The FORCE mission: A future Japan-lead mission for broadband X-ray imaging spectroscopy with high-angular resolution

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Y. Fukazawa (Hiroshima), H. Tsunemi (Osaka), T. Takahashi (Kavli IPMU/Tokyo),
and
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The FORCE mission: Focusing On the Relativistic universe and Cosmic Evolution

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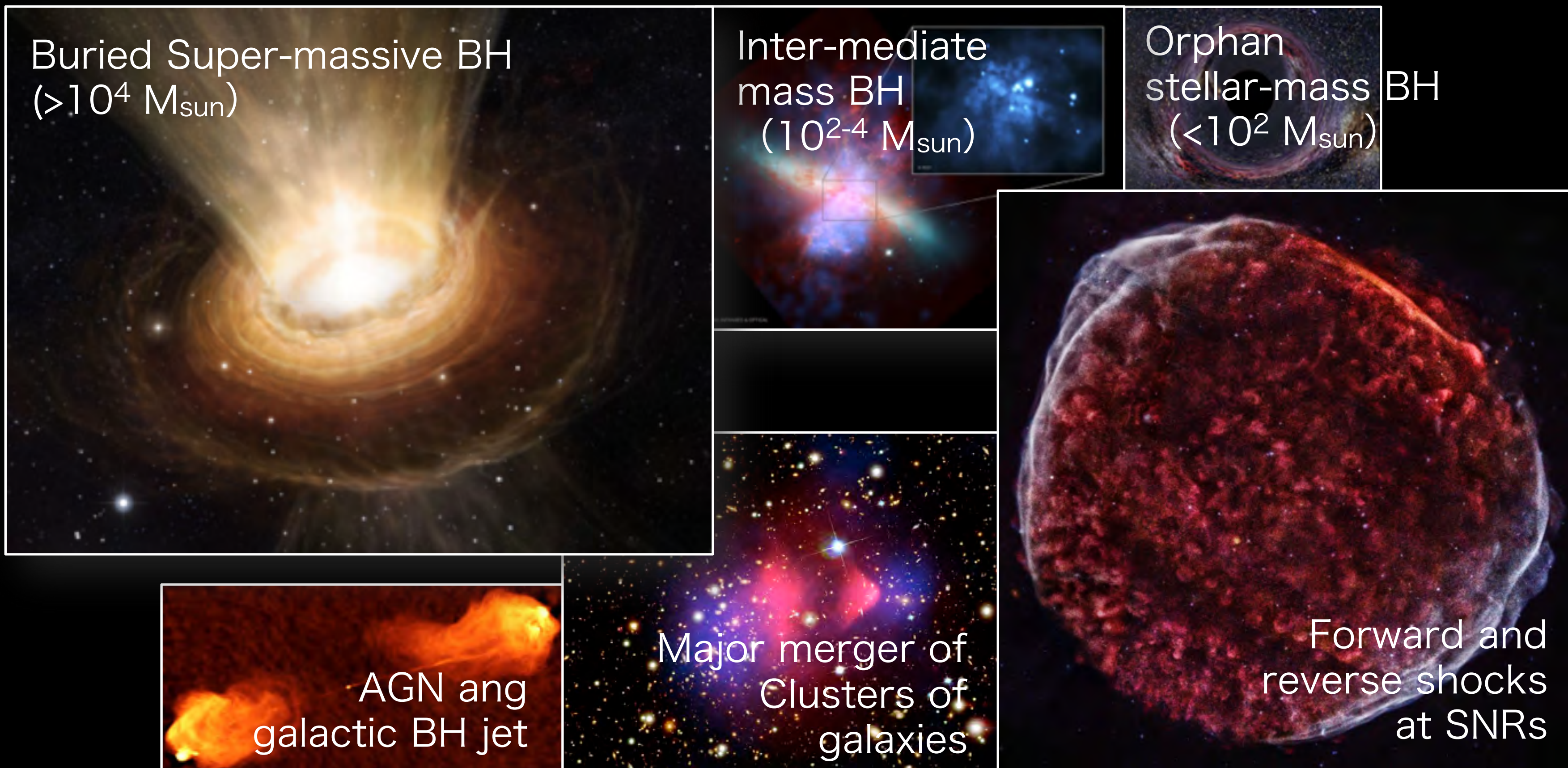
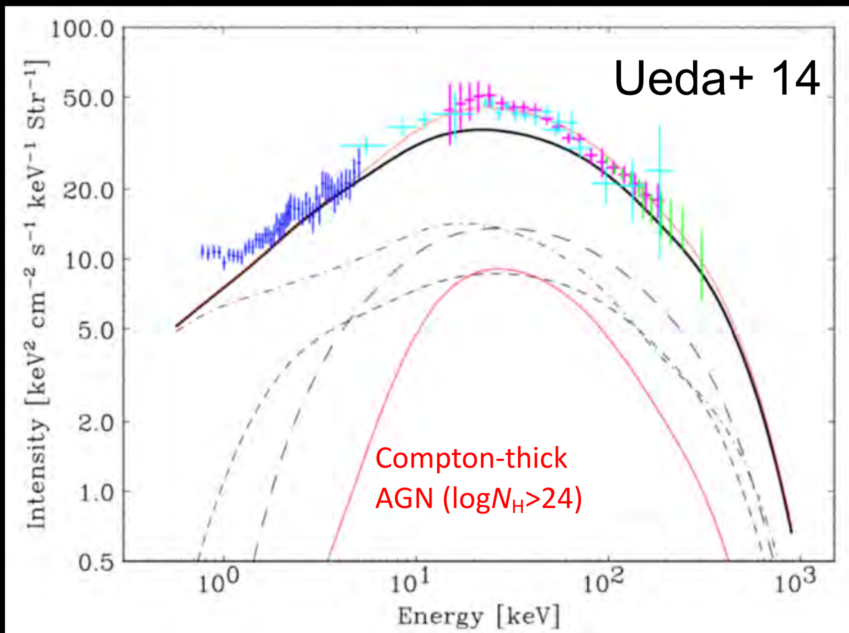
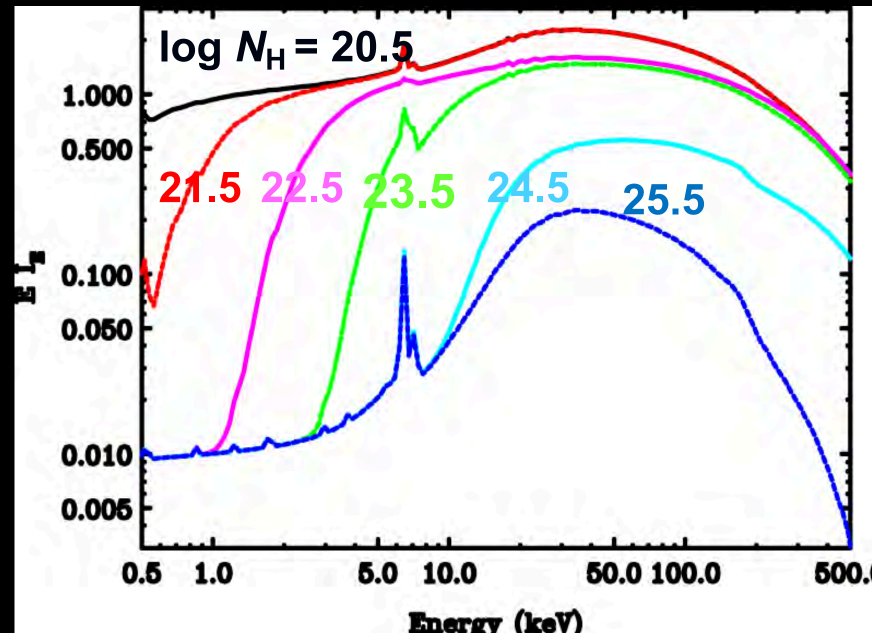
Scientific Objectives



