MINISTERIO
DE CIENCIA, INNOVACIÓN
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AGENCIA ESTATAL DE INVESTIGACIÓN

Unión Europea

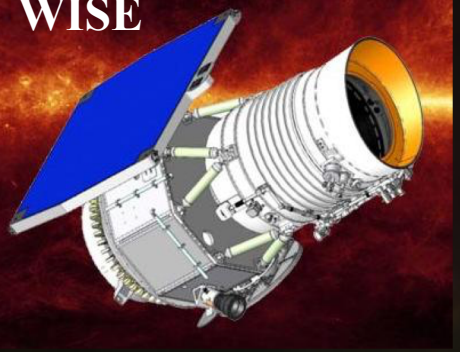
ULL Universidad de La Laguna

Census of Dusty Starburst in the distant Universe

Planck

GTC

WISE



IRAM NOEMA

Helmut Dannerbauer

Insituto de Astrofísica de Canarias

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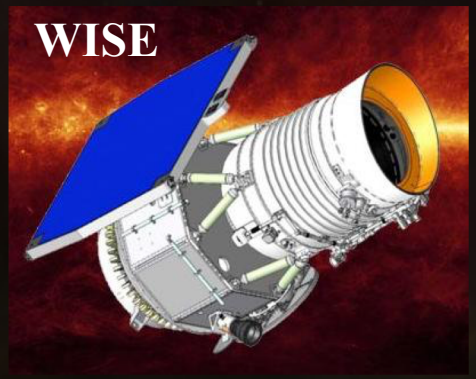
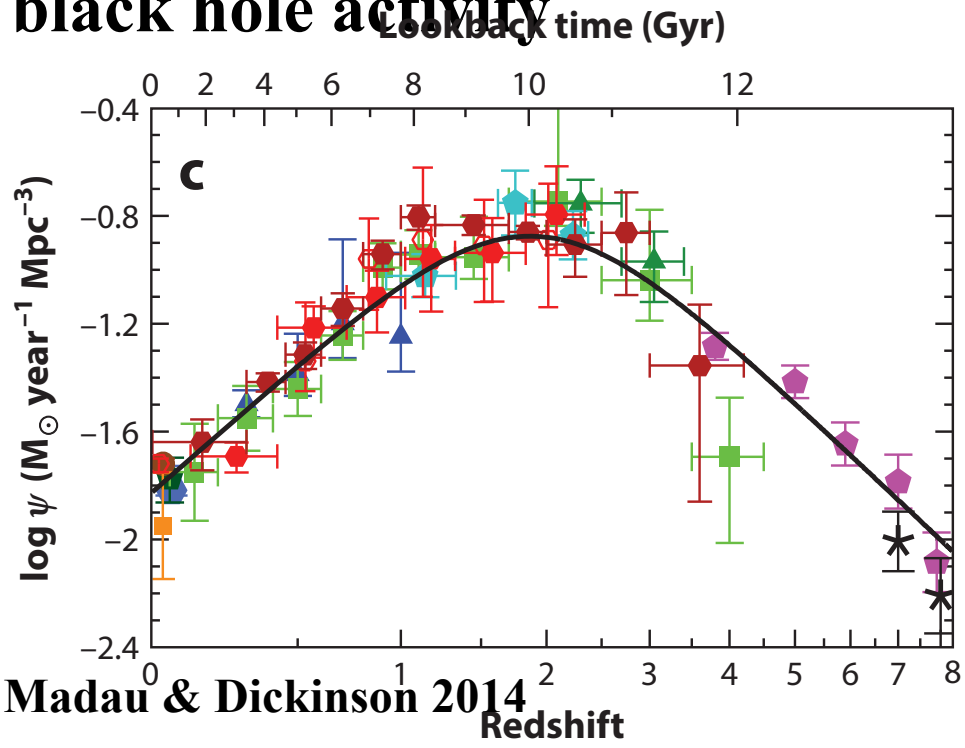
Census of Dusty Starburst in the distant Universe via strong Lensing



Helmut Dannerbauer
Insituto de Astrofísica de Canarias

Motivation

- **search for brightest lensed dusty starbursts in the whole sky**
- **search for most luminous sources, at least in apparent brightness**
- **detailed study at ~60-100pc scale (GMC size) of the interstellar medium in z=2 galaxies, the peak epoch of star-formation and black hole activity**



Madau & Dickinson 2014

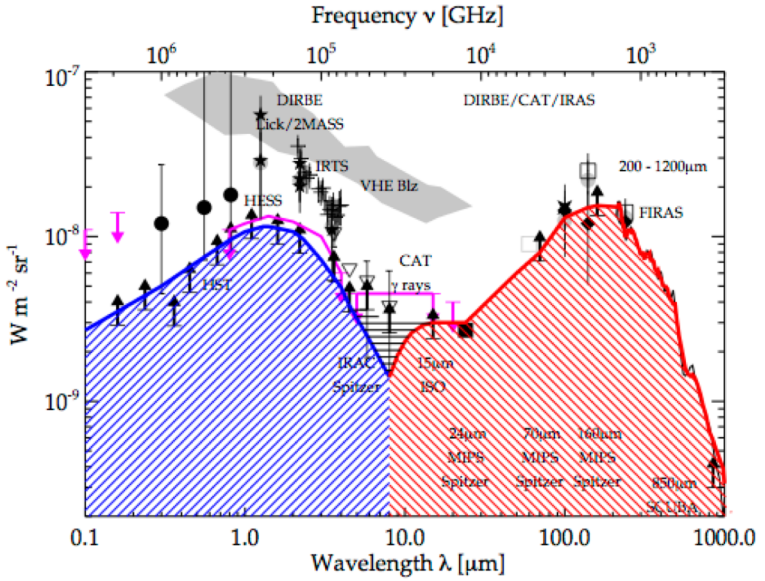


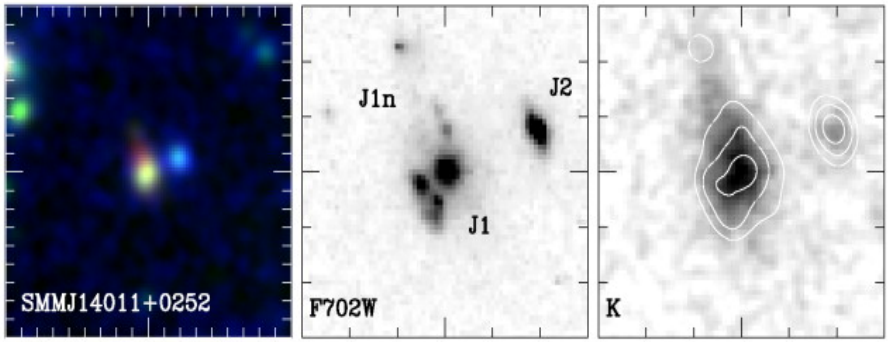
Fig. 13. Our best Cosmic Optical Background (blue-shaded) and Cosmic Infrared Background (red-shaded) estimates. The gray-shaded area represents the region of overlap. See Figure 9 for the other symbols.

Dole et al. 2006

Dusty Star-Forming Galaxies (DSFGs)

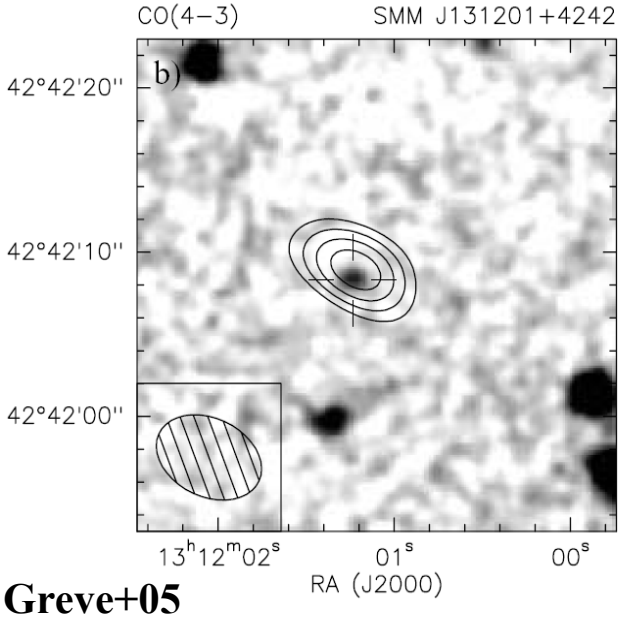
- very massive up to $10^{11} M_\odot$
- gas-rich
- high SFR: several 100 $M_\odot$/yr
- merger-like morphology
- ellipticals in formation
- <z>=2.5

➔ ***excellent tracers of mass-density peaks***

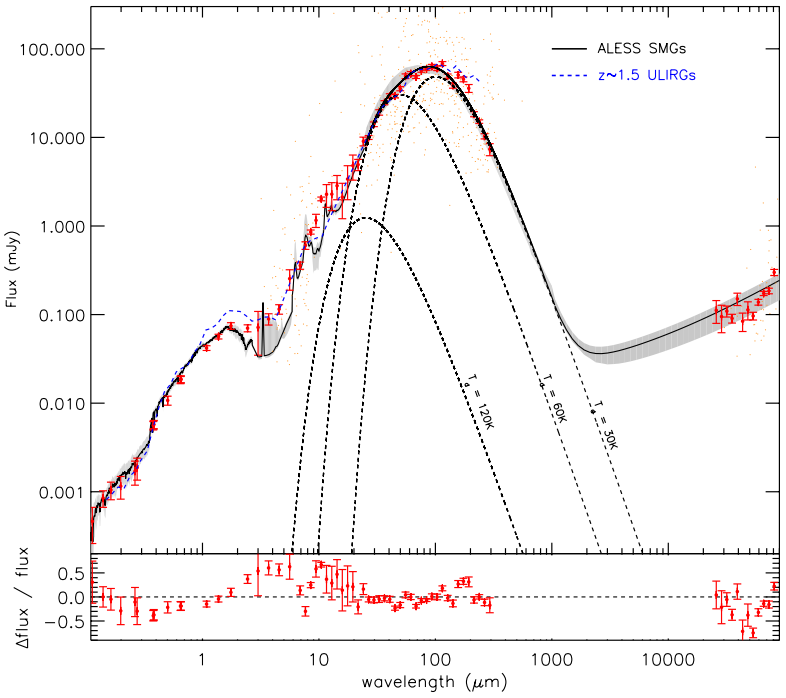


Ivison+00

see also review by Casey+2014



Greve+05

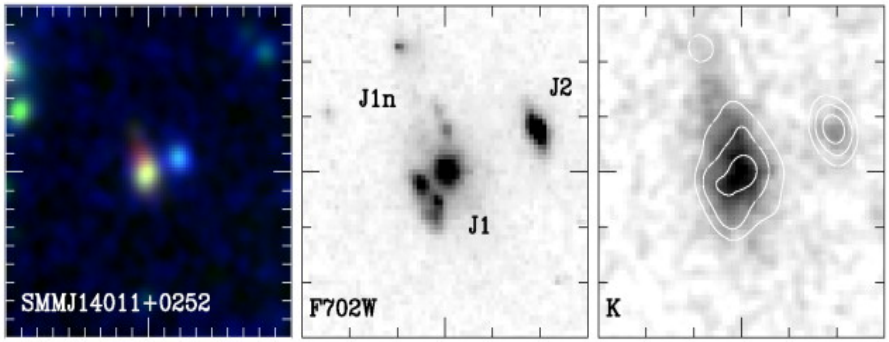


Swinbank+14

alias Submillimeter Galaxies (SMGs)

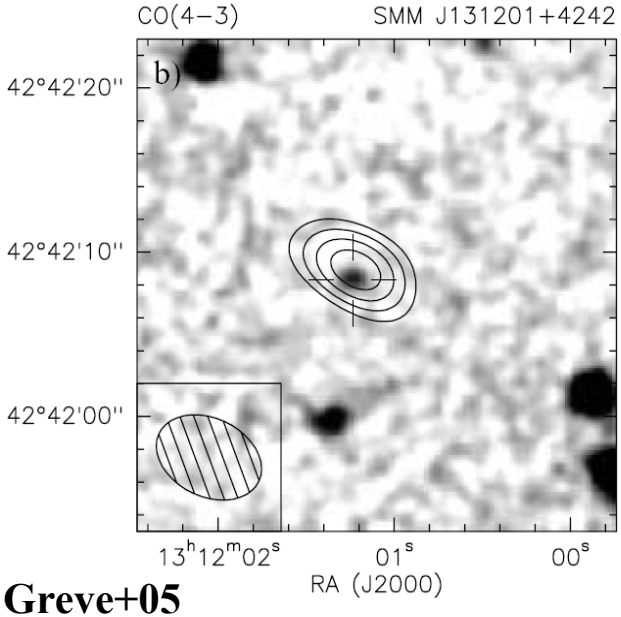
- very massive up to $10^{11} M_{\odot}$
- gas-rich
- high SFR: several 100 $M_{\odot}$/yr
- merger-like morphology
- ellipticals in formation
- <z>=2.5

