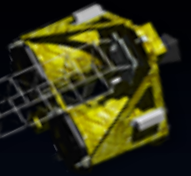
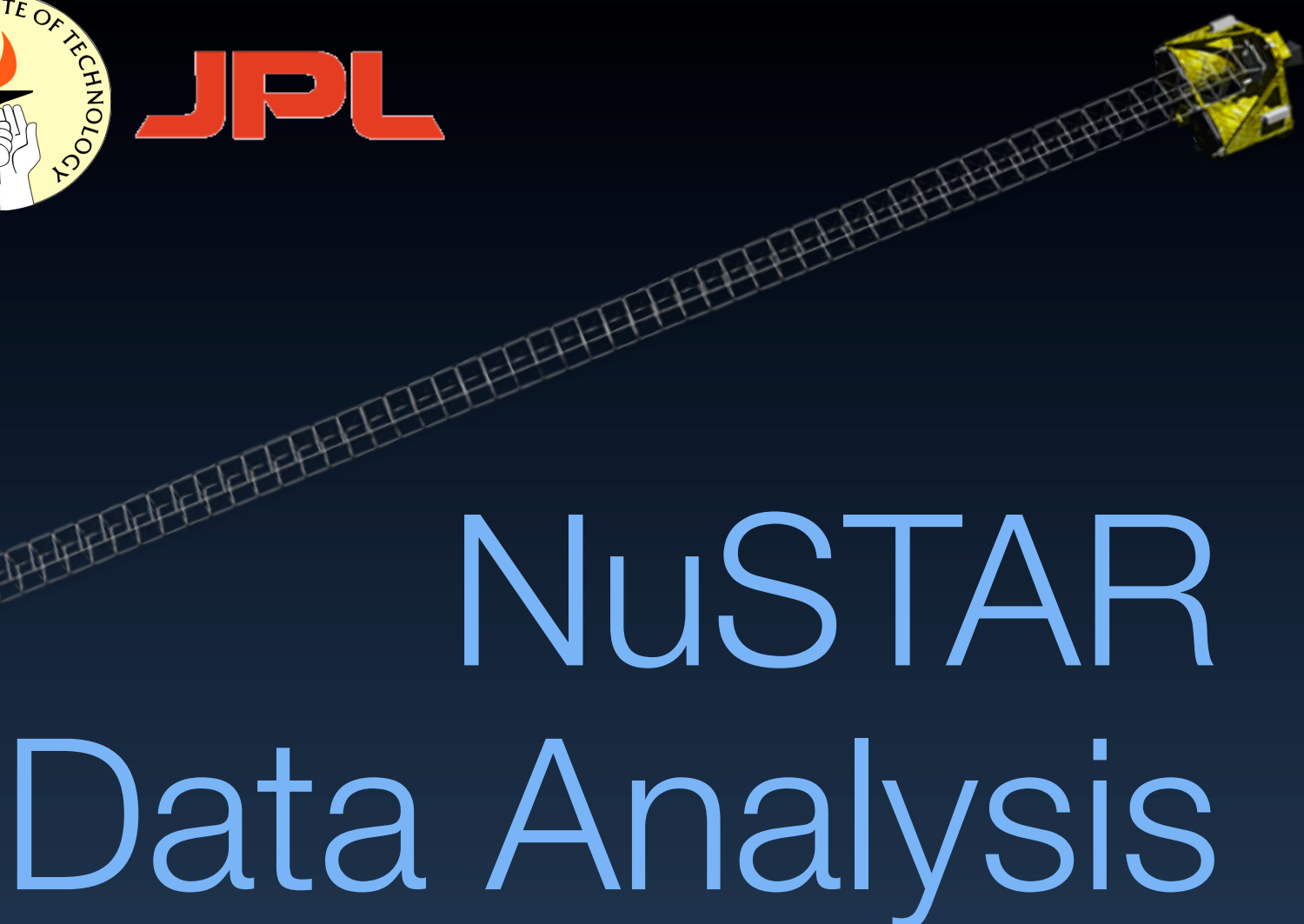
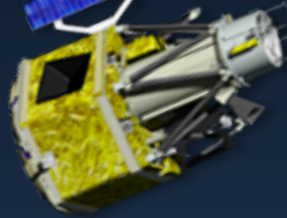
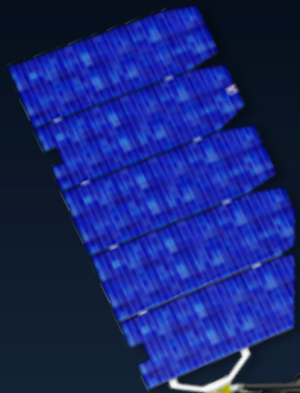




