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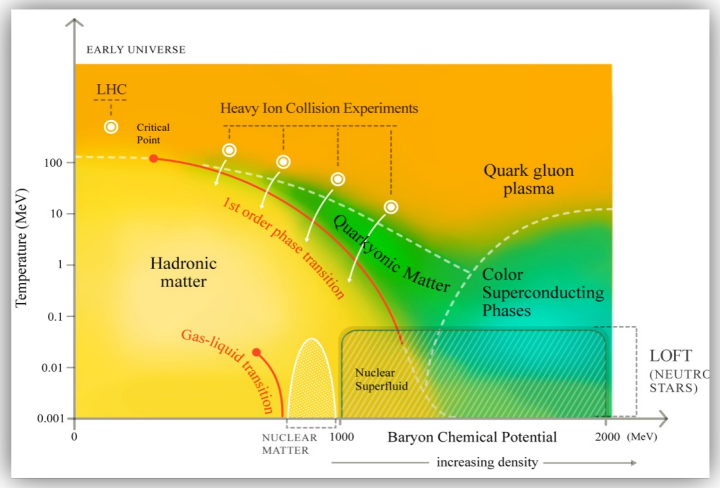
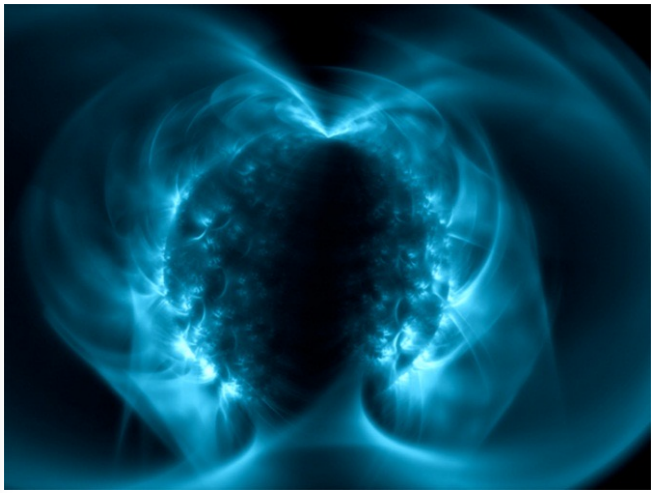
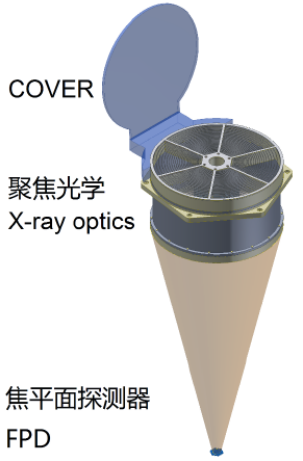
MATHEMATISCH-
NATURWISSENSCHAFTLICHE FAKULTÄT

Institute of Astronomy and Astrophysics







The eXTP mission

Andrea Santangelo*
IAAT Kepler Center, University of Tübingen

GROWING BLACK HOLES: ACCRETION AND MERGERS , 15 – 20 May 2022, Kathmandu, Nepal


News and Views
New ideas
New technology
By Sergio Colafrancesco

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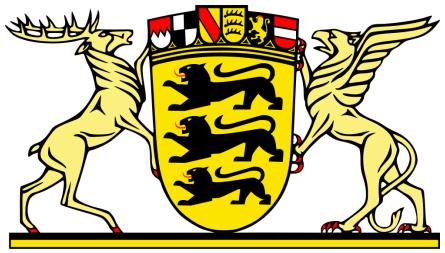
In Southwest Germany, the Heart of Europe

Population 85,000

University city

"Land" is Baden-Württemberg, Capital Stuttgart



Population 10.6 Million
Area about 36,000 km^2


According to an article on BBC travel: ‘Tübingen: Europe's fiercely vegan, fairy-tale city’

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Perhaps Tübingen's most famous student

Johannes Kepler
(1571-1630)

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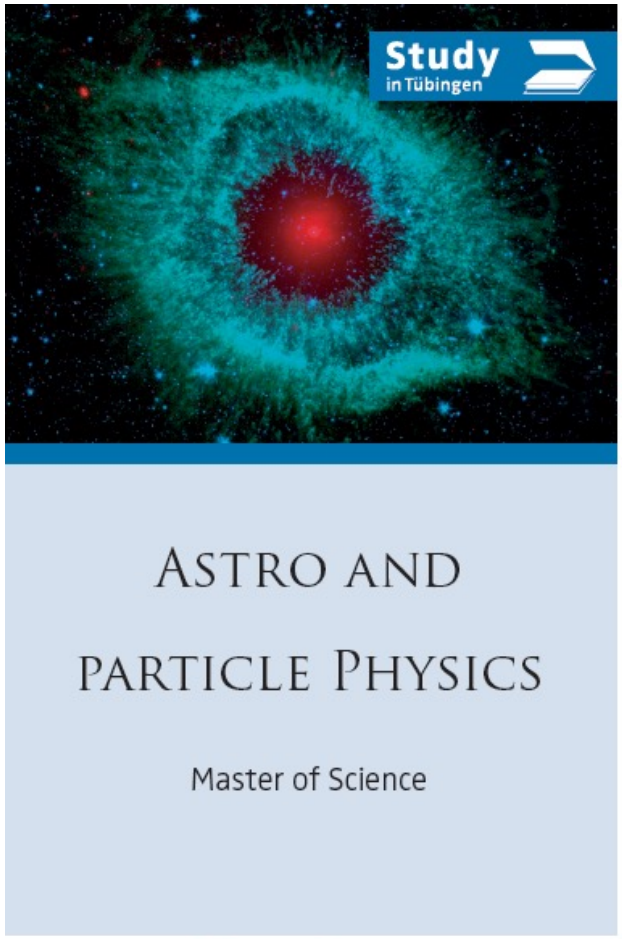
Master in Astro and Particle Physics



Basic Research in Astro and Particle Physics (Semester 1+2)	
Astronomy & Astrophysics	9 CP
Particle Physics	9 CP
Laboratory Work	6 CP
Modern Topics	6 CP
Specialisation Modules (Semester 1+2)*	**∑ 24 CP**
Theoretical Astrophysics	6 CP
Computational Methods	6 CP
Stellar Physics	6 CP
General Relativity	6 CP
Relativistic Astrophysics	6 CP
Neutrino Physics	6 CP
High Energy Astrophysics	6 CP
Cosmology	6 CP
Extragalactic Astrophysics	6 CP
Space Physics and Astrophysics	6 CP
Quantum Field Theory	6 CP
Neighboring Field (Semester 2)**	
Module of neighboring field	6 CP
Scientific Work (Semester 3+4)	
Methods and project planning	15 CP
Scientific specialisation in Thesis topic	15 CP
Master Thesis	30 CP

CP: Credit Points

Managed by the Kepler Center for Astro and Particle Physics, Tübingen

International Master, around 25-30 new students every year

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eXTP

The enhanced X-ray Timing and Polarimetry Mission (an update)

S.N. Zhang, A. Santangelo, M. Feroci, F. Lu, et al Sci. China-Phys. Mech. Astron (2019)

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Summary of the talk

eXTP is an **X-ray mission** which aims at reaching **unprecedent photon throughput with good angular and very good energy resolution.** The mission will also host **an X-ray Polarimeter**.

- eXTP – The science payload and the mission
- eXTP – The science case
- Conclusions

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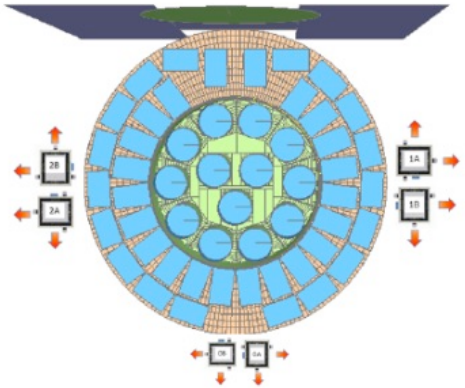

