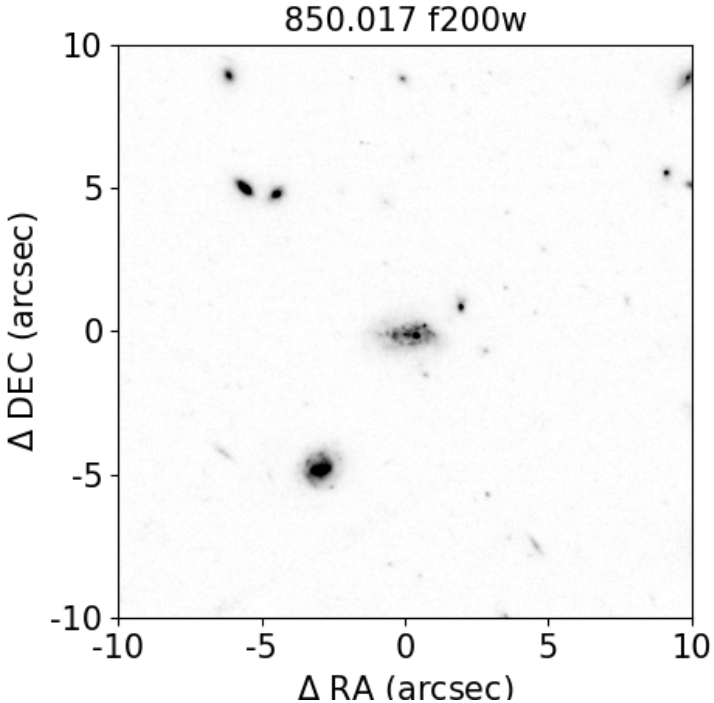
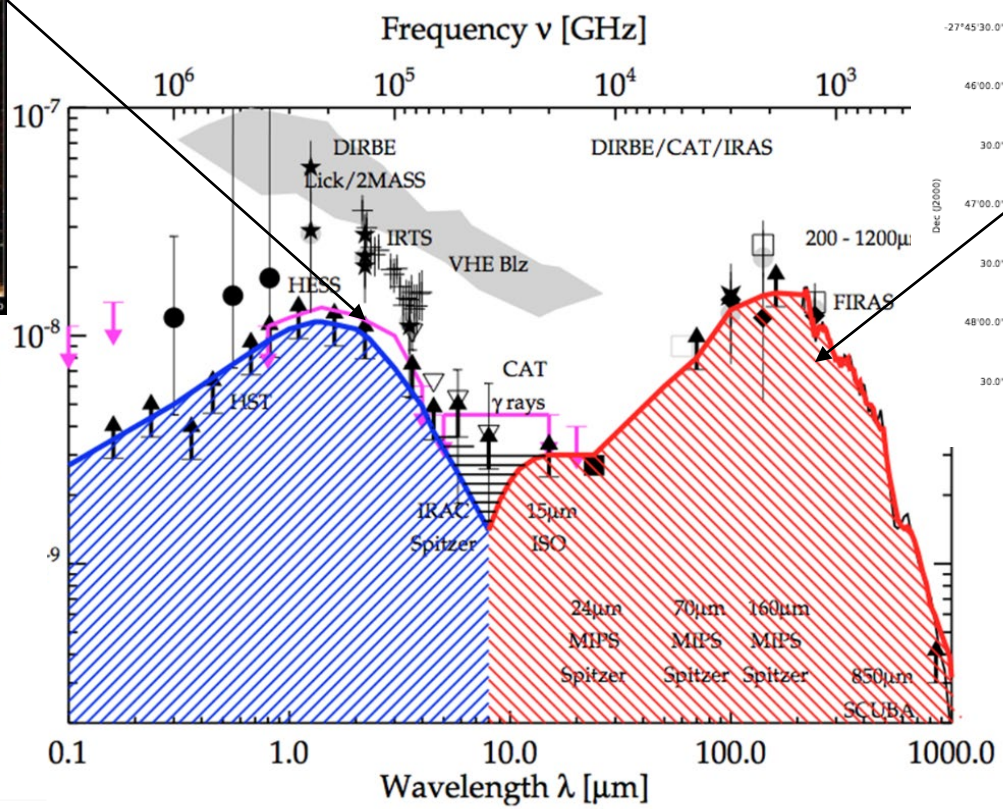
Large starbursts at z~2

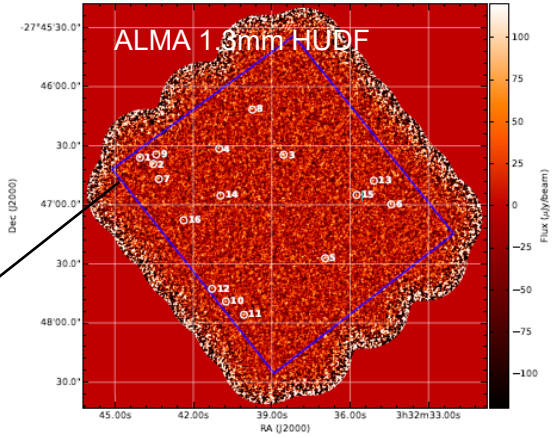
Itziar Aretxaga, Luisa Cardona (PhD student), Alfredo Montaña (INAOE, Mexico),
Jorge Zavala (NAOJ, Japan), Sandra Faber (UCSC, USA)
And the CEERS team



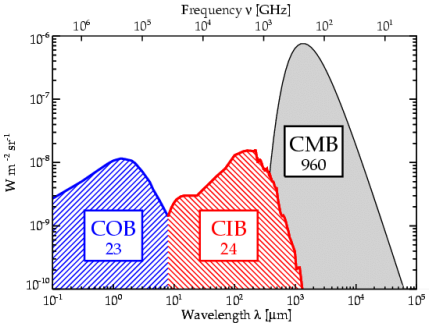
What is the extragalactic background made of?