**JPL**



# NuSTAR Data Analysis

Varun Bhalerao (IUCAA)

# NuSTAR

## Data access

## Data analysis

# NuSTAR

Data access

Data analysis

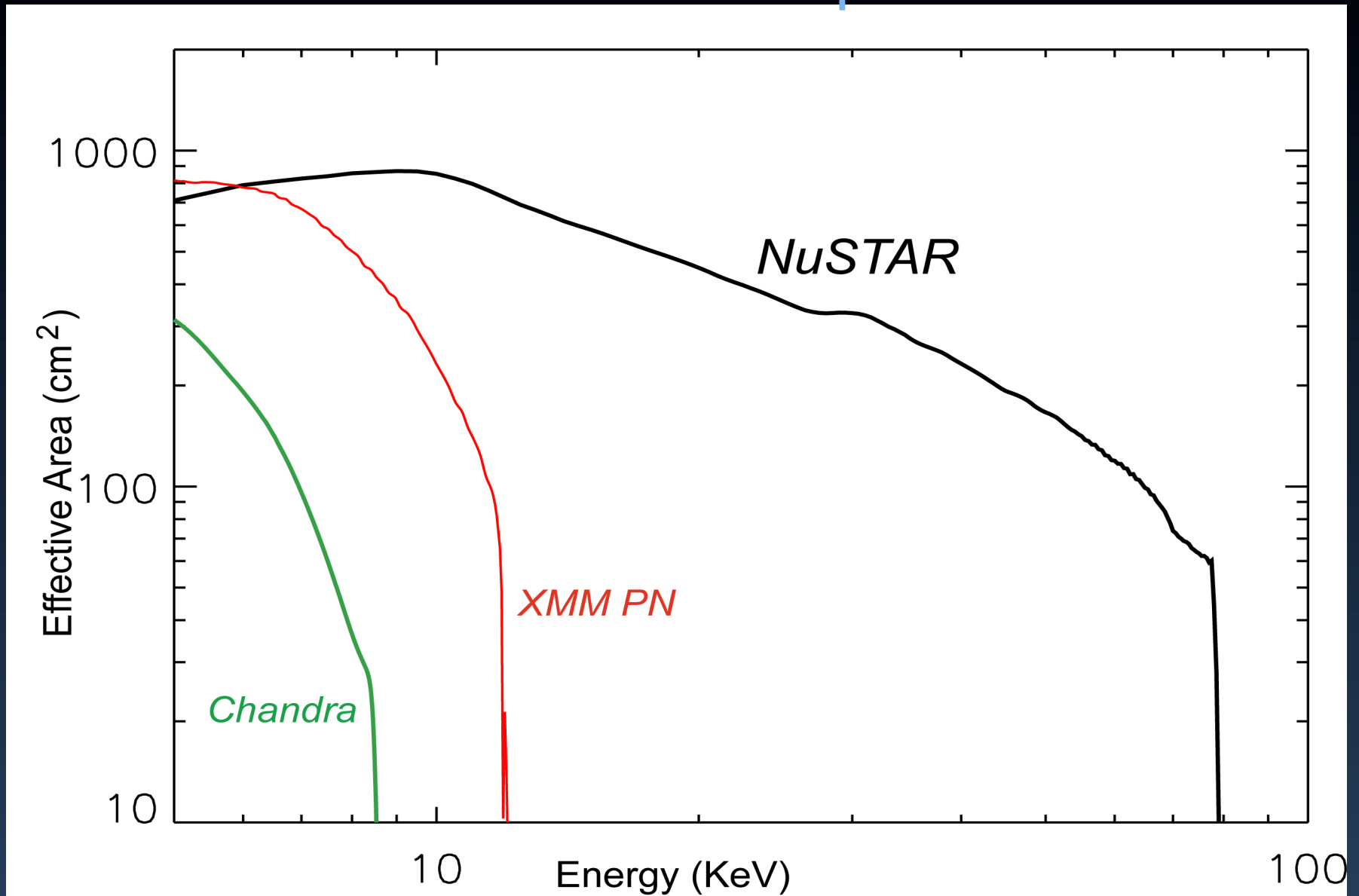
# What is NuSTAR?



