

The galaxy luminosity function at z = 9~ 0.5 Gyr after the Big Bang



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With Derek McLeod, Ross, McLure, Brant Robertson, Richard Ellis

See also Rebecca Bowler's talk to follow



PLAN

- 1. Background
- 2. Hubble Ultra Deep Field 2012 the LF out to z = 8
- 3. Hubble Frontier Fields the LF at z = 9
- 4. Early evolution of UV luminosity density reionization
- 5. Summary, issues & future prospects ALMA, JWST

Searching for high-redshift galaxies: looking for objects which disappear, or "drop-out" at bluer wavelengths due to the redshifted Lyman break



Observing a high-redshift Lyman-break galaxy





Optical

Y-band

J-band

H-band









The Hubble Ultra Deep Field 2012

The deepest near-infrared image

UDF12: Observational details



Final depths (AB mag)

Y ₁₀₅	= 30.0				
J ₁₂₅	= 29.5				
J ₁₄₀	= 29.5				
H ₁₆₀	= 29.5				

Ellis, McLure, Dunlop et al., 2013, ApJ, 763, L7

Use of 4 WFC3/IR filters allows robust searches for galaxies out to $z \sim 10$





Hubble Ultra Deep Field 2012 Hubble Space Telescope WFC3/IR First meaningful sample of galaxies at z > 8.5Ellis, McLure, Dunlop et al. (2013)

Now clear that galaxies exist and can be studied at z ~ 10 and beyond

The galaxy luminosity function at z=7 and z=8

McLure, Dunlop et al. 2013, MNRAS, 432, 2696

- Photometric redshift selection of z > 6.5 galaxies (10-band SED fits)
- Nested structure of deep/shallow WFC3/IR imaging fields
- Incorporate p(z) into maximum likelihood LF fitting



Example SED fits in UDF12 at z = 7 and z = 8

UV galaxy LFs out to z = 8 from UDF12 McLure et al. 2013, MNRAS, 432, 2696



 α and ϕ^* fixed, M* evolving: $\delta m=0.3\delta z$

Faint-end slope of the UV LF

So, α = -2 at z = 8.

Means luminosity density diverges if no lower limit, and is dominated by faint galaxies – implications for reionization.

The evolution of α – see Parsa, Dunlop, McLure et al. 2015



z

The luminosity function at z = 9 New results from the Hubble Frontier Fields



Six Hubble Frontier Fields planned

Sites of the Frontier Fields Observations



SOURCES: All-sky sky chart: J. Cornmell; Constellations: International Astronomical Union (IAU)

Observations of first two now completed

e.g. Abell 2744





Gravitational lensing – the excitement !



Gravitational lensing – the tricky reality....



Alternative published magnification maps for Abell 2477

So we have deliberately avoided inner cluster regions / high magnification areas, exploiting the blank areas to obtain new determination of z = 9 luminosity function

McLeod, McLure, Dunlop et al. 2015, arXiv: 1412.1472



12 galaxies at 8.4 < z < 9.5 in the 4 fields

HFF1C-9-1	optical	F105W	F125W	F140W	F160W	HAWKI-K
HFF1P-9-1	optical	F105W	F125W	F140W	F160W	HAWKI-K
HFF1P-9-2	optical	F105W	F125W	F140W	F160W	HAWKI-K
HFF2C-9-1	optical	F105W	F125W	F140W	F160W	HAWKI-K
HFF2C-9-2	optical	F105W	F125W	F140W	F160W	HAWKI-K
HFF2C-9-3	optical	F105W	F125W	F140W	F160W	HAWKI-K
HFF2C-9-4	optical	F105W	F125W	F140W	F160W	HAWKI-K
HFF2C-9-5	optical	F105W	F125W	F140W	F160W	HAWKI-K
HFF2P-9-1	optical	F105W	F125W	F140W	F160W	HAWKI-K
HFF2P-9-2	optical	F105W	F125W	F140W	F160W	HAWKI-K
HFF2P-9-3	optical	F105W	F125W	F140W	F160W	HAWKI-K
HFF2P-9-4	optical	F105W	F125W	F140W	F160W	HAWKI-K

Inferred z = 9 galaxy UV luminosity function

McLeod, McLure, Dunlop et al. 2015, arXiv: 1412.1472



High-redshift decline of UV luminosity/star-formation rate density

McLeod, McLure, Dunlop et al. 2015, arXiv: 1412.1472



Confirms continued smooth decline in star-formation density out to $z \sim 9$ At least some models struggle to drop off so gradually

Link to Cosmic Reionization

Agrees (just!) with WMAP-9 and other probes if LF extended to $M_{uv} < -13$ Robertson et al. 2013, ApJ, 768, 71

The reionization history implied by the high-redshift galaxy population matches the constraints from *WMAP*, observations of the Lyman- α Forest, and the evolving fraction of Lyman- α emitting galaxies.

Issues

- Extinction as a function of mass/luminosity/redshift dust at high z ?
- Should UV LF be integrated down to $M_{UV} \sim -13$? Beyond z ~ 12 ?
- Incompleteness and steepness of stellar mass functions ?
- Strength of emission-line contributions at high redshift ?
- What happens at z > 10?