(Dunlop et al. 2017)

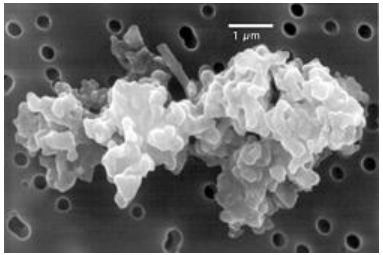


(Kardasev et al. 2014)

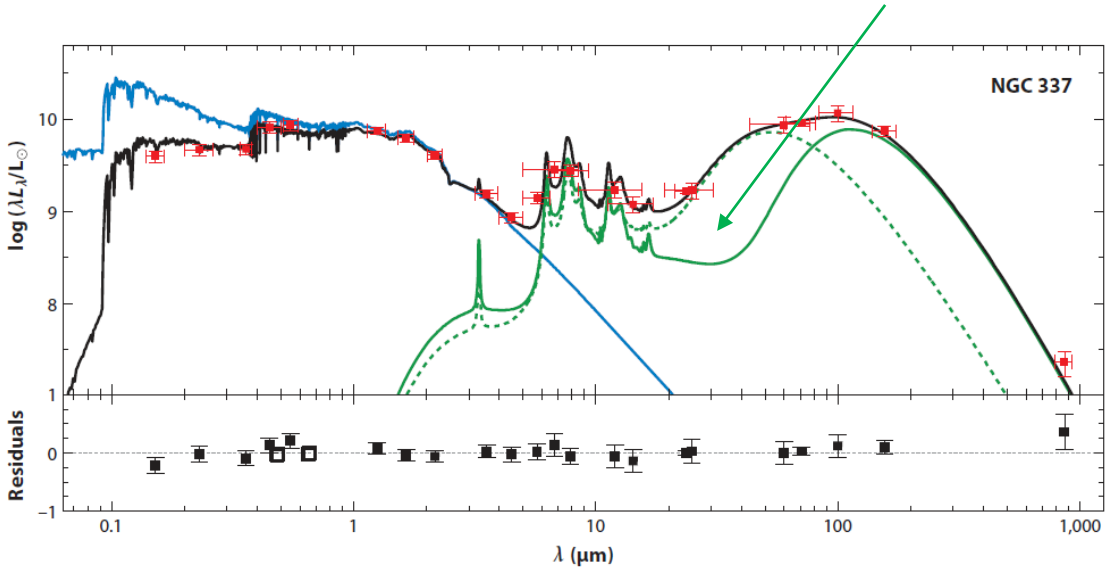
Similar energy outputs in the optical and in the far-infrared

Dust in galaxies: its effect on the SED

The interstellar medium is composed of gas and dust. Dust are solid agregates few molecules to 0.1 μm in size



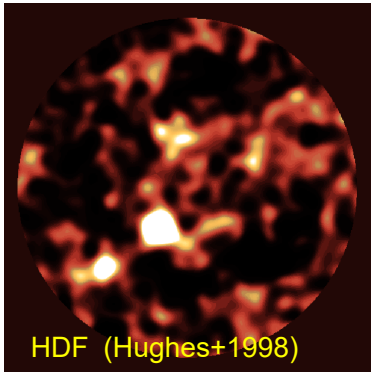
Dust is mixed with molecular gas, it absorbes the UV-optical radiation of stars and reemits it in the far- infrarred-millimeter



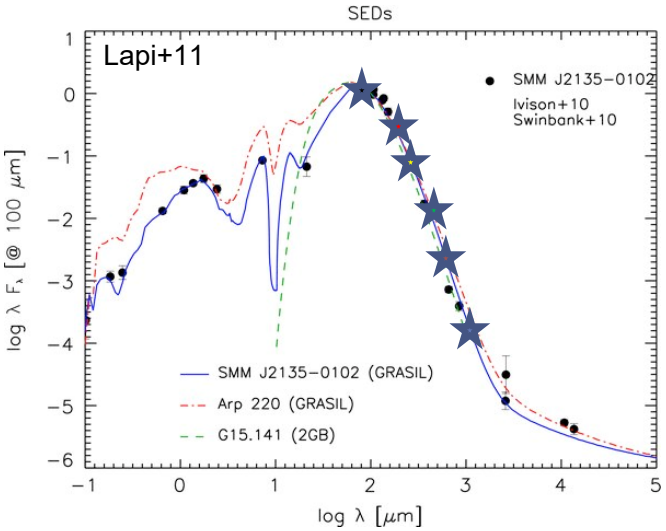
The search for proto-spheroids: SMGs

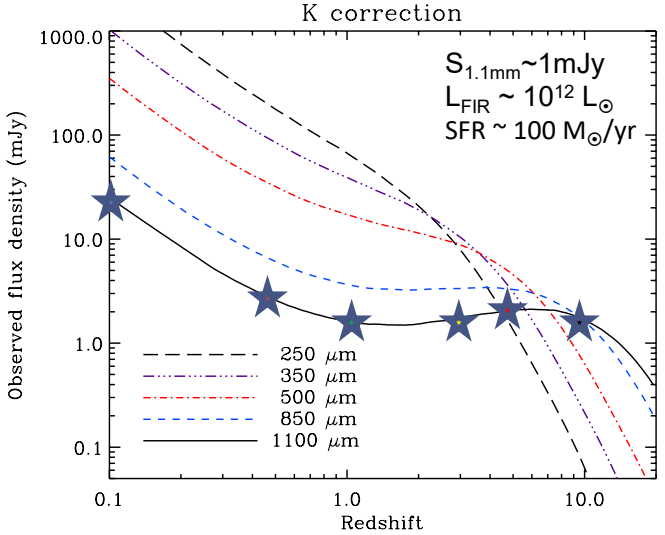
The search for massive ($L>L_*$) elliptical galaxies in formation

z~3, $SFR_{const} \sim M_E/t_{age} \approx 3\times10^{12}\ M_\odot / 2\times10^9$ yr $\approx 1500\ M_\odot$/yr

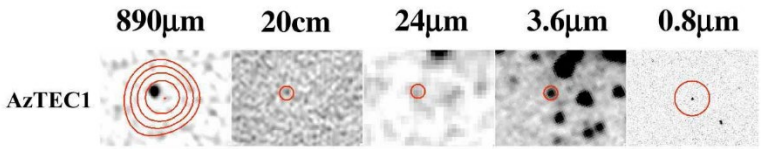


90's – 2000s: Sub-Millimeter Galaxies (SMGs) and QSO hosts PROMISSING CANDIDATE (Smail+1997, Hughes+1998, Barger+1998): SFR >500 – 1000 $M_\odot$/yr , z > 2. They might be related to QSO formation and/or evolution (Granato+04), as a precursor to these systems.

