Starbursts, normal galaxies & the molecular gas history of the Universe

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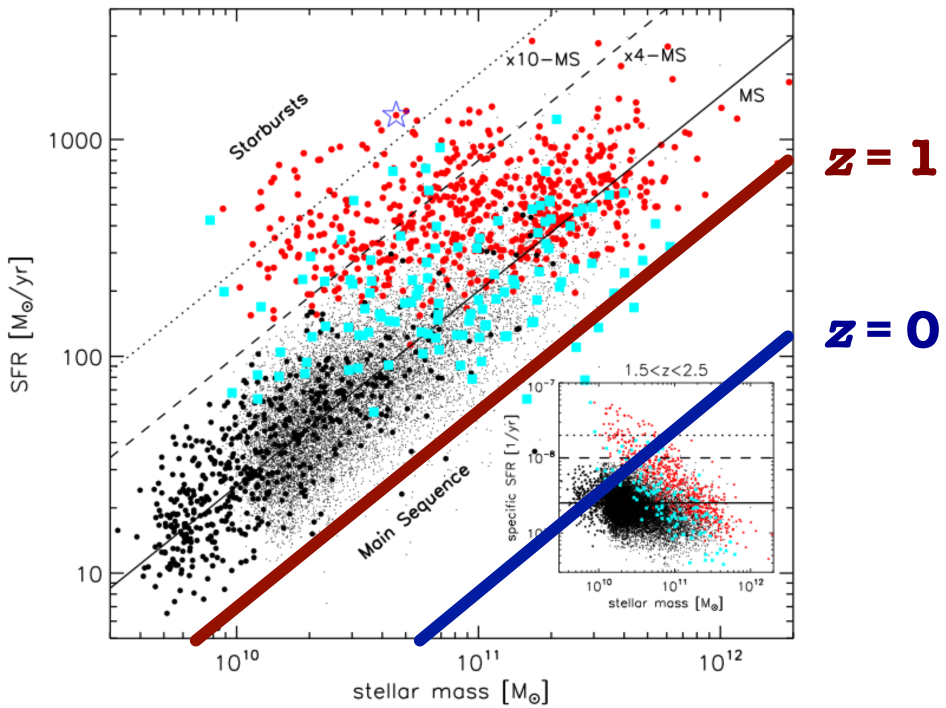
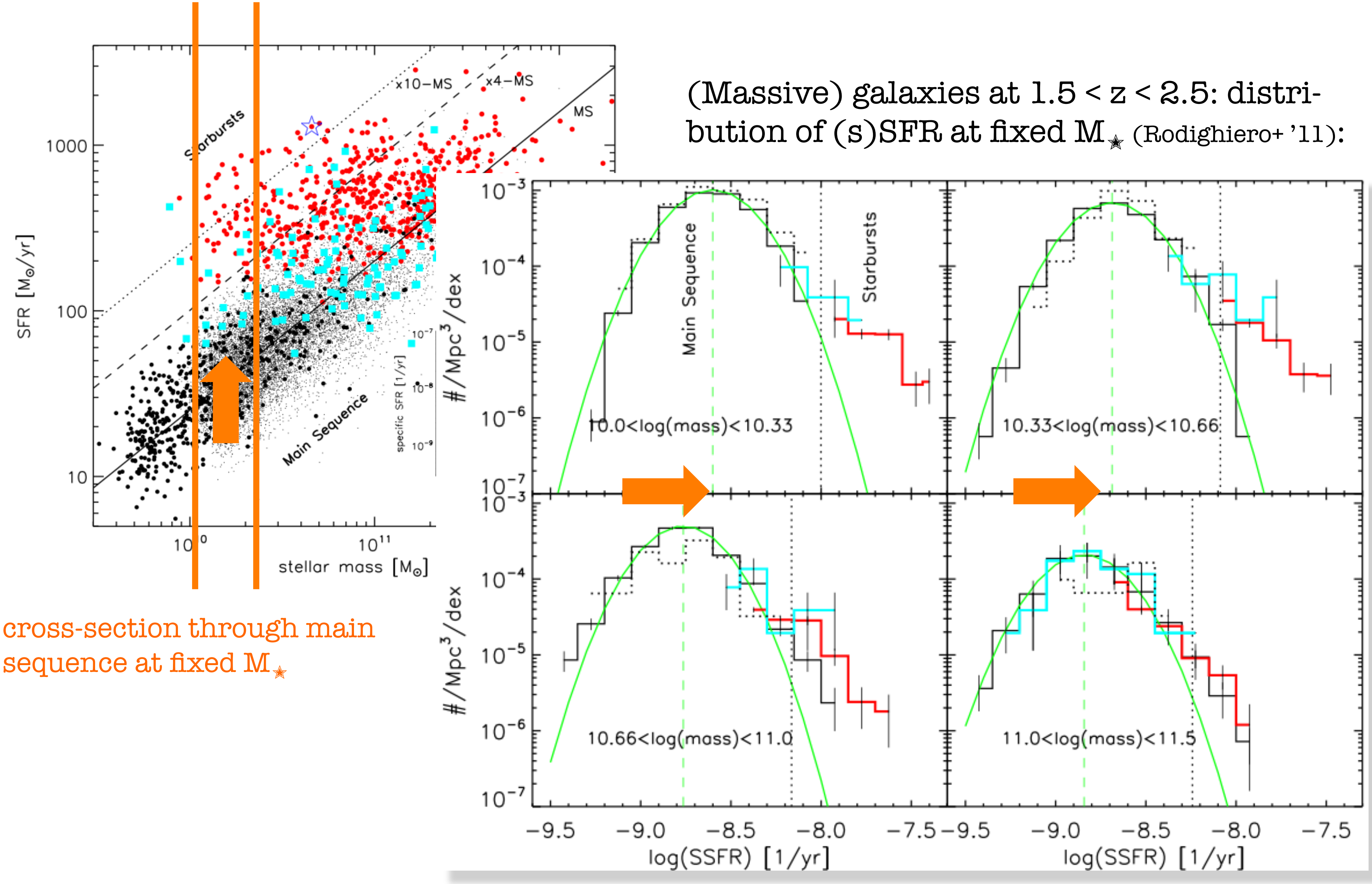
‘Starbursts’ – here: excess sSFR



'Starbursts' – here: excess sSFR

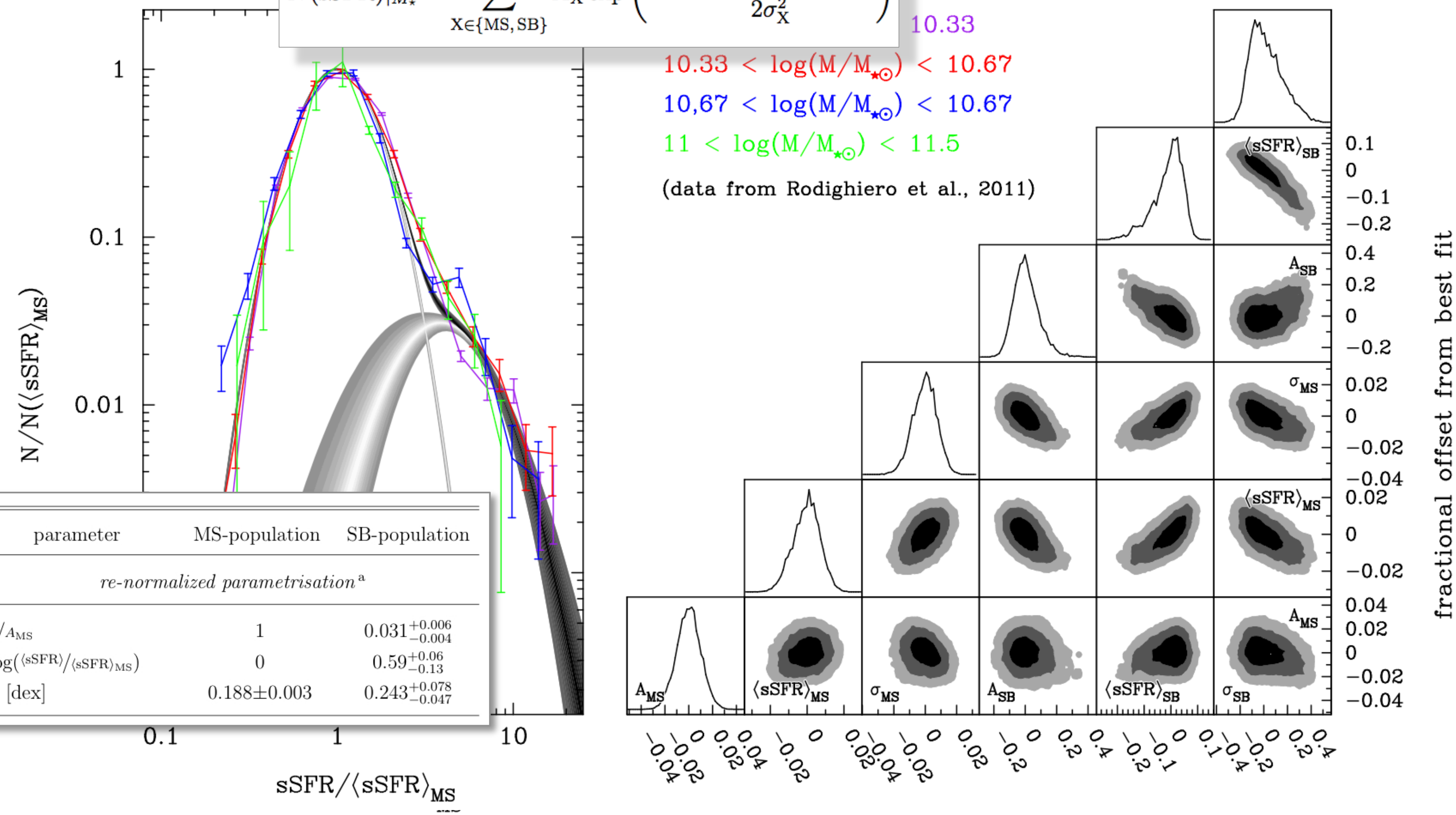
(Massive) galaxies at 1.5 < z < 2.5: distribution of (s)SFR at fixed $M_\star$ (Rodighiero+ '11):



cross-section through main sequence at fixed $M_\star$

(Main sequence + starburst) decomposition

$$N(\mathrm{sSFR})|_{M_\star} = \sum_{\mathrm{X}\in\{\mathrm{MS},\mathrm{SB}\}} A_\mathrm{X} \exp\left(-\frac{(\mathrm{sSFR}-\langle\mathrm{sSFR}\rangle_\mathrm{X})^2}{2\sigma_\mathrm{X}^2}\right)$$



