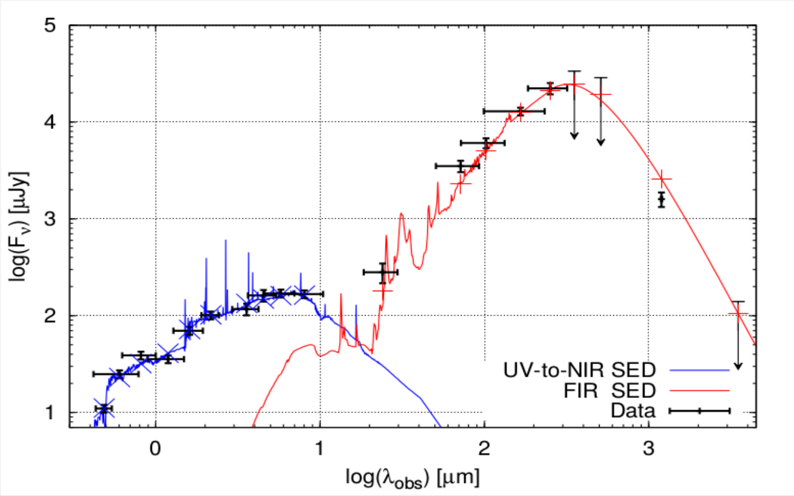
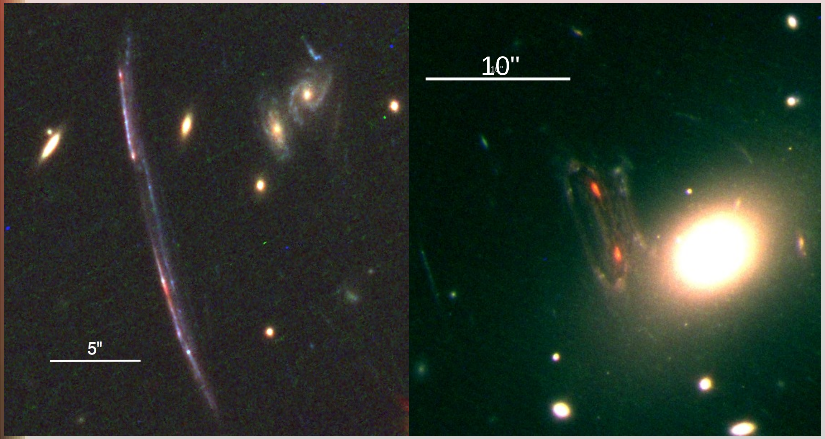
Constraining Star Formation Histories of IR-bright high-z Galaxies with Herschel





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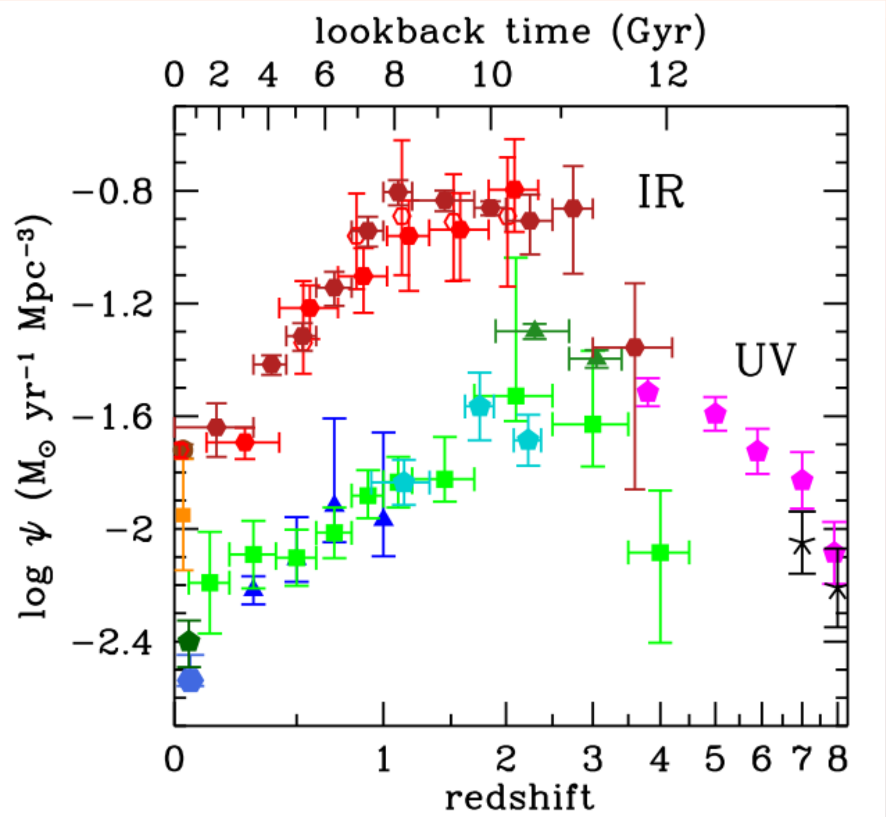
Outline

- Context - questions
- Aims
- Method
- Sample selection
- Results
- Conclusion - future work

Cosmological context



(Madau 2014)

- The cosmic star formation history
- Star formation density (ψ) increased in the early Universe, reached a peak around z ~ 1.5-2, and is declining since.
- *Could the global trend have an effect on individual galaxies depending on the epochs ?*

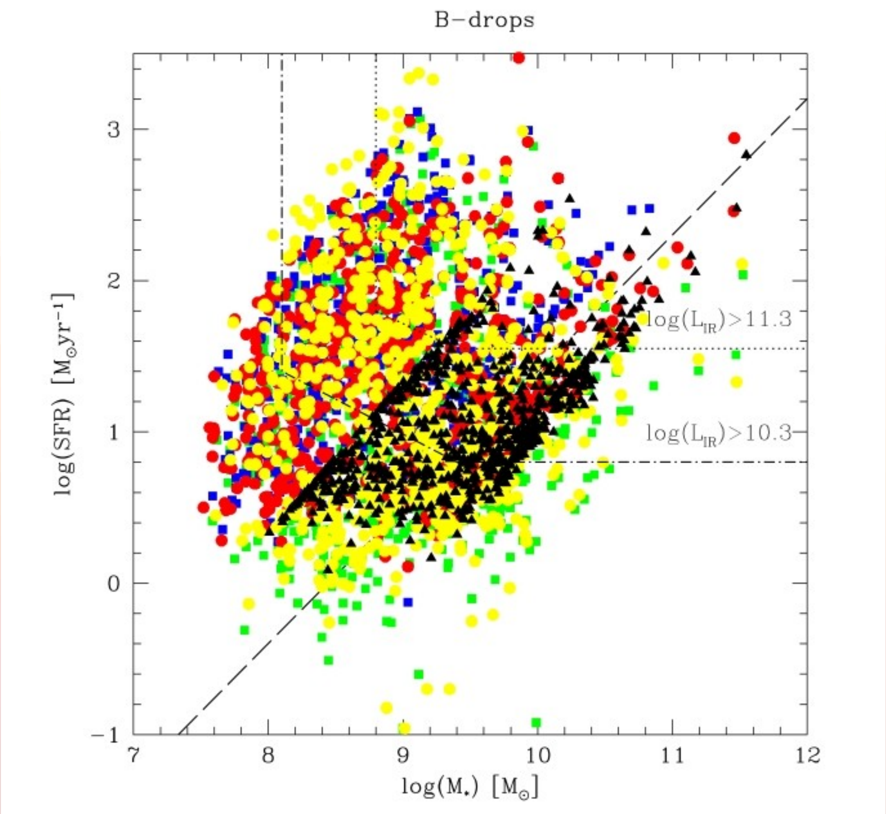
What star formation histories (SFHs) are best suited ?

