# Investigating a dark core : sparse reconstruction of A520

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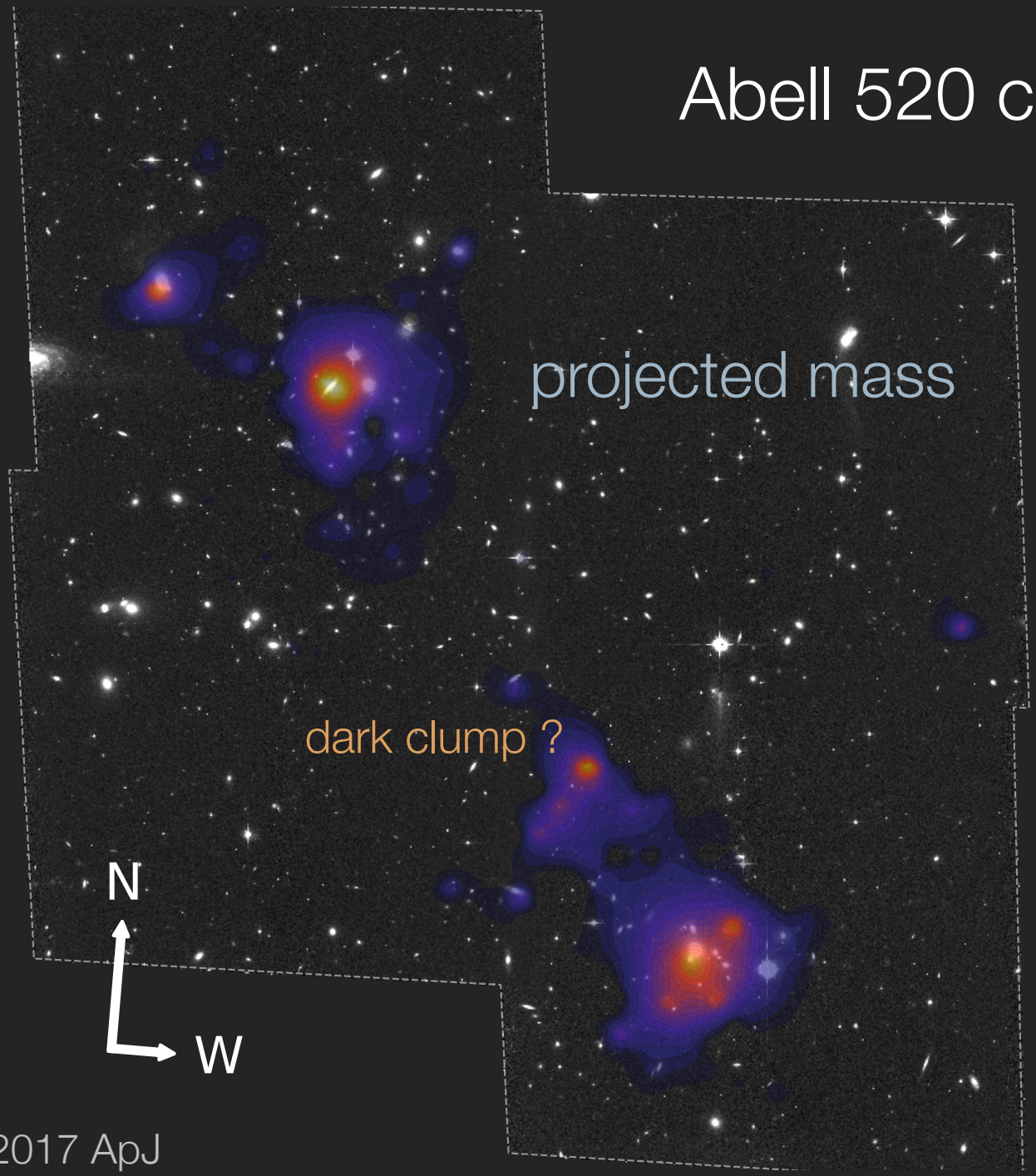
and J.-L. Starck (CEA Saclay)

26 Sept. 2017

DARKMOD Conference @IPhT

$z = 0.2$

# Abell 520 cluster




A. Peel et al. 2017 ApJ

# Motivation

1. Test Glimpse2D algorithm on real data
2. Revisit a disagreement in the literature

# Outline

i) Why mergers ?

ii) Context / history of A520

iii) Glimpse2D : sparsity-based mass mapping

iv) Applying Glimpse2D to A520 data

v) Recap and conclusion

# A lesson from mergers : DM is real

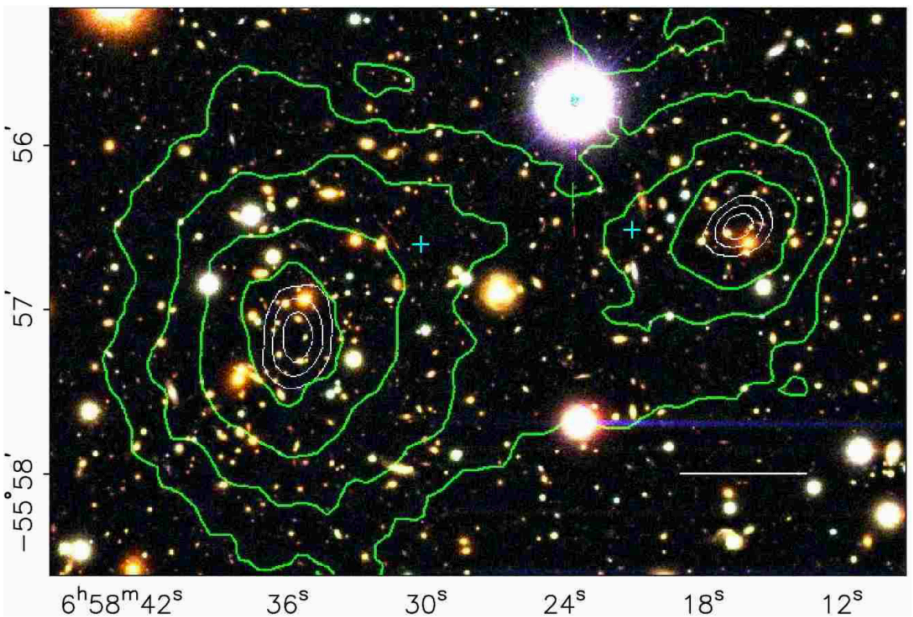
A DIRECT EMPIRICAL PROOF OF THE EXISTENCE OF DARK MATTER *

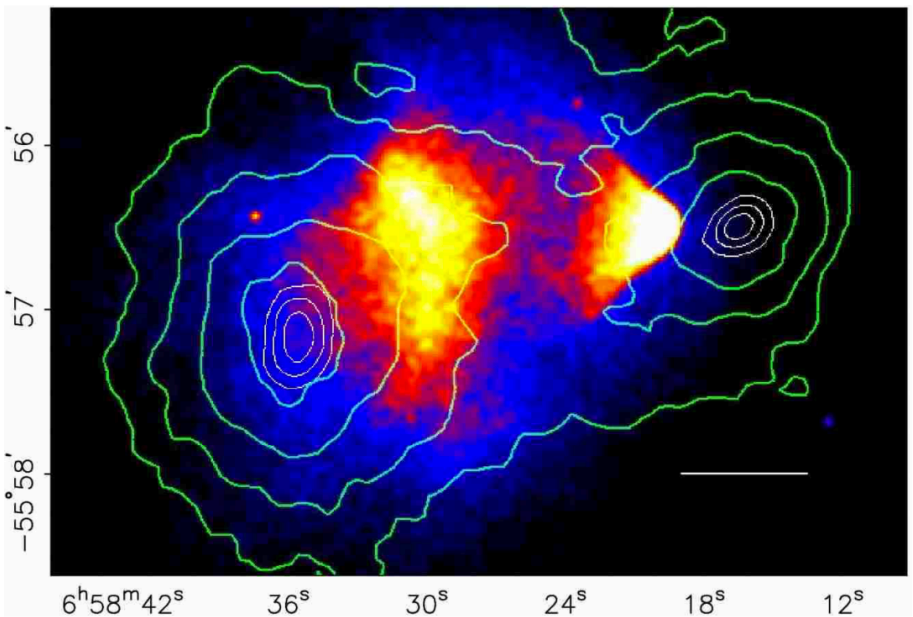
Douglas Clowe[1], Maruša Bradač[2], Anthony H. Gonzalez[3], Maxim Markevitch[4,5], Scott W. Randall[4], Christine Jones[4], and Dennis Zaritsky[1]

*ApJ Letters in press*

ABSTRACT

We present new weak lensing observations of 1E0657−558 ($z = 0.296$), a unique cluster merger, that enable a direct detection of dark matter, independent of assumptions regarding the nature of the gravitational force law. Due to the collision of two clusters, the dissipationless stellar component and the fluid-like X-ray emitting plasma are spatially segregated. By using both wide-field ground based images and HST/ACS images of the cluster cores, we create gravitational lensing maps which show



