UV Colors of z~2-7 Galaxies

Luminosity Functions of z~7-8 Galaxies

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Austin, Texas
First Stars and Galaxies: Challenges for the Next Decade
March 11, 2010

Special Thanks to My Collaborators

With a Special Thanks to:

Garth Illingworth, Marijn Franx, John Blakeslee, Holland Ford, Rodger Thompson, Louis E. Bergeron, Massimo Stiavelli, Dan Magee, Ivo Labbe, Pieter van Dokkum, Dan Coe, Larry Bradley, Valentino Gonzalez

HUDF09 WFC3 IR team: Garth Illingworth, **Rychard Bouwens**, Marijn Franx, Pieter van Dokkum, Massimo Stiavelli, Ivo Labbe, Michele Trenti, Marcella Carollo, Pascal Oesch, Dan Magee

ACS GTO team: Holland Ford, Garth Illingworth, Mark Clampin, George Hartig, Txitxo Benitez, John Blakeslee, Rychard Bouwens, Marijn Franx, Gerhardt Meurer, Marc Postman, Piero Rosati, Rick White, Brad Holden, Dan Magee + many other team members

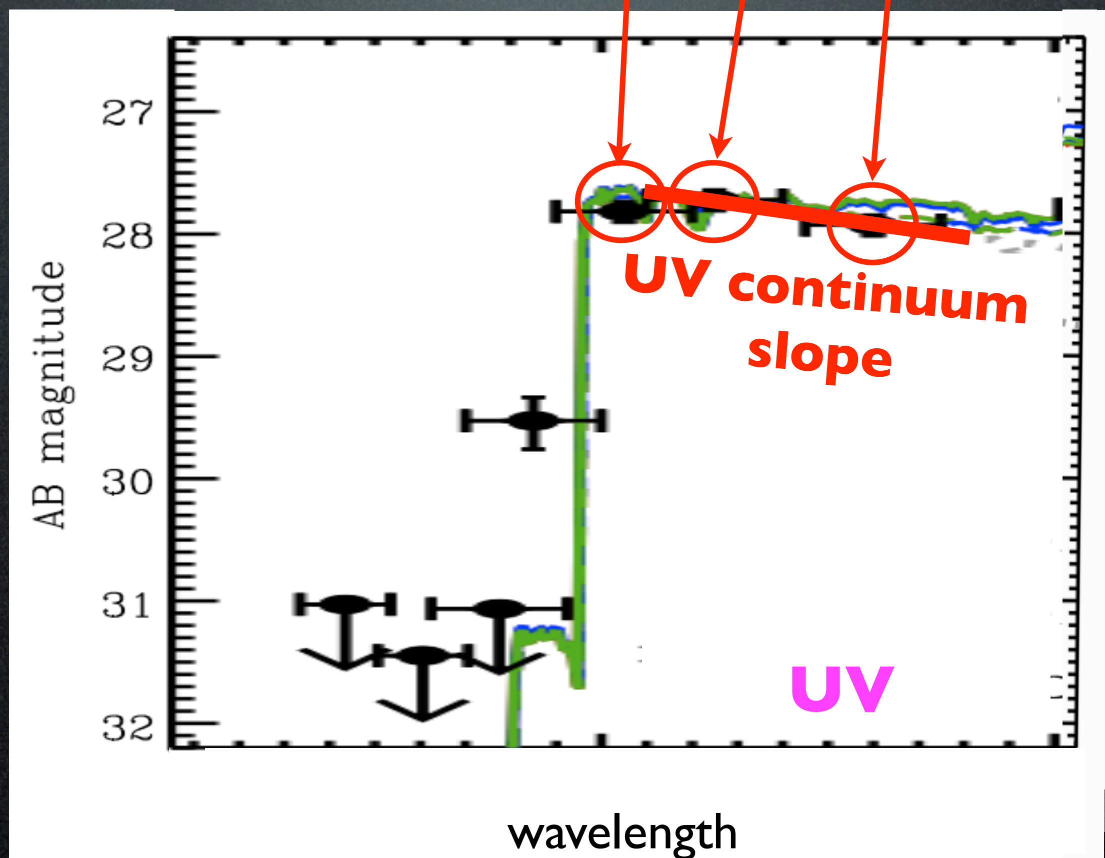
UDF-IR team: Rodger Thompson, Garth Illingworth, Rychard Bouwens, Mark Dickinson, Pieter van Dokkum, Dan Eisenstein, Xiaohui Fan, Marijn Franx, Marcia Rieke, Adam Riess

What is the UV color?

(UV continuum slopes β)

UV color is fundamental measurement

z~7 galaxy



Why study UV colors?

1. For studying the stellar populations of high-redshift star-forming galaxies
(providing information on age, dust, IMF, metallicity)

2. For estimates of the dust extinction in high-redshift galaxies
(z~2: Reddy et al. 2006, 2010; Erb et al. 2006)...

→ Important for estimating the SFR density at z~3-8...

Sensivities are not high enough for other techniques x-ray, Hα, radio, MIPS, far-IR(+UV) to work at z>2

Study dependence of UV color (dust)

1. Redshift

   → Evolution with cosmic time

2. Luminosity

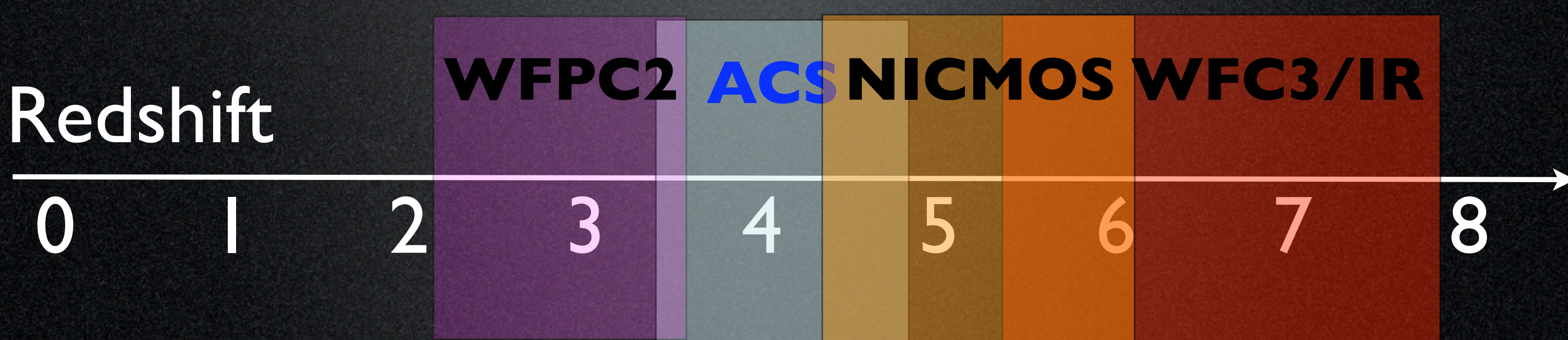
   → Proportional to mass

How can the UV colors be established?

By utilizing large samples of LBGs at z~2-7 in HST data

200 z~2-3
5000 z~4
1500 z~5
600 z~6
70 z~7

extended luminosity range



How does UV color depend upon luminosity (mass)?

