The evolution of the dust and gas content in galaxies

Paola Santini

INAF - Osservatorio Astronomico di Roma

Collaborators:

R. Maiolino, S. Eales, S. Berta, D. Lutz, G. Magdis, G. Rodighiero and the PEP + HerMES teams

"Star Formation Across Space and Time", ESA-ESTEC, 11–14 Nov 2014

Aim: investigating the scaling relations among galaxy fundamental physical parameters

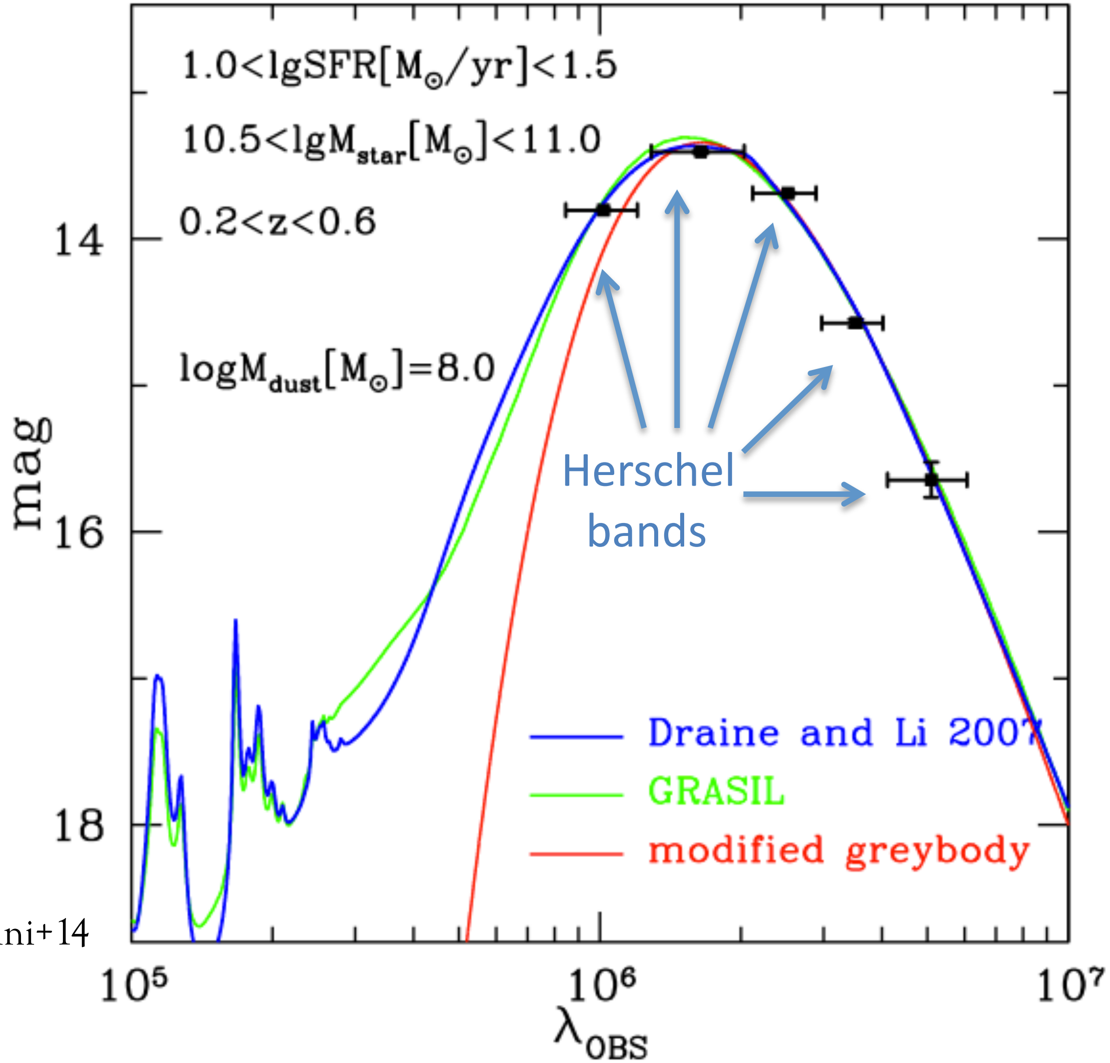
- Star Formation Rate
- stellar mass
- dust mass
- gas mass

Key physical properties to understand galaxy evolution,
linked with each other through the processes responsible for mass build-up

and their evolution across cosmic time.

Dust as gas tracer

M_{dust} from IR-submm SED → **dust-to-gas ratio** → **M_{gas}**



Santini+14

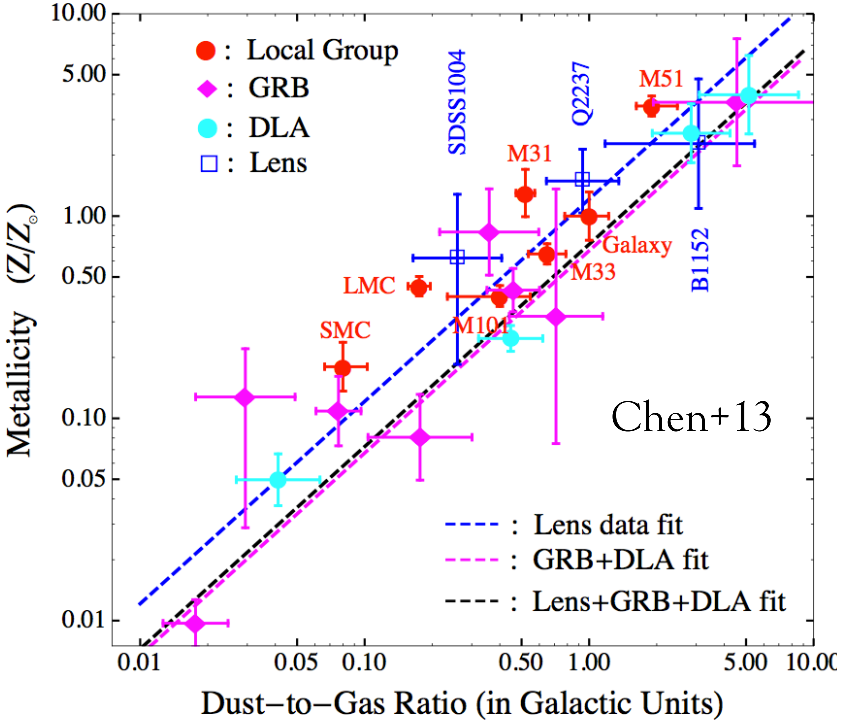
Bethermin+14
Bolatto+13
Eales+10, 12
Leroy+11
Magdis+11,12
Magnelli+12
Scoville+12,14

