AHEAD 2020
HIGH ENERGY ASTROPHYSICS

Funded by the Horizon 2020
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Grant Agreement No. 871158

HIGH ENERGY SATELLITES AND MULTIMESSENGER SYNERGIES

LUIGI PIRO

INAF/IAPS

SUMMARY

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- **AHEAD2020** and multimessenger
- High energy satellites & multimessenger synergies
  - High energy transients All/wide sky monitors
  - **Athena**

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AHEAD2020 in a nutshell

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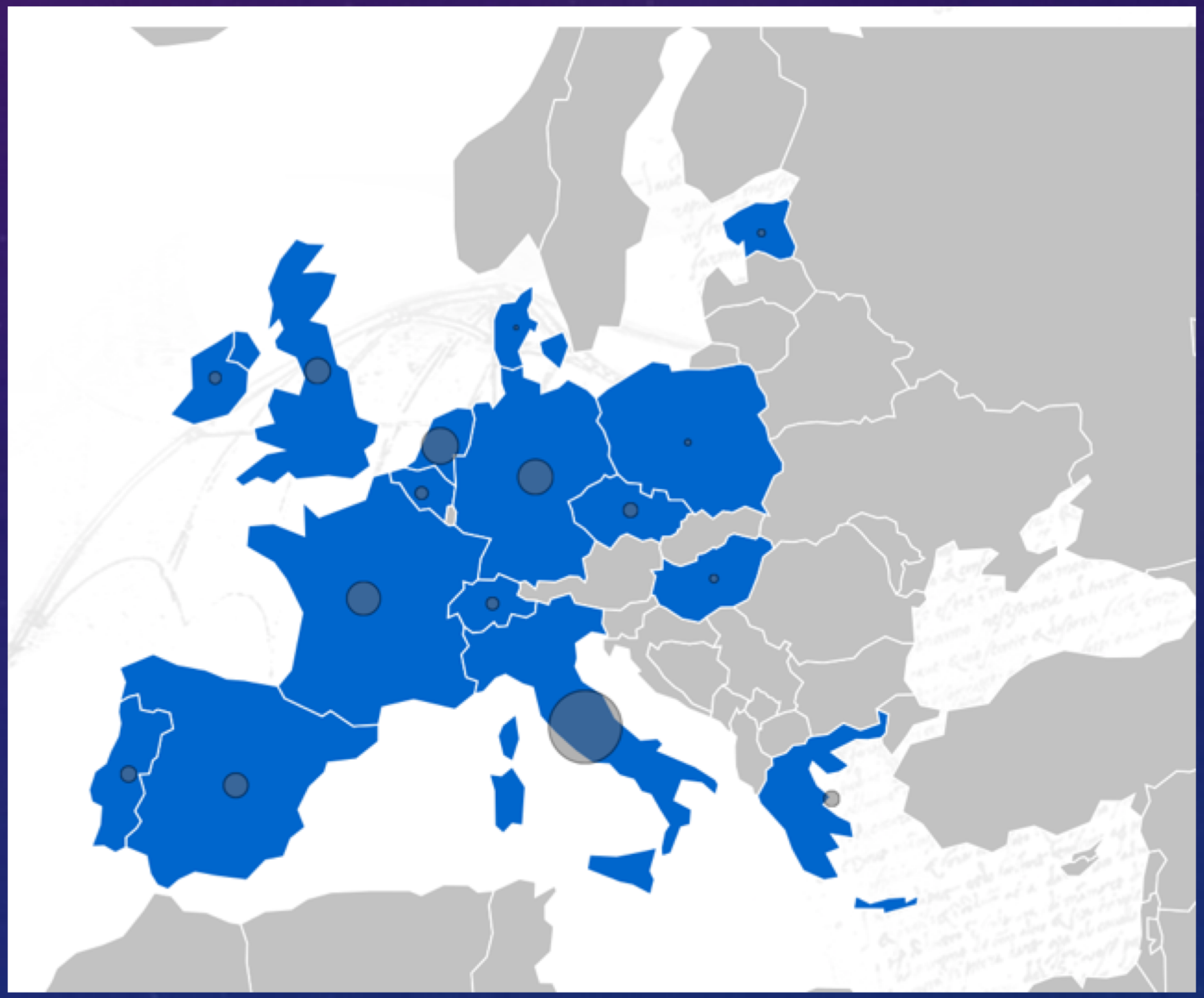
- AHEAD2020 (Integrated Activities for High Energy Astrophysics Domain) is the research infrastructure for High Energy Astrophysics selected as advanced community in the EU Horizon 2020 program.
- AHEAD2020 builds on our previous program, funded in H2020 as starting community, that allowed us to qualify now as advanced community. Its main goal is to improve the level of integration reached by the previous AHEAD program, while broadening its impact to include the new multi-messenger science and the European GW community.
- Started on 2 March 2020; scheduled end is 1 December 2024
- The Consortium is coordinated by INAF (coordinator: L.Piro) and includes 38 European institutions, including 3 SMEs



ahead.iaps.inaf.it

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AHEAD2020 GOALS

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- **Integrate and coordinate** national activities in high-energy astrophysics
- **Push the limits of current technology** and strengthen the infrastructure to maximise the scientific return of **new future high energy and multimessenger facilities**
- **Give access, free of cost to a network of ground-based** test facilities for H/W development, calibration and testing.
- **Ensure maximal scientific return from present and near future observing facilities** in the field of high energy and multimessenger astronomy: make accessible and usable multimessenger data, develop advanced data analysis and theory tools
- **Promote HE and multimessenger astrophysics** at various level
- **Prepare the community** to the scientific exploitation of the new facilities under development in Europe in high energy and multimessenger, by training the next generation of researchers.

AHEAD2020 WPs

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Multimessenger

Work package No	Work Package Title	Lead Partic. No	Lead Participant Short Name
WP1	AHEAD Management	1	INAF
WP2	NA1- General Networking for High Energy Astrophysics	6	UA
WP3	NA2- Networking activities for the synergies between the Gravitational Wave and High Energy Astrophysics community	7	EGO
WP4	NA3- Public Outreach	4	NOA
WP5	TA1- Access to experimental facilities	1	INAF
WP6	TA2- Access to Data Analysis	5	ULEIC
WP7	TA3- Computational Astrophysics	11	UNIGENEVE
WP8	VA1- Access to Gravitational Wave Science Archive and Tools	7	EGO
WP9	JRA1- Technologies and Techniques for Microcalorimeters	2	SRON
WP10	JRA2- Optics for next generation X-ray observatories	3	MPG
WP11	JRA3- Space Experiments for HE Astrophysics & Multimessenger Astronomy	16	NUID UCD
WP12	JRA4- Multimessenger Astronomy exploitation & tools	10	GSSI
WP13	JRA5- Laboratory Astrophysics	9	CNRS
WP14	JRA6- Advanced Tools for Data Analysis	1	INAF
WP15	JRA7- Technology Innovation and Exploitation for Society	15	TAS

3 Networking Activities (NA)

3 TransNational Access (TA)

1 Virtual Access (VA)

7 Joint Research Activities (JRA)

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HIGH ENERGY TRANSIENT SATELLITES

