Dust and gas in galaxies as seen by Herschel and what SPICA can do

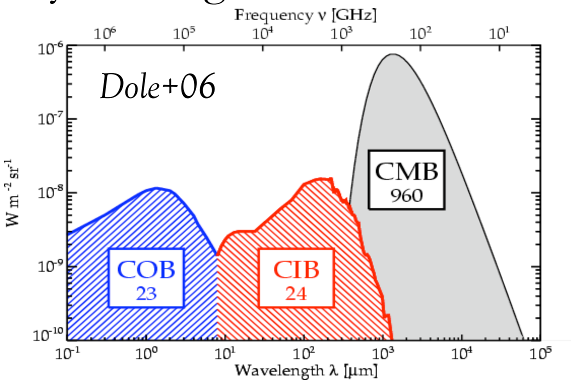
Paola Santini

INAF – Osservatorio Astronomico di Roma

Italian SPICA Workshop 2016, Roma, 4–5 April 2016

Herschel and the study of the dusty and gaseous Universe

Herschel has opened a whole new avenue to the study of the dusty Universe thanks to its improved sensitivity and angular resolution compared to previous IR telescopes.



Dust

- ~30–50% of the total mass of metals
- metal content determined by past SFH, gas inflow and outflow
- affects and drives SF
- affects detectability of galaxies
- **proxy of gas content (with assumptions on the dust/gas ratio)** (e.g., Eales+10,+12, Leroy+11, Magdis+12, Scoville+12,+14)

Gas

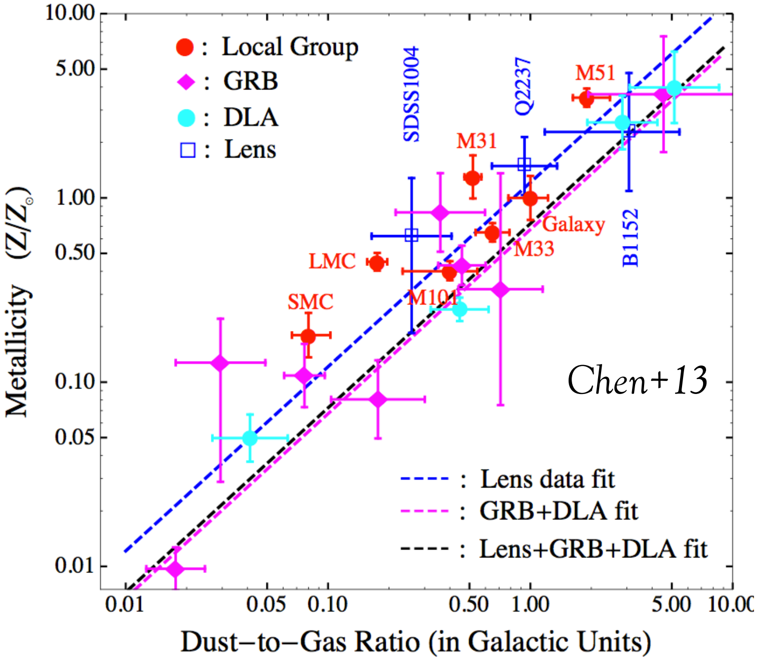
- primary ingredient for SF
- consistent fraction of the total baryonic galaxy mass
- gas abundance compared to the stellar abundance gives an idea of the evolutionary state of the galaxy
- relatively difficult to measure for large samples of galaxies

