Finding galaxy clusters in formation at redshifts > 3

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et al.

Talk outline

- Search for high-z clusters
  - Why submm searches for clusters in formation
  - The after Herschel era
  - Role of the gravitational lenses
- Follow-up of lenses' fields
  - Identification of overdensity sources
  - Candidate protoclusters at z~3

Galaxy clusters at high-z: why?

- Constraints on models of large scale structure
- Derive a detailed statistics of massive high density peaks:
  - Constrain the generation mechanism of cosmological perturbations in the early Universe (expected to be associated with massive haloes of dark matter)
  - Constrains its parameters (i.e. Ω_m, σ_8)
  - Sensitive to non-Gaussianity and dark energy
- Used to study the effect of environment on galaxy evolution

Cluster Number Counts and masses

$$N(M,z) = \int\int \frac{dn(M,z)}{dM}\, dM\, dz\, \frac{dV_c}{dz}$$

T-M relation → N(T,z)

Y-M relation → N(Y,z)

$\theta = (\Omega_{M0}, \sigma_8)$

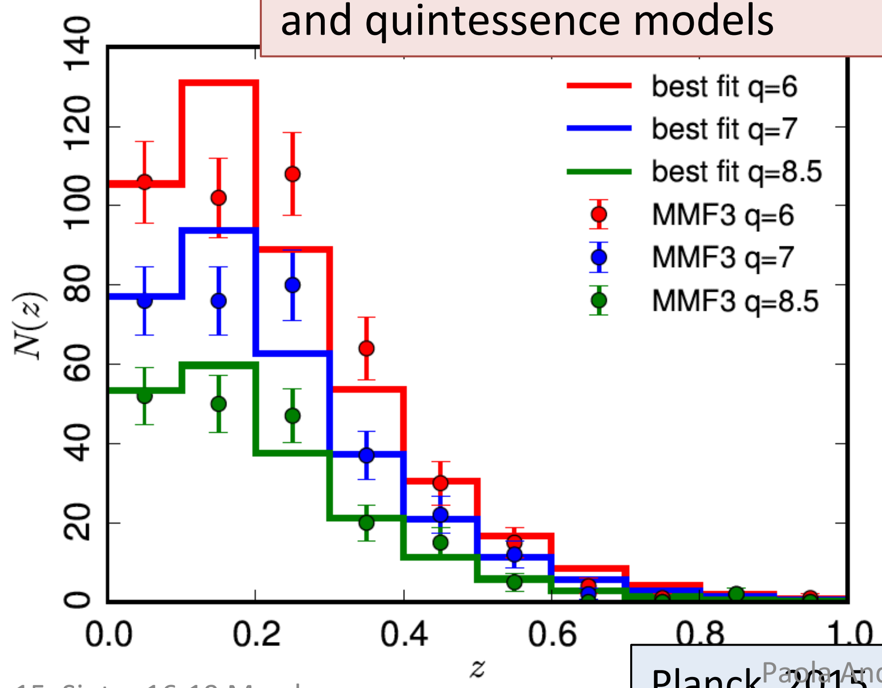
$\sigma_M(R=8\ h^{-1}\mathrm{Mpc},0) \equiv$ σ_8

Growth of structure

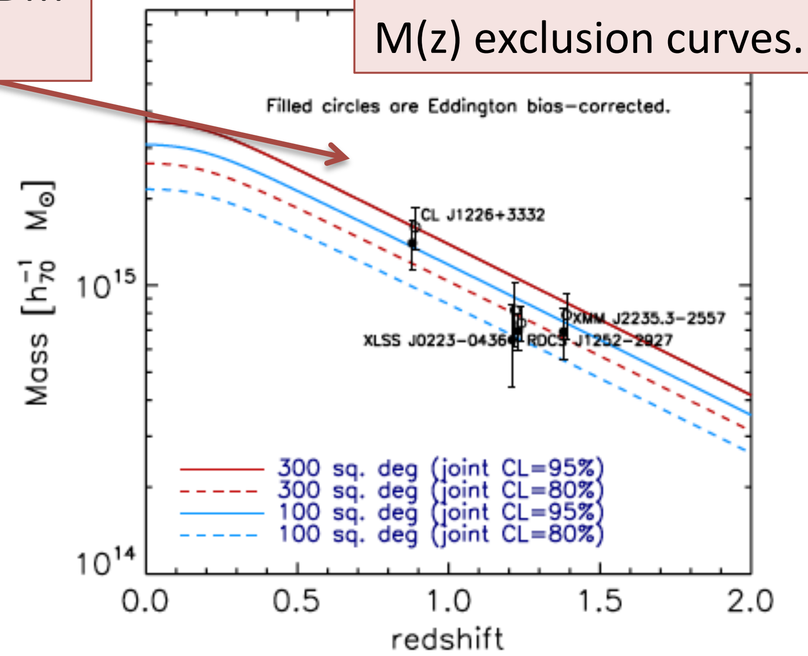
Geometry of the Universe

$$\Omega_{M0} = \frac{\rho_{M0}}{\rho_{cr0}} = \frac{8\pi G}{3H_0^2}\rho_{M0}$$

Even a single cluster with (M,z) above the curve would rule out ΛCDM and quintessence models



Planck, 2015



Mortonson et al., 2011; Jee et al., 2011

Protoclusters as FIR sources

- Cluster of galaxies expected to undergo phases of strong, simultaneous star-formation in the early phases of cluster life ($z \geq 1.5$)
- Most massive elliptical galaxies form in the cores of what will become today's most massive galaxy clusters
- Many galaxies in such cores undergo simultaneous starbursts, detectable as dust obscured sub-millimetre galaxies (SMGs), and producing integrated clumps of proto-spheroidal galaxies

How to find protoclusters

- identifying high-z structures very difficult
  - the dusty star-forming phase of a protocluster is short
  - objects will be rare on the sky
- X-ray survey techniques lack sensitivity (XMMU J0044.0-2033 @z=1.58) Santos+11, Santos+13, Santos+15
- optical, near-IR do miss the obscured phase and until recently lack large area on the sky needed to obtain large samples (wait for Euclid)
- Follow-up of Lyα- blobs (Chapman+00, Smail+02,Oteo+13)
- very efficient/successful method using powerful high-z radio galaxies as beacons: # of protoclusters small and possibly biased (i.e. Hatch et al. 2011, 2014).

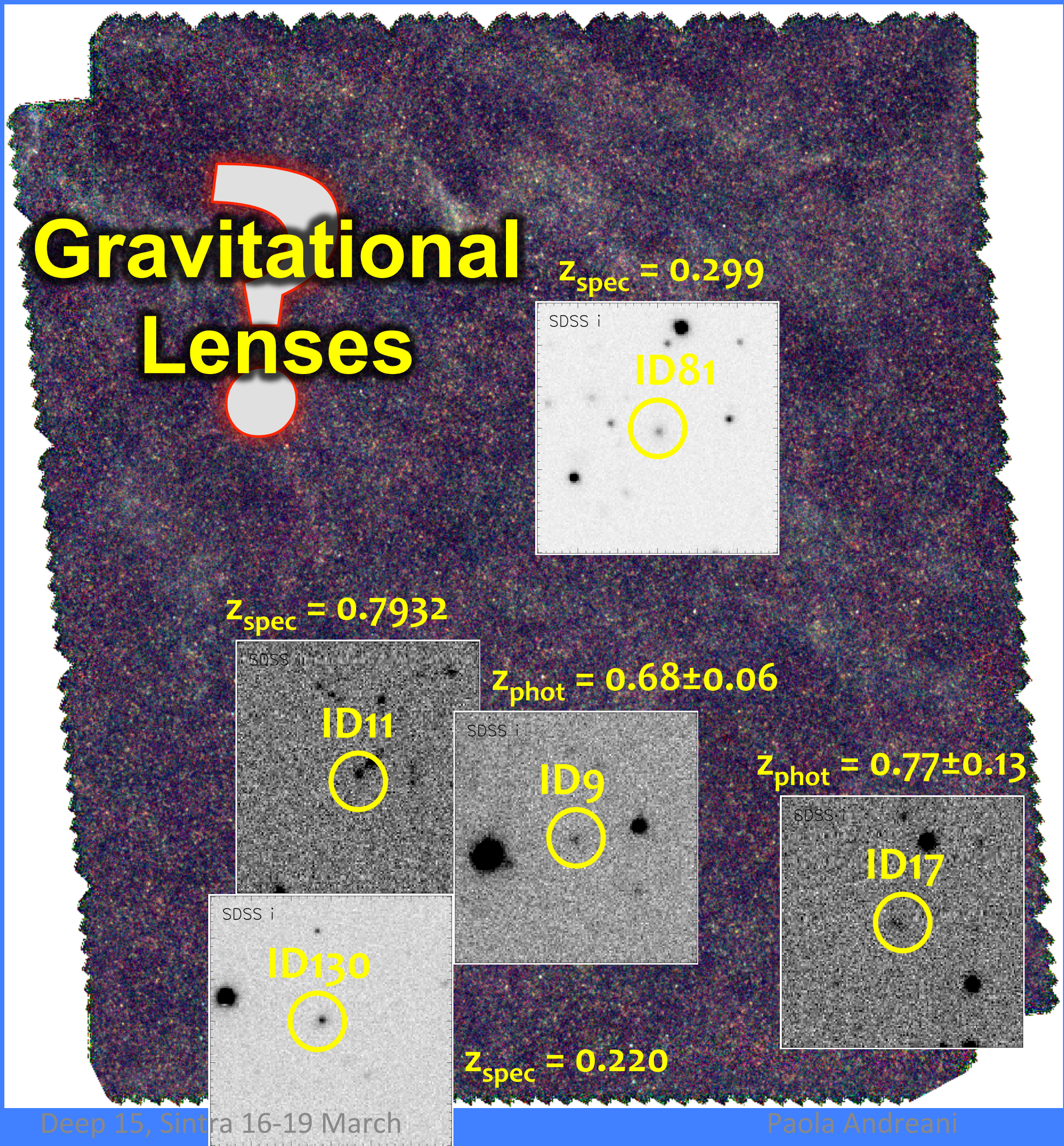
How to pursue an unbiased search of protoclusters?

Herschel surveys

- **H-ATLAS:**
- Largest Open Time Key Project (600 hours)
- A survey of 550 deg^2 of the sky
- 5 bands: 110,170,250,350 and 500 microns
- 5σ detection limits (including confusion noise) at 250,350, 500 μm of 33, 37.7, 44 mJy/beam, respectively
- ~ 1000 SLGs in the full H-ATLAS survey

- **HerMES:**
- Guaranteed Time Key Project (600 hours)
- A survey of 650 deg^2 of the sky
- 380 deg^2 in 5 bands: 110,170,250,350 and 500μm 270 deg^2 in 3 bands: 250,350,500 μm
- Fields range in size from 0.01 to ~ 20 deg^2
- 5σ limit at 250 μm of 64-91 mJy

Another way of selecting protocluster candidates: bright submm galaxies



ID9 : $S_{500\mu m}$ = 175 ± 28 mJy

ID11 : $S_{500\mu m}$ = 238 ± 37 mJy

ID17 : $S_{500\mu m}$ = 220 ± 34 mJy

ID81 : $S_{500\mu m}$ = 166 ± 27 mJy

ID130 : $S_{500\mu m}$ = 108 ± 18 mJy

What's the role of **gravitational lensing** ?

dust-obscured star-forming galaxies **lensed** by a foreground **galaxy cluster** lens

