Star forming galaxies at high redshift: news from Herschel

Maurilio Pannella

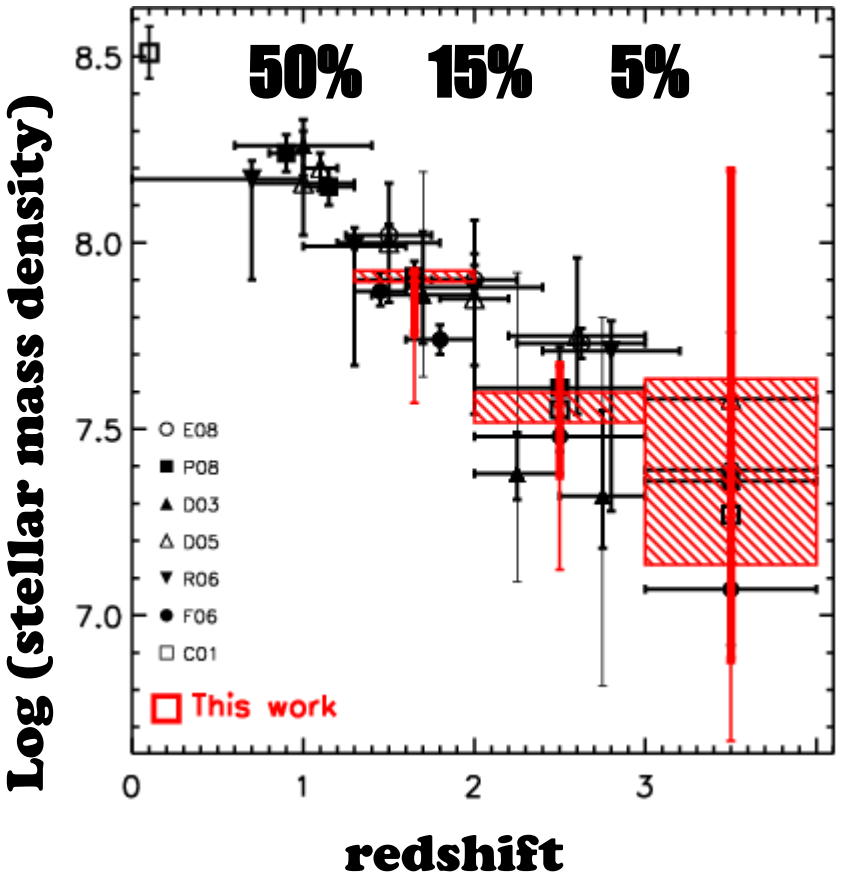
with
D. Elbaz, E. Daddi, H.S. Hwang, V. Strazzullo
and the GOODS-HERSCHEL team

Star forming galaxies at high redshift: news from Herschel

- The galaxy evolution puzzle in two slides
- Estimating star formation rates at high z
- The GOODS-HERSCHEL project
- Stacking data: music out of noise
- SFR, stellar mass, dust and … downsizing
- Conclusions

When and how galaxies formed

The growth of stellar mass in the Universe



(Marchesini et al., 2009)

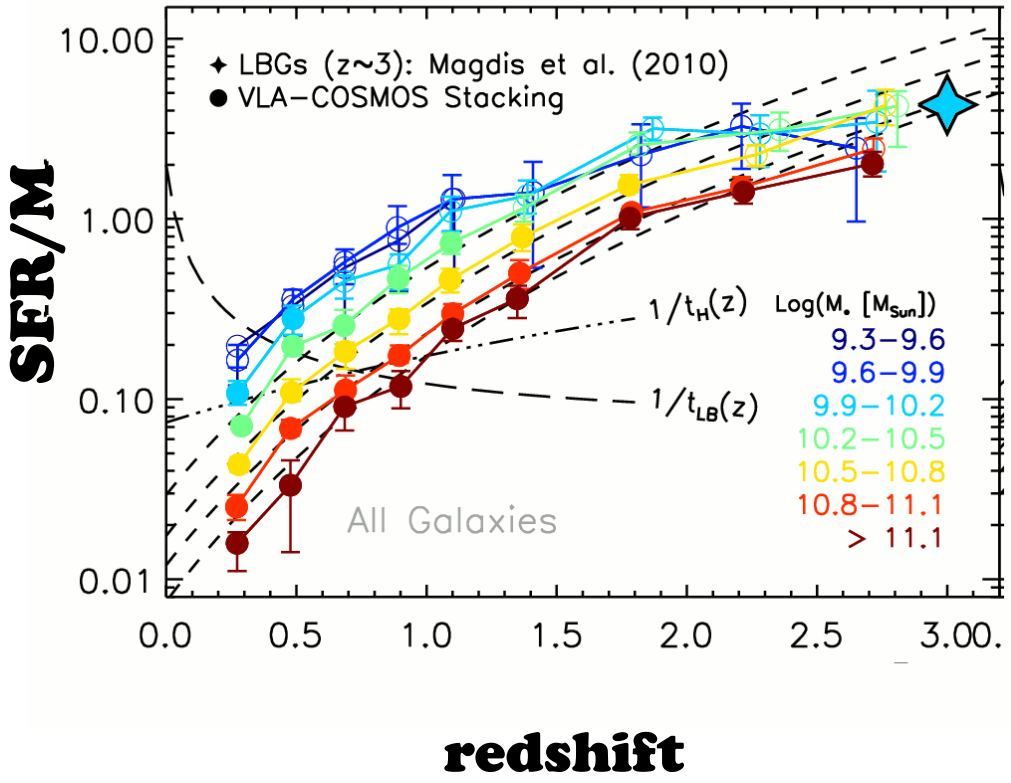
Broad consensus on the evolution of the galaxy stellar mass function up to high redshift

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 downsizing of cosmic star formation



(Karim et al., 2011)

The SSFR increases with z at a rate independent of mass

SSFRs of more massive galaxies are typically lower than those of less massive galaxies over the whole redshift range

The downsizing pattern seems to be at work up to high redshift

Chasing after star formation at high *z*

Known issues and still unanswered questions

- UV light
  - Av from SED fitting / UV spectral slope

Chasing after star formation at high *z*

Known issues and still unanswered questions

- **UV light**
  - **Av from SED fitting / UV spectral slope**
- **Radio continuum**
  - **Nuclear activity contribution**
  - **Radio-IR correlation**

Chasing after star formation at high *z*

Known issues and still unanswered questions

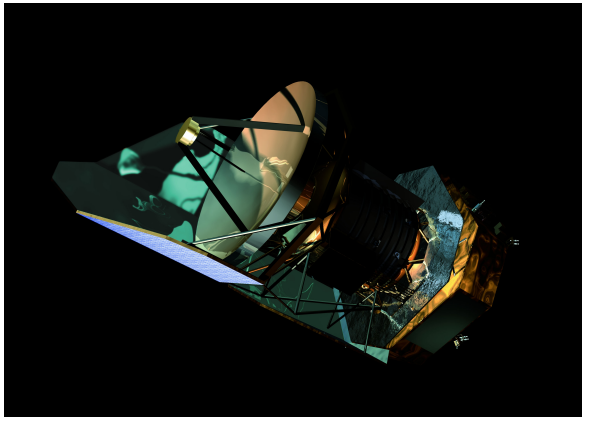
- UV light
  - Av from SED fitting / UV spectral slope
- Radio continuum
  - Nuclear activity contribution
  - Radio-IR correlation
- IR light (in the MIPS era)
  - coarse resolution + poor sensitivity
  - huge (and uncertain) bolometric corrections

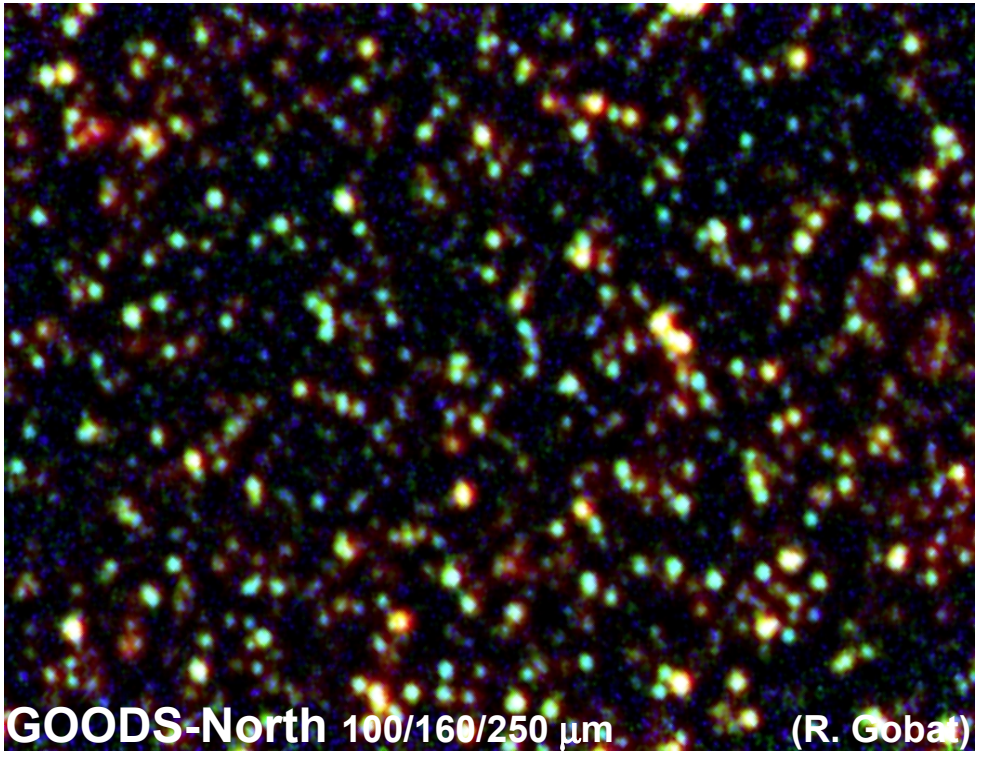
The GOODS-Herschel Survey

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 (7.6/8.2/20 mJy)





