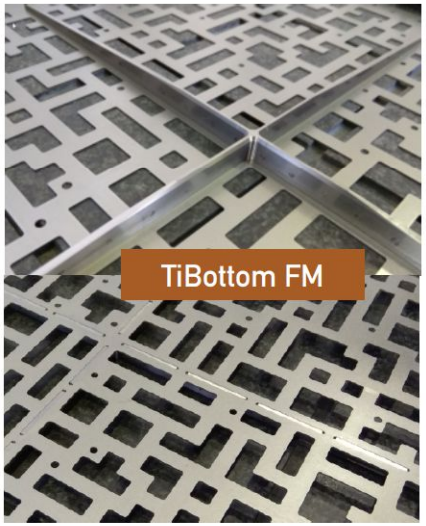
Flight Model in preparation

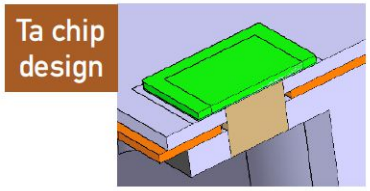
TiBottom requires laser welding to weld the cross.

Tantalum mask : a titanium one has been made to measure the precision of the process before the production of the tantalum one.

Tantalum chips have been produced (clean room).





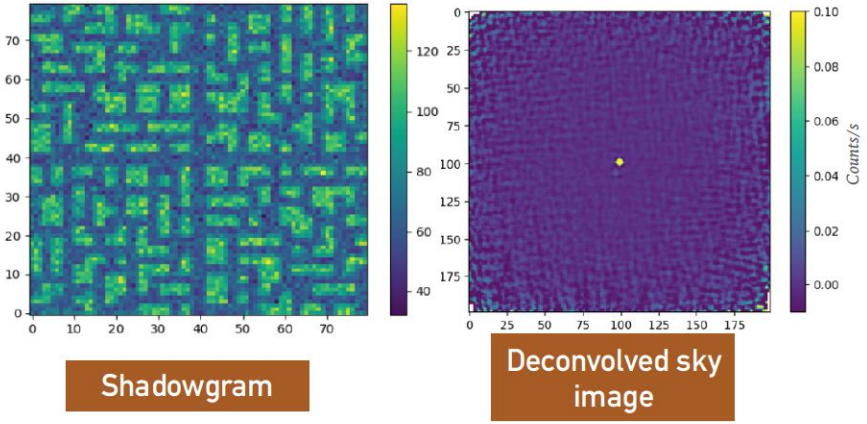


ECLAIRs pipeline

APC responsability with CEA Saclay and IRAP

Data Challenge 1 passed successfully : validate software architecture and interfaces + data processing of Crab FOV dataset

Simulation of the dataset *Deconvolution (imaging)*



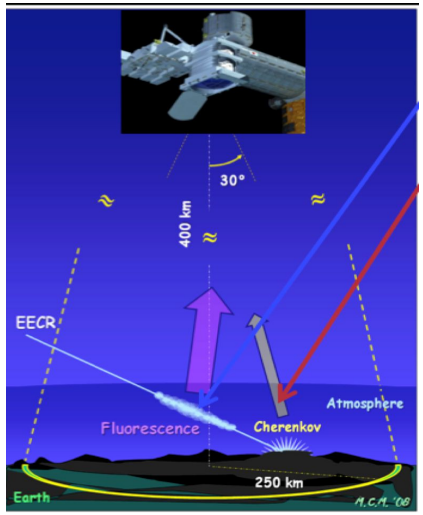
Imaging module + preliminary data preparation and correction ready

Background correction with Earth occultation ongoing

Spectra + lightcurves production in 2021

Future of UHECRS : JEM-EUSO

Space based detection of UHECRs and high-energy neutrinos through the fluorescence light of the induced showers.
Wide field UV telescope operating from the ISS



K-EUSO reviewed by ROSCOSMOS **approved** to go into Phase B (April 2019)

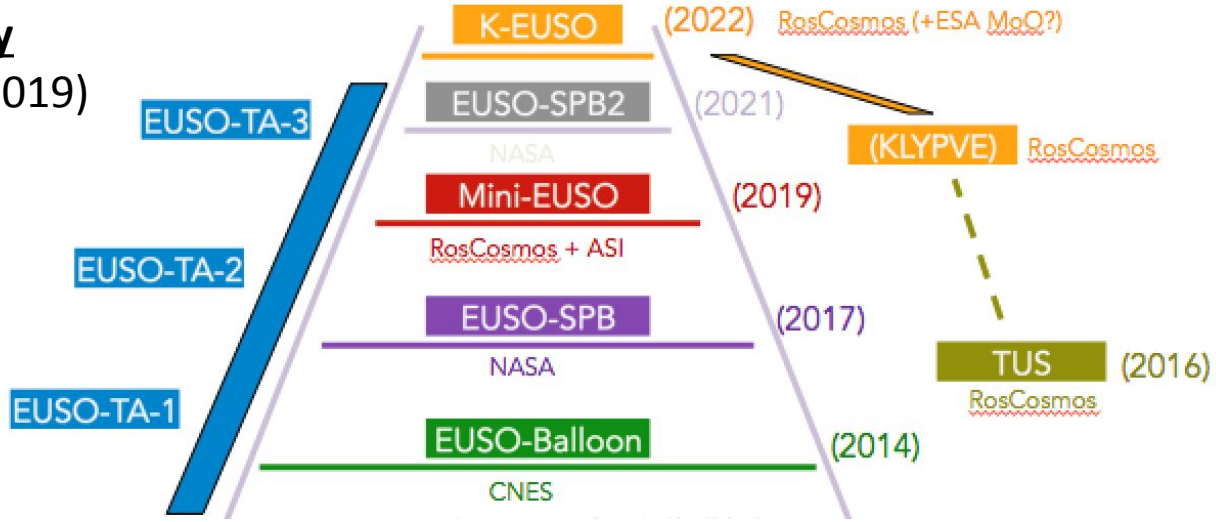
Detector units of the prototype developed and tested at APC

Mini-EUSO launched successfully to the ISS last summer (August 2019)

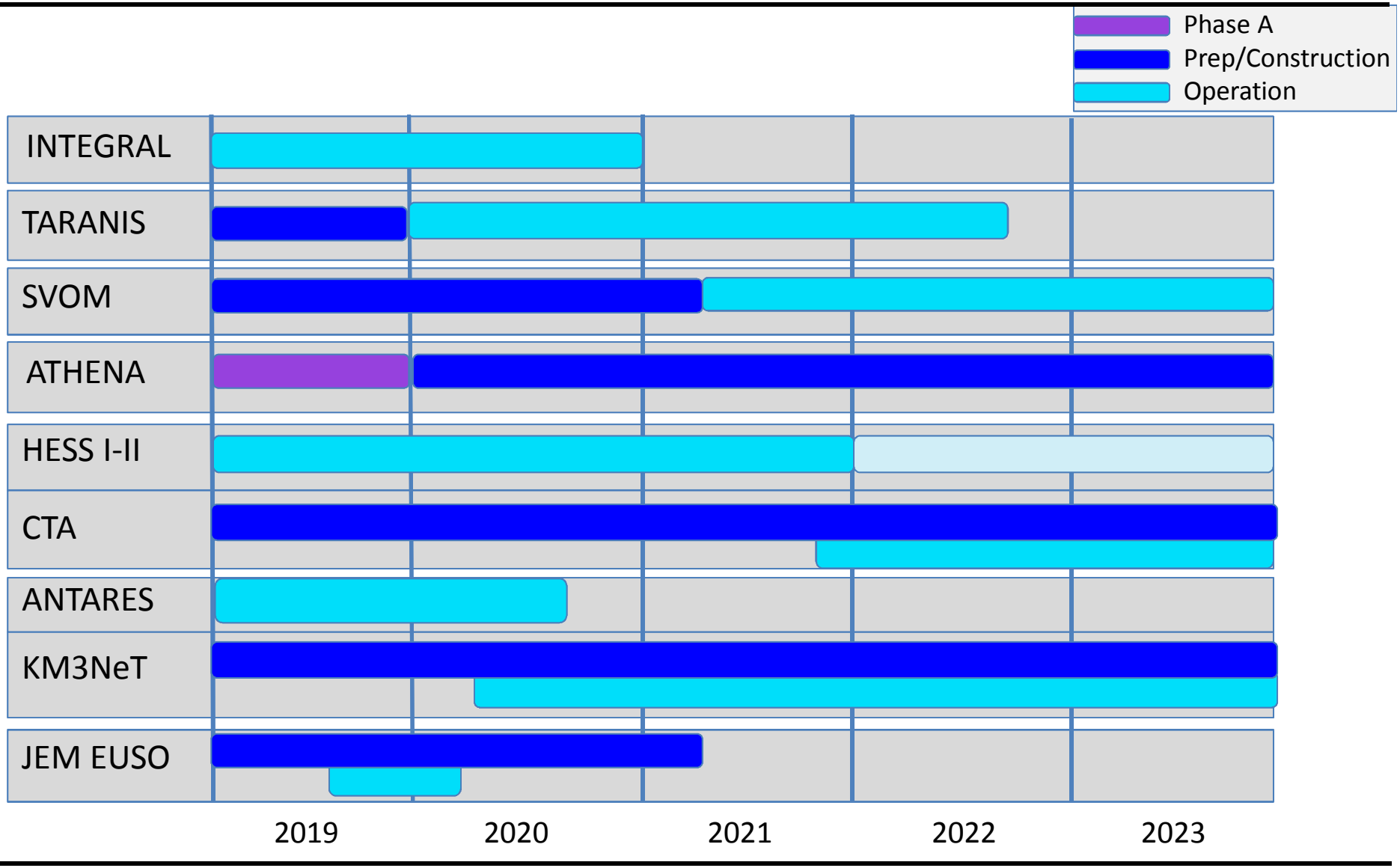
Detector units developed, produced & characterized by the APC team

