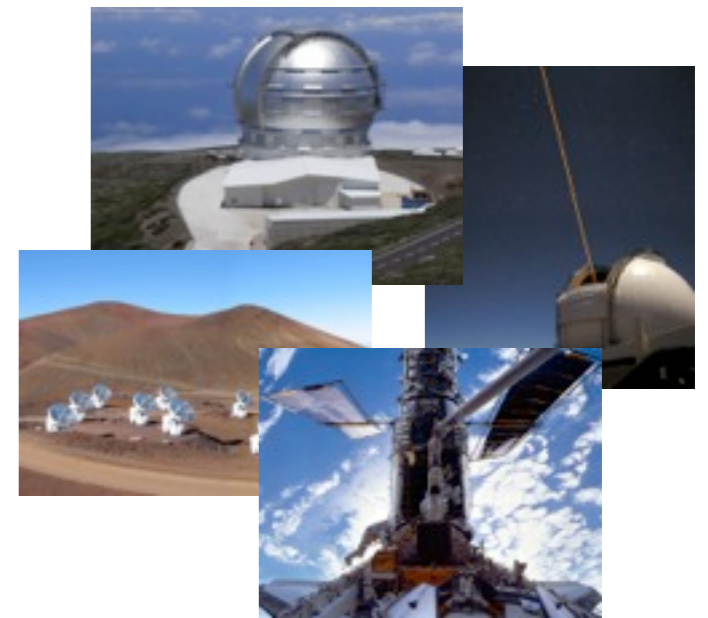
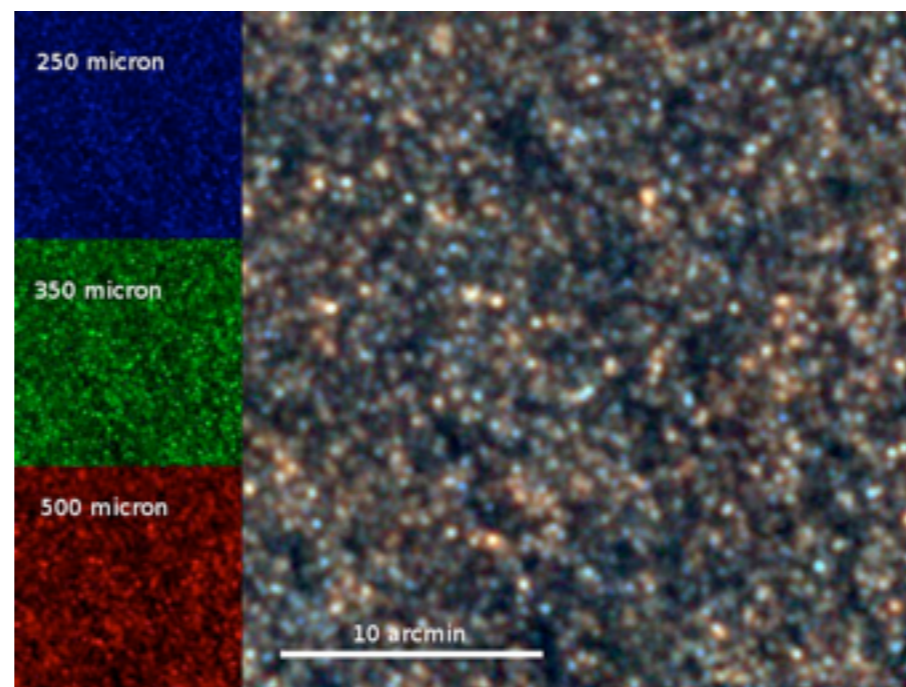


The ISM in Dusty Star Forming Galaxies at $z=1-3$

Julie Wardlow

Dark Cosmology Centre, University of Copenhagen



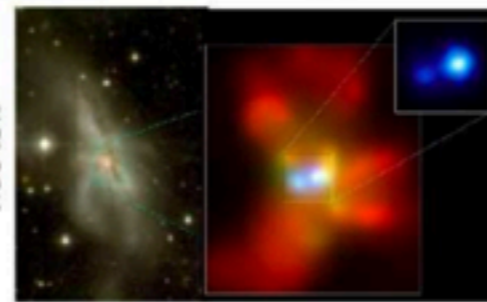
Dusty star formation as a crucial phase of galaxy evolution

(c) Interaction/"Merger"



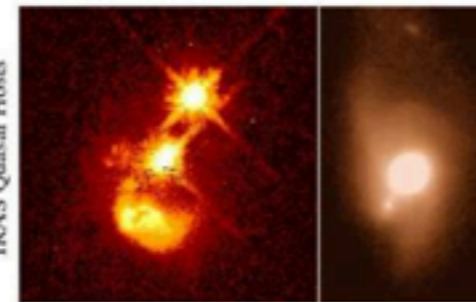
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(d) Coalescence/(U)LIRG



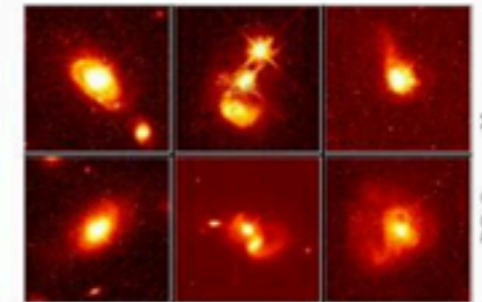
- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small

(e) "Blowout"



- BH grows rapidly: briefly dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO: recent/ongoing SF in host
- high Eddington ratios
- merger signatures still visible

(f) Quasar



- dust removed: now a "traditional" QSO
- host morphology difficult to observe: tidal features fade rapidly
- characteristically blue/young spheroid

(b) "Small Group"

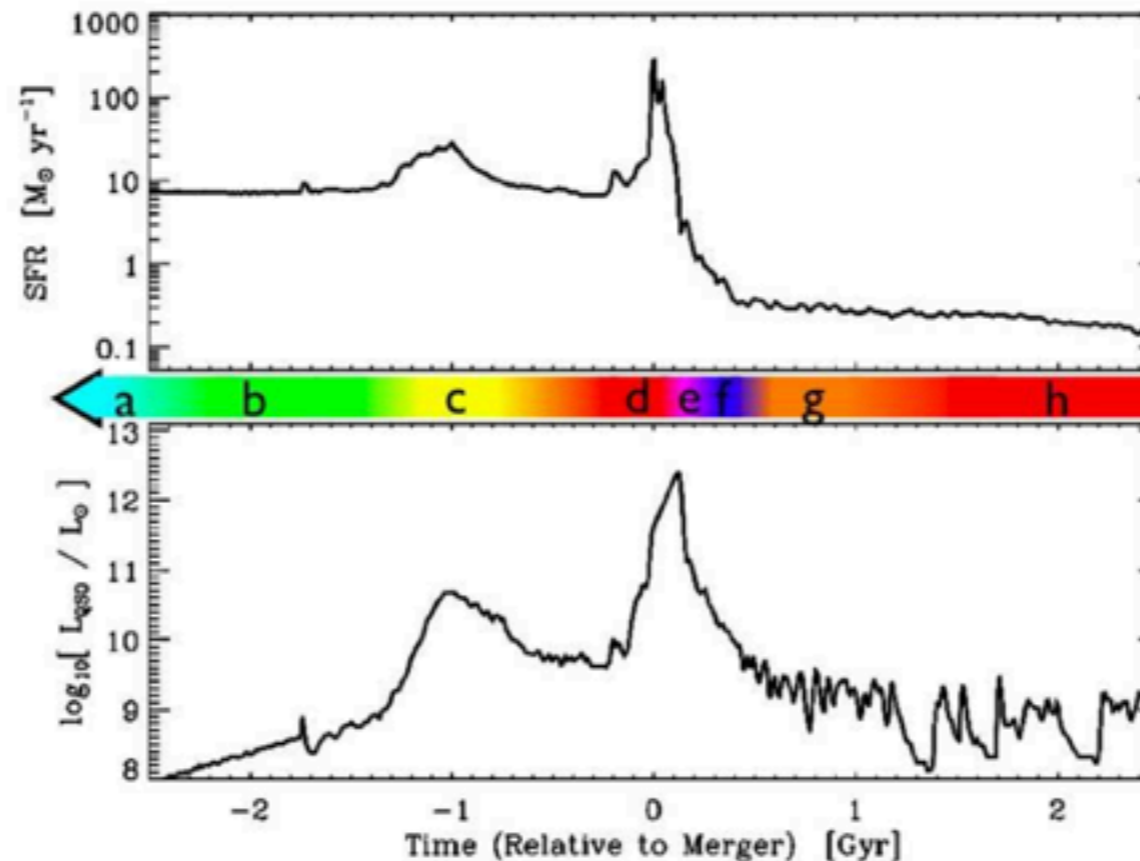


- halo accretes similar-mass companion(s)
- can occur over a wide mass range
- M_{halo} still similar to before: dynamical friction merges the subhalos efficiently

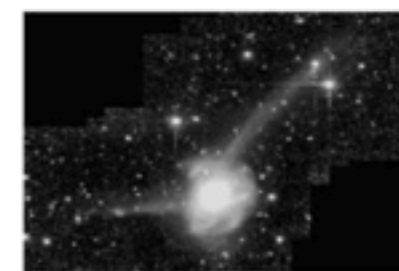
(a) Isolated Disk



- halo & disk grow, most stars formed
- secular growth builds bars & pseudobulges
- "Seyfert" fueling (AGN with $M_{\text{BH}} > \sim 23$)
- cannot redden to the red sequence



(g) Decay/K+A



- QSO luminosity fades rapidly
- tidal features visible only with very deep observations
- remnant reddens rapidly (E+A/K+A)
- "hot halo" from feedback
- sets up quasi-static cooling