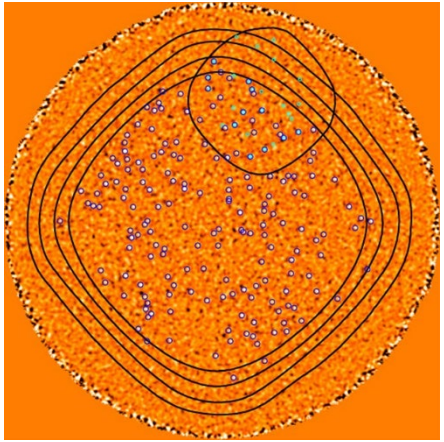




AzTEC1,
the brightest galaxy in COSMOS



Multiwavelength counterparts (Younger et al. 2007)



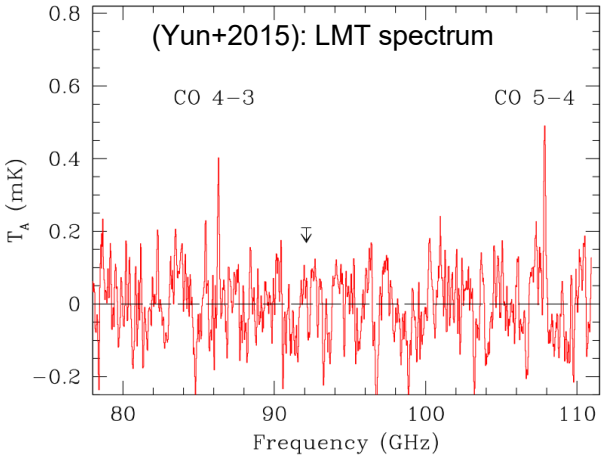
(Aretxaga+2011): 0.7 sq. deg

- AzTEC1 $S_{1.1mm}$=10.0 ± 1.1mJy the brightest in COSMOS, the brightest source.
- It does not show signs of being amplified.
- SMA 870μm interferometry (0.8" resolution), not resolved. (Younger et al. 2008)

z=4.3 SFR~1200 $M_\odot$/yr

M_*~1.5x$10^{11}M_\odot$ L_{FIR}=9 x 10^{12} $L_\odot$

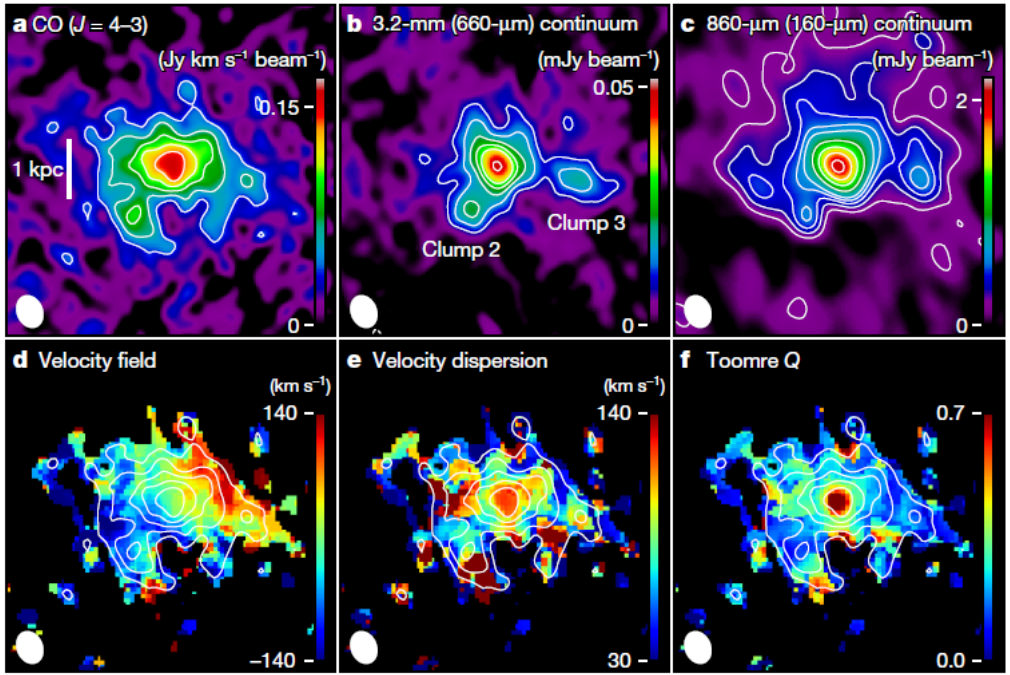
M_{gas}~3.7x$10^{11}M_\odot$ (Yun et al, 2015)



ALMA follow-up of AzTEC 1

75% of the flux is distributed in a smooth disk-like structure that extends 3-4kpc, but dominated by < 1.5kpc (Iono et la. 2016). It is a gravitationally unstable gas disk of a starburst galaxy (Tadaki et al. 2018).

Toomre $Q = \kappa\sigma_{0,gas}/(\pi G\Sigma_{gas})$ describes the balance between self-gravity of molecular gas and turbulent pressure by stellar radiation and other sources. Qcri < 0.67 for a thick disk, unestable.

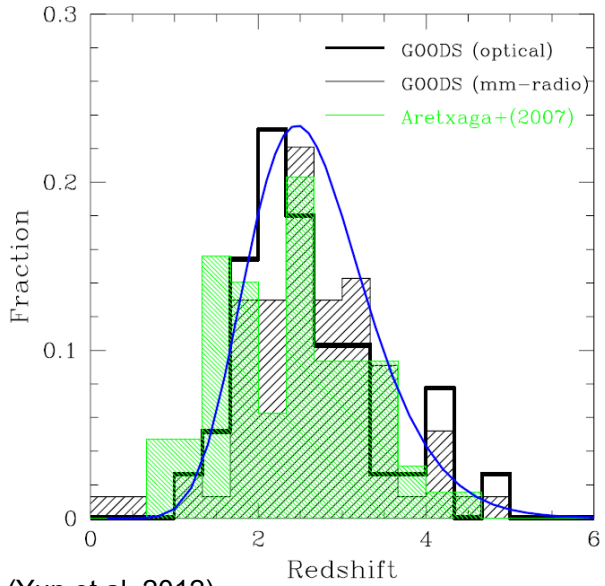


SMGs as progenitors of massive elliptical galaxies

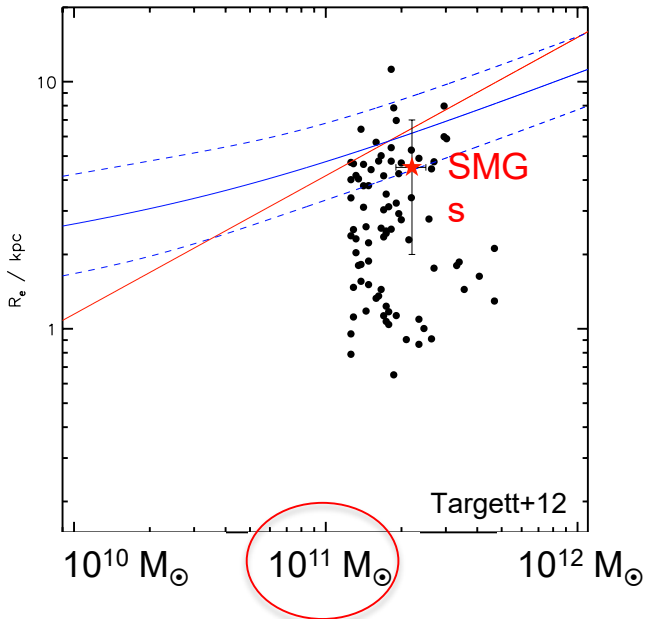
Properties:

