Lensing-corrected 1.1mm number counts in the ALMA Frontier Fields Survey

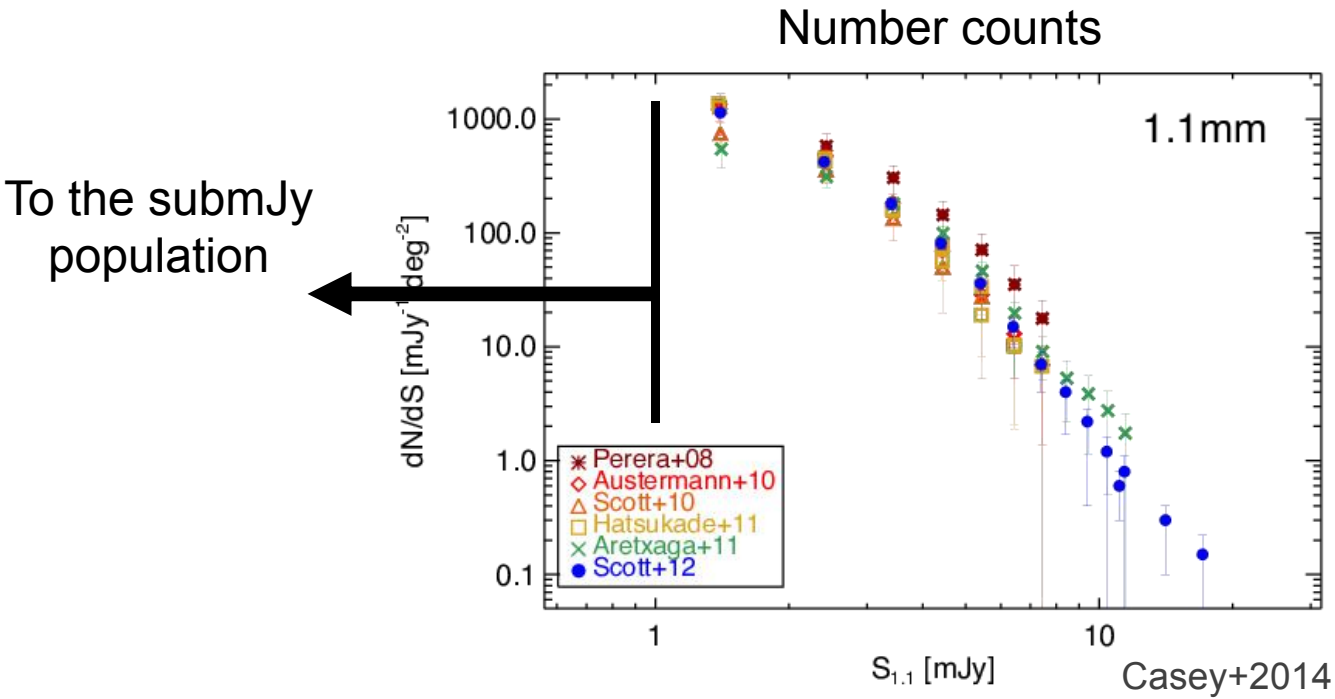
Alejandra M. Muñoz Arancibia
Fondecyt Postdoc
Universidad de Valparaíso, Chile

Collaborators:
Jorge González-López, Eduardo Ibar, Franz Bauer,
Mauricio Carrasco, Nicolas Laporte
and the ALMA Frontier Fields Team

Japan - Latin America Academic Forum
September 26, 2018

Galaxies in the far infrared to mm

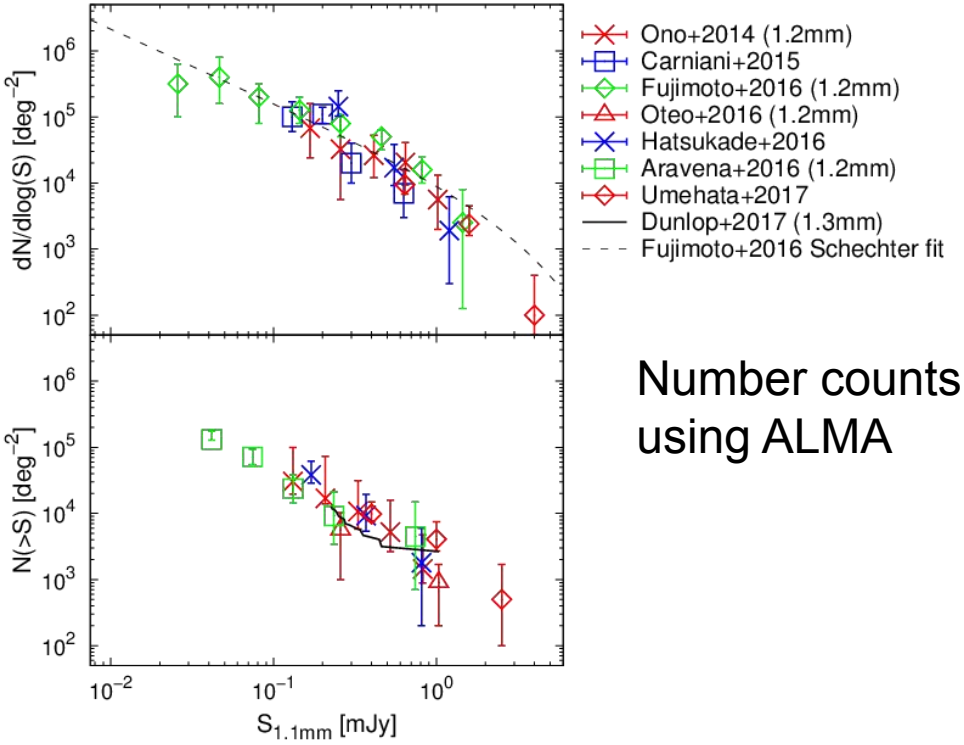
Submillimeter galaxies - dusty star-forming galaxies (DSFGs)



Galaxies in the far infrared to mm

Submillimeter galaxies - dusty star-forming galaxies (DSFGs)

