Science Briefing
8/8/2019

Deep Fields: Chandra and Hubble Uncover the Growth of Early Galaxies

Dr. Garth Illingworth (UC Santa Cruz)
Dr. Belinda Wilkes (CXC Director, CfA | Harvard & SAO)
Dr. Rutuparna Das (CfA | Harvard & SAO)

Facilitator: Dr. Chris Britt
Outline of this Science Briefing

1. Dr. Garth Illingworth (UC Santa Cruz)
   Exploring the Realm of the First Galaxies with Hubble and JWST

2. Dr. Belinda Wilkes (CXC Director, CfA | Harvard & SAO)
   NASA’s Chandra X-ray Observatory: Celebrating 20 years

3. Q&A

4. Dr. Rutuparna Das (CfA | Harvard & SAO)
   Resources on Deep Fields, galaxy growth, and Chandra’s 20th anniversary

5. Q & A
Exploring the Realm of the First Galaxies with Hubble and JWST

Garth Illingworth
University of California Santa Cruz
Hubble Wide Field Camera 3 (infrared light)

2009
our last (close) view of Hubble
NASA’s Great Observatories

Hubble

Chandra

Spitzer
telescopes are "time machines"
looking back through time

XDF: deepest ever Hubble image – in 2012 from 10 years of Hubble data
this image is a “history book”
the story of how galaxies formed and grew through nearly all of time
from a few hundred million years after the Big Bang through 13 billion years
each of the three Great Observatories – Chandra, Hubble and Spitzer – have contributed about 6-7 million seconds (about 75-80 days) of exposure on this field over the last 15-20 years.
size comparison:

the Hubble Legacy Field with the Chandra Deep Field-South and a nearby astronomical object
Hubble Legacy Field: Galaxies Across Time

Bly = billion light-years
seeing back in time almost to “cosmic sunrise”
artist impression of the time of the first galaxies

Artist credit: Adolf Schaller

James Webb Space Telescope
2021 - the beginning of a new era...

towards first light...

our “cosmic sunrise” telescope
NASA’s Chandra X-ray Observatory
Celebrating 20 years

The World’s Premier X-ray Observatory

- Dr. Belinda Wilkes
Director, Chandra X-ray Center
No longer operating

2008: Fermi Gamma Ray Telescope

NASA’s Great Observatories across the Electromagnetic Spectrum
Where do X-ray Come From?

X-rays originate in the hottest, most violent and most energetic places in the universe.

Some of these places are hard to see any other way.

*Chandra* turned its X-ray eyes to all kinds of celestial source, opening this window on the universe as never before.
Orion Nebula: star forming region
Unique, Exquisite (0.5””) Spatial Resolution

ROSAT:
~100 sources

Chandra, deep:
~1400 sources

Young stars are unstable and violent places

Chandra is an excellent “Young star finder”
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Active Galaxies/Quasars

Super-Massive Black Holes (~$10^6$-$10^9$ solar mass) in the nuclei of galaxies
Cosmic X-ray Background

Primary *Chandra* Science Goal

- Resolve CXRB, observed to be ubiquitous in previous X-ray missions
- Fully resolved to ~9 keV: Chandra Deep Field South (CDFS, 7 Ms)
- Looks back ~12-13 Gyrs, ~10% current age of Universe
- 1000 sources, mostly Super Massive Black Holes
- Source Density 50,500/deg\(^2\)
- Hardness: wide range, including highly obscured sources
- *Chandra* is a SMBH finder
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- Source Density: 50,500/deg$^2$
- Wide range of X-ray colors
- *Chandra* is a SMBH finder
Chandra X-ray Surveys: “Wedding Cake”

• Deep & narrow:
  • CDFS: 480 sq.arcmin, 7 Ms (11.6 wks) depth
  • 1000 sources
  • Not confusion limited

• Medium Depth, wider surveys:
  • 2 sq. degs, 160-200 ks depth,
  • >1000 sources

• Shallow depth, very wide:
  • 40 sq. degs, 5-25ks depth
  • >6000 sources
Evolution of AGN and Understanding the Population

- CDF-S, very faint flux limits: 4e-18 (cgs, soft); 2e-17 (cgs, hard)
- Galaxies dominate soft band at faintest fluxes
SMBH and Stellar Growth (SFR) vs Redshift/Age

