Gravitationally lensed galaxies selected in submillimeter surveys:
examples from *Herschel* HerMES

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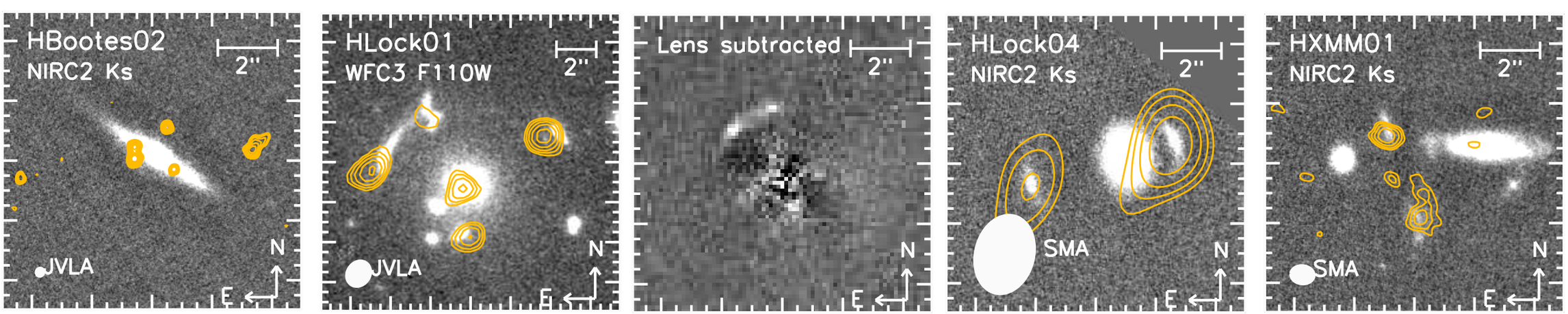

Wardlow et al. 2012 arXiv: 1205.3778

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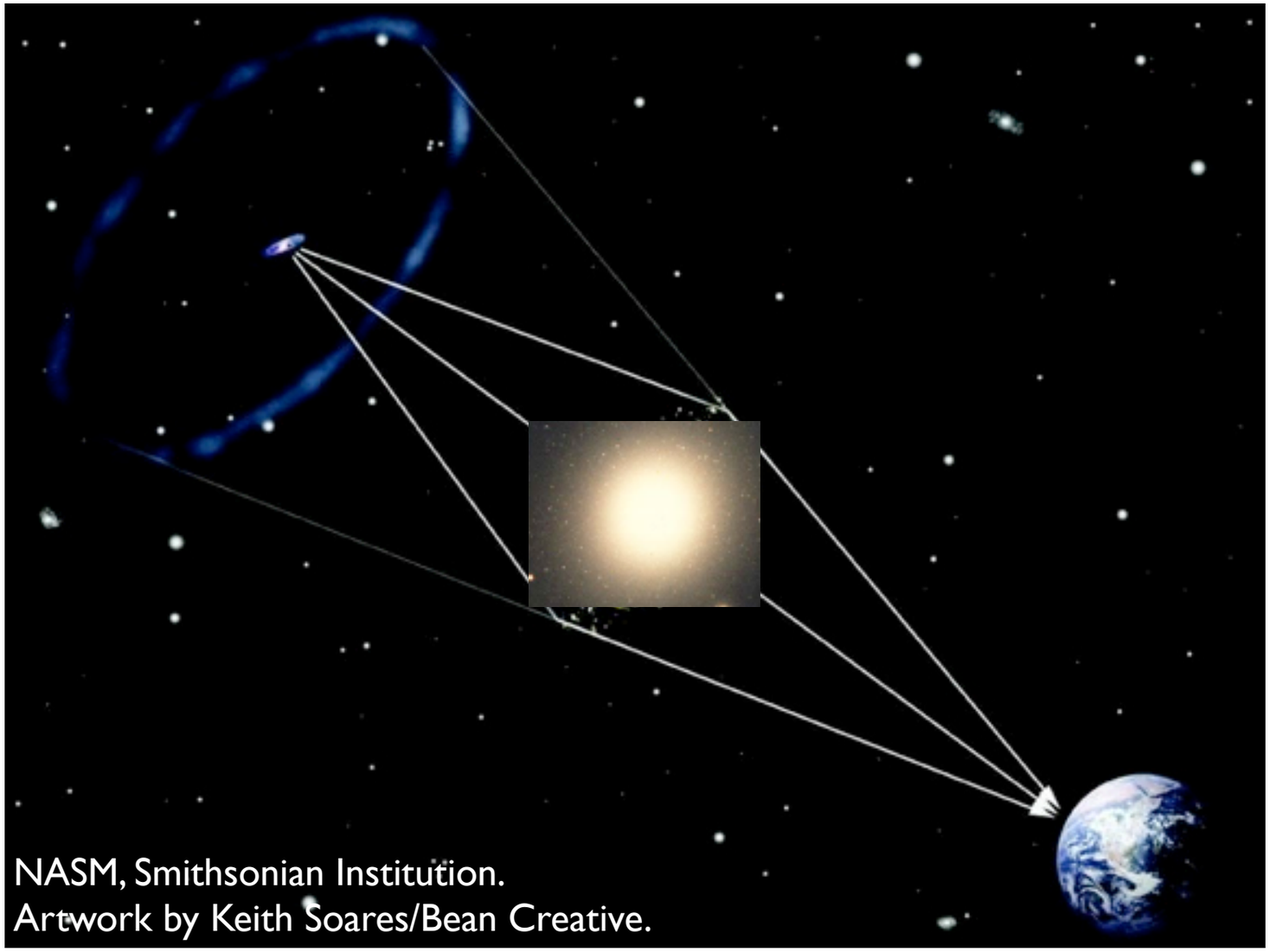
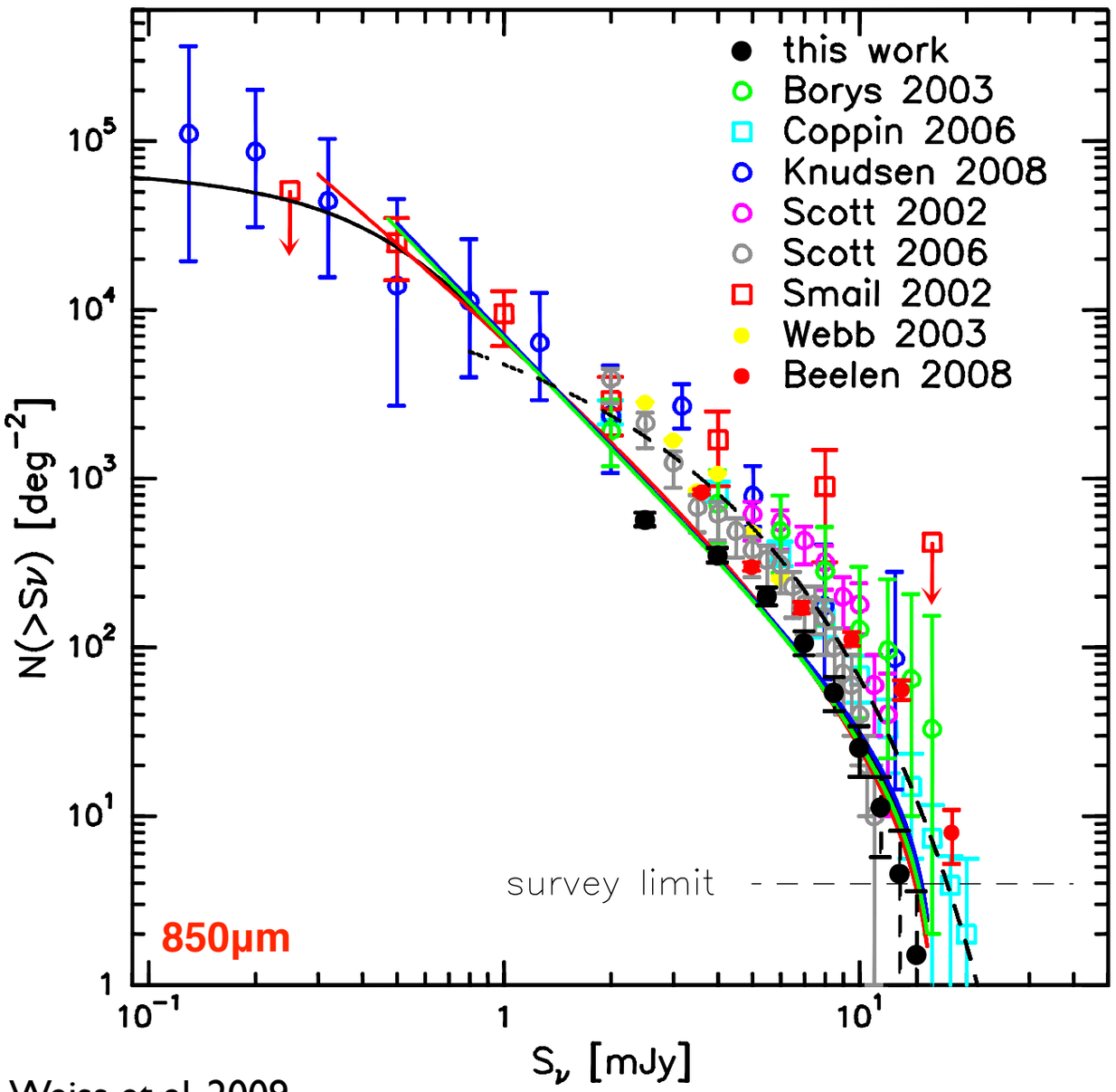
Gravitational Lensing

- Light affected by intervening mass (galaxy).
- Magnification: spatial distortion & resolution increase.
- Magnification: integrated flux boost.
- Details dependent on mass profile of foreground galaxy.



