MCMC Source Detection

Peter Hague

University of Cambridge

prh44@cam.ac.uk

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Background

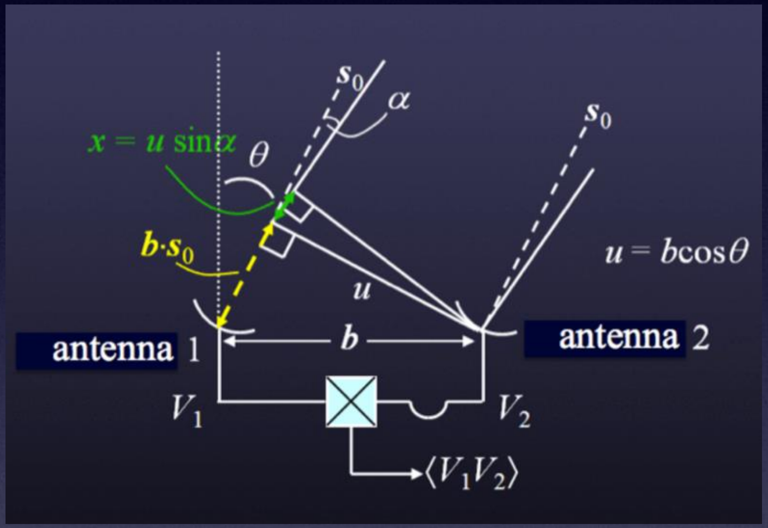
From the SExtractor manual:

DETECT_TYPE	CCD	*keyword*	Type of device that produced the image:
		CCD	– linear detector like CCDs or NICMOS,
		PHOTO	– photographic scan.

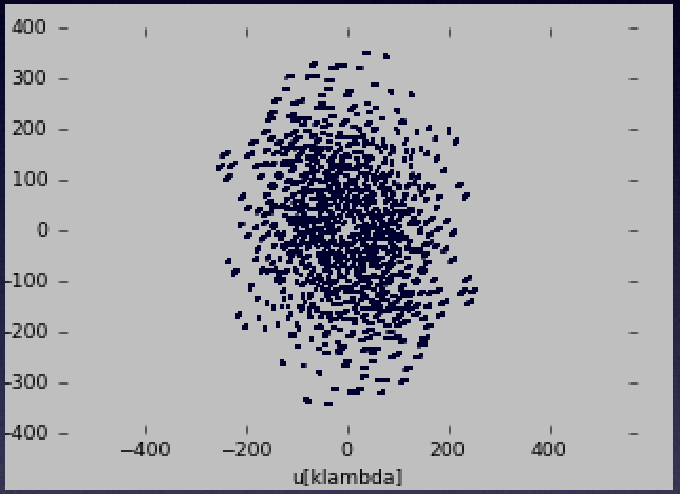
https://www.astromatic.net/pubsvn/software/sextractor/trunk/doc/sextractor.pdf

Background

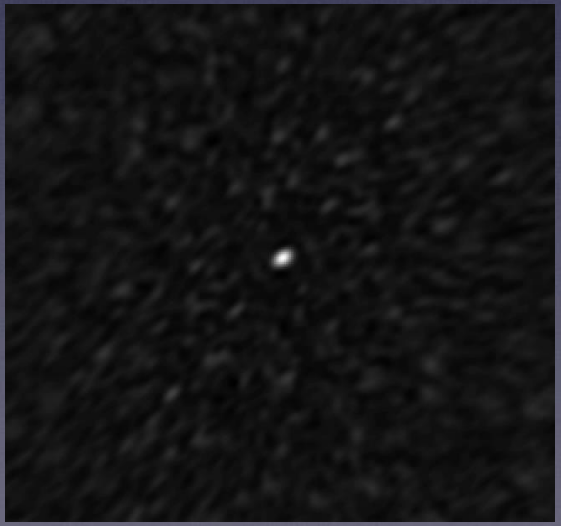
Each pair of antennas gives a component of the Fourier transform of the sky brightness



