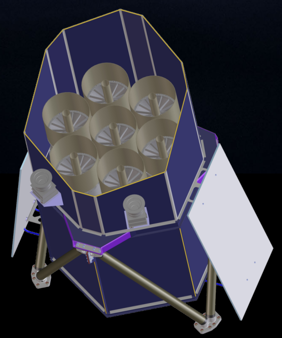
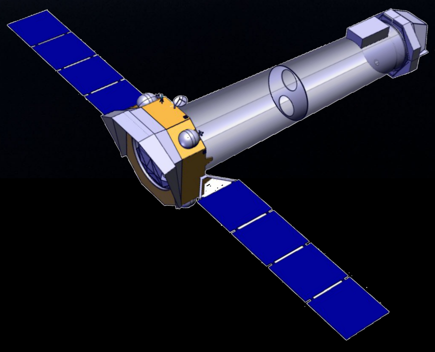
Instrumental Panorama: Space

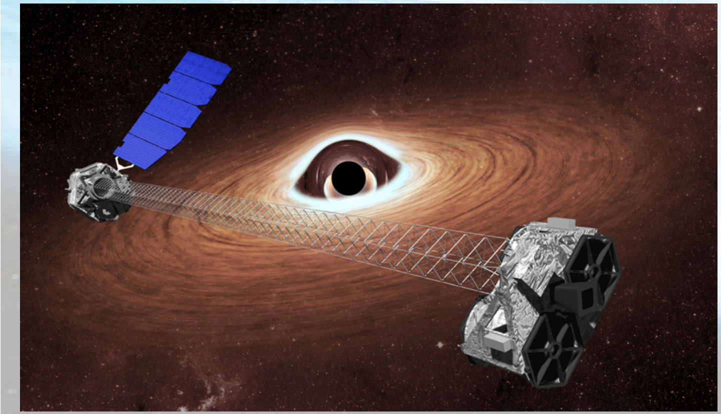
Jörn Wilms





XMM-Newton (ESA): 1999 Dec 10

Chandra (NASA): 1999 Jul 23



NuSTAR (NASA): 2012 Jun 16

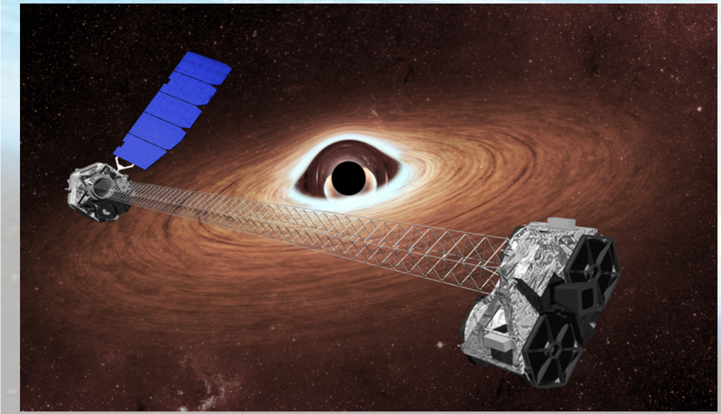
X-Ray Astronomy: The Present

Currently Active Missions:

- *Chandra* (USA),
- XMM-Newton (ESA),
- INTEGRAL (ESA),
- *Swift* (USA),
- *AGILE* (Italy),
- Fermi (USA),
- MAXI (Japan),
- ASTROSAT (India),
- Insight-HXMT (China),
- NICER (USA).

XMM-Newton (ESA): 1999 Dec 10

Chandra (NASA): 1999 Jul 23



NuSTAR (NASA): 2012 Jun 16

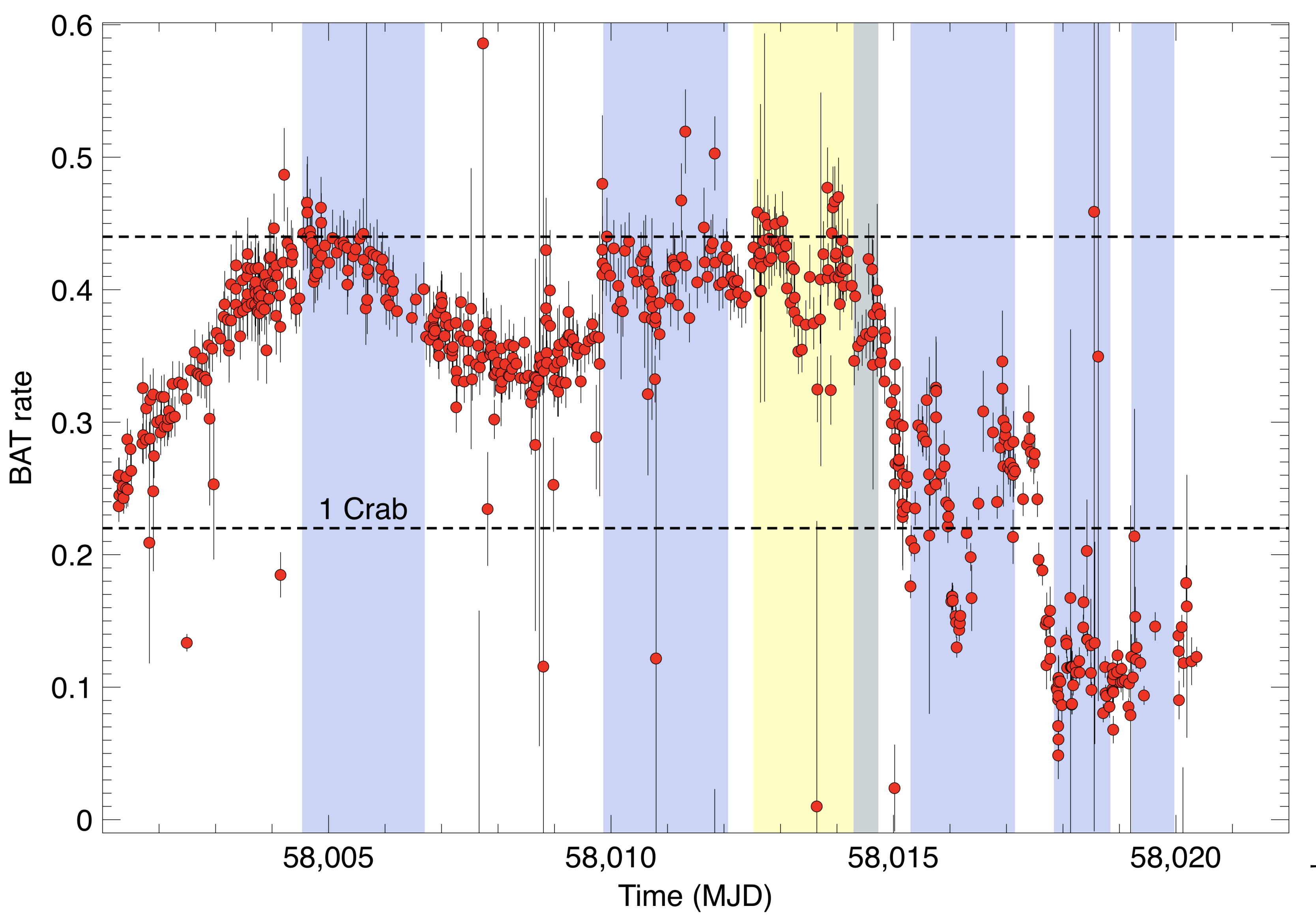
X-Ray Astronomy: The Present

Currently Active Missions:

- *Chandra* (USA),
- XMM-Newton (ESA),
- INTEGRAL (ESA),
- *Swift* (USA),
- *AGILE* (Italy),
- Fermi (USA),
- MAXI (Japan),
- ASTROSAT (India),
- Insight-HXMT (China),
- NICER (USA).

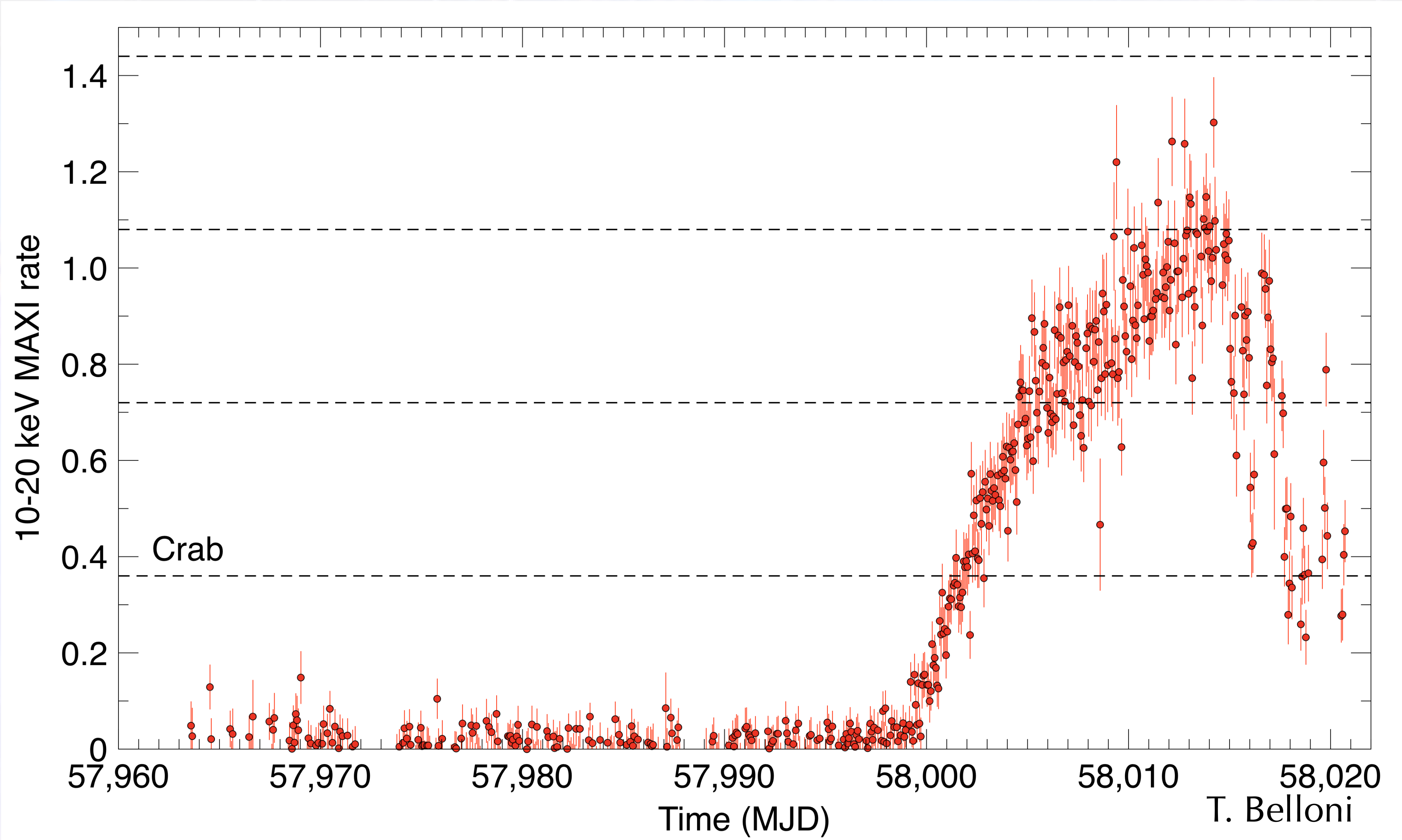
We are living in the "golden age" of X-ray and Gamma-Ray Astronomy