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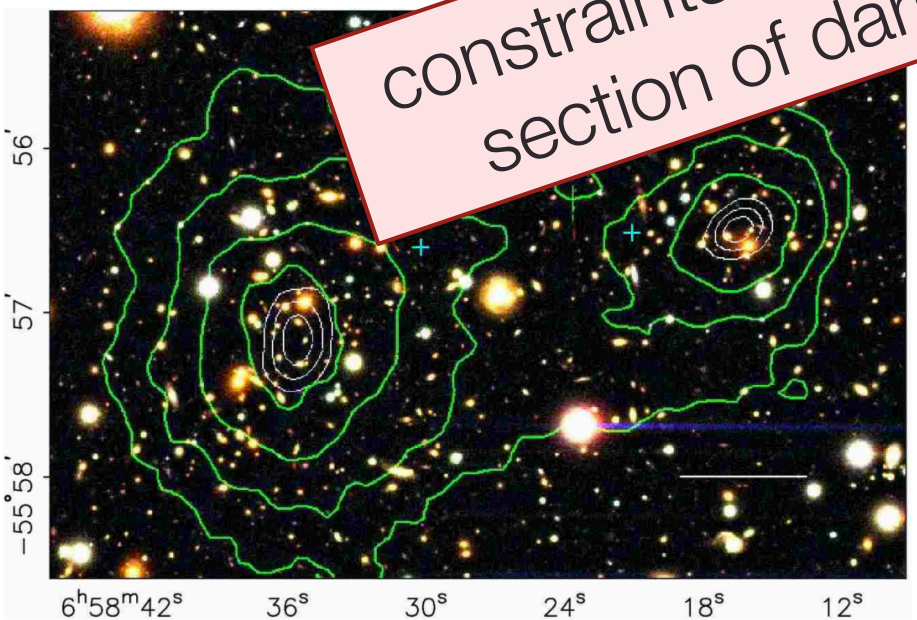
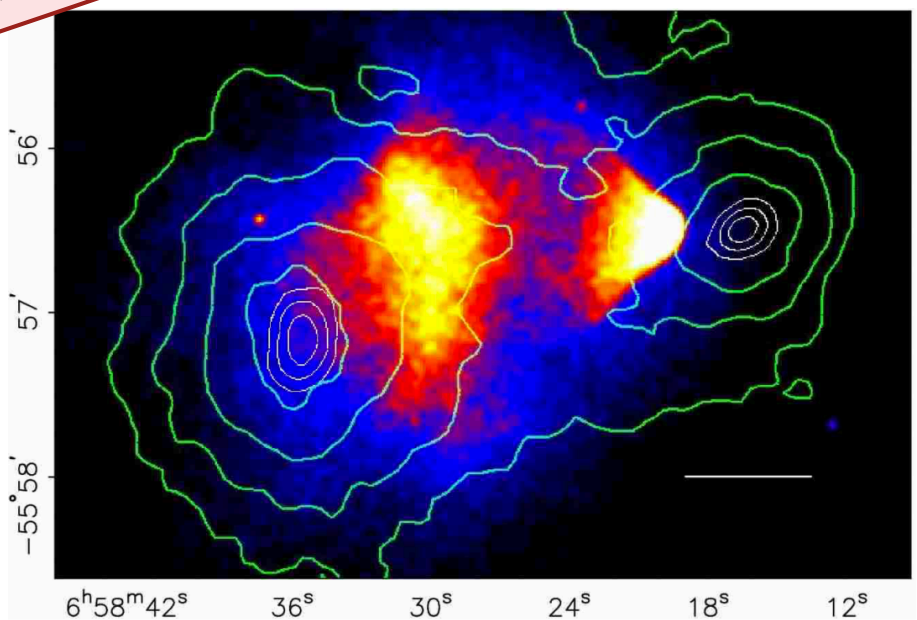
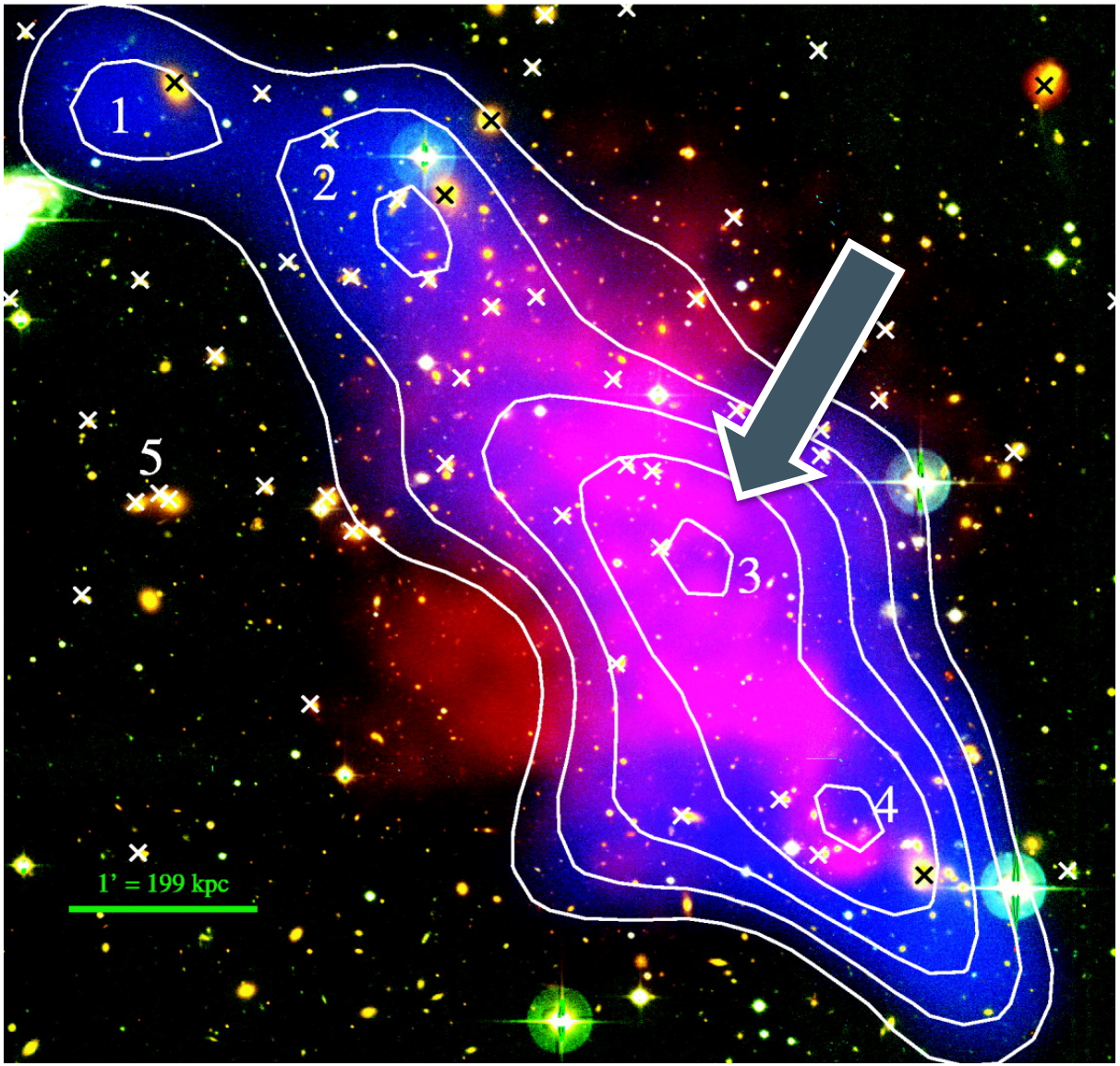


