The enhanced X-ray Timing and Polarimetry Mission

Enrico Bozzo
ISDC
Univerisity of Geneve

THESEUS Workshop 2017

The eXTP International Consortium

Principal Investigator:
Shuang-Nan Zhang
IHEP/CAS

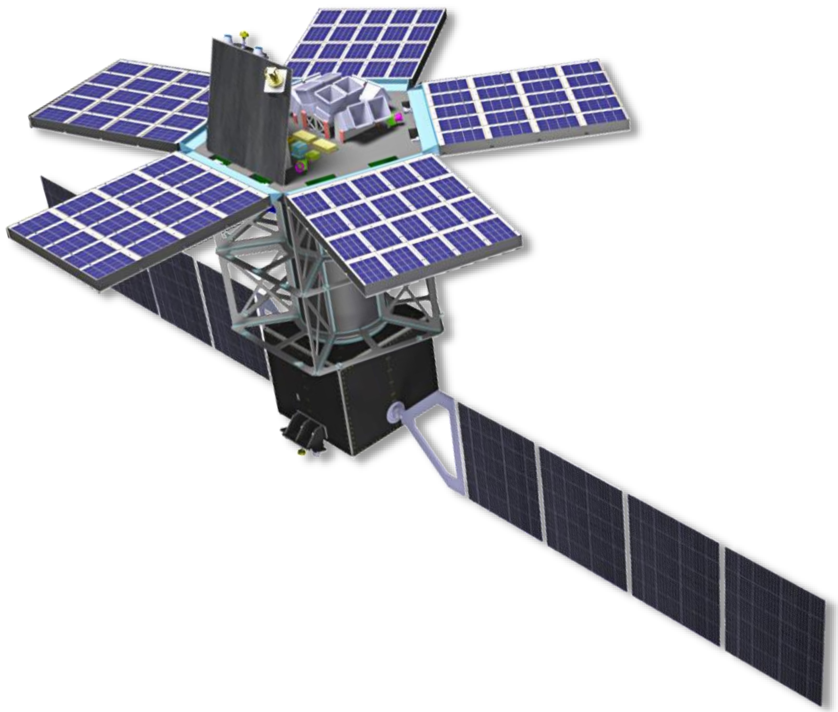
CAS	中国科学院 CHINESE ACADEMY OF SCIENCES
CNSA	
IHEP Beijing	Institute of High Energy Physics, Chinese Academy of Sciences
Tsinghua University	清華大学 Tsinghua University
Tongji University	同濟大學 TONGJI UNIVERSITY
CAST	中国空间技术研究院 China Academy of Space Technology 中国航天

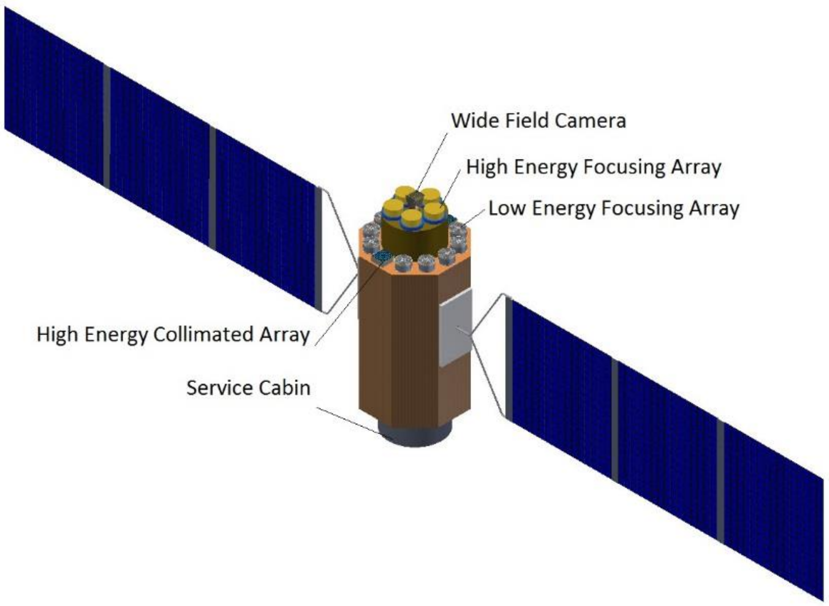
Italy:	INAF, INFN
Germany:	Eberhard Karls Universität Tübingen, MPE, FAU Friedrich-Alexander Universität Erlangen-Nürnberg
France:	cea
Spain:	CSIC, IEEC Institut d'Estudis Espacials de Catalunya
Switzerland:	Université de Genève, ISDC
Denmark:	DTU
Poland:	CBK PAN, CAMK PAN
Czech Republic:	Astronomical Institute of the Czech Academy of Sciences (asu)
United Kingdom:	UCL MSSL, University of Leicester
The Netherlands:	University of Amsterdam, SRON

LOFT+XTP → eXTP

- Mission proposed to ESA to study matter under extreme conditions (NS EoS, SFG)
- Selected in 2011 by ESA as one of the 4 M3 candidate missions in Cosmic Vision
- Phase A study by ESA and LOFT Consortium in 2011-2014

- Mission proposed to CAS to study matter under extreme conditions (NS EoS, SFG, Strong Magnetism)
- Selected in 2011 as one of 8 «Background missions»
- Phase A study by IHEP in 2011-2014



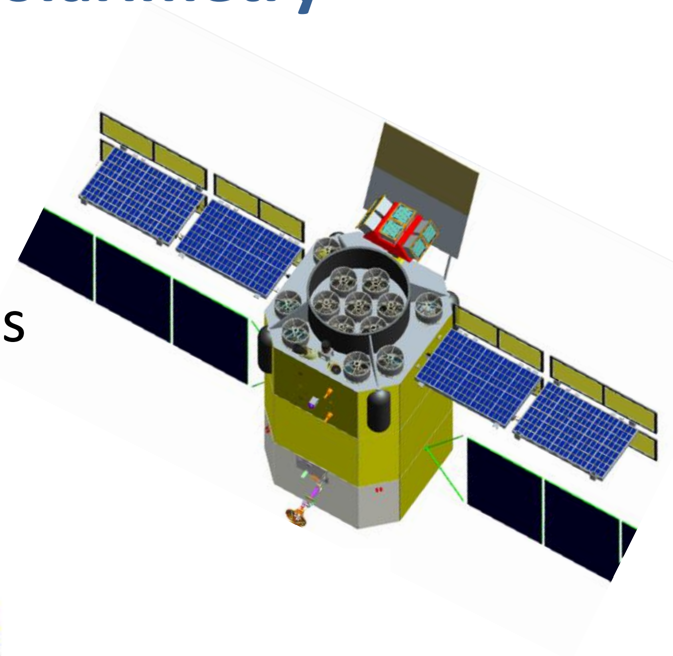


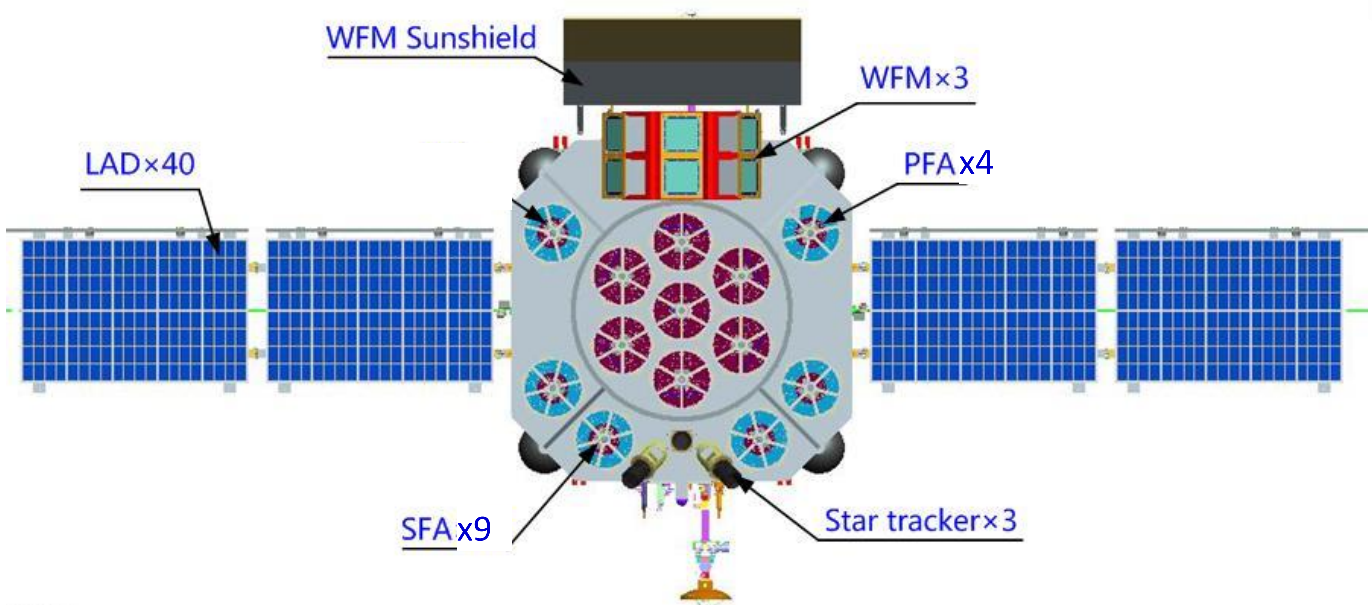
eXTP

enhanced X-ray Timing and Polarimetry

Payload concept

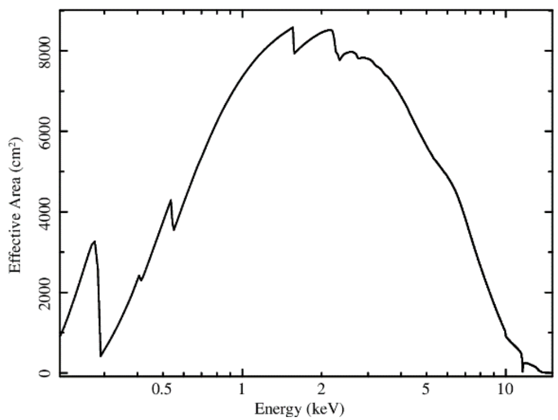
- Short focal-length for multiple modules
- Deployable panel for collimated modules
- Polarimeter with imaging capability
- Wide field monitor