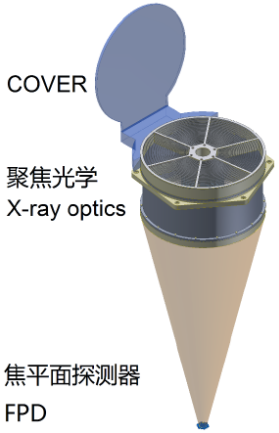

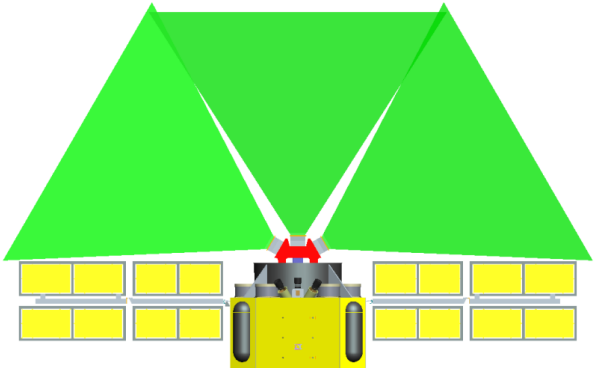

Part I

Mission and Instruments

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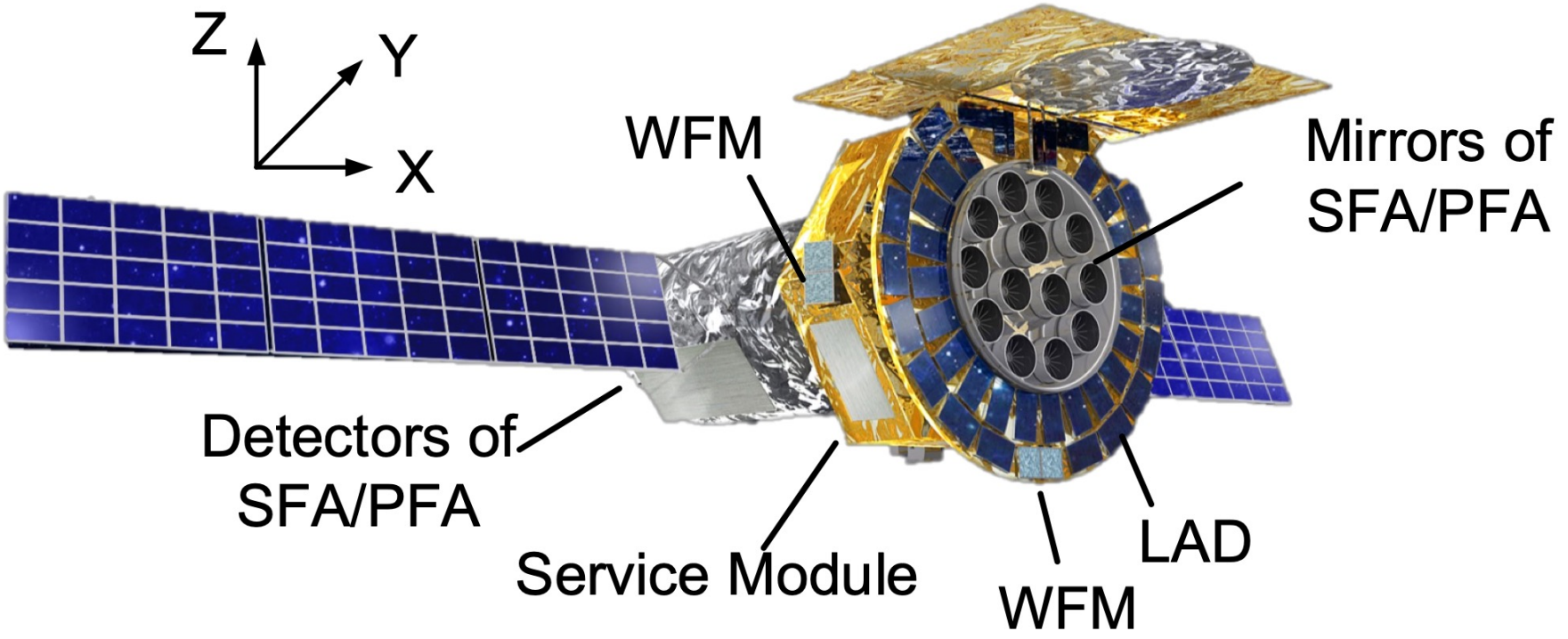
The mission: a large mission



To be launched in a low-earth orbit at an **altitude of ≤570 km.** The **inclination of the orbit is ≤2.5 deg** (to minimize background).

Baseline Launcher is the **Chinese Long March-5 (CZ-5)** vehicle. Nominal **science operations will last for 5 years.**

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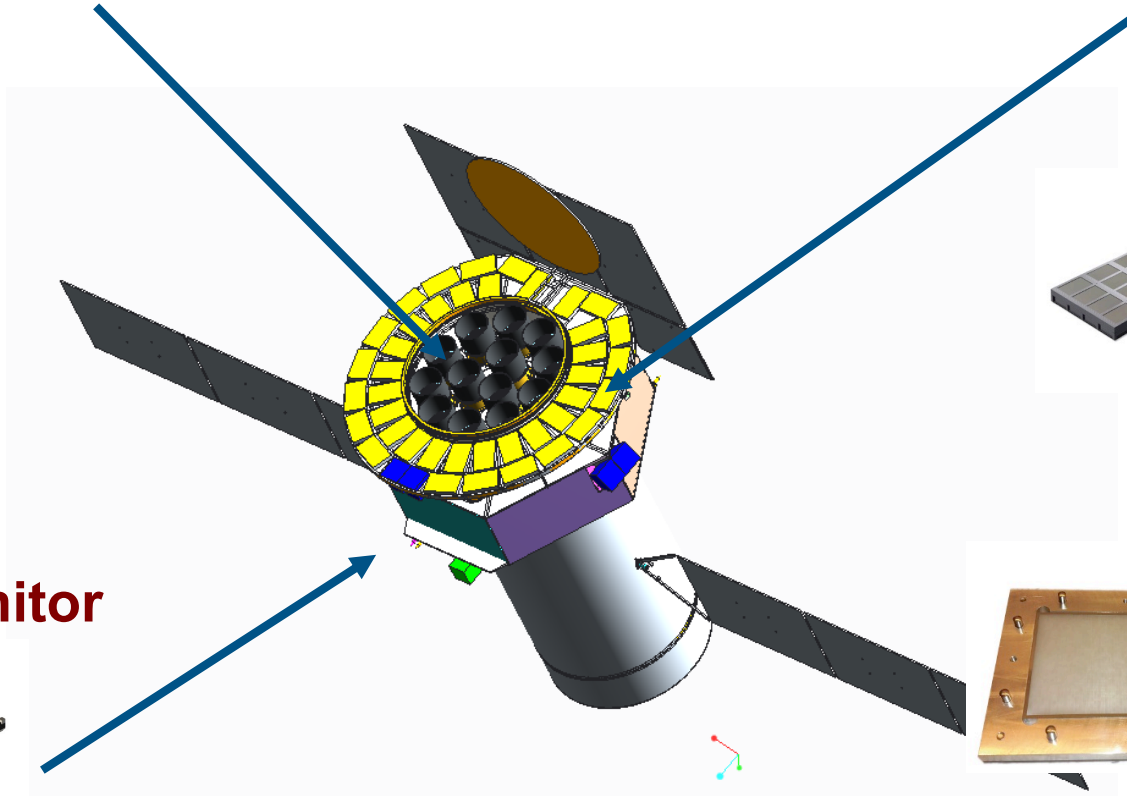
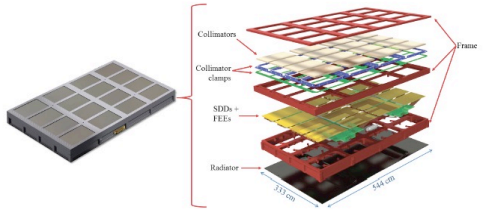
eXTP: a large mission

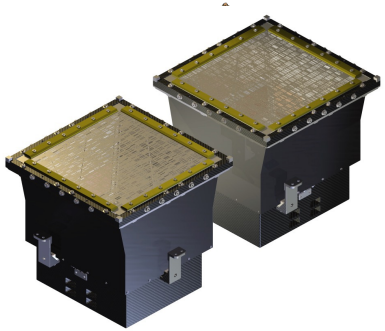
9 Tel. Spectroscopy Focusing Array
4 Tel. Polarimetry Focusing Array

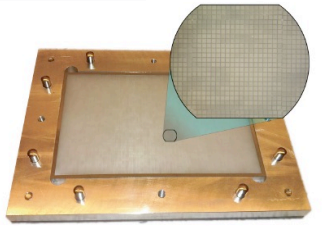
Large Area Detector

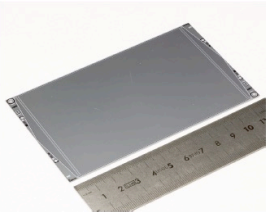




Wide Field Monitor







4.5 ton, lifetime 8 years

Excellent collaboration with Microsat

Innovation Academy for Microsatellites
Chinese Academy of Sciences
Shanghai Engineering Center For Microsatellites

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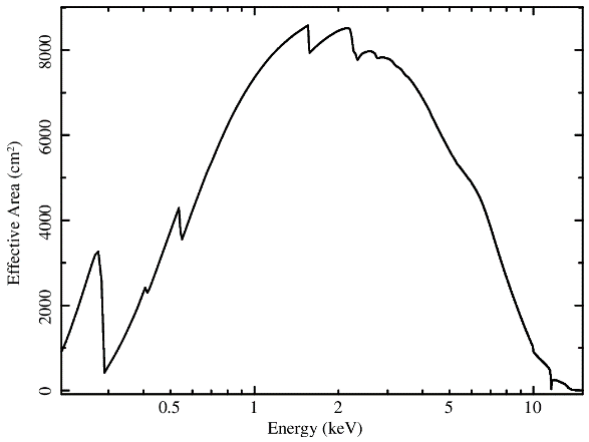
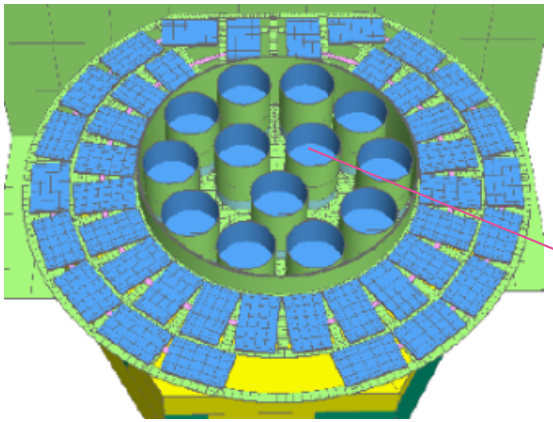
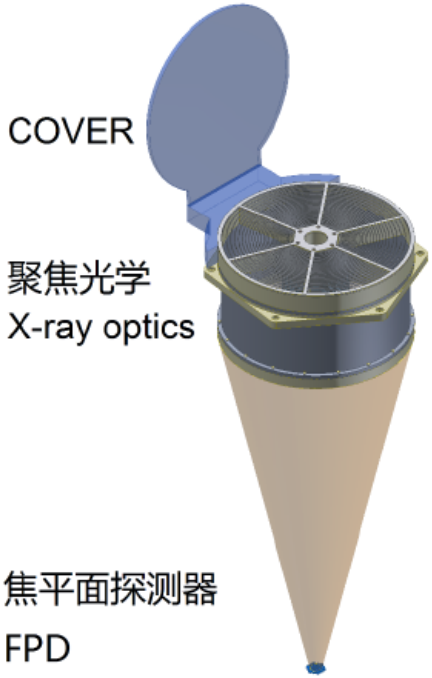
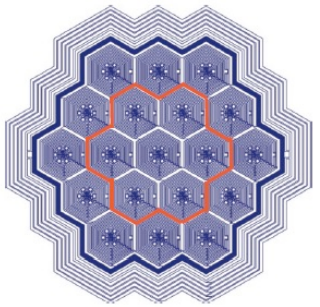
SFA – Spectroscopy Focusing Array