- Our primary scientific objectives are
  - to search for “missing black holes” in entire mass-scales and to trace their cosmic evolution, and
  - to investigate the acceleration mechanism of relativistic particles at various astrophysical shocks

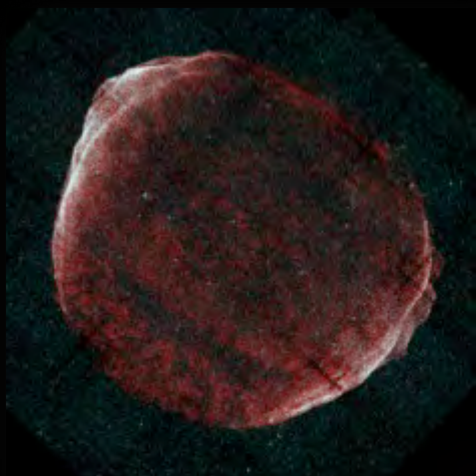
Resolving the CXB and constraining the SMBH growth

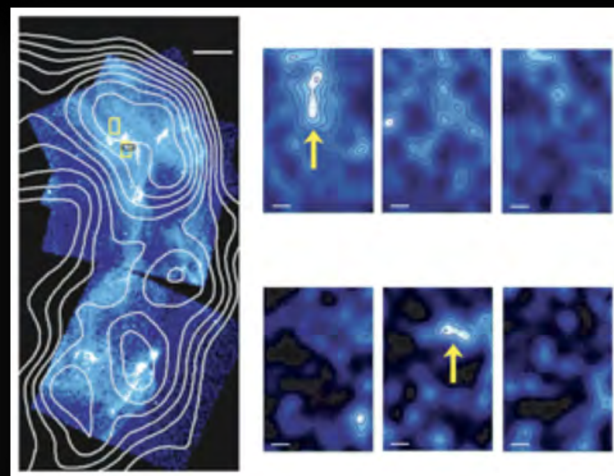


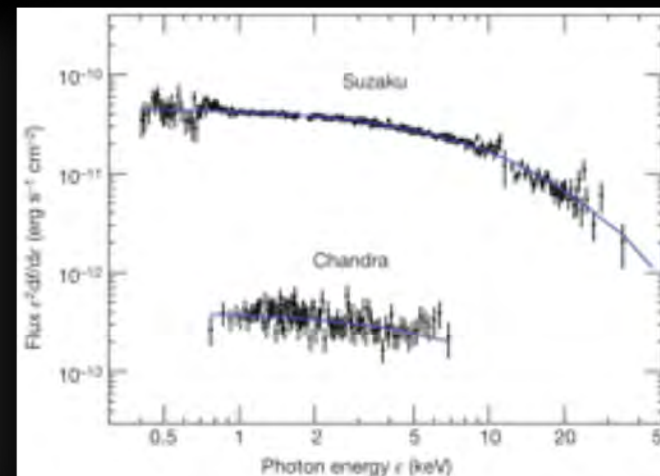


- The CXB peaks at around 30 keV where heavily-obscured AGNs significantly contribute
- The heavily-obscured, Compton-thick AGNs has barely been resolved by soft X-ray survey below 10 keV
- A sensitive hard X-ray survey is strongly demanded to understand the entire CXB spectrum and also the SMBH growth

Cosmic-ray acceleration in supernova remnants







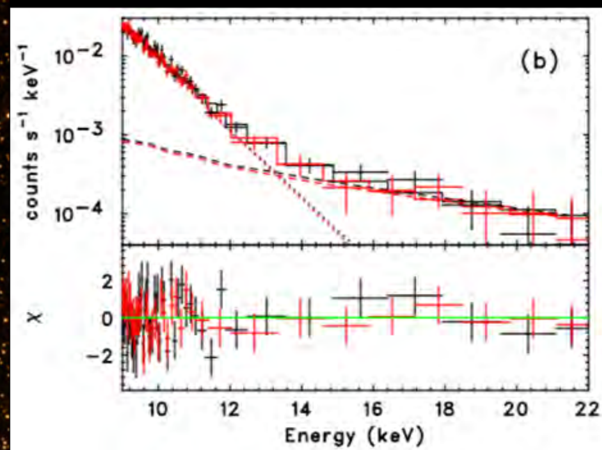
Bamba+03, 05, Uchiyama+07

- Hard X-ray imaging above the synchrotron cut-off energy (>10keV)
  - sensitive to the maximum-energy gained particles
  - Even small Emax variation leads to large flux variation in this band
  - Spatial resolved evaluation of B and ΔB

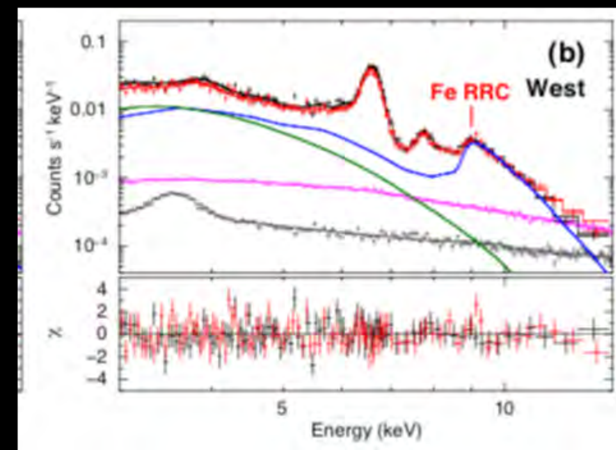
W49B: non-thermal and thermal emission in the hard X-ray band

X-ray Si X-ray Fe IR [Fe II] Radio continuum

NuSTAR Spectrum above 9 keV



NuSTAR Spectra of the West region



- Discovery of non-thermal emission and spatial variation of the RRC components from W49B with NuSTAR (Tanaka+18, Yamaguchi+18)
- flat spectrum (Γ~1.4), good for hard X-ray observations
  - likely non-thermal electron bremsstrahlung from sub-relativistic particles
- Strong RRC emission is a sign of recombination plasma, which is a new tool to study how SNRs evolves

