The Herschel Lensing Survey (HLS): a multi-wavelength survey to study distant galaxies

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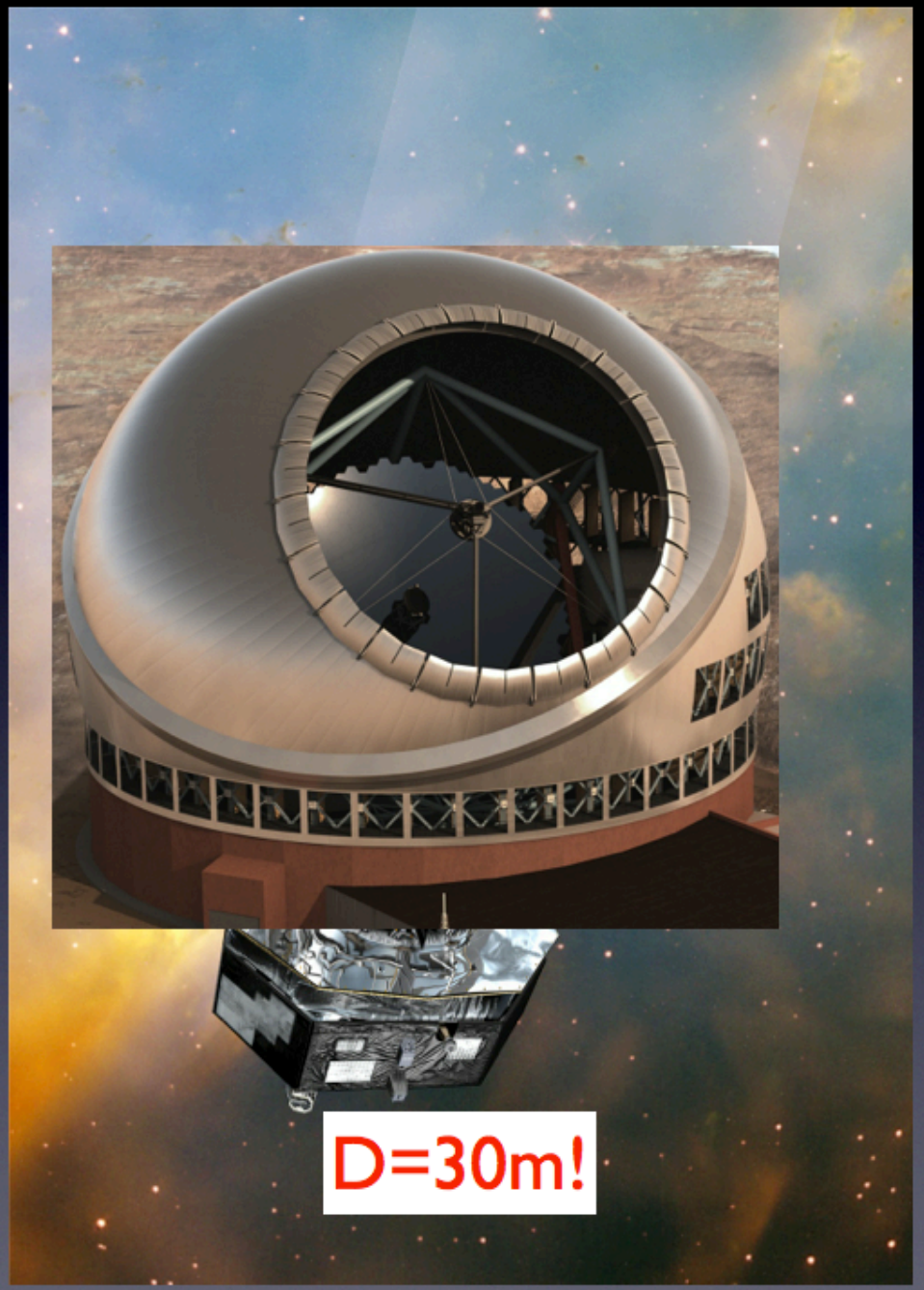
M. Rex (Arizona)	J. Bock (JPL/Caltech)	H. Ebeling (Hawaii)	J.-P. Kneib (Marseille)	D. Schaerer (Geneva)	M. Zemcov (JPL/Caltech)
B. Clement (Arizona)	F. Boone (Toulouse)	A. Edge (Durham)	D. Lutz (MPE)	I. Smail (Durham)	F. Combes (Paris)
M. Pereira (Arizona)	C. Bridge (Caltech)	R. Ellis (Caltech)	L. Metcalfe (ESAC)	M. Swinbank (Durham)	
G. Walth (Arizona)	S. Bussmann (CfA)	D. Fadda (IPAC/Caltech)	A. Omont (IAP, Paris)	G. Smith (Birmingham)	
Rujopakarn (Arizona)	A. Cava (Geneva)	O. Ilbert (Marseille)	R. Pello (Toulouse)	I. Valtchanov (ESAC)	
G. Rieke (Arizona)	S. Chapman (Dalhousie)	R. Ivison (Edinburgh)	P. Perez-Gonzalez (Madrid)	P. van der Werf (Leiden)	

With slides courtesy of E. Egami (PI HLS)

Main motivation

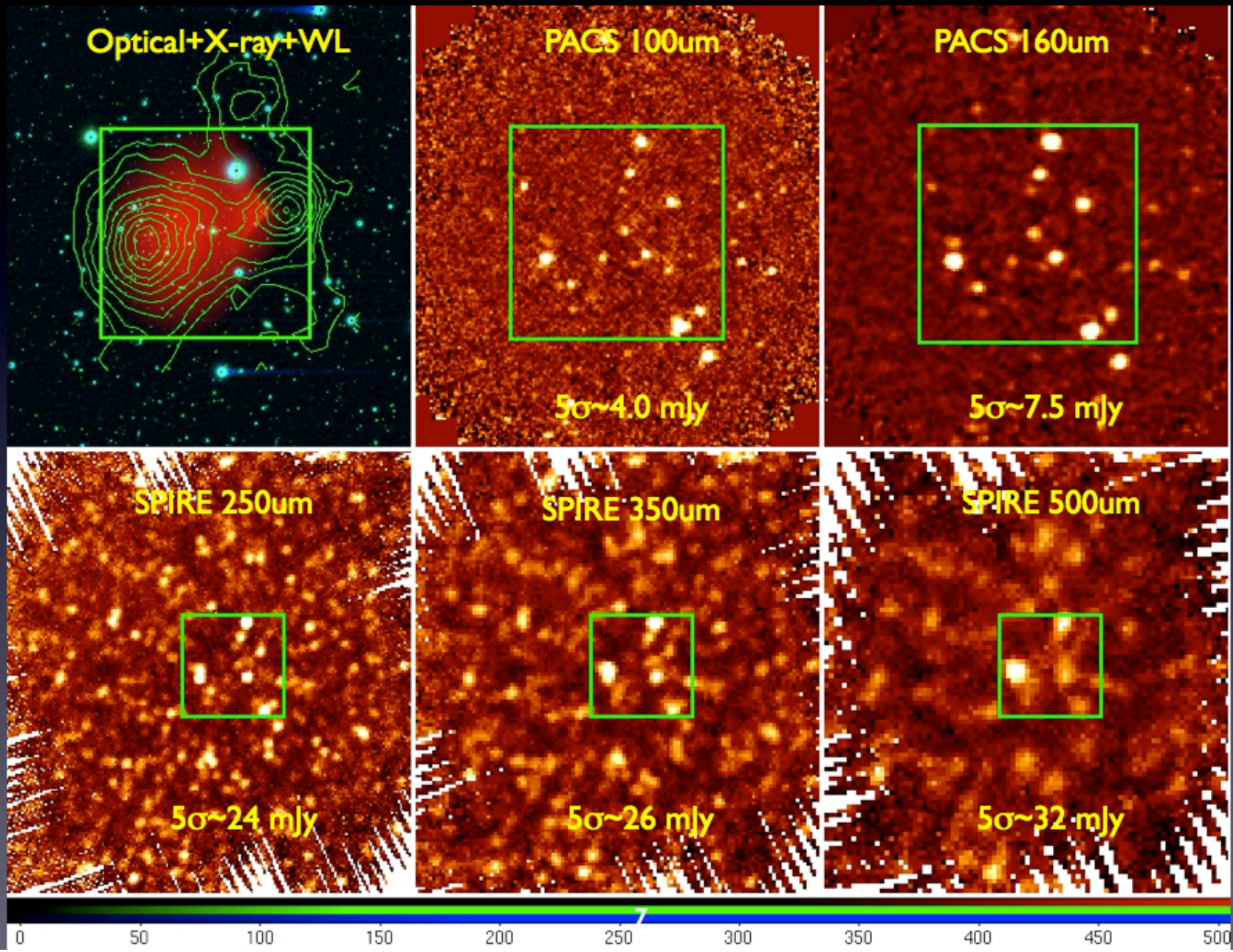
Herschel D=3m

x10
lensing
magnification



D=30m!

The Bullet Cluster (Egami+10, Rex+10, etc.)



