Uncertainties in

The Galaxy Luminosity Function at $z \gtrsim 6$

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Significance of $z \gtrsim 6$ galaxies

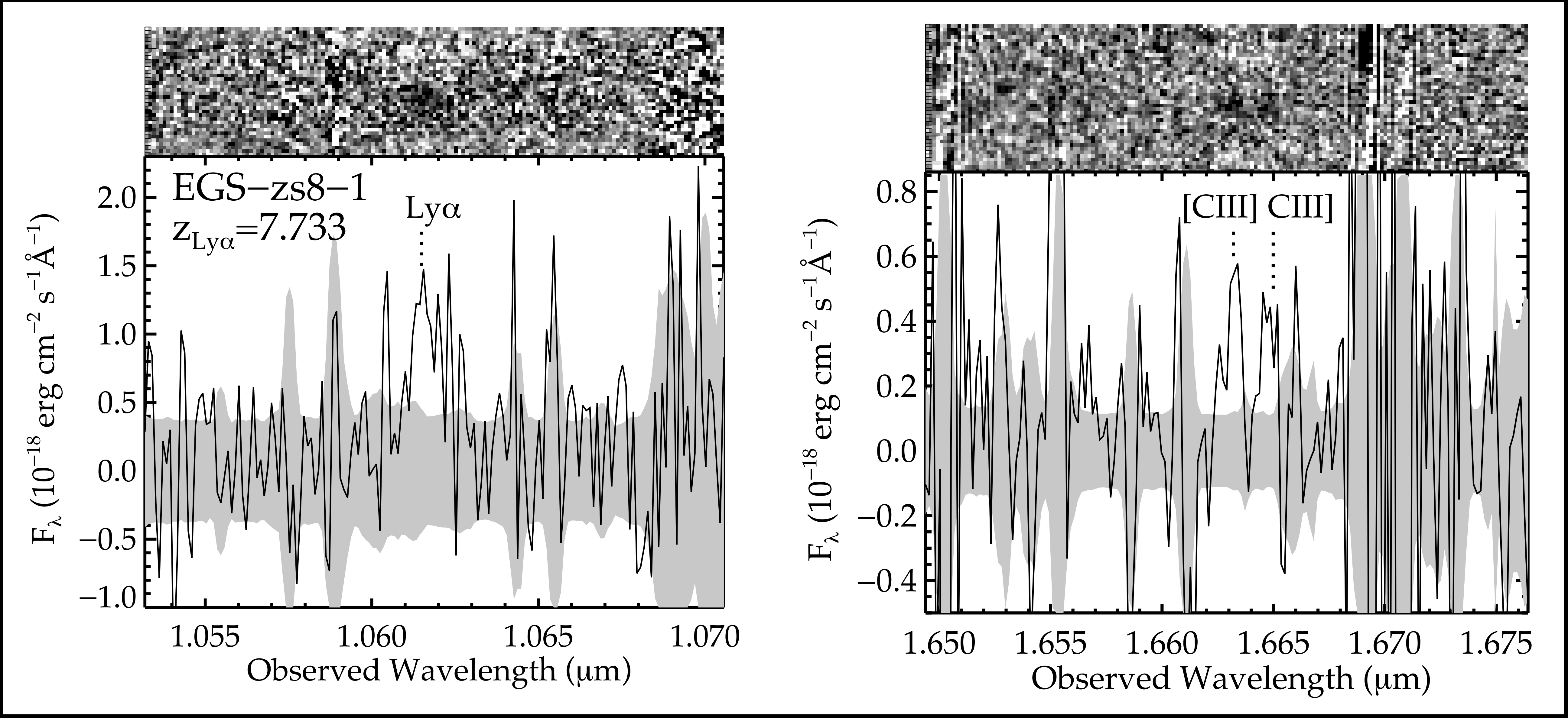
- Assembly of the first galaxies (and first SMBH)
- Ionization of the intergalactic medium
- Chemical enrichment in early times

The galaxy luminosity function ->
a census of the early galaxy population

Observations of high-redshift galaxies

Spectroscopy is hard...

Keck/MOSFIRE 3-4 hr total integration



Oesch et al. (2015); Stark et al. (2016)

Observations of high-redshift galaxies

A deep image is worth a thousand spectra

The XDF team, http://xdf.ucolick.org/xdf.html

Observations of high-redshift galaxies

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ARTICLES

Star-forming galaxies at very high redshifts

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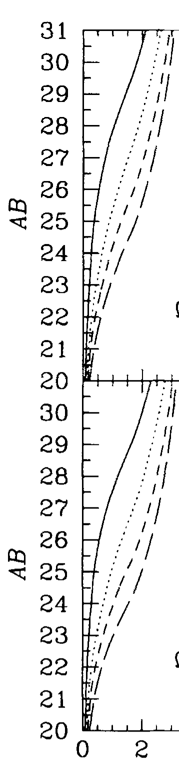
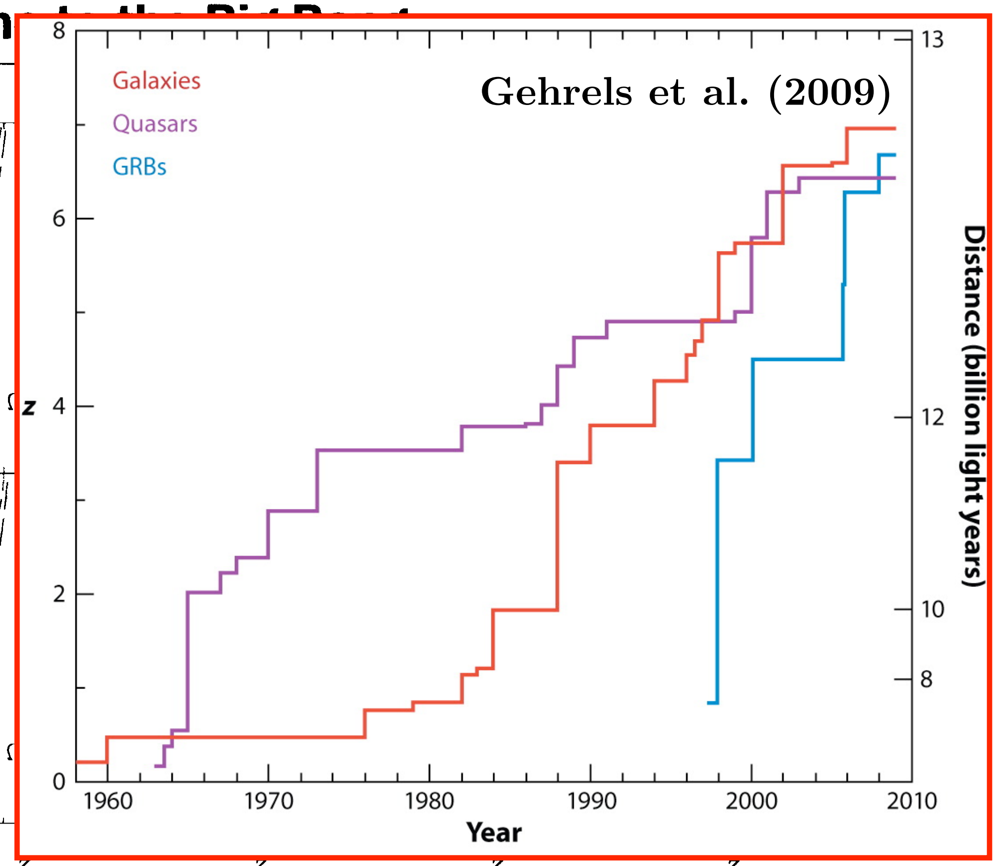
Analysis of the deepest available images of the sky, obtained by the Hubble Space Telescope, reveals a large number of candidate high-redshift galaxies. A catalogue of 1,683 objects is presented, with estimated redshifts ranging from $z = 0$ to $z > 6$. The high-redshift objects are interpreted as regions of star formation associated with the progenitors of present-day normal galaxies, at epochs that may reach back 95% of the tim