Use many antennas to get good coverage…



And invert it to get a map of the sky



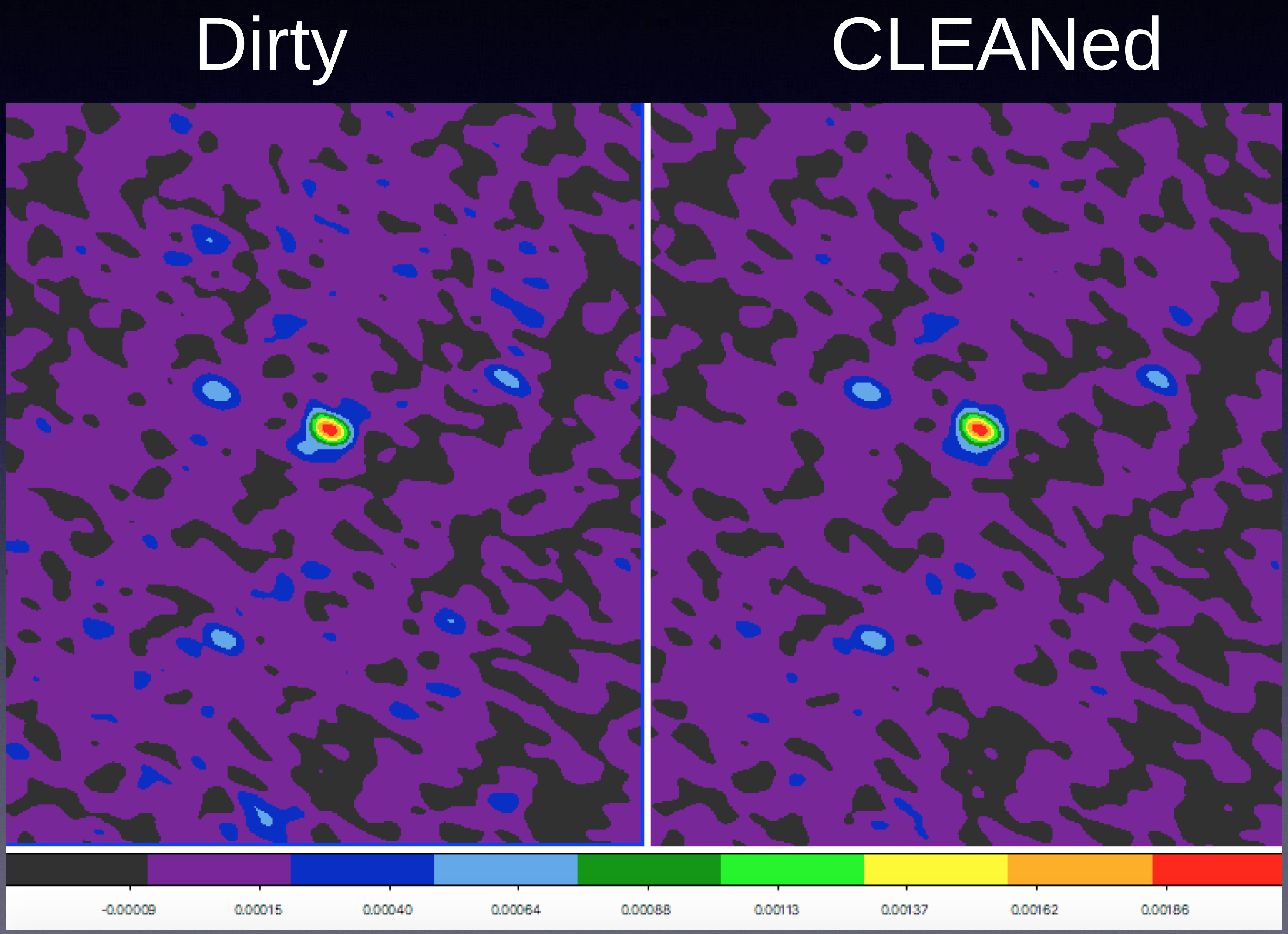
Background

- Need to use CLEAN to get interferometry maps to looks like optical images *before* application of SExtractor

- The construction of the CLEAN algorithm is based on aesthetics - does not have a strong mathematical foundation

- Ultimately human researcher needs an optical like visualisation - an algorithm does not

