ASTRODEEP

Unveiling the power of the deepest images of the Universe

WP3 Software tools : General overview

WP3: Software tools for deep photometry

exploitation of the deepest multi-frequency data from the major space and ground-based observatories

Objectives of WP3 :

softwares adapted to produce homogenized data products = uniqueness of Astrodeep

- Tune and test algorithms for object detection **DONE**
- Tune and test PSF-matching methods **DONE**
- Explore and test other techniques **DONE**

(matched aperture photometry, cross correlation, etc)

- Compare different recipes, quantify the differences **DONE**

Path :

→ start from existing softwares **Softwares tested, key features identified and implemented in single software for catalog production : TPHOT**

→ produce realistic mock images to test the softwares **DONE**

→ improve the softwares to optimize the catalogs **DONE**

(quality of the photometric catalogs and multi-wavelength associations)

→ lead to new generation of catalogs. **ONGOING**

3 regimes

exploitation of the deepest multi-frequency data from the major space and ground-based observatories

		GOODS North	EGS CANDELS	UDS	UDS CANDELS	COSMOS	COSMOS CANDELS	GOODS South	HUDFs	Frontier Fields
	Area / Wave.	150′²	150′²	1°²	150′²	1°²	150′²	150′²	15′²	
ALMA	1.3 mm								0.15mJy	
HERSCHEL	500μm	9 mJy	12.8 mJy	13.4 mJy	13.4 mJy	9.5 mJy	9.5 mJy	9 mJy	9 mJy	
	350μm	7.2 mJy	8.9 mJy	9.3 mJy	9.3 mJy	6.6 mJy	6.6 mJy	7.2 mJy	7.2 mJy	
	250μm	5.7 mJy	10.7 mJy	11.2 mJy	11.2 mJy	8.0 mJy	8.0 mJy	5.7 mJy	5.7 mJy	
	160μm	2.7 mJy				11 mJy	11 mJy	2.4 mJy	2.4 mJy	
	100μm	1.1 mJy	3.7 mJy	4.0 mJy	4.0 mJy	5 mJy	5 mJy	0.8 mJy	0.8 mJy	
	70 μm	2.4 mJy	3.5 mJy	18 mJy	18 mJy	10 mJy	10 mJy	3.1 mJy	3.1 mJy	
Spitzer	24 μm	21 mJy	50 mJy	230 mJy	230 mJy	60 mJy	60 mJy	20 mJy	20 mJy	
	16 μm	32 mJy						52 mJy	52 mJy	
	8 μm	1.7 mJy	4.8 mJy	10.2 mJy	10.2 mJy	17.3 mJy	17.3 mJy	1.7 mJy	1.7 mJy	
	5.8 μm	1.4 mJy	3.9 mJy	8.3 mJy	8.3 mJy	13.4 mJy	13.4 mJy	1.4 mJy	1.4 mJy	
	4.5 μm	0.2 mJy	0.6 mJy	1.2 mJy	1.2 mJy	2.0 mJy	2.0 mJy	0.2 mJy	0.2 mJy	26mag
	3.6 μm	0.1 mJy	0.3 mJy	0.6 mJy	0.6 mJy	1.1 mJy	1.1 mJy	0.1 mJy	0.1 mJy	26.6 mag
VLT/VISTA/ UKIDSS	2μm(K)	25.6	23.8	25.0	26.0	25.0	26.0	26.8	27.2	
HST-WFC3	1.6	27.8	26.7	---	26.7	---	26.7	27.8	29.9	
	1.4 (JW)								29.9	28.8
	1.2 μm(J)	27.8	26.7	---	26.7	---	26.7	27.8	29.9	28.8
	1 μm(Y)	28.0	---	---	---	---	---	28.0	30.0	28.8
VLT/VIS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26.7	
HST-ACS	0.85μm(	27.6	---	---	---	---	---	27.6	29.4	28.8
	0.75	28.7	27.8	---	27.8	27.2	27.8	28.7	29.9	
	0.6	28.2	27.9	---	27.9	27.2	27.9	28.2	30.1	28.9
	0.45μm(B)	28.2	---	---	---	---	---	28.2	29.7	28.9
CFHT/VLT LBT	0.36μm(U)	28.2	27.0	27.5	27.5	27.7	27.7	28.0	28.0	
XMM	2-10 keV	1.5×10^{-15}	---	3×10^{-15}	3×10^{-15}	3×10^{-15}	3×10^{-15}	4×10^{-16}	4×10^{-16}	
XMM	[illegible] keV	4×10^{-1}	---	1×10^{-14}	1×10^{-14}	1×10^{-14}	1×10^{-14}	7×10^{-16}	7×10^{-16}	
Chandra	[illegible]	[illegible]	[illegible] erg cm² s⁻¹	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

mid to far IR

Optical to near IR

X

Unresolved sources, uncertain counterparts, confusion

Resolved sources, morphology, segmentation map

Unresolved sources, uncertain counterparts

ASTRODEEP WP3 Software tools

Goals:

- Single code to produce catalogs of resolved (HST,…) and unresolved (Herschel,…) catalogs
  - generic, allowing others to reproduce the analysis
  - consistency between all wavelengths, single code for all wavelengths (for Herschel & Spitzer: Wang et al., TBS)
  - robust indicators of reliability
- Distribution & publication of code (Merlin et al., submitted)
- Production of realistic simulations to test the code (Schreiber et al. TBS)

ASTRODEEP WP3 Software tools
The products

1. T-PHOT a new public software [PSF-matched photometry starting from a list of “priors”]
   public (is currently used by more than 10 different teams also outside ASTRODEEP)
   a paper describing T-PHOT has already been submitted to A&A (Merlin et al. submitted)

2. A recipe to analyse Far-IR images: applied to Herschel and SCUBA2 (Wang et al. TBS)

3. A recipe to analyse X-ray images: modified existing software (originally designed for XMM data) = prior photometry in a way conceptually similar to T-PHOT, but allowing for the spatially variable PSF that is typical of Chandra images. (Cappelluti et al. TBS)

4. A complete tool for simulated images. We have developed a new code (GENCAT) that allowed us to produce very realistic simulated images at (practically) any wavelength (Schreiber et al. TBS)

→ set of simulated images and catalogs
→ software and recipe for catalog extraction from the real and mock images
→ 4 papers for each one of the products

Astronomy & Astrophysics manuscript no. tphot˙1˙working
May 12, 2015
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T-PHOT⋆: a new code for PSF-matched, prior-based, multiwavelength extragalactic deconfusion photometry

E. Merlin[1], A. Fontana[1], H. C. Ferguson[2], J. S. Dunlop[3], D. Elbaz[4], N. Bourne[3], V. A. Bruce[3], F. Buitrago[3,10,11], M. Castellano[1], C. Schreiber[4], A. Grazian[1], R. J. McLure[3], K. Okumura[4], X. Shu[4,8], T. Wang[4,9], R. Amorín[1], N. Cappelluti[5], A. Comastri[5], S. Derriere[6], S. M. Faber[7], and P. Santini[1]

ASTRODEEP: PRIOR SOURCE EXTRACTION IN CONFUSION-LIMITED ASTRONOMICAL IMAGES

T. WANG AND THE ASTRODEEP CONSORTIUM

Draft version May 12, 2015

CHANDRA COUNTERPARTS OF CANDELS GOODS-S SOURCES.