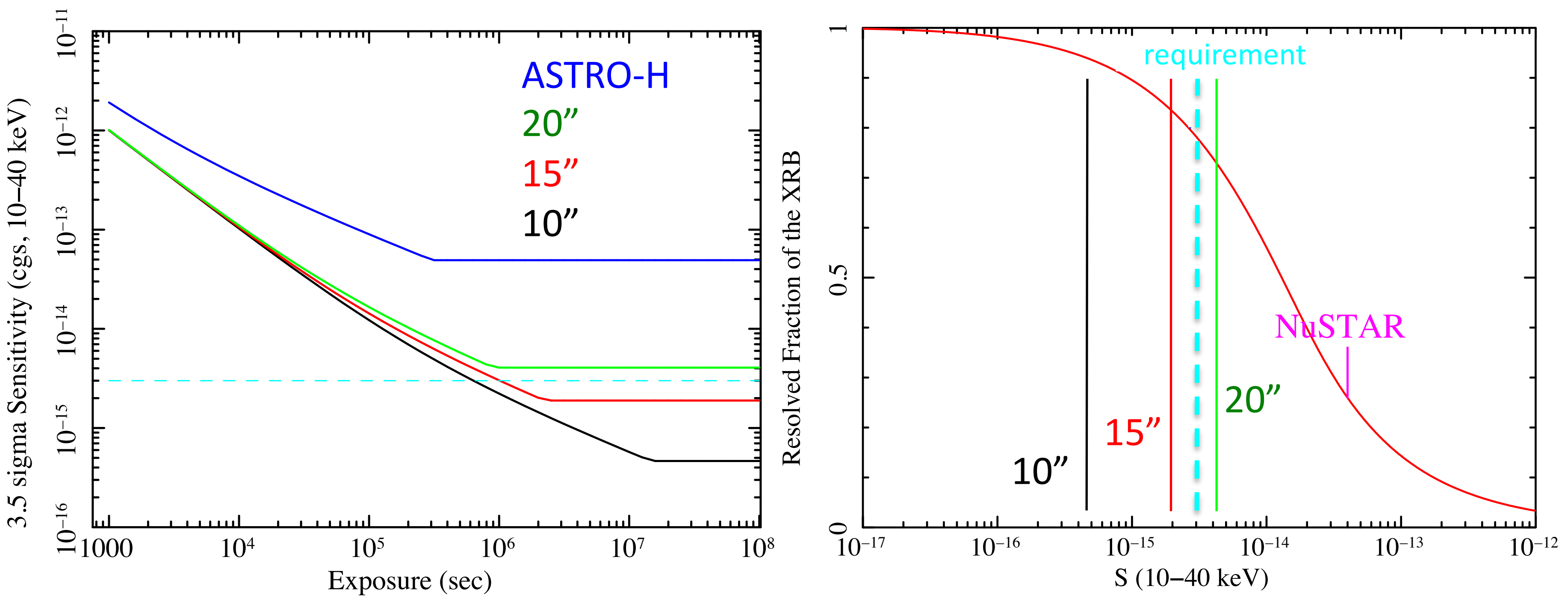
Mission Requirement

- High sensitivity in Hard X-ray
  - 2-3x10^{-15} erg/s in 10-40 keV
- Broadband response
- Effective area comparable with or larger than that of NuSTAR

Table 2: Performance Parameters

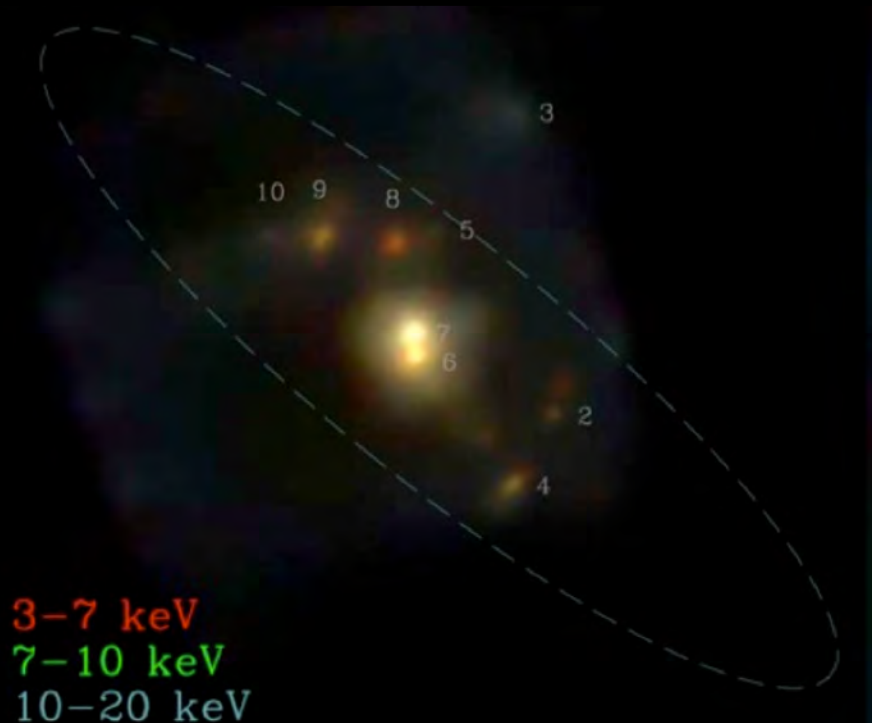
Parameter	FORCE	NuSTAR	ASTRO-H (HXT & HXI)
angular resolution (HPD)	<15″	58″	1.7′
bandpass (keV)	1–80	3–79	5–80
effective area (cm^2@30 keV)	>350	comarable with HXI	338
fov (50% resp. @30 keV)	>7′×7′	∼10′×10′	∼6′×6′
timing resolution	several × 10 μs	2 μs	several × 10 μs
energy resolution (FWHM)	<300 eV at 6 keV comparable with HXI	400 eV at 10 keV 900 eV at 68 keV	900 eV at 14 keV 1500 eV at 60 keV