- Nuclear Spectroscopic Telescope Array
- NASA small explorer mission
- First focusing hard X-ray space telescope
- Currently in guest observer phase

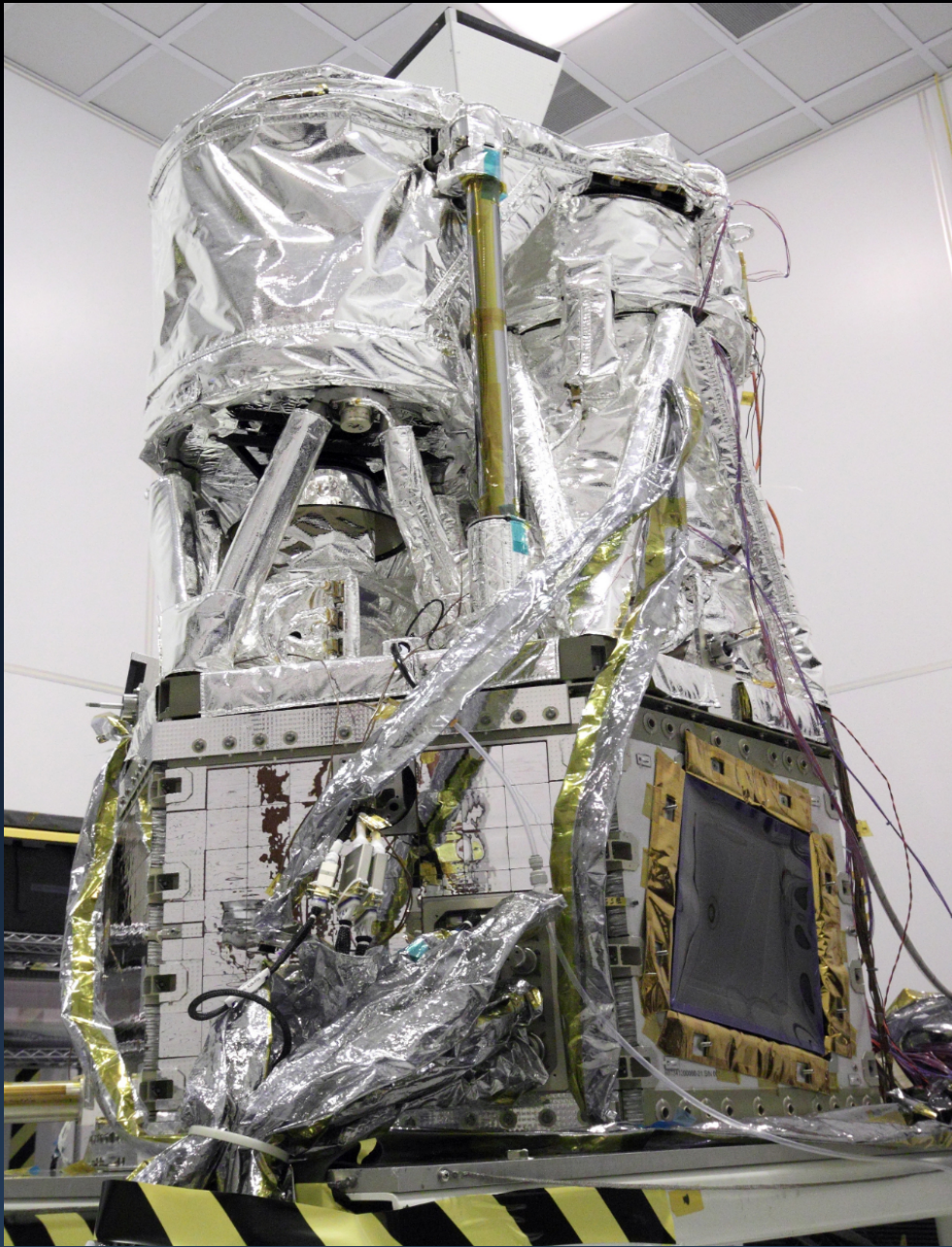
Proposals due 11 Dec !

# Instrument Specs



# Instrument Specs

- Energy range: 6 – 80 keV
- Angular resolution:
  - » Half-Power Diameter: 44”
  - » Sharp core of Point Spread Function: FWHM < 10”
- Point source positioning accuracy: 1.5”
- Field of view: 10’ at 10 keV, 6’ at 68 keV
- Sensitivity (1 Ms, 3-sigma):
  - » 6 – 10 keV :  $2 \times 10^{-15}$  erg cm<sup>-2</sup> s<sup>-1</sup>
  - » 10 – 30 keV :  $1 \times 10^{-14}$  erg cm<sup>-2</sup> s<sup>-1</sup>



