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
A.C. Hornschemeier, T. Okajima, W.W. Zhang (NASA/GSFC)
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

- 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

Bamba+03, 05, Uchiyama+07
W49B: non-thermal and thermal emission in the hard X-ray band

- Discovery of non-thermal emission and spatial variation of the RRC components from W49B with NuSTAR (Tanaka+18, Yamaguchi+18)
- flat spectrum ($\Gamma \sim 1.4$), 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
  – $2-3 \times 10^{-15}$ erg/s in 10-40 keV
• Broadband response
• Effective area comparable with or larger than that of NuSTAR

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FORCE</th>
<th>NuSTAR</th>
<th>ASTRO-H (HXT &amp; HXI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>angular resolution (HPD)</td>
<td>$&lt;15''$</td>
<td>58''</td>
<td>1.7'</td>
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<td>bandpass (keV)</td>
<td>1-80</td>
<td>3-79</td>
<td>5-80</td>
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<tr>
<td>effective area (cm$^2$@30 keV)</td>
<td>$&gt;350$</td>
<td>comparable with HXI</td>
<td>338</td>
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<tr>
<td>fov (50% resp. @30 keV)</td>
<td>$&gt;7'\times7'$</td>
<td>$\sim10'\times10'$</td>
<td>$\sim6'\times6'$</td>
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<tr>
<td>timing resolution</td>
<td>several $\times$ 10 $\mu$s</td>
<td>2 $\mu$s</td>
<td>several $\times$ 10 $\mu$s</td>
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<tr>
<td>energy resolution (FWHM)</td>
<td>$&lt;300$ eV at 6 keV</td>
<td>400 eV at 10 keV</td>
<td>900 eV at 14 keV</td>
</tr>
</tbody>
</table>

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Why less than 15”

- A sensitivity limit of $2-3 \times 10^{-15}$ 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 = 1.7 month
  - 360 arcmin$^2$ / 7’x7’ ≈ 7 pointings ≈ 1 yr
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 energy 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

- 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

<table>
<thead>
<tr>
<th>Year</th>
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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