g02-2

第21回宇宙科学シンポジウム

FORCEが切り開くサイエンス

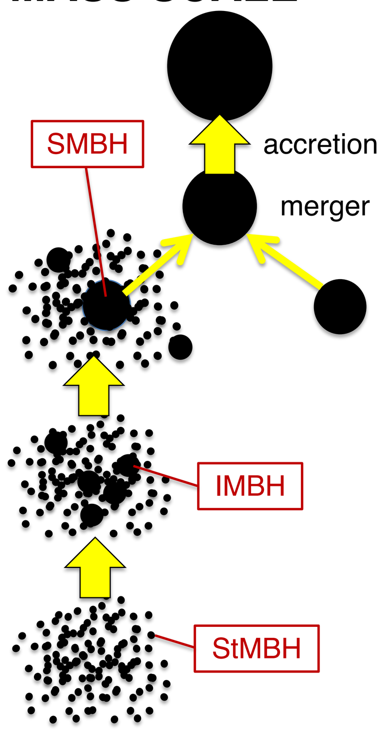
Scientific Goals of the FORCE mission

上田佳宏, 田中孝明（京都大学), 他 FORCE WG

Goal 1: COMPLETE A CENSUS OF BLACK HOLES ACROSS COSMIC TIME AND MASS SCALE

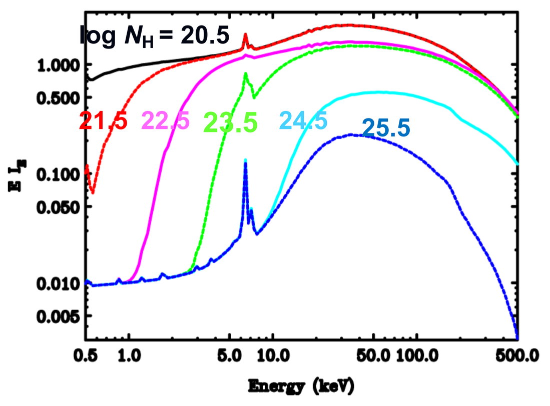
Objectives

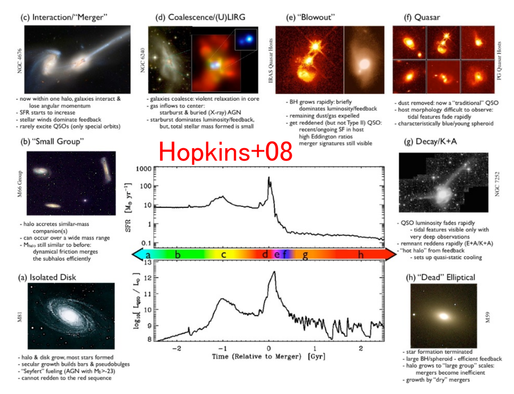
1. Survey accreting supermassive black holes (SMBHs) in the Universe over the redshift range from 0 to 3, including the most highly obscured objects that are currently "missing": observe the very site of co-evolution of galaxies and SMBHs at cosmic noon
2. Reveal the nature of intermediate-mass black hole candidates (IMBHs) in the local Universe: seeds of SMBHs
3. Identify and characterize stellar-mass black holes (StMBHs) that are currently missing in the Milky Way galaxy: connection to IMBH formation



Objective 1-1: Coevolution between SMBHs and Galaxies

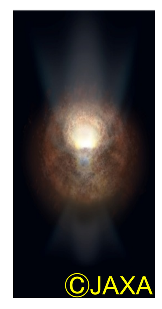
- Black holes: key players of cosmic evolution
  - Galaxies are shaped by tight interaction with central SMBHs
  - High energy astronomy is crucial to observe and characterize SMBHs
- Buried (or Compton thick) Active Galactic Nuclei (AGN)
  - Key population to understand "co-evolution"
  - Expected in rapid growth phase of BHs in intensively star-forming galaxies triggered by galactic mergers (unique tracers of mergers)
  - Difficult to observe except in hard X-rays (E>10 keV)
  - Their cosmological evolution is currently unknown