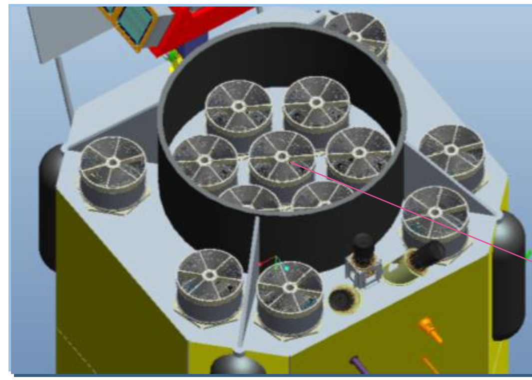


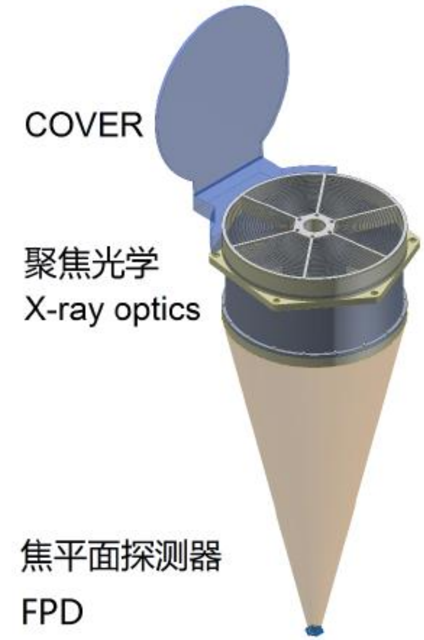


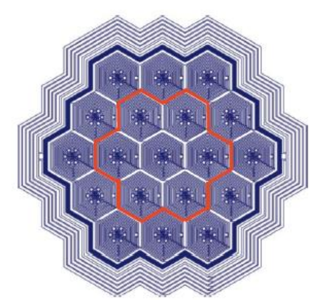
eXTP Scientific Payload

SFA – Spectroscopy Focusing Array





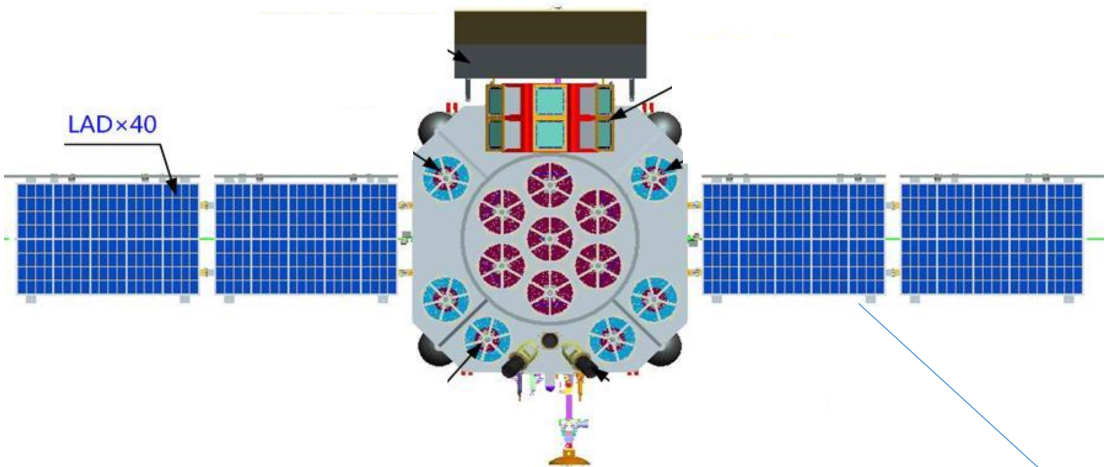


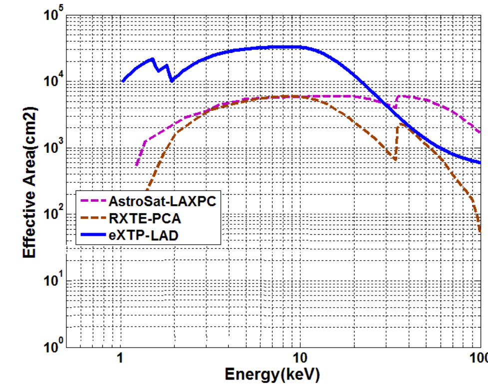


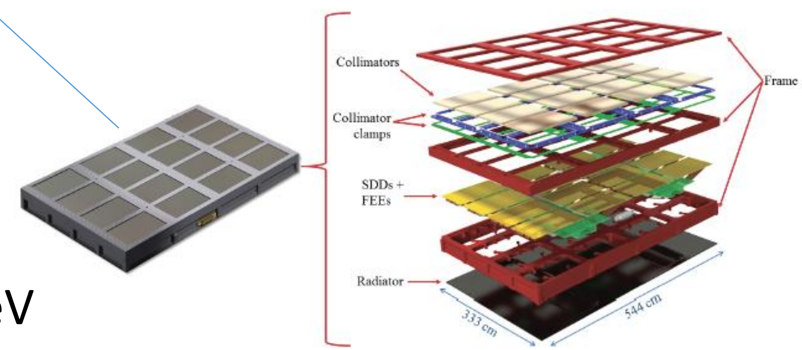
- ❖ Large collecting area achieved by multiple optics with short focal length. Baseline: 9 optics with 5.25m FL
- ❖ Non-imaging, PSF requirement 1 arcmin HPD, 12’ FoV
- ❖ Multi-pixel SDD detector (to enable background subtraction). Single photon, <100µs
- ❖ Energy band: 0.5-10 keV
- ❖ Energy resolution: <180 eV FWHM @6 keV
- ❖ Total effective area: >0.7 m^2 @1 keV, 0.5 m^2 @6 keV

eXTP Scientific Payload

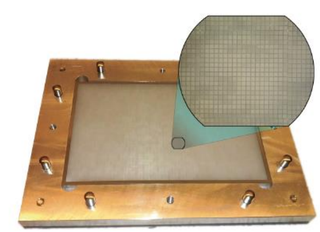
LAD – Large Area Detector





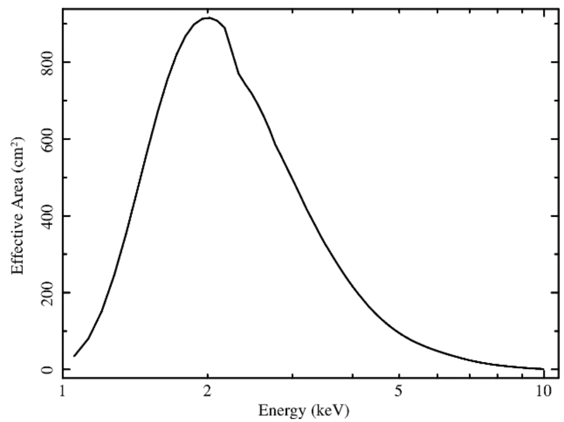


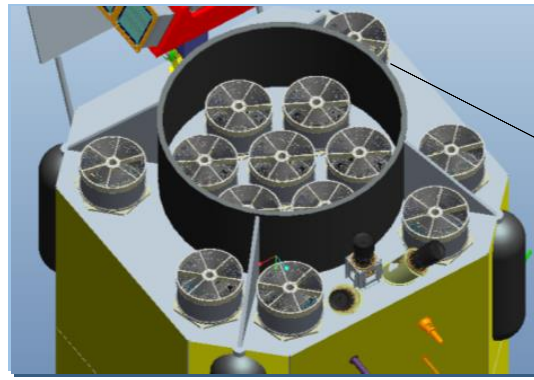
- Total effective area: 3.4 m^2 @8 keV
- Energy band: 2-30 keV
- Energy resolution: <240 eV FWHM @6 keV
- Based on the LOFT/LAD design
- 40 Modules on 2 deployable panels
- Collimated, large-area SDD detector.
  Single photon, <10μs

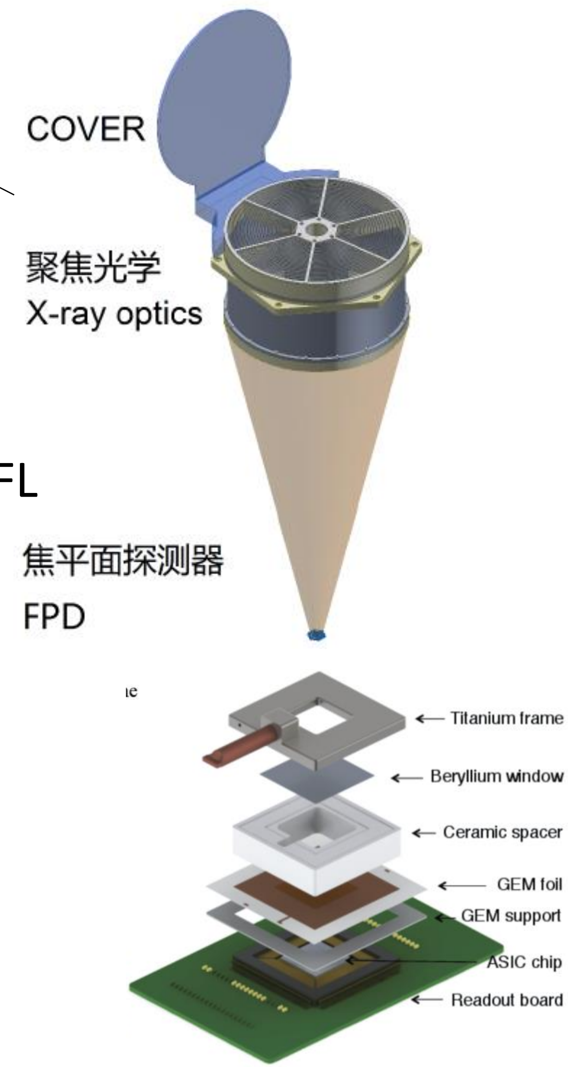


eXTP Scientific Payload

PFA – Polarimetry Focusing Array



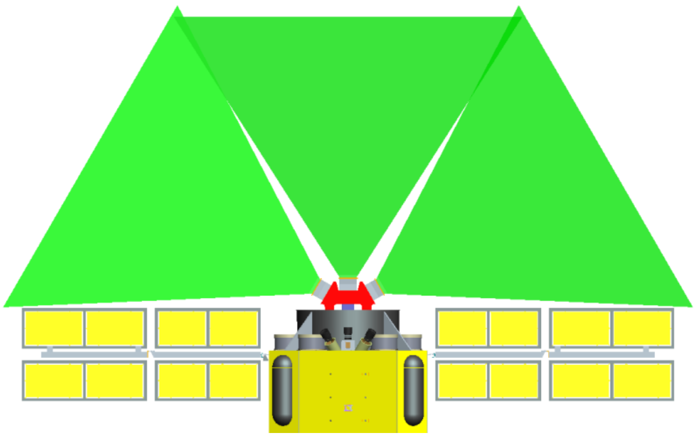


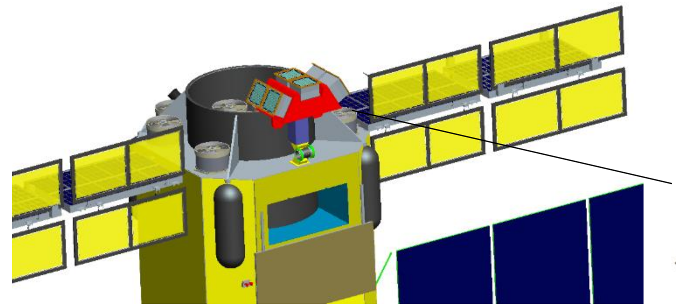


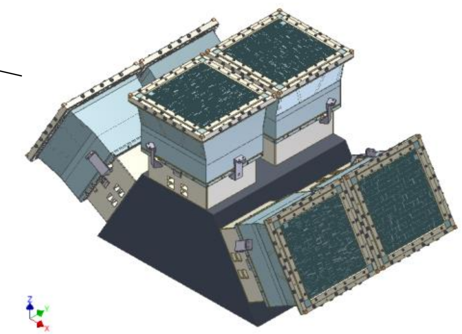
- Focal plane imaging polarimeter: 4 optics with 5.25m FL
- Imaging, PSF 20 arcsec HPD
- Gas Pixel Detector: single photon, <100µs
- Energy band: 2-10 keV
- Energy resolution: 20% FWHM @6 keV
- Total effective area: 900 cm^2 @2 keV (includes QE)

