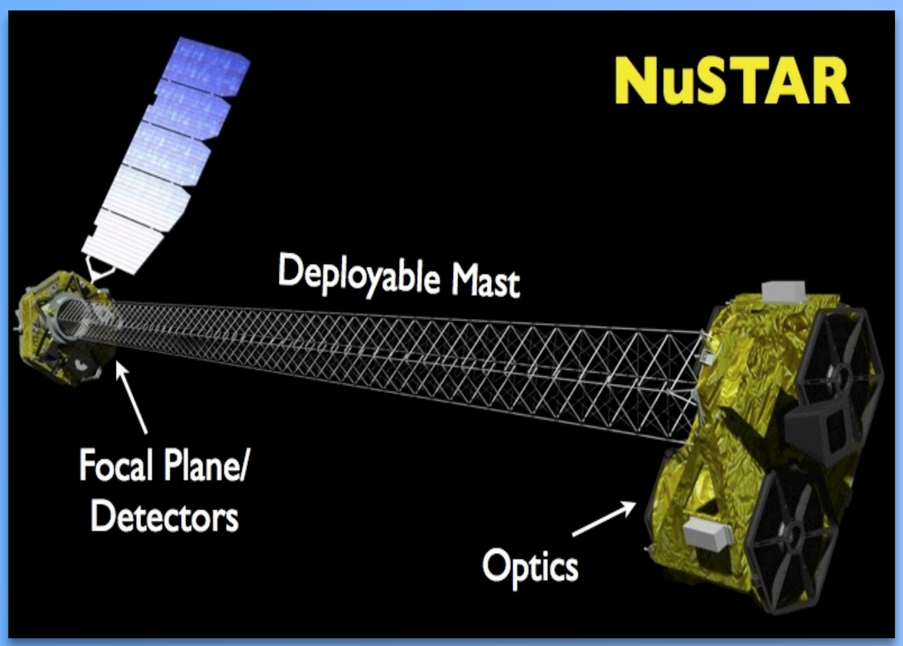
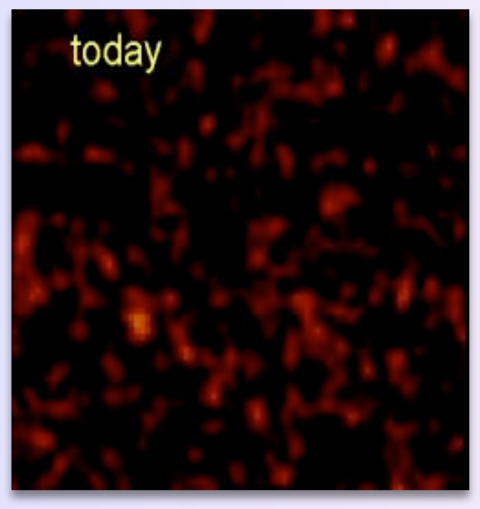