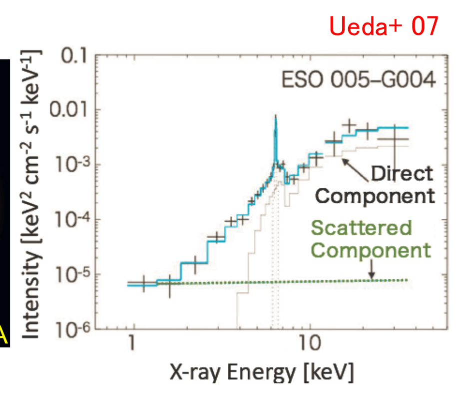


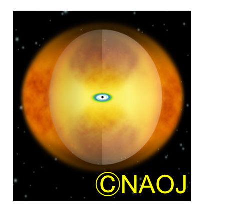


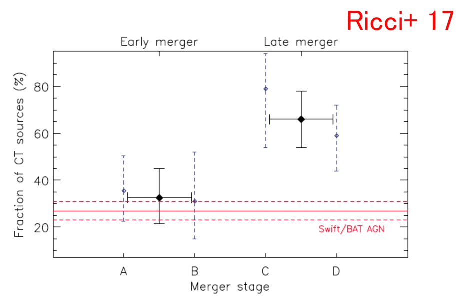
Key Population: Buried AGN

- Covered by Compton thick material with large solid angle
  - Narrow line regions are little developed because UV lights do not leak
  - Sometimes AGN can be identified only by using X-rays (ex. NGC 4945)
- Hard X-rays are the best band to catch such AGNs, thanks to
  - Strong penetrating power against obscuration
  - Little contamination from stars (cf. infrared band)

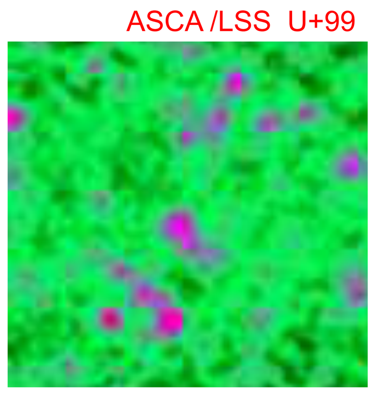


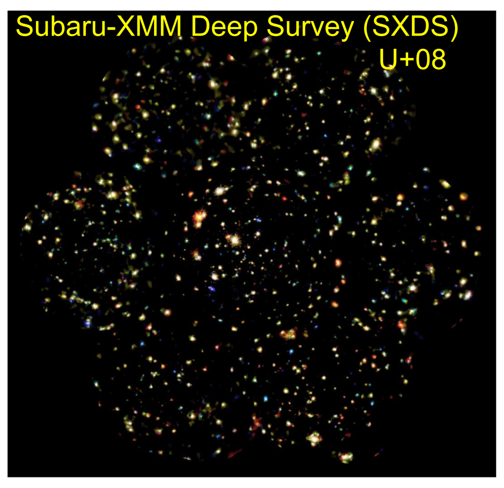






Completely New World Seen with High Angular Resolution

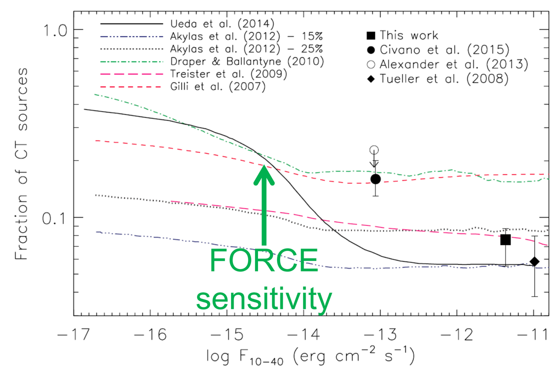


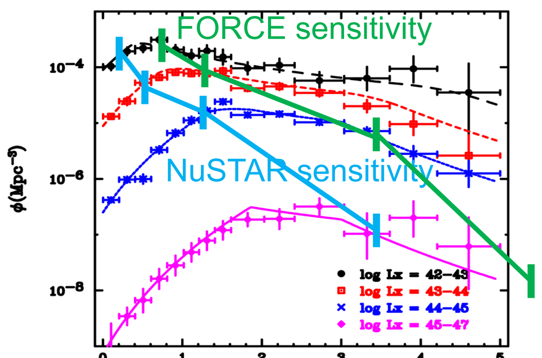


- Significant improvement of sensitivity for point sources
  - Left: blank sky seen with 2 arcmin resolution (10 deg^{-2})
  - Right: that seen with10 arcsec resolution (1000 deg^{-2})
- Crucial in studies of extended emission (point source removal)

