Star Formation Rate Density at z>3

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(UC Santa Cruz / Leiden)

“From First Light to Star Formation”
Tucson, Arizona
March 16, 2010

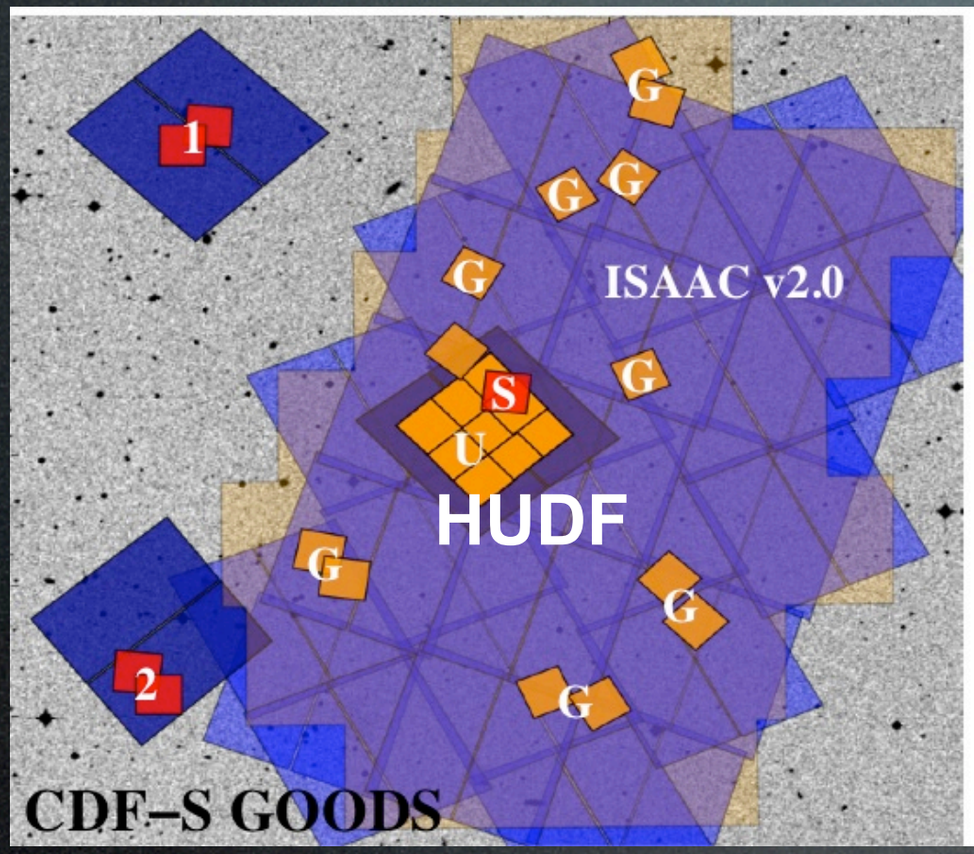
Deriving SFR densities:

UV Contribution

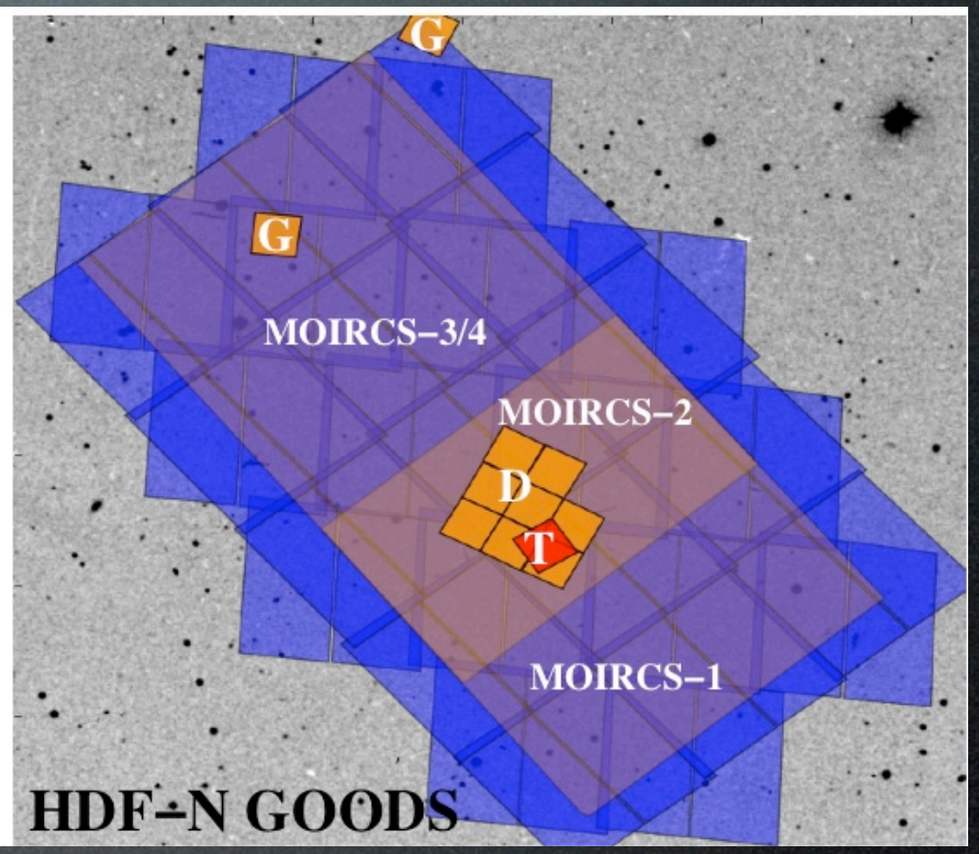
IR (Dust-Reprocessed) Contribution

UV Contribution

We have tremendous amounts of information on z>2 galaxies in the UV...

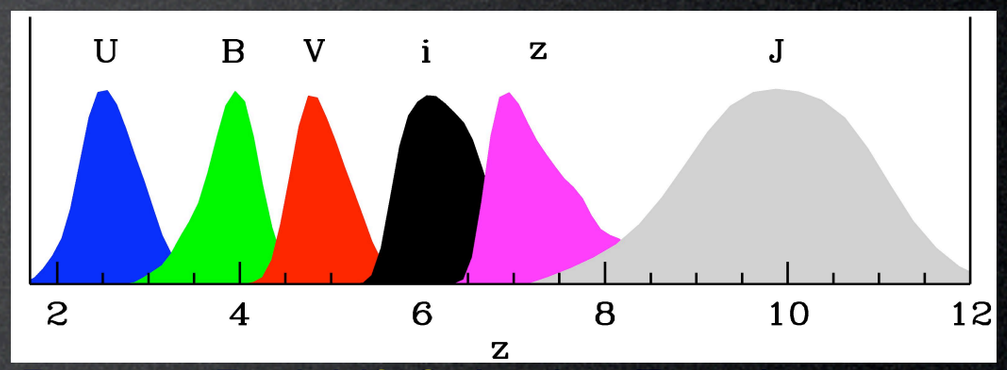


CDF-S GOODS



HDF-N GOODS

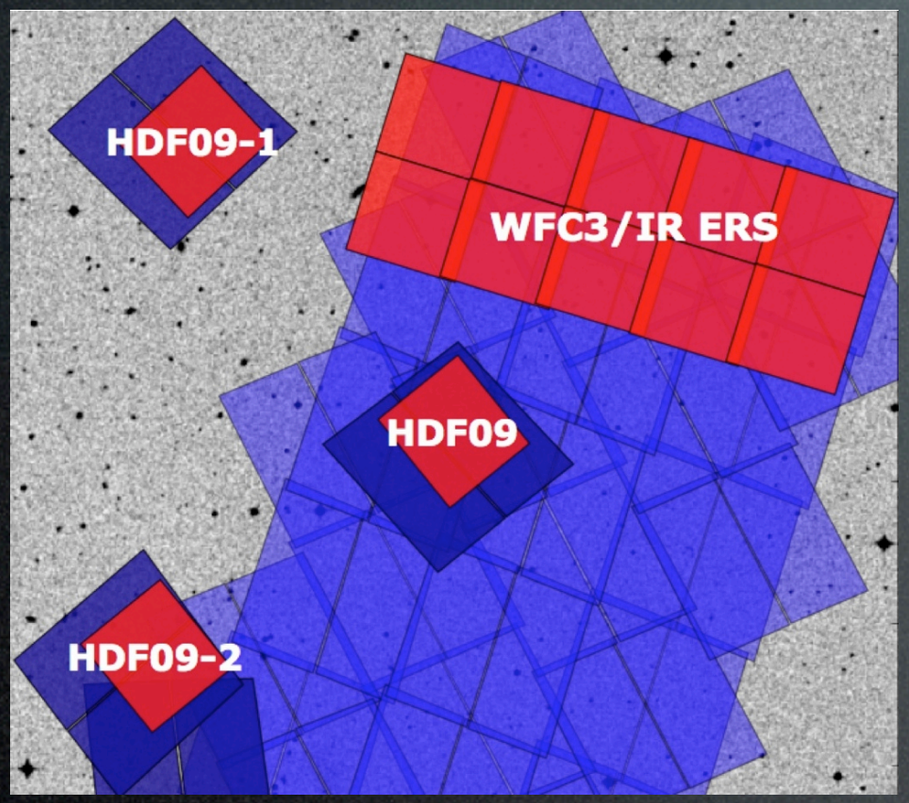
4671 z~4 B-dropouts
1416 z~5 V-dropouts
627 *z*~6 *i-dropouts*

