Sesto - 19th Jan 2017

The Cosmic Star-Formation History

revealed by ASTRODEEP and SCUBA-2

arXiv:1607.04283
(Bourne+2017; MNRAS)

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In collaboration with …
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Introduction:

WHY STUDY THE CSFH?

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WHY SCUBA-2?

Motivation

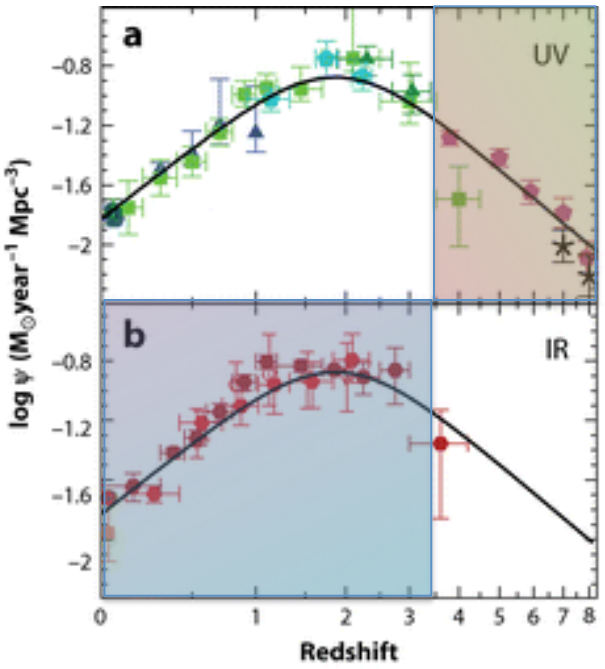
The cosmic star formation history: ***Building up the galaxy population***

evolution of SFR density of the Universe

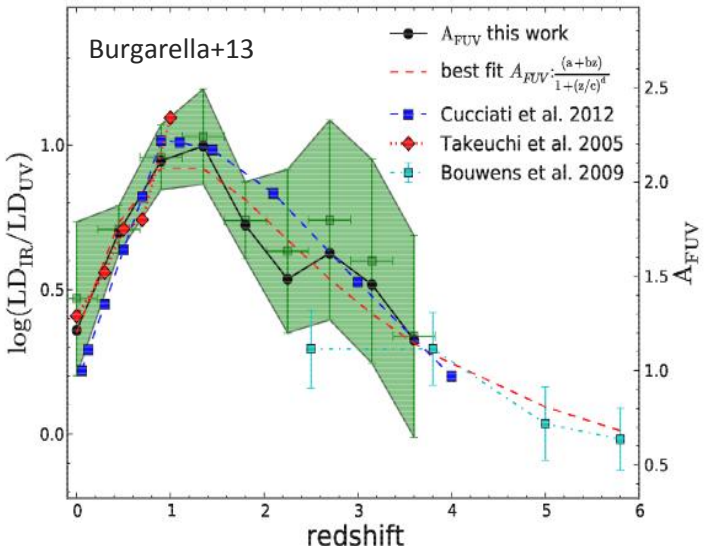
evolution of SFRs in the galaxy population

The most widely available tracers of SFR at high redshift are FUV and FIR

SFR density



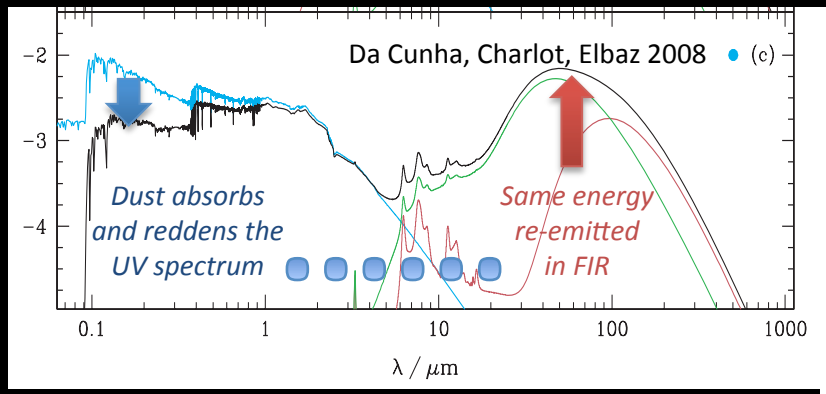
Madau P, Dickinson M. 2014.
Annu. Rev. Astron. Astrophys. 52:415



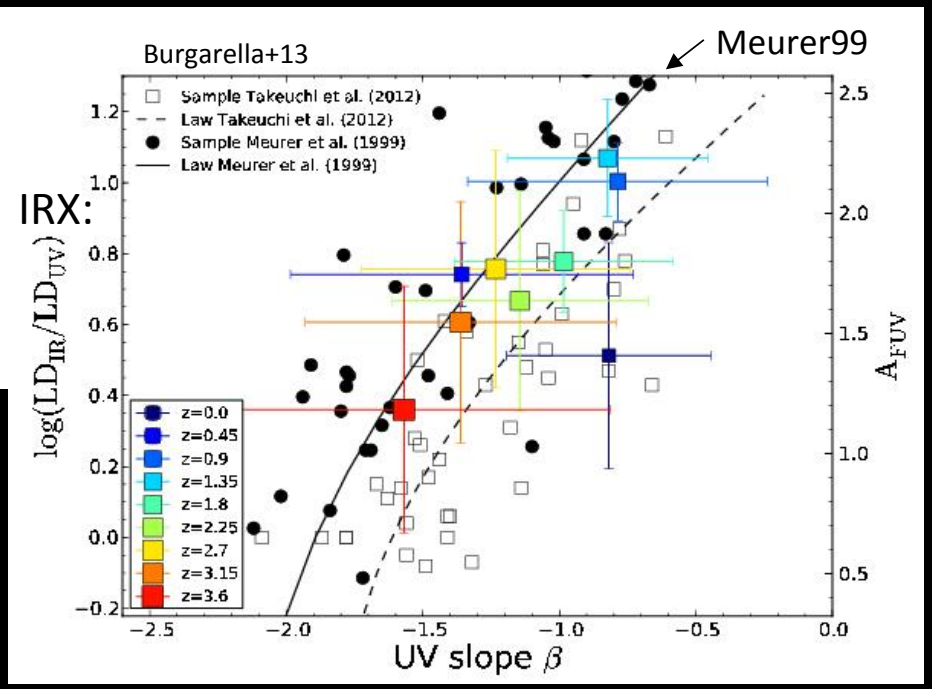
Predicting dust obscuration

How to estimate this in the absence of FIR detections?