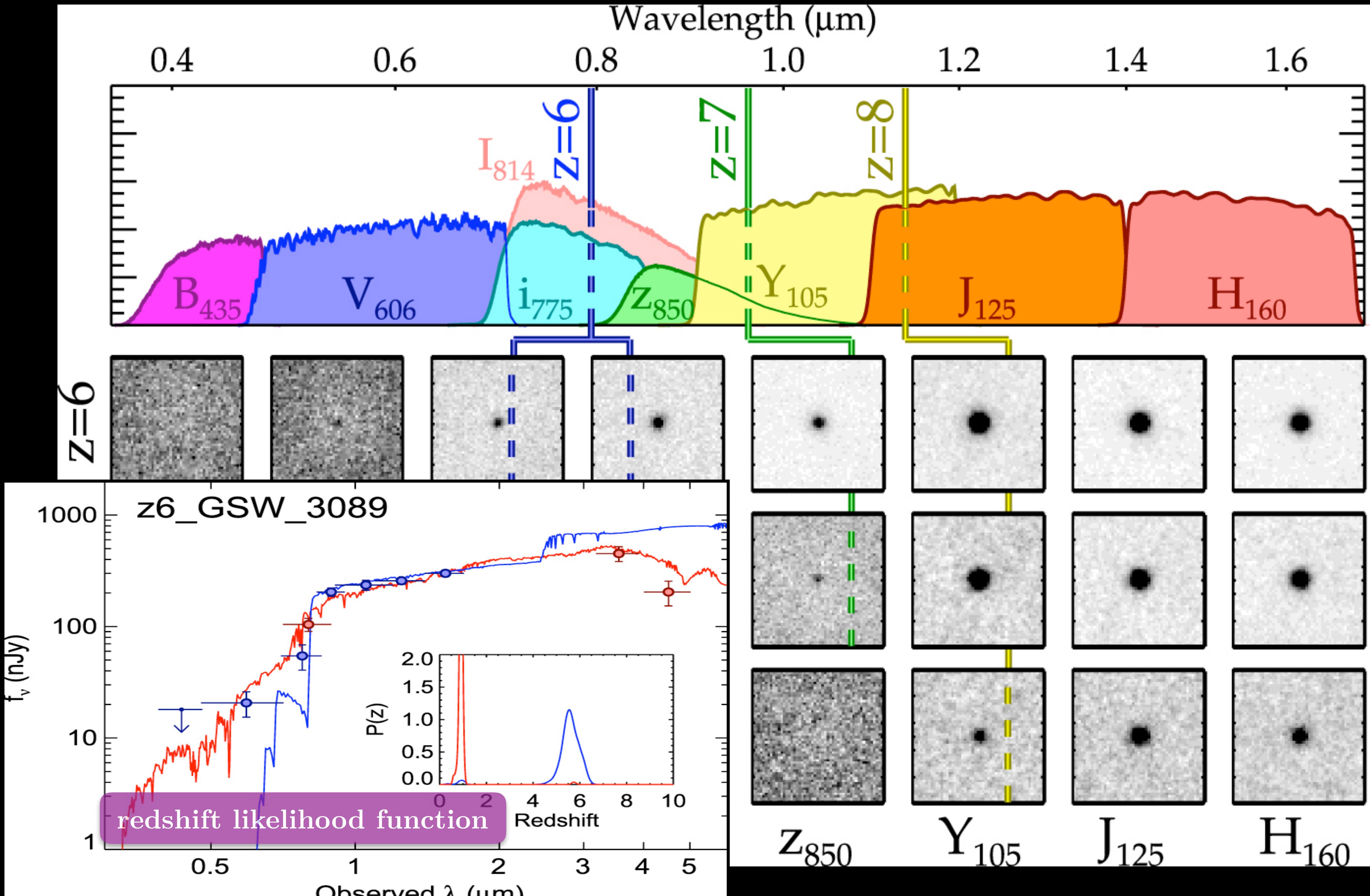
THE long-standing effort to identify normal galaxies at high redshifts has undergone dramatic progress in recent months. New observations by Steidel *et al.*[1] to magnitude $AB(6930) < 25$ (where $AB(\lambda)$ is the monochromatic magnitude at wavelength λ) have revealed a population of galaxies at redshift $z \approx 3$ and have demonstrated that the Lyman-limit spectral discontinuity and Lyα-forest spectral decrement, which arise owing to photoelectric absorption by neutral hydrogen along the line of sight, together constitute the most prominent spectral signature of very distant galaxies. This result has two important implications. First, it provides a means of identifying high-redshift galaxies. The spectra of high-redshift galaxies are characterized by (1) a complete absence of flux below the Lyman limit and (2) strongly absorbed flux in the Lyα forest. This spectral signature is observable by means of broad-band photometry and must apply irrespective of the underlying spectral properties of the galaxies because it is imprinted by intervening rather than intrinsic material. Second, it allows high-redshift interpretations of low-redshift galaxies to be





Selections of high-redshift galaxies (I)

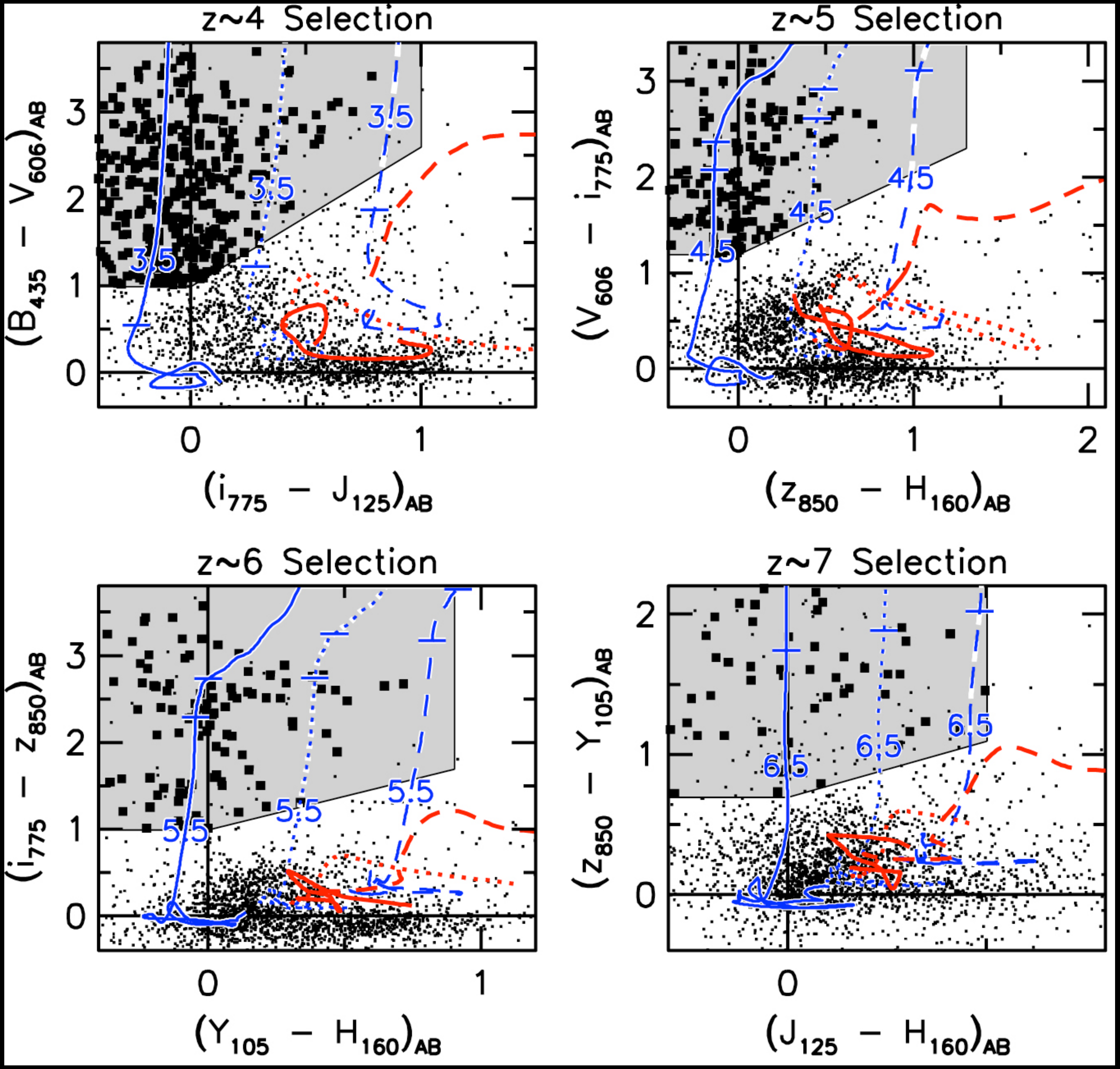
photometric redshifts based on broad-band SEDs



Finkelstein et al. (2015)

Selections of high-redshift galaxies (II)

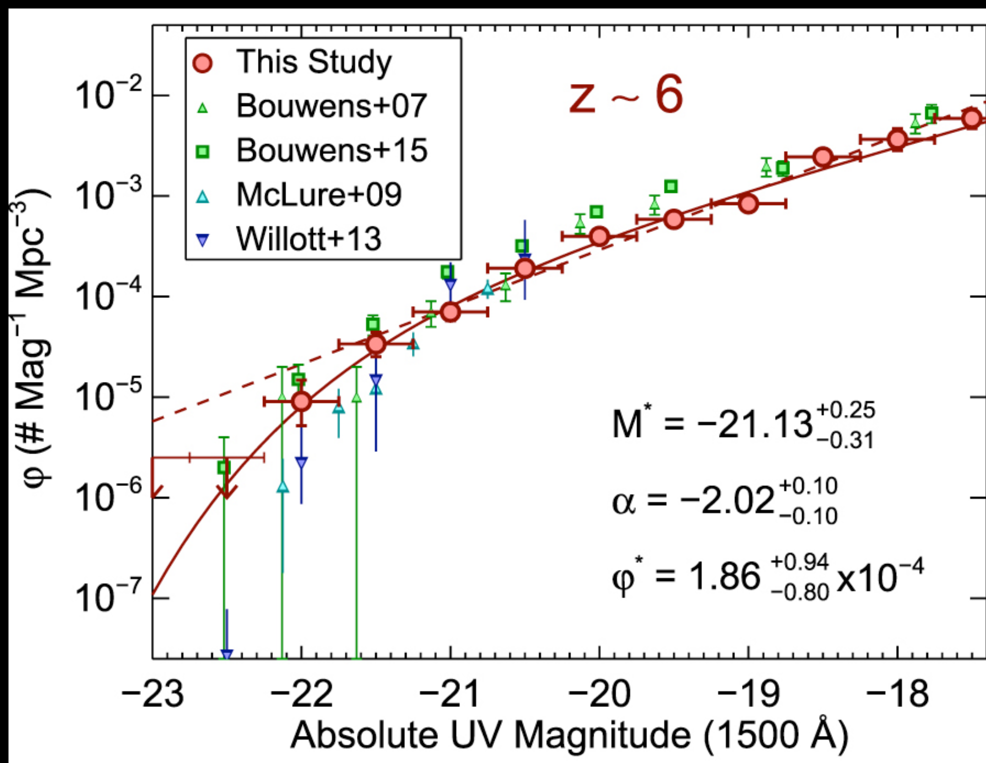
two-color selections based on expected Lyα discontinuities

