

Shapelets-based source reconstruction of spatially resolved, gravitationally lensed images

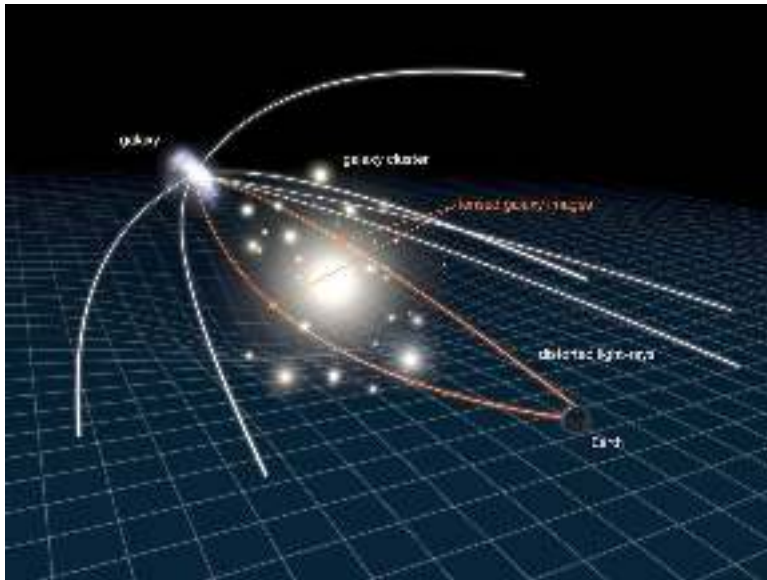


Image: NASA/ESA



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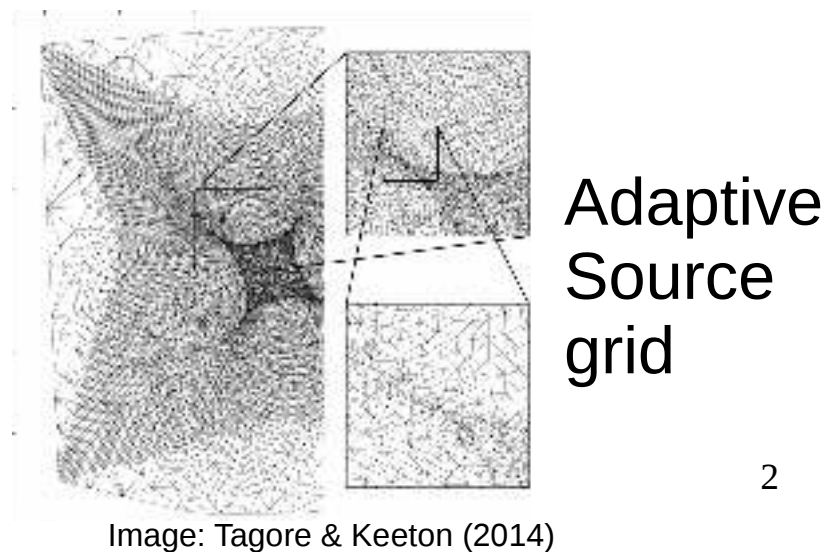
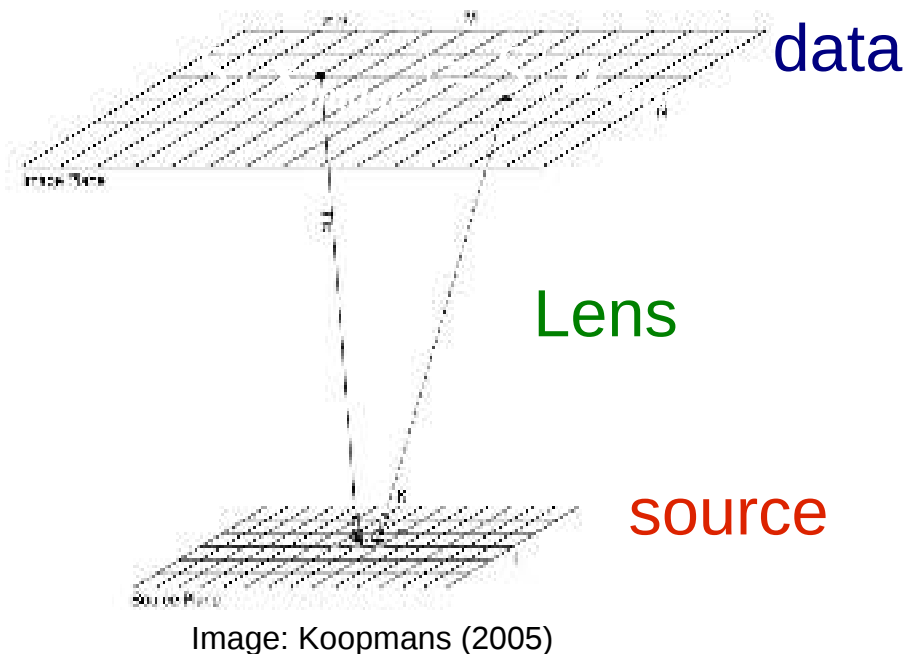
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Pixel-based source reconstruction