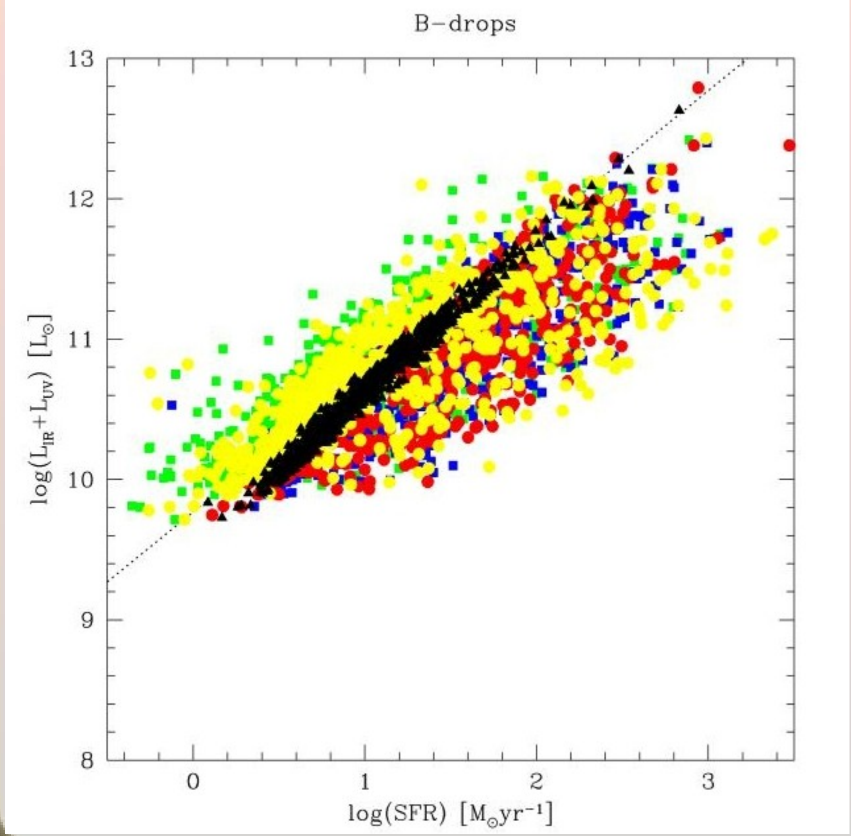
SFR(t) α $e^{-t/\tau}$	SFR(t) α $e^{t/\tau}$	SFR(t) α t $e^{-t/\tau}$	SFR(t) α cst.
declining	rising	delayed	constant

- It is argued that declining SFH models lead to irrealistically young ages (Maraston et al. 2010)
- Wuyts et al. 2011 show that although rapidly declining fit best, the mass functions of SF galaxies cannot well be traced back in time, with important discrepancies due to the rapid evolution, argue instead for longer e-folding timescales and maximal ages
- Renzini 2009 argues that strongly rising SFRs can lead to extreme overgrowth of galaxies that is not supported by observations, but instead should quench rapidly. Moderate rising SFRs can sustain SF longer
- More specifically in red/dusty galaxies, a strong age-extinction degeneracy can occur when the SFR is allowed to decline (Reddy et al. 2010; Sklias et al. 2014)

- The so-called Main Sequence (MS) of star-forming galaxies can be more or less scattered depending on the SFH used

Green : declining
Red, blue : rising
Black : constant, age prior
Yellow : delayed





→In Schaerer et al. 2013 it has been proposed that the knowlegde of the **IR luminosity (L_{IR})** and nebular line emission can effectively distinguish between SFHs

Aims of present work

- Main aspect :

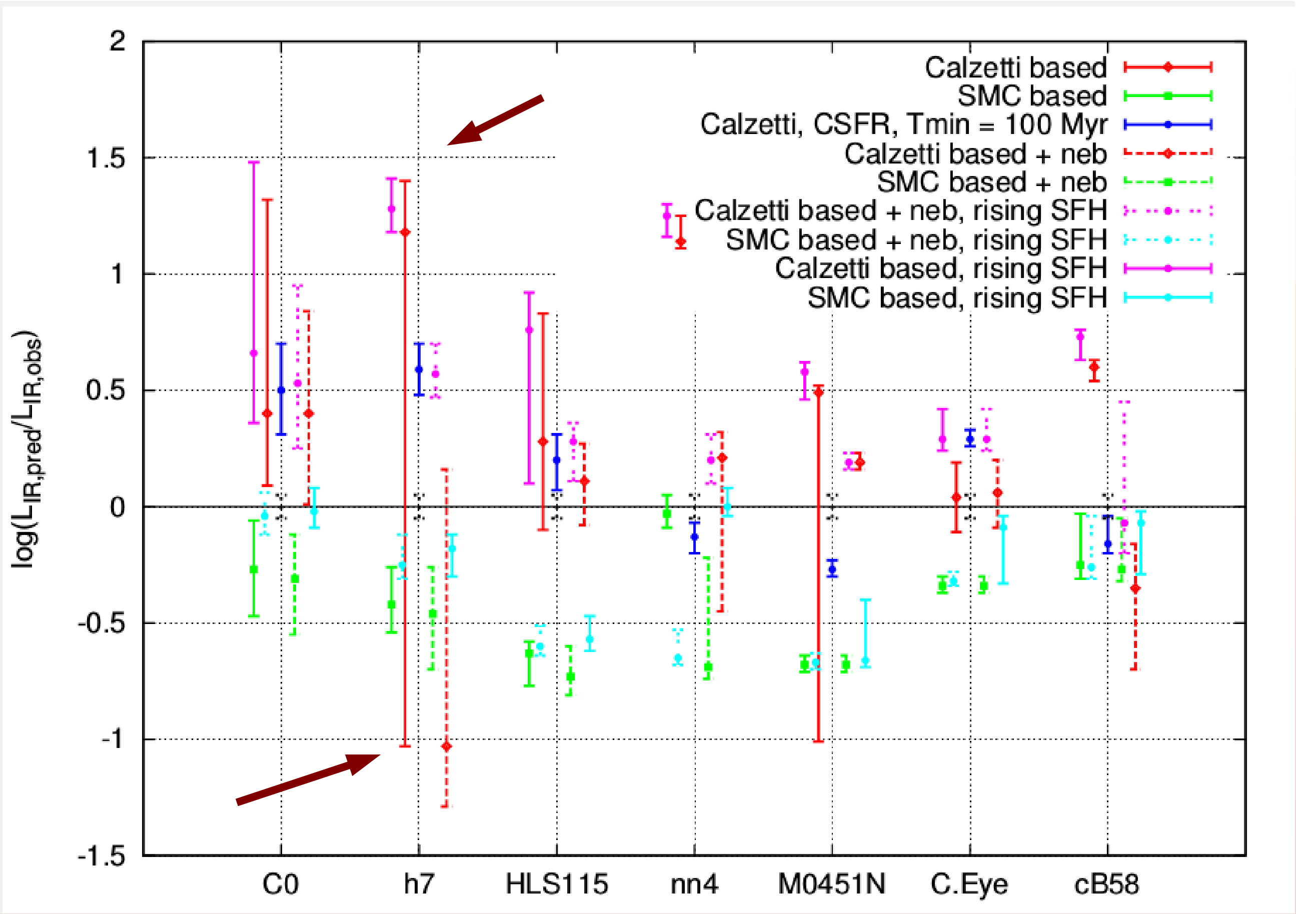
☞ use Herschel's IR observations to help constrain and/or discriminate between SFHs, in a statistical approach, using a large sample.