➔ ***excellent tracers of mass-density peaks***

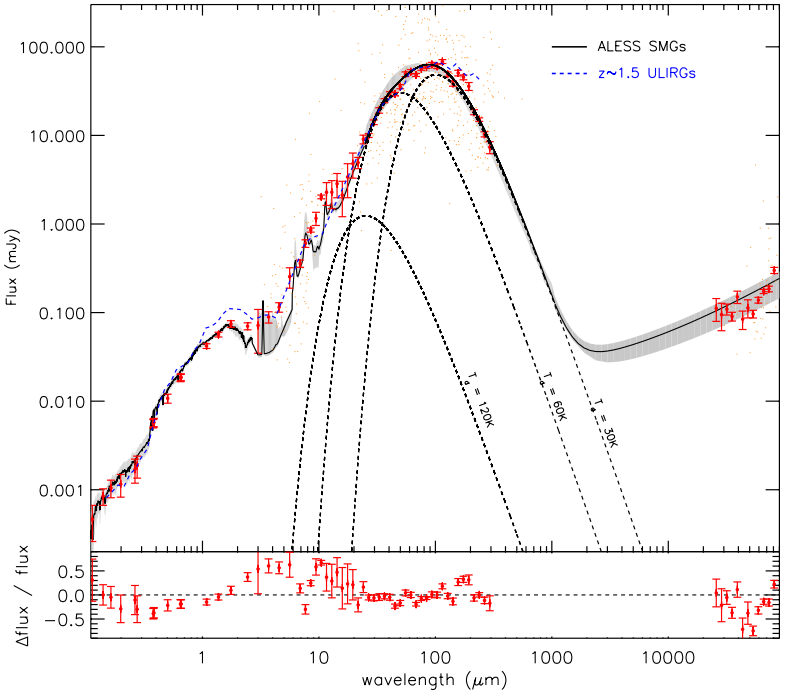


Ivison+00

see also review by Casey+2014

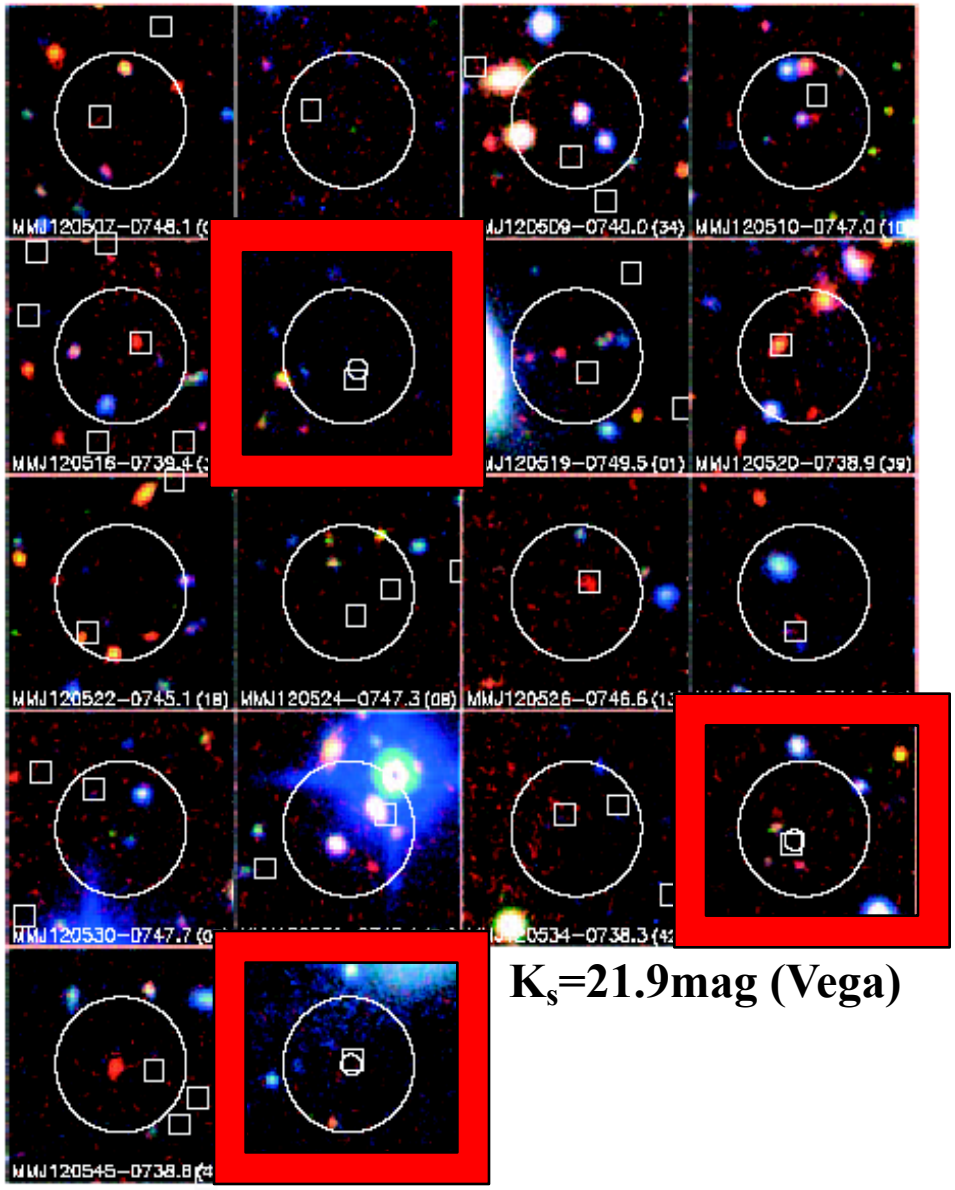


Greve+05



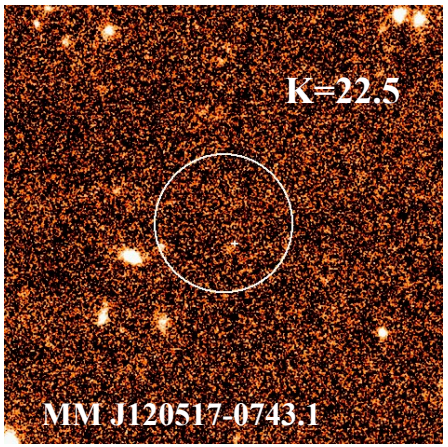
Swinbank+14

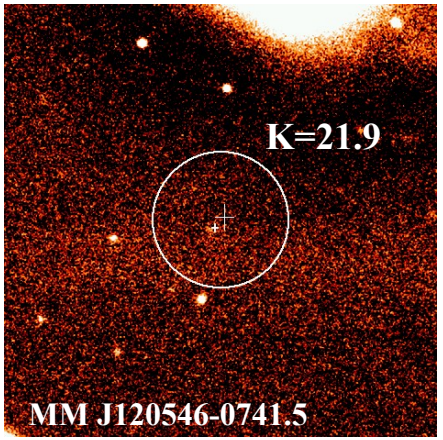
Faint in the optical/NIR - z>4 candidates



K_s=21.9mag (Vega)

VLT ISAAC

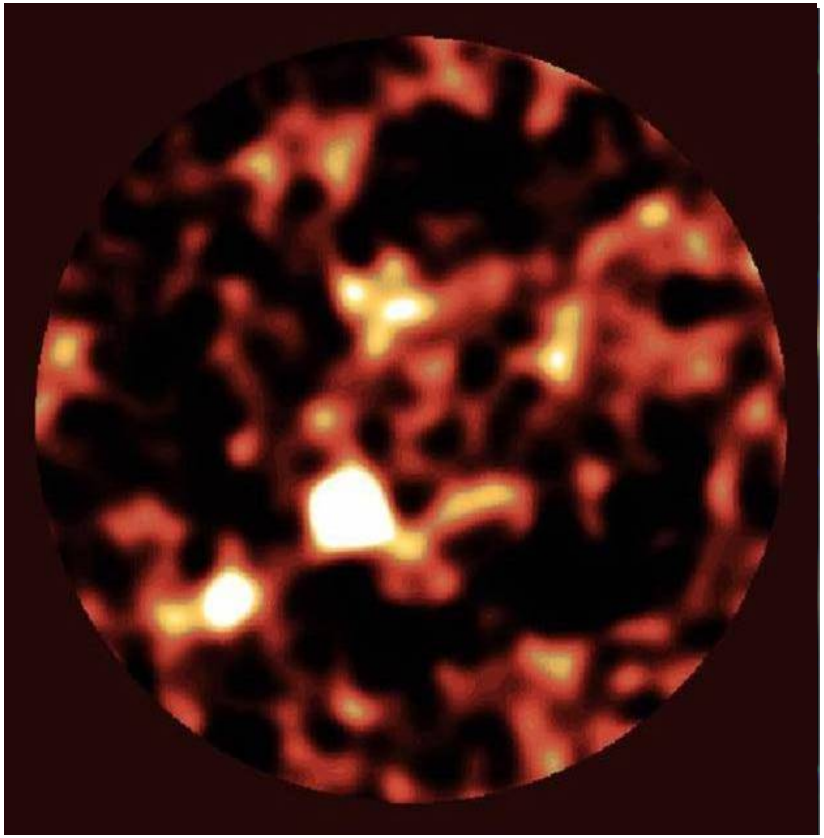




still no z-spec!!!

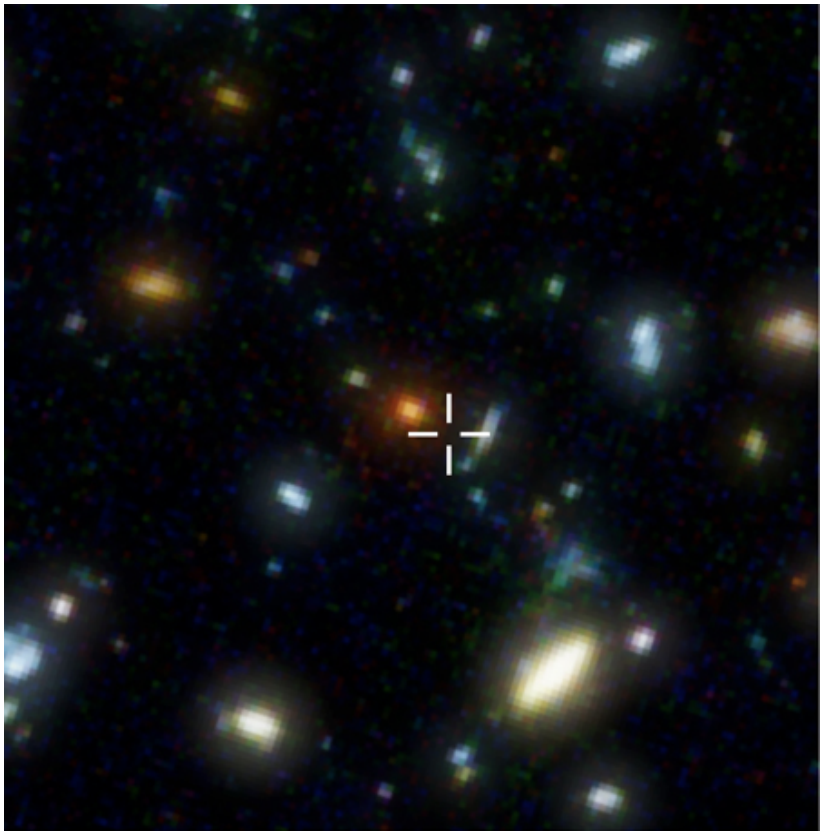
Dannerbauer et al., 2002, 2004

HDF850.1 at z=5.2



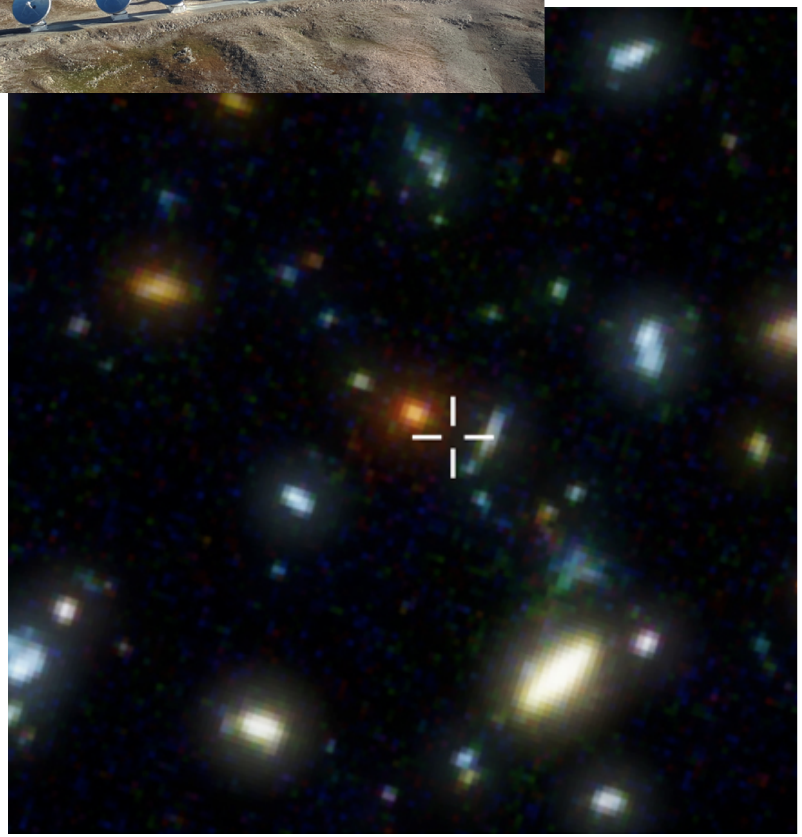
Hughes+98

HDF850.1 at z=5.2

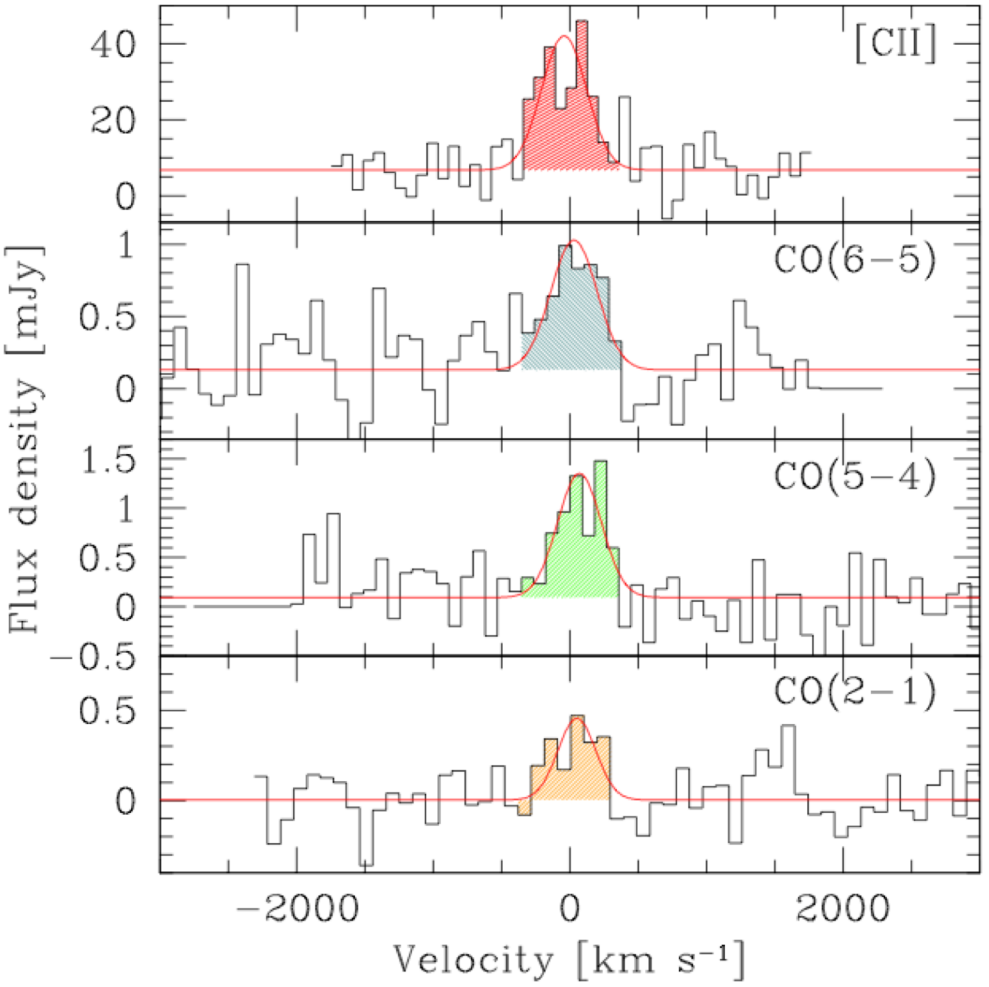


Walter…HD +, 2012, Nature

HDF850.1 at z=5.2



Walter…HD +, 2012, Nature



DSFGs at z>5

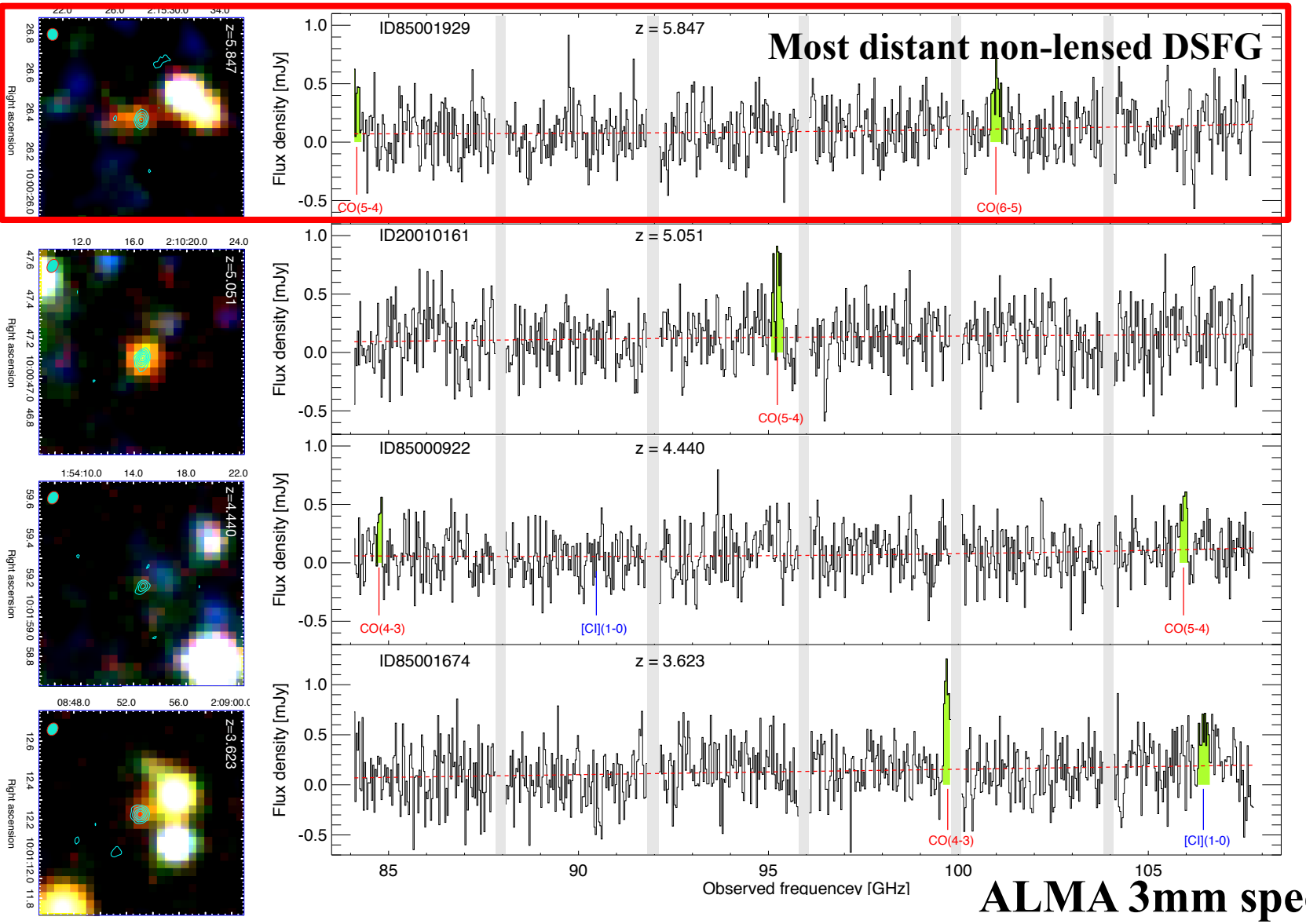
z=5.05 ID20020161 (Jin et al. 2019);
z=5.2 HLSJ (Combes et al. 2012);
z=5.2 HDF850.1 (Walter et al. 2012);
z=5.3 AzTEC3 in a proto-cluster (Riechers et al. 2010, Capak et al. 2011);
z=5.3 SPT2319-55 (Strandet et al. 2016);
two z=5.7 SPT sources (Vieira et al. 2013, Weiß et al. 2013);
z=5.7 ADFS-27 (Riechers et al. 2017);
z=5.7 CRLE (Pavesi et al. 2018);
z=5.81 SPT2351-57 (Strandet et al. 2016)
z=5.85 ID85001929 (Jin et al. 2019);

z=6.0 G09 83808 (Zavala et al. 2017, Fudamoto et al 2017);
z=6.3 HFLS3 (Riechers et al. 2013);
z=6.9 SPT0311–58 (Strandet et al. 2017, Marrone et al. 2017)

slide provided by Shuowen Jin (IAC)