- Lensing conserves surface brightness
- Warren & Dye (2003) pioneer pixel-based source reconstruction (PBSR)
- $d = Ls + n$
- Two-loop analysis
 - Non-linearly vary the lens model parameters
 - Linearly solve for the source model
- Discretized and noisy

Other important contributions:

Wallington et al. (1996); Dye & Warren (2005);
Brewer & Lewis (2006); Suyu et al. (2006);
Vegetti & Koopmans (2009)

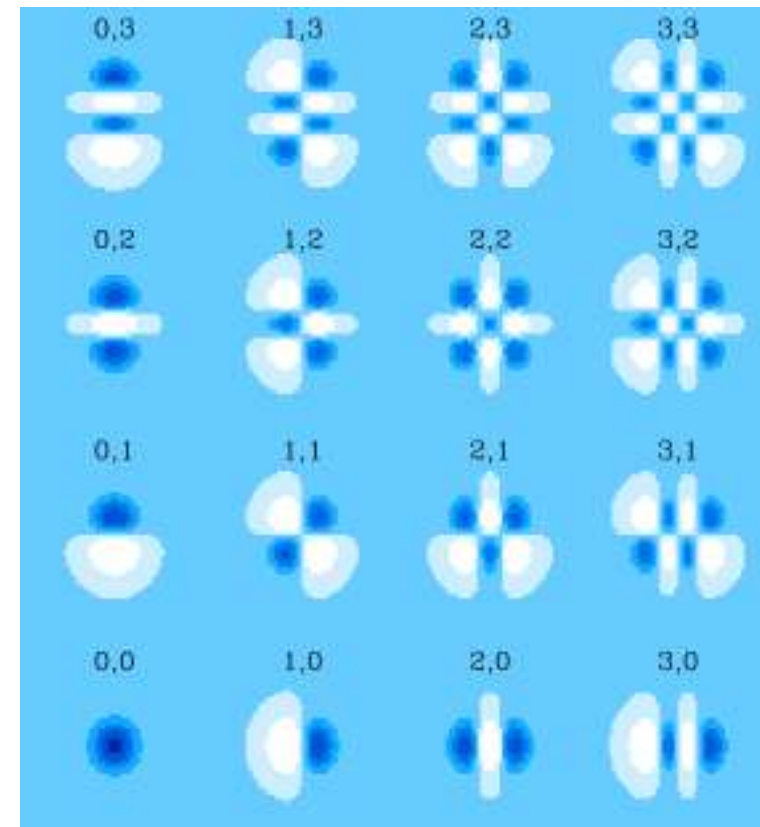
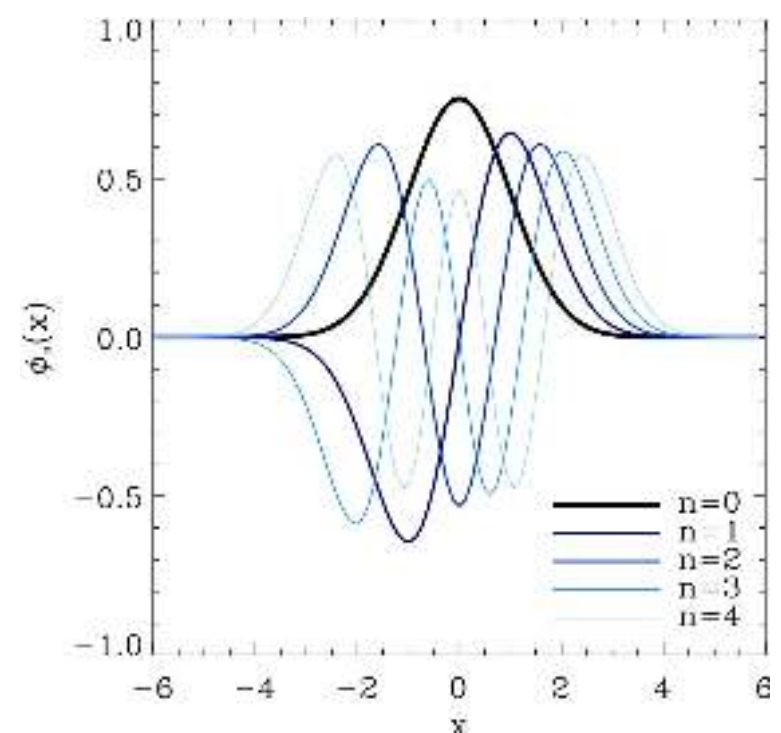


