FROM HERSCHEL TO ALMA: UNVEILING THE MAJOR MODE OF STAR FORMATION IN THE EARLY UNIVERSE

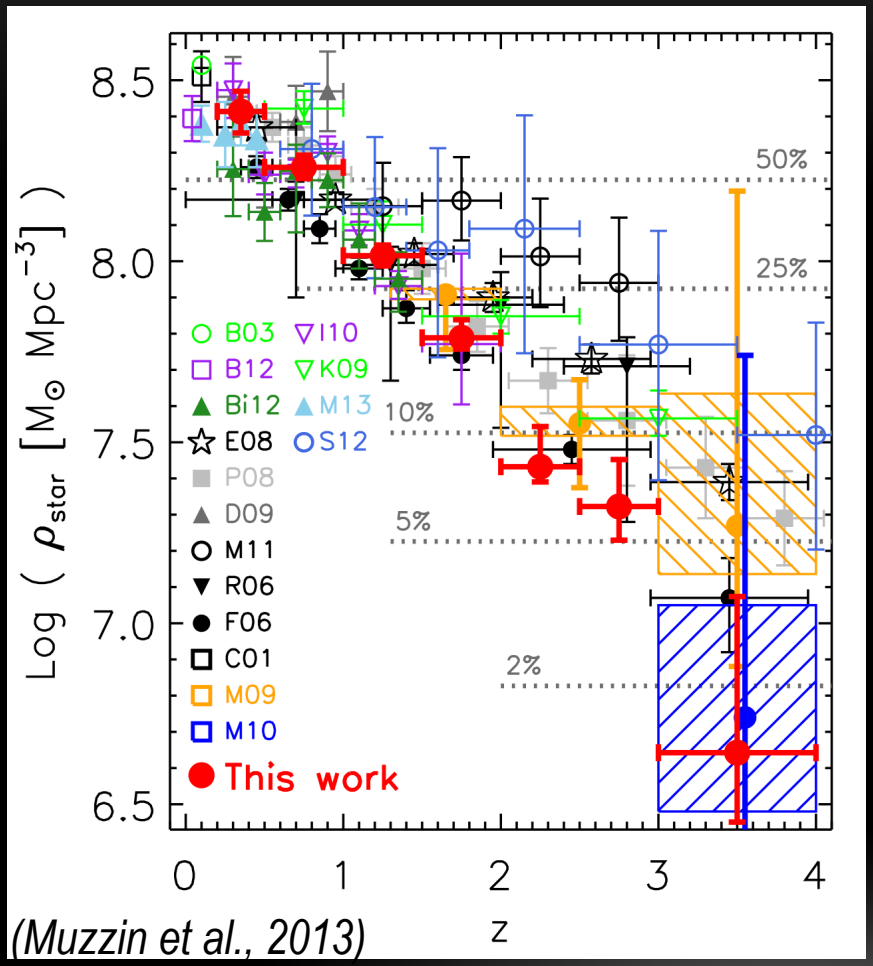
Maurilio Pannella

w David Elbaz, Emanuele Daddi, Mark Dickinson, Corentin Schreiber,

Roger Leiton and the CANDELS/GOODS-Herschel folks

WHEN AND HOW GALAXIES FORMED

THE GROWTH OF STELLAR MASS IN THE UNIVERSE



(Muzzin et al., 2013)

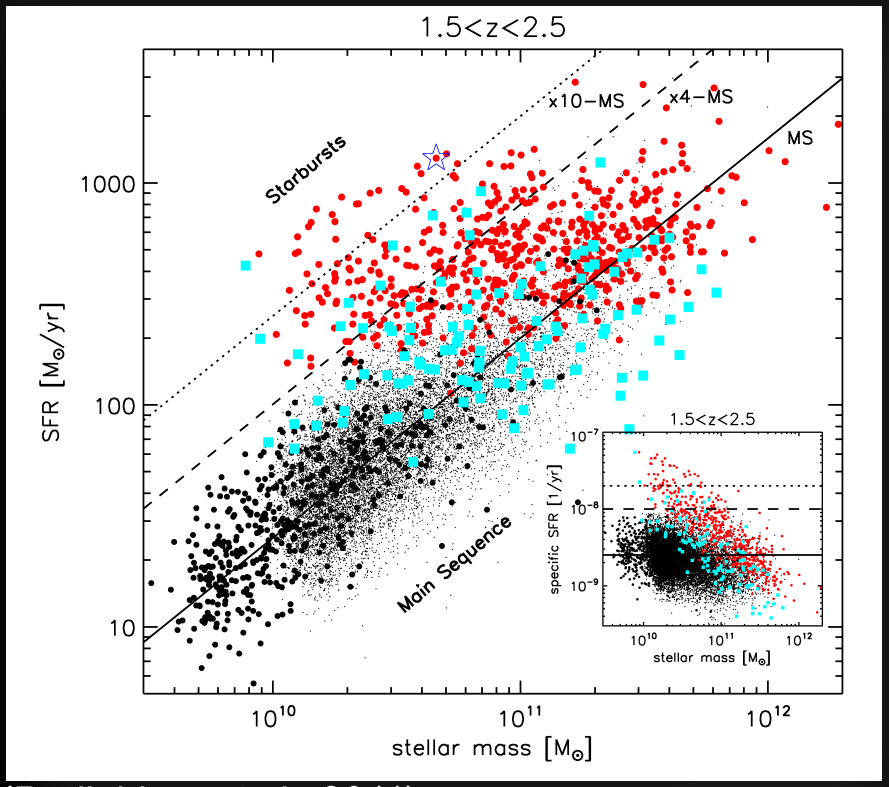
Broad consensus on the evolution of the galaxy stellar mass function up to high redshift

About 45% of the present day stellar mass has been produced in about 3.6 Gyrs at $1 < z < 3$