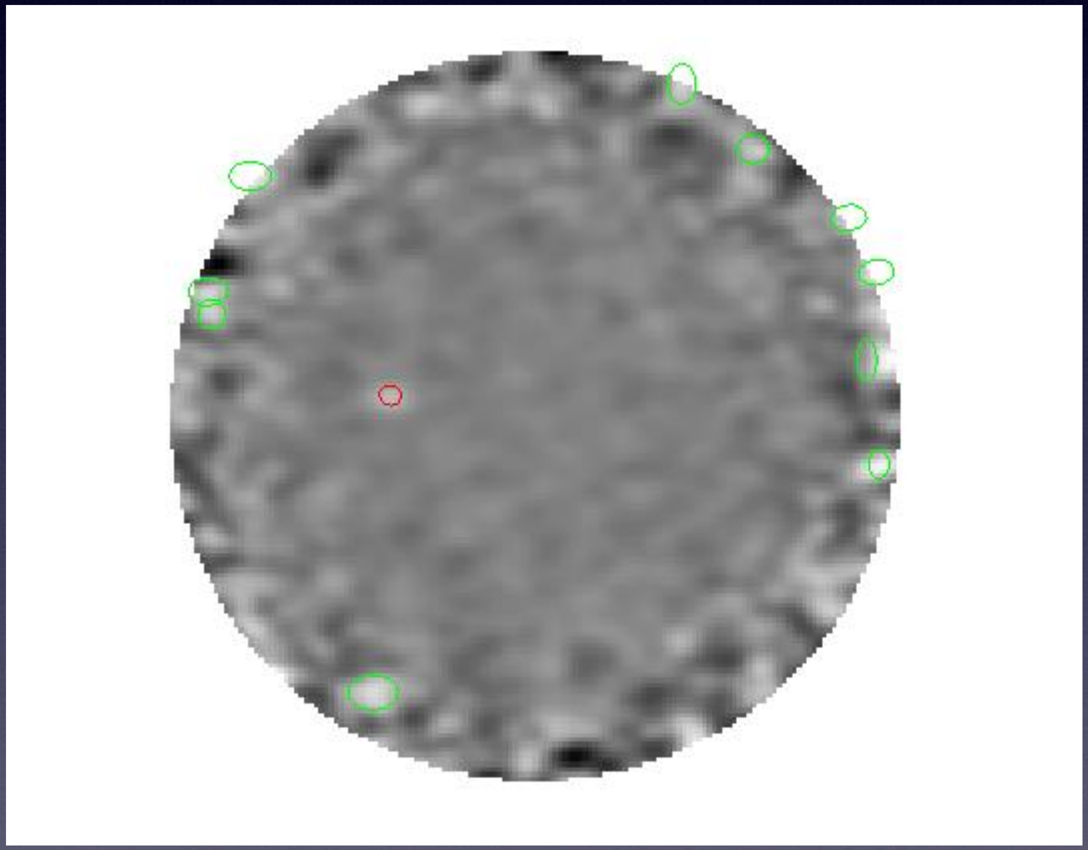
Background



Data from project 2013.1.00911.S, PI Dragan Salak

Background

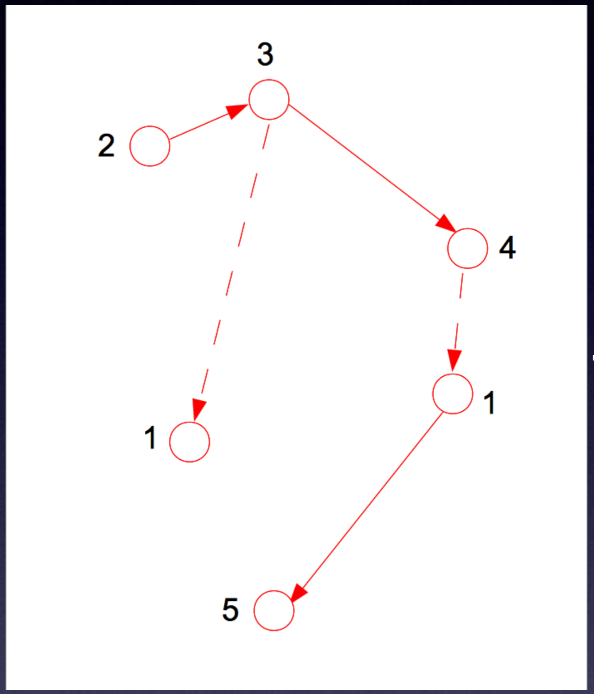
Primary Beam Correction



Correct fluxes or consistent noise – pick one

MCMC Method

- Starting from a random point **x** in a parameter space, pick a new point **x’** to jump, picked from Gaussian



$\longrightarrow$ P(D|M[**x**])

- If model M(**x’**) has better likelihood *L* than model M(**x**), always accept it, otherwise accept it with probability equal to ratio between the likelihoods

- Apply a prior and Bayes’ theorem to get a non normalised posterior distribution

$$\int_V P(M[\mathbf{x}]|D)dV \propto \int_V P(D|M[\mathbf{x}])\, P(M[\mathbf{x}])dV$$

MCMC Method

- Using **BayeSys** - MCMC software that allows multiple ‘atoms’ in the same parameter space with shared likelihood value

- Likelihood derived from

$$\chi^2 = \sum_k \frac{|V_k|^2}{\sigma_k^2} - \frac{1}{\sigma^2}\left(2\mathrm{D}^T \cdot \boldsymbol{F} - \boldsymbol{F}^T \cdot \mathrm{B} \cdot \boldsymbol{F}\right)$$

***D** is the map*
***B** is the beam*
***F** is the source flux*
σ is the map noise

- This computes the likelihood for *k* atoms. The number of atoms is controlled by BayeSys

MCMC Method

- In a map of point sources, as number of atoms increases, this likelihood calculation converges on the equivalent calculation with visibilities
- But $N_{visibilities}^2$ is much larger than $N_{sources}^2$
- This makes sense given how sources drive the likelihood

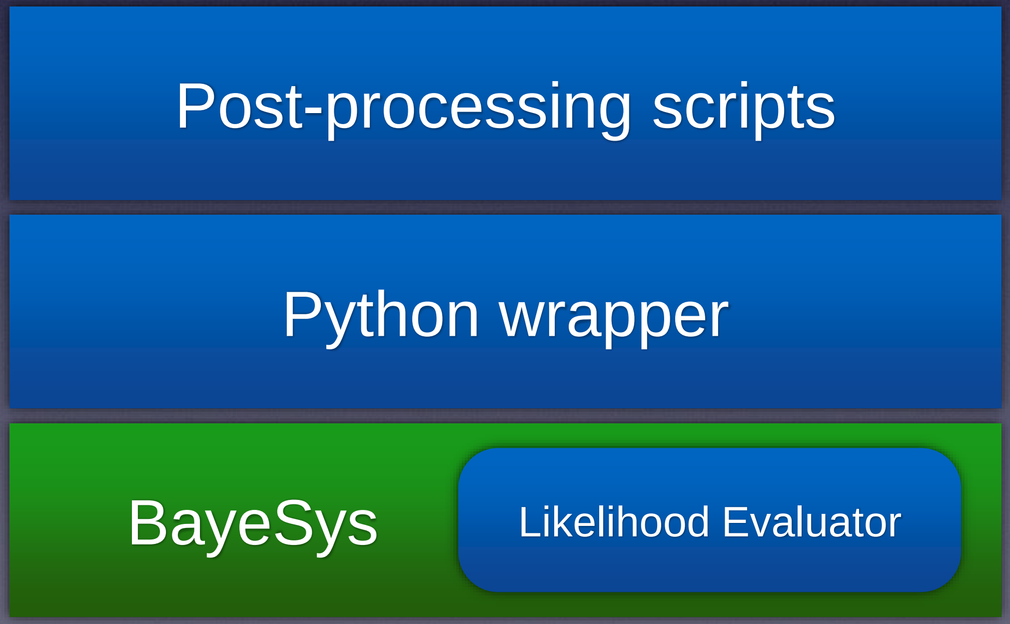
MCMC Method

- We can have flat priors on sky position
- Need an exponential prior for the flux **F** of each atom – derived from map noise
- Raw parameters flat in range {0,1}, so

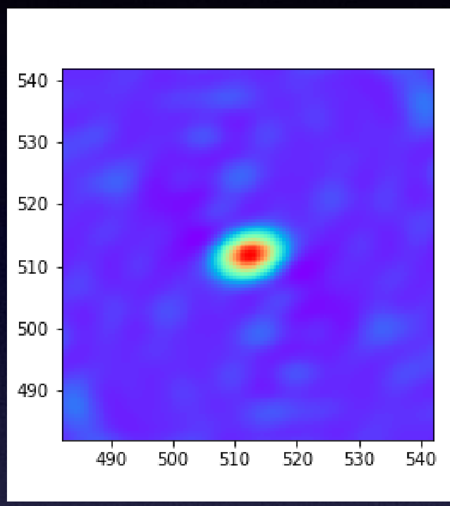
$\mathbf{F=F_0p/(1-p)}$ (where F_0 is map derived flux scale)