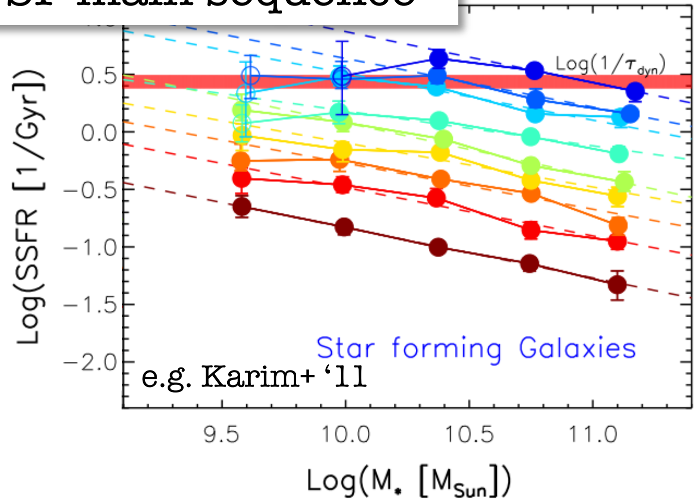
parameter	MS-population	SB-population
re-normalized parametrisation [a]		
A/A_{MS}	1	$0.031^{+0.006}_{-0.004}$
$\log(\langle\mathrm{sSFR}\rangle/\langle\mathrm{sSFR}\rangle_{\mathrm{MS}})$	0	$0.59^{+0.06}_{-0.13}$
σ [dex]	0.188 ± 0.003	$0.243^{+0.078}_{-0.047}$

Outline

- Introduction: 'normal' star-forming galaxies & starbursts
- Results:
    1. A simple framework (2-SFM) for predicting IR galaxy properties
        I. Starburst/main-sequence contribution to IR LFs & the SFRD at $z < 2$
        II. IR source counts
    2. Molecular gas reservoirs in main-sequence & starburst galaxies
        I. Redshift evolution of molecular gas mass & CO luminosity functions
        II. The CO-to-H_2 conversion factor at low & high redshift
        III. The cosmic cold gas history
- Summary

The '2-SFM' framework – basic ingredients

SF main sequence



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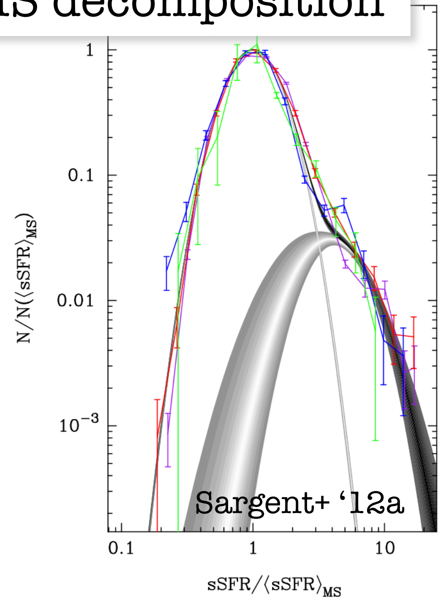
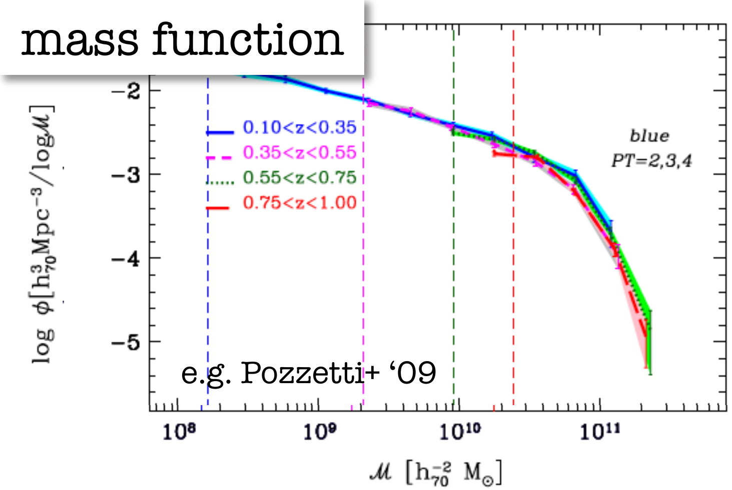
SB+MS decomposition



⊗

mass function



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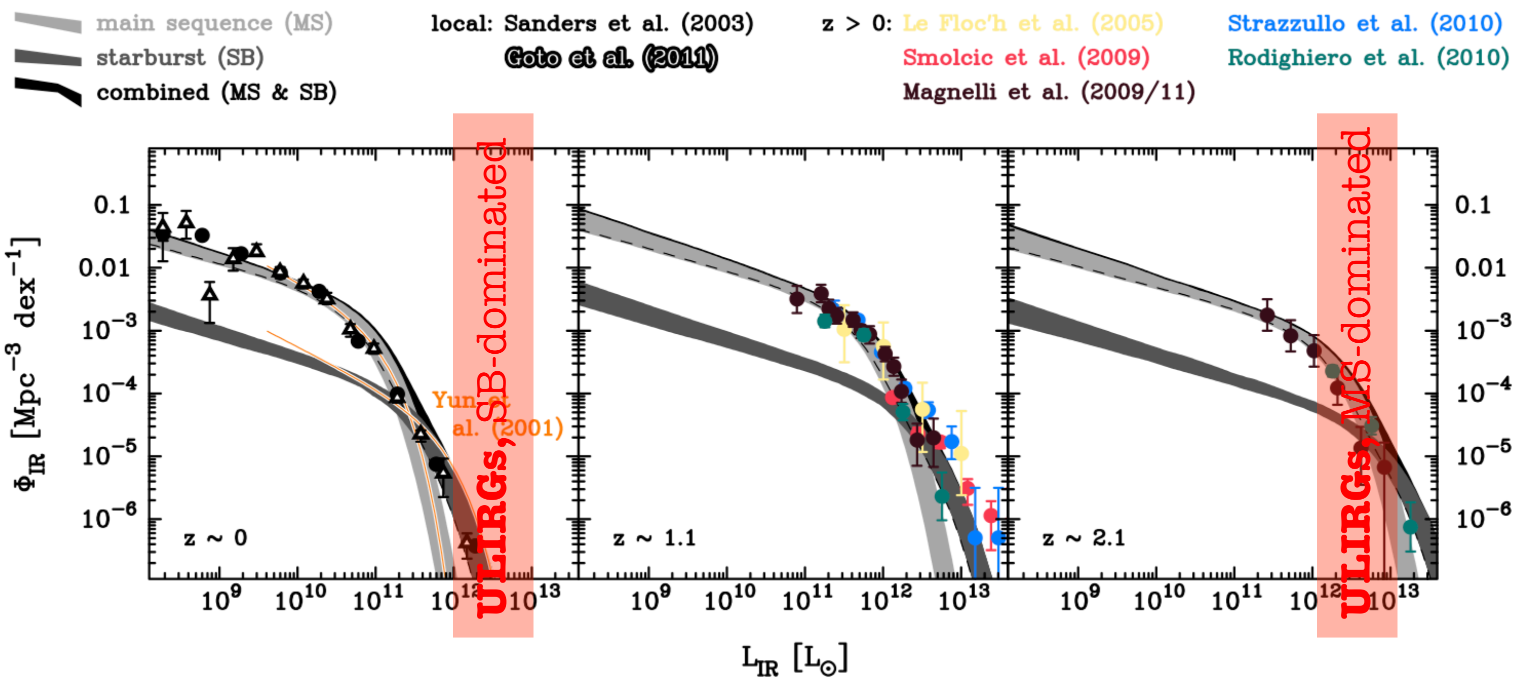
…