- $L_{FIR} > 10^{12} L_{\odot}$
- $SFR > 100\ M_{\odot}/yr$
- $M_{*} > 10^{11} M_{\odot}$
- $z_{median} \sim 2.5$

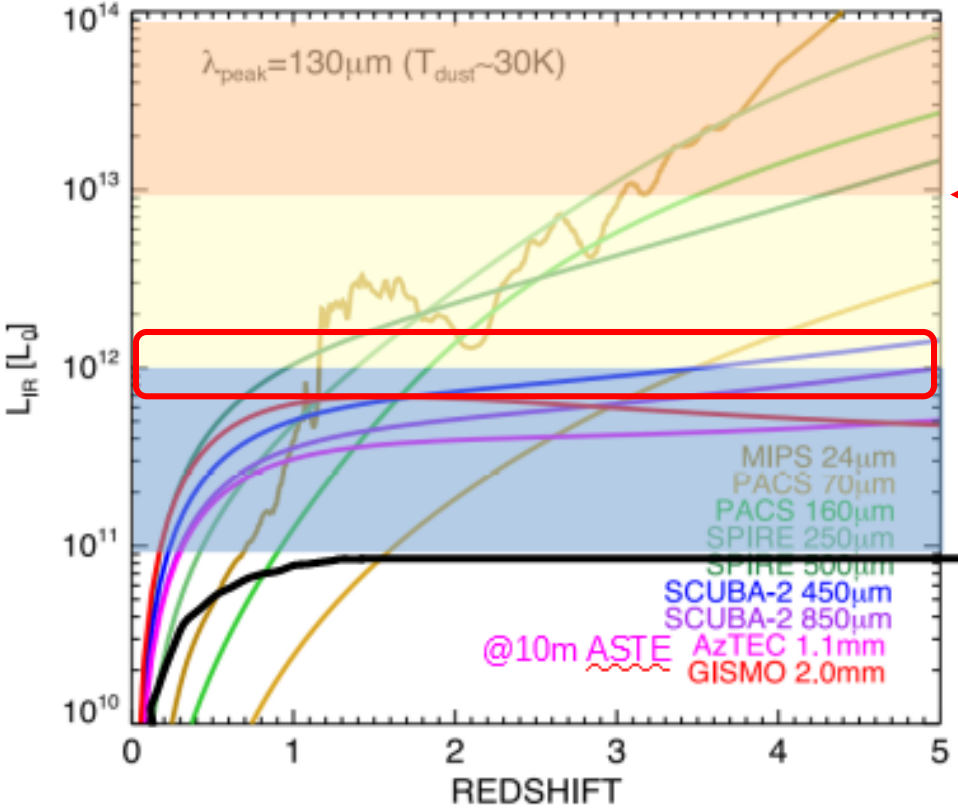
⇒ Good candidates



(Yun et al. 2012)



Dusty star forming galaxies (DSFGs)



HyLIRGs

AzTEC1

ULIRGs

LIRGs

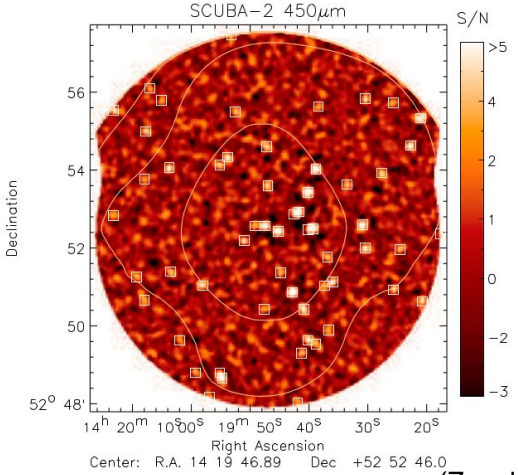
LMT @ 1.1mm

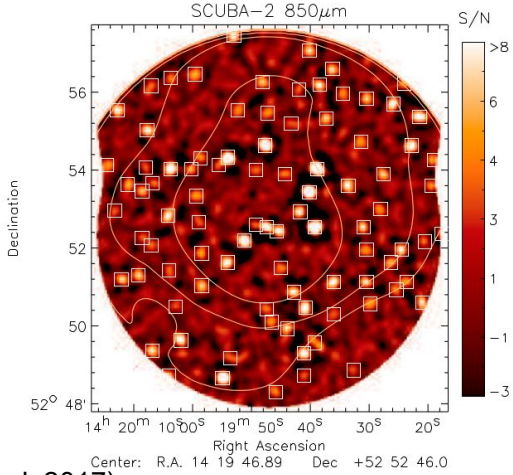
(Adapted from Casey et al. 2014)

Targett+12

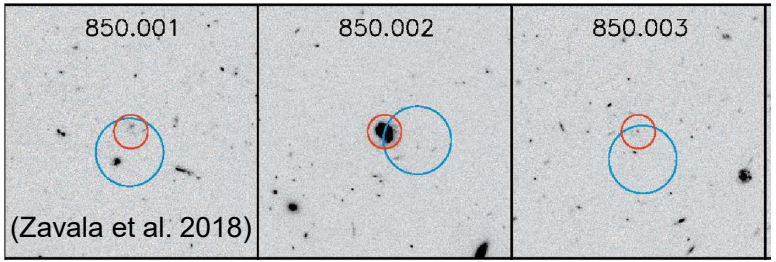
Scott+10

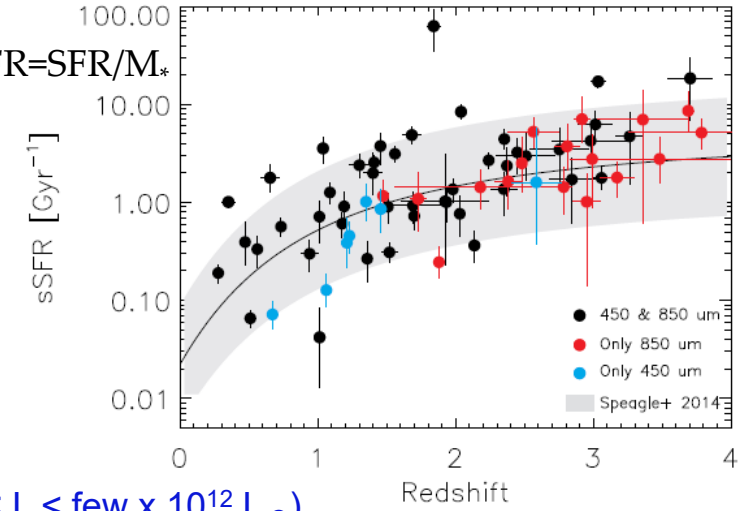
S2CLS dusty galaxy population





(Zavala et al. 2017)





