Measuring sizes of distant faint galaxies in sub-mm and radio

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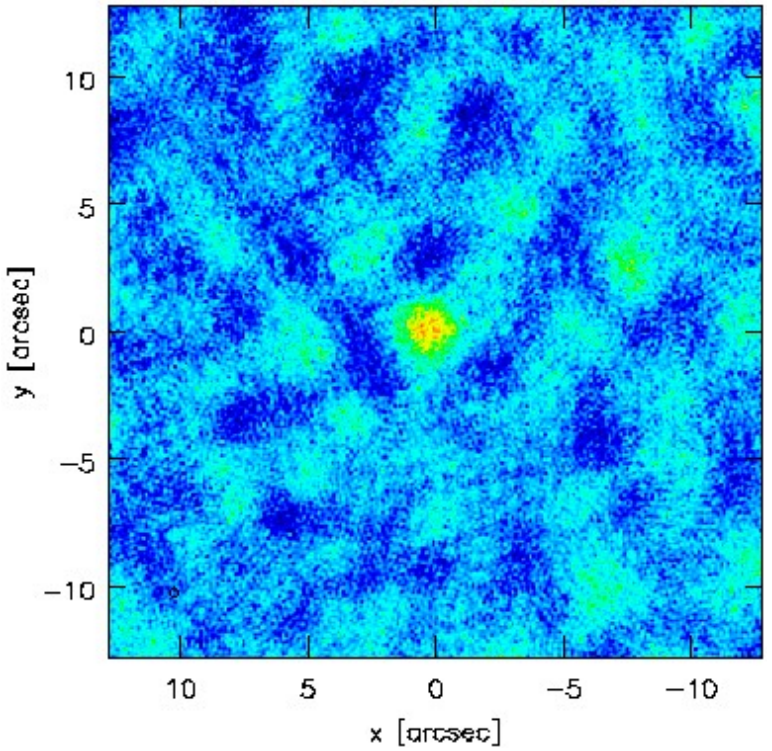
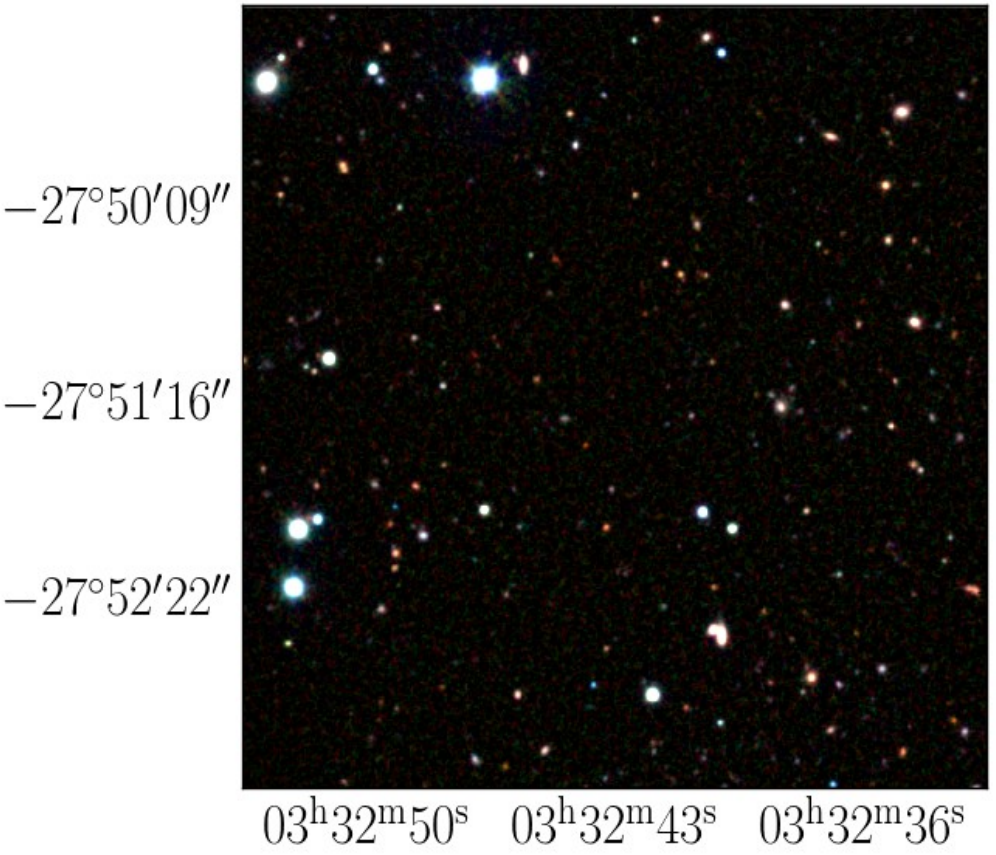


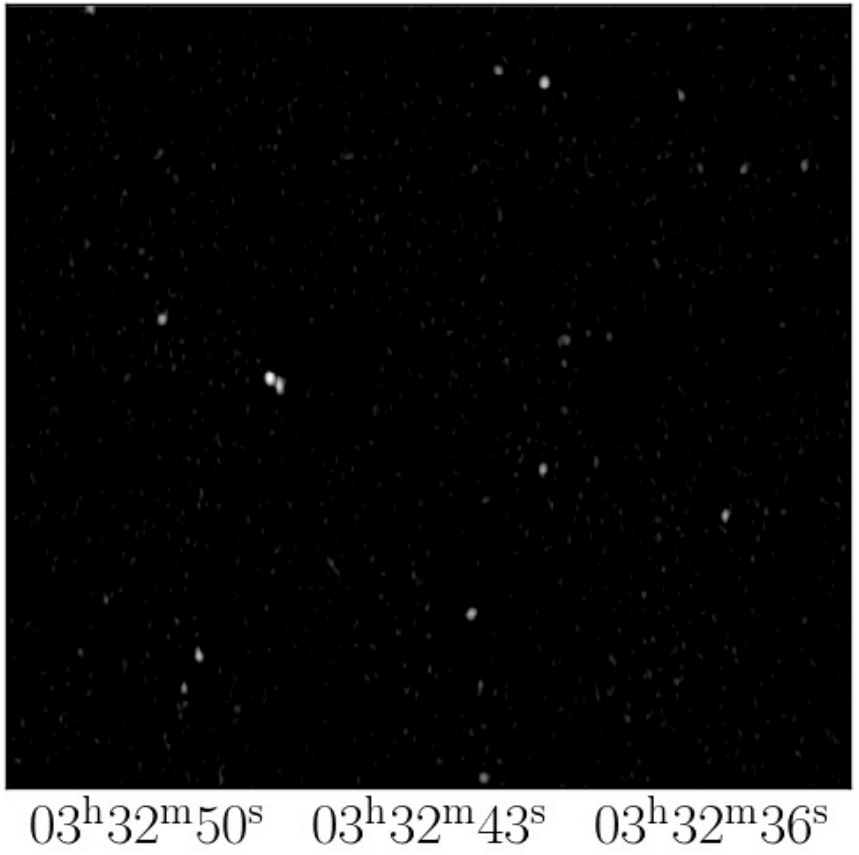
What is stacking?

16910 detected sources



I, *J*, and *K* image from MUSYC (Cardamone et al. 2010)

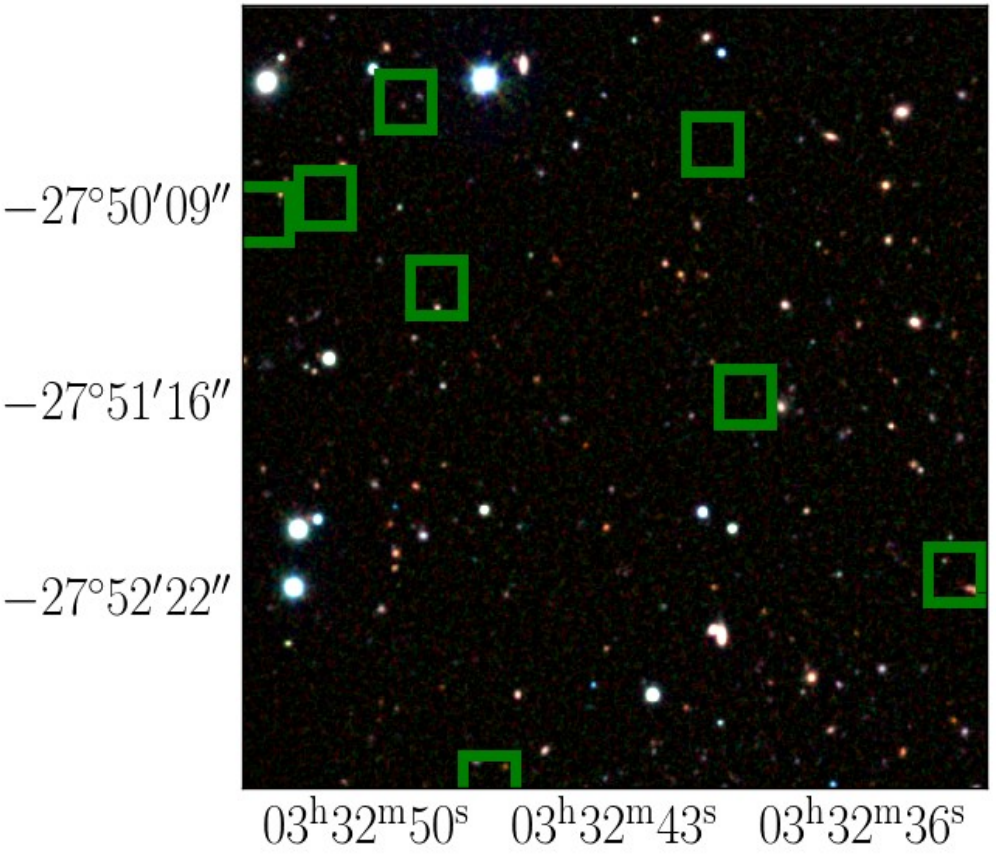
899 detected sources



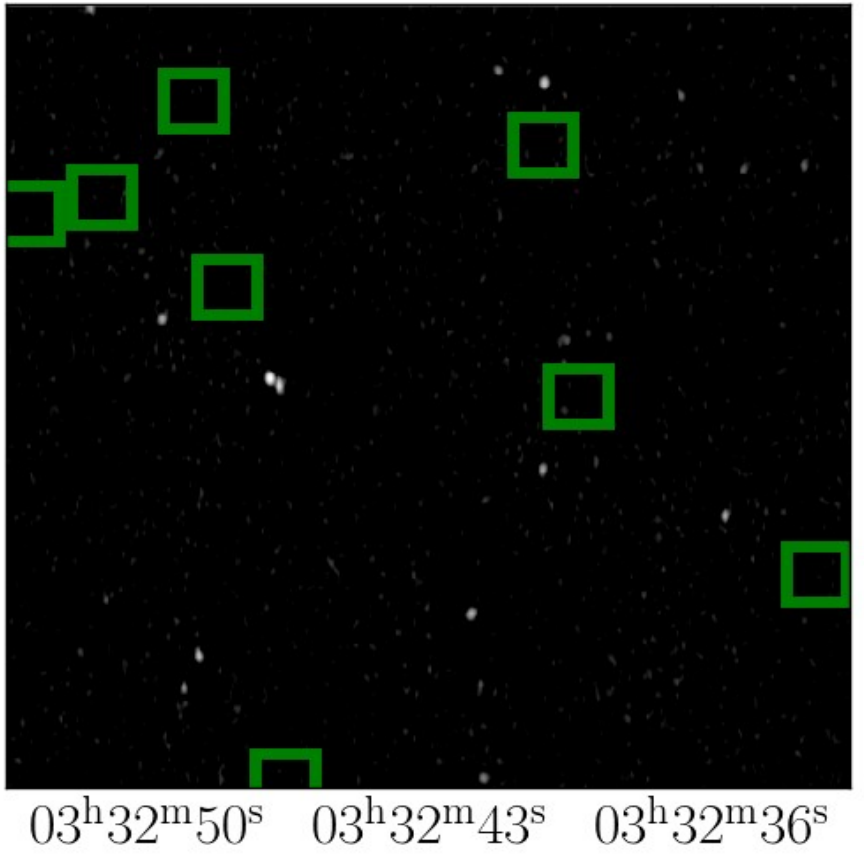
VLA map at 1.4 GHz (Miller et al. 2013)

