Searching for the dominant mode of galaxy growth from deep extragalactic Herschel surveys

D.Elbaz (CEA Saclay)

Star formation = local process (~pc scale)

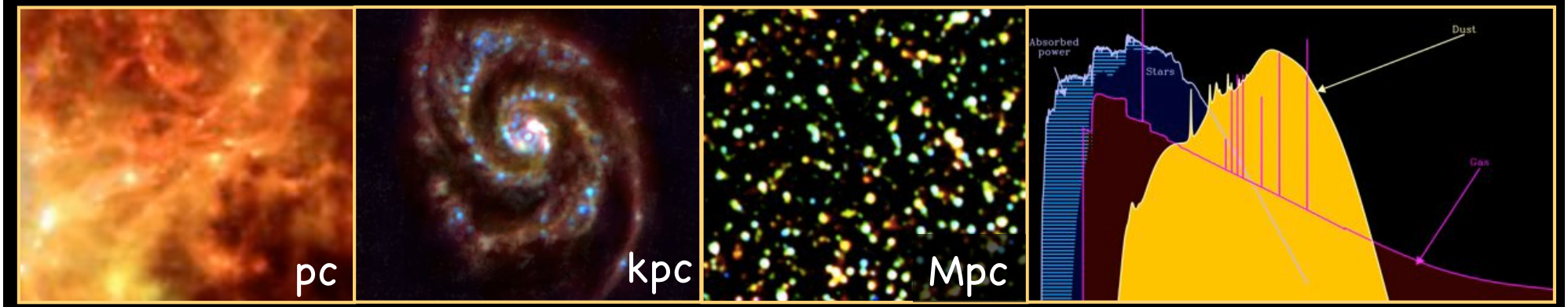
How sensitive is SF to larger scales *inside (kpc)* and *outside (Mpc)* galaxies ?

→ key : direct access to FIR radiation, young/massive stars dust embedded

stochasticity of star-formation ? role of mergers in star-formation ?

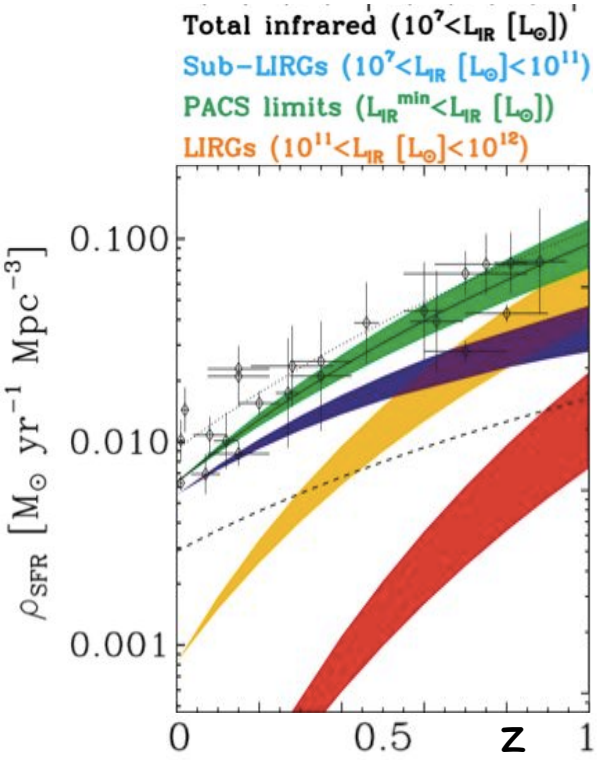
→ bridging Mpc and sub-pc scales has become possible

M.Pannella, C.Schreiber, M.Dickinson, H.S.Hwang, G.Magdis, B.Magnelli, P.Popesso, T.Díaz-Santos, R.Leiton, J.R.Mullaney, E.Daddi, H.Aussel, D.Le Borgne, F.Galliano, V.Charmandaris, C.Schreiber + GOODS-Herschel team

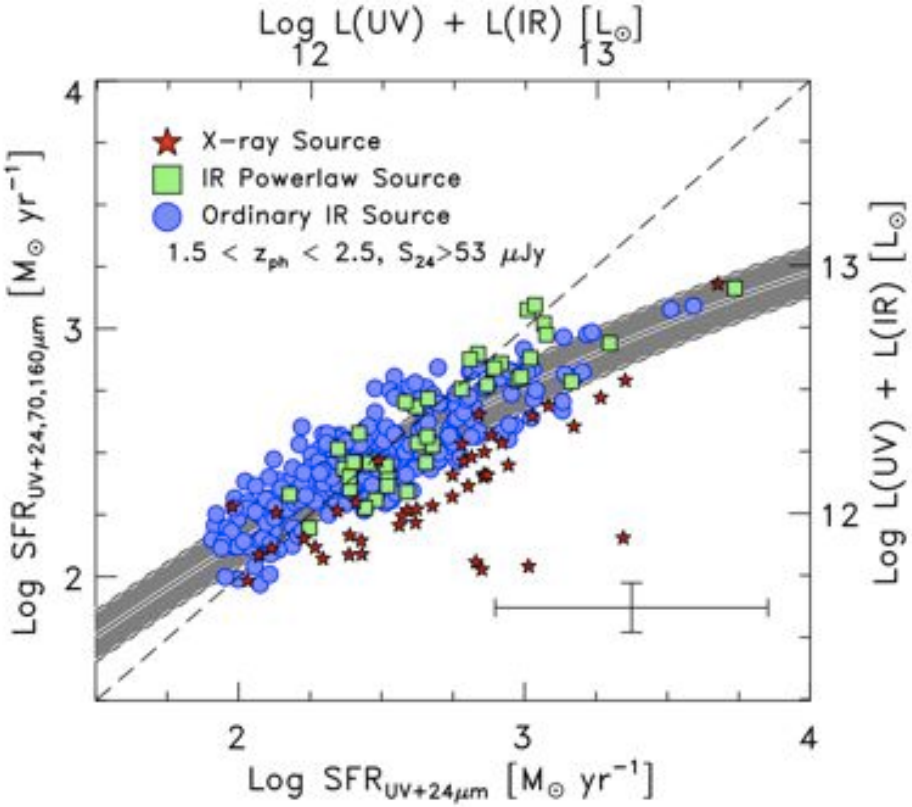


The Spitzer view on the cosmic SFR history

at z > 1-1.5 , mid-IR extrapolations inconsistent with radio, 70 μm stacks
→ mid-IR excess issue (Daddi +07, Papovich +07)

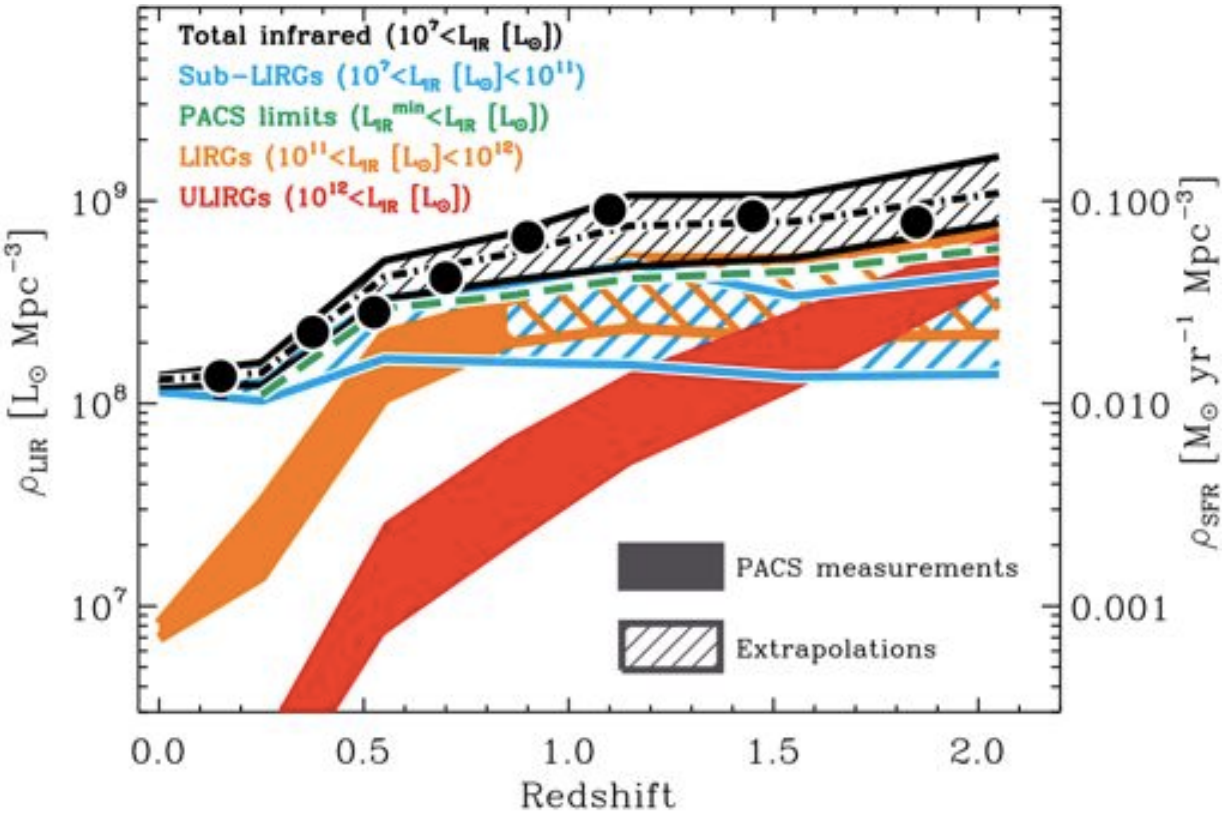


Le Floc'h +05



The Herschel view on the cosmic SFR density history

Star-formation history at z<1 consistent with Spitzer
ULIRGs continue to rise from z=1 to 2, LIRGs remain ~flat

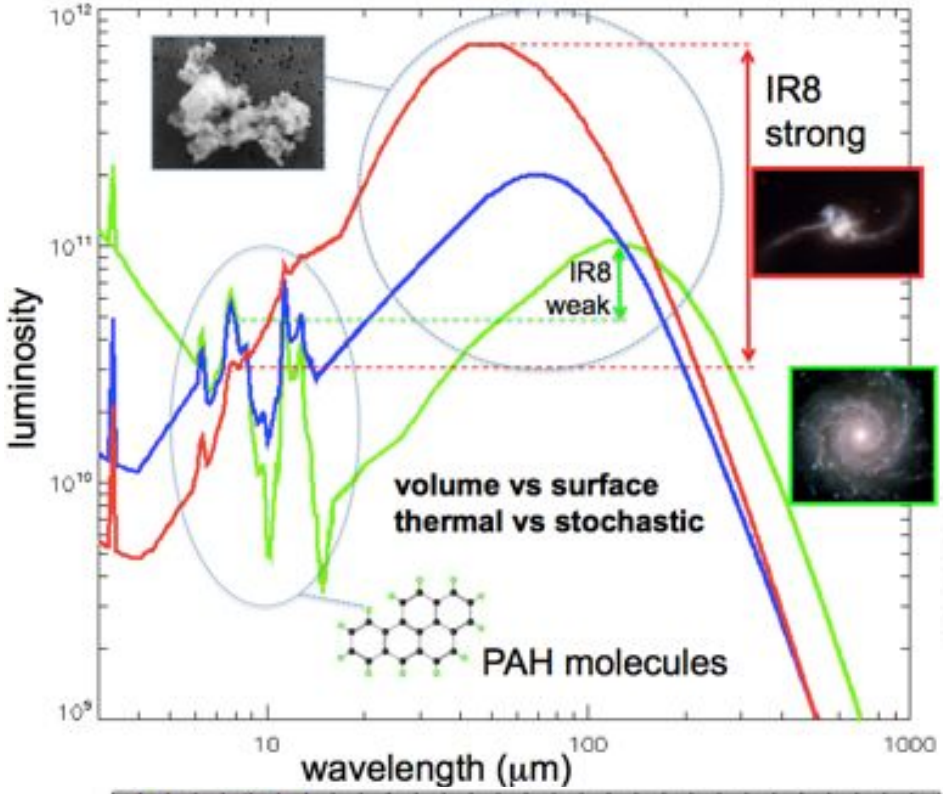


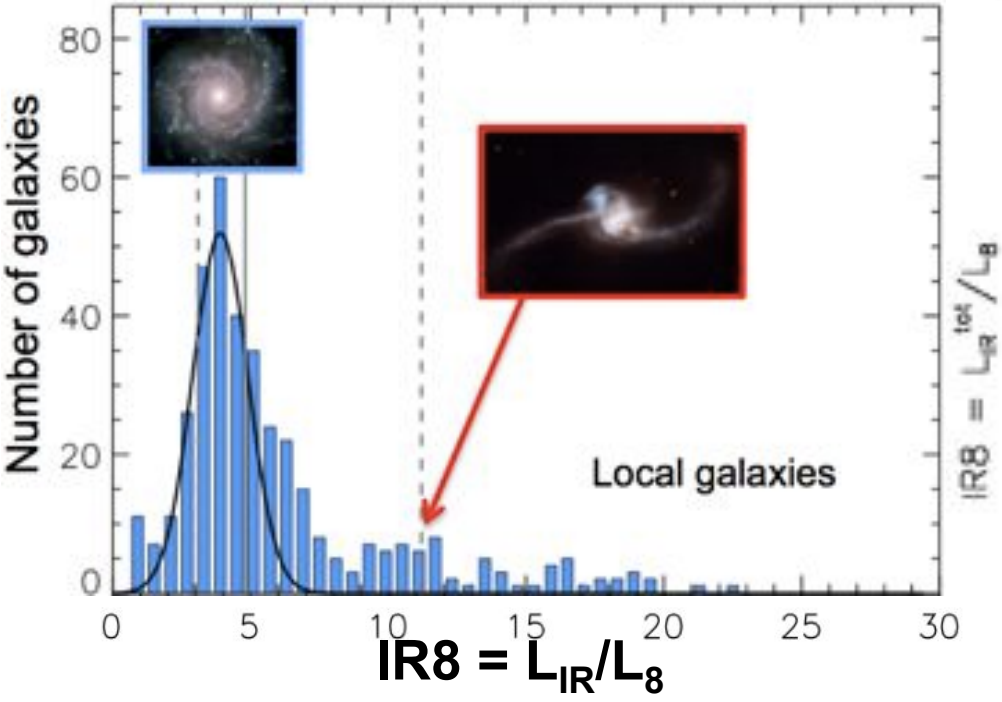
Magnelli +2013
(GOODS-Herschel + PEP)

How representative is the cosmic SFR history of individual galaxies histories ?

What is the dominant mode of galaxy growth ?

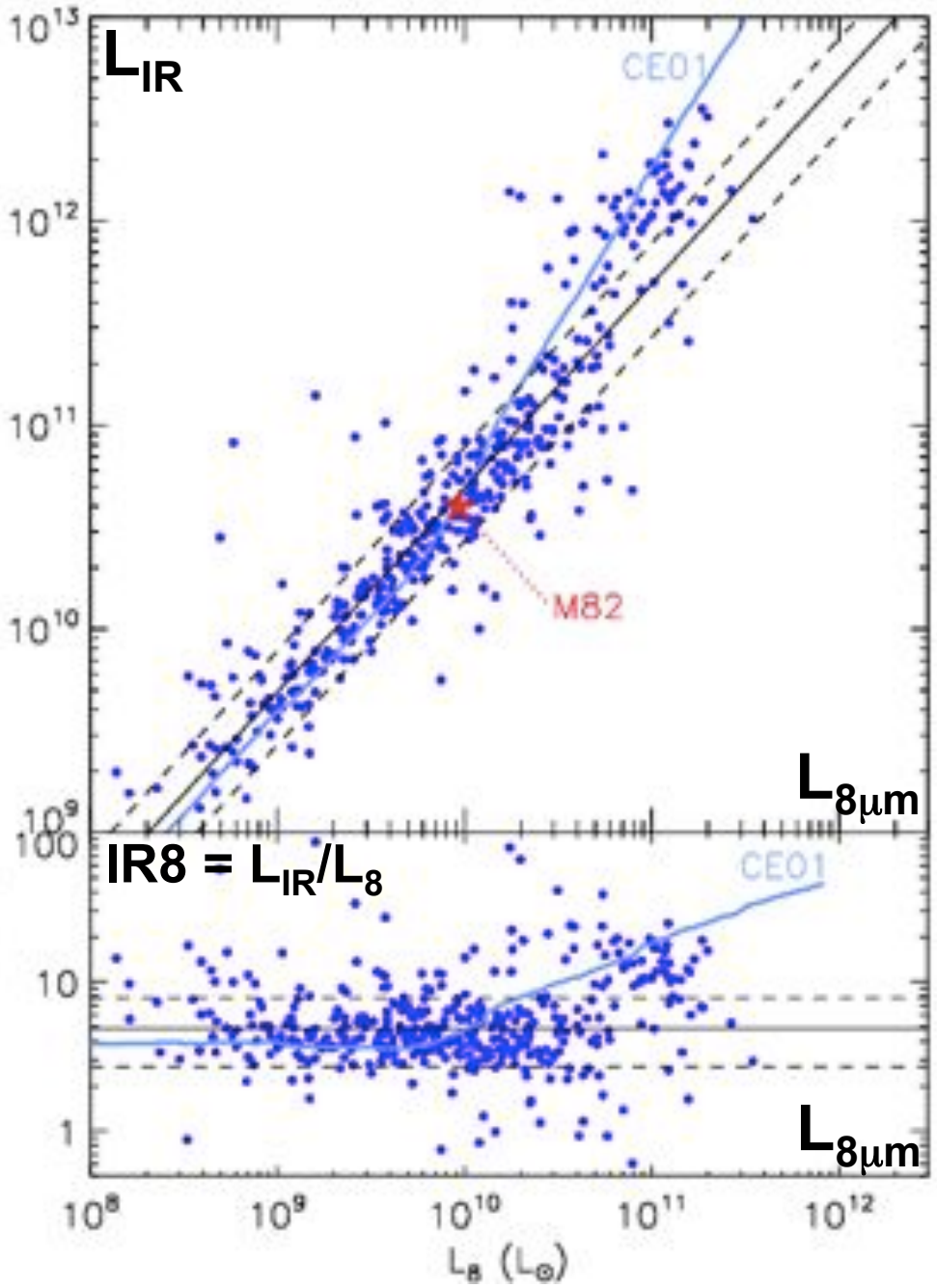
stochastic vs continuous... / role of starbursts , mergers