Why look in the far-IR for lensed galaxies?



Weiss et al. 2009

- Intrinsically VERY bright sources are rare
- VERY bright sources are as likely to be lensed as intrinsically luminous

Search for bright submm sources is an efficient lens selection

BUT :
need wide area surveys to find rare lensing events

Ideal science for CCAT's wide FoV: wide-field survey(s)

See Blain et al. 1996

HerMES:

www.hedam.oamp.fr/HerMES

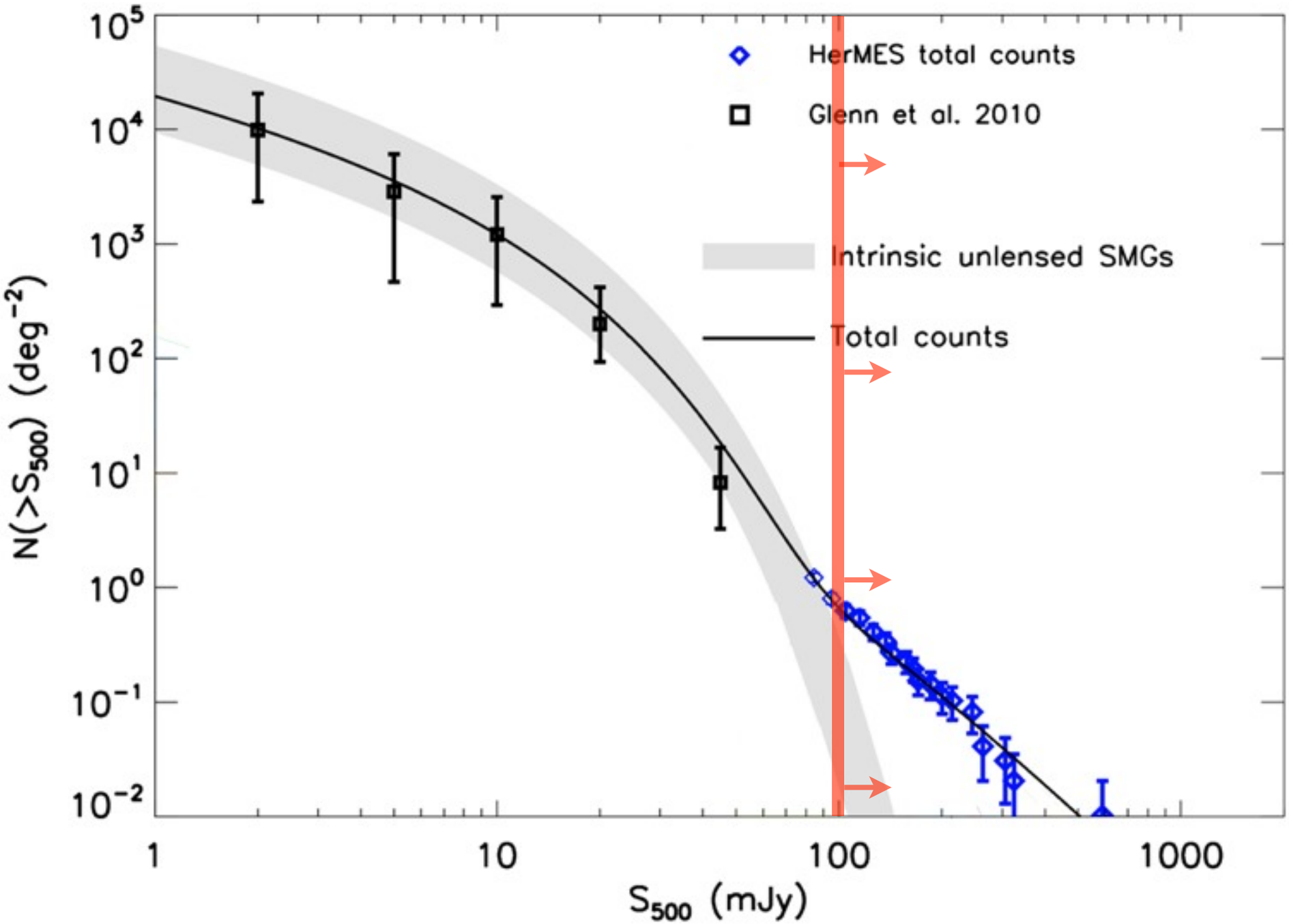
The *Herschel* Multi-tiered Extragalactic Survey

