Bayesian Inference of the 3D Galactic HI-Gas Density

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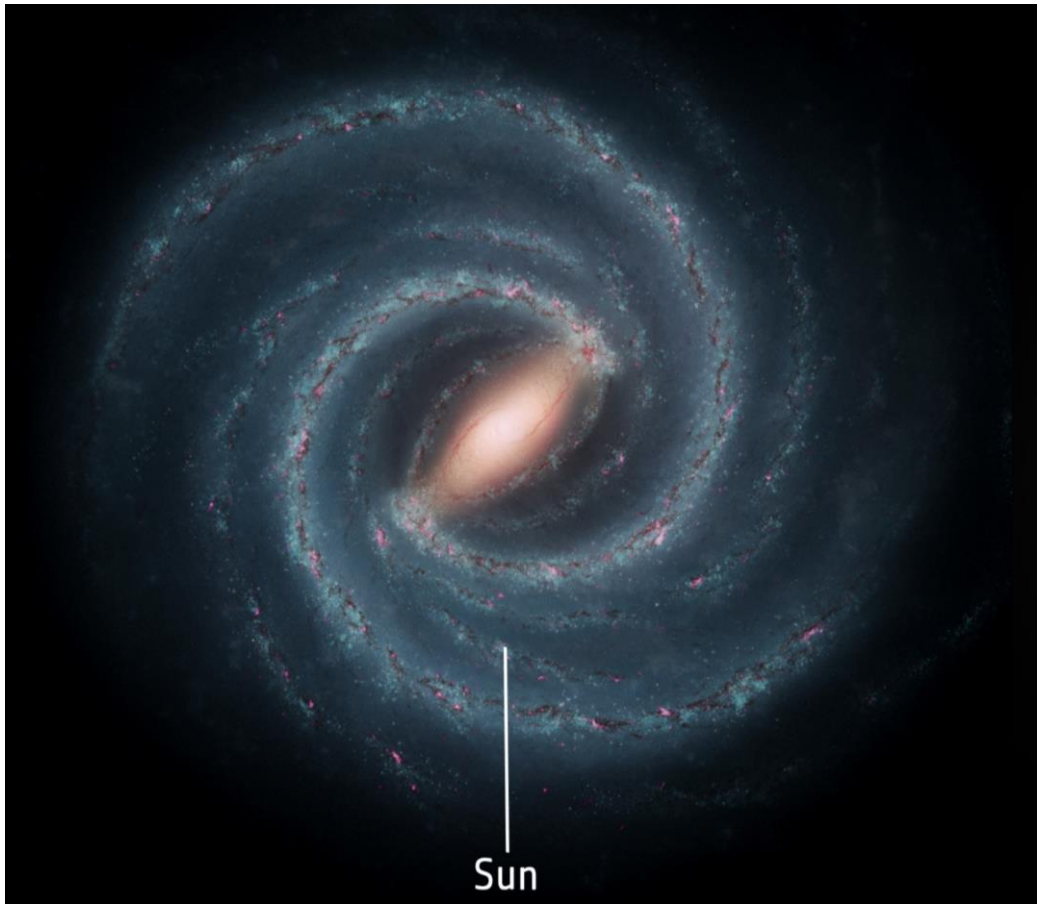
Structure of the Milky Way?



(Artist's impression; NASA/JPL-Caltech)

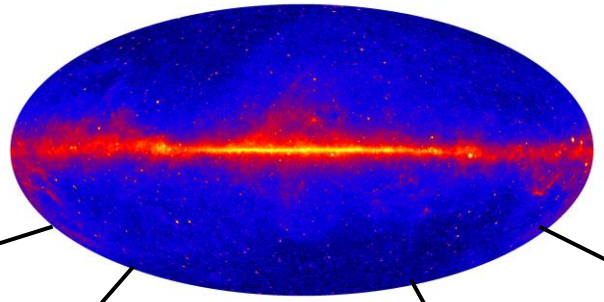
Structure of the Milky Way is obstructed from our view due to our vantage point!