Pick target galaxies, e.g., DRG galaxies

887 DRGs

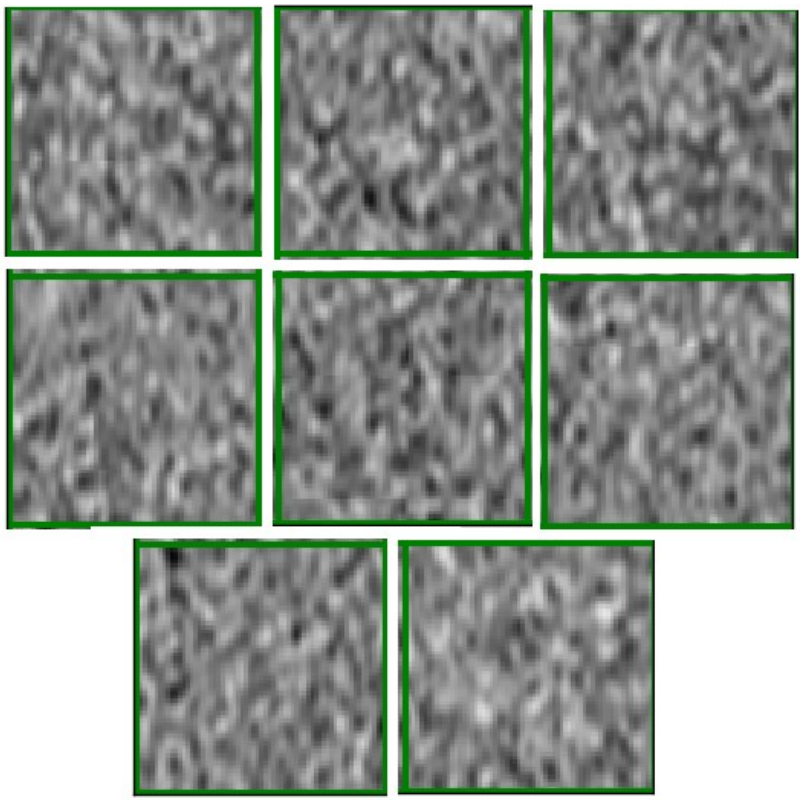


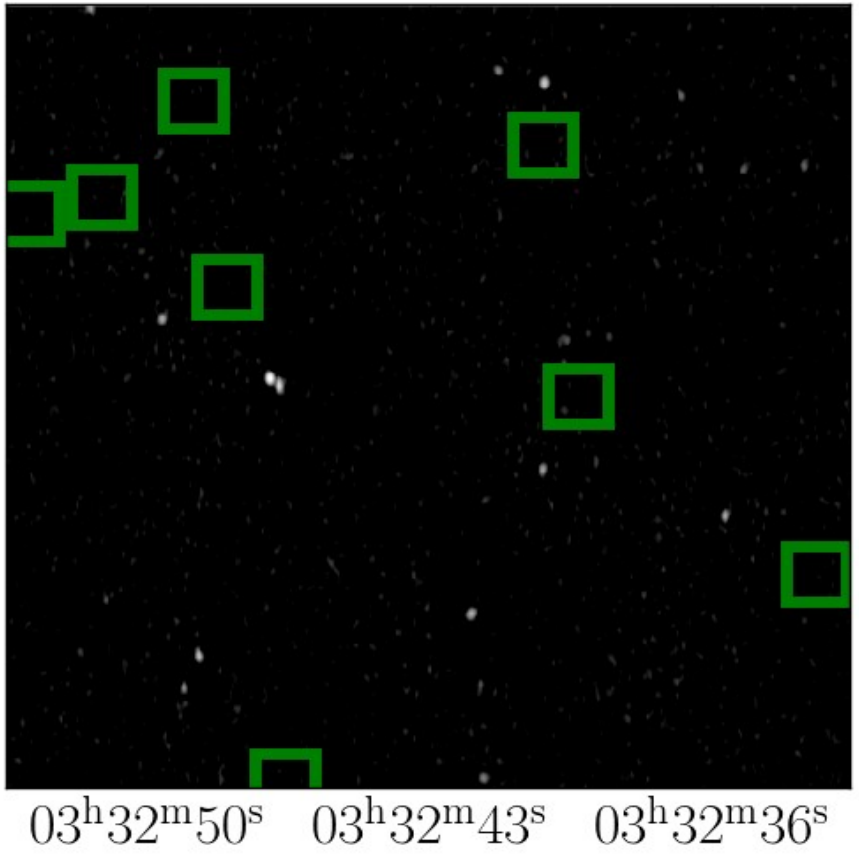
I, *J*, and *K* image from MUSYC (Cardamone et al. 2010)



VLA map at 1.4 GHz (Miller et al. 2013)

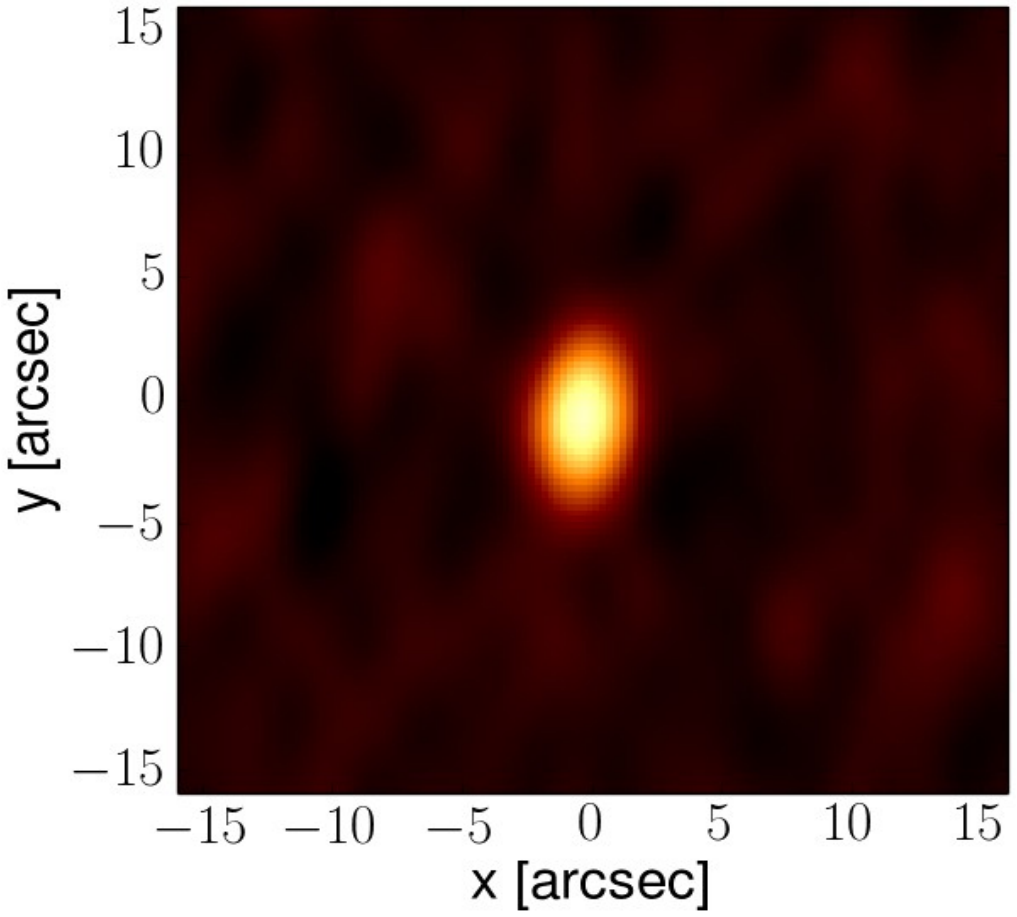
Cut out stamps from the VLA-map

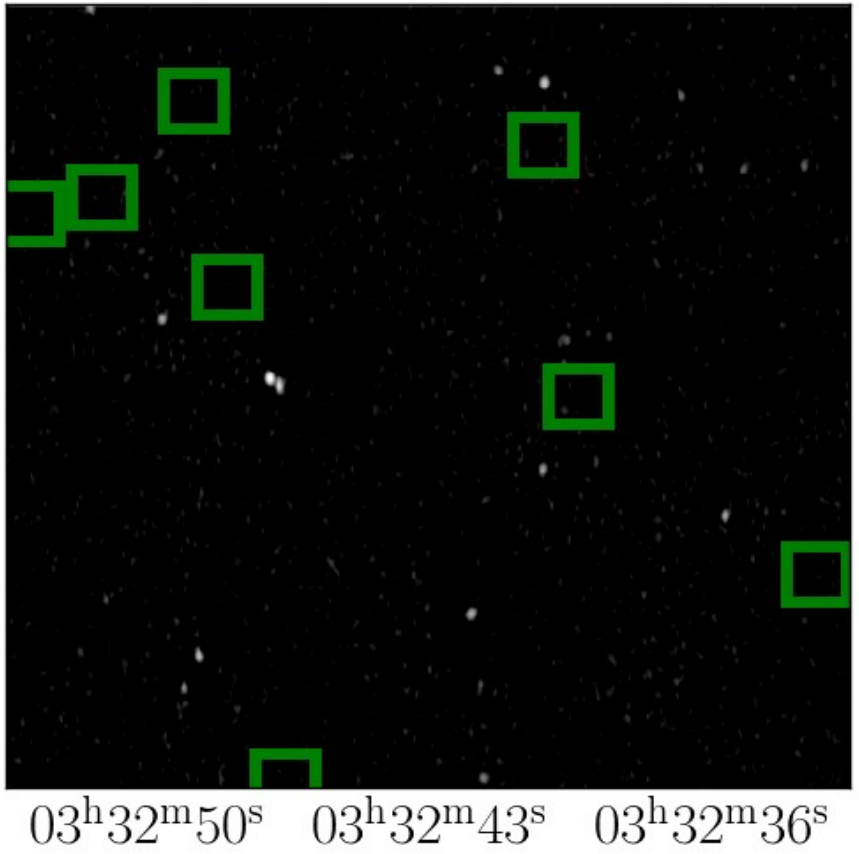




VLA map at 1.4 GHz (Miller et al. 2013)