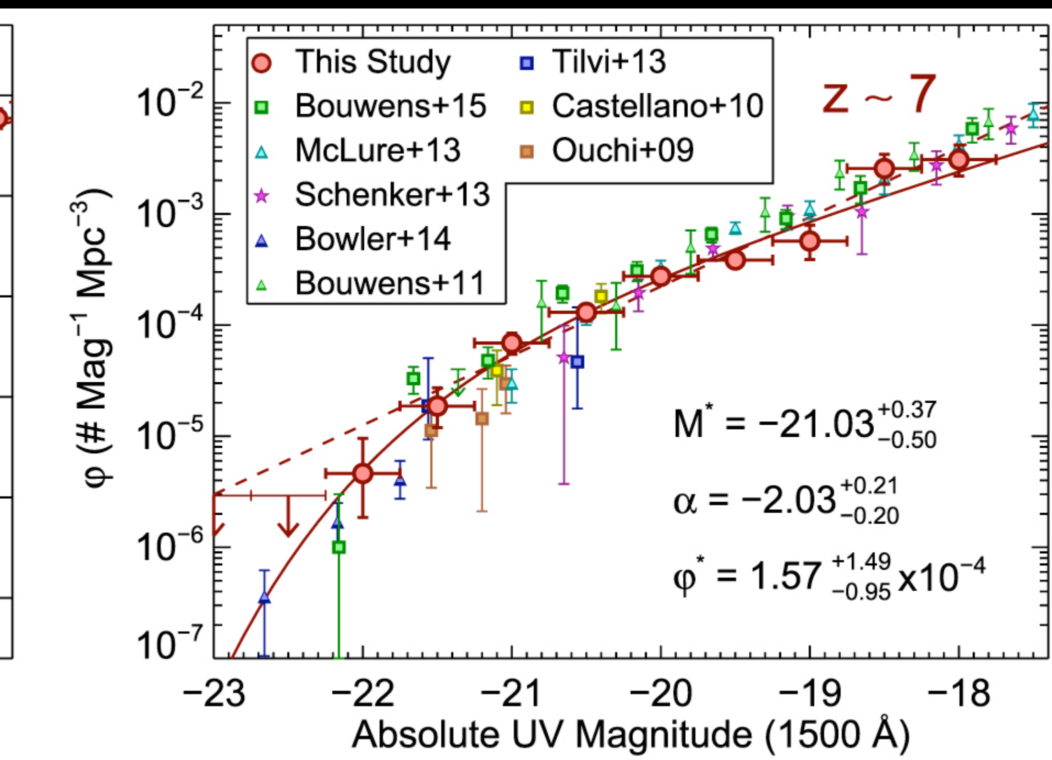


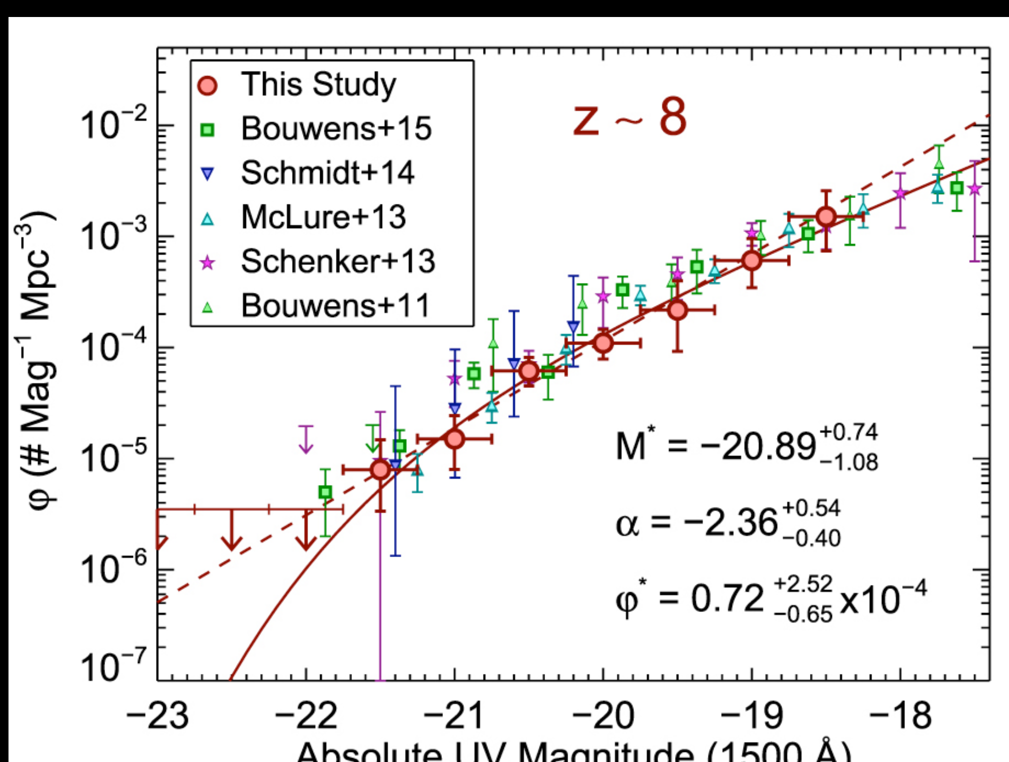
Bouwens et al. (2015)

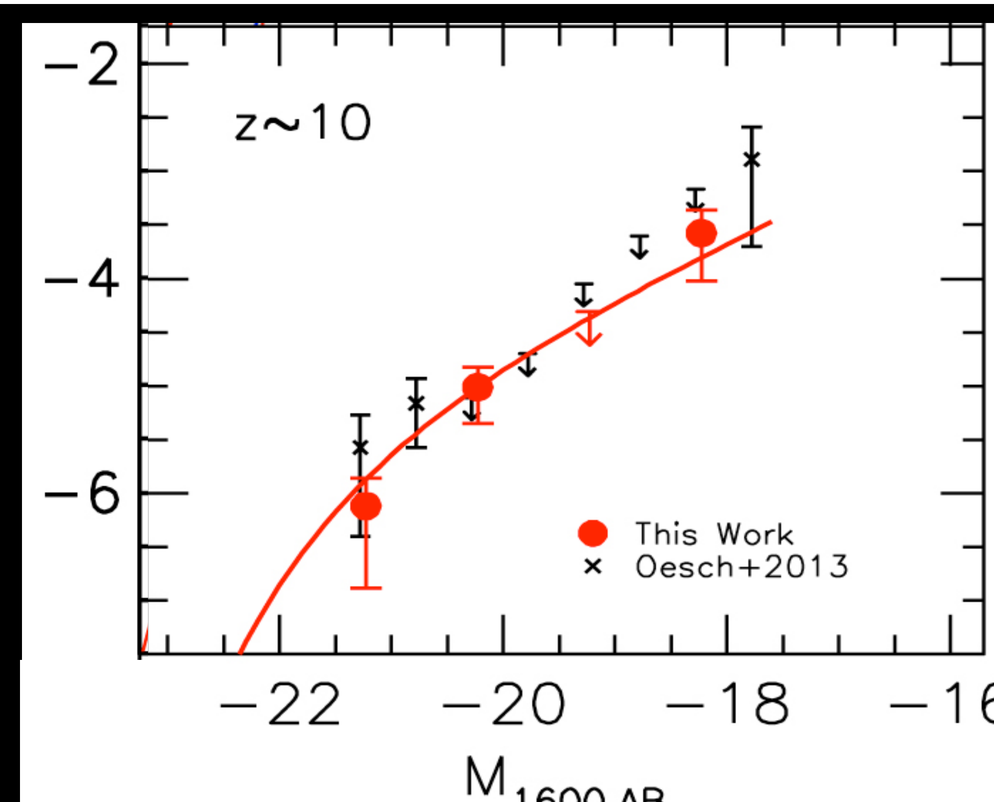
The galaxy luminosity function at $z \gtrsim 6$

