Metallicity evolution and scaling relations in galaxies

…feeding Francesca with some new observational results…

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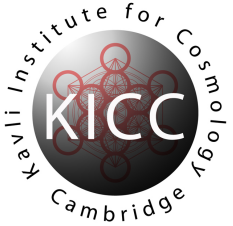
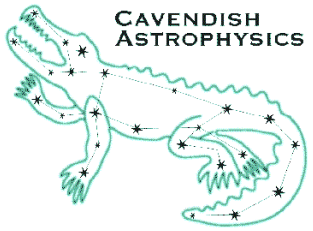




Pasadena, 2003

Basic equation of chemical evolution

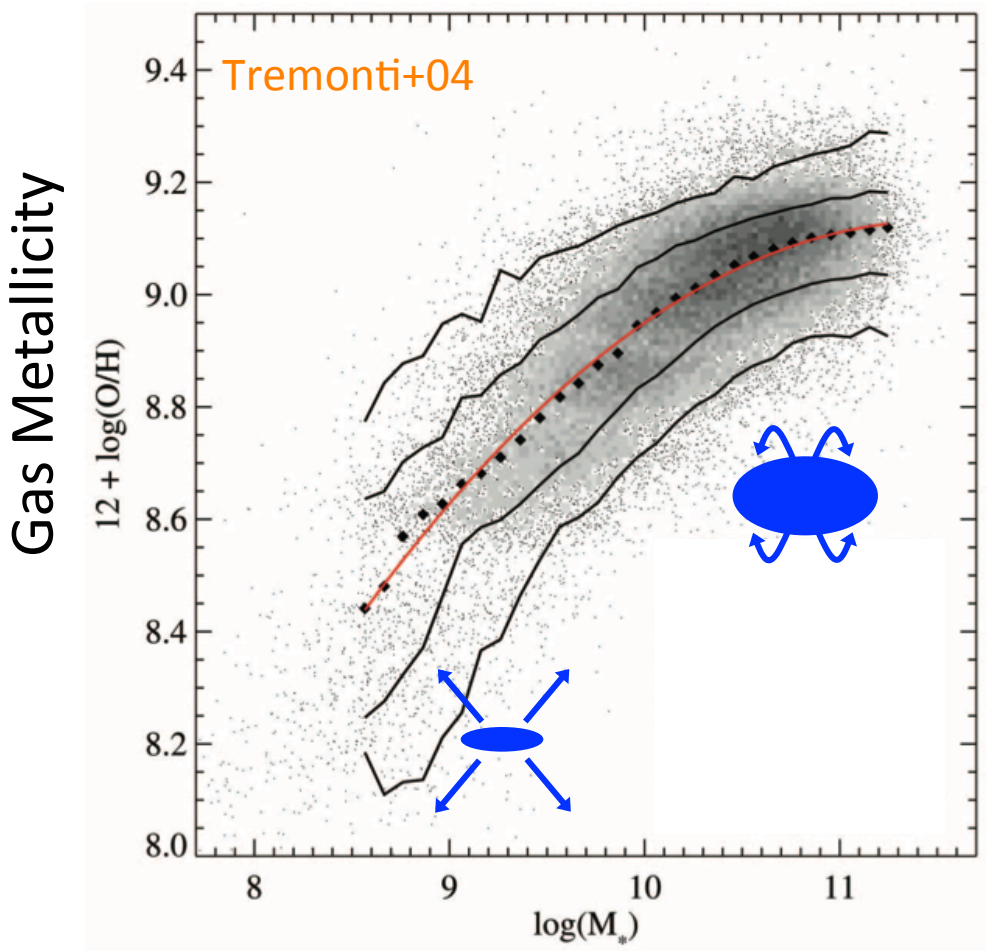
(Matteucci 2008)

$$\dot{\sigma}_i(t) = -\psi(t)X_i(t)$$
$$+\int_{M_L}^{M_{Bm}} \psi(t-\tau_m)Q_{mi}(t-\tau_m)\varphi(m)dm$$
$$+A\int_{M_{Bm}}^{M_{BM}} \phi(m)$$
$$\cdot[\int_{\gamma_{min}}^{0.5} f(\gamma)\psi(t-\tau_{m2})Q_{mi}(t-\tau_{m2})d\gamma]dm$$
$$+B\int_{M_{Bm}}^{M_{BM}} \psi(t-\tau_m)Q_{mi}(t-\tau_m)\varphi(m)dm$$
$$+\int_{M_{BM}}^{M_U} \psi(t-\tau_m)Q_{mi}(t-\tau_m)\varphi(m)dm$$
$$+X_{A_i}A(t) - X_i(t)W(t)$$

Key parameters:

- Star formation efficiency
- Infall/inflow rate
- Outflow rate

The Stellar Mass-Metallicity relation

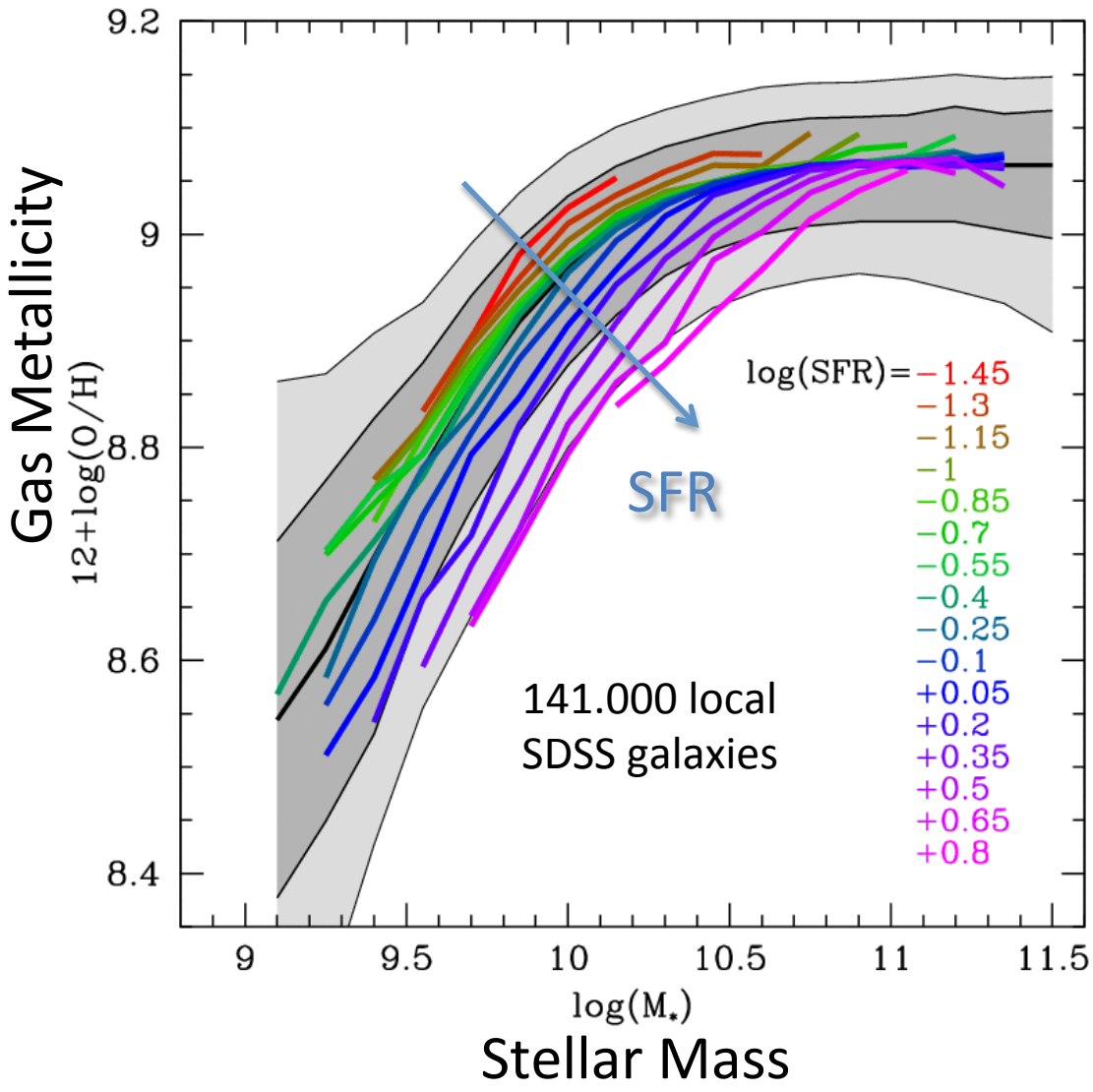


Early nterpretations: outflows...