- Need a calibration based on UV slope – *the "IRX-beta" relation*
- But this needs better validation at high redshifts



- Depends on intrinsic (unreddended) UV slope
- SFH (recent burst fraction)
- Metallicity
- Dust attenuation curve
- Geometry



Methods:

HOW TO GET BETTER DUST MEASUREMENTS AT HIGH-Z

Beating the confusion limit

How can existing datasets help us with our problems?

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Deep sub-mm imaging with low confusion and instrumental noise:

The SCUBA-2 Cosmology Legacy Survey

450+850μm imaging with beam = 7.5, 14 arcsec; Inst. Rms ~ 1.0, 0.2mJy/bm

Geach et al. 2013; 2016

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Deep & complete NIR-selected prior catalogues:

CANDELS/3D-HST

Spec+grism+photo-z

UV-MIR photometry

Derived stellar pop. params

Brammer et al. 2012; Skelton et al. 2014; Momcheva et al. 2015

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Photometric de-confusion algorithm:

T-PHOT

Measure faint confused sources by fitting the map with positional priors

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Beating the confusion limit

How can existing datasets help us with our problems?

S2CLS deep fields: ~230 arcmin^2 in UDS, COSMOS, AEGIS

Obtain flux measurements and covariance matrix for all priors

Sample: K<24 or [3.6]<24; 0<z<6; logM>9

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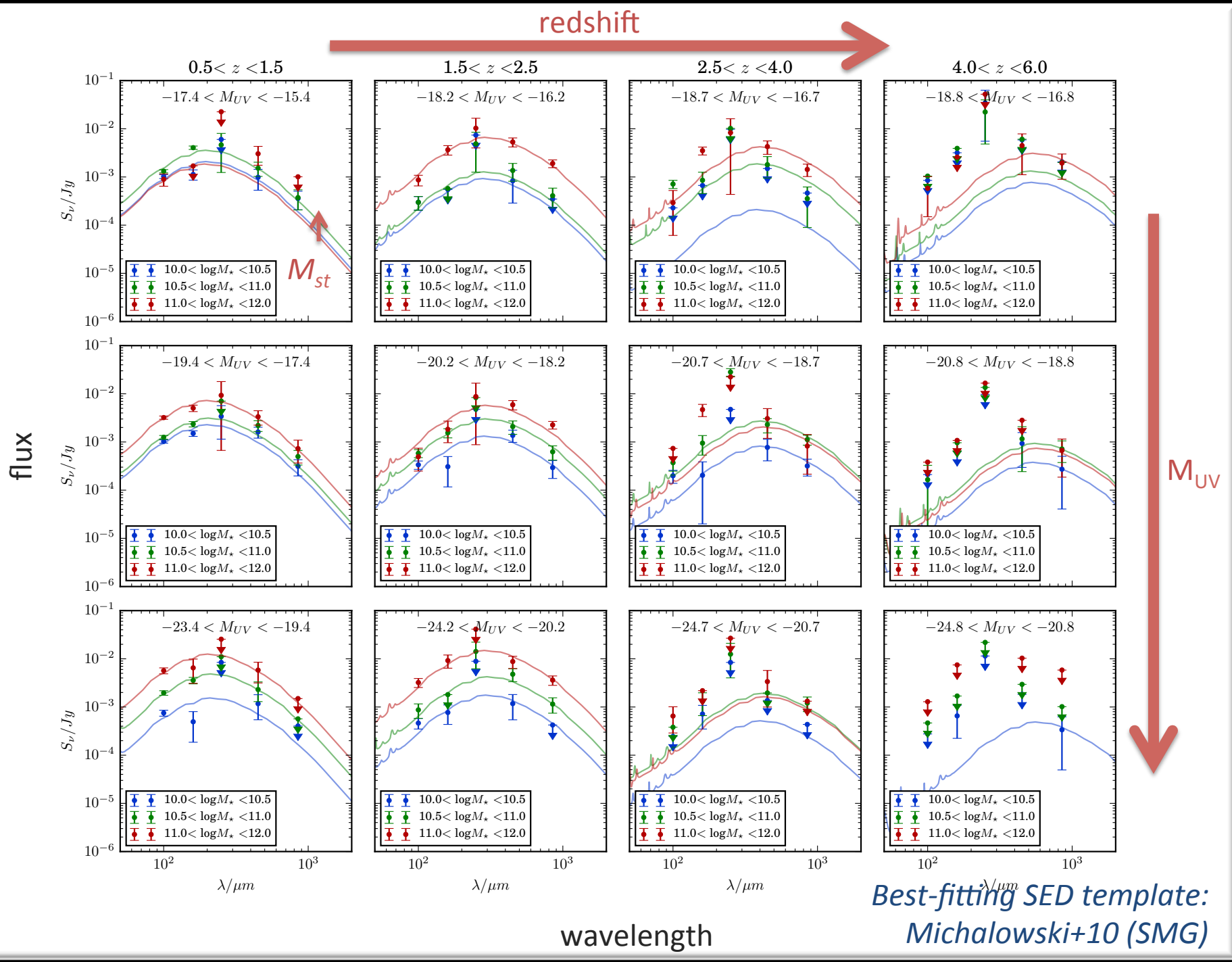
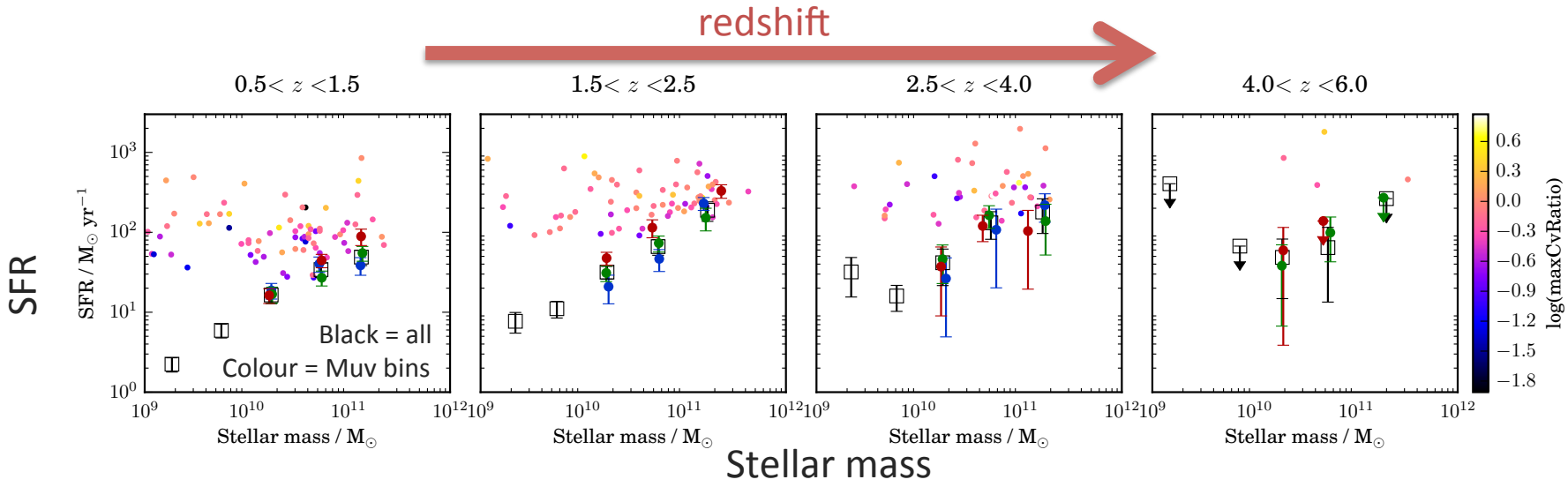

