Color Gradients in Galaxies Out to z~3

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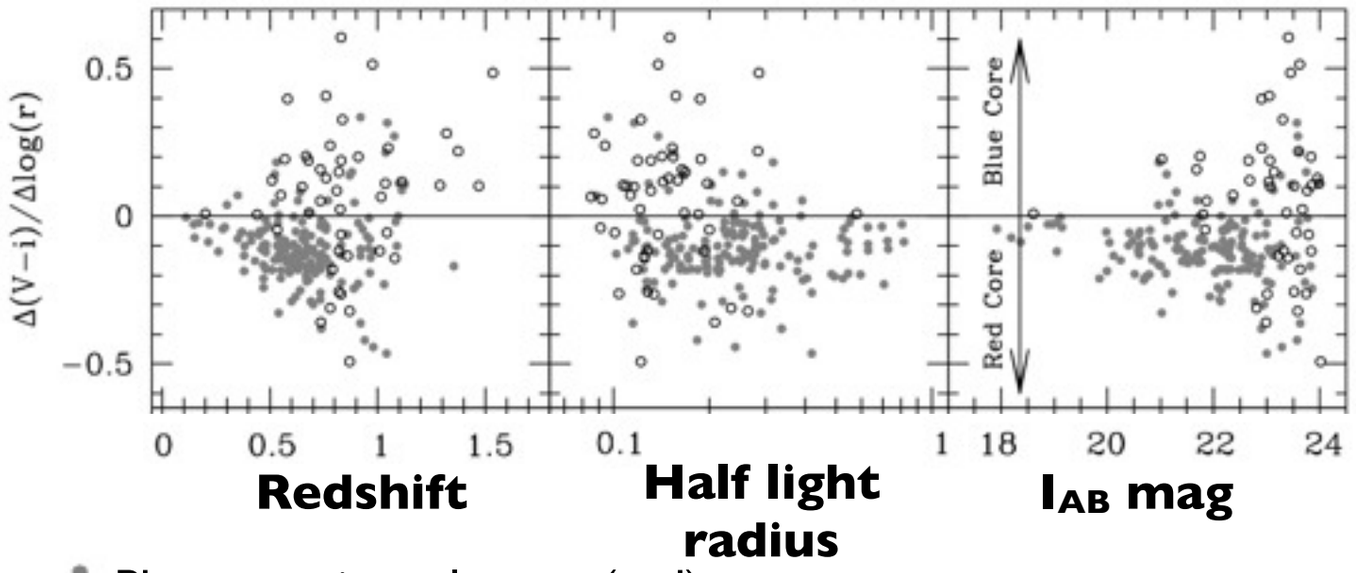
Background

- Color gradients indicative of mechanisms that govern the formation and assembly of stellar populations + indicate where in the galaxy star formation is concentrated (centre versus outskirts)

- **z<1**: SDSS galaxies in $0.01 < z < 0.17$ have redder cores and steeper gradients in early-type than late-type galaxies (Gonzalez-Perez et al. 2011)

- Some studies at higher redshift with relatively small samples e.g. Ferreras et al. (2005), Brok et al. (2011), Guo et al. (2011), La Barbera et al. (2011)



Ferreras et al. 2005

- Evolution of 249 field early-type galaxies in GOODS-South with median z~0.7.

- Most blue early types feature blue cores whereas most red early-types have passively evolving stellar populations with red cores (similar to local E-types).

- Color gradients and their scatter do not evolve significantly with redshift up to z~1 & compatible with z~0 observations

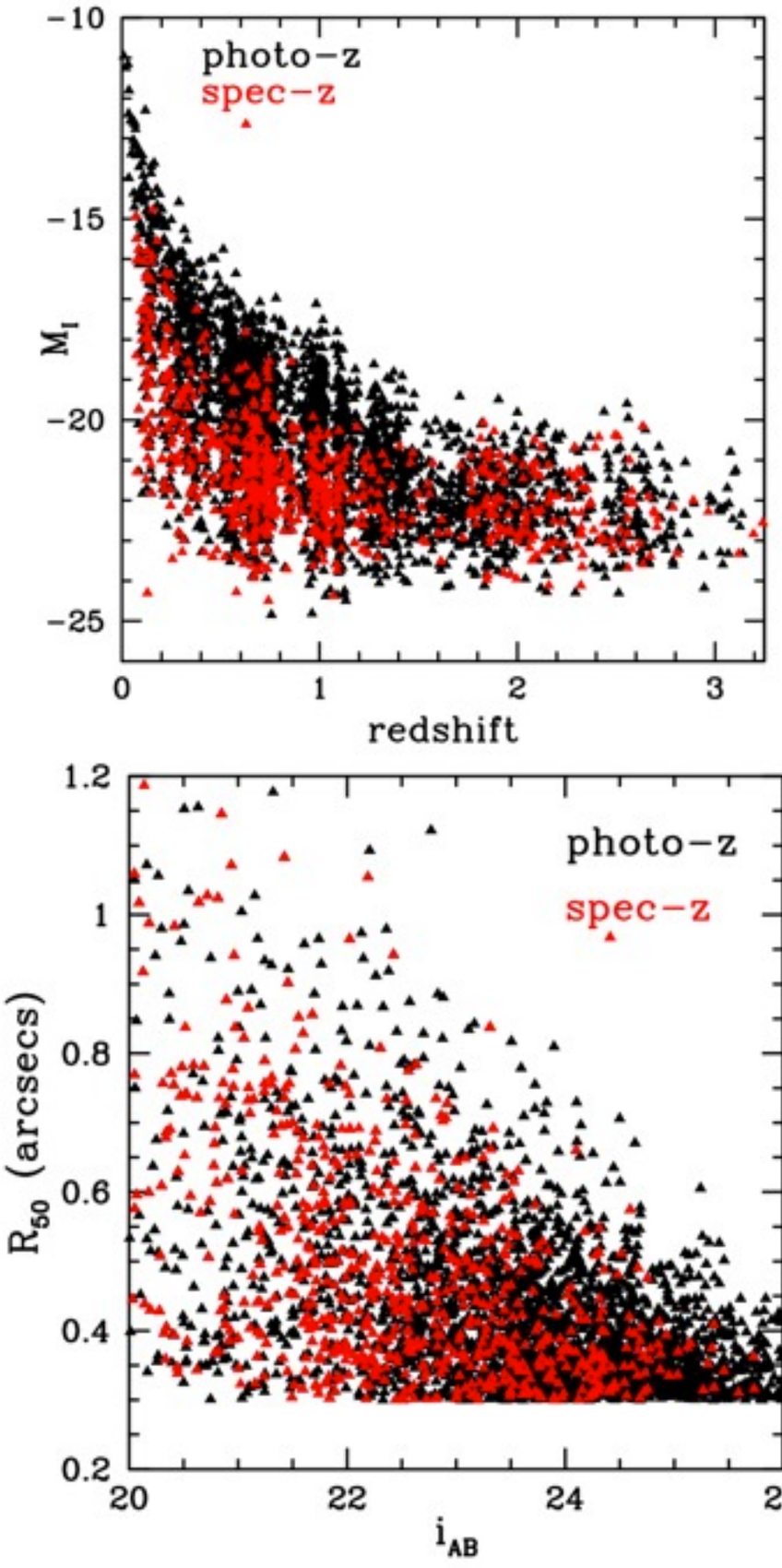
The Sample

- Magnitude-limited ($i_{AB} < 25.5$) sample of **3248** resolved galaxies with photometric redshifts out to z~3 in GOODS-S (Giavalisco+04, Cardamone+10) after applying a selection of R50>0.3" on galaxy size

- Photo-z sample complete down to z~2.5 and M_I< -20.0

- Subsample of **531** galaxies with photo-z and spec-z from GOODS-VIMOS (magnitude-limited IAB<24.5, complete down to z~2 and M_I < -21.0).