The Mass-Metallicity relation is a projection of more complex multi-dimensional relations: part of the scatter due to the mixing of other secondary relations

Fundamental Metallicity Relation (FMR):

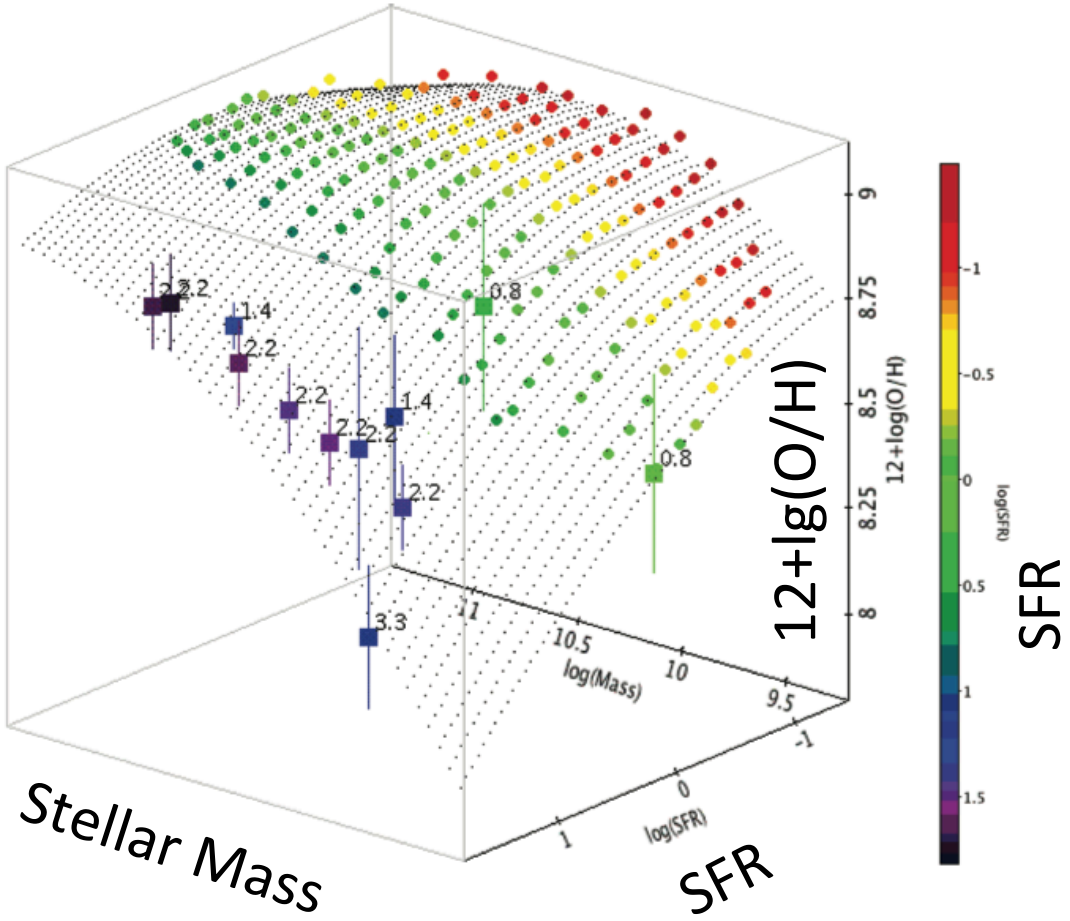
relation between M_{star}- Metallicity - SFR

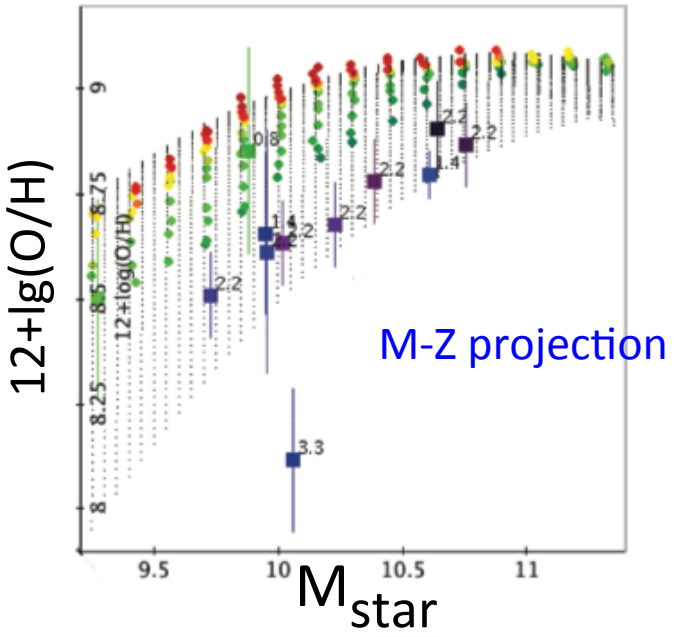


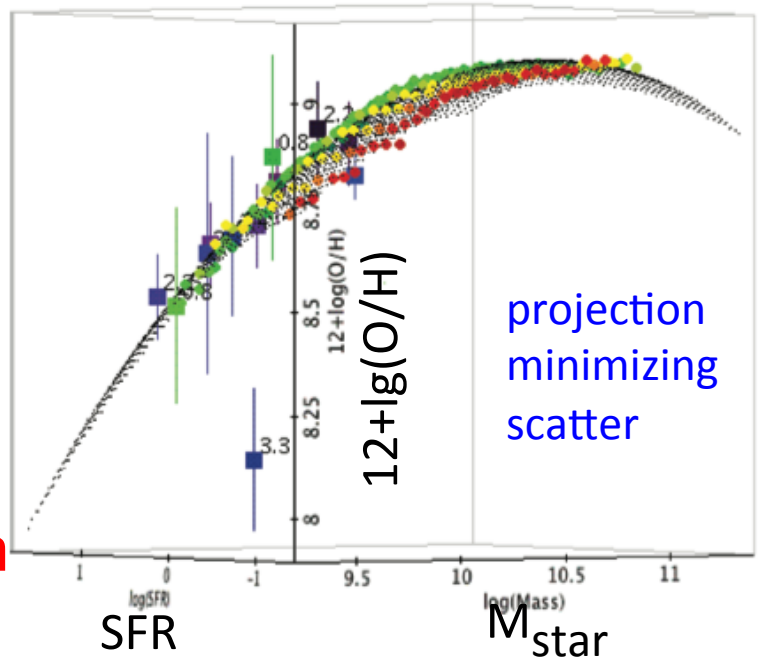
Mannucci et al. 2010

3D relation

Does not evolve with redshift out to z~2.5



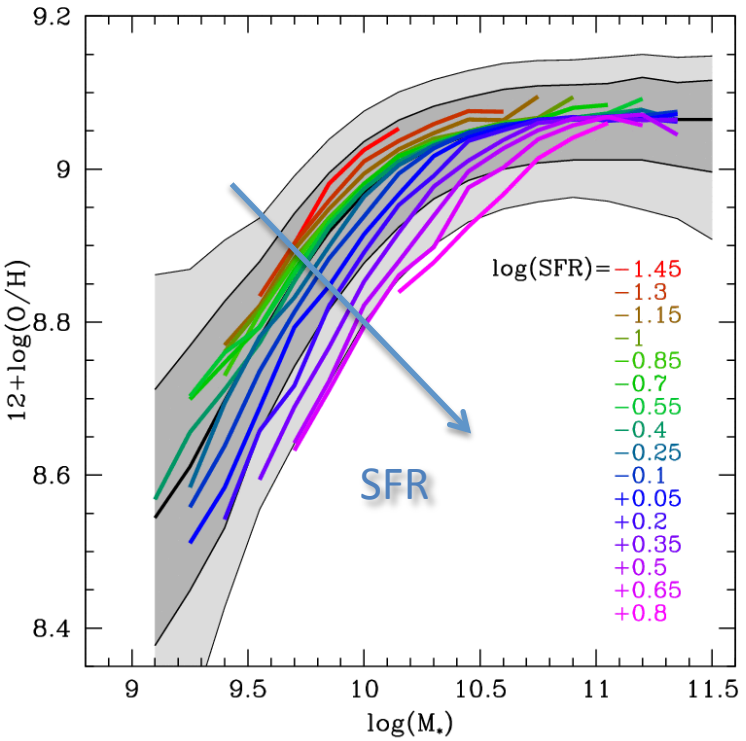


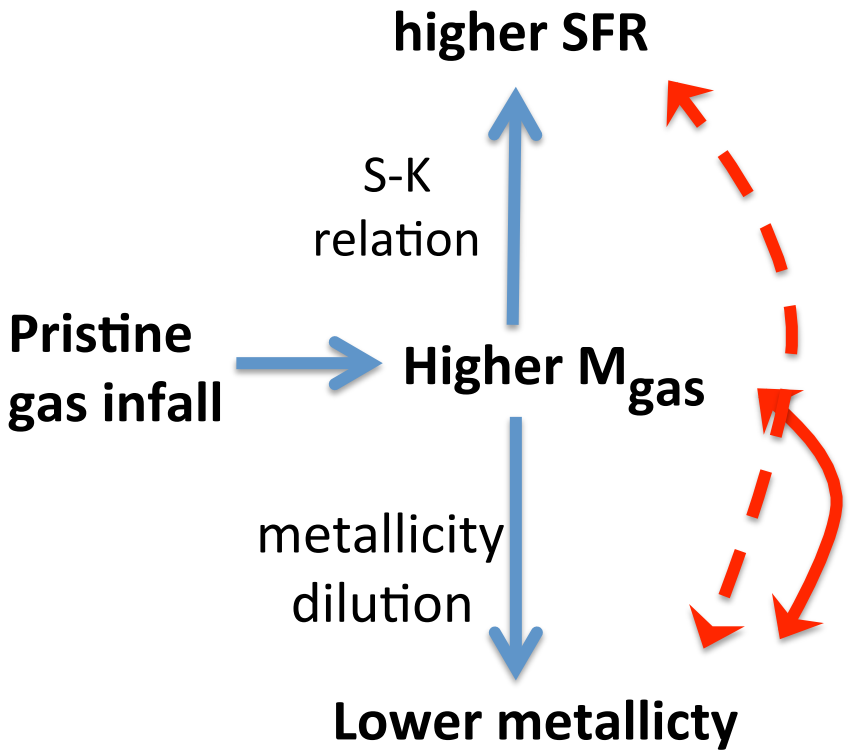


Various models:
Dayal+12, Lilly+13,
Dave'+12,
Rupke+12,

Very small dispersion
~0.07 dex

Metallicity, in principle, should be little related with *current* SFR in principle, (should be related to the whole past star formation history).
However, the metallicity can be DIRECTLY related to the gas content, and SFR is a proxy of the gas content…