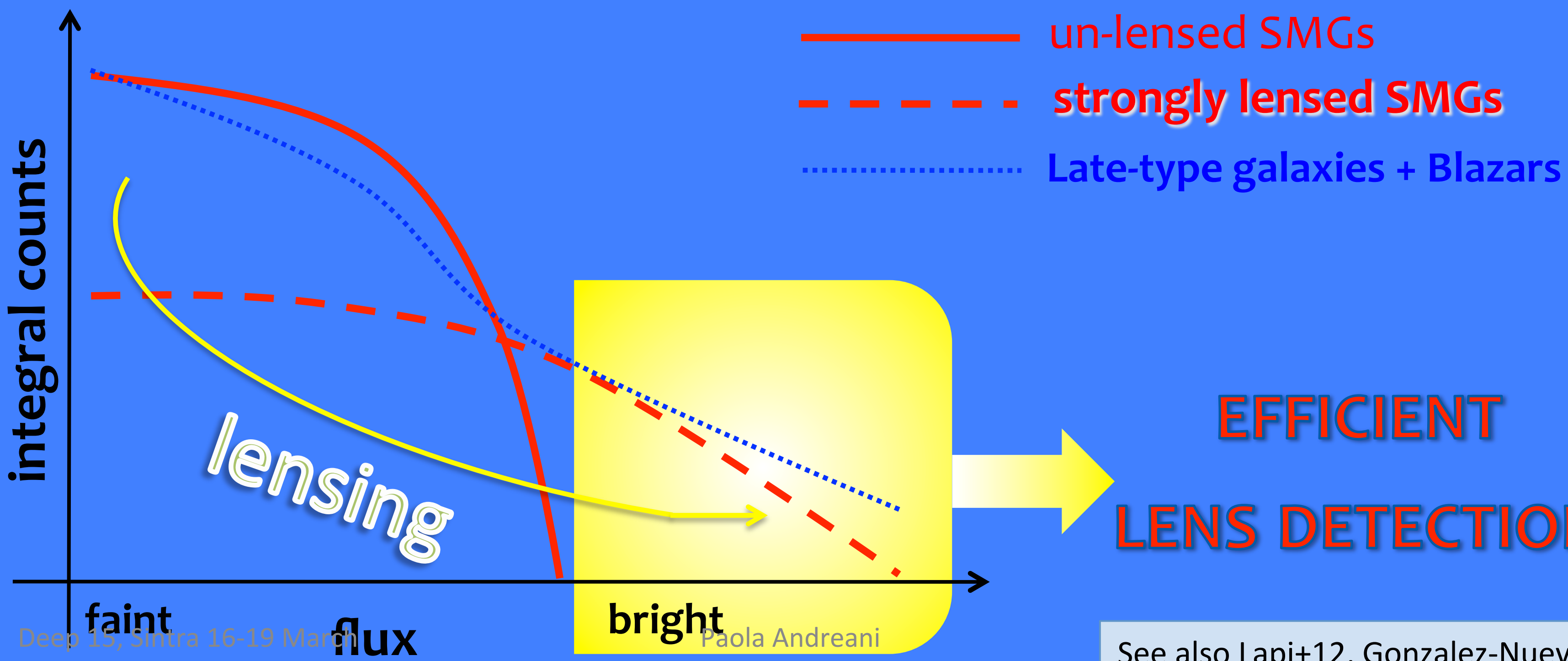
a Lensing science case for large FIR surveys (H-atlas)

Sub-mm surveys are ideal for finding lenses

Blain (1996), Perrotta et al. (2003), Negrello et al. (2007)

- **high redshift** → high efficiency for lensing
  Chapman et al. (2005)
- **steep counts** → strong *magnification bias*
  Coppin et al. (2006)

Negrello, 2010



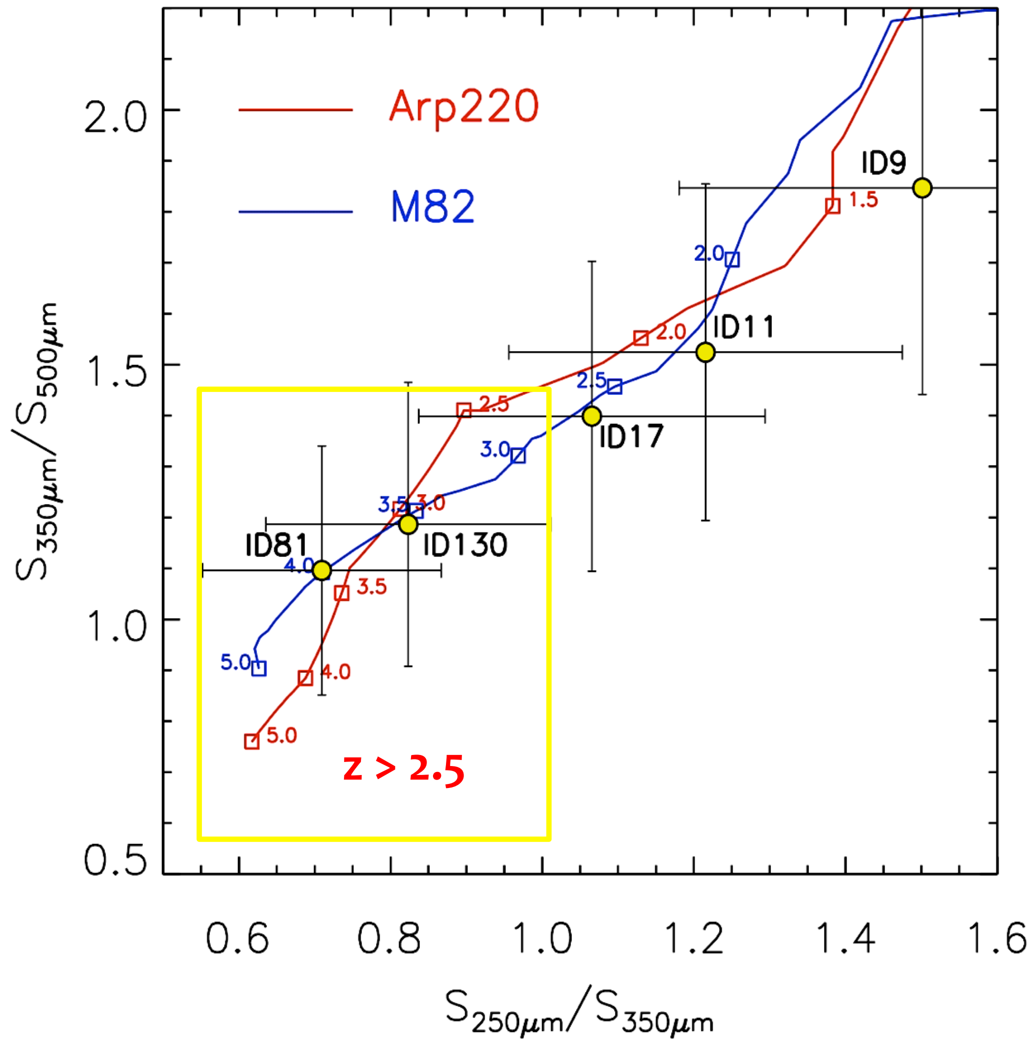
EFFICIENT LENS DETECTION

See also Lapi+12, Gonzalez-Nuevo+12

GRAVITATIONAL LENS CANDIDATES

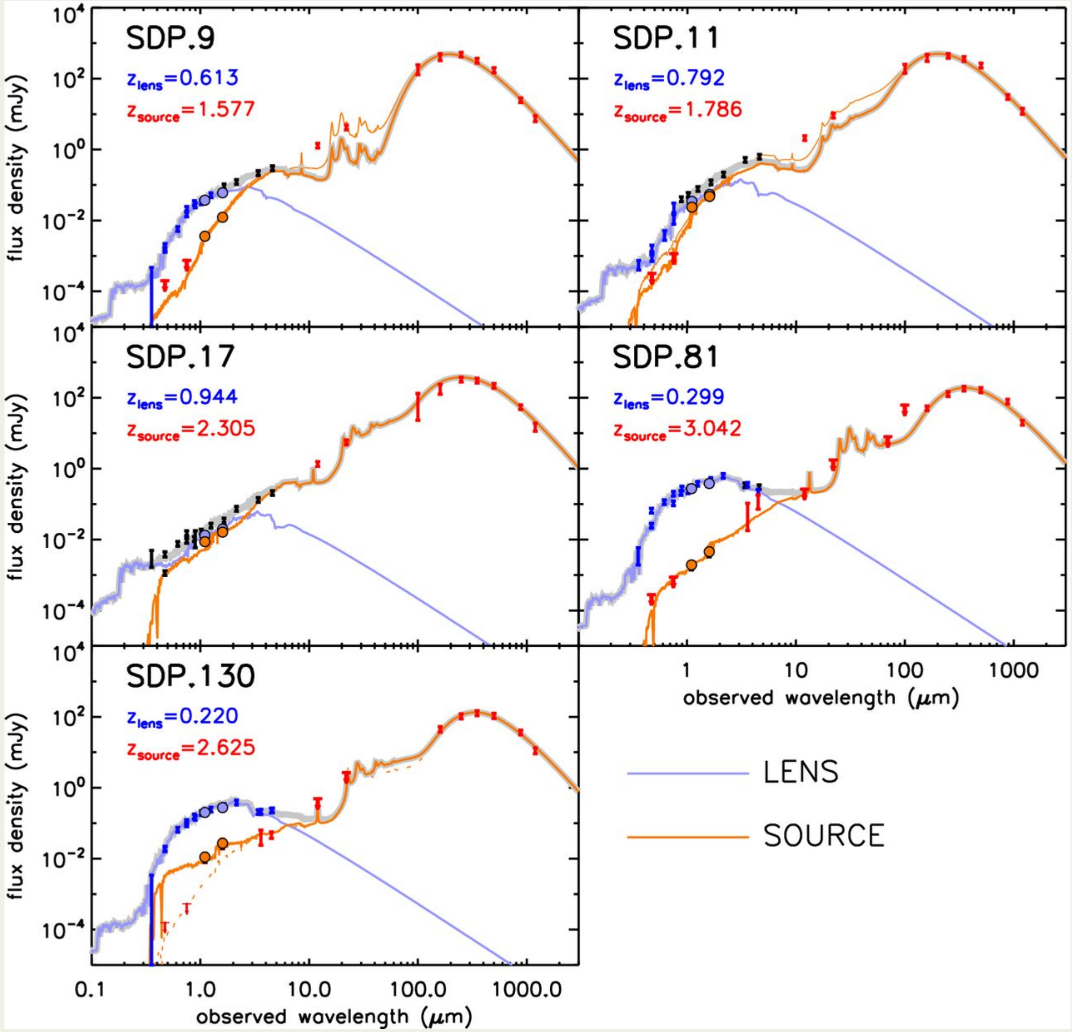
ID81 - ID130:
UV/optical/near-IR SED
inconsistent with
sub-mm SED !

best lens candidates
for follow-ups



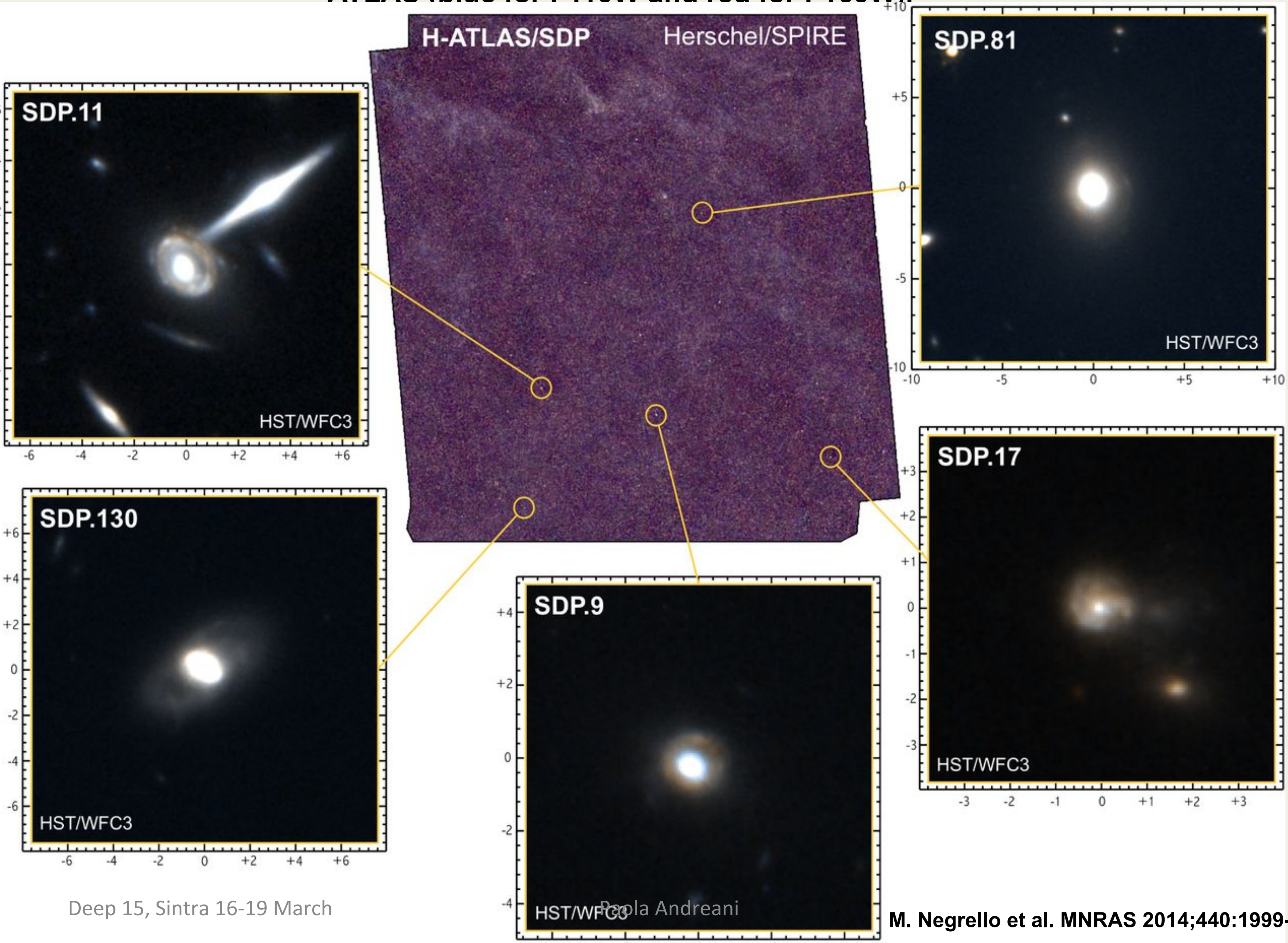
Negrello, ESLAB 2010

SEDs of the lens and of the background source for the five H-ATLAS/SDP gravitational lensing systems.