# The curious case of Abell 520




Madhavi A. et al. 2007, ApJ, 668, 806

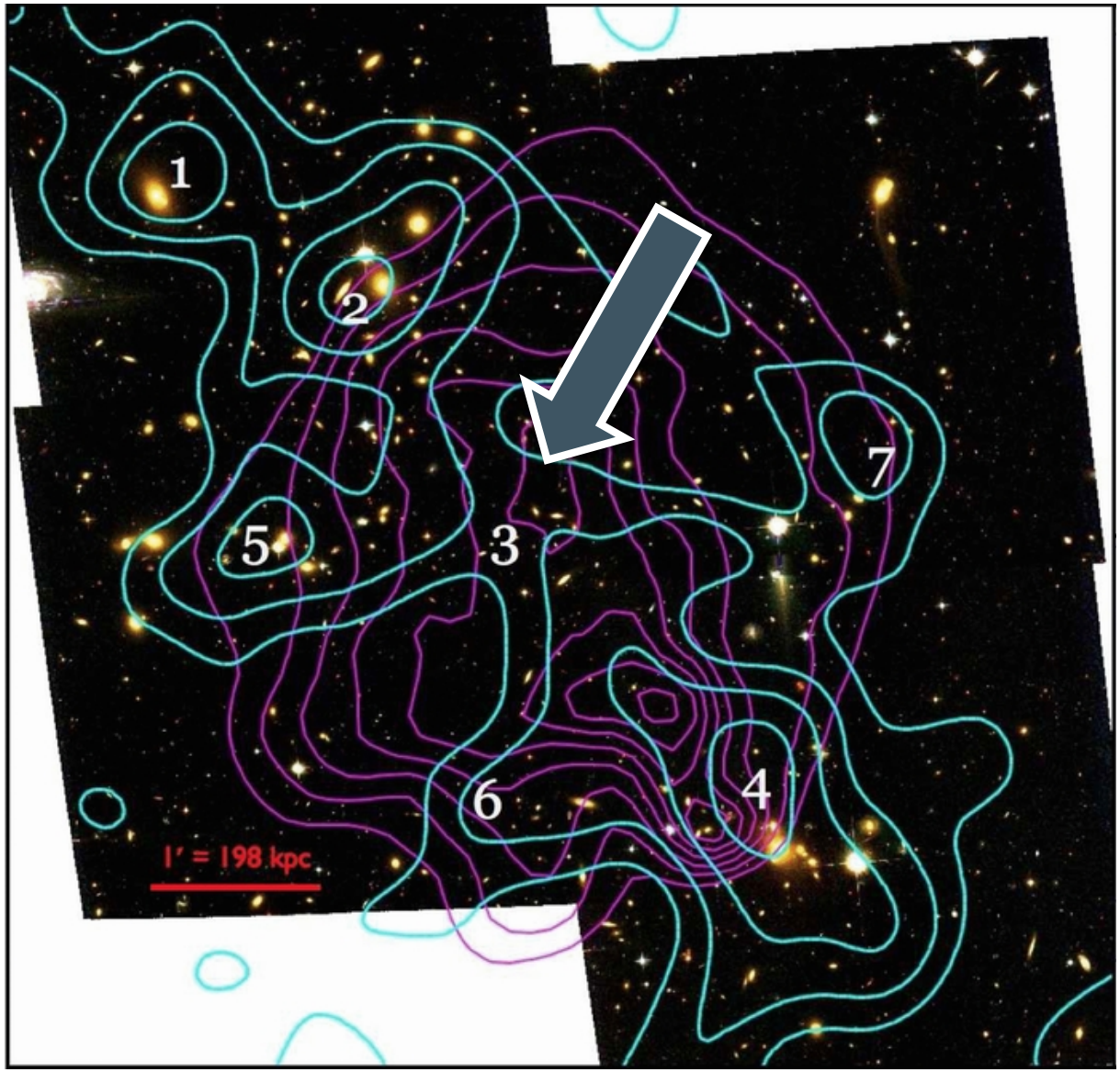
## Madhavi et al. 2007

**DATA**
CFHT + Subaru

**SURPRISE**
Dark clump detected at (3) coincident with peak in X-ray (Chandra) emission

**SIGNIFICANCE**
$> 5\,\sigma$ from bootstrap analysis

# The curious case of Abell 520




Clowe D. et al. 2012, ApJ, 758, 128

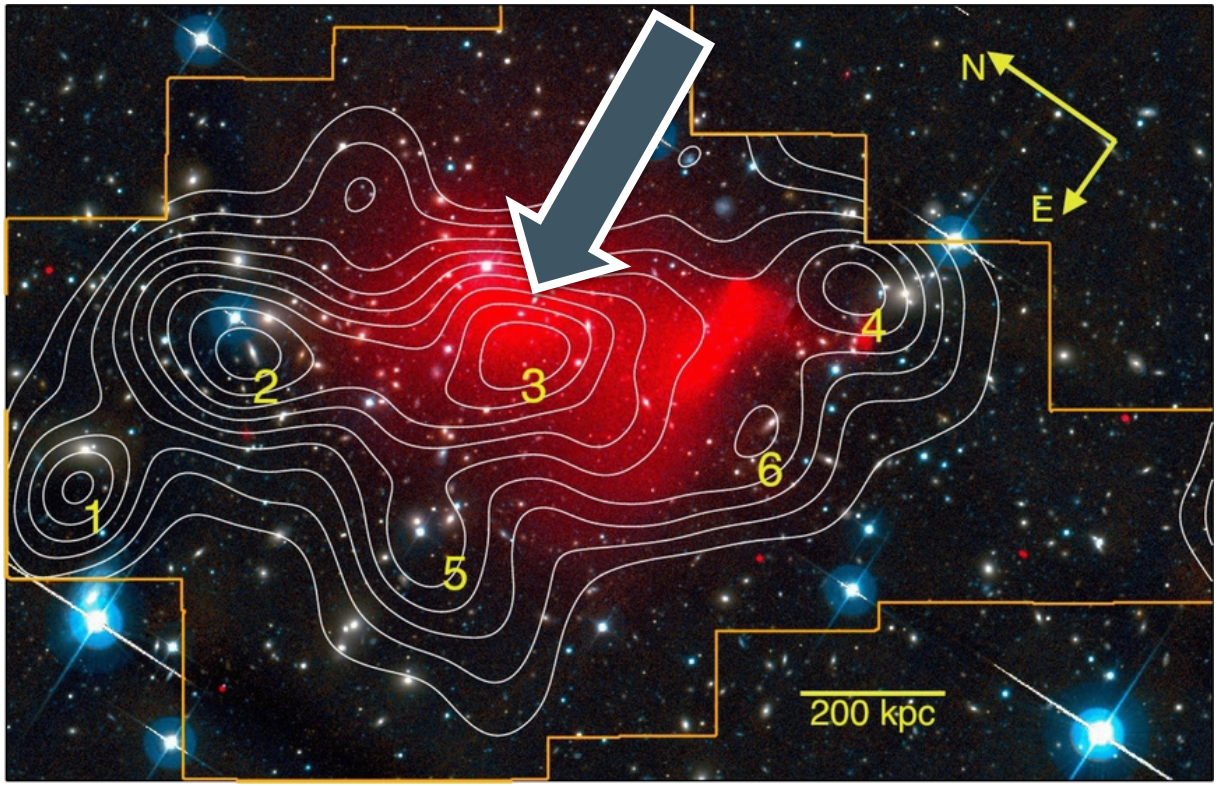
## Clowe et al. 2012

**DATA**
Magellan + HST / ACS

**EXTRAS**
New structure at location (7)

**CONCLUSION**
No dark clump detection at location (3)

# The curious case of Abell 520



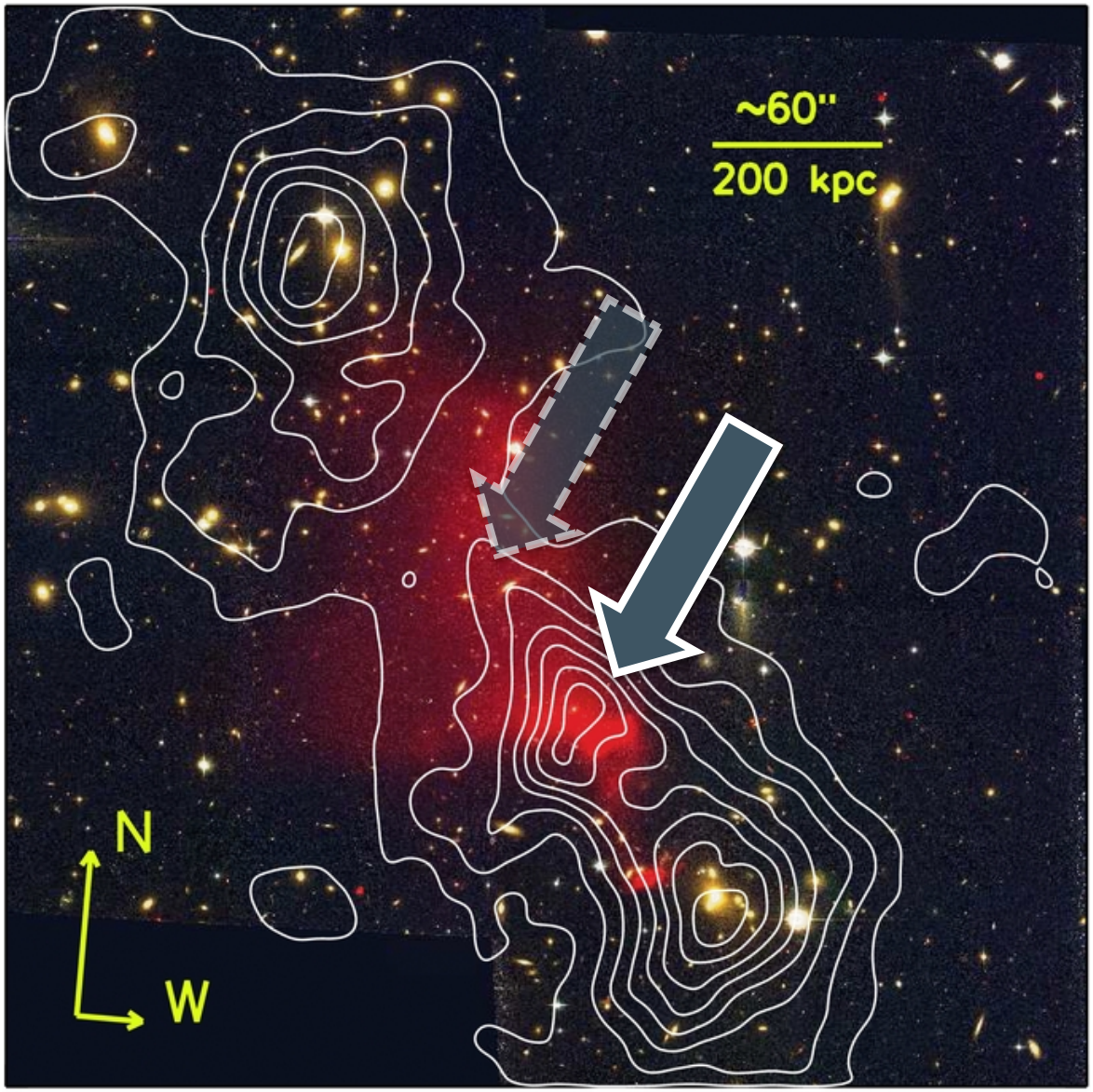

Jee M. J. et al. 2012, ApJ, 747, 96

Jee et al. 2012

**DATA**
HST / WFPC2

**CONCLUSION**
Yes indeed a dark mass detection at location (3) $> 10\,\sigma$

# The curious case of Abell 520




Jee M. J. et al. 2014, ApJ, 783, 78

## Jee et al. 2014

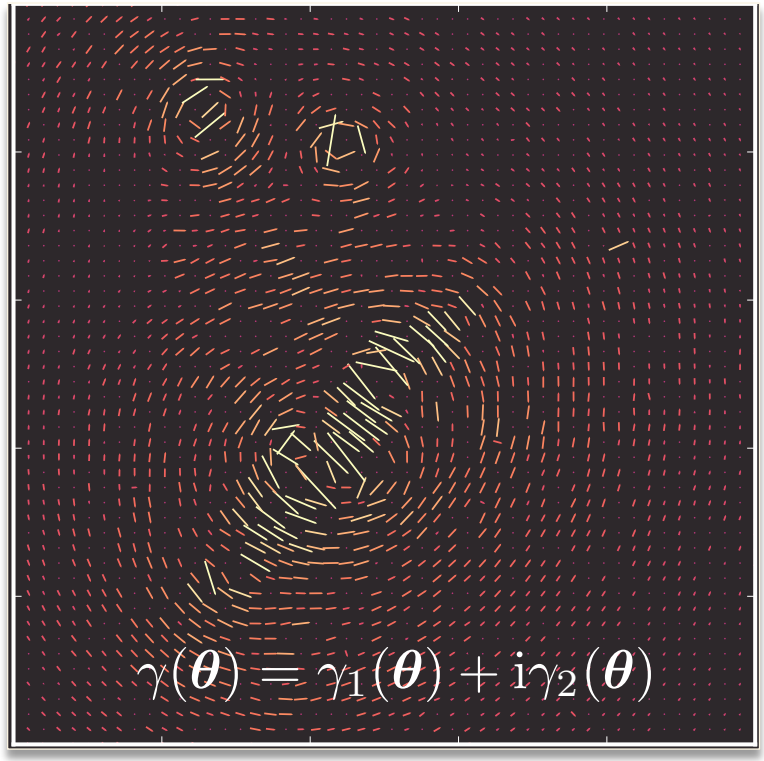
**DATA**
HST / ACS + CFHT

**SURPRISE**
Dark clump detection has *moved*

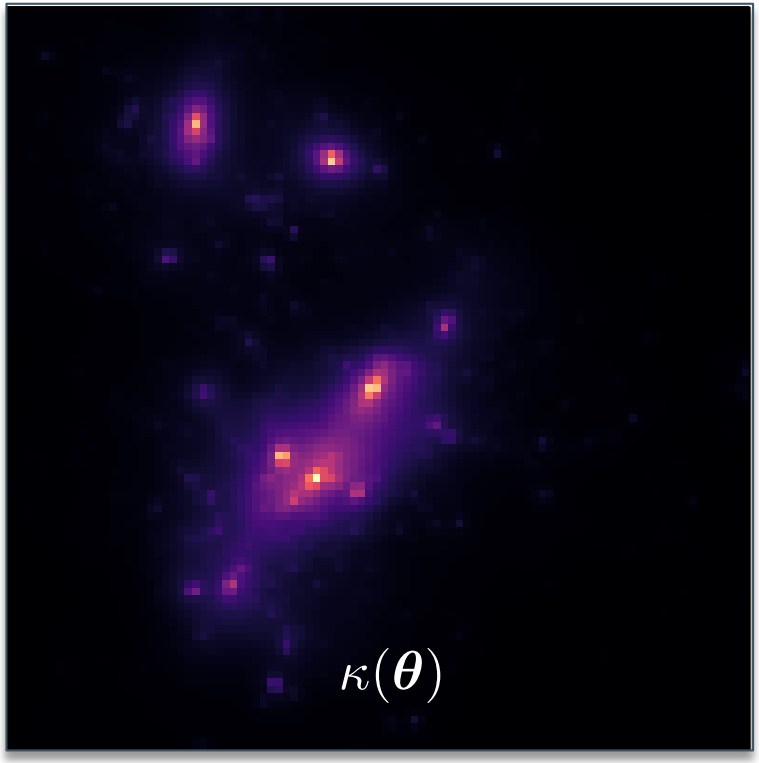
**SIGNIFICANCE**
$\sim 6.6\,\sigma$ from bootstrap analysis

# Mapping the mass

galaxy shape catalog




complex shear field




scalar convergence

**Kaiser-Squires '93 formula :**

$$\kappa(\boldsymbol{\theta}) - \kappa_0 = \frac{1}{\pi} \int_{\mathcal{R}^2} \mathrm{d}^2\theta' \, \mathcal{D}^*(\boldsymbol{\theta} - \boldsymbol{\theta}') \, \gamma(\boldsymbol{\theta}')$$

# Glimpse2D

http://www.cosmostat.org/software/glimpse

**G**ravitational **L**ensing **I**nversion and **M**a**P**ping with **S**parse **E**stimators

$$\bar{\mathbf{x}} = \arg\min_{\mathbf{x}} \frac{1}{2}||\mathbf{y} - \mathbf{A}\mathbf{x}||_2^2 + \lambda\,||\mathbf{\Phi}^*\mathbf{x}||_1$$

- Treat mass mapping as a general ill-posed inverse problem
- Impose regularizing sparsity prior on solution (convergence)
- Obtain sparsest solution in dictionary $\Phi$ compatible with the data

# Glimpse2D

http://www.cosmostat.org/software/glimpse

**G**ravitational **L**ensing **I**nversion and **M**a**P**ping with **S**parse **E**stimators

$\kappa(\boldsymbol{\theta})$ map solution

shear data $\gamma(\boldsymbol{\theta})$

non-invertible operator

dictionary (basis)

$$\bar{\mathbf{x}} = \arg\min_{\mathbf{x}} \frac{1}{2}||\mathbf{y} - \mathbf{A}\mathbf{x}||_2^2 + \lambda\,||\mathbf{\Phi}^*\mathbf{x}||_1$$

convergence map

regularization parameter

- Treat mass mapping as a general ill-posed inverse problem
- Impose regularizing sparsity prior on solution (convergence)
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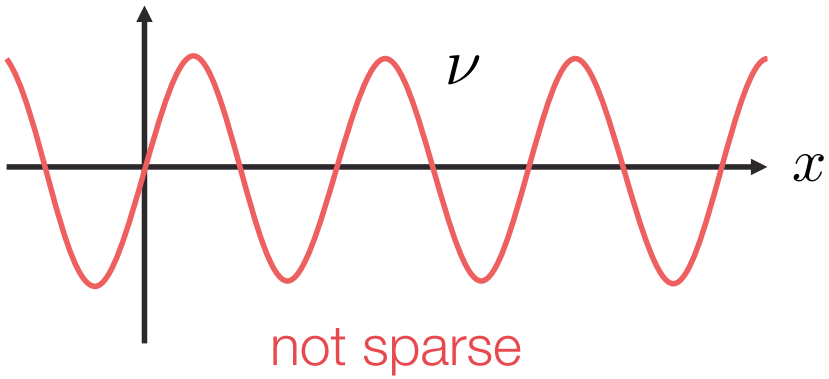
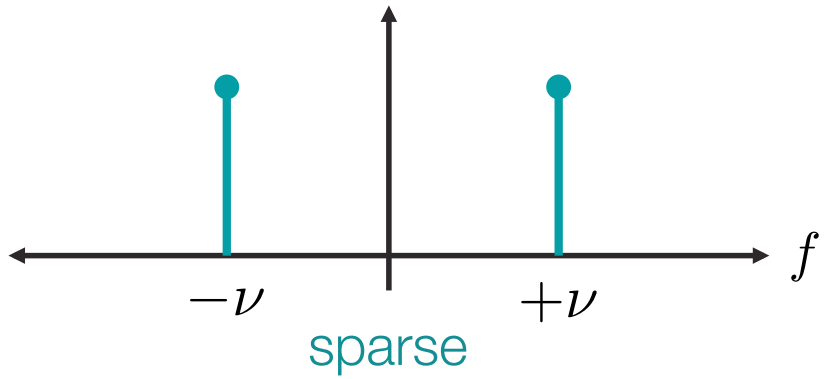
# Sparsity