eXTP Scientific Payload

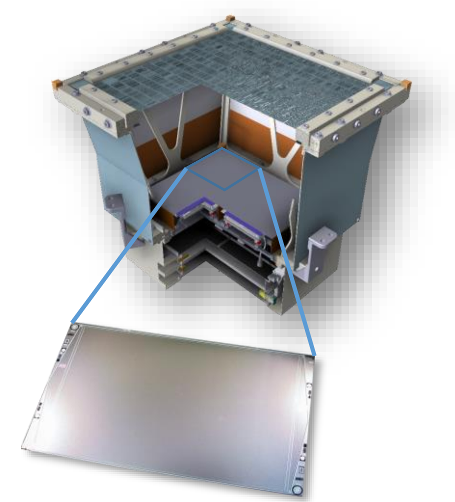
WFM – Wide Field Monitor





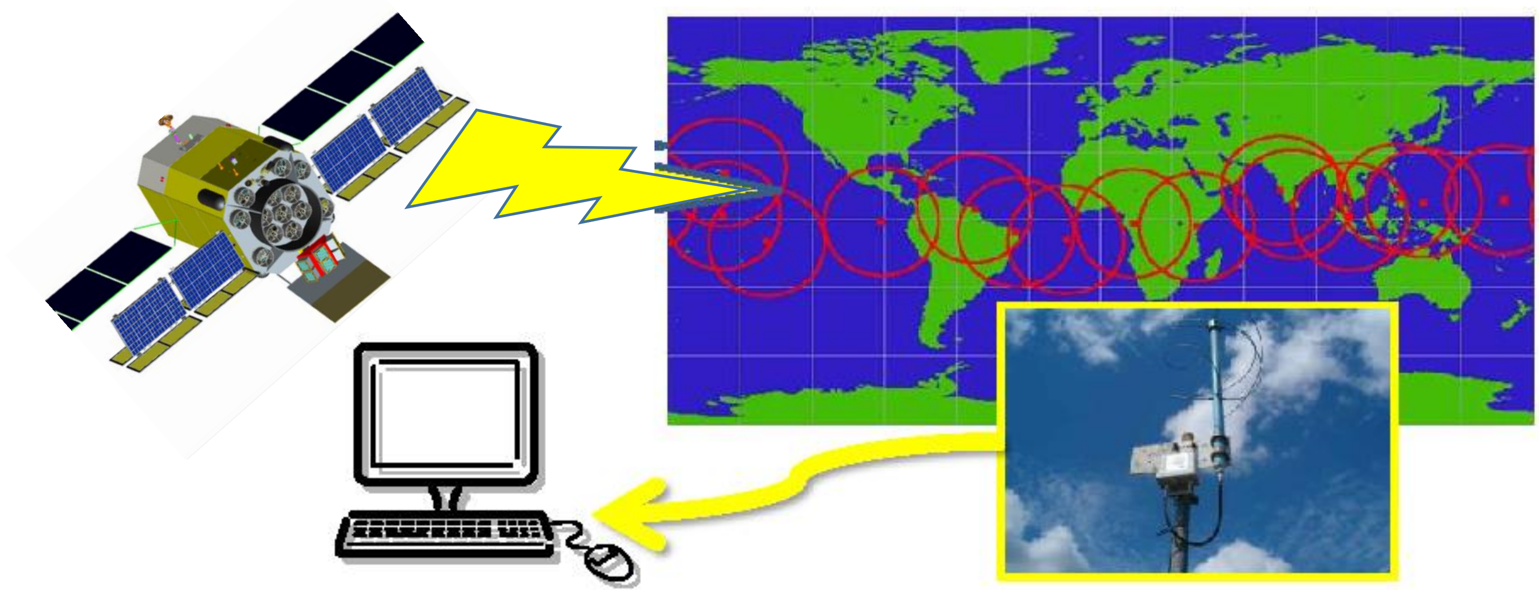


- Field of View: 4 steradian (at 20% response)
- Imaging, <5 arcmin angular resolution, 1 arcmin PSLA
- Energy band: 2-50 keV
- Energy resolution: 300 eV FWHM @6 keV
- Effective area: 80 cm^2 @6 keV (1 unit, on axis)
- Same design as LOFT/WFM, 3 units (6 cameras)
- Same detectors as LAD (SDD). Single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



eXTP Burst Alert System

- The large field of view of the WFM provides unique opportunities for detecting Gamma Ray Bursts (~100 GRBs per year)
- **Onboard Burst Trigger** and Localization
- **Onboard VHF transmitter** to transmit short message with time and sky position
- Network of small ground stations to receive message (SVOM)
- Delivery of trigger time and burst position to end users within 30 s for fast follow up of the fading GRB afterglow



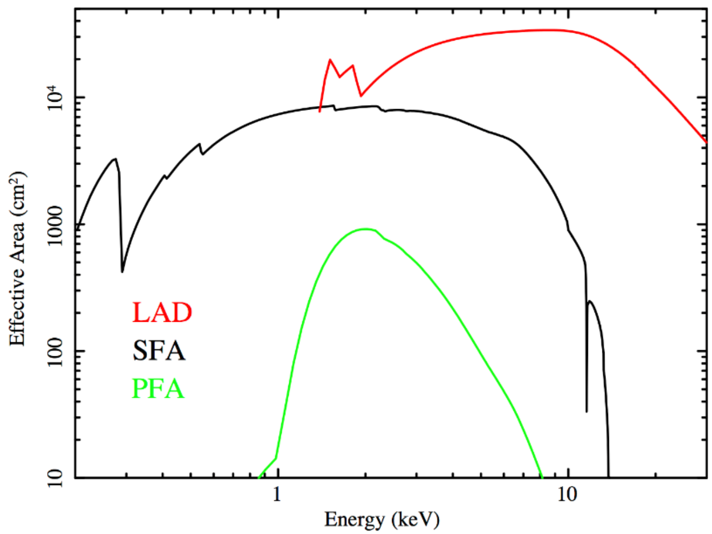
eXTP Mission Profile

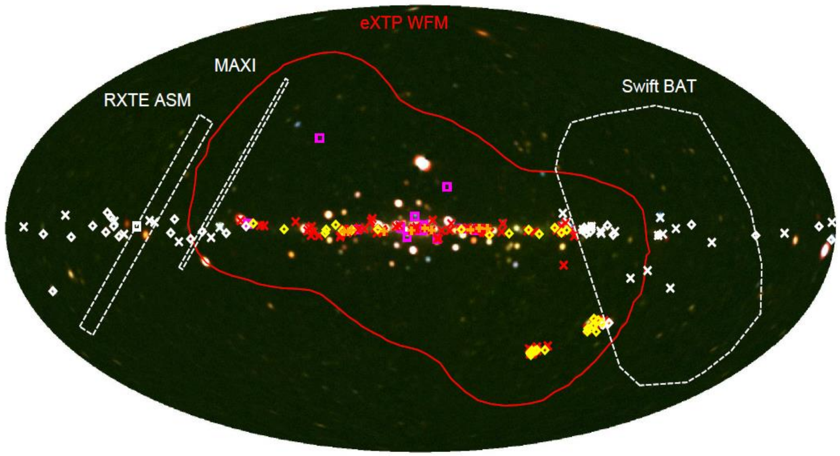
Parameter	Value
Orbit	550 km, <2.5° inclination
Launcher	Long-March CZ-7
Mass	3700 kg
Power	3.6 kW
Telemetry	3 Tb/day
Ground Stations	China, Malindi
Pointing	3-axis stabilized, < 0.01°
Sky visibility	50% (goal 75%)
Mission Duration	5 years (goal 10 years)
Launch date	2025

	Payload	Parameter	Specification
Soft Response	SFA	Energy range	0.5-10 keV
		Effective area	>7000 cm^2 @1 keV, >5000 cm^2 @6 keV
		Energy resolution	<180 eV FWHM @6 keV
		FoV/HPSD	12 arcmin / 1 arcmin
		Focal plane detector	Pixelated SDD (19 pixels)
Large area	LAD	Energy range	2-30 keV (extended: 30-80 keV for out-FoV)
		Effective area	34000 cm^2
		Energy resolution	<240 eV FWHM @6 keV
		FoV	1° (FWHM)
		Detector	Large area SDD (640 units, 40 Modules)
Polarization	PFA	Energy range	2-10 keV
		Effective area	>900 cm^2 @2 keV (including QE)
		Energy resolution	1.2 keV FWHM @6 keV
		FoV/HPD	12 arcmin / 20 arcsec
		Focal plane detector	GPD (4 units)
Monitoring	WFM	Energy range	2-50 keV
		Energy resolution	300 eV FWHM @6keV
		FoV	>4 sr (at 20% of peak response)
		Angular resolution	<5 arcmin
		Localization accuracy	<1 arcmin
		Detector	Large area SDD

eXTP Scientific Payload

Performance in context

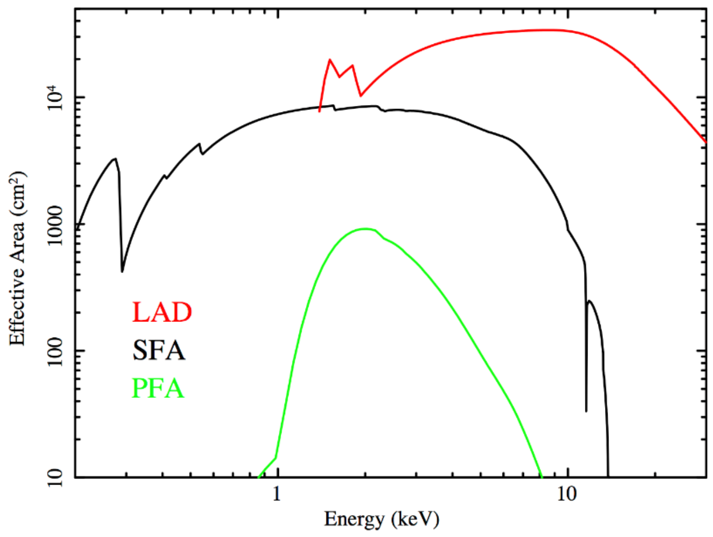


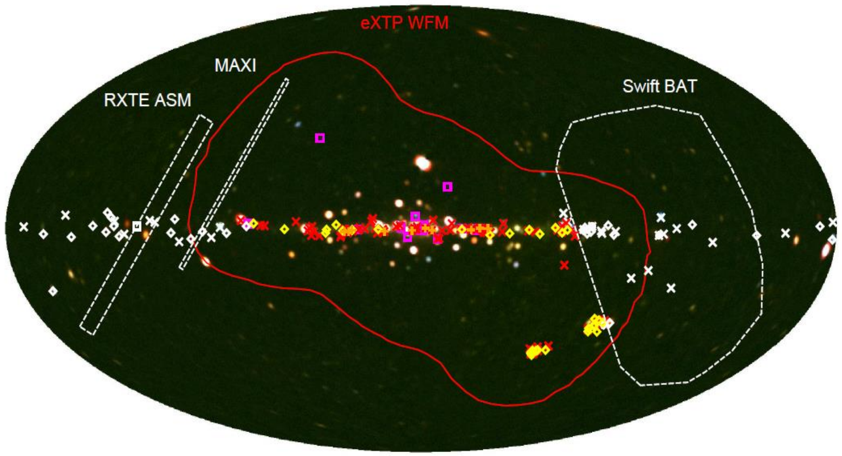


- **LAD**: 6x RXTE/PCA, 35x XMM-Newton (*but collimated*!) + hard-X response
- **SFA**: 8x XMM-Newton and 0.3-2x Athena/WFI (*but multiple optics and large PSF*!). Limiting sensitivity ~10^{-14}-10^{-15} erg cm^{-2} s^{-1}
- **PFA**: 5x IXPE, 2x XIPE. Sensitivity: 1% MDP in 50ks for a 100 mCrab source
- **WFM**: largest FoV ever, first time with 300 eV resolution. 3 mCrab in 50ks

