NuSTAR’s View of AGN
L.W. Brenneman on behalf of the NuSTAR AGN Physics Team

Harvard-Smithsonian Center for Astrophysics 60 Garden St. MS-67 Cambridge, MA 02138, USA, e-mail: lbrenneman@cfa.harvard.edu

Abstract. The launch of the Nuclear Spectroscopic Telescope Array (NuSTAR) in June 2012 has opened a new window onto the high-energy universe. The study of active galactic nuclei (AGN) and the supermassive black holes (SMBHs) within them stands to benefit greatly from this observatory. NuSTAR’s unique combination of focusing X-ray optics, large effective area and low background over the 3 – 79 keV energy band allows us to unambiguously probe the nature of complex AGN environs. I will review the planned AGN physics science goals for the mission with a particular focus on joint XMM/Swift/NuSTAR and Suzaku/NuSTAR observing campaigns to constrain the properties of the SMBHs, inner accretion disks and coronae in six bright, nearby AGN. Obtaining high signal-to-noise spectra across a broad bandpass is crucial for this work, enabling degeneracies between the continuum, reflection and absorption signatures in the spectrum to be broken for the first time. I will show early results from the Suzaku/NuSTAR campaign on the bright Seyfert IC 4329A as a preview of the quality of results we can expect from these collaborations.

Key words. Accretion, accretion disks – Galaxies: IC 4329A – Galaxies: active – Galaxies: nuclei – X-rays: galaxies

1. Introduction

High-energy studies of AGN offer the chance to shed light on some of the most powerful physical phenomena in the universe. Since the advent of the unified model ([Antonucci] 1993; [Urry & Padovani] 1995), great progress has been made in understanding the structure and energetics of the cores of active galaxies through the high spatial and spectral resolution made possible by orbiting X-ray telescopes such as Chandra, XMM-Newton, Suzaku and Swift. Yet with each new discovery unveiled by these instruments, more mysteries seemingly arise. Some of the most pressing unanswered questions in AGN astrophysics are:

- What is the nature and physical origin of the putative “corona?”
- What is the distribution of SMBH spins in the local universe?
- What is the true nature of the soft X-ray excess?
- How are jet triggered and what is their role in the overall energy budget of the AGN?
- What processes create the absorbing structures in AGN?
- What are the true physical properties of obscured AGN, and what is their role in the Cosmic X-ray Background (CXB)?

To answer these questions, the technological strengths of current X-ray observatories must be harnessed and extended over a wider energy range. In particular, a hard X-ray telescope with high effective area above 10 keV, adequate spatial resolution to unam-
NuSTAR and AGN

Brenneman: NuSTAR and AGN

bliquously detect AGN, and moderate-to-high spectral resolution would prove invaluable. Such an instrument would enable detection of even Compton-thick AGN, and would provide unprecedented signal-to-noise (S/N) over an energy range well suited to breaking spectral modelling degeneracies, thereby elucidating the physical processes at work in the hearts of the most energetic galaxies in the universe.

The launch of NuSTAR ([Harrison et al. 2005]) in June 2012 addresses these critical scientific requirements. Its two telescope modules each bear four 32 × 32 CZT detectors, enabling focused images above 10 keV for the first time. This technology offers a ~ 2 orders of magnitude improvement over coded apertures, while the 10 m extendable mast provides a long focal length critical to achieving its ~ 18 arcsec FWHM spatial resolution. The combination of higher effective area than the XMM/EPIC-pn above 6 keV and lower background than the Suzaku/PIN above 10 keV means that NuSTAR provides the highest S/N from 3 – 79 keV of any current X-ray telescope. With spectral resolution ranging from 0.4 keV at 6 keV to 1 keV at 60 keV, NuSTAR enables the most sensitive spectral measurements ever achieved of AGN in this energy band. Additionally, its 0.1 msec timing resolution ensures that even the shortest variability timescales for each AGN will be resolved.

2. The NuSTAR AGN physics program

The goals of NuSTAR’s research program in AGN physics are designed to overlap with the unanswered questions in AGN science laid out in §1. During the first two years of observations, NuSTAR will focus primarily on three topics of great interest to the X-ray astronomy community:

- Determining the properties of the corona;
- Measuring SMBH spins in bright, nearby AGN;
- Characterizing the role of complex absorption vs. reflection in AGN.

Separate NuSTAR science programs are dedicated more specifically to examining blazars and obscured AGN, so those two topics will not be further discussed here.

The three science goals of the AGN Physics Program are all complicated by the same challenge: determining the true shape of the X-ray continuum. Achieving this objective is a crucial first step toward accurately identifying the properties of the corona, absorption and reflection in a given AGN. Deconvolving these components is virtually impossible with spectra over a limited bandpass, even those with high S/N, due to inherent modelling degeneracies (e.g., Brenneman & Reynolds 2006 vs. Miller, Turner & Reeves 2008). With sensitivity down to 3 keV and up to 79 keV, NuSTAR can measure coronal properties with great precision by locating the cutoff energy of the coronal continuum component (typically parameterized by a power-law or Comptonization model). This precision is typically of the order of a few keV out to ~ 150 keV, and worsens to tens of keV beyond this energy as the effective area of the telescope decreases. The accuracy of this measured cutoff energy may be suspect without knowledge of the continuum ≤ 1 keV, however, owing to the change in shape of the spectrum due to complex absorption and reflection, as well any additional soft excess component that may be present in many AGN. Similar accuracy issues play a significant role in NuSTAR’s ability to address, on its own, measurements of black hole spin and separating absorption vs. reflection signatures, even in bright, nearby AGN.