Herschel and the study of the gaseous Universe

Gas mass from the dust mass

Dust-to-Gas ratio ∝ metallicity

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

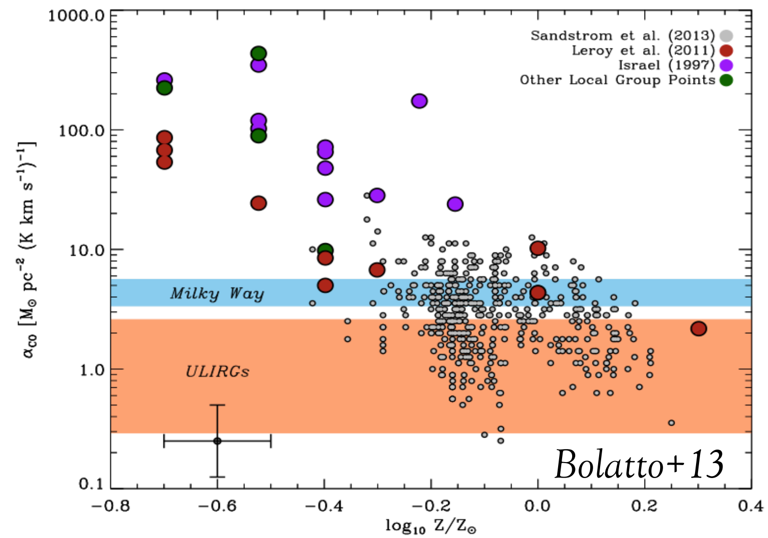


- Photo-z good enough
- Fast method: can quickly deliver gas masses for thousands of galaxies

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

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

(with larger spread)



- At high-z generally high-J CO transitions observed → need to correct for excitation
- Depend on galaxy type (?)
- Needs accurate spec-z
- Time demanding

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

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.

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:

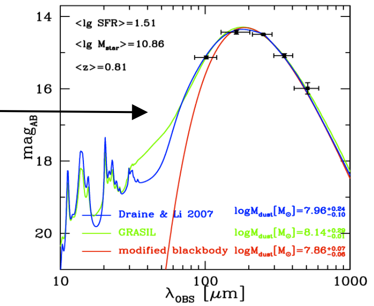
- **Star Formation Rate** → from 24 μm observations
- **stellar mass** → nearUV–to–nearIR multi–λ photometry