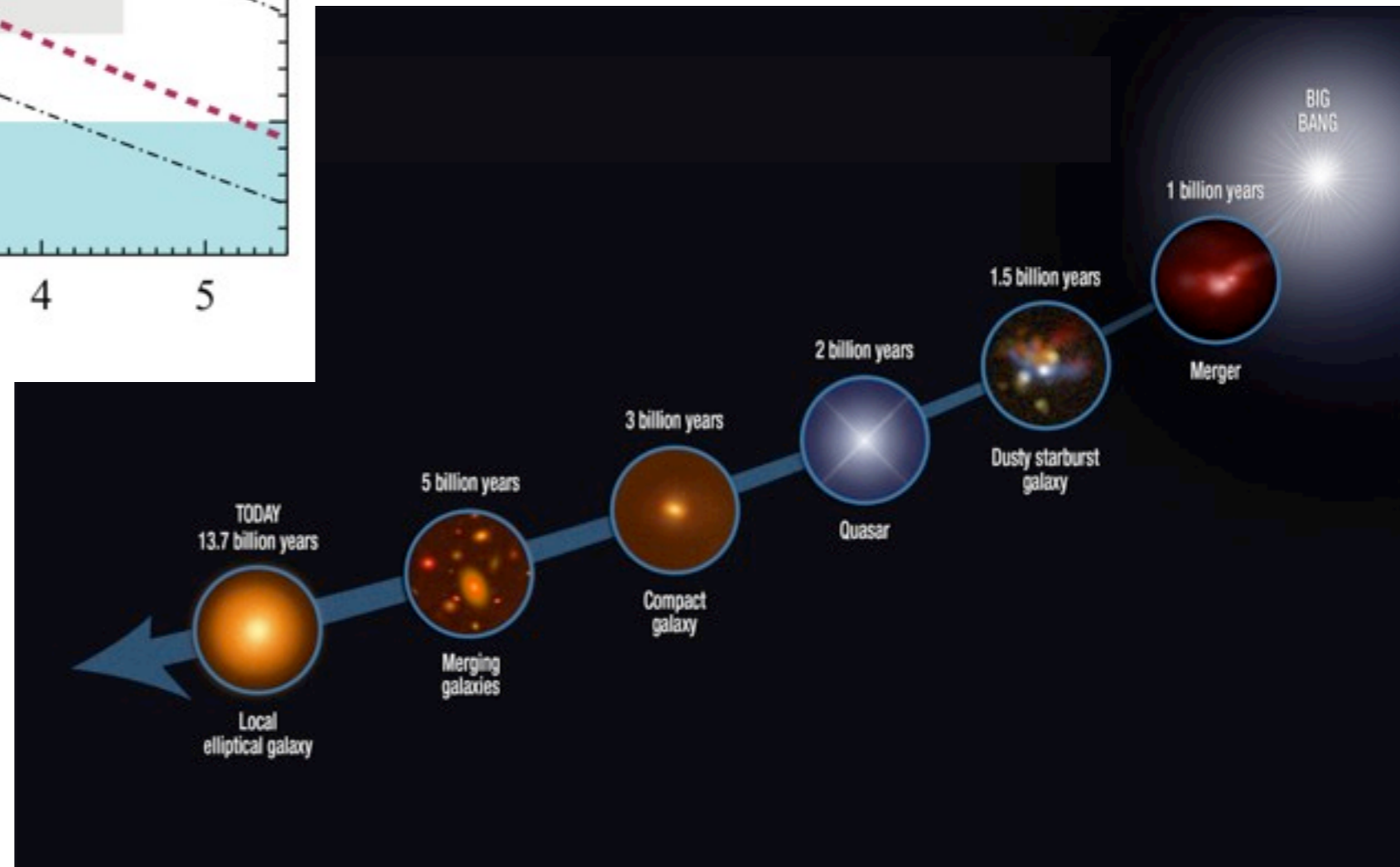
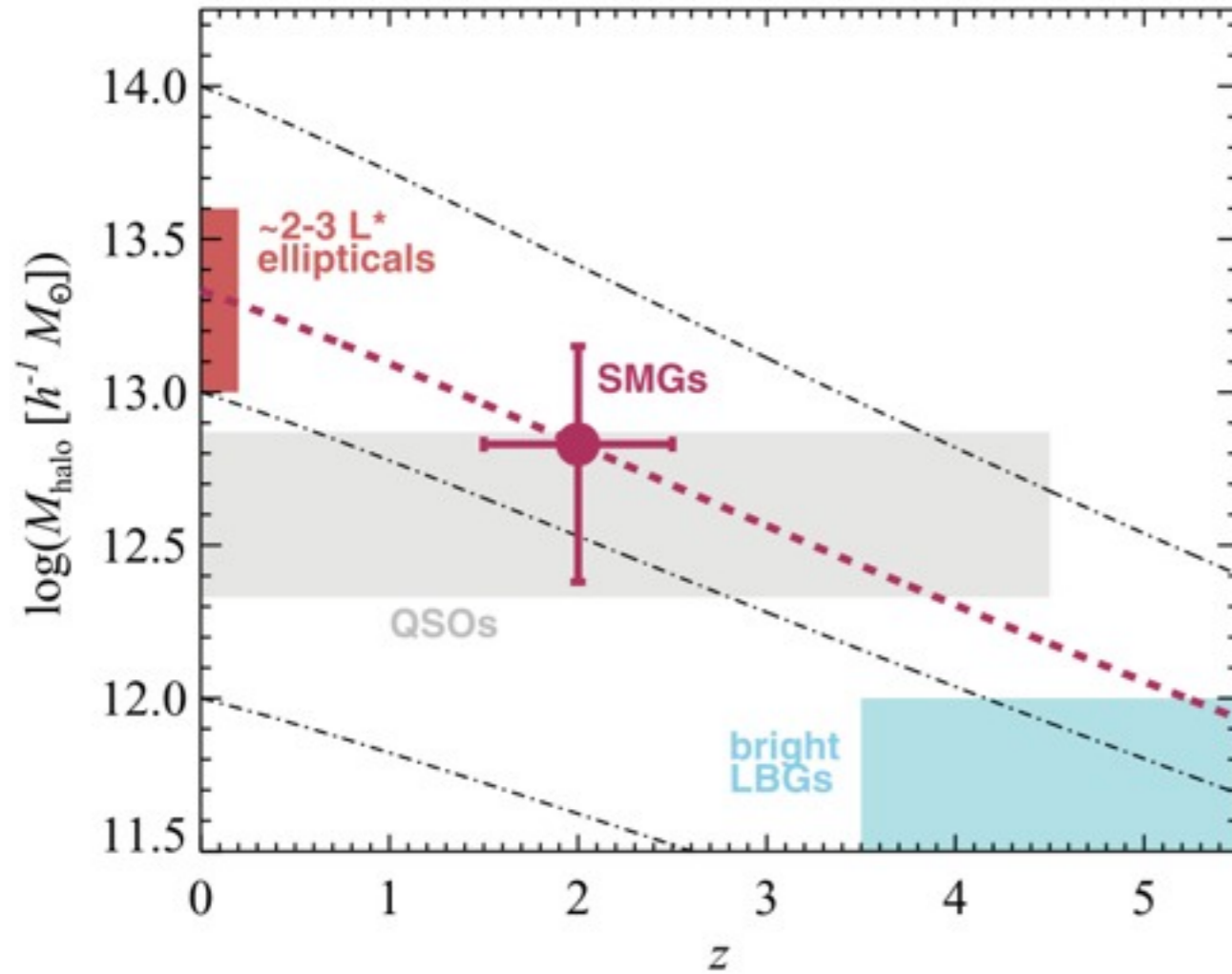
(h) "Dead" Elliptical



- star formation terminated
- large BH/spheroid - efficient feedback
- halo grows to "large group" scales: mergers become inefficient
- growth by "dry" mergers

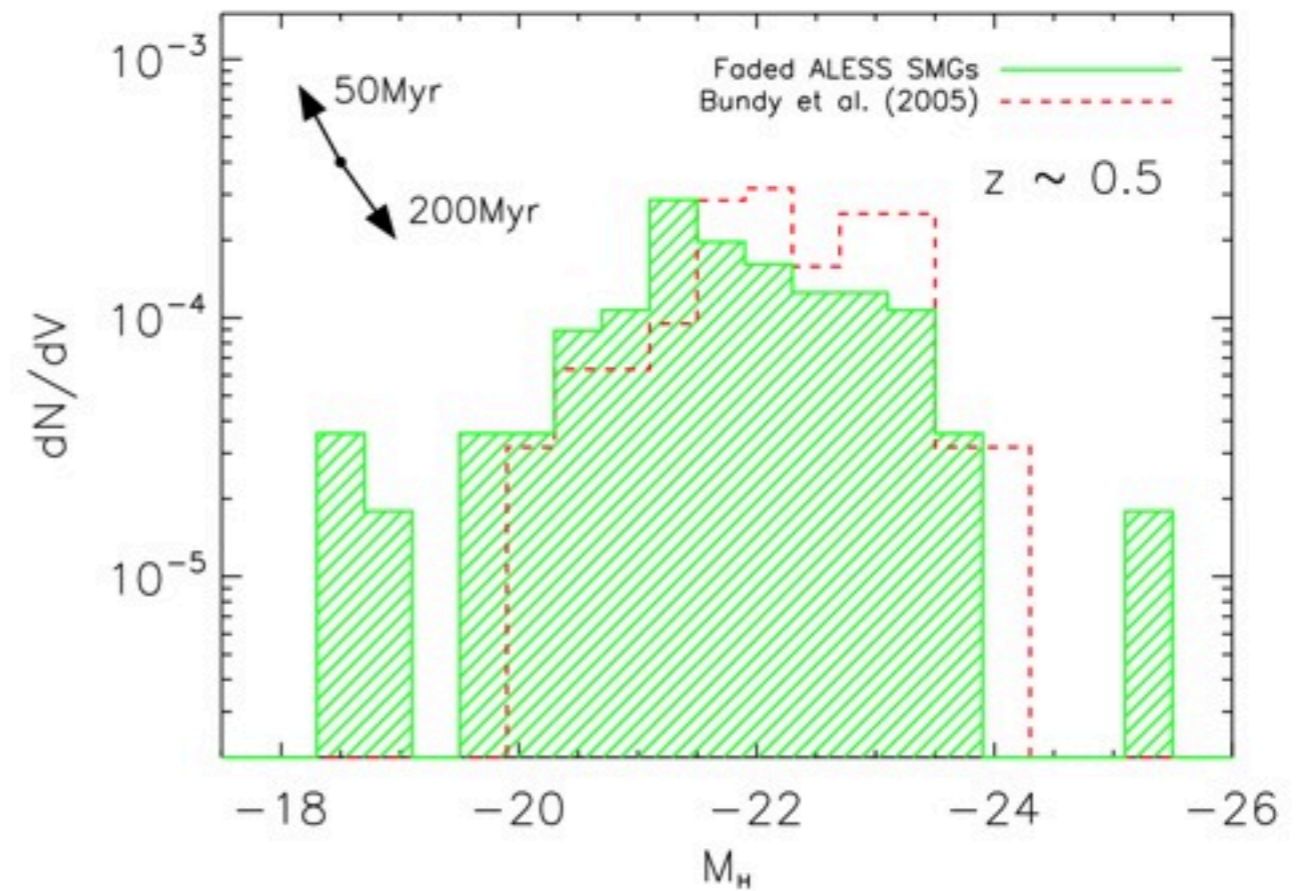
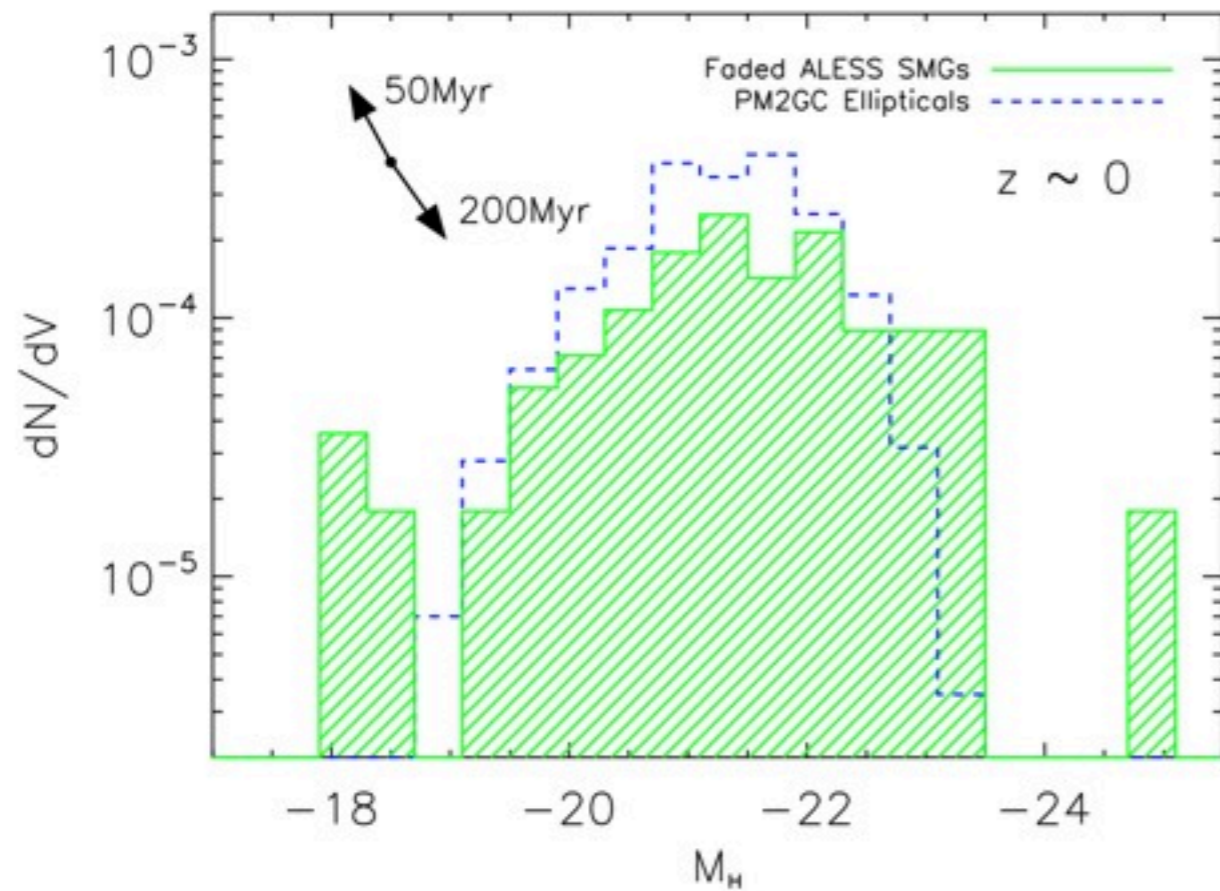
Hopkins et al. 2008

