



Understanding relationships between SFR, stellar mass and obscuration at high redshift with the SCUBA-2 Cosmology Legacy Survey

Deeper into the Dust

Nathan Bourne

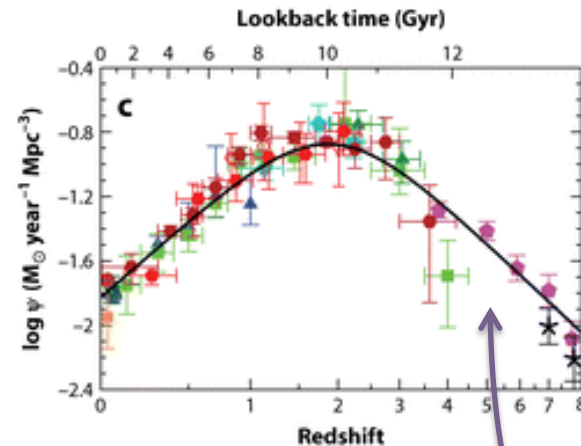
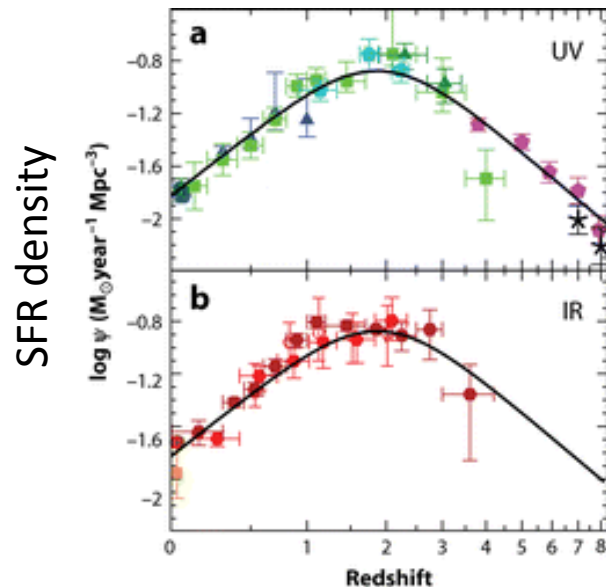
with Jim Dunlop, the AstroDEEP collaboration, and the
Cosmology Legacy Survey team