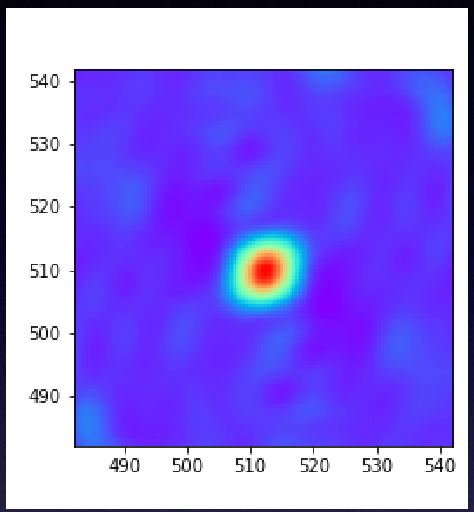
Software

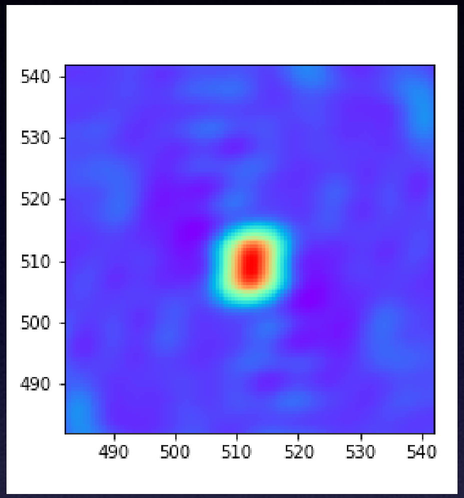
- Builds on existing MCMC work at Cambridge (BayeSys)
- Written in C/C++, Python 2/3 interface
- Available for download now
- Still experimental (although it does work)