Extragalactic Science with *NuSTAR*

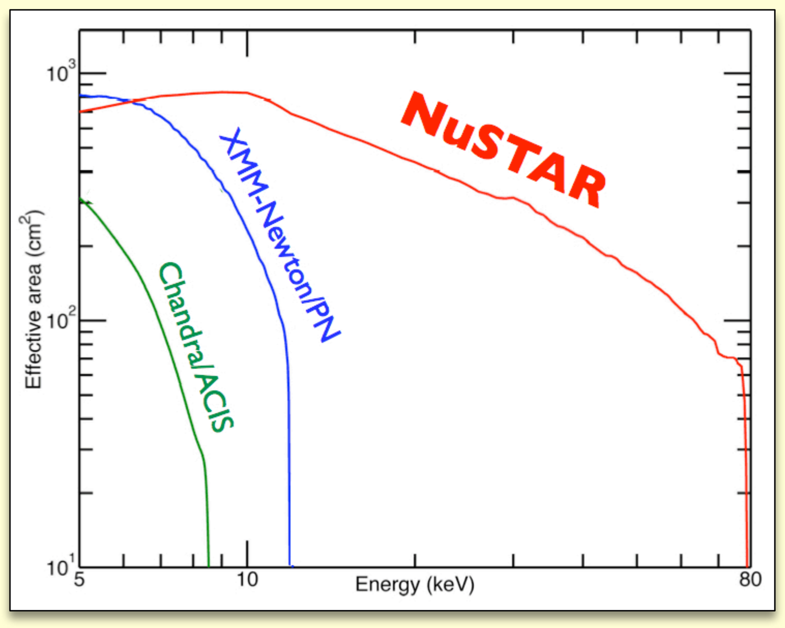
K. Madsen (Caltech) for the NuSTAR Team



ABSTRACT: The *Nuclear Spectroscopic Telescope Array (NuSTAR)*, scheduled for launch in 2012, will open the high energy extragalactic sky in the 5 - 80 keV band to sensitive study for the first time. The baseline 2-year mission includes a mixture of field surveys and targeted observations of known sources. A deep, several-month campaign observing the COSMOS and GOODS fields will significantly enhance our understanding of the sources contributing to the X-ray background at its 30 keV peak. In particular, models predict a population of heavily-obscured AGN, undetected in the soft X-rays, that will be seen in the hard X-ray observations of *NuSTAR*. Targeted observations include high energy studies of galaxy clusters to constrain non-thermal X-ray emission, coordinated blazar monitoring campaigns, observations of local starburst galaxies, and detailed studies of well-known AGN in order to study the physics of their high energy emission.

Overview

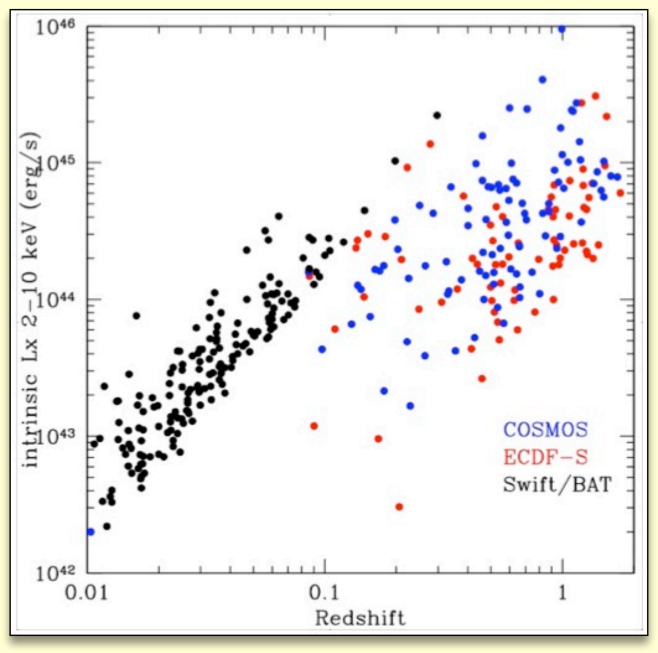
• *NuSTAR* will deploy the first focusing telescopes to image the sky in the high energy X-ray (5 - 80 keV) band. Our view of the universe in this window has been limited because previous orbiting hard X-ray telescopes have not employed true focusing optics, while focusing X-ray telescopes have had little sensitivity above 10 keV (see effective area curve below and poster #254.25 by Harrison *et al.*).
• A NASA Small Explorer (SMEX) mission, *NuSTAR* is currently in Phase C/D and is scheduled to launch into low-Earth orbit in Spring 2012.
• In addition to its core science program, *NuSTAR* will offer opportunities for a broad range of science investigations, ranging from probing cosmic ray origins to studying the extreme physics around collapsed stars to mapping microflares on the surface of the Sun.
• Here we survey planned extragalactic science targets and programs to be done with *NuSTAR*. See poster #254.09 by Kaspi *et al.* for Galactic science to be done with *NuSTAR*, and poster #142.42 by Elvis *et al.* for more details on *NuSTAR* AGN physics plans.



NuSTAR effective area vs. energy, compared to other focusing X-ray satellites.

