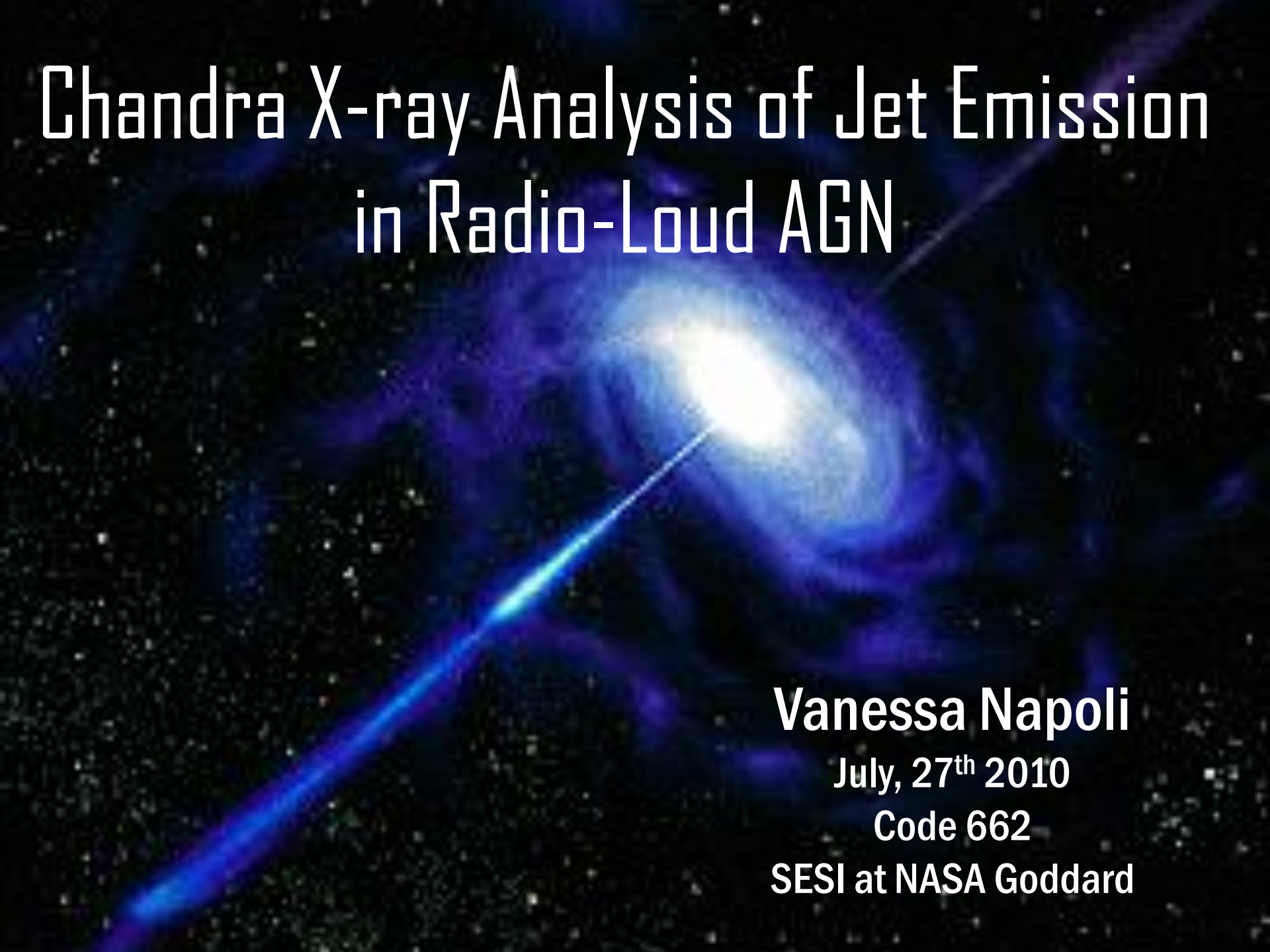
Chandra X-ray Analysis of Jet Emission in Radio-Loud AGN



Vanessa Napoli

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Code 662

SESI at NASA Goddard

What are AGN?

- Active Galactic Nuclei
  - Extremely compact objects
  - Believed to be powered by accretion of mass by SMBH
  - High luminosity across the electromagnetic spectrum
- Quasars, Blazars, Seyfert
  - Unification model
- Radio-Quiet
- Radio-Loud (~10%)