- Large collecting area achieved by multiple optics with short focal length. Baseline: 9 optics with 5.25m FL
- **Total effective area: >0.7 m² @1 keV, 0.5 m² @6 keV**
- **Non-imaging,** PSF requirement 1 arcmin HPD, 12' FoV
- Multi-pixel SDD detector (to enable background subtraction). Single photon timing <100µs
- **Energy band: 0.5-10 keV**
- **Energy resolution: <180 eV FWHM @6 keV**



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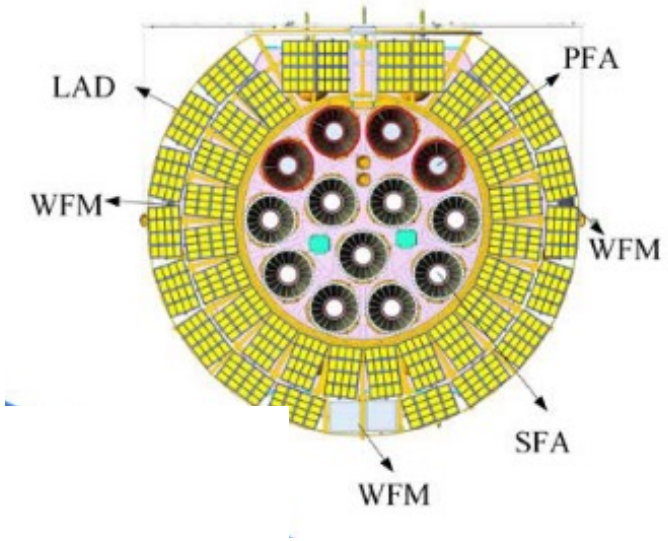
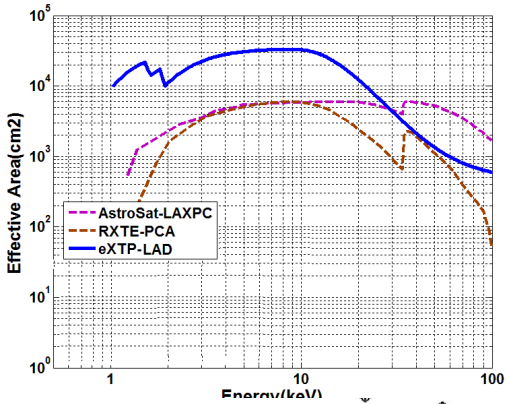
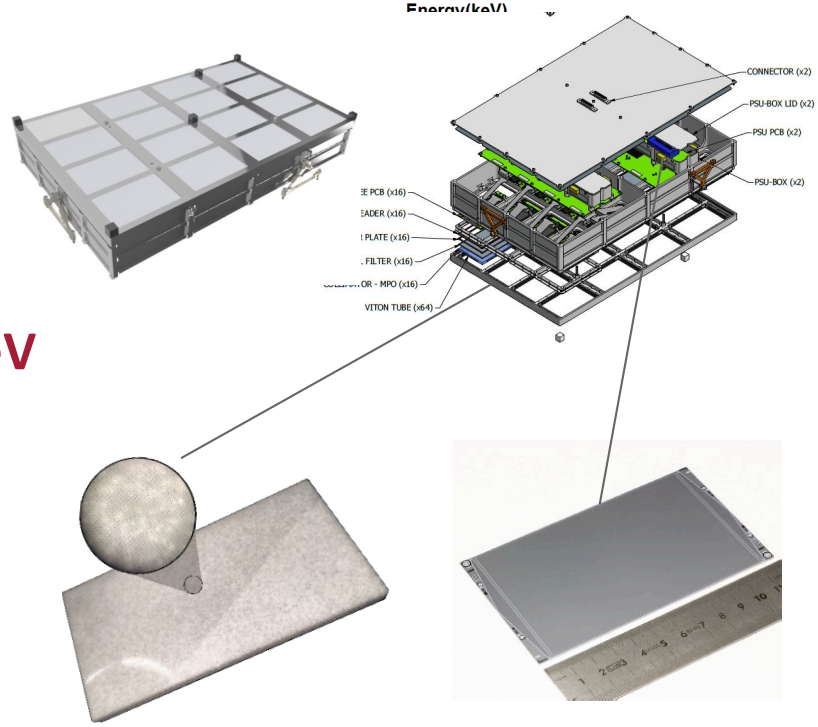
LAD – Large Area Detector







- **Total effective area: 3.4 m² @8 keV**
- **Energy band: 2-30 keV**
- **Energy resolution: <240 eV FWHM @6 keV**
- Based on the LOFT/LAD design
- 40 Modules on support panels
- 1° Collimated, large-area SDD detector.
  Single photon, <10μs

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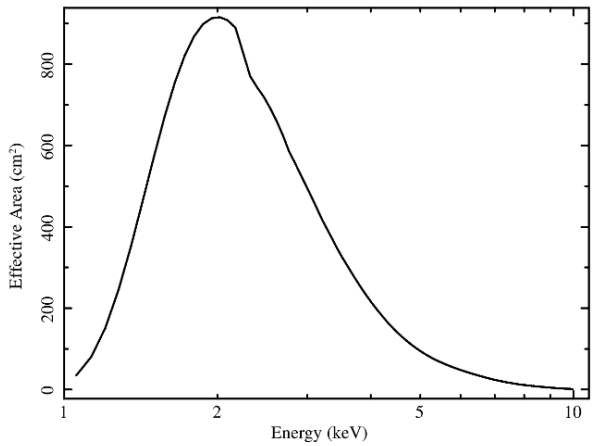
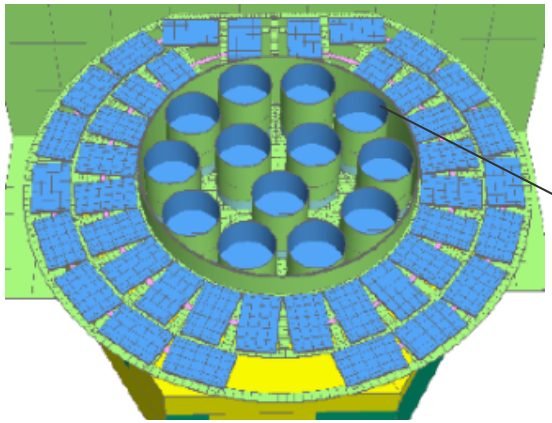
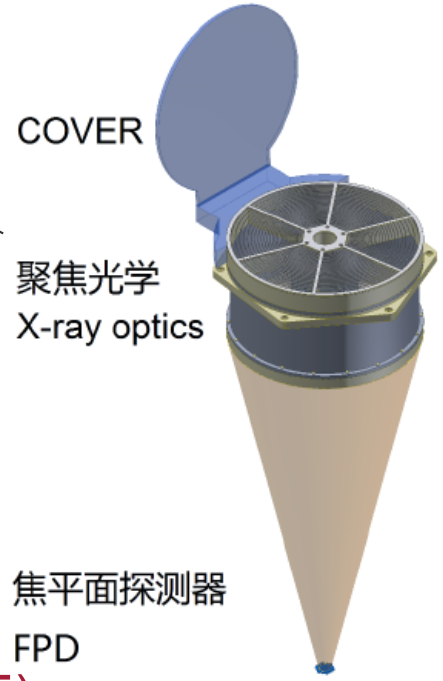
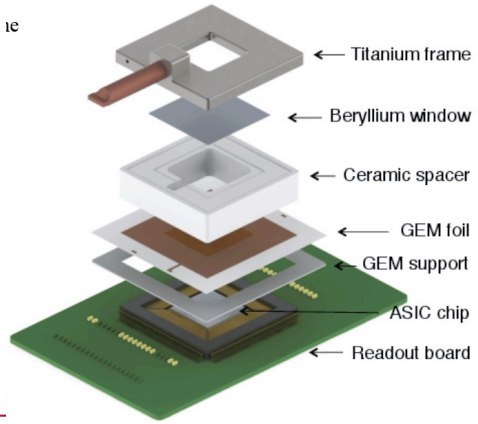
PFA – Polarimetry Focusing Array