EUSO-SPB2 is approved by NASA and funded **for a flight in 2022**

Detection units developed, produced and calibrated by the APC team



Timeline of the projects



ATHENA at APC

High Energy Astronomy Science with the Athena Mission

A. Goldwurm
APC / AHE group

The Mission

- **Athena is the large X-ray (0.1-15 keV) Space Observatory of the approved ESA CV L2 mission for the study of the Hot & Energetic Universe**

- **Science:**
  - **Hot Universe**: structure & formation of Galaxy Clusters
  - **Energetic Universe**: growth & evolution of Massive Black Holes (AGN)
  - **Observatory Science**: HE astrophysics, astro-particles & cosmology topics
  - **Multi-Messenger/Time Domain Astronomy:** X-rays from Gravitational Wave, Neutrino sources

- **Observatory:** Large X-ray mirror 12 m from 2 focal plane instruments, wide field imager (WFI), X-ray Integral Field Unit (X-IFU)

- **X-ray Integral Field Unit:** high resolution spectral-imager based on new technology for X-ray bolometers will have un-precedent spectral resolution (2.5 eV) over 7' FoV

- Launch 2031, 5 (nominal) – 10 (goal) yr operations: long term project structuring X-ray community and science of next 20+ yr. France deeply involved with INSU (X-IFU PI-ship), CNES (X-IFU Syst-Team), CEA (Sac, Grenoble) and IN2P3 (APC)

The Advanced Telescope for High Energy Astrophysics

CV L2 ESA mission 2031

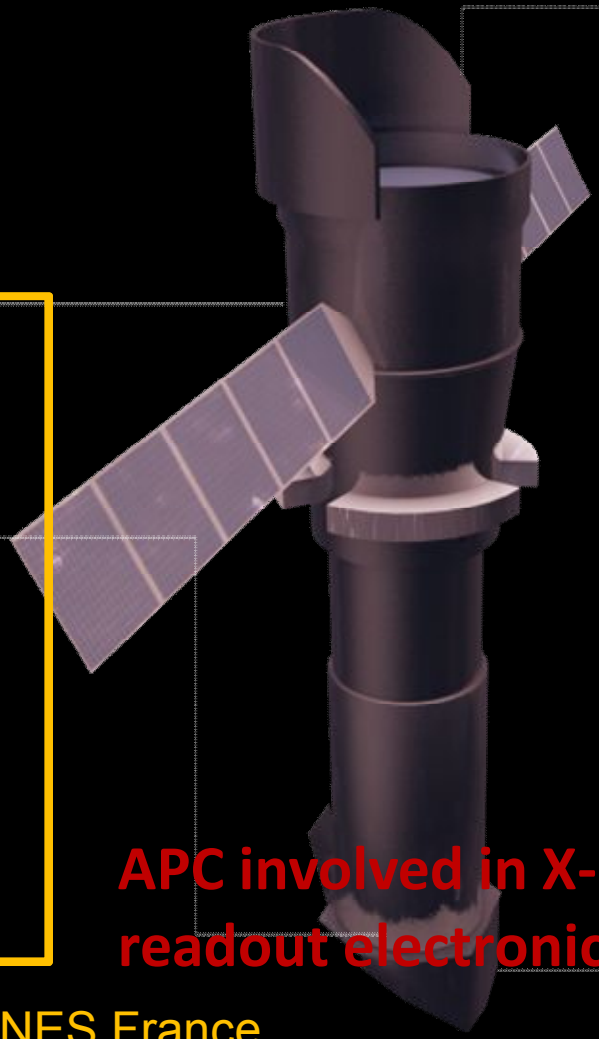
X-Rays (0.1-15 keV)

L2 orbit Ariane V
<5100 kg
power 2500 w
4 (goal 10) year mission
FoR>50%
ToO in 4hrs

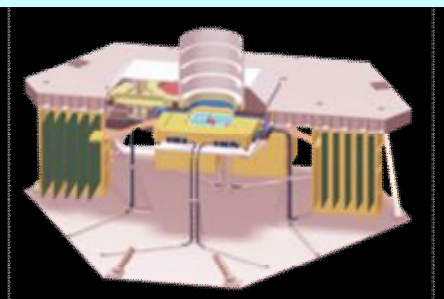
X-ray Mirrors ESA

Silicon Pore Optics:
1.4 m^2 at 1 keV
5 arcsec HEW
Focal length: 12m
Sensitivity: 3 10^{-17} erg cm^{-2} s^{-1}

X-ray Integral Field Unit:
ΔE: 2.5 eV
Field of View: 5 arcmin
Operating temp: 50 mk



APC involved in X-IFU readout electronics

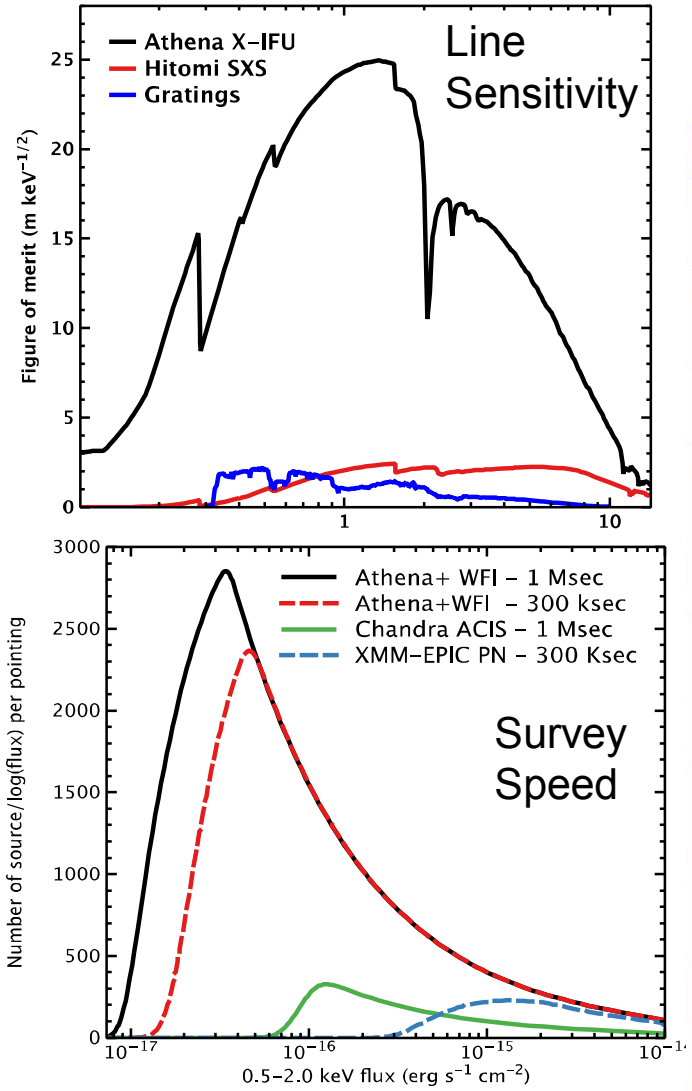


Wide Field Imager:
ΔE: 125 eV
Field of View: 40 arcmin
High countrate capability

PI IRAP / Project Team CNES France

PI MPE Garching Germany

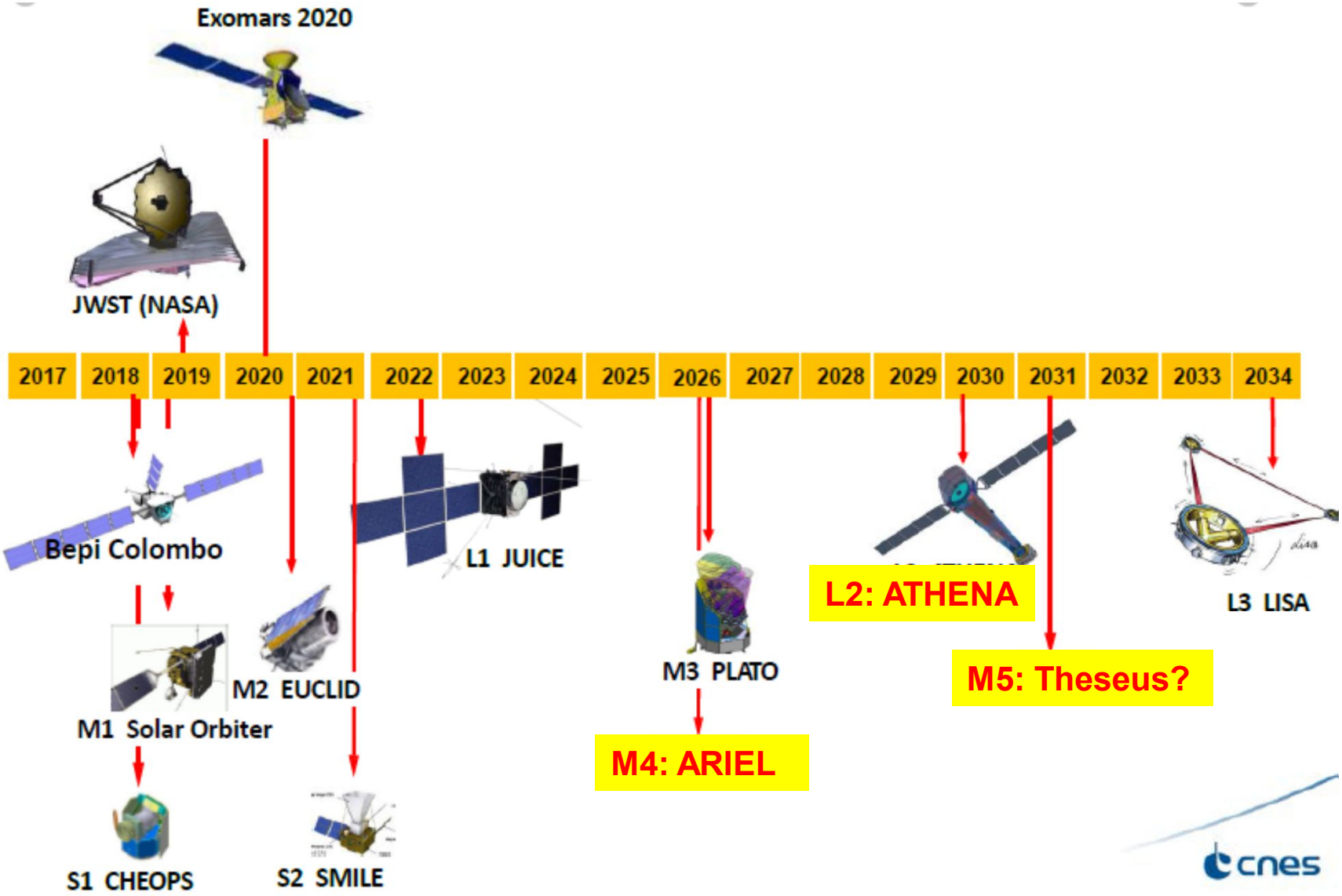
ATHENA Performances



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	Cluster energetics (gas bulk motions and turbulence), AGN winds & outflows, SMBH & GBH spins
PSF HEW (≤ 7 keV)	5" on axis, 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