Massive ellipticals formed early in the Universe



Hickox, JW et al. 2012
Toft et al. 2014

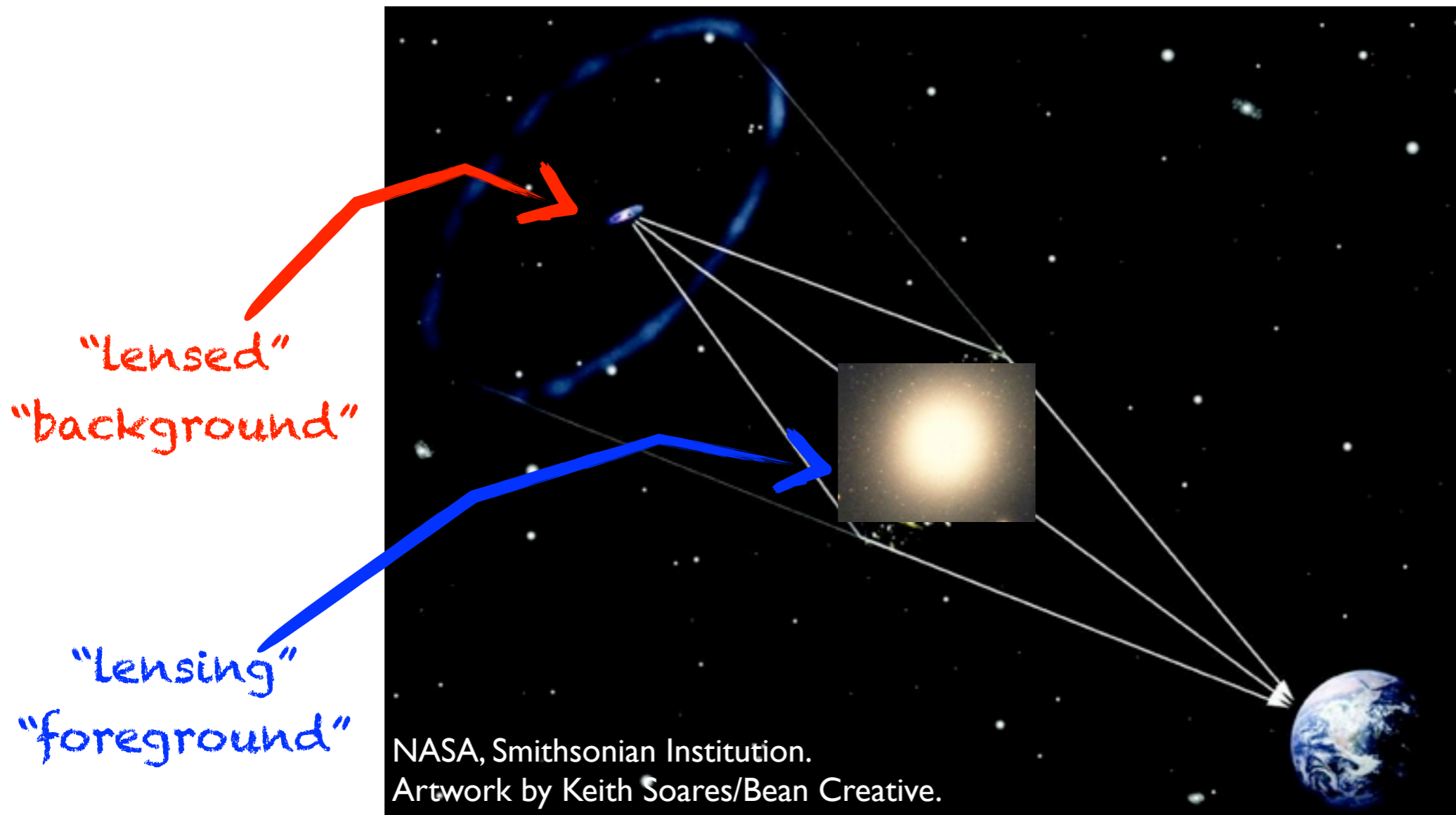
Faded DSFGs have brightness distributions consistent with nearby ellipticals



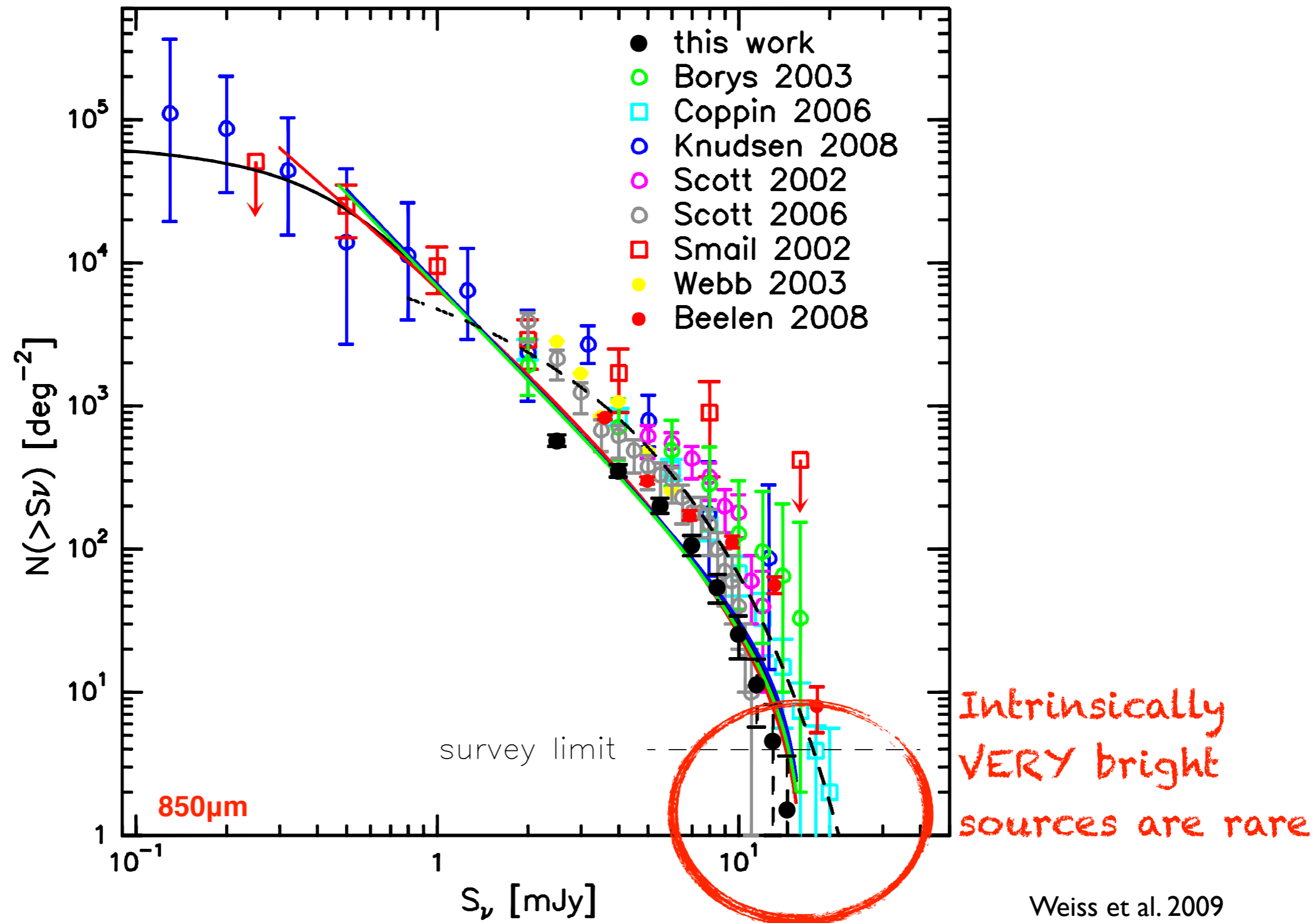
Simpson, JW et al. 2014

Gravitational Lensing

- **Background galaxy: flux boost**
- **Background galaxy: spatial resolution boost**
- Foreground galaxy: mass profile
- Cosmology: numbers and distribution of lensing



