NAM 2015 – Gal ISM – 8th July 2015

The Obscured History of Galaxy Evolution:

Resolving the Confusion with the SCUBA-2 Cosmology Legacy Survey

Nathan Bourne University of Edinburgh

with Jim Dunlop, the AstroDEEP collaboration, and the SCUBA-2 Cosmology Legacy Survey team

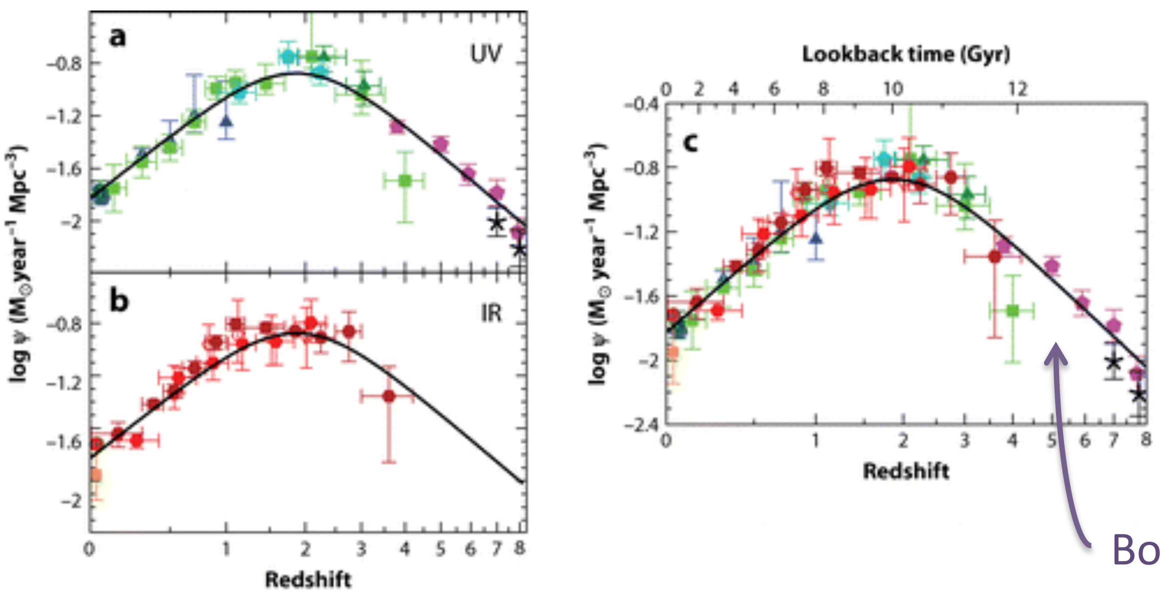
Understanding the evolution of galaxies

The Cosmic Star Formation History

Building up the galaxy population

- SFR density grows with lookback time from z=0 to z=2
- At z>3 UV observations indicate a fall, but we run out of FIR observations
- IR samples become dominated by extremely obscured systems
- Best estimates of SFRD from rest-FUV LFs from Lyman Break samples