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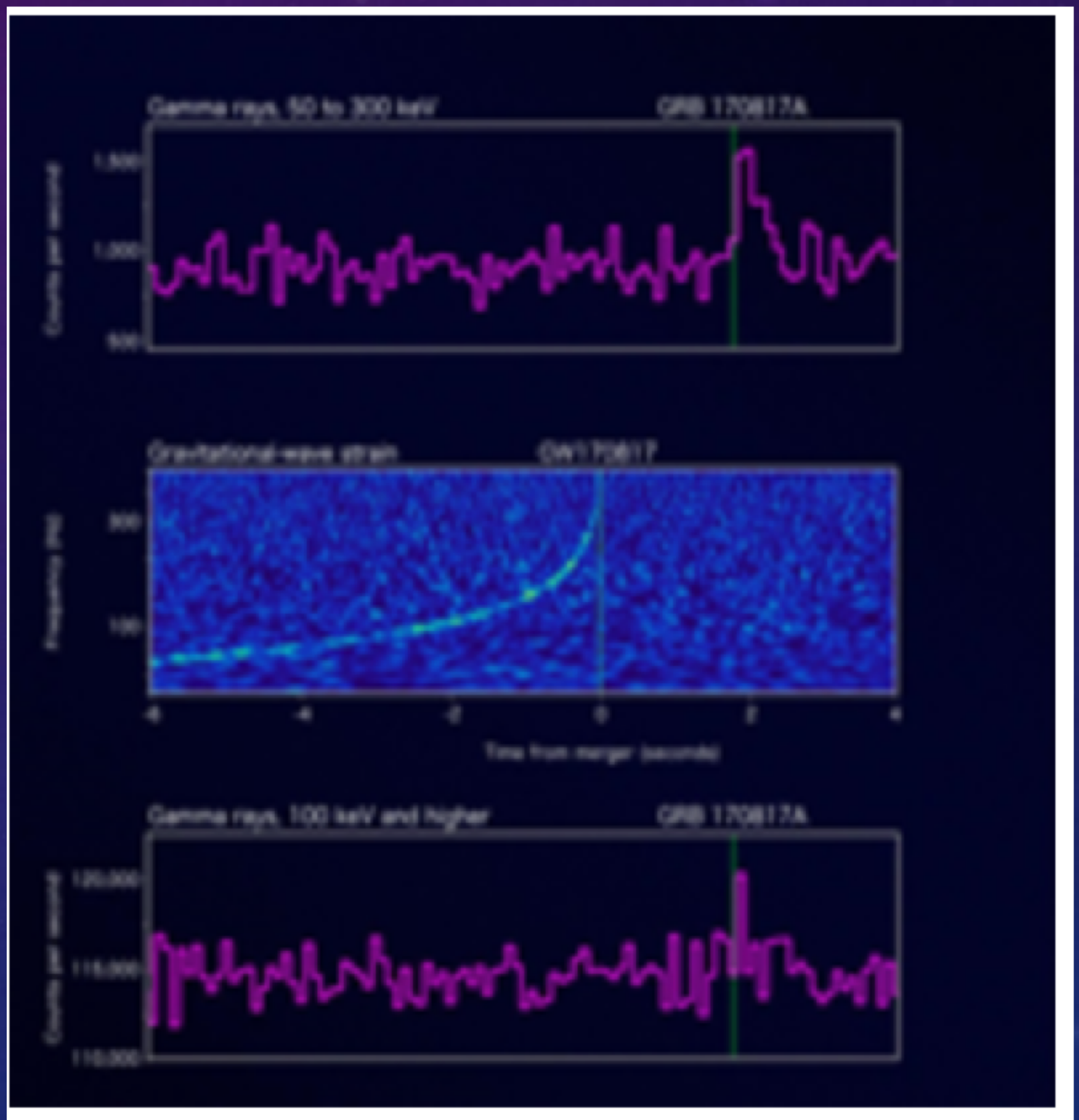
- All/wide sky monitoring in X and gamma-rays
- Localize promply counterparts of multimessenger transient sources
- Typology
  - Baricenter of different GBM modules (e.g. BATSE, Fermi GBM): all sky, typical accuracy: few sq.deg
  - Coded mask (BeppoSAX WFC, SWIFT/BAT, INTEGRAL, SVOM,..): 1 sr, few arcmin
  - Lobster eye (Einstein Probe, THESEUS, GAMOW,..); 1 sr, <1arcmin, high sensitivity
  - Nanosat constellations with localization by photon arrival time (HERMES,BURSTCUBE, EIRSAT, GRBAlpha,..): all sky, few arcmin
- To be launched in next years: SVOM (2021/22), Einstein Probe(2022), Nanosat pathfinders

GW170817 in GW and hard X-rays



Abbott et al. 2017

LOBSTER-EYE SENSITIVITY TO THE TRANSIENT UNIVERSE

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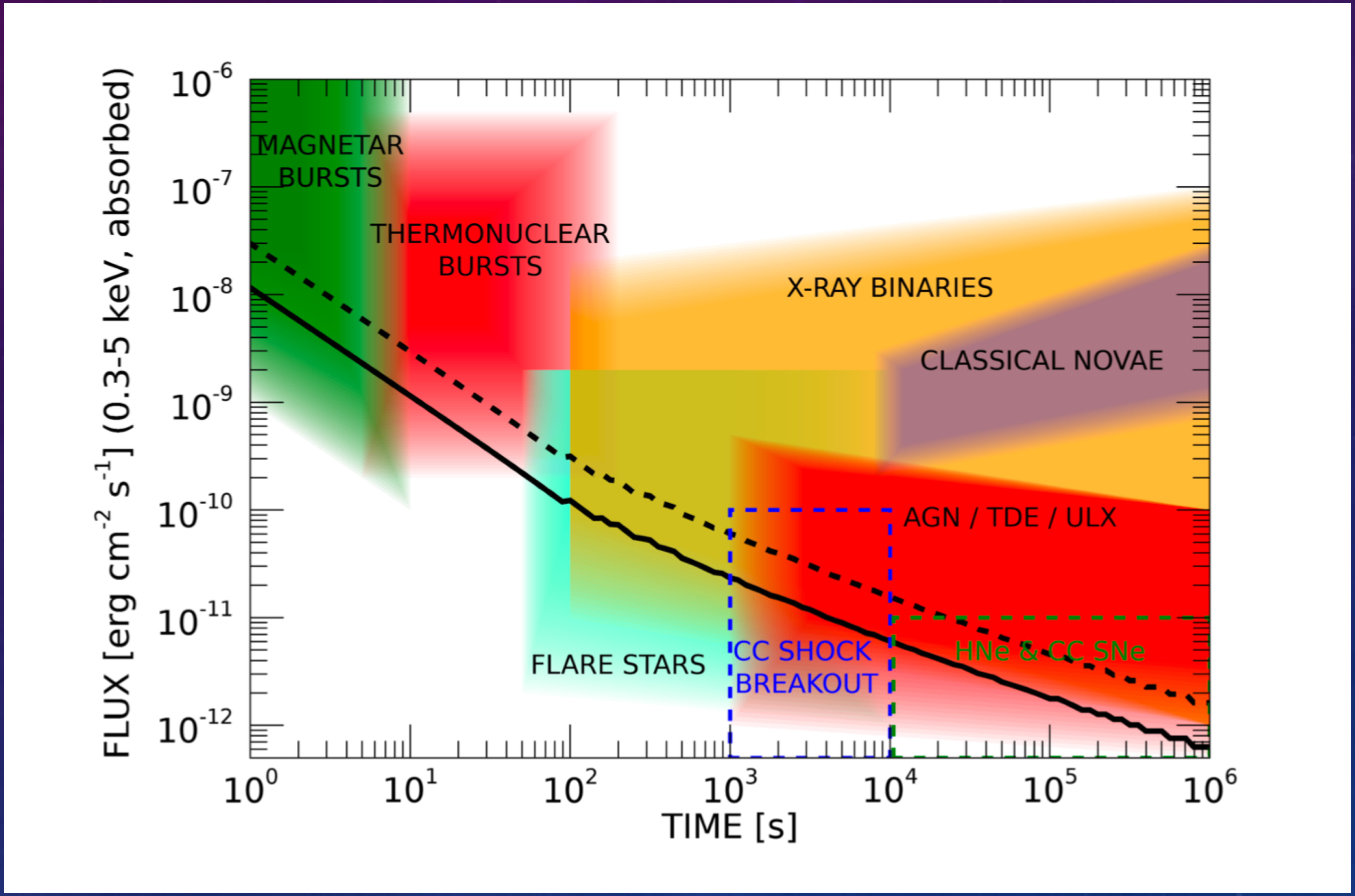

THESEUS: Mereghetti et al 2021

NANOSAT CONSTELLATIONS

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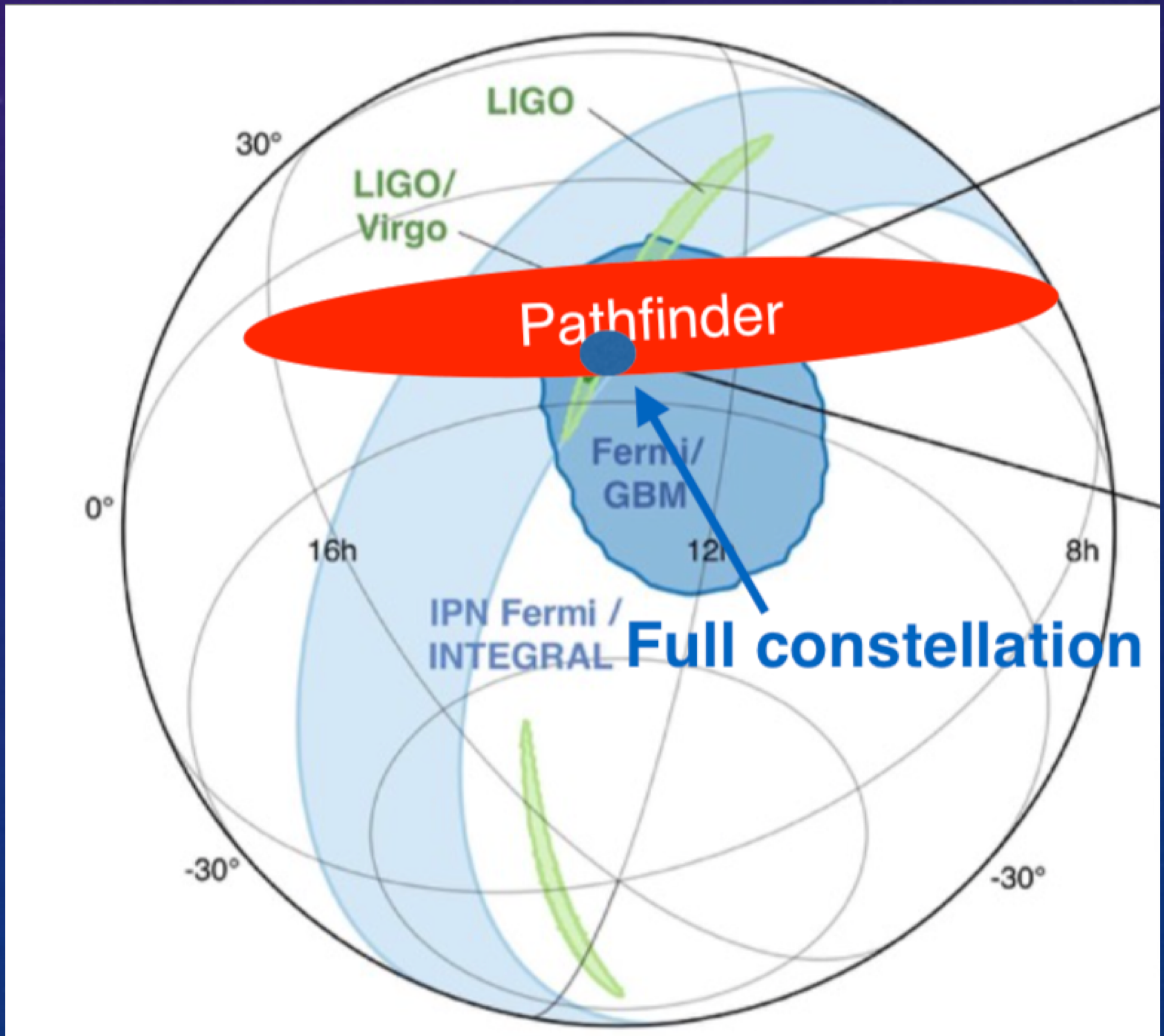
- New venue pursued by several groups (HERMES, BurstCUBE, EIRSAT, CAMELOT, GRBalpha,..) due to
  - consolidated instrument technology (typically hard X-ray scintillators)
  - Scalability from pathfinder to constellations (baloon=>1-2 nanosat=>constellation=>network)
- Measure GRB positions through delays between photon al times
- Typical performance of a 50-100 nanosat constellation:
  - > ½ sky coverage (Low-Earth Orbit)
  - Localization 10arcmin for a few dozens GRB /yr
  - Prompt dissemination