eXTP Scientific Payload

Performance in context

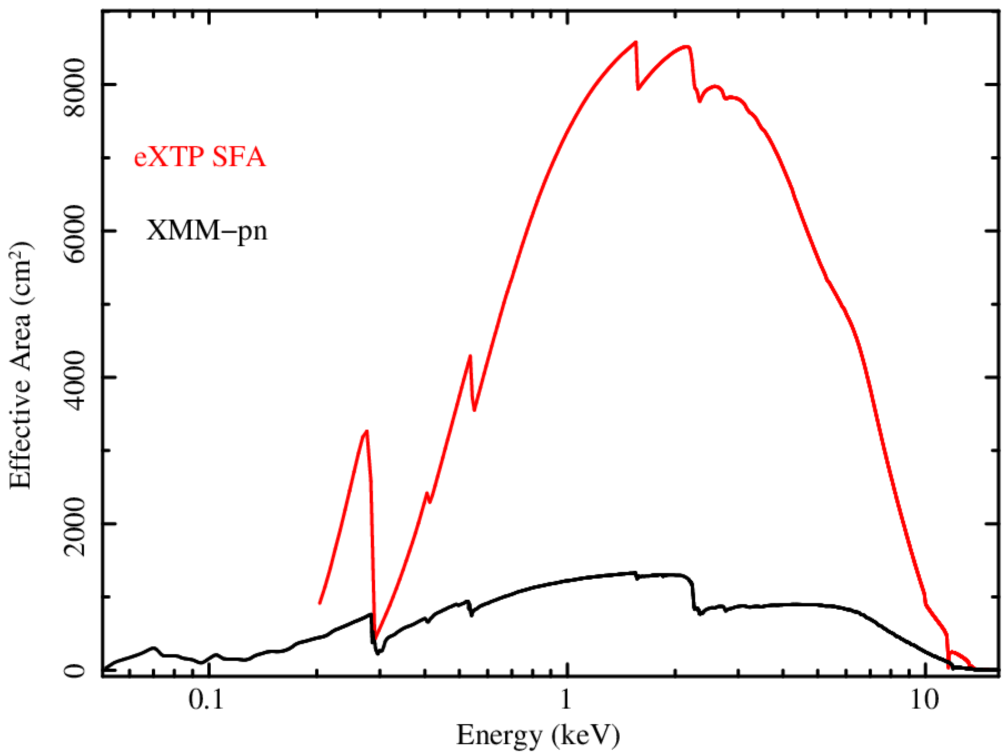


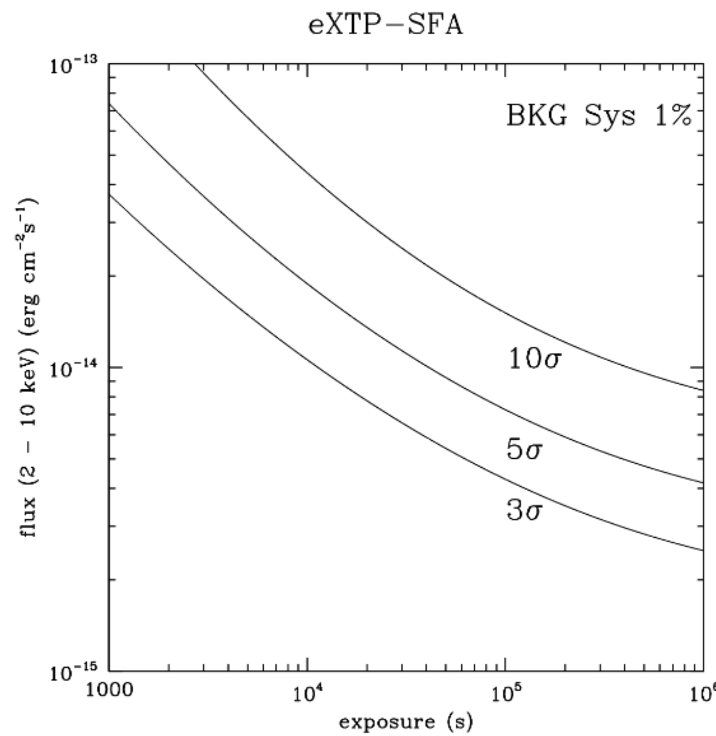


- **LAD**: 6x RXTE/PCA, 35x XMM-Newton (*but collimated*!) + hard-X response
- **SFA**: 8x XMM-Newton and 0.3-2x Athena/WFI (*but multiple optics and large PSF*!). Limiting sensitivity ~10^{-14}-10^{-15} erg cm^{-2} s^{-1}
- **PFA**: 5x IXPE, 2x XIPE. Sensitivity: 1% MDP in 50ks for a 100 mCrab source
- **WFM**: largest FoV ever, first time with 300 eV resolution. 3 mCrab in 50ks

eXTP Scientific Payload

Performance in context





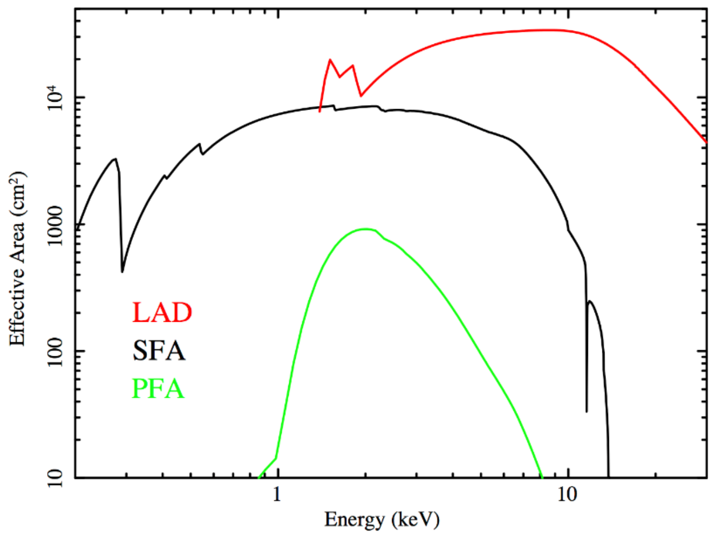
a/ WFI (*but multiple optics*!).

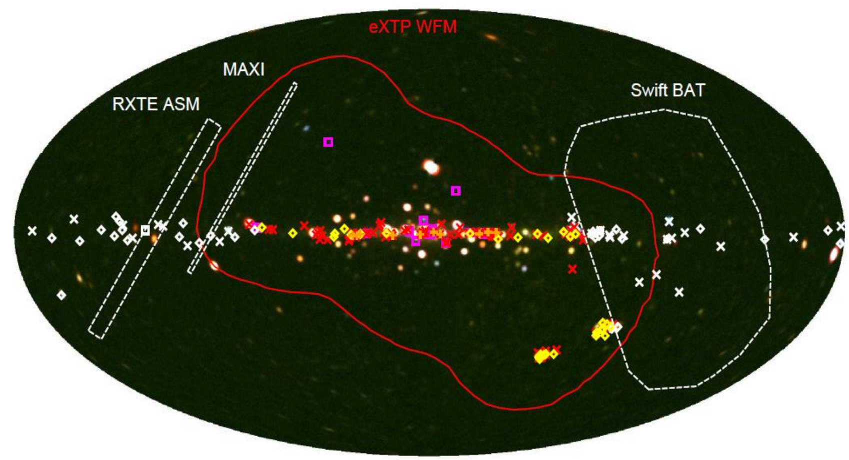
Limiting sensitivity ~10^{-14}-10^{-15} erg cm^{-2} s^{-1}

- **PFA**: 5x IXPE, 2x XIPE. Sensitivity: 1% MDP in 50ks for a 100 mCrab source
- **WFM**: largest FoV ever, first time with 300 eV resolution. 3 mCrab in 50ks

eXTP Scientific Payload

Performance in context

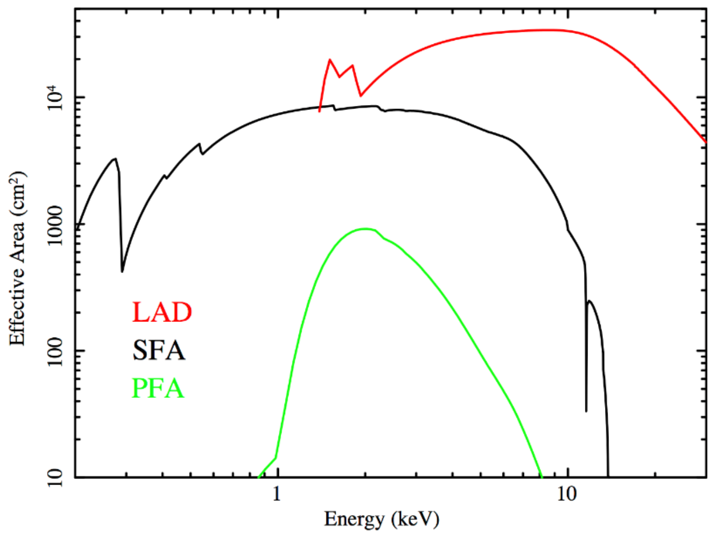


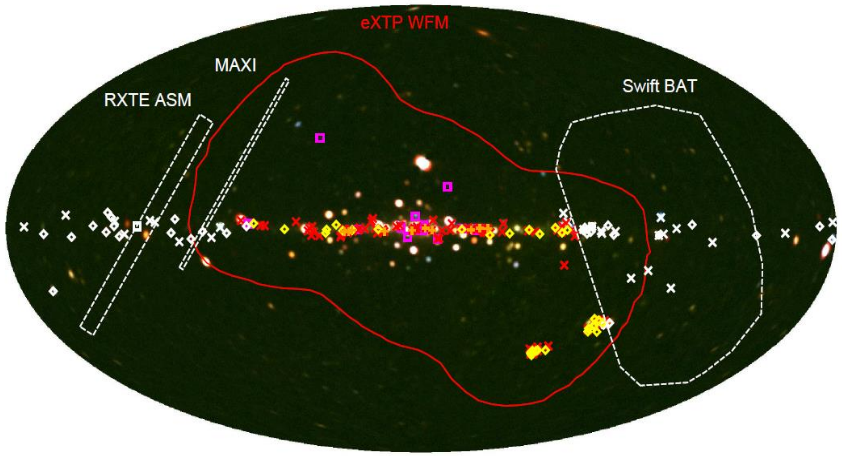


- **LAD**: 6x RXTE/PCA, 35x XMM-Newton (*but collimated*!) + hard-X response
- **SFA**: 8x XMM-Newton and 0.3-2x Athena/WFI (*but multiple optics and large PSF*!). Limiting sensitivity ~10^{-14}-10^{-15} erg cm^{-2} s^{-1}
- **PFA**: 5x IXPE, 2x XIPE. Sensitivity: 1% MDP in 50ks for a 100 mCrab source
- **WFM**: largest FoV ever, first time with 300 eV resolution. 3 mCrab in 50ks

eXTP Scientific Payload

Performance in context





- **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 large PSF*!). Limiting sensitivity ~10^{-14}-10^{-15} erg cm^{-2} s^{-1}
- **PFA**: 5x IXPE, 2x XIPE. Sensitivity: 1% MDP in 50ks for a 100 mCrab source
- **WFM**: largest FoV ever, first time with 300 eV resolution. 3 mCrab in 50ks

eXTP Science Working Groups

- In support to the mission study, four international working groups were preliminarily formed on the main science topics, preparing 4 White Papers (currently advanced drafts):
  - Accretion in Strong Field Gravity
  - Dense Matter
  - Strong Magnetism
  - Observatory Science
- In the framework of the ongoing joint China-Europe study, the preliminary working groups were further opened and expanded to interested scientists. Currently, a total of >260 scientists are contributing. More info at: http://www.isdc.unige.ch/extp/
- The 4 eXTP WPs are expected to be published on a special issue of the Science China journal by the end of 2017.