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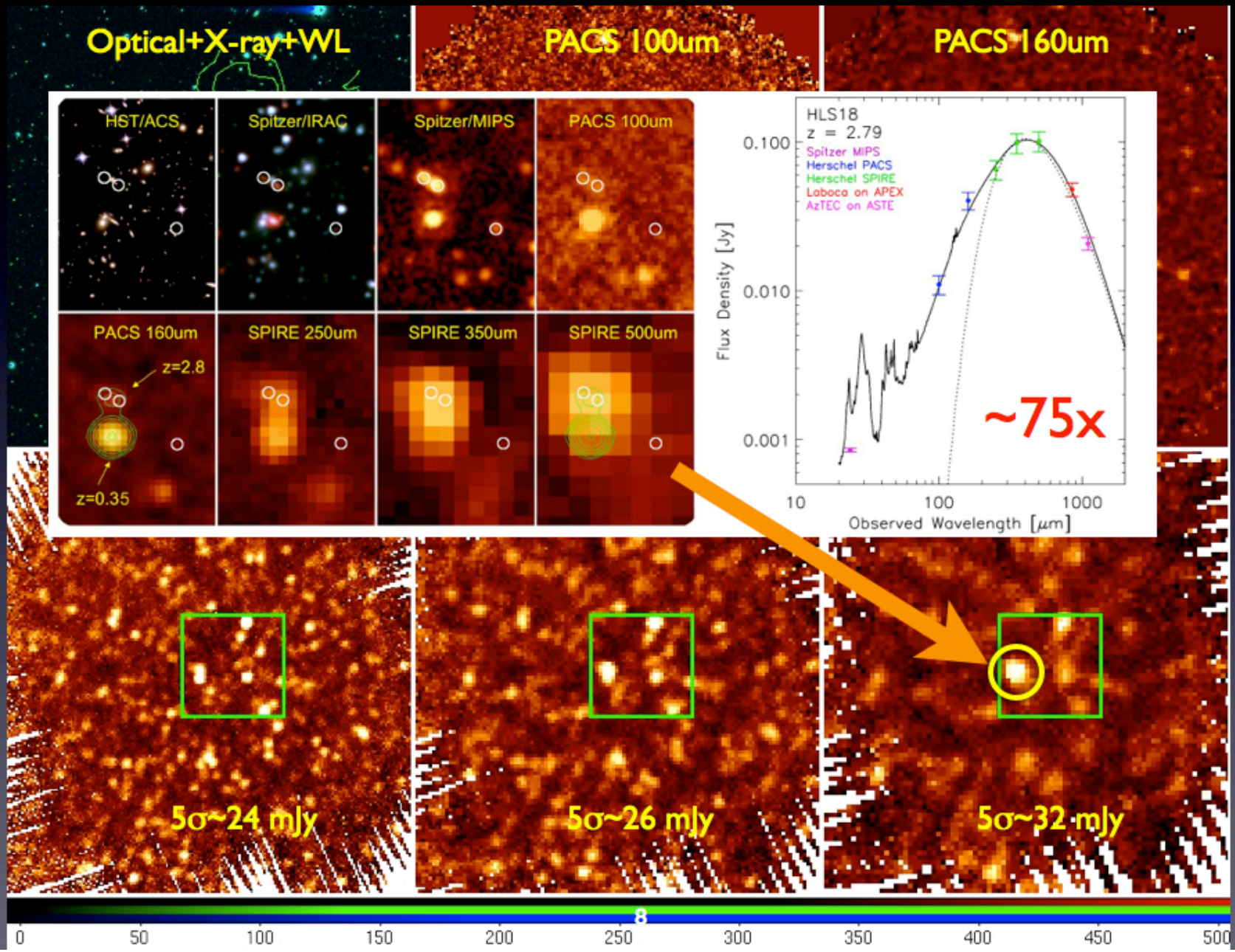


The Herschel Lensing Survey (HLS)

1. HLS-deep (366 hrs): Deep PACS (100/160 um) & SPIRE (250/350/500 um) imaging of 54 (➜ 65) massive (i.e., X-ray-luminous) cluster cores (z~0.1-0.5) to detect and study Herschel sources below the confusion limit.

2. HLS-snapshot (52 hrs): Shallow SPIRE-only imaging of 527 massive cluster cores (z~0.1-1) to discover exceptionally bright ($S_{peak} \gtrsim 100$ mJy) cluster-lensed galaxies that will allow a variety of multi-wavelength observations.

Note: Field surveys (H-ATLAS, HerMES, SPT, ACT, etc.)
➜ Galaxy-lensed systems

Some scientific highlights/results

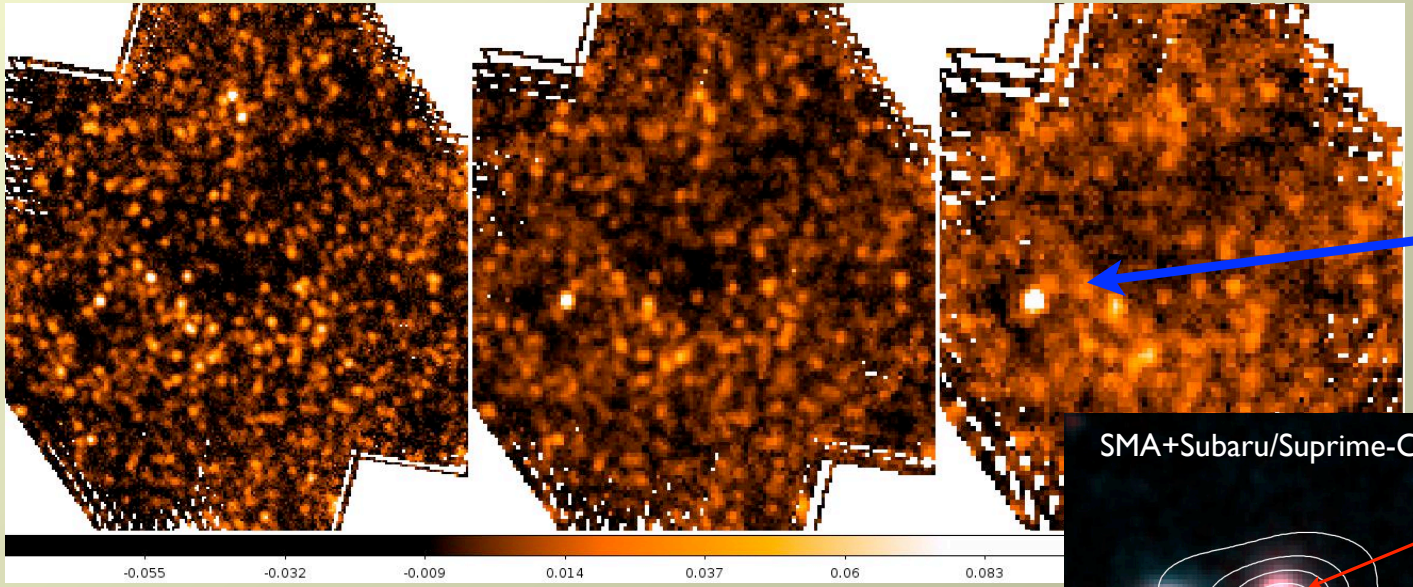
- A very bright z=5.2 galaxy under the microscope: IR-mm
  Combes+ 2012, Rawle+2013, Boone+2013

- Searching for IR/sub-mm galaxies at z>5-6
  Boone+2013

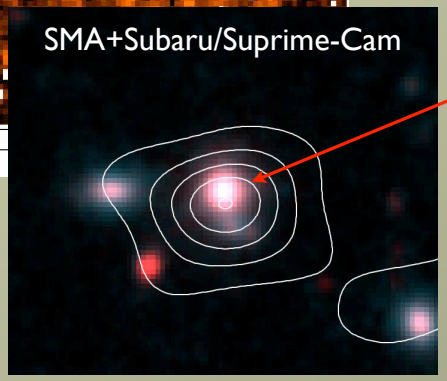
- « Normal » star-forming galaxies at z~1.5-3: a complete picture of their gas, dust, and stellar content
  Sklias+ 2013, Dessauges-Zavadsky+2013, Zamojski+2013

- First hints on dust in « normal » z>5 galaxies with IRAM and ALMA
  Boone+2007, Schaerer+2013

A very bright z=5.2 galaxy under the microscope

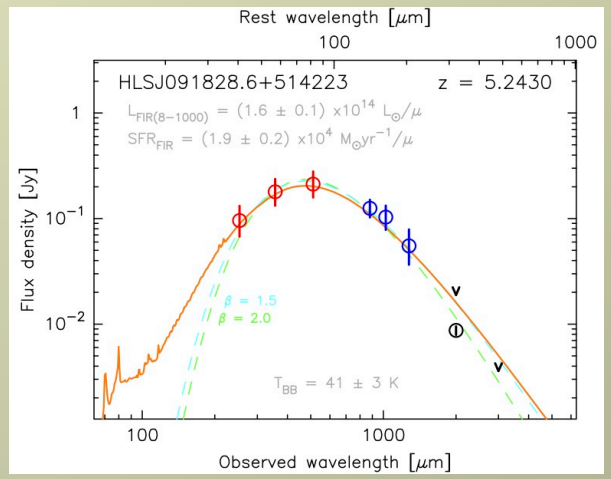


~200 mJy
at 500um



Lensing galaxy at z=0.6

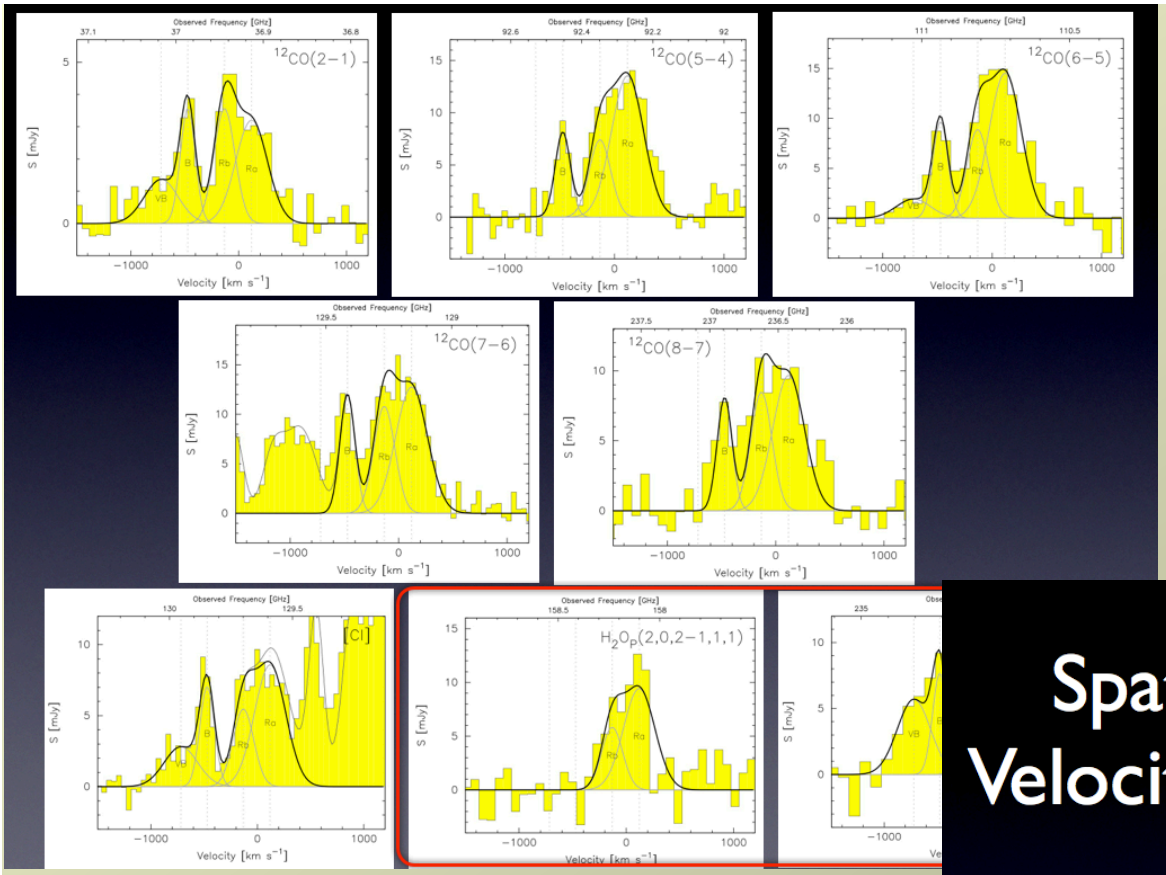
50 mJy at 1.3 mm!
(SMA Compact)