= this project, 9 independent fields, 95deg²

Public data

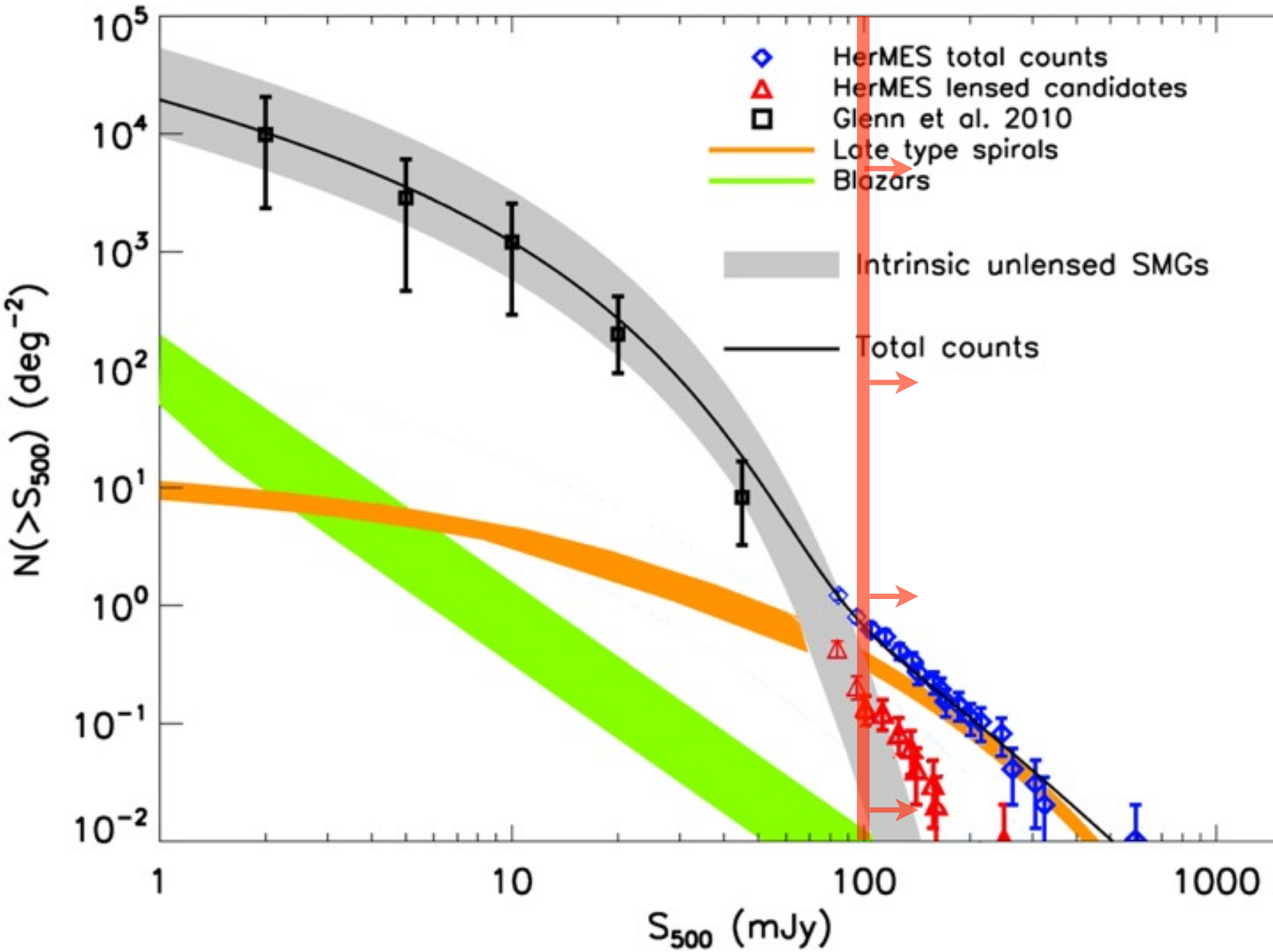
Sample selection:
S_{500}>100mJy

HerMES 500μm number counts

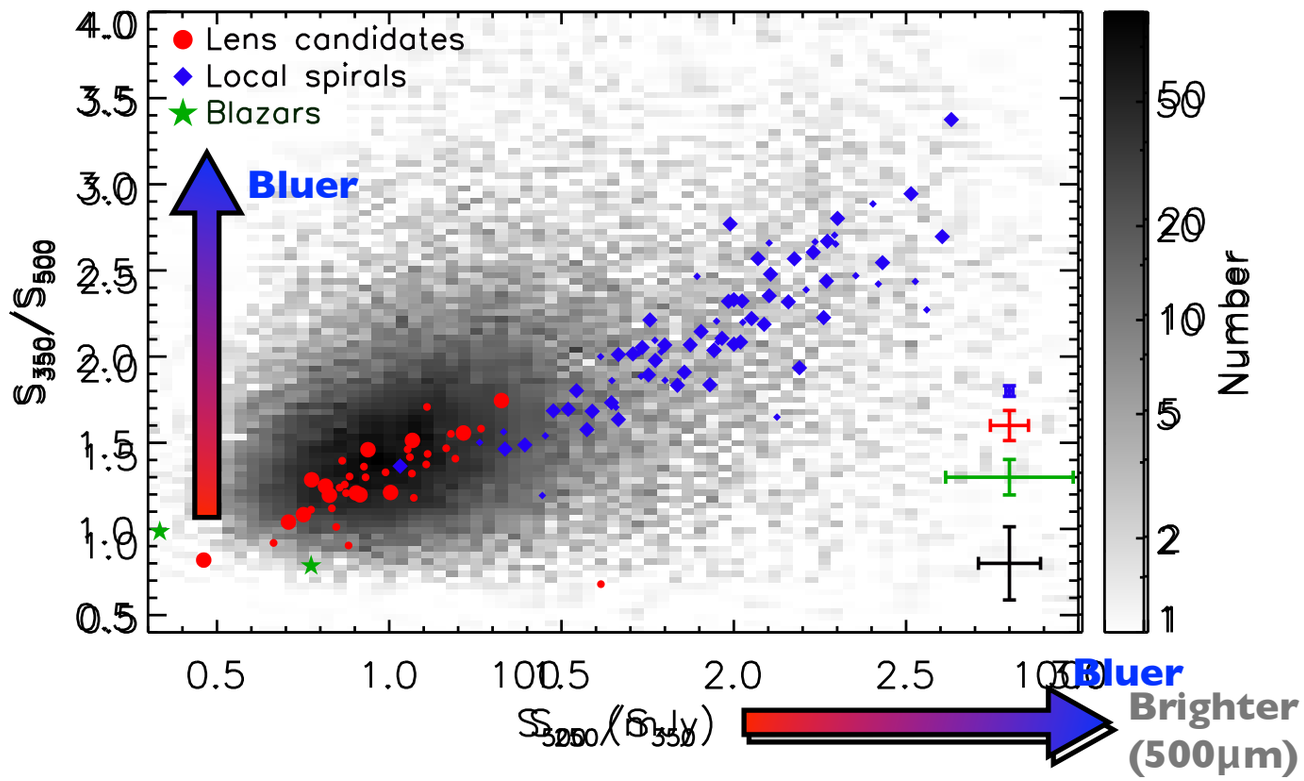


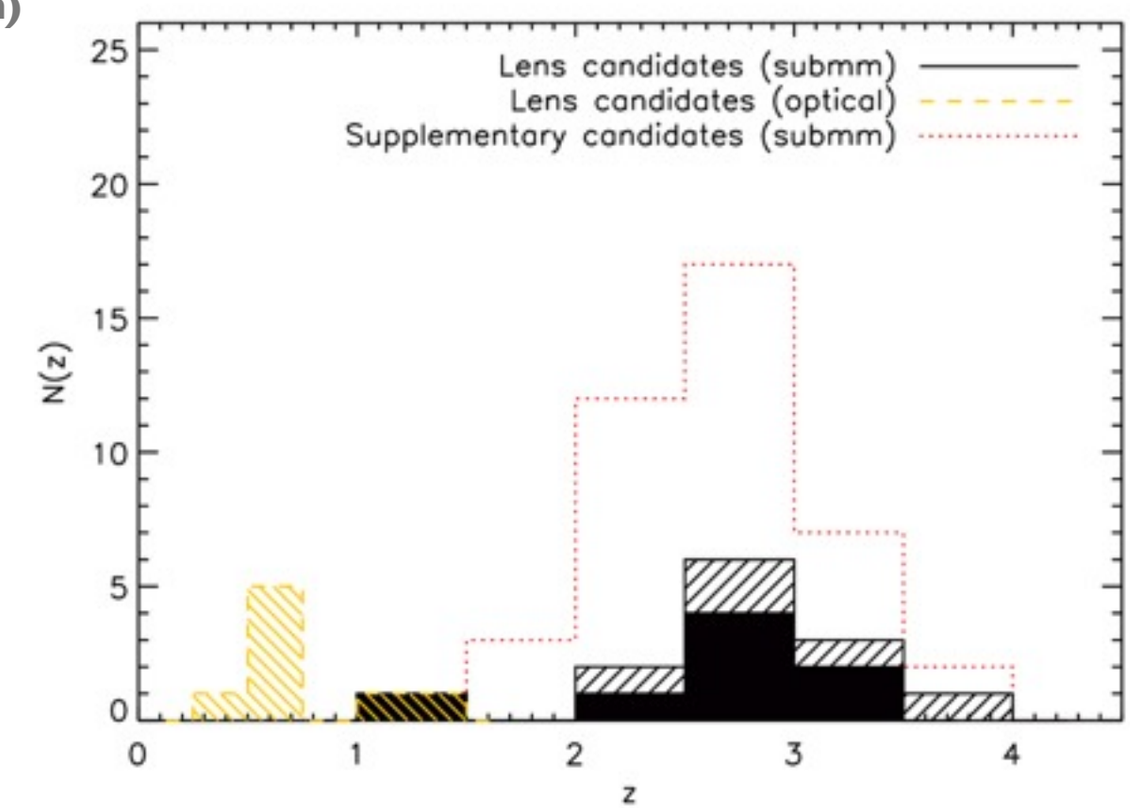
Sample selection:

S_{500}>100mJy & no blazars or local spirals



Lensed SMGs are typically submm red, at z=2–3, and lensed by galaxies at z<1





Modelling lensed SMGs

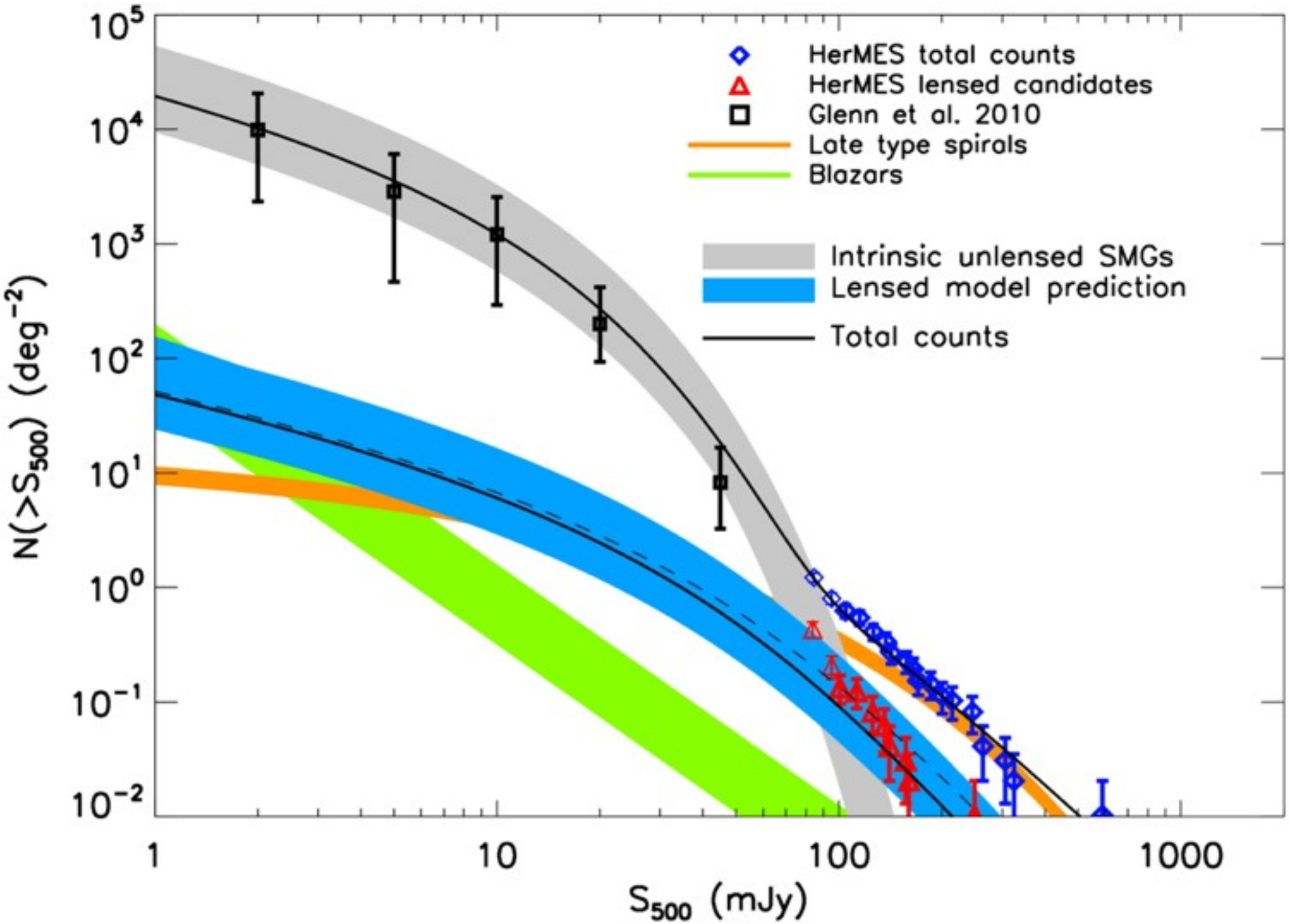
Components

- ΛCDM cosmology: $\Omega_M = 0.27$, $\Omega_\Lambda = 0.73$, $H_0 = 71$km s^{-1} Mpc^{-1}
- NFW or SIS foreground mass profiles
- Sheth & Tormen distribution of foreground masses
- Béthermin et al. N(z) for SMGs

The model

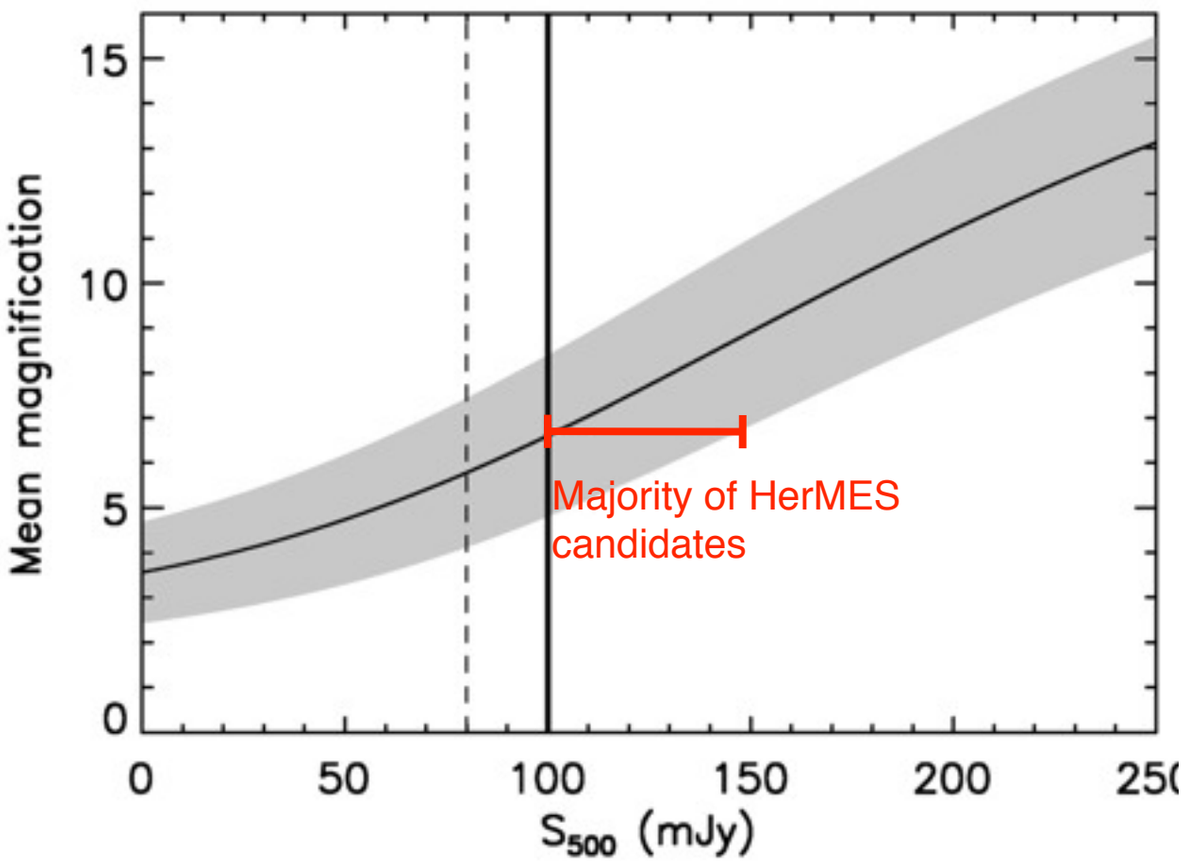
- Calculate the fraction of the sky that is strongly ($\mu>2$) lensed = f_μ
- Use f_μ to calculate lensing probability = $P(\mu)$
- Assume intrinsic counts have the shape of a Schechter function
- Integrate to apply $P(\mu)$ to the intrinsic counts
- Use MCMC to fit to the total observed HerMES number counts
- *Number counts of lensed SMGs are predicted*