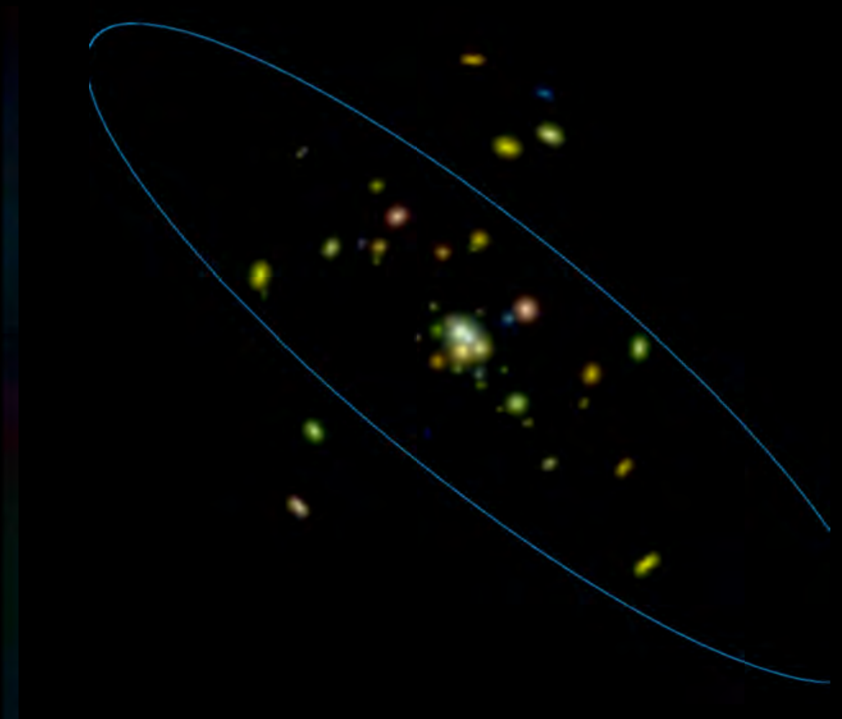
Why less than 15”



- A sensitivity limit of 2-3x10^{-15} erg/cm^2/s is our goal
  - Confusion limit determined the sensitivity assuming the A-H HXI BG level, which requires <15”
  - equivalent to 80% resolution of CXB in 10-40 keV
- 1 Ms exposure is necessary for one-pointing
  - Considering Vignetting effect, the number could be double, 2Ms = 1.7month
  - 360 arcmin^2 / 7’x7’ ≈ 7 pointings ≈ 1yr

Starburst Galaxy, clouded with X-ray point sources including ULXs

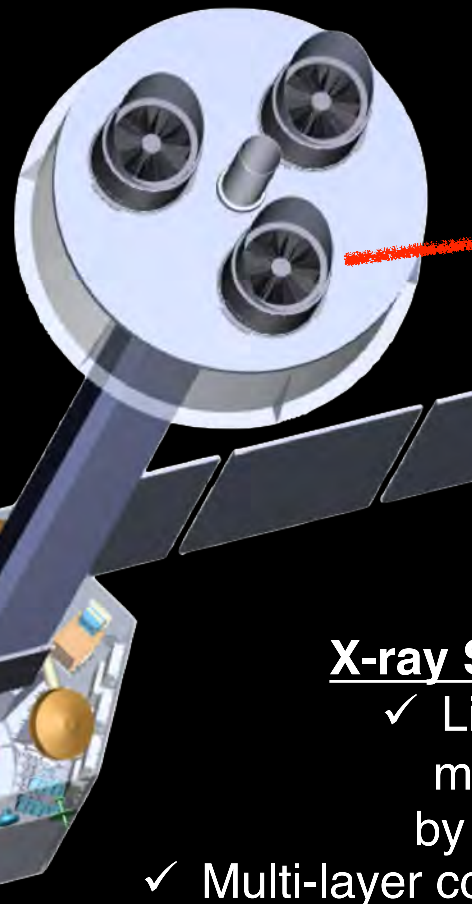




- NGC 253, bright, nearby, and one of the best-studied starburst galaxies
- Left shows 495 ks NuSTAR image while right shows ~400 ks FORCE image as expected from the current design

FORCE satellite

- Focal length 10 m
- 3 identical pairs of super-mirror and detector



Wideband Hybrid X-ray Imager (WHXI)