Extragalactic Surveys

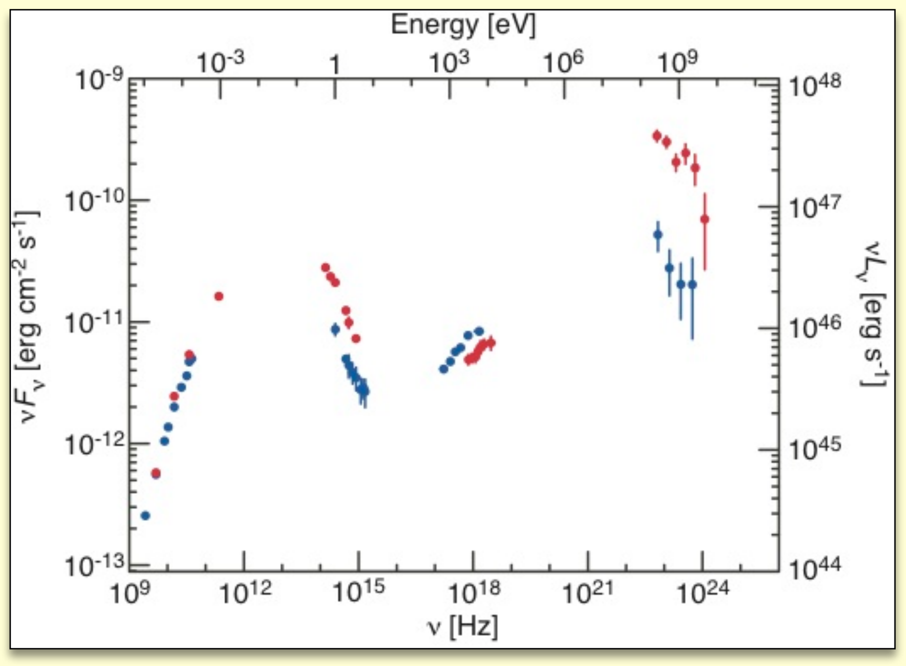
• *NuSTAR*'s excellent spatial resolution will allow extragalactic surveys of unprecedented sensitivity.
• Surveys will characterize the high-energy spectra of extragalactic sources, primarily AGN, and identify the most heavily obscured, Compton-thick AGN.
• The current baseline plan is a two-part survey, comprised of (i) one deg^2 in the COSMOS field observed to a depth of 50 ks per position, and (ii) 0.3 deg^2 of the E-CDFS field observed to a depth of 200 ks per position. The latter survey will be spread over the 2-year baseline mission, allowing temporal variability studies as well.
• This coordinated program will (i) determine what AGN populations dominate the X-ray background at 30 keV, (ii) measure the cosmic history of black hole growth independently of absorption, (iii) identify the most heavily obscured, Compton-thick AGN, and (iv) perform broad-band 0.3 - 80 keV spectral analyses of distant AGNs to search for the presence of absorption and spectral complexity.



Predicted redshift-luminosity plane for *NuSTAR*-detected AGNs in the baseline, two-part extragalactic survey, compared to AGNs from the *Swift*/BAT survey (Tueller *et al.* 2010; ApJS, **186**, 378). Properties of the *NuSTAR* AGN determined using the Treister *et al.* (2009; ApJ, **696**, 110) model.

