Back at the Edge of the Universe – Sintra – 18th March 2015

Institute for Astronomy

Understanding relationships between SFR, stellar mass and obscuration at high redshift

with the SCUBA-2 Cosmology Legacy Survey

Deeper into the Dust

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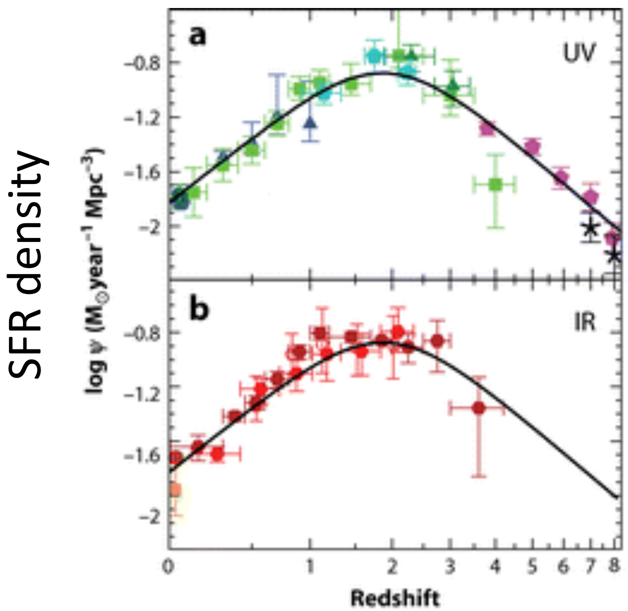
with Jim Dunlop, the AstroDEEP collaboration, and the Cosmology Legacy Survey team

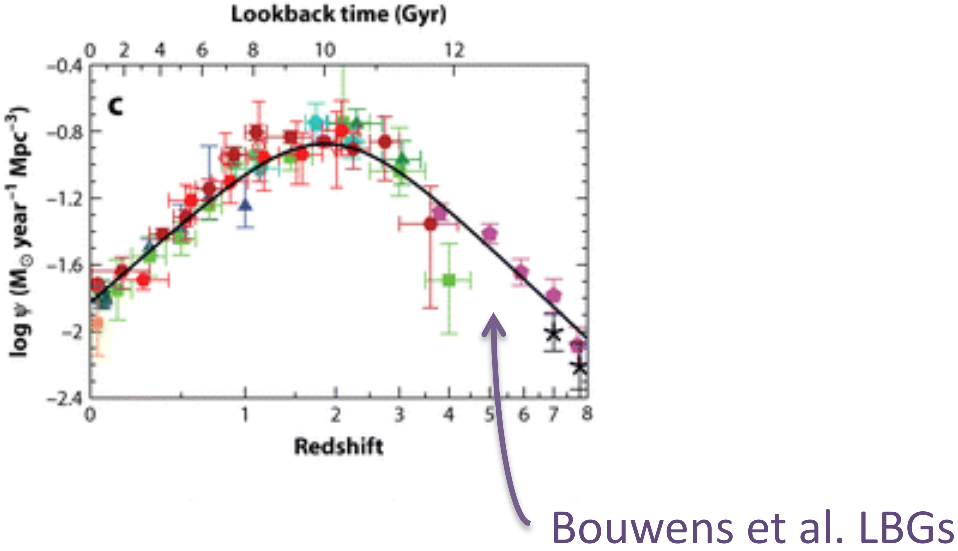
Understanding the evolution of galaxies

The Cosmic Star Formation History

Building up the galaxy population

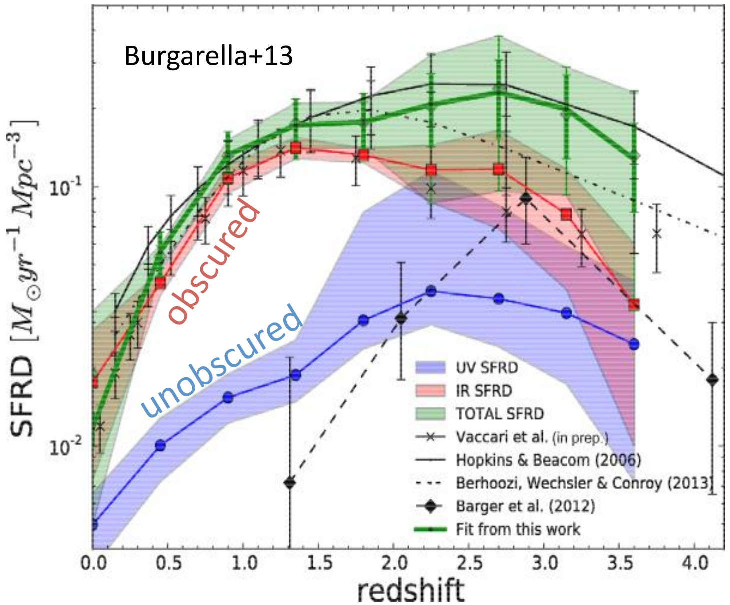
- SFR density grows with lookback time from z=0 to z=2
- At z>3 UV observations indicate a fall, but we run out of FIR observations
- IR samples become dominated by extremely obscured systems
- Best estimates of SFRD from rest-FUV LFs from Lyman Break samples