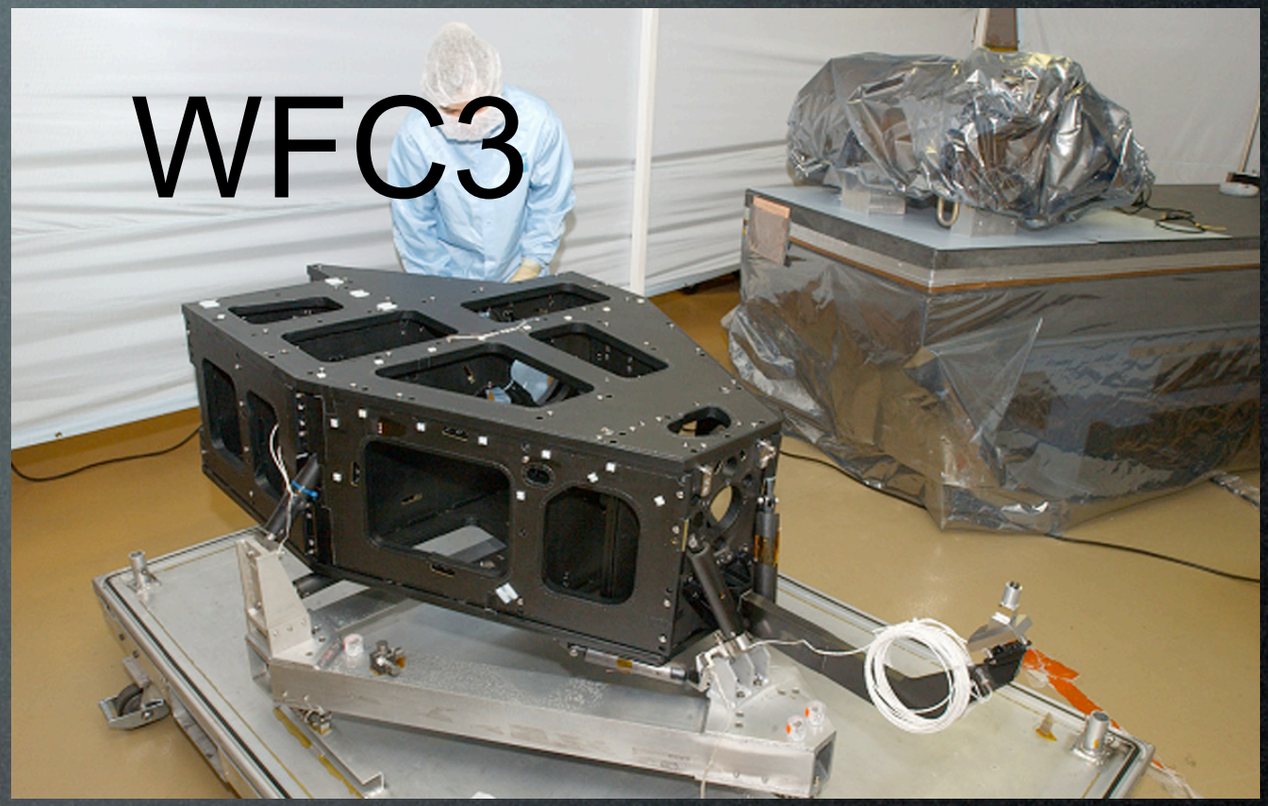


Dropout Redshift Selection Functions

And more recently information on z~7-8 galaxies from WFC3/IR

HST GOODS + HUDF



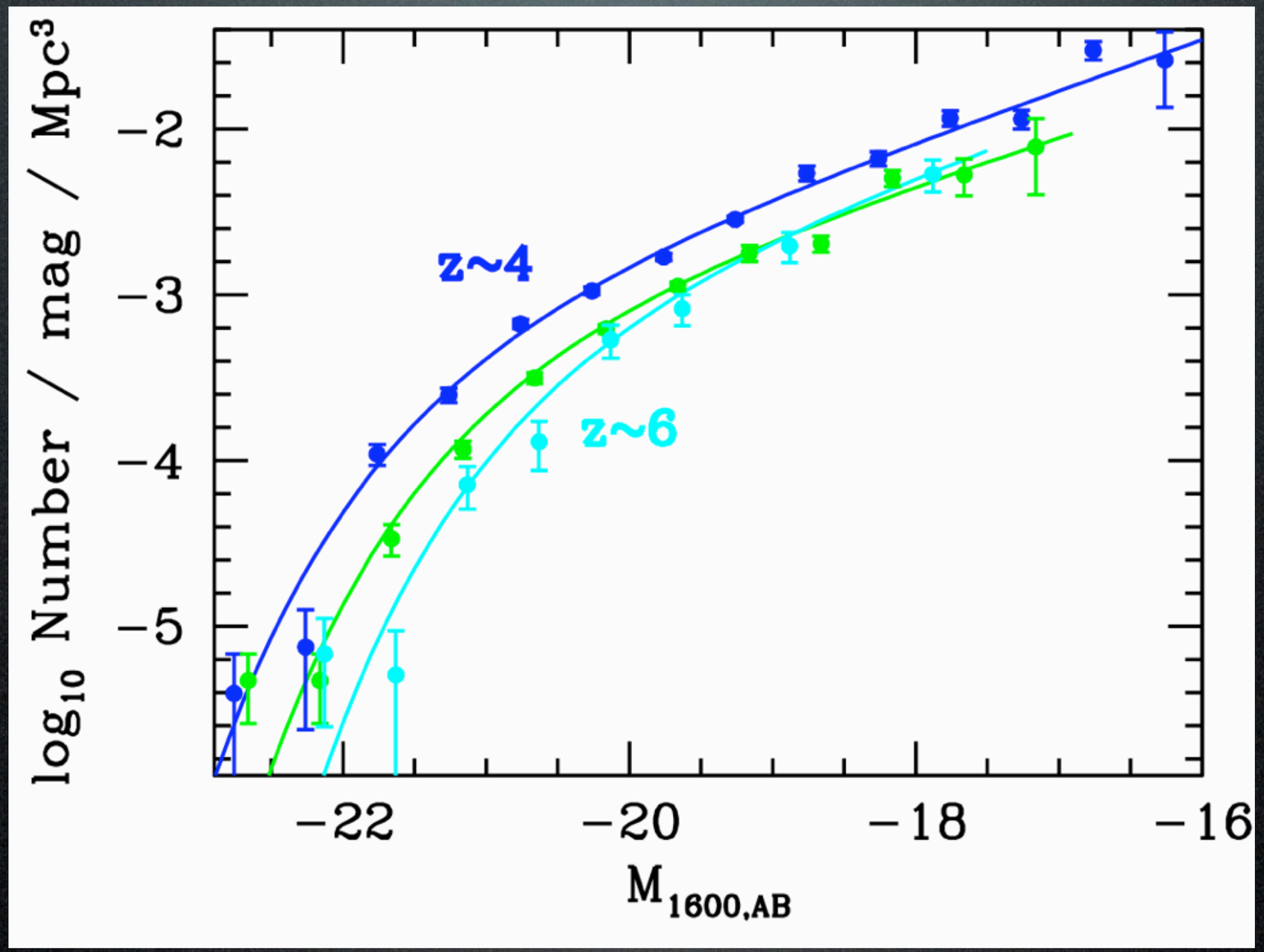


65+ z~7 z-dropouts
35+ z~8 Y-dropouts

Establish UV contribution from Luminosity Functions

Deep HST ACS data allow us to establish LFs at z~4-6

UV Luminosity Functions



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

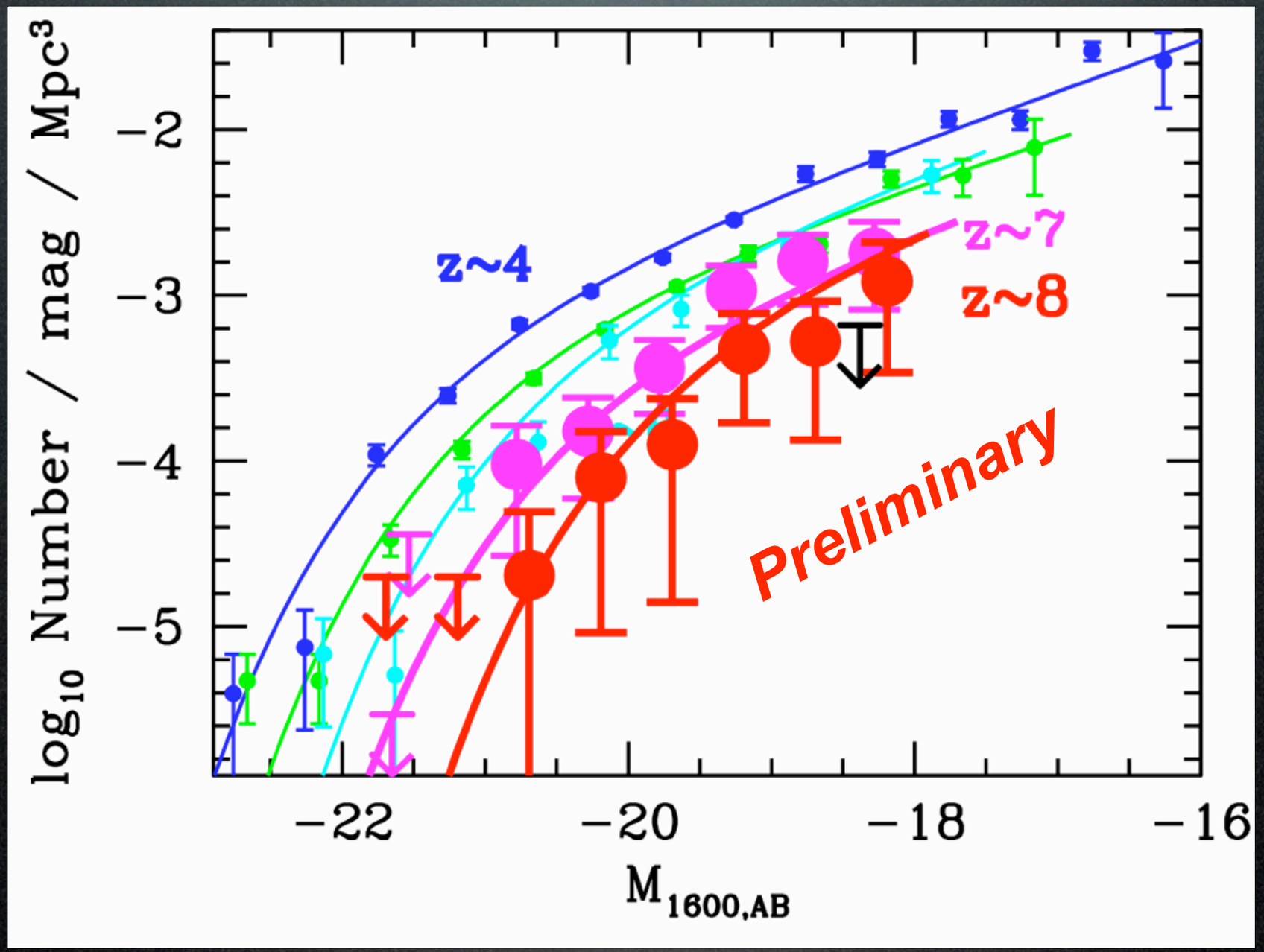
Bright

Faint

Bouwens et al. 2010

WFC3/IR allows us to extend to z~7-8 with great statistics

UV Luminosity Functions



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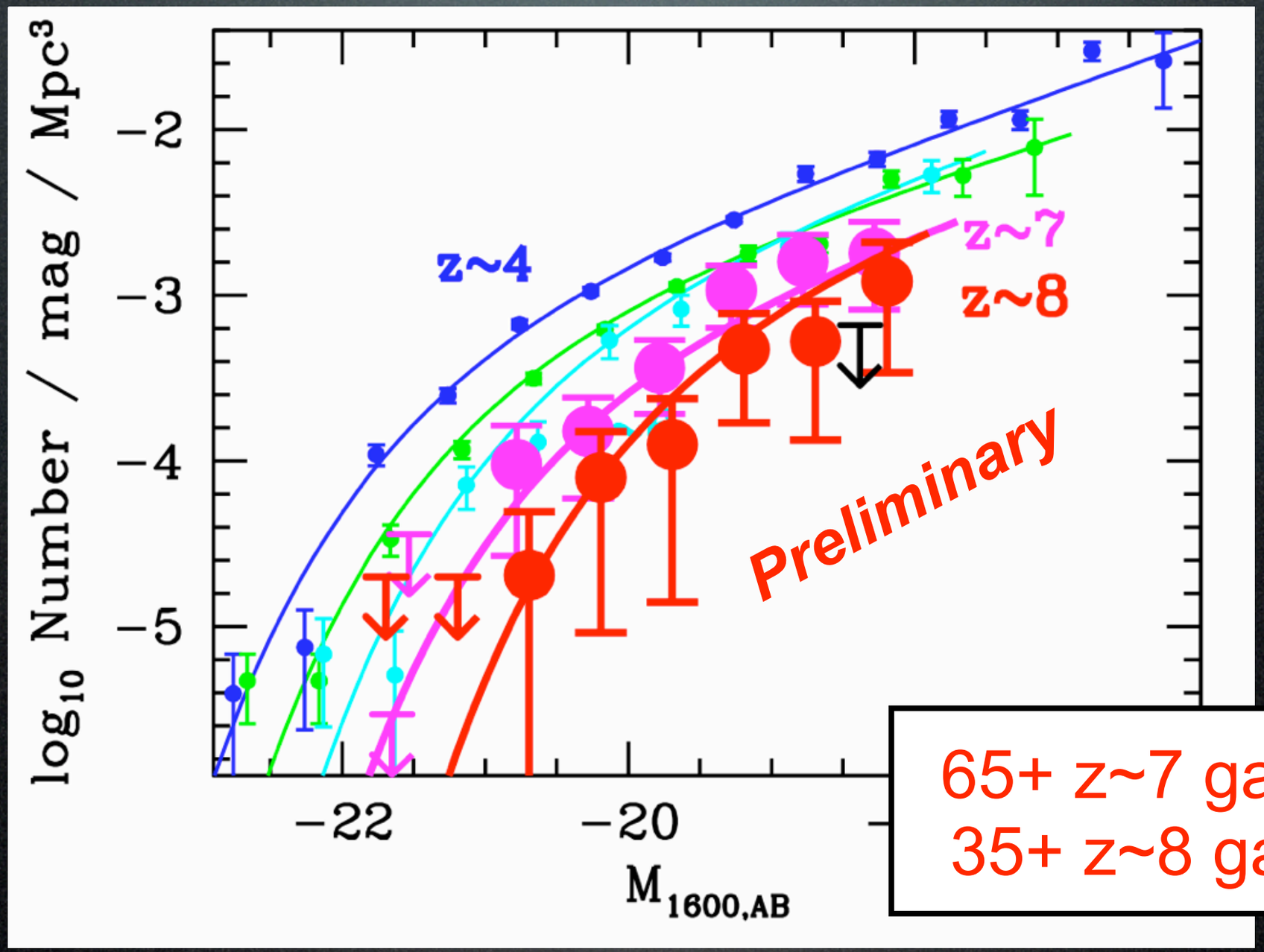


Log # mag^{-1} Mpc^{-3}

65+ z~7 galaxies,
35+ z~8 galaxies

Bright

Faint

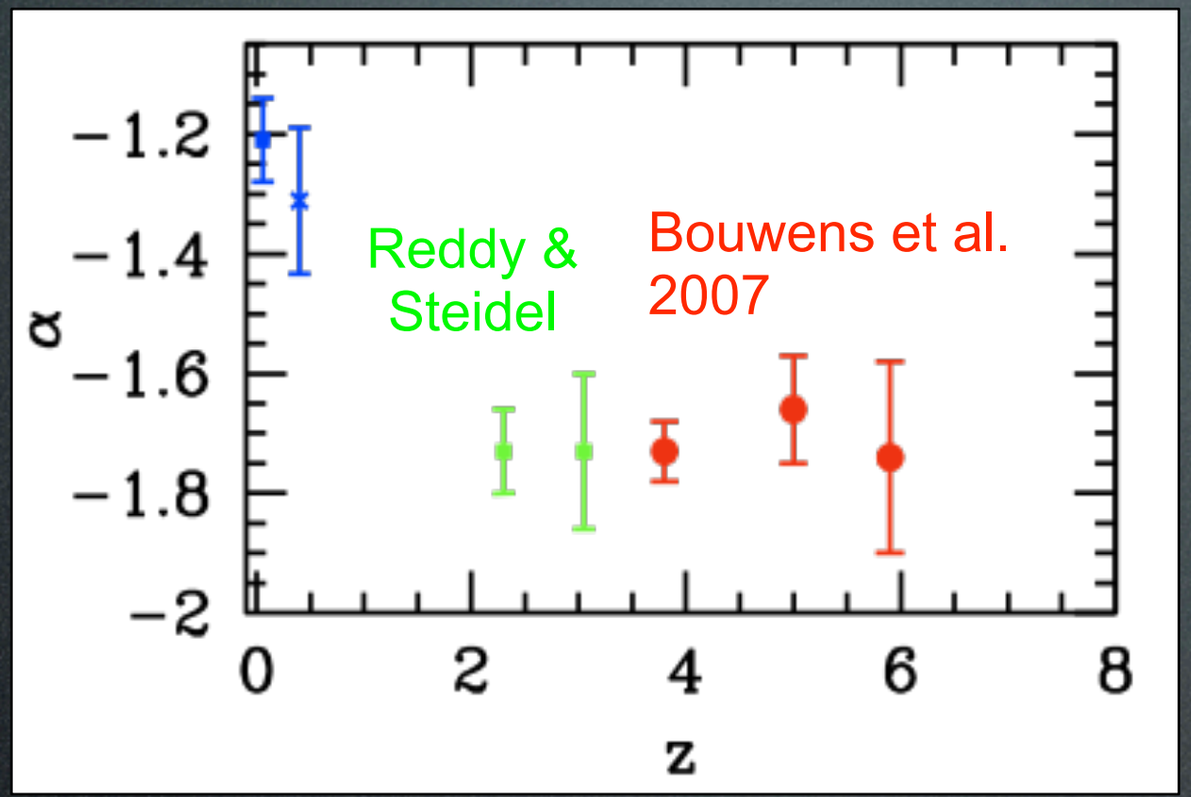
Bouwens et al. 2010

Faint-end Slope of the UV Luminosity Function

Shallow

Faint-end Slope

Steep



Bouwens et al. 2007; Reddy & Steidel 2009

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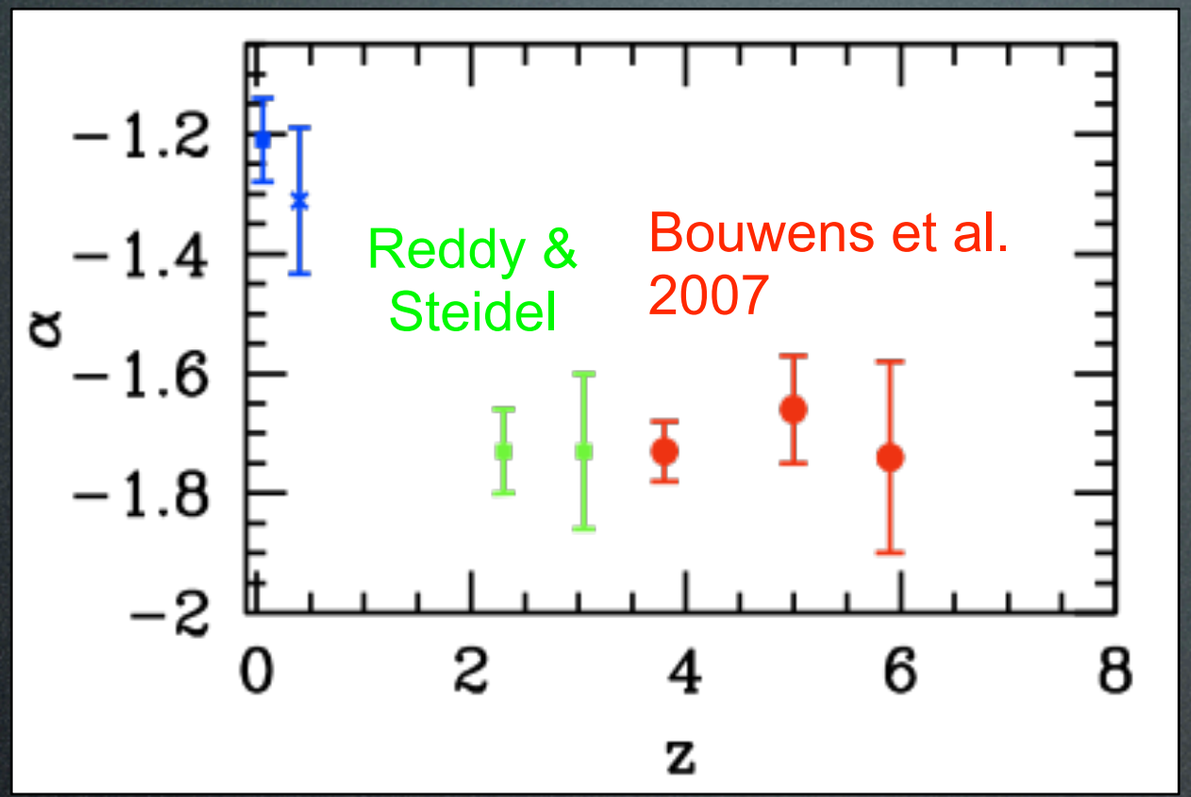
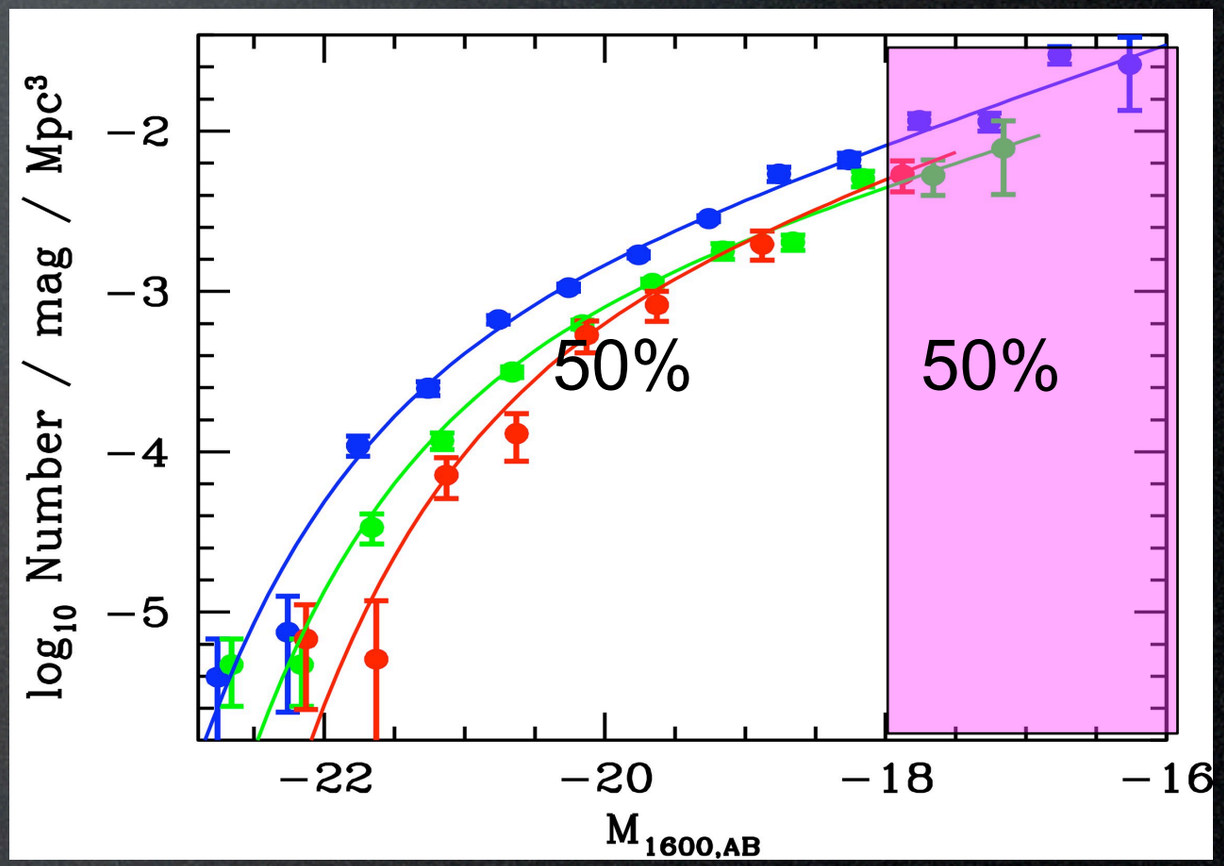


Fraction of light in lower luminosity galaxies is substantial:

50% of the UV luminosity density is faintward of 0.06 L*

Bouwens et al. 2007; Reddy & Steidel 2009



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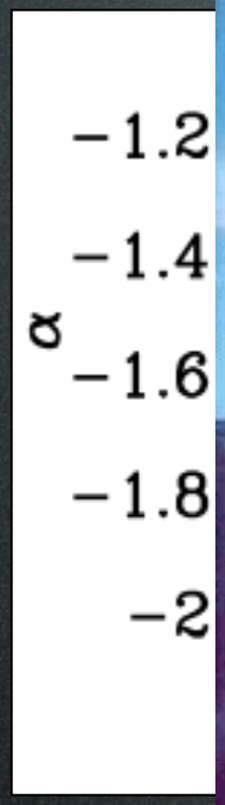