Science with PBSR methods

- Detect luminous and/or dark substructure.
Suyu & Halkola (2010); Czoske & Koopmans (2010);
Vegetti et al. (2010, 2012)
- Disentangle disk, bulge, and halo components of the lens.
Suyu et al. (2012)
- Explore the structure and morphology of the background source.
Sharon et al. (2012); Dye et al. (2013); Rybak et al. (2015)
- Explore uncertainties in modelling approaches.
Tagore & Keeton (2014); Nightingale & Dye (2015)

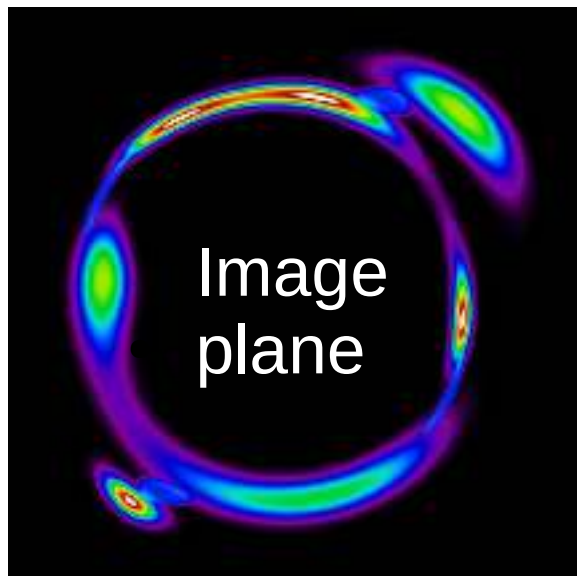
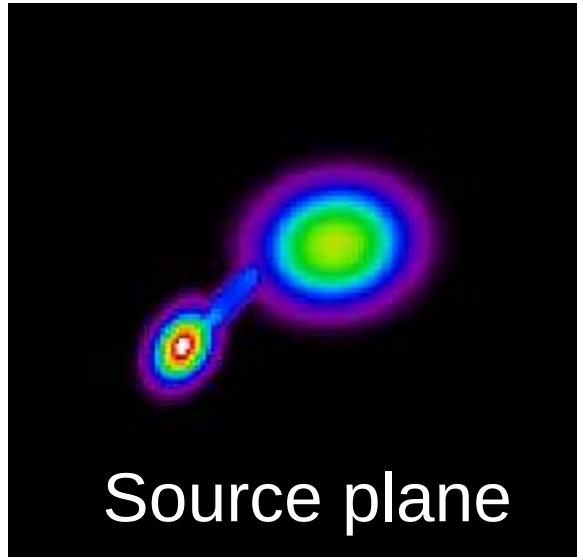
Shapelets

- Complete and orthonormal set of functions.
- Analytic expression for source's brightness.
- Relatively few shapelets needed.
- Invariant under Fourier transform.



Images: Refregier (2003)

Methodology



- Split image plane into triangles.
- Ray-trace triangles to source plane.
- Integrate shapelets over the source plane triangles.
- Use data and priors in a Bayesian framework to constrain source model.