  - How are the physical parameters affected
  - Are there limitations – caveats
  - Do MS galaxies show any particular preference in SFHs

Method

- SED fitting tool *HyperZ* (Bolzonnella et al. 2000)
  - Upgrated version that includes nebular emission (Schaerer & de Barros 2009,2010)
  - Fit stellar and dust emission separately :
    - Use of Bruzual & Charlot 2003 library, variable SFRs, extinction as a free parameter → Derive ***stellar properties, predict IR luminosity***

      (use Calzetti law, t_{min}=50 Myr, solar Z)
    - IR fits to measure ***observed IR luminosity,*** using various sets of templates (Chary & Elbaz 2001, Vega et al. 2008, Rieke et al. 2009, Berta et al. 2013)
- The comparison of the predicted versus observed L_{IR}'s allows us to assess the plausibility of the performed stellar population fits



Sample :

five *Herschel Lensing Survey* (HLS) sources (PI : Egami et al. 2010) plus two other strongly lensed Herschel-bright z~3 galaxies.

(Sklias et al. 2014)

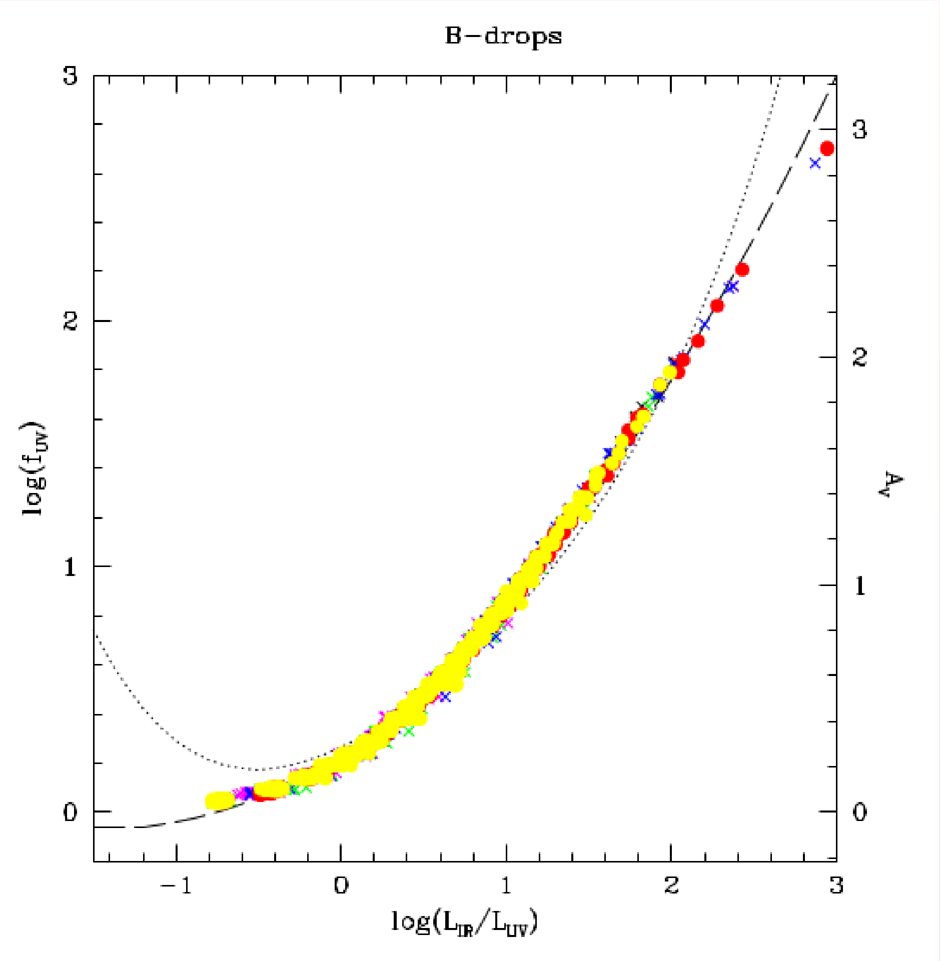
Illustration of the effects of the age-extinction degeneracy, depending on SFHs, extiction laws, and nebular emission treatment.

1σ confindence levels from fitting 1000 MC realizations of each source's photometry.

Method (II)

- Use of the ***observed IR/UV ratio to fix the extinction***, based on the law of ***energy conservation*** (star light absorbed by dust re-emitted in the IR).
  - The L_{IR}/L_{UV} ratio is an effective tracer of UV attenuation (Burgarella et al. 2005; Buat et al. 2010, Reddy et al. 2012)
  - We use the relation between L_{IR}/L_{UV} and A_V from Schaerer et al. 2013

Method (II)



Schaerer et al. 2013

Possible caveats :

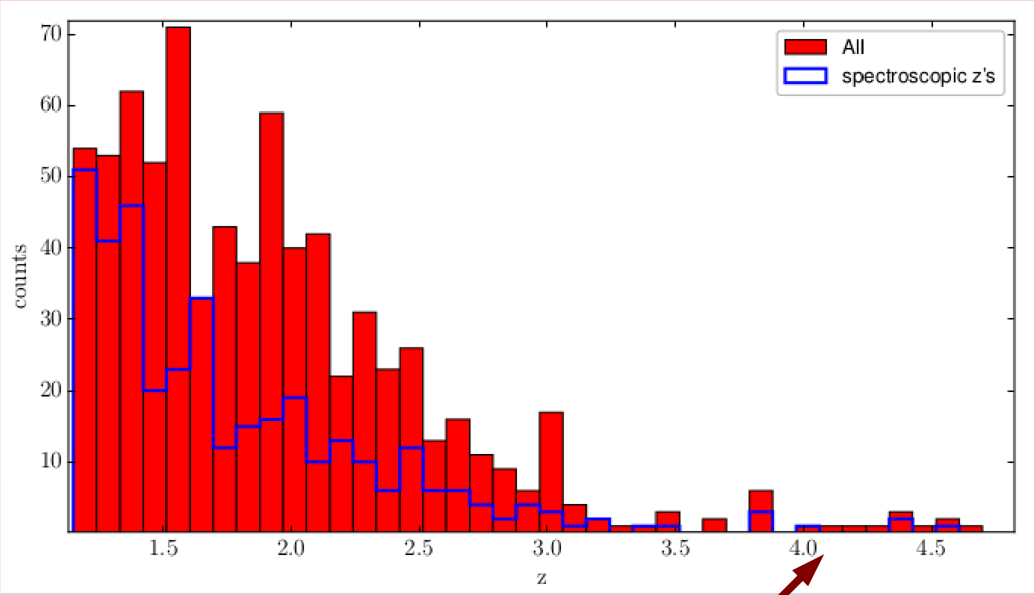
- In very dusty galaxies the UV light reaching us may come from their less obscured regions and may not be representative of the total extinction, thus making us underestimate the IR luminosity (Calzetti 2001)
- The observed IR luminosity may overestimate the SFR in cases like post-starbursts or recently quenched galaxies where many stars can still be enshrouded in dust, or if there is non-negligeable heating by older stars (Hayward et al. 2014)

