Spatial inference for astronomical data sets with INLA

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S6 - Software in Astronomy

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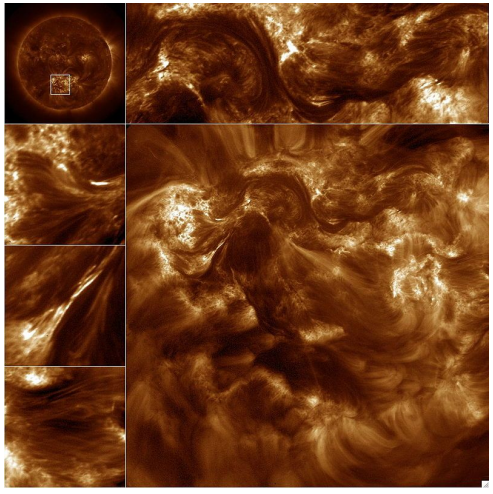
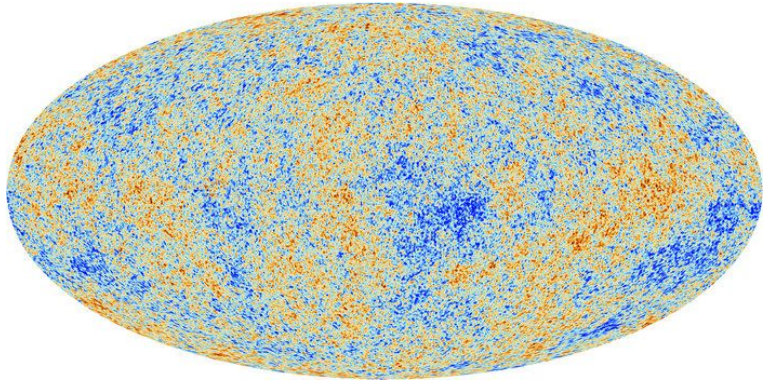
On behalf of
Santiago Gonzalez-Gaitan
and the COIN Collaboration