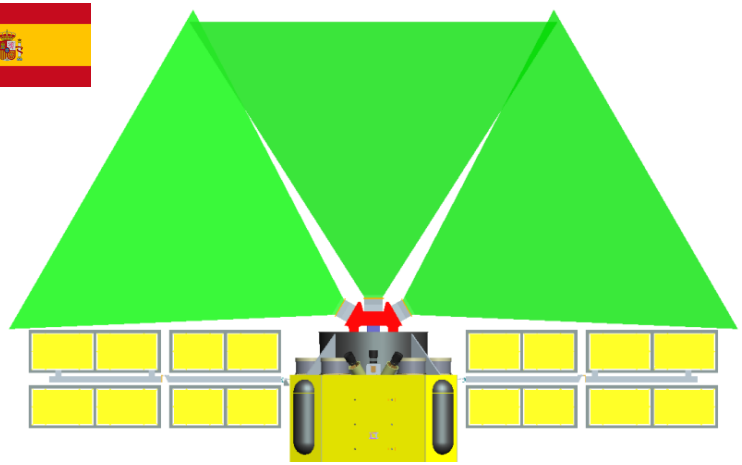


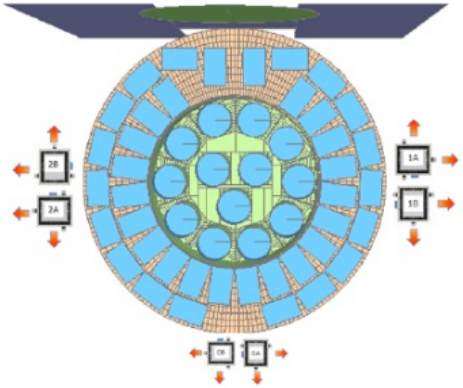


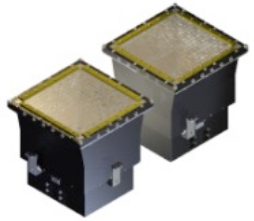
- Focal **plane imaging polarimeter**: 4 optics, 5.25m FL
- Imaging, **PSF 20 arcsec HPD**
- Total effective area: 900 cm^2 @2 keV (includes QE)
- Gas Pixel Detector: single photon, <100µs
- **Energy band: 2-10 keV**
- **Energy resolution: 20% FWHM @6 keV**



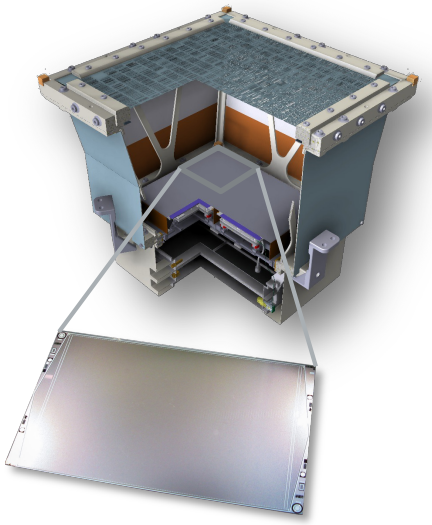
WFM – Wide Field Monitor







- **Field of View: 4 steradian (at 20% response)**
- **Imaging, <5 arcmin angular resolution, 1 arcmin PSLA**
- Energy band: 2-50 keV
- Energy resolution: 300 eV FWHM @6 keV
- Effective area: 80 cm^2 @6 keV (1 unit, on axis)
- Same detectors as LAD (SDD). Single photon, <10µs
- 3 Units (6 Cameras)



PSLA: Point source location accuracy

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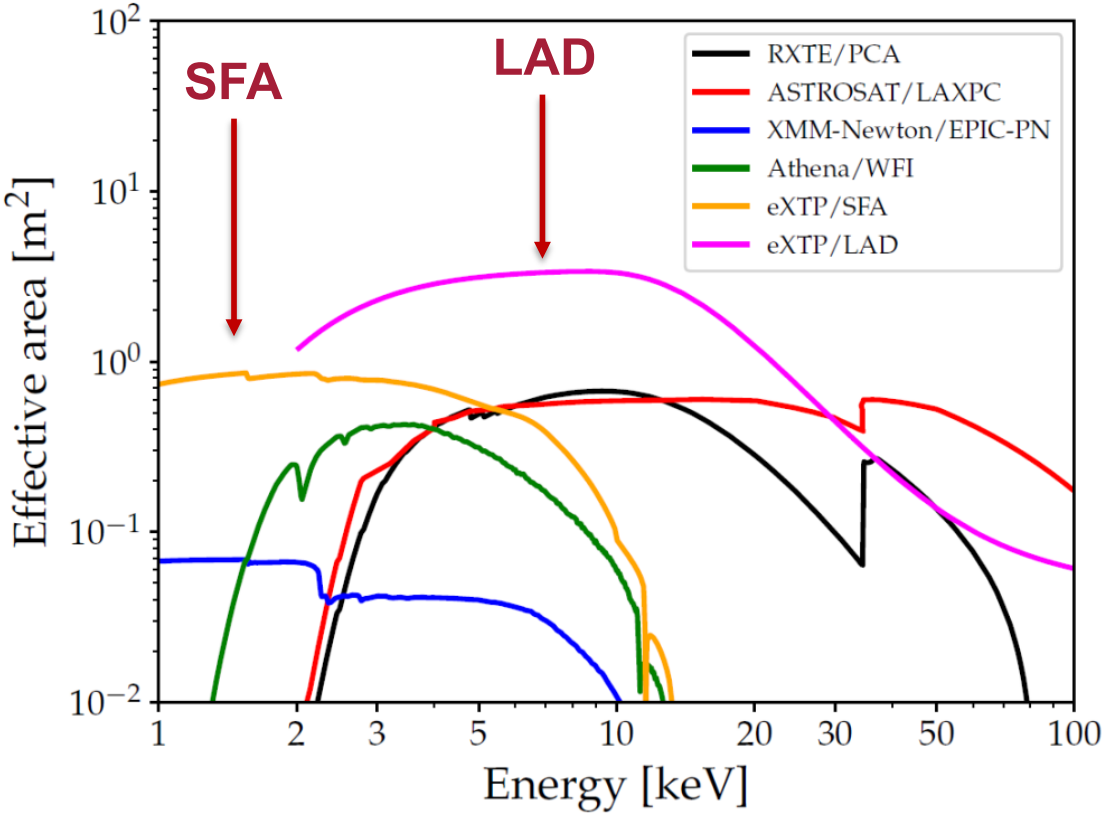
SFA and LAD effective area



SFA: a 'factory' for soft photons, ready to operate in 2027.

LAD: a transformational instrument of exceptionally high photon throughput in the 2-30 keV range ready to operate in 2027.

- LAD: 6x RXTE/PCA, 35x XMM-Newton (*but collimated*!) + hard-X response
- SFA: 8x XMM-Newton and 0.3-2x Athena/WFI (*but multiple optics and larger PSF*!). Limiting sensitivity ~10^{-14}-10^{-15} erg cm^{-2} s^{-1}

Transformational payload for spectral- timing studies of bright sources!

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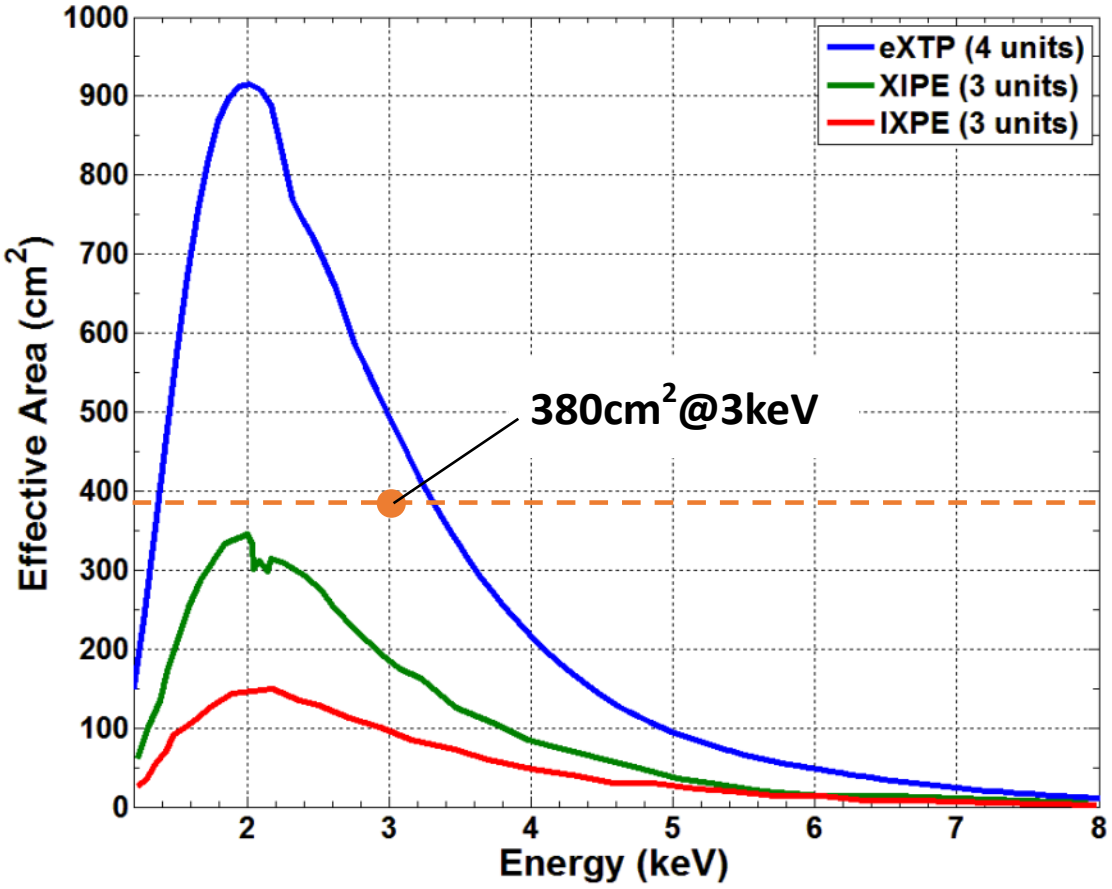
PFA a game changer in polarimetry



The PFA will bring studies of X-ray polarimetry to a mature stage

In addition, PFA Baseline: low angular resolution! → better than 30" and possibly 20"