Discovery of cold DSFGs at z=3.6-5.8

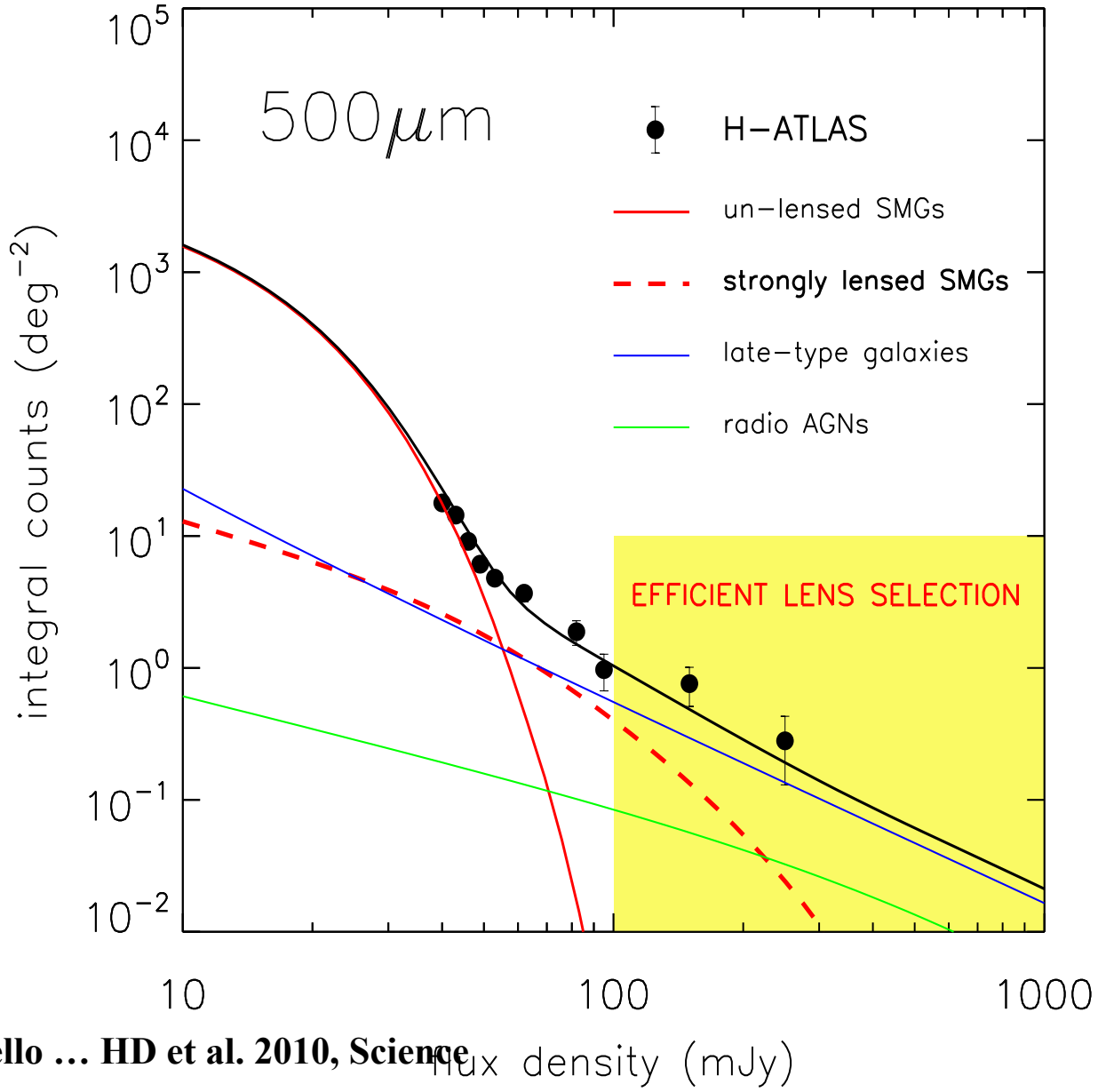
Jin et al.



ALMA 3mm spectral scan

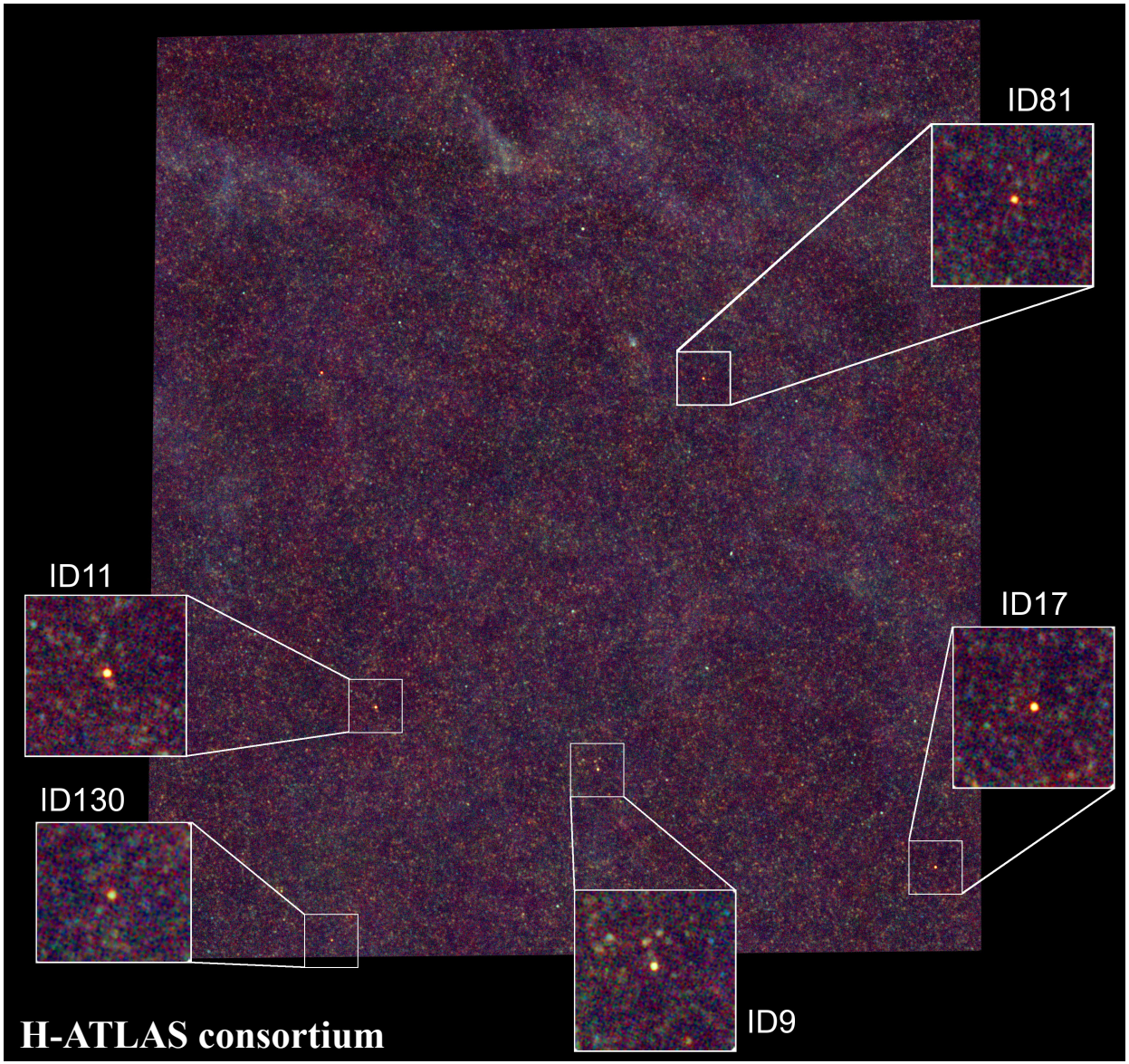
Jin, Daddi et al 2019, ApJ, submitted (astroph/1906.00040)

