GOODS-ALMA : 1.1 mm extragalactic survey

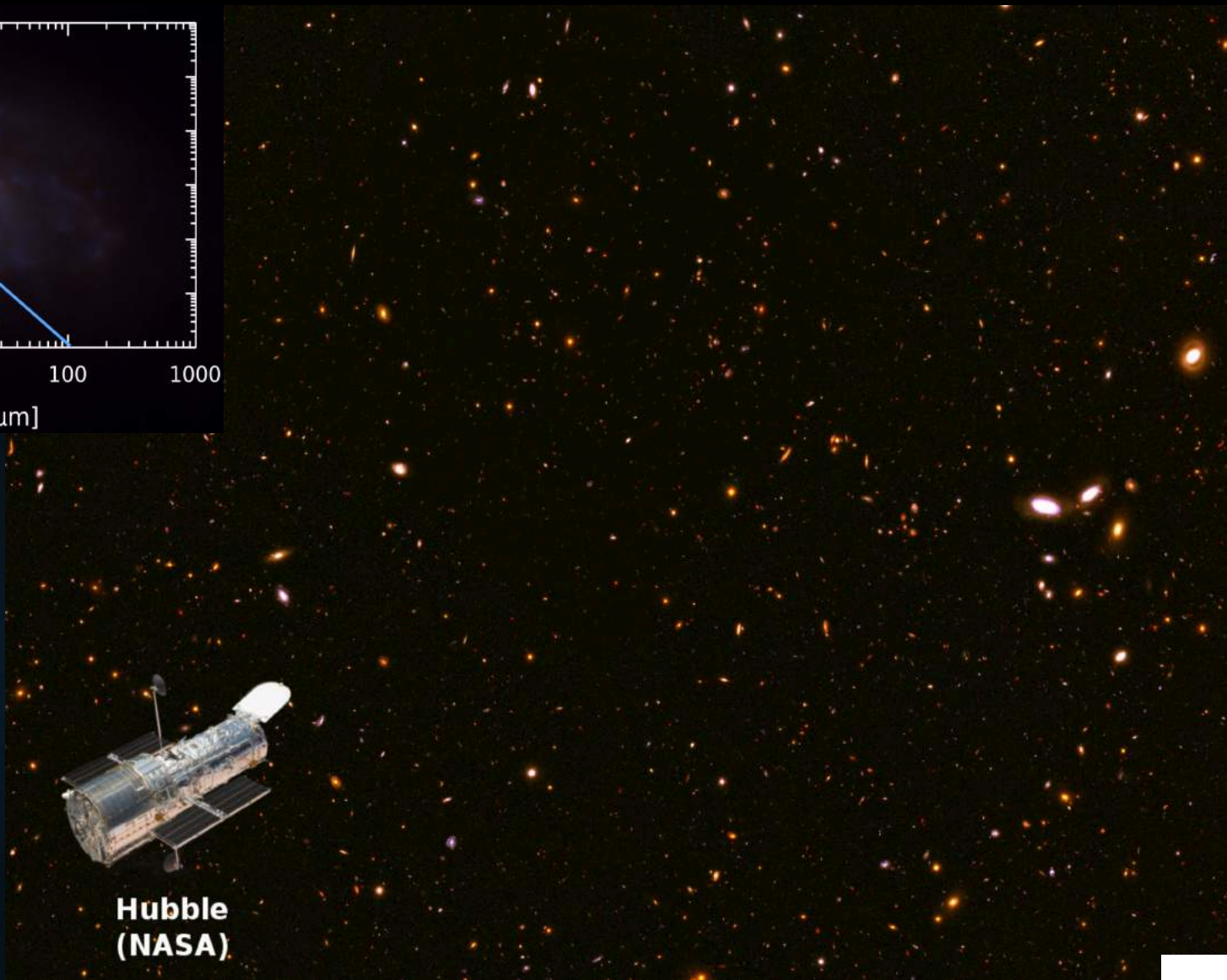# A hidden population of massive star-forming galaxies at z > 2
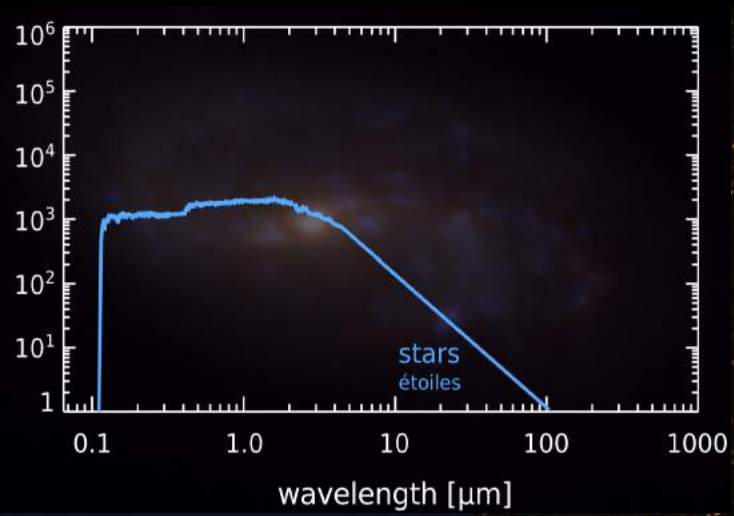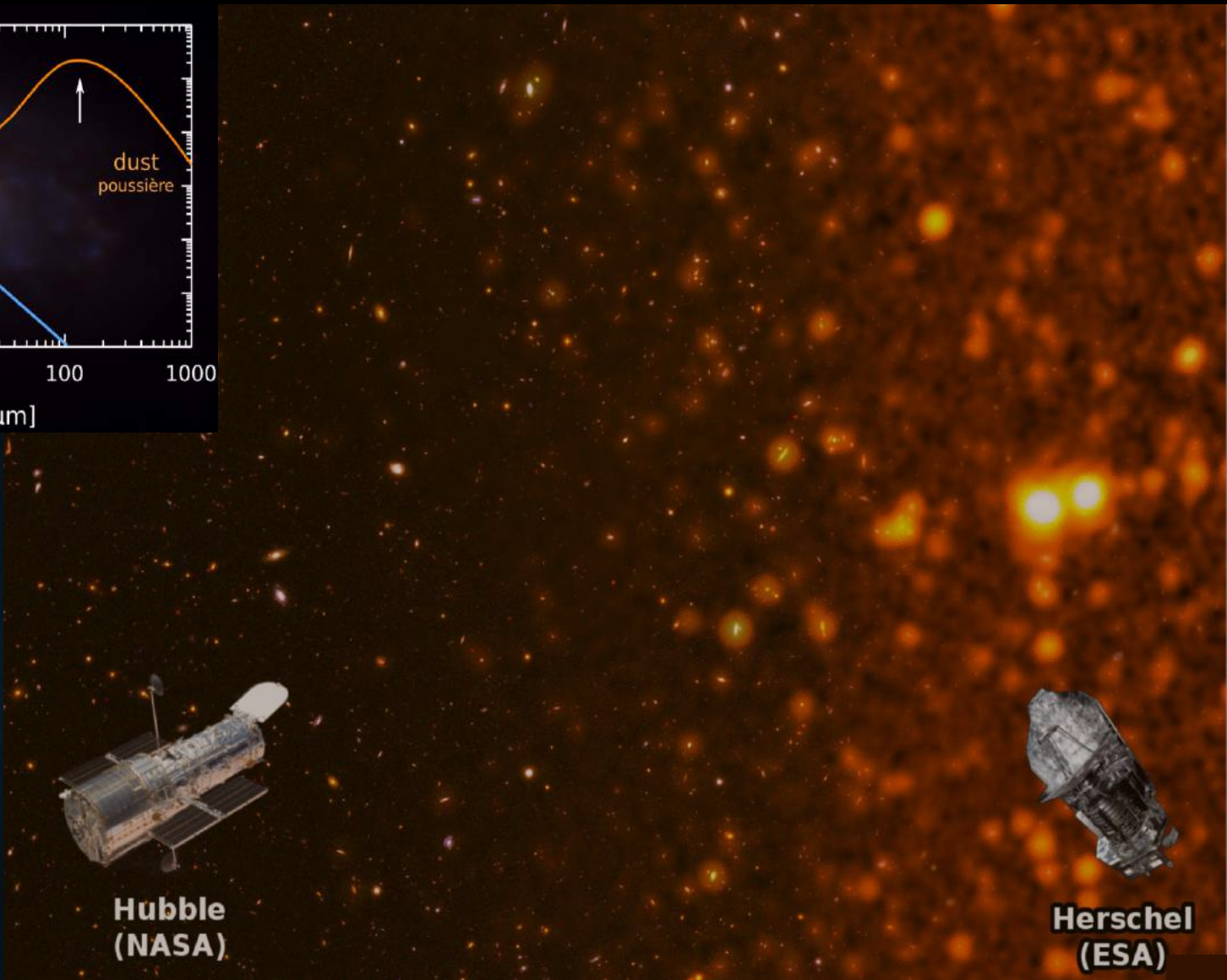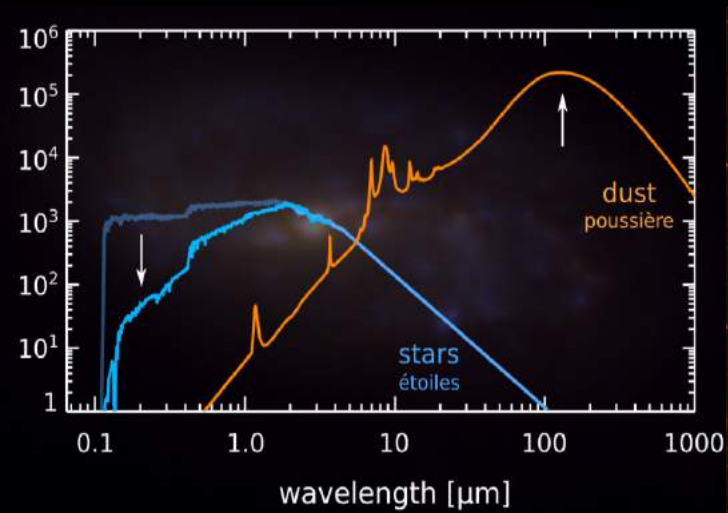
M. Franco, D. Elbaz and the
GOODS-ALMA team

Observing the millimeter Universe with the
Nika2 Camera – 7th June 2019 – LPSC - Grenoble

stars
étoiles

wavelength [μm]
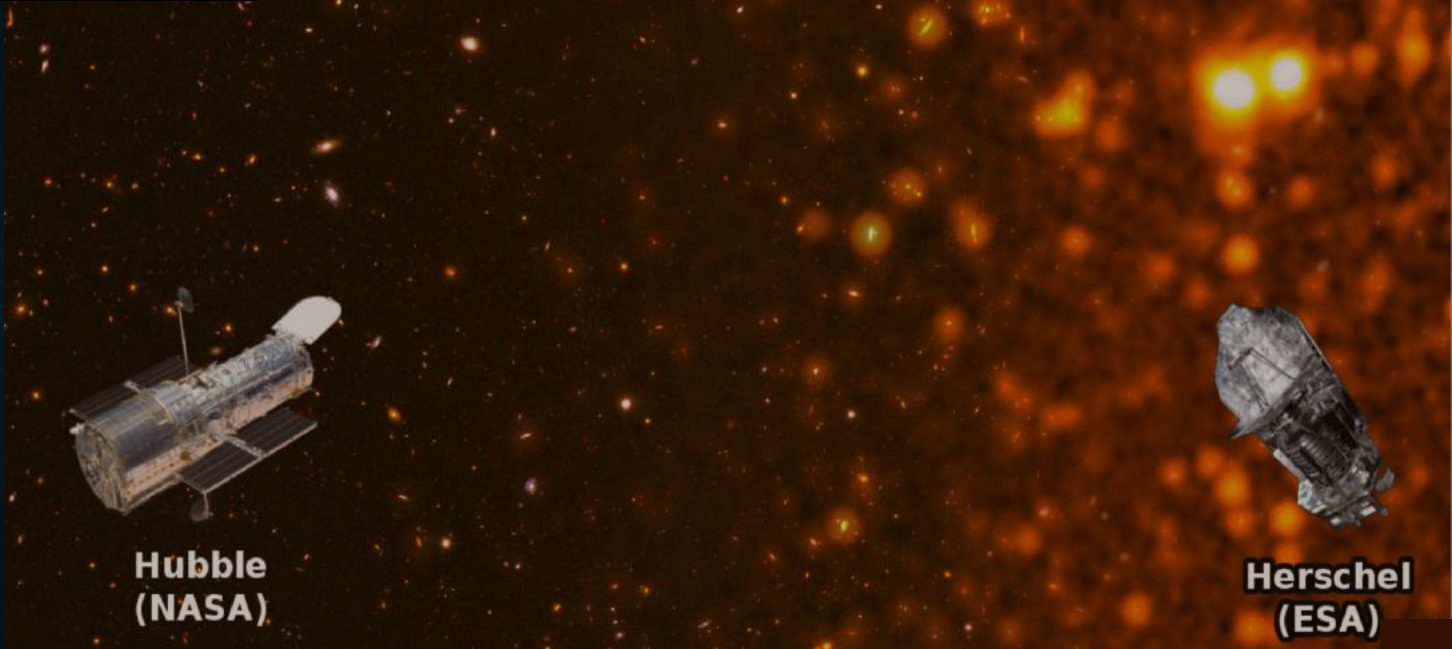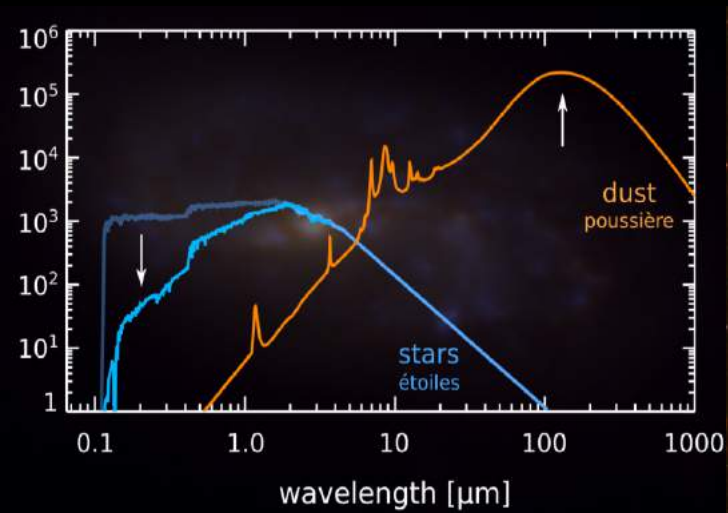
Hubble
(NASA)

stars
étoiles

dust
poussière

wavelength [μm]

Hubble
(NASA)

Herschel
(ESA)
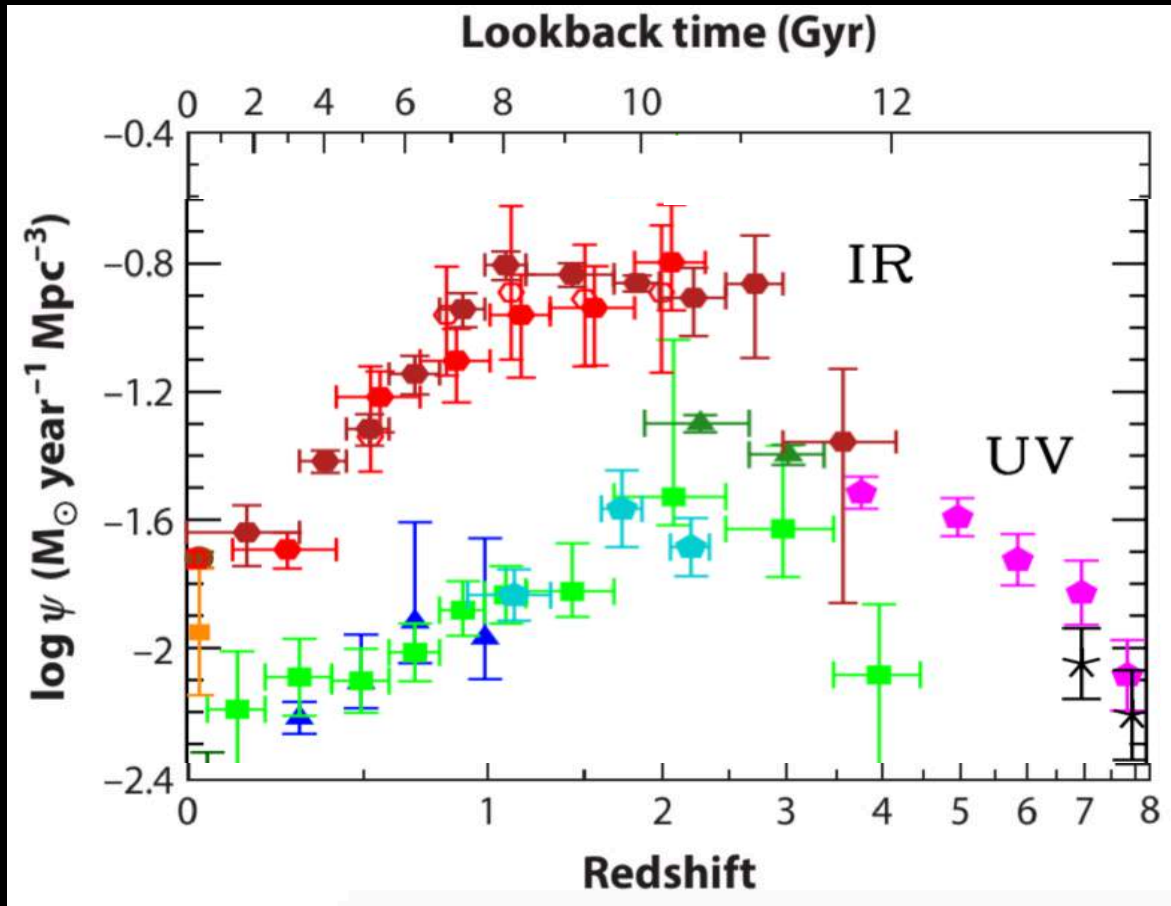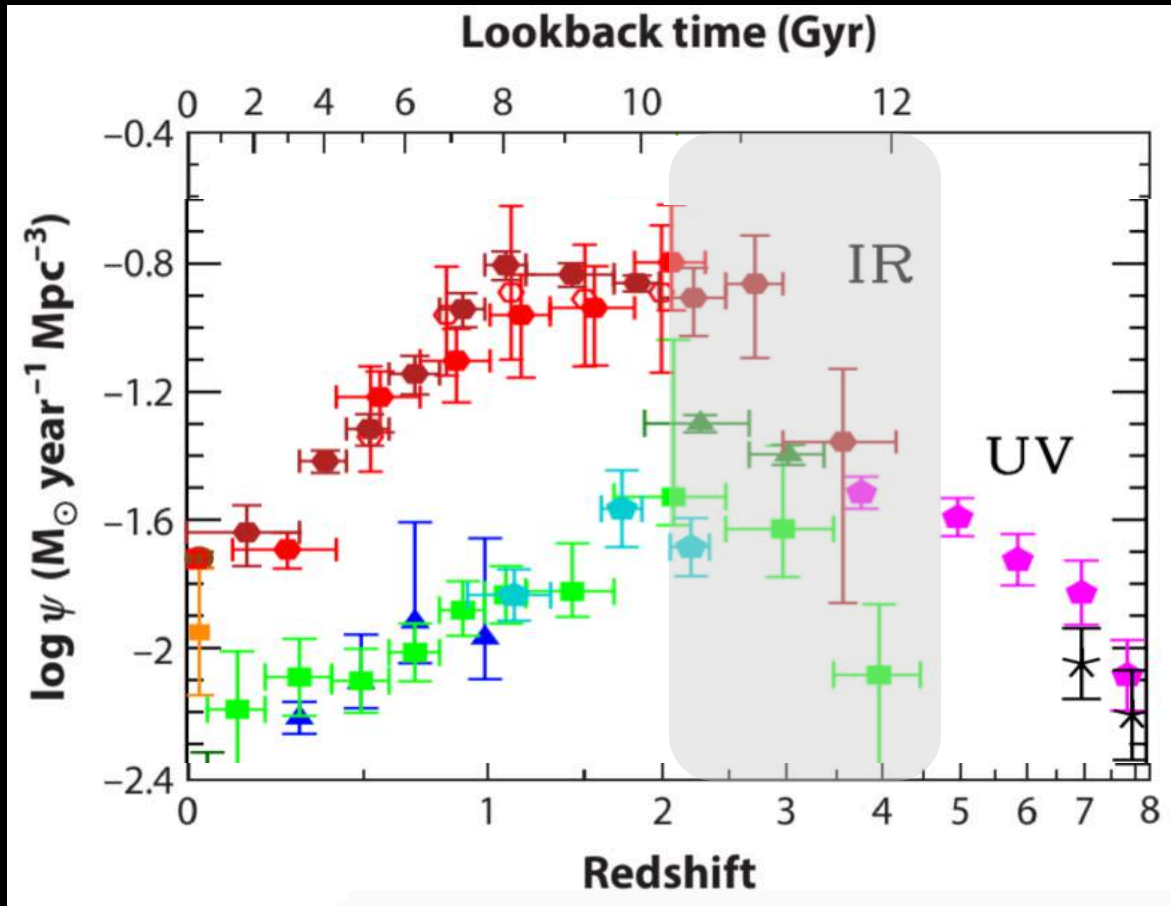
Hubble
(NASA)