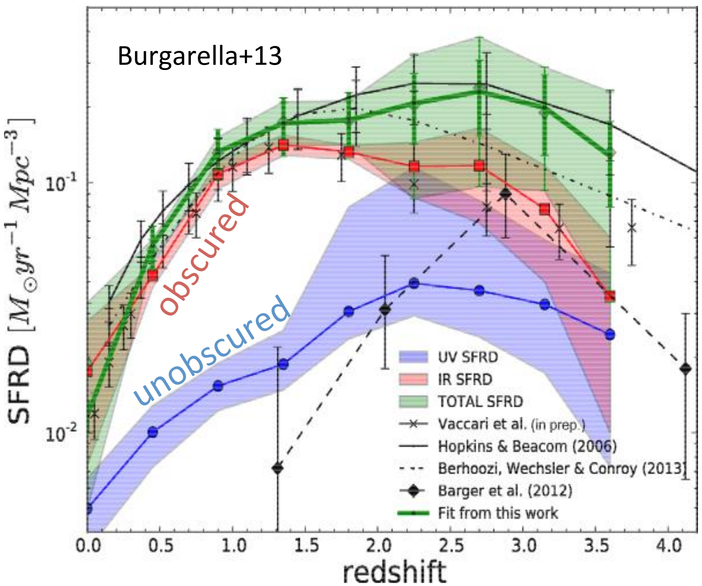
SFR density

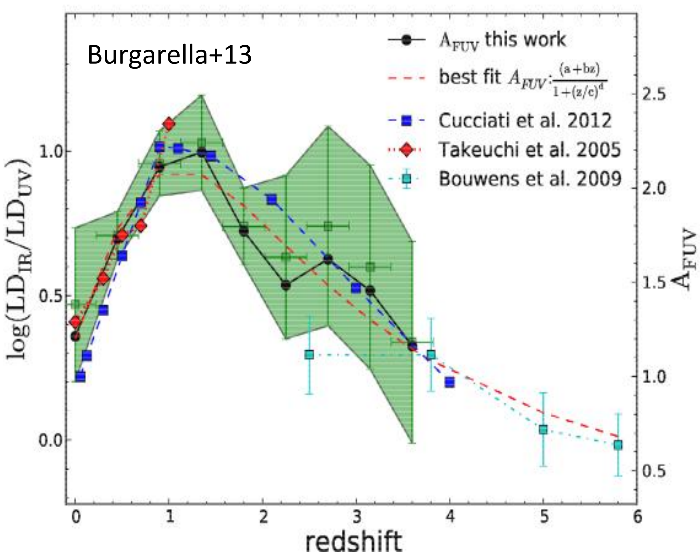


Bouwens et al. LBGs

Madau P, Dickinson M. 2014.
Annu. Rev. Astron. Astrophys. 52:415–86

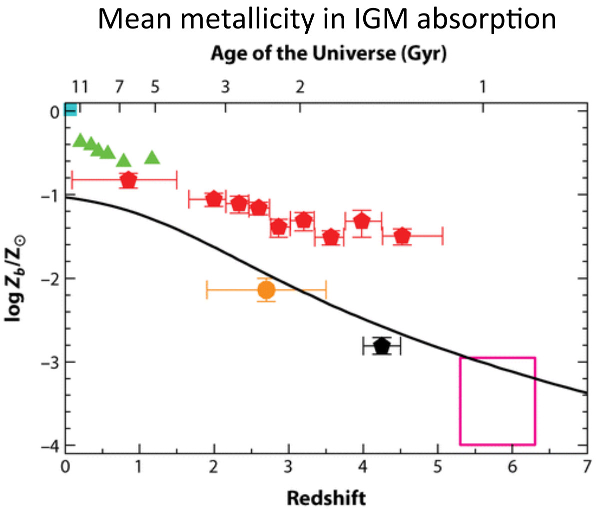
Dust obscuration





Why is this so difficult?

- Dust is a severe obstacle to measuring total SFRs
- Young stars are preferentially obscured within their birth-clouds
- IR SFRs > UV SFRs
- The obscuration is higher at the peak epoch of SF (z=1-2) than at z=0
- Beyond z=2, it is more uncertain

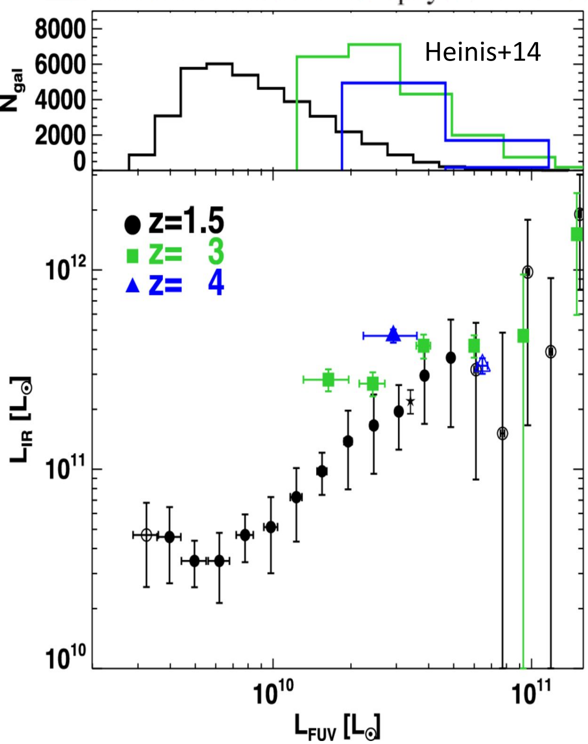


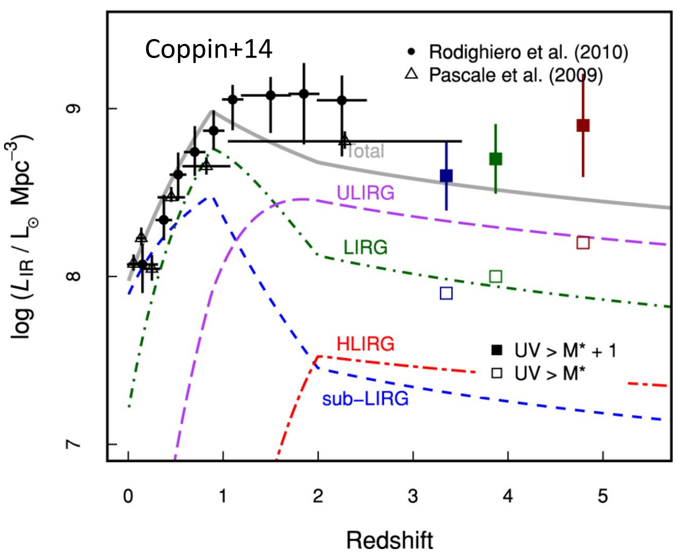
Madau P, Dickinson M. 2014.
Annu. Rev. Astron. Astrophys. 52:415–86

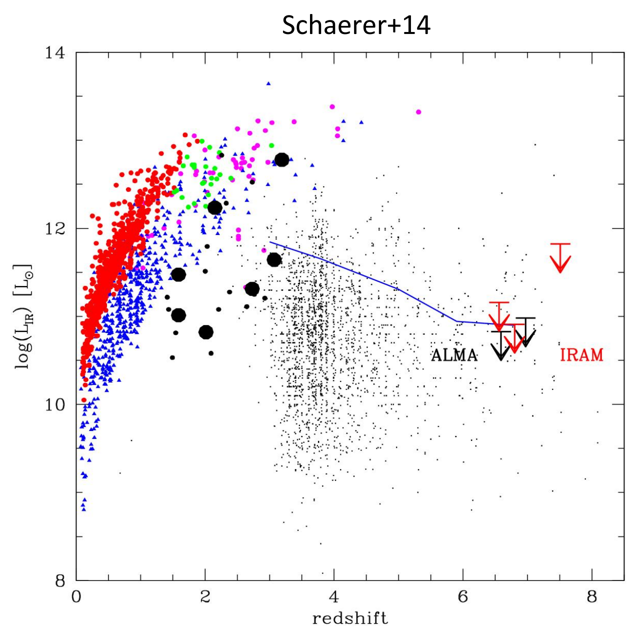
Dust at z>3

How dusty were (normal) SFGs at high redshift?

- High dust masses measured in SMGs and quasars at z>4... But these are atypical
- Lyman-break-selected and rest-UV selected samples may be FIR-bright at z<5







Addressing the gaps in our knowledge

Breaking through the confusion limit

How can new datasets help us with our problems?

