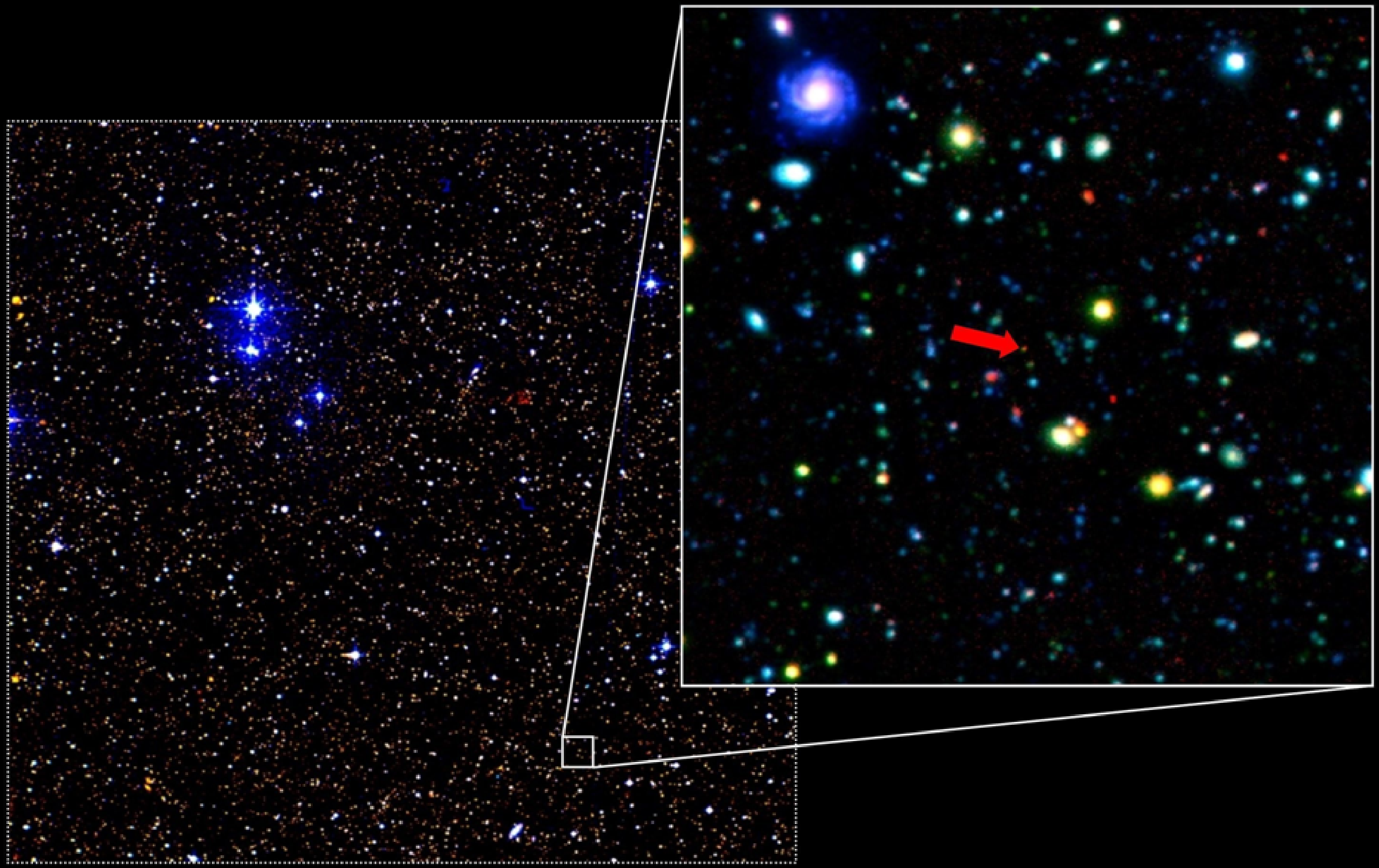
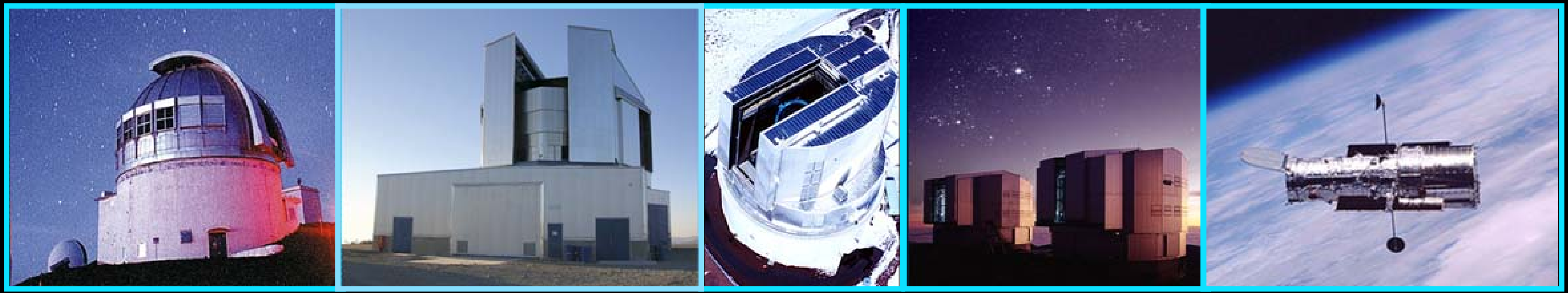
Exploring massive galaxy evolution with the UKIDSS Ultra-deep Survey



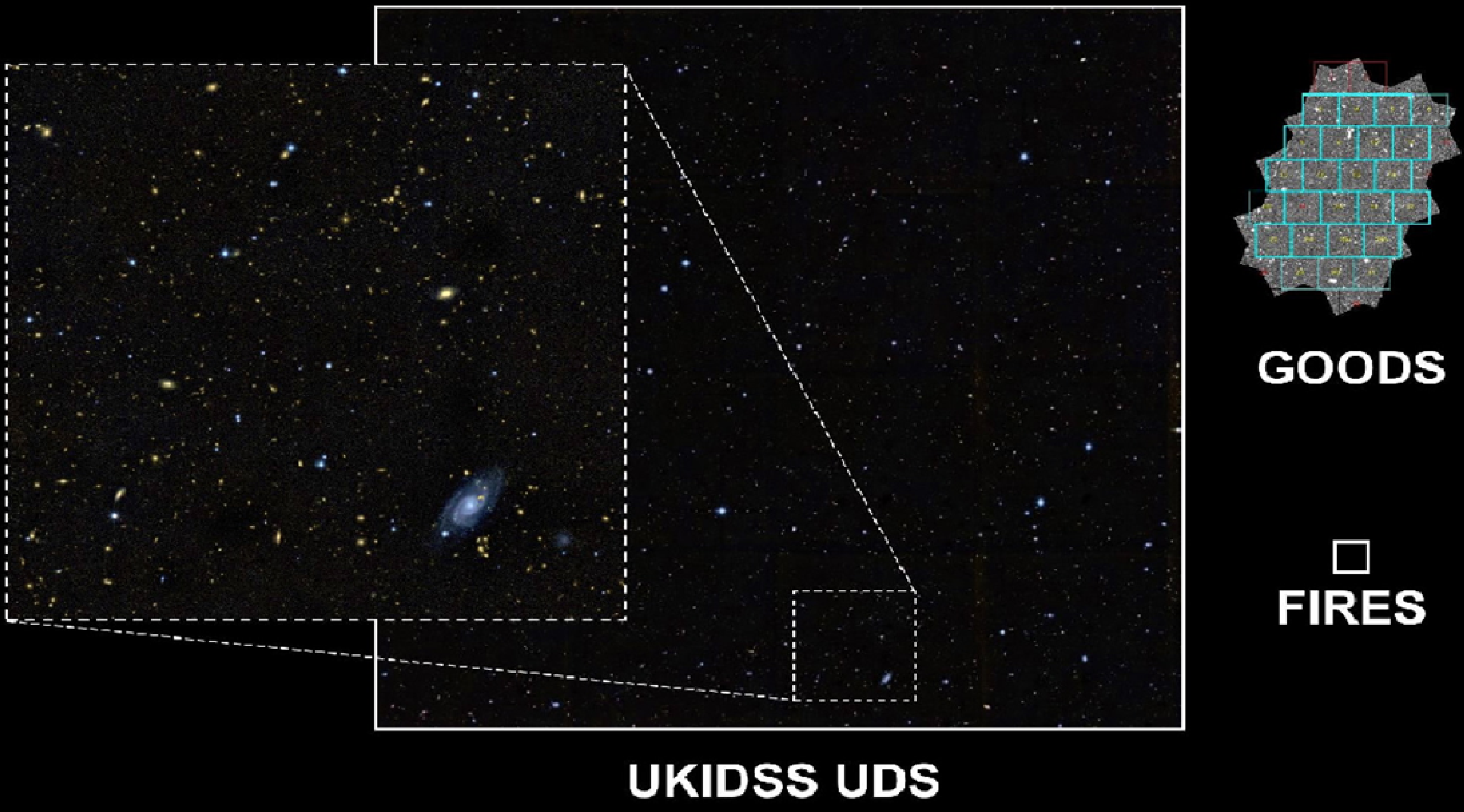
Ross McLure, Michele Cirasuolo, Jim Dunlop,
Omar Almaini, Sebastien Foucaud

Exploring massive galaxy evolution with the UKIDSS Ultra-deep Survey

1. UKIDSS Ultra-deep survey
2. Massive galaxy evolution at $4<z<6$ with UKIDSS UDS
3. Prospects for studying galaxies at $z>7$



UKIDSS Ultra-deep Survey



Unique depth+area in NIR plus strong + multi-wavelength coverage

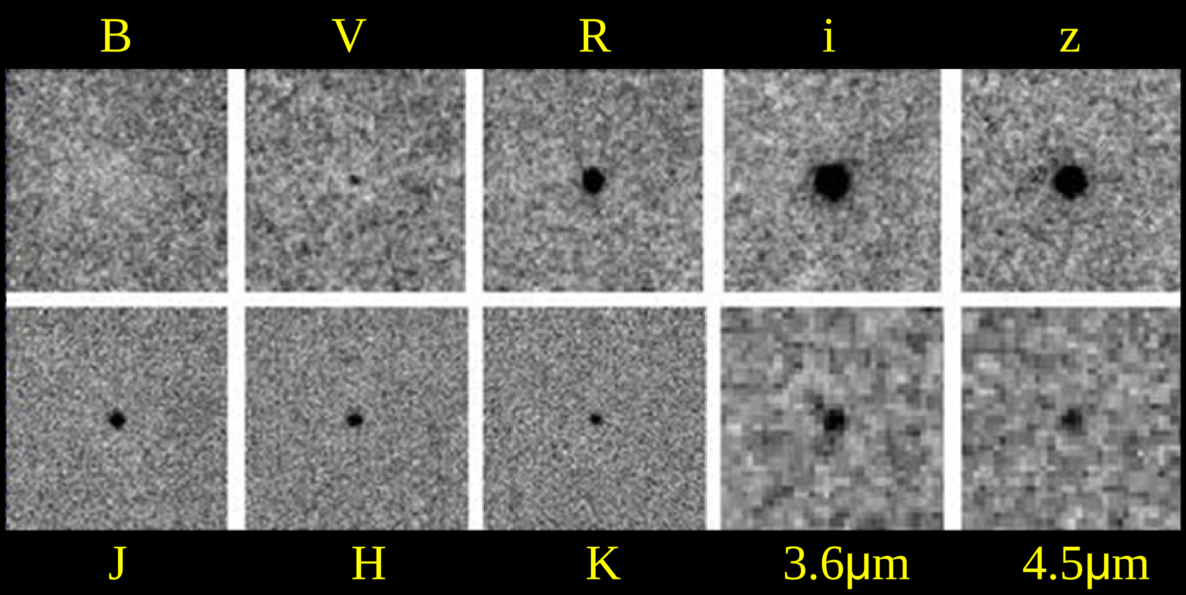
However: ultra-deep optical, near-IR & mid-IR make UDS a powerful resource for studying massive galaxies at 4<z<7

Massive galaxies at 4<z<6

Selecting galaxies at high redshift

Two basic techniques:

1. Lyman-break selection (LBGs)
2. Narrow-band selection of Lyman alpha emitters (LAEs)



Massive galaxies at 4<z<6

Hubble Ultra Deep Field
Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, S. Beckwith (STScI) and the HUDF Team STScI-PRC04-07a

The depth and spatial resolution of the HST ACS imaging in the Ultra Deep Field and wider GOODS N+S fields has been crucial

Has allowed high-redshift luminosity function be traced as faint as ~0.1 L*

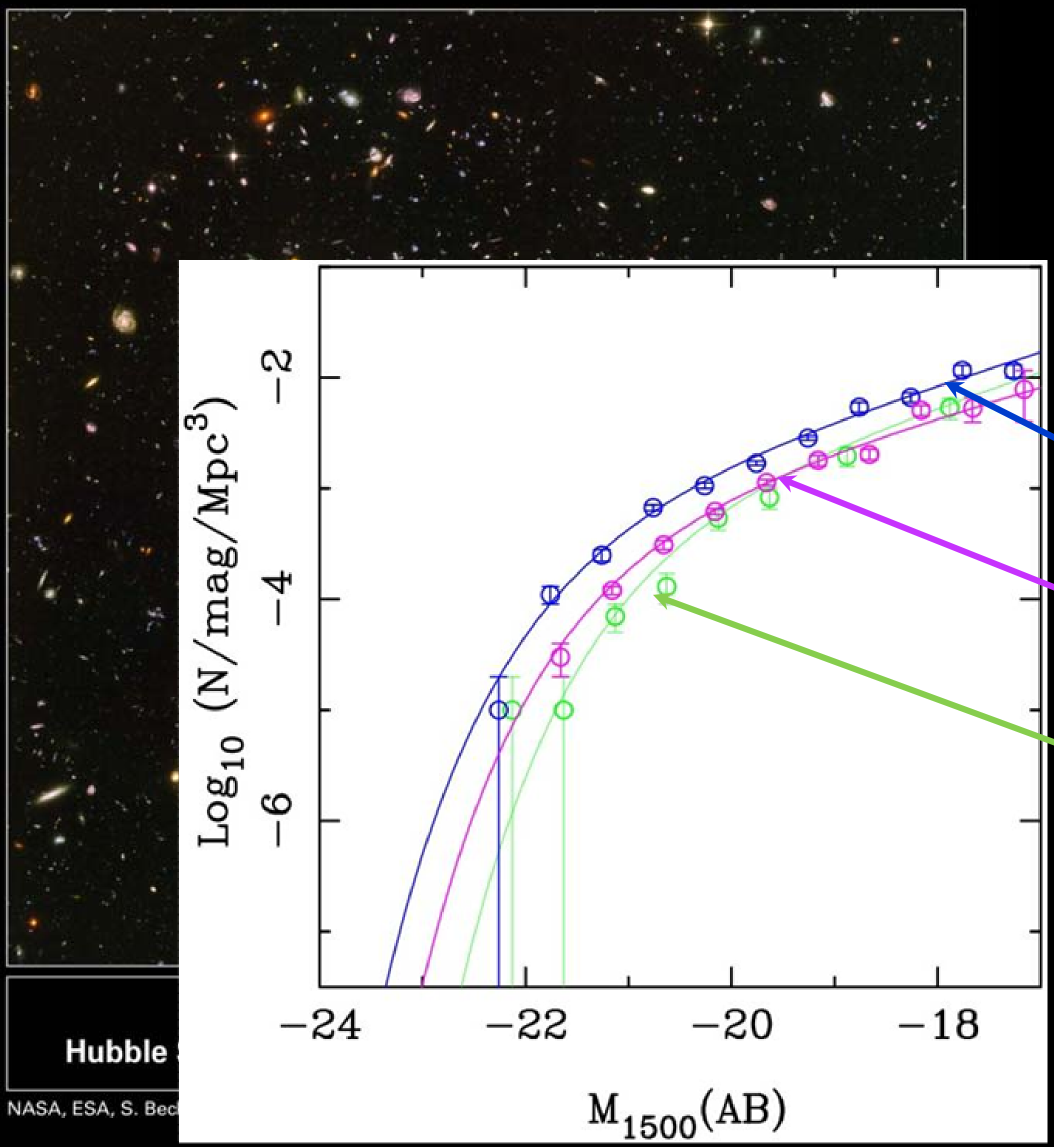
However

Very small areas (HUDF ~13 arcmin^2]