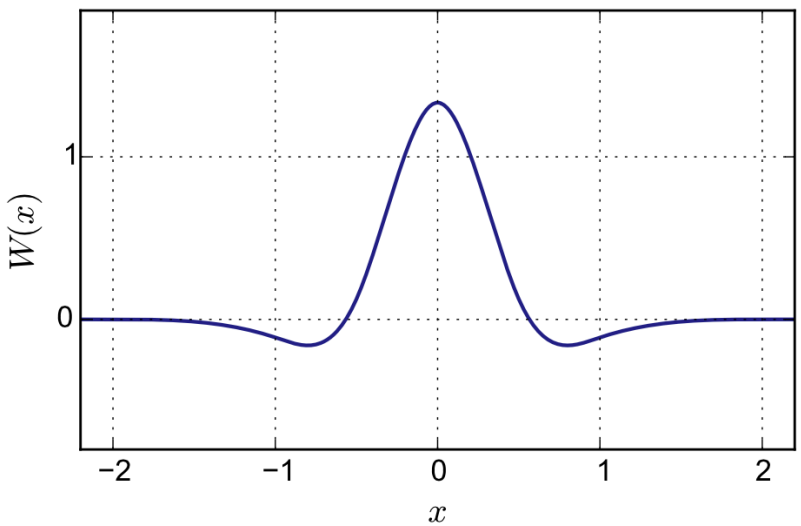
direct space




Fourier space




Wavelet function
(*starlet*)



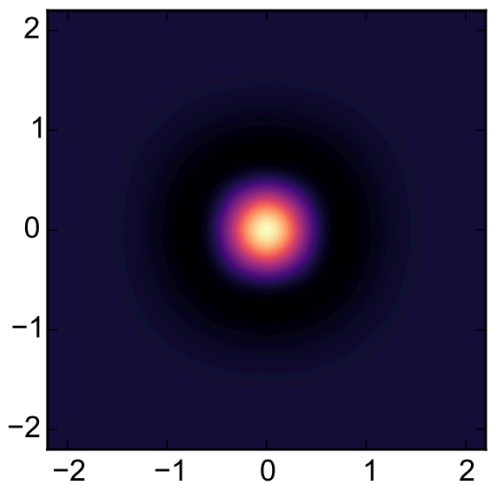




Image credit : C.-A. Lin

# Sparse recovery test on simulations

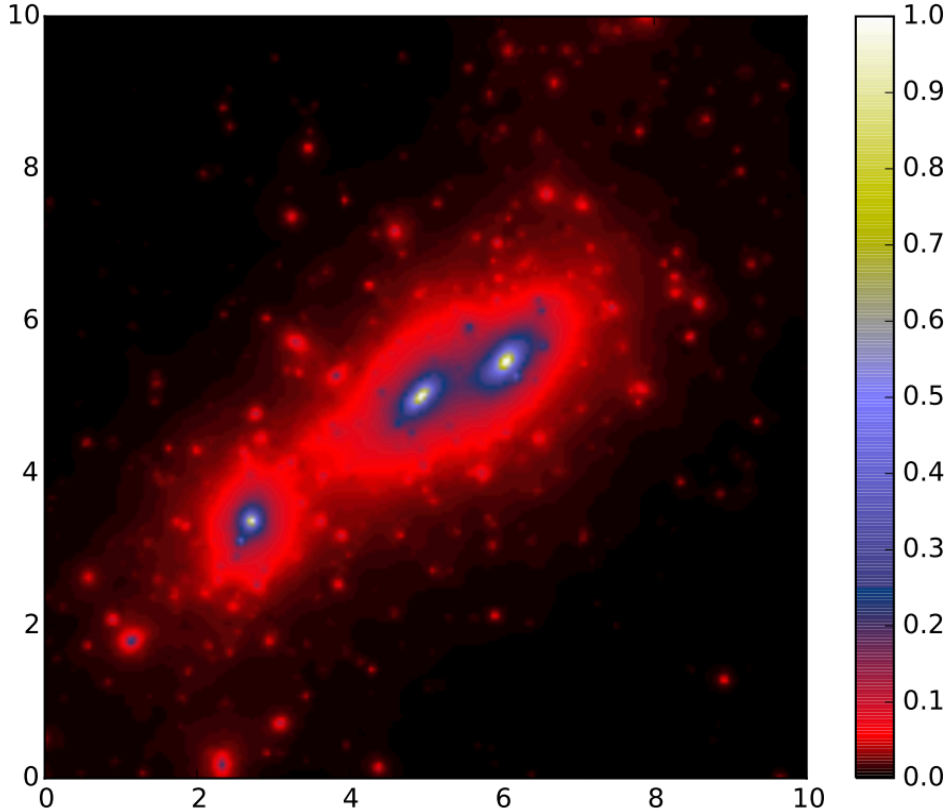
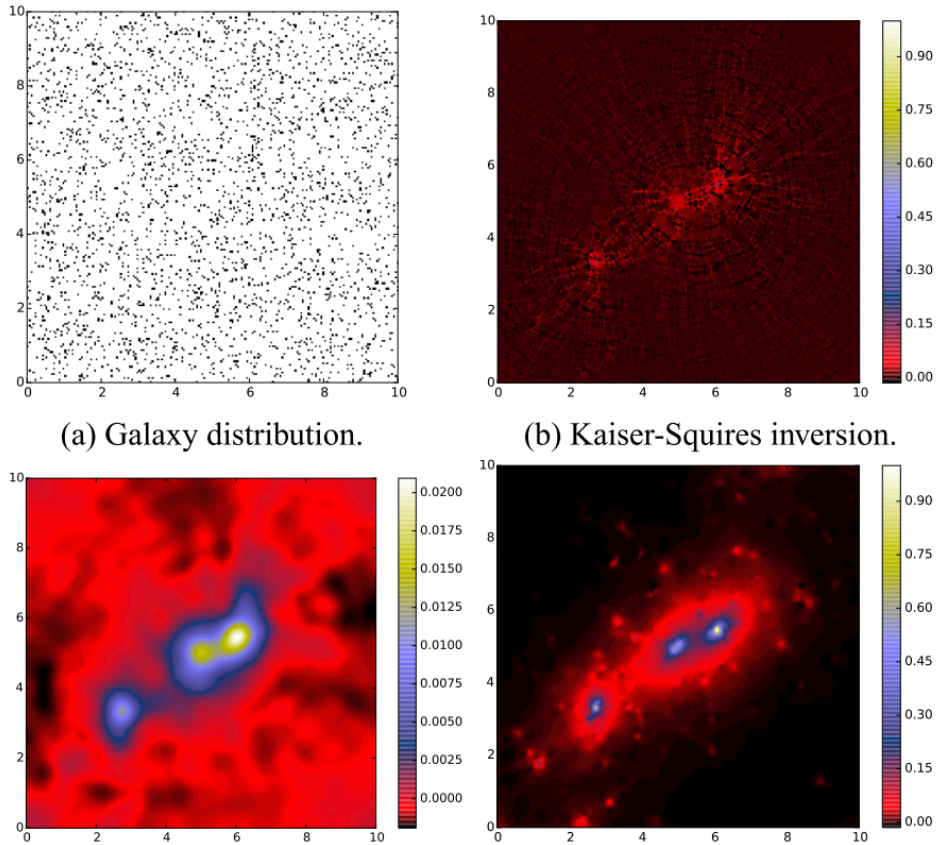



**Fig. 5.** Test convergence map generated from an $N$-body simulation. The clusters are located at $z_l = 0.3$ while the source plane is placed at $z_s = 1.2$.




(a) Galaxy distribution.

(b) Kaiser-Squires inversion.

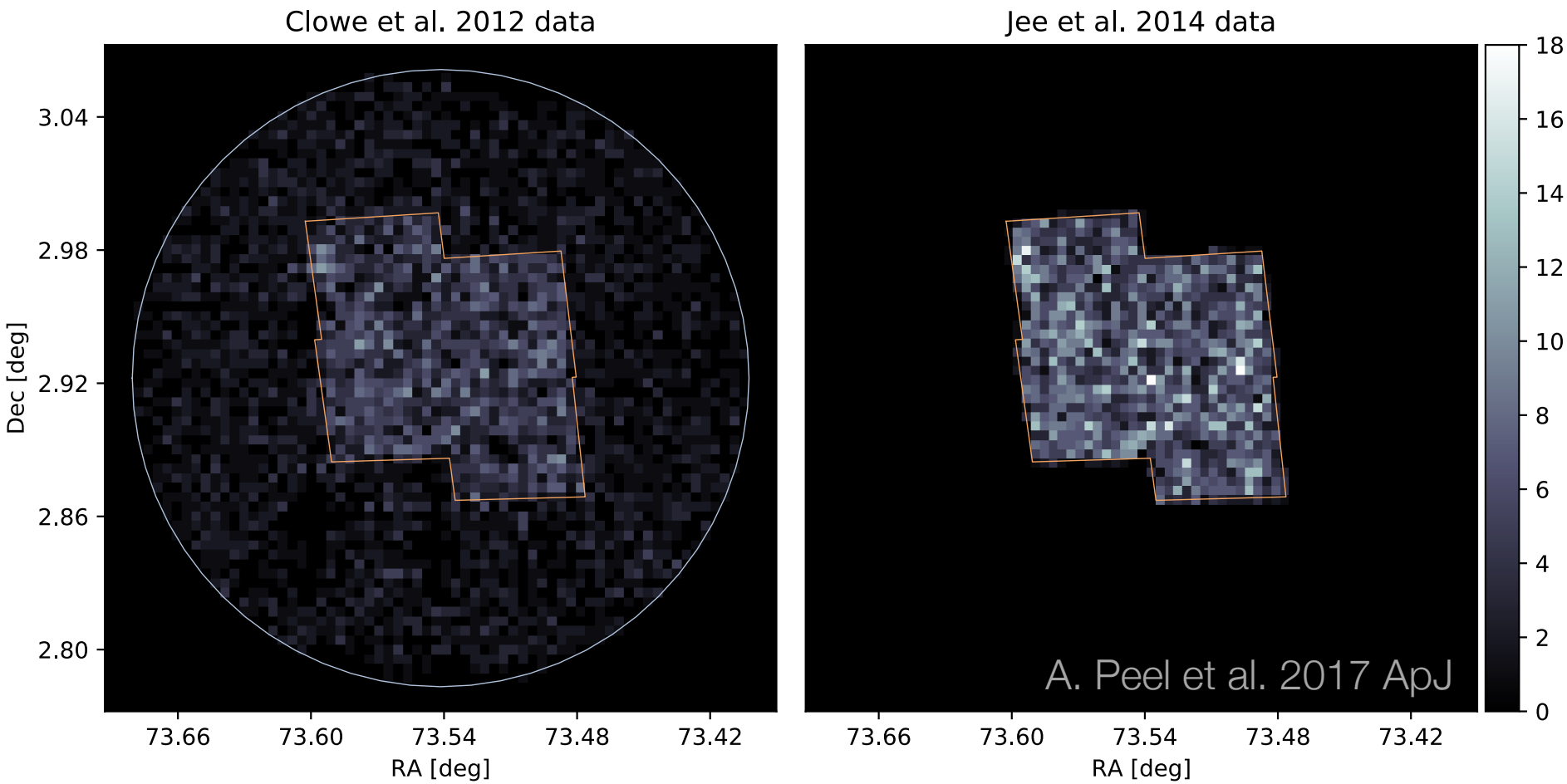
(c) Kaiser-Squires with a 0.25 arcmin Gaussian smoothing.

(d) Sparse recovery.

**Fig. 6.** Reconstruction of the input convergence map using 30 galaxies per square arcminute using a Kaiser-Squires estimator **b**–**c**) and sparse recovery **d**). The *top left panel* shows the mask applied to the binned shear map with empty pixels marked in white. In this test, 93% of the pixels are masked.