About 1000 *clean* detections

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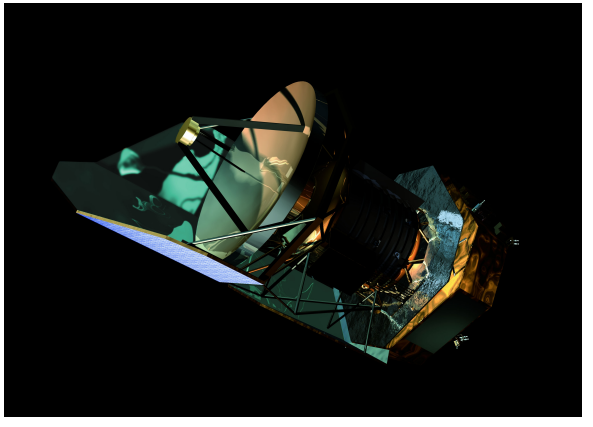

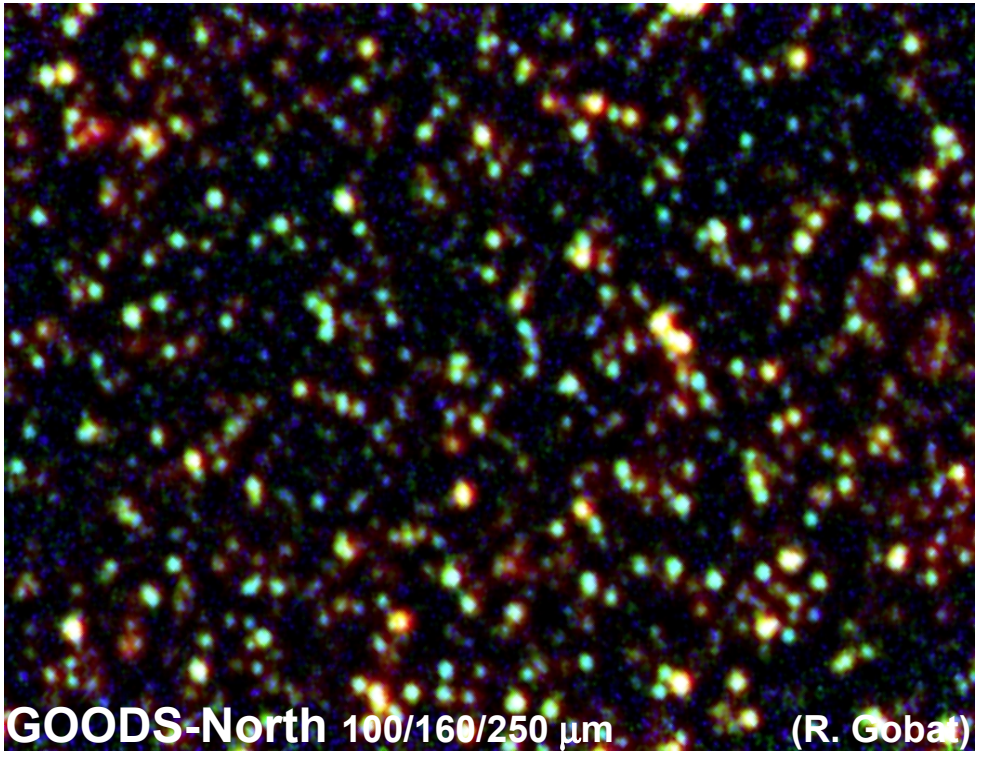

About 1000 *clean* detections against ~24000 IRAC sources !

– Tip of the iceberg ?
– SFR biased view
– What about *normal* galaxies ?

The GOODS-Herschel Survey

Tracing galaxies over cosmic time

A deep K selected multi band catalog

GALEX/KPNO/SUBARU/CFHT/SPITZER
NUV + U + BVRIz + JK + Ch1/Ch2

~ 16000 sources in PACS area to K < 24.5

The GOODS-Herschel Survey

Tracing galaxies over cosmic time

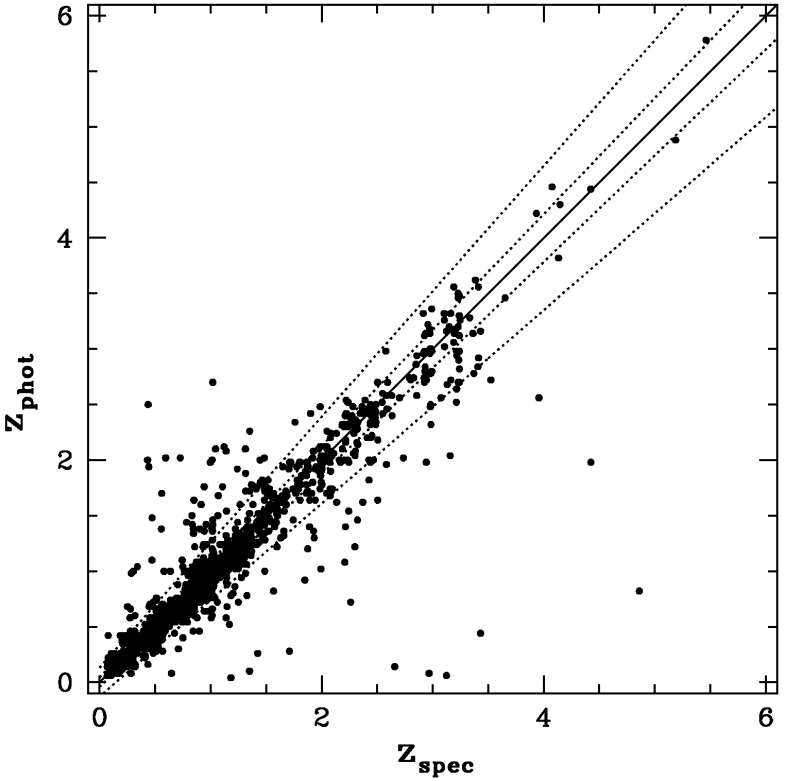

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photo-z vs 2700 spec-z: 4% accuracy

stellar masses from SED fitting

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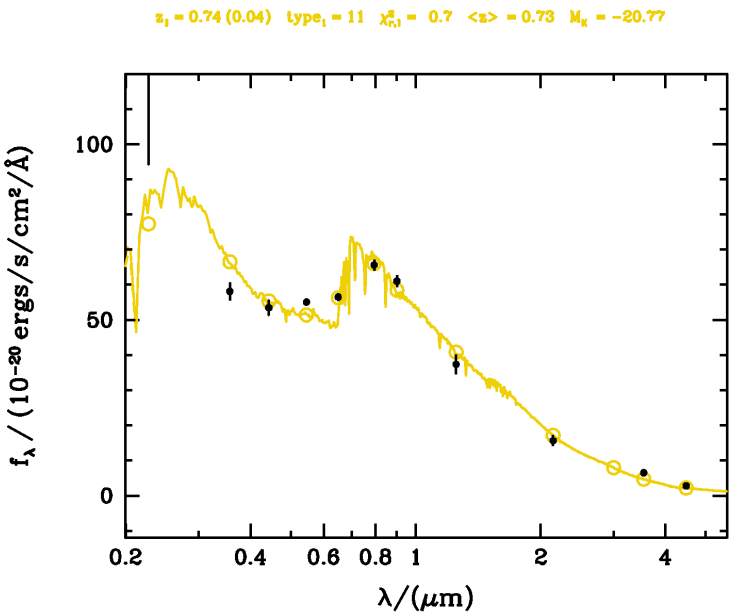

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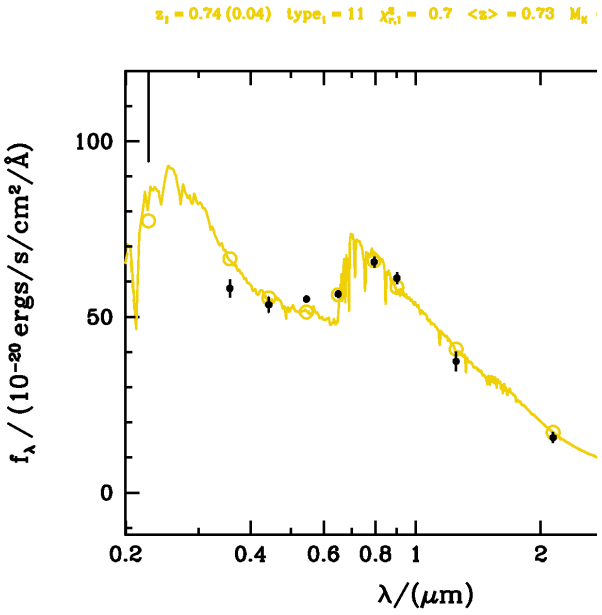