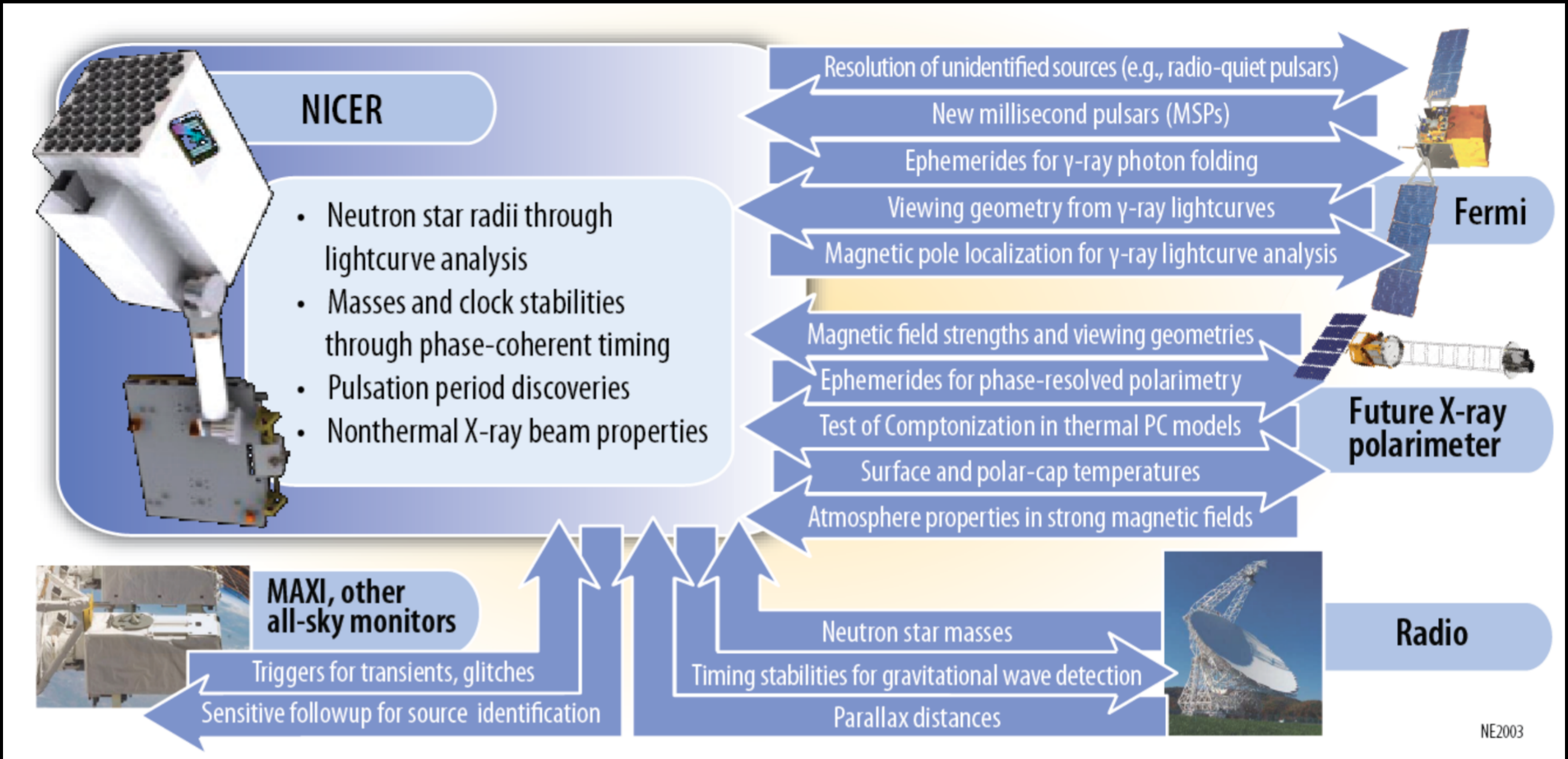
MAXI J1535−571



T. Belloni

MAXI J1535−571





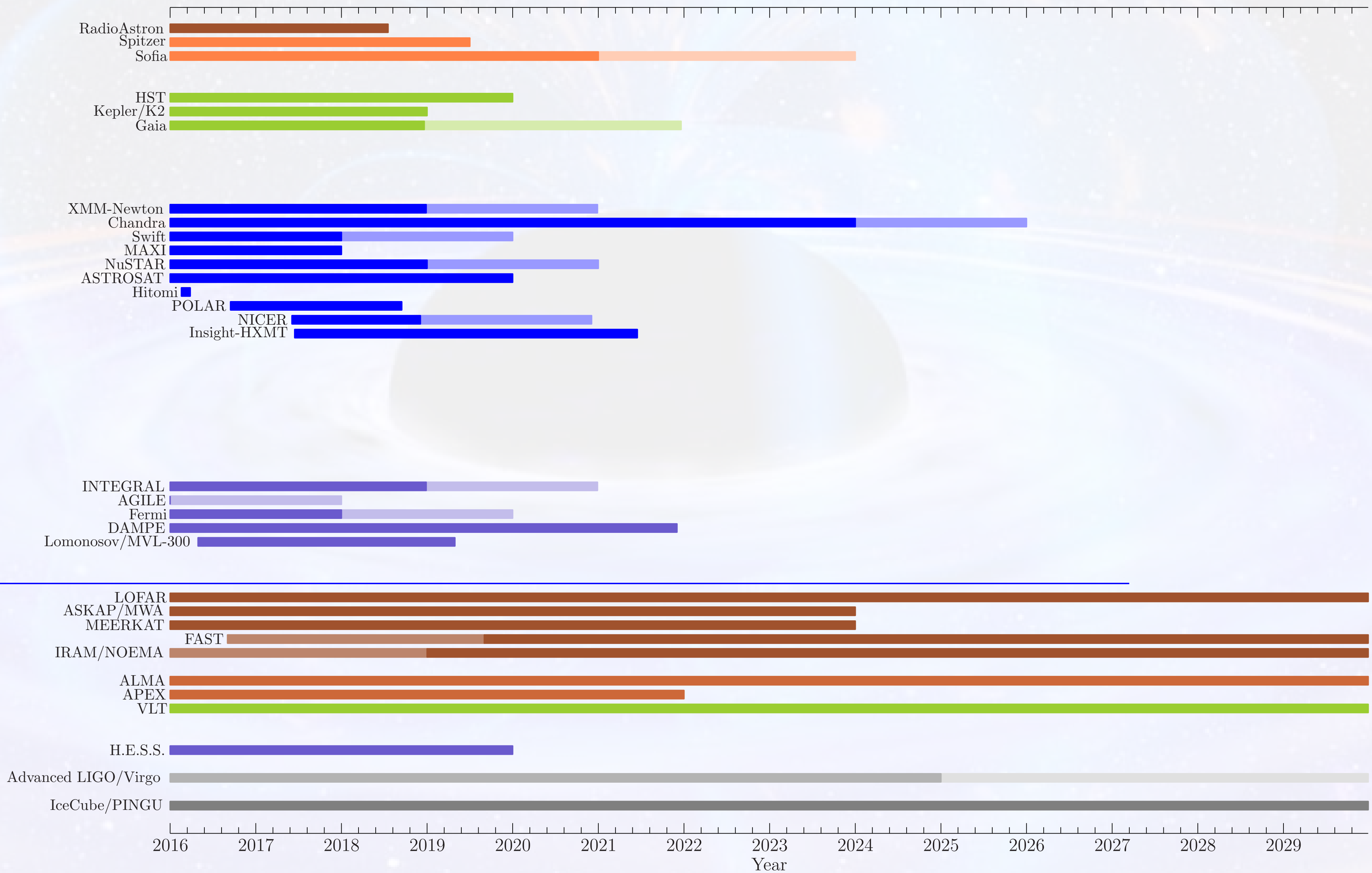
Studies of X-ray binaries require the simultaneous use of multiple observational and theoretical techniques.

MAXI J1535−571

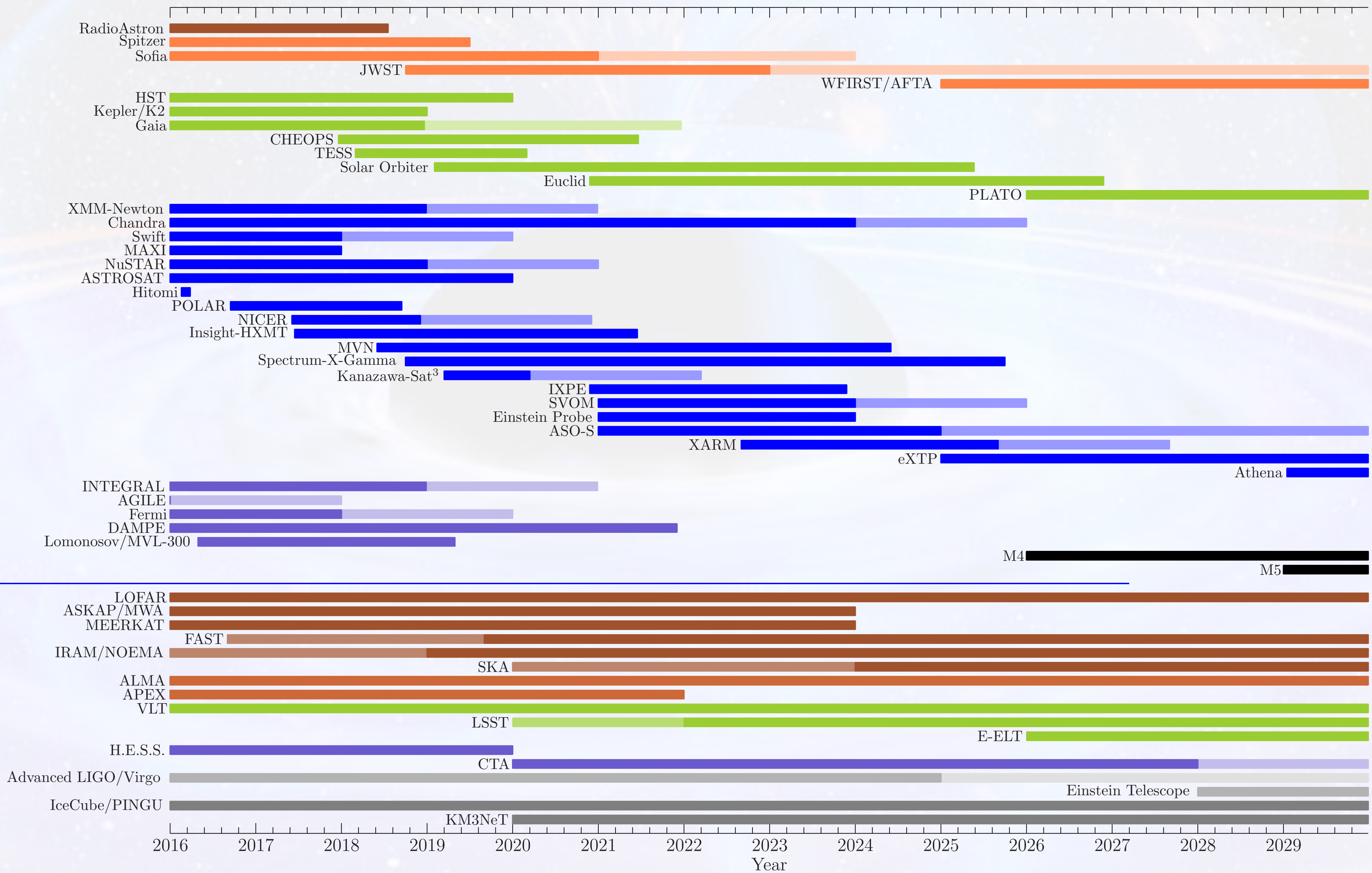
Observational needs for black hole studies in the next 20 years:

- Stellar wind physics, disk winds:
  high E-resolution (gratings/calorimeter) X-ray spectroscopy [few eV; underutilized!]
- Accretion disk physics:
  polarization, timing, CCD–type E-res. spectroscopy [100 eV'ish]
- Nature of compact objects (e.g., spin):
  timing [μs, ms], spectroscopy [CCD sufficient]
- Population of compact objects:
  surveys
- Search and monitor transients:
  all sky (sr) monitors, large field of regard ($= \angle(\text{Sun}, \text{opt. axis})$)
- States, jet physics:
  Broad band coverage: 0.5–150 keV

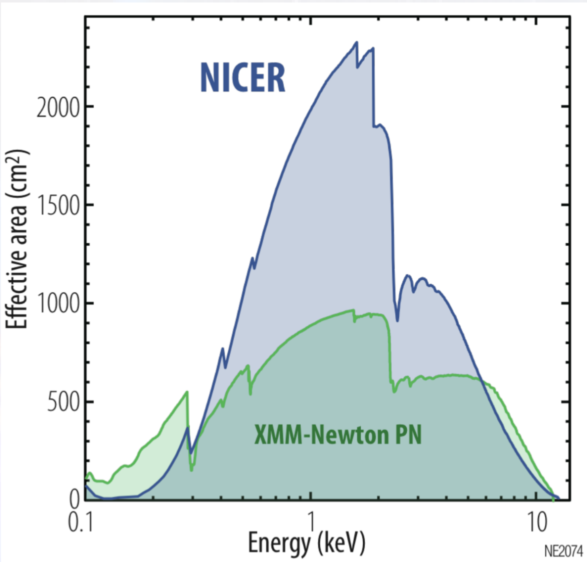
Current Facilities



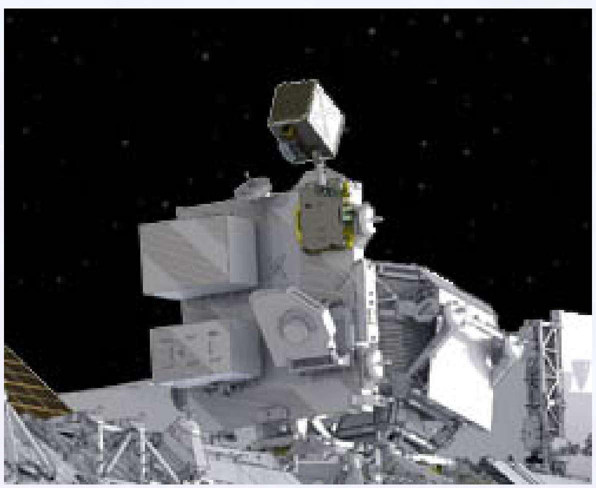
Approved Facilities



NICER



Gendreau et al., 2012, Proc. SPIE 8443

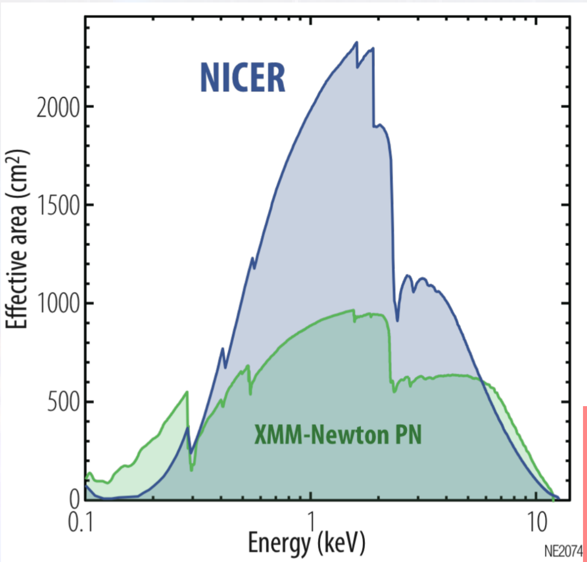


Science aim: focused on neutron star EOS (lightcurve modeling) and navigation

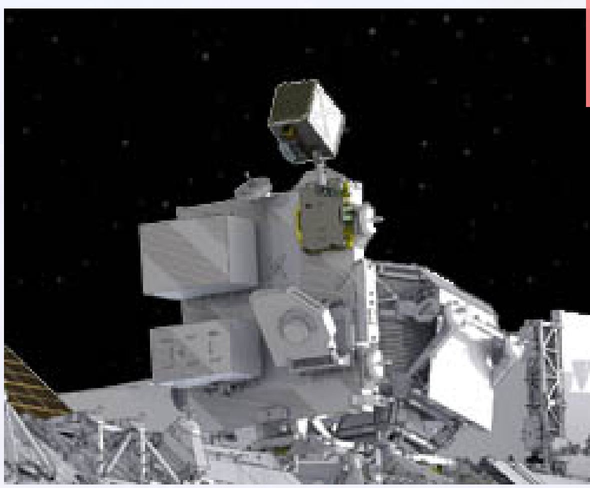
- successfully installed on ISS science program has started
- Eff. area: $\sim 2\times$ XMM EPIC-pn (soft X-rays)
- CCD resolution (85 eV 1 keV, 137 eV 6 keV)
- time tagging: $<$300 ns absolute $\Longrightarrow 25\times$ better than RXTE-PCA, $100\times$ XMM
- $5'$ FoV, non-imaging
- very low background
- sensitivity: $3\times10^{-14}\,\mathrm{erg\,s^{-1}\,cm^{-2}}$ in 5–10 keV, 5σ in 10 ks

GO programm envisaged for year 2ff.: BH QPOs, HMXB spin evolution, accretion geometry,…

NICER



Gendreau et al., 2012, Proc. SPIE 8443



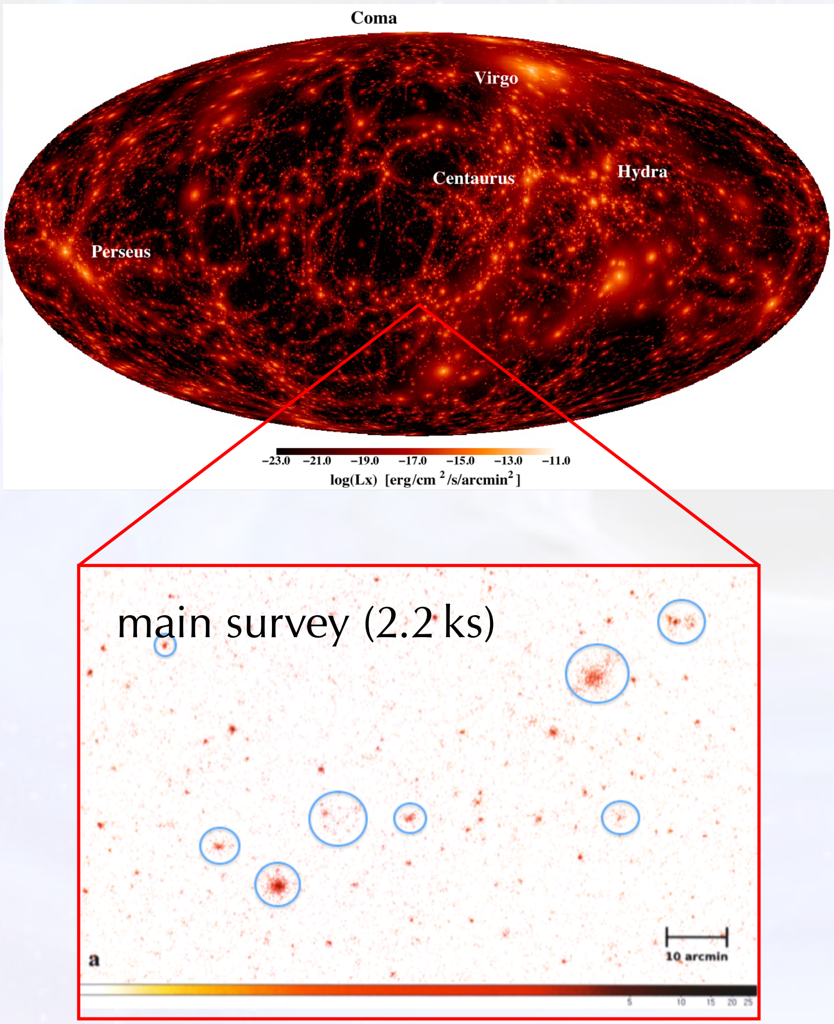
Science aim: focused on neutron star EOS (lightcurve modeling) and navigation

- successfully installed on ISS science program has started
- Eff. area: ~ 2× XMM EPIC-pn (soft X-rays)
- CCD resolution (85 eV 1 keV, 137 eV 6 keV)
- time tagging < 300 ns absolute $\Longrightarrow$ 25× better than RXTE-PCA, 100× XMM
- 5′ FoV, non-imaging
- very low background
- sensitivity: $3 \times 10^{-14}\,\mathrm{erg\,s^{-1}\,cm^{-2}}$ in 5–10 keV, 5σ in 10 ks

See talks by Ron Remillard and Jack Steiner for more details.