ASCA was great! However, we cannot go back there once we know new world seen with XMM-Newton/Chandra

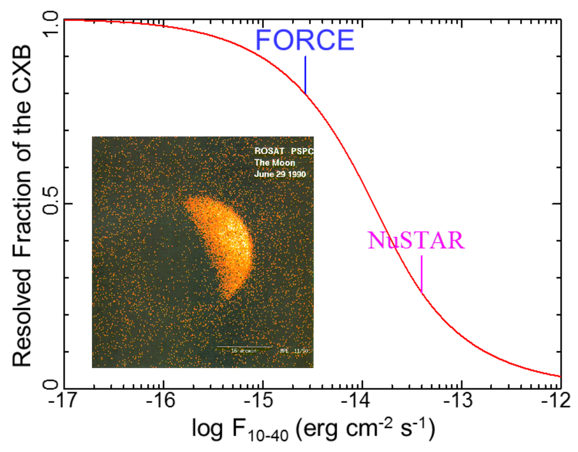
Cosmological Evolution of CTAGNs

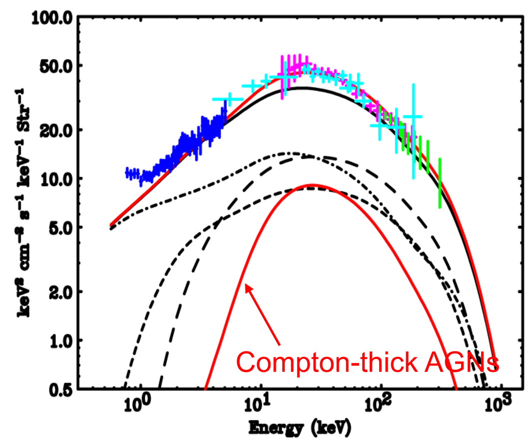




- CTAGNs rapidly increases at fluxes below the NuSTAR limit
  - Fraction of CTAGN predicted from a standard CXB model (black line)
  - NuSTAR results suggest a few times more CT AGNs than in the prediction
- Requirements to FORCE
  - Flux limit: to cover redshifts where the space number density peaks, 3x10^{-15} erg cm^{-2} s^{-1} (10-40 keV)
  - Survey area: to detect 10 CTAGNs in each luminosity bin

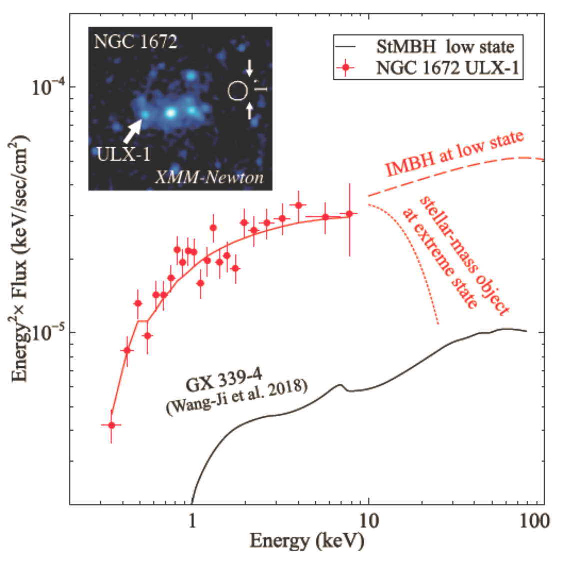
Resolving the X-ray background at E>10 keV





- FORCE will resolve a majority (>80%) of the X-ray background at its energy density peak
  - Finally solving the 60 year mistery of X-ray Astronomy
  - Quantitative estimate of contribution from Compton thick AGNs