Herschel
(ESA)

The cosmic star formation history
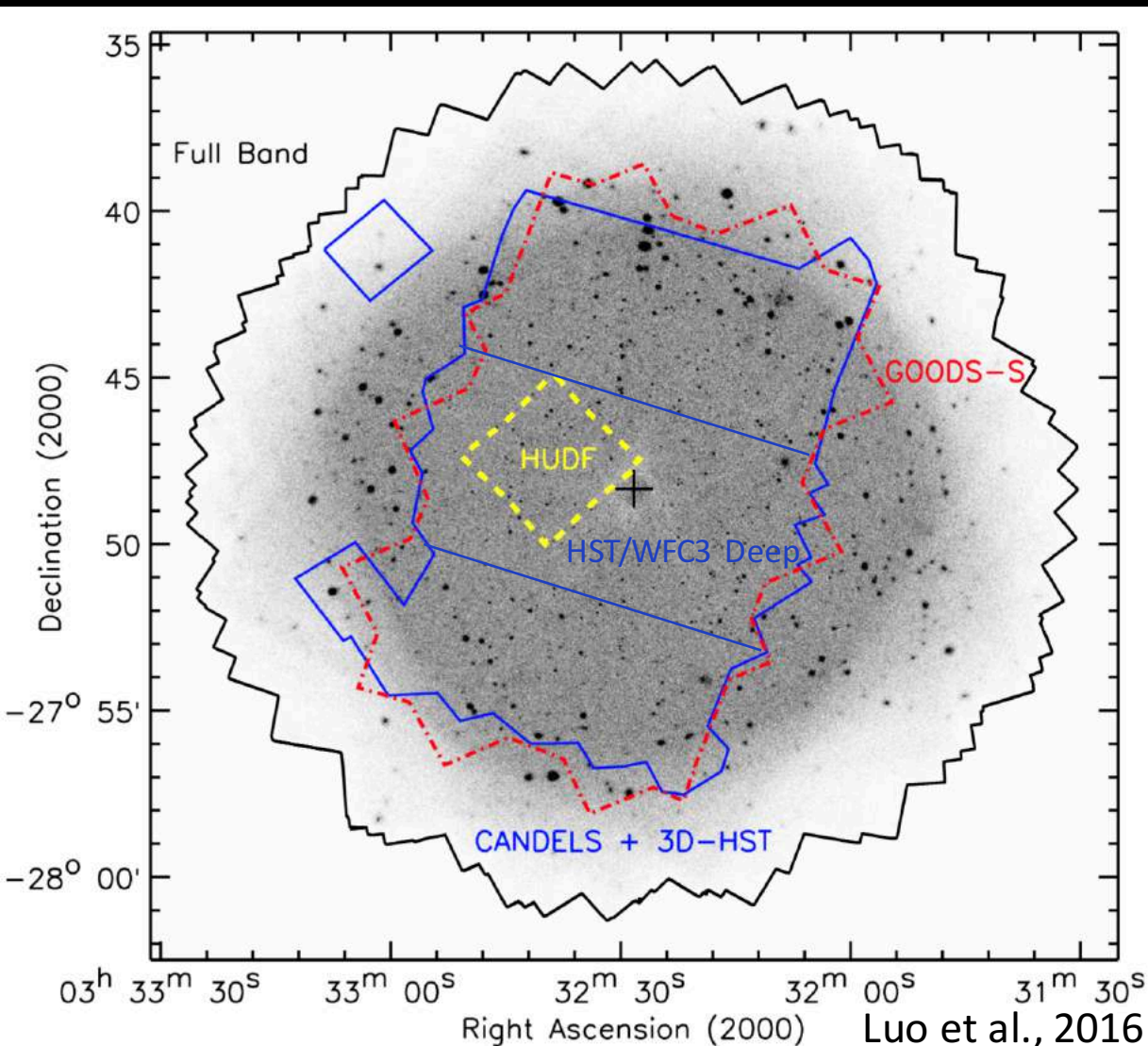

Madau & Dickinson 2014

The cosmic star formation history

Madau & Dickinson 2014

The GOODS-South Field
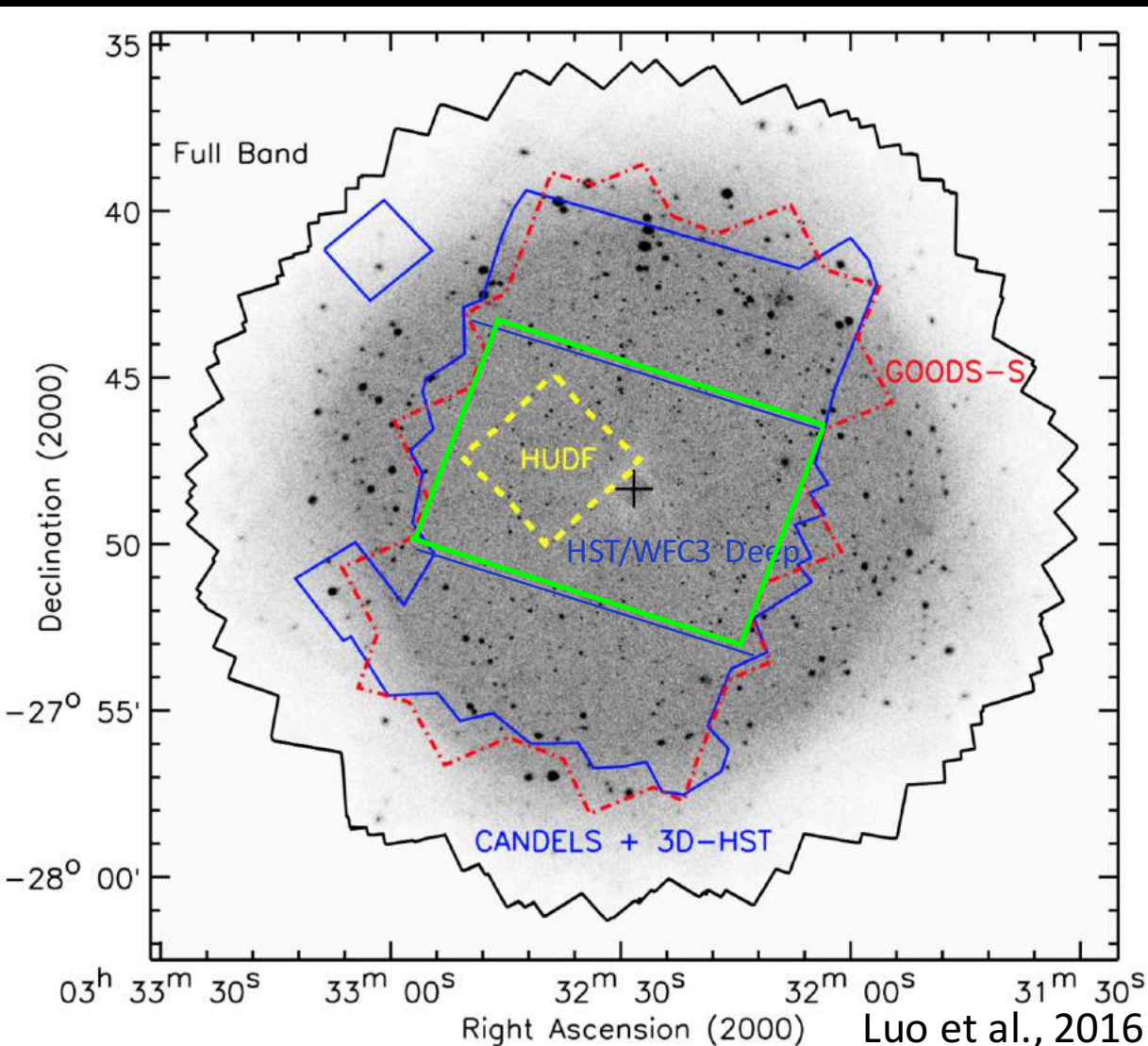# A multi-wavelength view

Luo et al., 2016

- UV/Optical/near-infrared
  - WFC3/IR
  - ACS
  - HAWK-I Ks
  - ISAAC Ks
  - VIMOS U
  - FourStar
- Mid-Far IR
  - IRAC
  - MIPS
  - PACS
  - SPIRE
- Radio
  - JVLA (CO-I)
- X-Ray
  - Chandra 7Ms

The GOODS-South Field
A multi-wavelength view

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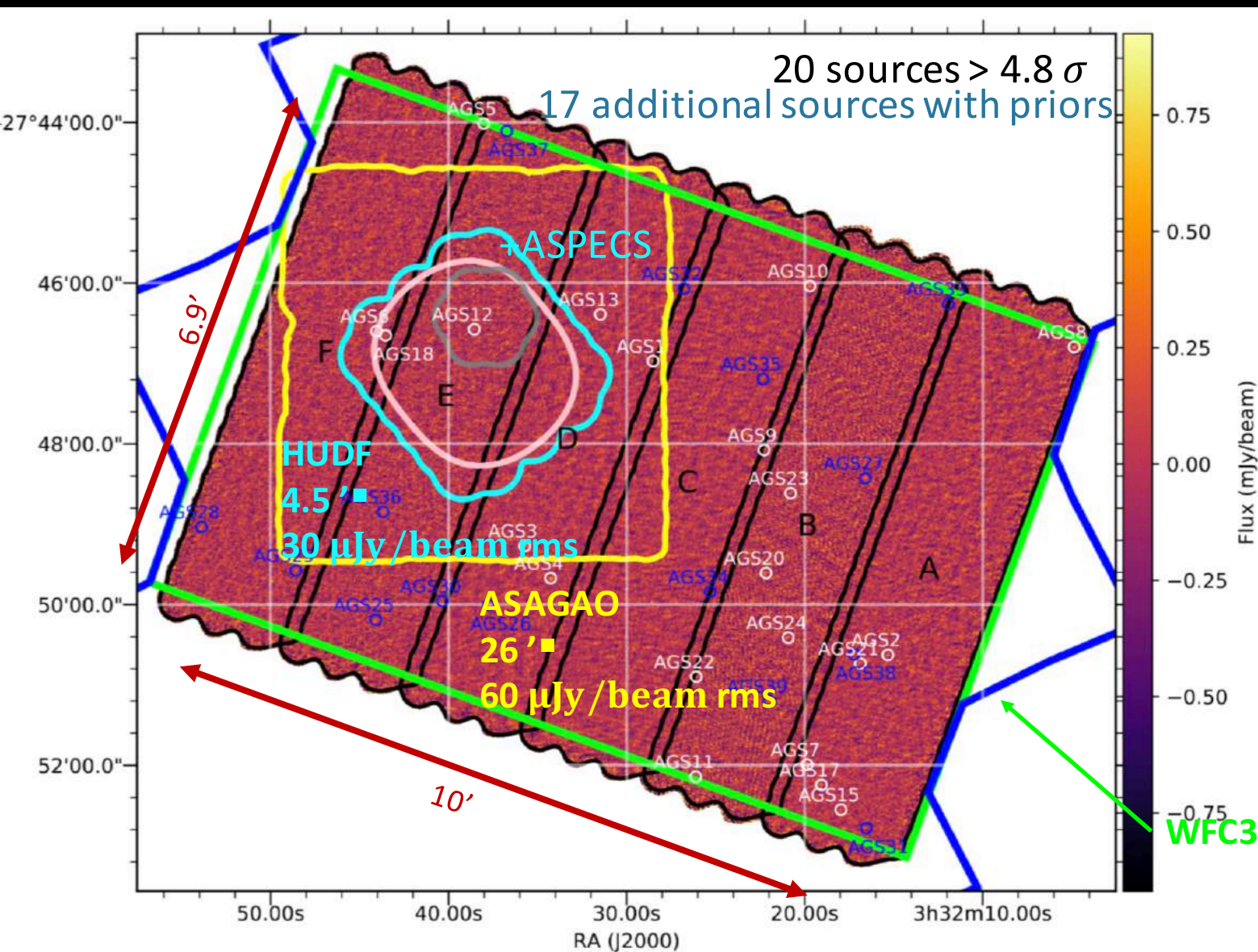 - JVLA (CO-I)
- X-Ray
  - Chandra 7Ms

Our ALMA 1.1mm survey

20 sources > 4.8 σ
17 additional sources with priors

ASPECS

HUDF
4.5 '■
30 μJy/beam rms

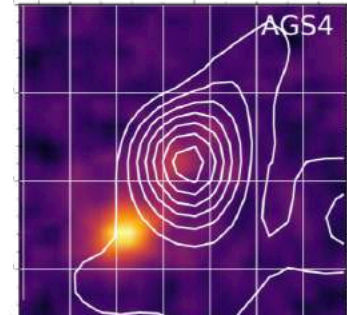ASAGAO
26 '■
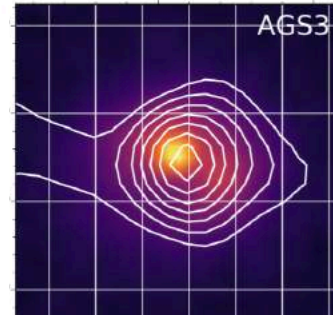60 μJy/beam rms
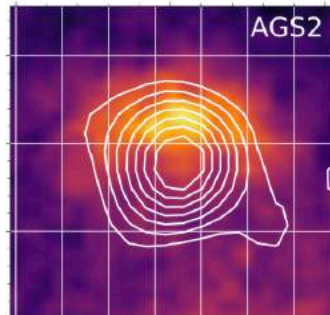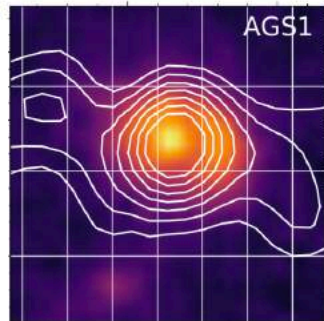
WFC3

6.9'
10'

Observation:
~22 h

Size: 69 '■

Comoving scale
15.1 x 10.5 Mpc
at z = 2

Depth:
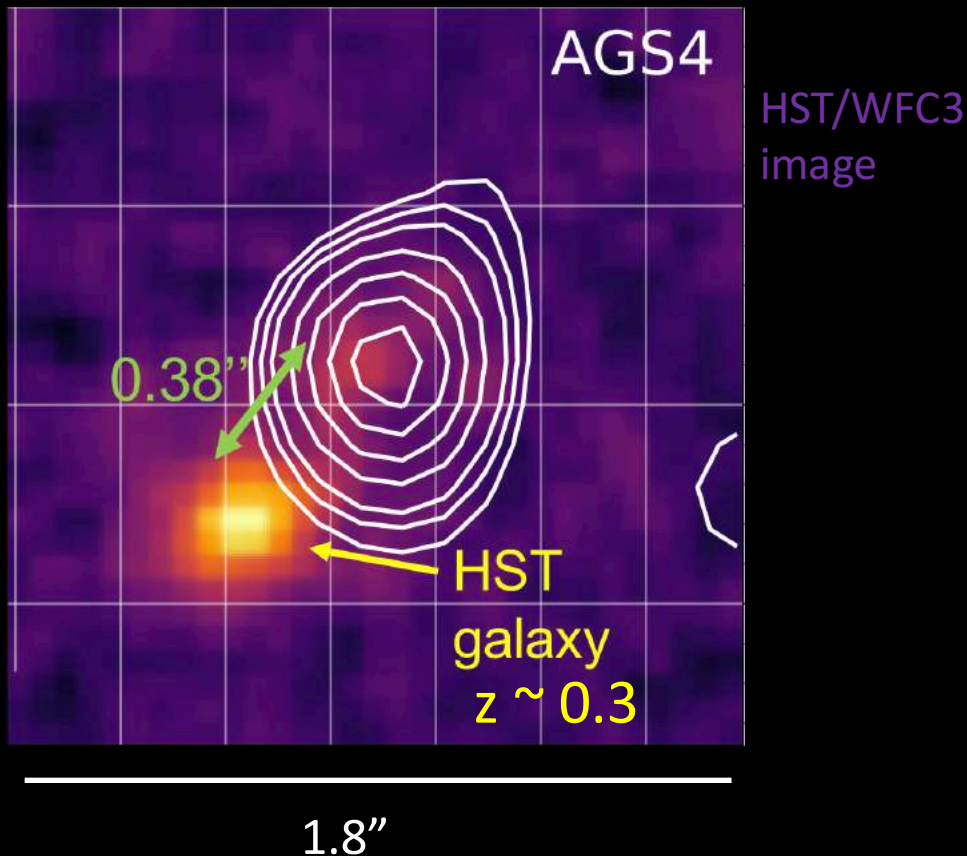Rms ~ 0.185 mJy

Resolution:
   Intrinsic
   θ = 0.24''
   Homogeneous
   θ = 0.29''
   Tapered
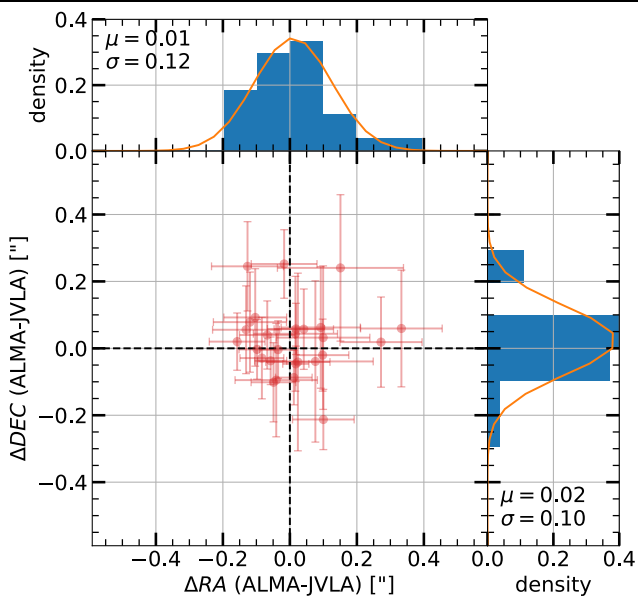 θ = 0.60''
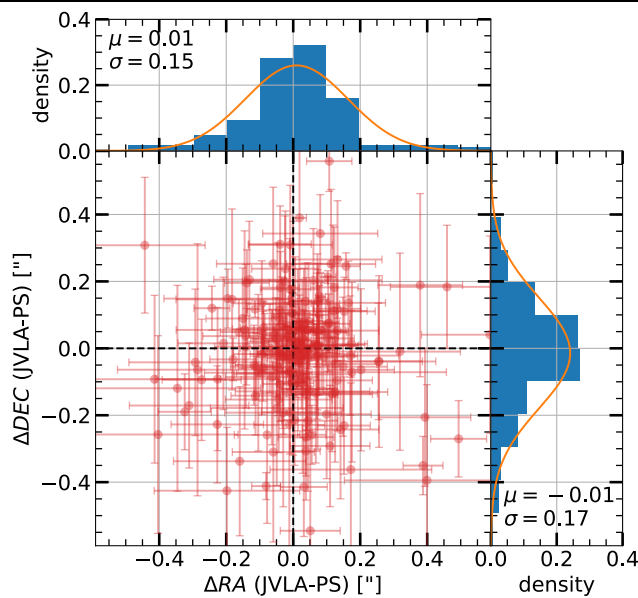
9