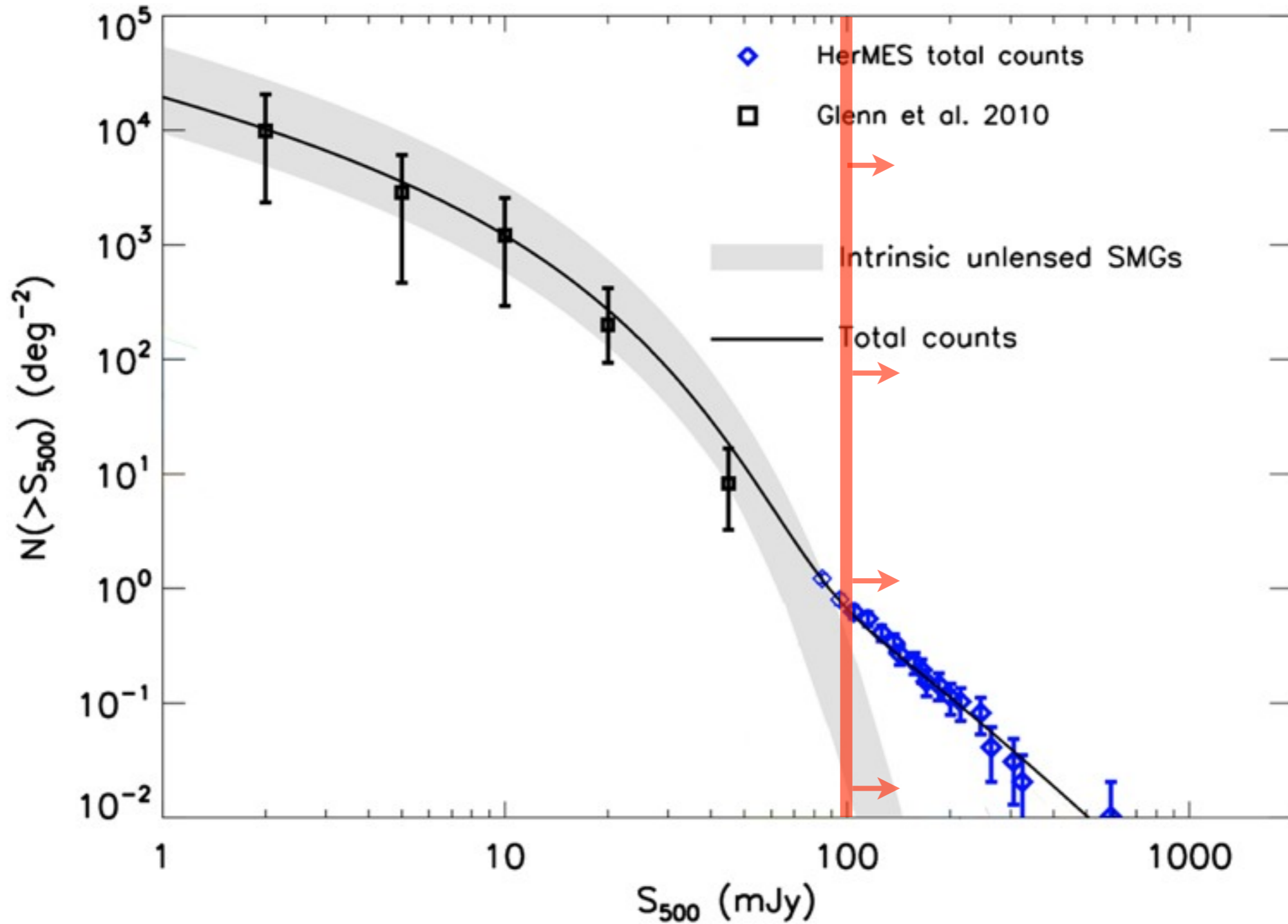
Lensed galaxies are readily identifiable in wide far-IR data



Weiss et al. 2009

See also Blain et al. 1996

HerMES lens candidates: $S_{500} > 100 \text{ mJy}$

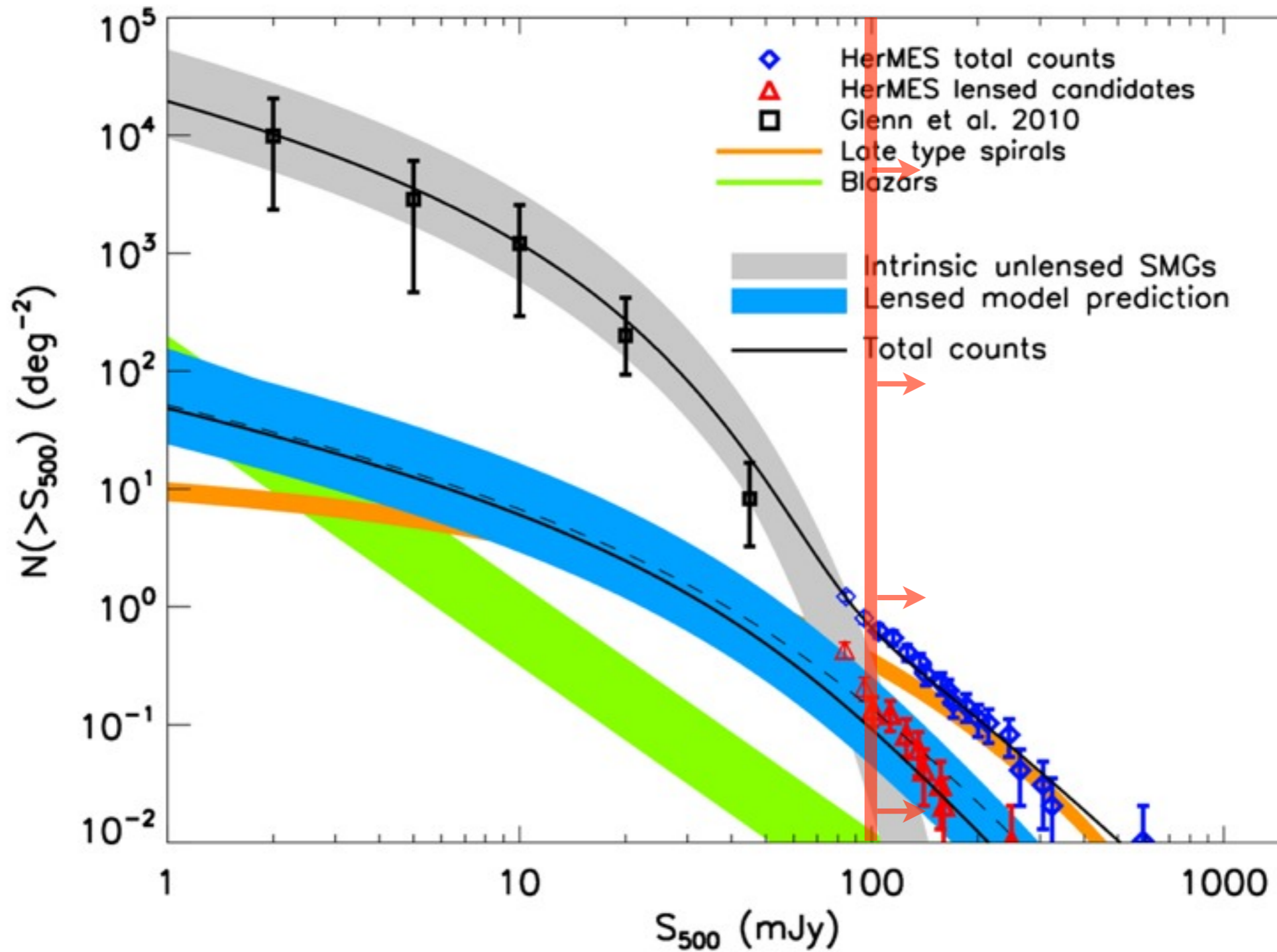


Candidates: $\sim 0.15 \text{ deg}^{-2}$

Wardlow et al. 2013

HerMES lens candidates

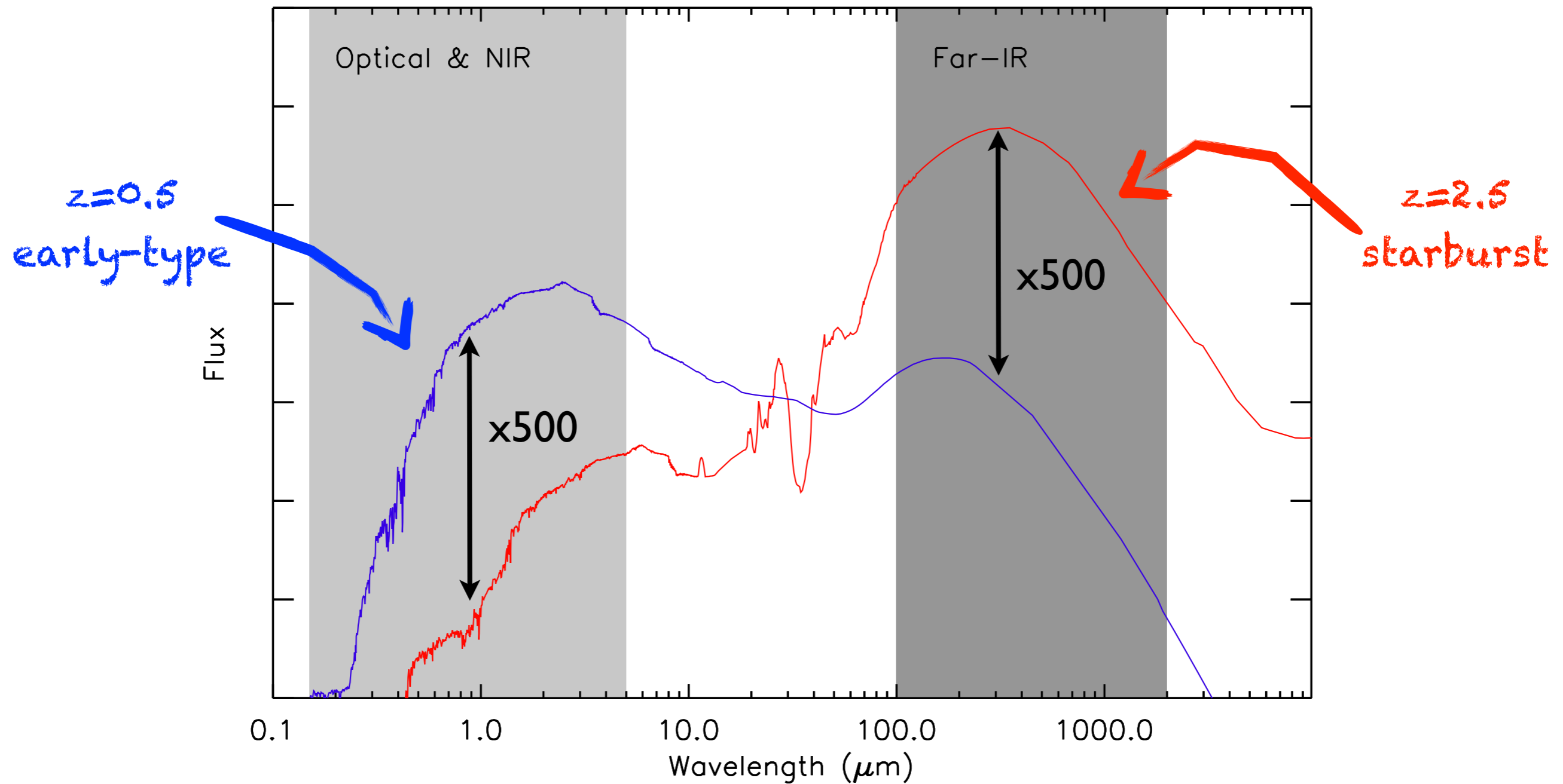
$S_{500} > 100 \text{ mJy}$ & no blazars or local spirals \rightarrow



