X-RAY ANALYSIS OF THE STRUCTURE OF RELATIVISTIC AGN JETS OF CYGNUS A

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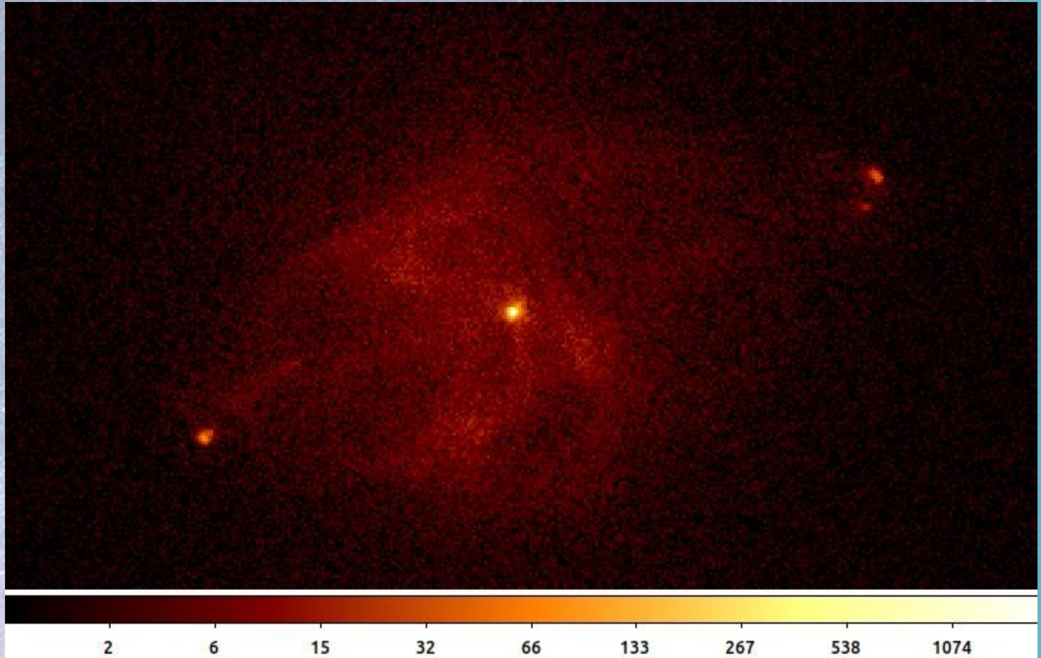
2021

WHAT IS CYGNUS A?

Cygnus A is a giant elliptical galaxy, one of the most powerful radio galaxy and quasar with a distance of 232 Mpc from Earth.