To the submJy population

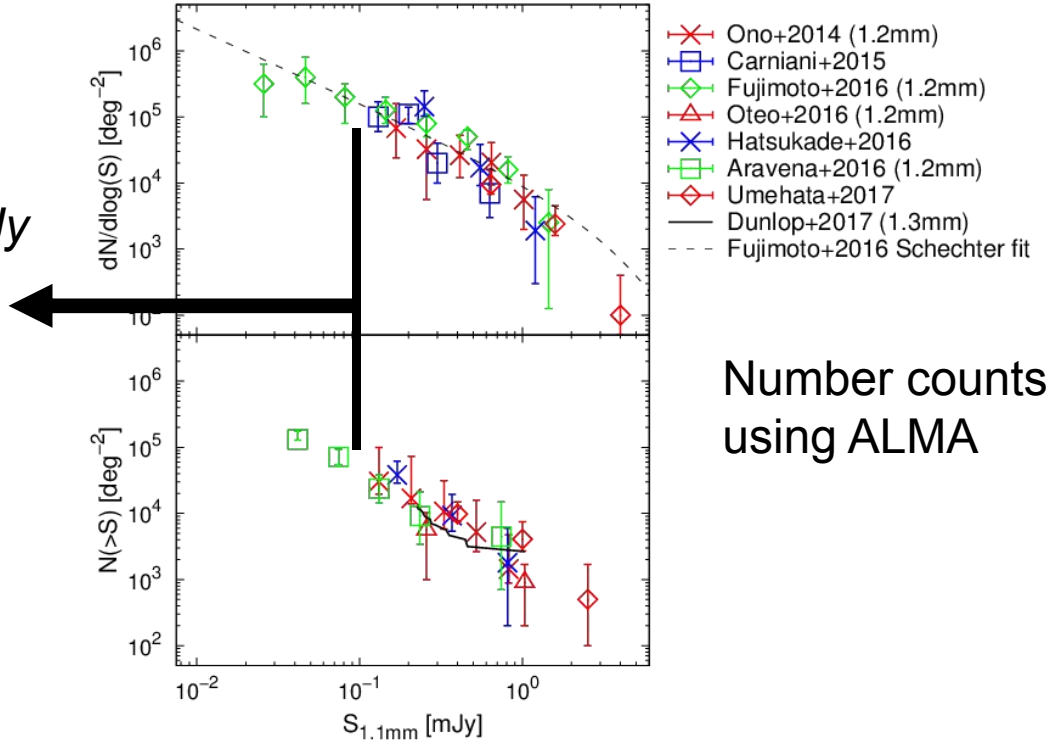


Number counts using ALMA

Galaxies in the far infrared to mm

Submillimeter galaxies - dusty star-forming galaxies (DSFGs)

To the *sub-0.1mJy* population

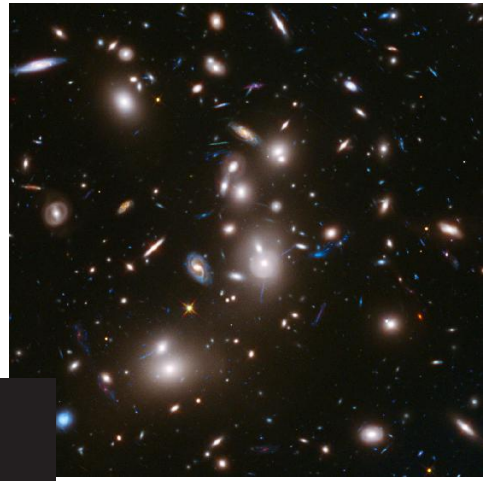


Number counts using ALMA

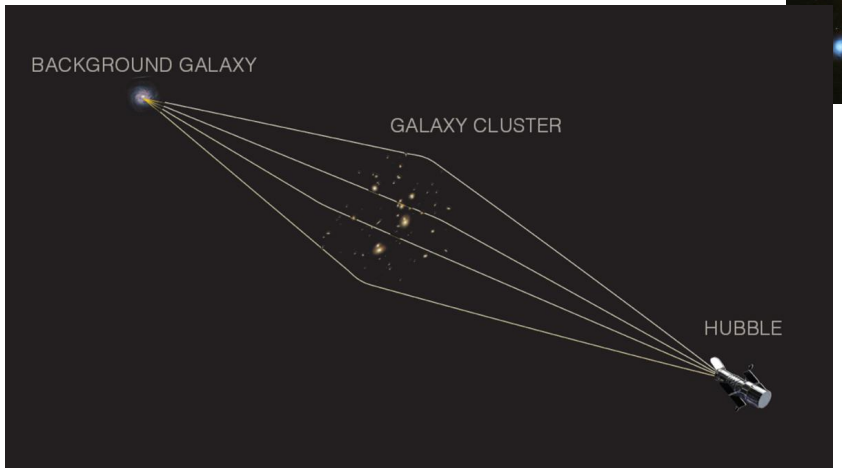
Probing faint DSFGs

Two ways

1) Deeper observations
2) Strong lensing by galaxy clusters



Lotz+2017



frontierfields.org

Probing faint DSFGs

Two ways

1) Deeper observations
2) Strong lensing by galaxy clusters

We use both!
ALMA observations in the Frontier Fields

The Frontier Fields (FF)

Director's discretionary time campaign

Deep multi-band HST and Spitzer imaging of 6 strong lensing galaxy clusters

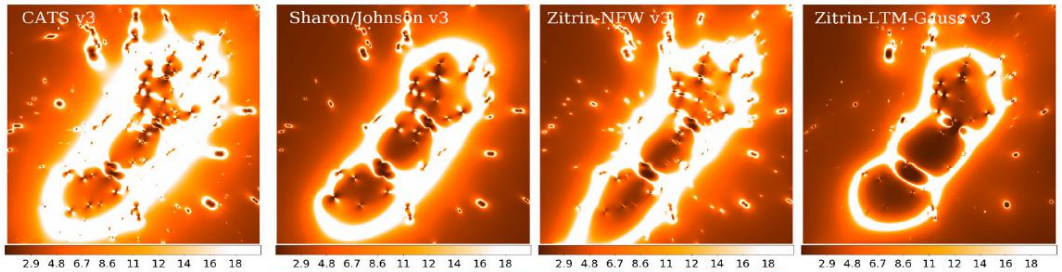
The Frontier Fields (FF)