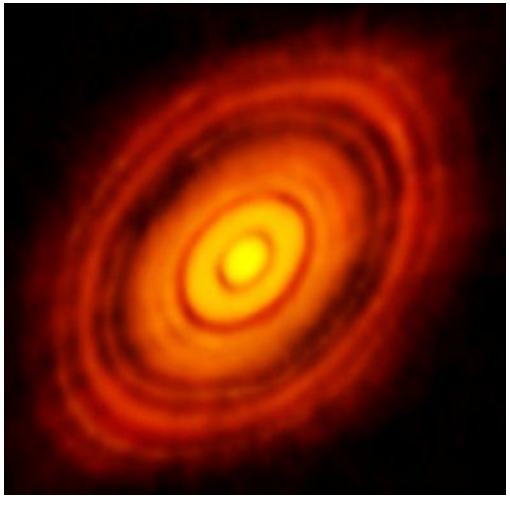
Spatial fields: crucial to astronomy



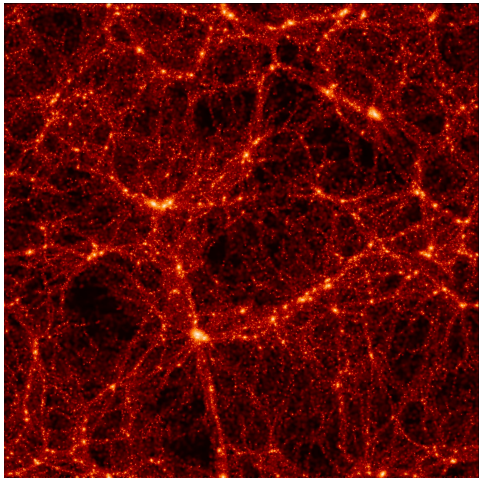
Sun's corona
in UV
(Hi-C)
Cirtain+13



Cosmic Microwave Background
(Planck) - *Planck+13*



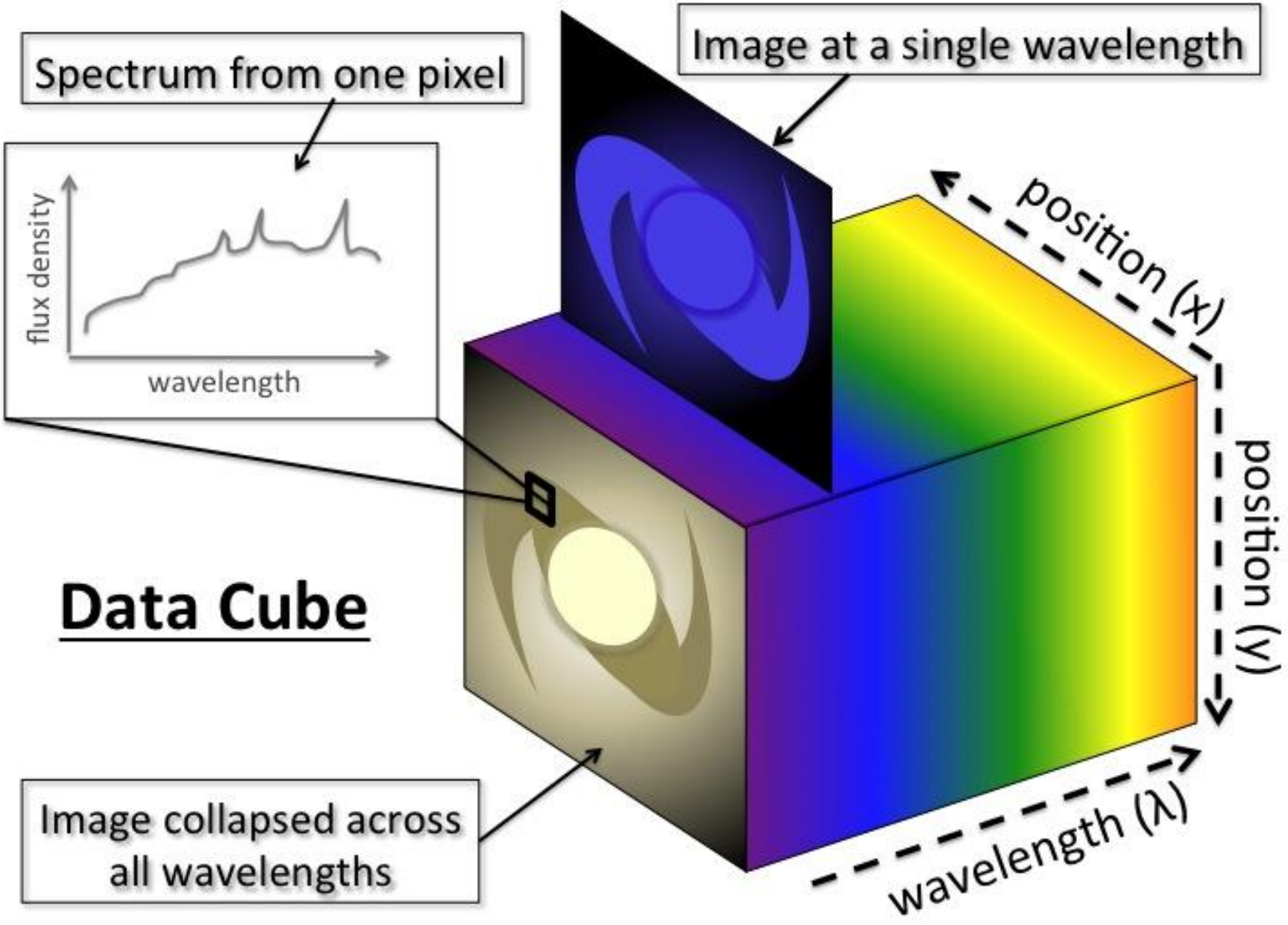
Protoplanetary
disk with
interferometry
(ALMA)
ALMA+14



N-body
Simulation
(VIRGO)
Jenkins+98

Slide by Santiago Gonzalez-Gaitan

Spectral Data-Cubes



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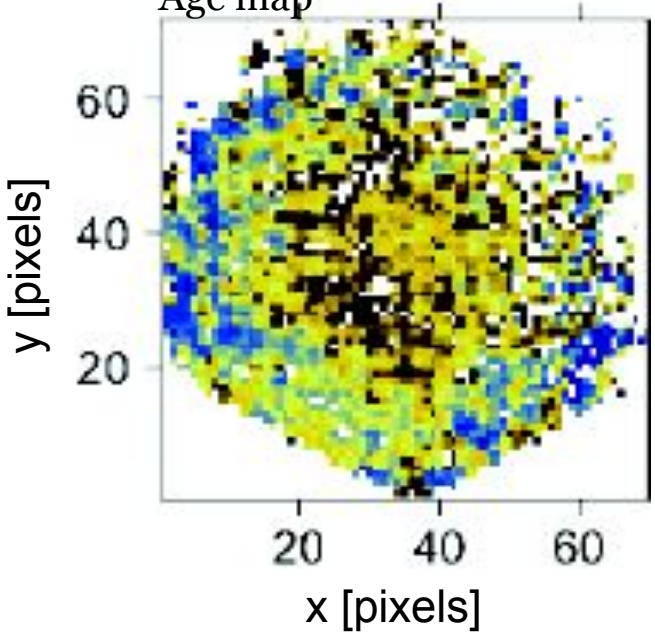
From Harrison thesis (2014), available here