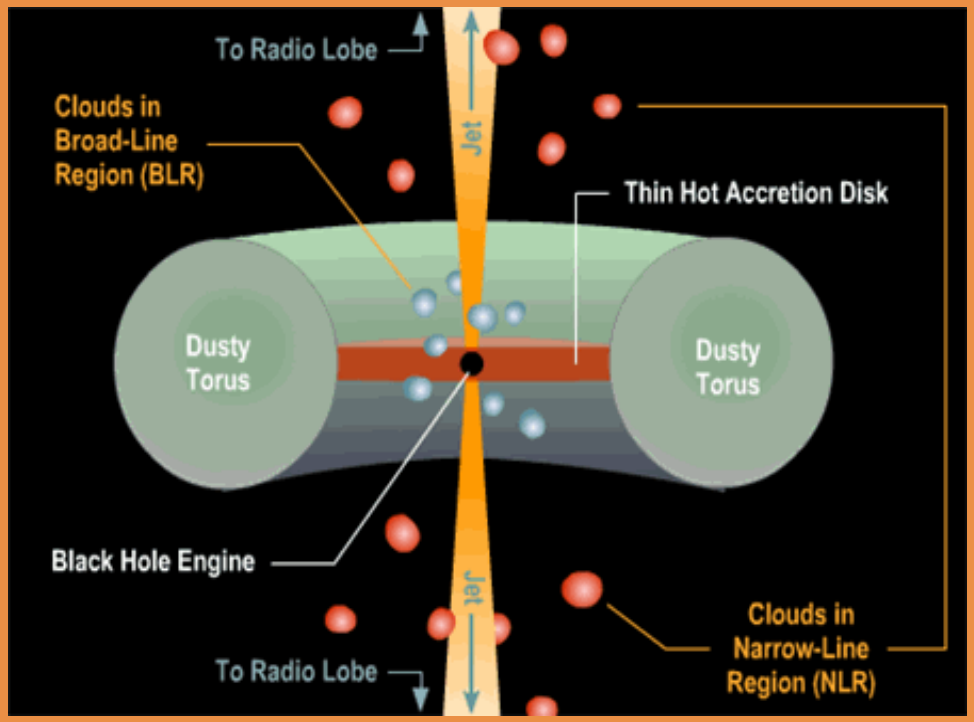
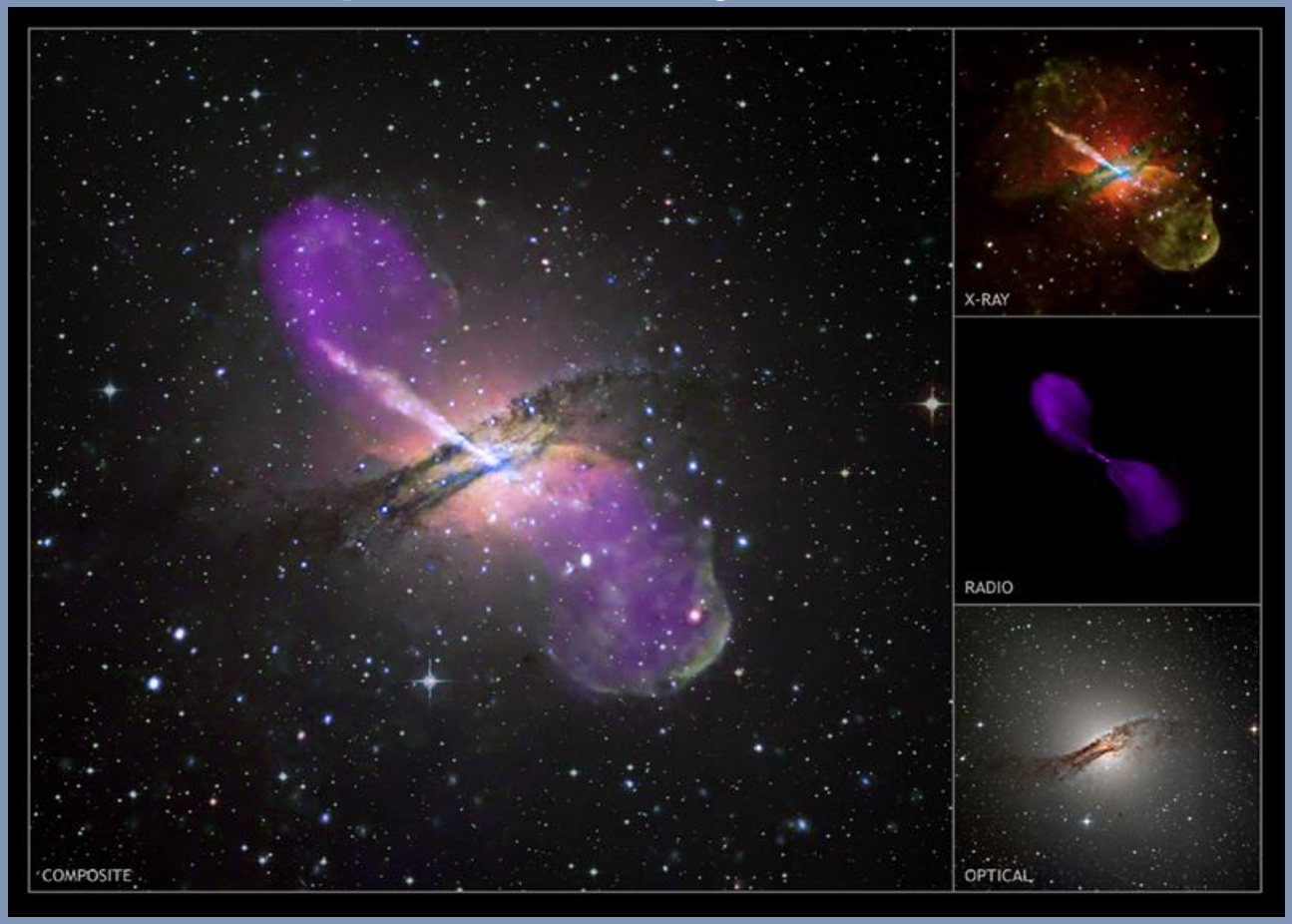


Image from www.astro.ufl.edu

AGN Jets

- Extend from Radio-Loud AGN
- What is within the jets: particles and magnetic fields
- Knot: compact feature in jet



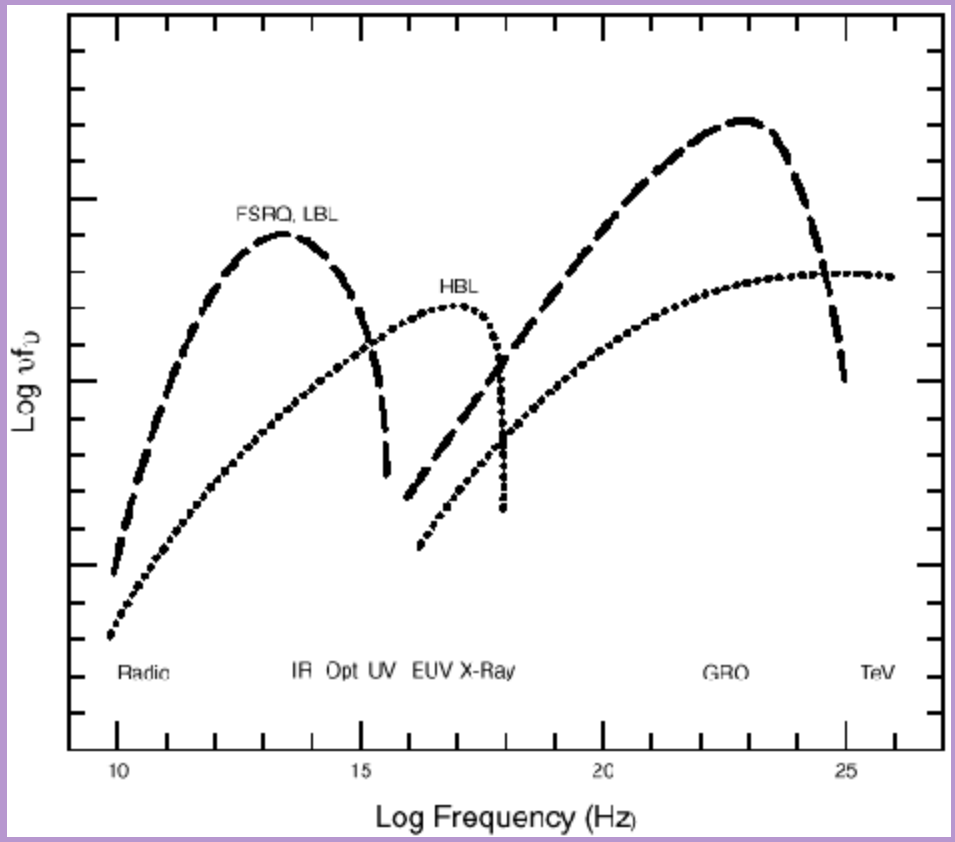
Centaurus A

Example of Jets in X-ray, radio and optical

Image from http://chandra.harvard.edu

Reasons for Strong Radiation in AGN Jets

- Synchrotron radiation
  - Radio to X-ray range
  - Relativistic electrons spiral around magnetic field lines
- Inverse Compton Scattering (IC)
  - X-ray to gamma-ray range
  - Photon gains energy at expense of electrons
  - Synchrotron self-compton vs. external compton (star, CMB, disk, broadline regions)



Spectral Energy Distribution (SED)

Image from http://nedwww.ipac.caltech.edu

Why look at X-rays?