- SFR and SMBH density as a function of redshift
- Density peaks at $z \sim 2$ for both populations
- Is SMBH and stellar growth in galaxies directly related?
- SMBH appears to start later and increase more rapidly
Active Galaxies/Quasars

Super-Massive Black Holes (~$10^6$-$10^{10}$ solar mass) in the nuclei of galaxies

Obscured in an edge-on view
AGN Obscuration

- X-ray Surveys can see obscured sources (unlike UV/O/NIR)
- All X-ray surveys find more obscured & edge-on AGN
- Fraction obscured ↑ as distance ↑
AGN Obscuration

- X-ray Surveys can see obscured sources (unlike UV/O/NIR)
- All X-ray surveys find more obscured & edge-on AGN
- Fraction obscured ↑ as distance ↑
- Edge-on ~ 5% of sample
- But: X-ray surveys remain biased against edge-on sources, which are ~100-1000* fainter
Chandra observations of 3CR Radio Sources

• Low Frequency, Radio-selection is unbiased by obscuration/orientation

• 3CR: distant, high luminosity, radio active galaxies

• Strong correlation between orientation and obscuration

• Fractions:
  • 50% obscured
  • 21% Compton-thick sources
First Targeted Source
Quasar: PKS 0637-75

- Point Source to focus: Quasar (SMBH in galaxy nucleus)
- 6 billion light years away
- X-ray Jet visible: 9” long, (300 kly)
- Jet $L \sim 10^{44.6}$ erg s$^{-1}$
- Radiation mechanisms: Non-thermal Synchrotron radiation
First Targeted Source
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- Point Source to focus: Quasar (SMBH in galaxy nucleus)
- 6 billion light years away
- X-ray Jet visible: 9” long, (300 kly)
- Jet $L \sim 10^{44.6}$ erg s$^{-1}$
- Radiation mechanisms: Non-thermal Synchrotron radiation (very high energy electrons)
X-ray-Radio Jets in Quasars: M87

- SEDs of components (knots, lobes) $\rightarrow$ B, electron: energies & acceleration
- Highly variable, superluminal motion $\rightarrow$ region sizes, structure (Harris et al. 2009++)
- Detailed jet models, e.g. popular spine-sheath model (blazars)
- EHT-image of SMBH event horizon released, April 10$^{th}$ (SAO, NSF)

- $D=16$ Mpc
- Jet length $\sim 1.6$ kpc (Marshall et al. 2001)
- SMBH $\sim 6.5*10^9 M_{\text{sun}}$
X-ray-Radio Jets in Quasars: M87

- 40 μas across
- 12,000 times smaller than Chandra resolution
- EHT-image of SMBH event horizon released, April 10th (SAO, NSF)
Additional Resources

Rutuparna Das
Center for Astrophysics | Harvard & SAO

NASA’S UNIVERSE OF LEARNING
Additional Resources: Chandra 20th Anniversary

• [http://chandra.harvard.edu/20th/](http://chandra.harvard.edu/20th/)

• Event calendar:
  • Aug 20, Nantucket, MA: NASA's Chandra X-ray Observatory: 20 Years of the X-ray Sky in Sharp Focus!
  • Sep 5, Huntsville, AL: 20 Years of Science with NASA's Chandra X-ray Observatory
  • Sep 20, Framingham, MA: 20 Years of Chandra Science
  • Sep 27 - Nov 14, Columbia, TN: Chandra Art Installation
  • Oct 10, Orono, ME: Chandra Public Talk
  • Nov 15, Framingham, MA: 20 Years of Stellar Explosions with the Chandra X-ray Observatory
  • Nov-Dec, NASA HQ: Chandra exhibit

• Printables:

• Video:

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NASA'S UNIVERSE OF LEARNING
Galaxy Hunter activity using the Hubble Deep Fields:
- http://galaxies.amazingspace.org/
- Includes teaching tips: preparation and execution time, educational standards met, common misconceptions, example lesson plans, vocabulary, learning outcomes
Additional Resources: Deep Fields

• Webinar: Looking Out is Looking Back in Time
  • https://www.youtube.com/watch?v=UDGou8KMJoQ
Additional Resources: Deep Fields