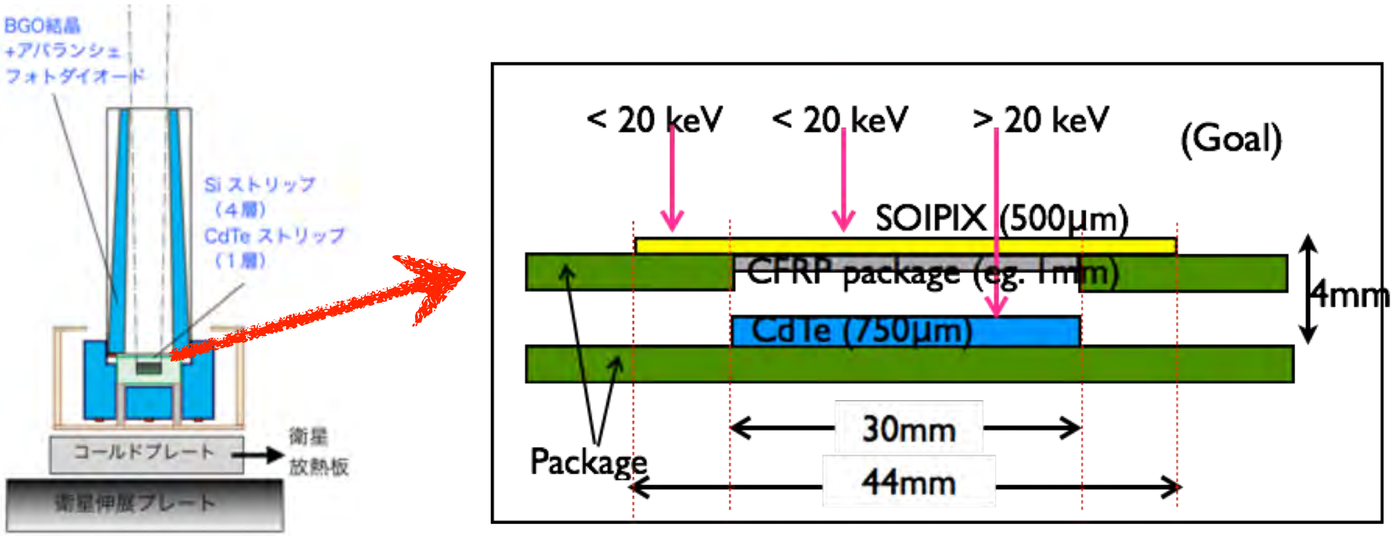
✓ New Si sensor (SOI-CMOS) + CdTe hybrid
✓ Low BG with active shield, the same concept as the A-H's hard X-ray detector
✓ Wideband sensitivity of 1-80 keV

X-ray Super-mirror

✓ Light-weight Si mirror provided by NASA/GSFC
✓ Multi-layer coating directly on the Si mirror surface

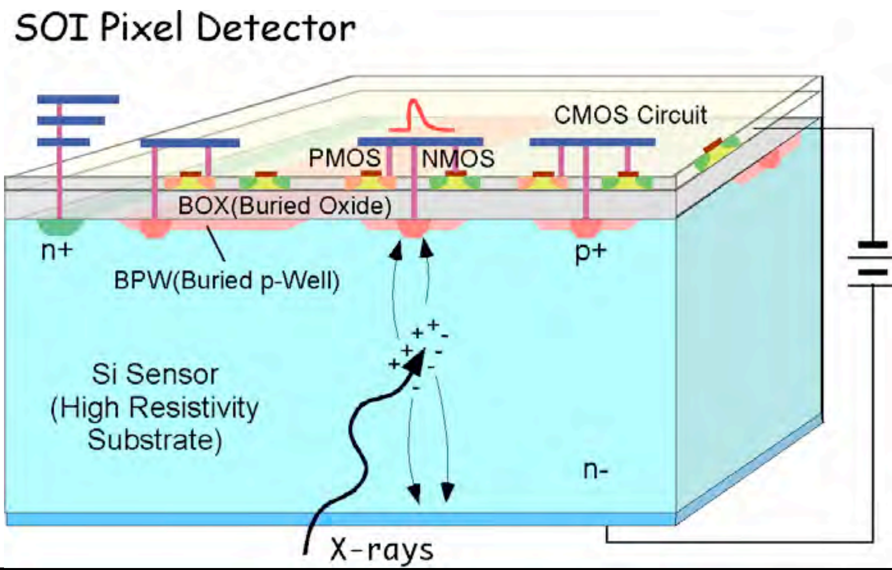
angular resolution of <15" in hard X-ray