- Within the X-ray region, it is where the emission is at a cross section of being caused from Synchrotron radiation and IC
- Synchrotron Radiation: Photon Index ≥ 2
- IC: Photon Index < 2

Chandra

- Observing the sky from 0.2-10keV but we focus in 0.5-7keV
- Because of Chandra's capabilities we can observe many x-ray jets and they can be resolved at x-rays
- Sensitive to x-ray sources 100 times fainter then any other x-ray telescope due to high angular resolution
- Perform both spectral and spatial analysis

Chandra X-ray Observatory (CXO)

Image from http://www.physics.udel.edu

Why These 5 Images from Chandra?

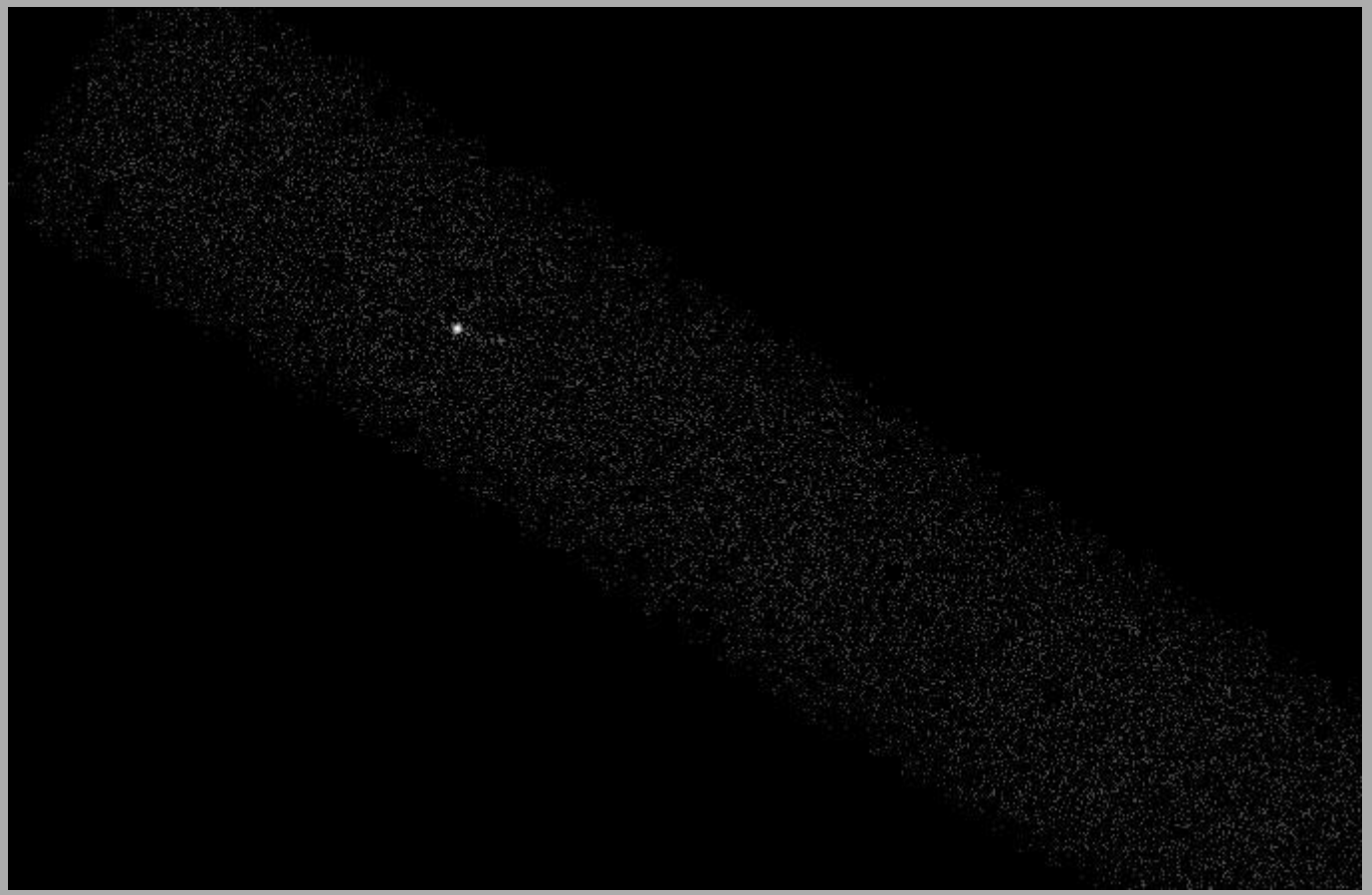
Sources:

- 0730+257, z=2.7
- 0805+046, z=2.877
- 1311-270, z=2.260
- 1318+113, z=2.171
- 1834+612, z=2.274

- All sources are at a intermediate redshift (z)
- These sources picked for their extended radio morphology and multiple knots
- At these redshifts the IC is proposed to be a key source of X-ray production

