Spatial field reconstruction with INLA: application to IFU galaxy data

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Astrostats club

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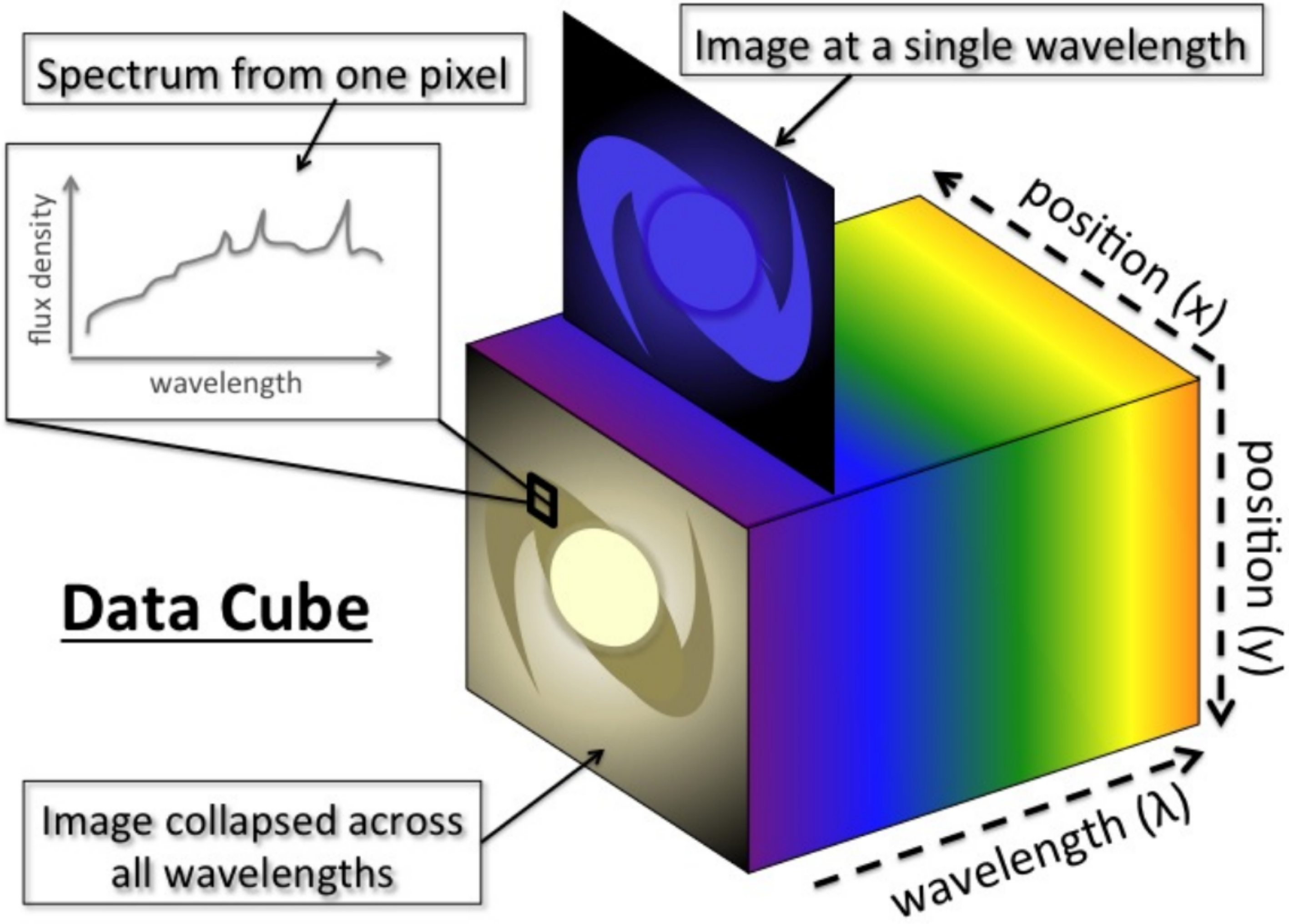
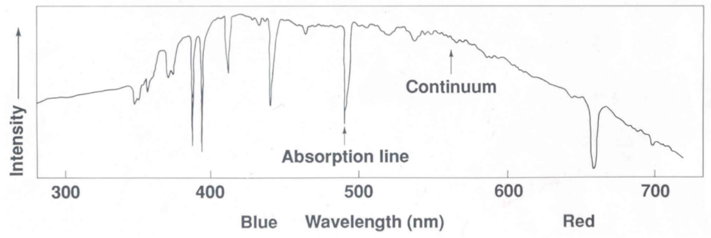
IFU data