Magnification μ= 8.9

HyLIRG:
L(FIR) =1.8x10^{13} $L_\odot$
SFR(FIR) = 2100 $M_\odot$/yr

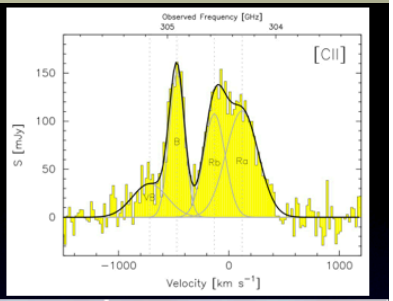
CO redshift from IRAM: z=5.24
Combes et al. (2012)

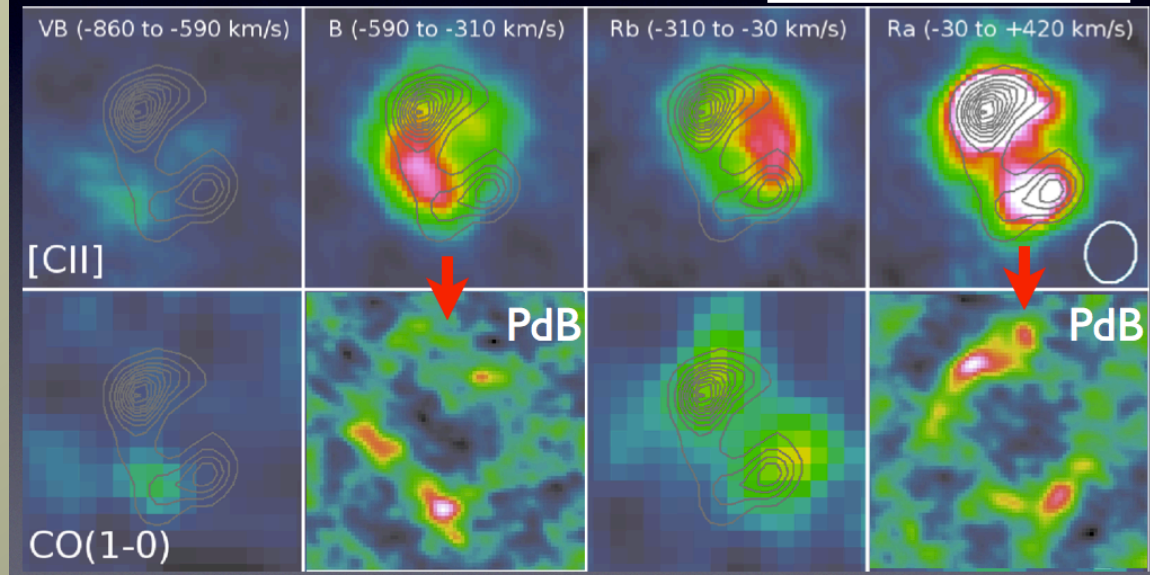


IRAM (30m, PdBI) and SMA observations:

Combes et al. (2012), Rawle et al. (2013, arXiv:1310.4090), Boone et al. (in prep).

Spatially Distinct Velocity Components

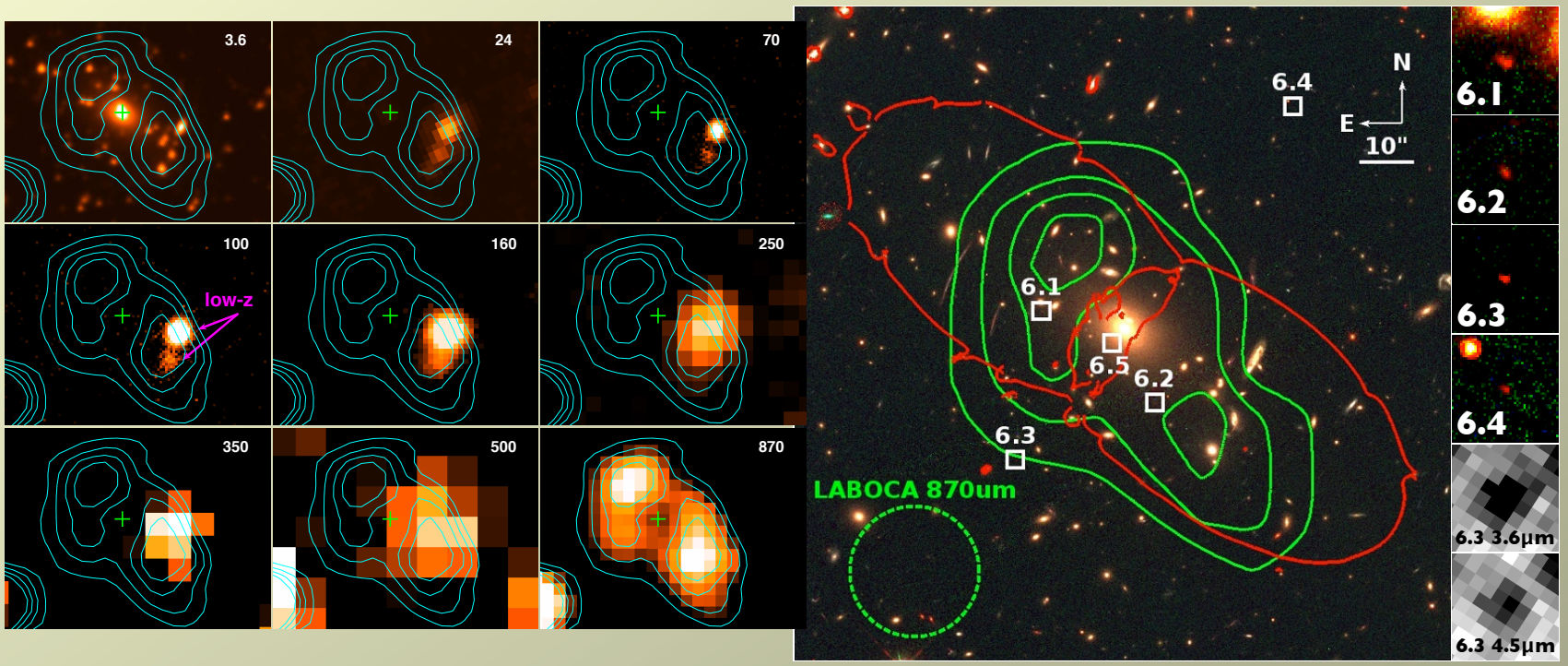




- Complex line profiles: Likely suggesting merging system Outflow signatures?
- First detection of [NII]205μm
- Spatially resolved components and KS law

Slides courtesy of E. Egami (PI HLS)

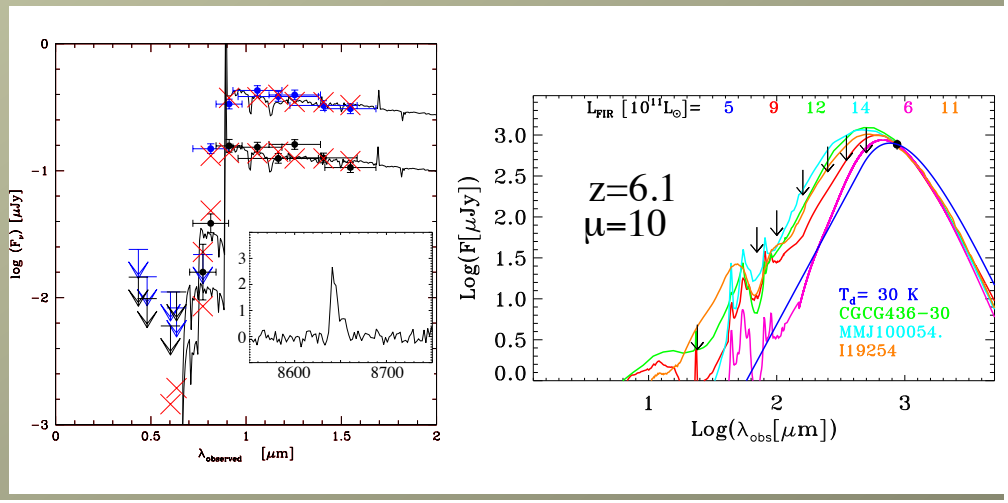
Searching for IR/sub-mm galaxies at z>5-6