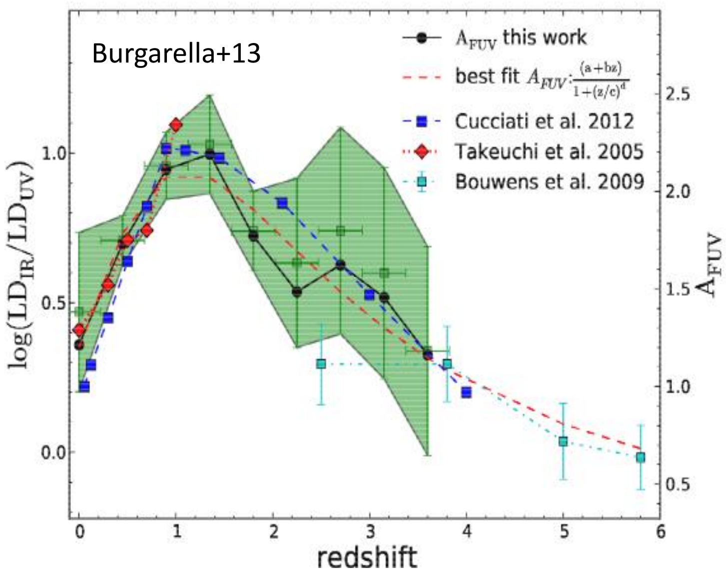




Madau P, Dickinson M. 2014.
Annu. Rev. Astron. Astrophys. 52:415–86

Dust obscuration





Why is this so difficult?

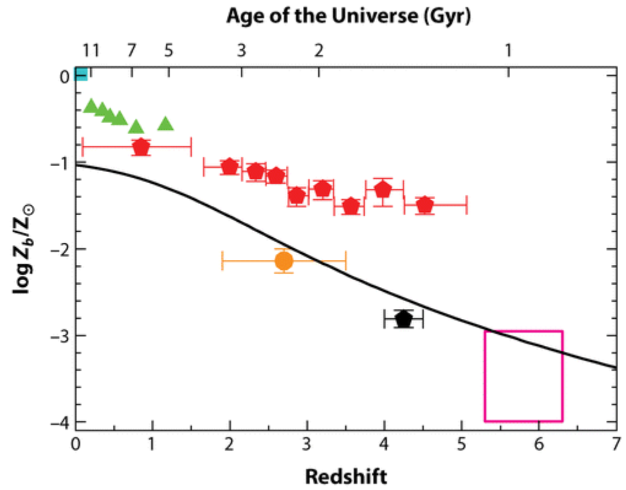
- Dust is a severe obstacle to measuring total SFRs
- Young stars are preferentially obscured within their birth-clouds
- IR SFRs > UV SFRs
- The obscuration is higher at the peak epoch of SF (z=1-2) than at z=0
- Beyond z=2, it is more uncertain

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

Mean metallicity in IGM absorption



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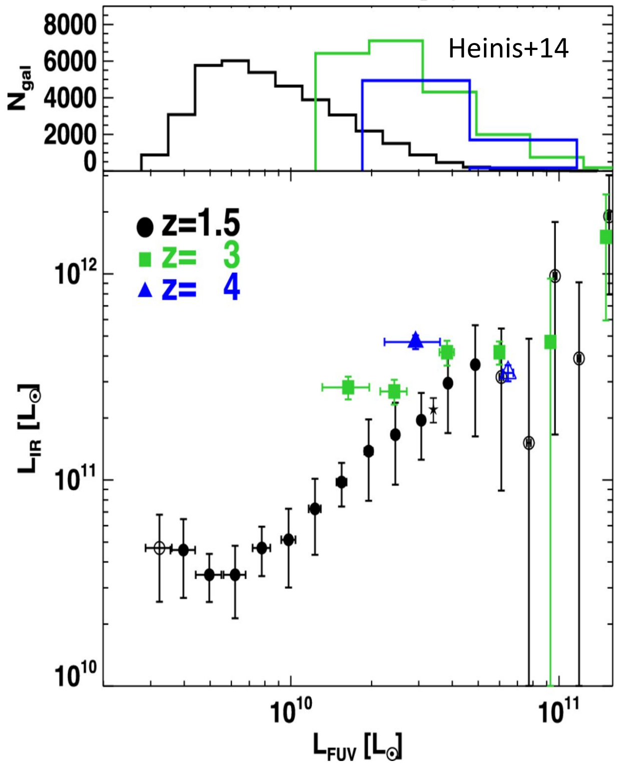
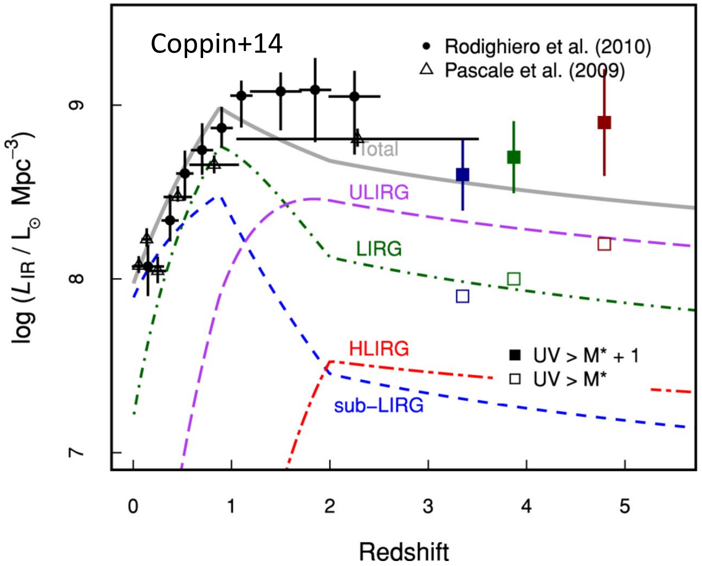
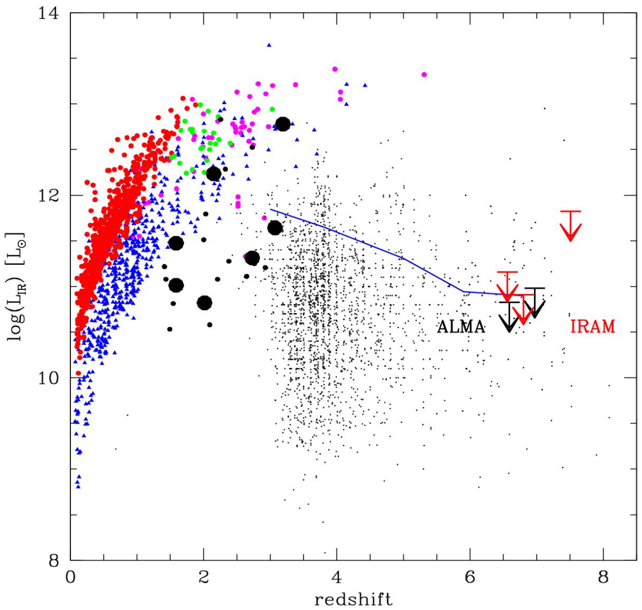