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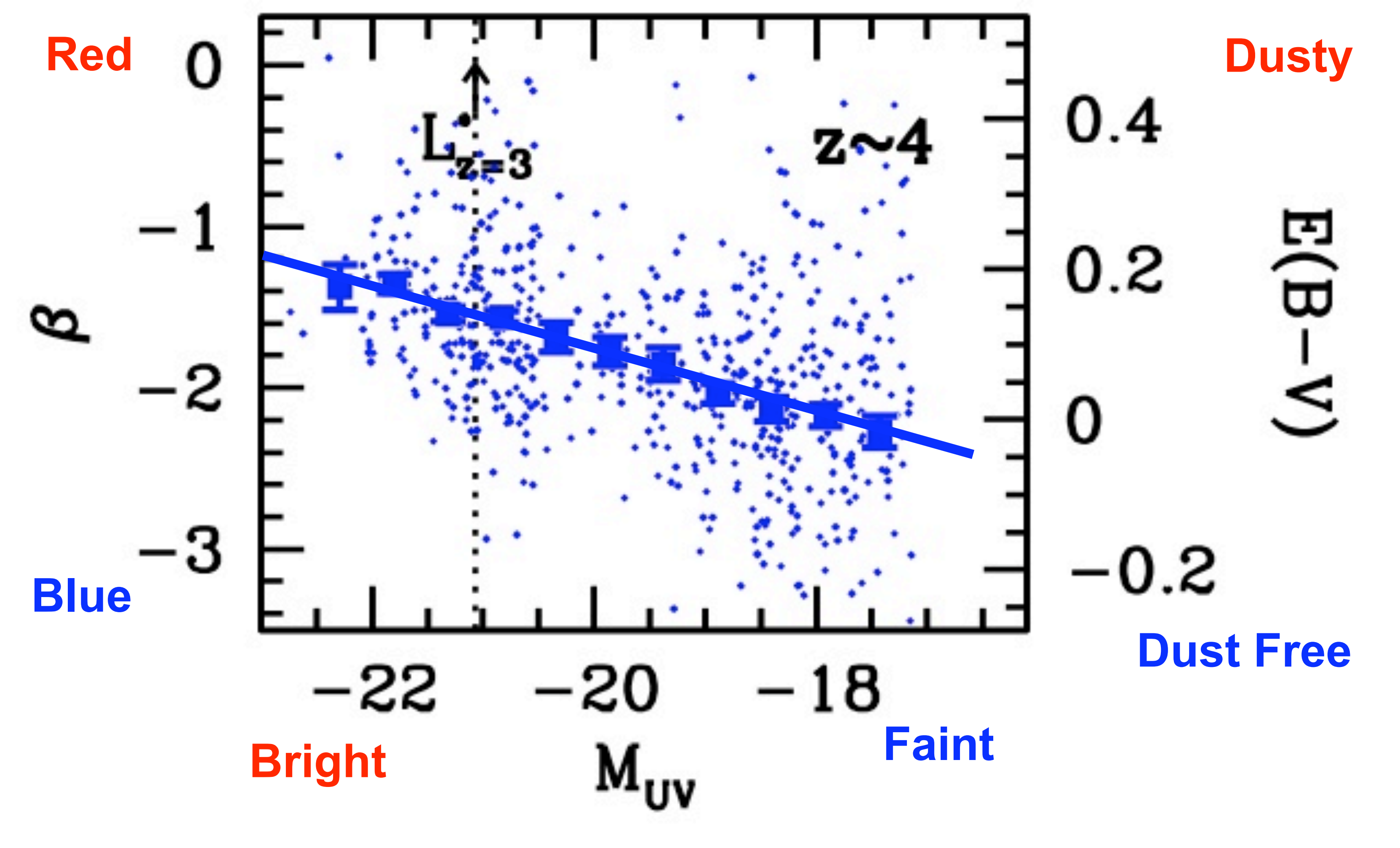

Bouwens et al. 2009

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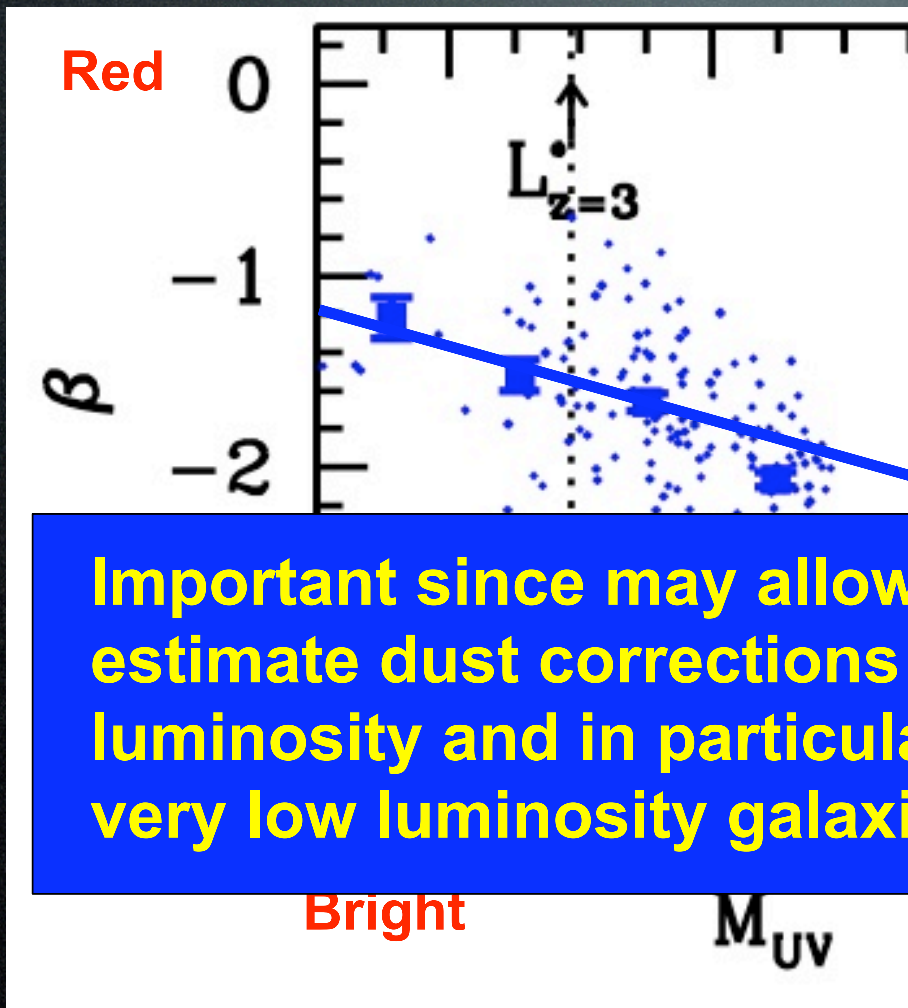
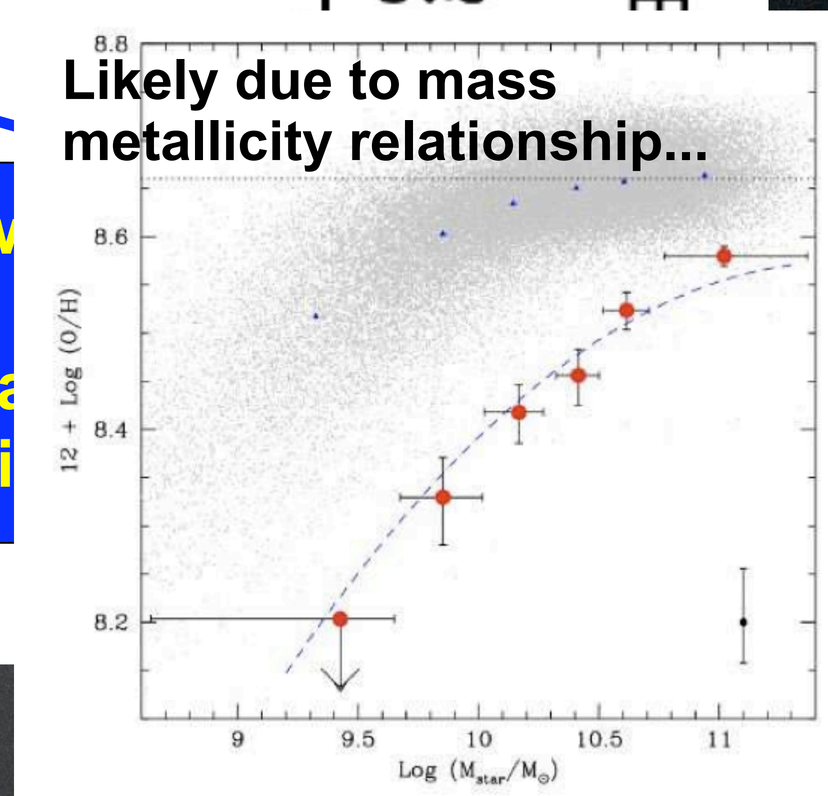


Important since may allow estimate dust corrections luminosity and in particula very low luminosity galaxi



Likely due to mass metallicity relationship...