Director's discretionary time campaign

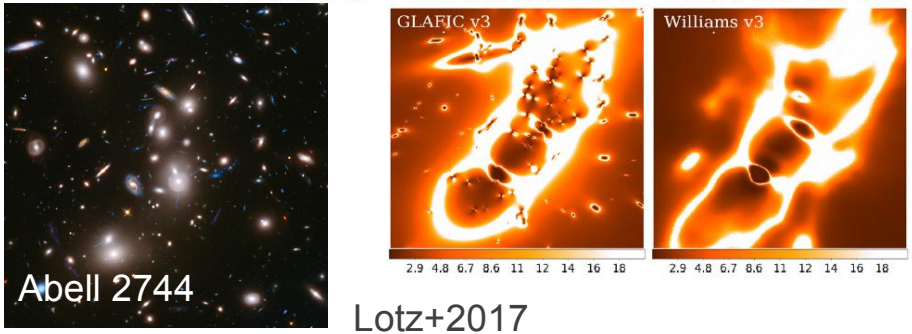
Deep multi-band HST and Spitzer imaging of 6 strong lensing galaxy clusters

Gravitational lensing models by several independent teams

- Publicly available (archive.stsci.edu/prepds/frontier/lensmodels/)



Priewe+2017



Lotz+2017

Magnification maps at a given z for different models

This work

Part of the ALMA Frontier Fields Survey (PI: F. Bauer)

1.1mm number counts in five FF galaxy clusters

- Continuum maps ~4.6 arcmin^2 each (≈ 23 arcmin^2 total observed area)

	A2744	**MACSJ0416**	**MACSJ1149**	**A370**	**AS1063**
Full name	Abell 2744	MACSJ0416 .1-2403	MACSJ1149 .5+2223	Abell 370	Abell S1063
Redshift	0.308	0.396	0.543	0.375	0.348
Beam size	0.63" × 0.49"	1.52" × 0.85"	1.22" × 1.08"	1.25" × 1.00"	0.96" × 0.79"
rms [μJy/beam]	55	59	71	62	67

This work

Part of the ALMA Frontier Fields Survey (PI: F. Bauer)

1.1mm number counts in five FF galaxy clusters

- Continuum maps ~4.6 arcmin^2 each (≈ 23 arcmin^2 total observed area)

	A2744	**MACSJ0416**	**MACSJ1149**	**A370**	**AS1063**
Full name	Abell 2744	MACSJ0416 .1-2403	MACSJ1149 .5+2223	Abell 370	Abell S1063
Redshift	0.308	0.396	0.543	0.375	0.348
Beam size	0.63" × 0.49"	1.52" × 0.85"	1.22" × 1.08"	1.25" × 1.00"	0.96" × 0.79"
rms [μJy/beam]	55	59	71	62	67

ALMA observations introduced by González-López+2017

Counts reported by Muñoz Arancibia+2018 (A&A in press)

In preparation

This work

Part of the ALMA Frontier Fields Survey (PI: F. Bauer)

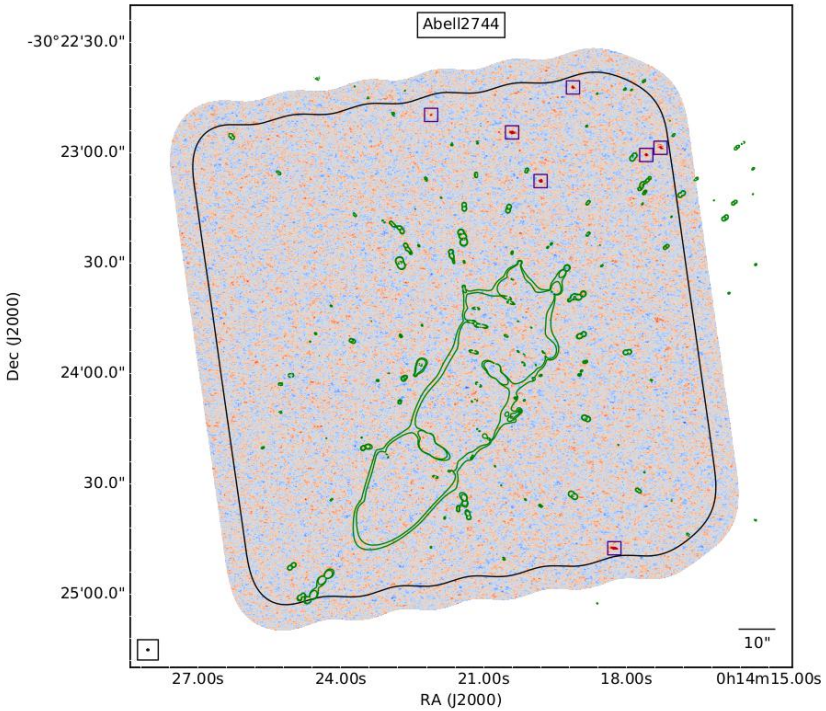
1.1mm number counts in five FF galaxy clusters

- Continuum maps ~4.6 arcmin^2 each (≈ 23 arcmin^2 total observed area)

	A2744	MACSJ0416	MACSJ1149	A370	AS1063
S/N ≥ 5	7	4	1	2	3
4.5 ≤ S/N < 5	4	1	2	2	2
Total	**11**	**5**	**3**	**4**	**5**

- **19** detections at **S/N ≥ 4.5**
- Observed peak intensities 0.2-1.5 mJy/beam
- Integrated flux densities 0.2-3 mJy