Data acquired 2012-2015, 70 sq. arcmin^2

σ_{450} = 1.9 mJy/beam $1\sigma_{850}$ = 0.5 mJy/beam

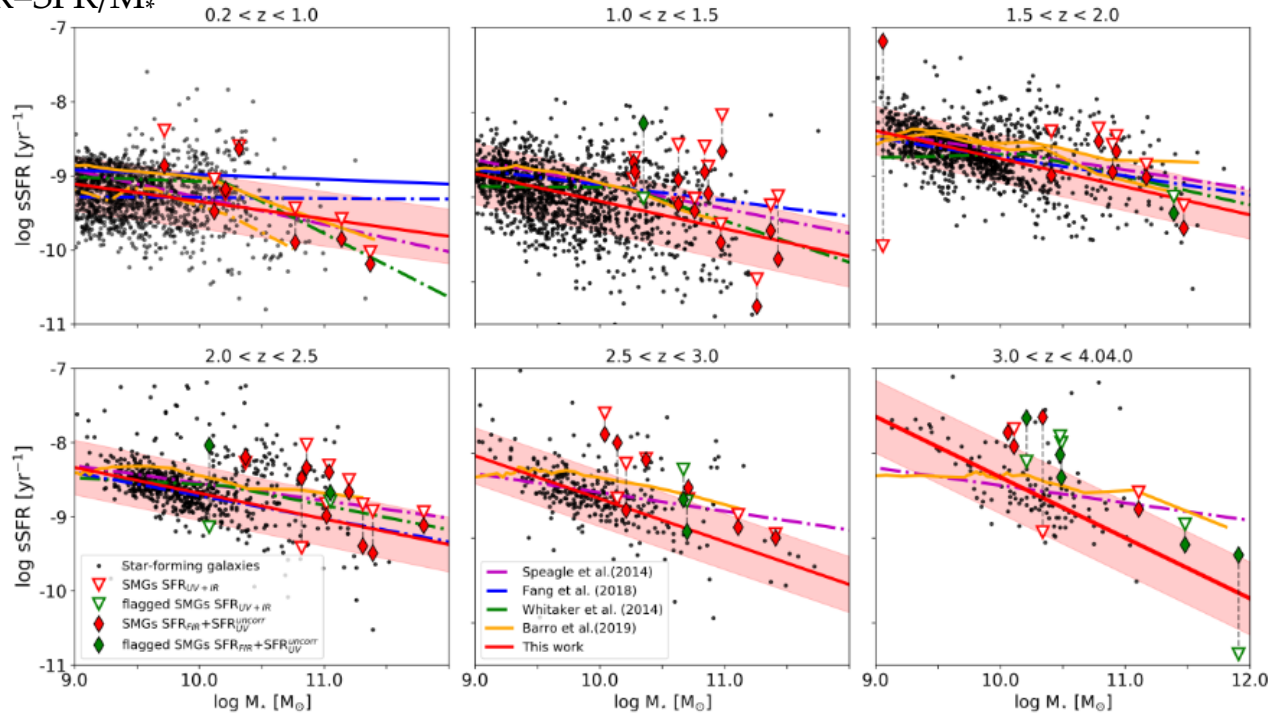
57 sources 90 sources at S/N>3.5 -> 95 unique IDed

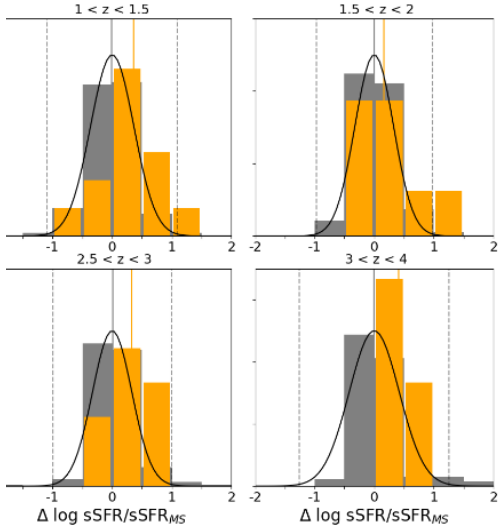
θ~8.5” θ~14.5”

Faint SMGs (S_{850um}< 6 mJy) Most Dusty SF gals (few x 10^{11} $L_\odot$ < L < few x 10^{12} $L_\odot$) on Main Sequence