Spatial auto-correlations

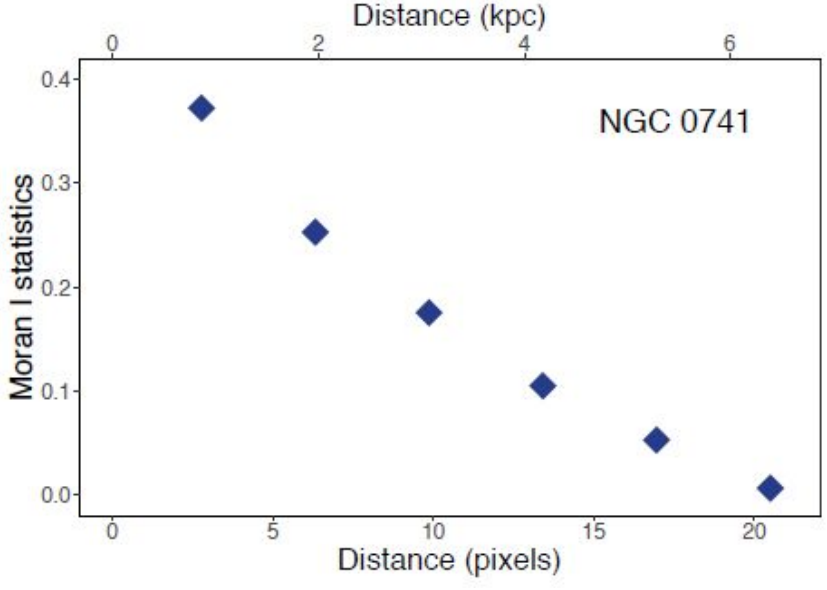
Age map



Correlations arise from:

➔ **physical effects**: physical properties may extend regions that cover several spaxels

➔ **instrumental effects**: crosstalks, multiple fibres within each spaxel (due to dithering in fibre-bundles IFUs)



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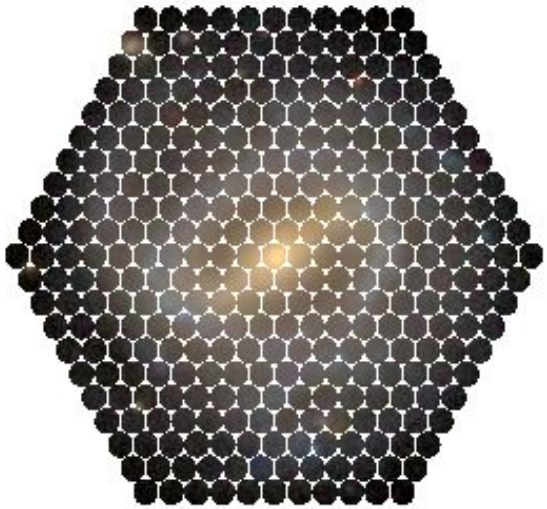
CALIFA SURVEY



Specs: PMAS/PPAK instrument with 382 dibres and hexagonal Field of View of 74”x64” at Calar Alto 3.5m telescope.

Obs: 667 galaxies at z<0.03 + 104 galaxies from CALIFA/PISCO (Sanchez+12,Galbany+18)

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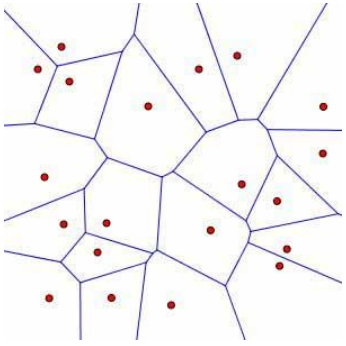
http://califa.caha.es/

Current statistical approaches, in IFU Astronomy, solely based on image-segmentation