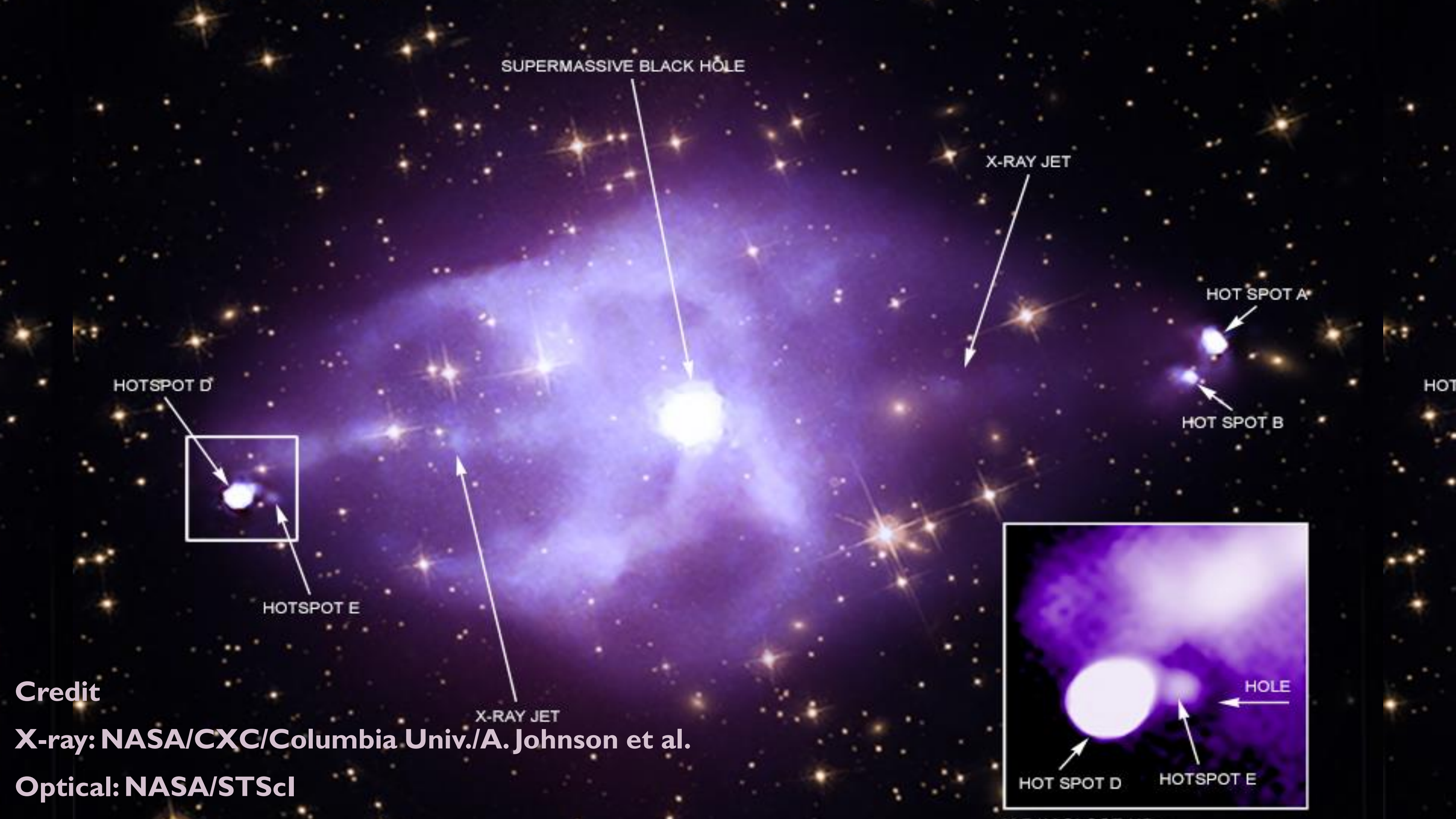
The first recorded radio galaxy, discovered by pioneer radio astronomy Grote Reber in 1939.

Like other radio galaxies, has a structure that includes **AGN** (active galactic nucleus), **accretion disk**, and **two relativistic jets**, diverging in opposite directions from the supermassive black hole.



Cygnus A image

The image was obtained by processing the ObsID data with SAOImageDS9



Credit

X-ray: NASA/CXC/Columbia Univ./A. Johnson et al.