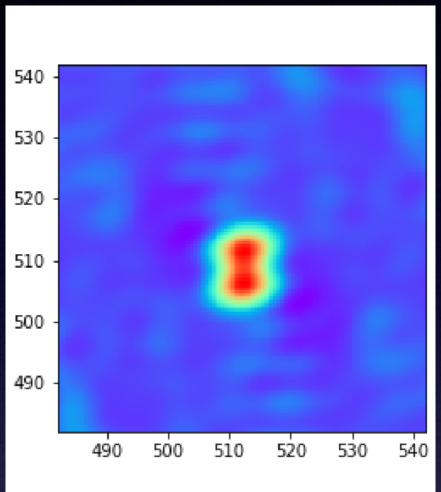


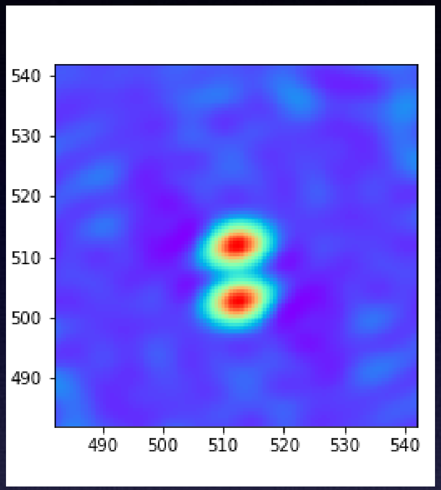
Resolving points









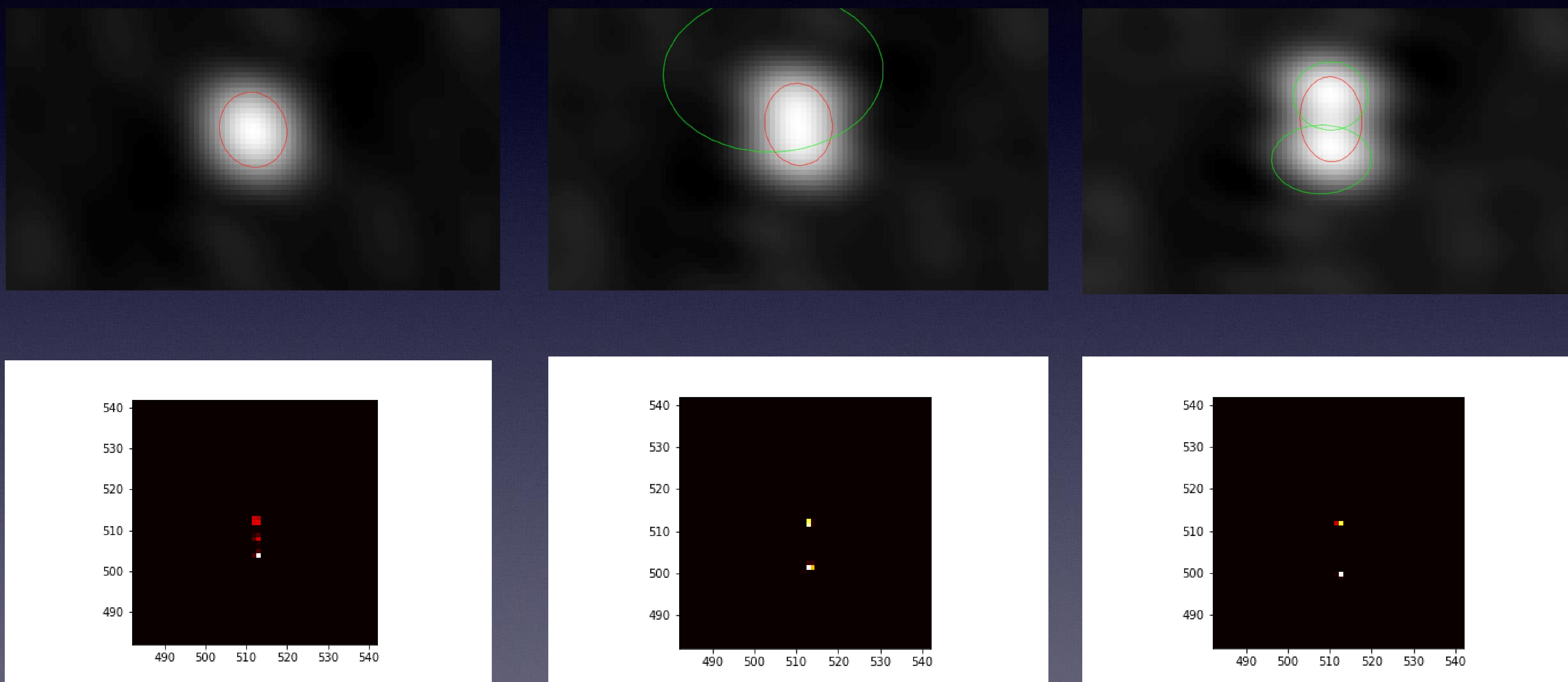


Use ALMA simulation software in CASA to create maps of two points at separations of 0-9 cells.