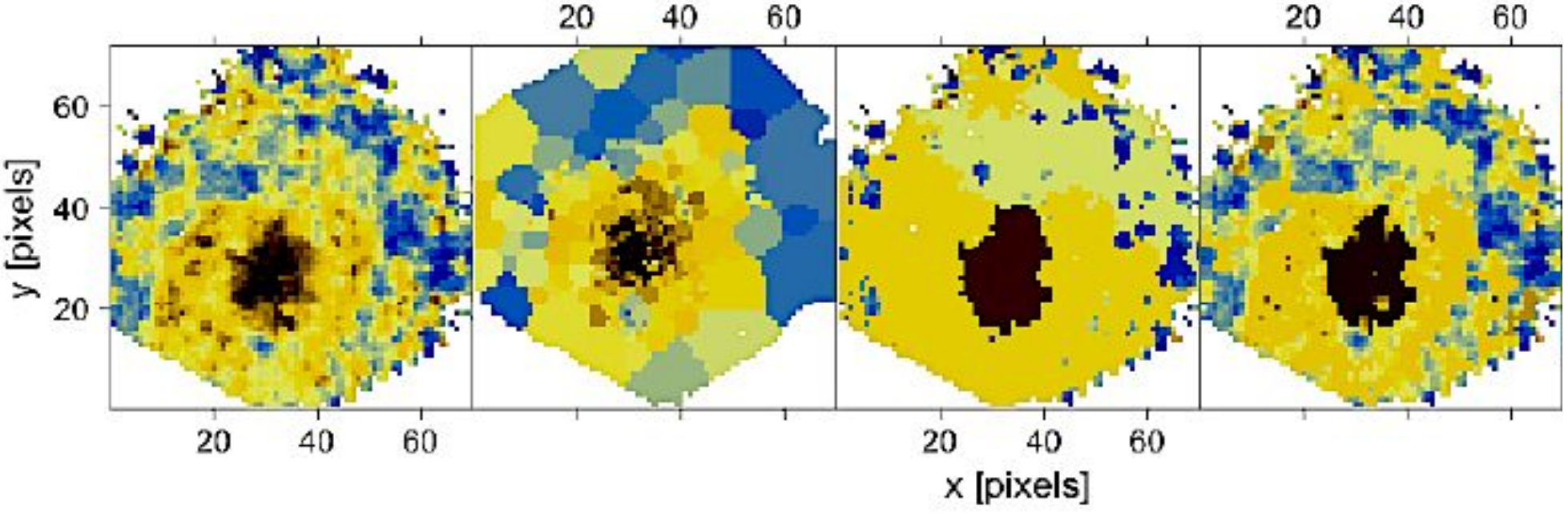
Current approaches are summary statistics-based no real spatial models.

Issues: sparse data; heterogeneous signal to noise, resolution loss.

Voronoi tessellation



Age map | Voronoi | Bayesian Voronoi | Multivariate Bayesian Voronoi



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From CRP #4, Gonzalez-Gaitan et al., 2018 - arXiv:astro-ph/1802.06280

Spatial Modelling

Gaussian Markov Random Field

$$\mathcal{N}_{\mathrm{GMRF}}(\mu, Q) = (2\pi)^{-n/2}|Q|^{1/2}\exp\left(-\frac{1}{2}(x-\mu)'Q(x-\mu)\right),$$

Hierarchical Bayesian Model

$$\begin{aligned} z_i &\sim \mathcal{N}(f(x_i), \sigma_i^2), \\ f(\cdot) &= g(\cdot) + h(\cdot), \\ g(\cdot) &\sim \mathcal{N}_{\mathrm{GMRF}}[\sigma, \kappa], \\ h(\cdot) &= \alpha + \beta \times \mathrm{edist}(\cdot), \\ \sigma, \kappa, \alpha, \beta &\sim \pi. \end{aligned}$$

Physical quantity (age, metallicity, etc.)

Allows global radial profile

Integrated Nested Laplace Approximation (INLA)