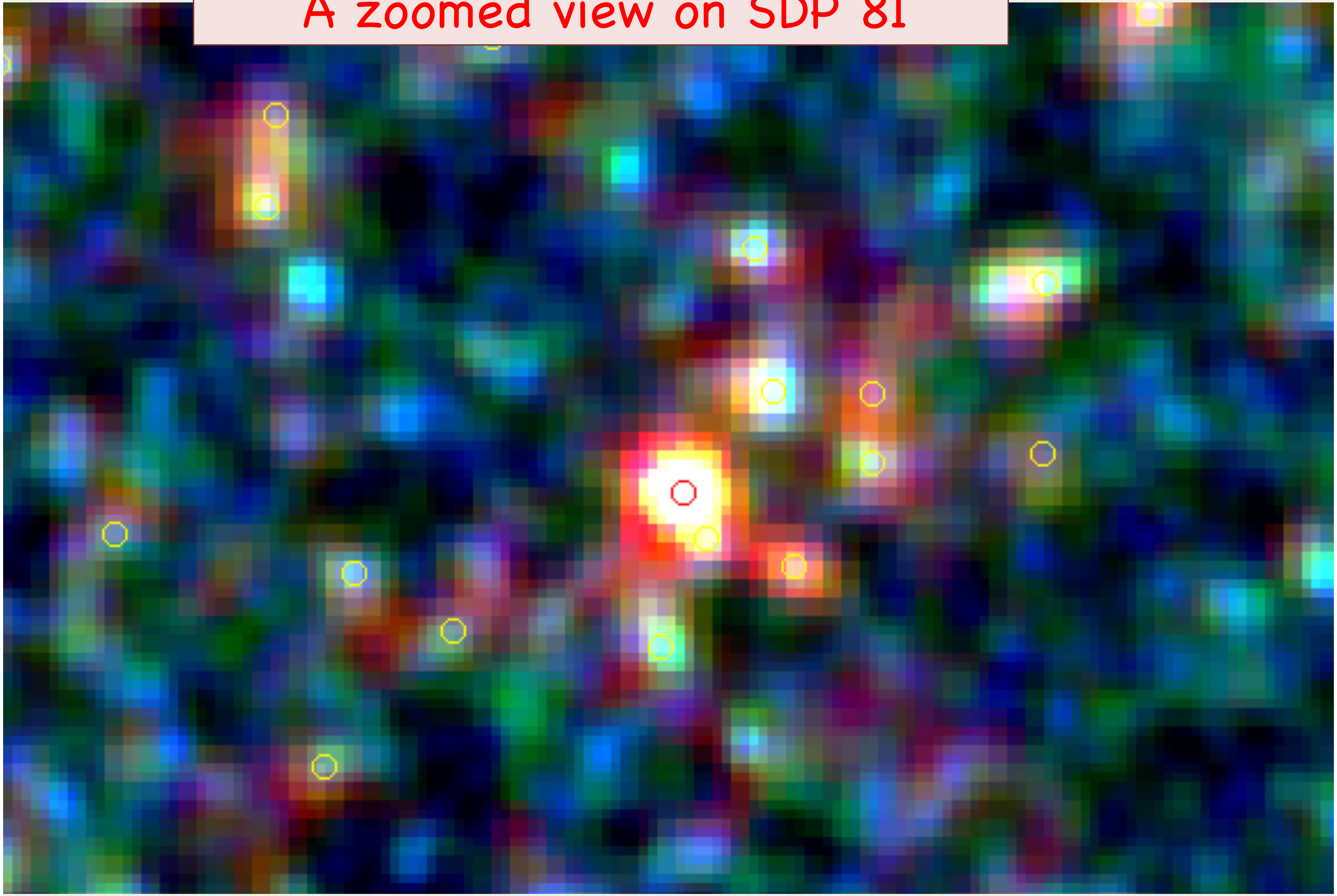
M. Negrello et al. MNRAS 2014;440:1999-2012

HST/WFC3 images of the first five confirmed gravitational lensing systems discovered by H-ATLAS (blue for F110W and red for F160W).



M. Negrello et al. MNRAS 2014;440:1999-2012

A zoomed view on SDP 81



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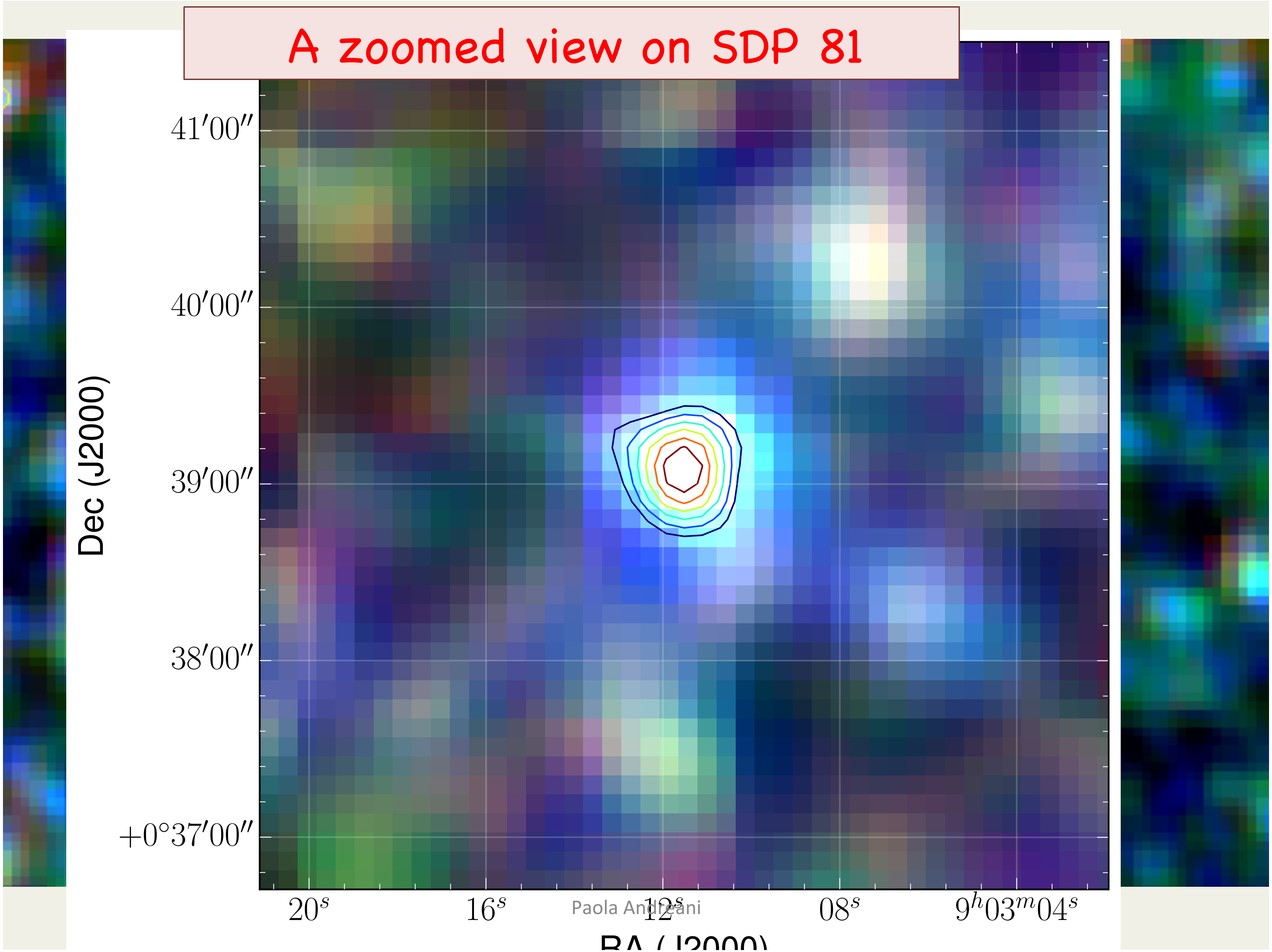