Candidates: $\sim 0.15 \text{ deg}^{-2}$

Wardlow et al. 2013

Lensed SMGs are easily distinguished from lenses



HerMES Boötes image

1.3°

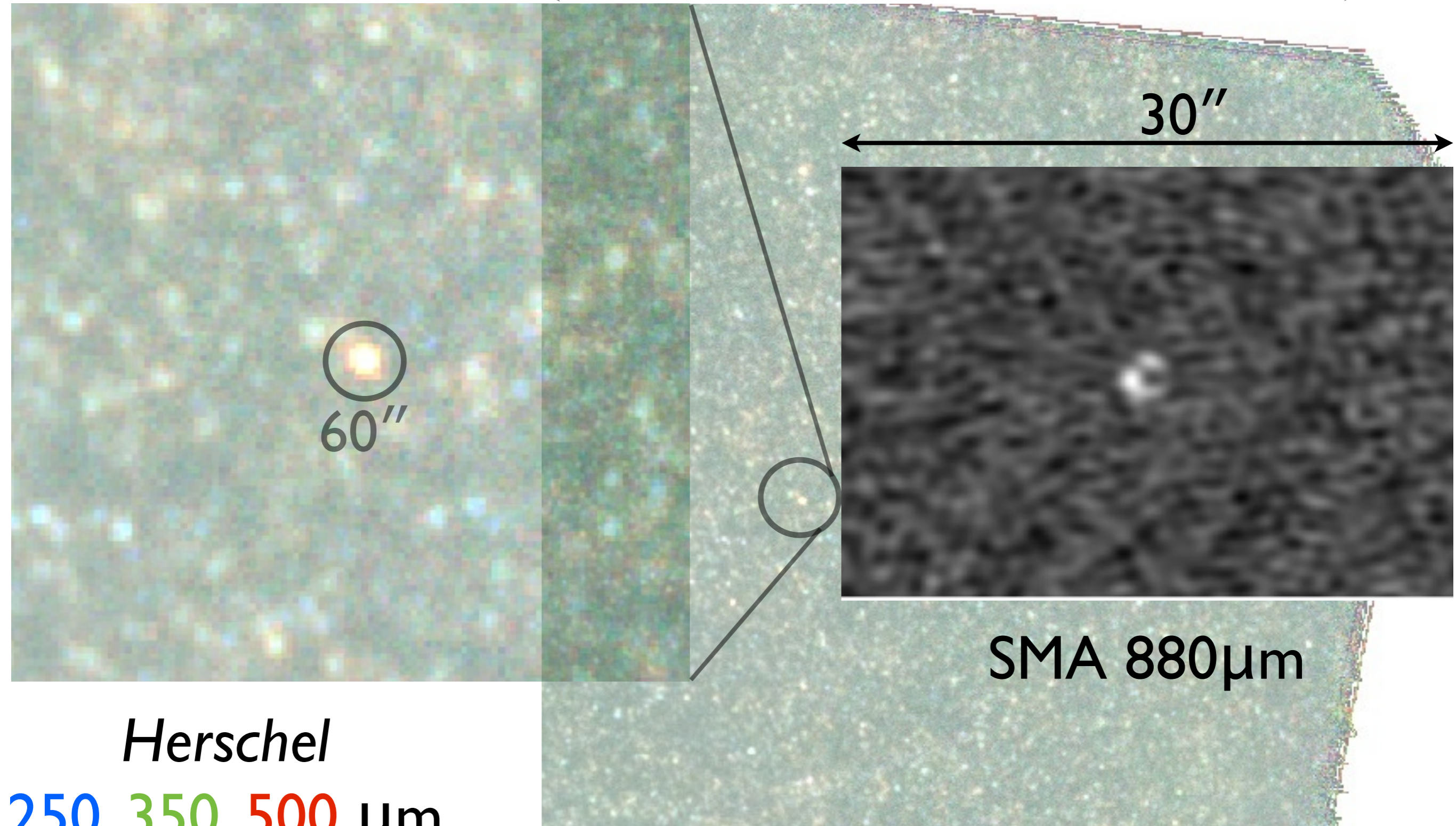
30''

60''

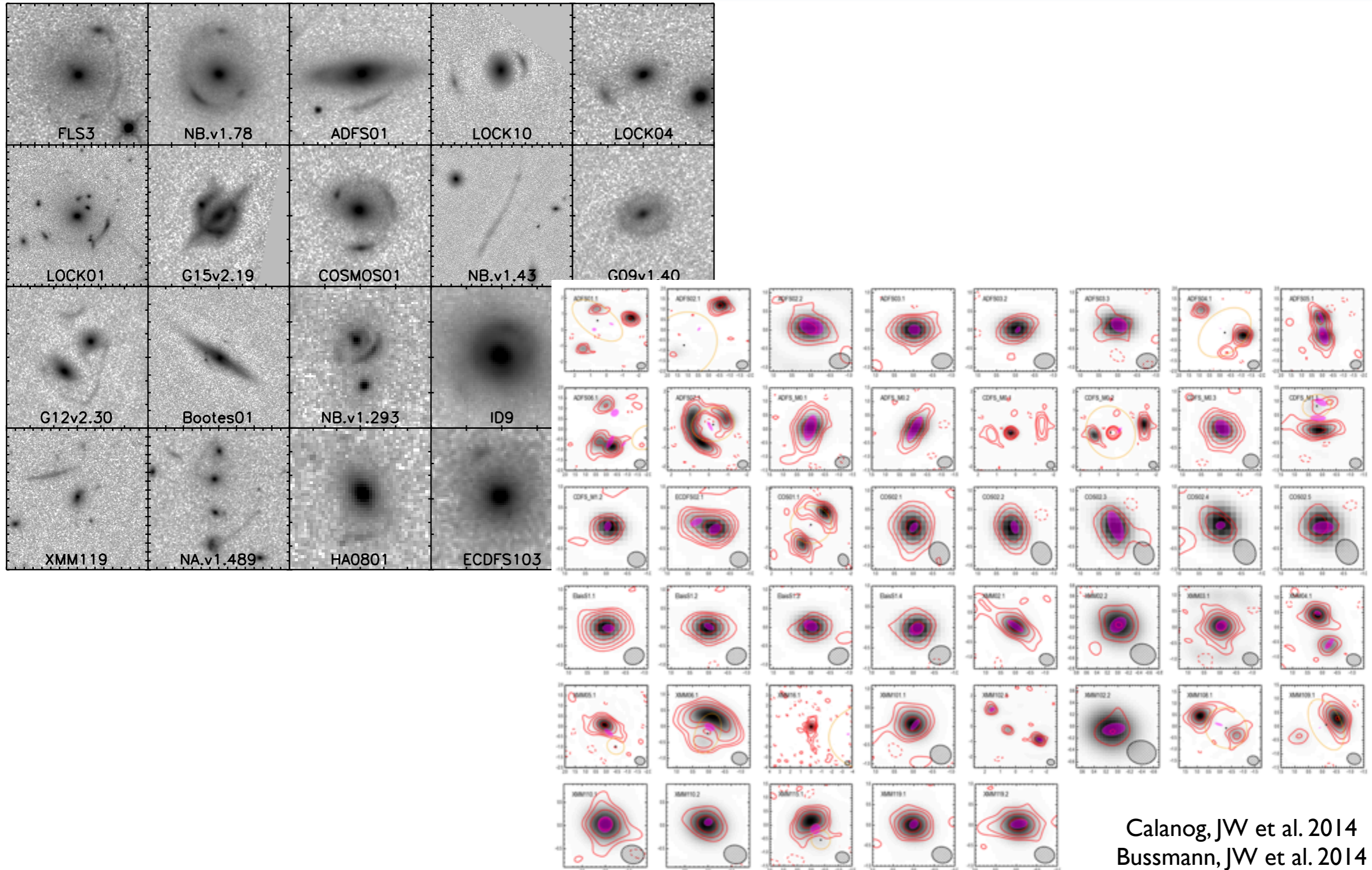
SMA 880 μ m

Herschel

250, 350, 500 μ m



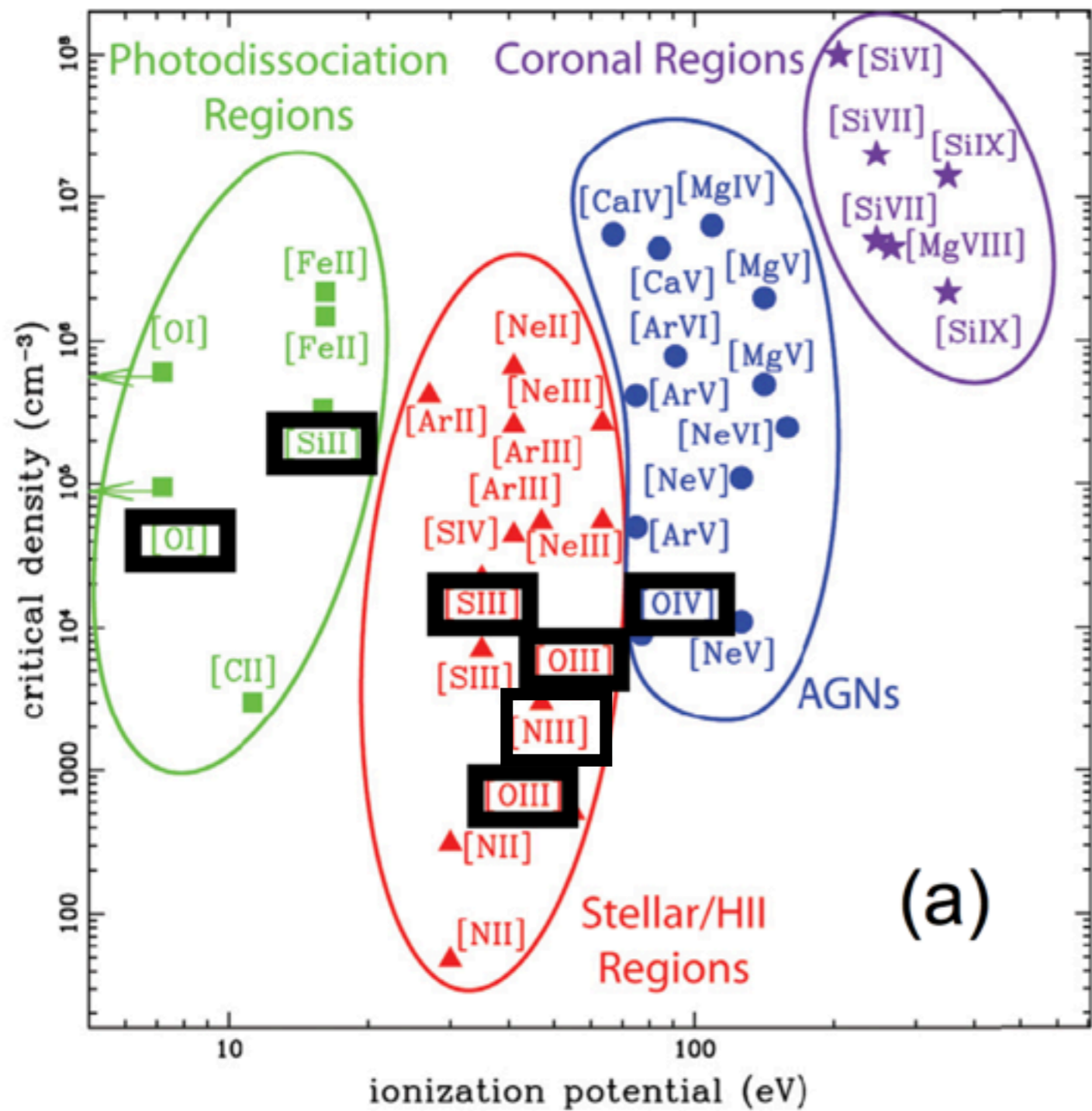
A sample of Herschel lens systems in submm & NIR