Used a realistic PSF from an ALMA archive observation

Resolving points

SExtractor ellipses in red, Aegean in green

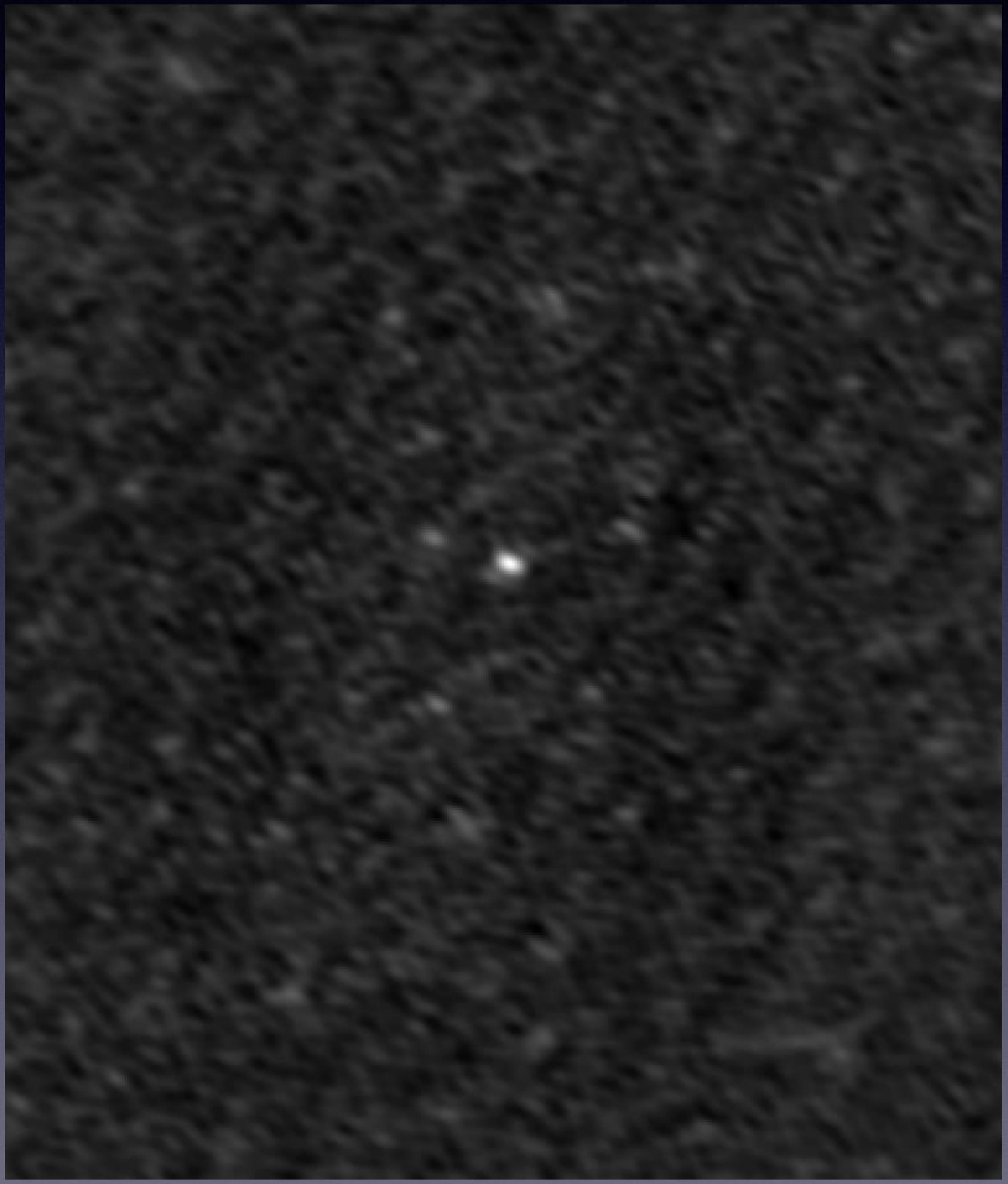


NGC 1808

- A complex target - the centre of NGC1808

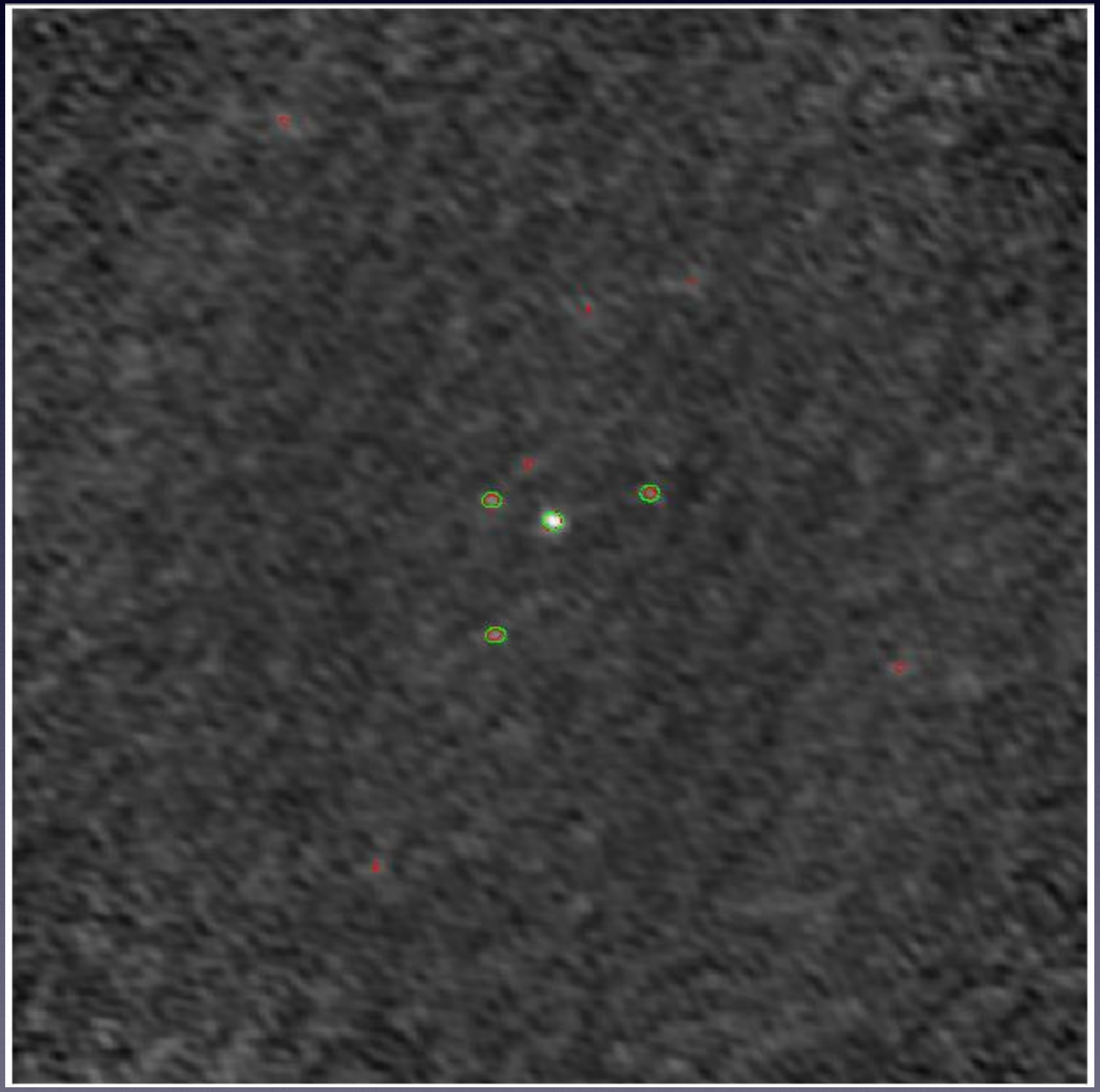
- Starburst galaxy imaged in project 2013.1.00911.S (Molecular gas conditions and shocks, PI Dragan Salak)

- 0.87mm continuum map shown



NGC 1808

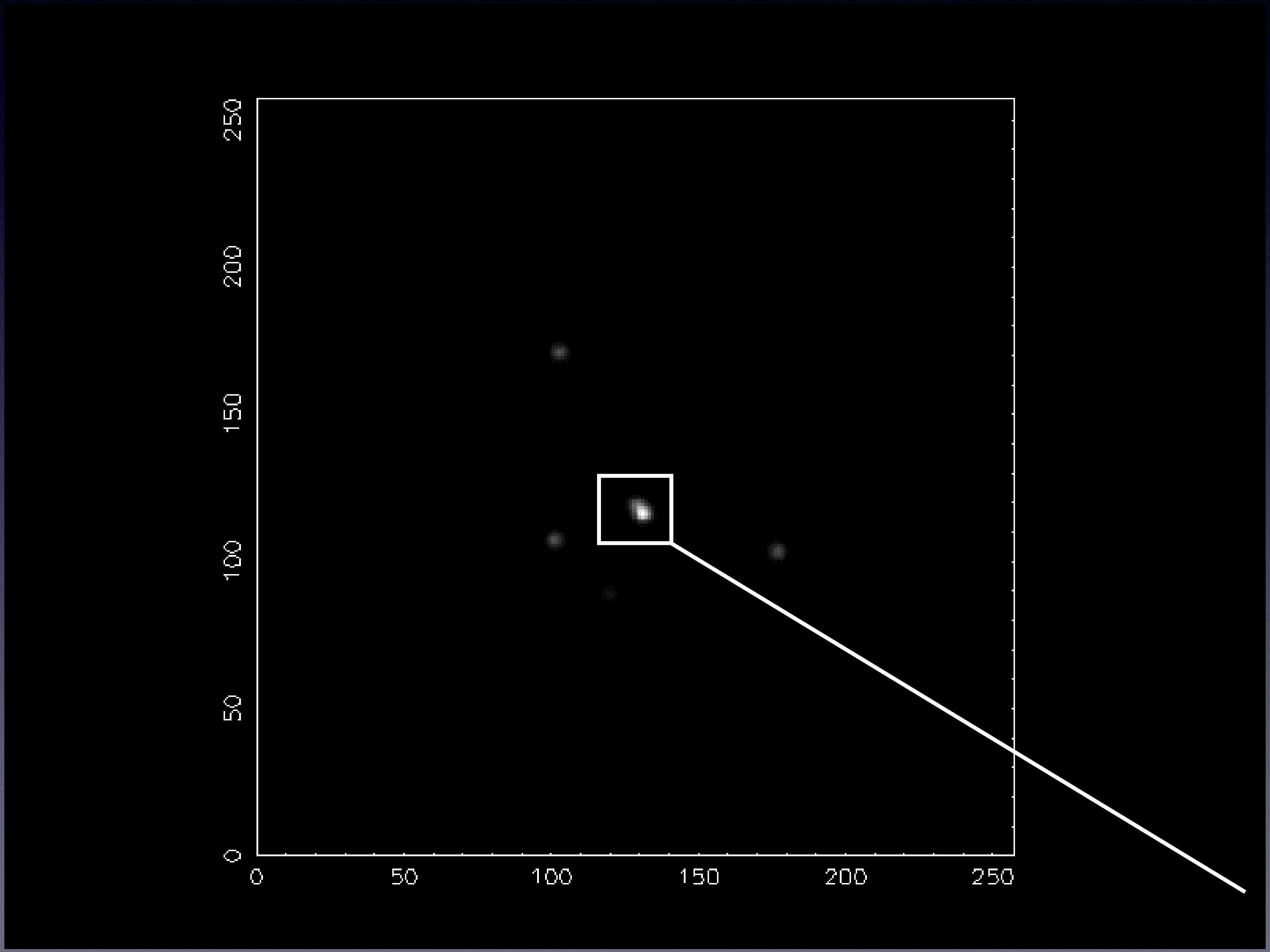
SExtractor ellipses in red, Aegean in green