Dusty galaxy population: extreme SF galaxies

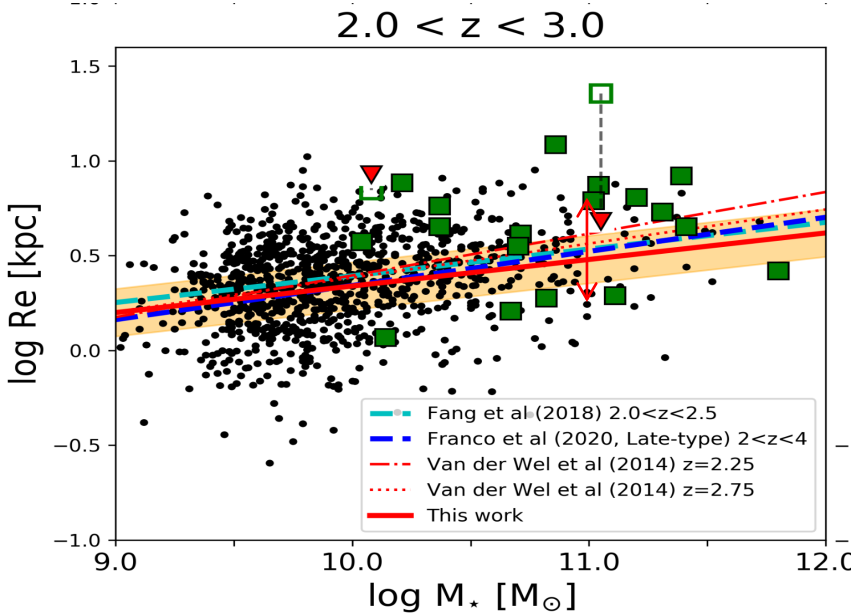
sSFR=SFR/M_*

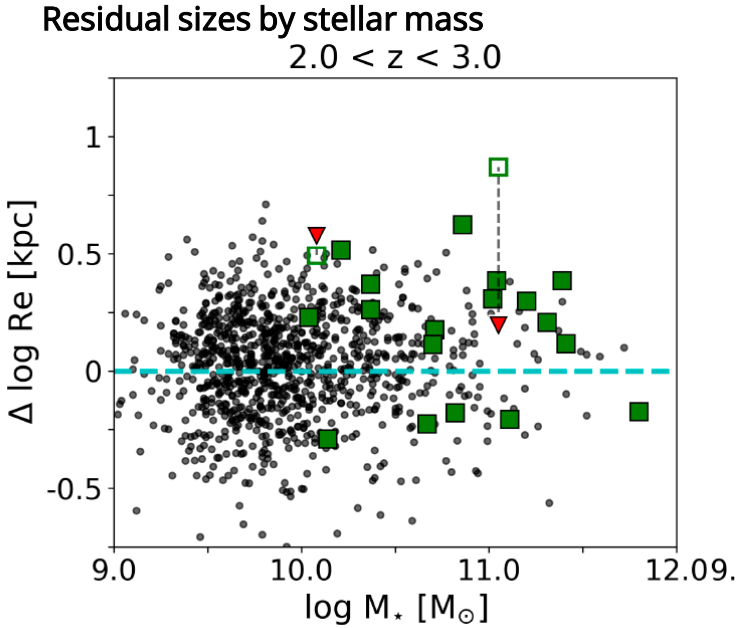




35% SMGs are starbursts with R_{SB}= SFR_{FIR}/SFR_{MS} > 3, 75% above the Main Sequence, and 2% above 3σ. Notice the differences in MS among different fields. (Cardona-Torres et al. 2023)

F160W morphology: size-mass relation





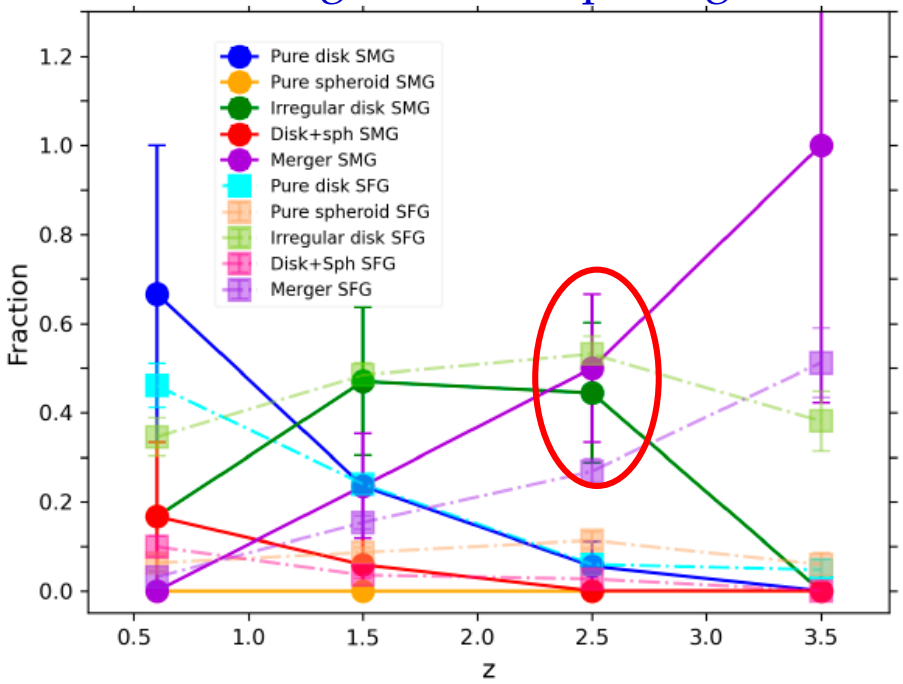
SMGs are significantly larger than SFGs at z<3. When we explore residuals to size-mass relation we find they are significantly larger than typical SFGs of the same stellar mass only at 2<z<3.

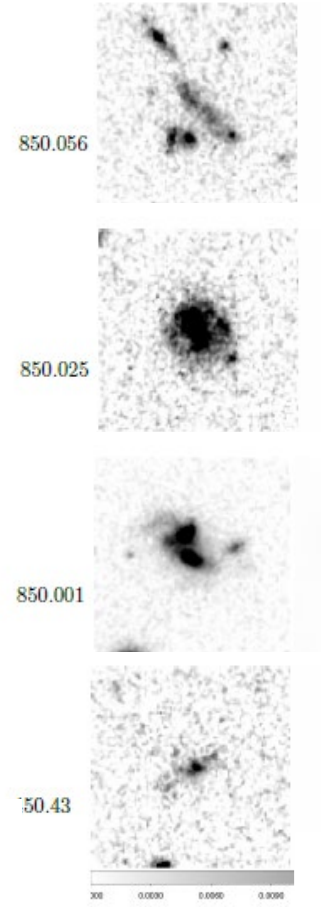
Median SFG R_e=2.71±0.03 kpc

Median SMG R_e=4.8±0.4 kpc

Cardona-Torres et al (2023)