IR8 = L_{IR}/L_8

Local Universe

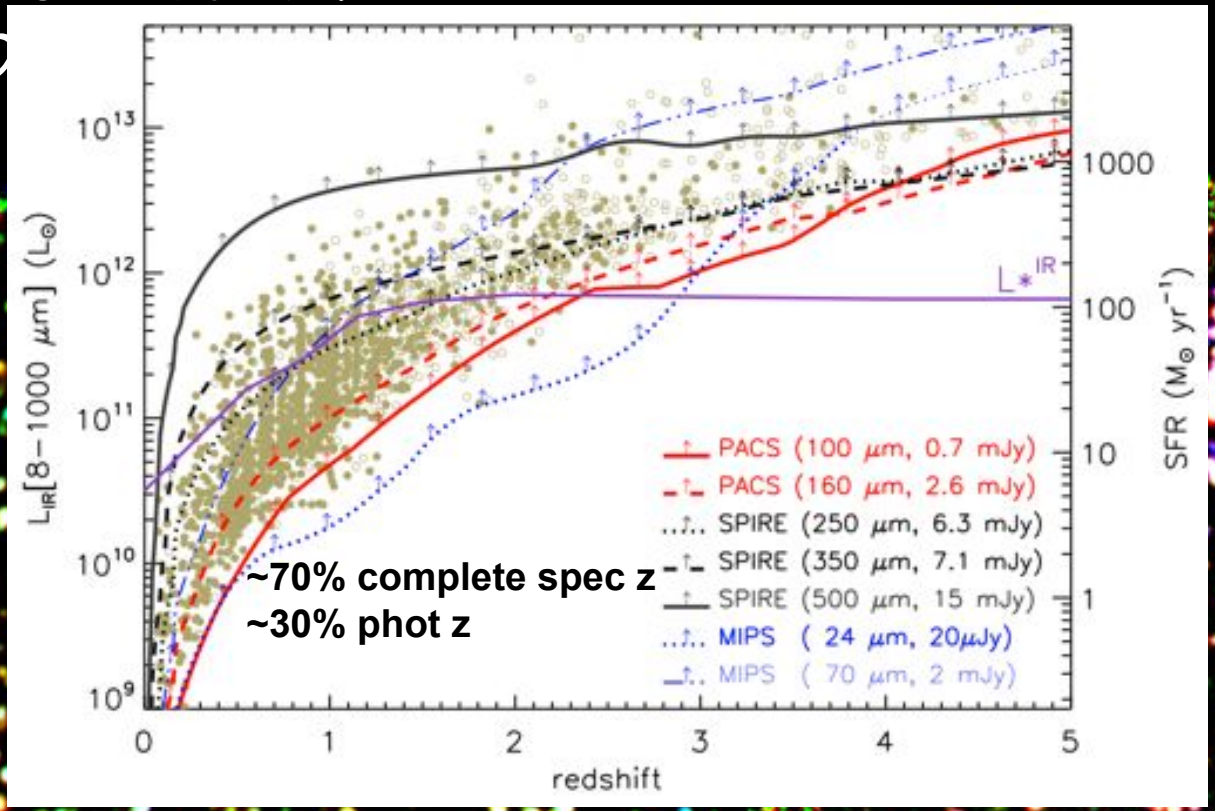


Deepest far infrared images of the sky in the 2 GOODS fields

1818 sources from z~0 to ~4

GOODS-*Herschel*
(+ CANDELS-*Herschel*
UDS & CO

down to 0.8 mJy@100 μm, 2.4 mJy@160μm
5.7mJy@250μm, 7.2mJy@350μm, 9mJy@500μm

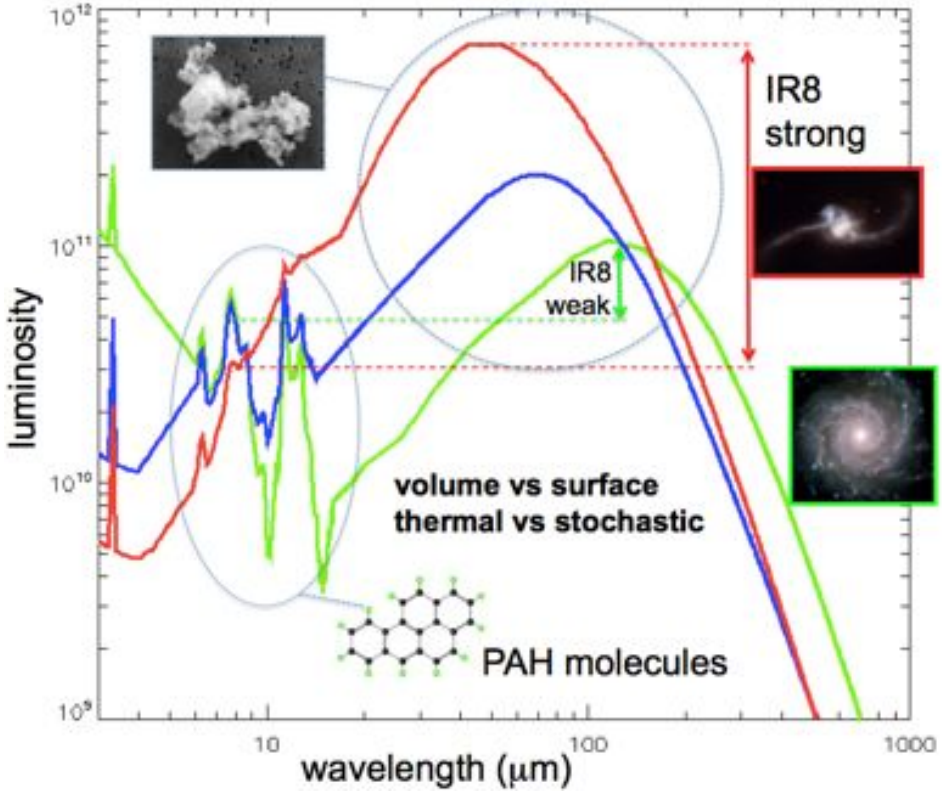


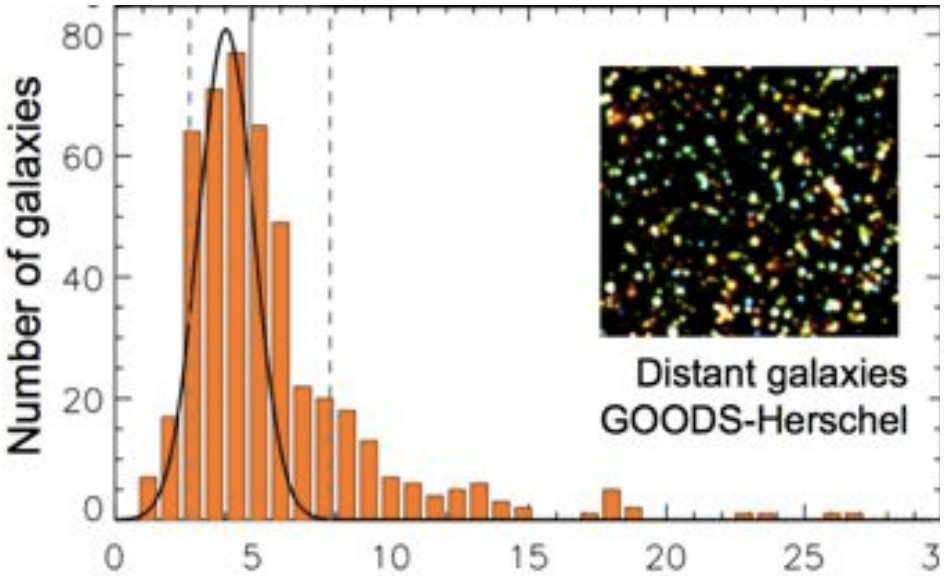
15'
= 15 com.Mpc
@z=1

GOODS-North
100 160 250 μm
10'x15'

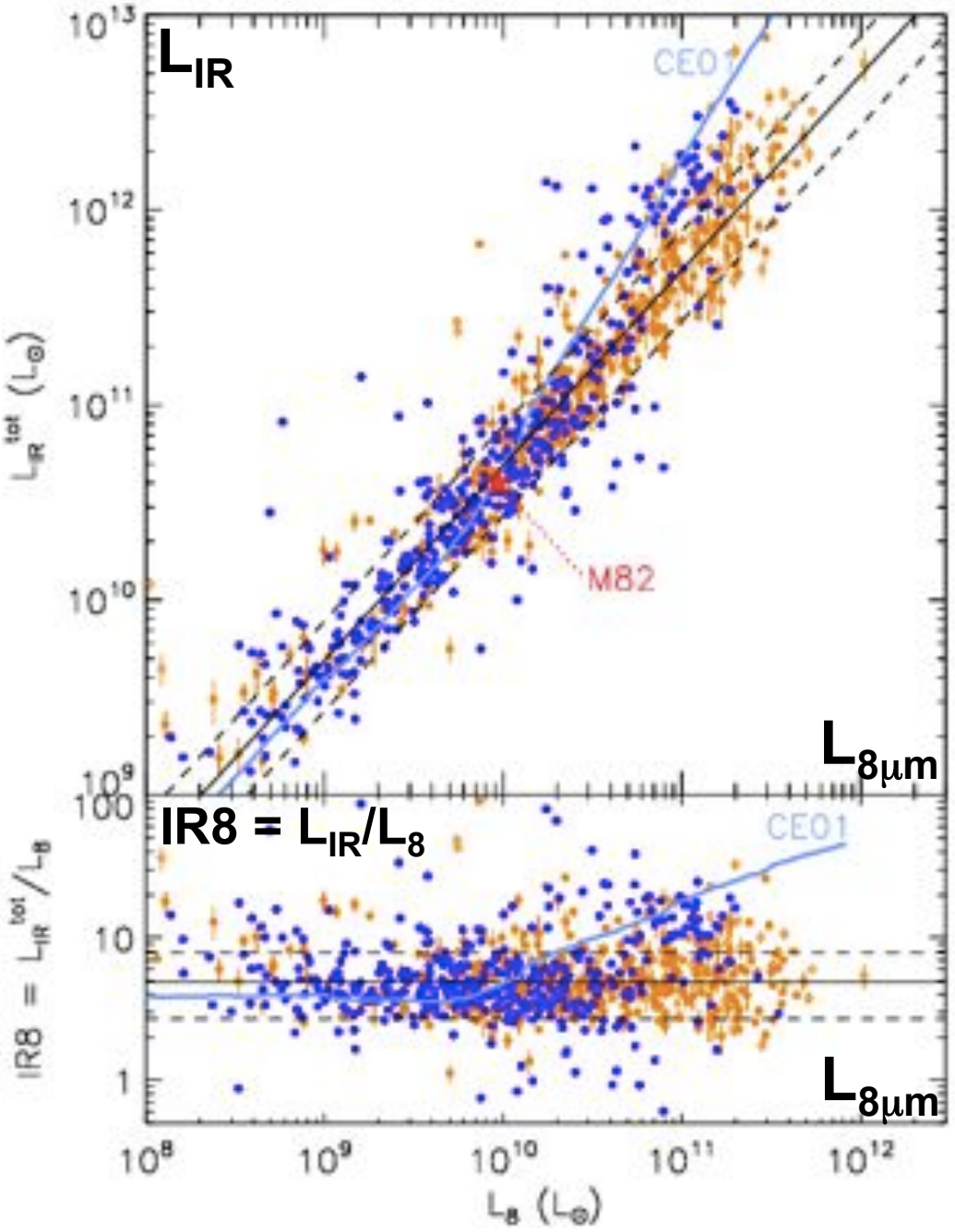
GOODS-South
24 100 160 μm
10'x10'