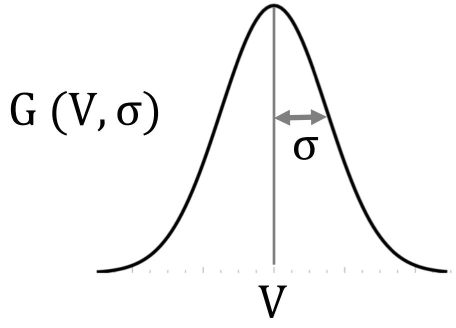

Spectrum from one pixel
flux density
wavelength
Image at a single wavelength
position (x)
position (y)
wavelength (λ)
Data Cube
Image collapsed across all wavelengths

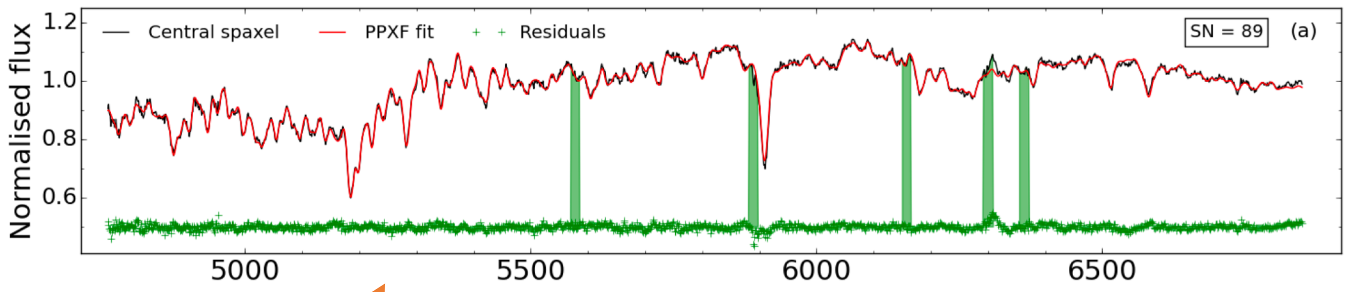
Stellar Spectrum template

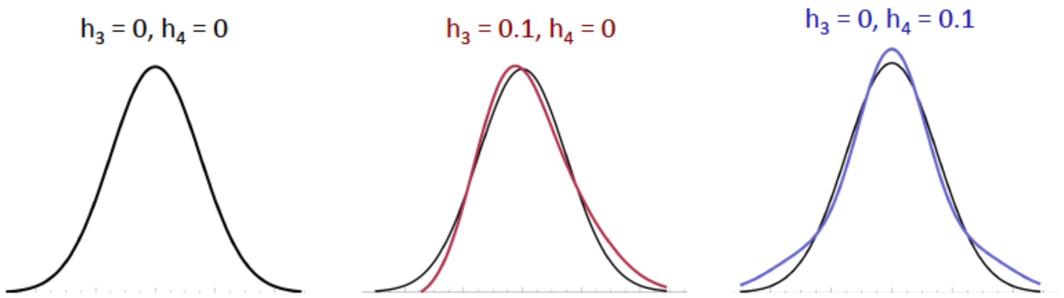


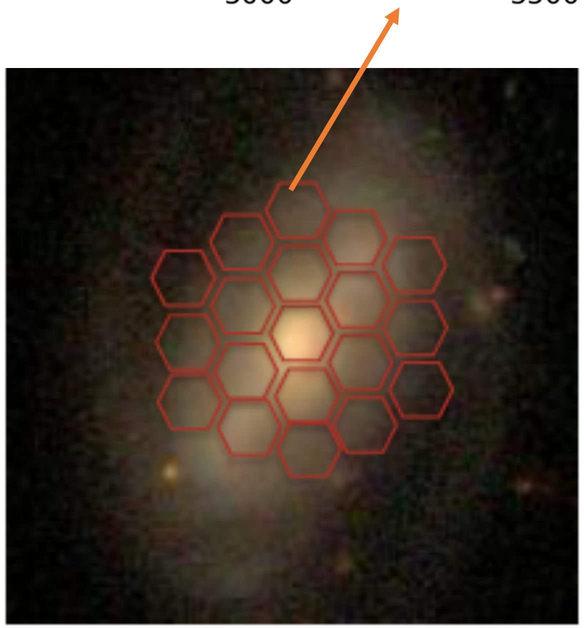
By spectral fitting we can get Age, metallicity and kinematics

