Strongly lensed galaxies in *Herschel* surveys
&
the identification of *Planck* extragalactic sources with *Herschel*

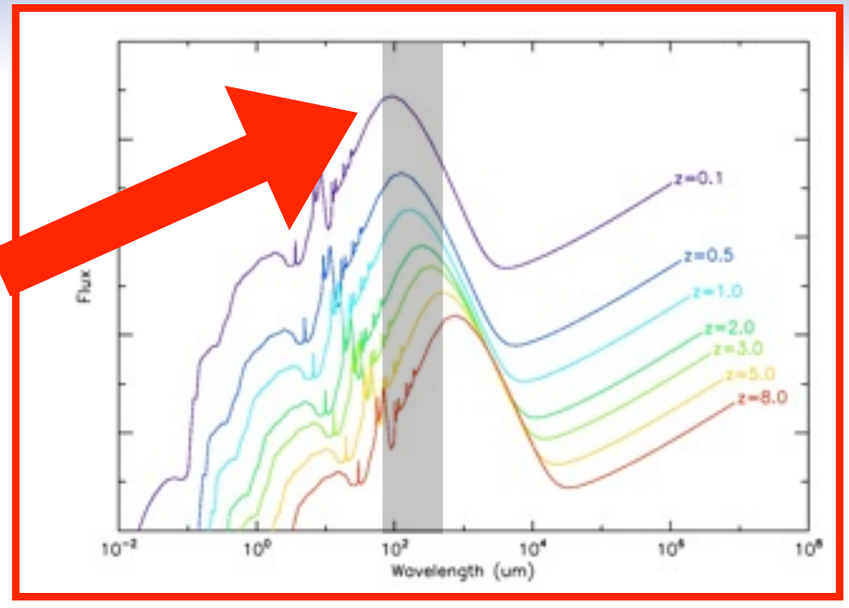
Julie Wardlow, Asantha Cooray (UC Irvine)
& the HerMES and H-ATLAS collaborations

HerMES & H-ATLAS

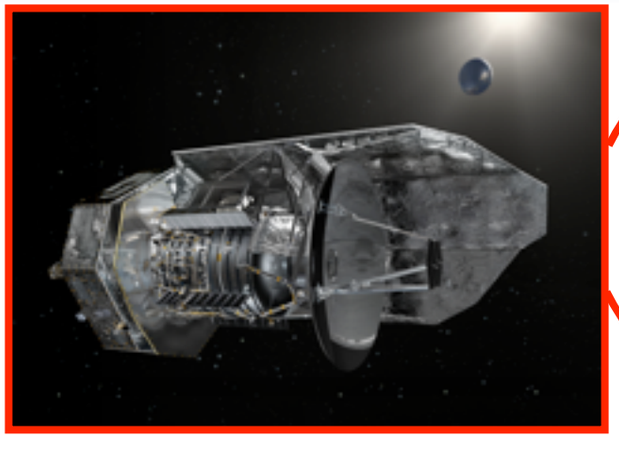
PACS @
70, 100,
160μm

SPIRE @
250, 350,
500μm

Probe the
dust peak



HerMES & H-ATLAS



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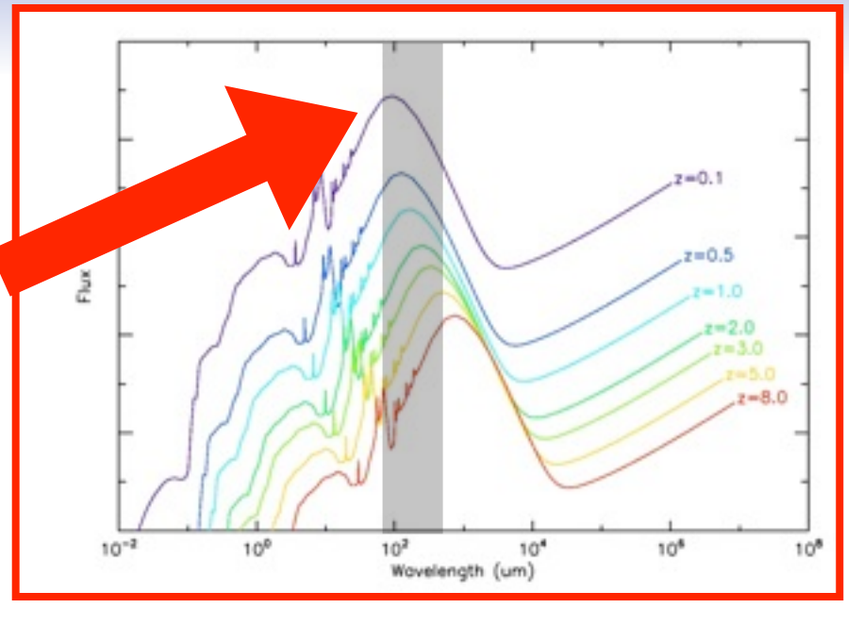
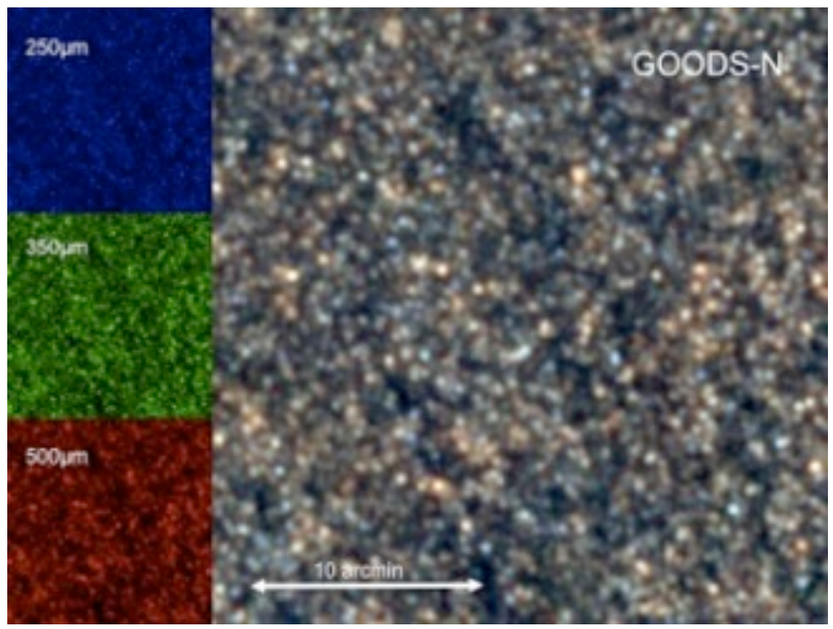


HERMES

***Herschel* Multi-tiered Extragalactic Survey**

- ~350 deg^2 when complete
- Wedding cake structure probes deep & wide areas
- "Famous" fields with existing deep multi-λ data (e.g. GOODS, CDFS, ELAIS, Boötes, + Clusters)



(Oliver et al.2012)

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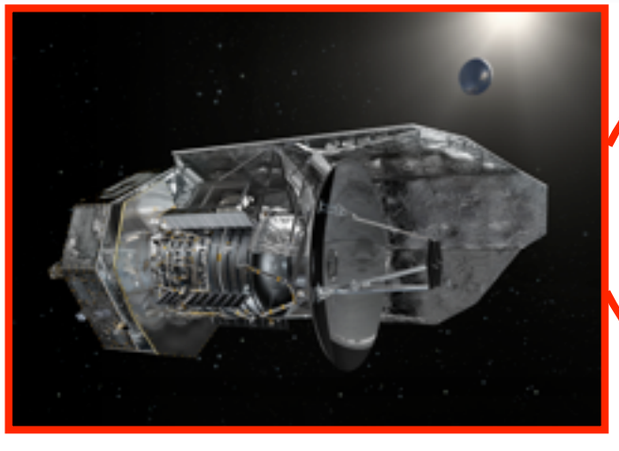

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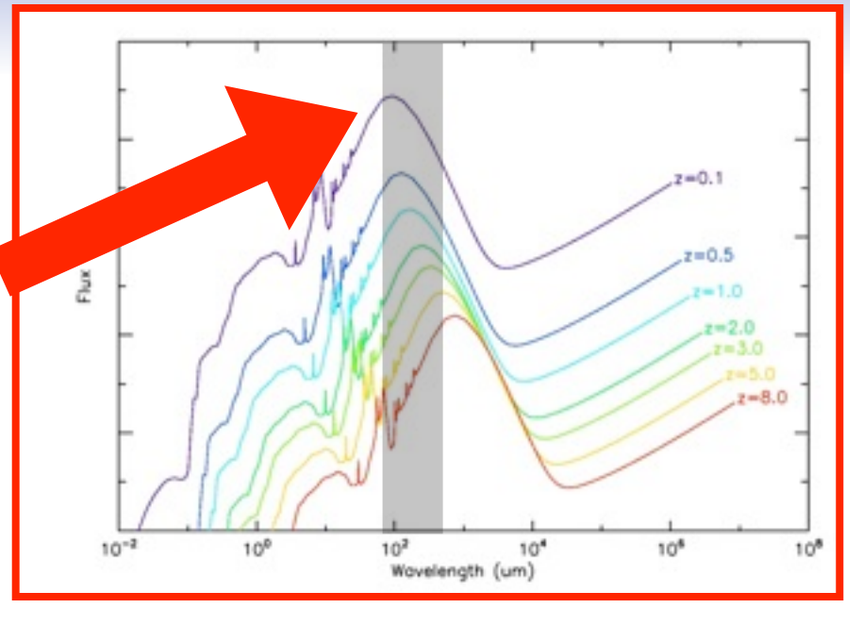

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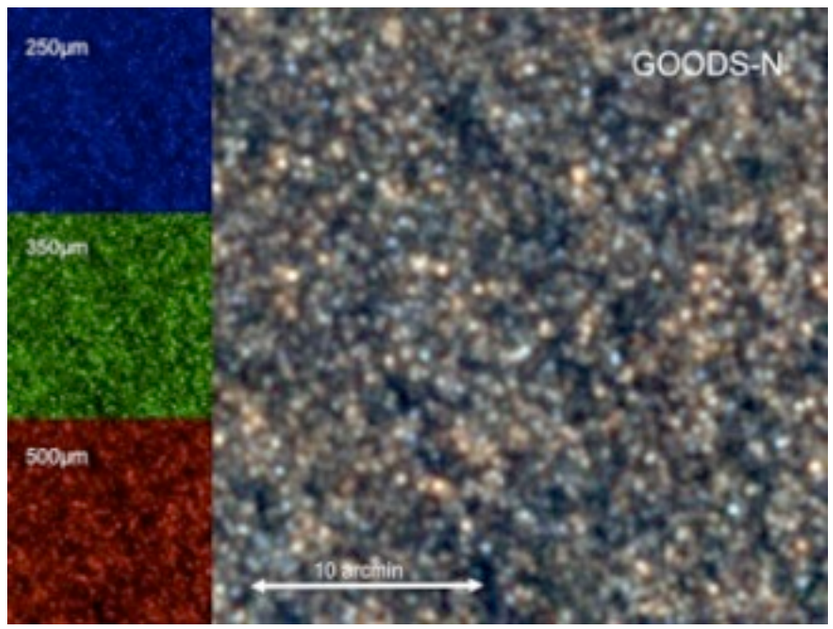
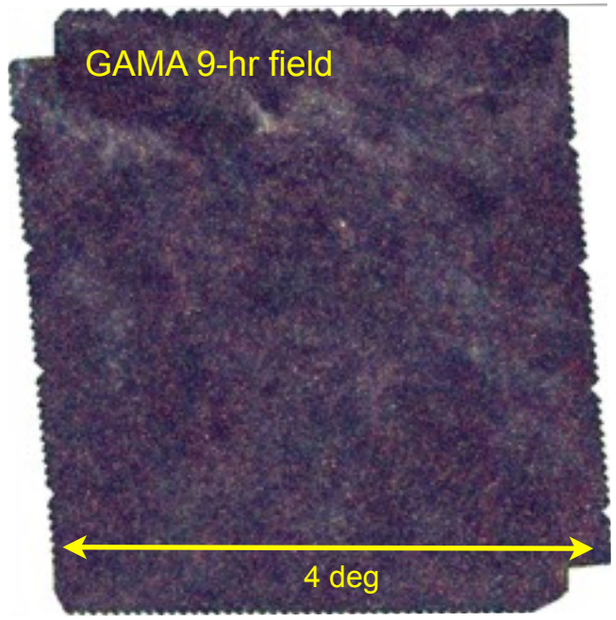


(Oliver et al.2012)

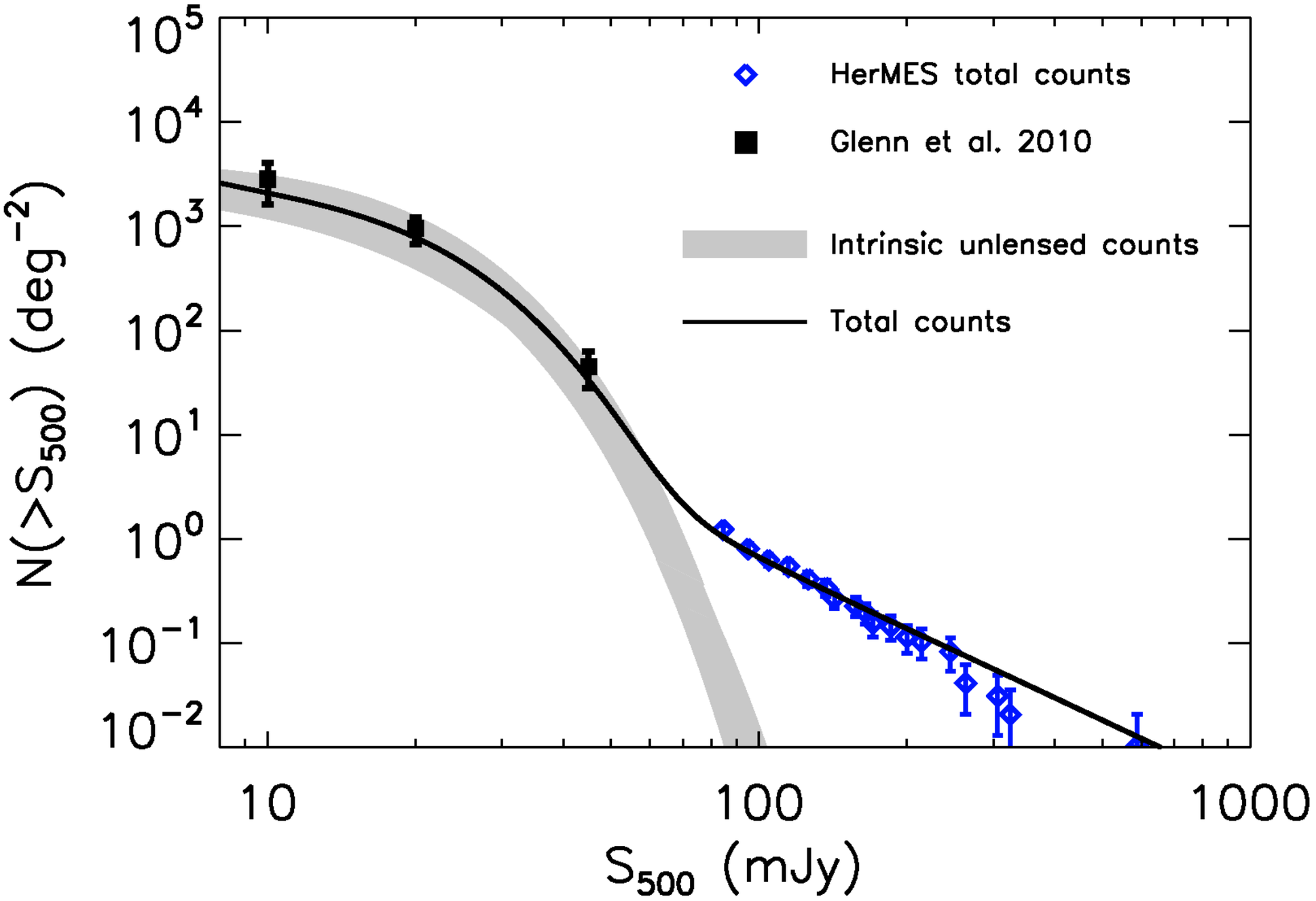
Herschel-Astrophysical Terahertz Large Area Survey

- Largest *Herschel* survey: 550 deg²
- Probes wide, shallow areas
- Well-studied large fields: (GAMA 9, 12 & 15hr fields; NGP & SGP)



(Eales et al. 2010)

The brightest 500μm sources are usually magnified



(Wardlow et al. in prep.)

(See also Negrello et al. 2010)

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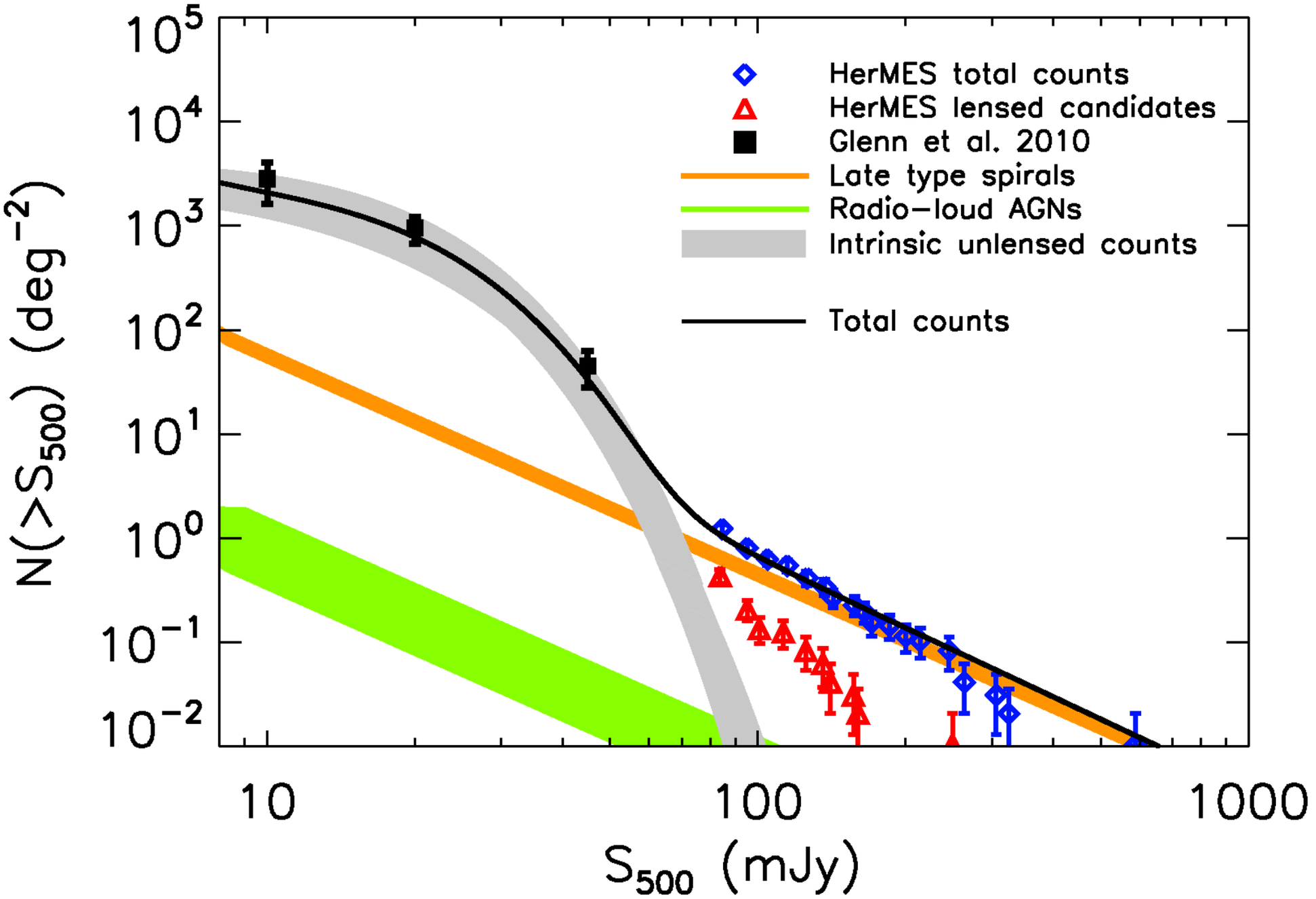

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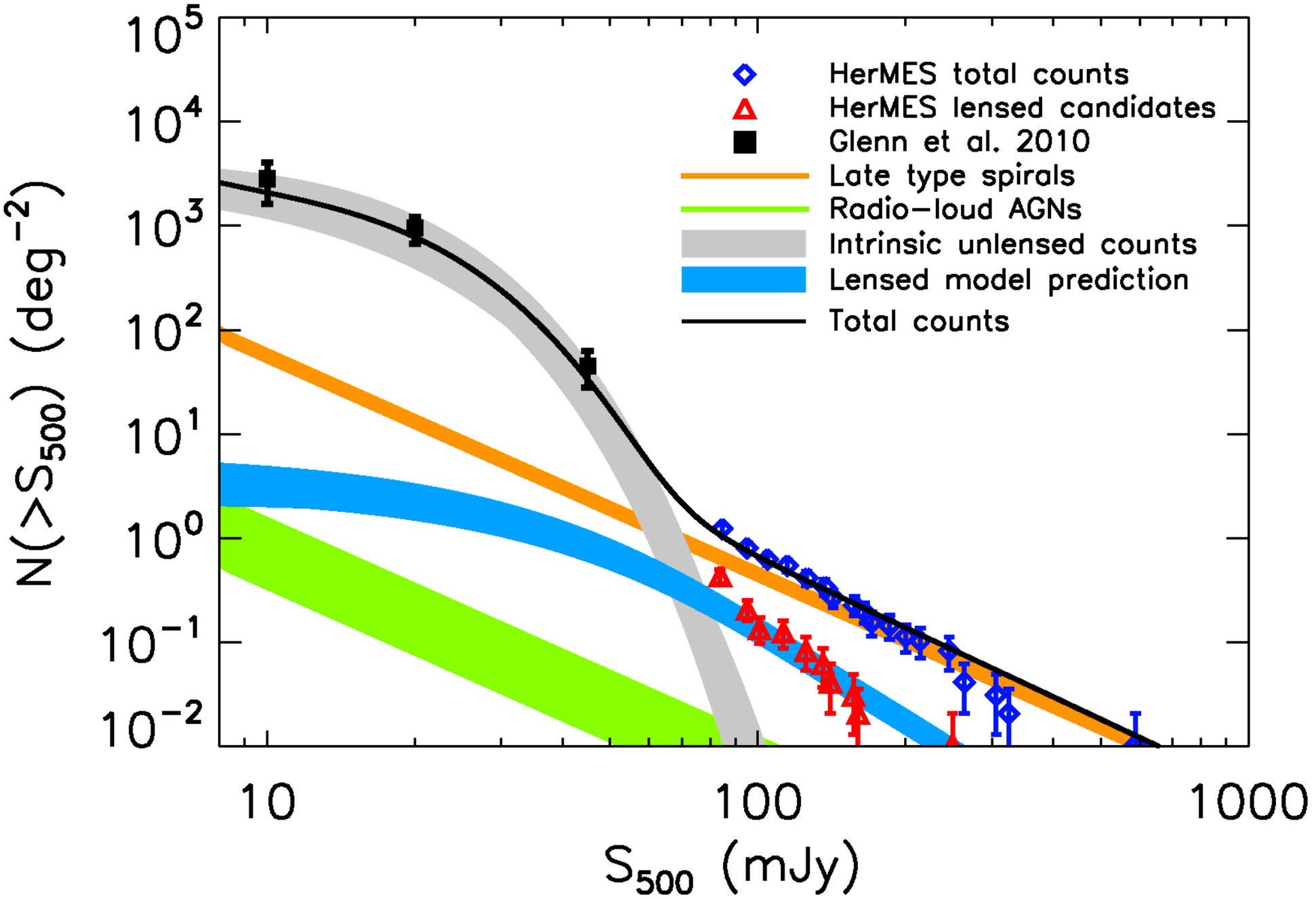

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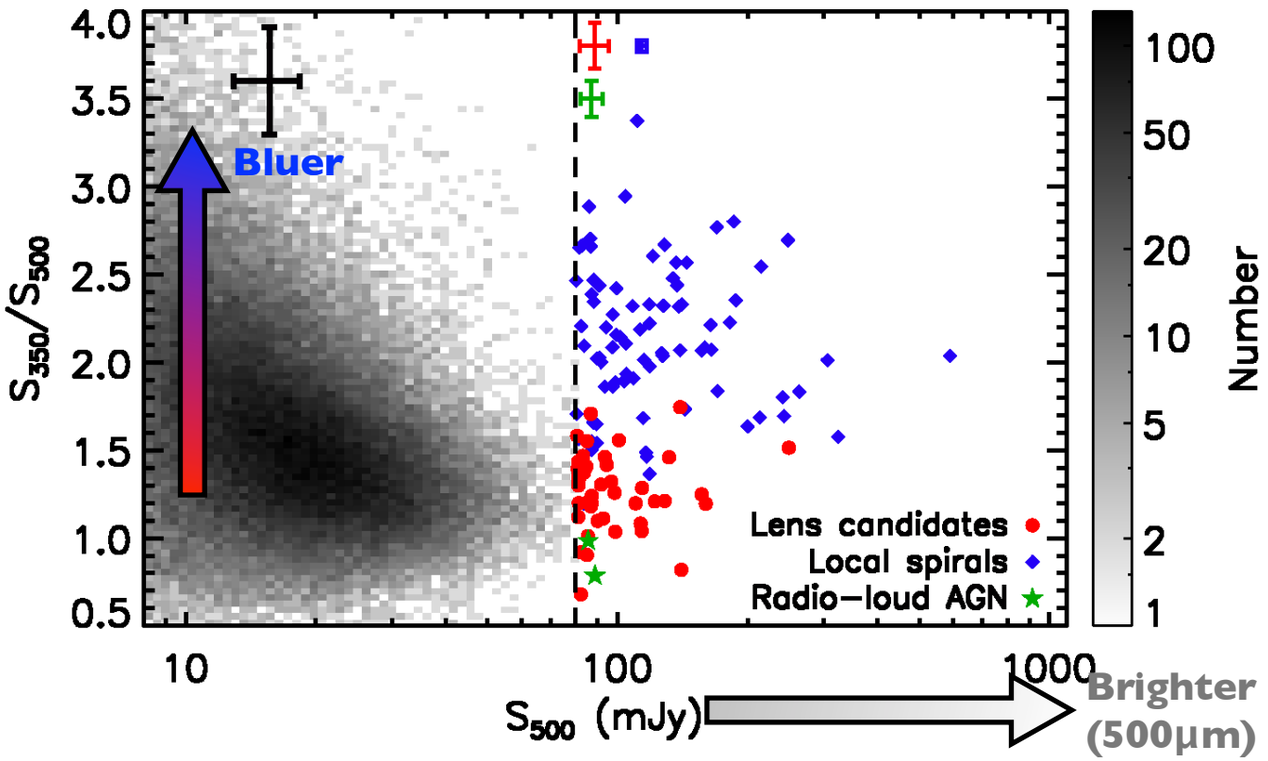
Lens candidates have red submm colours