Modelling lensed SMGs

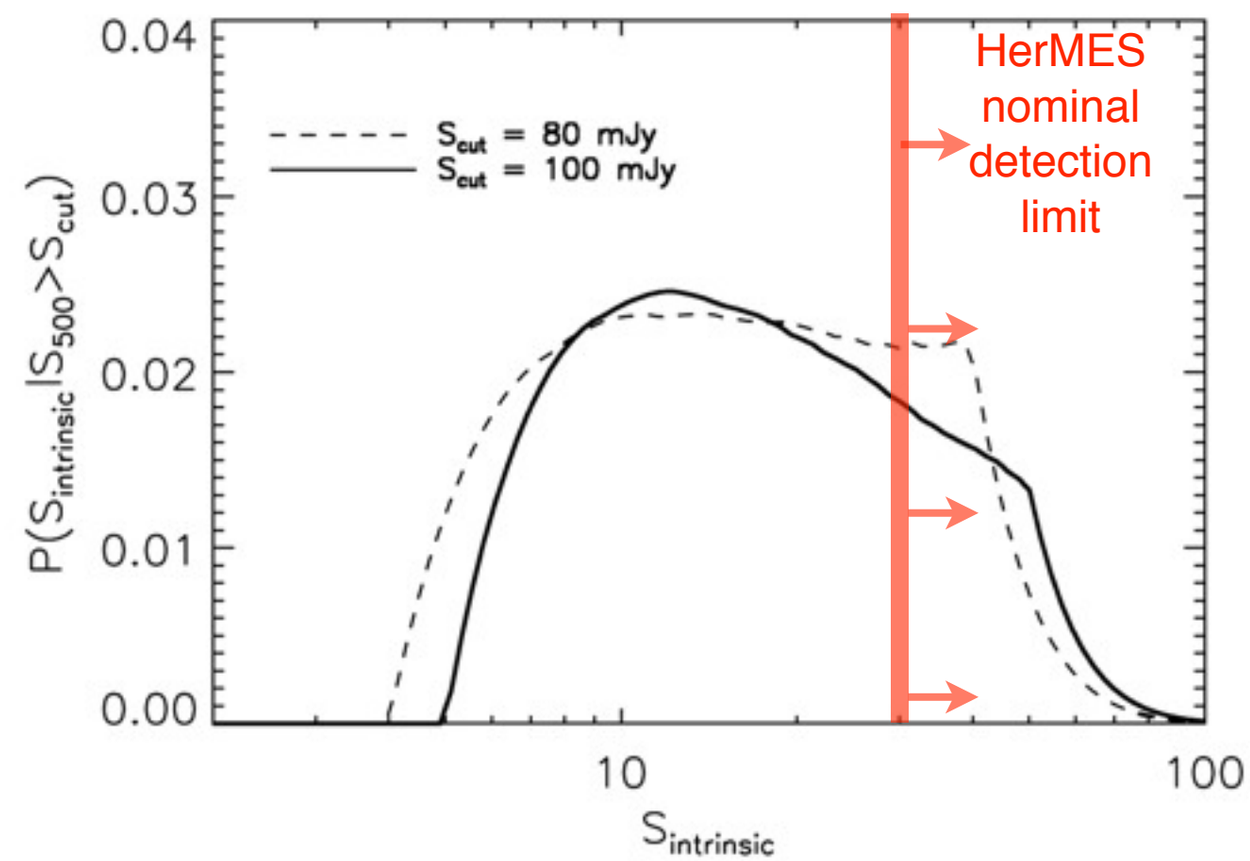


Predictions: magnification factor

Mean magnification is μ~5–10

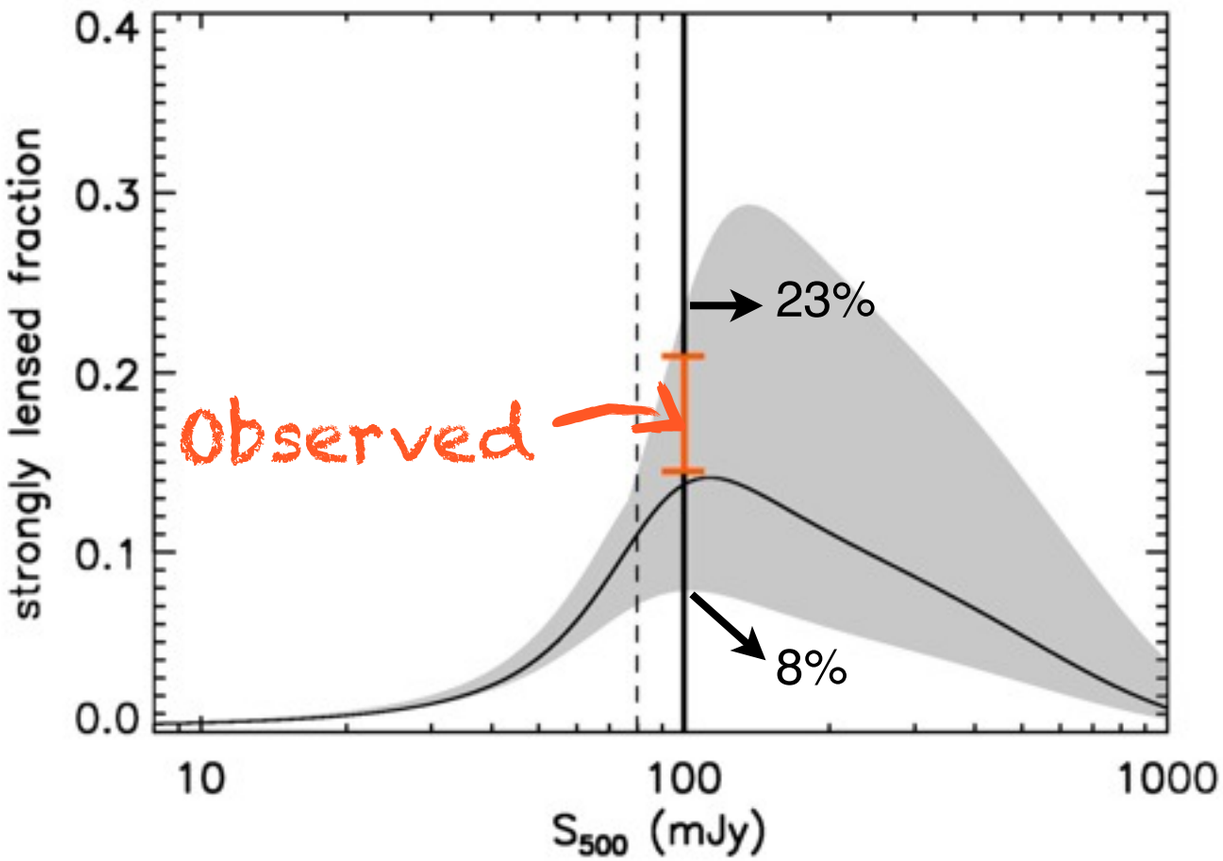


Sources are intrinsically faint

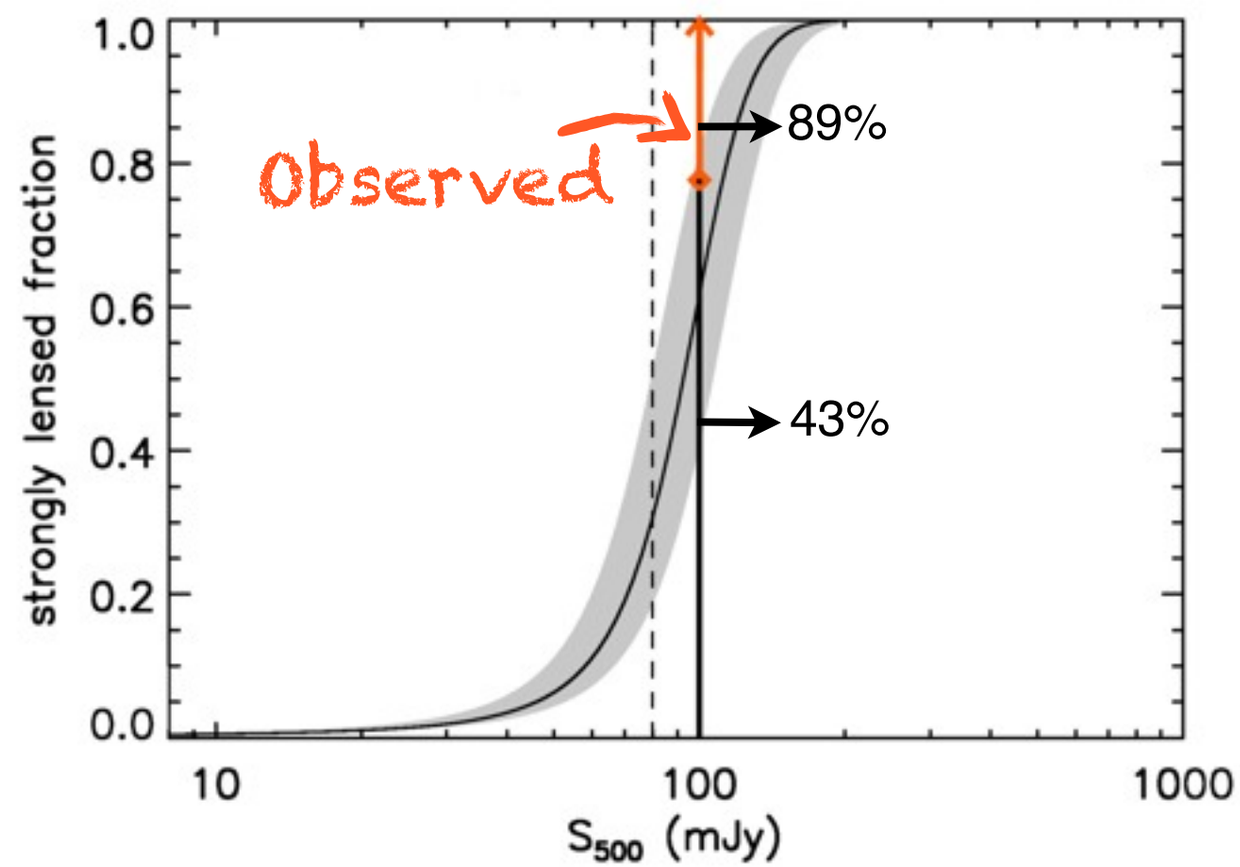


Lens candidates have high fidelity: ~45–80%

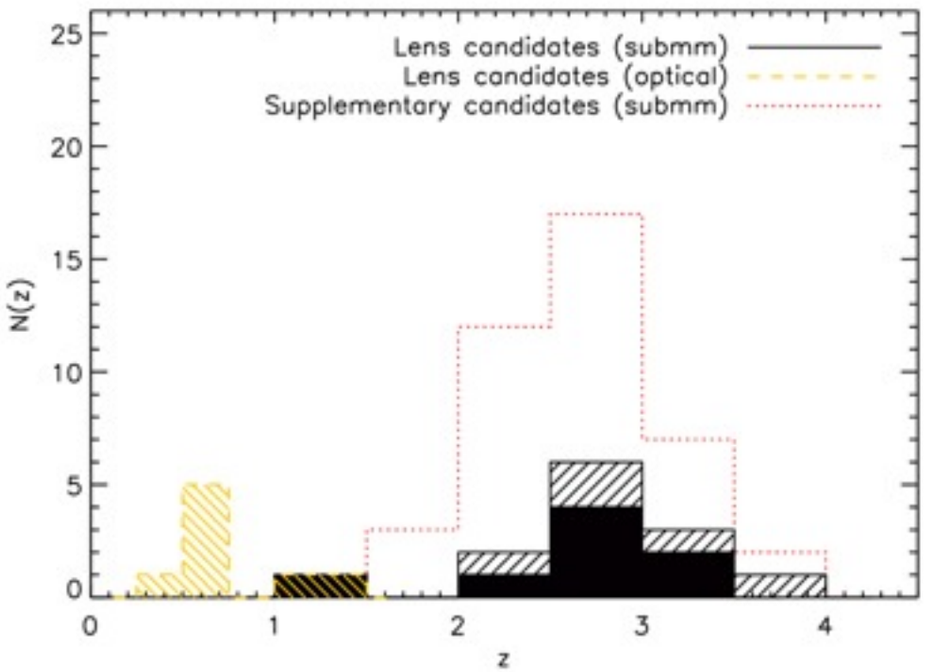
All sources

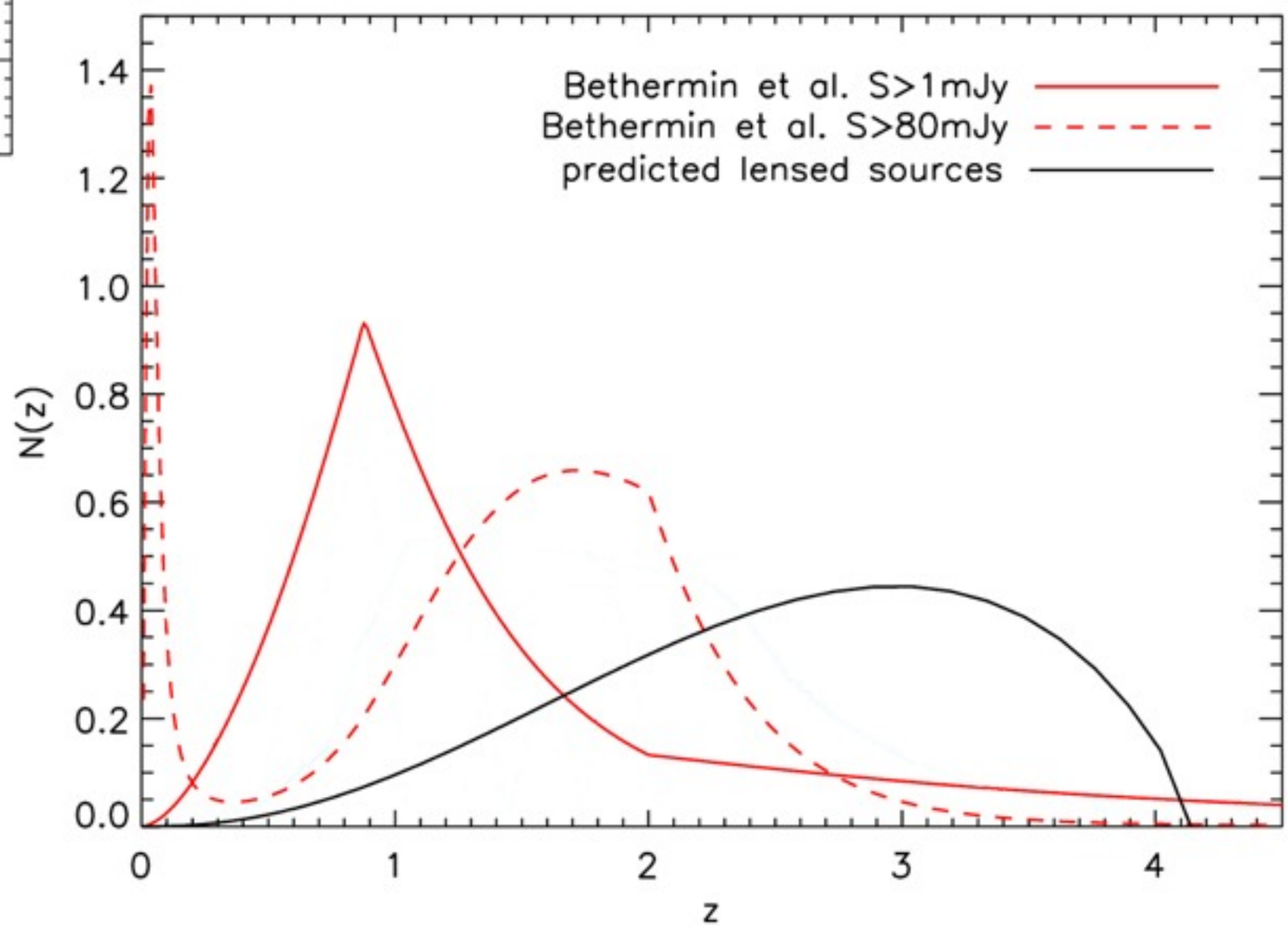


Blazars & spirals removed