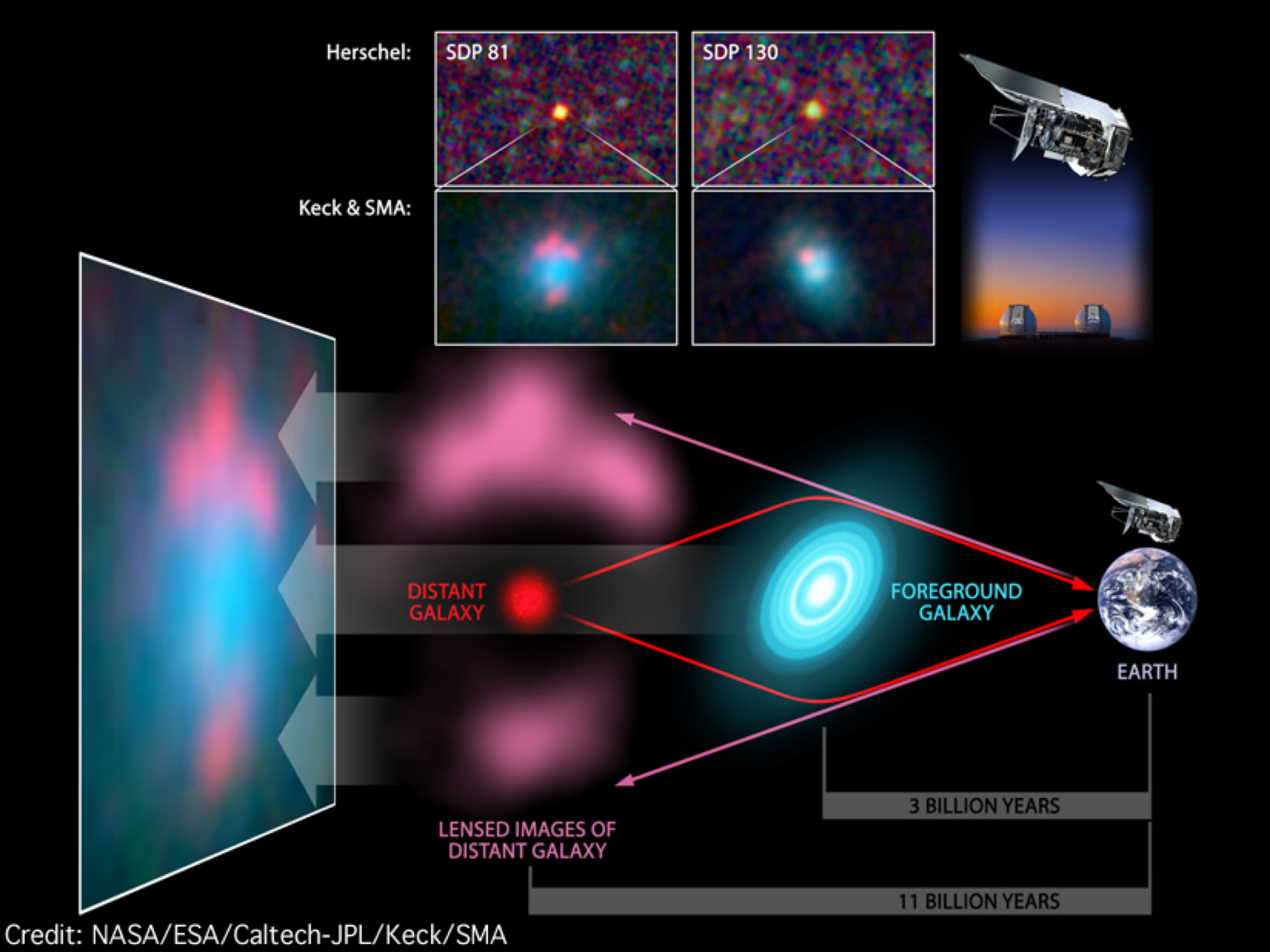
Lensing in the (sub)mm regime



Negrello … HD et al. 2010, Science

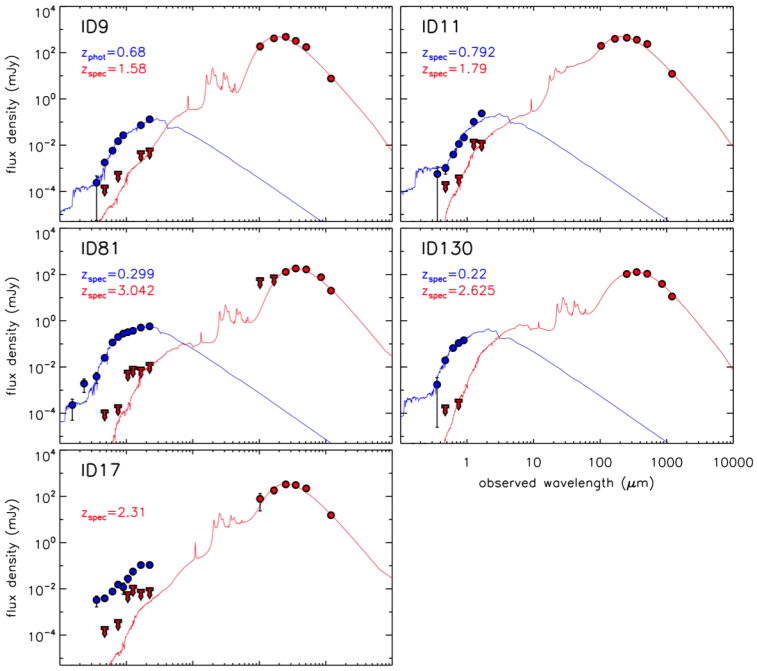
Lensed SMGs discovered by Herschel



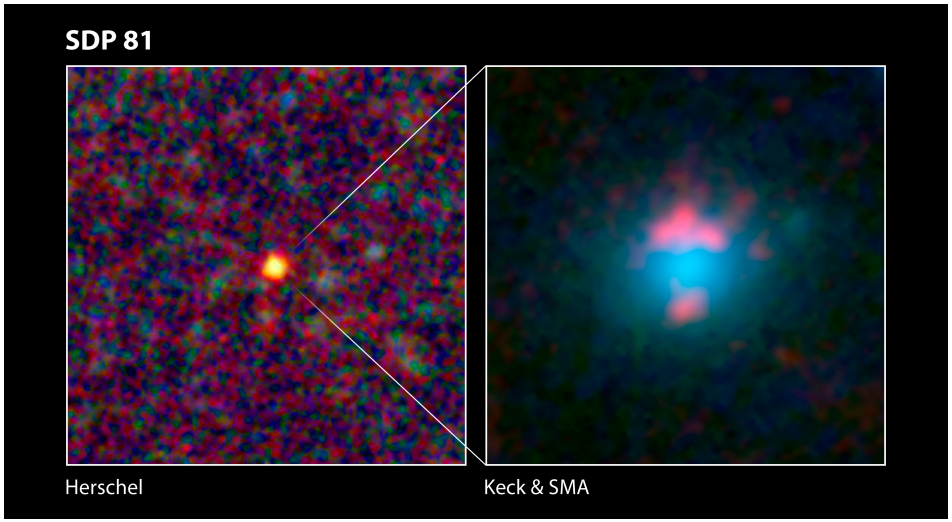


Credit: NASA/ESA/Caltech-JPL/Keck/SMA

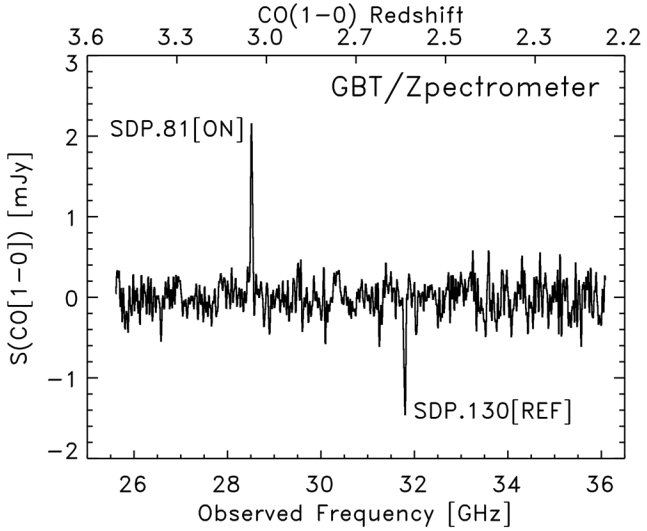
Lensed SMGs discovered by Herschel



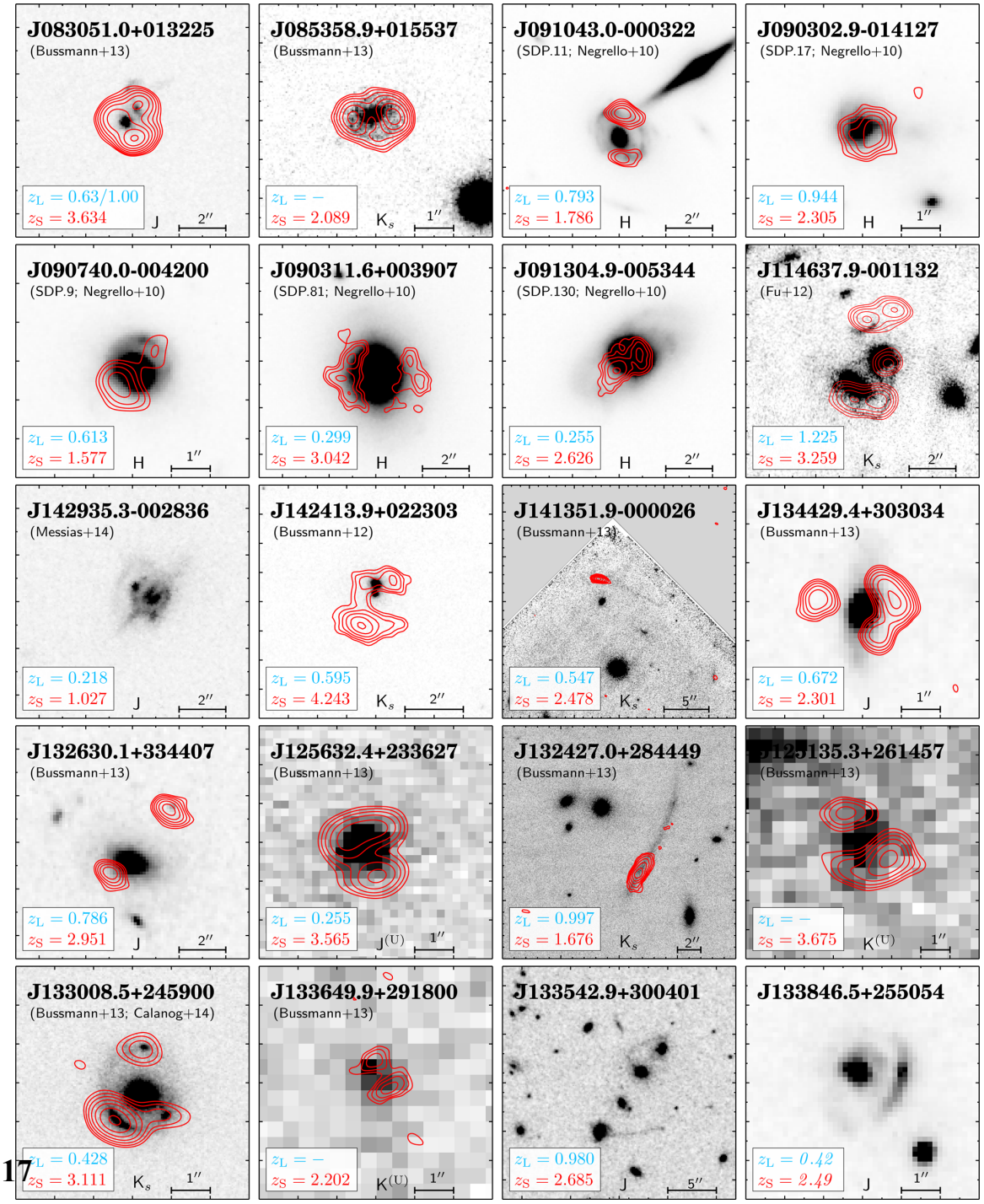
Negrello … HD et al., 2010, Science



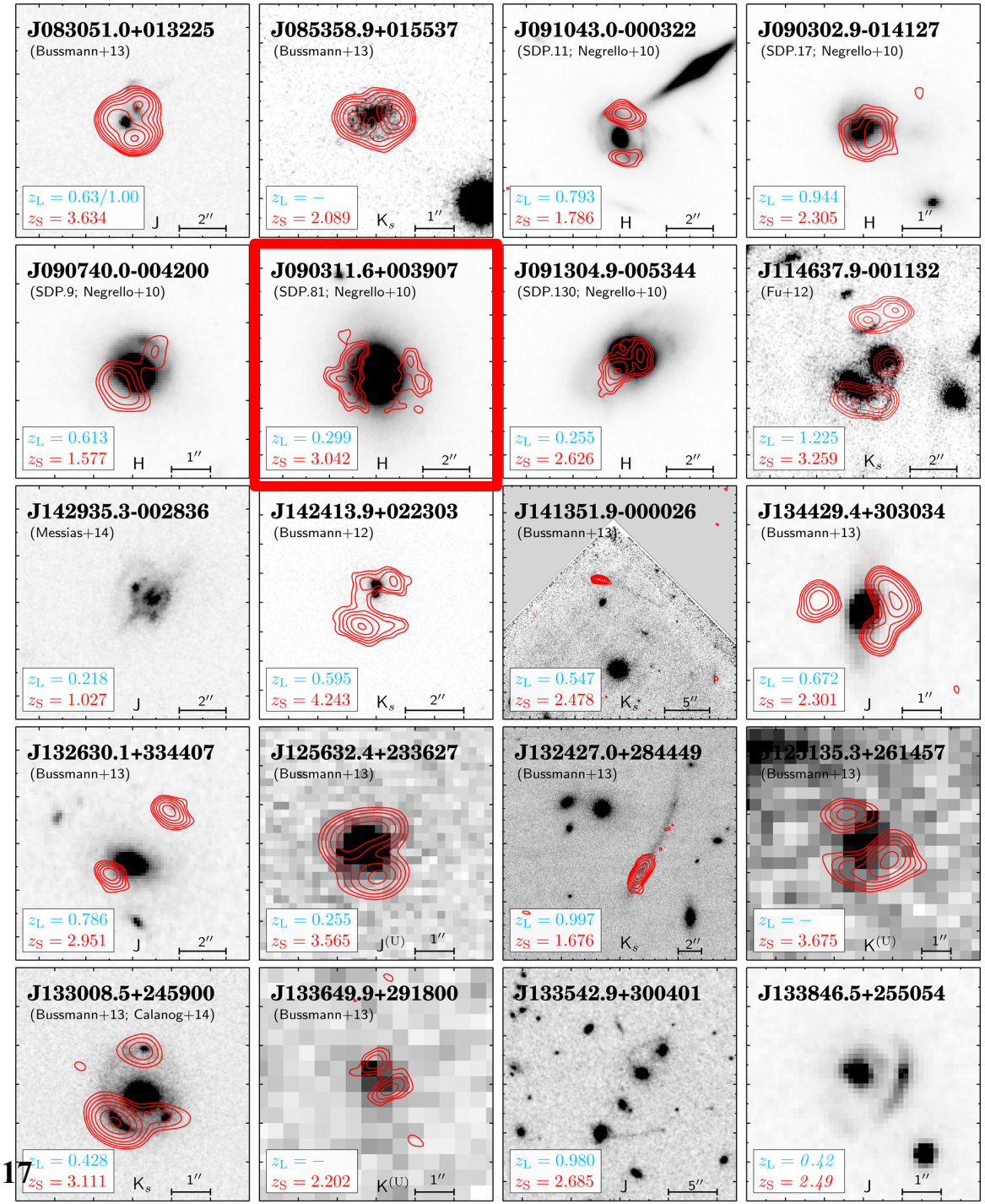
Negrello … HD et al., 2010, Science



Frayer … HD et al. (2010) using Zspetrometer at GBT



Negrello…HD et al. 2017

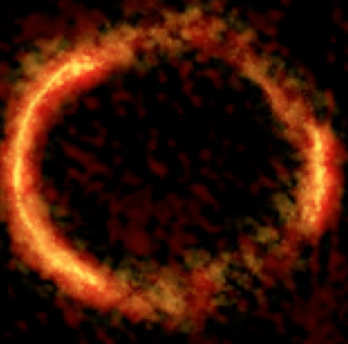


Negrello…HD et al. 2017

ALMA Observations of SDP.81 @ z=3.04

ALMA PR on 7 April 2015: long-baseline observations with ALMA down 30mas resolution

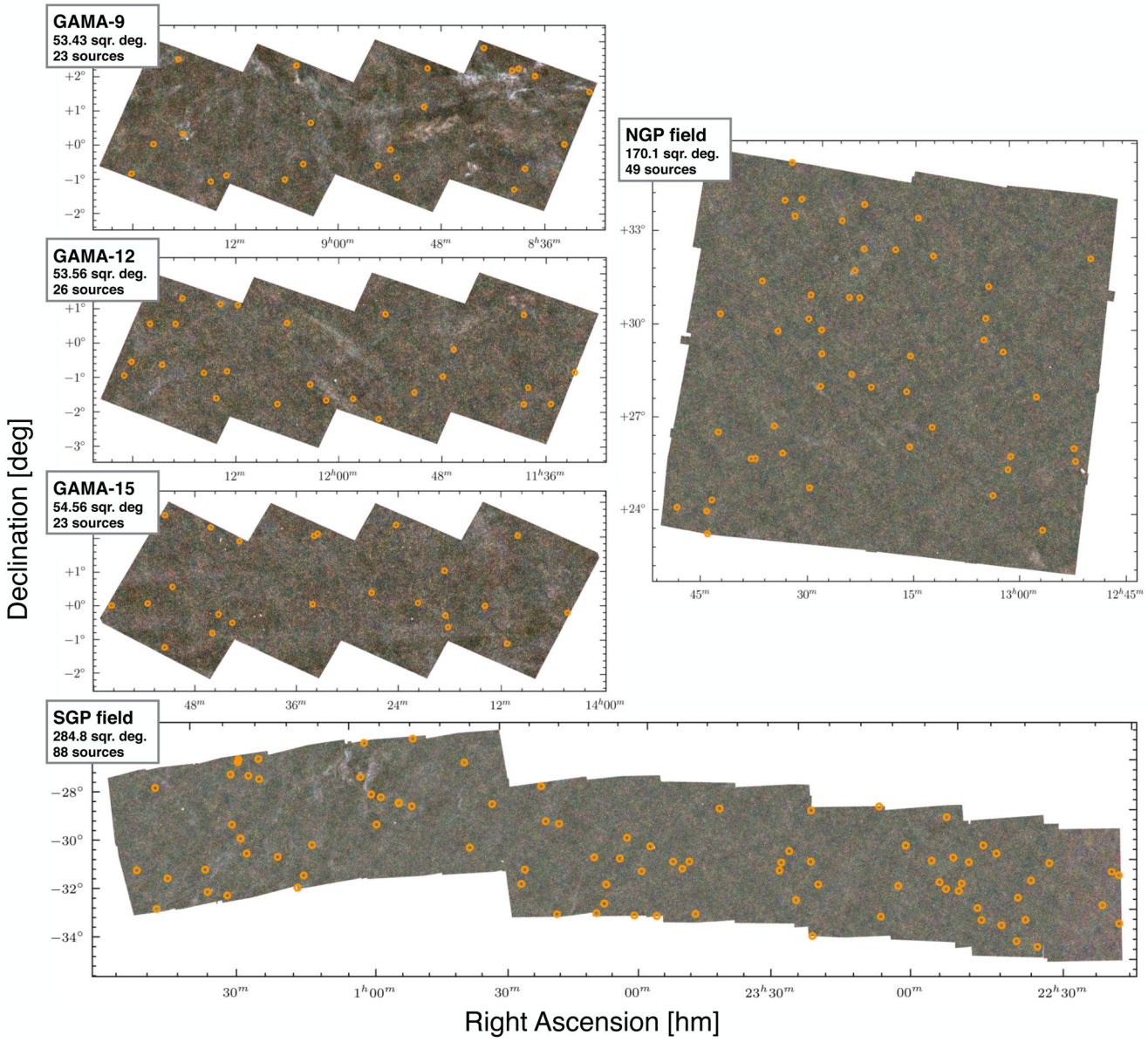
Sauron´s Eye



3arcsec

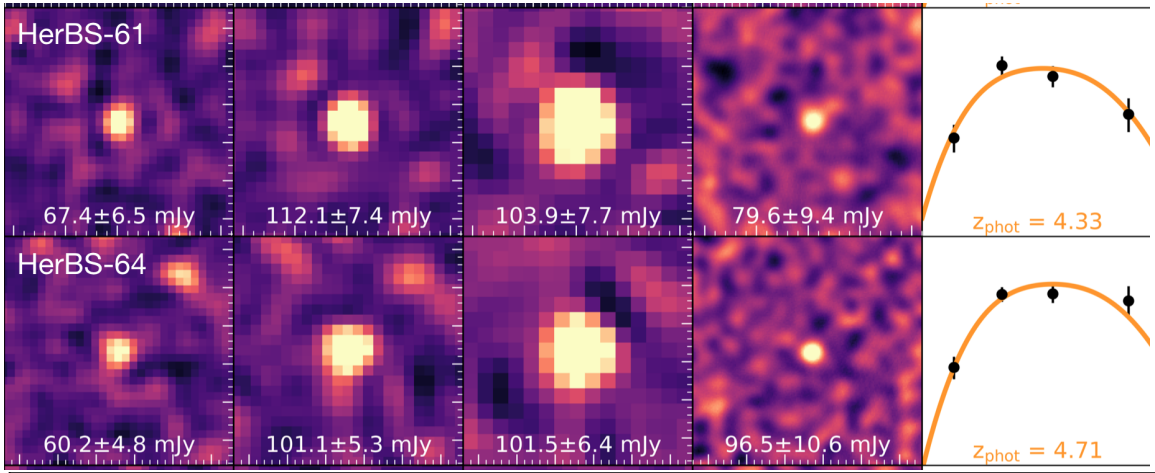
ALMA spatial resolution could be pushed down to 10mas