Potential for large cosmic variance, *particularly* at bright-end of LF

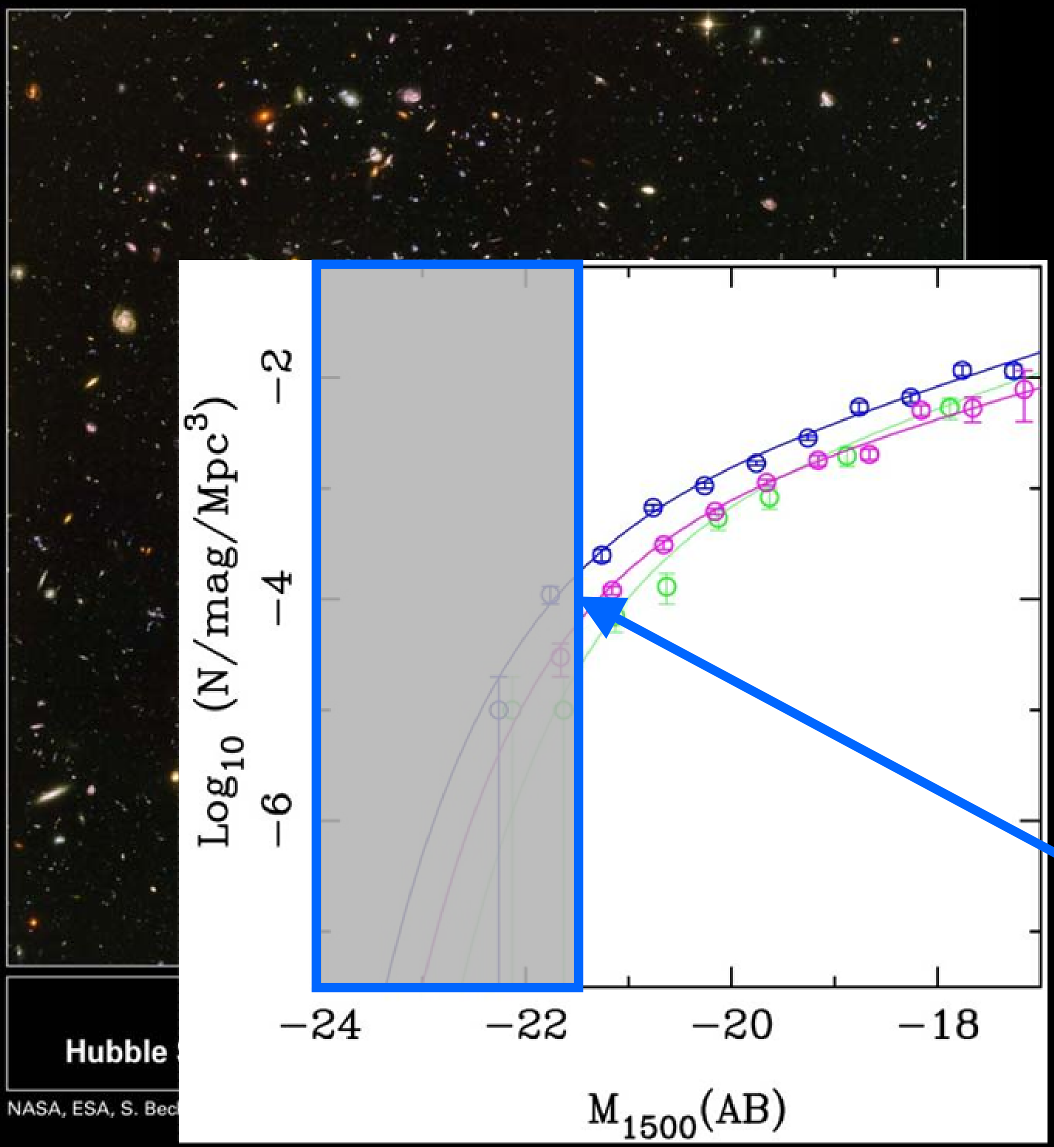
Massive galaxies at 4<z<6

The high-redshift galaxy luminosity function:



Adapted from Bouwens et al. (2007)

Massive galaxies at 4<z<6



The high-redshift galaxy luminosity function:

Small area of HST fields means there is virtually no information brighter than M*

Massive galaxies at 4.5<z<6.5

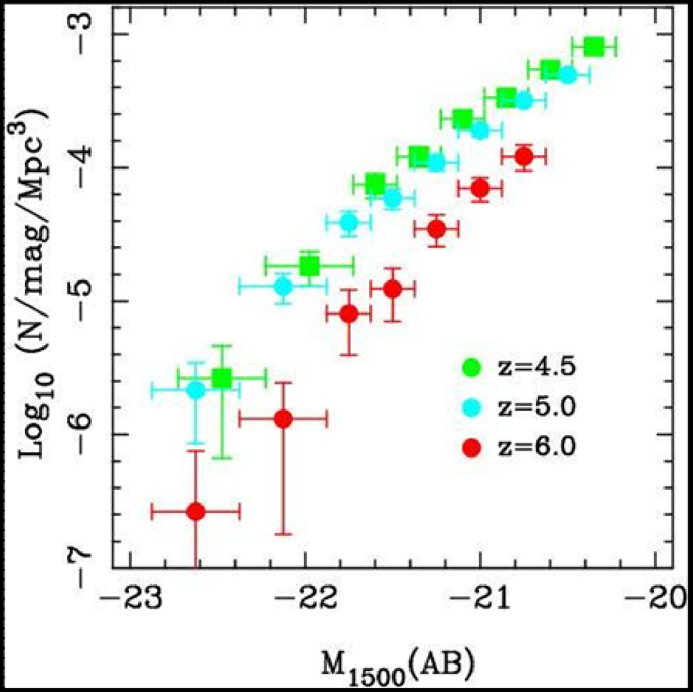
McLure et al. (2009)

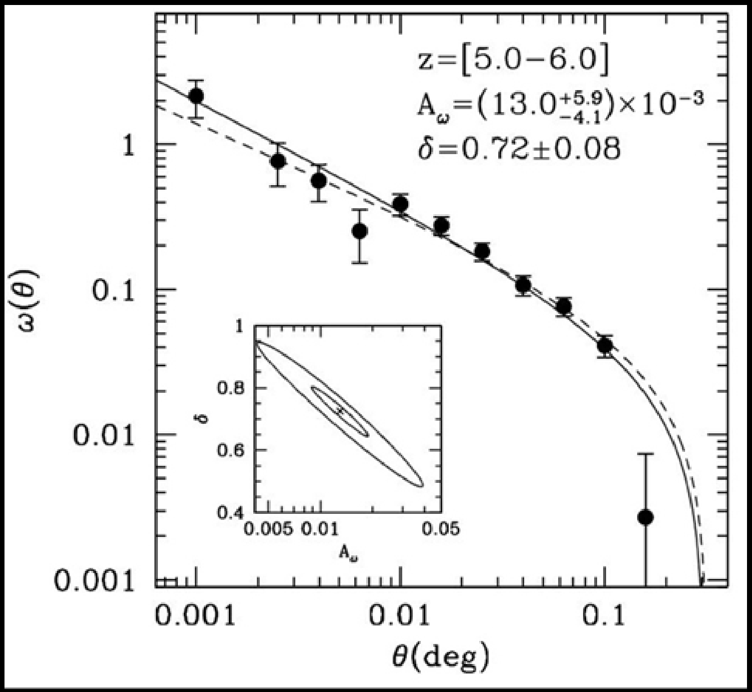
Strategy:

- Selected z<26 (AB) catalog from UDS+SXDS data (z=6.5 limit)
- Rejected anything formally detected in B-band image (4.5<z<6.5)
- Photometric redshift fitting for all candidates (~6000 objects)
- Used redshift probability function P(z) to construct V/V_{max} LF estimate

More inclusive than strict “drop-out” selection
Maximizes available redshift information

Massive galaxies at 4.5<z<6.5

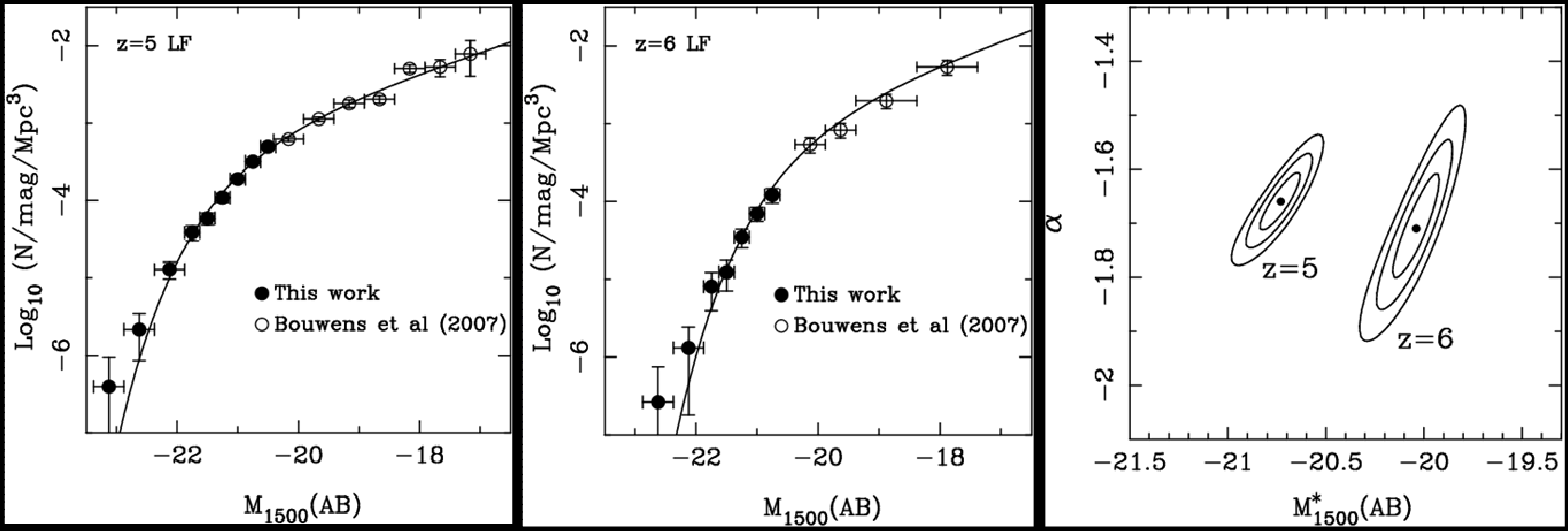




1. Clear evolution in UV LF from z=5 to z=6 :
   can't be evolution in $\Phi^{\star}$ alone

2. Wide area allows accurate clustering analysis:
   r_o=8 Mpc , halo masses ~ $5\text{x}10^{11}M_{\odot}$

Massive galaxies at 4.5<z<6.5

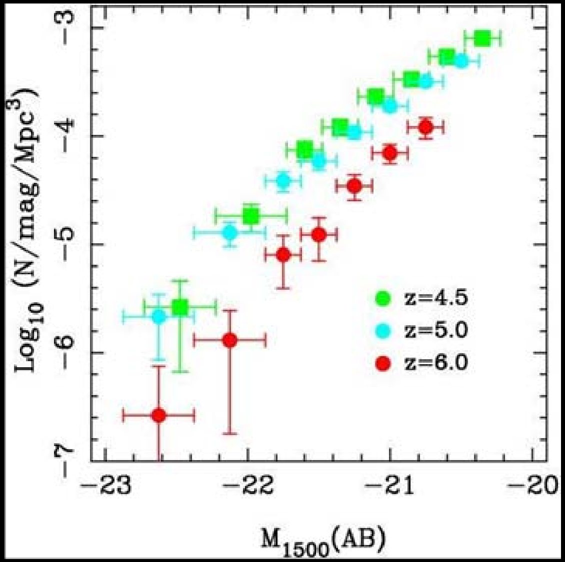


ML fits to the combined ground+HST data-sets

M* brightens by ~0.7 magnitudes from z=6 to z=5

No significant evolution of normalization or faint-end slope

Massive galaxies at 4.5<z<6.5



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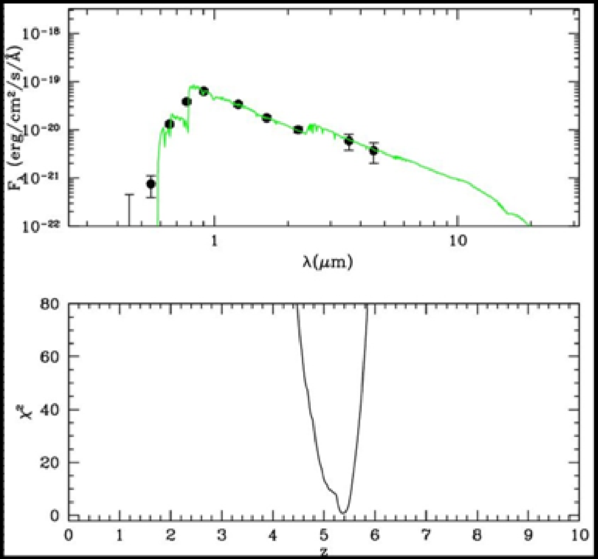
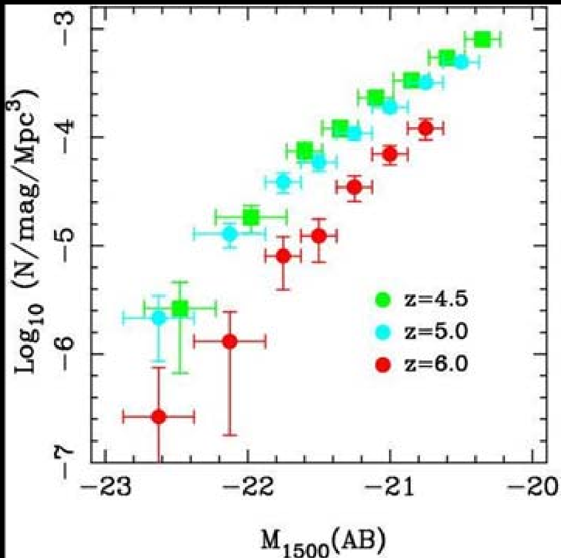


Massive galaxies at 4.5<z<6.5



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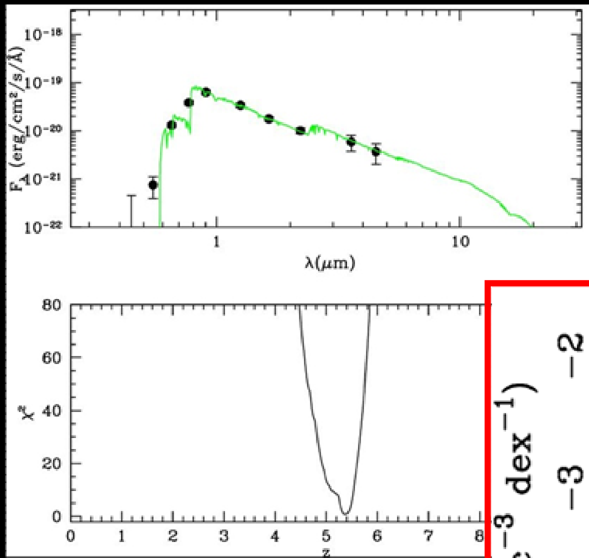
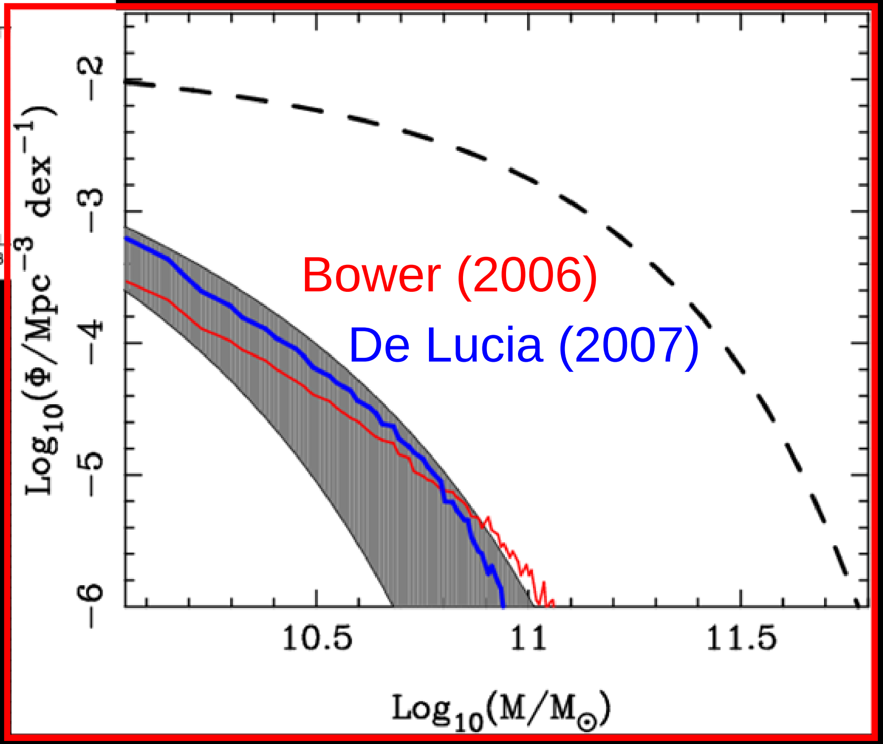




Combination of LF and typical M/L allows rough estimate of stellar mass function/density:

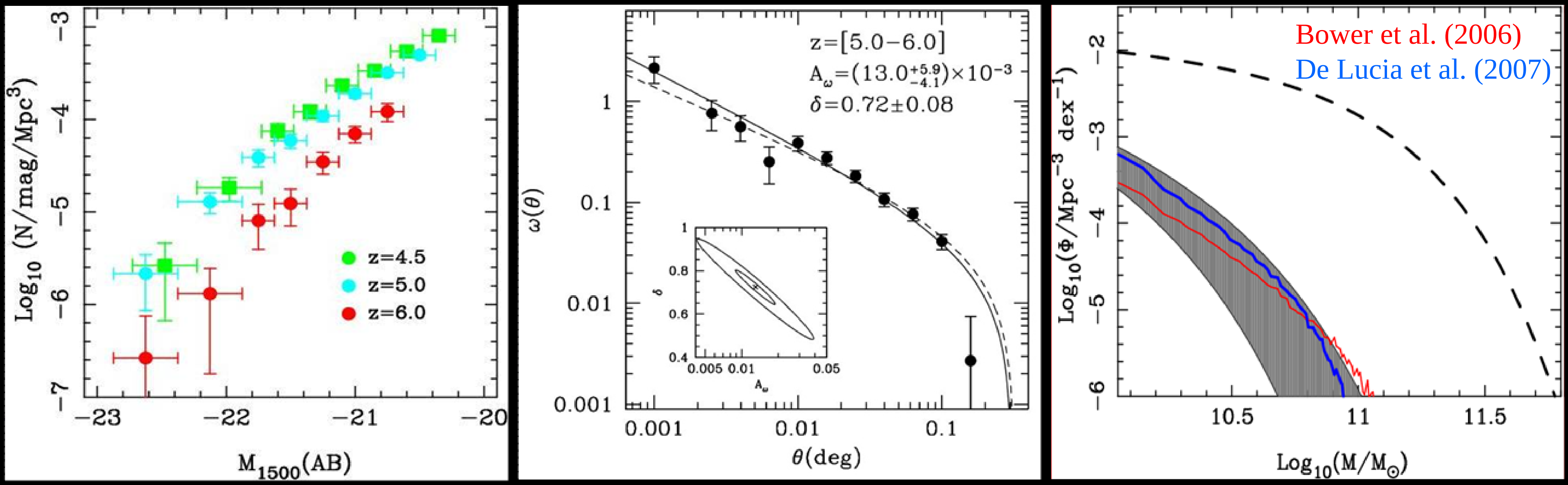
Stellar mass in place by z~5 is ~ $1\times10^{7} M_\odot$ Mpc^{-3}

Stellar mass in place by z~6 is ~ $4\times10^{6} M_\odot$ Mpc^{-3}

(c.f. Yan et al. 2006; Stark et al. 2007)

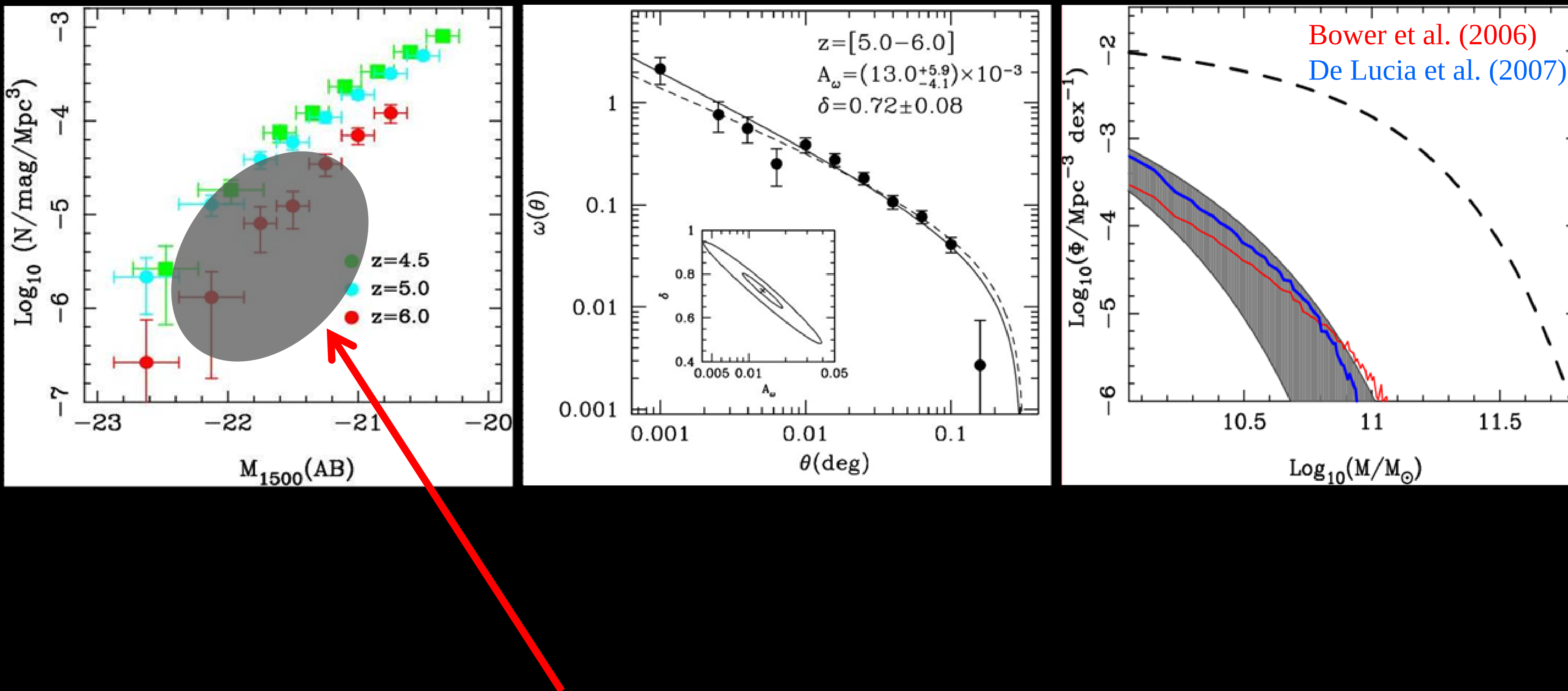
Massive galaxies at 4.5<z<6.5

McLure et al. (2009)



Massive galaxies at 4.5<z<6.5

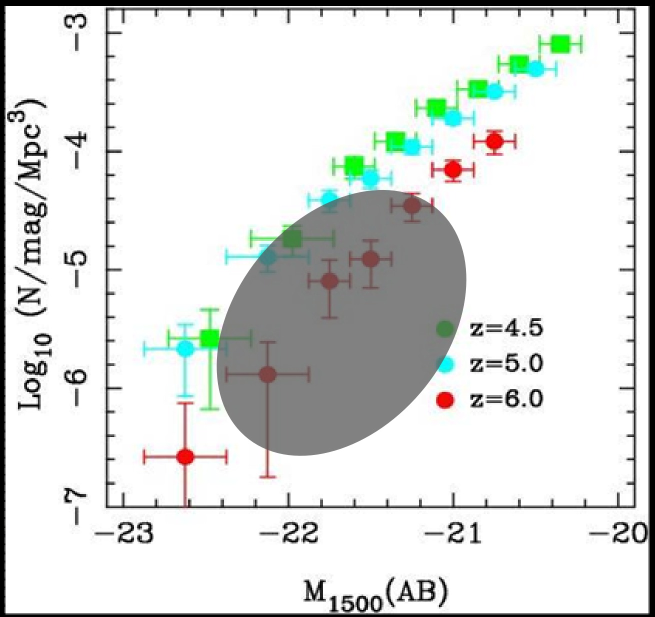
McLure et al. (2009)

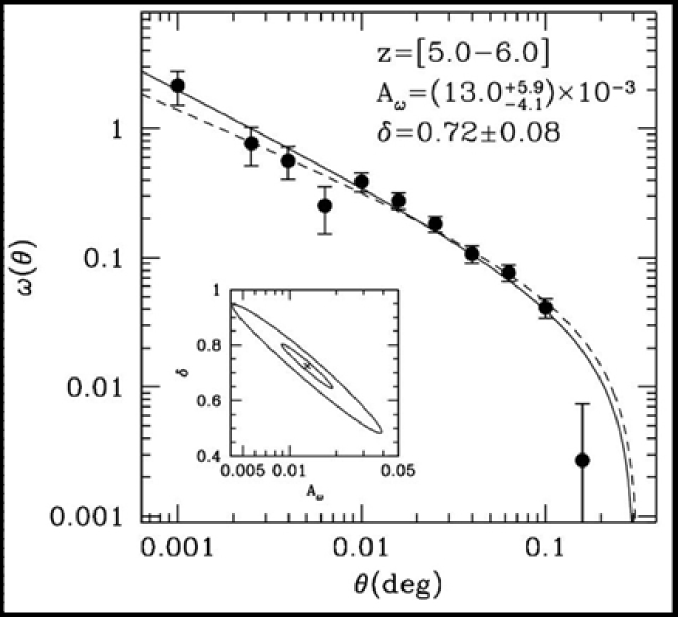


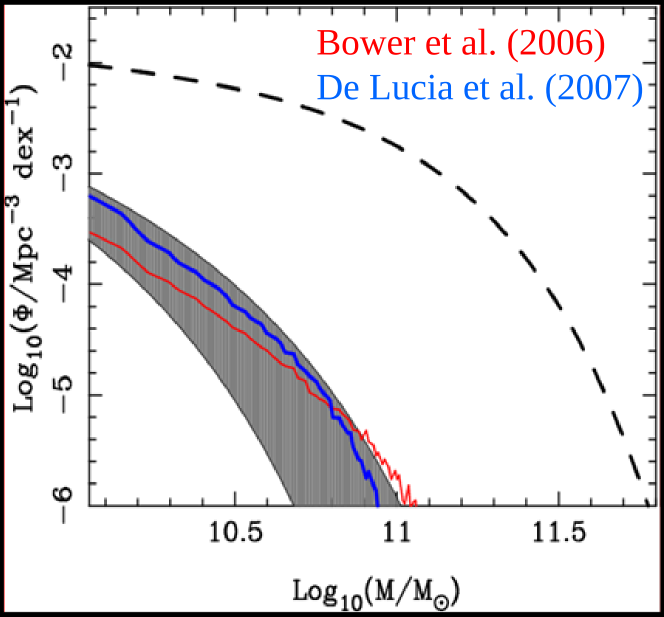
LBGs at bright-end of LF can be targeted with for 8m-class spectroscopy

Massive galaxies at 4.5<z<6.5

McLure et al. (2009)







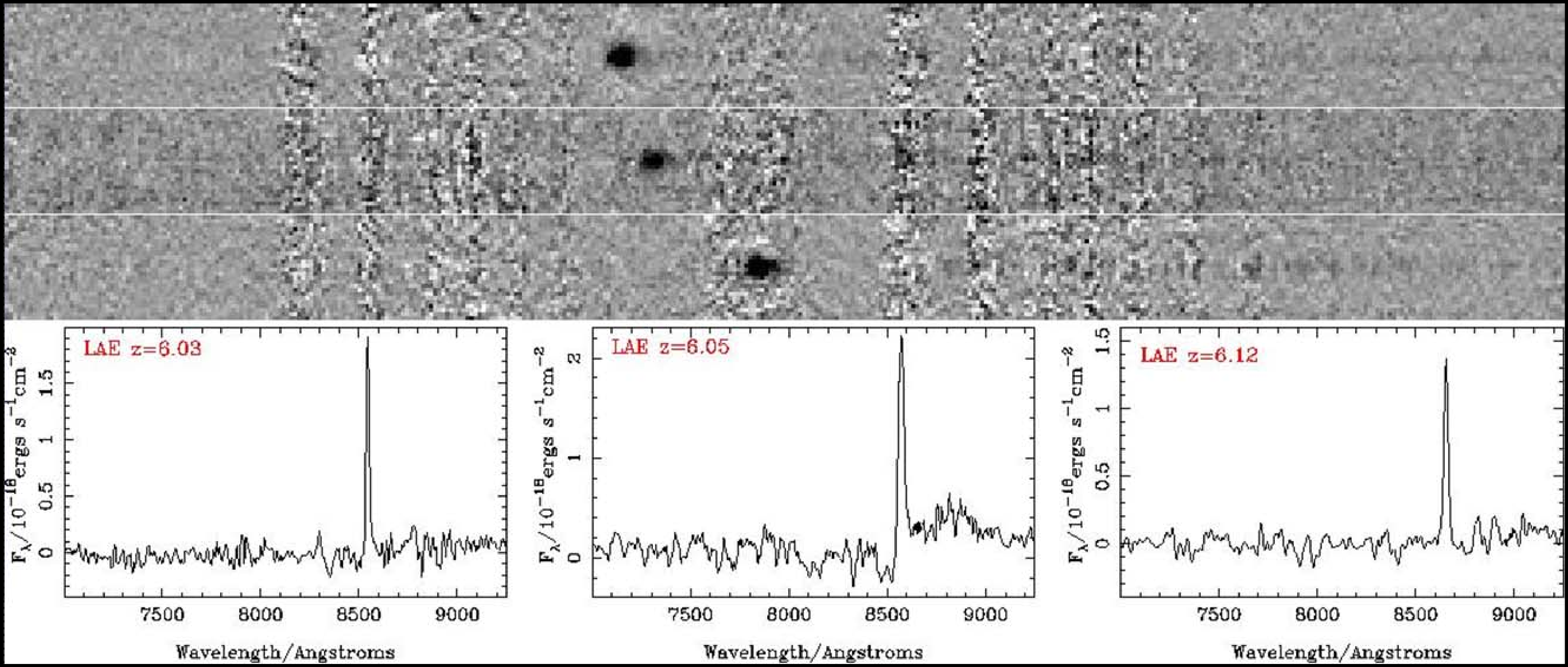
ESO Large Programme: UDSz

93 hours VIMOS

142 hours FORS2

Massive galaxies at 4.5<z<6.5

McLure et al. (2009b), in prep



>50% of luminous LBGs observed at z>6 are strong LAEs

Lyα line fluxes are typical 3×10^{-17} cgs, i.e. SFR~10 $M_\odot$ yr^{-1}

Exploring massive galaxy evolution with the UKIDSS Ultra-deep Survey

1. UKIDSS Ultra-deep survey

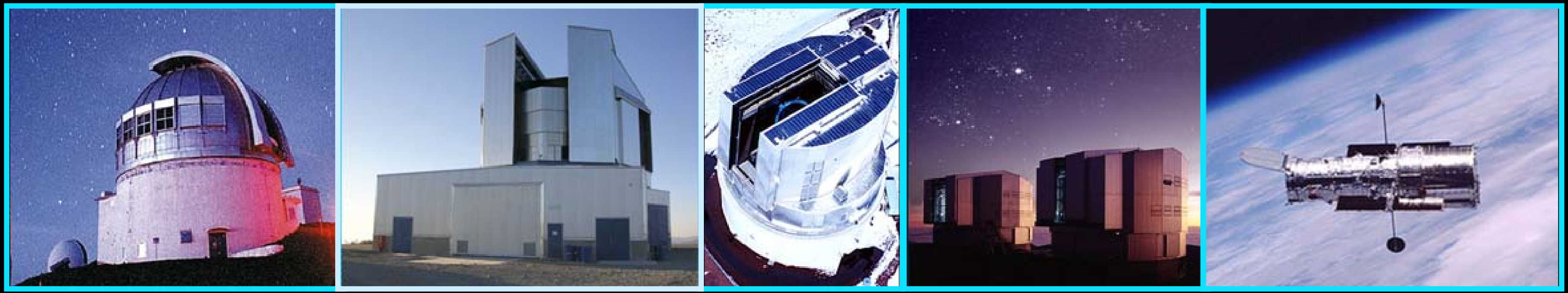
2. Massive galaxy evolution at 4<z<6 with UKIDSS UDS

3. Prospects for studying galaxies z>7

Future progress: the galaxy population at z>7

1. Bright-end of the luminosity function

2. Faint-end of the luminosity function



Future progress: the galaxy population at z>7

1. Bright-end of the luminosity function

Deep, wide-field imaging in the optical+nearIR is essential

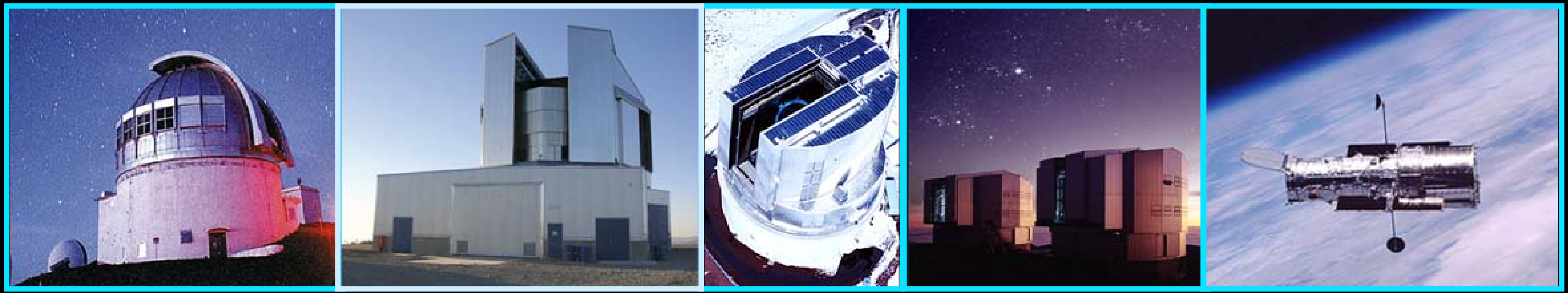
Future progress: the galaxy population at z>7

1. Bright-end of the luminosity function

Deep, wide-field imaging in the optical+nearIR is essential

Degree-scale imaging from UKIRT and VISTA will be crucial

(e.g. UDS is only ~15% complete, much more science to be done!)