Blazars

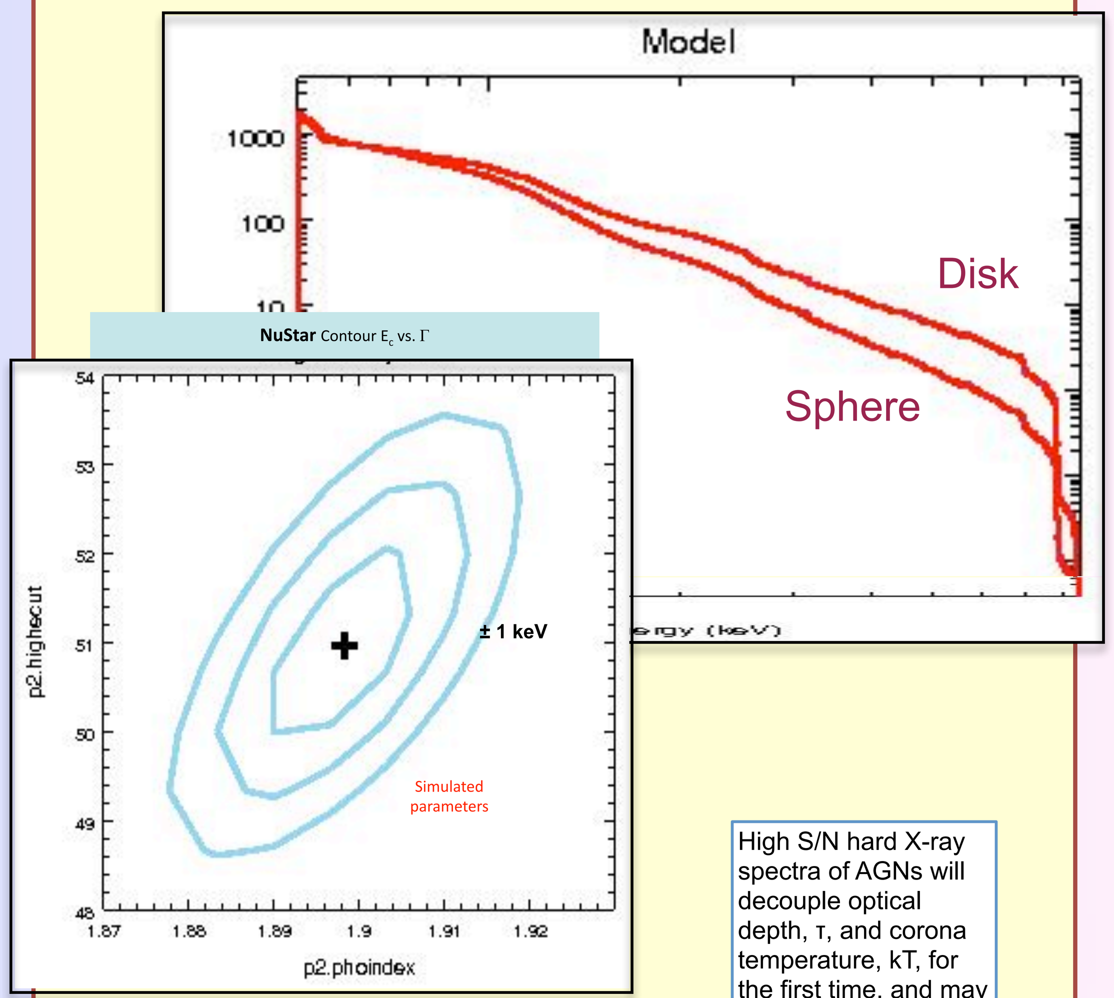
• Coordinated temporal monitoring of bright, jet-dominated blazars will determine the structure of AGN jets, primarily their content and the location of the dissipation region.
• We plan to perform coordinated observation campaigns with ground-based low-energy facilities (e.g., radio, near-infrared, and optical telescope), *Swift*, *Fermi*, and ground-based Cerenkov arrays.
• Targets will include two classes of blazars: (i) those with powerful jets associated with luminous quasars and detected as strong GeV emitters by *Fermi*, and (ii) less luminous BL Lac-type objects which are weaker in the GeV band but are strong TeV emitters.



Spectral energy distribution of 3C 279 from the radio to the γ-ray at two different epochs. Note that the total energy associated with the X-ray flare is relatively modest, about 30 times less than the energy associated with the γ-ray flare which accompanied a dramatic polarization change. From Abdo *et al.* (2010; Nature, **463**, 919). *NuSTAR* will help fill the gap between the soft X-ray and γ-ray observations.

AGN Physics: Corona Temp.