N. Cappelluti[1], A. Comastri[1], A. Fontana[2], R. Amorín[2], A. Grazian[2], M. J. Michałowski[4], C. Schreiber [3], and F. Vito [1]

Simulating the observable Universe from the UV to the FIR using empirical prescriptions

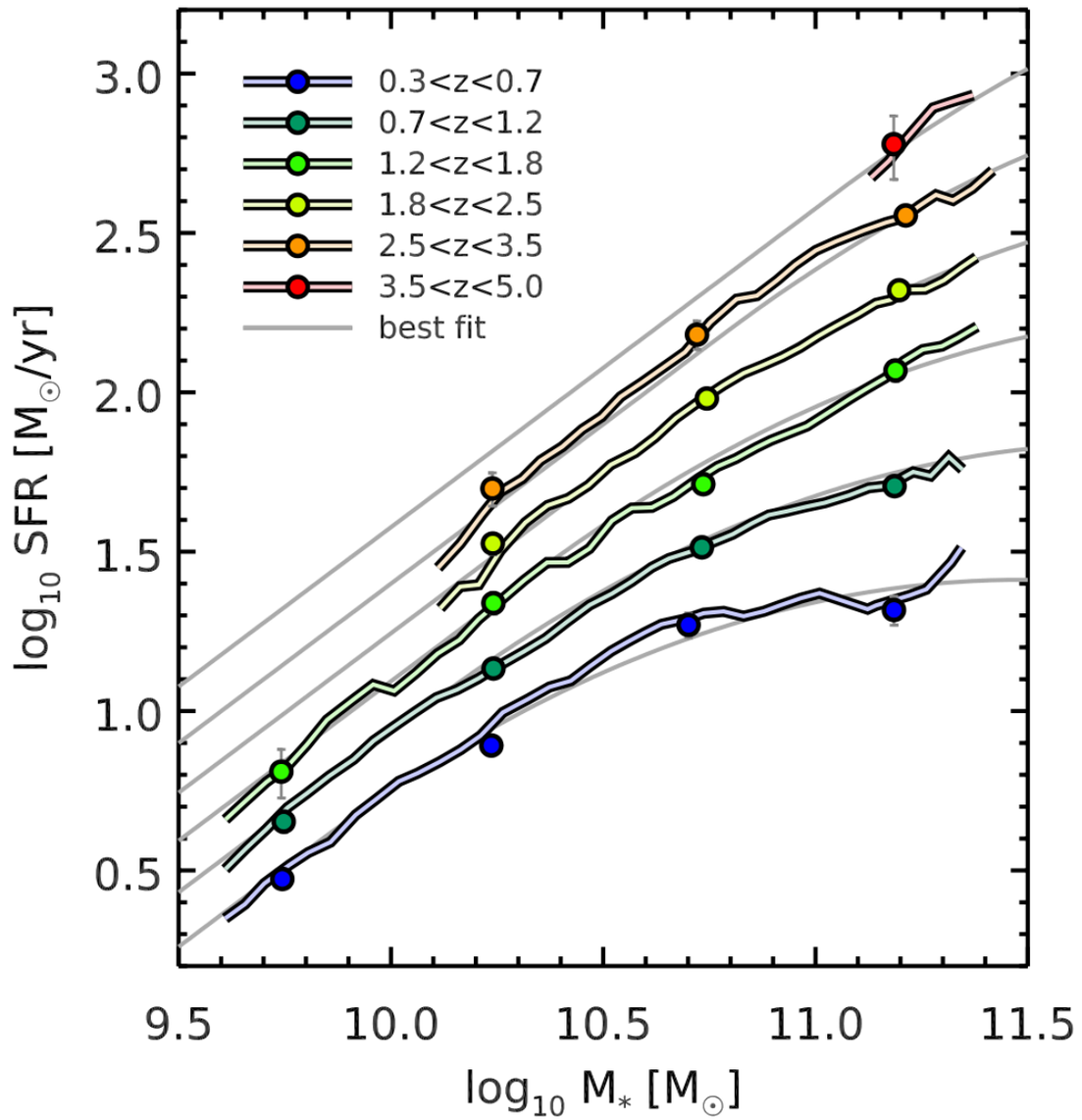
C. Schreiber[1] and the ASTRODEEP collaboration

→ set of simulated images and catalogs

→ software and recipe for catalog extraction from the real and mock images

→ 4 papers for each one of the products

A tool to **gen**erate simulated **cat**alogs (GENCAT, Schreiber +2015b)



A&A 575, A74 (2015)
DOI: 10.1051/0004-6361/201425017
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Astronomy & Astrophysics

The *Herschel*⋆ view of the dominant mode of galaxy growth from $z = 4$ to the present day⋆⋆

C. Schreiber[1], M. Pannella[1,2], D. Elbaz[1], M. Béthermin[1], H. Inami[3], M. Dickinson[3], B. Magnelli[4,5], T. Wang[1,6], H. Aussel[1], E. Daddi[1], S. Juneau[1], X. Shu[1], M. T. Sargent[1,7], V. Buat[8], S. M. Faber[9], H. C. Ferguson[10], M. Giavalisco[11], A. M. Koekemoer[10], G. Magdis[12,13], G. E. Morrison[14,15], C. Papovich[16], P. Santini[17], and D. Scott[18]

A tool to **gen**erate simulated **cat**alogs
(GENCAT)

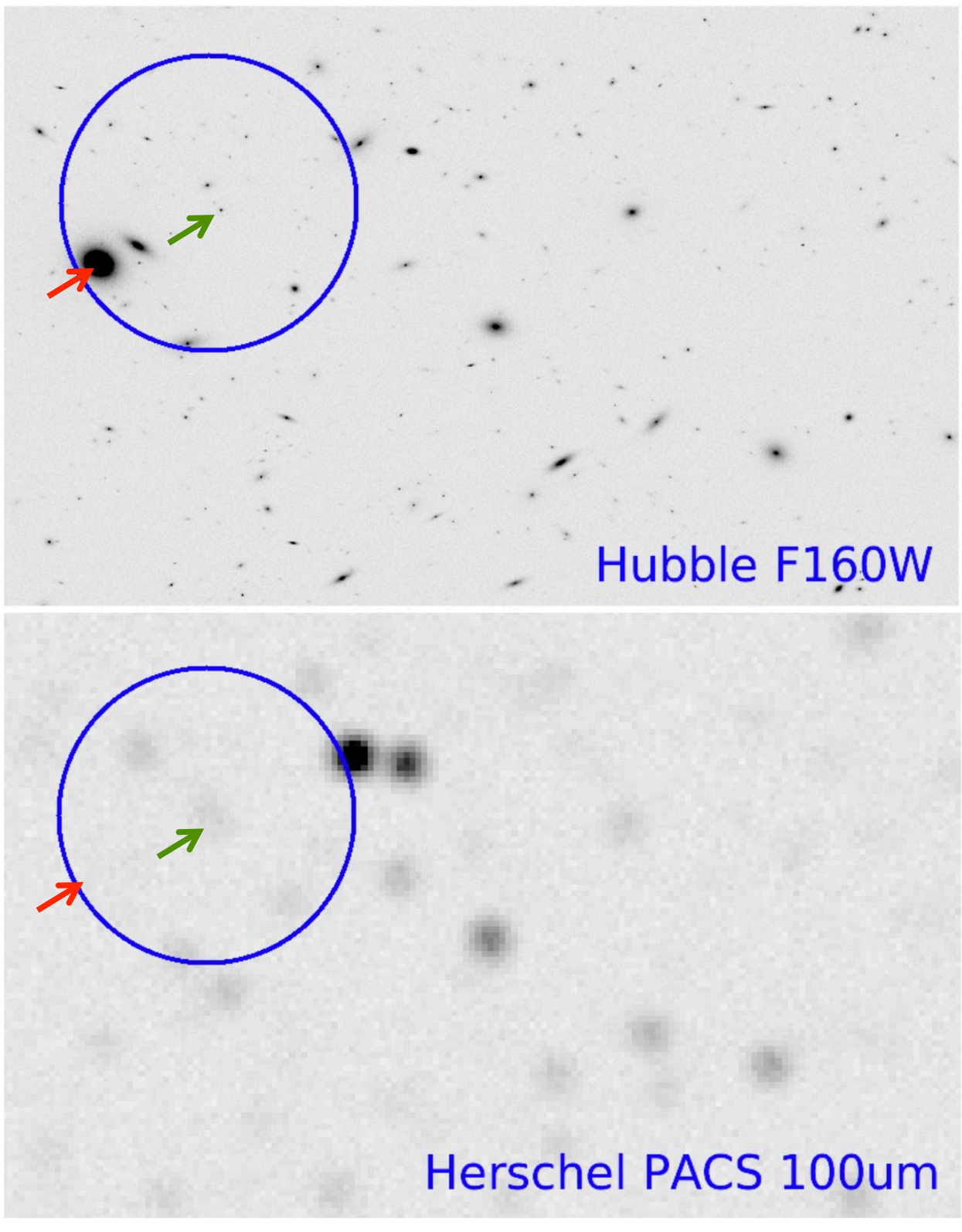
simulated galaxy catalog : X-ray – UV - opt - NIR – FIR - SMM