# NuSTAR

## Data access

## Data analysis

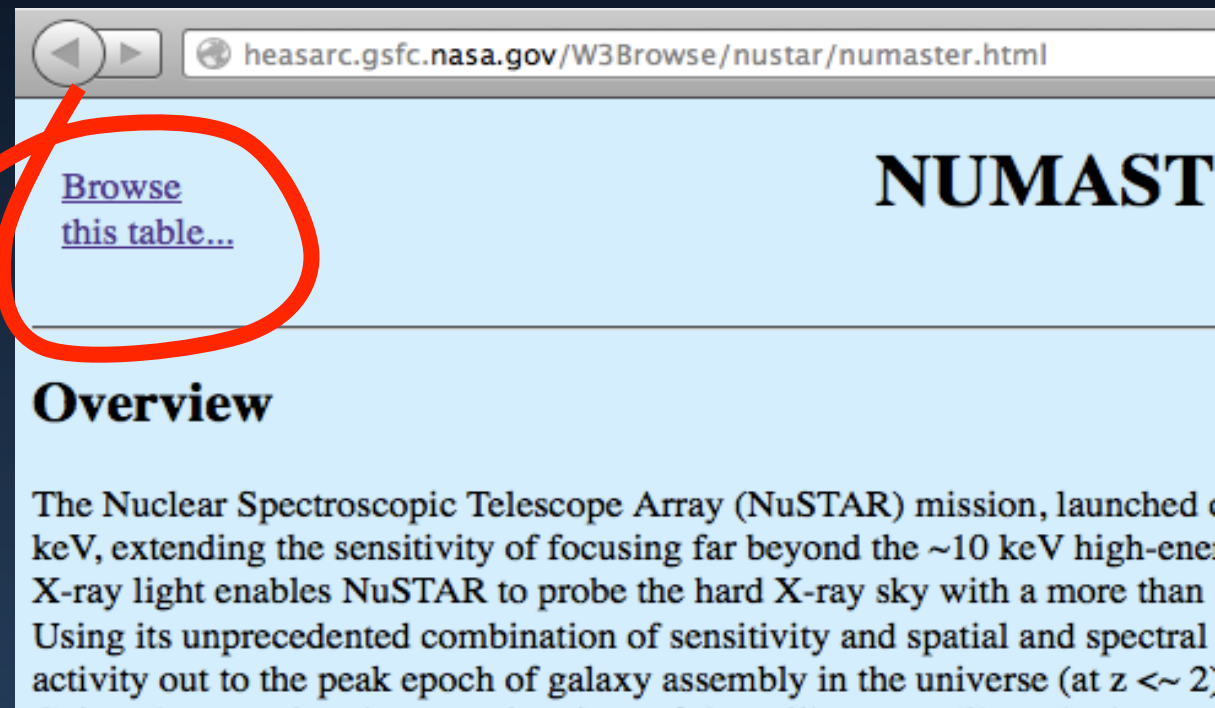


# Objects in the first release

- The nustar master catalog: **numaster**

<http://heasarc.gsfc.nasa.gov/W3Browse/nustar/numaster.html>

- Samples:
  - » Mkn 421, 3C 273
  - » LMC X-4, SMC X-1
  - » GRS 1915+105



# Accessing data

- Standard HEASARC interfaces:
  - » Browse
  - » Xamin
  - » FTP
- CALDB through HEASARC CALDB service
  - » Download (~800 MB, recommended)
  - » Web interface
- The NuSTAR archive on heasarc:

[http://heasarc.gsfc.nasa.gov/docs/nustar/nustar\\_archive.html](http://heasarc.gsfc.nasa.gov/docs/nustar/nustar_archive.html)



National Aeronautics and Space Administration  
Goddard Space Flight Center  
Sciences and Exploration

GO Search HEASARC website [Advanced Search]

HEASARC Quick Links  
---Quick Links---

<a href="#">HEASARC Home</a>	<a href="#">NuSTAR Home</a>	<a href="#">Archive</a>	<a href="#">Callbration</a>	<a href="#">Analysis</a>	<a href="#">Technical Description</a>	<a href="#">Students/Teachers/Public</a>
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<a href="#">About NuSTAR</a>	<a href="#">FAQ/Help</a>	<a href="#">What's New</a>	<a href="#">Related Sites</a>	<a href="#">Gallery</a>
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### NuSTAR Archive

After observatory activation, and a calibration and a verification phase, the first sets of NuSTAR data became publicly available on August 29th, 2013 through NASA's High Energy Astrophysics Science Archive Research Center ([HEASARC](#)). NuSTAR data are most easily accessible via the usual HEASARC archive interfaces, i.e., [Browse](#) and [Xamin](#), specifically making use of the master table of NuSTAR data sets archived at the HEASARC, the [NUMASTER table](#). Notice that some of these data sets may not yet be public: users should check the public\_date parameter in NUMASTER to determine the public availability of observations. Proprietary data are indicated by having either a null value or a future date for the public\_date parameter in the NUMASTER table. Users can query this table and download the data associated with the selected observation(s) using the usual Browse/Xamin procedures. Expert users who already know the Observation IDs (ObsIDs) of the dataset(s) in which they are interested, can also directly access NuSTAR data via the [HEASARC's ftp site](#).