Sample selection

- We select all Herschel-detected galaxies from GOODS-N and S (Elbaz et al. 2011, 24μm priors) starting from z~1.2 (spec and phot)
- Some were excluded on the basis of ill-constrained photo-z (9)
- Starting sample of 753 (365 spec-z)

- After the free A_V fits, we exclude also all sources with a reduced $\chi^2 > 10$, thus avoiding very bad photometries, and also most of the strongly AGN-contaminated ones up to z~3 (IRAC colors)

→ 704 sources

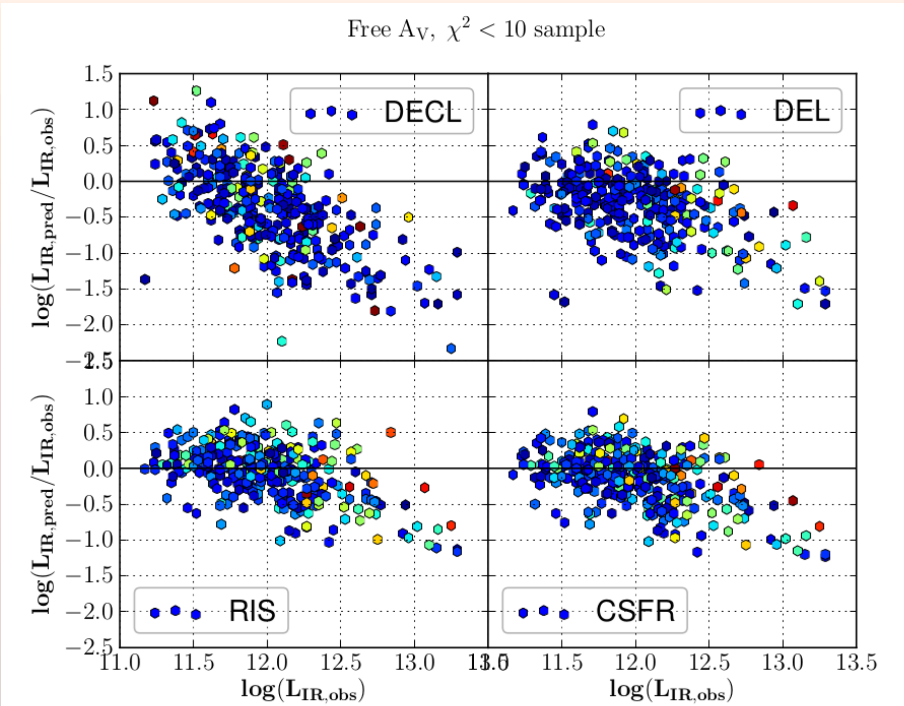


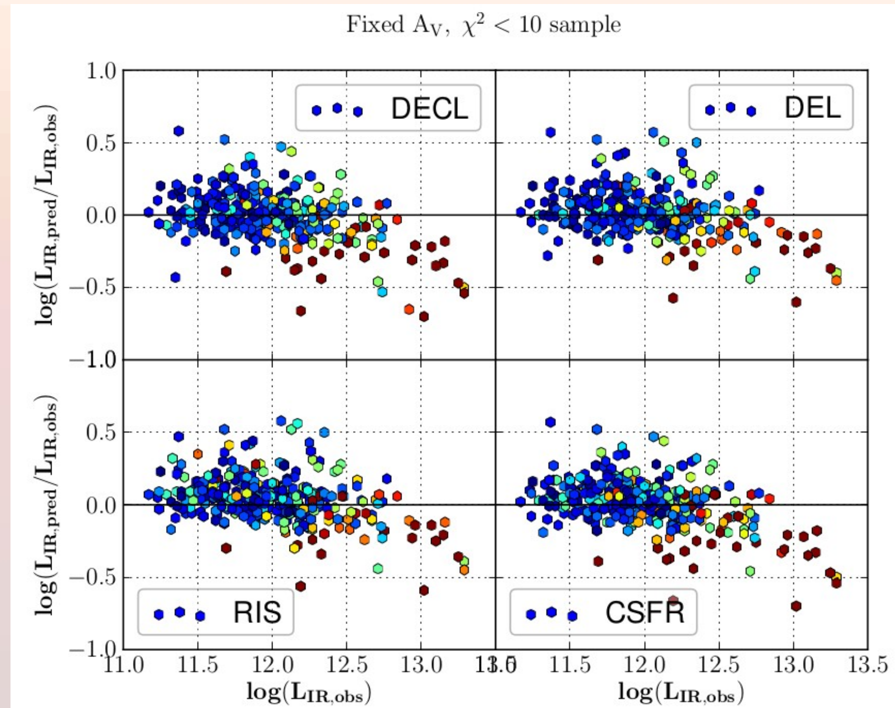
Limited by luminosity → small numbers

We thank D. Elbaz, C. Schreiber and M. Pannella for sharing data and advice.