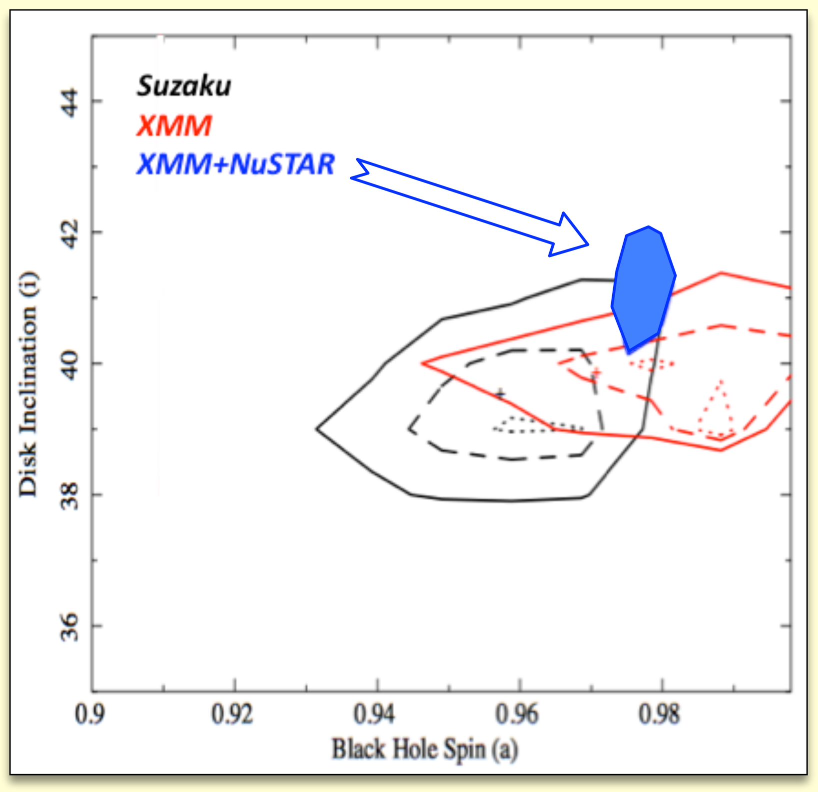
• *NuSTAR* observations of bright, nearby AGN will provide the best constraints to date on the corona temperature, breaking the degeneracy between two key corona parameters, temperature and optical depth. The target sample will include up to 10 AGN with a wide range of black hole masses and accretion rates. The sample will be used to test how Comptonization models, and particularly the assumed geometry, depend on physical parameters.



High S/N hard X-ray spectra of AGNs will decouple optical depth, τ, and corona temperature, kT, for the first time, and may also allow tests of the corona geometry.