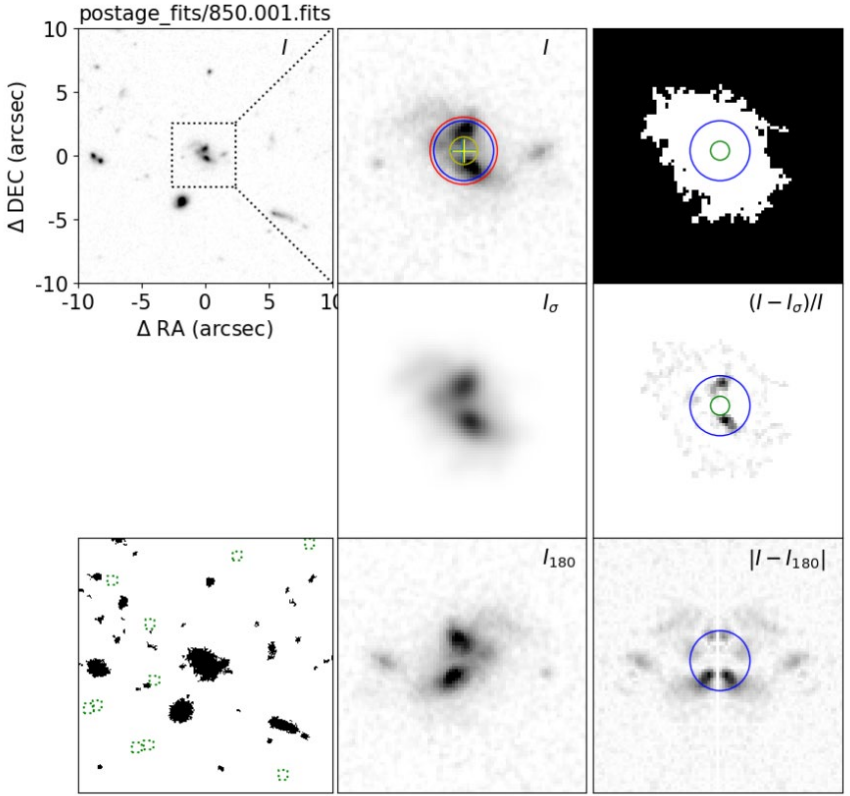
Dusty star-forming galaxy population at ~10^{12} $L_\odot$ more merger-like morphologies



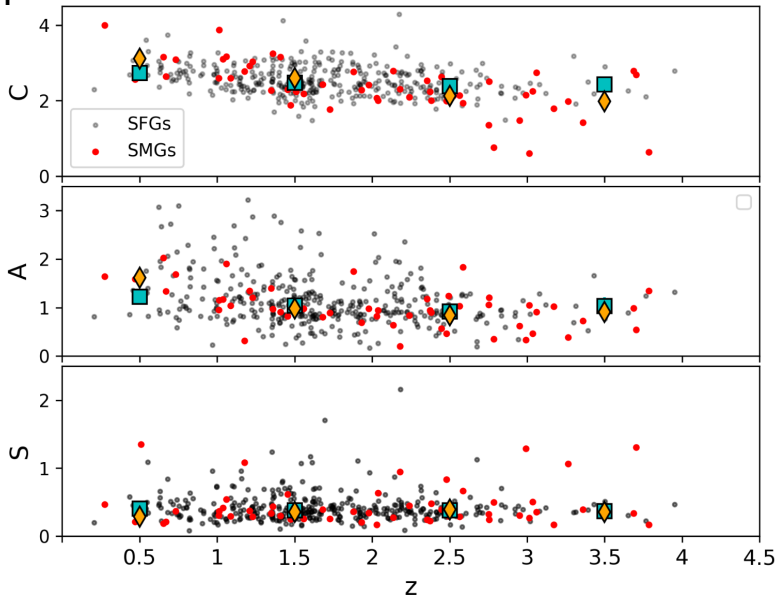


57 S2CLS EGS dusty SFGs (L_{IR} ~ 10^{12} $L_\odot$) : at 2<z<3 they are 50% larger sizes than SFGs of similar mass. Coincident with peak of SBs (~80%) , and indeed most have merger morphologies (43%) or irregular disks (57%) (Cardona-Torres et al. 2023)

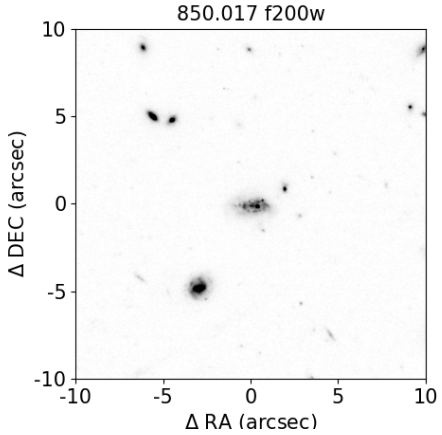
Dusty star-forming galaxy population at ~10^{12} $L_\odot$ evolution of the concentration with time

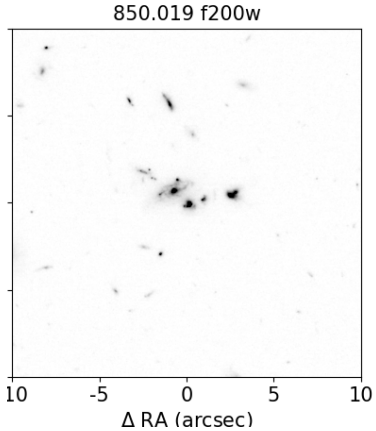


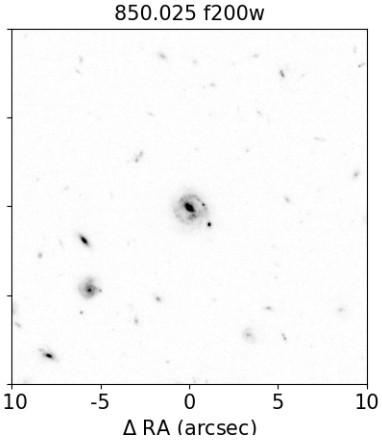
We find evolution of the concentration of SMGs, and SMGs are significantly more concentrated than SFGs of M★>1011 M⊙ at z < 1.4

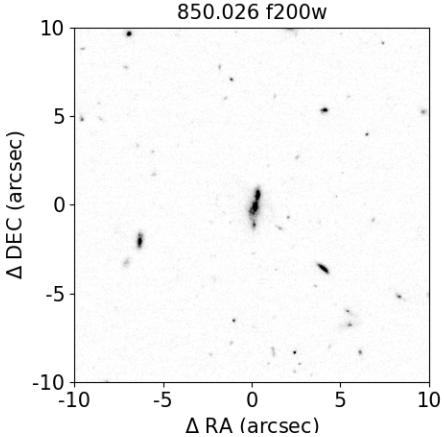


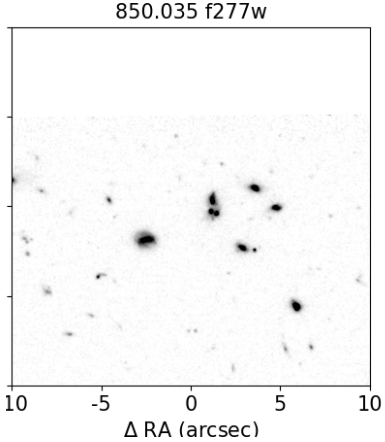
Cardona-Torres et al. (2023)