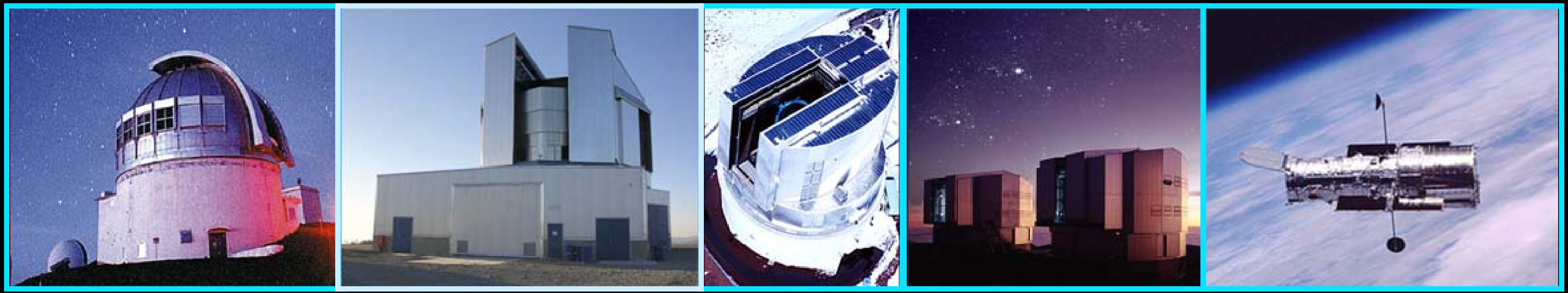
Future progress: the galaxy population at z>7

1. Bright-end of the luminosity function

Deep, wide-field imaging in the optical+nearIR is essential

Degree-scale imaging from UKIRT and VISTA will be crucial

UKIDSS UDS has demonstrated power of UKIRT+Subaru



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Future progress: the galaxy population at z>7

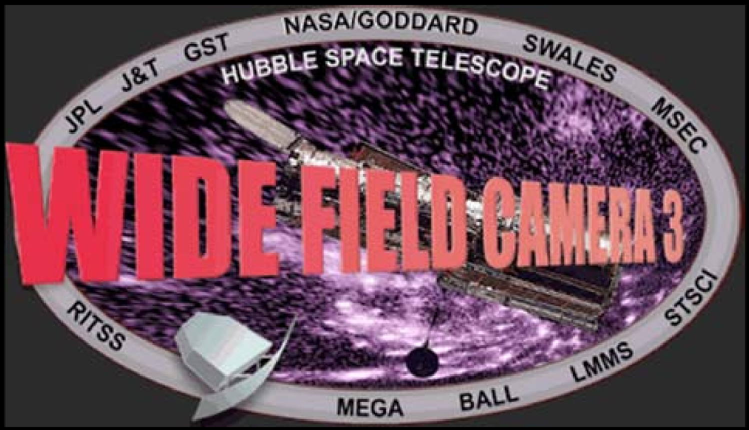
1. Bright-end of the luminosity function

2. Faint-end of the luminosity function

↓

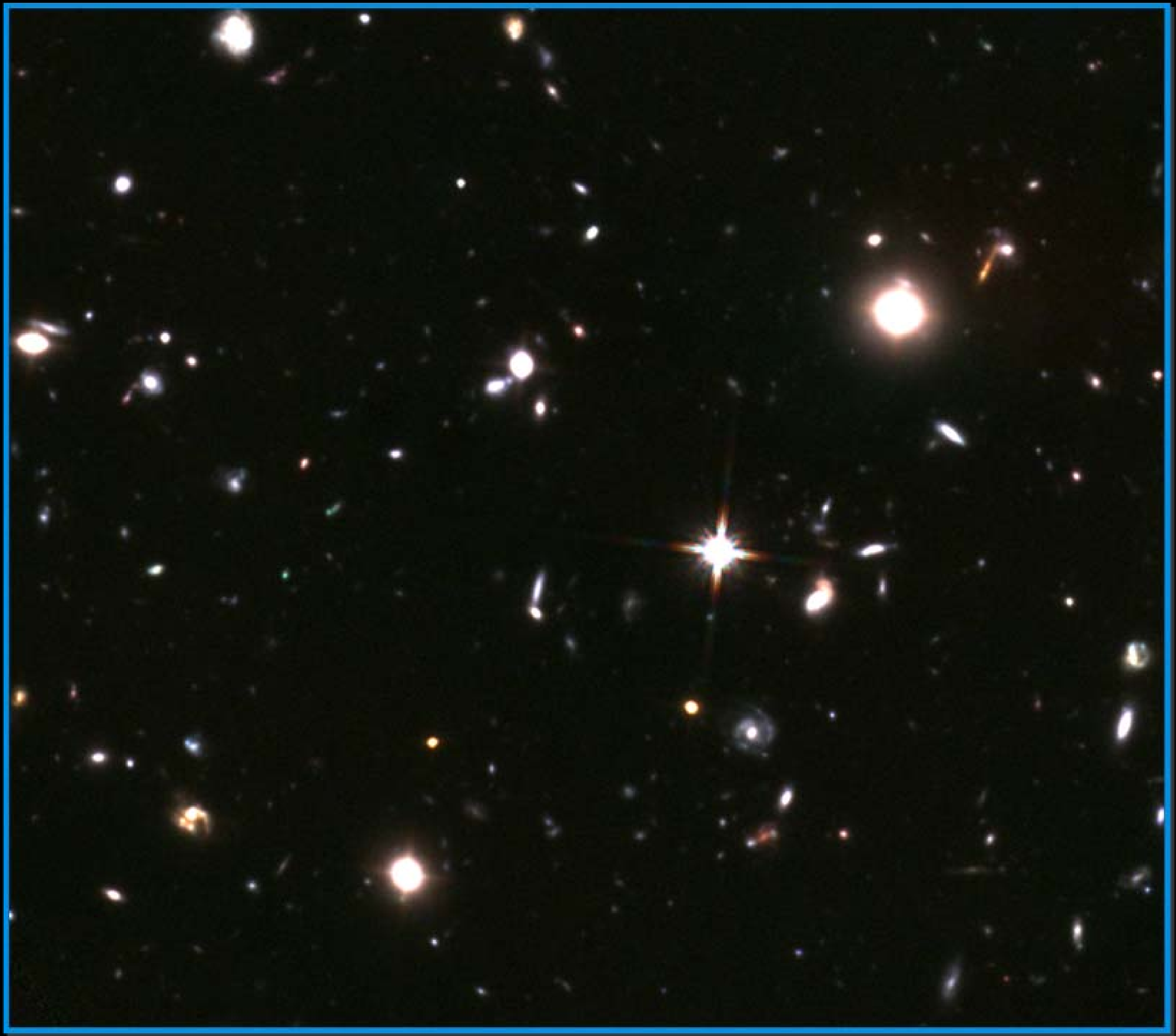
Rely on ultra-deep, pencil beam HST imaging

→



WFC3 Imaging of the HUDF

data released 9th September



Data reduction by A. Koekemoer & E. Sabbi (STSCI)

The basic numbers:

~11 hours in Y

~12 hours in J

~22 hours in H

FWHM: 0.15-0.18”

5σ depths: Y=29.0 (AB)

J=29.1

H=29.2

What do we find?