GO programm envisaged for year 2ff.: BH QPOs, HMXB spin evolution, accretion geometry,…

eROSITA



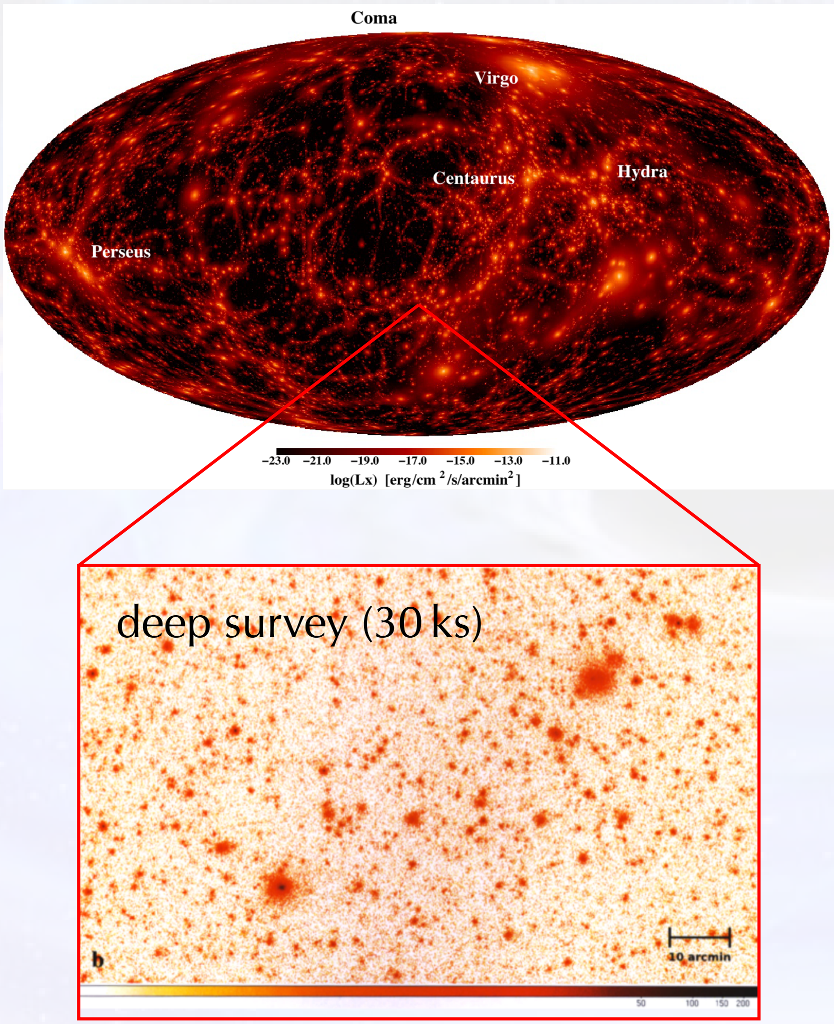
Primary science:

- cluster cosmology (100000 clusters),
- BH evolution (2×10^6 AGN)

Strategy:

- launch: Sept 2018
- All Sky Survey to 6×10^{-14} cgs
- Deep survey ($\sim 100\,\square^\circ$) to 10^{-14} cgs
- 1° FoV, moderate angular resolution ($30''$ avg.)
- large effective area ($>2000\,\mathrm{cm}^2$ at 1 keV)
- CCD-type spectral resolution (155 eV at Fe K)

eROSITA



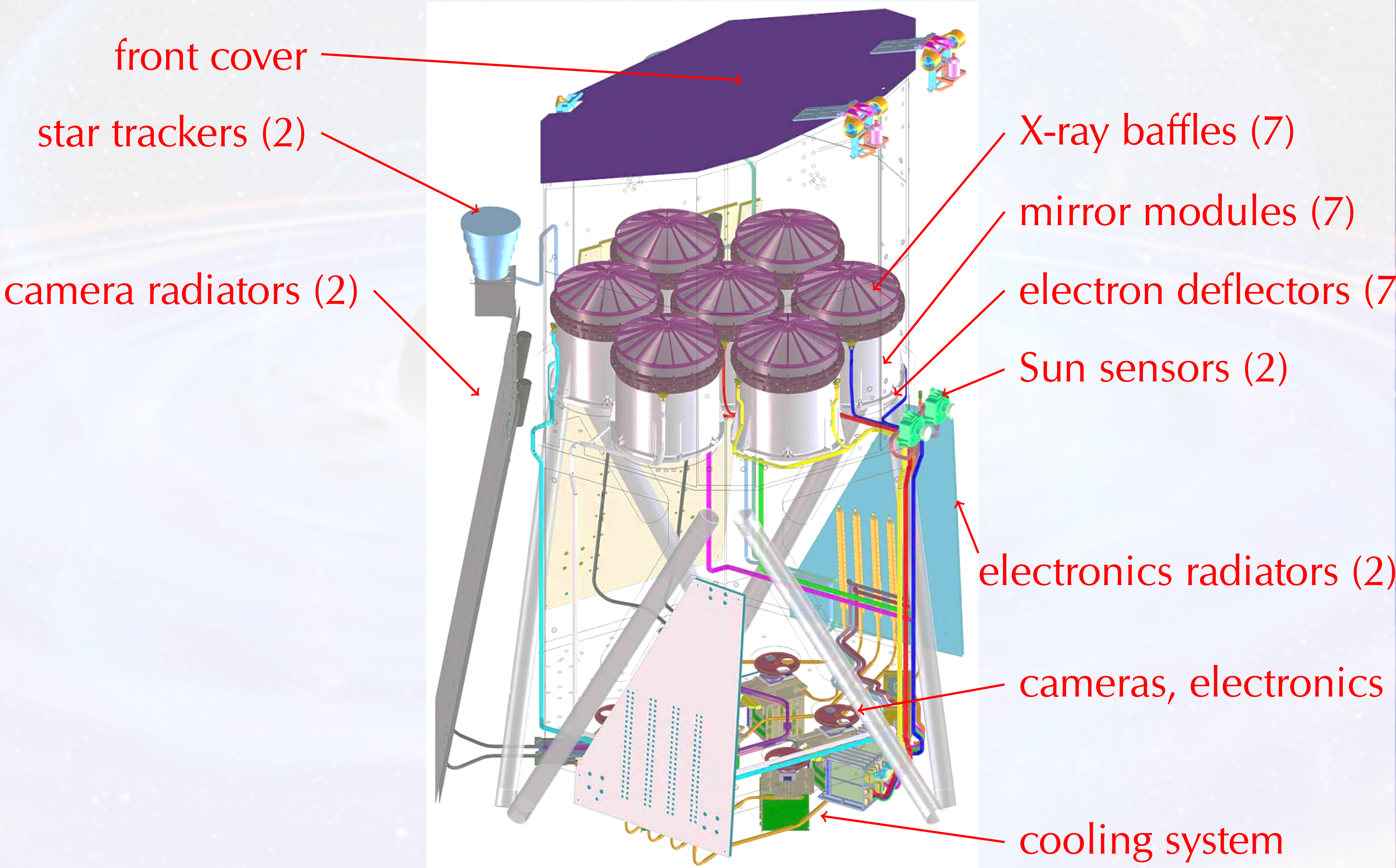
Primary science:

- cluster cosmology (100000 clusters),
- BH evolution (2×10^6 AGN)

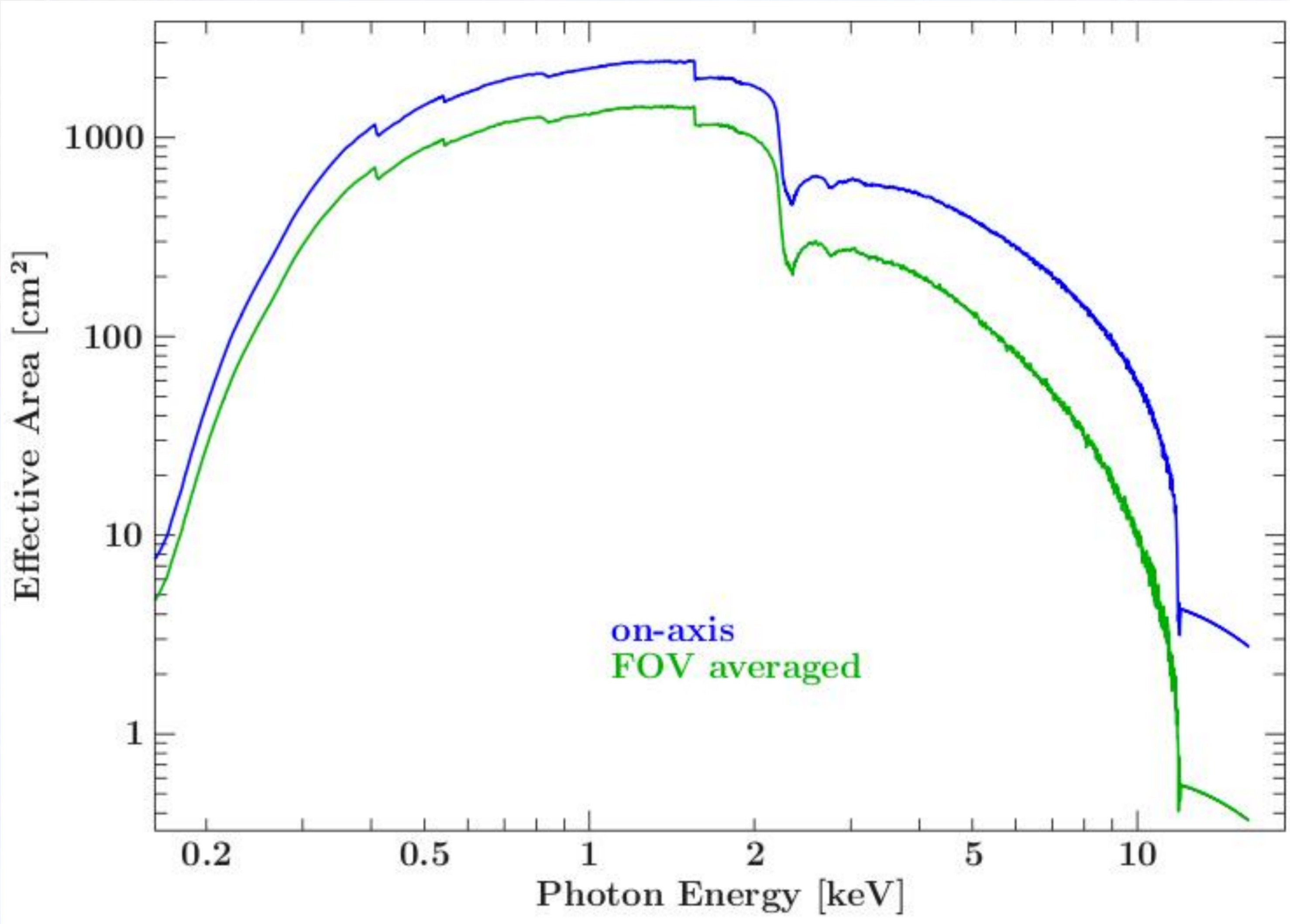
Strategy:

- launch: Sept 2018
- All Sky Survey to 6×10^{-14} cgs
- Deep survey ($\sim 100\,\square^\circ$) to 10^{-14} cgs
- 1° FoV, moderate angular resolution ($30''$ avg.)
- large effective area ($>2000\,\mathrm{cm}^2$ at 1 keV)
- CCD-type spectral resolution (155 eV at Fe K)

eROSITA

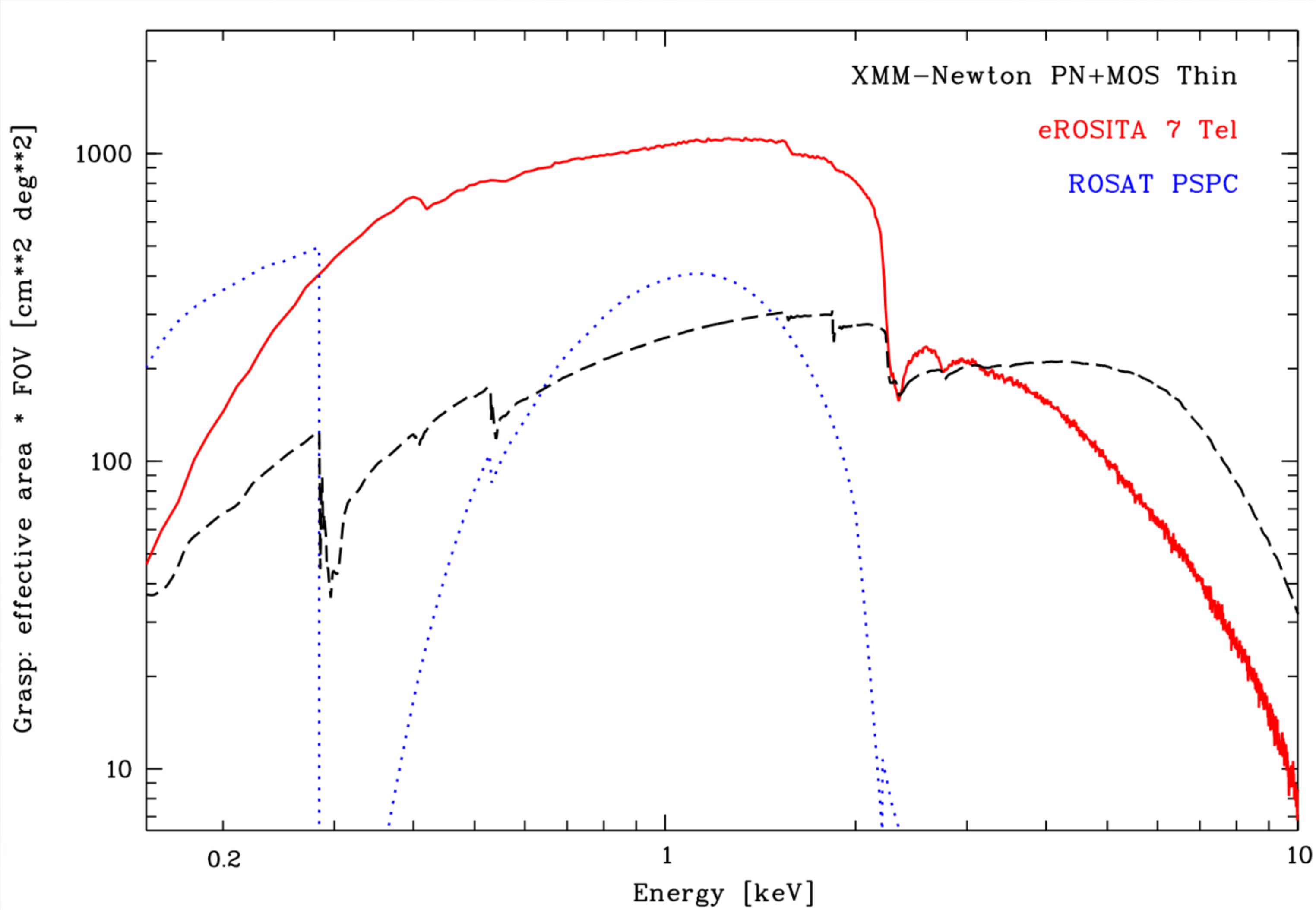

front cover
star trackers (2)
camera radiators (2)
X-ray baffles (7)
mirror modules (7)
electron deflectors (7)
Sun sensors (2)
electronics radiators (2)
cameras, electronics
cooling system