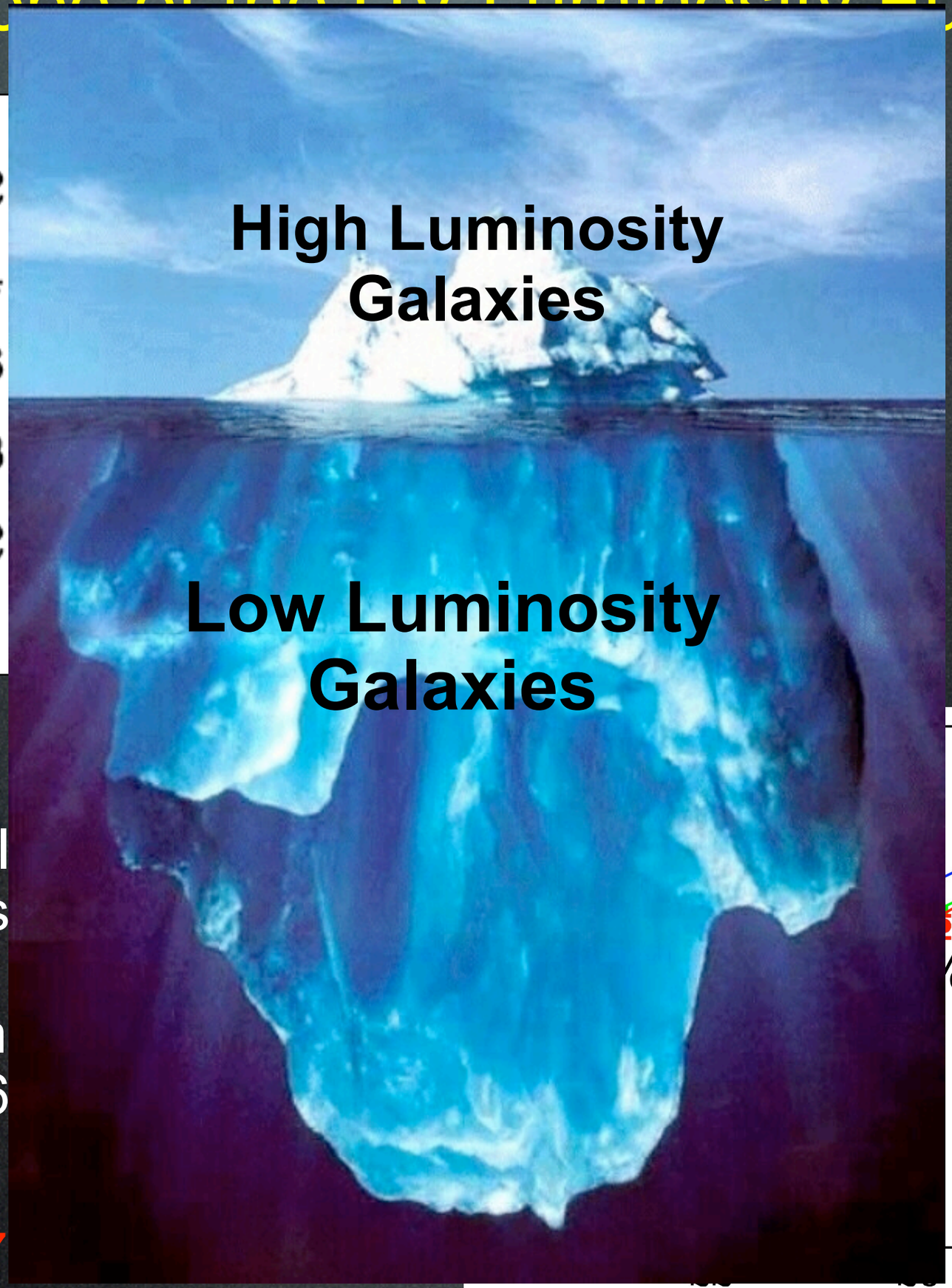

Fraction of light in l
luminosity galaxies

50% of the UV lum
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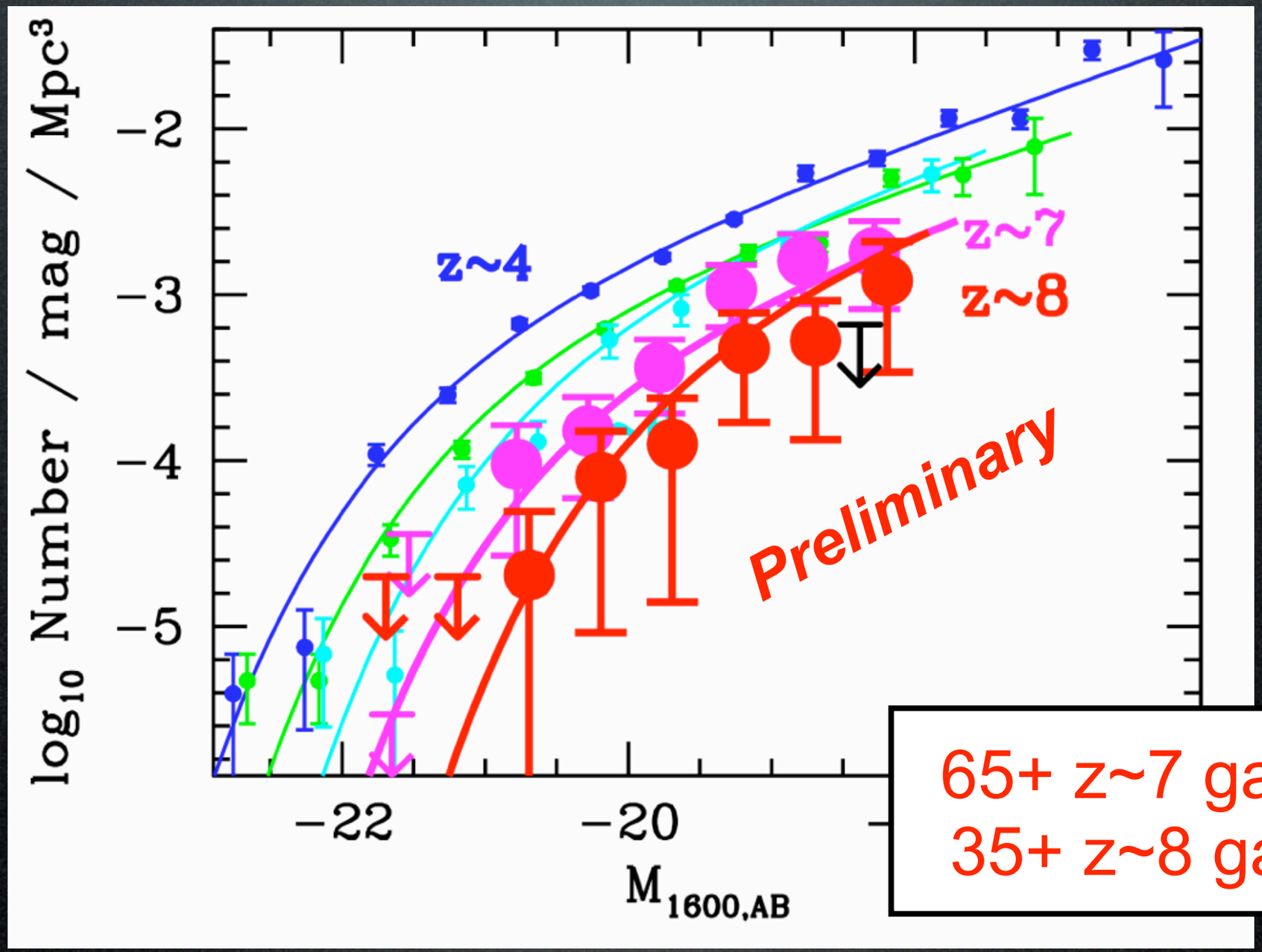
Bouwens et al. 2007
Steidel 2009

Other primary conclusion regards the overall rate of evolution in LF in vol density + luminosity

UV Luminosity Functions



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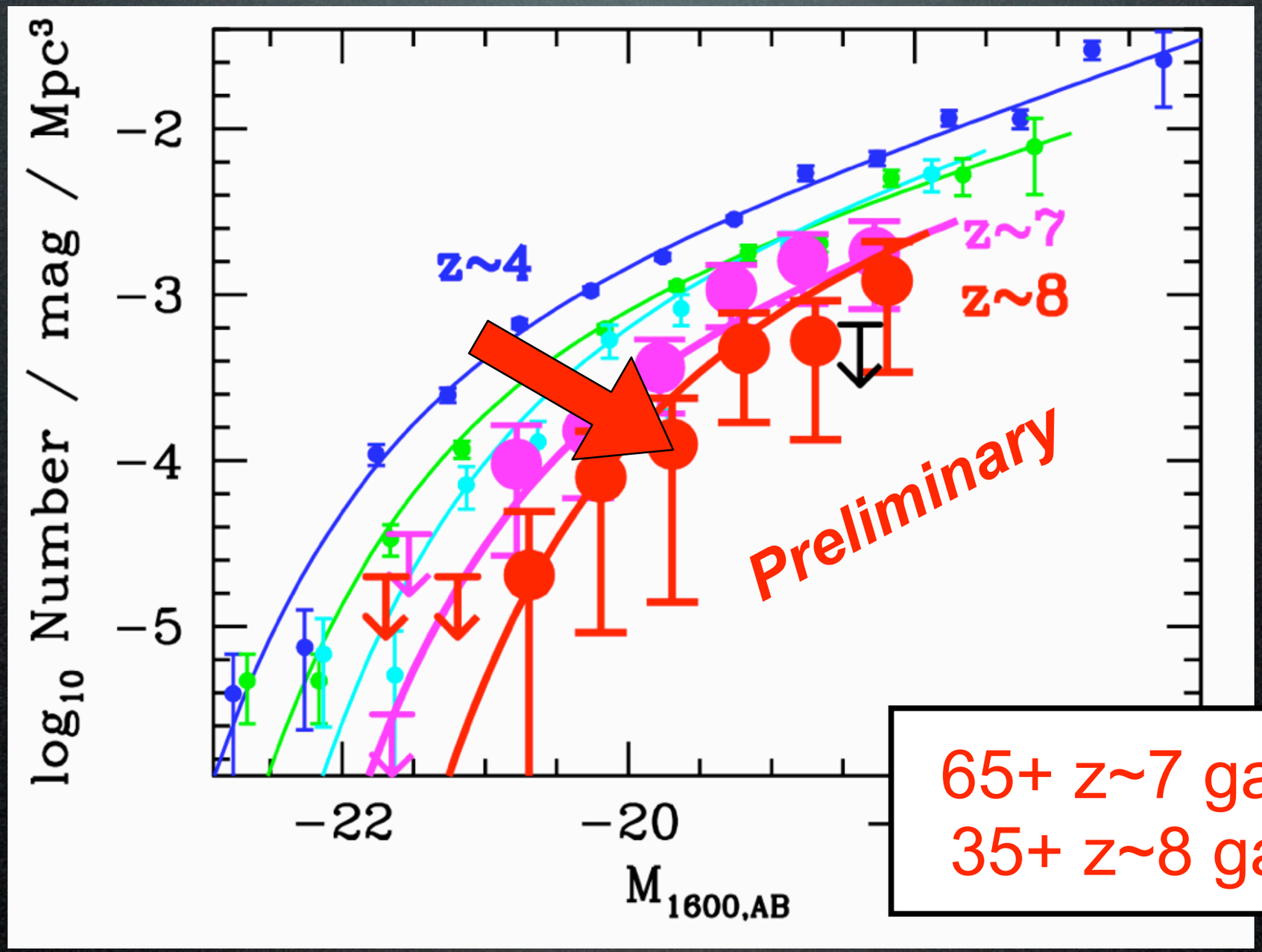

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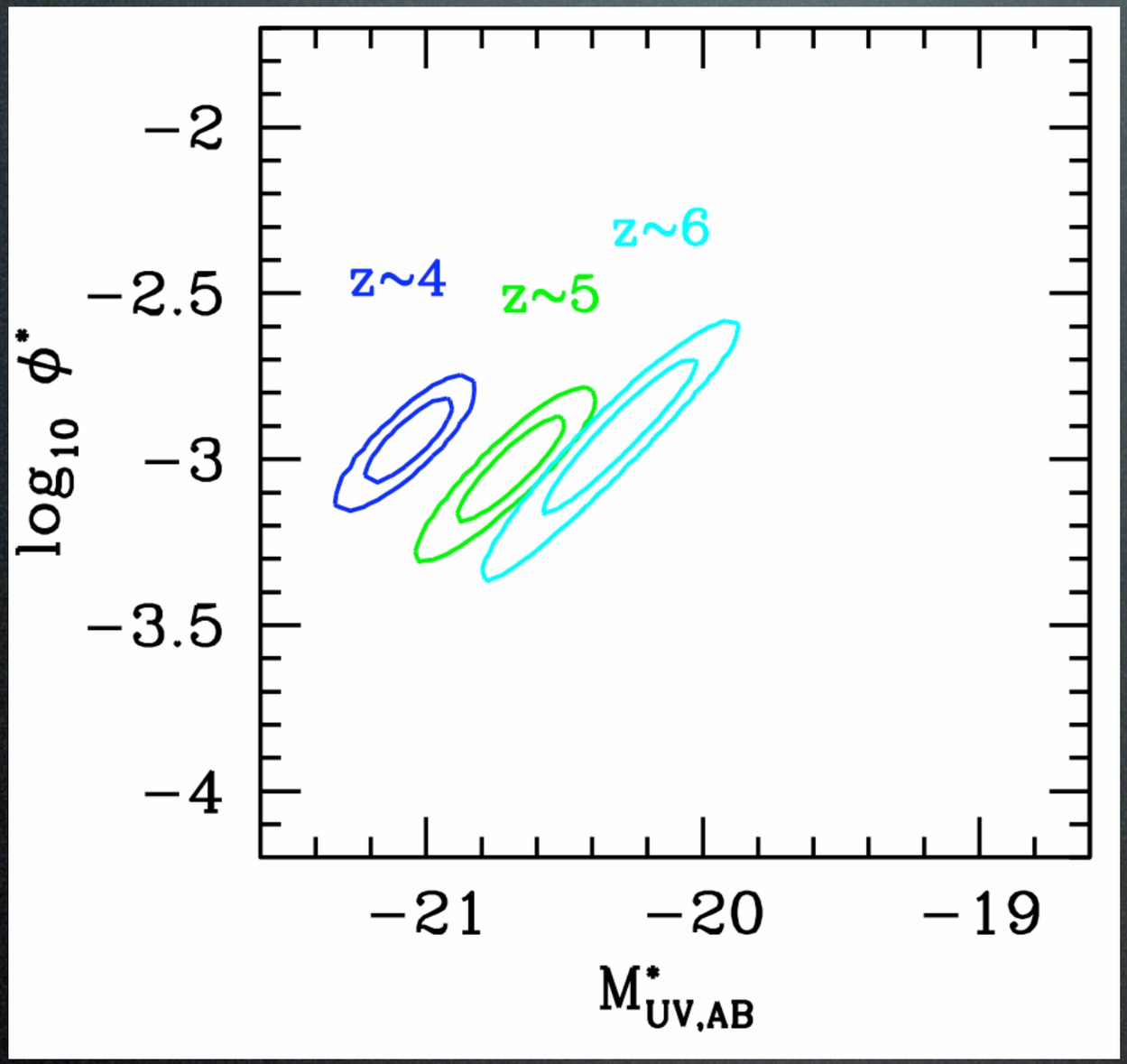