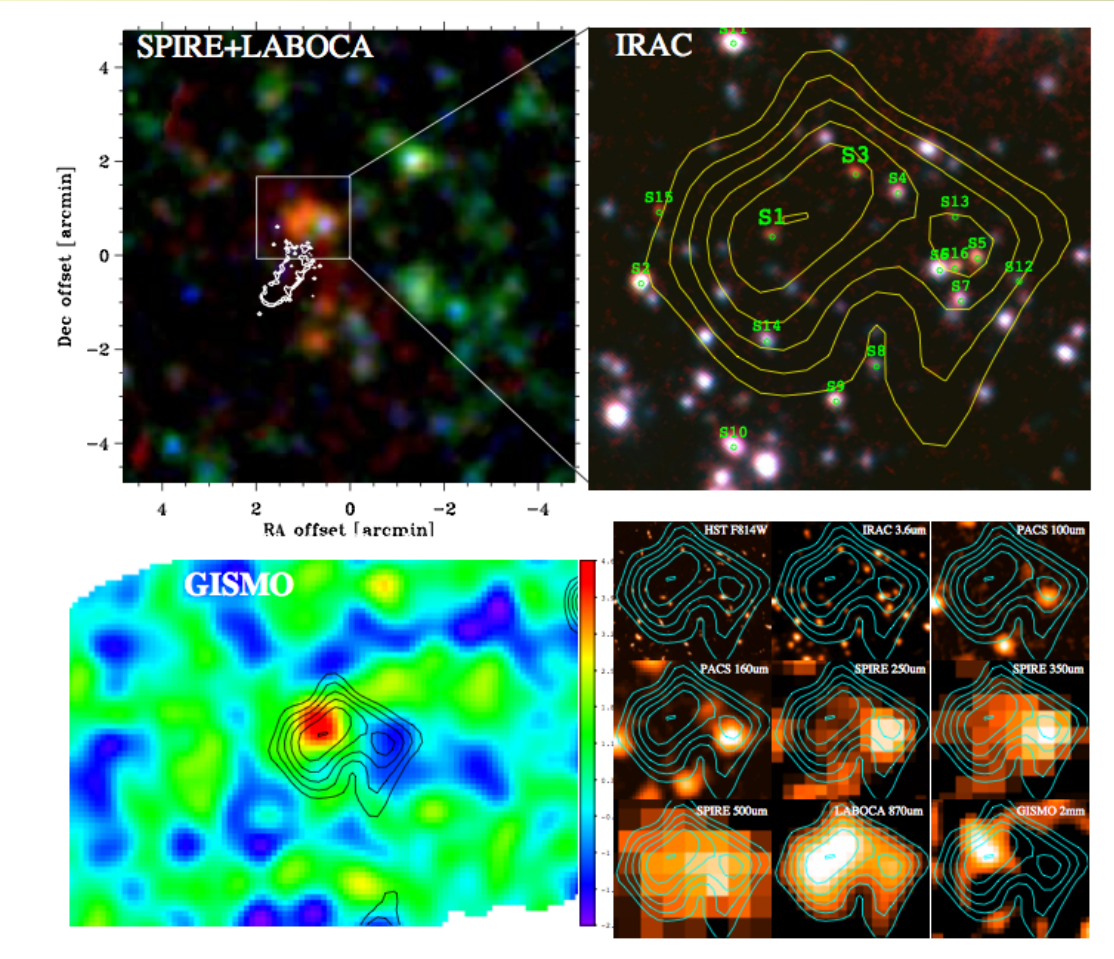
- Multiply imaged Herschel 500 micron dropout, detected with LABOCA
- Associated with multiply imaged z=6.1 LBG (HST + VLT)?

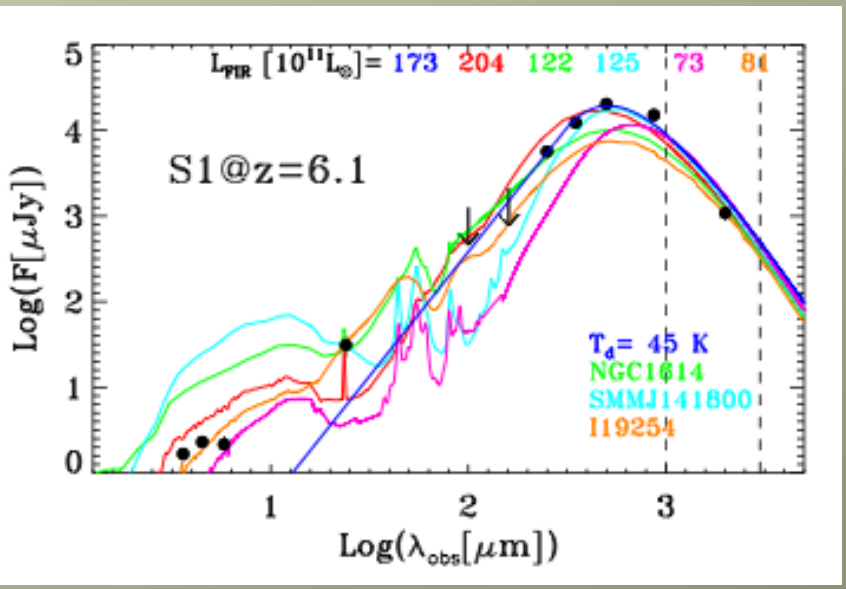
→ **Dusty galaxy at z=6.1 or SZ substructure**

Boone et al. (2013, arXiv:1308.6707)



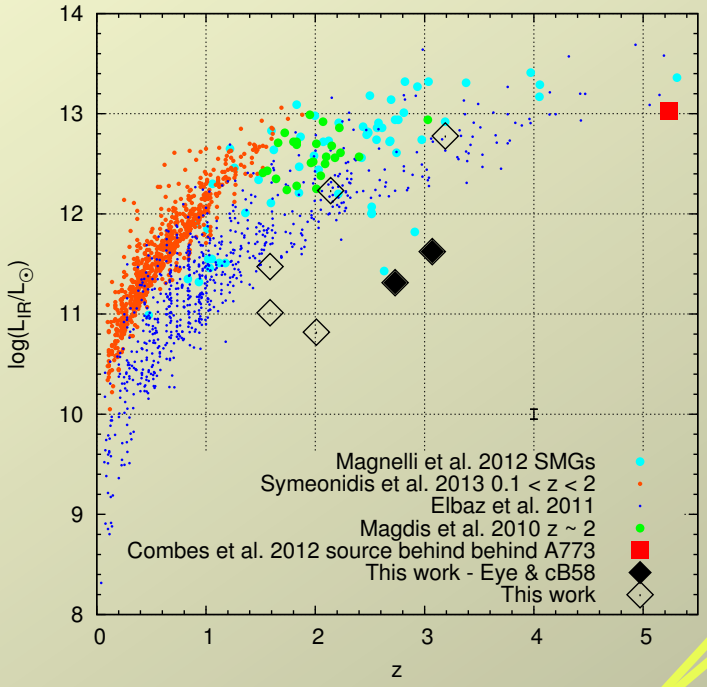
Searching for IR/sub-mm galaxies at z>5-6





Other high-z candidates from the HLS + LABOCA LP (PI Boone) followed up at IRAM

« Normal » star-forming galaxies at z~1.5-3: a complete picture of their gas, dust, and stellar content



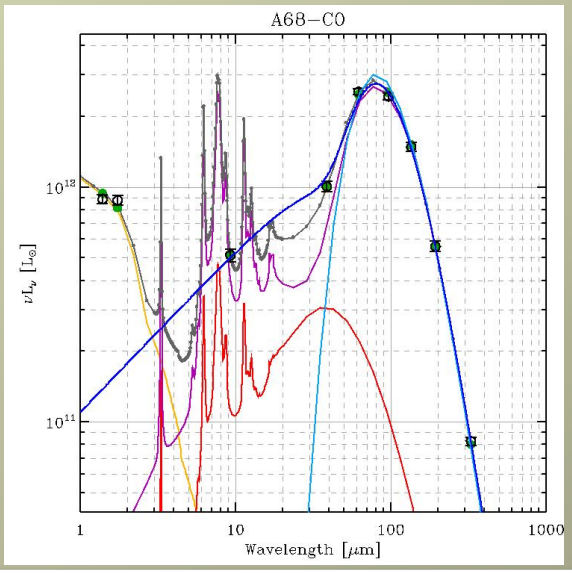
The « space invader » galaxy behind Abell 68
(APOD)

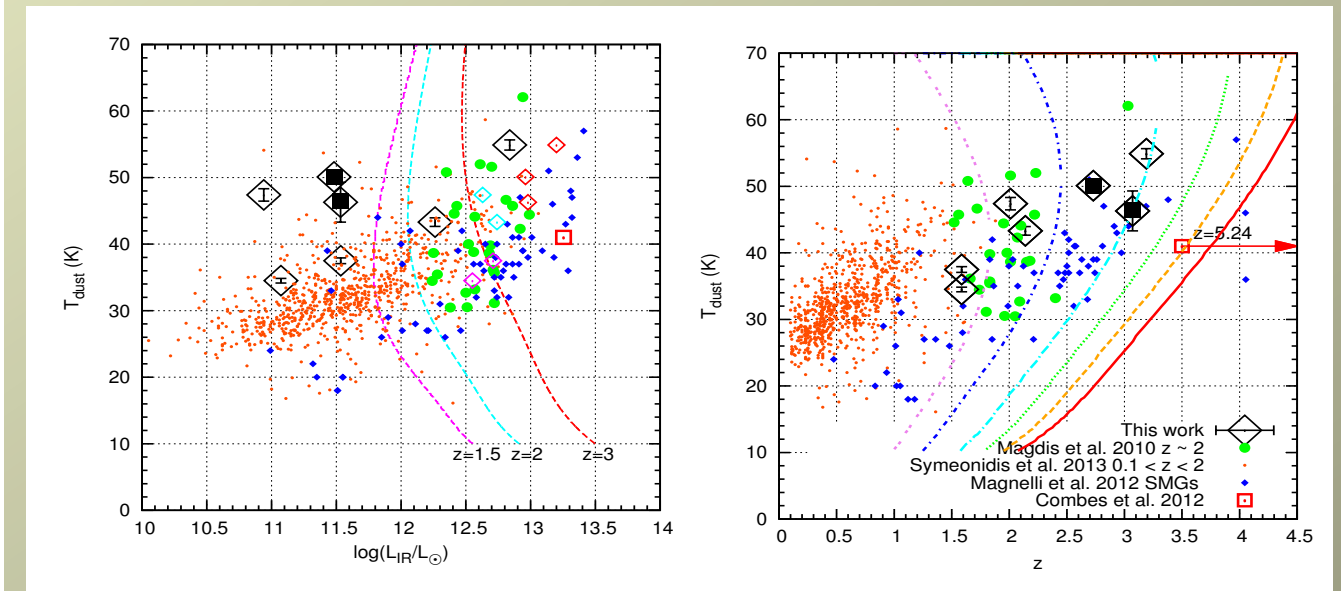
« Normal » star-forming galaxies at z~1.5-3: a complete picture of their gas, dust, and stellar content