eROSITA



Effective area

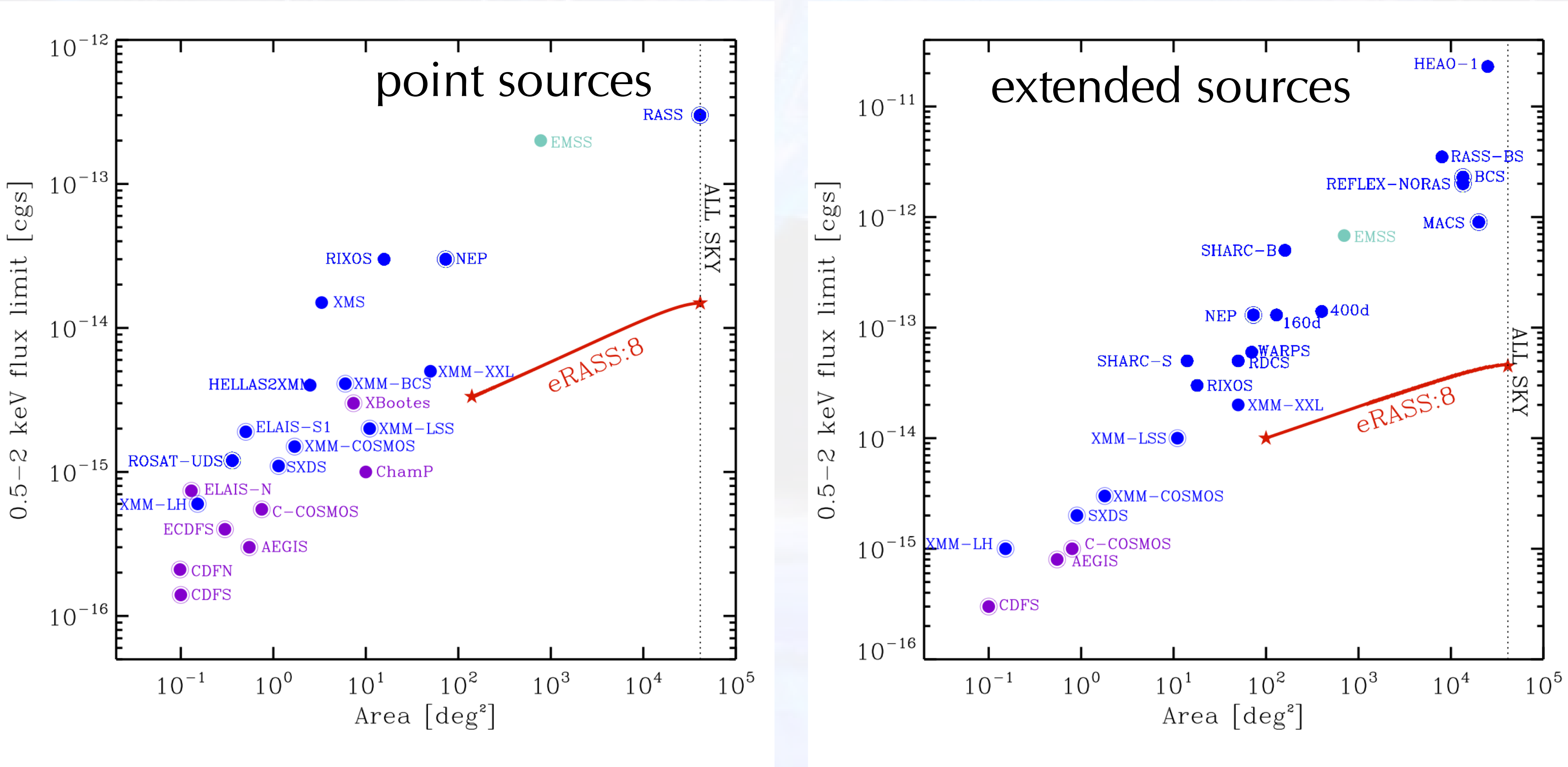
eROSITA

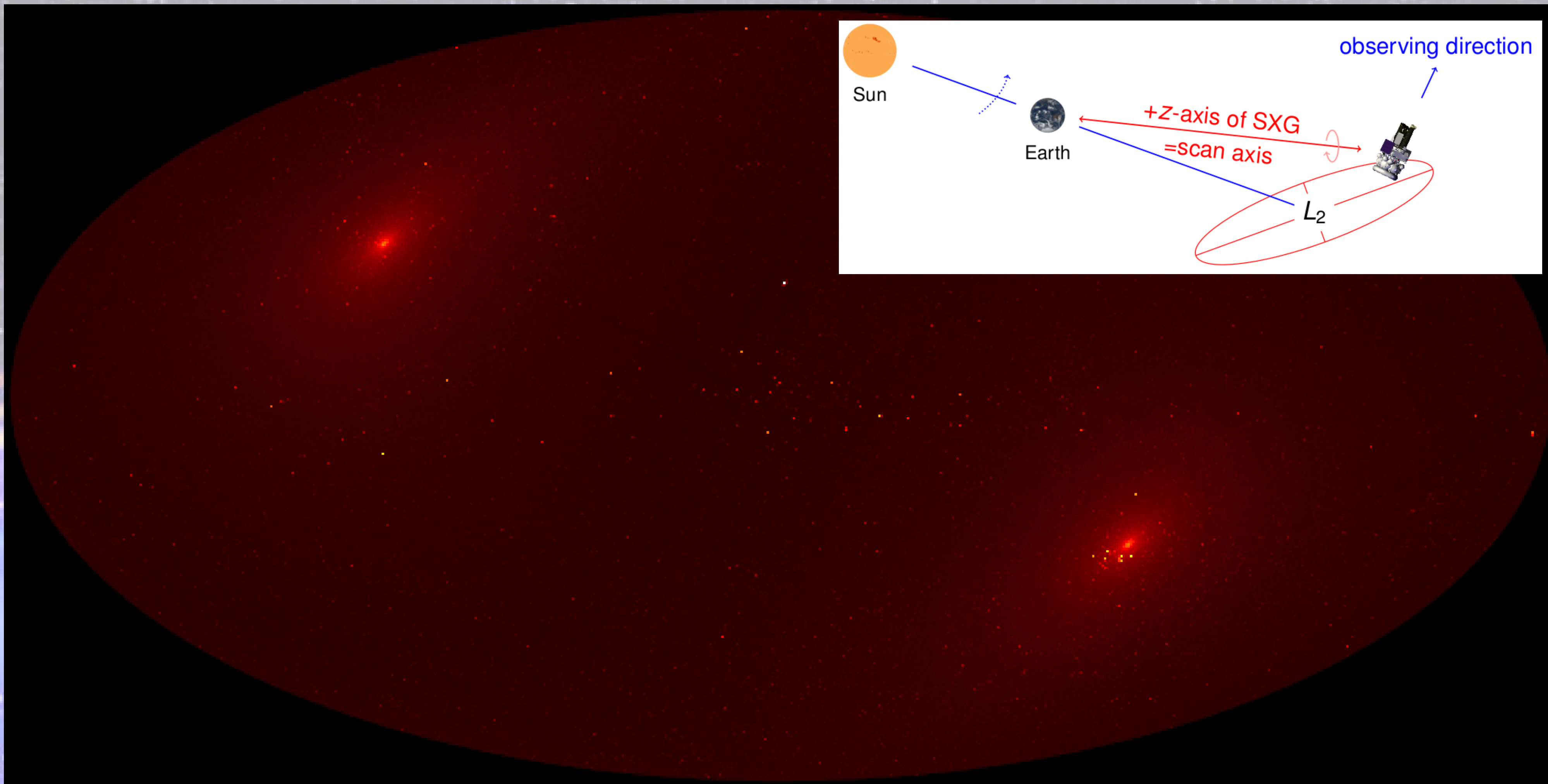


Survey grasp: $A_{eff} \times$ FOV

0.5–2 keV: ~30× ROSAT, 2–10 keV: ~100× HEAO/RXTE

eROSITA


point sources
extended sources
0.5−2 keV flux limit [cgs]
Area [deg²]
ALL SKY
eRASS:8
RASS
EMSS
RIXOS
NEP
XMS
XMM−XXL
HELLAS2XMM
XMM−BCS
XBootes
ELAIS−S1
XMM−LSS
XMM−COSMOS
ROSAT−UDS
SXDS
ChamP
ELAIS−N
XMM−LH
C−COSMOS
ECDFS
AEGIS
CDFN
CDFS
HEAO−1
RASS−BS
BCS
REFLEX−NORAS
MACS
SHARC−B
160d
400d
SHARC−S
WARPS
RDCS

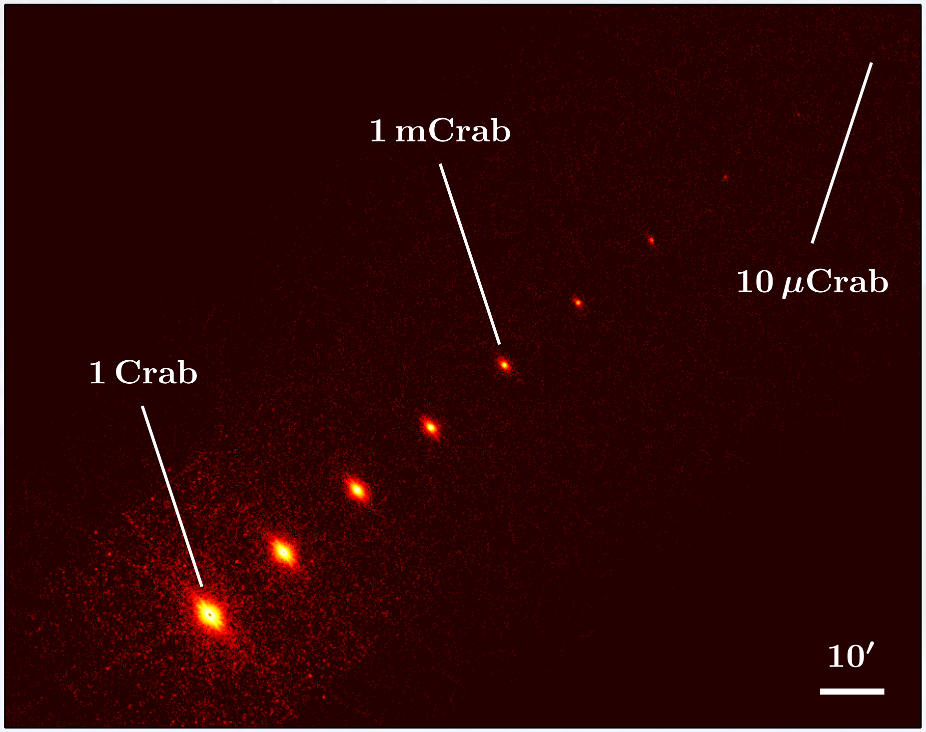


Single eROSITA survey

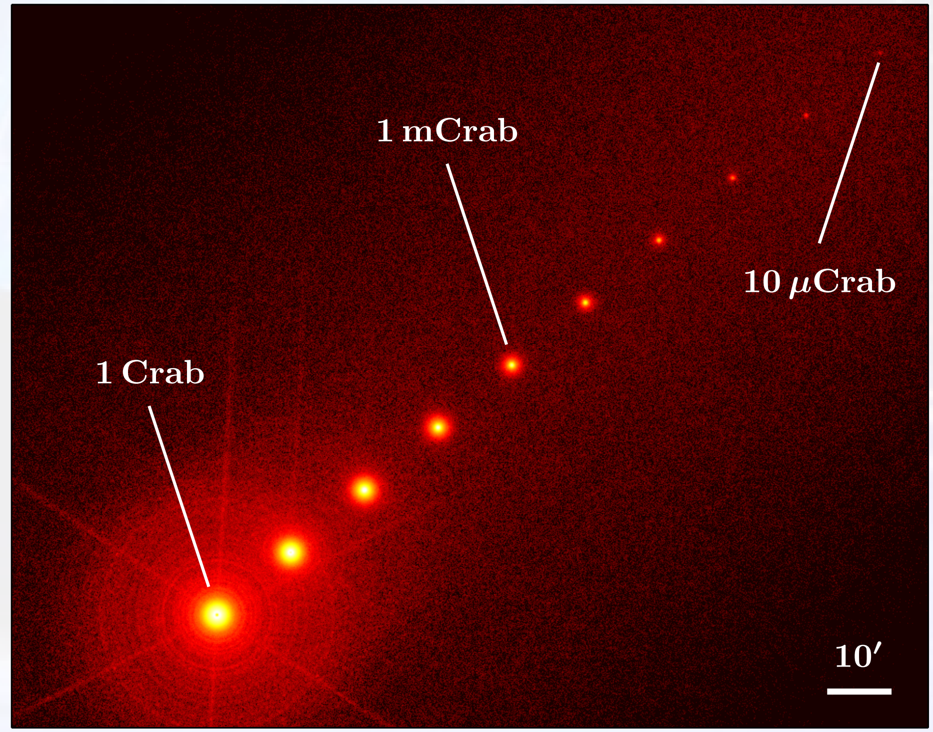
X-ray binaries with eROSITA:

- survey mode: 4 years, sources seen on a 6 month cadence, during this time: every 4 h for ~1 d at survey equator
- pointed observations: 3 years pointed phase (w/GO program)

eROSITA



Single scan sensitivity (T. Dauser)



One eRASS scan sensitivity (T. Dauser)