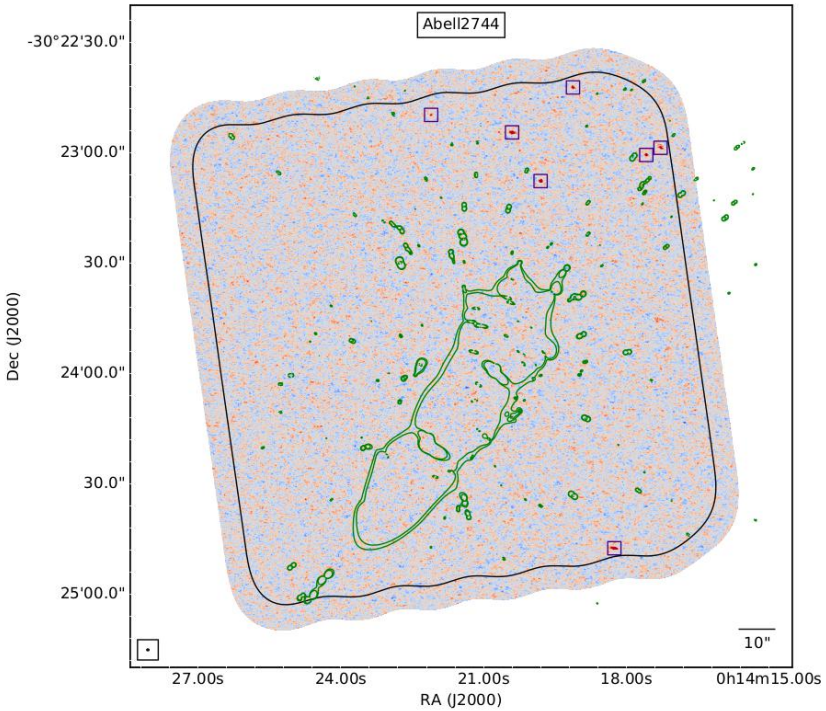
Example observation+model



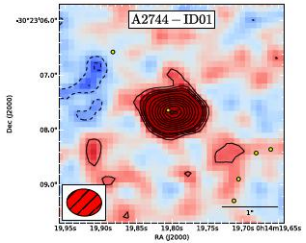
A2744, S/N ≥ 5 detections,
Zitrin-NFW v3 lens model

González-López+2017

Example observation+model



A2744, S/N ≥ 5 detections,
Zitrin-NFW v3 lens model



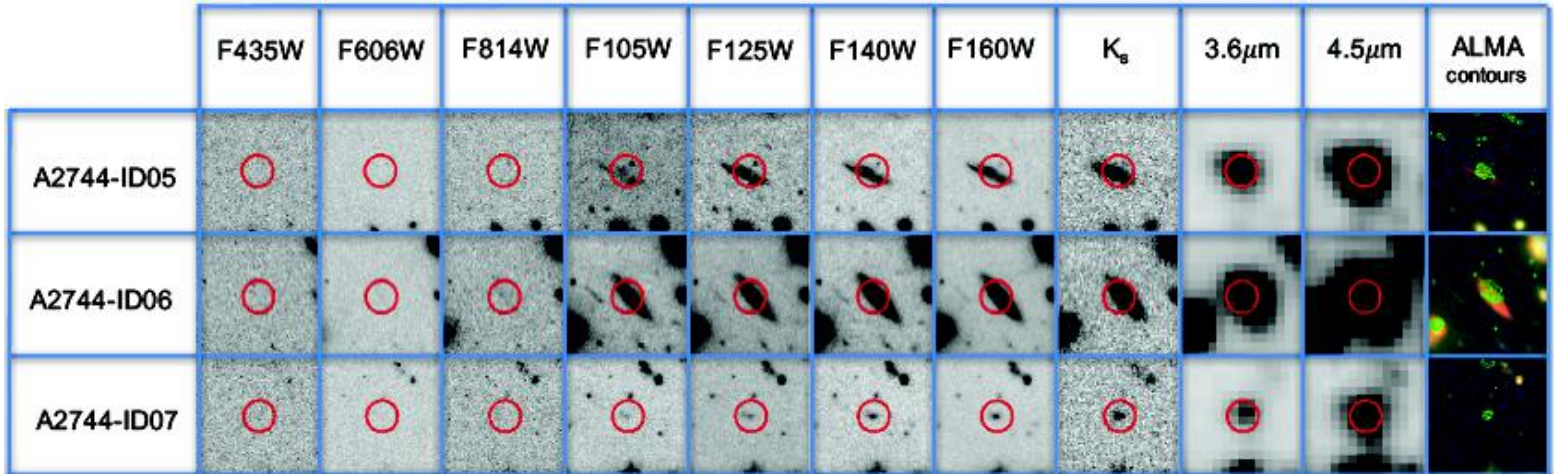
Some sources
are extended
(median $r_{eff,obs}$ = 0.23"
for S/N ≥ 5 sources)

González-López+2017

A multiwavelength view

Several detections have extremely red and faint counterparts

- $m_{F814W} - m_{F160W} \geq 4$, $m_{F160W} > 22.5$ (Laporte+2017)



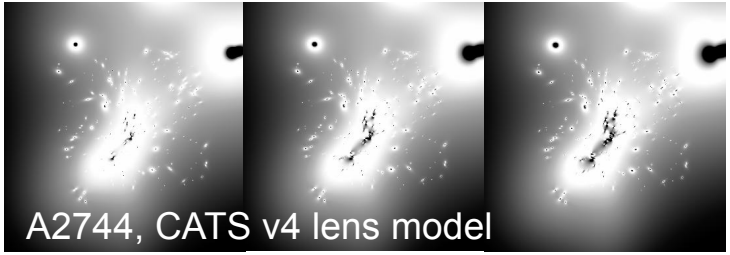
Laporte+2017

From lens plane to source plane

Flux density conversion: $S_{demag}=S_{obs}/\mu$

Source magnification μ depends on

- Source redshift z
- Source coordinates
- Lens model



μ maps

From lens plane to source plane

Flux density conversion: $S_{demag}=S_{obs}/\mu$

Source magnification μ depends on

- Source redshift z
- Source coordinates
- Lens model

Adopted redshifts for first 3 FFs

- When available: spec-z
- S/N ≥ 5: phot-z probability distributions from Laporte+2017, ‹ z › = 1.99 ± 0.27
- S/N < 5: assume N(2,σ=0.5)

