Galaxies at z~7-10

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Special Thanks to Marijn Franx, Ivo Labbe, Larry Bradley, Louis Bergeron, Rodger Thompson, Dan Magee, John Blakeslee

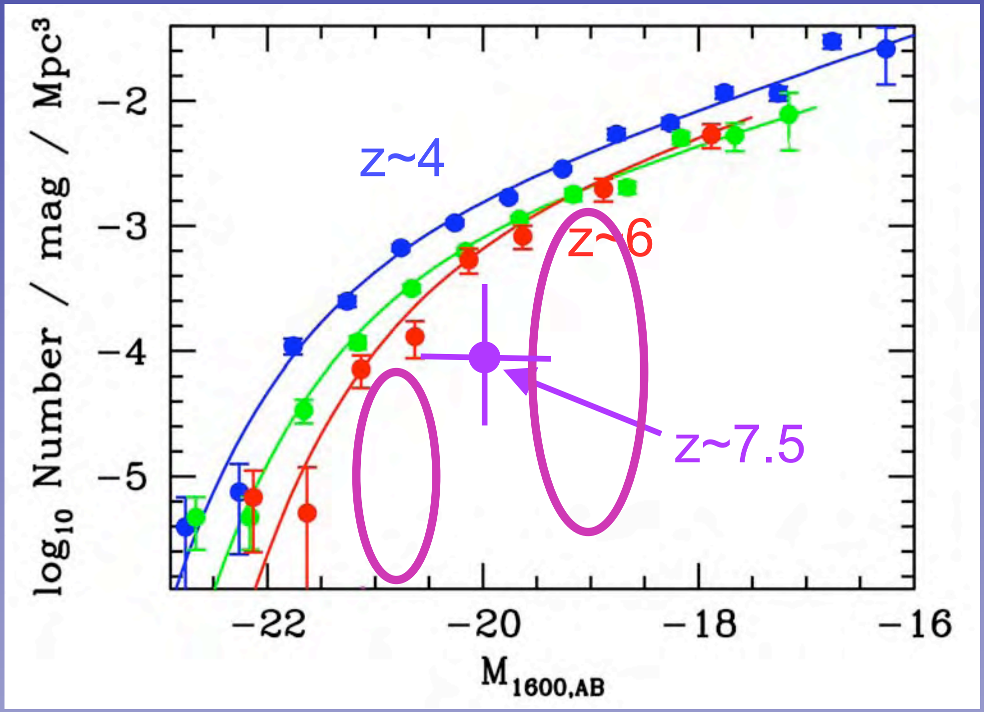
February 15, 2008
Aspen, Colorado
The First Two Billion Years of Galaxy Formation: The Reionization Epoch and Beyond

Galaxies at *z~4, 5, 6, 7.4 (B, V, i, z-dropouts)*

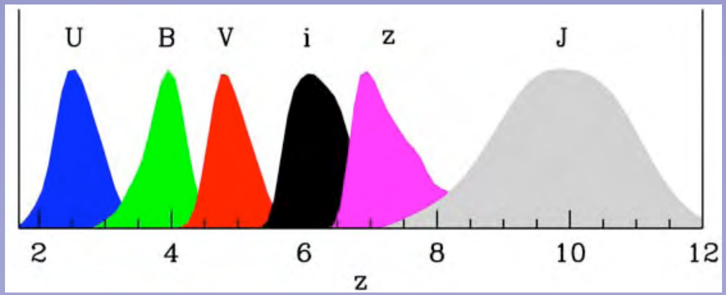
UV Luminosity Functions

Using all deep, wide-area ACS data to select large samples of dropouts at all redshifts

4671 z~4 B-dropouts,
1416 z~5 V-dropouts,
627 *z~6 i-dropouts*,
4 z~7.4 z-dropouts



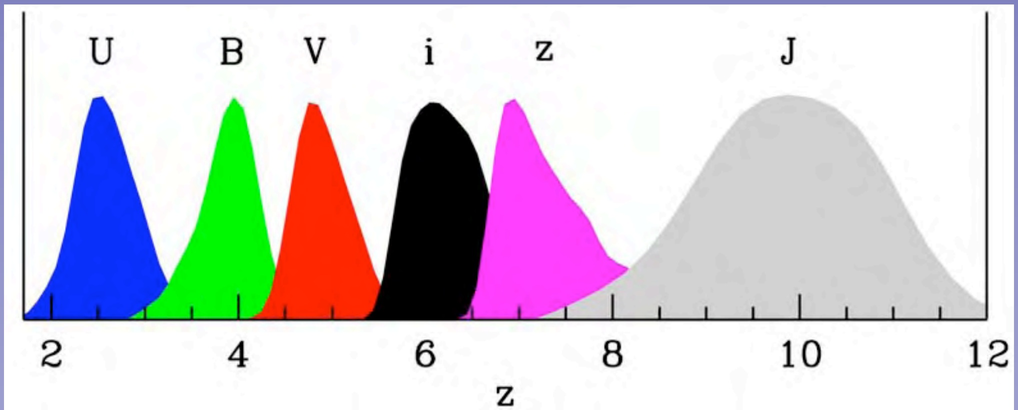
Bouwens, Illingworth et al 2007



Dropout Redshift Selection Functions

Galaxies at *z*~7-8

(z-dropouts)

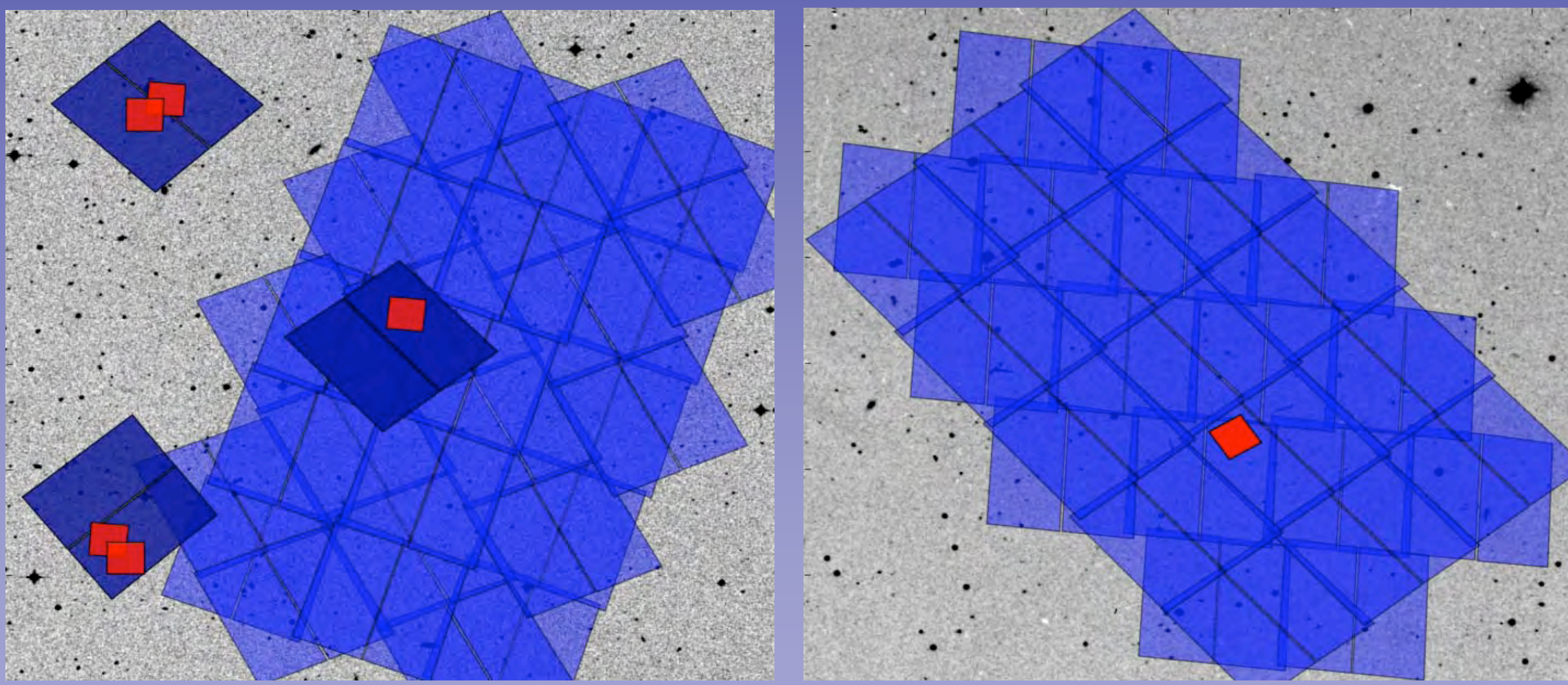


Dropout Redshift Selection Functions

Deep near-IR / Optical Data

Many fields with deep ACS and NICMOS data for dropout searches

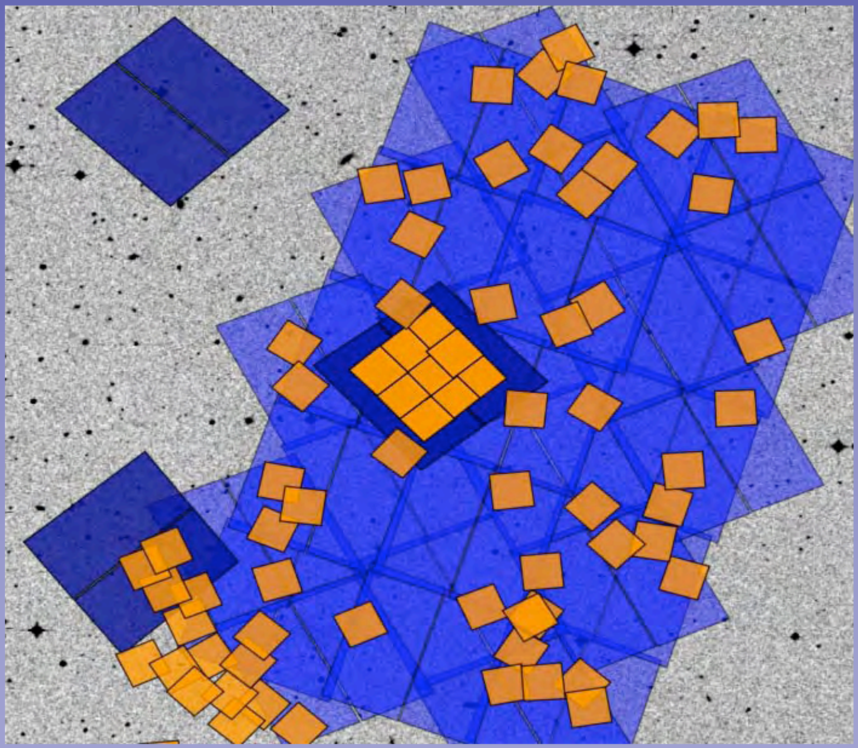
~4 arcmin^2 of Ultra Deep ($J_{110} \sim H_{160}$ >= 28 AB mag) NICMOS coverage