F. Lanusse et al. 2016 A&A

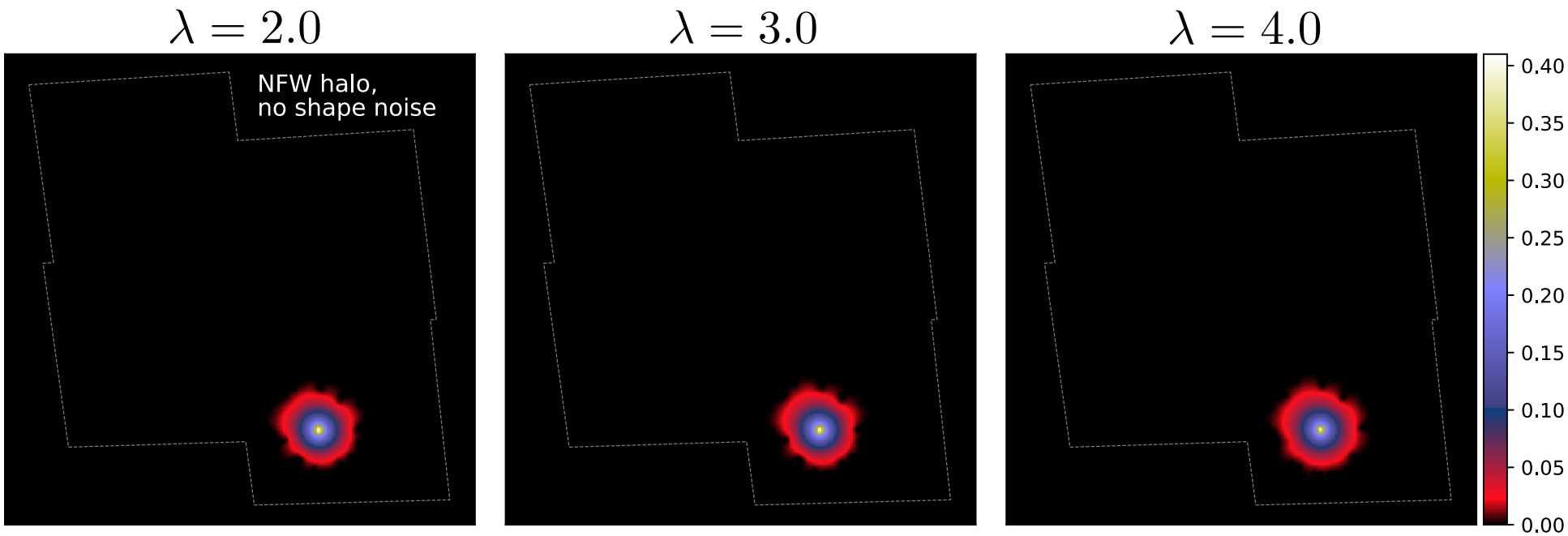
# Application to A520




Magellan + HST/ACS

CFHT + HST/ACS

# Glimpse2D tests on A520-like simulations



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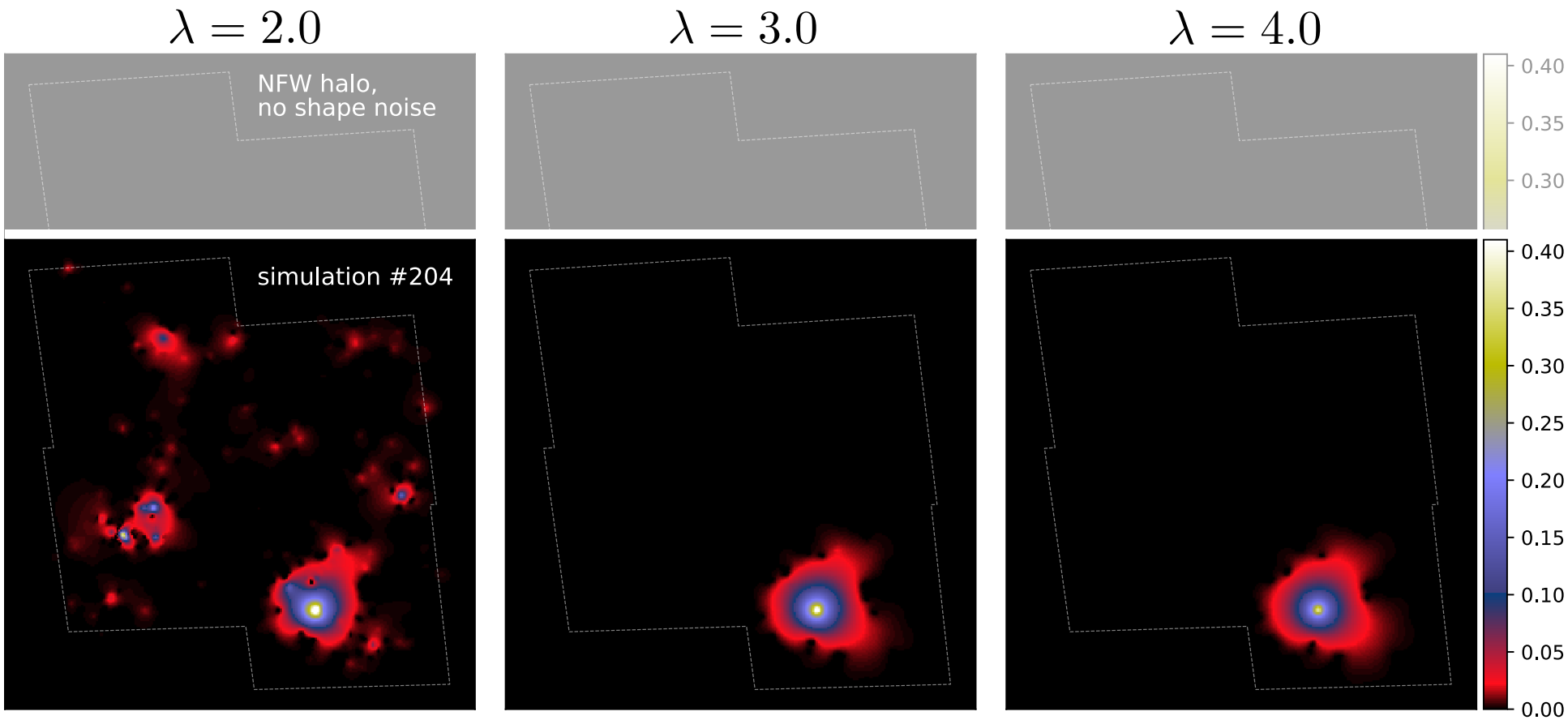

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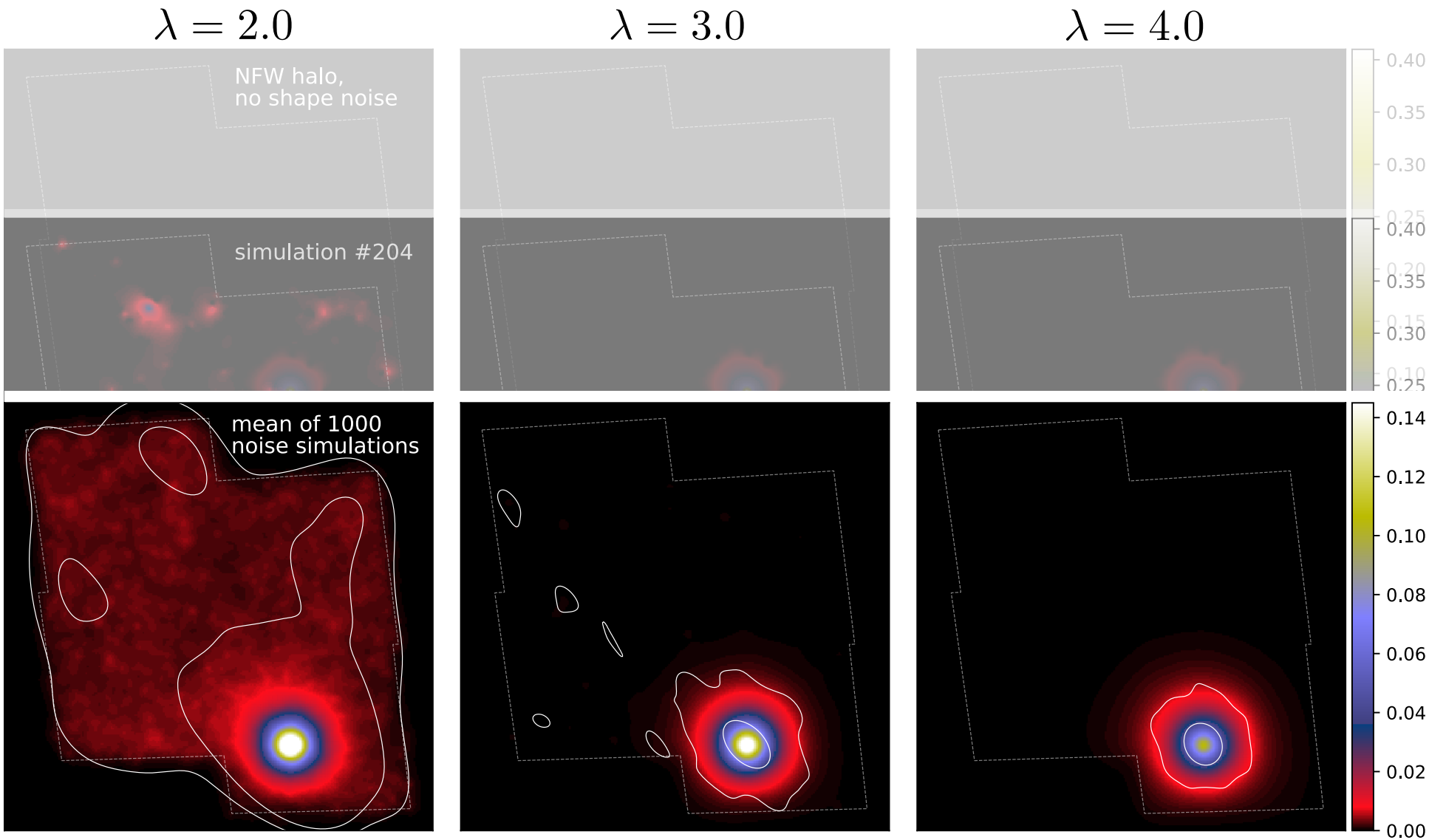
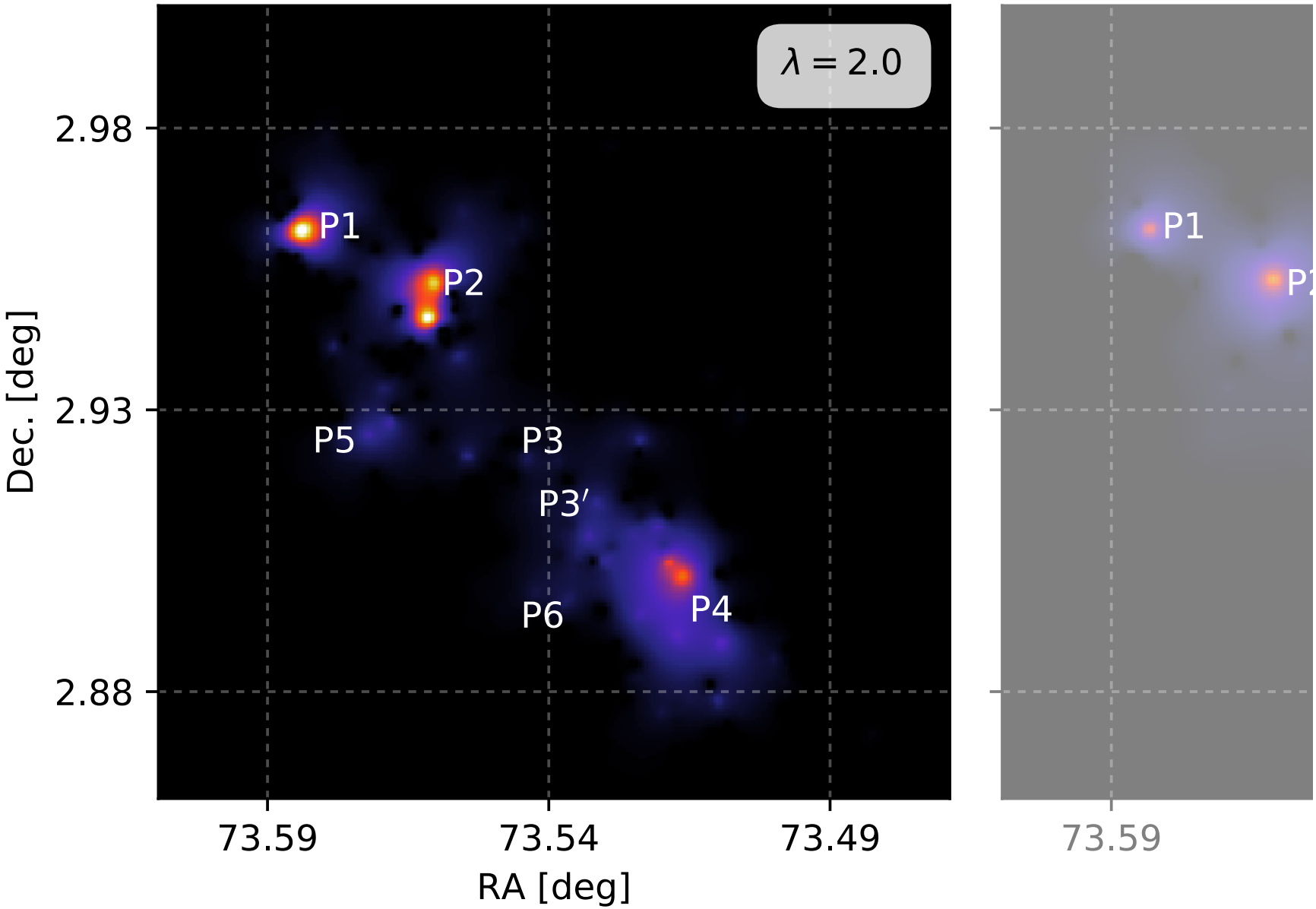