AGN Physics: BH Spin

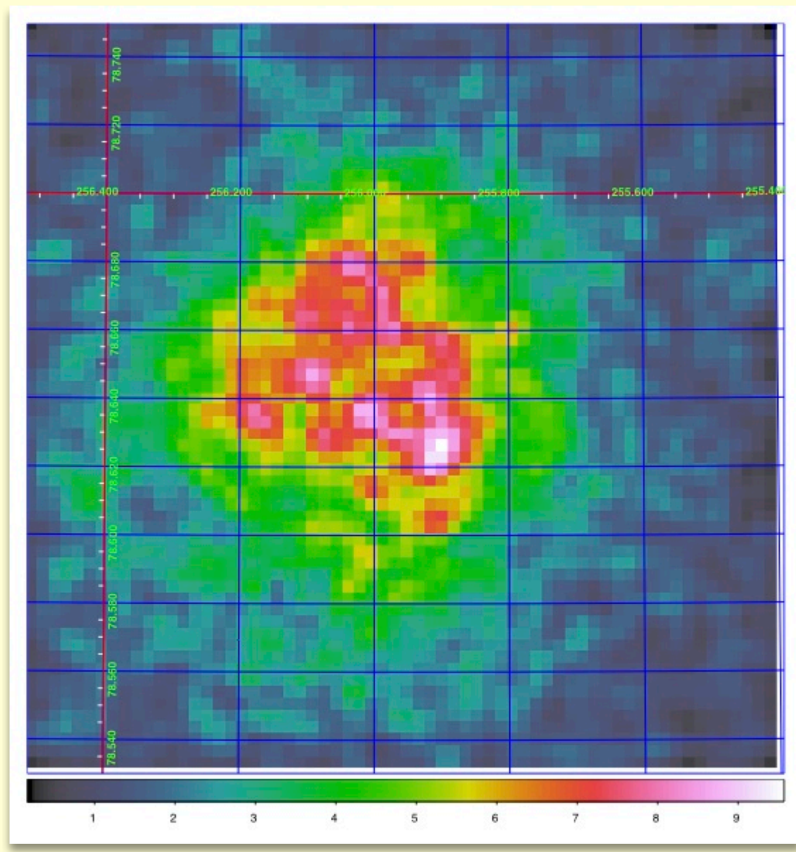
• Hard X-ray observations of AGN above 10 keV provide a critical complement to the more standard 0.5-10 keV window, allowing more precise constraints to be placed on the physical properties of the continuum and accretion disk.
• Combined with spectral data from *Chandra*, *XMM-Newton* and/or *Suzaku*, *NuSTAR* will differentiate between complex absorption and reflection models in a sample of luminous AGN spectra. If the reflection spectrum is robustly detected, *NuSTAR* will be a uniquely powerful probe of supermassive black hole spin.



Contours showing a dual error analysis of black hole spin and disk inclination angle performed on simulated observations of MCG-6-30-15. *NuSTAR* observations will provide a factor of five improvement in BH spin measurements, compared to *Suzaku* or *XMM-Newton* observations.

Galaxy Clusters

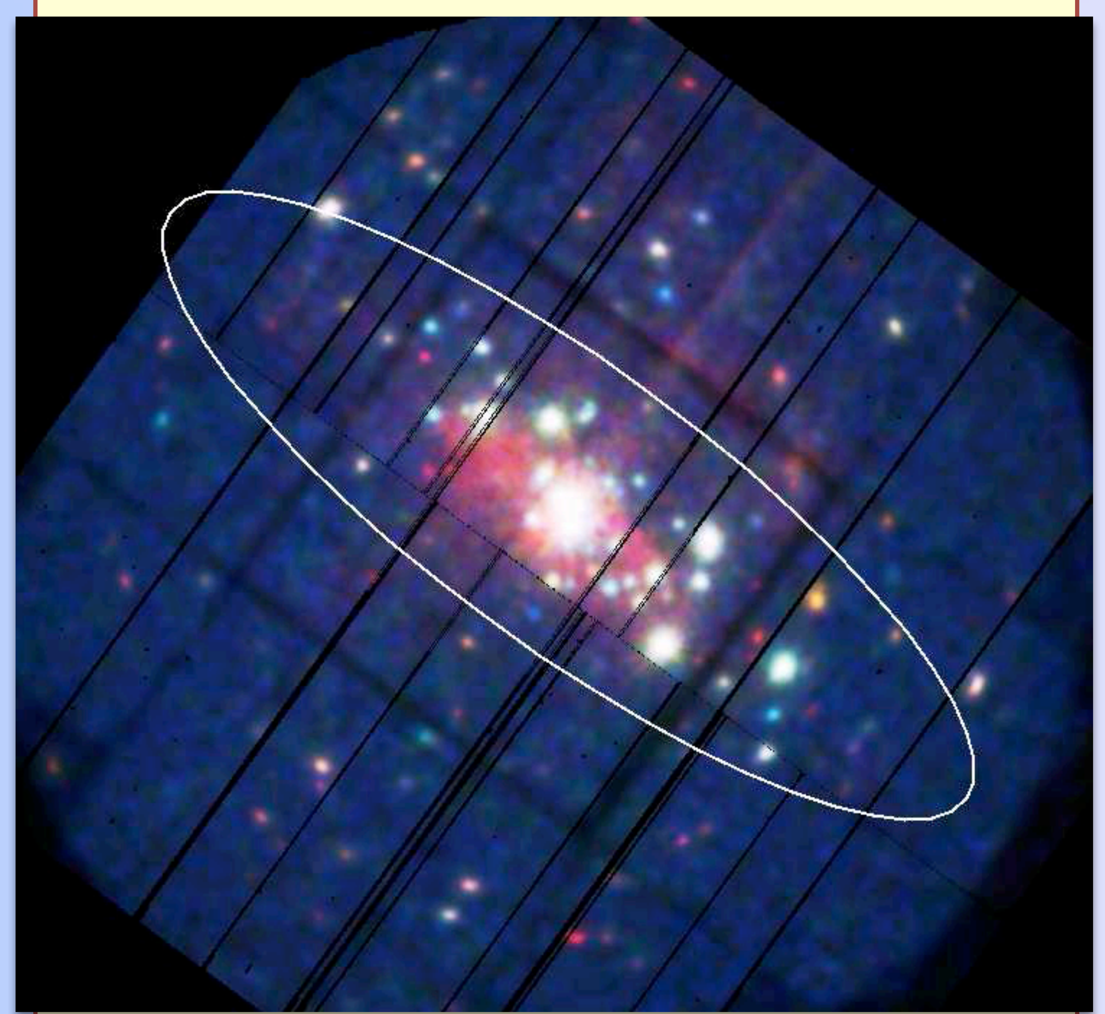
• The intracluster medium (ISM) of rich galaxy clusters is known to be magnetized. Radio observations imply magnetic field strengths of a few μG. However, hard X-ray observations have the capability to improve such measurements: the same non-thermal electrons which are responsible for synchrotron emission at radio energies will inverse Compton CMB photons into the X-ray band. Results to date have been controversial (see recent review in Rephaeli *et al.* 2008; Space Sci. Rev., **134**, 71).
• *NuSTAR* observations will (i) detect and characterize the controversial non-thermal components reported thus far at high energies, and (ii) characterize the hot thermal emission in the vicinity of shock fronts.