ESA Program


Exomars 2020
JWST (NASA)
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
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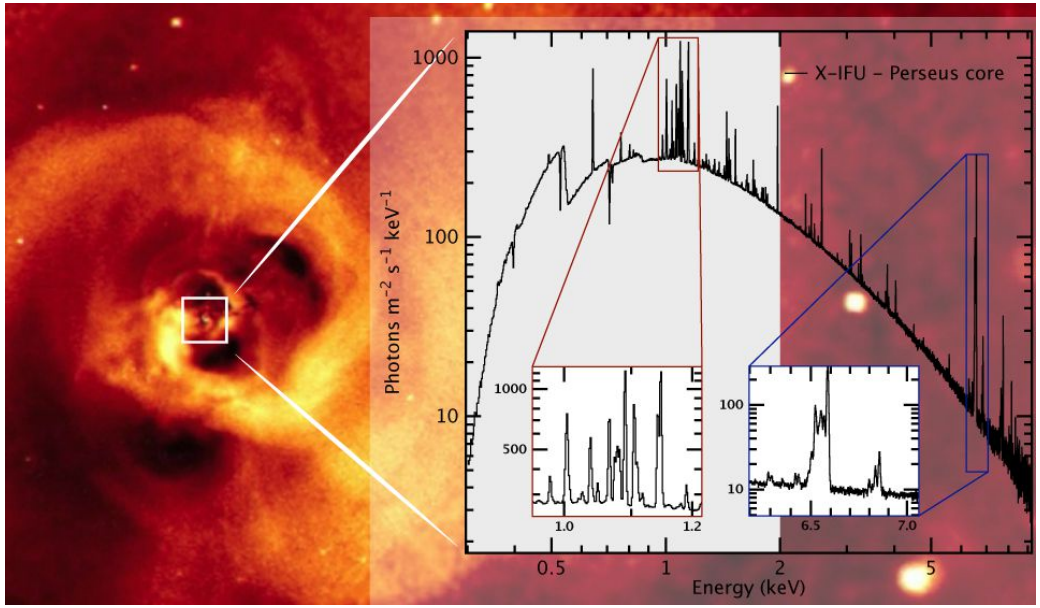
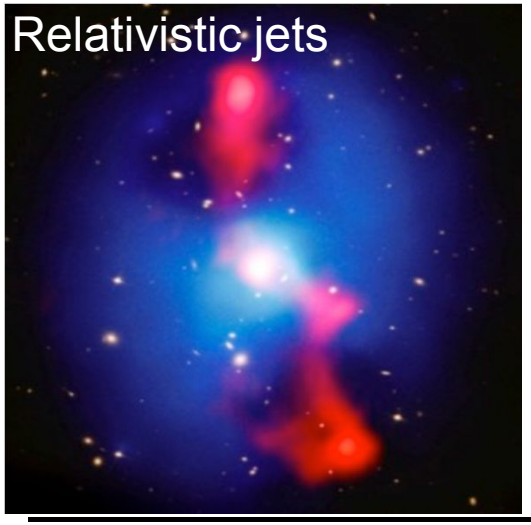
2028
2029
2030
2031
2032
2033
2034
Bepi Colombo
L1 JUICE
L2: ATHENA
L3 LISA
M1 Solar Orbiter
M2 EUCLID
M3 PLATO
M5: Theseus?
M4: ARIEL
S1 CHEOPS
S2 SMILE
cnes

Athena Milestones

- **28/11/13** **ESA Selection of the Hot and Violent Universe theme for the ESA L2 mission of C.V.**
- **17/01/14** **ESA Call for Mission Concept**
- **2014-2015** **WFI and X-IFU Consortia established: Submission & Selection of Mission Concept**
- **June 2015** **Start Phase A**
- **2015-2019** **Assessment + Feasibility - Phase A**
- **2019**-2021 Preliminary Definition Phase – Phase B1
- 2021 Mission selection by ESA - Start Phase B2 C D
- 2026 Delivery of subsystems
- 2031 Launch => 5 / 10 yr operations

ATHENA Science





- **HOT UNIVERSE: Galaxy Clusters and the Large Scale Structures of the Universe**
- **ENERGETIC UNIVERSE: AGN, how Black Holes Grow and Shape the Universe (spins, outflows, ..)**
- TRANSIENT and MULTI-MESSENGER Astronomy: GRBs, GW ev., ν ev., CR
- OBSERVATORY SCIENCE: Galactic CO, SNR, SN, Stars, Solar System
- SYNERGIES:
  - aLIGO/aVIRGO, LISA, (ET)
  - CTA, KM3NeT
  - JWST, ELT, SKA, ALMA
  - (THESEUS, …)

APC Scientific Interests

- **Science themes** of Athena intersects the science domains of APC (AHE and Cosmo)
- **Science topics (APC scientists, in bold core team members)** :
  - **Galactic Center physics** (**A. Goldwurm, R. Terrier,** A. Lemière)
  - **AGN variability and spectroscopy** (P. Goldoni, S. Pita, V. Beckmann)
  - **Galactic Compact Objects** (**P. Varnière, P. Laurent**, A. Djannati)
  - **Deep Extragalactic Surveys for dark matter/energy** (J. Bartlett, J. Delabrouille)
  - **Particle acceleration and interaction (GC, SNR, GRB)** (**S. Gabici**, E. Parizot)
  - **Transient Events(GRB) and Multi-messenger Astronomy** (**A. Coleiro**, C. Lachaud)

  > 10 permanent scientists interested in specific science topics of Athena

- **High-Level Technological dev.** on Cryo Microelectronics for Bolometers (**D.Prêle**, M.Piat, **F. Voisin**)
- **APC Missions and Projects of Astroparticle Physics (=> synergies with Athena):**
  - **X-Rays / Soft Gamma Rays:** INTEGRAL, Taranis, SVOM**,** (eAstrogam, **Theseus**)
  - **VHE gamma Rays: CTA**
  - **Gravitational Waves :** aVIRGO**, LISA, (Einstein Telescope)**
  - **Particle experiments (**neutrinos, Cosmic-Rays): **KM3NeT,** (JEM-EUSO)
  - **Cosmology : LSST, Euclid**

APC Participation in Athena

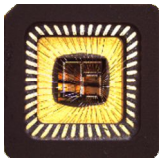
Contributions:

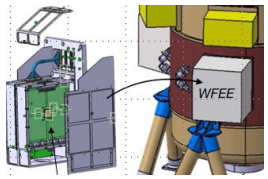
- Participation to **X-IFU Instrument**
- Responsibility for the **Warm Front End Electronic (WFEE) Sub-System of the X-IFU read out chain**
- Participation to **science ground segment** in the contest of the X-IFU instrument center.
- Contribution to **simulations for the evaluation of background** in X-IFU

Responsibilities within the X-IFU Consortium:

- A. Goldwurm **science Co-I**, member of Science Advisory Team
- D. Prêle **Instrument Co-I**, member of Instrument-Detection Chain Team
- D. Prêle / F. Ardellier, **WFEE Project Manager**, member of Subsystem Project Manager Team

Responsibility Level: 2 Co-I out of 10 from France and 38 total





ATHENA Science for APC / AHE

APC / AHE Science

- Focus on Astroparticle science: Particle acc.-prop.-inter., High energy (non-thermal) emission, energetic outflows, relativistic jets, extreme G/B fields
- Multi-wavelength / Multi-Messenger Astronomy / Time Domain : X-ray counterparts of Hard-X / Gamma-rays, CR, Neutrinos, GW sources