Fiore et al 2020

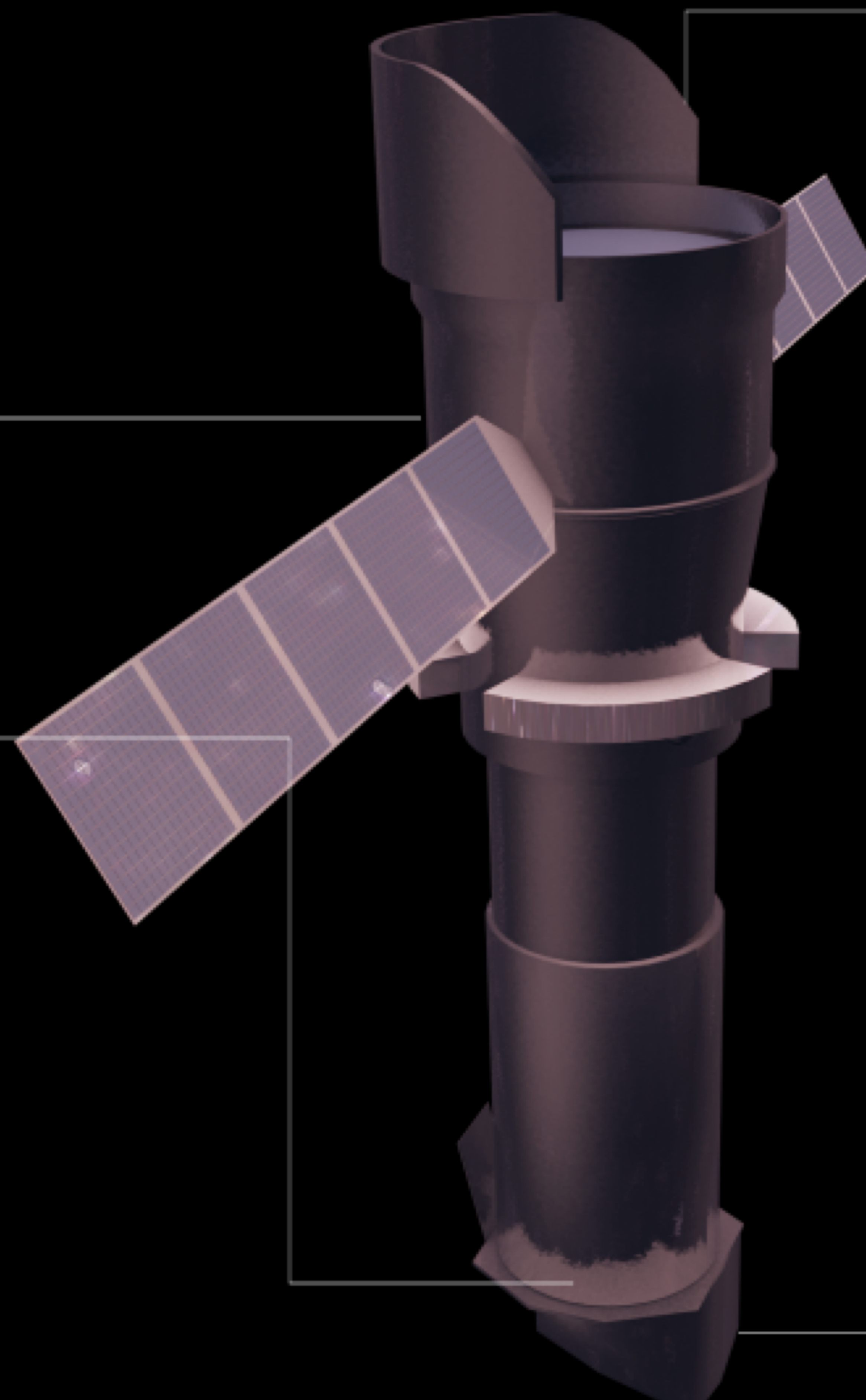
ATHENA

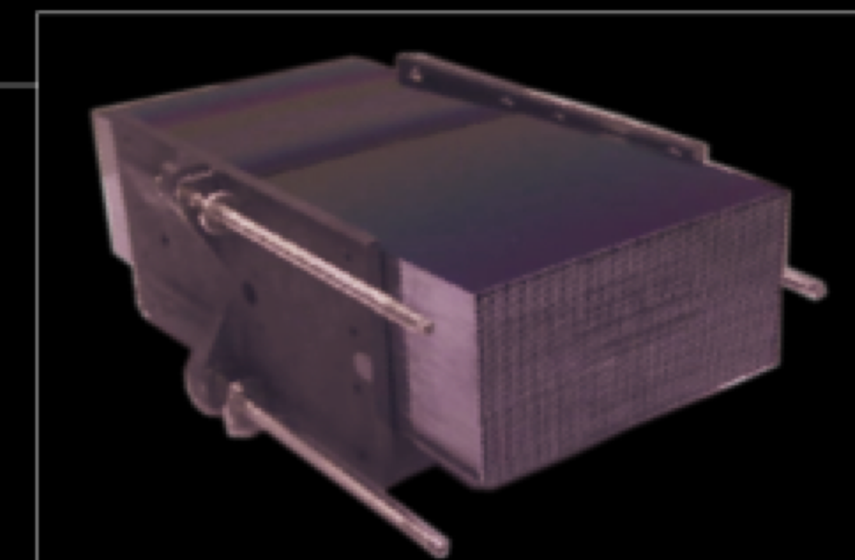
esa

The Athena Observatory

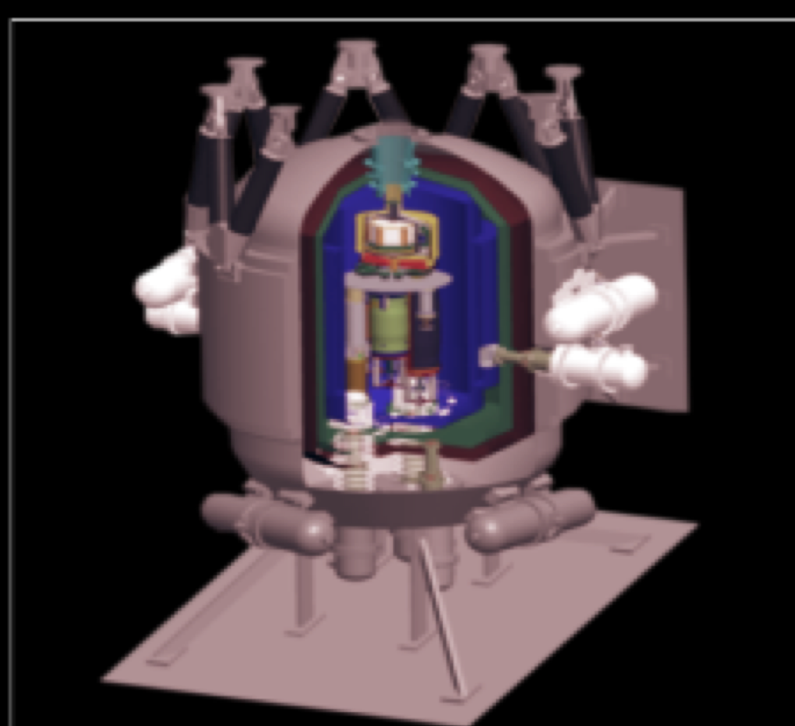
Willingale et al, 2013
arXiv1308.6785

L1 orbit Ariane VI
TOO in 4 hrs
Mass 7 tons
Power 2500 W
4+6 year mission



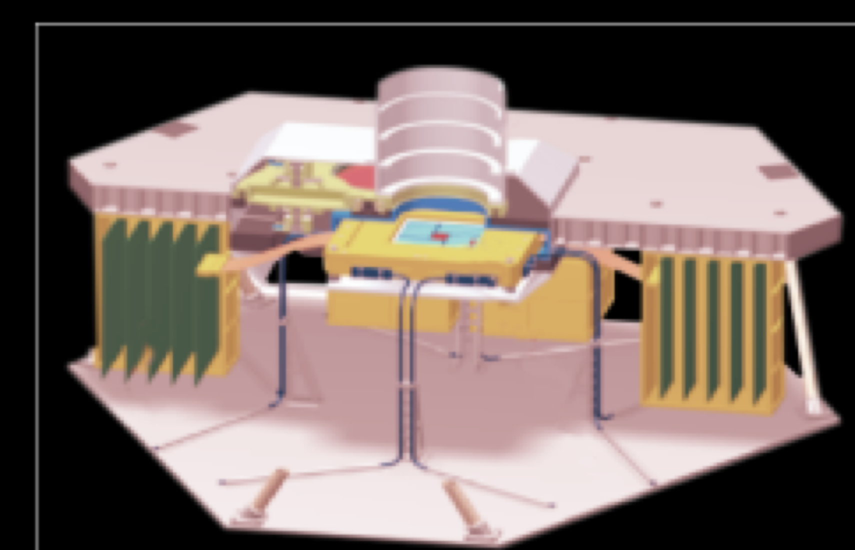


Silicon Pore Optics:
$1.4\ m^2$ at 1 keV
5 arcsec HEW
Focal length: 12 m
Sensitivity: $3\ 10^{-17}$ erg cm^{-2} s^{-1}



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

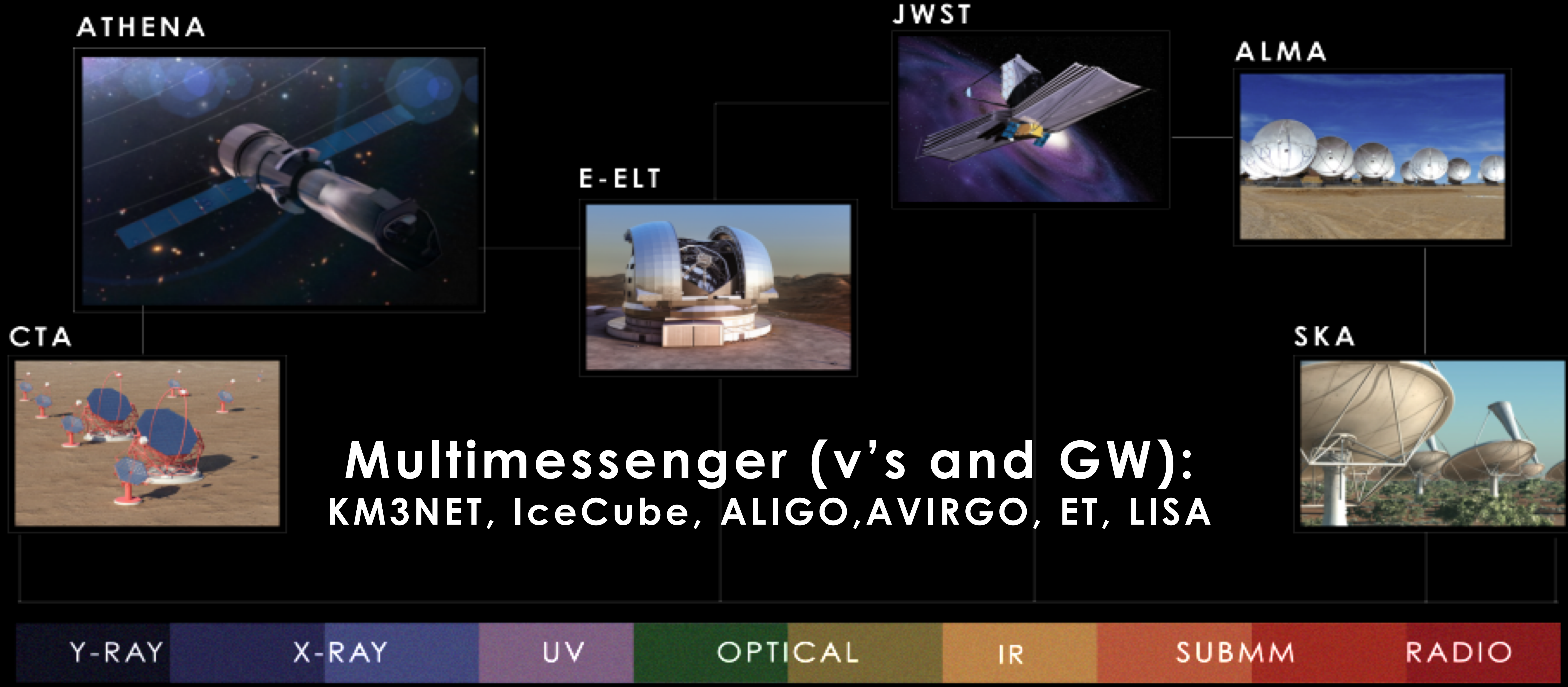
Barret et al., 2013 arXiv:1308.6784



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

Rau et al. 2013 arXiv1307.1709

Athena in context of large facilties



Multimessenger (ν's and GW):