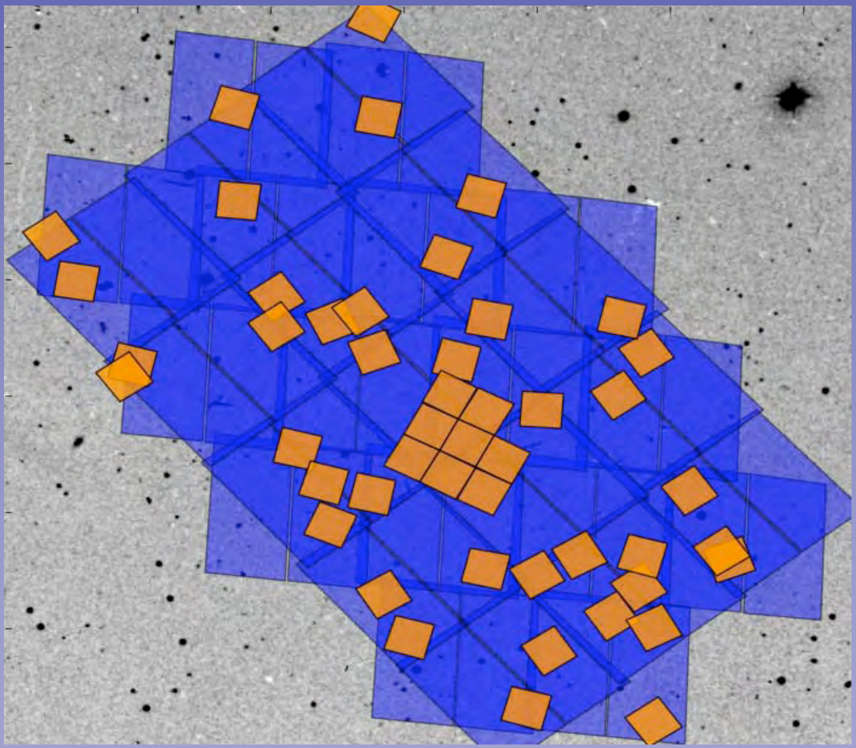


Deep near-IR / Optical Data

Many fields with deep ACS and NICMOS data for dropout searches

~72 $arcmin^2$ of Deep (J_{110} ~ H_{160} >= 26.5 AB mag) NICMOS coverage

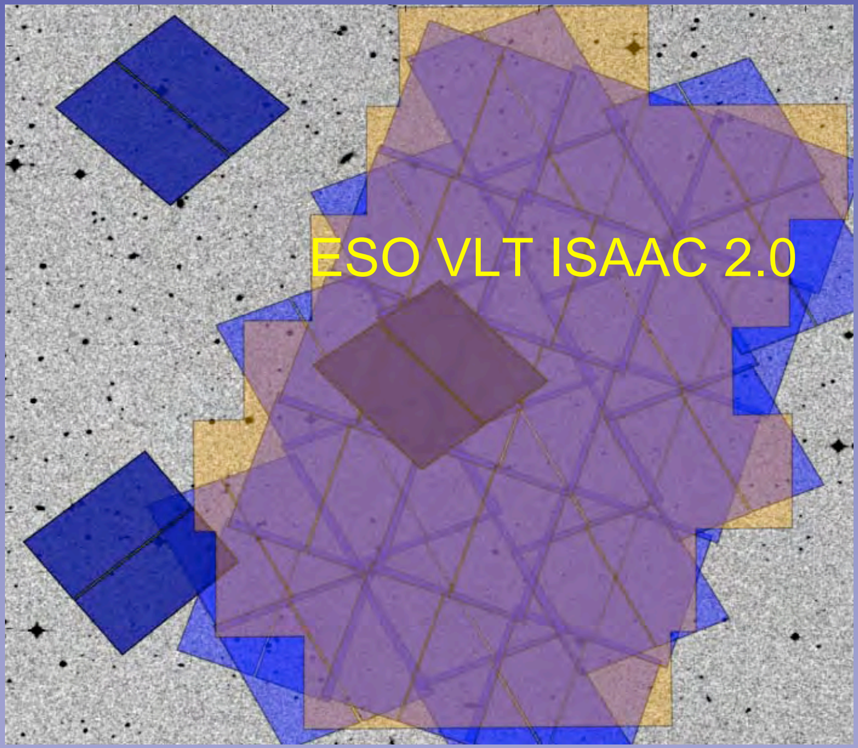


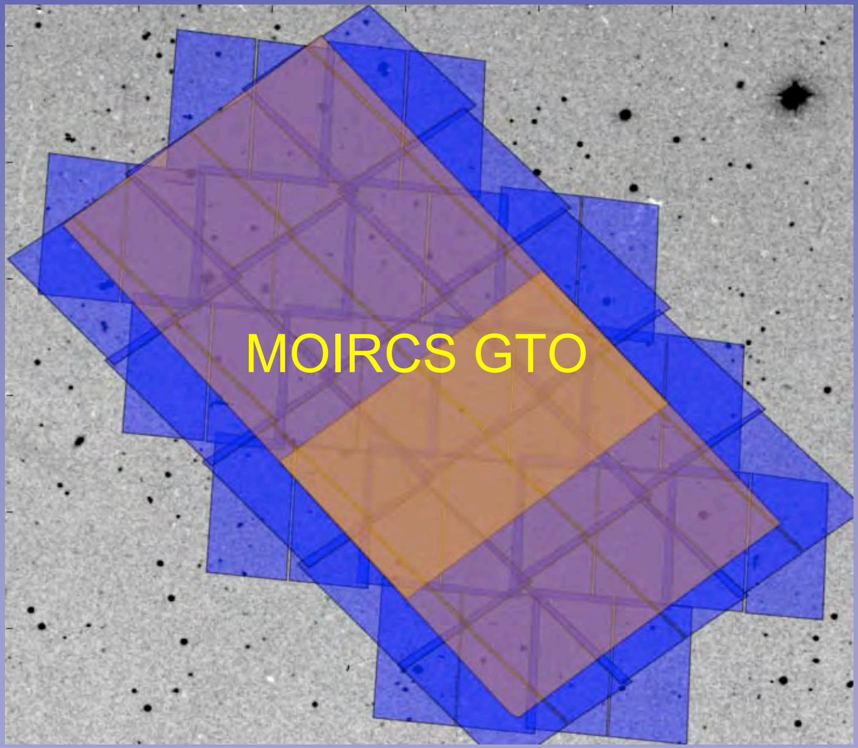


Deep near-IR / Optical Data

Many fields with deep ACS and NICMOS data for dropout searches

~163 arcmin^2 of Deep (J >= 25.3 AB mag) ground-based coverage

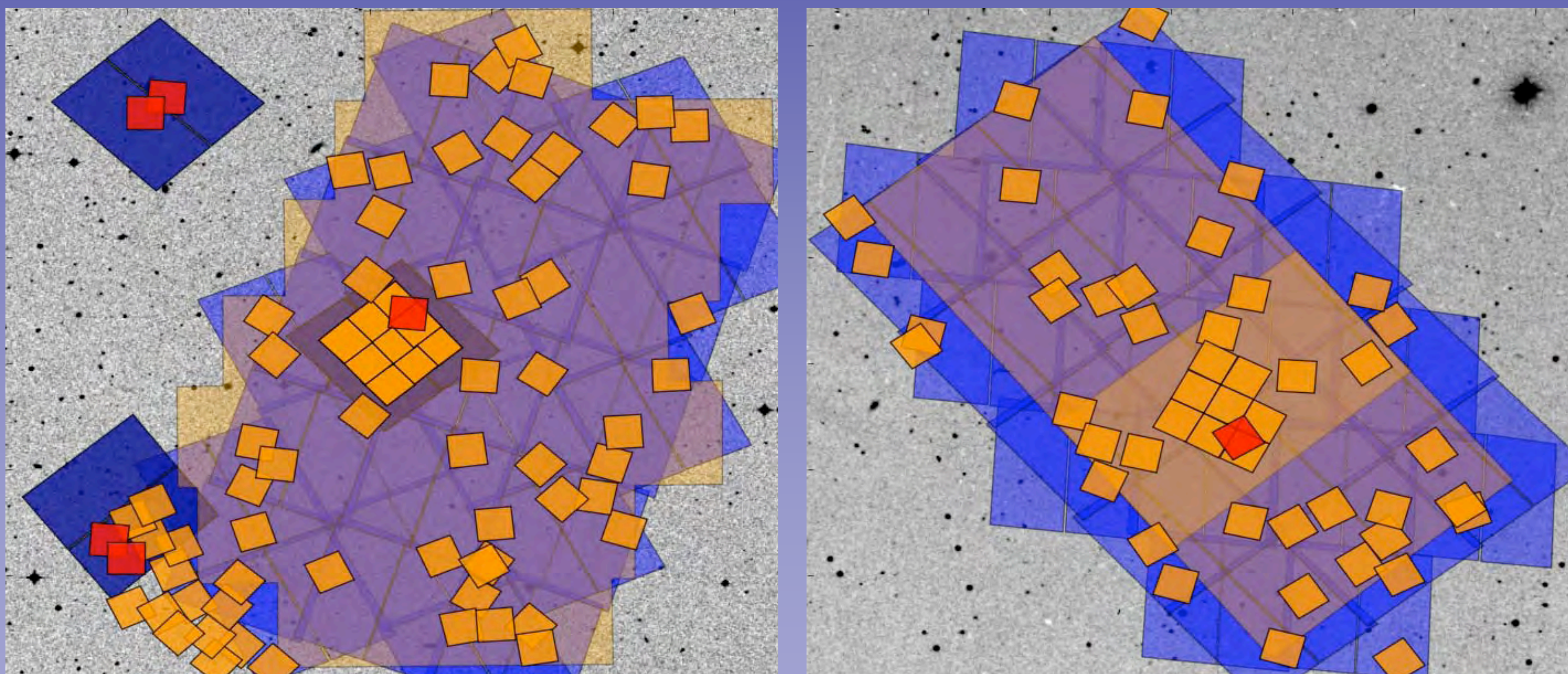




Deep near-IR / Optical Data

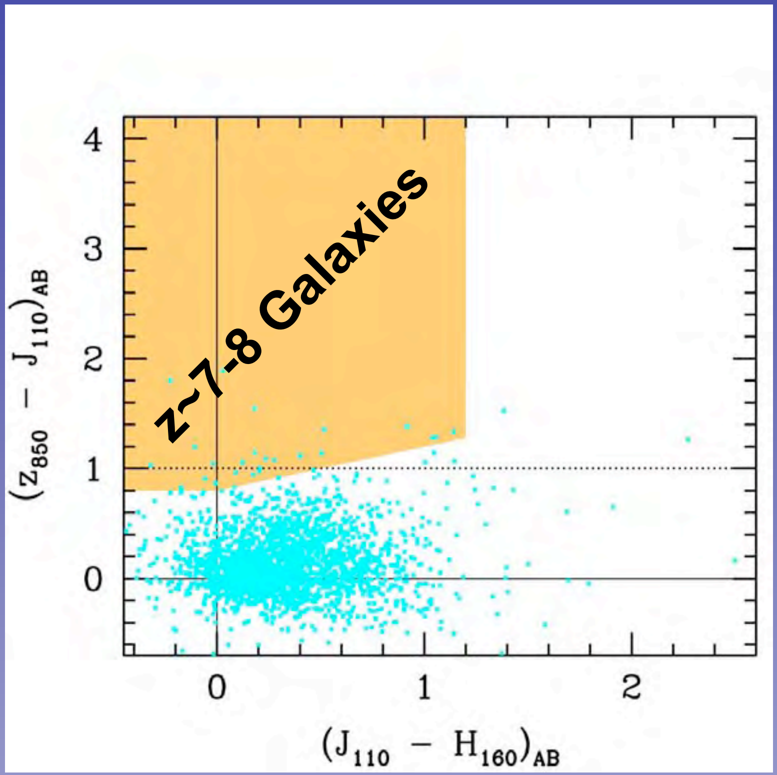
Many fields with deep ACS and NICMOS data for dropout searches