JCMT/SCUBA-2:

- Higher resolution imaging:
  reduce confusion noise
- Deep imaging:
  minimise instrumental noise
- High-res. multi-wavelength priors:
  apply deconfusion algorithms to probe dense source populations (T-PHOT; Merlin et al. 2015)

The SCUBA-2 Cosmology Legacy Survey:

- 2 tiers:
  - Wide 850µm imaging over 35 sq.deg. to ~1mJy in several large survey fields
  - Deep 450+850µm imaging over 1.3 sq.deg. to ~0.5mJy rms (450µm) coinciding with CANDELS fields
- Exploiting multi-wavelength coverage from Spitzer, Herschel, ground-based optical-NIR, and HST

This work:

- Deep COSMOS-CANDELS + AEGIS-CANDELS fields: 230 arcmin^2
- Deepest multi-wavelength coverage from CANDELS, 3DHST, S-COSMOS, SEDS, etc.
- 3DHST photo-z and SED-fitting (Skelton+14)

De-confusing sub-mm maps with T-PHOT

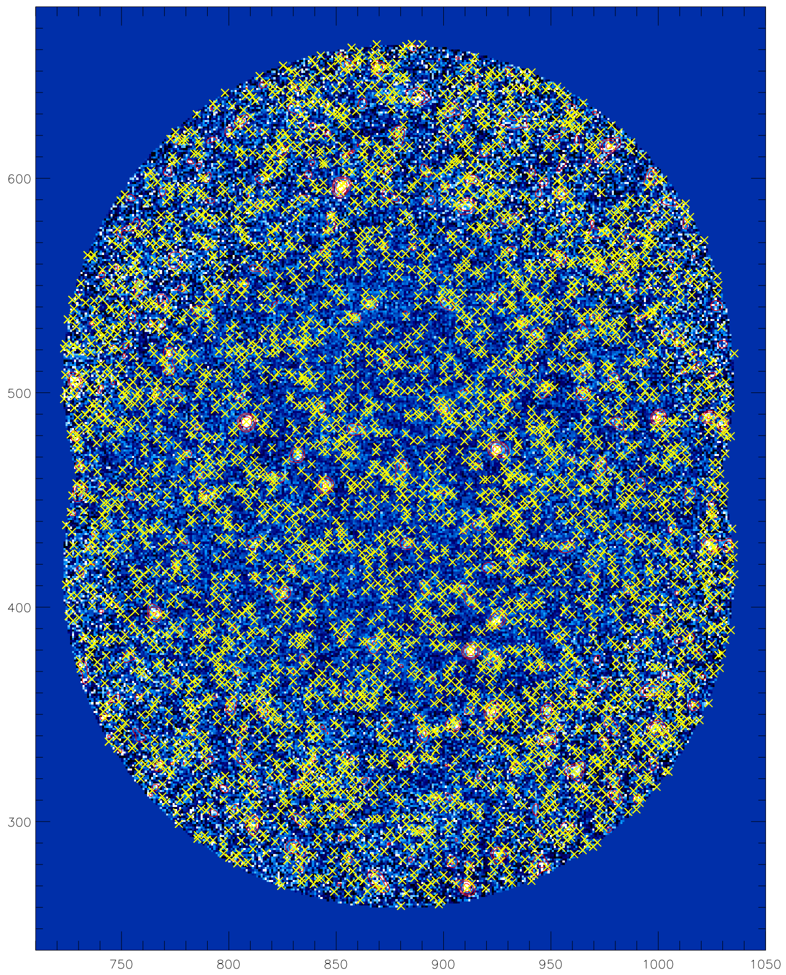
- T-PHOT: Merlin et al. (2015)

- Prior list: 3D-HST photometric catalogue including photo-z and SED-fitting results (Skelton+14):
  [K<24 or IRAC1<24]
  +USE flag
  +logM>9

- T-PHOT models the map as the result of a set of blended point sources at the positions of the prior catalogue

- The fluxes are free to vary until a minimum chi-squared solution is obtained

- Background is a fixed parameter, so is obtained by iteration of the algorithm



Preliminary results

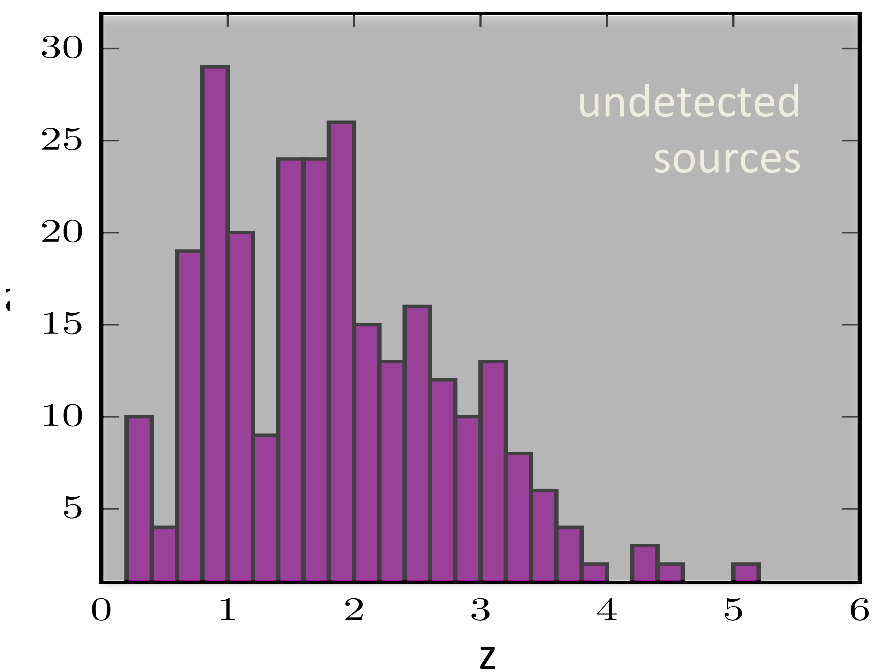
Work in progress...