The remaining 50% has formed in the last 7.5 Gyrs at $0 < z < 1$

WHEN AND HOW GALAXIES FORMED

THE NEW PARADIGM: A MAIN SEQUENCE OF STAR FORMING GALAXIES

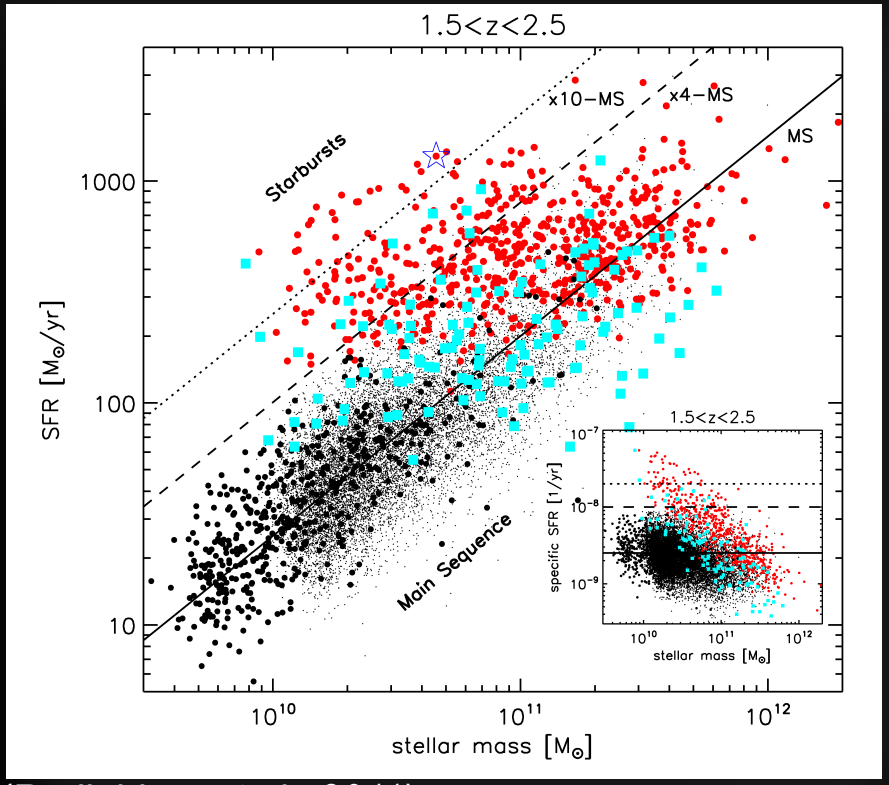


(Rodighiero et al., 2011)

- log M_* ~ log SFR
- Inefficient and long lasting conversion of gas in stars (1/SFE = M_{gas}/SFR ~ 1Gyr)
- 0.3 dex scatter is incompatible with SFR/ mass growth driven by stocastic events, e.g. mergers
- Outliers ("Starburst") are a minority (~2%) and almost irrelevant (~10%) in terms of SFRD and stellar mass growth budget at all z

WHEN AND HOW GALAXIES FORMED

SKEPTICAL SAM ASTRONOMER ON THE MAIN SEQUENCE "PROPAGANDA"



(Rodighiero et al., 2011)

- I don't see any correlation but only a scatter plot. Look at the Herschel detections !
- Above z~1 you need to apply important dust correction to the UV light to estimate SFR. How do you know you can trust'em ?
- Stacking shows only median values but to say that it is a real correlation you need to quantify the scatter.
- NO MATTER WHAT, I DON'T BELIEVE IT !

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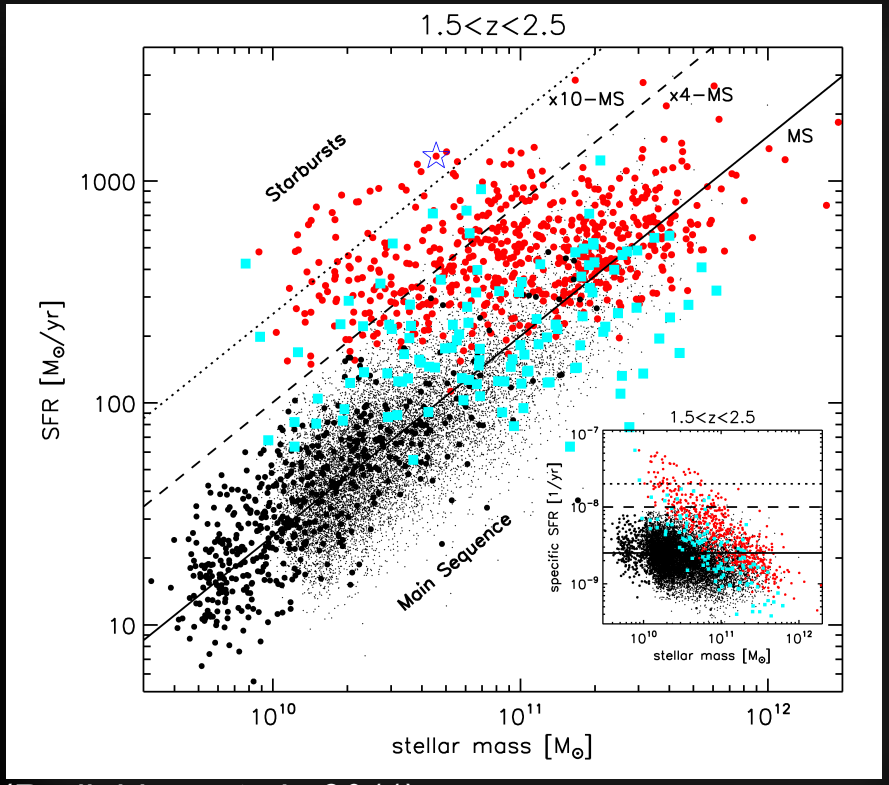

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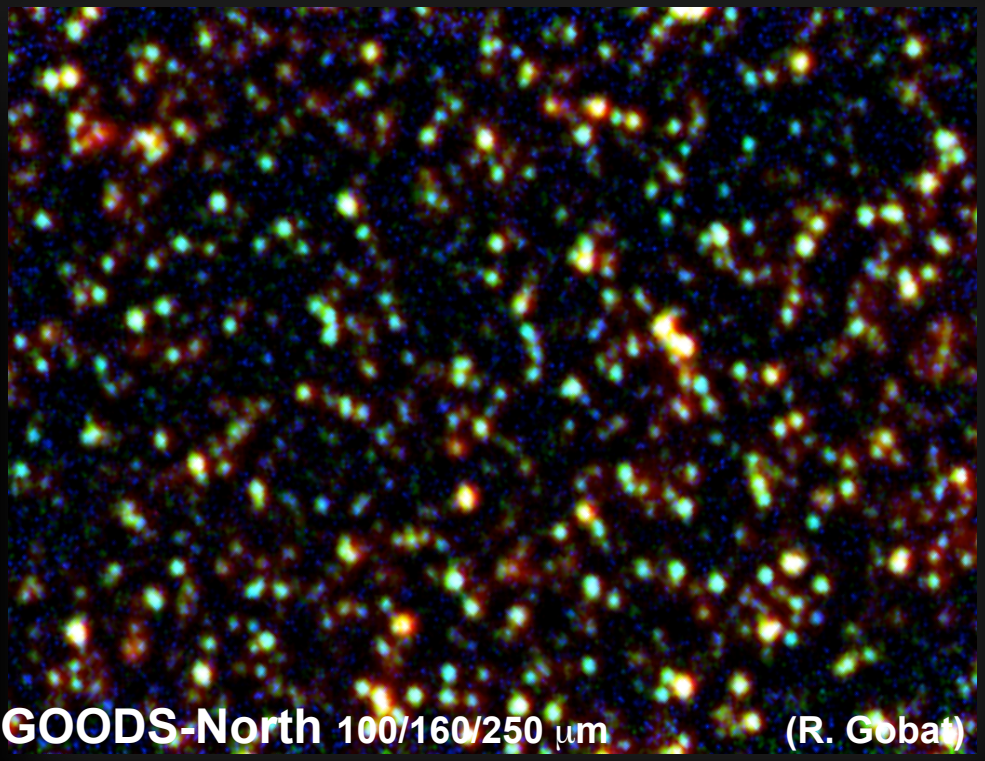
THE GOODS-HERSCHEL SURVEY