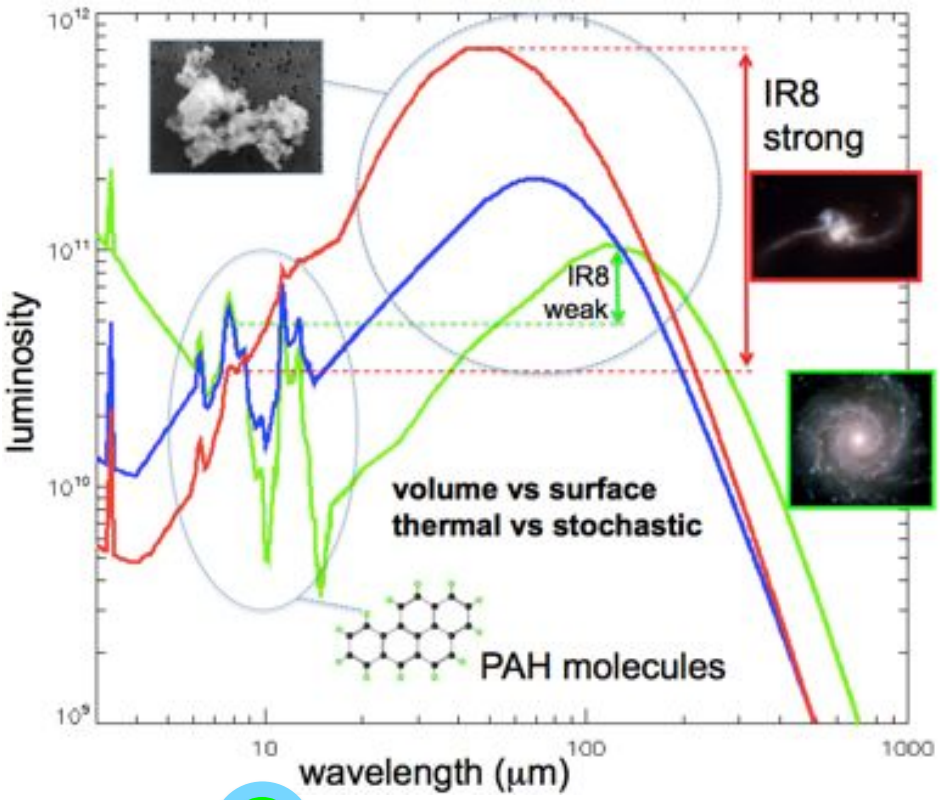
Local vs distant Universe

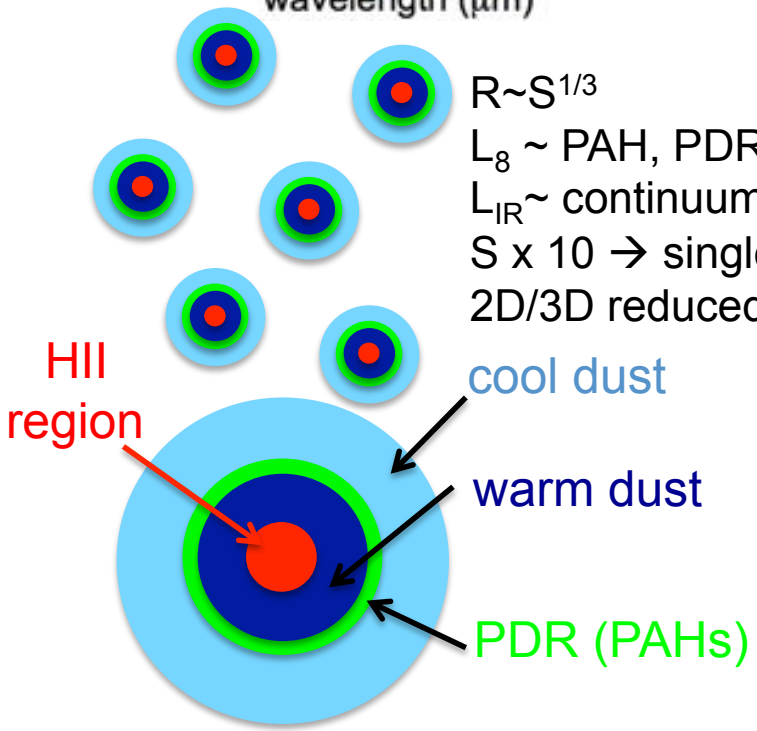




$IR8 = L_{IR}/L_8$







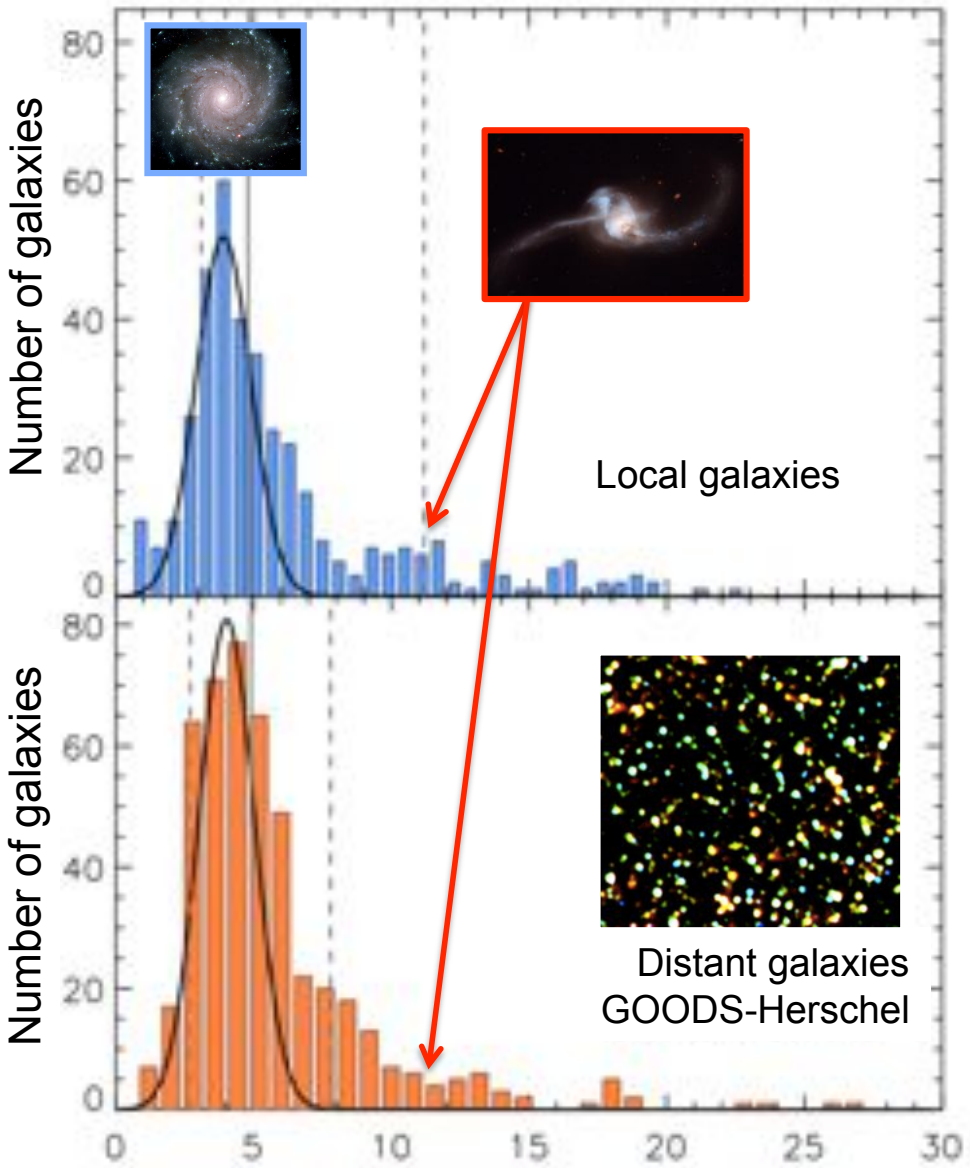
$R \sim S^{1/3}$

L_8 ~ PAH, PDR ~ 2D

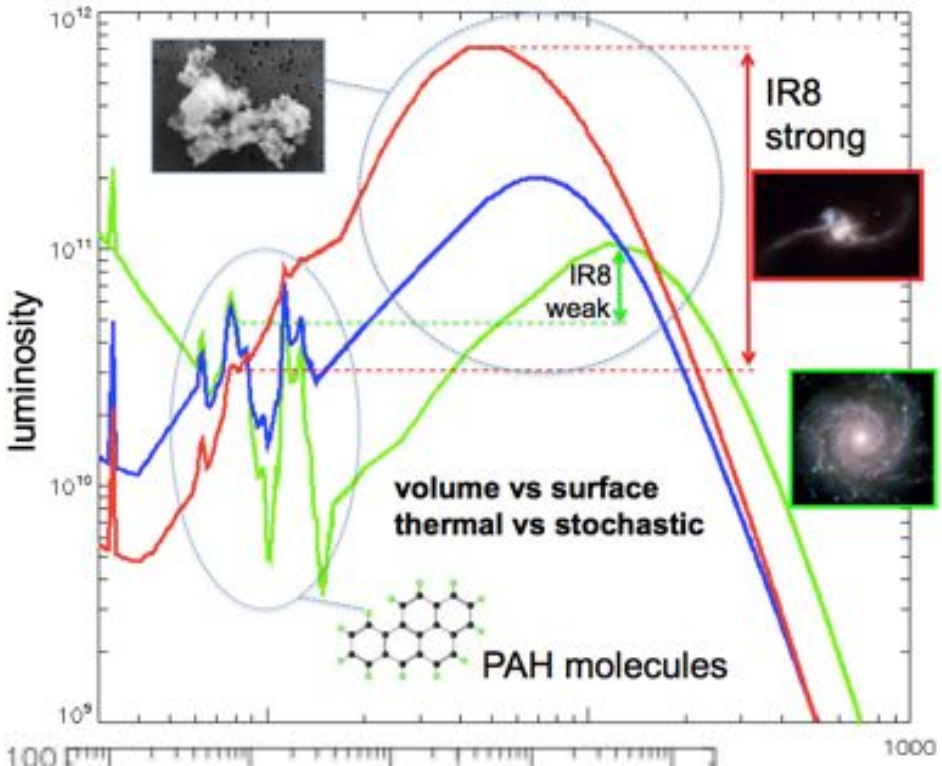
L_{IR} ~ continuum ~ 3D

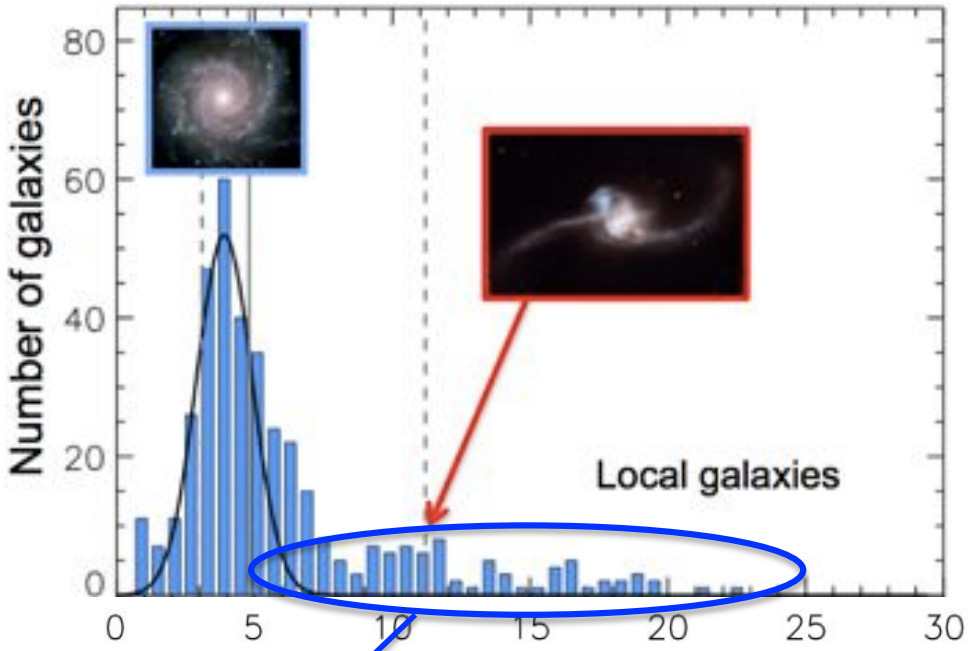
S x 10 → single region:

2D/3D reduced by ~2

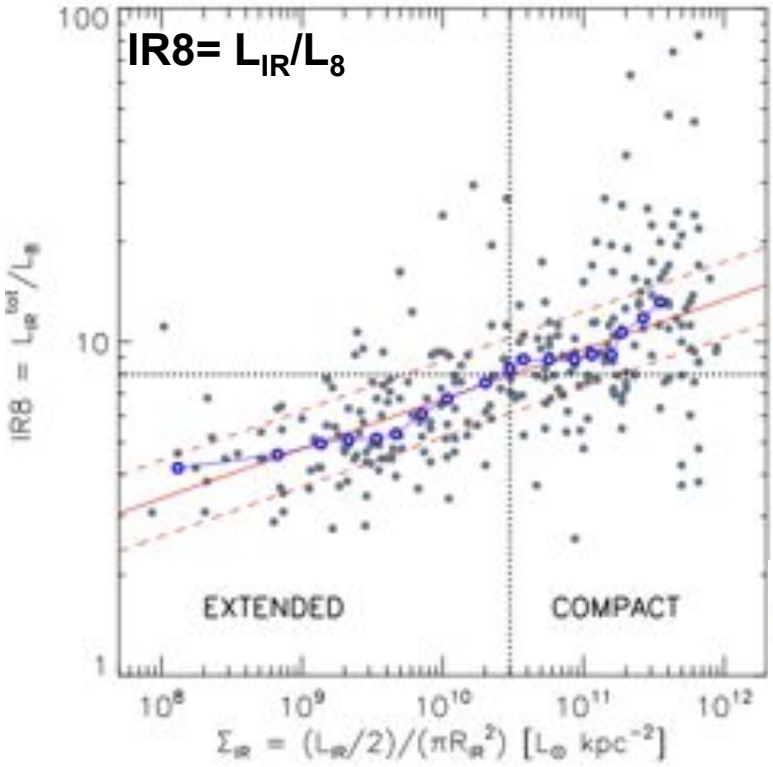


IR8= L_{IR}/L_8= robust / fragile dust emission
a signature of galaxy mergers

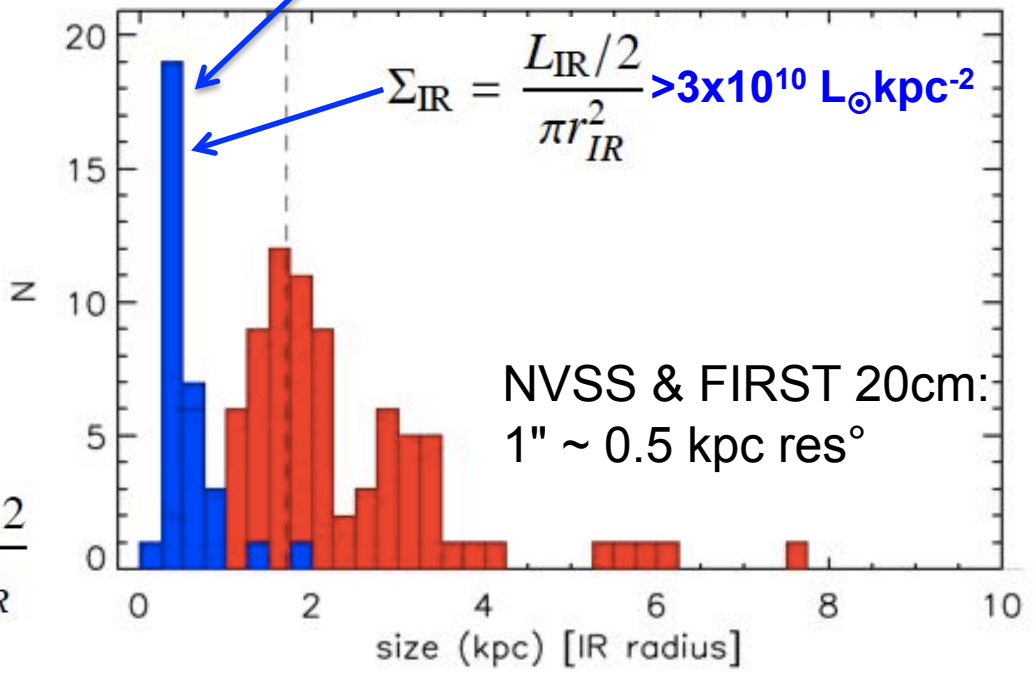




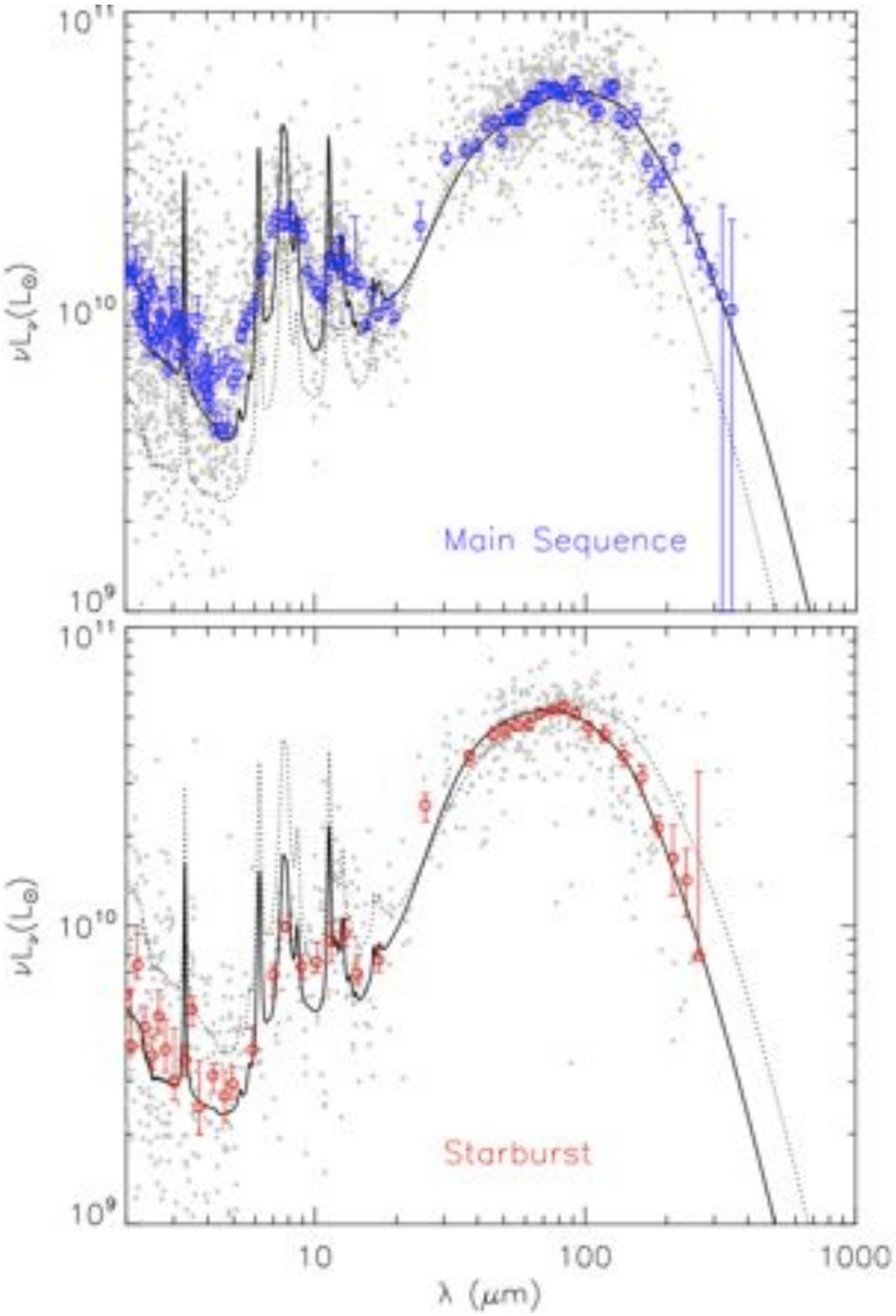
IR8= L_{IR}/L_8= robust / fragile
dust emission= signature of mergers

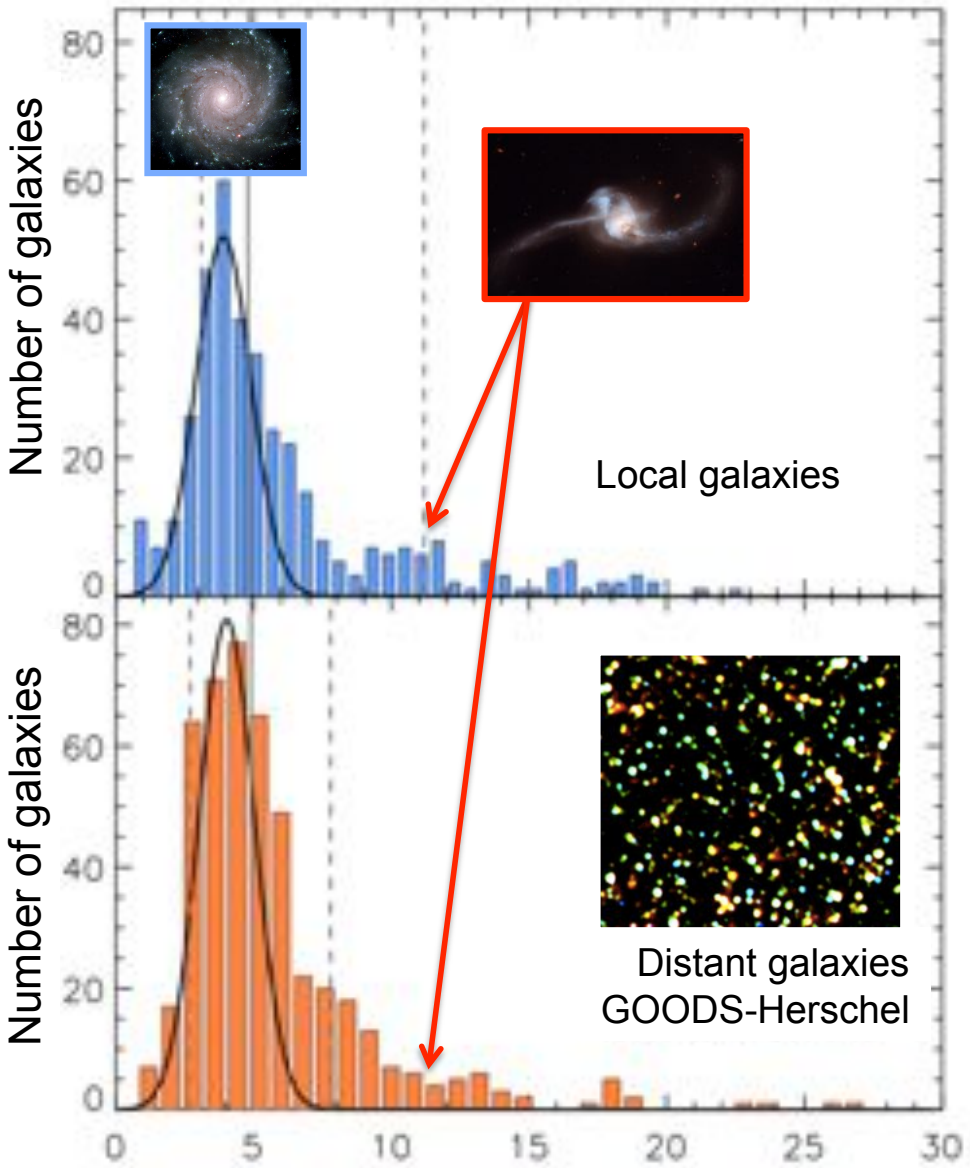


$$\Sigma_{IR} = \frac{L_{IR}/2}{\pi r_{IR}^2}$$



$$\Sigma_{IR} = \frac{L_{IR}/2}{\pi r_{IR}^2}$$ **>3x10^{10} L$_\odot$kpc^{-2}**

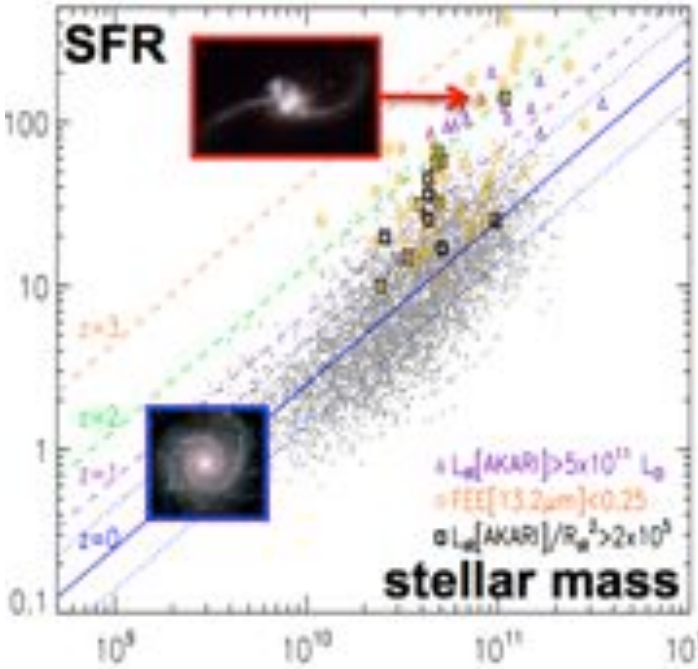




IR8= L_{IR}/L_8= robust / fragile dust emission
a signature of galaxy mergers

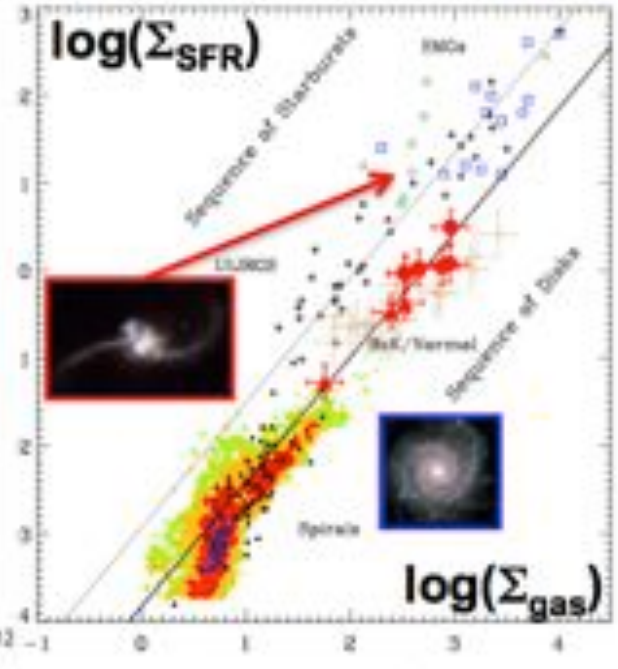
the 3 sides of the Main Sequence

sSFR (starburstiness)



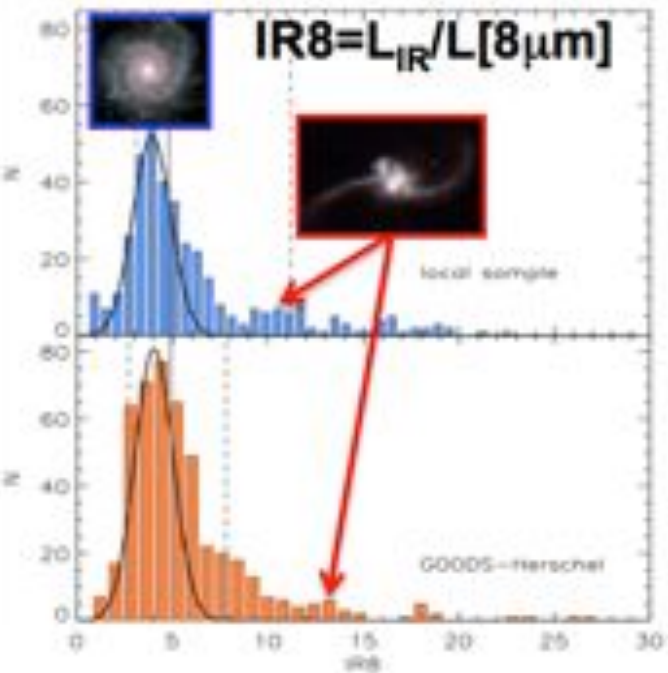
Noeske +07, Elbaz +07, Daddi +07 ...