see also talks from N. Scoville, S. Madden, …

Gas mass from dust

Dust-to-Gas ratio ∝ metallicity

(at Z>~$0.1Z_{sun}$, not true at lower metallicities)



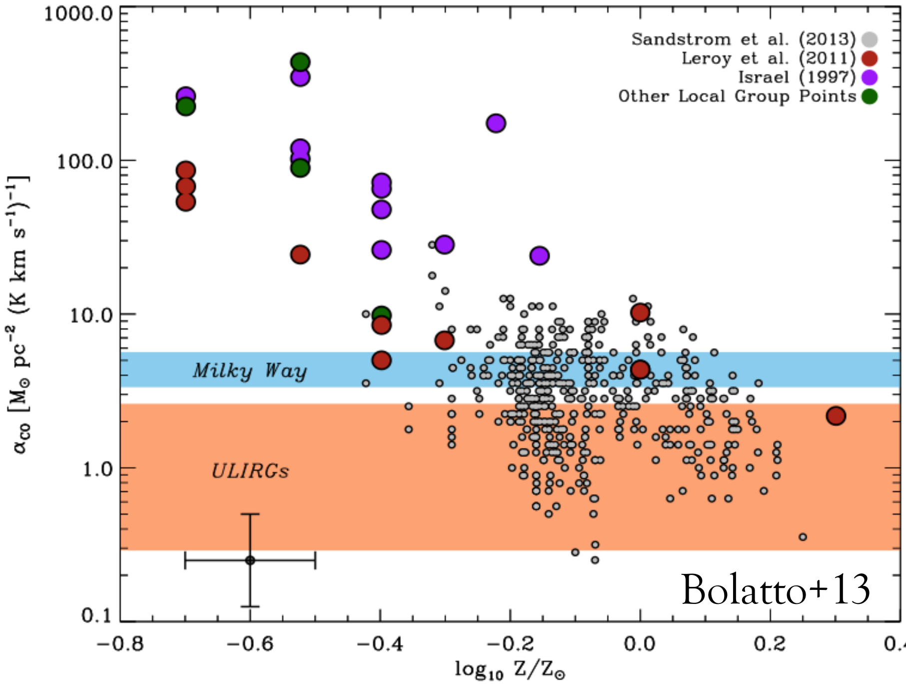
- Photometric redshifts good enough
- Fast method: can quickly deliver gas masses for thousands of galaxies

James+02; Draine+07; Leroy+11; Smith+12; Corbelli+12; Sandstrom+13; Zafar & Watson 13; Chen+13; Remy-Ruyer+14

Gas mass from CO

CO-to-H_2 conv. factor ∝ metallicity$^{\sim -1.5}$

(with larger spread)



- **Different for ULIRGs, SMGs, and "normal galaxies"(?)**
- **At high-z generally high-J CO transitions observed →** need to correct for excitation
- Needs accurate spectroscopic redshifts
- Time demanding

Bolatto+13; Genzel+12; Leroy+11; Papadopulos +12; Sandstrom+13; Lee+14; Dannerbauer+09; Ivison+11; Carilli & Walter 13

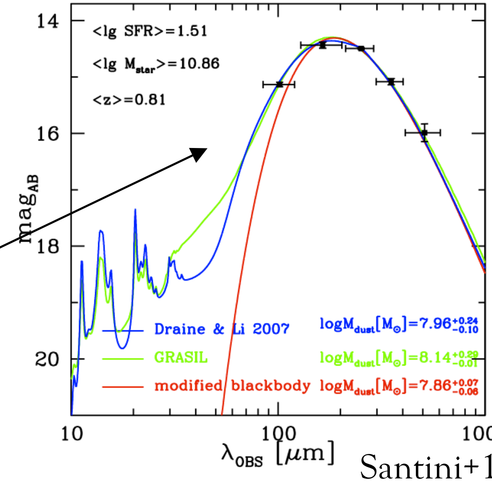
Sample and basic ingredients of the analysis

Large statistics: GOODS–S + GOODS–N + COSMOS

- multiwavelength photometry from X-rays to FIR
- **Herschel** data from PEP (PACS survey, Lutz+11) and HerMES (SPIRE survey, Oliver+10)
- zspec or photo–z

Basic ingredients:

- **Star Formation Rate** → from 24 μm observations
- **stellar mass** → nearUV–to–nearIR multi–λ photometry
- **dust mass** → fit Herschel fluxes to Draine & Li 2007 model
- **gas mass** → conversion through the dust/gas ratio (metallicity from the FMR of Mannucci+10)