- $\langle R_{50} \rangle$=0.45" (D_{50} ~ 8 PSF FWHM(i)) (i))



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Sample characteristics

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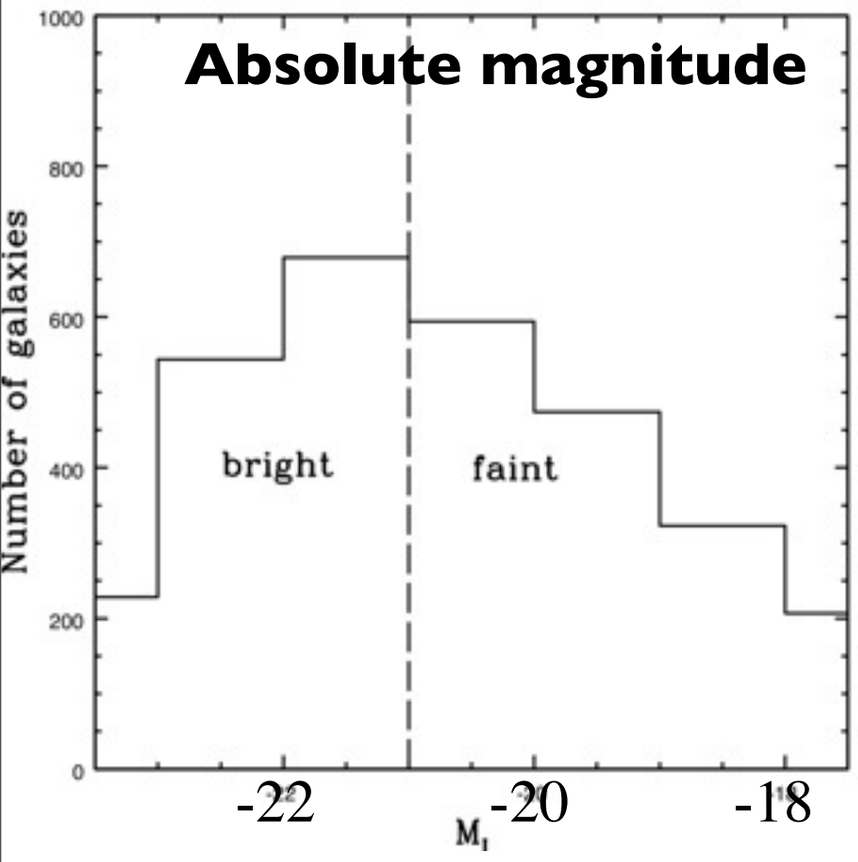