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

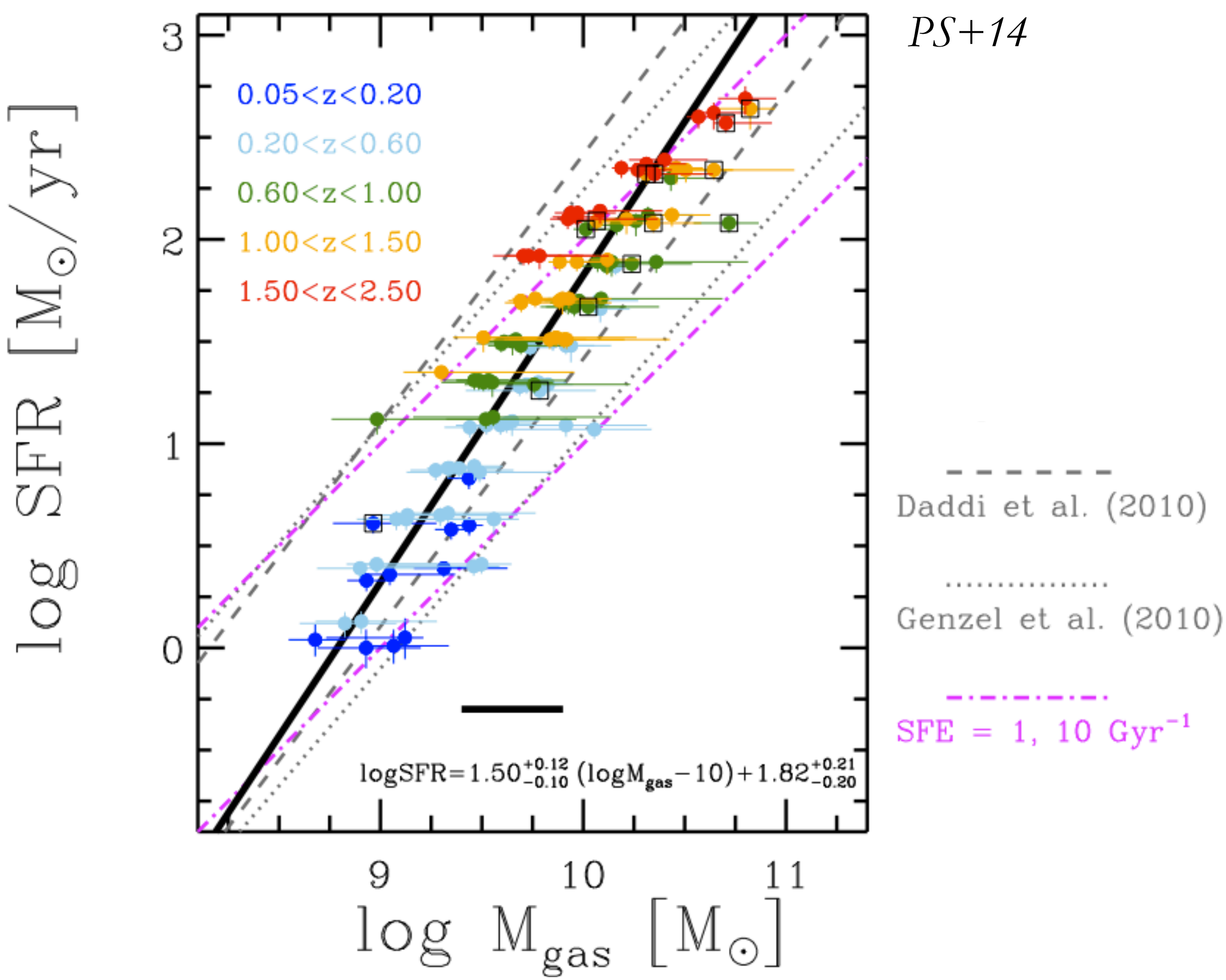
~30000 galaxies in the final sample

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

- **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)



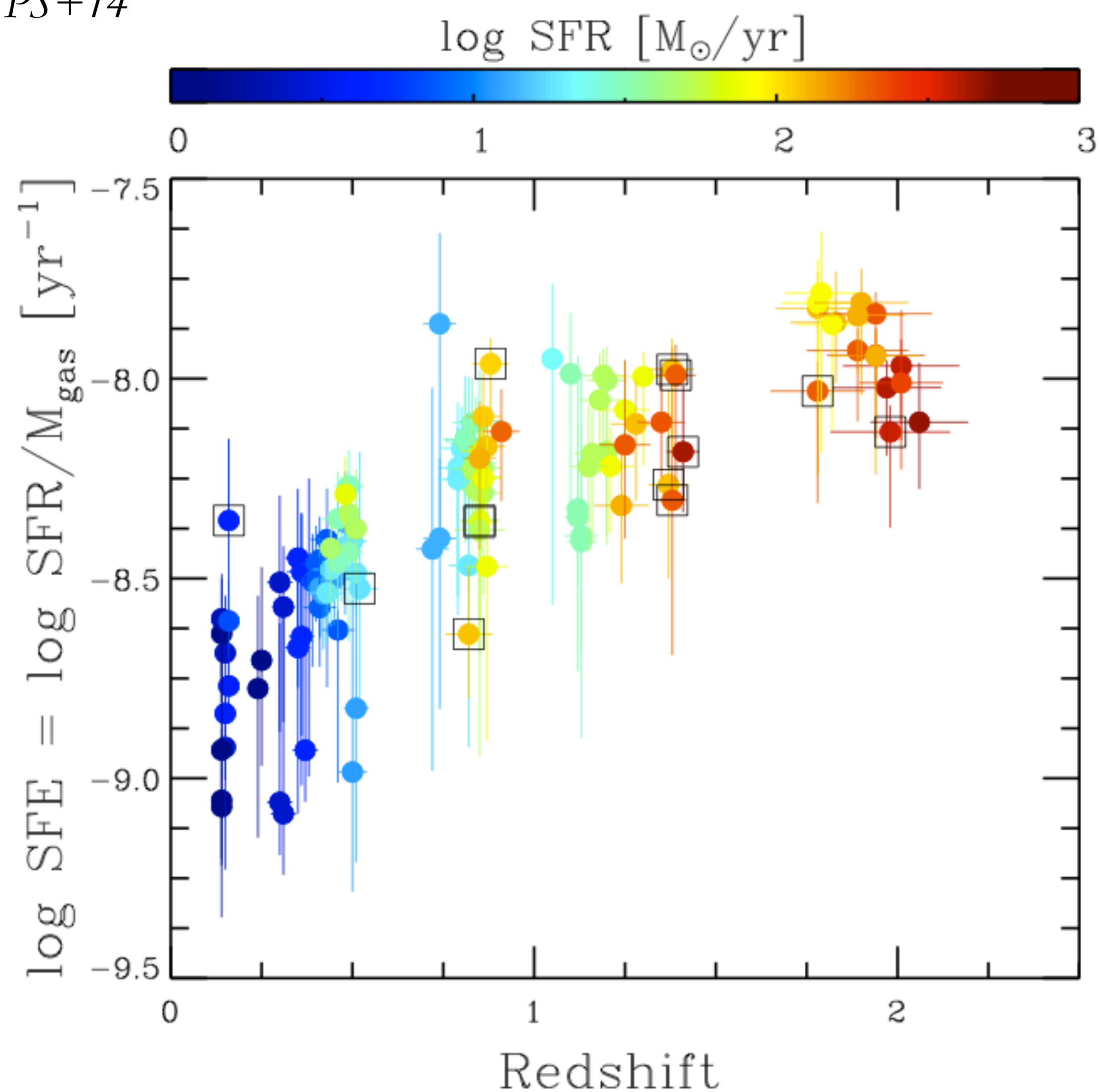
The "dust-based" integrated Schmidt-Kennicutt law