KM3NET, IceCube, ALIGO,AVIRGO, ET, LISA

Athena is a crucial part of the suite of large observatories needed to reach the science objectives of astronomy in the coming decades

ATHENA AS A MULTIMESSENGER TOOL

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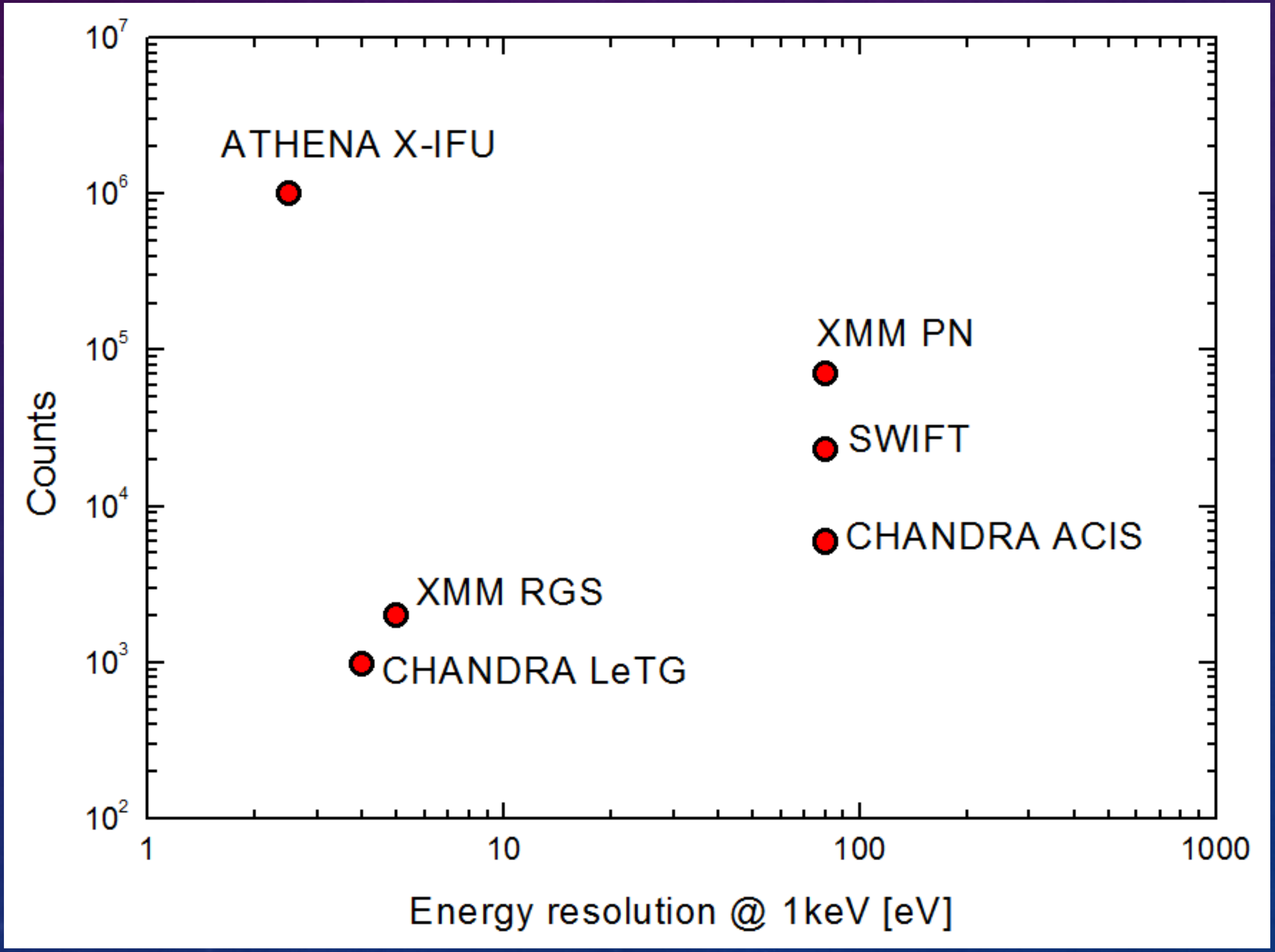
- Energetic phenomena explosions, accelerations sites, transients
- Athena assets:
  - 10-100 fewer field sources (per sq degree) compared to lower frequencies
  - Wide field (40 arcmin2) (+mosaic/raster scan)
  - arcsec imaging (location accuracy 1arcsec)
  - sensitivity down to few 10^{-17} erg/cm2/s
  - Integral field spectroscopy with high spectral resolution (R=1000@2.5keV)
  - Fast Too (4hrs) , large FoR(>50%)