# Glimpse2D on Clowe et al. 2012 data



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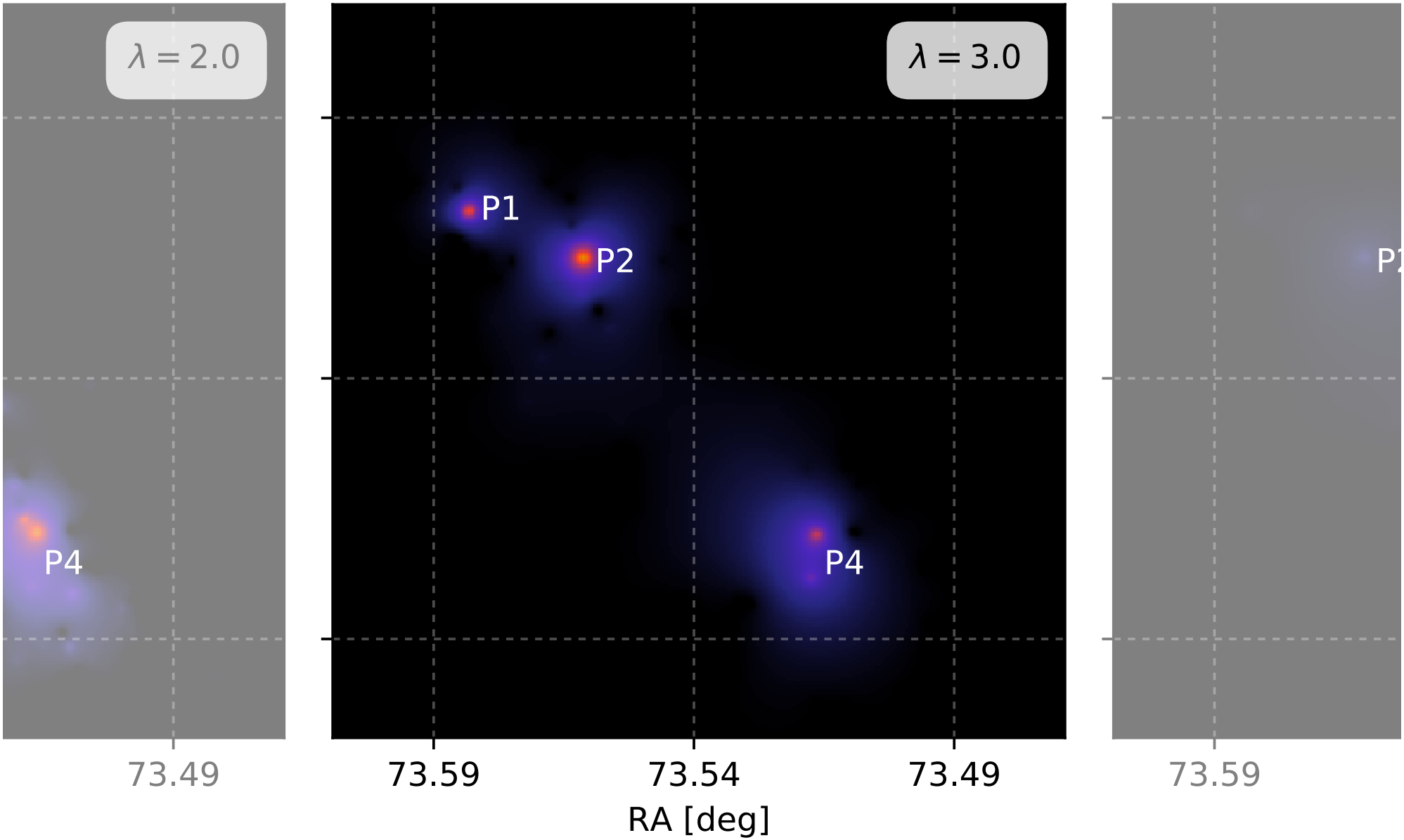

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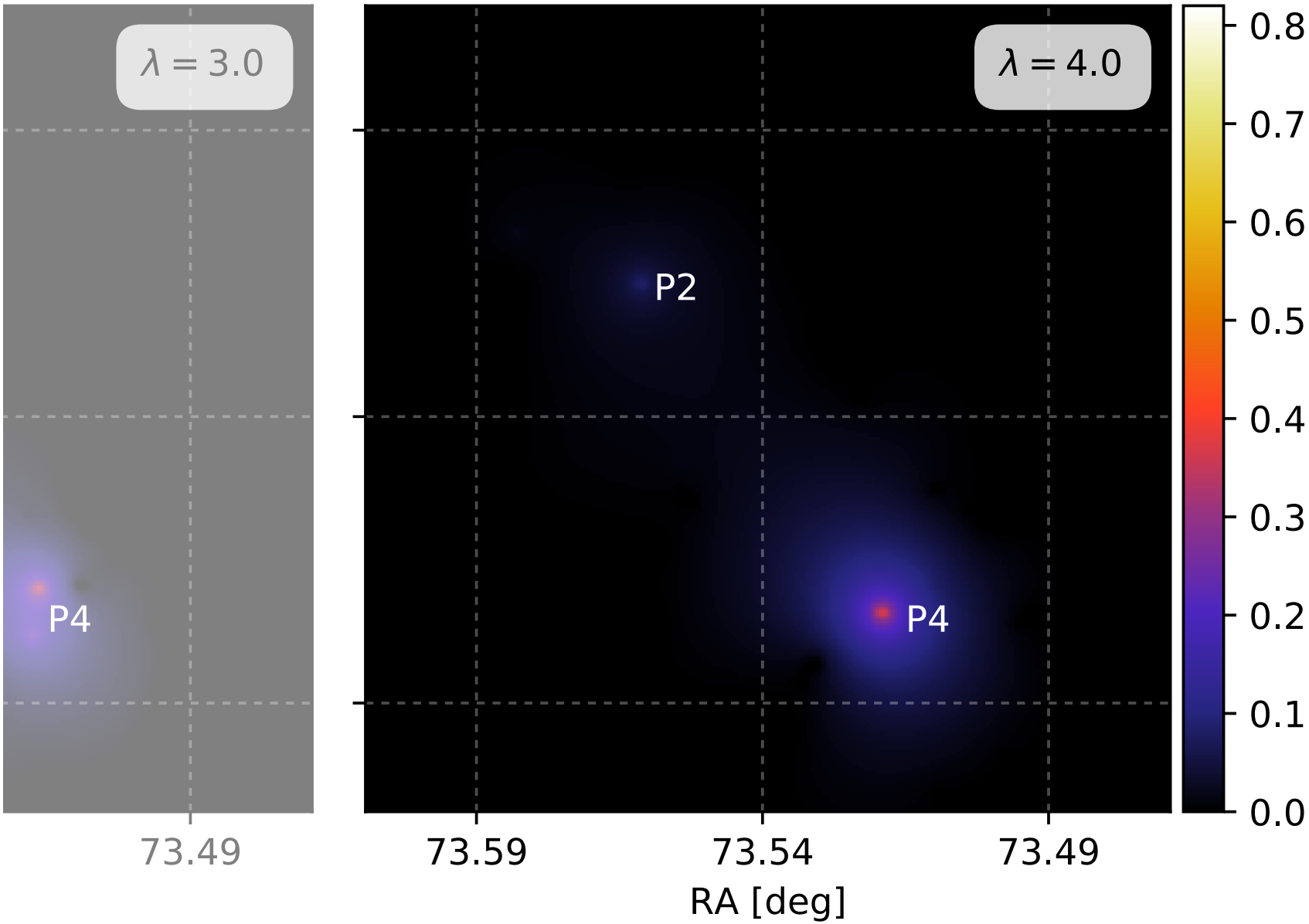

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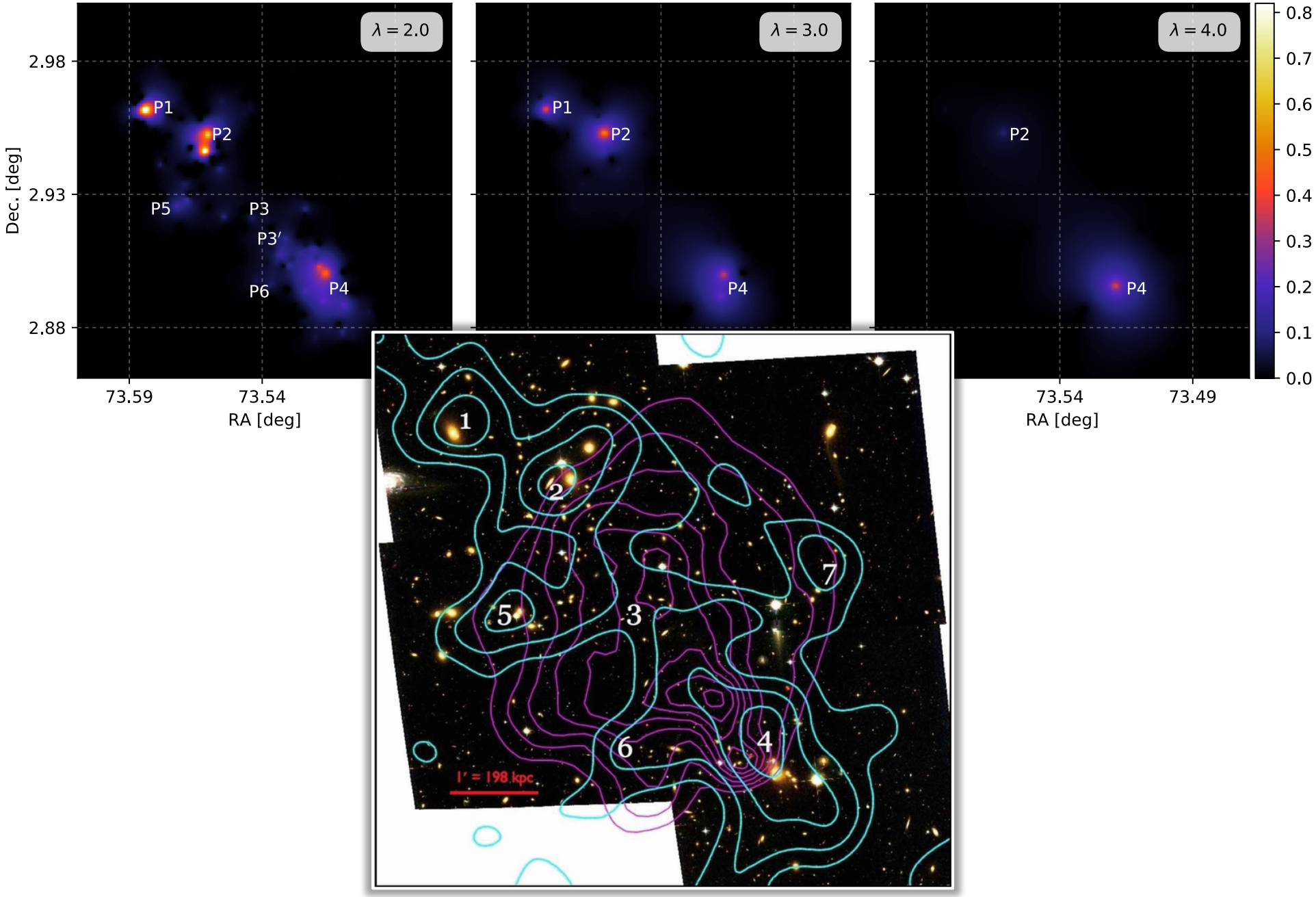