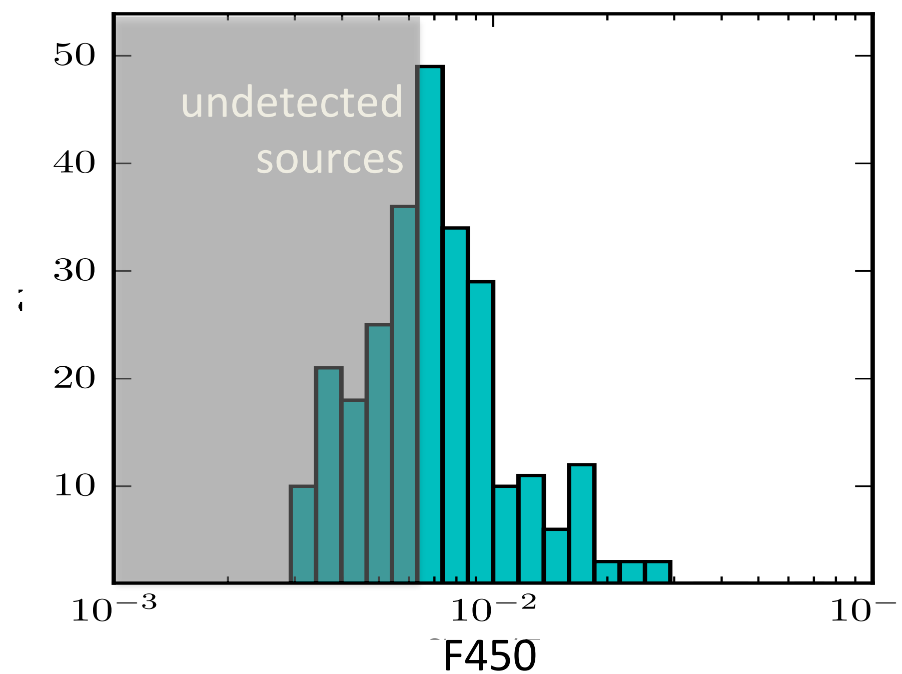
450μm detections

- But the chief value of our method is in making deblended flux measurements for sources *below the confusion limit*

- We therefore divide the full prior catalogue into bins and measure *average* 450μm properties as a function of the prior properties

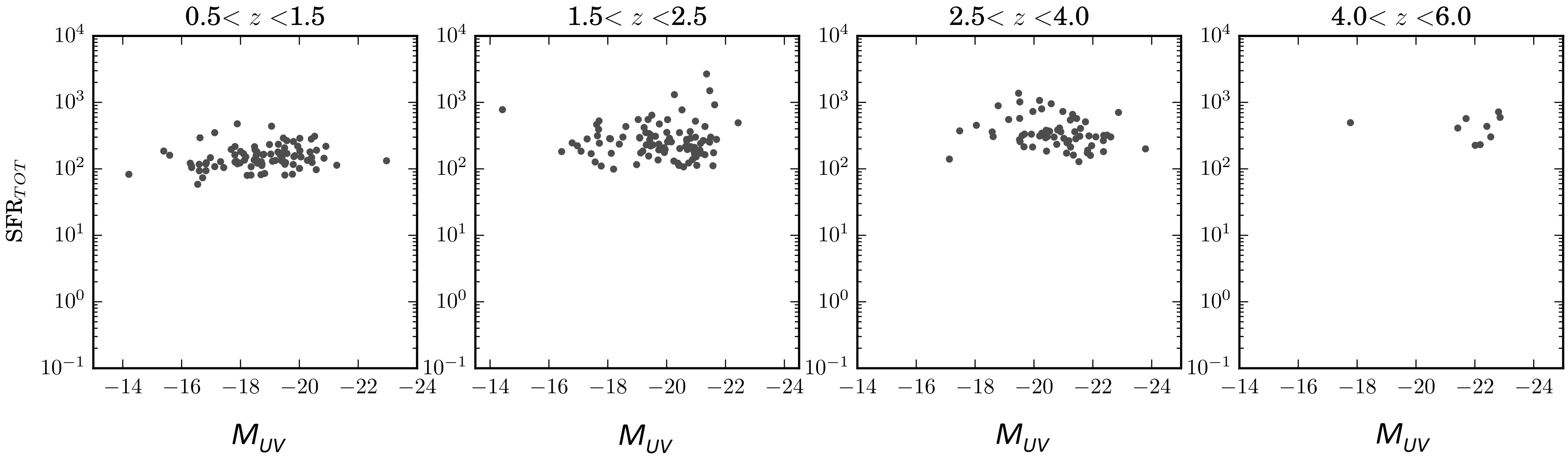
- Similar to stacking, but explicitly accounting for correlations between sources in the sample