Understanding the evolution of galaxies

The Cosmic Star Formation History

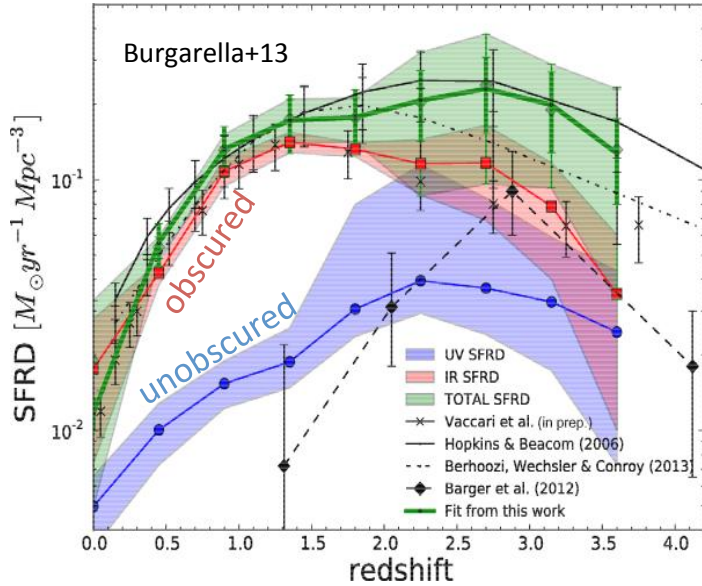
Building up the galaxy population

- 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



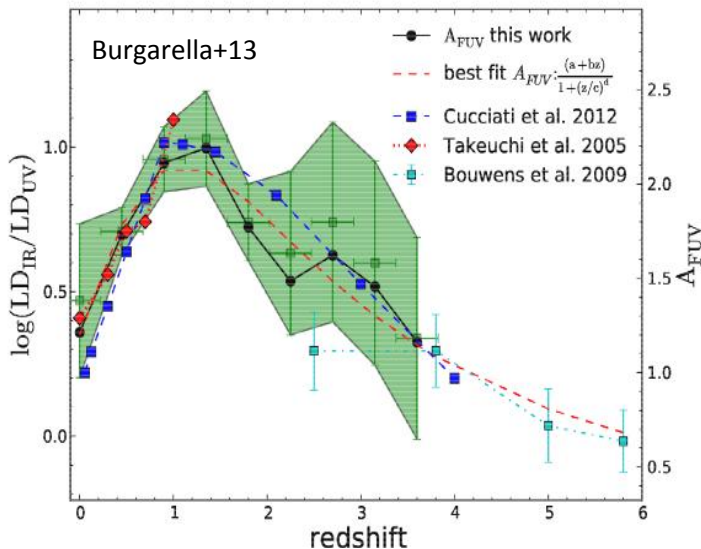
Bouwens et al. LBGs

Dust obscuration

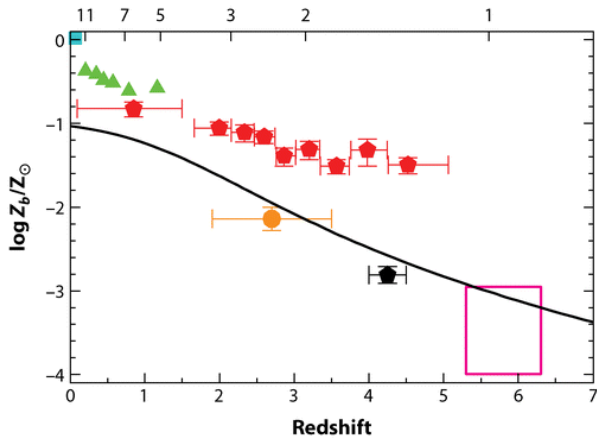


Why is this so difficult?

- 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



Mean metallicity in IGM absorption
Age of the Universe (Gyr)

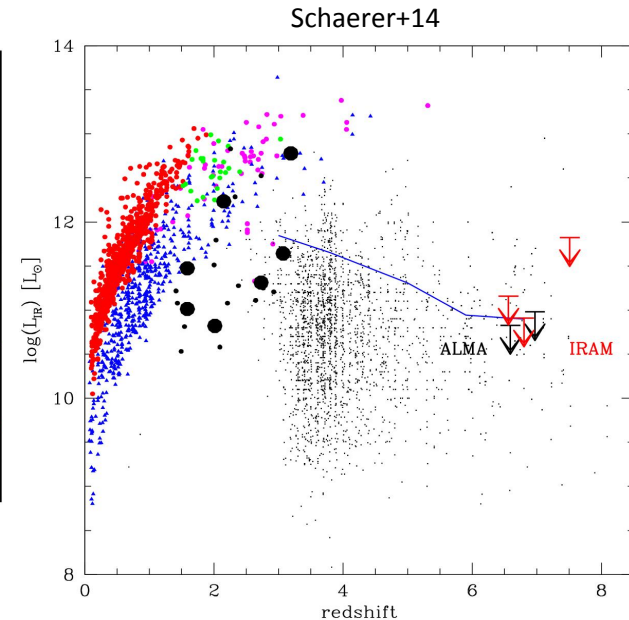
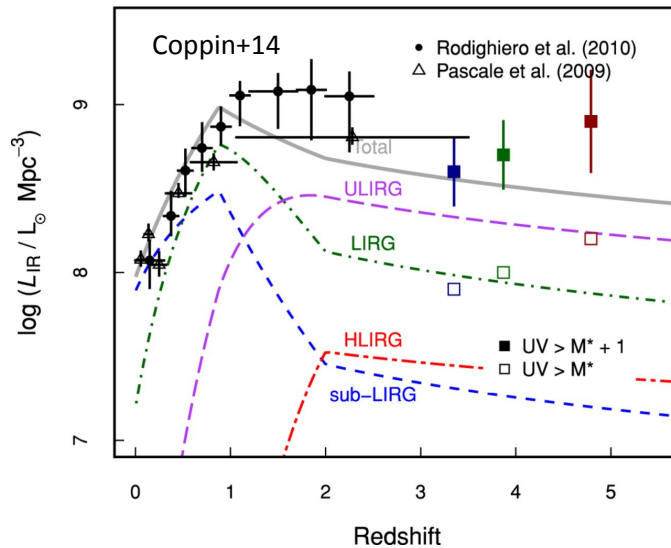
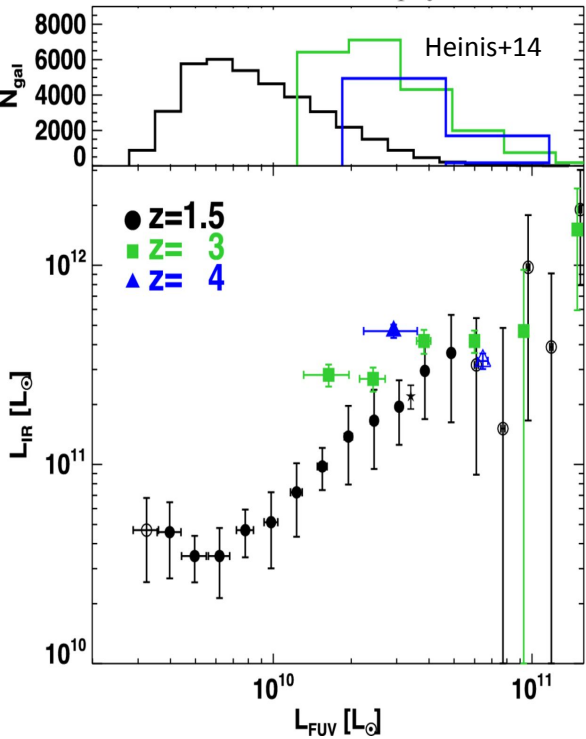


Dust at $z > 3$

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 $z < 5$

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



**Addressing the gaps in our
knowledge**

Breaking through the confusion limit

How can new datasets help us with our problems?