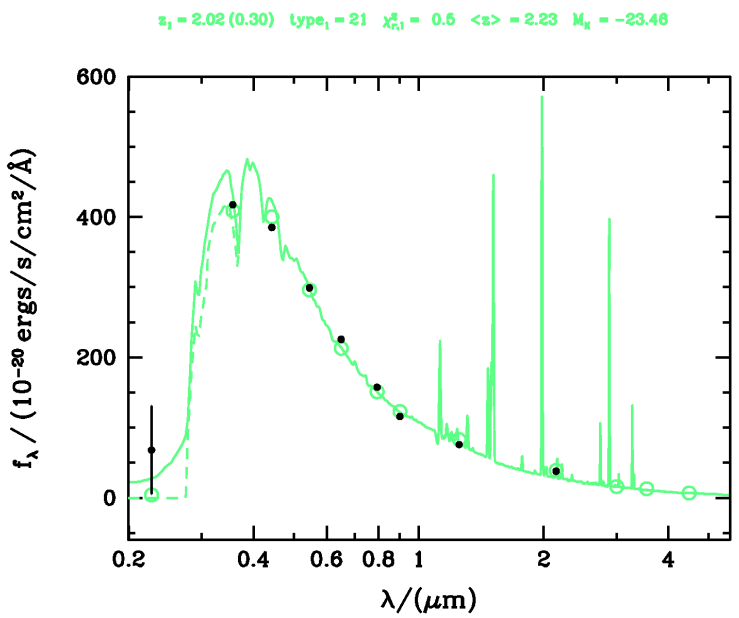

multi band catalog

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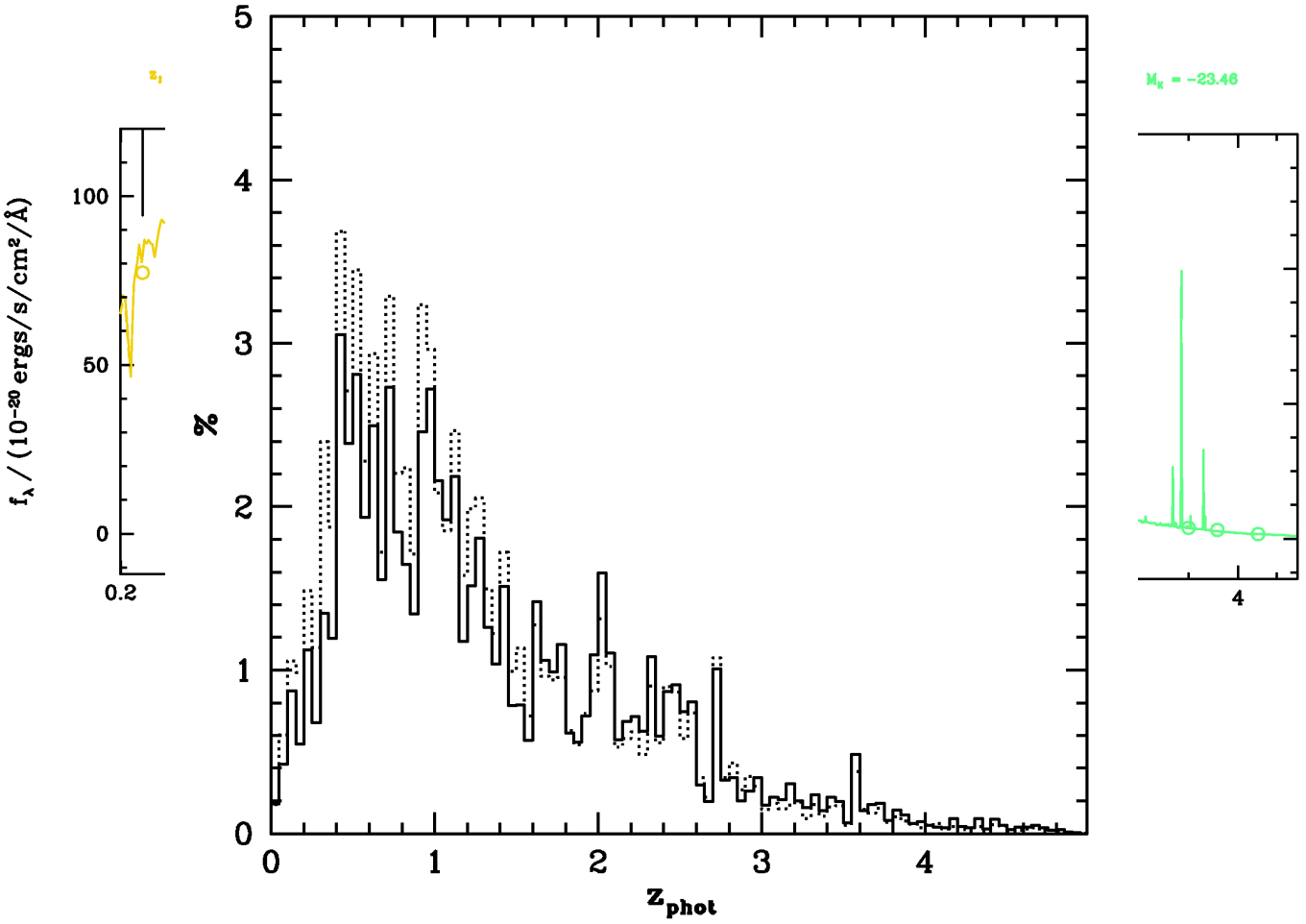


multi band catalog

ARU/CFHT/SPITZER
lz + JK + Ch1/Ch2

PACS area to K < 24.5

c-z: 4% accuracy

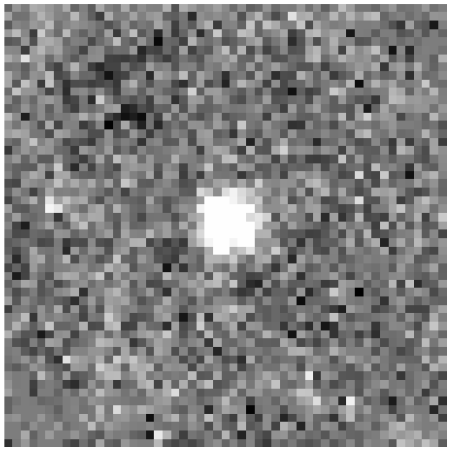
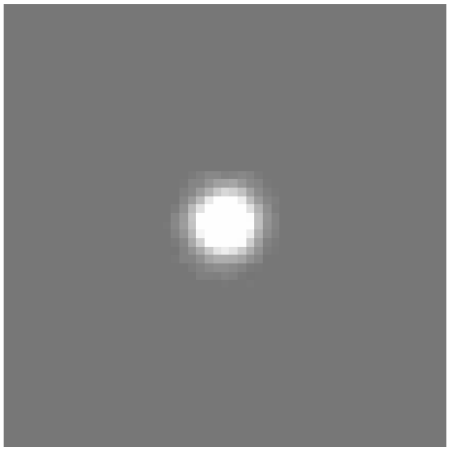
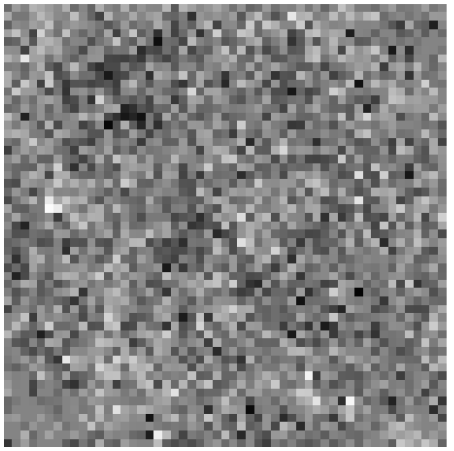
SED fitting

Music out of noise

Median stacking:

- more robust than mean against detections
- rms goes down by ~ $\sqrt{N}$
- "normal" star forming galaxy at high z