UV luminosity vs Total SFR

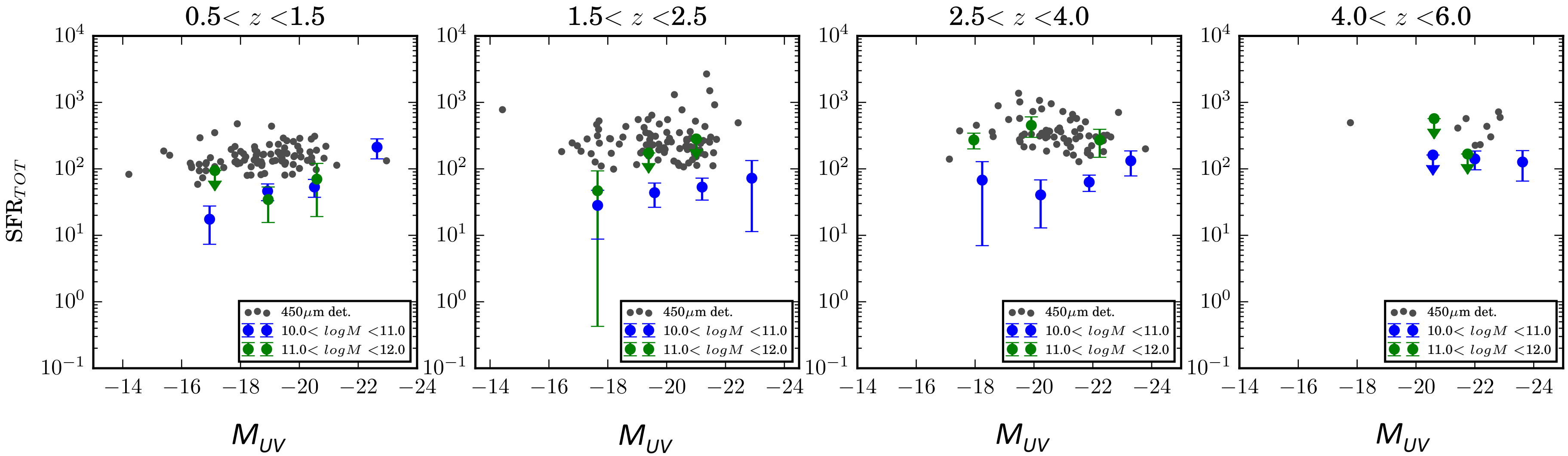
$= SFR_{FIR} + SFR_{FUV}$



- 450µm detections:
  - limiting SFR ≈ 100$M_{\odot}yr^{-1}$, roughly constant with redshift – extreme starbursts at z≈0, but main-sequence at z≈3-6
  - Wide range of M_{UV} detected in FIR – significant UV flux can escape these high-SFR galaxies

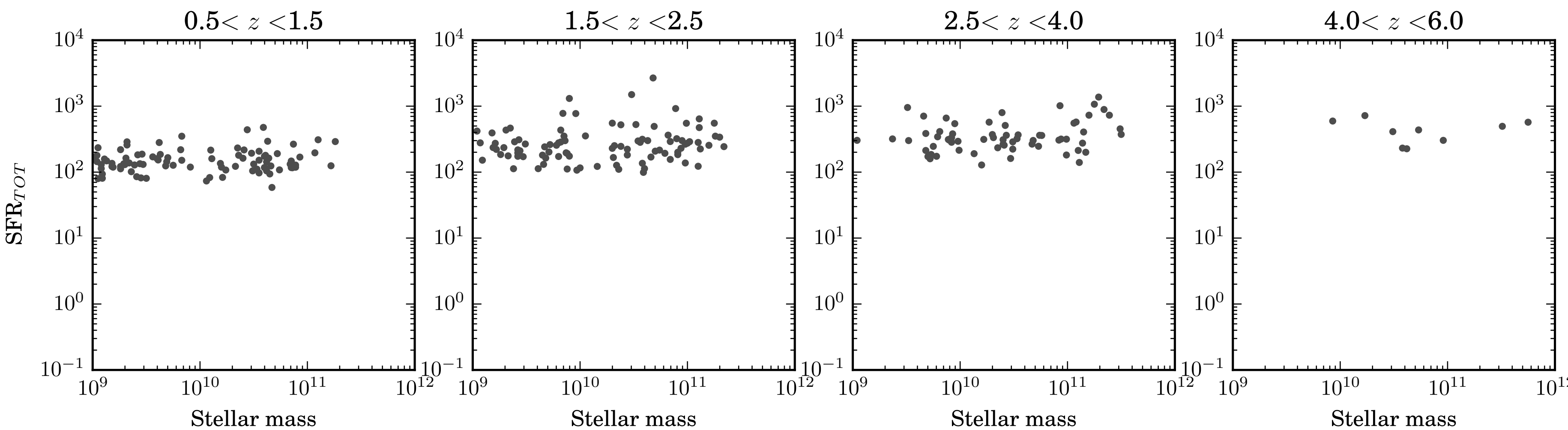
UV luminosity vs Total SFR

= $SFR_{FIR} + SFR_{FUV}$



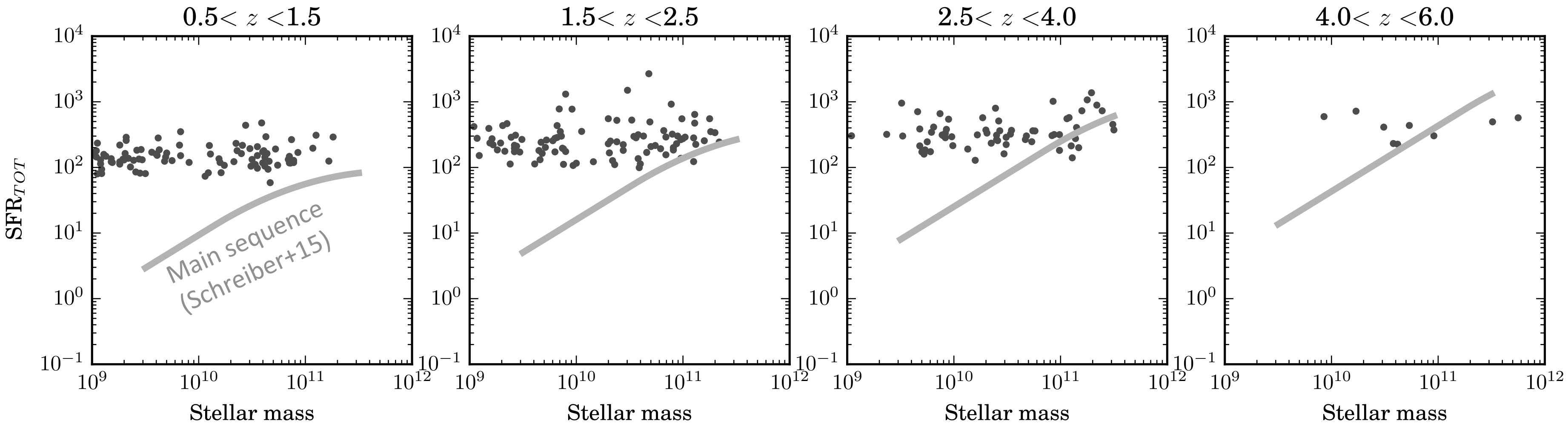
- 450μm detections:
  - limiting SFR ≈ $100 M_\odot yr^{-1}$, roughly constant with redshift – extreme starbursts at z≈0, but main-sequence at z≈3-6
  - Wide range of M_{UV} detected in FIR – significant UV flux can escape these high-SFR galaxies
- Average IR+UV SFRs by mass, M_{UV}:
  - Raw UV luminosity (before dust correction) does not trace SFR at high-z.
  - Average SFR of mass/UV-selected galaxies approaching that of FIR-detected galaxies from SCUBA-2.