An Open Time Key Program, P.I. D. Elbaz

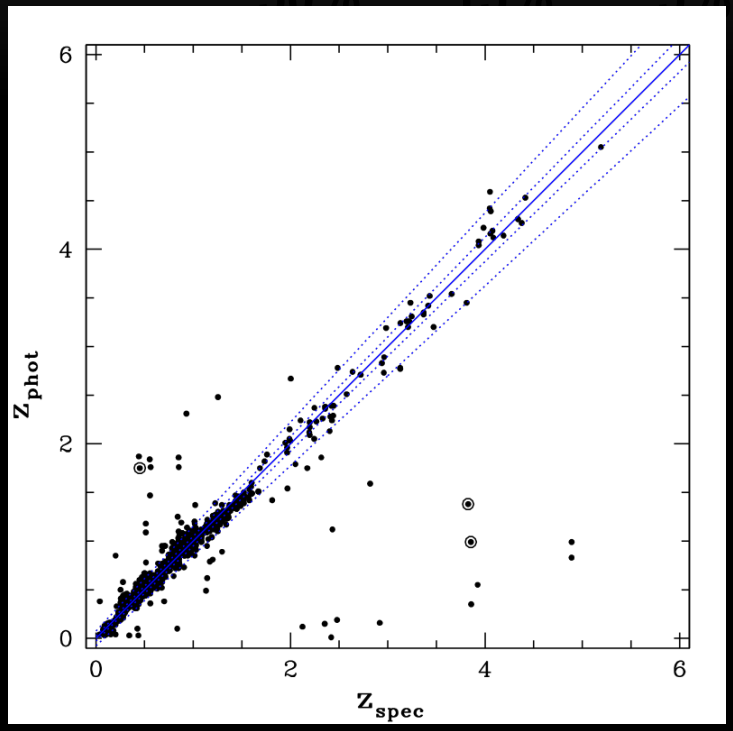
The deepest IR images of the sky

GOODS-North 10'x15' – 154hrs
PACS 100/160 μm (1.1/2.6 mJy)
SPIRE 250/350/500 μm (5.7/7.2/9 mJy)

About 1000 Herschel detections

THE GOODS-HERSCHEL SURVEY

TRACING GALAXIES OVER COSMIC TIME



(MP et al., 2014)

A deep WIRCAM_K selected multi band catalog

GALEX/KPNO/SUBARU/CFHT/SPITZER
NUV + U + BVRIzY+ JHK + 3.6/4.5μm

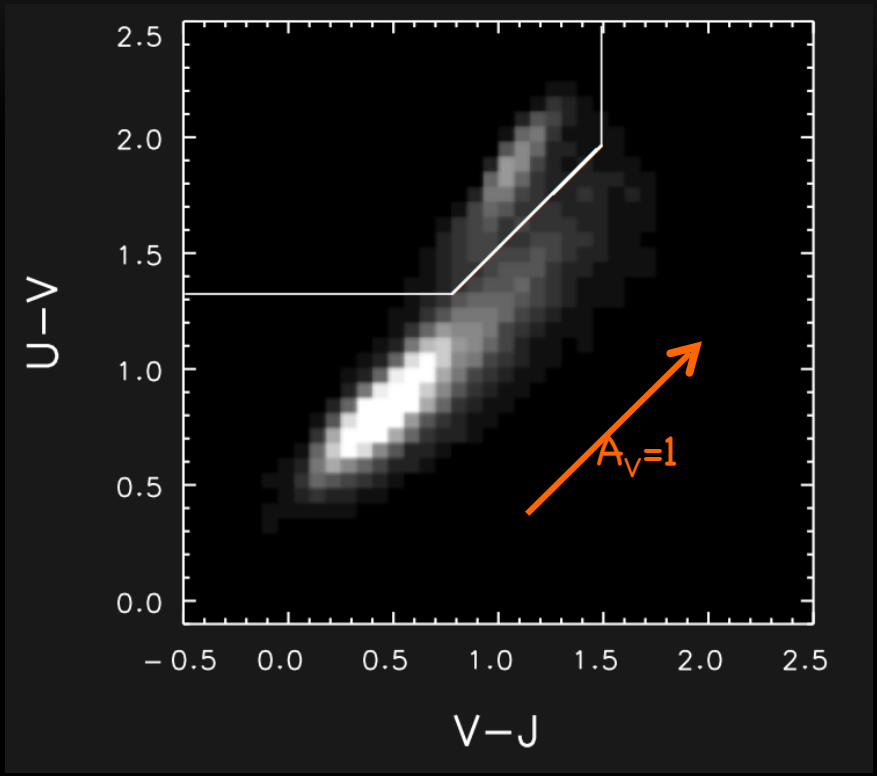
~ 18000 sources in PACS area to K < 24.5