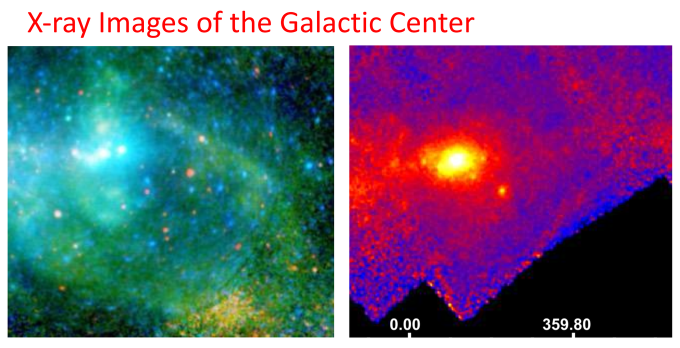
Objective 1-2: Search for Intermediate-Mass Black Holes



- IMBHs (M_{BH}～10$^{2-4}$ Mo): missing link between SMBHs and StMBHs
- No firm candidate yet: discovery of a single IMBH will give a large impact
- Targets: Ultra-Luminous X-ray sources (ULXs)
- Energy spectra above 10 keV are key to discriminate IMBH vs StMBH (sub- or super-critical accretion)
- Increase a ULX sample with broad-band X-ray spectra to 100 (~10 times the NuSTAR one): L_x~3x10^{40} erg s^{-1} at D<30 Mpc ⇒ requirement for spectroscopic sensitivity, F_x~3 x 10^{-13} (10-40 keV)
- It will also allow to construct mass function: Are IMBHs a distinct or continuous population from StMBHs?

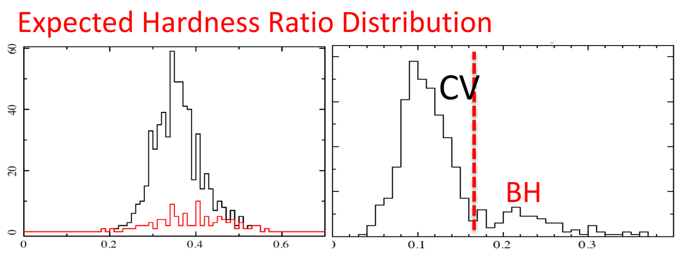
Objective 1-3: Finding Missing Stellar-mass Black Holes

X-ray Images of the Galactic Center



with XMM-Newton (~15") with NuSTAR (~1')

Expected Hardness Ratio Distribution



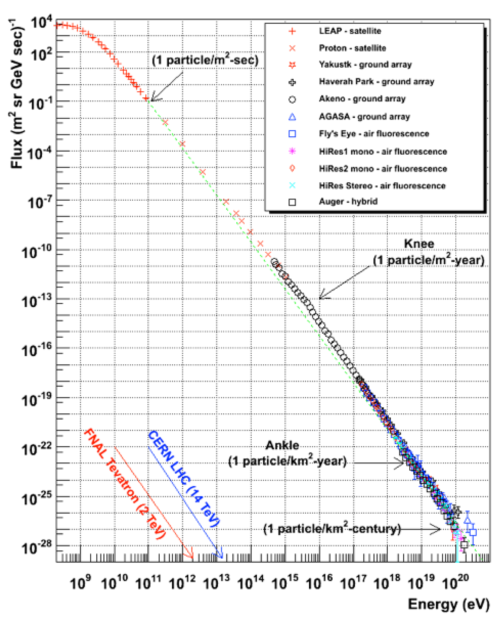
[7.5-10keV]/[5-10keV] [15-50keV]/[5-50keV]

- Assuming 0.01 SN per year, ~10^7 StMBHs should exist in our Galaxy, among which only 20 are known !
- Faint StMBHs with advection dominant accretion flows have hard spectra (Γ~1.5-2)
- StMBHs in dense molecular clouds have Lx ~10^{32} erg s-1 (flux ～10^{-14} cgs)
- Spectra above 10 keV are key to discriminate between CVs (white dwarfs) and StMBHs
- Final goal: the black hole mass distribution by multiwavelength follow-up (e.g., with TMT, ALMA)

Goal 2: Measure the energetic content of relativistic particles in the Universe

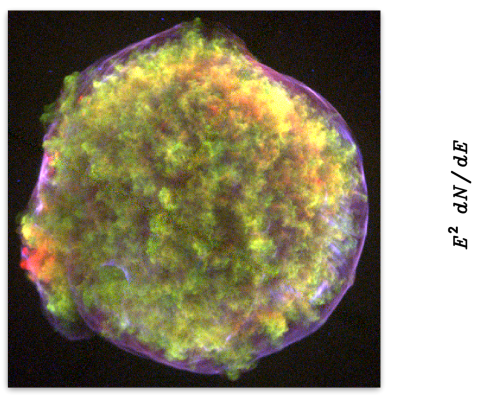
- Origin of cosmic rays = long-standing problems in the field of astrophysics.
- Occupies significant portion of energy density in interstellar space.
- Key ingredients in star formation as well as large structures in the Universe.