Stellar Mass vs Total SFR
$= SFR_{FIR} + SFR_{FUV}$



- 450μm detections:
  - Limited to SFR>100 independent of mass

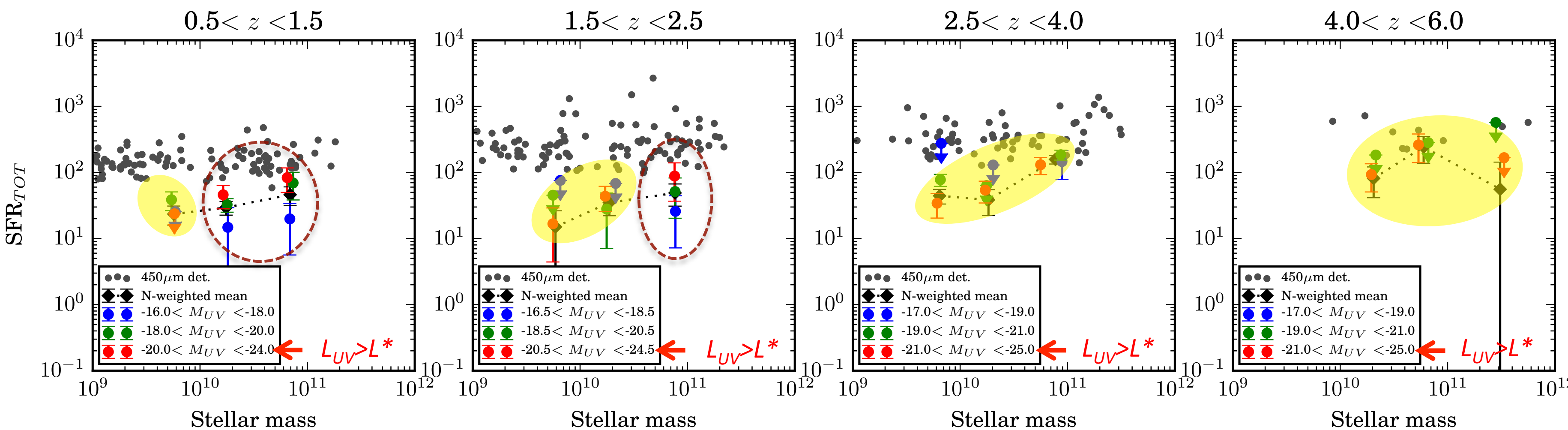
Stellar Mass vs Total SFR
$= SFR_{FIR} + SFR_{FUV}$



- 450µm detections:
  - Limited to SFR>100 independent of mass
  - Selecting main-sequence SFGs at high-z/high-mass