SFE (=SFR/Mgas, SK law)



Daddi +10, Genzel +10

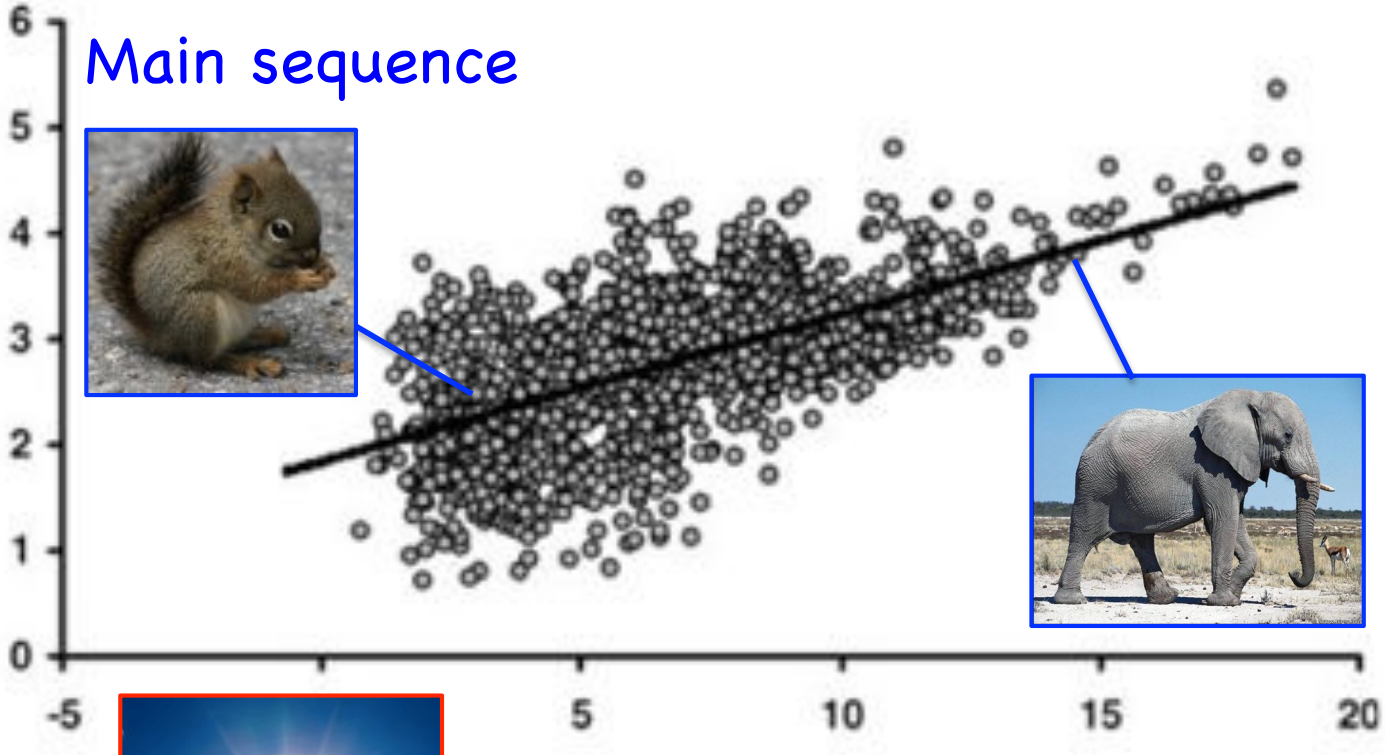
IR8 (SF geometry)



Elbaz +11, Nordon +12

mergers modulate star-formation

more numerous in the past, small impact on SF

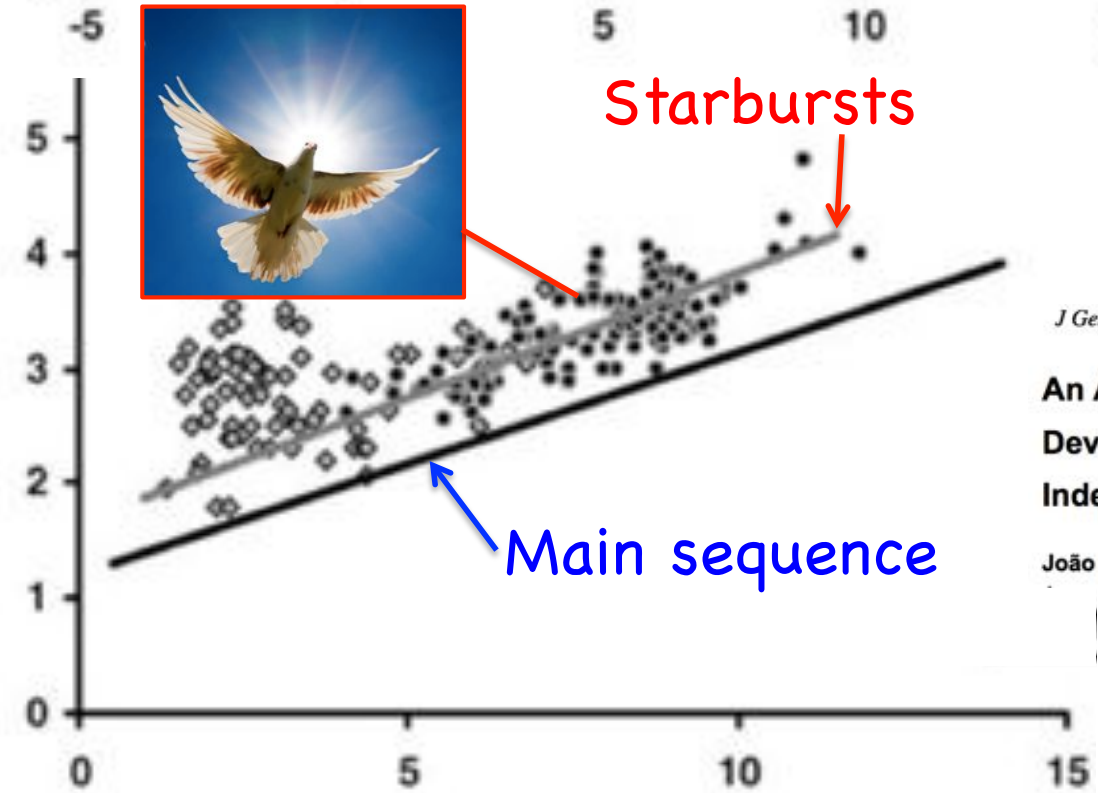


longevity

~1 billion heart beats

heart rate ~ 1/SFR

mass



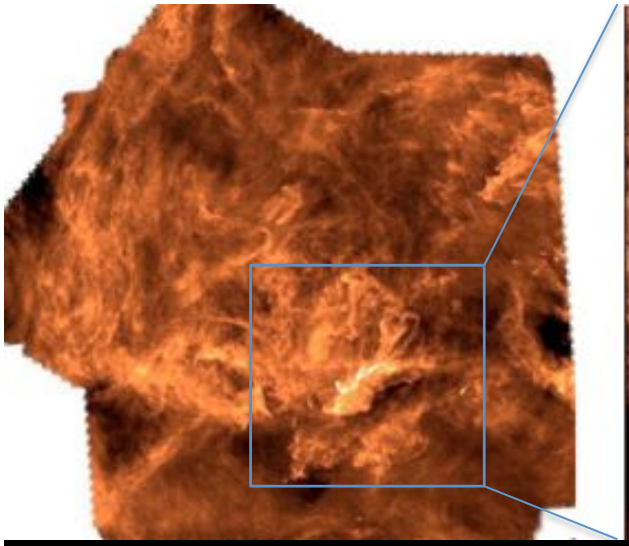
J Gerontol A Biol Sci Med Sci. 2007 February ; 62(2): 149–160.

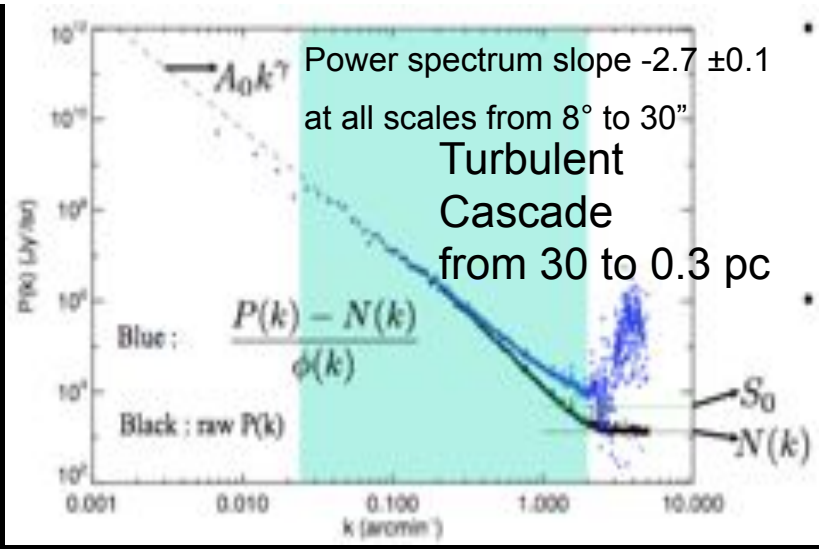
An Analysis of the Relationship Between Metabolism, Developmental Schedules, and Longevity Using Phylogenetic Independent Contrasts

João Pedro de Magalhães[1], Joana Costa[2], and George M. Church[1]

1456 mammals, birds, amphibians, reptiles

mass



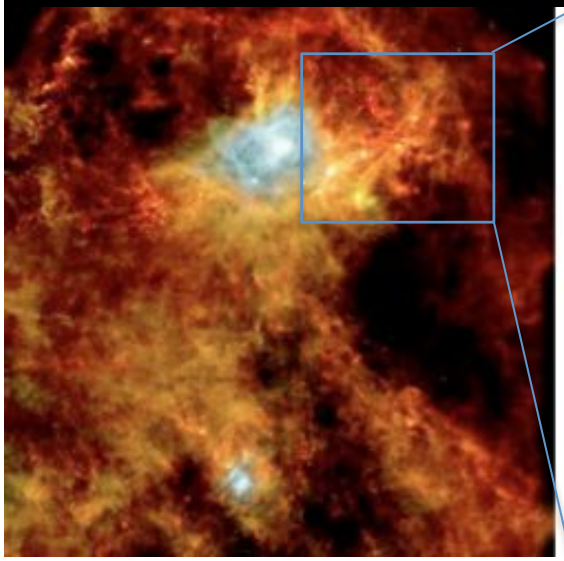


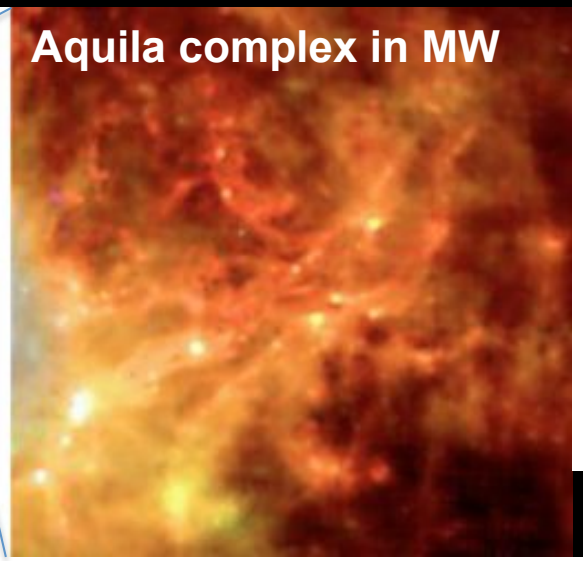
Universality of filamentary structure (0.1 pc width) but...

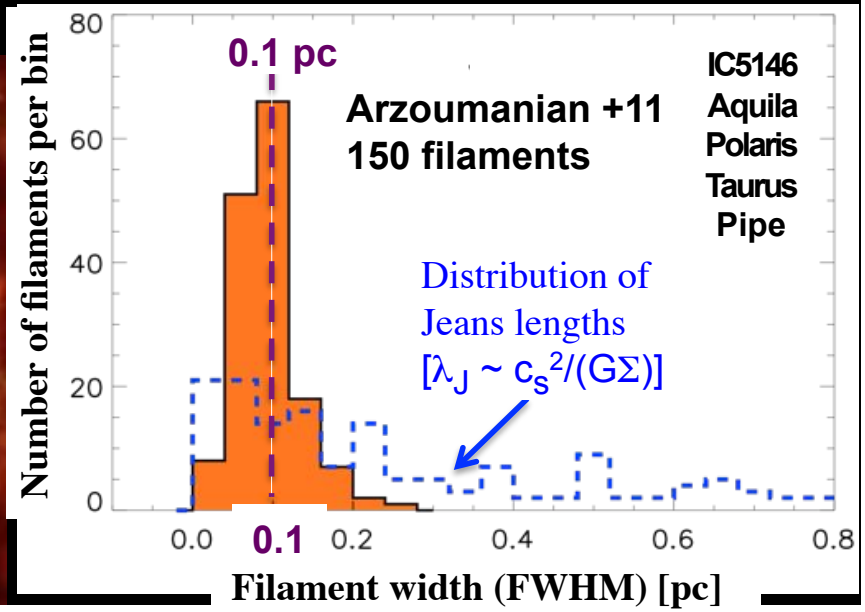
Fraction of dense molecular gas (>2x10^4 part.cm^{-3}) ≠ in both complexes

0% in Polaris, 15% in Aquila → role of turbulence

Within the dense gas: universality of star-formation efficiency







SFR driven by efficiency of dense gas production

few pc scales: P.Andre (10):

SFR = 15% dense mol. gas (>2x10^4 cm^{-3}, >10^{22} cm^{-2} in filam.) → pre-stellar cores

x 30% mass in pre-stellar cores form stars in 1 Myr

SFR = $4.5 \times 10^{-8}\ M_{dense}\ M_\odot yr^{-1}$

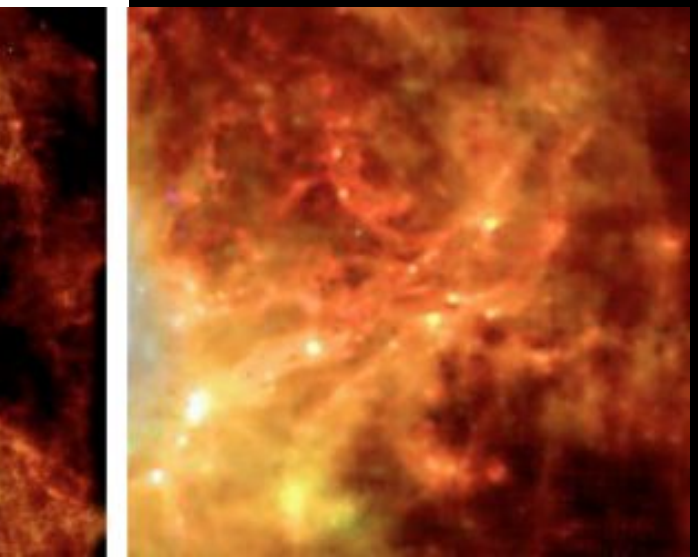
<500 pc scales: C.Lada (12):

SFR = $4.6 \times 10^{-8}\ M_{dense}\ M_\odot yr^{-1}$ for molecular clouds in MW

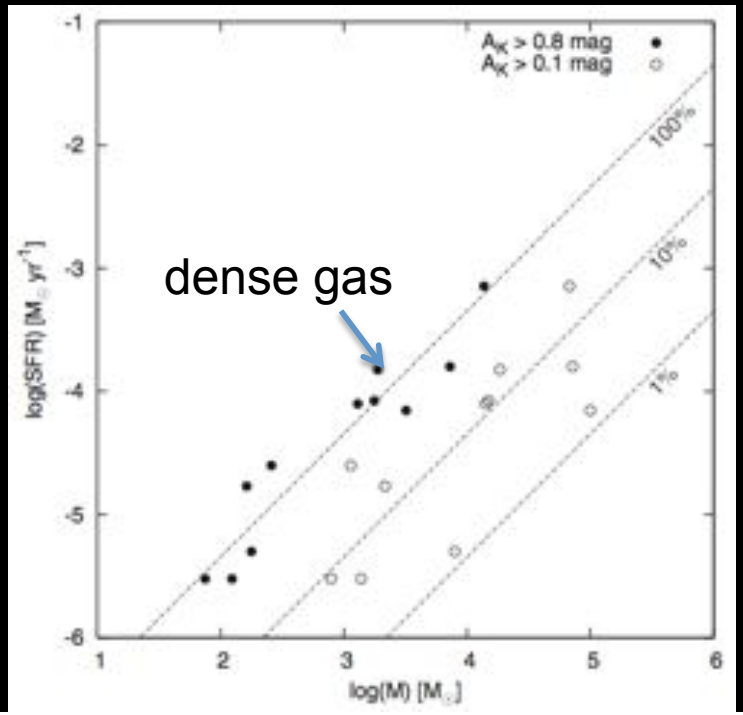
kpc scales : Gao & Solomon (04):

SFR= $1.8 \times 10^{-8}\ M_{dense}\ (10/\alpha_{HCN})\ M_\odot yr^{-1}$; $\alpha_{HCN}=M_{dense}/L_{HCN} \sim 10\ M_\odot (K\ km\ s^{-1}\ pc^{-2})^{-1}$

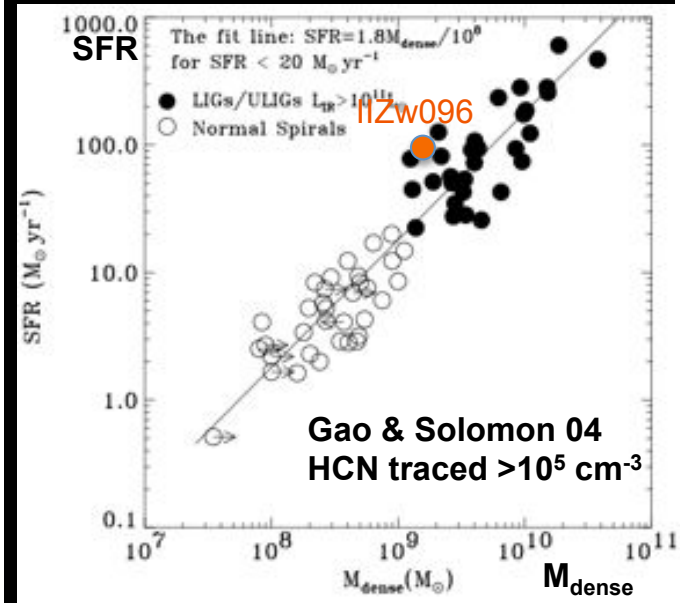
few pc scales (Andre +10)