LOS Velocity distribution

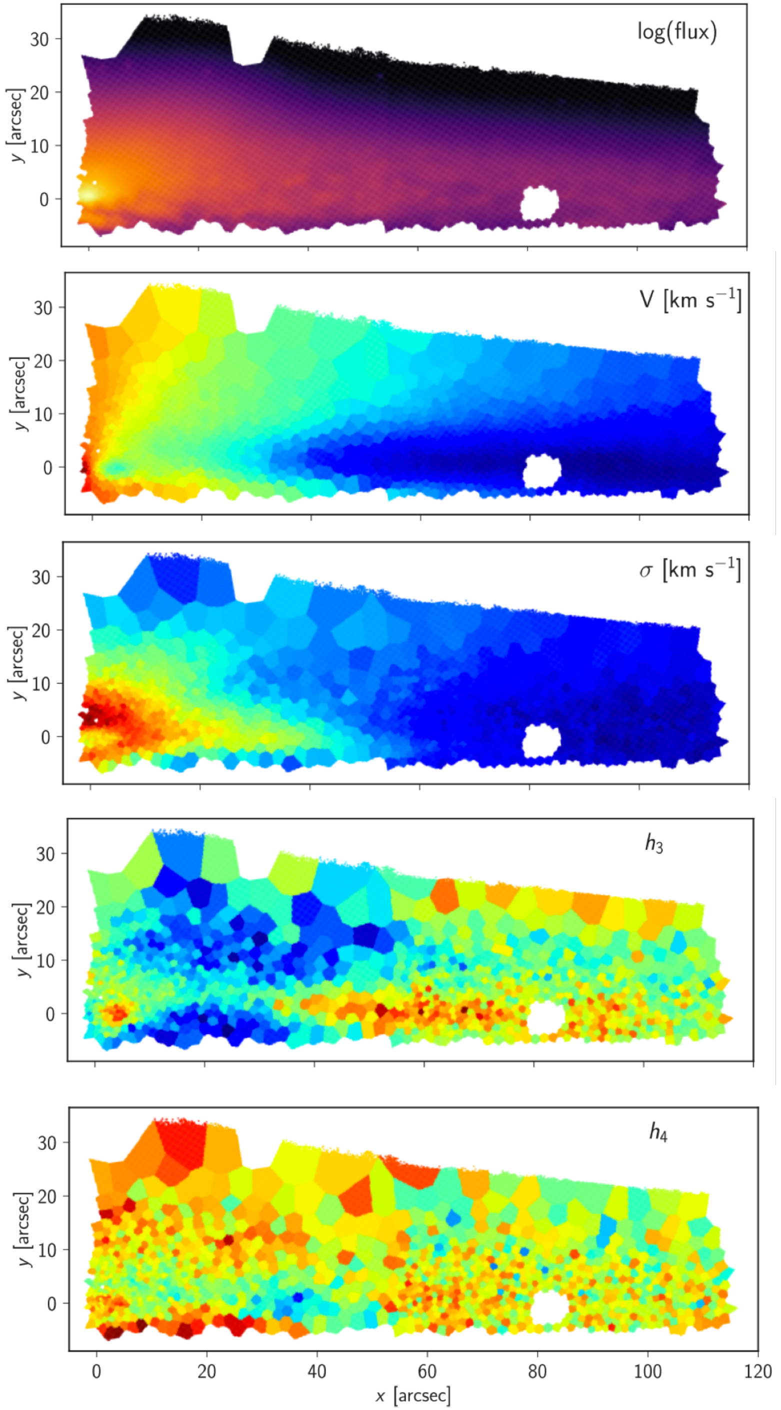


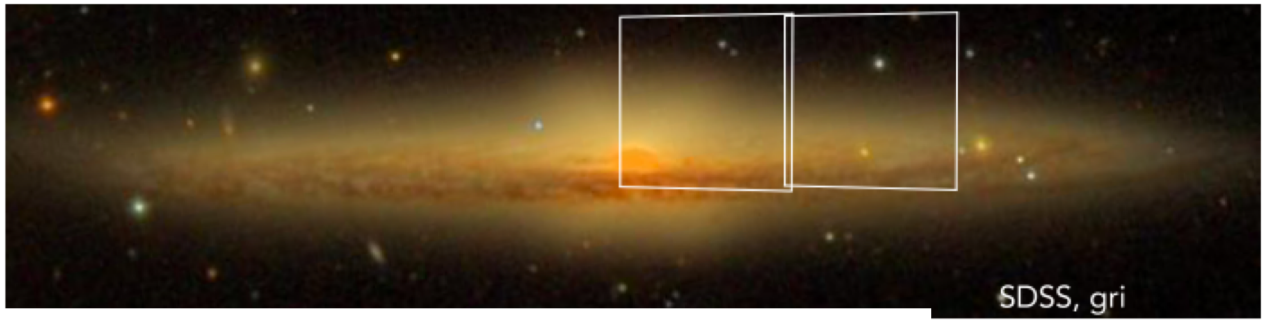






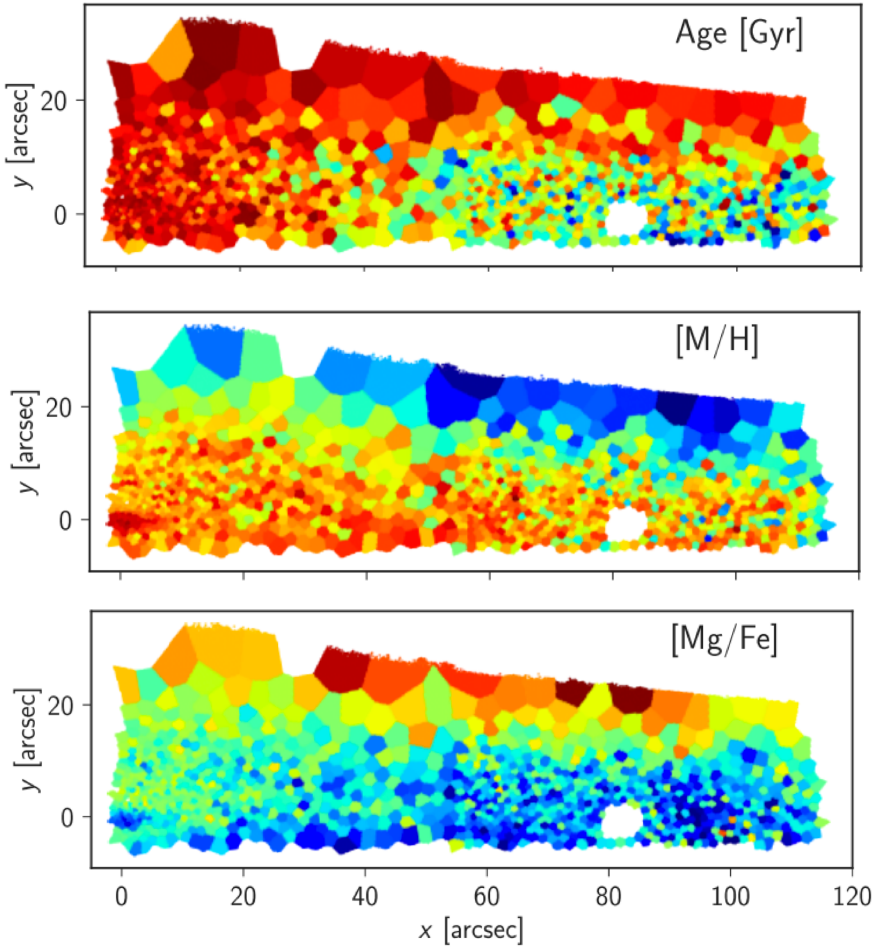
ATLAS 3D: 260 early type galaxies
CALIFA: 300 all Hubble types, filed galaxies
MANGA: ~10,000, all Hubble types, filed galaxies
SAMI: a few thousands, galaxies in clusters