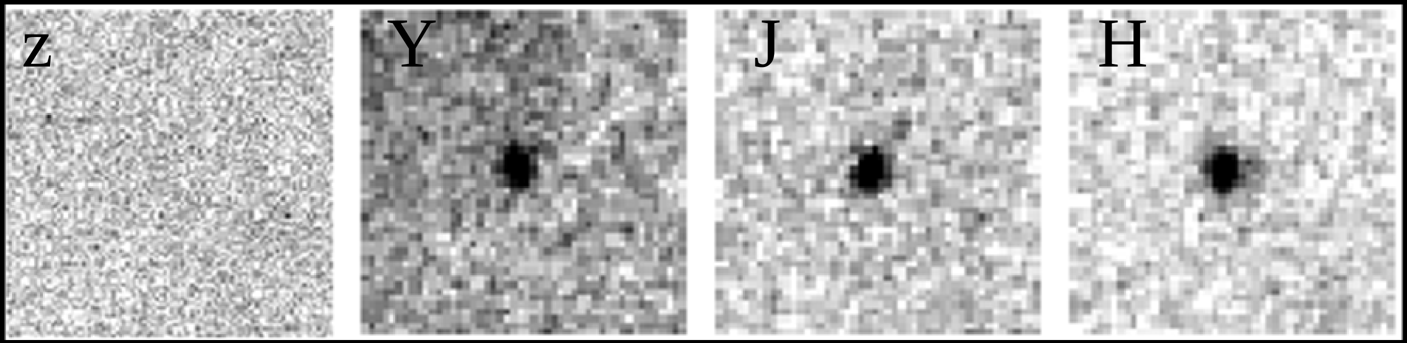
49 candidates at z>5.9

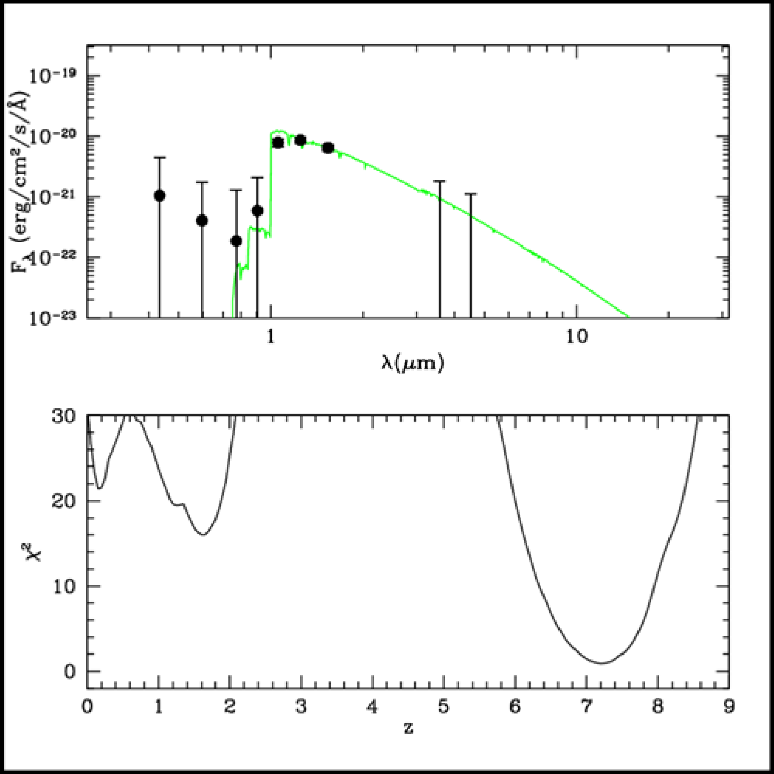
15 candidates at z>7.0

3 candidates at z>8.0

WFC3 Imaging of the HUDF: Galaxy LF at z>7

McLure, Dunlop, Cirasuolo et al. 2009, arXiv: 0909.2437

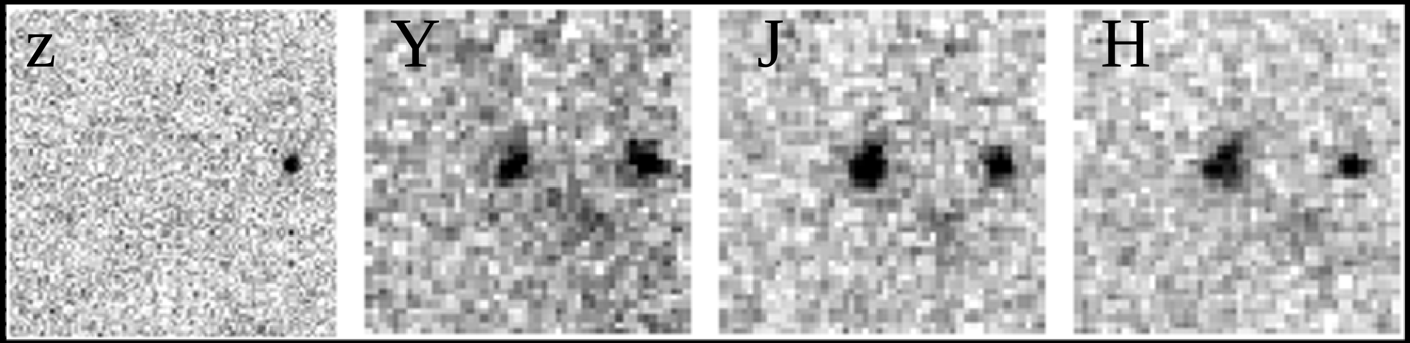


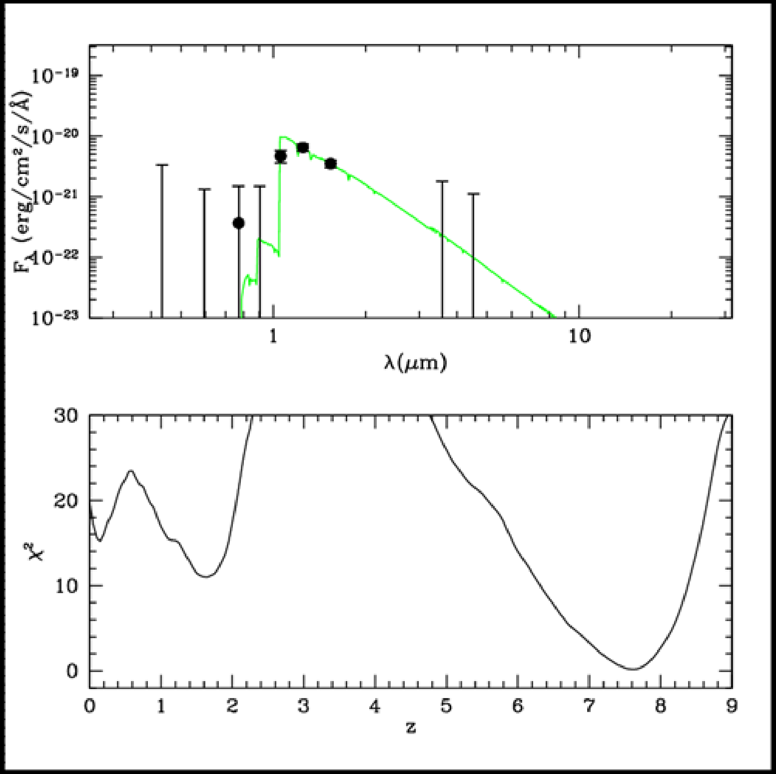


ID No. 835 z_{phot} = 7.20

WFC3 Imaging of the HUDF: Galaxy LF at z>7

McLure, Dunlop, Cirasuolo et al. 2009, arXiv: 0909.2437

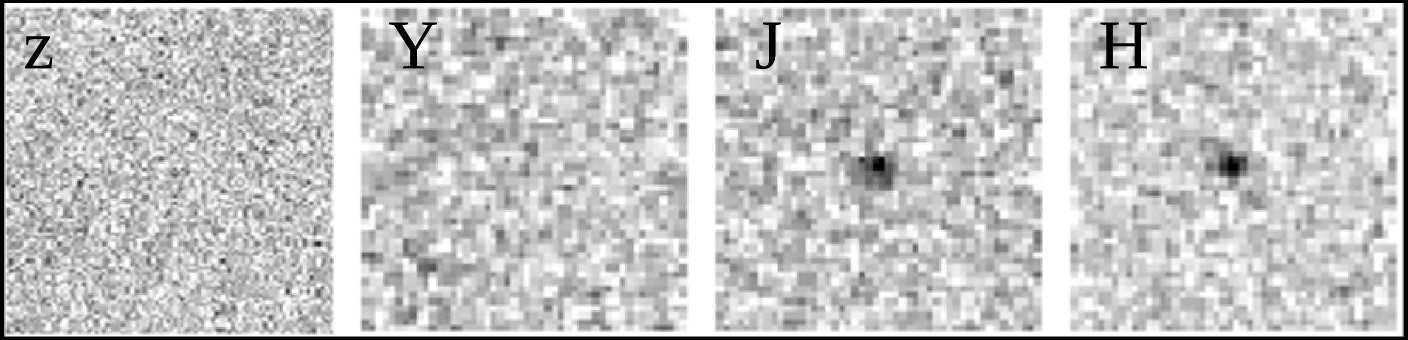


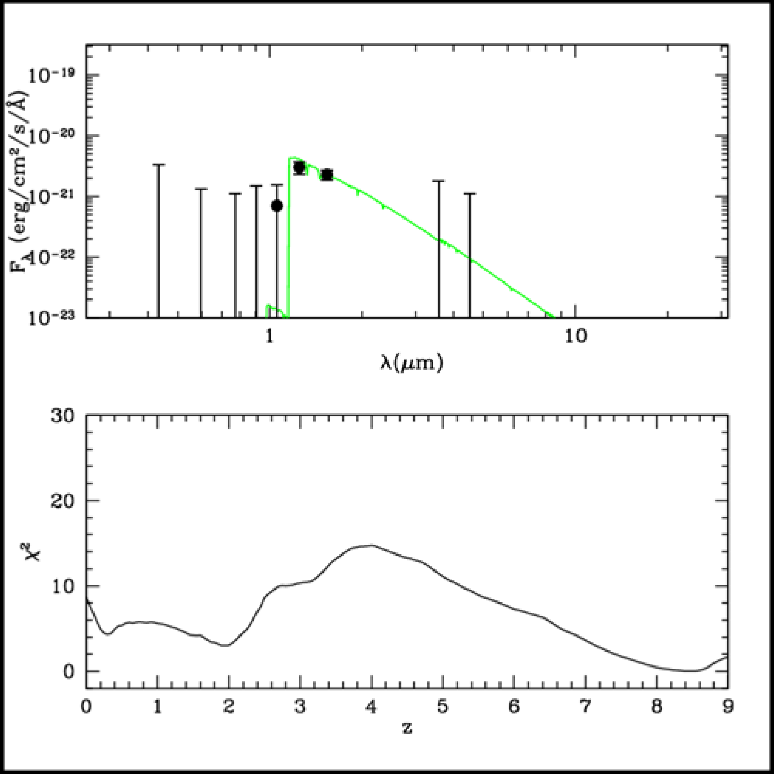


ID No. 1107 $z_{phot} = 7.60$

WFC3 Imaging of the HUDF: Galaxy LF at z>7

McLure, Dunlop, Cirasuolo et al. 2009, arXiv: 0909.2437

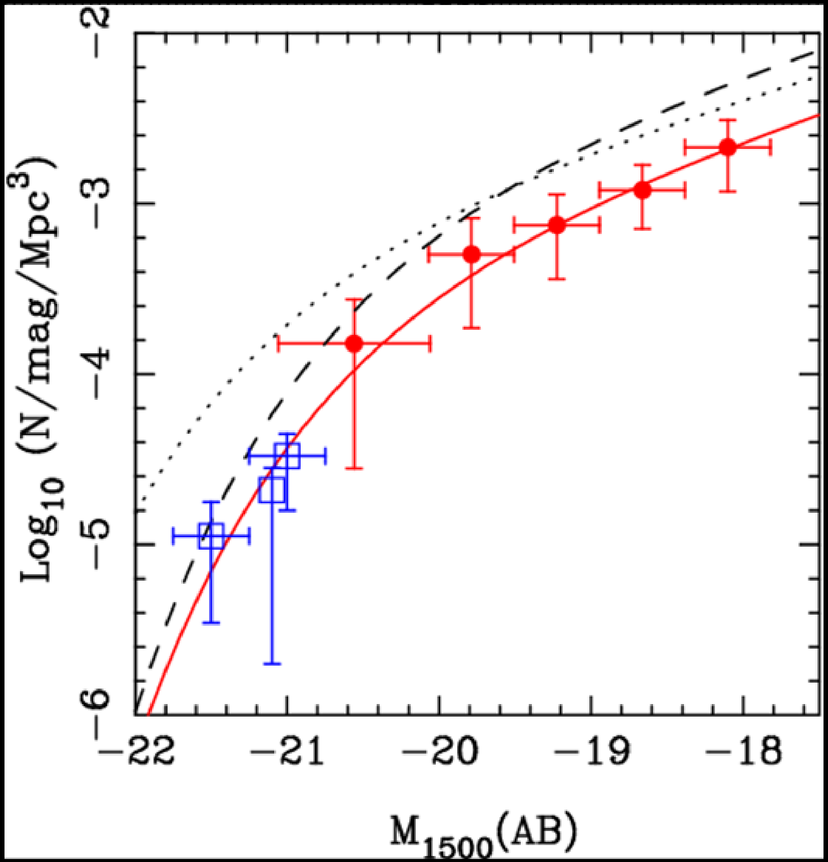


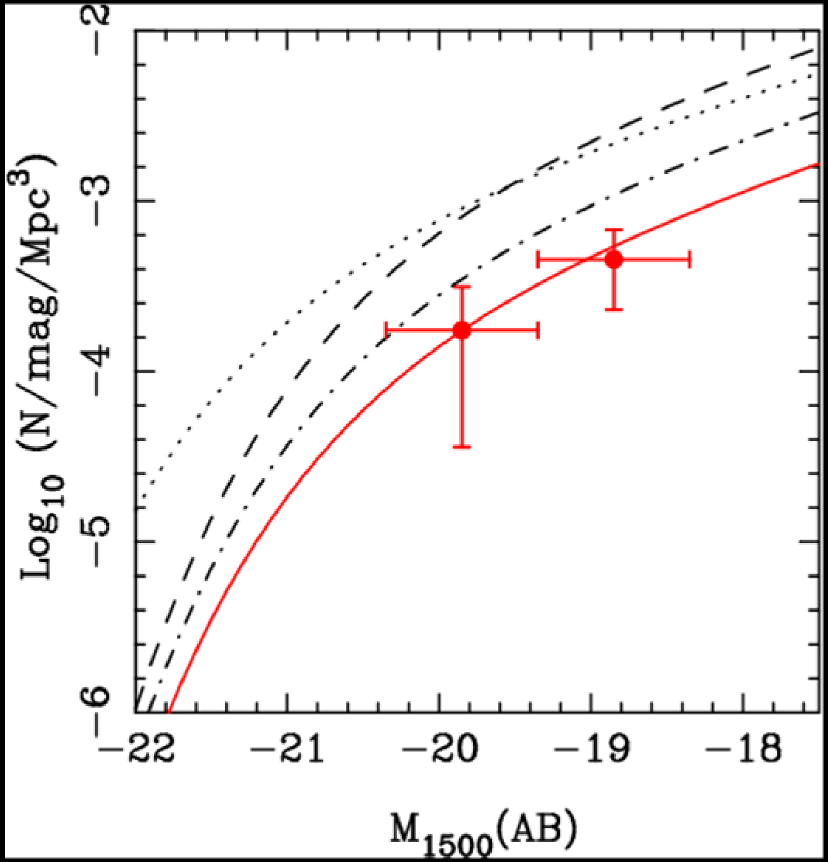


ID No. 1721 z_{phot} = 8.45

WFC3 Imaging of the HUDF: Galaxy LF at z>7

McLure, Dunlop, Cirasuolo et al. 2009, arXiv: 0909.2437



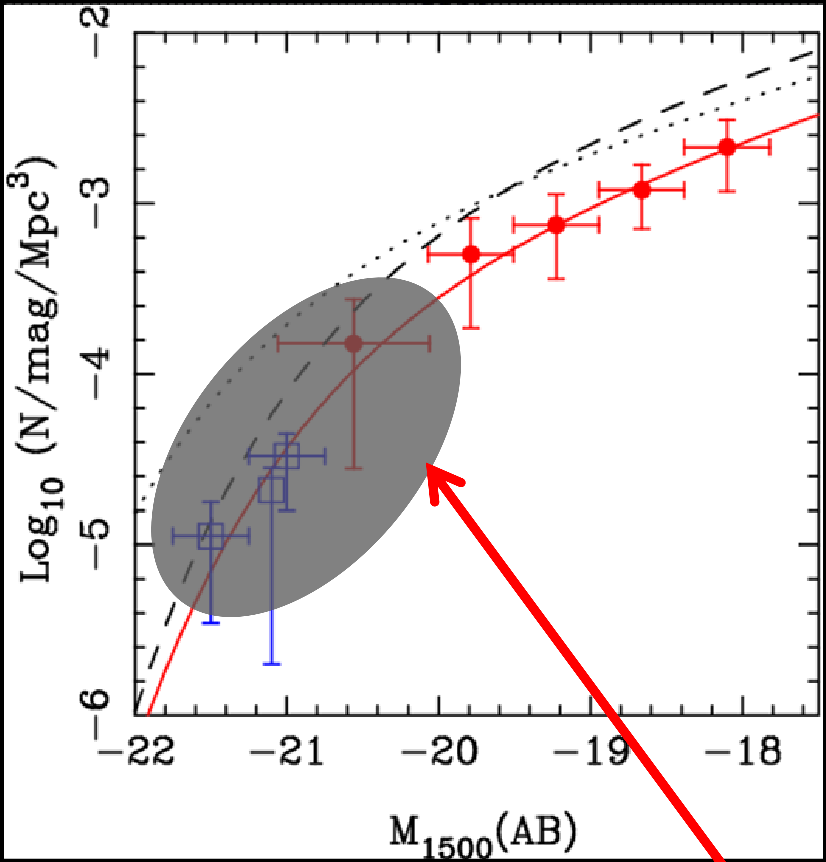


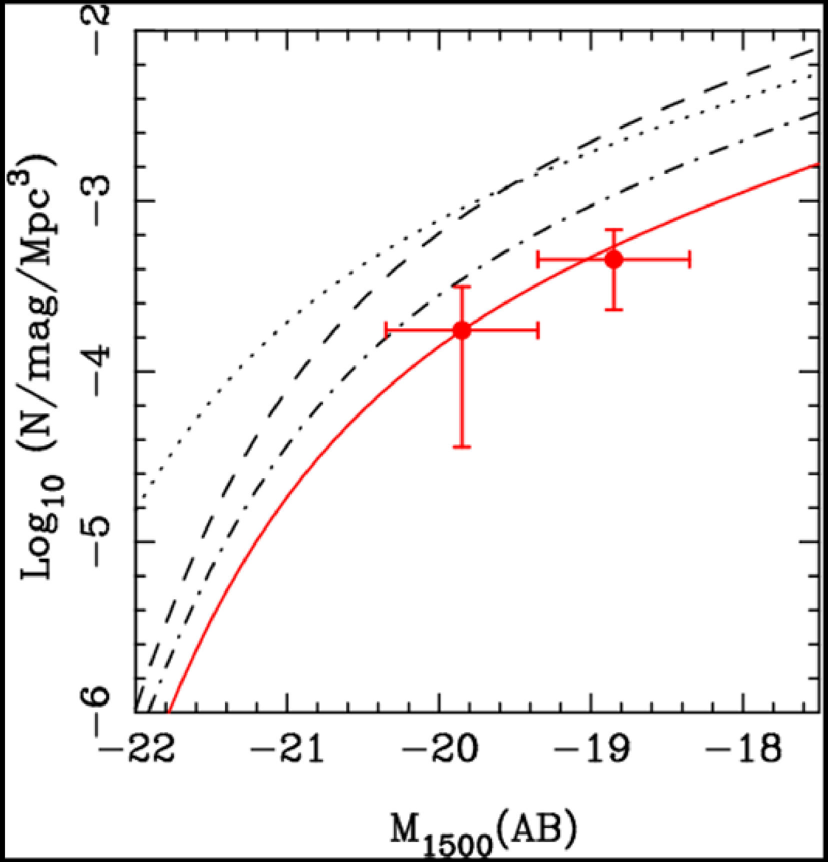
First cut at z=7 LF: same shape as z=6, normalization down by 60%

Weak constraints on z=8 LF: normalization down by a further 50%??

WFC3 Imaging of the HUDF: Galaxy LF at z>7

McLure, Dunlop, Cirasuolo et al. 2009, arXiv: 0909.2437





Tighter constraints required: can tackle this with deep, widefield, ground-based imaging in the nearIR

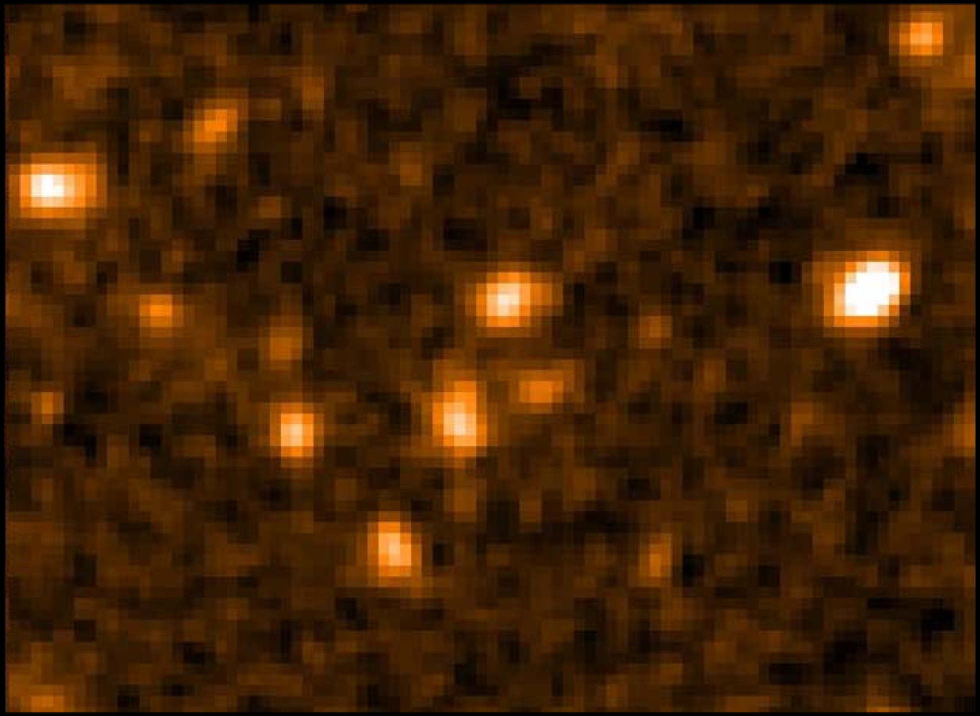
Summary

1. UKIDSS Ultra-deep survey powerful resource for studying z>4 galaxies
2. Current data-set has allowed studies of z=5 and z=6 galaxy population
3. Prospect of good progress at z>7 with deeper near-IR+optical imaging
4. In combination with deep HST imaging, robust constraints on the galaxy population at z>8 is now within reach…..

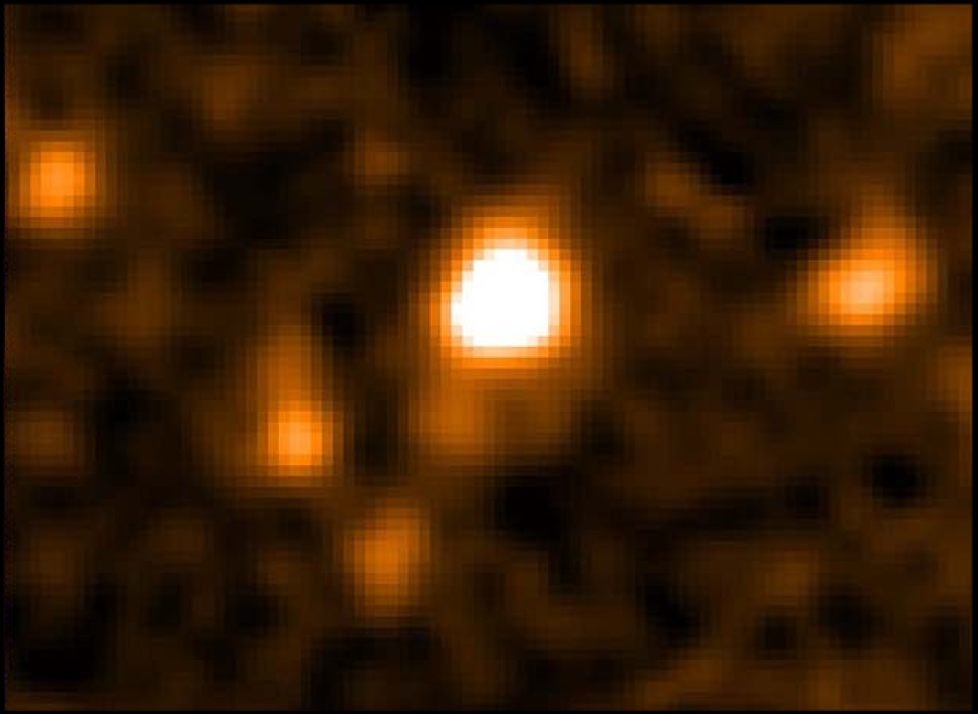

Spitzer Warm Mission
Spitzer extra-galatic deep survey (SEDS)
Ultra-deep 3.6+4.5 micron imaging of five, 0.2 sq deg fields:
1.GOODS-N
2.GOODS-S
3.Groth Strip
4.COSMOS
5.UKIDSS UDS
Spitzer in Space
www.spitzer.caltech.edu
SPITZER
SPACE TELESCOPE

Spitzer IRAC data: confusion?

Combination of depth and broad PSF means that source confusion is a real problem with new IRAC data:



Subaru z-band

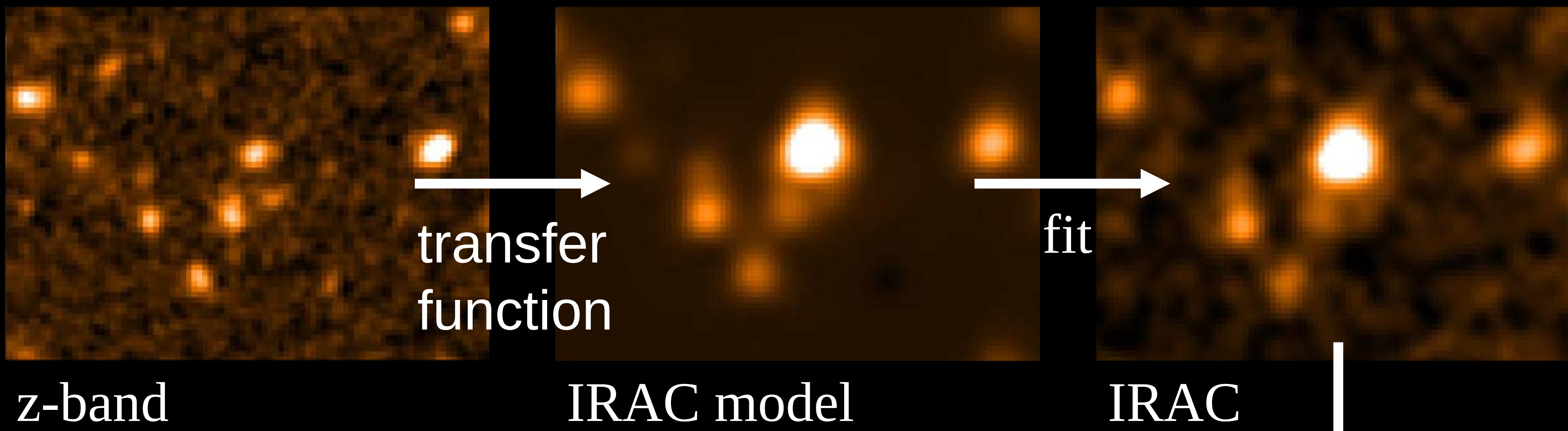


IRAC 3.6 micron

Now using z-band imaging to provide templates for each source: produce model IRAC image and fit individual flux components

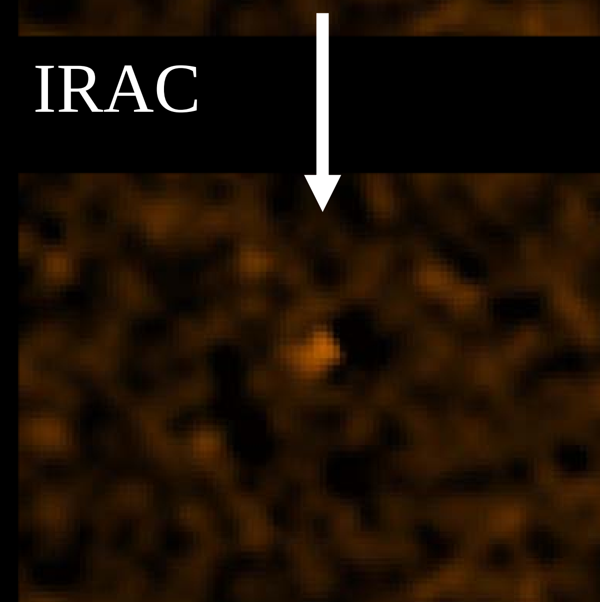
Spitzer IRAC data: confusion?