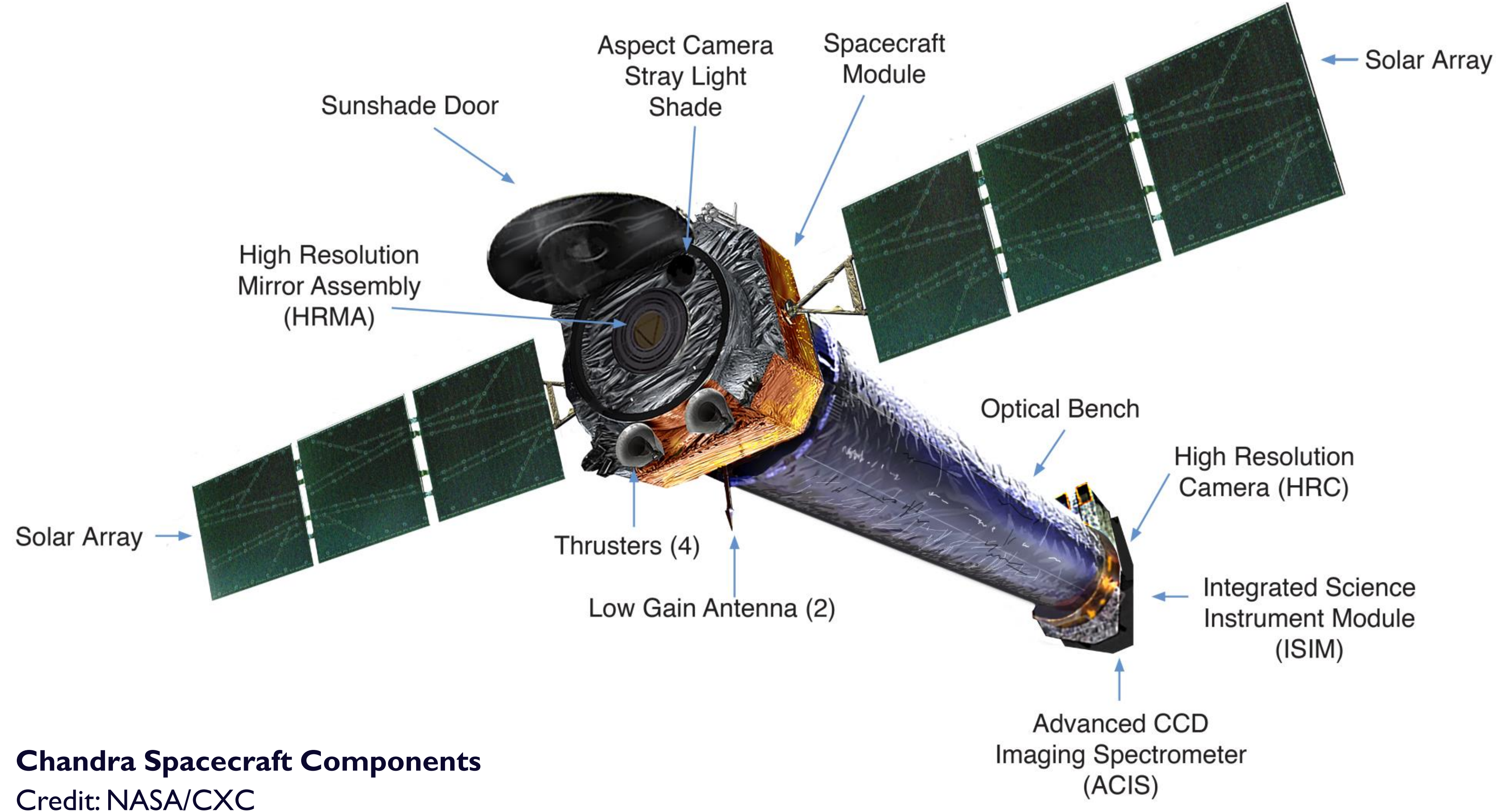
Optical: NASA/STScI

WHAT IS CHANDRA?

NASA's **Chandra X-ray Observatory** is one of the Great Observatories and designed to observe X-rays from high-energy regions of the Universe. Observatory was named in honor of the late Indian-American Nobel laureate, Subrahmanyan Chandrasekhar.