Non-standard Observation strategies

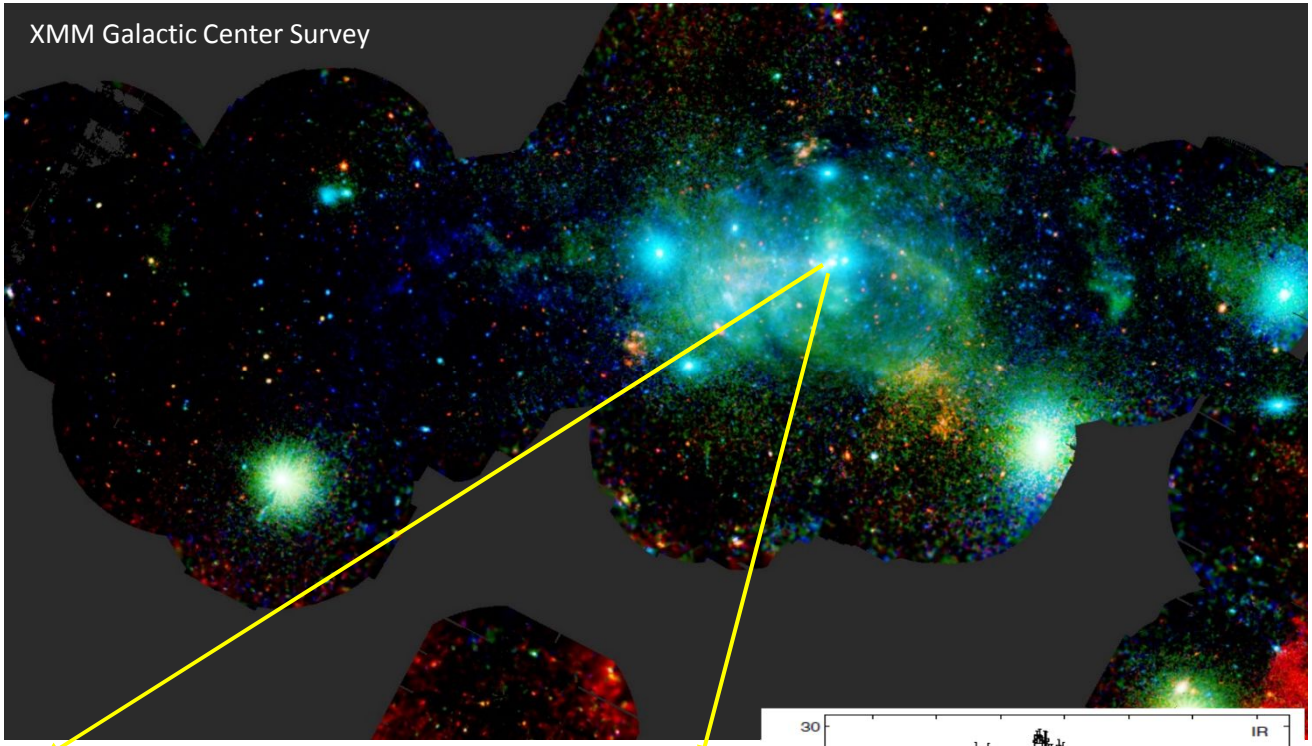
1. **Extended large deep surveys of weak (diffuse) sources. Planned Coordinated Multi-Wave / M-Messenger campaigns. Comparison with large amount (archives) of other data (hard-X, TeV, MeV, CR, ..)**
2. **Fast (MW-MM) observations (ToO) of transient events => Time domain Astronomy**

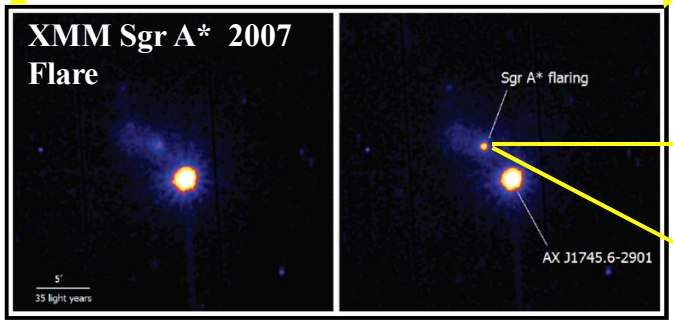
Direct Project implication

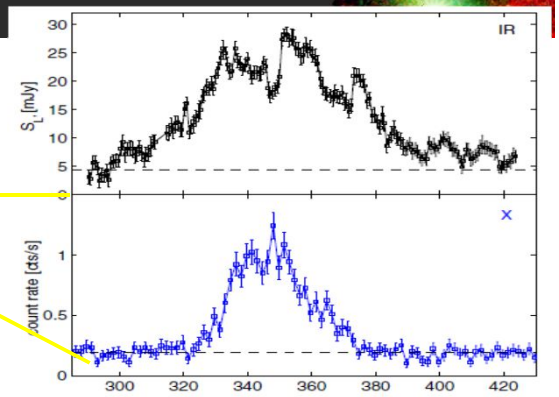
- Instrument knowledge, data analysis expertise, planning capabilities
- Competitive objectives (core science): Guarantee time rather than GO
- Large / deep surveys: large observation programs, planned M-λ M-M
- Fast reaction: ToO, preplanned M-λ M-M, triggering from M-λ M-M obs.

=> PARTICIPATION TO THE MISSION PROJECT MANDATORY

AHE Athena-Science: Galactic Center







Galactic Center:

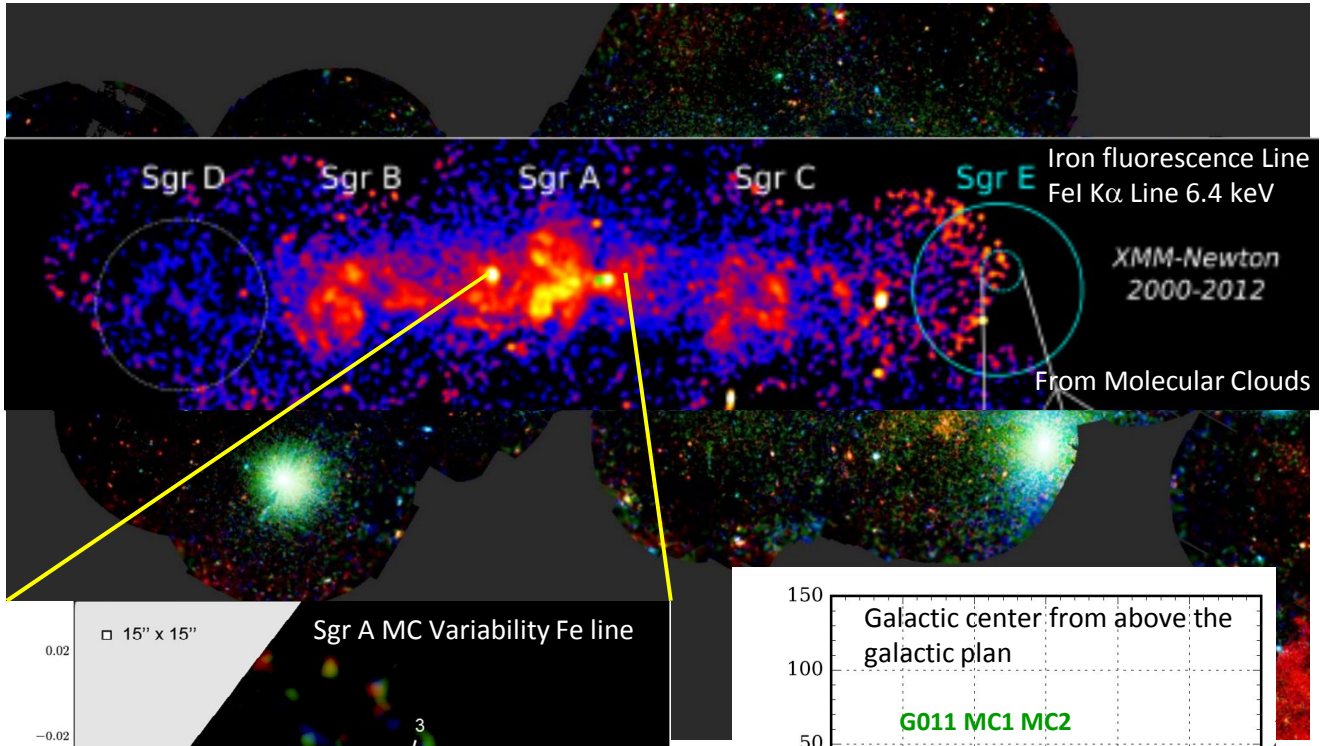
- ❑ Astroparticle Physics Laboratory
- ❑ Large Concentration of HE sources phenomena
- ❑ Nearest SMBH (Sgr A*), * clusters, CMZ ..

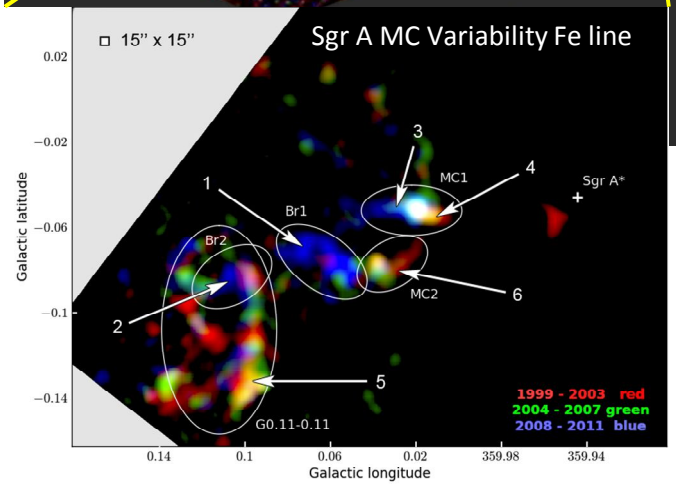
AHE researches:

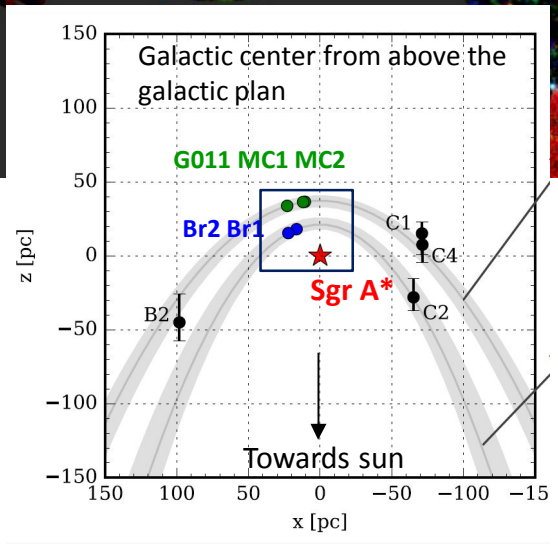
- ❑ **Sgr A* flares in X-rays (XMM, Multi-wl)**

ATHENA will study in detail the accretion flow and the X-ray flares of Sgr A*

Sgr A* past activity from GC Obs.