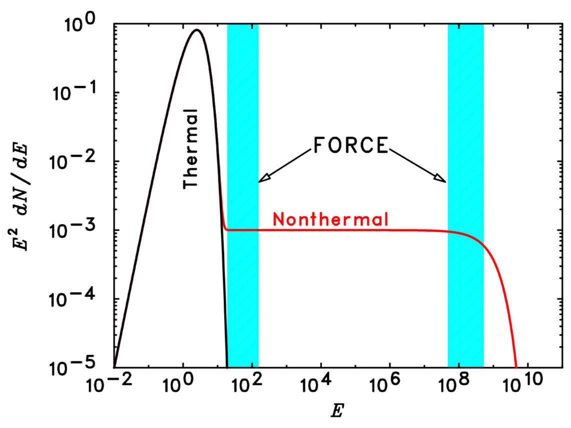
- **Obj-2-1: Characterize the particle acceleration in SNRs**
- **Obj-2-2: Determine the role of shock heating and particle acceleration in the evolution of galaxy clusters**



Particle acceleration in SNRs

- SNRs have long been promising candidates for origins of Galactic cosmic rays up to the energy of 10^{15} eV (= PeV) (Baade & Zwicky 1934).
- Recent X-ray and gamma-ray observations support the hypothesis (e.g., Koyama et al. 1995; Ackermann et al. 2013).
- FORCE will give answers to unsolved questions, what is the total energy of cosmic rays that each SNR can produce, and what is the highest energy that particles accelerated in SNRs can gain by probing both lowest- and highest-end of accelerated particles.

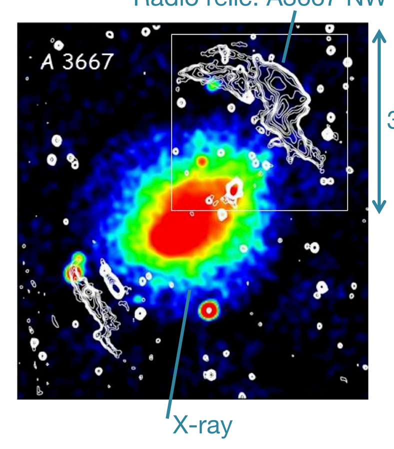




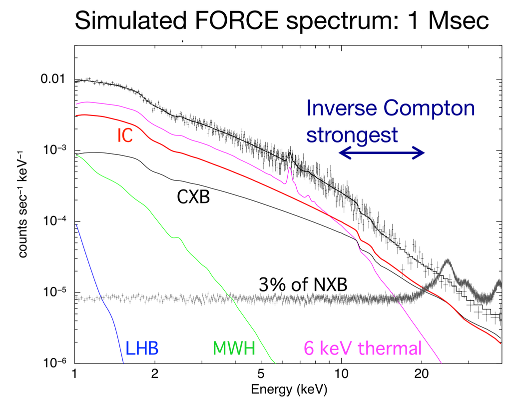
Clusters of galaxies: radio relics

- Radio relic (northwest) of A3667: prominent merger shock with $\mathcal{M} \approx 3$.
- Superior angular resolution of FORCE will reduce the cosmic X-ray background (CXB) to about half the level of ASTRO-H.
- FORCE will enable us the first clear measurement of the inverse Compton spectrum from radio relics, as shown by the simulated spectrum: giving both the electron spectrum and magnetic field intensity.