X-ray image from Chandra

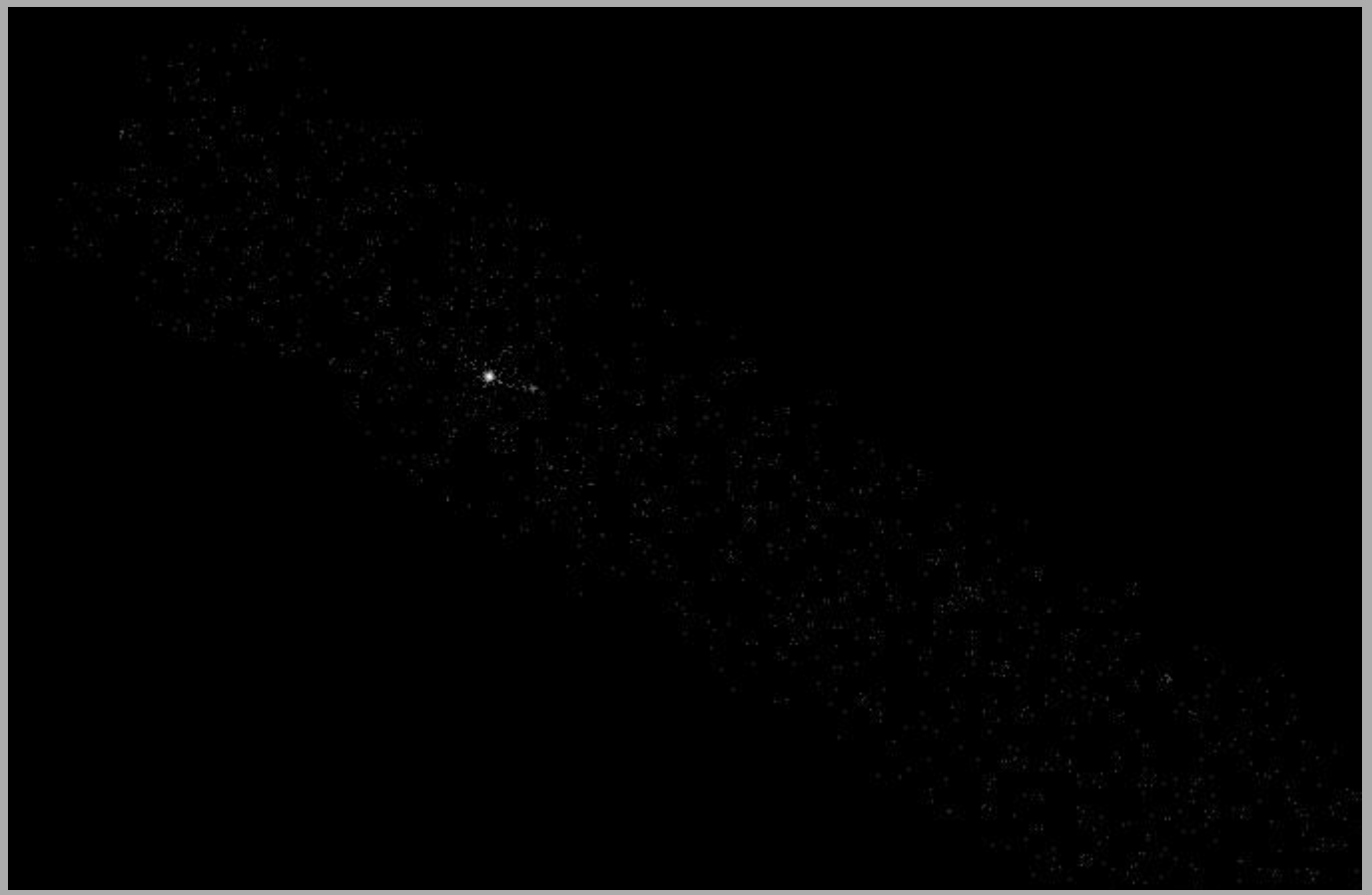
Object 1311-270



Energy range 0.2-10keV

X-ray image from Chandra

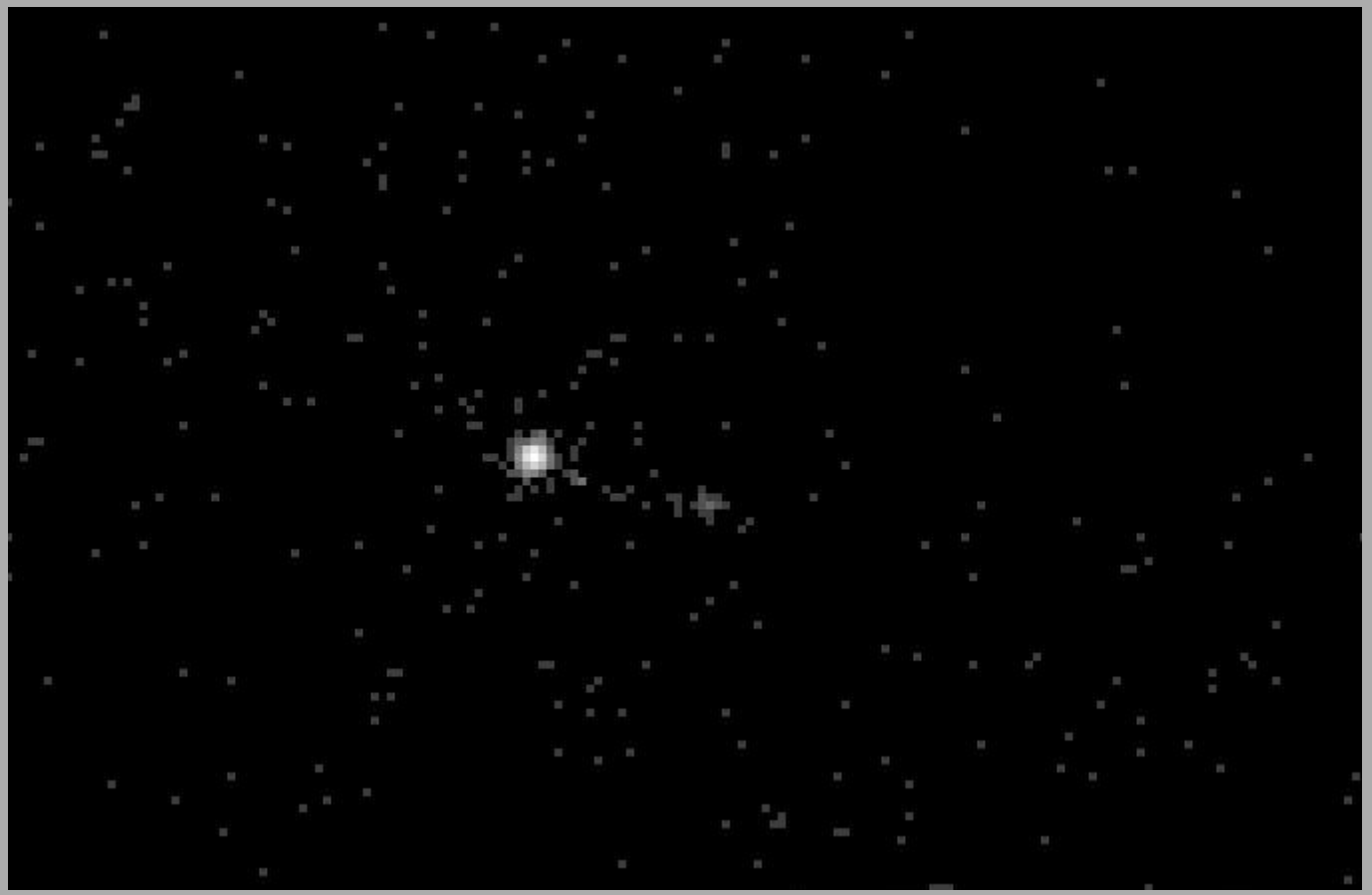
Object 1311-270



Energy range 0.5-7keV

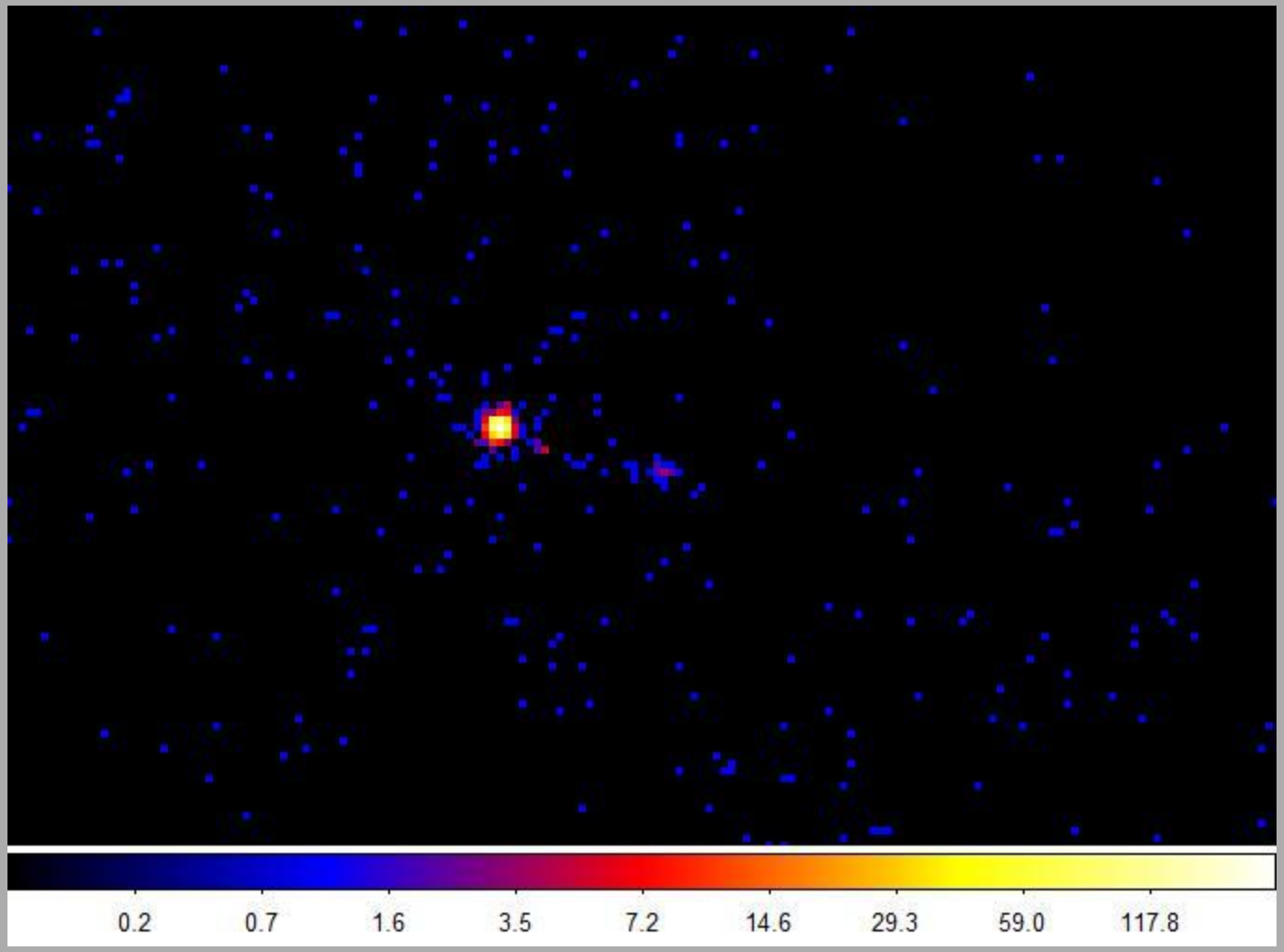