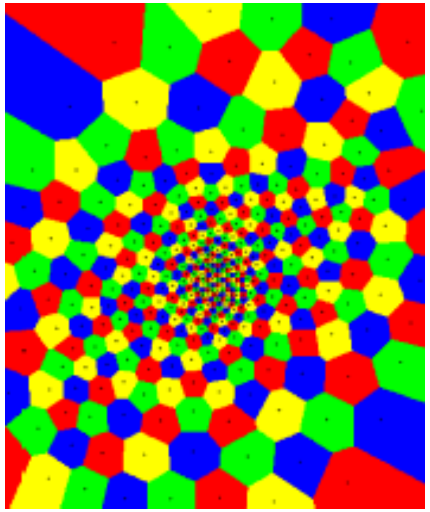


NGC 5746

MUSE observations



Voronoi tessellation



Marie Martig et al. 2021

The integrated nested Laplace approximation (INLA)

- A method for approximate Bayesian inference.
- Focuses on models that can be expressed as latent Gaussian Markov random fields (GMRF)
- Faster then other methods such as Markov chain Monte Carlo.
- Ease of use via the R-INLA package.

Method: The integrated nested Laplace approximation (INLA)

- Bayesian inference

$$p(\theta|y) = \frac{\mathcal{L}(y|\theta)\pi(\theta)}{\int \mathcal{L}(y|\theta)\pi(\theta)\mathrm{d}\theta}.$$

- Treat the entire matrix as a realization of an underlying random field of a given property.

e. g. In other words, if treating an age map, the age at a given pixel is not treated as independent, but as spatially correlated to the estimated ages in nearby pixels

- Assumption: For a given property z, normally distributed around the i-th pixel with mean value μi and variance σ2px.

$$z_i \sim \mathcal{N}(\eta_i, \sigma^2_{px}),$$
$$\eta_i = \mu_i.$$

- To approximations of continuous random fields. This work use Gaussian Markov random fields.

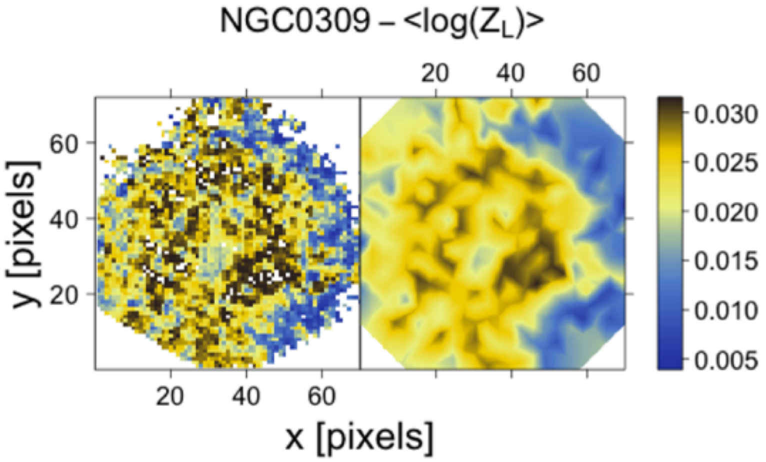
With the GMRF definition in place, The model for the spatial distribution of measured galaxy properties can be written in Bayesian.