- photo-z vs 2700 spec-z: 3% accuracy

- stellar masses from SED fitting

THE GOODS-HERSCHEL SURVEY

SELECTING STAR FORMING GALAXIES

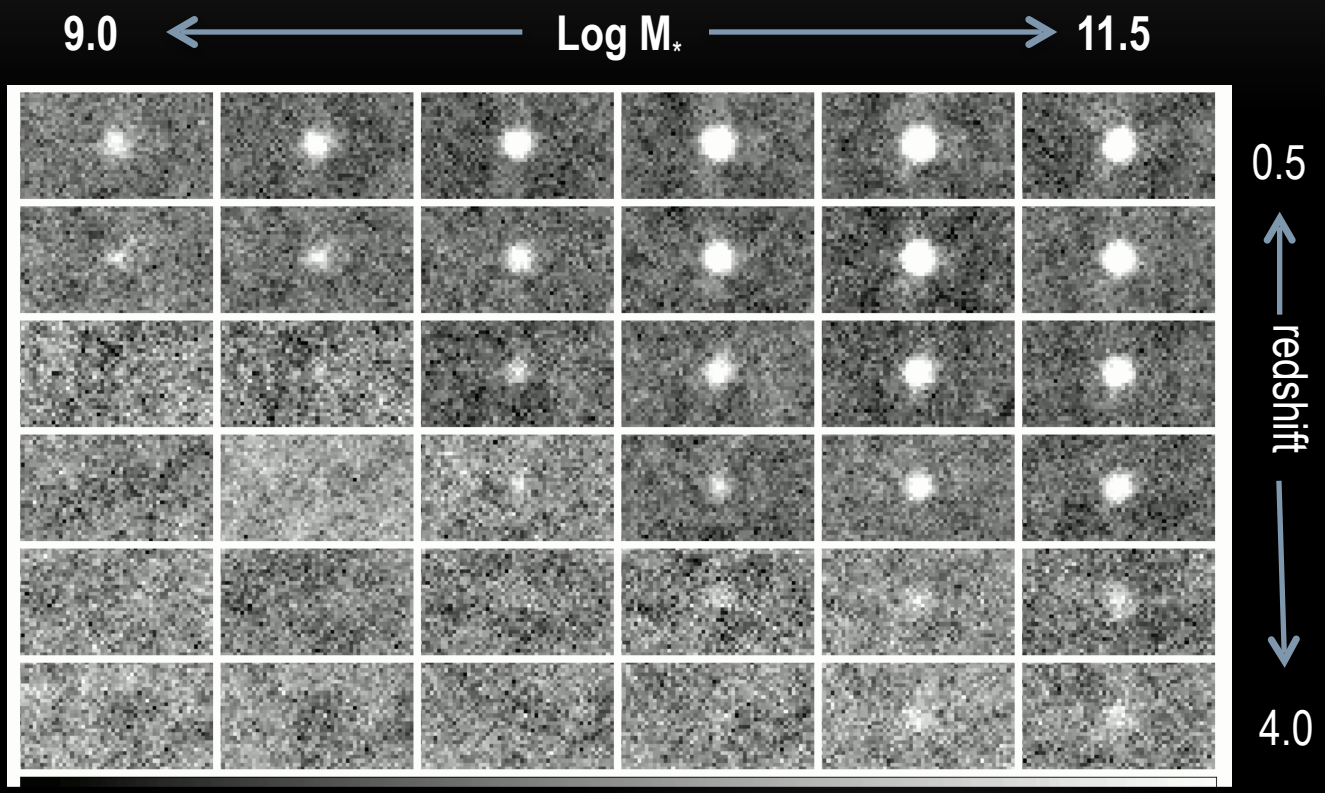


-- sBzK selection at z~2 (Daddi et al. 2004)

-- the UVJ selection (Wuyts et al., 2007)

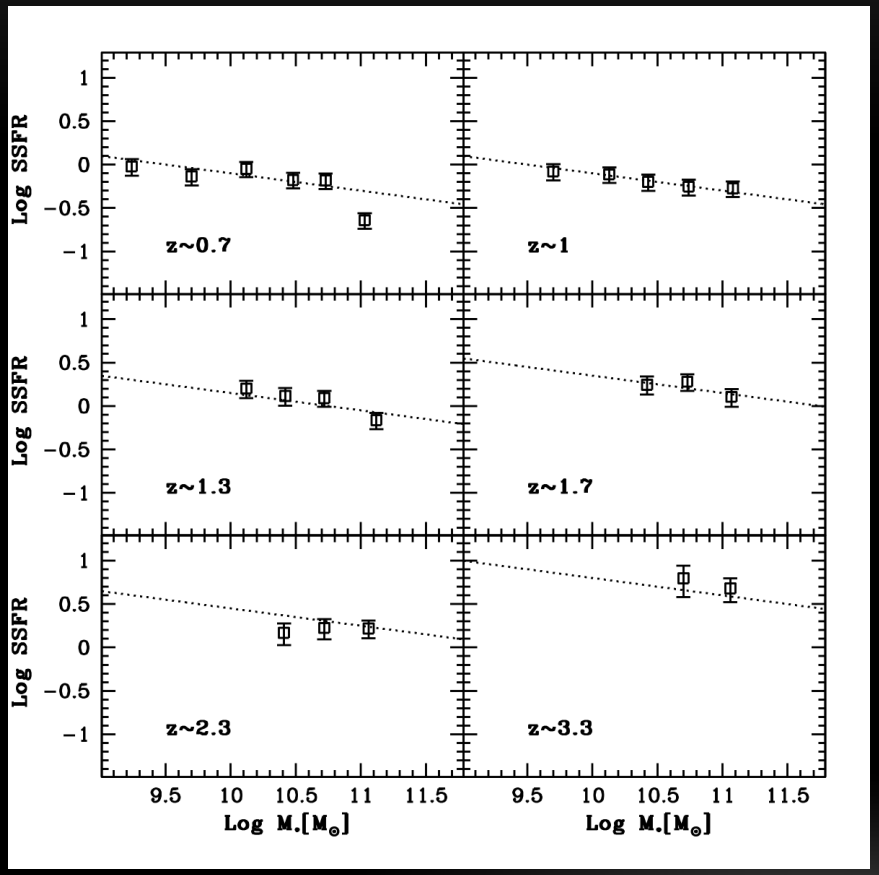
TRACING GALAXIES OVER COSMIC TIME

THE STACKING ANALYSIS



NORMAL GALAXIES AT HIGH REDSHIFT

THE SSFR-M_* CORRELATION UP TO Z~4



(MP et al., 2014)

– the slope is consistent with being the same and relatively flat (-0.2) at all redshifts

– the normalization keeps growing in redshift instead: no plateau signature …

NORMAL GALAXIES AT HIGH REDSHIFT

DUST ATTENUATION UP TO Z~4

$A_{UV} = 2.5 \text{ LOG } (SFR_{IR}/SFR_{UV} + 1)$

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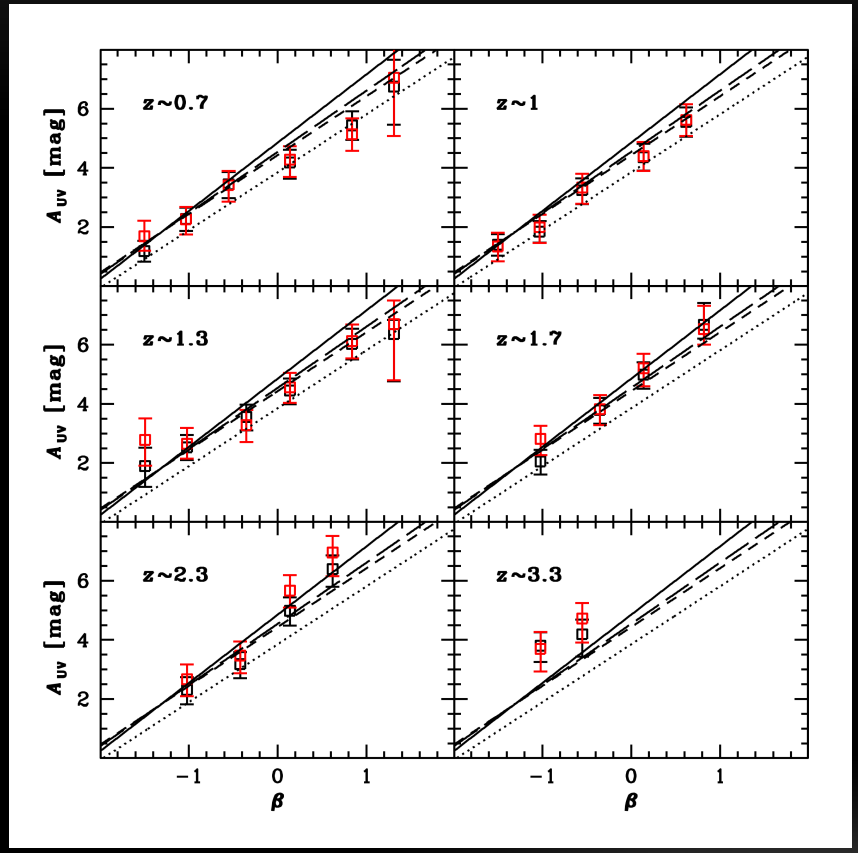