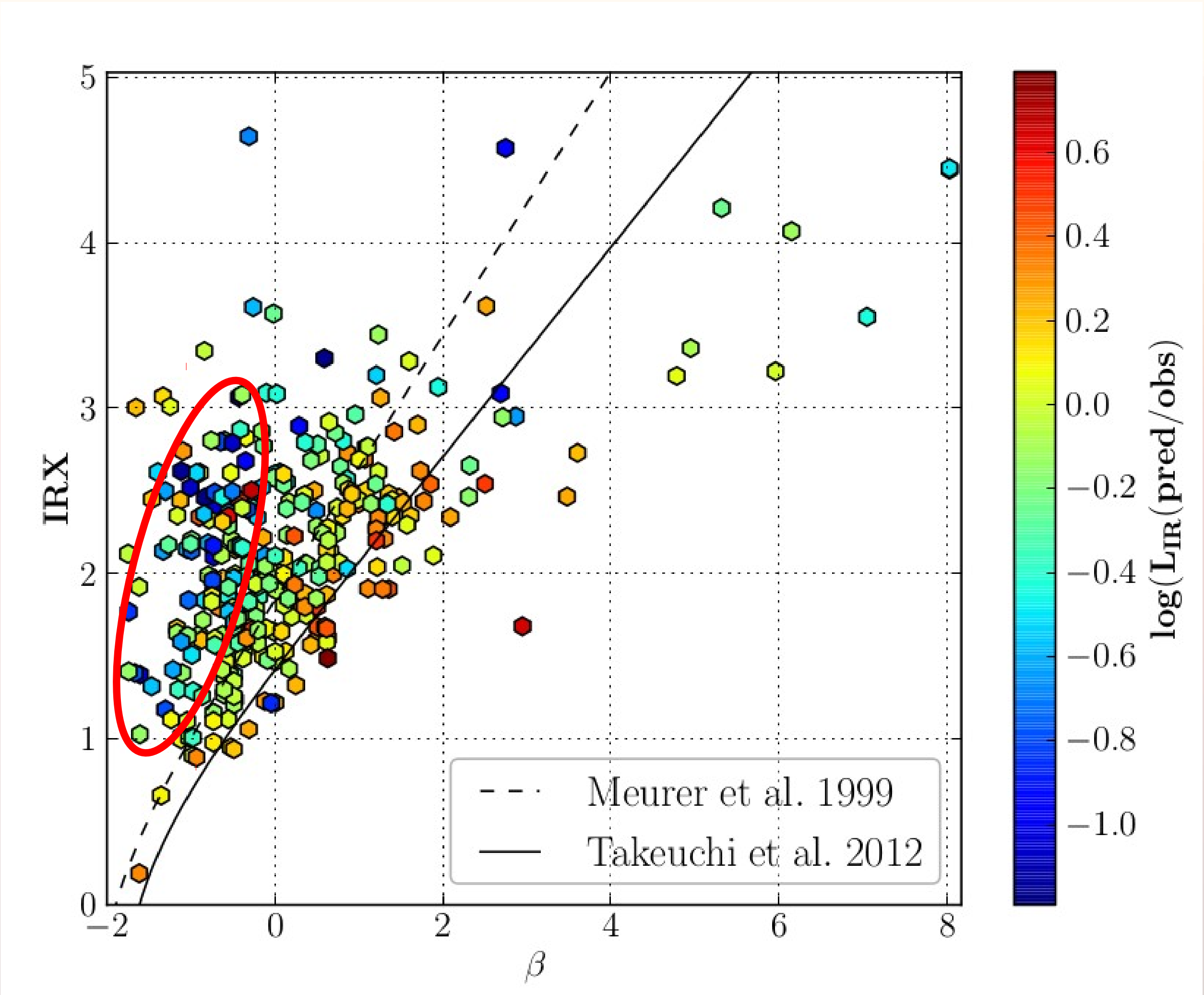
Results : before / after constraining A_V

- Reproducibility of the observed L_{IR}





- Unconstrained fits underpredict L_{IR}, the underestimation increases with L_{IR} (z ?)
- Constrained fits work well : 87 % of the sample reproduce L_{IR} within 0.2 dex
  - But, the high luminosity end still is underpredicted, and the χ^2 values are among the largest in the sample



… the reasons why are not well understood.

The most underpredicted sources are found on the blue end of the UV-slopes.

« too blue for their L_{IR}'s »

One plausible suggestion is that their UV emission is dominated by unobscured stars. (Calzetti 2001)
In such a case our energy conservation approach is not verified in effect, as different stars are responsible for the UV and for the IR.

→ "extra UV" → lower IRX
→ underpredicted L_{IR}

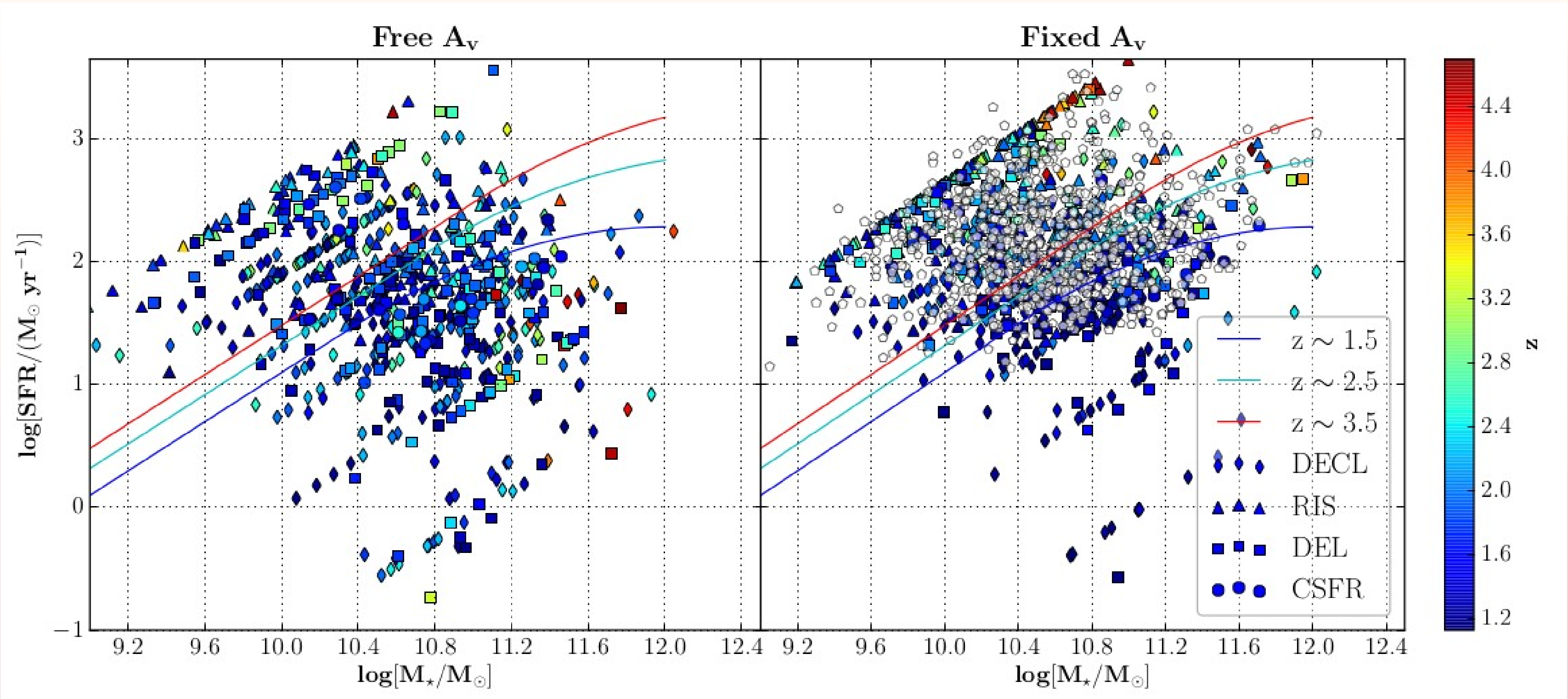
…to be continued

SFH Preferences

	CSFR(%)	DECL(%)	DEL(%)	RIS(%)
Free A_V	3.5	50.8	22.4	23.3
Fixed A_V	1.8	36.6	19.5	42.1
L_{IR} within 0.2 dex	1.8	41.0	20.1	37.1

- Before constraining A_V, the majority of the sample is best fit with declining SFHs
- Fixing A_V gives a relative majority to the rising SFHs
- Ultimately, many of the rising tend to overpredict the L_{IR}