From lens plane to source plane

Flux density conversion: $S_{demag}=S_{obs}/\mu$

Source magnification μ depends on

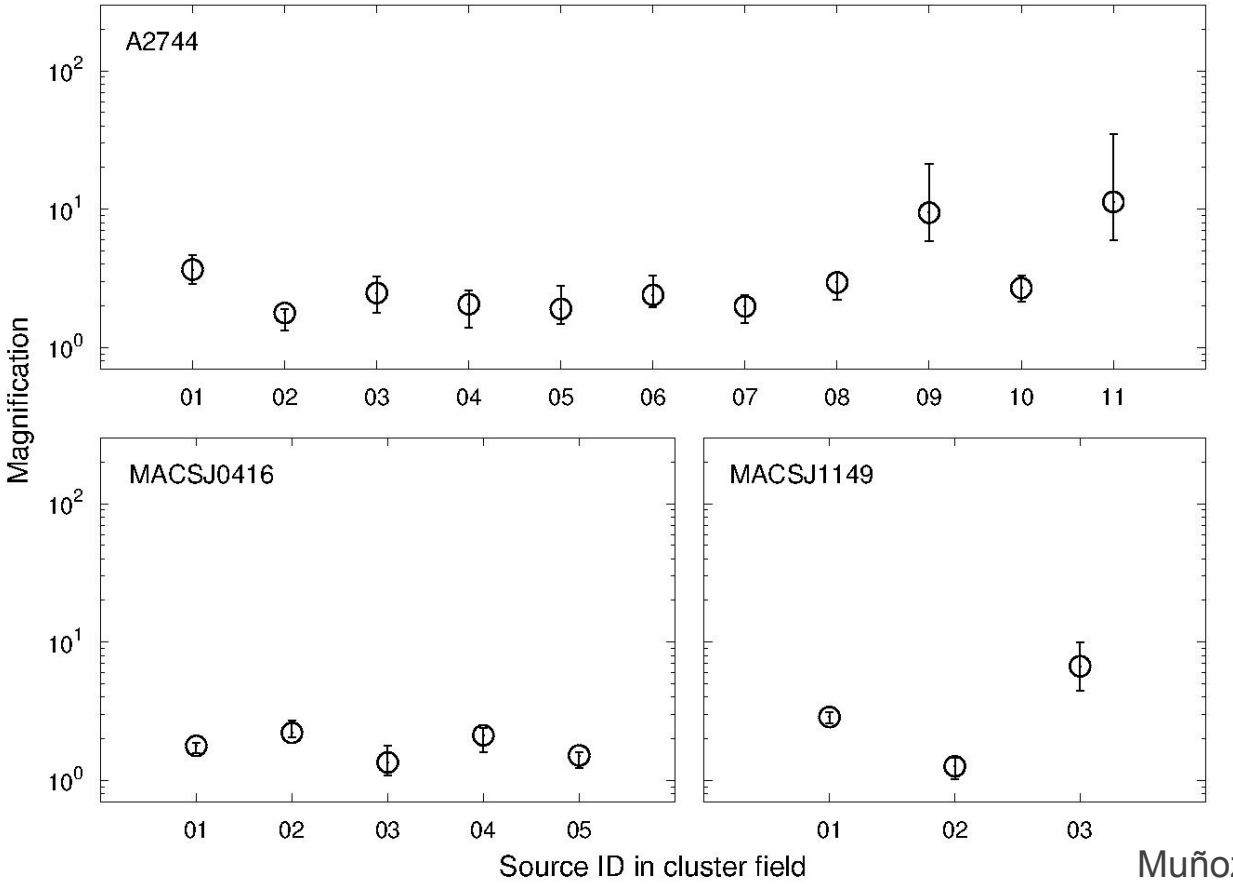
- Source redshift z
- Source coordinates
- Lens model

Use set of μ map realizations for each model and z:
μ uncertainties are not necessarily Gaussian

S_{obs} and μ uncertainties propagated through Monte Carlo simulations

Adopted approach for source properties and number counts:
find median values among all newest lens models