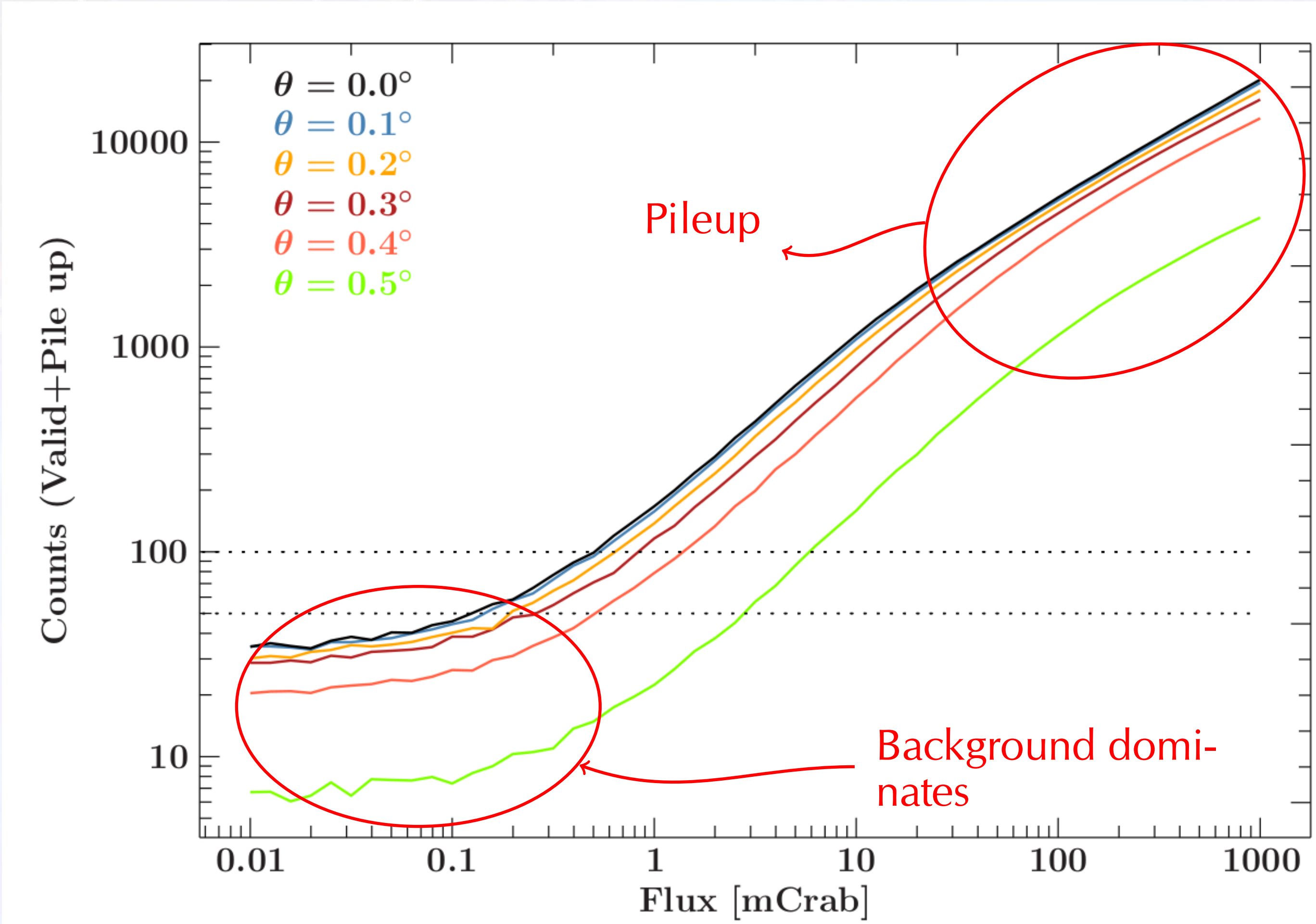
Sensitivity during individual scans: $\mathcal{O}(0.1\,\mathrm{mCrab})$

$\Longrightarrow$ better than MAXI,

$\Longrightarrow$ comparable to *RXTE*-PCA slews

1 Crab: 2–10 keV: $2.05 \times 10^{-8}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$ (3.2 ph); 0.3–2 keV: $1.01 \times 10^{-8}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$ (5.5 ph)

eROSITA



Counts per single (!) telescope and per single visit as function of flux (T. Hain, MSc thesis)

Bright sources (>0.1 mCrab) will allow spectroscopy and variability analysis in a single slew (~minute)

shown counts are without source extraction, bg subtraction [i.e., as quick and dirty as it gets]

eROSITA

Calibration / PV Phase	eRASS1	eRASS2	eRASS3
Manual source vetting.			
Distribution of man. vetted alerts to interested eROSITA_DE members (e.g., TDA working group, external collaborators) via mailing list and/or internal web page.			
Public announcement of exceptional transients via Astronomer's Telegrams, GCNs.			
		Distribution of semi-automatically generated alerts to interested eROSITA_DE members (e.g., TDA working group, external collaborators) via VOEvent or similar.	
		Public web page for high significance alerts. Public block-announcement of new events via Astronomer's Telegram.	
			Distribution of semi-automatically generated alerts to the public via VOEvent or similar.
			Public web page for semi-automatically generated alerts.

Strategy for variability detection during survey phase:

1. Directly after downlink: Near Real-Time Data Analysis (NRTA)
2. NRTA will produce SASS-compatible raw data
3. Special version of SASS will run on these new data
4. New bright sources and strong changes in source luminosity will be flagged
5. If phenomenon interesting: ATEL and/or special email lists

eROSITA

Calibration / PV Phase	eRASS1	eRASS2	eRASS3
Manual source vetting.			
Distribution of man. vetted alerts to interested eROSITA_DE members (e.g., TDA working group, external collaborators) via mailing list and/or internal web page.			
Public announcement of exceptional transients via Astronomer's Telegrams, GCNs.			
		Distribution of semi-automatically generated alerts to interested eROSITA_DE members (e.g., TDA working group, external collaborators) via VOEvent or similar.	
			Distribution of semi-automatically generated alerts to the public via VOEvent or similar.
			Public web page for semi-automatically generated alerts.

Help needed – done through associated membership in eROSITA consortium

Contacts:

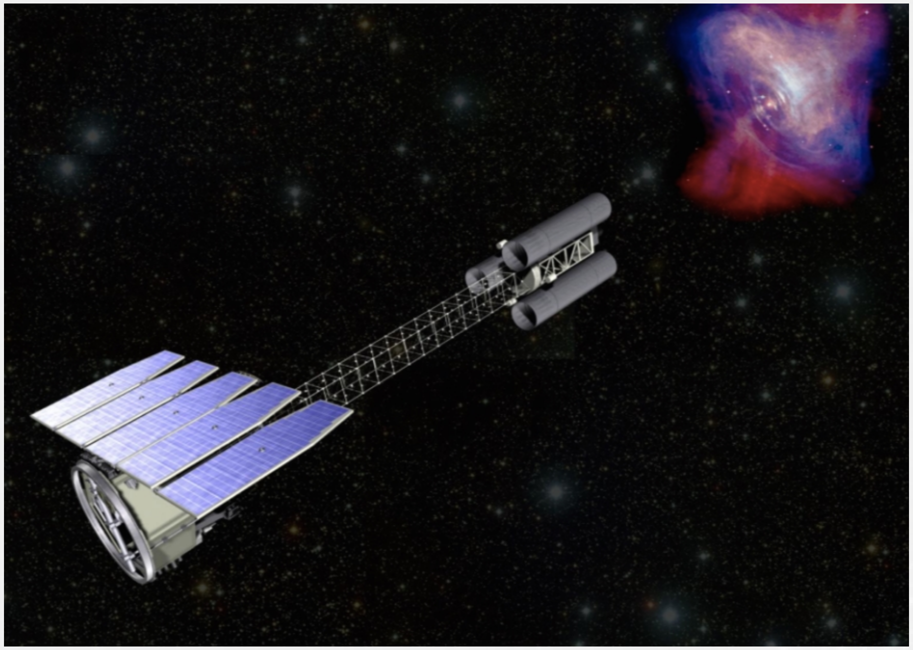
Transients working group: J. Wilms (ECAP) / A. Rau (MPE)

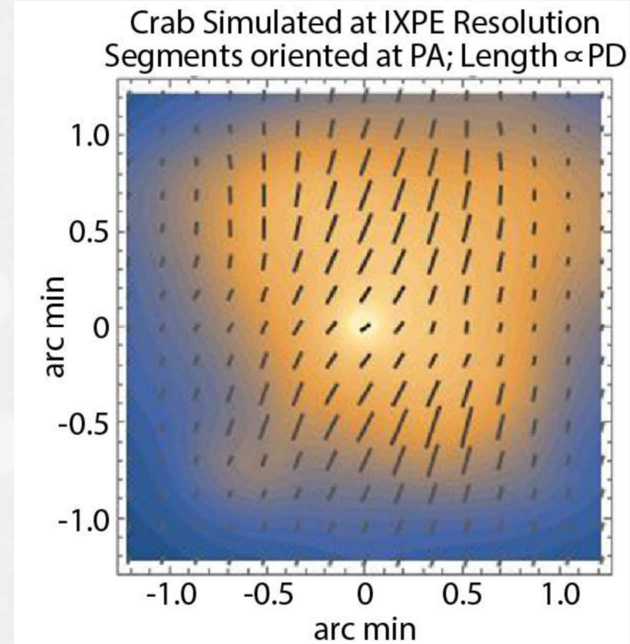
Binaries working group: A. Schwope (AIP) / A. Santangelo (IAAT)

Strategy for variability detection during survey phase:

1. Directly after downlink: Near Real Time Data Analysis (NRTA)
2. NRTA will produce SASS-compatible raw data
3. Special version of SASS will run on these new data
4. New bright sources and strong changes in source luminosity will be flagged
5. If phenomenon interesting: ATEL and/or special email lists

IXPE





Weisskopf et al., 2016, SPIE 9905

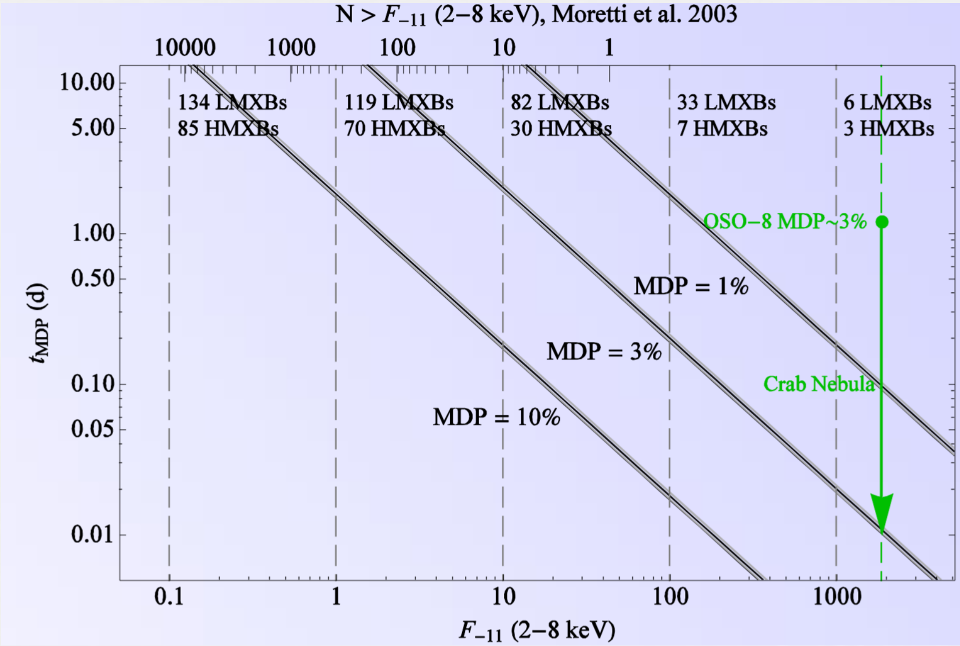
X-ray Polarization: expected from synchrotron emitting sources, scattering (e.g., X-ray reflection)

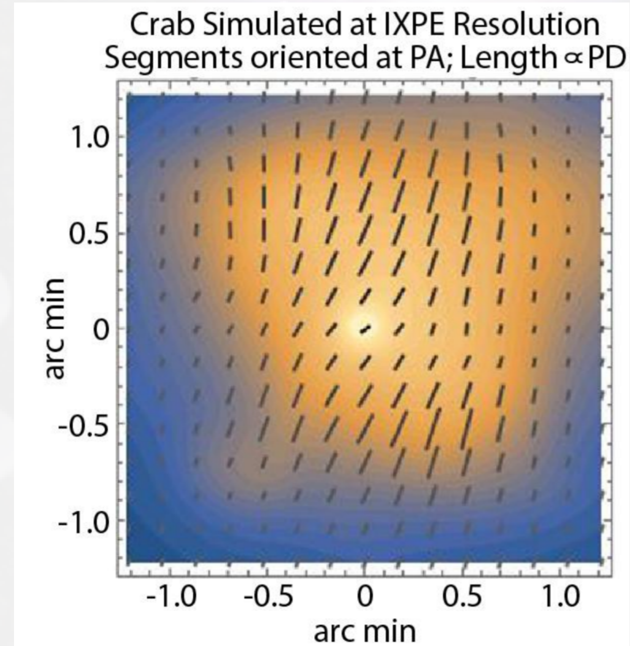
First mission to study X-ray polarization: IXPE: launch 2020

- $A_{\mathrm{eff}} \sim 750\,\mathrm{cm}^2$ in 3–6 keV
- $25''$ spatial res., $12.9\,\square'$ FoV

Similar technology approach also chosen for European XIPE study (identical detectors); unlikely both will be funded

IXPE





Weisskopf et al. (HEAD 2014)

Weisskopf et al., 2016, SPIE 9905

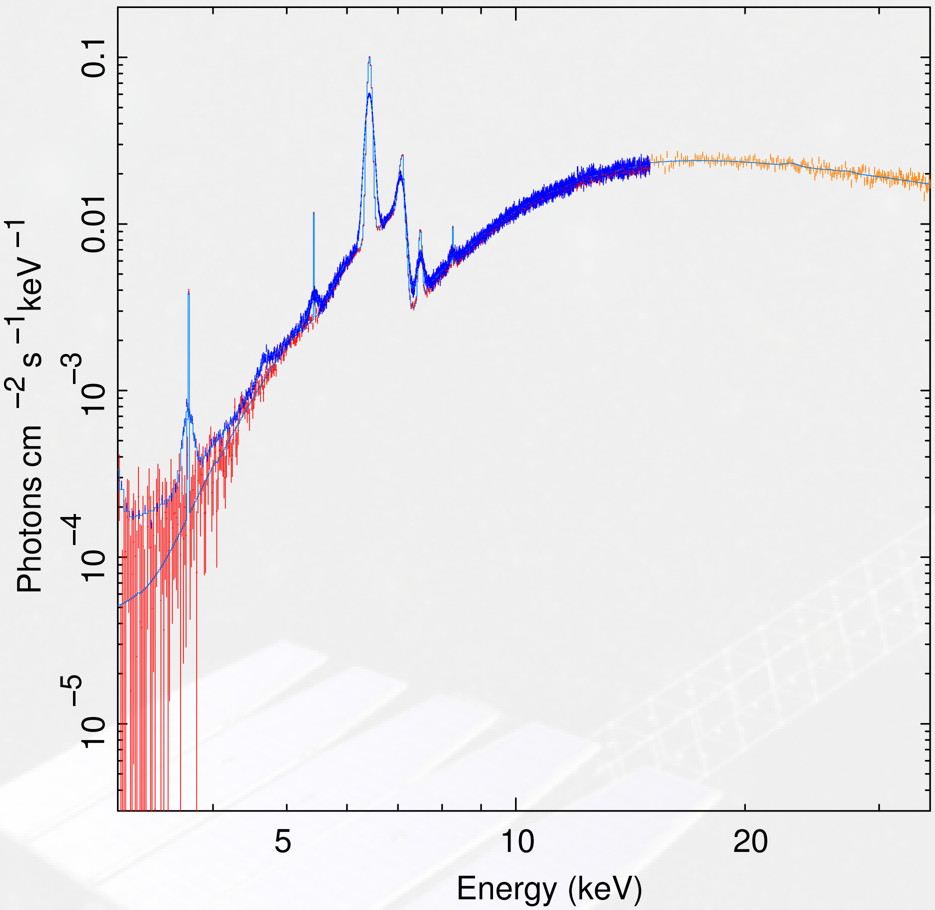
X-ray Polarization: expected from synchrotron emitting sources, scattering (e.g., X-ray reflection)