ALMA detections

1.8"
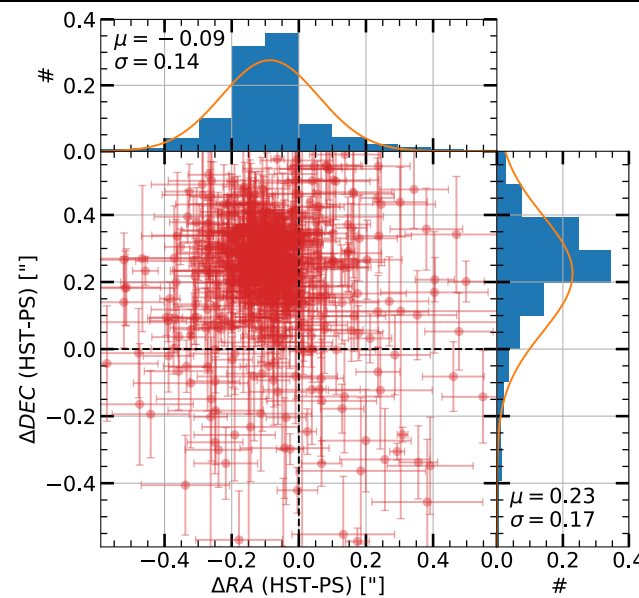
ALMA unveils a new population of HST-dark galaxies (20%)

AGS4

HST/WFC3 image

0.38"

HST galaxy
z ~ 0.3

1.8"

GOODS-South offsets

ALMA vs JVLA   JVLA vs Pan-STARRS   HST vs Pan-STARRS

GOODS-South ALMA-HST offset

After the subtraction of the systematic offset
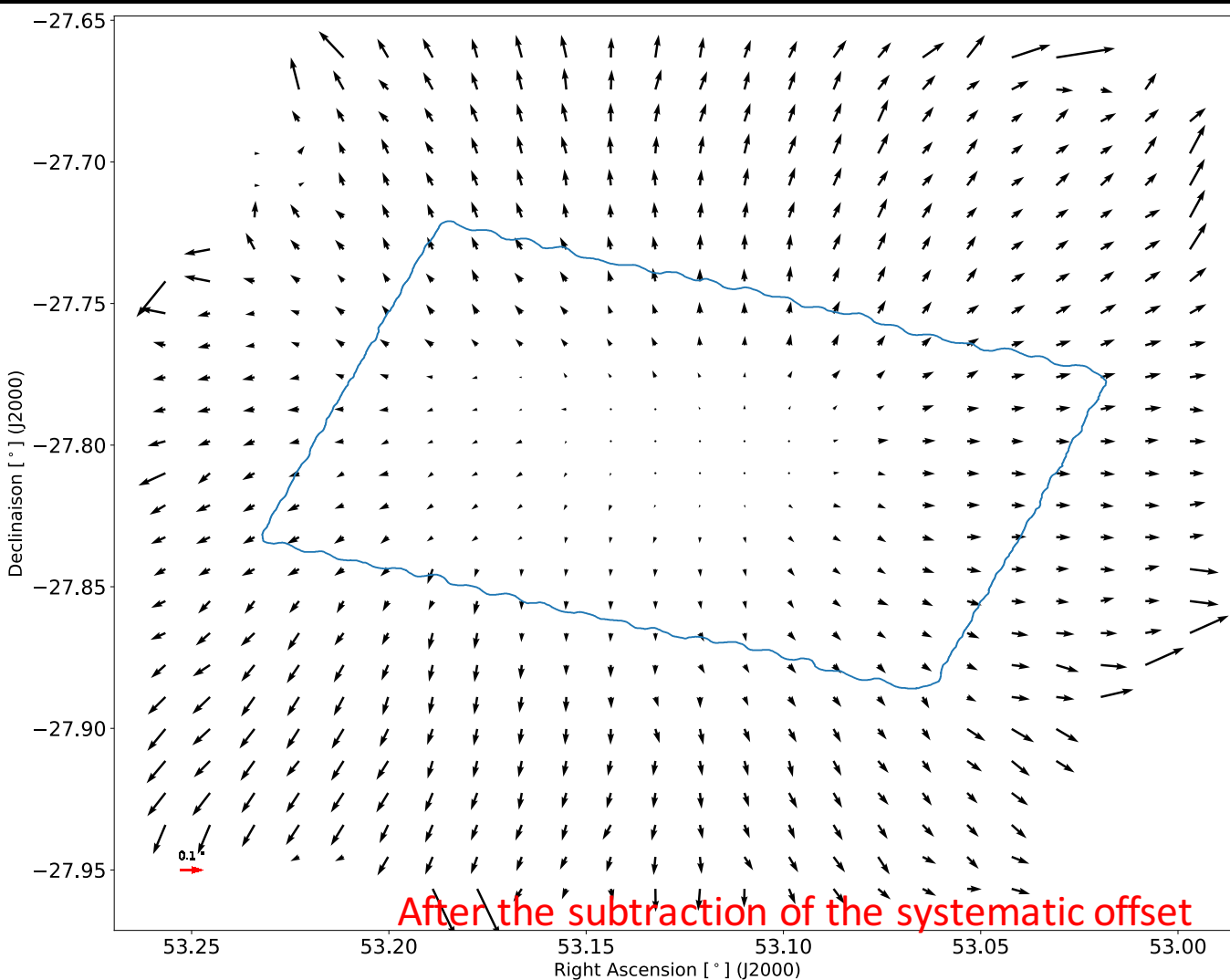
Systematic offset

Previously found :
$\Delta\alpha$ = 80 ± 110 mas
$\Delta\delta$ = -260 ± 130 mas
(Rujopakarn et al. ,2016)

This work :
$\Delta\alpha$ = 94 ± 42 mas
$\Delta\delta$ = -262 ± 50 mas

After the subtraction of the systematic offset

Discovery of a local offset

13

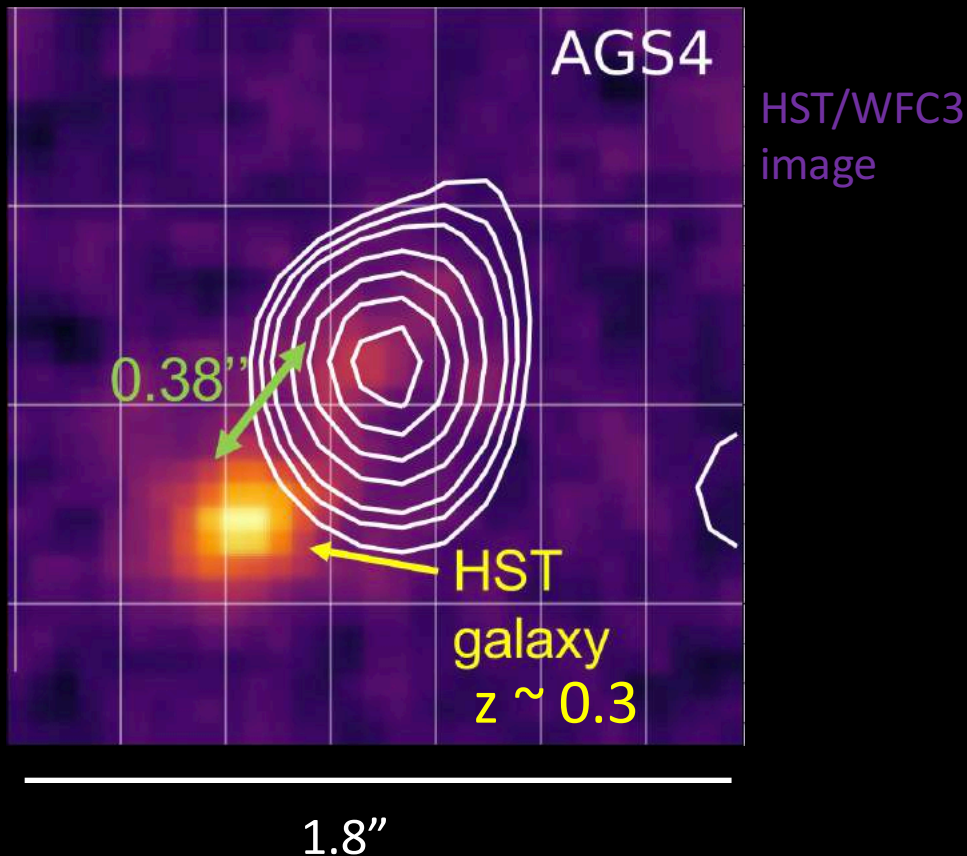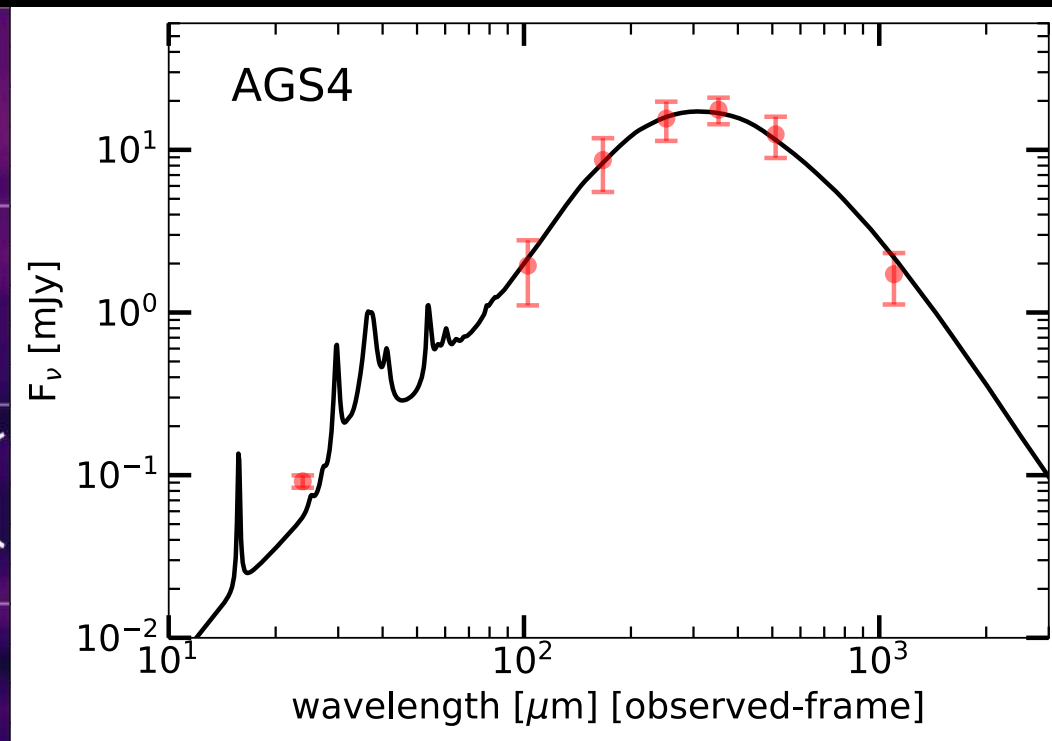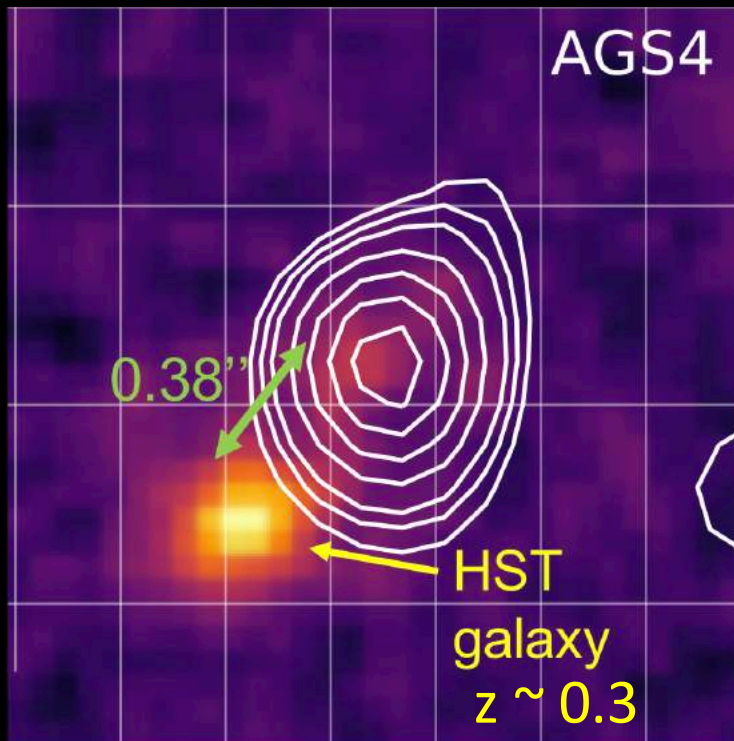# ALMA unveils a new population of HST-dark galaxies (20%)

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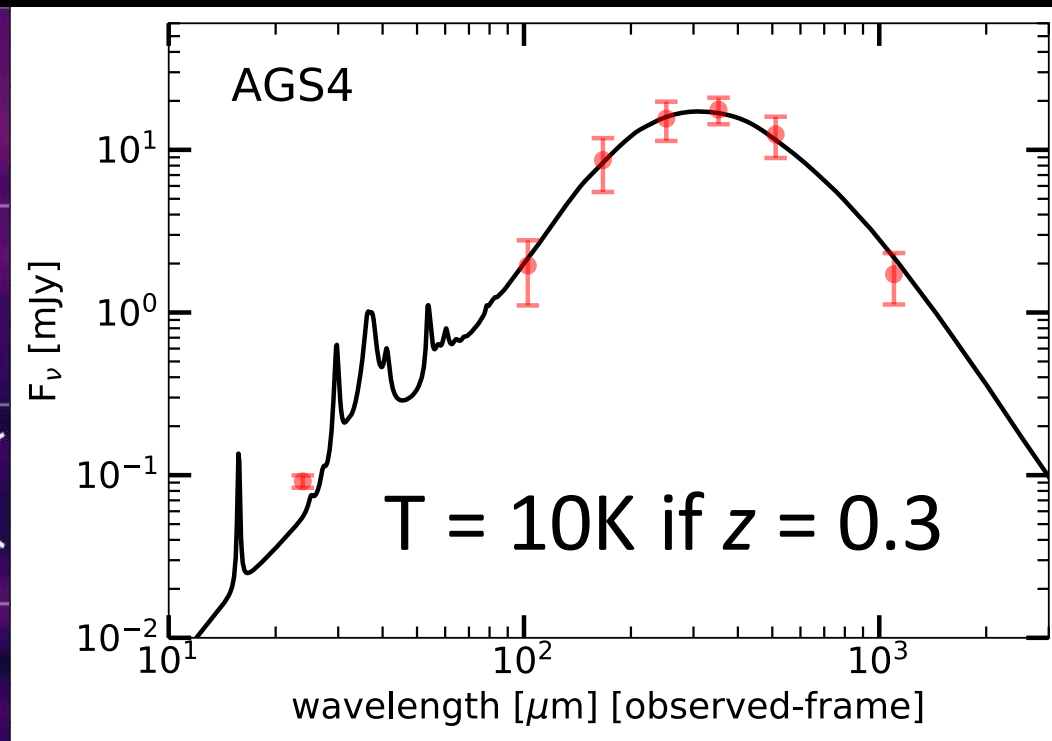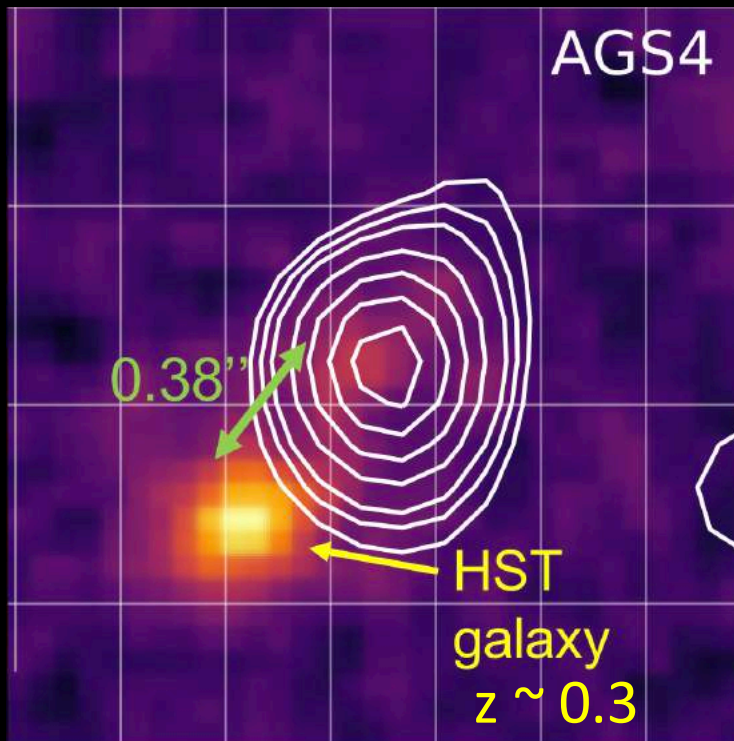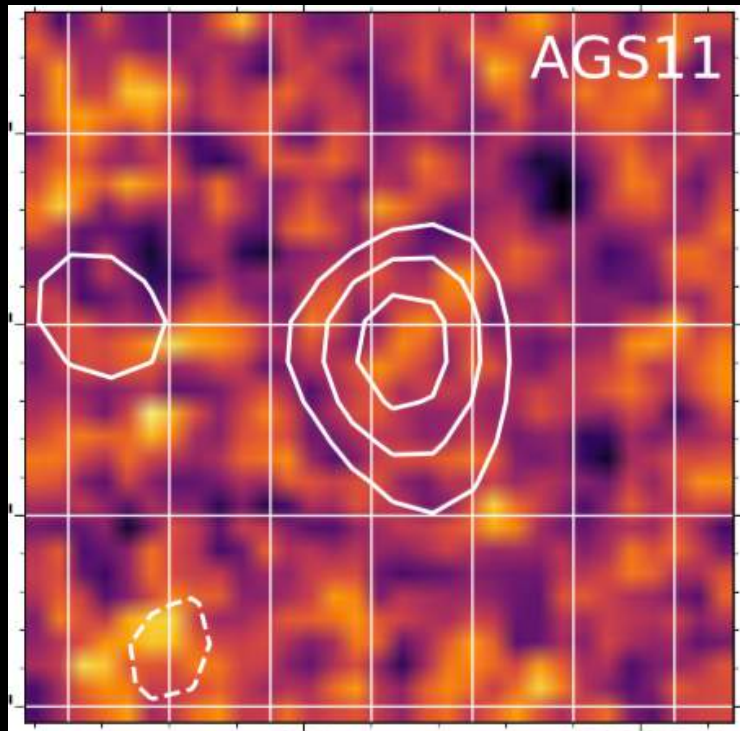# ALMA unveils a new population of HST-dark galaxies (20%)

ALMA unveils a new population of HST-dark galaxies (20%)

1.8"

ALMA unveils a new population of HST-dark galaxies (20%)

HST/WFC3 image

IRAC contours

AGS11

1.8"

9"

ALMA unveils a new population of HST-dark galaxies (20%)

Zhou et al., in prep

ALMA unveils a new population of HST-dark galaxies (20%)

Zhou et al., in prep

ALMA unveils a new population of HST-dark galaxies (20%)

Zhou et al., in prep

ALMA unveils a new population of HST-dark galaxies (20%)