Santini+14

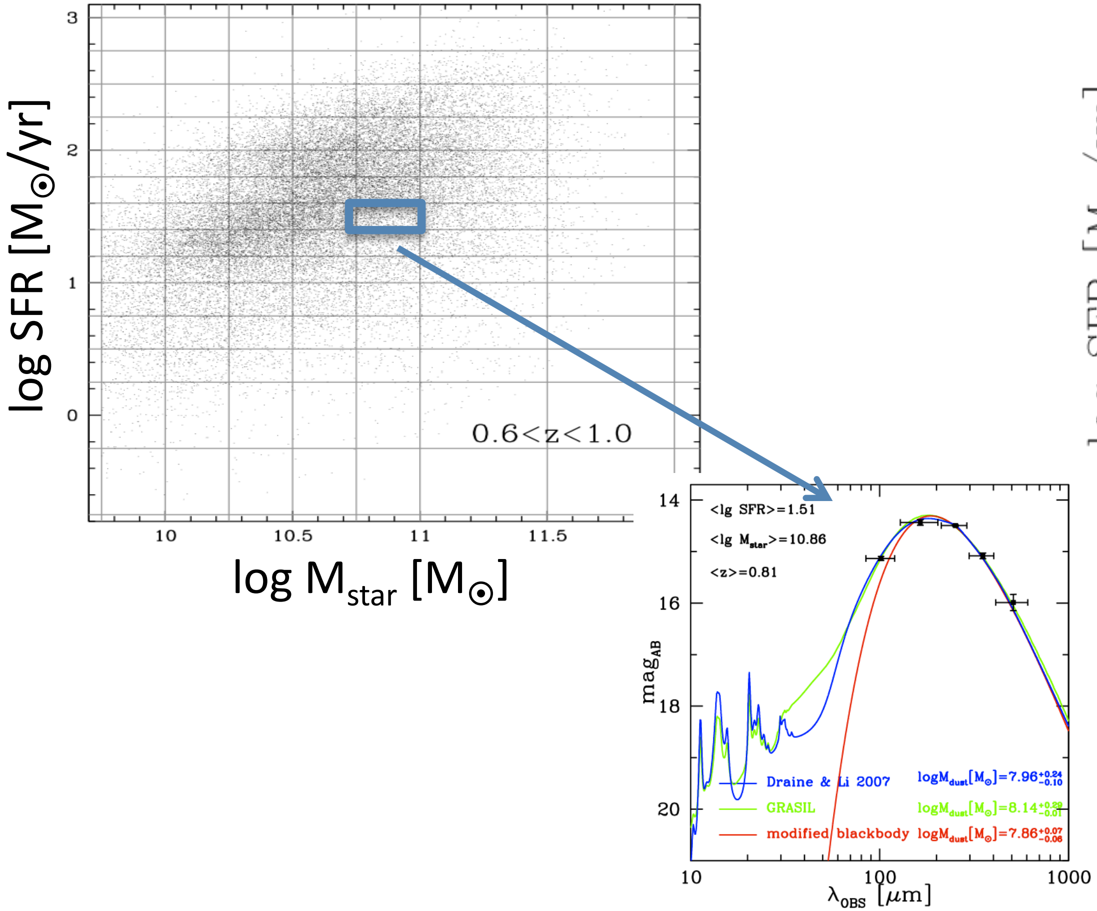
Selections: S/N > 10 in K band + AGNs removed + $\begin{cases} 0.05 < z < 2.5 \\ 9.75 < \log M_{star} < 12 \\ -0.75 < \log SFR < 3 \end{cases}$

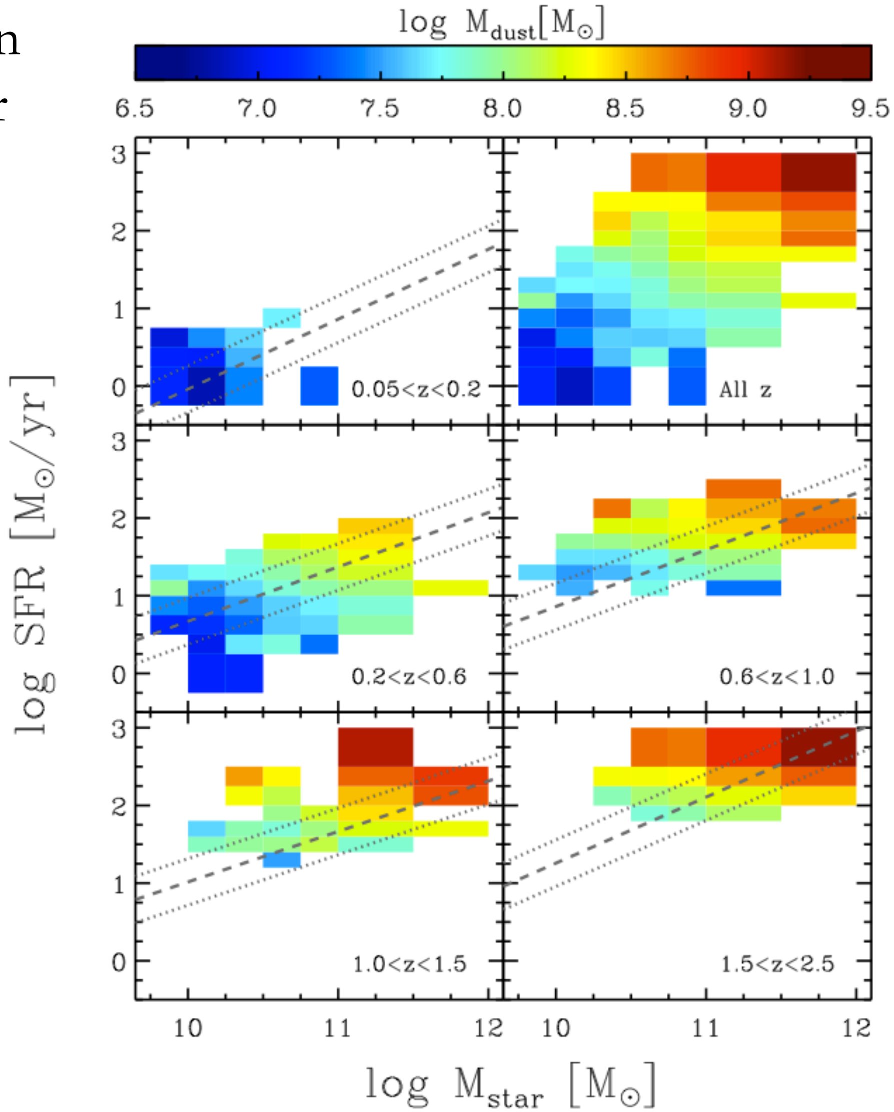
~30000 galaxies in the final sample

The z-M_{star}-SFR grid sampling

Average fluxes in Herschel bands by **stacking** on the maps at the positions of sources with similar properties (redshift, M_{star}, SFR)