redshift
0.5< z <1.5
1.5< z <2.5
2.5< z <4.0
4.0< z <6.0
−17.4 < M_UV < −15.4
−18.2 < M_UV < −16.2
−18.7 < M_UV < −16.7
−18.8 < M_UV < −16.8
−19.4 < M_UV < −17.4
−20.2 < M_UV < −18.2
−20.7 < M_UV < −18.7
−20.8 < M_UV < −18.8
−23.4 < M_UV < −19.4
−24.2 < M_UV < −20.2
−24.7 < M_UV < −20.7
−24.8 < M_UV < −20.8
10.0< logM_* <10.5
10.5< logM_* <11.0
11.0< logM_* <12.0
M_st
M_UV
S_ν/Jy
λ/μm
flux
wavelength
Best-fitting SED template:
Michalowski+10 (SMG)

Results:

STAR FORMATION AND OBSCURATION AT HIGH-Z

SFR

comparing FIR, UV, and mass-selected samples:

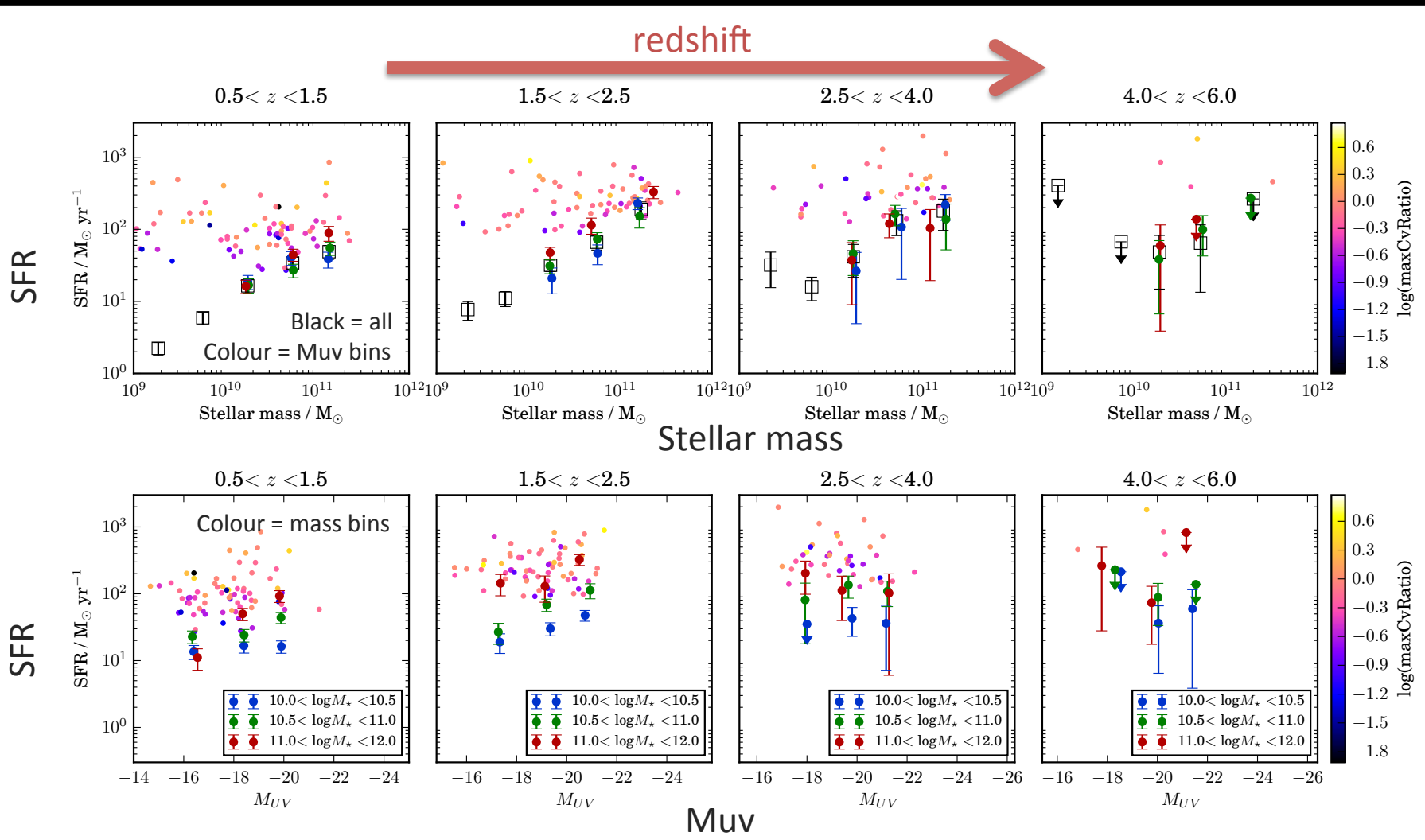


SFR_tot = SFR_IR + SFR_UV

- 450-µm detected sources (FIR-luminous): SFR>~100Mo/yr, 0<z<4
- Mass-selected sample (open black squares): SFR correlated with stellar mass
- Binning by UV luminosity (blue, green, red symbols): not well separated in SFR