eXTP Science

Dense matter

Accretion in strong field gravity

Strong magnetism

Observatory science

eXTP Science

Dense matter

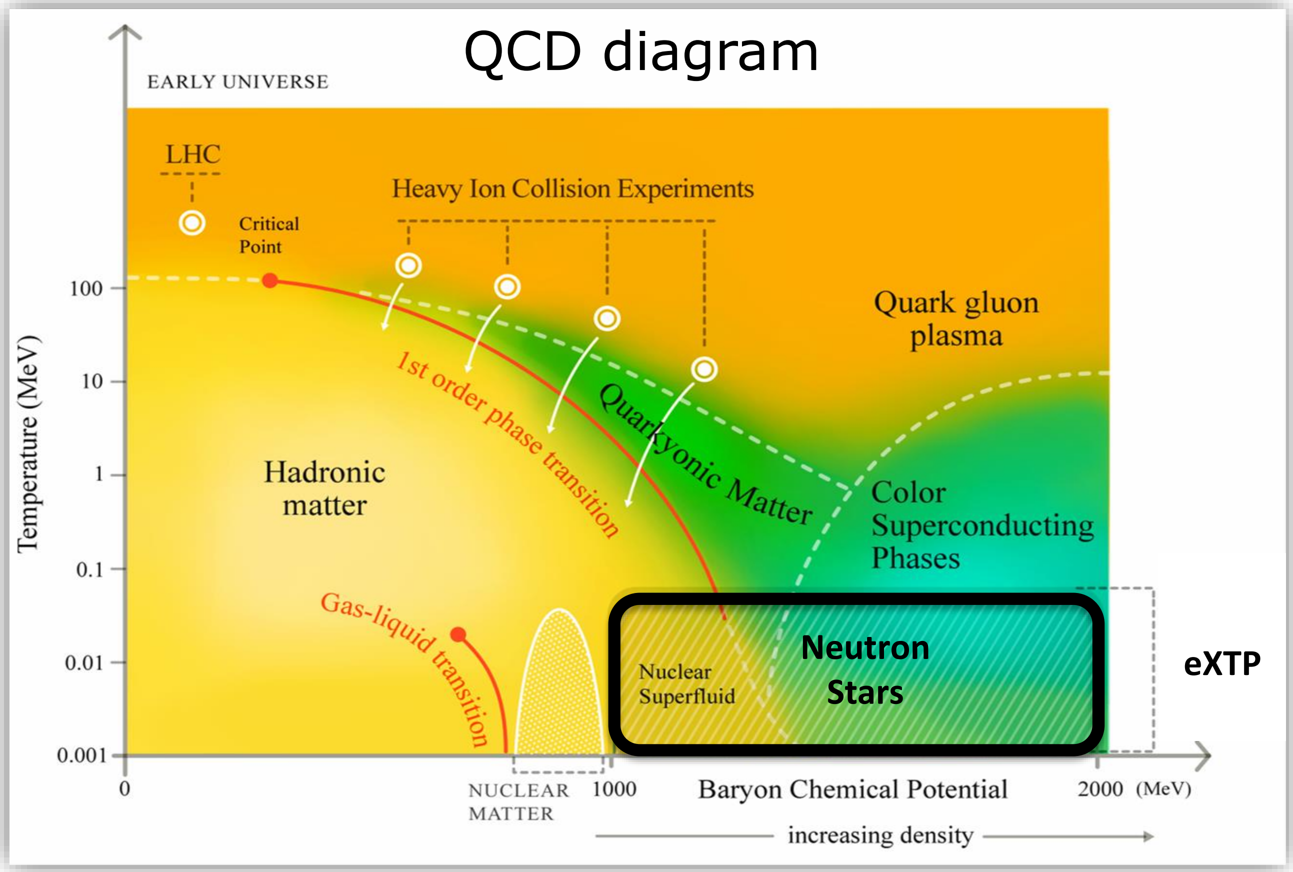
Accretion in strong field gravity

Strong magnetism

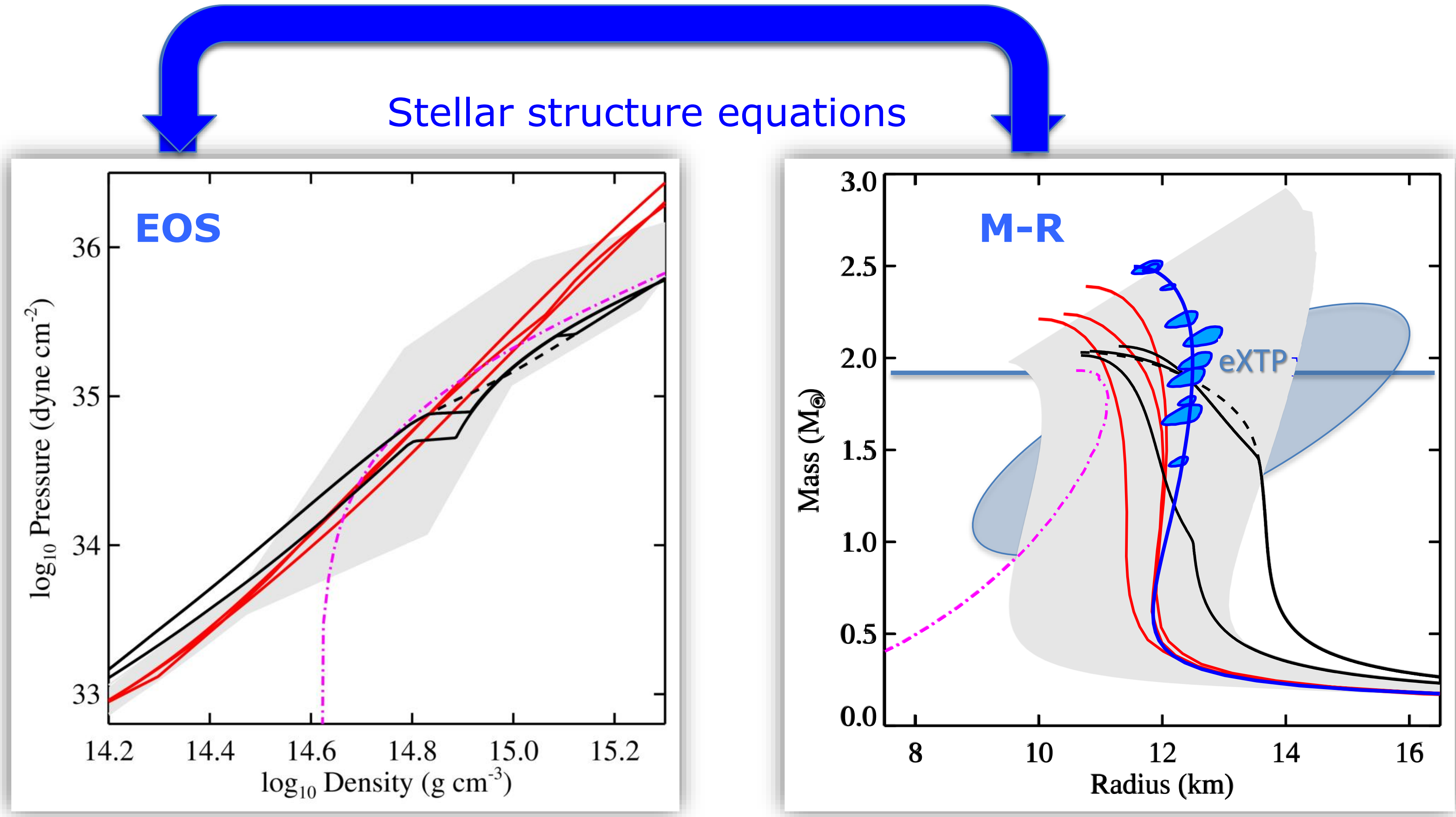
Observatory science

The strong force determines the state of nuclear matter from atomic nuclei to neutron stars:

- a major open problem in modern physics
- progress driven by experiment and obervation



Neutron stars contain the **densest** and most **neutron-rich** matter **in the Universe**.



MUST MEASURE **BOTH M AND R** TO **HIGH PRECISION**
(LOW STATISTICAL AND SYSTEMATIC ERRORS) FOR A **RANGE OF M.**

Dense Matter White Paper

- Pulse profile modelling
  - Accretion-powered millisecond pulsars
  - Burst oscillation sources (rise and tail)
  - Rotation-powered pulsars
- Spin measurements
- QPOs in NS LMXBs
  - kHz QPOs
  - mHZ QPOs

eXTP Science

Dense matter

Accretion in strong field gravity

Strong magnetism

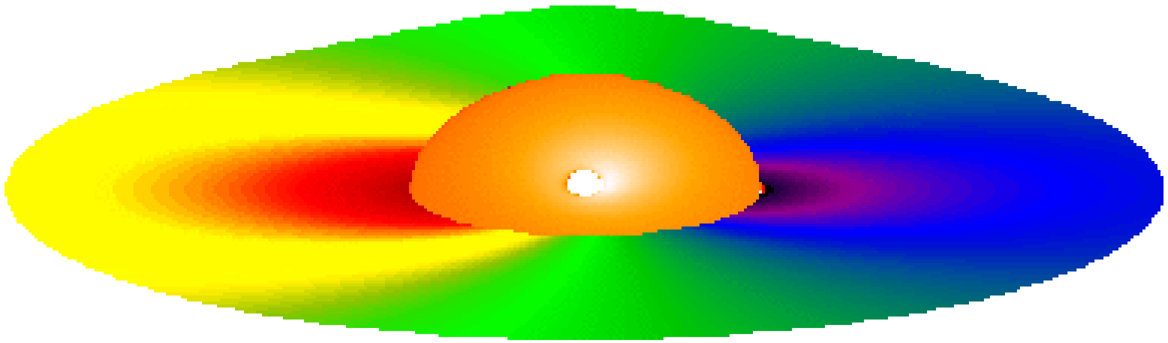
Observatory science

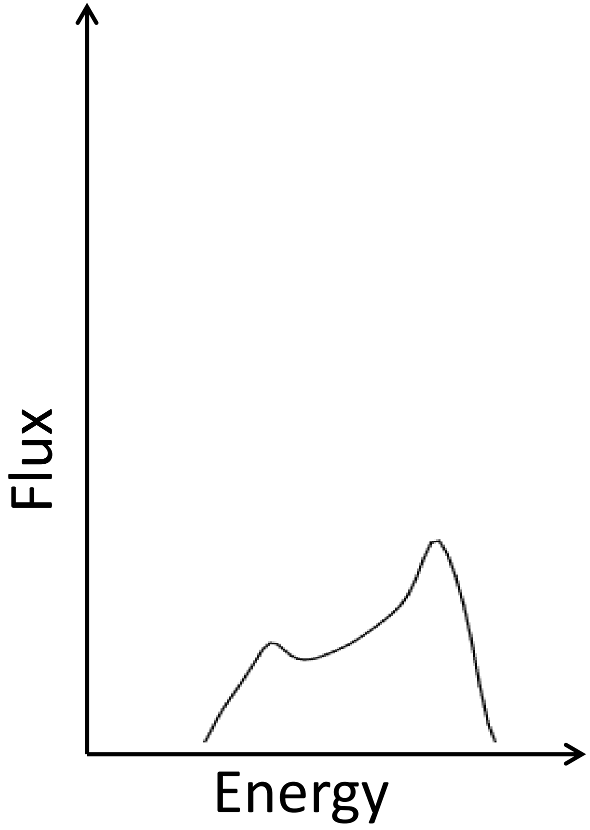
Accretion in SFG diagnostics

- SMBHs - AGN
  - Disk Fe line profile
  - Phase resolved Fe line. Orbiting Hot Spot
  - X-ray reverberation. Time lags
  - Polarization of the corona
- Stellar mass BH and NS - XRB
  - Disk Fe line profile
  - Continuum fitting
  - X-ray reverberation. Time lags
  - QPOs
  - QPOs phase resolved polarimetry

Frame dragging in BHB

Tell-tale sign of precession: a rocking iron line





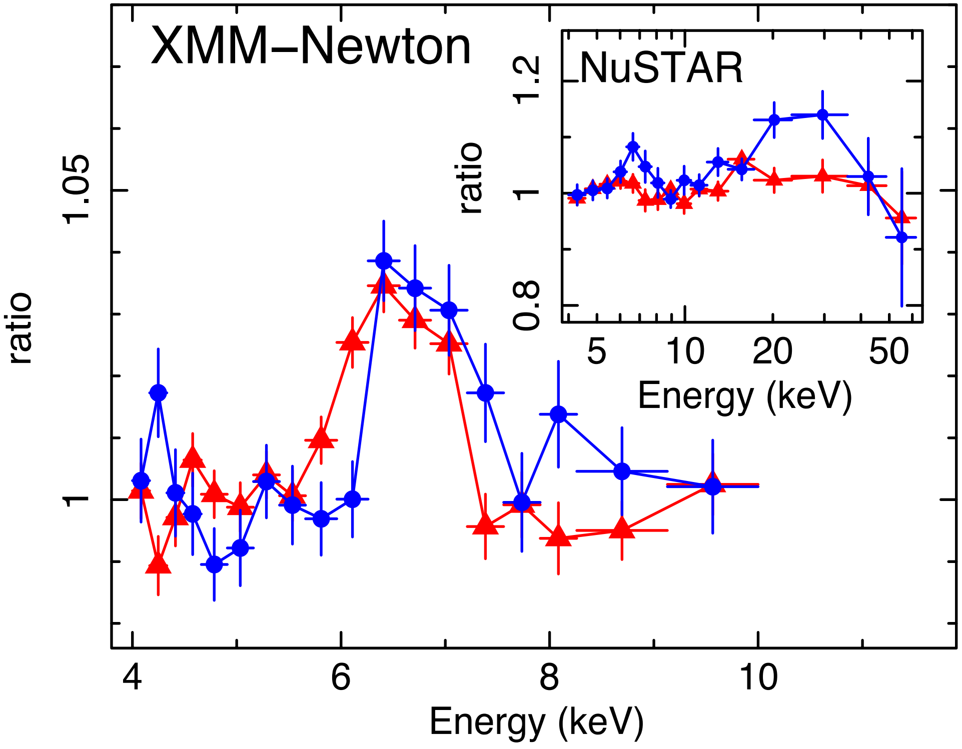
https://www.youtube.com/watch?v=e1QmLg5mGbU