Calanog, JW et al. 2014
Bussmann, JW et al. 2014

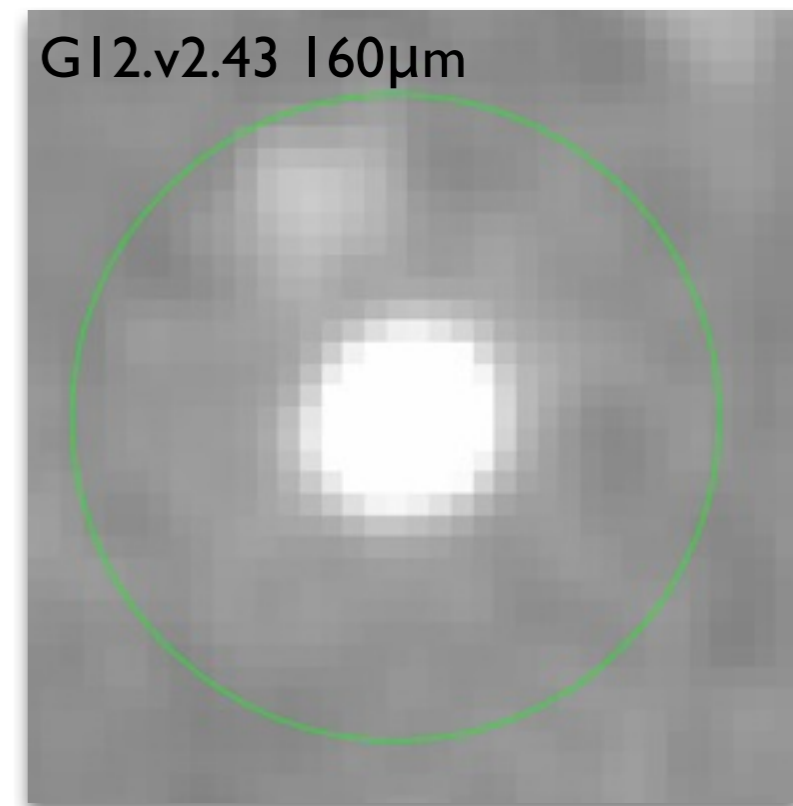
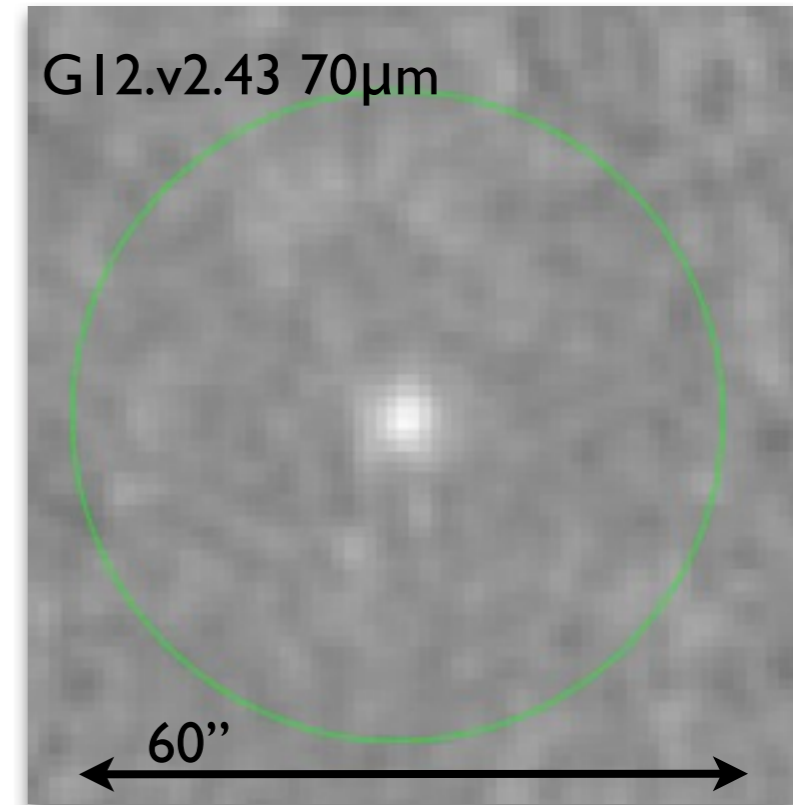
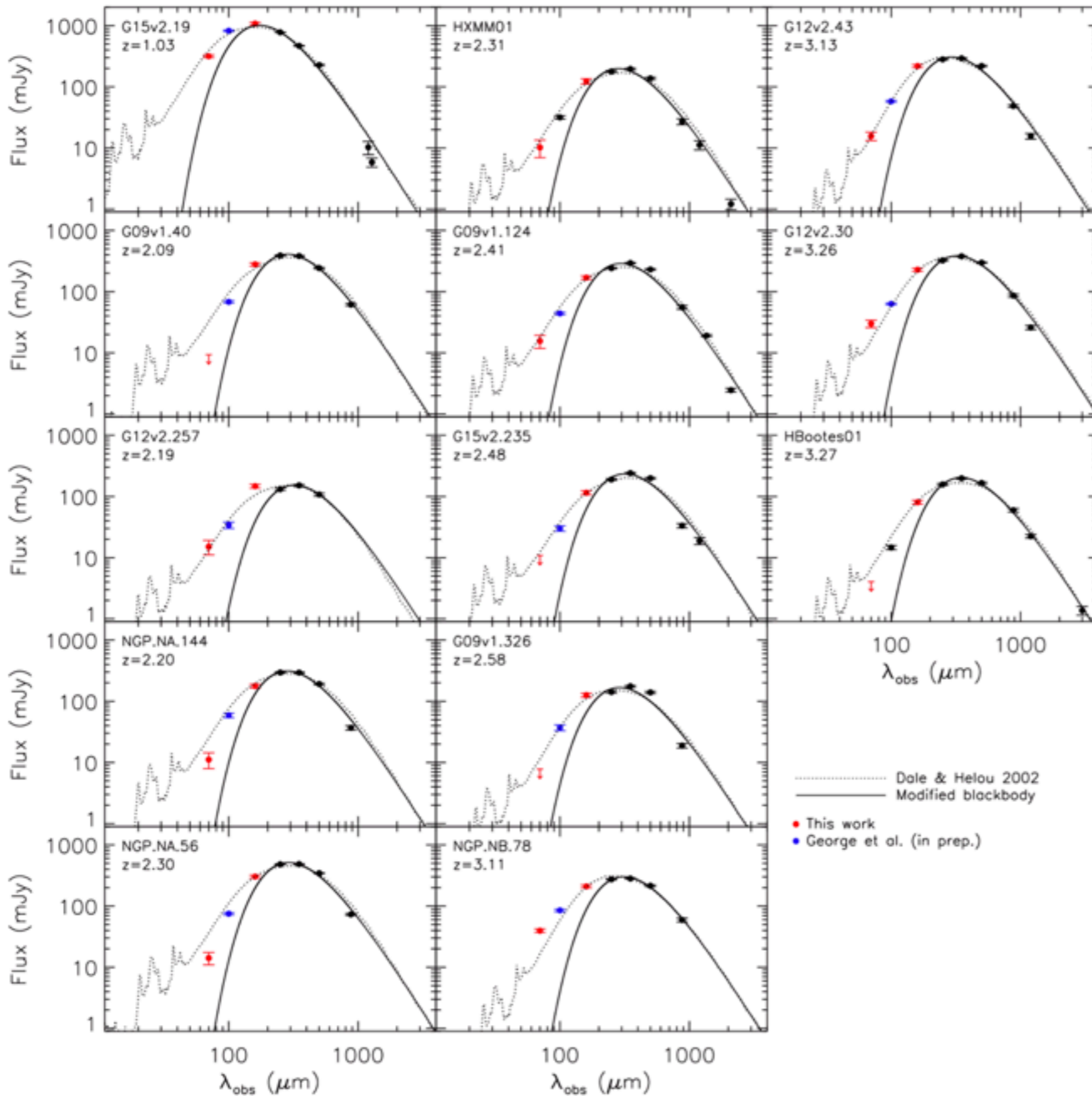
Herschel PACS OT2 survey of 13 lenses: targets

Target	Short Name	z_{source}	z_{lens}	Magnification
H-ATLAS J142935.3-002836	G15v2.19	1.027	0.218	9.7 ± 0.7^a
H-ATLAS J085358.9+015537	G09v1.40	2.091	...	15.3 ± 3.5
H-ATLAS J145000.0-010750	G12v2.257	2.191	...	13.0 ± 7.0
H-ATLAS J145000.0-010750	NGP.NA.144	2.202	...	4.4 ± 0.8
H-ATLAS J145000.0-010750	NGP.NA.56	2.302	0.672	11.7 ± 0.9
H-ATLAS J145000.0-010750	HXMM01	2.307	0.654	1.5 ± 0.3
H-ATLAS J145000.0-010750	G09v1.124	2.410	0.348	2.8 ± 0.2
H-ATLAS J145000.0-010750	G15v2.235	2.479	...	1.8 ± 0.3
H-ATLAS J145000.0-010750	G09v1.326	2.581	...	1
H-ATLAS J145000.0-010750	NGP.NB.78	3.111	0.428	13.0 ± 1.5
H-ATLAS J145000.0-010750	G12v2.43	3.128	...	2.8 ± 0.4
H-ATLAS J145000.0-010750	G12v2.30	3.259	1.225	9.5 ± 0.6
H-ATLAS J145000.0-010750	HBootes01	3.274	0.590	4.5 ± 0.4