Athena TOO

enabling high spectral resolution and high sensitivity in the Transient Universe



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THE ATHENA MULTI-MESSENGER SYNERGY WHITE PAPER

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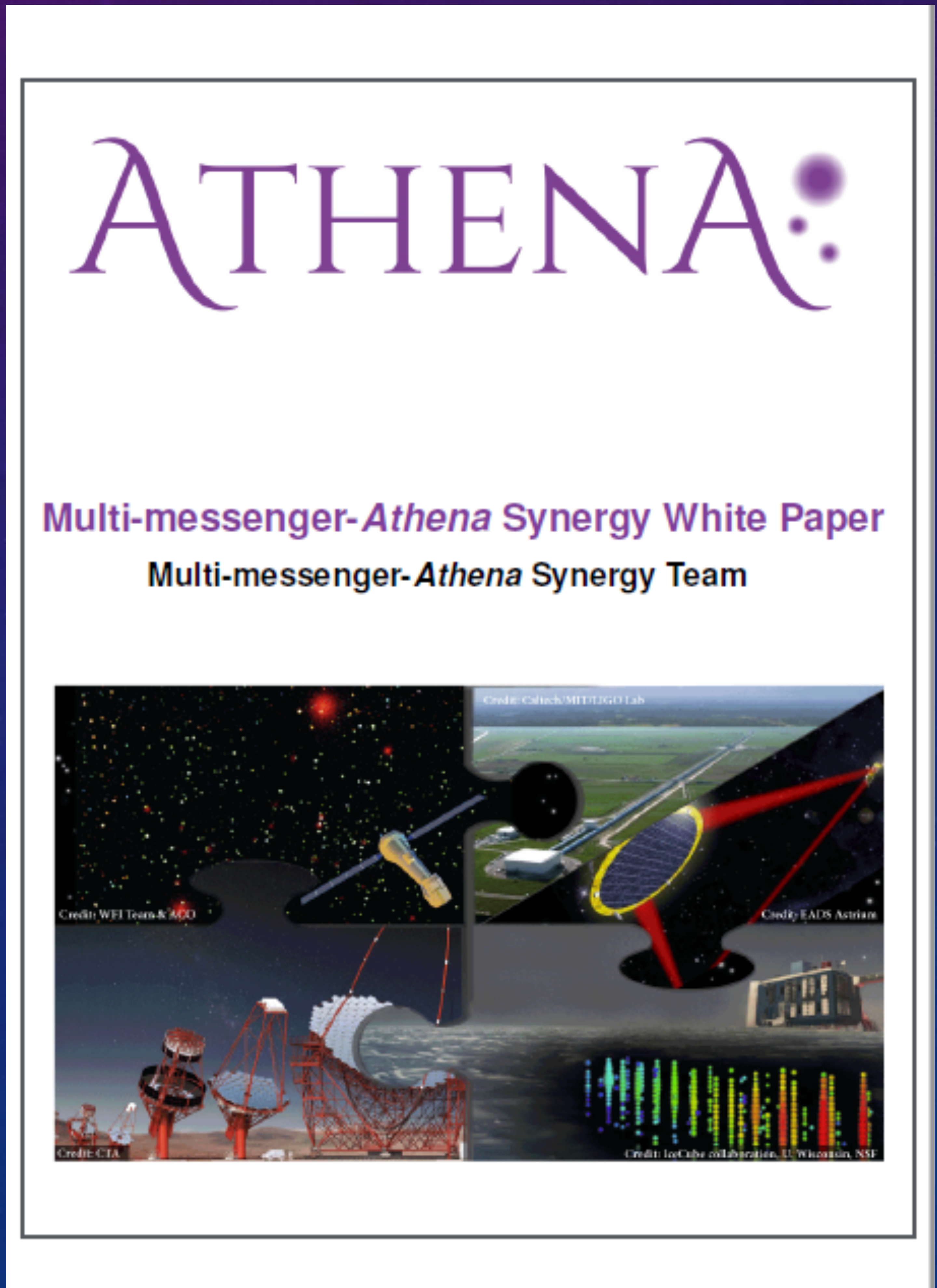
- Scientific synergies between the Athena and Gravitational Waves, neutrinos, high energy and Gamma Ray Burst transient facilities that will be operational contemporary to Athena.
- Outline the operational scenario to successfully implement the synergy science goals
- Each facility (incl Athena): contact person + experts
  - **A& ground based GW, AVirgo/Aligo and future facilties**
  - **A& LISA**
  - A& ν's and HE (ICECUBE, KM3Net, CTA)
  - A& Transient Universe experiments a la Theseus
- To be released by Oct. 2021


ATHENA

Multi-messenger-*Athena* Synergy White Paper

Multi-messenger-*Athena* Synergy Team

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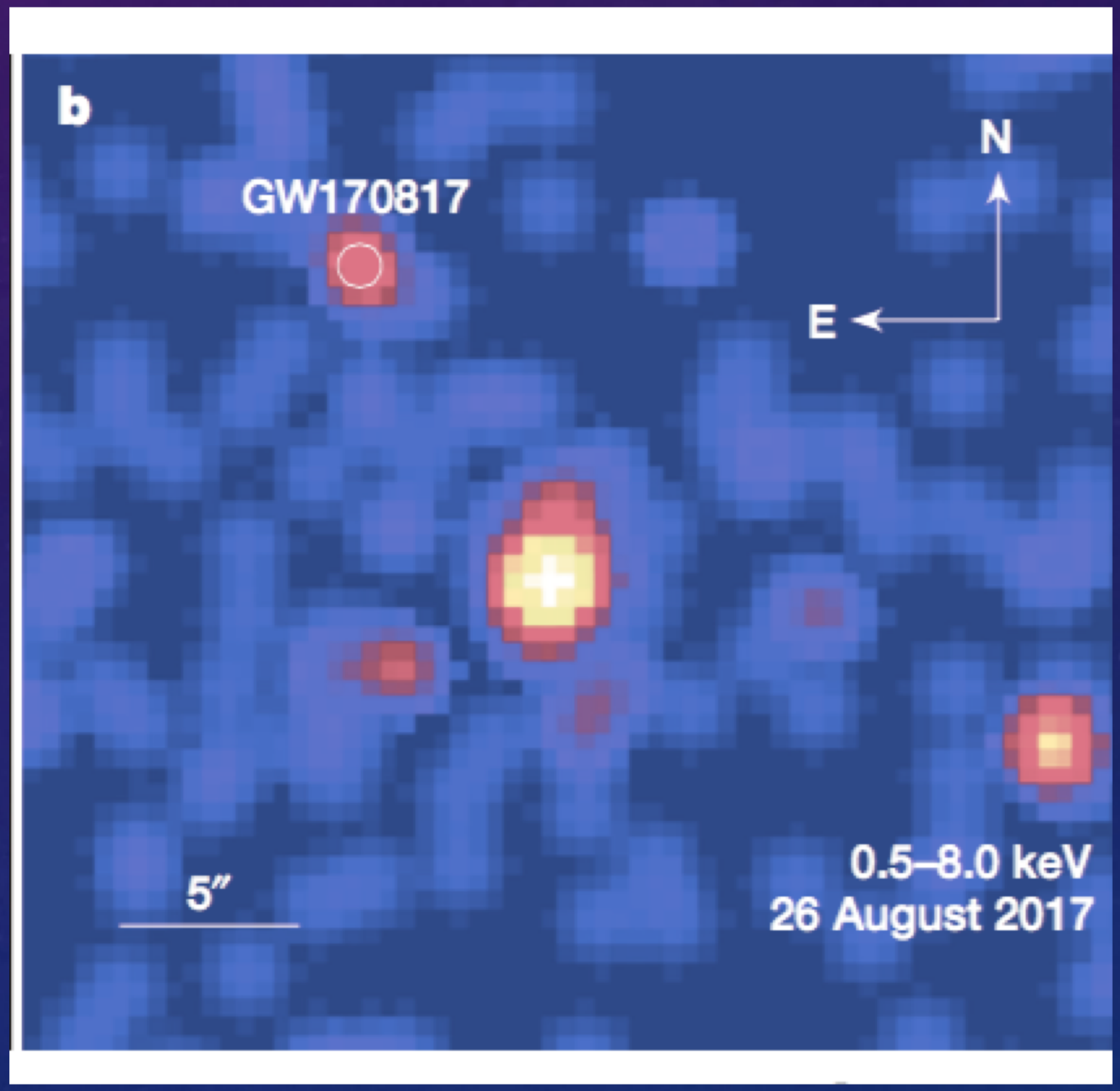
ATHENA AND GROUND-BASED GW DETECTORS