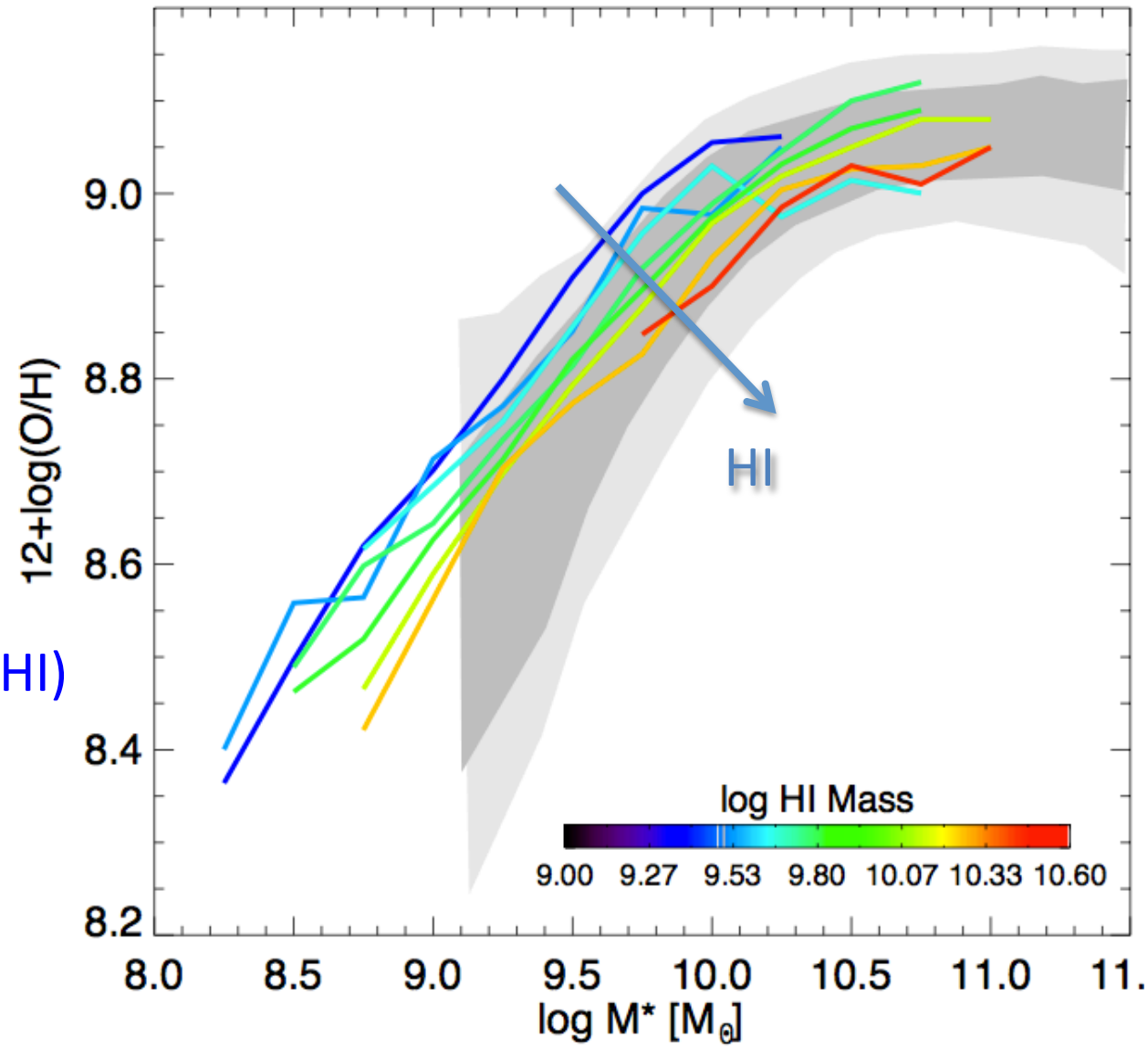
anticorrelation
between SFR and metallicity
may be a **by-product**
of a more fundamental
anticorrelation between
M$_{gas}$ and metallicity

Cross-correlation of SDSS with the AlphaAlpha HI survey

Bothwell+13

5,000 galaxies

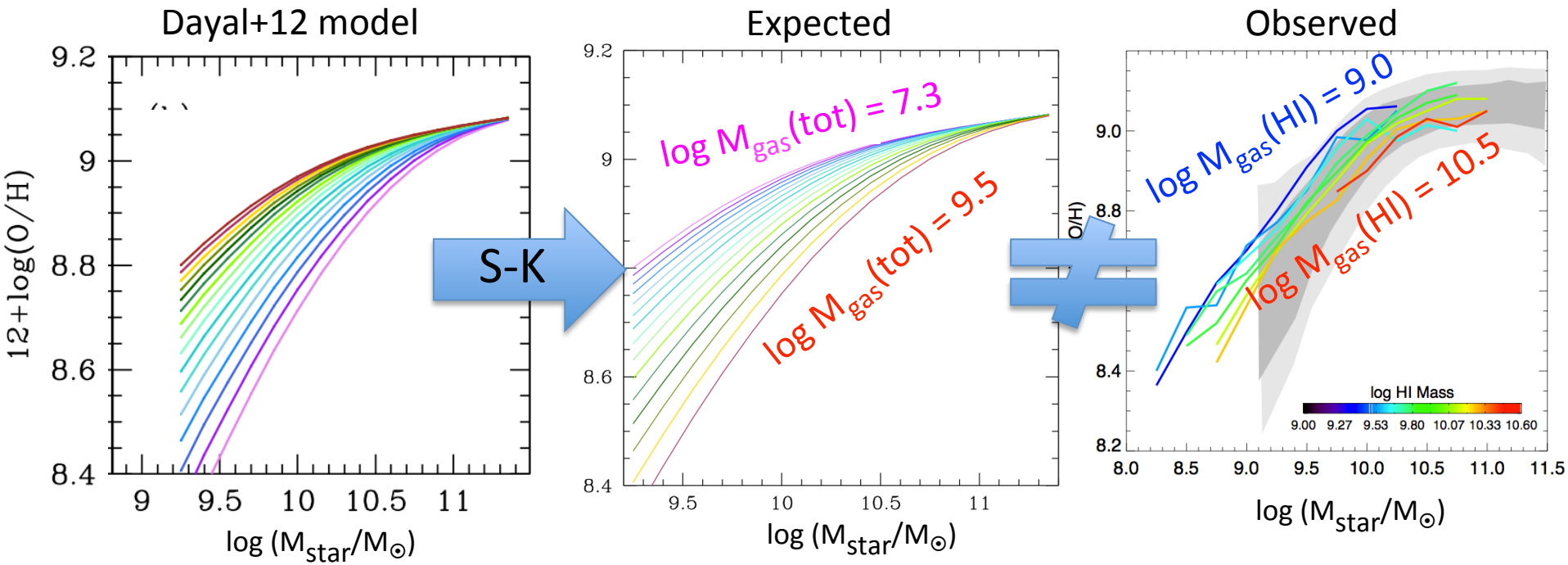
HI – FMR :
Fundamental
Metallicity Relation
between
M_{star}- Metallicity- Mgas(HI)



Dispersion significantly smaller (~half) than the SFR-FMR

-> ok with expectations, cool!

But do models explaining the SFR-FMR automatically explain the HI-FMR?... **NO**!