Fast Bayesian inference

From CRP #4, Gonzalez-Gaitan et al., 2018 - arXiv:astro-ph/1802.06280

Spatial field reconstruction with INLA: Application to IFU galaxy data

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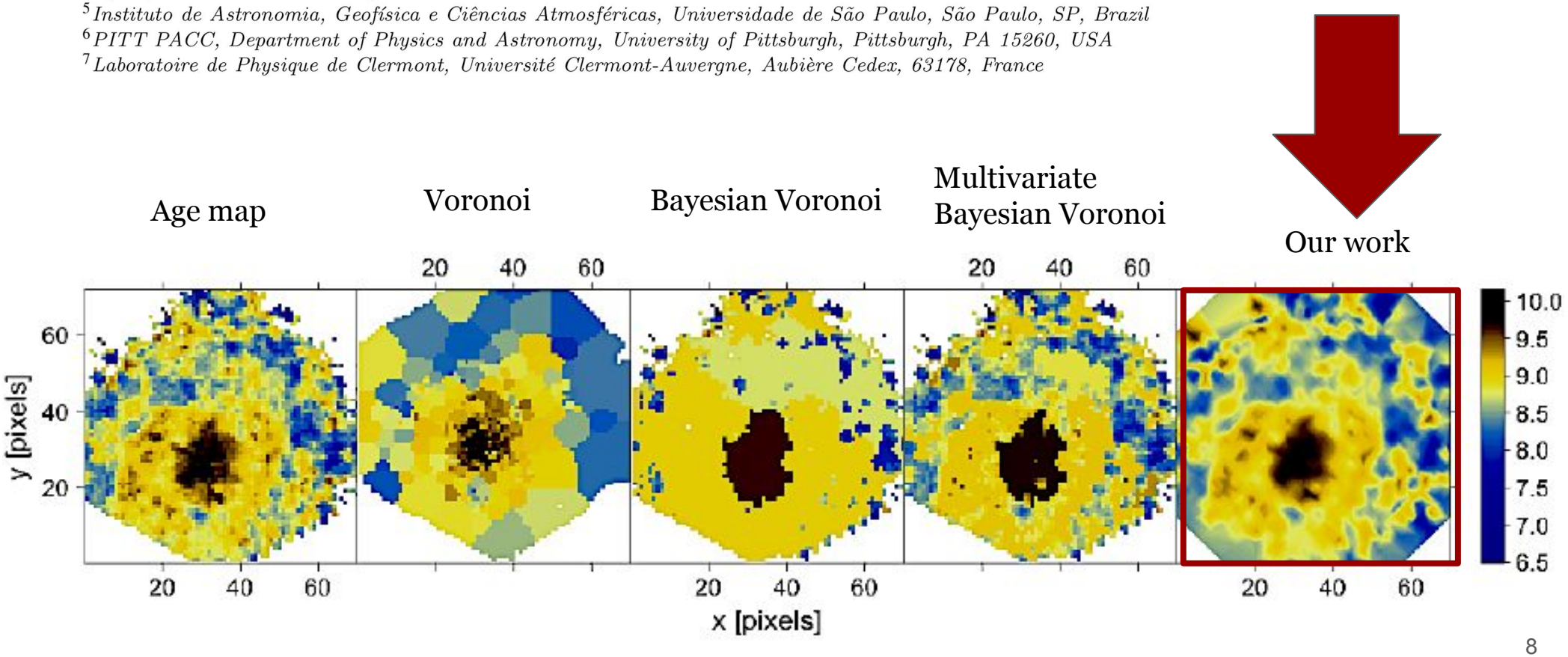

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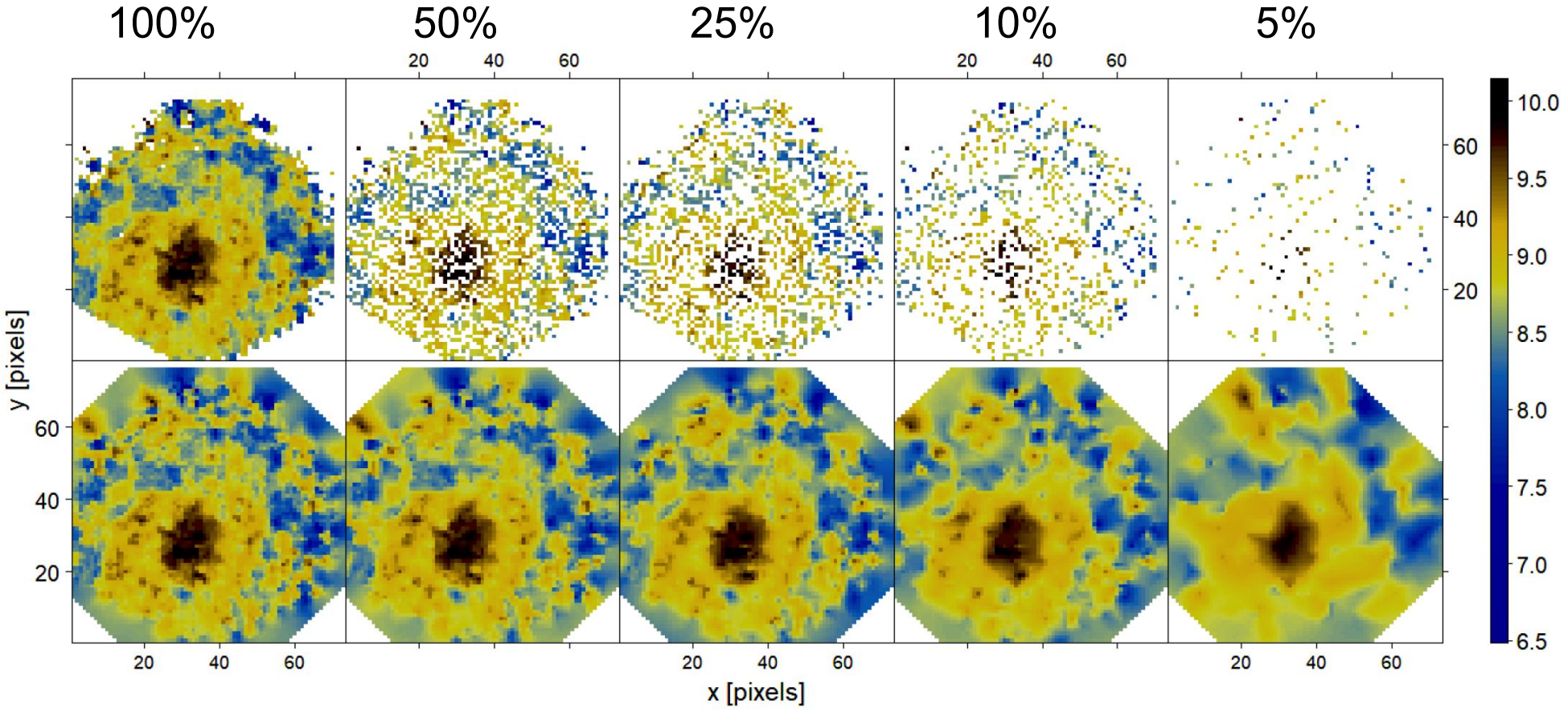
Reconstruction of missing data (Inpainting)