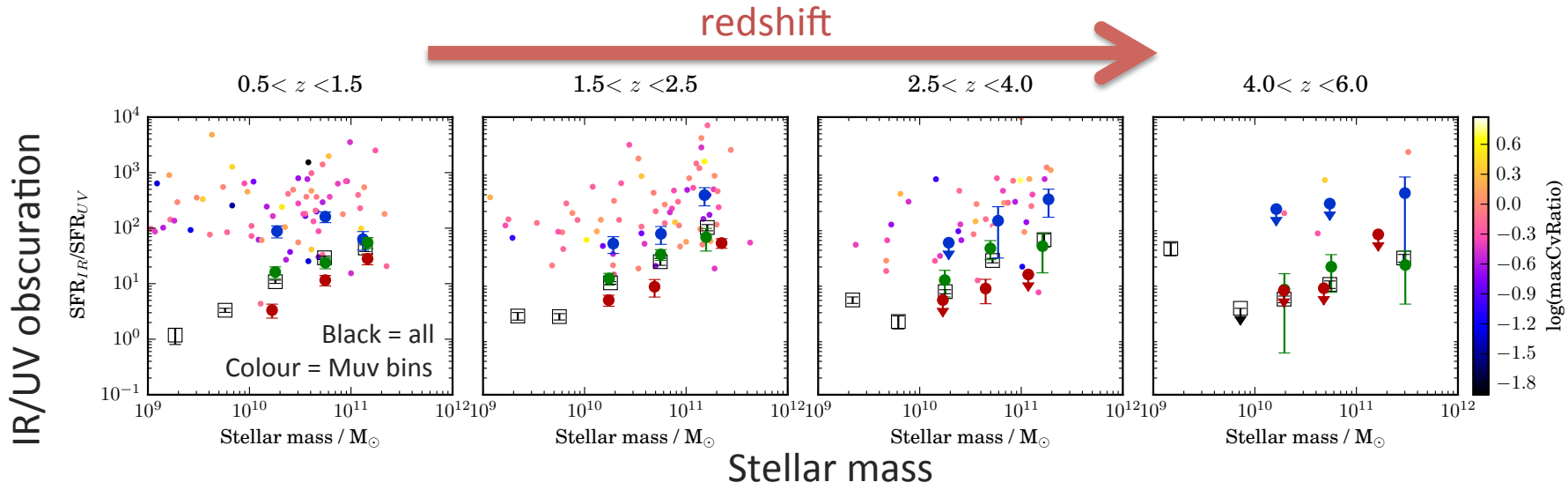
SFR

comparing FIR, UV, and mass-selected samples:



SFR Obscuration

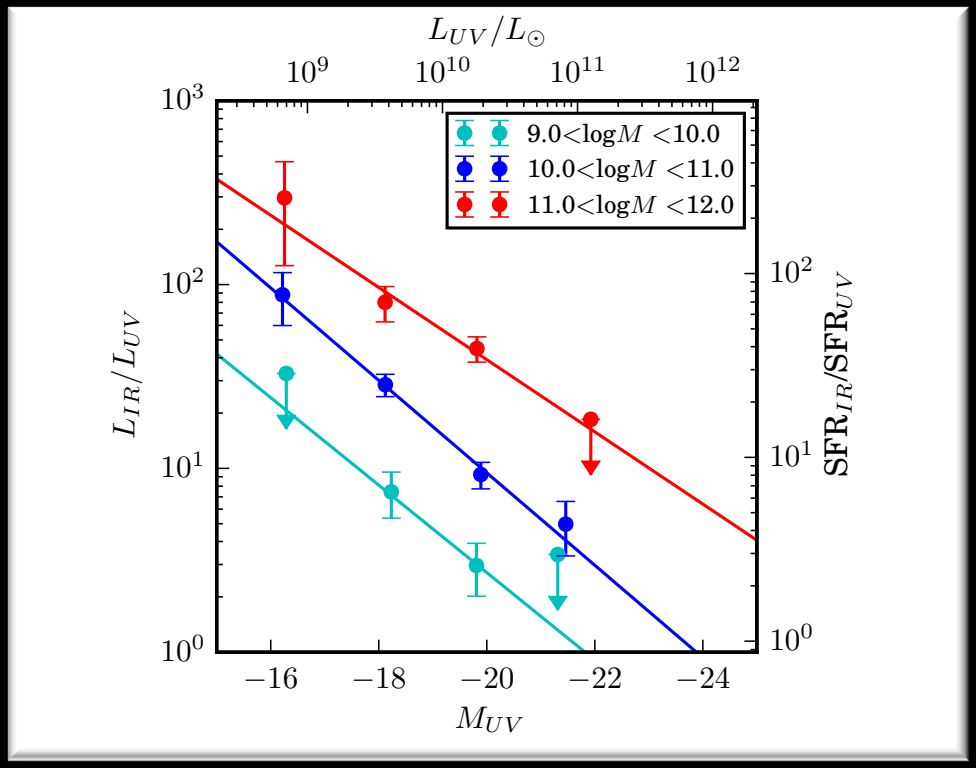
L_{IR}/L_{UV} strongly correlated with mass and M_{UV}



- More massive galaxies have higher SFR, and more of their star formation is obscured
- High FIR luminosities trace galaxies with the highest SFRs (wide range of obscuration)
- High UV luminosities trace the most unobscured star-forming galaxies

Obscuration as f(M,L_{UV})