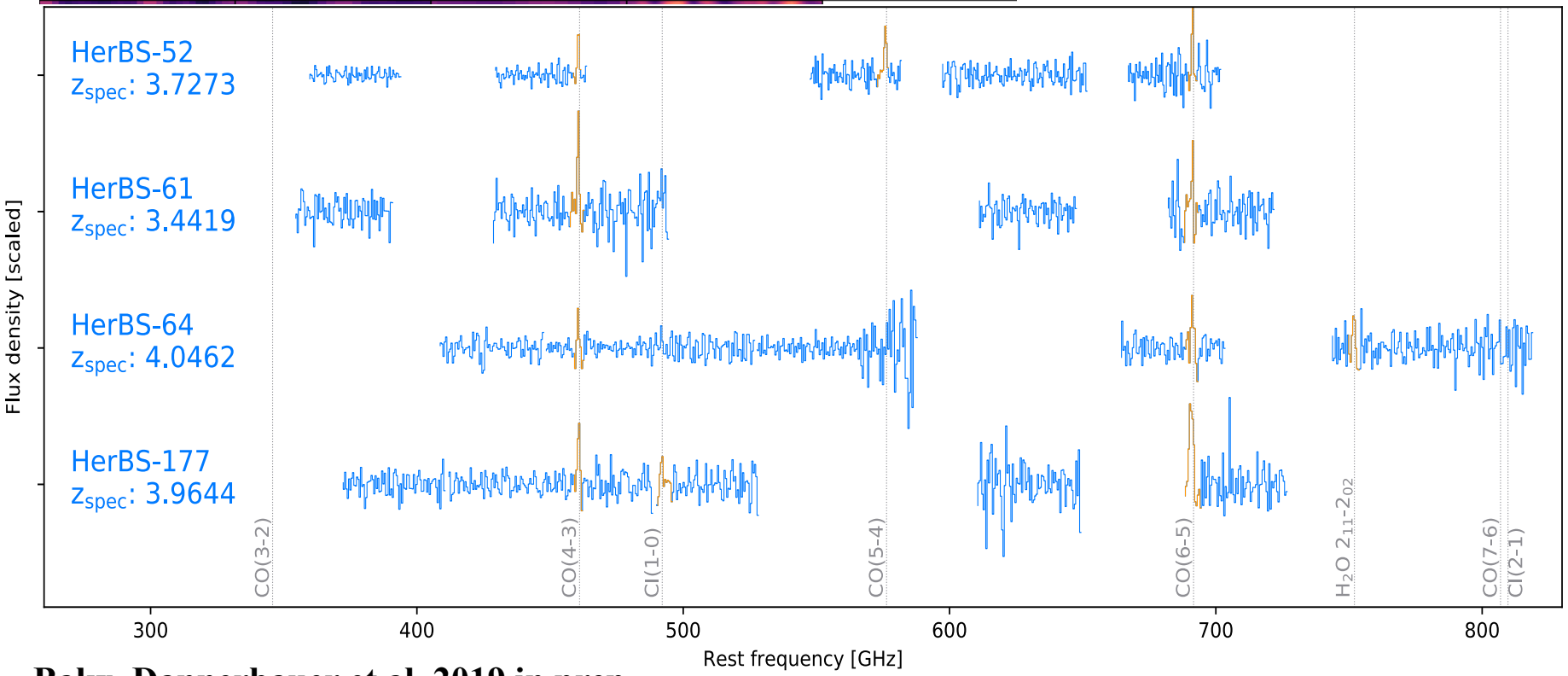
HerBS survey – lensed SMGs



Bakx et al. 2018

HerBS survey – lensed SMGs

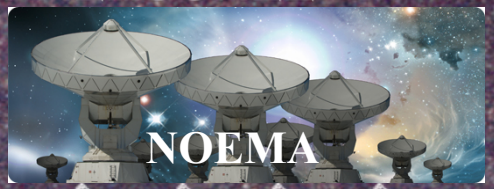




Bakx, Dannerbauer et al. 2019 in prep.

Z-GAL

A COMPREHENSIVE REDSHIFT SURVEY OF THE BRIGHTEST HERSCHEL GALAXIES



PIs: Cox, Bakx, Dannerbauer

R. Neri, A. Omont, S. Eales, R. Ivison, M. Lehnert, R. Gavazzi, S. Serjeant, L. Marchetti, M. Negrello, S. Dye, D. Riechers, M. Krips, A. Cooray, I. Perez-Fournon, I. Oteo, D. Hughes, H. Messias, V. Buat, A. Baker, C. Vlahakis, P. van der Werf, L. Dunne, C. Yang, S. Berta, A. Beelen, A. Weiss, C. Herrera, A. Harris, S. Jin, A. Young

Overview

Z-GAL is a NOEMA Large Program that aims for a comprehensive redshift survey of a sample of 127 of the brightest SMGs from the Herschel deep fields (H-ATLAS and HerMES).

191 hrs.

Together with the results of previous projects, Z-GAL will provide a sizeable and homogeneous sample of about 190 SMGs with reliable redshifts to achieve the following goals:

- increase the number of lensed SMGs with known redshifts at the peak of the cosmic star-formation rate density,
- find a substantial number of high-redshift hyper-luminous SMGs and study their statistical properties,
- trace other rare objects,
- enable follow-up observations of lensed sources, and derive the properties of the massive deflector dark matter haloes at z~0.5-1 and the large-scale structures they trace,
- measure cosmological parameters and distinguish between mass functions of dark-matter haloes, and
- further explore the physical properties of these dusty luminous star-forming galaxies in the early universe.

ESO Public Survey *SHARKS*
Southern H-ATLAS Regions Ks band Survey

PI: Helmut Dannerbauer

Oteo, Sutherland, Cross, Ivison, Bayo, Clements, Davies, Driver, Dunne, Dye, Eales, Furlanetto, C. Gonzalez, E. Gonzalez, Hurley, Hughes, Ibar, Irwin, Jarvis, Leiton, Maddox, Mann, Oliver, Robotham, Seymour, Scudder, Smith, Vaccari, Valiante

provide counterparts of (high-z) sources selected through on-going and future infrared and radio surveys

- **1200hrs of observing time with ESO 4m telescope VISTA and instrument VIRCAM are approved**
- **300 square degree in Ks-band down to 22.7mag (AB, 5sigma)**
- **Surveying Herschel fields from survey H-ATLAS**
- **more than 70% of the data are taken**
- **huge legacy value (Euclid, LSST, WEAVE, radio surveys from LOFAR, ASKAP, SKA)**

(Another) Selection technique

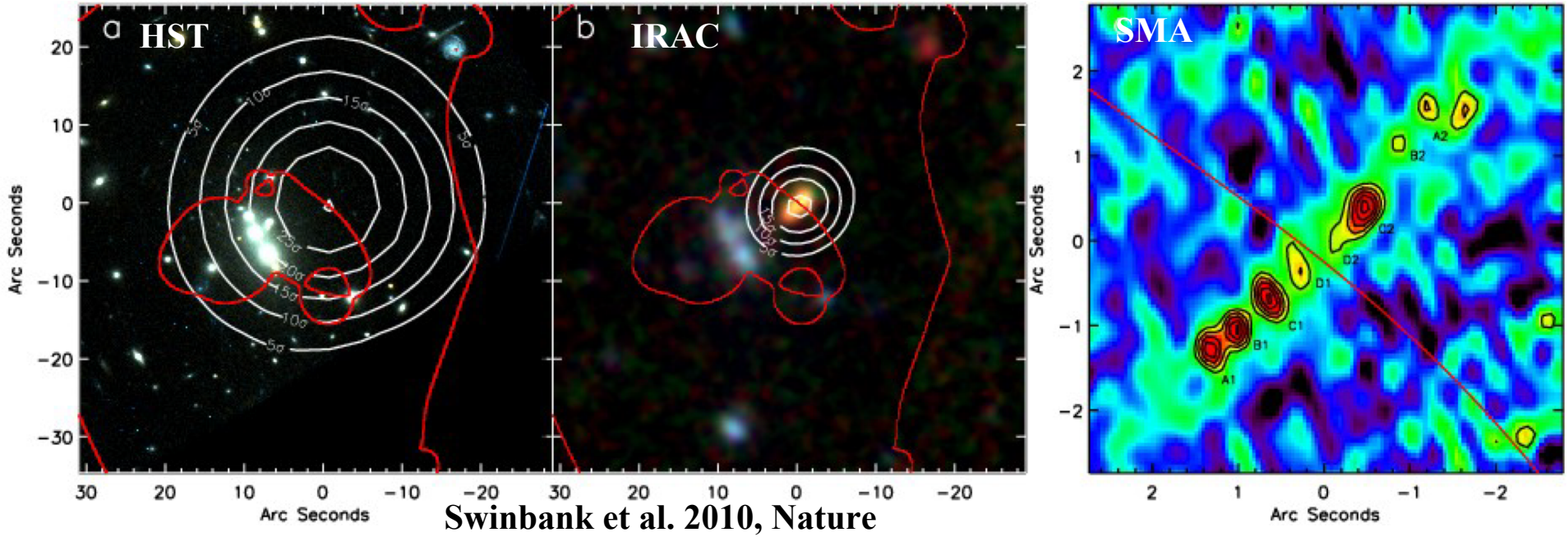
- **search for sources with a similar SED in the infrared as a well-known reference source**

- **we started search with VISTA and WISE**

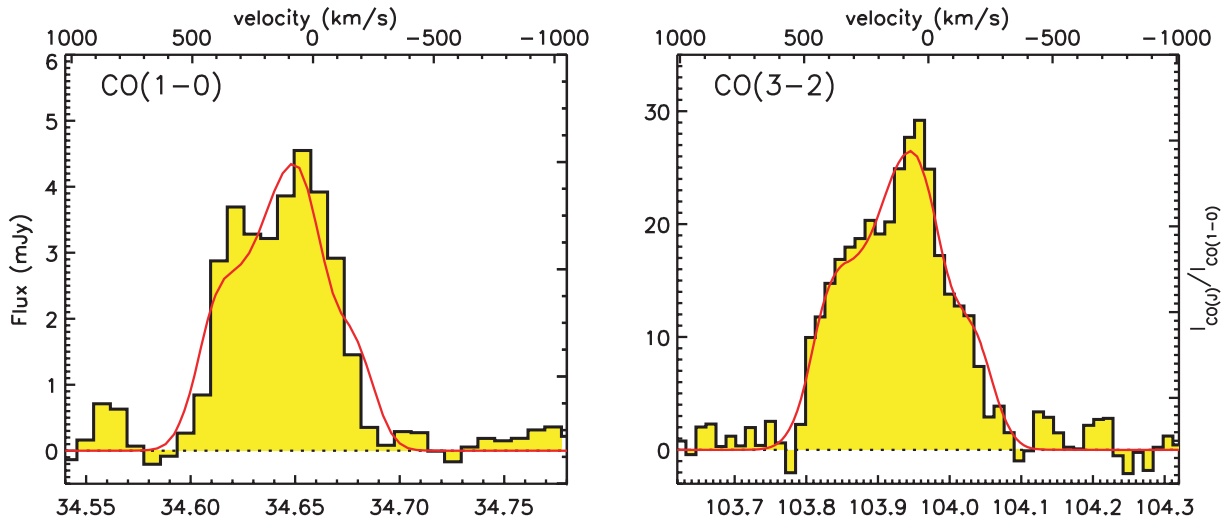
- **focus on cluster-galaxy lensing**

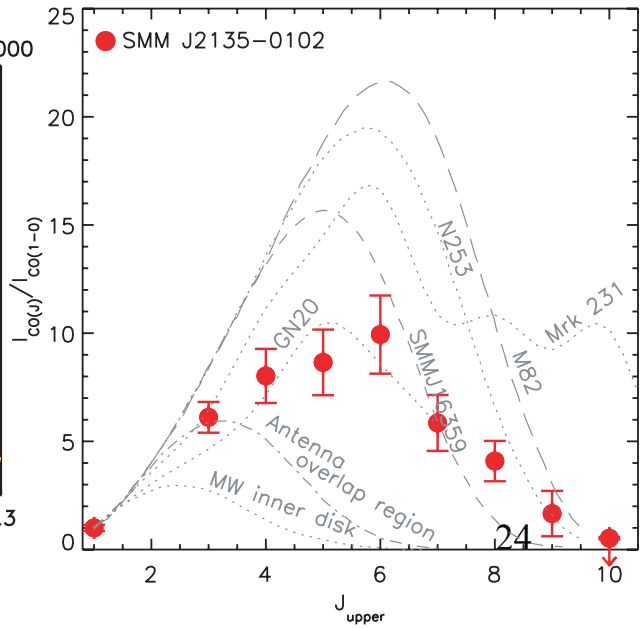
- **galaxy cluster algorithm developed within Euclid**