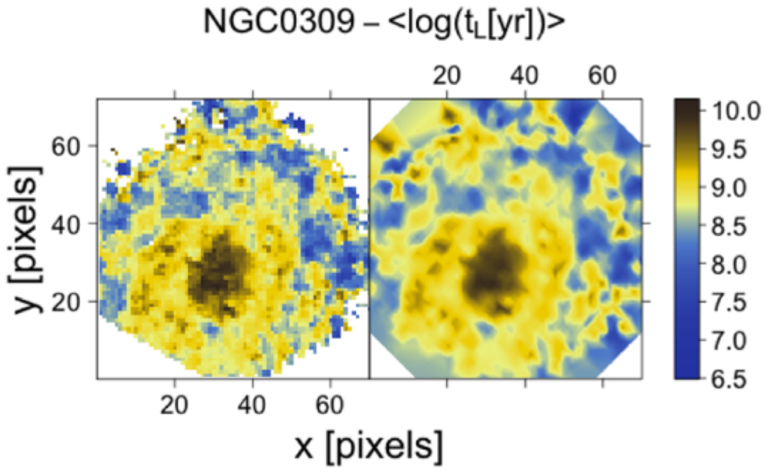
latent image

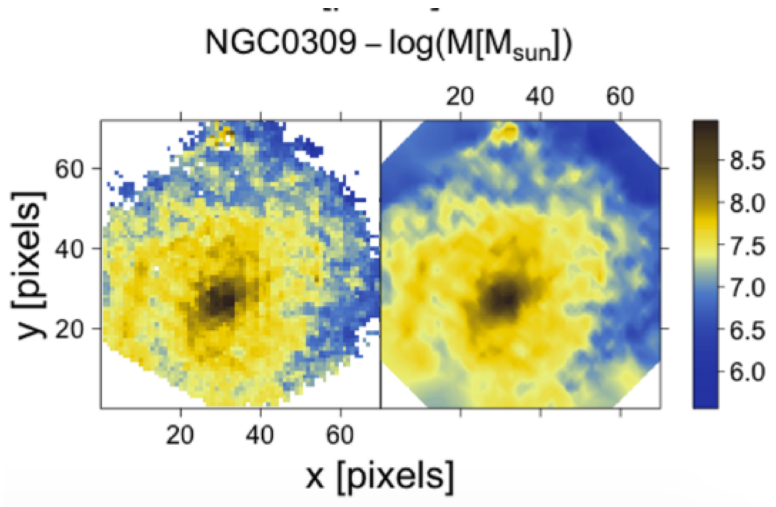
$$
\begin{aligned}
z_i &\sim \mathcal{N}(f(x_i), \sigma_i^2), \\
f(\cdot) &= g(\cdot) + h(\cdot), \\
g(\cdot) &\sim \mathcal{N}_{\mathrm{GMRF}}[\sigma, \kappa], \\
h(\cdot) &= \alpha + \beta \times \mathrm{edist}(\cdot), \\
\sigma, \kappa, \alpha, \beta &\sim \pi.
\end{aligned}
$$