Ingram & Done (2012)

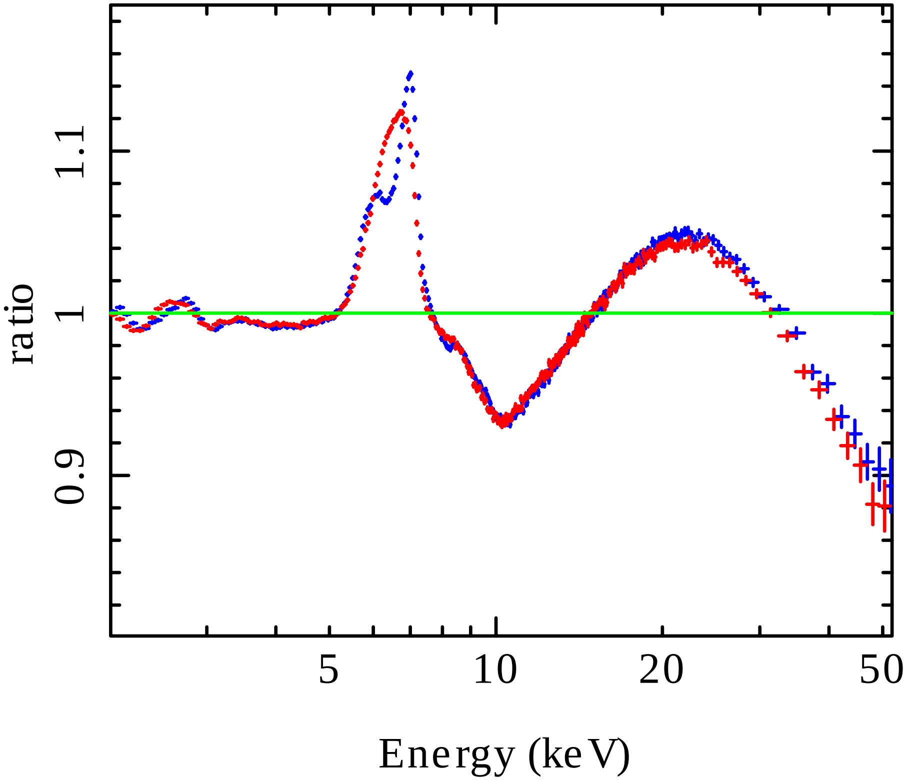
Tomography with eXTP

QPO phase-selected spectroscopy (here 2 phases shown)

130 ks XMM + 70 ks NuSTAR
H 1743-322

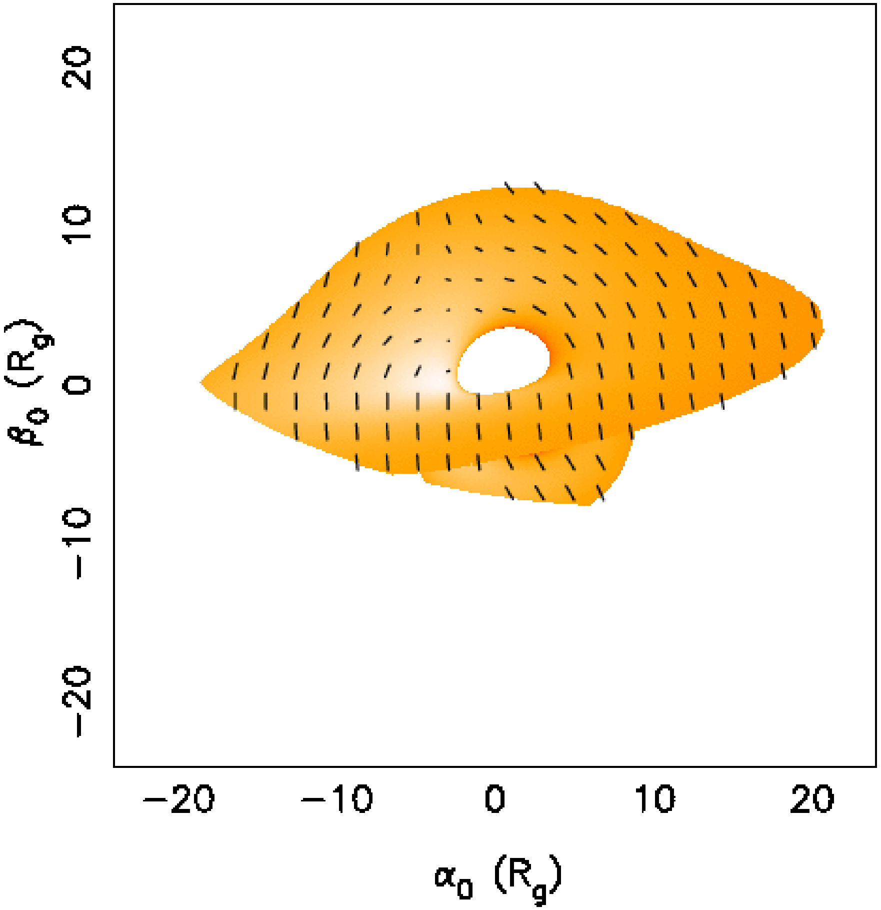


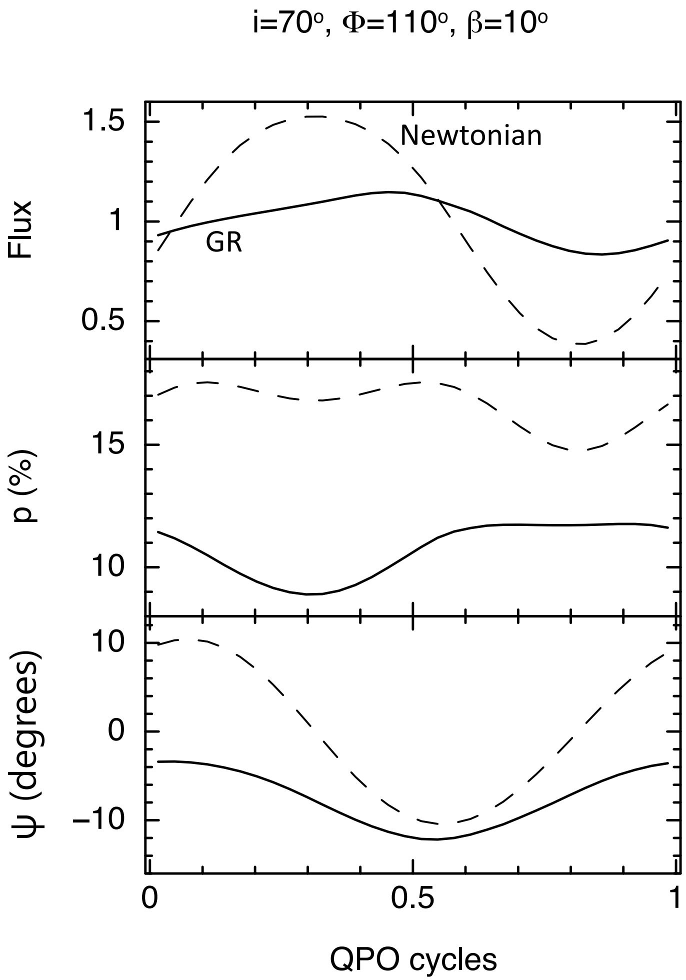
30 ks LAD simulation
GX 339-4



Courtesy: Adam Ingram

Simultaneous polarization variability in LFQPOs





www.youtube.com/watch?v=ieZYYfCapJg&feature=youtu.be

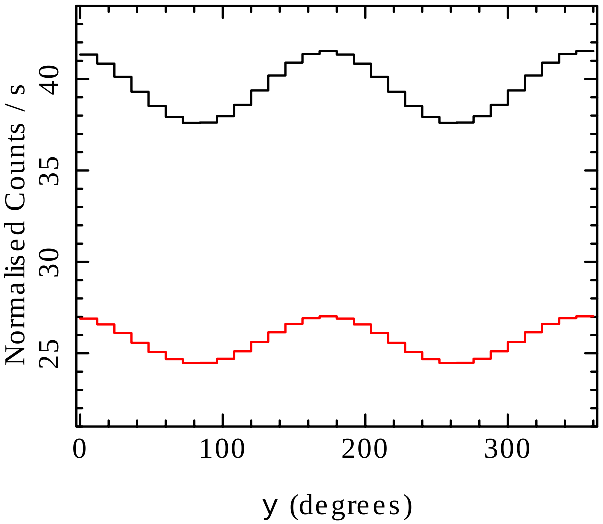
Ingram et al (2015)

Detection

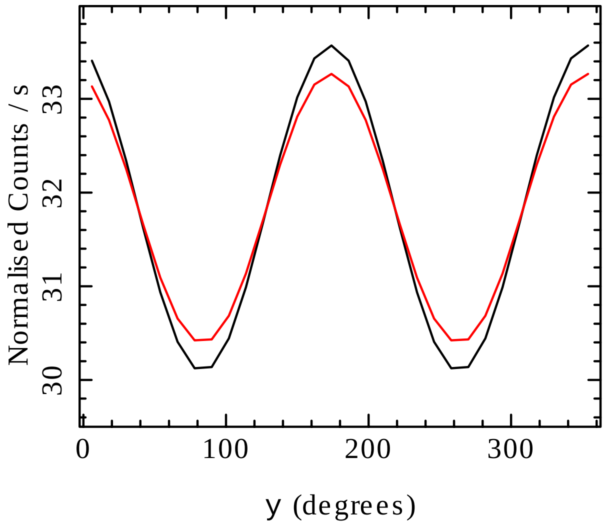
Can't measure p and ψ in arbitrarily small time bins