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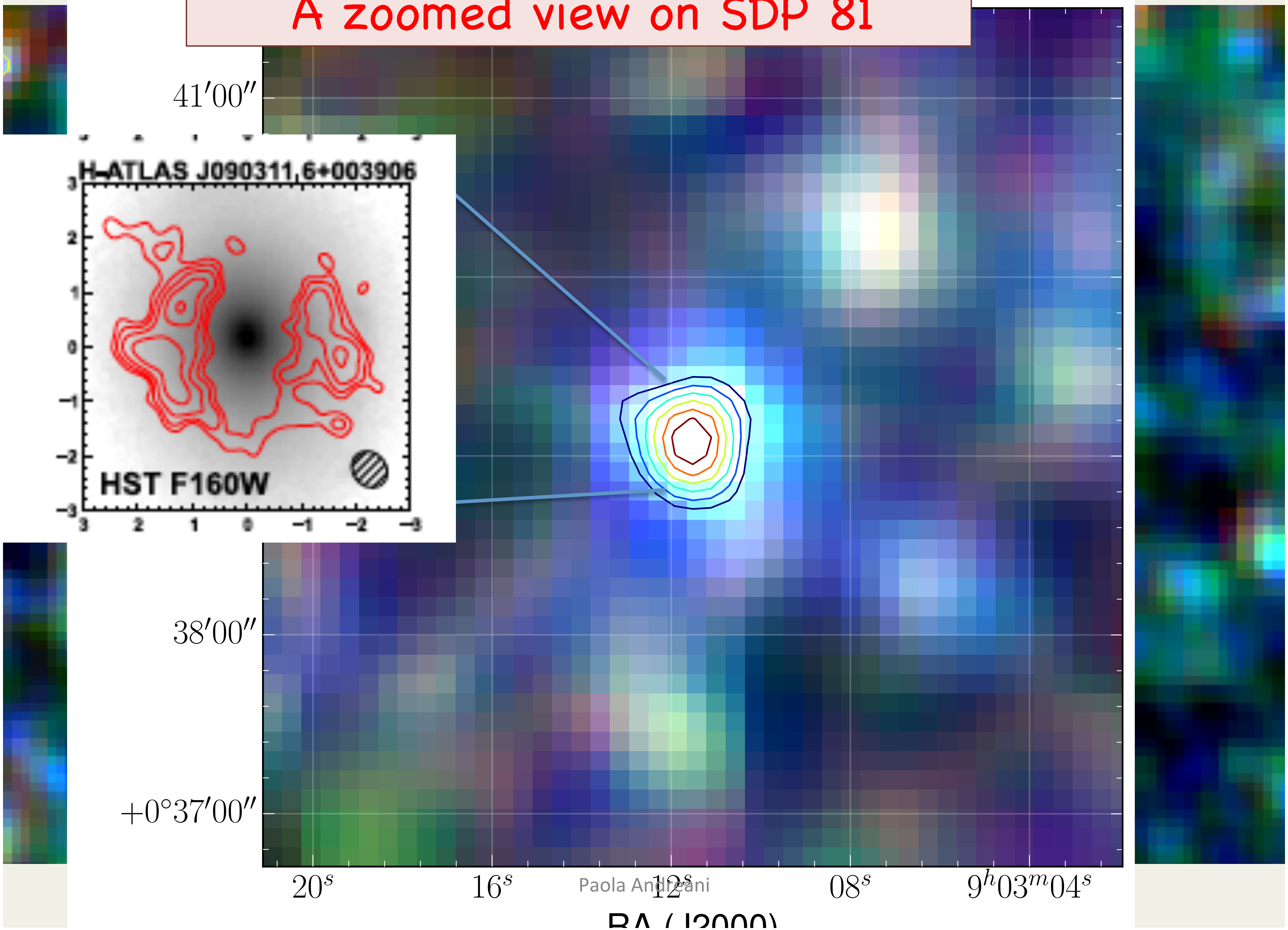
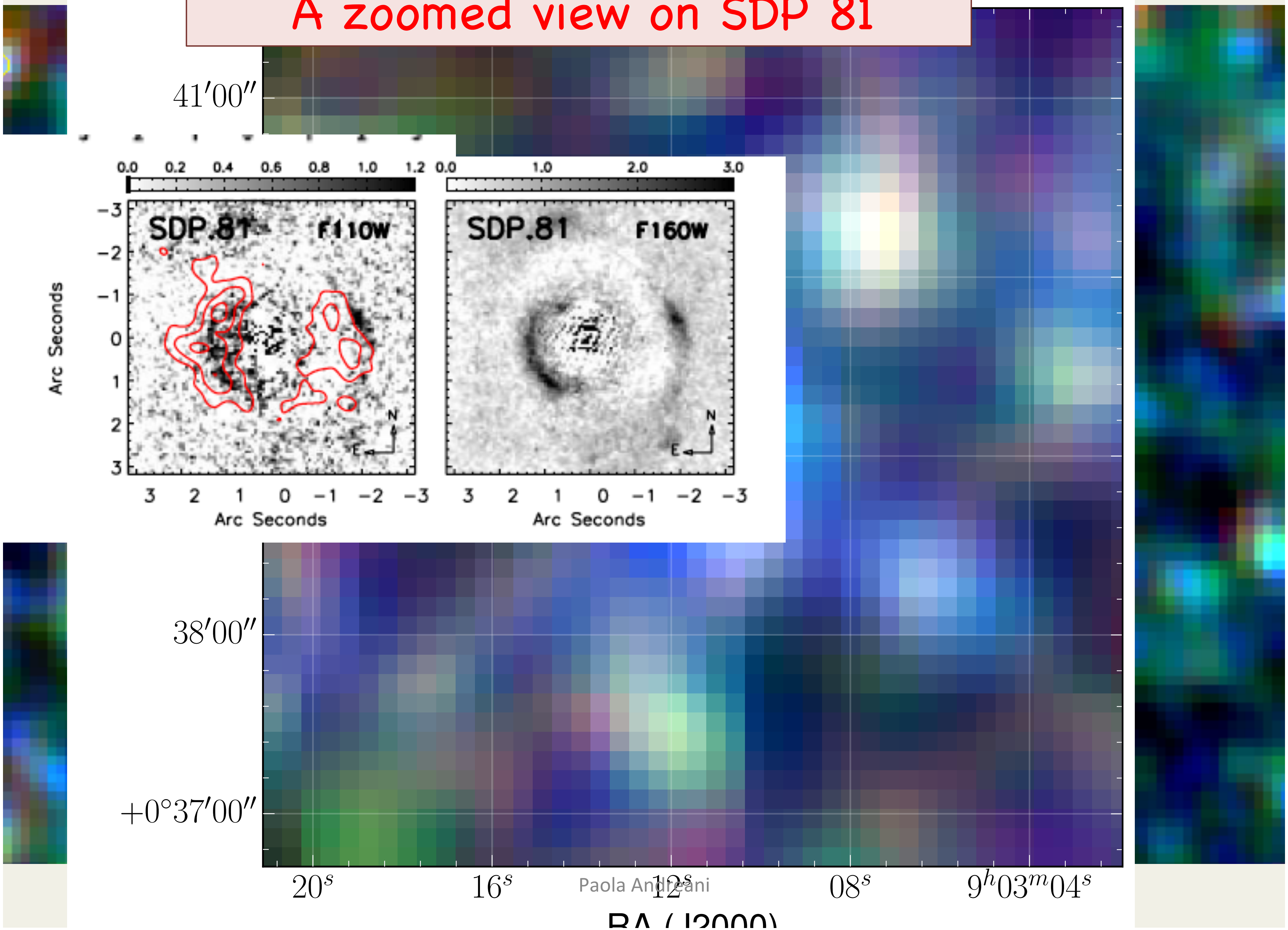


Paola Andreani

A zoomed view on SDP 81



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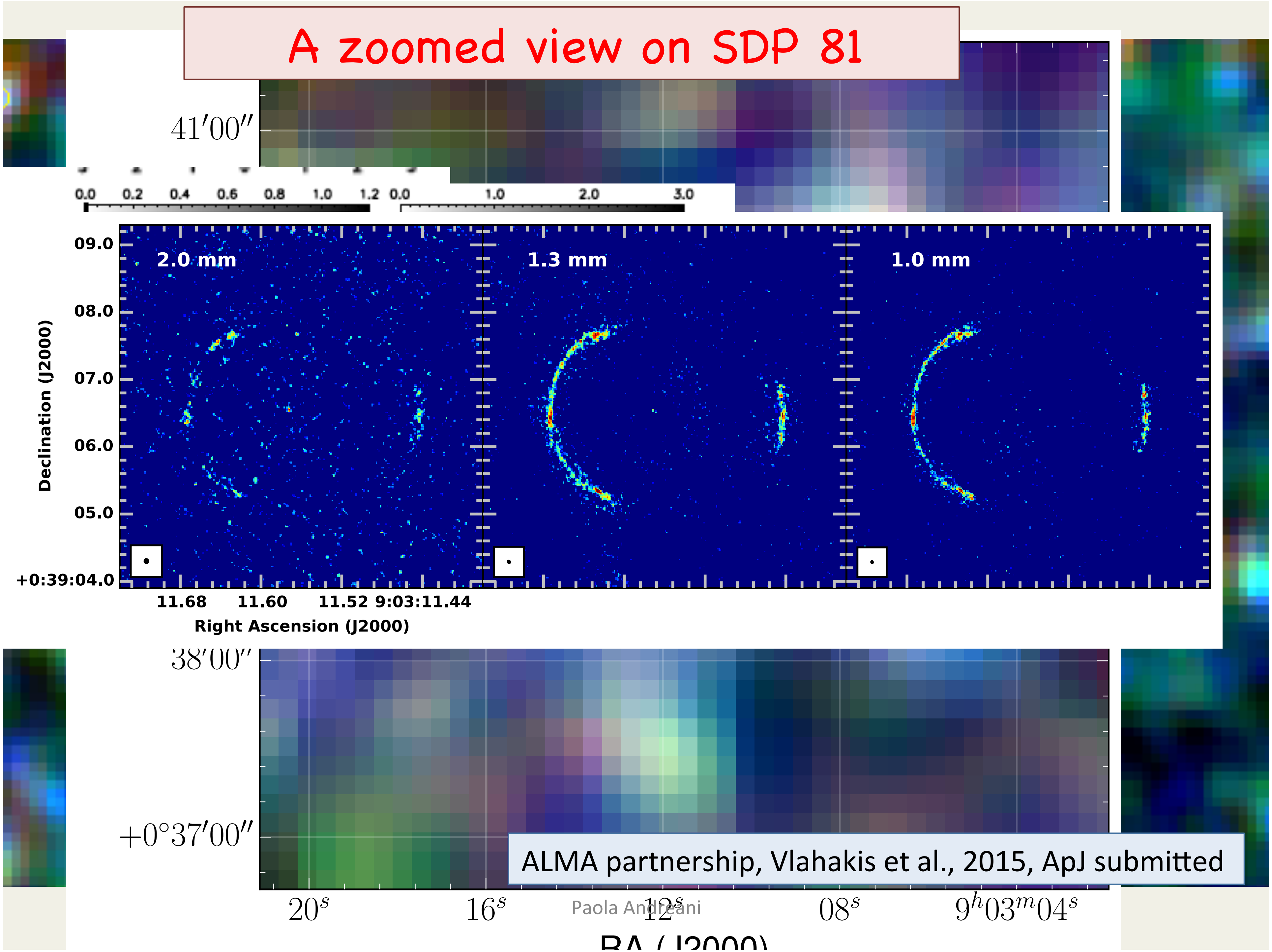
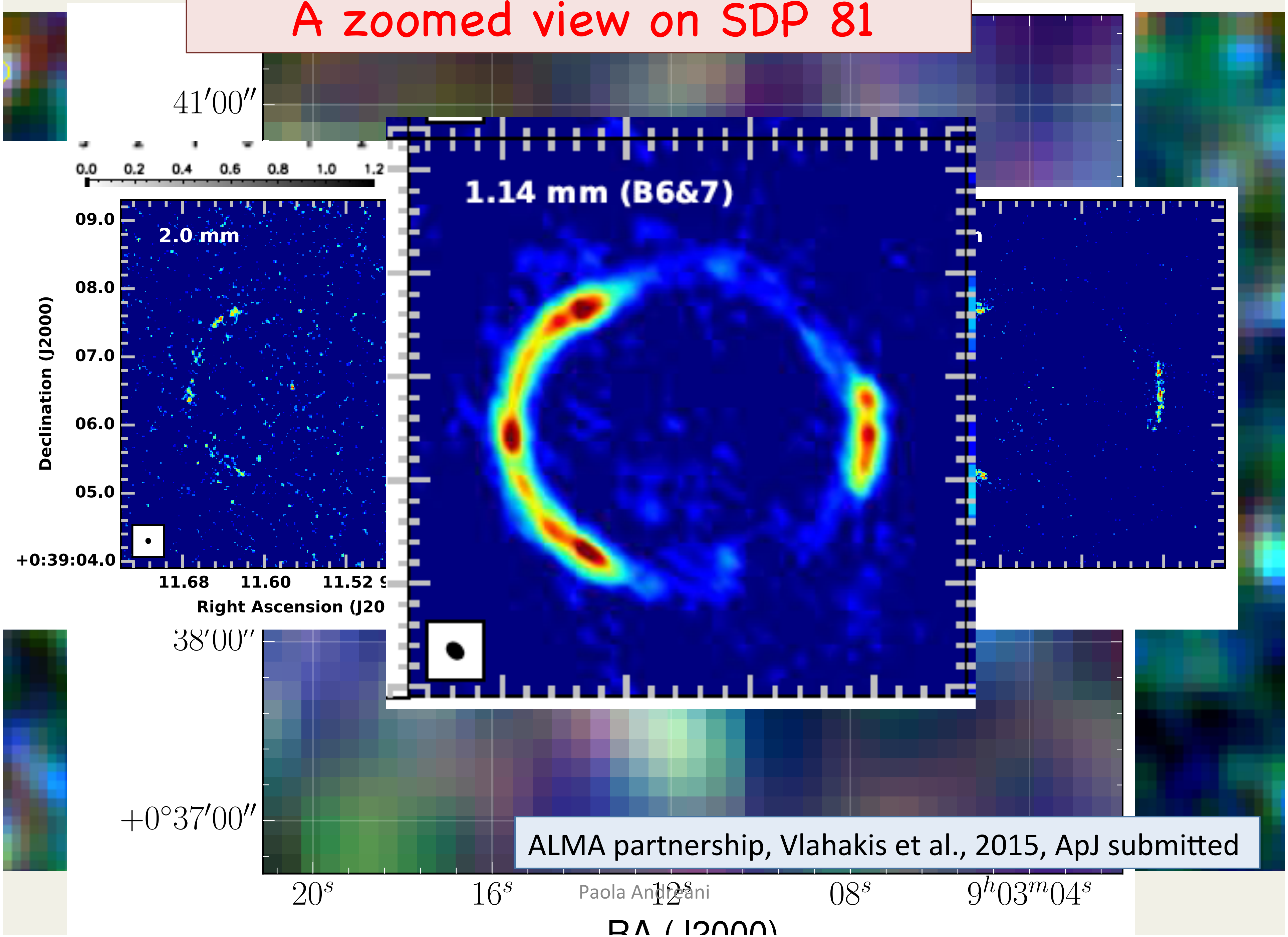