observed M* distribution vs z for active & passive galaxies → 104 000 galaxies

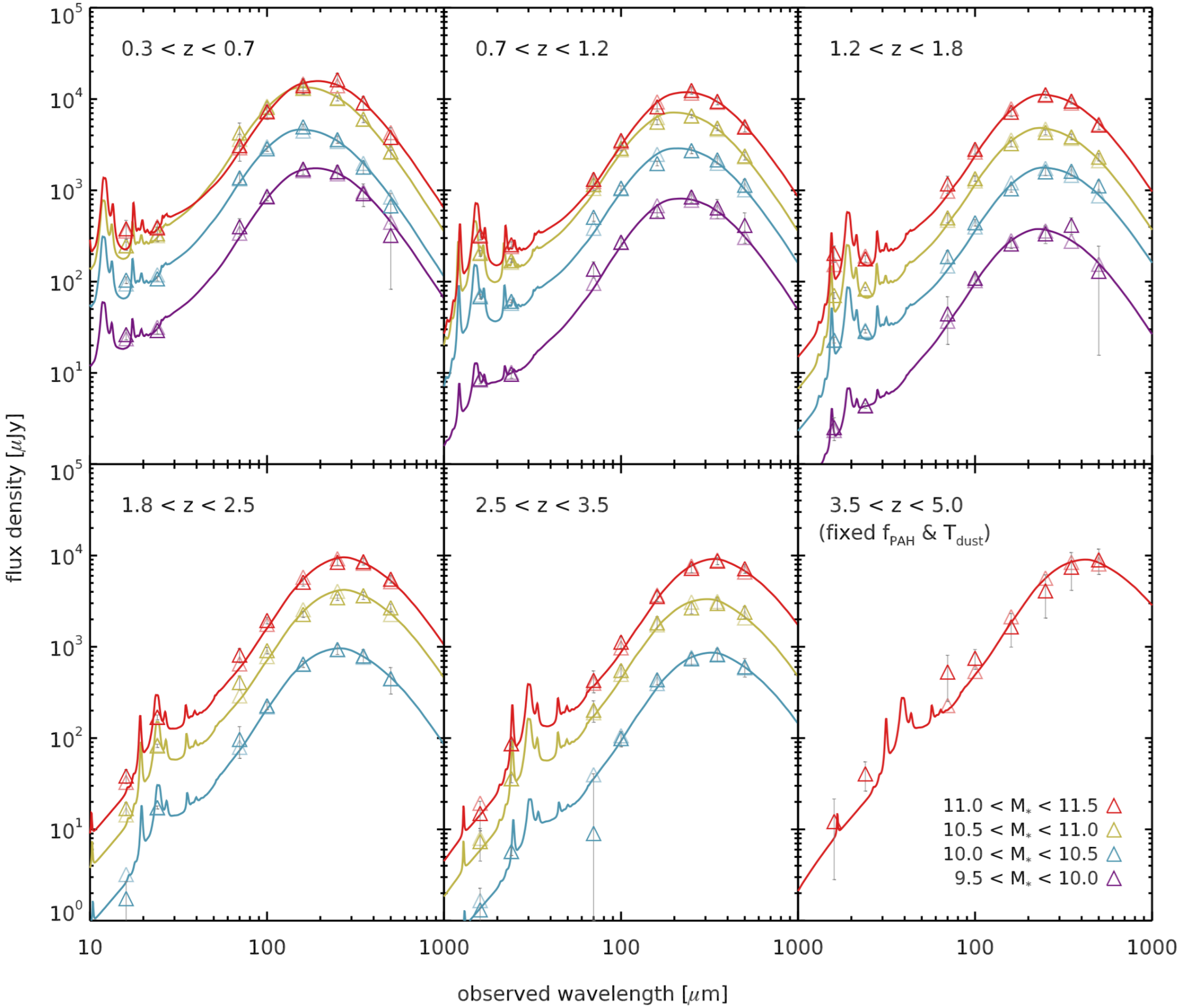
- **morphology** : bulge (de Vaucouleur, Sérsic n = 4) + disk (exponential, n = 1)
- **SFR** : from SFR – M* + fraction of starbursts + dispersion
- **attenuation**: IRX ≡ L_{IR}/L_{UV} observed in *Herschel* stacks
- **optical colors**: start from UVJ active/passive + observed average rest-frame SED for each UVJ bin → **850 reference SEDs (M*,z) from UV to NIR**
- **FIR SEDs** from observed stacks in (M*, z)
- **X-ray luminosity from $L_{IR} – L_X$ for SF**(Basu-Zych 2013)
- **Clustering + blur z to mimick zphots**

→ mock catalog :
104 000 galaxies in 17'x17' ; 90% complete down to H = 29, z = 0.01 - 6.
min (M*)= $5\times10^4 M_\odot$ at z=0.01 / $7\times10^6 M_\odot$ at z=1 / $10^8 M_\odot$ at z=4

A tool to **gen**erate simulated **cat**alogs (GENCAT)



A tool to **gen**erate simulated **cat**alogs (GENCAT)



normalized counts

16μm
12μJy
24μm
20μJy
70μm
1.0mJy
100μm
0.8mJy
160μm
1.7mJy
250μm
5.7mJy
350μm
7.2mJy
500μm
9.0mJy

median subtracted pixel value [mJy/beam]

16μm (x0.2) 24μm (x0.6) 70μm (x0.3) 100μm (x0.5) 160μm (x1) 250μm (x2) 350μm (x6) 500μm (x20) 1.2mm (x1)

differential counts [1/dex/deg^2]

GOODS-South
mock catalog

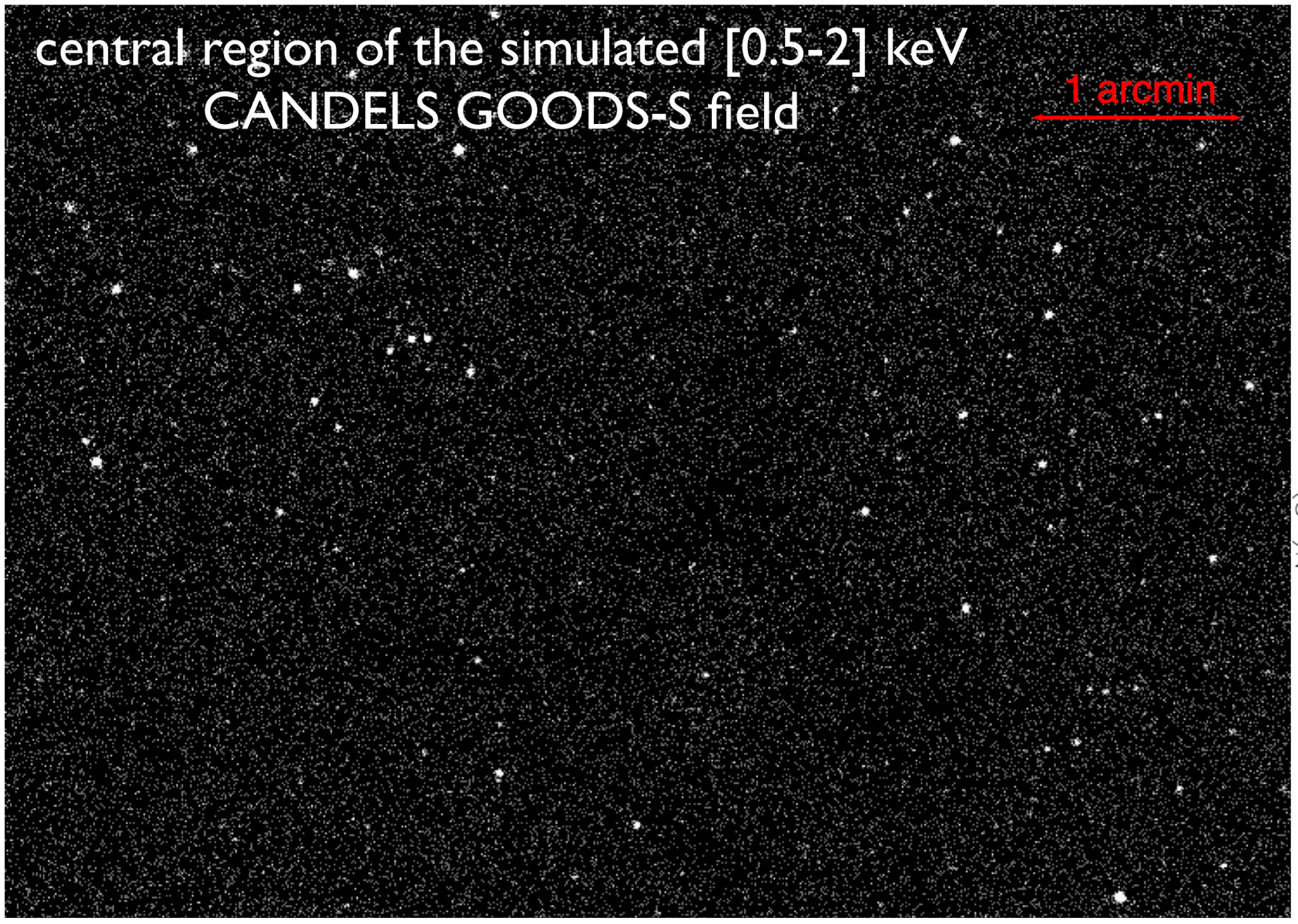
Ono+14
Hatsukade+11
mock catalog

flux [mJy]