Age Map



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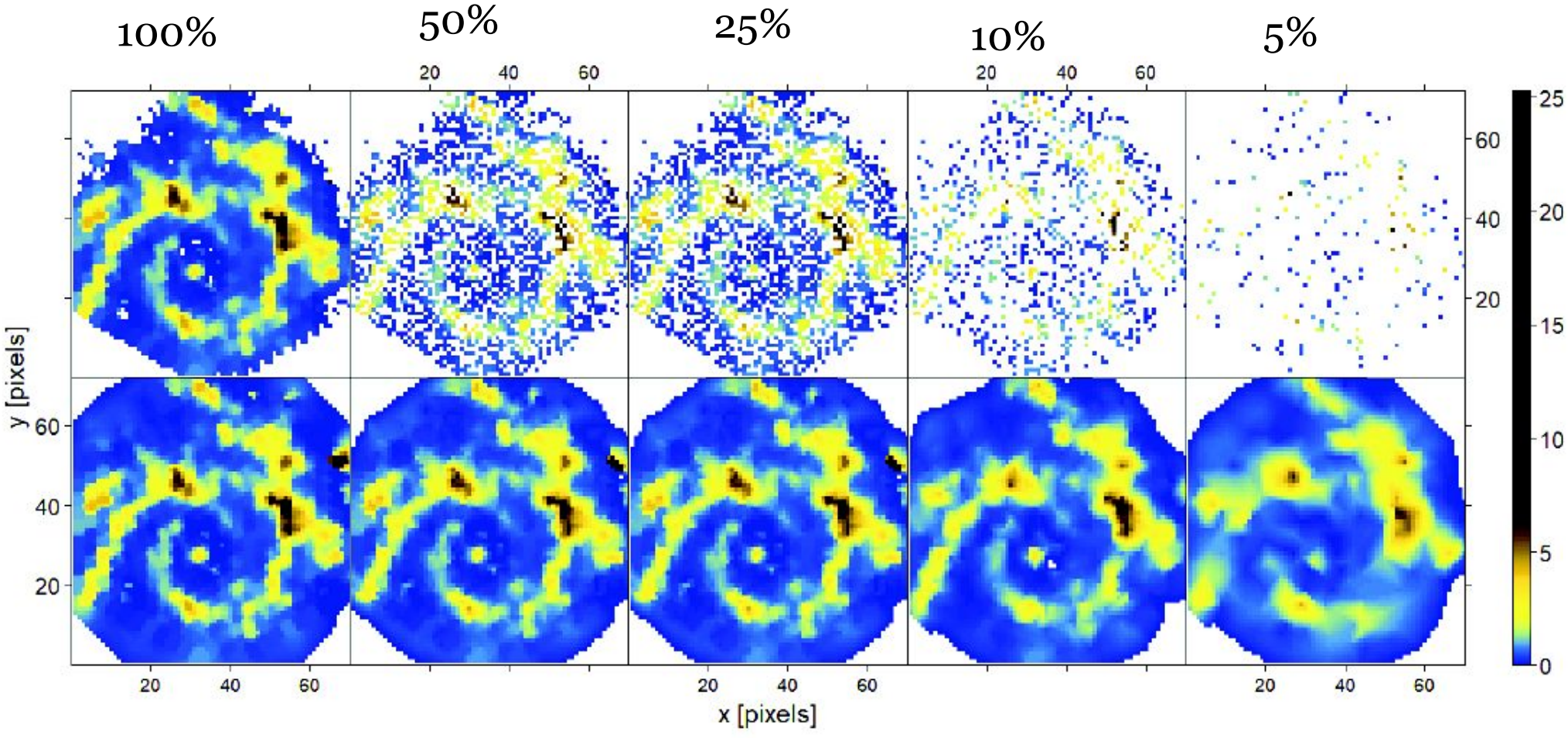
Reconstruction of missing data (Inpainting)