Combination of depth and broad PSF means that source confusion is a real problem with new IRAC data:



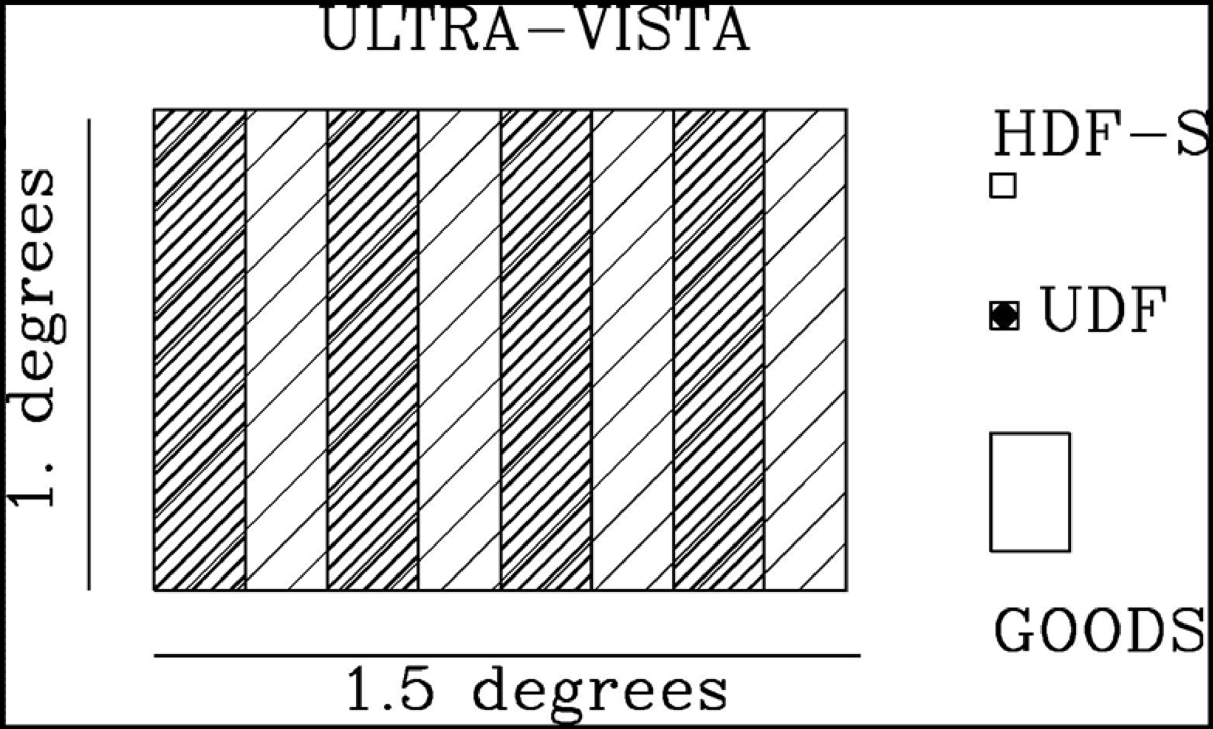
- Produces de-blended IRAC mags for all z-band sources

- Also identifies ultra-red objects missing in the optical



Ultra-Vista – new public survey with Vista telescope

- PIs Dunlop, Franx, Le Fevre, Fynbo
- 0.9 sq deg, in COSMOS / CFHTLS D2, Y=26.7, J=26.6, H=26.1, K=25.6
- Narrow-band survey at z = 8.8
- shallower survey covering full 1.5 sq. deg
- 1800 hr over 5 years – expect commence Jan 2010



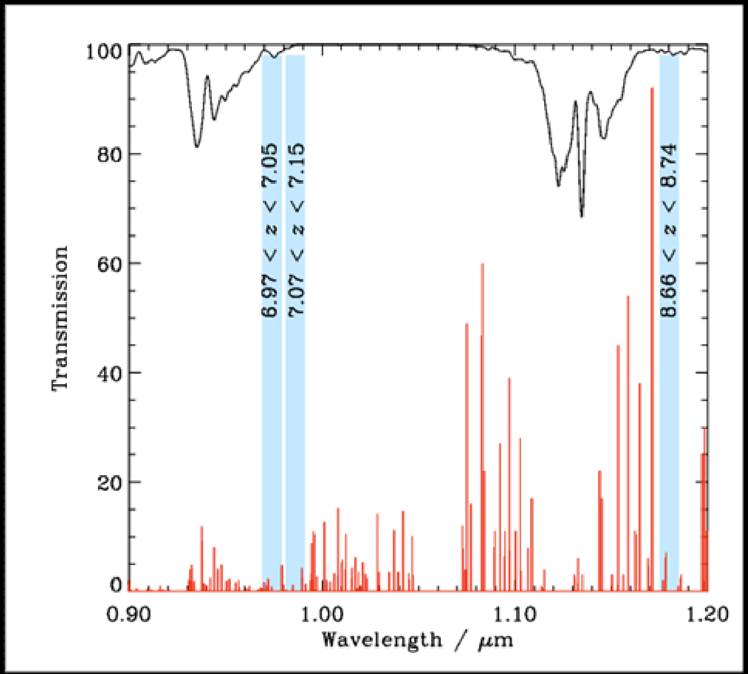
Predicted Numbers of LBGs:

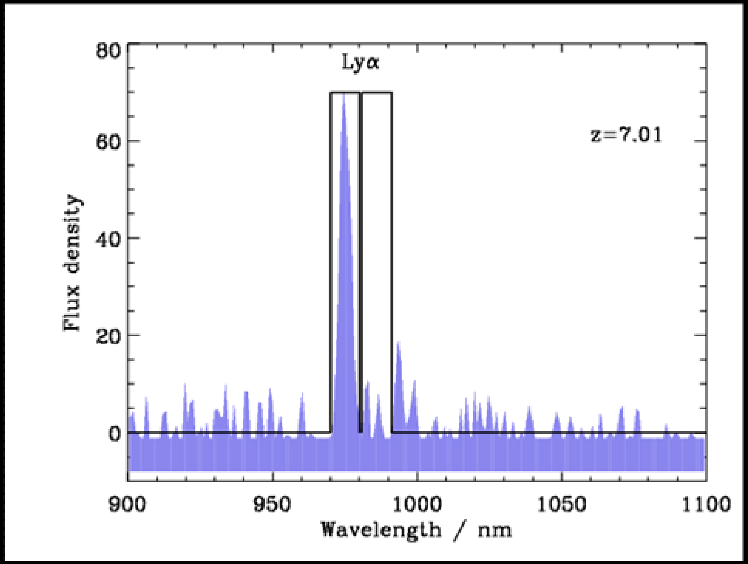
~ 400 Y-drops at z~7.5
~ 200 J-drops at z~8.5

Clear that 100s of "plausible" candidates will require NIR spectroscopy

VISTA narrow-band search for z~7 galaxies

(Herts, Oxford, Edinburgh, Liverpool)



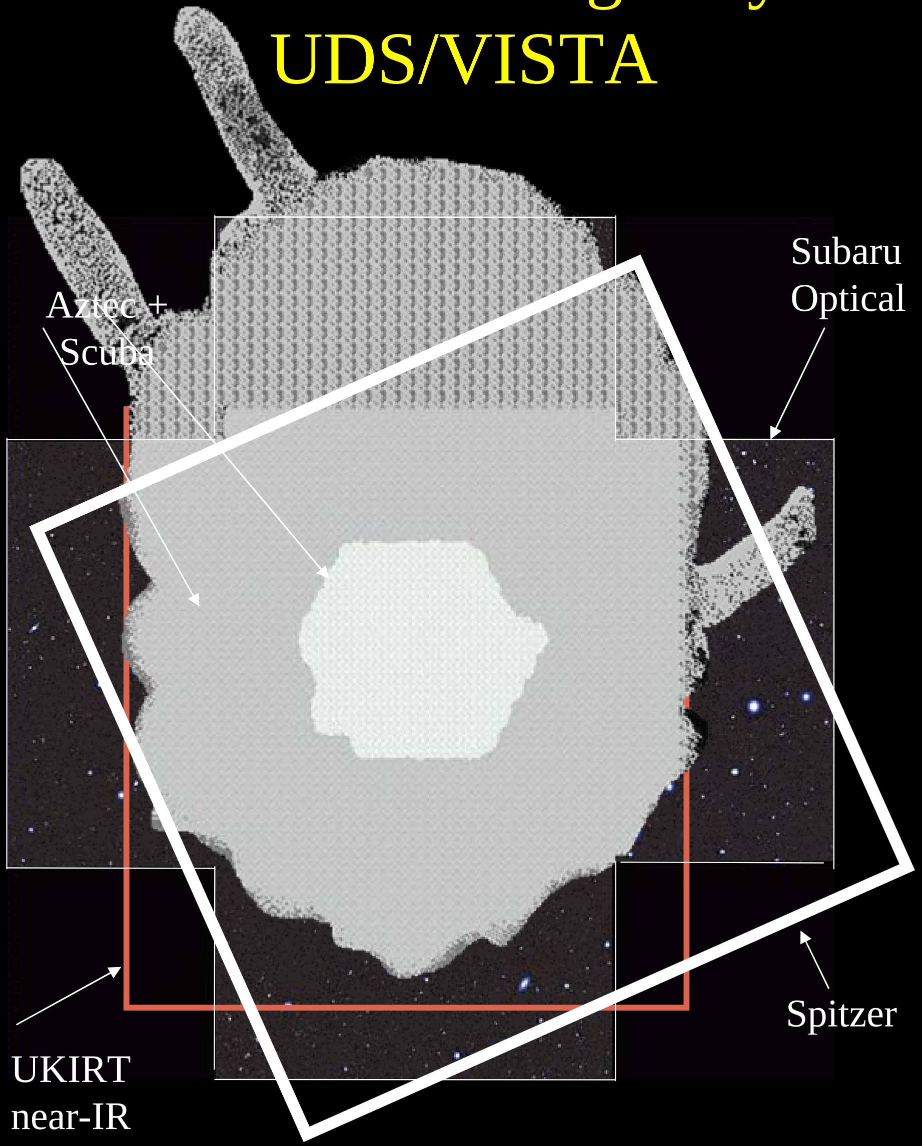


- Find the first large sample of galaxies within the epoch of reionisation (expect 50-200 in GT)
- Determine their luminosity function and clustering properties
- Ideal candidates for integral-field spectroscopy with SWIFT and E-ELT in the future.
- Also measure the properties of [OII] and Hα emitting galaxies at lower redshifts.
- Current plan is to target UDS+COSMOS

Summary

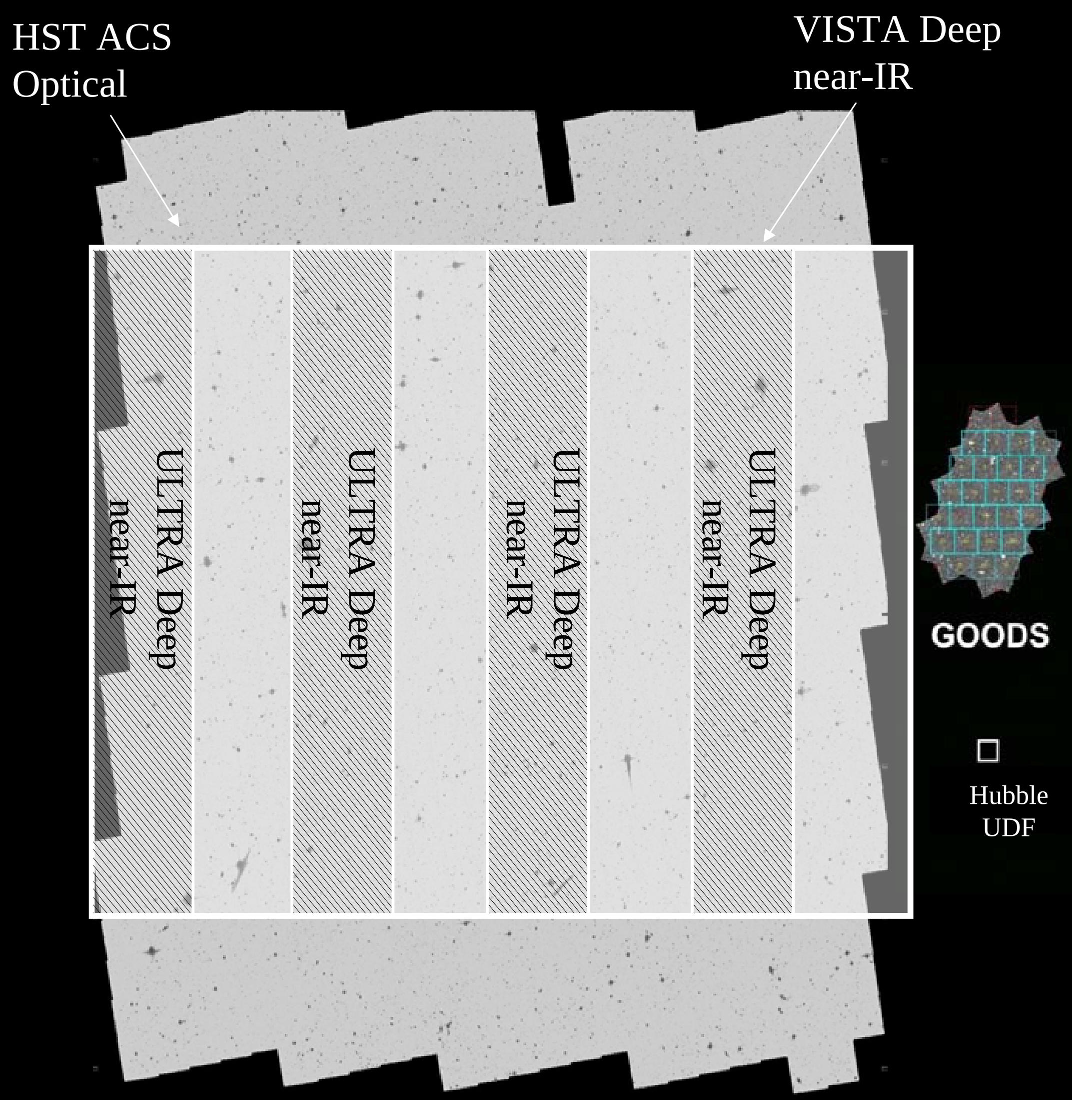
- The UDS is currently the deepest, multi-wavelength field at 0.85-4.5μm
- Excellent multi-wavelength coverage ⟶ ideal for galaxy evolution studies
- All the Subaru optical and UKIRT-IR data is publicly available
- Large Spitzer legacy programme completed - public in 6 months time
- Large ESO spectroscopic programme on-going

