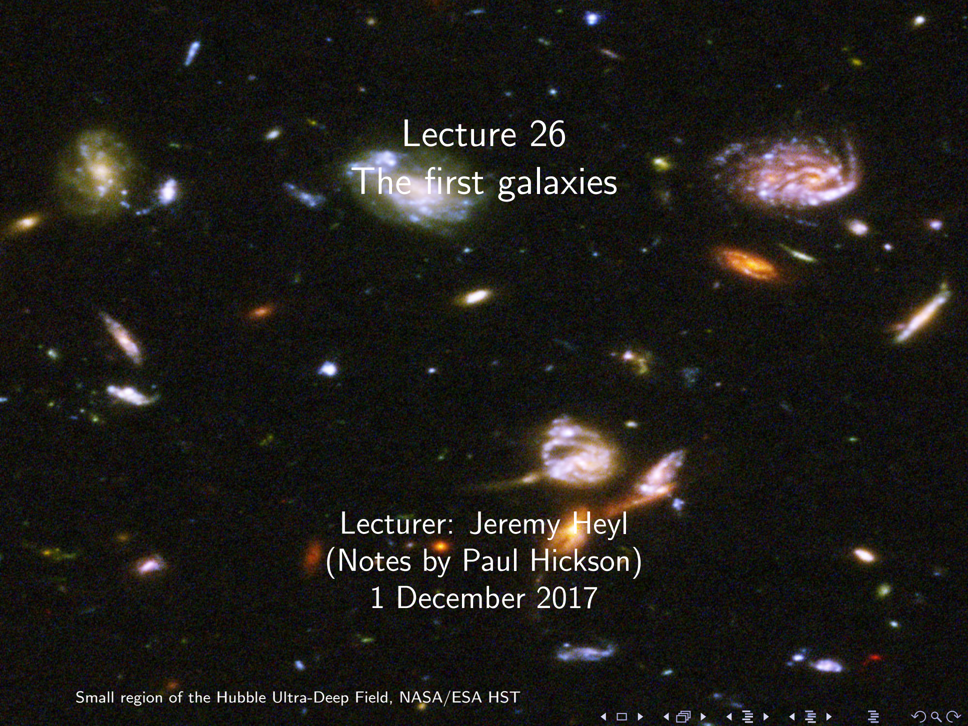
Lecture 26
The first galaxies

Lecturer: Jeremy Heyl
(Notes by Paul Hickson)
1 December 2017



Small region of the Hubble Ultra-Deep Field, NASA/ESA HST

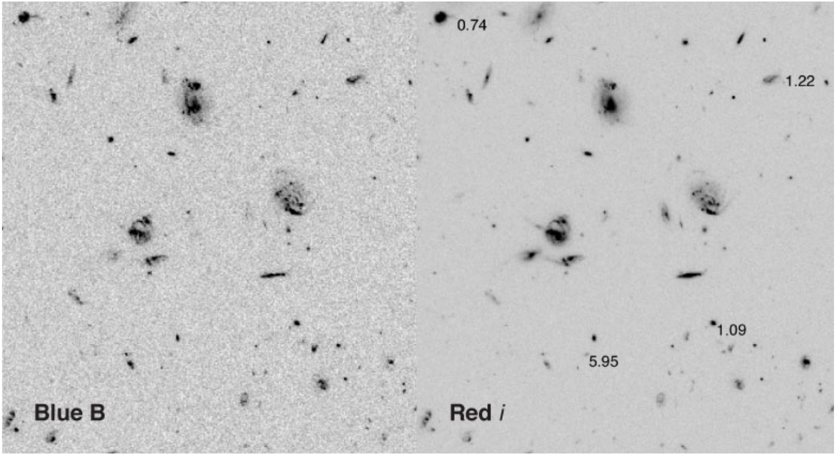
Early galaxies

The galaxies visible in the Hubble Ultra-Deep Field have redshifts as high as $z \sim 5$. We see them as they were about 1 Gyr after the big bang.