~76 arcmin^2 of Deep (J_{110} ~ H_{160} >= 26.5 AB mag) NICMOS coverage



~163 arcmin^2 of Deep (J >= 25.3 AB mag) ground-based coverage

z ~ 7-8 Galaxies



➡ **10 z-dropouts**

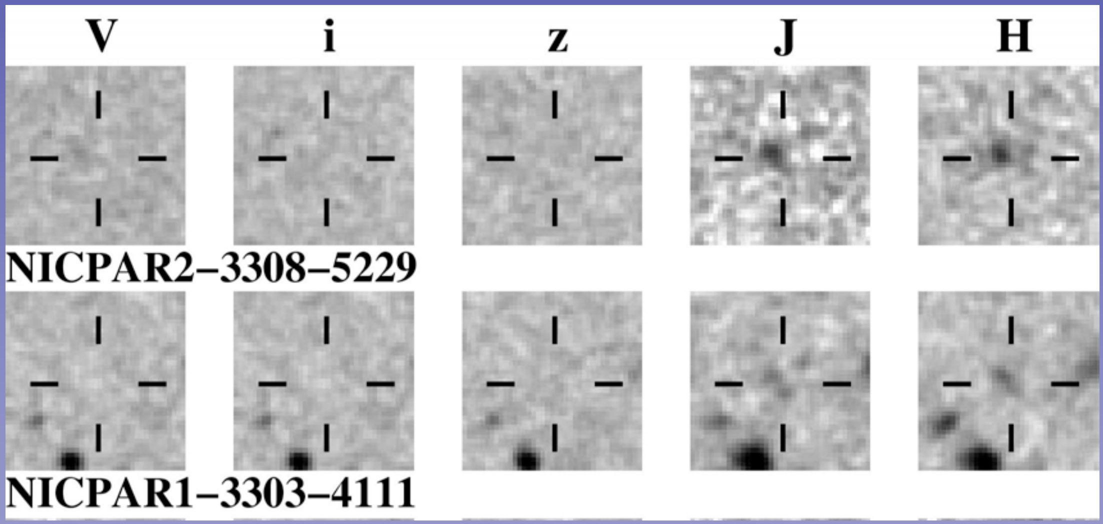
Selection Criteria for z-dropouts:

- **>4.5 sigma detections in J and H,**
- **z-J > 0.8,**
- **J-H < 1.2**
- **No Detection in deep B, V, i data**
- **Remove sources with point source morphologies in the z-band (to eliminate brown dwarfs)**
- **Examine IRAC / MIPS data to exclude lower redshift sources**

z ~ 7-8 Galaxies

10 z-dropouts found over many search fields

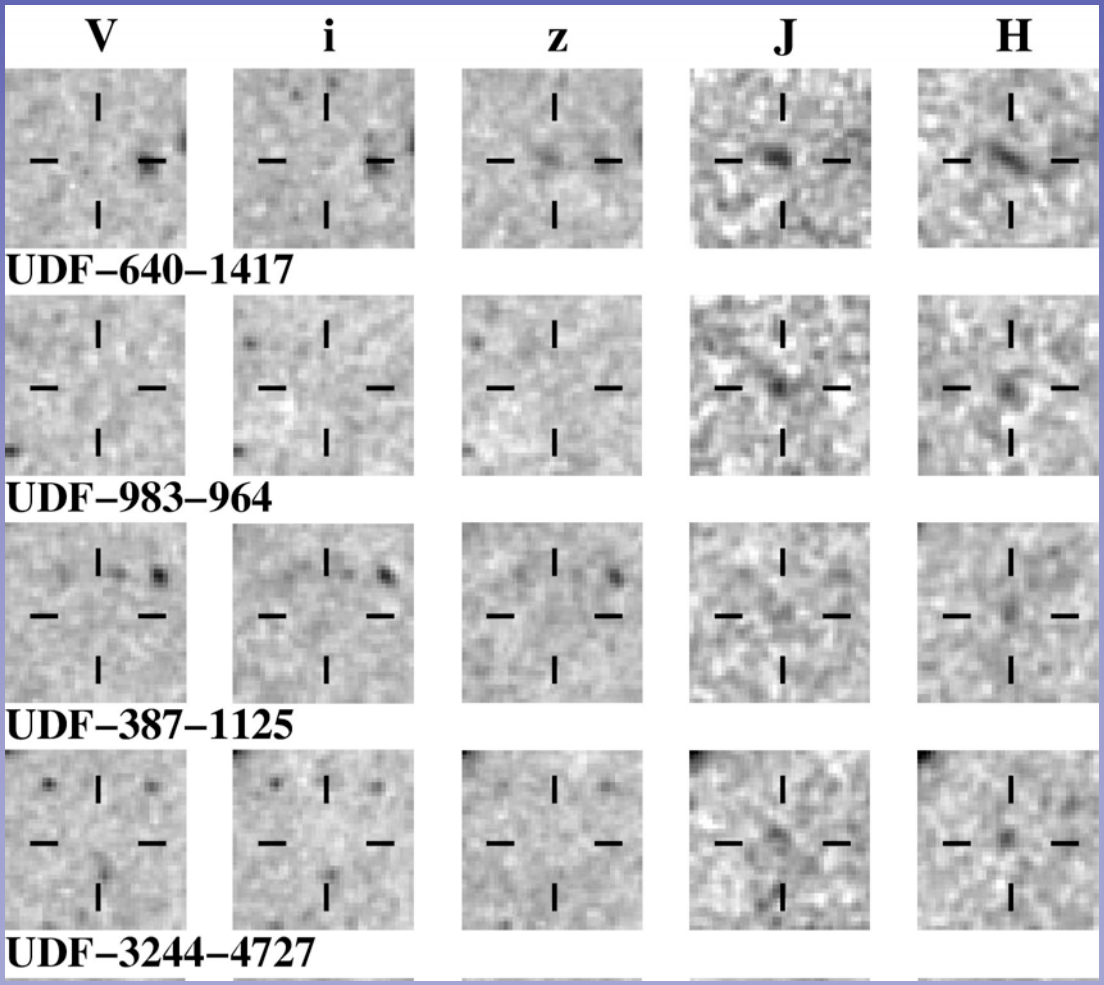
From the HUDF NICMOS Parallel Fields (4 arcmin^2)
(H_{160} < 28.3 AB mag)



z ~ 7-8 Galaxies

10 z-dropouts found over many search fields

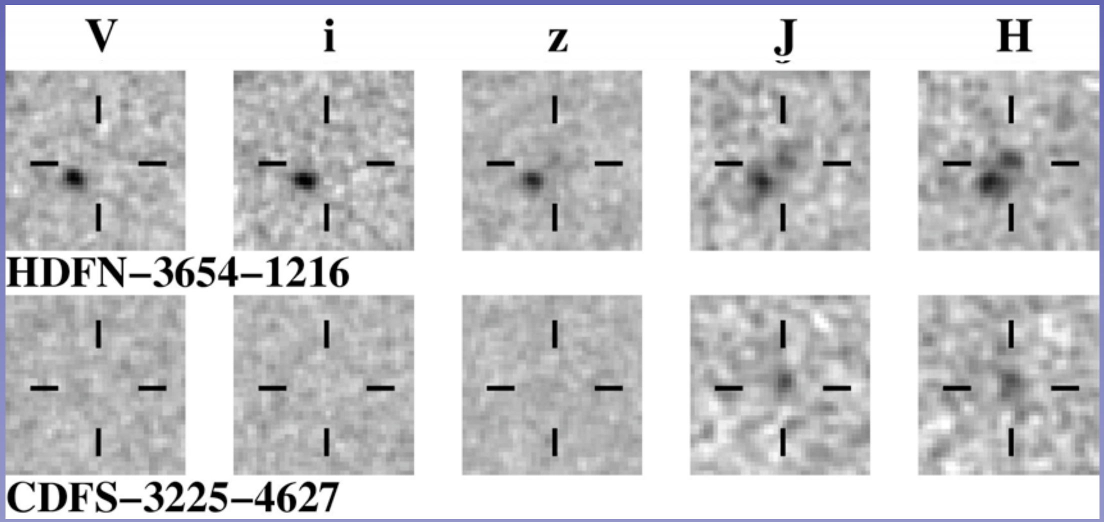
From the HUDF Thompson NICMOS Field (6 arcmin2)
(H_{160} < 27.4 AB mag)



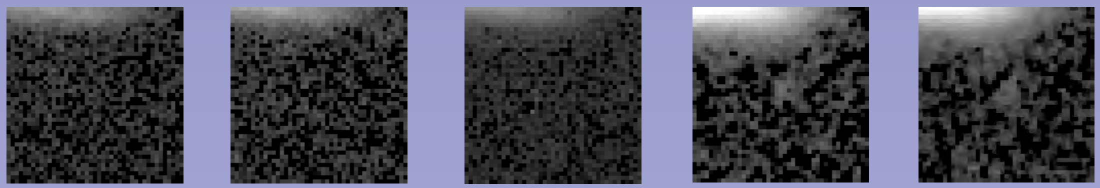
z ~ 7-8 Galaxies

10 z-dropouts found over many search fields

From the Wide-Area NICMOS Data (41 arcmin^2)
(H_{160} < 26.9 AB mag)



+ other z-dropout



z ~ 7-8 Galaxies

10 z-dropouts found over many search fields

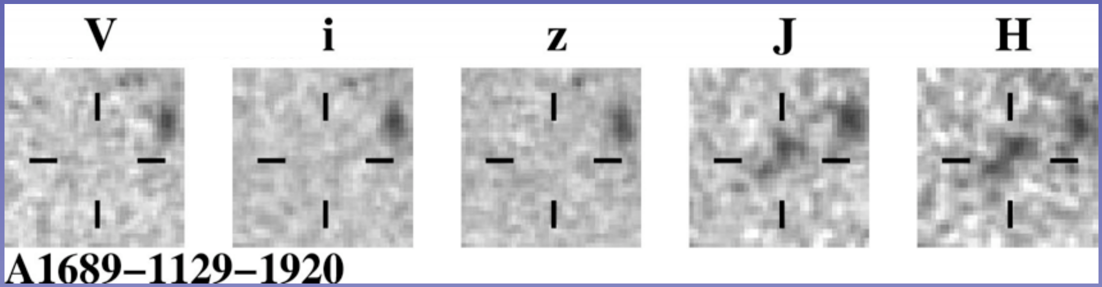
From the Ground-Based Data (163 arcmin^2)
(J < 25.6 AB mag)

NONE

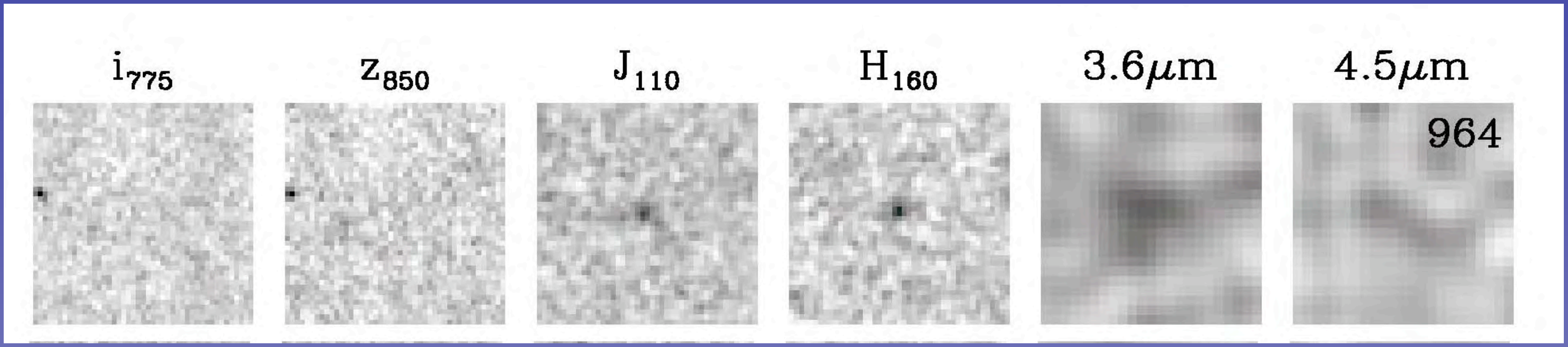
z ~ 7-8 Galaxies

10 z-dropouts found over many search fields

From the NICMOS Data Around Galaxy Clusters
(H_{160} < 27 AB mag)



Are we really finding z>7 galaxies?