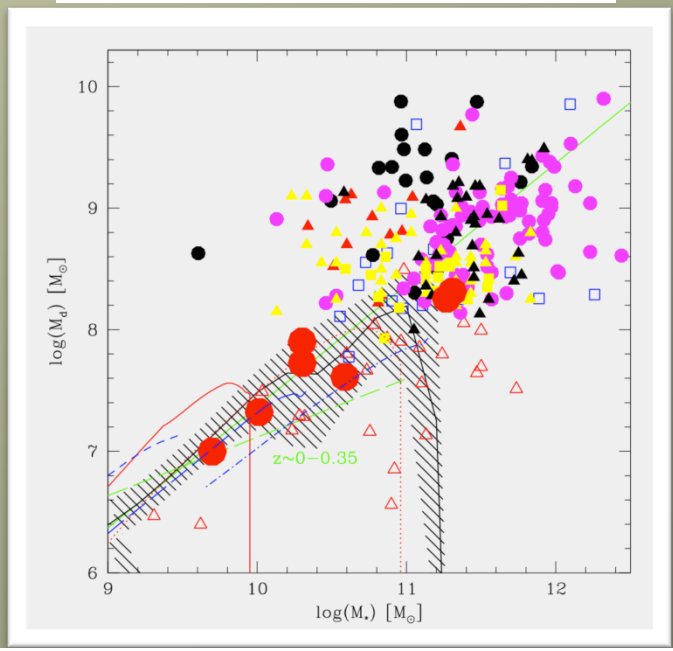
- T_{dust} and M_{dust} determined for ~10x fainter galaxies

→ higher dust temperature at high-z?
→ Same ratio of dust/stellar masses at high-z as in local/nearby galaxies

Sklias et al. (2013, arXiv:1310.2655)



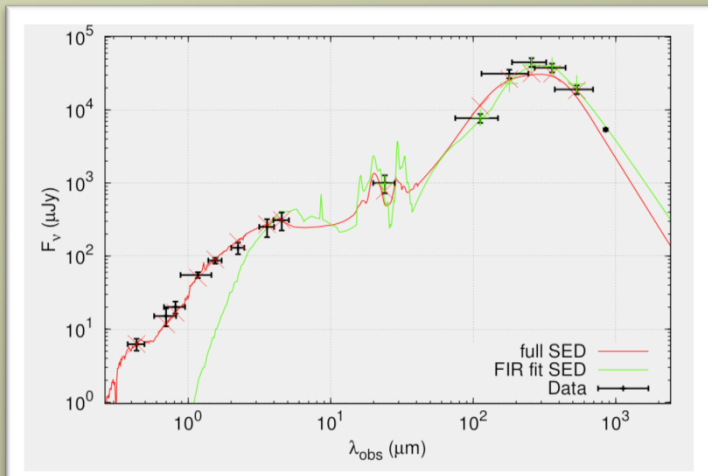


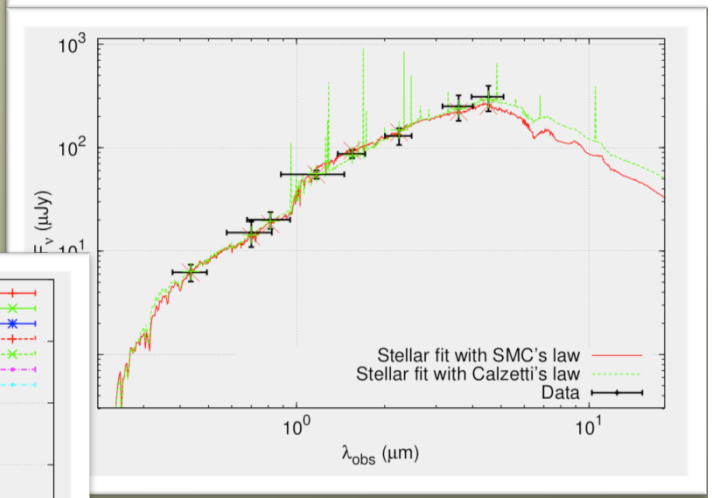


« Normal » star-forming galaxies at z~1.5-3: a complete picture of their gas, dust, and stellar content

- Direct dust attenuation measurements consistent with stacking results at z~1-2.2

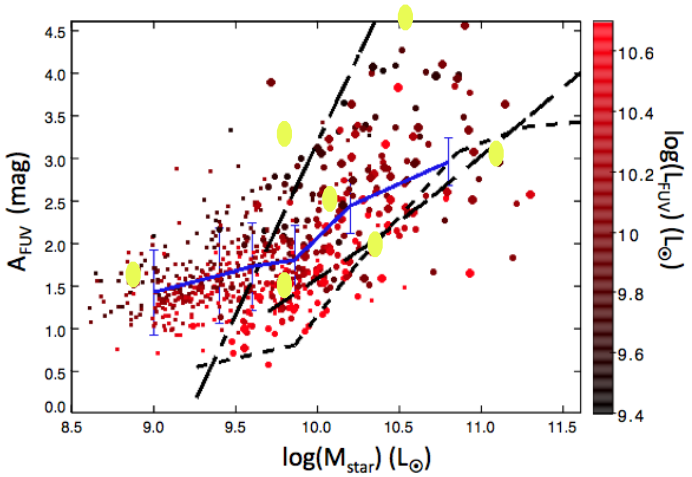
- **Energetically consistent SED modeling (vis – IR):**
  - SMC attenuation law excluded, Calzetti OK
  - **Constrains SF history: rising SFH disfavoured**

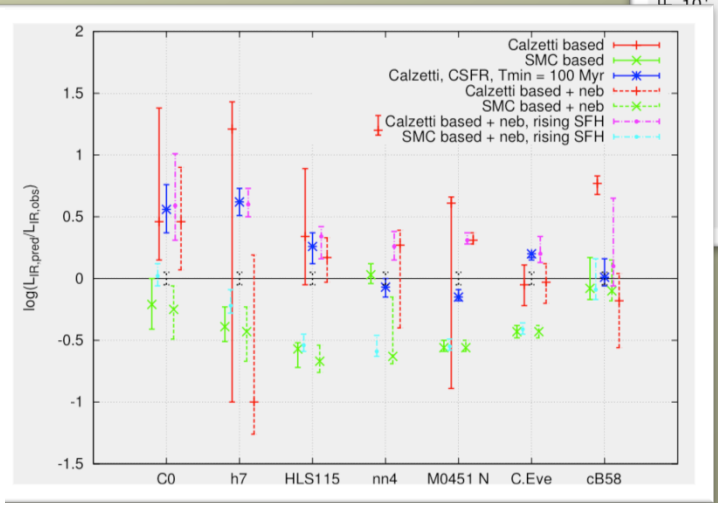




Sklias et al. (2013)

Buat et al. (2012)

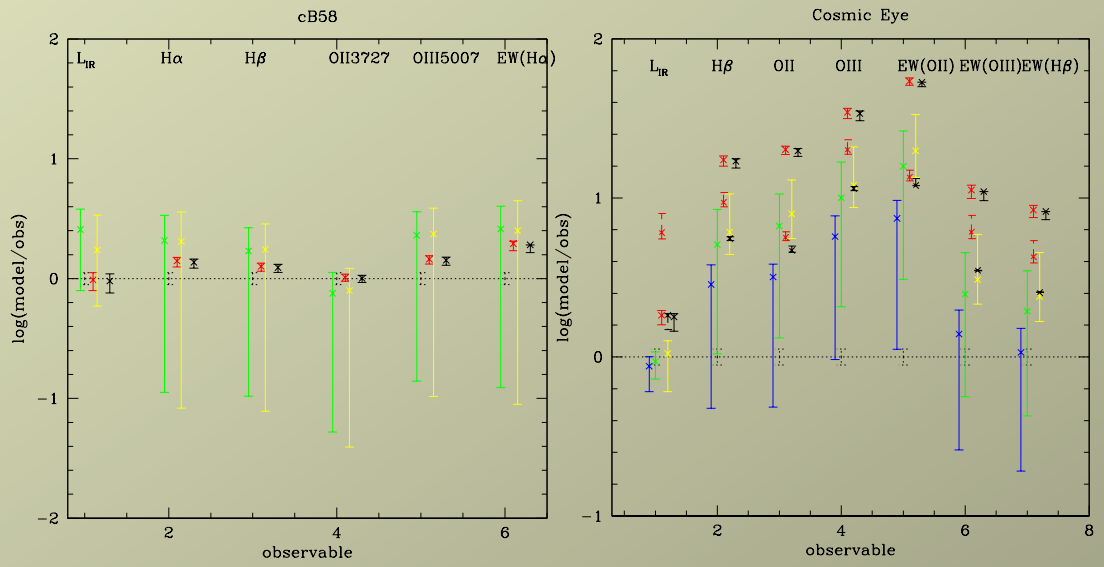


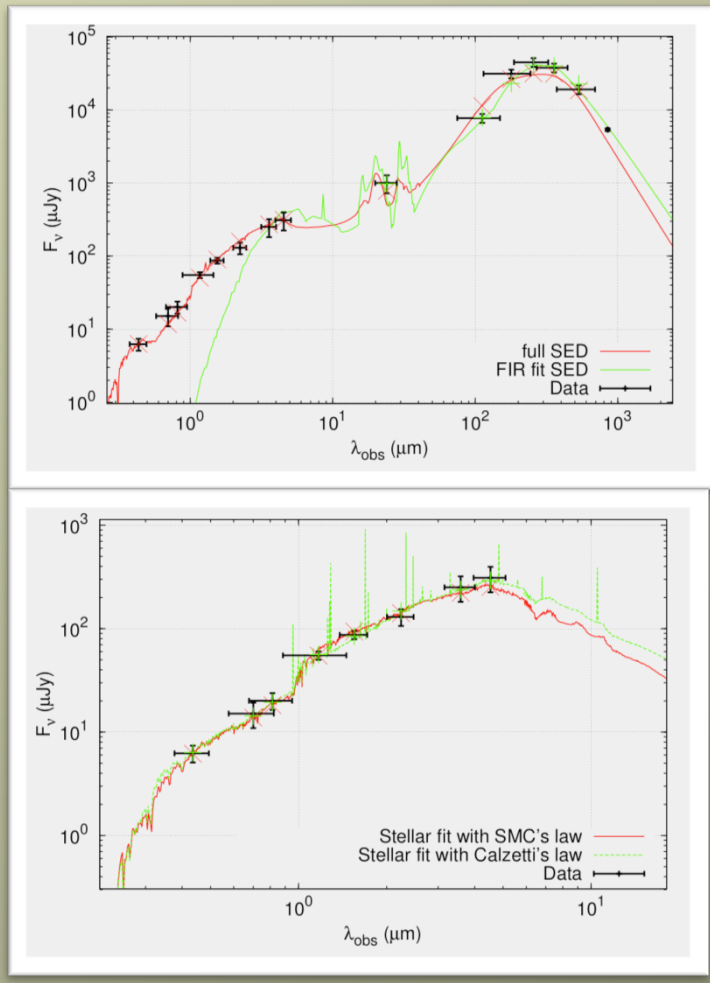


« Normal » star-forming galaxies at z~1.5-3: a complete picture of their gas, dust, and stellar content

Other lensed galaxies: cB58, Cosmic Eye (z=2.7- 3.)