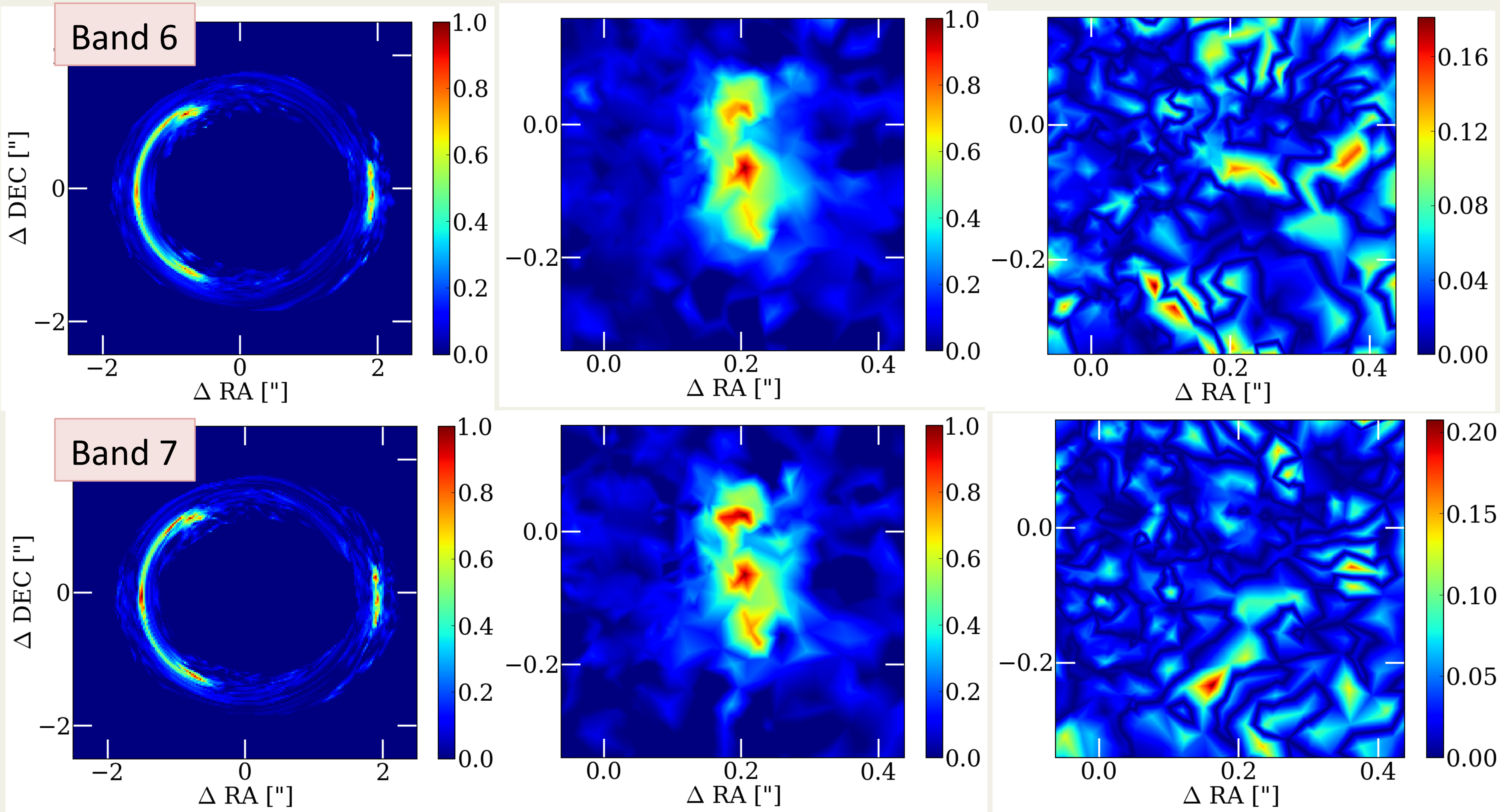
ALMA partnership, Vlahakis et al., 2015, ApJ submitted

A zoomed view on SDP 81



ALMA partnership, Vlahakis et al., 2015, ApJ submitted

The lensed galaxy at redshift 3 SDP81



Rybak et al., 2015, MNRAS submitted

Why submm?
how to select protocluster candidates?

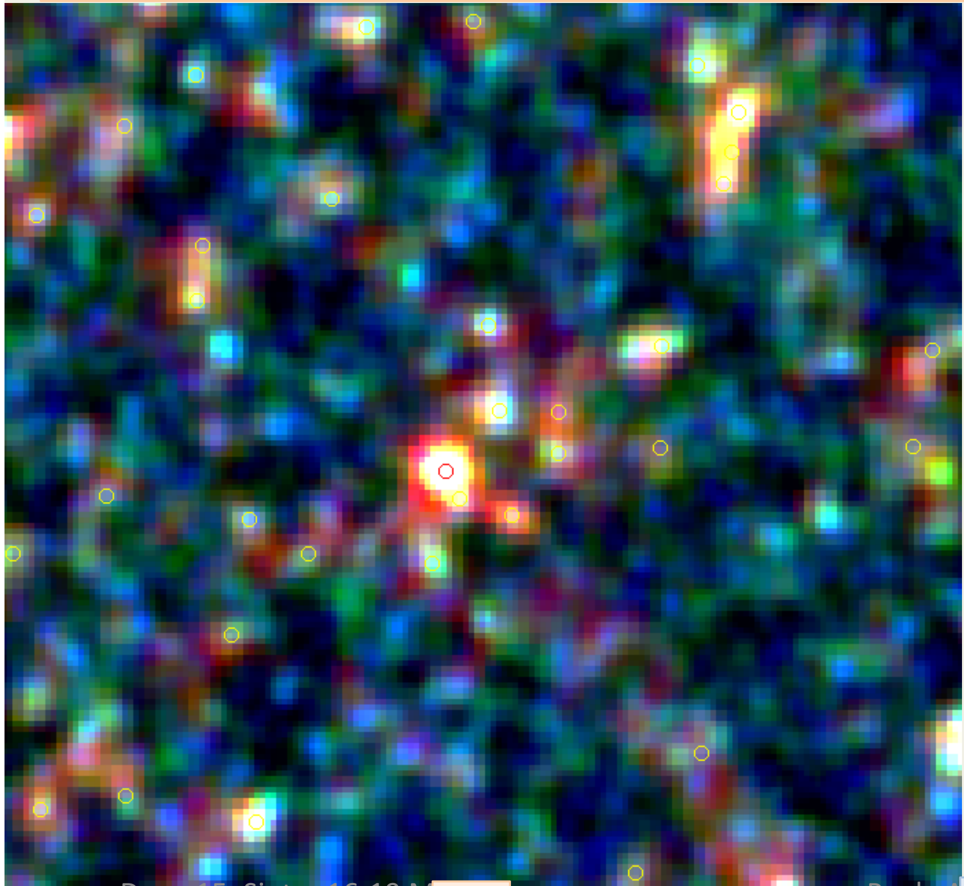
- Submm lensed galaxies as signspots
- Fields of lensed galaxy with sources overdensities of dusty galaxies
- Herschel Colours suggest high-z ($z \geq 2\text{-}3$)

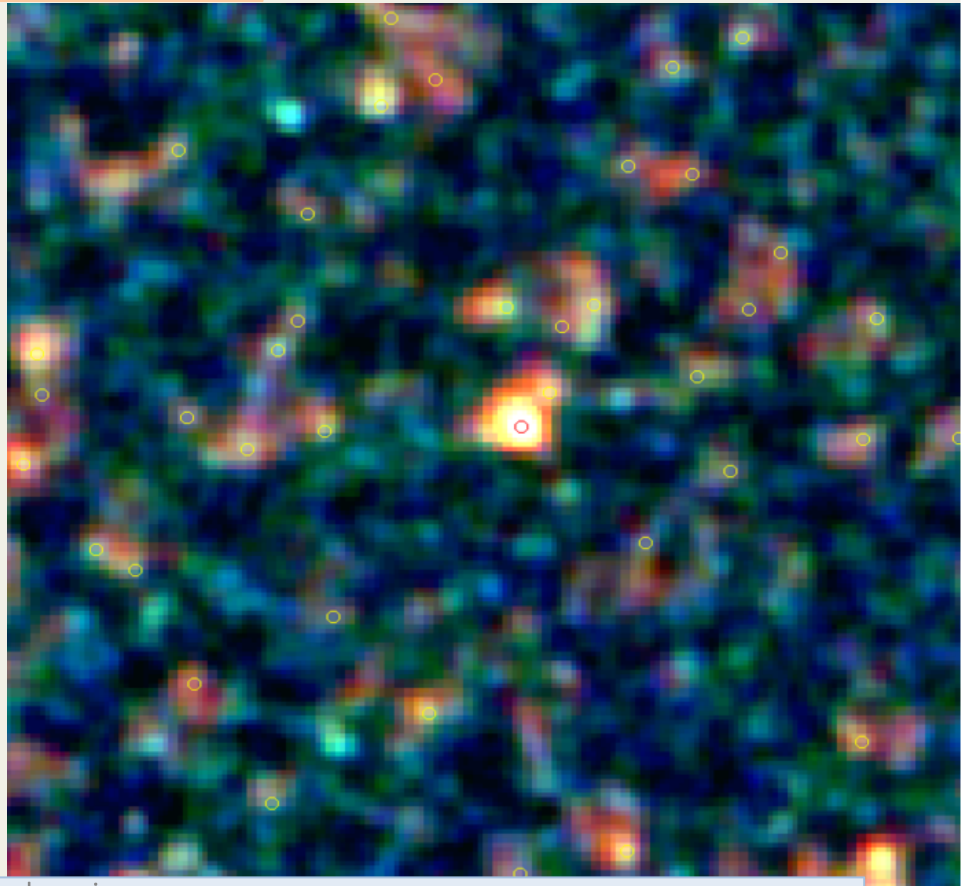
Overdensities in H-ATLAS fields

3 colour maps of the overdensity fields

candidate protoclusters around the lenses H-ATLAS J09+00 at z=3.04 and H-ATLAS J11-01 at z=3.12

Lenses: red circles, Herschel high-z sources: yellow circles

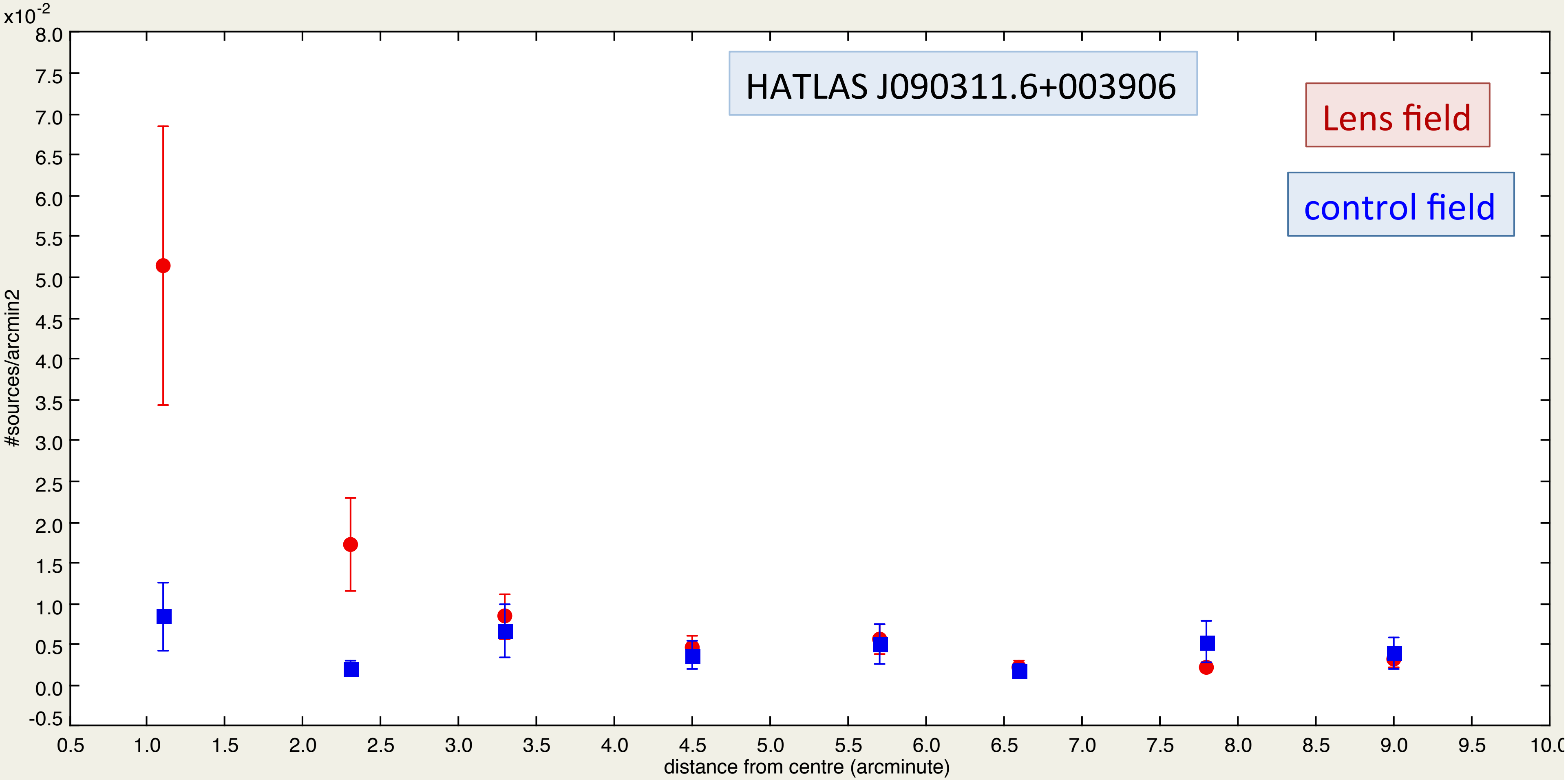




8'