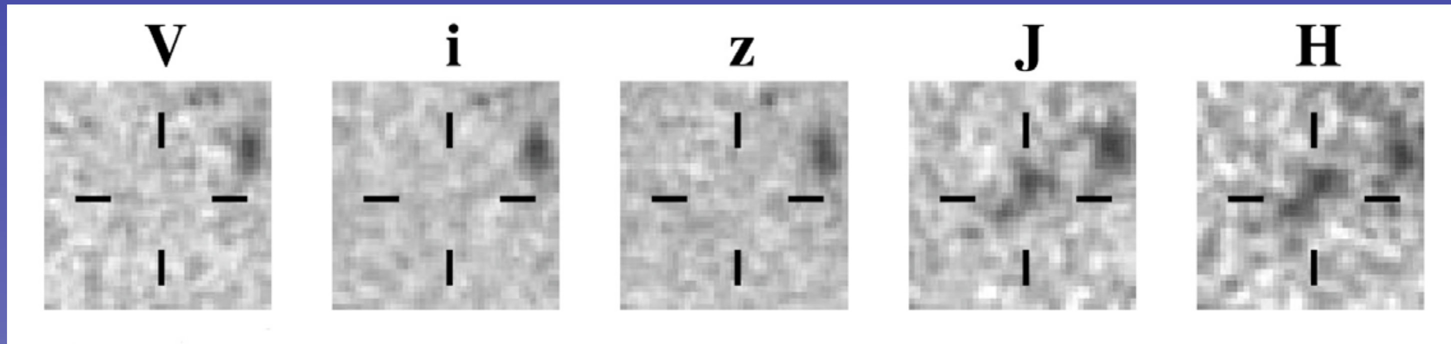


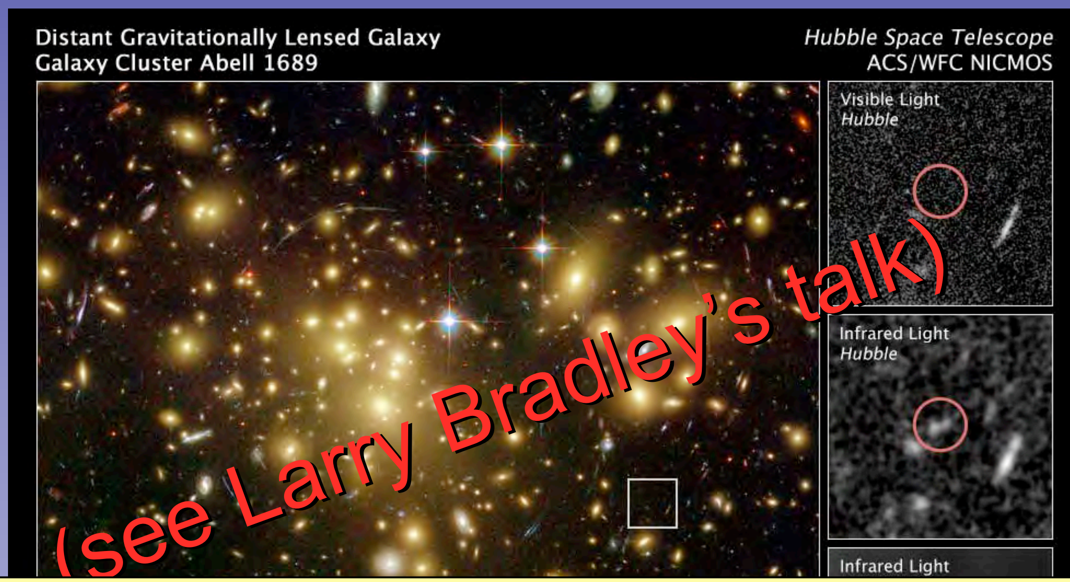
- 5s detections in J, H, IRAC 3.6m channel, and 2.5 s in IRAC 4.5 m channel
- Very Blue J - H colors
- Undetected in the HUDF B, V, i, and z band imaging
- (z-J) > 3 -- too red to be a brown dwarf
- (H - 3.6m) colors similar to z~6 objects

(see also Pascal Oesch's talk)

Garth Will Buy Everyone Here a Beer if at z << 7 !

Are we really finding z>7 galaxies?





(see Larry Bradley's talk)

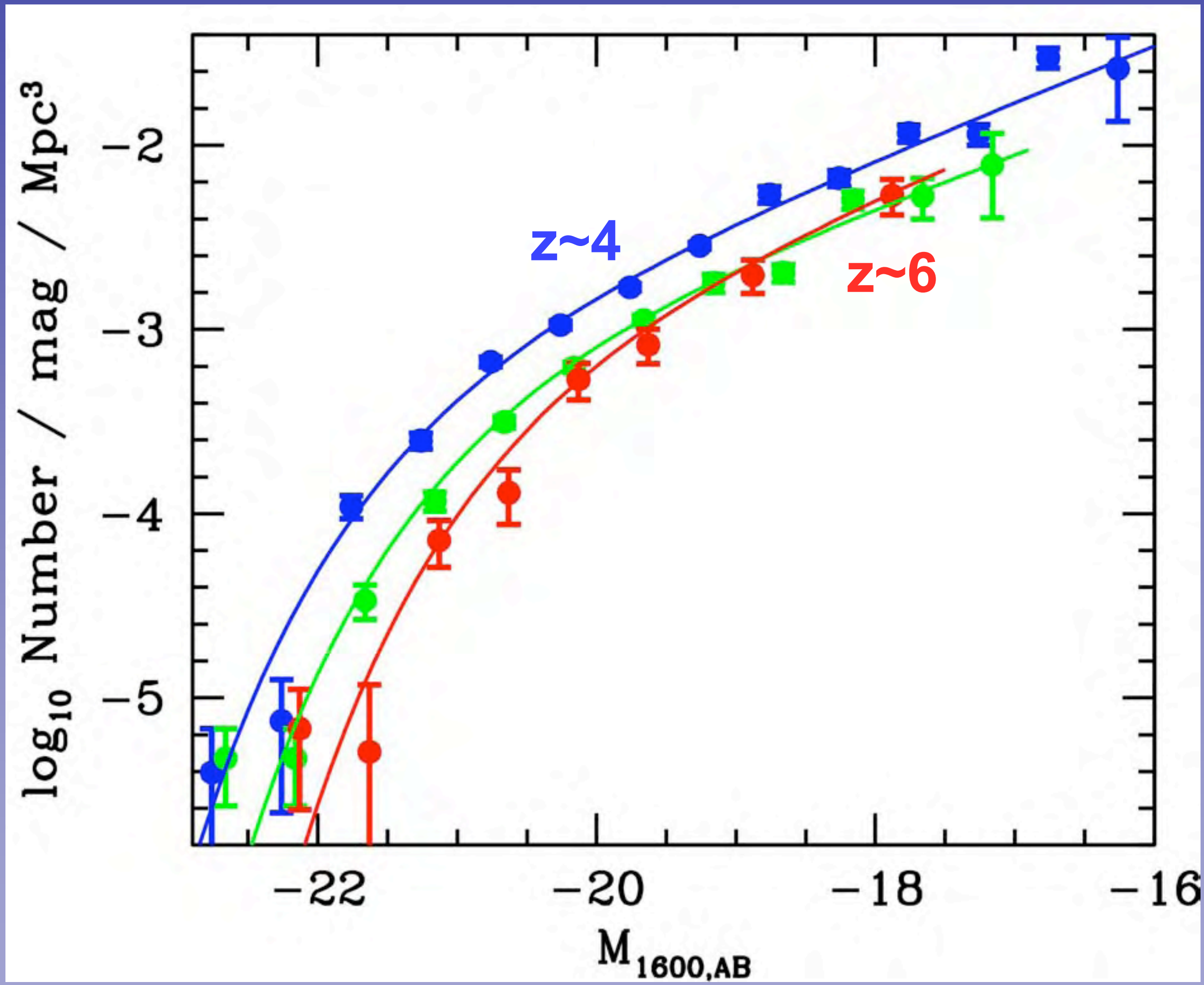
Will Larry Buy Everyone Here a Beer if at z << 7 ?

NASA/STScI Press Release 2/12/08 (earlier this week)