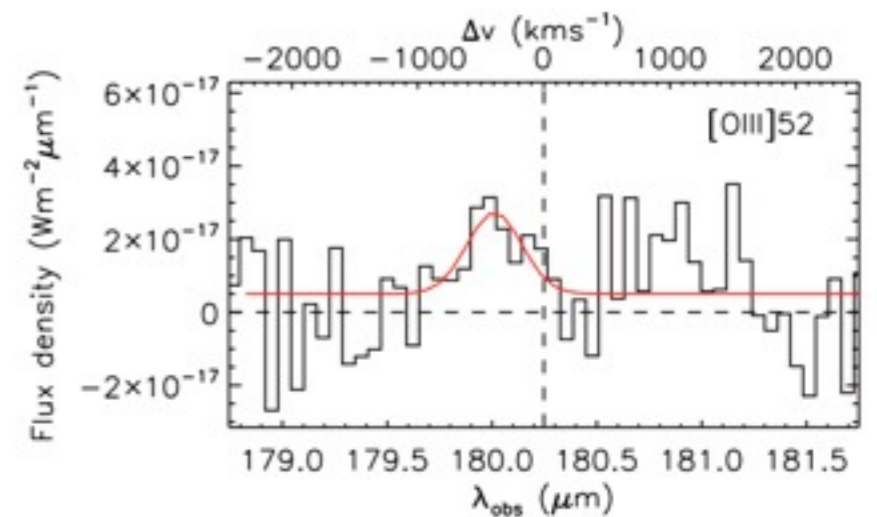
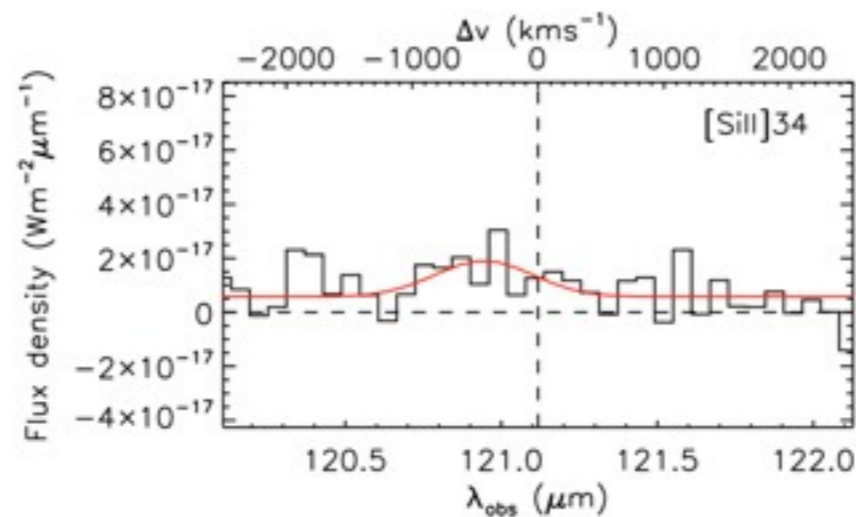
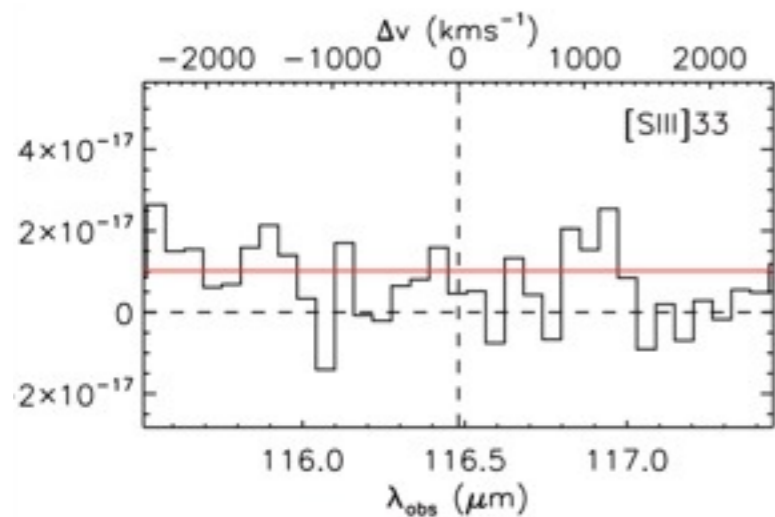
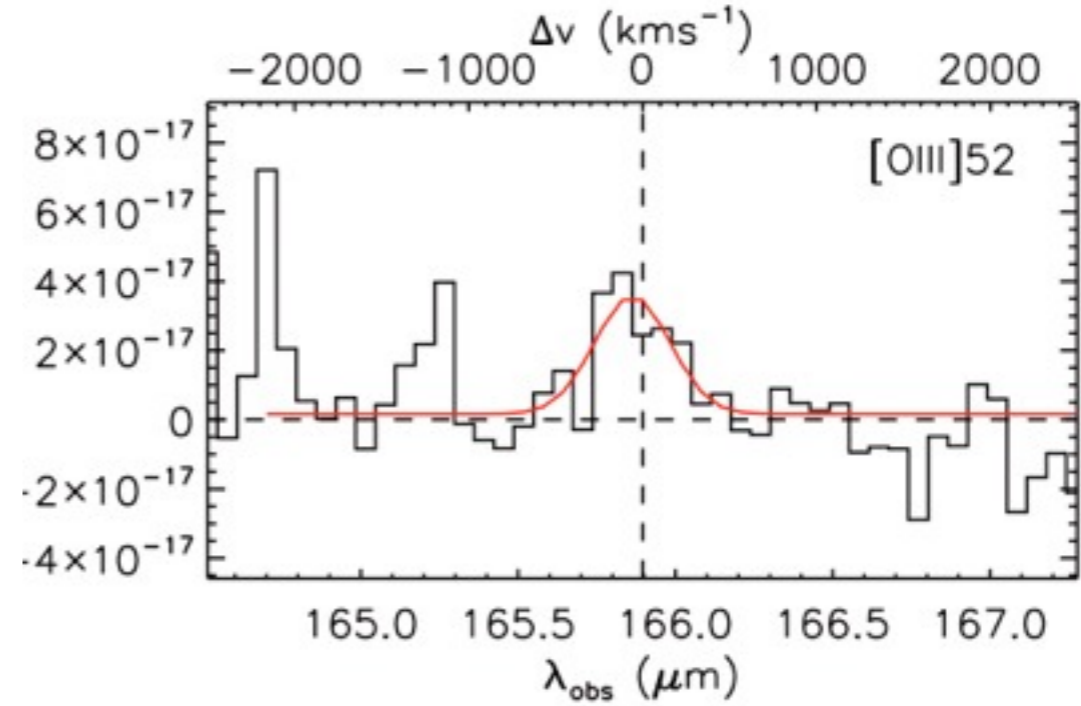
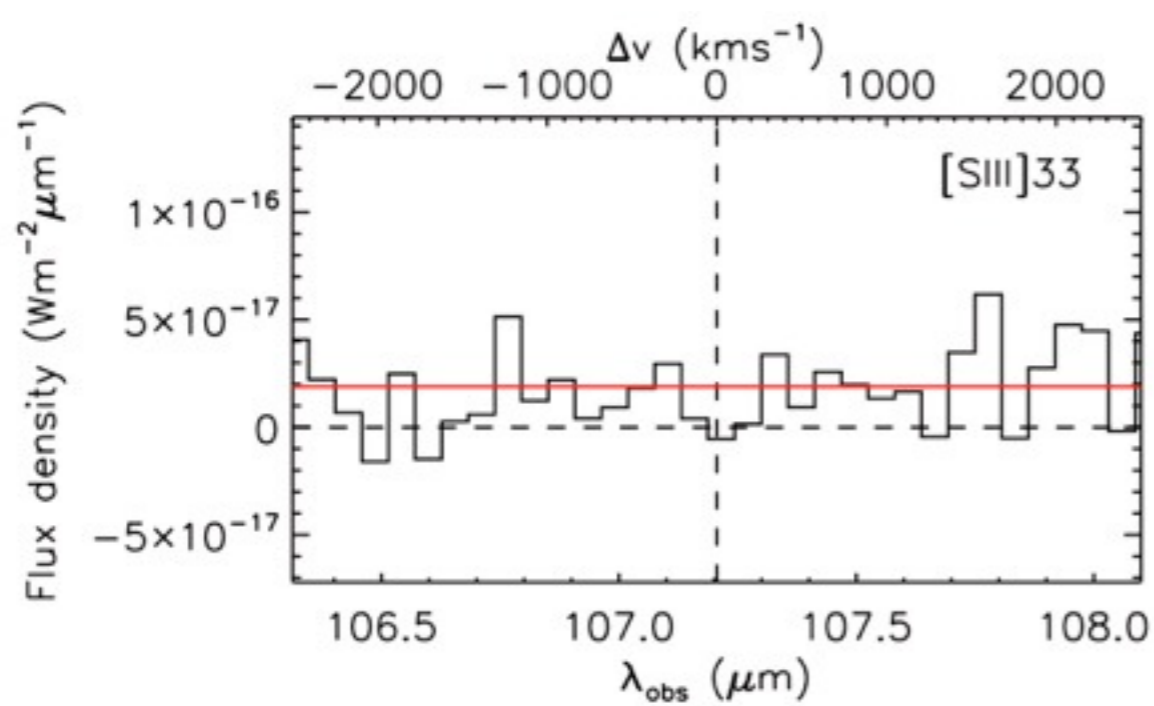