Blue = 250μm Green=350μm Red=500μm

Surface density of sources in one of the targeted fields

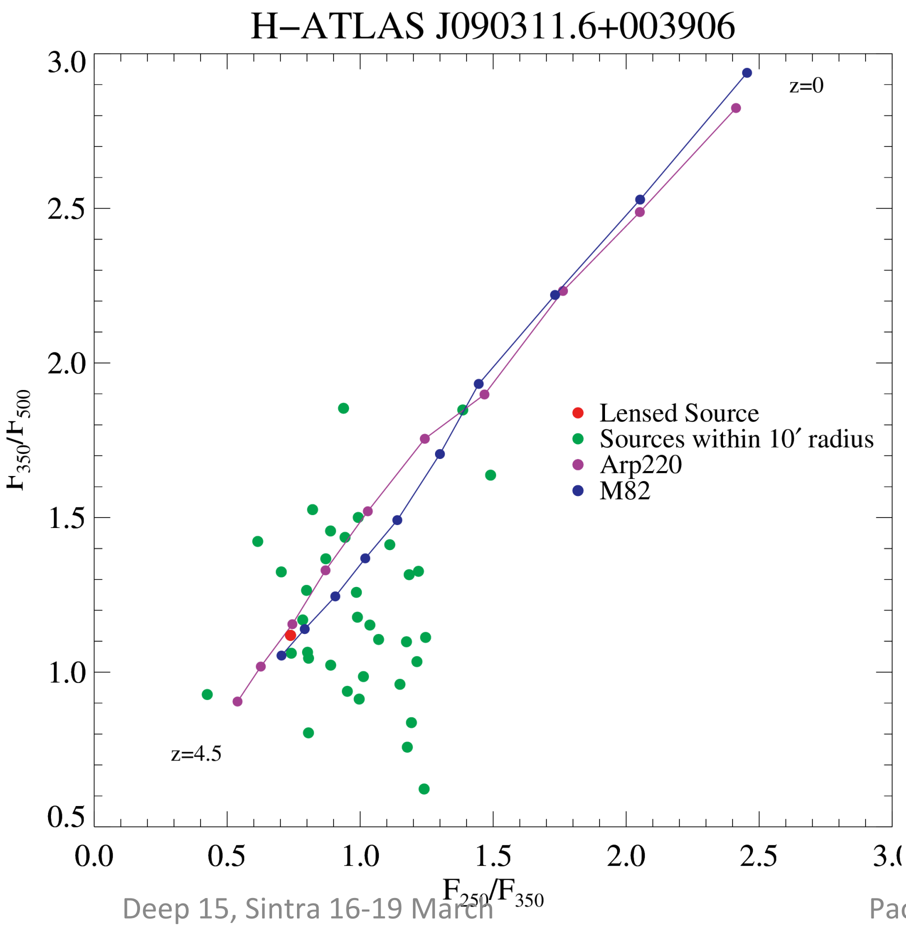


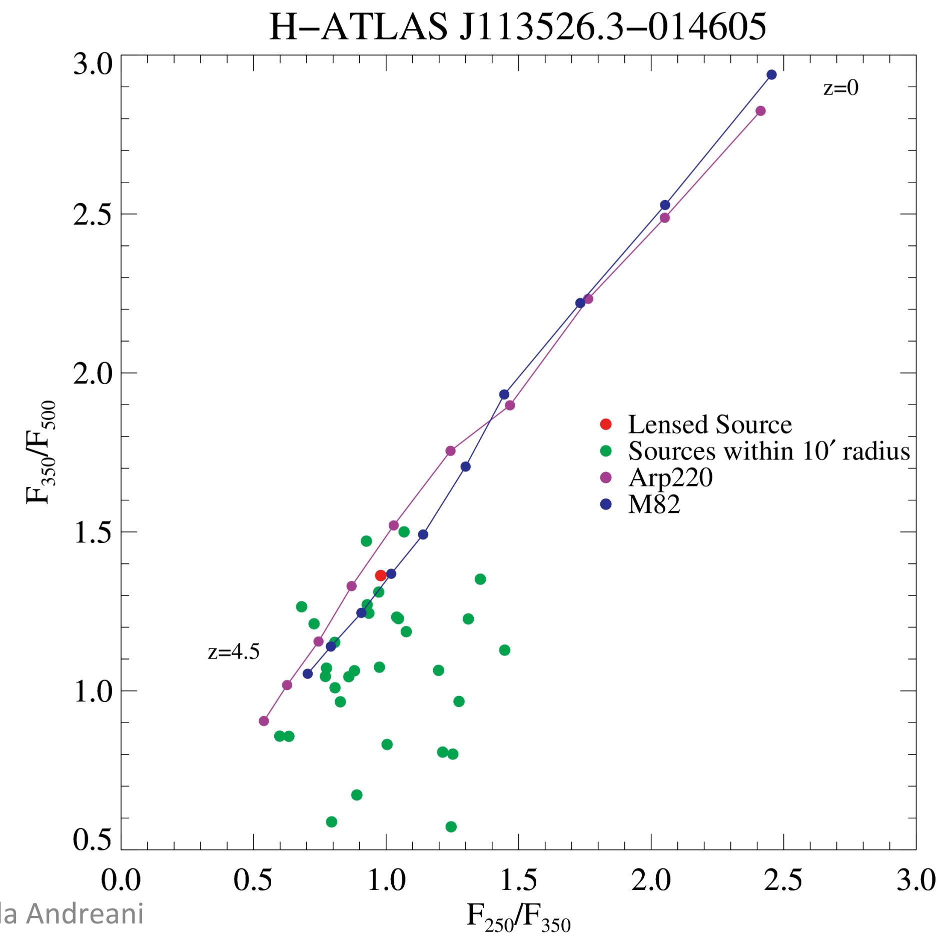
Number of sources in the overdensity field compared with a control field