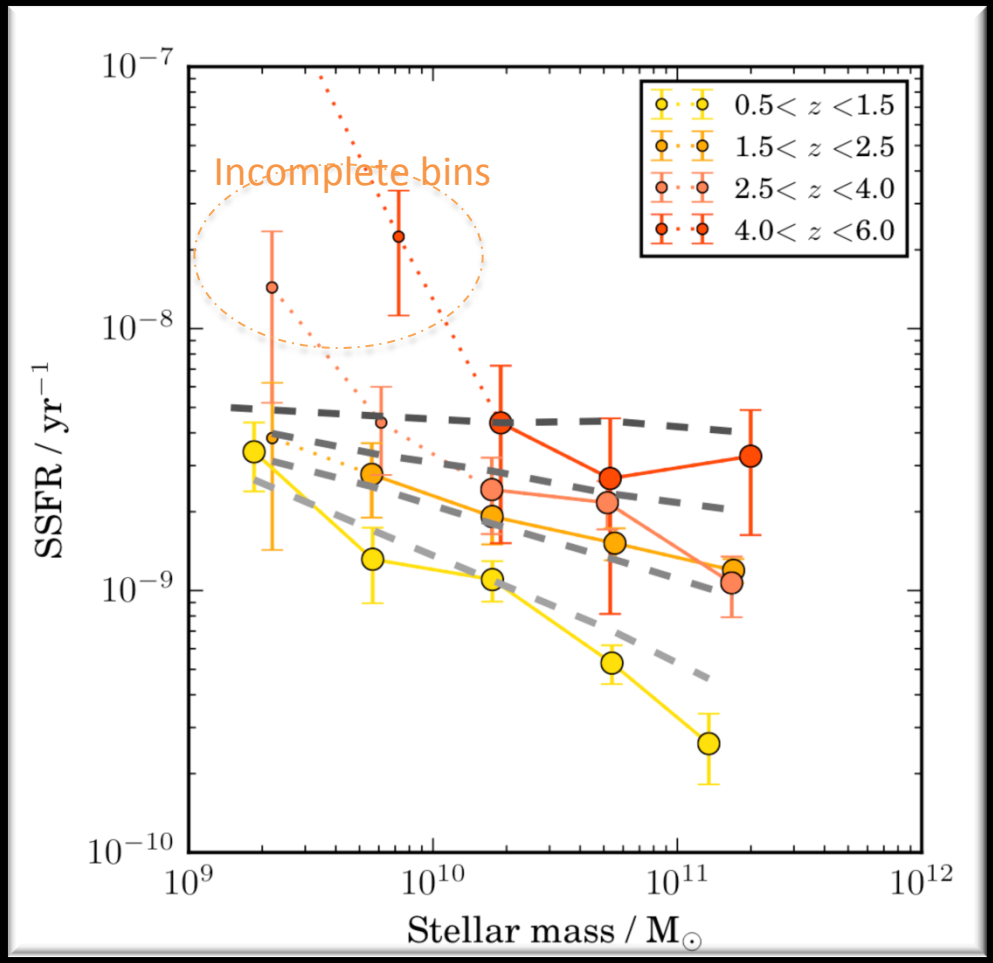
$L_{IR}/L_{UV} \sim M_{star}^{0.7} L_{UV}^{-0.6}$ – independent of z



- The most obscured galaxies are the ones with the highest stellar mass and lowest UV luminosity, but obscuration doesn't depend on redshift

…See also previous Herschel work – Buat+12, Hilton+12, Heinis+14, etc

SSFR(M,z)



Total (IR+UV) SSFR in UVJ-selected star-forming galaxies:

- SSFR(M) slope and normalization evolves with redshift
- At logM=10.5:

  SSFR ~ $(1+z)^{1.6(+/-0.2)}$
- At z=1, slope = -0.4
  At z=5, slope = 0.0

  slope ~ $(1+z)^{0.8(+/-0.5)}$

See also Whitaker+14; Schreiber+15; Tomczak+16

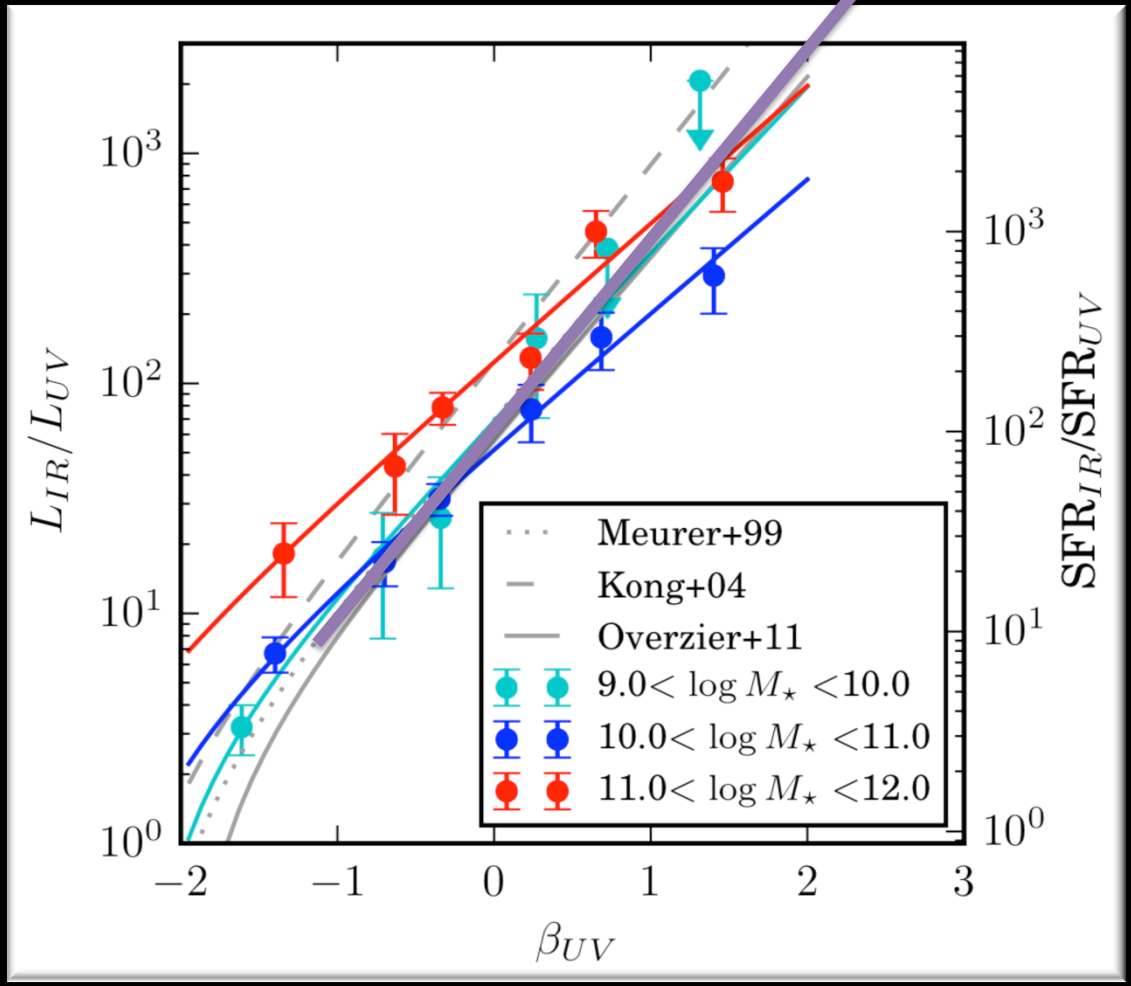
Results:

UV DUST CORRECTIONS

The IRX-beta relation

- Excluding passive galaxies based on UVJ colours
- $M<10^{11}M_{\odot}$ galaxies close to Meurer law
- $M>10^{11}M_{\odot}$ galaxies have higher extinction for given UV slope