Cosmic Eyelash: lensed SMG at z=2.32



Swinbank et al. 2010, Nature



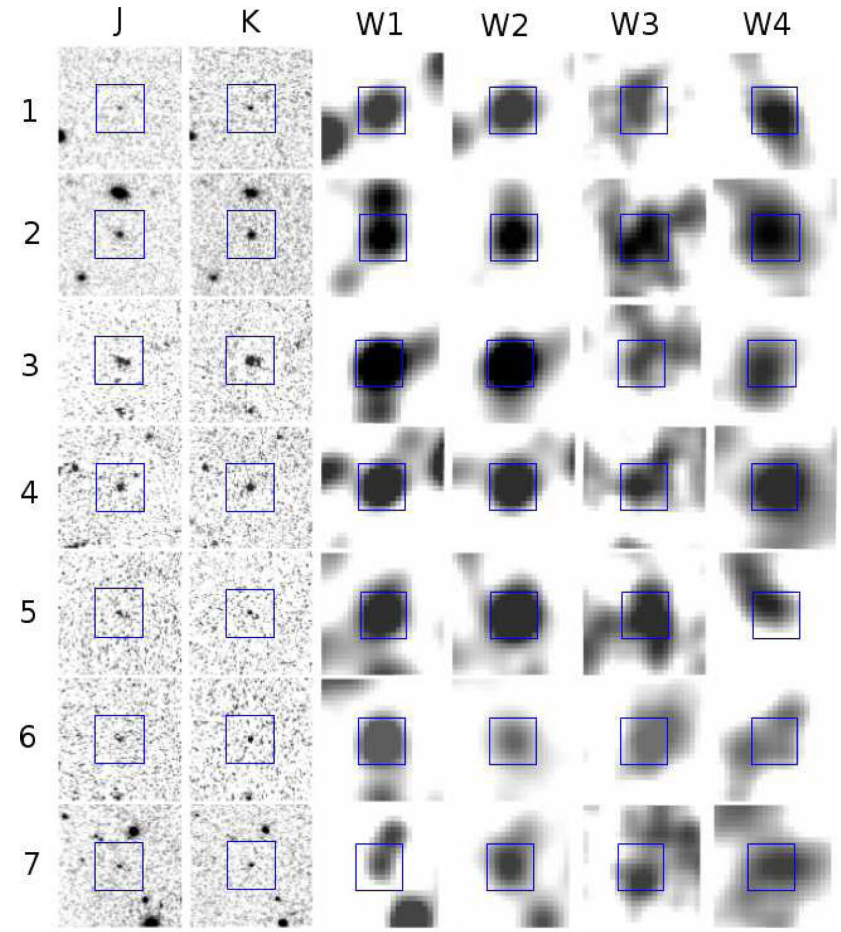


Danielson et al. 2011

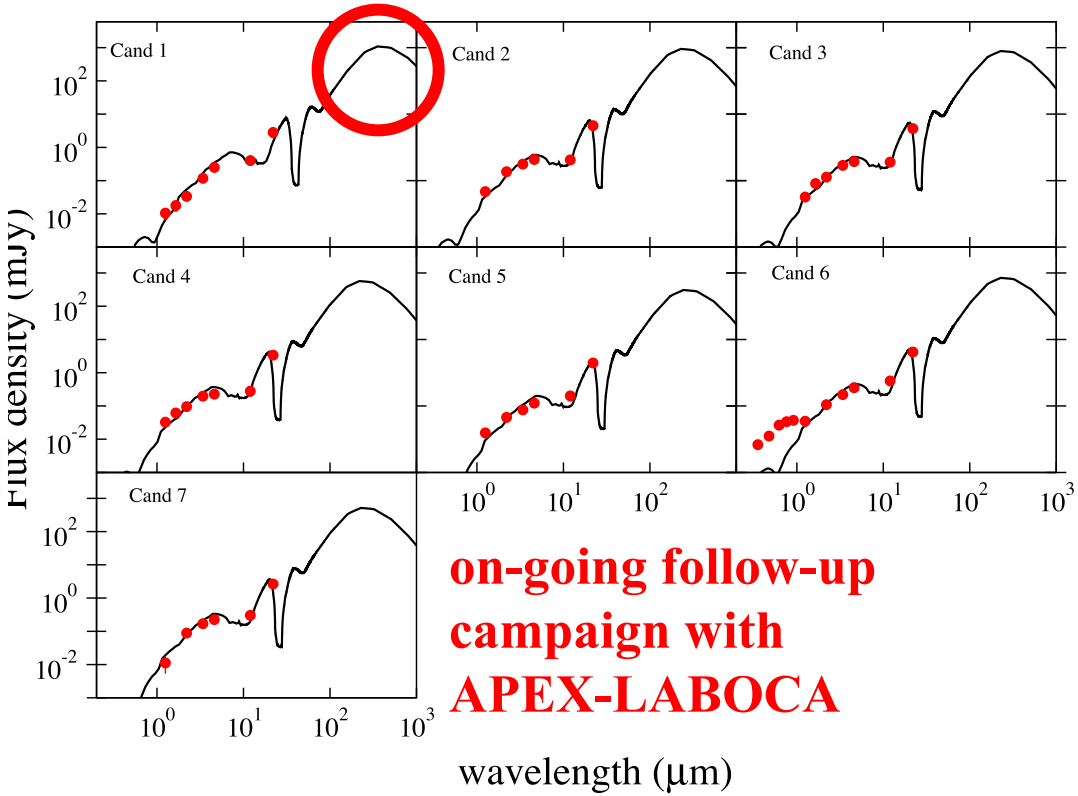
(Another) Selection technique

- **search for sources with a similar SED in the infrared as a well-known reference source**
- **we started search with VISTA and WISE**
- **focus on cluster-galaxy lensing**
- **galaxy cluster algorithm developed within Euclid**
- **refinement of selection criteria: we search in WISE and Planck all-sky dataset**
- **search for multi-wavelength information in archives/literature**

Selection technique



far-infrared needed



on-going follow-up campaign with APEX-LABOCA

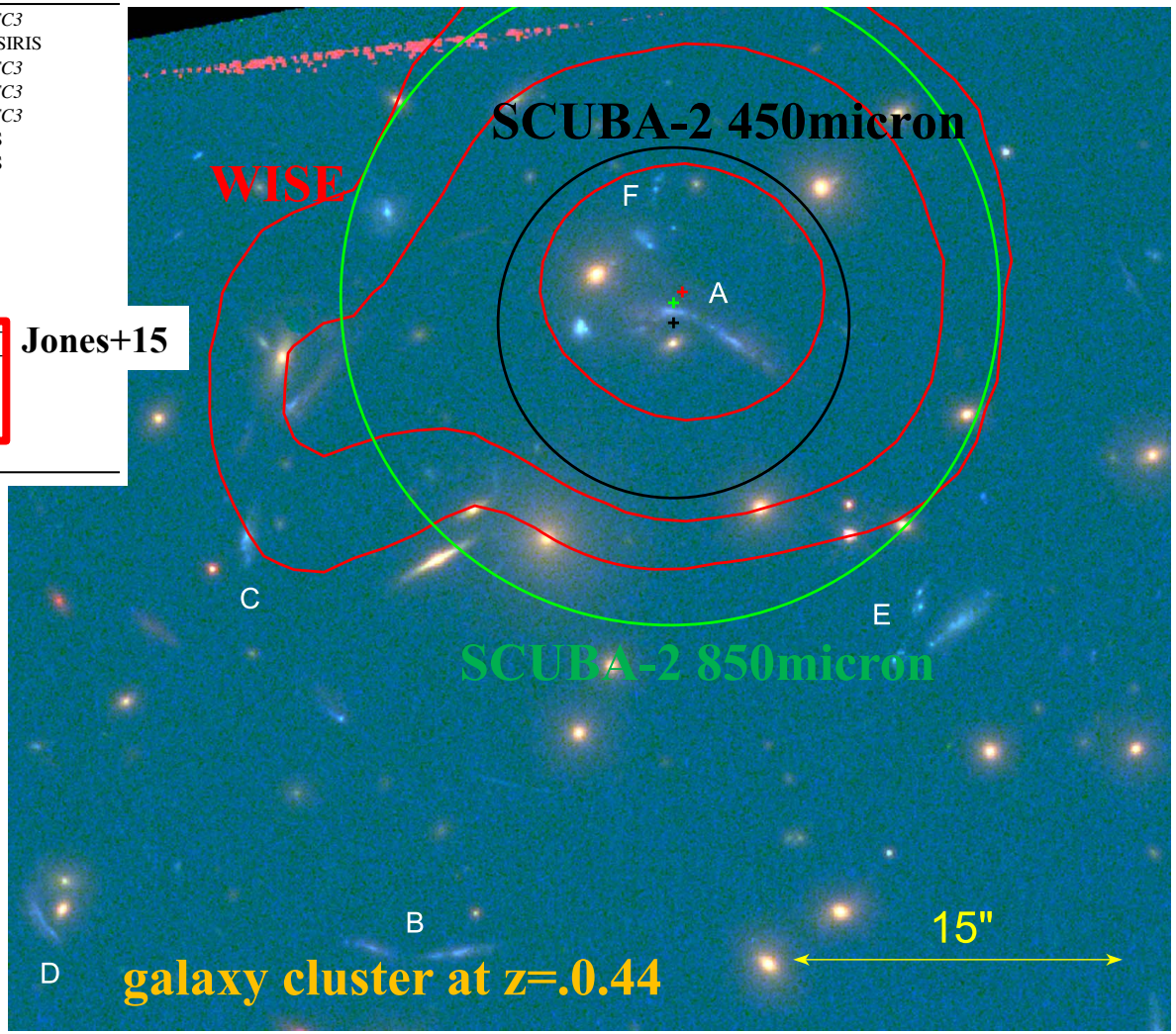
Iglesias-Groth, Diaz-Sanchez, Rebolo & Dannerbauer, 2017, MNRAS

WISE J132934.18+224327.3

Table 1
Photometry

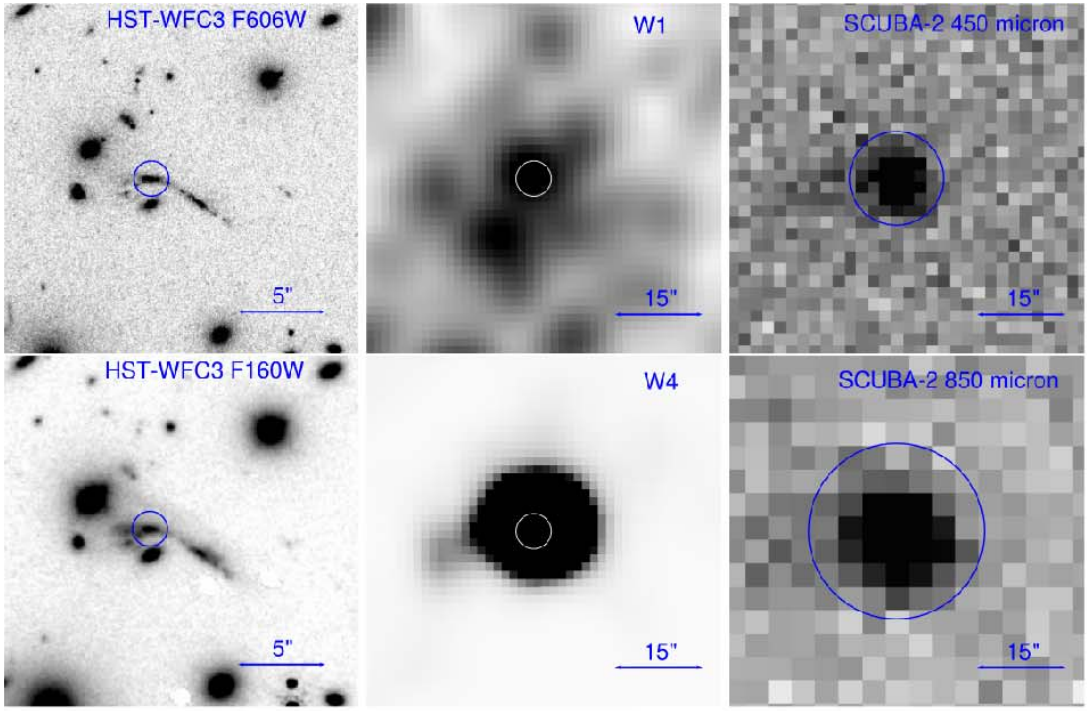
Wavelength(μm)	Flux (mJy)[a,b]	Observatory/Instrument
0.3921	0.0022 ± 0.0001	*HST/WFC3*
0.45	0.004 ± 0.002	GTC/OSIRIS
0.5887	0.0043 ± 0.0001	*HST/WFC3*
1.0552	0.0252 ± 0.0004	*HST/WFC3*
1.5369	0.0614 ± 0.0006	*HST/WFC3*
1.644	<0.112[c]	UKIDSS
2.199	<0.110[c]	UKIDSS
3.4	0.37 ± 0.01	*WISE*
4.6	0.45 ± 0.02	*WISE*
12	0.7 ± 0.1	*WISE*
22	10.6 ± 0.8	*WISE*
60	<100[c]	*IRAS*
100	<300[c]	*IRAS*
450	604 ± 86	SCUBA-
850	127 ± 11	SCUBA-
350	1298 ± 200	*Planck*
550	692 ± 100	*Planck*
850	271 ± 90	*Planck*
21.4[a]	3.56 ± 0.14	FIRST