Stack@100μm **Model** **Residuals**

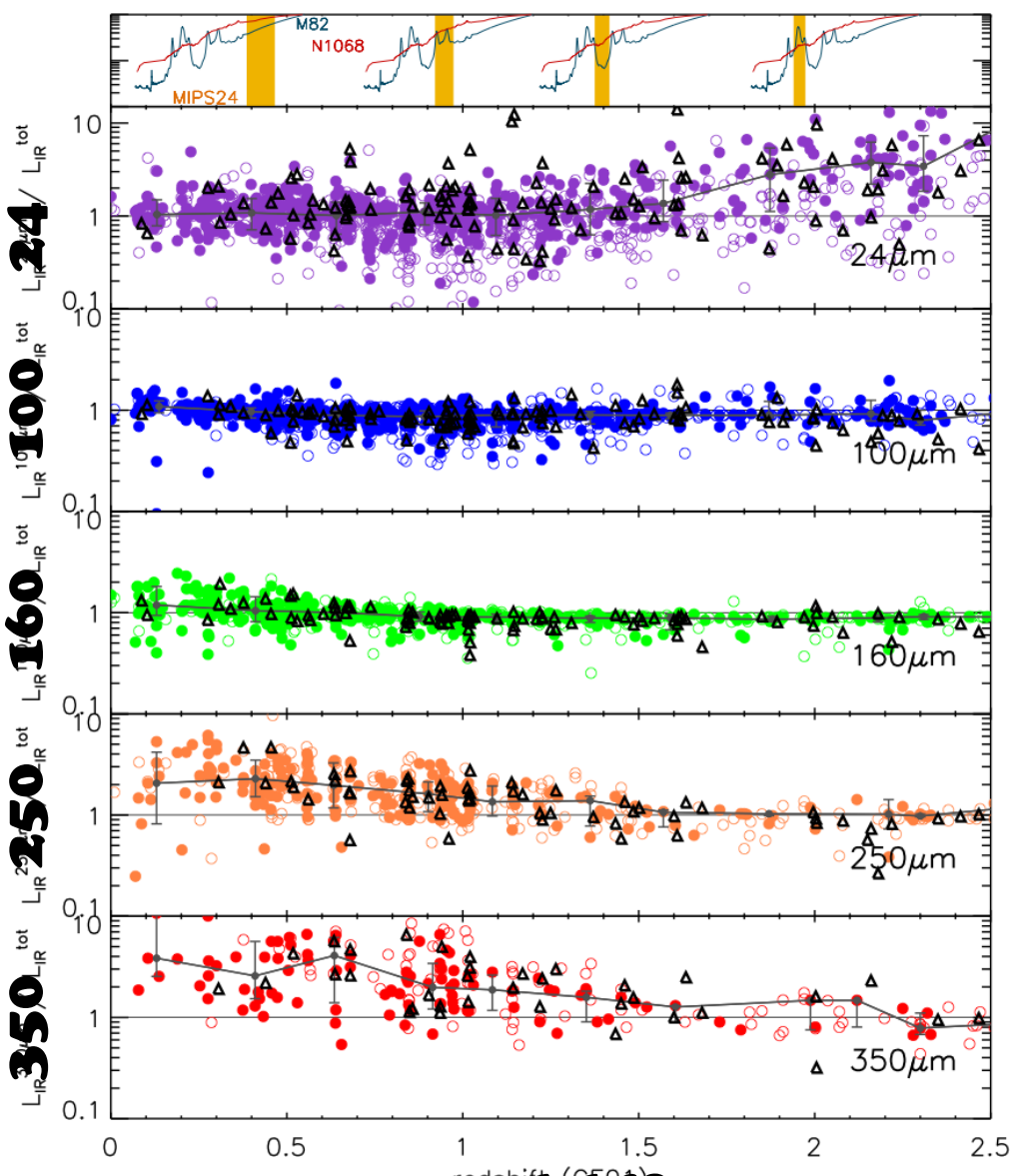




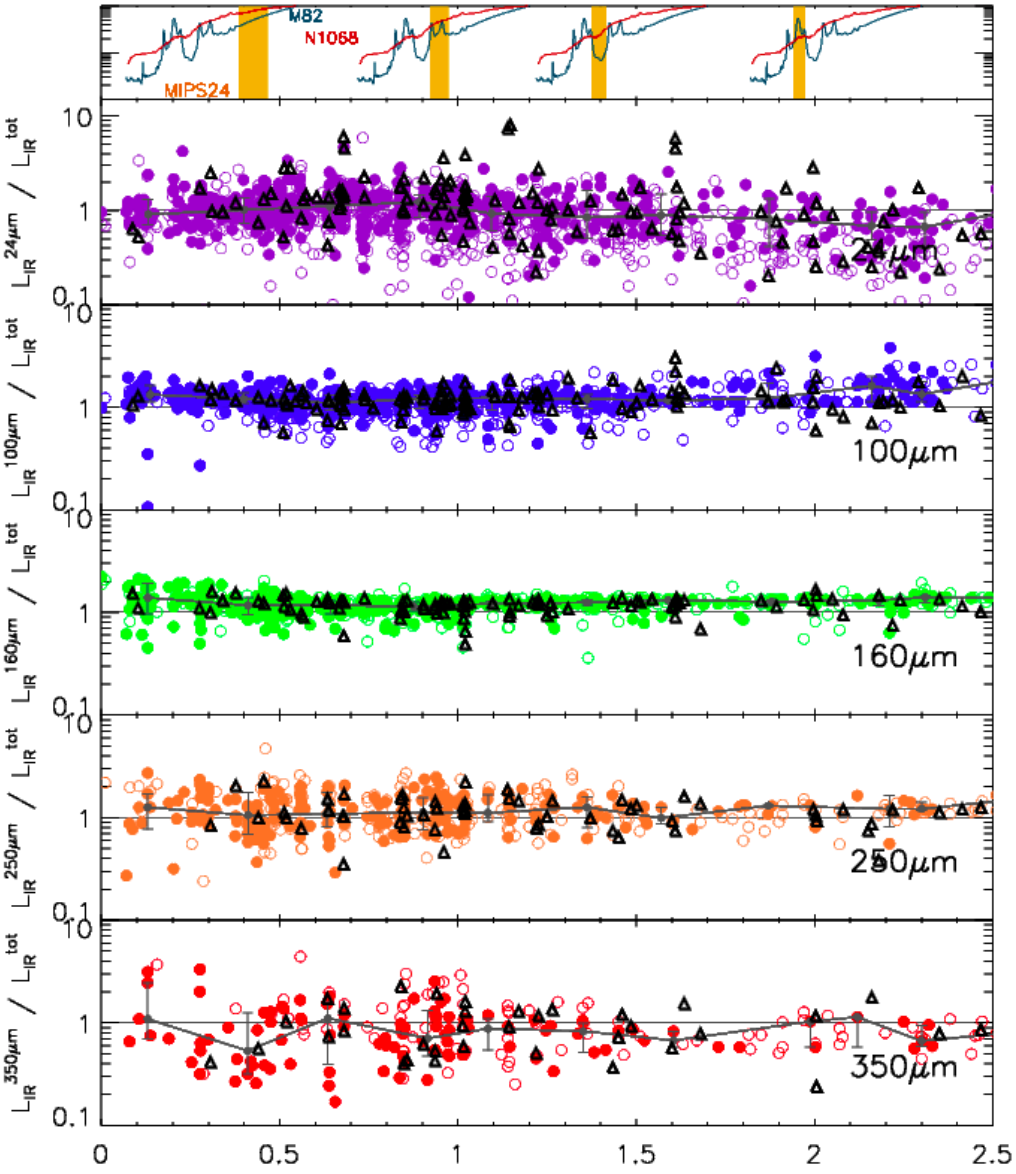
- 450 sources
- z = 1
- Log M_*= 10.2
- 0.058±0.02 mJy