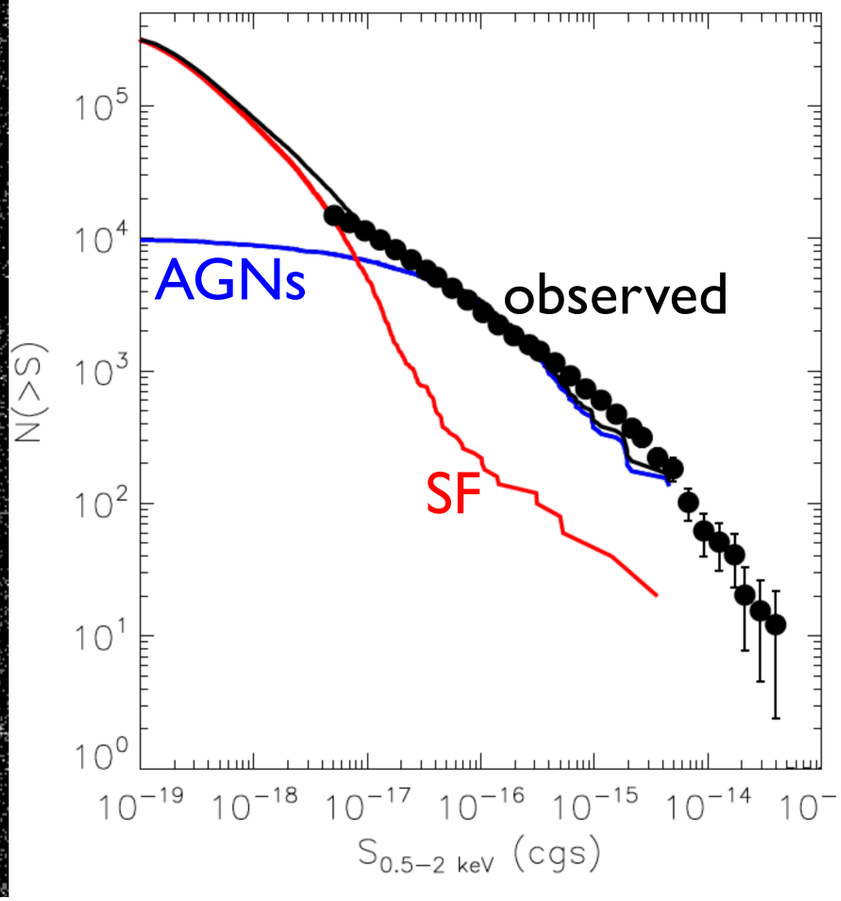
flux [mJy]

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X-ray for AGNs from observed logN-logS



Astronomy & Astrophysics manuscript no. tphot˙1˙working
May 12, 2015
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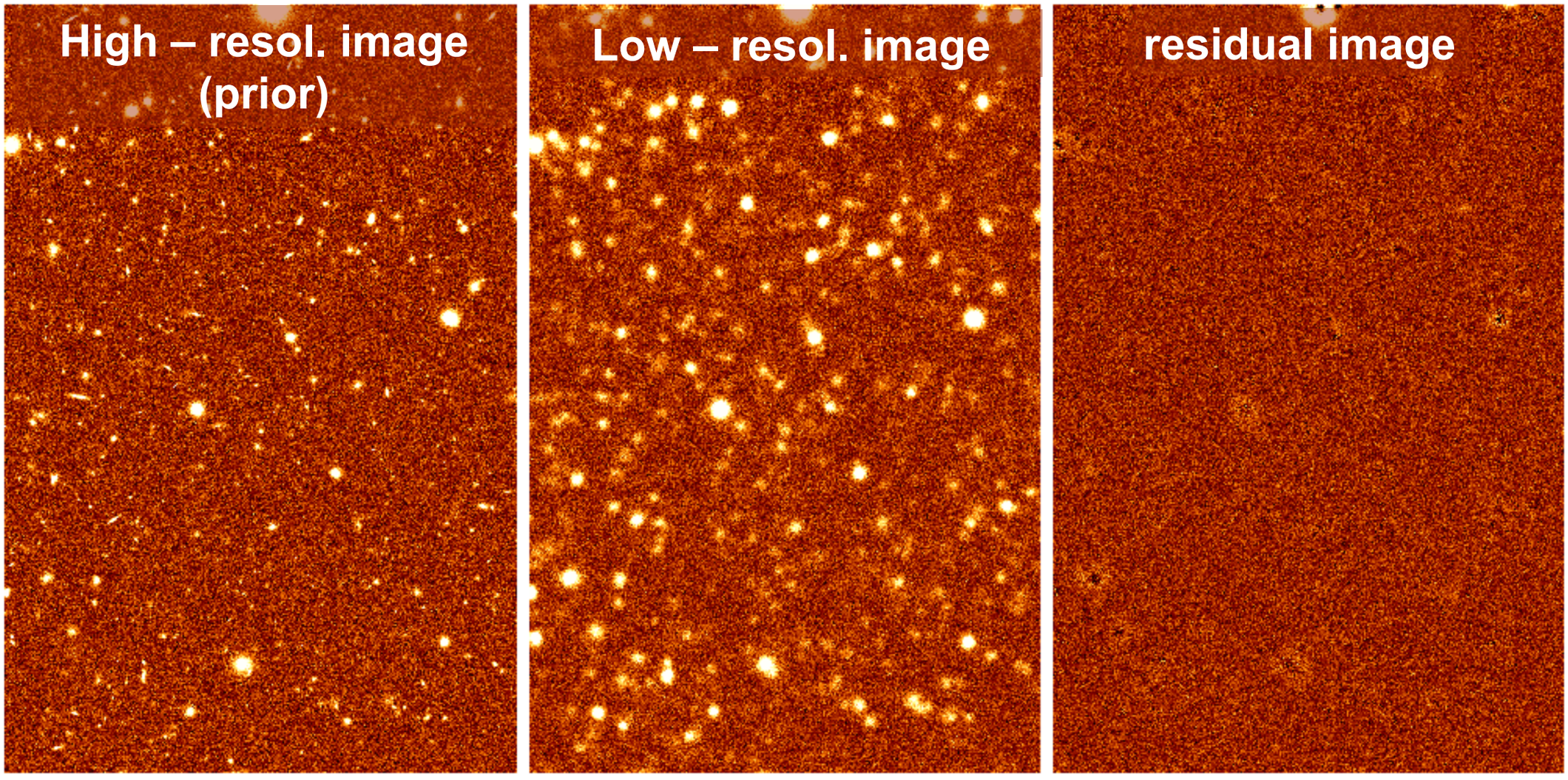
T-PHOT*: a new code for PSF-matched, prior-based, multiwavelength extragalactic deconfusion photometry

E. Merlin[1], A. Fontana[1], H. C. Ferguson[2], J. S. Dunlop[3], D. Elbaz[4], N. Bourne[3], V. A. Bruce[3], F. Buitrago[3,10,11], M. Castellano[1], C. Schreiber[4], A. Grazian[1], R. J. McLure[3], K. Okumura[4], X. Shu[4,8], T. Wang[4,9], R. Amorín[1], N. Cappelluti[5], A. Comastri[5], S. Derriere[6], S. M. Faber[7], and P. Santini[1]

- HST to NIR and Spitzer IRAC images : high-resolution priors or 2-d profiles
- H-band priors → Spitzer IRAC → Spitzer MIPS → Herschel