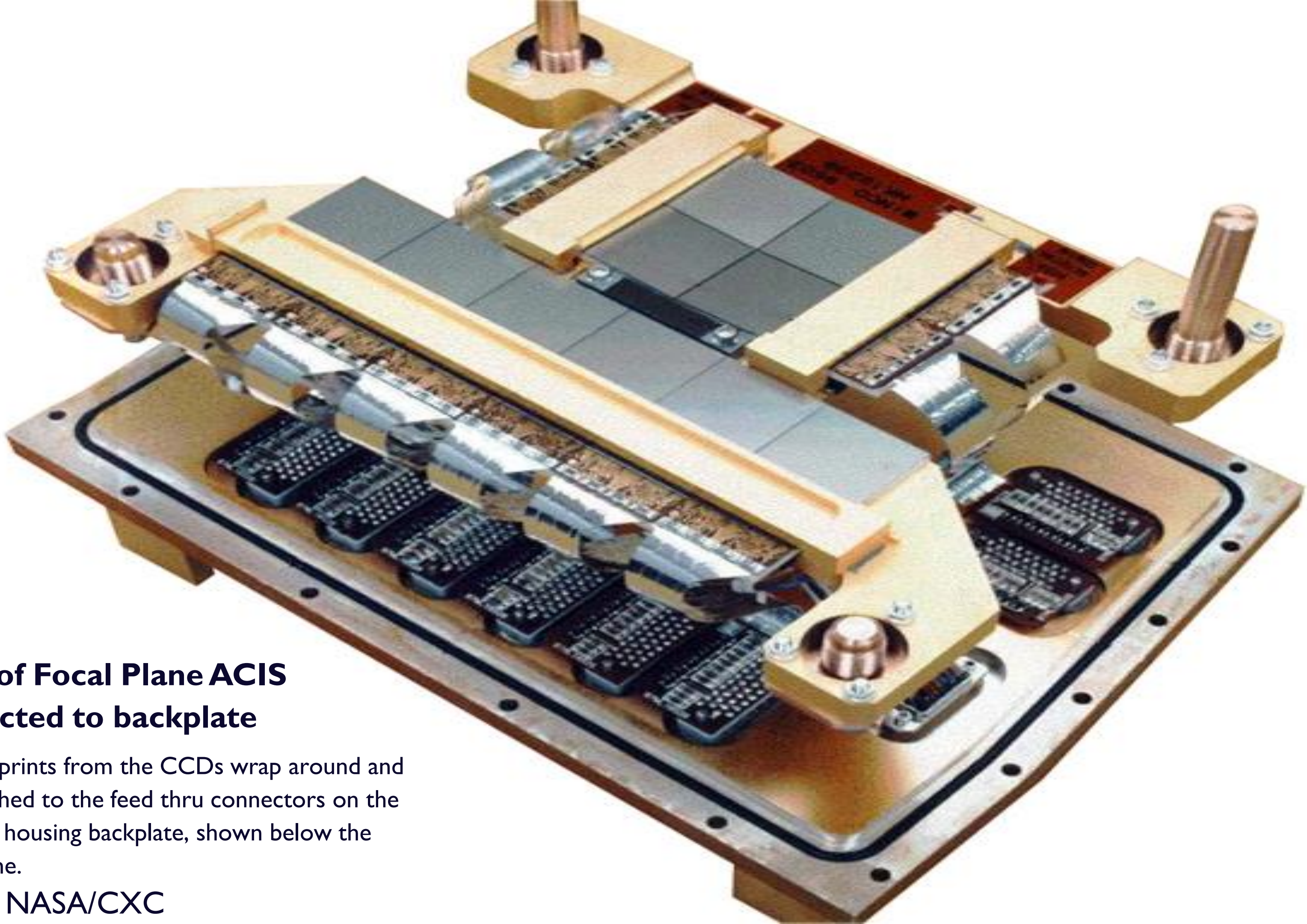
Launched aboard the Space Shuttle Columbia by NASA on July 23, 1999.

All analyzed observations in this study were obtained using **Chandra Advanced CCD Imaging Spectrometer (ACIS).** This instrument is an array of charged coupled devices (CCD's), which are sophisticated versions of the crude CCD's used in camcorders. It is the instrument of choice for studying temperature variations across X-ray sources such as vast clouds of hot gas in intergalactic space, or chemical variations across clouds left by supernova explosions, or radio galaxy like Cygnus A.



Chandra Spacecraft Components

Credit: NASA/CXC



View of Focal Plane ACIS connected to backplate

The flex prints from the CCDs wrap around and are attached to the feed thru connectors on the detector housing backplate, shown below the focal plane.

Credit: NASA/CXC

WHAT ARE WE EXPLORING?

At the end of the eastern relativistic jet Cygnus A is located in two hotspot – A and B, which we are investigating. We analyze these hotspots in the X-ray range using observation data from **Chandra Data Archive**.

For analysis we used special software:

- **CIAO 4.13** (Chandra Interactive Analysis of Observations). The software package developed by the Chandra X-Ray Center for analysing data
- **SAOImageDS9.** An astronomical imaging and data visualization application. DS9 supports FITS images, which we used in work.

HOW HAS IT BEEN EXPLORED BEFORE?

For a long time structure of relativistic AGN jets have been explored at radio frequencies. But in recent decades, scientists have received data on such objects in other ranges and began to do multiwavelength analysis [1].