Galactic Center:

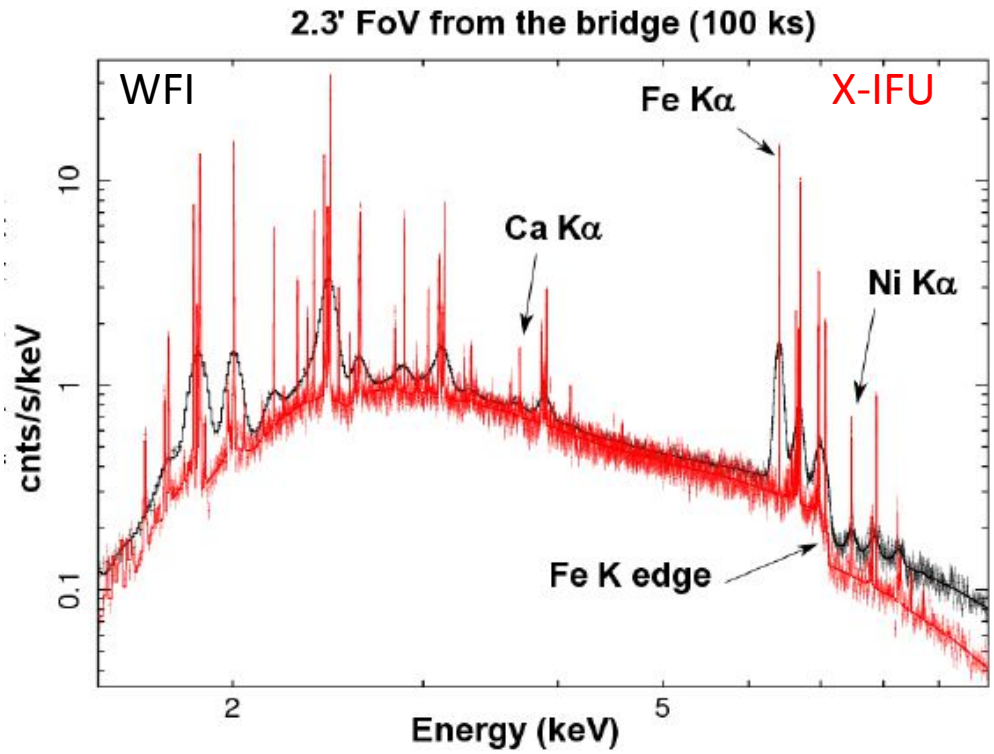
- Astroparticle Physics Laboratory
- Large Concentration of HE sources & phenomena
- Nearest SMBH (Sgr A*), * clusters, CMZ ..

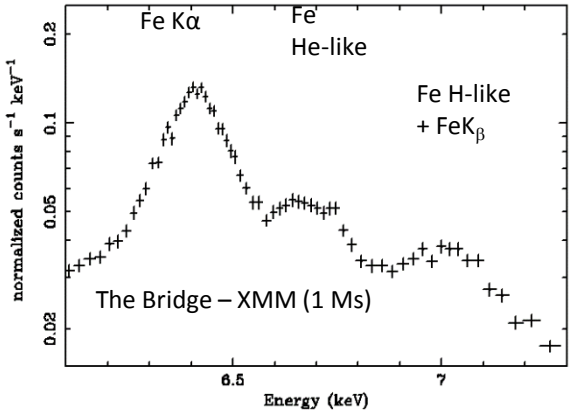
AHE researches:

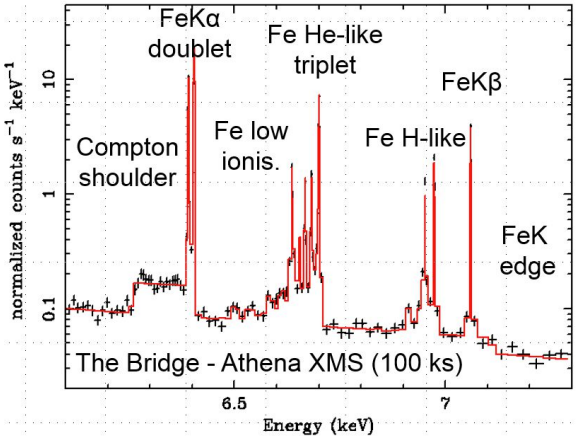
- **Diffuse variable X-ray/γ-ray reflection emission from Molecular Clouds reveals BH past activity (Integral, XMM, Chandra)**

ATHENA will observe with unprecedented energy resolution the Fe lines from the GC MC and will allow to reconstruct Sgr A* light curve in the past 1000 yr

ATHENA Expected Performances for GC



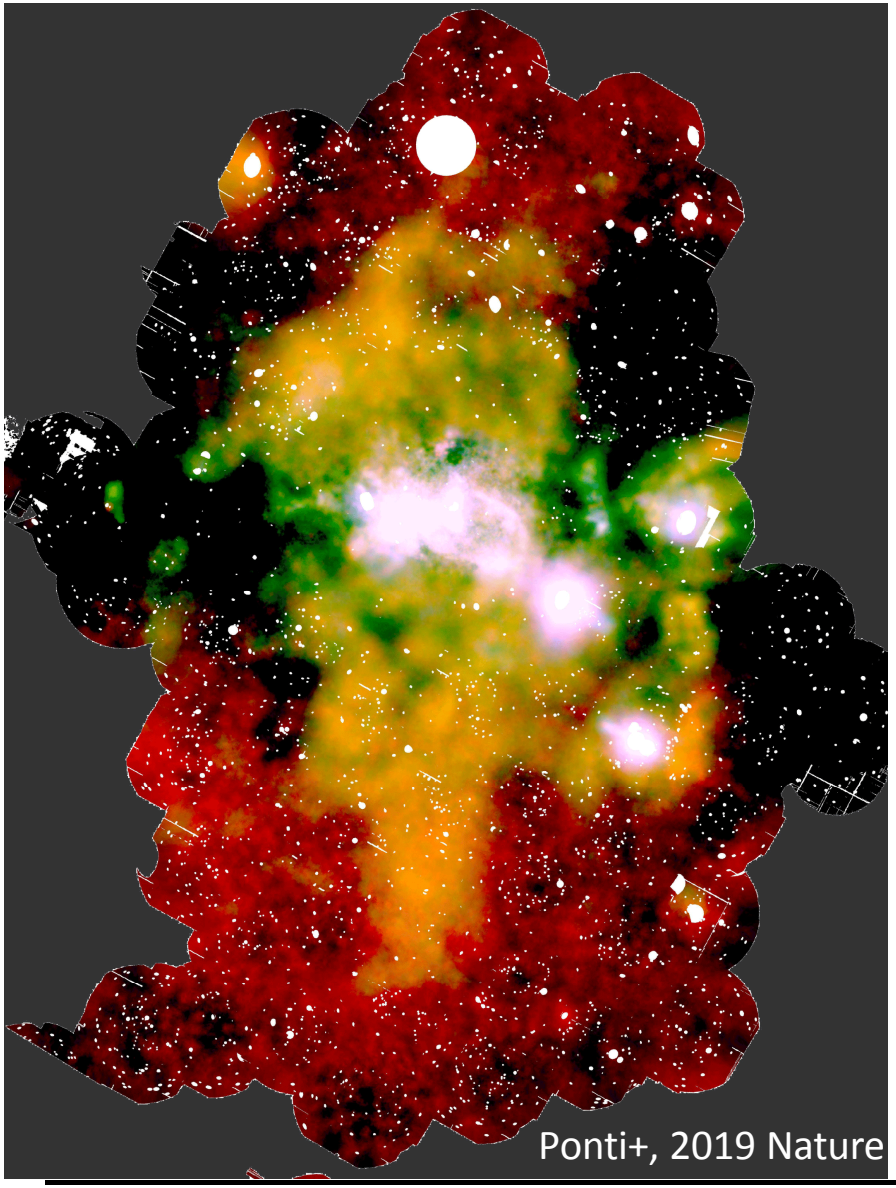


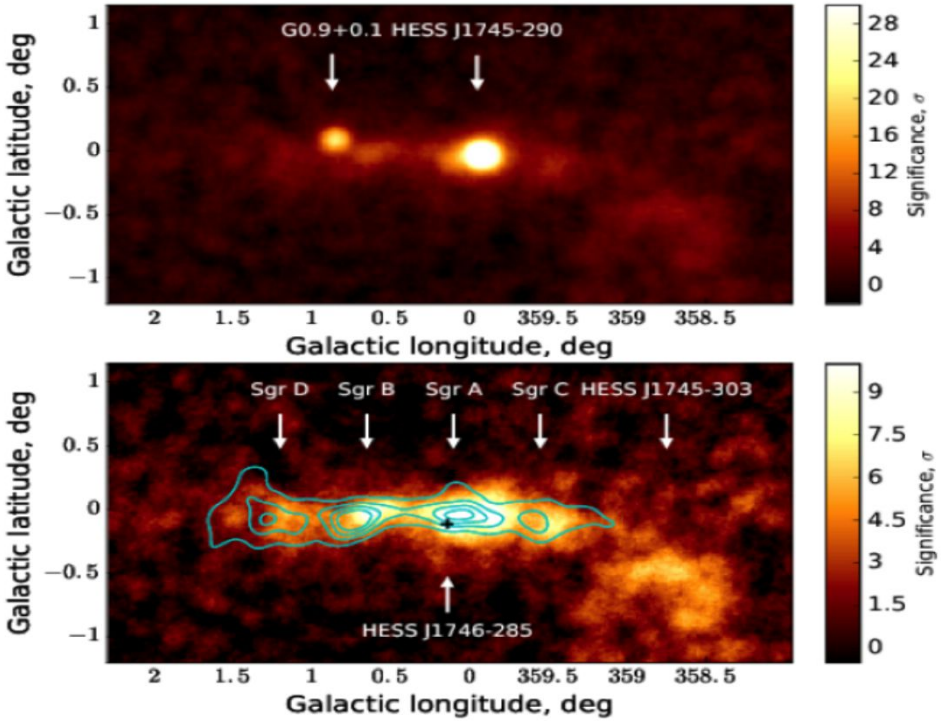


- Line position known at ~ 2.5 eV accuracy
  => cloud velocity ($\Delta v \approx 100$ km/s) determine the 3D position of echoes
- Geometry constraints from detailed spectral modelling (K-edge and continuum)
- GC cloud metallicity measurements
- Athena will distinguish XRN and LECRE contributions in GC clouds

(credit Terrier & Ponti)