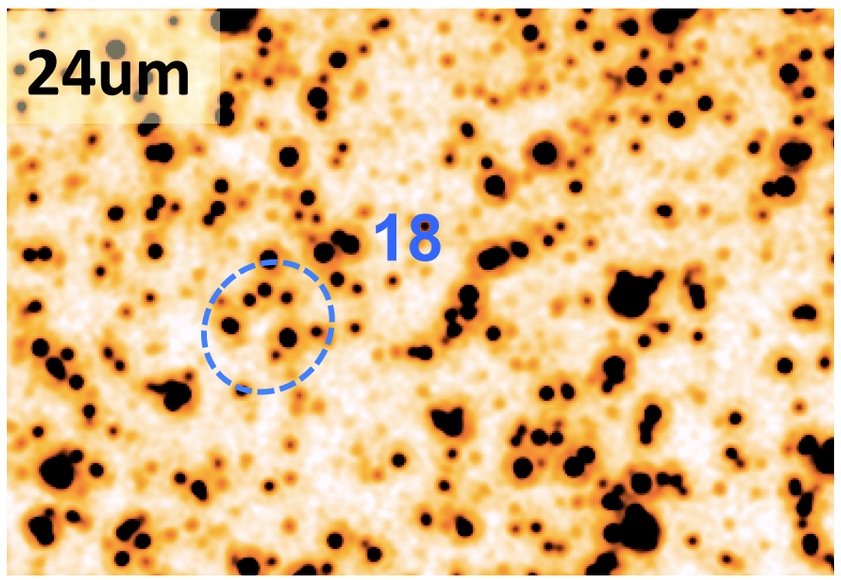
Noise on photometry:

- covariance noise → photometric uncertainty due to confusion / noise in residual map

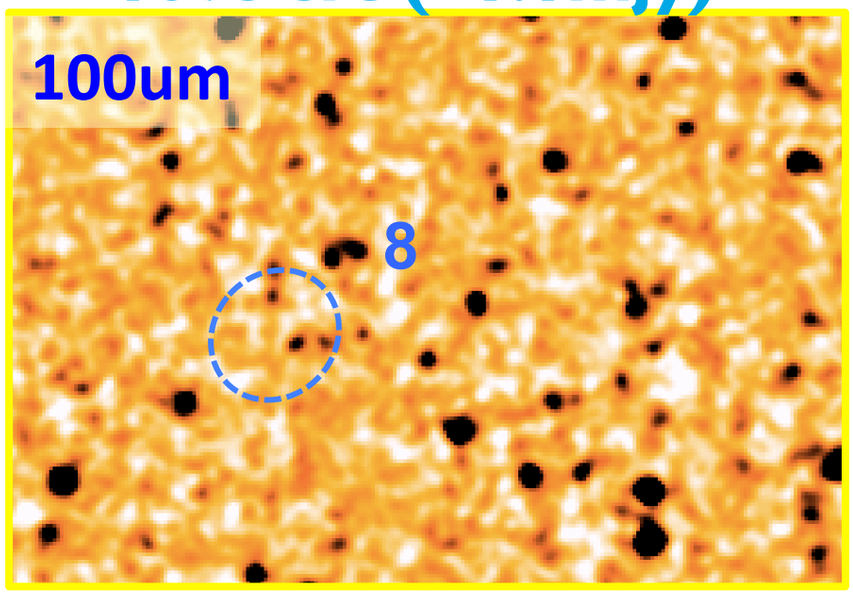


FWHM=	6.7"	11"	18.1"	24.9"	36.9"
λ (μm)=	100	160	250	350	500

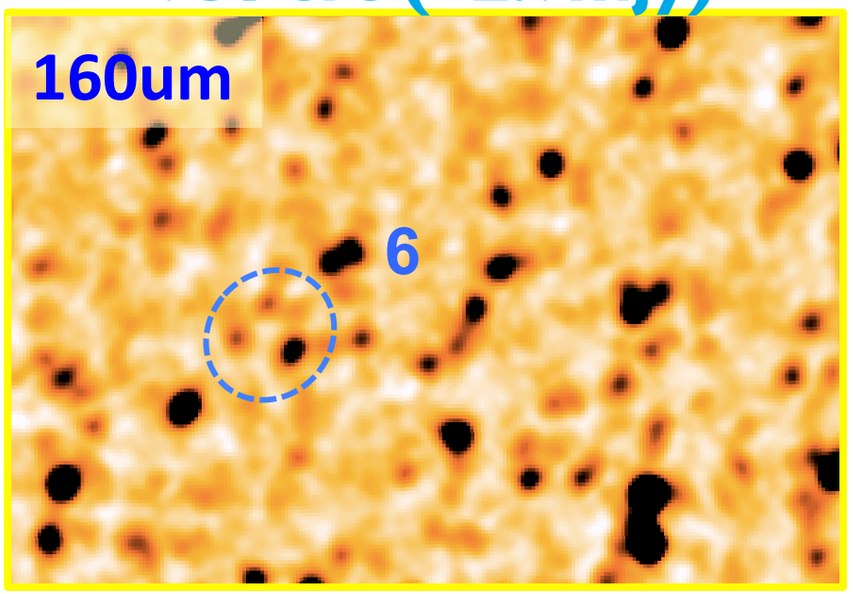
2575 (>21μJy) 7.5'x6.5'



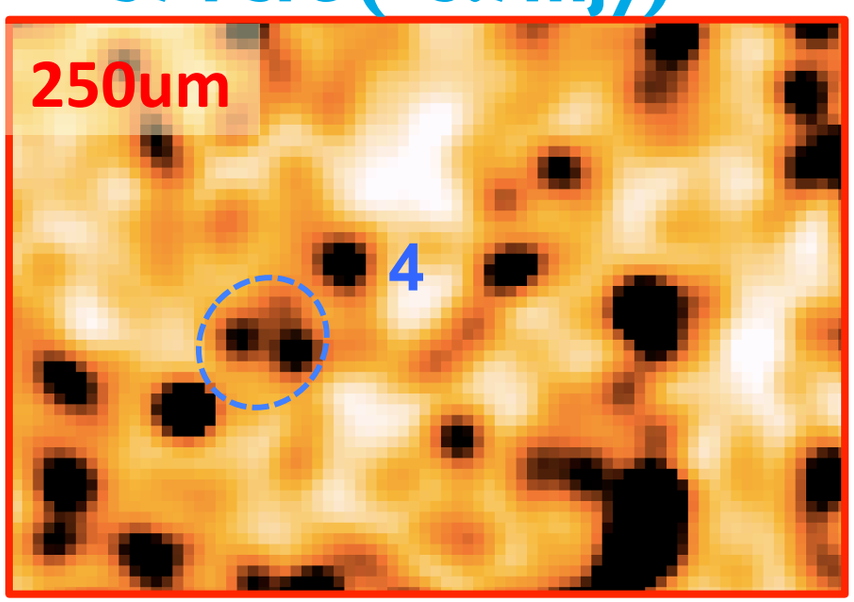
1095 src (>1.1mjy)



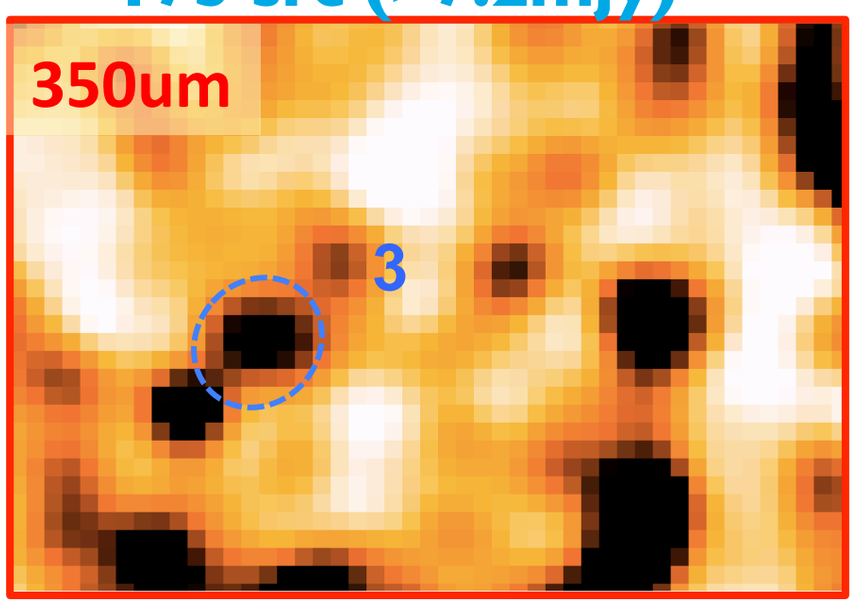
781 src (>2.7mjy)