Traditional algorithms identify sources correctly in most cases here

But can they *characterize* them?

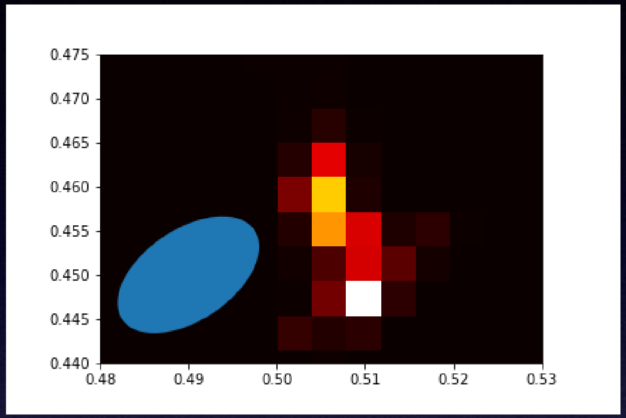
NGC 1808



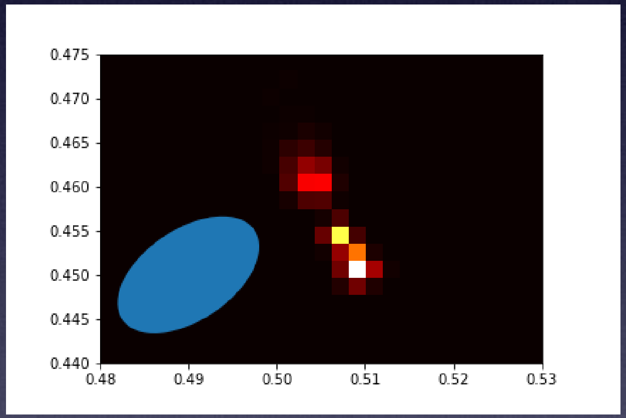
Posterior probability density of MCMC atoms weighted by flux

