ASTROPHYSIC
TERAHERTZ
LARGE
AREA
SURVEY

HALOS: TOWARD A SAMPLE OF ~1000 STRONGLY LENSED GALAXIES

(Gonzalez-Nuevo et al. 2012)

Joaquin Gonzalez-Nuevo
On behalf of
A. Lapi, M. Negrello, G. de Zotti & L. Danese

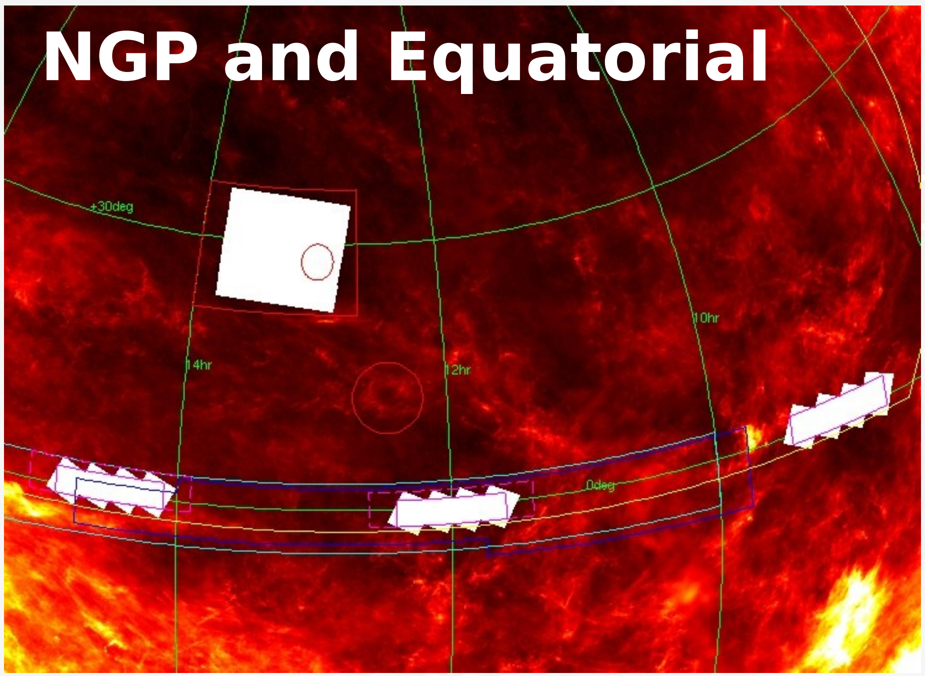
Rencontres de Moriond, La Thuile 10-17th April

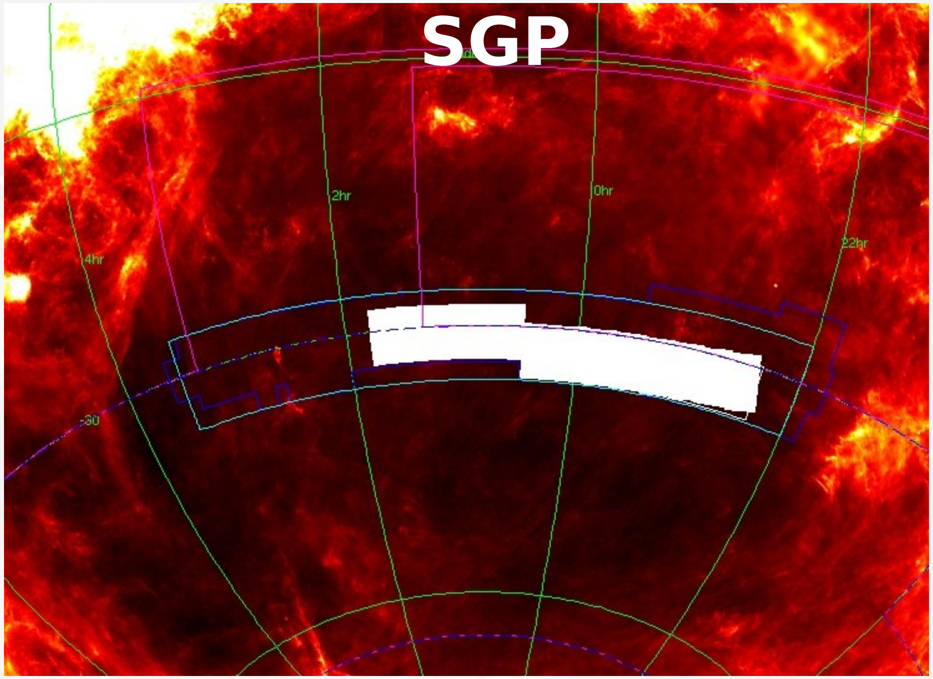
UC UNIVERSIDAD DE CANTABRIA
IFCA Instituto de Física de Cantabria
CSIC Consejo Superior de Investigaciones Científicas

The *Herschel*-ATLAS

Largest Area Survey on Herschel (PIs: Eales and Dunne)

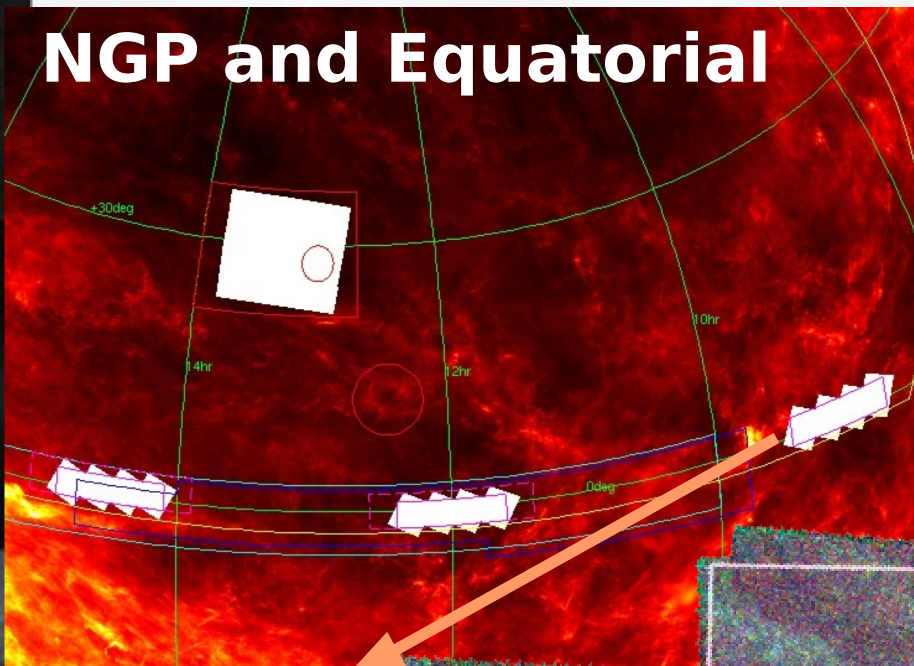
http://www.h-atlas.org/





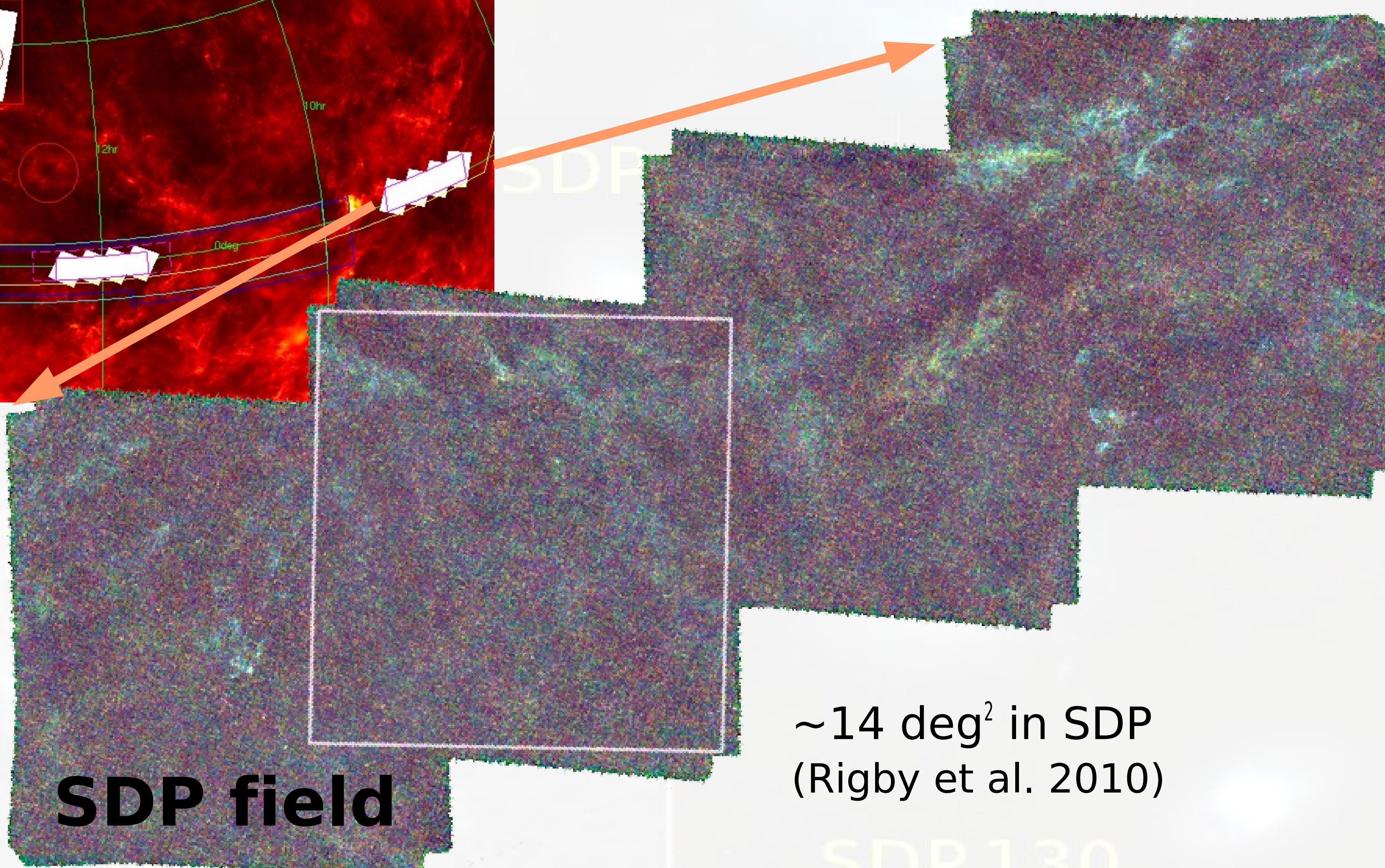
~550 deg^2 with PACS 100+160 μm and SPIRE 250+350+500 μm