Music out of noise

Checking bolometric corrections

CE01 library vs MS template

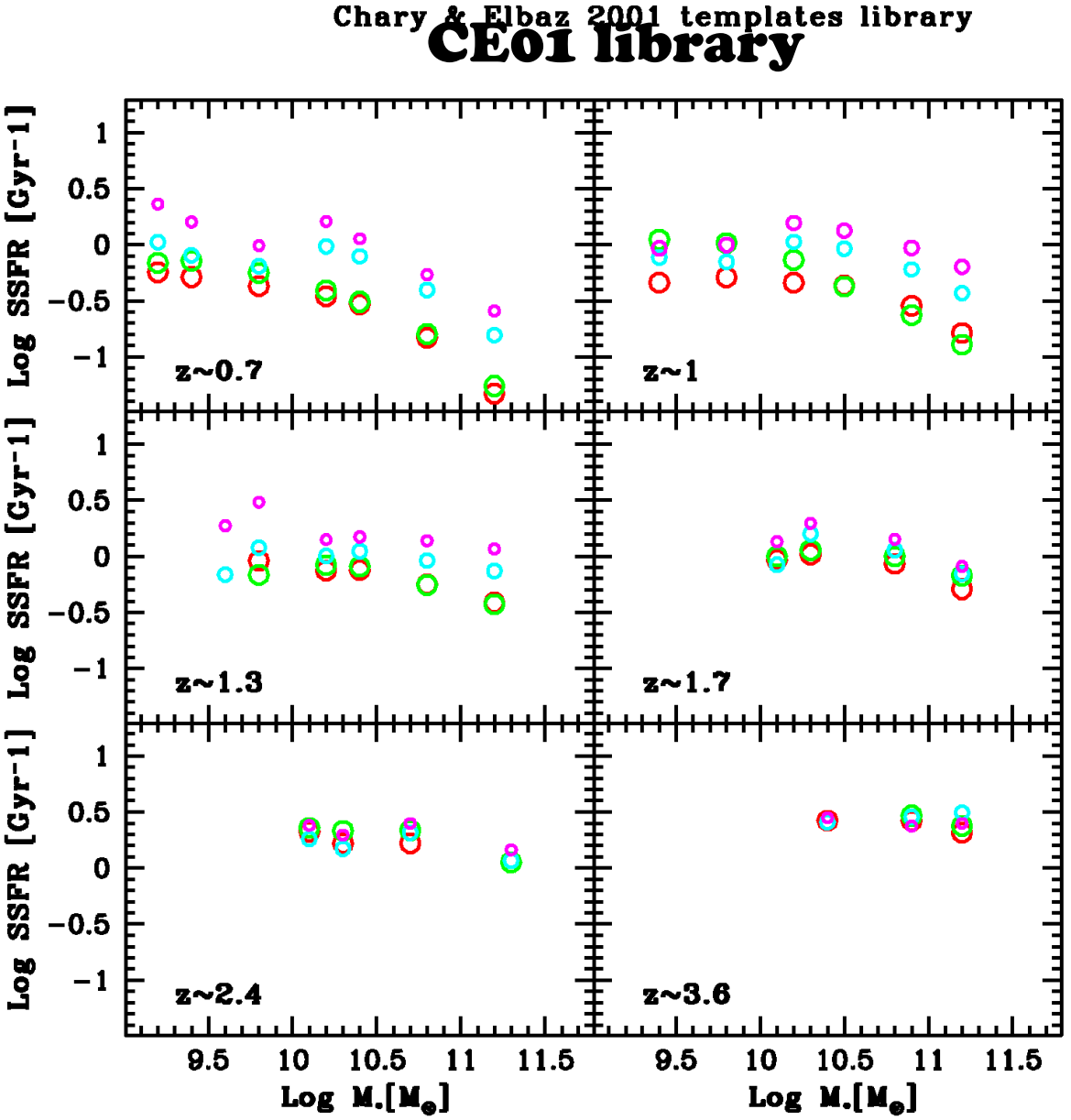




(Elbaz et al., 2010/2011)

Music out of noise

Checking bolometric corrections



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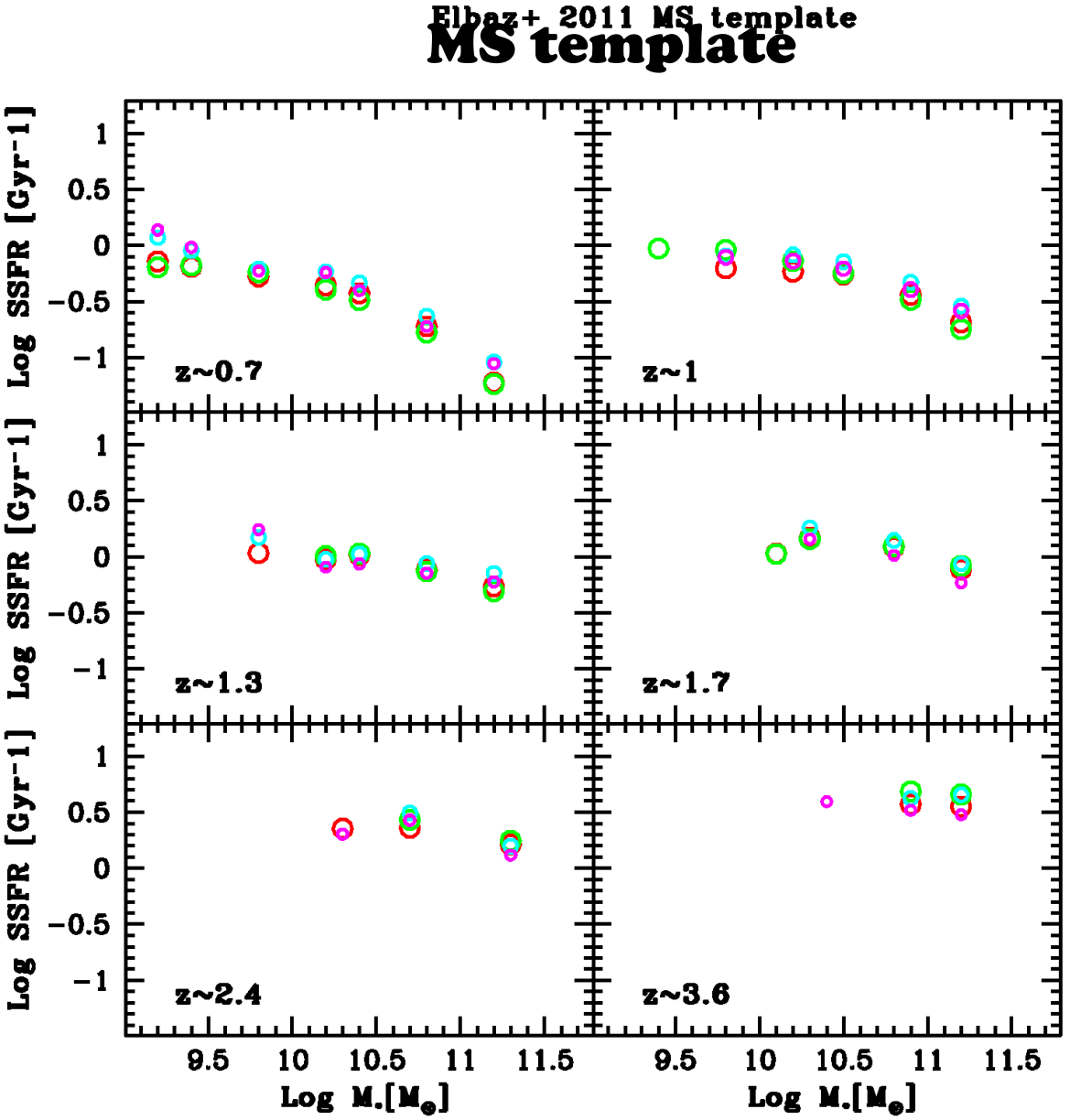

- the FIR SED is meaningful
- consistent results over very different resolutions !
- correlation boosting at a level < 20%
- template uncertainties