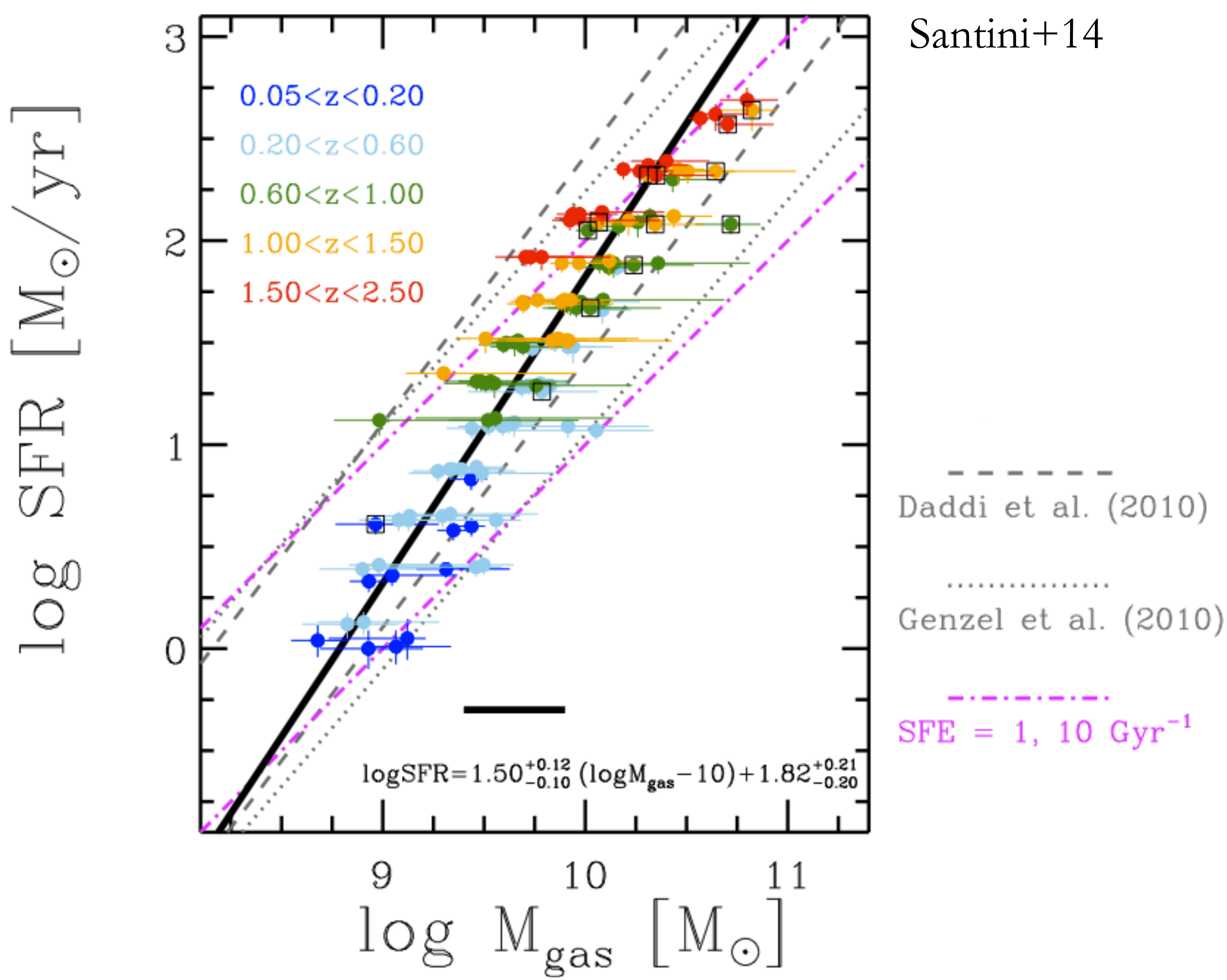
In each redshift bin…





Santini+14

The “dust-based” integrated Schmidt-Kennicutt law



- consistent with a single power law of slope 1.5 (original S-K slope, Kennicutt+98)
- broadly consistent with previous CO–based works for the majority of galaxies

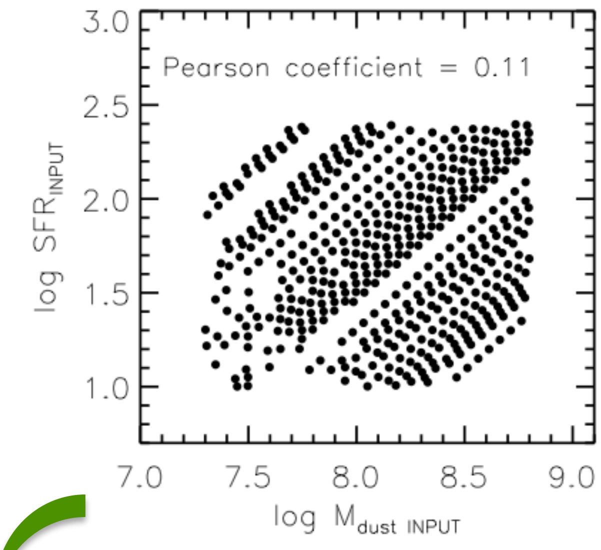
Are SFR and M_{dust} (hence M_{gas}) correlated by construction?