Schaerer+14



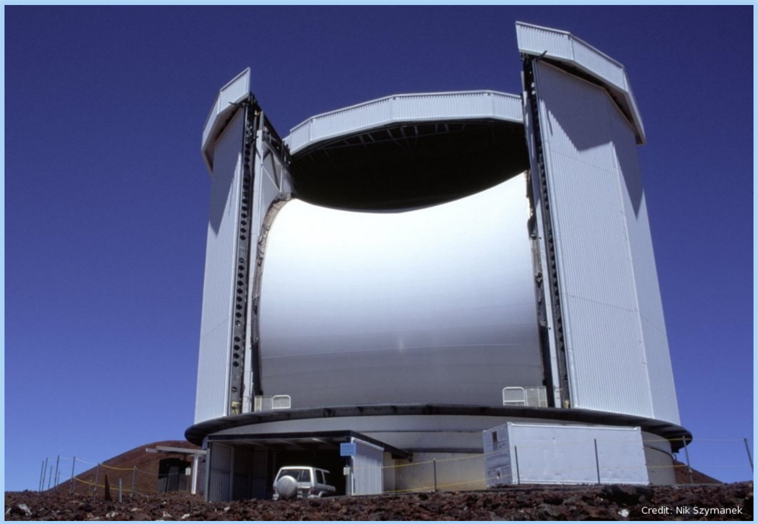
Addressing the gaps in our knowledge

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; E. Merlin et al. in prep.)



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

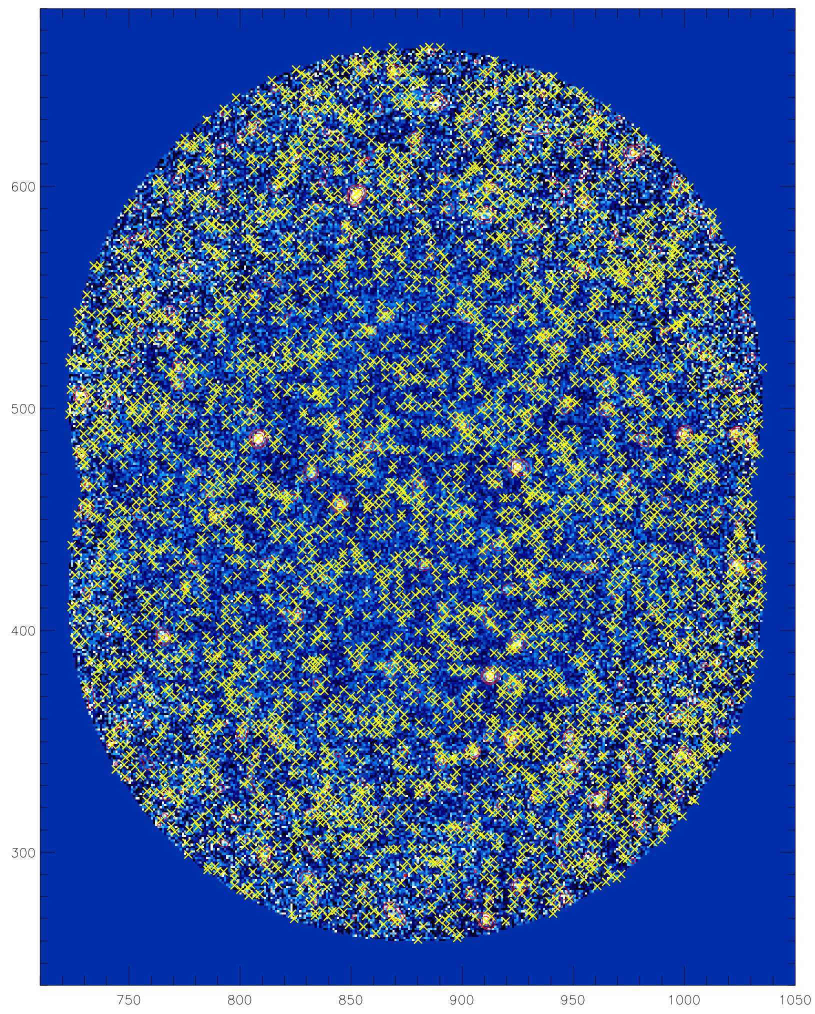
- T-PHOT: E. Merlin et al. (in prep.)