~ 1500 galaxies from ~ five deep fields





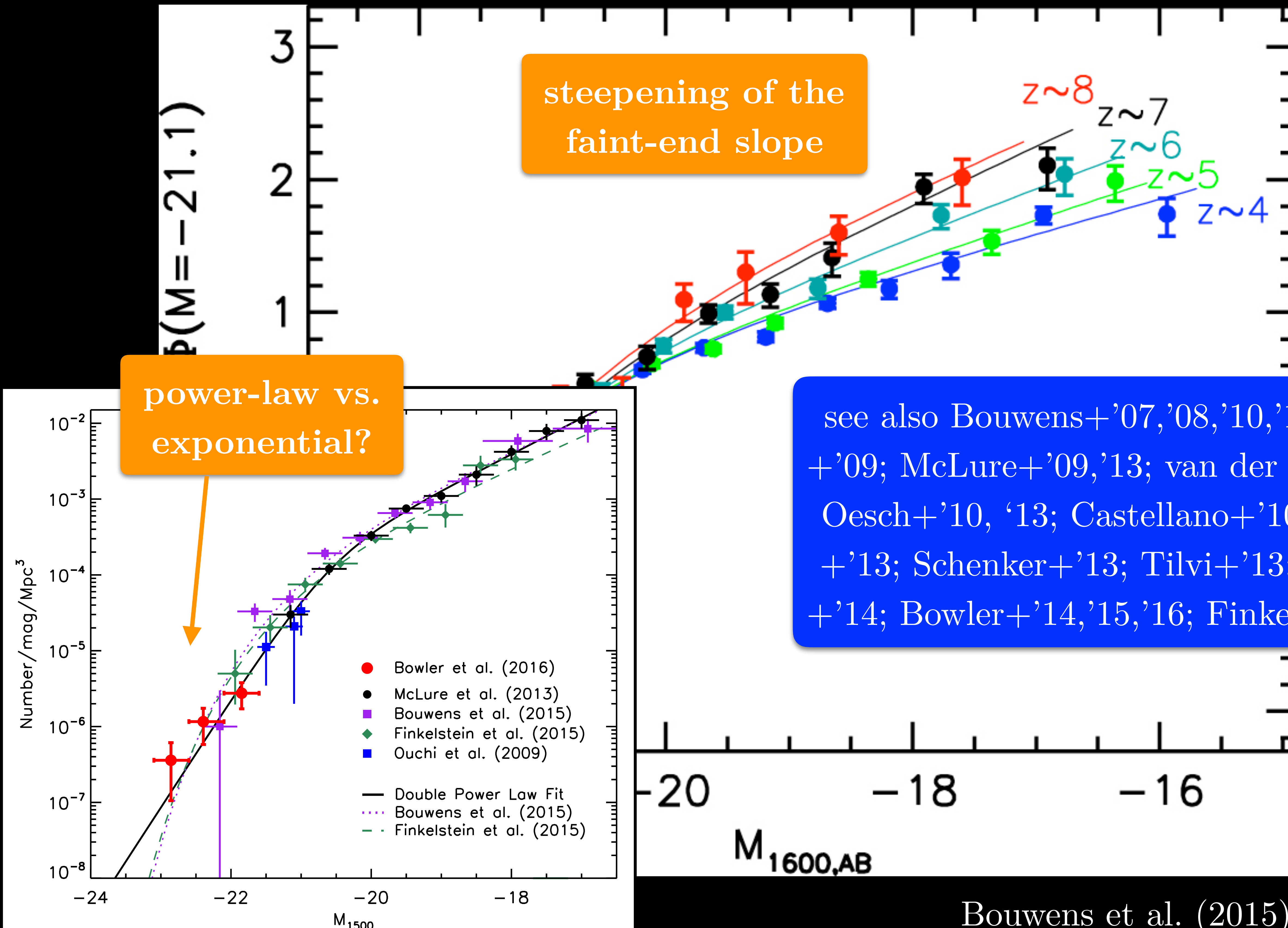




Finkelstein et al. (2015)

Bouwens et al. (2015)

The galaxy luminosity function at $z \gtrsim 6$



see also Bouwens+’07,’08,’10,’11; Ouchi +’09; McLure+’09,’13; van der Burg+’10; Oesch+’10, ‘13; Castellano+’10; Willott +’13; Schenker+’13; Tilvi+’13; Schmidt +’14; Bowler+’14,’15,’16; Finkelstein+’15

Bouwens et al. (2015)

Uncertainties in the luminosity function

Bouwens+'07,'08,'10,'11,'15; Ouchi+'09; McLure+'09,'13; van der Burg +'10; Oesch+'10, '13; Castellano+'10; Willott+'13; Schenker+'13; Tilvi +'13; Schmidt+'14; Bowler+'14,'15,'16; Finkelstein+'15

- photometry (matching apertures, deblending, etc.)
- contaminations (stars, low-redshift interlopers, etc.)
- cosmic variance
- sample selection (completeness, photometric redshift errors / errors in color selection)

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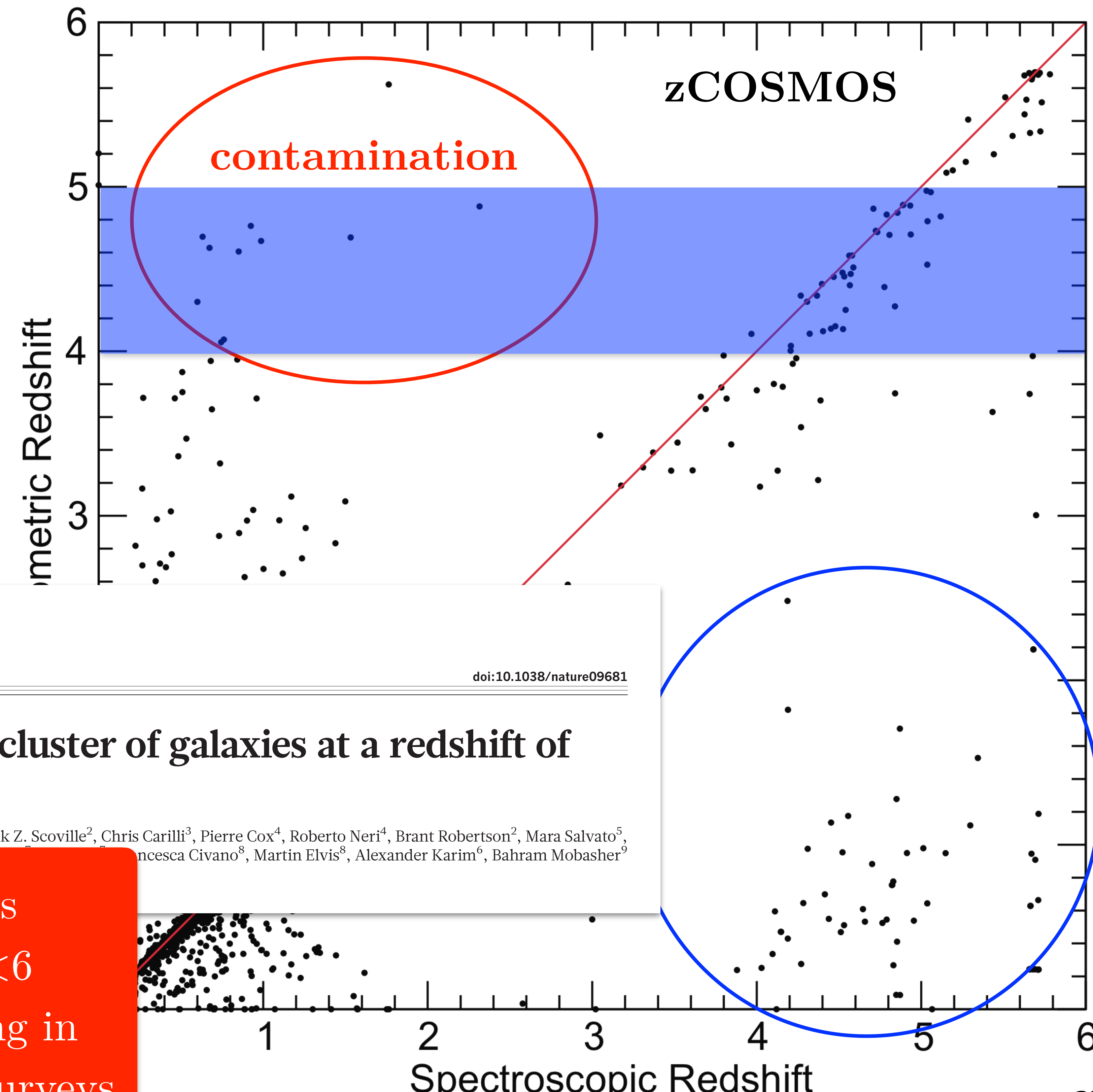
Uncertainties in photometric redshifts (I)



missed by a fixed z_{phot}/color cut?