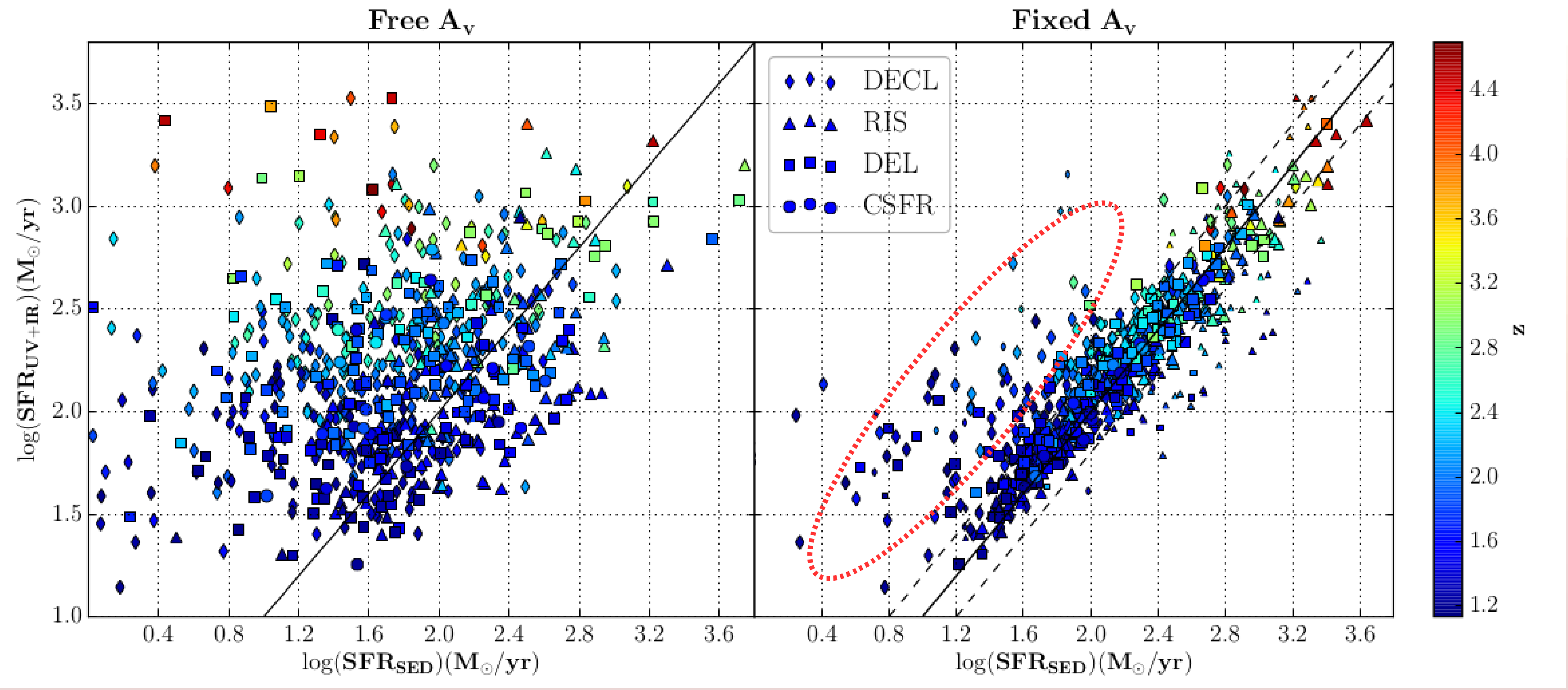
Main Sequence



Both GOODS fields

MS calibration : Schreiber et al. 2014

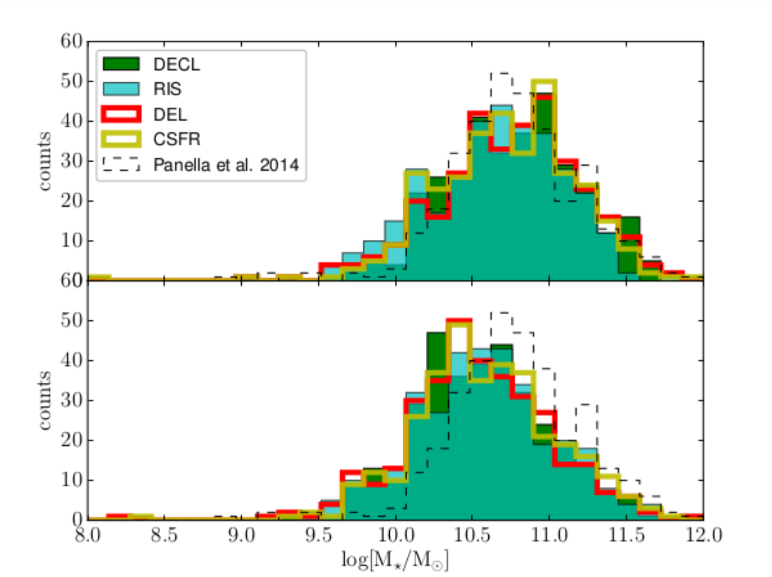
- Large scatter when extinction is unconstrained, most galaxies appear below MS, having very little SF, evolved old populations.
- The fixed A_V models significantly reduce the scatter, mostly occupy the same area than the IR-infered SFRs (white pentagons)



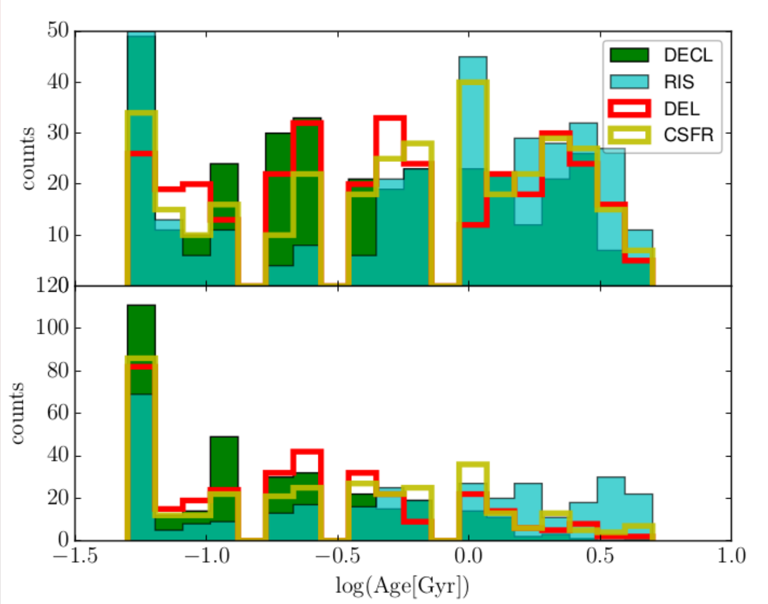
Comparison of Kennicutt-infered total SFRs with our SED models

- The bulk of the succesful energy conserving models reproduce the observed SFR (small symbols indicate the models for which L_{IR} was not matched within 0.2 dex)
- A fraction of the sample has SFR(SED)'s below the observed values, while still matching the L_{IR}: → 23 % , ¼ (6 % of total) of which is >0.6 dex below, and are potentially **quenched galaxies** still bright in the IR