- **Energetically consistent SED modeling (vis – IR):**
  - SMC attenuation law excluded, Calzetti OK
  - **Constrains SF history:**
    rising SFH and SFR=const disfavoured
    from IR and emission line strength





Sklias et al. (2013)

« Normal » star-forming galaxies at z~1.5-3: a complete picture of their gas, dust, and stellar content

CO OBSERVATIONS AT IRAM

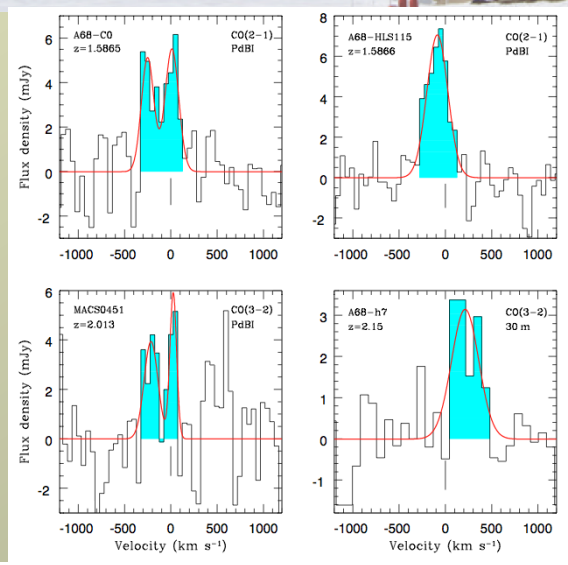
4 strongly lensed SFGs observed with the Plateau de Bure interferometer (PdBI)

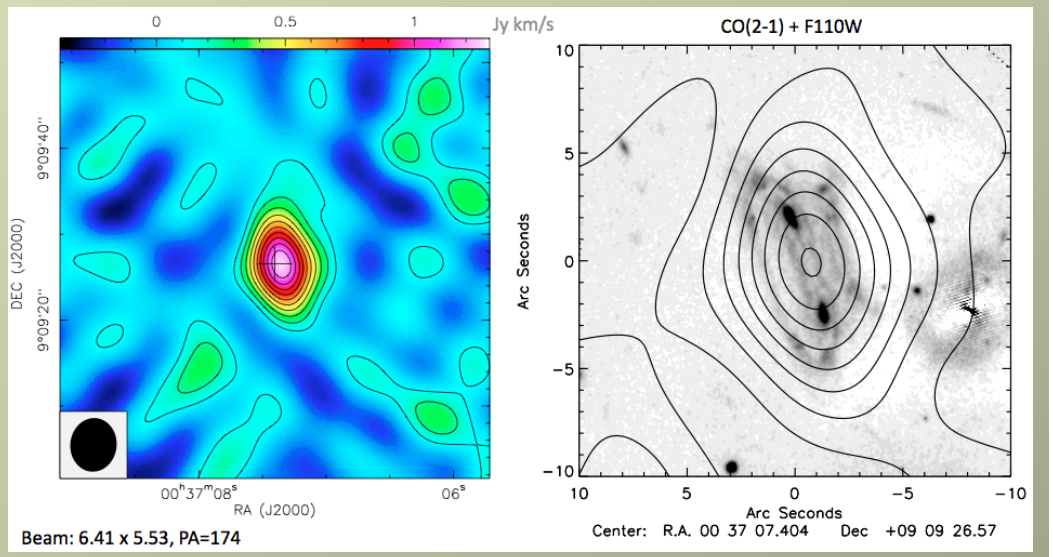
Source	z (opt/UV)	CO transition	μ	$T_{on\text{-}source}$ (h)	$L_{IR,\ intrinsic}$ (10^{11} $L_\odot$)	$M_{stars,\ intrinsic}$ (10^9 $M_\odot$)
A68-C0	1.5865	2-1	30	5.2	1.1	13
A68-HLS115	1.5866	2-1	15	4.6	3.3	5
MACS0451	2.013	3-2	49	30.2	1.3	3
A2218-Mult	3.104	3-2	23	9.2	3.0	-

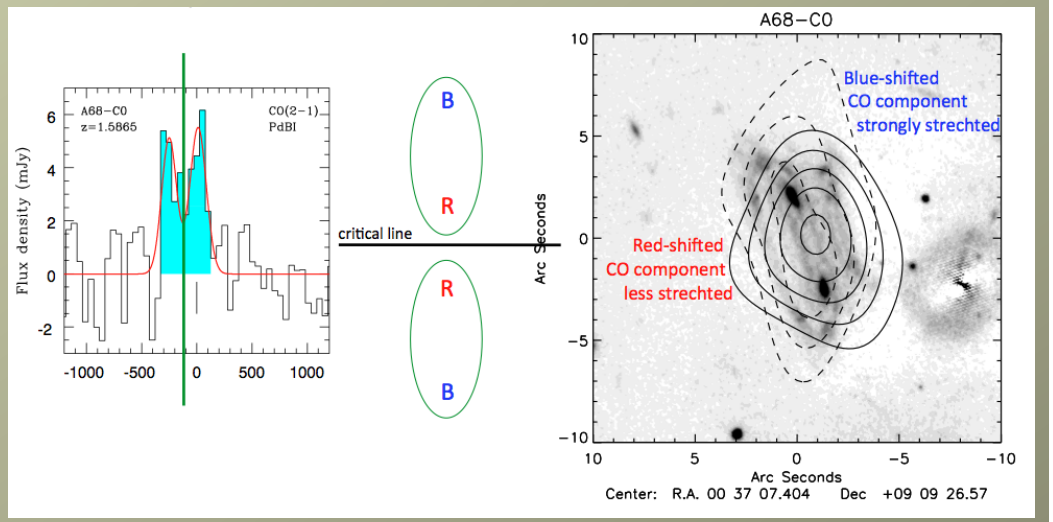
Observations done in compact D-configuration: highest sensitivity with the lowest spatial resolution

1 lensed SFG observed with the 30-m single dish antenna

A68-h7	2.15	3-2	3.2	5.5	17.3	51

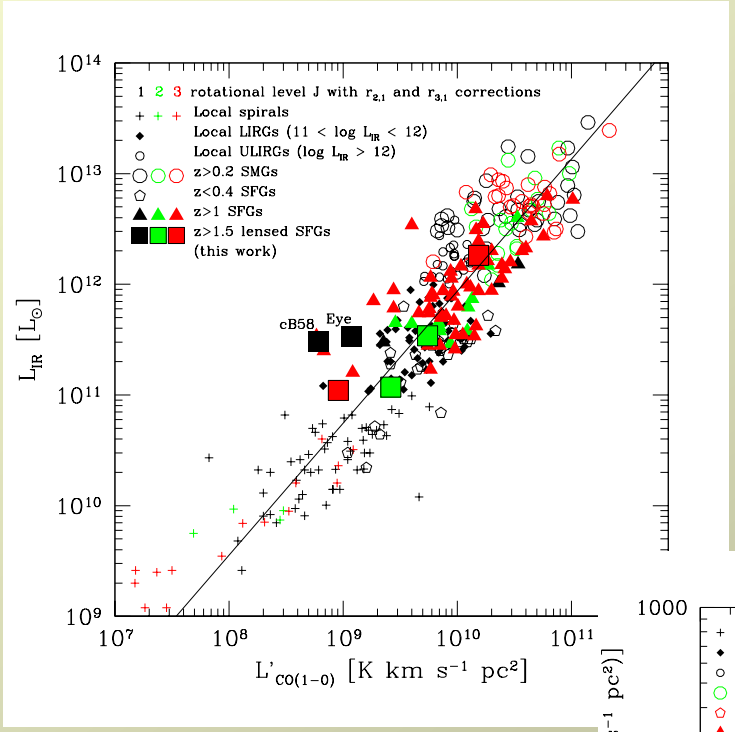


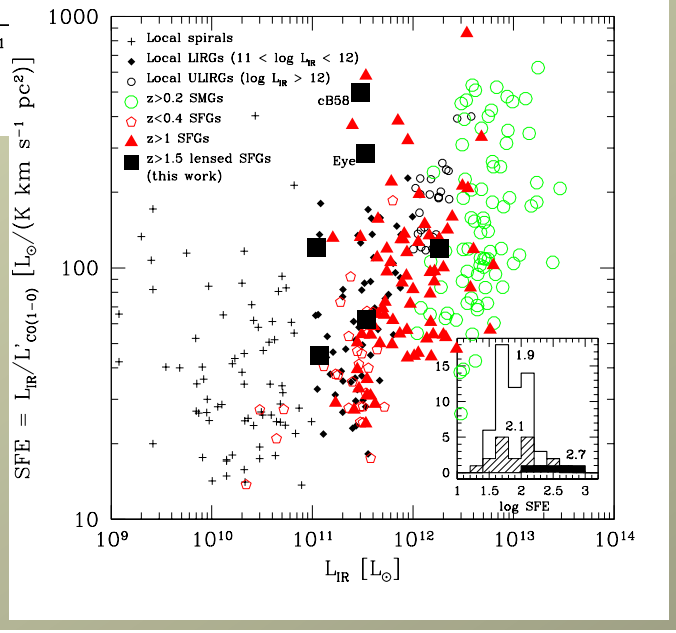




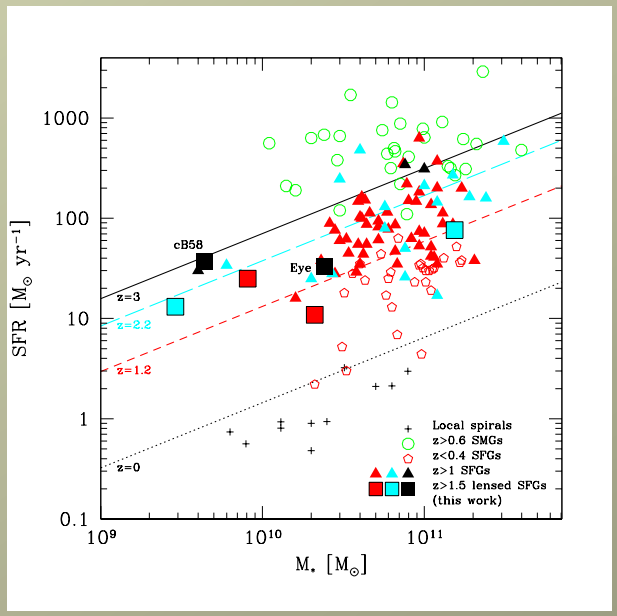
Dessauges-Zavadsky et al. (2013)