INLA Applications in Astronomy

- Dealing with noisy data



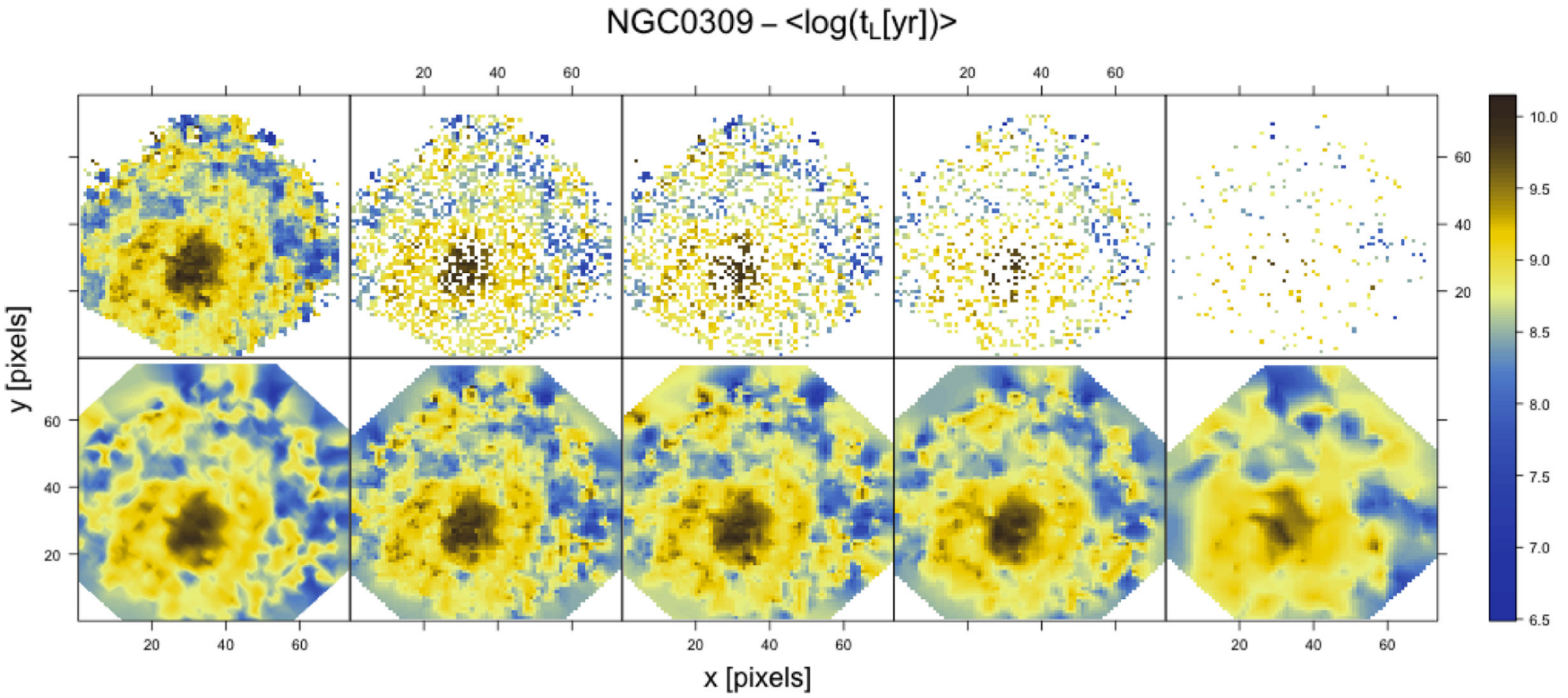




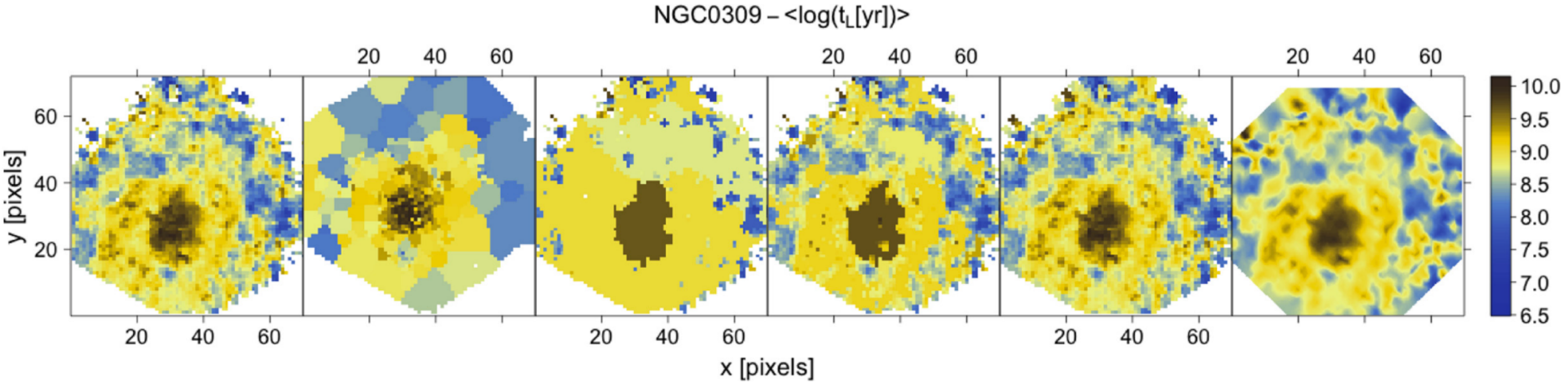
- INLA prediction is not a smoothing convolution of the original data
- Nor does it degrade unnecessarily the image resolution by prior binning of the maps to increase the signal.

- INLA is able to reconstruct the missing data points

Predictions from INLA for input STARLIGHT age of NGC0309 when 100, 75, 50, 25, and 5 % of the data are used.



Comparison to other techniques



STARLIGHT map Voronoi tessellation BATMAN INLA's prediction

Thank you