X-Ray Surveys of the Galactic Center



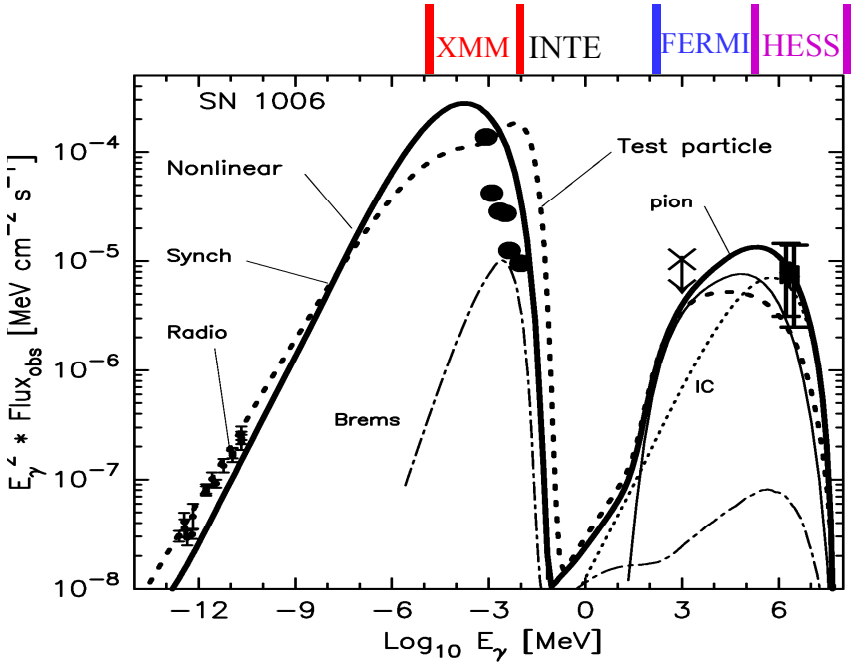


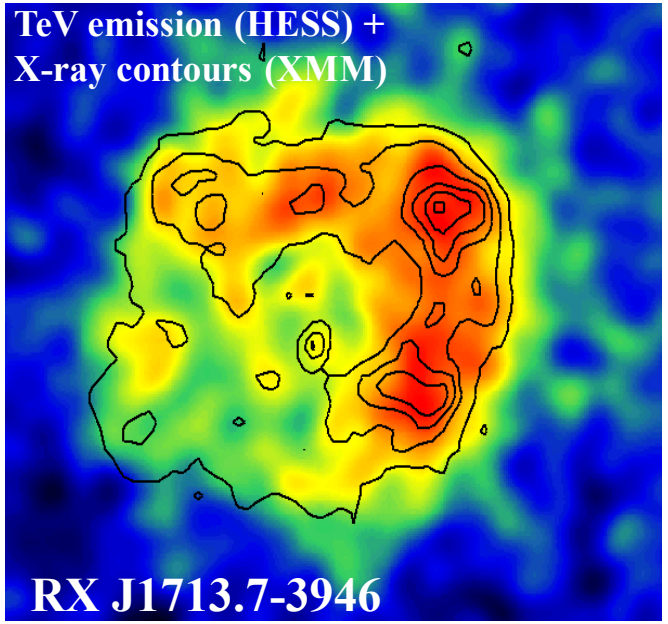
AHE researches:

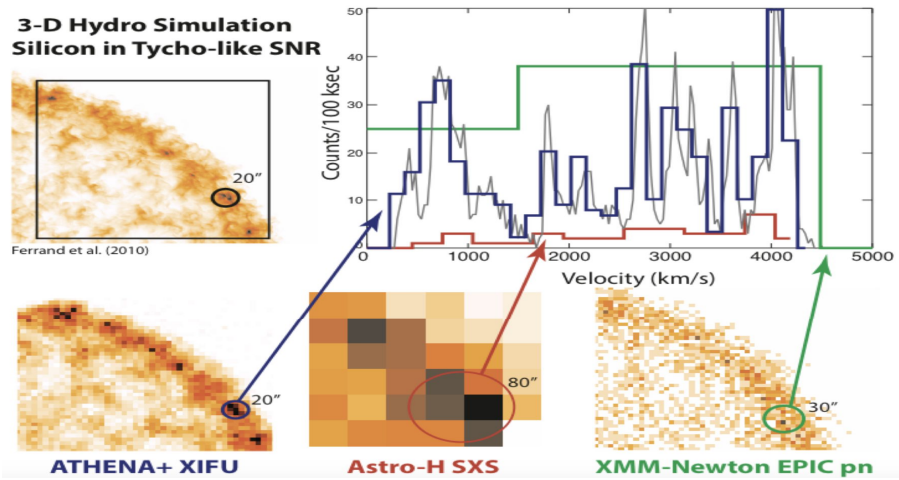
- ❑ Discovery of X-ray Chimneys connecting central regions to the Fermi Bubbles
- ❑ A PeVatron in GC produces TeV Diffuse emission (Hess coll. Nat 2016)
- ❑ Links with Central TeV source, GeV Excess

Athena will explore GC hot gaz outflows

Particle Acceleration in Shocks of SNR

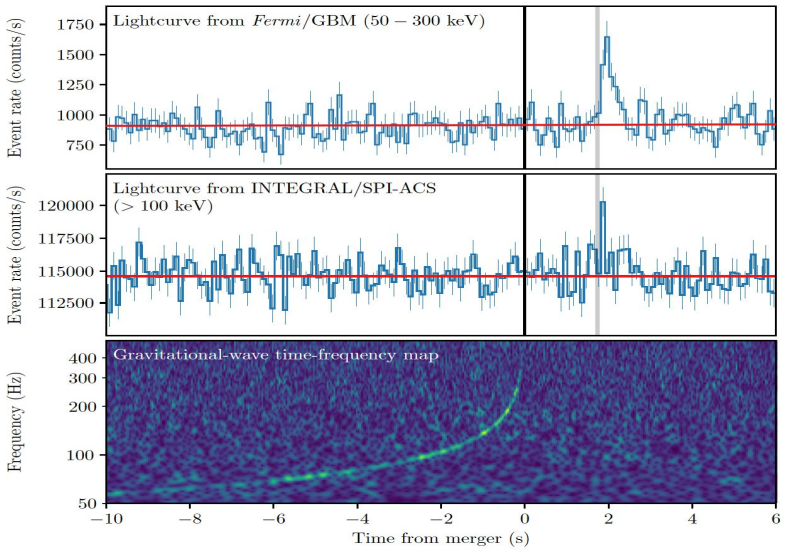




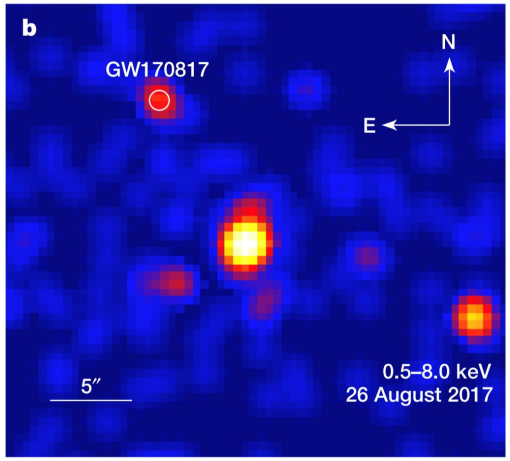


- RX1713.7 SNR in TeV and in X-Rays
- X-γ correlation: constraints on magnetic field & hadronic/leptonic models
- ATHENA/X-IFU, ASTRO-H and XMM images and silicon velocity profiles from a 3D hydrodynamic simulation of Tycho's SNR
- Synergies with CTA and KM3NeT

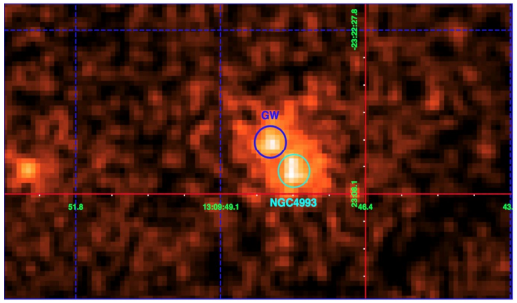
ATHENA Performances for GRB/Mergers



Chandra (Troja et al., 2017)



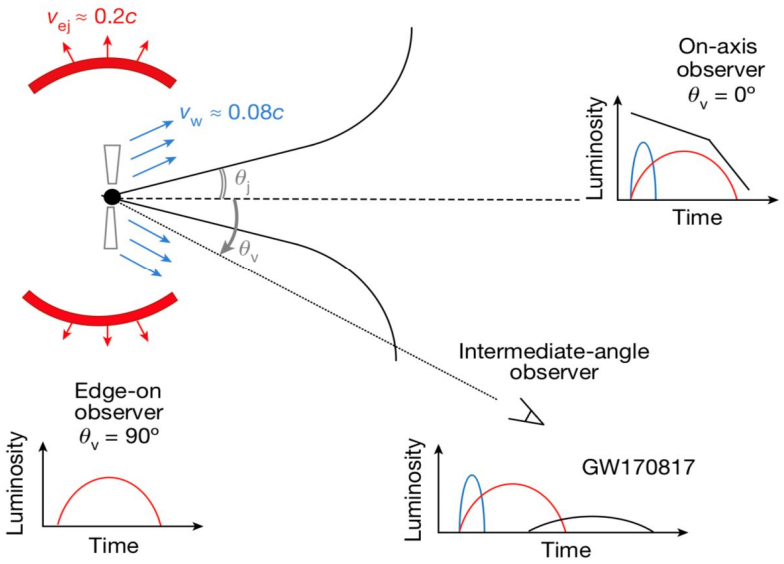
XMM (D'Avanzo et al., 2018)



→ **X-ray counterpart consistent with a short GRB viewed off-axis.**

GW170817: First Detection of a GW event coincident with short GRB => NS-NS coalescence, relativistic jet, kilo-nova