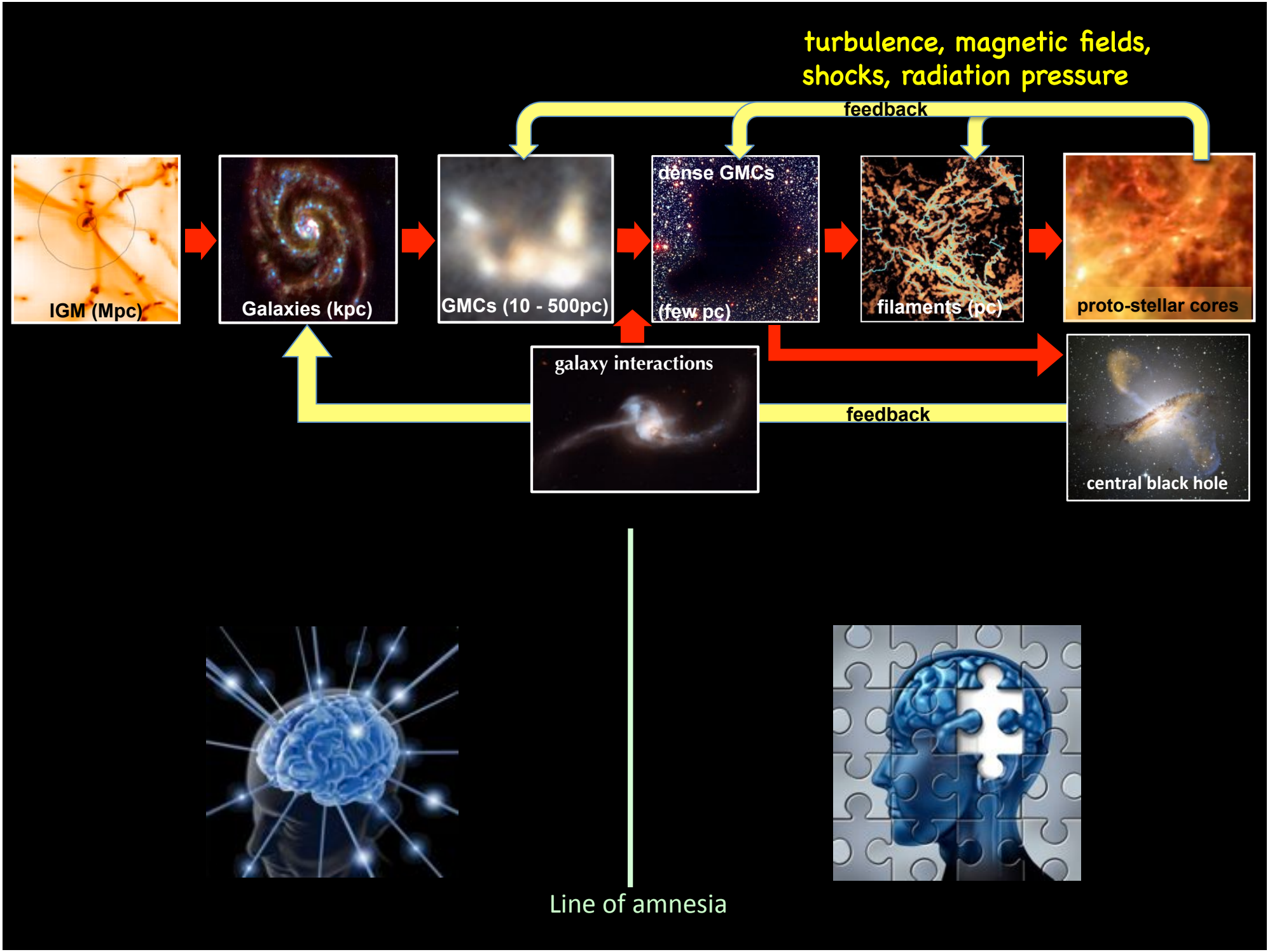


few 100 pc scales (Lada +12)



10 kpc scales = galaxies (Gao & Solomon 04)



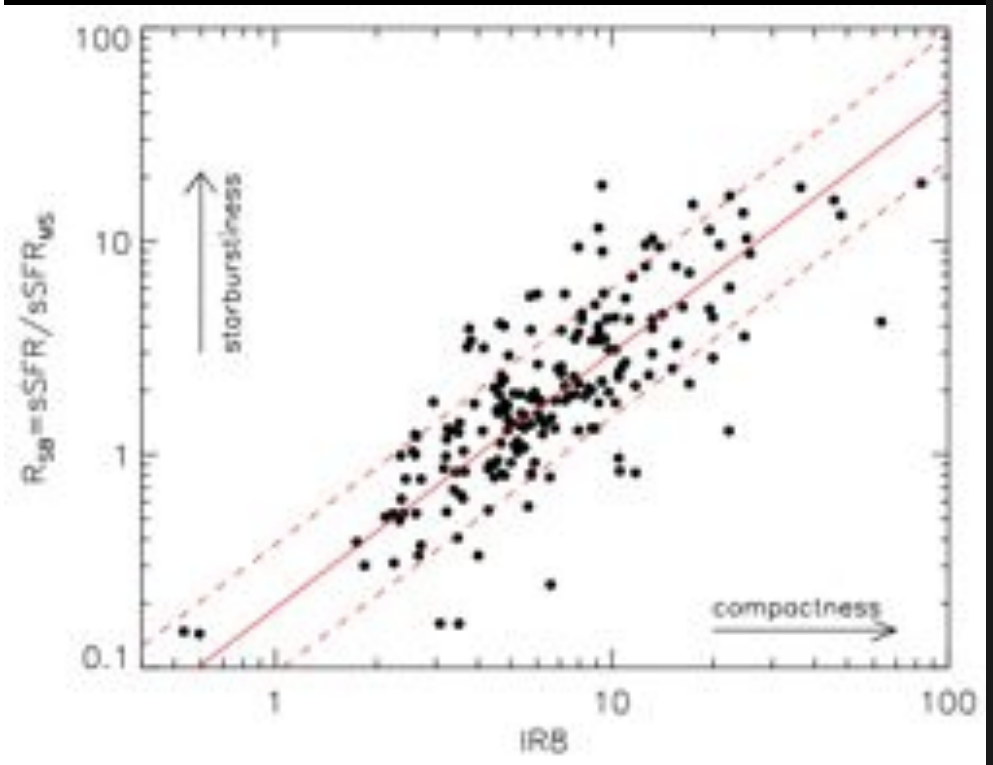

turbulence, magnetic fields,
shocks, radiation pressure
feedback
IGM (Mpc)
Galaxies (kpc)
GMCs (10 - 500pc)
dense GMCs
(few pc)
filaments (pc)
proto-stellar cores
galaxy interactions
feedback
central black hole
Line of amnesia

IR main sequence : role of starburstiness

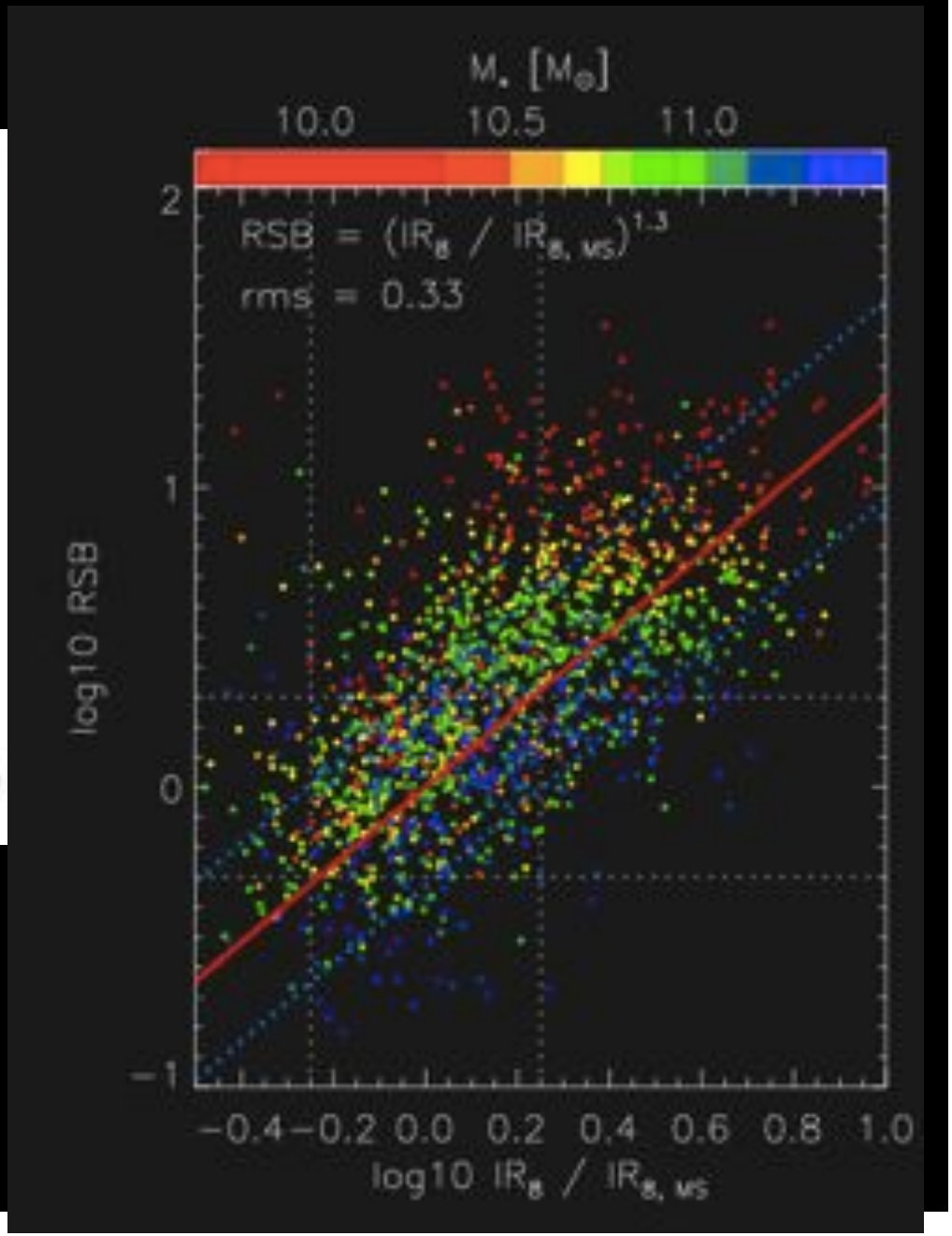
local galaxies

distant galaxies

starburstiness: RSB = $sSFR/sSFR_{MS}$

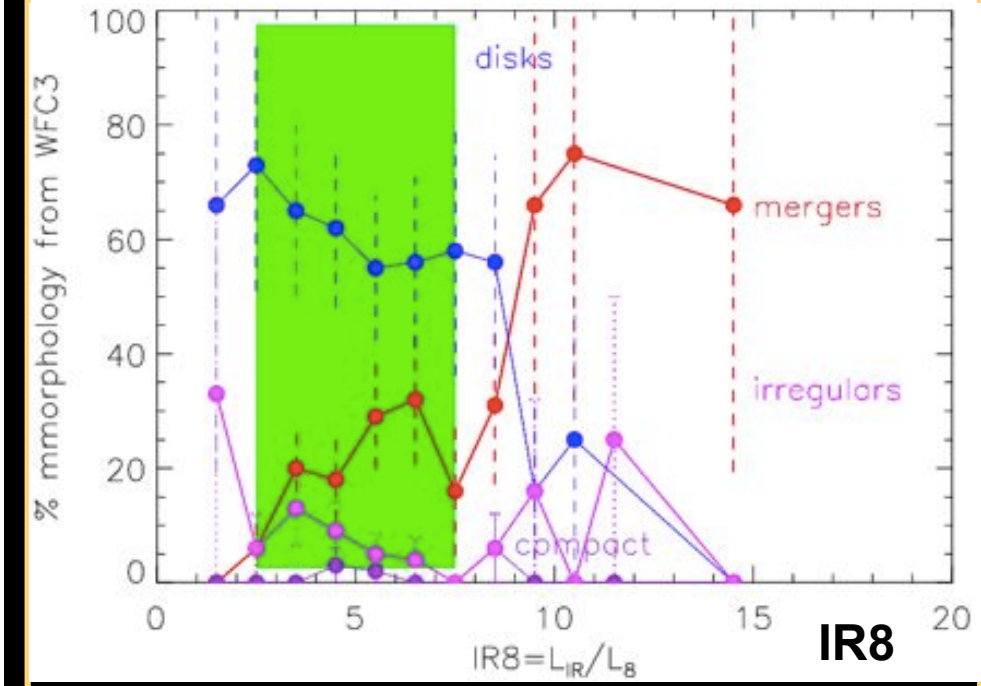


IR8 index = $L_{IR}/L_{8\mu m}$



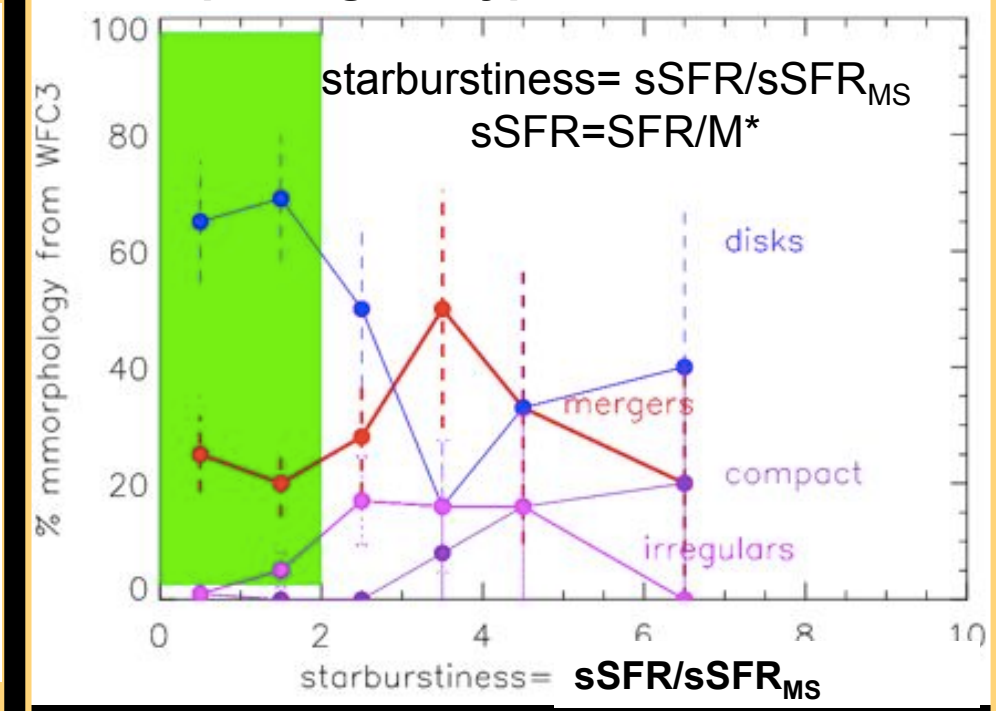
IR8, sSFR and morphology

% morphological type



IR8 rises with mergers / irregulars fraction
"IR8 MS" galaxies: 80 disks, 20 % mergers
"excess-IR8" galaxies: 75 % mergers

% morphological type

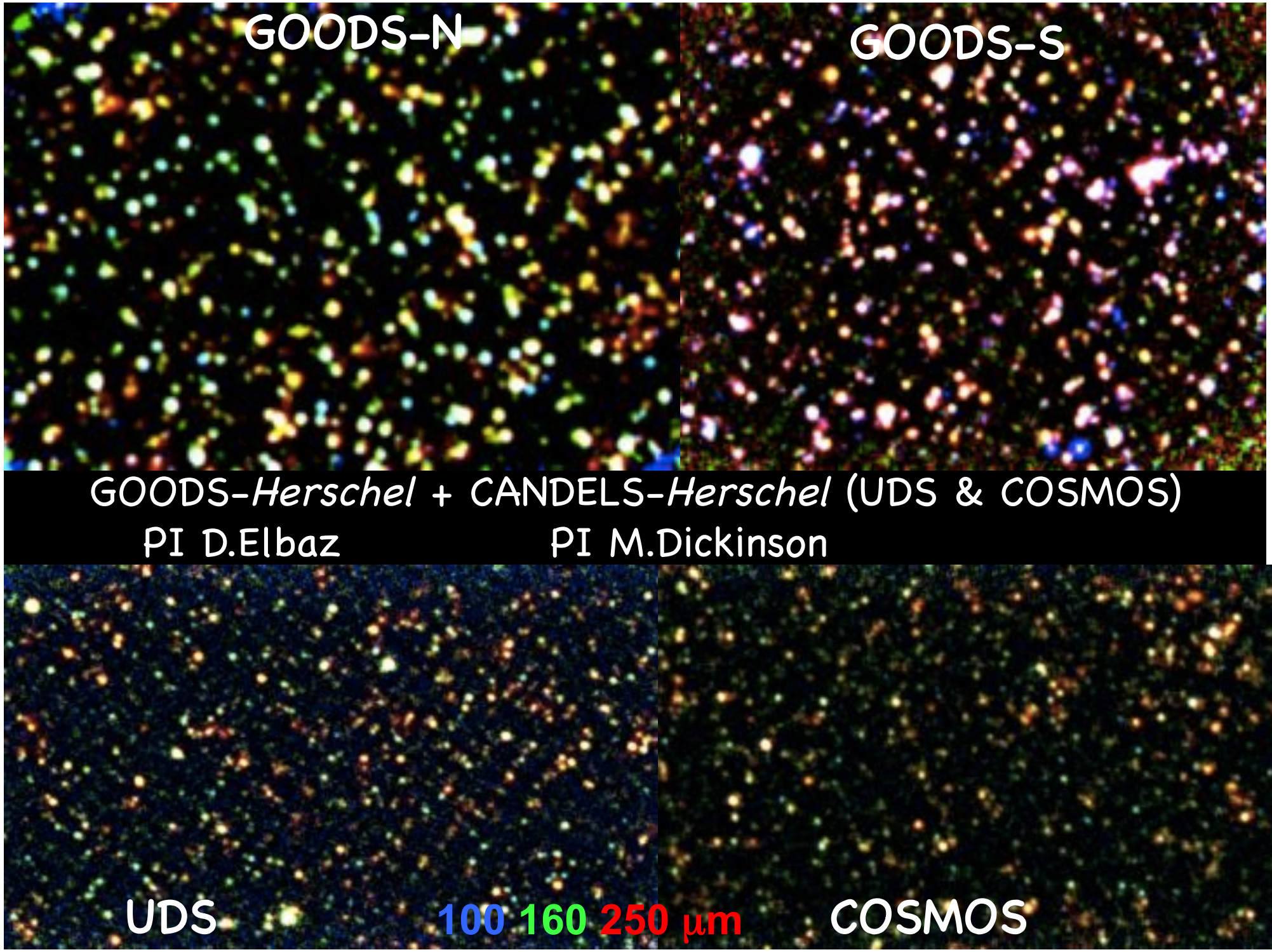


sSFR rises with mergers then compact fraction
"sSFR MS" galaxies: 80 disks, 20 % mergers
"excess-sSFR" gals: 50% mergers/compact

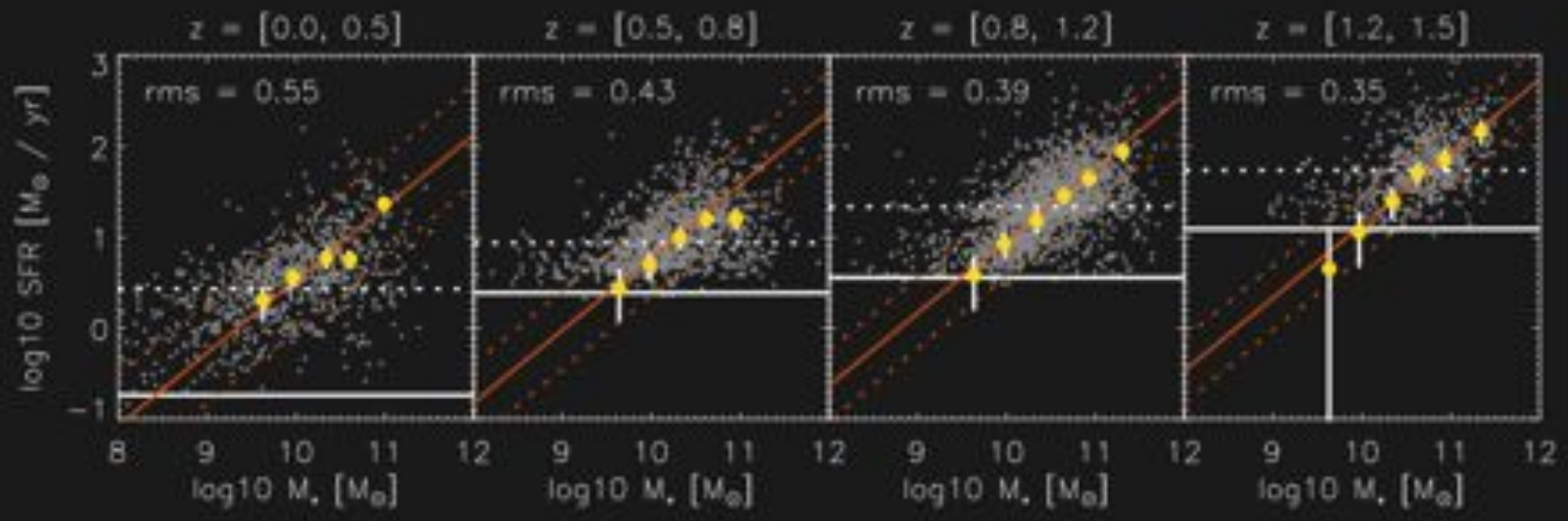
IR8 clearly correlated with morphology perturbations