68% and 95% confidence intervals

ϕ*

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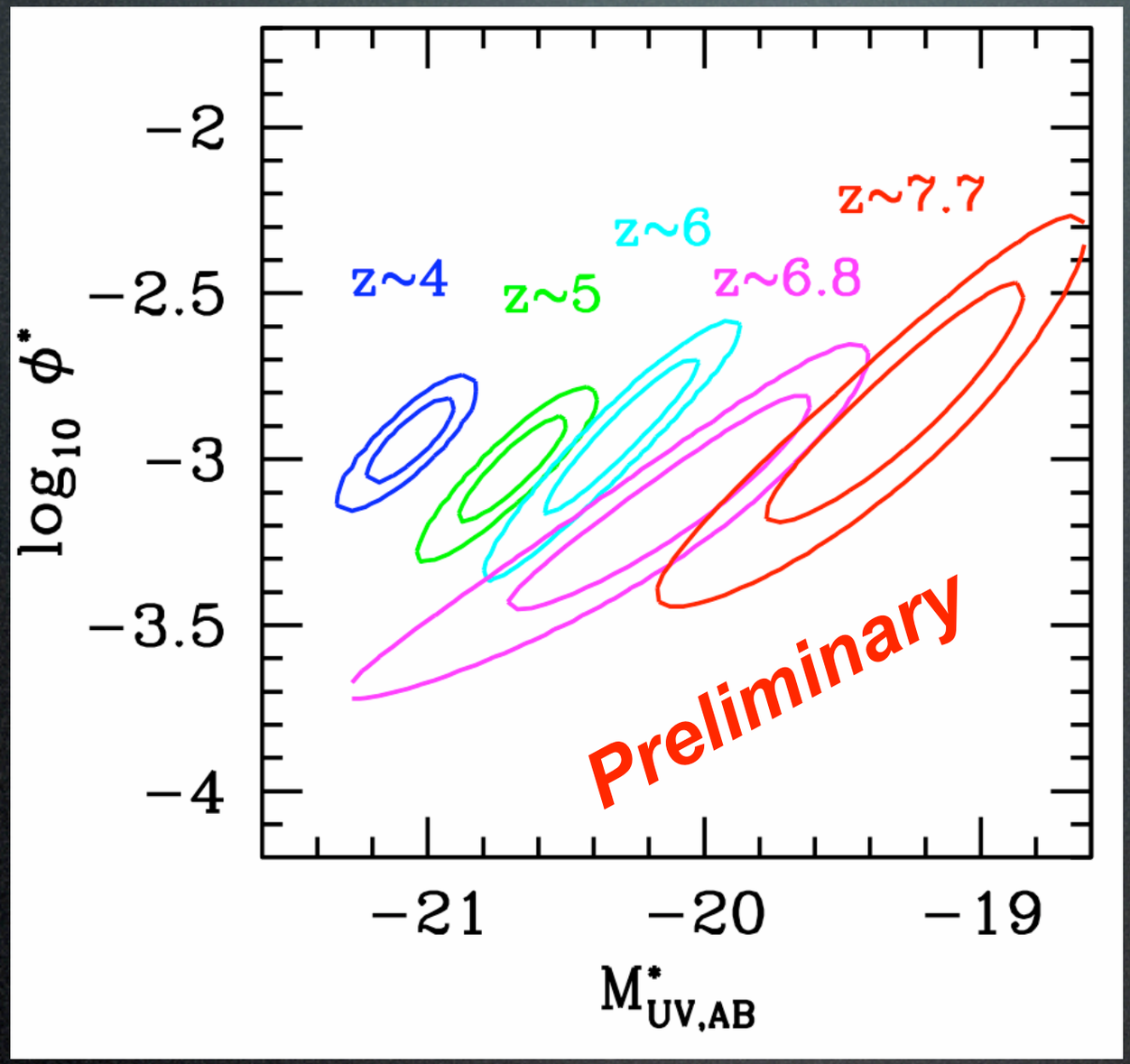

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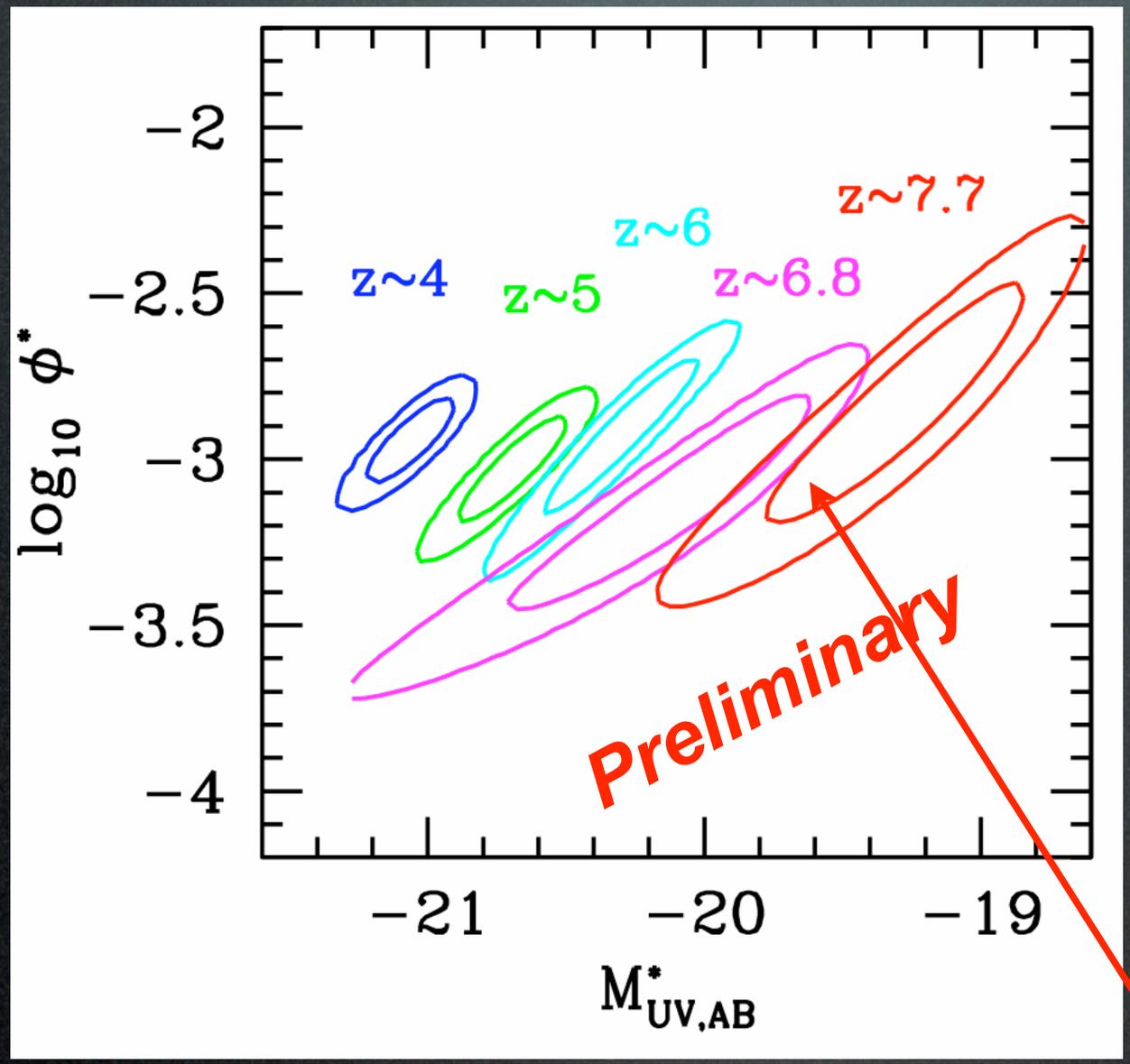

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Assuming that α=-1.7

Bouwens et al. 2010

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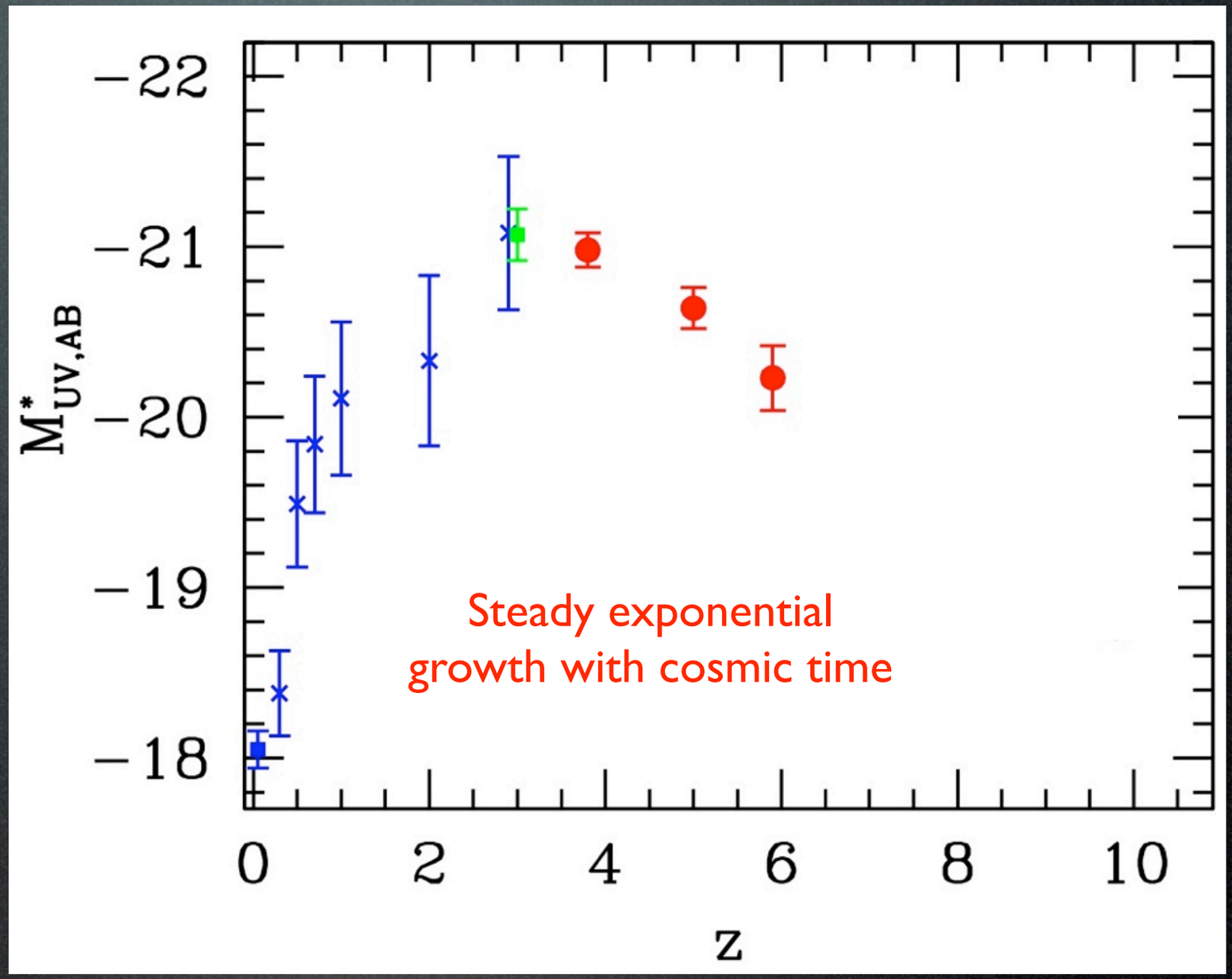
Parametrize evolution of LF in terms of M*
(for simplicity)



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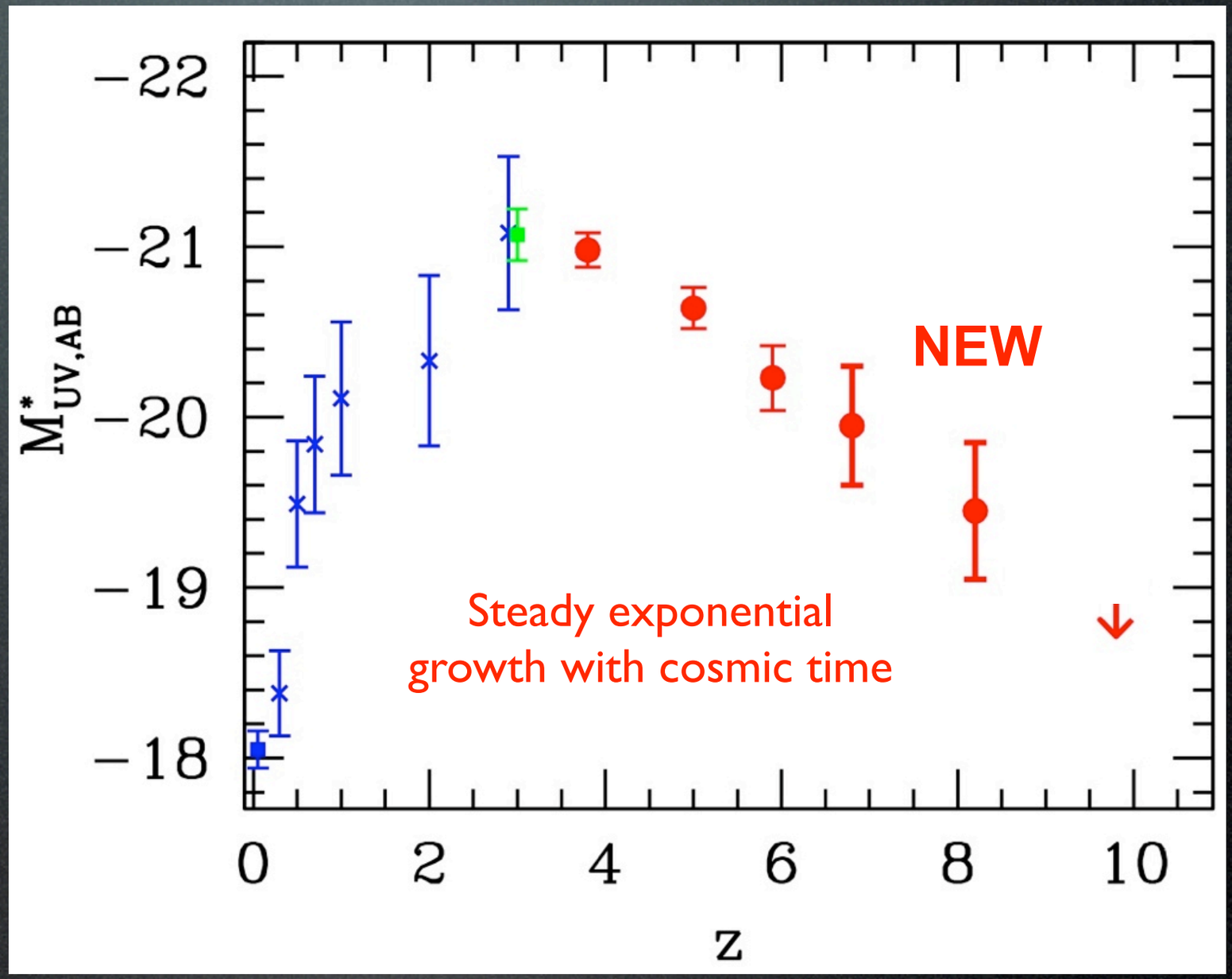

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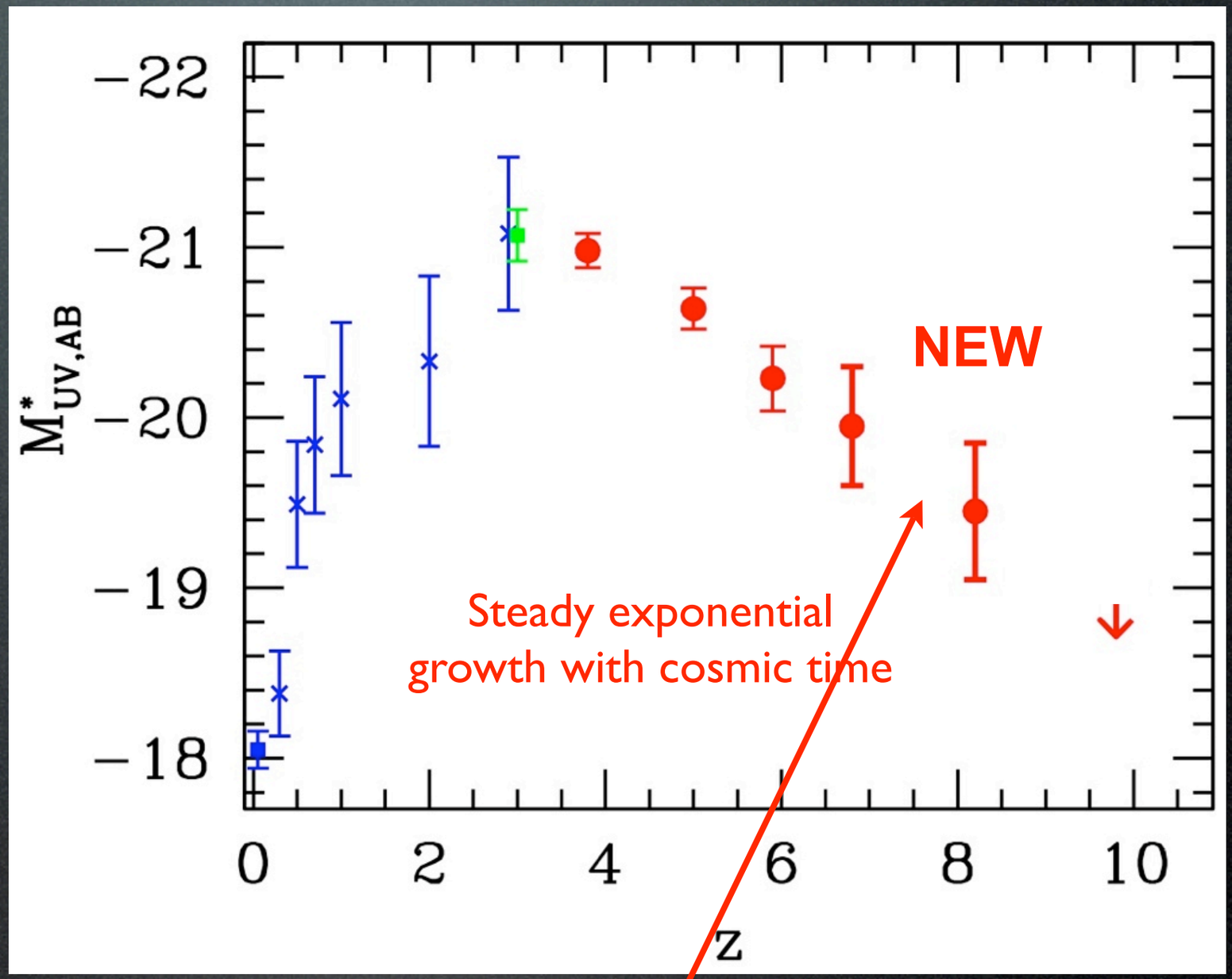