- 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

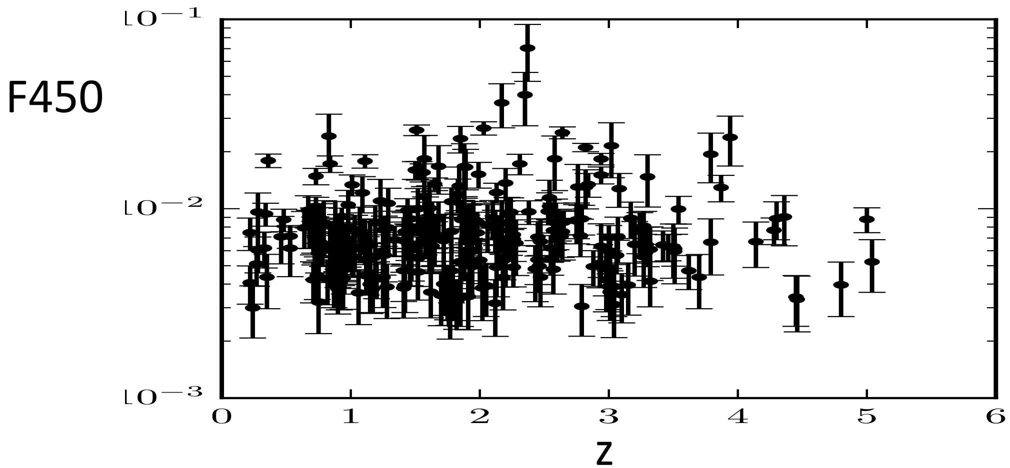
- The fluxes are free to vary until a minimum chi-squared solution is obtained

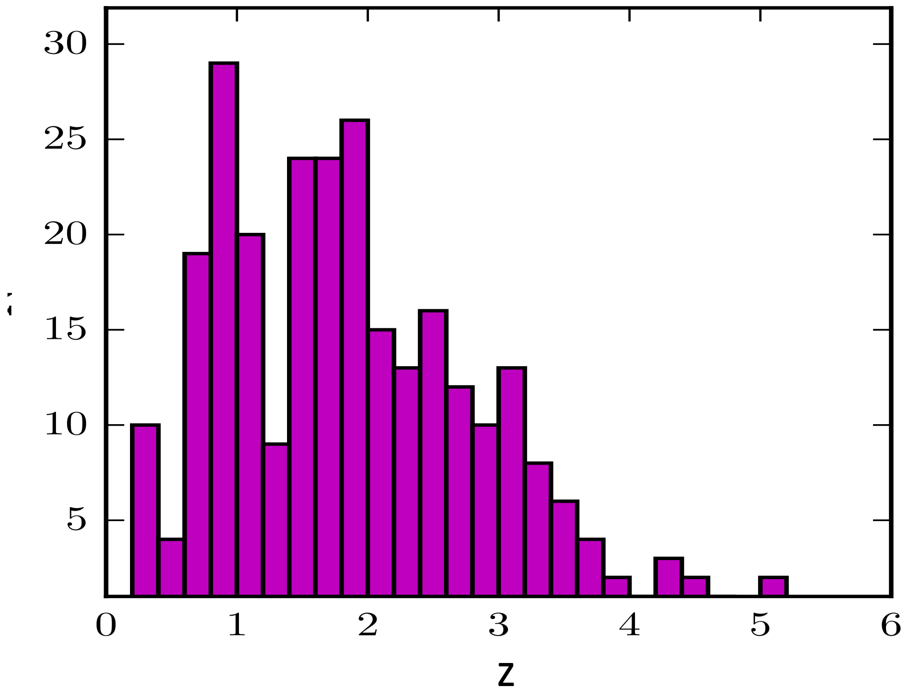
- Background is a fixed parameter, so is obtained by iteration of the algorithm