Selecting candidates from col-col plots

SDP81: HATLAS J090311.6+003906

G12v2.43: HATLAS J113526.3-014605

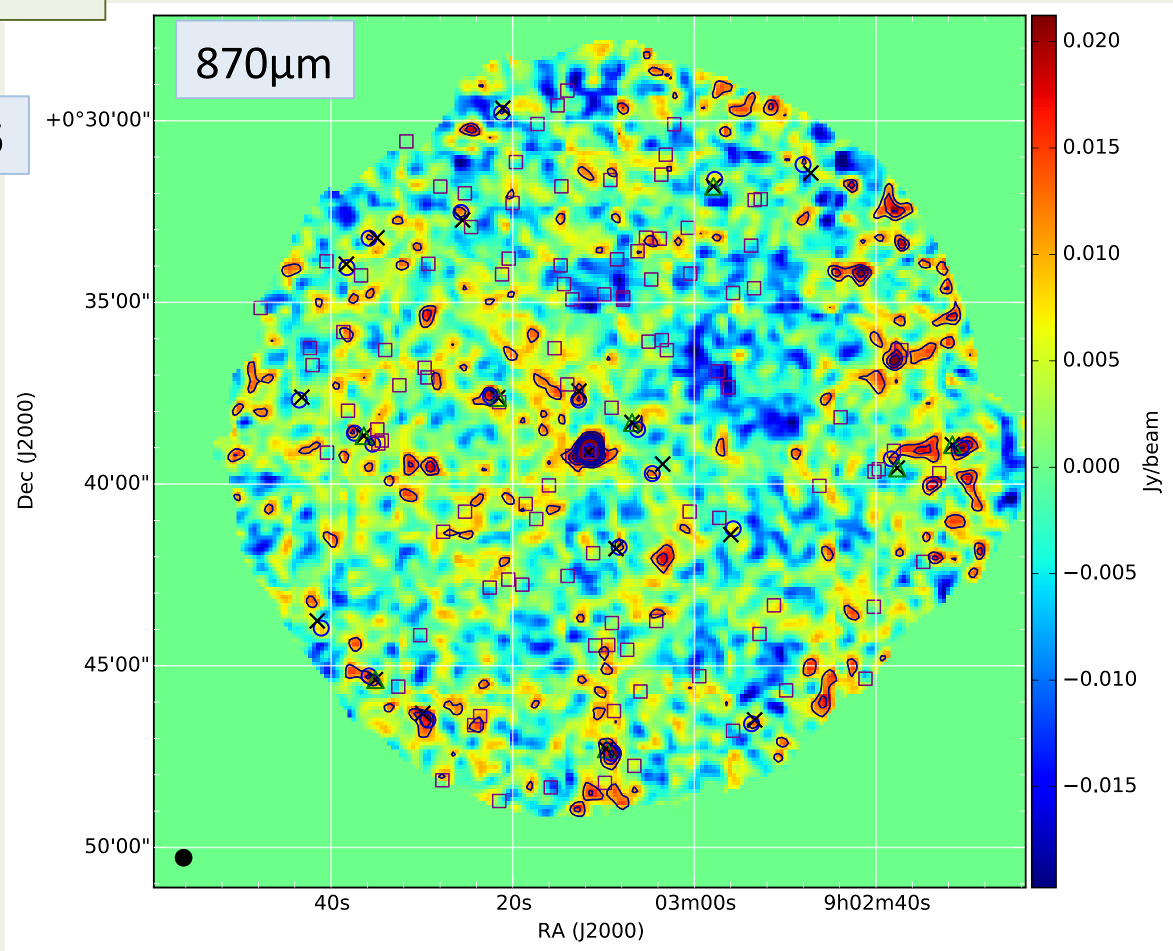




Follow-up APEX/LABOCA

SDP81

HATLAS J090311.6+003906



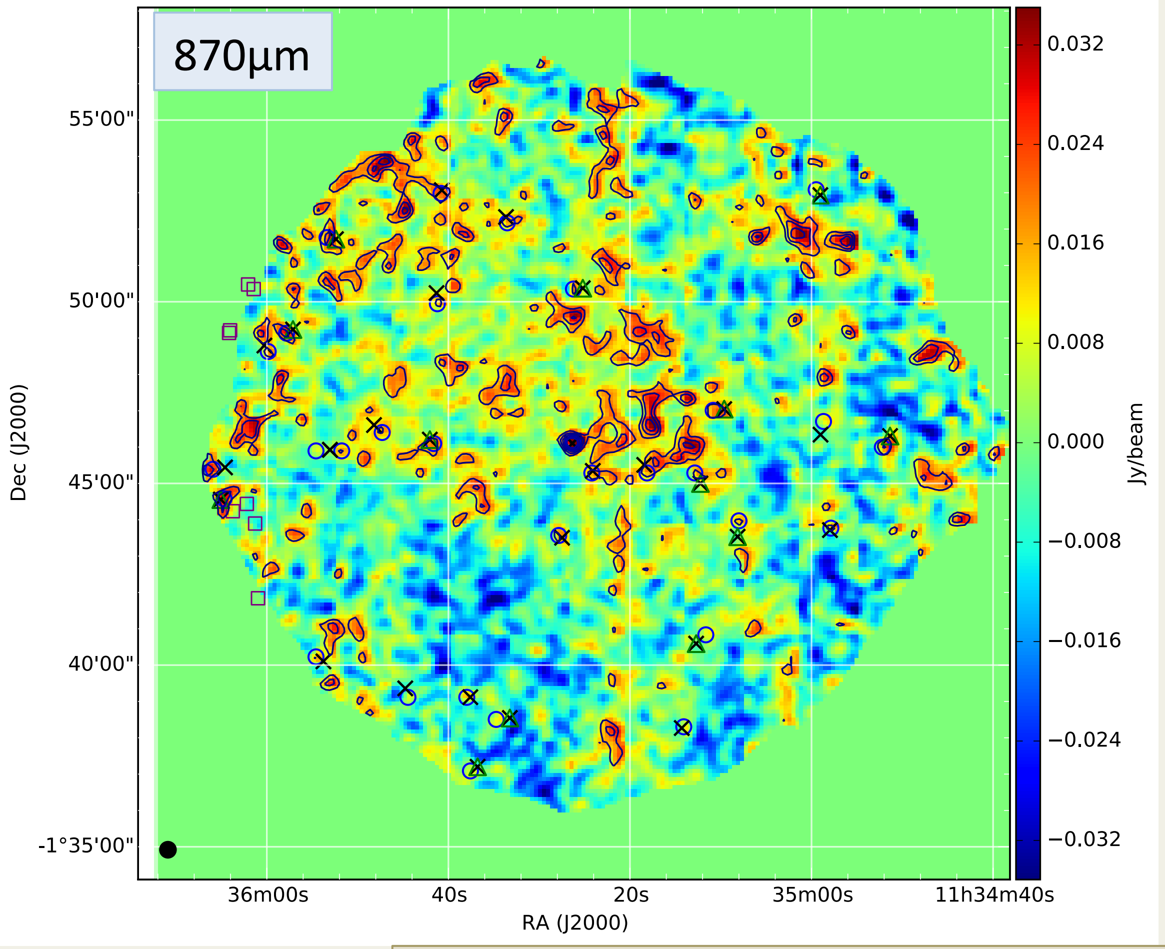
- O SPIRE
- □ GAMA
- × LABOCA

Retana-Montenegro, P.A., et al., in preparation

Follow-up APEX/LABOCA

G12v2.43

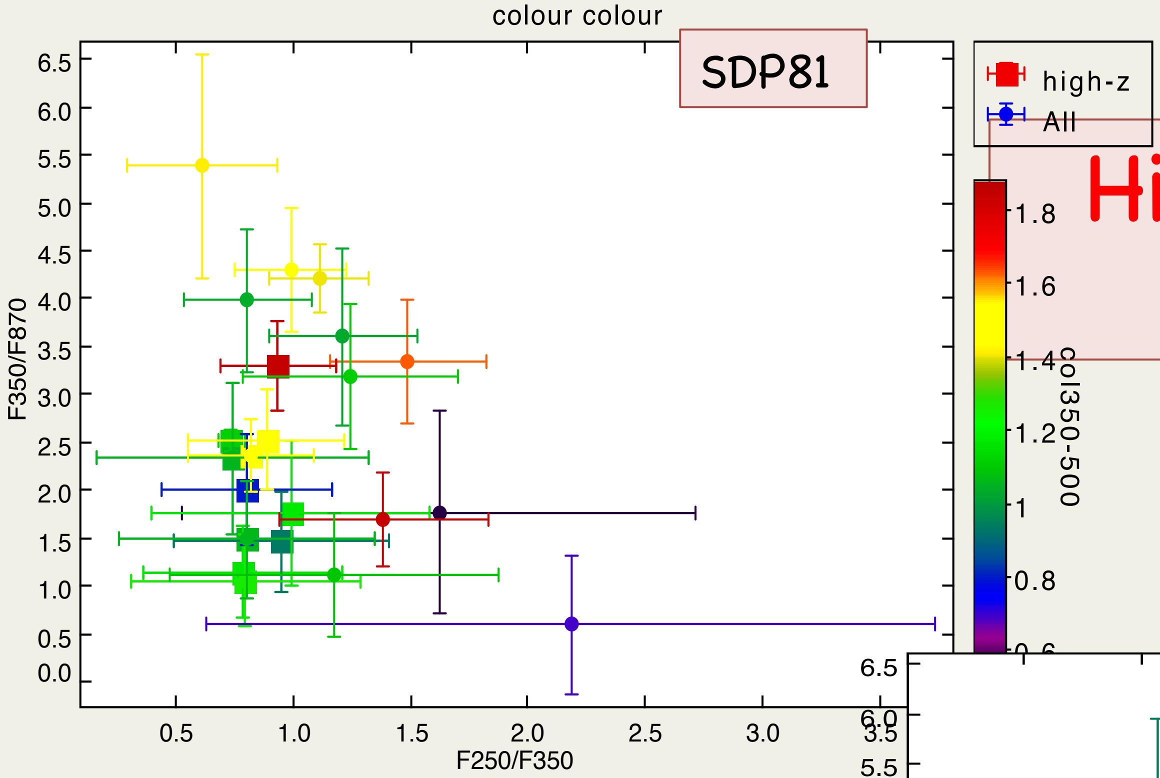
HATLAS J113526.3-014605

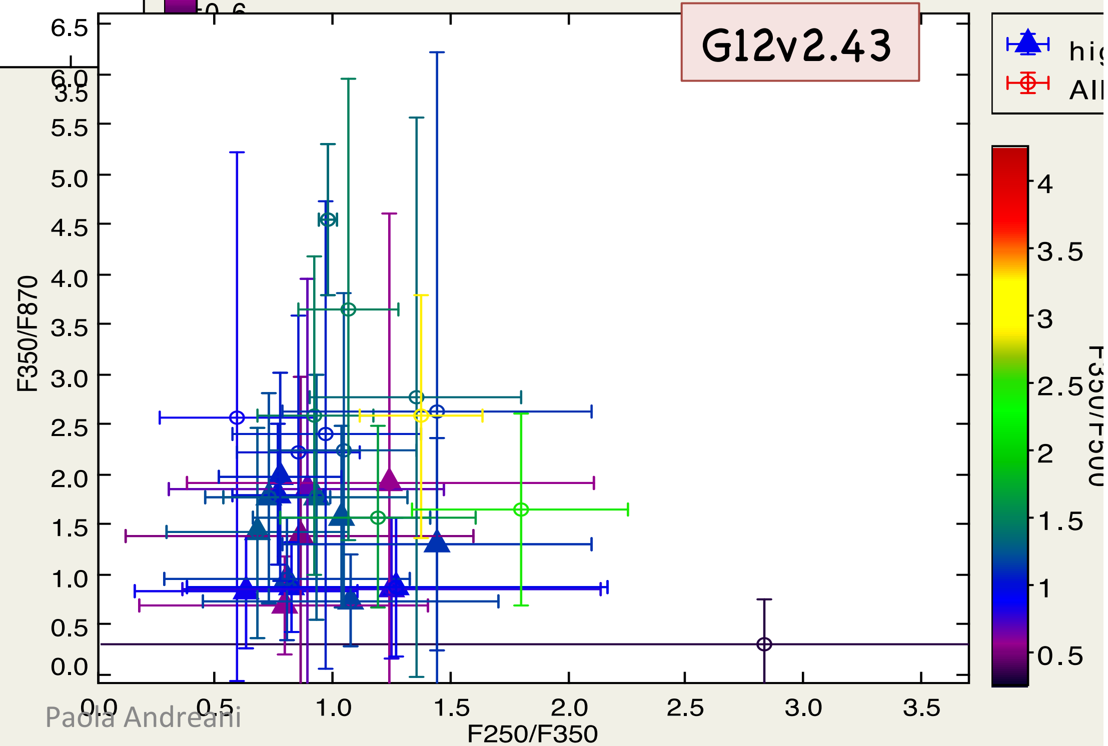


SPIRE
GAMA
LABOCA

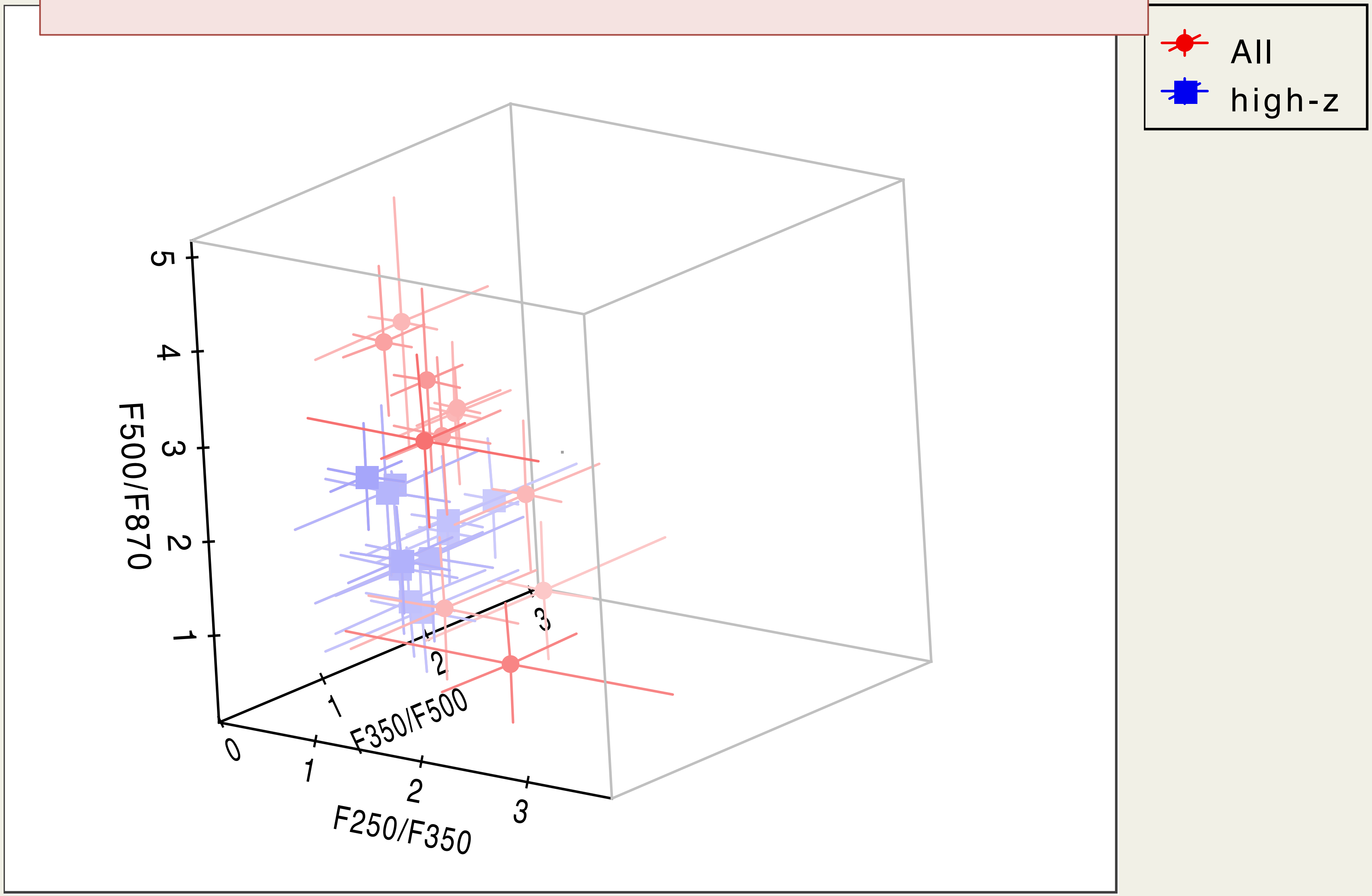
Retana-Montenegro, P.A., et al., in preparation