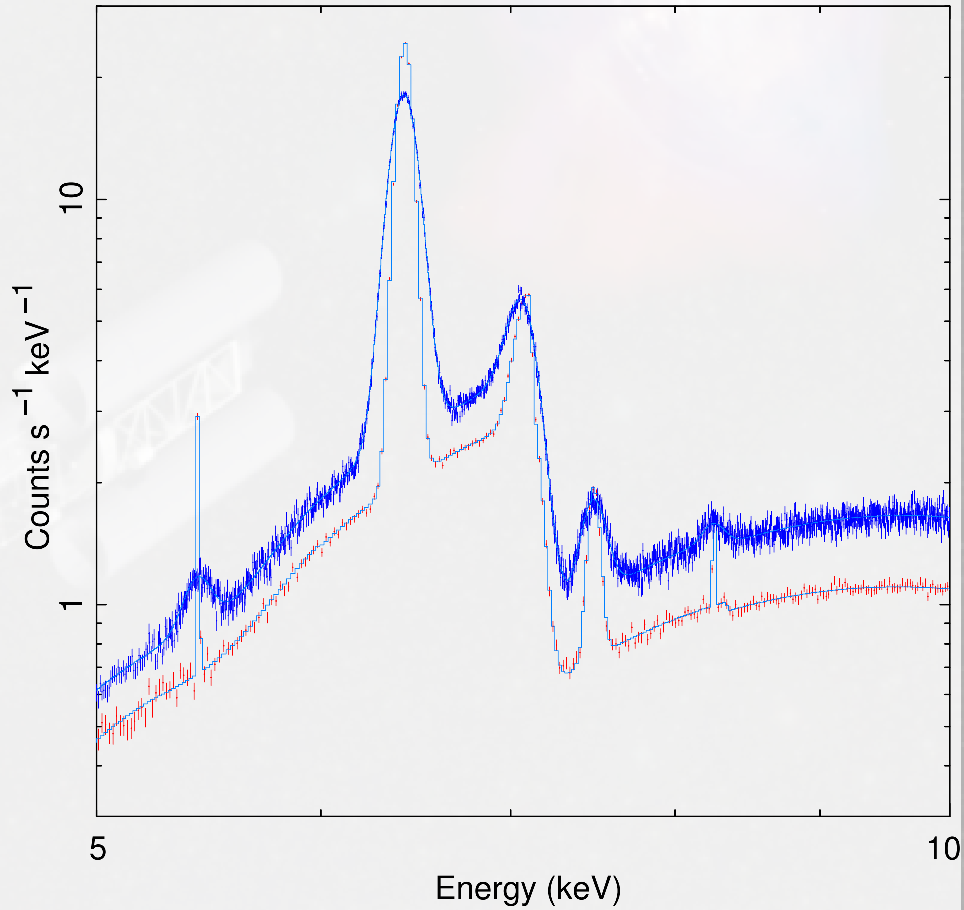
First mission to study X-ray polarization: IXPE: launch 2020

- $A_{eff} \sim 750\,\mathrm{cm}^2$ in 3–6 keV
- $25''$ spatial res., $12.9\,\square'$ FoV

Similar technology approach also chosen for European XIPE study (identical detectors); unlikely both will be funded

XARM



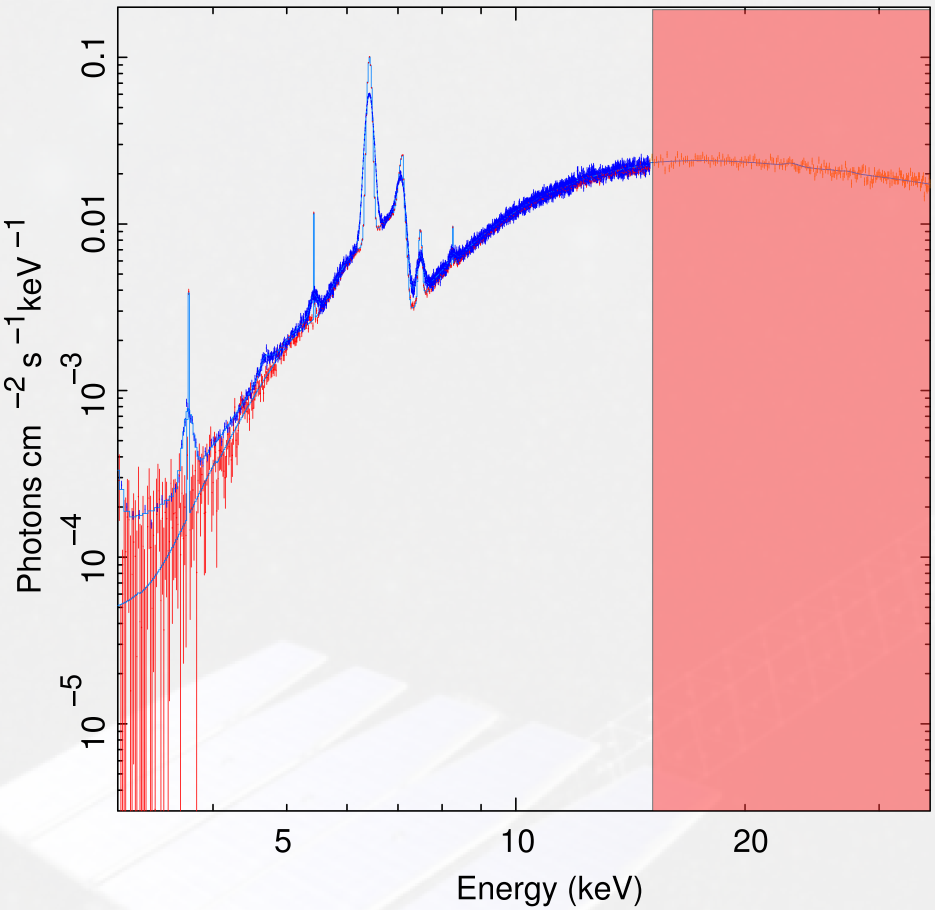


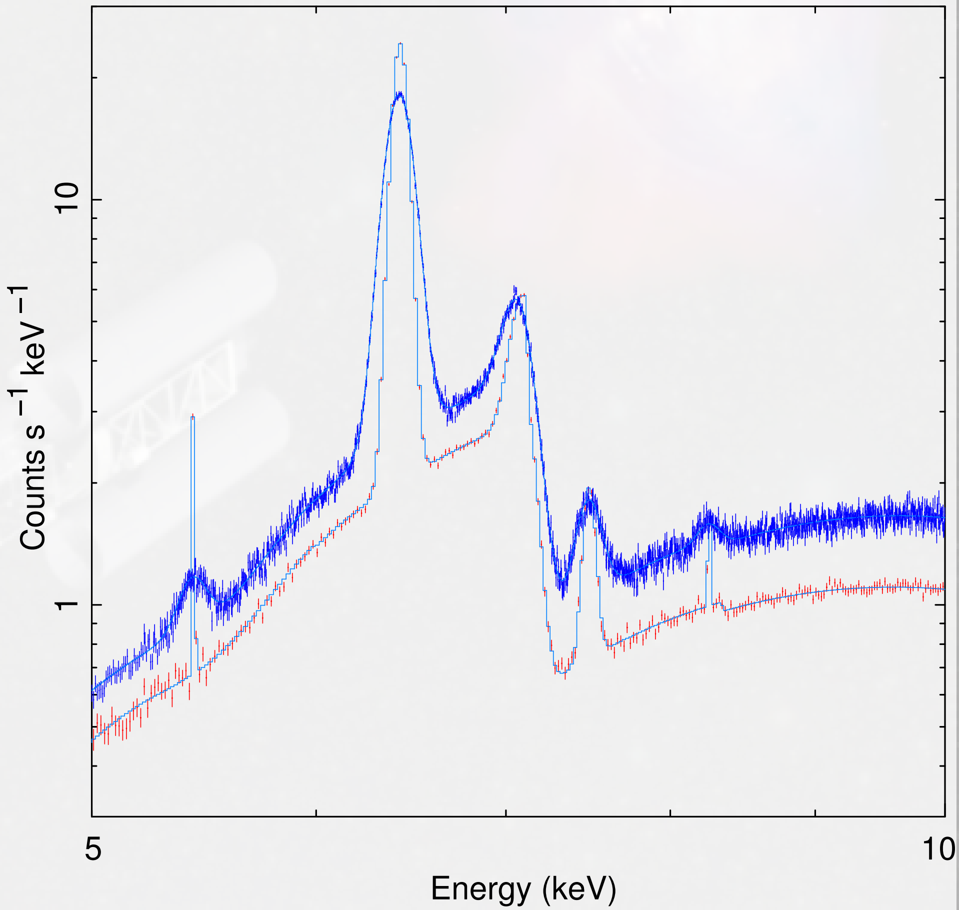
100 ks generic X-ray binary; simulations for Hitomi

XARM: planned for Japanese fiscal year 2021, replacement for Hitomi: Microcalorimeter observations of X-ray binaries will be one of the core goals

Design: Hitomi microcalorimeter and CCD

XARM



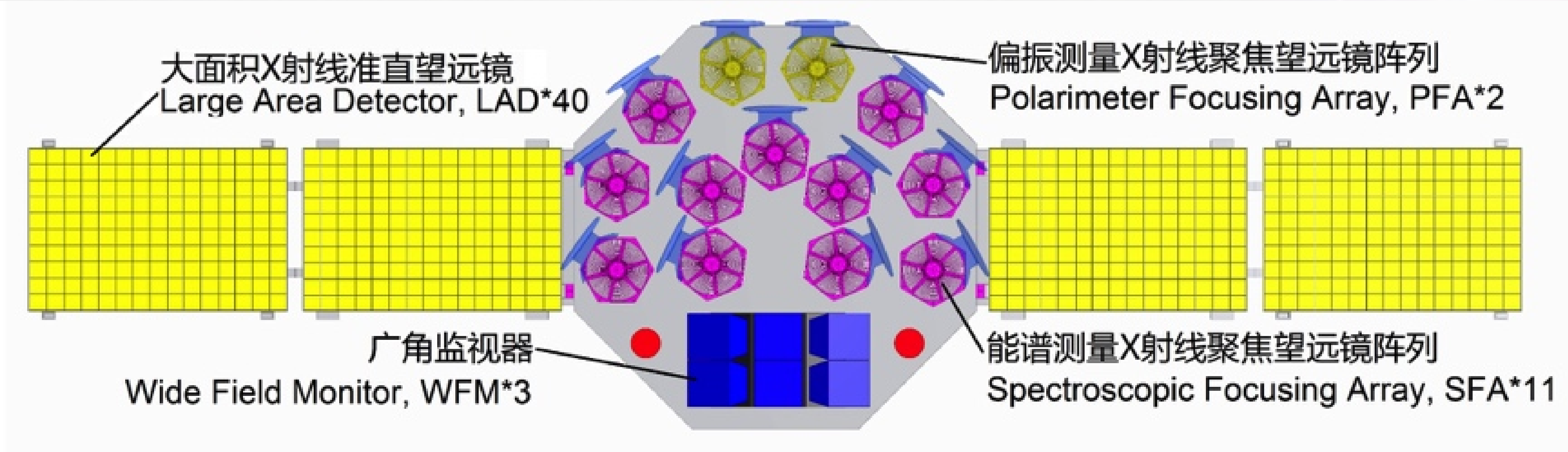


100 ks generic X-ray binary; simulations for Hitomi

XARM: planned for Japanese fiscal year 2021, replacement for Hitomi: Microcalorimeter observations of X-ray binaries will be one of the core goals

Design: Hitomi microcalorimeter and CCD , no instrument >15 keV!

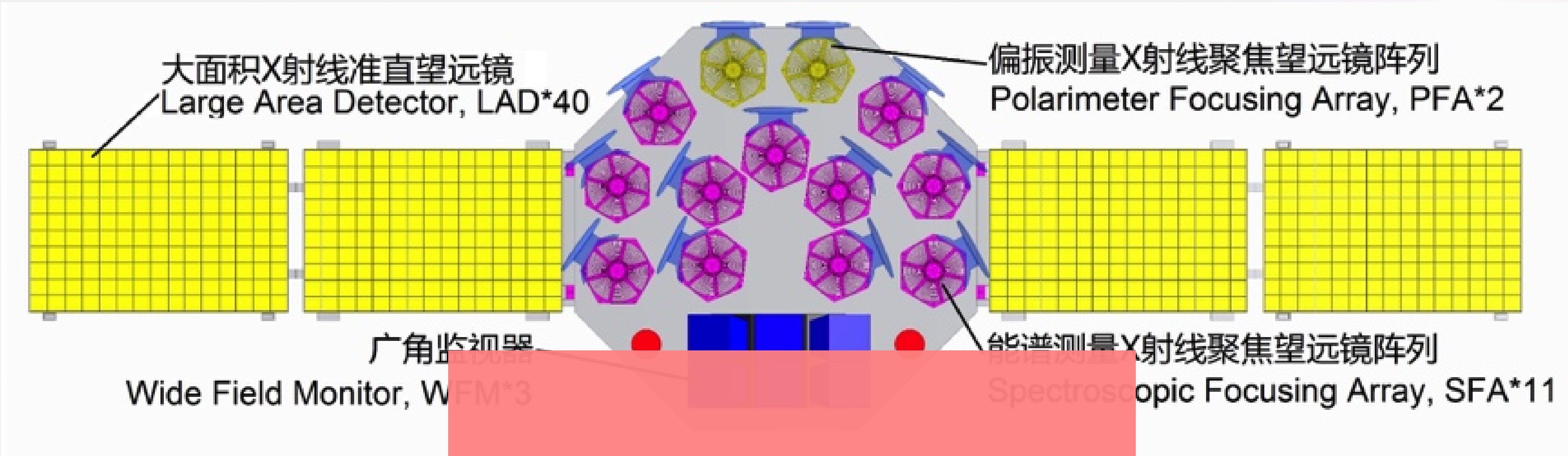
eXTP



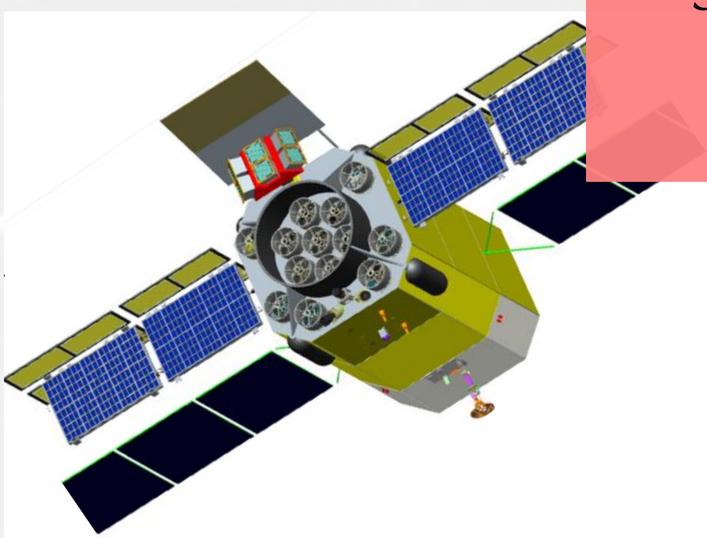
enhanced X-ray Timing and Polarimetry (eXTP):