JCMT/SCUBA-2:

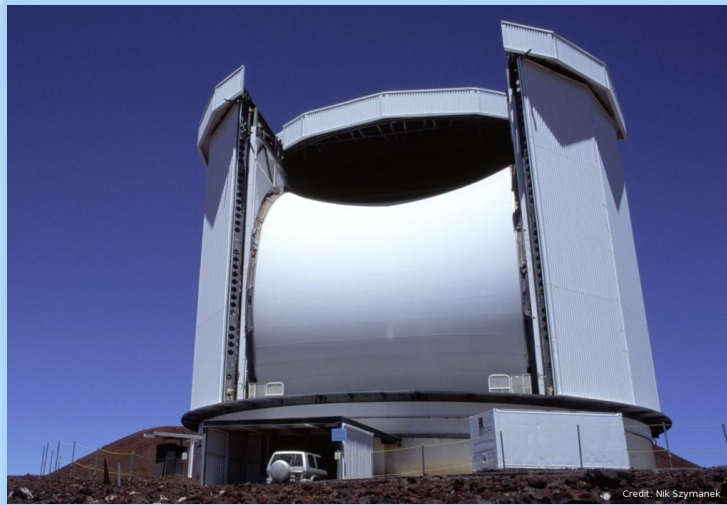
- Higher resolution imaging: reduce confusion noise
- Deep imaging: minimise instrumental noise
- High-res. multi-wavelength priors: apply deconfusion algorithms to probe dense source populations (T-PHOT; E. Merlin et al. in prep.)

The SCUBA-2 Cosmology Legacy Survey:

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

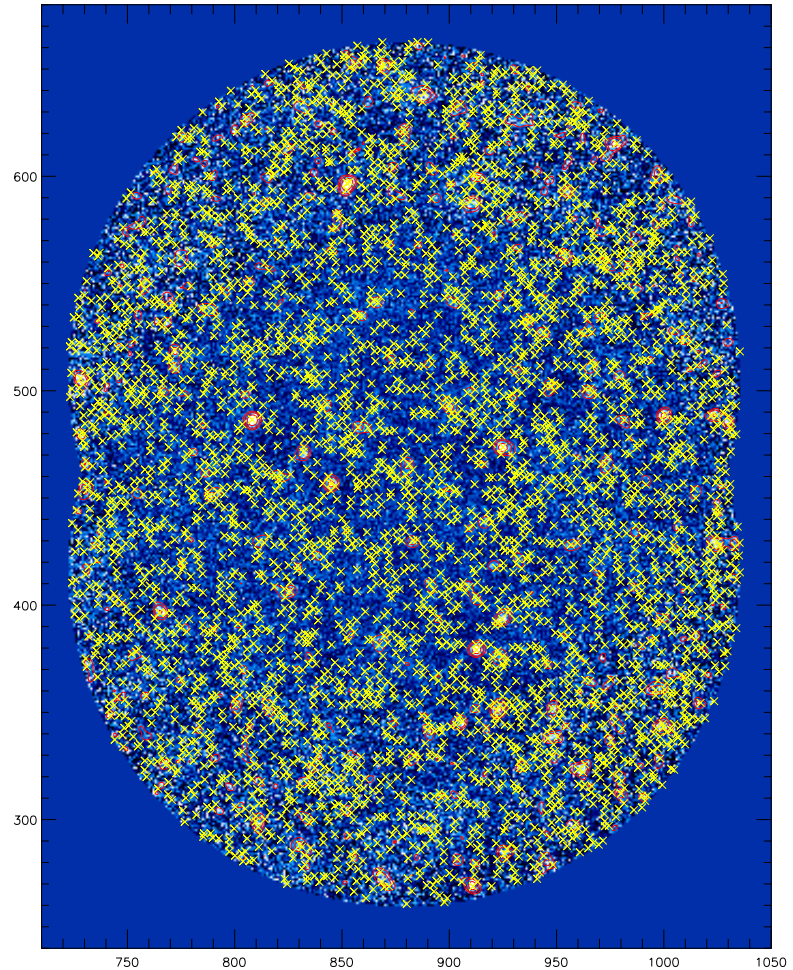
This work:

- Deep COSMOS-CANDELS + AEGIS-CANDELS fields: 230 arcmin²
- Deepest multi-wavelength coverage from CANDELS, 3DHST, S-COSMOS, SEDS, etc.
- 3DHST photo-z and SED-fitting (Skelton+14)