« Normal » star-forming galaxies at z~1.5-3: a complete picture of their gas, dust, and stellar content





SFE=L_{IR}/L_{CO}
~ SFR/M_{gas}

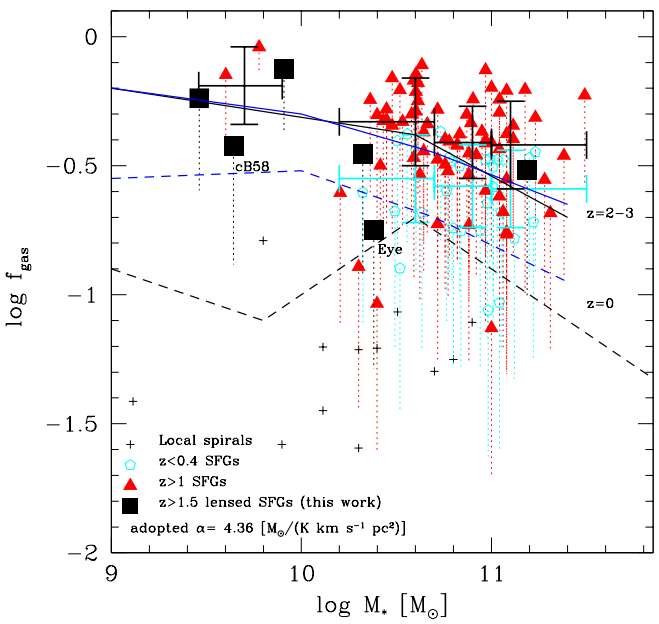


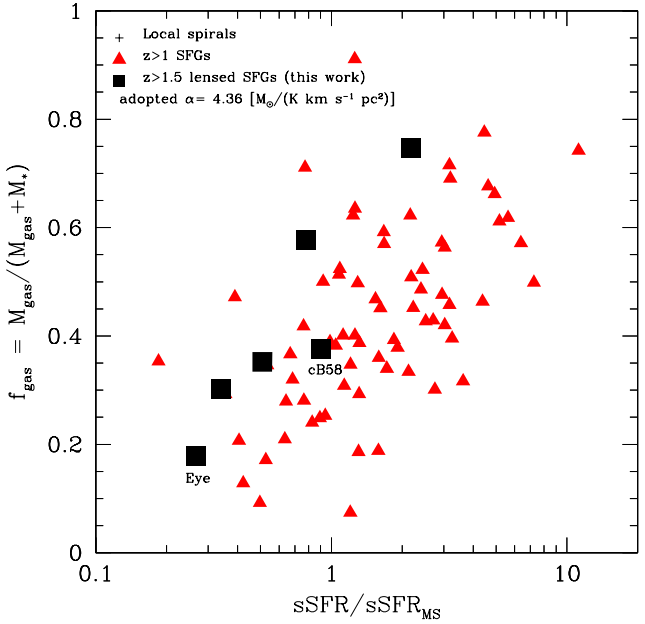
SFR-M_*

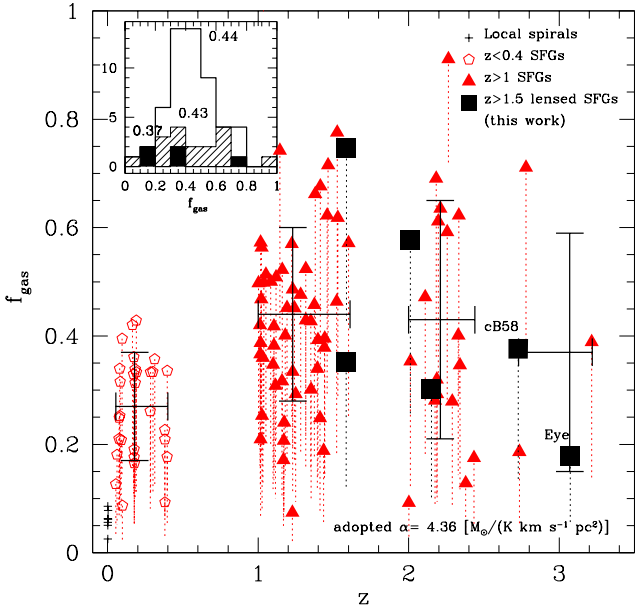
Dessauges-Zavadsky et al. (2013)

« Normal » star-forming galaxies at z~1.5-3: a complete picture of their gas, dust, and stellar content

Molecular gas fraction $f_{gas}=M_{gas}/(M_{gas}+M_*)$







Cf. Tacconi+ 2012 sample

Dessauges-Zavadsky et al. (2013)

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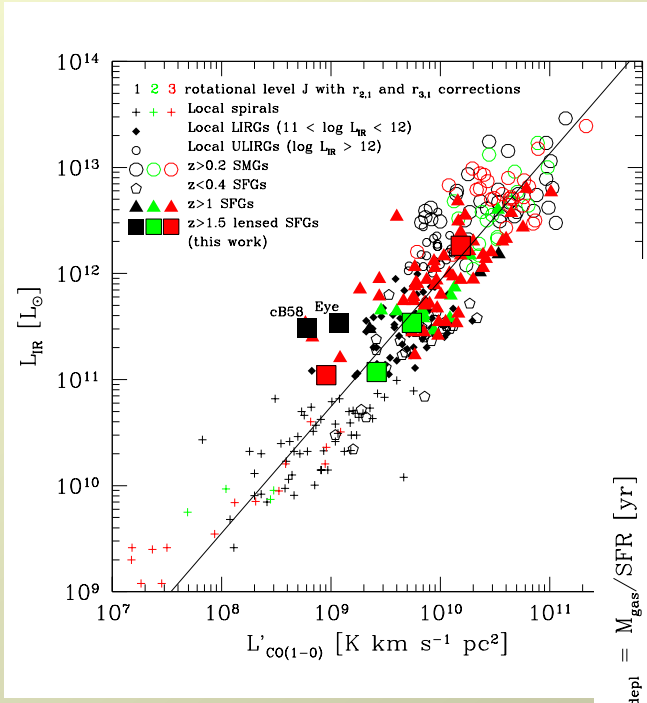
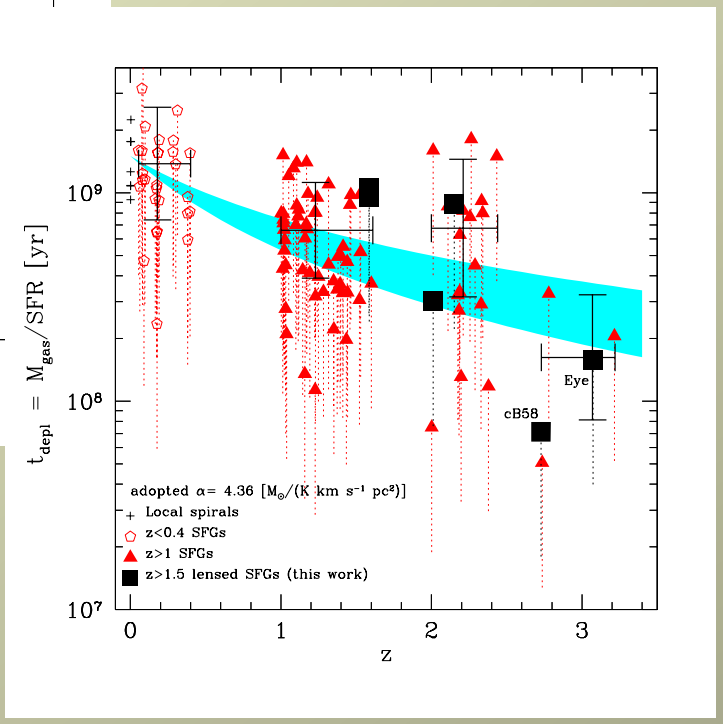




→ Shorter gas depletion timescales at high-z

Cf. Saintonge+ 2013

Indicative of shorter SF timescales found also at z>3 from LBG studies (de Barros et al. 2012)

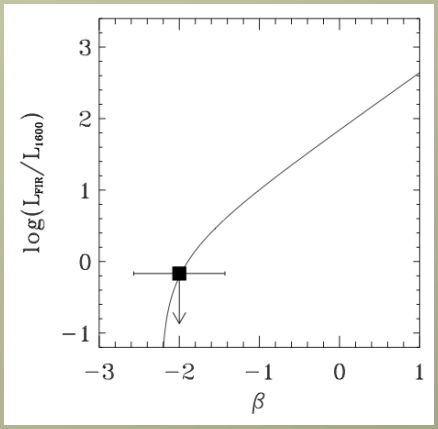
Dessauges-Zavadsky et al. (2013)

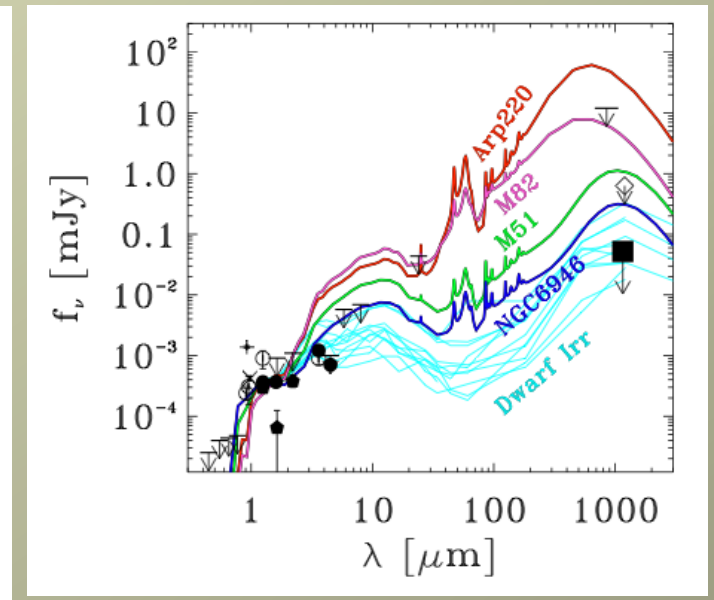
First hints on dust in « normal » z>5 galaxies with IRAM and ALMA