Ray tracing simulation of 50 ks *NuSTAR* observation of Abell 2256, based on *Chandra* observations of this rich galaxy cluster (Sun *et al.* 2002; ApJ, **565**, 867). The energy range is 15-40 keV. The high surface brightness visible in the SW corner is related to the high termperature in this region.

Starburst Galaxies

• Star-forming galaxies dominate the census of X-ray emitting galaxies in the local universe, but our knowledge of their high-energy properties is sparse.
• *NuSTAR* plans to temporal monitoring of two nearby star-forming galaxies, NGC 253 and M82. These observations will characterize their hard X-ray properties and populations, including the ultraluminous X-ray source (ULX) M82 X-1. We will also look for diffuse inverse Compton emission.



XMM-Newton image of NGC 253, from Barnard *et al.* (2008; MNRAS, **388**, 849). The image extends over 30' x 30', demonstrating that this galaxy will be well-resolved with the ~45" angular resolution of *NuSTAR*.

NuSTAR Specifications

Energy Range	5-80 keV
Angular Resolution	43 arcsec (HPD) 7.5 arcsec (FWHM)
Field of View (50% response)	10 arcmin (10 keV) 8 arcmin (40 keV) 6 arcmin (68 keV)
Strong Source Positioning (>10σ)	1.5 arcsec (1σ radius)
Spectral Resolution	1.2 keV at 68 keV (FWHM)
Sensitivity (3σ, 1 Ms)	2×10^{-15} cgs (6-10 keV) 1×10^{-14} cgs (10-30 keV)
Temporal Resolution	0.1 msec
ToO Response	<48 hr
Launch Date	February 2012
Orbit	6 degrees 550 km x 600 km
Mission Lifetime Orbit Lifetime	2 years baseline >7 years orbit lifetime
Maximum Flux Measurement Rate	10,000 cts/sec

Current best estimates (CBEs) as of June 2010. For more details, see *NuSTAR* website, http://nustar.caltech.edu.