Correlation unexpected:

SFR $\propto$ integrated light in the FIR peak
M_{dust} depends on the normalization AND on the shape (T_{dust})

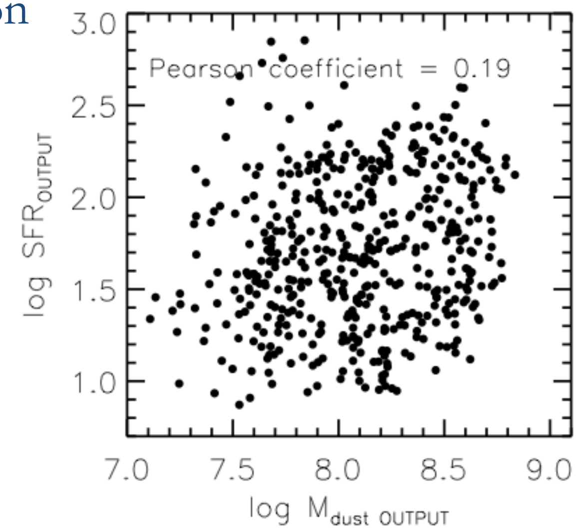
We run a <u>simulation</u>:

1) Start from a mock catalog of uncorrelated SFR and M_{dust} (from GRASIL templates)



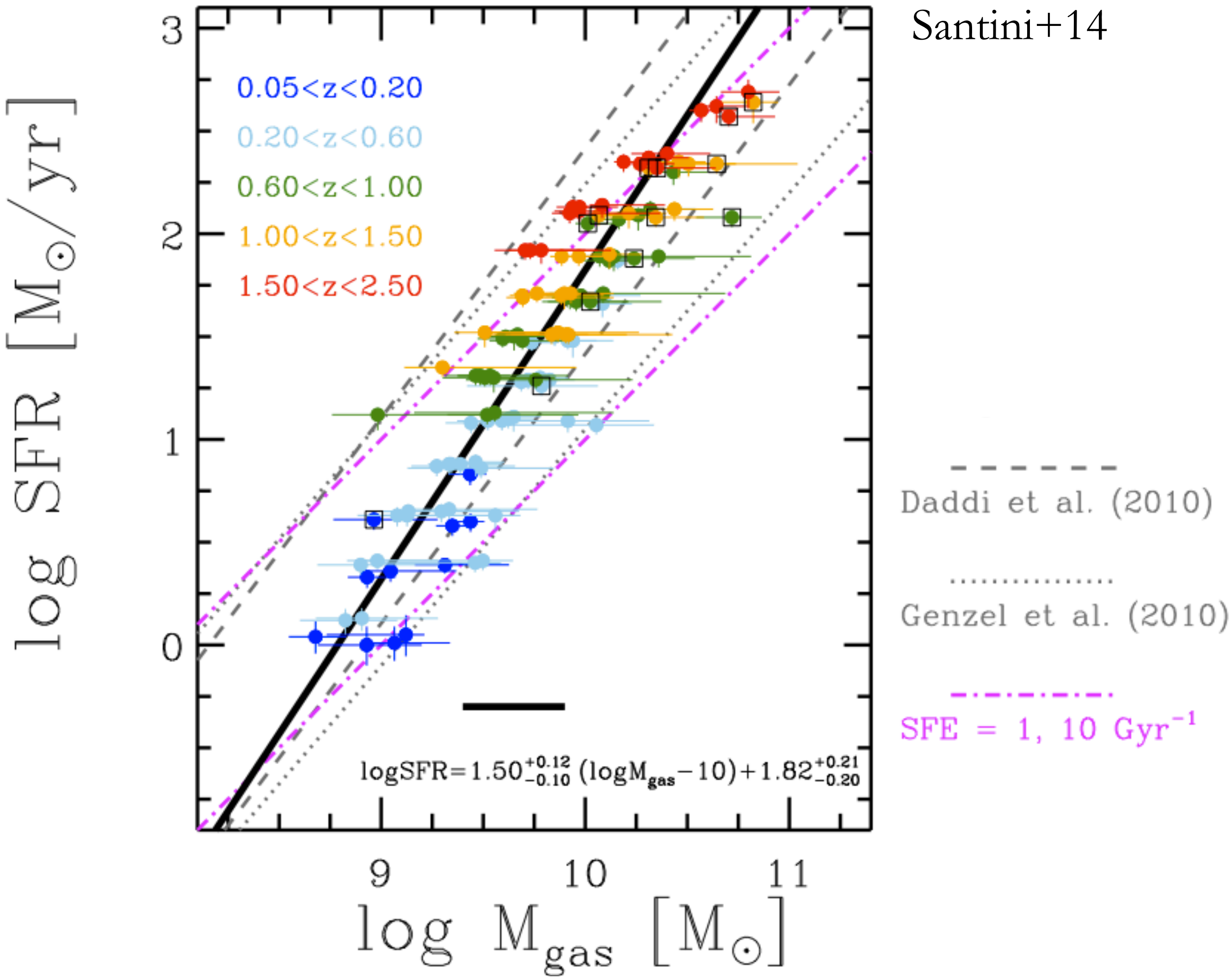
2) Associate a random redshift, K-correct the SEDs and perturb the photometry according to Herschel noise

3) Estimate SFR and M_{dust} according to our method → recover an uncorrelated distribution



Conclusion:
the correlation between SFR and M_{gas} is physical and not and artefact of the method