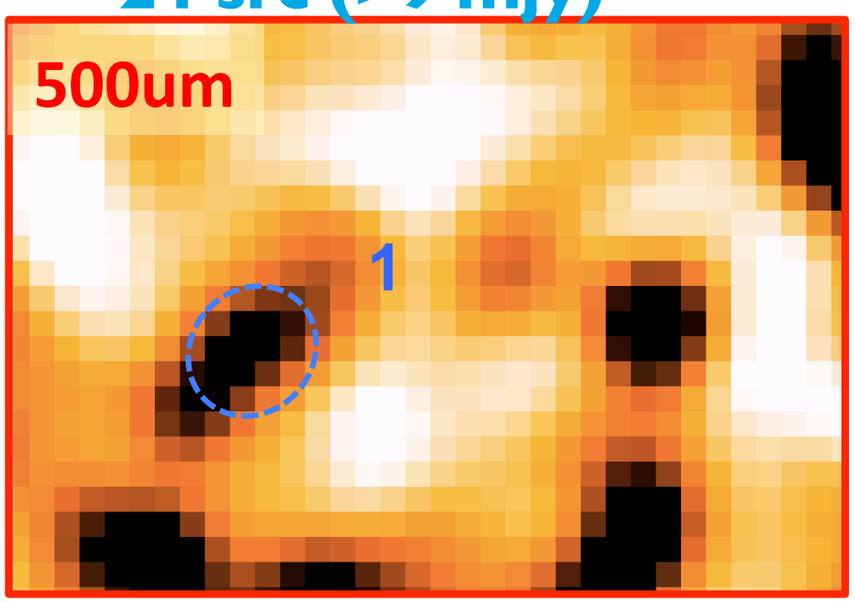
374 src (>5.7mjy)



173 src (>7.2mjy)

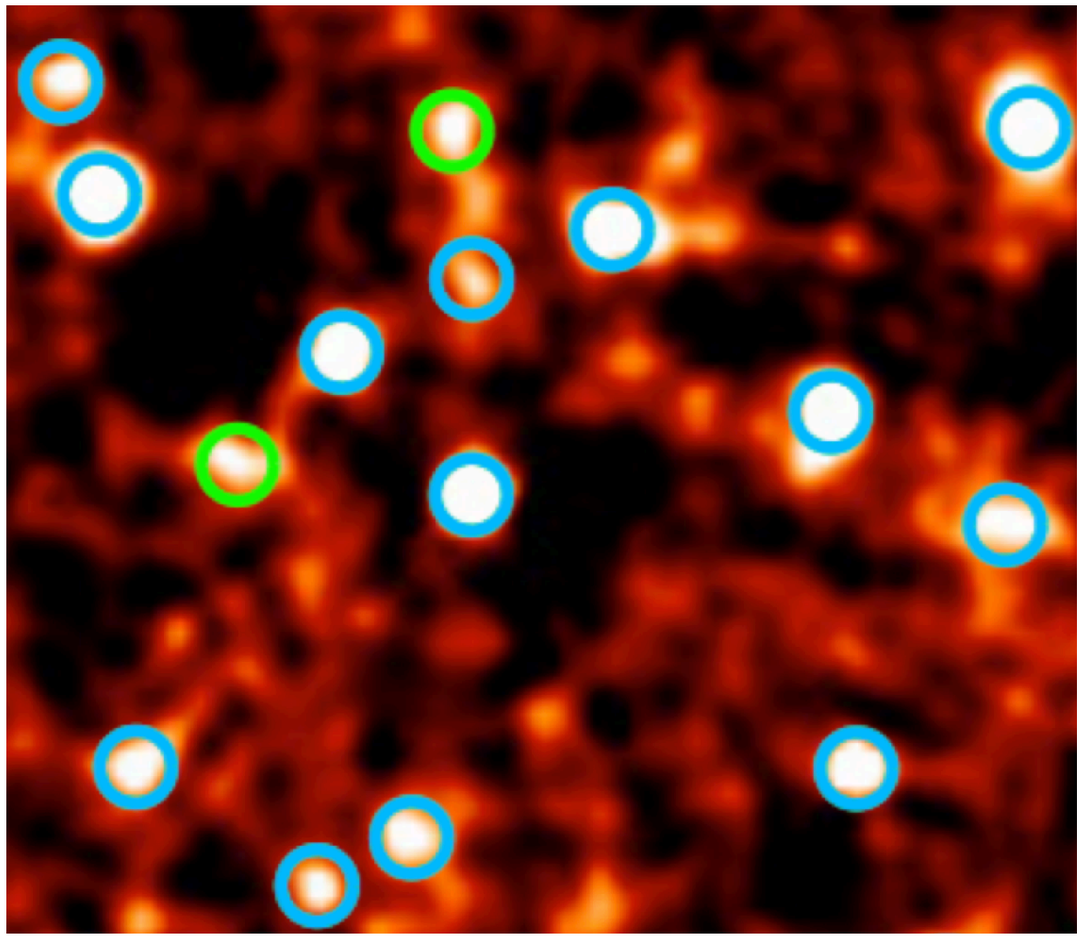


24 src (>9 mjy)

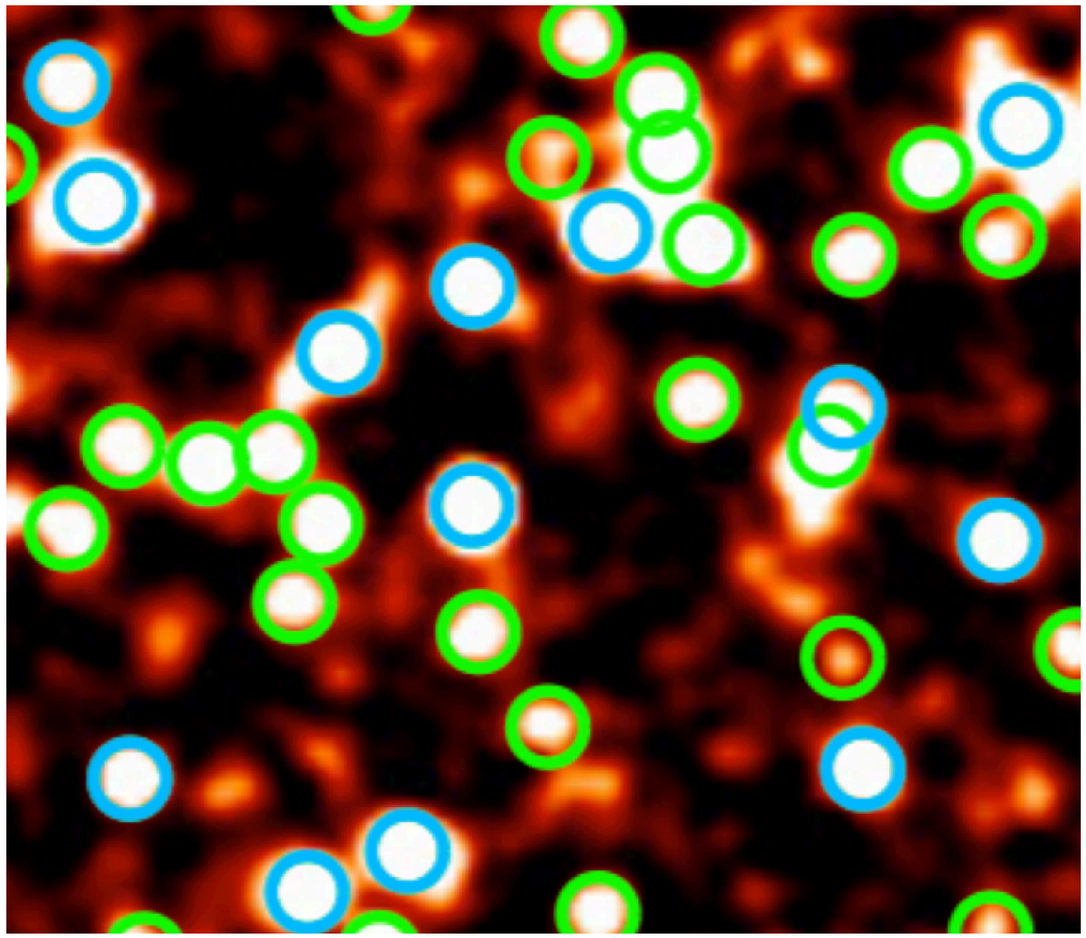


SCUBA-2 Cosmology Legacy Survey (CLS)