Bouwens et al. 2009

How does UV color depend upon redshift?

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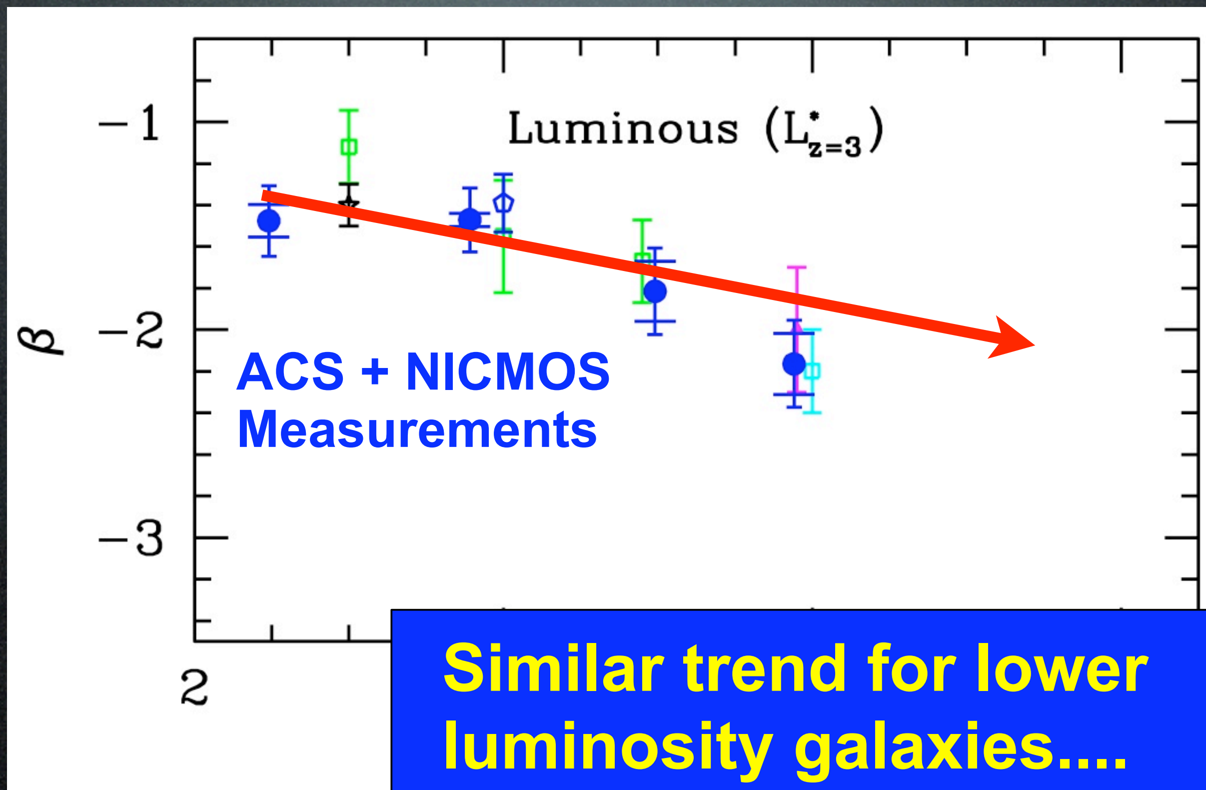
Luminous Galaxies

Red

Blue

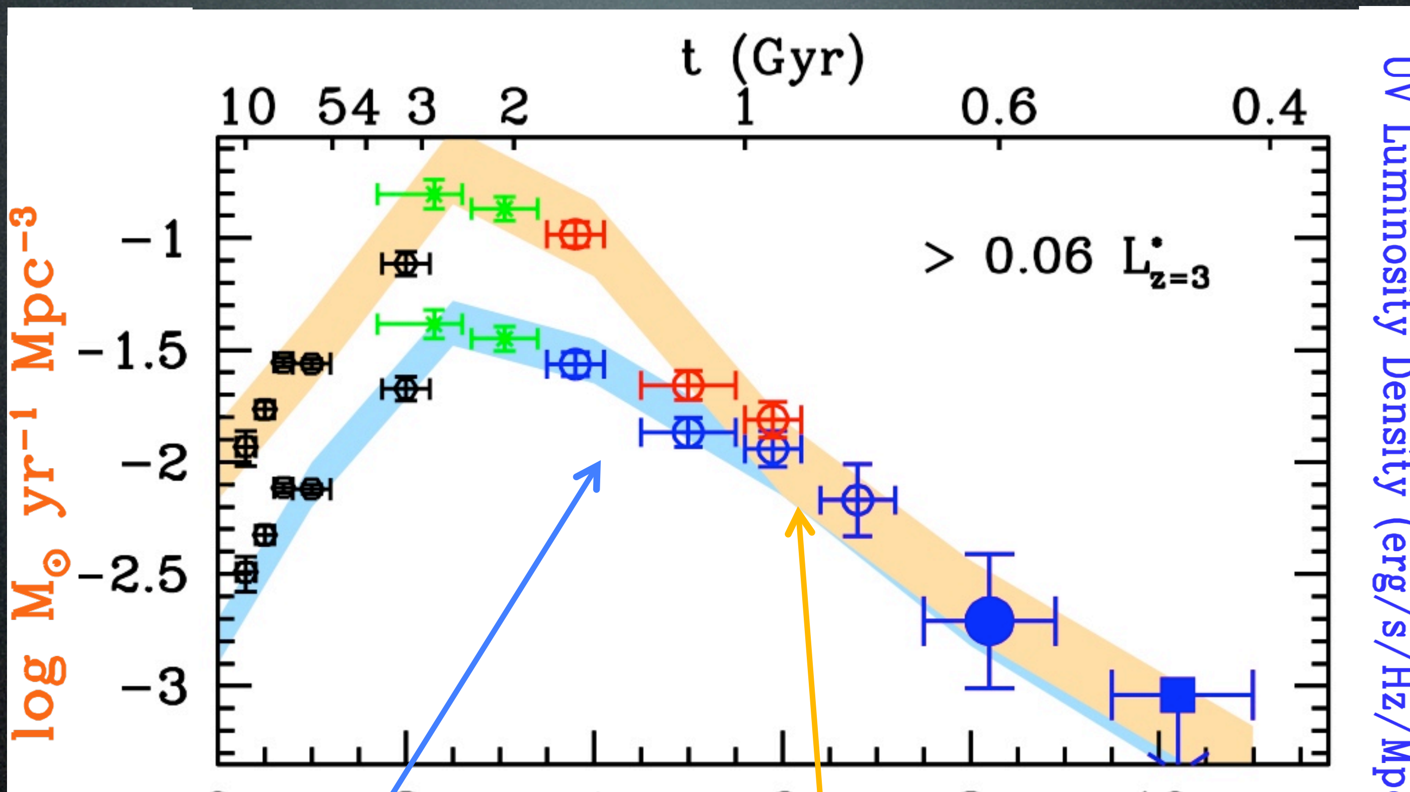


Similar trend for lower luminosity galaxies....