And stack the stamps

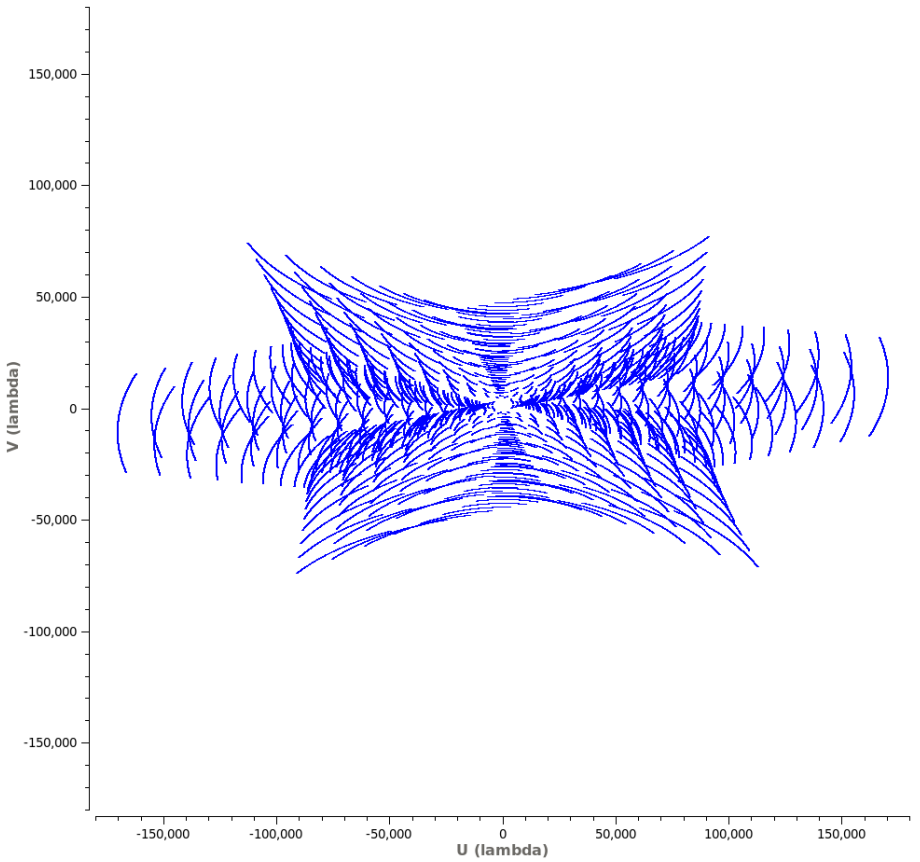




VLA map at 1.4 GHz (Miller et al. 2013)

VLA **and ALMA** are interferometers

- Interferometric telescopes produces visibilities
- Need to Fourier-transform visibilities to get actual image
- The image is only a model of the observed data

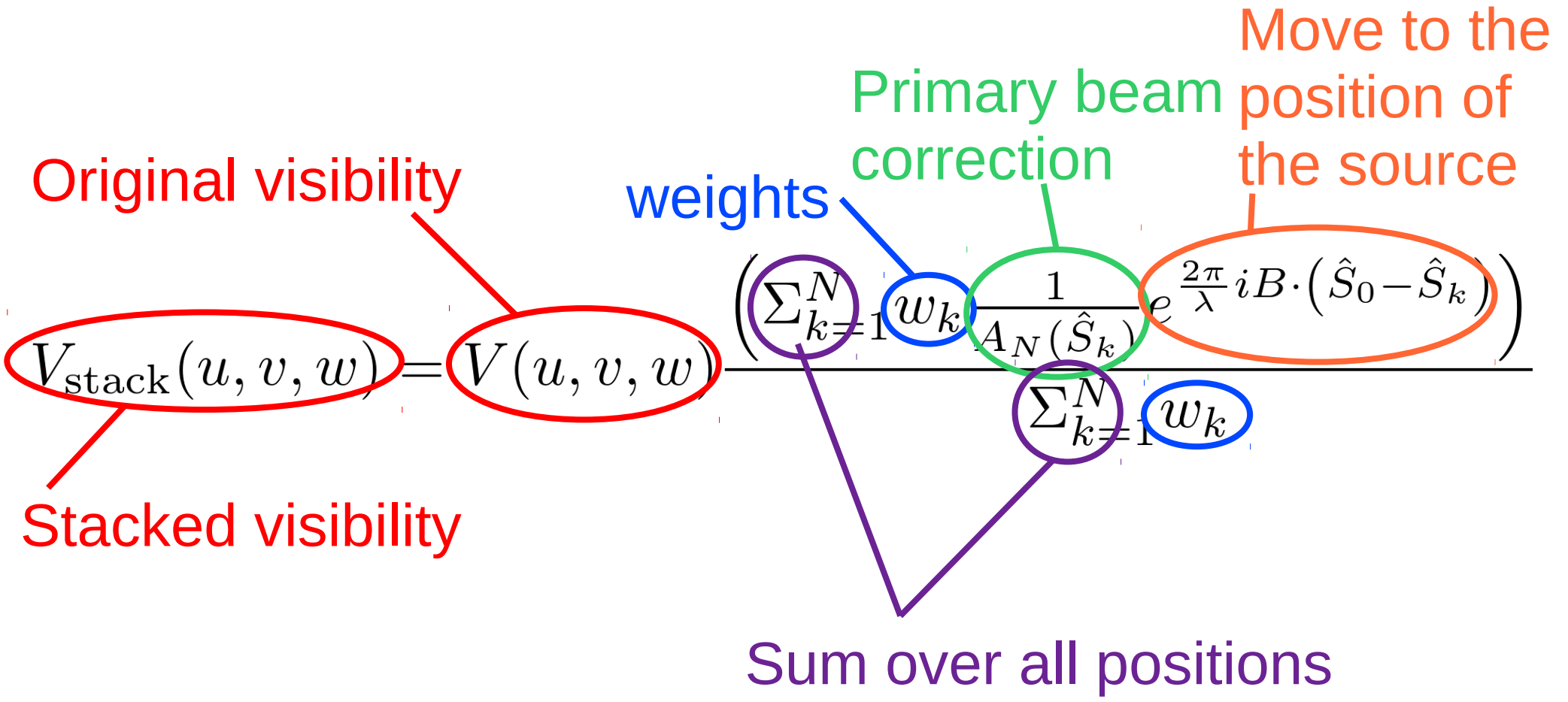


uv-stacking

$$V_{\mathrm{stack}}(u,v,w) = V(u,v,w)\frac{\left(\Sigma_{k=1}^{N} w_k \frac{1}{A_N(\hat{S}_k)} e^{\frac{2\pi}{\lambda} iB\cdot\left(\hat{S}_0-\hat{S}_k\right)}\right)}{\Sigma_{k=1}^{N} w_k}$$

Lindroos et al. 2015

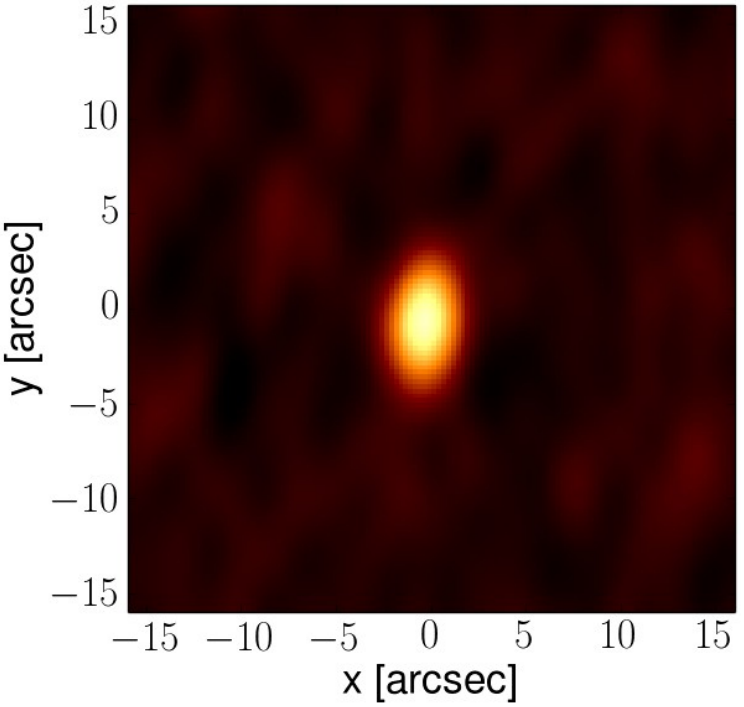
uv-stacking



Lindroos et al. 2015

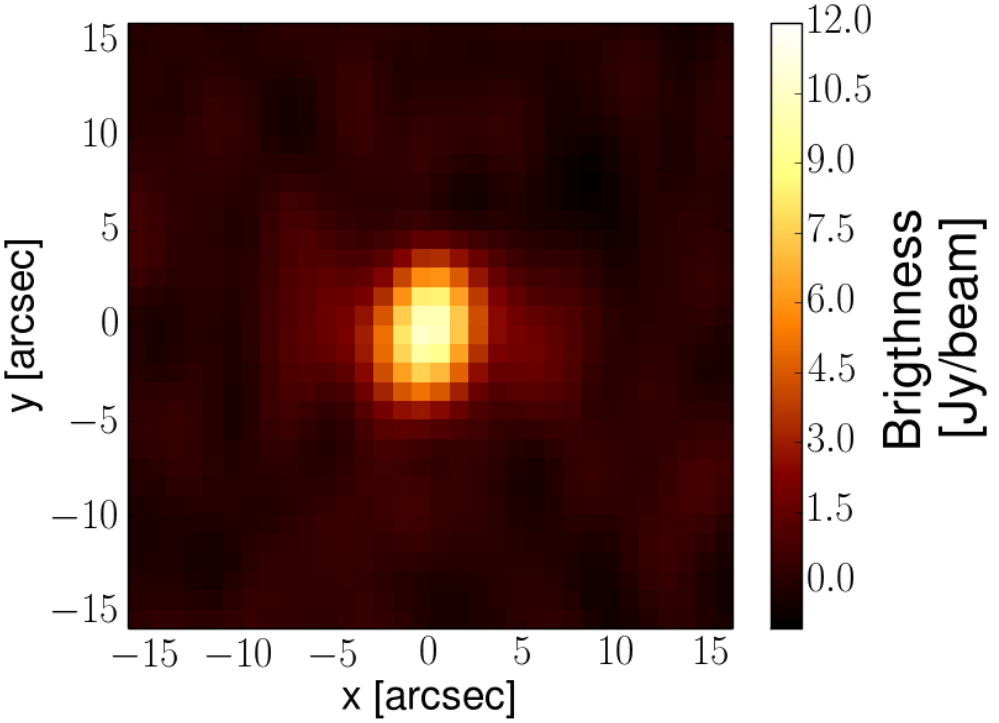
Real data, image- vs. uv-stacking 300 DRGs (Distant Red Galaxies)