Observed amount of gas much larger than expected by models

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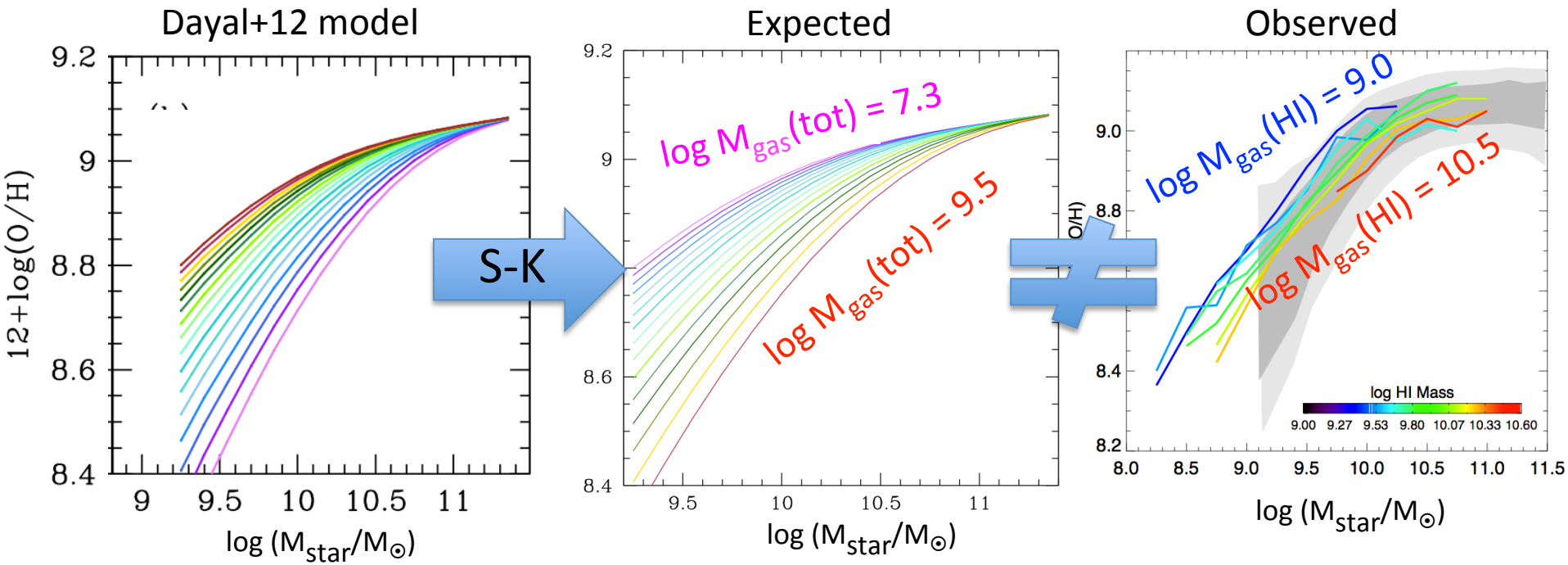
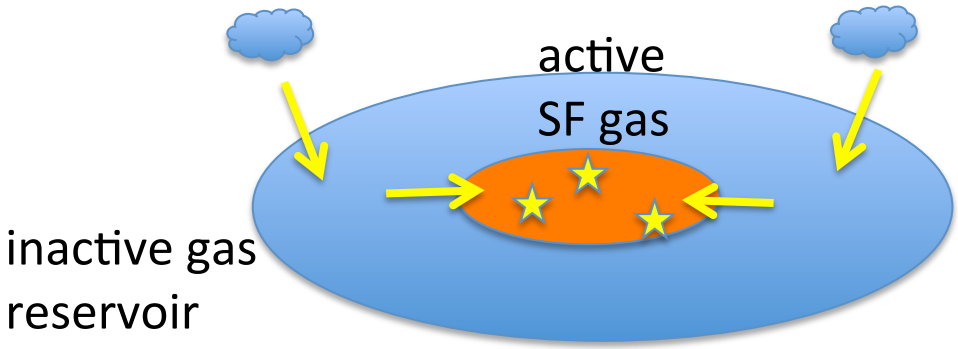


Observed amount of gas much larger than expected by models

2-phase scenario



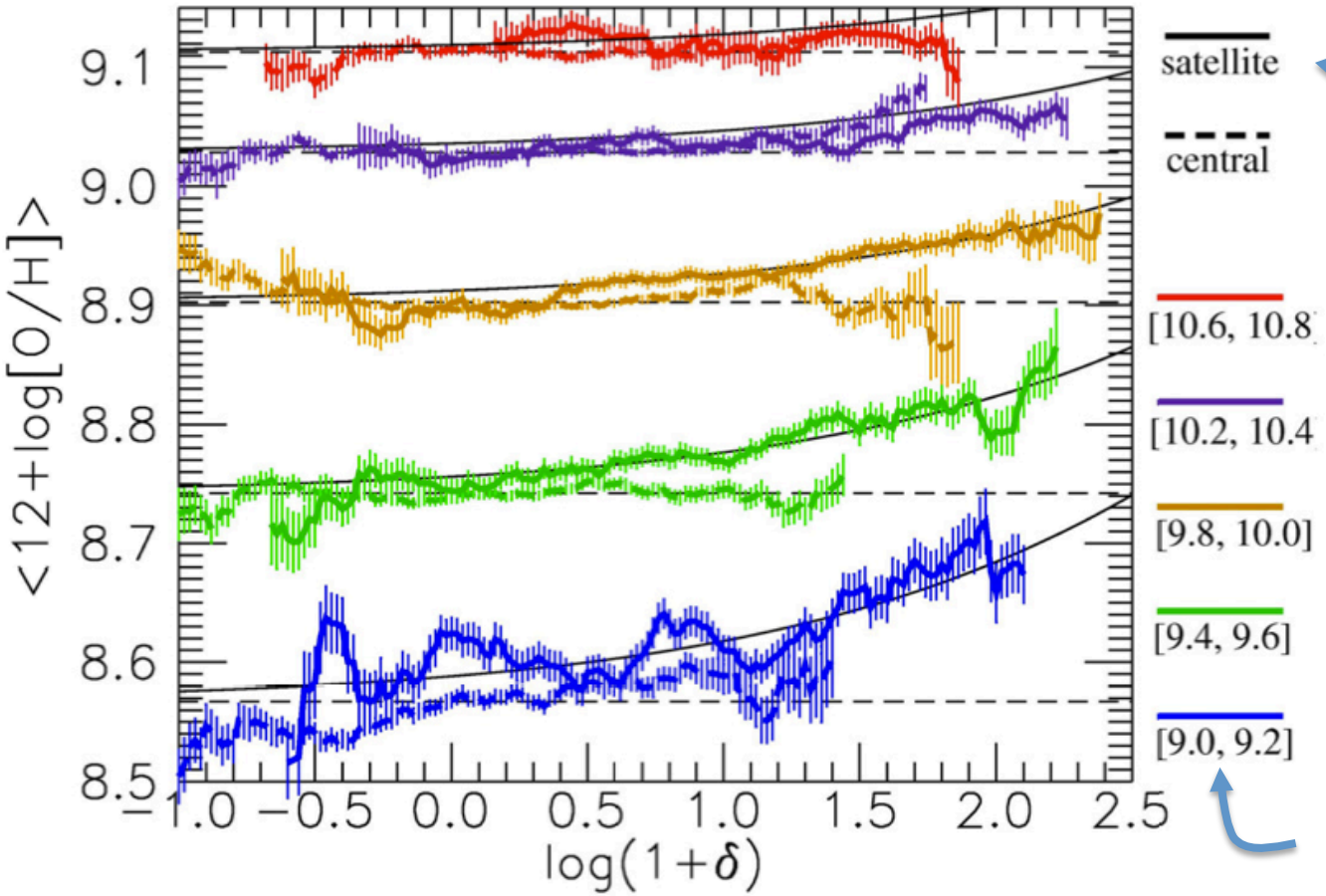
Expected (Spitoni's talk)
and observed in galaxies…

…yet, impressive that the metallicity in the "active region" is so tightly related to HI content on larger scales
➔ smooth and universal process

Inflow… generally assumed pristine (most models) or pre-enriched by the halo…
environment independent…
indeed so far no evidence of metallicity-environment relation…

Peng+Maiolino'13

Disentangling central from "satellites"