UV colors bluer at very high redshifts!

Bouwens et al. 2009, 2010; but see also Stanway et al. 2005; Lehnert et al. 2003

Dust-corrected SFR history



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

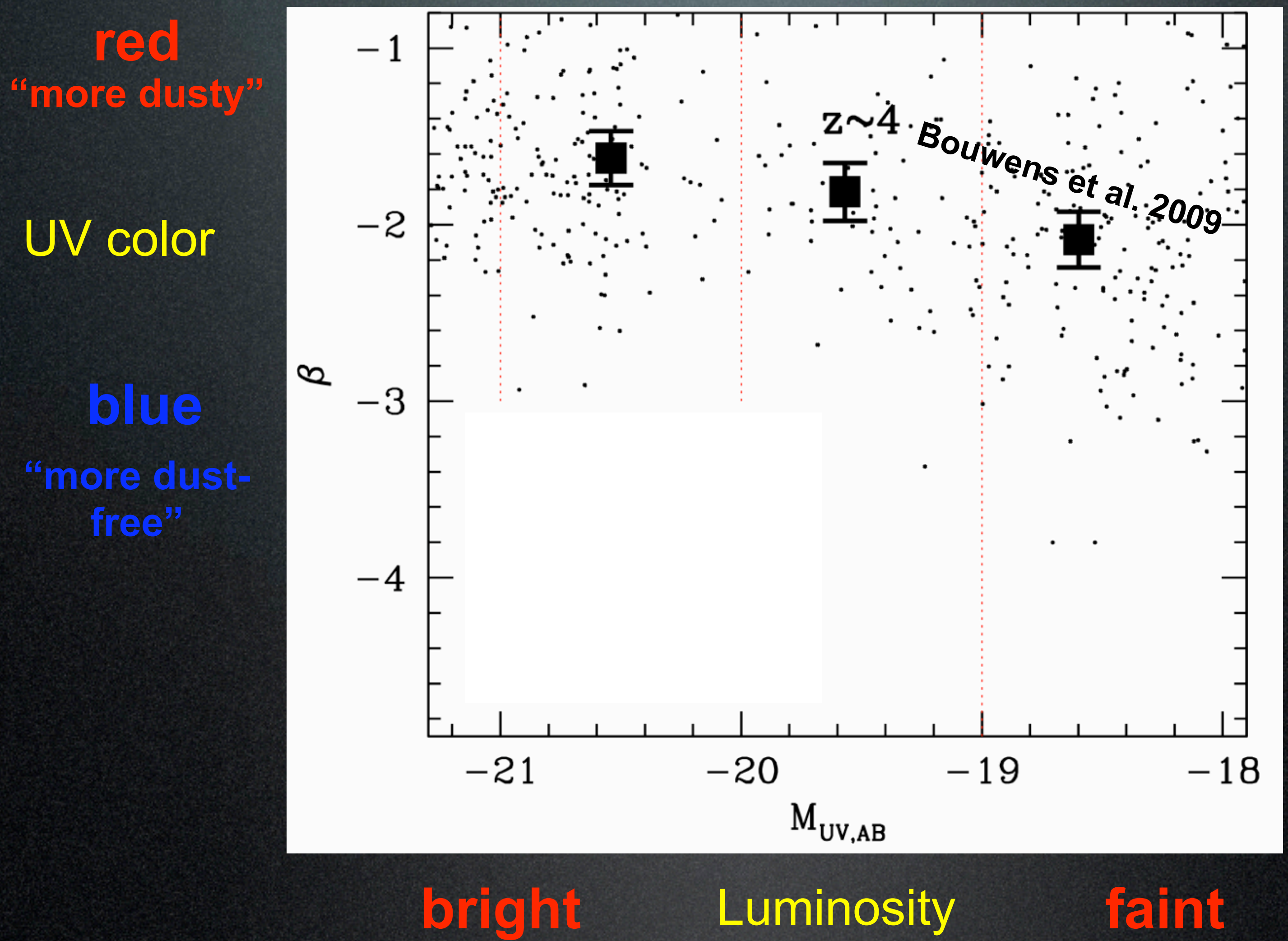
SFR density

dust – and dust(L)

Bouwens et al. 2009

UV colors of z~6-8 galaxies with WFC3/IR

z~7 galaxies from ultra-deep WFC3/IR observations of the HUDF: What about their UV colors?



Bouwens et al. 2010

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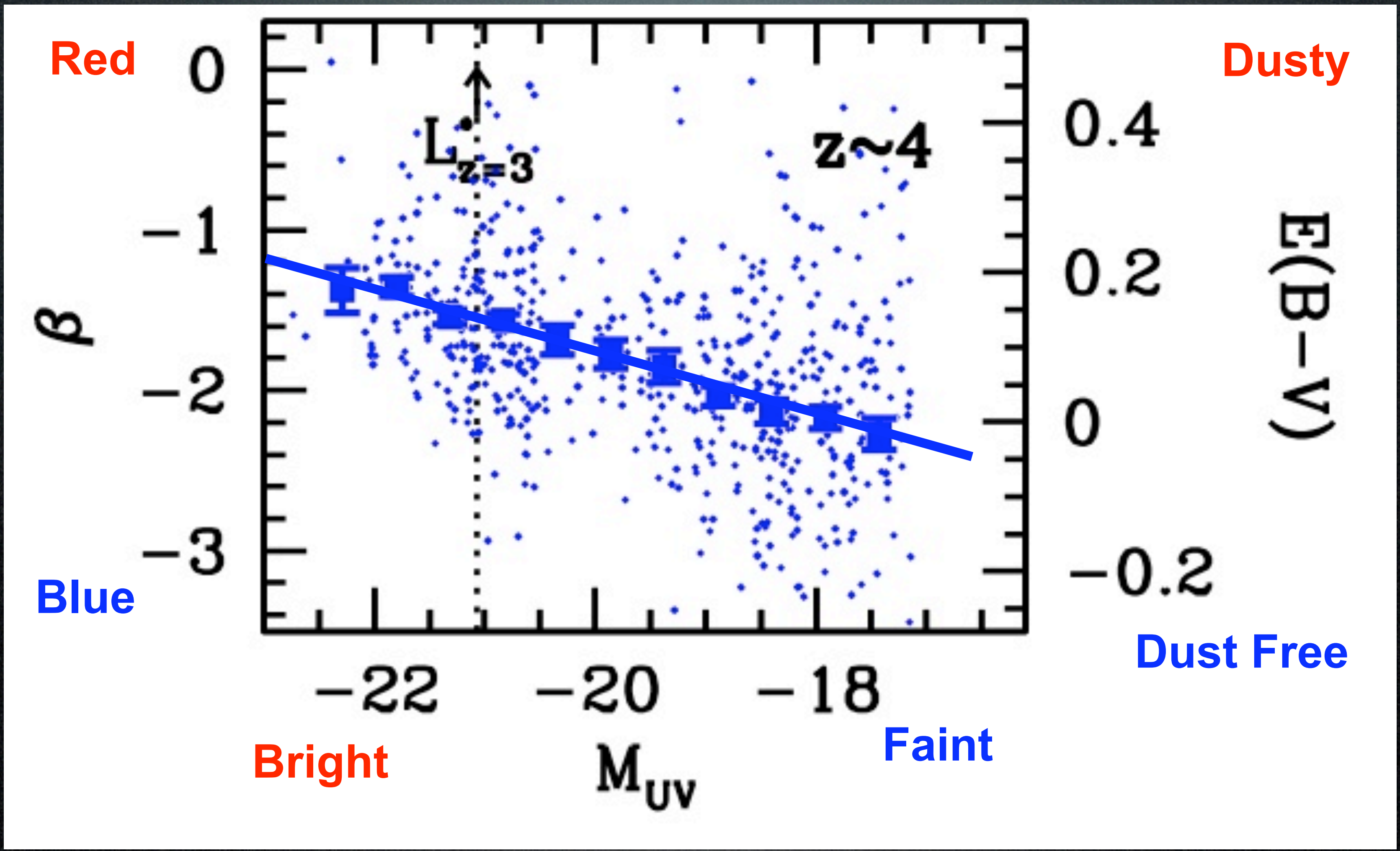