An example, such analysis is carried out in the publication:

1. **"Novel Analysis of the Multiwavelength Structure of the Relativistic Jet in Quasar 3C273"** – Volodymyr Marchenko, D.E. Harris, Michal Ostrowski, Lukasz Stawarz, Artem Bohdan, Marek Jamrozy, Bohdan Hnatyk

2. **"Complex Structure of the Eastern Lobe of the Pictor A Radio Galaxy: Spectral Analysis and X-ray/Radio Correlations"** – R. Thimmappa, L. Stawarz, U. Pajdosz-Smierciak, K. Balasubramaniam, and V. Marchenko

MAIN STEPS IN ANALYSIS OF CHANDRA DATA

1. Select data from **Chandra Data Archive** (ObsID, which we have chosen, will be shown below).

2. Analysis of the data quality and selection the data.

3. Simulate the PSF (point spread function).

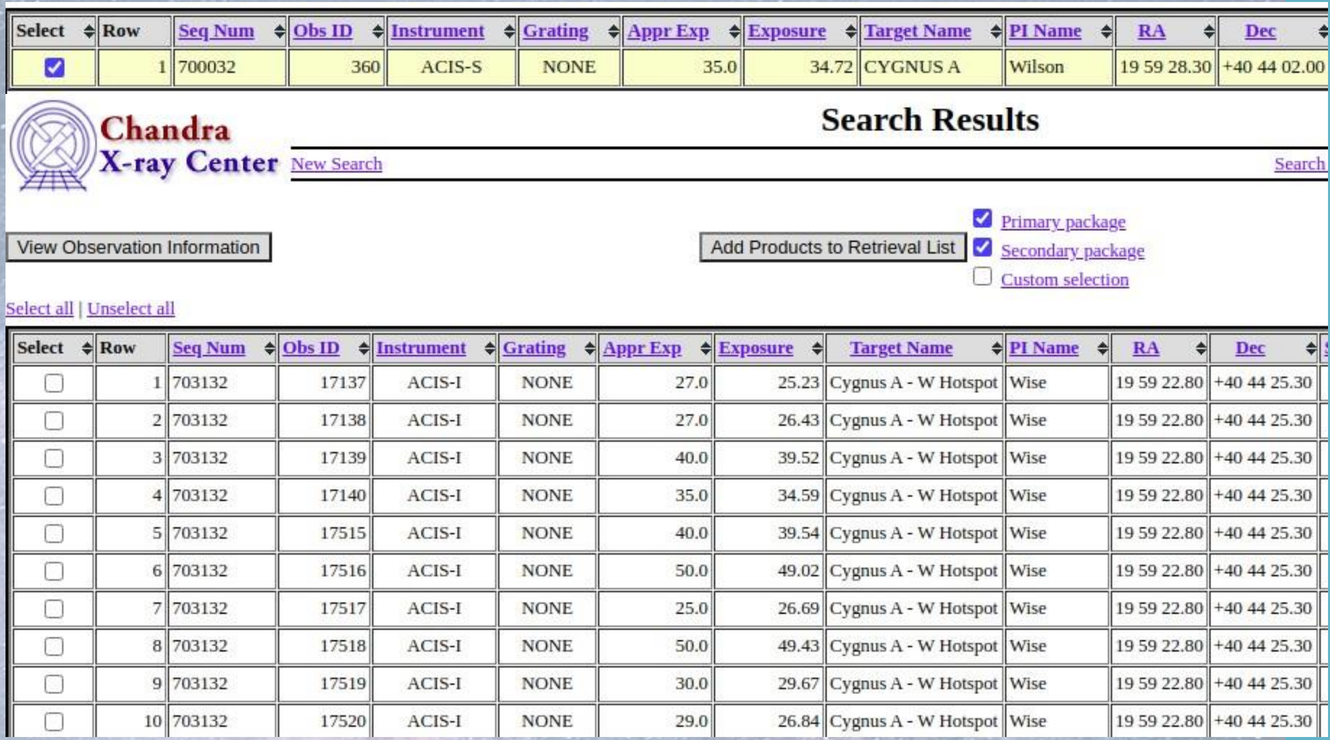
4. Deconvolve the data using simulated PSF.

5. Our results.

1. SELECT DATA FROM CHANDRA DATA ARCHIVE

We selected next observation data from the Chandra Advanced CCD Imaging Spectrometer (ACIS):

Next step we used ***chandra_repro*** reprocessing script.