It is expected that additional datasets will be released in October and December 2013, and that by early 2014 the HEASARC Archive will have 'caught up' with the available NuSTAR data: from then on, the data for a NuSTAR observation should become public no more than 60 days after the completion of that observation. The exceptions to this rule are:

[heasarc.gsfc.nasa.gov/docs/nustar/news/nustar\\_whatnew.html](#) will be released at the end of the exclusive use period associated with the other observatory,

# Alternate access

- ASI Science data center: <http://nustar.asdc.asi.it/>

The screenshot shows a web browser window with the URL [nustar.asdc.asi.it](http://nustar.asdc.asi.it). The page header features the ASDC logo (ASI Science Data Center) and the ASI logo (agenzia spaziale italiana). The main title is "ASI Science Data Center". Below this is a navigation menu with links: Home, About ASDC, Public Outreach, Quick Look, Missions, Multimission Archive, Catalogs, Tools, Links, Bibliographic services, and Helpdesk. The main banner displays the "NUSTAR" logo in large red letters over an image of the satellite in orbit against a starry background. Below the banner is another navigation menu: NuSTAR Home, NuSTARDAS Download, NuSTAR Archive, NuSTAR Observations, Malindi Ground Station, Gallery, and Links. The main content area has the heading "The Nuclear Spectroscopic Telescope Array Mission (NuSTAR)". Underneath is a "Mission Overview:" section with text describing the mission: "NuSTAR -launched June 13, 2012- is a Small Explorer mission led by the California Institute of Technology (Caltech) and managed by NASA's Jet Propulsion Laboratory in Pasadena. The observatory is the first focusing high-energy X-ray mission (3-80 keV) in orbit, opening the hard X-ray sky for sensitive study for the first time." To the right of the text is a circular logo for the "Nuclear Spectroscopic Telescope Array" featuring the "NUSTAR" name and the tagline "Bringing the High Energy Universe into Focus". The logo also includes a list of partner institutions: Caltech, MIT, UC Berkeley, Stanford, Cornell, Columbia, UCSD, Penn State, Johns Hopkins, Princeton, MIT Lincoln Lab, NASA, ASI, INAF, CNRS, IRTG, Garching, Durham, OSE, KIRAC, McGill, UofT, Berkeley, LLNL, SDSC, RAL, and OAC.

# Search “all” by object class

The screenshot shows a web browser window with the URL [www.asdc.asi.it/mmia/index.php?mission=numaster](http://www.asdc.asi.it/mmia/index.php?mission=numaster). The browser's address bar includes a search icon, a Google logo, and a search input field. Below the browser window is a navigation bar with icons for various space missions: AGILE, SWIFT, FERMI, HERSCHEL, PLANCK, BeppoSAX, NUSTAR, and Gaia. Below the mission icons are three tabs: "Astrophysics and Cosmology", "Exploration of the Solar System", and "Astroparticle Physics".

## Multi-Mission Interactive Archive

**Mission Selected**  
**Nustar Master**

**Search Type**

- Coordinates
- Time
- Parameter
- Class**

Stars-all types  
Late type stars  
RSCVn  
AGN-all types  
R-Quiet QSOs  
Clusters of galaxies  
Cataclismic Variables  
**X-ray binaries**  
Blazars-all types

Early type stars  
Pulsars  
Seyfert Galaxies  
R-Loud QSOs  
BL Lacs  
Galaxies  
White Dwarfs  
SNR

Output sorted by  
 RA  DEC  BII  
Radius  (arcmin)