- Synergy science themes
  - Jet physics and BH accretion
  - Formation and evolution of black holes,
  - NS EOS,
  - Acceleration processes
  - How did intermediate- and high-Z elements form
- Class of Sources
  - Binary stellar mergers (BNS, BBH, NS-BH)

Discovery image of GW170817 with Chandra



Troja, Piro, van Eerten+ Nature, 2017

THE HORIZON OF GW INTERFEROMETERS

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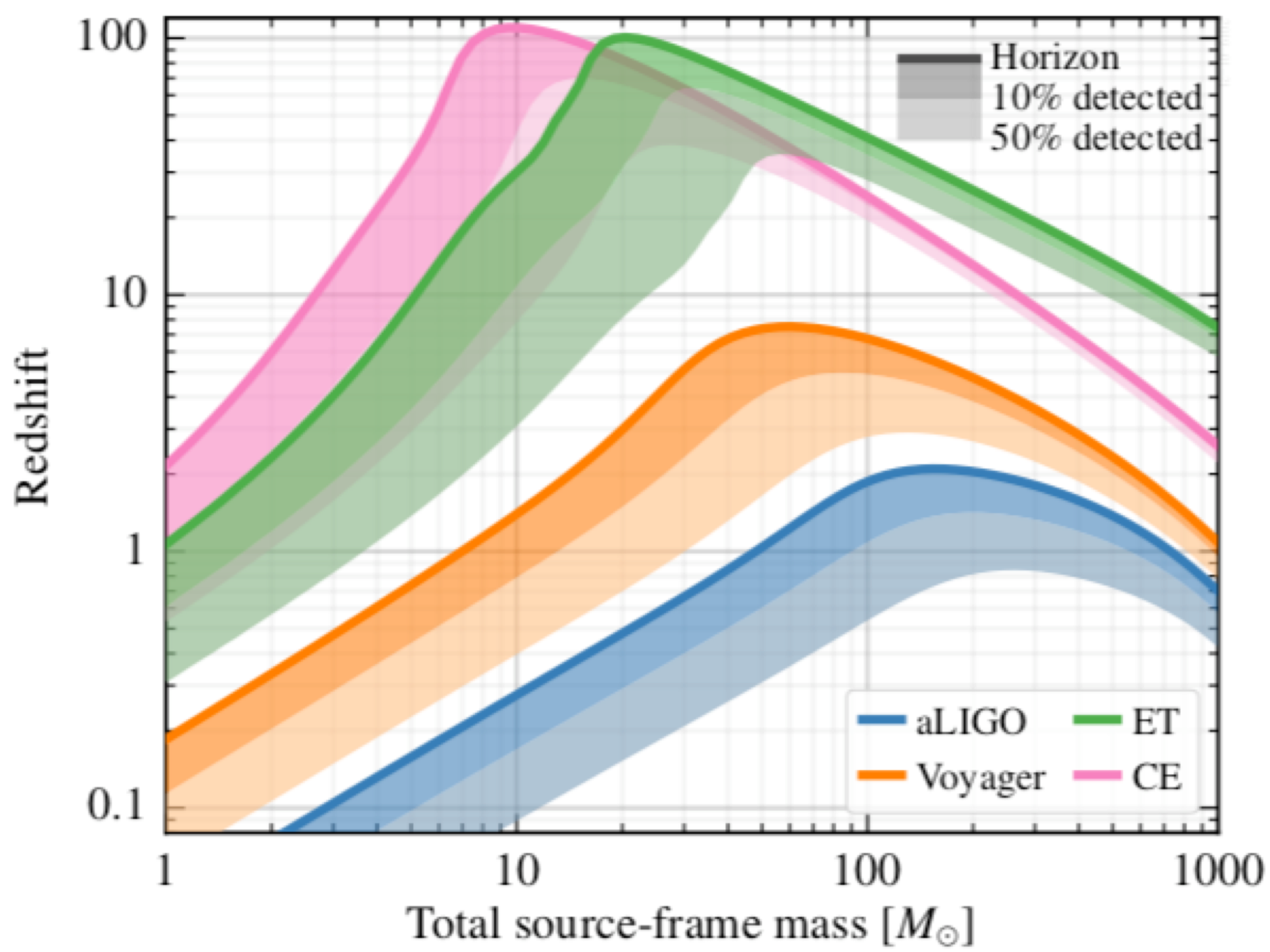

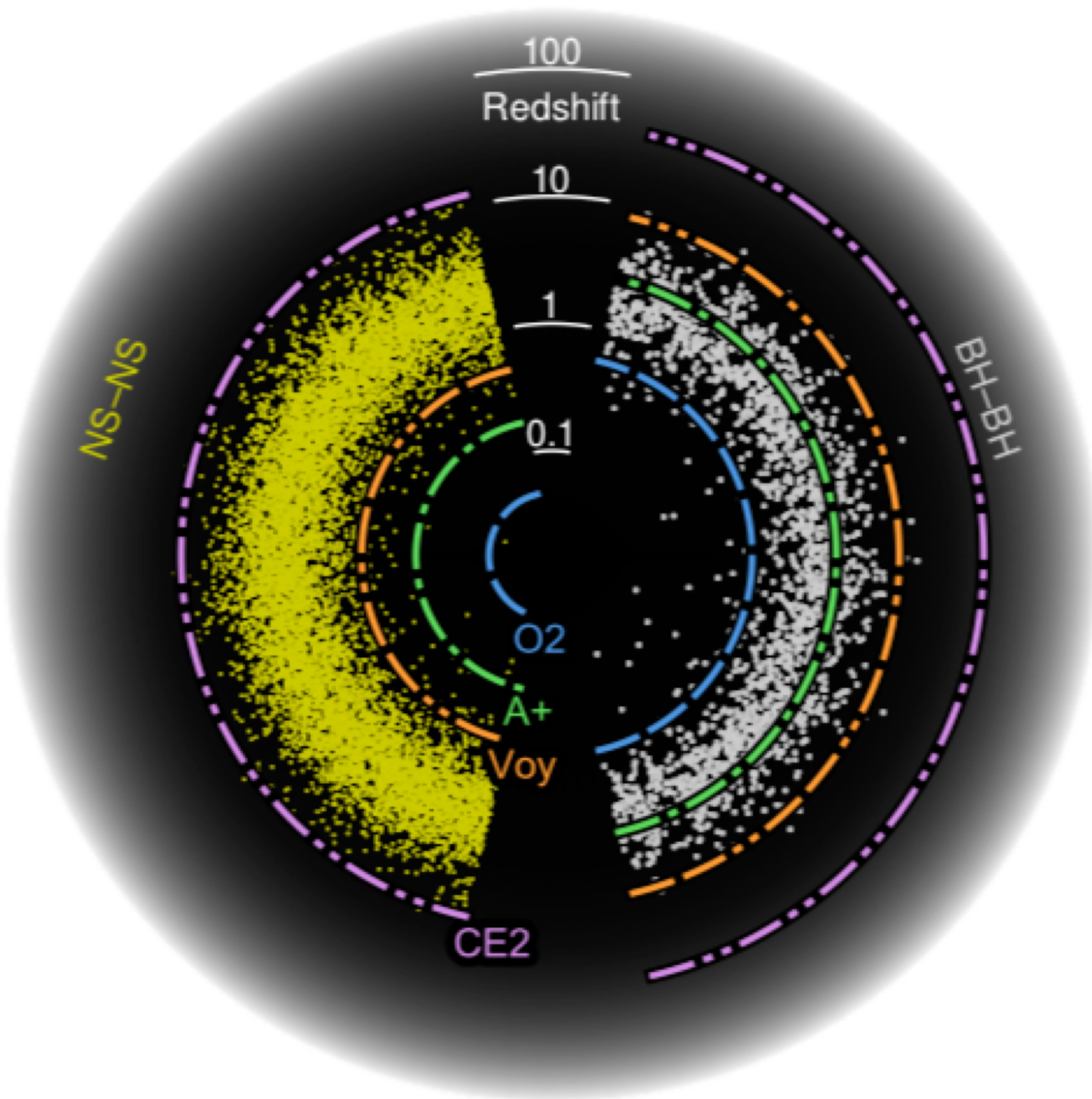

Network	N(detected) [yr^{-1}]	Median loc. [sq.deg]	N(<1 sq.deg.) [yr^{-1}]	N(<10 sq.deg.) [yr^{-1}]	N(<100 sq.deg.) [yr^{-1}]
HLVKI	15	7	0	15	15
3Voyager	800	20	5	170	770
1ET+2Voyager	6,100	21	20	960	6,100
1ET+2CE	320,000	12	4,500	130,000	310,000