N(z) predicted from the model





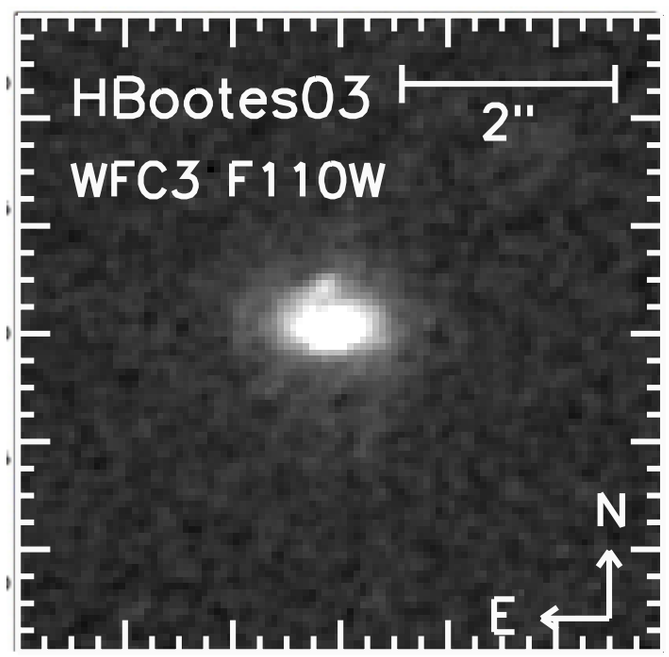
13 HerMES lens candidates

9 confirmed;
4 unknown

3 previously published lenses

MIPSJ1428/HBootes03

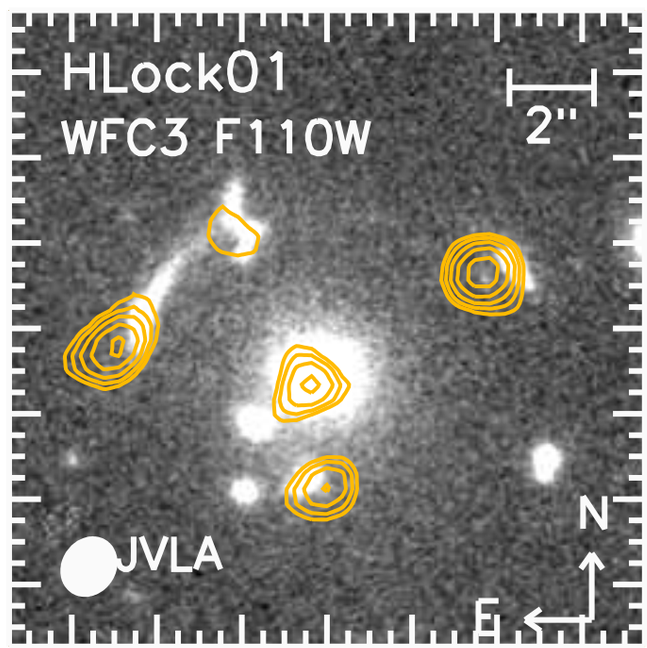
- z=1.3 lensed by z=1.0
- μ<10



Borys et al. 2006 • Desai et al. 2006 • Iono et al. 2006ab • Swinbank et al. 2006 • Hailey-Dunsheath et al. 2010 • Stacey et al. 2010 • Sturm et al. 2010