- 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

The evolution of the Star Formation Efficiency

PS+14

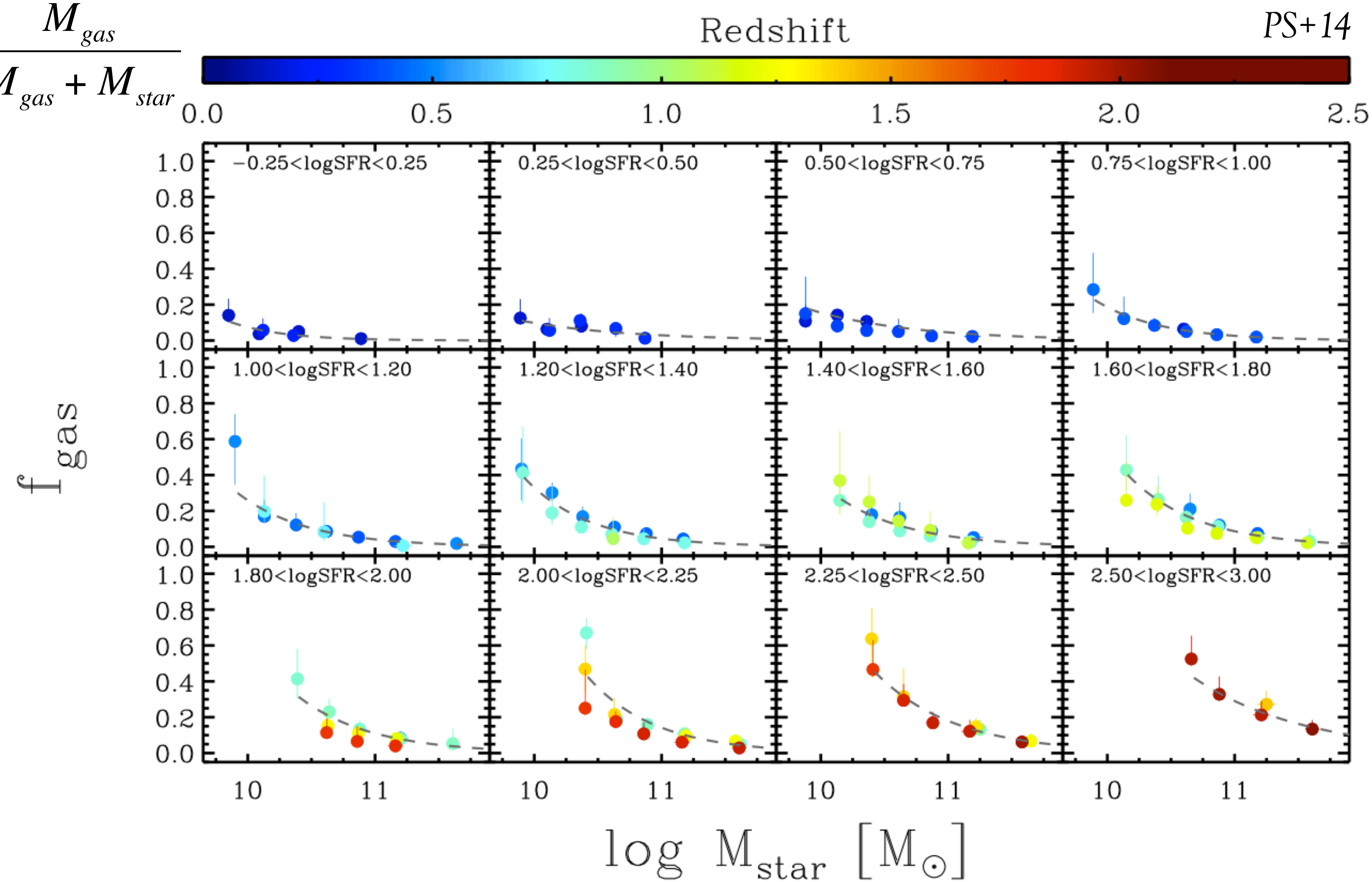


Higher star formation efficiency at high redshift:

- partly consequence of S-K slope>1 together with higher SFR at high-z
- partly real evolution (?)