The "dust-based" integrated Schmidt-Kennicutt law

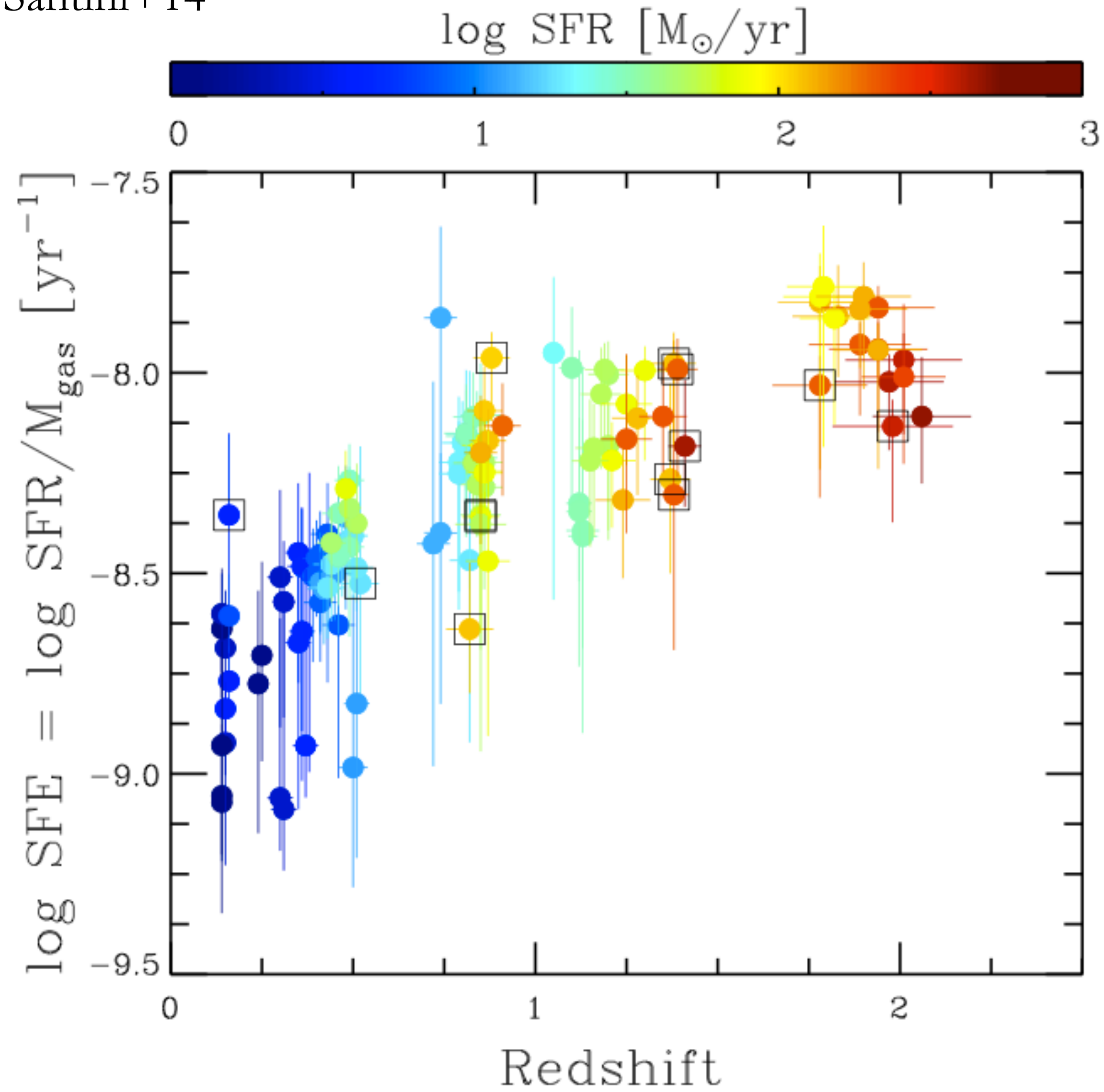


Santini+14

- consistent with a single power law of slope 1.5 (original S-K slope, Kennicutt+98)
- broadly consistent with previous CO–based works for the majority of galaxies

The evolution of the Star Formation Efficiency

Santini+14



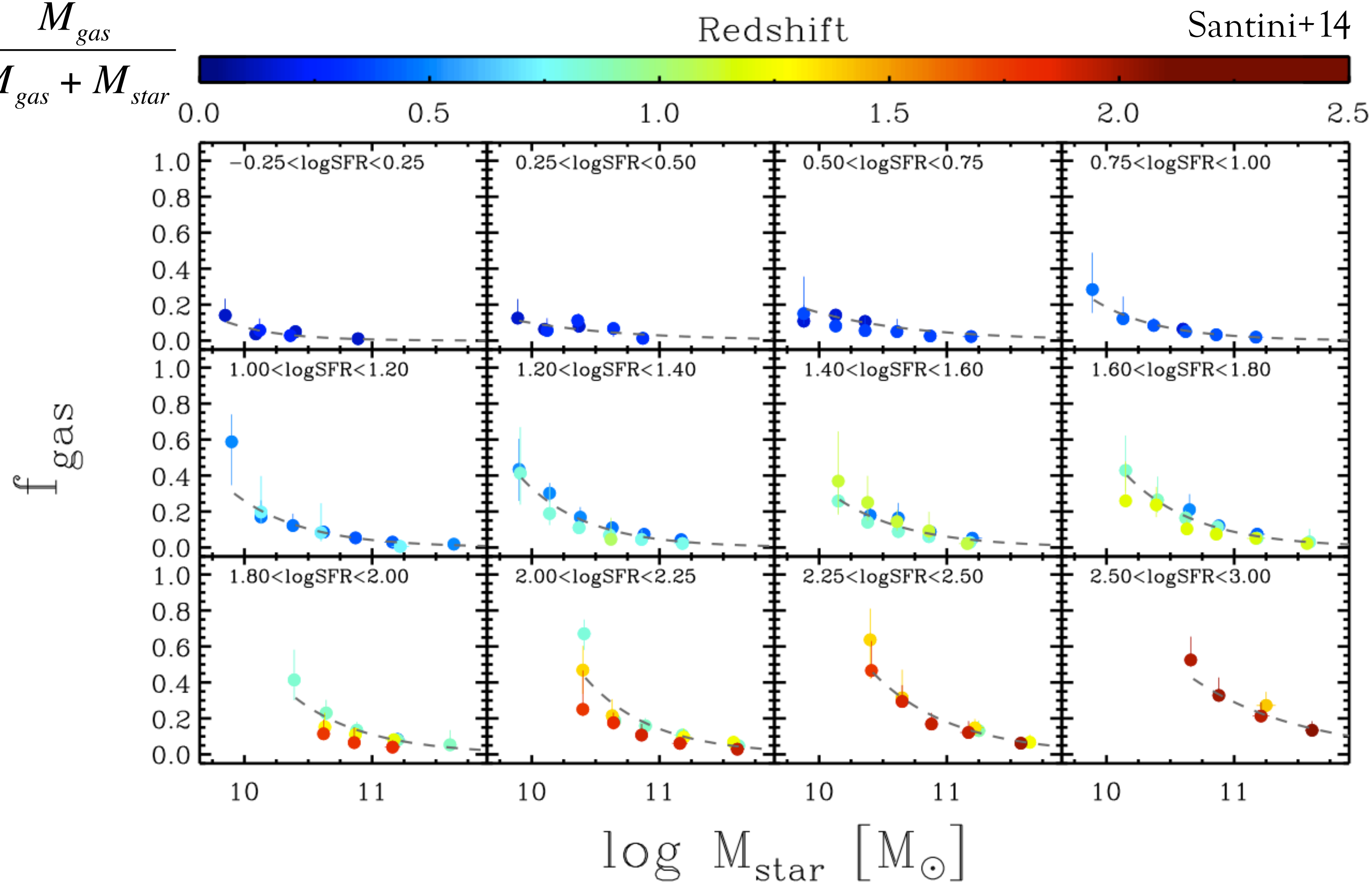
Higher star formation efficiency at high redshift:

- partly consequence of S-K slope>1 together with higher SFR at high-z

- partly real evolution (?)

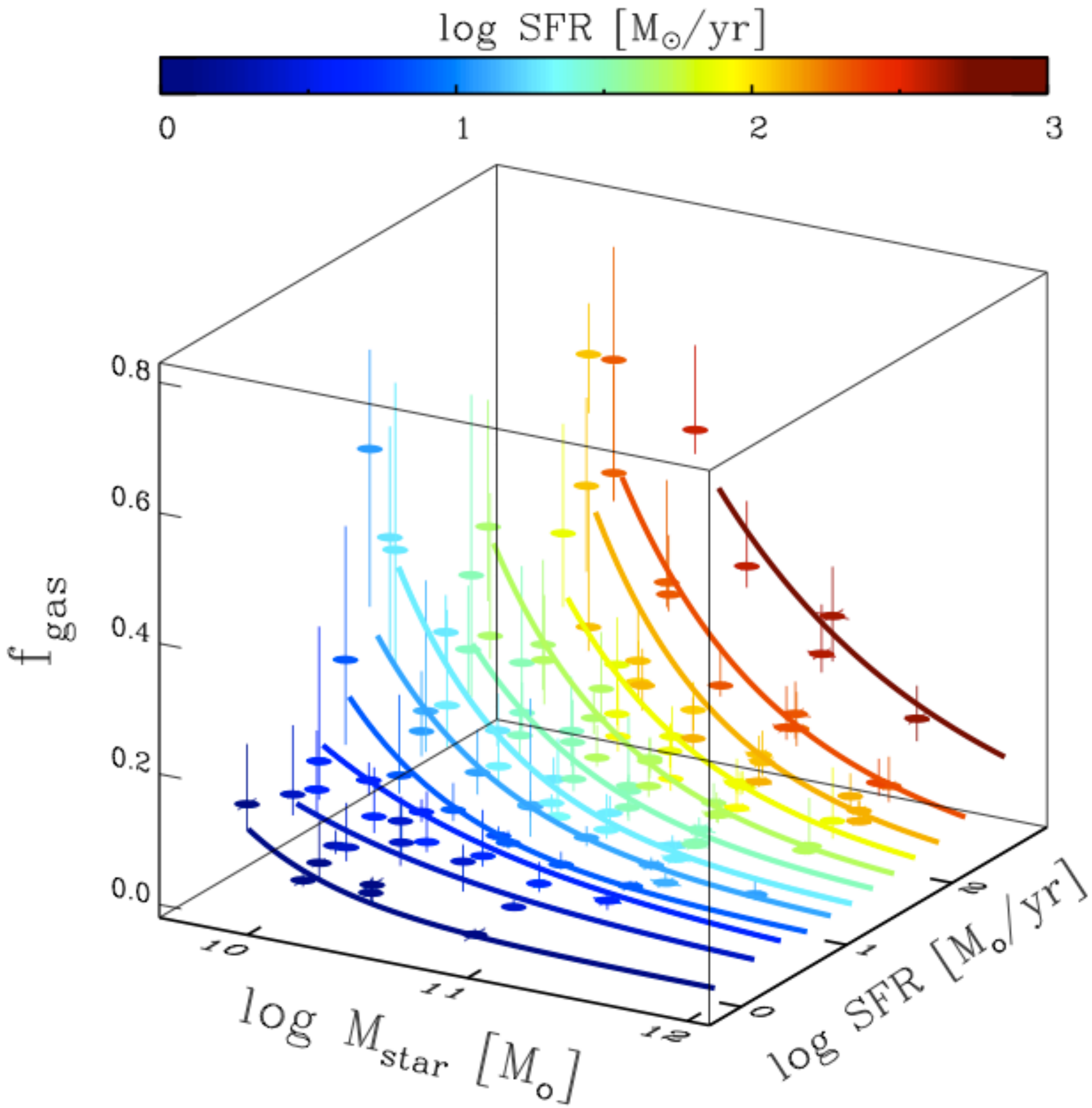
The evolution of the gas fraction

$$f_{gas} = \frac{M_{gas}}{M_{gas} + M_{star}}$$



- f_{gas} decreases with M_{star} and increases with SFR
- no redshift evolution at fixed M_{star} *and* SFR (at least out to z~2.5)