Open questions :

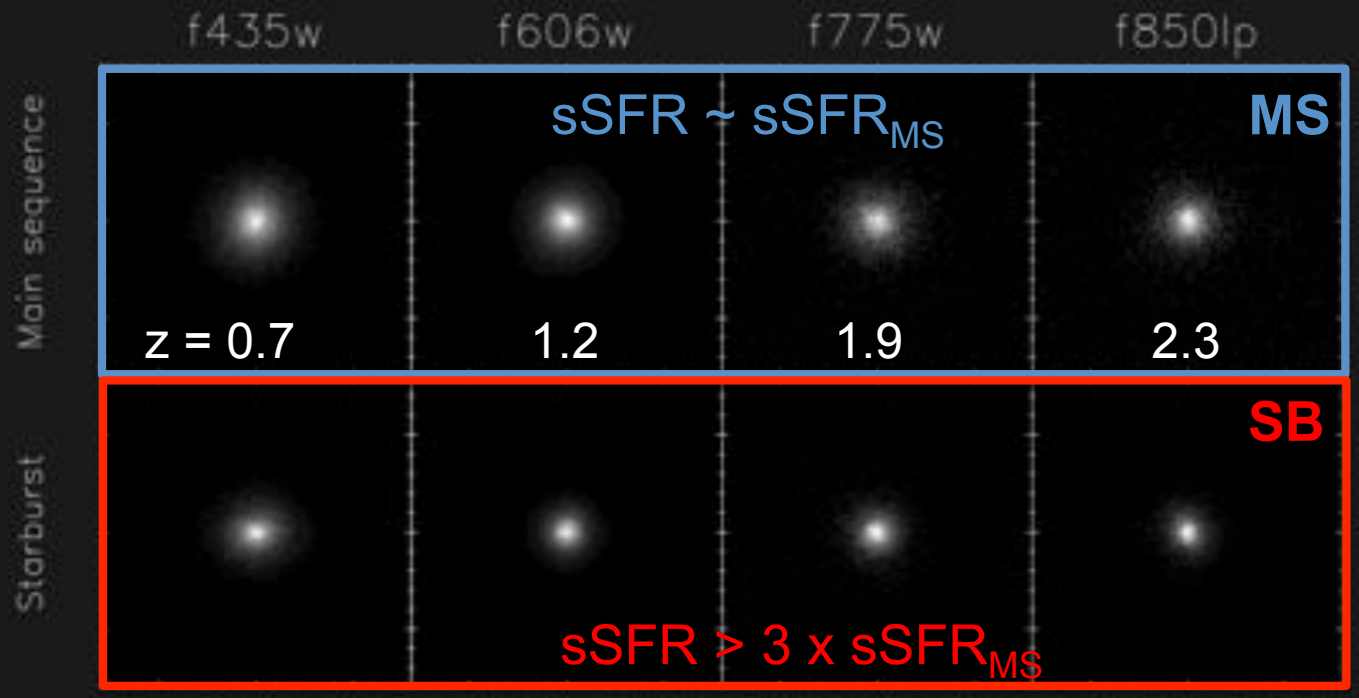
excess-IR8 traces younger mergers than excess-sSFR ?...


GOODS-N
GOODS-S
GOODS-*Herschel* + CANDELS-*Herschel* (UDS & COSMOS)
PI D.Elbaz
PI M.Dickinson
UDS
100 160 250 μm
COSMOS

Stacking Herschel images → normalisation of MS with z + slope
individual detections → dispersion of MS → separation of SB

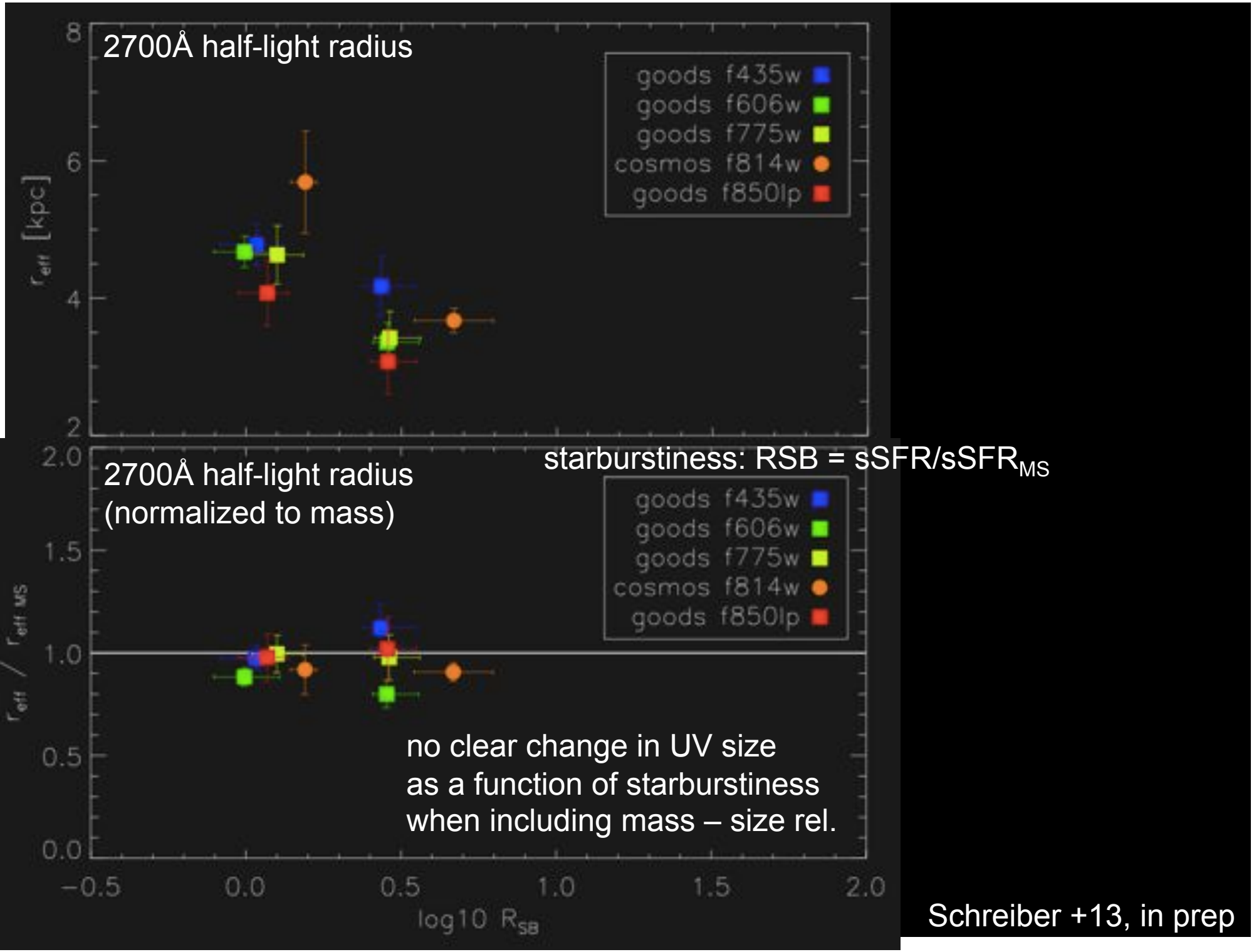


Stacking HST-ACS images → rest-frame 2700Å effective radii of **MS** & **SB** galaxies

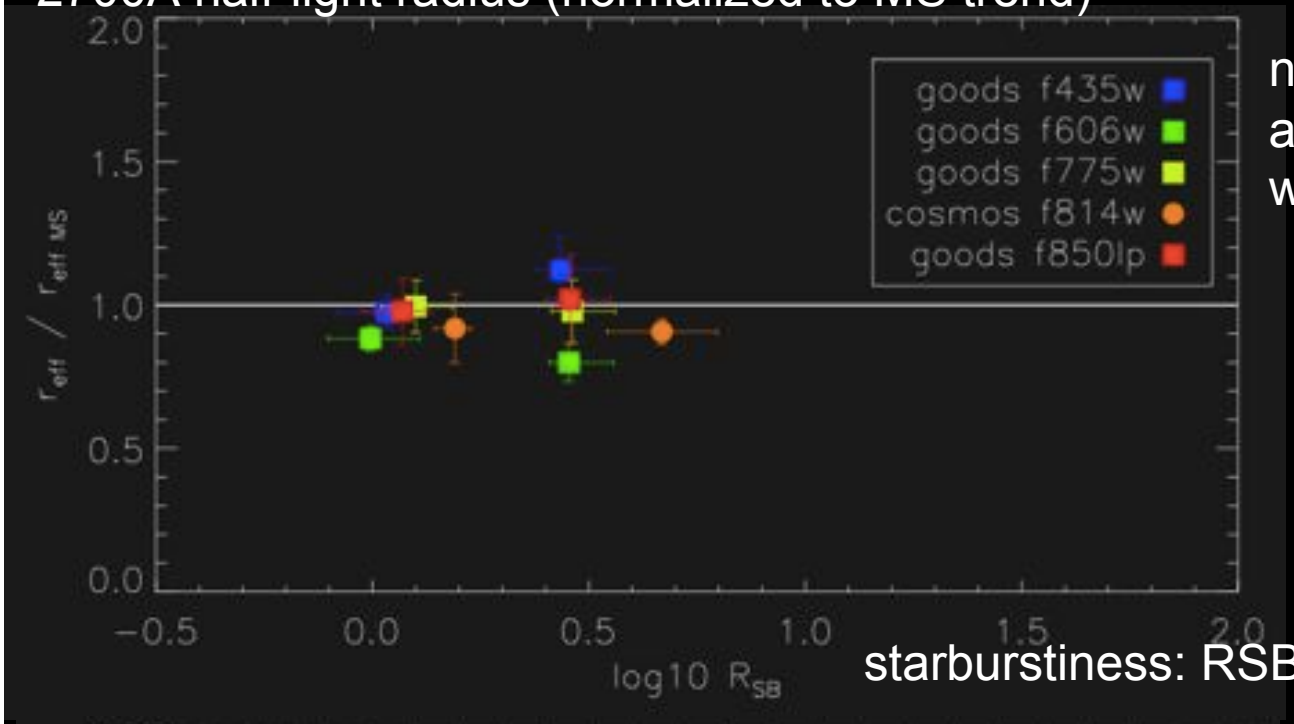


z~1 : 0.2"→1.5 kpc resolution

Schreiber +13, in prep

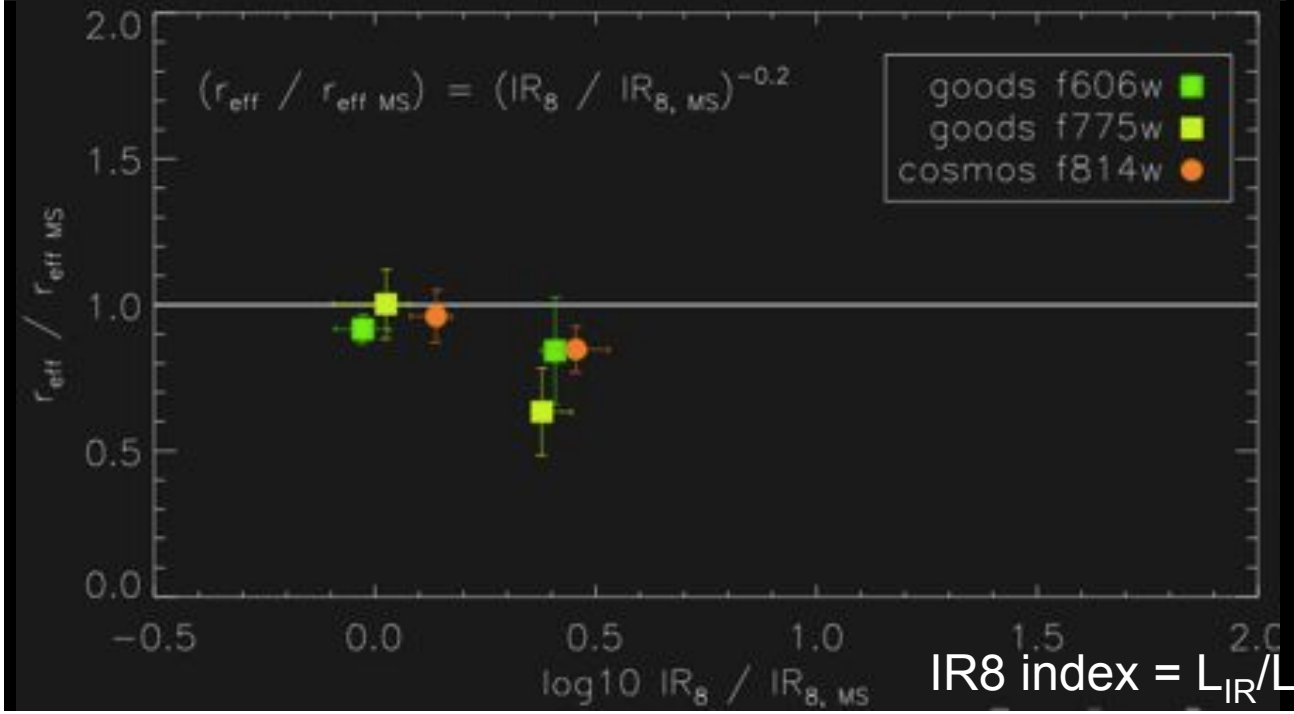

2700Å half-light radius
goods f435w
goods f606w
goods f775w
cosmos f814w
goods f850lp
r_{eff} [kpc]
8
6
4
2
2700Å half-light radius
(normalized to mass)
starburstiness: RSB = sSFR/sSFR$_{MS}$
r_{eff} / $r_{eff\ MS}$
2.0
1.5
1.0
0.5
0.0
no clear change in UV size
as a function of starburstiness
when including mass – size rel.
−0.5
0.0
0.5
1.0
1.5
2.0
log10 R_{SB}
Schreiber +13, in prep

2700Å half-light radius (normalized to MS trend)



no clear change in UV size
as a function of starburstiness
when including mass – size rel.

starburstiness: RSB = $sSFR/sSFR_{MS}$



moderate but robust change
in UV size
as a function of IR8

more linked to SF compactness

IR8 index = $L_{IR}/L_{8\mu m}$

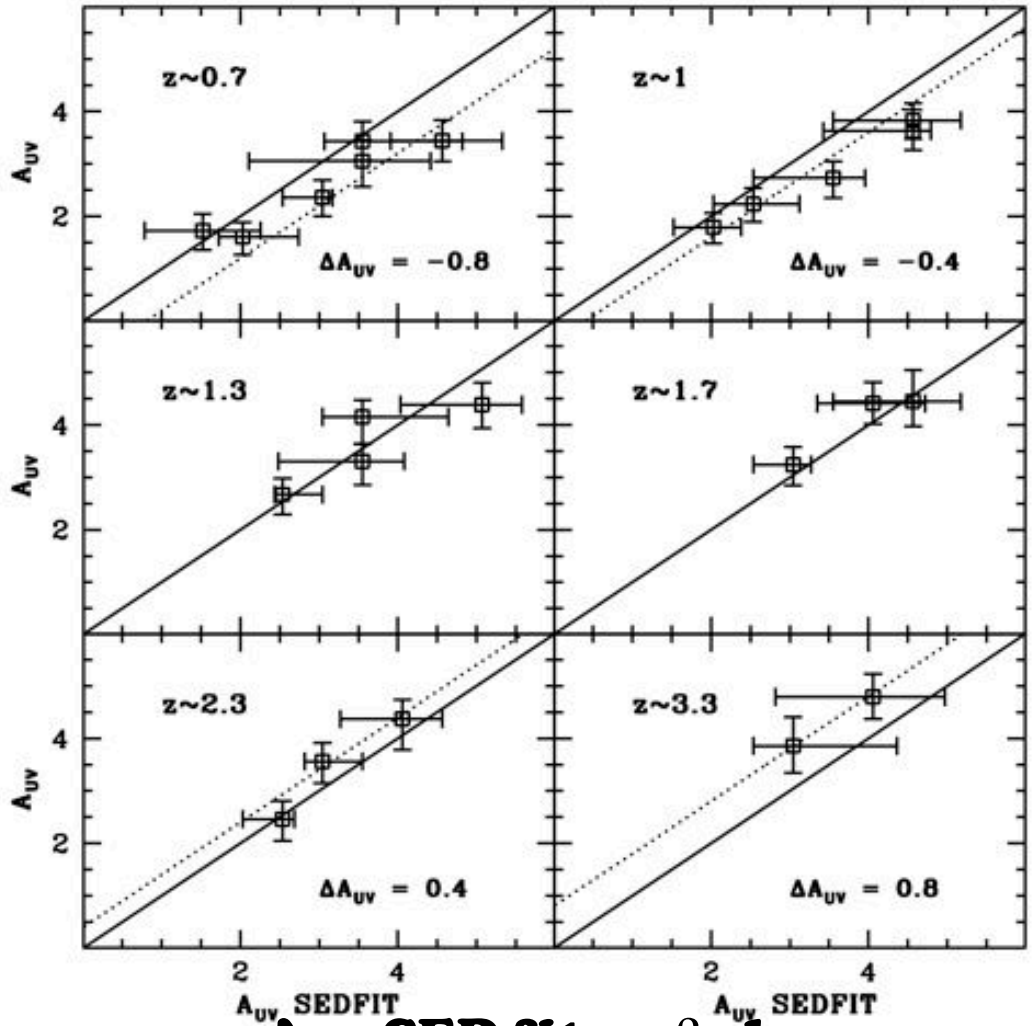
Schreiber +13, in prep

Pannella +13

Calzetti law, β slope:
SFR overestimated at z < 1
SFR underestimated at z > 2

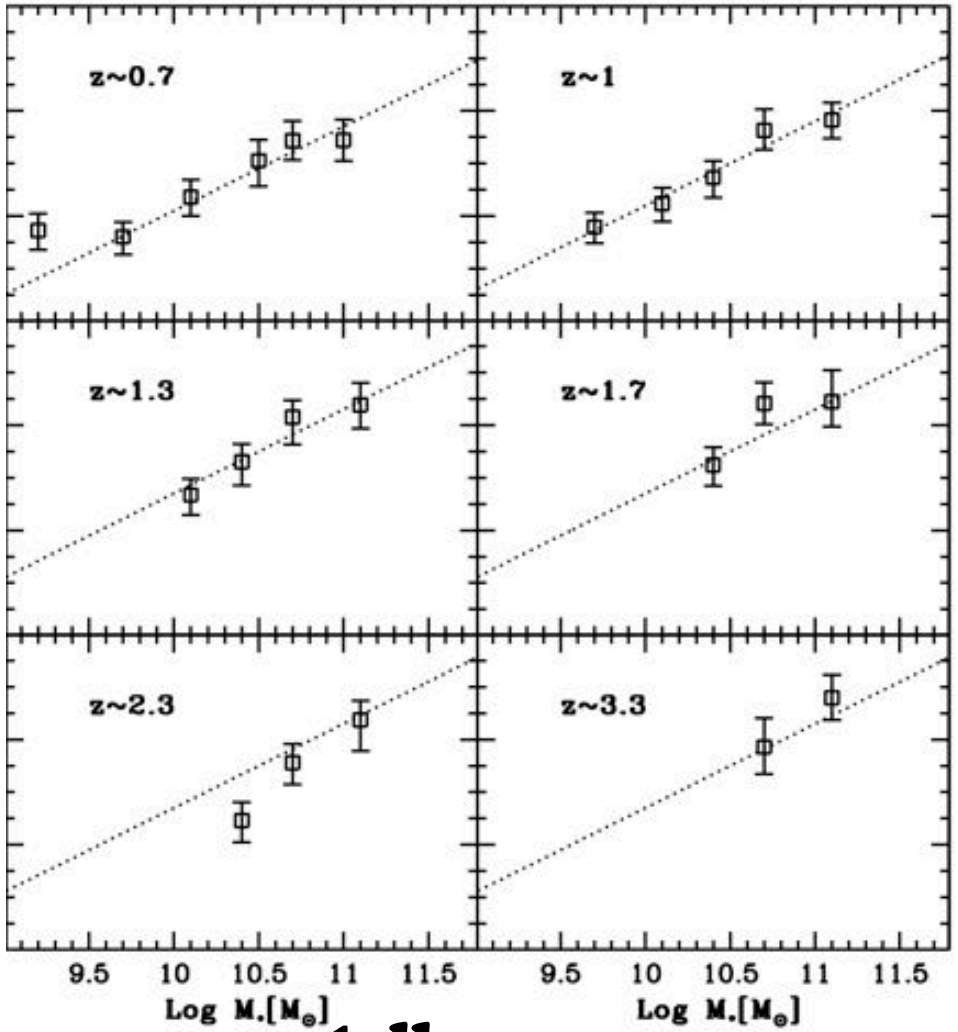
Mstar = best proxy for A_{UV}
(for MS galaxies)