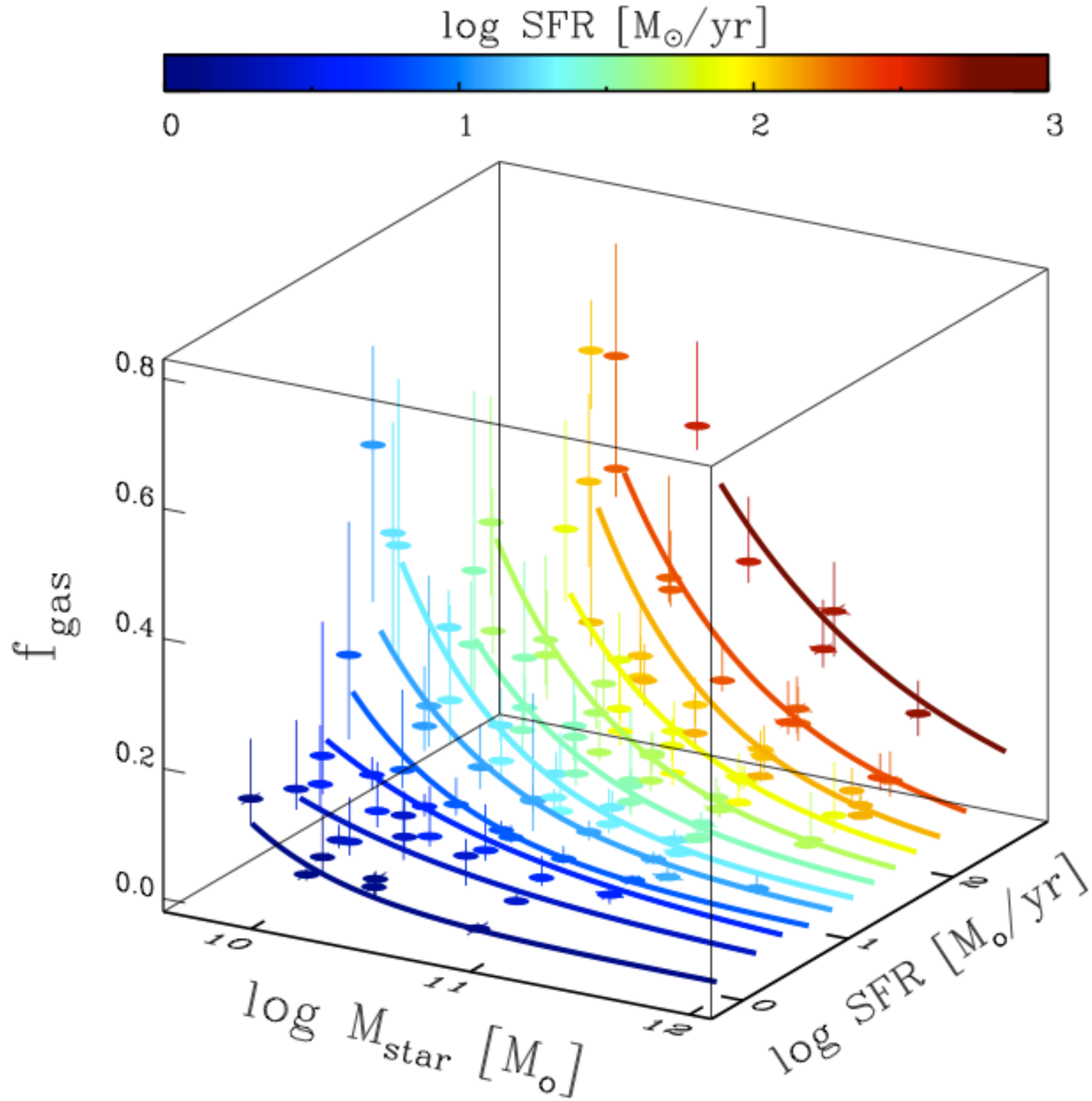
The evolution of the gas fraction

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



- 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

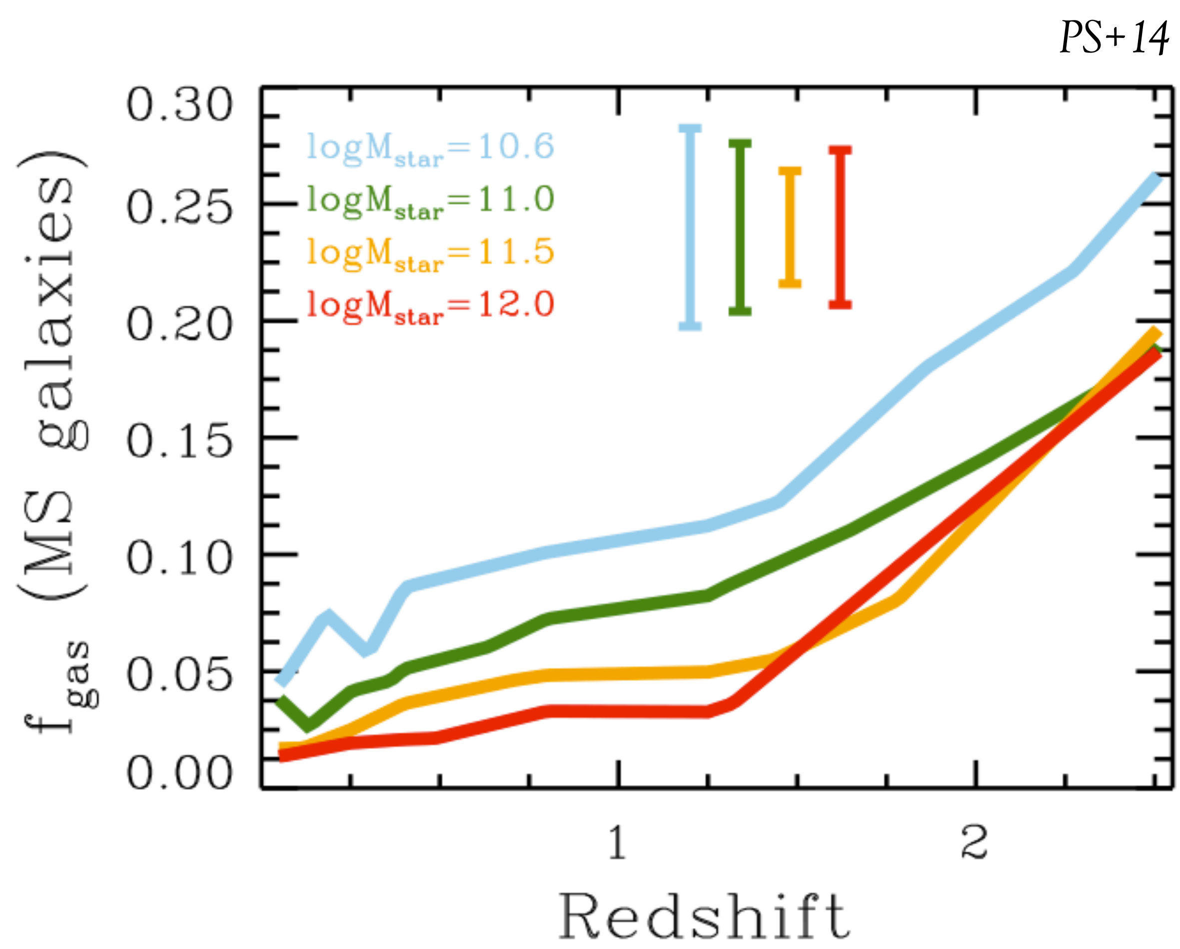


PS+14

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

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

The evolution of the gas fraction in Main Sequence galaxies



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

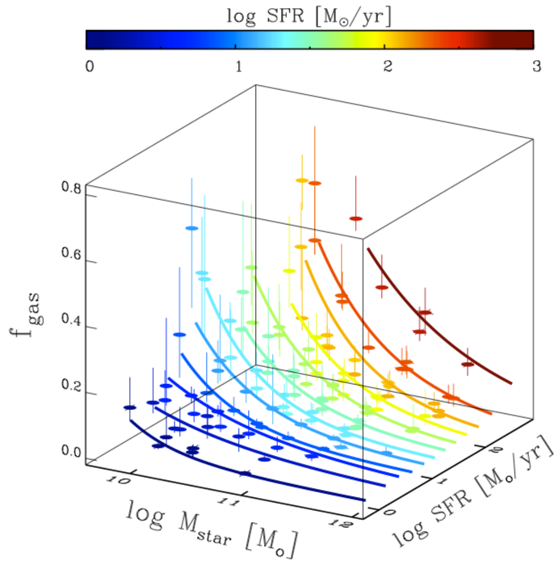
❑ Dust is a powerful gas proxy

FIR surveys allow 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 the majority of galaxies populate different regions of the fundamental f_{gas}-M_{star}-SFR relation across cosmic epochs