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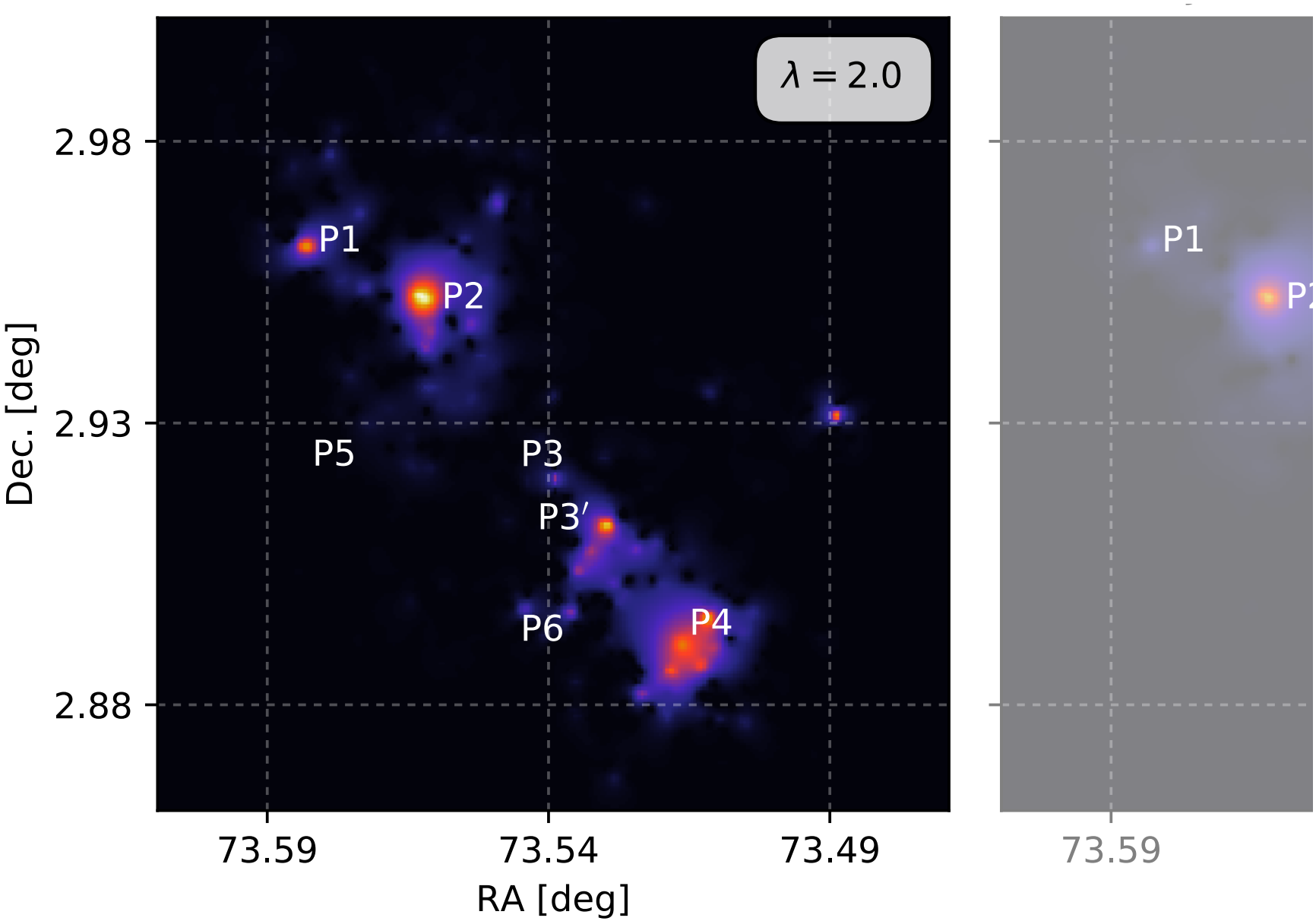

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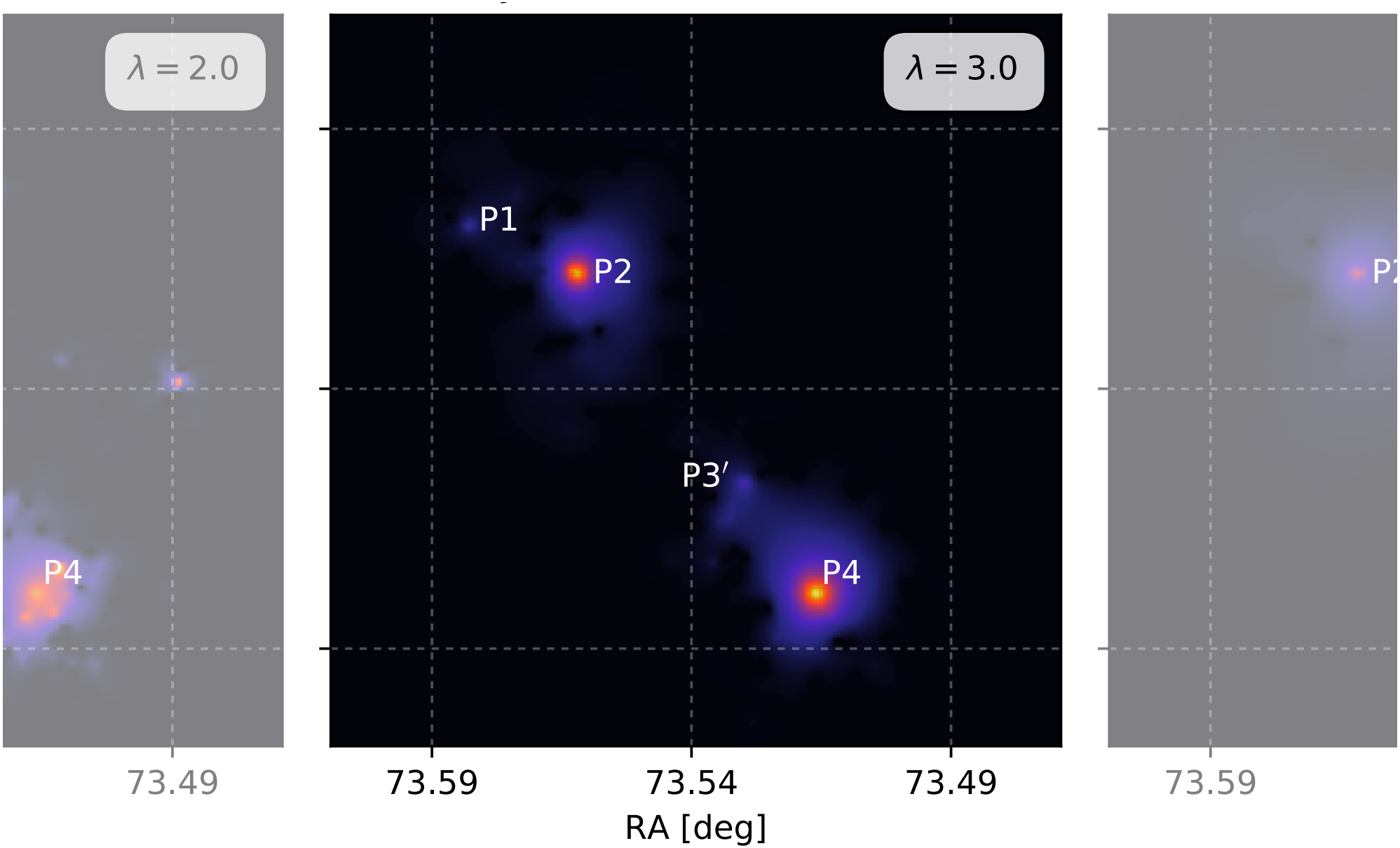

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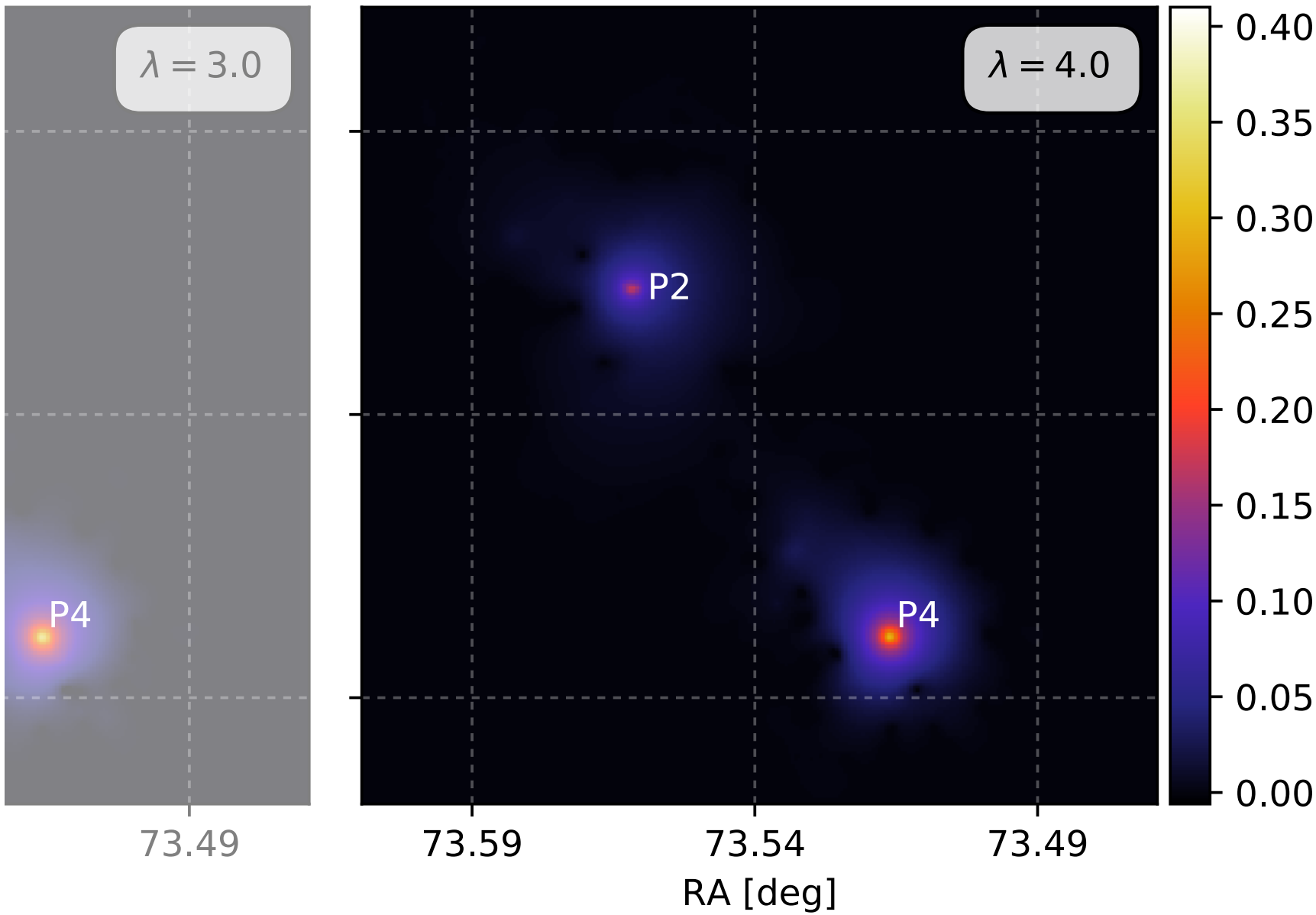