The *Herschel*-ATLAS



"GAMA-9h" field

(for GAMA see Driver et al. 2011)



~14 deg^2 in SDP

(Rigby et al. 2010)

SDP.11

RESEARCH ARTICLES *Science* **330**, 800 (2010)

The Detection of a Population of Submillimeter-Bright, Strongly Lensed Galaxies

Mattia Negrello,[1*] R. Hopwood,[1] G. De Zotti,[2,3] A. Cooray,[4] A. Verma,[5] J. Bock,[6,7] D. T. Frayer,[8] M. A. Gurwell,[9] A. Omont,[10] R. Neri,[11] H. Dannerbauer,[12] L. L. Leeuw,[13,14] E. Barton,[4] J. Cooke,[4,7] S. Kim,[4] E. da Cunha,[15] G. Rodighiero,[16] P. Cox,[11] D. G. Bonfield,[17] M. J. Jarvis,[17] S. Serjeant,[1] R. J. Ivison,[18,19] S. Dye,[20] I. Aretxaga,[21] D. H. Hughes,[21] E. Ibar,[18] F. Bertoldi,[22] I. Valtchanov,[23] S. Eales,[20] L. Dunne,[24] S. P. Driver,[25] R. Auld,[20] S. Buttiglione,[2] A. Cava,[26,27] C. A. Grady,[28,29] D. L. Clements,[30] A. Dariush,[20] J. Fritz,[31] D. Hill,[25] J. B. Hornbeck,[32] L. Kelvin,[25] G. Lagache,[33,34] M. Lopez-Caniego,[35] J. Gonzalez-Nuevo,[3] S. Maddox,[24] E. Pascale,[20] M. Pohlen,[20] E. E. Rigby,[24] A. Robotham,[25] C. Simpson,[36] D. J. B. Smith,[24] P. Temi,[37] M. A. Thompson,[17] B. E. Woodgate,[38] D. G. York,[39] J. E. Aguirre,[40] A. Beelen,[34] A. Blain,[7] A. J. Baker,[41] M. Birkinshaw,[42] R. Blundell,[9] C. M. Bradford,[6,7] D. Burgarella,[43] L. Danese,[3] J. S. Dunlop,[18] S. Fleuren,[44] J. Glenn,[45] A. I. Harris,[46] J. Kamenetzky,[45] R. E. Lupu,[40] R. J. Maddalena,[8] B. F. Madore,[47] P. R. Maloney,[45] H. Matsuhara,[48] M. J. Michaowski,[19] E. J. Murphy,[49] B. J. Naylor,[6] H. Nguyen,[6] C. Popescu,[50] S. Rawlings,[5] D. Rigopoulou,[5,51] D. Scott,[52] K. S. Scott,[40] M. Seibert,[47] I. Smail,[53] R. J. Tuffs,[54] J. D. Vieira,[7] P. P. van der Werf,[19,55] J. Zmuidzinas[6,7]

Gravitational lensing is a powerful astrophysical and cosmological probe and is particularly valuable at submillimeter wavelengths for the study of the statistical and individual properties of dusty star-forming galaxies. However, the identification of gravitational lenses is often time-intensive, involving the sifting of large volumes of imaging or spectroscopic data to find few candidates. We used early data from the Herschel Astrophysical Terahertz Large Area Survey to demonstrate that wide-area submillimeter surveys can simply and easily detect strong gravitational lensing events, with close to 100% efficiency.

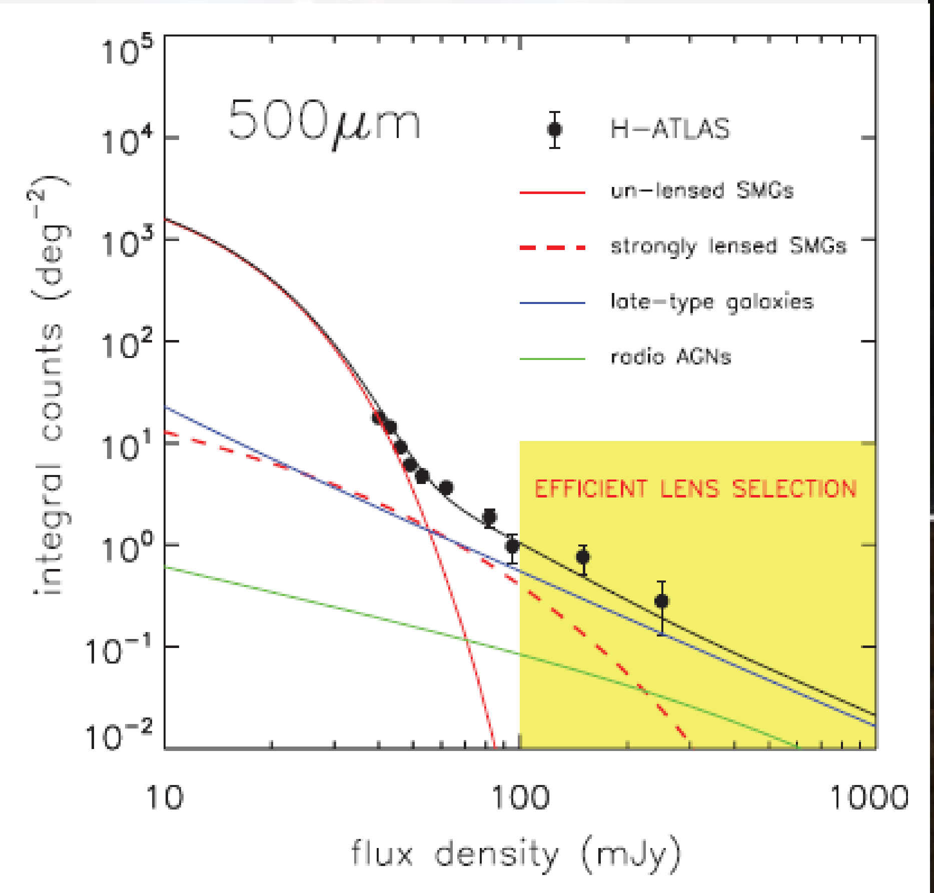
SDP.11 SDP.9

How it works?

- Ingredients:
  - SMGs have steep counts

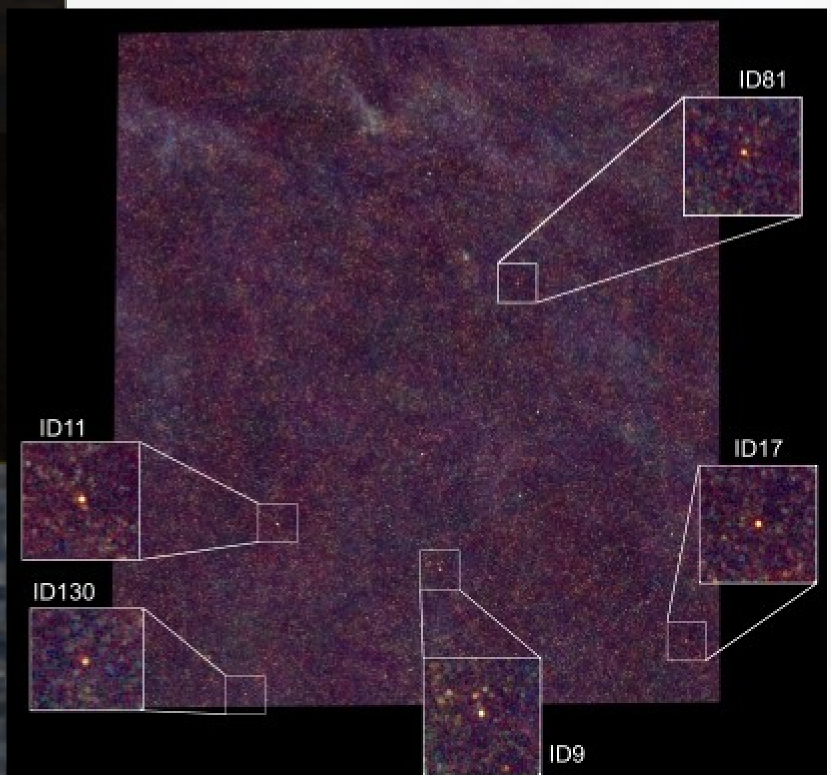
    (e.g. Granato et al. 2004, Lapi et al. 2006, 2011 see poster)
  - Efficient lens selection in the sub-mm

    (e.g. Blain 1996; Perrotta et al. 2002, 2003; Negrello et al. 2007)
  - Remove local spirals and well-known blazars



SDP.81 SDP.130

5 confirmed SLGs in the SDP!