Music out of noise

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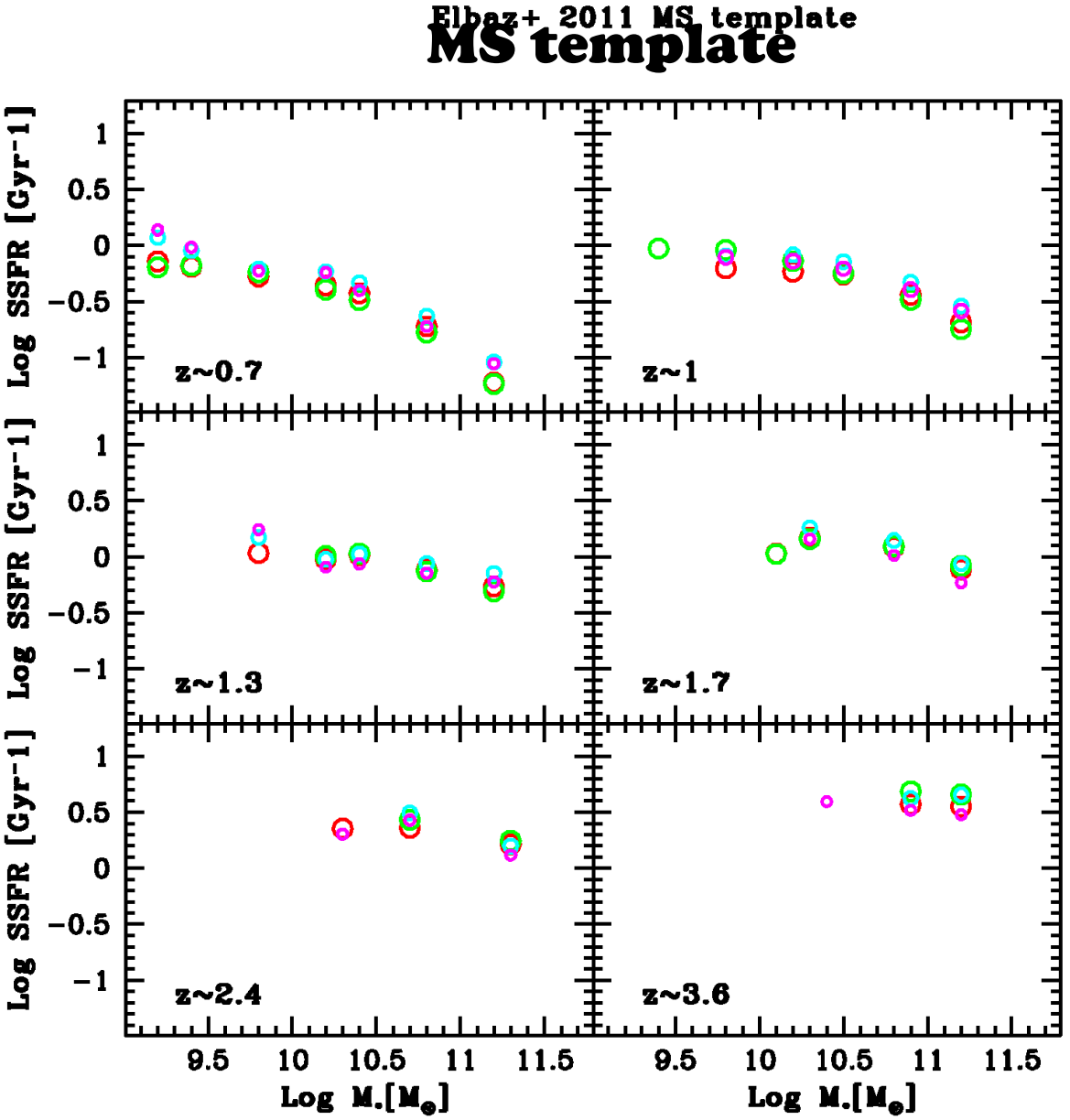
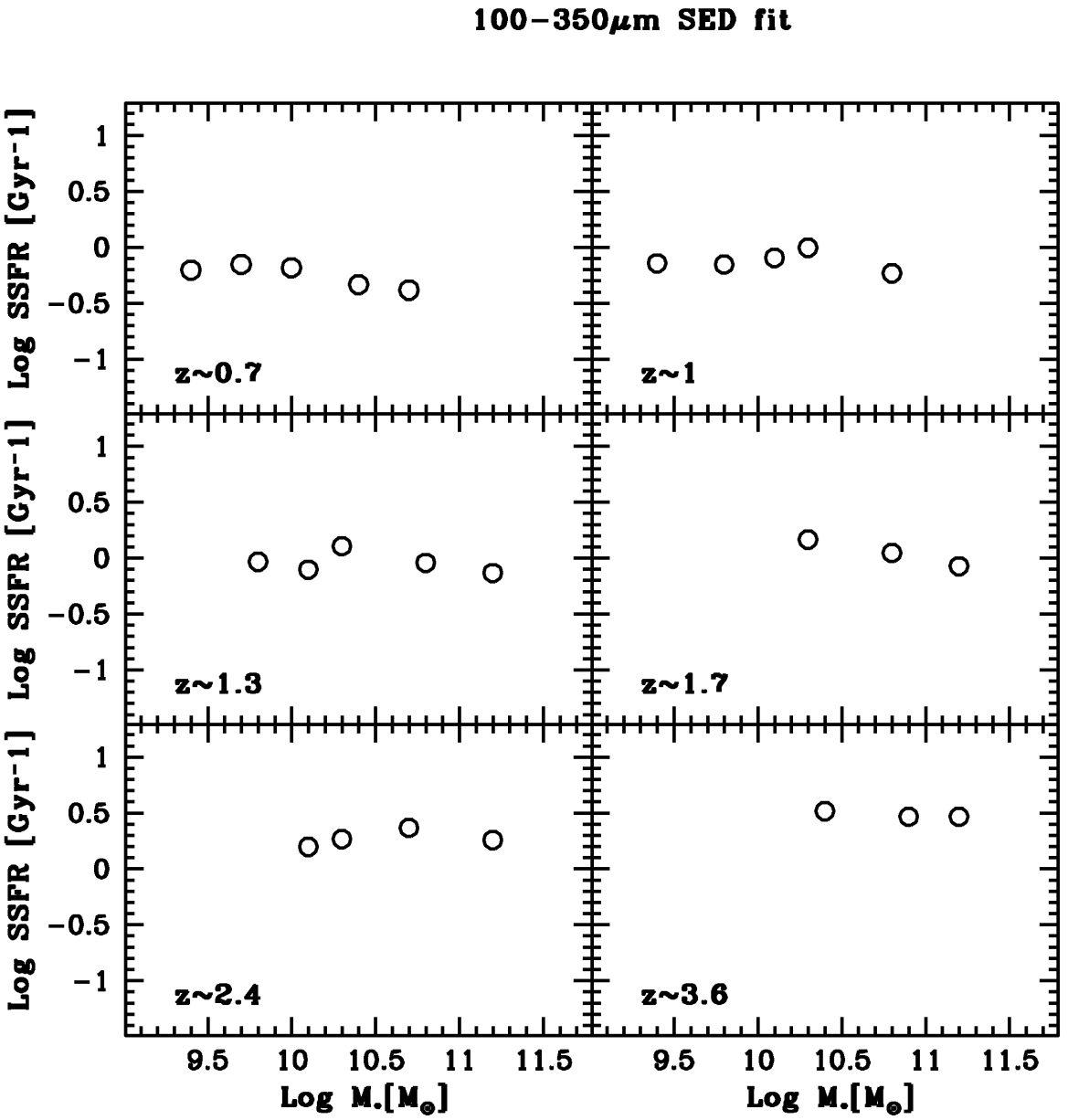


- the FIR SED is meaningful
- consistent results over very different resolutions !
- correlation boosting at a level < 20%
- template uncertainties
- there is an evolution in the slope of the SSFR-M*

Music out of noise

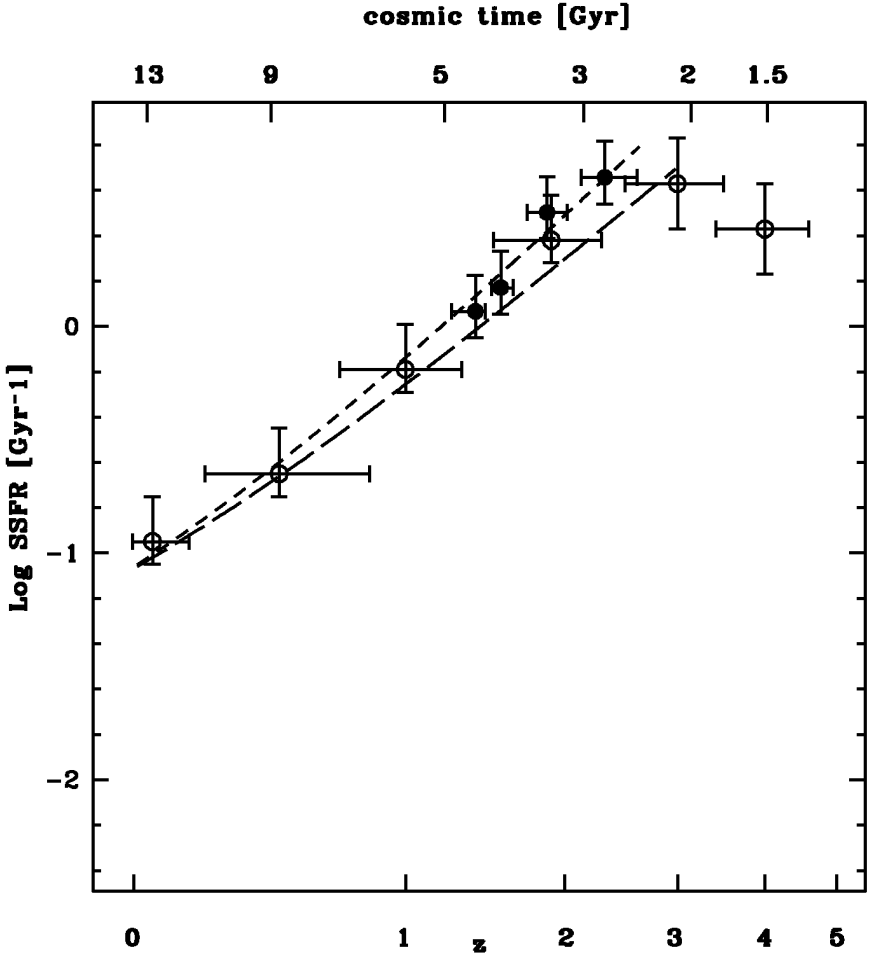
Looking at the star forming population



- an almost flat relation at all redshifts
- consistent with previous results
- star forming galaxies are growing all at the same rate

Music out of noise

The evolution of the SSFR-z relations



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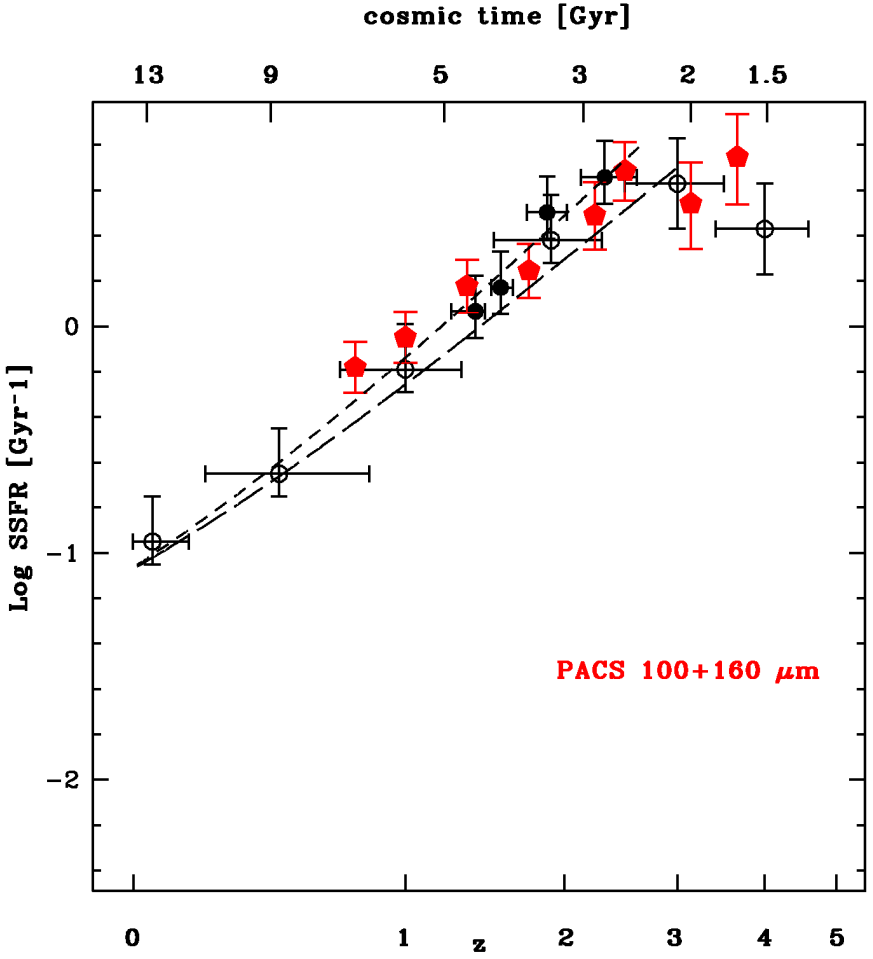