– the correlation between dust attenuation and UV slope evolves with redshift

– UV spectra becomes bluer and bluer with redshift

-- good agreement at 1 < z < 3

(MP et al., 2014)

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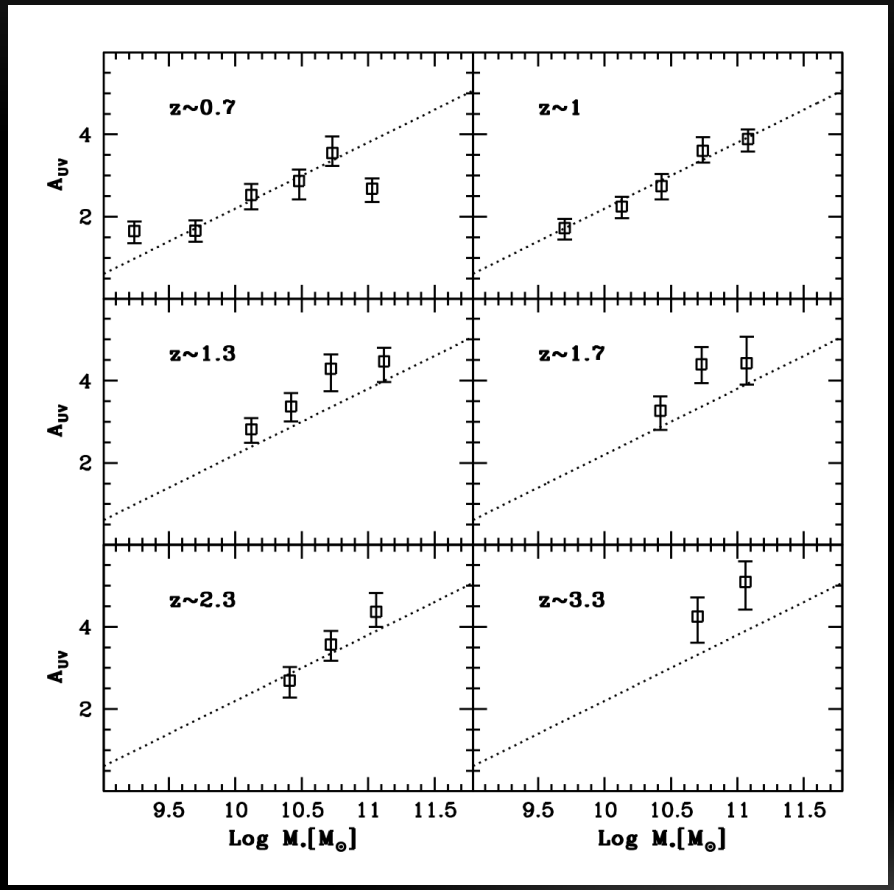

(MP et al., 2014)

— The correlation between M_* and A_{UV} does not evolve much up to z~4

— The same amount of SFR is less attenuated at higher redshift

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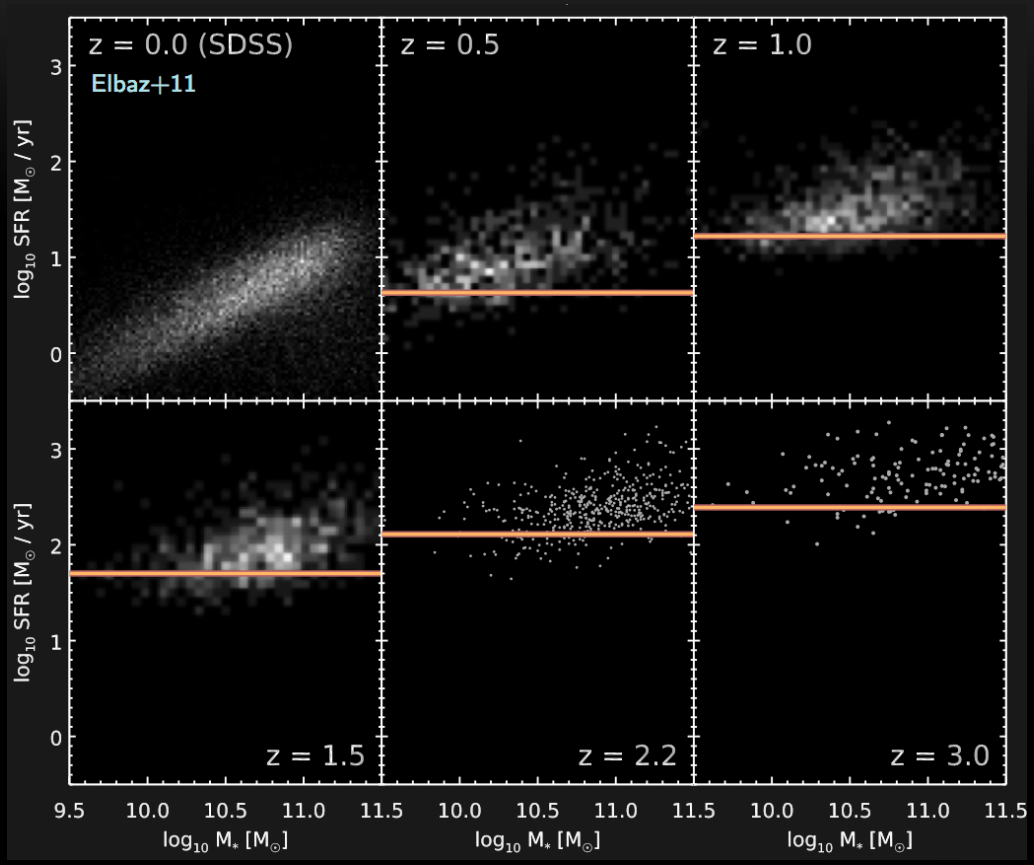

(Schreiber, MP et al., 2015)

The deepest IR images of the sky

GOODS-Herschel, CANDELS+Herschel, PEP
P.I.s D. Elbaz, M. Dickinson, D.Lutz

About 5000 Herschel detections

CANDLES-HST multi wavelength database

About 100000 H band galaxies [< 27 mag]