IR luminosity function: prediction vs. observations



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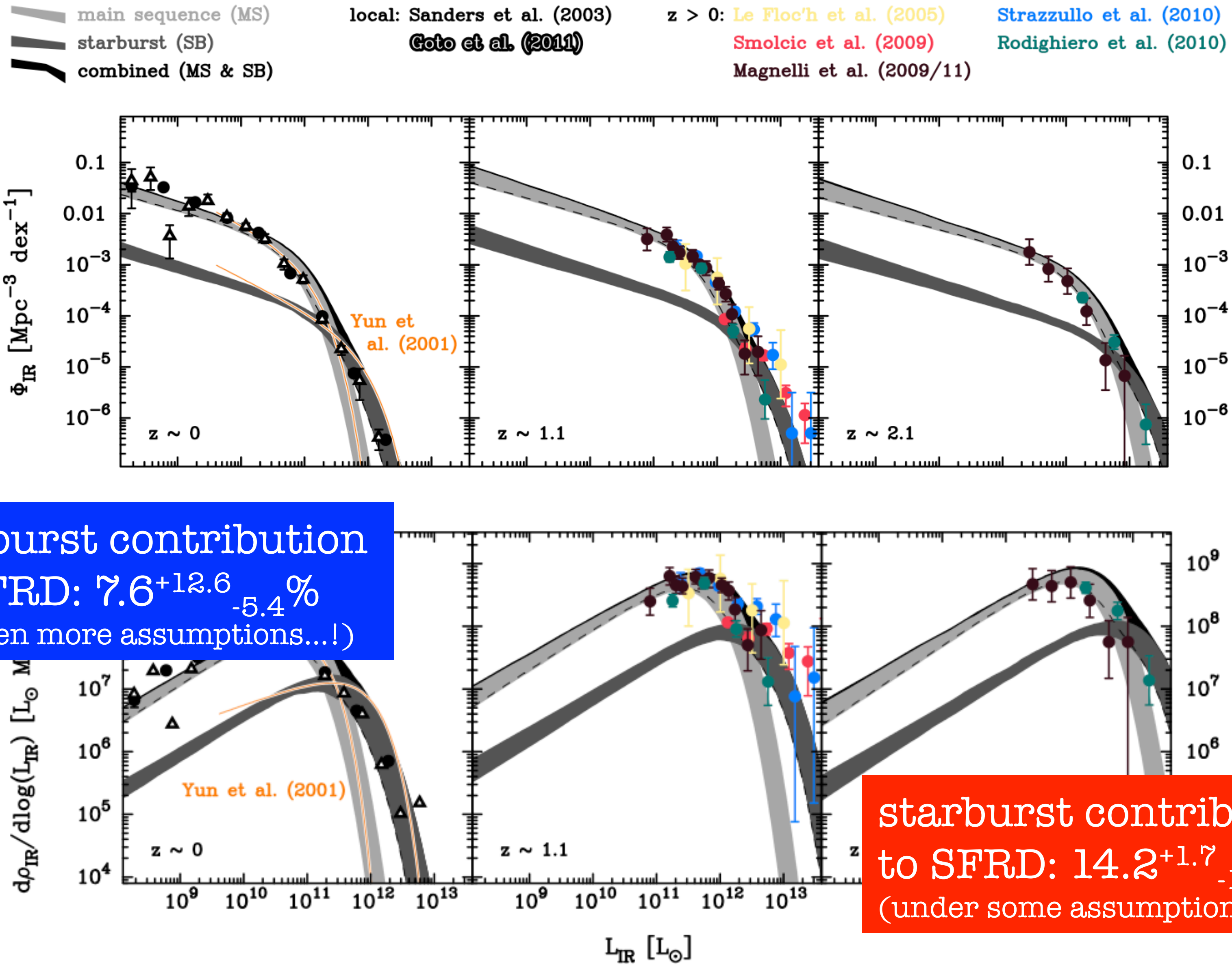


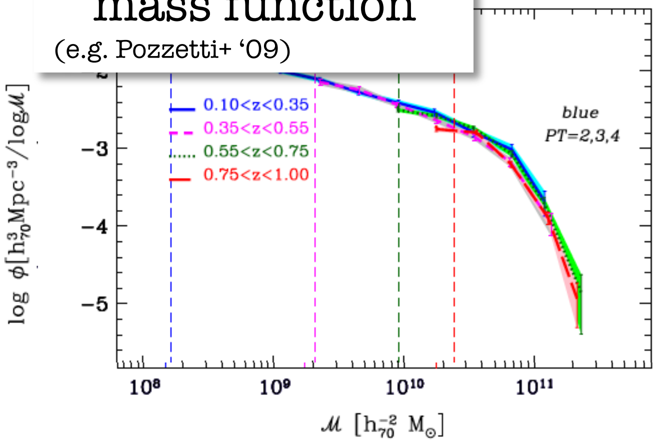
starburst contribution to SFRD: $7.6^{+12.6}_{-5.4}$%
(w/ even more assumptions...!)

starburst contribution to SFRD: $14.2^{+1.7}_{-1.3}$%
(under some assumptions...!)

The '2-SFM' framework – application I

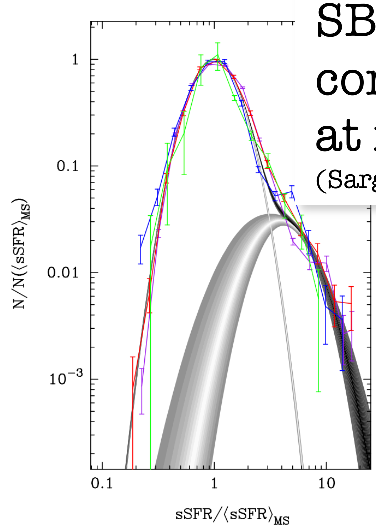
1)

mass function
(e.g. Pozzetti+ '09)



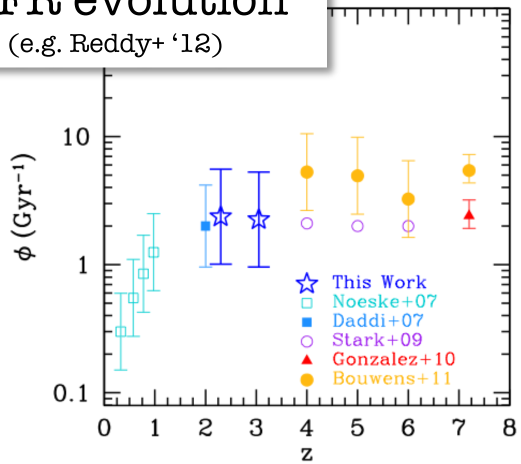
2)

SB+MS de-composition at fixed $M_\star$
(Sargent+ '12)



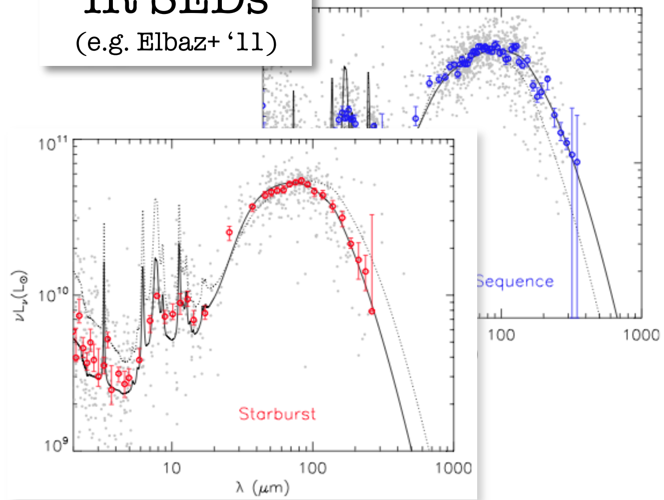
3)

sSFR evolution
(e.g. Reddy+ '12)



4)

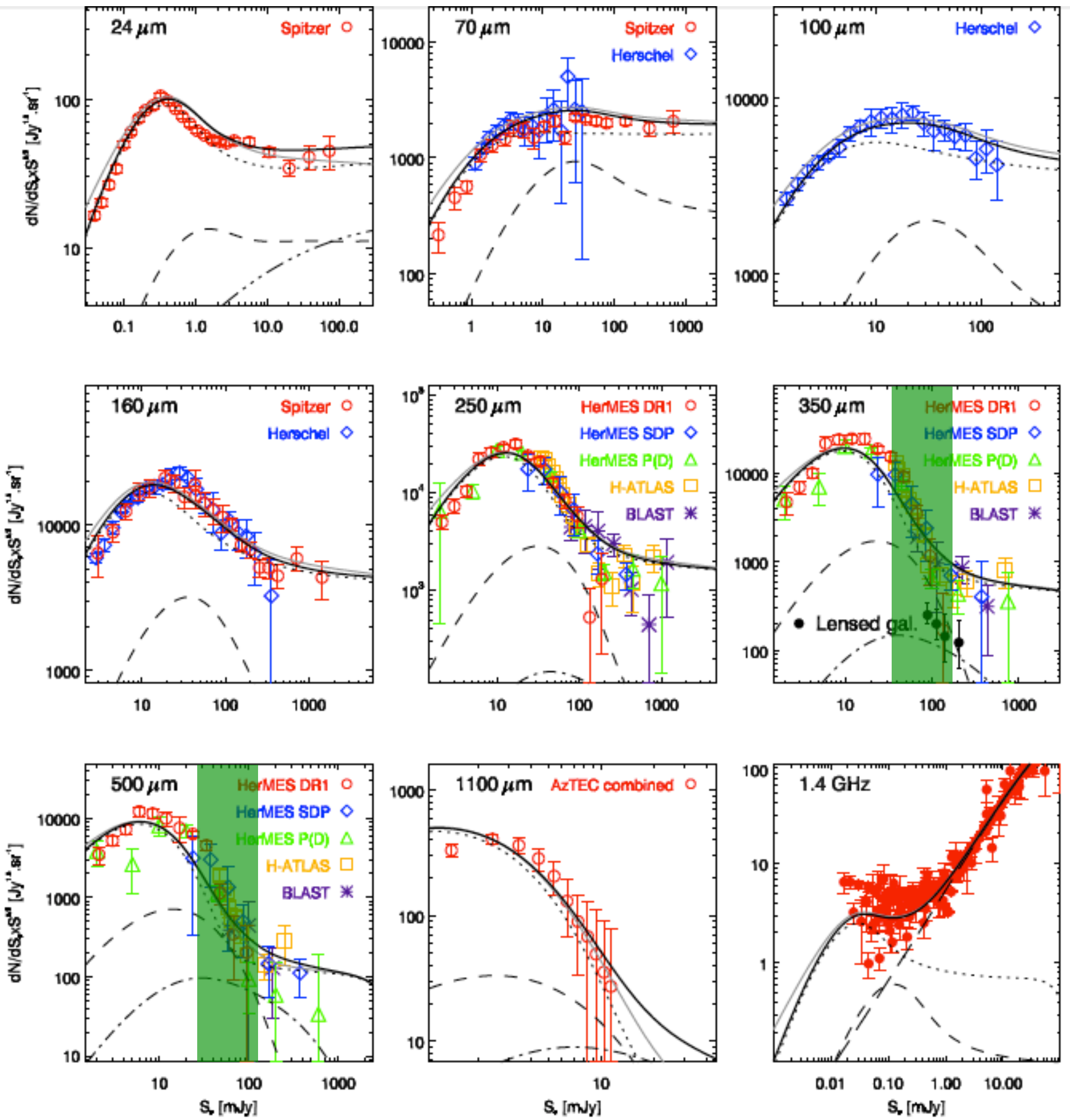
IR SEDs
(e.g. Elbaz+ '11)



24 µm to 1.4 GHz source counts

Simple recipe:
1. take evolution of IR LF
2. assign characteristic SED-shape to normal & starbursting galaxies
(3. as a 'dusting', add model for AGN emission)

IR (& radio) source counts, split into MS & SB contribution...