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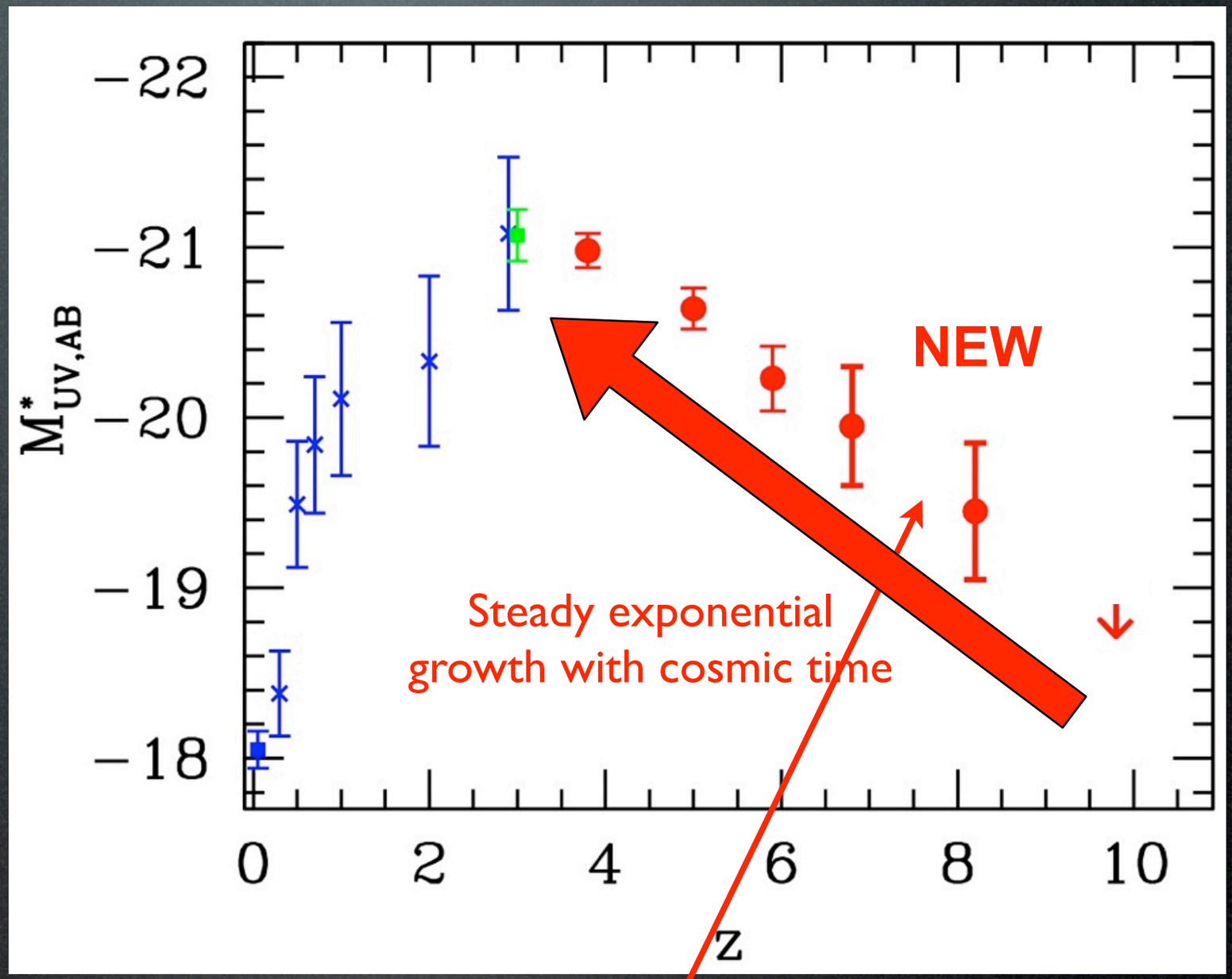

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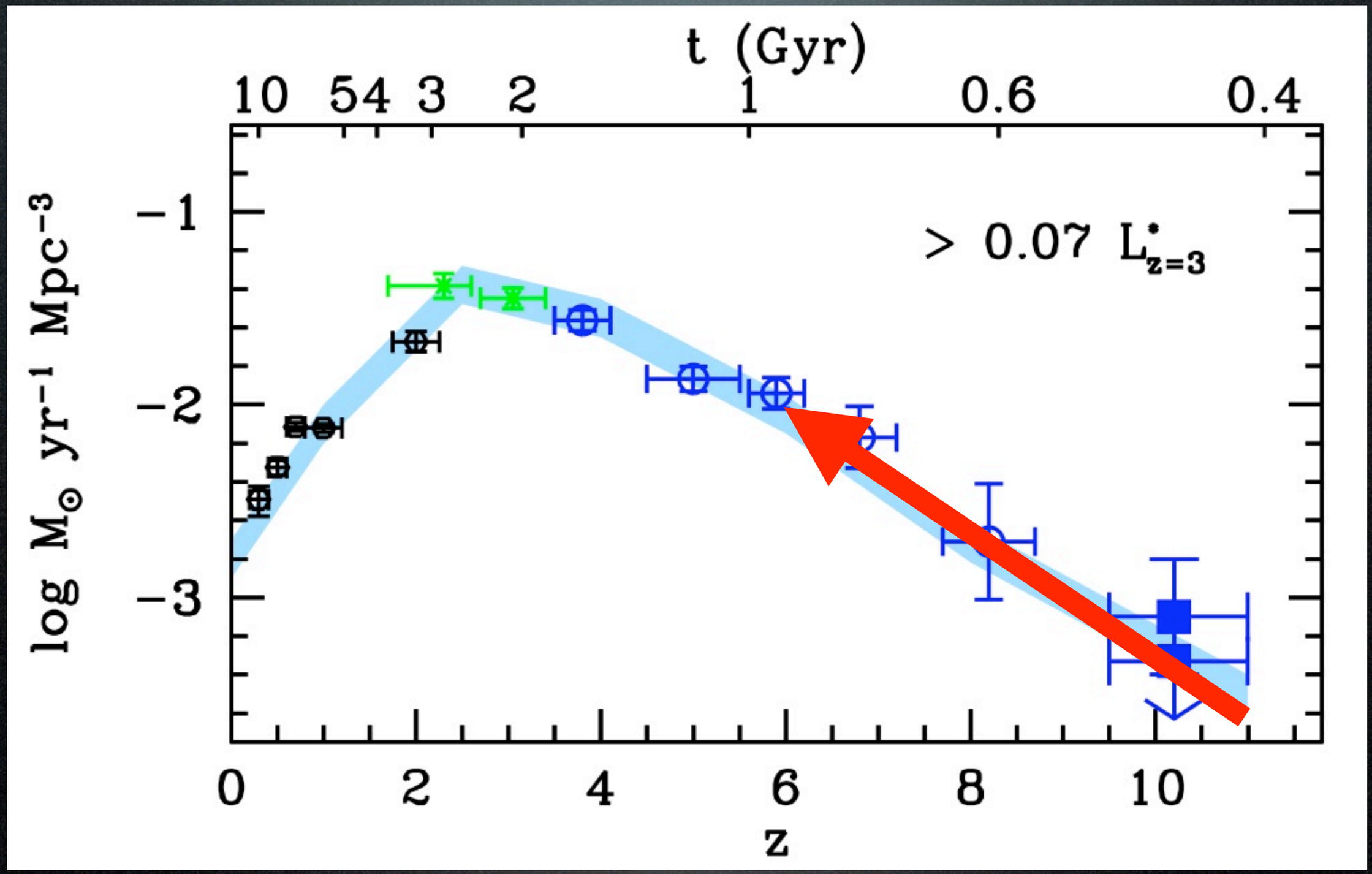
Integrate the UV LFs at z~7 and z~8, one derives the SFR density



But what about the SFR density hidden by dust?

How do we estimate effect of dust extinction?

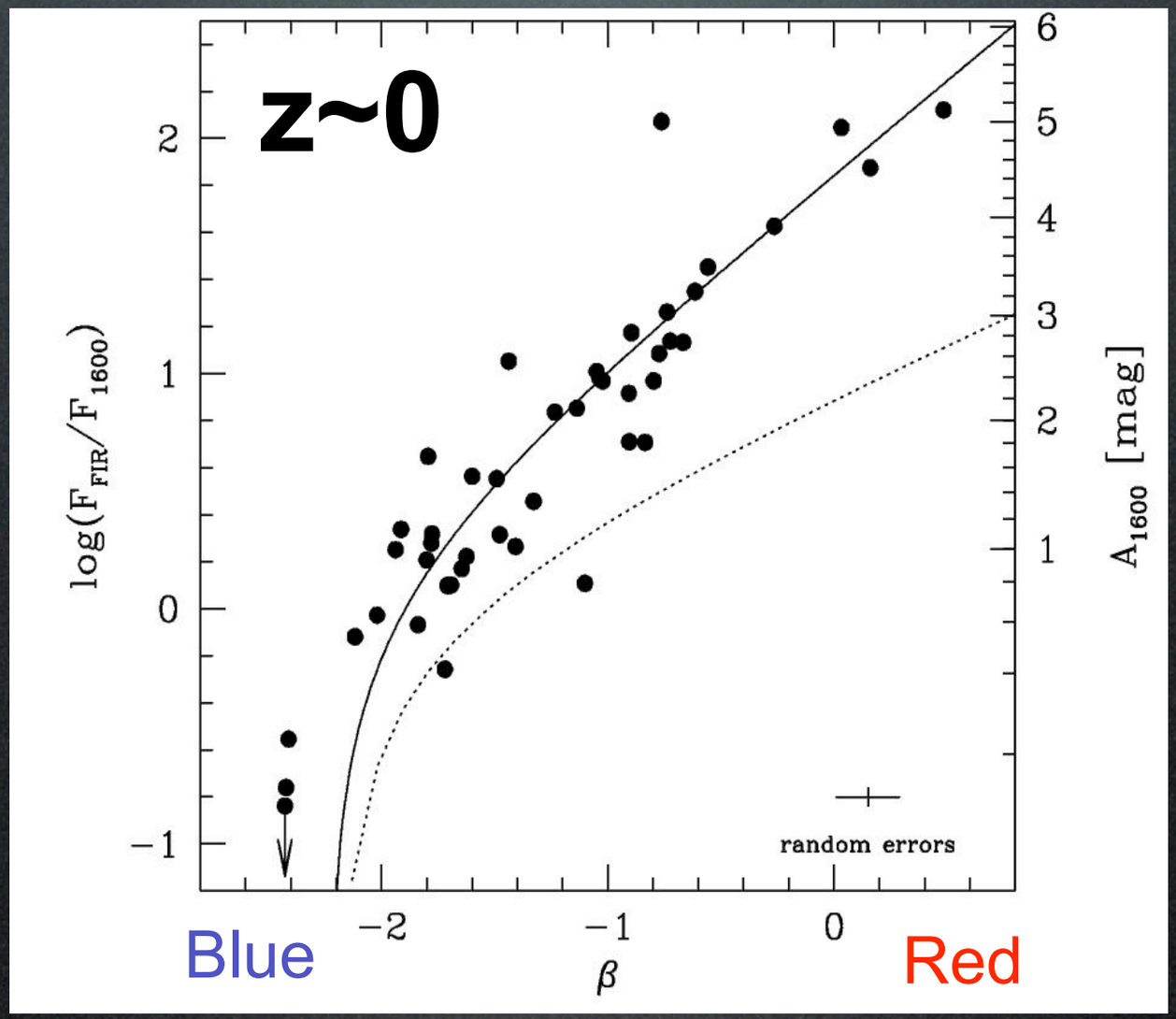
1. Estimate dust extinction in LBG population using Meurer et al. 1999 IRX-beta relation

Correction Factor (Meurer et al. 1999)

Most Light Absorbed By Dust First →

Infrared Light / UV Light

Most Light Escapes Without Absorption →



UV continuum slope (β)

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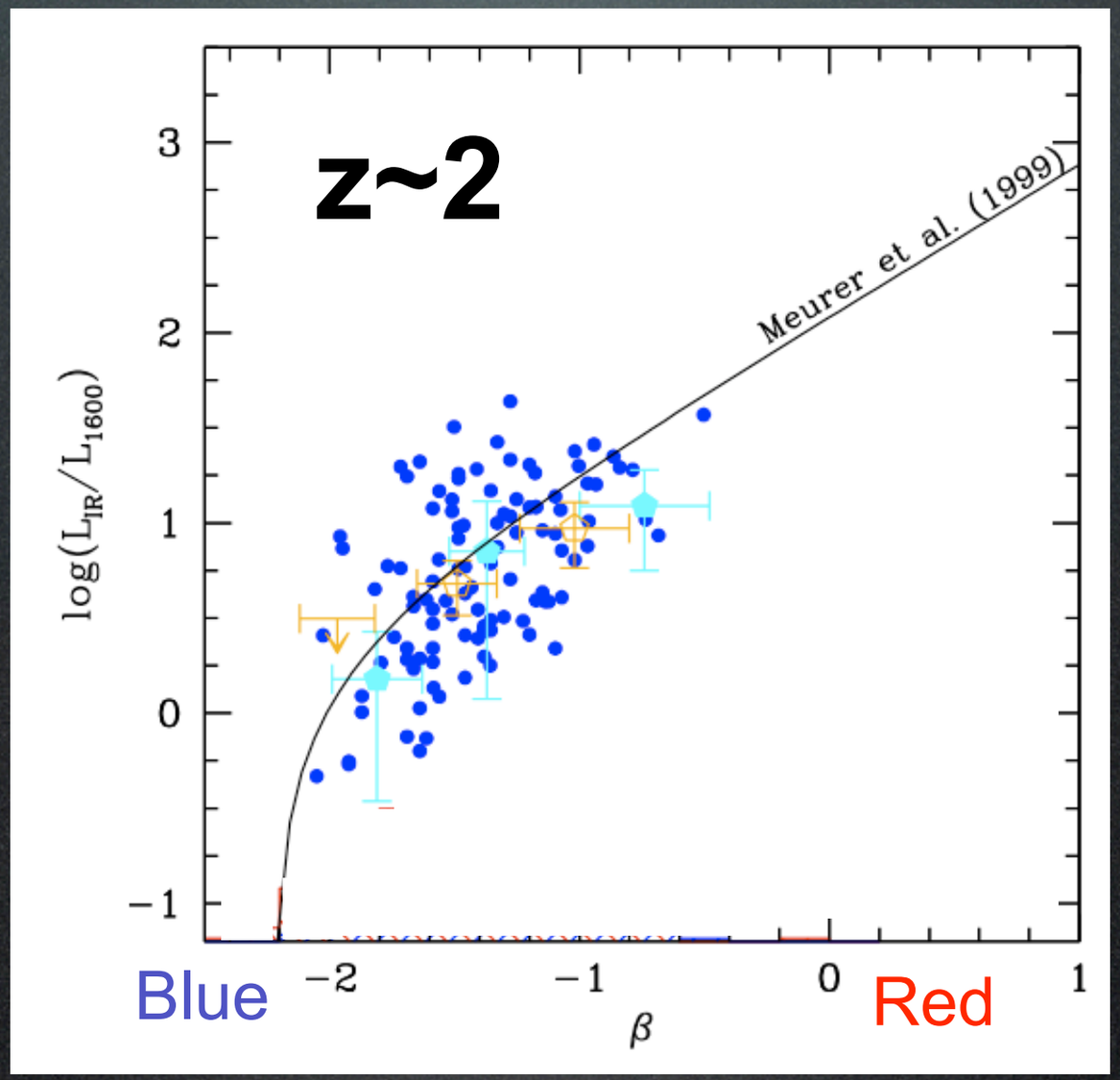
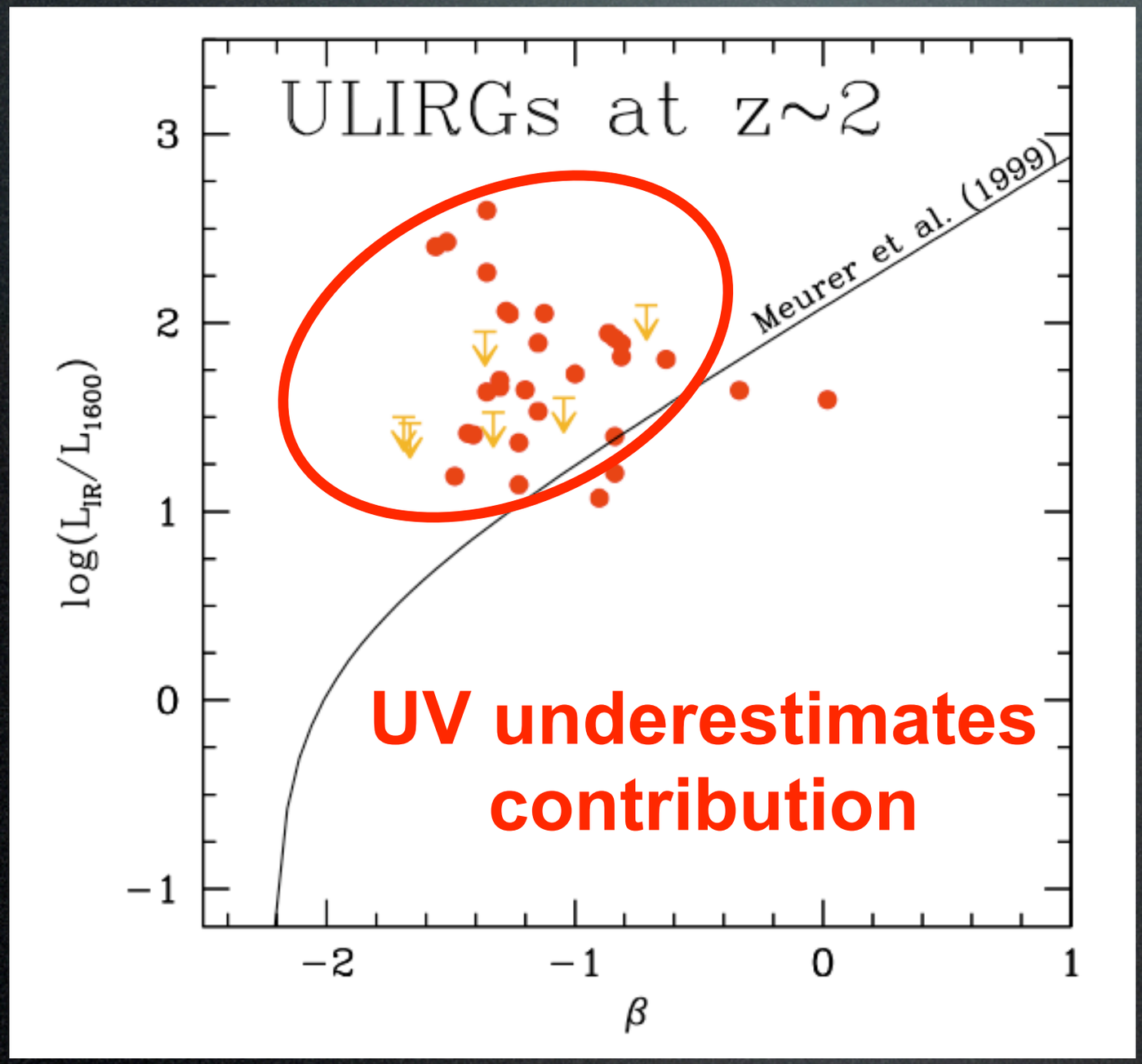