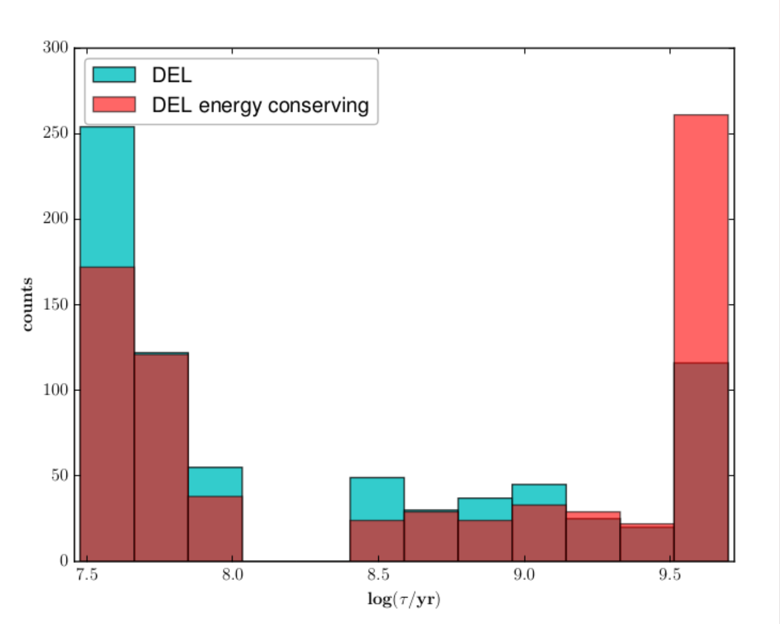
Changes in physical parameters



- Mass distribution shifted ~0.2 dex downwards
- Ages become a little younger, with the smallest ones concerning starbursts mainly
- *e*-folding timescales shift towards larger values

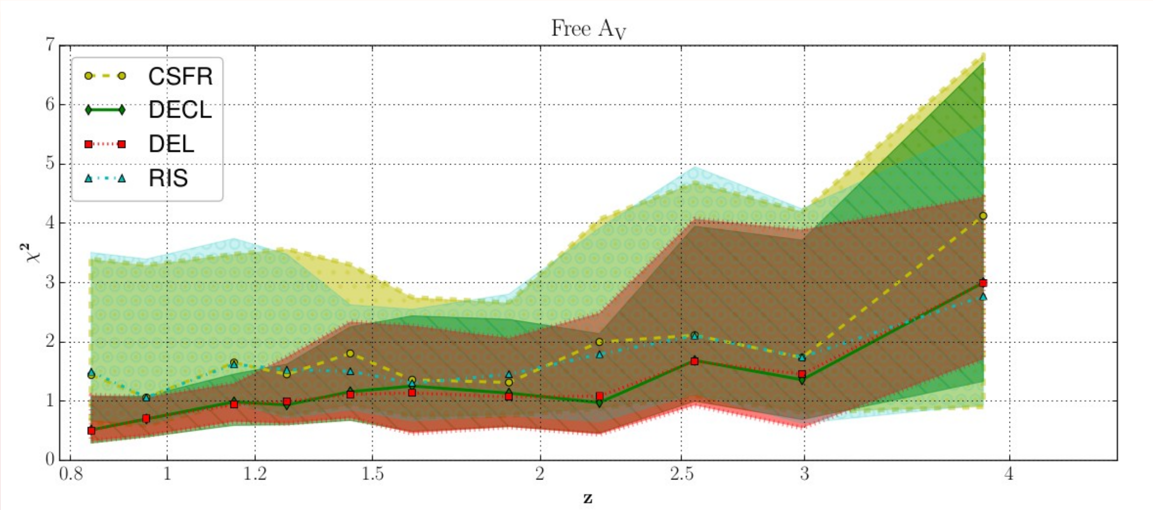


GOODS-N only

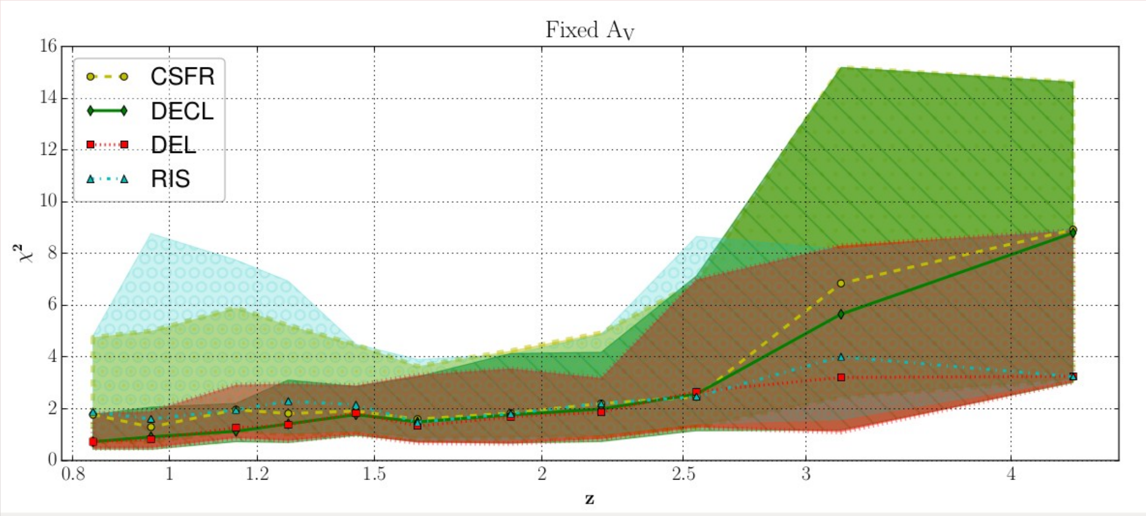


Both GOODS fields

SFH preferences in the MS as a function of z



Median χ^2 values, 1σ intervals



NB : for this plot our analysis was extended to lower z~0.8

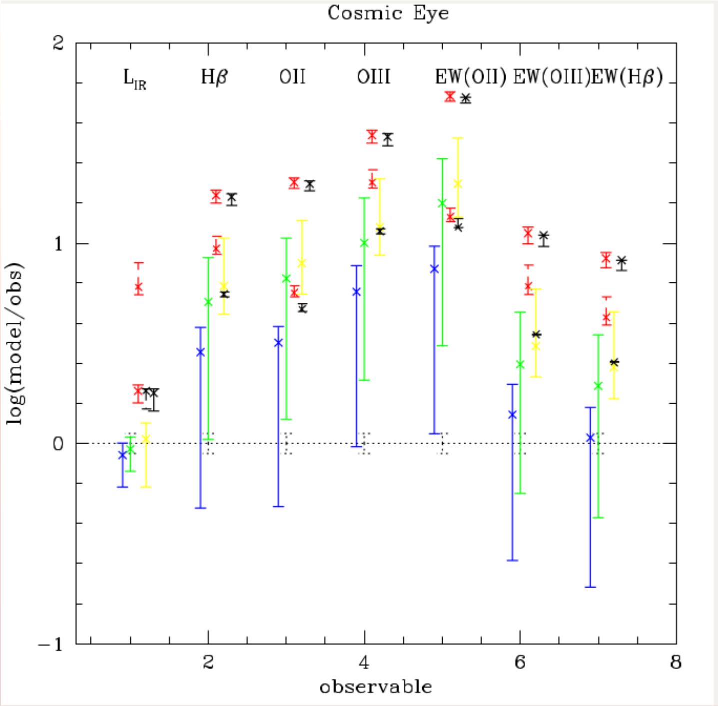
- For the unconstrained models, there is discrimination mostly at z<1.5
- High-z is very poorly populated as few sources are found in the MS for these fits
- The constrained fits show subtle but interesting behaviour :