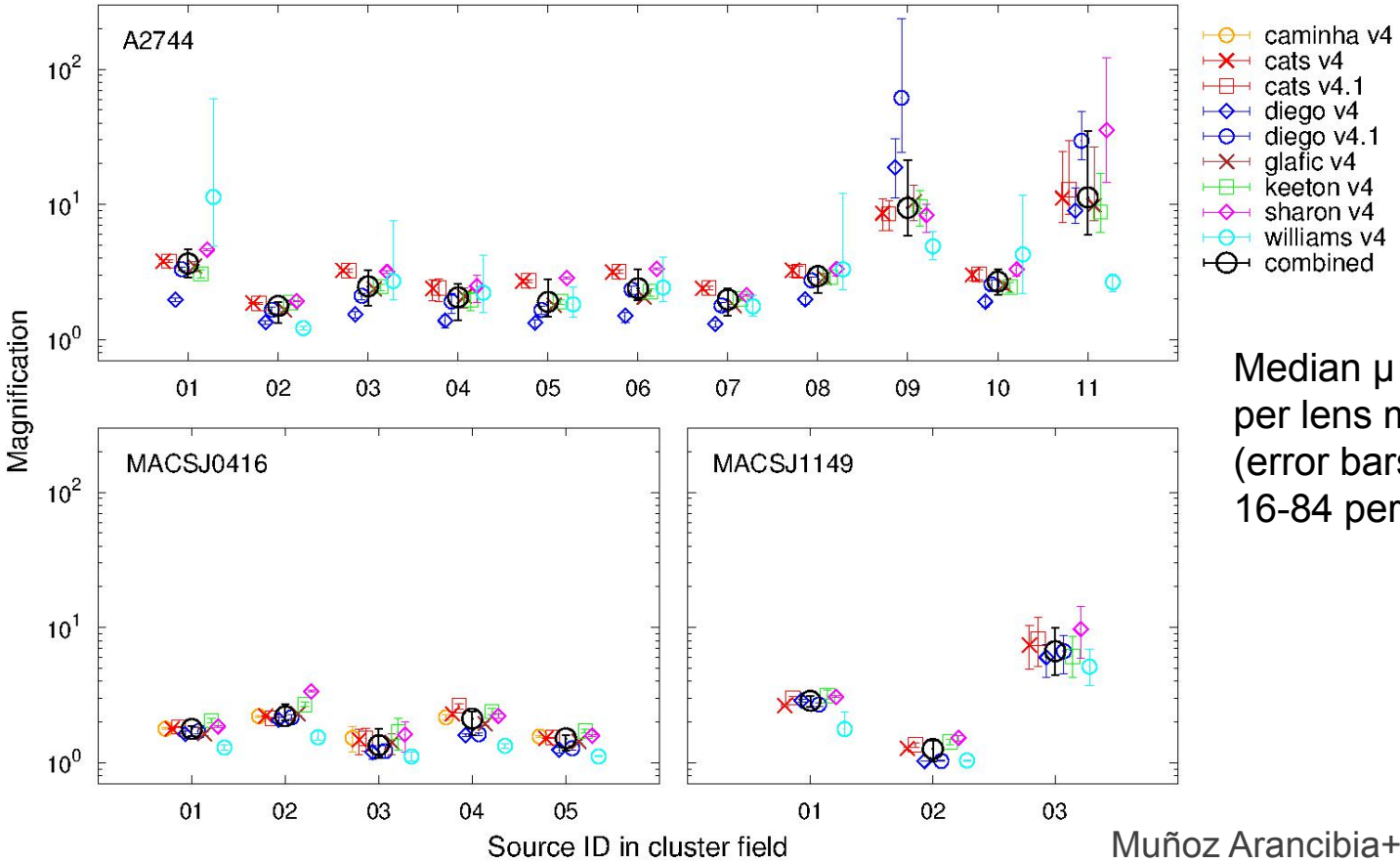
Source magnifications



Median μ
per lens model
(error bars:
16-84 percentiles)

Muñoz Arancibia+2018

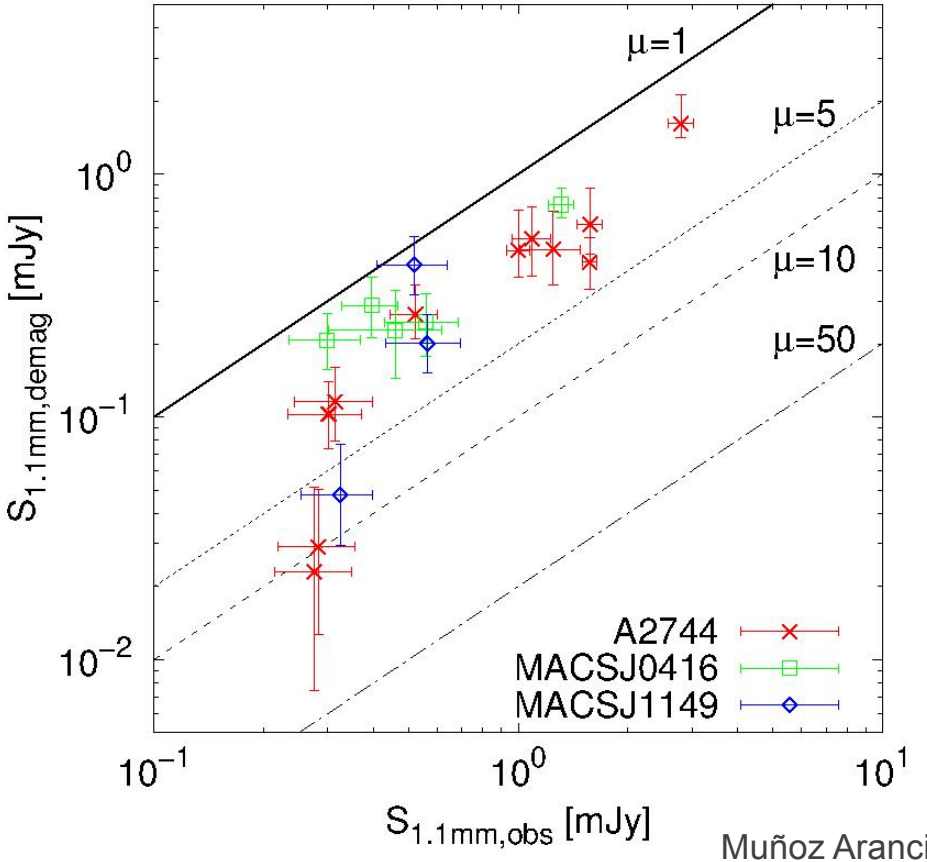
Source magnifications



Median μ
per lens model
(error bars:
16-84 percentiles)

Muñoz Arancibia+2018

Source flux densities at 1.1mm



Demagnified integrated flux densities
0.02-1.62 mJy

"Typical" z ≥ 1-2
galaxy populations

Muñoz Arancibia+2018

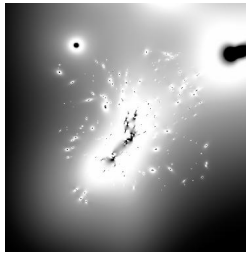
From lens plane to source plane

Differential number counts:

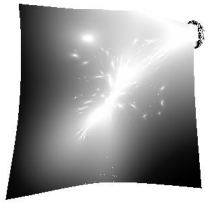
$$\frac{dN}{d\log S} = \frac{1}{\Delta \log(S)} \sum X_i \quad \text{with} \quad X_i = \frac{1 - p_{false,i}}{C_i \, A_{eff,i}}$$

where

- $p_{false,i}$: fraction of spurious sources
- C_i: completeness
- $A_{eff,i}$: effective source-plane area where sources at S/N ≥ 4.5 are detected (recall that $S_{demag}=S_{obs}/\mu$)