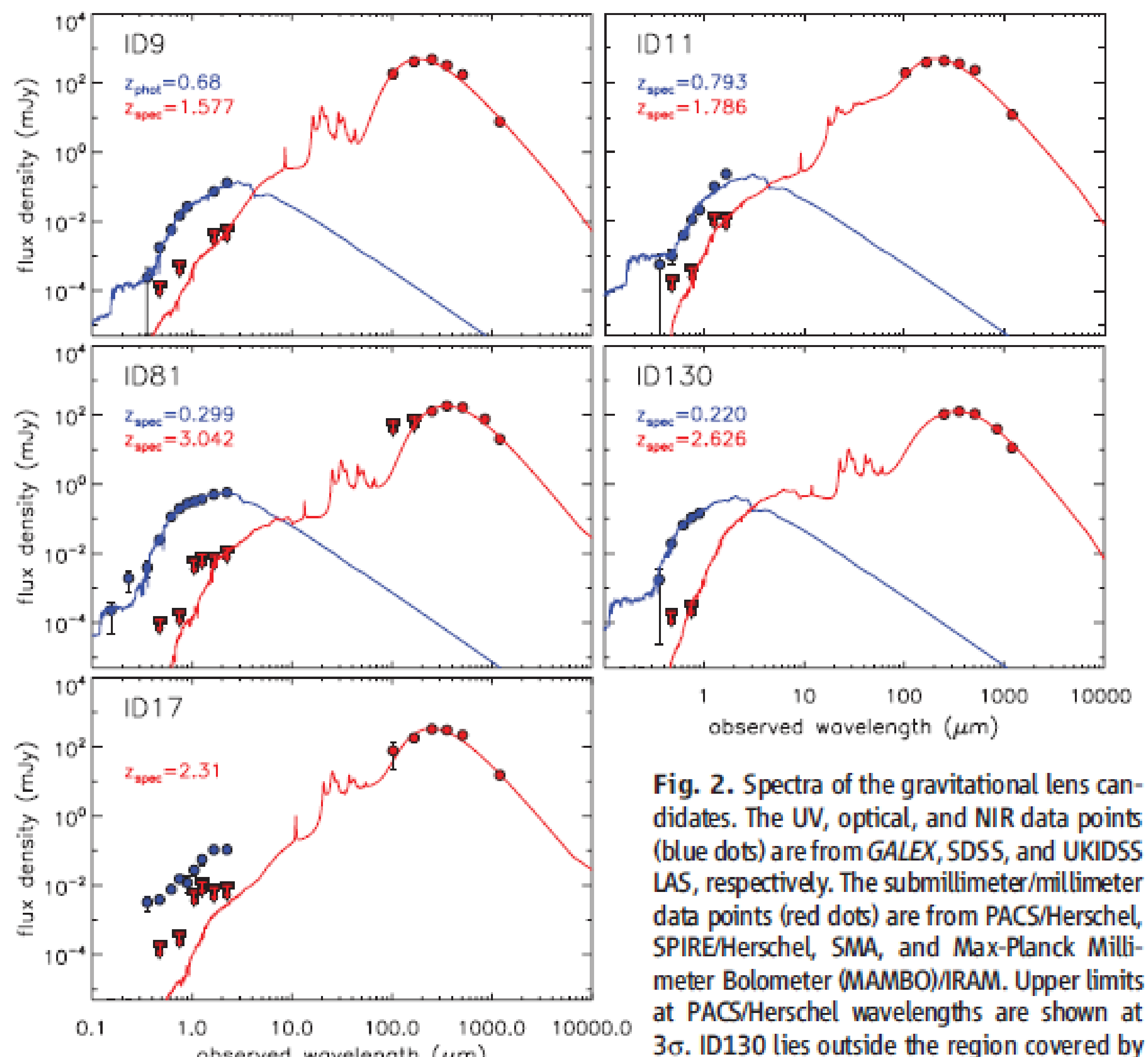
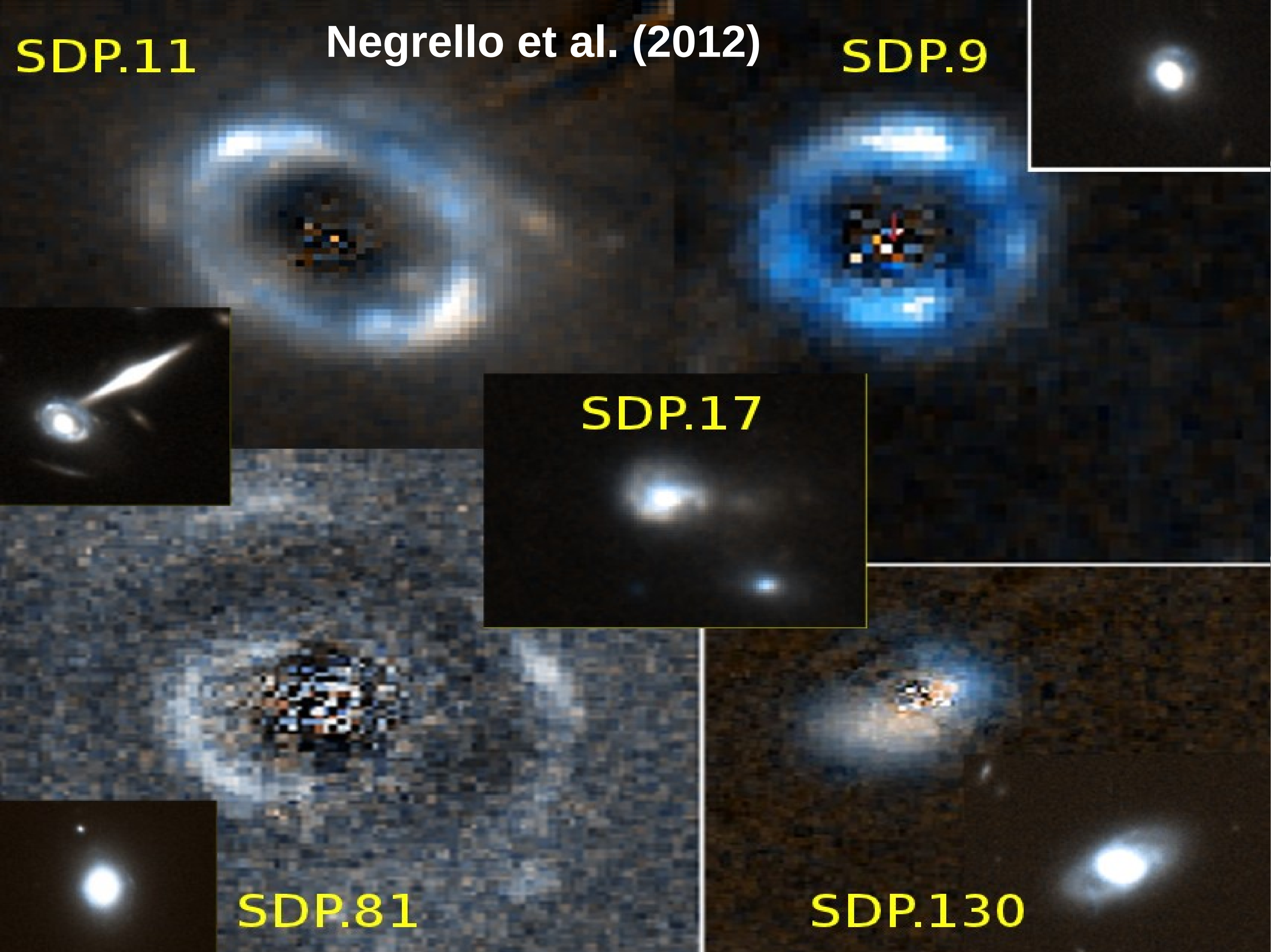