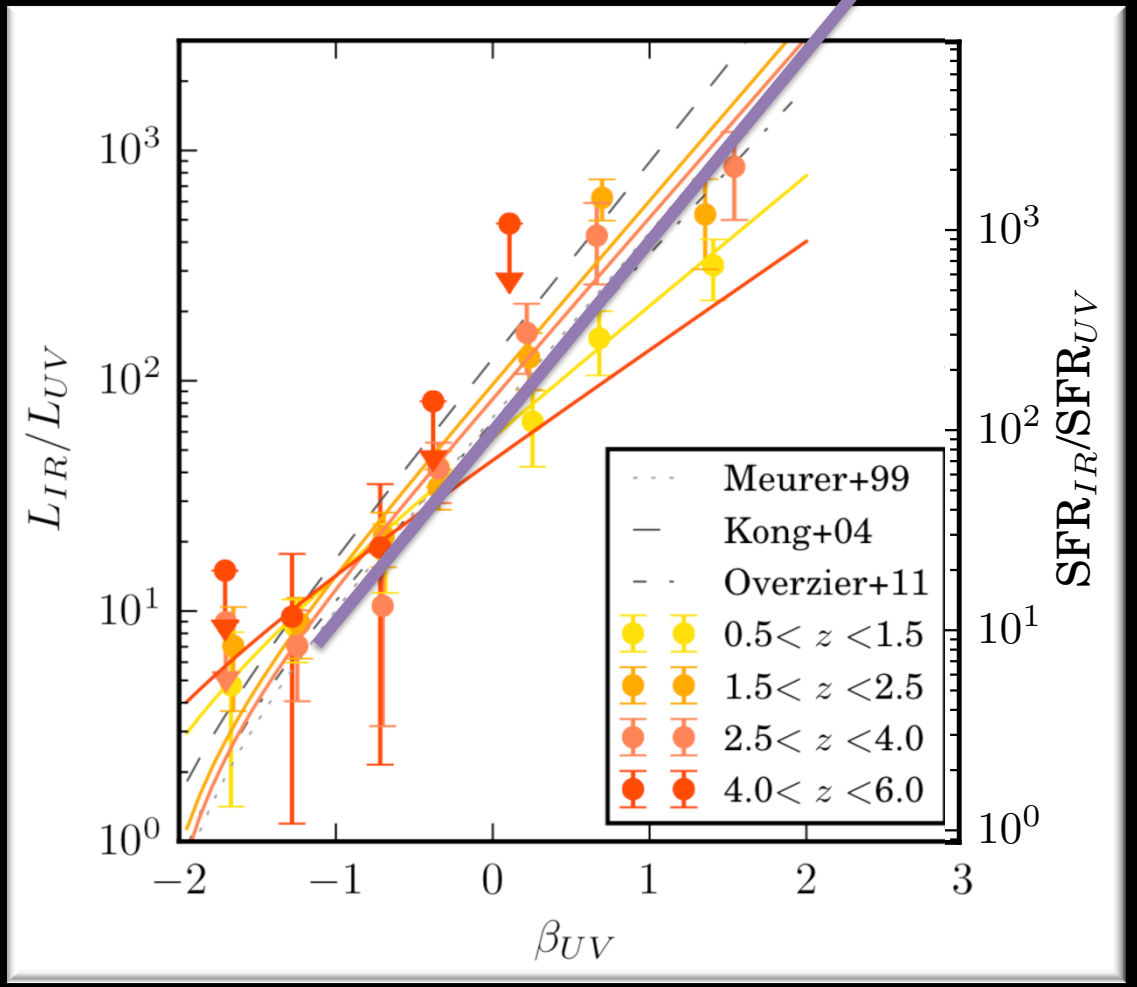
See also Coppin+15; Alvarez-Marquez+16; Bouwens+16 (studies of z~3 LBGs)



The IRX-beta relation

- Does the IRX-beta relation evolve with z?
- No evidence for this at z>1.5
- At z<1.5, maybe contaminated with red, passive galaxies?

But see also Oteo 14; Pannella+15: evolution in Herschel-detected samples

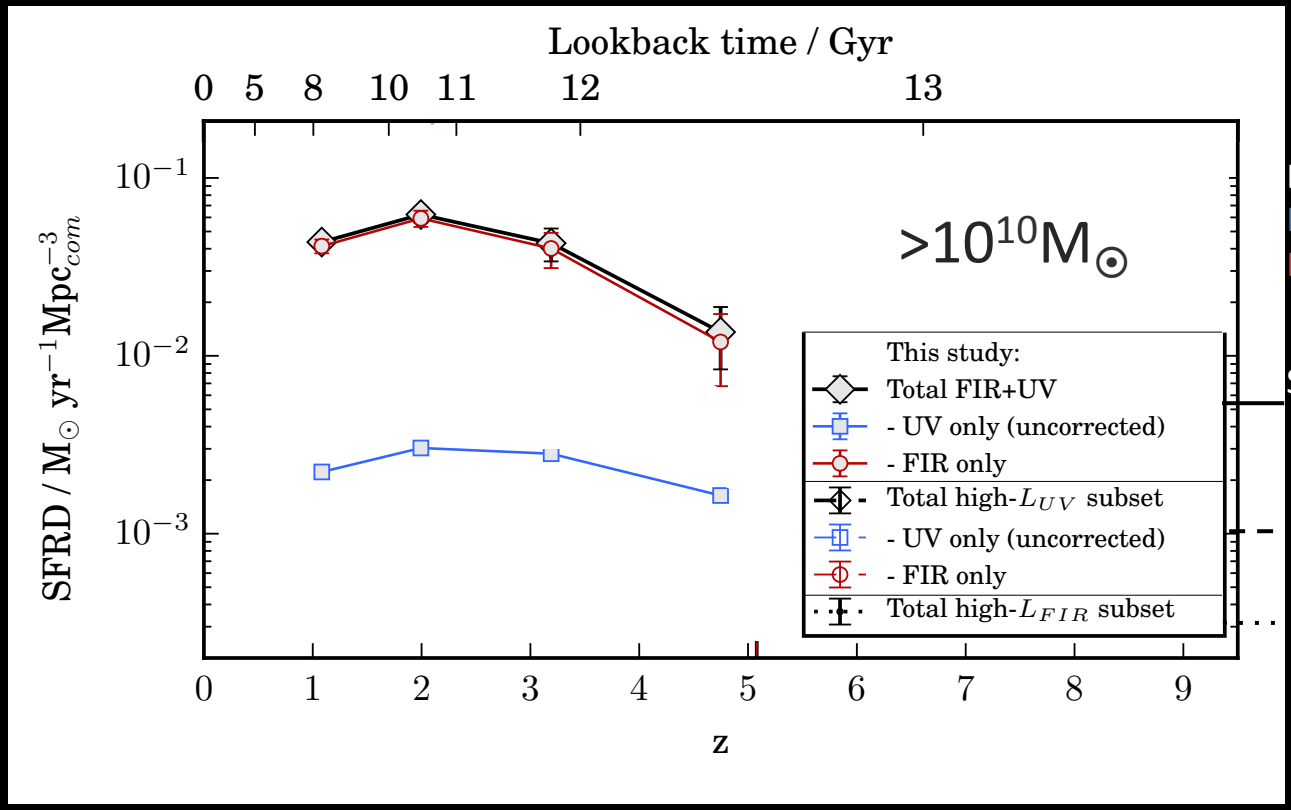


Scatter across the population induces strong sample-selection effects

Results:

COSMIC STAR FORMATION DENSITY AT Z<6

Cosmic SFR density in massive galaxies

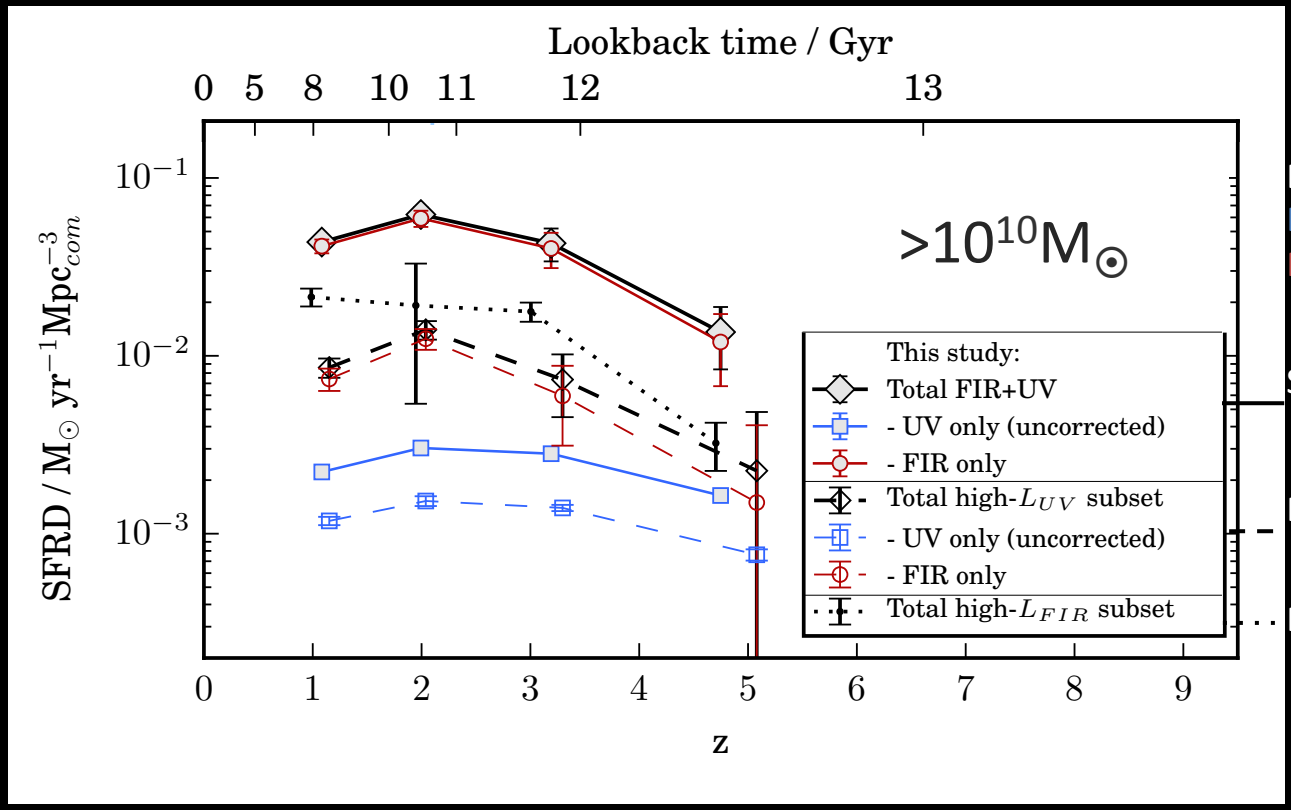


Black=total
Blue=unobscured
Red=obscured

Solid lines = all galaxies

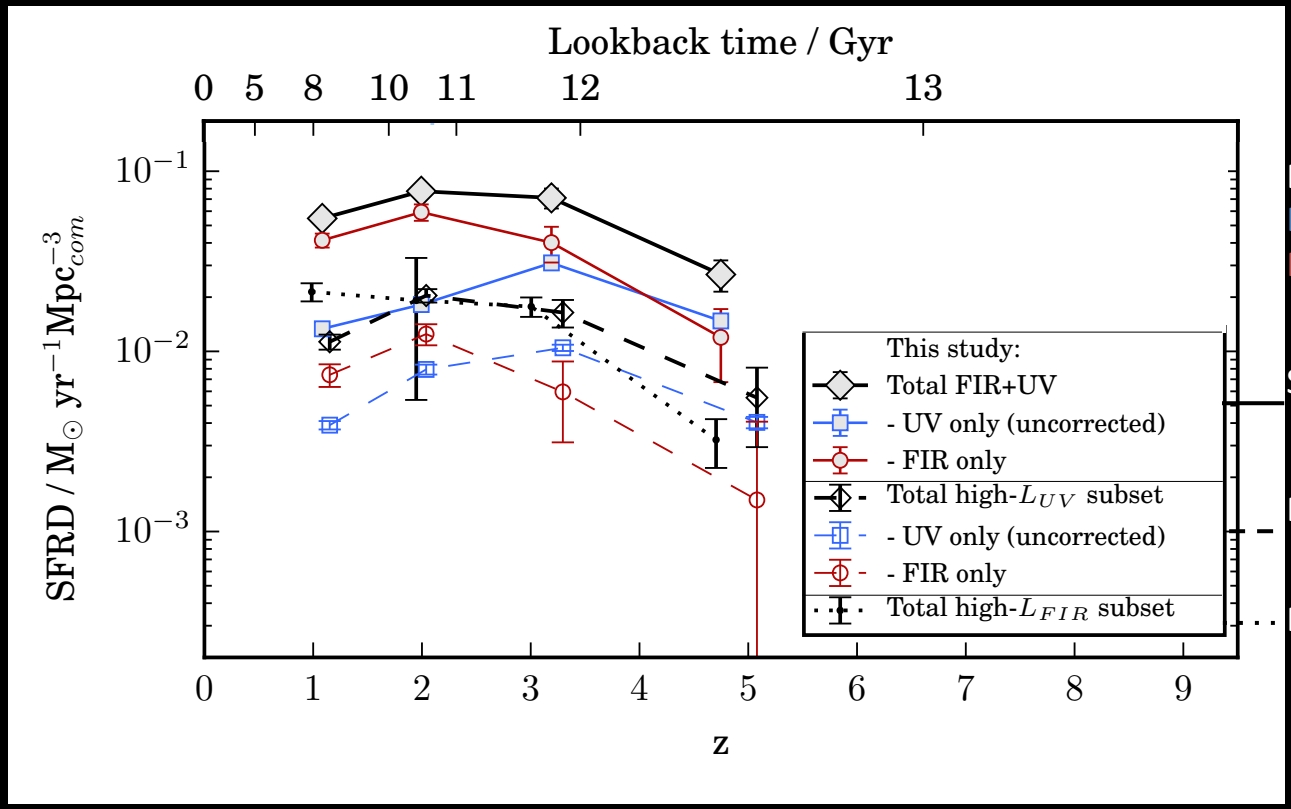
- SFRD peak at z~2
- SFRD in massive galaxies is dominated by obscured SFR