uv stacking



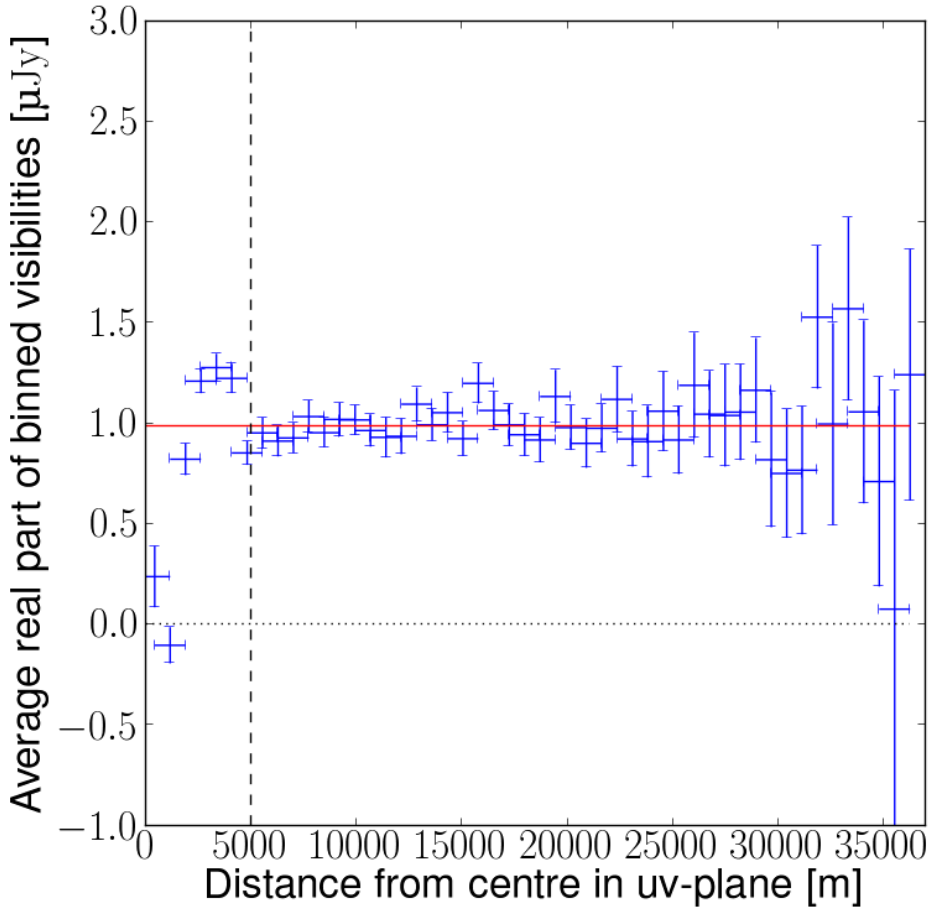
Flux ~ 10.2μJy, σ ~ 0.25μJy

image stacking



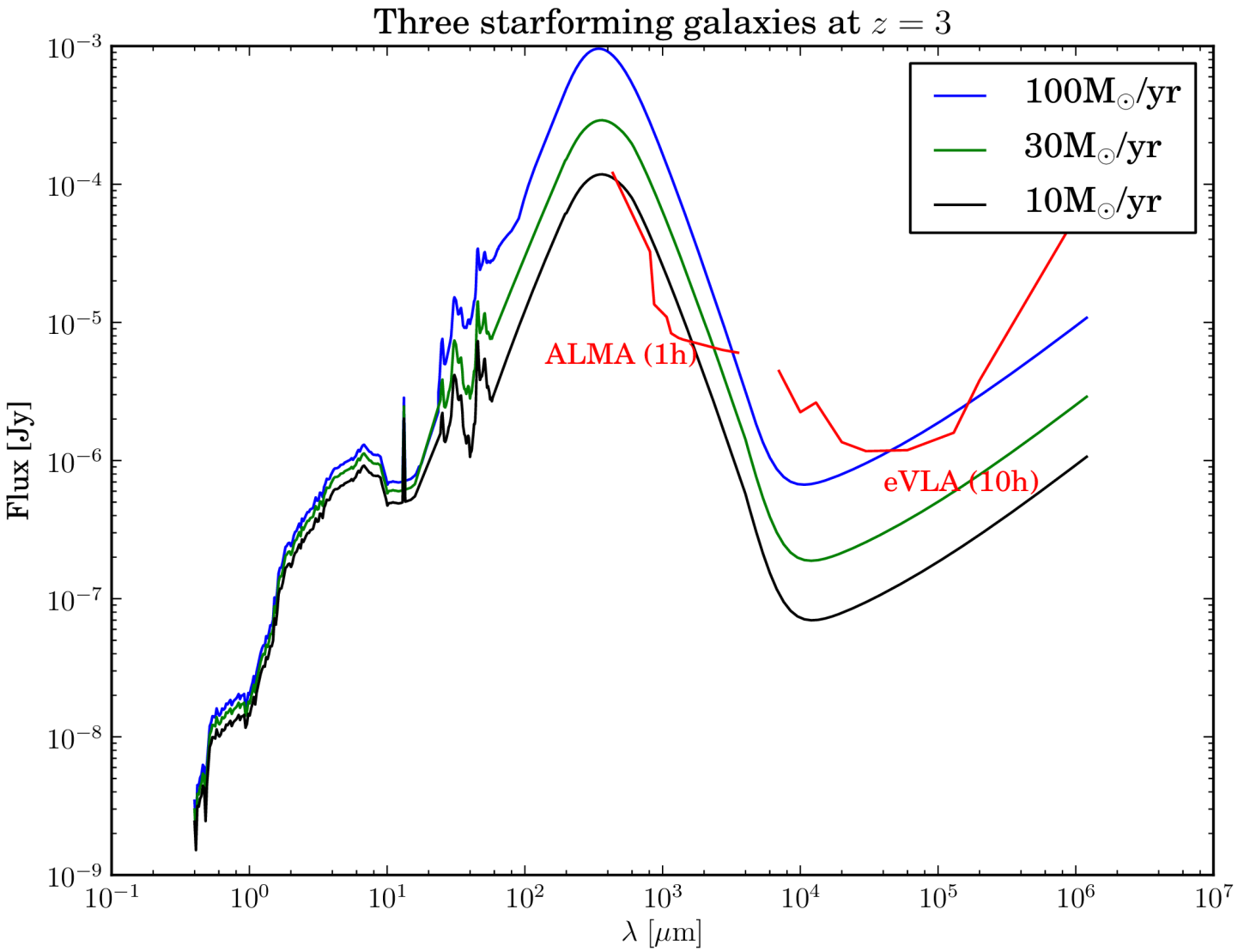
Flux ~ 10.2μJy, σ ~ 0.40μJy

uv-stacking in the *uv*-plane

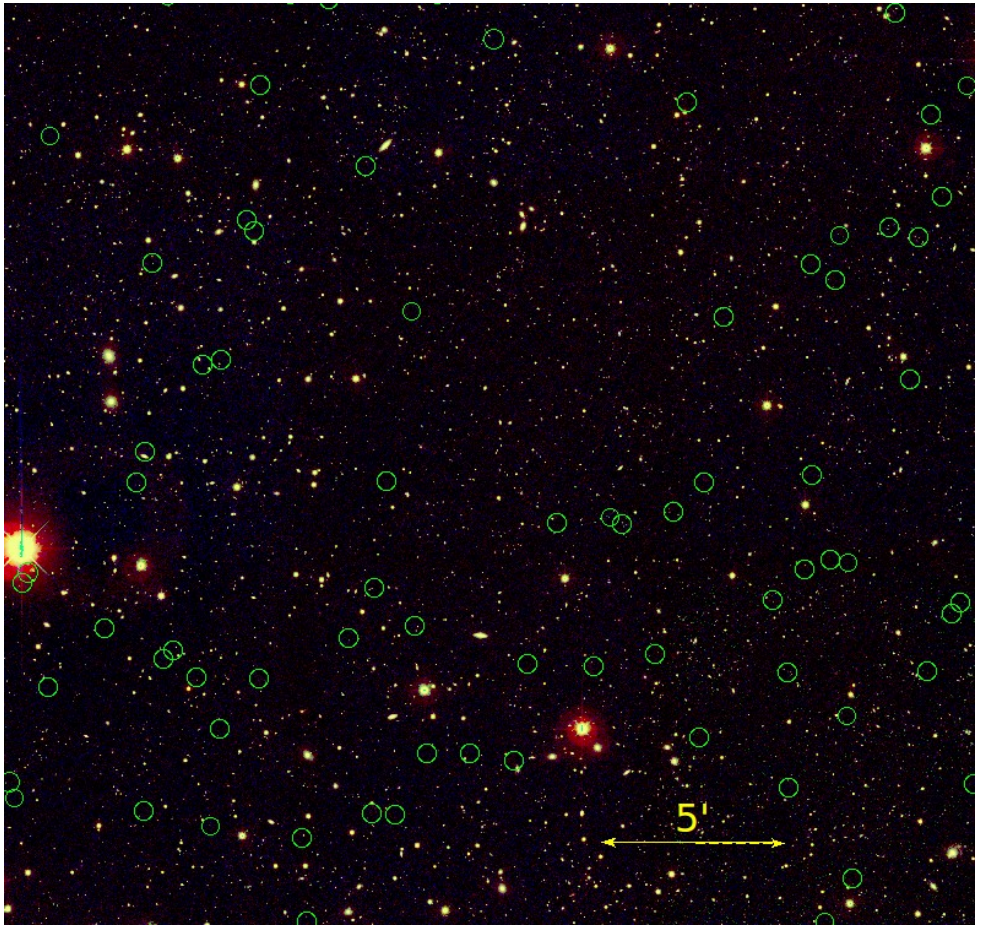


Lindroos et al. 2015

Do we really need to stack with ALMA?



ALMA Survey of the LABOCA ECDFS sub-mm Survey



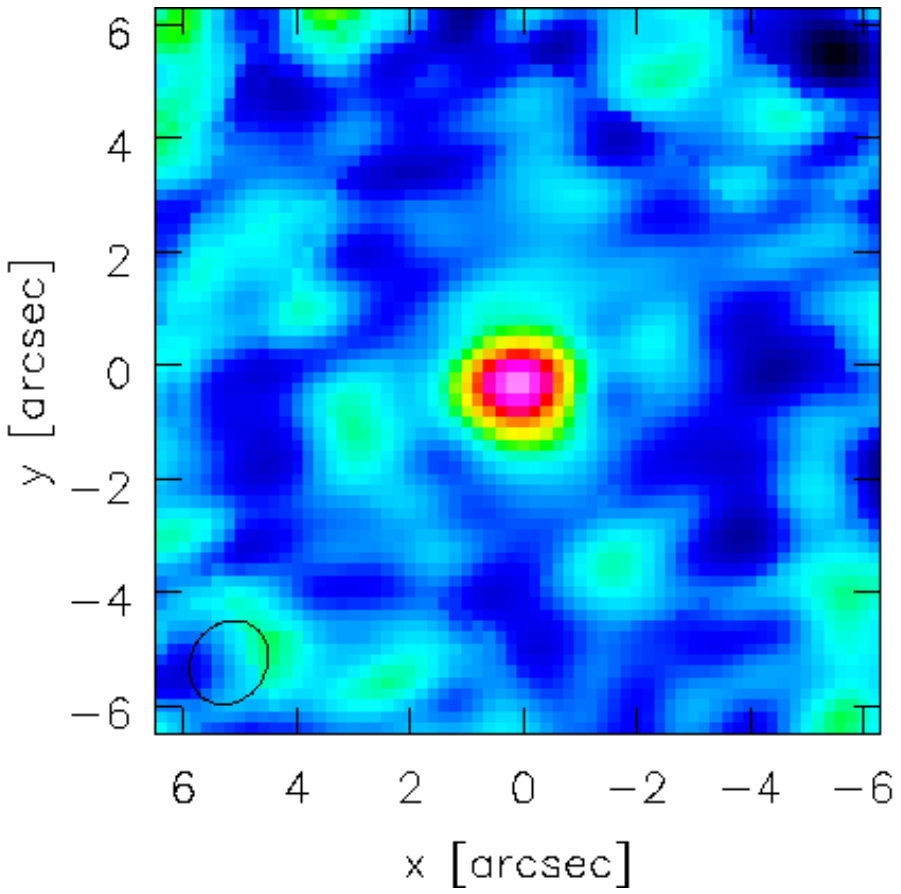
Hodge et al. 2013

The galaxies

- Found in infrared *K*-band and selected using colours in *B*, *z*, *J*, and *K*
- Distant red galaxies (DRG), 22 galaxies
- BzK galaxies, 26 galaxies
- Extremely red objects (ERO), 20 galaxies
- Decarli et al. 2014