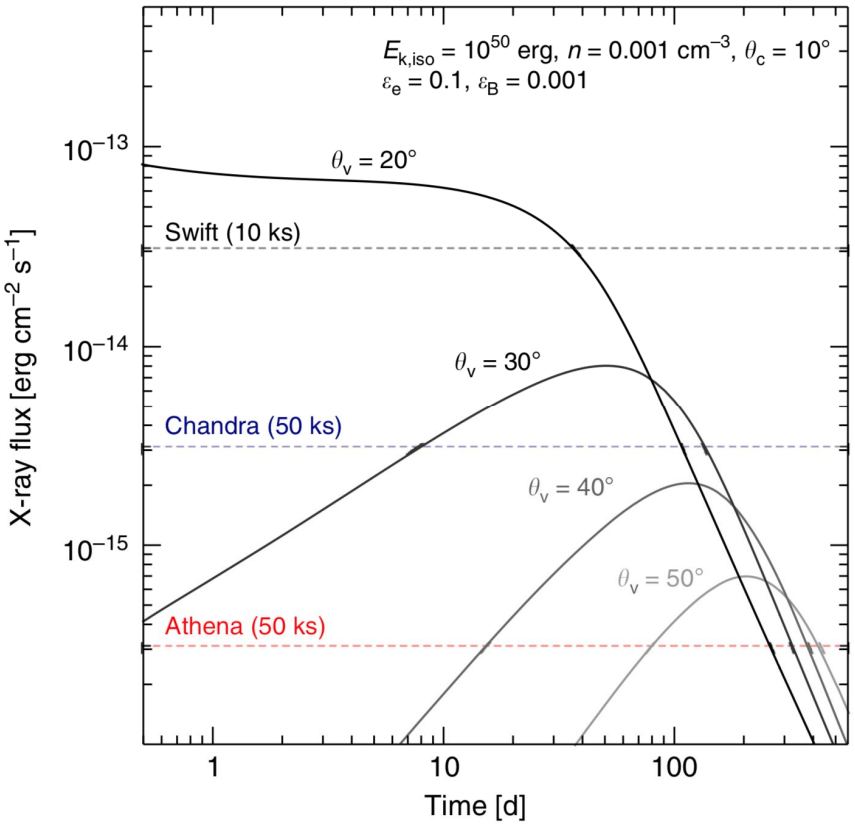
- LIGO/Virgo detection => narrow location box
- INTEGRAL & Fermi detection in gamma-rays
- Large Multi-wavelength Campaigns
- A weak counterpart in X-rays detected with Chandra => excellent science topic for Athena (ToO within 4 hr)
- X-ray obs. revealed view off-axis angle ~ 20°-25°



X-rays: unveil dynamics and geometry of the ejecta and are crucial for modelling the systems

ATHENA Performances for sGRB / NS-NS M.

Athena sensitivity
(ToO in 4 hr from alert)

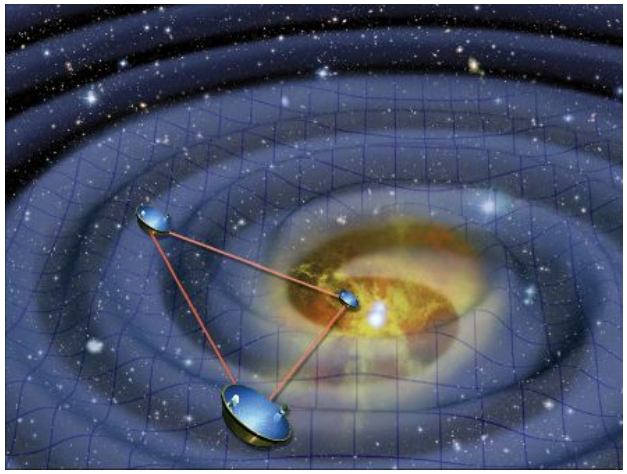


Predicted X-ray light curves of GW counterparts for different viewing angles, assuming a standard afterglow at 100 Mpc. (Troja et al 2018)

- Detections expected for viewing angles of as high as 50°: Athena needed for viewing angles $\geq 50°$ for most distant mergers
- Future X-ray observations will probe a variety of viewing angles (pop. studies, jet structures, constraint on H_0, …)
- Map the geometry of NS mergers and impact of different outflows (relativistic / sub-relativistic)
- Probe the relation between jet's orientation (EM) and binary's inclination (GW)
- Break the NS/BH remnant degeneracy (a long-lived NS might affect the X-ray emission either through X-ray flares or long-lasting X-ray plateau)

LISA–Athena Synergies: SMBHB Mergers

Multi-messenger astronomy combining low-freq gravitational wave obs. by LISA, and contemporary or follow-up X-ray Athena obs. of the same source



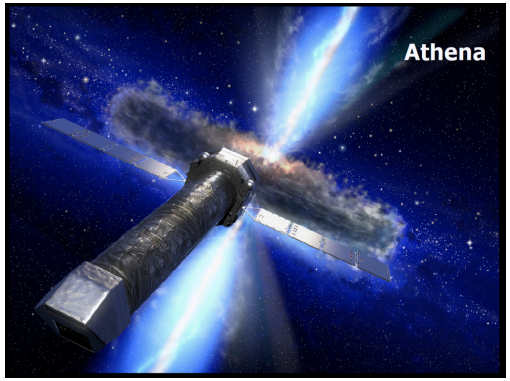
Detection of X-ray counterpart of coalescing SMBH of 10^5-10^7 $M_\odot$ that LISA will detect to large z: Athena be able to detect X-ray emission from sources at z < 2

Pre-Merger Inspiral Phase

from Colpi+ 19 WP on LISA-Athena Syn

- Environment of the SMBH-B
- Speed of gravity

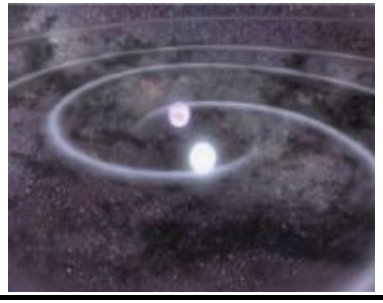
=> probing for 1st time behavior of matter in S-T merging



Post-Merger Phase

- Cosmic distance scale
- AGN Physics: AGN rebirth
- Jet Launching and ISM-interaction

=> Exploring origin of most powerful objects



SMBHB Mergers: X-Ray Variability

X-ray emission during the late stages of the inspiral (days to hours before final merger) from:

Circum-binary disc: X-ray emission in soft x-rays (≤ 1keV)

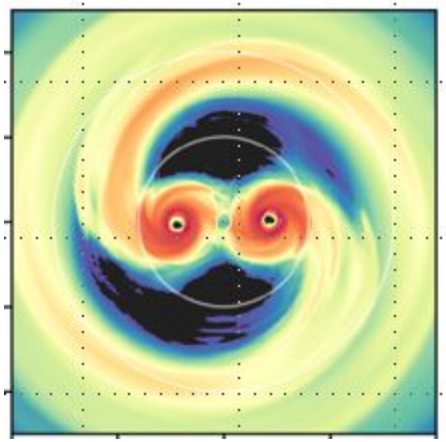
Minidisks around BH: Hard X-ray emission (≥ 10 keV) from accretion coronae

Interaction of circumbinary and minidisks:

- Accretion of circumbinary disk onto minidisks via streams
- Thermal radiation by inner edge of the circumbinary disk
- Thermal Emission from shocks in cavity walls of streams

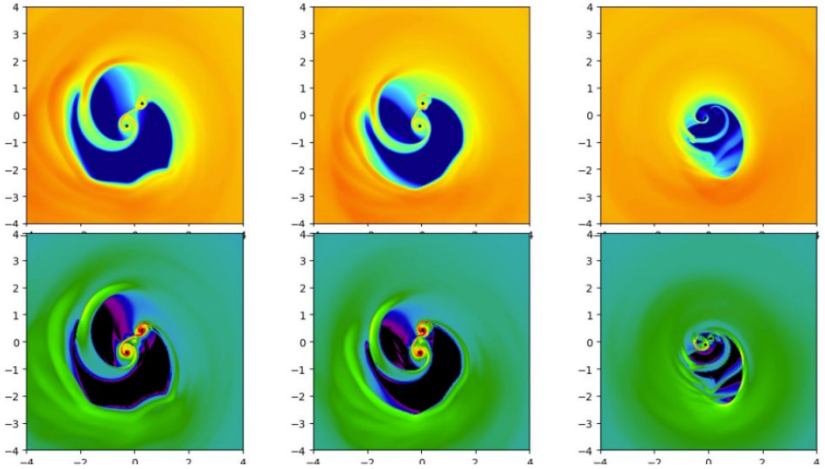
X-ray emission shows clear modulation on timescales as short as a few hours

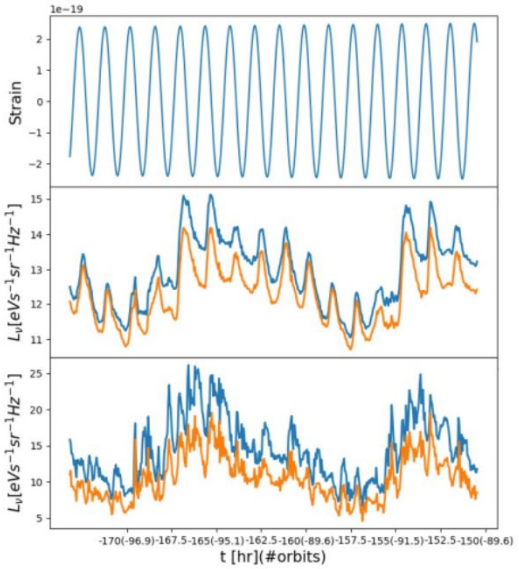
- Linked to orbital period and in-spiral (late) phases
- **EM variability linked to the GW period up to merger**