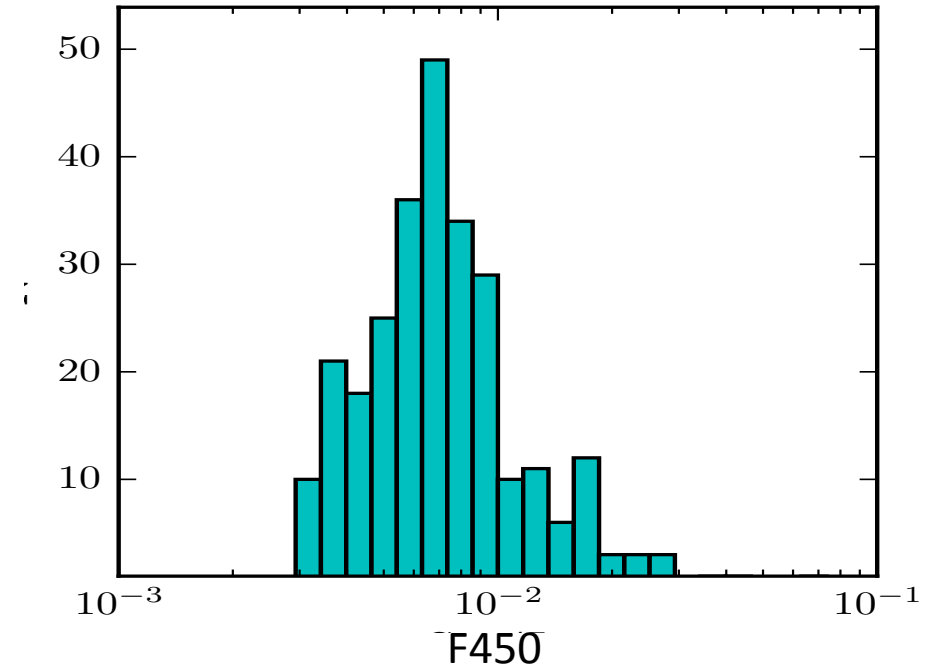
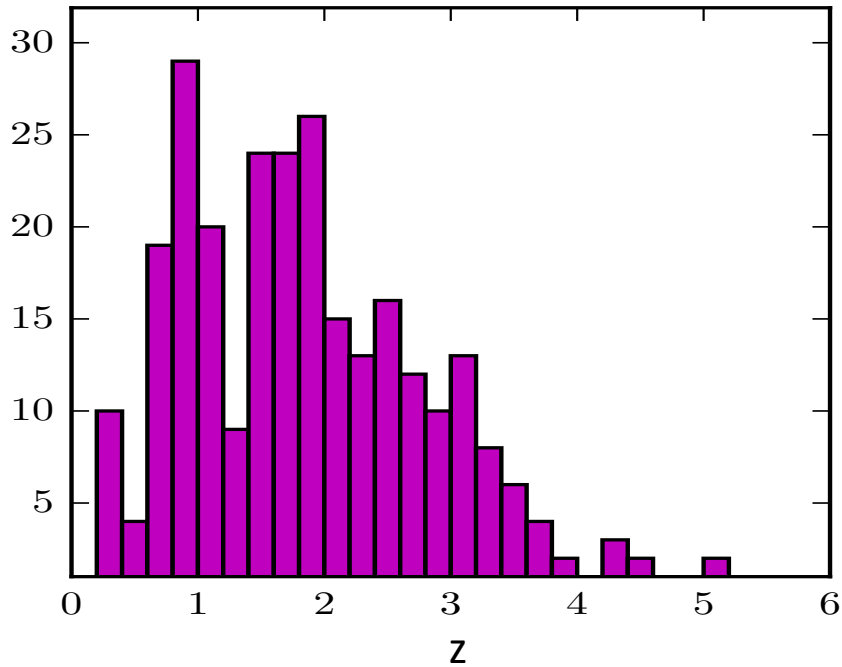
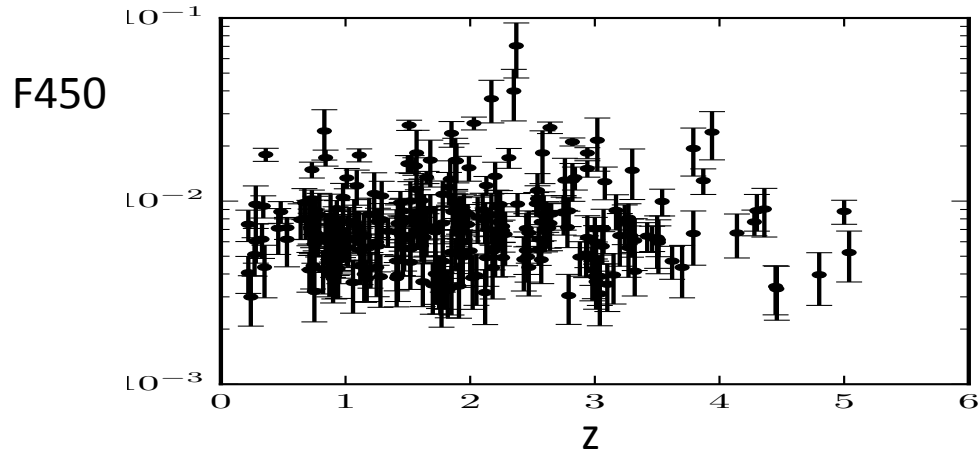
De-confusing sub-mm maps with T-PHOT