Can make light curves for different ψ bins

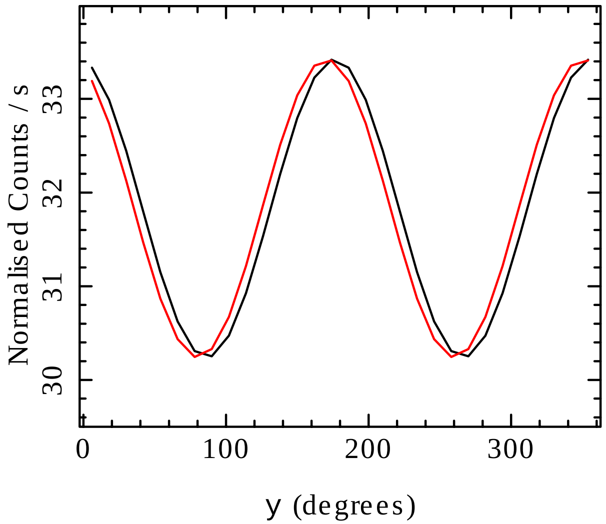
Just variability in count rate



Just variability in pol degree



Just variability in pol angle

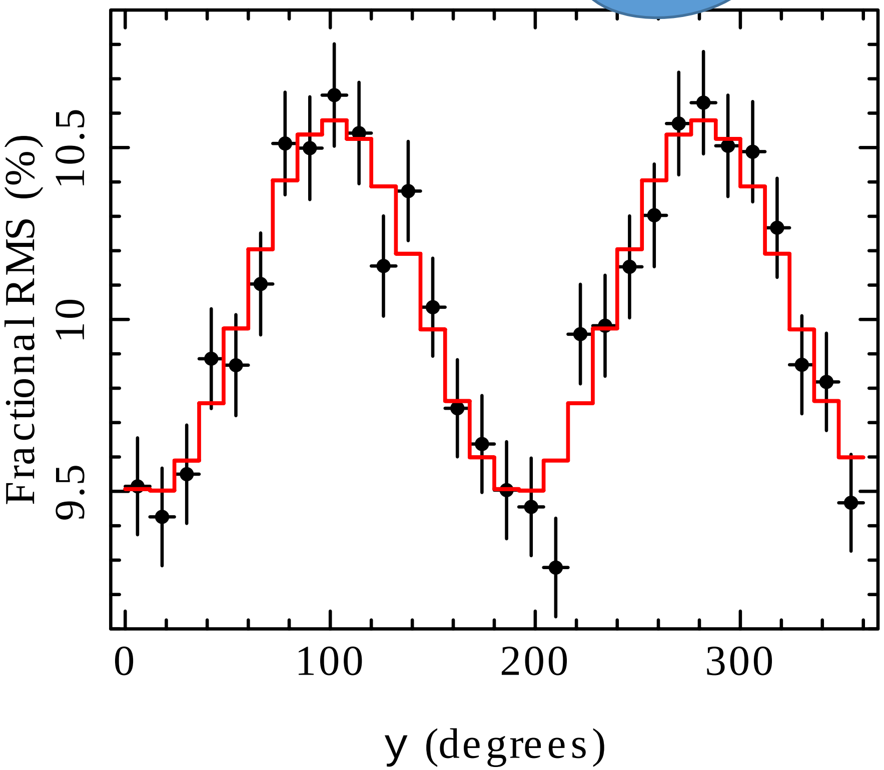


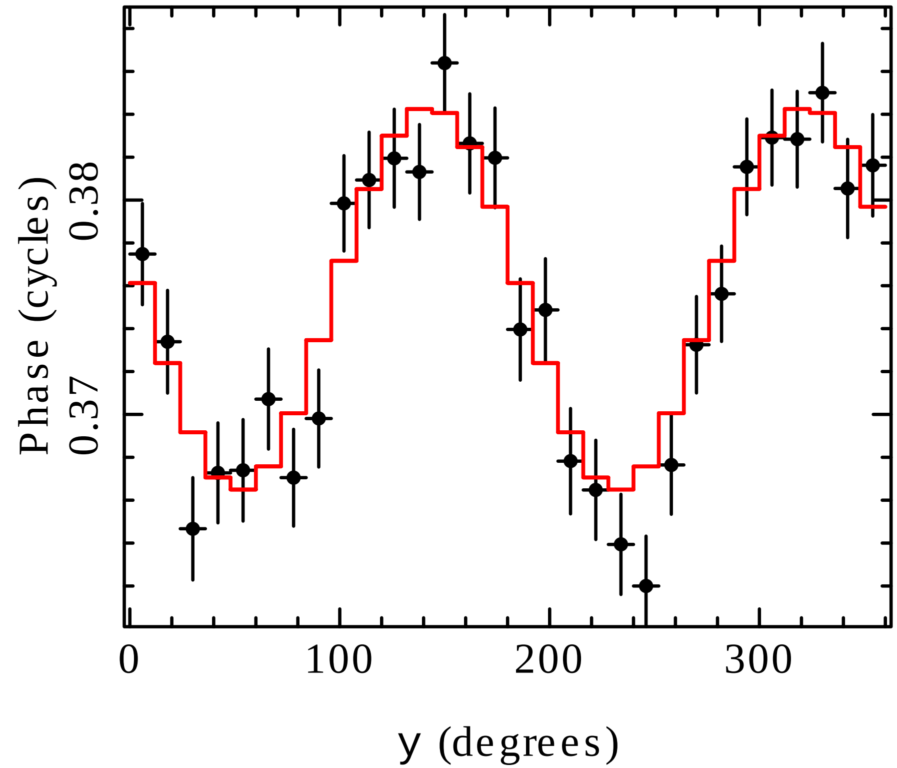
Courtesy: Adam Ingram

Simulated eXTP detection

100 ks exposure of GX 339-4 with eXTP
GPDs: 200 c/s; LAD 38,000 c/s

Now 2x!





Courtesy: Adam Ingram

eXTP Science

Dense matter

Accretion in strong field gravity

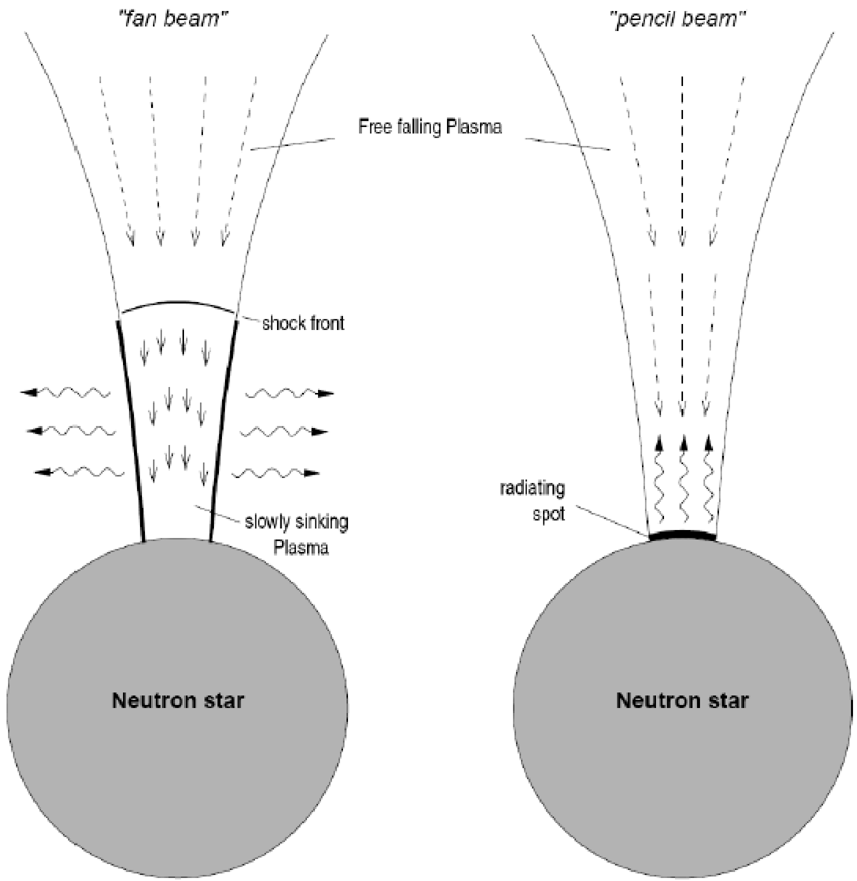
Strong magnetism

Observatory science

Strong Magnetism White Paper

- Physics and astrophysics of magnetars
  - Burst emission
  - Outburst decay
  - Glitches
  - Precessions
  - Braking index
  - Asteroseismology
  - Spectral lines
  - Magnetars in binaries
- Accreting pulsars
  - Polarization studies
  - Pulse-phase resolved spectroscopy and cyclotron features
  - Microsecond variability in HMXB
- Rotation-powered pulsars
- QED studies in NS, BH and WD

Accreting X-ray pulsars



High accretion rate: *shock is formed*, plasma is decelerated to subsonic speed and heated. *The Plasma then sinks to the NS surface*. Emitted photons can only escape perpendicularly to the column forming a wide *Fan beam.*

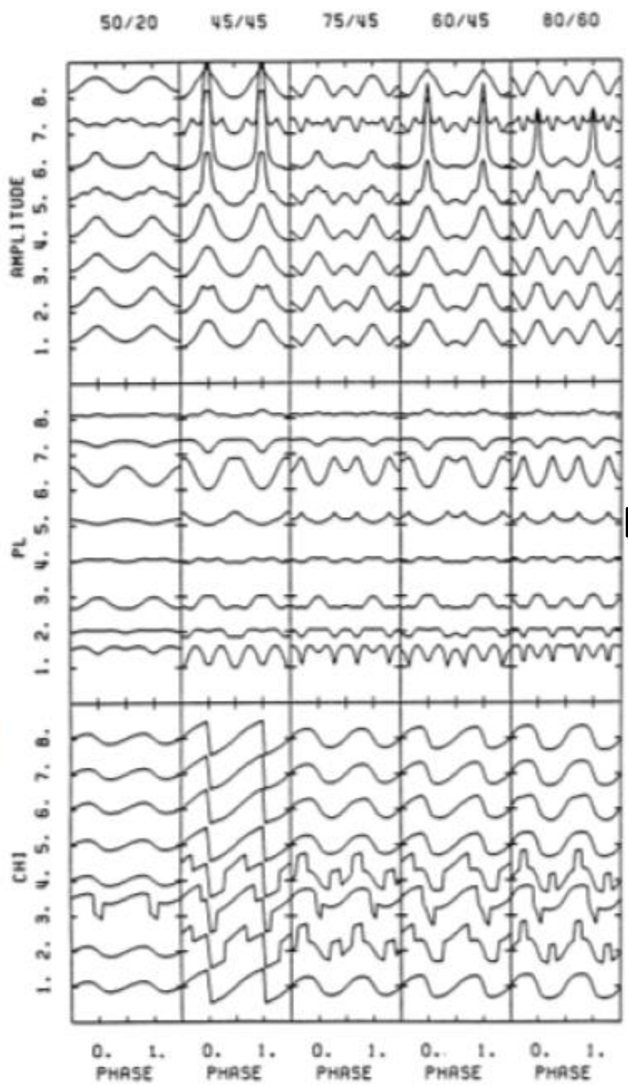
Lower accretion rate No shock is formed, *plasma is decelerated onto the neutron star surface* by Coulomb collisions; photons are generated by Bremsstrahlung and Compton Cooling. They can escape along the accretion column, generating a *pencil beam*

Accreting X-ray pulsars

Eight values of energy, from bottom to top: 1.6, 3.8, 9.0, 18.4, 38.4, 51.7, 84.7 keV.