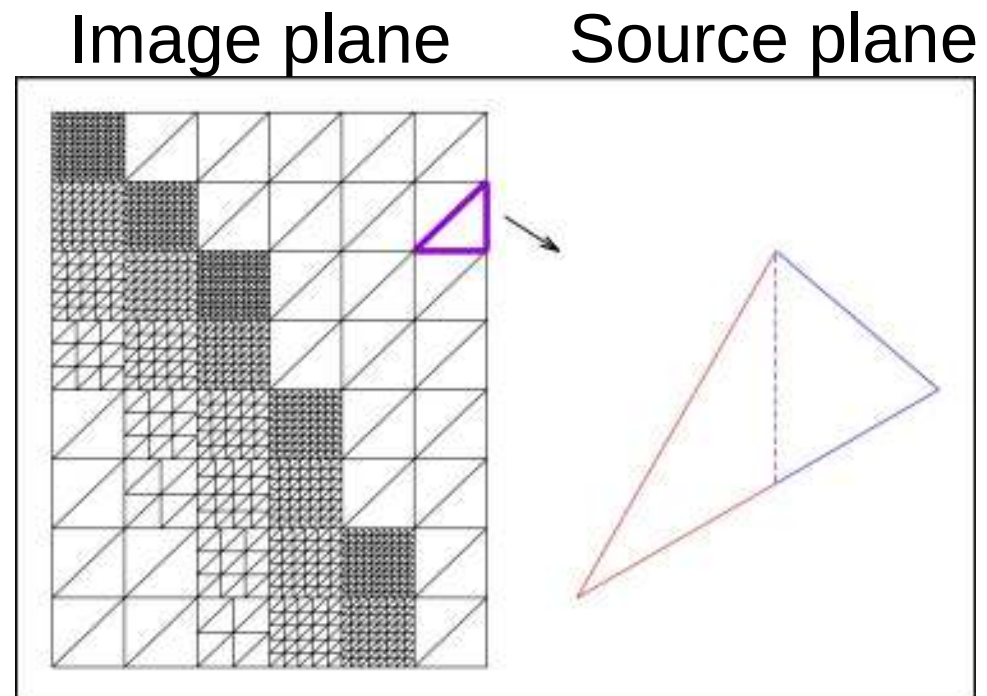
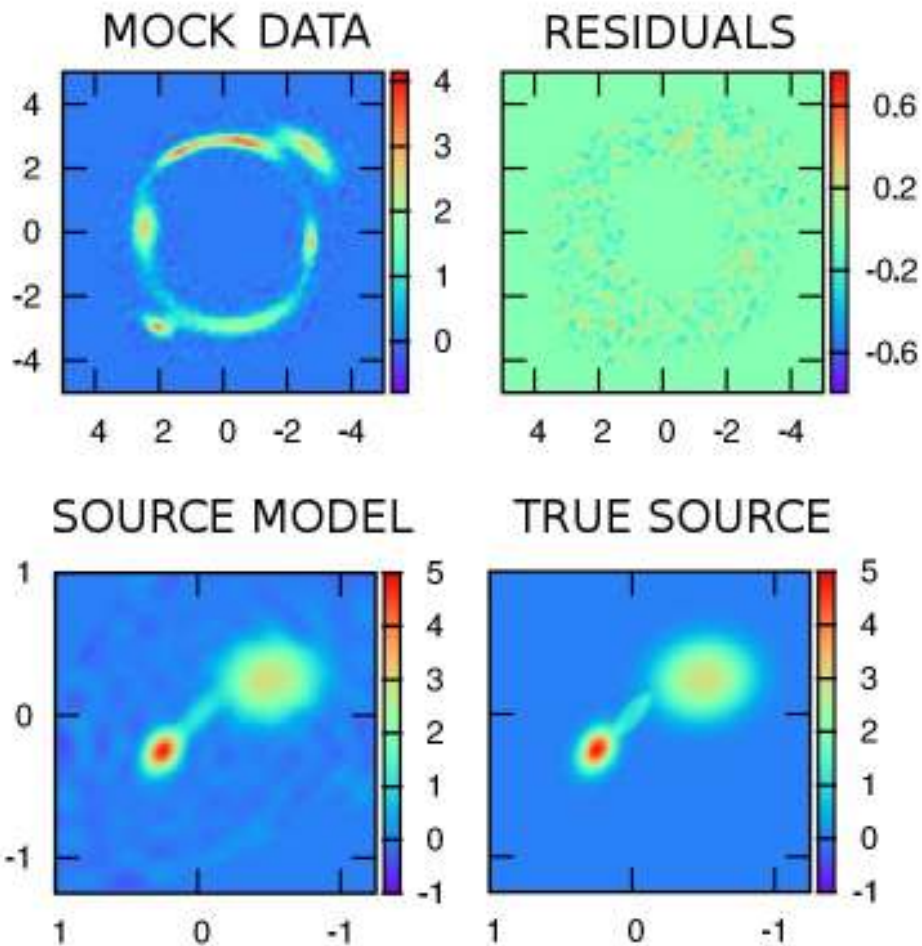


Image: Tagore & Jackson (2015, submitted)