X-ray image from Chandra

Object 1311-270



X-ray image from Chandra

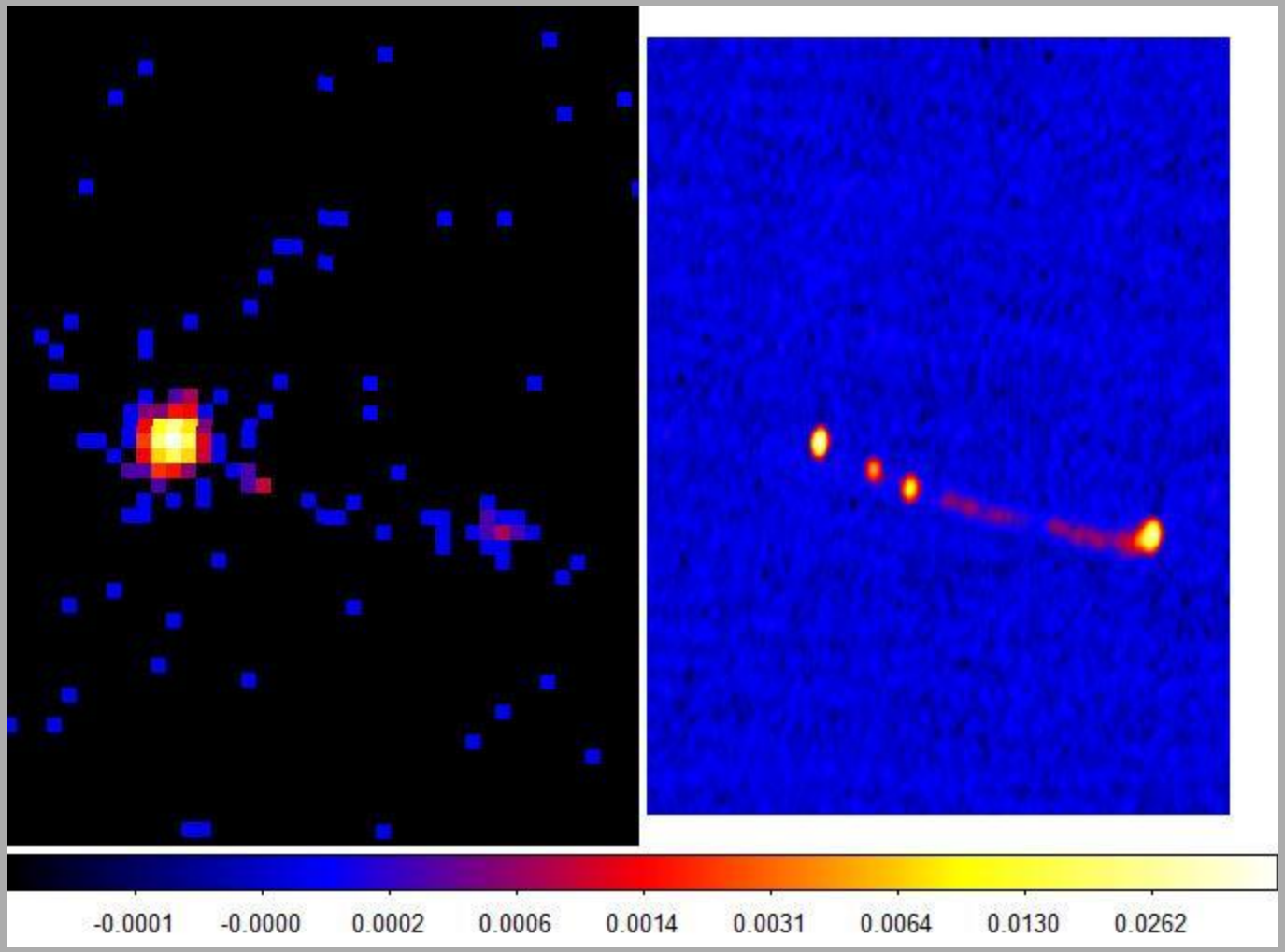
Object 1311-270



X-ray image from Chandra

Object 1311-270

X-ray



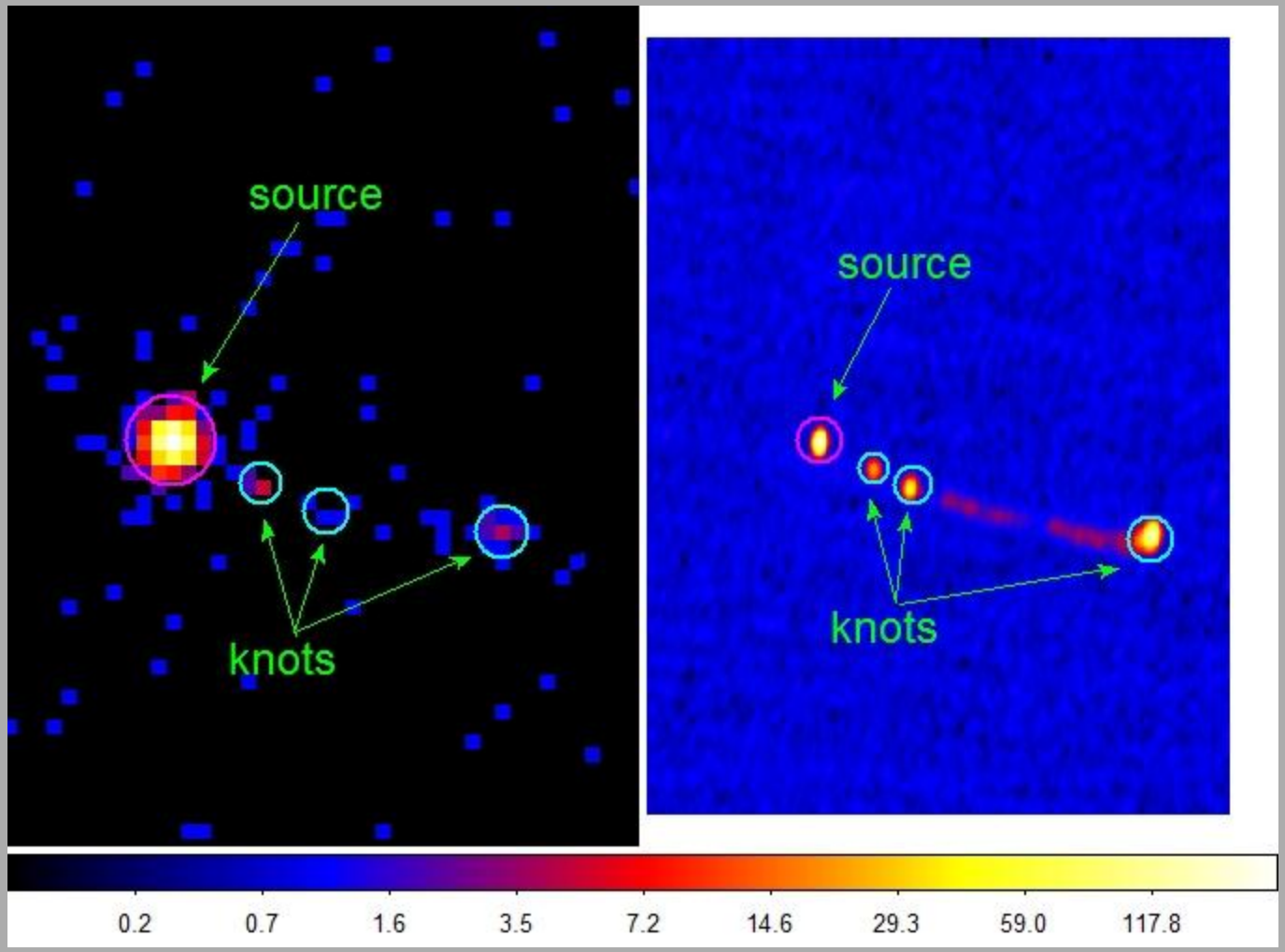
radio