$A_{UV} = 2.5 \log (SFR_{IR}/SFR_{UV} + 1)$

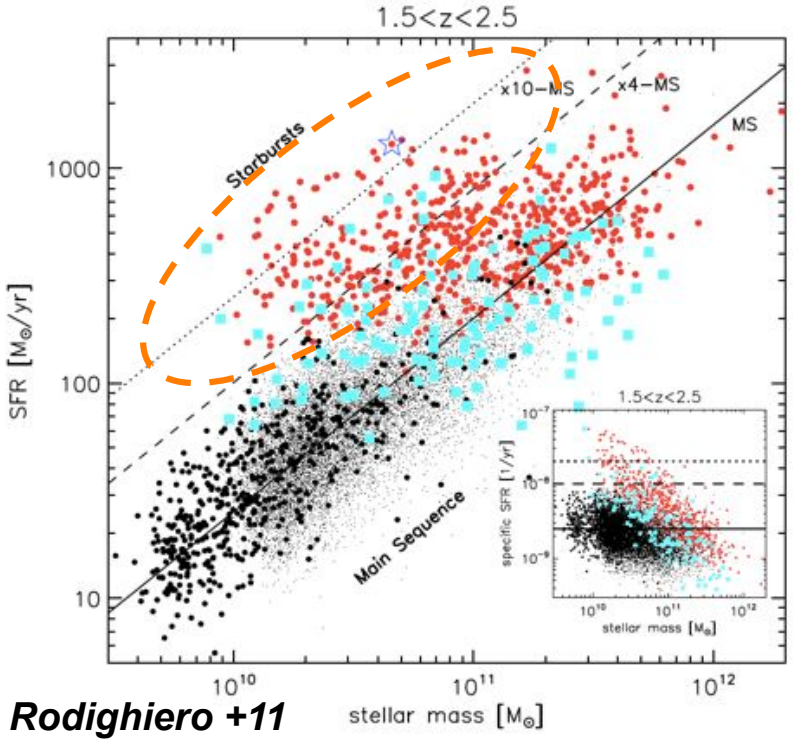


A_{UV} SED fit or β slope

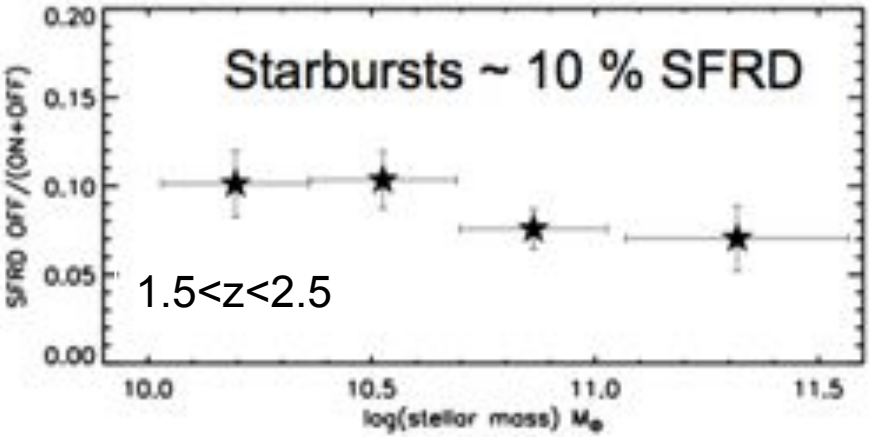
$A_{UV} = 2.5 \log (SFR_{IR}/SFR_{UV} + 1)$



stellar mass

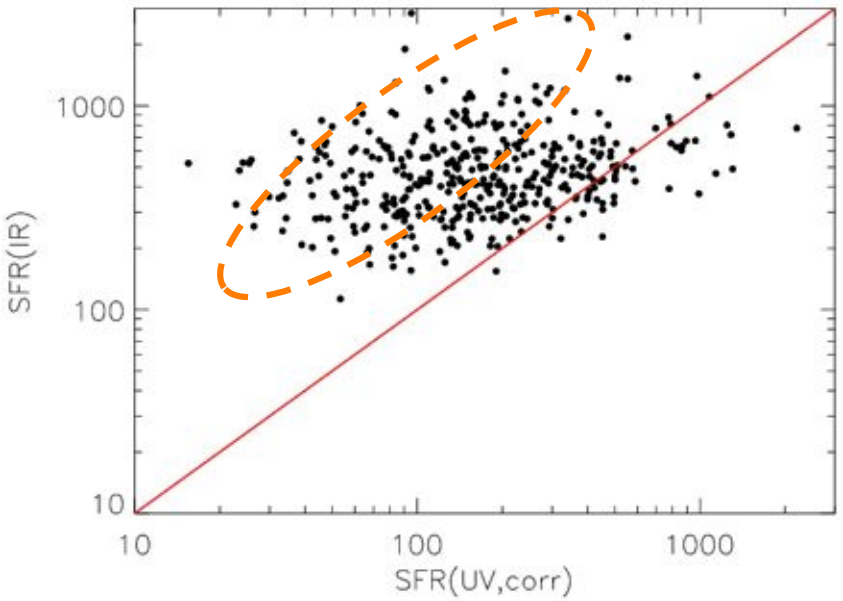


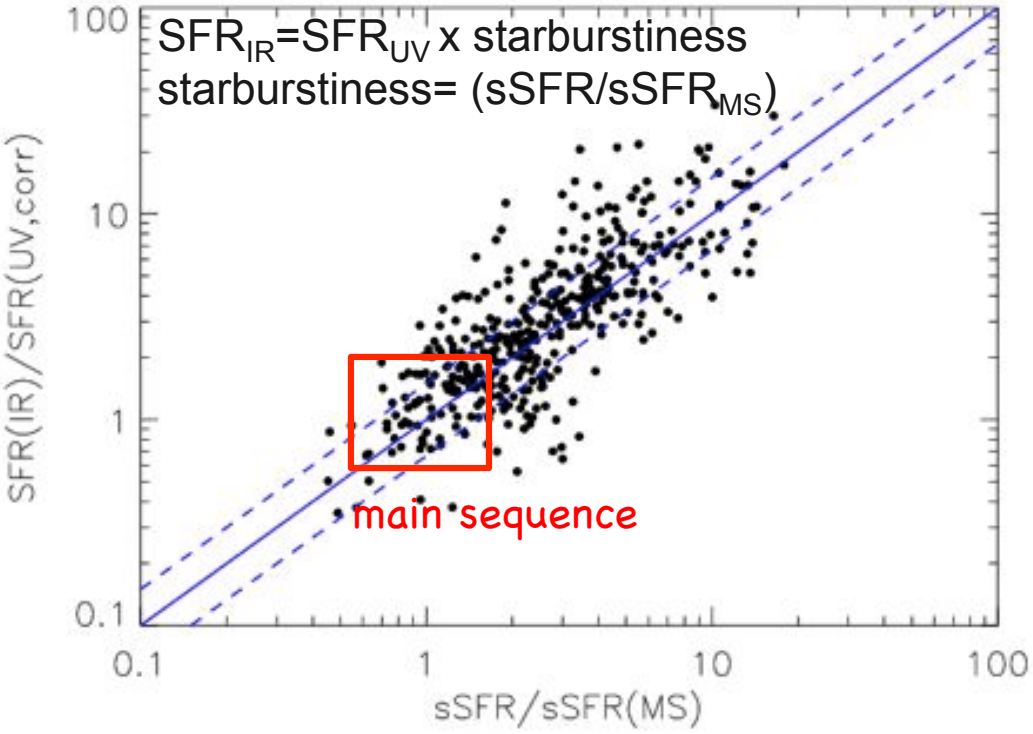
Rodighiero +11



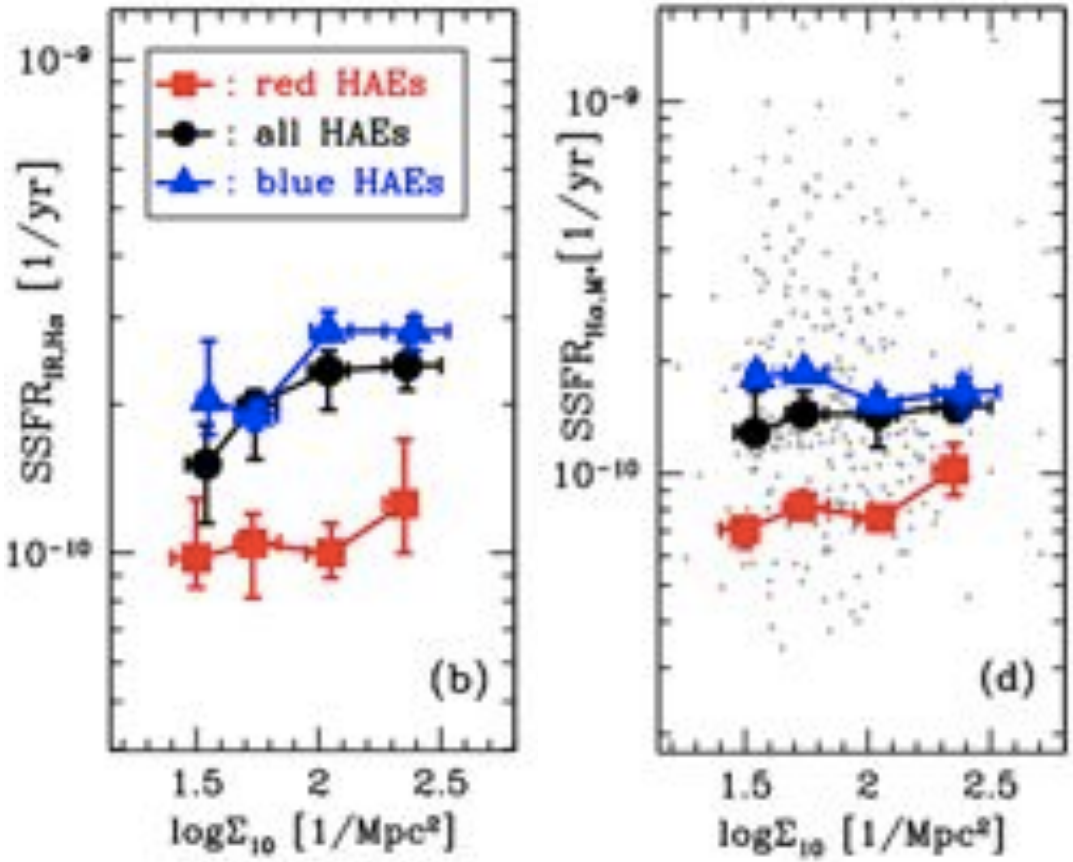
dust unreddened UV from UV slope works for "main sequence" mode

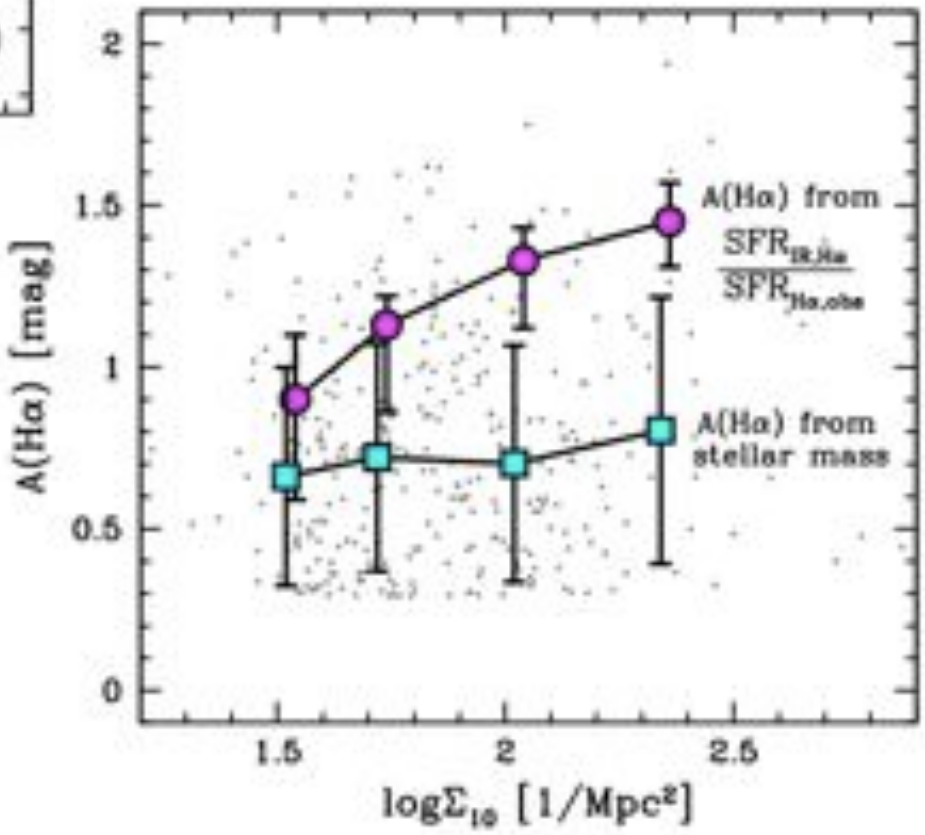
but fails for the stochastic stronger SF events !





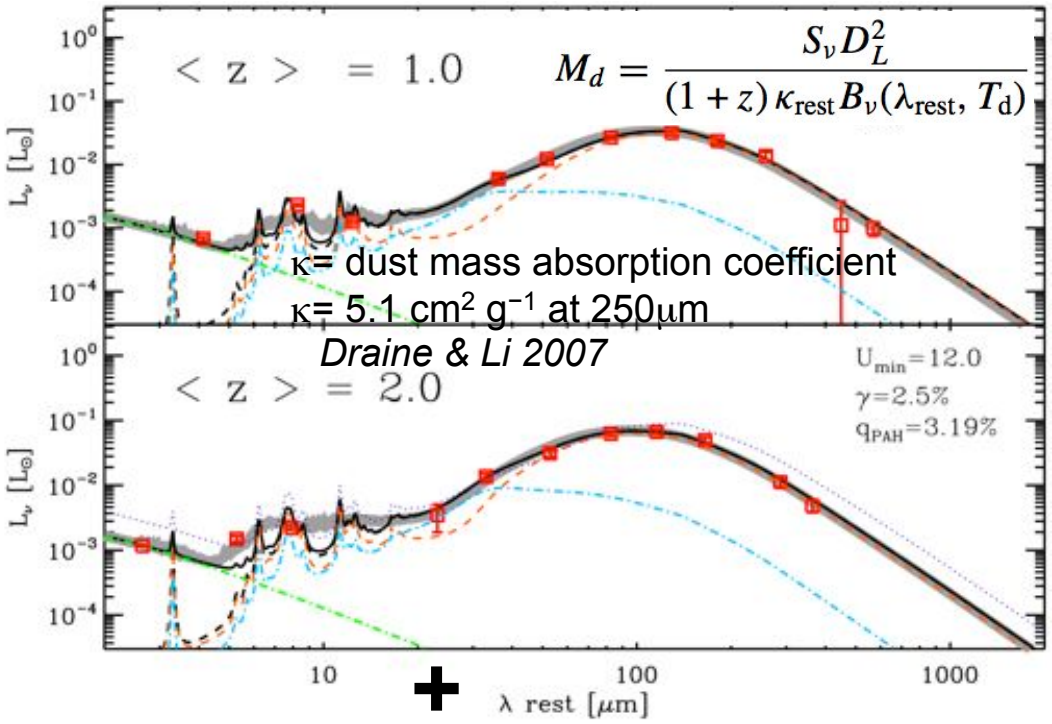
SFR – local density



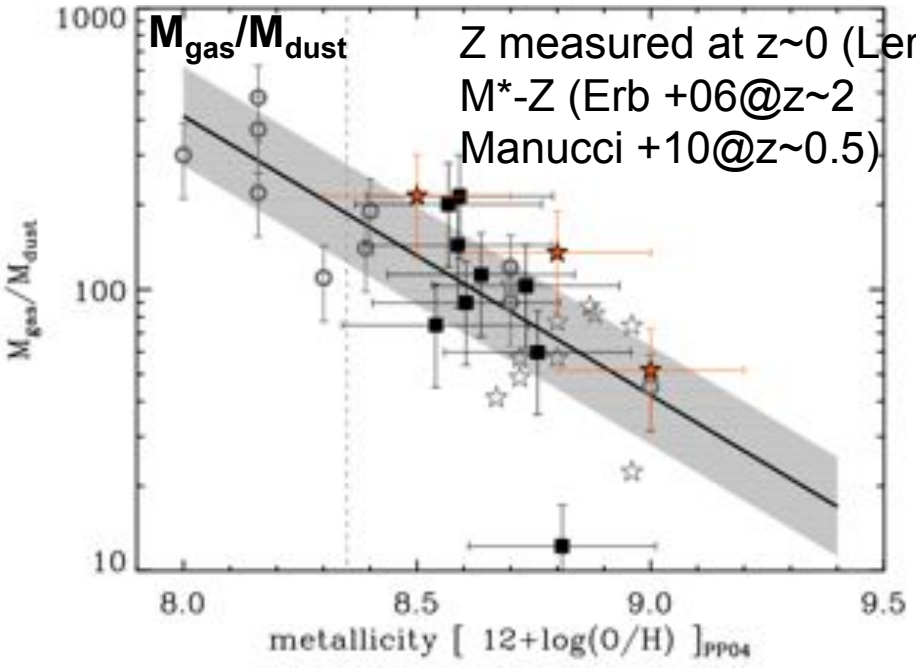


Koyama +13

Estimating the gas content of galaxies from their dust mass (Magdis +12)