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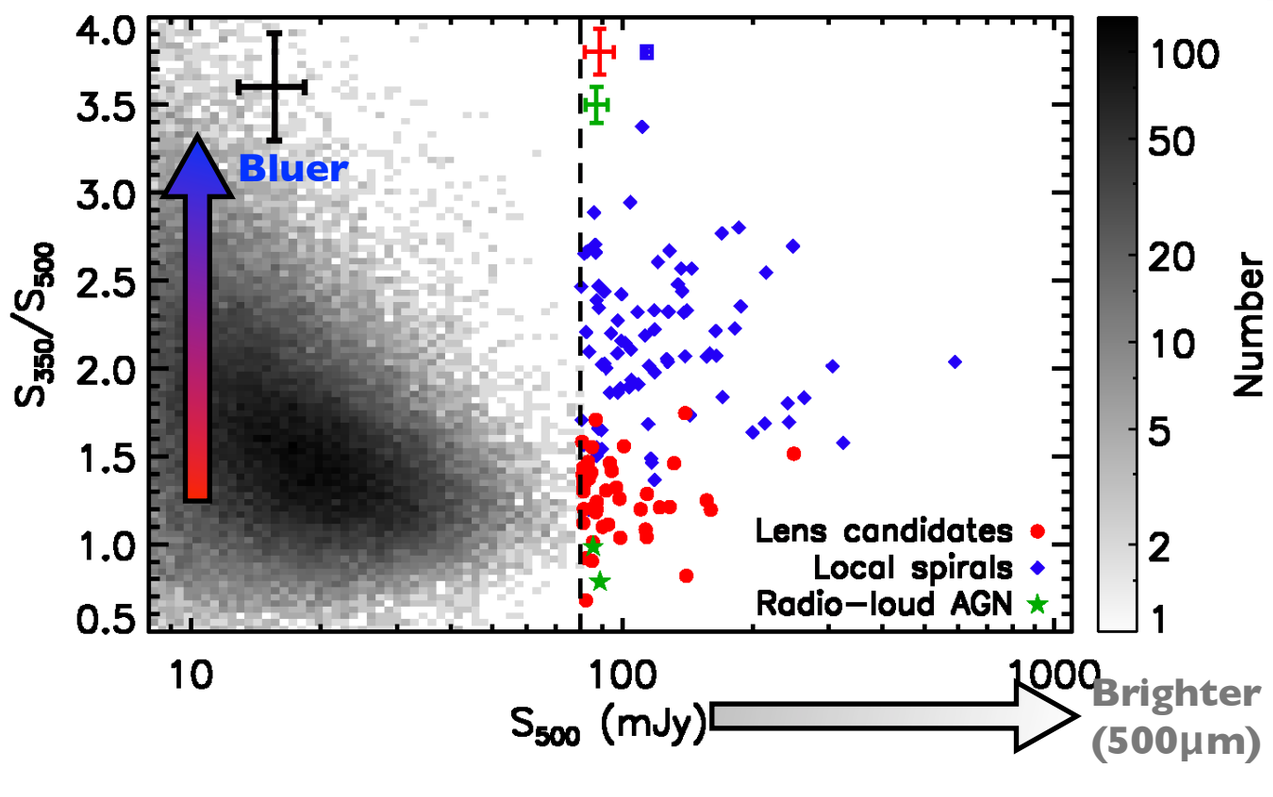

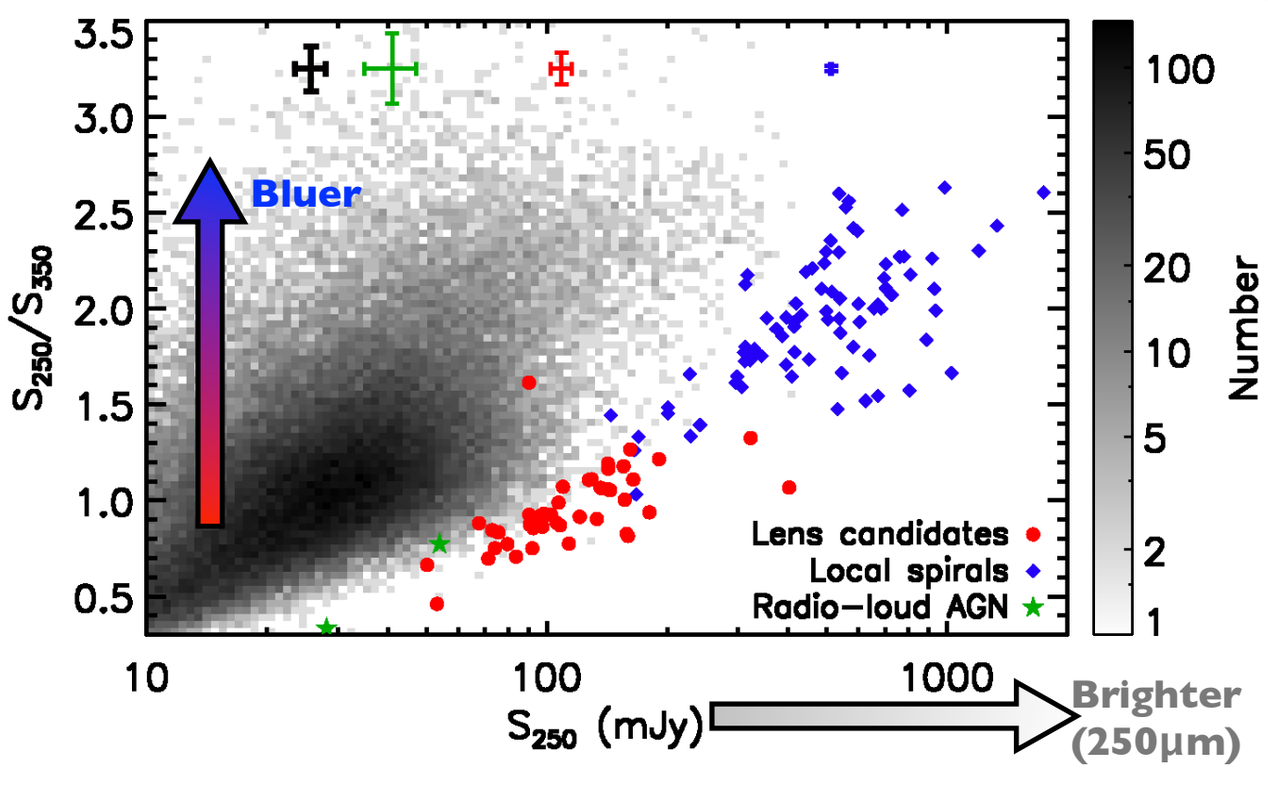

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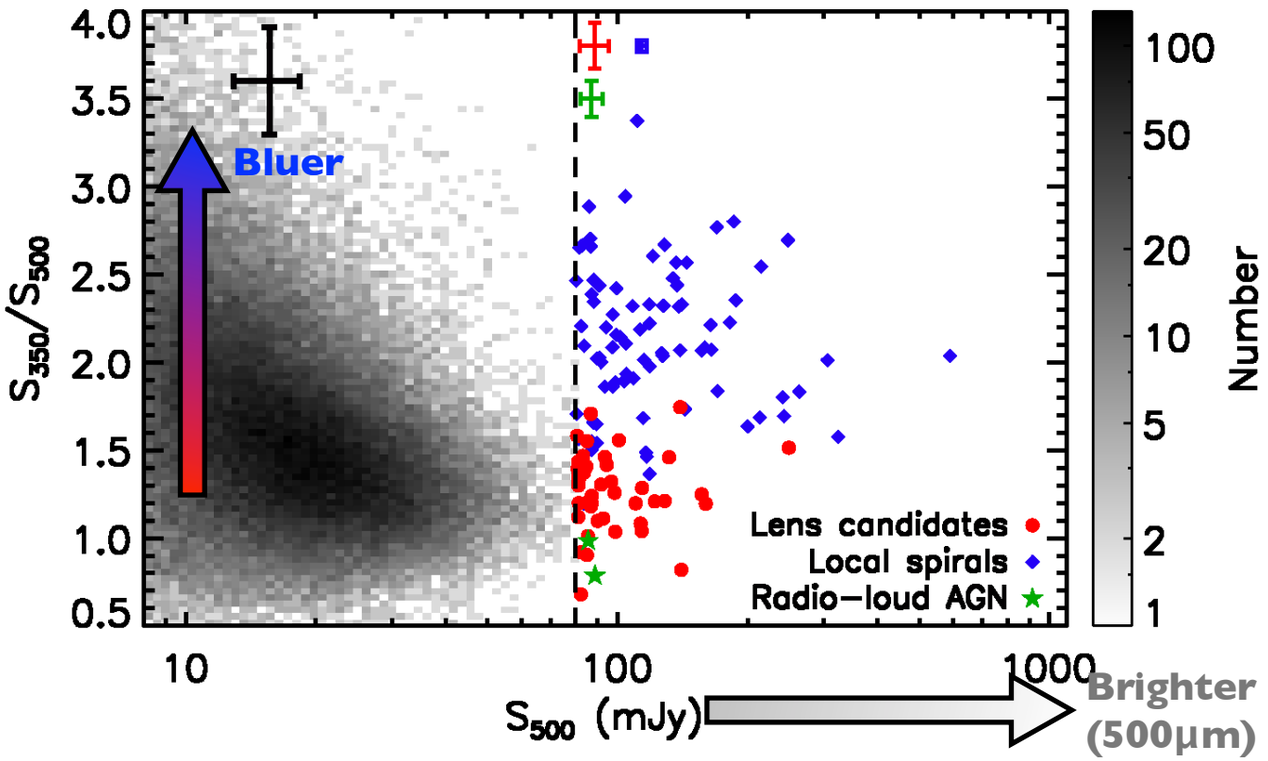

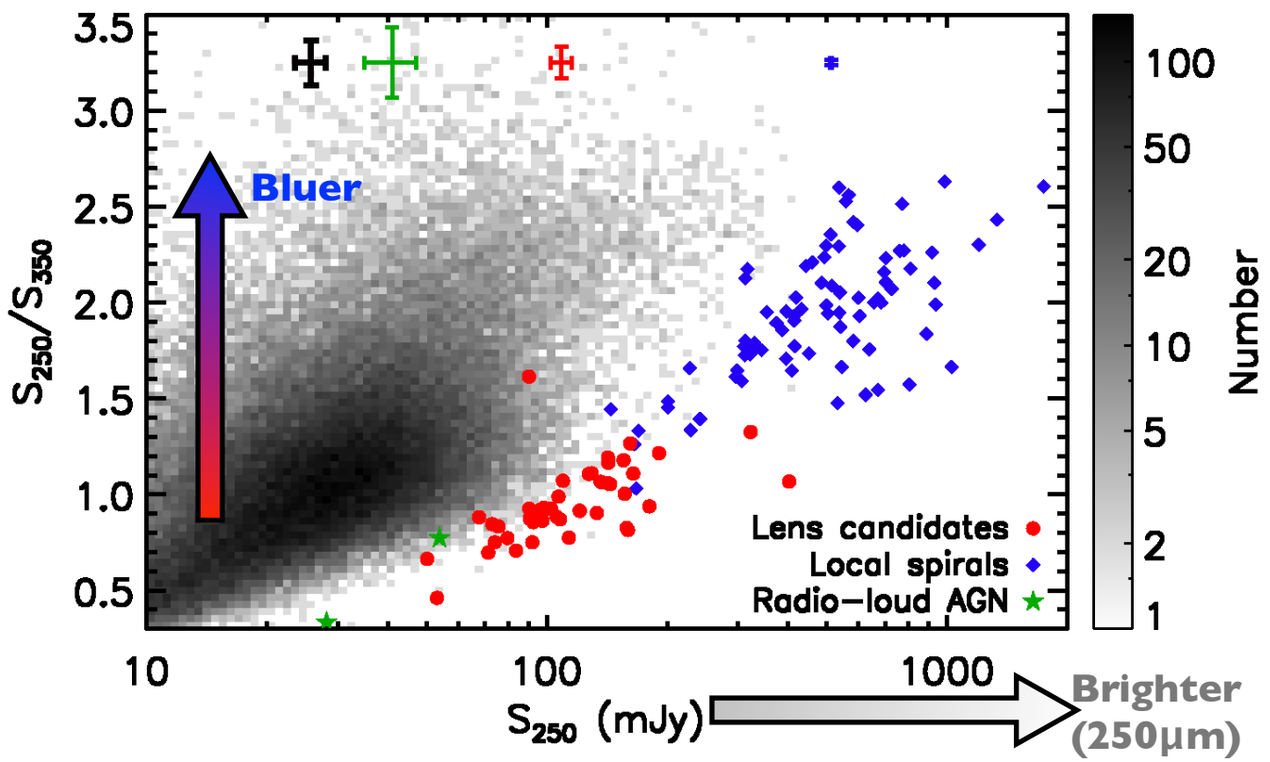

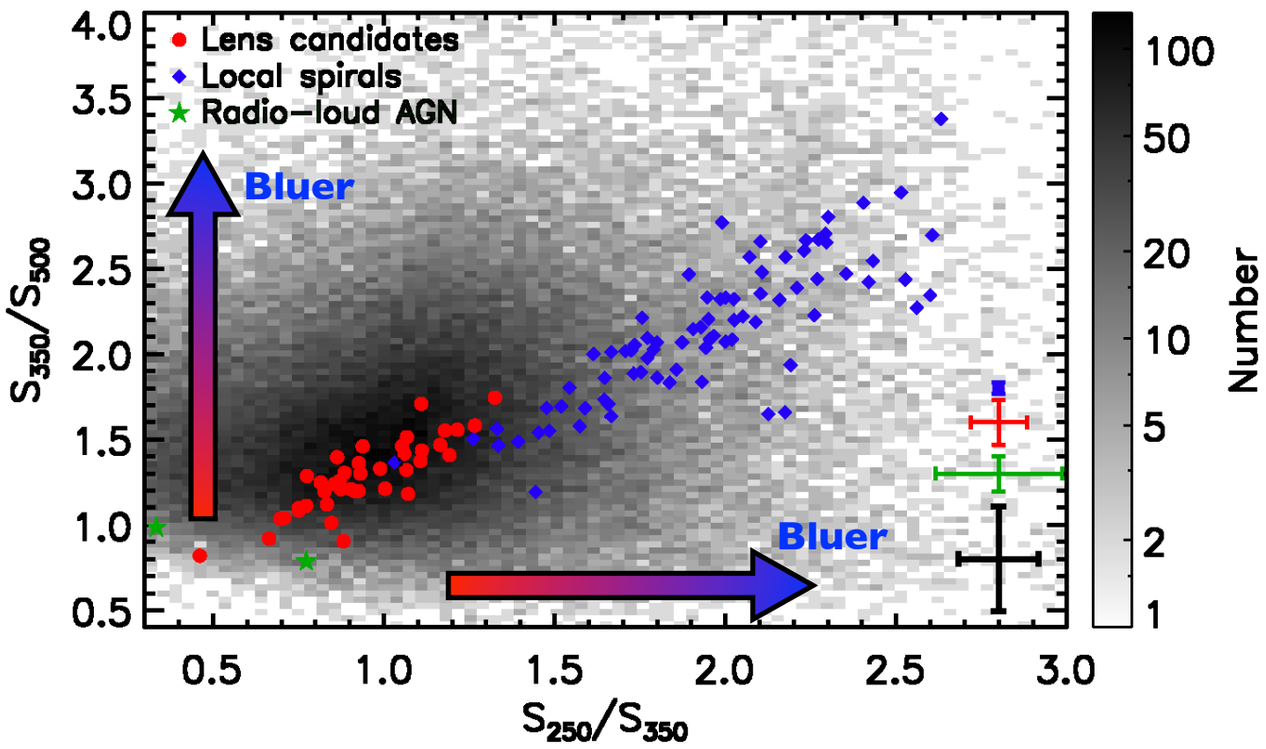

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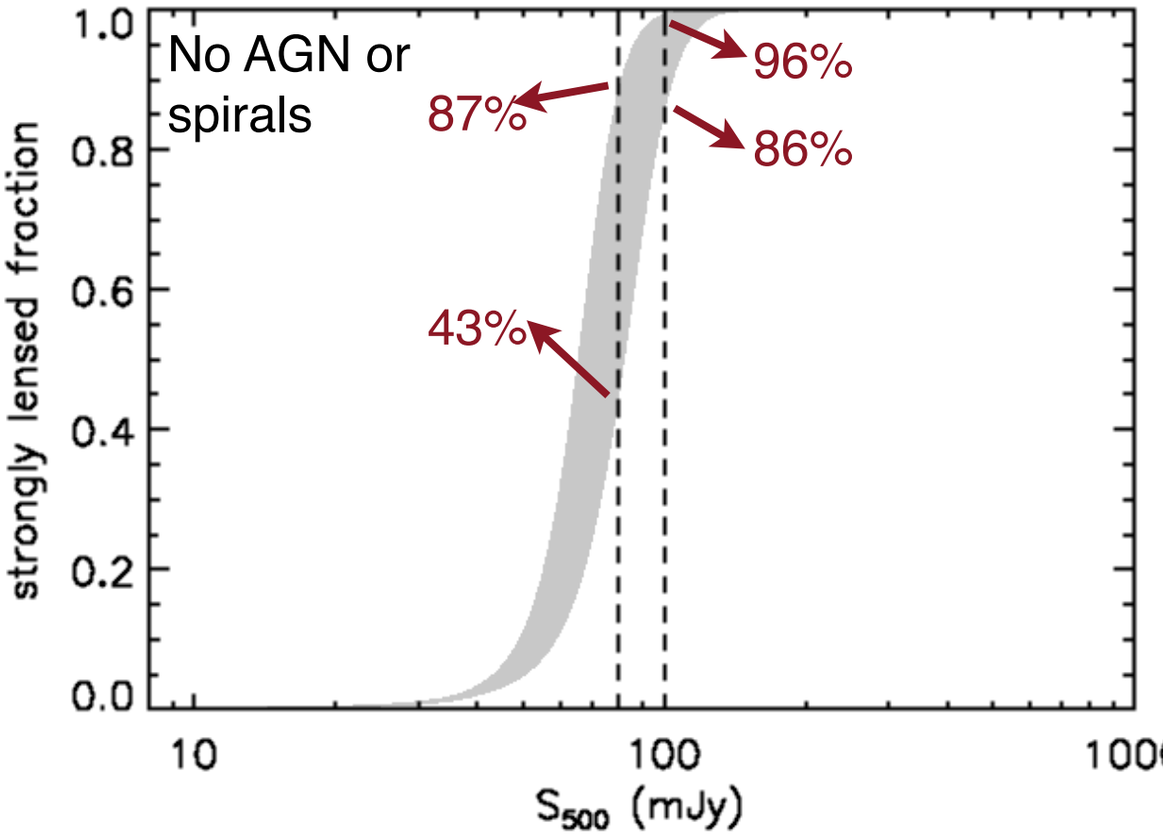
Cosmological modelling predicts high fidelity catalogues & average magnifications <10



The model predicts that
~40-90% of S_{500}=80 mJy &
~85-95% of S_{500}=100 mJy
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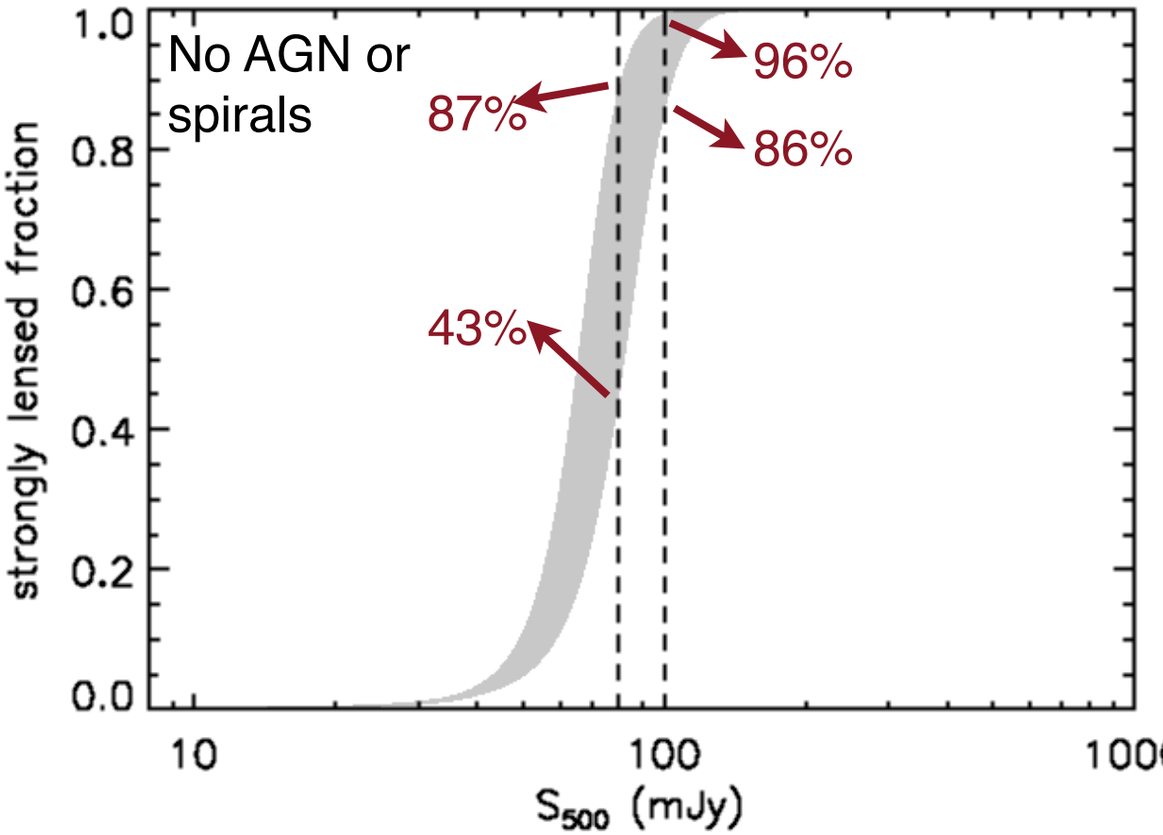

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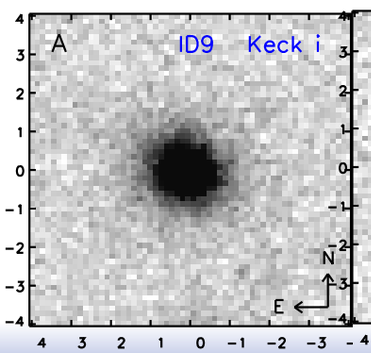
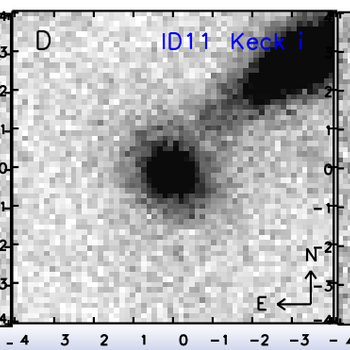
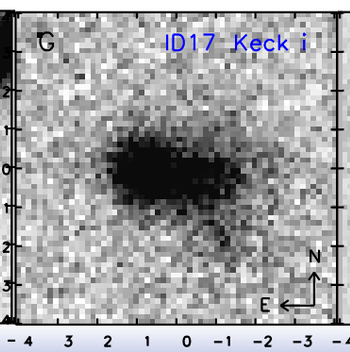
z_{SMG}=1.58; z_{lens}=0.7



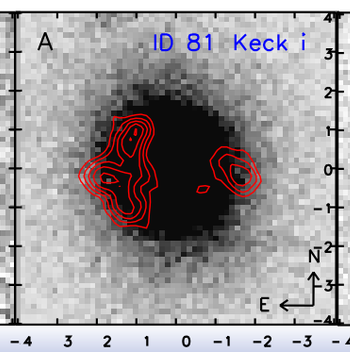
z_{SMG}=1.79; z_{lens}=0.79



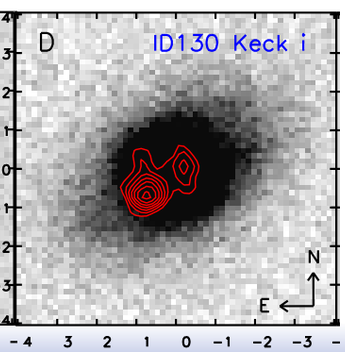
z_{SMG}=2.30; z_{lens}=0.94



z_{SMG}=3.04; z_{lens}=0.30



z_{SMG}=2.62; z_{lens}=0.22



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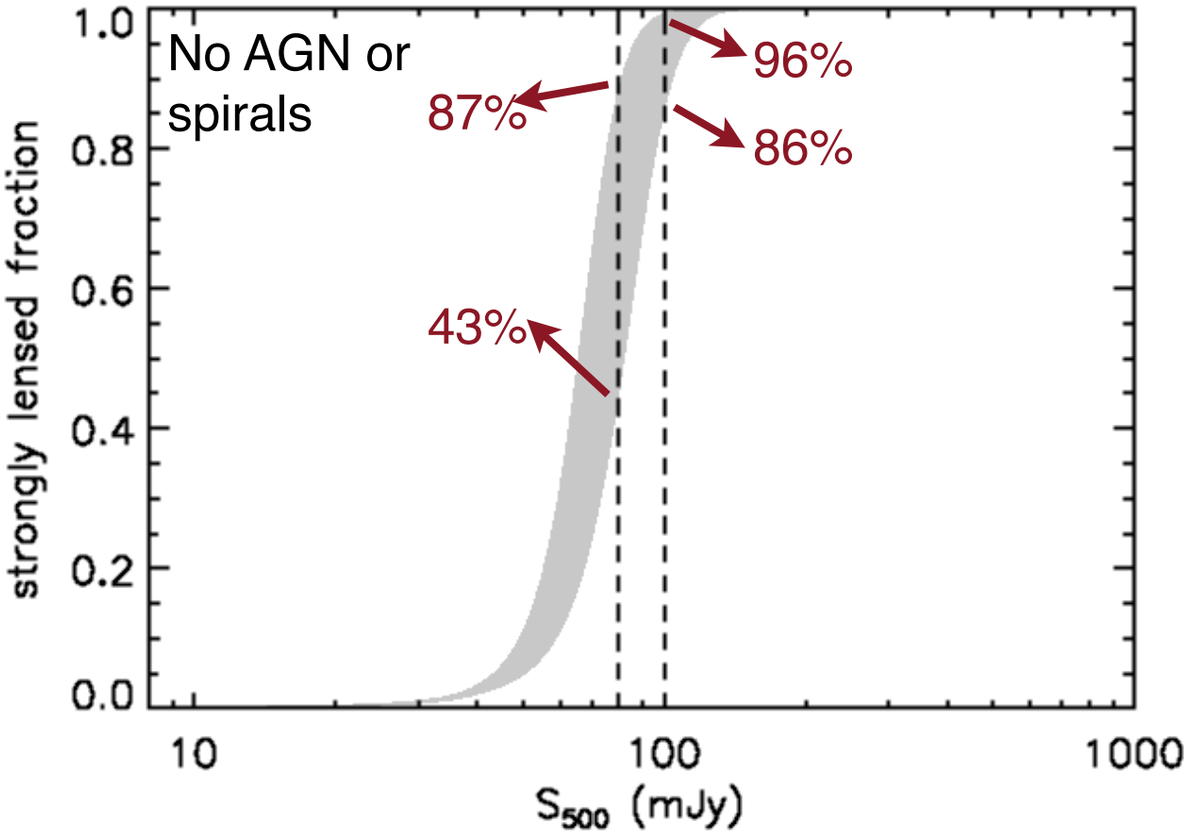