**Submit**

**Catalog used for cross-correlation** XRBCAT - XRAY BINARIES

# NuSTAR

Data access

Data analysis

# NuSTARDAS

## NuSTAR Data Analysis Software

RAW  
DATA



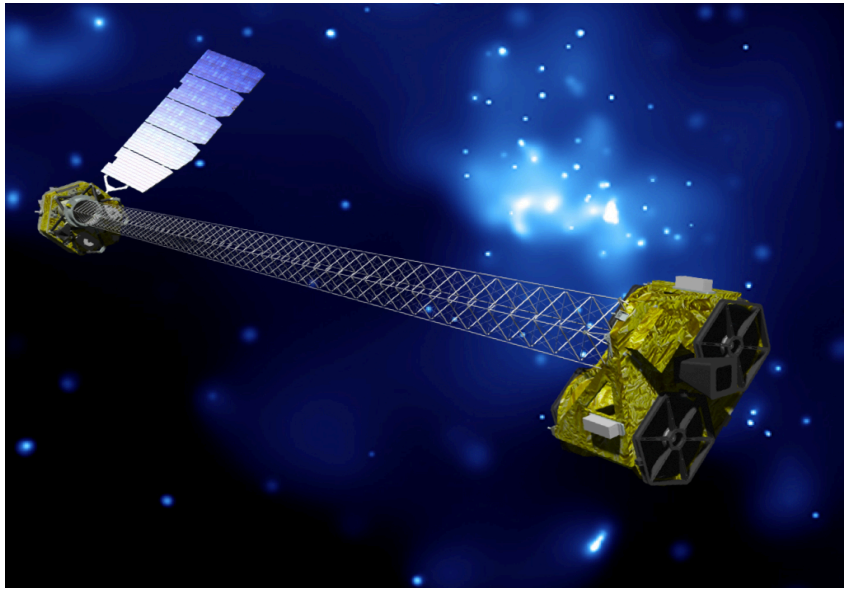
SCIENCE !  
xselect,  
xspec...

# Getting started

- Heasoft 6.17 (~ 350 MB source code)
  - » <http://heasarc.gsfc.nasa.gov/docs/software/lheasoft/>
- NuSTAR CALDB files (~ 800 MB compressed)
  - » <http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/nustar/>
- Read the caveats:
  - » <http://heasarc.gsfc.nasa.gov/docs/nustar/analysis/>



# NuSTAR DATA ANALYSIS Quickstart Guide



Version 1.0 (August 2013)

Karl Forster, Brian Grefenstette, & Kristin Madsen  
NuSTAR Science Operations Center,  
California Institute of Technology

[http://www.srl.caltech.edu/NuSTAR\\_Public/NuSTAROperationSite/Home.php](http://www.srl.caltech.edu/NuSTAR_Public/NuSTAROperationSite/Home.php)



## The NuSTAR Data Analysis Software Guide

M. Perri, S. Puccetti, N. Spagnuolo  
(ASI Science Data Center)

&

A. Davis, K. Forster, B. Grefenstette, F. Harrison, K. Madsen  
(California Institute of Technology)

Version 1.3  
August 2013

# Guides

- Quickstart guide – v1.1
  - » [http://heasarc.gsfc.nasa.gov/docs/nustar/analysis/nustar\\_quickstart\\_guide.pdf](http://heasarc.gsfc.nasa.gov/docs/nustar/analysis/nustar_quickstart_guide.pdf)
- Software manual – v1.8
  - » [http://heasarc.gsfc.nasa.gov/docs/nustar/analysis/nustar\\_swguide.pdf](http://heasarc.gsfc.nasa.gov/docs/nustar/analysis/nustar_swguide.pdf)
- FAQ:
  - » [http://heasarc.gsfc.nasa.gov/docs/nustar/nustar\\_faq.html](http://heasarc.gsfc.nasa.gov/docs/nustar/nustar_faq.html)

# Steps 1-2

- Download and extract data
  - » Organized by OBSID
- Run nupipeline
  - » Run time estimates: 11 ksec data set: 2.5 min
- Products:
  - » Cleaned event files (filtered for GTIs etc)

# Downloaded data

OBSID

80002013024/auxil:

nu80002013024\_att.fits    NUSTAR\_TLE\_ARCHIVE.txt.2013226  
nu80002013024\_orb.fits

Unfiltered event lists

80002013024/event\_uf:

nu80002013024A\_uf.evt    nu80002013024B\_uf.evt

Housekeeping data

80002013024/hk:

nu80002013024A\_dspix.fits    nu80002013024\_chu123.fits  
nu80002013024A\_fpm.hk    nu80002013024\_chu4.fits  
nu80002013024B\_dspix.fits    nu80002013024\_eng.hk  
nu80002013024B\_fpm.hk    nu80002013024\_met.fits  
nu80002013024\_ceb.hk    nu80002013024\_obeb.hk

# nupipeline

```
nupipeline \  
indir=./80002013024/ \  
steminputs=nu80002013024 \  
outdir=./80002013024/event_cl/
```