Stellar Mass vs Total SFR

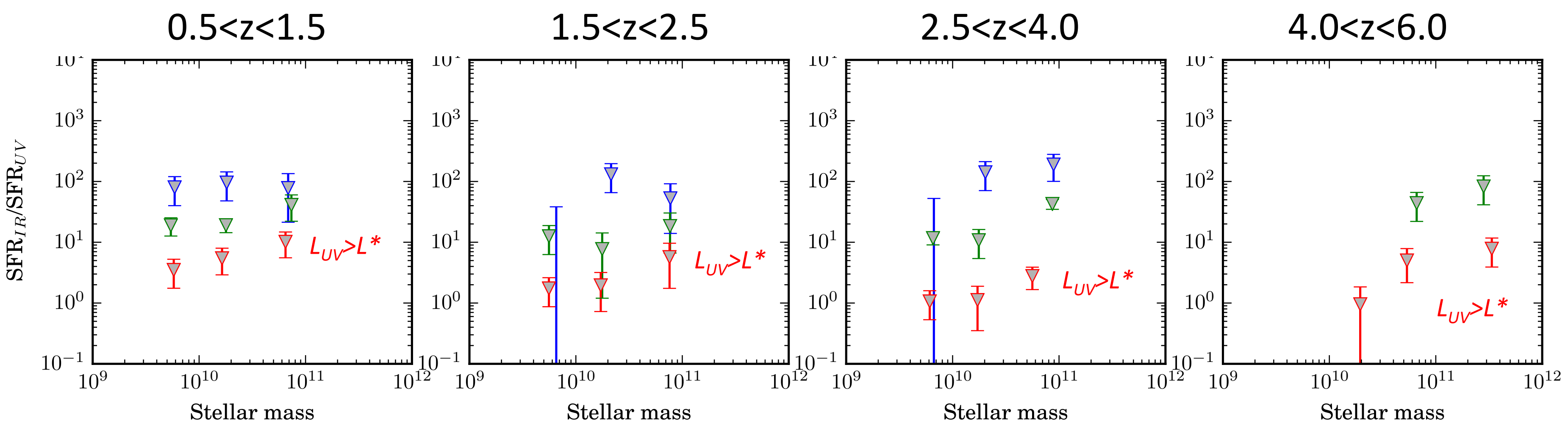
= SFR_{FIR} + SFR_{FUV}



- 450µm detections:
  - Limited to SFR>100 independent of mass
  - Selecting main-sequence SFGs at high-z/high-mass
- UV-luminous sample:
  - Massive galaxies at z<2.5: High L_{UV} luminosity → High SFR
  - z>2.5: SFR correlated with mass but consistent with average mass-selected galaxies (same at z<2.5 for M≈$10^{10}M_{\odot}$)
- Is stellar mass is a better indicator of total SFR than raw UV luminosity?

Stellar Mass vs Obscuration Fraction

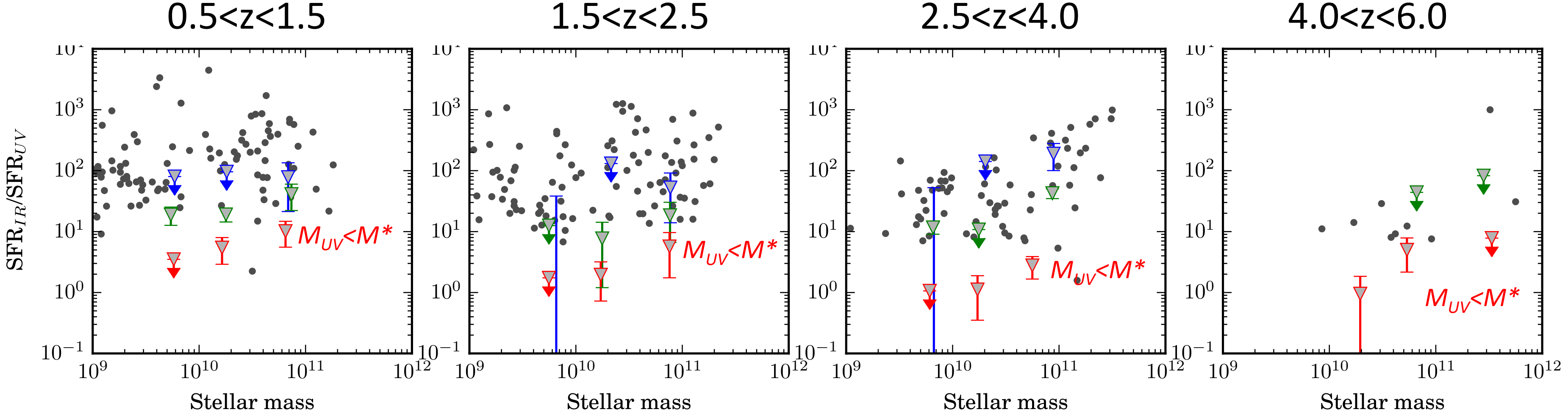
$= SFR_{FIR} / SFR_{FUV}$



- Instead, M_{UV} is an excellent tracer of obscuration fraction

Stellar Mass vs Obscuration Fraction

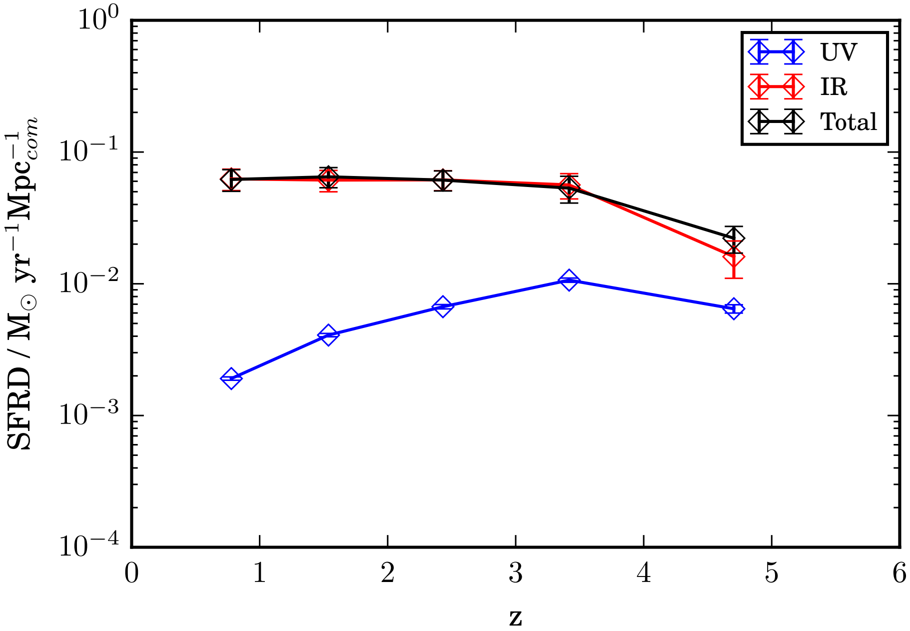
= SFR_{FIR} / SFR_{FUV}



- Instead, M_{UV} is an excellent tracer of obscuration fraction
- While 450μm detections (high SFRs) span a wide range of obscuration fractions
- *FIR-detected sources are not necessarily (only) the most obscured ones*