Zhou et al., in prep
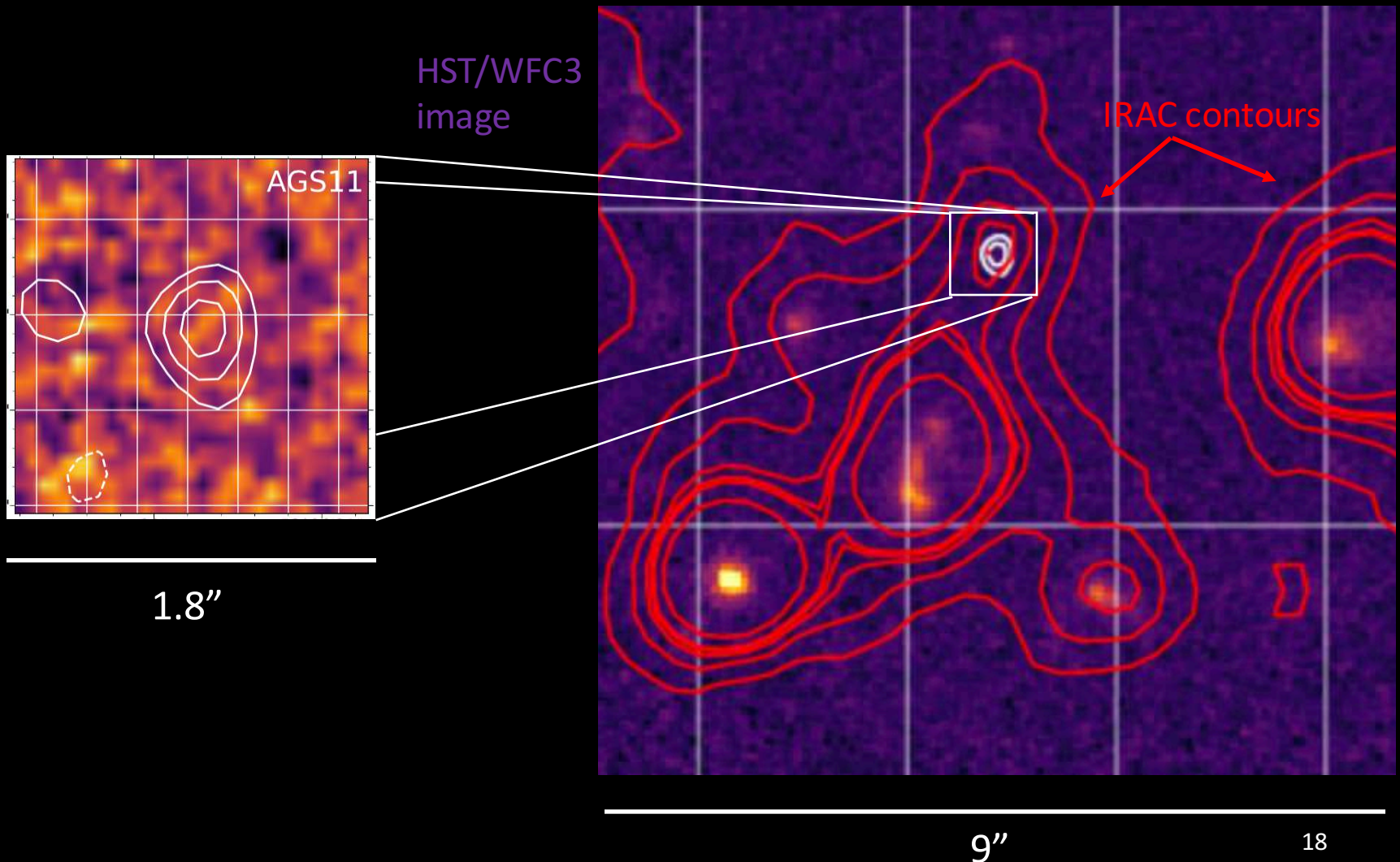
ALMA unveils a new population of HST-dark galaxies (20%)

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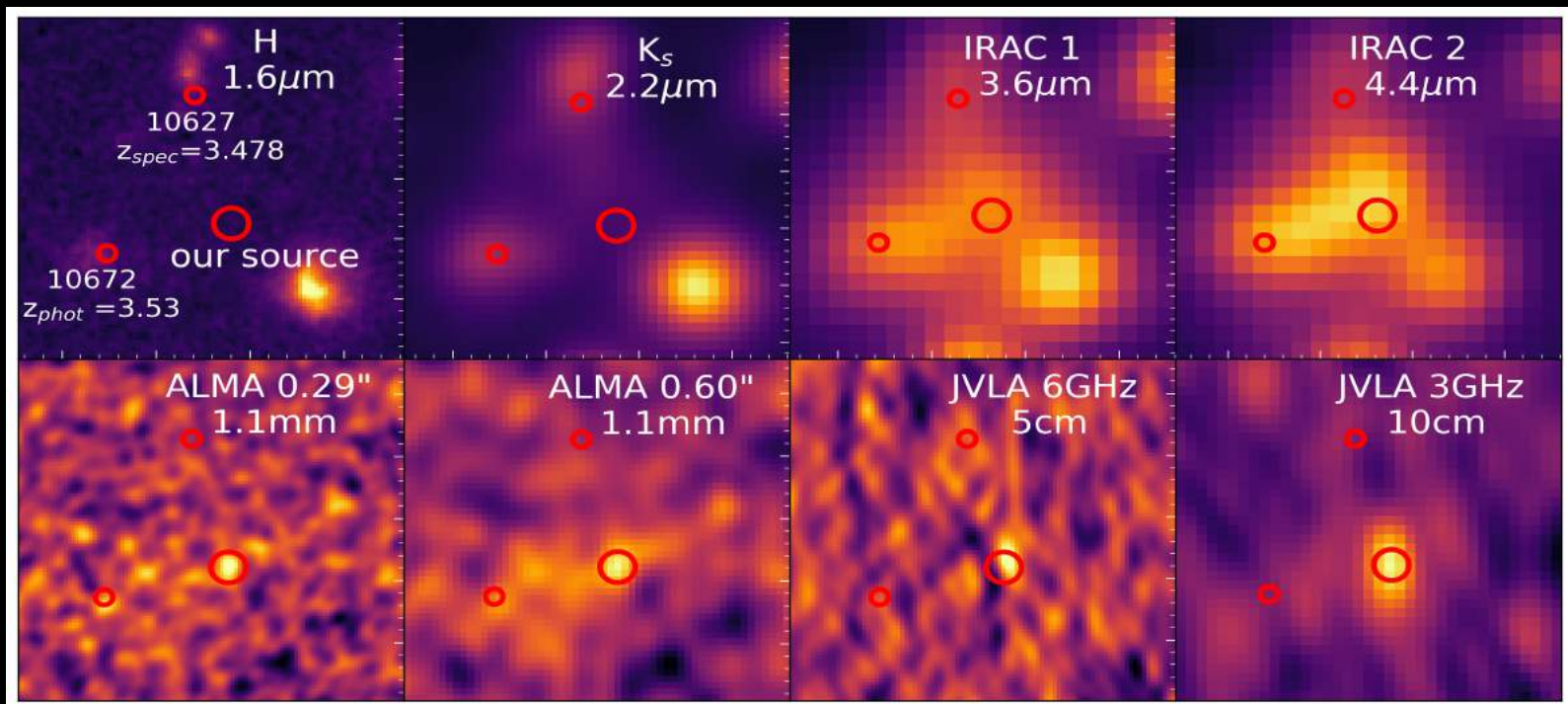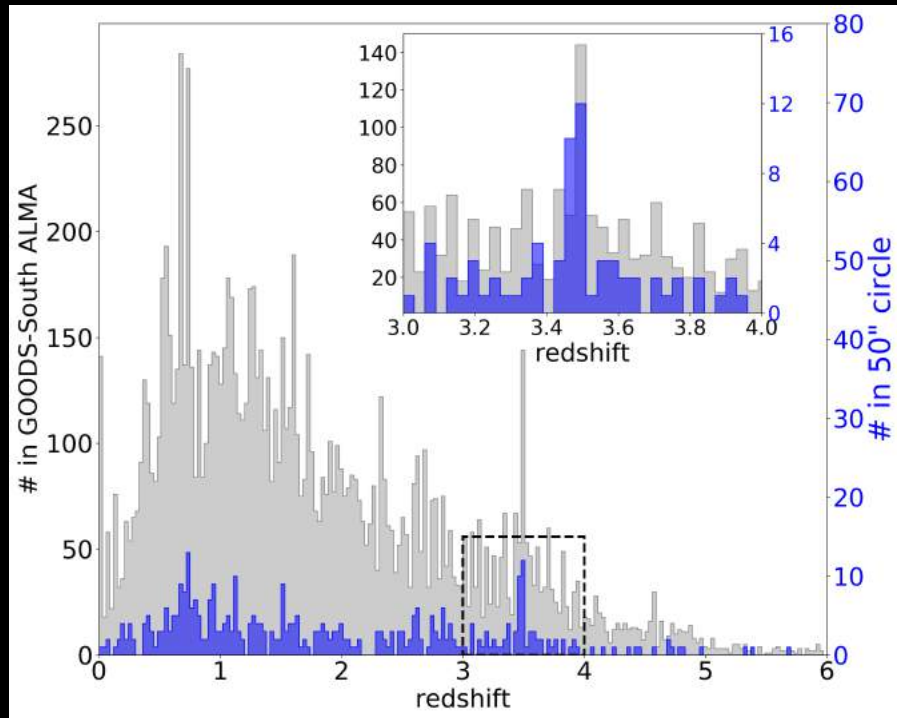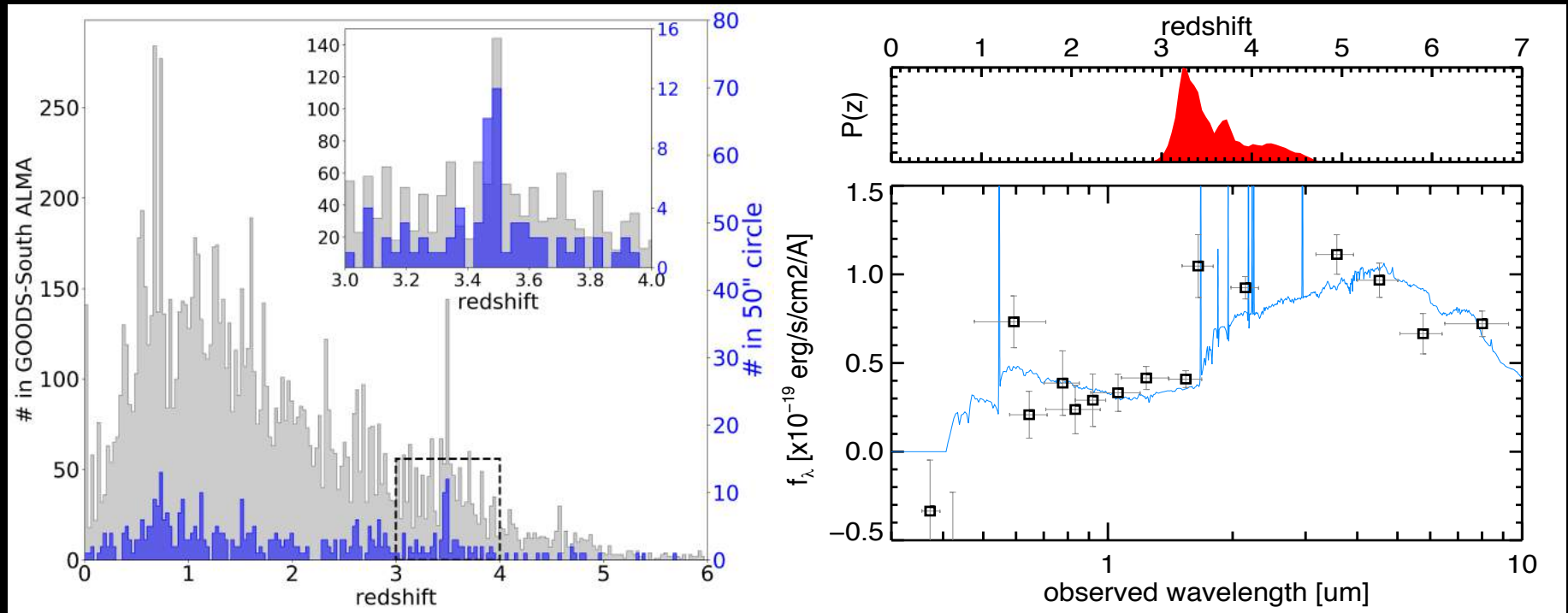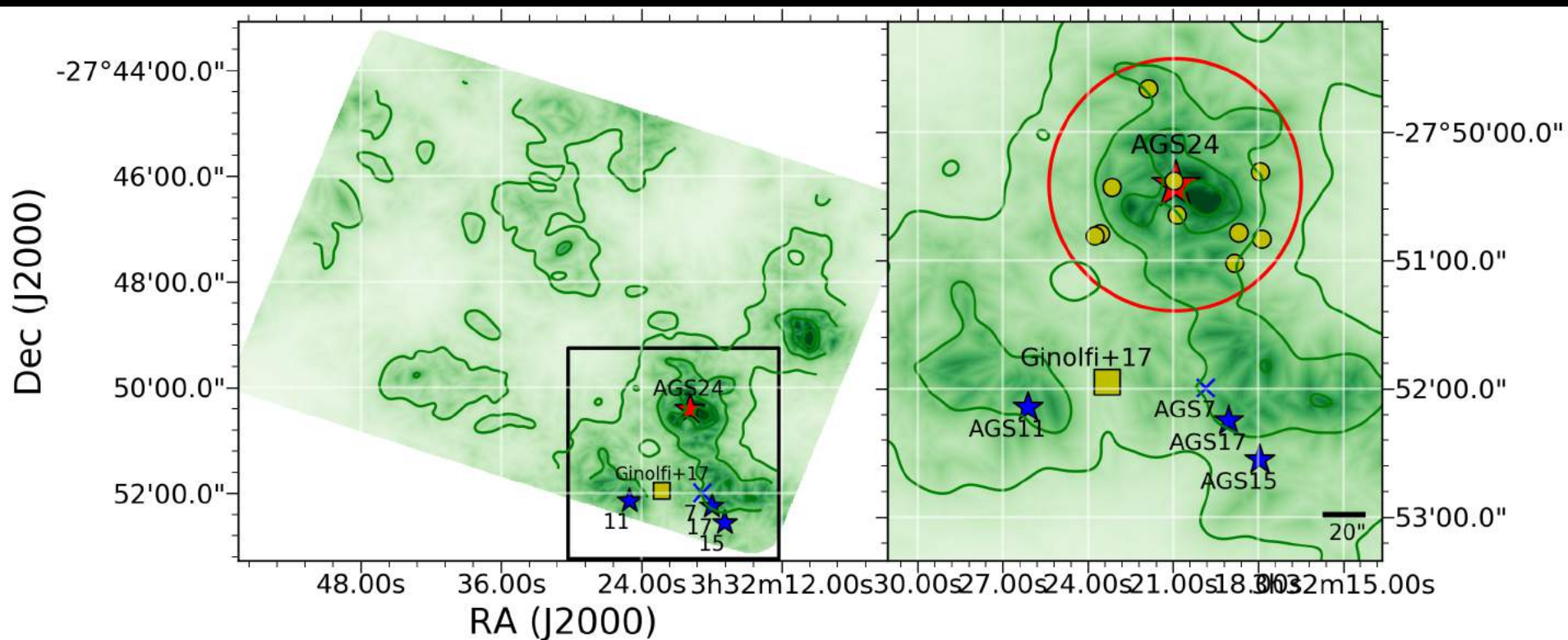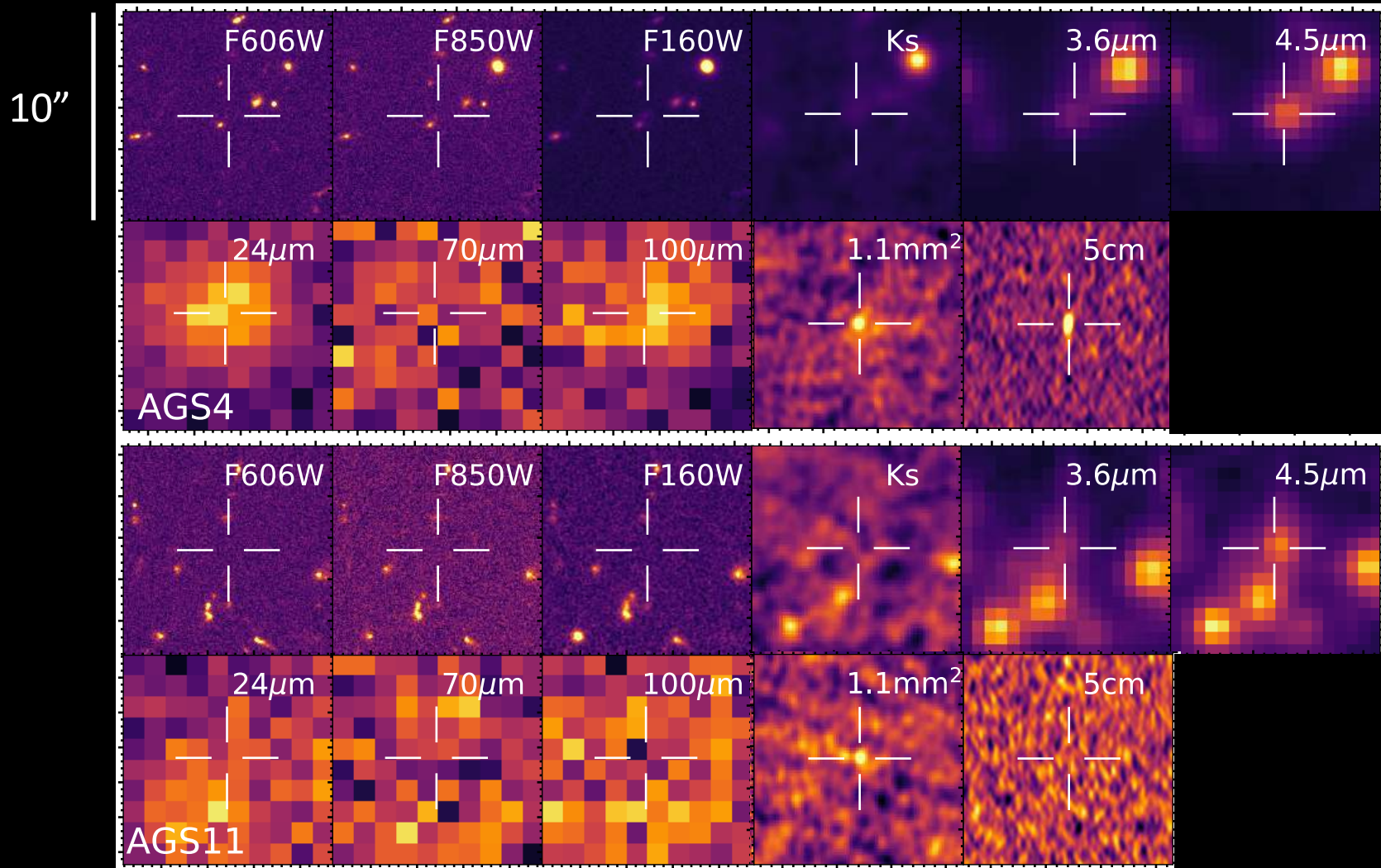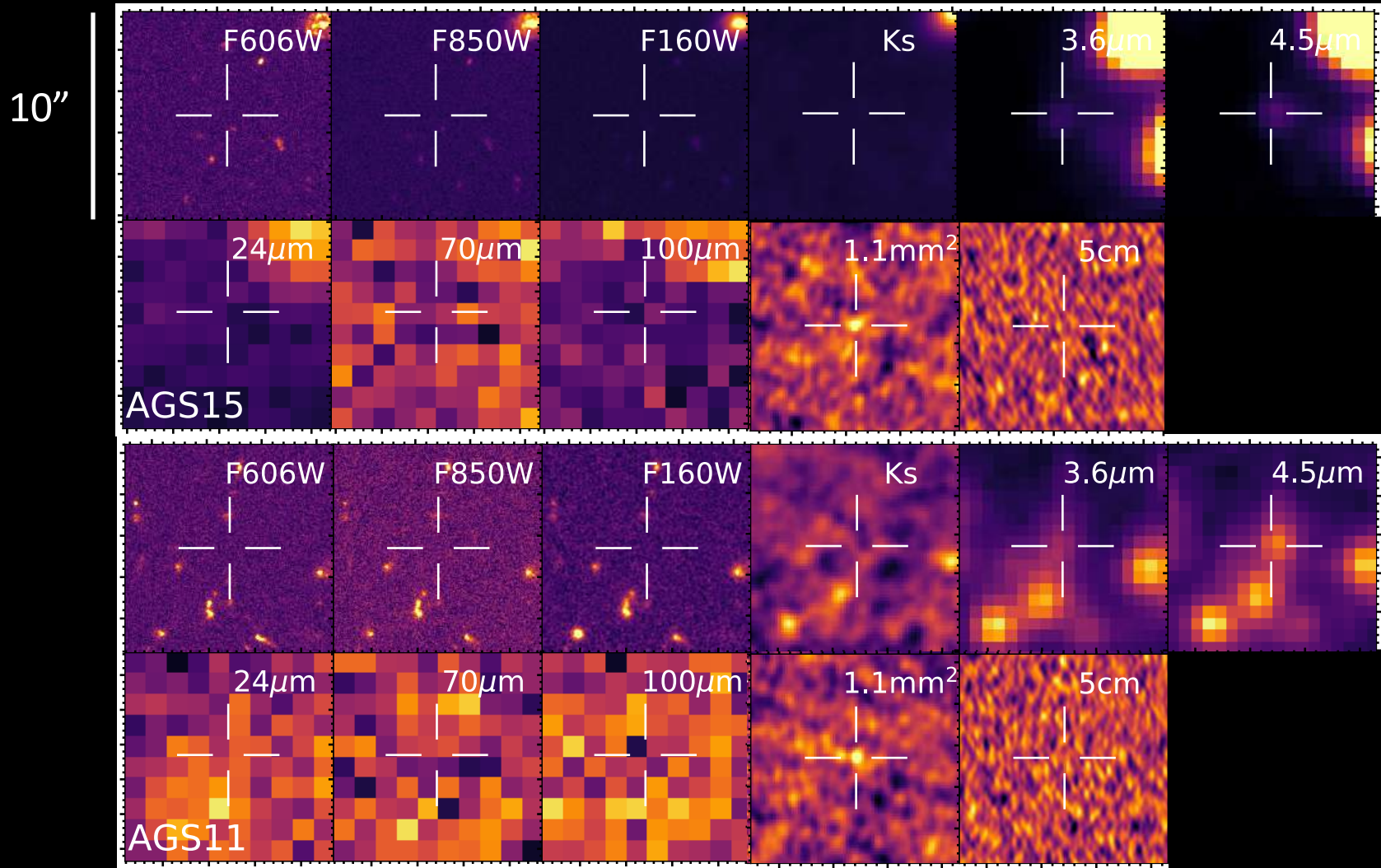# What is the nature of the ALMA detected galaxies ?
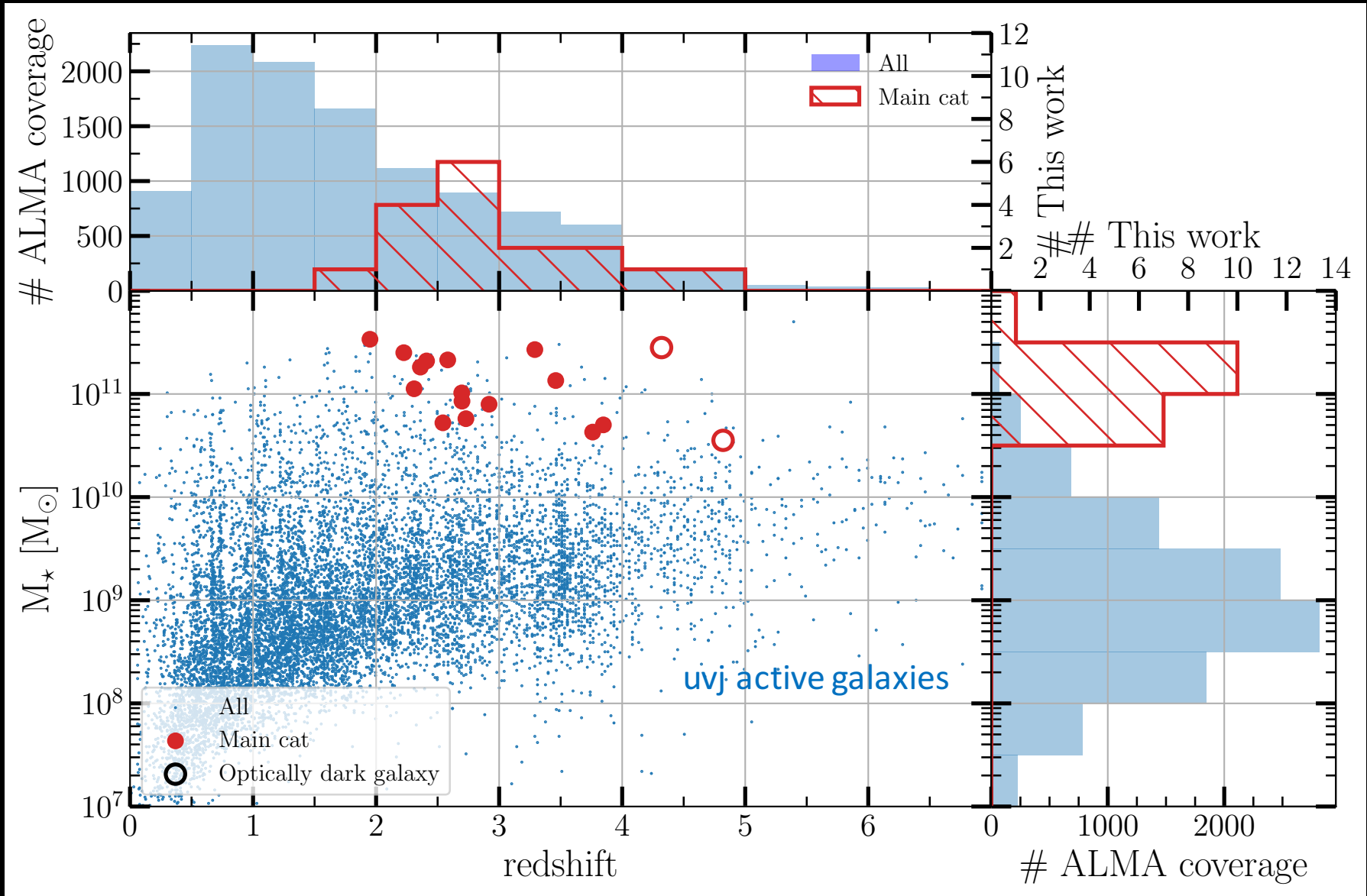
ALMA detects distant massive SFGs