- 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



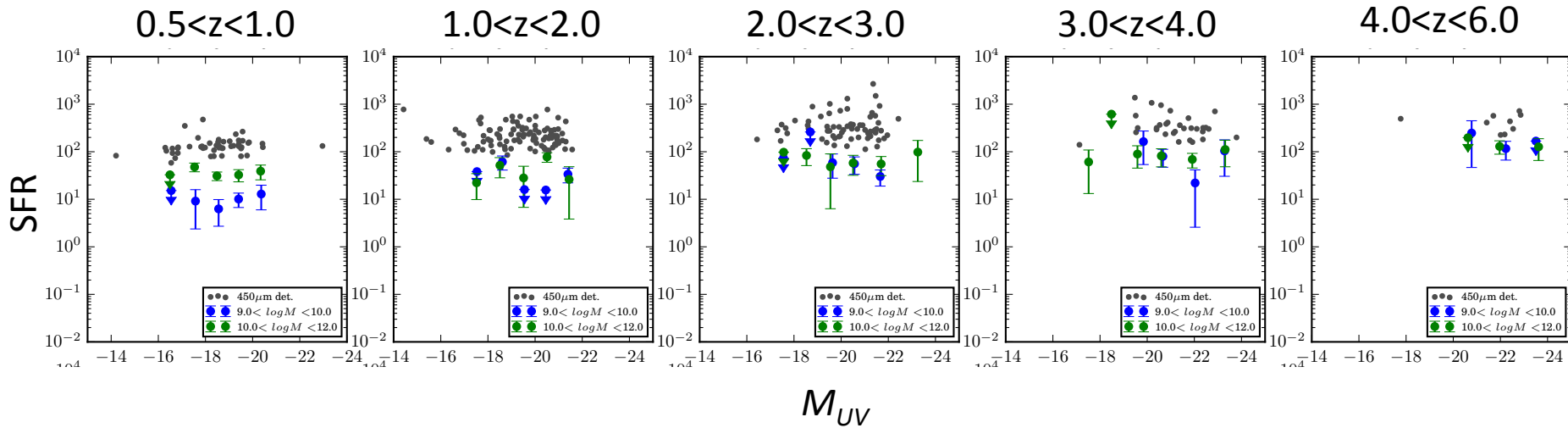
Preliminary results

450 μm detections



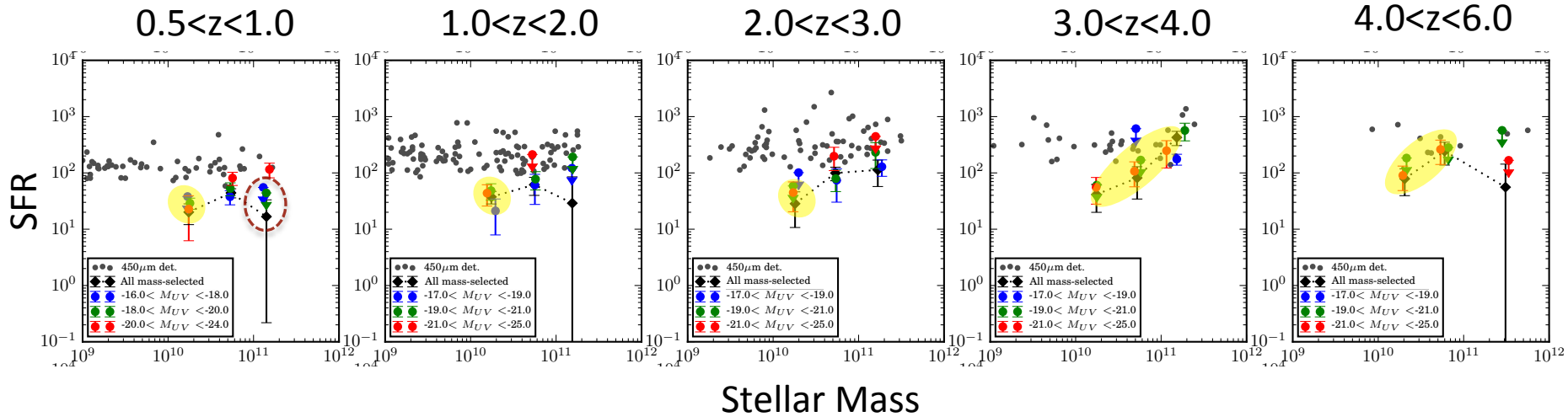
UV luminosity vs Total SFR

$$= \text{SFR}_{\text{FIR}} + \text{SFR}_{\text{FUV}}$$



- 450 μm detections:
 - limiting SFR $\approx 100M_{\odot}\text{yr}^{-1}$, roughly constant with redshift – extreme starbursts at $z \approx 0$, but main-sequence at $z \approx 2-6$
 - 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.

