Paysage instrumental dans le domaine des rayons X

Jean-Marie Hameury

Objectifs scientifiques

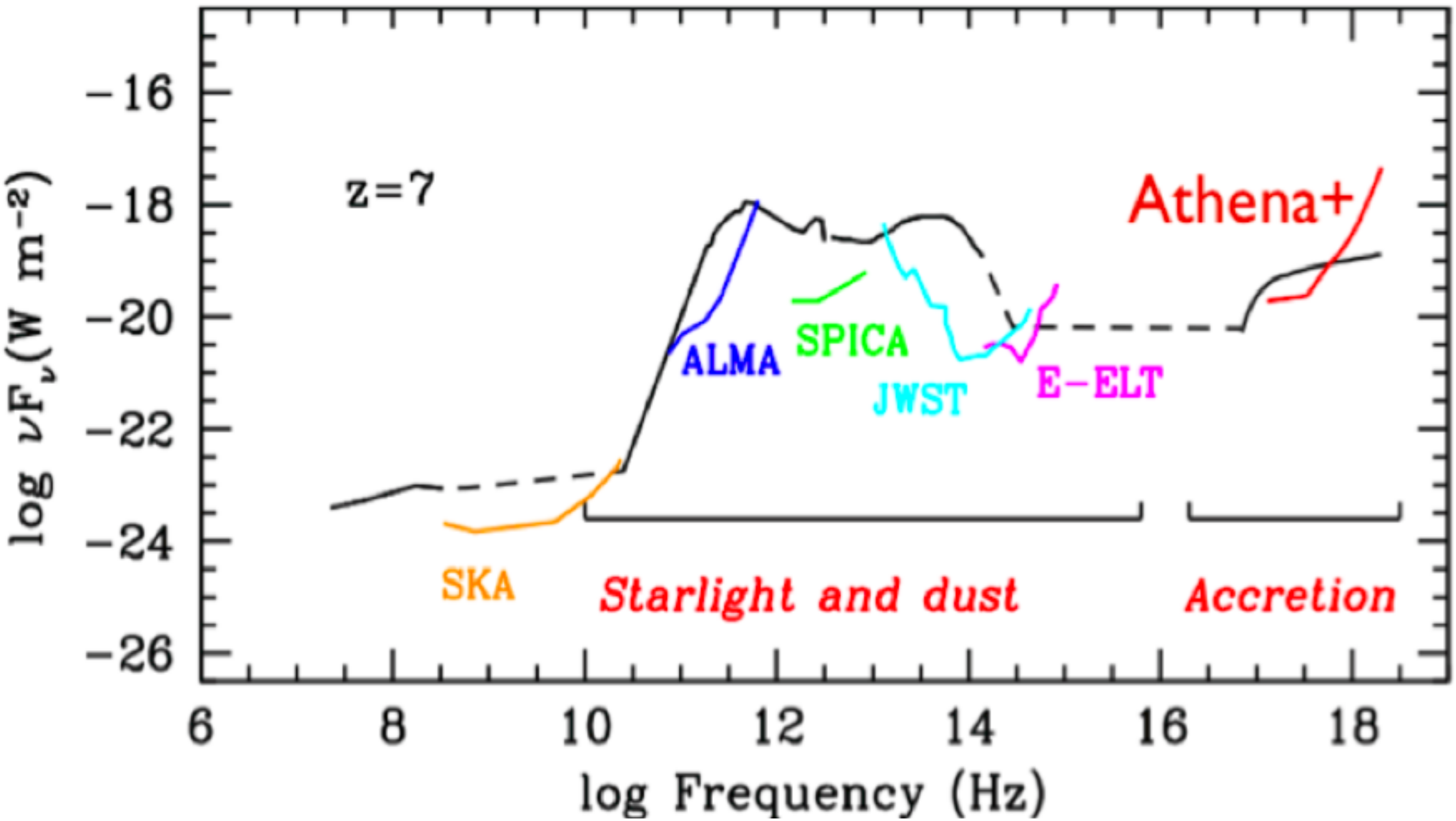
- Quelques coûts (CU incluse)
  - mission M ESA: ~1 G€; mission L: 1.5 G€;
  - ELT ~ 1.5 G€; ALMA ~ 1.5 G€; CTA : 0.5 G€ (?)
- Les nouveaux projets doivent répondre à des questions scientifiques que les moyens actuels ne permettent pas d'aborder, et non faire (un peu) mieux que ce qui existe aujourd'hui
- Et s'appuyer sur des priorités. Dans le domaine des rayons X
  - Cosmologie, formation des galaxies
  - Physique des milieux extrêmes: tests de la RG, etc.
- Même si d'autres thématiques utiliseront ces outils, et si les priorités scientifiques auront évolué d'ici 10-20 ans.
- Grandes catégories de missions X
  - Observatoires généralistes: e.g. XMM, Athena+. Des cas scientifiques forts mis en avant
  - Grands relevés; e.g. ROSAT, e-ROSITA. Objectifs cosmologioques centraux
  - Niches: e.g. SWIFT, LOFT

Caractéristiques instrumentales

- Gamme d'énergie
  - X mous: 0.1 – 10 keV
  - X durs : 10 – 100 keV: plutôt astrophysique des objects compacts
- Surface effective
  - Atteindre les sources faibles (objectifs cosmologiques)
  - Etude détaillée de sources relativement brillantes (spectro HR ou spectro-imagerie, variabilité temporelle)
  - Mais ne détermine pas de façon univoque la sensibilité
- Résolution spectrale
- Champ de vue, pour surveys de tout le ciel ou profonds
- Résolution spatiale
  - Confusion et sources faibles
  - Identification et morphologie des sources étendues

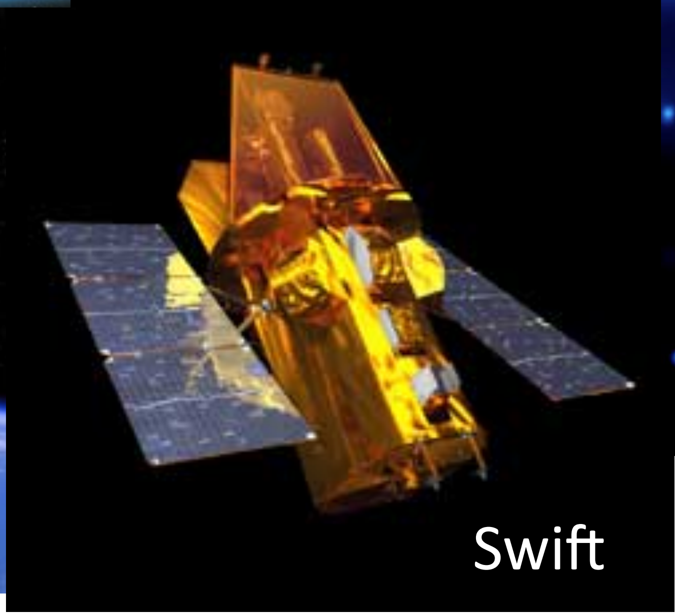
	Gamme	FOV	ΔE	Rés. Spat.	S_{eff}	Lancement
Integral	15keV-10 MeV	10°	10%	12'	~1000@20keV	2002
Chandra	0.1 - 10	17' 30' ?	100eV - E/ΔE = 200 - 1000	0.5" 0.4" 1D	600@1.5 keV 230@1 keV 1-200	1999
XMM	0.15 - 12 0.35 - 2.5	30' 5'	70eV 3 eV	5" 1D seult.	1500 @1.5 keV 100	1999
Suzaku	0.2 - 12 10 - 600 (0.4-12)	17' 34'/5° ()	130eV@6keV 10% (7eV@6keV)	2' 36 pixels	400@1 keV 260@100keV (200@6keV)	(2000 échec) 2005
NuSTAR	5-80	6-12'	1keV@60 keV	20"	800@10 keV 200@40 keV	2012
Astro-H	0.3-12 12-80	3'/38' <9'	7eV/150eV 1.5 keV@60keV	1.7' ?	200@6keV 300@30keV	2015
Athena+	0.3 - 12	40'/5'	150eV/2.5 eV @ 6 keV	5"	20000 @ 1 keV 2500 @ 6 keV	2028 (!) ?
e-ROSITA	0.3 - 10	1°	140 eV @ 6 keV	30"	1000@1 keV 300@4 keV	2014
Loft	2 - 30	45'	260 eV	-	10000@10 keV	2024 ?
Nicer	0.2 - 12	5'	85eV@1 keV 135eV@6 keV	-	2000@1.5 keV 600@6 keV	2017
Swift	0.2 - 10 15-150 UV/Vis	24' 2sr 17'	150eV@6keV 5 keV@60 keV filtres	17' (1-4') 18" (3-5") 1"	130 @1.5keV 1400 30cm diam.	2004
SVOM	0.3 - 26 4 - 150 50 - 5000 VIS/IR	1° 90° 2 π sr 26'		1' 10' ≥ 1° 1"	50 @ 1keV 400@20 keV 850 40 cm	2020 ?