LETTER

doi:10.1038/nature09681

A massive protocluster of galaxies at a redshift of $z \approx 5.3$

Peter L. Capak[1], Dominik Riechers[2], Nick Z. Scoville[2], Chris Carilli[3], Pierre Cox[4], Roberto Neri[4], Brant Robertson[2], Mara Salvato[5],
ncesca Civano[8], Martin Elvis[8], Alexander Karim[6], Bahram Mobasher[9]

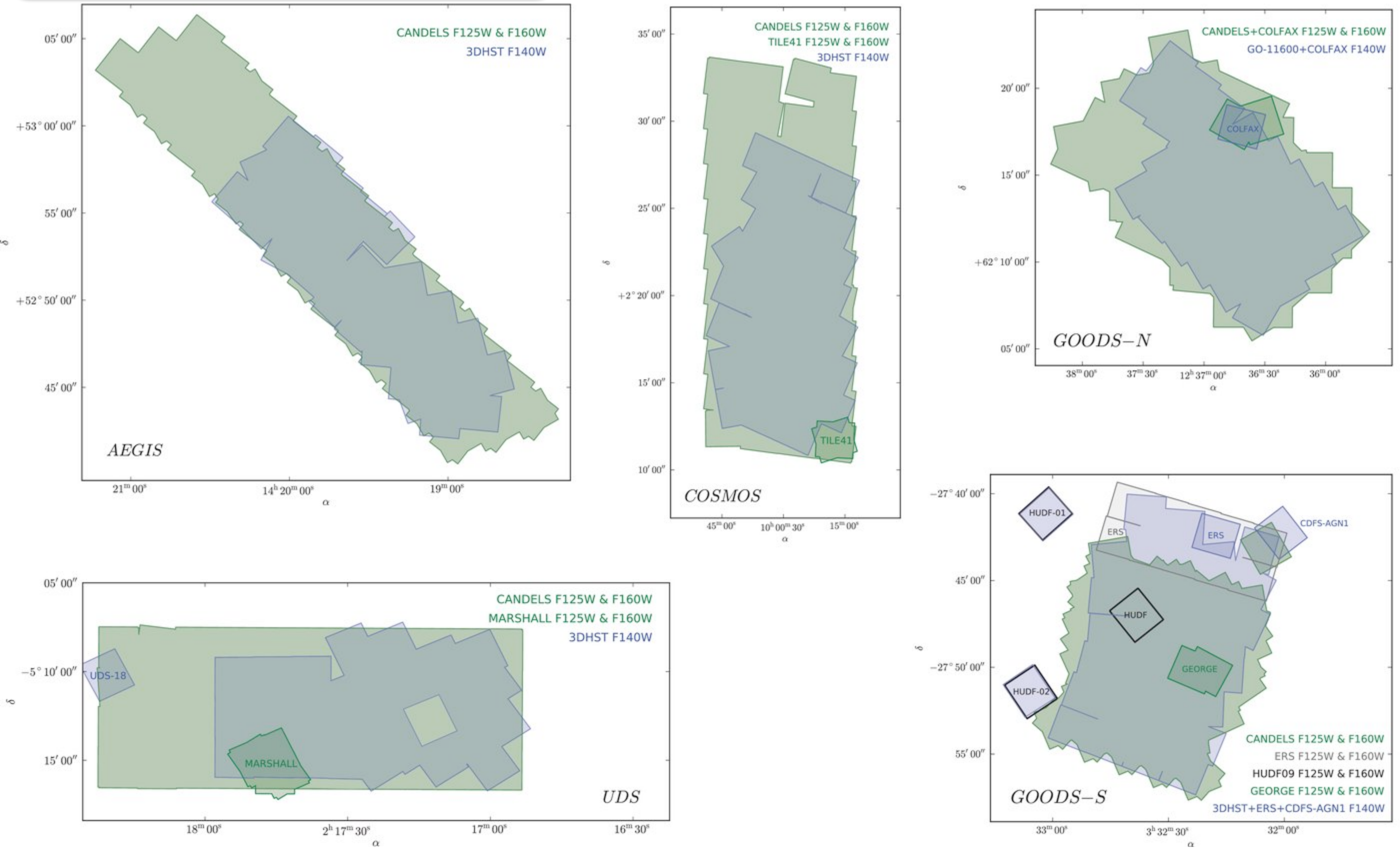
- photo-z analysis restricted to z<6
- uneven sampling in spectroscopic surveys

Capak et al. (2011)

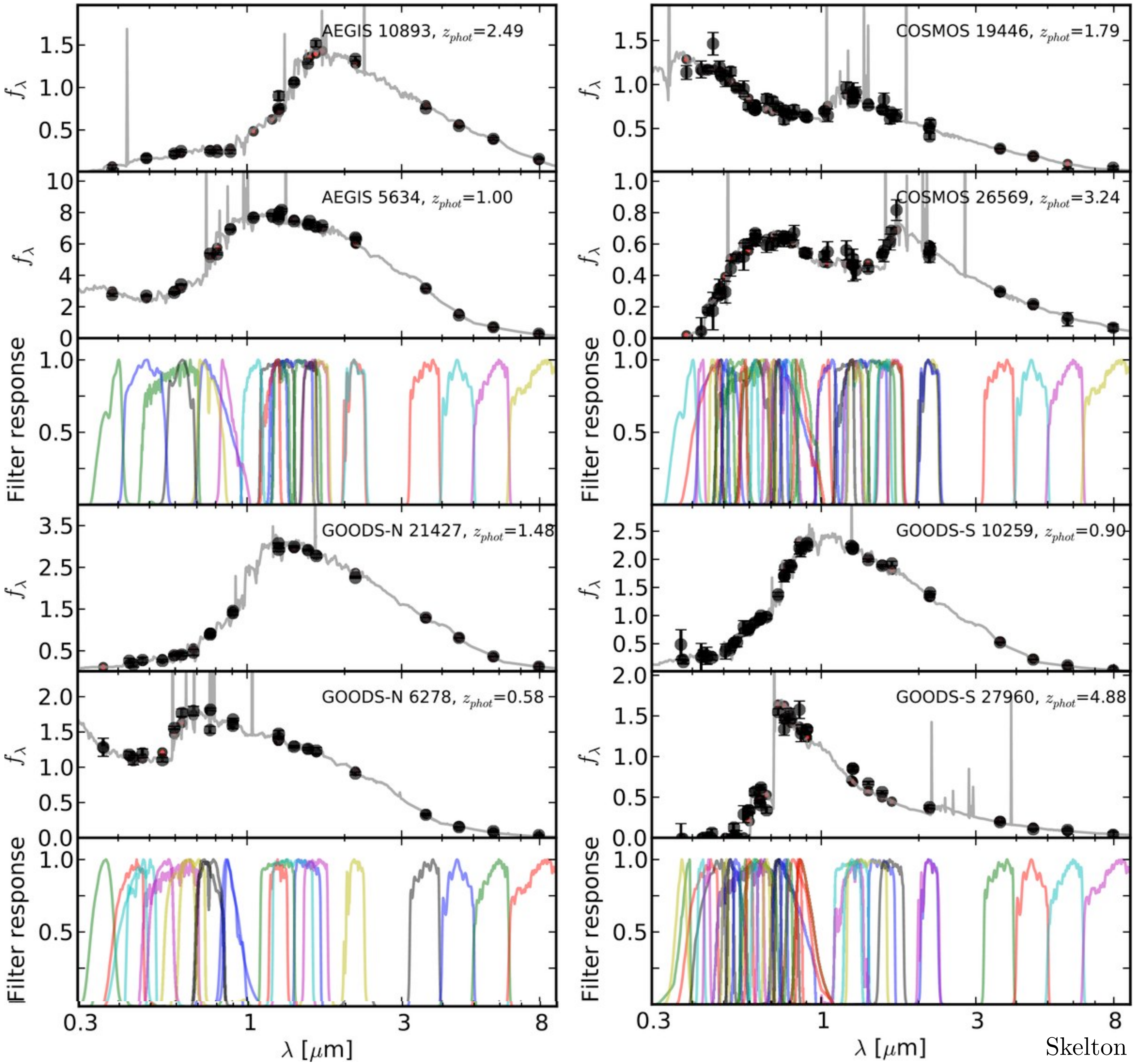
Five deep fields with ~ 20 - 44 broad/narrow-band images in UV, optical, to IR

3D-HST

Skelton et al. (2014)