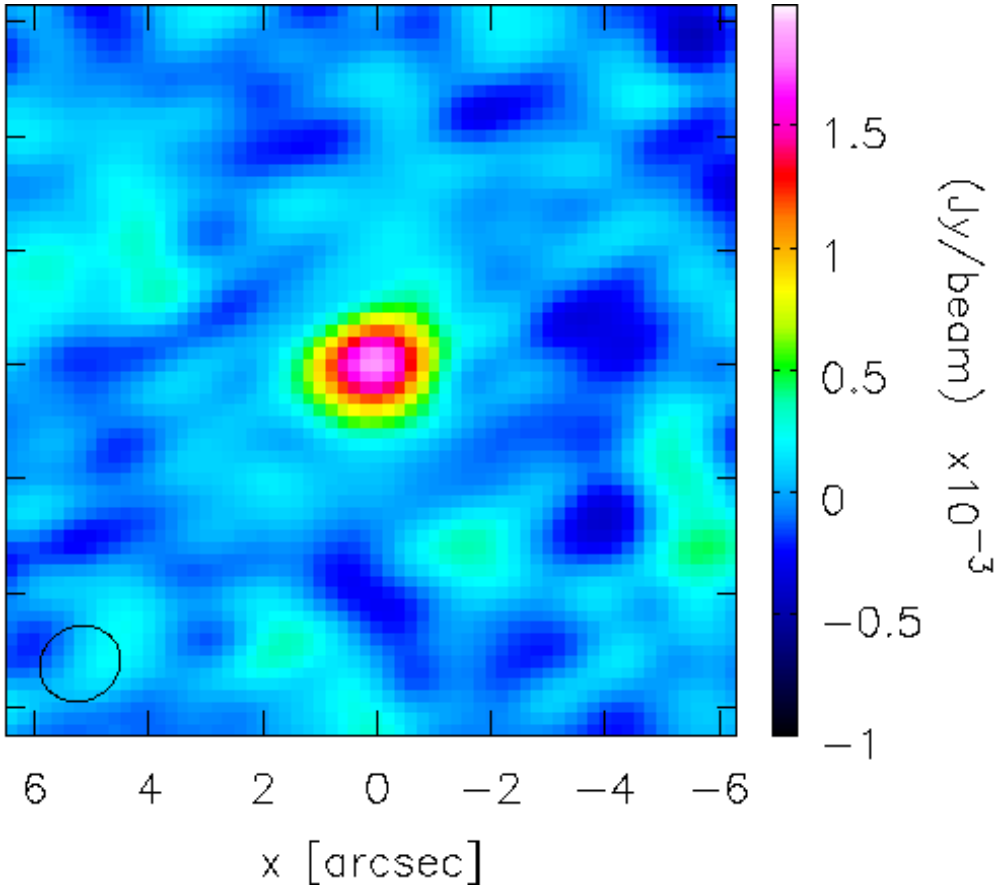
uv- and image-stacking (DRG)

image-stacking



Flux ~ 1.77 mJy, σ ~ 0.13 mJy

uv-stacking

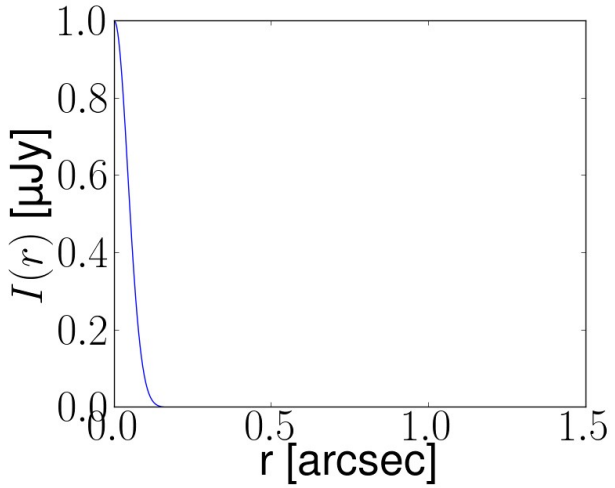


Flux ~ 2.57 mJy, σ ~ 0.14 mJy

Lindroos et al. in prep., Lindroos 2014 (lic. thesis)