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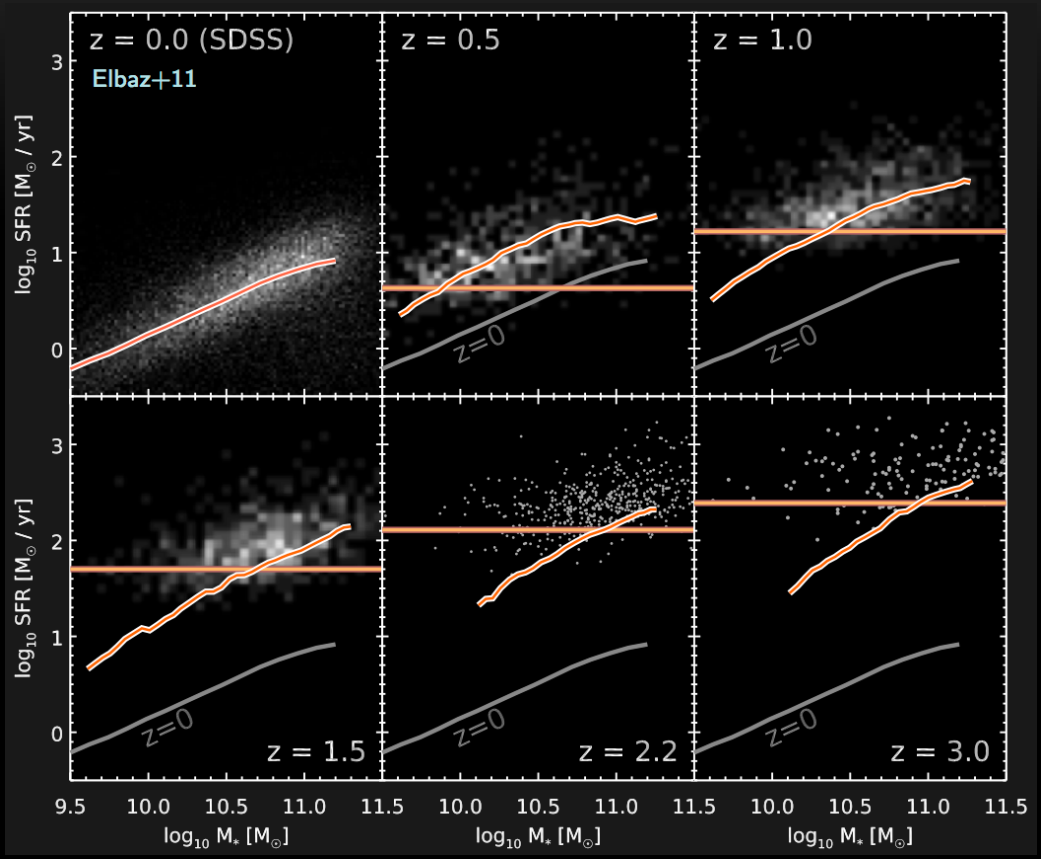

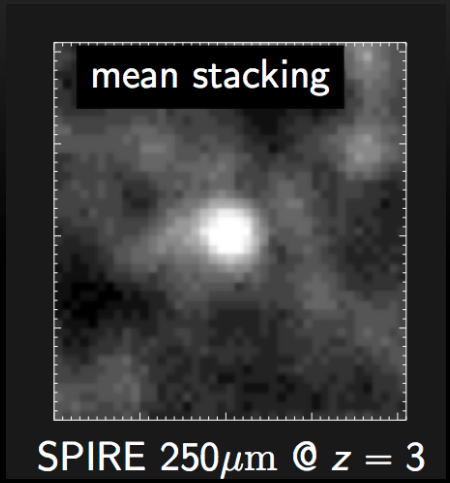

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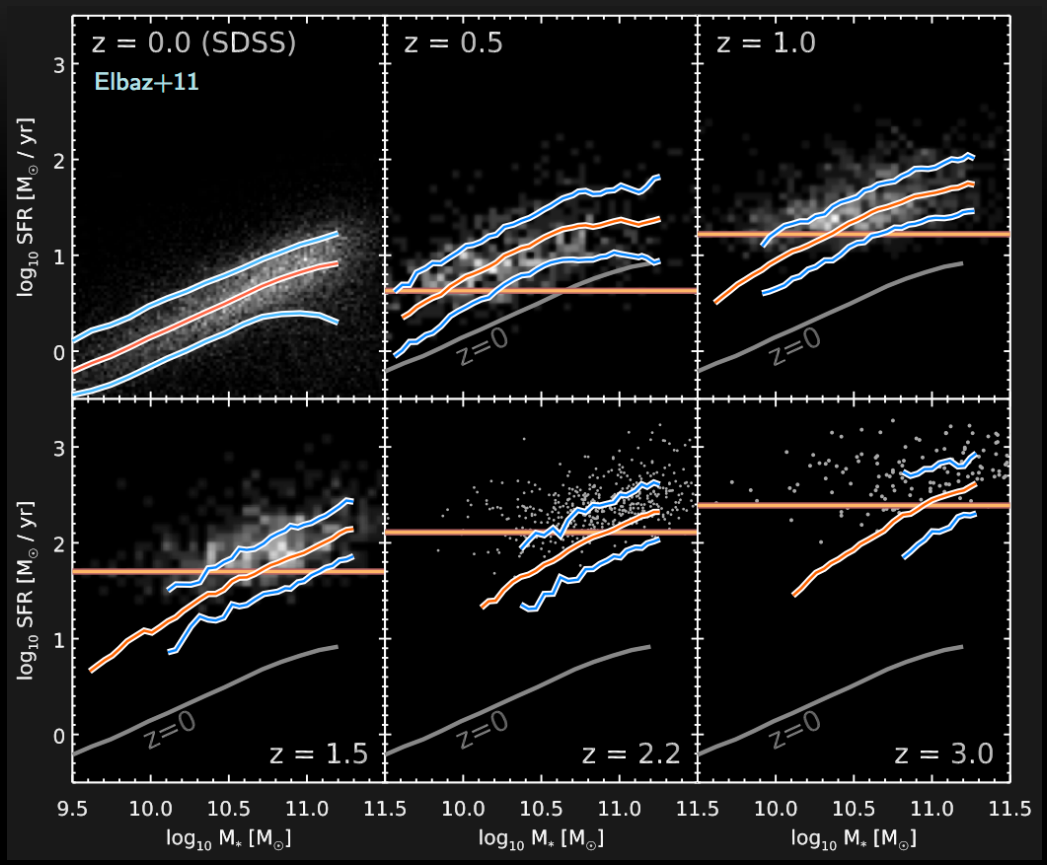