Summary thus far (further reading in Sargent+ '12a; Béthermin+ , subm.):

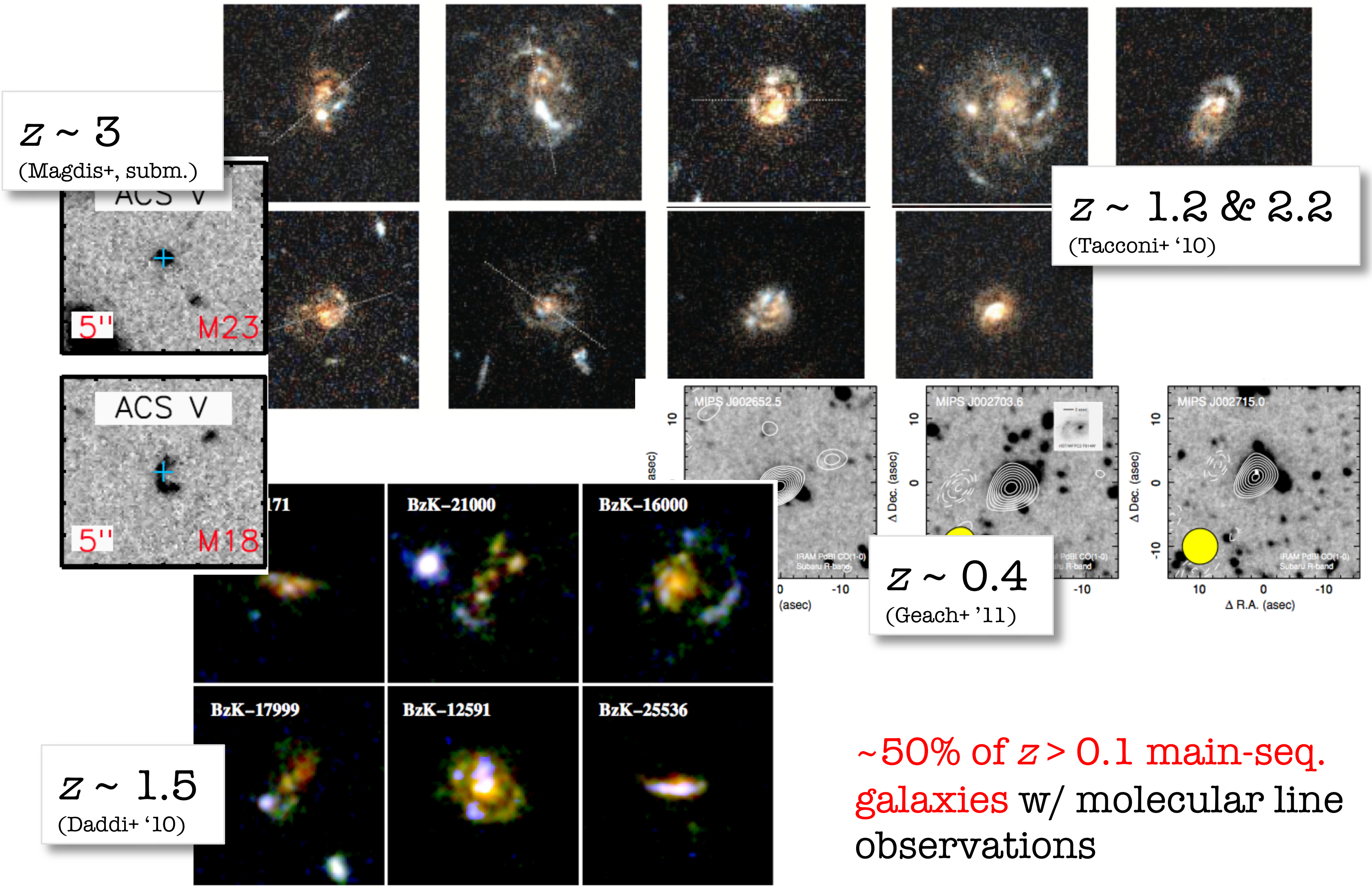
- Evolution of IR luminosity function, as well as IR source counts successfully predicted in the 2-SFM framework based on three basic observables (and without any tuning!):
    1. Evolution of *mass function*
    2. *Evolution of specific SFR* of main sequence galaxies
    3. *SB:MS-decomposition* of sSFR-distribution at fixed $M_\star$
    4. Choice of *characteristic SEDs* for SB & MS galaxies

- Weak evolution of the starburst contribution to the SFRD at z < 2 (despite steep decrease of merging rate at z < 2...; but see similar low-*z* estimates, e.g. Brinchmann+ 04, Kennicutt '05)

- ULIRGs at z = 0 & z >1 are an entirely different kind of source:
    1. z = 0: starburst galaxies with frequent evidence of interactions
    2. z > 1: typical, main sequence galaxies (disk-like)

- Useful, self-consistent framework for the *prediction* of cosmological observables, e.g. *molecular gas mass functions*.

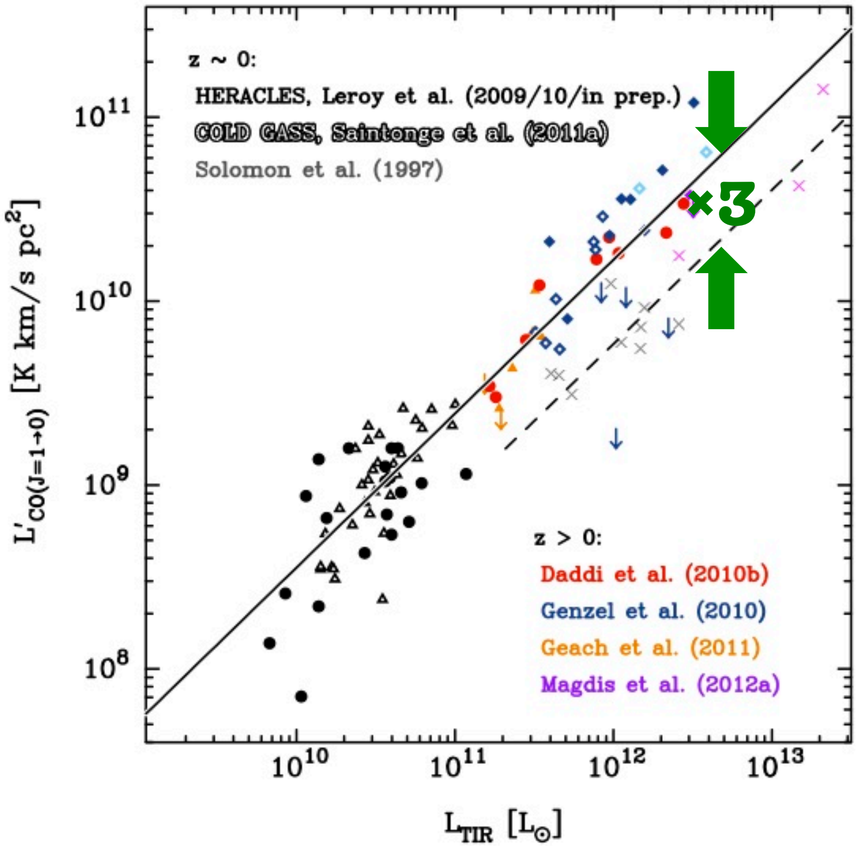
Intro (II) - ‘normal’ galaxies w/ gas measurements

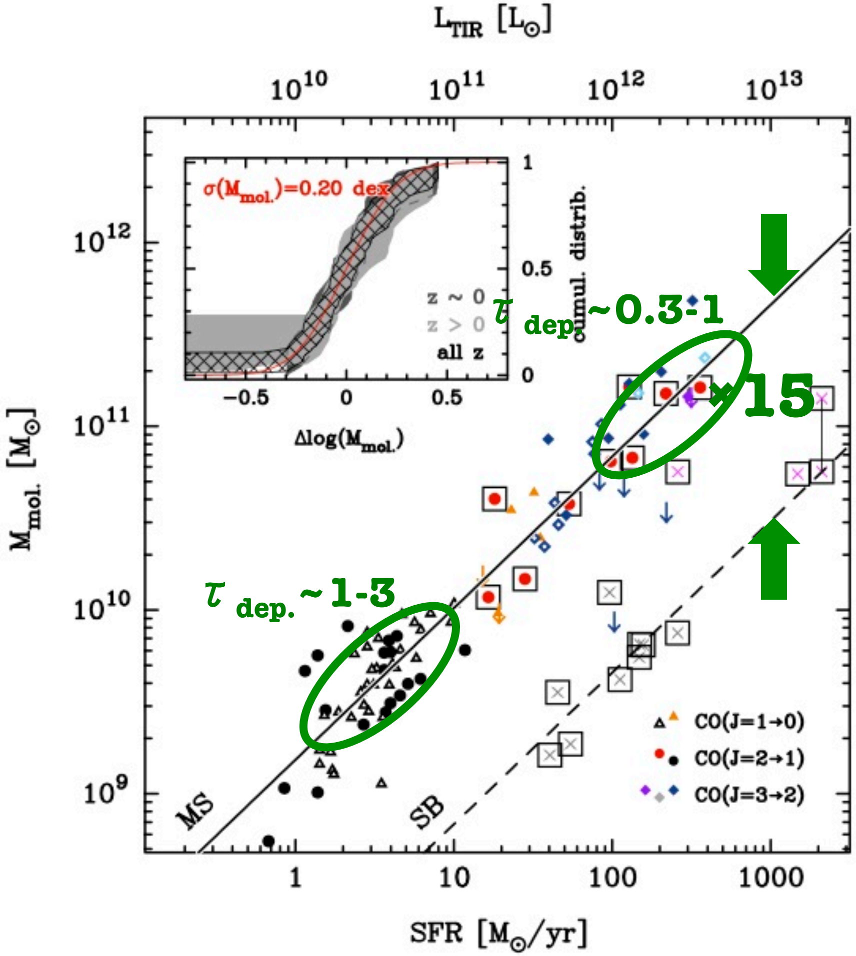


~50% of $z > 0.1$ main-seq. galaxies w/ molecular line observations

Basic correlations (observed & inferred)...