- 7.5” resolution at 450μm in 100’2 CANDELS pointings = deepest and highest-resolution single-dish sub-mm survey. Will be included in final catalogs.
- Excellent tool to test deblending methods on Herschel fields and simulations: here actual positions of the sources in the mock image (smaller rms)



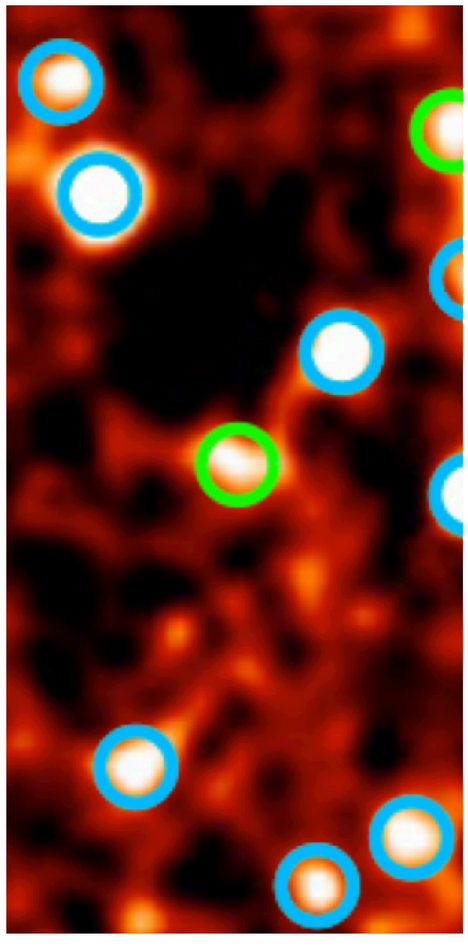
real SCUBA 450μm image



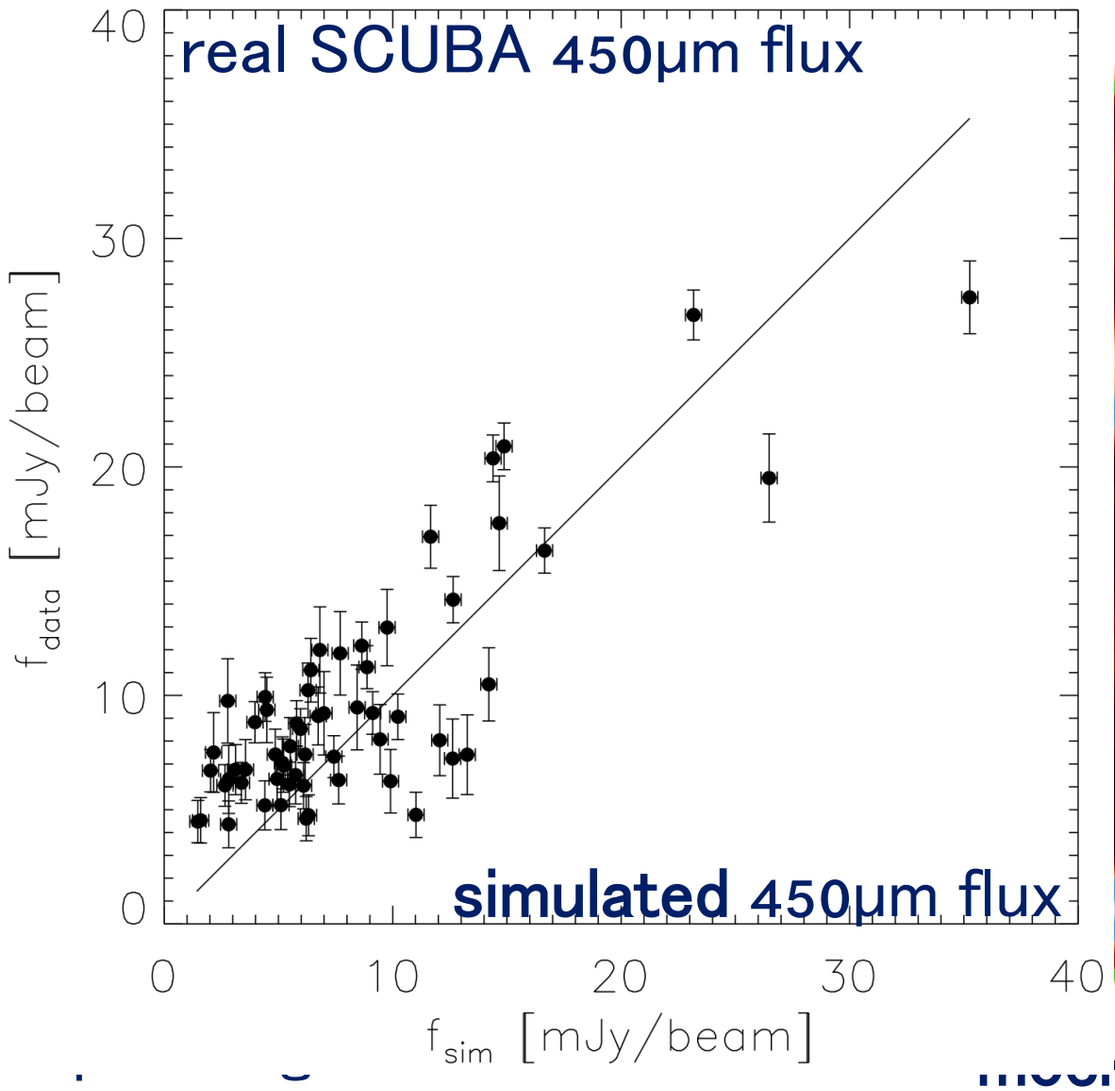
mock SCUBA 450μm image

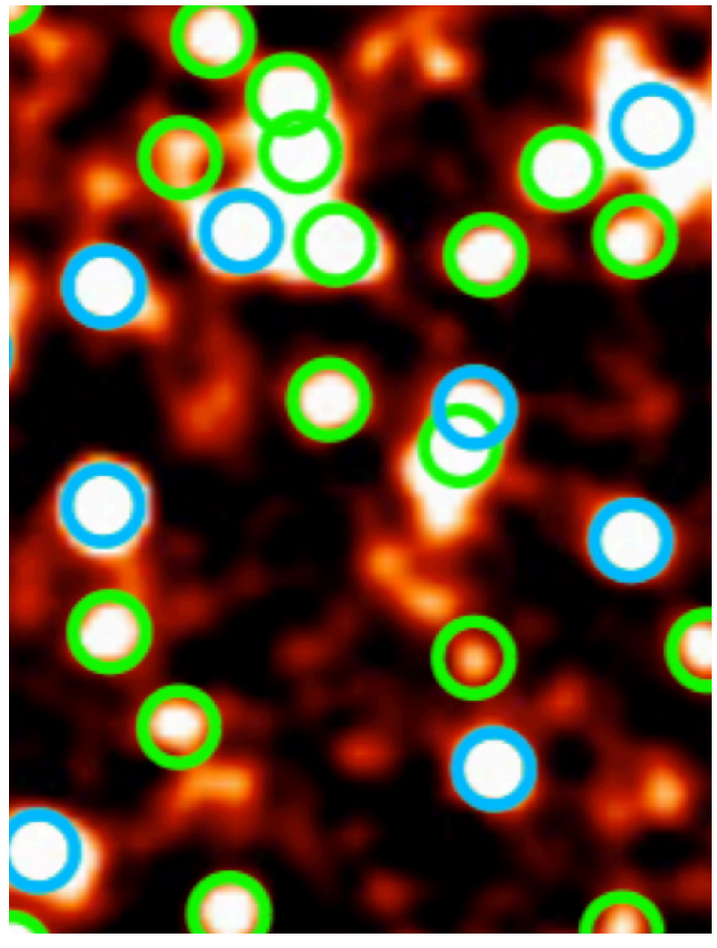
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real SCUBA 4