Frequency =8.5 GHz

X-ray image from Chandra

Object 1311-270

X-ray



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X-ray image from Chandra

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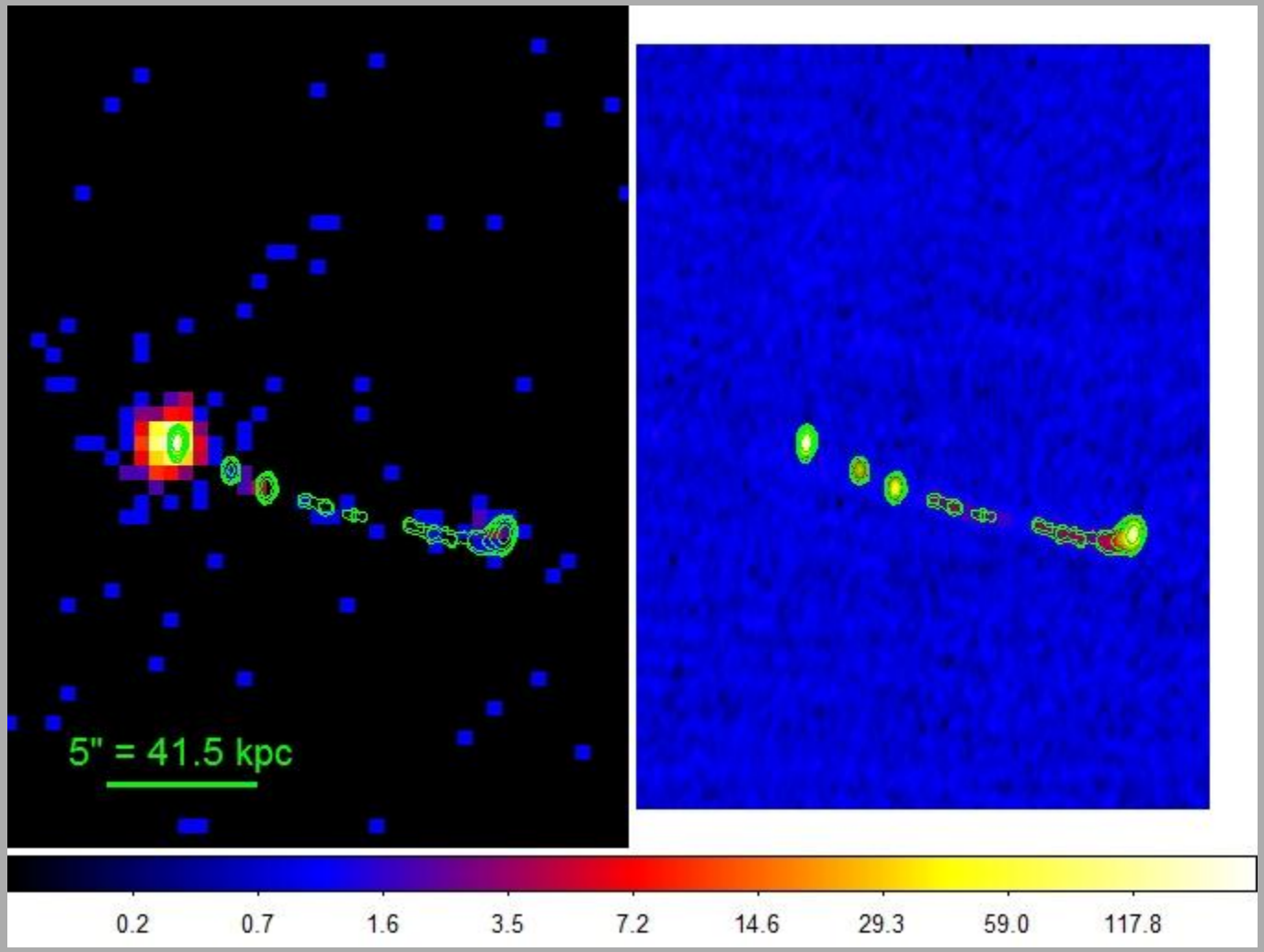