EW(Hα)



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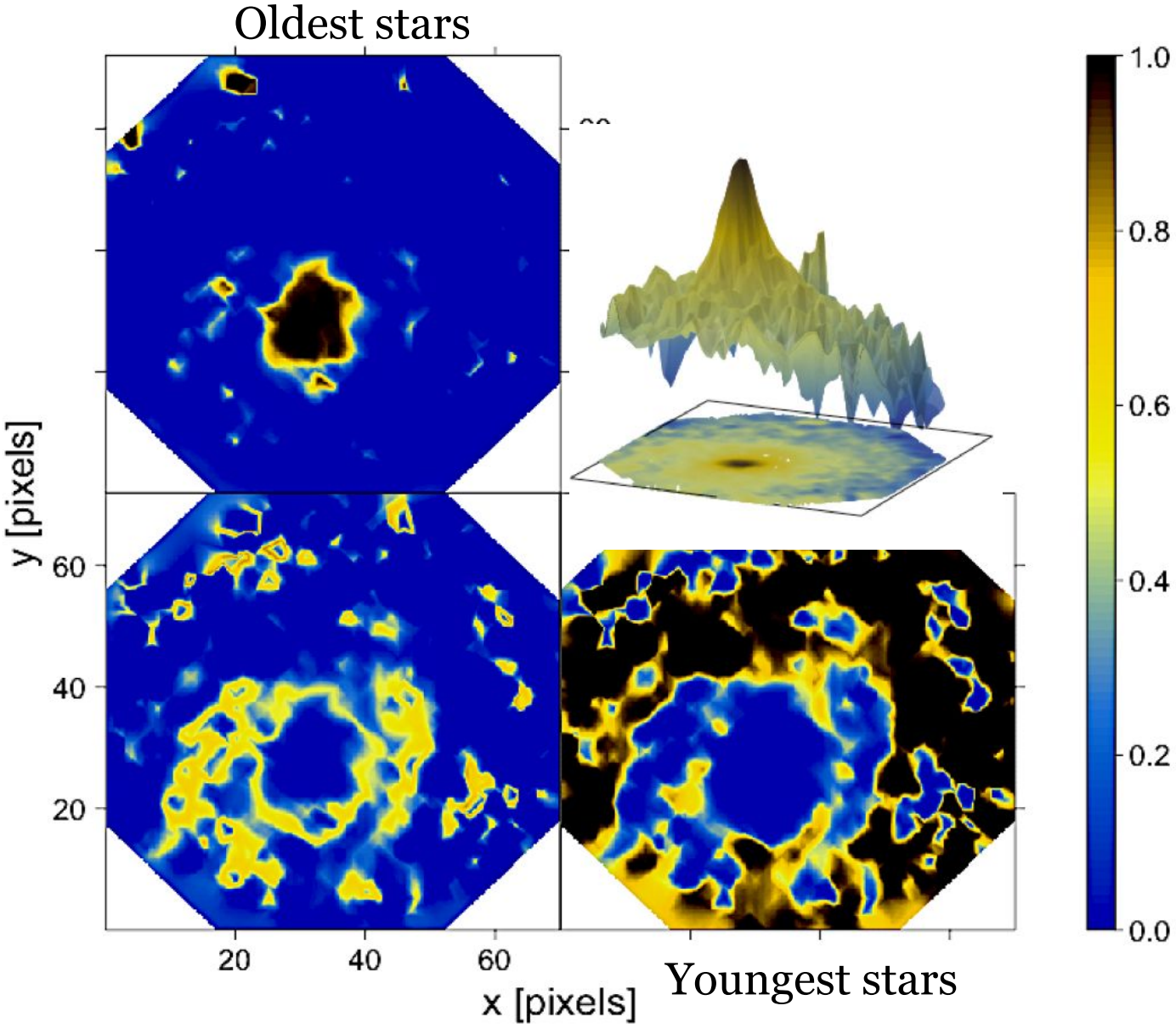
Probabilistic Description



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Software

Our paper has been submitted: arXiv:astro-ph/1802062806

We provide snippet codes and data products:
https://github.com/COINtoolbox/Galaxies_INLA

R-INLA is an available software written in R largely used in many fields **outside** of astronomy: http://www.r-inla.org/

INCREDIBLE POTENTIAL FOR ASTRONOMY!