# Pipeline products

Cleaned  
event lists

Science  
mode data

2 sets of  
files: two  
telescopes

80002013024/event\_cl/:  
nu80002013024A01\_cl.evt  
nu80002013024A01\_gti.fits  
nu80002013024A02\_cl.evt  
nu80002013024A02\_gti.fits  
nu80002013024A03\_cl.evt  
nu80002013024A03\_gti.fits  
nu80002013024A04\_cl.evt  
nu80002013024A04\_gti.fits  
nu80002013024A05\_gti.fits  
nu80002013024A06\_cl.evt  
nu80002013024A06\_gti.fits  
nu80002013024A.attorb  
nu80002013024A\_bp.fits  
nu80002013024A\_det1.fits  
nu80002013024A\_fpm.hk  
nu80002013024A\_hp.fits  
nu80002013024A.mkf  
nu80002013024A\_oa.fits  
nu80002013024\_att.fits  
nu80002013024A\_uf.evt  
nu80002013024B01\_cl.evt  
nu80002013024B01\_gti.fits  
nu80002013024B02\_cl.evt  
nu80002013024B02\_gti.fits  
nu80002013024B03\_cl.evt  
nu80002013024B03\_gti.fits  
nu80002013024B04\_cl.evt  
nu80002013024B04\_gti.fits  
nu80002013024B05\_gti.fits  
nu80002013024B06\_cl.evt  
nu80002013024B06\_gti.fits  
nu80002013024B.attorb  
nu80002013024B\_bp.fits  
nu80002013024B\_det1.fits  
nu80002013024B\_fpm.hk  
nu80002013024B\_hp.fits  
nu80002013024B.mkf  
nu80002013024B\_oa.fits  
nu80002013024B\_uf.evt  
nu80002013024\_mast.fits  
nu80002013024\_psdcorr.fits  
nu80002013024\_psd.fits\_att.fits

# Steps 3-4

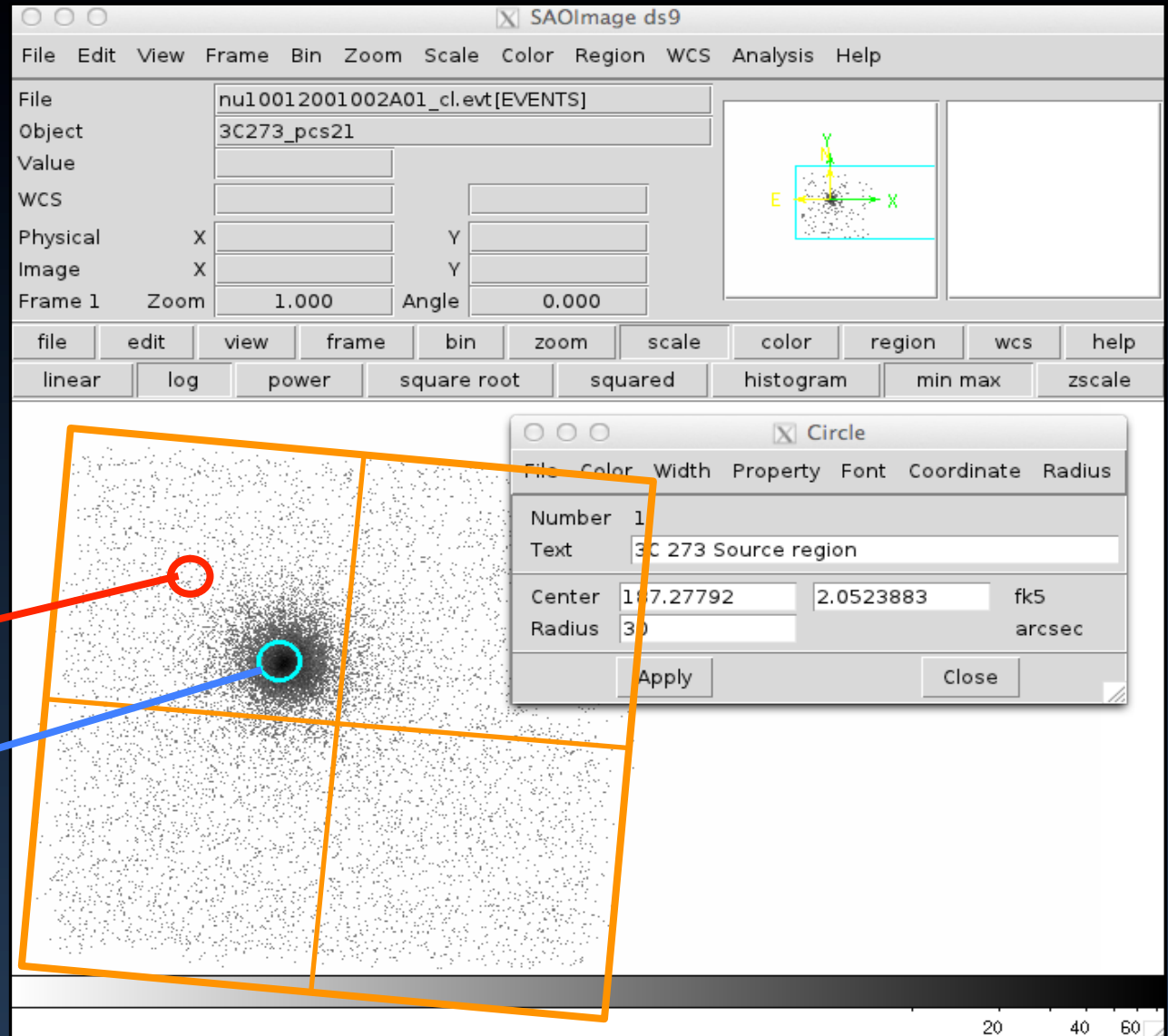
- Select source and background regions
  - » DS9 or FV
  - » Background on same chip
- Run nuproducts
  - » Run time estimates: 11 ksec data set:  $2 \times 1.5$  min
  - » Once for each telescope
- Products:
  - » PHA files, lightcurves, ARF, RMF...