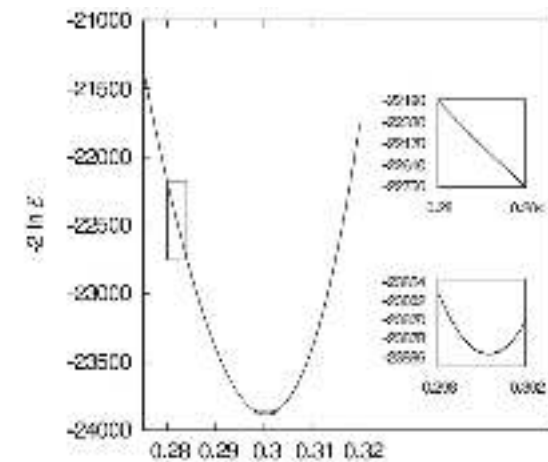
Applications – 1/2

Mock data modelling

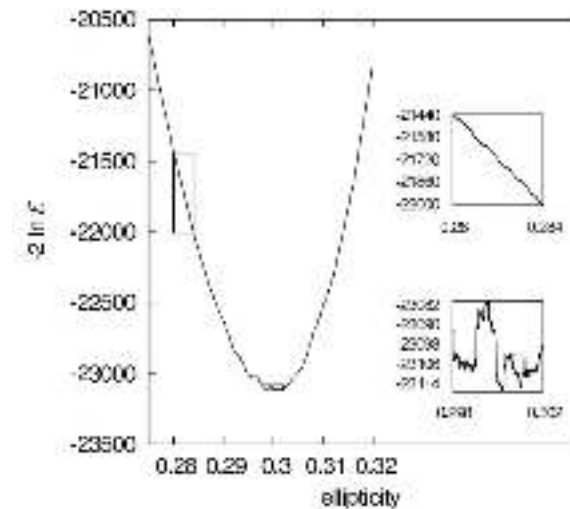


Error estimation

Shapelets-based

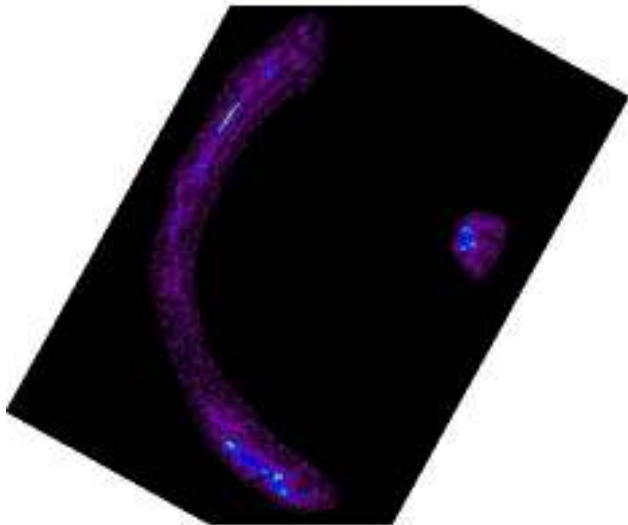


Pixel-based

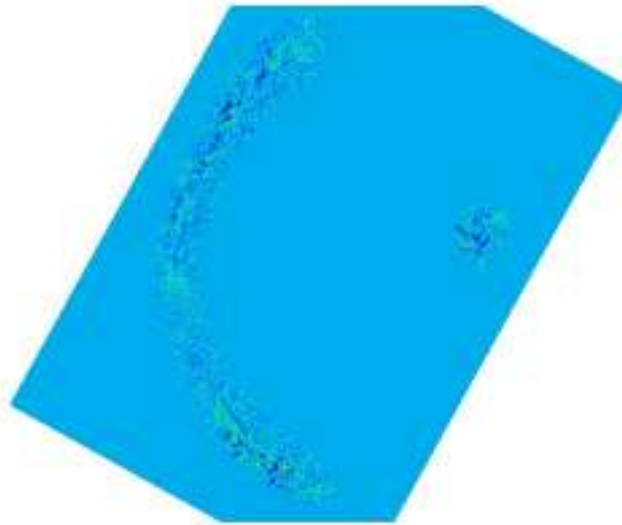