Select	Row	Seq Num	Obs ID	Instrument	Grating	Appr Exp	Exposure	Target Name	PI Name	RA	Dec
☑	1	700032	360	ACIS-S	NONE	35.0	34.72	CYGNUS A	Wilson	19 59 28.30	+40 44 02.00

Chandra X-ray Center

Search Results

New Search | Search

View Observation Information

Add Products to Retrieval List

☑ Primary package
☑ Secondary package
☐ Custom selection

Select all | Unselect all

Select	Row	Seq Num	Obs ID	Instrument	Grating	Appr Exp	Exposure	Target Name	PI Name	RA	Dec
☐	1	703132	17137	ACIS-I	NONE	27.0	25.23	Cygnus A - W Hotspot	Wise	19 59 22.80	+40 44 25.30
☐	2	703132	17138	ACIS-I	NONE	27.0	26.43	Cygnus A - W Hotspot	Wise	19 59 22.80	+40 44 25.30
☐	3	703132	17139	ACIS-I	NONE	40.0	39.52	Cygnus A - W Hotspot	Wise	19 59 22.80	+40 44 25.30
☐	4	703132	17140	ACIS-I	NONE	35.0	34.59	Cygnus A - W Hotspot	Wise	19 59 22.80	+40 44 25.30
☐	5	703132	17515	ACIS-I	NONE	40.0	39.54	Cygnus A - W Hotspot	Wise	19 59 22.80	+40 44 25.30
☐	6	703132	17516	ACIS-I	NONE	50.0	49.02	Cygnus A - W Hotspot	Wise	19 59 22.80	+40 44 25.30
☐	7	703132	17517	ACIS-I	NONE	25.0	26.69	Cygnus A - W Hotspot	Wise	19 59 22.80	+40 44 25.30
☐	8	703132	17518	ACIS-I	NONE	50.0	49.43	Cygnus A - W Hotspot	Wise	19 59 22.80	+40 44 25.30
☐	9	703132	17519	ACIS-I	NONE	30.0	29.67	Cygnus A - W Hotspot	Wise	19 59 22.80	+40 44 25.30
☐	10	703132	17520	ACIS-I	NONE	29.0	26.84	Cygnus A - W Hotspot	Wise	19 59 22.80	+40 44 25.30

2. ANALYSIS OF THE DATA QUALITY AND SELECTION THE DATA (θ<0.6).

ObsID	Off-axis Angle θ (arcmin)
17137	0.5868091389763506
17138	0.4276602007684388
17139	0.4364905393471611
17140	0.4989991119713608
17515	0.6037250510547275
17516	0.4219097945511669
17517	0.3828765348592204
17518	0.4280946213571629
17519	0.5438022832659652
17520	0.4958773038914377
17521	0.4278971340760241
17522	0.4852946486168582
18886	0.4286609553903318
19888	0.5436051044321261
19956	0.5173039101487974
20043	0.5728957204367101
20044	0.5004238324659646
20048	0.5718400154699982
360	(for PSF)

α	δ (+)
19:59:22.9124	40:44:25.500
Ra	**Dec**
299.8458	40.7406
for all ObsID	

3. SIMULATE THE PSF (POINT SPREAD FUNCTION)

In a broad sense the **PSF (point spread function)** describes the response of an imaging system to a point source or point object.

The Chandra Point Spread Function (PSF), is highly variable across the field of view (the greater the off-axis angle from the optical axis, the greater the value of the PSF). The PSF is also a function of energy. The PSF is also affected by the detector geometry, placement in the focal plane, and detector readout.

Given these problems, there is no single analytical model for PSF. The only way to get Chandra's PSF is to model it.