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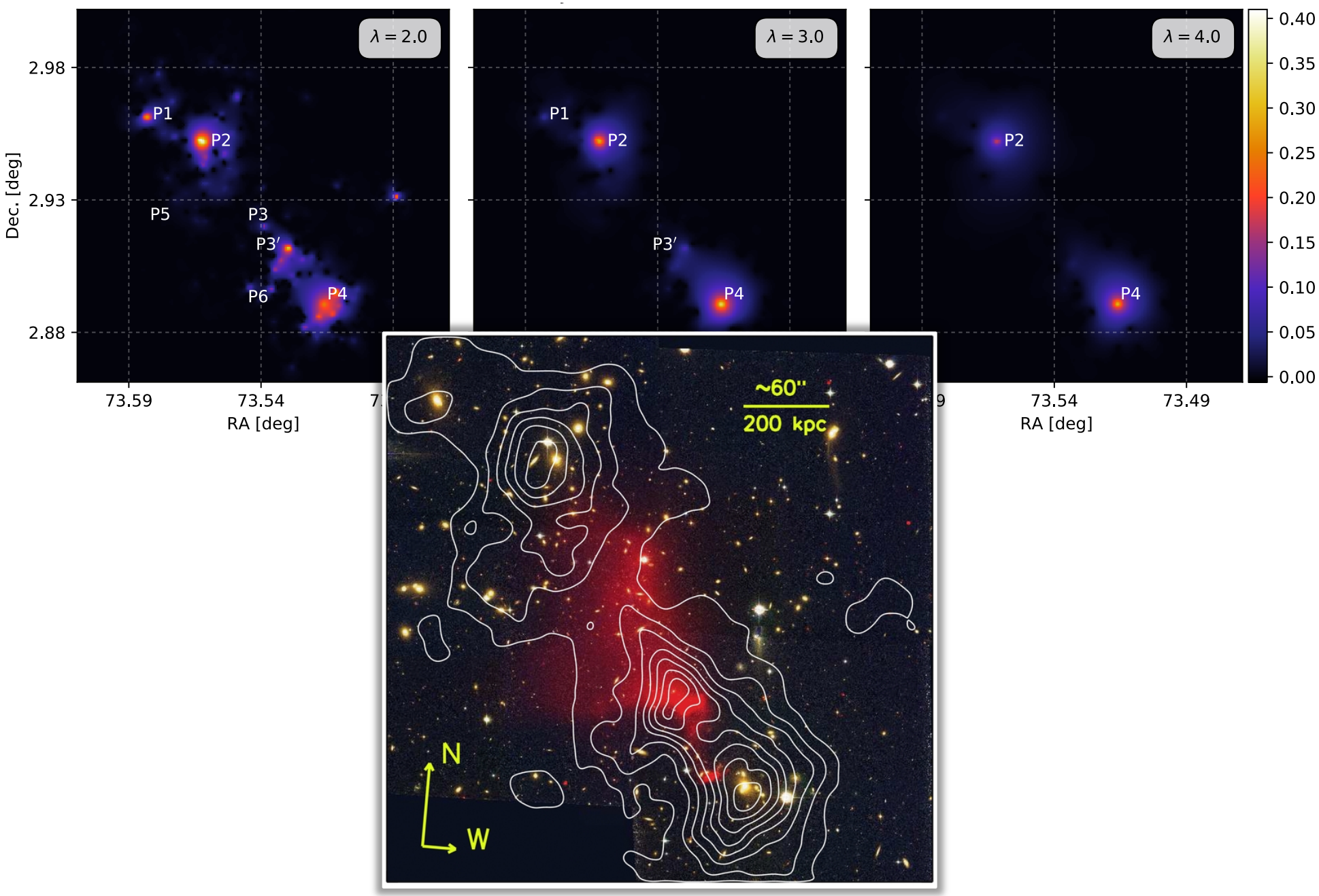
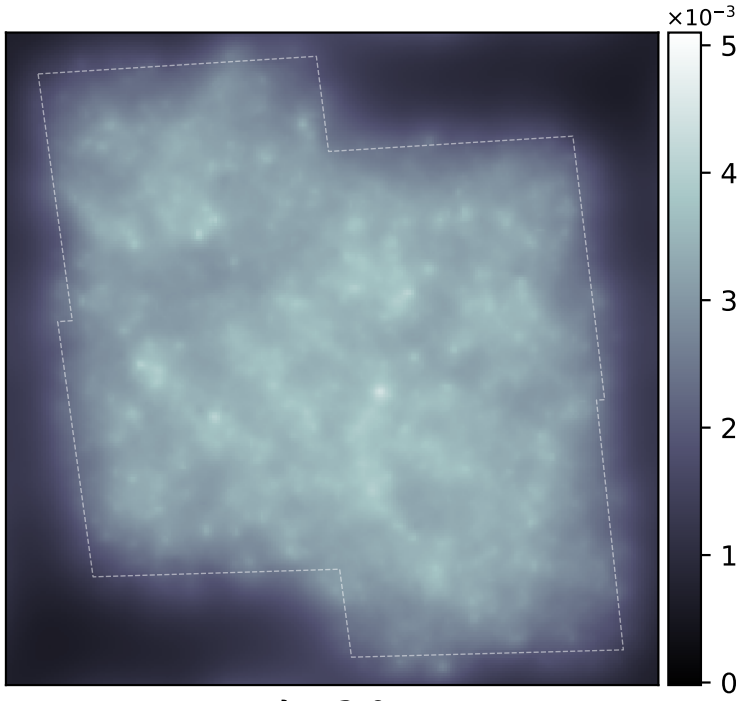
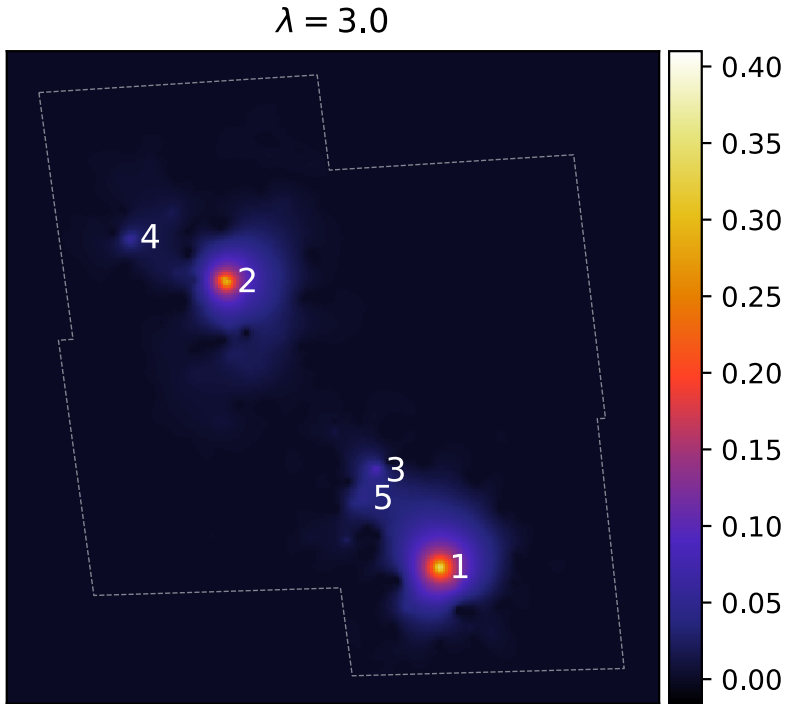


# How significant is the dark peak ?

Ex. noise simulations of J14 data, N=1000




mean noise map

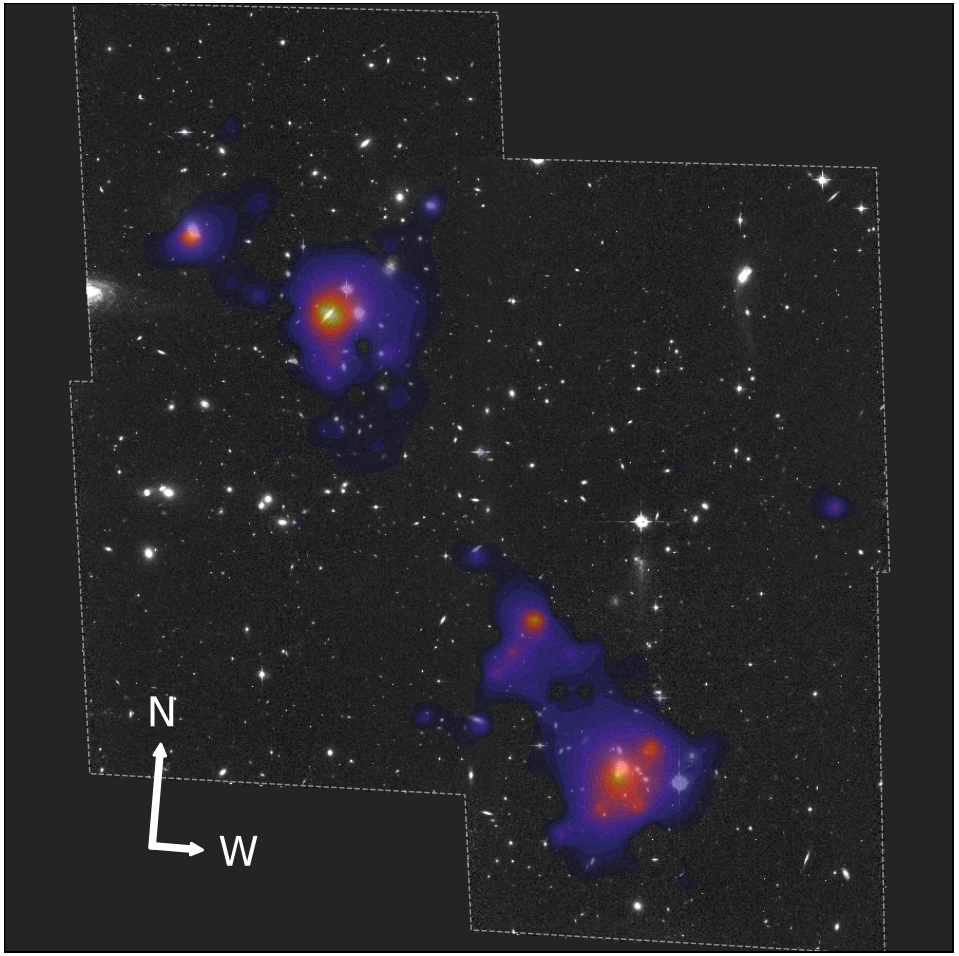



original: rank-ordered peaks

| | P2 | P3' (dark) | P4 |
|---|---|---|---|
| J14 | $> 3.3\sigma$ | $< 2.0\sigma$ | $> 3.3\sigma$ |

## Summary

- Mergers are interesting
- Re-analysis of A520 merger
- Sparsity-based mass mapping with Glimpse2D applied to A520
- Cannot confirm detection of the anomalous dark peak




## Reproducible research

Catalogues, software, and instructions available at
http://www.cosmostat.org/software/glimpse

Peel, Lanusse, Starck 2017, *in press* ApJ (arXiv:1708.00269)