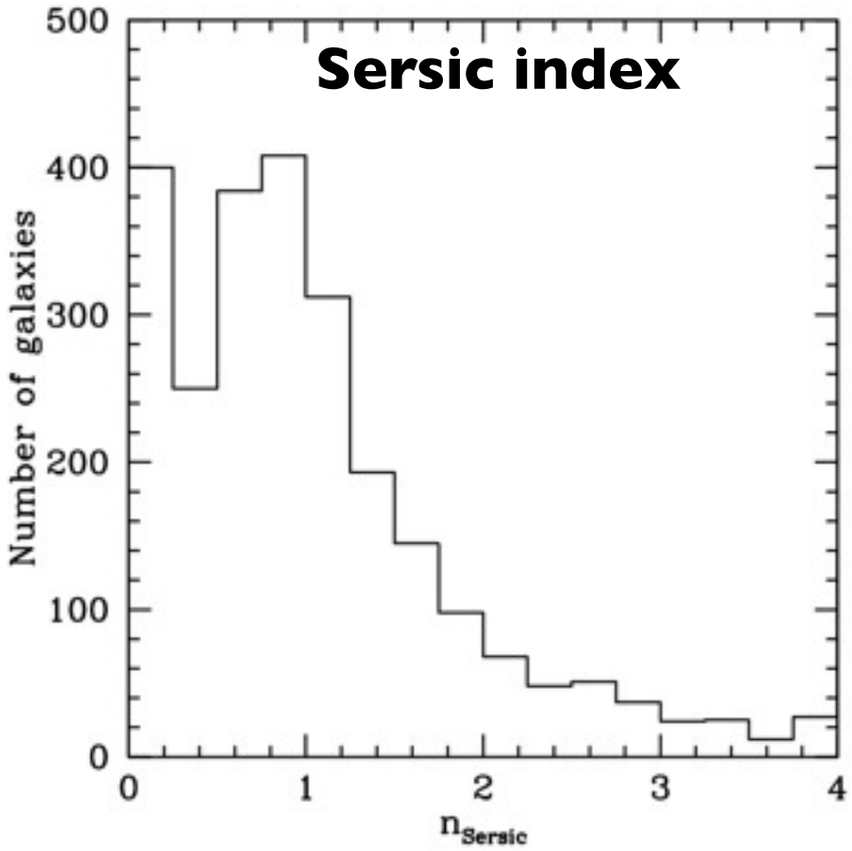
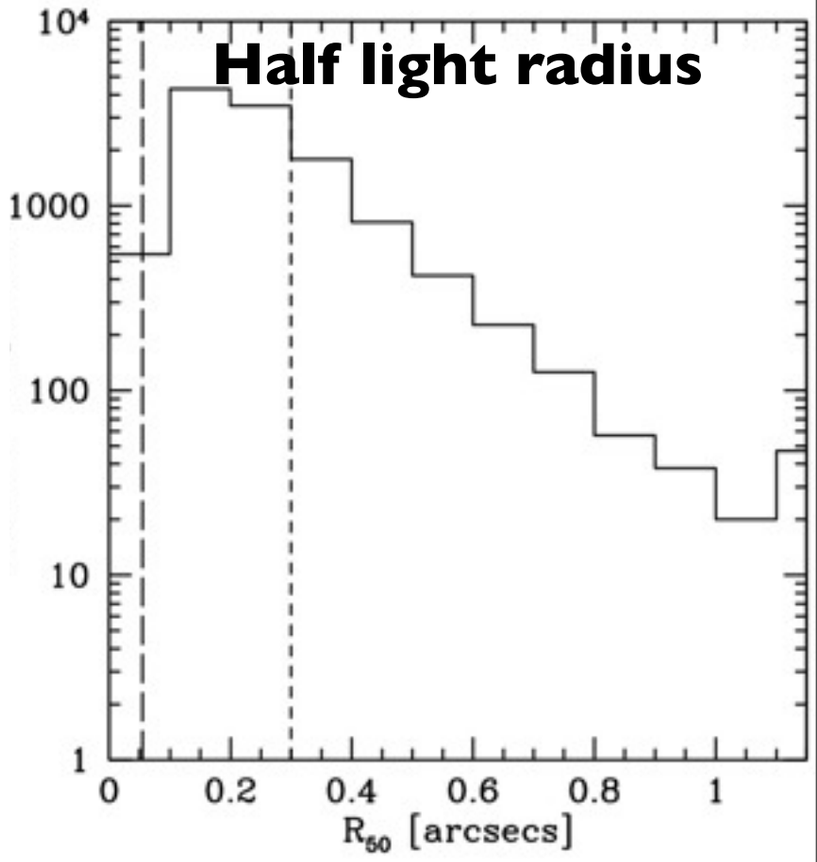
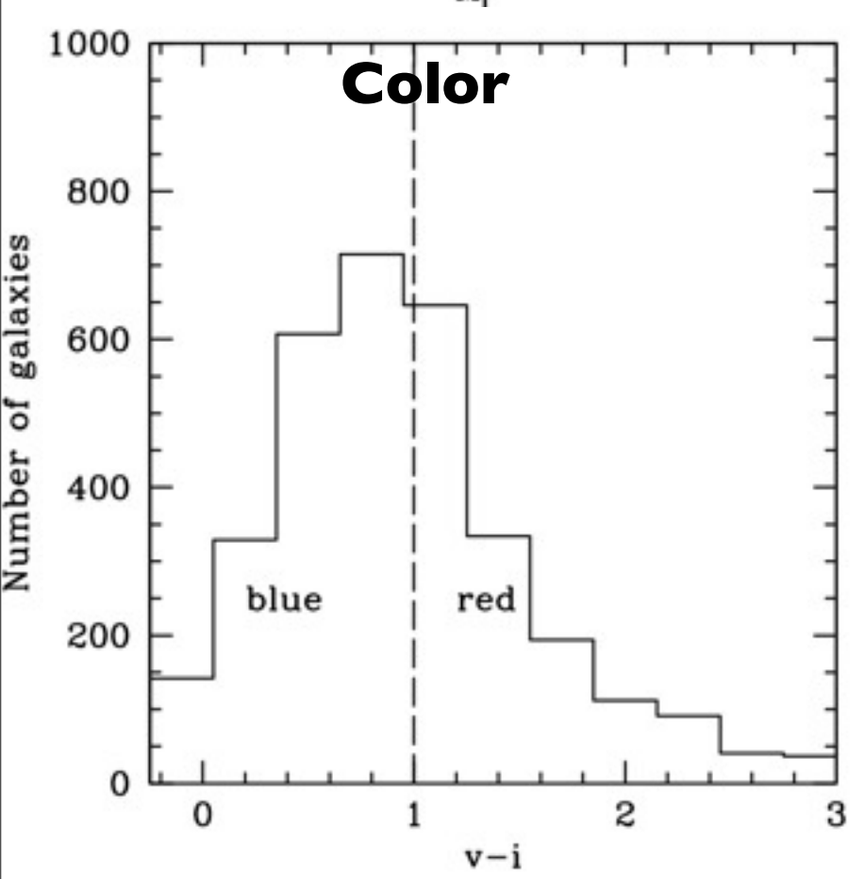
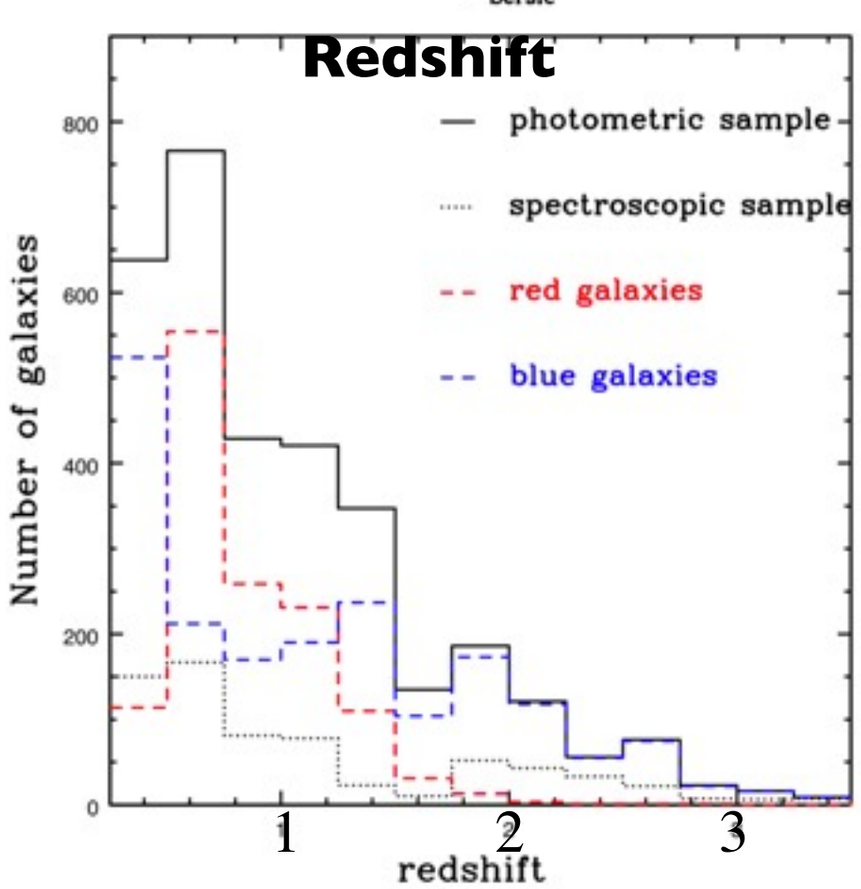
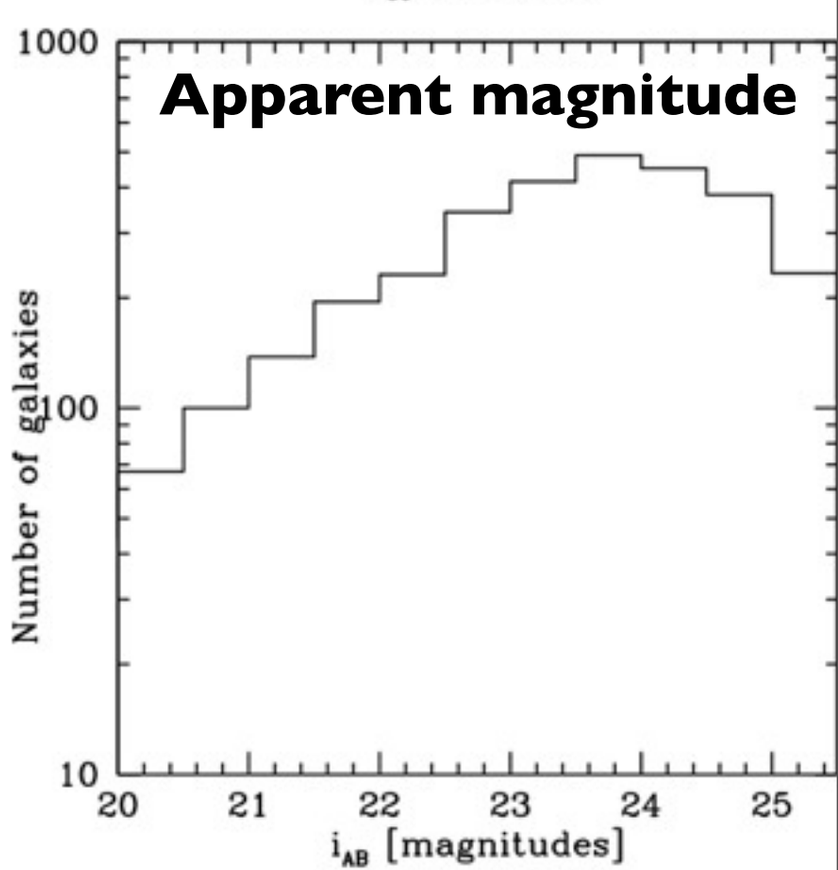