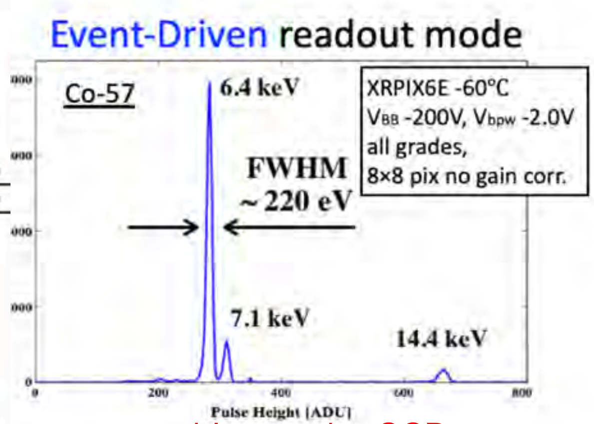
Wide-band Hybrid X-ray Imager



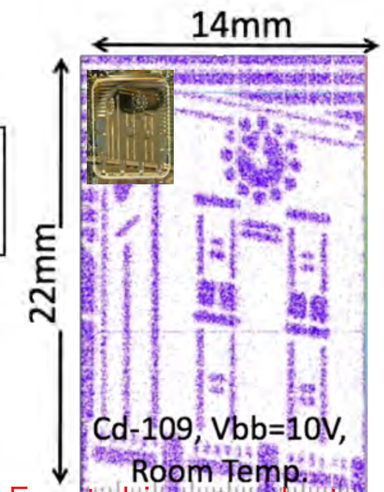
- Si + CdTe Hybrid detector with active shield
  - The same concept as ASTRO-H HXI, low cost and low risk
- Replacing Si top layer from strip detector to SOI-CMOS pixel sensor
  - Low readout noise could be achievable, lowering the enregy threshold down to 1 keV
  - similar working temperature to that of CdTe
  - anti-coincidence technique can be utilized thanks to good time resolution and self-trigger function

SOI-CMOS pixel sensor, SOIPIX





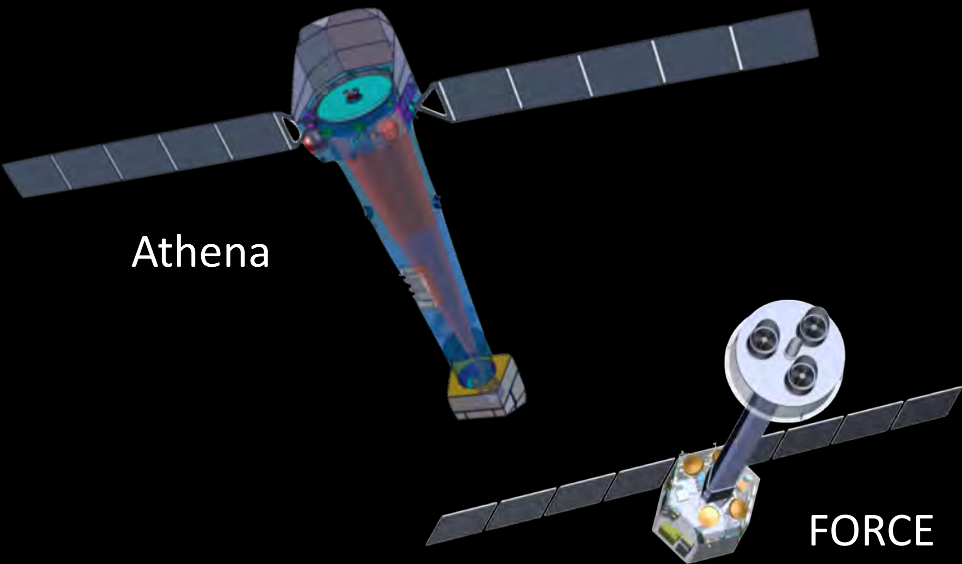
reaching to the CCD energy resolution

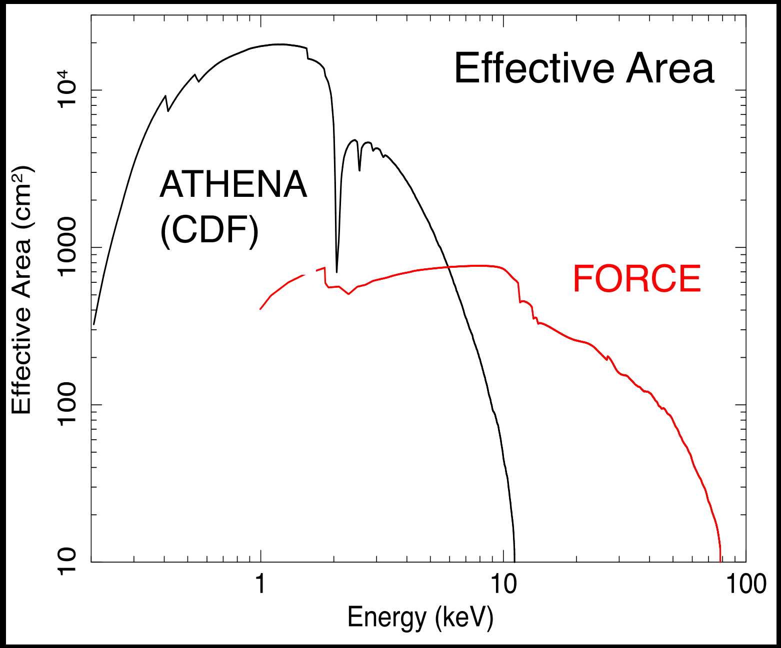


Event-driven readout imaging

- CMOS pixel sensor with Silicon-On-Insulator (SOI) technique
  - Monolithic, thick depletion layer
- Active pixel sensor with self-trigger function
  - pile-up free and anti-coincidence with active shield
- Its fast readout allows relatively high working temperature and also hybrid design with CdTe