EXTENDING THE EM HORIZON OF GW MERGERS WITH ATHENA

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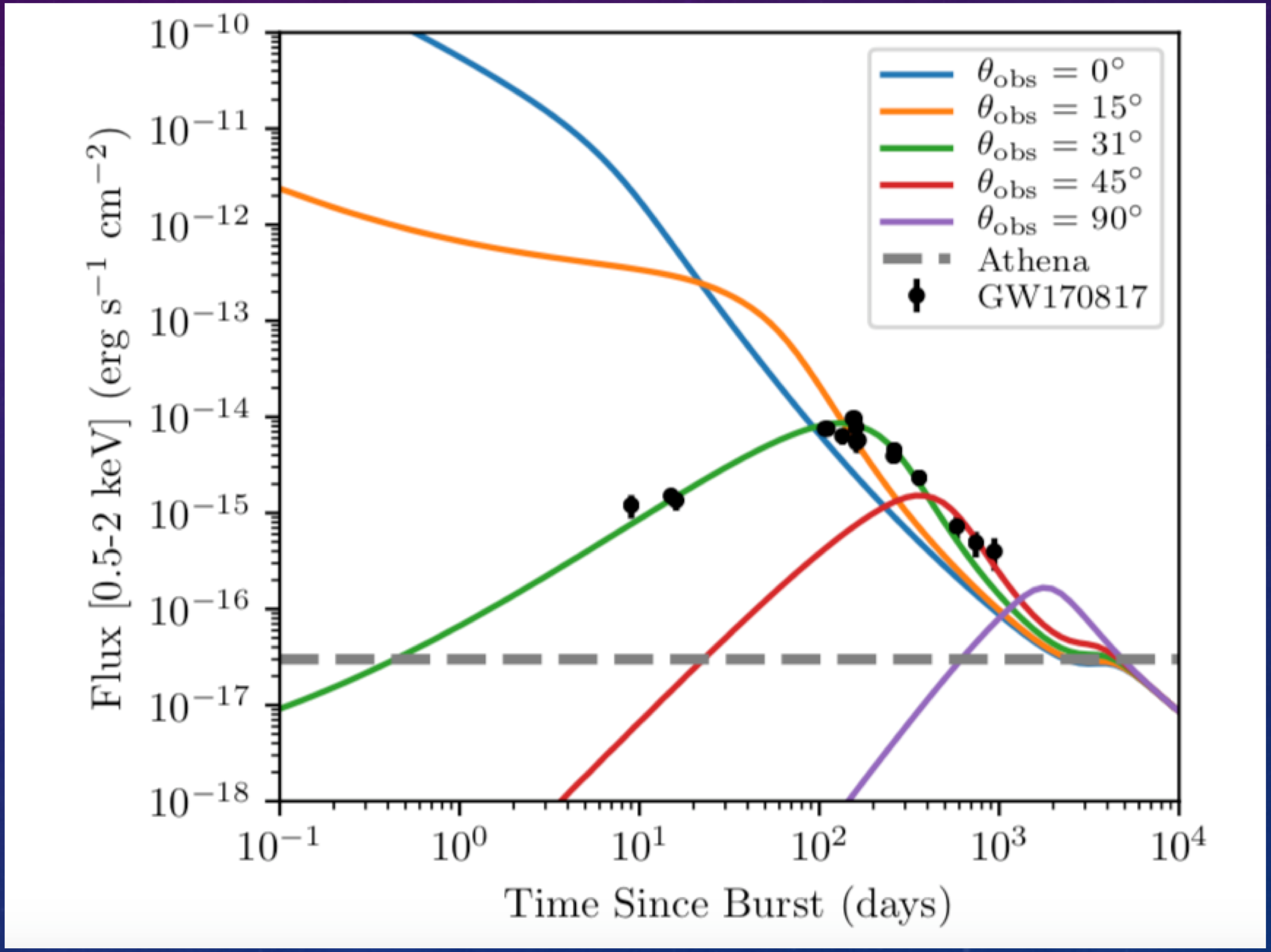
- GW170817-like



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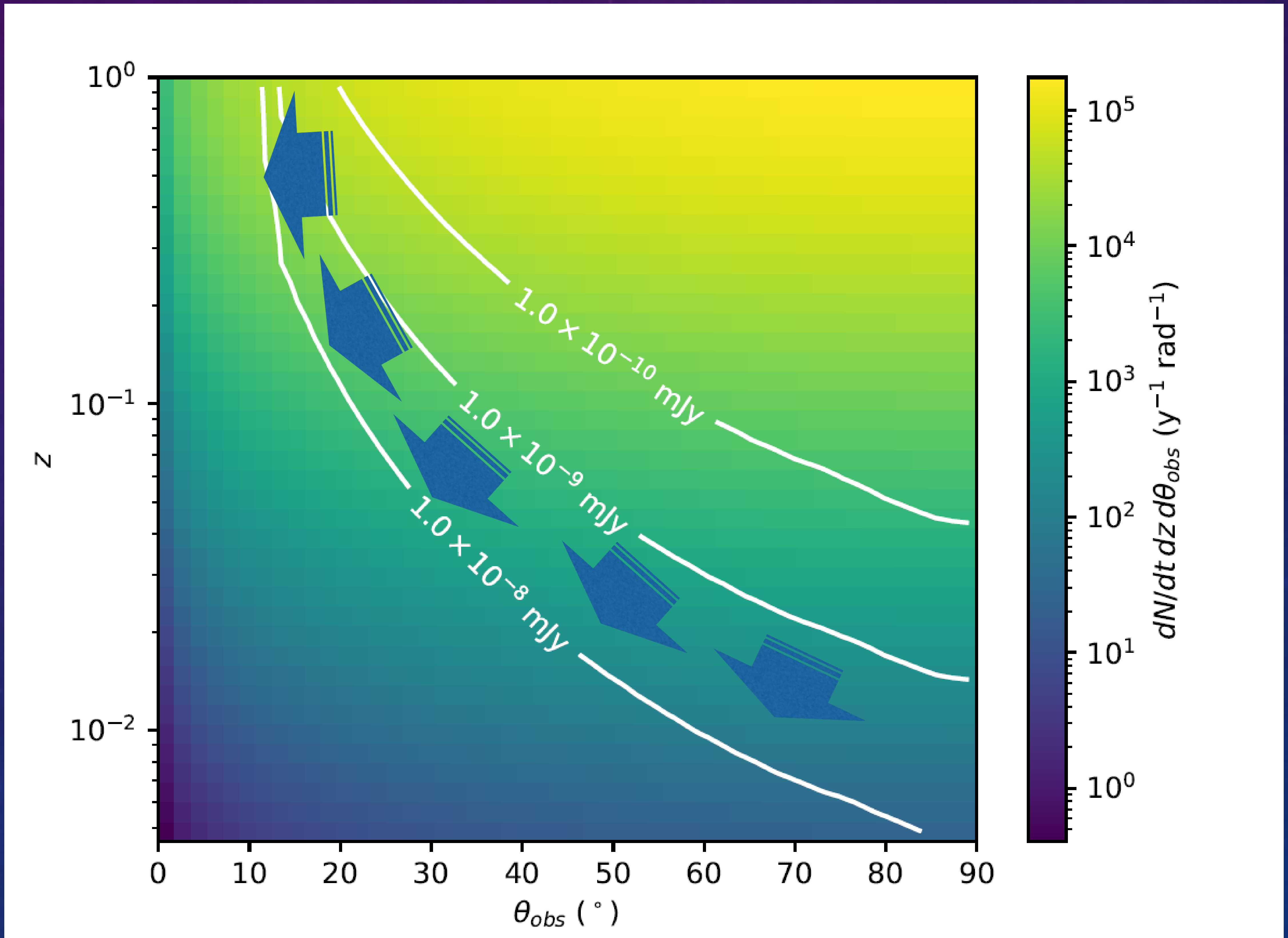
EXTENDING THE EM HORIZON OF OFF-AXIS JET FROM GW MERGERS

- Rate of chocked jets
- Jet geometry, launch
- Shock acceleration
- Calorimetry of the jet explosion
- Properties of the environment and stellar evolution



GW170817-like upto 40 deg for 2G and 15 deg for 3G

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ATHENA AND LISA

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- Synergy science themes
  - Accretion flows, formation of X-ray corona and jet launching around newly formed horizons
  - Testing General Relativity as theory of gravity and measuring the speed of GWs and dispersion properties *(GW and EM chirp)*
  - Enhancement of the cosmic distance scale using GW sources as standard sirens (*GW=> luminosity distance; EM=> redshift)*
- Sources
  - Massive black hole binary coalescences in gas-rich environments
  - Extreme mass ratio inspirals (EMRIs) where a stellar black hole is skinning the horizon of a large black hole surrounded by an AGN disc
  - coalescence of stellar mass binary BHs
  - interacting double white dwarf and accreting binary systems