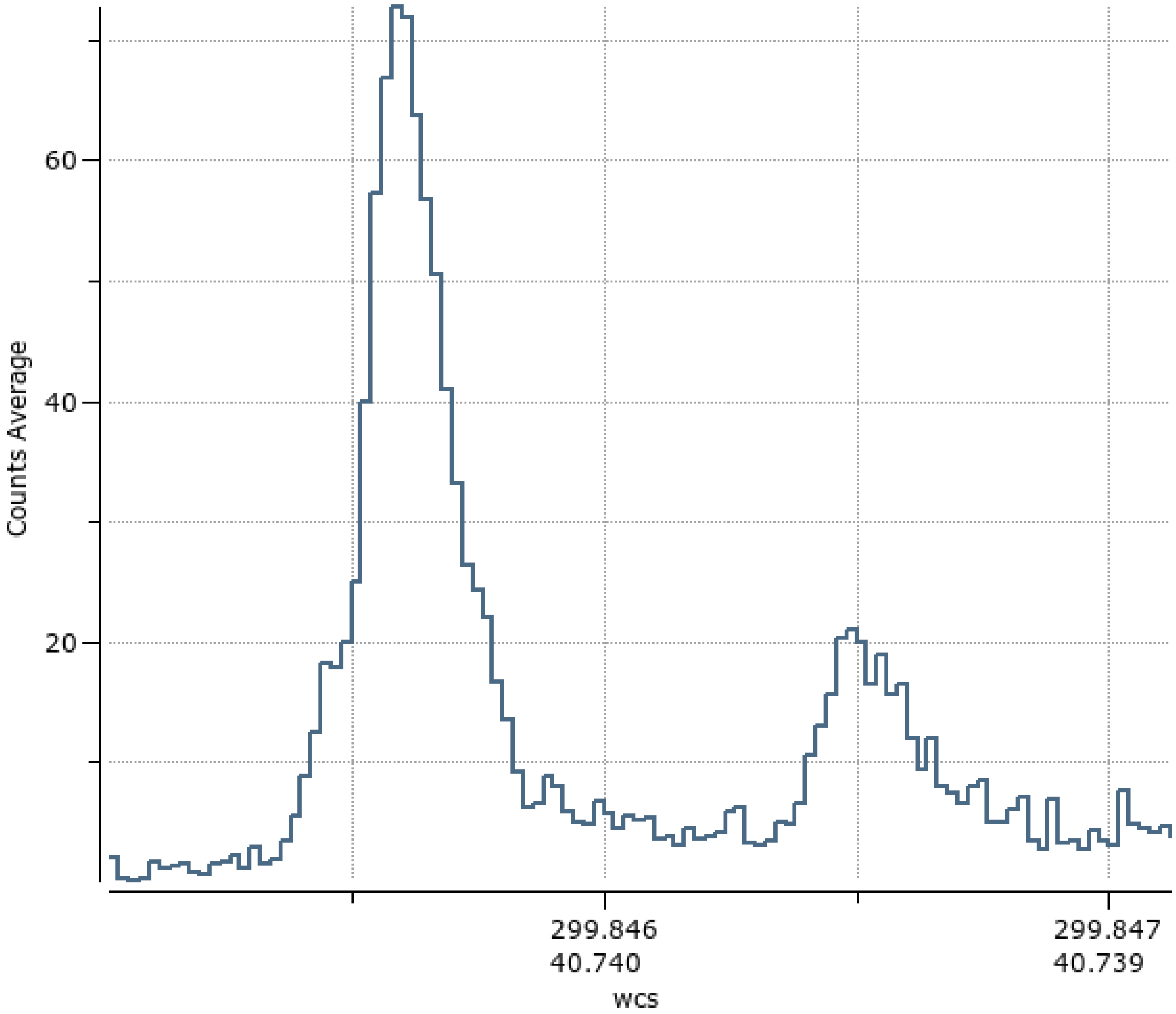
To simulate the Chandra PSF we used **MARX 5.3,** the ***simulate_psf*** script and **ObsID 360**.

4. DECONVOLVE THE DATA USING SIMULATED PSF

Next step is restore image resolution using **deconvolution** techniques. So, what is deconvolution? This is operation inverse to convolution. Convolution and deconvolution are *used to reconstruct signals and images in physics and astronomy*.