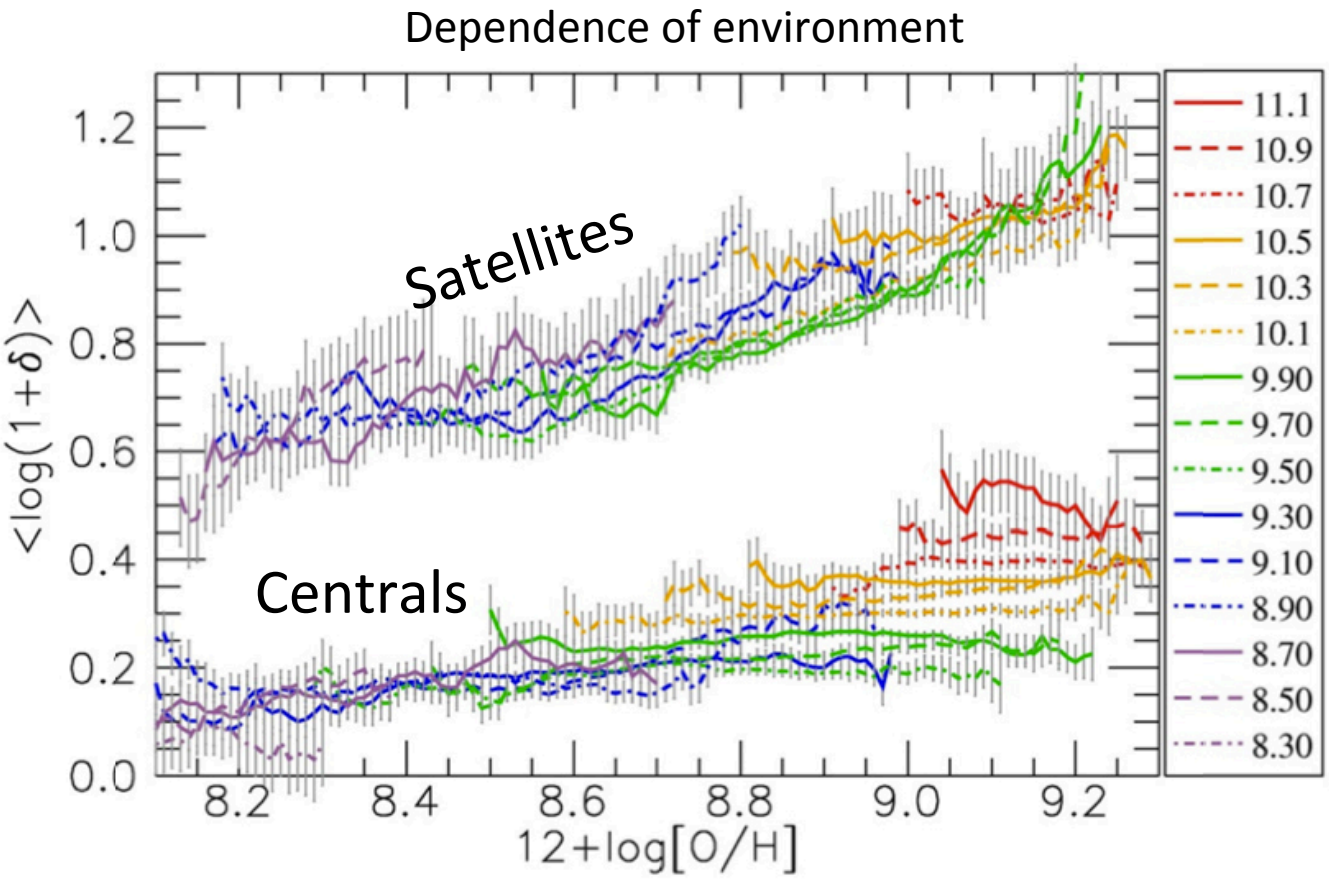
(any member of a group/cluster that is not the central galaxy, i.e. MOST galaxies)

stellar mass

Centrals: gas metallicity ~ independent of environment

Satellites: gas metallicity strongly dependent of environment

Environment vs. Metallicity: combining all satellites and all centrals



Metallicity-environment relation of satellites *independent* of mass

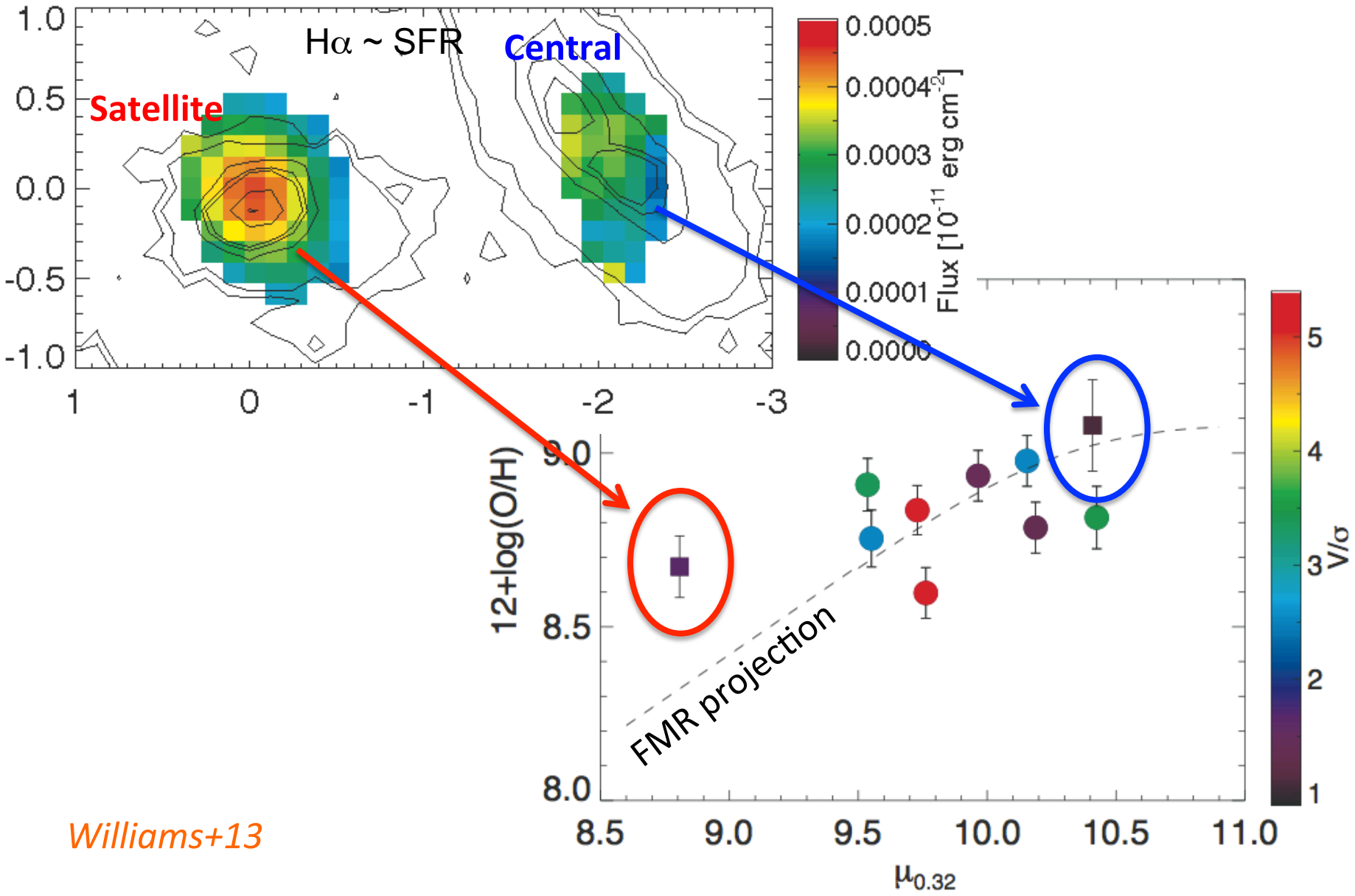
Responsible for part of the scatter in the mass-metallicity relation

Peng+Maiolino'13

Can be reproduced by inflow of metal enriched gas, with Z_{inflow}-environment relation

Role of environment in enhancing the metallicity of satellites already in place at high-z

Group at z~1.5 SINFONI Integral Field Observations of Hα+[NII]

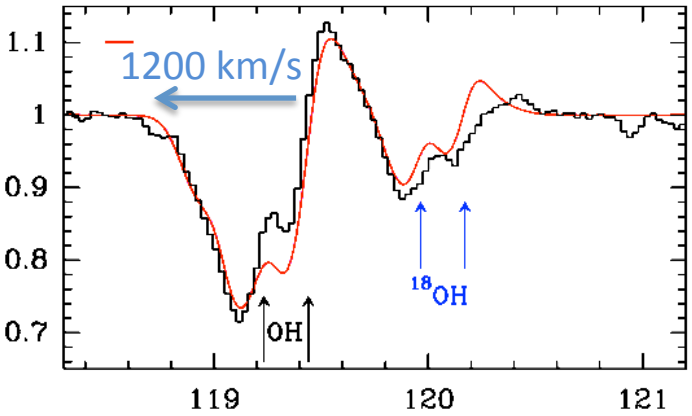


Williams+13

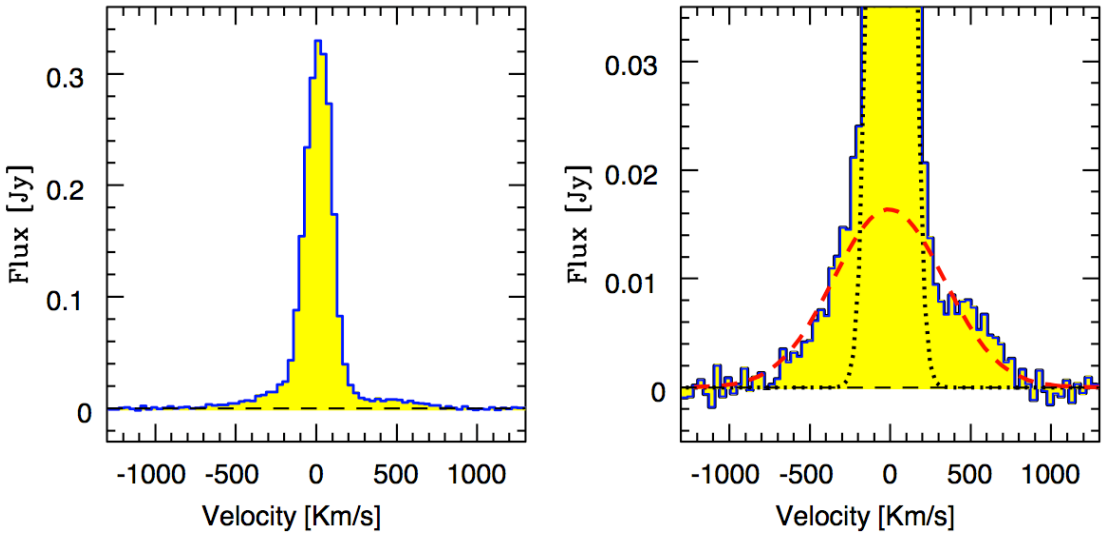
Outflows… generally assumed SF-driven

The importance of AGN:

OH P-Cygni profiles

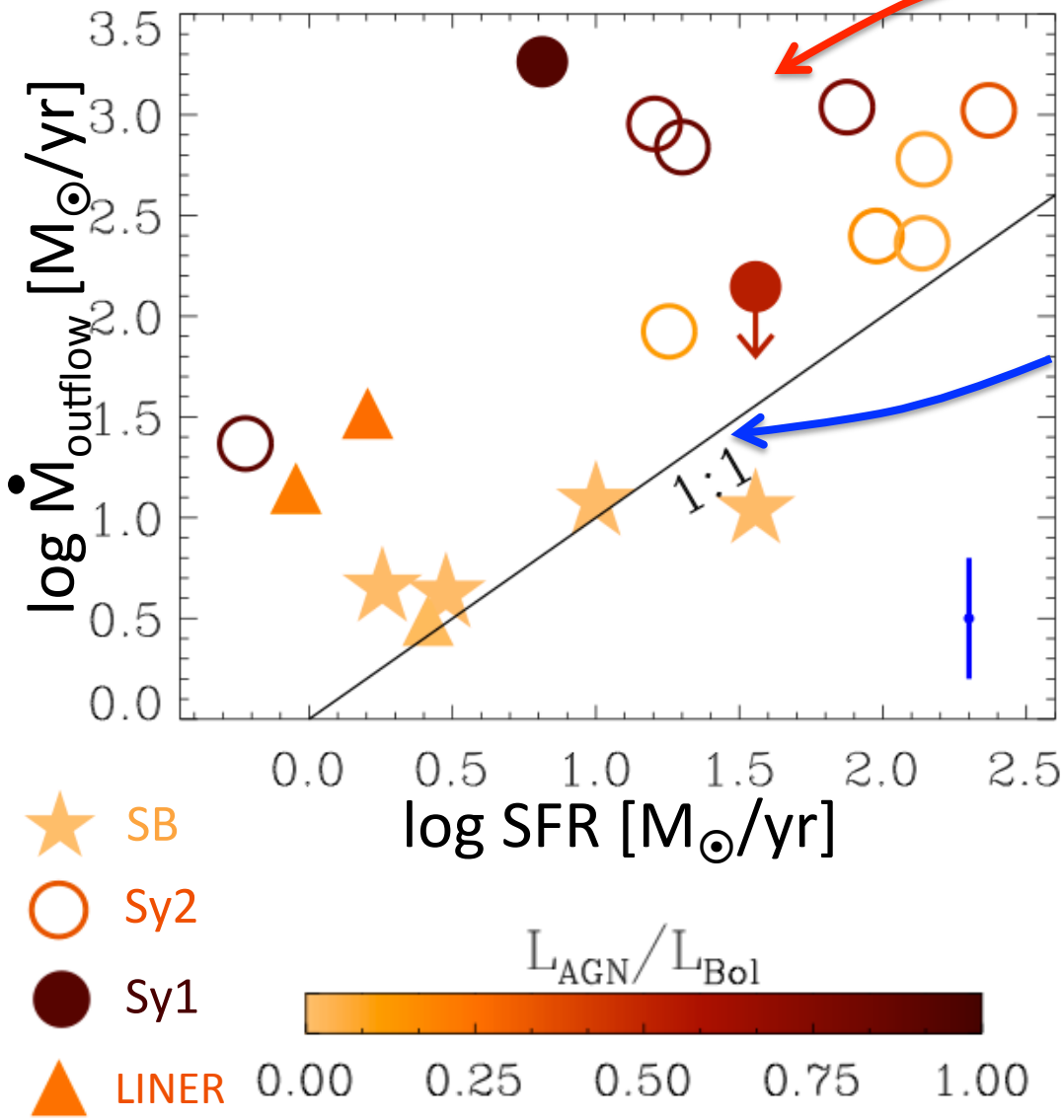


CO(1-0) high velocity wings



- Discovery of massive quasar-driven molecular outflows (1000 $M_{\odot}$/yr)
  ➔ removal of large amount of metals from the central regions
- Velocities in excess of 1000 km/s ➔ implications for fountain models
- Extended on kpc scales
- Revealed out to z~6.4

Feruglio+10,13, Cicone+12, Aalto+12
Fischer+10, Sturm+11, Maiolino+12

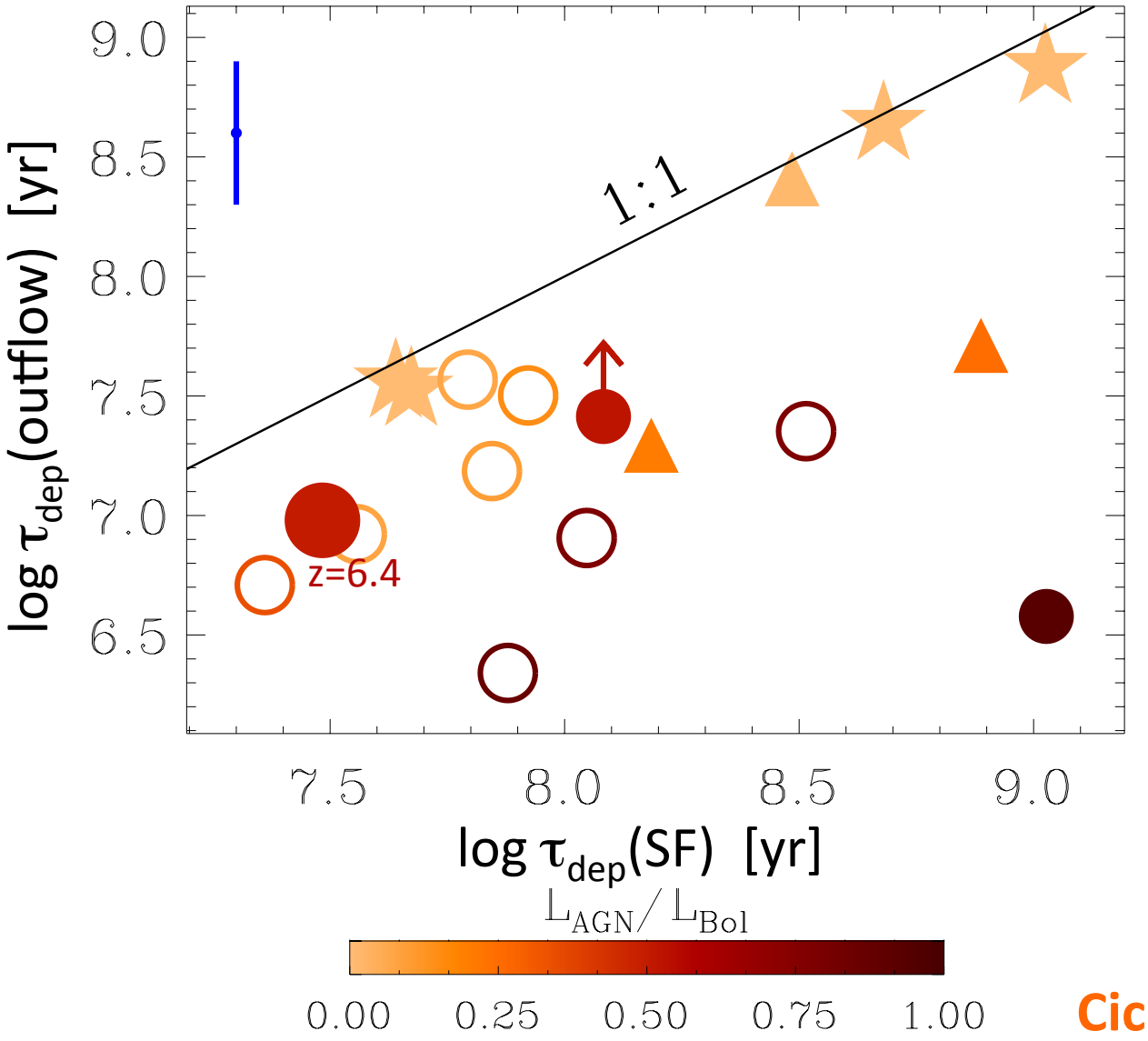


AGN-dominated gals. deviate from the starburst 1:1 relation with extra outflow boost by a factor of 5-100!

Starburst-driven outflow rate ~ SFR as required by feedback models

Cicone+13

Depletion timescale due to AGN-driven outflow much shorter than depletion due to Star Formation



very short outflow depletion timescales can greatly help α-enhancement in ellipticals (Kobayashi's talk)

Cicone+13

Star Formation Efficiency (SFE)

$$SFR = \varepsilon \, M_{gas}$$

Does it change with stellar mass?
Does it change with redshift?
Does it change with SFR?