Measuring the color gradient

- Measured as difference in ***v-i*** observed color (after PSF homogenization) between (R_{50} <r<$2R_{50}$) and r<R_{50}

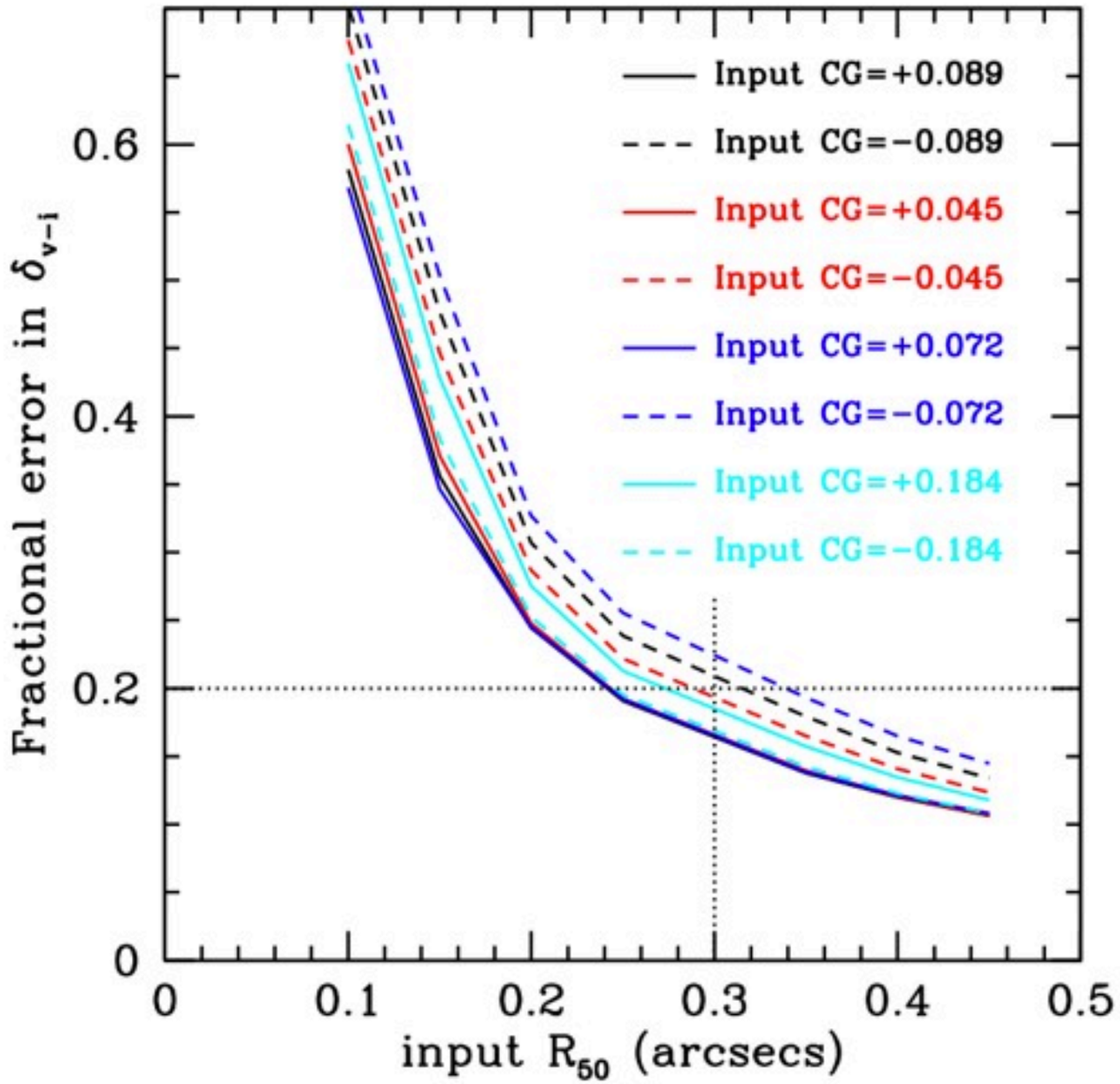
- Radial dependence of SNR in volume-limited subsample ⇨ **r<2.5R_{50}**

- At z~2-3, when galaxies are stacked, SNR=9.0 at 1.5<r<$2R_{50}$

- SNR of stack < 2.0 for r > 2.5 R_{50}

- Simulate disk galaxies with input color gradient and resolution to determine effect of galaxy size: for **R_{50} < 0.3" (D_{50} < 5.5 FWHM)**, fractional error exceeds 0.2:

- Limit more conservative than **D >1.6 FWHM** used in COSMOS survey for shape measurements (Leauthaud+07)



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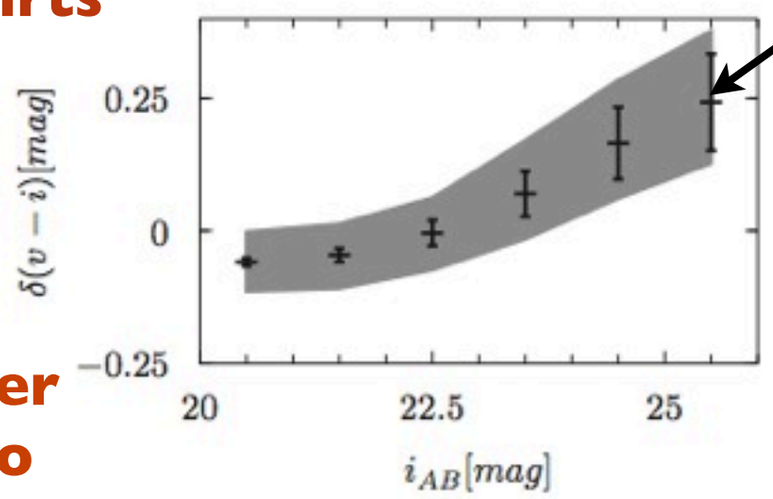
Results: Dependence on Galaxy Properties

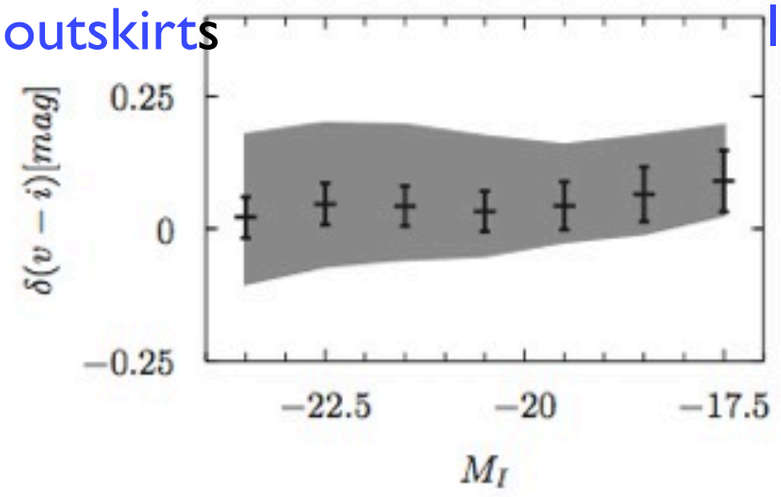
Core bluer relative to outskirts

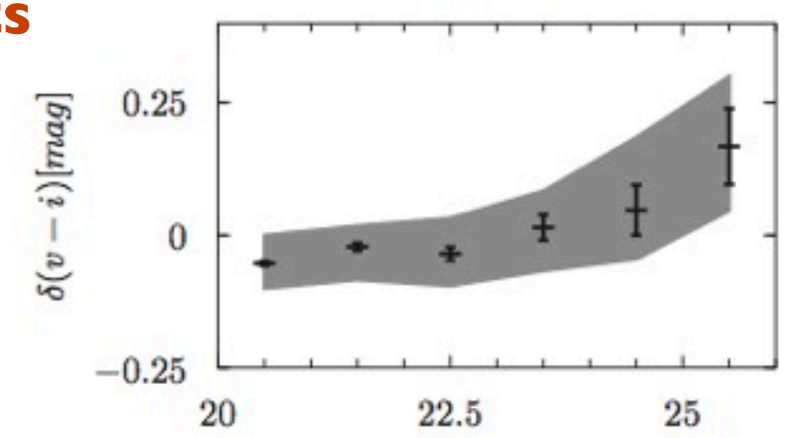
Core redder relative to outskirts

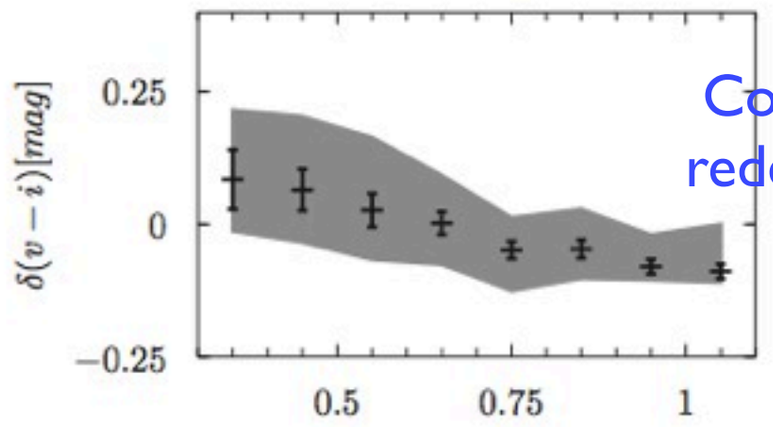
Fainter galaxies progressively redder in outskirts