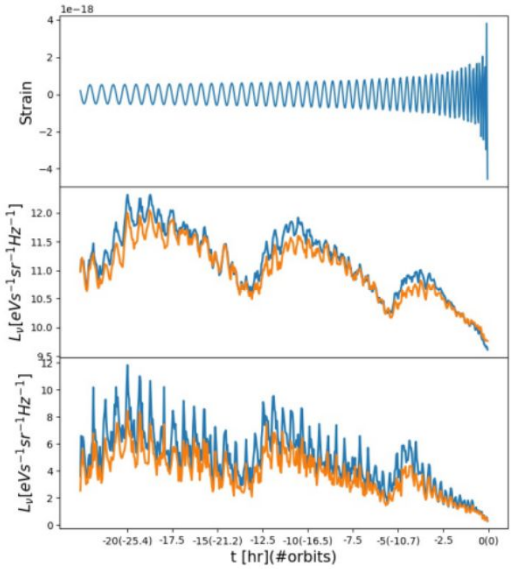


(Tang+ 18, d'Ascoli+ 18)

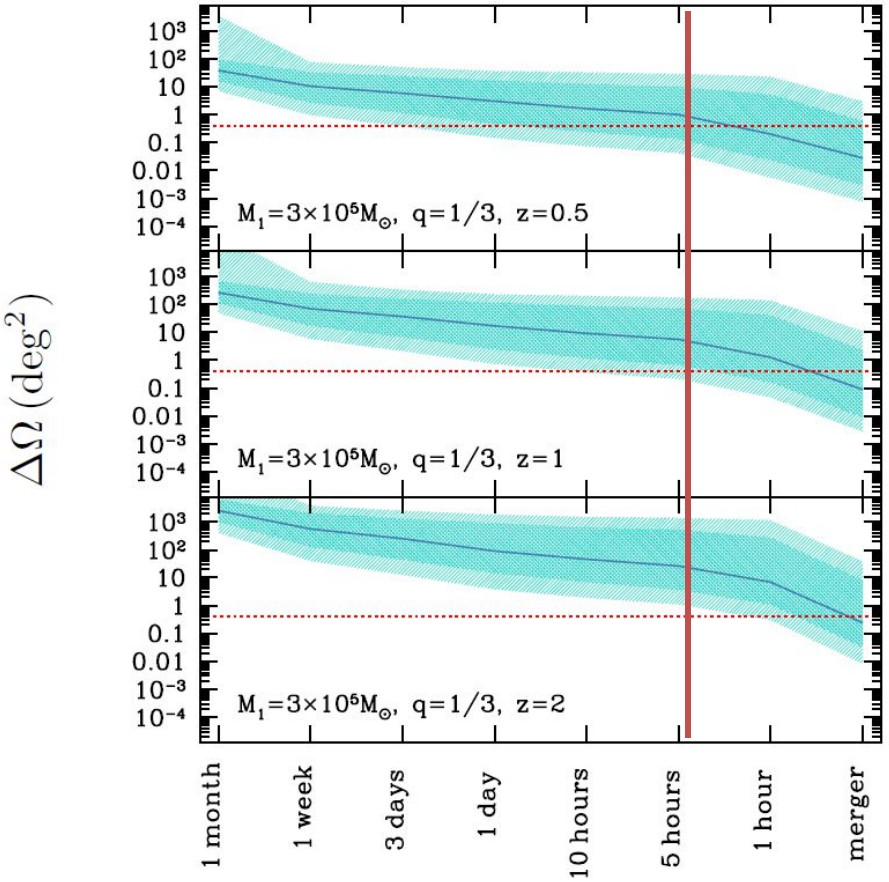
Smoking gun of the Merger !







LISA Localisation of SMBHB Mergers



Sky localization error in deg² versus time to merger for non-spinning black hole binaries (------- = WFI FoV size 0.4 deg², ___ = 5hr)

LISA expected to detect SMBHB M of 10^3-10^7 $M_\odot$ to z = 20 with uncertain rate of 10-300 in 4 yr. Majority of low S/N but several/yr will be high S/N of > 3 10^5 $M_\odot$ at z < 2 => small error boxes

GW signal increases with time, from in-spiral to merger => best localization derived post-merging, with best cases down to arcminutes

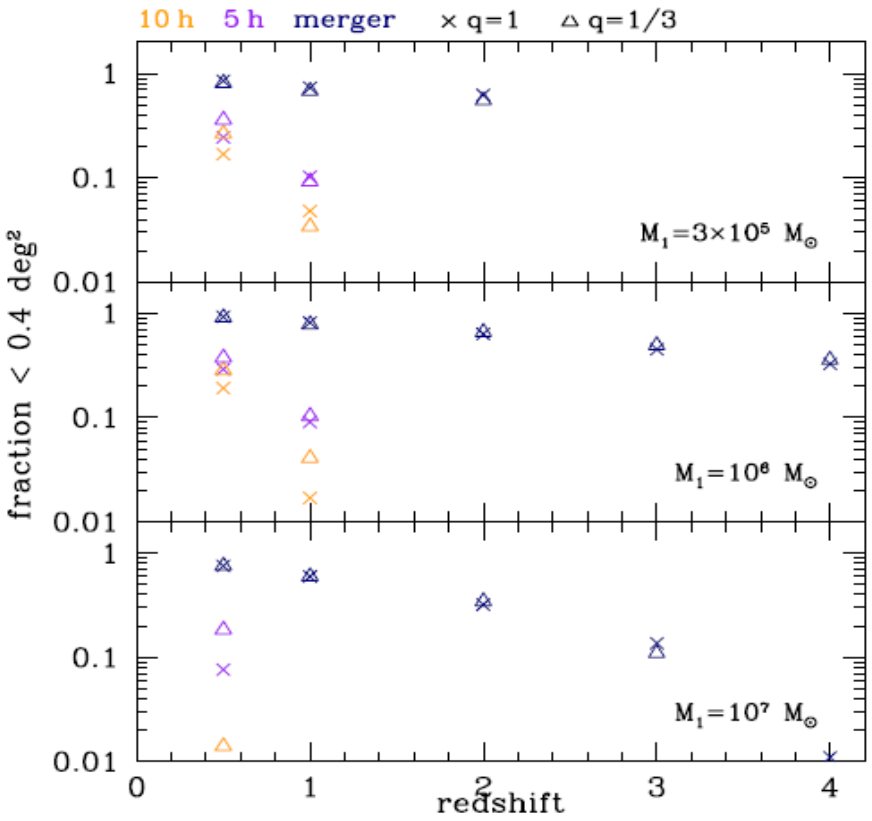
Fraction that LISA can detect within WFI FoV (0.4 deg²) at diff times from Merging :

- 3 10^5-10^6 $M_\odot$ (indep of q) in 5 hr b. m.
  - 20-40 % at z < 0.5
  - 10 % at z = 1
- 10 % of 10^7 $M_\odot$ at z=0.5 in 5 hr b. m.
- > 60 % of 3 10^5 $M_\odot$ at z=2 and 50 % of 10^6 $M_\odot$ at z=4 at merging

Results:

1. Localizing within WFI FoV during late GW in-spiral possible only for low-z 10^5-10^6 $M_\odot$
2. At merger all systems even 10^7 $M_\odot$ at z < 2; can be localized within fractions of a deg²

LISA Localisation of SMBHB Mergers



SMBH-B Fraction with localization by LISA within the WFI FoV (0.4 deg²) vs. redshifts for different Total Masses, times before merger and mass ratios

LISA expected to detect SMBHB M of 10^3-10^7 $M_\odot$ to z = 20 with uncertain rate of 10-300 in 4 yr. Majority of low S/N but several/yr will be high S/N of > 3 10^5 $M_\odot$ at z < 2 => small error boxes

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LISA-Athena: SMBHB Obs. Strategy

Expected Fluxes (cgs) & exposure (ks) for L-A detection at Bol. Eddington Luminosity

Unobscured AGN

	$M=10^6\ M_\odot$	$M=10^7\ M_\odot$
$z = 1$	8×10^{-16} (5)	8×10^{-15} (<1)
$z = 2$	1.5×10^{-16} (70)	1.5×10^{-15} (2)

Obscured AGN ($N_H = 10^{23}$ cm^{-2})

	$M=10^6\ M_\odot$	$M=10^7\ M_\odot$
$z = 1$	8×10^{-17} (200)	8×10^{-16} (5)
$z = 2$	5×10^{-17} (400)	5×10^{-16} (10)

SMBHB Mergers – premerger phase

- SMBH-B with Error Boxes < 10 deg² few days before M. => covered by 3-d WFI scan (23 obs. x 9 ks)
- Estimates of Athena Detection Fluxes for these events (L_X / L_{bol} ~ 2-10 %) => Large exposure needed
- Identification of the counterpart in the FoV => use the model predicted specific temporal variability
- **ToO (4 hr Athena reaction time) only not sufficient for obs. of inspiral, need observation strategy:**
- **Strategy: cover these events with scans of tiled obs. then a direct pointed obs. when small EB obtained**

=> Measurement of the X-ray counterpart of a SMBH binary merging during the pre-merging phase an **extremely challenging, albeit exciting**, possibility

Athena at APC / AHE: Conclusions

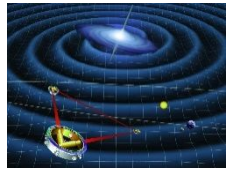
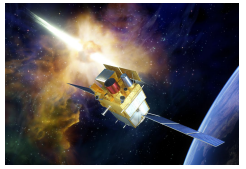
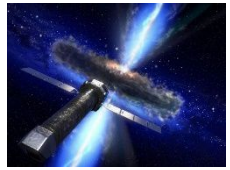
- **Athena Mission** fully in the line with AstroParticle topics and long-term Multi-Messenger scientific strategy of APC and the AHE group

- **Two type of X-Ray AstroParticle sources / Observation strategies**:
  - Persistent Localised (Weak) Sources => Large / Deep MM programs (GC, SNR)
  - Fast Unlocalised (Bright) Events => Time Domain MM Astro (sGRB/GW, SMBH-B)

- **Large Synergies with the MM** projects of APC: excellent (risky but rewarding) prospect for LISA-Athena science

- => **Participation to the project**

- APC Participation in **Athena/X-IFU** well established since 2014 with resp. of **WFEE** read-out subsystem

Today	**in few years**	**10 yr+**
		
aVirgo	aVirgo+	LISA
		
INTEGRAL	SVOM	Athena