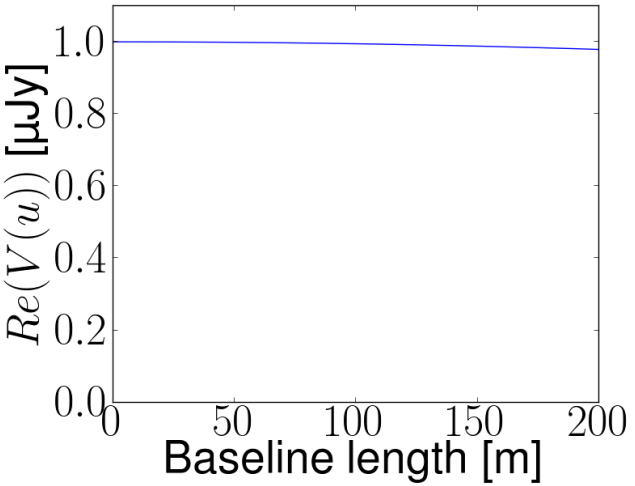
Fourier transform of small sources

Compact

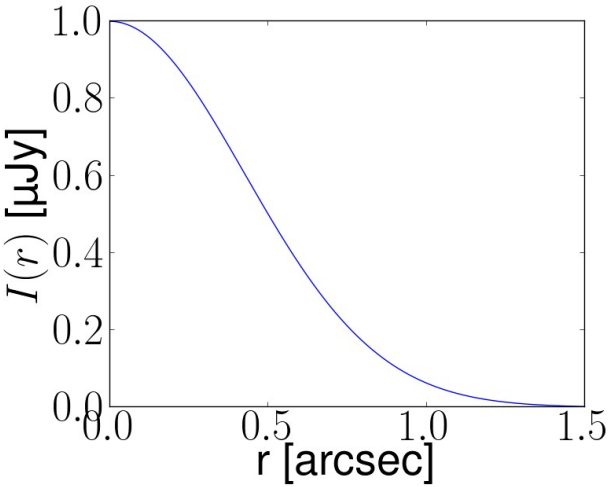


FT

Compact

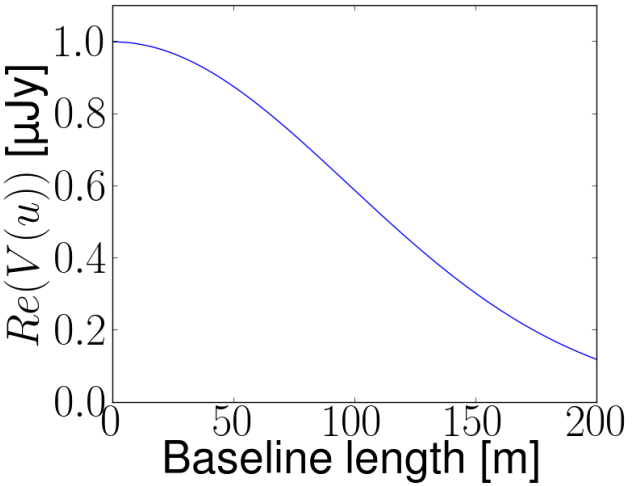


Extended

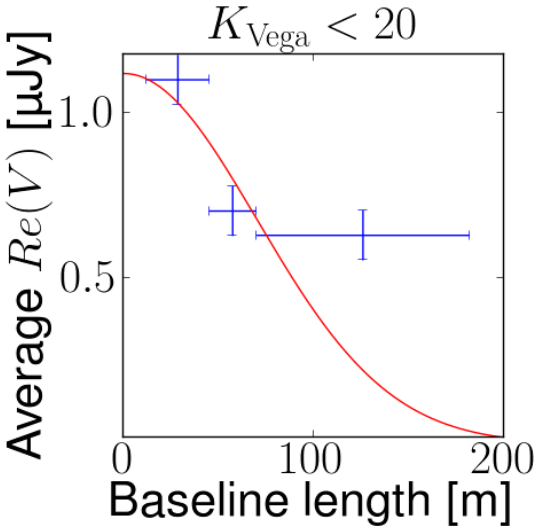


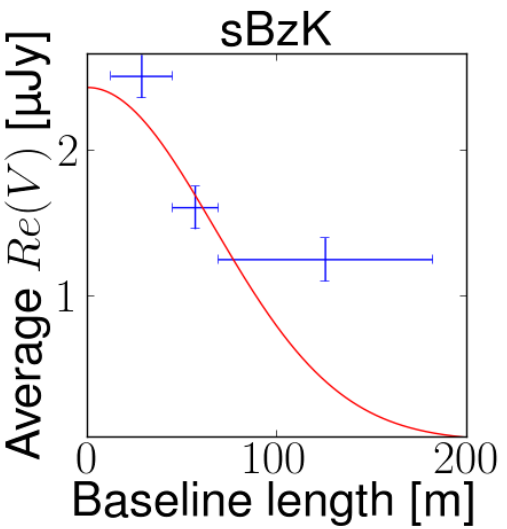
FT

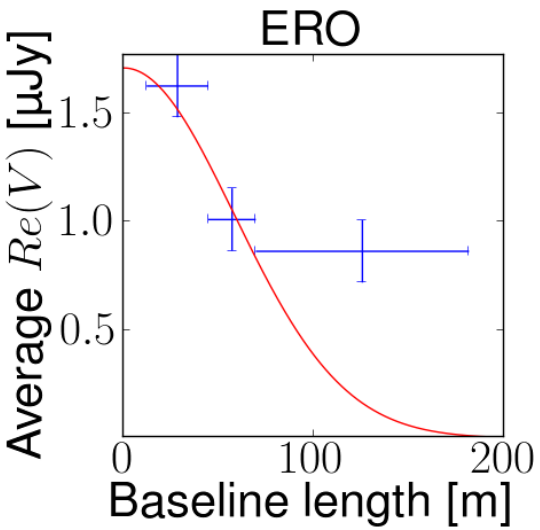
Extended

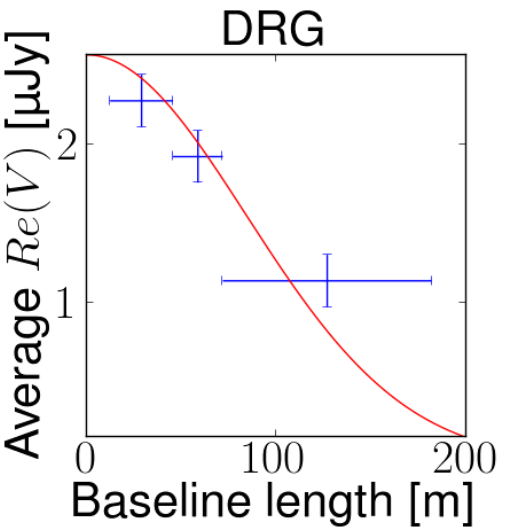


Sizes of the galaxies









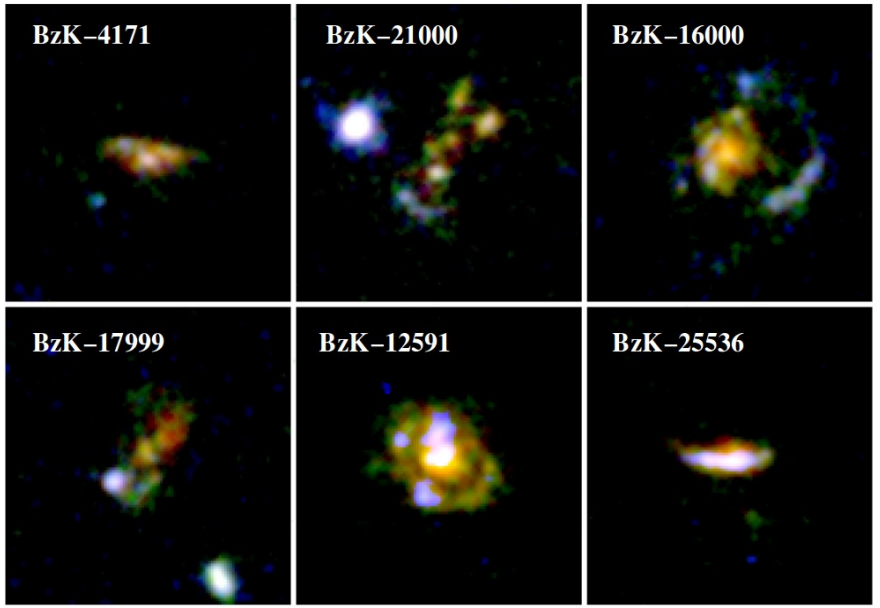
Lindroos et al. in prep., Lindroos 2014 (lic. thesis)

Sample	Flux 345 GHz	Flux 1.4 GHz	Size 345 GHz	Size 1.4 GHz	$\Sigma_{\rm SFR}(FIR)$ $M_\odot\,{\rm yr}^{-1}{\rm kpc}^{-2}$	$\Sigma_{\rm SFR}(1.4{\rm GHz})$ $M_\odot\,{\rm yr}^{-1}{\rm kpc}^{-2}$
$K_{\rm Vega}<20$	$1.12\pm0.06\,$mJy	$22.2\pm2.6\,\mu$Jy	$0\farcs96\pm0\farcs08$	1.16 ± 0.09	1.79	1.90
sBzK	$2.44\pm0.13\,$mJy	$37.8\pm5.1\,\mu$Jy	$1\farcs02\pm0\farcs08$	1.89 ± 0.15	3.10	4.56
ERO	$1.71\pm0.15\,$mJy	$34.1\pm5.0\,\mu$Jy	$1\farcs16\pm0\farcs12$	1.15 ± 0.09	2.60	1.82
DRG	$2.57\pm0.14\,$mJy	$35.3\pm4.9\,\mu$Jy	$0\farcs80\pm0\farcs08$	1.90 ± 0.13	5.64	6.03

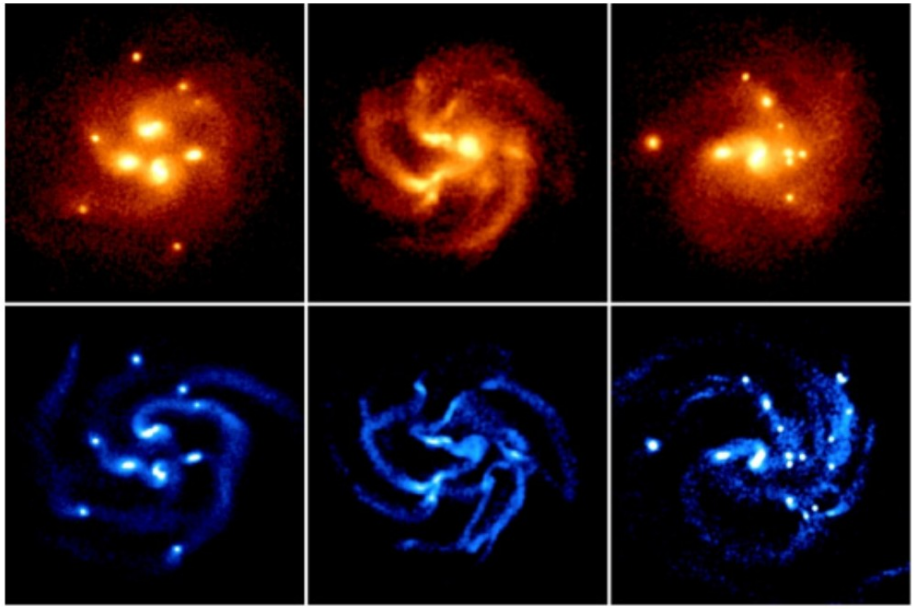
All samples have star-formation rate of ~100 $M_\odot{\rm yr}^{-1}$

Lindroos et al. in prep., Lindroos 2014 (lic. thesis)

1 arcsec ~ 8 kpc

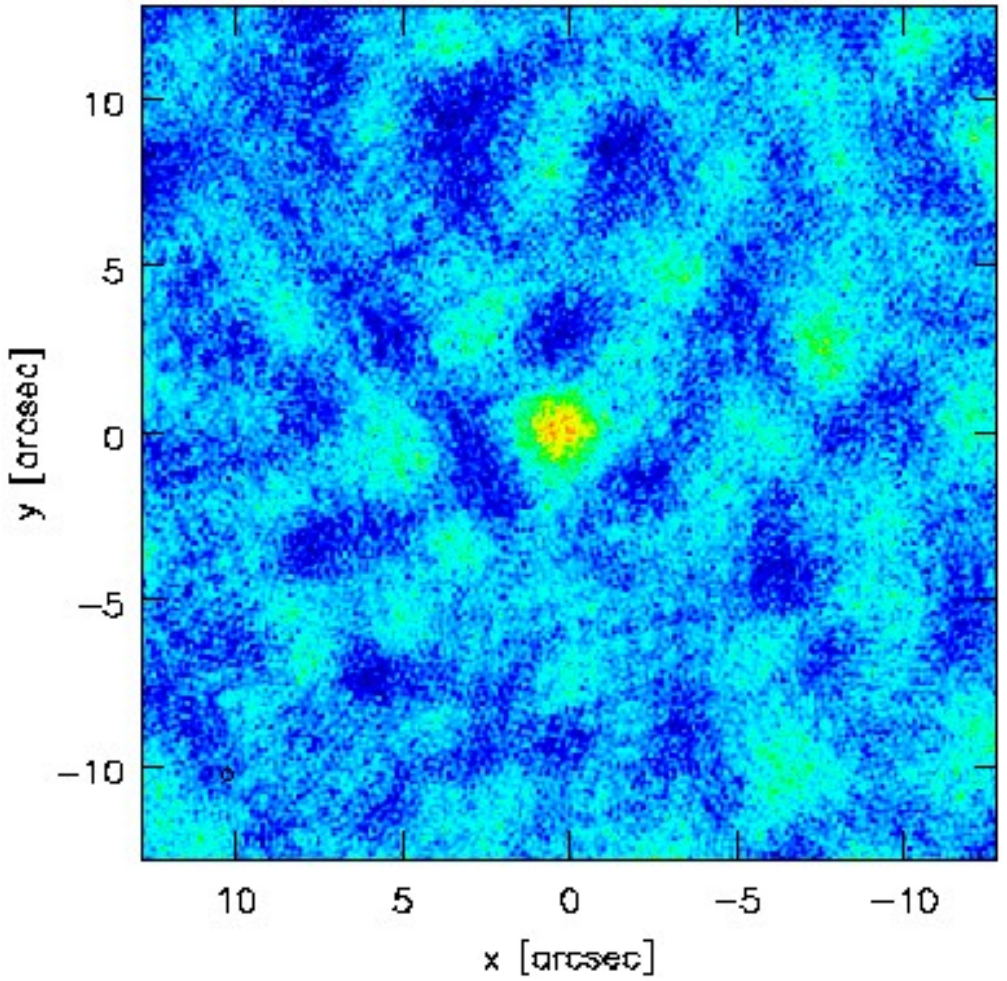


blue=435, green=775, and red=850 μm
Daddi et al. (2010)



Simulations of high-redshift galaxies
Daddi et al. (2010)

Stacking galaxies in MERLIN+VLA survey of HDF-N

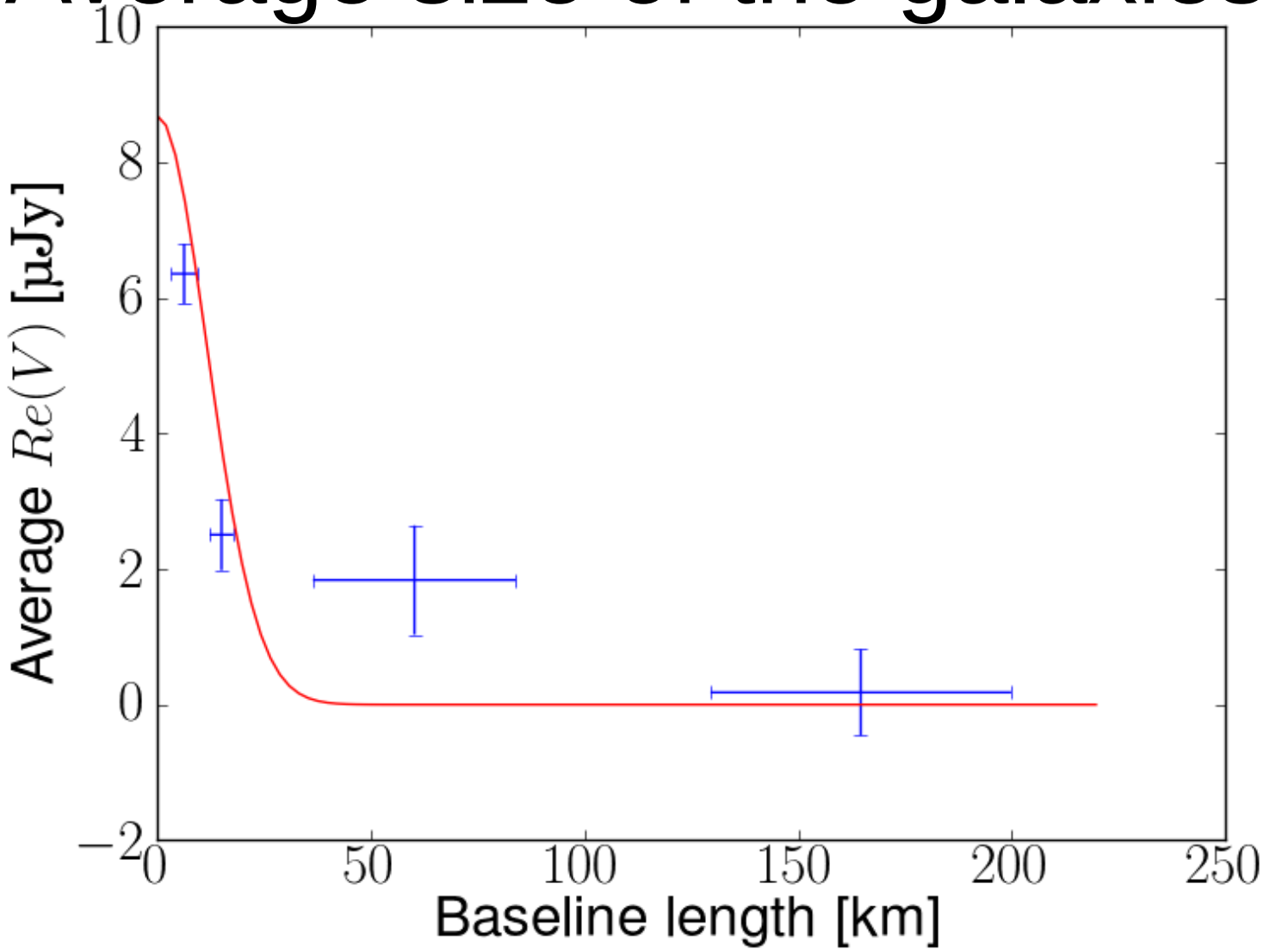


- Frequency: 1.4GHz
- Galaxies taken from Barger et al. 2008
- Compilation of UV-selected galaxies with spectroscopic follow-up
- Data:

  Wrigley, N., Beswick, R.
- Stack:

  Lindroos et al in prep.