Apparently high homogeneity between low- and high-z main-sequence galaxies w/ $M_{\star}/M_{\odot} = 10^{10}$ (*low scatter of ~0.2 dex* in integrated K-S relation)





Sargent+ (in prep.)

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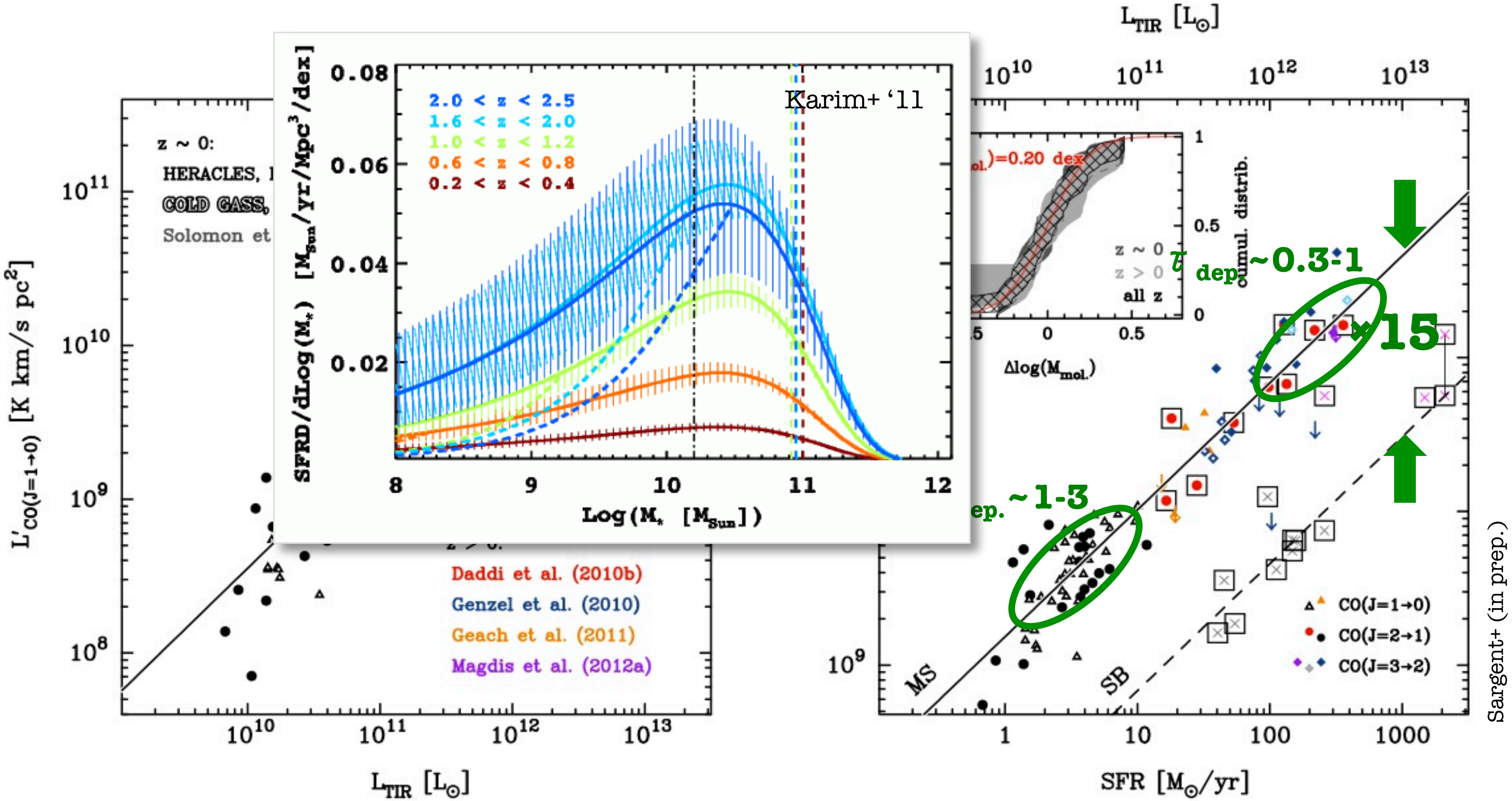
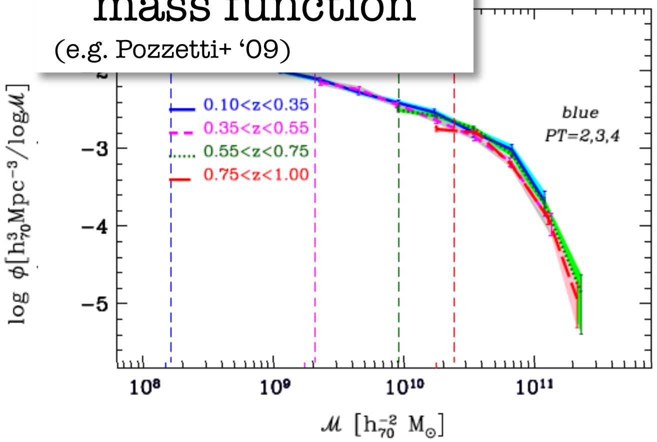


The '2-SFM' framework – application II

1) mass function
(e.g. Pozzetti+ '09)



2) SB+MS de-composition at fixed $M_\star$
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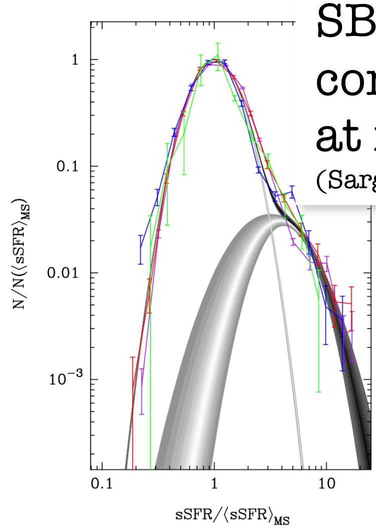
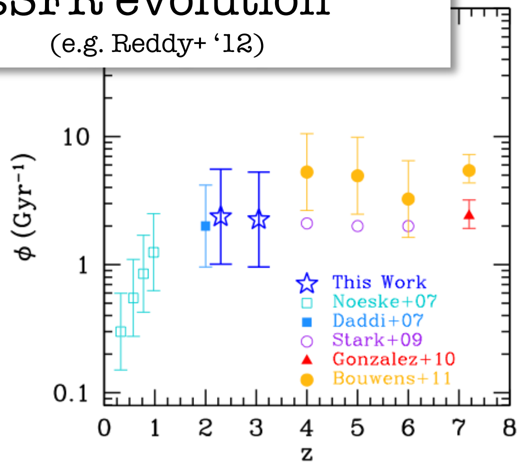
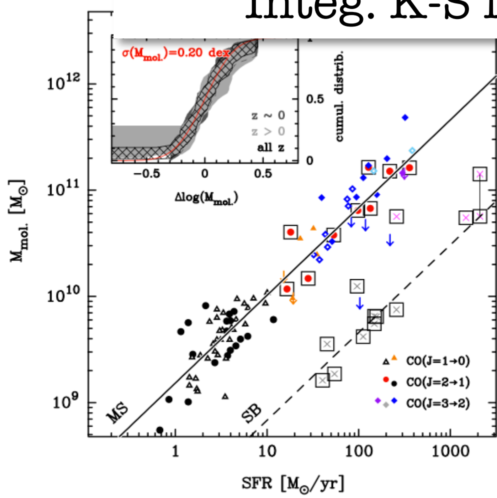


3) sSFR evolution
(e.g. Reddy+ '12)