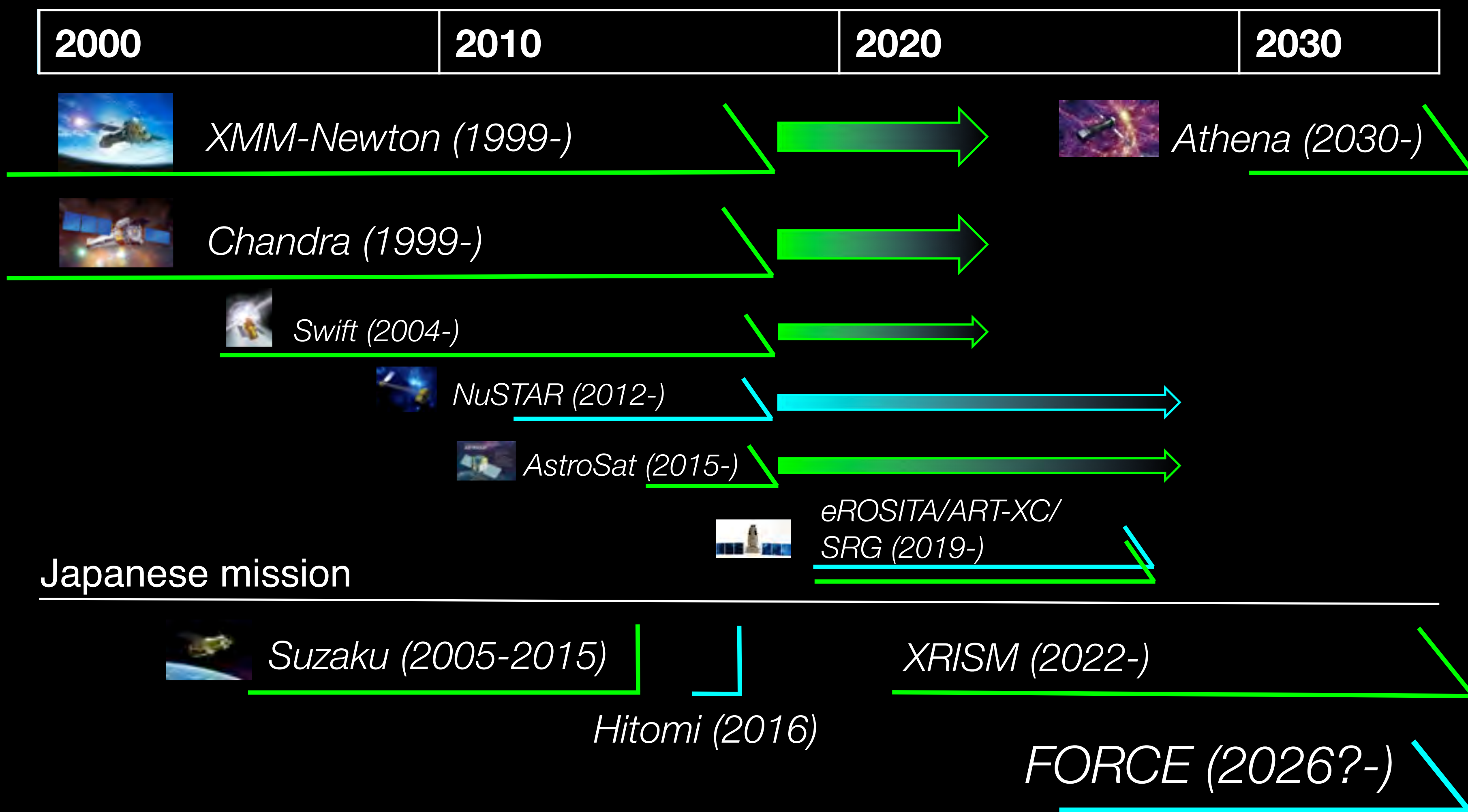
Athena and FORCE





- Athena and FORCE will play complementary roles to each other
- AGN survey
  - high redshift AGNs (Athena) with z>3 and low redshift AGNs (FORCE)
  - broad band spectra come into the soft X-ray band due to K-correction
- SNR spectroscopy
  - thermal (Athena) and non-thermal (FORCE)
  - high energy resolution and broad-band coverage

Timeline of X-ray missions with focusing optics



Summary

- FORCE (Focusing On Relativistic universe and Cosmic Evolution) is a concept of next Japanese-small class mission after XRISM, characterized by broadband (1-80 keV) X-ray imaging spectroscopy with high angular resolution (<15")
- FORCE will trace the cosmic evolution of black holes in entire mass-scales, and investigate the origin and acceleration mechanism of relativistic particles at various astrophysical shocks
- We are proposing this mission to be realized in the mid/late 2020s

May the force be with you