The fundamental f_{gas}-M_{star}-SFR relation



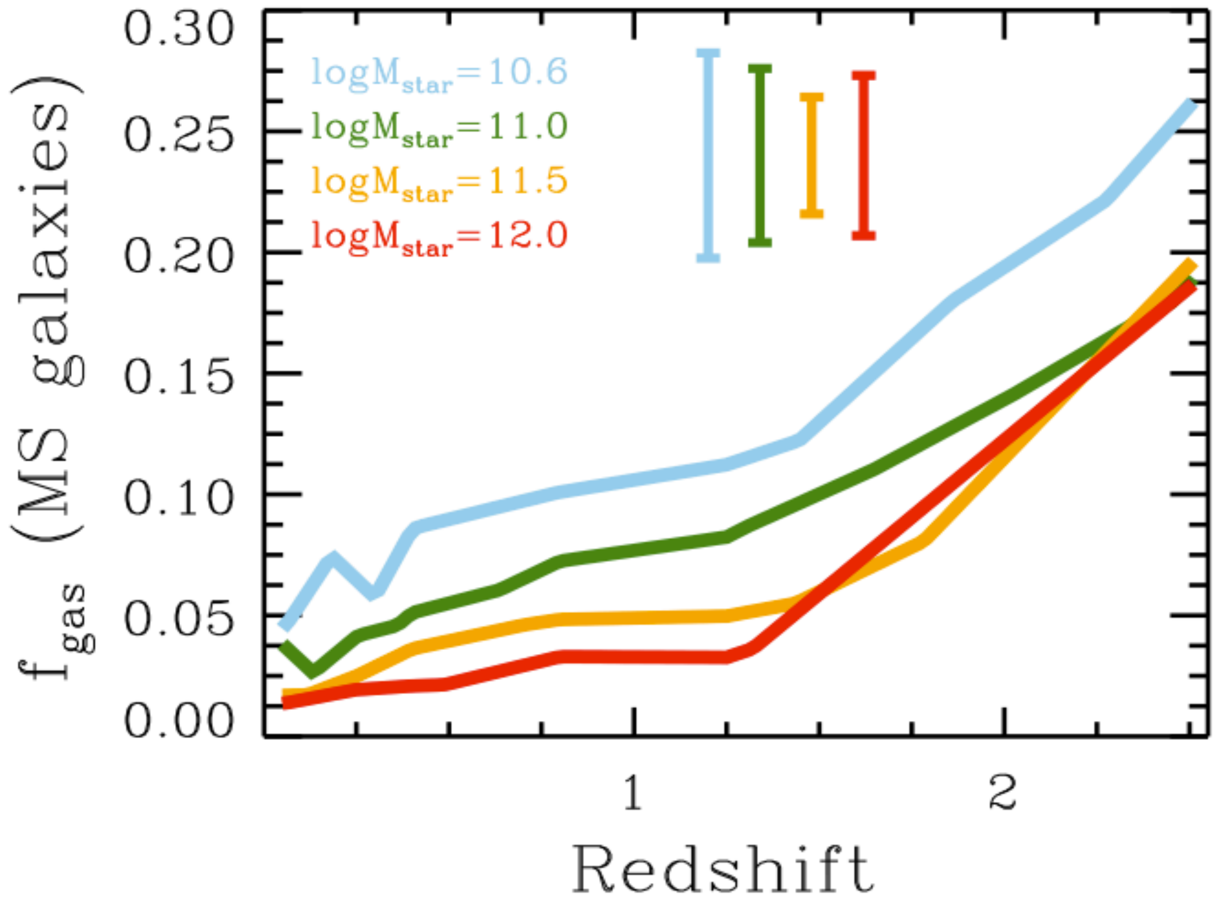
- redshift–independent (➔ fundamental) 3D relation → the physics of SF is independent of redshift

- does not imply lack of evolution: galaxies populate different regions of this surface at different epochs

Santini+14

The evolution of the gas fraction in Main Sequence galaxies

Santini+14

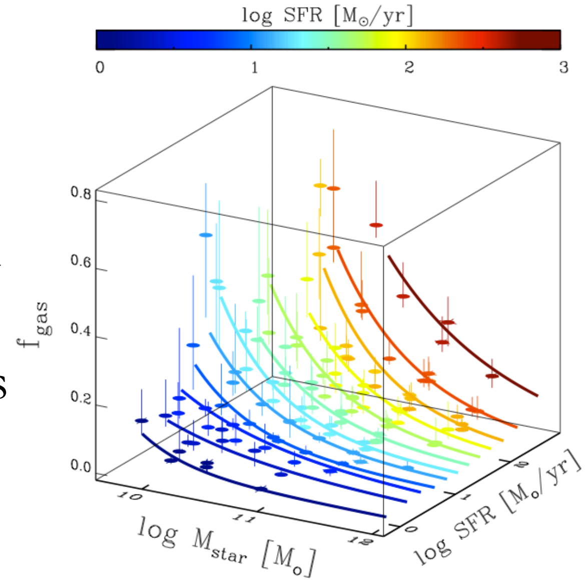


see also M. Bethermin's talk

Evidence of downsizing: massive galaxies have consumed their gas earlier and more rapidly than low mass galaxies

- **Dust is a powerful gas proxy**

It is possible to extend gas studies to much larger samples of galaxies, save much time and get rid of many systematics



- **The physics of star formation is independent of redshift** (at least out to z~2.5)

At fixed M_{star} *and* SFR, gas and dust masses are consistent with no evolution with redshift (within uncertainties)

BUT the global gas and dust content does evolve since galaxies populate different regions of the fundamental f_{gas}-M_{star}-SFR relation across cosmic epochs

Thanks