Based on the GPD

Area (cm²)	2 keV	3 keV	4 keV	6 keV
eXTP	915	495	216	48
IXPE	151	101	52	16

5-6 times IXPE

Dashed line current requirement, lower than the expected performance

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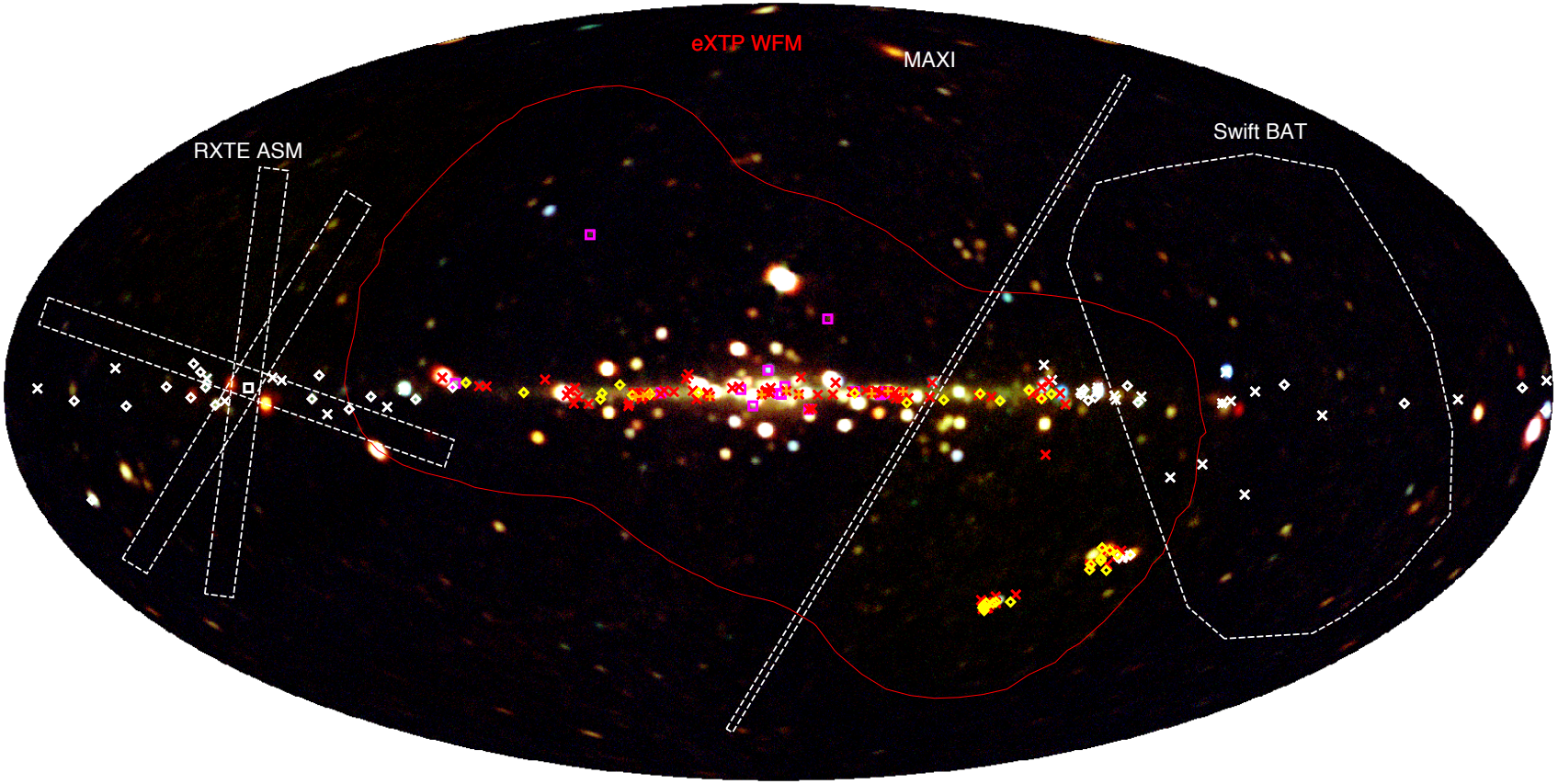
WFM – a much needed monitor



WFM: Largest FoV ever, first time with 300 eV resolution. 3 mCrab in 50ks

Field of View: >4 steradian (at 20% of peak response)

WFM will continuously monitor a large fraction of Galactic XRB population

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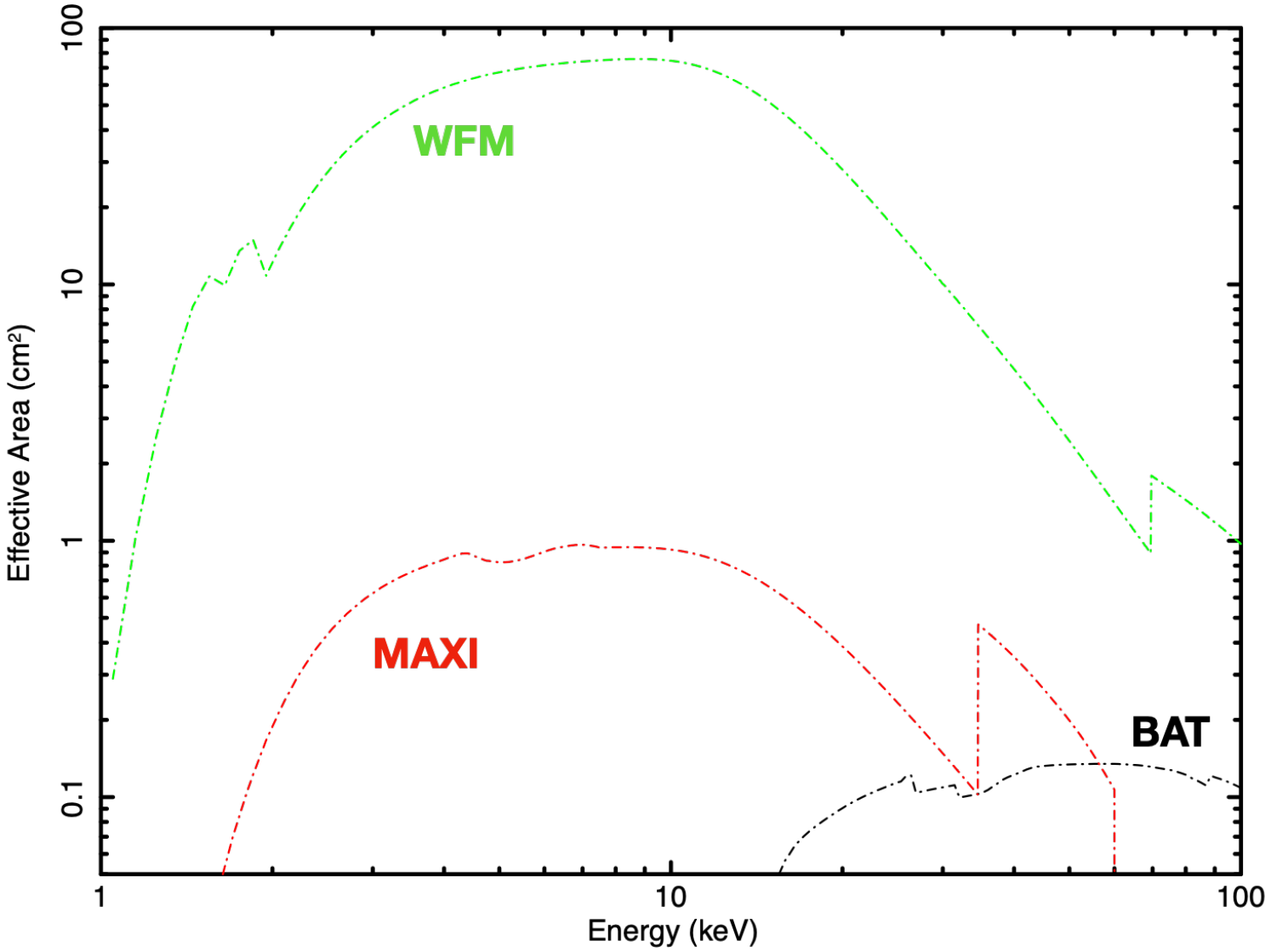
Large effective area



Large effective area + long exposures = science with WFM alone

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Synopsis of the eXTP Instruments

Table 1.1: The instrument configuration and key specifications

Instrument	SFA	LAD	PFA	WFM
Configuration	9 telescopes	40 modules	4 telescopes	6 cameras
Optics or Collimator	Wolter-I, Nickel F = 5.25 m	capillary-plate collimators	Wolter-I, Nickel F = 5.25 m	Coded mask
Detector	19-pixel Silicon Drift Det. (SDD)	SDD	Gas Pixel Detector (GPD)	SDD
Energy range	0.5 – 10 keV	2-30 keV	2-8 keV	2-50 keV
Effective area or FoV	≥0.6 m^2@1-2 keV 0.4 m^2 @ 6 keV	3.0 m^2 at 8 keV	500 cm^2 @ 2 keV 300 cm^2 @ 3 keV	FoV ≥ 3.1 sr
Energy res. (FWHM)	180 eV @ 6 keV	260 eV @ 6 keV	25% @ 6 keV	≤500 eV@6 keV
Time res.	10 μs	10 μs	10 μs	10 μs
Remarks	unprecedented effective area in the soft X-ray energy range	high throughput; effective area is a factor of 5-10 larger than any previous mission	~ 5 times the area of IXPE, X-ray polar. Pathfinder by NASA; Min. Detectable Polarization ~3% in 2-8 keV range	peak sensitivity: 1 Crab in 1s and 5 mCrab in 50 ks (5σ source); Point source localization ≤ 1′

Most updated numbers as of March 2022.