The big observatories of the next decade



Obscured AGN at z=7

Missions X en opération

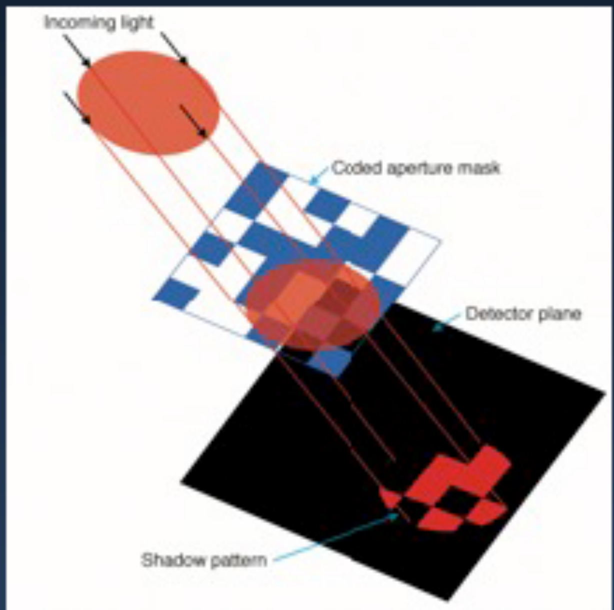


NUSTAR

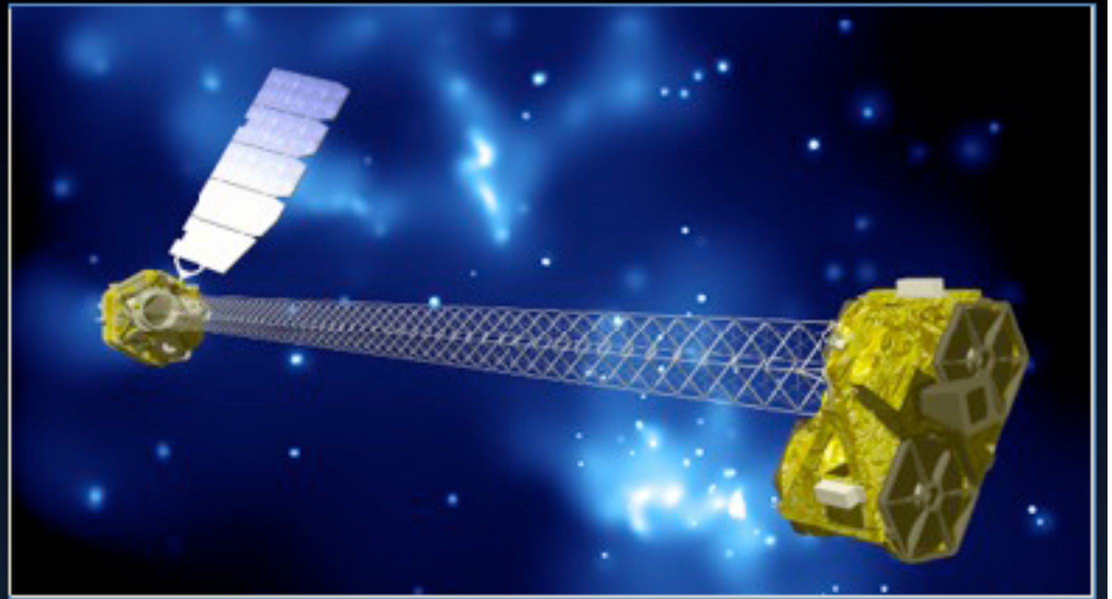
Haute résolution spatiale et sensibilité fortement accrue dans le domaine des X durs par l'utilisation de miroirs

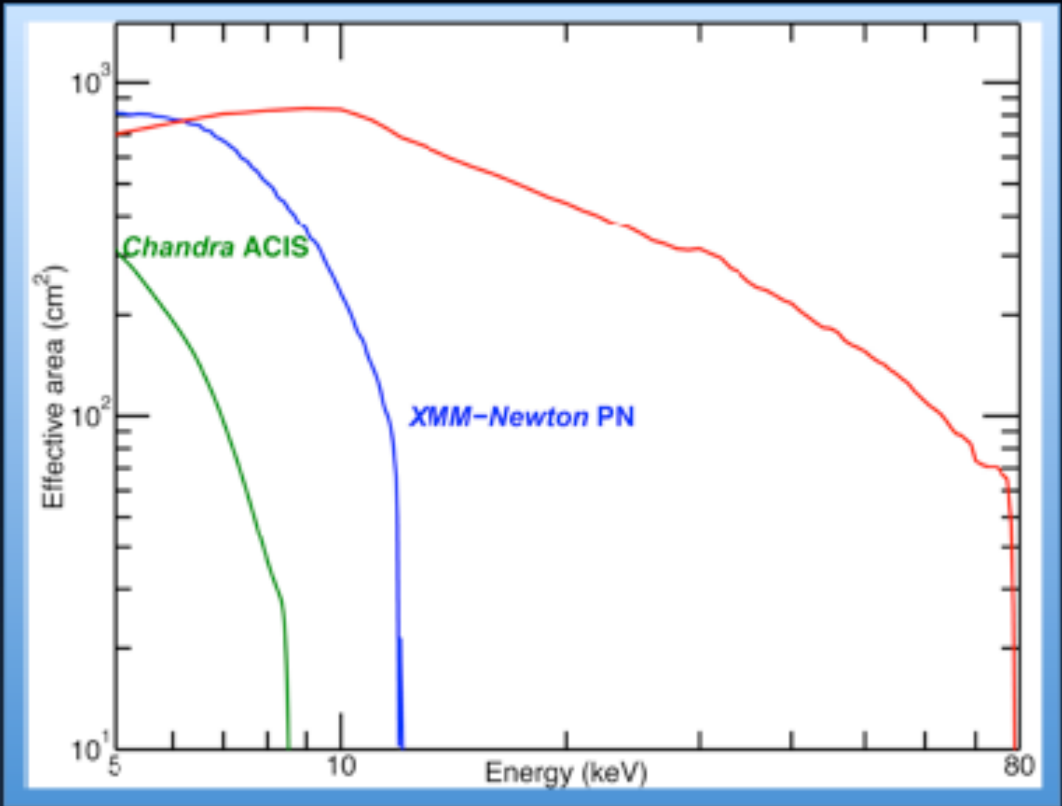
Reprend les objectifs de Simbol-X

INTEGRAL, Swift BAT



NuSTAR

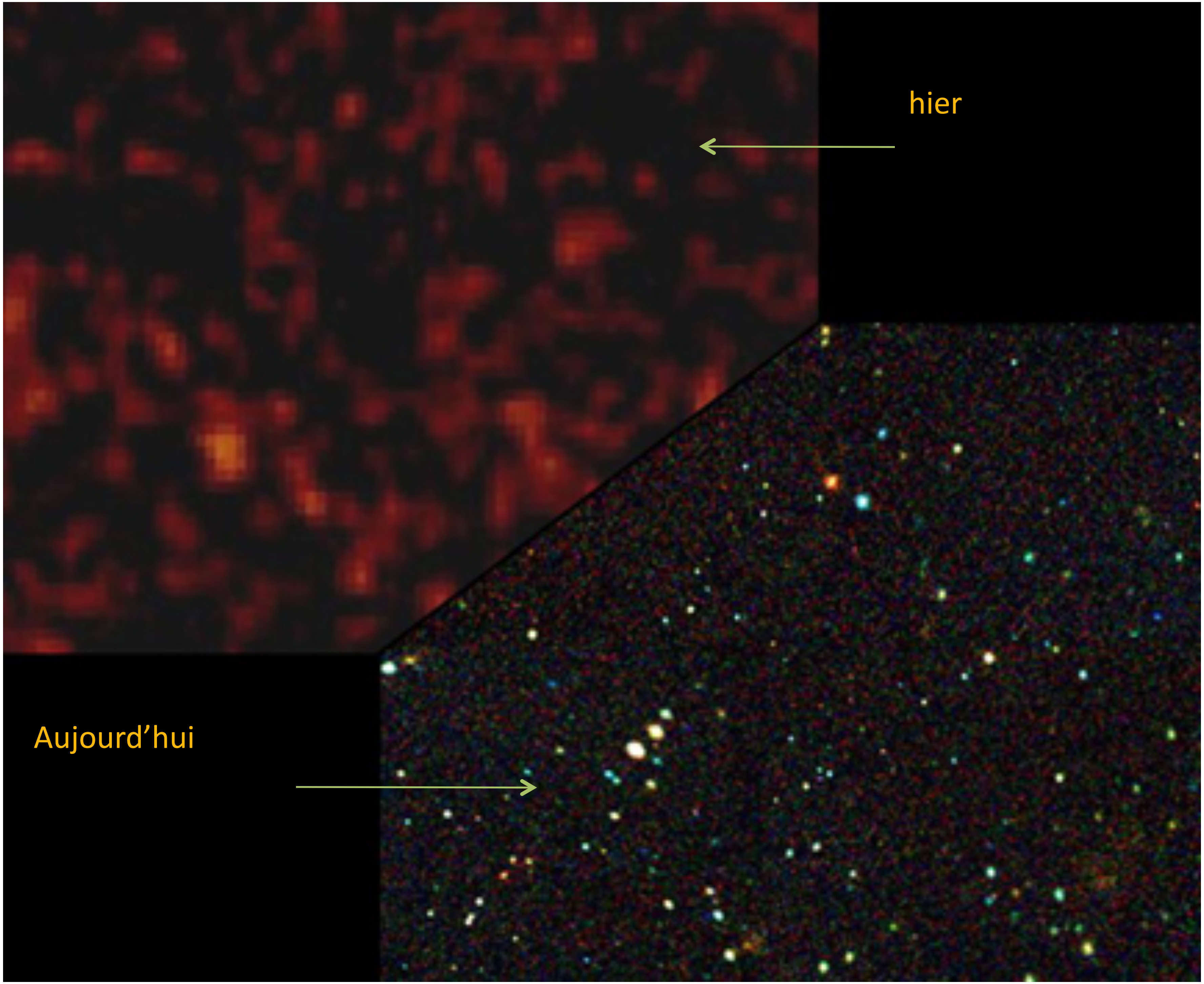




Satellite (instrument)	Sensitivity
INTEGRAL (ISGRI)	~0.5 mCrab (20–100 keV) with >Ms exposures
Swift (BAT)	~0.8 mCrab (15–150 keV) with >Ms exposures
NuSTAR	~0.8 μCrab (10–50 keV) in 1 Ms