Applications – 2/2

DATA



RESIDUALS



SOURCE MODEL

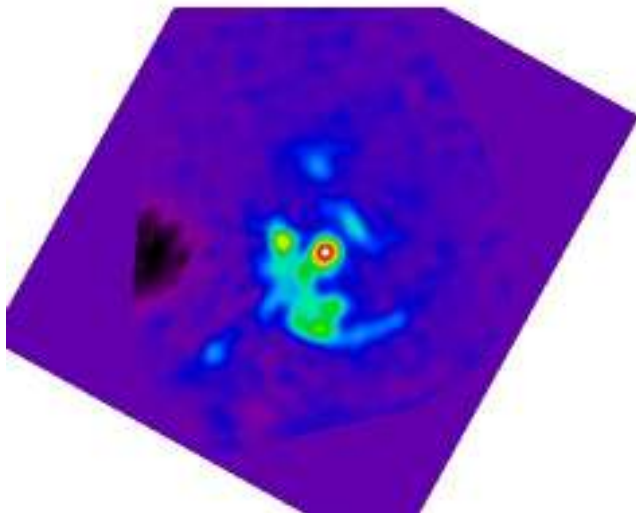
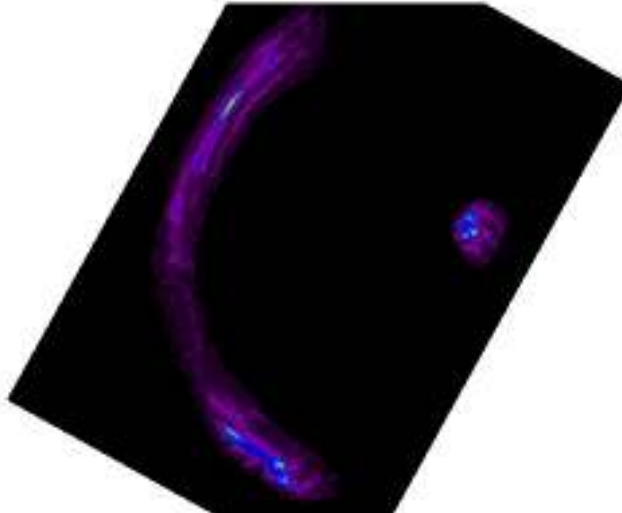


IMAGE MODEL



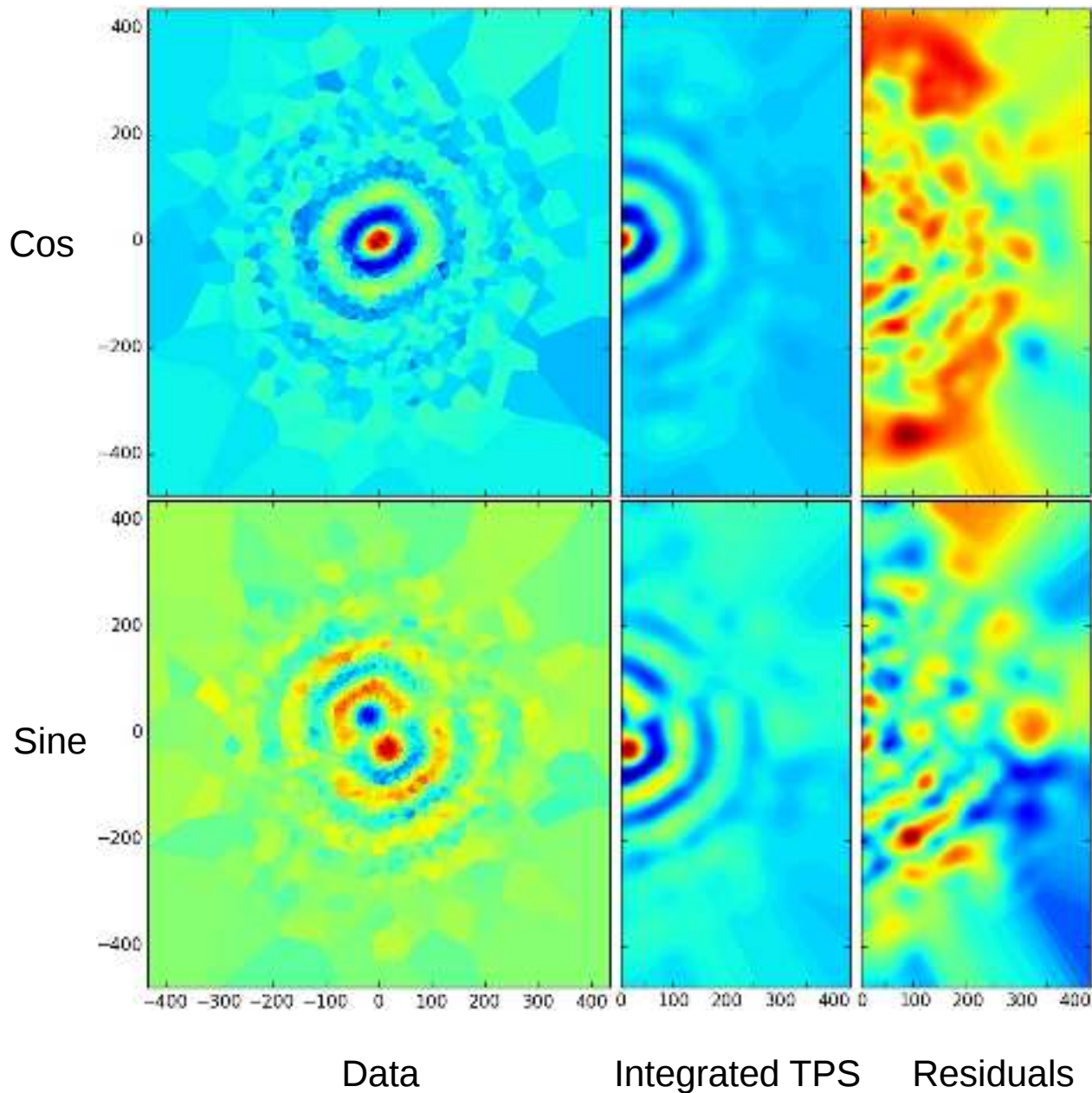
Preliminary source reconstruction of a lensed, $z=2.26$ starburst galaxy.