Lens plane

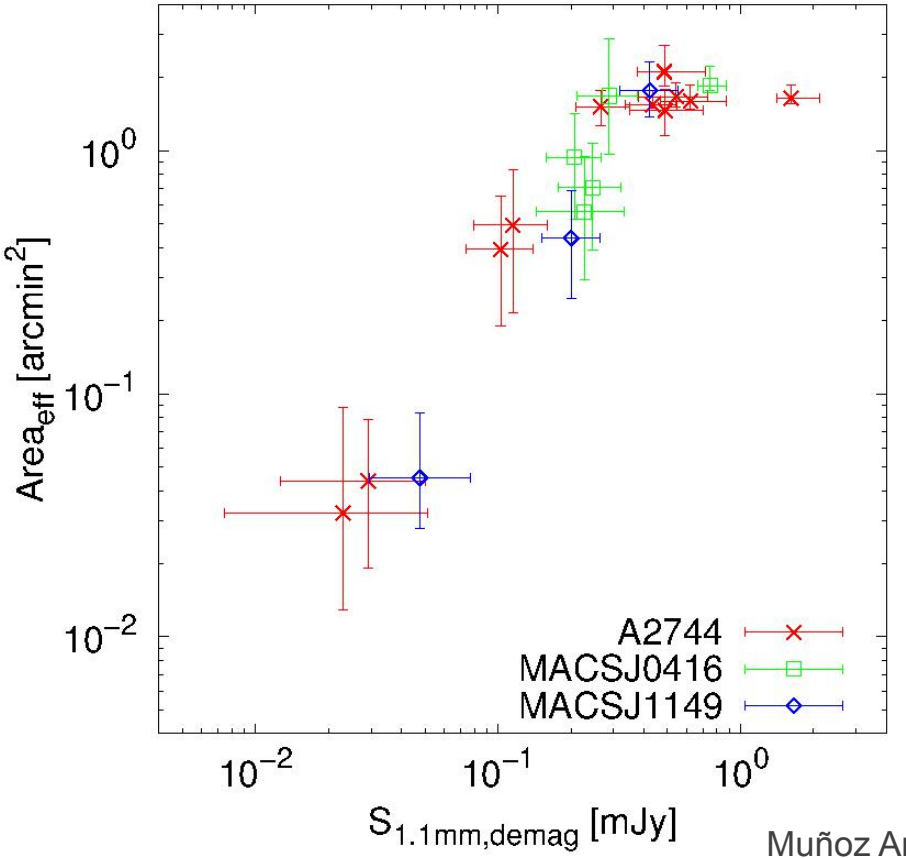


Source plane at z=2

A2744
CATS v4

Impact of uncertainties

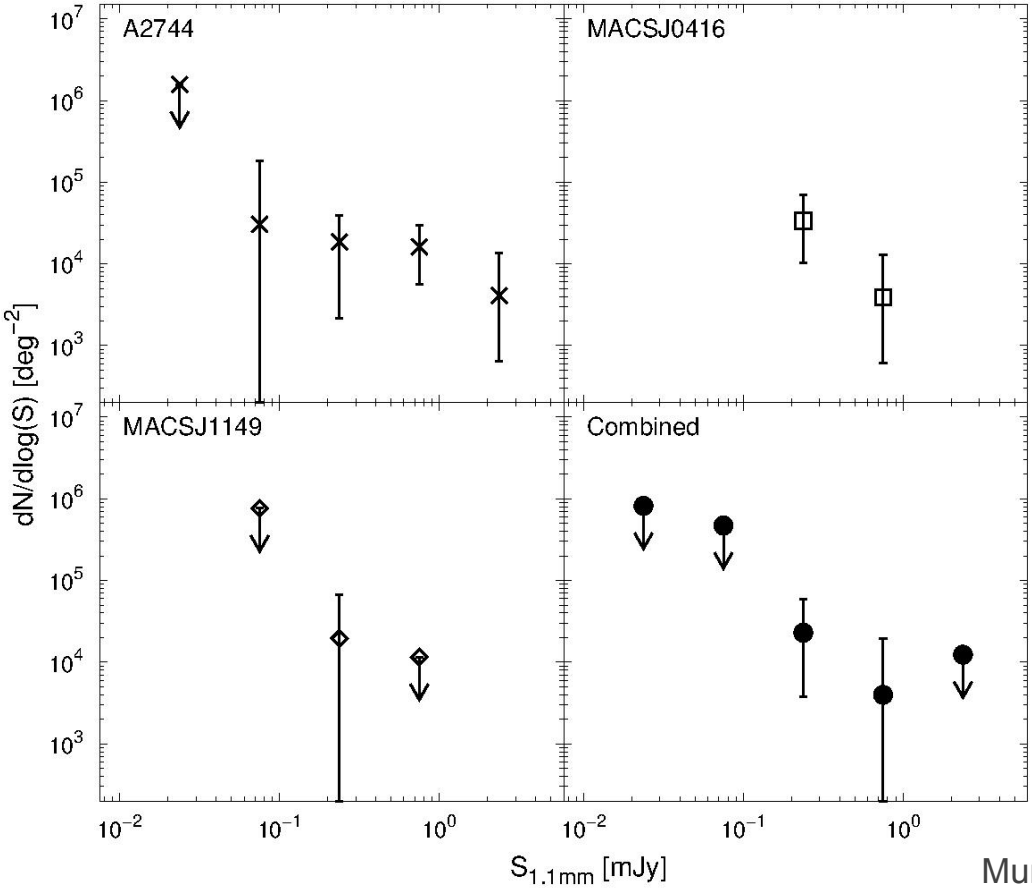
Median A_{eff} and S_{demag} per source, combining all lens models (error bars: 16-84 percentiles)