Weak dependence o luminosity





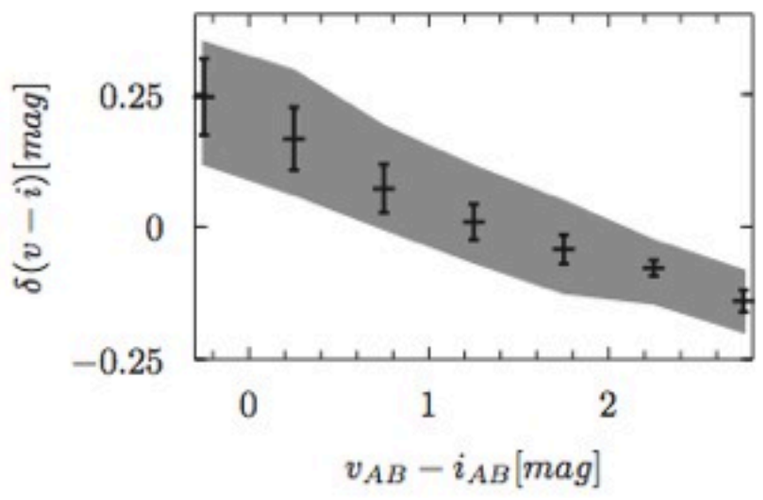


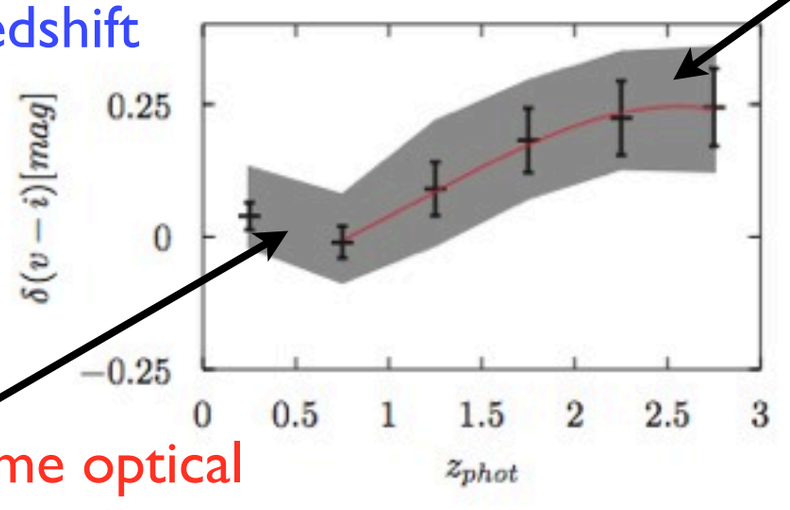


Core becomes redder with size

Core becomes bluer with redshift

Strong color dependence: Redder galaxies have redder cores (~ local S0/Sa)





Rest-frame UV (younger stellar populations)

Rest-frame optical (older stellar populations)

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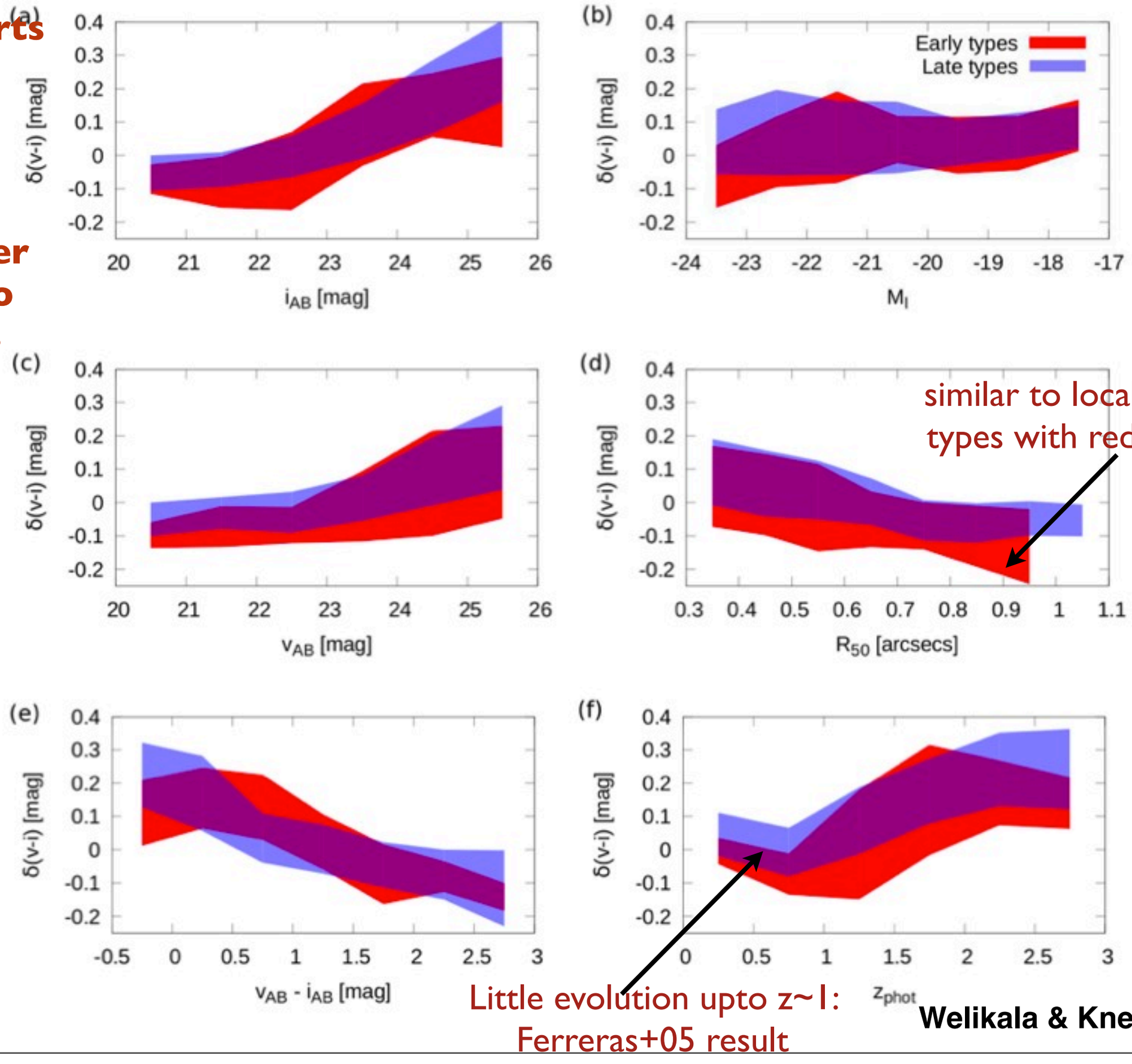
Results: Morphological Type Dependence