To enable NuSTAR to achieve its scientific objectives, we have coordinated simultaneous observations of seven AGN with XMM, Suzaku, and/or Swift, totaling ~ 1.5 Ms in the current cycle. These observations will yield the highest quality data ever achieved over the 0.2 – 79 keV range, and will enable us to examine both time-averaged and time-resolved broad band spectra. By isolating the true continuum shape of each AGN, we will be able to accurately and precisely measure the physical properties of their coronae for the first time, converting the high-energy cutoff to an electron temperature and thus breaking the degeneracy between the temperature and optical depth of the plasma. In so doing, we will also
be able to characterize the nature and location of the absorbing structure(s) within the AGN, and to separate the effects of this absorption from the presence of inner disk reflection signatures. If such reflection can be conclusively identified, we can measure the spin of the SMBH at the AGN’s core by modelling the effects of frame-dragging on fluorescent spectral lines emitted from matter about to be accreted onto the SMBH (e.g., Reynolds & Beckmann et al. 2009, 2012, 2013). The addition of simultaneous Swift/UVOT data to this observation will enable us to examine multi-wavelength evidence to establish the true inner radius of the disk, and to assess whether it is recessed in conjunction with a major radio outburst from the jet (Marscher et al. 2002, Chatterjee et al. 2009). If it is not recessed, a rare spin measurement for a radio-loud AGN will be possible.

3. Preliminary results: IC 4329A

Though several of the AGN in our campaign have been observed to date, calibration of NuSTAR data is ongoing, and our spectral analysis depends critically on precise calibration. As such, we stress that the results quoted in this proceeding are preliminary in nature. Here, we showcase some early work on the simultaneous Suzaku/NuSTAR observation of IC 4329A (z = 0.0161, Willmer et al. 1991). Light curves for Suzaku/XIS and NuSTAR are shown in Fig. 1. Note that there is a ~ 34% secular decrease in flux over the course of the Suzaku observation after an initial ~ 12% increase during the first 50 ks. The NuSTAR data follow this behavior.

Based on the lack of significant variability in this source on any time scale in the observation, it is safe to make physical inferences about the system by modelling the time-averaged data in order to maximize S/N. An examination of the time-averaged spectrum fit with a simple power-law model modified by Galactic photoabsorption (Fig. 2) shows three prominent residual features: (1) a ~ 60% drop in the data-to-model ratio below 2 keV, owing to the presence of complex absorption; (2) a relatively narrow Fe Kα emission line at 6.4 keV, likely originating from neutral gas in the outer accretion disk or torus; (3) a Compton hump above 10 keV, also originating from reflection. This simple fit yields χ²/ν = 160 and is clearly not an adequate representation of the spectrum. Applying an ionized absorber, a distant, neutral reflection component and a high-energy cutoff to the power-law improves the fit...
Table 1. Targets in the NuSTAR AGN Physics Program to be observed simultaneously with XMM, Suzaku and/or Swift.

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4. Conclusions

With its unique combination of high effective area, low background, focusing optics and broad spectral bandpass, NuSTAR is providing the highest S/N spectra of AGN above 10 keV that has ever been achieved. When used simultaneously with X-ray telescopes at lower energies with high spectral resolution, such as XMM, Suzaku and Swift, unprecedented advances in our understanding of AGN physics are possible.

We have reported on an ongoing campaign to observe seven AGN simultaneously with some or all of these four telescopes. The primary science goals of this campaign are three-fold: (1) to achieve a better understanding of the nature of the corona, breaking the degeneracy between its temperature and optical depth, (2) to achieve the most precise, accurate spin constraints to date for a small sample of AGN, and (3) to robustly deconvolve the continuum, reflection and absorption signatures in these galaxies.
To date, we have completed observations on four of our targets. Though the calibration of *NuSTAR* is ongoing, we report on our preliminary analysis of the spectral and timing properties of IC 4329A here. This AGN displays little spectral variability during the course of its 120 ks *Suzaku/NuSTAR* observation, and an examination of the time-averaged spectrum reveals that the principal spectral components are a continuum power-law with a high-energy cutoff, modest reflection from distant, neutral material, and a relatively small amount of ionized absorption. Evidence to support the presence of inner disk reflection is marginal, at best, which will prohibit us from measuring the spin of the supermassive black hole in this AGN. However, the combined spectrum is of sufficiently high quality that we expect to derive the most accurate, precise measurement ever obtained for the high-energy cutoff of the power-law in IC 4329A.

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Fig. 2. Left: Ratio of the simultaneous Suzaku/NuSTAR time-averaged spectrum of IC 4329A to a power-law. The power-law is fit over the 3 – 5 keV and 7 – 79 keV bands to highlight the residual, non-continuum components of the spectrum, i.e., the ionized absorber and reflection features. Black and red data points depict the Suzaku/XIS-FI and XIS-BI spectra, respectively. Green and dark blue data points show the NuSTAR/FPMA and FPMB spectra, respectively. Light blue data points show the Suzaku/PIN data. The horizontal green line represents a data-to-model ratio of unity. Right: The preliminary best-fit model components for the simultaneous Suzaku/NuSTAR spectrum of IC 4329A. The summed model is shown by the black solid line, while the individual model components are shown as dashed lines: absorbed power-law in red, distant reflection in blue (including the narrow fluorescent lines of Fe Kα and Kβ, as well as a Compton shoulder) and the marginal presence of a broadened Fe Kα line in magenta. The O vii emission line is shown in green.

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References
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