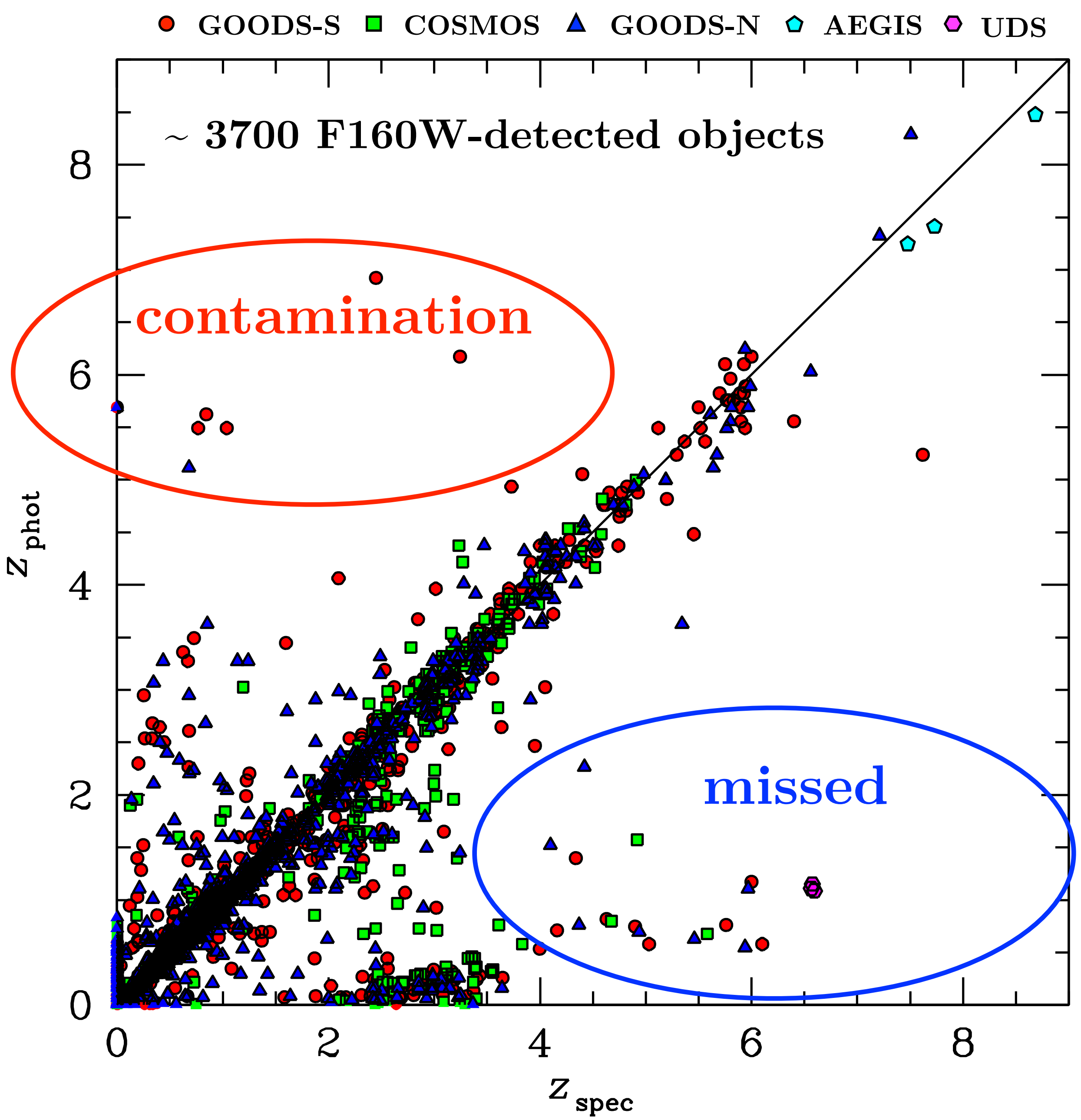
3D-HST

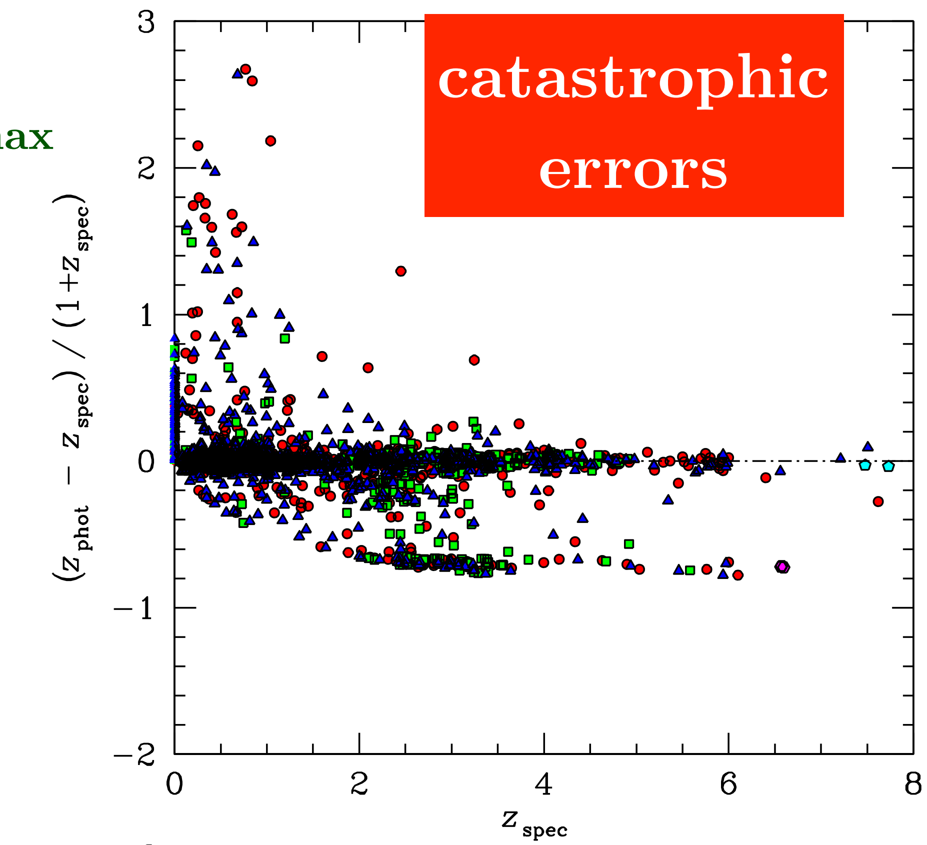


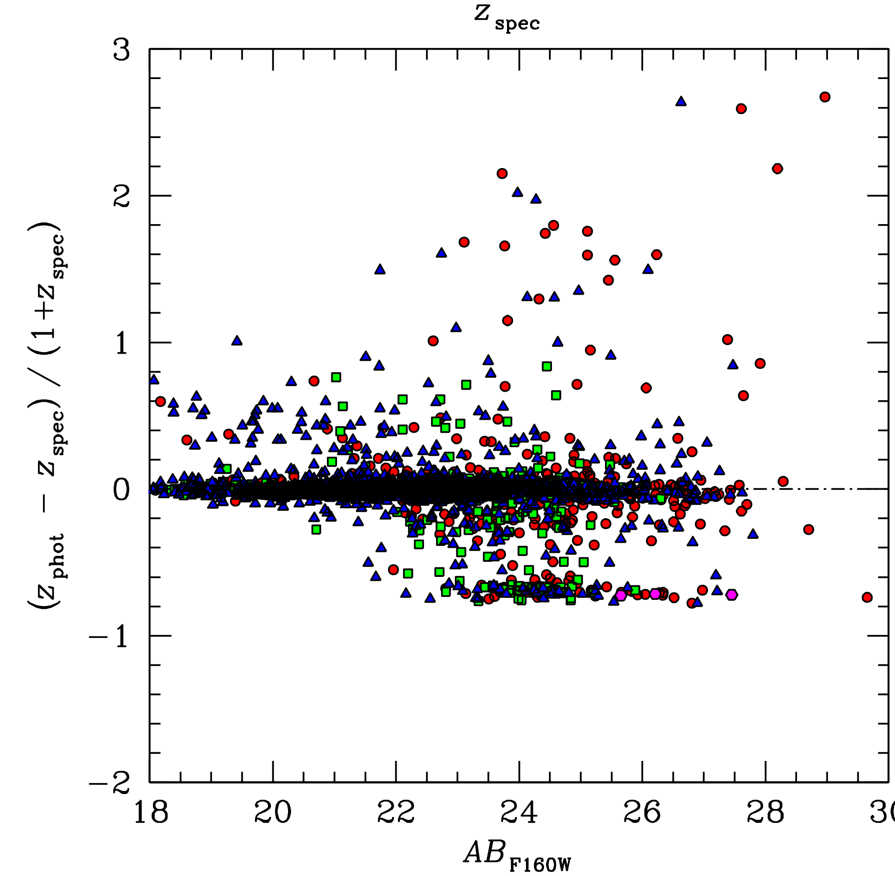
Skelton et al. (2014)

Uncertainties in photometric redshifts (I)

F160W detected objects in 3D-HST with
(1) updated z_{phot} using latest EASY code w/o z_{max}
(2) z_{spec} from our own literature searches