For any spatially resolved environment, clusters, galaxies, CMB, interferometry, N-body simulations and much more...

Use it in your research!!
Recommend it!

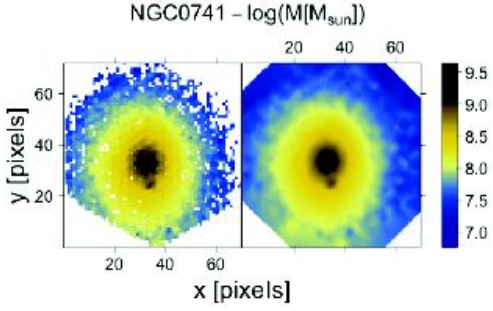
Slide by Santiago Gonzalez-Gaitan

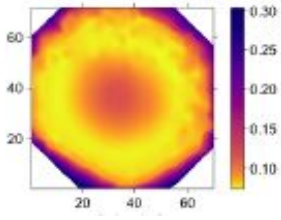
https://github.com/COINtoolbox/Galaxies_INLA

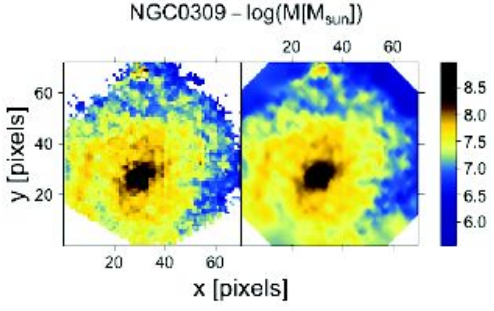
Thank you!

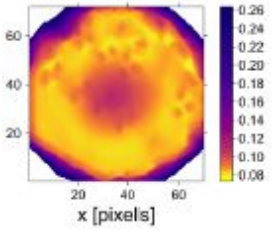
Results on CALIFA maps: **errors**

Given the Bayesian nature of INLA, we can obtain errors assuming here normally distributed 1sigma of posteriors

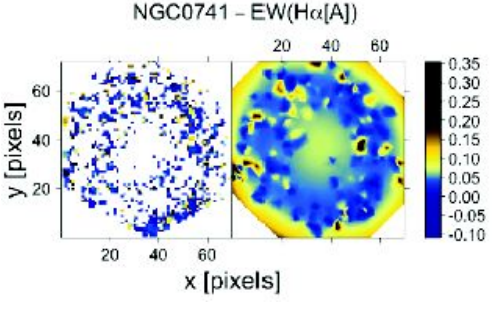


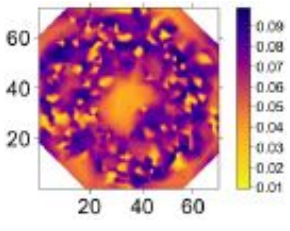


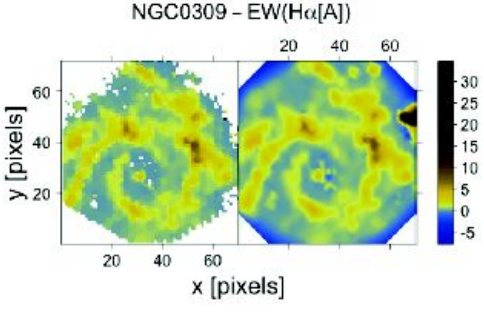


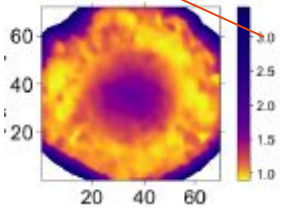


Most uncertain areas at edges where data is missing









Summary and outlook

- INLA is a powerful technique to model spatial fields taking into account spatial correlations
- INLA uses a) Gaussian Markov Random Fields to model space and b) Integrated Laplace Approximation for Bayesian inference
- R-INLA provides an efficient free supported software for immediate application
- INLA has been extensively used in geostatistics and this is its first use in astronomy (to our knowledge) with **IMMENSE POTENTIAL** in many areas of astronomy
- Finally, the INLA model, besides a single input parameter, could handle more complicated multi-dimensional models (future work)