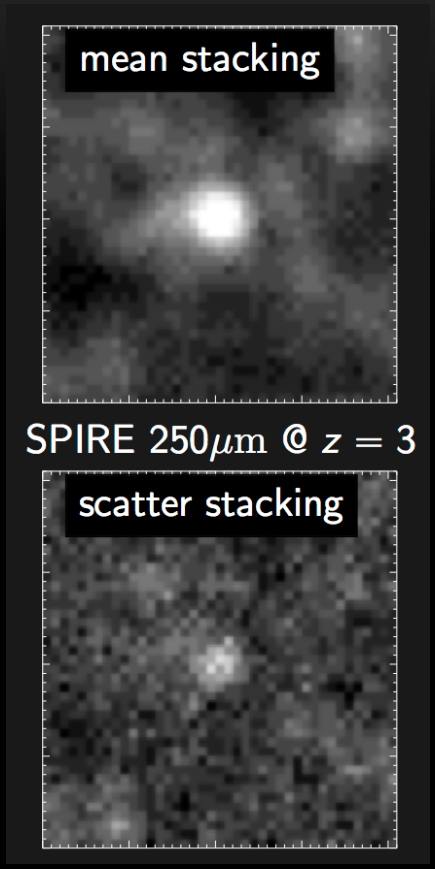

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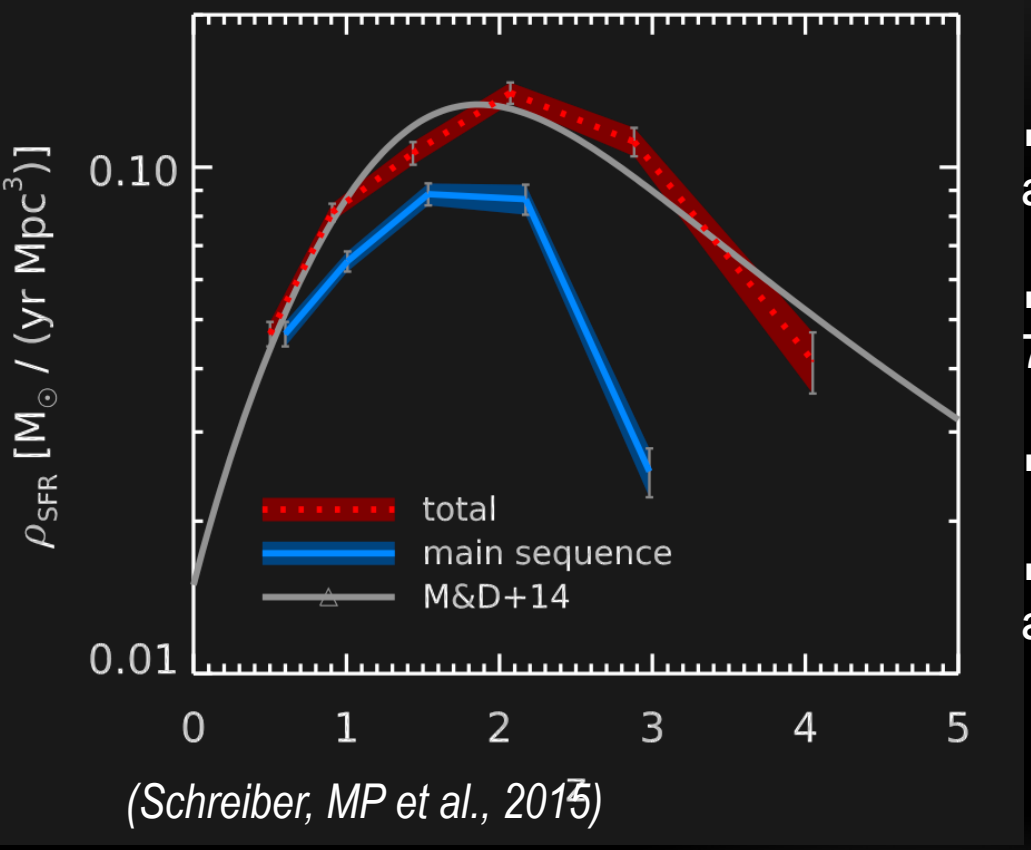
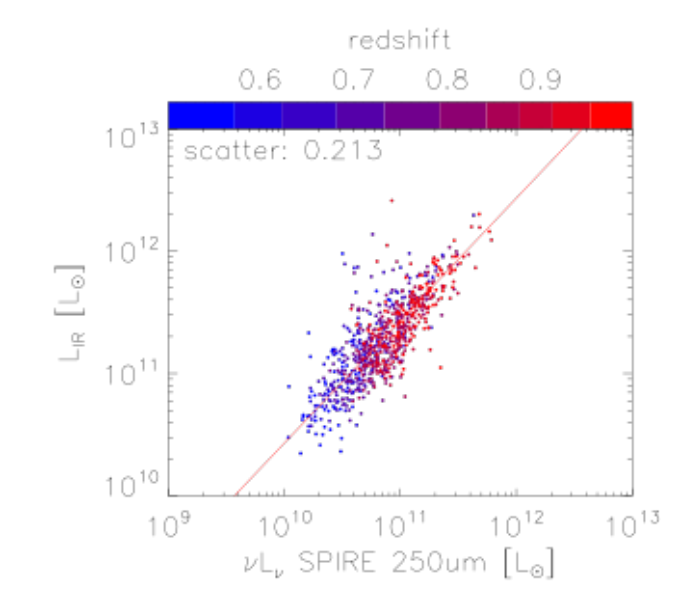


(Schreiber, MP et al., 2015)

- Scatter is ~0.3 dex at all stellar masses and all redshifts up to z~3
- Galaxies on the MS produce more than 70% of present day stars
- The Main Sequence is REAL and …
- it is the dominant mode of star formation at least up to z ~3

ALMA TO UNVEIL THE MS IN THE EARLY UNIVERSE



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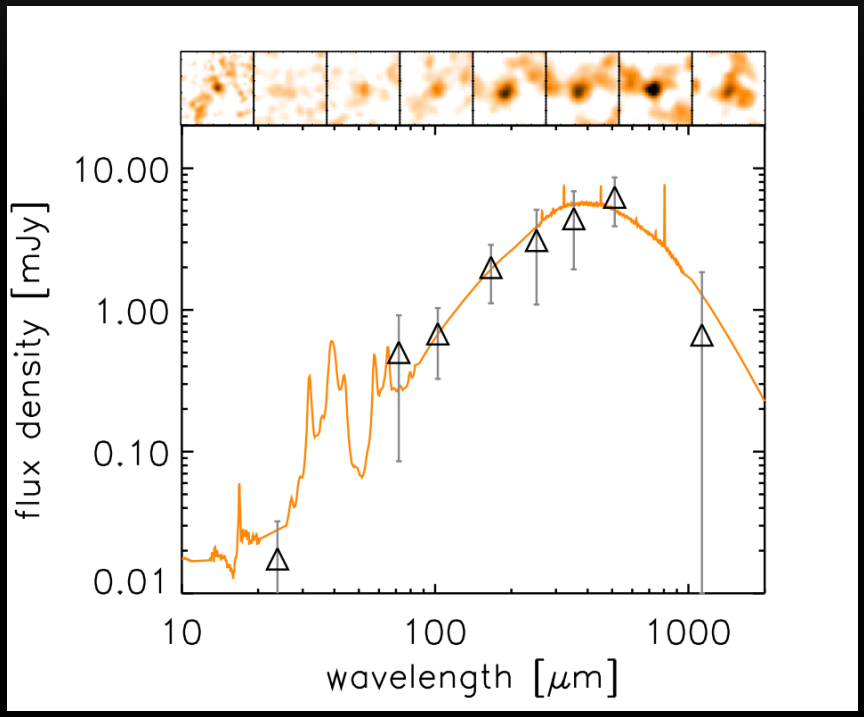

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-- Using our stacking results, we estimated that 80% of the z~4 MS galaxies down to **Log M_*** =10.5 would need ~1.5 minutes of band 7 integration to be detected.