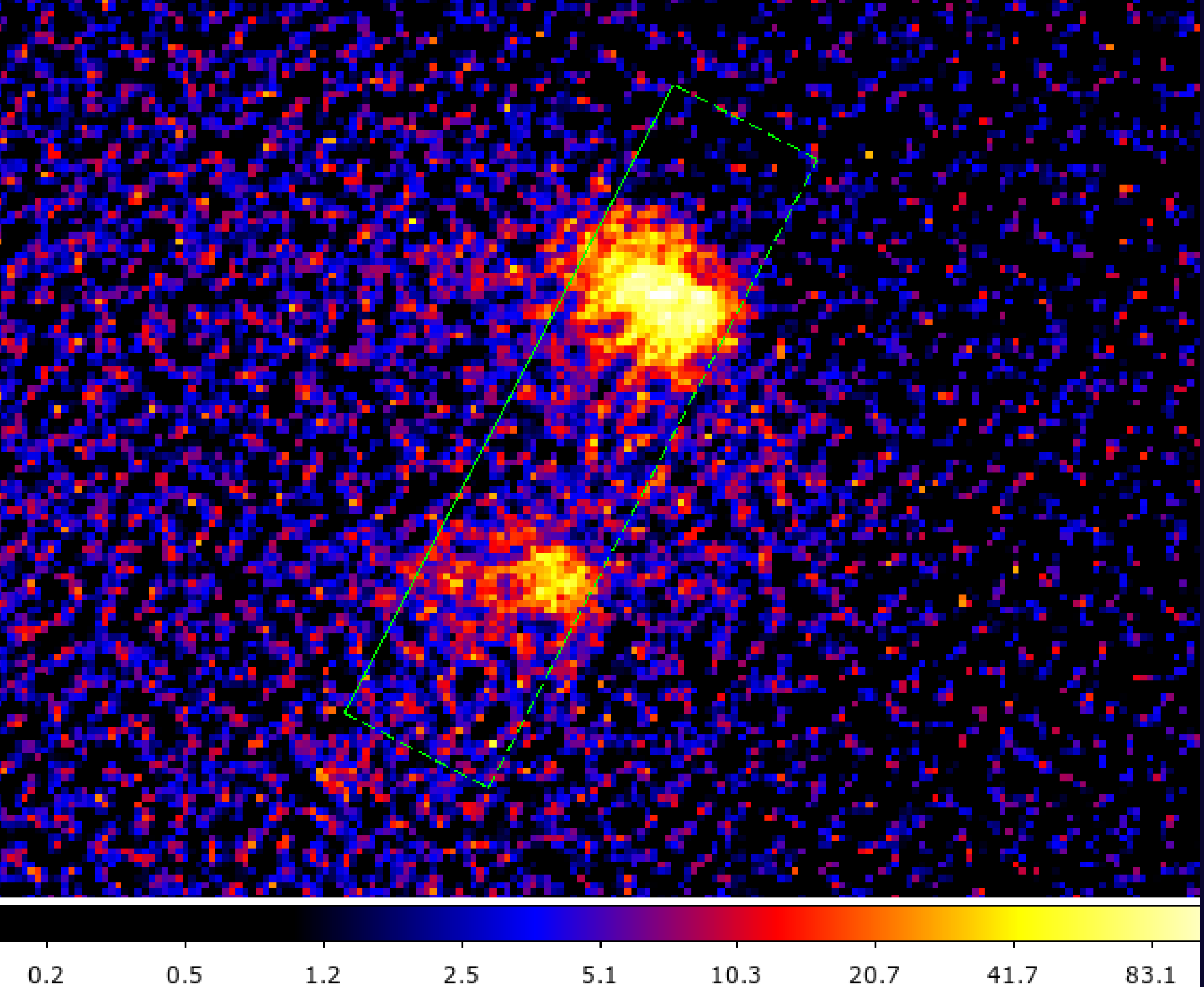
An image of an astronomical object can be described as a convolution of the intrinsic brightness distribution of the source with a PSF. There are various ways of deconvolution to obtain a clear noise-free image using PSF.

We used **Lucy-Richardson deconvolution** algorithm as an ***arestore*** package. Lucy-Richardson deconvolution is an iterative procedure for recovering an underlying image that has been blurred by a known point spread function.



5. OUR RESULTS

The deconvolved image of the merged observations of Cygnus A. The merged image is binned with a binning factor of 0.25 which corresponds to a pixel size of 0.125".



5. OUR RESULTS

The distribution of intensity on a deconvolved image along the longer
side of the green region that is shown on a deconvolved map (with averaging along the shorter side of the green region).

HOW WE WILL CONTINUE

In the future to make multiwavelength analysis of relativistic AGN jets of Cygnus A.

To be continued…

THANK YOU FOR YOUR ATTENTION