ALMA detects distant massive SFGs

100 % of detected galaxies
$M_* > 3 \times 10^{10}$ M_{sun}
~ 50 % of detected galaxies
$M_* > 10^{11}$ M_{sun}

ALMA detects distant massive SFGs

The most massive galaxy in the GOODS-South field at $4 < z < 5$
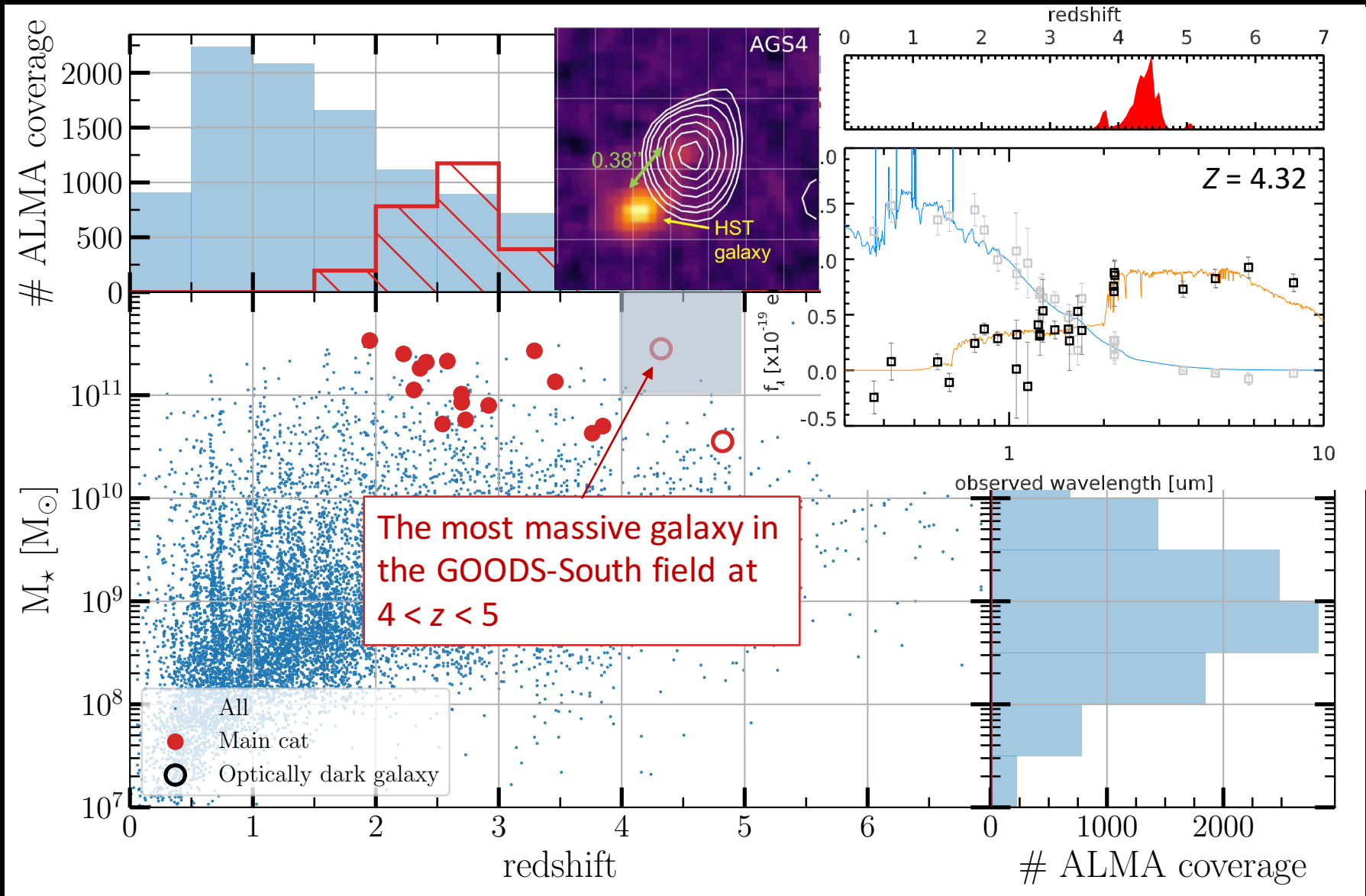
ALMA detects distant massive SFGs

Redshift distribution
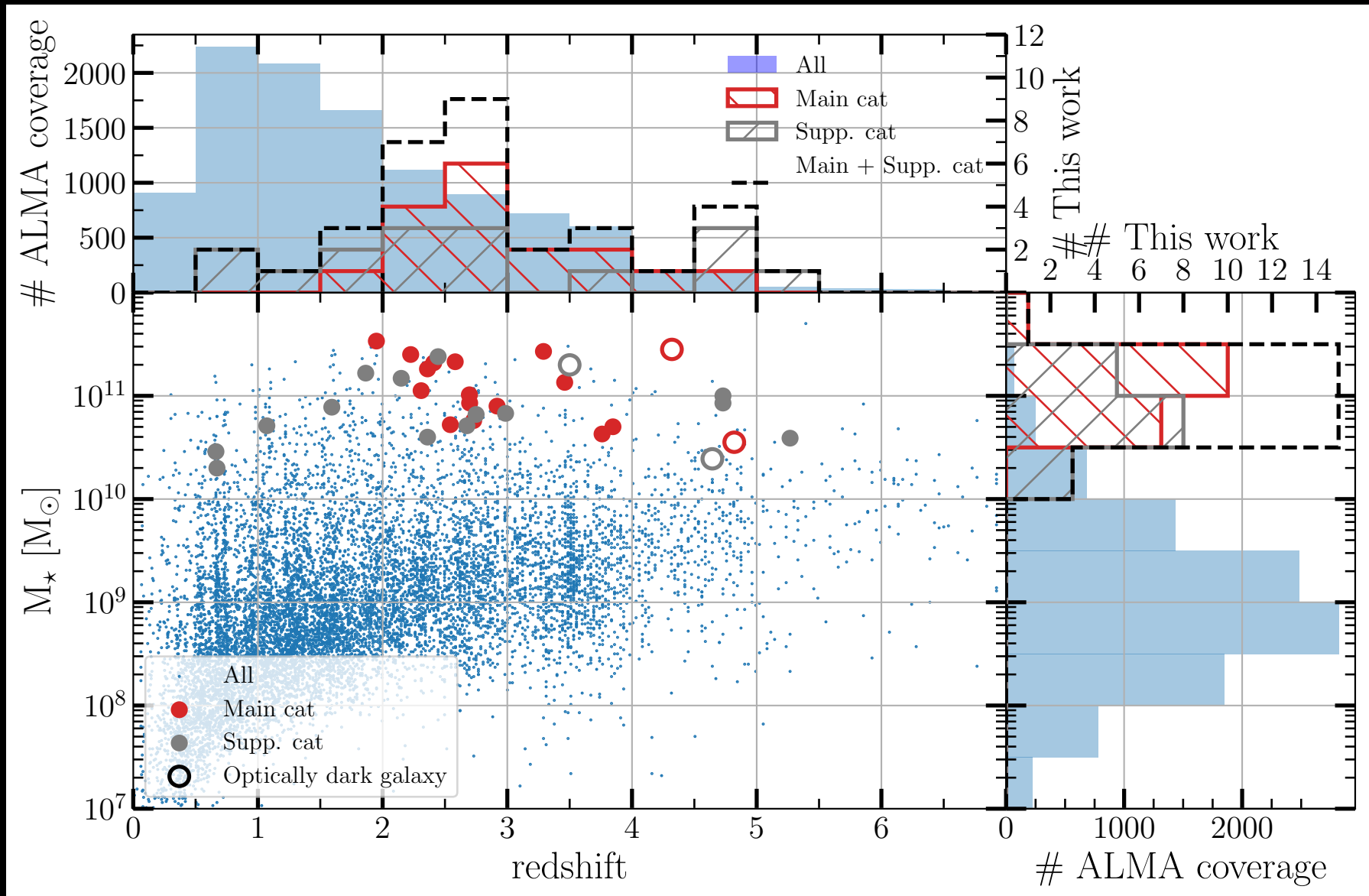
Redshift distribution

Median redshift

Opening of a new
parameter space at z > 3

Partly or totally missed in
smaller blind surveys

Even if our survey is
shallower :
Our rms ~ 180μJy

ALMA detects compact galaxies

- Flux extraction & size stacking reveals that galaxies are compact
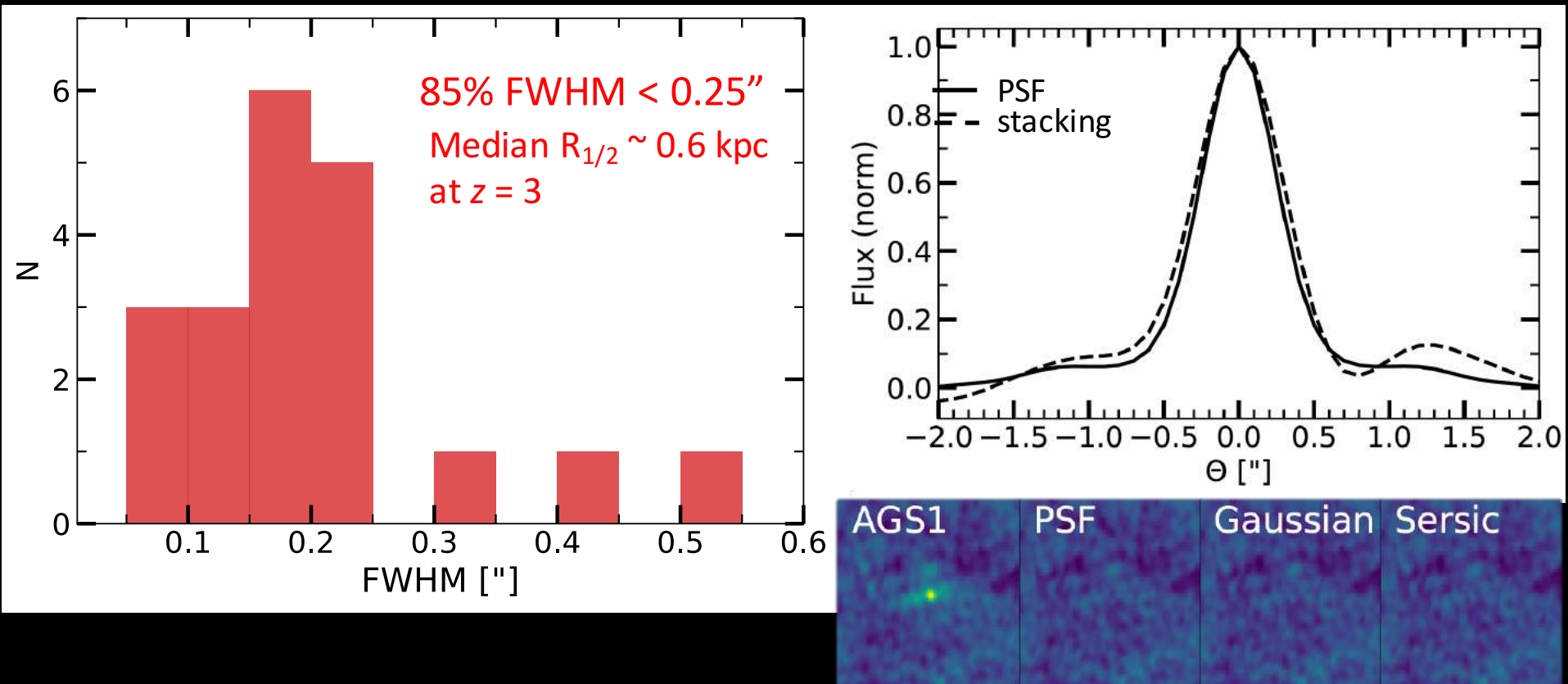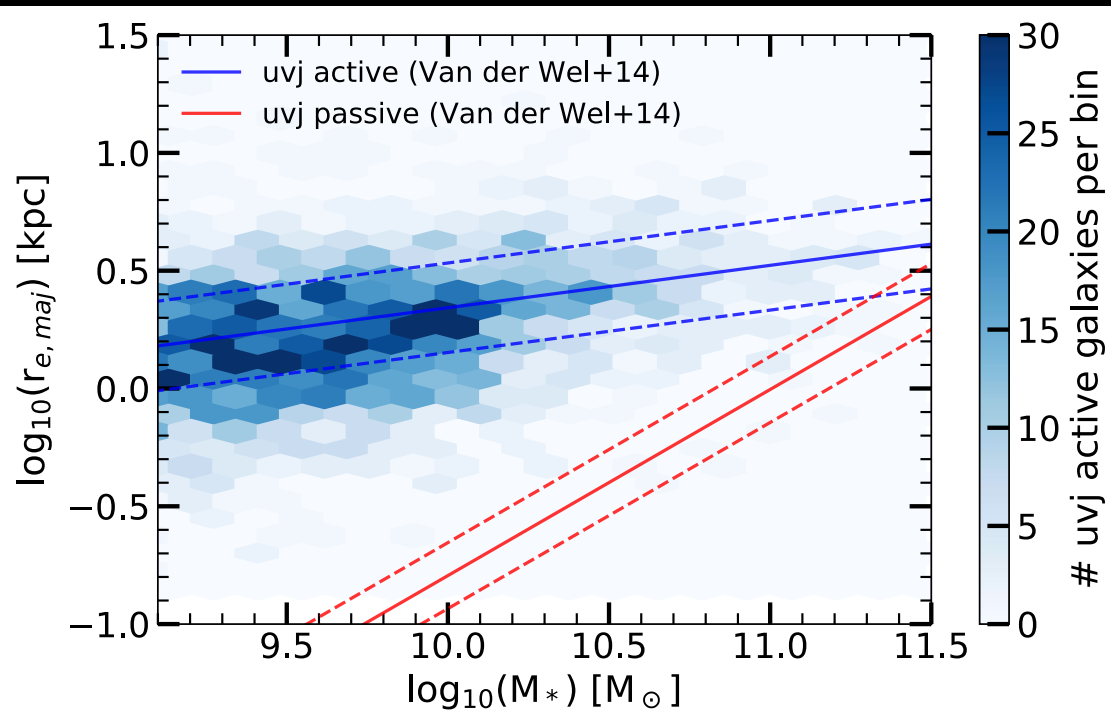
85% FWHM < 0.25"
Median $R_{1/2}$ ~ 0.6 kpc
at z = 3