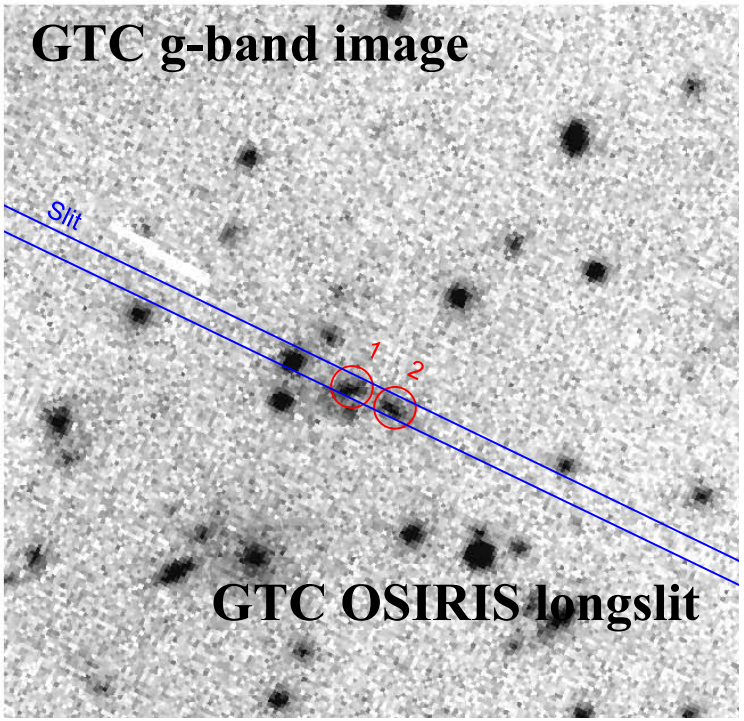
Jones+15



Diaz-Sanchez, Iglesias-Groth, Rebolo & Dannerbauer, 2017, ApJL

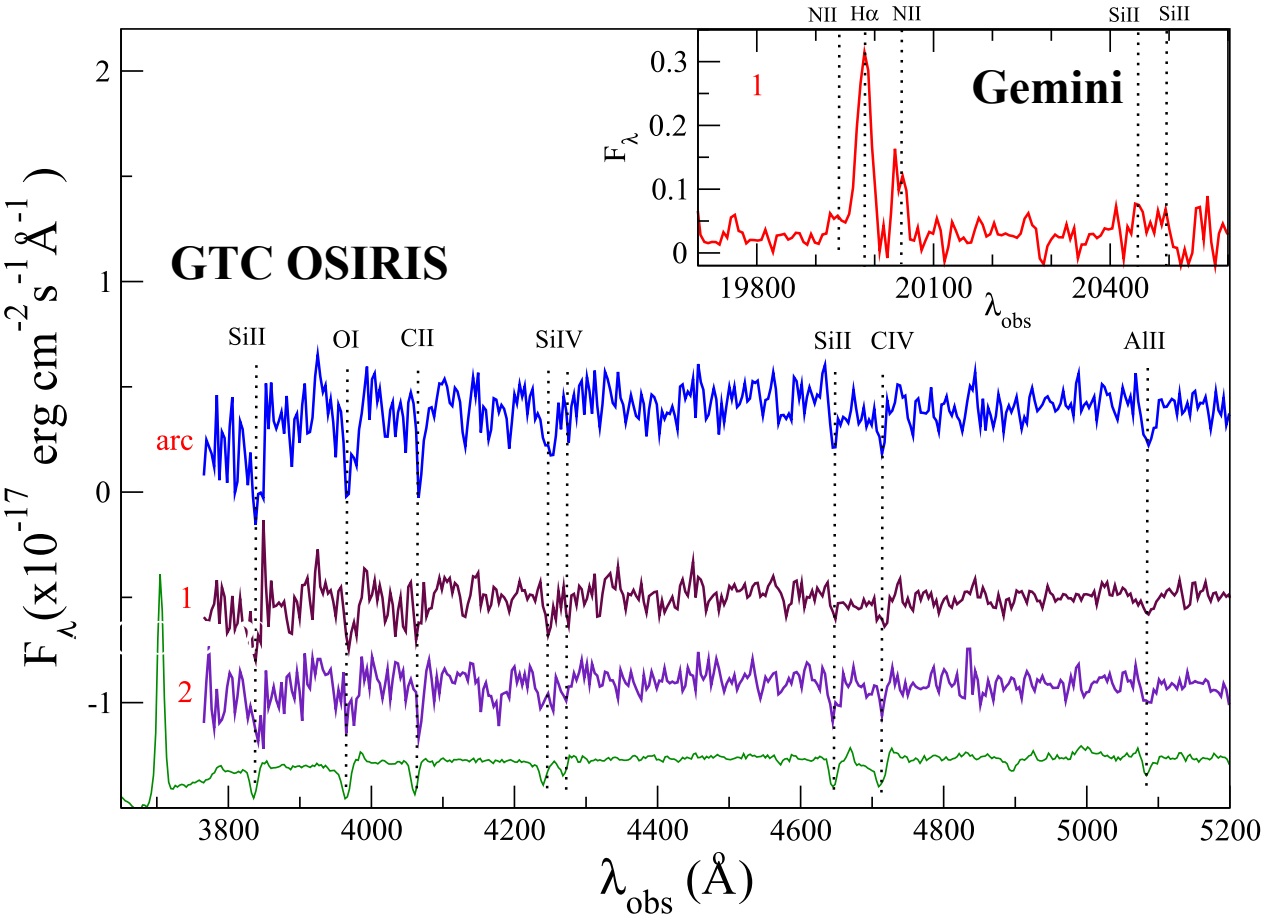
Multi-wavlength coverage





Diaz-Sanchez, Iglesias-Groth, Rebolo & Dannerbauer, 2017, ApJL

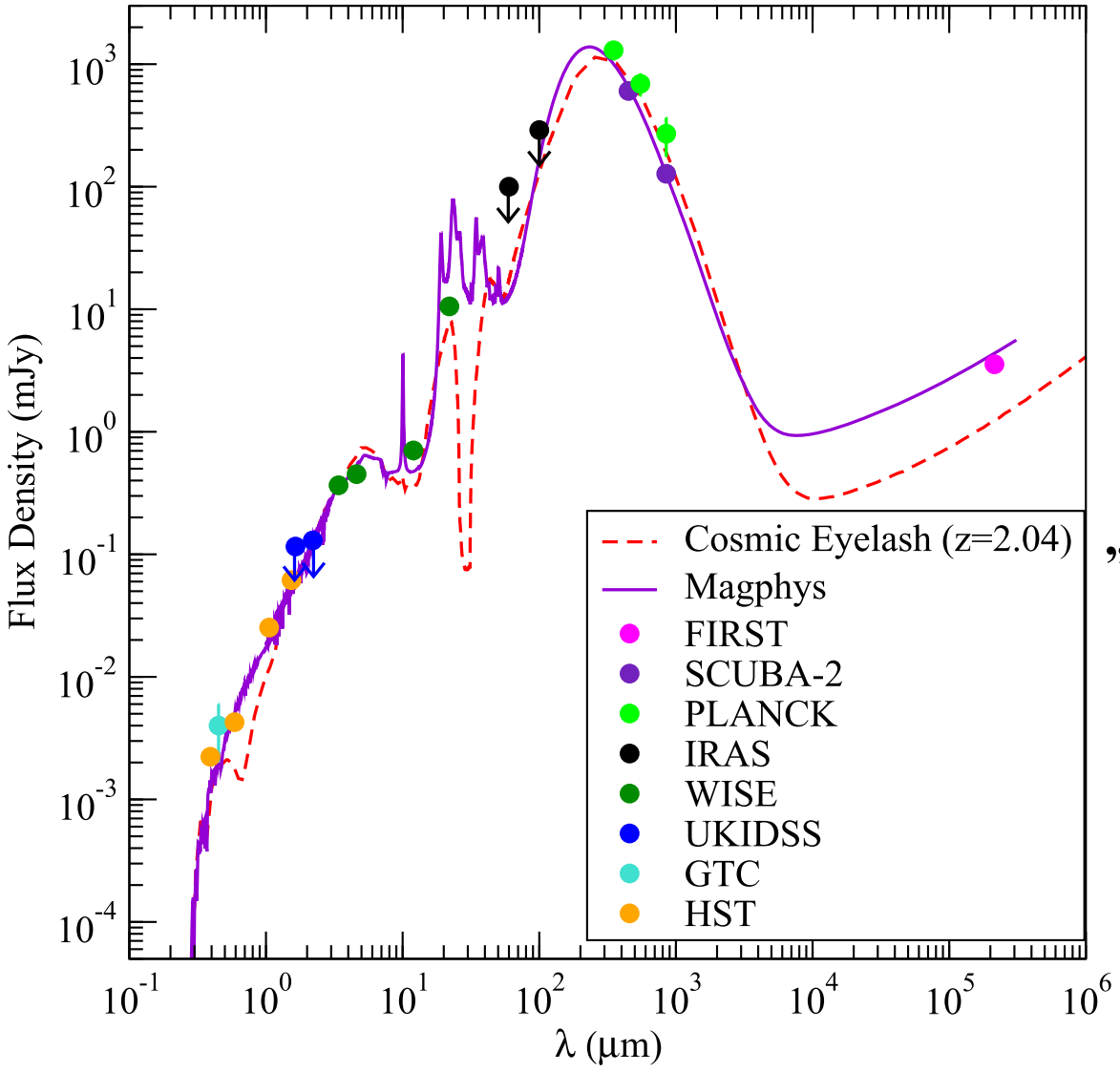
Cosmic Eyebrow: ultra-bright lensed SMG at z=2.04



lens magnification factor= 11+-2

Diaz-Sanchez, Iglesias-Groth, Rebolo & Dannerbauer, 2017, ApJL

SED (Spectral Energy Distribution)



up to a factor 4 brighter than the Cosmic Eyelash

$L_{IR}=1.3x10^{13}\ L_{sun}$

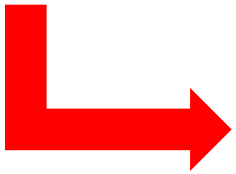
factor 10 in IR-luminosity

„Big brother of Cosmic Eyelash“

Diaz-Sanchez, Iglesias-Groth, Rebolo & Dannerbauer, 2017, ApJL

Is the Cosmic Eyebrow indeed a lensed SMG?

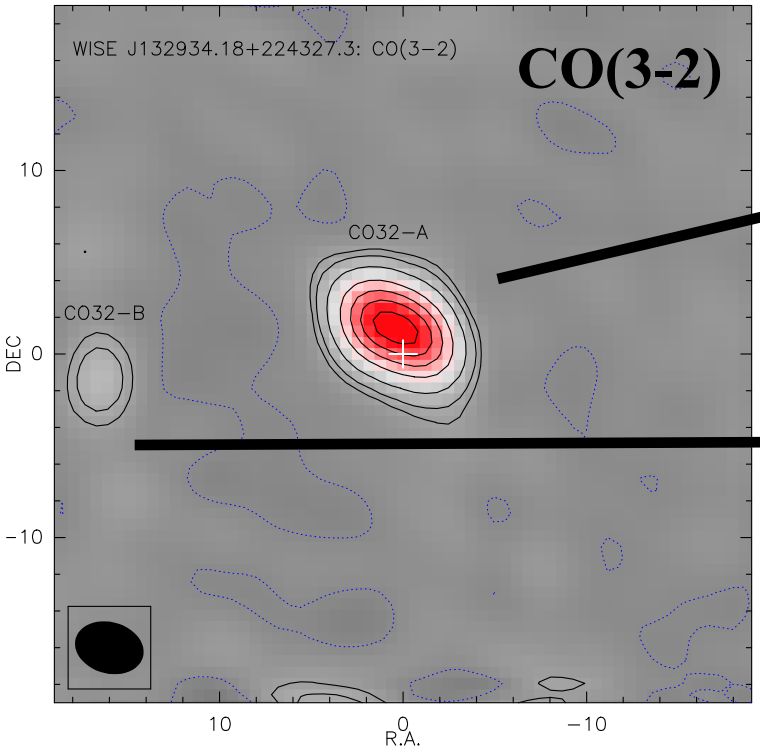
- within WISE/SCUBA-2 position galaxy at z=2.04 with GTC revealed
- emitter of dust emission?
- unambiguous proof would be detection of cold ISM lines

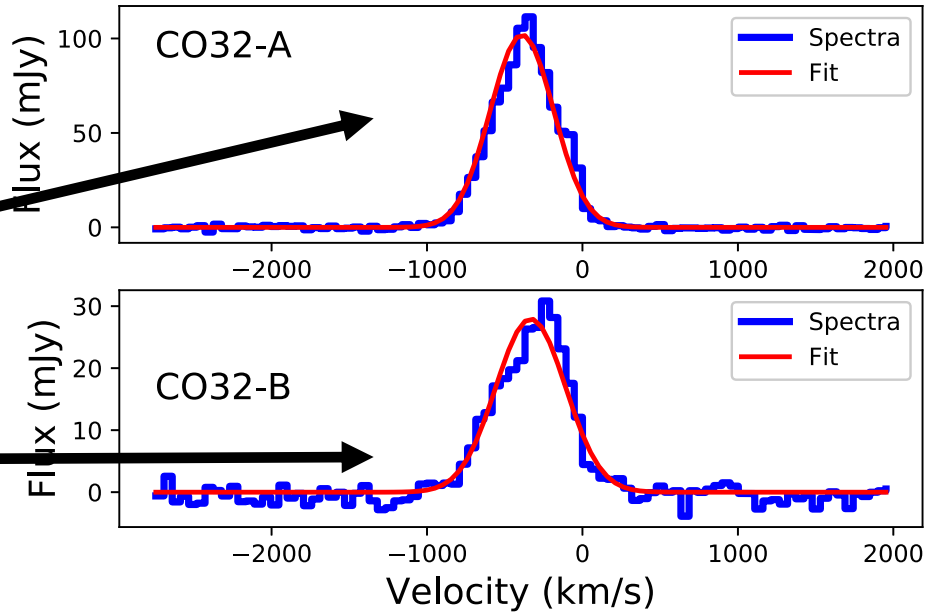


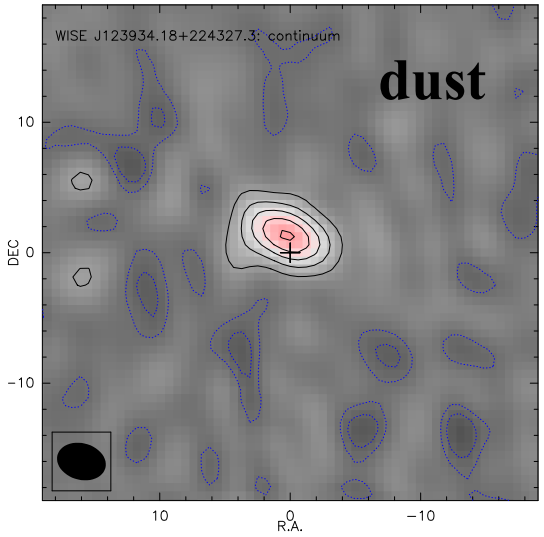
need to go to the far-infrared/millimeter regime

Cold ISM detected!