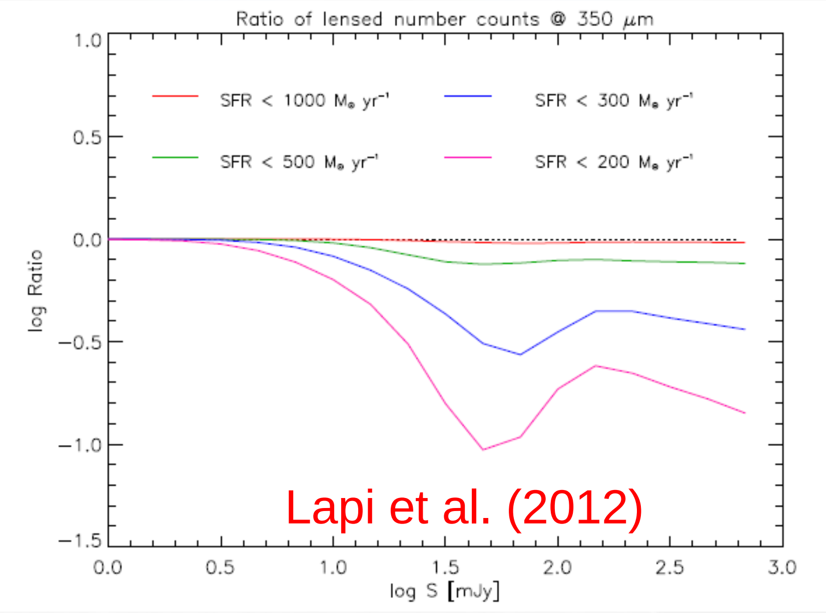
Fig. 2. Spectra of the gravitational lens candidates. The UV, optical, and NIR data points (blue dots) are from *GALEX*, SDSS, and UKIDSS LAS, respectively. The submillimeter/millimeter data points (red dots) are from PACS/Herschel, SPIRE/Herschel, SMA, and Max-Planck Millimeter Bolometer (MAMBO)/IRAM. Upper limits at PACS/Herschel wavelengths are shown at 3σ. ID130 lies outside the region covered by PACS. The photometric data were fitted using SED models from (*47*). The background source, responsible for the submillimeter emission, is a heavily dust-obscured star-forming galaxy (red solid curve), whereas the lens galaxy, which is responsible for the UV/optical and NIR part of the spectrum, is characterized by passive stellar evolution.

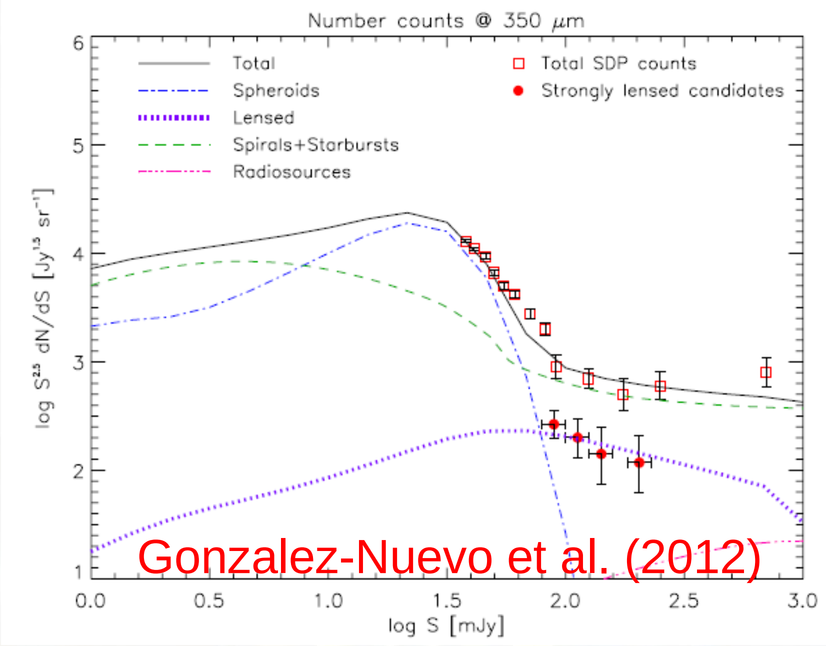

Negrello et al. (2012)
SDP.11
SDP.9
SDP.17
SDP.81
SDP.130

Why we need more SLGs?

- Negrello et al. 2010:
  - 5 SLGs in ~14deg^2 → ~200 SLGs in ~550deg^2
  - Demagnified SFR> 500 M⊙/yr
- Samples of thousands of strongly lensed systems are needed to make substantial progress on several major astrophysical and cosmological issues, as stressed by Treu (2010).
  - Unexpected features in individual SLG analysis.
- Most effective star formers in the universe have high but far less extreme SFRs (~100-200 M⊙/yr; e.g., F¨orster Schreiber et al. 2009).
- Gravitational lensing can be exploited to study the lens galaxy structure and its evolution.
  - there is observational evidence of a strong size evolution of massive early-type galaxies from z $\sim$ 1 (e.g., Trujillo et al. 2011)

Some numbers...



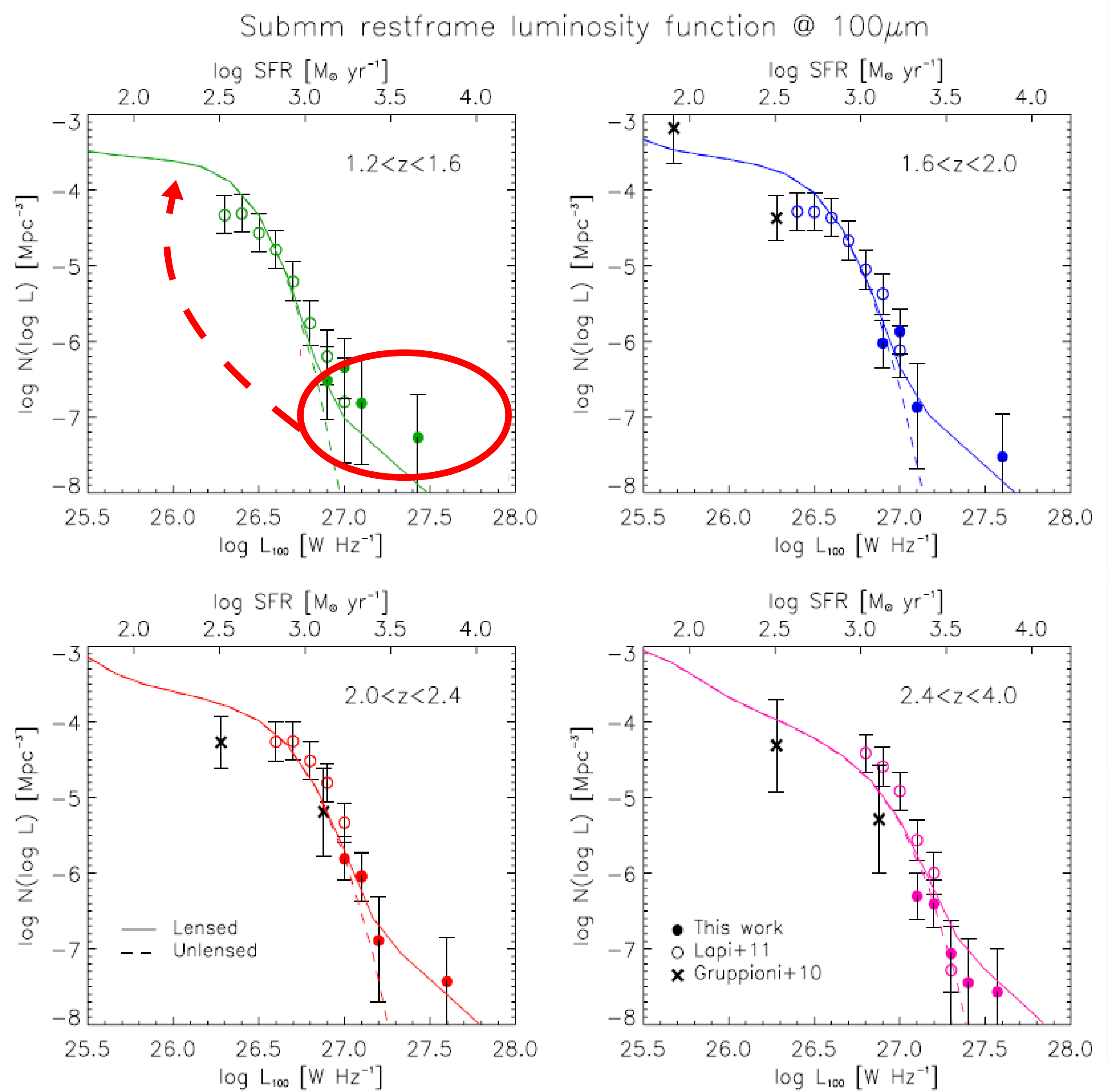


- SLG predictions @350um

- S>~200mJy
  - ~120 SLGs in HATLAS
  - ~25%=30 SFR<200M⊙/yr

- S> ~65mJy
  - ~1700 SLGs in HATLAS
  - ~10%=170 SFR<200M⊙/yr

Lensing=Much better instrument for free!