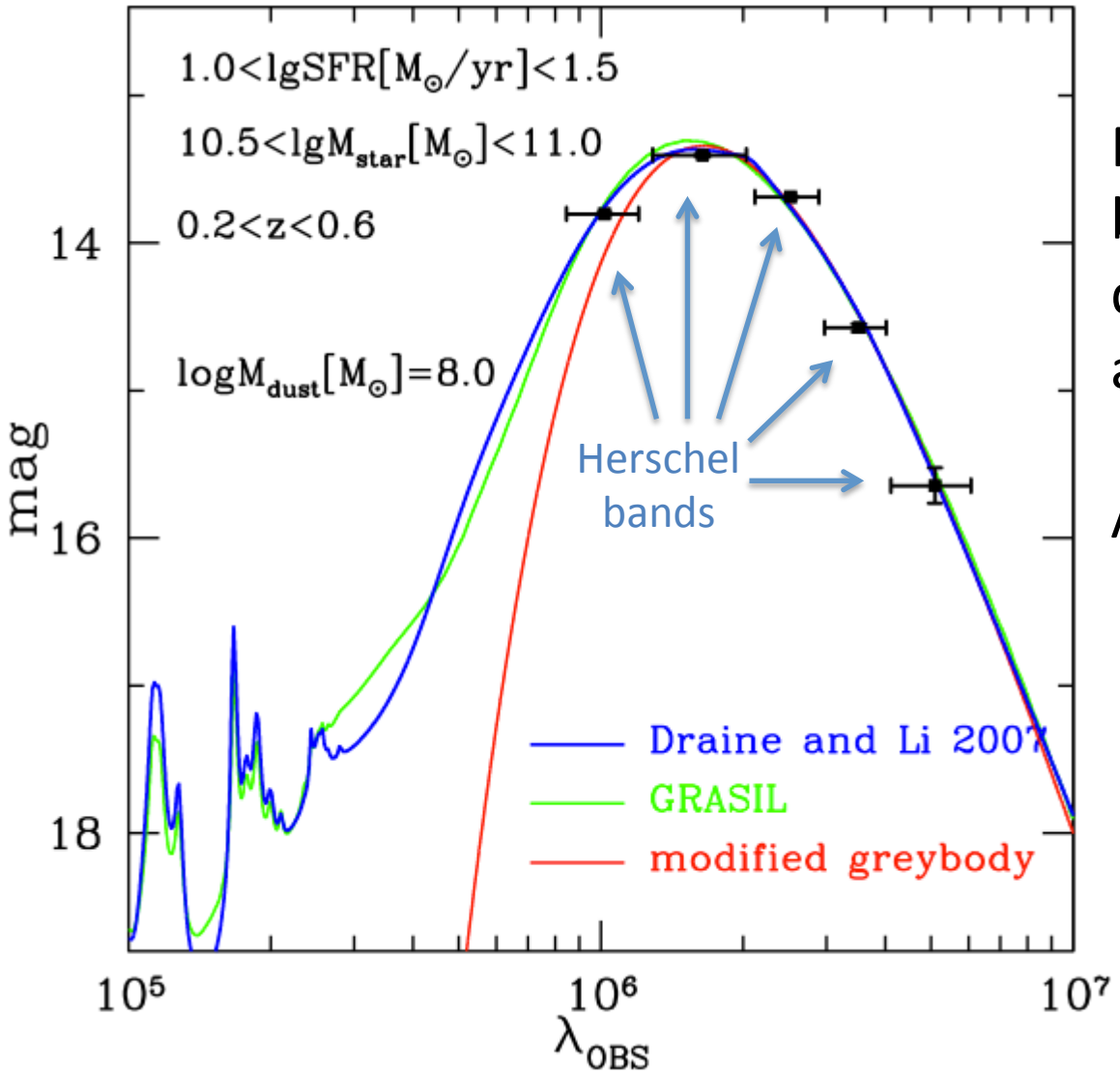
Observational constraints:
need to measure M_{gas}

Classical method: CO measurements
- time demanding
- lots of assumptions and uncertainties in CO-to-H_2 conversion factor(s)

Inferring M(gas) from the dust content

M(dust)
from IR-submm SED

M(gas)



May sound indirect…
but actually more direct and more accurate than CO

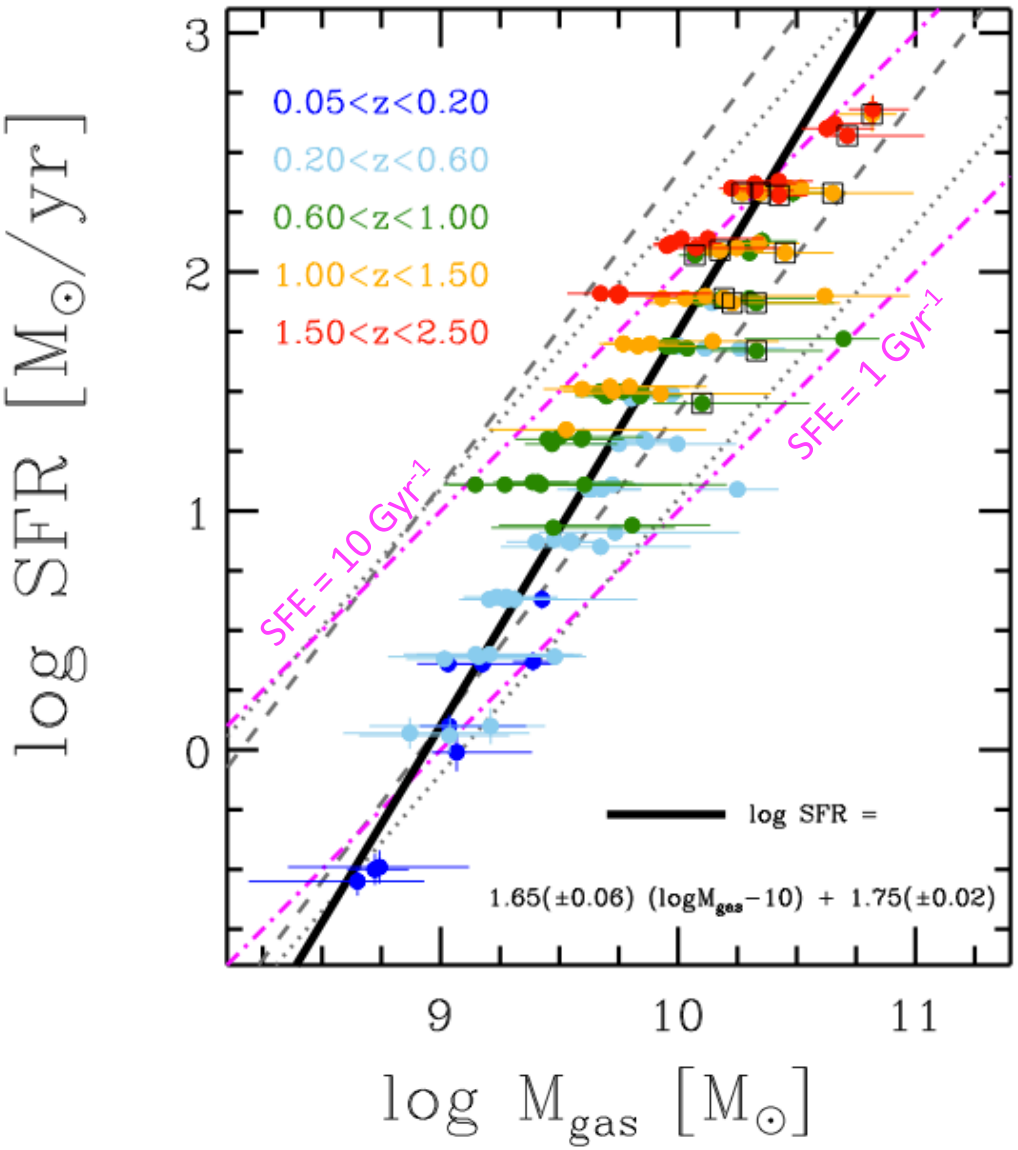
Also, much faster than CO

Leroy+11
Israel+12
Bolatto+13
Eales+10,11
Dunne+11,13
Magdis+12

Integrated S-K: single relation (slope 1.5)