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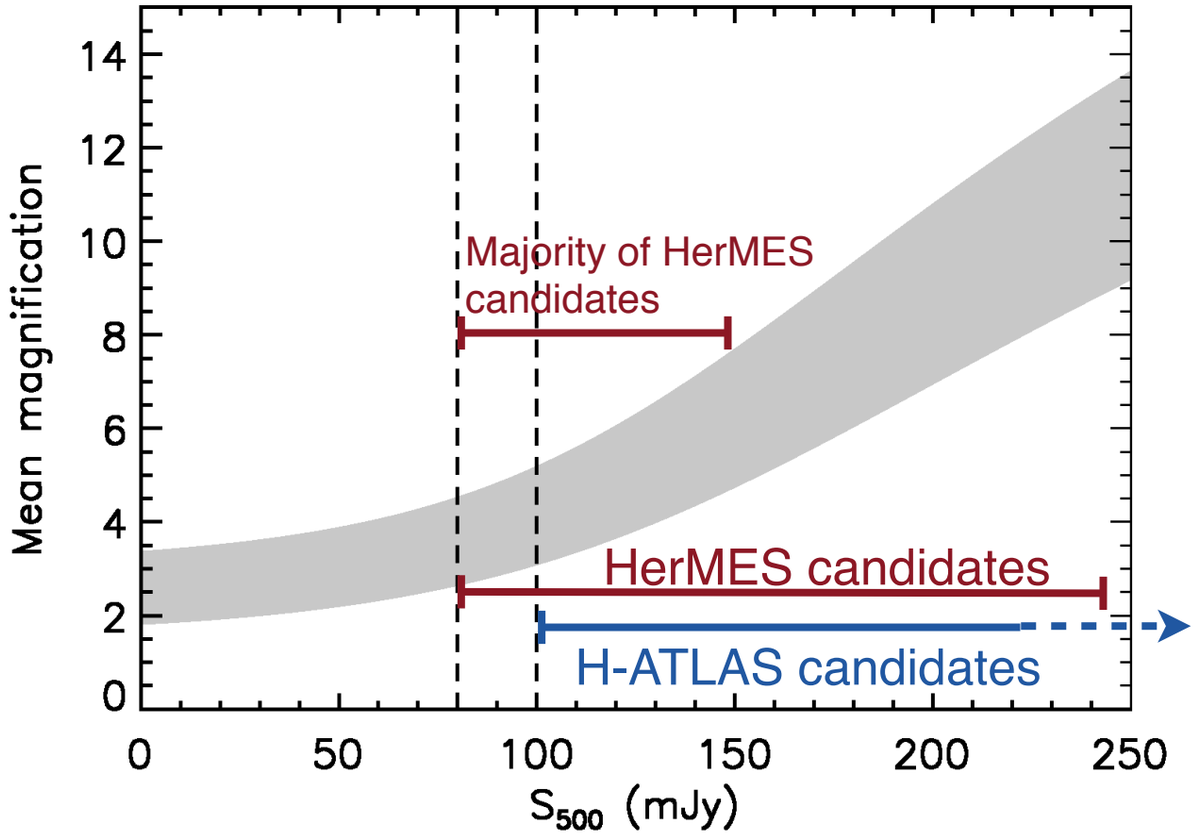
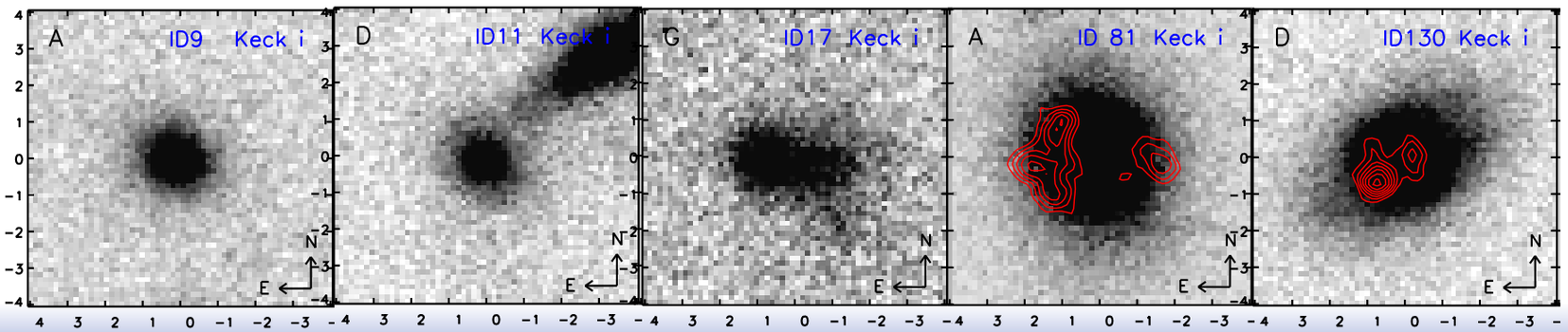
The model predicts that μ_{mean} ~3-8 for majority of lenses



z_{SMG}=1.58; z_{lens}=0.7 | z_{SMG}=1.79; z_{lens}=0.79 | z_{SMG}=2.30; z_{lens}=0.94 | z_{SMG}=3.04; z_{lens}=0.30 | z_{SMG}=2.62; z_{lens}=0.22



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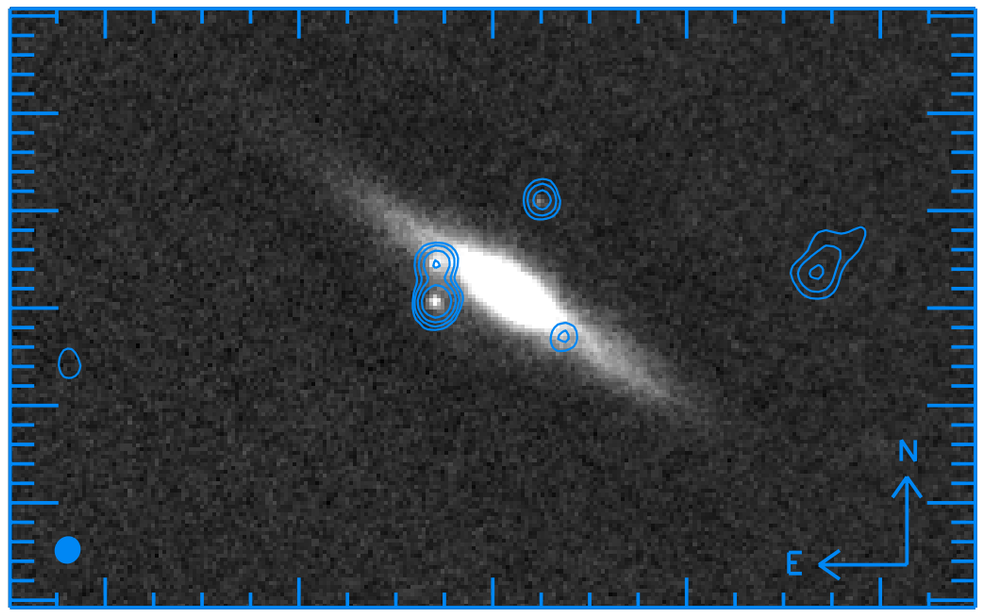

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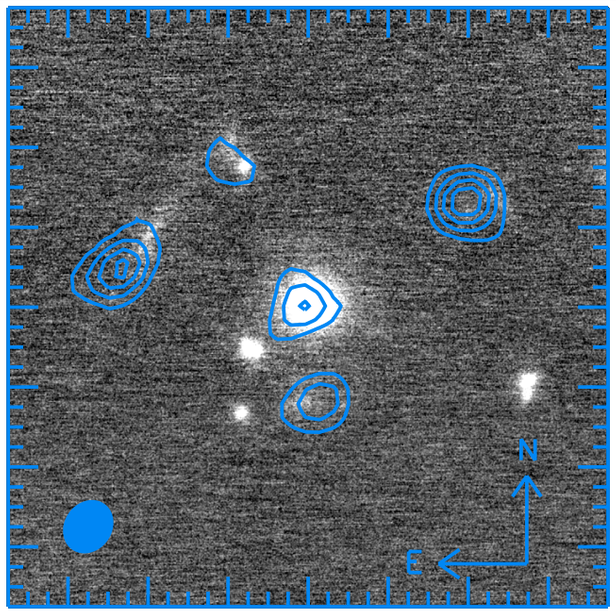
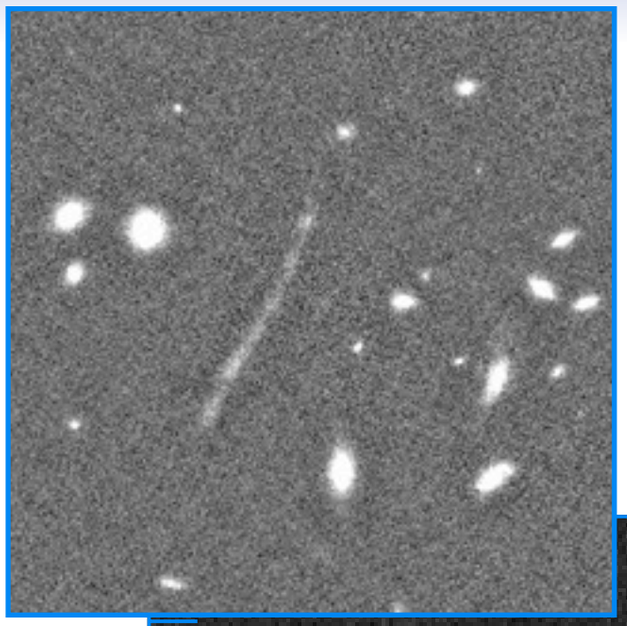
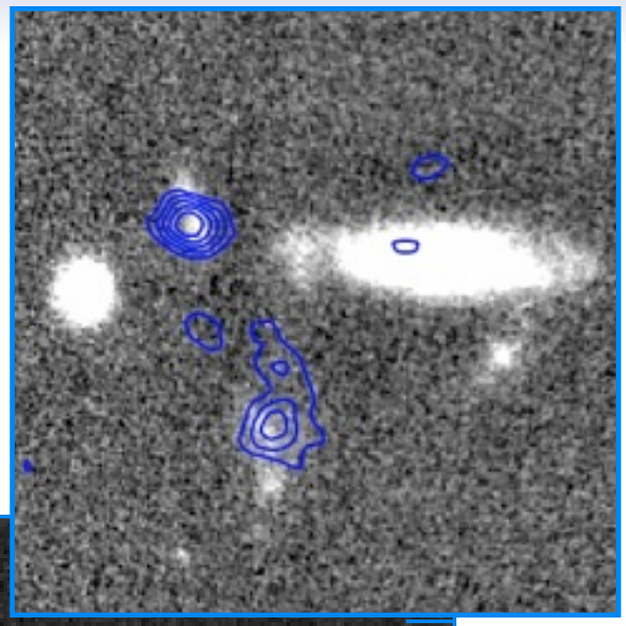
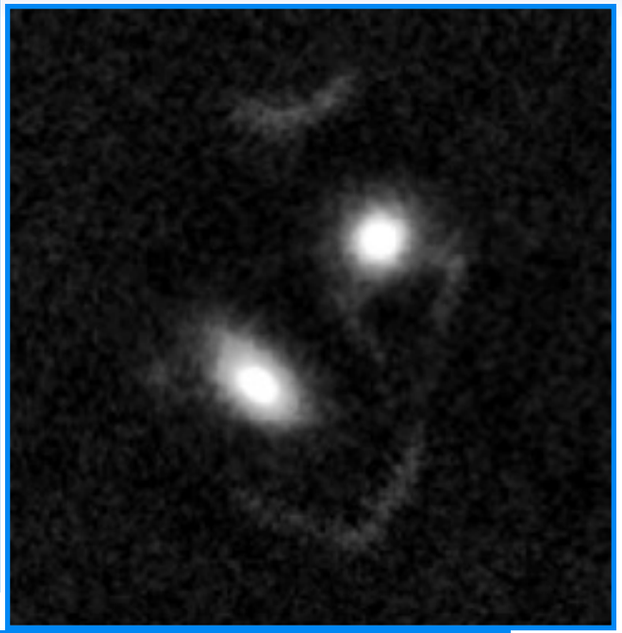
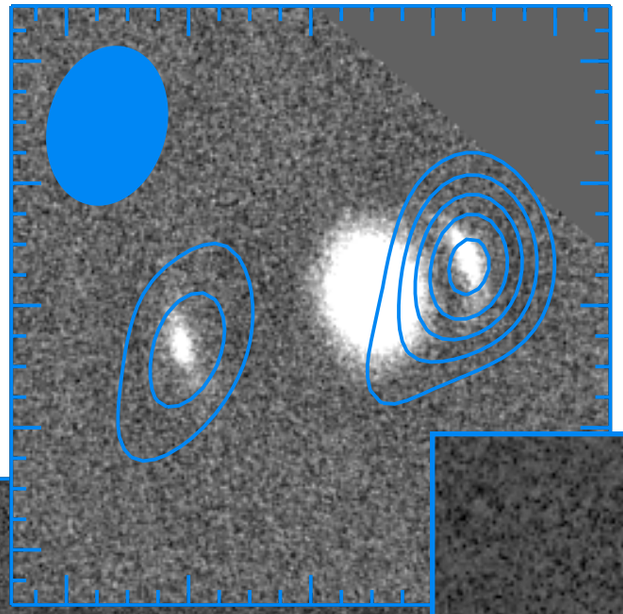
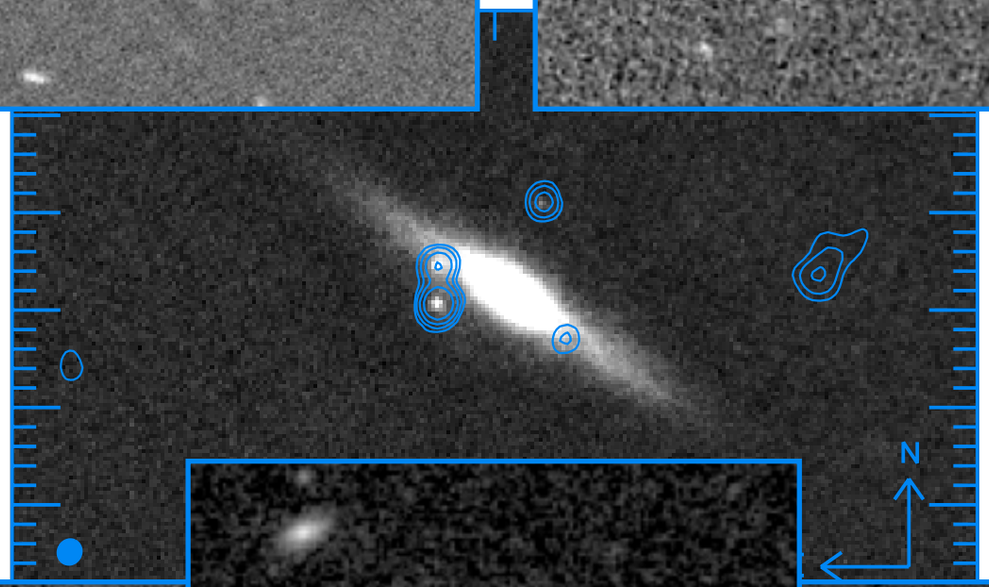


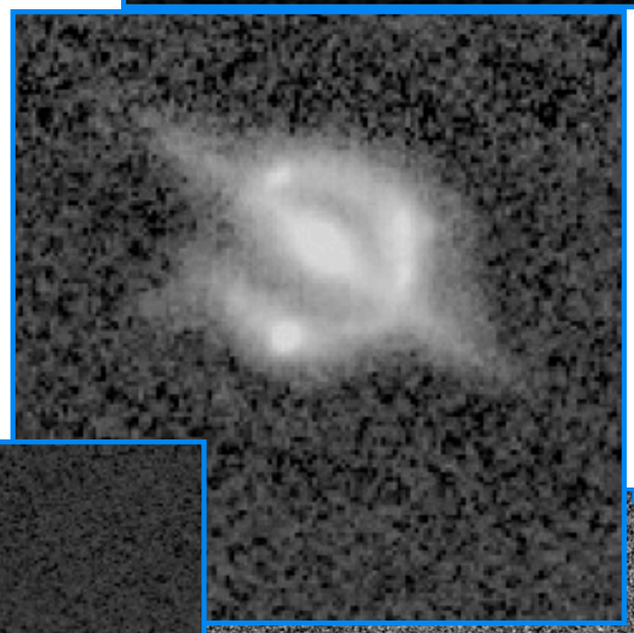


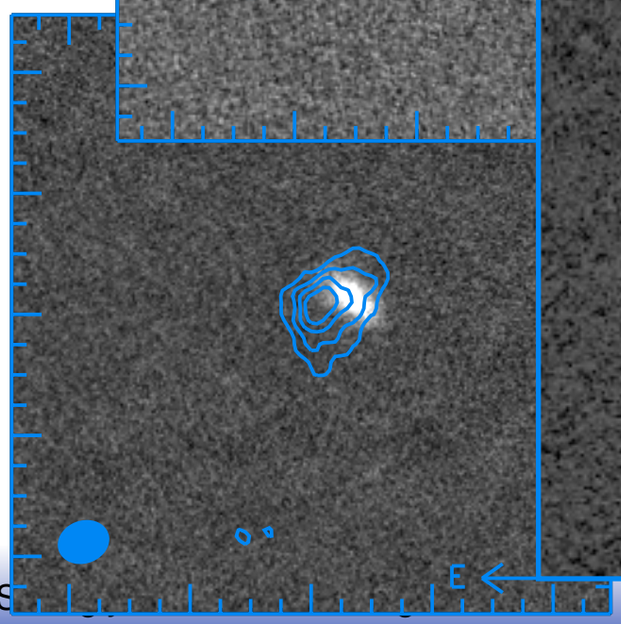


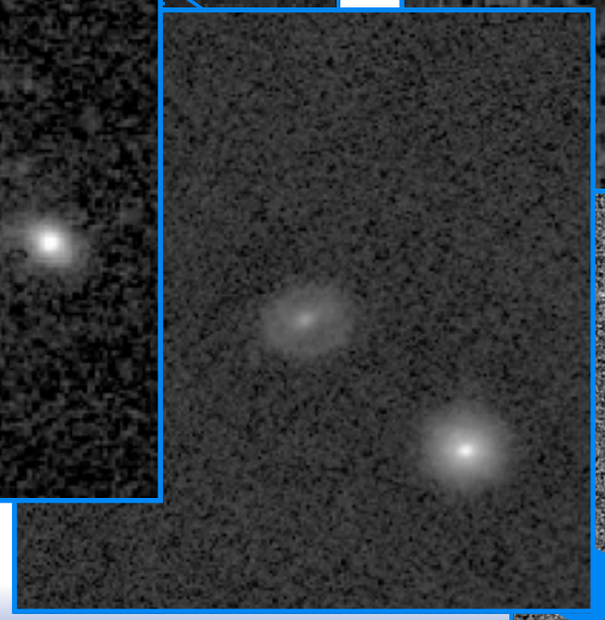


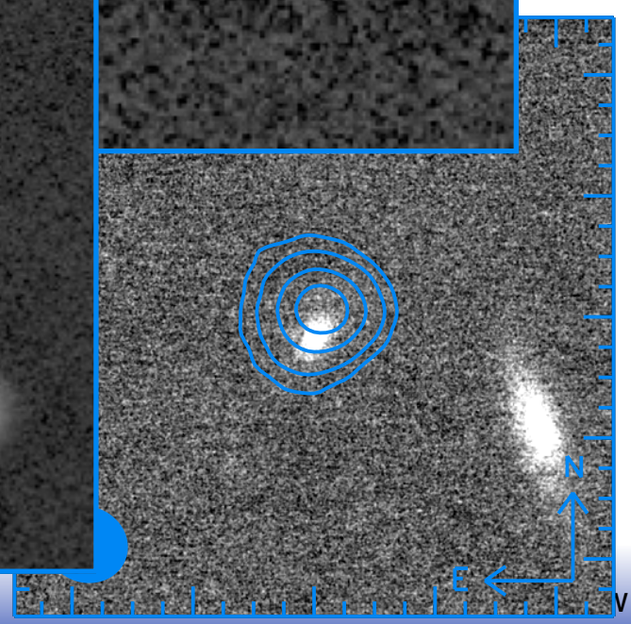




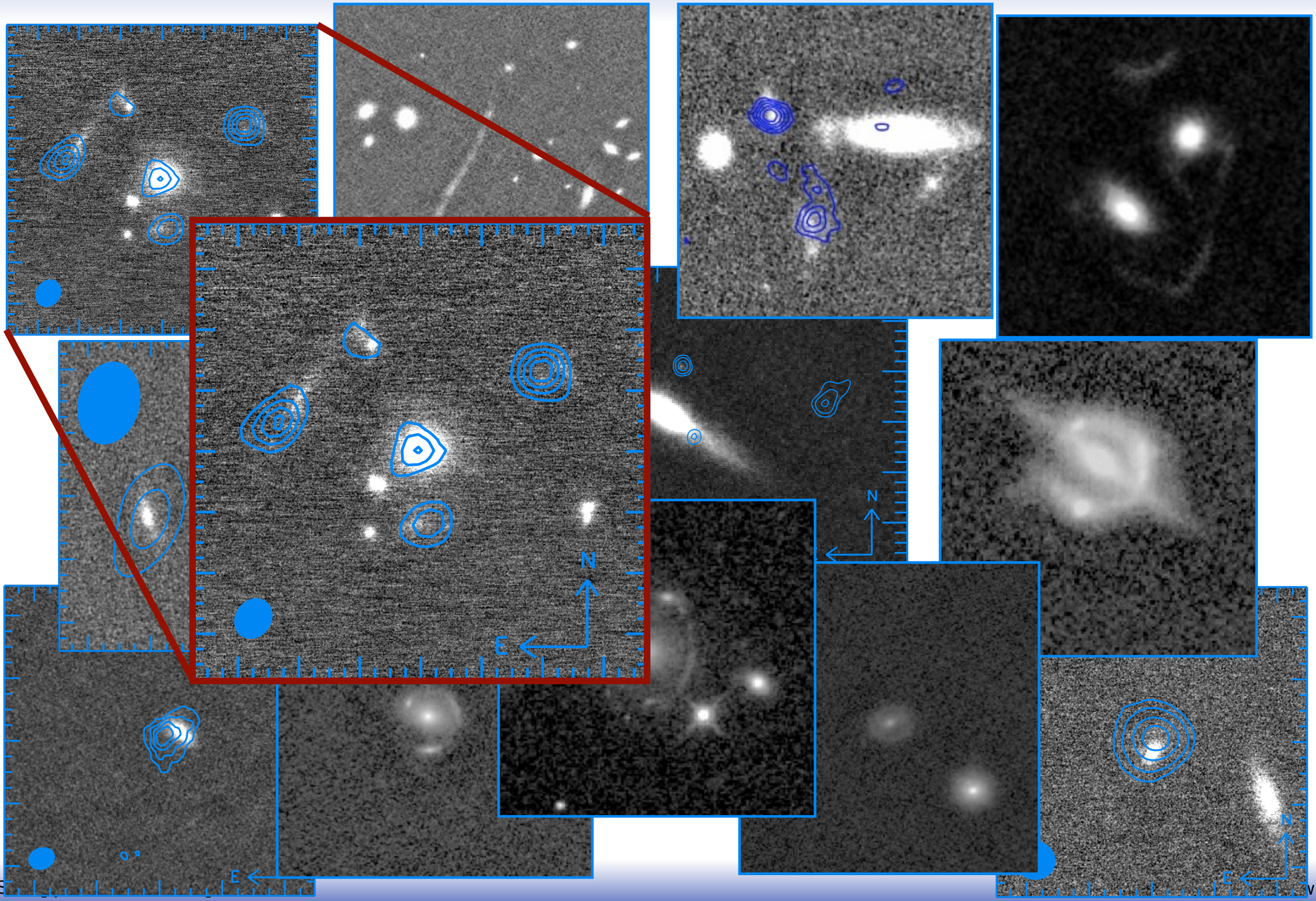








Strongly lensed SMGs



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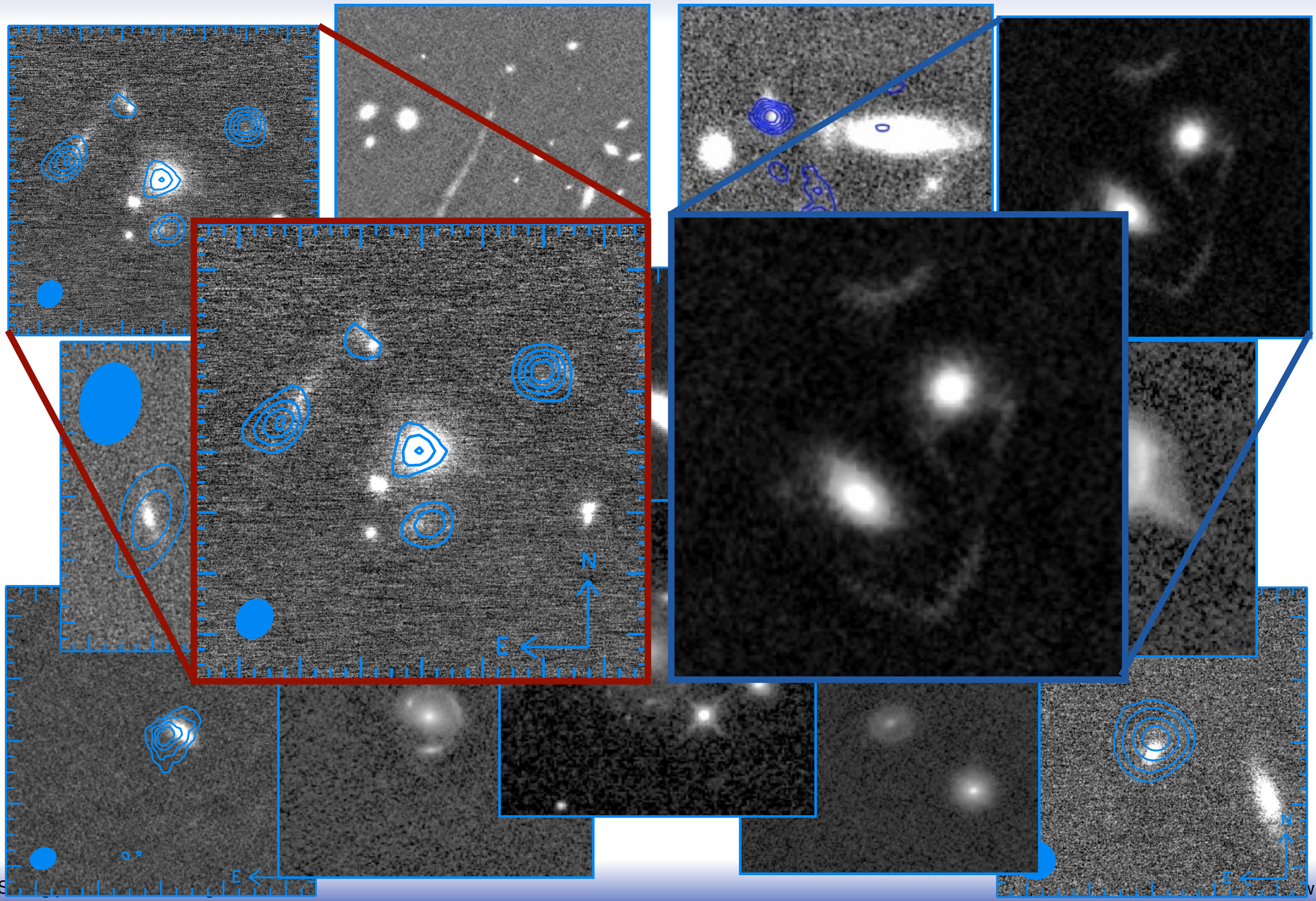
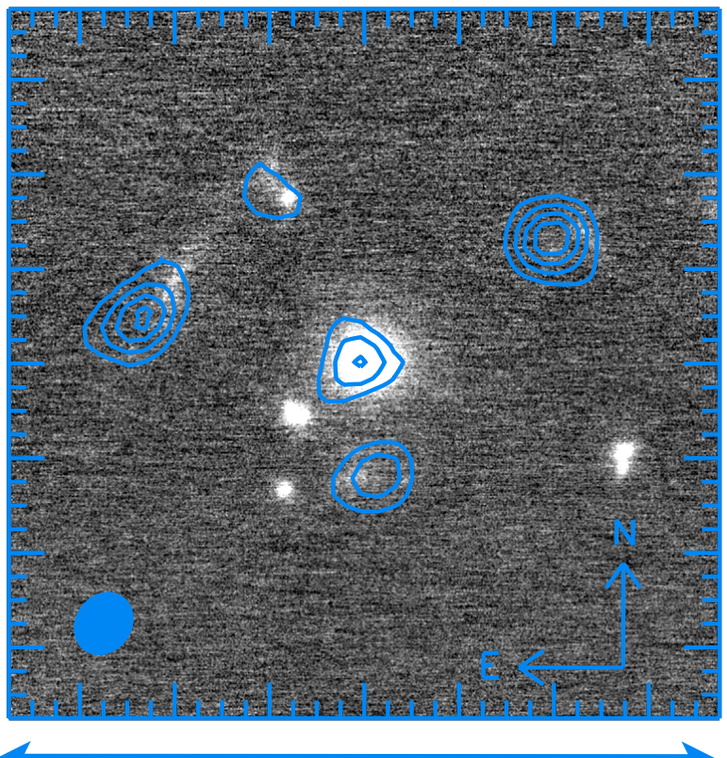