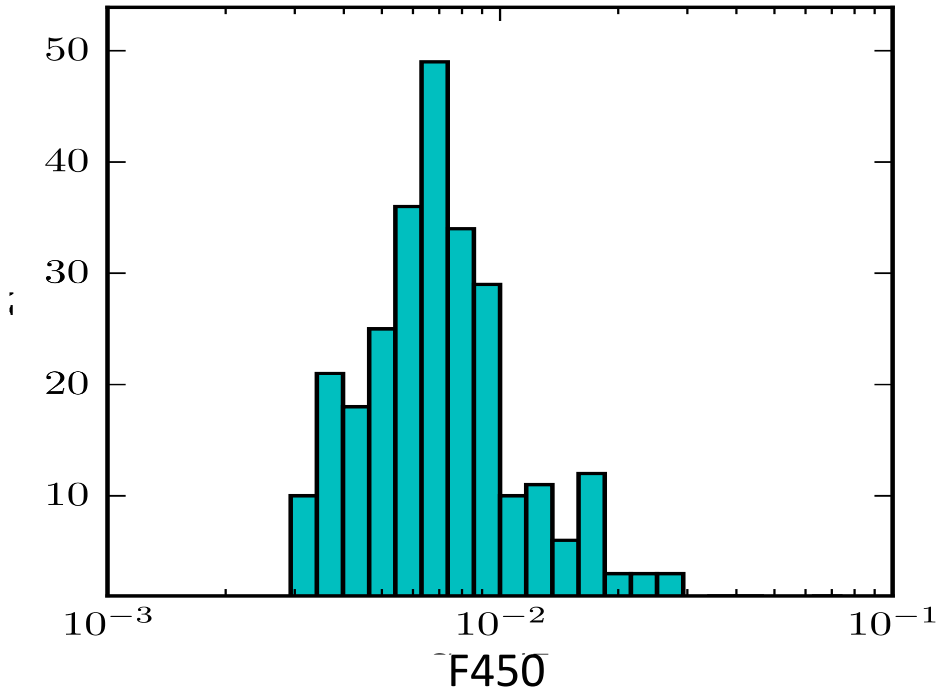


Preliminary results

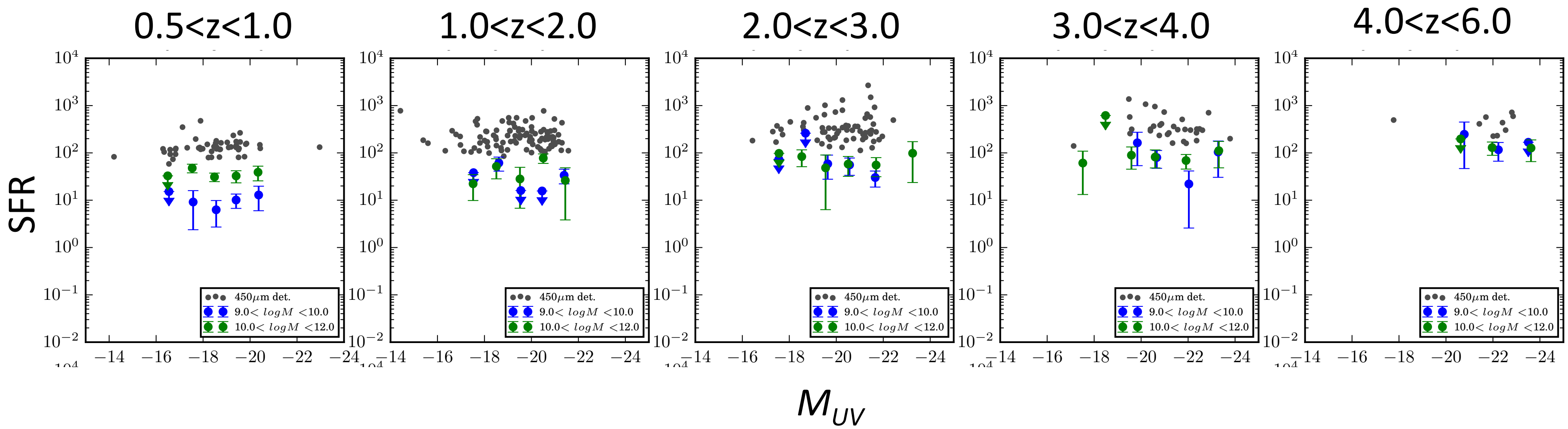
450μm detections







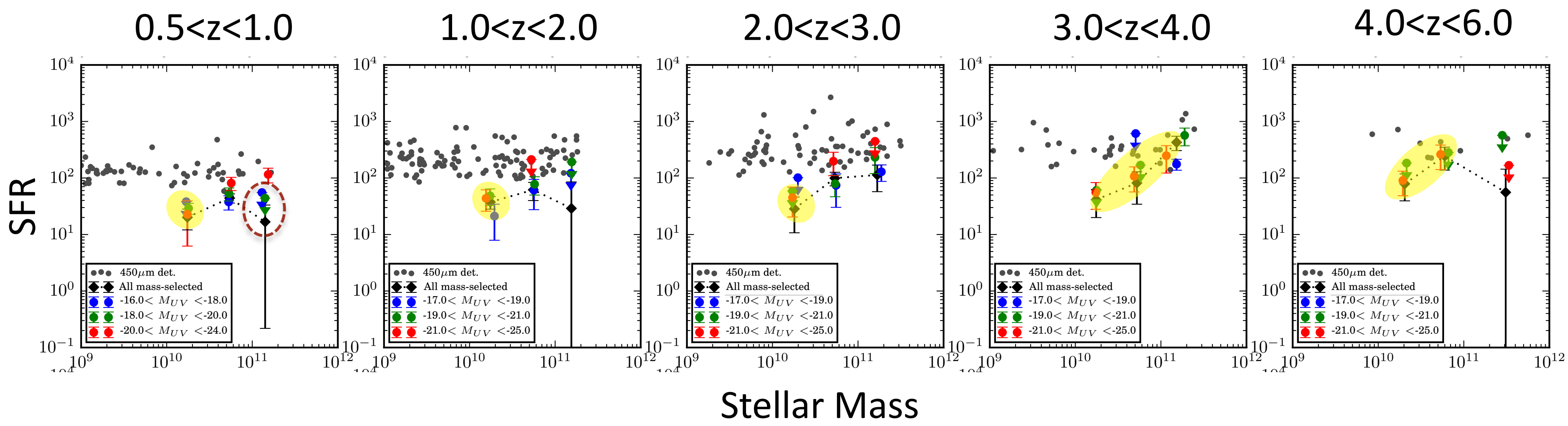
UV luminosity vs Total SFR
= $SFR_{FIR} + SFR_{FUV}$



- 450μm detections:
  - limiting SFR ≈ $100 M_{\odot} yr^{-1}$, roughly constant with redshift – extreme starbursts at z≈0, but main-sequence at z≈2-6
  - 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.
  - Average SFR of mass/UV-selected galaxies approaching that of FIR-detected galaxies from SCUBA-2.