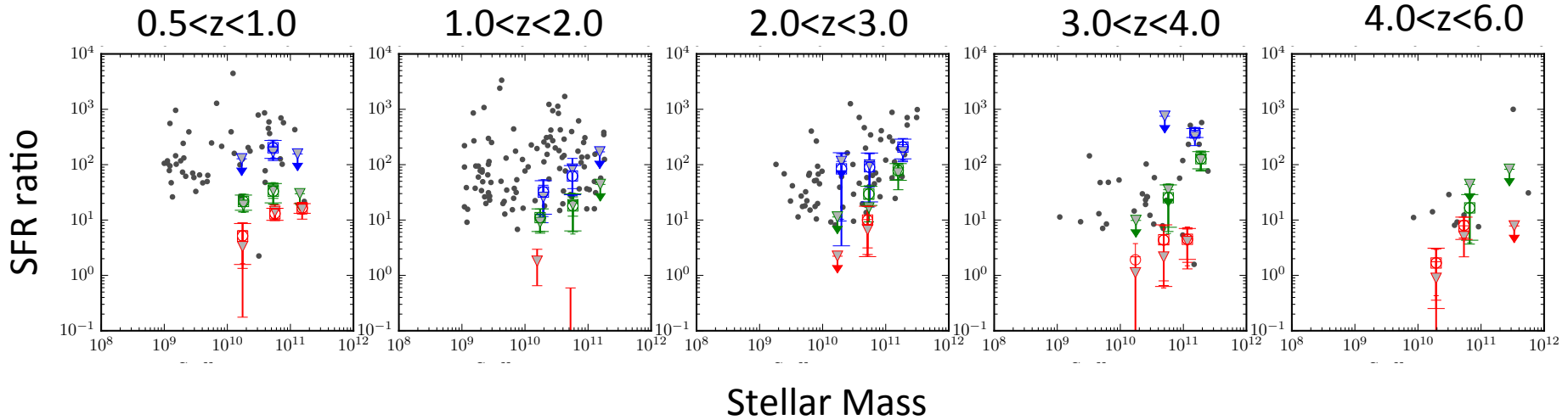
Stellar Mass vs Total SFR

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- 450 μm detections:
 - Limited to $\text{SFR} > 100$ 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 \rightarrow High SFR; Low L_{UV} \rightarrow Passive
- Overall, stellar mass is a better indicator of total SFR than raw UV luminosity