- Hubble Deep Field Academy
  - https://deepfield.amazingspace.org/
  - Includes optional lab worksheets
Additional resources: Deep Fields

- ViewSpace interactives: Gathering Light
- [https://viewspace.org/interactives/unveiling_invisible_universe/gathering_light/hubble_ultra_deep_field](https://viewspace.org/interactives/unveiling_invisible_universe/gathering_light/hubble_ultra_deep_field)
Additional resources: Deep Fields

• ViewSpace interactives: Gathering Light
• https://viewspace.org/interactives/unveiling_invisible_universe/gathering_light/hubble_ultra_deep_field
Additional resources

- ViewSpace videos: Video Library coming soon (~2 months)
- https://viewspace.org/playlists/featured
- Create playlists from keyword tags or use new, pre-formulated playlists
Additional Resources: Deep Fields

• “A Quick Look at Chandra Deep Field South” video
• http://chandra.harvard.edu/photo/2017/cdfs/
Additional Resources: Deep Fields

• Animations showing Black Hole growth in the Chandra Deep Field South
• http://chandra.harvard.edu/photo/2018/cdfs_bh/animations.html
Growth of early black holes in the Chandra Deep Field South – includes video

http://chandra.harvard.edu/photo/2017/cdfs2/
• Galaxy lithographs from Hubble, including images of the Hubble Deep Fields:
  • [http://amazingspace.org/resource/resource_index/galaxies/topic](http://amazingspace.org/resource/resource_index/galaxies/topic)
Additional Resources: Deep Fields

- Deep Fields photo gallery from Chandra:
  - [http://chandra.harvard.edu/photo/category/background.html](http://chandra.harvard.edu/photo/category/background.html)
Additional Resources: Black Holes

- Chandra page on black holes: [http://chandra.si.edu/blackhole/]
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- Chandra page on black holes: [http://chandra.si.edu/blackhole/](http://chandra.si.edu/blackhole/)
- New discoveries:
- Q&A:

- Black hole basics:

- Chandra as a black hole hunter:

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**What is a black hole?**

When a star runs out of nuclear fuel, it will collapse. If the core is at or near the critical mass, the star will collapse all the way down to a black hole. Because black holes have no mass, they emit no light. They are so dense that even light cannot escape their gravity.

- Chandra page on black holes: [http://chandra.si.edu/blackhole/](http://chandra.si.edu/blackhole/)
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**Black Holes**

- [NASA’s Universe of Learning](https://nasauniverse.org)
Additional Resources: Black Holes

• Chandra’s black hole photo gallery
  • http://chandra.si.edu/photo/category/blackholes.html
Additional Resources: Black Holes

• Black hole printables:
  • http://chandra.harvard.edu/graphics/resources/handouts/lithos/blackhole_poster.pdf
  • http://chandra.harvard.edu/resources/handouts/lithos/bhA_low.pdf
  • http://chandra.harvard.edu/graphics/resources/illustrations/bh_infograph.pdf
Additional Resources: Black Holes

- Tinkercad activity: build an accretion disk
  - http://chandra.cfa.harvard.edu/tinkercad/

TRYING IT OUT
Create an accretion disk

1. Launch Tinkercad
2. Click "Create New Design" button.
3. Move around your grid until you're at the top down perspective.
4. On the right menu, under Basic Shapes, select 'Torus' and click anywhere on grid.
5. Using the shift key to keep the torus in the original ratio, size the torus to be about 1/2 of your grid size or slightly larger.
6. Change perspective until you are viewing your torus from the side. Using the white box at the top of the torus, shrink your shape down until it's only a few mm thick.
7. Experiment with aligning your torus to the middle of your grid.
8. With your new shape selected, the 'Shape' panel appears in the upper right corner. Click on "Solid" to see color options. Select color and grab a red or orange tone.
9. Click on Tinkercad logo in upper left corner to save and close your file. Once returned to 'My Recent Designs' screen, hovering over the new design, click the gear icon and select 'Properties' to rename your file to be 'Accretion Disk 1.'
Additional Resources: Black Holes

• UoL Traveling Exhibits (include black holes): https://www.universe-of-learning.org/community-programs
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