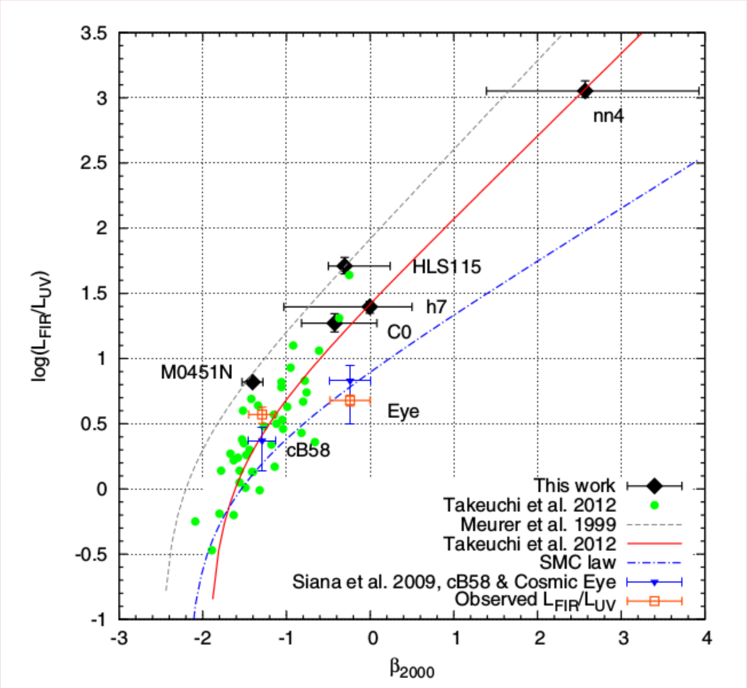
  - low-z galaxies still prefer declining or delayed SFHs

  -the high-z end rejects declining SFHs and instead fits better with the rising models
- Temptative similarity with CSFH, but keep in mind that high-z sources are few and biased towards very high L_{IR}

A particular case : the Cosmic Eye

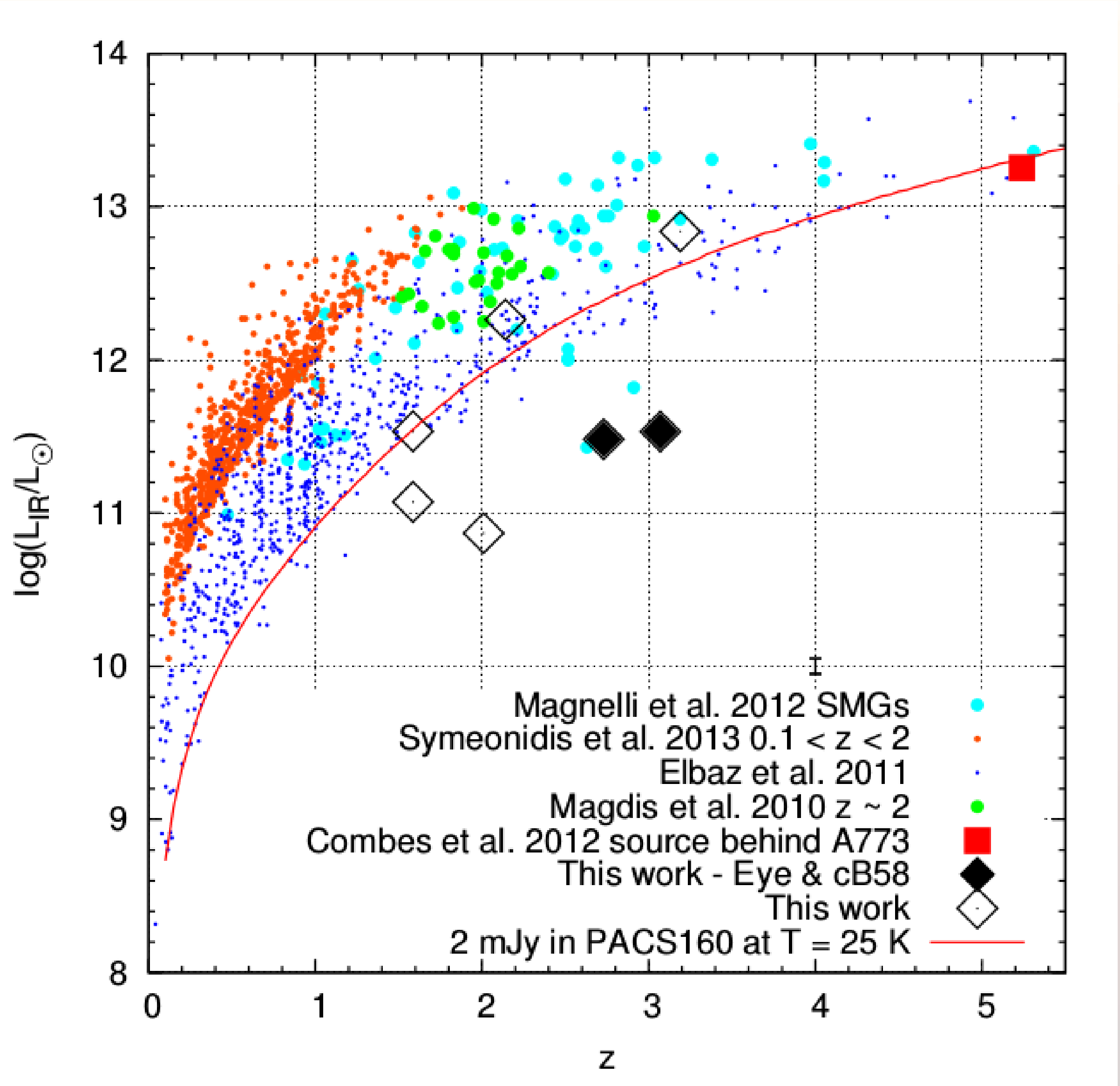
- Z=3.07, ~30x lensed LIRG
- IR emission, nebular lines, and SED analysis (Sklias et al. 2014) and CO observation (Dessauges-Zavadsky, *accepted*) point towers the notion that it is a post-starburst galaxy, now declining.





Conclusions

- Our energy-conserving models based on the observed IR/UV ratio work well for the bulk of the sample, with the notable exception of the high-luminosity end
- They allow to retrieve the Kennicutt-infered SFRs for most of the sample but also are capable to produce decreased SFRs, while matching the L_{IR}, thus catching eventual quenching galaxies for which SFR(IR) can be an overestimation
- Smaller masses by ~0.2 dex, slightly younger age
- Scatter around MS is reduced
- SFH preference is shifted towards rising models thanks to the IR constrain
- It's tempting to perceive he change of preference with redshift as related to the cosmic trends from early epochs to the more recent Universe
- **Future work**
- Further explore the ability to constrain SFHs with the use of nebular emission
- Explore why this approach of energy conservation is less effective with the highest luminosity sources
- Increase the faint lumisity end beyond z~2 thanks to lensing, with the HLS and recent ALMA observations of lensed fields (PI : Boone)



14
13
12
11
10
9
8
0
1
2
3
4
5
z
log(L_IR/L_⊙)
Magnelli et al. 2012 SMGs
Symeonidis et al. 2013 0.1 < z < 2
Elbaz et al. 2011
Magdis et al. 2010 z ~ 2
Combes et al. 2012 source behind A773
This work - Eye & cB58
This work
2 mJy in PACS160 at T = 25 K