NuSTAR two-telescope total collecting area

Sensitivity comparison


hier
Aujourd'hui

Baseline Science Mission

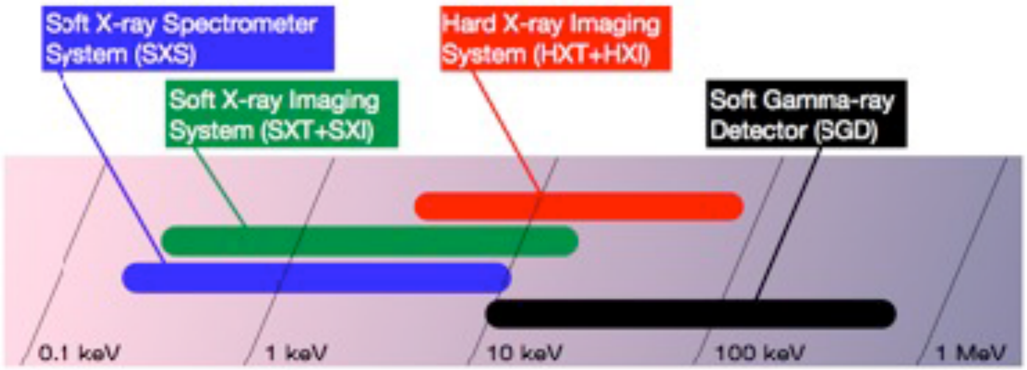
Key science goal	Observations	Time (weeks)
Locate massive black holes	Deep and wide-field extragalactic surveys (GOODS S, COSMOS, BAT-shallow)	23
Study the population of compact objects in our Galaxy	Survey Galactic Center and other fields of varied ages (spiral arms, bulge)	20
Explosion dynamics and nucleosynthesis in core collapse and 1a SNe	Pointed observations of young ($\tau < 500$ yr) remnants – Cas A, SN1987A, GX1+9 ToO observations of nearby SN1a	22
Understanding relativistic jets in supermassive black holes	Contemporaneous multiwavelength observations of GeV/ TeV blazars	6
Other Objectives	Observations	Time
Varied	In final planning stage	33

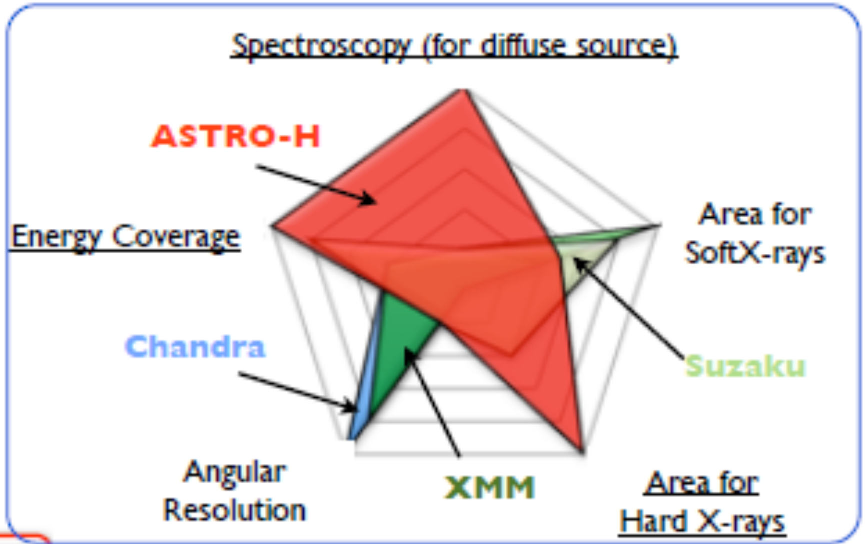
ASTRO-H

Spectro-imagerie à haute résolution spectrale des sources étendues (e.g. AGN, SNR, etc.

Poursuite des objectifs scientifiques de NuSTAR

4. ASTRO-H Mission Instruments





SXT-S (telescope) | SXS

Soft X-ray Spectrometer System

- 0.3-12 keV
- Large Area Soft X-ray Telescope
- X-ray micro calorimeter
- super resolution (<7eV at 6 keV)

SXT-I (telescope) | SXI

Soft X-ray Imaging System

- 0.5-12 keV
- Large Area Soft X-ray Telescope
- Large FOV 38x38 arcmin^2
- CCD spectroscopy

HXT (telescope) | HXI

Hard X-ray Imaging System

- Hard X-ray Telescope (5-80 keV)
- Focal Length 12 m
- New CdTe Imager (Fine Pitch Cross Strip)

SGD

Soft Gamma-ray Detector

- 10-600 keV non-imaging
- Si/CdTe Compton Camera with Narrow FOV Active Shield
- most sensitive gamma-ray detector ever

Appendix. ASTRO-H Scientific goals and Objectives

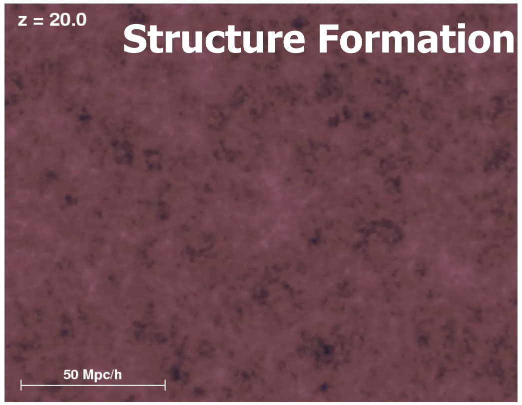
Revealing the large-scale structure of the Universe and its evolution	Observe clusters of galaxies, the largest structure of the Universe, and uncover their entire picture of interplays among thermal energy, kinetic energy of matter, and non-thermal energies, and see dynamic evolutions of clusters of galaxies.
	Unveil super massive black holes behind thick intervening material in the distant past with a 100 times higher sensitivity than Suzaku, and reveal the role they play in the galaxy evolution and formation.
Understanding the extreme conditions in the Universe	Measure the motion of matter at extreme proximity of black holes, sense the gravitational deformation of the space, and understand the structure of relativistic space-time.
Exploring the diverse phenomena of non-thermal Universe	Derive the physical condition of the sites where high energy particles (cosmic rays) gain energy, and elucidate the process in which gravity, collision, and explosions give rise to cosmic rays
Studying dark matter and dark energy	Obtain the distribution and total mass of dark matter in clusters of galaxies at different distances (ages), and study the roles of dark matter and dark energy in the evolution of clusters of galaxies

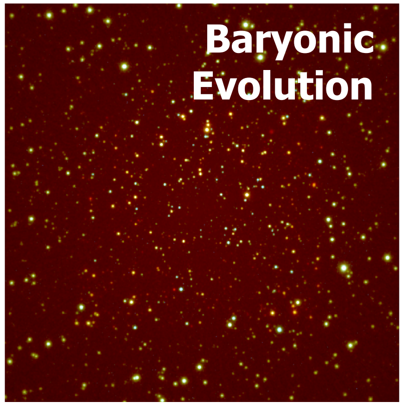
ATHENA +

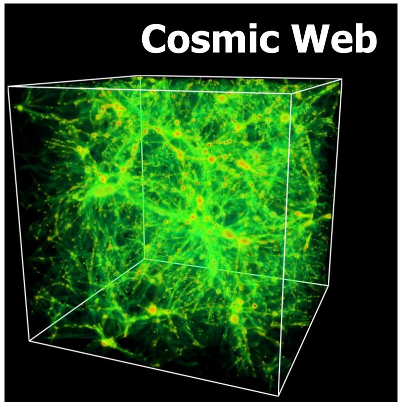
Spectroimagerie haute résolution et excellente sensibilité par (1) l'utilisation de

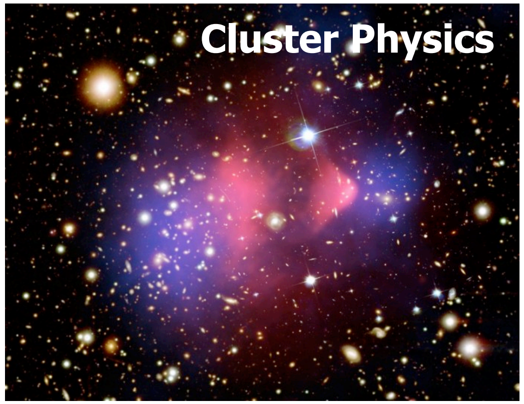
1. Where are the hot baryons and how do they evolve?

- **Reveal and map the first viralised baryonic structures**
  - *Wide field X-ray imaging, imaging X-ray spectroscopy*
- **Determine their dynamical, thermal and chemical evolution**
  - *Spatially-resolved X-ray spectroscopy, wide field imaging*
- **Complete the census of baryons in the local Universe**
  - *High resolution X-ray spectroscopy*
- **Understand the physics of clusters and groups**
  - *Imaging X-ray spectroscopy, wide field of view imaging*