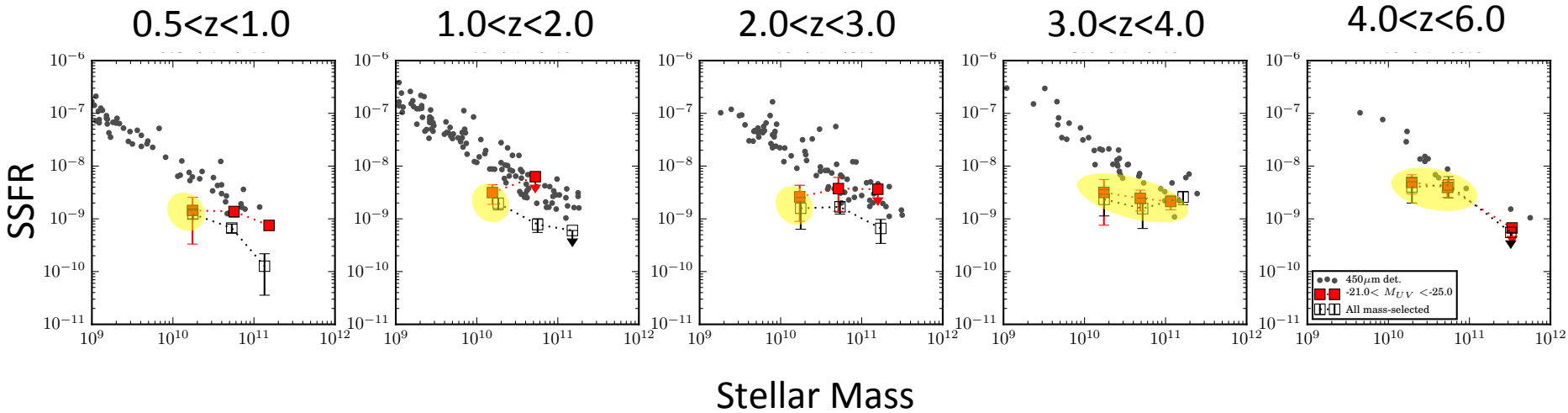
Stellar Mass vs Obscuration Fraction

$$= \text{SFR}_{\text{FIR}} / \text{SFR}_{\text{FUV}}$$



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

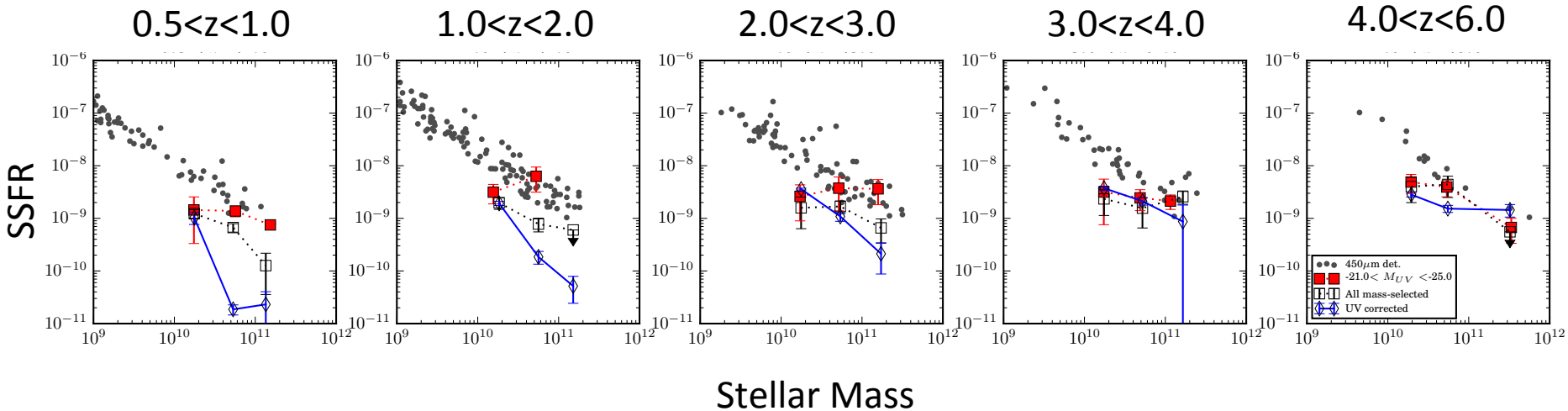
Stellar Mass vs Median SSFR



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

- 450 μ m 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)

Stellar Mass vs Median SSFR

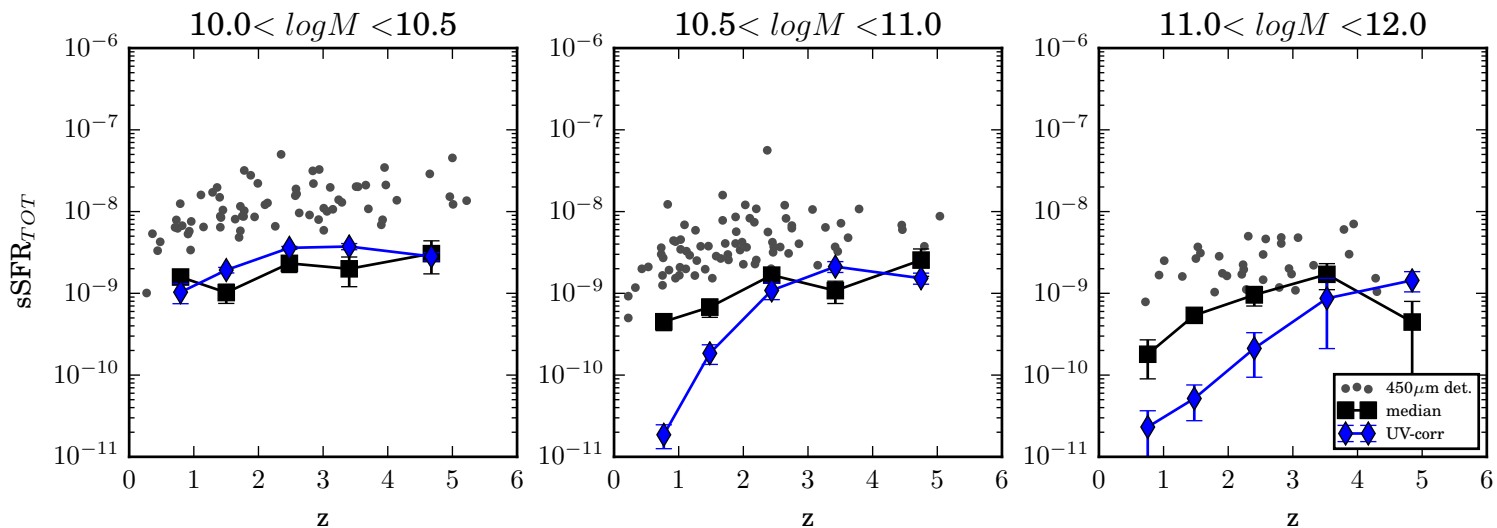


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- UV-luminous sample:
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- All massive galaxies:
 - Shallow negative slope of SSFR(M)
 - Much steeper slope at $z < 3$ in dust-corrected UV SFRs (*without* FIR information)