UV continuum slope (β)

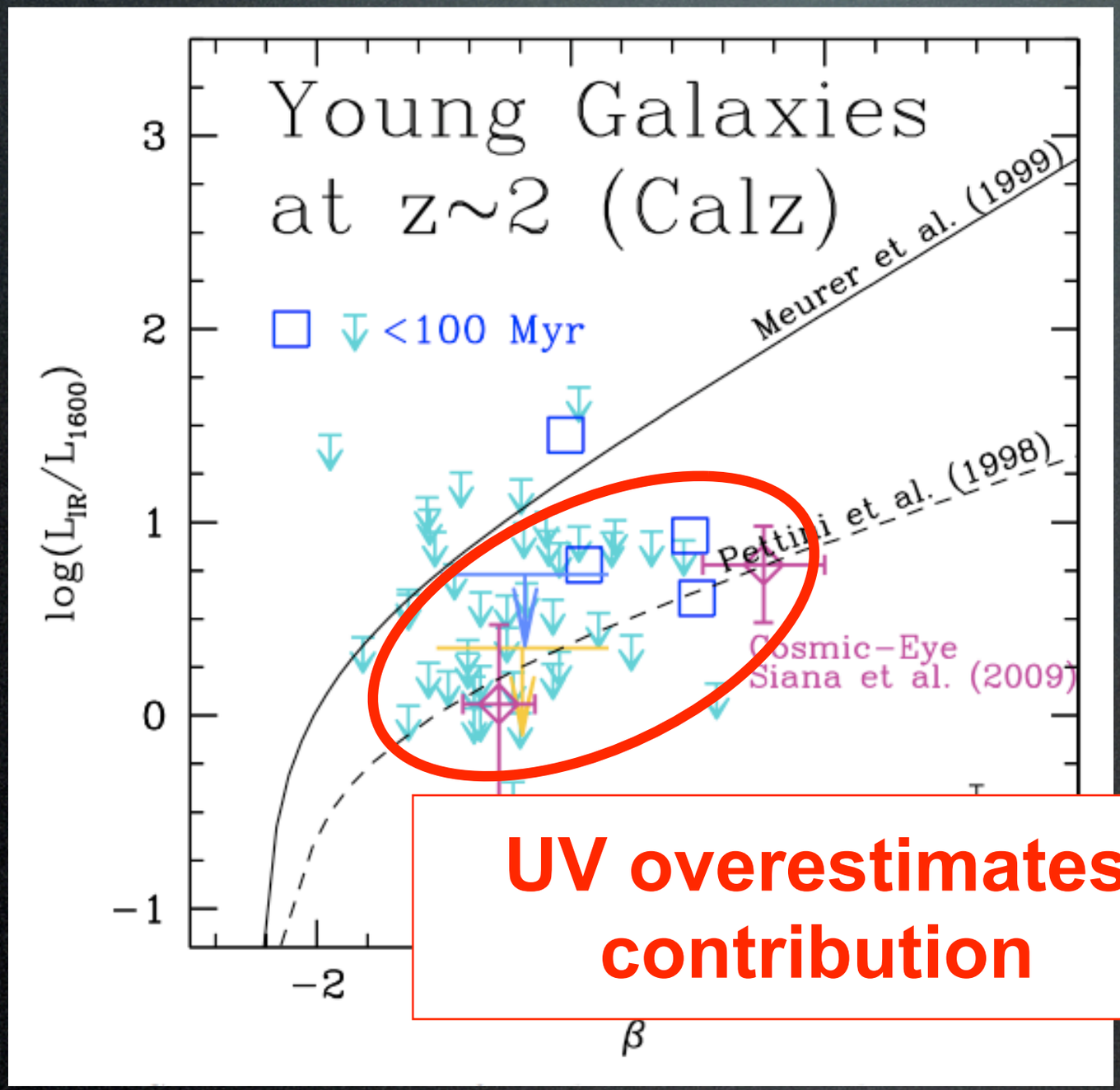
Of course, not all galaxies fit this relationship!!

1. Bolometrically luminous > 10^{12} $L_{\odot}$ galaxies (SFR of >200 M/yr)



Of course, not all galaxies fit this relationship!!

2. Young (<100 Myr) Galaxies



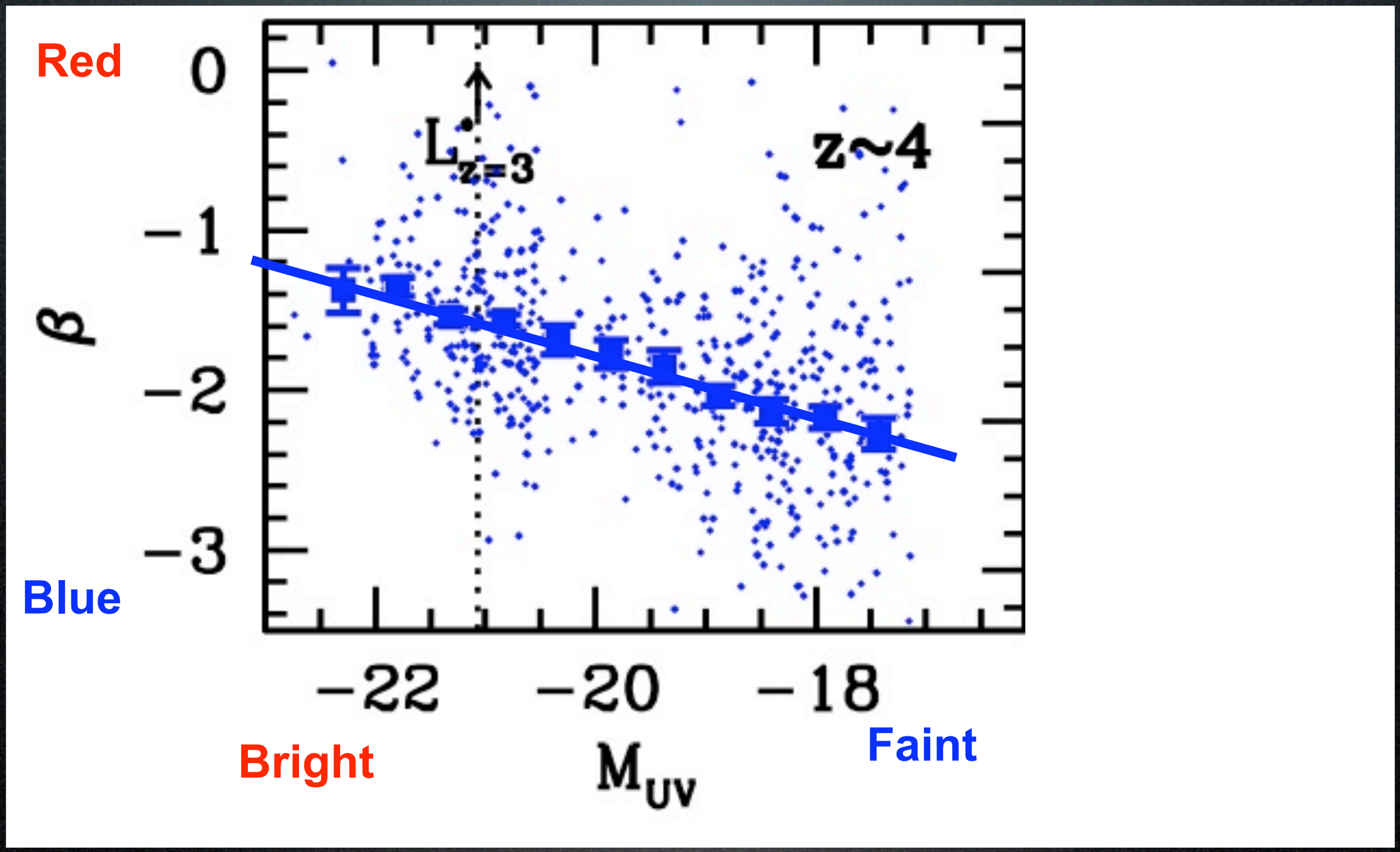
UV overestimates contribution

UV corrections --
challenging but manageable

What UV corrections do we infer from observations?

What are the UV slopes?

What is the dust extinction in one of these samples?



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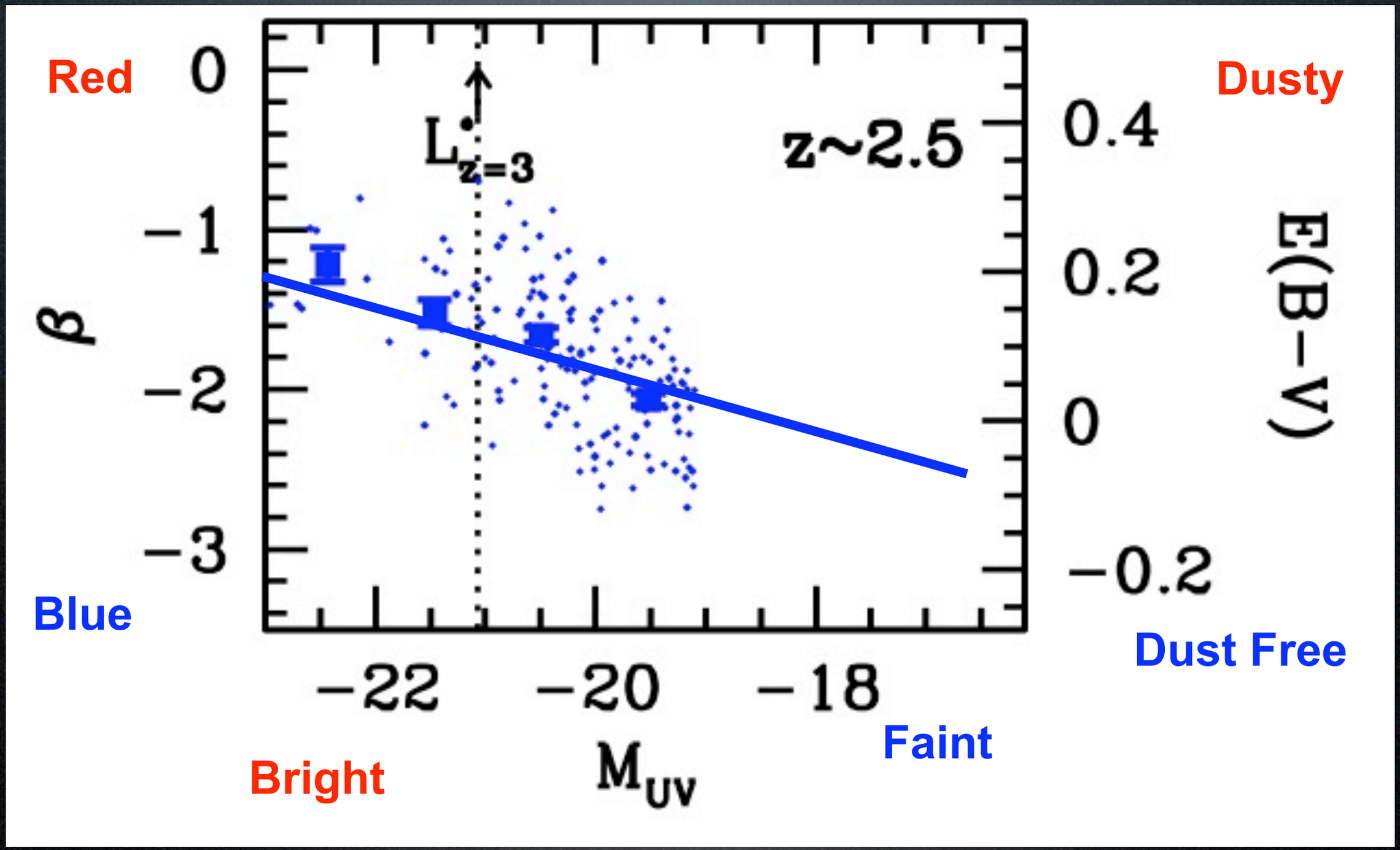
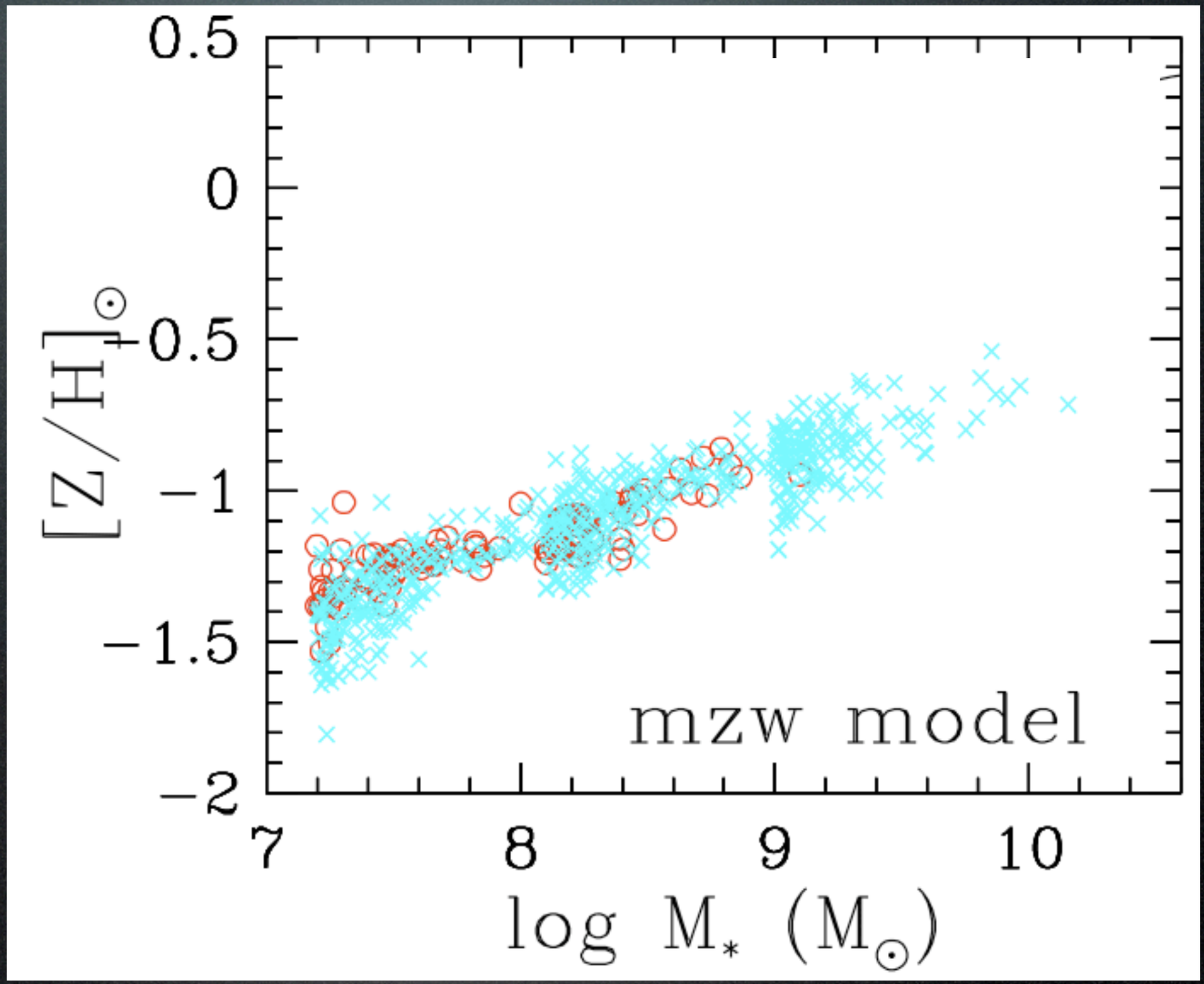


Bouwens et al. 2009

This is very similar to the correlation expected from the steady growth model...