# Select source and background regions

DS9 or FV

Background

Source





# nuproducts

```
nuproducts \  
srcregionfile=source.reg \  
bkgregionfile=bkg.reg \  
indir=./80002013024/event_cl/ \  
infile=./80002013024/event_cl/  
  nu80002013024A01_cl.evt \  
instrument=FPMA \  
steminputs=nu80002013024 \  
bkgextract=yes \  
outdir=./80002013024/event_cl/products
```

# Final products

```
ls products/
```

```
nu80002013024A01_bk.lc
```

```
nu80002013024A01_bk.pha
```

```
nu80002013024A01_im.ps
```

```
nu80002013024A01_lc.ps
```

```
nu80002013024A01_ph.ps
```

```
nu80002013024A01_offaxishisto.fits
```

```
nu80002013024A01_sk.img
```

```
nu80002013024A01_sr.arf
```

```
nu80002013024A01_sr.lc
```

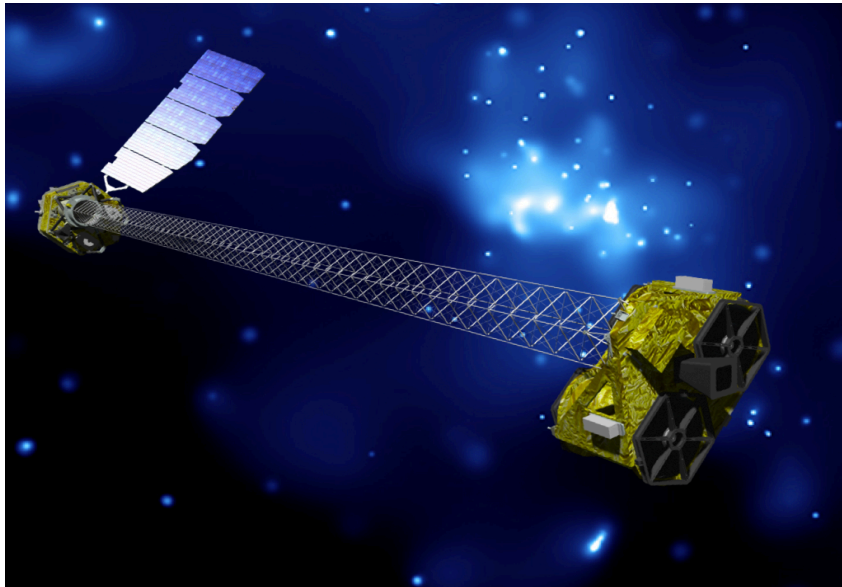
```
nu80002013024A01_sr.pha
```

```
nu80002013024A01_sr.rmf
```

Postscript files

Optional outputs

# NuSTAR DATA ANALYSIS Quickstart Guide



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(California Institute of Technology)

Version 1.3  
August 2013

# Links

## DATA:

<http://heasarc.gsfc.nasa.gov/W3Browse/nustar/numaster.html>

<http://nustar.asdc.asi.it/>

## Software:

<http://heasarc.gsfc.nasa.gov/docs/software/lheasoft/>

<http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/nustar/>

## Methods:

<http://heasarc.gsfc.nasa.gov/docs/nustar/analysis/>

[http://heasarc.gsfc.nasa.gov/docs/nustar/nustar\\_faq.html](http://heasarc.gsfc.nasa.gov/docs/nustar/nustar_faq.html)