Widefield galaxy studies at z>7 with UDS/VISTA



UKIDSS UDS

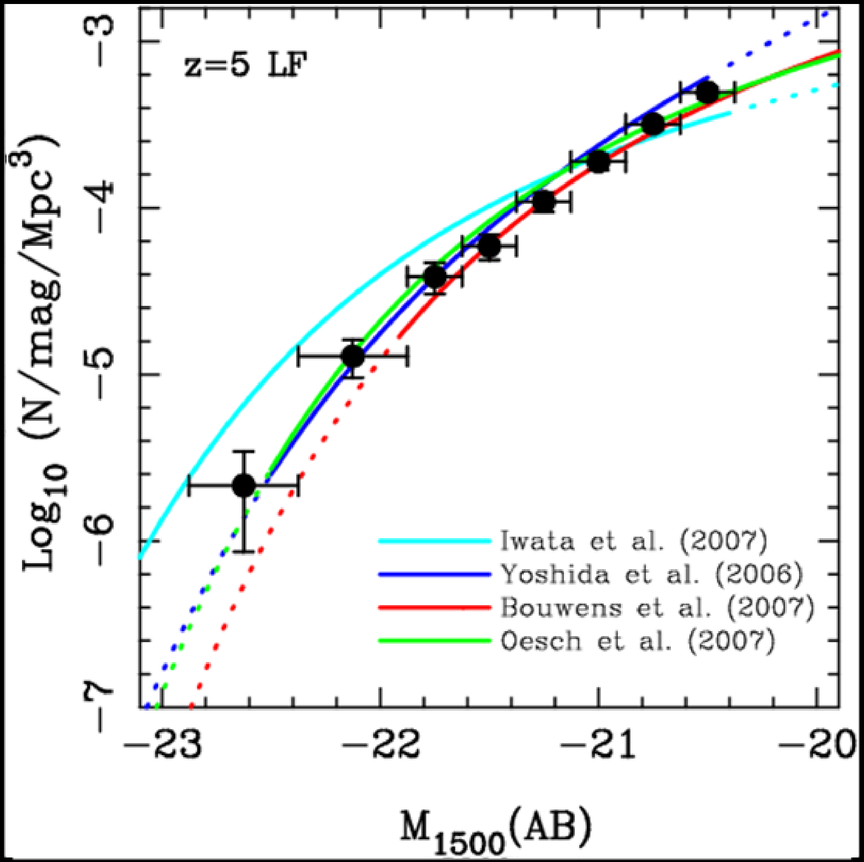
RA = 02 18 00, Dec = -05 00 00

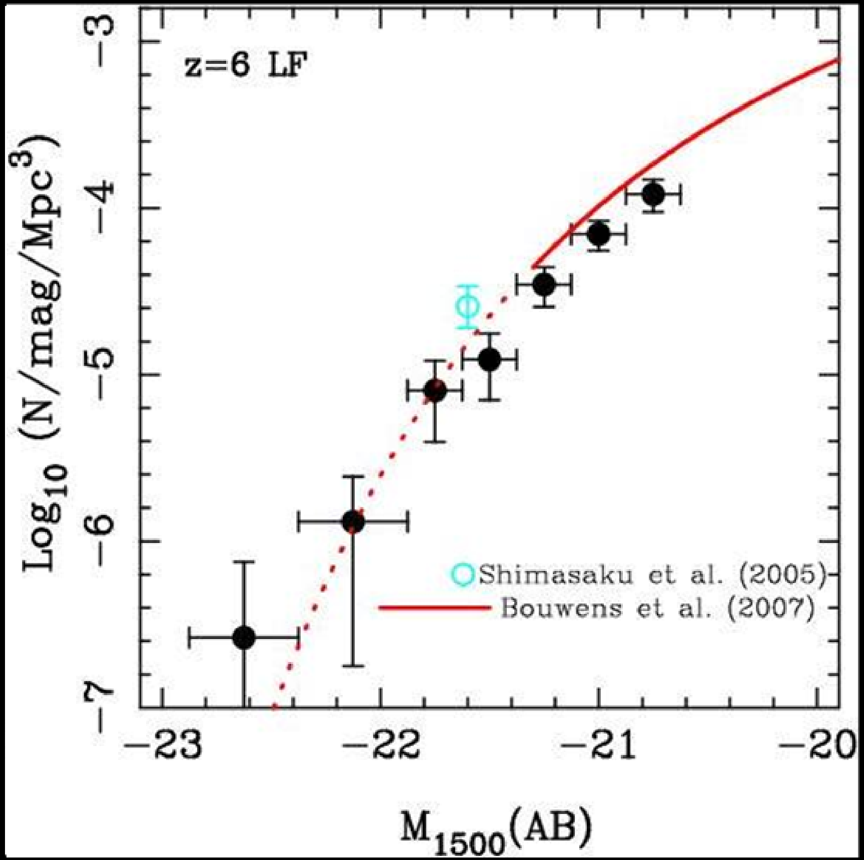


COSMOS Ultra-VISTA

RA = 10 00 28, Dec = +02 12 21

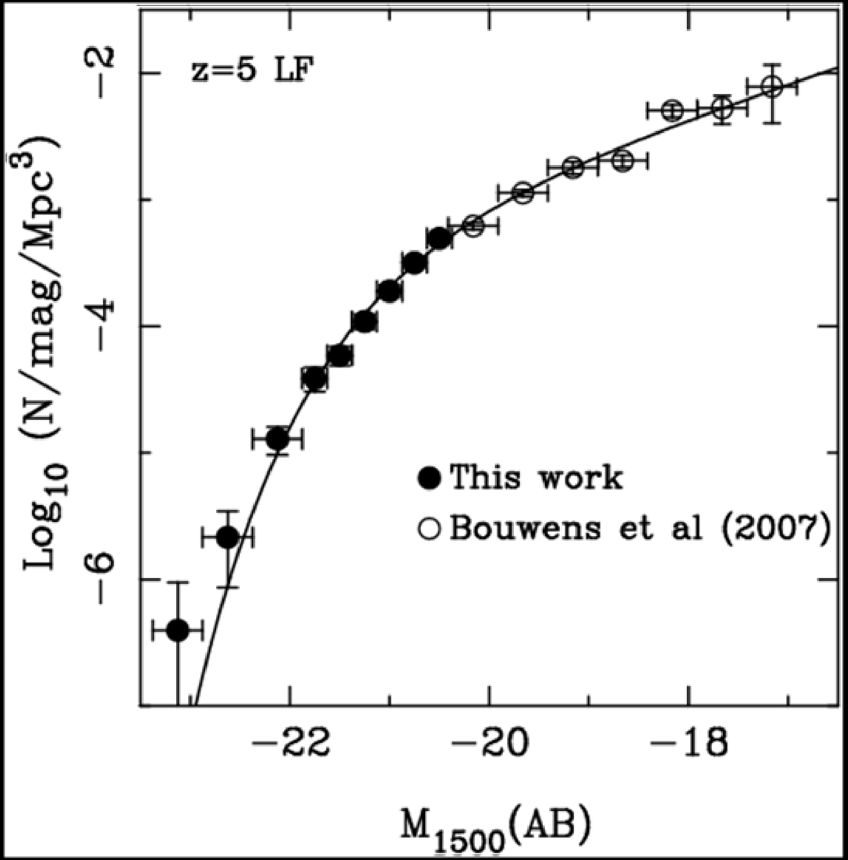
Massive galaxies at 4.5<z<6.5

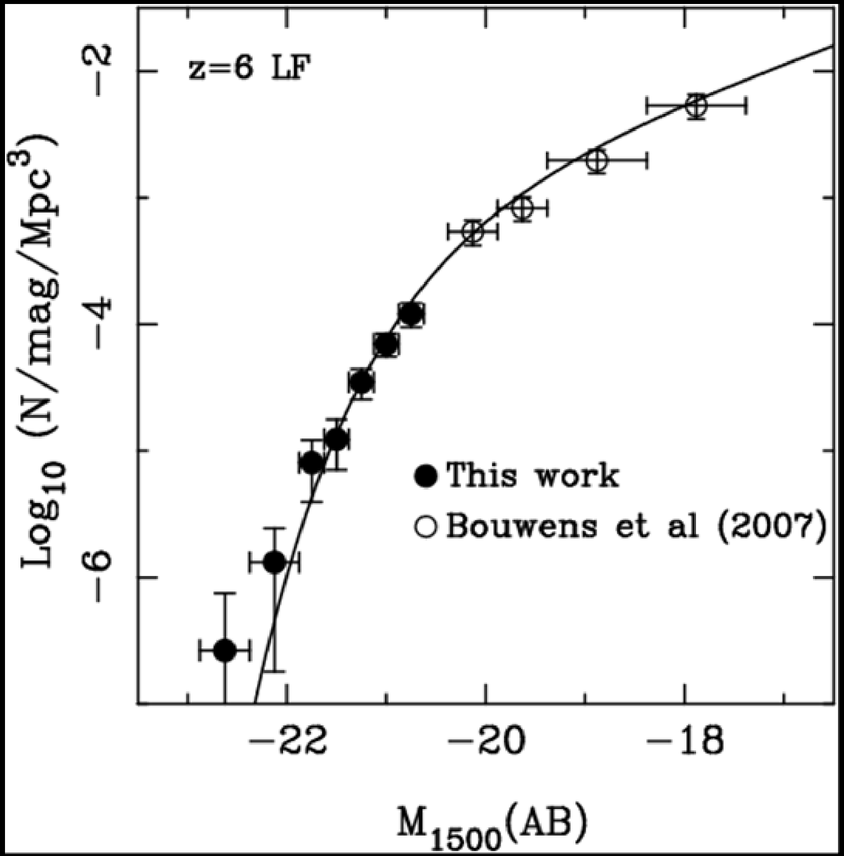




How do we compare with previous studies?

Massive galaxies at 4.5<z<6.5





ML fits to the combined ground+HST data-sets

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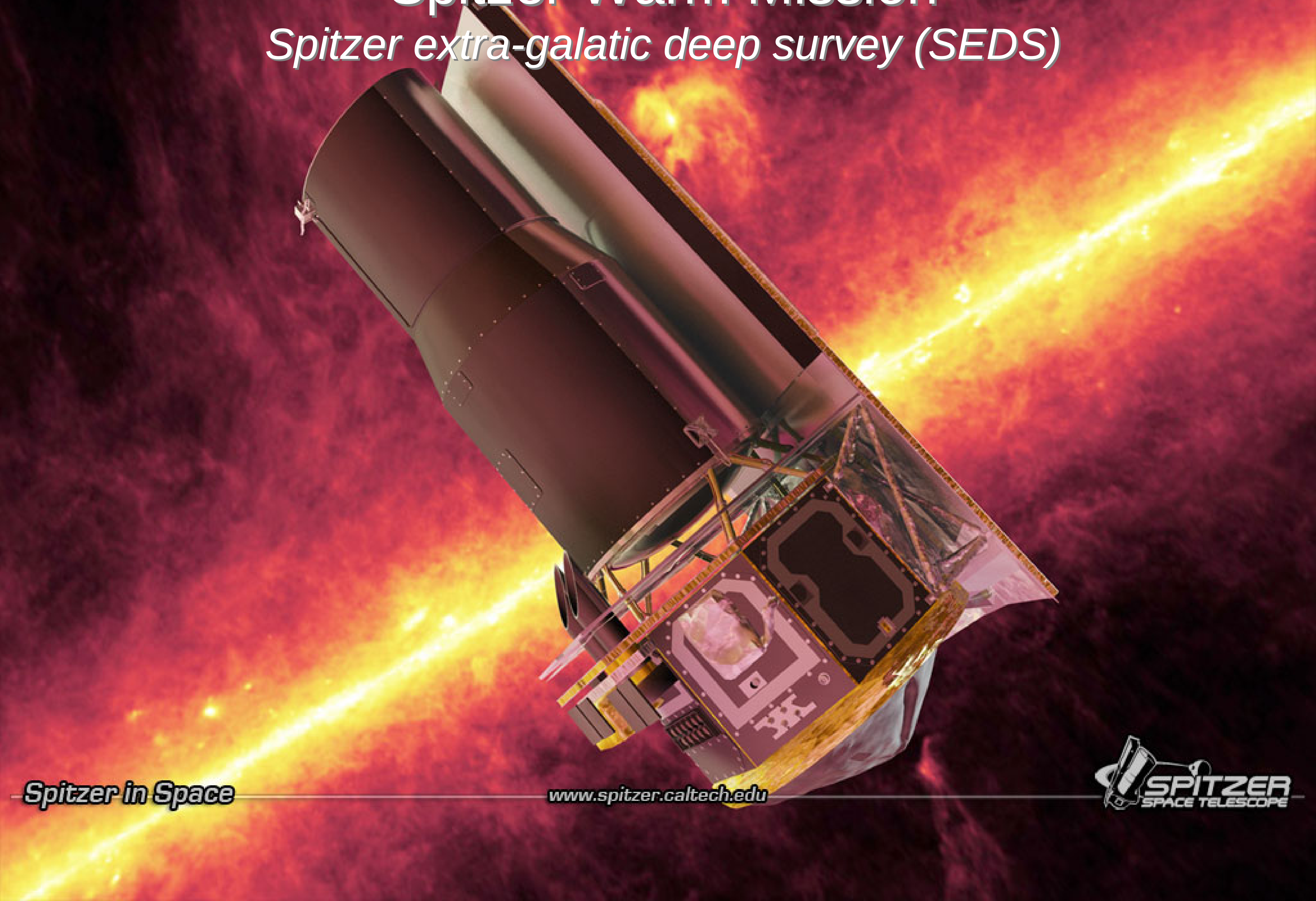
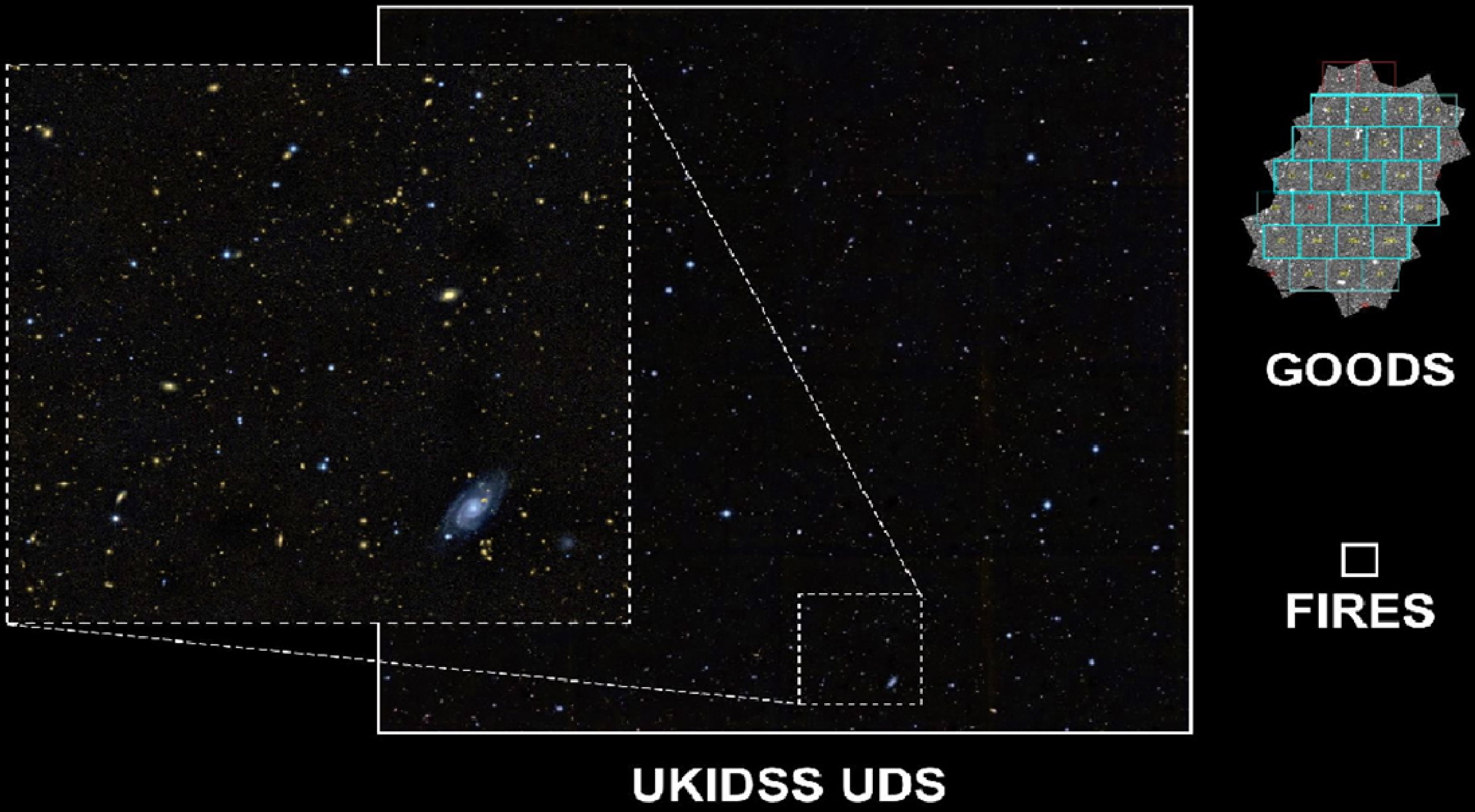


UKIDSS Ultra-deep Survey



5σ depths: B=28.2, V=27.6, R=27.5, i'=27.2, z'=26.3, J=24.3, H=23.9, K=24.0, 3.6μm=24.2, 4.5μm=24.0

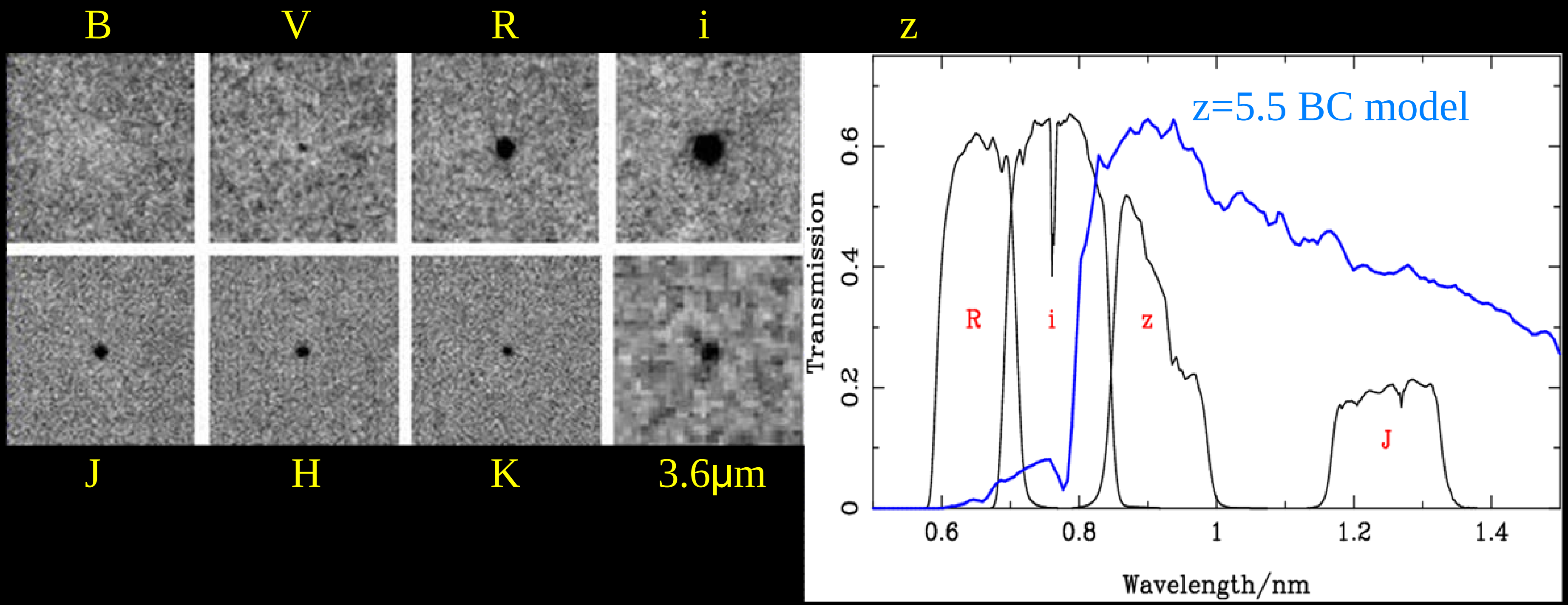
UDS is deepest ~1 sq. degree field from 0.85-4.5μm