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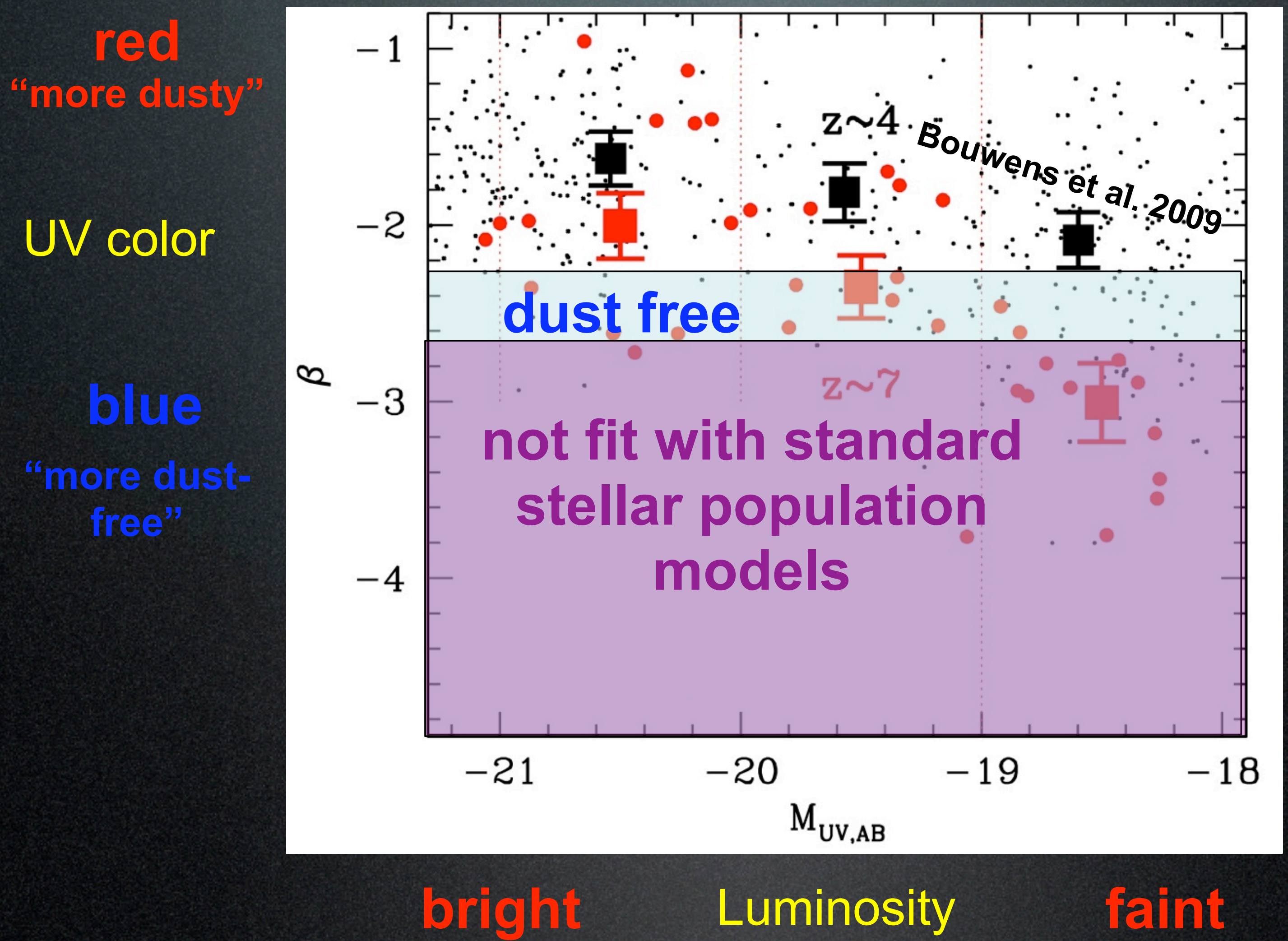
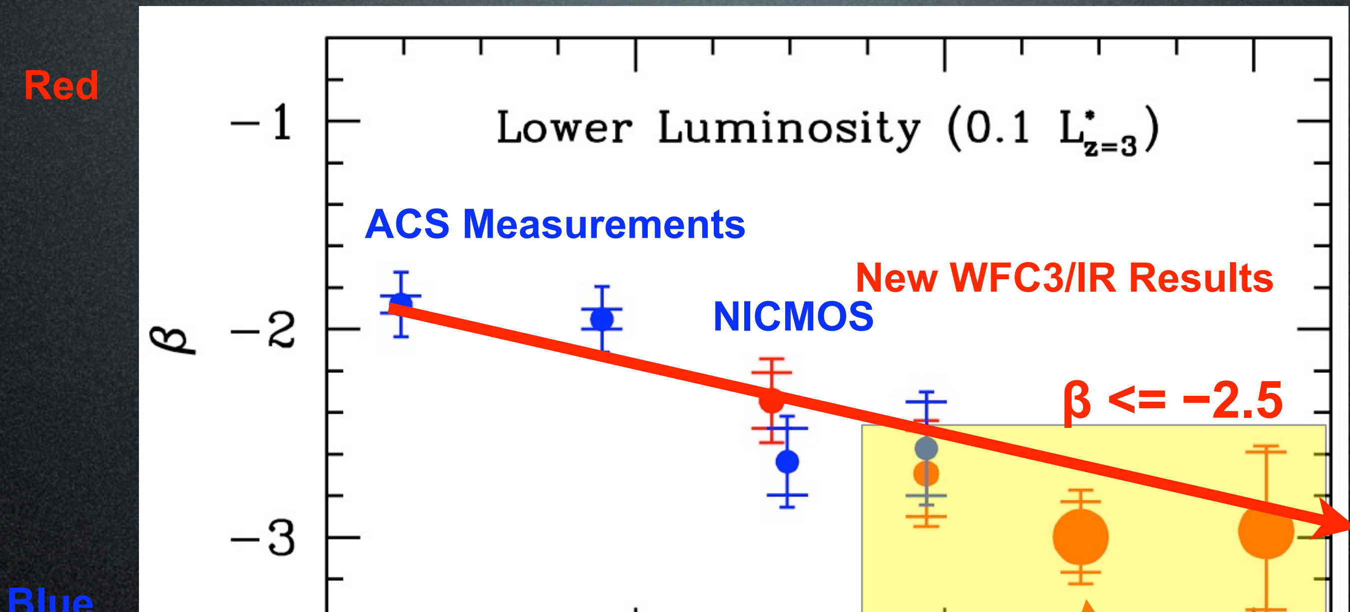


Bouwens et al. 2010

Are faint galaxies at z~6 and z~8 similarly blue?