Stellar Mass vs Total SFR

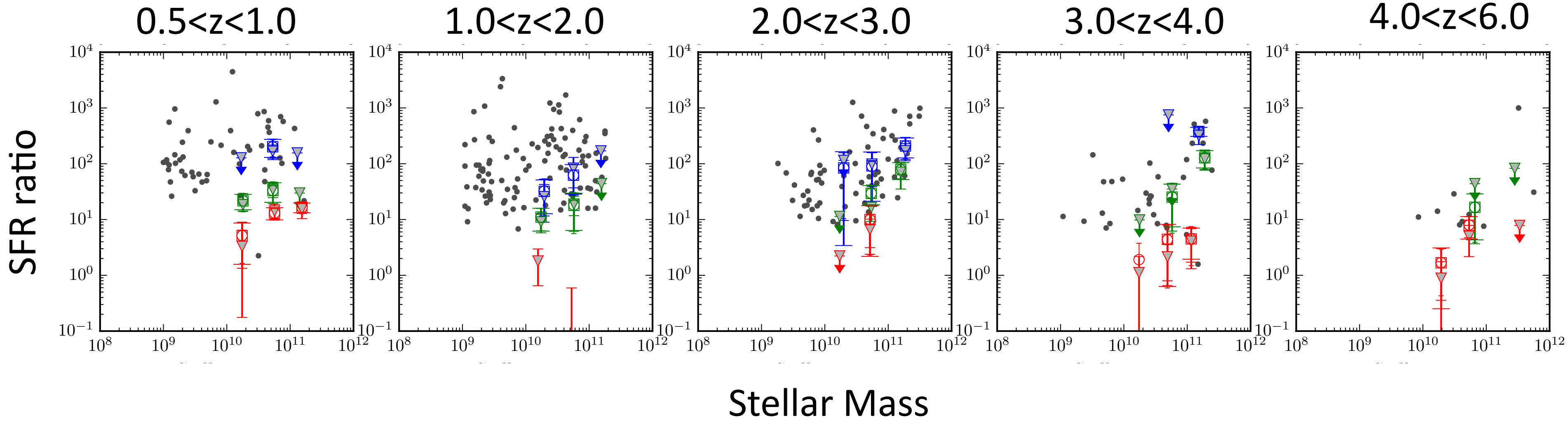
$= SFR_{FIR} + SFR_{FUV}$



- 450μm detections:
  - Limited to SFR>100 independent of mass
  - Selecting main-sequence SFGs at high-z/high-mass
- UV-luminous sample:
  - SFR correlated with mass but SFRs consistent with average mass-selected galaxies at z>3, and also at z<3 for $M \approx 10^{10} M_{\odot}$
  - Massive galaxies at z<1: High L_{UV} luminosity → High SFR; Low L_{UV} → Passive
- Overall, stellar mass is a better indicator of total SFR than raw UV luminosity

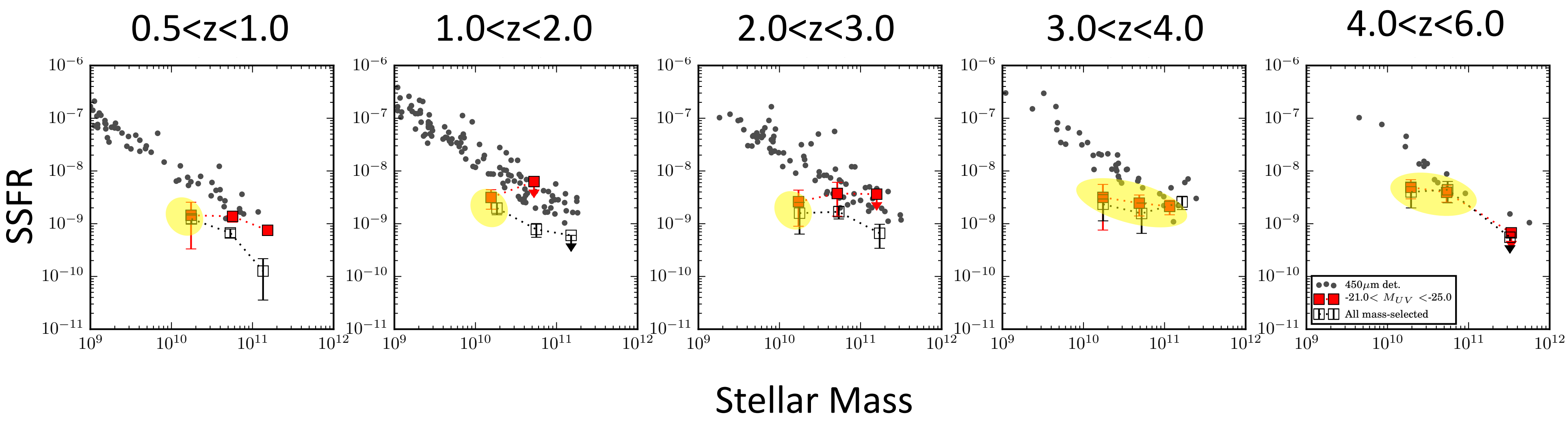
Stellar Mass vs Obscuration Fraction

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



- Instead, M_{UV} is an excellent tracer of obscuration fraction
- But 450µm detections span a wide range of obscuration fractions

Stellar Mass vs Median SSFR



Closing the gap between the rest-frame UV and FIR selected galaxies

- 450μm detections:
  - Extreme starbursts at low mass
  - Main sequence at high-mass, consistent with mass or UV selected samples
  - No high-mass outliers above main-sequence
- UV-luminous sample:
  - At high redshift, consistent with mass-selected sample and FIR-detected
- All massive galaxies:
  - Shallow negative slope of SSFR(M)