Average size of the galaxies



Flux 8.7 μJy, Size ~ 1.4", Lindroos et al in prep.

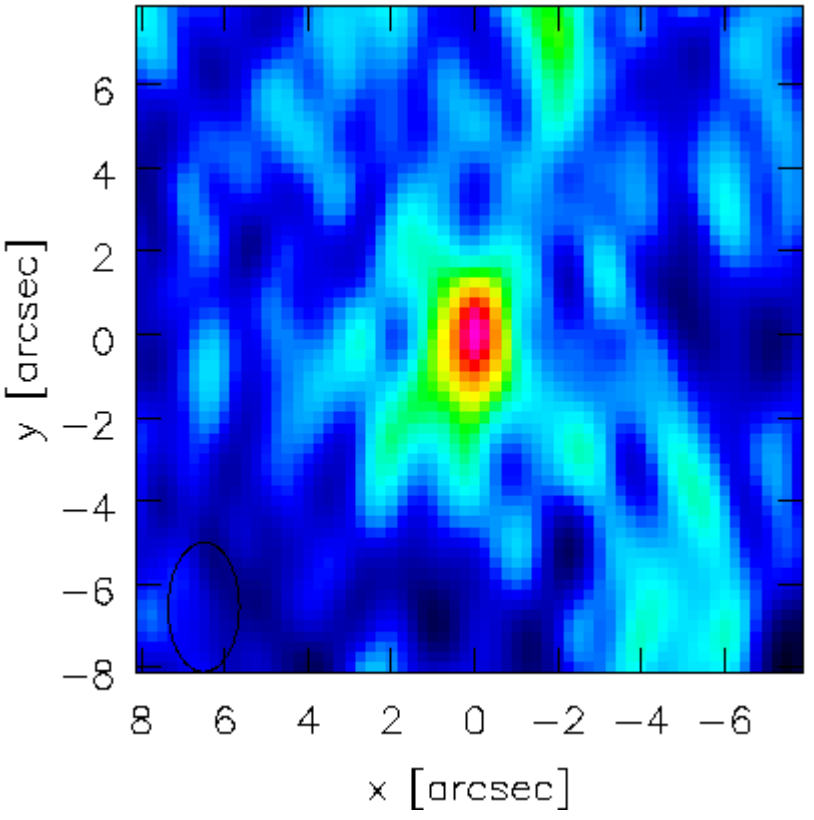
Conclusions

- Our *uv*-stacking algorithm is a powerful method to stack interferometric data.
  - The *uv*-stacking often provides more robust results than image-stacking, and never worse
  - Combinations of multiple pointings
  - The *uv*-stacking allows for full *uv*-data after stacking to find problematic baselines and *uv*-model fitting of stacked sources.
- The stacking tools is available for general use through the nordic ARC node (nordic-alma.se)

- A significant fraction of galaxies observed with ALMA at z~1-3 will be extended (~1")
  - Comparable to the near infrared sizes
  - Must be considered when designing future ALMA surveys

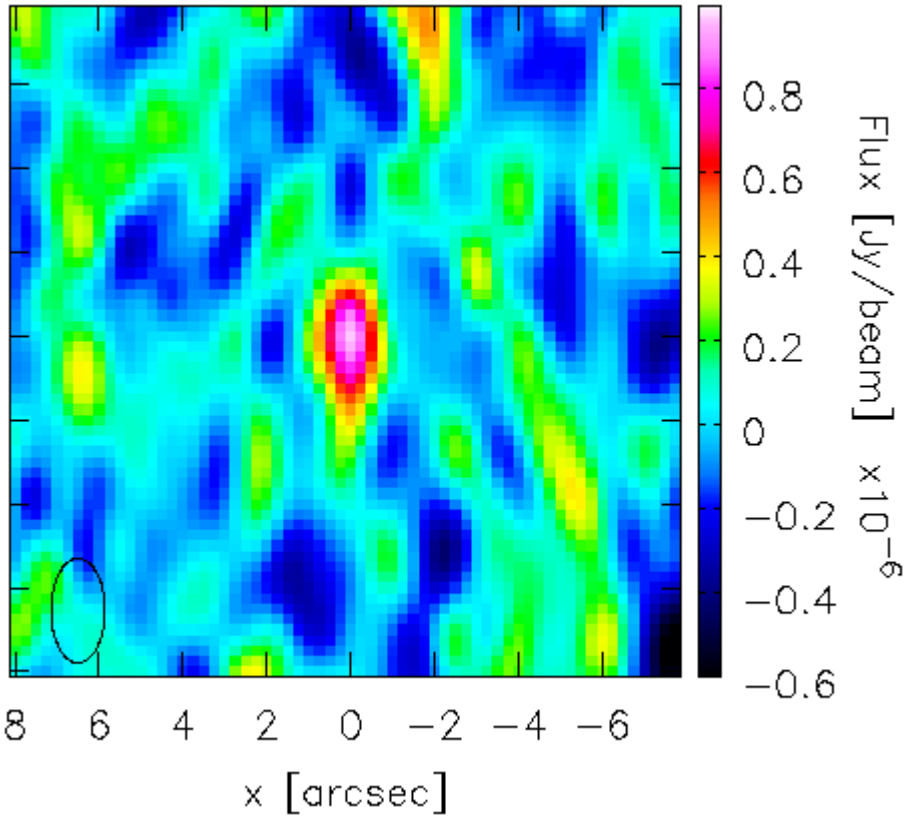
How do the methods compare? Simulated data