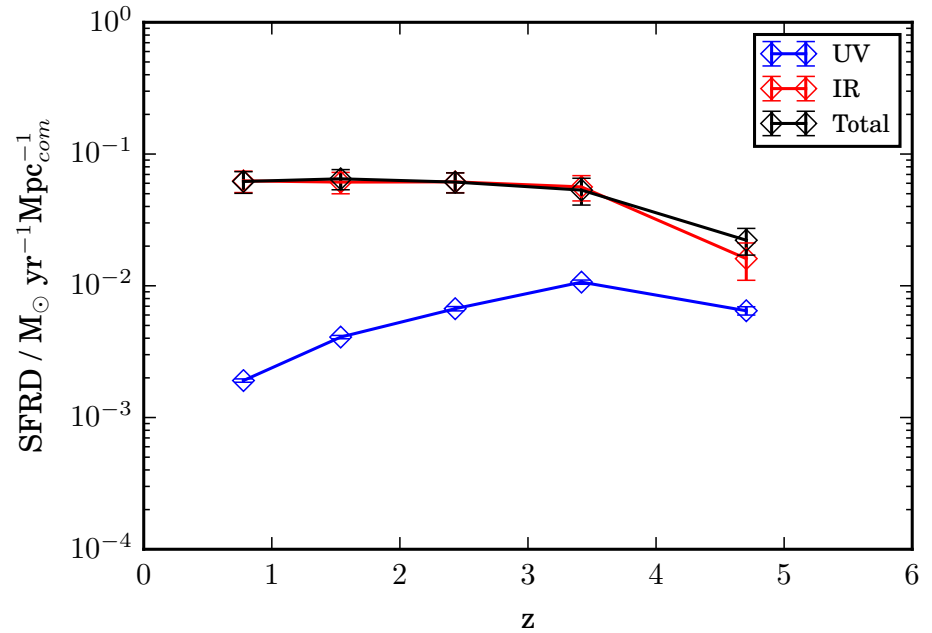
Evolution in SSFR

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



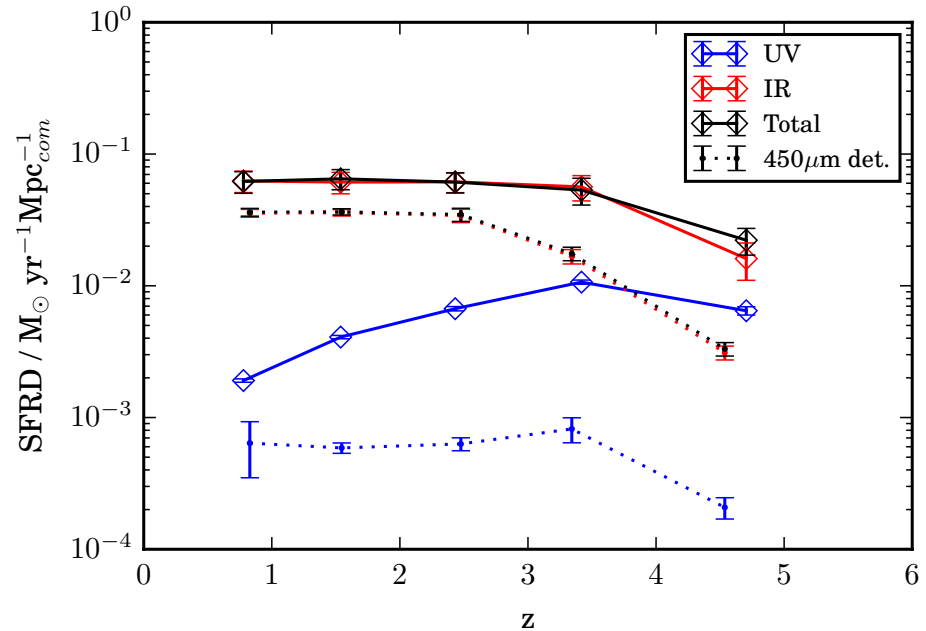
Cosmic SFR density = $\Sigma\text{SFR}/V_{\text{com}}$

- 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 $z \approx 3-4$



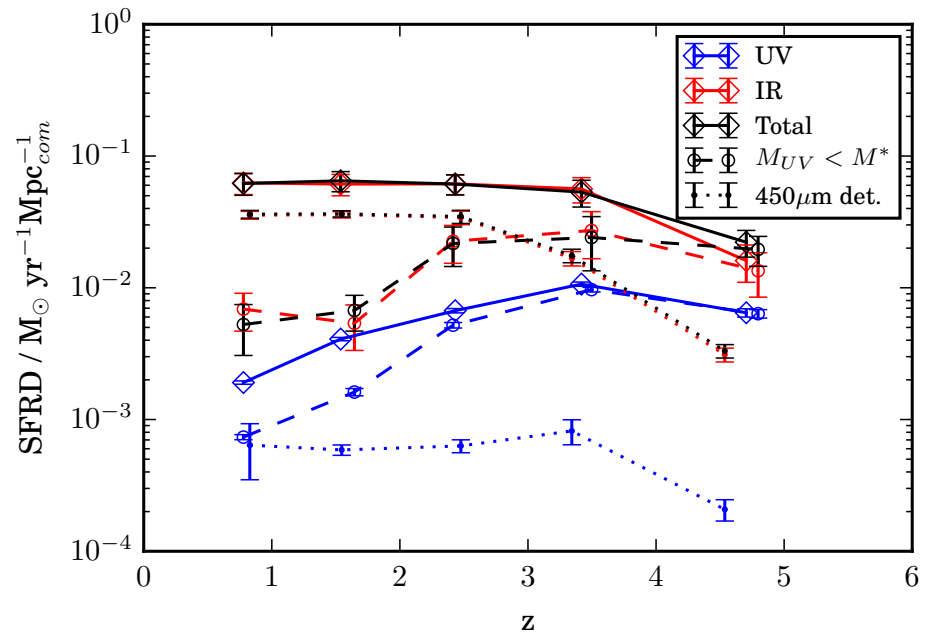
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- Constitute smaller fraction at $z > 3$ as negative k -correction less effective
- Unobscured UV SFRD from these is 100x lower than FIR



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- 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
- 450 μm -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 $L_{\text{UV}}>L^*$ galaxies increases from $1<z<3$ and remains high up to $z\approx 5$, but galaxies remain significantly obscured

Thank you for listening!