UV rest-frame size

H-band sizes 2<z<4
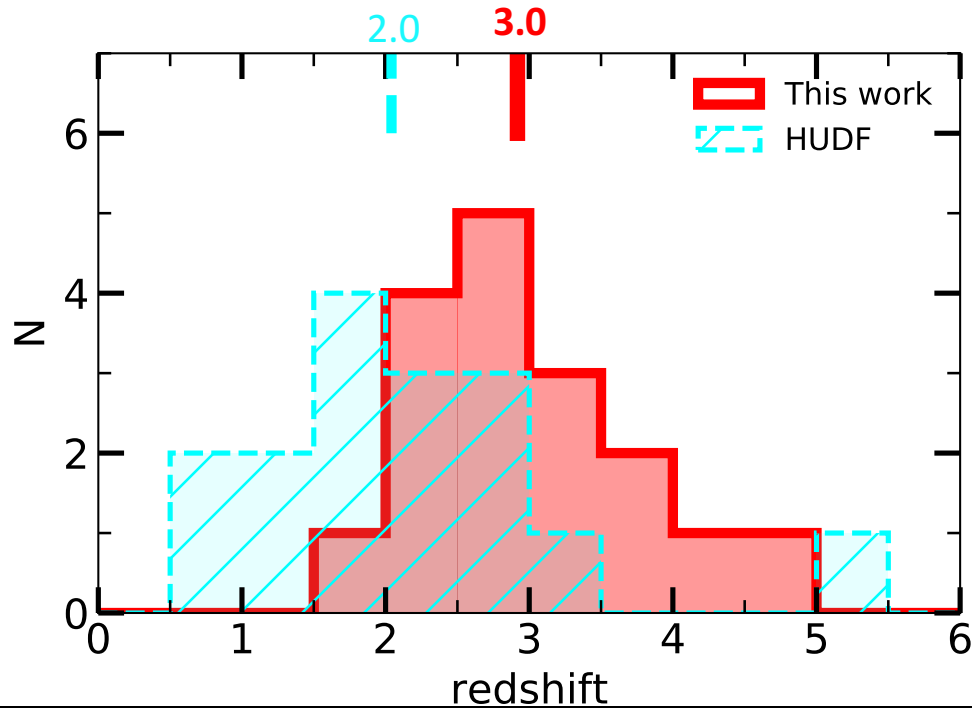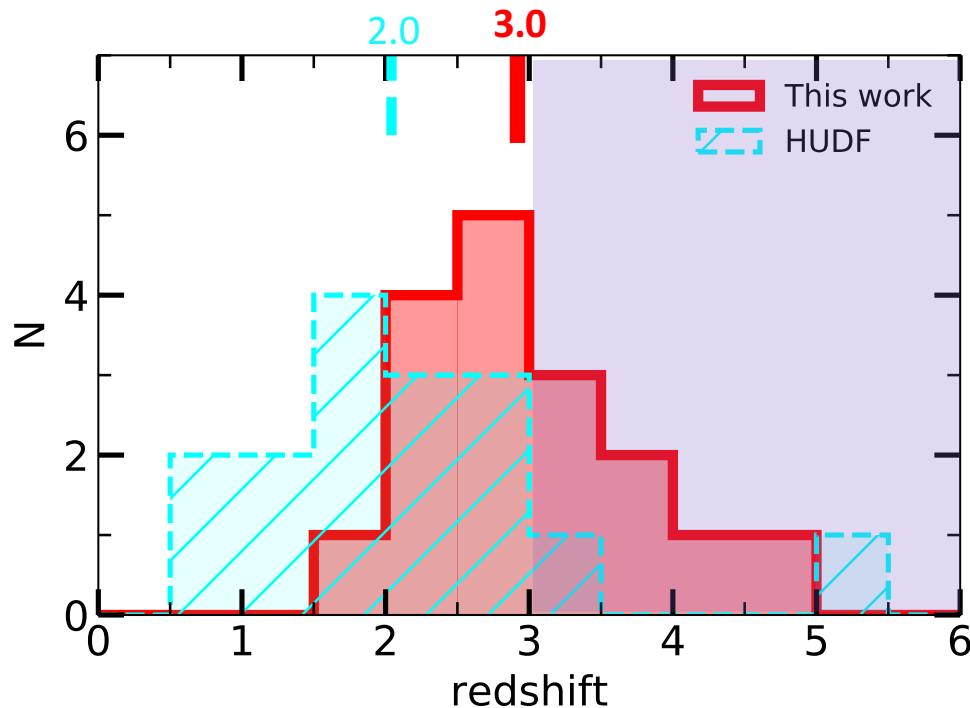
At z ~ 2.75 (Van der Wel+14)

Early-type Galaxies
$R_e = (0.87 \pm 0.06) (M_*/5 \times 10^{10} M_\odot)^{(0.79 \pm 0.07)}$

Late-type Galaxies
$R_e = (3.23 \pm 0.06) (M_*/5 \times 10^{10} M_\odot)^{(0.18 \pm 0.02)}$

UV rest-frame size

H-band sizes 2<z<4

At z ~ 2.75 (Van der Wel+14)

Early-type Galaxies
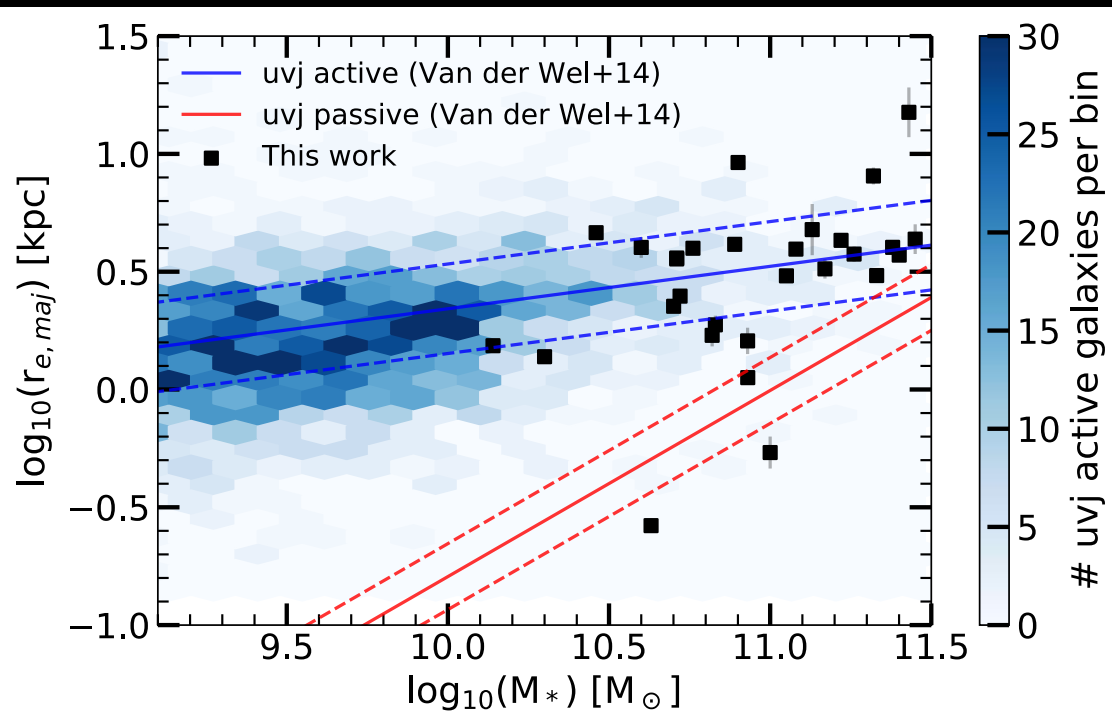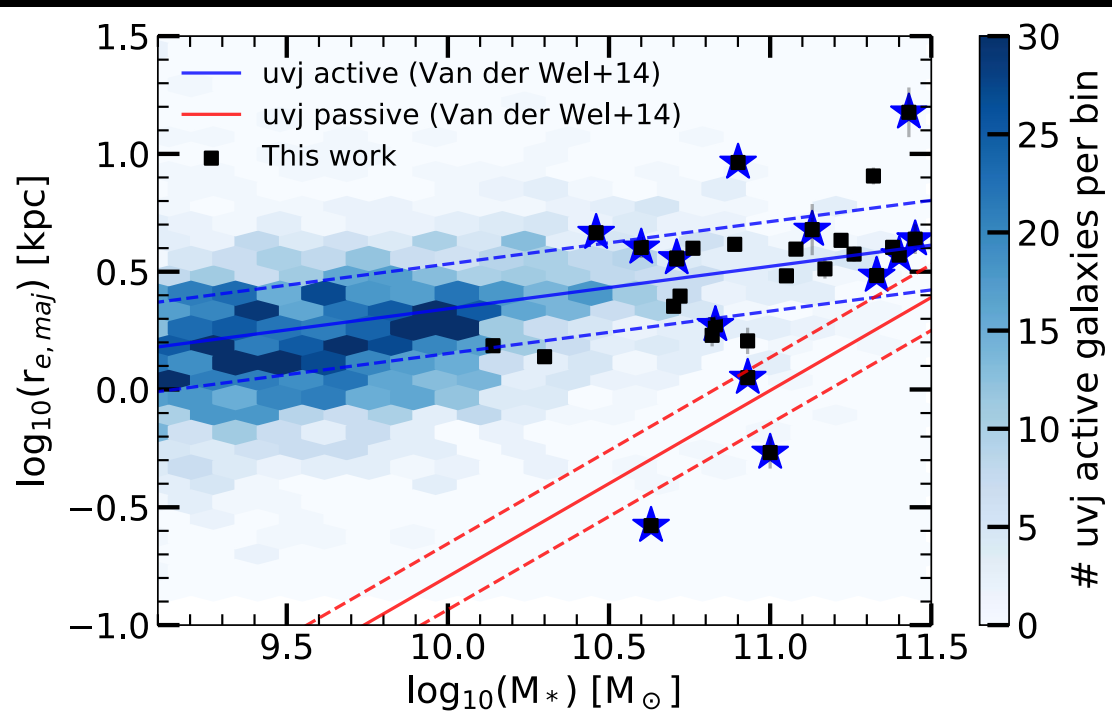$R_e = (0.87 \pm 0.06) \, (M_*/5 \times 10^{10} \, M_\odot)^{(0.79 \pm 0.07)}$

Late-type Galaxies
$R_e = (3.23 \pm 0.06) \, (M_*/5 \times 10^{10} \, M_\odot)^{(0.18 \pm 0.02)}$

UV rest-frame size

AGN $\left\{ \begin{array}{l} L_X > 10^{43} \text{ erg.s}^{-1} \\ \text{or} \\ \Gamma_{eff} < 1.0 \text{ (hard X-ray sources)} \end{array} \right.$
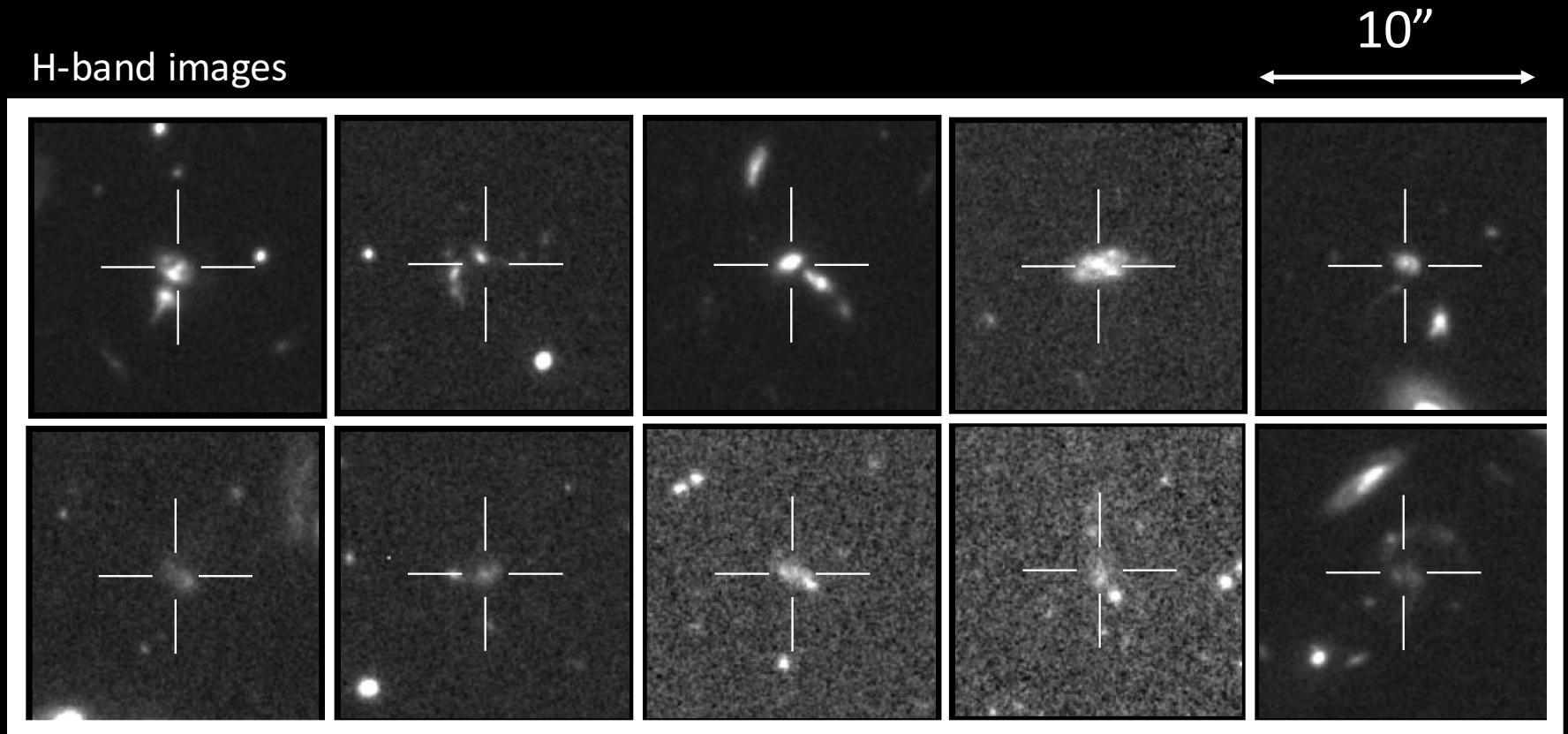
Sérsic index :
active   = 1.35
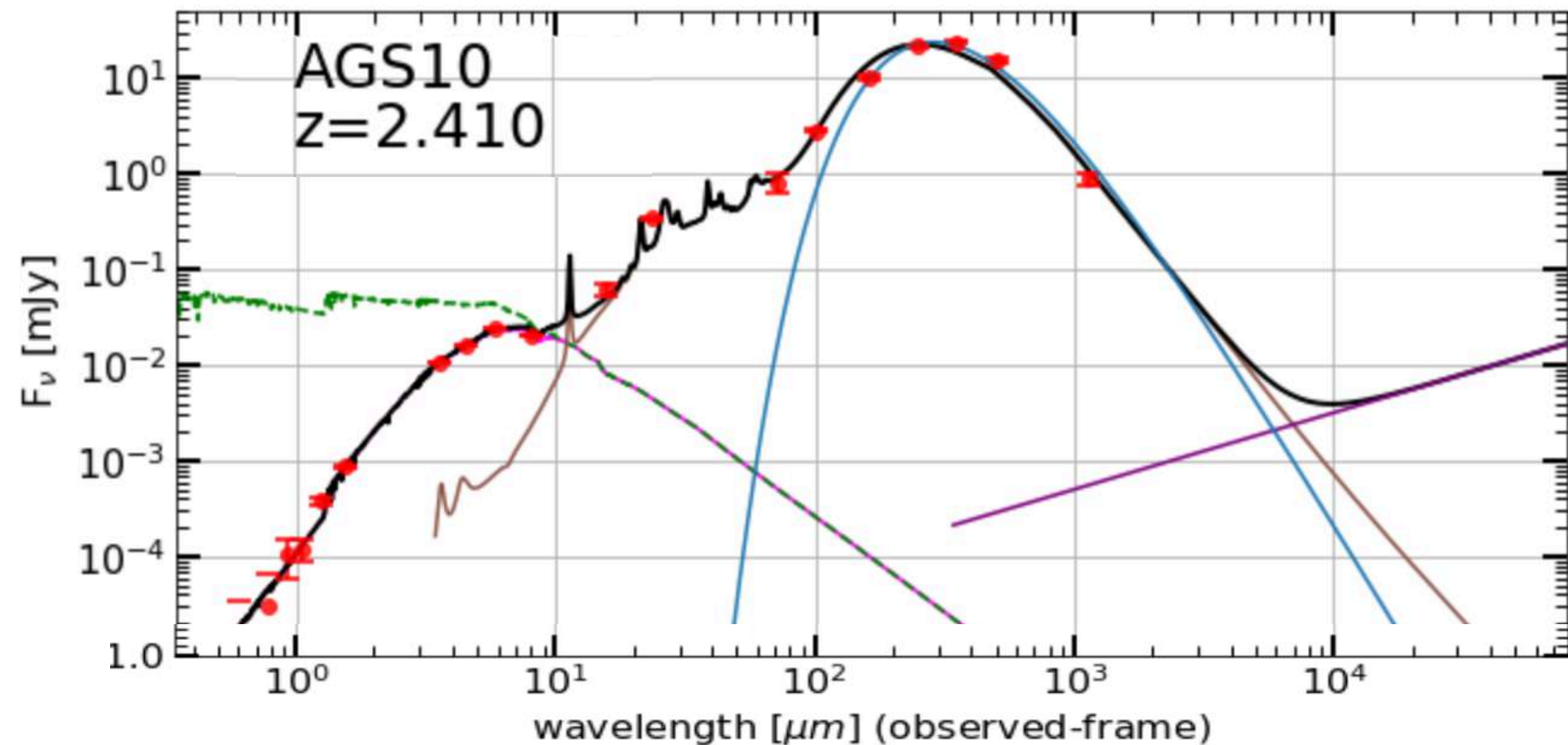quiescent   = 2.63
ALMA detected   = 1.08

If progenitors of z ~ 2 quiescent galaxies,
they need to increase their Sérsic indices
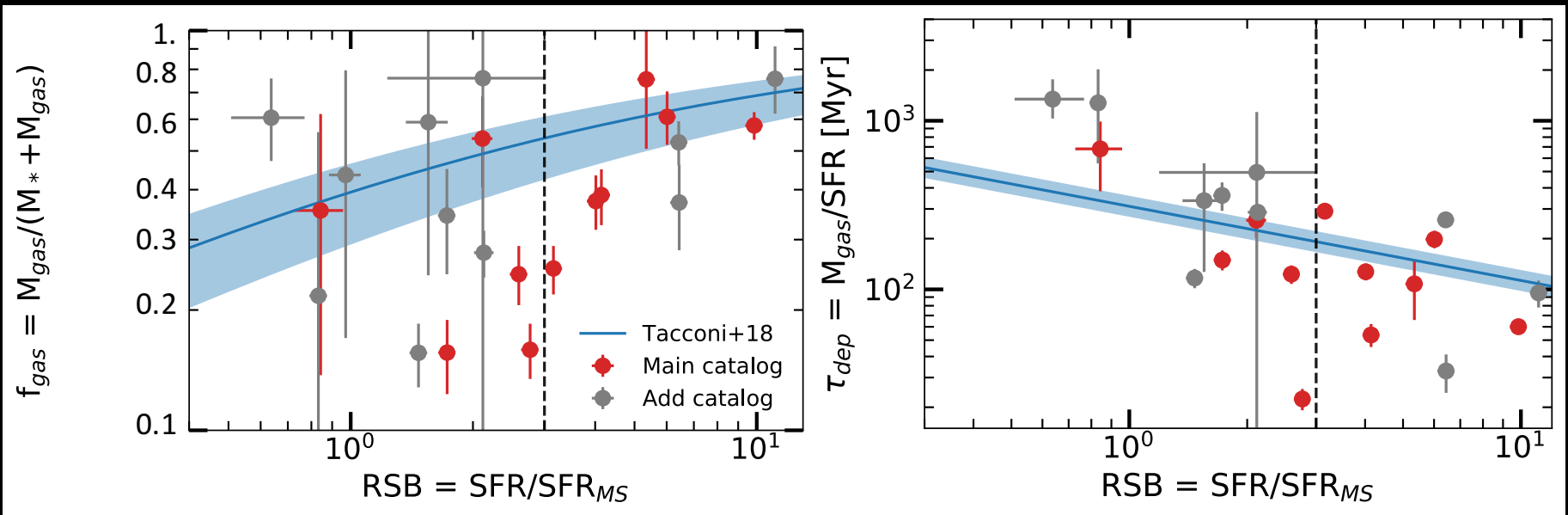
Morphology of the galaxies