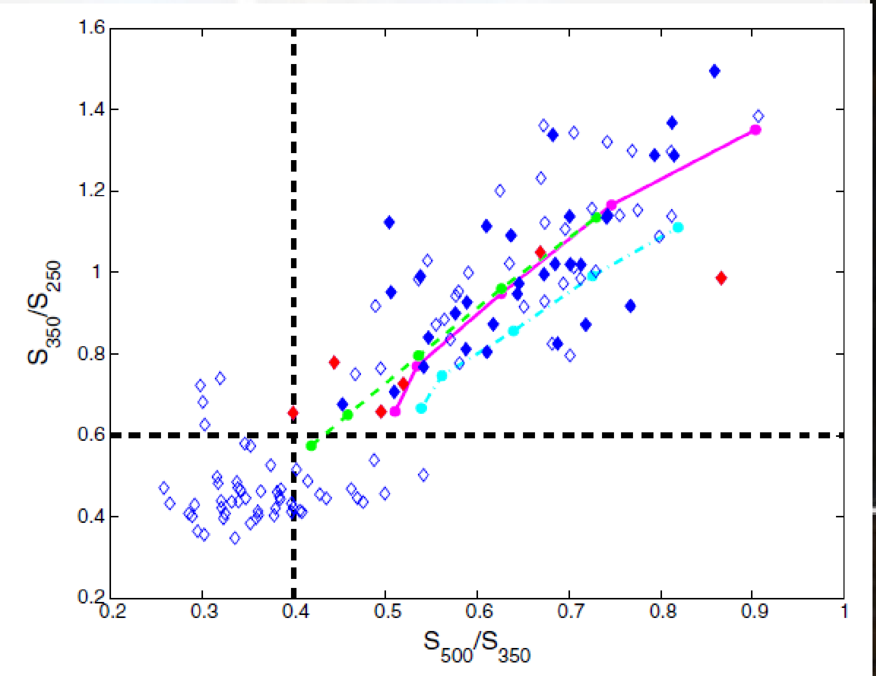
HALOS

- Herschel-ATLAS Lensed Objects Selection
  - SLGs inevitably dominate the highest apparent luminosity tail of the high-z luminosity function.
    - Selection of **High-z bright** sources
  - Lens candidates observed in the optical/near-IR bands.
    - **Close optical counterpart** with incompatible SED
  - Available data compatible with a simple SLG system model.
    - Individual **purity** greater than 30%

Without a proper follow-up confirmation they are only "strong" SLG candidates

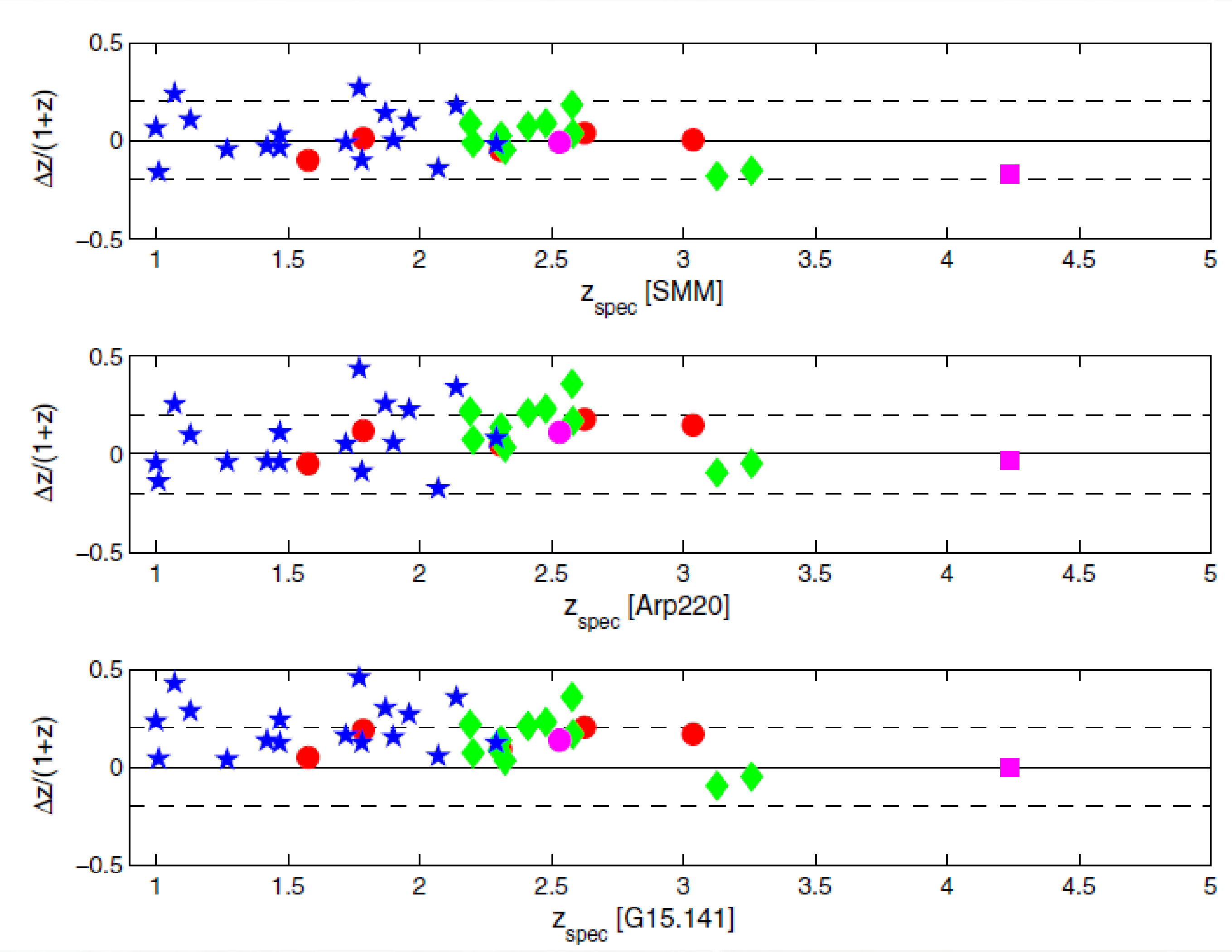
Parent sample (high-z bright sources)

- $S_{350\mu m}$>85mJy (and $S_{250\mu m}$>35mJy)
  - Similar number of lensed-unlensed sources
- S_{350}/S_{250}>0.6 & S_{500}/S_{350}>0.4
  - z>~1.2
- Removal of “problematic” sources



74-10= 64 high-z bright sources

Photometric redshifts

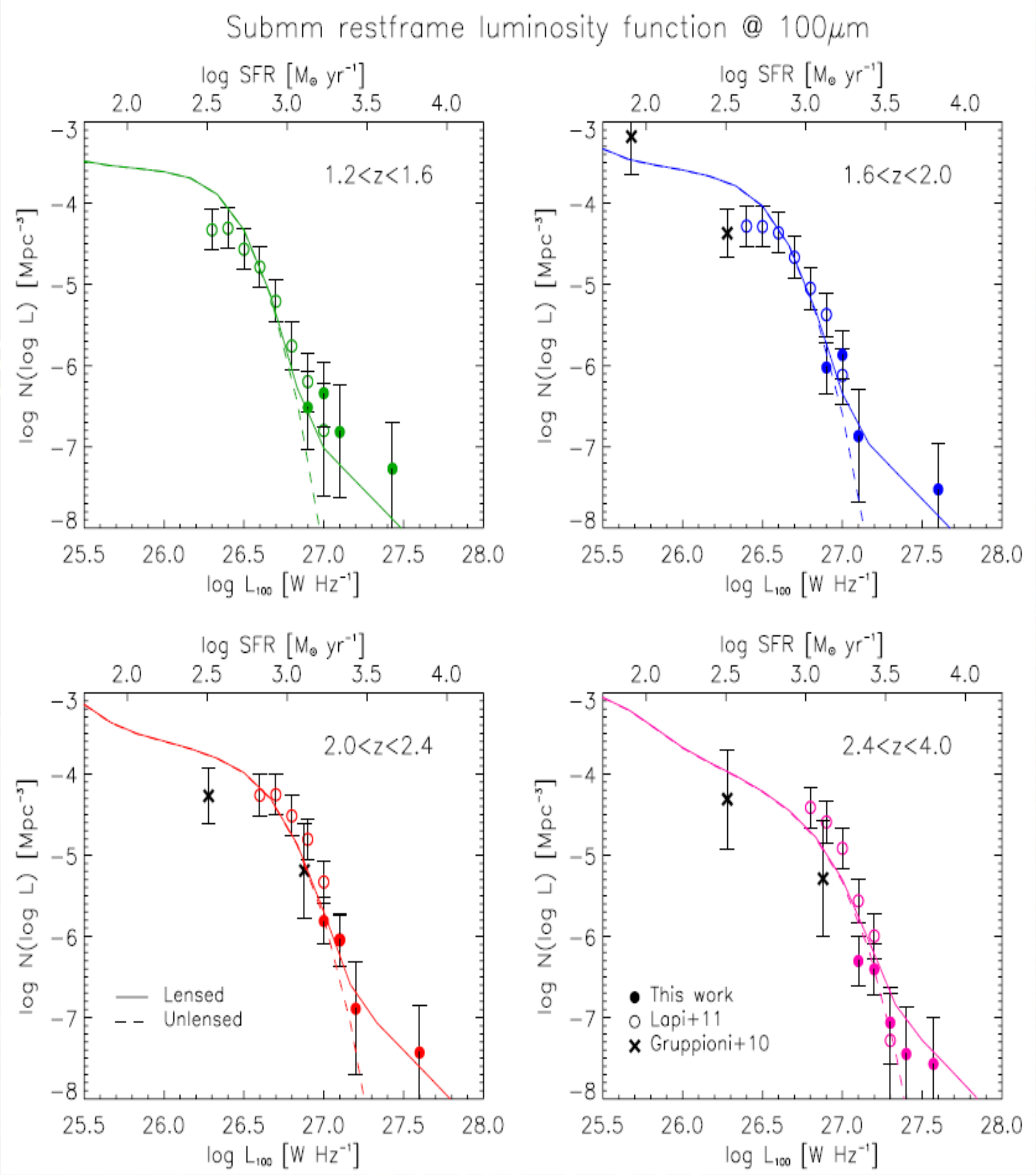


SMM J2135-01012 (Cosmic Eyelash):