The galaxies that we see at this redshift were smaller and less luminous that the Milky Way, and have an irregular or fragmented appearance. This is at least partly due to the fact that we see only the UV light, redshifted into the visible.

Nevertheless, the small size and asymmetric appearance suggests that these may be the building blocks of luminous present-day galaxies.

This is likely due largely to interaction-triggered starburst activity.



A section of the Hubble Ultra Deep Field in blue (B, left) and red (i, right) light. Redshifts of selected galaxies are marked. Note the normal-looking spiral at $z \lesssim 1$ to the right of the center, and the merging group to the left.

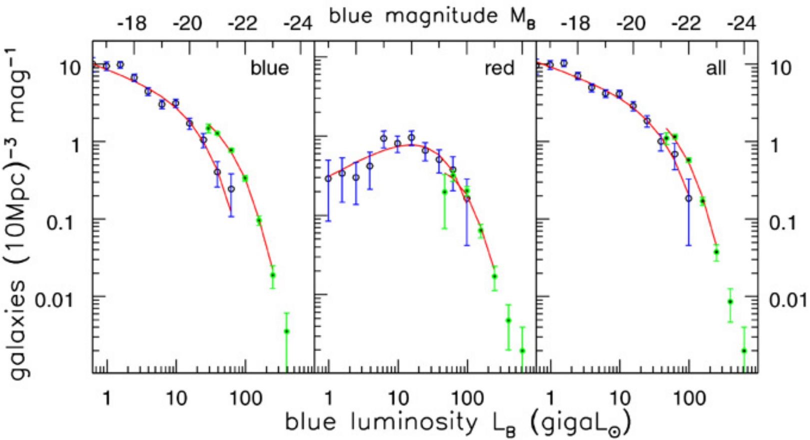


Fig 9.15 (DEEP2) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Numbers of galaxies per comoving 10 Mpc cube between absolute magnitude M(B) and M(B) + 1: open circles are for nearby galaxies with $0.2 < z < 0.4$, and filled dots for those at $1 < z < 1.2$. The number of red galaxies at each luminosity has changed little, but luminous blue galaxies are far more common at $z \simeq 1$. Very luminous galaxies are mainly red, while most of the the dimmer ones are blue.

Lyman-break galaxies

Hi redshift galaxies tend to have little flux beyond the Lyman break at 912 Å, due to intergalactic absorption.

At $z \sim 3$ the Lyman break is redshifted to about 3650 Å so these galaxies are not visible in U-band images. Similarly, they disappear from B-band images at a redshhift $z \sim 4 - 5$ and from the I band at $z \sim 6$.

These galaxies have lower than solar metallicity. At $z = 2.7$ the oxygen abundance is about 0.4 solar and the iron abundance is about 0.1 solar, This indicates fairly recent star formation (< 1 Gyr).

Even galaxies with redshift $z \gtrsim 6$ contain stars that are already $600 - 700$ Myrs old.