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eXTP Operations

Sky visibility

- **>50% of the sky accessible by the narrow field instruments at any time (requirement)** – current baseline: ~65% (-60° /+30°)
- ¼ of the sky instantaneously monitored by the WFM at any time

Transient events

- Onboard triggering and transient localization capability (WFM)
- **Autonomous slewing (about 3° /min minimum speed)**
- Transmission of coordinates to the ground: Bei Dou (<30s delay)

Targets of Opportunity

- Large allocation to ToO observations
- Fast uplink of ToO coordinates (Bei Dou)
- <12 hours execution time (requirement)

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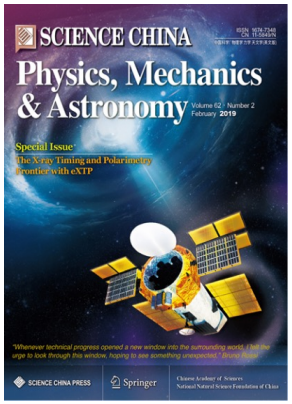

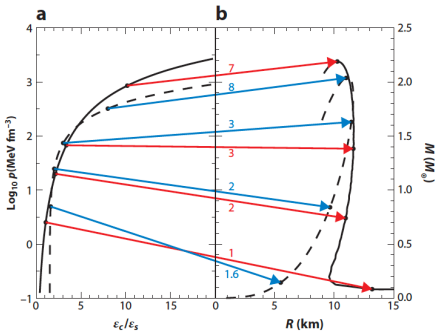

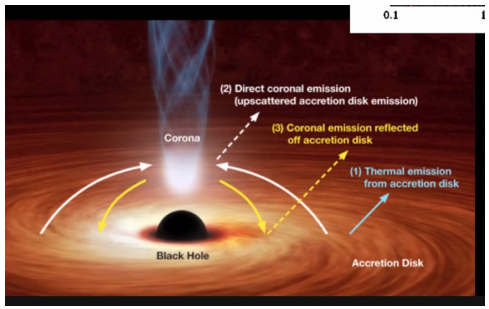

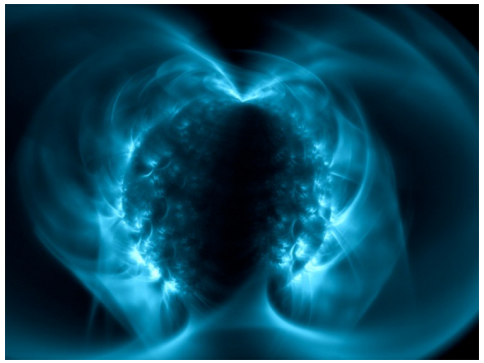

Part II

The Science case

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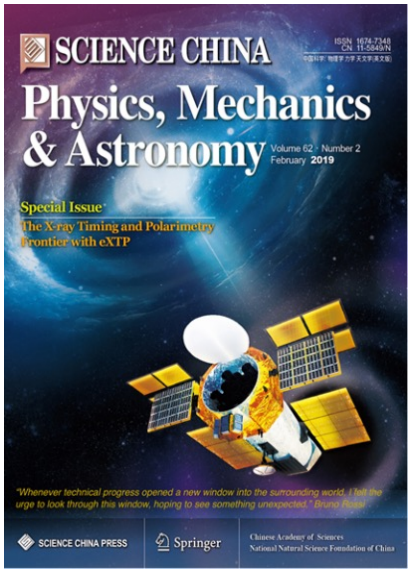
Science goals: Special Issue of Science China



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Physics, Mechanics & Astronomy
• Invited Review •
Special Issue: The X-ray Timing and Polarimetry Frontier with eXTP
February 2019 Vol. 62 No. 2: 029503
https://doi.org/10.1007/s11433-017-9188-4

Dense matter with eXTP

Anna L. Watts[1*], WenFei Yu[2], Juri Poutanen[3,4], Shu Zhang[5], Sudip Bhattacharyya[6], Slavko Bogdanov[7], Long Ji[8], Alessa
Federico Bernardini[12,13], Ig
Deepto Chakrabarty[19], Jérôi
Tiziana Di Salvo[22], Victor Doroshe
Angelo F. Gambino[22], MingYu
Dieter H. Hartmann[29], Kai Hebe
Jean in 't Zand[31], Oleg Kargaltsev
ZhaoSheng Li[38], Manuel Linarc
M. Coleman Miller[42], Sl
Chanda Prescod-Weinstein[45], Jin
Andrea Santangelo[8,5], Hendrik Sc
Benjamin Stappers[49], Holger S
Gabriel Török[10], David Tsa
YuPeng Xu[5], Silvia Zane[58]

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Special Issue: The X-ray Timing and Polarimetry Frontier with eXTP
February 2019 Vol. 62
https://doi.org/10.1007/s11

Accretion in strong field gravity with eXTP

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Observatory science with eXTP

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Physics and astrophysics of strong magnetic field systems with eXTP

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Nanda Rea[16,17],
Cristina Baglio[25], Fe
Ersin Göğüş[32], Can Gi
Romana Mikusir
Andrea Tieng

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The enhanced X-ray Timing and Polarimetry mission—eXTP

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- Five white papers for science case and mission
  - Dense Matter
  - Strong Field Gravity
  - Strong Magnetism
  - Observatory Science
  - Instrument and mission

Andrea Santangelo, editor, 2019

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eXTP Key science goals

eXTP is a machine to study the **extreme of physics**: understanding the behavior of matter and light under **extreme conditions of density, gravity and magnetism:**

Dense Matter: which is the state of matter at supranuclear densities (i.e., in the neutron star's interior)? Exotic states of matter? Quark stars?

Strong Gravity: what are the properties of space-time under extreme gravity (i.e., in the vicinity of neutron stars and black holes)? Any deviations from Einstein's General Relativity theory?

Strong Magnetism: which is the behavior of light in the presence of ultra-strong magnetic fields (e.g., in magnetars)? Are the predictions of the QED theory verified?

Physics with the astrophysics of bright sources.

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Observatory Science

Terrestrial Gamma-ray Flashes
Stellar flares
Cataclysmic variables
LMXBs
HMXBs
Accretion and ejection
Thermonuclear flashes on neutron stars
Pulsars
Tidal disruption events
Flares on AGN and Blazars
Gamma-ray bursts Supernova remnants
Galactic Center
eXTP synergy with other messengers: Gravitational Waves, TeV, neutrinos

Observatory science

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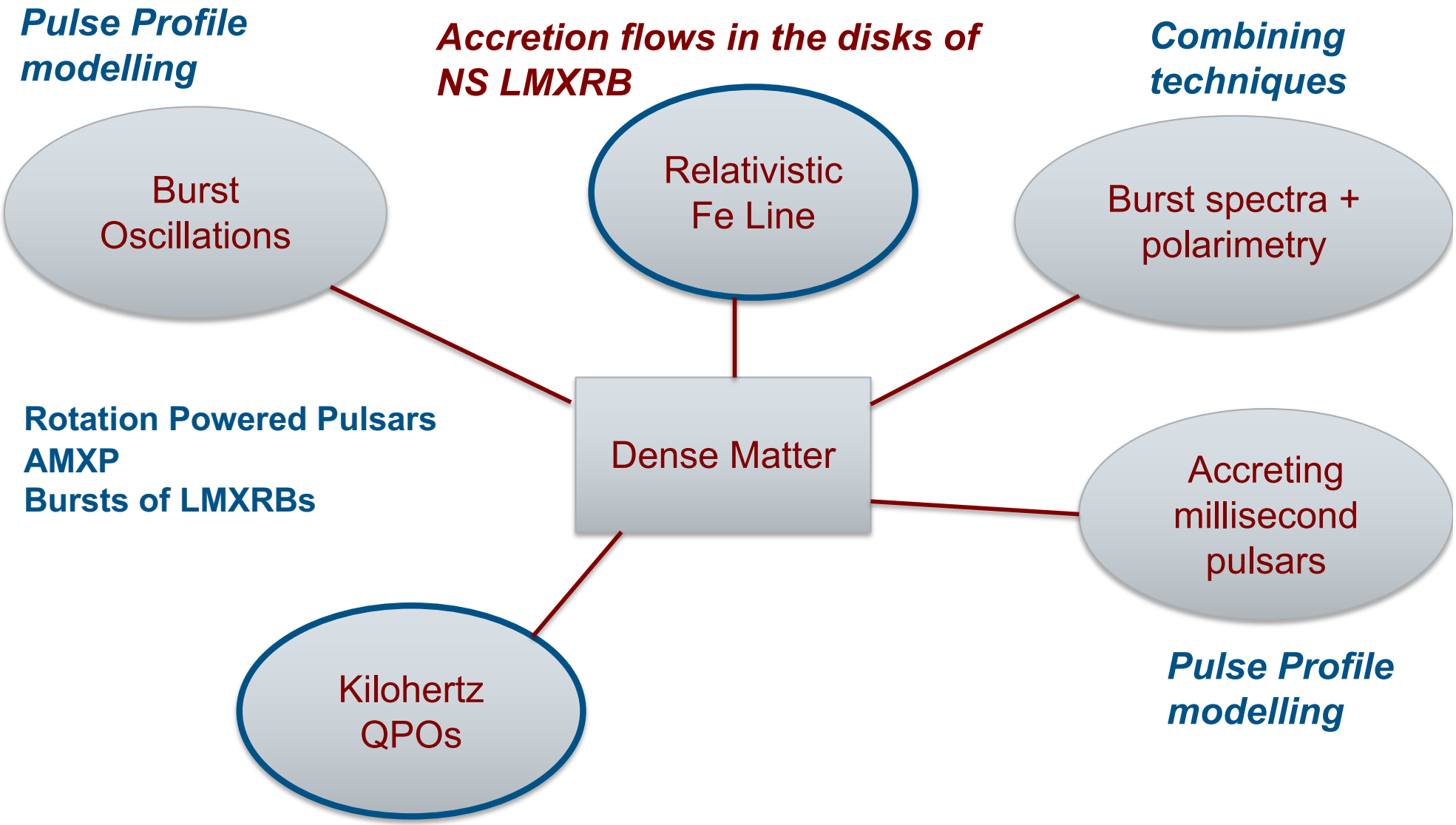
Dense matter (DM): synopsis