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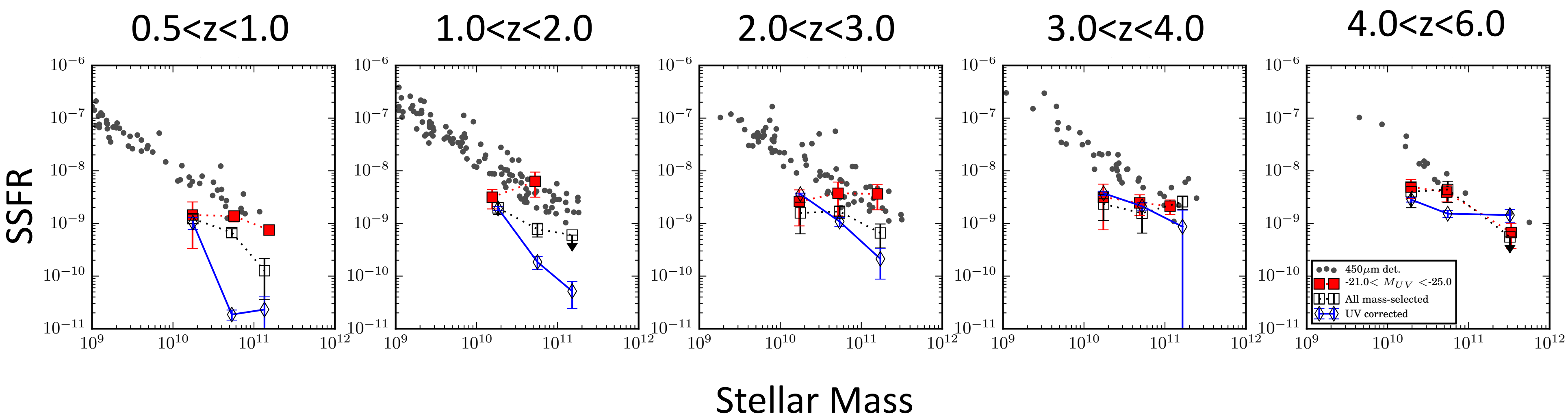

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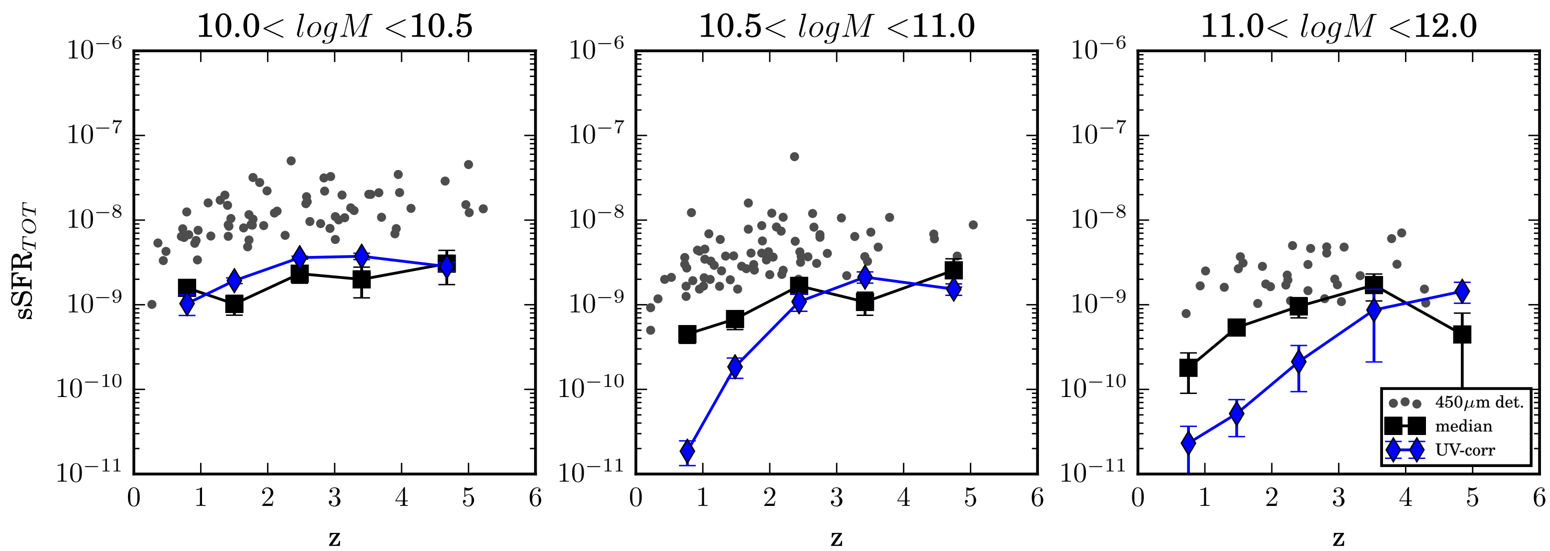
- UV-luminous sample:
  - At high redshift, consistent with mass-selected sample and FIR-detected
- All massive galaxies:
  - Shallow negative slope of SSFR(M)
  - Much steeper slope at z<3 in dust-corrected UV SFRs (*without* FIR information)