Metallicity

(∝ Dust)



Stellar mass

Dave et al. 2006

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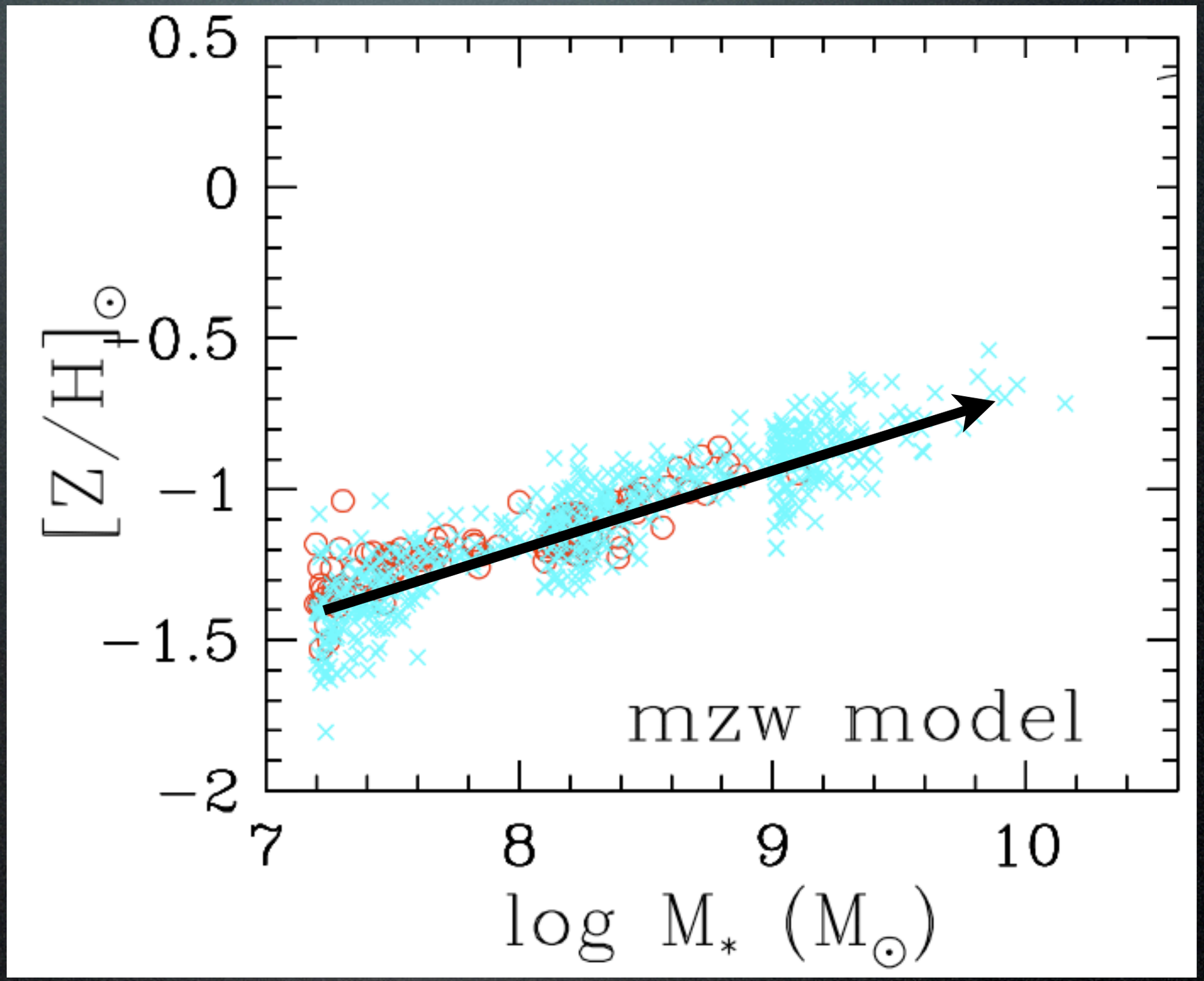

Stellar mass

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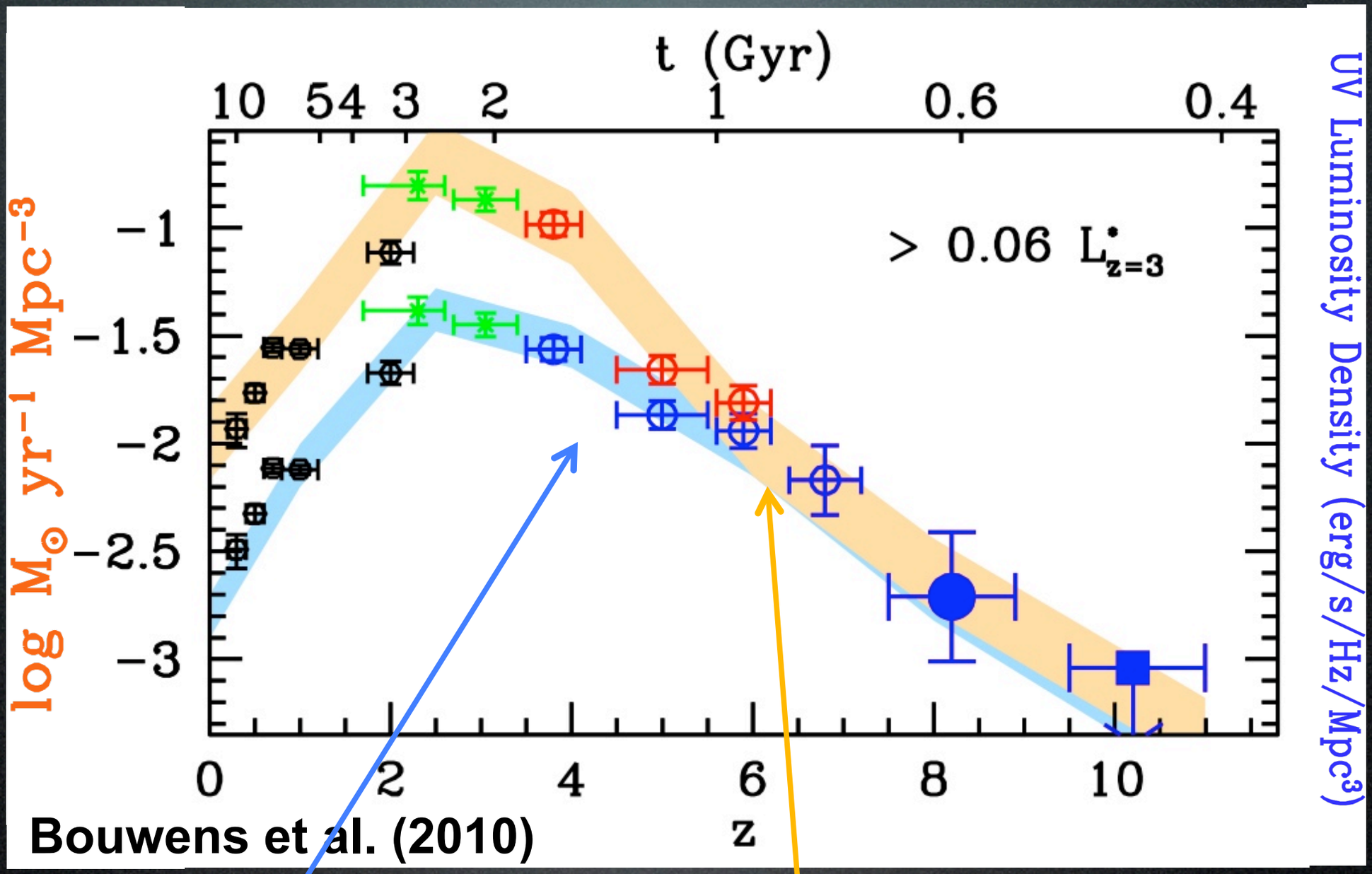
Dust-corrected SFR history

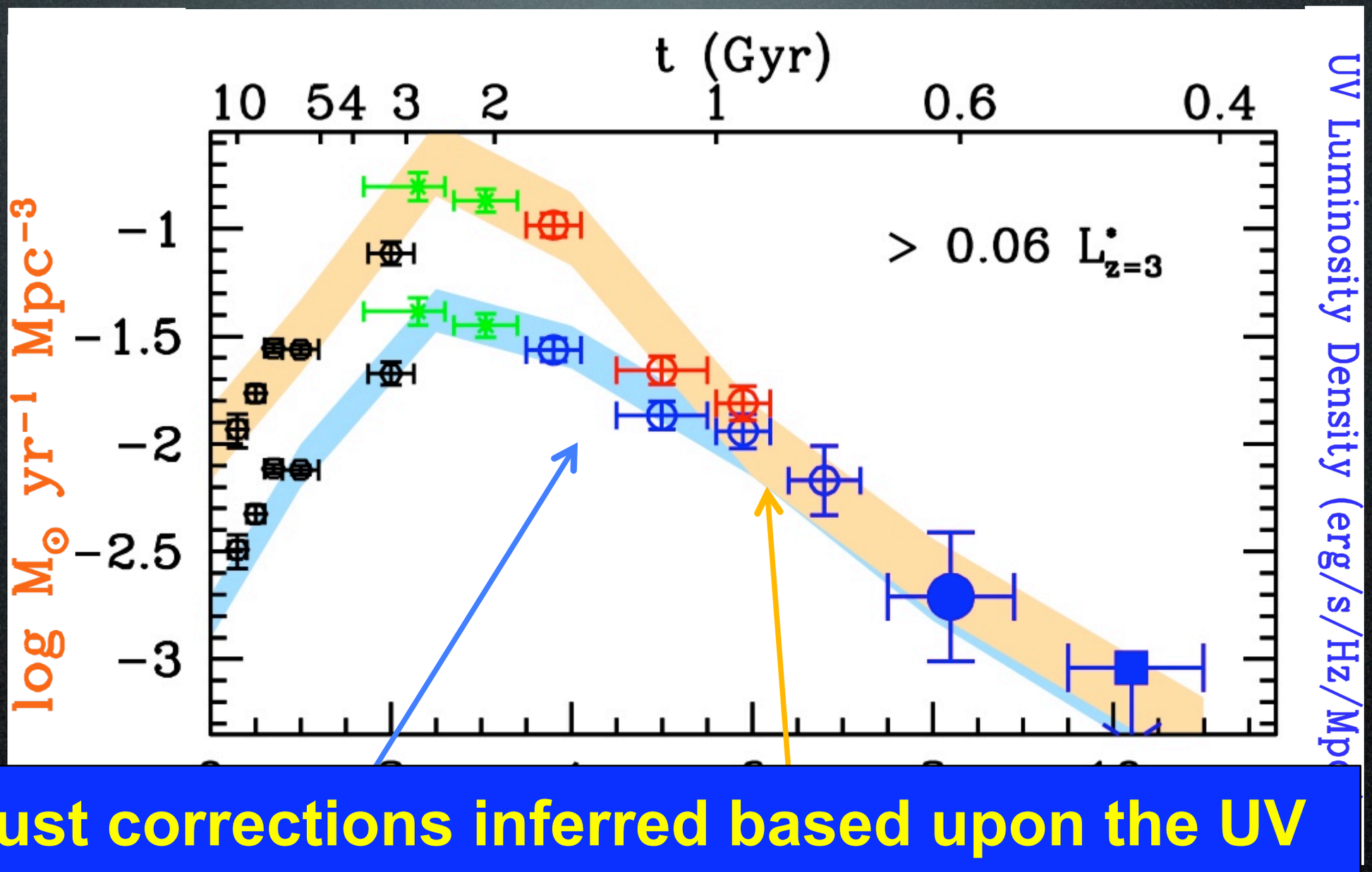


UV luminosity density – or uncorrected UV SFR density

Star Formation Rate Density: corrected for dust – and dust(L)

Bouwens et al. 2009

Dust-corrected SFR history



Dust corrections inferred based upon the UV color distribution (vs. redshift, luminosity)

of uncorrected UV SFR density

Density: corrected for dust – and dust(L)

Bouwens et al. 2009

But what about the very dusty galaxies we miss?

But what about the very dusty galaxies we miss?

Use Scuba, Herschel, Scuba2, AZTEC, etc.

Fortunately IR facilities probe down to precisely the same luminosities... that UV dust corrections appear to fail

$10^{12}\ L_{\odot}$

Study with UV

Low Stellar Mass
Low Metallicity
Low Dust

→

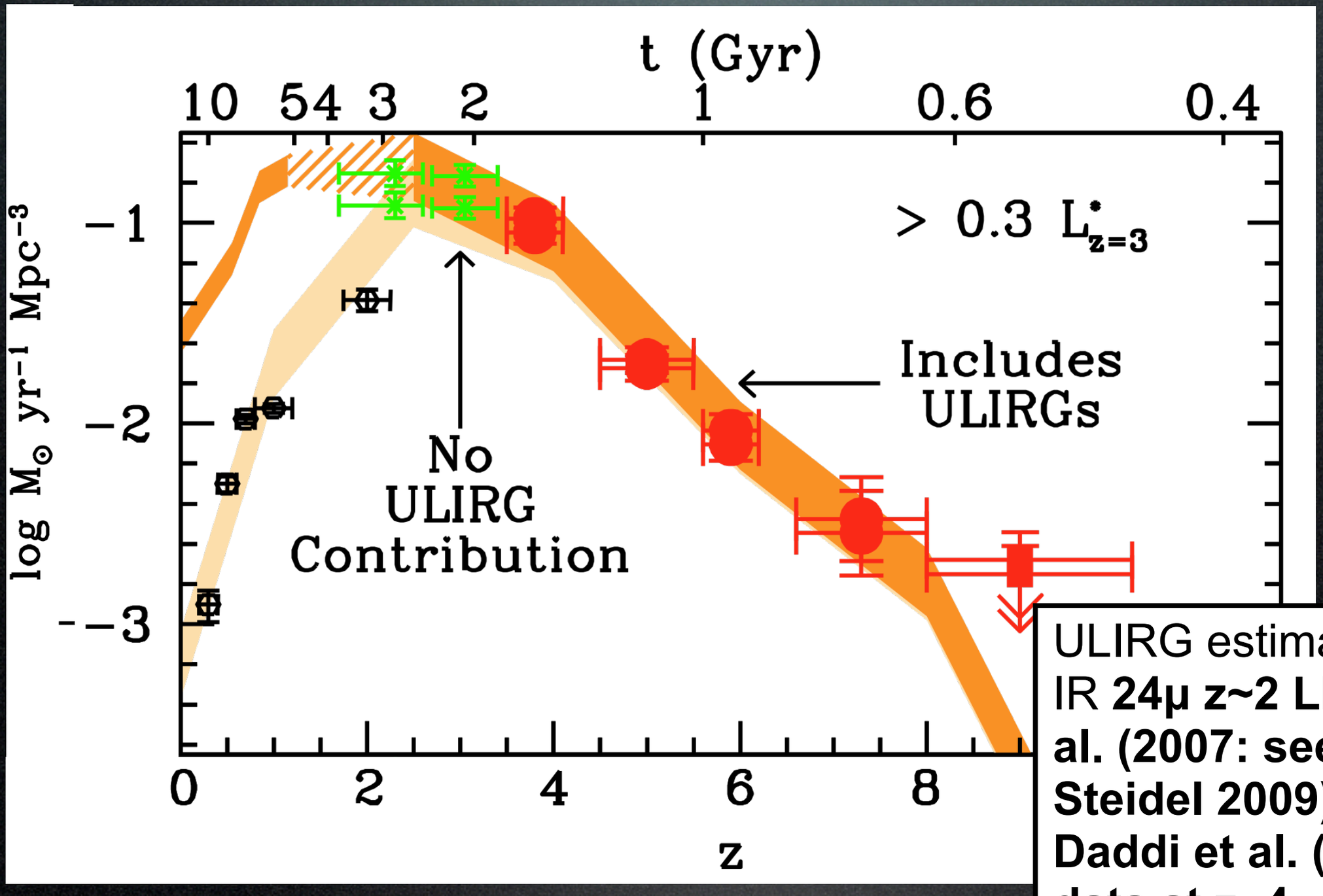
Modest Stellar Masses
Moderate Metallicities
Moderate Dust