- Spectroscopy Focusing Array: 0.9 m^2 at 1 keV
- Large Area Detector: 3.4 m^2 at 8 keV
- Polarimetry Focusing Array: 240 cm^2 at 6.4 keV
- Wide Field Monitor: 3 units (4 sr FoV)

eXTP



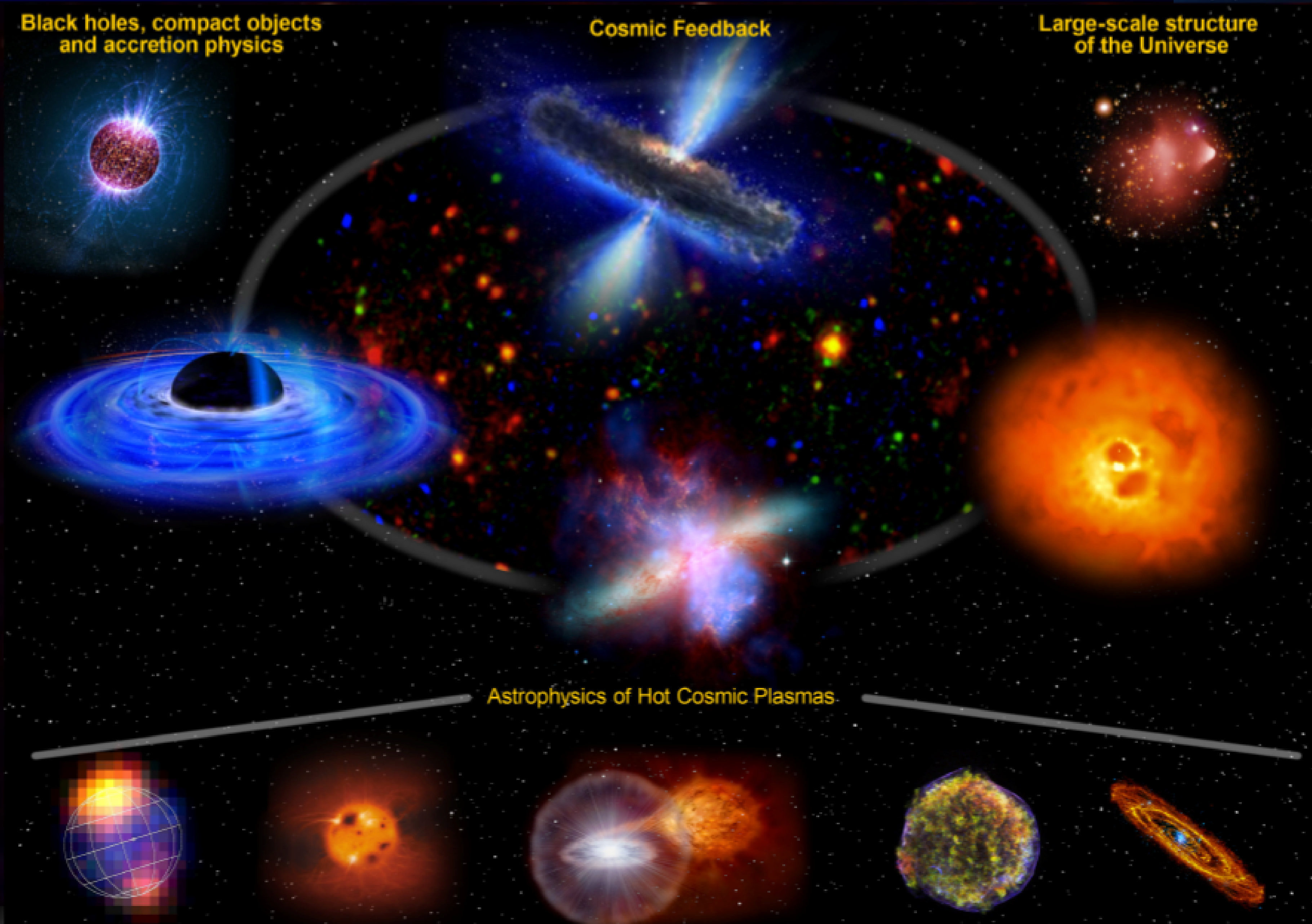
See talk by Phil Uttley



enhanced X-ray Timing and Polarimetry (eXTP):

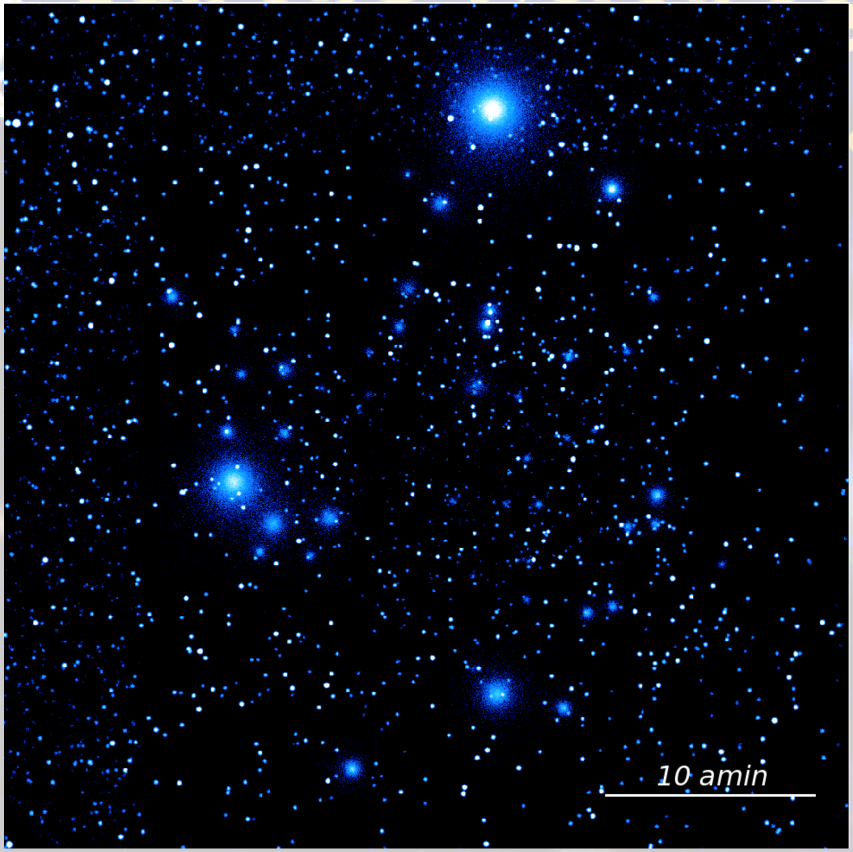
- Spectroscopy Focusing Array: 0.9 m^2 at 1 keV
- Large Area Detector: 3.4 m^2 at 8 keV
- Polarimetry Focusing Array: 240 cm^2 at 6.4 keV
- Wide Field Monitor: 3 units (4 sr FoV)

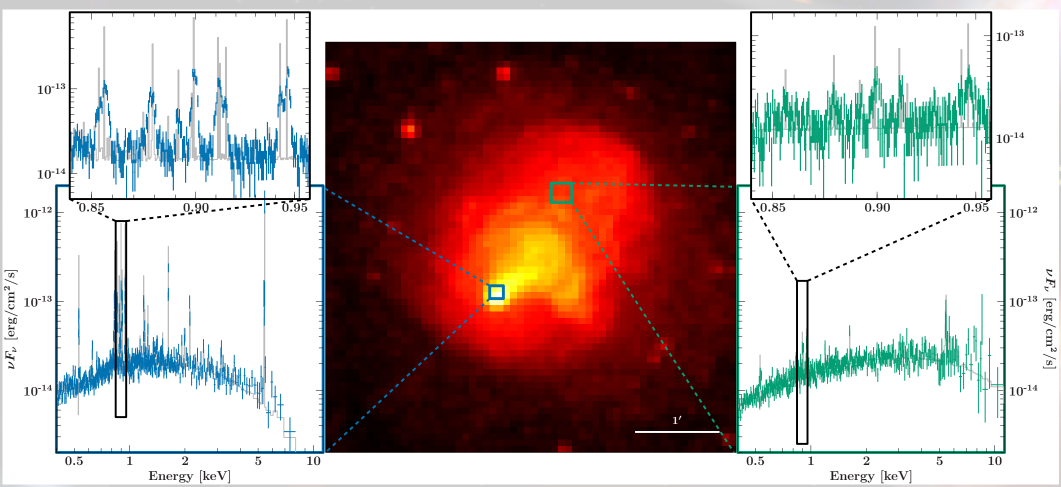
Athena Science Objectives



Athena – Advanced Telescope for High Energy Astrophysics

Objectives





Cosmic Feedback

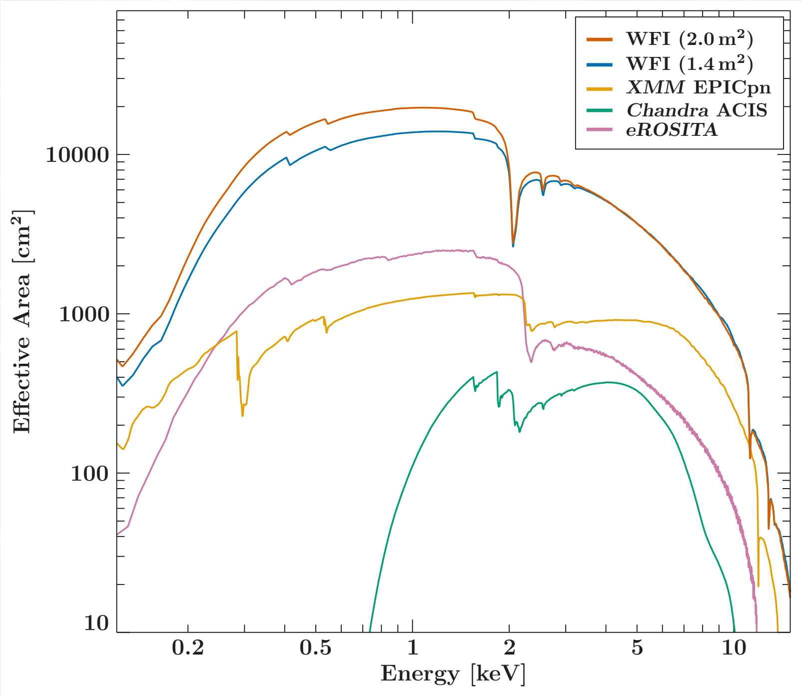
Large-scale structure
of the Universe

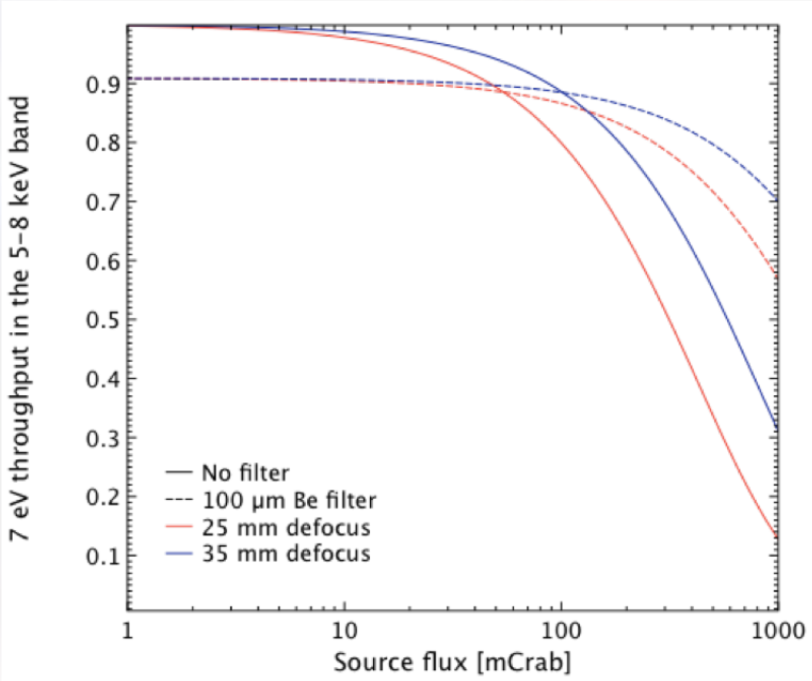
ATHENA:

- ESA L2-Mission
- Launch: 2028, to L2
- Two instruments:
  - Wide Field Imager (PI: Kirpal Nandra, MPE, D): CCD-type instrument
  - X-ray Integral Field Unit (PI: D. Barret, IRAP, F): Transition edge sensor w/1.5 eV resolution
- Aim: detect missing hot baryons (absorption spectroscopy [O-lines])
- Operated as observatory – proposal driven!

Cosmic Plasmas

ATHENA



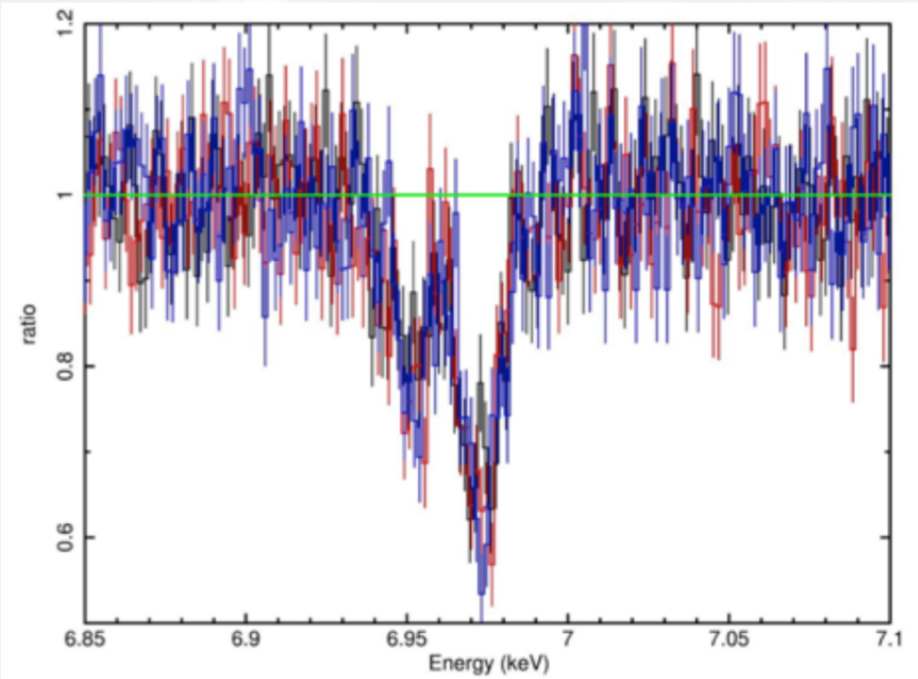


Athena: 2 m^2 effective area

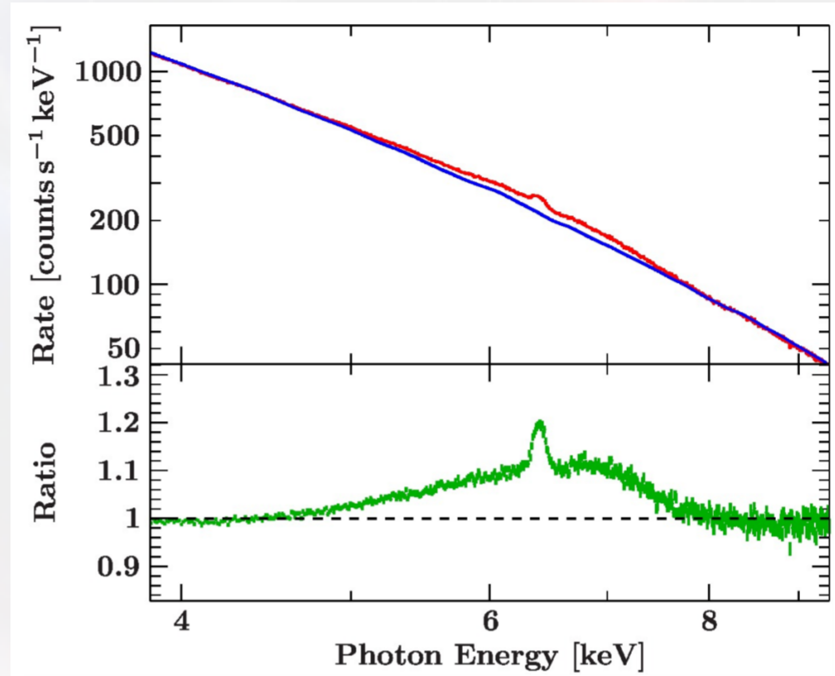
(note: cost reasons will very likely force area down to $\sim$1.4 m^2)

- 1 Crab = 80000 counts/s $\Longrightarrow$ challenging BUT: very high throughput reachable through defocusing
  (WFI: dedicated sensor; X-IFU: defocusing of mirror assembly)
- telemetry limits observations to 15 ks for a 100 mCrab source
  = 64 million events...; Be filter or and gray filtering will increase this to 100% coverage