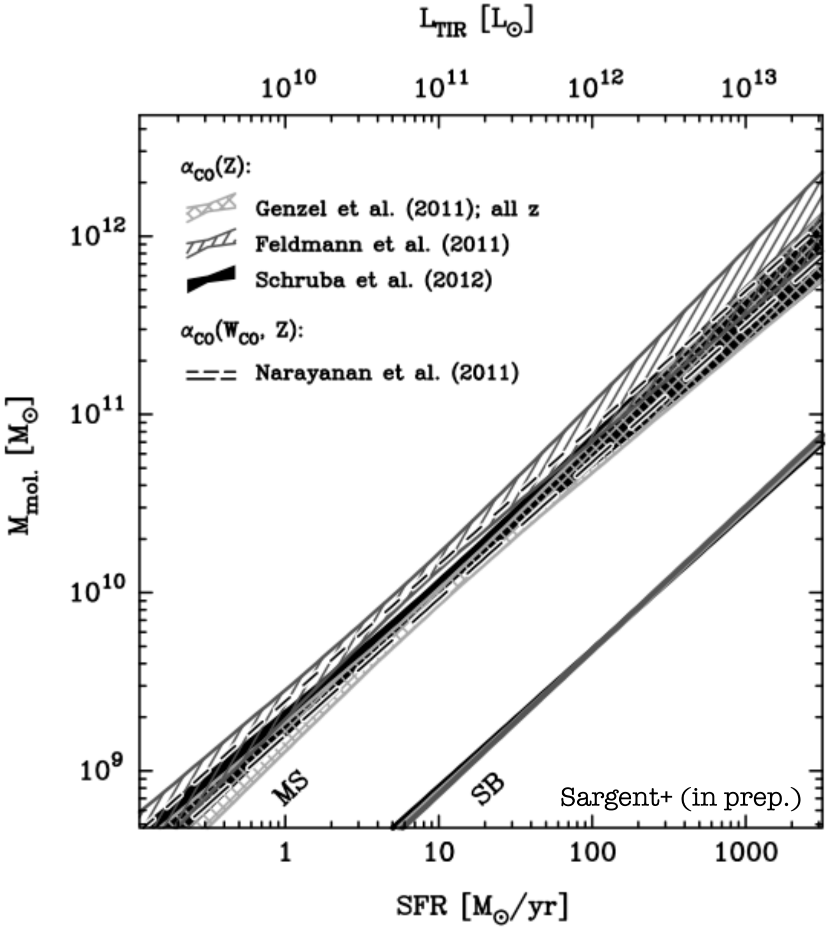


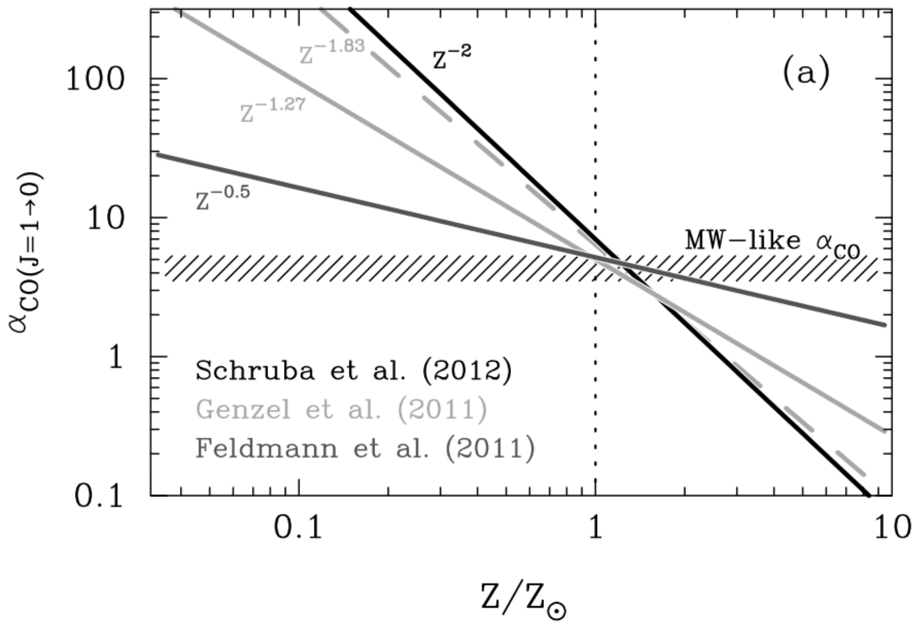
4) Integ. K-S law



Metallicity-dependent α_{CO}

Different prescriptions (from both simulations & observations) for the metallicity–dependence of α_{CO}...





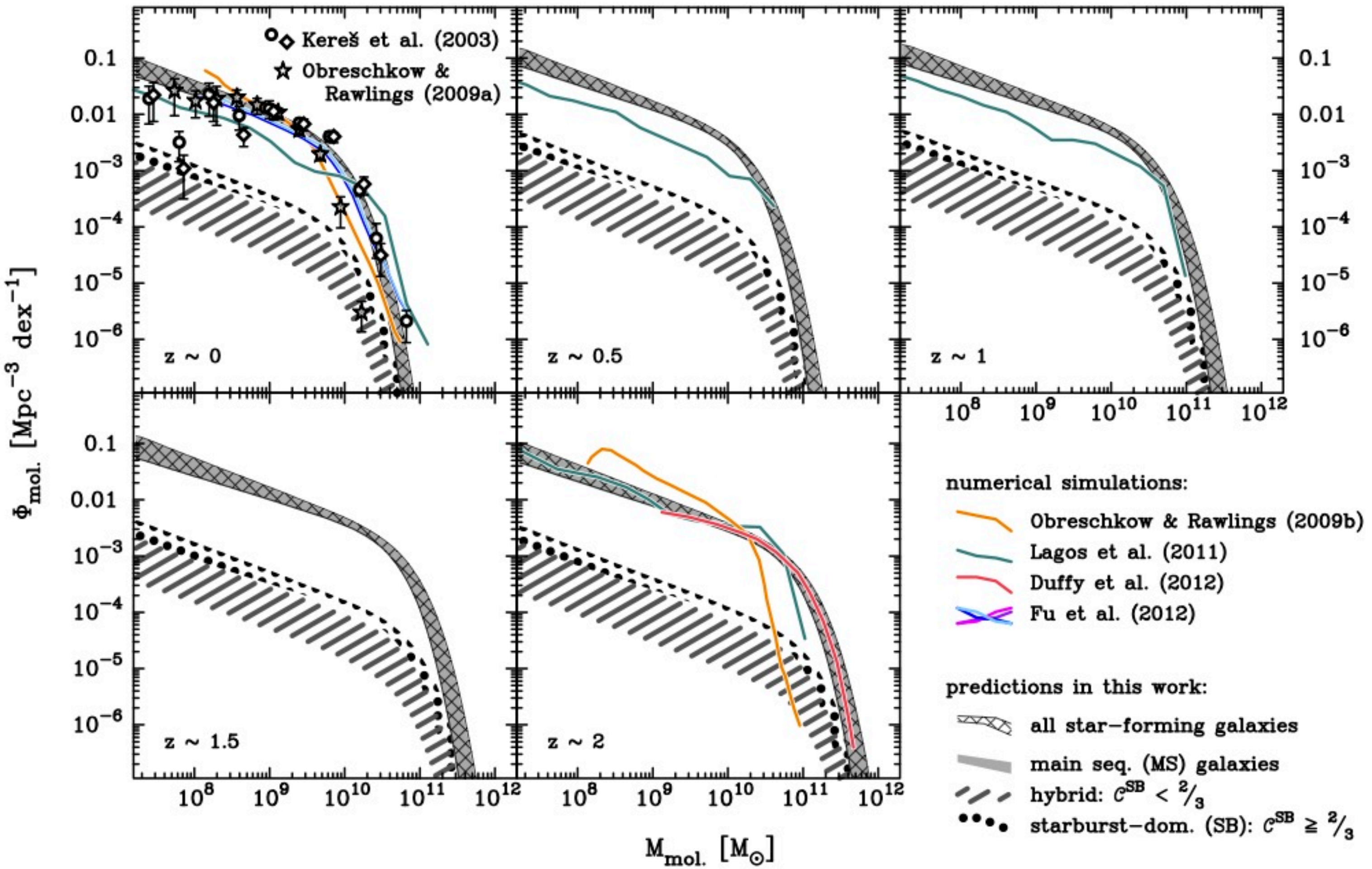
... turn out not to have a strong impact on the integrated K-S law inferred for the massive galaxies ($M_\star/M_{sun}$ ~ $10^{10\text{-}11}$) that *contribute most to the cosmic SFRD*.

➠ Estimate of the bulk of the cosmic H_2-reservoir w/in reach based on *current, pre-ALMA understanding*.

The molecular gas mass function ($z < 2.5$)

Predictions! (Currently we only have ~40 high-z mol. gas mass measurements in main-seq. galaxies)

Sargent+ (in prep.)