A *Herschel* source lensed by a group

eVLA 1.4GHz + Keck K-band



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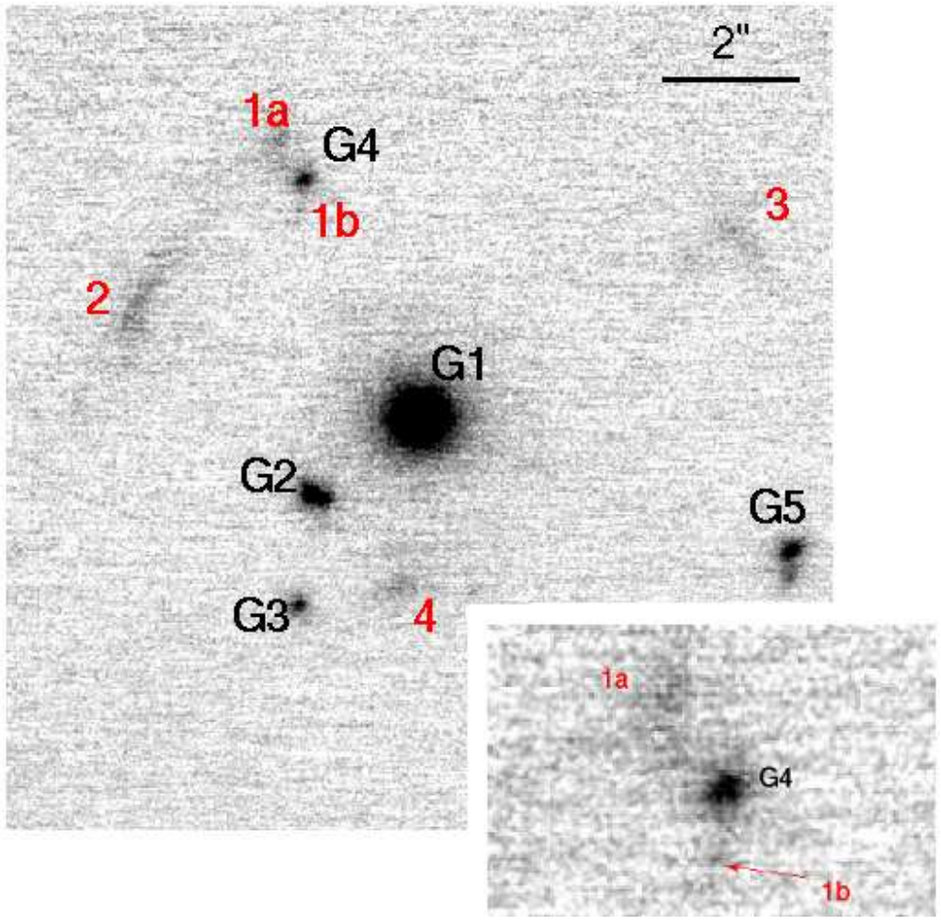

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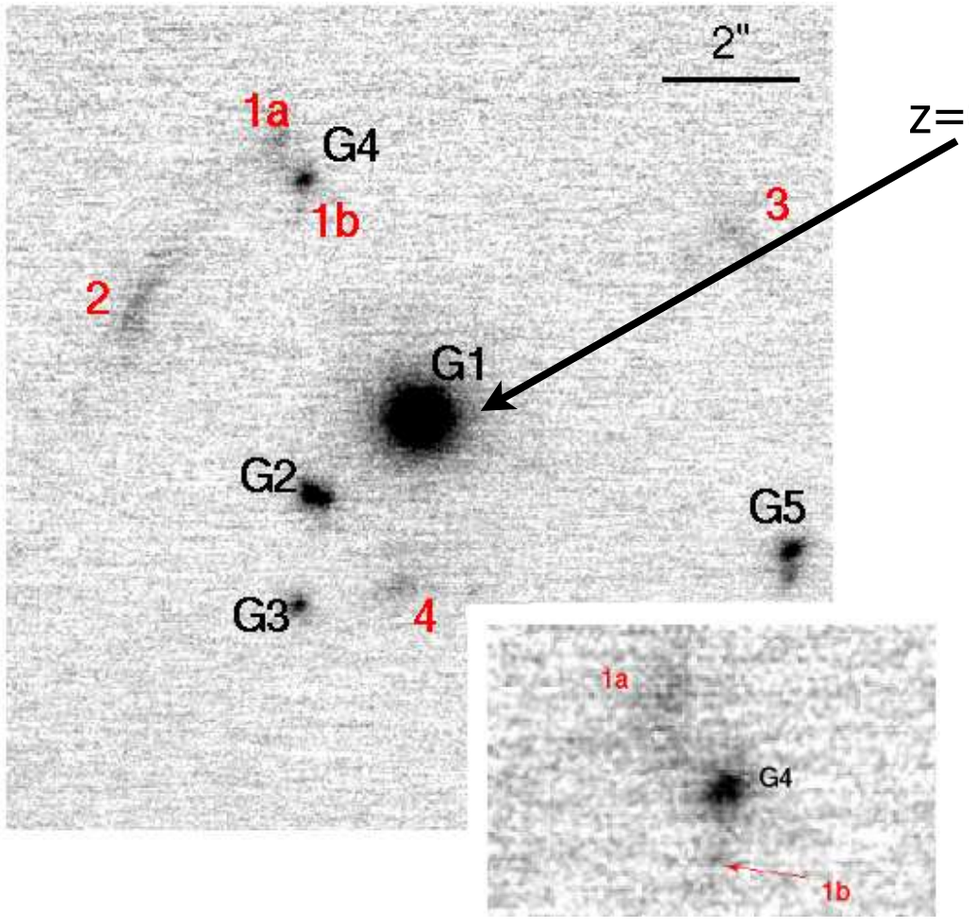


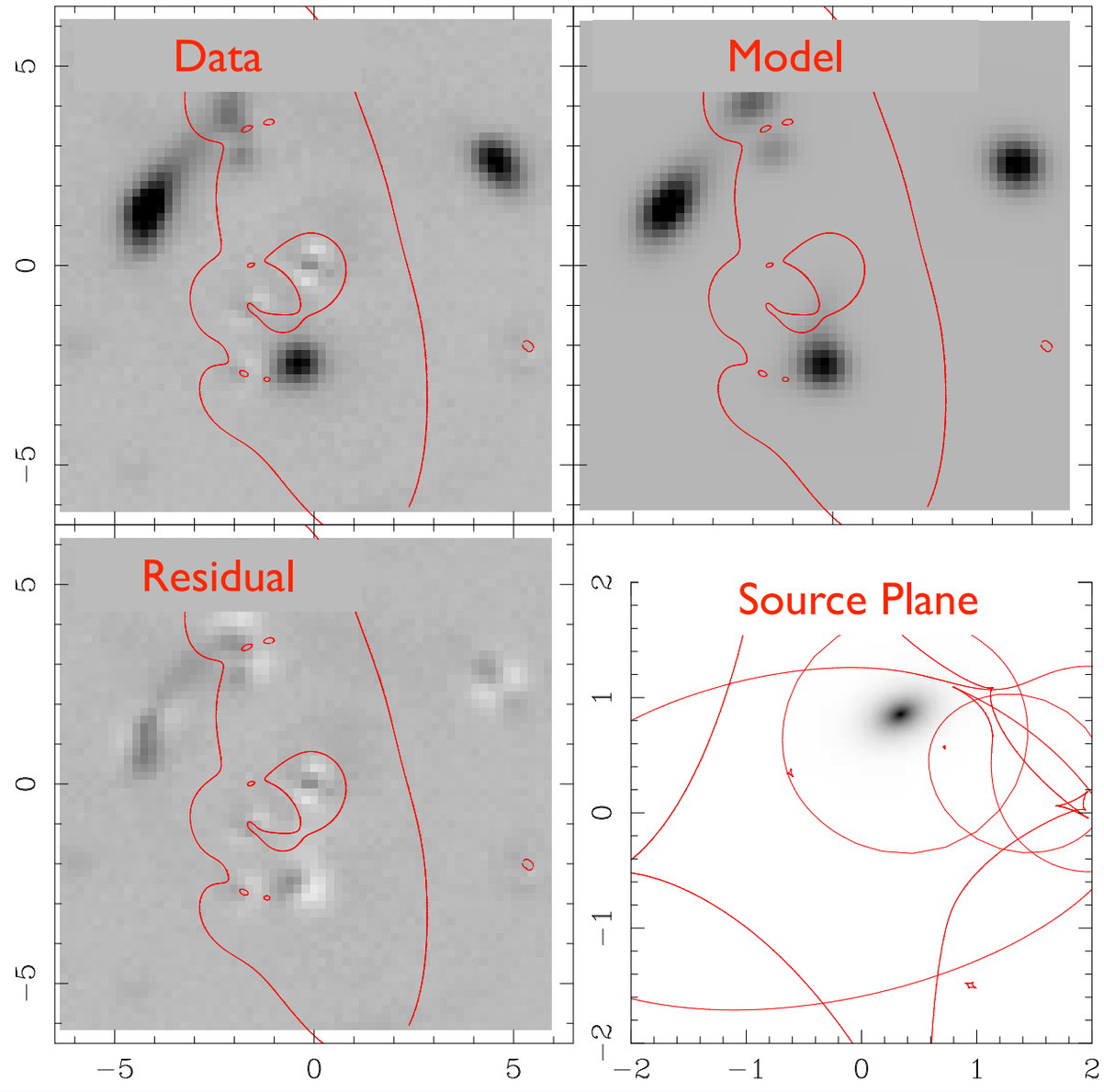
z=0.60 ± 0.04

Other lens redshifts are unclear but

R_{Ein} = 4.02 ± 0.03 kpc

=> σ_v = 480 ± 20 km/s

....indicative of a small group deflector



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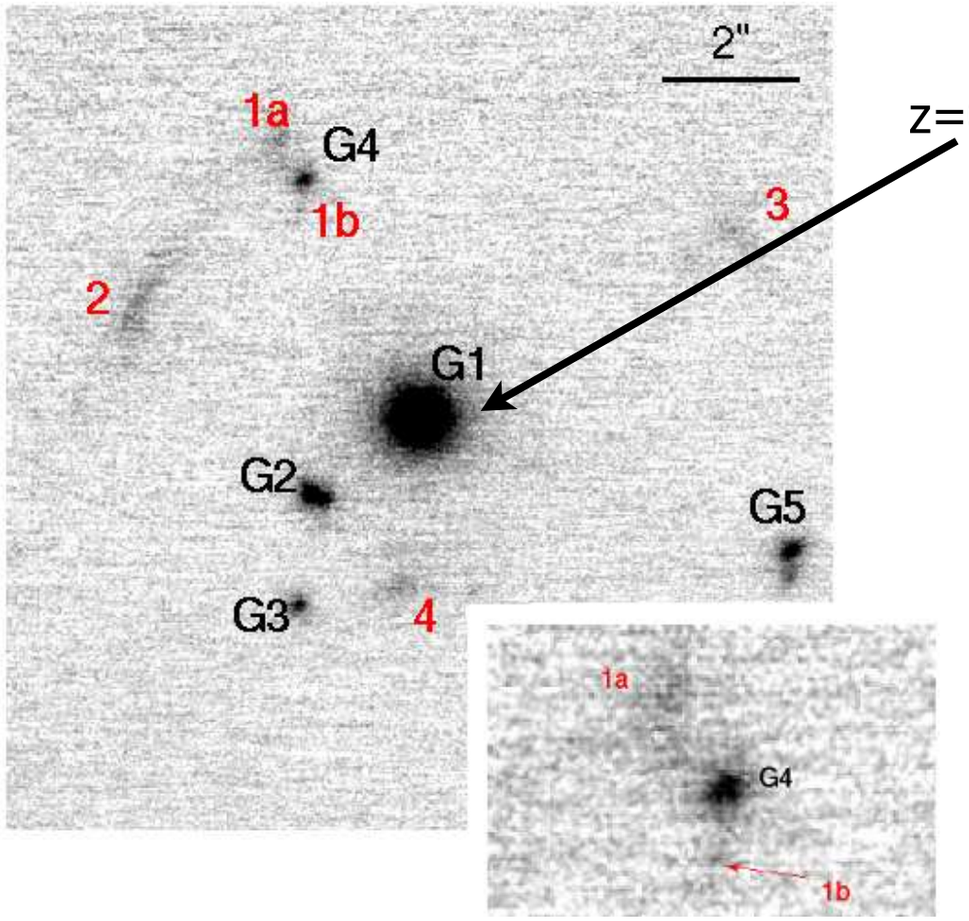

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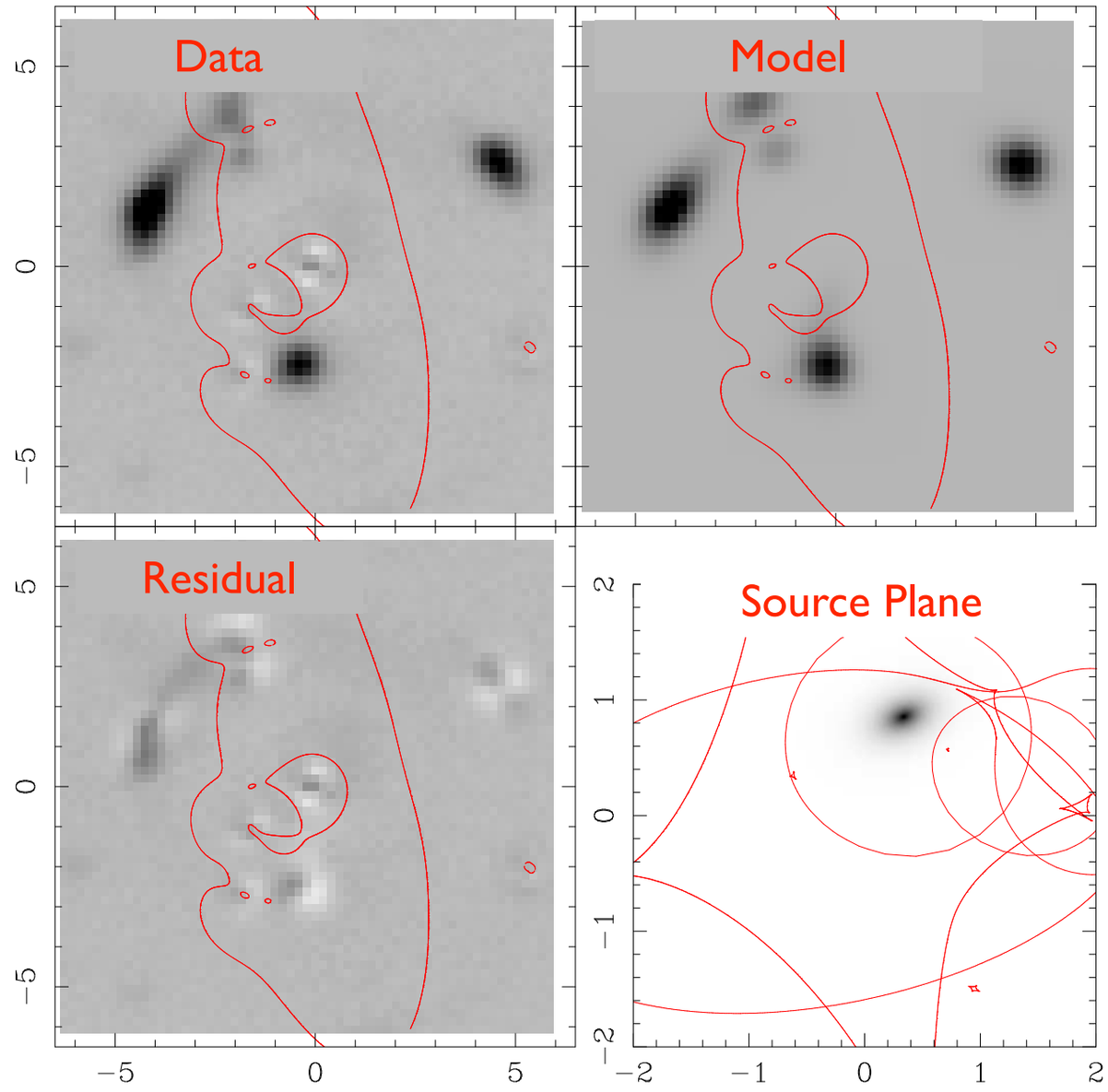

Half-light radius of the SMG:

$R_{eff,s}$ = 1.9 ± 0.1 kpc.

Magnification:

μ = 10.9 ± 0.7

(Conley et al. 2011; Scott et al 2011;
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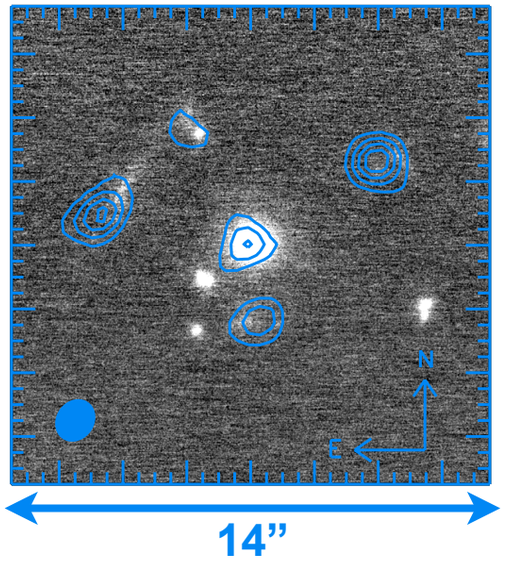
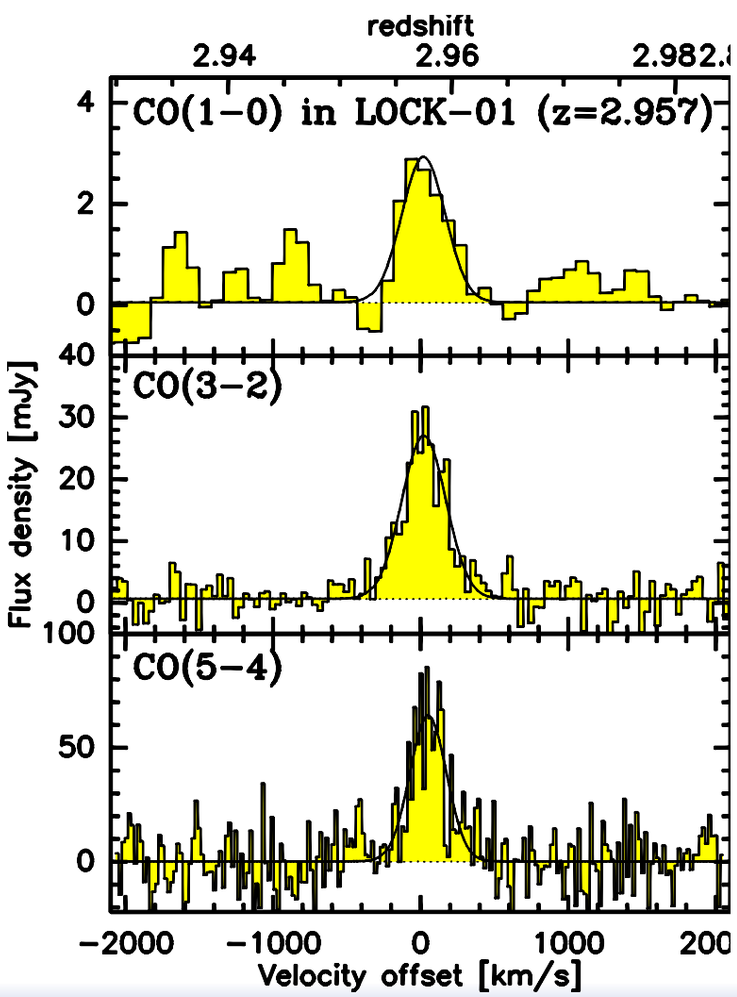


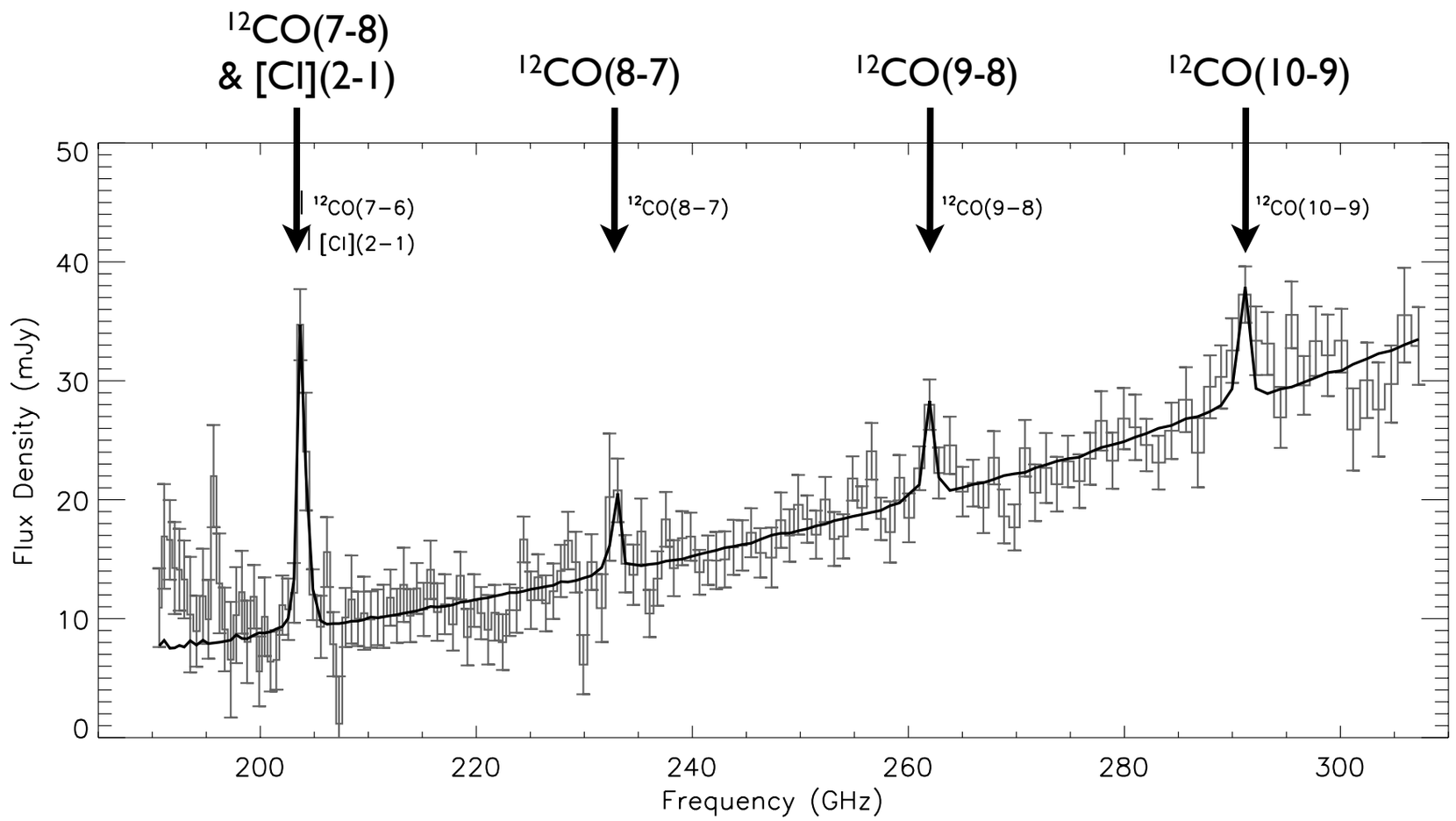
z_{CO}=2.957

T_{kin} = 86 – 235 K
n_{H2} = (1.1 – 3.5) ×10^3 cm^{-3}

(intrinsic)
L_{FIR} = 1.4 x10^{13} $L_\odot$
SFR ~ 2500 $M_\odot$/yr

T_D = 88 ± 3 K
β = 1.94 ± 0.14
Md ~ 10^8 $M_\odot$





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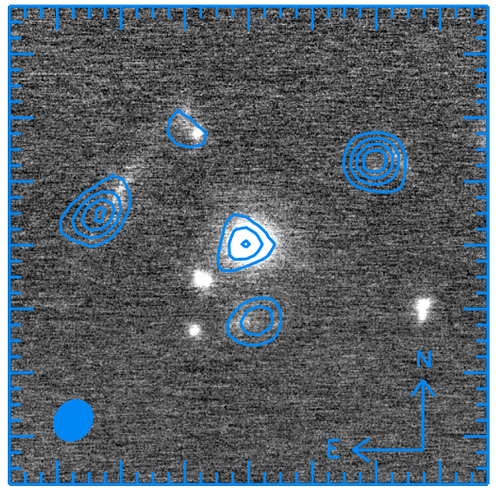