UV colors for low luminosity z>5 galaxies

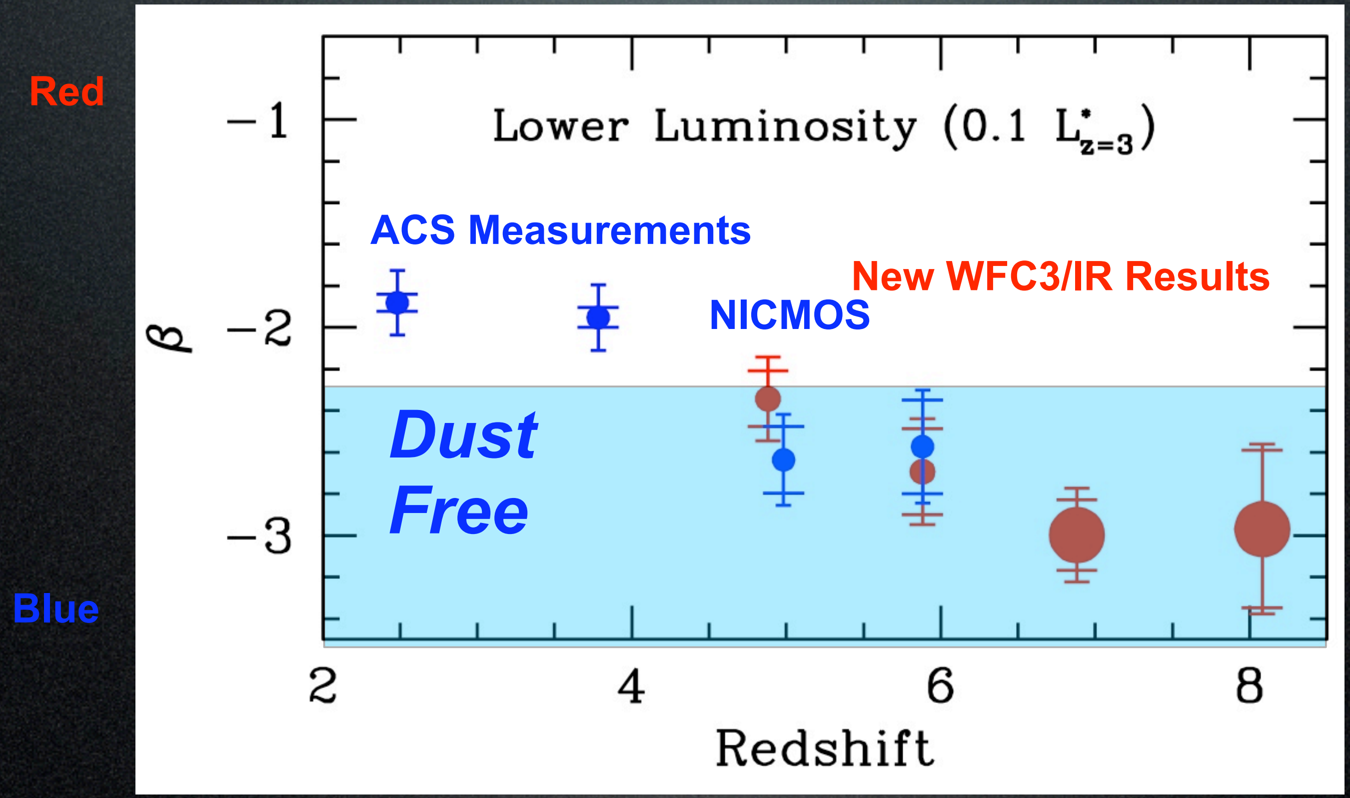


Conclusion:
UV slopes β <~ −2.5 for low luminosity galaxies at z >= 6

Bouwens et al. 2009, 2010; but see also Finkelstein et al. 2010; Bunker et al. 2010

What might a UV slope β <~ −2.5 or even β ~ −3 imply?

1. **Lower Luminosity z>=5 Galaxies Must be Essentially Dust Free**



Bouwens et al. 2010

What might a UV slope $\beta <\sim -2.5$ or even $\beta \sim -3$ imply?

2. **Galaxies are dominated by very hot, young stars ...**

To produce very blue β's (i.e., -3) **we require hot, young stars...**

Emitted Light

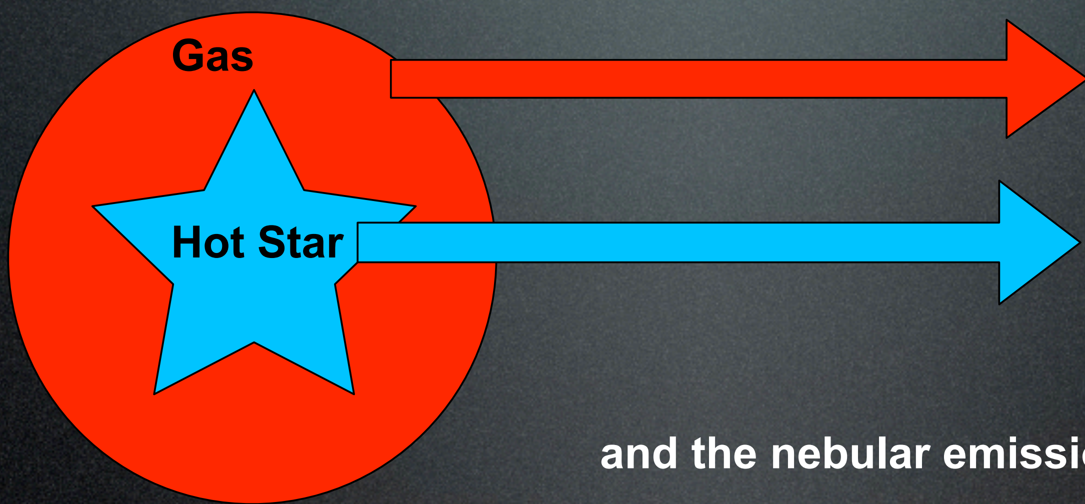
Very Hot Stars

$\beta \sim -3$ (blue)

Bouwens et al. 2010

What might a UV slope β <~ −2.5 or even β ~ −3 imply?

IMPORTANT TWIST: But hot stars ionize gas surrounding them...



and the nebular emission is redder....

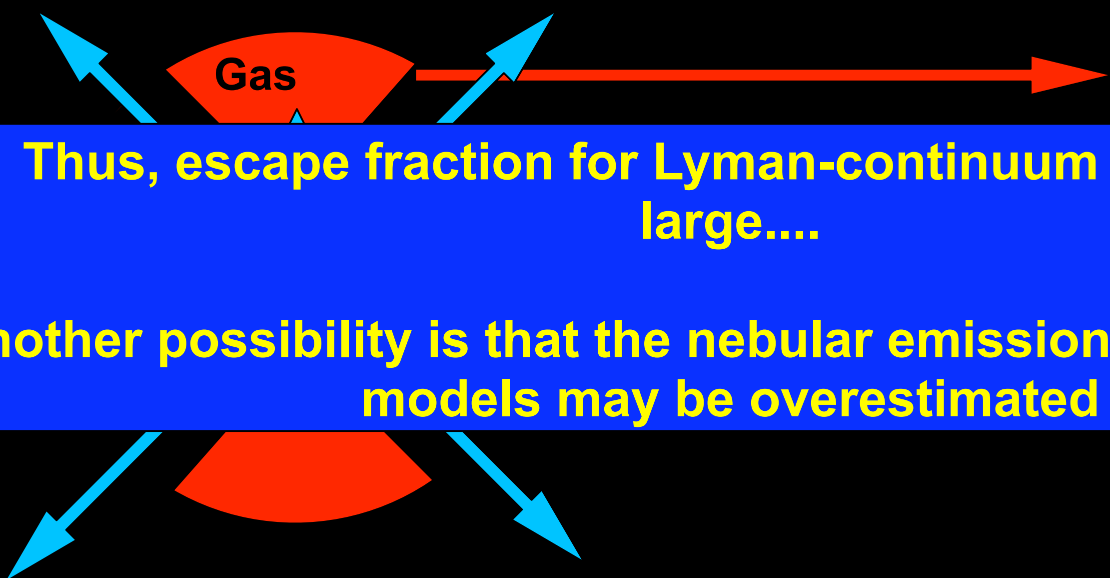
→ Total Light (Stars + Nebula) = moderately blue

Nebular Continuum Emission Keeps Us from producing very blue β's

Bouwens et al. 2010

What might a UV slope $\beta <\sim -2.5$ or even $\beta \sim -3$ imply?