H-band images

Between 1/4 and 1/3 of the ALMA-detected galaxies show evidence of merging, a disturbed morphology or are very clumpy.
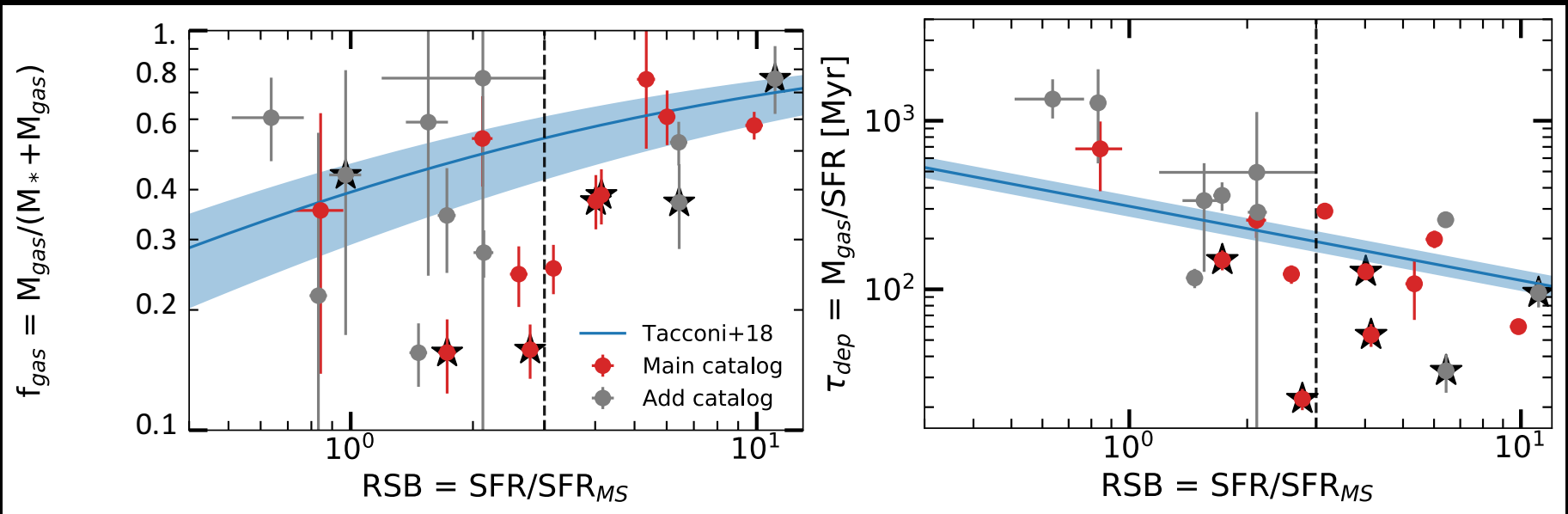
SED fitting improved thanks to the new Astrodeep Herschel catalog
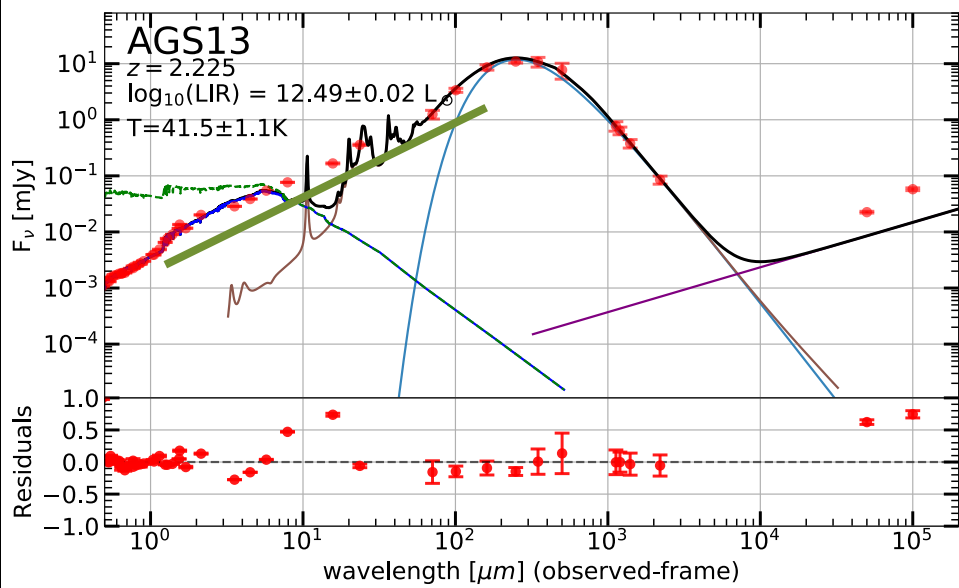
Gas fraction and depletion time
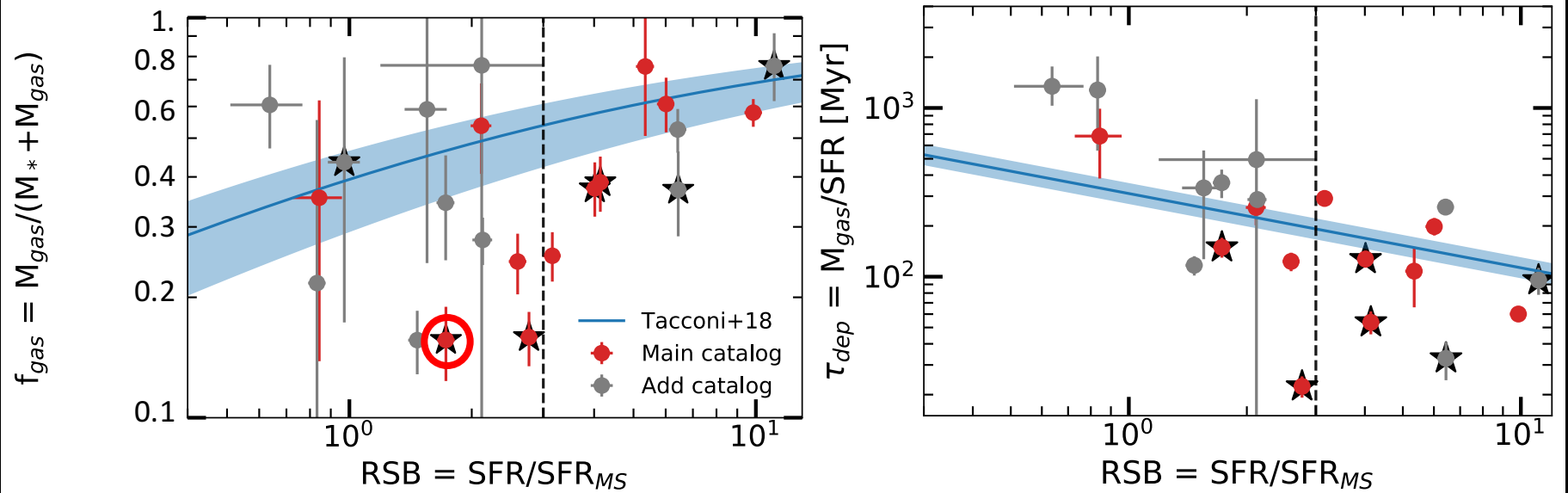
Gas fraction and depletion time

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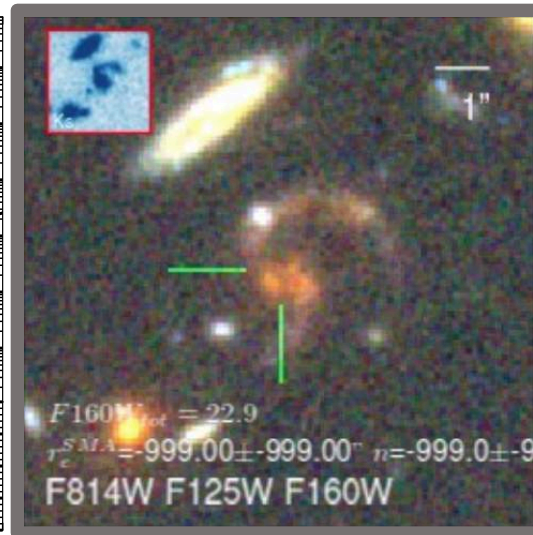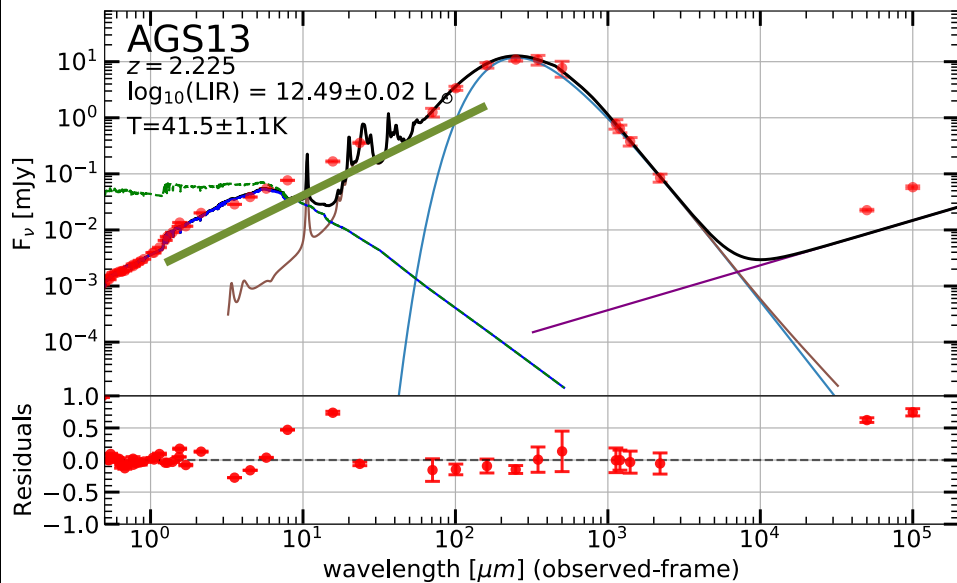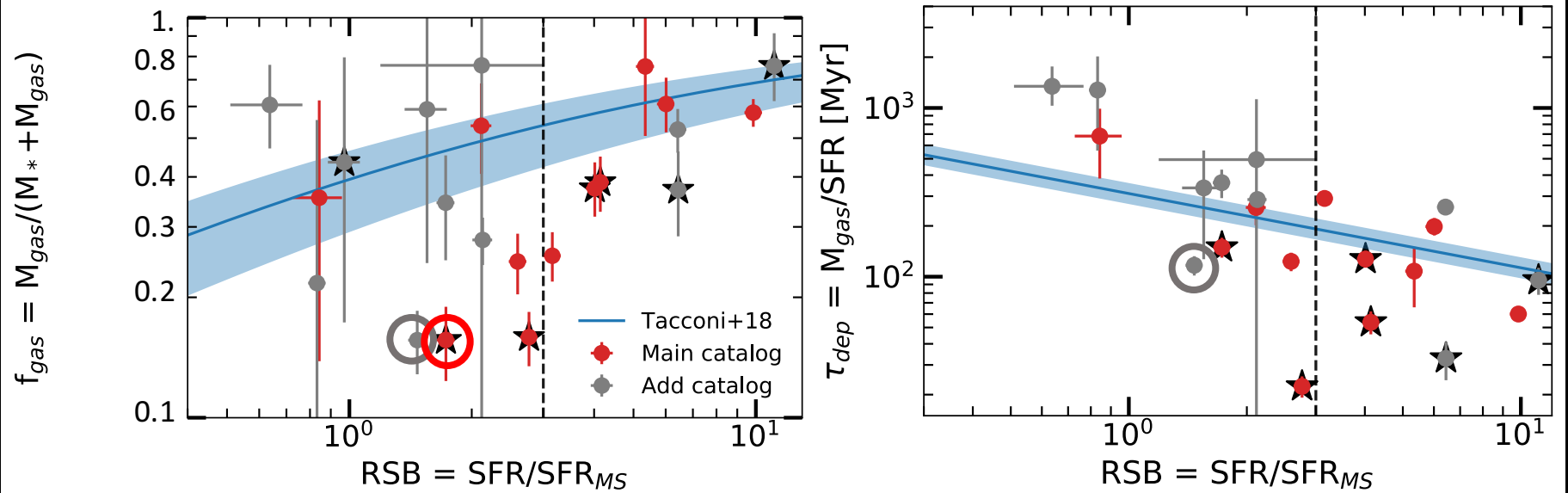
SFR density/depletion time
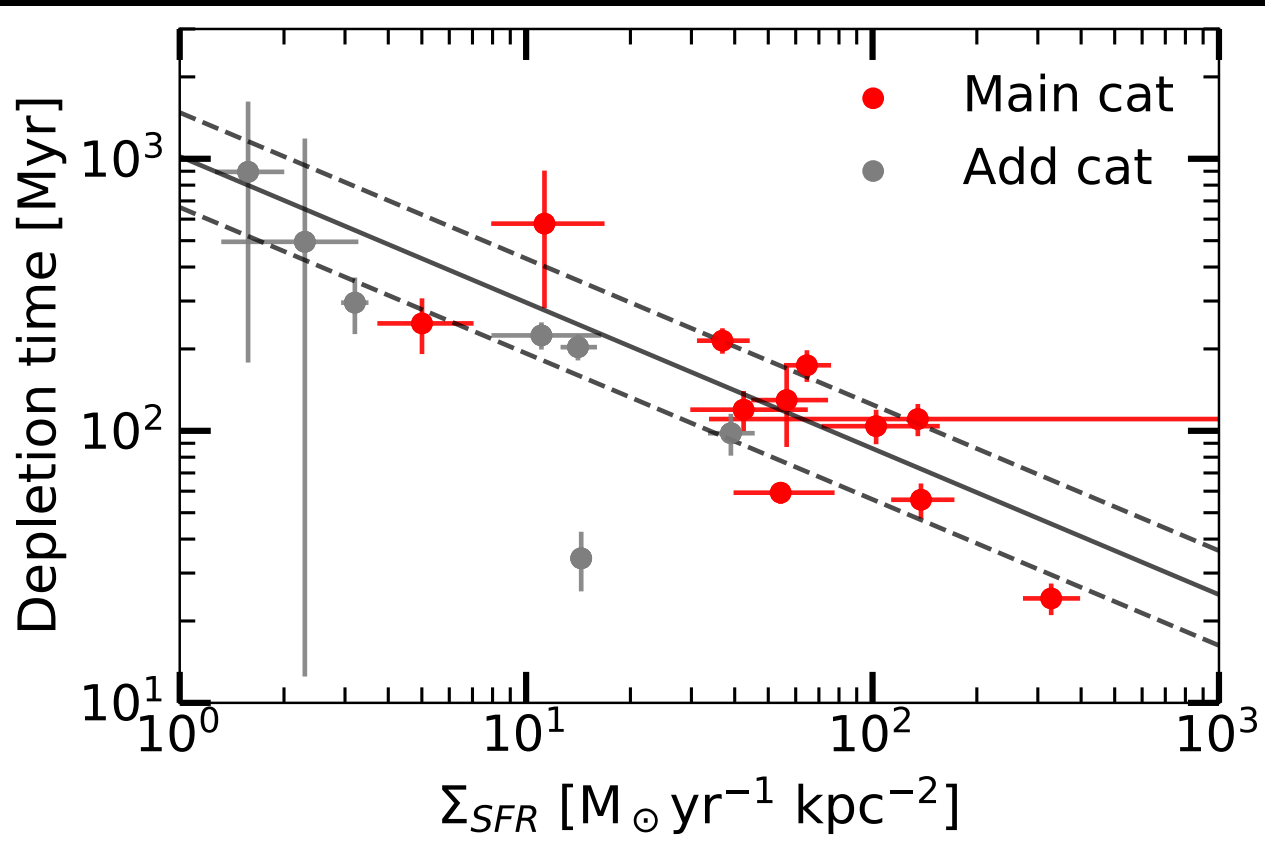
$$\Sigma_{SFR} = \frac{SFR}{2\pi R_e{}^2}$$

size from ALMA

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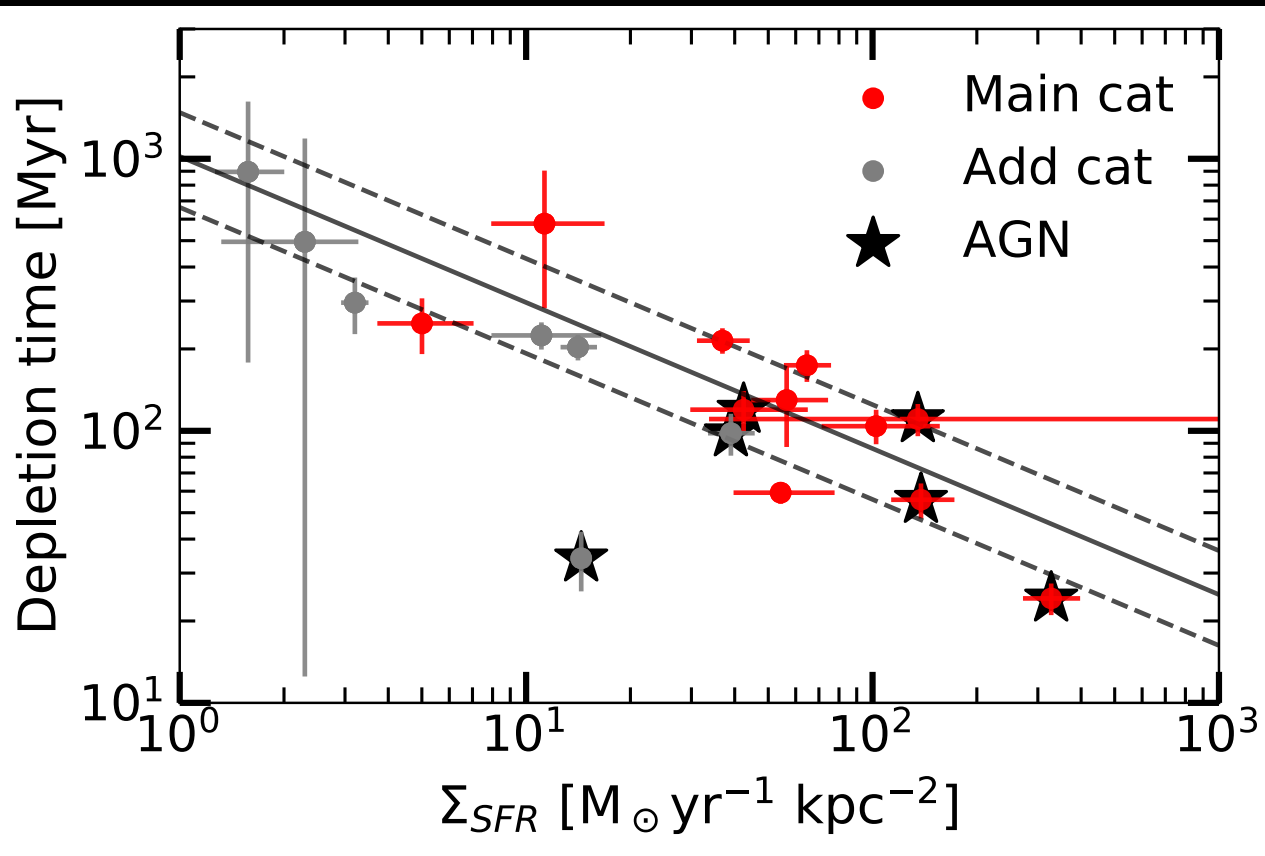
$$\Sigma_{\mathrm{SFR}} = \frac{\mathrm{SFR}}{2\pi \mathrm{R_e}^2}$$