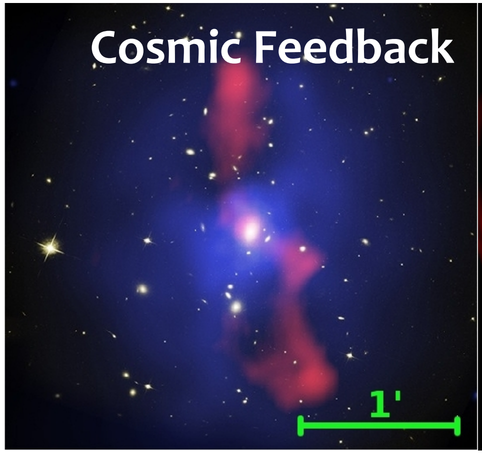


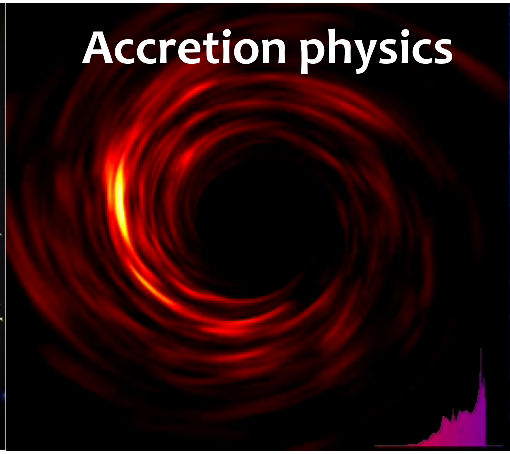


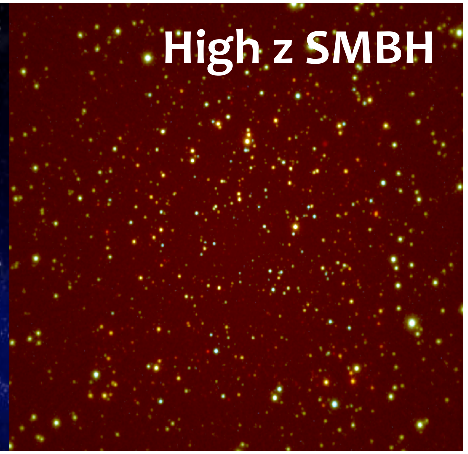


2. How do black holes grow and influence the Universe?

- **Reveal the causes and effects of cosmic feedback**
  - *Imaging X-ray spectroscopy, high resolution spectroscopy*
- **Understand the physics of accretion onto compact objects**
  - *Fast spectral timing, high throughput spectroscopy*
- **Track obscured accretion through the epoch of galaxy**
  - *High throughput wide field X-ray imaging, high throughput spectroscopy*
- **Perform a census of black hole growth at high redshift**
  - *Deep wide field X-ray imaging*

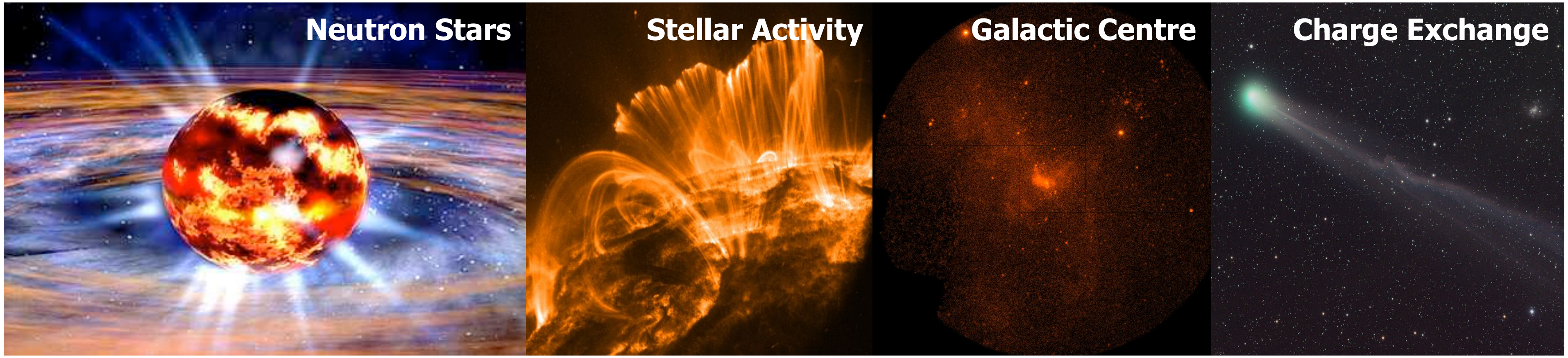






3. The Astrophysics of the Hot and Energetic Universe

- **Compact Objects**
  - *X-ray binaries, neutron star and pulsars, white dwarfs*
- **Stellar Evolution**
  - *Young stars, stellar winds, stellar activity, supernovae, GRBs*
- **The Milky Way**
  - *Galactic centre, interstellar dust and gas, hot gas halo*
- **Planets and the solar system**
  - *Planets, exoplanets, comets, solar wind*



Science Requirements

	Requirement	Driver
Effective Area	$2m^2$@ 1 keV (goal $2.5m^2$) $0.25m^2$ @ 6 keV (goal $0.3m^2$)	Hot Baryons Black hole evolution Accretion Physics
Angular Resolution	5" (goal of 3")	Black Hole Evolution Hot Baryons
Fields of view	WFI: 40' diameter (goal 50') XMS: 5' x 5' (goal 7' x 7')	Hot Baryons Black Hole Evolution
Spectral resolution	150 eV @ 6 keV (WFI) 2.5 eV (X-IFU) goal 1.5 eV	Black Hole Evolution Hot Baryons
Count rate capability	>1 Crab	Accretion Physics
Timing resolution	50 µs	Accretion Physics
TOO response	8 hours (2 hours goal)	Hot Baryons

The Athena+ focal plane instruments

X-IFU (X-ray Integral Field Unit)
(PI D. Barret ?)

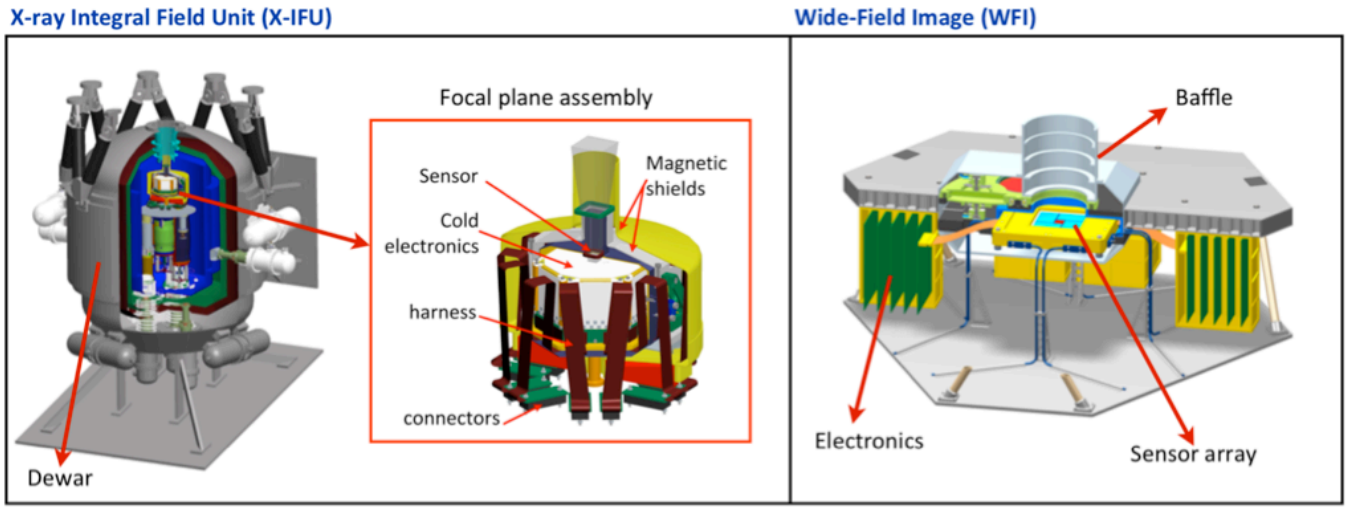
TES calorimeter
Cooled to 50 mK

High spectral resolution spatially resolved spectroscopy over limited FoV

WFI (Wide Field Imager)

Si-based DEPFET

Low spectral resolution, spatially resolved spectroscopy on wide FoV and high count-rate capability



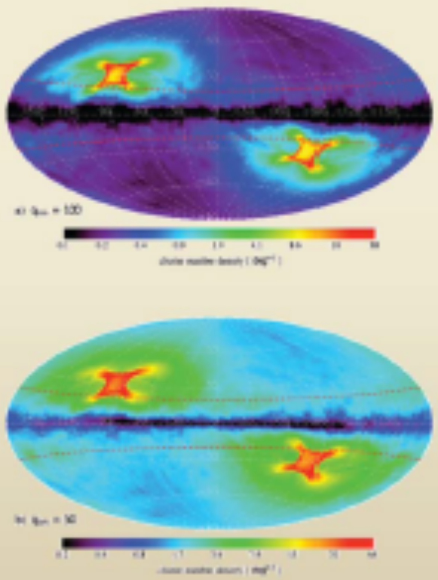
E-ROSITA

A la recherche de l’énergie noire via un relevé de tout le ciel pour détecter les amas de galaxies

eROSITA Core Science

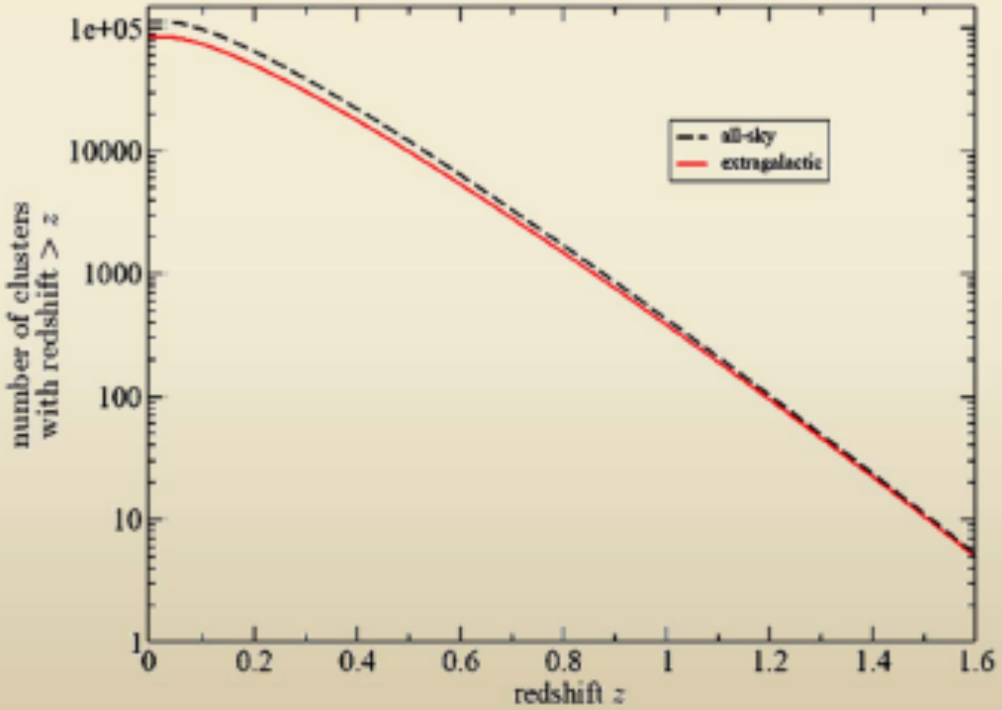
100.000 GCs in eRASS

- Cluster mass function evolution with redshift for different cosmologies
  → constraints on Ω_m, Ω_λ, σ_8