A. L. Watts, W. Yu, J. Poutanen, S. Zhang, et al Sci. China-Phys. Mech. Astron (2019)

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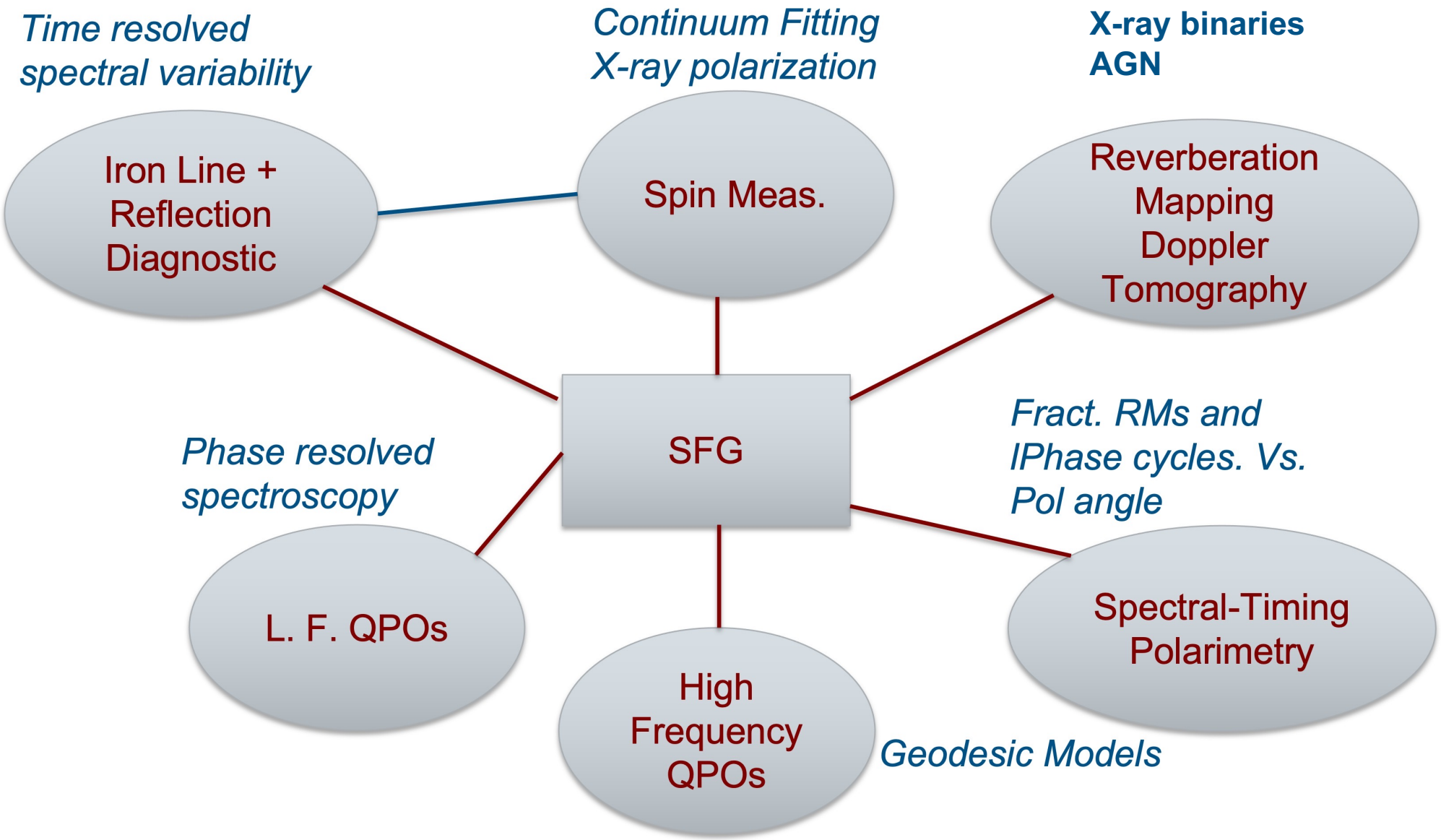
Strong Field Gravity



De Rosa, Uttley et al., Sci. China-Phys. Mech. Astron (2019)

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SFG Example: Mass and Spins of BHs

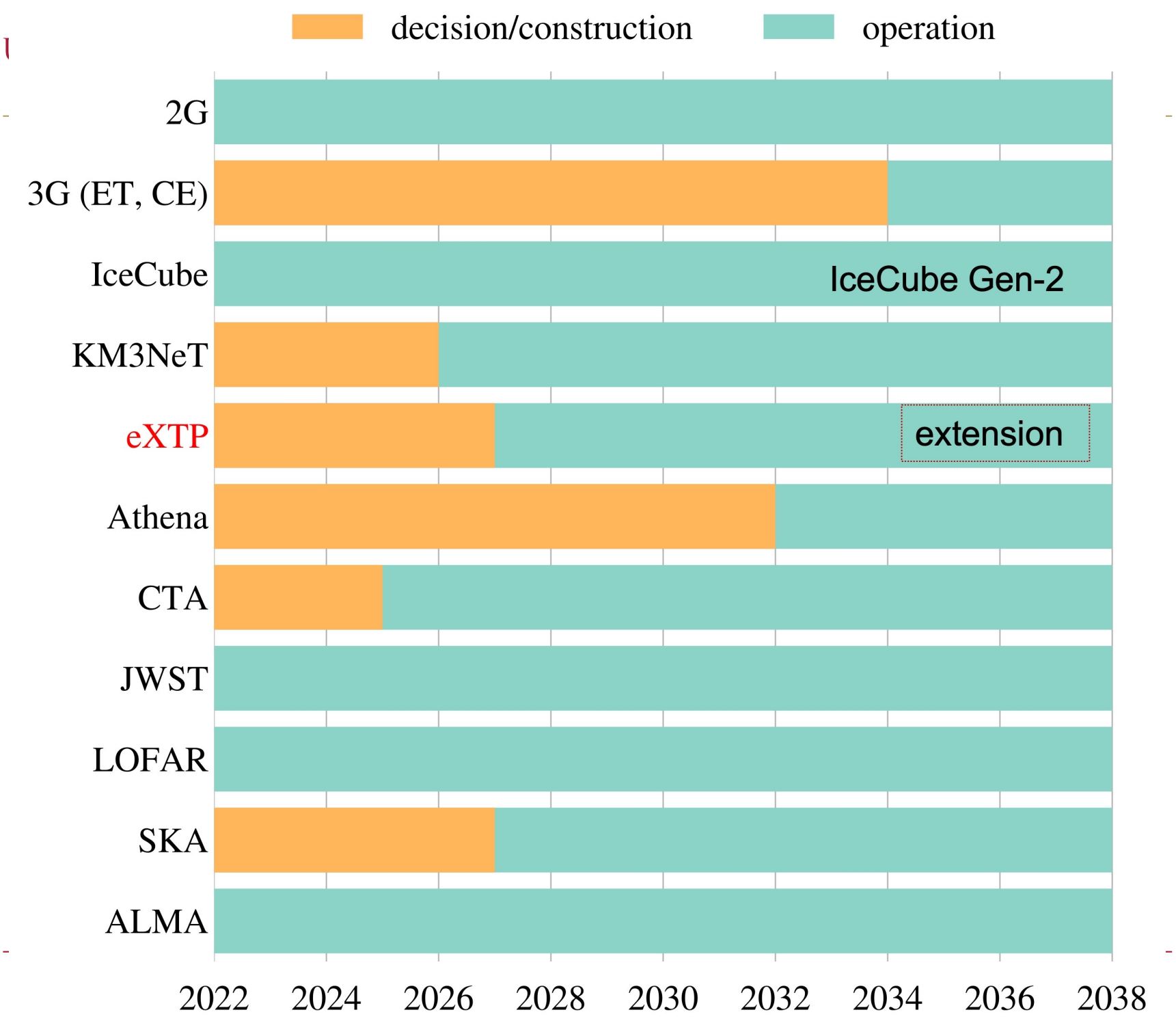
Goal: Measure black hole masses to a precision of 6% or better and spins to a precision of 5% and test the strong field gravity effects on the inner accretion flows, as they change significantly in structure and accretion rate.