Sharon et al.
(2015, in prep.)

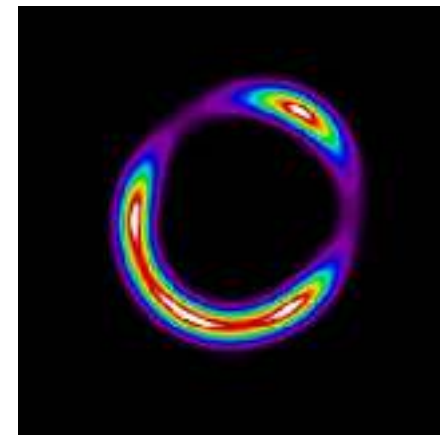
Modelling in the uv plane

- General steps
 - Lens source into image plane.
 - Perform shapelet decomposition of image plane.
 - Fourier transform shapelets into uv plane.
- Practical considerations
 - Constrain in reverse direction.
 - Construct thin plate spline (TPS) to uv data.
 - Integrate TPS and shapelets over uv plane.

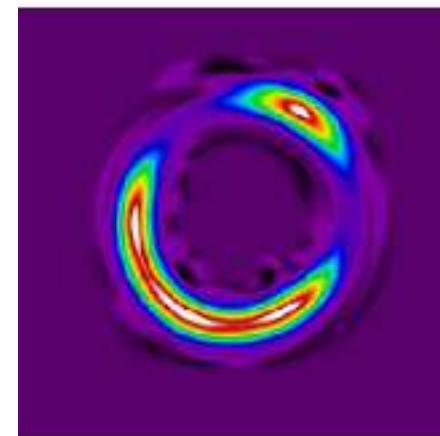
Mock data analysis – 1/2



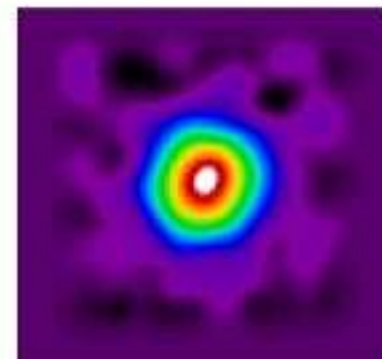
True
sky
brightness



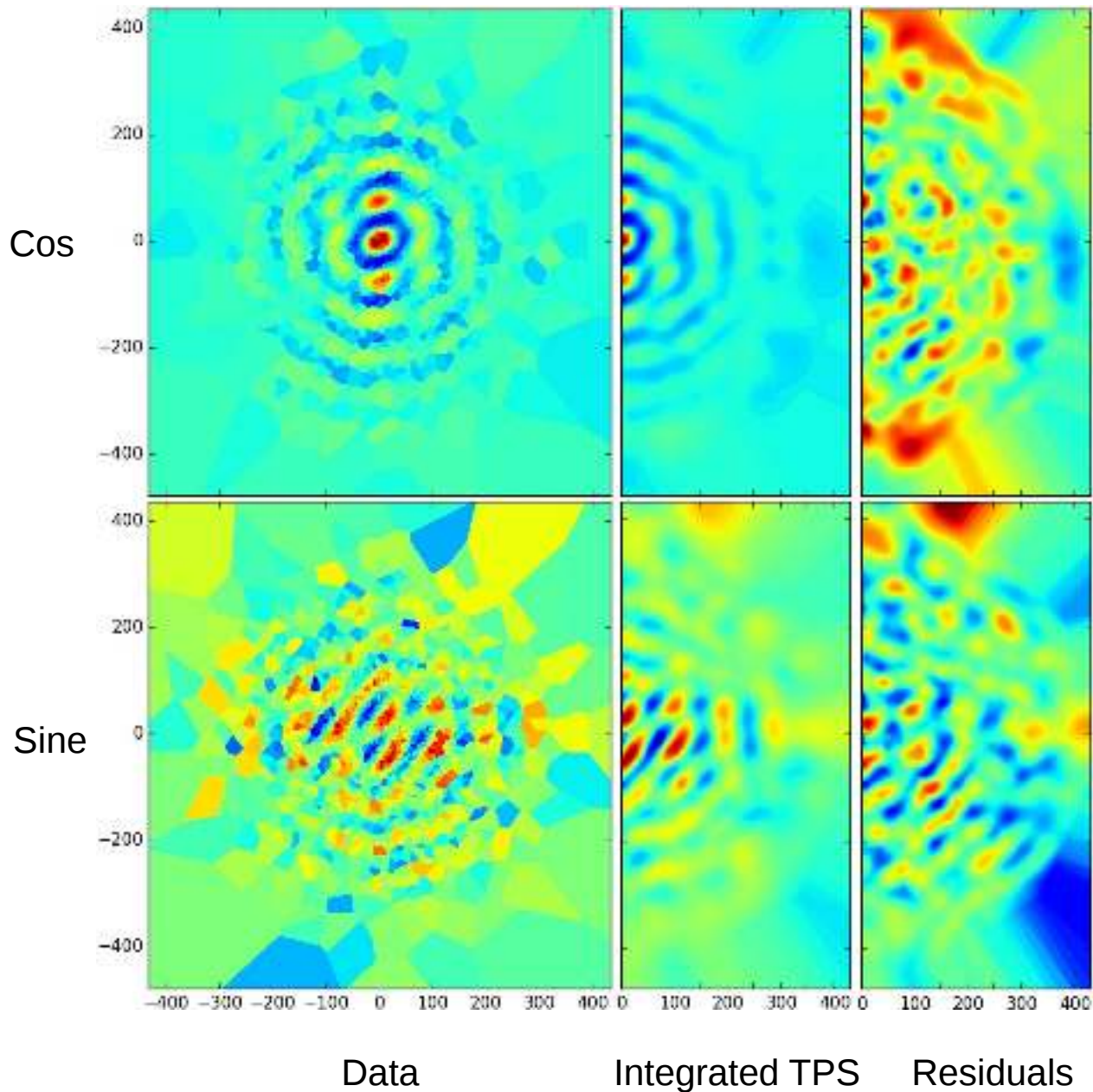