$\Delta z/(1+z)$= -0.002 +/- 0.115 (no outliers)

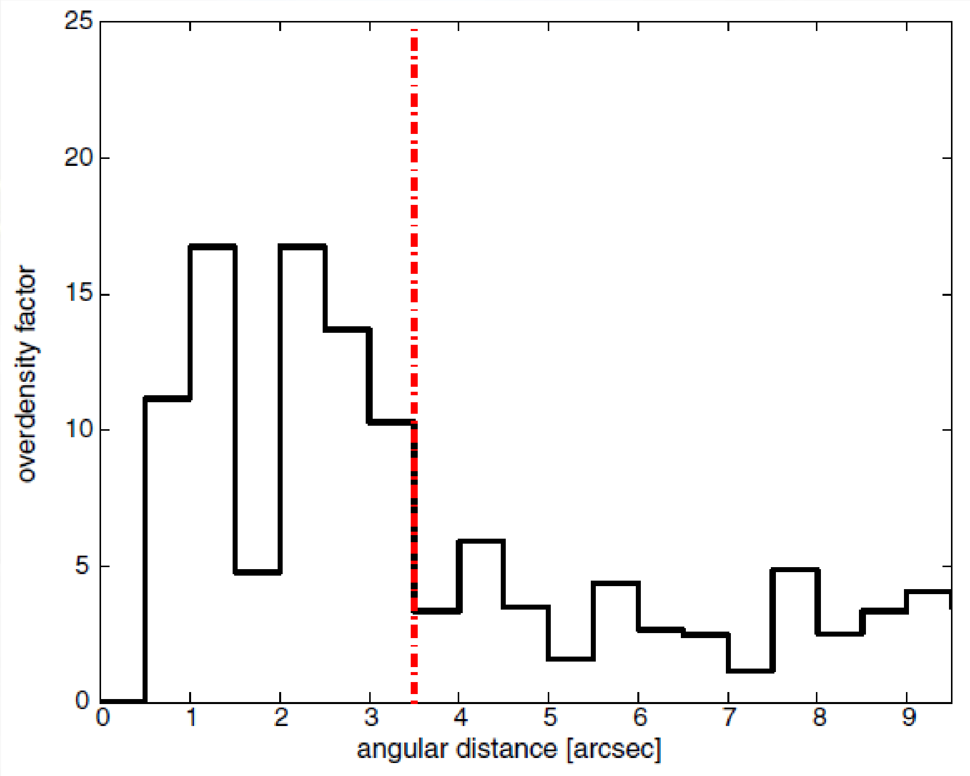
(*apparent*) Luminosity Functions

- Parent sample + photometric redshifts
- Parent sample: high-z luminous galaxies
- Apparent plateau produced by lensing



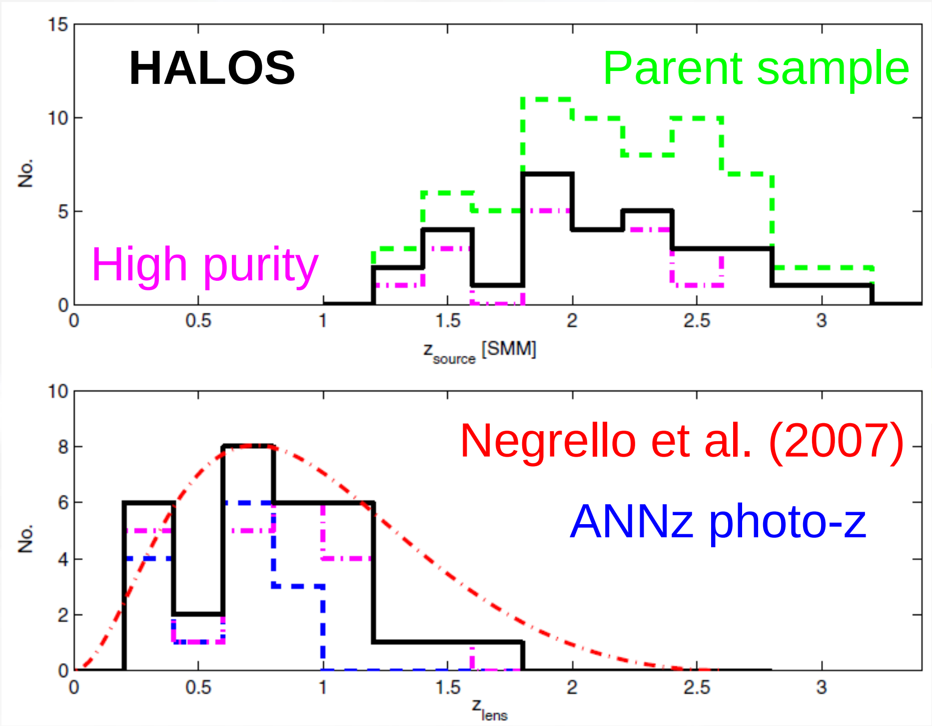
HALOS: SLG candidates selection

- VIKING (Fleuren et al. 2012) optical counterparts within 10''
    - 58 of 64 (91%)
    - 106 counterparts: selection of the nearest source (~higher R)
- ang_dist<3.5''
    - Clear overdensity: physical relation
    - ~distance between lens/source images



33 SLG candidates

HALOS: redshift distributions



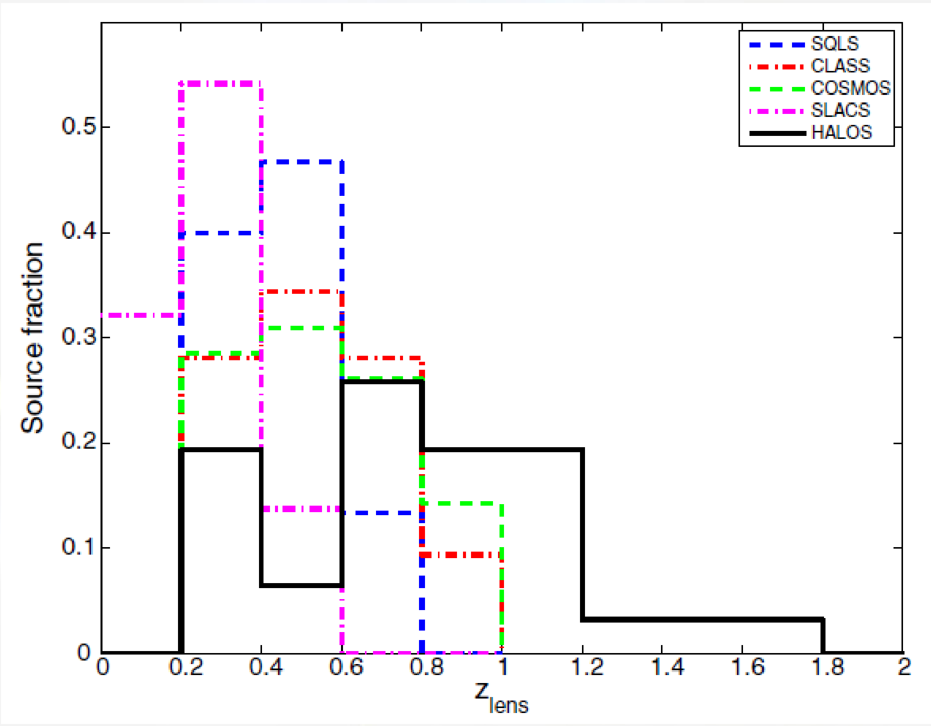


Photo-z for the lens:

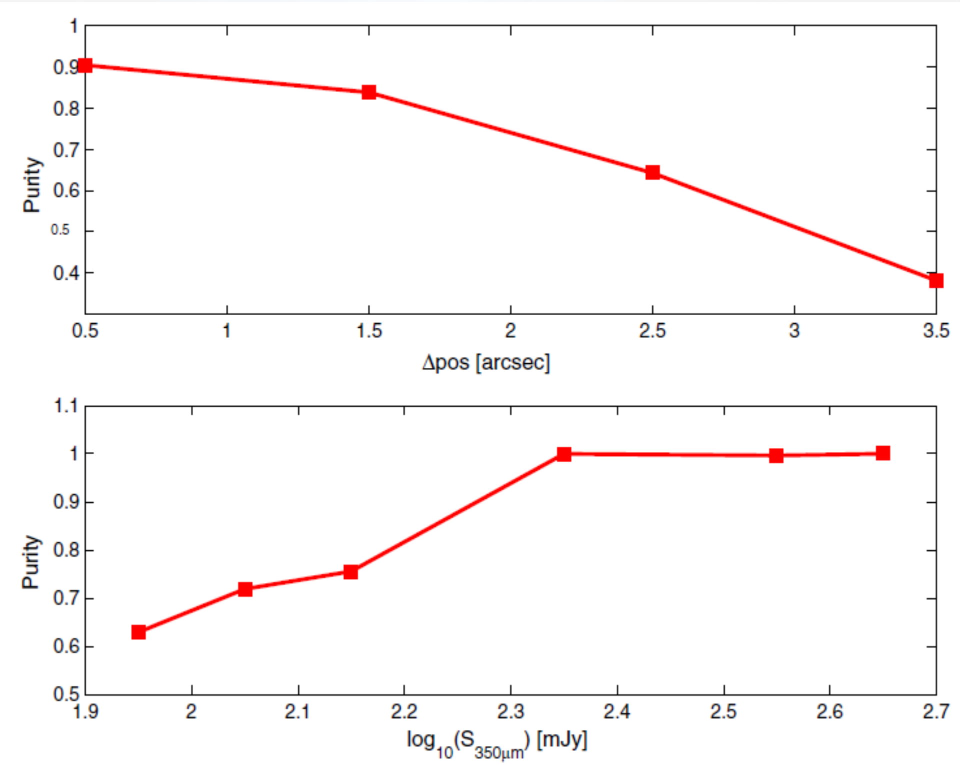
- SDSS+VIKING data
- ANNz when available (z<0.8)
- 16 early-type galaxy SEDs

HALOS lenses at higher z

- lens galaxy structure at z>1
- (size) evolution

HALOS: simple “purity” analysis

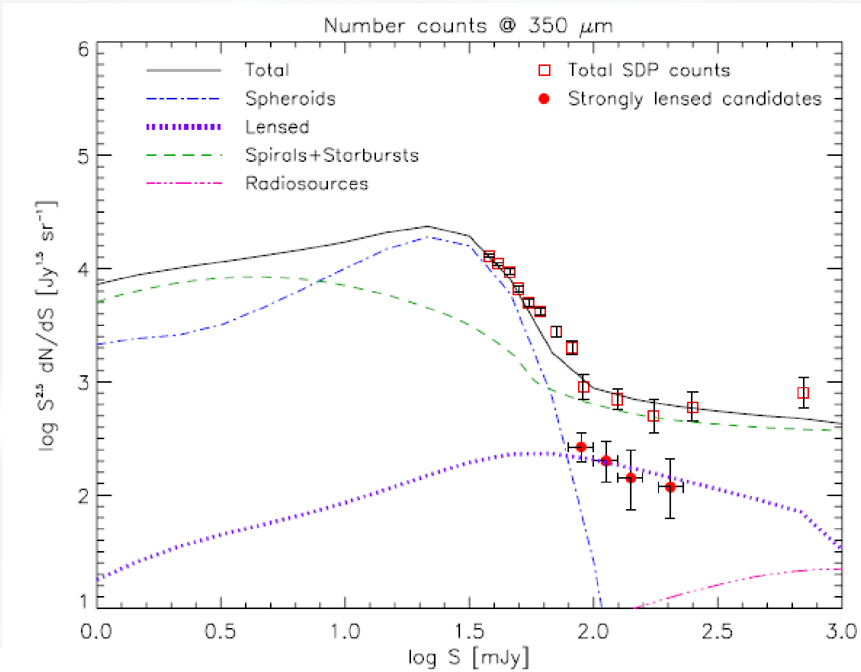
- Tentative estimation of the “lens probability”
  - SIS profile & μ>2
  - Individual “lens probabilities” are quite uncertain
- Sample “purity”: ~72%

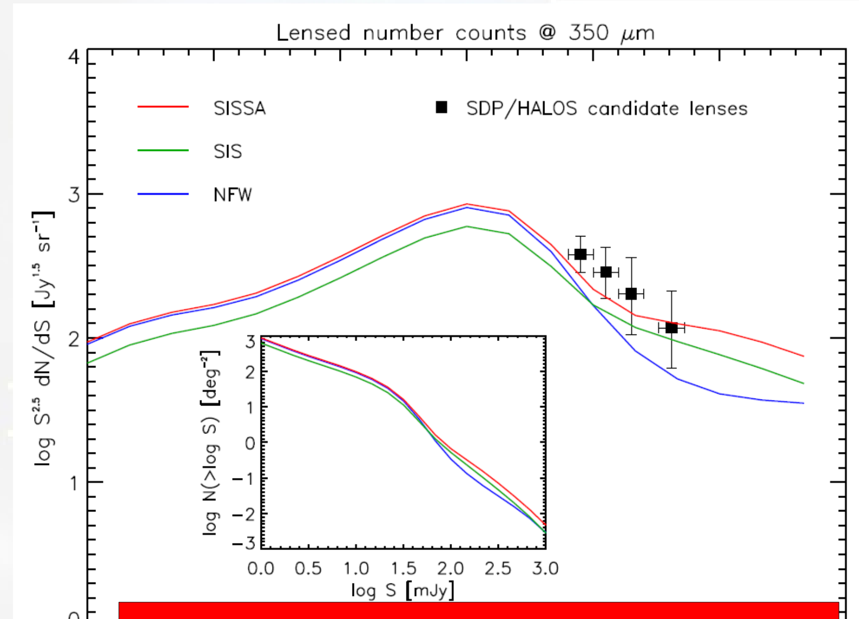


“strong” SLG candidates: 31 candidates with P>30%

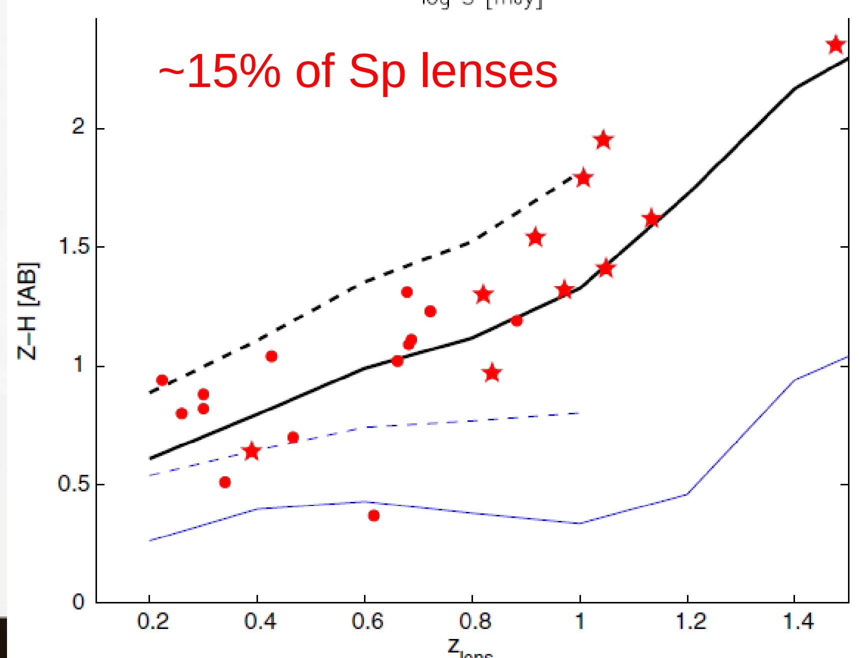
(~1000 SLG candidates in the full H-ATLAS!)

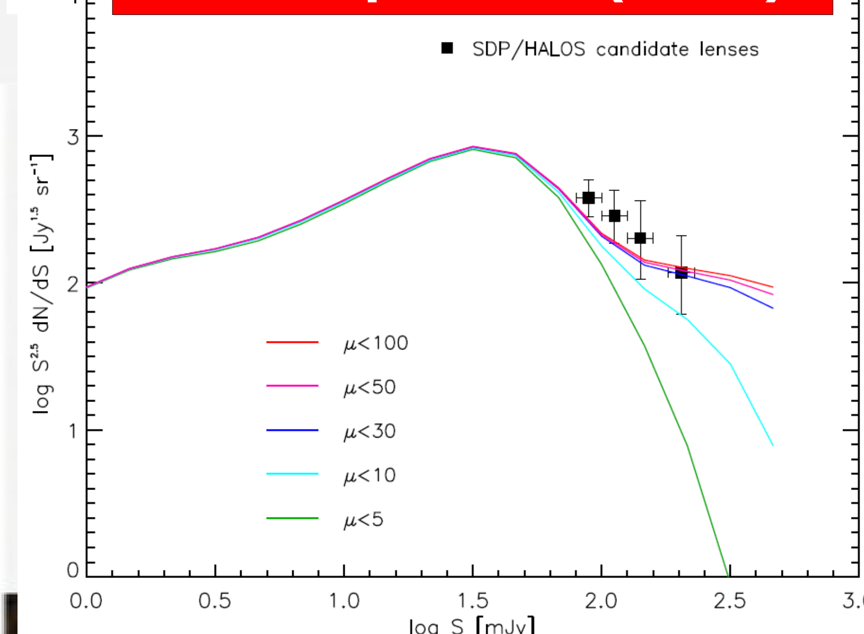
HALOS: statistical analysis!





