Studying the First Galaxies with the Hubble and the Webb Space Telescopes

Hubble Science Briefing
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Massimo Stiavelli
Space Telescope Science Institute
Modern Cosmology
The Universe at redshift $\sim 1300$

COBE satellite
Perturbations

**Redshift** $z$: $1+z$ gives the ratio of the radius of the Universe today and that at a given epoch in the past.

It also gives the ratio of the wavelength we observe over the one that was emitted.

Computer simulations show the growth of structure.
Growth of perturbations

**Underdensities** grow like miniature Universes. They expand becoming rounder. **Overdensities** collapse and can become flattened or filamentary. This is the origin of the filamentary structures seen in simulations. Galaxies form along filaments. Clusters of galaxies form at the intersection of filaments.
Growth of perturbations

From random initial conditions it is “easy” to study the evolution of dark matter through computer simulations. The reason is that dark matter interacts only by gravity.

It is much more difficult to study the evolution of ordinary matter (gas) since its interactions are much more complex. Thus the formation of stars and galaxies share the complexity of weather forecast.

We think the first galaxies form at a redshift between 6 and 15 but there are many uncertainties. Thus, the input from observations is essential.
REIONIZATION OF THE UNIVERSE
z~1300, Hydrogen recombines, CMBR “released”
Spectra of distant QSOs tell us that there is no diffuse neutral Hydrogen.
Spectra of distant QSOs tell us that there is no diffuse neutral Hydrogen.

few neutral hydrogen clouds

many neutral hydrogen clouds but no diffuse neutral hydrogen
Hydrogen is ionized: we see radiation at $912 < \lambda < 1216$ Å in QSOs at $z < 6$.

$z \sim 1300$, Hydrogen recombines, CMBR “released”
Hydrogen is ionized: we see radiation at $912 < \lambda < 1216$ Å in QSOs at $z < 6$.

Here something reionizes Hydrogen.

$z \sim 1300$, Hydrogen recombines, CMBR "released"
“Dark ages”
7% of the age of the Universe

- first light sources
- Population III
- reionization of H
- reheating of IGM
Galaxies at $z > 6$ redshift out of the ACS filters
Objects at $z > 7$ are faint and relatively rare. We need a sensitive IR instrument: the IR channel of the Wide Field Camera 3.
Galaxies remain in the WFC3 filters up to $z \sim 10$
NICMOS 72 orbits
WFC3 16 orbits
Initially 16 galaxies at $z \sim 7$, 5 galaxies at $z \sim 8$ (currently 100+ at $z > 6$)

(see also Finkelstein et al. 2010, and others)
What about $z > 8$ ?

Our team has detected one candidate at $z = 10$ (Bouwens et al. 2011).

**UDFj-39546284** $H = 28.9$ $J - H > 2.0$

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What did we learn?

- We can say is that first galaxies are at \( z \geq 10 \).
- The galaxies we see are capable of reionizing the Universe but we need a contribution from lower mass galaxies that we do not detect directly.

The number density of galaxies above the WFC3 UDF limit is decreasing with redshift.
THE FIRST GALAXIES
Reionization is not necessarily completed by the First Galaxies. However, the First Galaxies must have formed before the completion of reionization.
Indication from theory

Models predict that the first galaxies might form around redshift 15 but they will be faint and rare. Thus, they might be outside the capability of Hubble.
The James Webb Space Telescope

The James Webb Space Telescope was designed from the ground up to study high-z galaxies. Four science themes guided the design, two extragalactic and two galactic. The one most relevant for us is the End of the Dark Ages theme.

End of the dark ages:

- **First light**
- Nature of reionization sources
**Description**

- Deployable cryogenic telescope
  - 6.5 meter ø, segmented adjustable primary mirror
- Launch on an ESA-supplied Ariane 5 to Sun-Earth L2
- 5-year science mission (10-year goal): launch 202"?

**Organization**

**Mission Lead:** Goddard Space Flight Center

International collaboration with ESA & CSA

**Prime Contractor:** Northrop Grumman Space Technology

**Instruments:**
- Near Infrared Camera (NIRCam) – Univ. of Arizona
- Near Infrared Spectrograph (NIRSpec) – ESA
- Mid-Infrared Instrument (MIRI) – JPL/ESA
- Fine Guidance Sensor (FGS) – CSA

**Operations:** Space Telescope Science Institute (STScI)
6.5m James Webb Space Telescope
JWST improves over Hubble’s resolution

The Hubble UDF
(F105W, F105W, F160W)

Simulated JWST
JWST–Spitzer image comparison
1’x1’ region in the UDF – 3.5 to 5.8 μm

Spitzer, 25 hour per band (GOODS collaboration)

JWST, 1000s per band (simulated)
(simulation by S. Casertano)
JWST is 7 tons and fits inside an Ariane V shroud. This is enabled by:

- Ultra-lightweight optics (~20 kg/m²)
- Deployed, segmented primary
- Multi-layered, deployed sunshade
- *L2 Orbit allowing open design/passive cooling*
JWST: Status

72% of the observatory mass is in fabrication

All mirror segment have completed rough polish to 150nm

6 flight segment have been coated and are completed

MIRI  NIRSPEC  NIRCam
Sunshield: full scale membrane test
NIRSpec DM testing is Complete!

FGS EM integration is complete

NIRCam ETU undergoing I&T

MIRI VM testing is complete!
ETU Instruments in the GSFC SSDIF

- MIRI
- NIRSpec
- NIRCam
- FGS

OSIM

ISIM Structure
NIRCam ETU ready for Cryo Vacuum Test
FLIGHT NIRSpec
NIRSpec first light
Flight MIRI
Gold Coated Mirror Assemblies

After coating, final steps for flight mirrors are 3 axis vibe + optical testing
Cryo Cycle 5 at MSFC XRCF with Gold-Coated EDU
OTE Progress

- Fine Steering Mirror - Coated
- Aft Optics Bench for Cryo Test
- Primary Mirror EDU - Coated
- Backplane Center Sections – PF and Flight
- Backplane Support Frame – PF
- 12 containers store either an assembled PMSA, SMA EDU or TM
- Tertiary Mirror - Coated
Optical End-to-End Test @ JSC

- Verify Optical alignment; center of curvature, autocollimator flats
- Verify workmanship
- Thermal balance
  - Chamber outside dimensions 65’ x 120’
• JWST is folded into stowed position to fit into the payload fairing of the Ariane V launch vehicle
Conclusions

WFC3–IR has allowed us to begin studying galaxies at redshift up to 10.

Progress on these objects is going to be slow because they are too faint for any existing telescope to take spectra and verify their redshift and measure their properties.

The James Webb Space Telescope has the sensitivity required to study these objects (and even higher redshift ones).