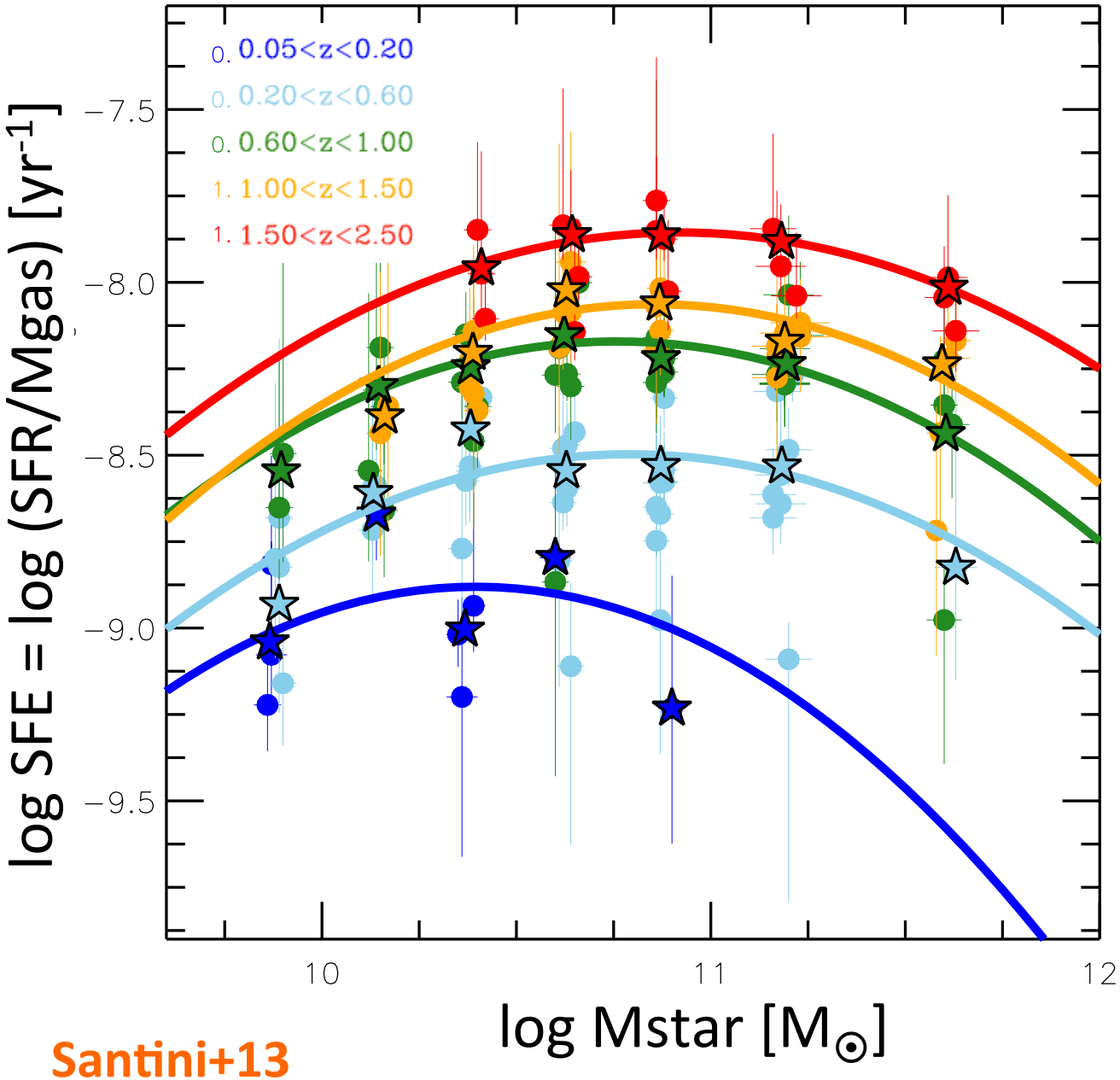
- "Main Sequence" galaxies (secular)
- "Starburst" galaxies

Star Formation Efficiency (SFE=SFR/M_{gas}) higher for more strongly star forming galaxies



Santini+13

SFE higher in high-z galaxies (but not because they are starburst)…
SFE peaks between lg(M/M$_\odot$)~10.5 and ~11 Msun, but possibly evolving with redshift…



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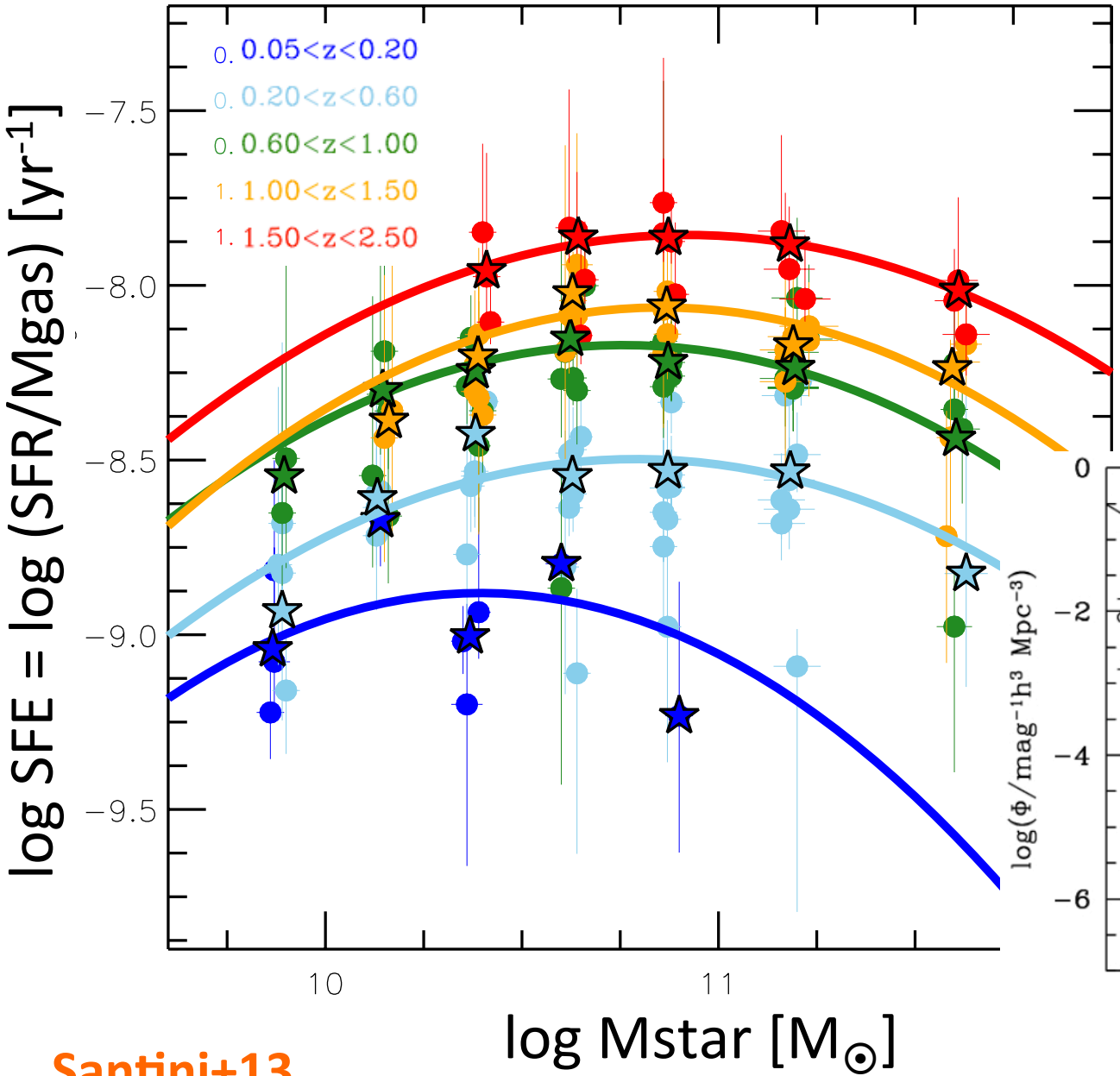
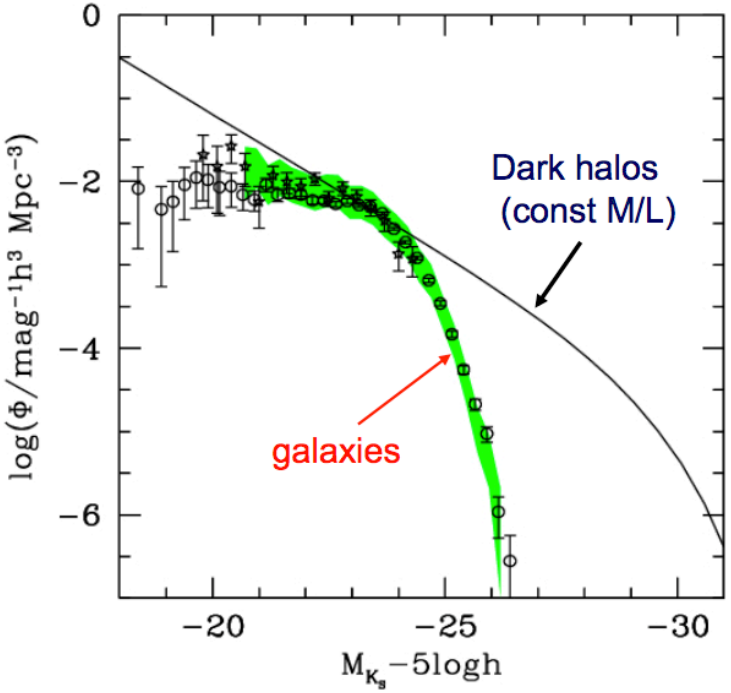


Santini+13

the key to explain
the stellar mass function
of galaxies???



Thanks to:
(those who did most of the work)

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(Kavli/Cavendish, Cambridge)

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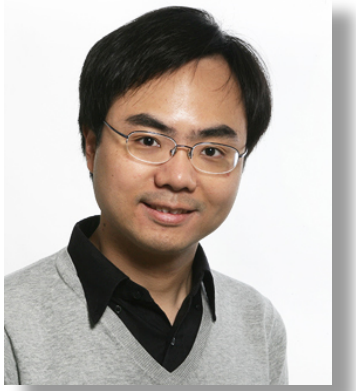
(Kavli/Cavendish, Cambridge)



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(Osservatorio di Roma)

And…

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