Radio relic: A3667 NW



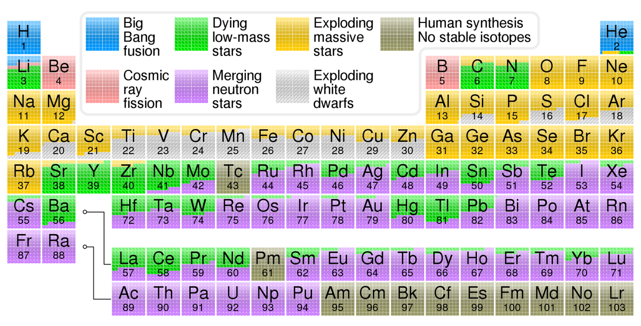
Simulated FORCE spectrum: 1 Msec

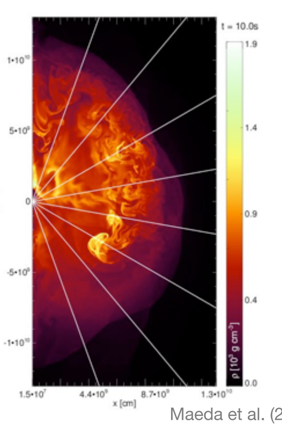


Goal 3: Understand the explosion mechanism and nucleosynthesis in supernovae

- Sources of the elements around us and energy in interstellar space
- Type Ia SNe important also for distant indicators used in cosmology.
- Nevertheless, the explosion mechanisms largely unknown for both type Ia and core-collapse SNe.

- **Obj-3-1: Measure the spatial distribution of ejecta elements synthesized in SNe**

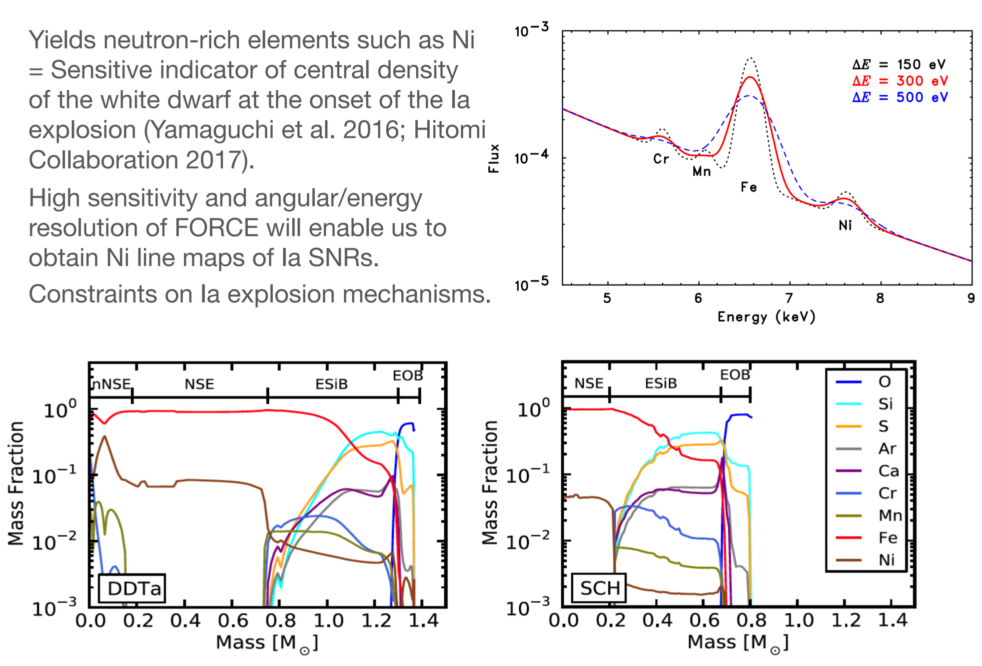




Maeda et al. (2010)

SN Studies: Type Ia

- Yields neutron-rich elements such as Ni = Sensitive indicator of central density of the white dwarf at the onset of the Ia explosion (Yamaguchi et al. 2016; Hitomi Collaboration 2017).
- High sensitivity and angular/energy resolution of FORCE will enable us to obtain Ni line maps of Ia SNRs.
- Constraints on Ia explosion mechanisms.



SN Studies: Core Collapse

- Asymmetry = a key ingredient to make core-collapse SN explode?
- ^{44}Ti, synthesized in the innermost part of ejecta, can serve as a good tracer of asymmetry (Grefenstette et al. 2014).
- FORCE will reveal most detailed 3D mapping of line emissions from radioactive decay of ^{44}Ti ($T_{1/2}$ = 60 yr) at 68 keV and 78 keV.
- Comparison with distributions of Fe K-shell line (^{56}Ni) essential to study the explosion mechanisms (e.g., Wongwathanarat et al. 2017).