Sky
model



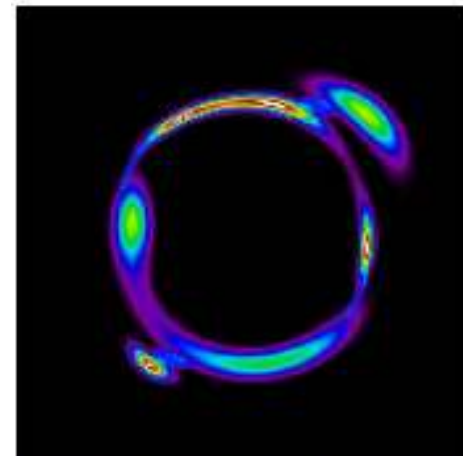
Source
model



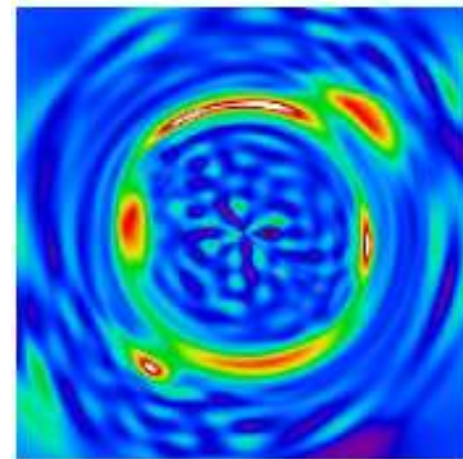
Mock data analysis – 2/2



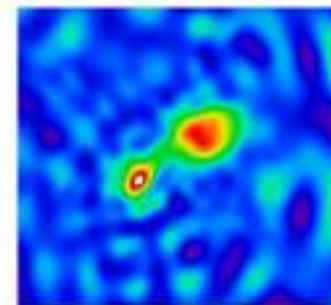
True sky model



Sky model



Source model



Summary

- Shapelets provide a grid-free, efficient method for modelling strong lenses.
- Compact and extended features can be reproduced quickly with large data sets.
- Their invariance under the Fourier transform facilitate uv plane modelling.
- Methodology is being refined and systematics are being explored.
- Publicly available soon!