Spinoglio et al. 2009

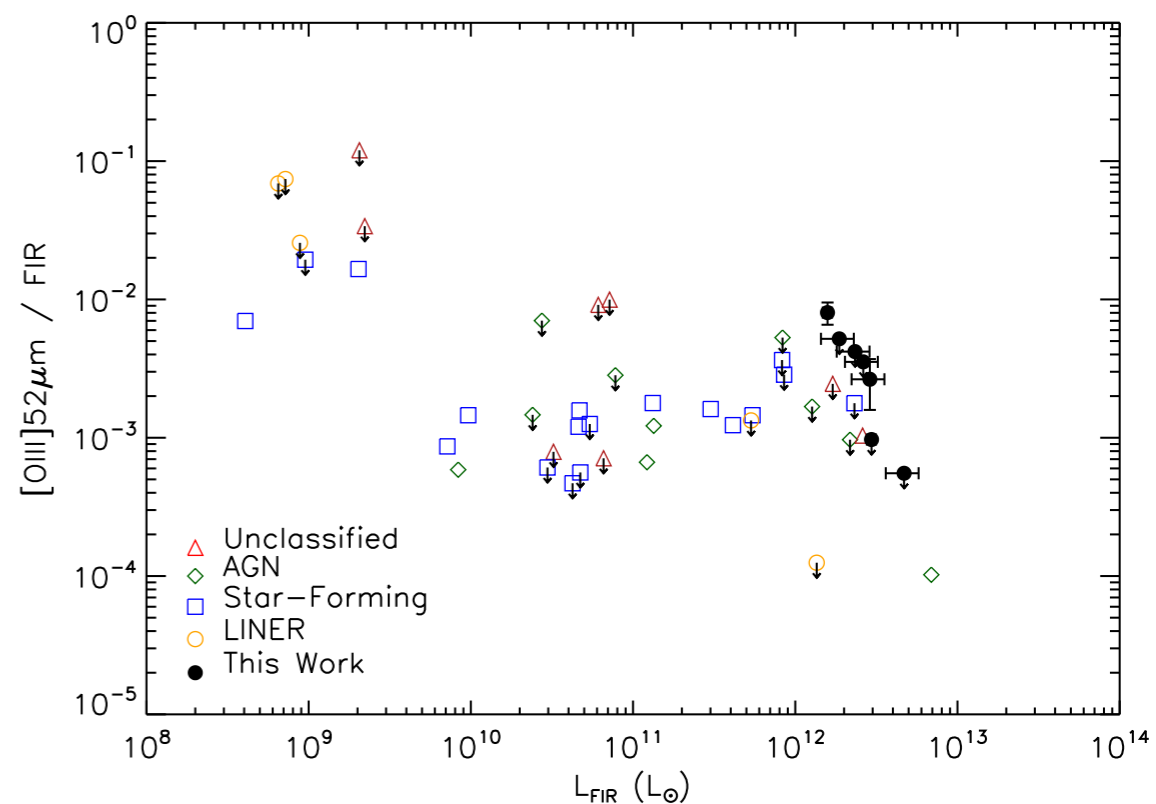
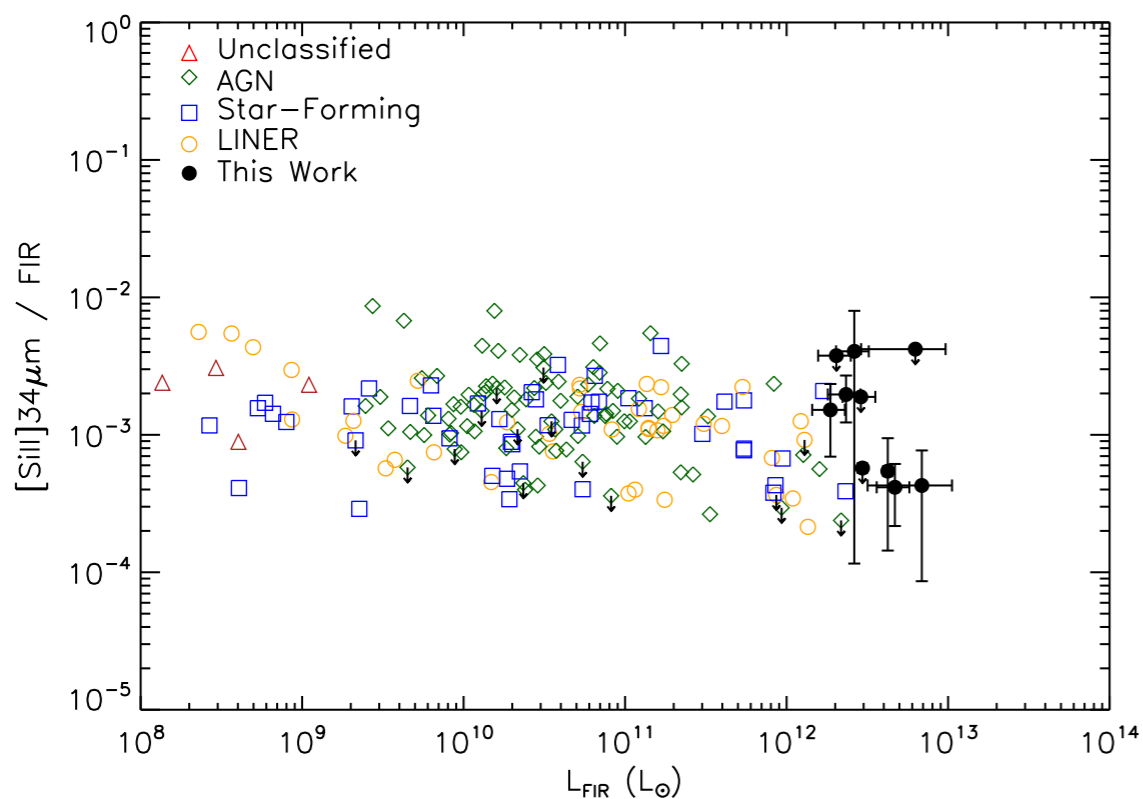
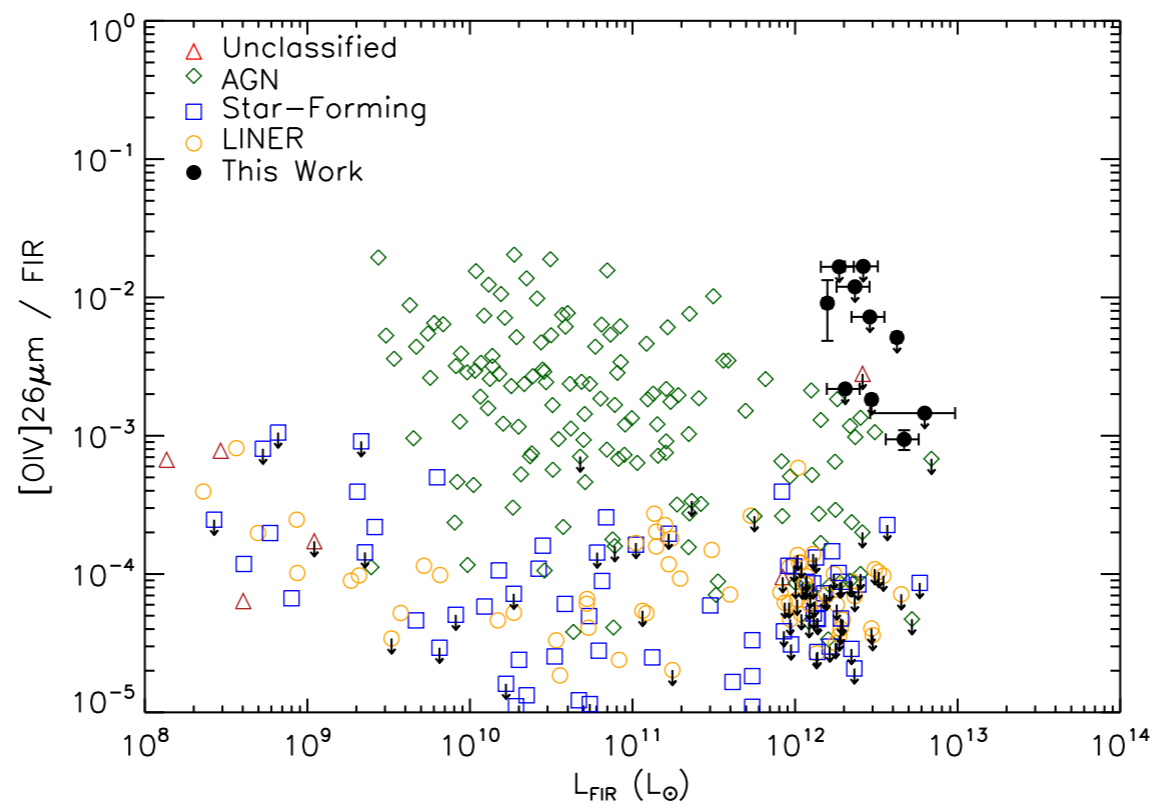
All targets have apparent $L_{\text{FIR}} > 10^{13} L_{\odot}$



Examples of the spectroscopy

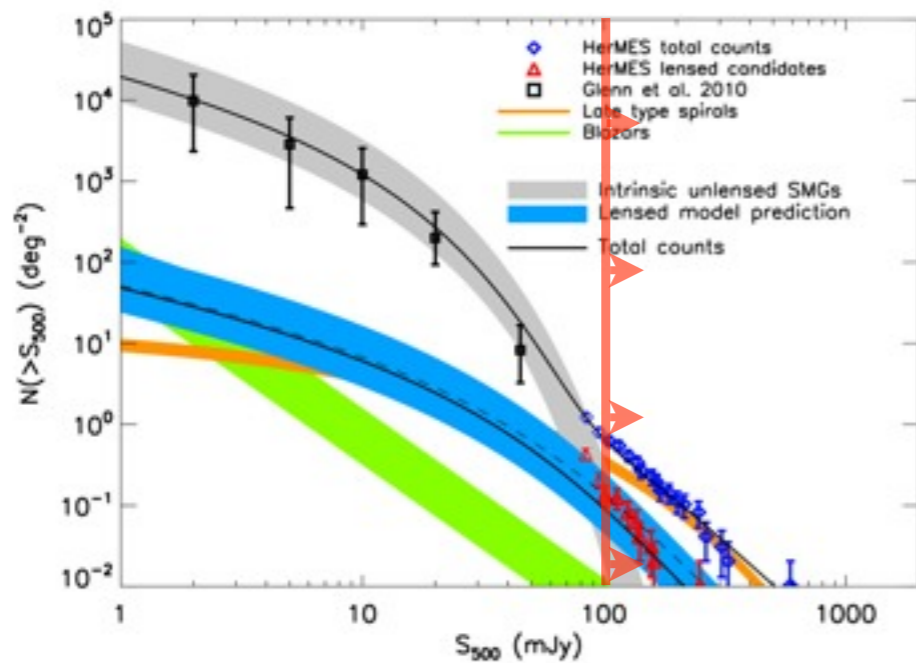


No [OIV]26 μm (AGN tracer) in most DSFGs, but evidence of [SII]34 μm (PDRs) & [OIII]52 (HII regions)

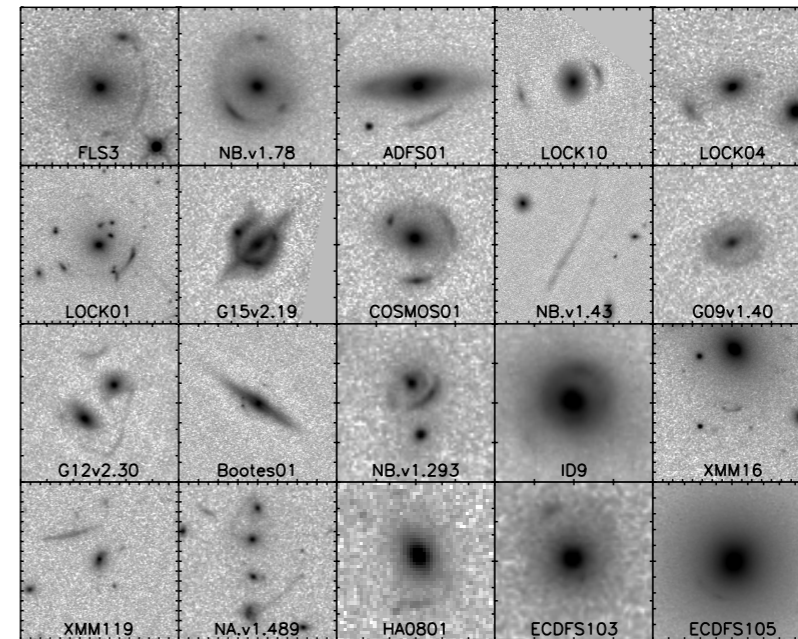


Summary

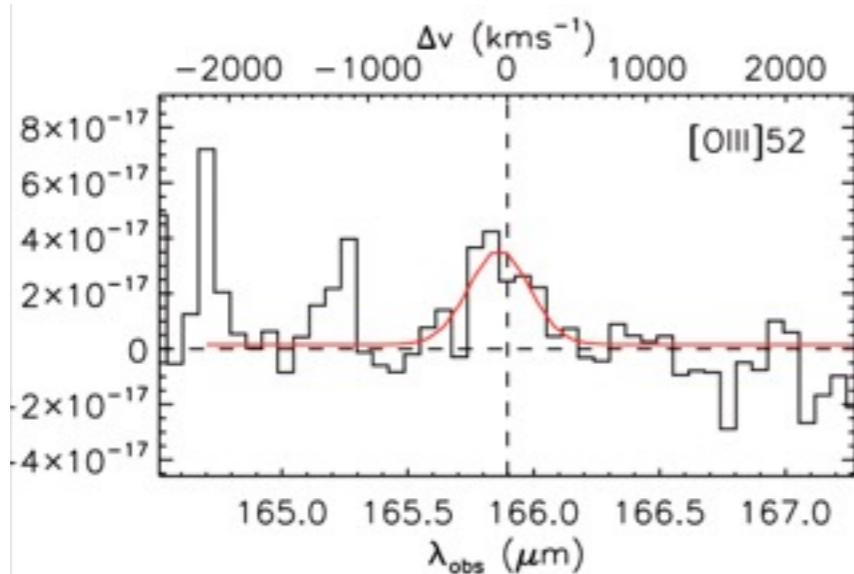
Wide-area, submm surveys can efficiently identify strongly lensed dusty star-forming galaxies by simply selecting the brightest sources.



The lensing amplification makes studies of faint features possible.



Our PACS survey is breaking new ground detecting many fine structure lines at $z > 1$.



The fine structure lines confirm IR emission dominated by HII regions and PDRs (star formation)