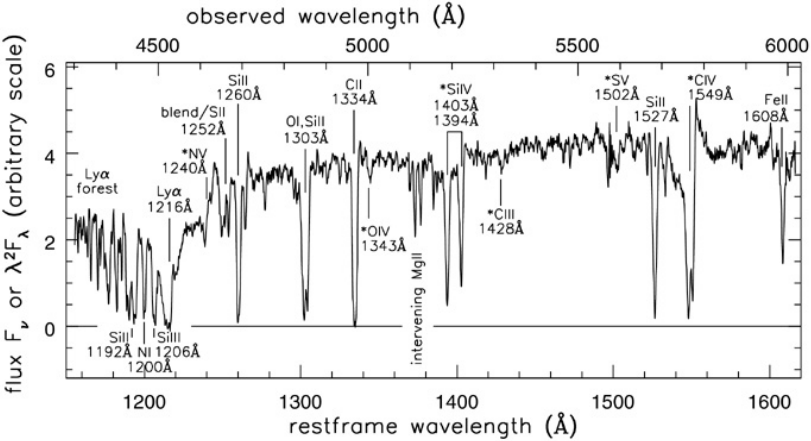


Fig 9.16 (C. Steidel) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

The spectrum of the Lyman break galaxy cB58 at $z = 2.723$. Lines characteristic of hot stellar photospheres are marked *; near 5100 Å, we see MgII absorption from gas at lower redshift. The spectral lines are similar to starburst galaxies, but this galaxy is bluer with F_ν approximately constant; that starburst has roughly $F_\lambda \sim \lambda^{-1}$ or $F_\nu \sim \nu^{-1}$.

Submillimetre galaxies

Recent observations have revealed a populations of galaxies that are bright a sub-mm wavelengths. These are dusty star-forming galaxies, typically at redshifts $z \sim 1.5 - 3$.

At sub-mm wavelengths (eg. 850 um), we see the low-frequency Rayleigh-Jeans tail of the dust thermal emission, which rises as $F_\nu \propto \nu^2$.

This compensates for the usual decrease of flux with increasing redshift, making the flux of these galaxies nearly constant over the range $1 \lesssim z \lesssim 10$.
The sub-mm galaxies tend to have large quantities of molecular gas and are forming stars at a rapid rate.

Old red and dead galaxies

Very-red galaxies are seen at redshifts as high as $z \sim 6$.

These show a strong 4000Å break, indicating stars that are at least $200 - 600$ Myrs old. This corresponds to star formation at $z \sim 7 - 13$.

Already, these galaxies are $20 - 50\%$ as massive as the Milky Way.

By $z \sim 1.5$ ($t \sim 4$ Gyr) some of these galaxies have grown to $\sim 10^{12} M_{\odot}$.

Their stars are ~ 2 Gyr old so their last star formation would have been at $z \sim 3$.

Could these be the evolutionary products of the sub-mm starburst galaxies?

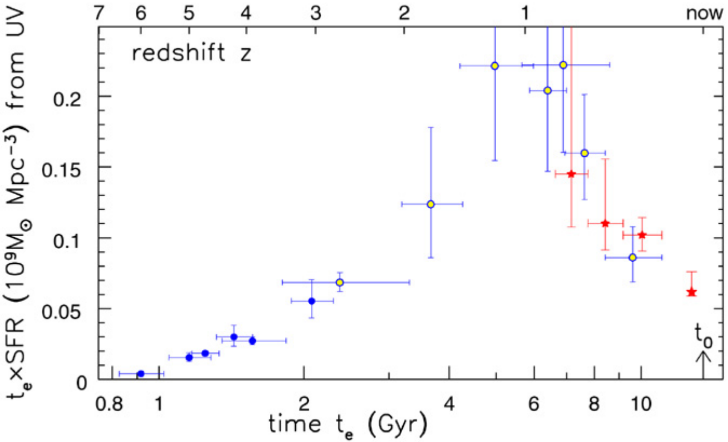


Fig 9.17 (Stanway/Barger) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Star formation per comoving Mpc^3, derived from light emitted at ultraviolet wavelengths, calculated for the benchmark cosmology. Stars show points measured in the ultraviolet by Galex, and filled circles are from Lyman break galaxies. The mass of stars formed in any time interval is proportional to the area under the points

Star-formation history of the Universe

The rate of star formation can be estimated by measuring the UV luminosity of a galaxy, which is proportional to the number of hot young stars.

From this one can also estimate the rate of metal production, to follow the buildup of heavy elements.

The star formation rate appears to have peaked around a redshift of $z \sim 1$, about 6 Gyr after the Big Bang. At that time it was about five times greater than at present.

Roughly one quarter of all stars had been formed by $z \sim 2$. This corresponds a mean metallicity about 3% of solar.

So far no 'first stars' (with zero metalicitly) have been detected. We must wait for the next generation of telescopes, such as JWST and extremely-large ground-based telescope, which might see the first stars and galaxies.