HLock01

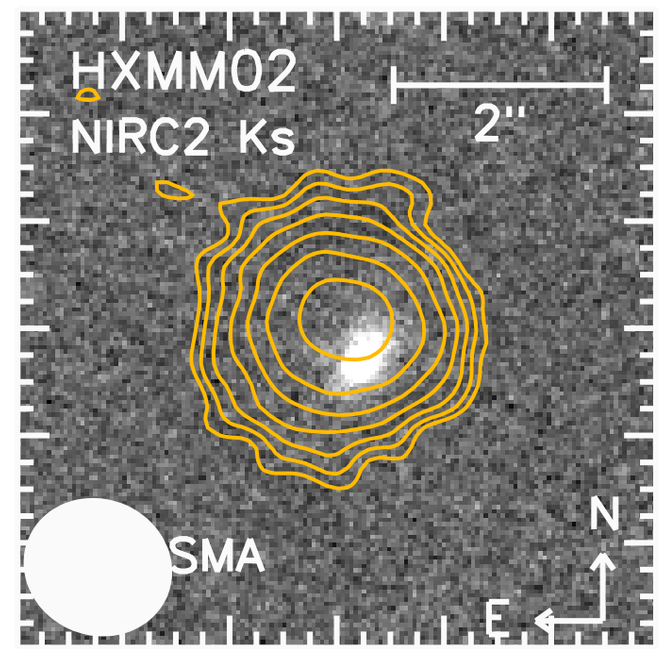
- z=2.9 lensed by group at z~0.6
- μ~11



Conley et al. 2011 • Scott et al. 2011 • Riechers et al. 2011 • Gavazzi et al. 2011

SXDF1100.01/HXMM02

- Identified by AzTEC
- z=3.4 lensed by z=1.3
- μ~1.5

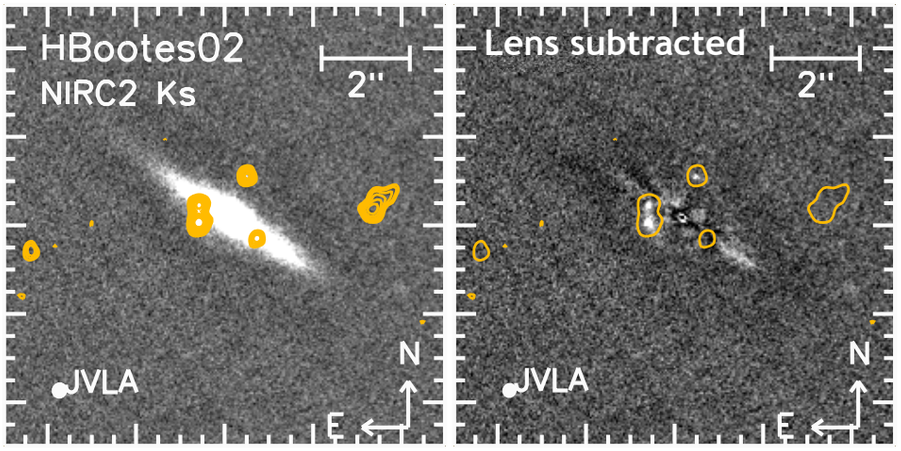


Ikarashi et al. 2011 (also Iono et al. submitted • Inoue et al. in prep.)

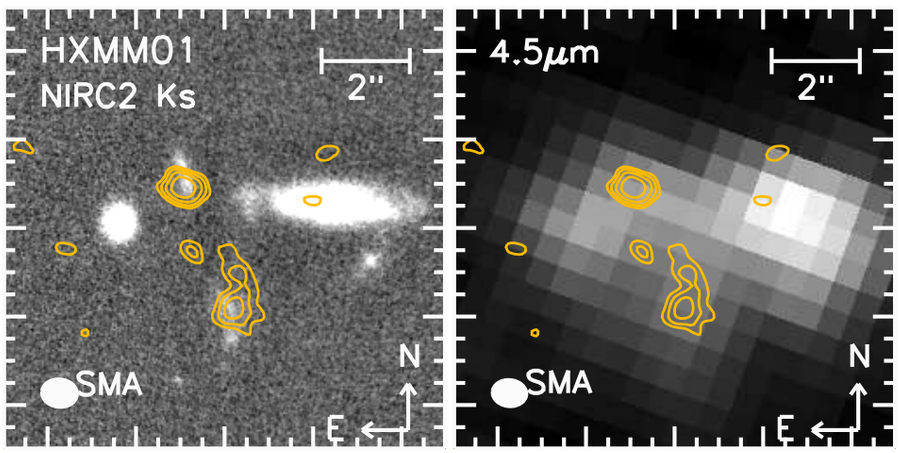
13 HerMES lens candidates

9 confirmed;
4 unknown

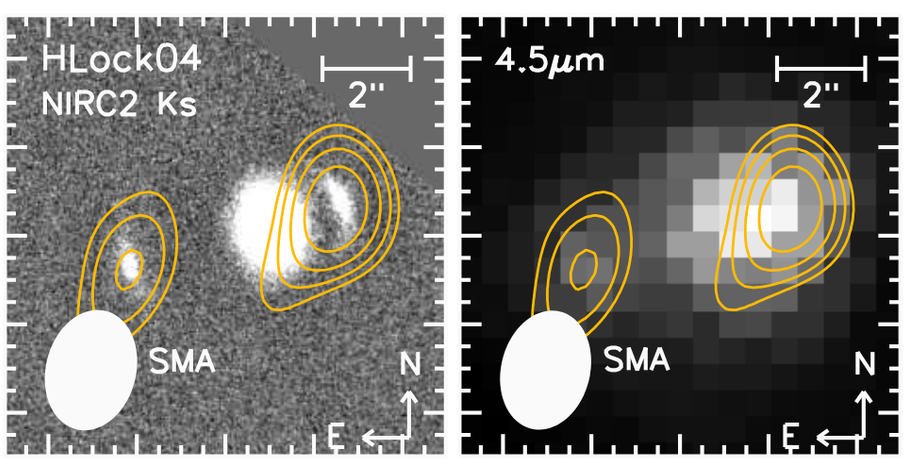
6 additional confirmed lensing systems



z_{SMG}=2.8
z_l=0.4
μ~23
lensed AGN

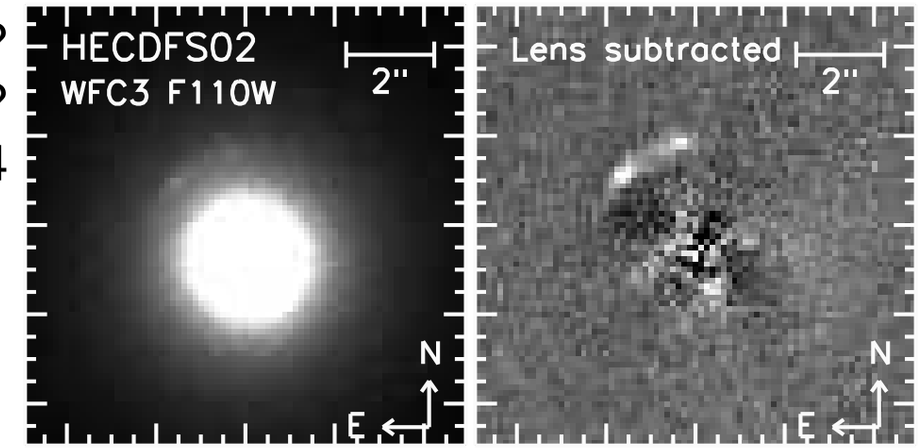


z_{SMG}=2.3
z_l=0.6 & 0.5
μ~2
lensed merger?