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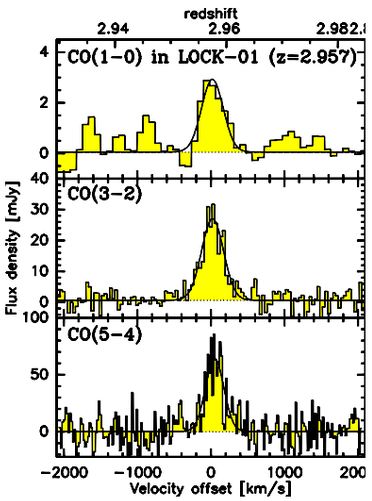
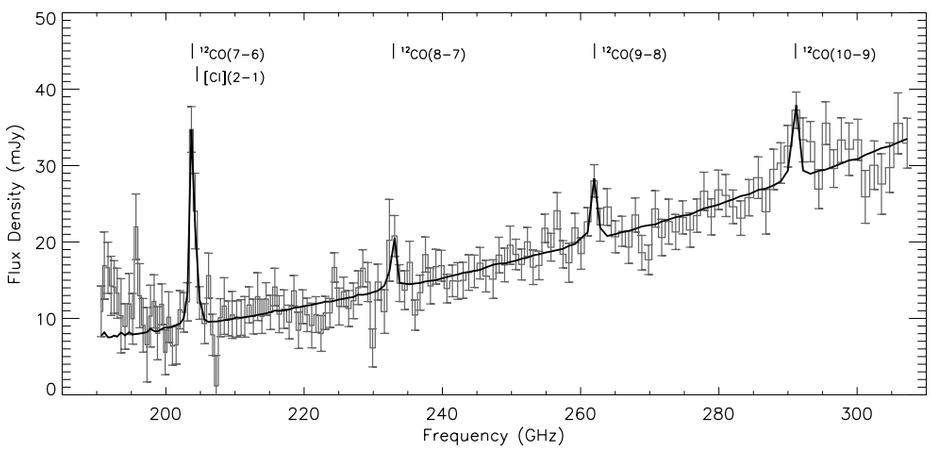
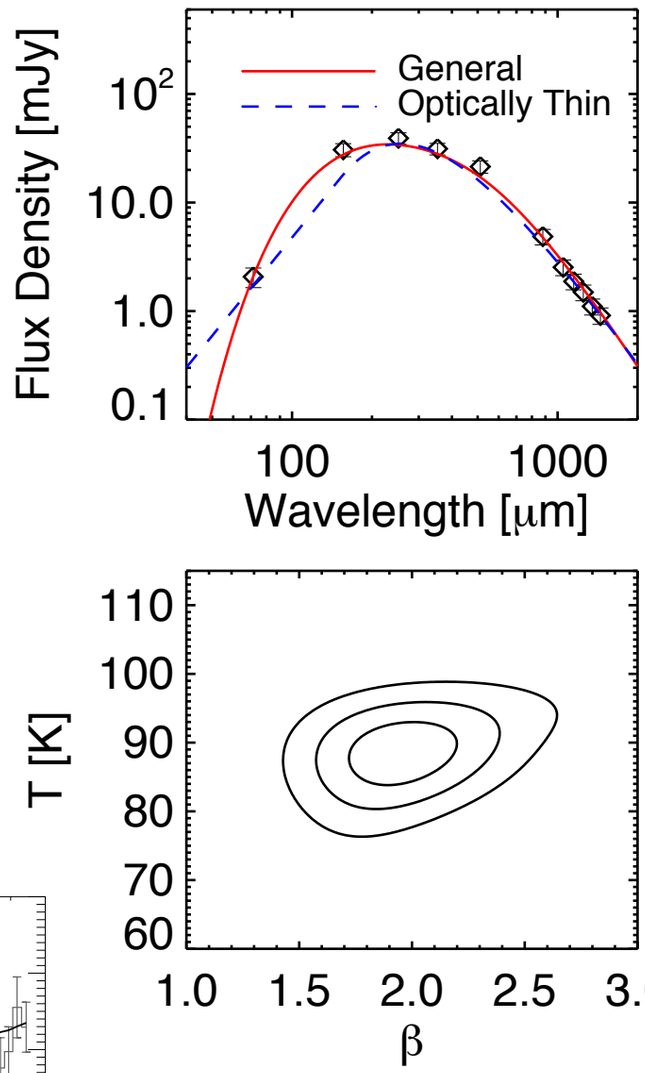
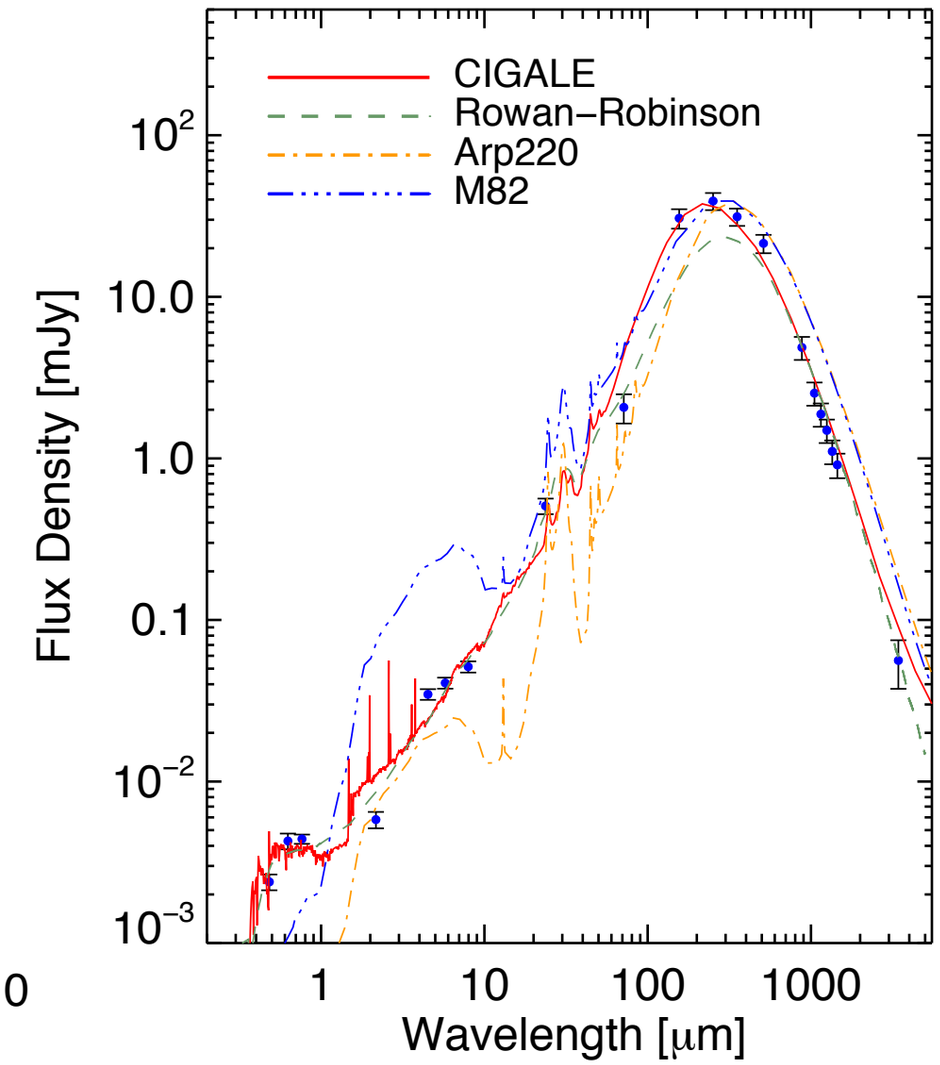
L_{FIR} = 1.4 x10^{13} $L_\odot$
SFR ~ 2500 $M_\odot$/yr

T_D = 88 ± 3 K
β = 1.94 ± 0.14
Md ~ 10^8 $M_\odot$



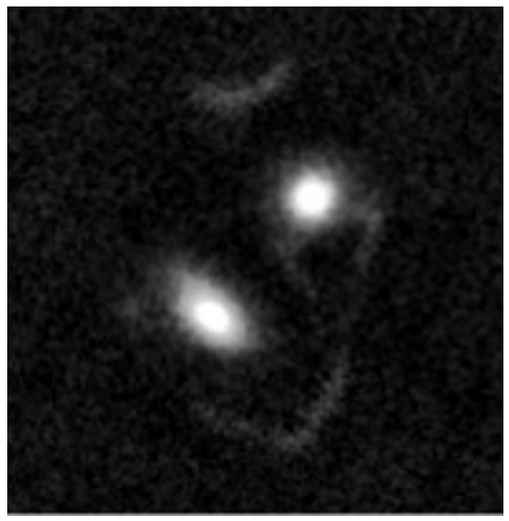






(Conley et al. 2011; Scott et al 2011;
Riechers et al. 2011; Gavazzi et al 2011)

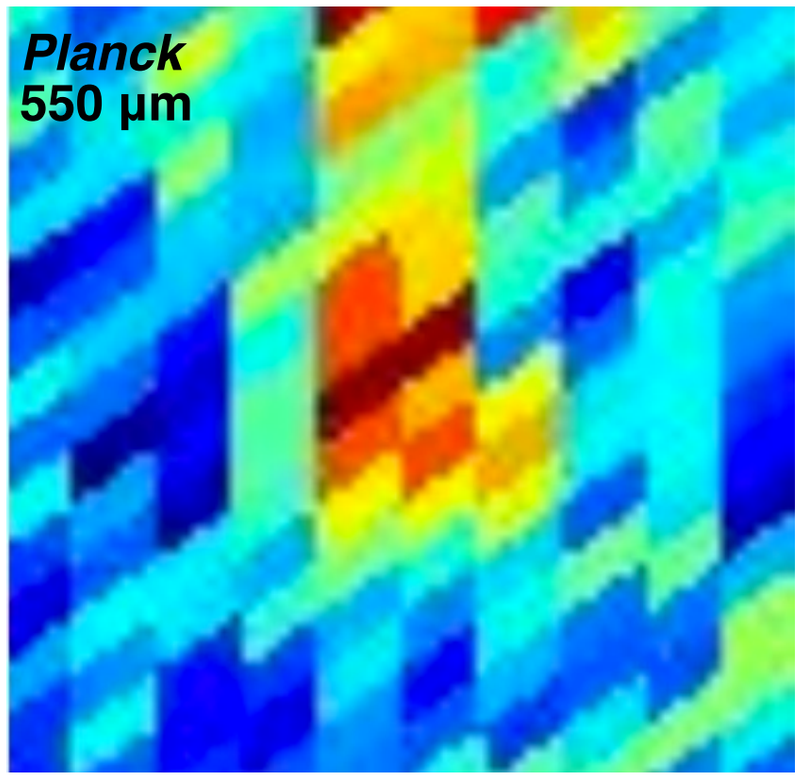
A lensed *Planck* source resolved by *Herschel*



(Fu et al. arXiv: 1202.1829)

A lensed *Planck* source resolved by *Herschel*

S_{550} = 1.07 ± 0.12 Jy
S_{350} = 1.1 ± 0.2 Jy



(Fu et al. arXiv: 1202.1829)

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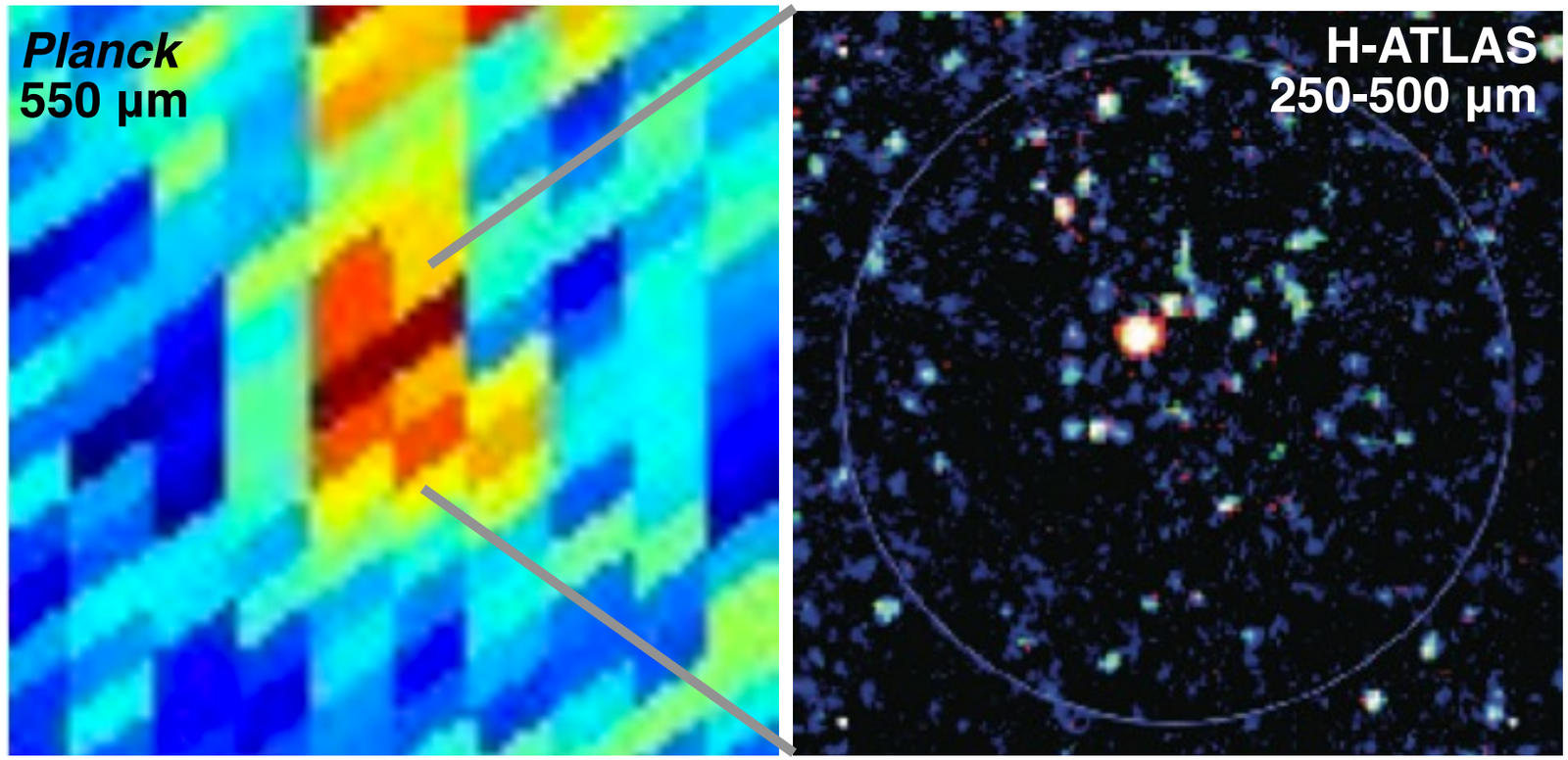

(brightest source)
S_{250} = 320 ± 20 mJy
S_{350} = 380 ± 60 mJy
S_{500} = 300 ± 20 mJy

(Fu et al. arXiv: 1202.1829)

A lensed *Planck* source resolved by *Herschel*

S_{550} = 1.07 ± 0.12 Jy
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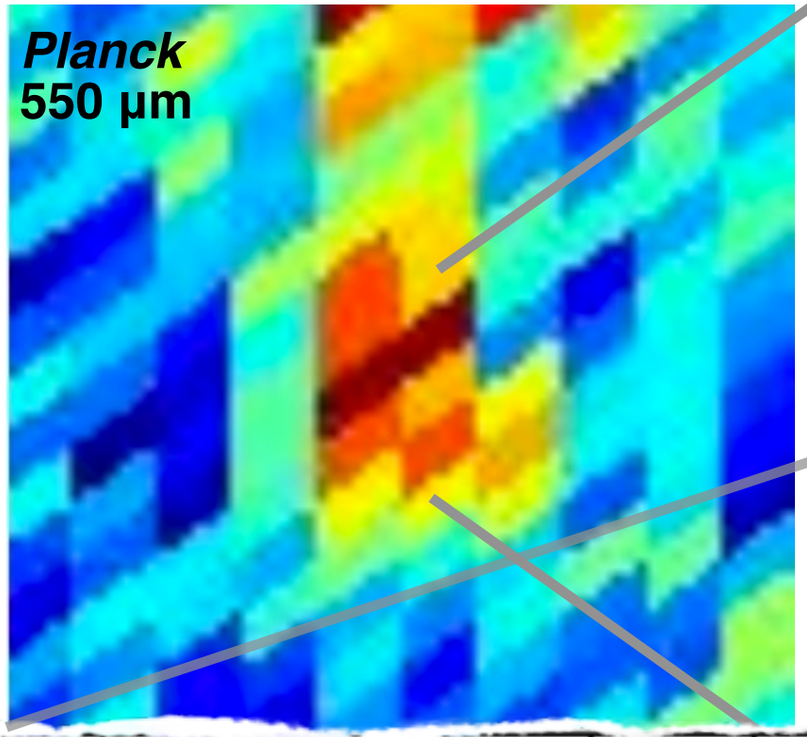
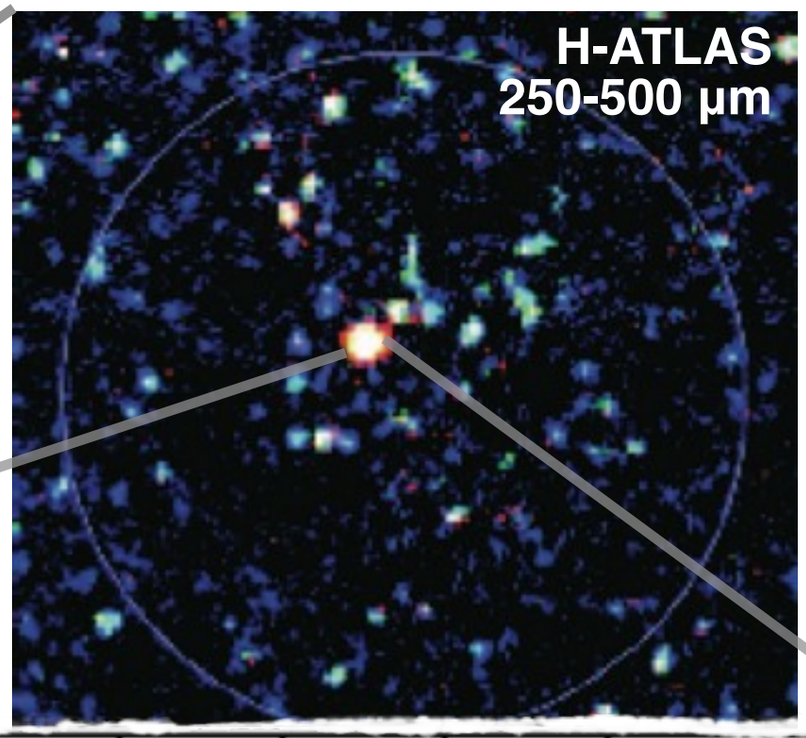
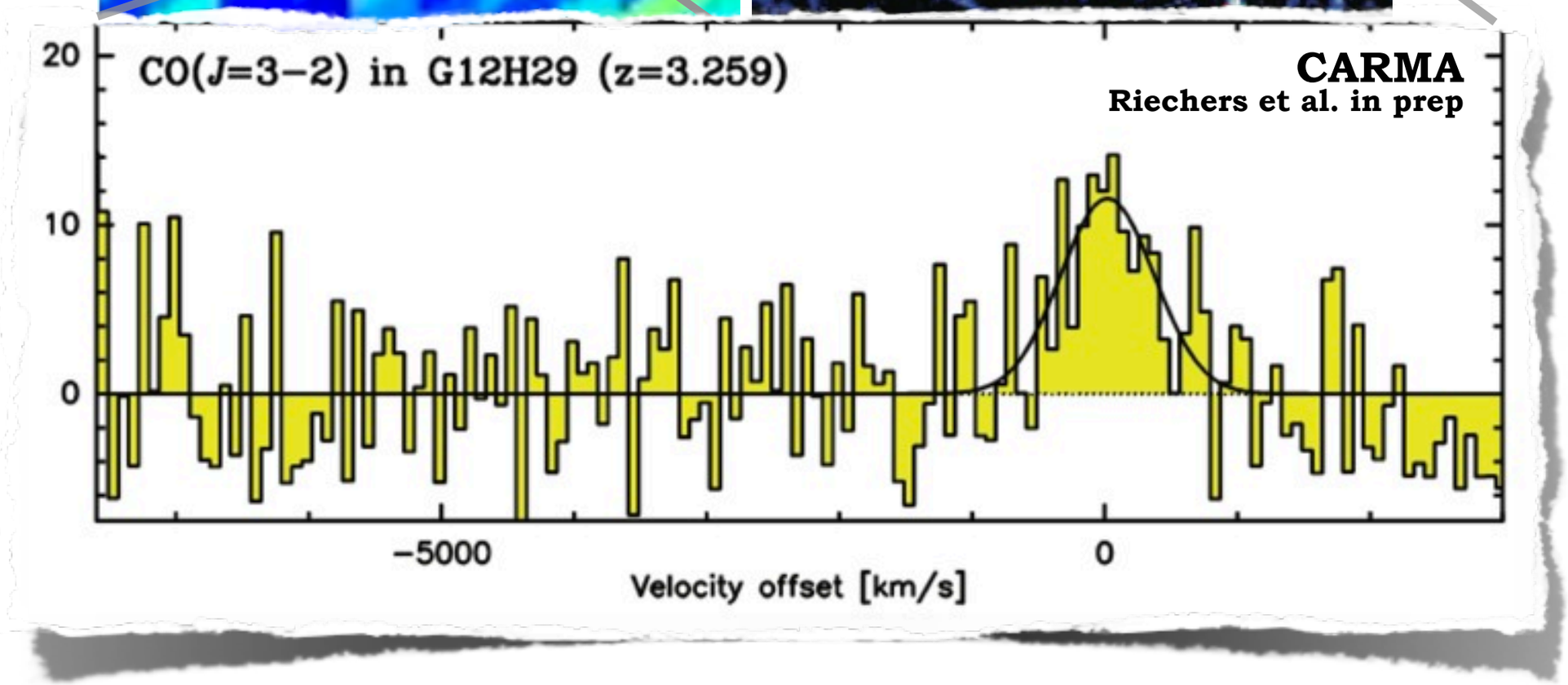




(brightest source)
S_{250} = 320 ± 20 mJy
S_{350} = 380 ± 60 mJy
S_{500} = 300 ± 20 mJy

z_{CO} = 3.26



(Fu et al. arXiv: 1202.1829)

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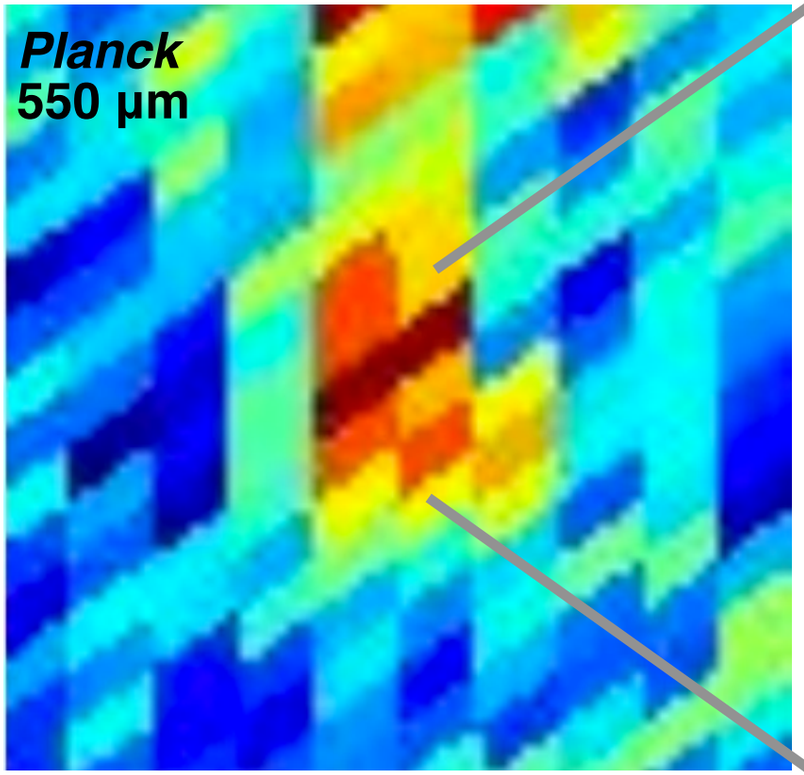

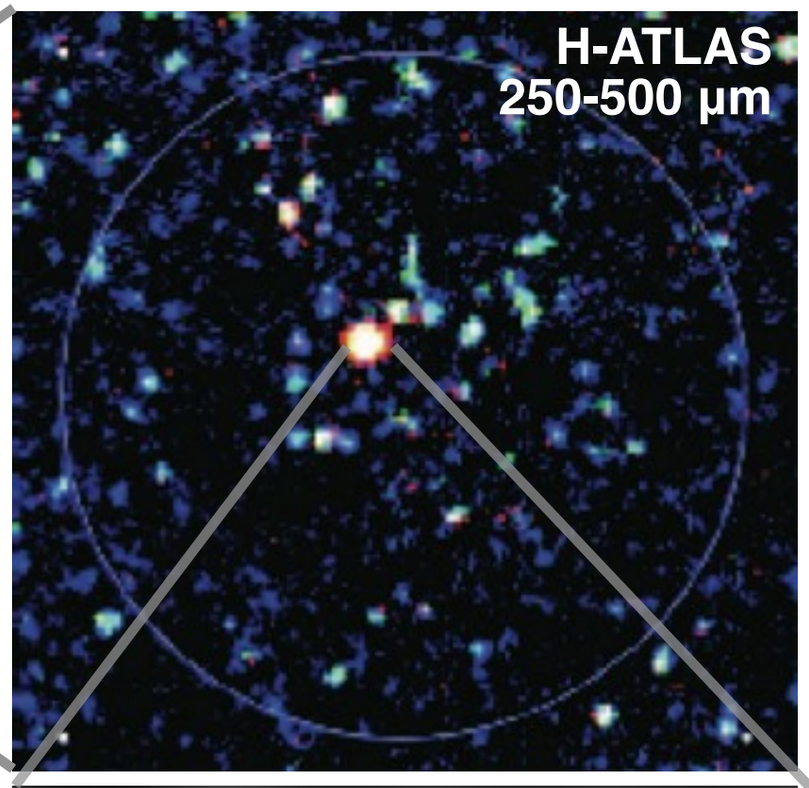

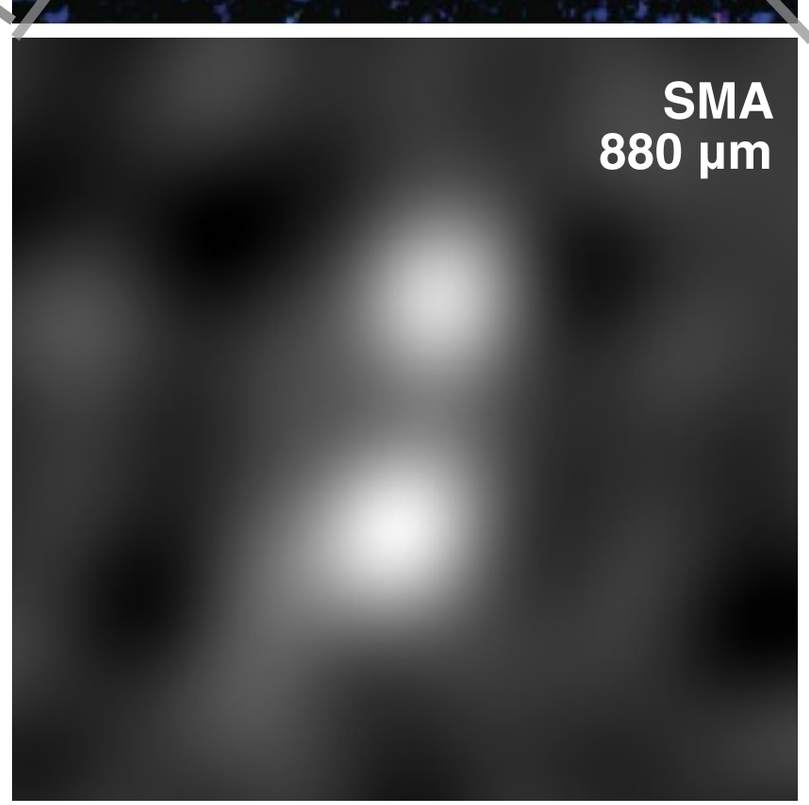

(brightest source)
S_{250} = 320 ± 20 mJy
S_{350} = 380 ± 60 mJy
S_{500} = 300 ± 20 mJy

z_{CO} = 3.26

S_{880} = 70 ± 10 mJy

(Fu et al. arXiv: 1202.1829)

A lensed *Planck* source resolved by *Herschel*

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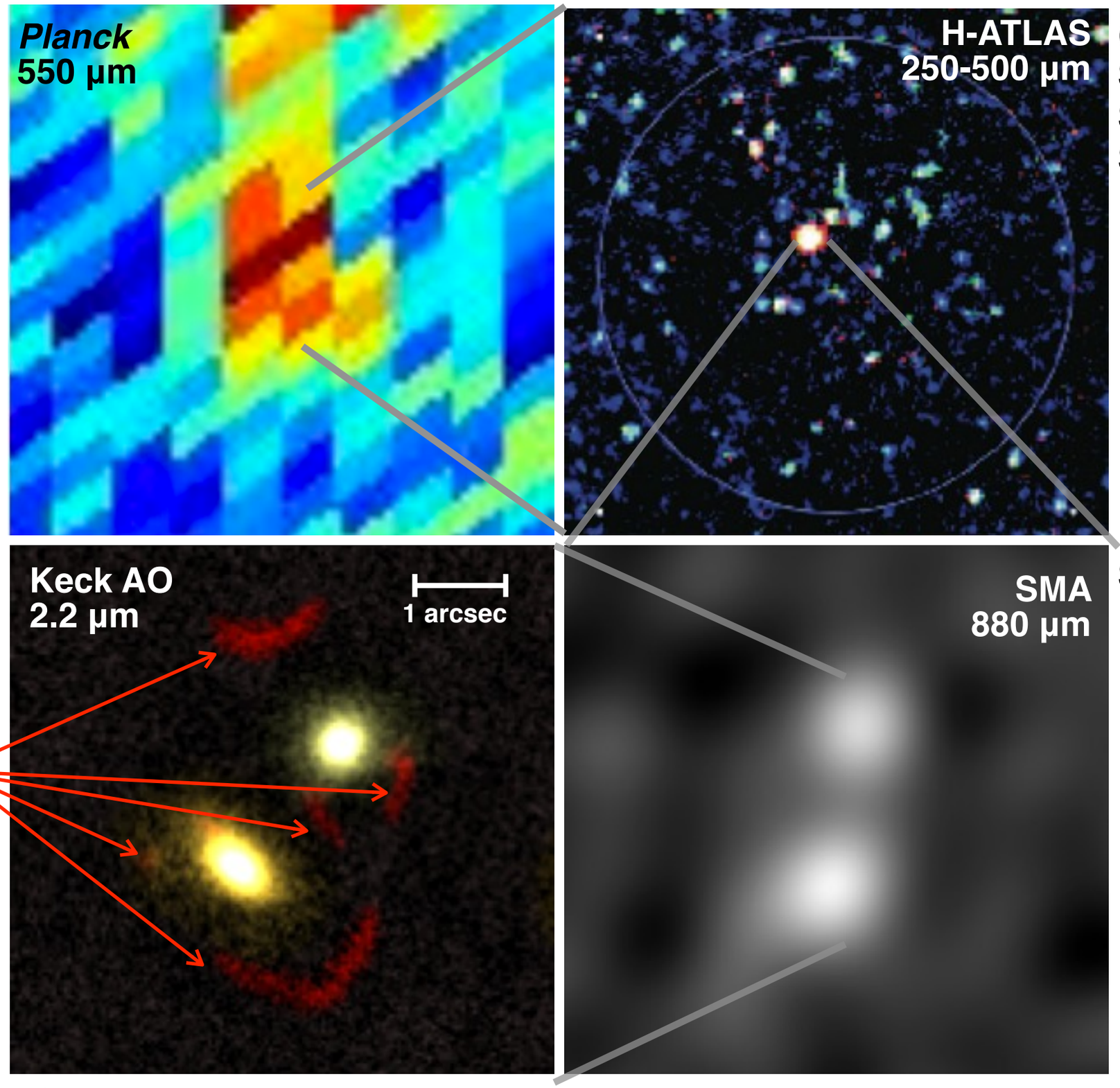