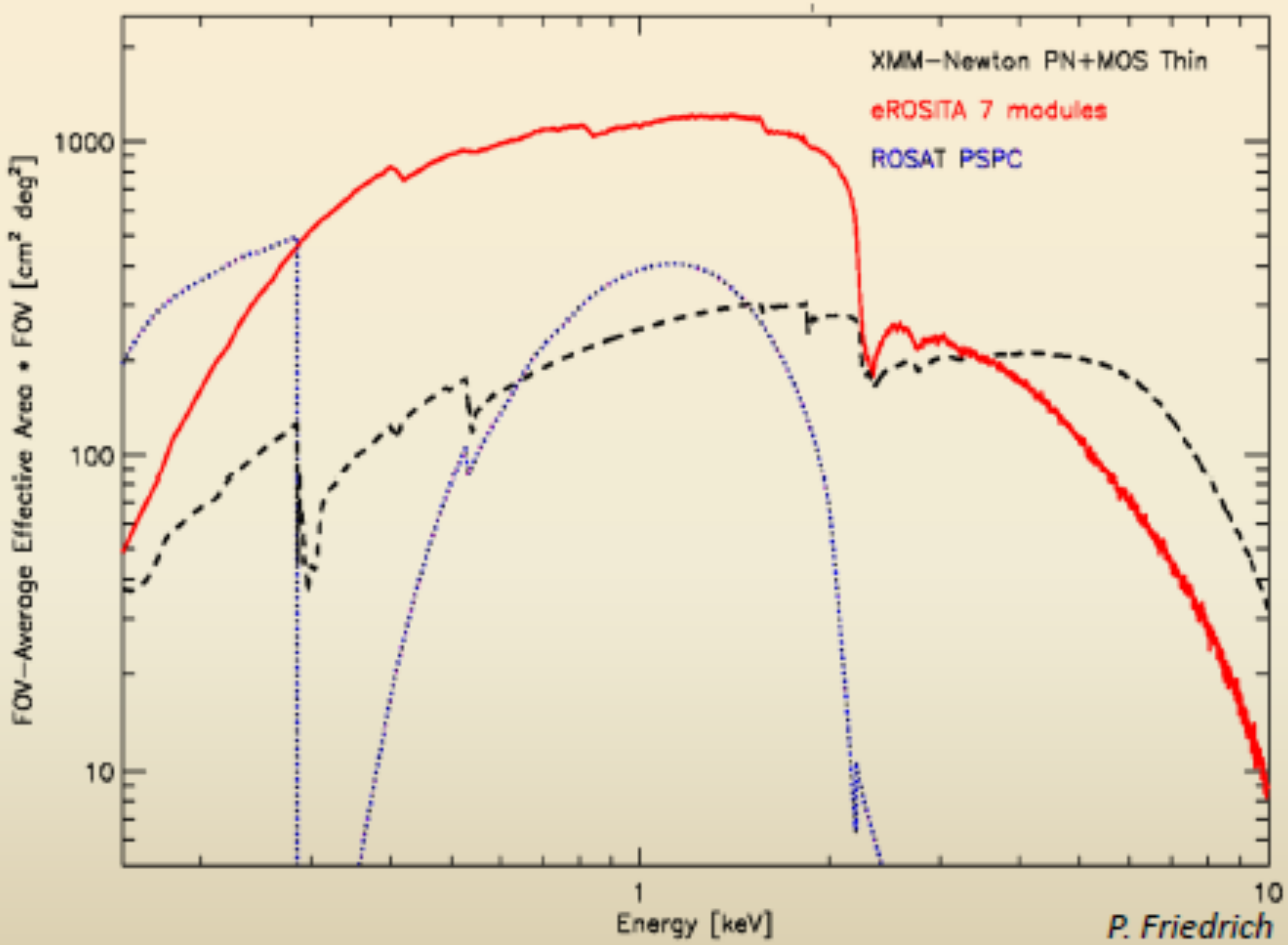


Nphot.	all sky	extragal sky
30	393810	293767
50	236503	176946
100	113227	85139
500	17272	13159
1000	7191	5514

M. Mühlegger

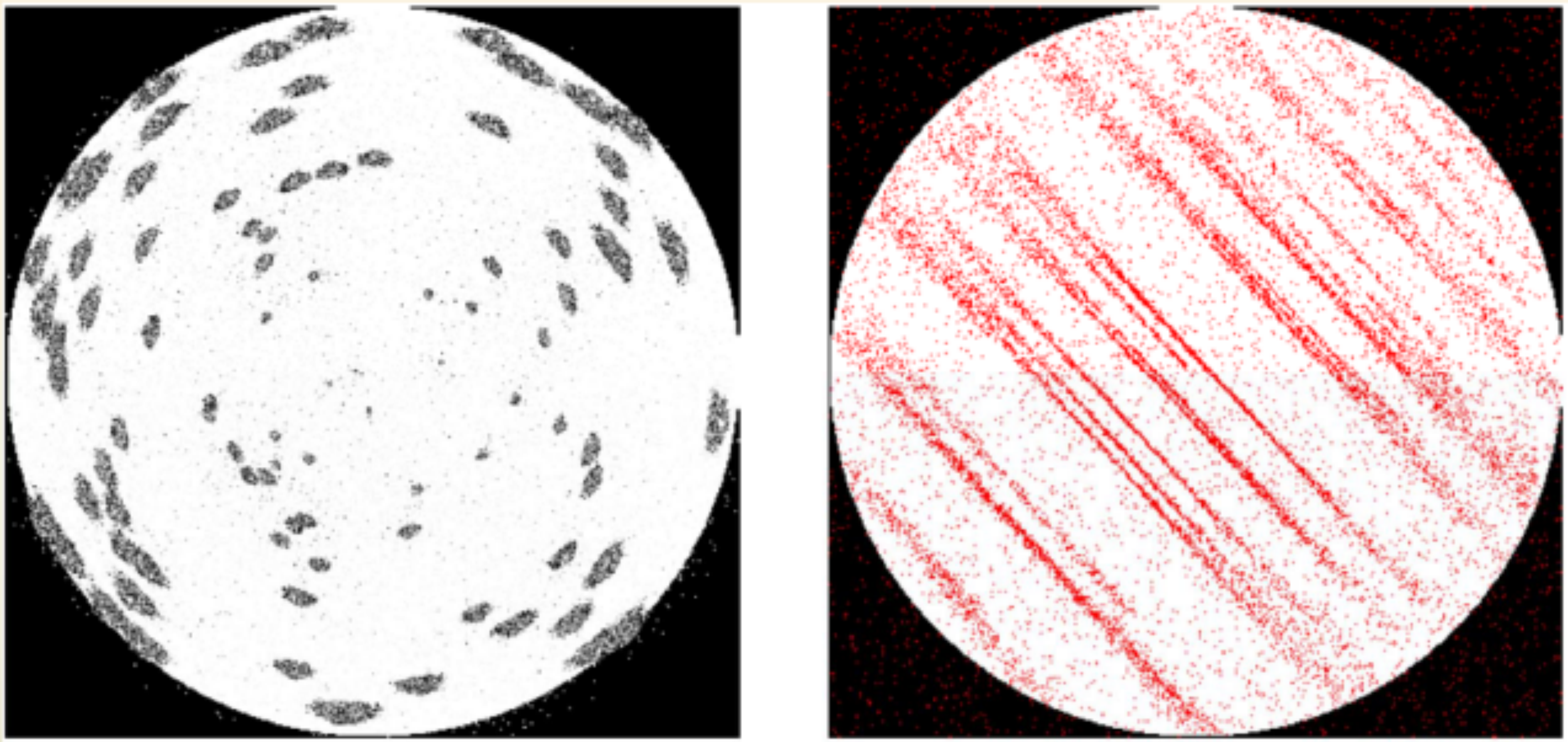


Grasp



P. Friedrich

Simulations



Pointing **Scan** *Ch. Schmid*

Off-axis blurring of a Wolter-I telescope →
PSF has to be averaged over the FoV
15 arcsec on-axis → 28 arcsec averaged

ART-XC

- Lancé avec e-Rosita sur Spektr-RG
- Survey du ciel 5-30 keV, avec Seff = 500 cm² à 7 keV, 7 miroirs, résolution angulaire ~1’ dans un FOV de 30’
- Statut ?