But what if there are holes in the gas distribution



3. Thus, escape fraction for Lyman-continuum photons may be large....

Another possibility is that the nebular emission from theoretical models may be overestimated

and a substantial fraction of the light escapes...

then light from nebula will be less, and galaxies bluer

Bouwens et al. 2010

What might a UV slope β <~ −2.5 or even β ~ −3 imply?

1. **Lower Luminosity z>=5 Galaxies Must be Essentially Dust Free**

2. **Faint z>=5 Galaxies are dominated by very hot, young stars ...**

3. **Contribution from nebular light to galaxy must be less (or bluer)**

   → Could imply large escape fractions

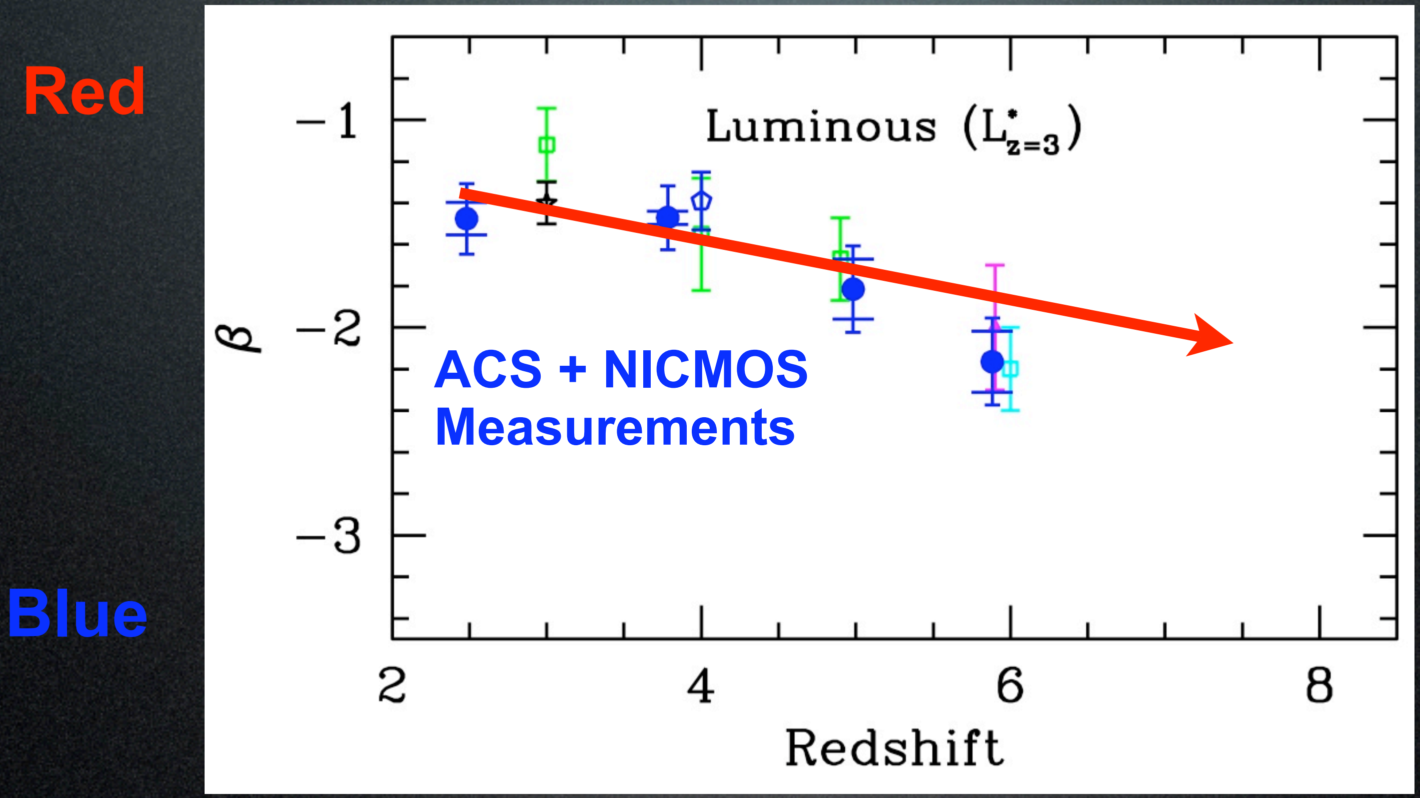
Bouwens et al. 2010

UV Colors

Are the blue slopes due to selection biases?

How does UV color depend upon redshift?

Luminous Galaxies



UV colors bluer at very high redshifts!

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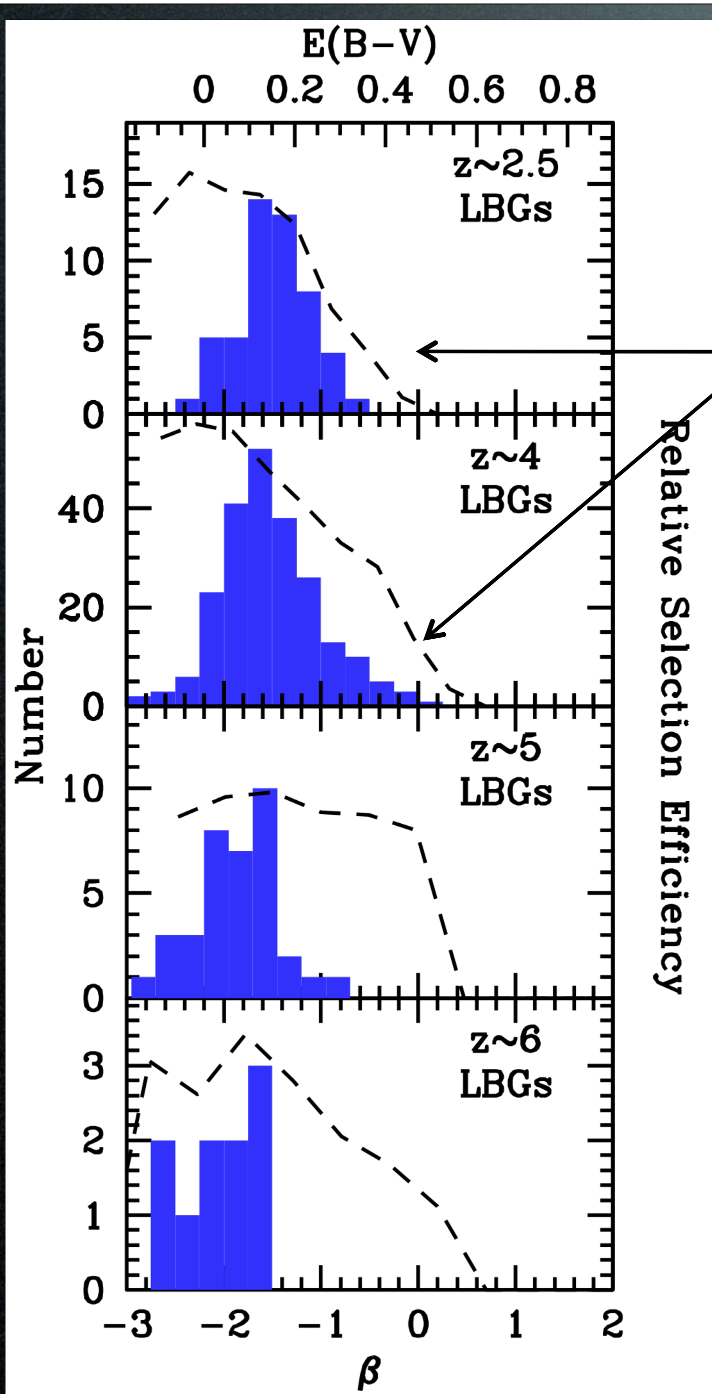
Is the lack of dusty z~4 galaxies a selection effect?