(brightest source)
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S_{880} = 70 ± 10 mJy

(Fu et al. arXiv: 1202.1829)

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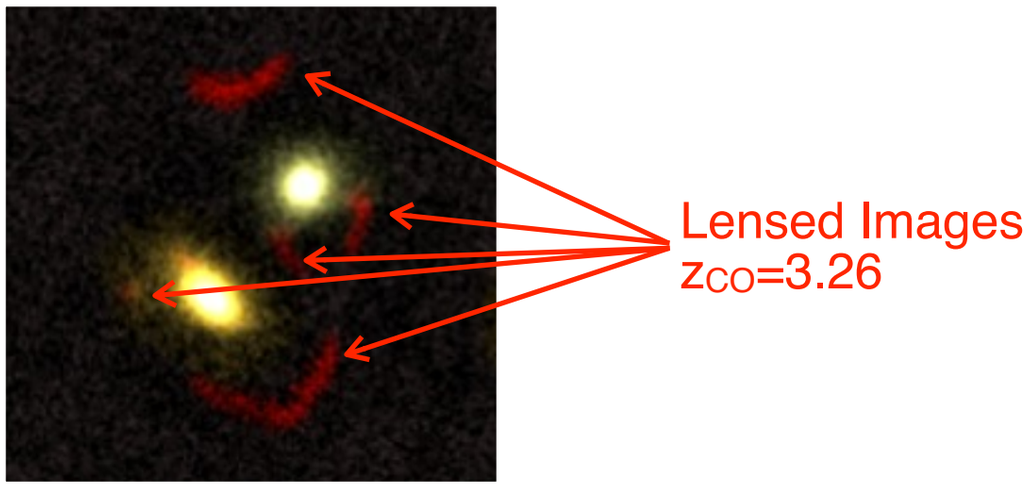

(Fu et al. arXiv: 1202.1829)

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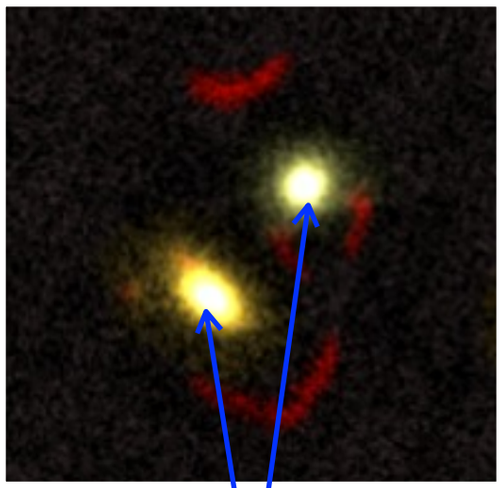
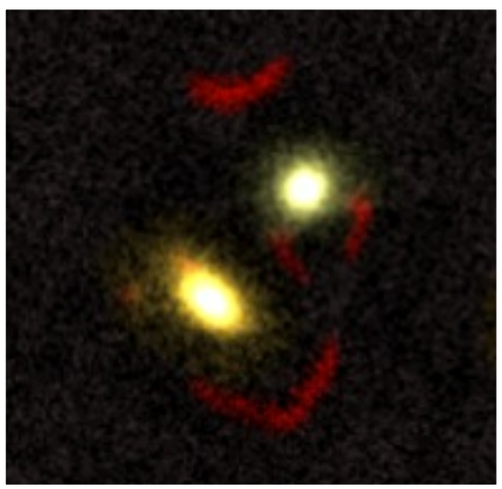


Deflectors
z=1.1 ± 0.2

Lensed Images
z_{CO}=3.26

(Fu et al. arXiv: 1202.1829)

A lensed *Planck* source resolved by *Herschel*

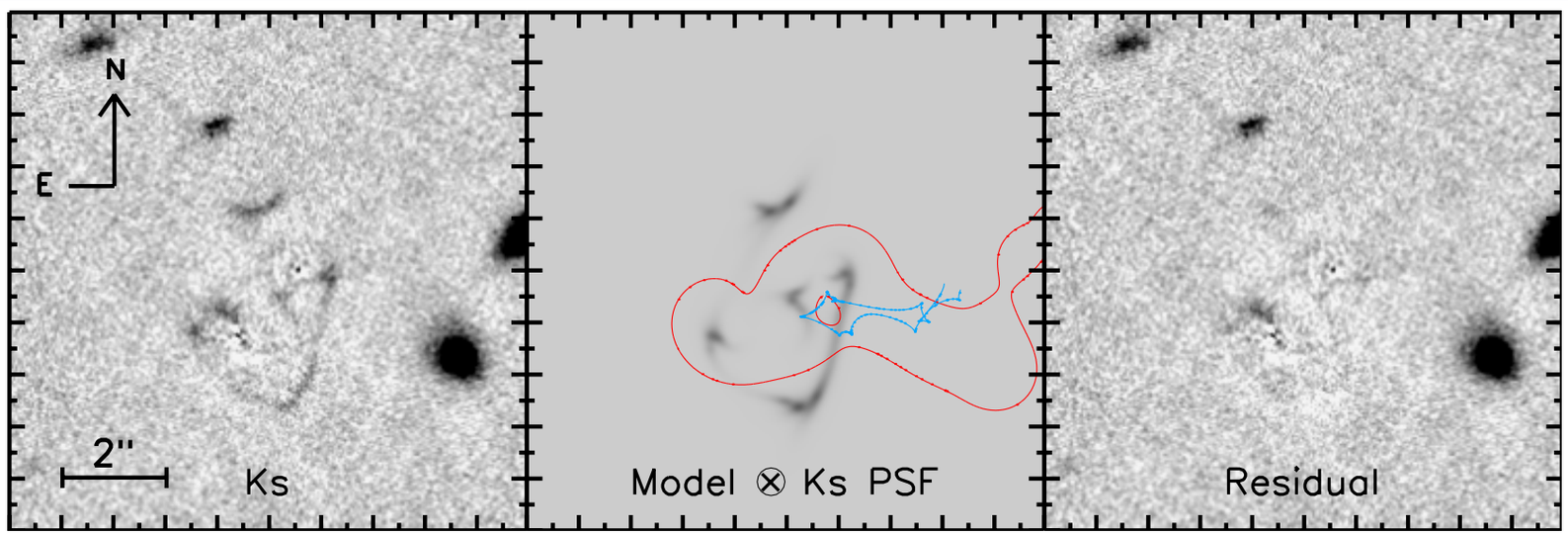


Deflectors
z=1.1 ± 0.2

Lensed Images
z_{CO}=3.26

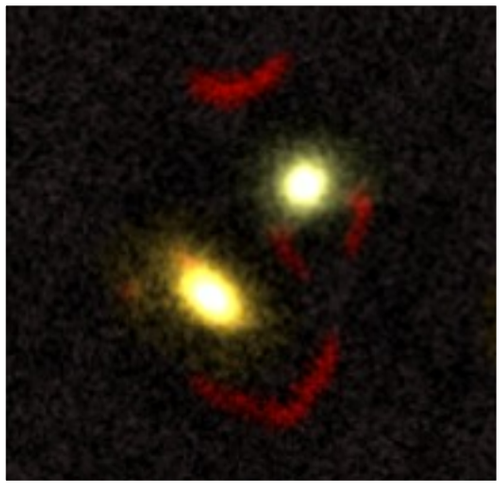
Keck K-band

μ(K) = 16.7±0.8



(Fu et al. arXiv: 1202.1829)

A lensed *Planck* source resolved by *Herschel*



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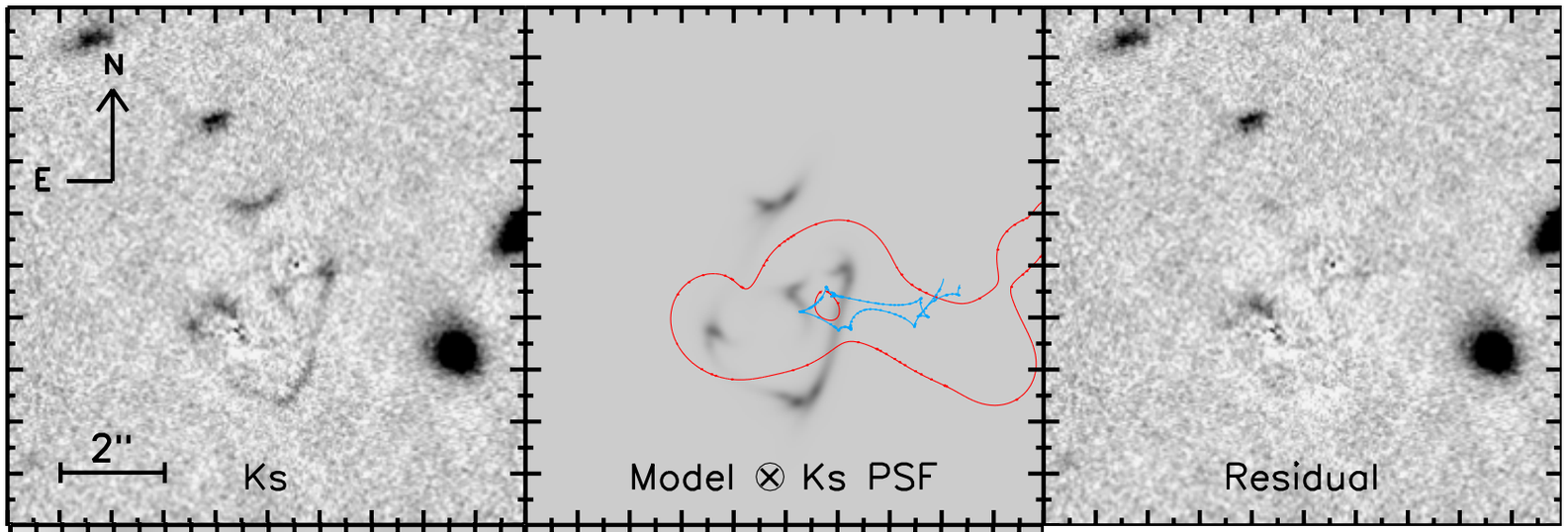
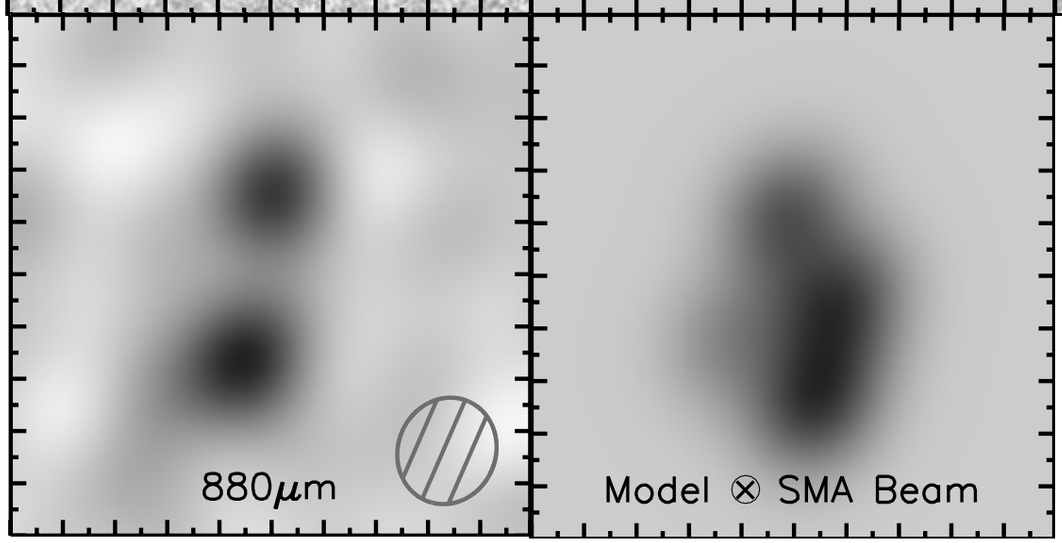
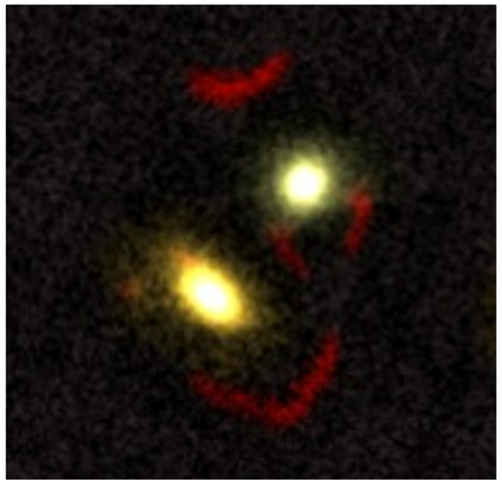


SMA 880 μm



(Fu et al. arXiv: 1202.1829)

A lensed *Planck* source resolved by *Herschel*



Deflectors
z=1.1 ± 0.2

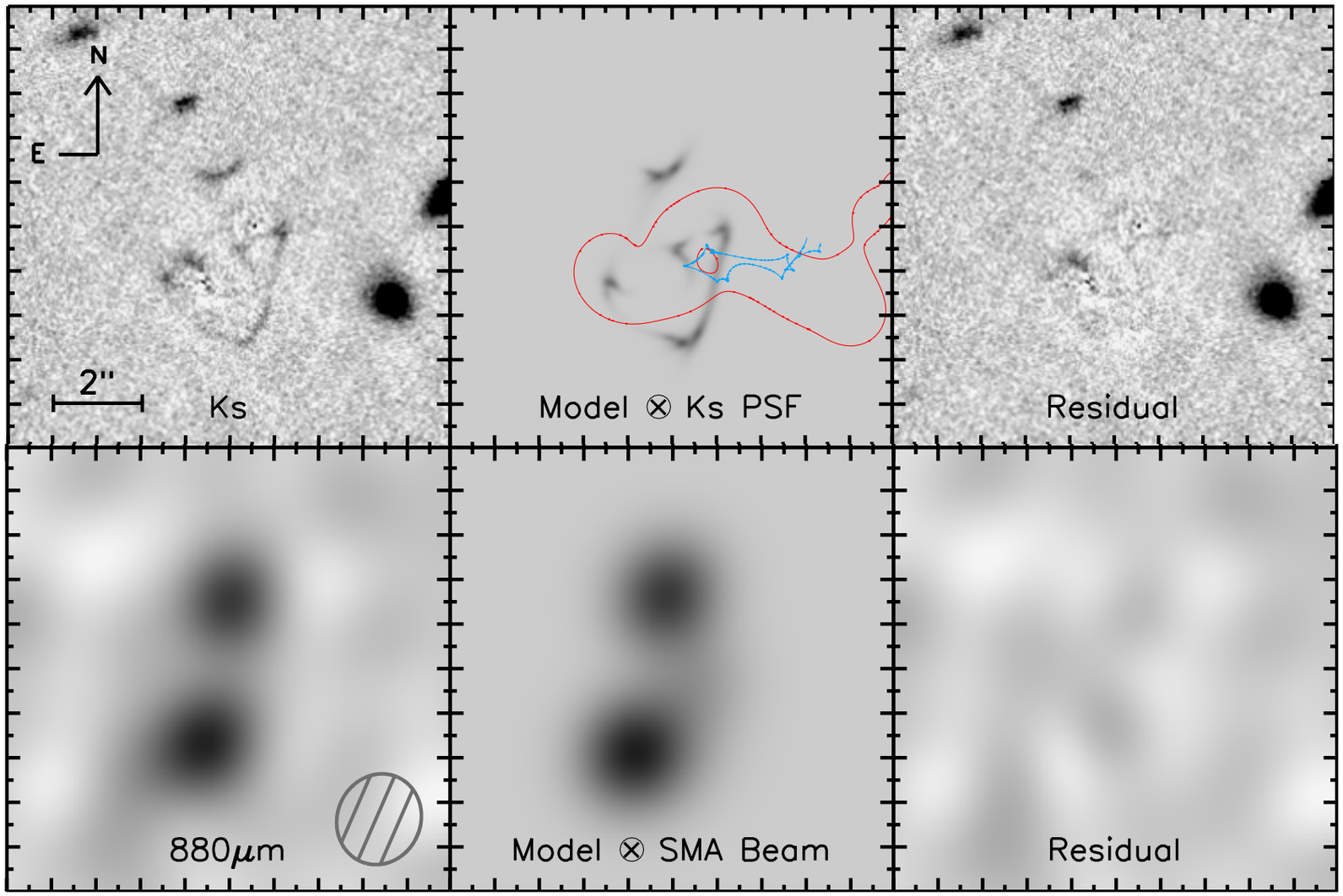
Lensed Images
z_{CO}=3.26

Keck K-band

μ(K) = 16.7±0.8

SMA 880 μm

μ(880 μm) = 7.6±1.5



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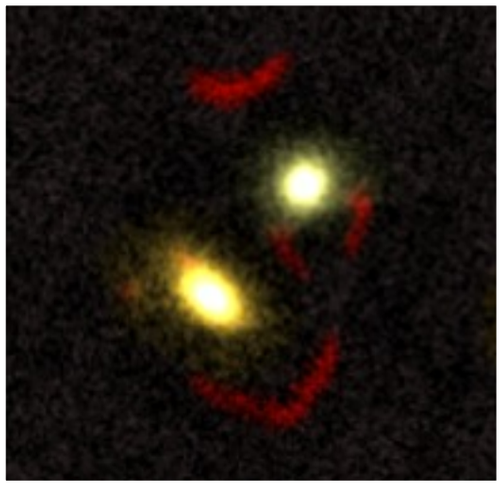
A lensed *Planck* source resolved by *Herschel*



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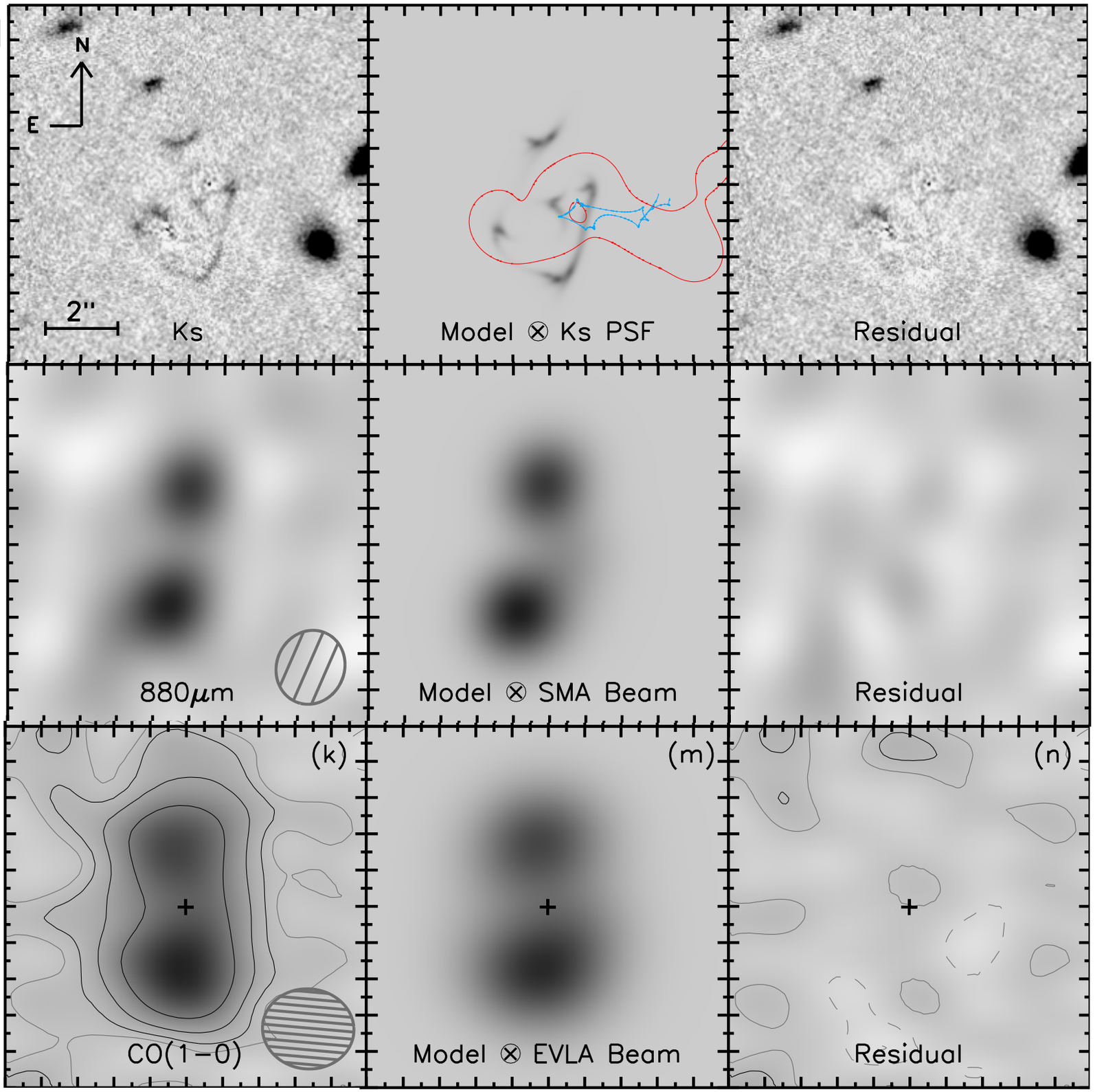
SMA 880 μm

μ(880 μm) = 7.6±1.5

EVLA CO(1-0)

μ(CO(1-0)) = 6.9±1.6



(Fu et al. arXiv: 1202.1829)

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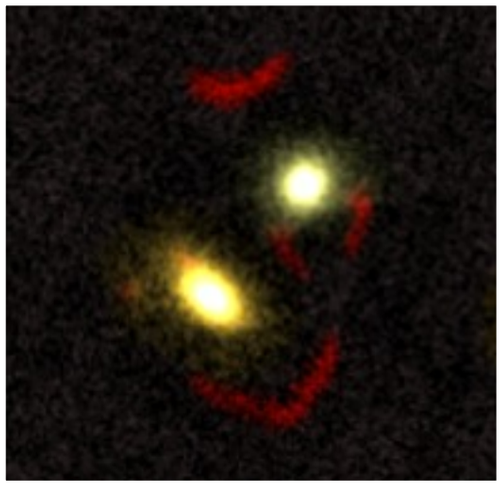

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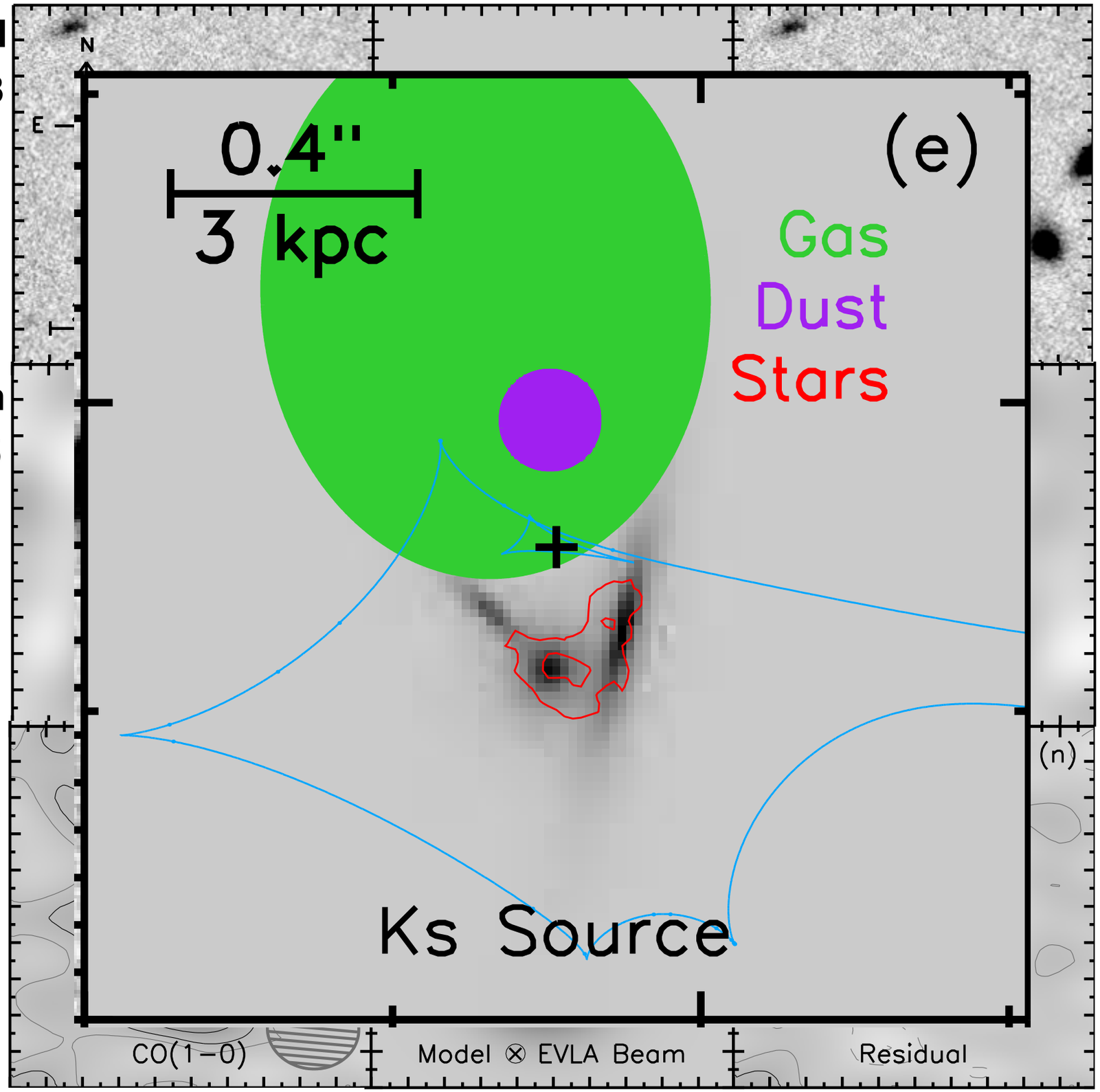

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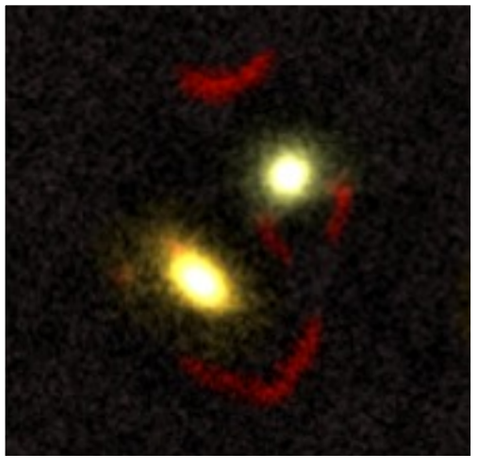