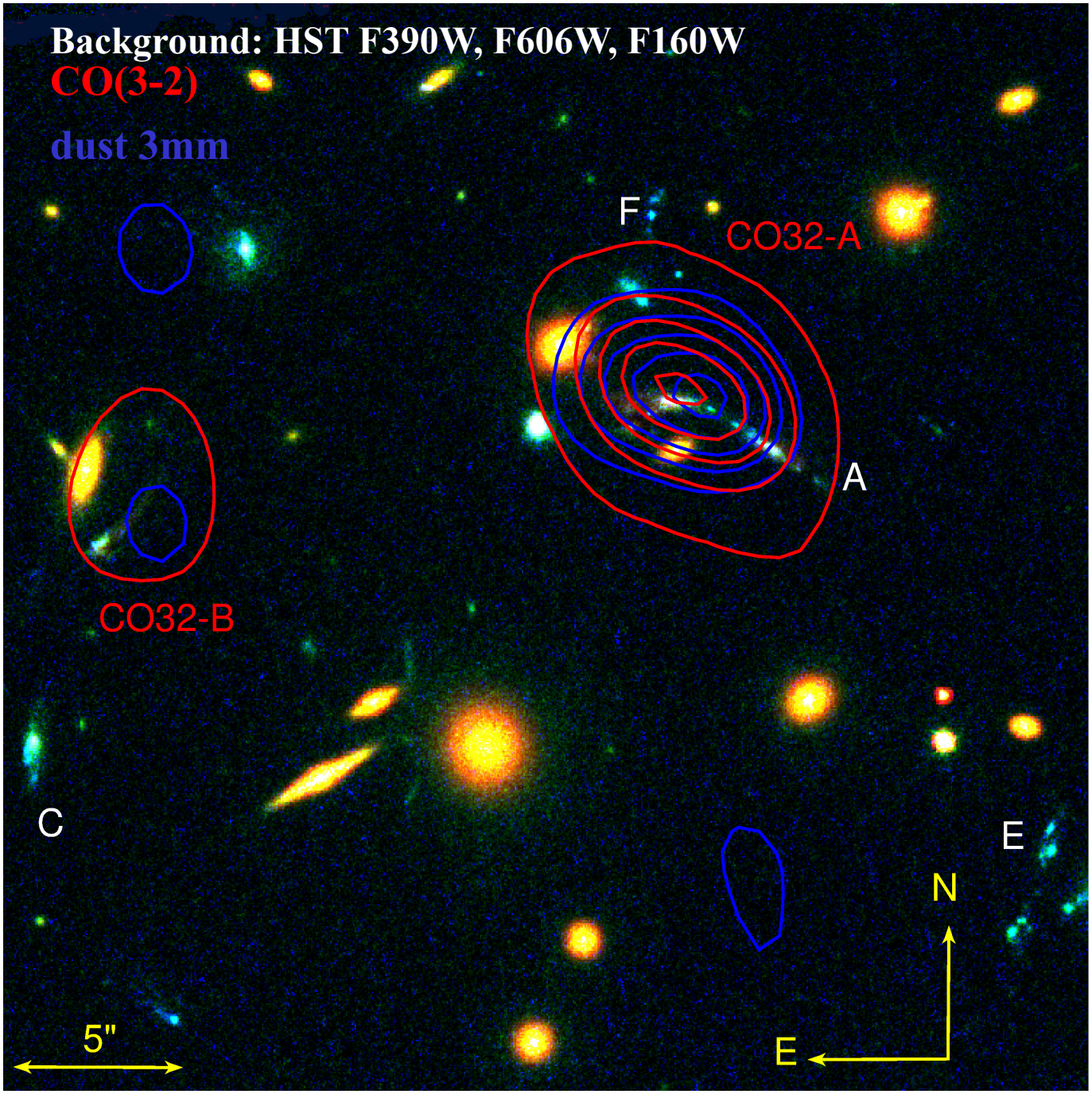
$I_{CO(3-2)}$>50Jy km/s

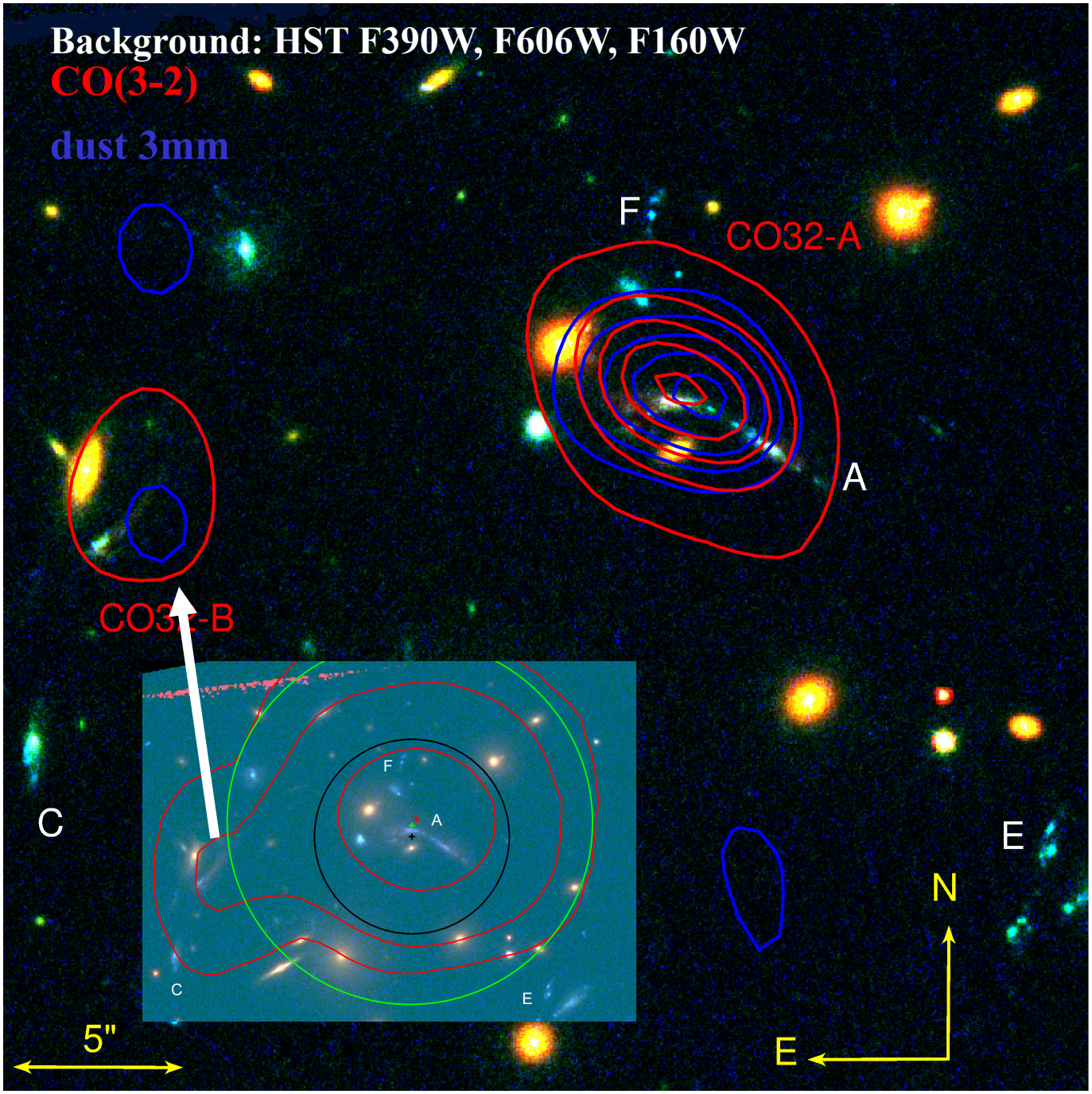




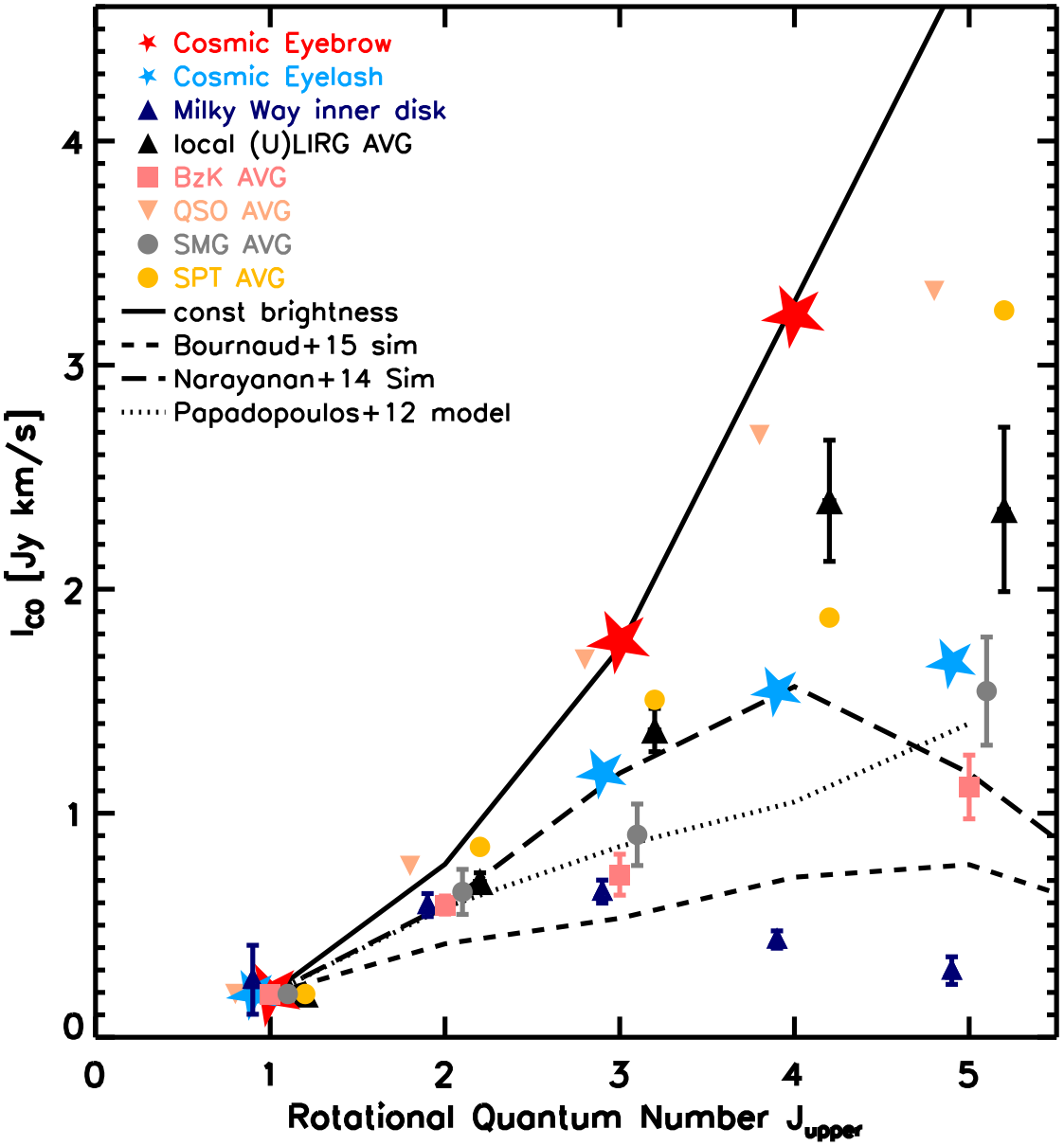


Dannerbauer, Harrington, Diaz-Sanchez, Iglesias-Groth, Rebolo, Genova-Santos & Krips, 2019, AJ, 158, 34

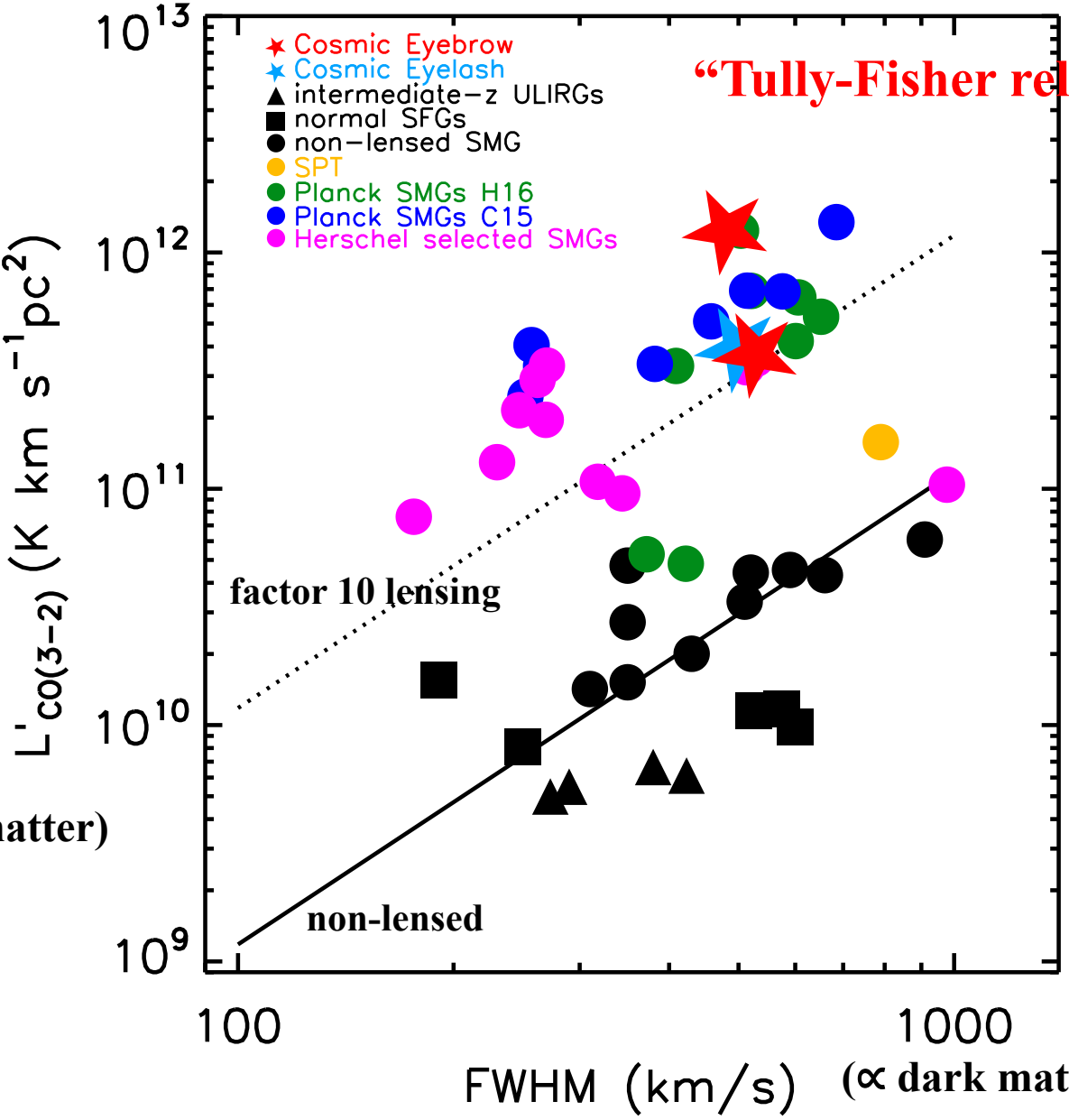

Background: HST F390W, F606W, F160W
CO(3-2)
dust 3mm
F
CO32-A
A
CO32-B
C
E
N
E
5"


Background: HST F390W, F606W, F160W
CO(3-2)
dust 3mm
F
CO32-A
A
CO32-B
C
E
N
E
5"
F
A
C
E

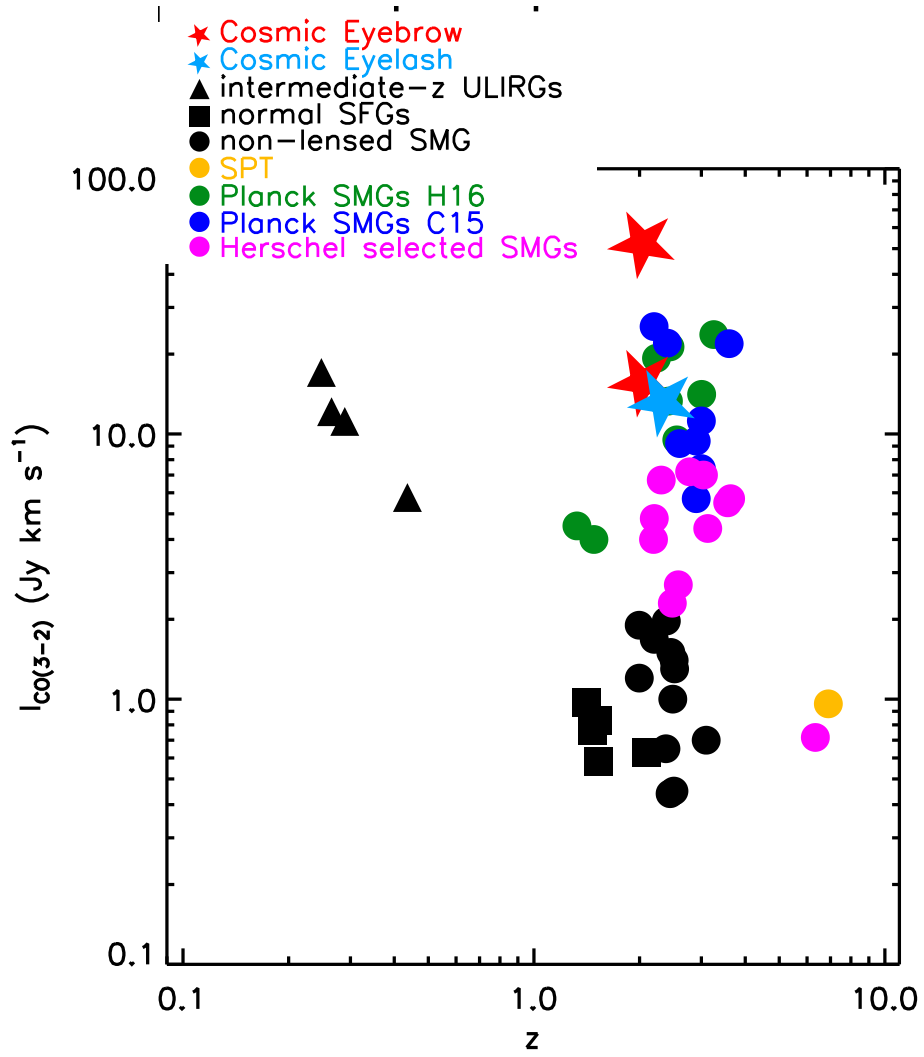
CO Spectral Line Energy Distribution

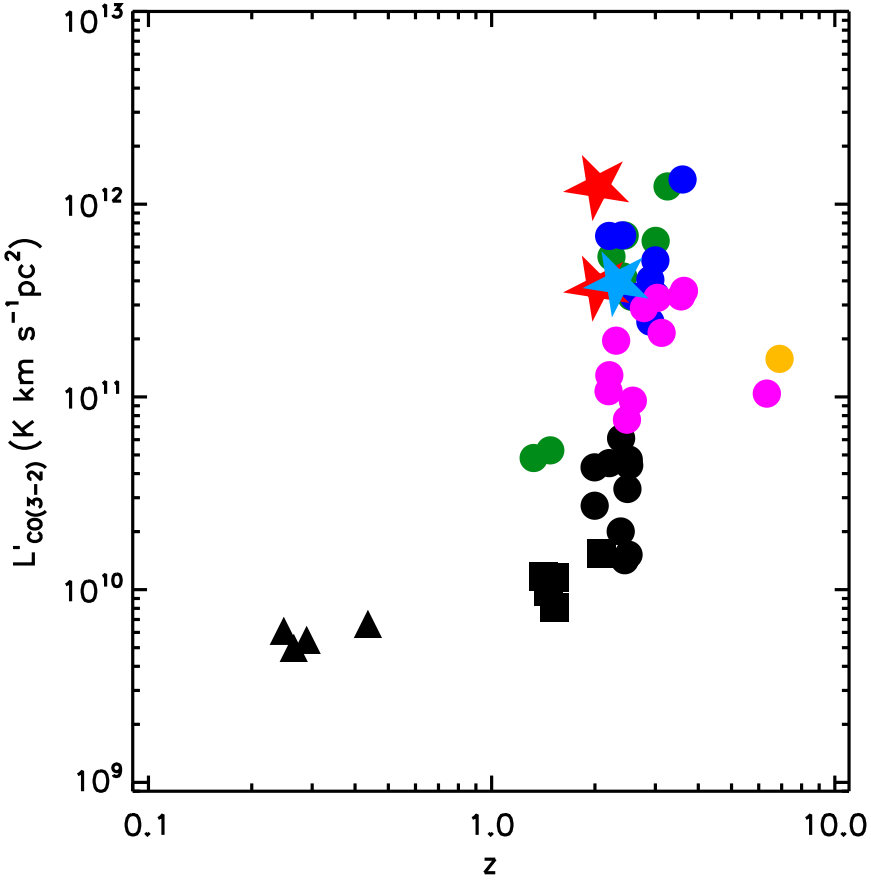


Cosmic Eyebrow is indeed lensed



Apparent and intrinsic ultra-luminous SMG





Future Prospect with the Big Glasses

•the optical/NIR counterparts of (lensed) dusty starbursts are well suited targets for Big Eyes

•DSFGs/SMGs trace/are members of galaxy clusters in formation (protoclusters) →MOS mode would be great to have (see also E. Daddi & L. Zhou)

•E.g. at the ELT: MICADO, HARMONI, MOSAIS and METIS (lensed sources) could be used to follow-up counterparts of DSFGs/SMGs both in imaging and spectroscopy

•indeed, a "Quantensprung" is expected with the ELTs: e.g. spectroscopic redshifts, physical properties

•synergy with ALMA

Conclusion

- **still hard to get spectroscopic redshifts, even with ALMA**
- **Big Eyes could reveal optical/NIR counterparts of (lensed) dusty starbursts**
- **combination of GTC and NOEMA discovers an ultra-bright lensed dusty starburst at z=2.04, the Cosmic Eyebrow**
- **most luminous SMG in CO(3-2) at z=2**
- **new reference source for studies in the early universe**
- **expand this work to z=4**
- **ESO Public Survey SHARKS**

➔*Iglesisas-Groth, Diaz-Sanchez, Rebolo & Dannerbauer, 2017, MNRAS, 467, 330*

➔*Diaz-Sanchez, Iglesias-Groth, Rebolo & Dannerbauer, 2017, ApJL, 843, 22*

➔*Dannerbauer, Harrington, Diaz-Sanchez, Iglesias-Groth, Rebolo, Genova-Santos & Krips, 2019, AJ, 158, 34*