Continuum fitting method to measure disk inner radius (in km) (accuracy 3%), and **polarimetric measurement** to yield a BH mass estimate to 5% accuracy (SFG1.1);

Reflection spectroscopy and polarimetry to measure disk inner radius to a precision of 2% (SFG1.2);

X-ray reverberation to measure the disk inner radius (in km), to a precision of 5% (SFG1.3) and with SFG1.2 to yield a BH mass to a precision of 6%;

polarimetric and spectral-timing polarimetric measurements to confirm the coronal geometry, use **disk reflection tomography** to confirm that the azimuthal pattern of relativistic effects is consistent with the disk inner radius inferred from SFG1.2, assuming GR (SFG1.4).


decision/construction
operation
2G
3G (ET, CE)
IceCube
IceCube Gen-2
KM3NeT
eXTP
extension
Athena
CTA
JWST
LOFAR
SKA
ALMA
2022
2024
2026
2028
2030
2032
2034
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2038

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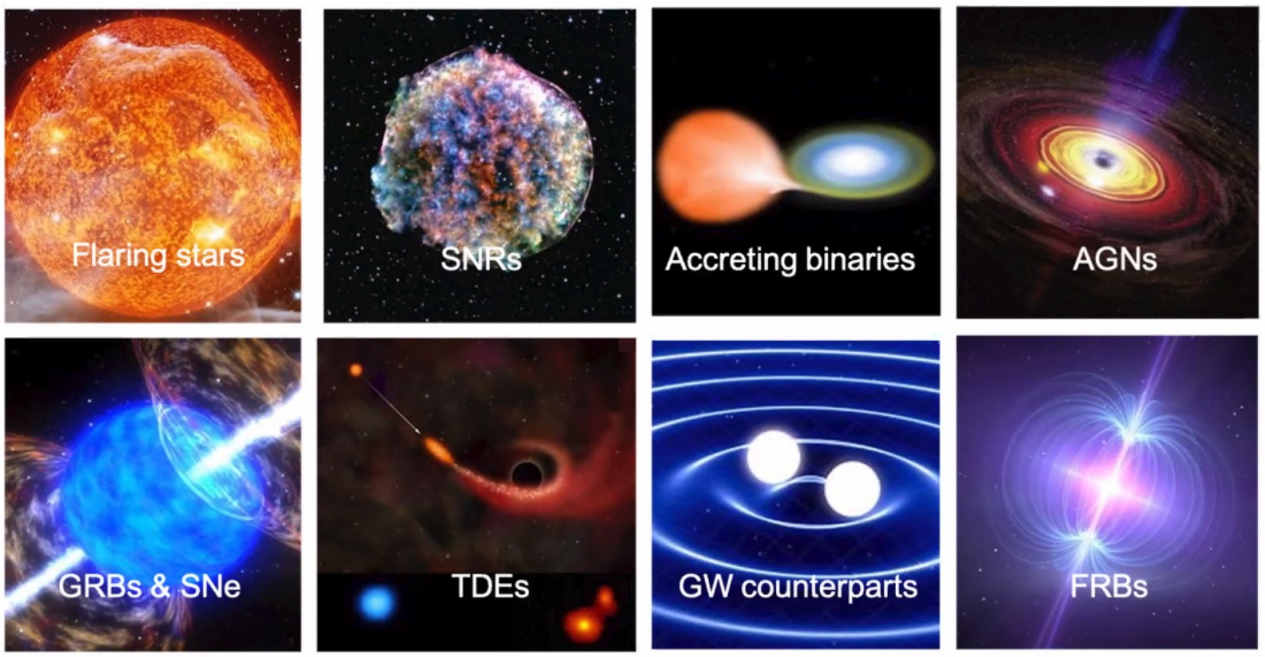
The Extreme transient sky



Key WFM Features:

- Arcmin localization allows optical follow up with single pointing
- Large instantaneous FOV probes rare events
- Autonomous repointing of pointed instruments and fast response to ground TOOs
- 300 eV resolution sensitive to lines and absorption features

Not only eXTP on the International scene…

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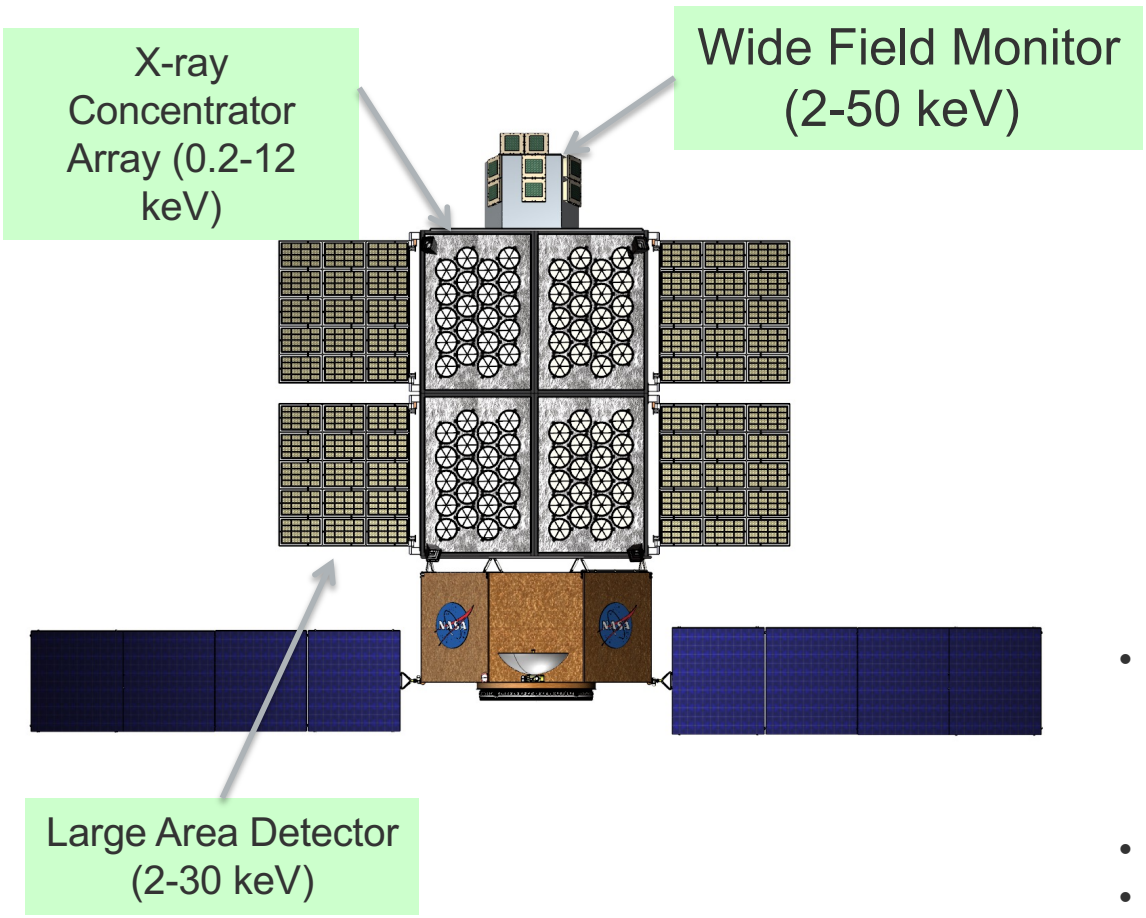
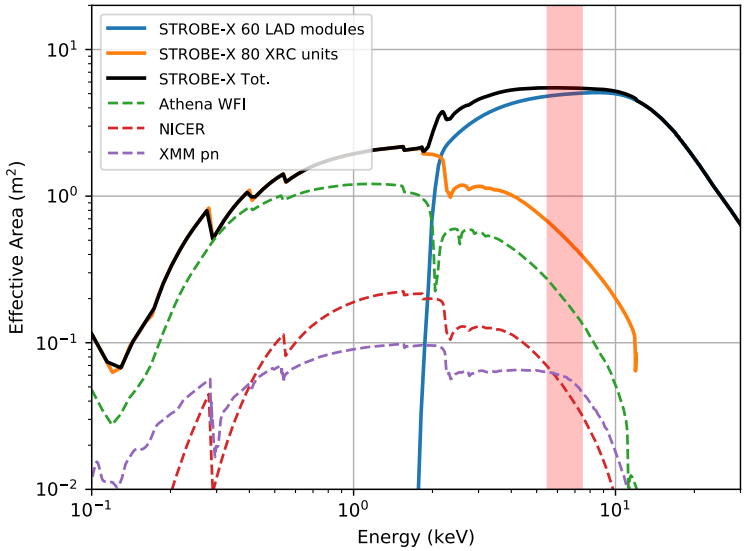
Strobe-X a NASA's Probe mission candidate



Large effective area >5 m^2 @ 6 keV



- STROBE-X combines the strengths of NICER and LOFT: High throughput X-ray spectral timing with good powerful sky monitor
- All components are already high TRL
- Highly modular design improves reliability at reduced cost and allows easy scaling.

Slides courtesy of Paul Ray

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eXTP PI Institute: IHEP/CAS, Beijing

- CAS — CHINESE ACADEMY OF SCIENCES
- CNSA
- IHEP Beijing — Institute of High Energy Physics, Chinese Academy of Sciences
- Tsinghua University — Tsinghua University
- Tongji University — TONGJI UNIVERSITY
- CAST Beijing — 中国空间技术研究院, China Academy of Space Technology
- IAMC Shanghai — microsat

- Italy — INAF, INFN, Fondazione Bruno Kessler, Politecnico Milano
- Spain — CSIC, IEEC
- Germany — Eberhard Karls Universität Tübingen, MPE, FAU Friedrich-Alexander Universität Erlangen-Nürnberg
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- Denmark — DTU
- The Netherlands — NOVA, SRON
- Austria — universität wien
- Turkey — Sabancı Üniversitesi, TÜBİTAK

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Conclusions

- The science potential of a **spectral-timing-polarimetry mission is enormous.**
- eXTP is an X-ray mission which aims at reaching **unprecedent throughput** with good angular and very good energy resolution. The mission hosts **an X-ray Polarimeter**. This unique combination enables simultaneous **spectral-timing-polarimetry analysis** (e.g., QPOs phase resolved polarimetry).
- Thanks to its WFM, **eXTP will be essential for multi-messenger studies**
- The mission **is currently in its phase B.** In China, the SRR has been passed and they are moving toward the PDR. Try to reach adoption at beginning of next year.
- The European Instruments SRR is on its way.
- Technically there are no major issues…

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Stay Tuned for surprises!

Thank you.

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