Study with IR

High Stellar Masses
High Metallicities
Substantial Dust

Luminosity

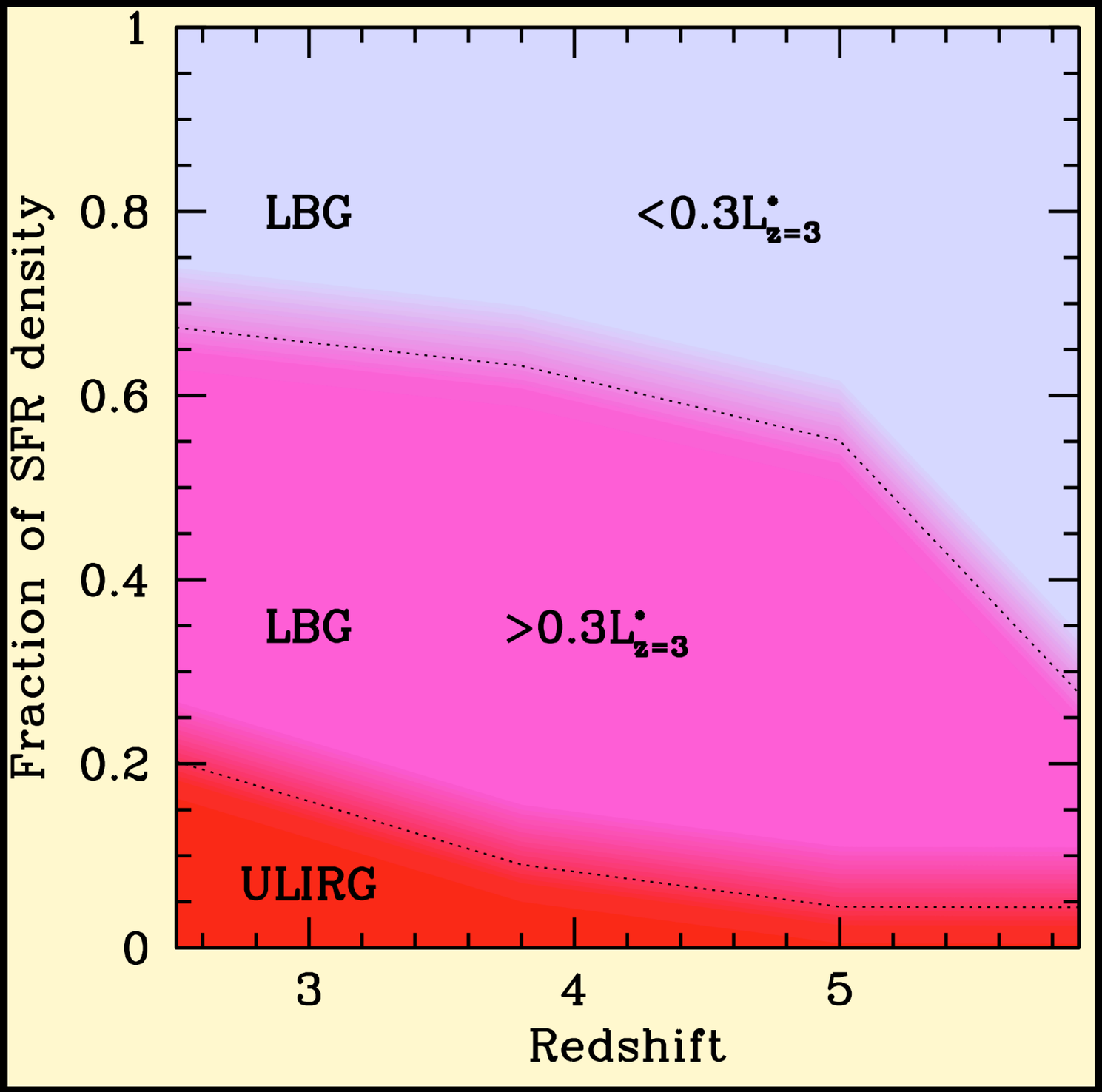
The Star Formation Rate Density from z~7 to z~0, including ULIRGs/SMGs etc



UV data for LBGs & IR data for dusty luminous sources (ULIRGS)

ULIRG estimate based on IR **24μ z~2 LF by Caputi et al. (2007: see Reddy and Steidel 2009) and from Daddi et al. (2009) SCUBA data at z~4**

The Star Formation Rate Density from z~7 to z~2.5: LBGs and ULIRGs/SMGs



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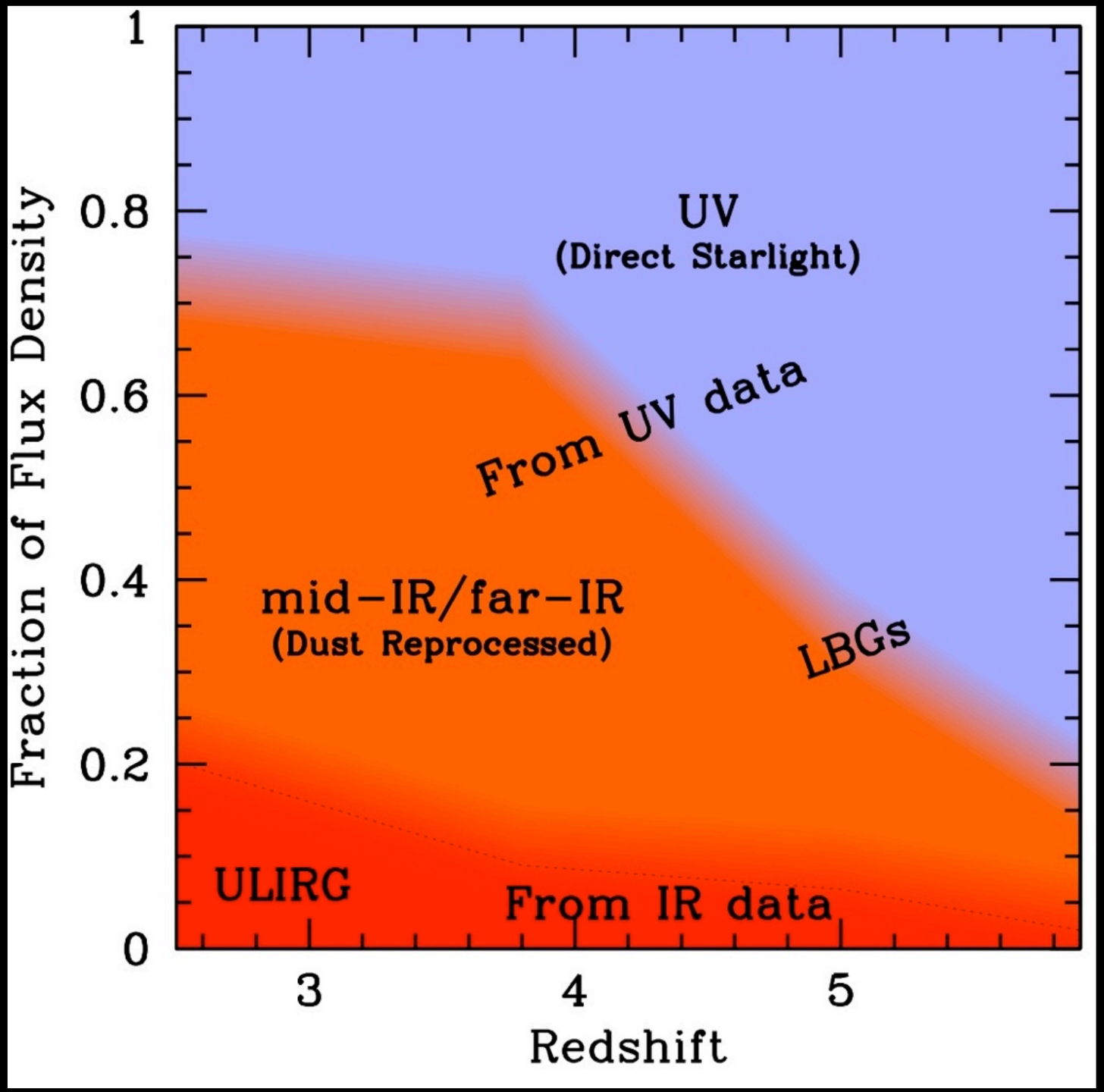
Faint LBGs

Luminous LBGs

IR ULIRGs/SMGs

z~2 baseline ULIRG estimate from Reddy et al (2008)

But most energy still comes out in IR...



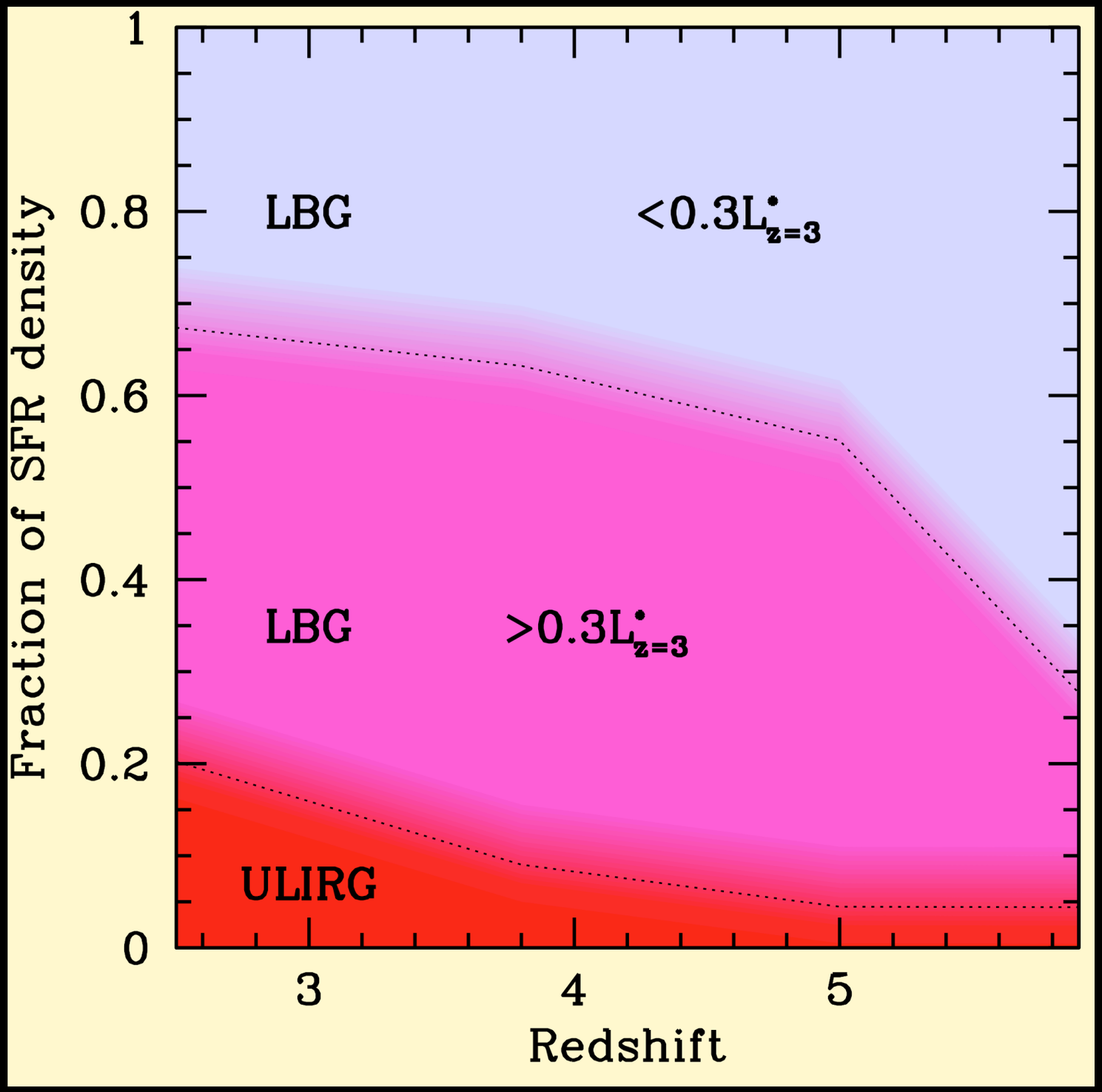
Fraction of Energy in IR

70% at z~3-4

40% at z~5

< 20% at z>6

The Star Formation Rate Density from z~7 to z~2.5: LBGs and ULIRGs/SMGs



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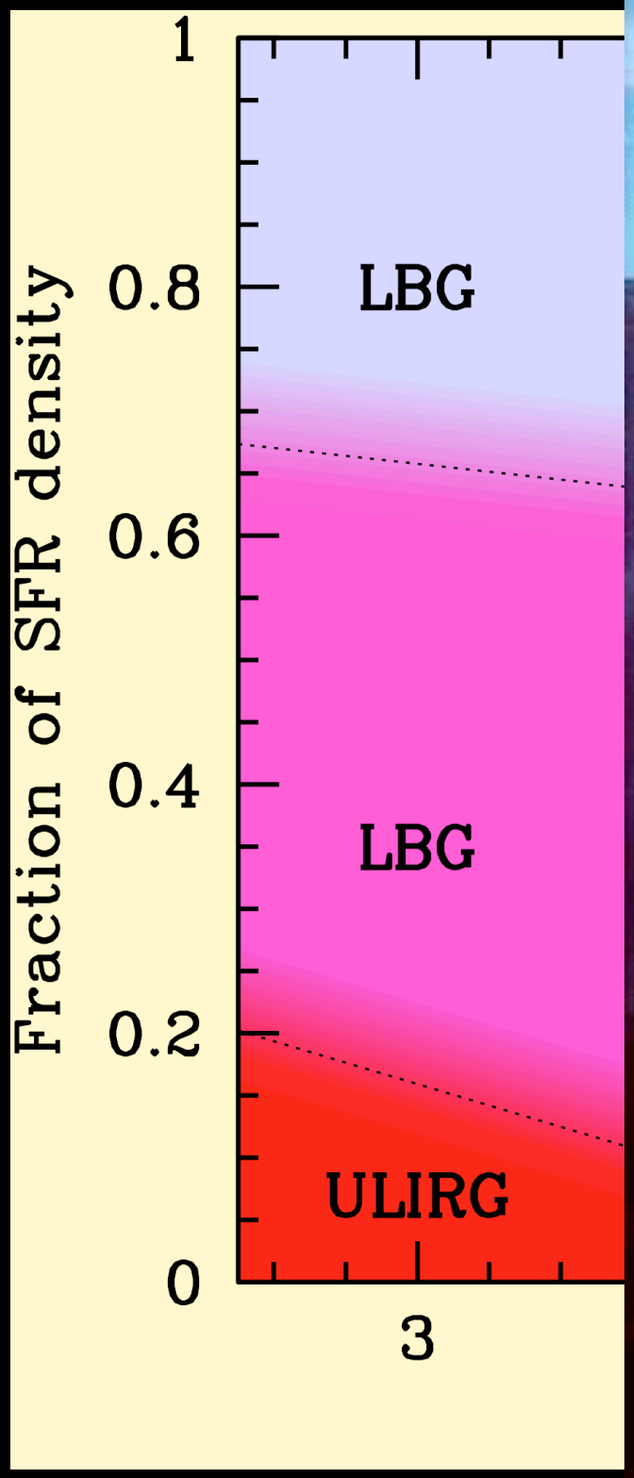

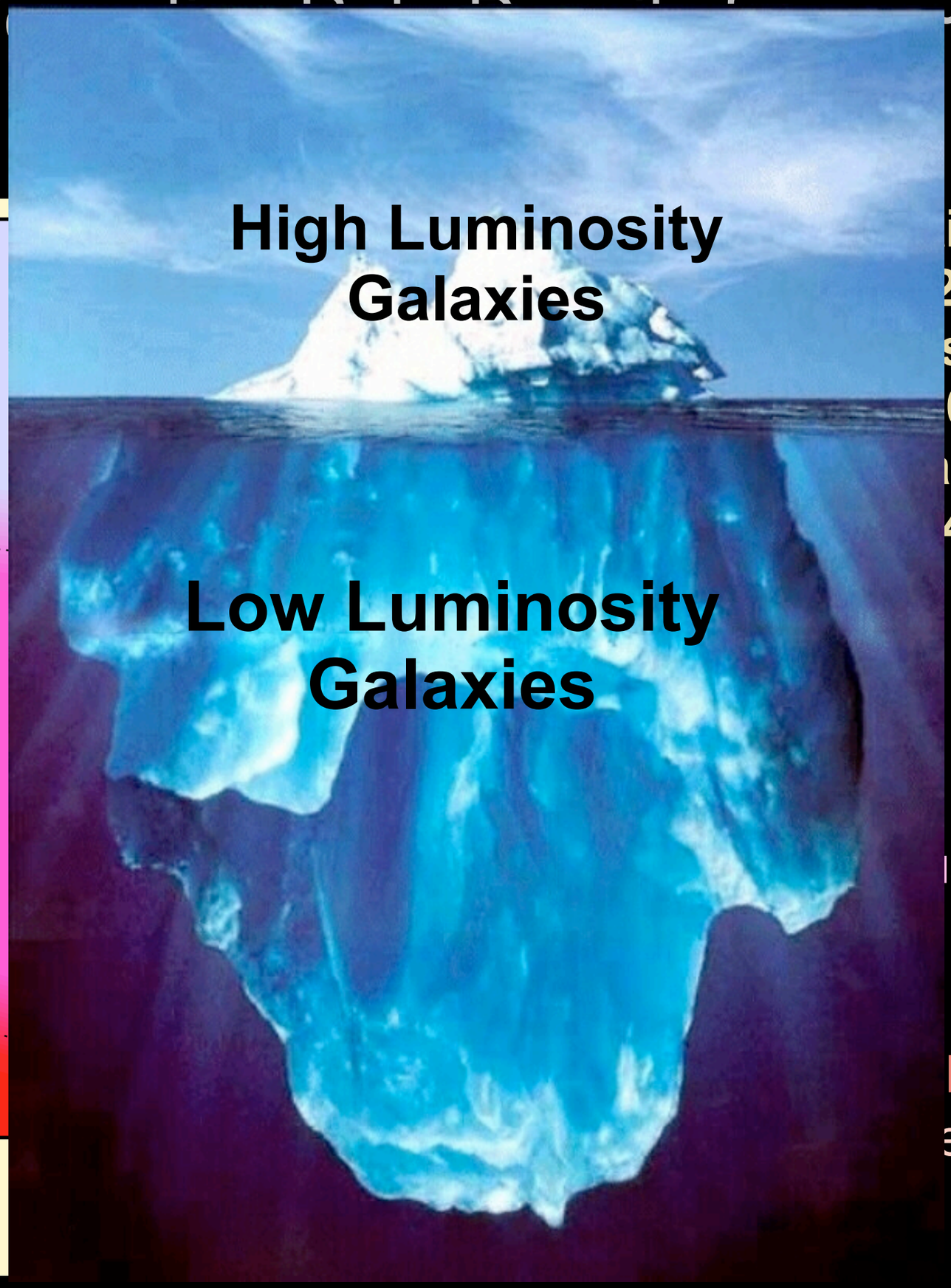

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