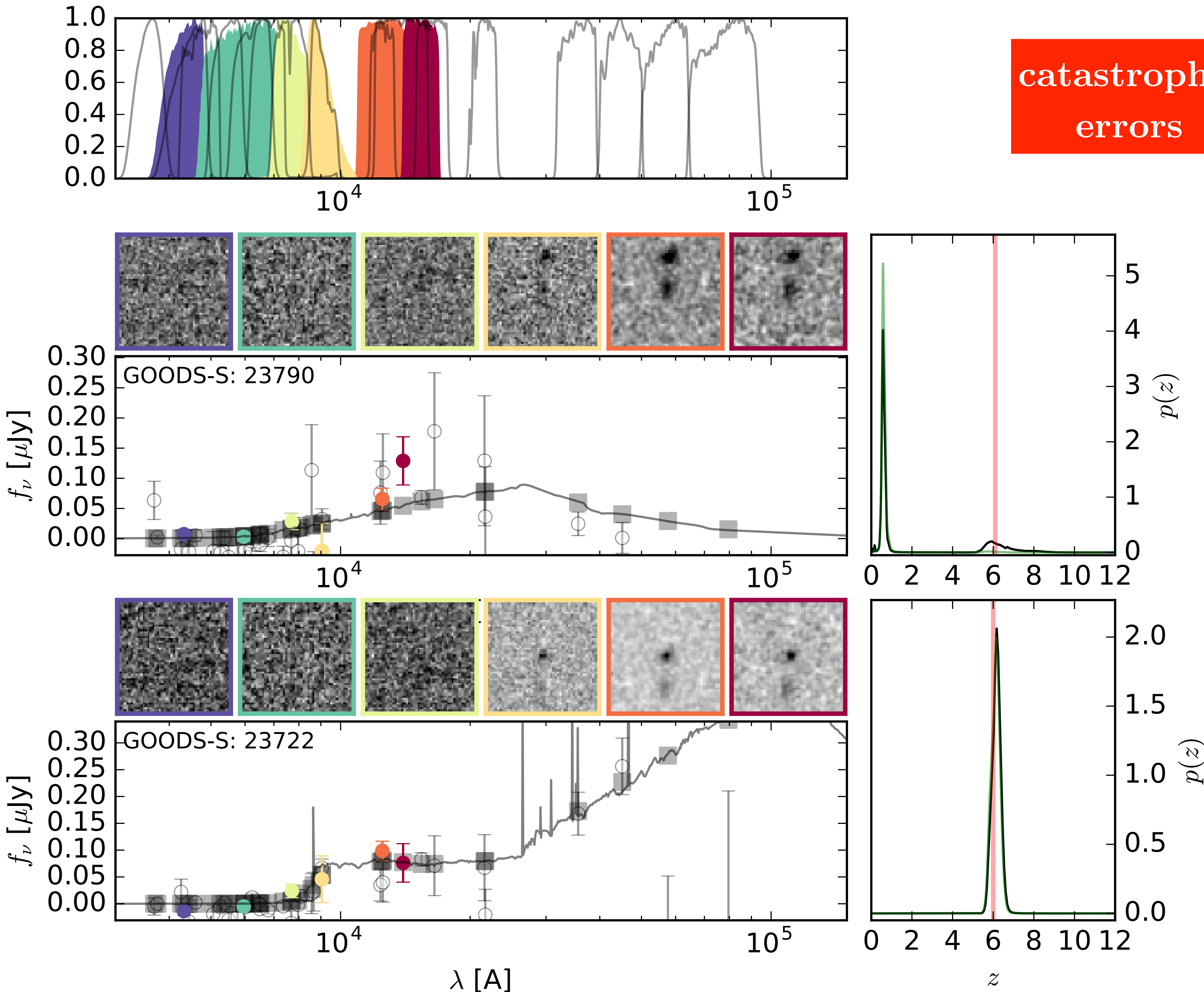




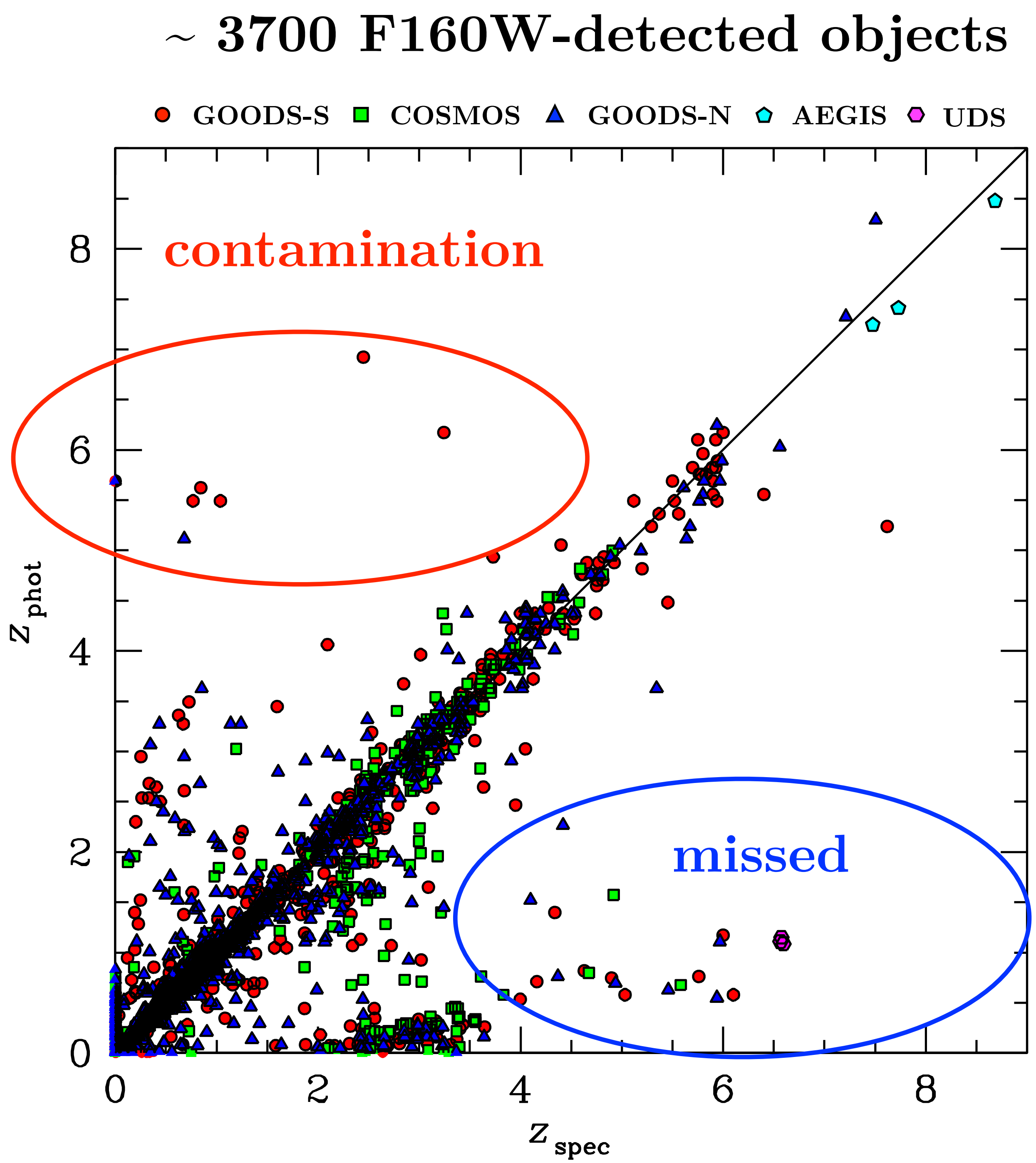


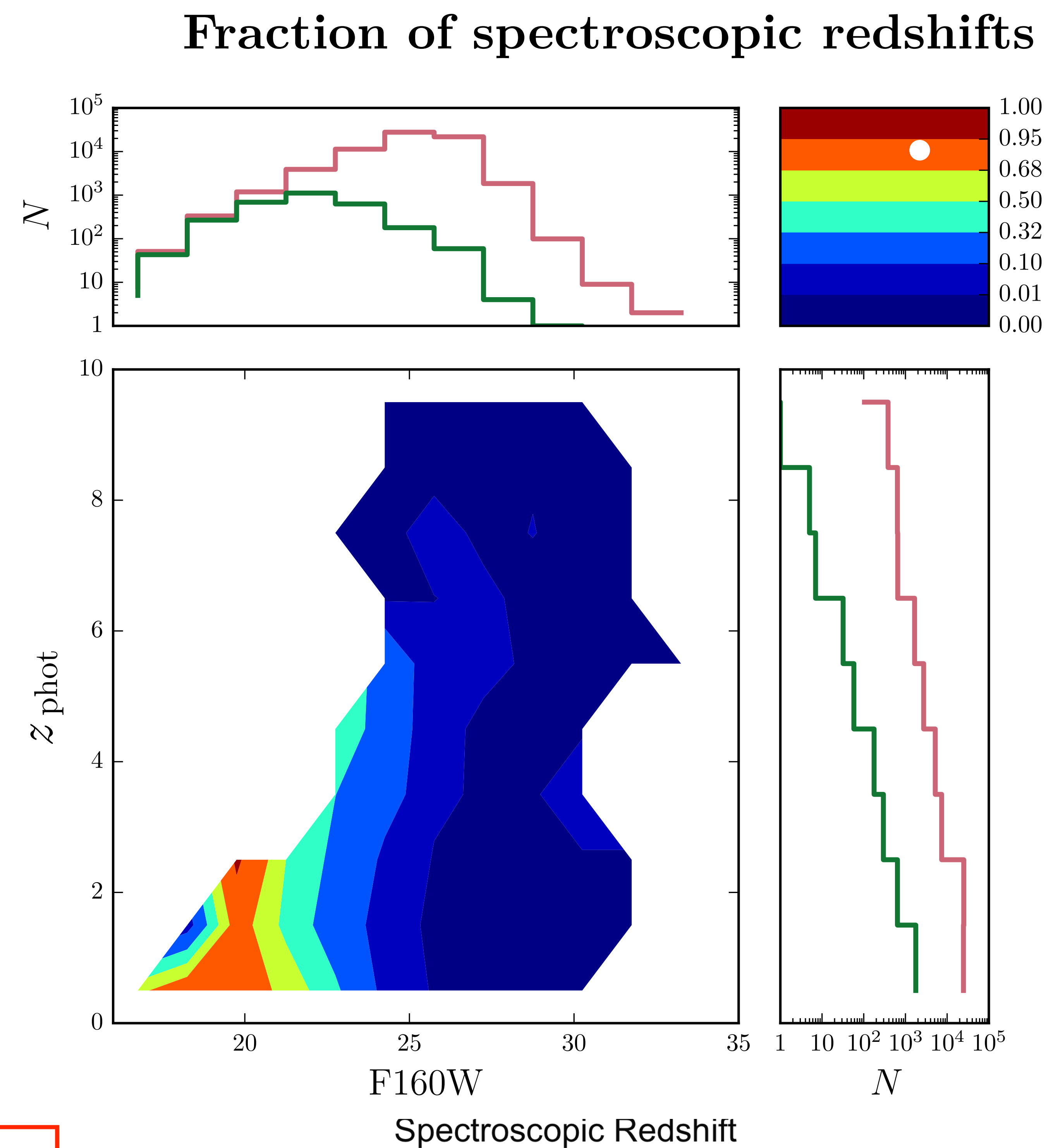
Uncertainties in photometric redshifts (I)