NB Central source is extended, not a Gaussian ellipse

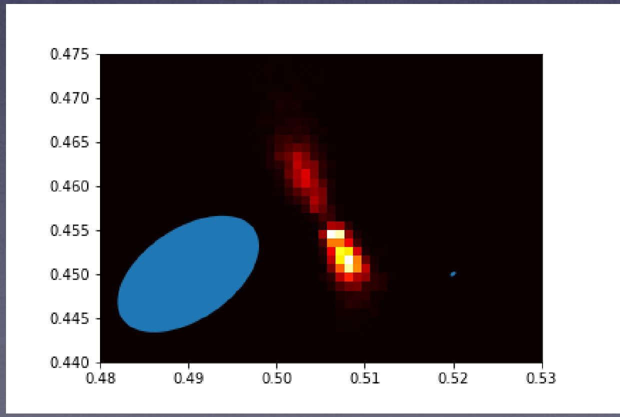
NGC 1808



512x512 grid, 0.1’ cell

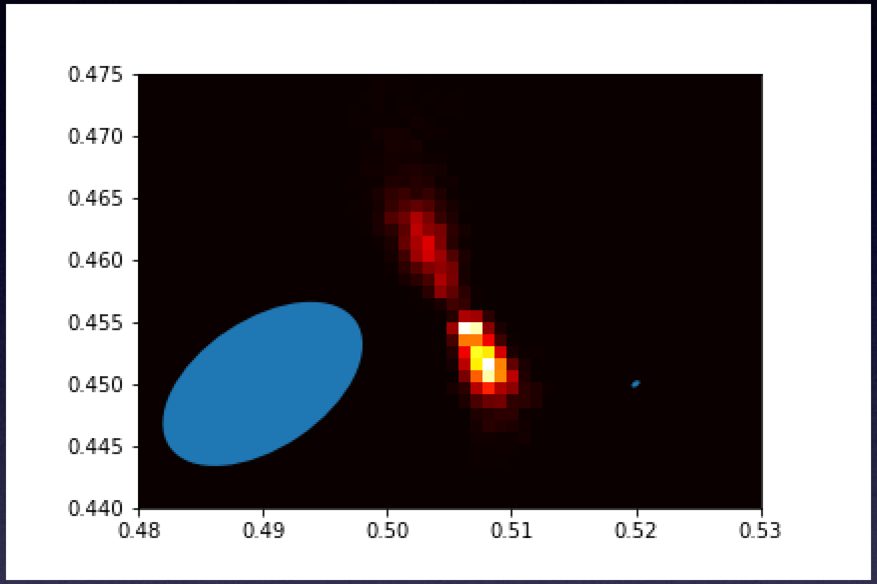


1024x1024 grid, 0.05’ cell



2048x2048 grid, 0.025’ cell

NGC 1808



Is this real?

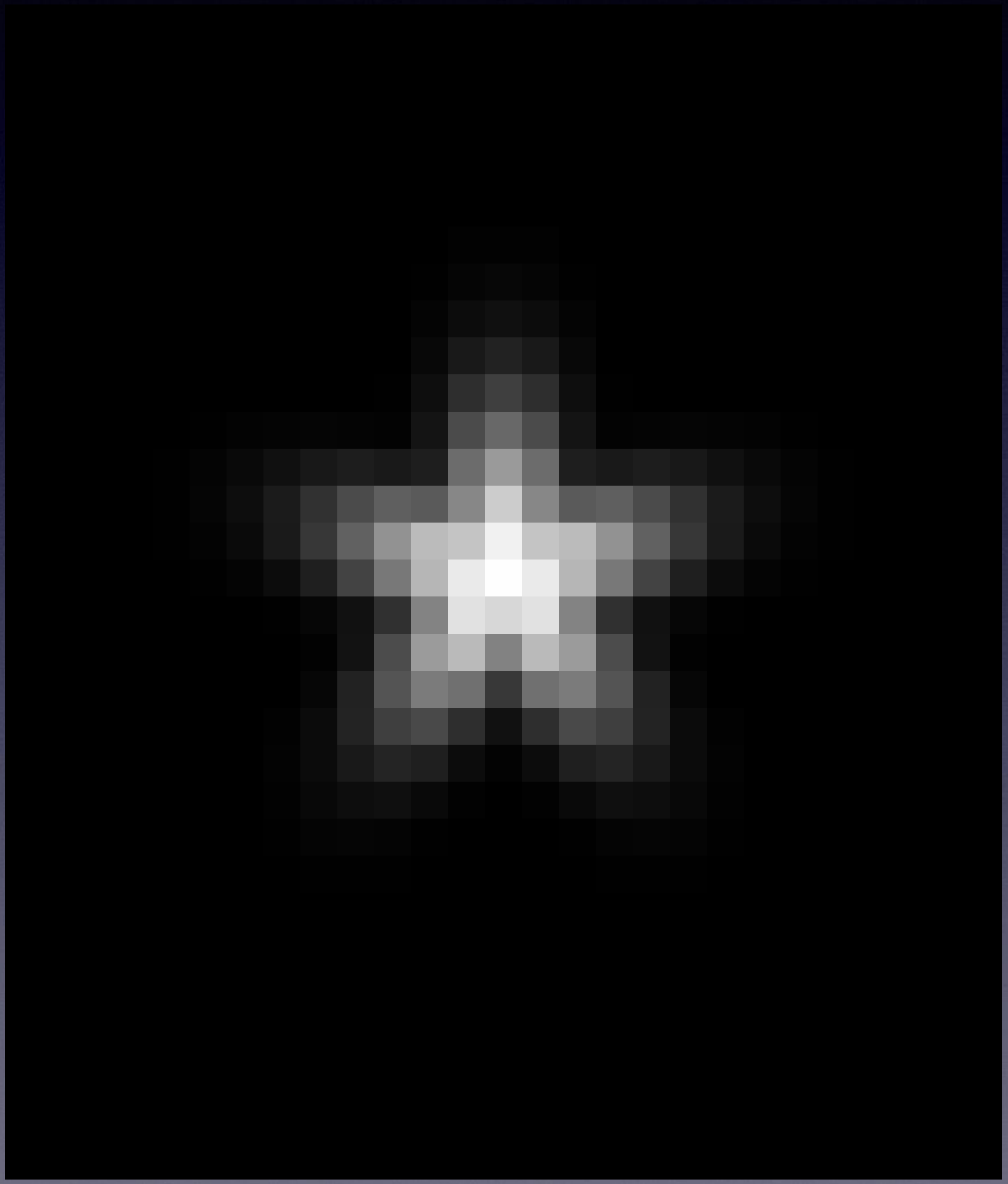
Pro: Increasing Bayesian evidence

Map	Grid Size	Cell Size "	Map noise (Jy/beam)	N_{atoms}	Evidence
A	512	0.1	8.18×10^{-5}	3.59 ± 1.42	170.695
B	1024	0.05	8.18×10^{-5}	3.16 ± 1.24	158.129
C	2048	0.025	8.17×10^{-5}	3.61 ± 1.37	75.757

-ve log evidence

Limiting Case

- This map still gives the algorithm trouble – number of atoms diverges
- Maximum entropy method does this better at present
- But, BayeSys is potentially faster



Continuing Work

- We are working to extend the method – catalogue matching and analysis of data cubes
- Bring me data!

https://bitbucket.org/PeterHague/basc

Acknowledgements

- BayeSys created by Steve Gull
- Maps provided by Haoyang Ye
- H2020-Astronomy ESFRI and Research Infrastructure Cluster (Grant Agreement number: 653477).

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