Galaxies at *z*~4, 5, 6, 7.4 *(B, V, i, z-dropouts)*

UV Luminosity Functions

Log # mag^{-1} Mpc^{-3}



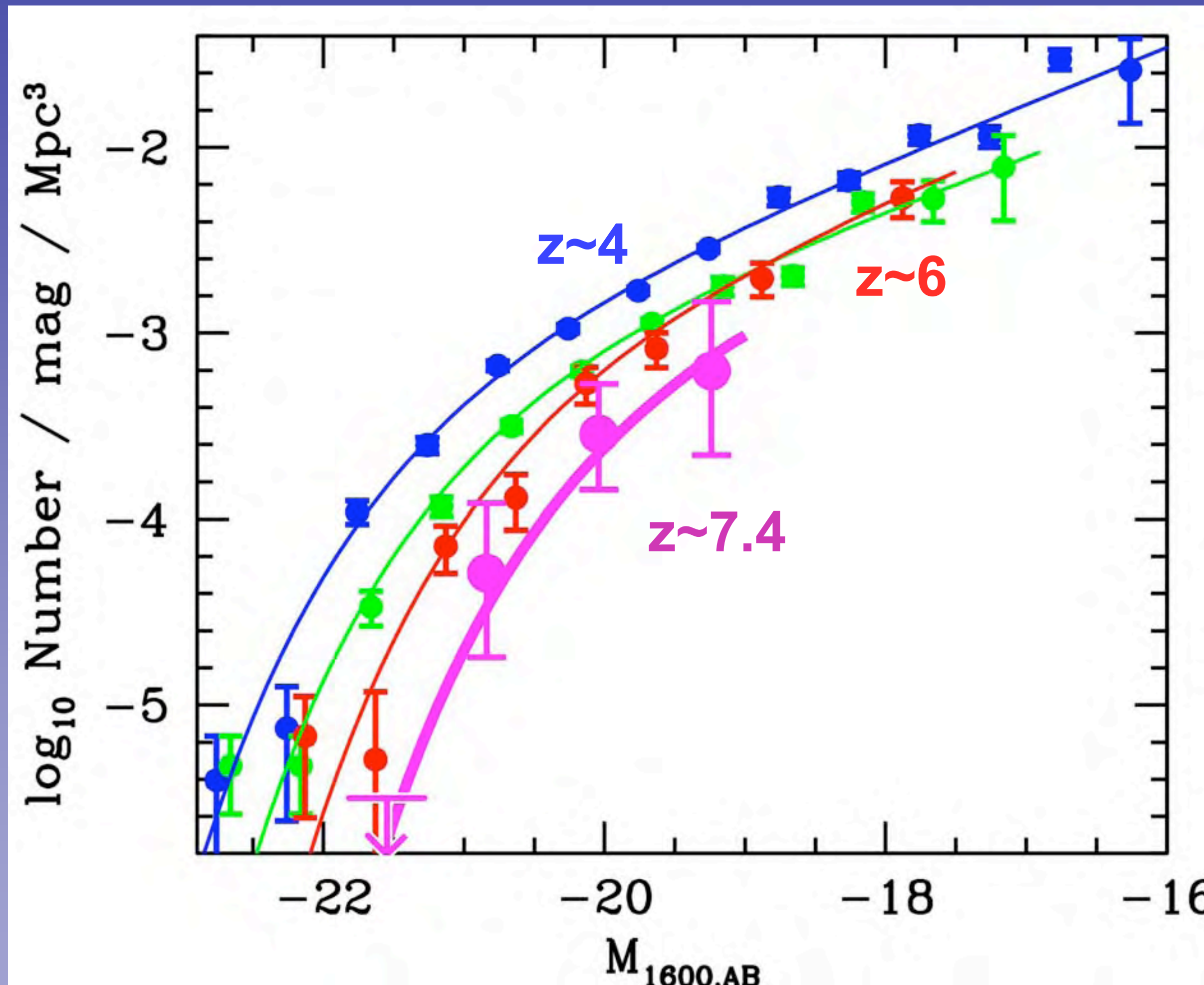
Bright   Faint

Bouwens, Illingworth et al. 2008

Galaxies at *z~4, 5, 6, 7.4 (B, V, i, z-dropouts)*

UV Luminosity Functions

Log # mag^{-1} Mpc^{-3}



Bright

Faint

Bouwens, Illingworth et al. 2008

Aspen 02/15/08 RJB

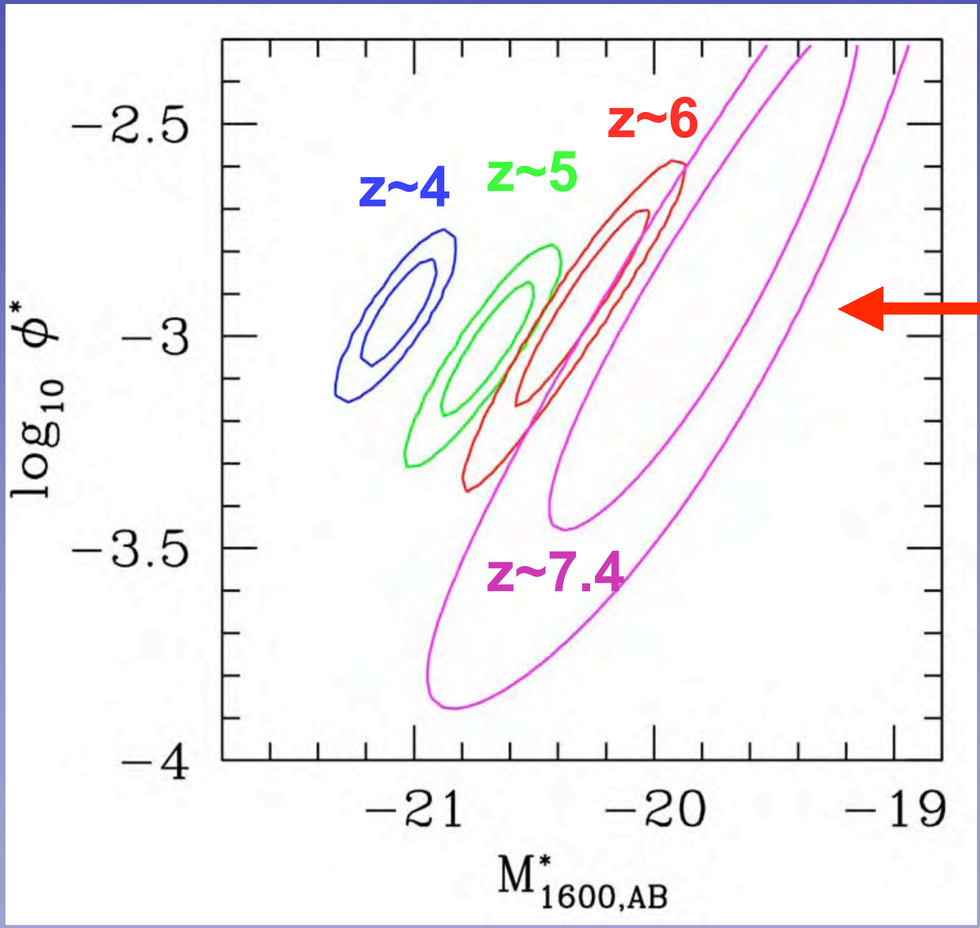
Galaxies at z~4, 5, 6, 7.5 (*B, V, i, z-dropouts*)

UV Luminosity Functions

High

Volume Density ϕ^*

Low



Bright M* Faint

ϕ^* ~ 0.001 Mpc^{-3} at z~4, 5, 6, 7.4

z~7-8 contours fit in nicely with z~4-6 trends!

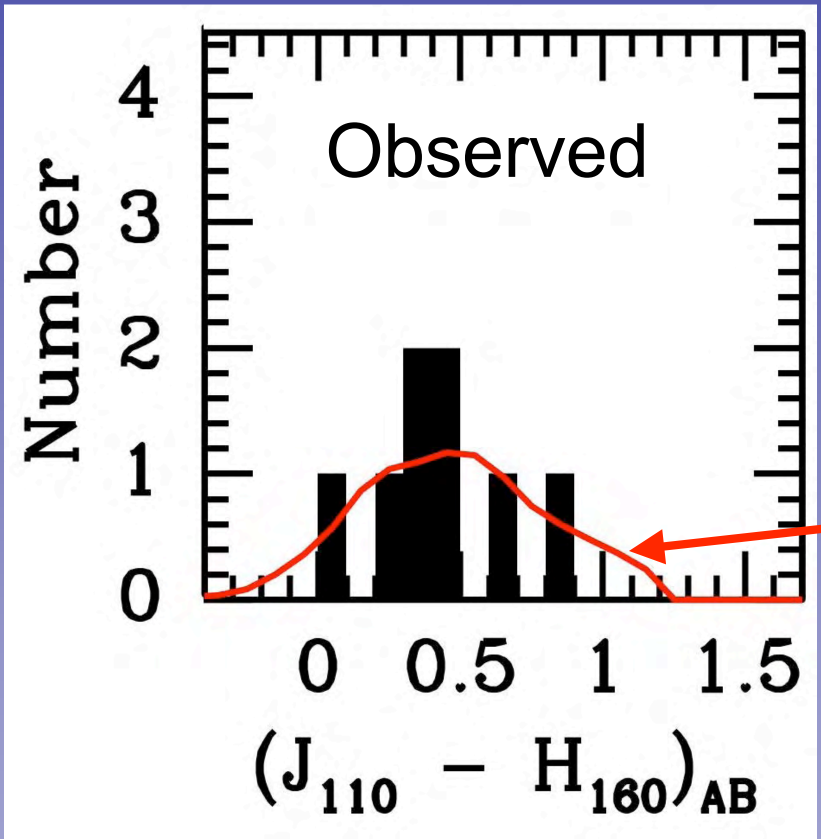
Suggests we are actually finding z~7-8 galaxies!

Bouwens, Illingworth et al. 2008

Aspen 02/15/08 RJB

Colours of the discovered z-dropout population agree with model expectations!

Number



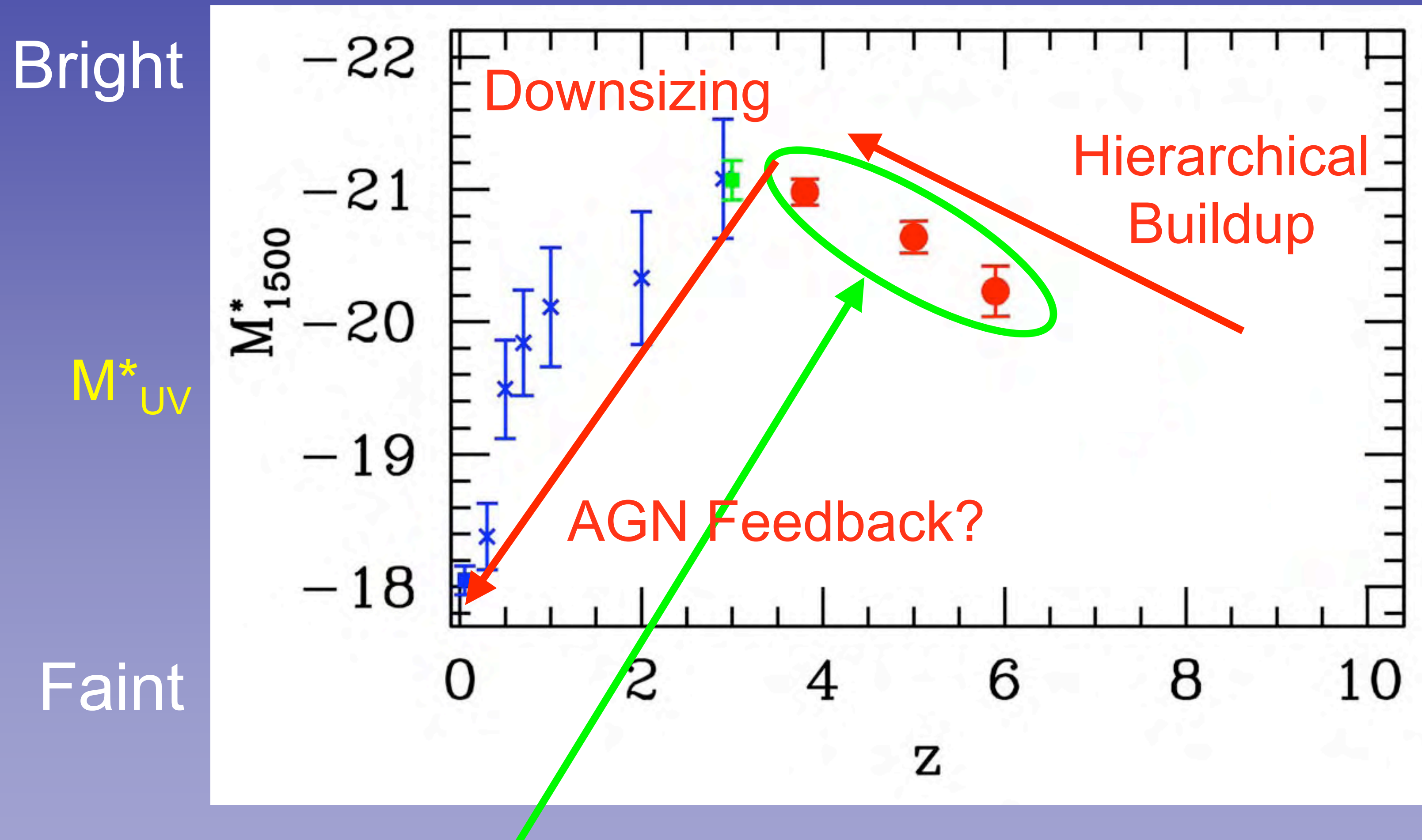
Expected for young star-forming objects at z~7-8

Near-IR J-H Colour

Suggests we are actually finding z~7-8 galaxies!