Core bluer relative to outskirts

Core redder relative to outskirts



similar to local early-types with red cores

Little evolution upto z~1: Ferreras+05 result

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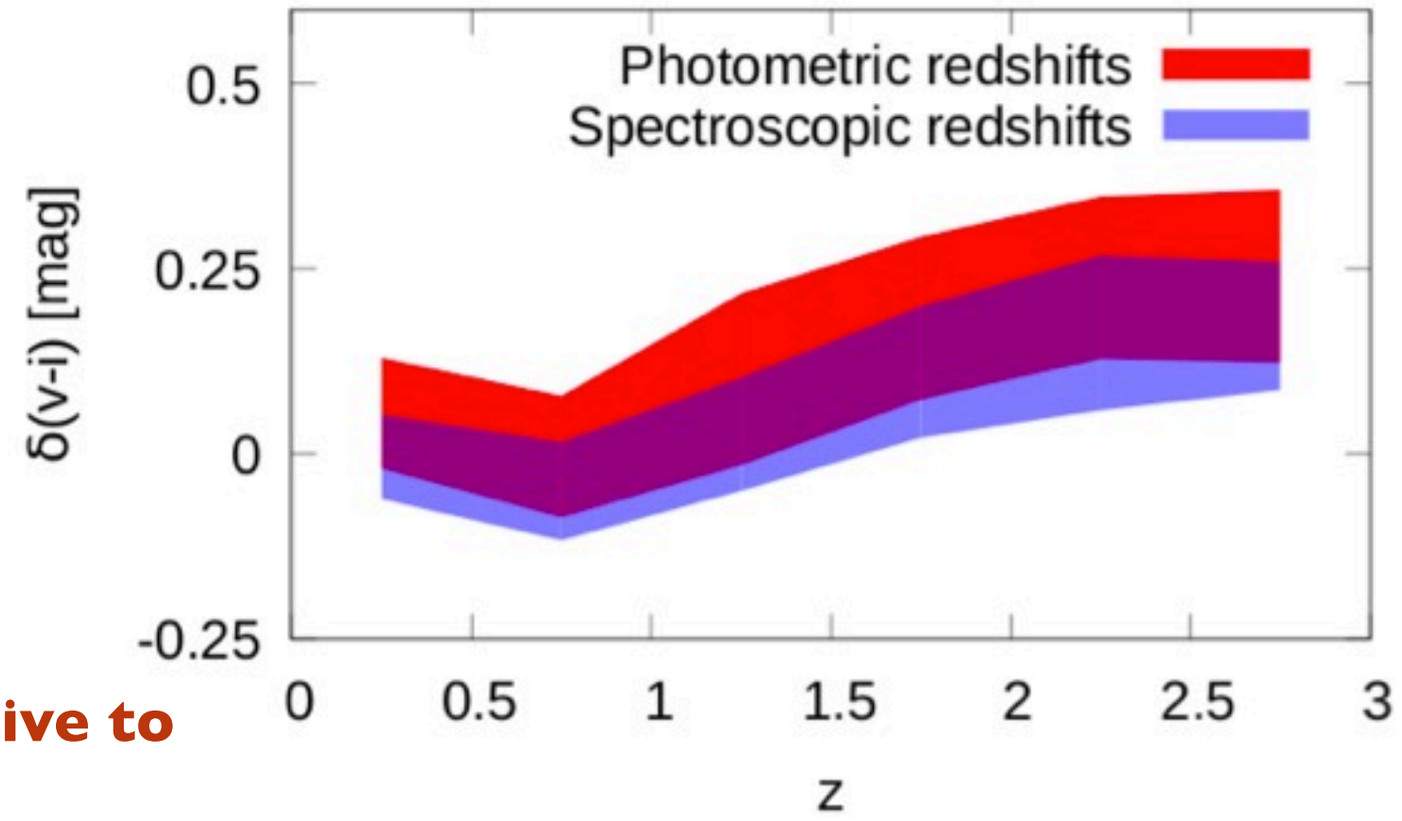
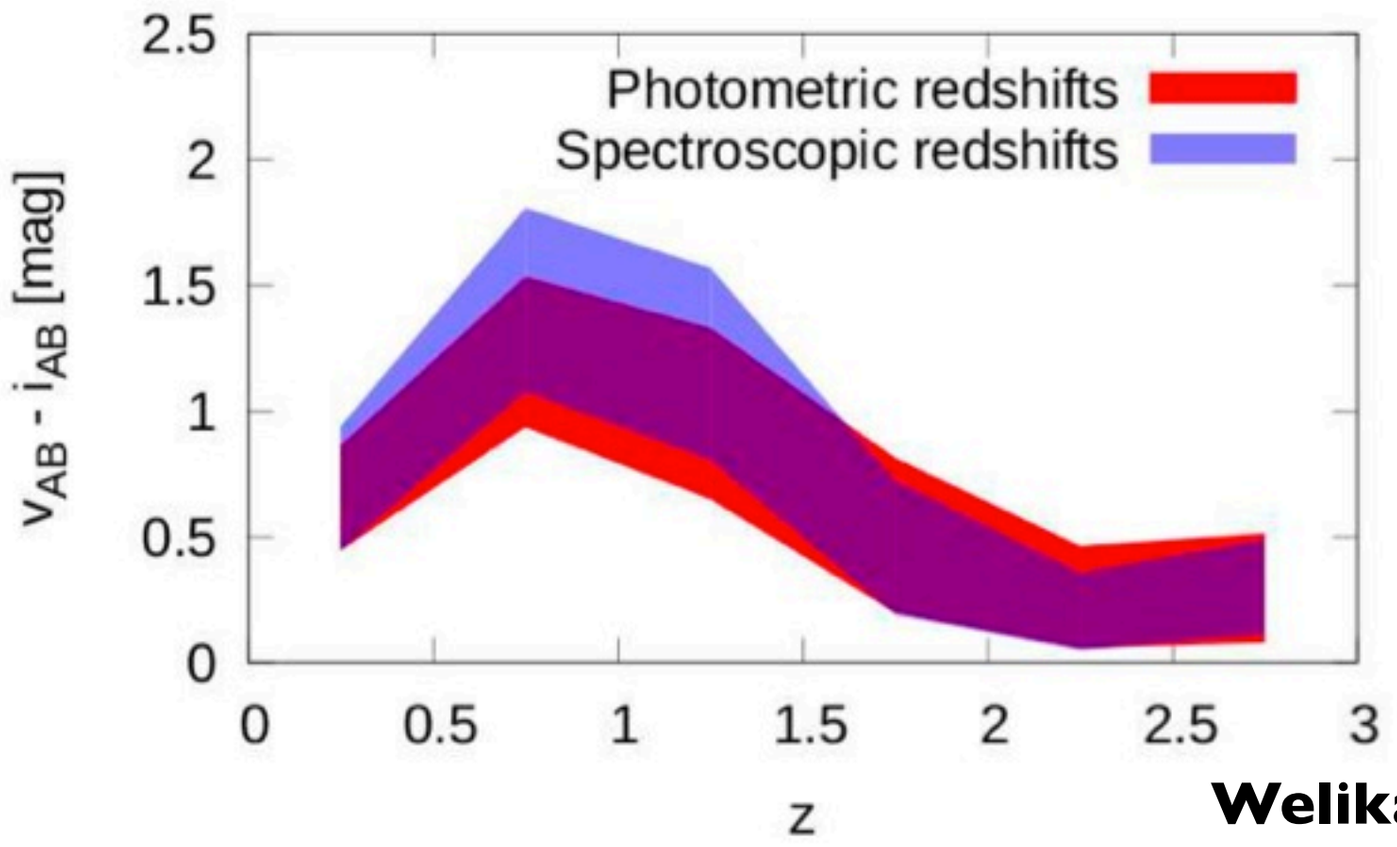
Photo-z versus spec-z