NICER

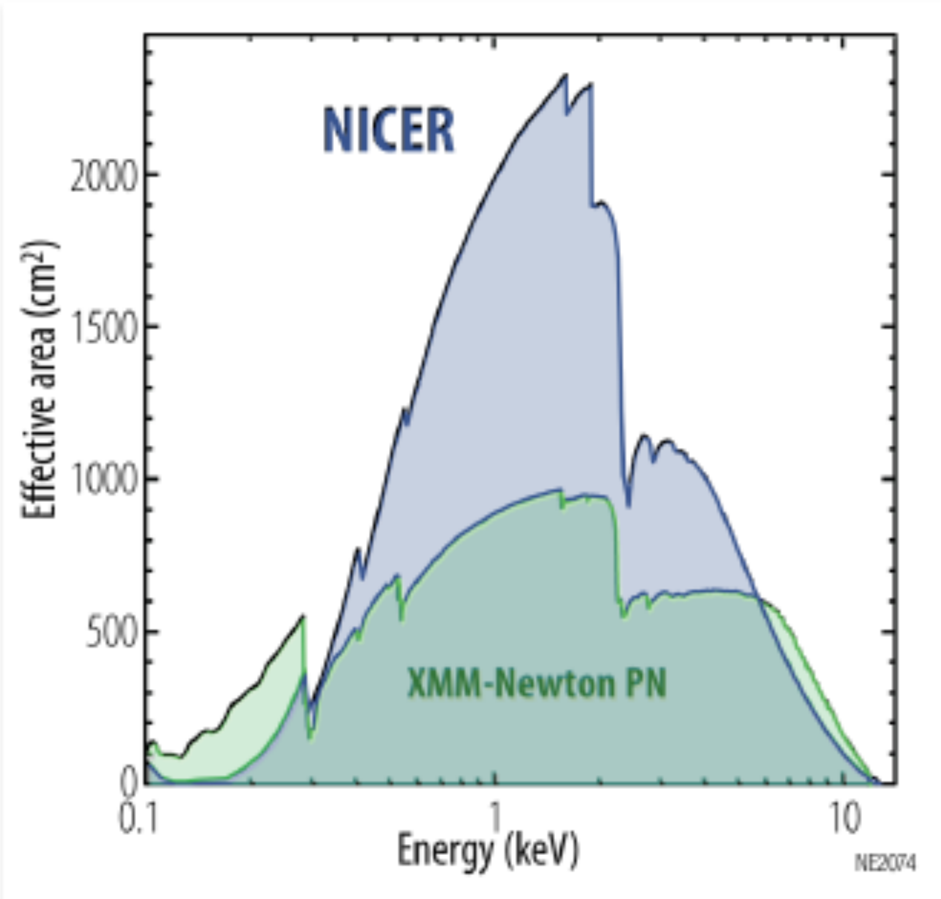
Petite mission pour déterminer l 'équation d'état de la matière dans les étoiles à neutrons

Instrument Performance

NICER

High-throughput, low-background soft X-ray timing and spectroscopy

- ***Bandpass:*** 0.2–12 keV
- ***Effective area:***
  > 2000 cm² @ 1.5 keV,
  600 cm² @ 6 keV
  2x XMM-Newton for soft X-ray timing
- ***Energy resolution:***
  85 eV @ 1 keV,
  137 eV @ 6 keV
  Similar to XMM and Chandra
- ***Time-tagging resolution:***
  < 300 nsec (absolute)
  ~25x better than RXTE
  ~100–1000x better than XMM
- ***Spatial resolution:*** 5 arcmin diam.
  non-imaging FOV
- ***Background:*** Dominated by diffuse
  cosmic XRB (soft)
- ***Sensitivity:*** 3×10^{-14} ergs s^{-1} cm^{-2}
  (0.5–10 keV, 5σ in 10 ksec)
  ~30x better than RXTE,
  ~4x better than XMM

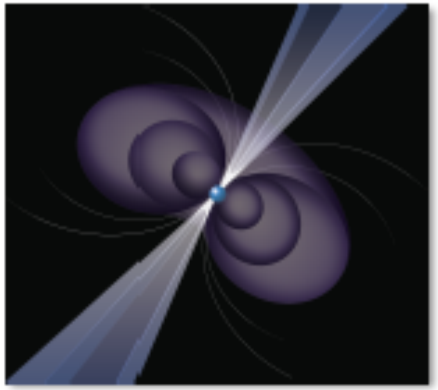


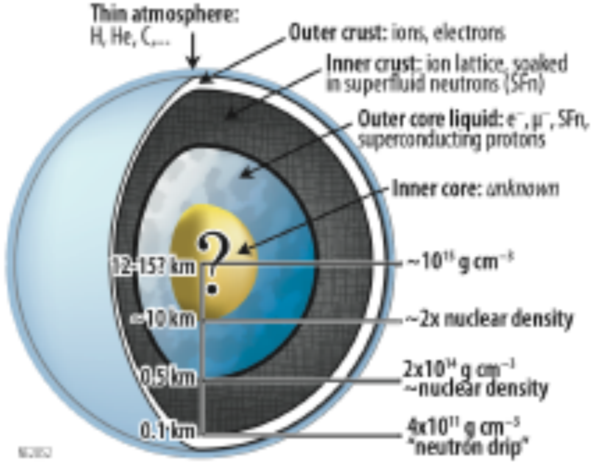
Science Objectives

NICER

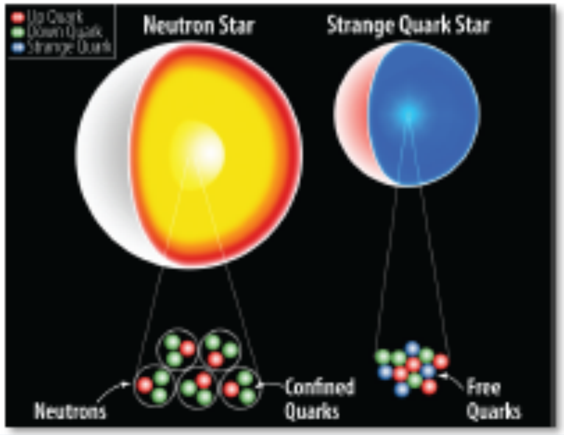
Neutron stars — Unique environments in which all four fundamental forces of Nature are simultaneously important.

- To address NASA and National Academy of Sciences strategic questions
- To resolve the nature of ultradense matter at the threshold of collapse to a black hole
- To reveal interior composition, dynamic processes, and radiation mechanisms of neutron stars.





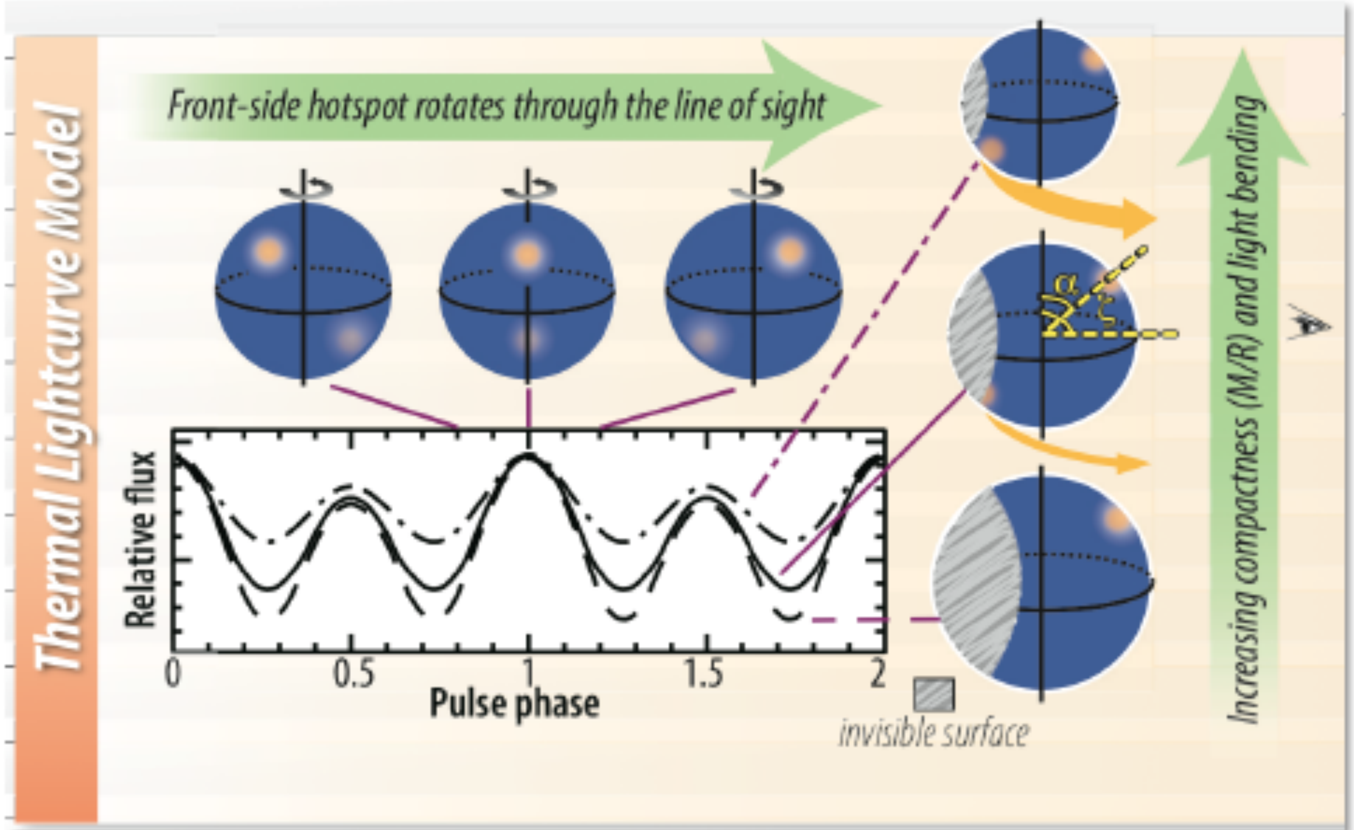
Objective	Measurements
Structure — Reveal the nature of matter in the interiors of neutron stars	Neutron star radii to ±5%. Cooling timescales
Dynamics — Uncover the physics of dynamic phenomena associated with neutron stars	Stability of pulsars as clocks. Properties of outbursts, oscillations, and precession
Energetics — Determine how energy is extracted from neutron stars.	Intrinsic radiation patterns, spectra, and luminosities.