Bouwens, Illingworth et al. 2008

Evolution of the UV Luminosity Function



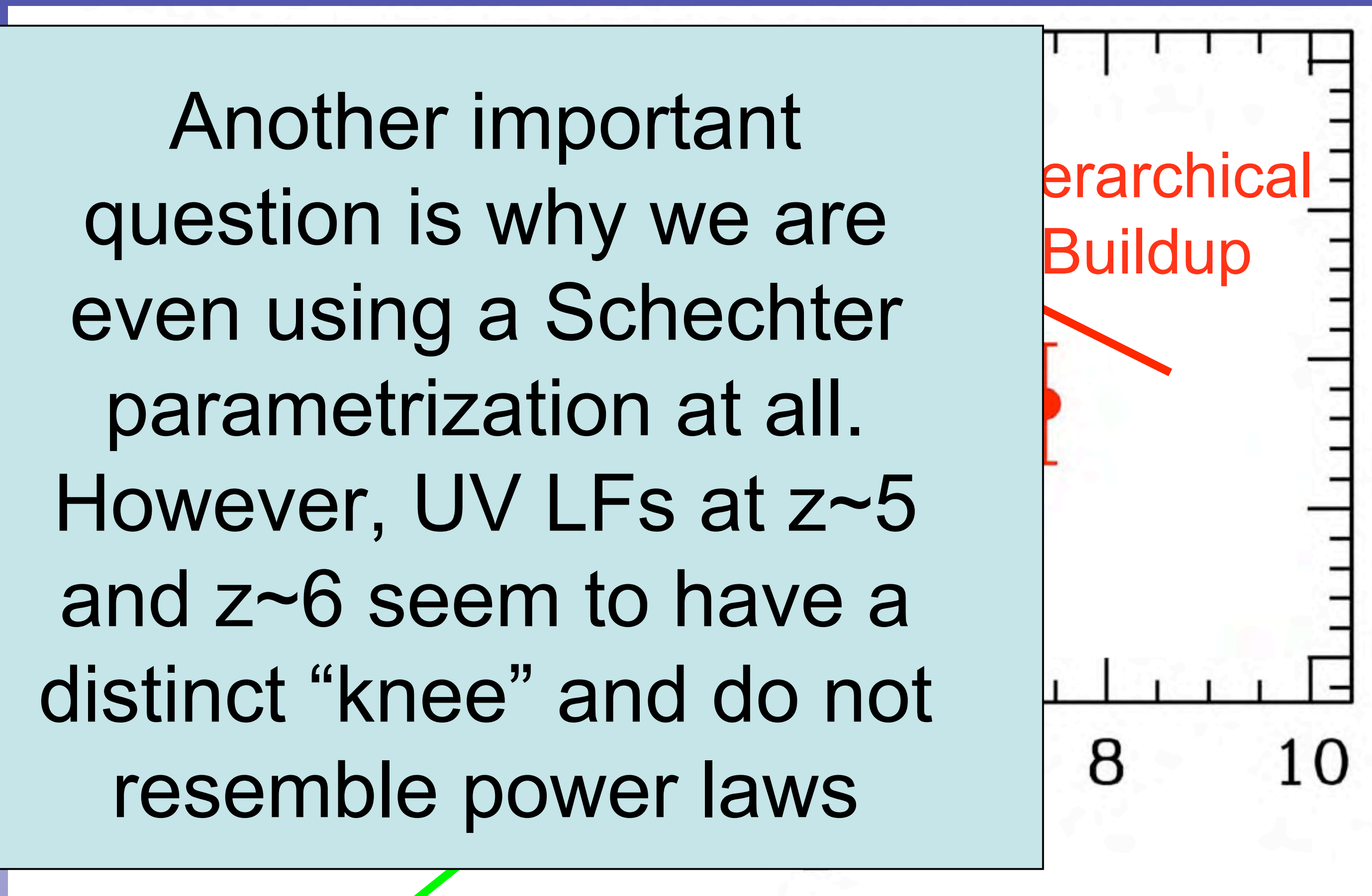
Bouwens, Illingworth, Franx, & Ford 2007

Evolution of the UV Luminosity Function

Bright

M^*_{UV}

Faint

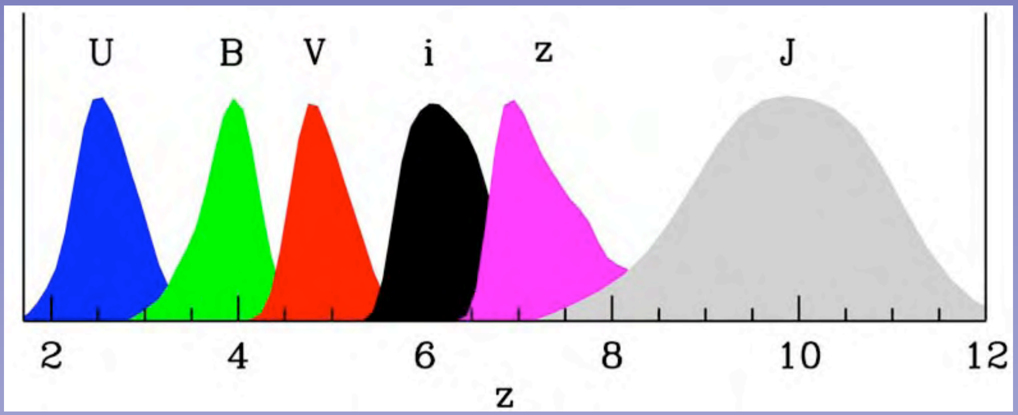


Another important question is why we are even using a Schechter parametrization at all. However, UV LFs at z~5 and z~6 seem to have a distinct "knee" and do not resemble power laws

Bouwens, Illingworth, Franx, & Ford 2008

Galaxies at z~10

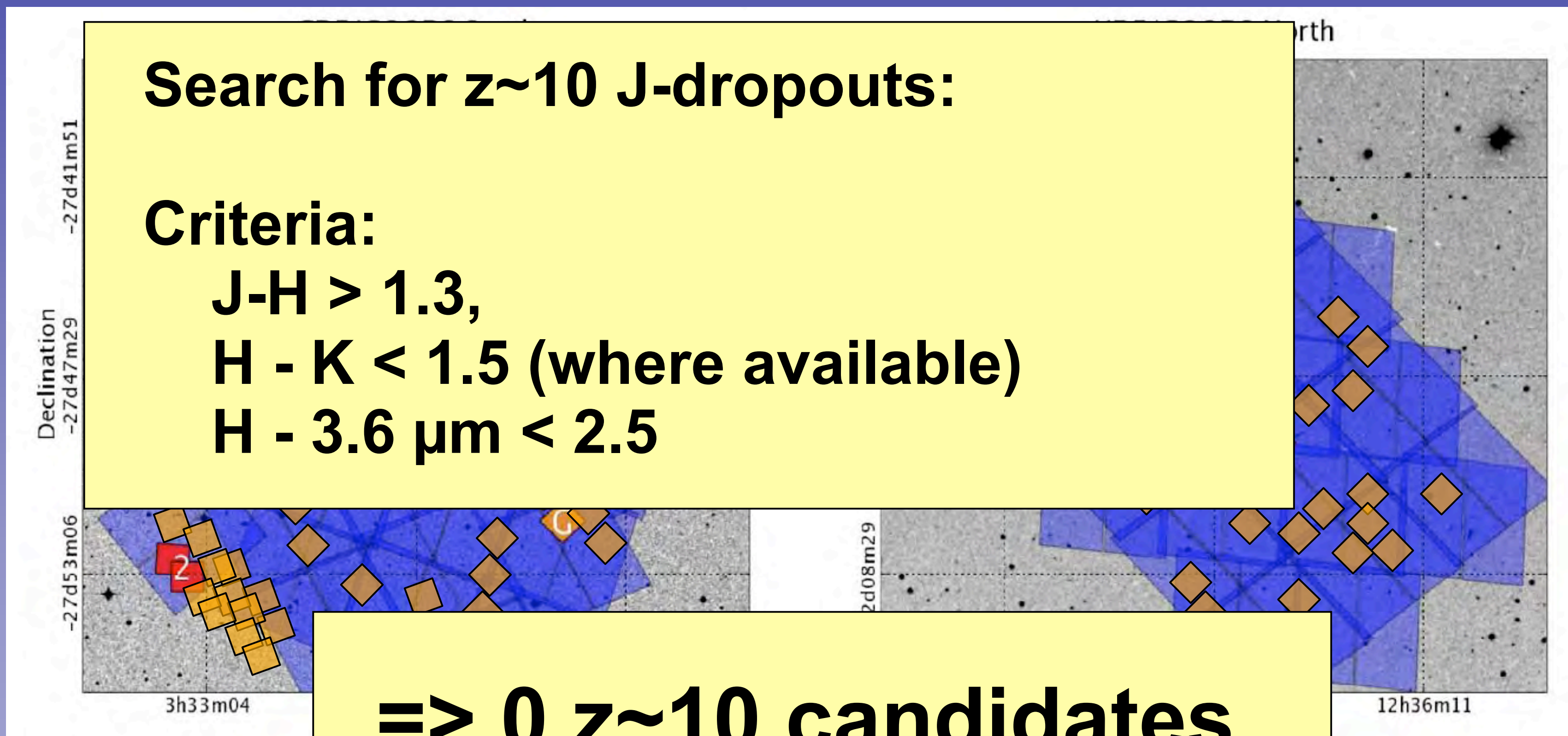
(J-dropouts)



Dropout Redshift Selection Functions

Galaxies at *z~10 (J-dropouts)*

Many fields with deep ACS and NICMOS data for dropout searches



Search for z~10 J-dropouts:

Criteria:

- **J-H > 1.3,**
- **H - K < 1.5 (where available)**
- **H - 3.6 μm < 2.5**

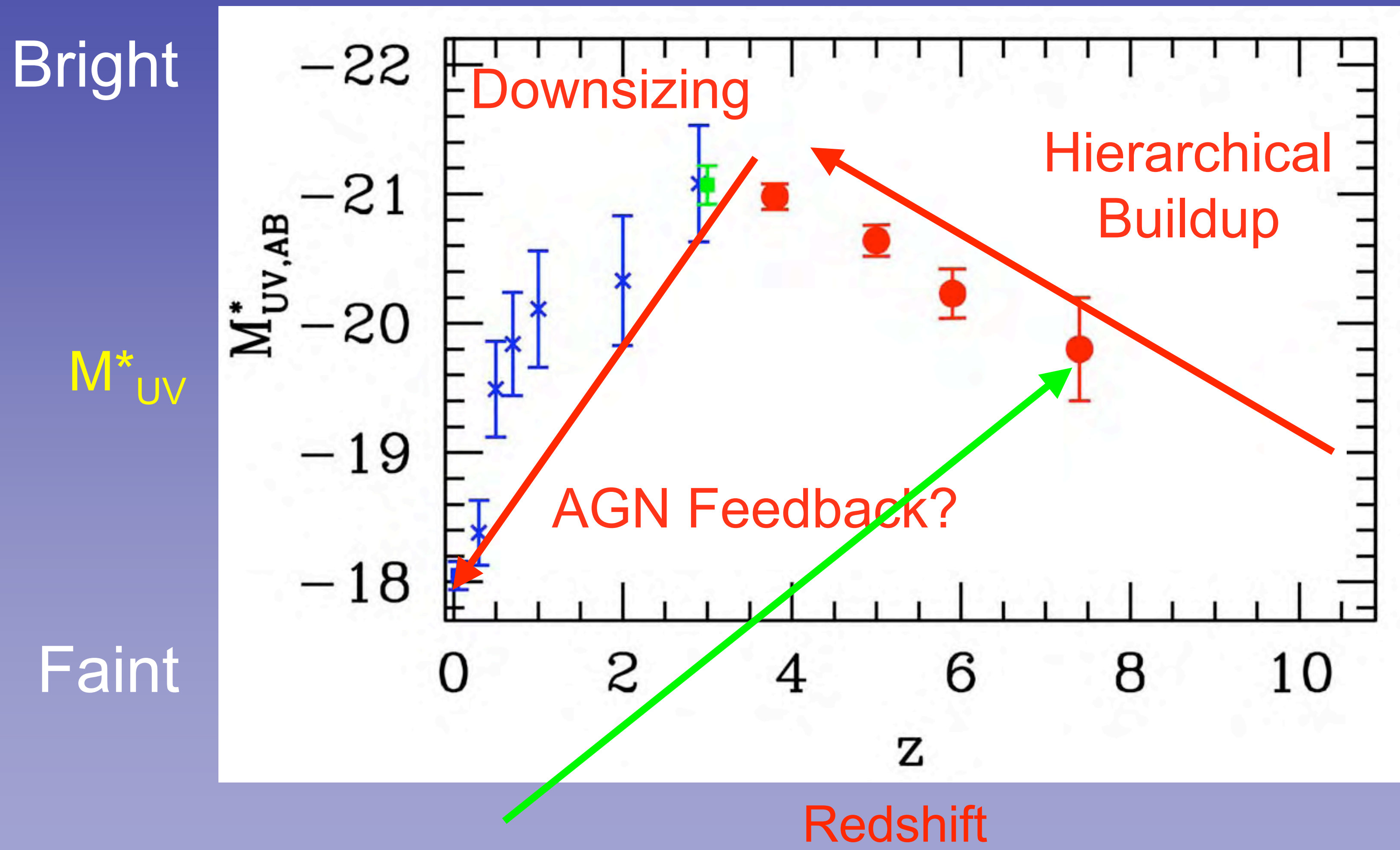
=> 0 z~10 candidates

Deep NICMOS ... ~80 arcmin^2

ACS *NICMOS*

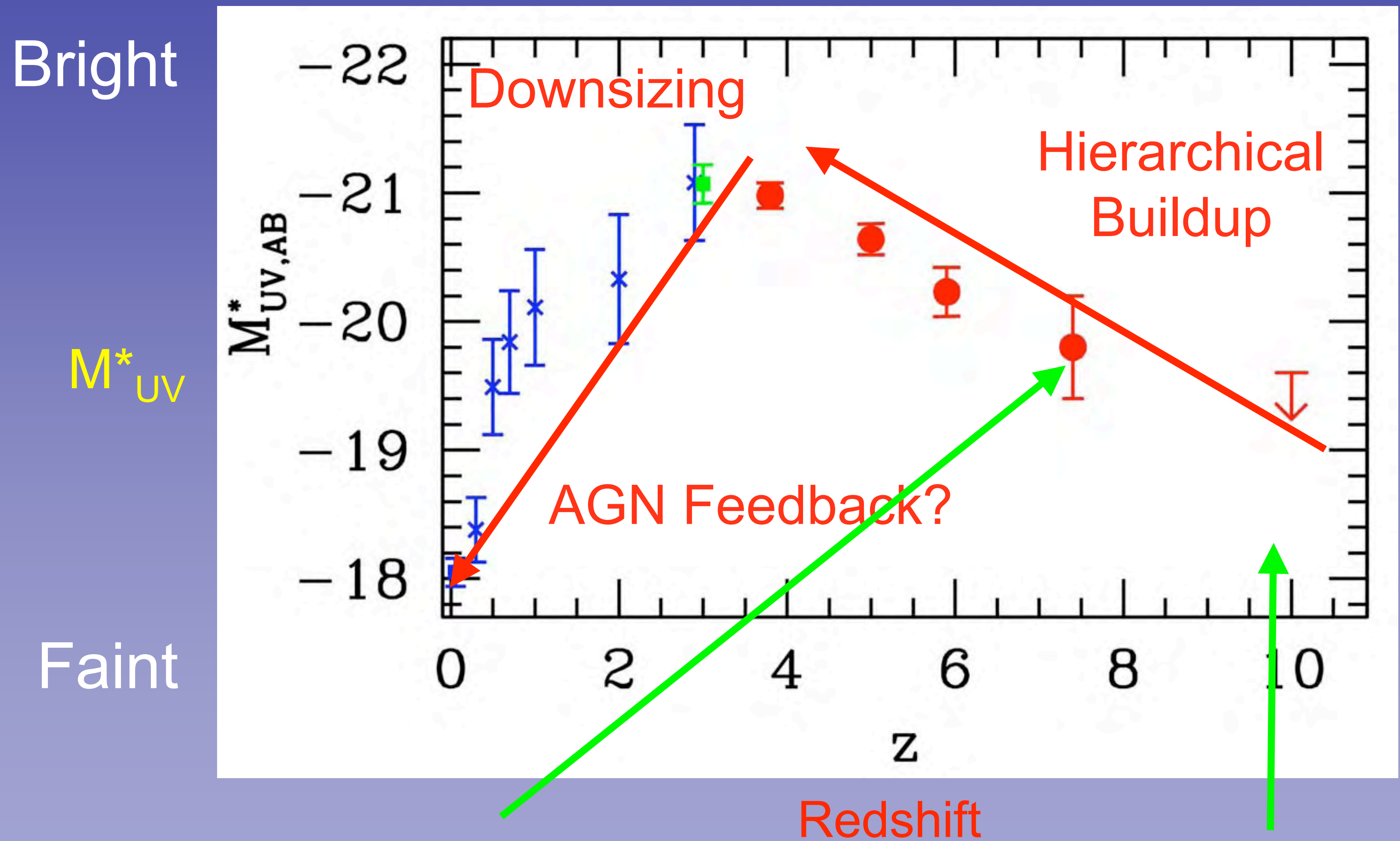
$J_{AB} \sim H_{AB}$ >= 26.5 mag

Evolution of the UV Luminosity Function



Bouwens, Illingworth et al. 2007

Evolution of the UV Luminosity Function

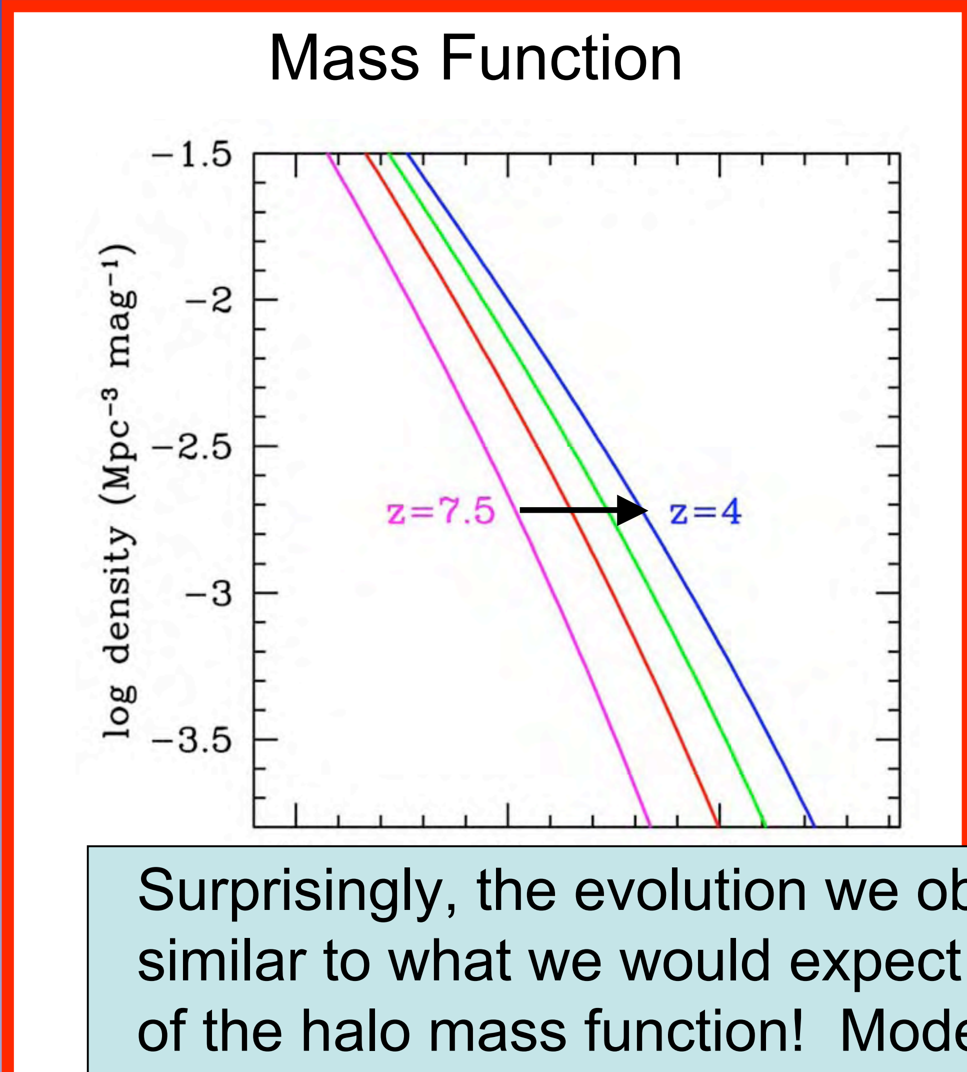


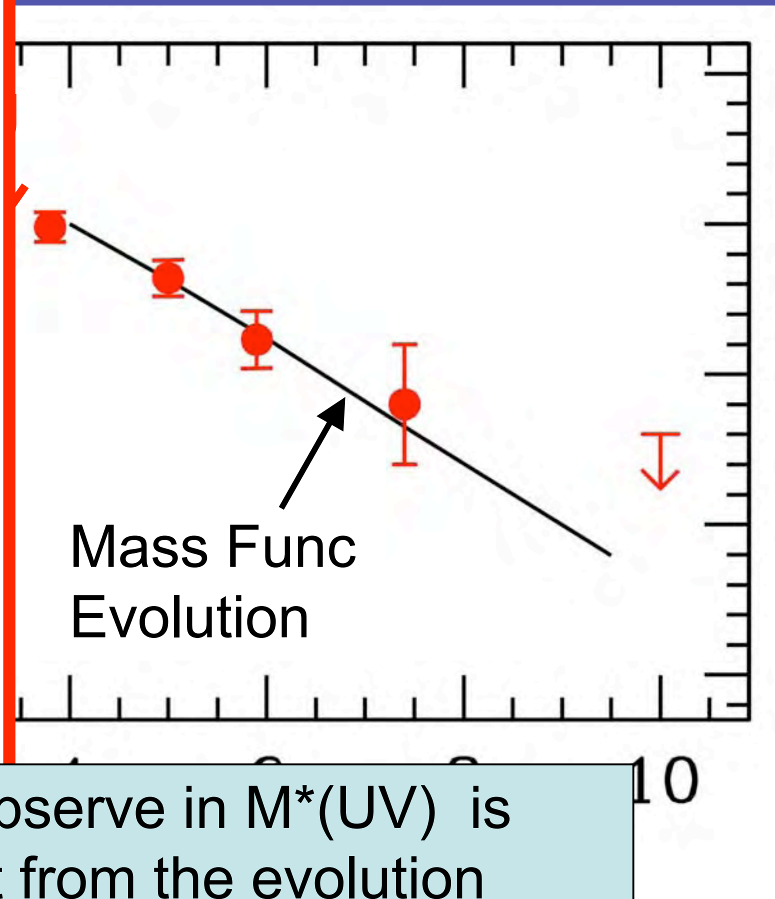
Bouwens, Illingworth et al. 2007

Assuming phi* ~ 0.001 Mpc^{-3} at z~10 (i.e., no evolution)