High-z candidate selection





A 3 D colour-colour plot



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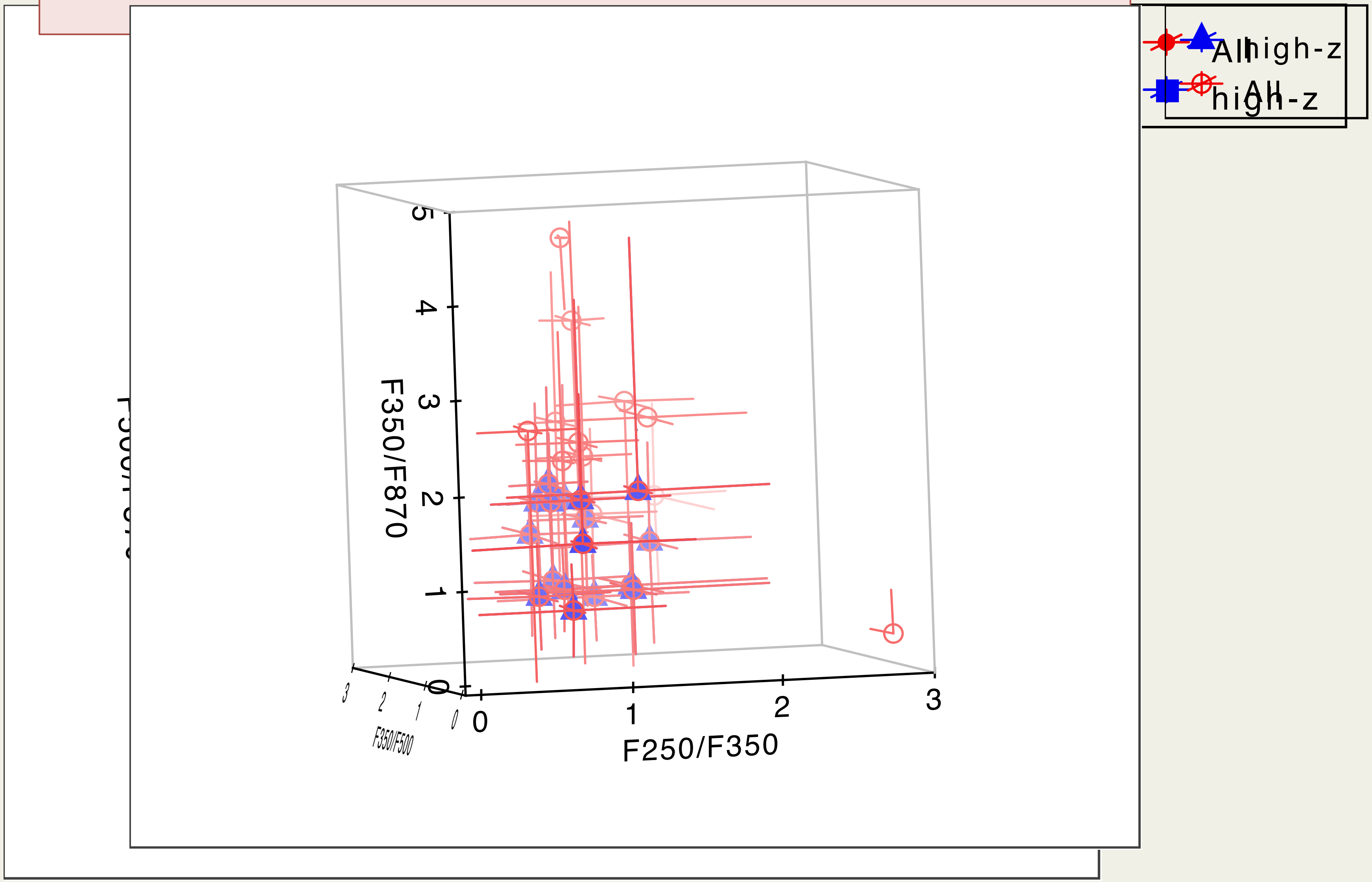

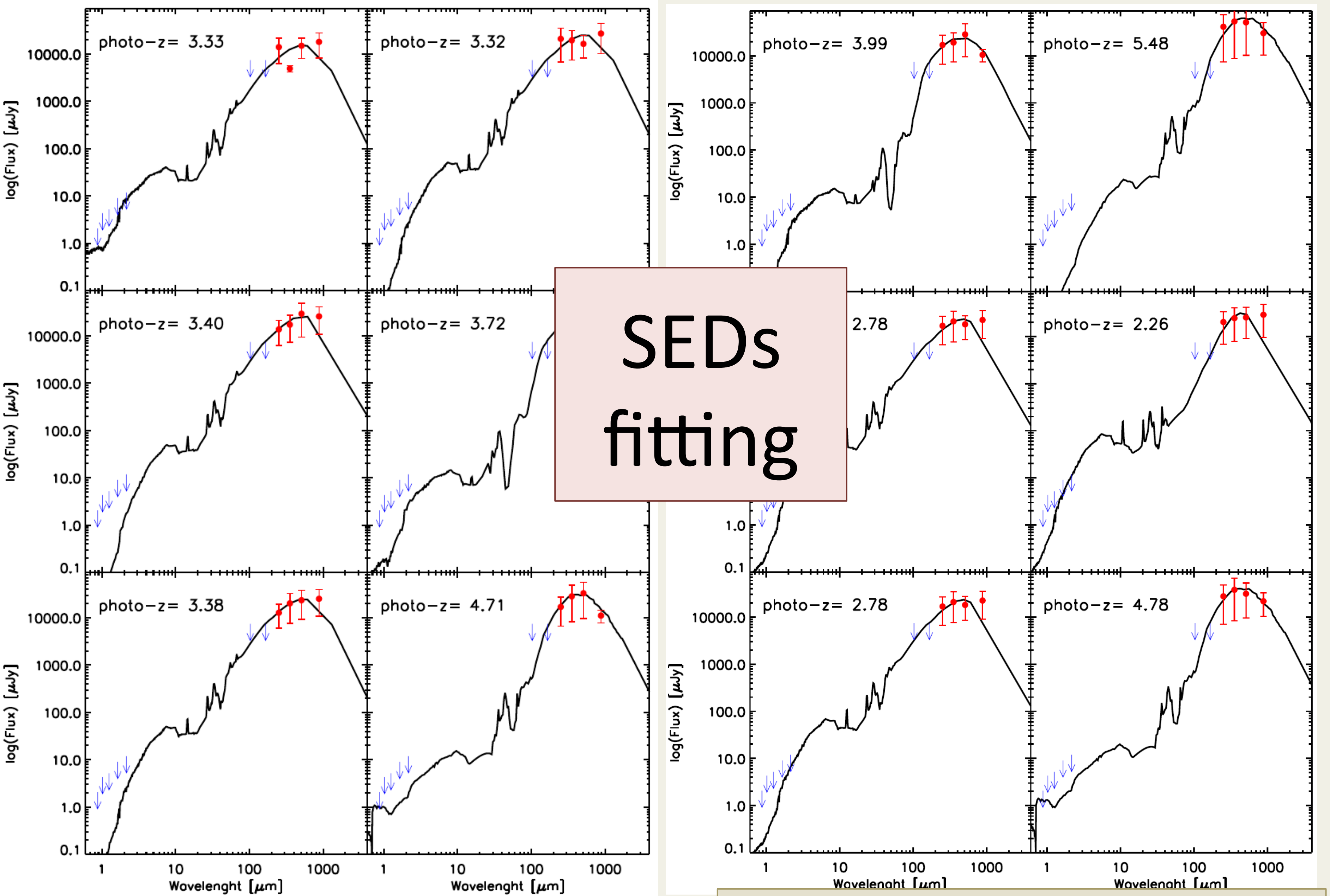

SEDs fitting

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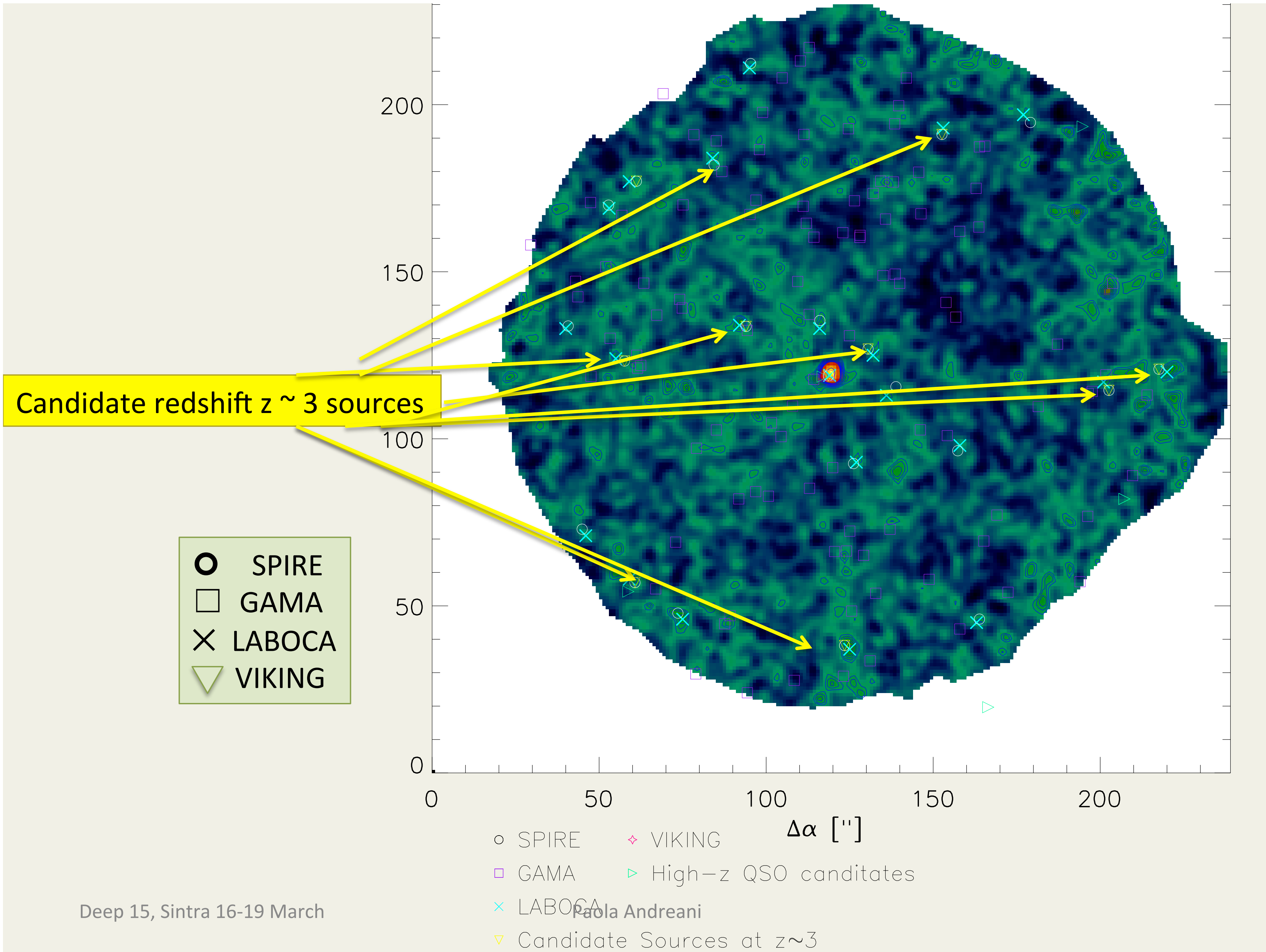
Candidate redshift z ~ 3 sources
SPIRE
GAMA
LABOCA
VIKING
200
150
100
50
0
0
50
100
150
200
Δα ['']
SPIRE
VIKING
GAMA
High−z QSO canditates
LABOCA
Candidate Sources at z~3

Value of the overdensity

$$\delta_{pc} = \frac{\rho_{pc} - \rho_{field}}{\rho_{field}} = 11$$

$$\rho_{pc} = \frac{Nobj}{\pi\, r^2_{com}\; l_{com}} = 2.4\; 10^{-4}$$

$$\rho_{field} = \frac{N_{SDP}}{A/3\,(l^3_{max} - l^3_{min})} = 2\; 10^{-5}$$

An overdensity of 11 means that the proto-cluster is likely not gravitationally bound but it is making its turnaround

see also Diener et al 2014

Evolution of this overdensity

$$1 + b\,\delta_m = \mathrm{I\,C\,I}\,(1+\delta_{pc})$$

Amblard et al. 2011, Berthemin et al. 2015

- b= bias (values from Herschel sources between 2.5-3.3)
- δ_m= true mass overdensity
- $C = V_{app}/V_{true} = 1+f-f(1+\delta)^{1/3} \sim 0.53$
- V_{app} = comoving volume in which measurements have been made
- δ_m= 2.55
- The linear overdensity δ_0 corresponding to δ_m=2.55:

$$\delta_0 \sim -1.35\,(1+\delta)^{-2/3} + 0.78785(1+\delta)^{-0.5866} - 1.12431\,(1+\delta)^{-1/2} + 1.68647 \sim 0.88$$

(true for spherical collapse, from Mo and White 1996)

This overdensity would evolve from z≈3 to z≈0

$\delta(z=0) = \delta_0\,(1+z) \approx 3.5 \gg \delta_c = 1.69$ (collapse threshold)

The mass of the dark halo could be estimated from its bias and z $\sigma(M,z) = \delta_c/\sqrt{\{(b-1)\,\delta_c + 1\}} \rightarrow 10^{12}\,M_\odot$

See also Steidel et al., 1998; Chapman et al 2008

Summary

- >1000 lenses in Herschel surveys
- Colour selection of candidate z>3 Herschel lenses' fields with overdensity of sources (roughly 10%)
- Follow-ups: preliminary results confirm the overdensity of sources at the same z as the lens
- These overdensities may evolve into today clusters, DM halo host ~ 10^{12} $M_{\odot}$
- multi-λ follow-ups needed
- More statistics + Estimate of the mass!

Questions?