Science Measurements

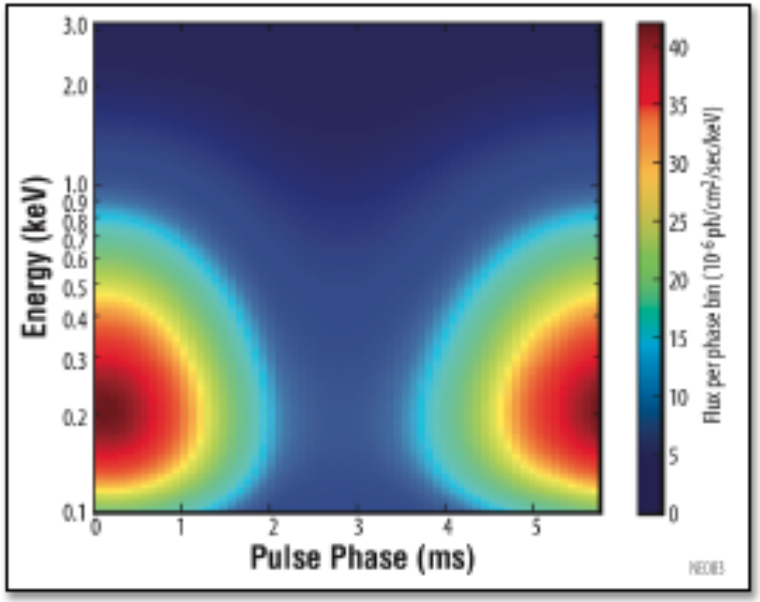
NICER

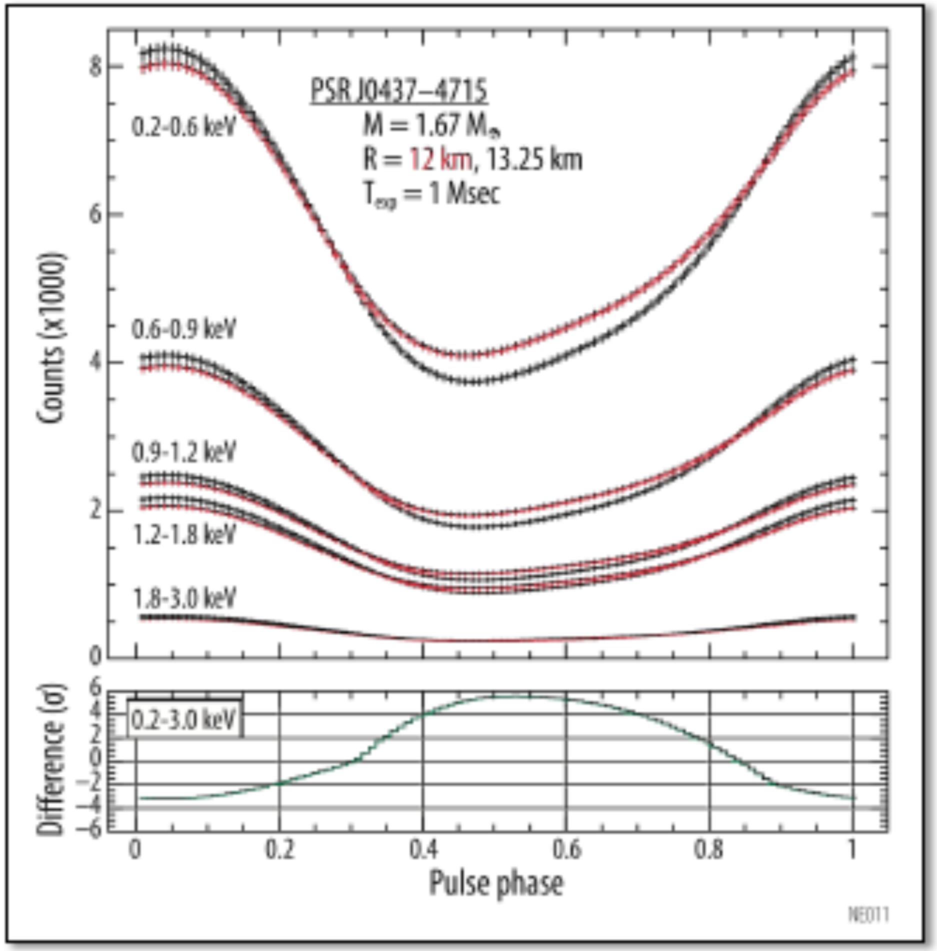
Reveal stellar structure through lightcurve modeling, long-term timing, and pulsation searches



Lightcurve modeling constrains the compactness (*M/R*) and viewing geometry of a non-accreting millisecond pulsar through the depth of modulation and harmonic content of emission from rotating hot-spots, thanks to gravitational light-bending…

Science Measurements (cont.)



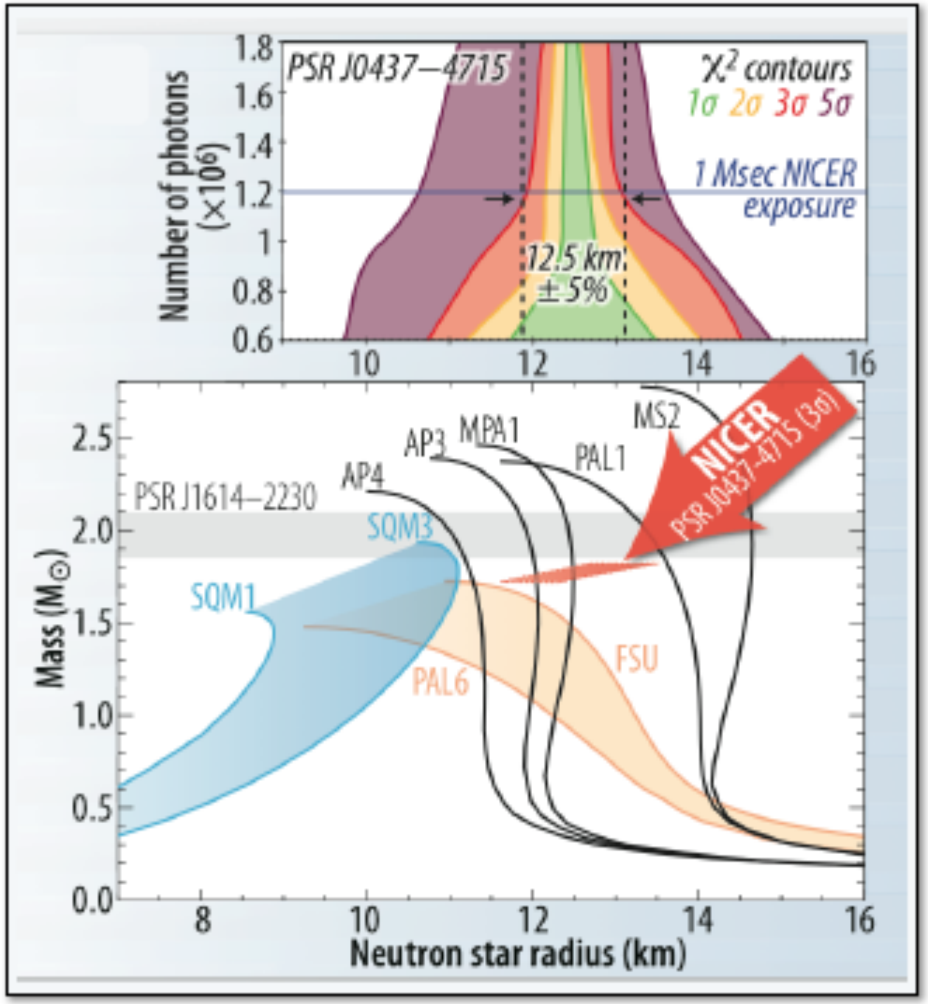


… while phase-resolved spectroscopy promises a direct constraint of radius *R*.

Science Measurements (cont.) NICER

Simulations demonstrate how well an assumed neutron star radius can be recovered. The ±5% (3σ) measurement goal is attained in less than 1 Msec.

The resulting allowed regions in the *M-R* plane rule out proposed families of neutron star equations of state. The best mass measurements alone can't distinguish among competing models.

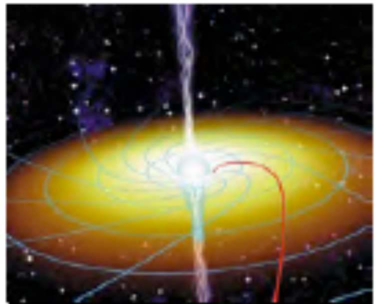


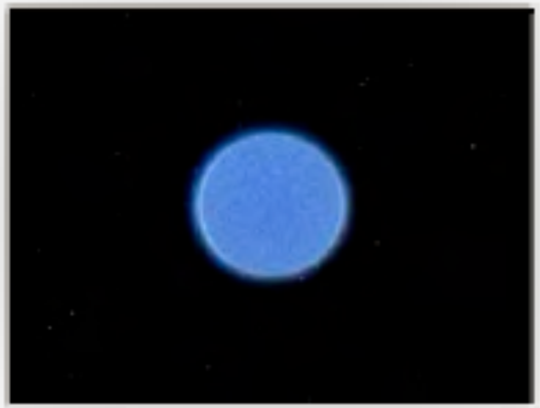
LOFT

La dimension temporelle largement ouverte dans le domaine X, après RXTE et NICER

Objectifs scientifiques

- **Deux objectifs scientifiques principaux:**
  - ✓ La gravité extrême autour des objets compacts
  - ✓ La matière à densité supra-nucléaire au coeur des étoiles à neutrons
    - ➡ Etudier la matière et son comportement dans des conditions non reproductibles en laboratoire
- **Les objets d'étude:**
  - ✓ Systèmes binaires X et noyaux actifs de galaxie brillants (galactiques ou proches)
- **La technique: Analyse spectrale et temporelle (ou analyse spectrale résolue temporellement) de l'émission X générée dans les parties internes des disques d'accrétion autour des objets compacts**