See Lapi et al. (2012)





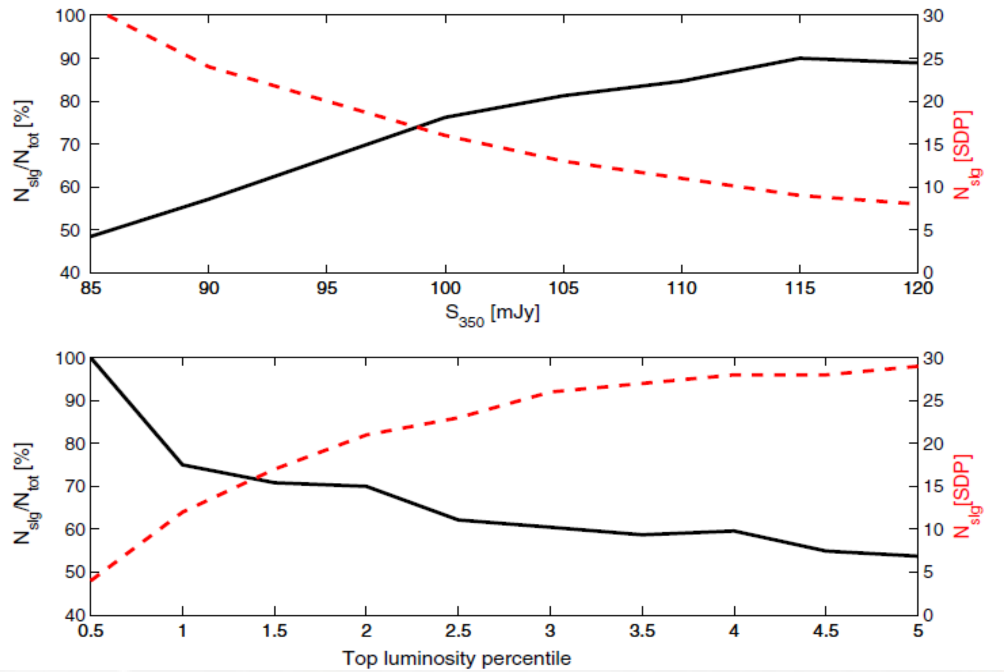
Confirming HALOS SLGs candidates

- Huge follow-up campaign will be needed
  - Currently focusing on bright SLG candidates
- Strategy:
  - Spectroscopy of CO transitions
    - High-z nature
    - preliminary estimation of amplification (Harris et al. 2012)
  - Deep high resolution imaging (better at sub-mm)
- Current situation:
  - The 5 brightest are the confirmed SLGs from Negrello et al. (2010)
  - 5σ tentative detection of CO line with ATCA (Massardi et al. in prep)
  - Two sources observed with Keck NIRC2 AO but only K band

If you have free observational time in ALMA, HST, Keck, IRAM, … Please contact us!!

HALOS without good optical data?

- VIKING will cover ~1200deg^2 but not the whole H-ATLAS area
- Simply S_{350} criteria (+z>1) gives >50% selection effectiveness
  - Removing blazar/local sources
- Top apparent luminosity percentile selection (+z>1) gives similar results
  - Independent of any S_{350} limit.



[x40 for the whole HATLAS area]

S_{350}>100mJy: ~15 SLG cand. (~70%)

Top 2% Lum: ~20 SLG cand. (~70%)

Summary

General.-

* The detection of bright SLGs in the sub-mm is easy!
* ~200 SLGs in H-ATLAS but we need more for statistical analysis...

HALOS.-

* Efficient selection method for fainter SLGs candidates
* ~1000 SLG candidates in H-ATLAS
* Lenses at z>1

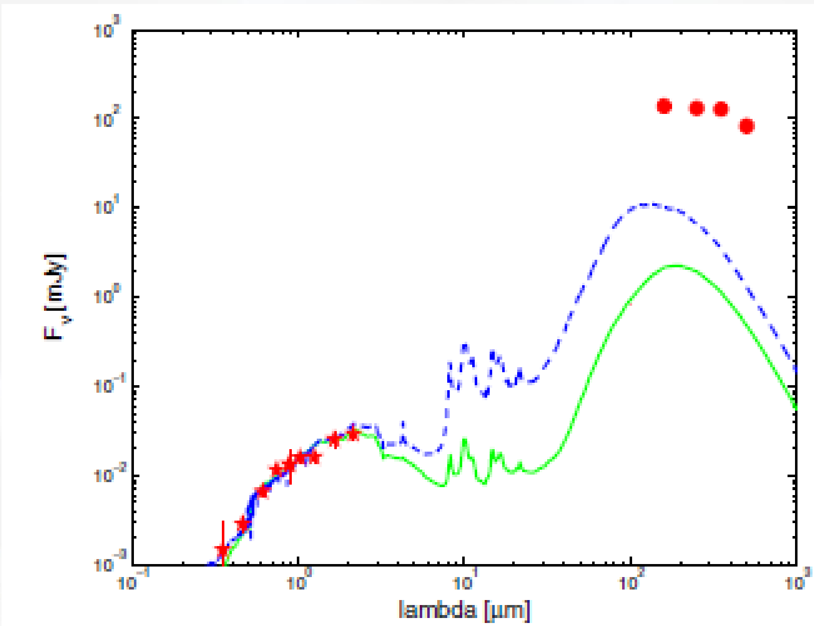
Necessity of follow-ups.-

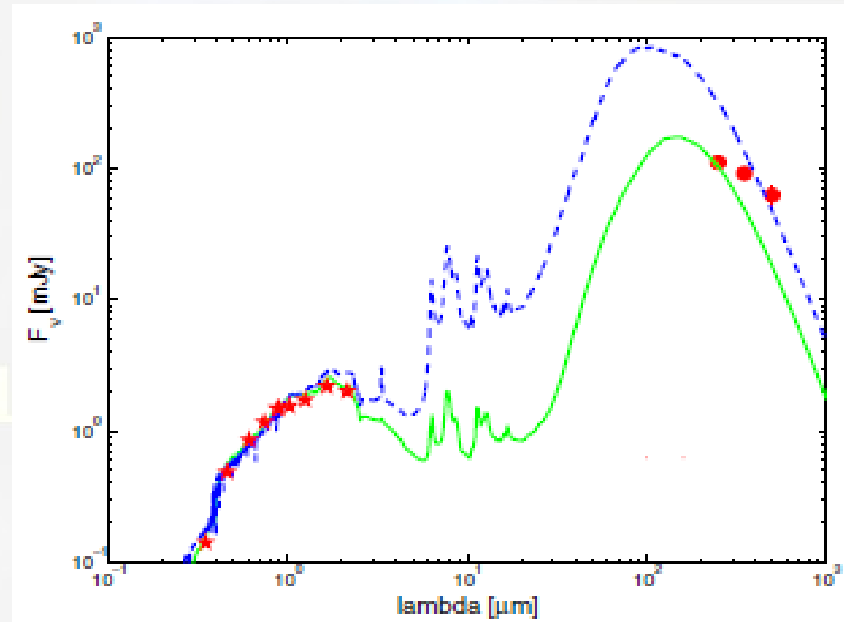
* CO spectroscopy
* Deep high-resolution imaging (better in sub-mm)

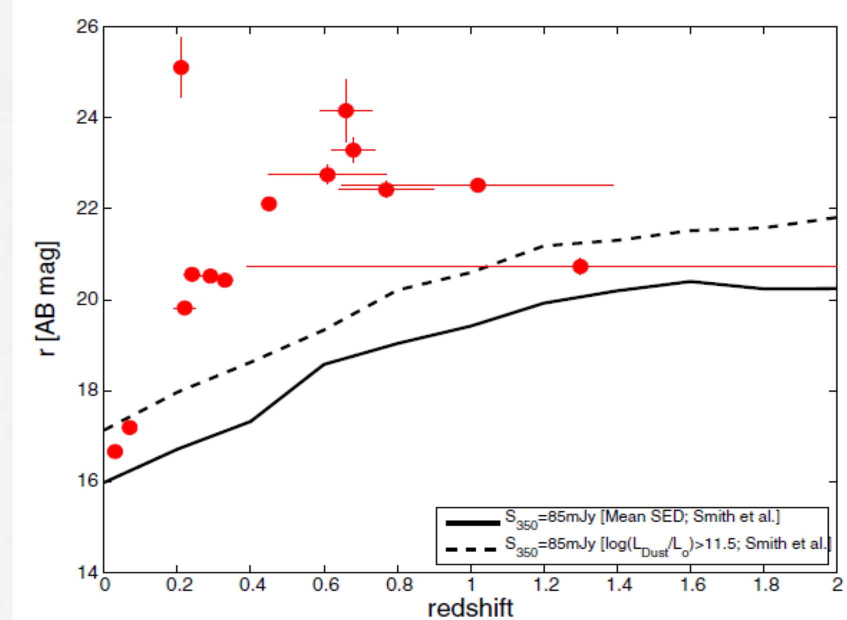
Statistical analysis.-

* Source number counts and luminosity functions
* lens galaxy mass, structure and evolution
* density profile: barions/DM relationship
* and many more...

Parent sample







- Anomalous colors (2)
- Blazar+QSO
- PACS data indicates z<1 (3)
- Optical counterpart= genuine identification (3)