TIMELINE OF SMBH BINARIES

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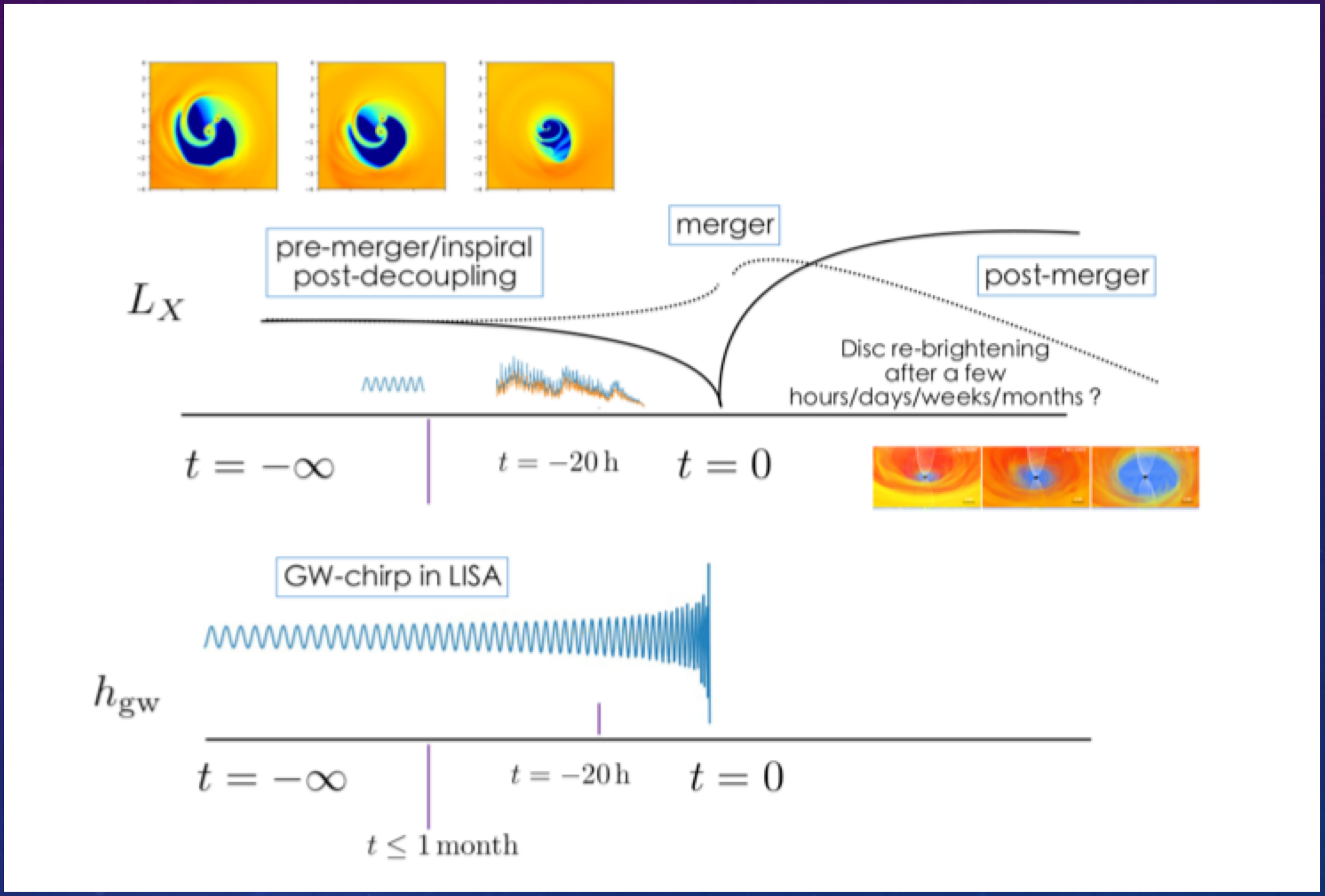
X-ray emission based on theory, widespread range of prediction

- Premerger: Gas accretion may be present before the merger (modulated): X-ray precursor
- Post-merger: formation of hot corona, launch of jet



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RATES

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- SMBH binary by LISA from 10 to 300 in 4 years
- At z<2 for mass a few 10^5-10^7 Msun(most promising for X-ray detection):

Table 3.1: Observational-based predicted number of expected SMBH merging events visible by *Athena* and LISA over 5 years.

	$M=10^6\ M_\odot$	$M=10^7\ M_\odot$
$z=1$	1.5	0.5
$z=2$	12	1.2

Table 3.2: Fluxes(0.5-2 keV) in cgs units and exposure times (in brackets, units of ks) to detect a X-ray unobscured AGN at the Eddington limit with the current configuration of the *Athena* mirror+WFI.

	$M=10^5\ M_\odot$	$M=10^6\ M_\odot$	$M=10^7\ M_\odot$
$z=1$	5.3×10^{-17} (250 ks)	5.3×10^{-16} (7 ks)	5.3×10^{-15} (<1 ks)
$z=2$	1.1×10^{-17} ($\gtrsim$1 Ms)	1.1×10^{-16} (70 ks)	1.1×10^{-15} (3 ks)

FEASIBILITY OF A JOINT ATHENA-LISA OBSERVATION OF SMBBH

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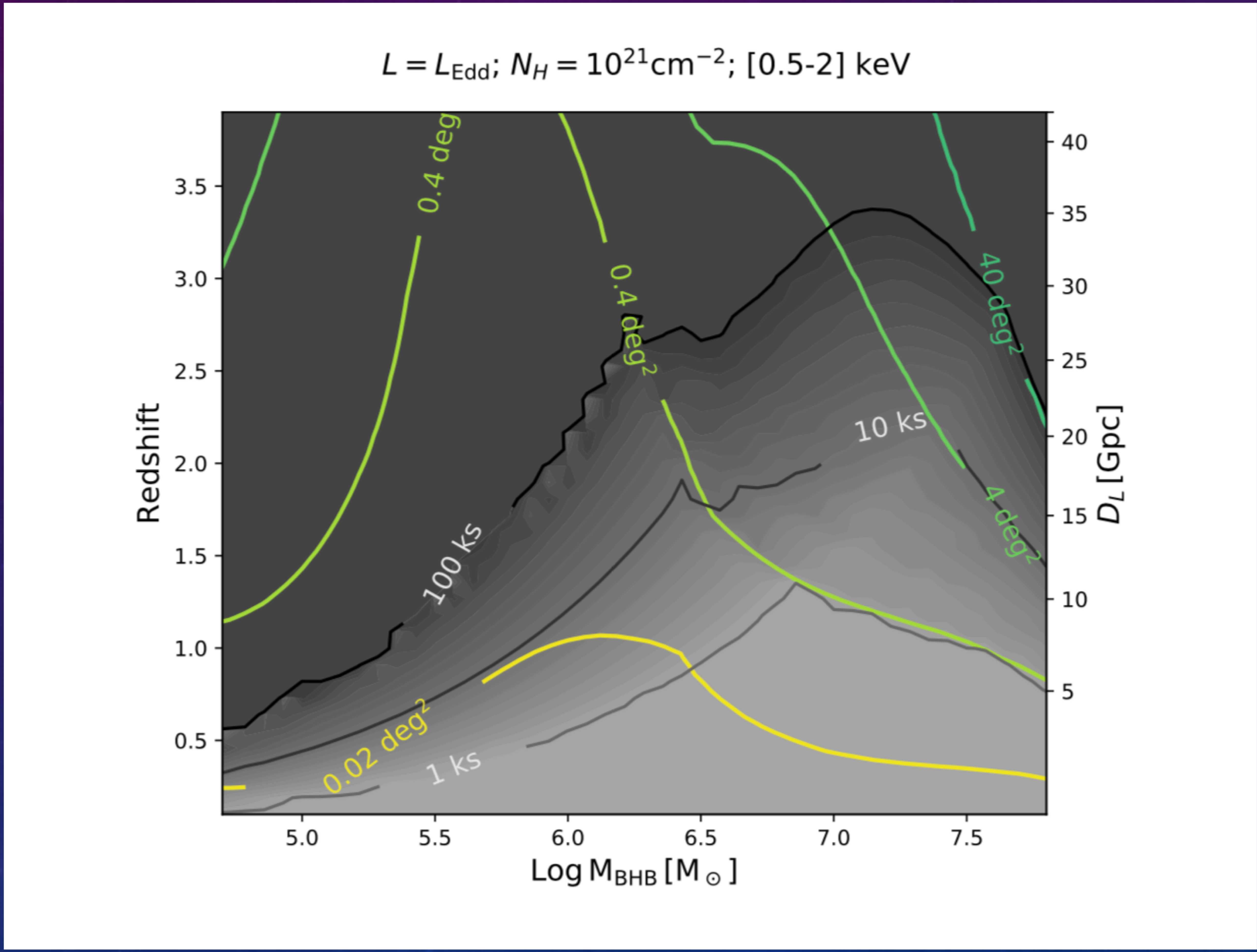

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CONCLUSIONS

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- Synergy of high energy satellites with multimessenger facilities covers exciting and numerous scientific themes (energetic universe), boosting the scientific return
- Common ground for high-energy astronomers and astro-particle communities.
- Joint effort in developing a common infractructure (experiment, theory, data analysis) already in place: AHEAD2020
- Exciting perspective in the next decade