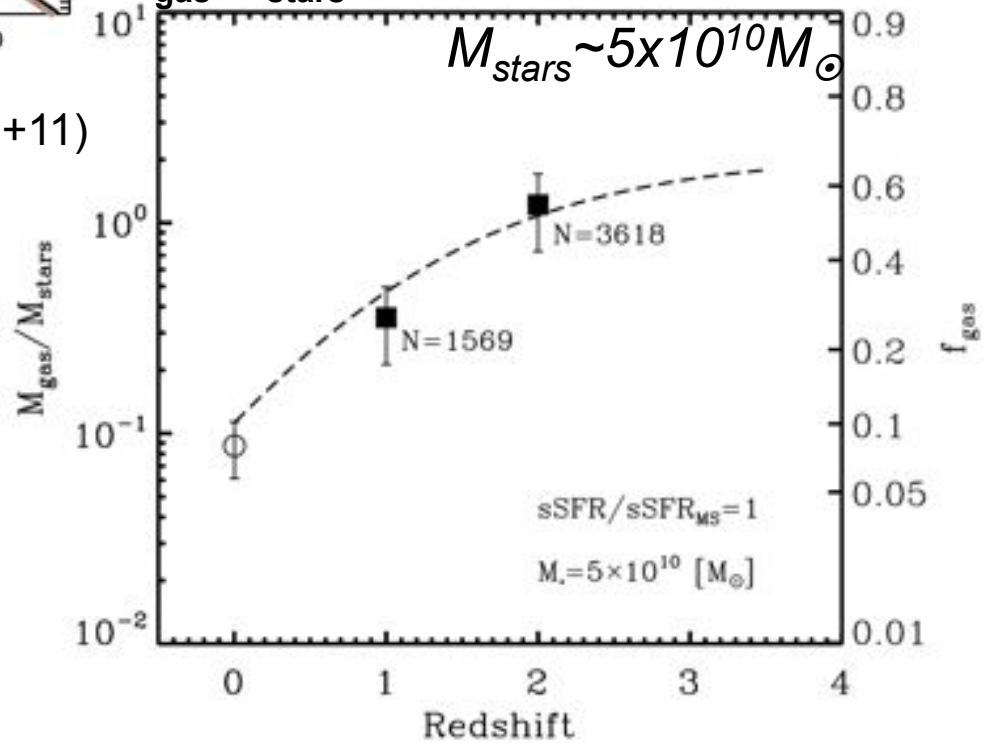
+

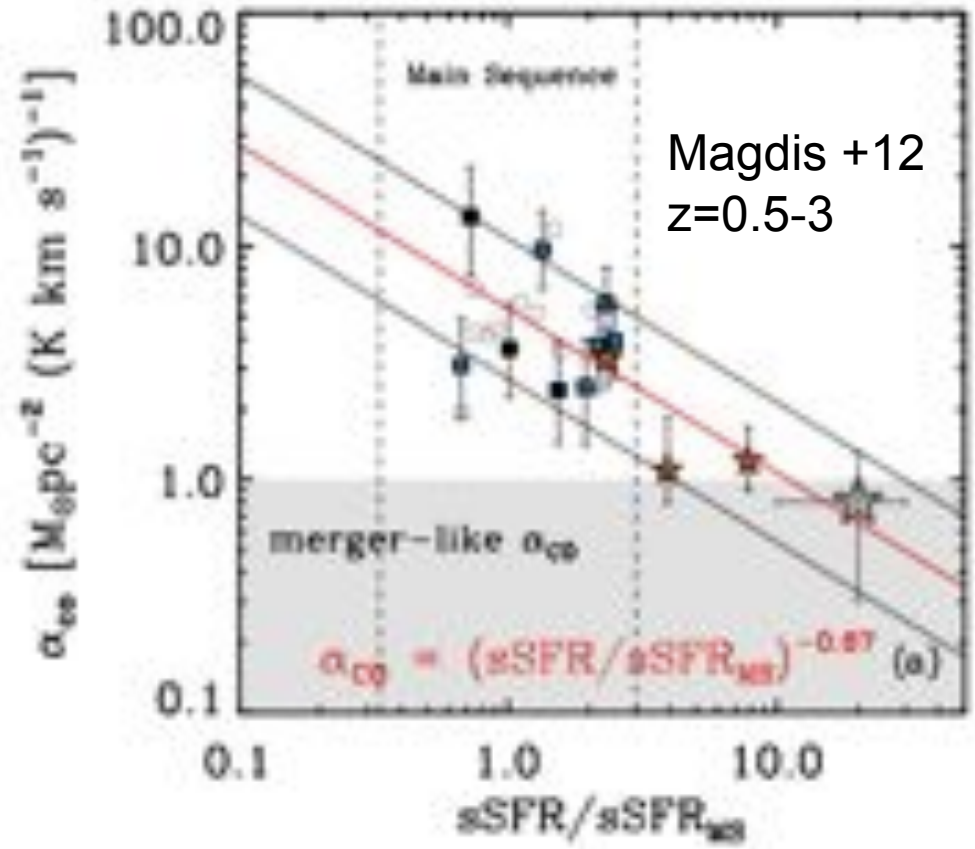


Z measured at z~0 (Leroy +11)
M*-Z (Erb +06@z~2
Manucci +10@z~0.5)

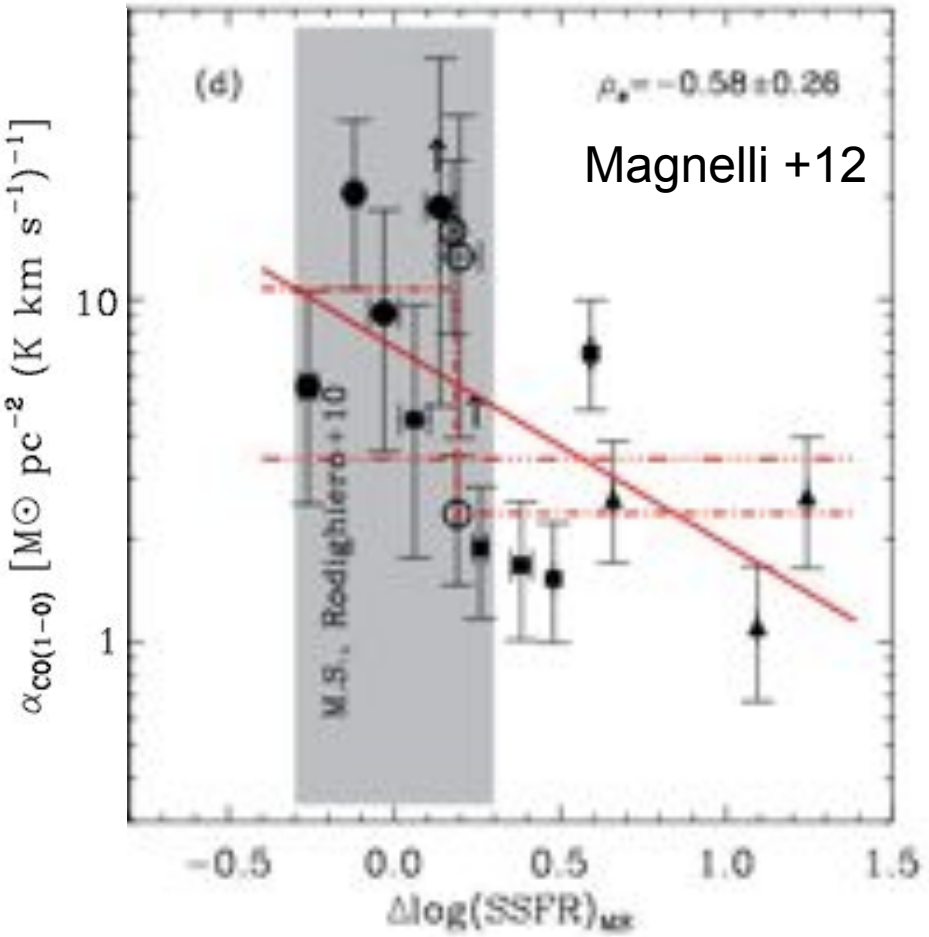
M_* → metallicity → Mgas/Mdust (1)
IR SED → Mdust (2)
(1) & (2) → Mgas

M_{gas}/M_{stars}

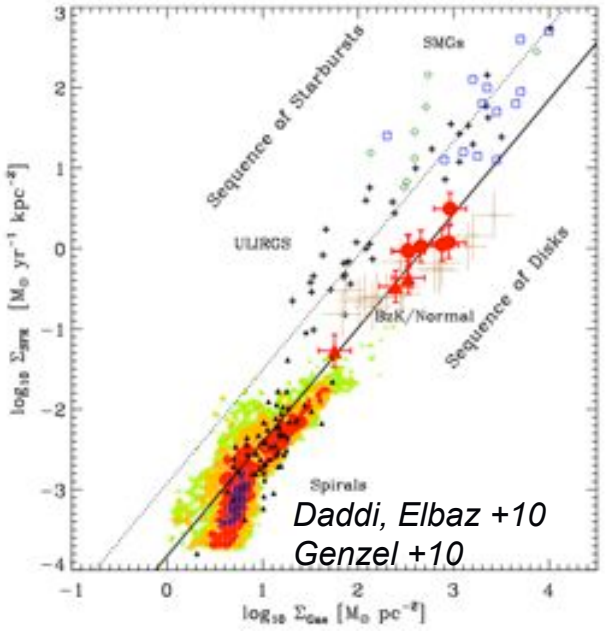




Magdis +12
z=0.5-3

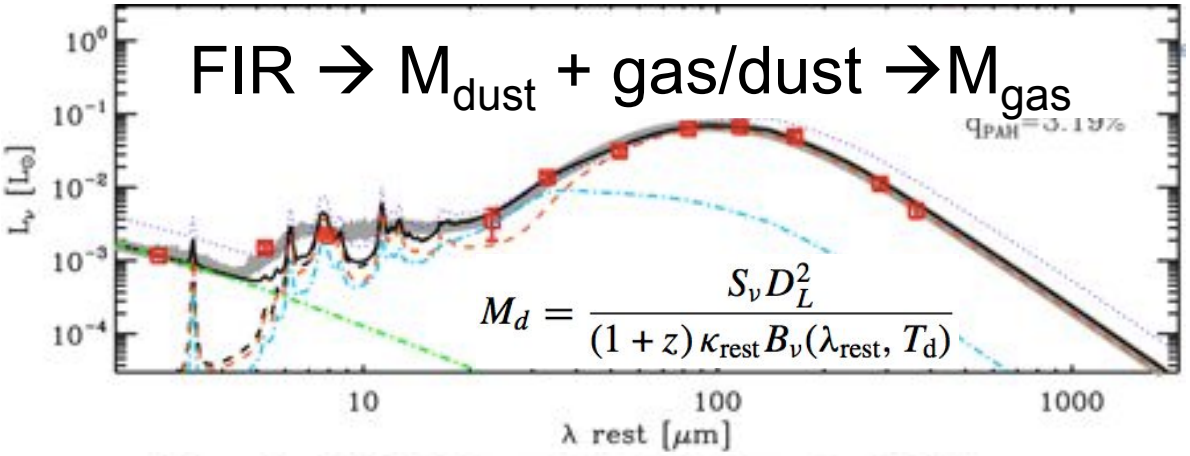


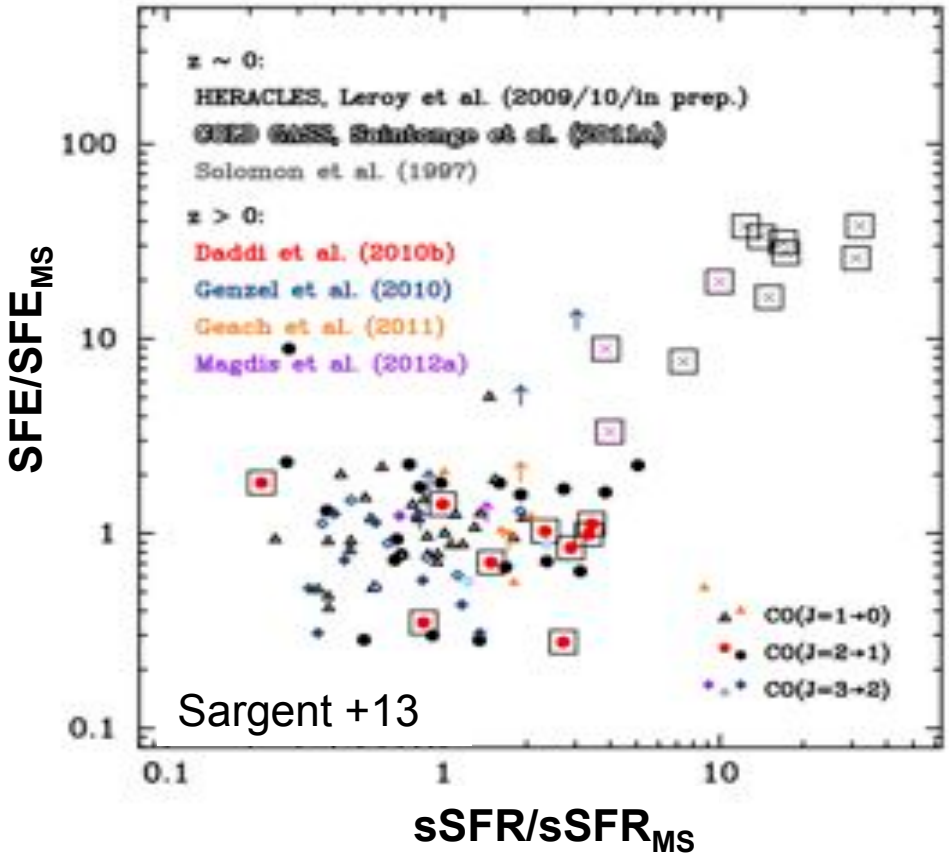
Magnelli +12

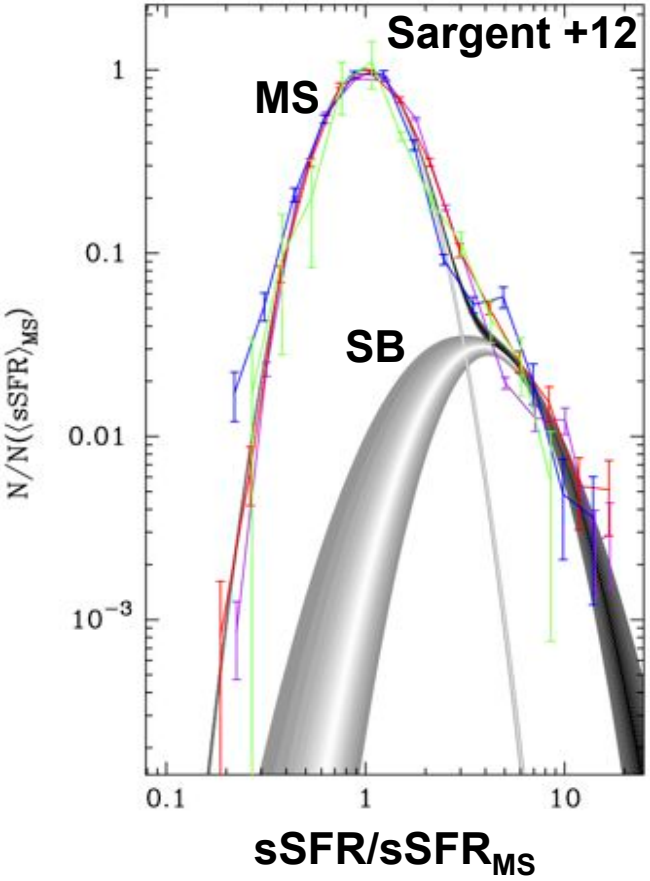


Daddi, Elbaz +10
Genzel +10

2SFM model (two star-formation modes)

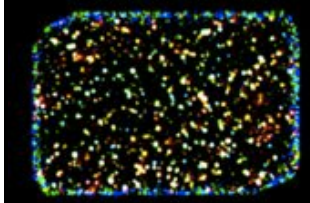
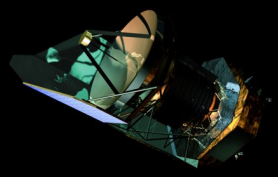




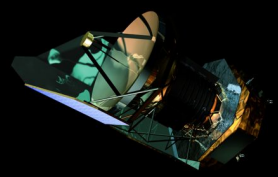
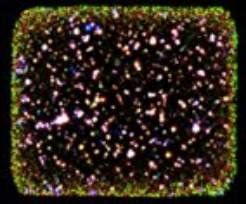


+ stellar mass function vs z :
- fits IR LF from z~0 to 2 (Sargent +12)
- fits number counts from MIR to SMM (Béthermin +12)
- cosmic evolution of H_2 (Magdis +11,12a,b , Sargent +13)

cosmic SFR history mainly from gas content + modest SFE evolution

Conclusions

- a universal star-formation mode dominates the growth of galaxies

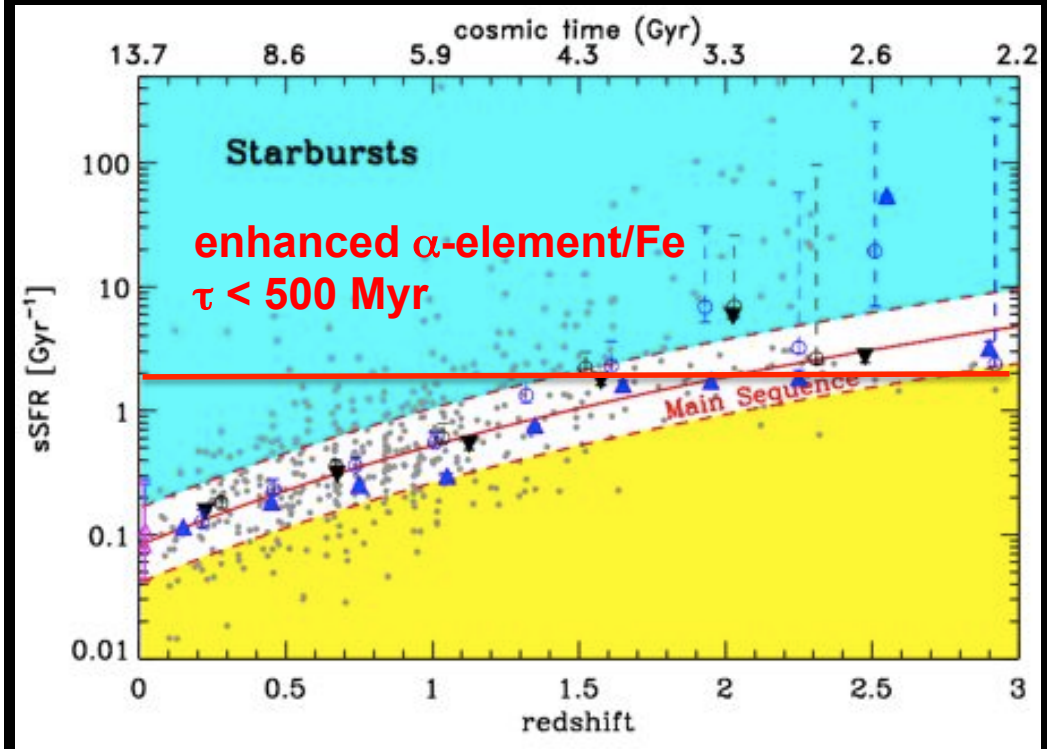
sSFR (starburstiness) & SFE (=SFR/M_{gas}, SK law) & IR8 (SF geometry, compactness)

- yet z>2 MS galaxies formed their stars in <500Myr → bulges

while most z<2 MS galaxies → disks

Variety of objects ← large-scale effects

At small scales, high-densities, matter looses memory of its large-scale origins



Open questions

- main sequence dispersion not well measured at z>2... exists at high-z ?
- what is the physical mechanism responsible for starbursts ?

(mergers/VDI ? Many mergers in main sequence galaxies... Timescale ? low mass SB ?)