Cosmic SFR density = $\Sigma SFR/V_{com}$

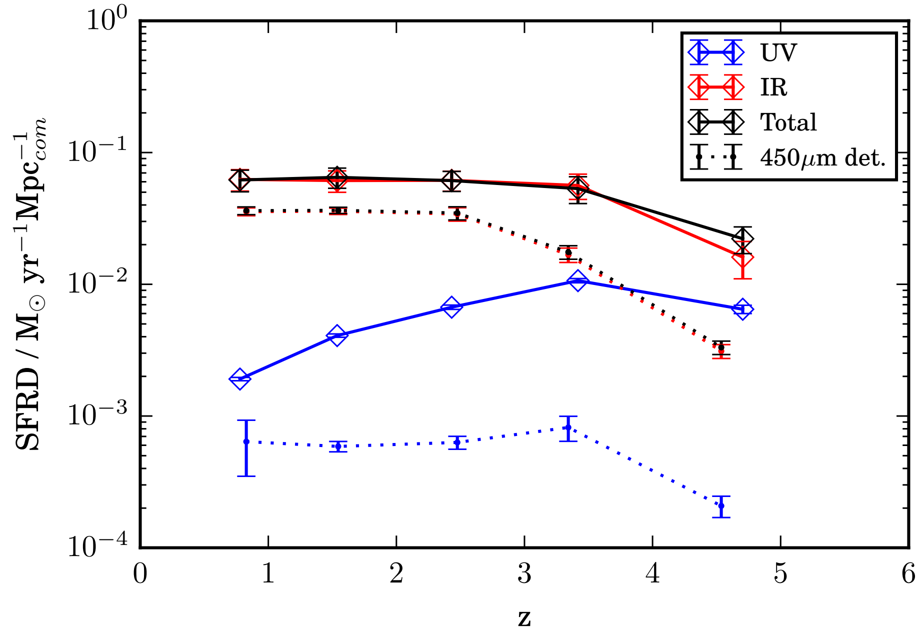
- **Integrated over $M>10^{10}M_{\odot}$**
- Raw UV SFRD increases with z
- Stacked FIR and total SFRD approx constant 0.5<z<3.5
- Begins to fall off beyond z≈3-4



Cosmic SFR density = ΣSFR/V_{com}

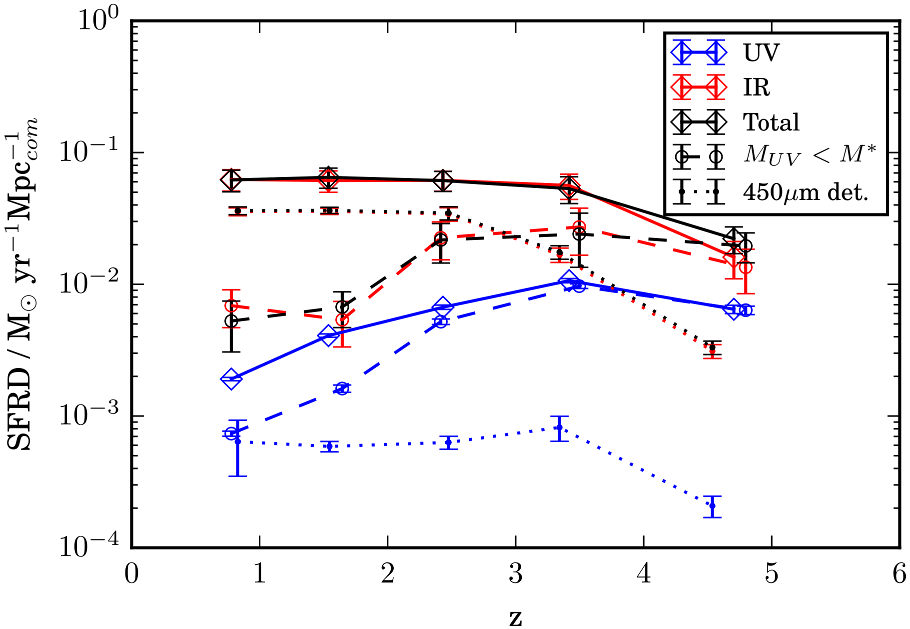
- **Integrated over $M>10^{10}M_{\odot}$**
- Raw UV SFRD increases with z
- Stacked FIR and total SFRD approx constant 0.5<z<3.5
- Begins to fall off beyond z≈3-4

- FIR detections closely trace SFRD at z<3
- Constitute smaller fraction at z>3 as negative k-correction less effective
- Unobscured UV SFRD from these is 100x lower than FIR



Cosmic SFR density = ΣSFR/V_{com}

- **Integrated over $M>10^{10}M_{\odot}$**
- Raw UV SFRD increases with z
- Stacked FIR and total SFRD approx constant 0.5<z<3.5
- Begins to fall off beyond z≈3-4



- FIR detections closely trace SFRD at z<3
- Constitute smaller fraction at z>3 as negative k-correction less effective
- Unobscured UV SFRD from these is 100x lower than FIR

- UV-luminous (>L*) galaxies contribute a small fraction of SFRD at z<2
- But a much higher SFRD at z>2
- Total SFRD of these is still dominated by the obscured portion
- Unobscured UV SFRD around 4-5x lower than total

Summary

- SCUBA-2 offers an opportunity to probe deeper into the obscured cosmic star-formation history – thanks to lower confusion noise than Herschel
- Prior-based deconfusion techniques (e.g. T-PHOT) can push even deeper into the confusion noise with samples selected from high-resolution data

Results:

- Observed UV luminosity is a poor tracer of total SFR, which may be better correlated with stellar mass
- 450μm-detected samples and UV-luminous samples probe similar total SFRs at $z>3$, tracing the high-mass end of the main sequence
- Total SFR density of $M>10^{10}M_{\odot}$ galaxies roughly constant at $0.5<z<4$
- Total SFR density of $L_{UV}>L^*$ galaxies increases from $1<z<3$ and remains high up to $z\approx5$, but galaxies remain significantly obscured

Thank you for listening!