Core bluer relative to outskirts

Core redder relative to outskirts





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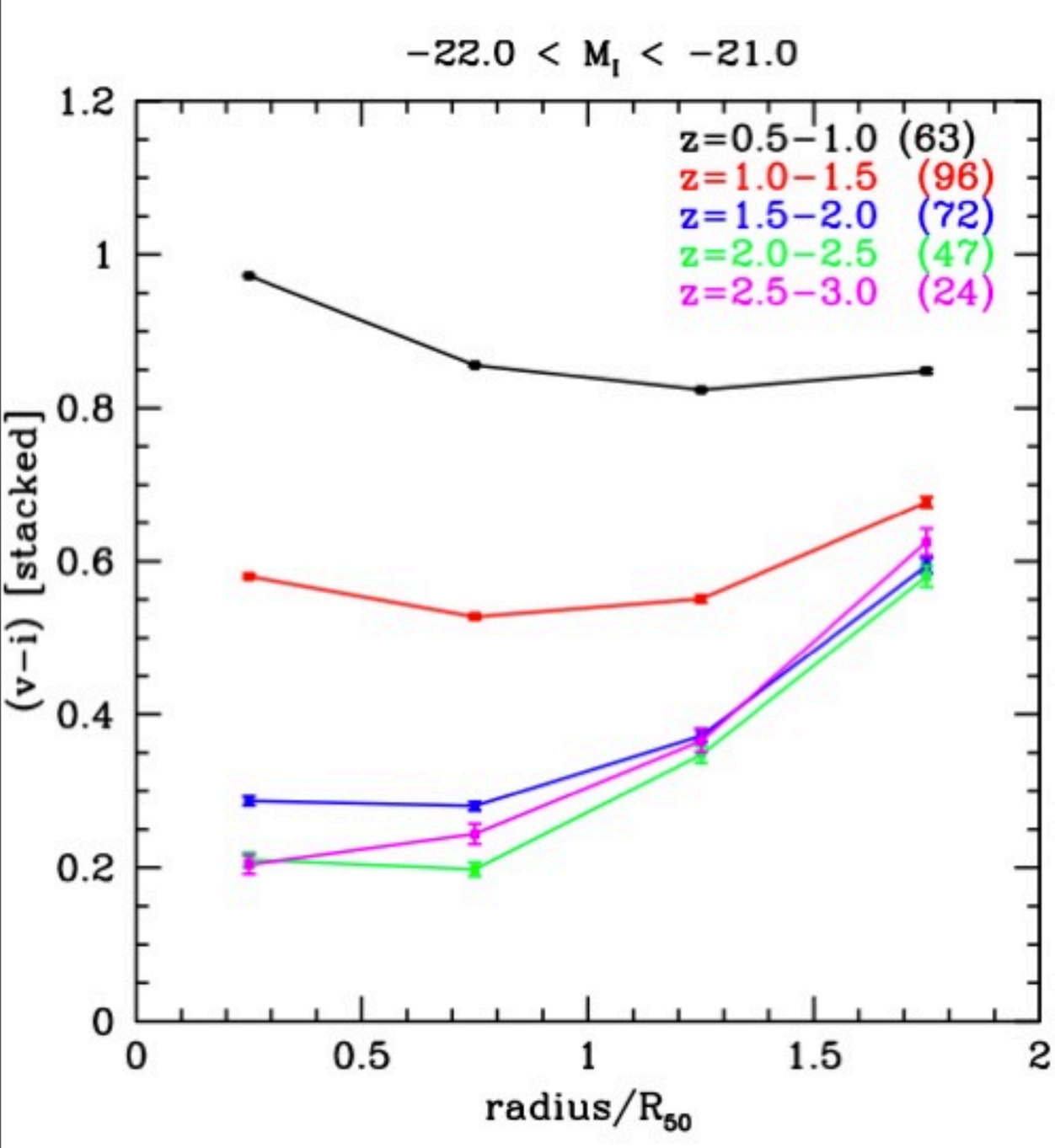
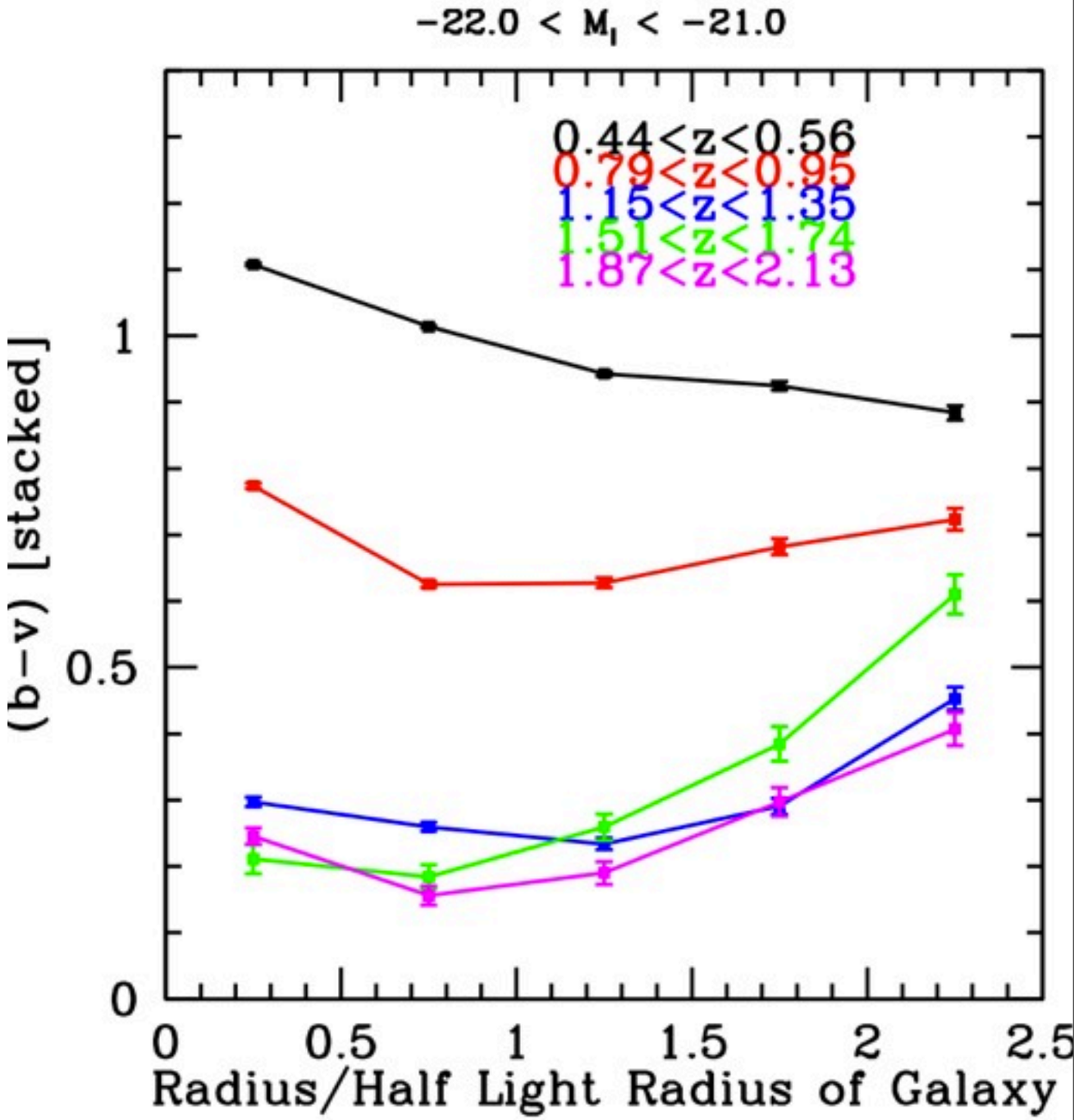
The stacked color variation: Bright galaxy sample





Bluer cores relative to outskirts at high redshift
Color difference between centre and outskirts becomes larger at high z (0.4 mag at z~2.5)