Deflectors
z=1.1 ± 0.2

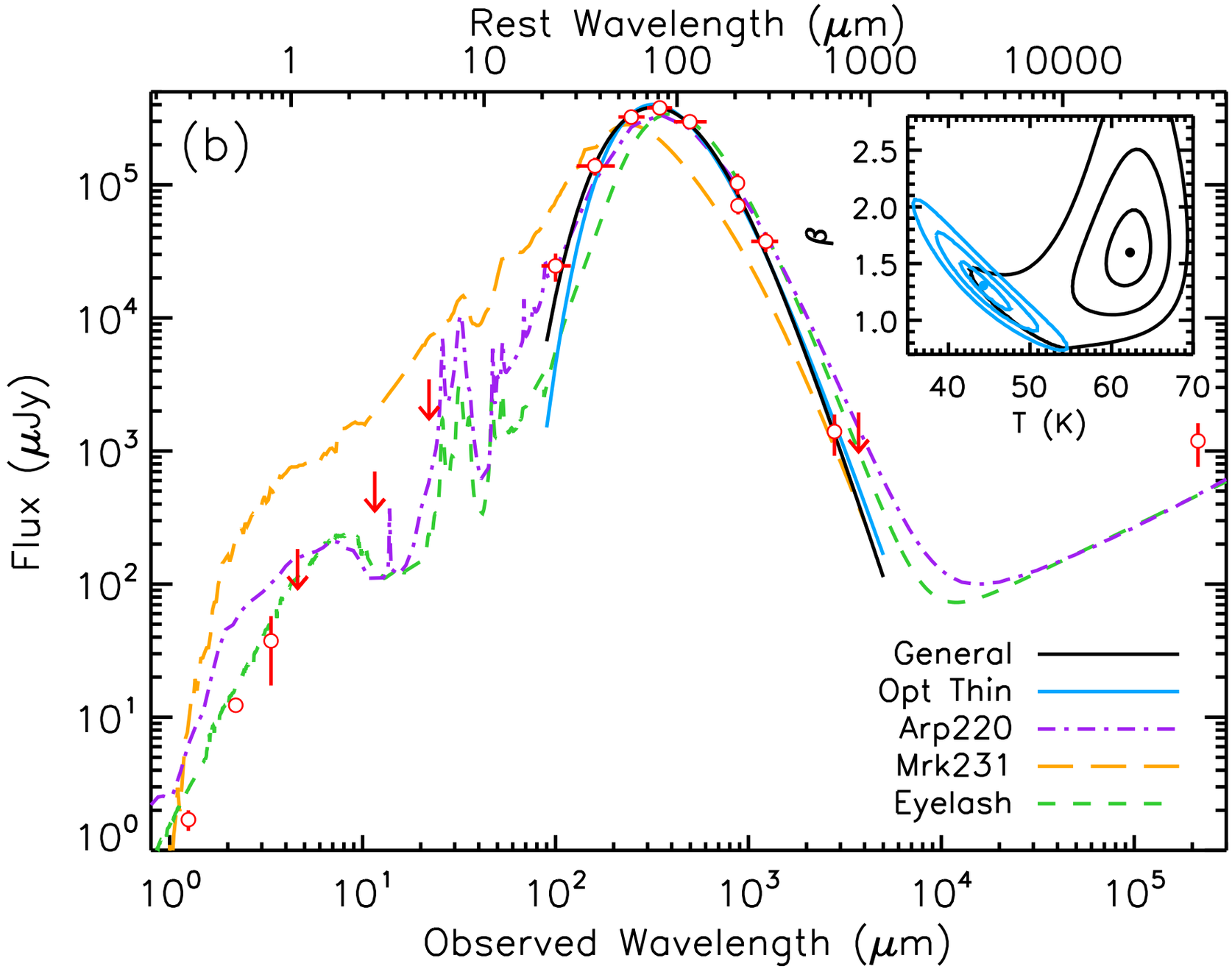
Lensed Images
z_{CO}=3.26

(intrinsic)
L_{FIR} = 1.6 x10^{13} $L_\odot$
SFR ~ 1900 $M_\odot$/yr

T_D = 62 ± 3 K
β = 1.6 ± 0.4

No evidence for AGN

M* ~ 3 x10^{10} $M_\odot$



(Fu et al. arXiv: 1202.1829)

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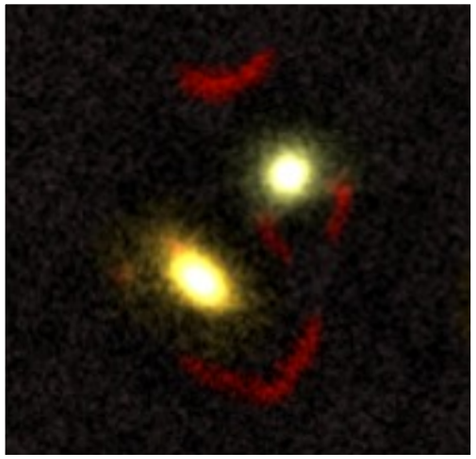

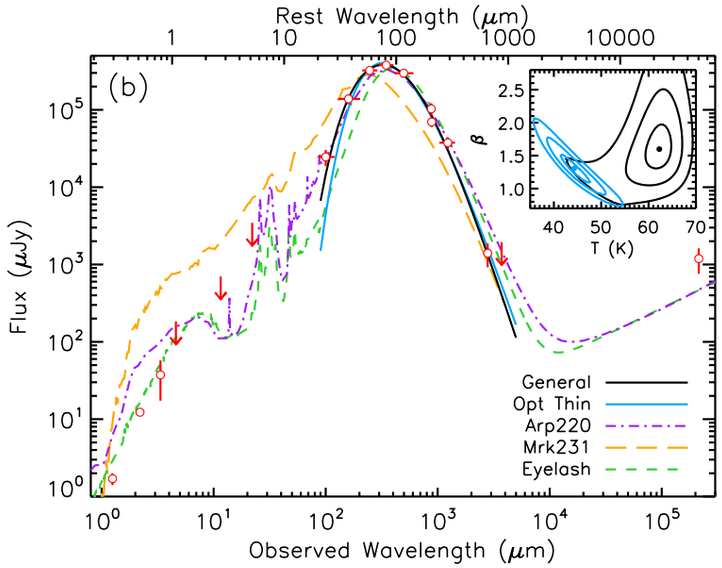

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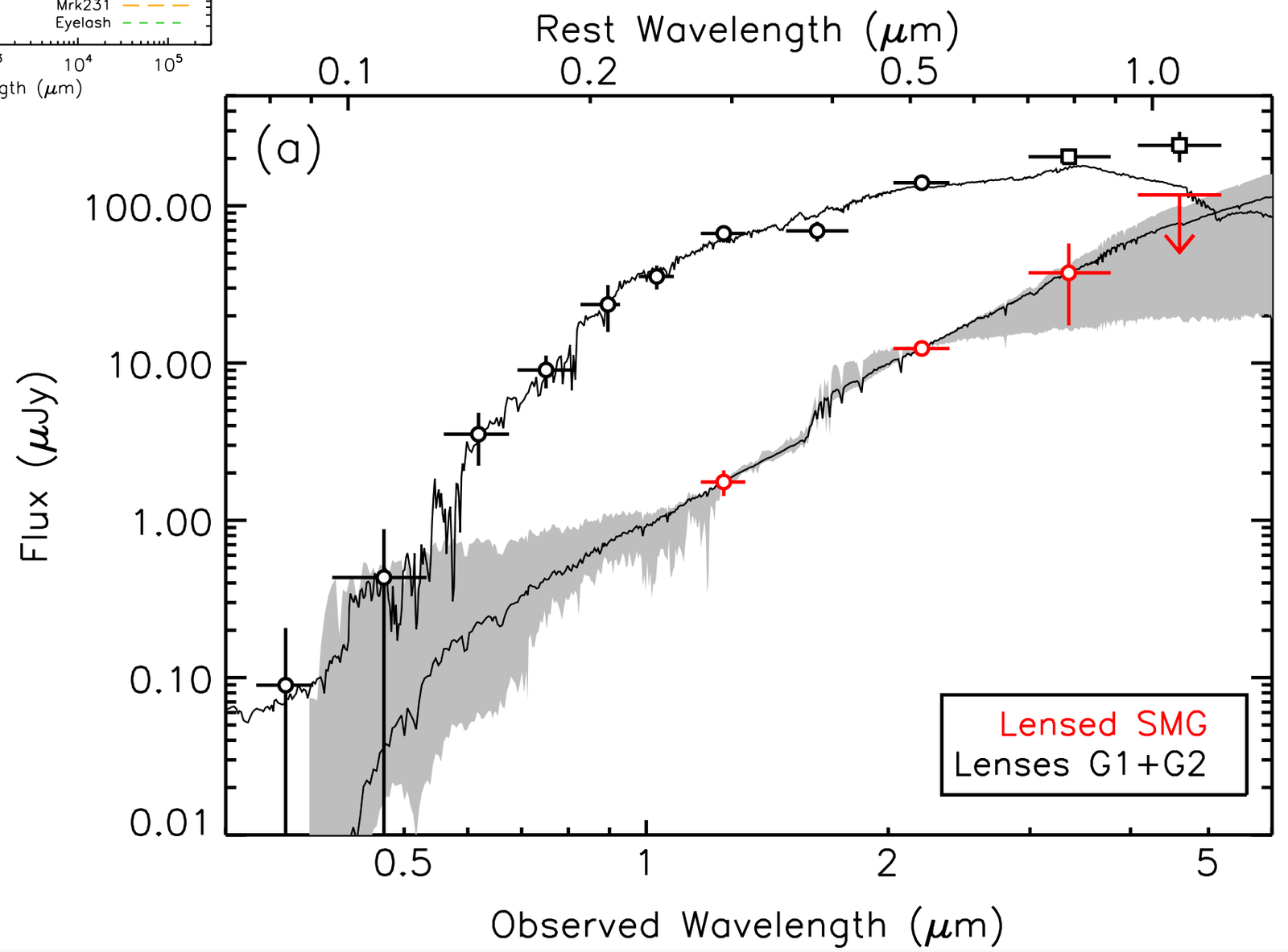


(Fu et al. arXiv: 1202.1829)

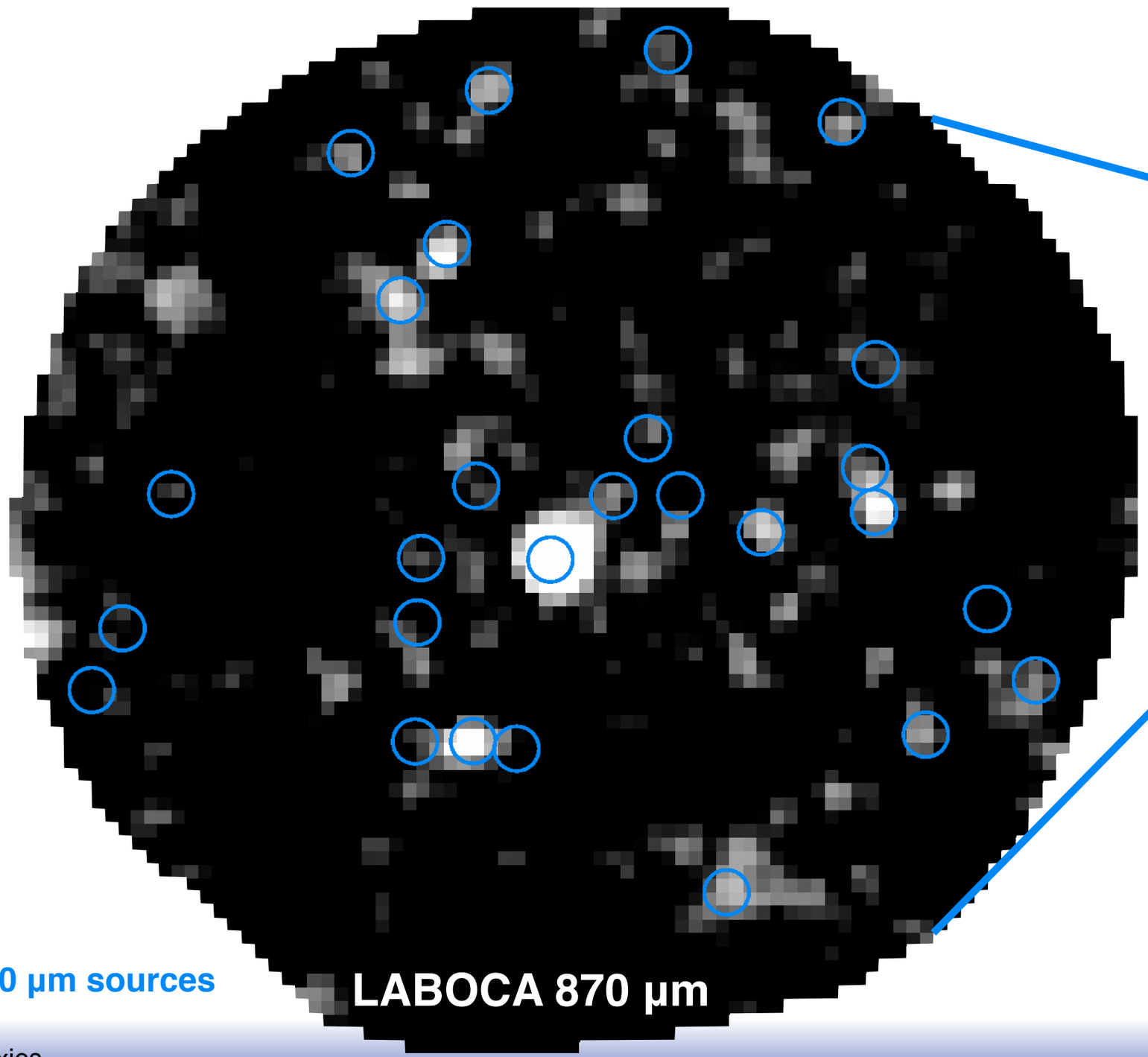
A lensed *Planck* source resolved by *Herschel*

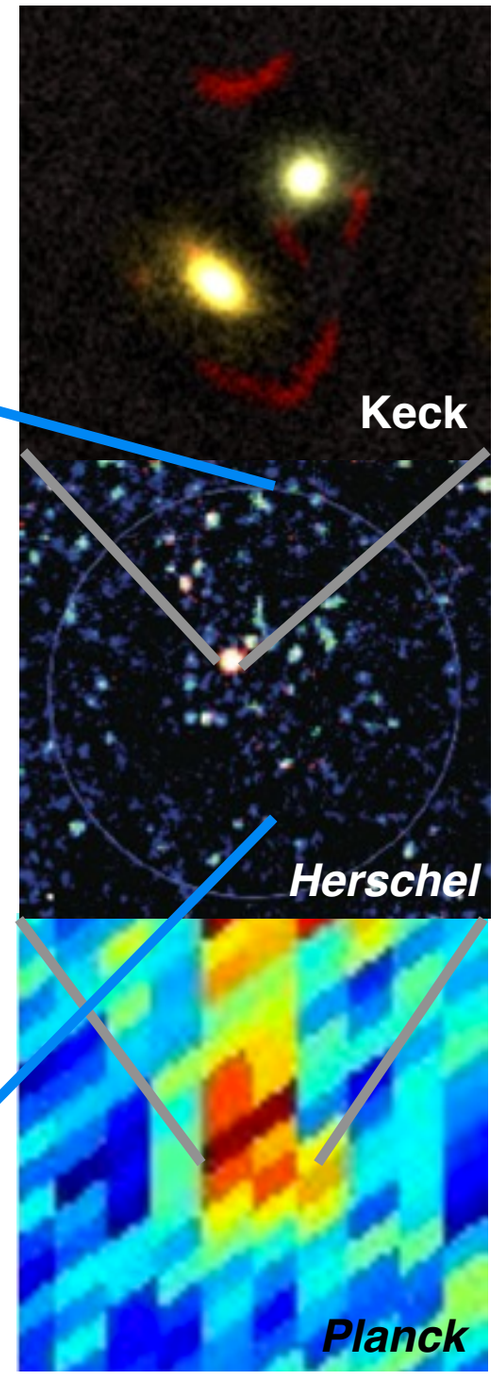
Only some 250 μm sources are detected at 870 μm.

⇒ different SEDs

⇒ different z

Detected sources likely at z~3
Undetected sources likely at z~1



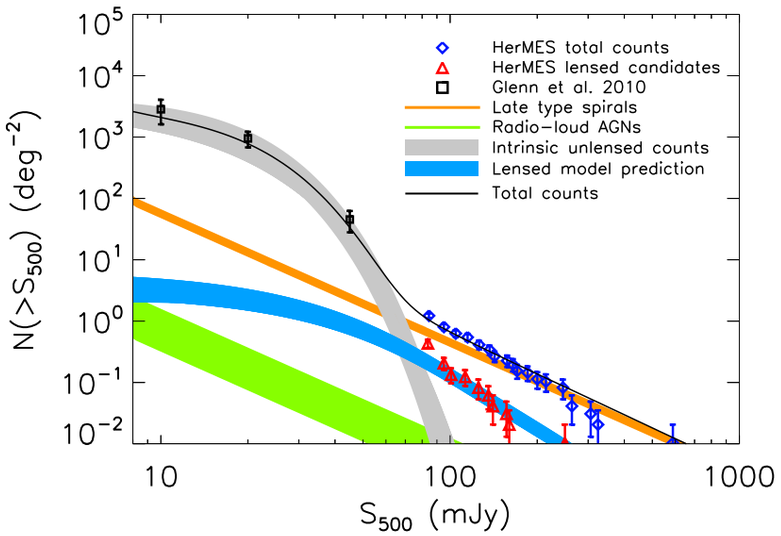


○ = 250 μm sources

(Clements et al. in prep.)

Summary

Wide-area, submm surveys can efficiently identify strongly lensed galaxies by simply selecting the brightest sources



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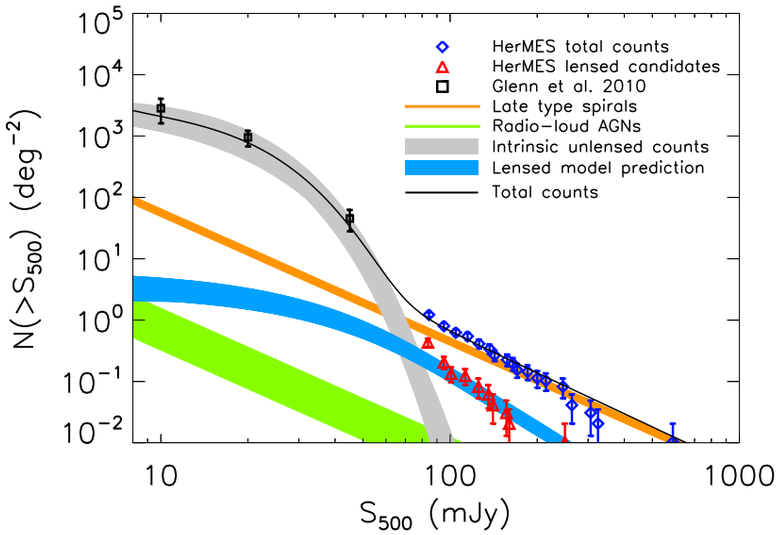
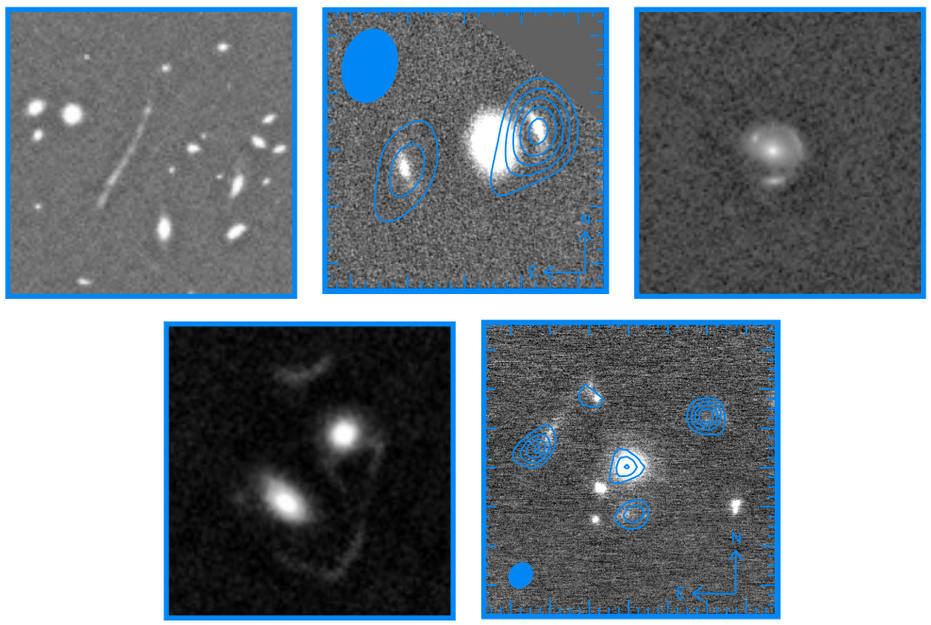


Extensive followup programs are providing a detailed view of high-z star-formation.



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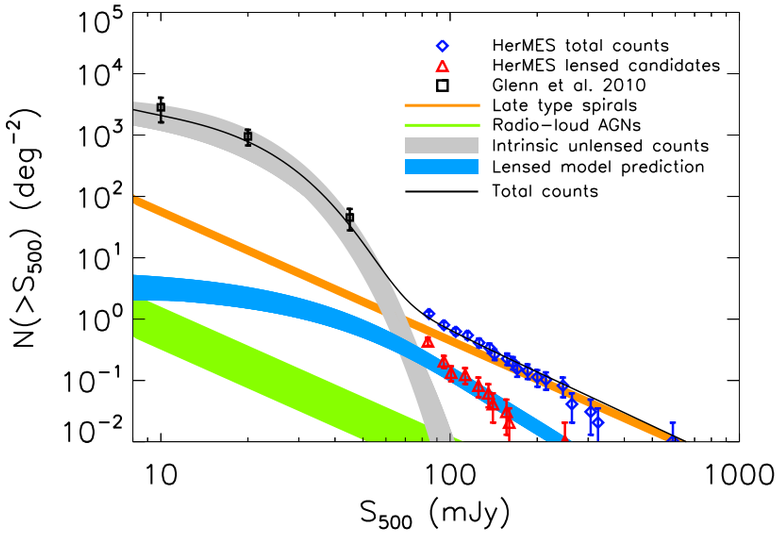

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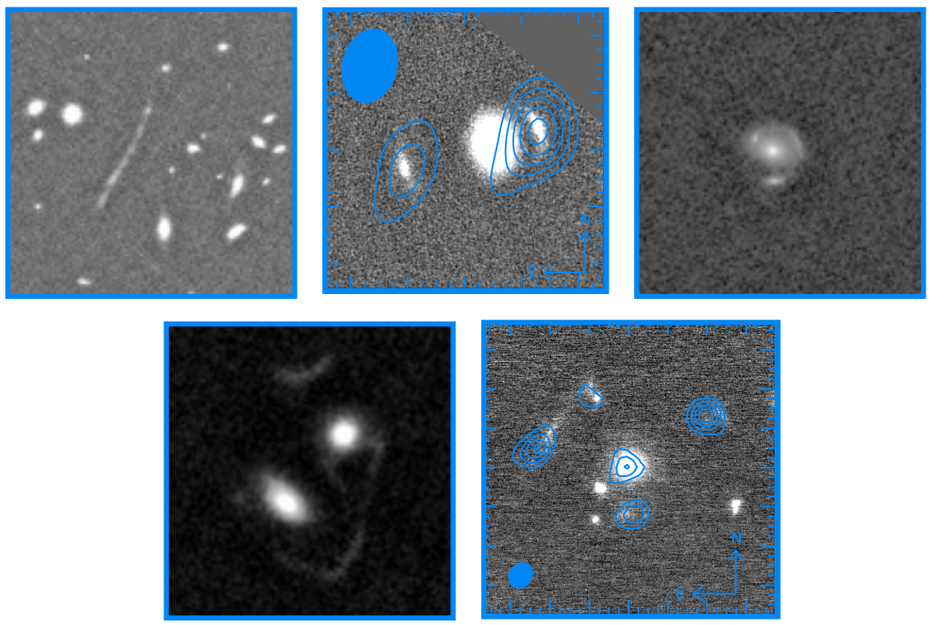
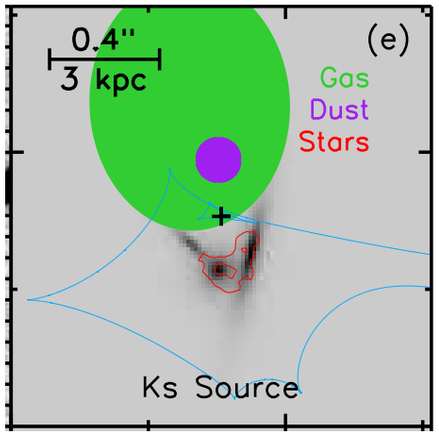


In at least one galaxy the stellar distribution is clumpy and the stars offset from the gas and dust.