Aspen 02/15/08 RJB

Evolution of the UV Luminosity Function



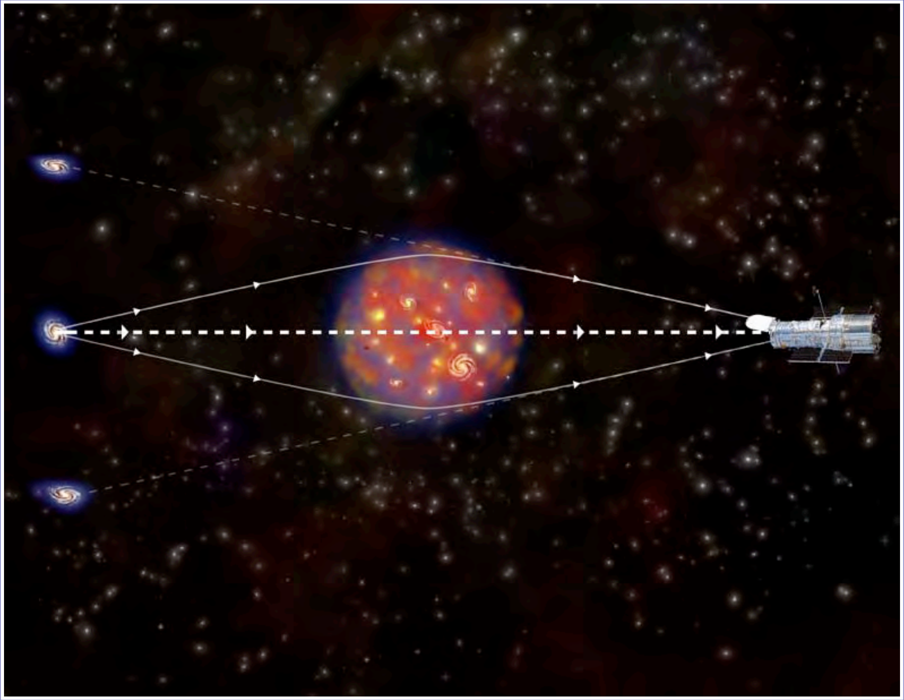


Surprisingly, the evolution we observe in M*(UV) is similar to what we would expect from the evolution of the halo mass function! Modest evolution in M/L ratios likely!

Searches for z>6 Galaxies Behind Galaxy Clusters

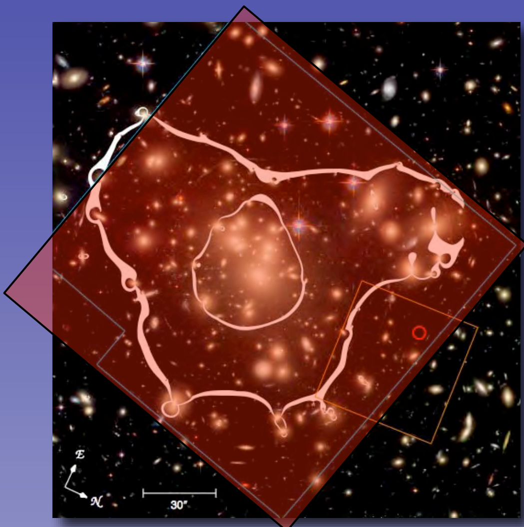
(see also talks by Richard, Bradac, and Bradley)

- High-redshift galaxies are extremely faint (L_* ~ 27.5 - 28 H_{AB} mag at z ~ 7)
- Use gravitational lensing clusters as cosmic telescopes – cluster "optics" need to be well-constrained by models
- However, the source plane area is inversely proportionally to the magnification….

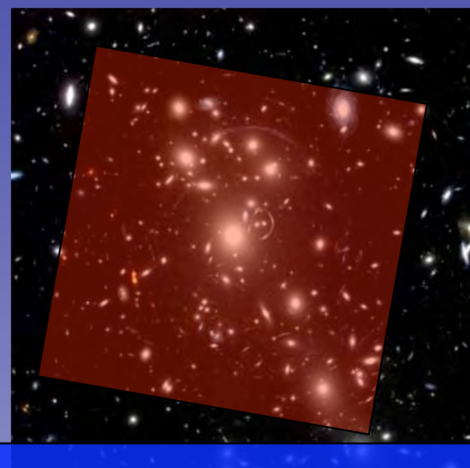


Searches for z>6 Galaxies Behind Galaxy Clusters

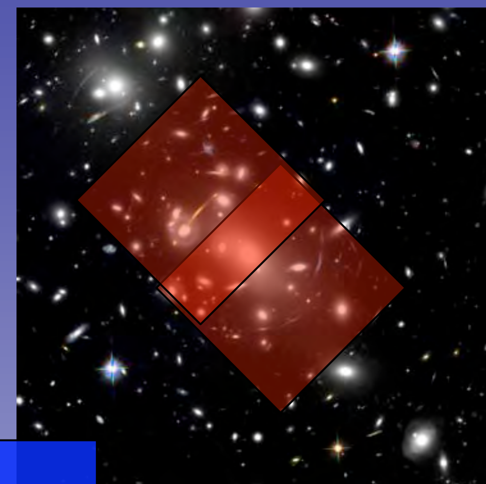
Abell 1689



Abell 1703

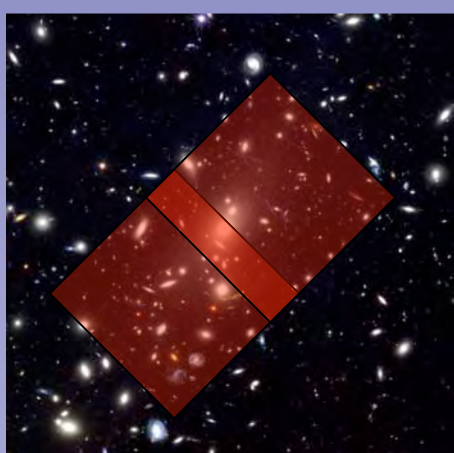


Abell 2218

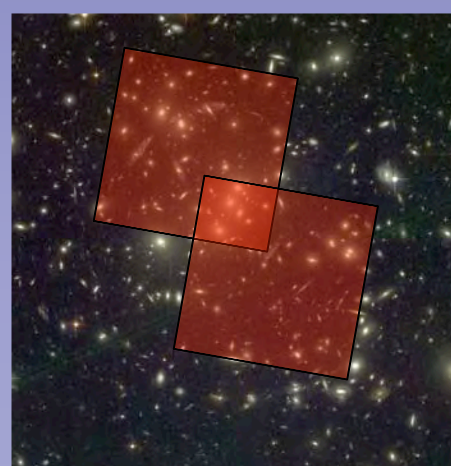


+ 5 other clusters

MS1358



CL0024



BULLET CLUSTER

Searches for z>6 Galaxies Behind Galaxy Clusters

Total Search Fields:

-- 23 $arcmin^2$ search area around 11 galaxy clusters

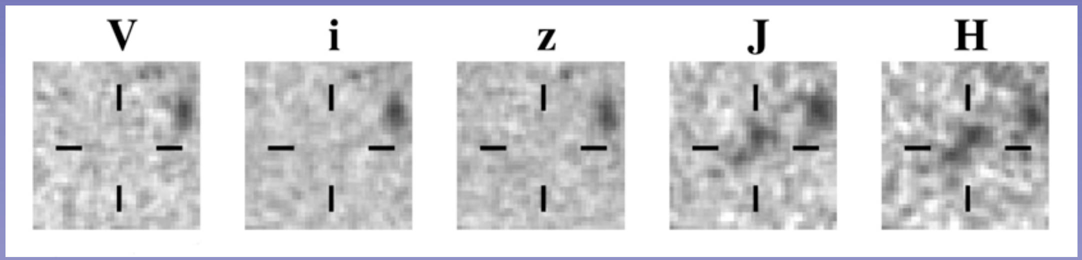
Search for z>=7 z-dropouts:

-- Use same selection criteria as for field sample

-- Prefer to use robust selection criteria

Results:

1 robust z-dropout -->



2 other possible z-dropouts (but which do not have deep enough optical data to be sure)

The reason these numbers may be different from Johan Richard is that we only consider z>=7 candidates we consider reasonably robust (we prefer to keep our selections fairly conservative) and we do not subtract foreground galaxies (perhaps ~20-30% covering area).

Searches for z>6 Galaxies Behind Galaxy Clusters

How efficient are dropout searches in the field vs. behind lensing clusters?

	In the Field	Behind Lensing Clusters
# of z-dropouts	9	1
HST NICMOS Orbits	~1000	~150
Cost	~ 100 orbits	~100 orbits

Similar results are found with z~5 V-dropout and z~6 I-dropout selections

Searches behind lensing clusters do not appear to be much more efficient in practice than in the field. Given the uncertainties In the magnification maps, we are not convinced that the use of lensing clusters is the best way to constrain quantities like the luminosity function.

New Measurements of the UV LFs at z>6: Conclusions

- UDF and GOODS ACS and NICMOS data are superb for z~4 to z~7-10 dropout searches
- Soon >=80 arcmin^2 of deep (>=26.5 AB mag) near-IR data will be available over areas with deep optical coverage
- Using these data, we have identified 10 z~7-8 z-dropout candidates, with luminosities ranging from 0.1 L*(z=3) to 1.0 L*(z=3)
- The characteristic luminosity of galaxies in the UV appears to brighten substantially (by ~1.2 mag) from z~7.4 to z~3.
- The increase in the characteristic luminosity M* is similar to that expected for the halo mass function -- suggesting that the observed evolution is largely driven by hierarchical build-up.
- We find only 1 highly robust z-dropout over > ~20 arcmin^2 of deep NICMOS data around galaxy lensing clusters