- consistent with radio stacking results
- we confirm a flattening at Log SSFR ~ 0.6 Gyr^{-1}
- the peak of the relation is reached at z~ 2.5

Music out of noise

Dust attenuation and UV slope

$$A_{UV} = 2.5 \, \mathrm{Log} \, (SFR_{IR}/SFR_{UV})$$

Music out of noise

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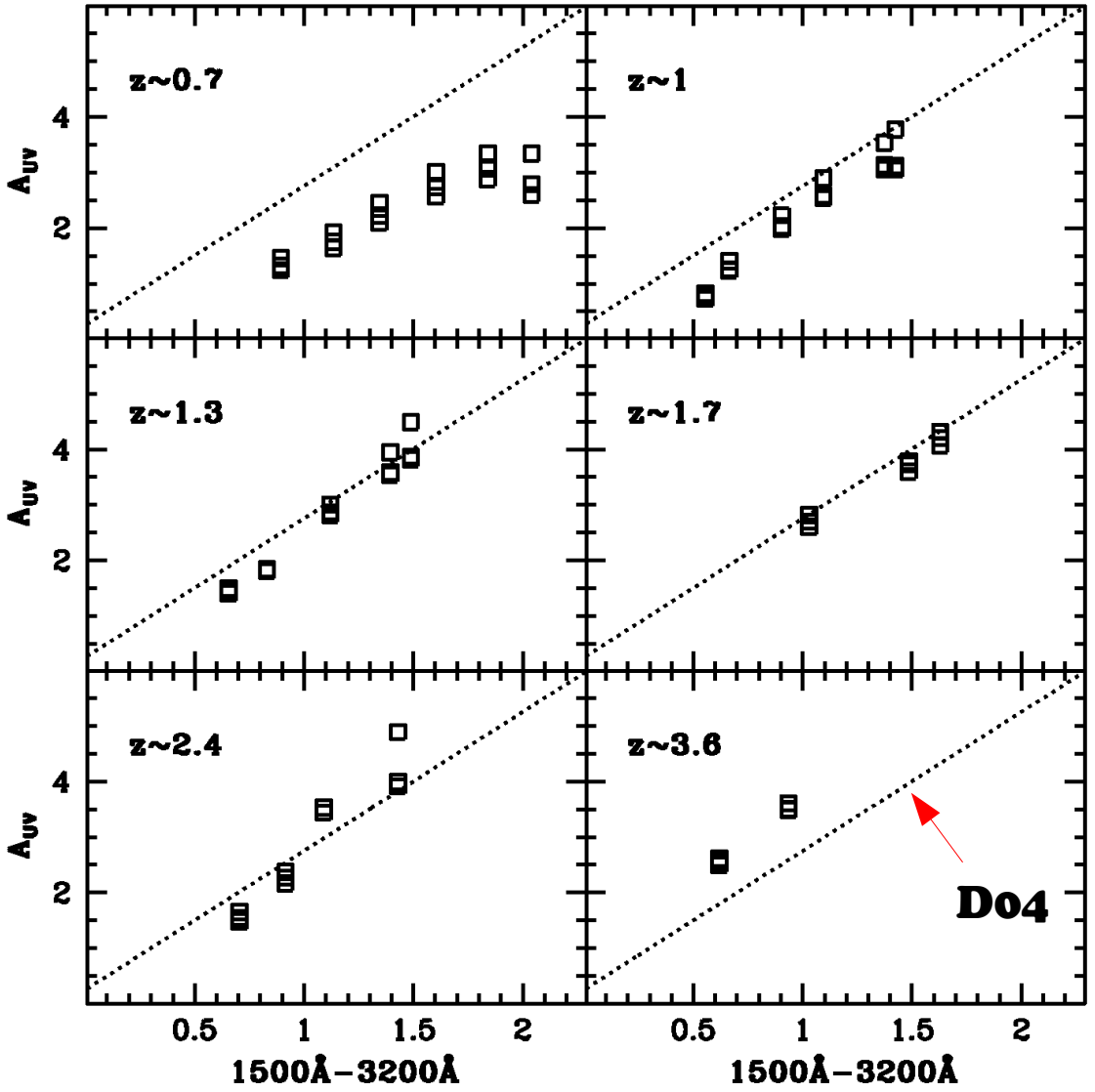
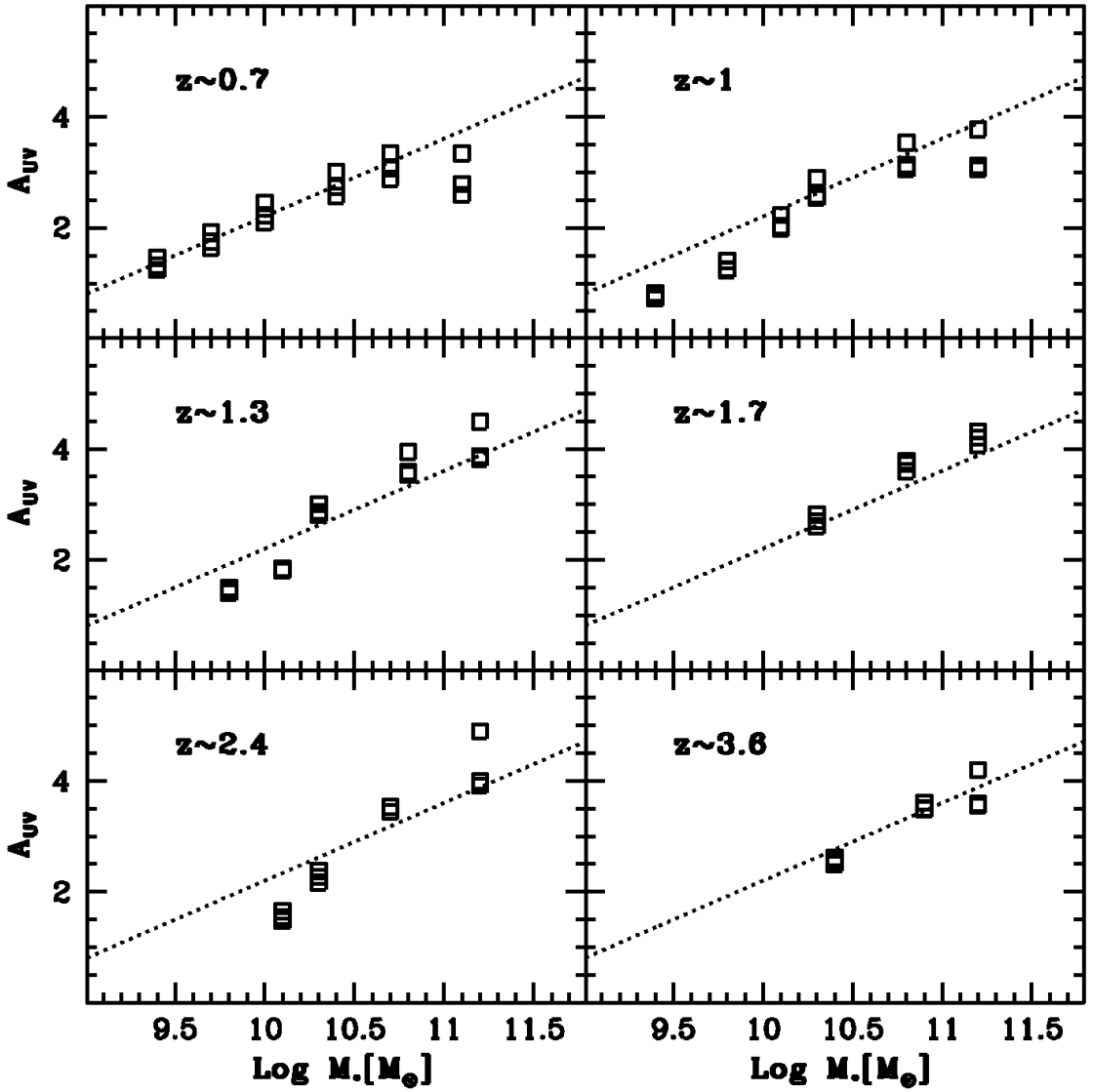