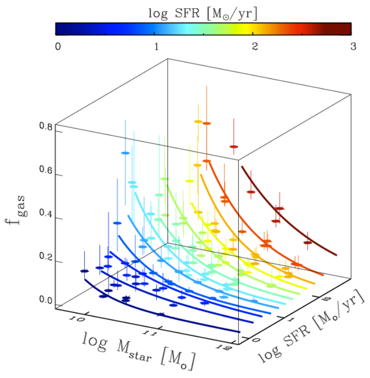


It's not the end of the story...

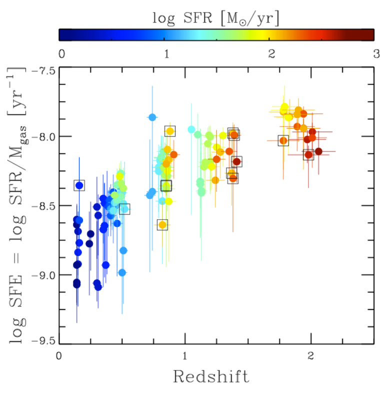
Limitations of the analysis

Confirmation of the redshift invariance of the fundamental f_{gas}–M_{star}–SFR relation:

1. crucially depends on the uncertainties
    - SFR based on 24μm
    - Stacking
    - Gas metallicity inferred assuming the FMR

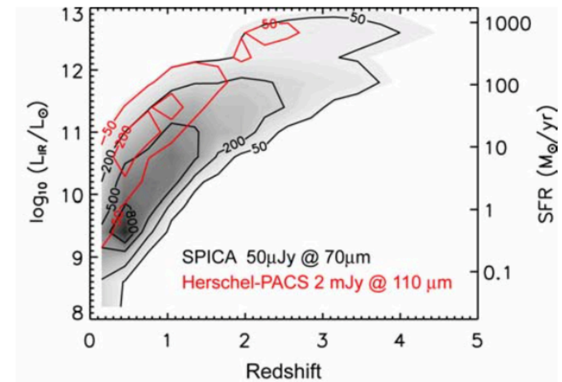


2. would benefit from extension of the dynamical range (mostly in z and SFR)
    - Basically limited by Spitzer (SFR from 24 μm) and Herschel sensitivity
    - (and area not large enough)

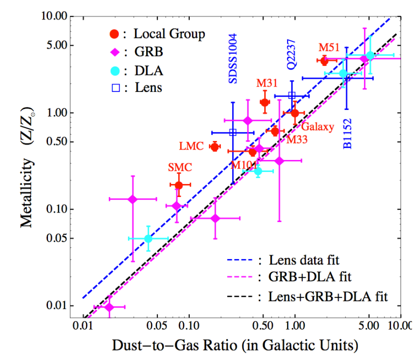


Large room for improvement with SPICA

- SAFARI MW and LW bands free of contamination from PAH features (out to z~3) → reduce the scatter and systematics in the SFRs by a factor of 2–4 (+ 2 orders of magnitude deeper wrt Herschel)



- direct measure gas metallicity from far-IR lines (unaffected by dust extinction, e.g. Nagao+11) with SAFARI → 10–20% reduction in uncertainties + avoid possible systematics



- reduce the scatter in the dust/gas ratio vs gas metallicity relation by analysing dependences on physical conditions

- nearly 2 orders of magnitude deeper than Spitzer and Herschel → can deal with individual detections
- allows extension to higher redshift

} with a photometric band or low res spectrum + combination with submillimeter telescopes (or a FIR imager on-board SPICA)