Massive galaxies at 4.5<z<6.5

Selecting galaxies at high redshift

Two basic techniques:

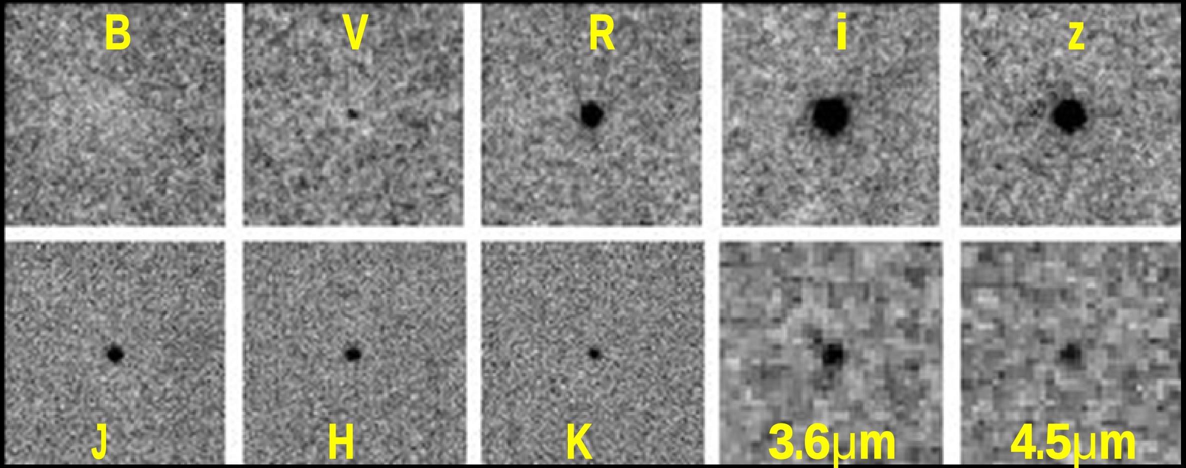
1. Lyman-break selection (LBGs)
2. Narrow-band selection of Lyman alpha emitters (LAEs)



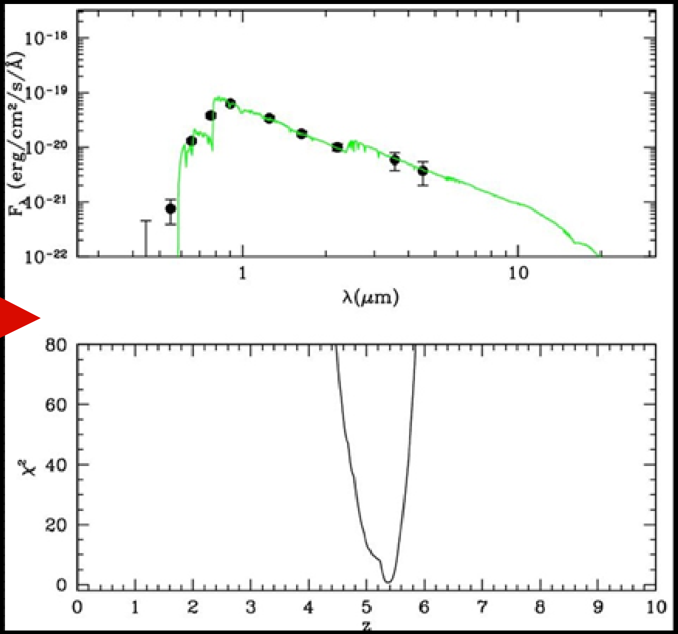
Massive galaxies at 4.5<z<6.5

Stacking analysis: 5<z<6 LBG sample

stacked data for ~750 5<z<6 LBGs

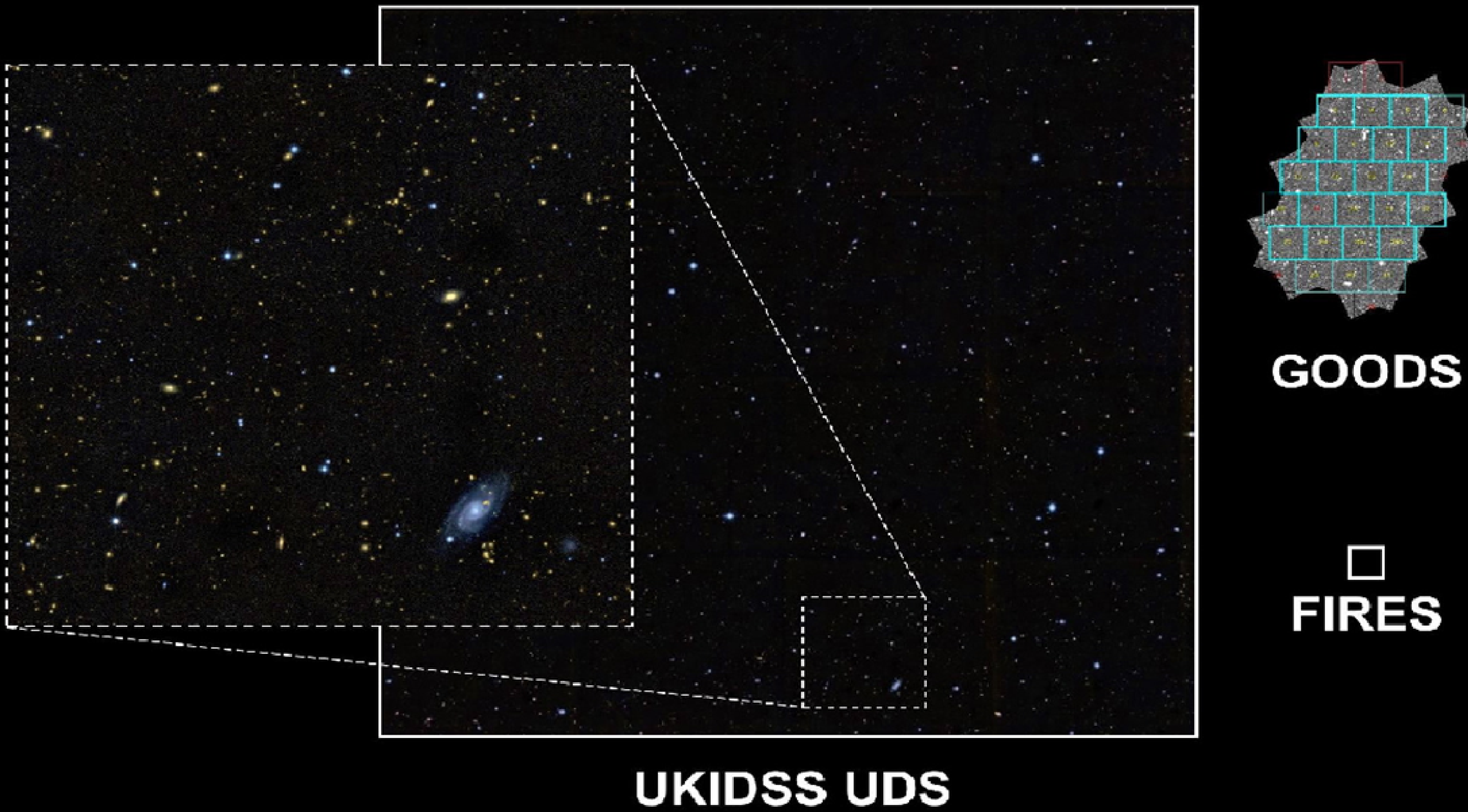


SWIRE data only



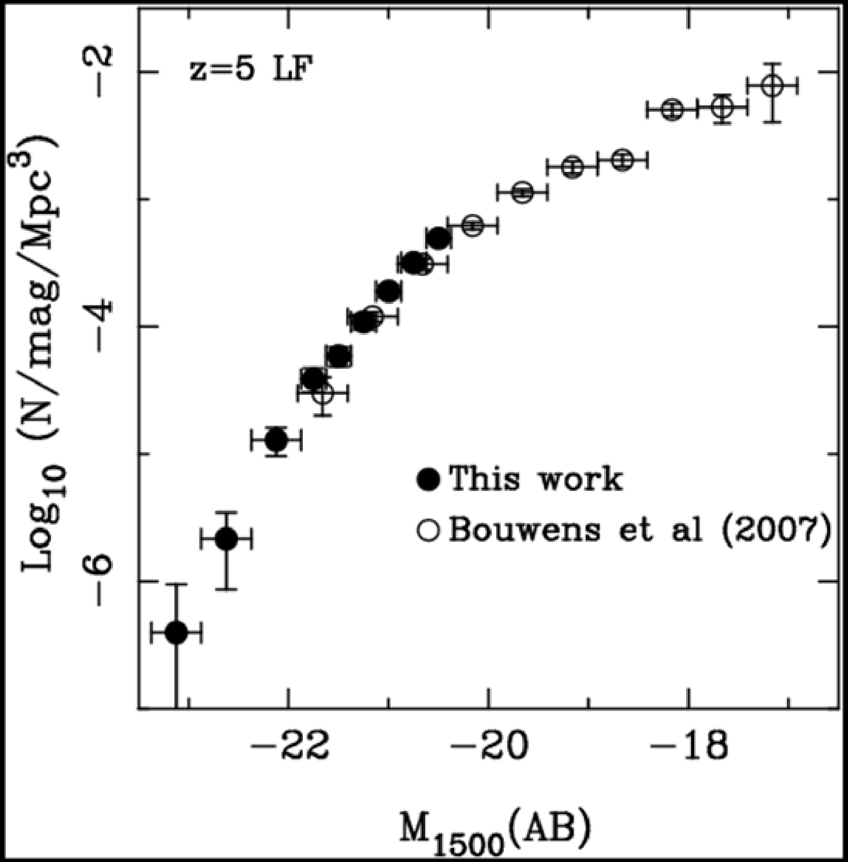
- $z_{phot} = 5.43$
- Av = 0.0
- Age = 400 Myr
- Mass = $10^{10.0}\ M_\odot$

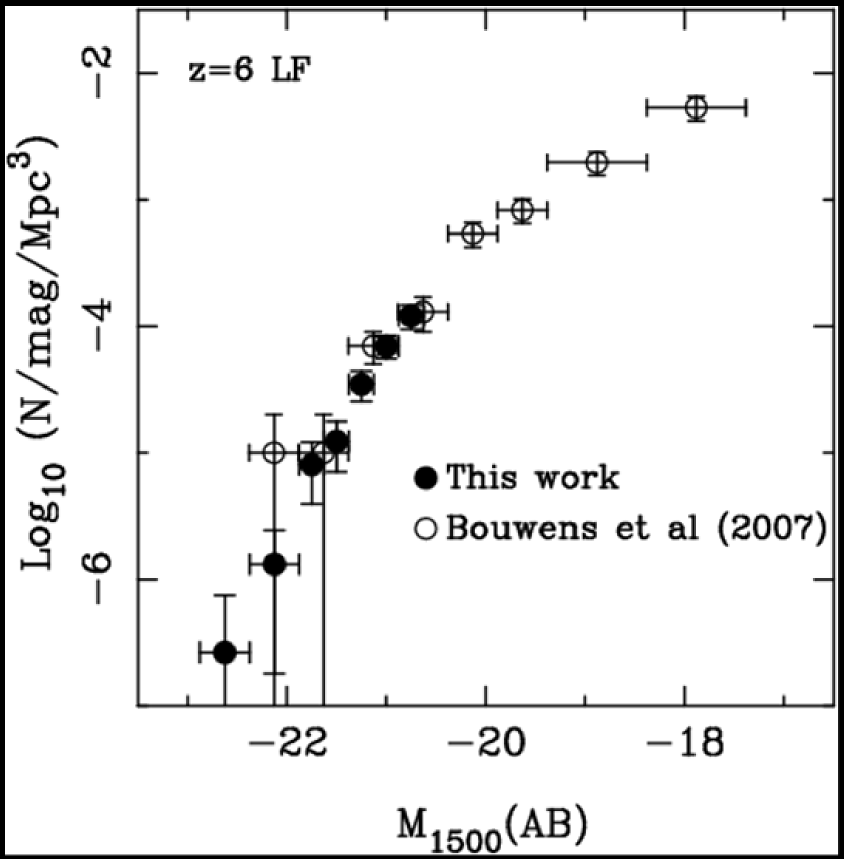
UKIDSS Ultra-deep Survey



Unique depth+area in NIR plus strong + multi-wavelength coverage

Massive galaxies at 4.5<z<6.5





Excellent agreement with HST pencil beam studies

Surprising given: greatly differing areas, data & techniques

Future progress: the galaxy population at z>7

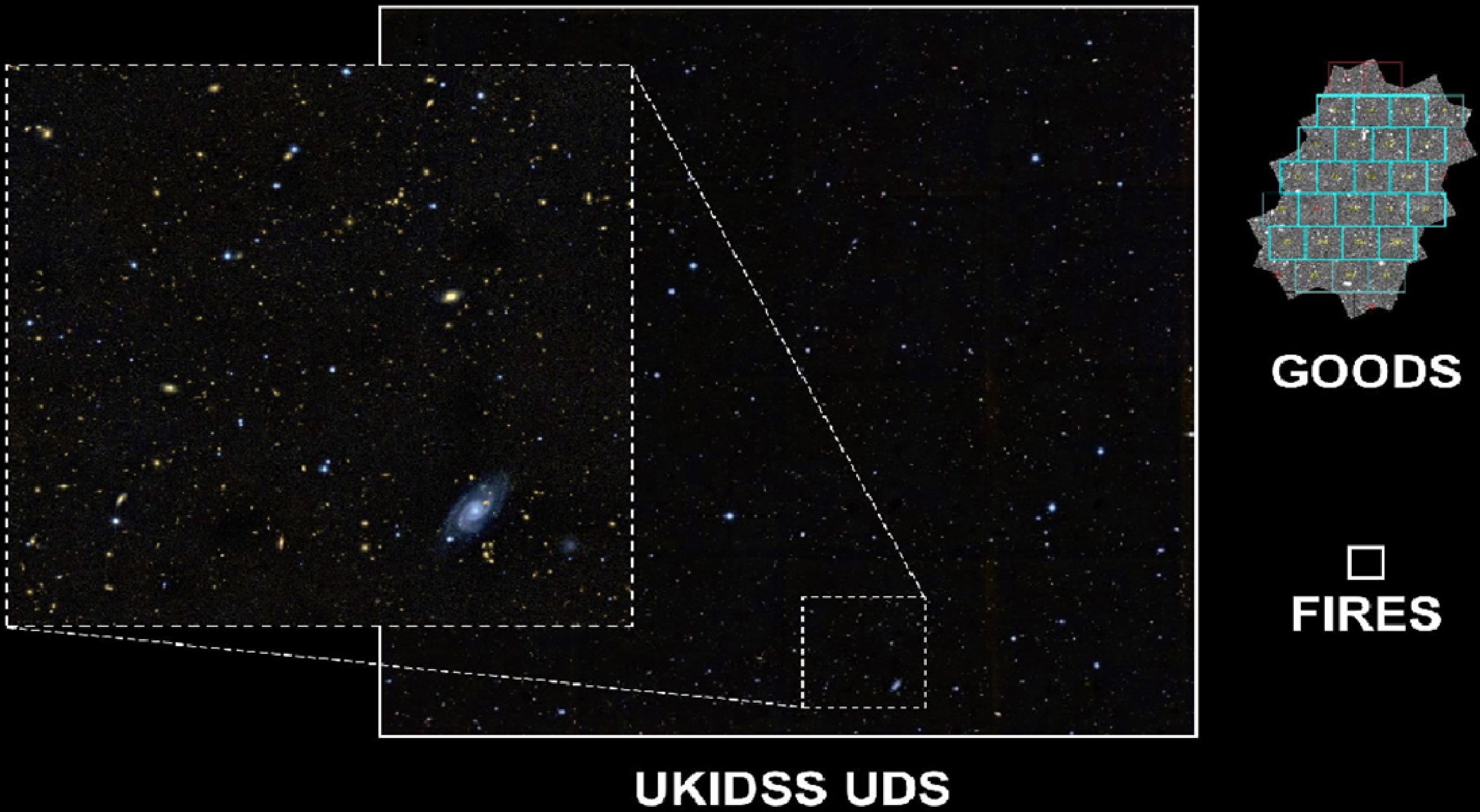
1. Bright-end of the luminosity function

2. Faint-end of the luminosity function

↓

Rely on ultra-deep, pencil beam HST imaging

UKIDSS Ultra-deep Survey



Unique depth+area in NIR plus strong + multi-wavelength coverage

Key science goal: study assembly of massive galaxies at $1<z<3$