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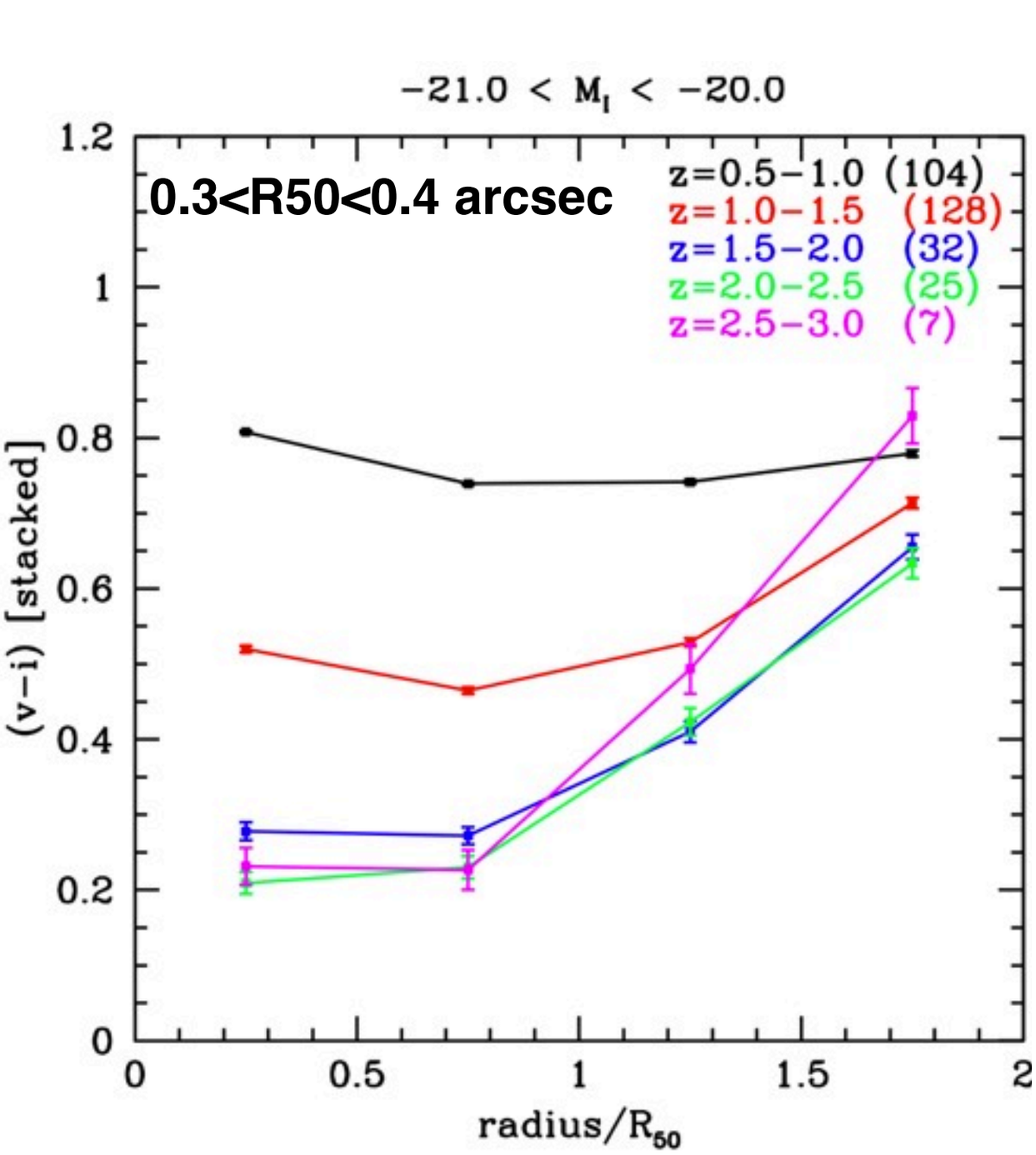
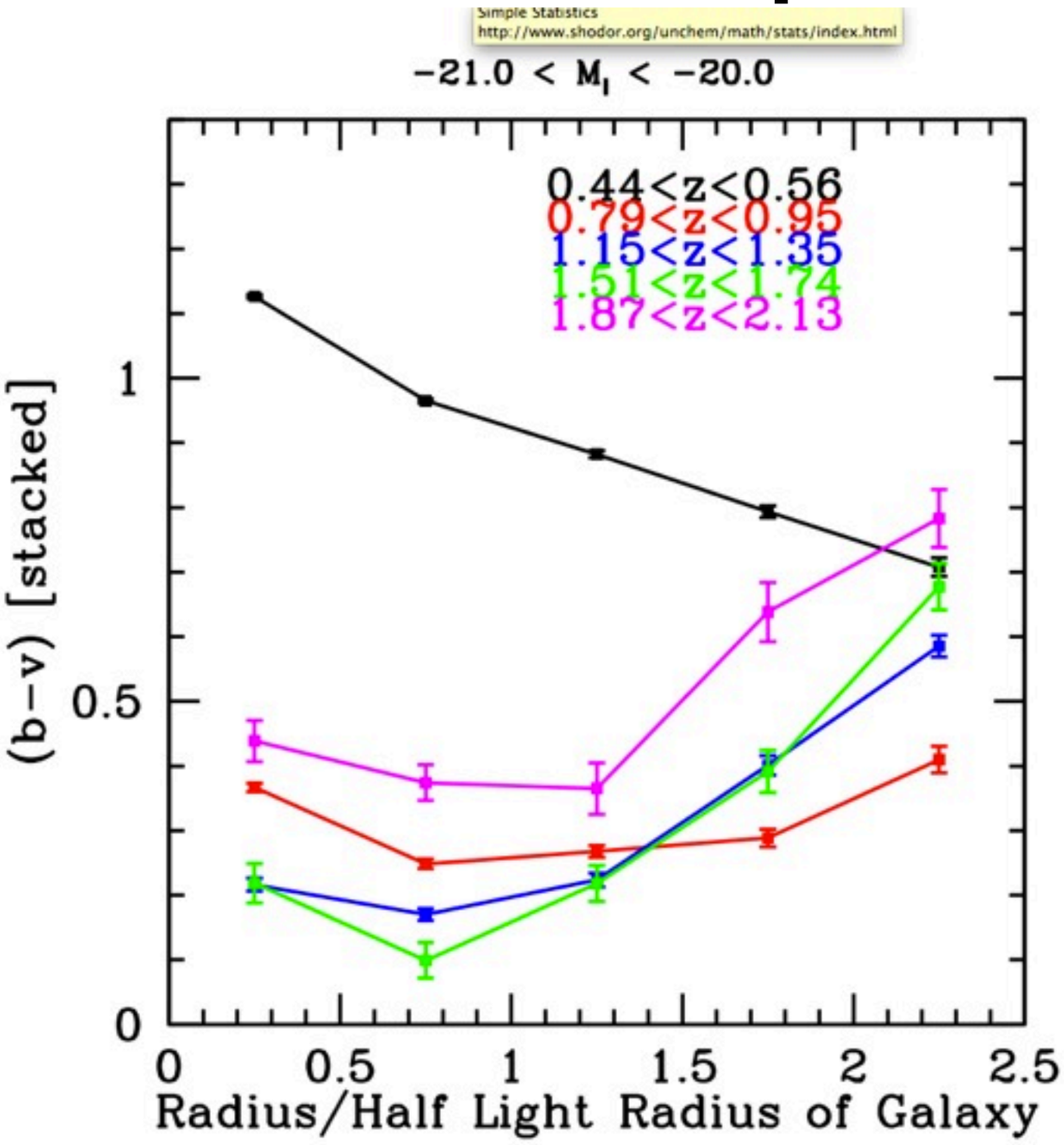
The Stacked color variation: Fainter sample





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Summary

- Suggest bluer centers compared to outskirts
- **Lehnert+09**: large Hα line widths observed in z~1-3 intensely star-forming galaxies driven by self-regulated SF through the mechanical energy liberated by massive stars
- Intensity of SF in these distant galaxies as high as local starbursts but SF occurs on a much larger physical scale, maintained by high gas fractions & mass-surface densities

- **Le Tiran+11** stacked rest-frame optical emission lines ([SII]λλ7616,6731 and [OI]λ6300) of ~50 color-preselected galaxies at z=1.2-2.6 with high Hα surface brightnesses

- Found evidence for outflows + higher gas densities (and pressures) in intensely star-forming regions compared to fainter, diffuse gas - similar values to starburst regions & diffuse ISM in nearby galaxies.

- Thus: if very high gas densities are present in the centers of z>1.5 galaxies → strong star formation driven by feedback & self-regulation and is concentrated in the centers → could be consistent with our observed color gradient trends

PSF homogenization

- Alard (1999), Alard & Lupton (1998)
- Find the kernel that matches input image to a reference image
- Kernel is decomposed into a linear combination of basis functions (delta functions or Gaussians of varying FWHM)