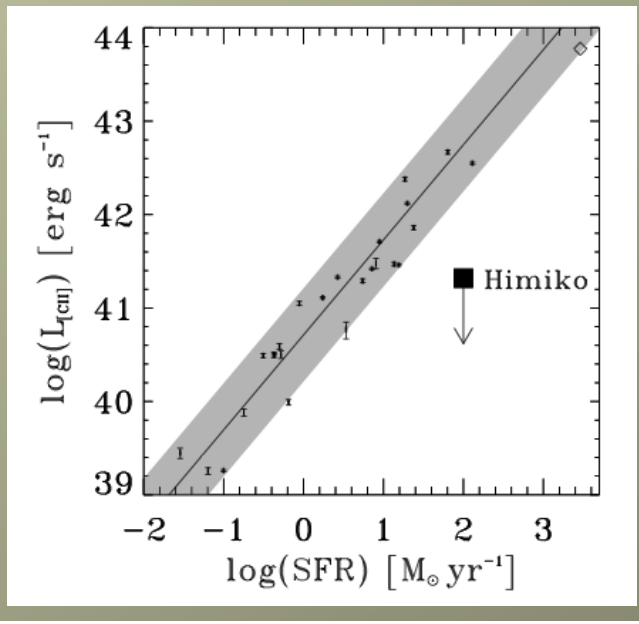
ALMA [CII]158μm and continuum observations of a bright z=6.56 Lyman-α emitter: Ouchi et al. (2013)

TABLE 1
ALMA Observations and Sensitivities

ν_{cont} (GHz) (1)	ν_{line} (GHz) (2)	σ_{cont} (μJy beam^{-1}) (3)	σ_{line} (μJy beam^{-1}) (4)	f_{cont} (μJy) (5)	f_{line} (μJy) (6)	L_{FIR} ($10^{10} L_\odot$) (7)	$L_{[CII]}$ ($10^7 L_\odot$) (8)
259.007	250.239	17.4	83.3	< 52.1	< 250.0	< 8.0	< 5.4

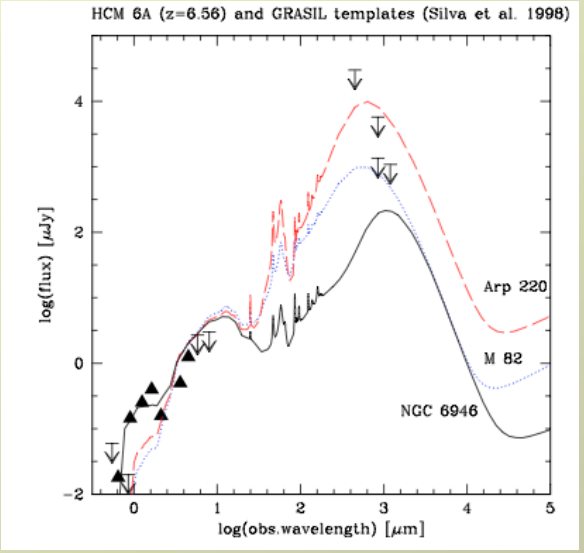


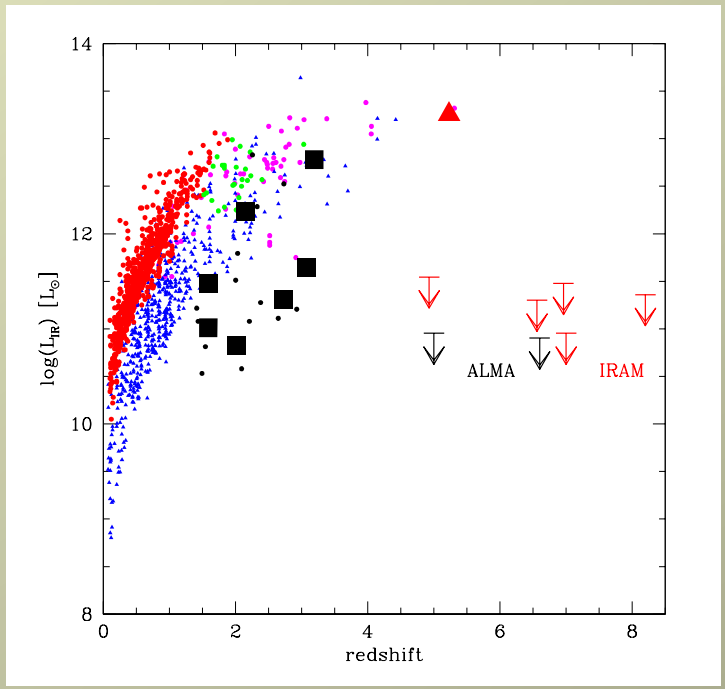




First hints on dust in « normal » z>5 galaxies with IRAM and ALMA

IRAM dust continuum observations of a lensed z=6.56 Lyman-α emitter: Boone+ 2007



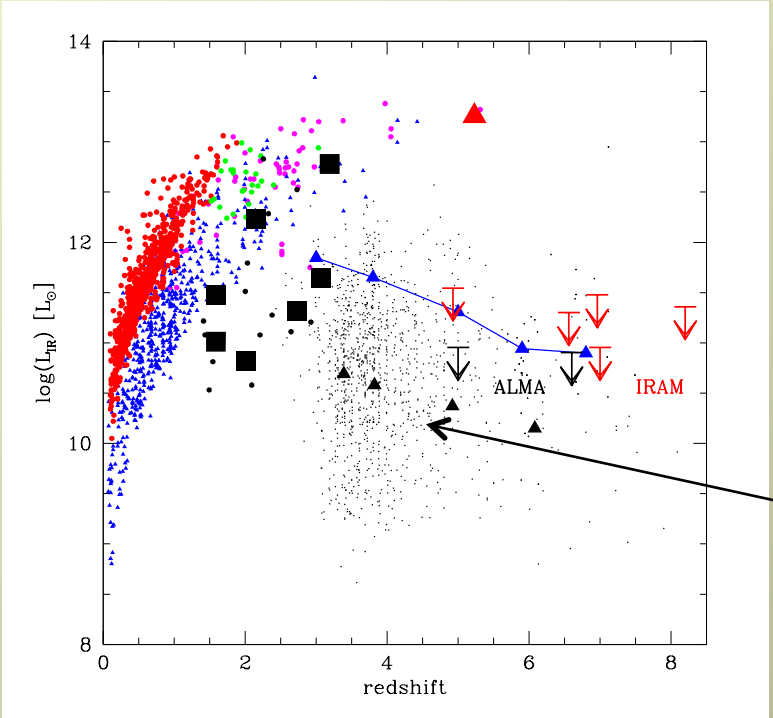


Lensed galaxies:
- z=4.9 MS1248arc: Livermore+ 2012
- z=6.56 HCM6A: Boone+2007
- z=7 A1703: Schaerer+2014

Blank fields:
- z=6.56 LAE Himiko: Ouchi+2013
- z=6.96 LAE IOK-1: Walter+2012
- z=8.2 GRB090423: Walter+2012

MAMBO-2 @30m, 1.2mm: σ=0.36 mJy, 4h on-source (Boone+2007)
WIDEX@PdBI: σ_{cont}~0.09-0.15 mJy/beam (Walter+2012, Schaerer+2014)
GISMO@30m, 2mm: σ_{cont}=0.15 mJy (Schaerer+2014)

First hints on dust in « normal » z>5 galaxies with IRAM and ALMA



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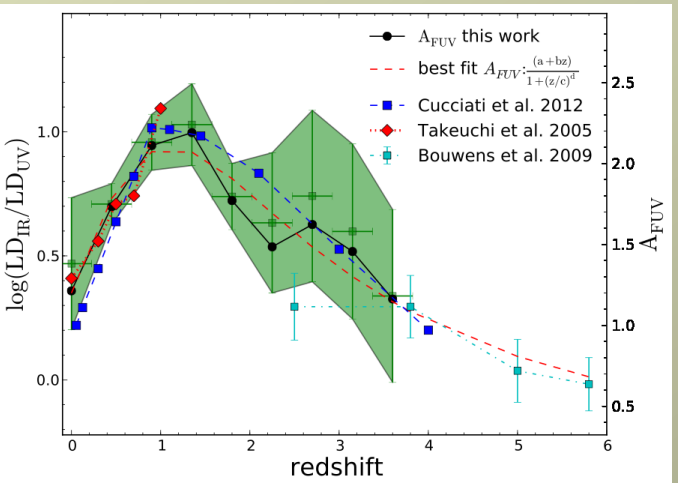
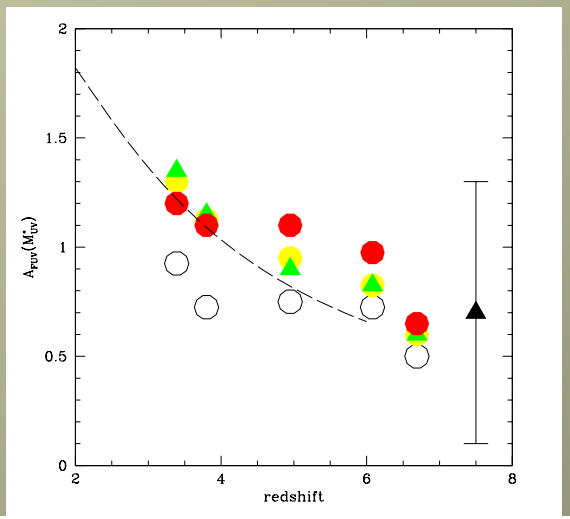
- z=8.2 GRB090423: Walter+2012

Predicted L_{IR} of ~1400 LBGs from z~3.4 – 7 (Schaerer+ 2013)



Mean attenuation from IR/UV: Burgarella et al. (2013)



LBGs: attenuation from SED fits
Schaerer & de Barros (2013)

Conclusions

- Herschel Lensing survey (HLS) provides important base for multi-wavelength studies of strongly lensed galaxies: 65 clusters covered, including CLASH and Hubble Frontier Field clusters
- Significant follow-up work done at IRAM. Thanks!

Some science results:

- Detailed study of ISM @ z=5.2
- Candidate sub-mm galaxies found at z>6
- Complete picture of « normal » SF galaxies at z~1.5-3:
  gas, dust and stars
  → provides important constraints for galaxy formation/evolution models
- First direct constraints on dust and attenuation in « normal » SF galaxies at z~5-7

→ Vast domain to be explored with IRAM (NOEMA, NikaII, EMIR) and ALMA