ATHENA



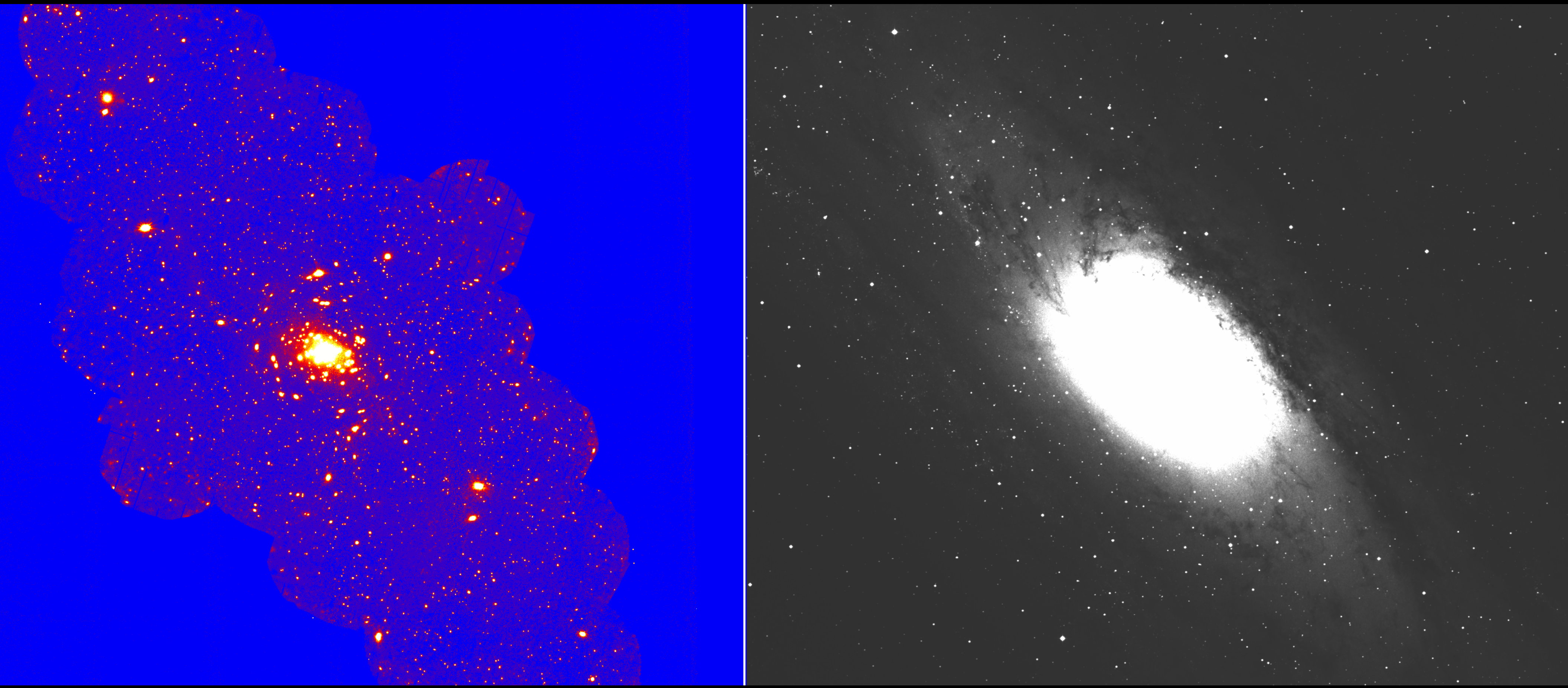
Fe XXIV doublet: n, T
(X-IFU, 1 ks, 1 Crab black hole)



Relativistic Fe Kα line in Cyg X-1
(WFI, 10 ks, 250 mCrab)

X-ray binary science with ATHENA:

- high resolution absorption spectroscopy in binaries
- relativistic Fe Kα lines
- variability at very short up to ms scales



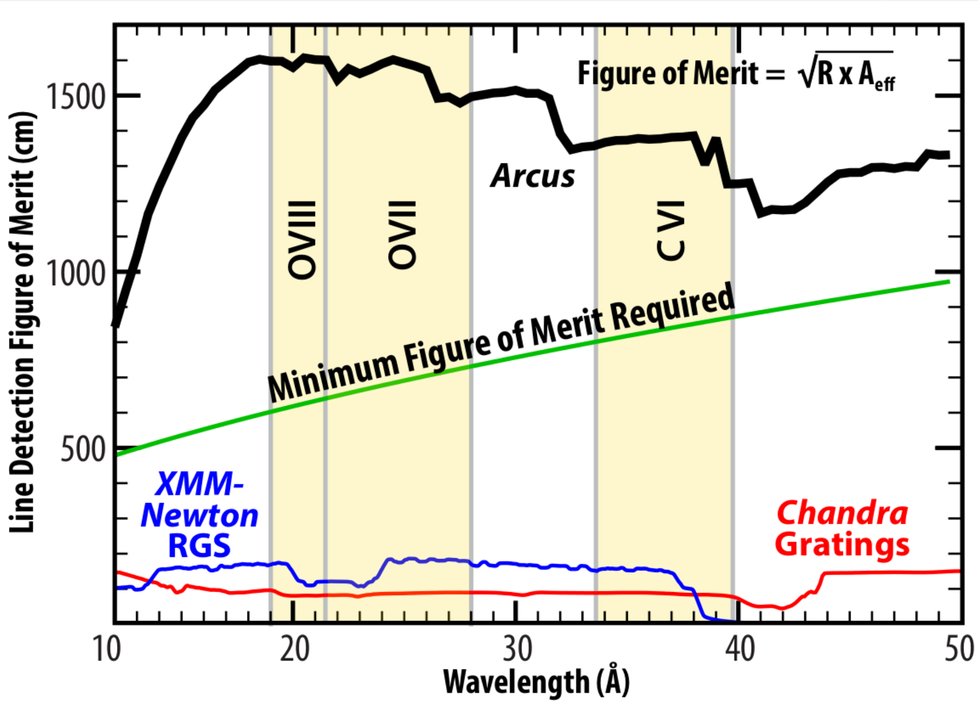
T. Dauser

Athena WFi 5 $\times$ 5 mosaic of Andromeda (200 ks total)

Basis: XMM mosaic (Ms exposure; no data available outside of the galaxy)

X-ray population studies will be possible w/much less exposure time than today; should make monitoring possible…

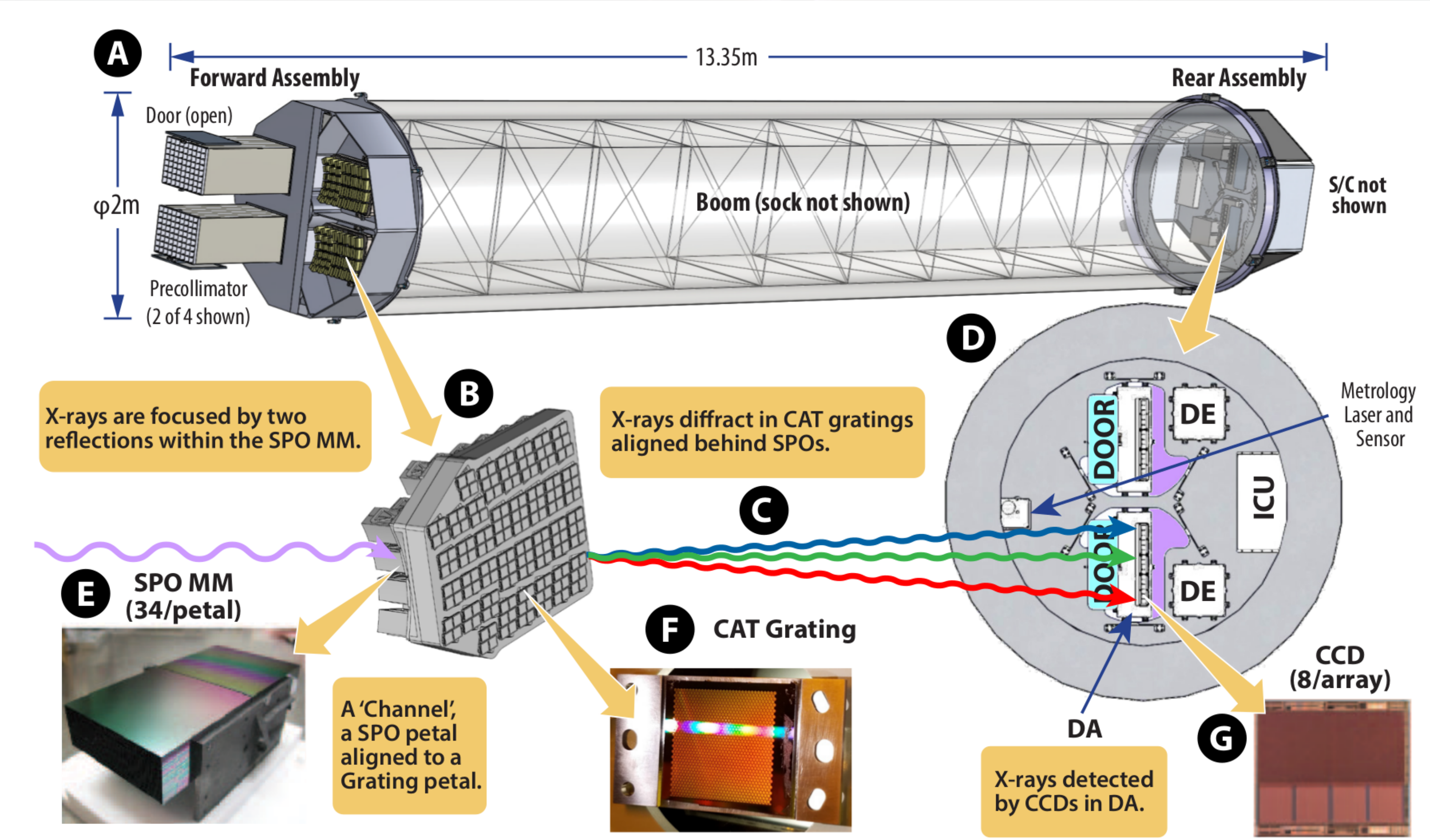
Arcus



August 2017: NASA selected 3 missions for phase A studies, including ARCUS.
End of phase A: May 2018

- launch ~2023 into 4:1 lunar resonant orbit
  100 ks observations w/o interruption
- Soft X-ray mission; complementary to Athena in bandpass
  $> 450\,\mathrm{cm}^2$), resolution $\Delta E/E > 2500$
- some TOO capabilities
  3 d turnaround time

Arcus



Smith et al., 2017, SPIE

Summary

Future missions will greatly extend current capabilities, many missions also focus on X-ray binaries

- Stellar wind physics, disk winds: high E-resolution X-ray spectroscopy

  XMM-Newton, Chandra, NuSTAR $\Longrightarrow$ XARM, Athena, [Arcus, eXTP]

- Accretion flow physics: polarization, timing, CCD–type E-res.:

  ASTROSAT, NICER $\Longrightarrow$ IXPE, [eXTP]

- Population of compact objects: surveys

  XMM-Newton, Chandra, NuSTAR $\Longrightarrow$ eROSITA, Athena

Summary

Future missions will greatly extend current capabilities, many missions also focus on X-ray binaries

- Stellar wind physics, disk winds: high E-resolution X-ray spectroscopy

  XMM-Newton, Chandra, NuSTAR $\Longrightarrow$ XARM, Athena, [Arcus, eXTP]

- Accretion flow physics: polarization, timing, CCD–type E-res.:

  ASTROSAT, NICER $\Longrightarrow$ IXPE, [eXTP]

- Population of compact objects: surveys

  XMM-Newton, Chandra, NuSTAR $\Longrightarrow$ eROSITA, Athena

But serious problems will arise:

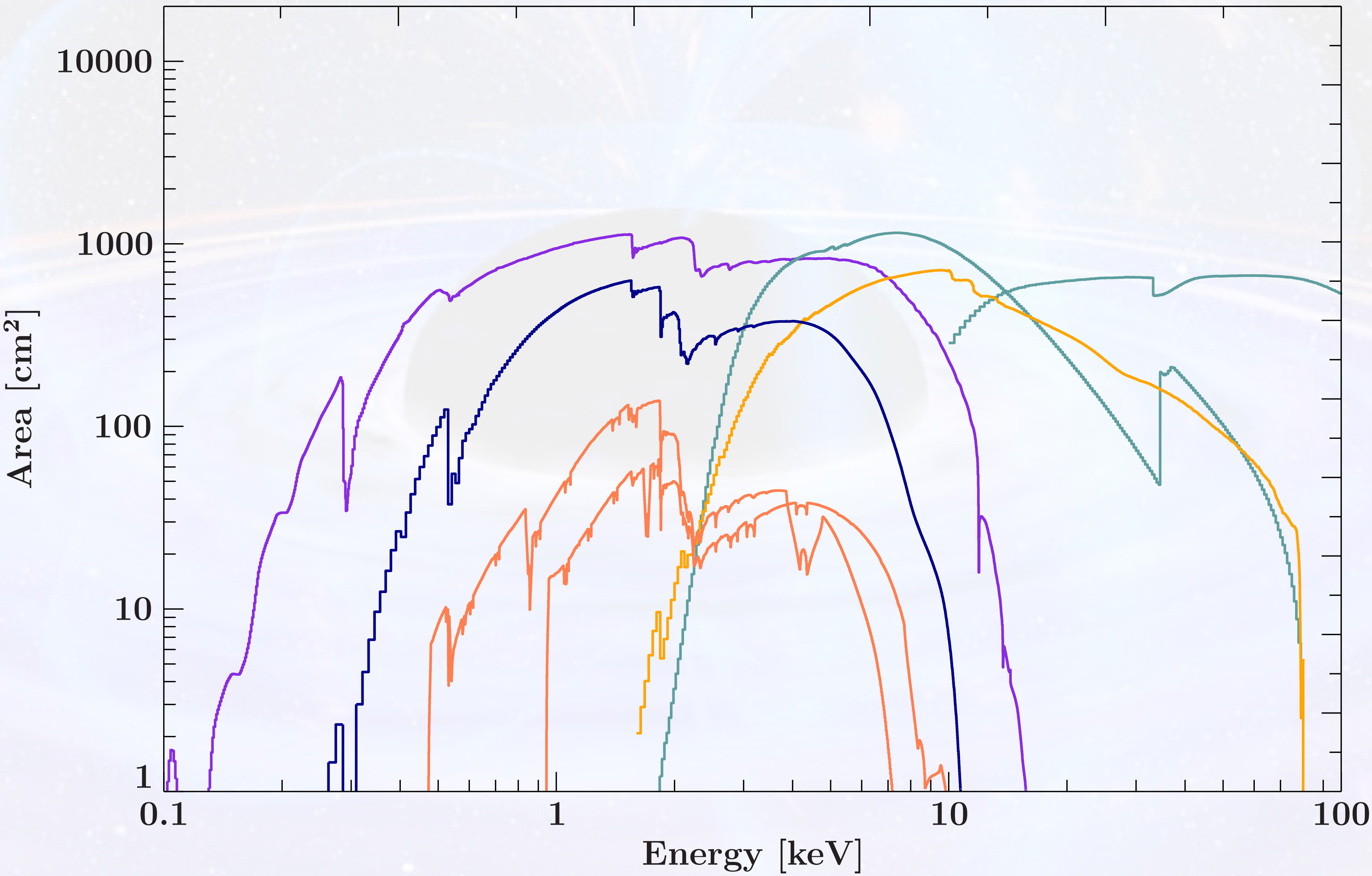
- Search and monitor transients

  eXTP, SVOM might help

- Broad band coverage: 0.5–150 keV

  nothing on the horizon yet $\Longrightarrow$ unlikely to change until the 2030s

Effective Areas



Effective Areas