



Observations of Compact Stars and Supernova Remnants with NuSTAR

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The Nuclear Spectroscopic Telescope Array (NuSTAR), scheduled for launch in 2011, will open the high energy X-ray sky, from 6 - 79 keV, for sensitive study for the first time. As part of its primary science program NuSTAR will undertake two Galactic key programs. Here we describe the observational program, and present simulations of the expected data quality.

Compact Stellar Remnants

Galactic center:

- Highest source density
- Thousands of point sources
- Highly absorbed sources
- Extremely hard spectrum

Expected Source Populations:

- White Dwarfs (CVs, Intermediate Polars)
- HMXBs, LMXBs
- Pulsars: Rotation powered, magnetars
- Black Holes

Survey Goals:

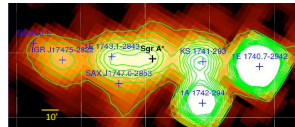
- Map the region with High Sensitivity and High Spectral Resolution
- Measure spectra and long term variability
- New constraints on star formation rate
- Study origin and evolution of primordial binaries
- Duration: 4 months
- Area: $0.8^\circ \times 2^\circ$

As part of the key science case, NuSTAR will accomplish several things. First, it will carry out a survey of the densest part of the Galaxy, the Galactic center, in order to identify a large sample of accreting neutron stars and black holes. Shown below is a comparison between the current state-of-the-art Integral maps of the galactic center and simulated NuSTAR images. NuSTAR has much better angular resolution, and is therefore two orders of magnitude more sensitive. The tighter PSF allows one to resolve the bright X-ray binaries from a background of fainter sources. Based on population synthesis models, we expect there to be around 100 black holes and neutron stars accreting from the winds of high mass companions in this region. These will have harder spectra than the more-numerous cataclysmic variables, and so should be easily identifiable. This will nearly double the sample of known HMXBs. Finding them will allow us to pursue ground-based near-IR observations to measure the masses of the compact objects.

As a by-product, we will also survey hard X-ray emission from past outbursts of the supermassive black hole Sgr A*, in reflection nebulae. The broadband spectrum of these nebulae is produced by Compton scattering, and peaks in the NuSTAR bandpass around 30-60 keV. Temporal evolution of small scale structures in the nebulae will tell us about the past outbursts of Sgr A*, and how it interacts with its environment.

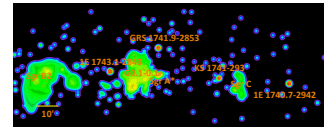
Simulations

IBIS image (Belanger et. al. 2005)



•12' resolution
 •Sensitivity $\sim 10^{-13}$ erg $\text{cm}^{-2} \text{s}^{-1}$ (20-40 keV).

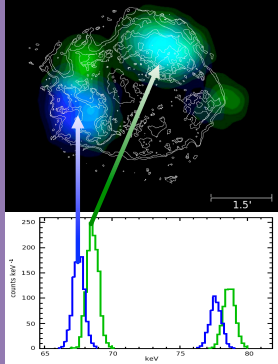
Simulated NuSTAR image



•40" resolution
 •Sensitivity $\sim 10^{-15}$ erg $\text{cm}^{-2} \text{s}^{-1}$ (20-40 keV, 10⁶s)

Cas A supernova remnant

NuSTAR simulation + Chandra contours



Galactic supernova remnants

Supernovae seed the interstellar medium with the heavy elements formed in the quasi-equilibrium conditions of stellar burning and in the non-equilibrium conditions of the explosion itself. A detailed understanding of the explosion dynamics could be obtained from spatially resolved abundance maps of remnants that have not yet swept up enough surrounding interstellar material to enter the Sedov self-similar expansion phase. A particularly valuable isotope is ⁴⁴Ti decays into ⁴⁴Sc, producing de-excitation lines at 68 keV (91%) and 78 keV (97%) with characteristic lifetime $\tau \sim 85$ yr. In core collapse events, the predominant production of ⁴⁴Ca, as ⁴⁴Ti, occurs during α -rich freeze-out around the mass cut, between the innermost ejecta and the material that falls back to form a collapsed remnant. This location implies that ⁴⁴Ti production and ejection are very sensitive to the explosion mechanism and ejecta dynamics. The X-ray lines have been detected only in Cas A so far, hinting towards the possibility that Cas A might have produced an anomalously high amount of ⁴⁴Ti. NuSTAR has the sensitivity to detect ⁴⁴Ti in other nearby young supernova remnants: telling us about the spatial and velocity distribution of ⁴⁴Ti.

SNe Ia, the thermonuclear explosions of degenerate white dwarfs, are profoundly radioactive events. As much as one-half of the white dwarf mass is fused to ⁵⁶Ni ($t_{\text{half}} = 6.1$ d). After a short time, it is the decay of this nucleus and its daughter, ⁵⁶Co ($t_{\text{half}} = 77$ d), which power the entire visible display of the supernova. Most of this power, however, is emitted in the form of γ -ray lines, some of which begin to escape several days. While these γ -ray lines are the most direct diagnostic of the dominant processes in the nuclear burning and explosion, they are inaccessible to current γ -ray instruments. NuSTAR, however, is potentially sensitive to the photoabsorbed Compton-scatter continuum of these lines which extends down into the NuSTAR bandpass for SNe Ia within ~ 3 -4 Mpc. The flux and spectral shape of this hard X-ray component is sensitive to both the overall nucleosynthesis (level of the Compton-scatter continuum) and the amount of mixing in the ejecta (measured by the photoabsorption). Through these measurements, NuSTAR is uniquely poised to help answer fundamental questions like nature of the binary companion, nuclear flame propagation, asymmetries, and even shed light on the physics behind the Phillips relation.

Survey Goals:

- Spectral and Spatial mapping of young supernova remnants
- Duration: 6 months

⁴⁴Ti lines:

- De-excitation lines at 68 keV and 78 keV
- Sensitive tracers of explosion and dynamics

Targets:

- Cas A
- Kepler/1987 A
- G1.9+0.3
- Tycho

Other Galactic Objectives

A number of other compelling investigations can be undertaken either with data obtained for the key goals, or with additional observations. The investigations described here will in some cases be carried out as part of other goals, during calibration target observations, or as community proposed targets as part of a post mission.

- Cyclotron lines in accreting pulsars
- Magnetars (AXPs, SGRs)
- X-ray bursters
- Pulsar Winds in the Crab
- TeV sources: binaries, star forming regions, SNR
- Hard X-rays from protostars
- Stellar flares
- Solar corona
- Sites of Cosmic Ray acceleration
- Hard, Diffuse Galactic emission
- Black holes in active state and quiescence
- Targets of opportunity (Novae, Local SNe)

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