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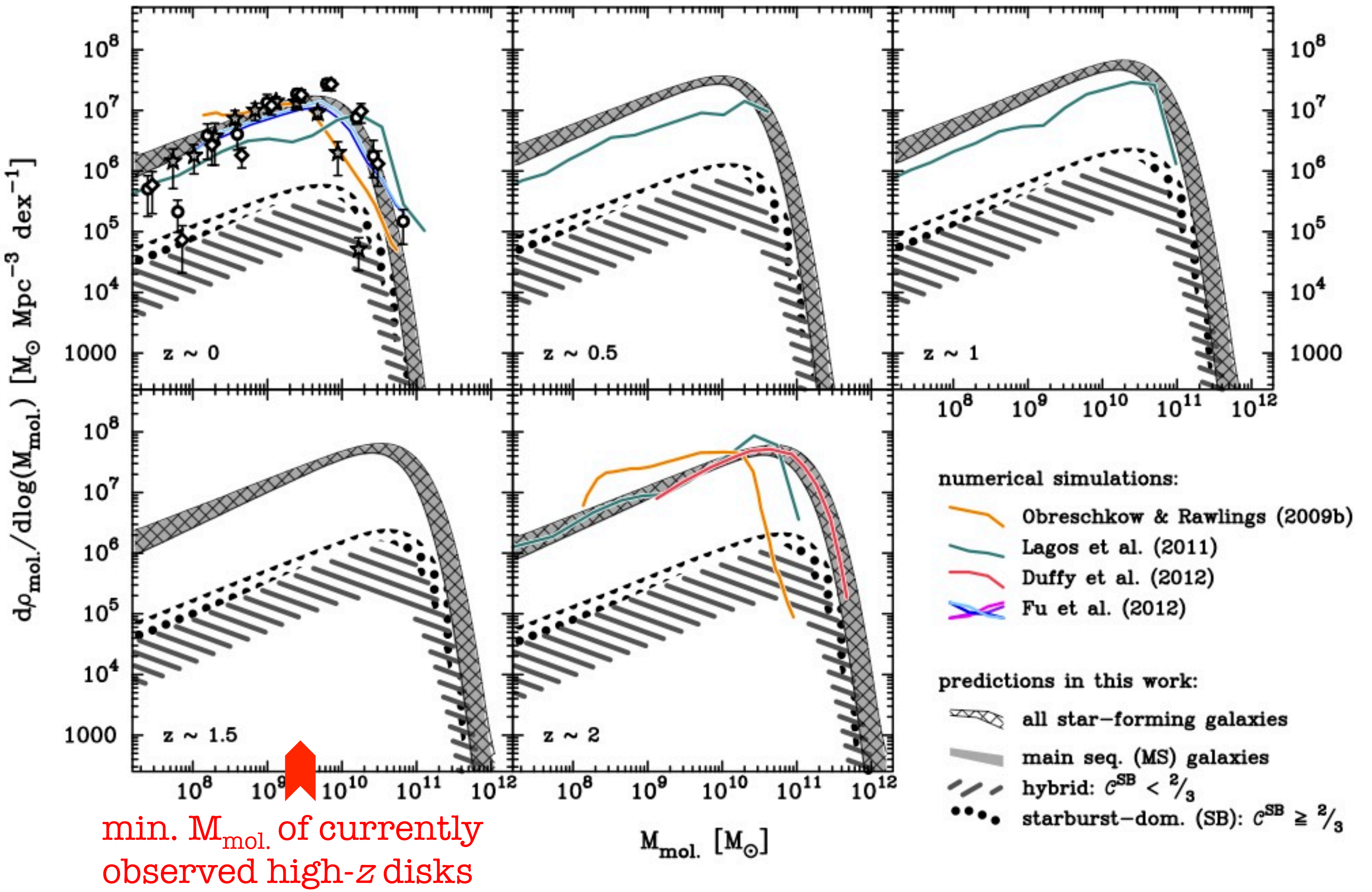
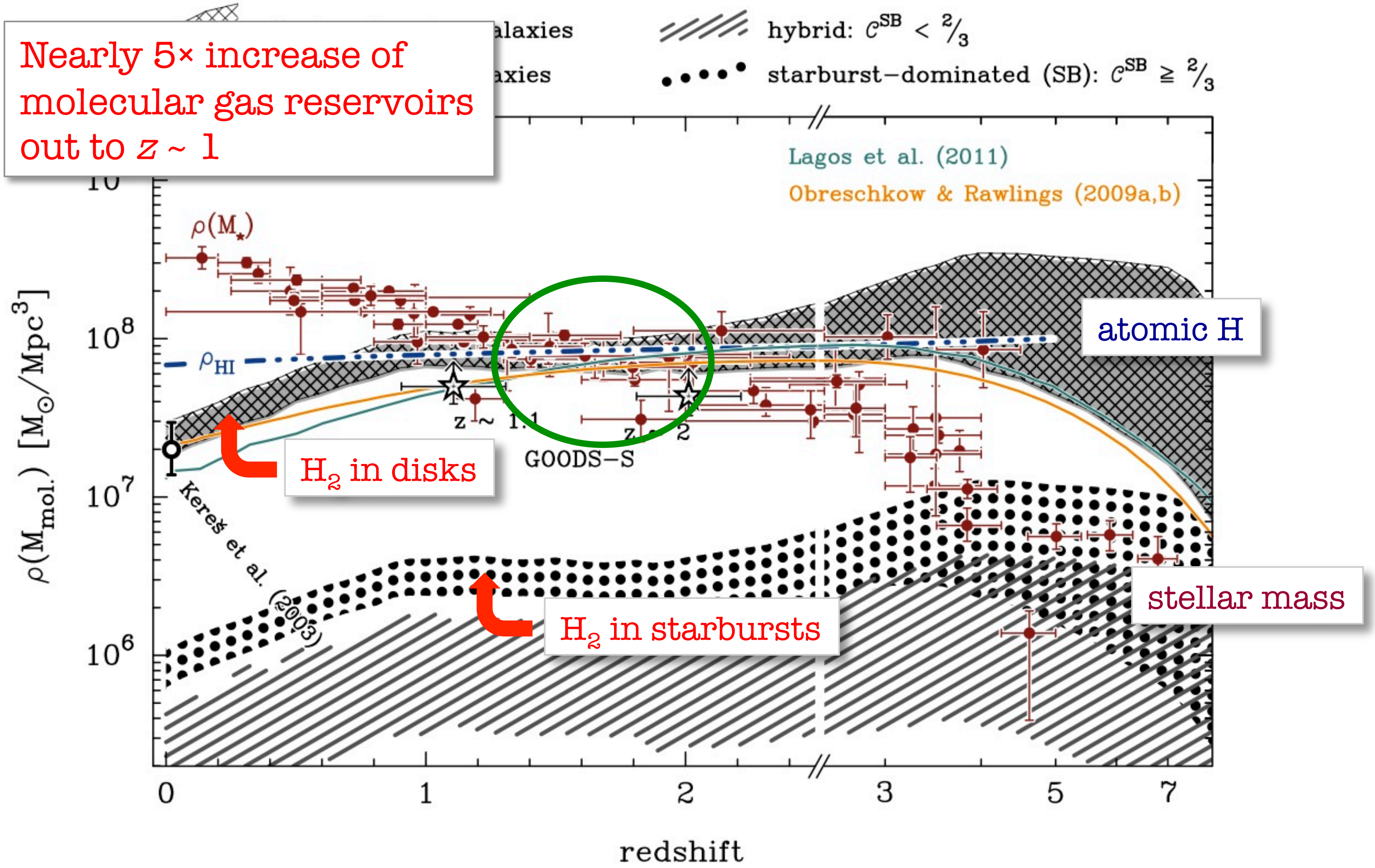
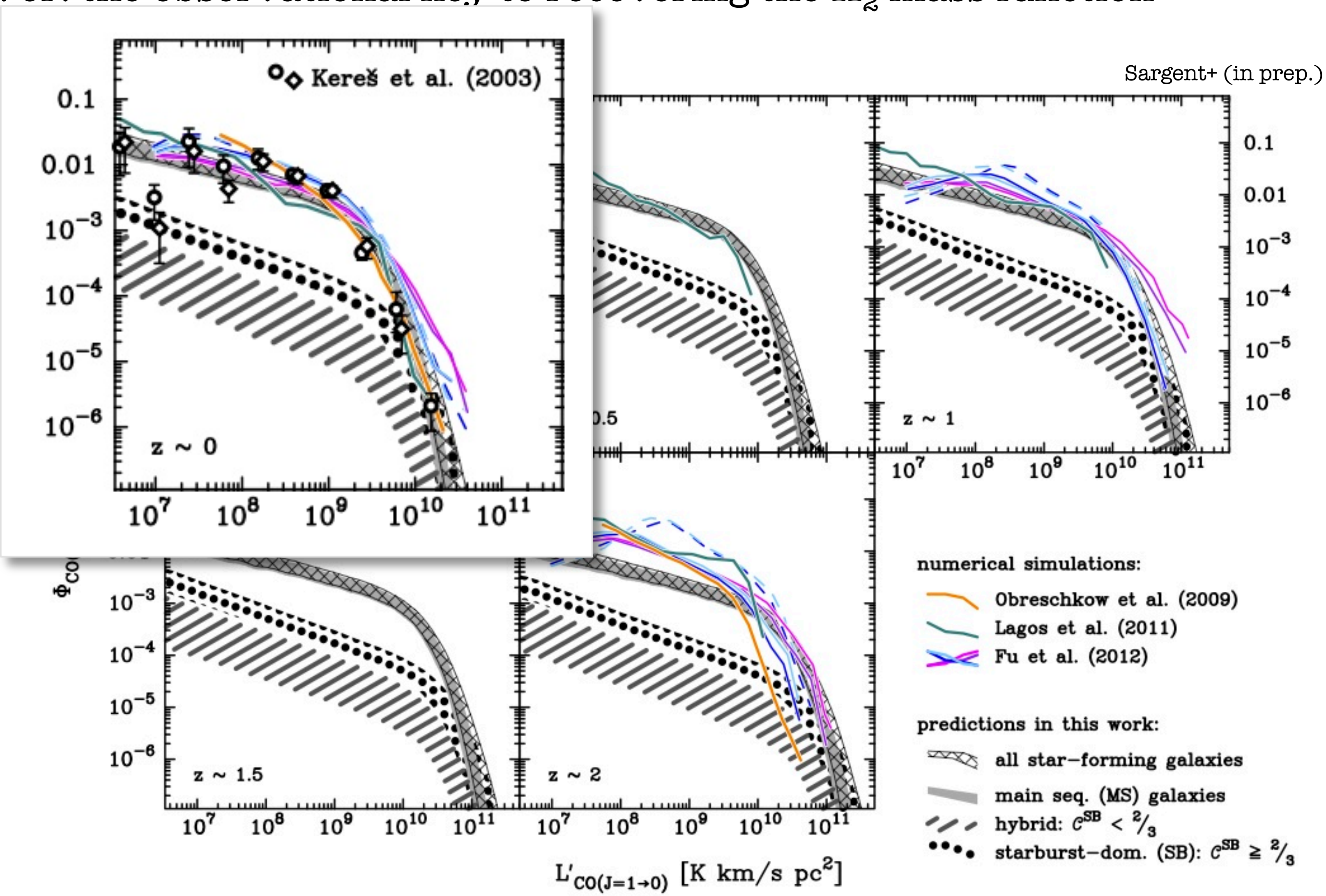