image-stacking



Flux ~ 0.75 μJy, σ ~ 0.18 μJy

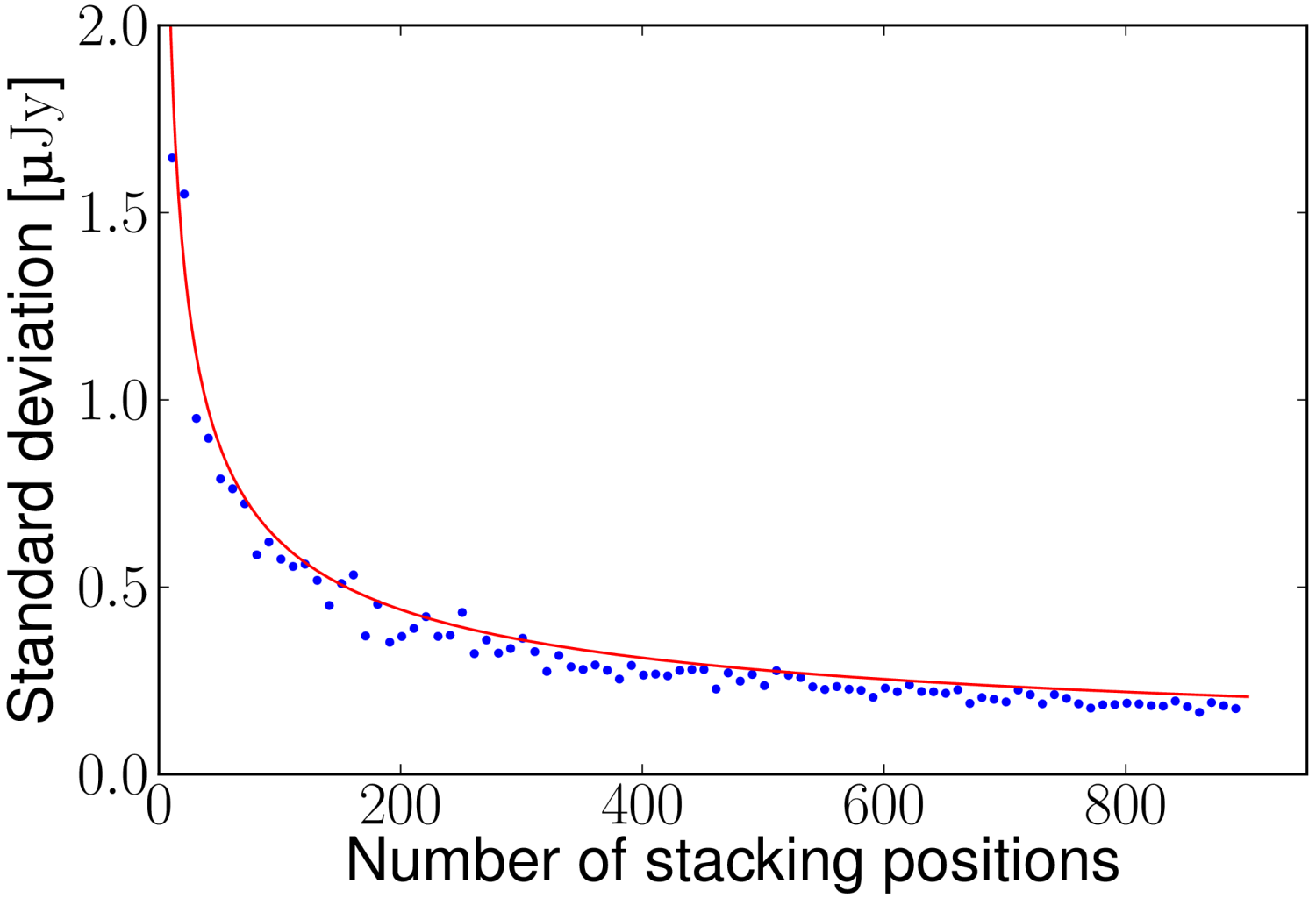
uv-stacking



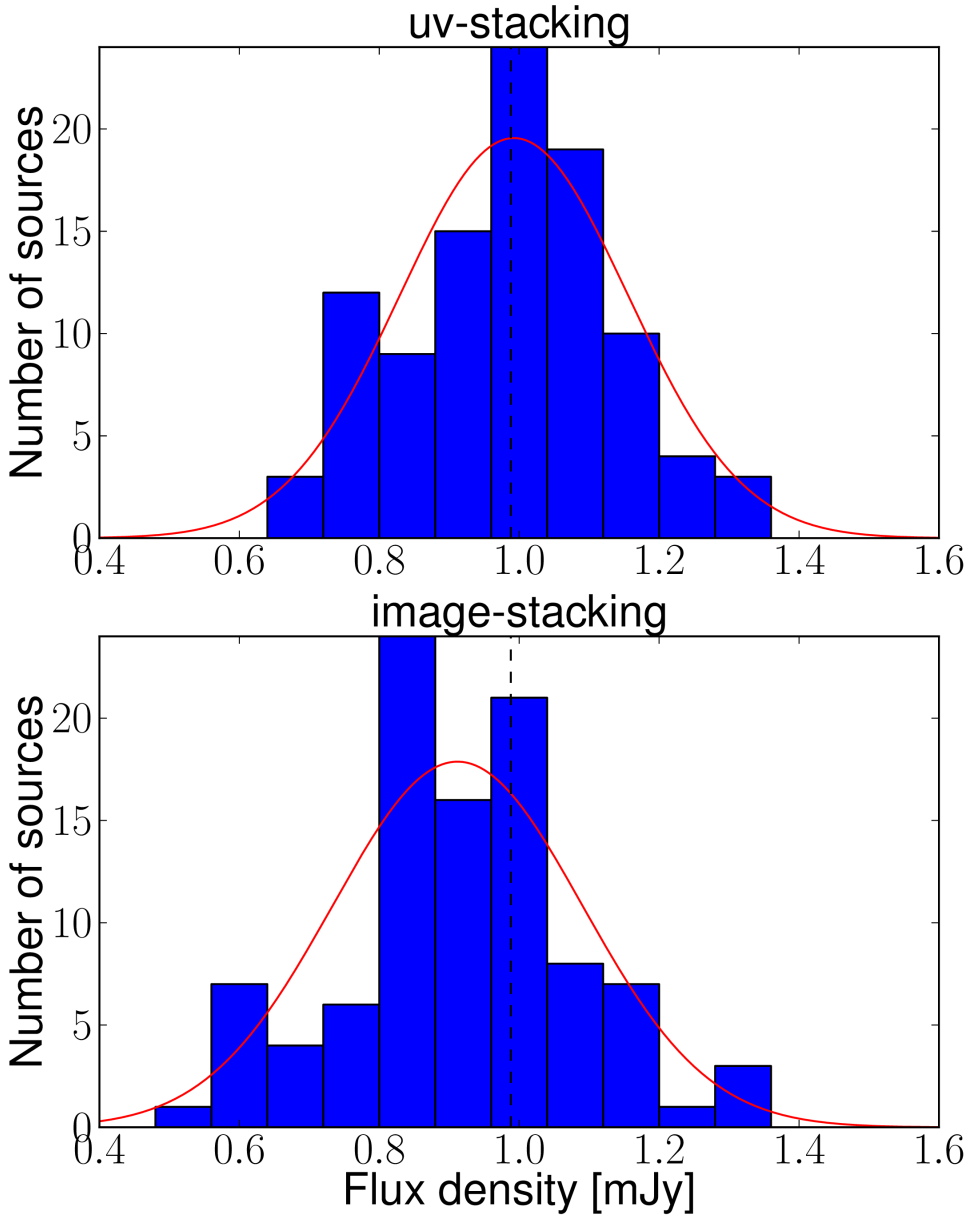
Flux ~ 0.96 μJy, σ ~ 0.15 μJy

Significant negative offset!

Noise vs stacking positions



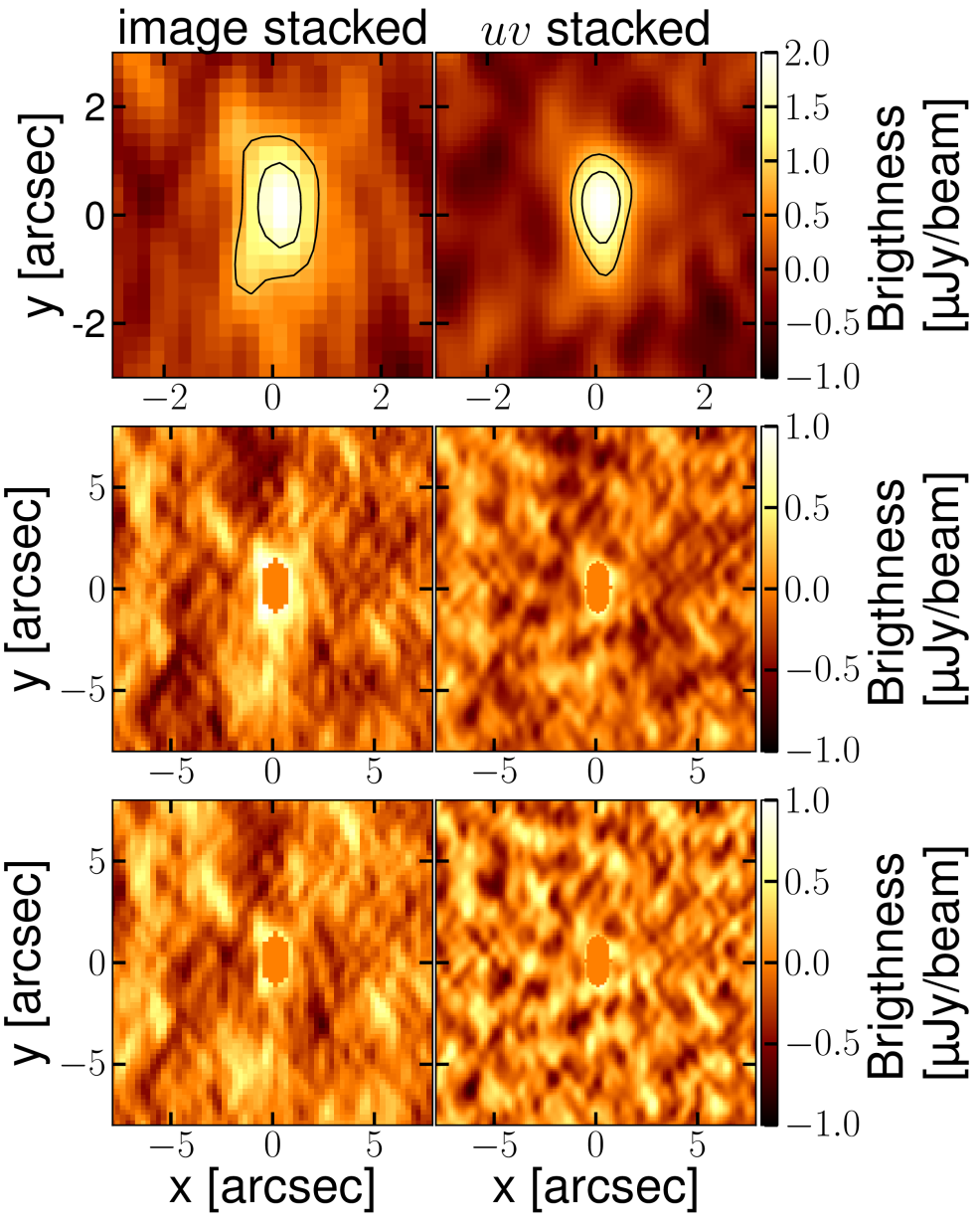
Stacked flux dist. in simulation



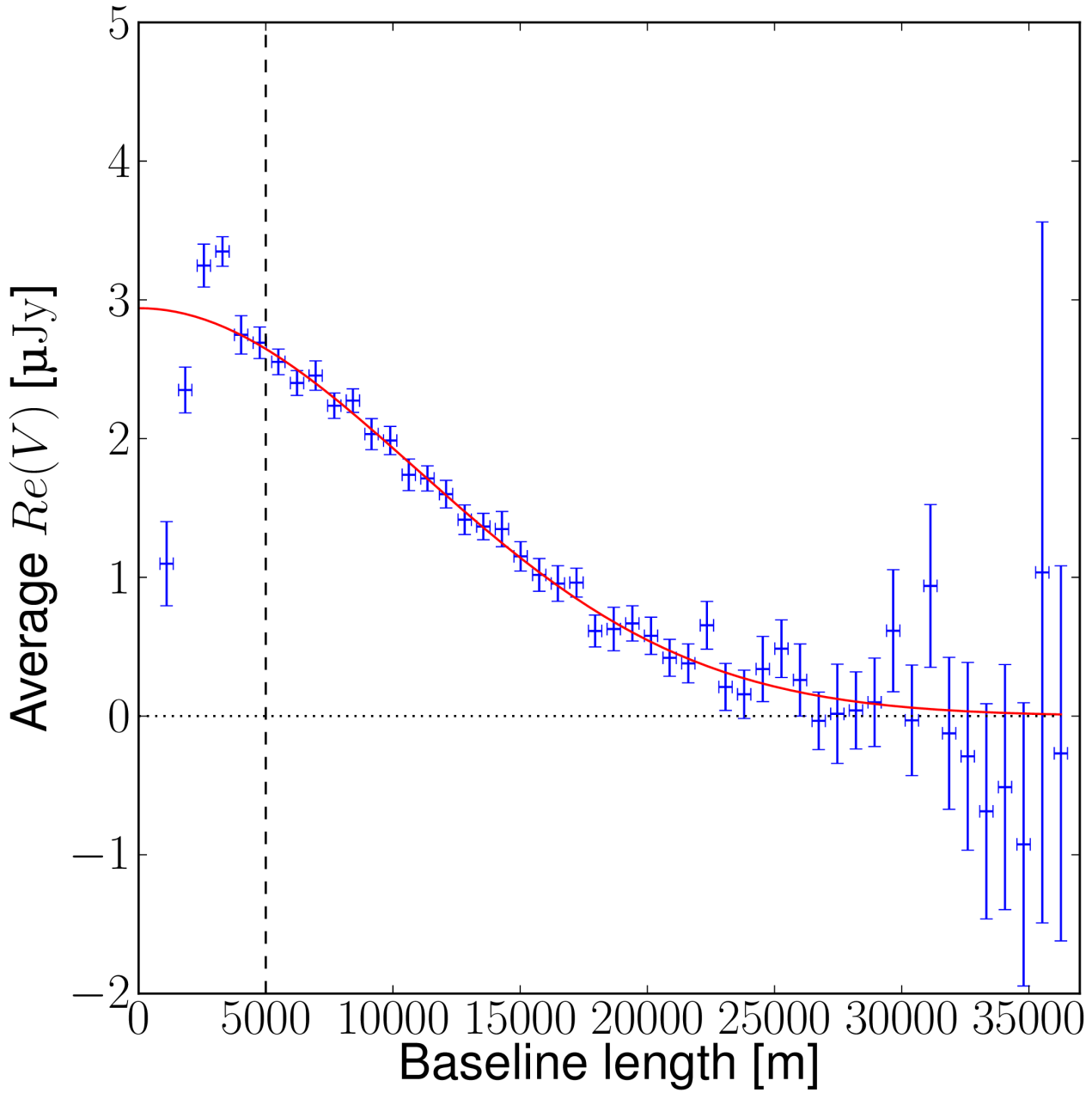
Simulated stacked stamps

Mask over centre of source

Short baselines removed from uv-plane



Simulated data



Fitted size of simulated sources