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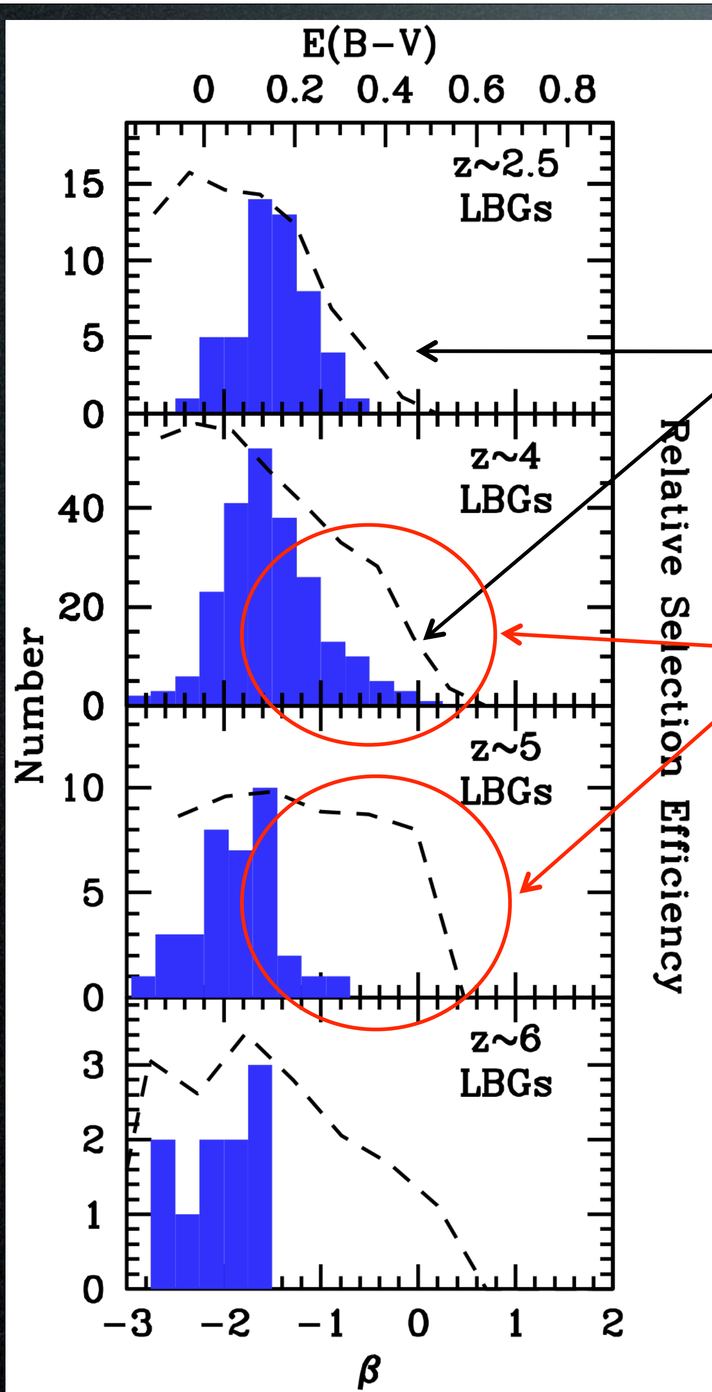

Selection Efficiency

"Redder", evolved sources could be detected in these ~0.1L* to ~2L* samples at z~4 and z~5+

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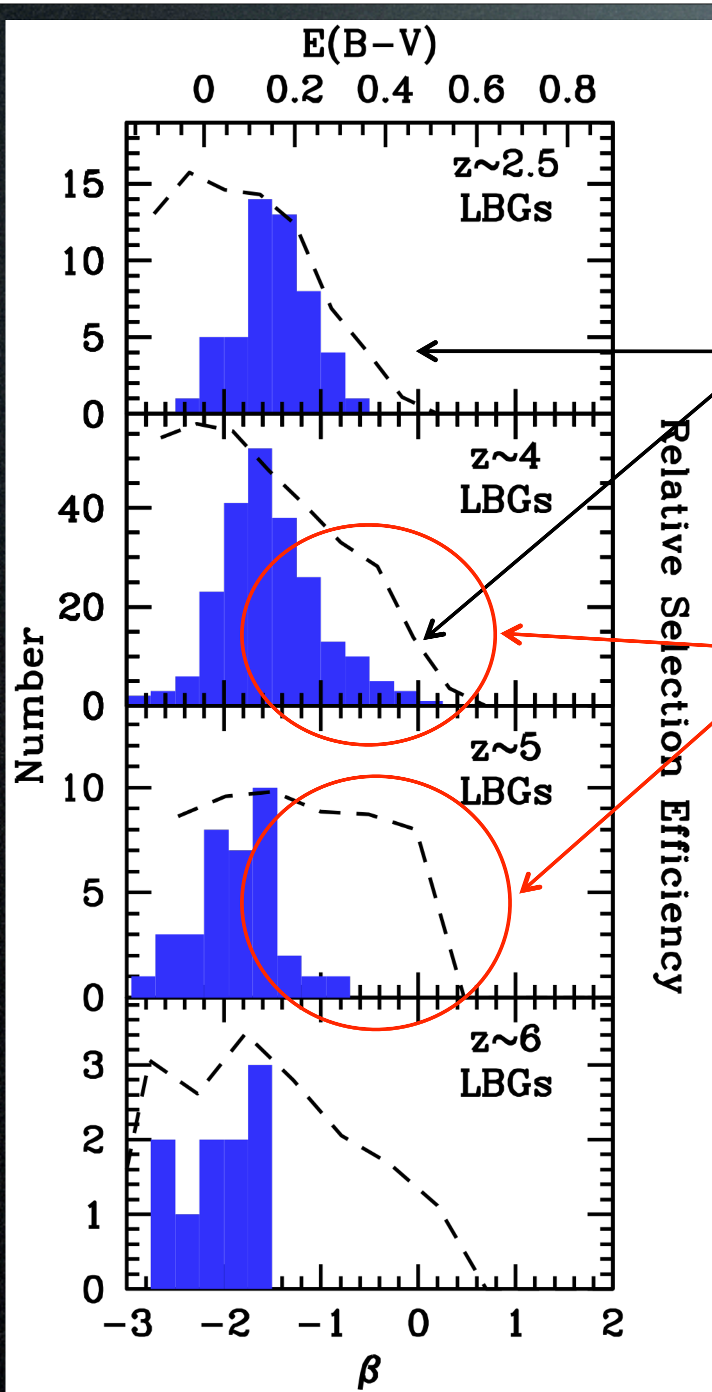

Selection Efficiency

"Redder", evolved sources could be detected in these ~0.1L* to ~2L* samples at z~4 and z~5+

There is *NOT* a continuum of UV slopes: => if there are evolved galaxies or dusty galaxies at z>4 they must have *distinctly* different UV properties or be quite rare

What can we learn about galaxy formation and evolution from observations of very high redshift galaxies

- Deep HST data are available to determine UV continuum slopes, over wide range in redshift and luminosity
- Less extinction: (1) low luminosity galaxies; (2) at higher z
- These UV colors (or UV continuum slopes) can be used to make estimates of the dust corrections and SFR density at z>3
- The UV-continuum slopes beta we measure at z~7 are very blue, particularly at very low luminosities and suggest minimal dust extinction there.
- The very blue UV-continuum slopes suggests that nebular light may not contribute as expected in some models -- and escape fraction may be large > 30%