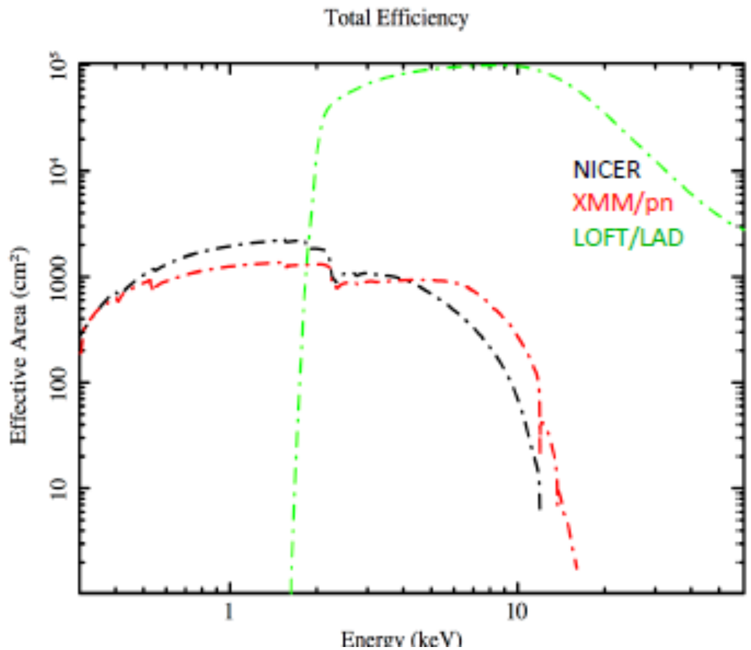
Spécifications scientifiques

- Spécifications scientifiques de LOFT en terme de fréquences relativistes, de nombre d'objets, de mesures de spin et mesures de masse, etc.

SFG1	Detect strong-field GR effects by measuring epicyclic motion in high frequency QPOs from at least 3 black hole X-ray binaries and about 8 NS binaries.
SFG2	Detect disk precession due to relativistic frame dragging with the Fe line variations in low frequency QPOs for typically 10 NSs and 5 BHs.
SFG3	Detect kHz QPOs at their coherence time, measure the waveforms and quantify the distortions due to strong-field GR for about 10 NSs covering different inclinations and luminosities.
SFG4	Measure the Fe-line profile and carry out reverberation mapping and tomography of typically 5 BHs and 10 NSs in binaries to provide spins to an accuracy of 5% of the maximum spin (a/M=1), constraining fundamental properties of stellar mass black holes, neutron stars and of accretion flows in strong field gravity.
SFG5	Measure the Fe-line profile of about 30 AGNs, and carry out reverberation mapping and tomography of the 8 AGNs most suitable for the latter purpose, to provide BH spins to an a typical accuracy of 20% of the maximum spin (10% for fast spins) and measure their masses with 30% accuracy, constraining fundamental properties of supermassive black holes and of accretion flows in strong field gravity.

LOFT vs NICER

- Un facteur > 100 en surface efficace, une gamme en énergie plus élevée
- LOFT confirmera (ou pas) les résultats de NICER sur EOS (cf. Planck vs. WMAP) par des méthodes différentes
- Gravité autour des trous noirs reste inatteignable par LOFT
- Science secondaire beaucoup plus riche

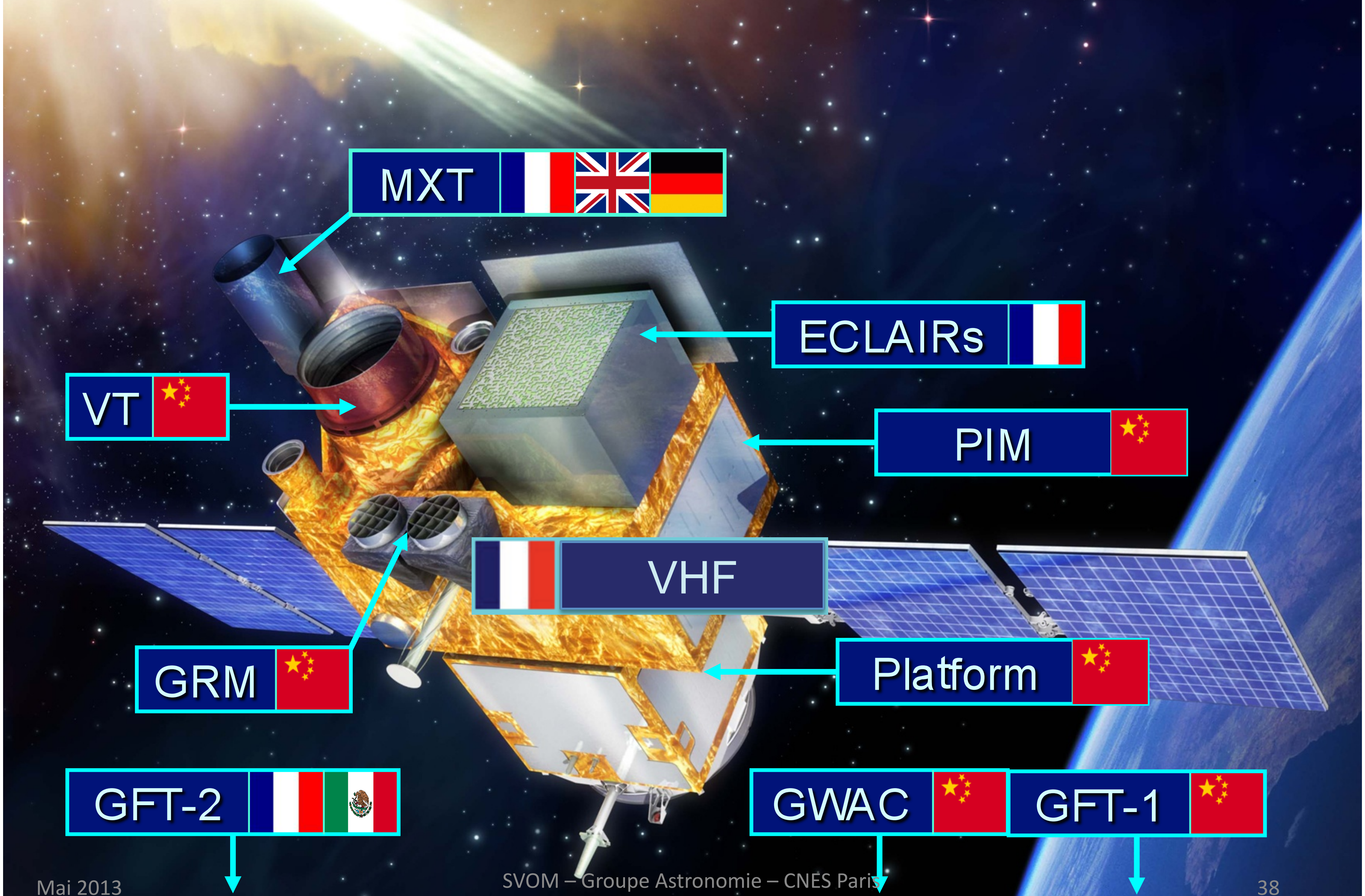


Contribution française

- ASIC (IPAG)
- Alerte sursauts gamma (SAp)
- Segment sol (Strasbourg)

SVOM

Présentation de la mission : Configuration SVOM février 2013



SVOM : Un observatoire multi-λ d'instruments complémentaires

	FOV	Energy range	Sensitivity
ECLAIRs	~90x90 deg^2	4-150 keV	~30 mCrab (1000 sec)
BAT	70x70 deg^2	15-150 keV	24 mCrab (1000sec)
MXT	64'x64' (TBC)	0.3-26.0 keV	~5x10-11 erg/cm2/s in 10 s
XRT	24'x24'	0.2-10.0 keV	10-14 erg/cm2/s in 10 ks
VT	21'x21'	400-950 nm	V=23 (300 sec)
UVOT	17'x17'	160-600 nm	B=22.3 (1000 sec)
GRM	~2 pi	50keV-5 MeV	200 cm2 at 1meV (TBC)
GFT-C	21'x21'	400-950 nm	R=21.5 (100 sec)
GFT-F	30'x30'	400-1700 nm	J=17.5 (10 sec)
GWACs	90x90 deg2	400-950 nm	Mv=15 in 10 s

SVOM vs SWIFT

- Les instruments sont similaires, avec des performances comparables; mais
  - Seuil en énergie bas pour Eclairs bien adapté aux sursauts très distants
  - Stratégie observationnelle optimisée pour le suivi des sursauts
  - Opération concommittante avec les grands observatoires (Advances Virgo/LIGO, JWST, ELT, etc.)
- Par contre, la science hors sursauts pénalisée par l'optimisation sursauts gamma

En guise de conclusion

- Ni l'Europe ni la France ne savent réaliser des missions sur un temps court. La compétition, lorsqu'elle existe, peut être mortelle.
- Pourquoi, avec une mission comme NuStar à moins de 200 M$ atteint-on les objectifs de Simbol-X ?
- L'astronomie X vit aujourd'hui un âge d'or; les projets ne manquent pas, mais les conditions économiques de 2010 ne sont plus celles des années 1990
- D'où l'impérieuse nécessité de faire une prospective X cohérente, réaliste, appuyée sur un argumentaire scientifique particulièrement solide et qui s'intègre parfaitement dans le paysage de l'astronomie prise dans son ensemble
- En sachant que la réalité de 2030 sera sans doute assez différente de ce que nous imaginons aujourd'hui.

I think that 2012 is more like 1609, when astronomy led physics (R. Giacconi)