catastrophic errors



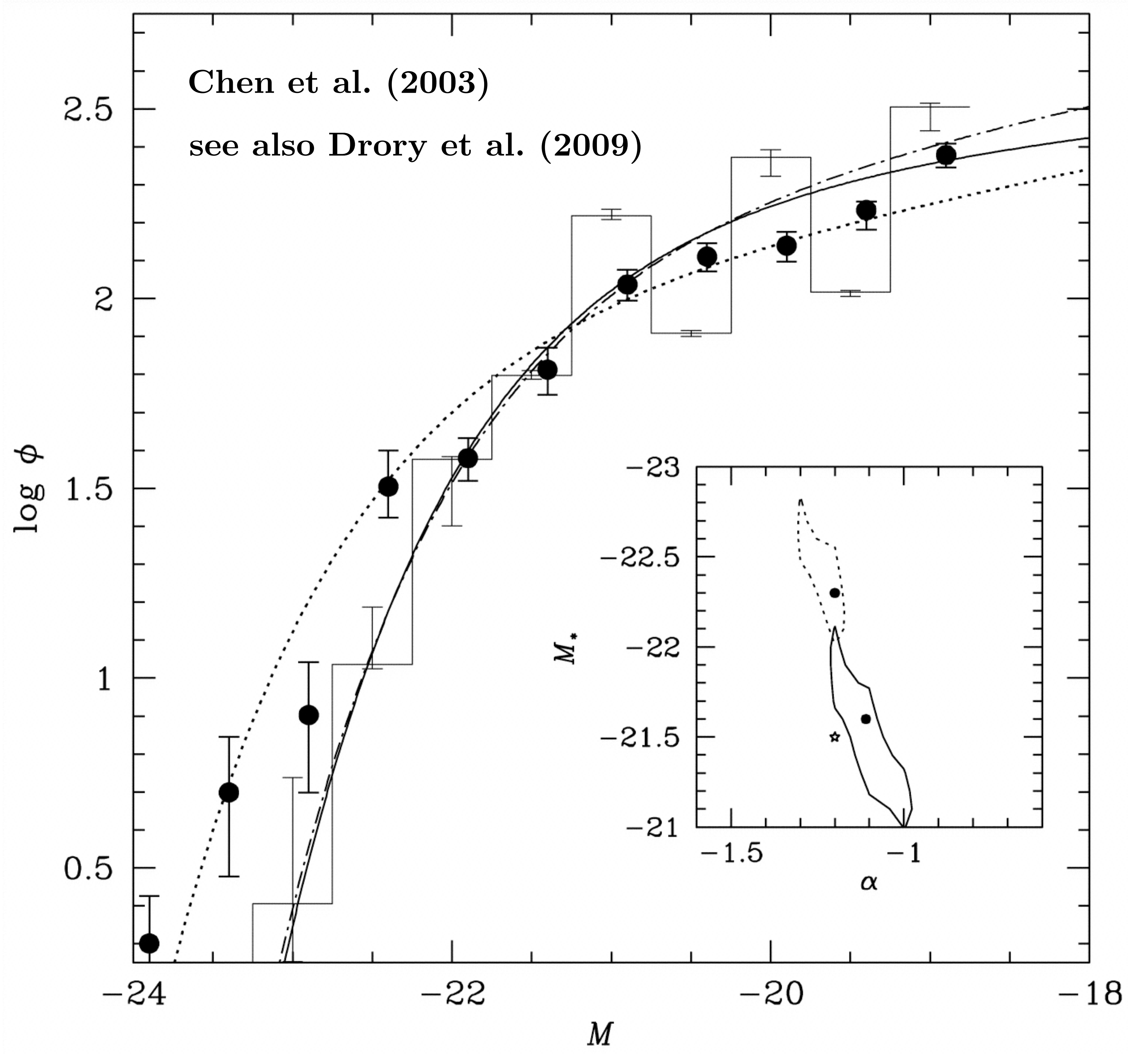
Uncertainties in photometric redshifts (I)





A highly incomplete and inhomogeneous spectroscopic sample!

Uncertainties in photometric redshifts (II)



systematic bias due to imprecise redshift

$$P_i(m_i, z_i | M_*, \alpha)$$

$$\propto \int_0^{z_f} 10^{0.4\,[M_* - M_i(m_i, z')](1+\alpha)}$$

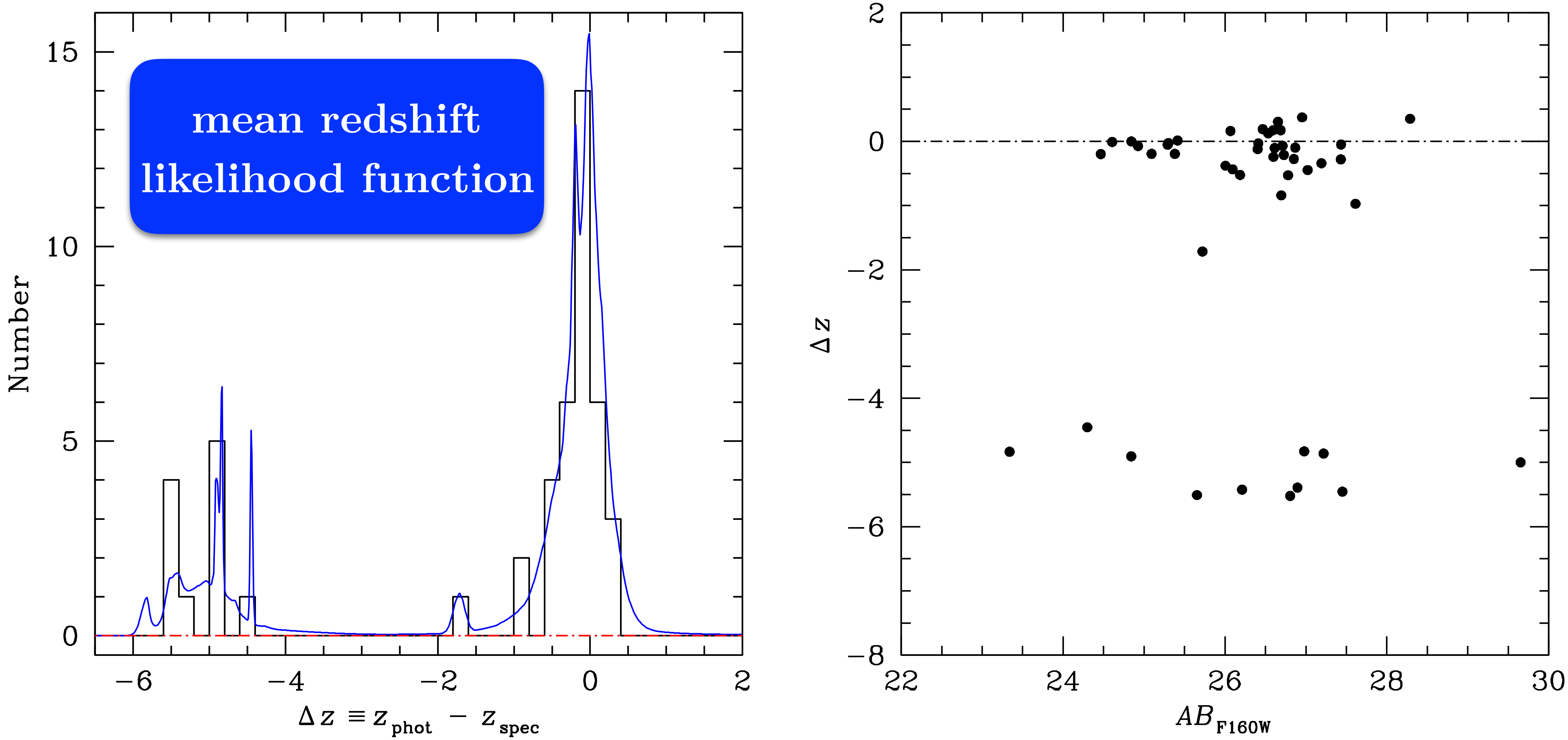
$$\times \exp(-10^{0.4\,[M_* - M_i(m_i, z')]})$$

$$\times\, p_i(z_i - z'; z_i)\, dz'$$

redshift error function

Uncertainties in photometric redshifts (II)

combined redshift error function using
~ 50 F160W-detected objects at $5 < z_{\rm spec} < 7$



redshift error function is similar to the mean redshift likelihood function but with an underestimated missed fraction

Summary

- High-z galaxy samples selected based on fixed color/photo-z cuts may have missed a significant fraction of the high-z population
- Uncertainties in photometric redshifts are expected to result in flattening in the luminous end of the galaxy luminosity
- A uniform spectroscopic survey of galaxies at $z > 6$ is needed and critical for calibrating and characterizing photometric redshift errors