- The Daddi recipe is well consistent with our data
- We can extend it from the local Universe to z ~4

Music out of noise

Dust attenuation and Stellar Mass

$$A_{UV} = 2.5 \text{ Log } (SFR_{IR}/SFR_{UV})$$



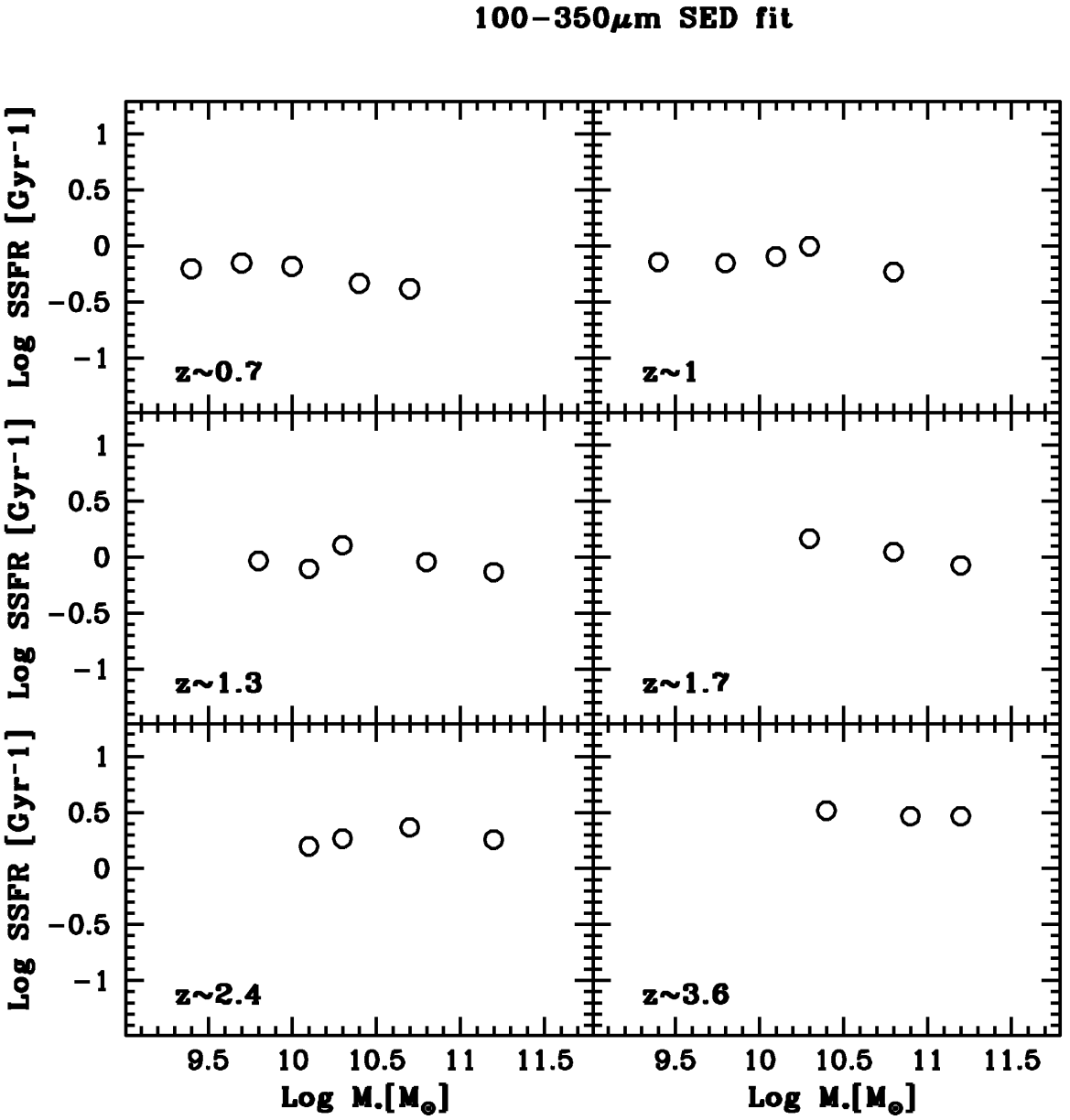
- The correlation between M_* and A_{UV} does not evolve

- If true, this would say that the relation SFR-A_{UV} has to evolve instead

- A new scaling relation for star forming galaxies ?

Music out of noise

The Radio-FIR correlation up to z~4



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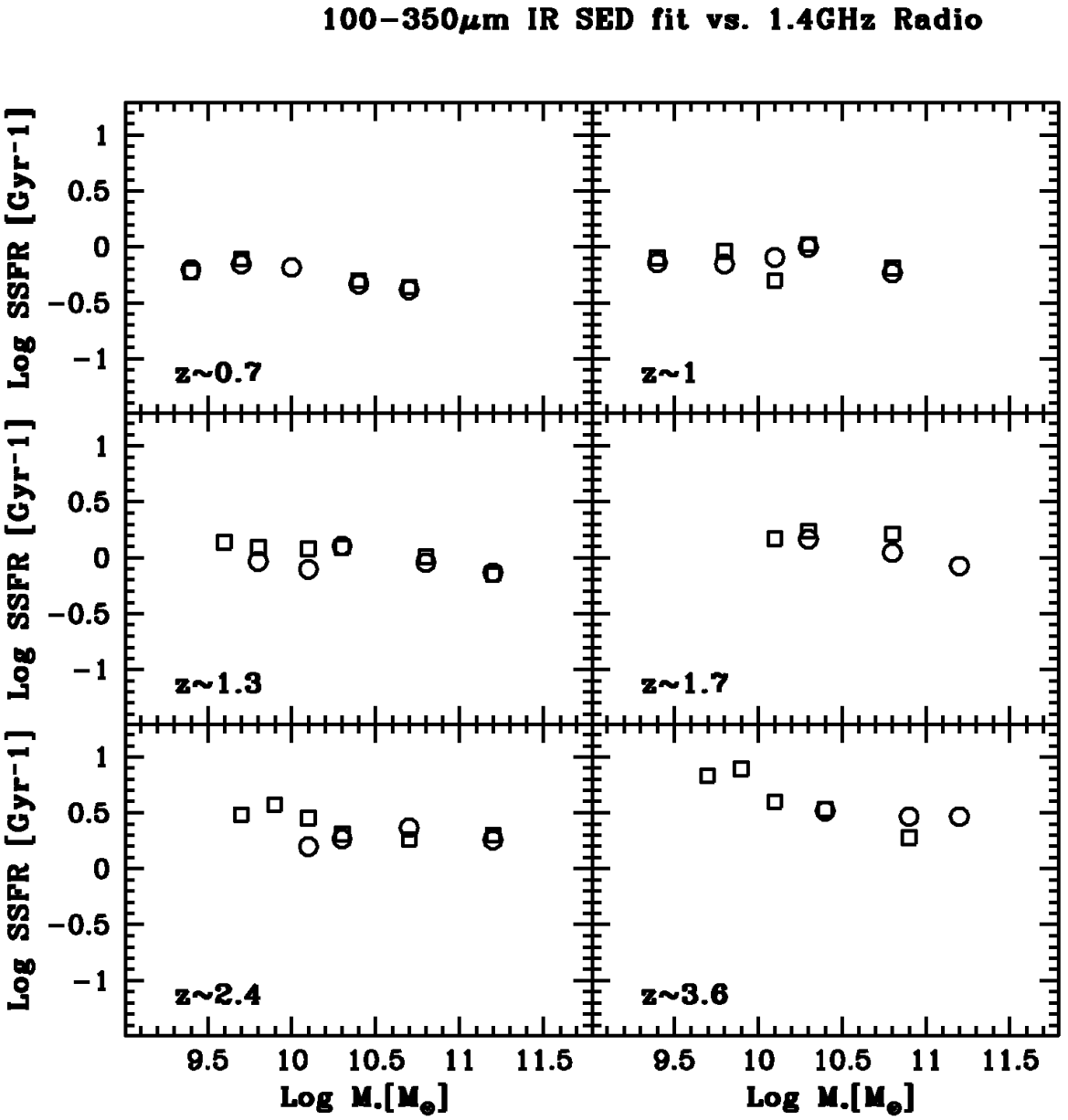

- all the results would stay unchanged by using radio continuum stacking
- the RADIO-FIR correlation holds all the way to z~4
- resolution plays in favor of 1.4 GHz data for stacking experiments

Conclusions

“And the winner is: galaxy mass” Daniel Thomas 2011

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"And the winner is: galaxy mass" Daniel Thomas 2011

The A_{UV}-M_* is the same at all redshifts

This would imply that the same amount of star formation would be less attenuated at high redshift compared to the local Universe

The main-sequence of star forming galaxies might just be the projection of a more fundamental plane between dust(metal) content, SFR and stellar mass

The Radio-IR correlation holds at least up to z ~4