Pencil beam:
I-P anticorrelation

Fan beam:
I-P correlation

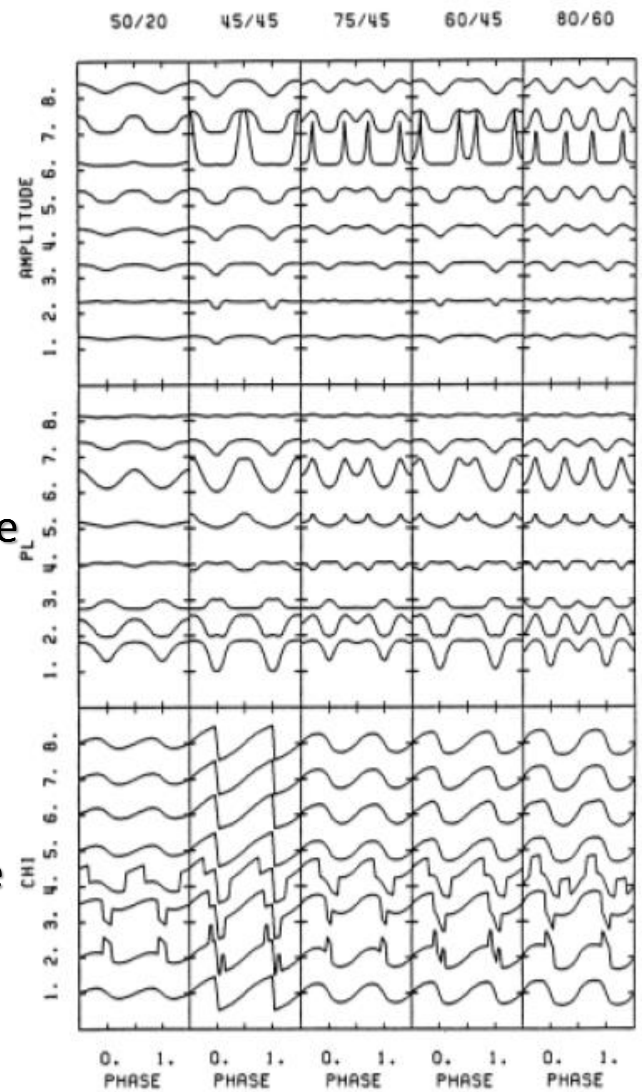


“pencil” beam

Flux

Pol. Degree

Pol. Angle

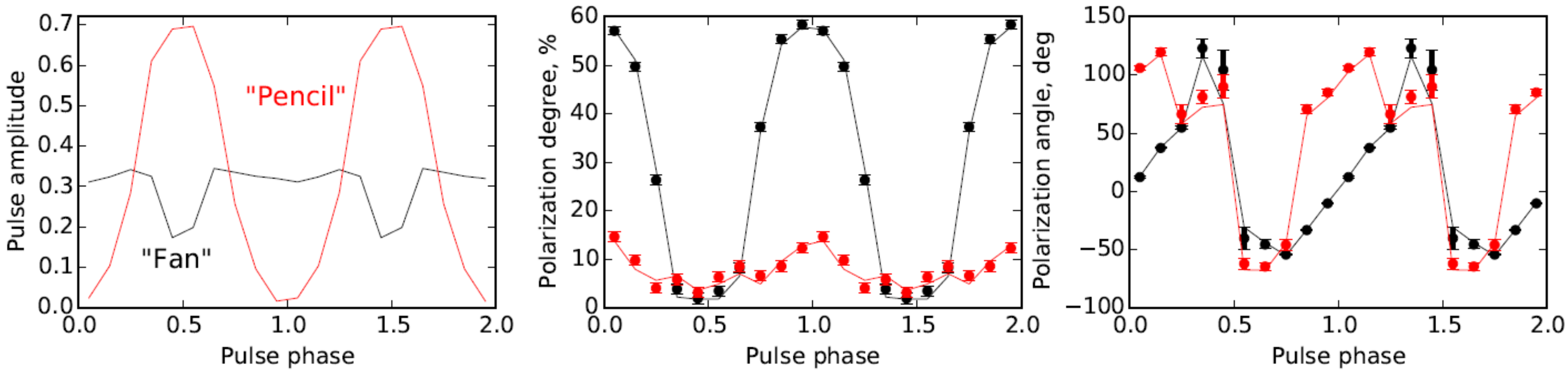


“fan” beam

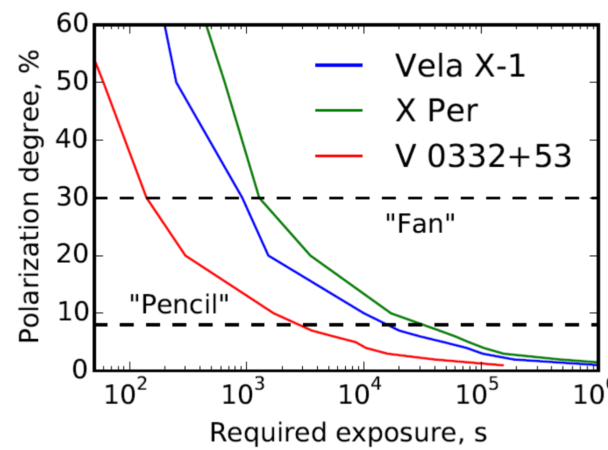
Meszaros et al. 1988

Accreting X-ray pulsars with eXTP

From the eXTP Strong Magnetism white paper: the case of Vela X-1 (10ks /phase for 10 phases).



Exposure required to constrain linear polarization fraction for different sources for the pencil and fan beam models (here 2 GPD).



eXTP Science

Dense matter

Accretion in strong field gravity

Strong magnetism

Observatory science

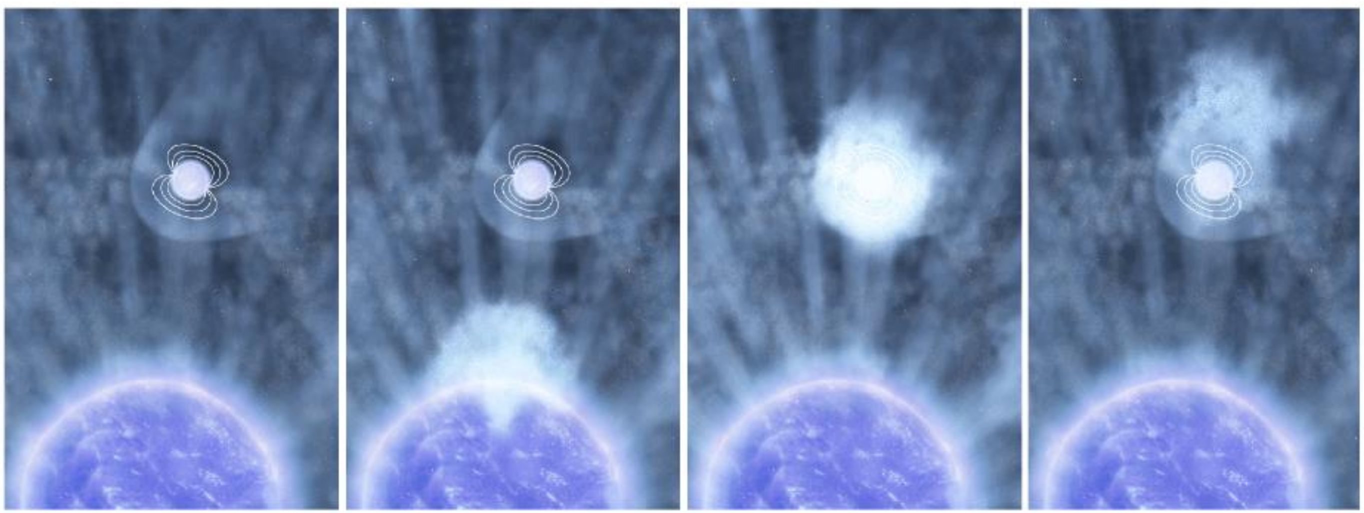
Observatory Science White Paper

- Low-mass X-ray binaries
- Thermonuclear X-ray bursts
- Accreting White Dwarf Binaries
- High-mass X-ray binaries
- Radio-loud AGN
- Radio-quiet AGN
- Tidal disruption events
- Gamma-ray bursts, SuperNovae, and Gravitational wave events
- Flare stars
- Supernova remnants

Example from eXTP Observatory Science

Clump accretion in Supergiant Fast X-ray Transients:

the case of the XMM-Newton observation of a clump accretion in IGR J18410-0535 (Bozzo et al. 2011)

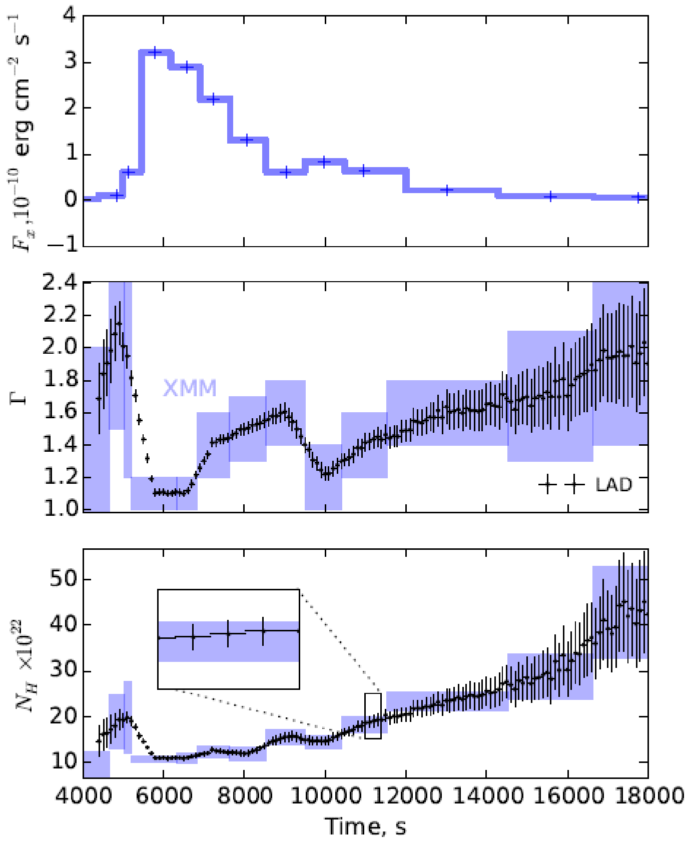


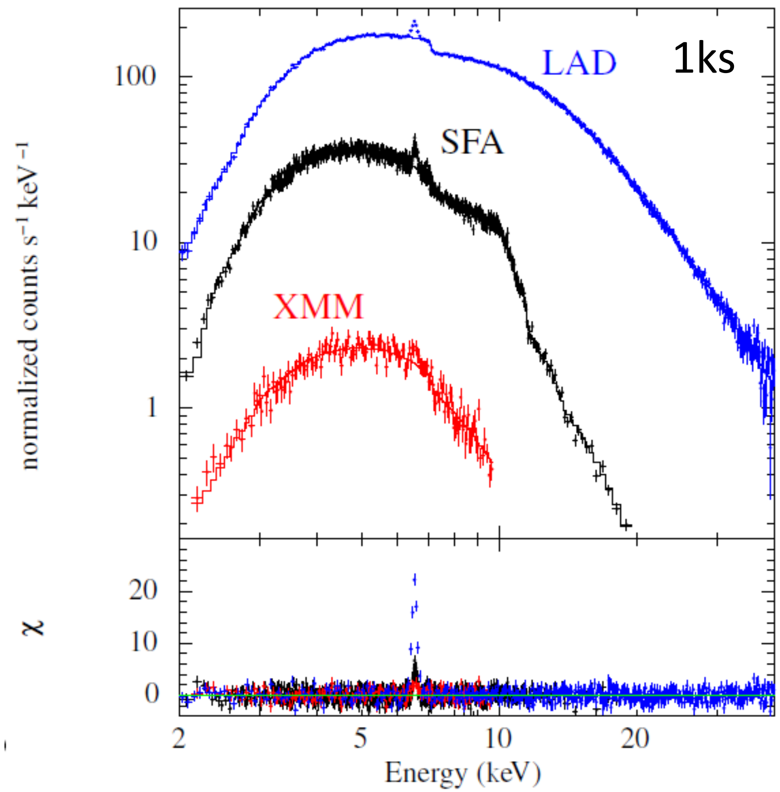
(Credit: ESA)

Example from eXTP Observatory Science

Clump accretion in Supergiant Fast X-ray Transients:

the case of the XMM-Newton observation of a clump accretion in IGR J18410-0535 (Bozzo et al. 2011)





eXTP Programmatics

Mission currently entering an **extended Phase A** study in China, in collaboration with a consortium of European institutes. Formal European participation currently under discussion. Strong interest and support available in several member states institutions and agencies.

Baseline implementation schedule:

- 2011-2016: background study (Phase 0/A1)
- 2017-2018: international coordination and preliminary design (Phase A2)
- 2019-2020: Detailed design (Phase B)
- 2021-2023: Space qualification model (Phase C)
- 2024-2025: flight model (Phase D)
- **2025: launch**

- 2025-2035: science operation

eXTP Data Policy

eXTP is proposed an observatory open to the worldwide science community.

The specific data policy will be discussed by the participating agencies at later stages in the development of the mission. However, it is expected that the eXTP observing plan will be designed based on Core Program observations as well as on a Guest Investigator Program, through time allocation committees.

Conclusions

eXTP is conceived as the most powerful and general observatory for compact Galactic and bright extragalactic objects ever.

eXTP will change the game. It will offer for the first time the most complete diagnostics of compact sources: excellent spectral, timing and polarimetry sensitivity on a single payload.

eXTP is proposed as a cooperative effort between (at least) **China and Europe**. The support and contribution of the wide scientific community is crucial to achieve this goal.