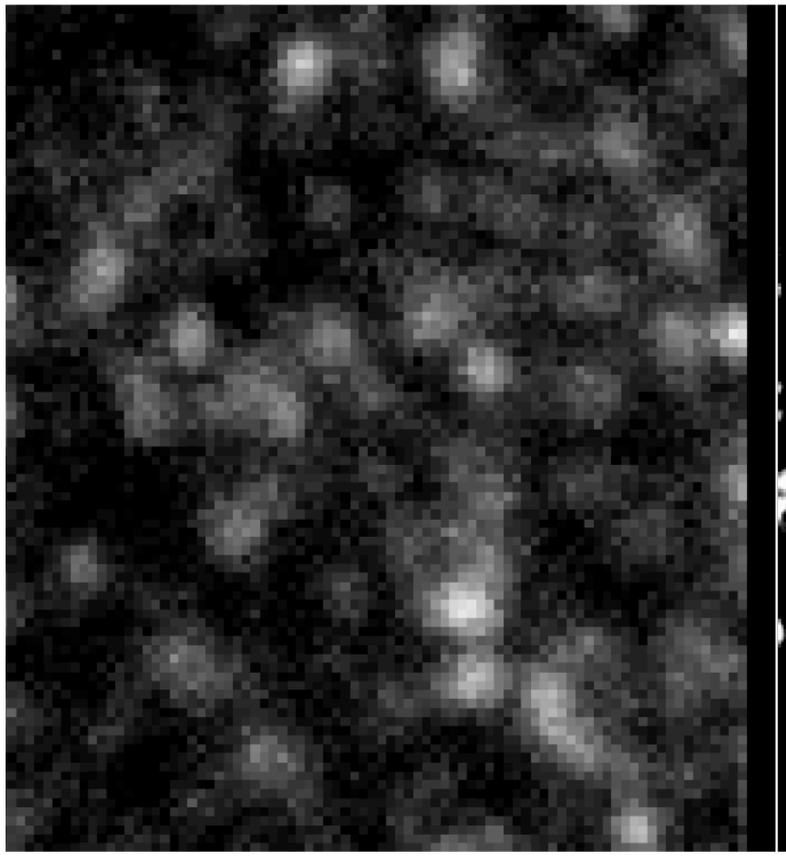


mock 450μm image

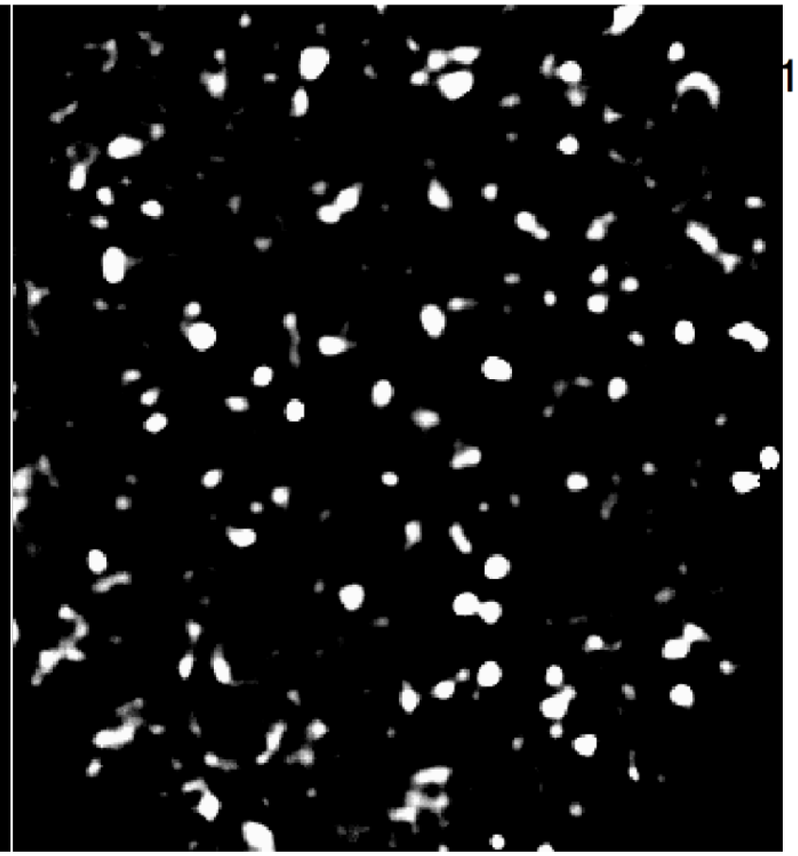
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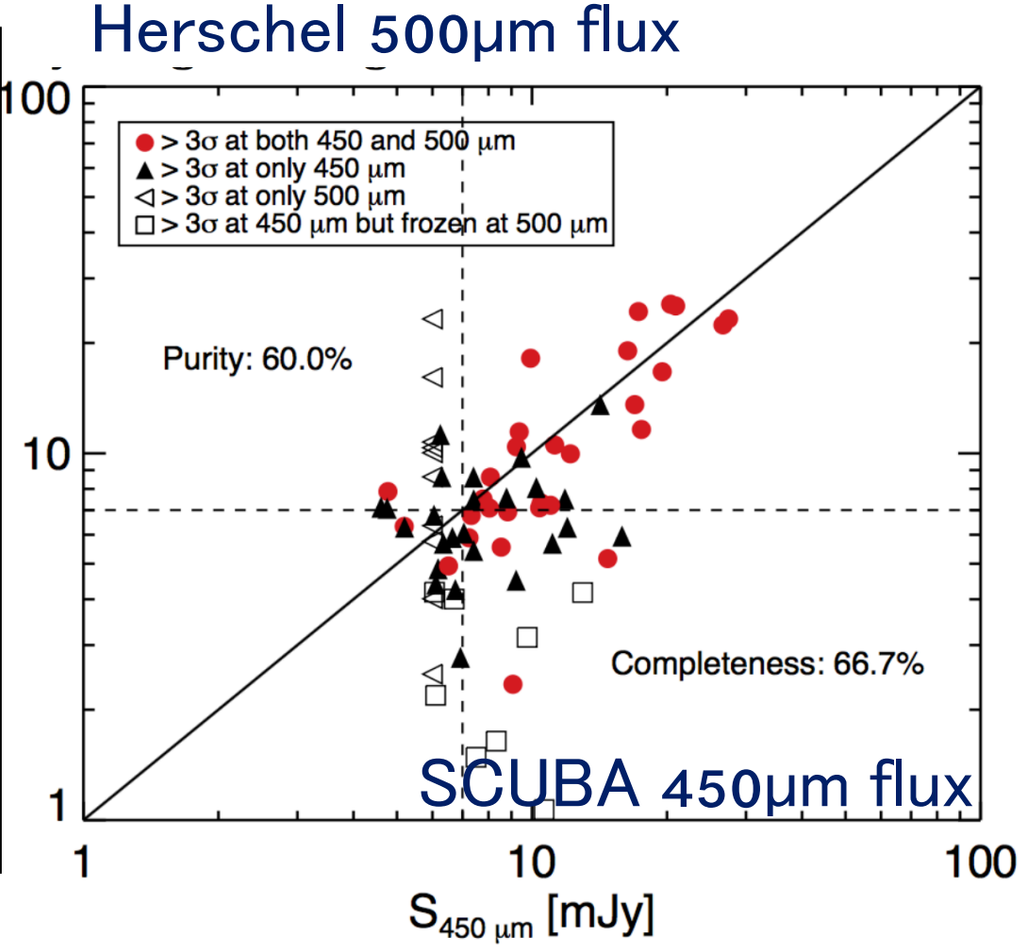
Draft version May 12, 2015



Herschel 500μm image



SCUBA 450μm image



ASTRODEEP WP3: plan for Period #3

- Unique codes for simulations (gencat) and source extraction (TPHOT) from X-ray to SMM
- Some refinements on TPHOT will continue
  - possibility to freeze within 30% fluxes of faint sources
  - account for differences in profile as a function of wavelength due to colour gradients
- Need to define a strategy for the definition of priors used for Herschel catalogs in fields with shallower 24μm data (use IRAC fluxes and redshift) → needed for UDS and COSMOS fields
  - test the possibility to include deep radio and ground-based SMM priors

Source extraction process

mid to far IR | Optical to near IR | X

Image pre-processing for catalog production :

- high-pass filtering of low frequency noise
- stacking for centering astrometry of individual overlapping mosaics
- rejection of bad observations / cosmic-ray impacts
- injection of fake sources of known flux density to :
  - determine the unknown background level
  - calibrate the catalogs in flux density

→ **Done**

Next steps:

improved astrometry using gyroscopes rather than star tracker (ESA revised pipeline to be released)

Test of Unimap tool for mosaic production (instead of PhotProject + low frequency noise filtering)

3 categories of softwares

- Single band blind source extraction
- Multi-band blind source extraction
- Prior source extraction