Cosmic evolution of H_2-reservoirs

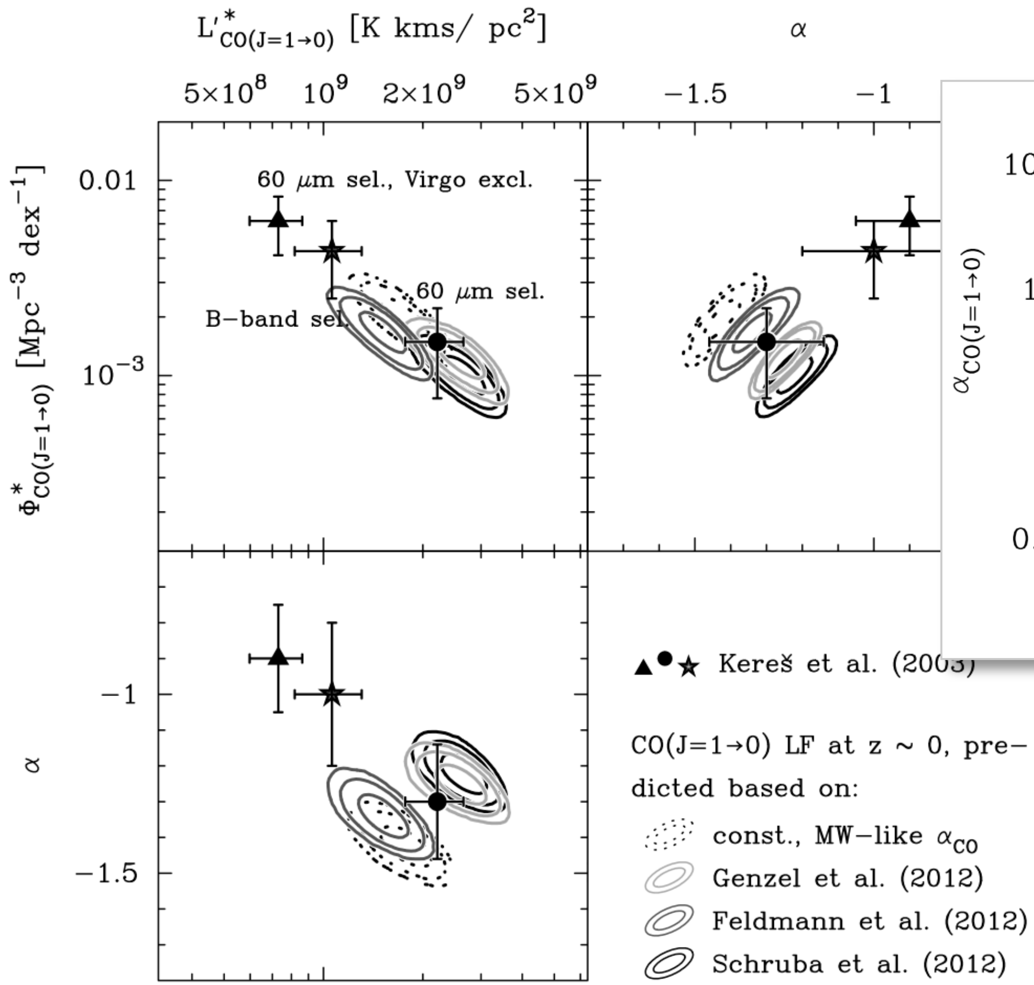


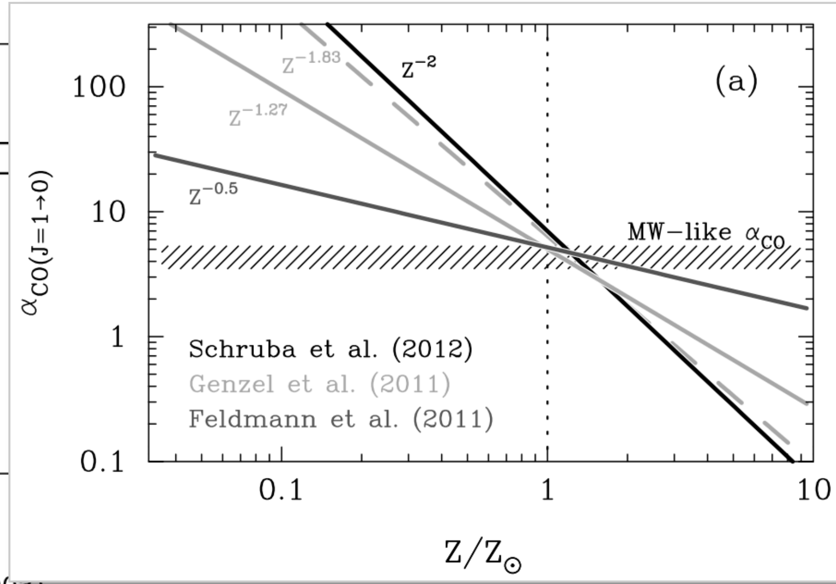
The CO[1-0] luminosity function (I)

… or: the observational key to recovering the H_2 mass function



Constraints on α_{CO} vs. metallicity





Under the current assumptions, none of the metallicity trends proposed based on observations or simulations matches the z = 0 data exactly…

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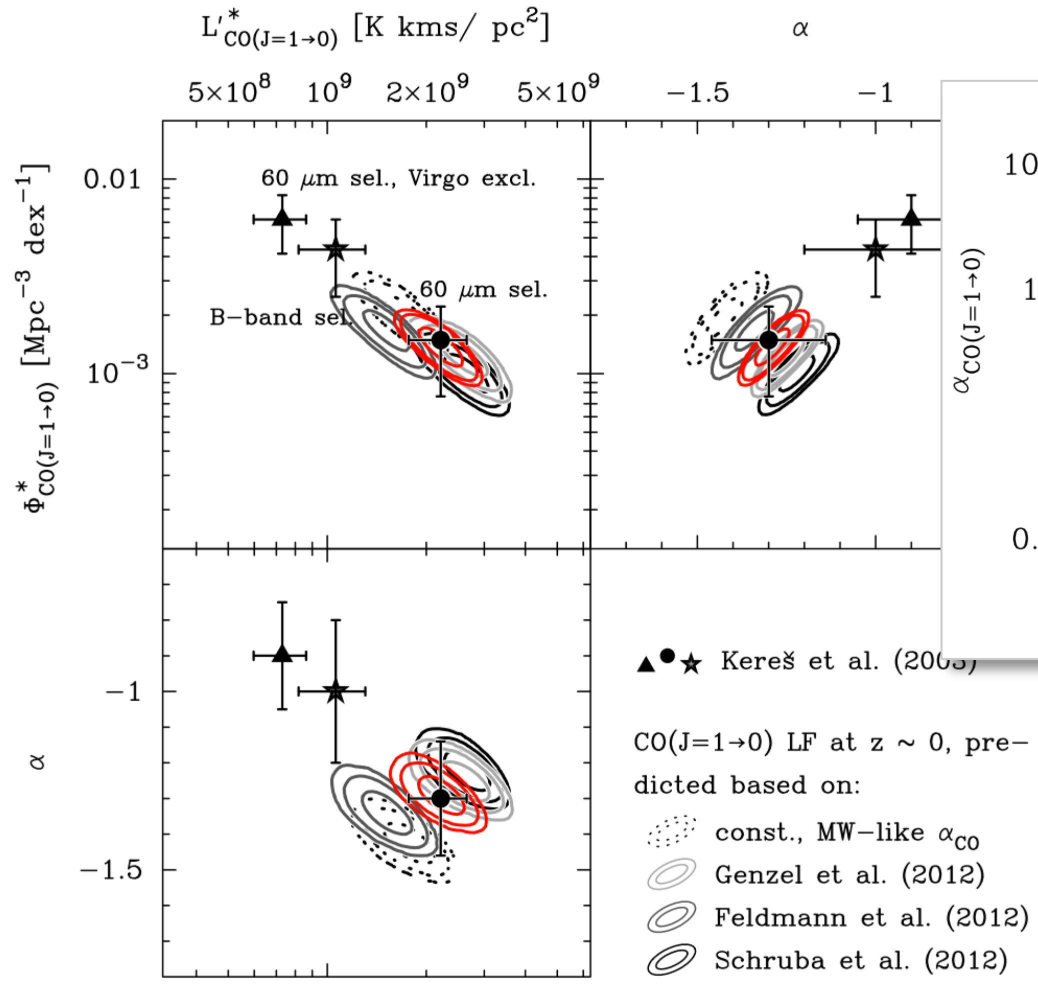

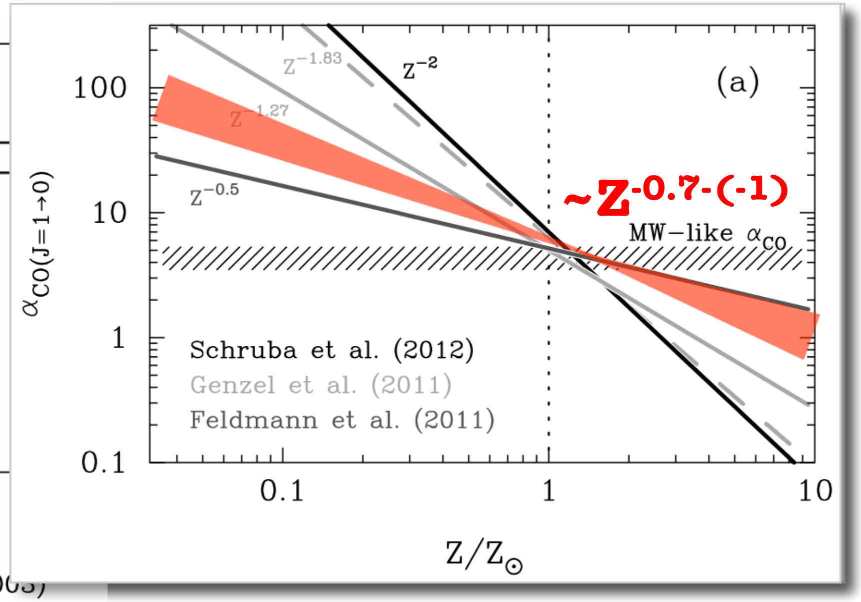

Under the current assumptions, none of the metallicity trends proposed based on observations or simulations matches the z = 0 data exactly...

...best fit obtained for $\alpha_{CO} \sim Z^{-0.7-(-1)}$

Summary

- Very tight (somewhat *sub-linear*) relation (~0.2 dex) between SFR and $M_{mol.}$ for 'normal', *massive* star-forming galaxies:

  -> measuring SFR is equivalent to determining cold gas mass

- Our *current understanding of molecular gas properties* in local & distant star-forming galaxies make it possible to infer $z \leq 2.5$ H_2-mass functions & CO-luminosity functions (+ gas fractions)

- The most important contributors to the SFRD ($M_\star \sim 5\times10^{10}$) likely have approx. Milky Way-like α_{CO}

- cosmic molecular fuel supply was approx. 5× larger than nowadays at $1 < z < 2.5$ (mirrored in *accordingly higher gas fractions*), and completely dominated by molecular gas *in main-seq. galaxies*

- Can predict much more (out to z=8 if reckless...):
  - high-J CO luminosity functions
  - source counts (ALMA!)