size from ALMA

(Sub)Millimeter Survey
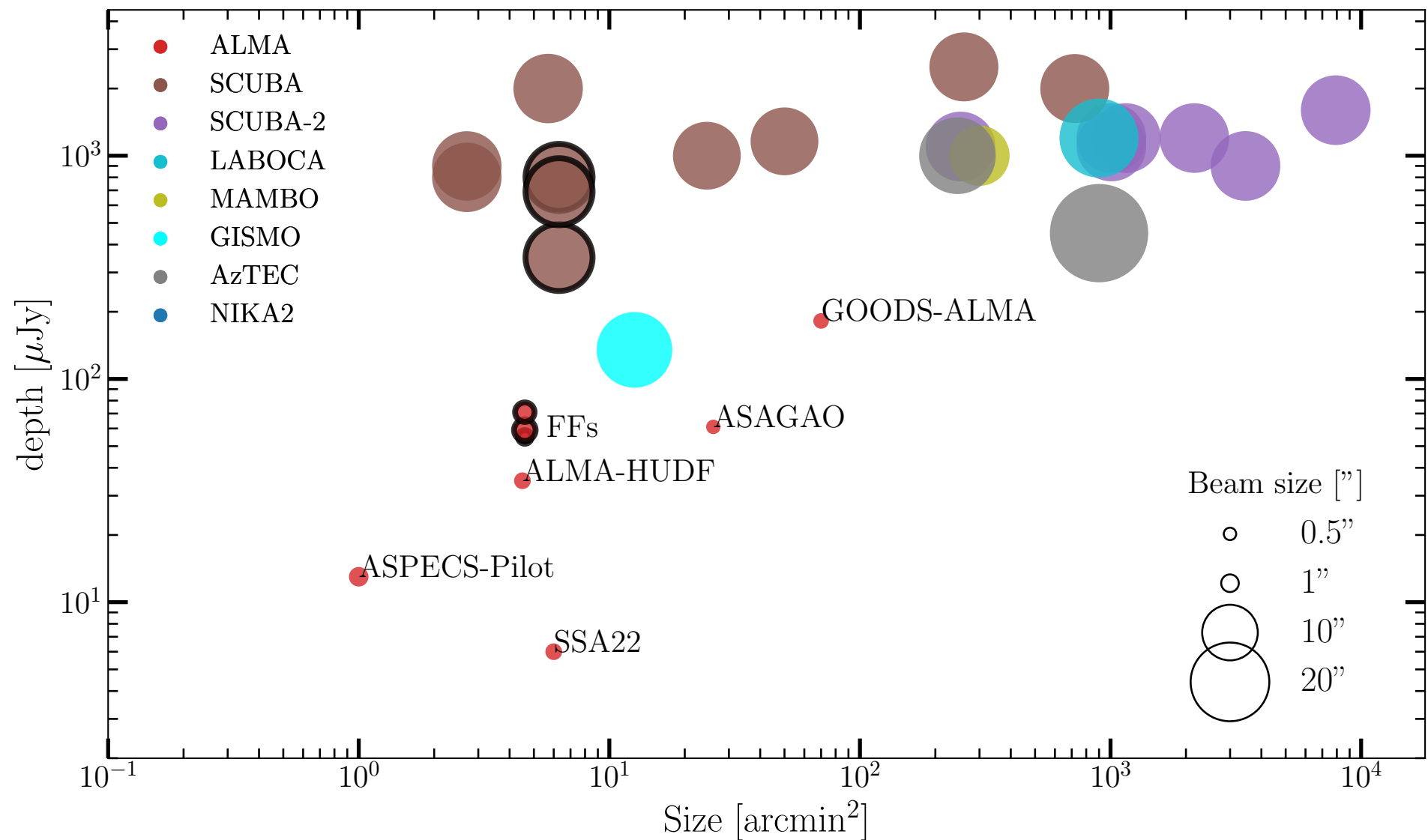
(Sub)Millimeter Survey

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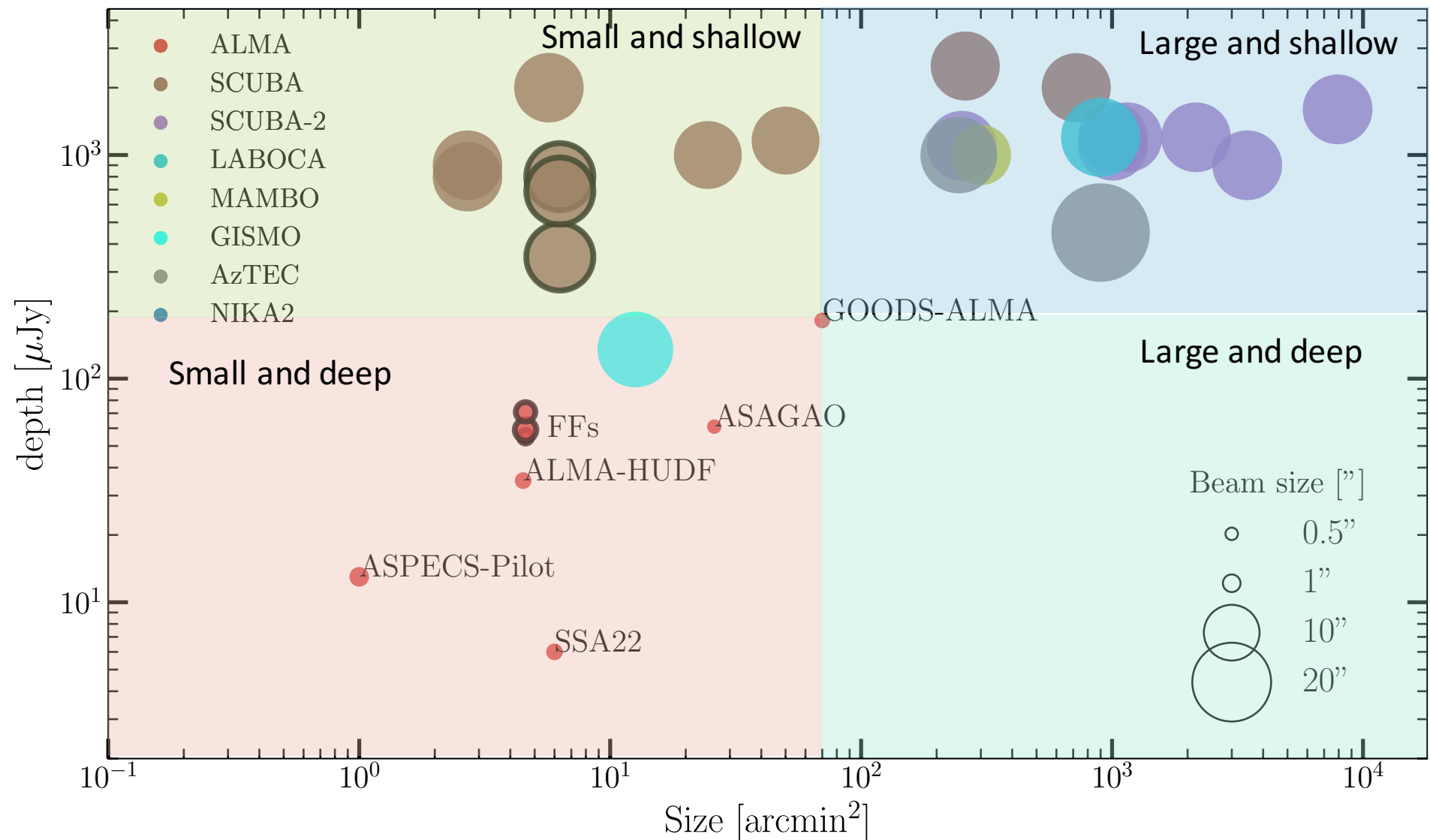
(Sub)Millimeter Survey
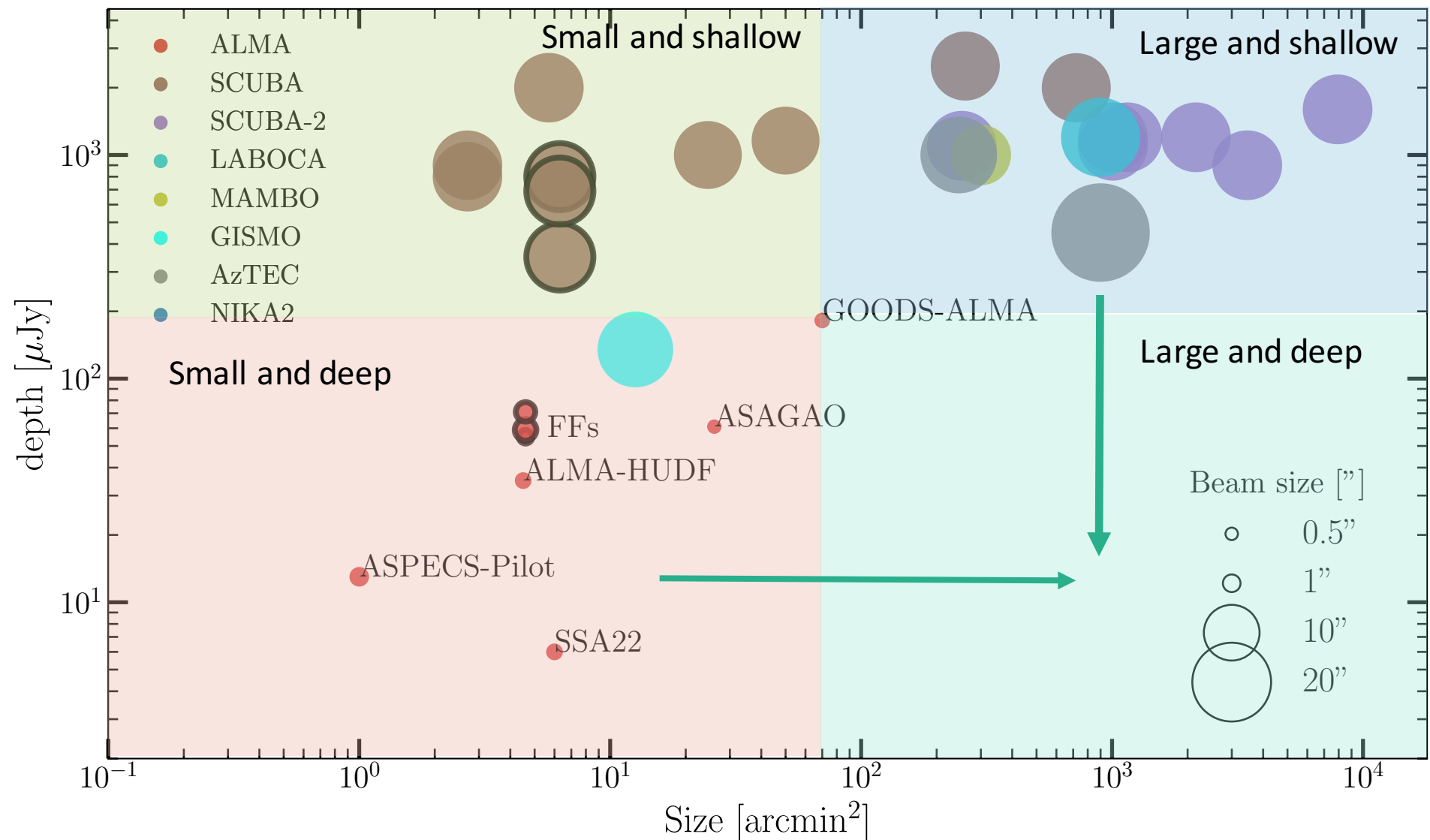
(Sub)Millimeter Survey
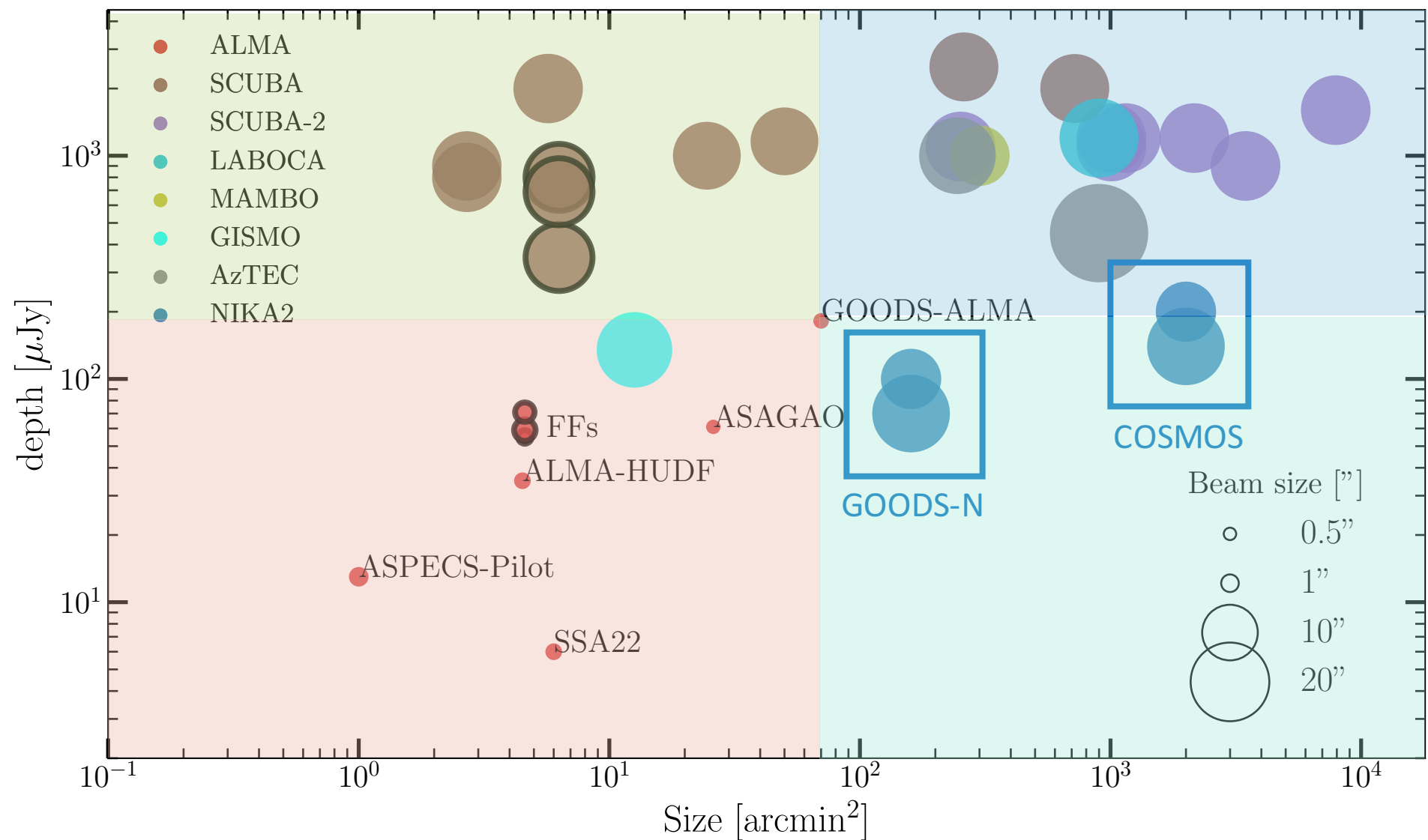
(Sub)Millimeter Survey
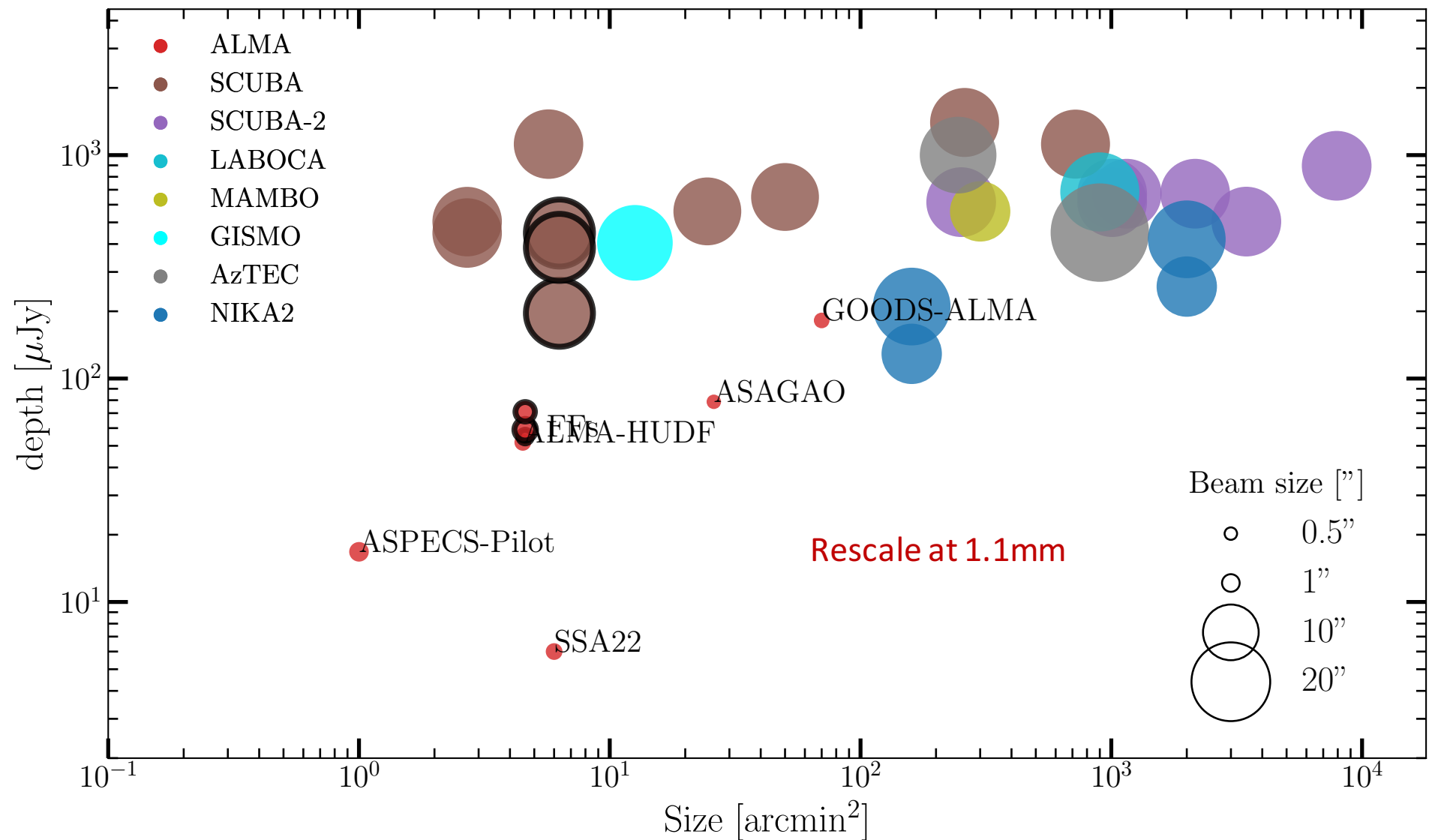
Why it's so important to go wide

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- To go deeper in redshift among the most massive galaxies

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- Despite the fact these sources have a low projected surface density, they are clustered. A wide field allows us to:
  - To have enough sources to study their statistics
  - To go further in redshift
  - To find more candidate protoclusters

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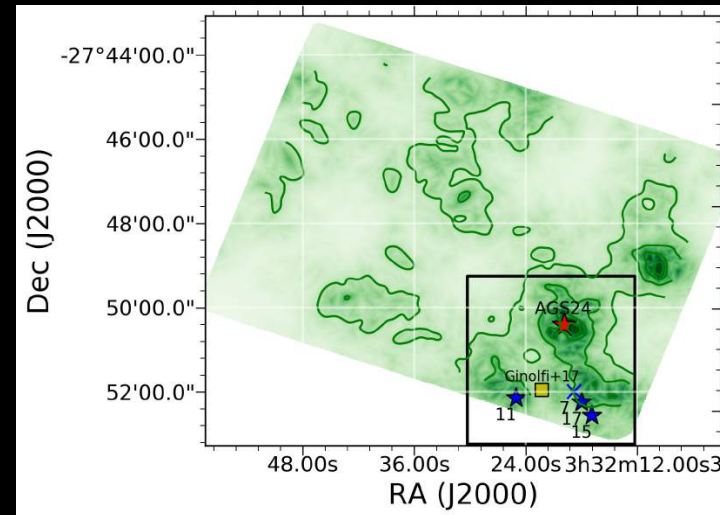
- Not possible with ALMA -> NIKA2

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- Because we know the general properties of optically-dark galaxies ([H] – [4.5] < 2.25), it becomes possible to detect most likely optically dark galaxies despite the size of the beam for follow-up