Summary

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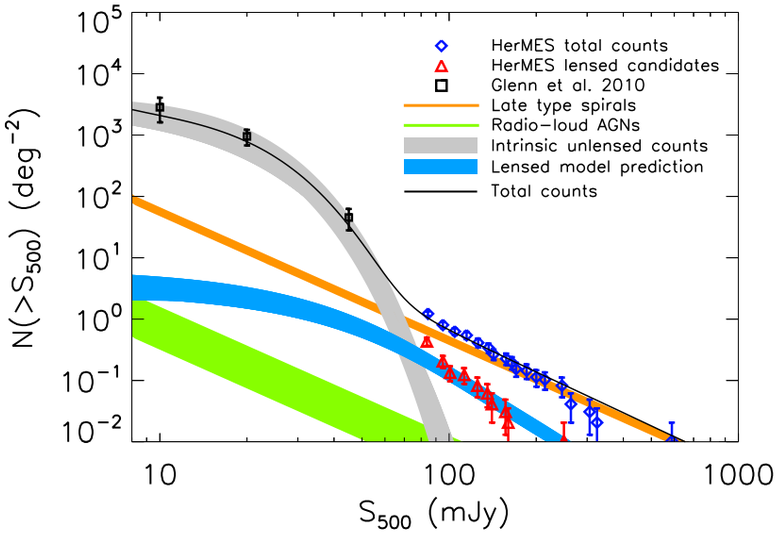

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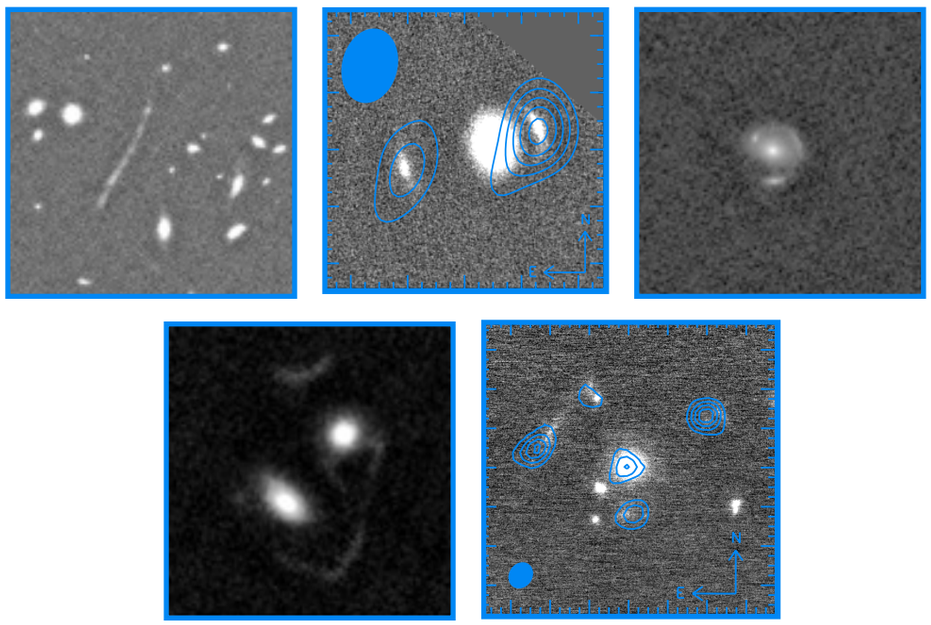

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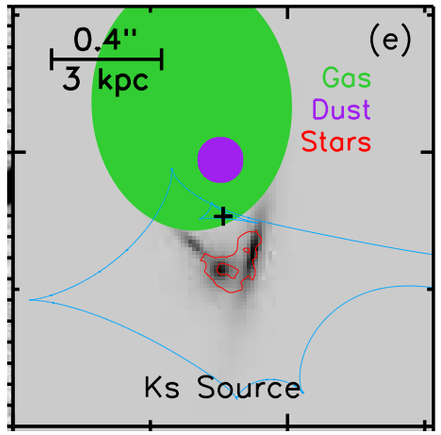
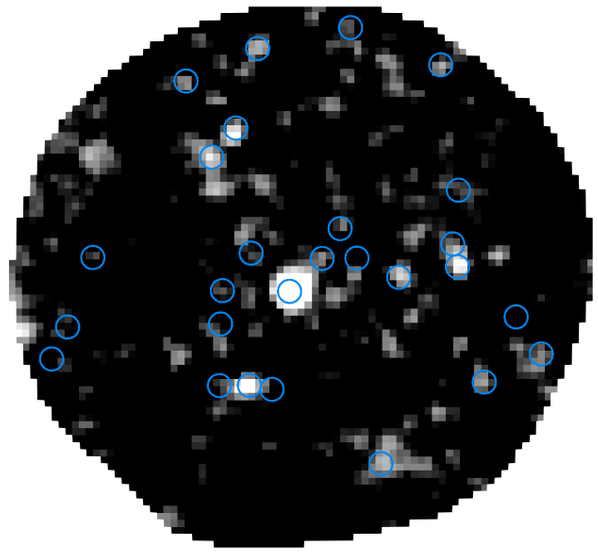
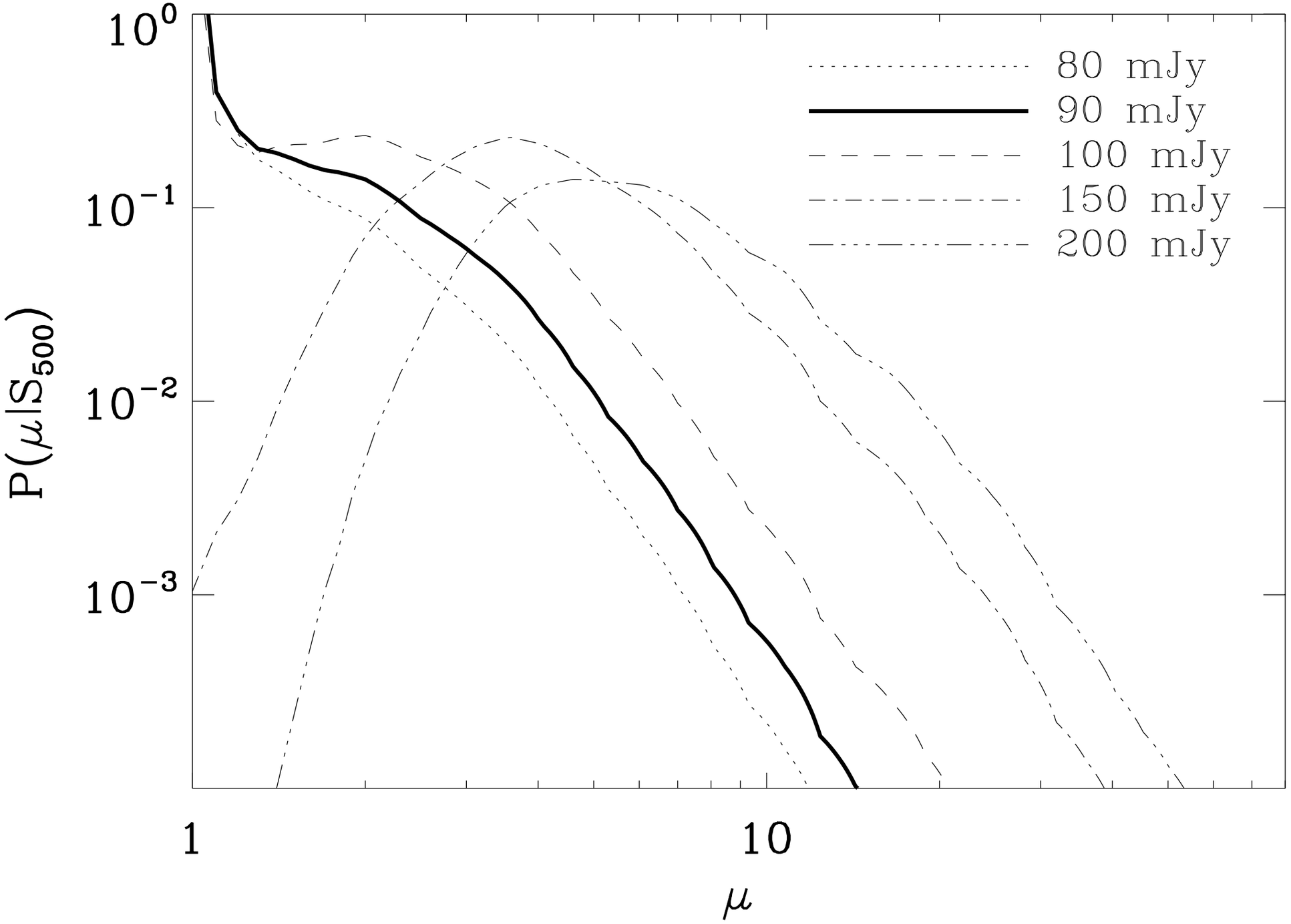
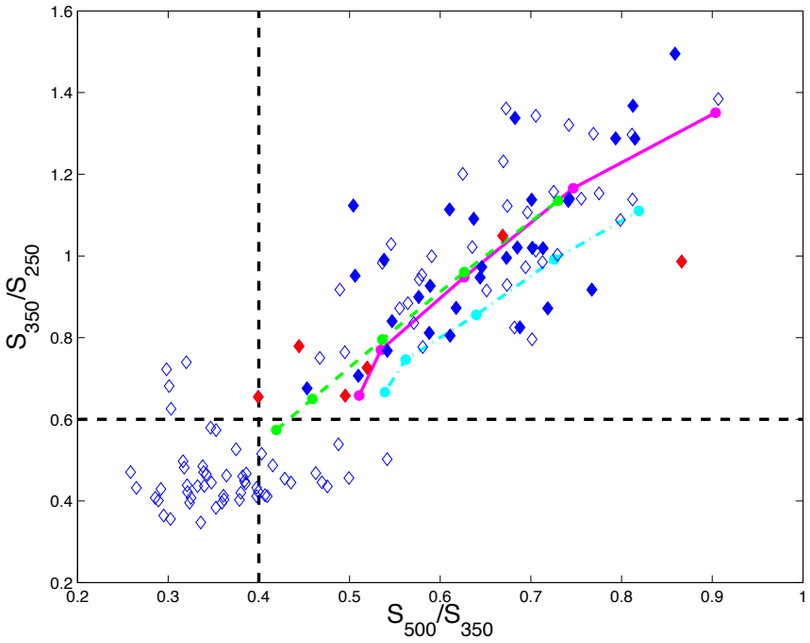


Wide-field longer wavelength data is critical for understanding the environments of these sources.




10^0
10^{-1}
10^{-2}
10^{-3}
$P(\mu|S_{500})$
80 mJy
90 mJy
100 mJy
150 mJy
200 mJy
1
10
μ

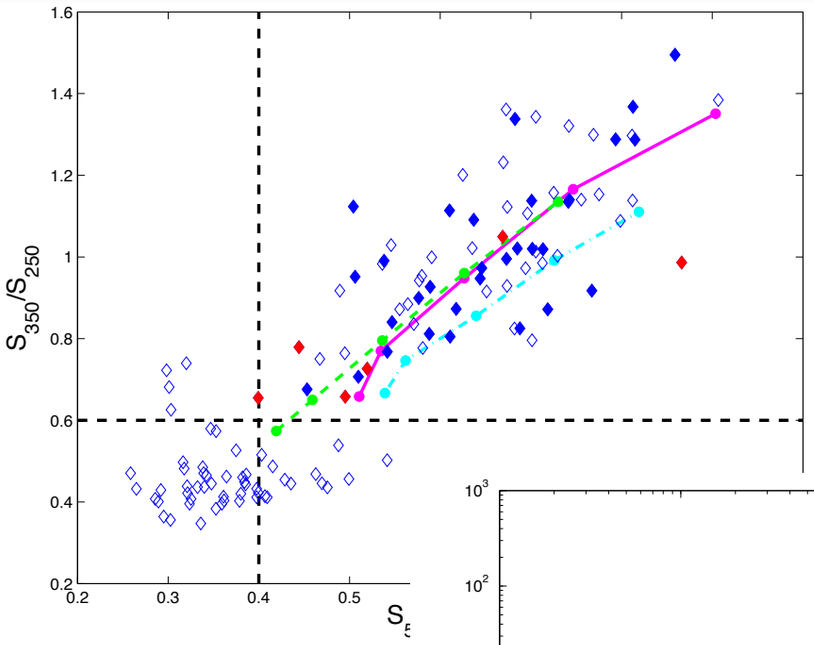
Lensed galaxies can be selected from their colours



1) Select sources with z>1.2 submm colours

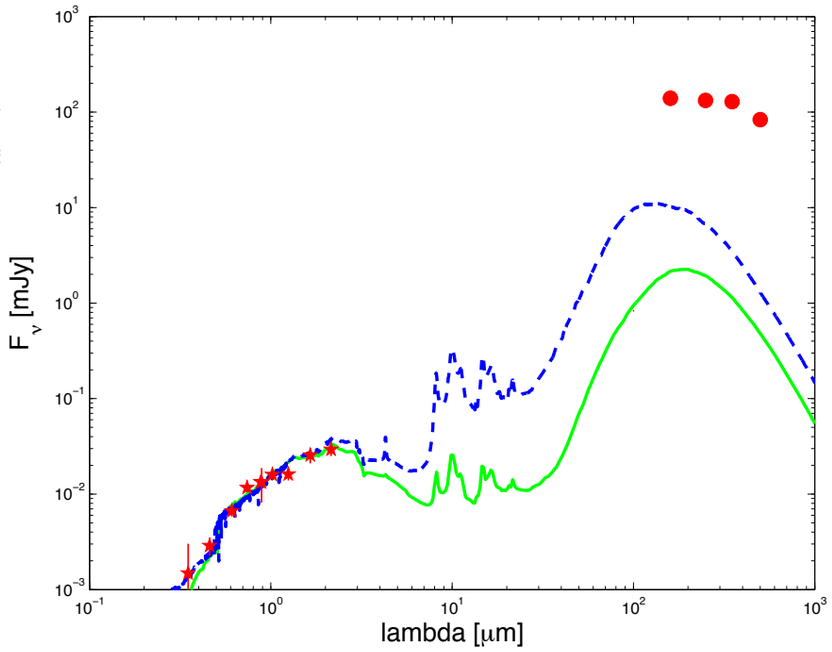
(HALOS: González-Nuevo et al. 2012)

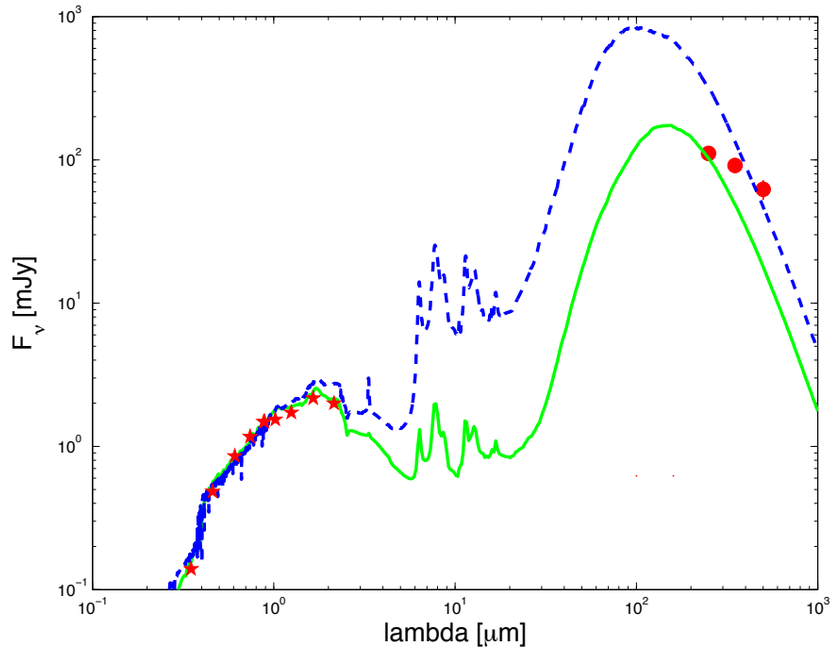
Lensed galaxies can be selected from their colours



1) Select sources with z>1.2 submm colours

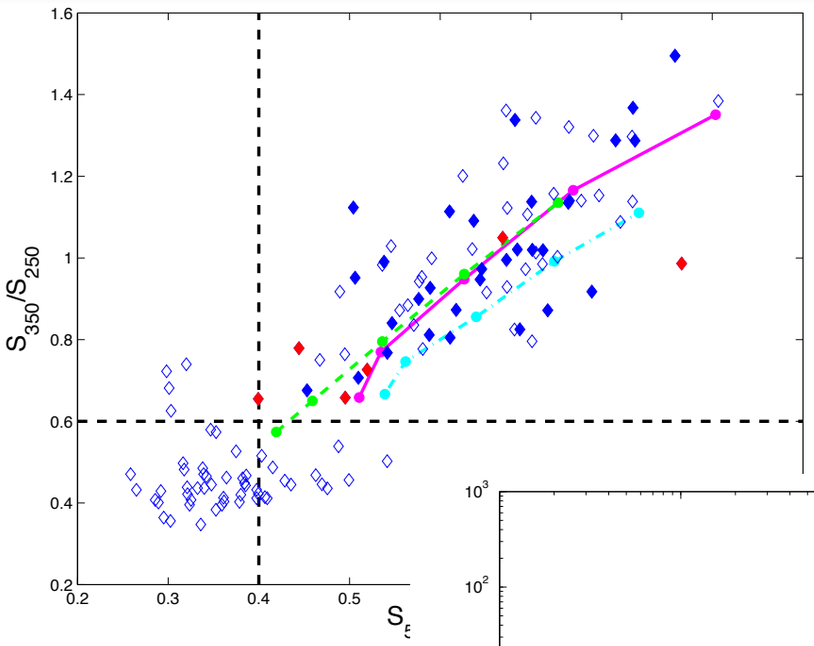
2) Identify sources with mismatched optical and submm SEDs





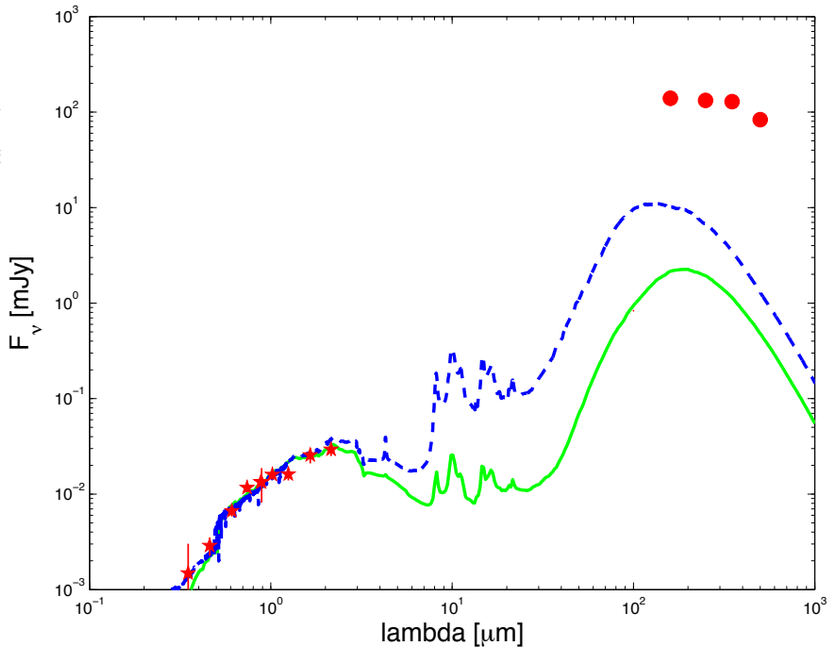
(HALOS: González-Nuevo et al. 2012)

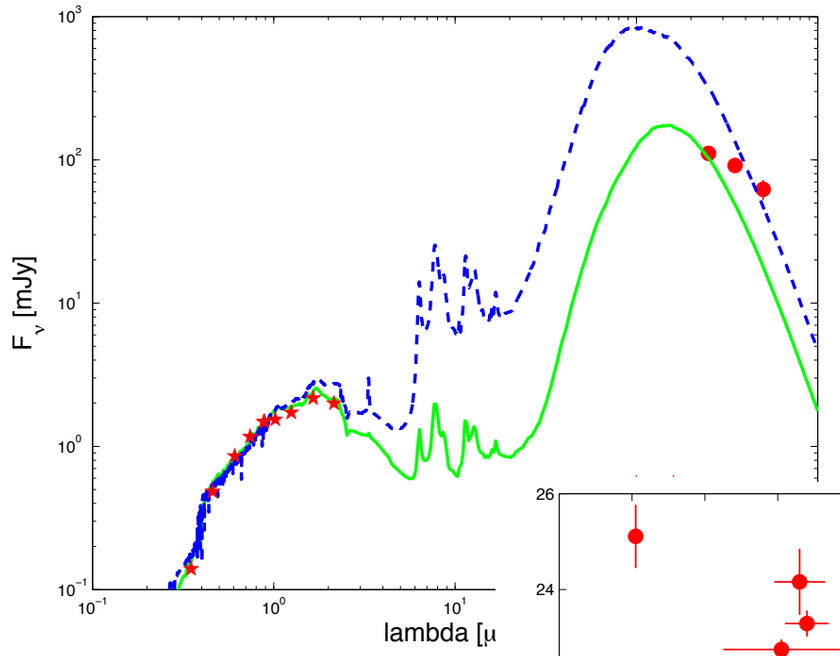
Lensed galaxies can be selected from their colours

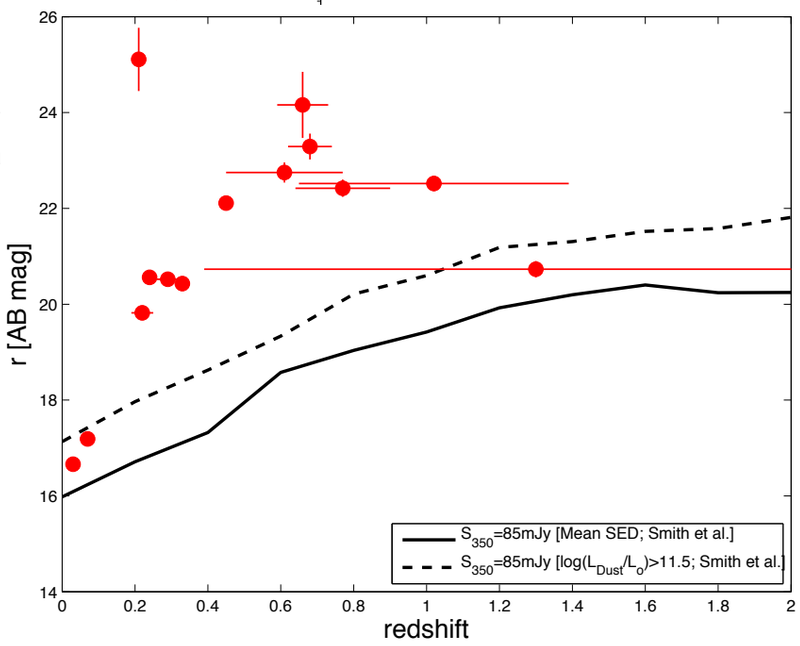


1) Select sources with z>1.2 submm colours

2) Identify sources with mismatched optical and submm SEDs





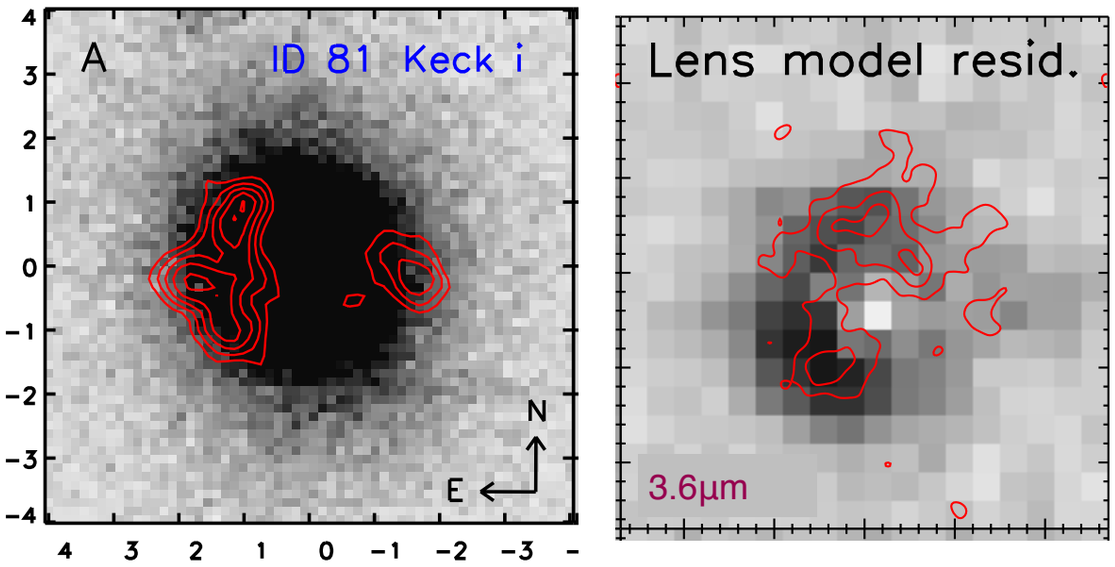


If at the optical *z* these galaxies are to optically faint to simply contain cold dust. Therefore, the optical source is mostly likely lensing a background SMG.

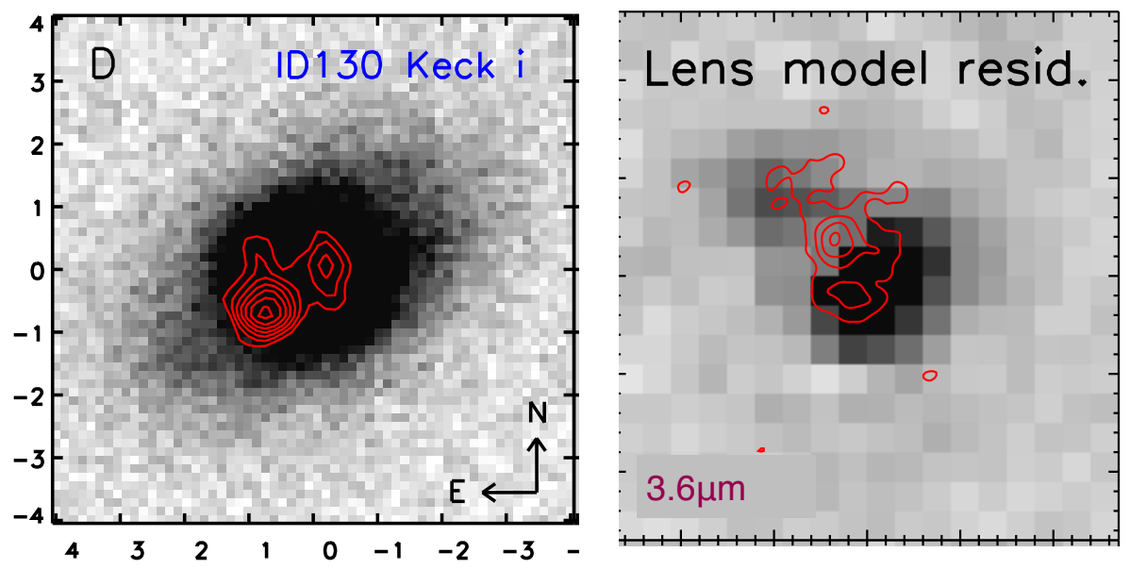
(HALOS: González-Nuevo et al. 2012)

The first lensed *Herschel* galaxies

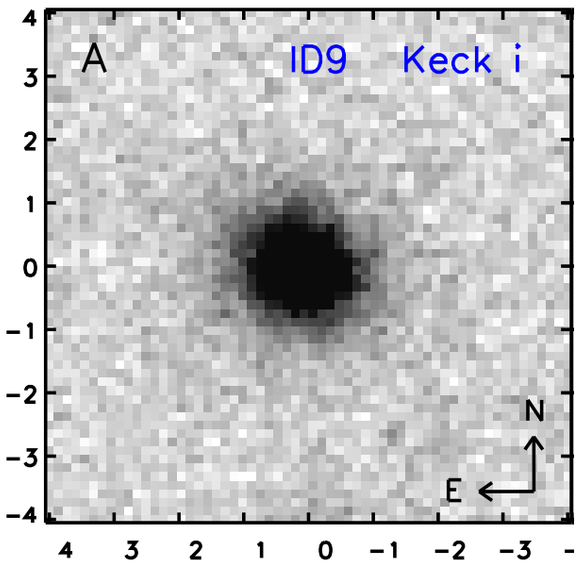
z_{SMG}=3.04; z_{lens}=0.30
μ=25±7



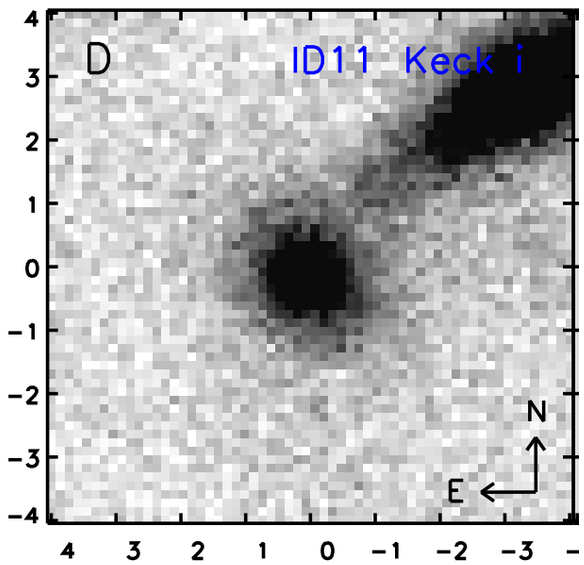
z_{SMG}=2.62; z_{lens}=0.22
μ=6±1



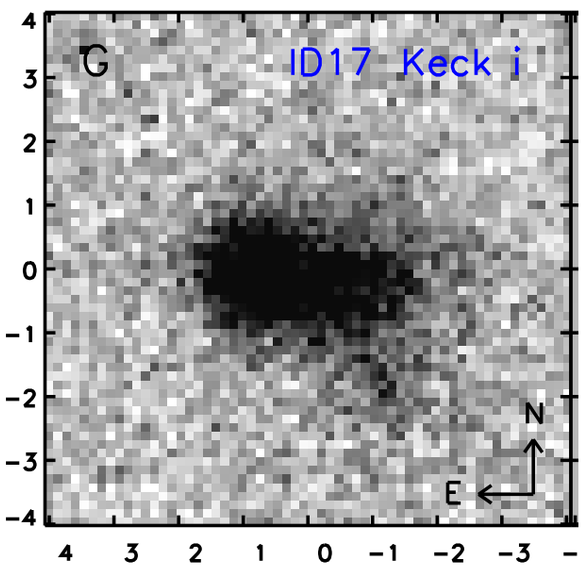
z_{SMG}=1.58; z_{lens}=0.7



z_{SMG}=1.79; z_{lens}=0.79



z_{SMG}=2.30; z_{lens}=0.94



(Negrello et al. 2010; Lupu et al. 2010; Hopwood et al. 2011; Harris et al. 2012)