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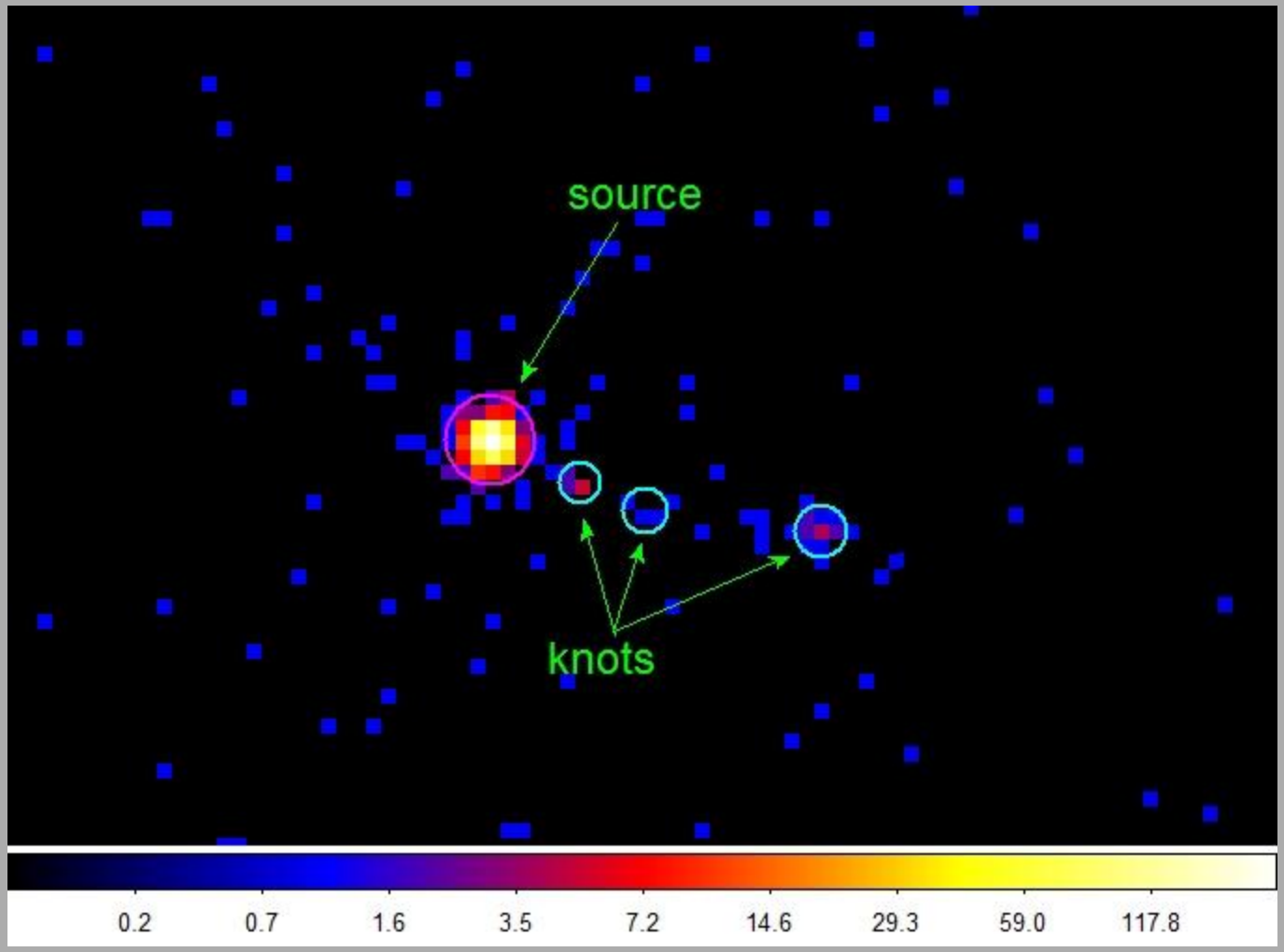


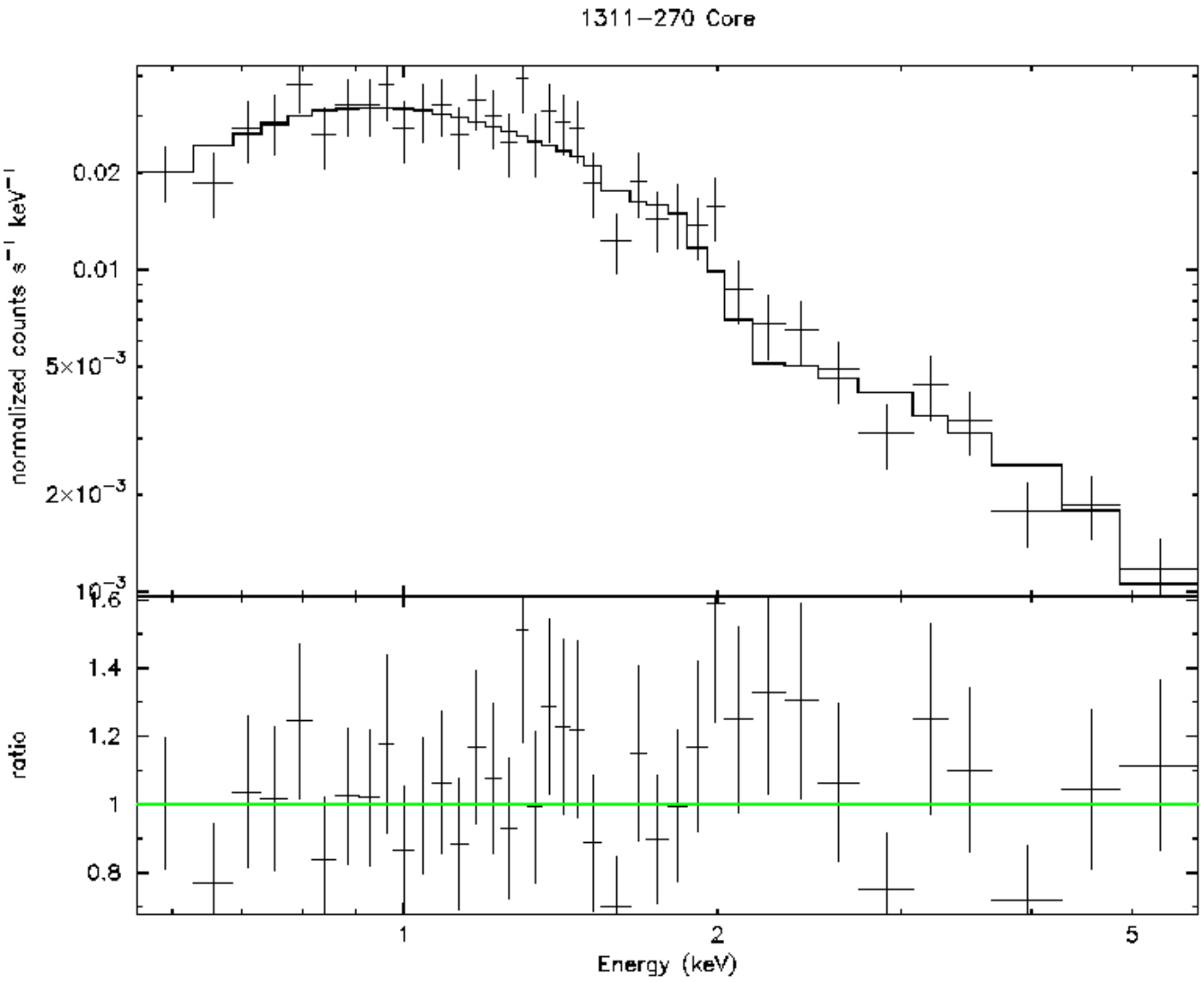
AGN Spectra

- Goal of spectral analysis: estimate the photon index in the X-ray range and the intensity of the emission
  - To determine if the X-rays are produced by IC or synchrotron radiation or both
  - To put physical constrains on emission models