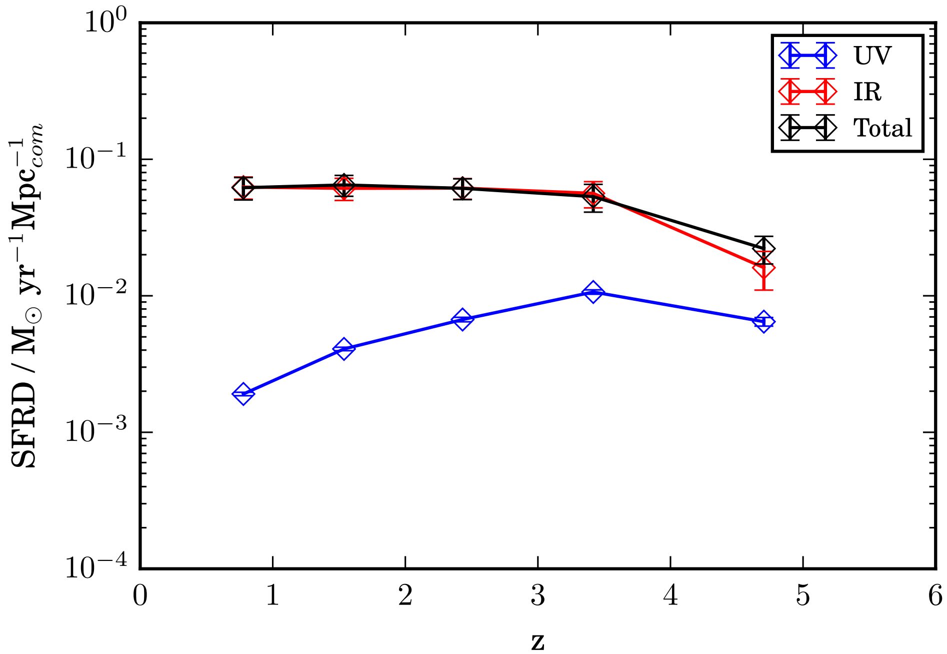
Evolution in SSFR

- Average SSFRs of star-forming galaxies evolve gradually up to z≈5
- Highest masses evolve more steeply (many will be passive by z=1)
- Corrected UV SFRs show a turnover not apparent in the FIR



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



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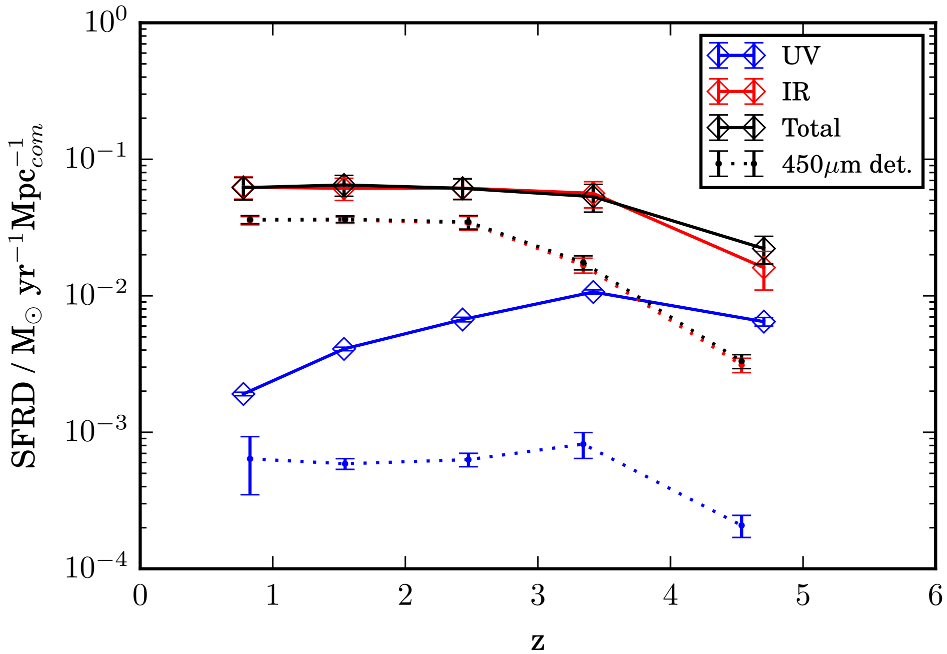
- Constitute smaller fraction at z>3 as negative k-correction less effective
- Unobscured UV SFRD from these is 100x lower than FIR



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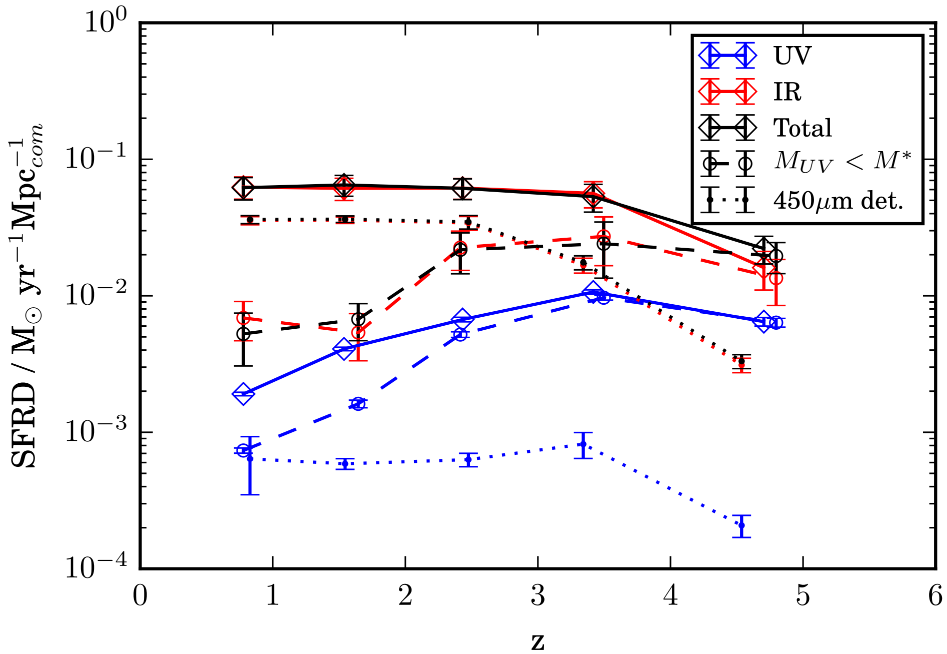

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- UV-luminous (>L*) galaxies contribute a small fraction of SFRD at z<2
- But a much higher SFRD at z>2
- Total SFRD of these is still dominated by the obscured portion
- Unobscured UV SFRD around 4-5x lower than total

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 is 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
- Dust-corrected UV SFRs may not give a good estimate of total SFR at all masses and redshifts (further work needed)
- 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!