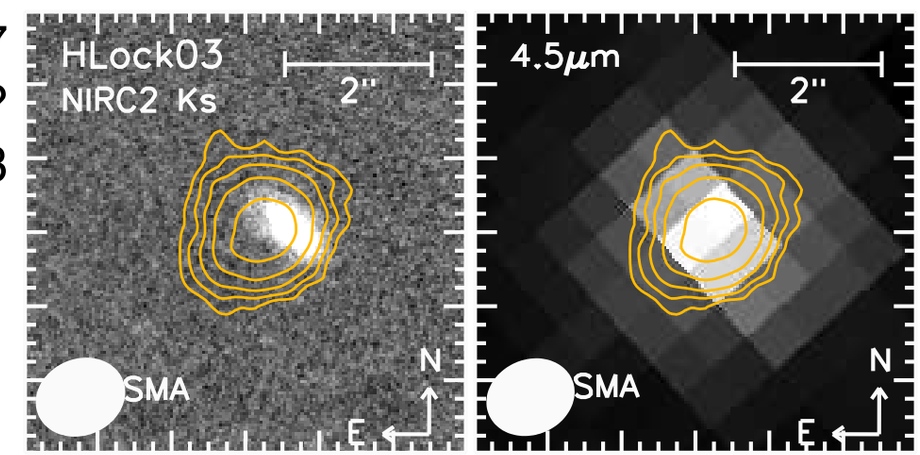


z_{SMG}=?
z_l~0.6
μ~3

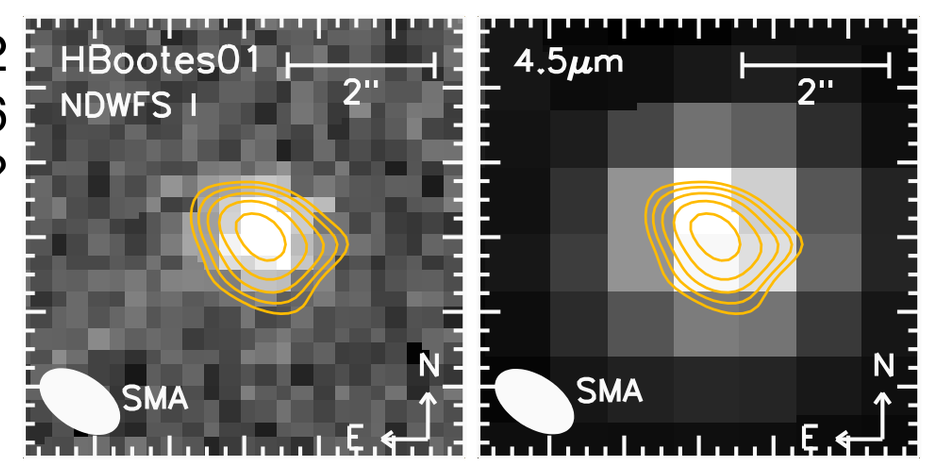
z_{SMG}=?
z_l=?
μ~4



z_{SMG}=2.7
z_l=?
μ~3



z_{SMG}=3.2
z_l~0.6
μ~?

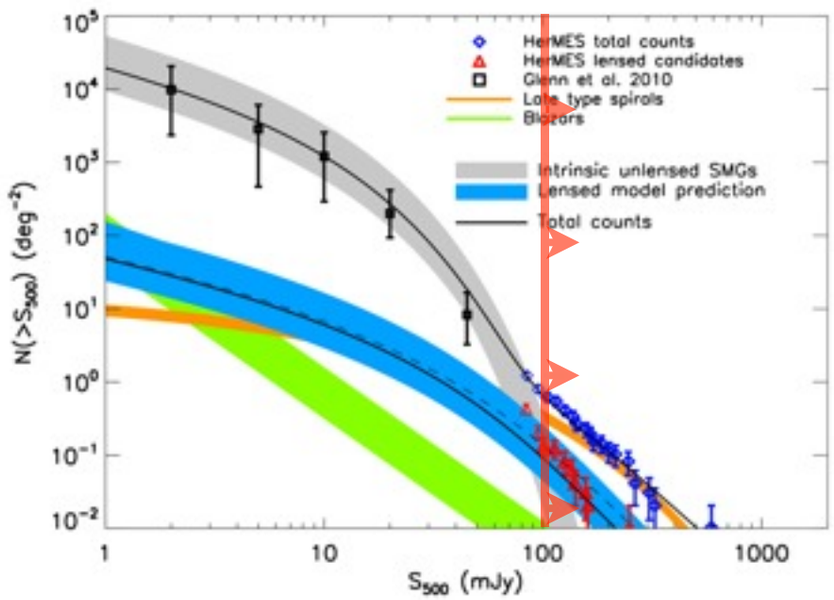


What to expect from CCAT

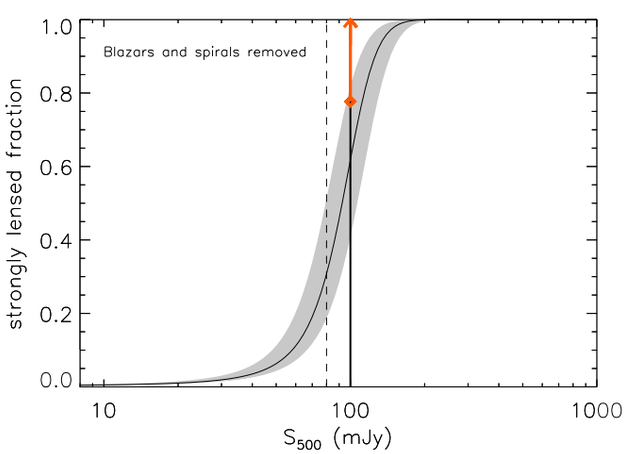
- Wide FoV & efficient mapping
  ⇒ Large numbers of candidates
  (e.g. in 5000deg^2 ~750 new "robust" & ~1500 "supplementary" lenses)
  ⇒ More candidates ⇒ better model constraints
  ⇒ More "extreme" sources: high μ, high flux, high *z*
  e.g. in 5000deg^2: ~50 with S_{500}=200mJy, ~10 with μ>20
- Wide(r) multi-wavelength coverage
  ⇒ Better initial source characterisation
  (lens/low-z spiral/blazar)
  ⇒ More accurate submm photo-*z*
  ⇒ Different wavelengths to select different populations
- Multi-object spectroscopy
  ⇒ CO redshifts for all candidates
- Smaller beam
  ⇒ Easier counterpart/lens identification

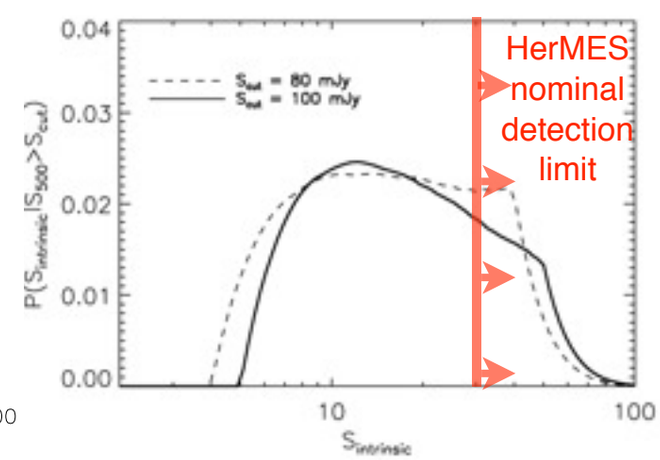
Summary

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

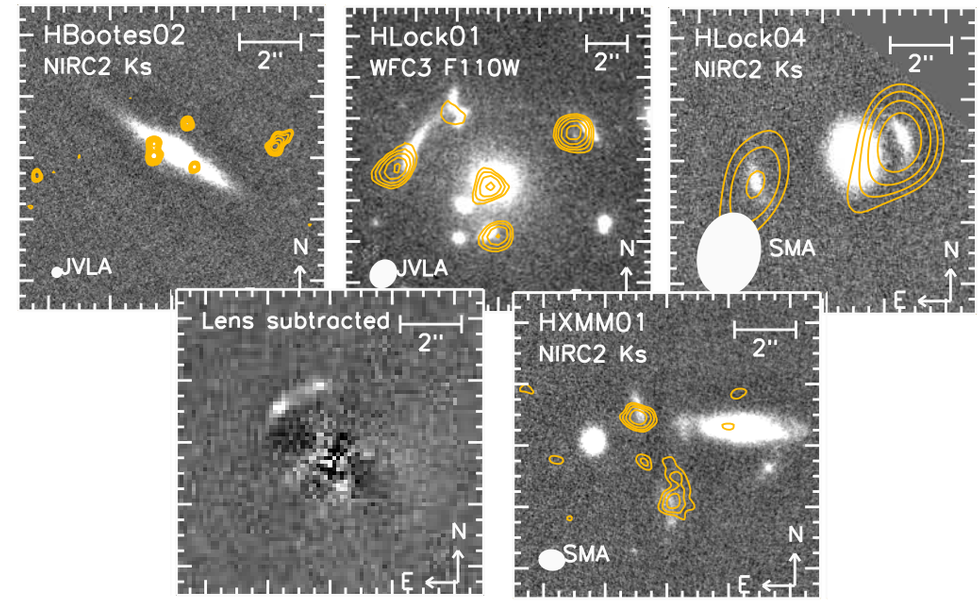


Simple cosmological modelling of SMG number counts can predict the numbers of lensed sources & predicts high fidelity samples of intrinsically faint SMGs magnified by factors of ~5–10 on average.





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



CCAT will detect & provide useful information for many more of these sources