Fitting the Spectra using Xspec

- Using Xspec to do model fit
  - Xspec: X-ray spectral fitting software
- The source spectrum is:
  - Fitted by a simple power law, absorbed at soft energies by intervening material (neutral Hydrogen, or nH) between the observer and the source

1311-270 : Spectrum of the core



Results

Source	nH (Gal)	PhoIndex	Reduced Chi-Squared	Model Flux (ergs/cm^2/s)
0730+257	5.16×10^{20}	1.60 +/- 0.16	0.373 for 7 dof	(8 +/- 1) $\times 10^{-14}$
0805+046	3.83×10^{20}	1.80 +/- 0.12	0.362 for 12 dof	(1.2 +/- .14) $\times 10^{-13}$
1311-270	5.78×10^{20}	1.80 +/- 0.07	0.819 for 36 dof	(3.2 +/- .51) $\times 10^{-13}$
1318+113	1.77×10^{20}	1.70 +/- 0.08	0.584 for 21 dof	(1.9 +/- .16) $\times 10^{-13}$
1834+612	4.49×10^{20}	1.50 +/- 0.03	1.143 for 90 dof	(1.1 +/- .05) $\times 10^{-12}$

Conclusions thus far

- As a result, for all 5 sources the Photon Index of the core is below 2
- Recall, If the Photon Index is below 2, then the radiation is most likely caused by Inverse Compton Scattering and not by Synchrotron radiation

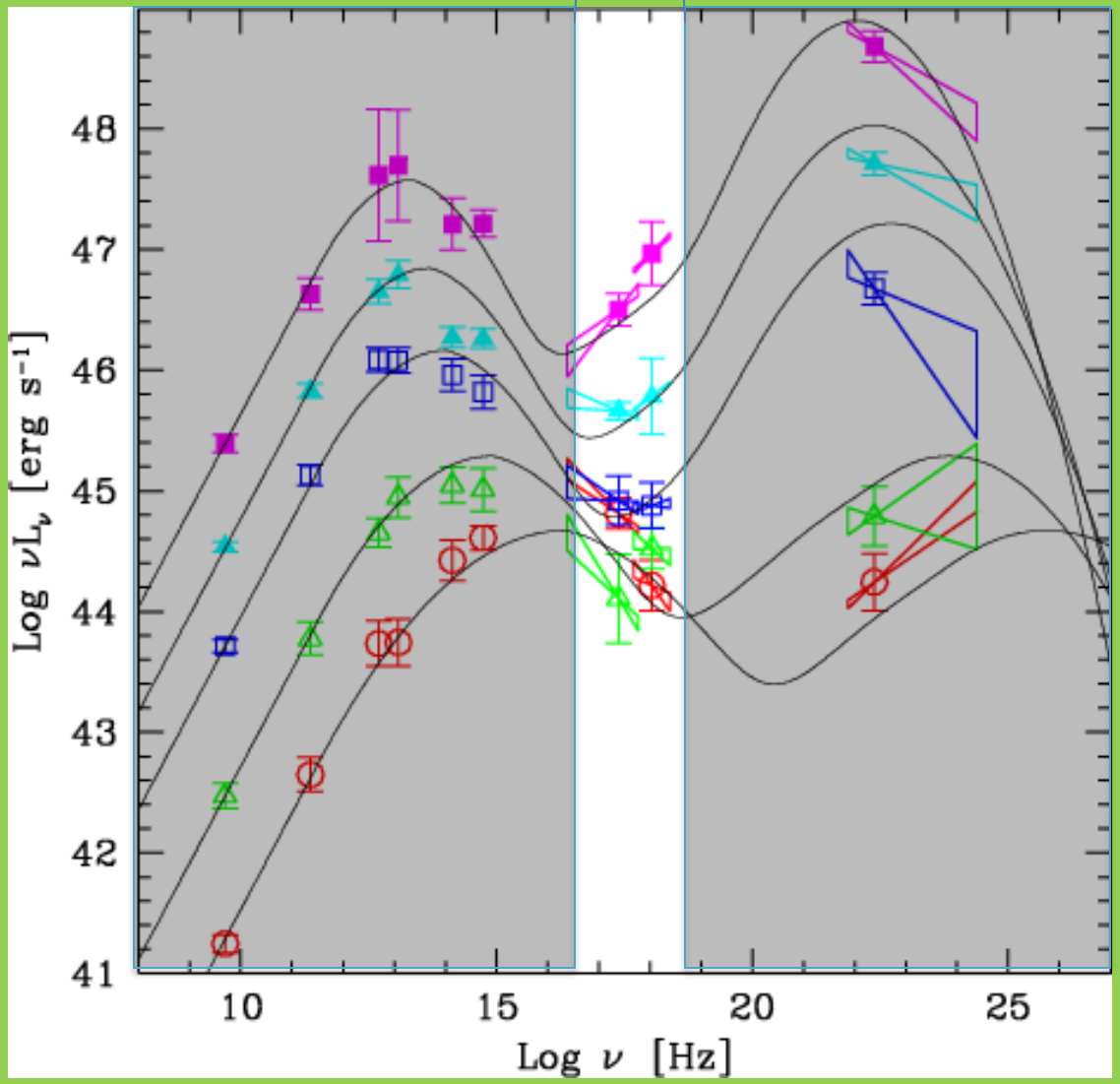
Future Work

- Focus on the jets
  - Spatial analysis (match radio and x-rays)
  - Spectral analysis:
    - Average jet
    - Single knots (if statistics permits)

What else I learned at NASA

- Learning my way around UNIX
- Developed skills in Perl Programming
  - Created a wide variety of programs pertaining to the Astrophysics I learned (flux, luminosity, spin of a BH)
- Used CIAO (X-ray Data Analysis Software)
  - Also wrote programs for CIAO in Perl
- Learned how to work and converse with scientists and got to experience how staff meetings work and had a lot of fun doing it all!

Why look at X-rays?



- Can determine if emission is from synchrotron or IC or both
- Photon Index: $\Gamma = \alpha + 1$
- Energy Index: $F \propto \nu^{-\alpha}$
- $F_\nu \propto \nu^{-(\Gamma-1)}$
- Depending on Photon Index
  - Below 2-radiation due to IC
  - Above 2-radiation due to Synchrotron radiation