Muñoz Arancibia+2018

1.1mm number counts for first 3 FFs

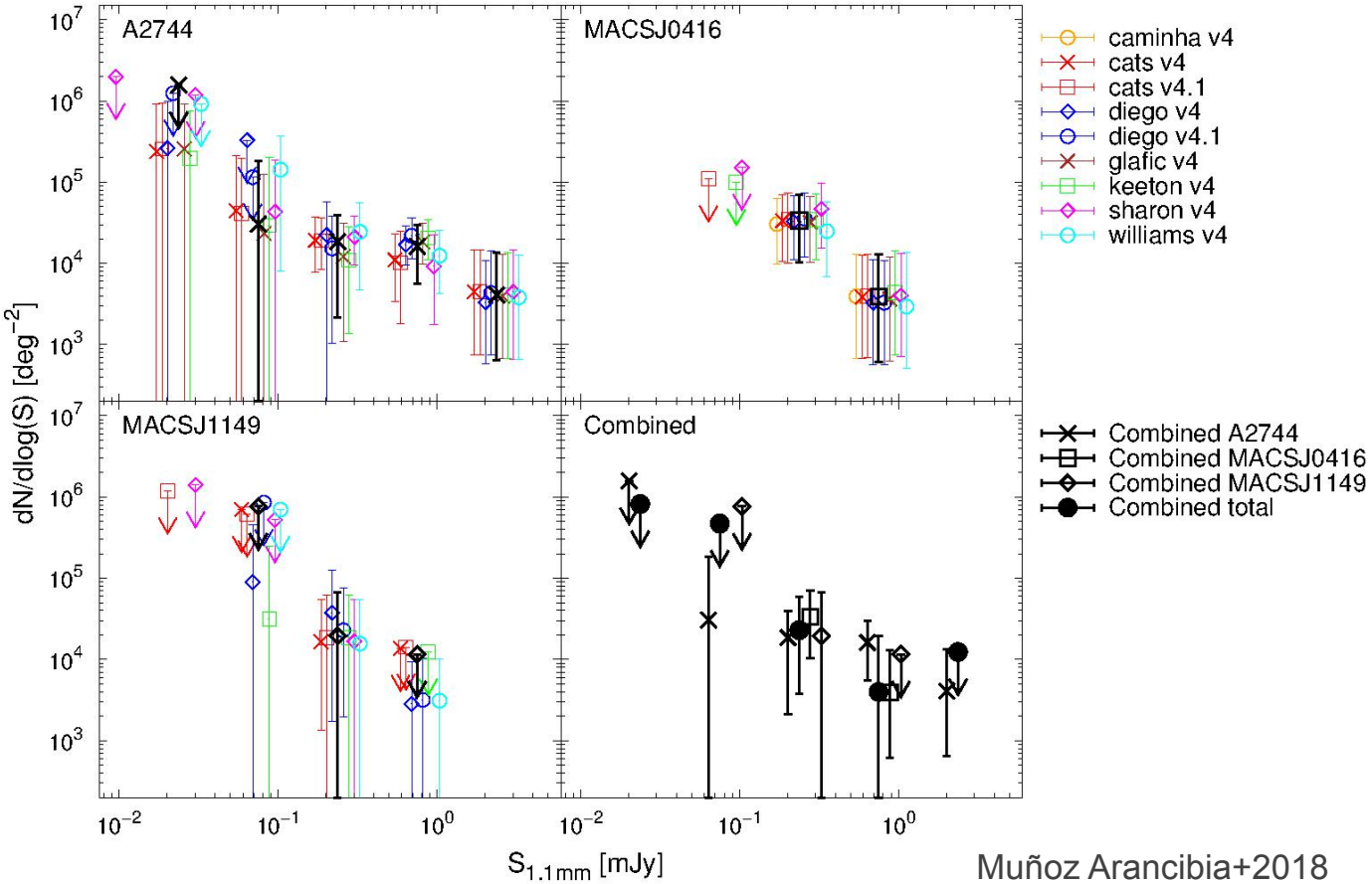
Median differential counts (error bars: 16-84 percentiles and Poisson)



Muñoz Arancibia+2018

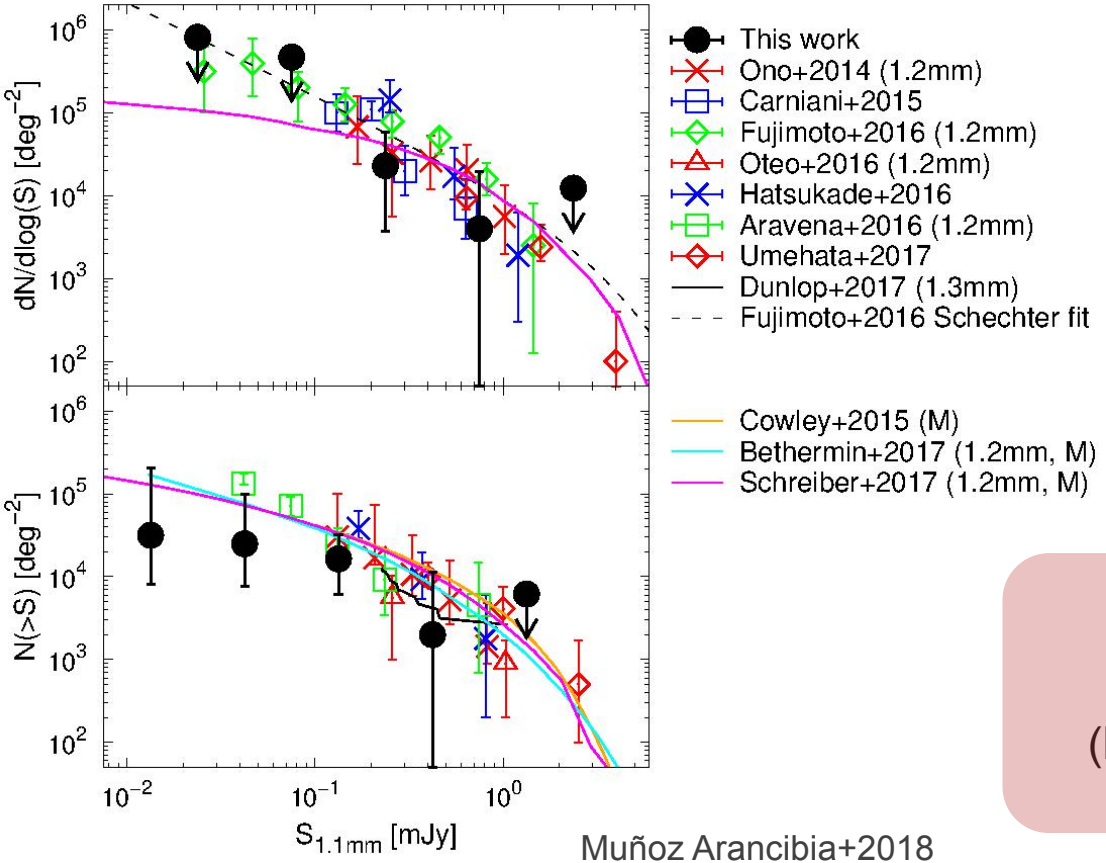
1.1mm number counts for first 3 FFs

Median differential counts (error bars: 16-84 percentiles and Poisson)



Muñoz Arancibia+2018

1.1mm number counts for first 3 FFs



Comparison with ALMA observations and galaxy formation models

Agreement with other works at 3σ (but large uncertainties!)

Muñoz Arancibia+2018

Summary

- We derive 1.1mm counts exploiting:
  - The high resolution and depth reached in a dedicated ALMA survey of five FF galaxy clusters
  - The public availability of several models for the mass reconstruction of these clusters

- Our survey probes the DSFG population at 1.1mm down to ~ tens of μJy
  - Derived counts are ~4× deeper than deepest ALMA mosaic rms

- Counts in agreement with ALMA data in other fields and galaxy formation models