Cosmic SFR density in massive galaxies



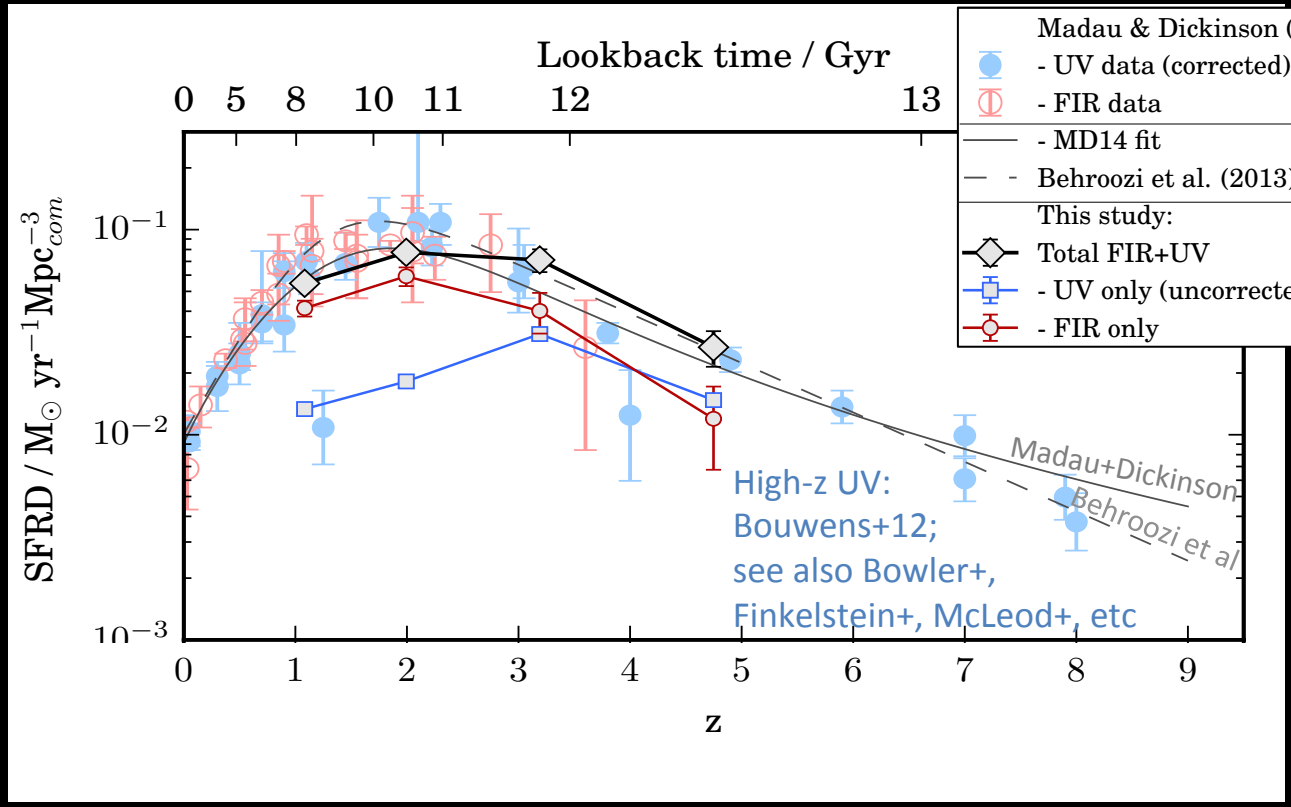
- SFRD peak at z~2
- SFRD in massive galaxies is dominated by obscured SFR
- 1/5 of SFRD from L_{UV}>L* galaxies (also obscured)
- 1/3 of SFRD from 450μm-detected sources

Cosmic SFR density in *all* galaxies



- Including UV emission from full LF integrated to -15 (Parsa+16)
- SFRD peak at z=2-2.5
- z<3: dominated by obscured SFRD (peaks at z=2)
- z>3: unobscured SFRD takes over (this peaks at z=3)

Cosmic SFR density in *all* galaxies



- SFRD at high-z broadly consistent with Behroozi+13, Madau & Dickinson14
- UV-corrected SFRD from the literature at z~5 is consistent with our IR+UV
- *The early universe (z>3) is increasingly dominated by unobscured SFRD*
- *But the peak epoch of SFRD (z=1-3) is dominated by obscured growth of high-mass galaxies – and in this regime, Meurer dust corrections are inadequate*

Take-home messages

- **Strong relationship between IR/UV, L_{UV} and M_*, independent of redshift:** $L_{IR}/L_{UV} \sim M_{star}^{0.7} L_{UV}^{-0.6}$
- UV luminosity traces obscuration rather than SFR
- More massive galaxies have higher SFR and higher IR/UV

- **The SFRD is mostly obscured at z=1-3, and is dominated by the growth of high-mass star-forming galaxies**
  - These galaxies are heavily obscured and Meurer dust corrections are insufficient

- **At z>4, the SFRD is predominantly *unobscured* and is dominated by lower-mass galaxies**
  - Because they have lower stellar mass, Meurer dust corrections appear to be successful

If you want to know more? → arXiv:1607.04283

Thank you for listening…… any questions?