ALMA TO UNVEIL THE MS IN THE EARLY UNIVERSE

- Cycle 2 ALMA Band 7 program (PI R. Leiton)
- CANDELS FIELDS : GOODS-S, UDS, COSMOS
- $3.5 < z_{phot} < 5$
- mass complete sample ($10.5 < \log M_* < 11.7$)
- 122 objects targeted for a total of 5.6 hours ALMA time

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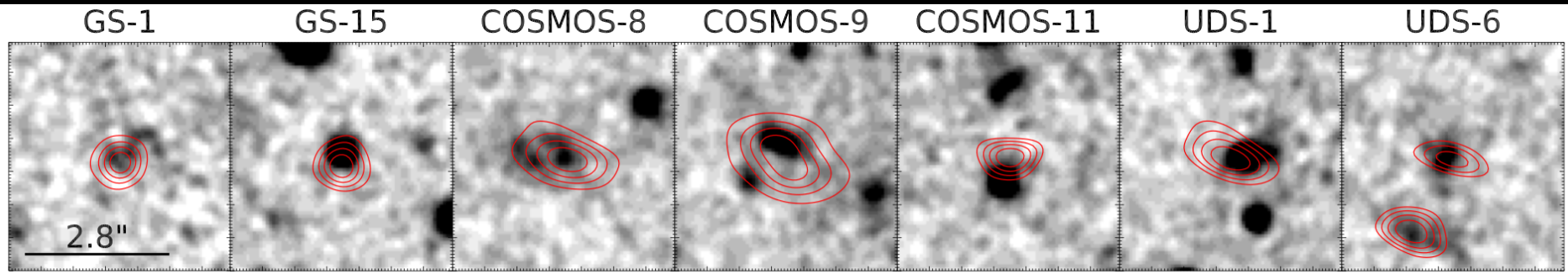

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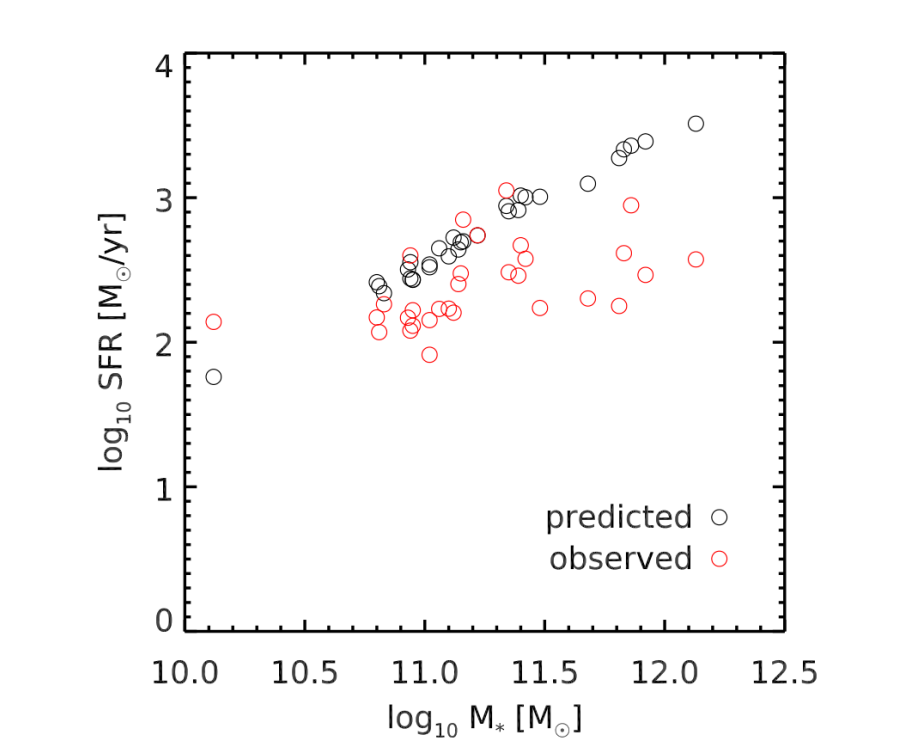

— Very preliminary analysis shows:
- only 40% detection rate and
- around a factor 2 lower SFR in the ALMA data as compared to Herschel estimates

— Physical ?
Increased scatter of the MS at z > 3
Changing slope/Wrong normalization

— Technical ?
Residual correlation boosting in H-stacks
Over-resolution of the ALMA data
Need for a more careful data reduction

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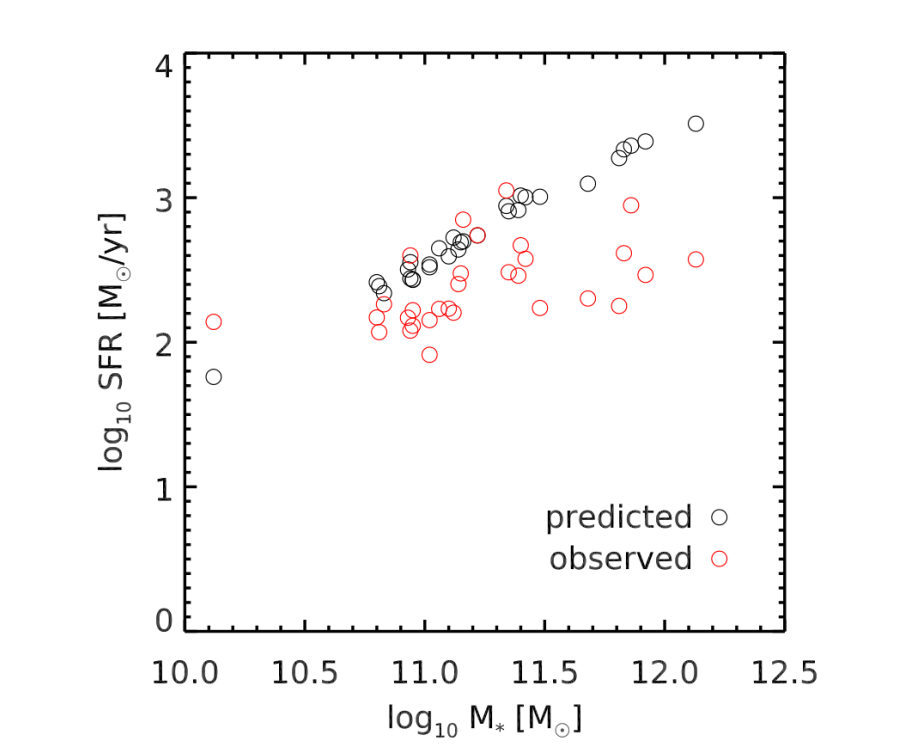

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WE DON'T KNOW YET … STAY TUNED !