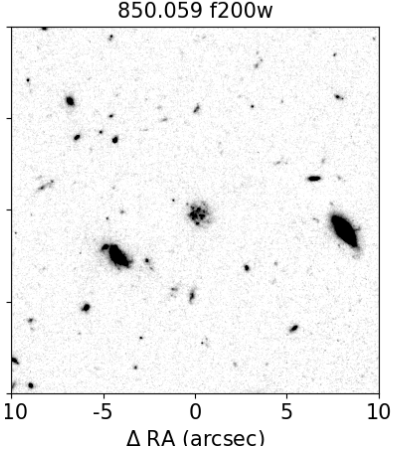

850.017 f200w
Δ DEC (arcsec)
Δ RA (arcsec)
10
5
0
-5
-10


850.019 f200w
Δ RA (arcsec)
10
-5
0
5

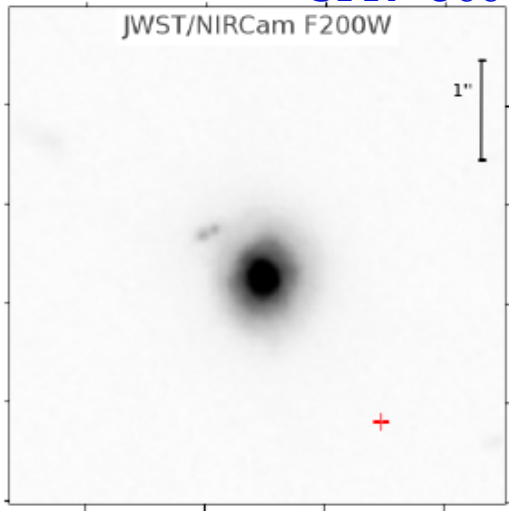

850.025 f200w
Δ RA (arcsec)
10
-5
0
5

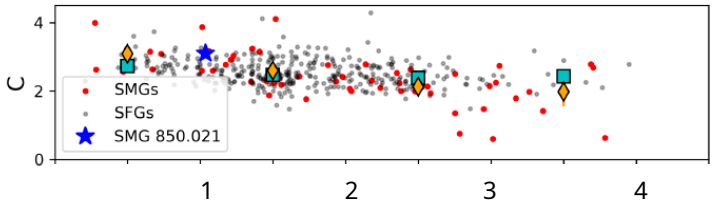

850.026 f200w
Δ DEC (arcsec)
Δ RA (arcsec)
10
5
0
-5
-10


850.035 f277w
Δ RA (arcsec)
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-5
0
5

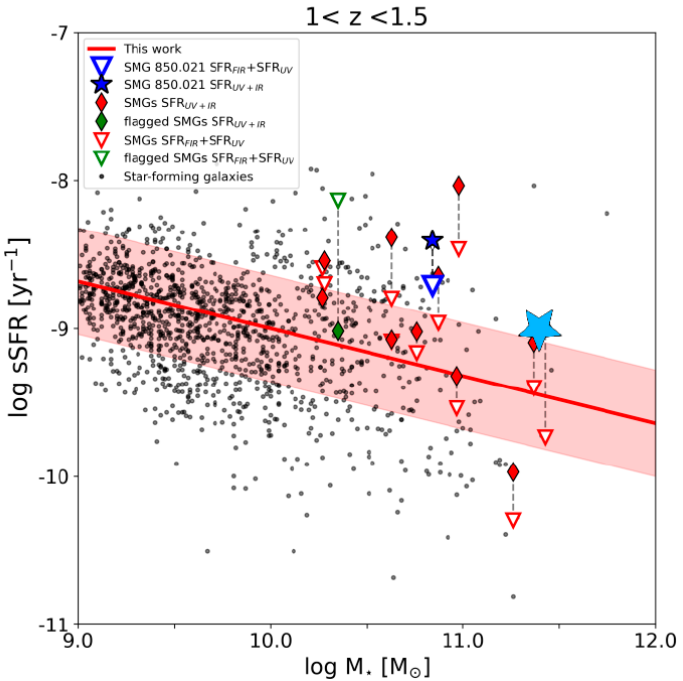

850.059 f200w
Δ RA (arcsec)
10
-5
0
5

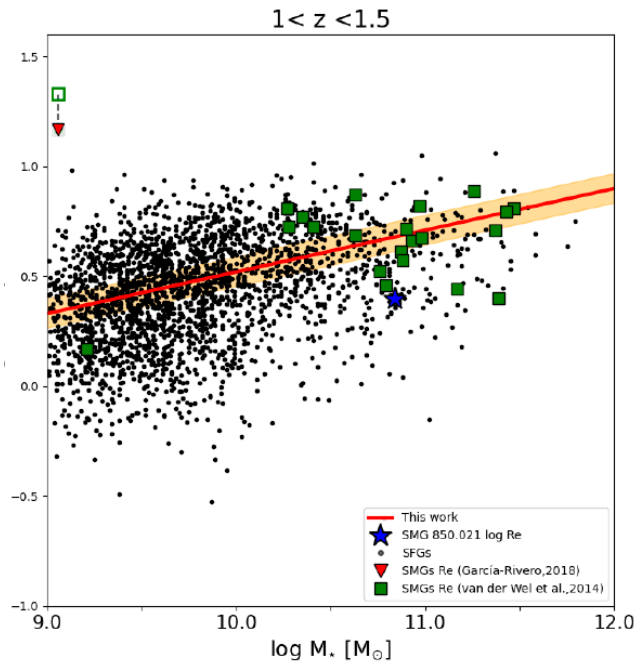
Work in progress: 850.21 a very concentrated SFR~ 300 Msun/yr SMG at z=1.037… with a buried AGN





Cardona-Torres et al. (in prep)





Conclusions

Much of our knowledge on dusty star formation is still limited to bright sources in the HyLIRG/ULIRG SMG regime ($L>10^{12}L_{sun}$). ALMA gives us a view on the LIRG regime in small fields. Although these results are to explore the build-up of stellar mass and the chemical evolution of the Universe, we still need deep surveys like those that TolTEC will provide to characterize the population.

Most faint SMGs are within 3σ of the main sequence of star formation and 35% are starbursts.
- SMGs are ~50% larger than optically selected SFGs at 2<z<3 -> likely mergers
- There is evidence of morphological transformation with time, concentration developing at later times both SMGs and SFGs, but SMGs more concentrated at later times for massive galaxies.

Some of the very concentrated SMGs could be very obscured AGN. However, detail análisis of SED indicates most of the emisión in dominated by the starburst.



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