In order to understand our galaxy better, we want to learn about:

- Stars
- Dust
- Gases
- Magnetic fields
- Cosmic rays
- etc…

Gamma-ray sky

(Diffuse) gamma-ray sky



(Fermi LAT Collaboration)

Cosmic rays

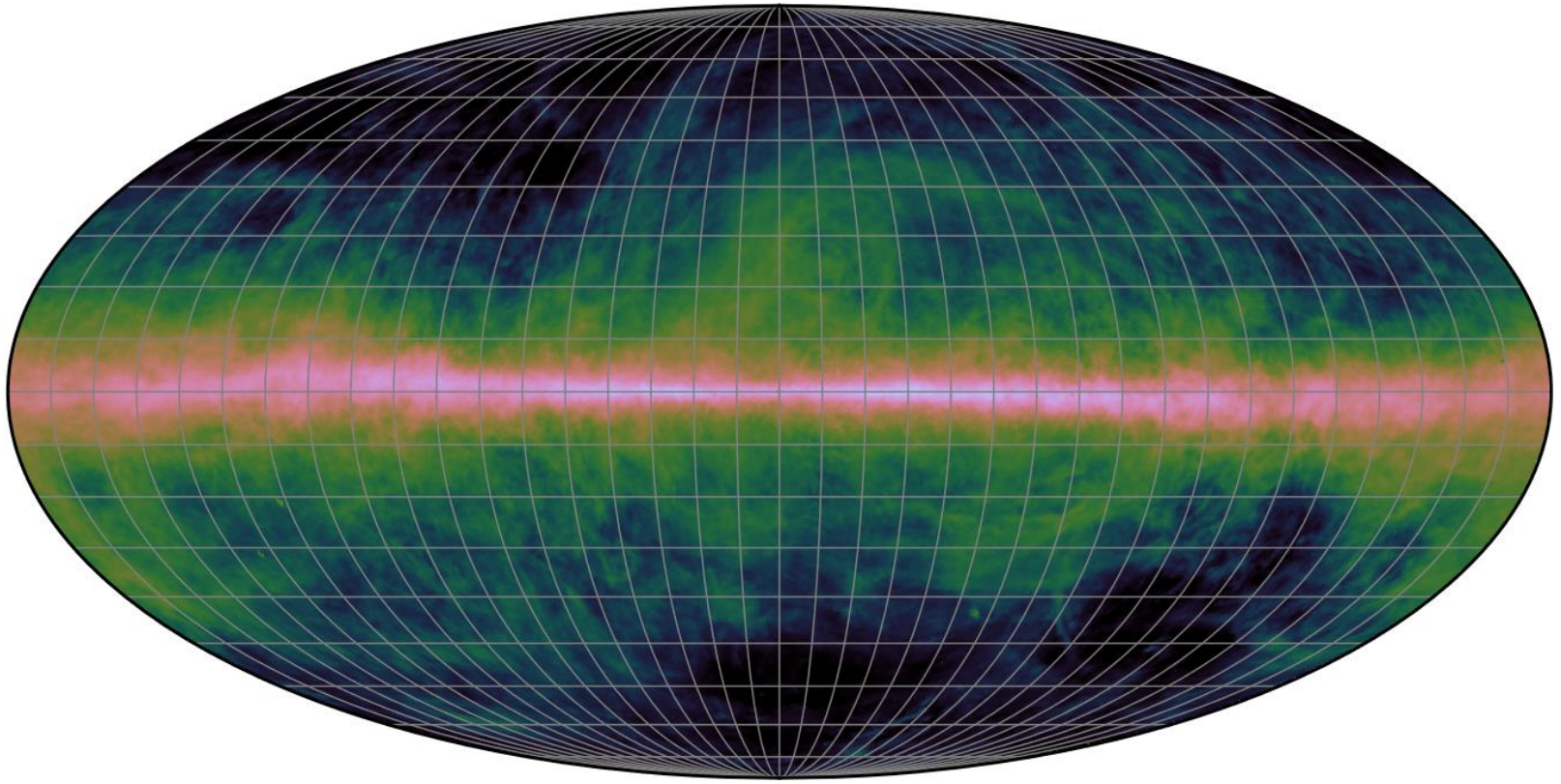
Magnetic fields

Gases

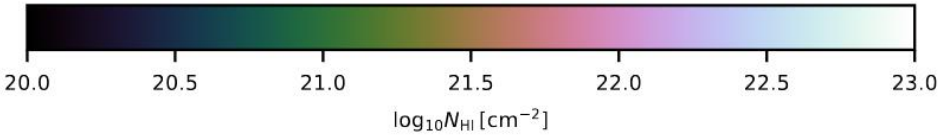
Interstellar radiation fields

Neutral hydrogen (HI)

Observed Data: 21cm-Line



(HI4PI collaboration (2016))



HI4PI: full sky survey

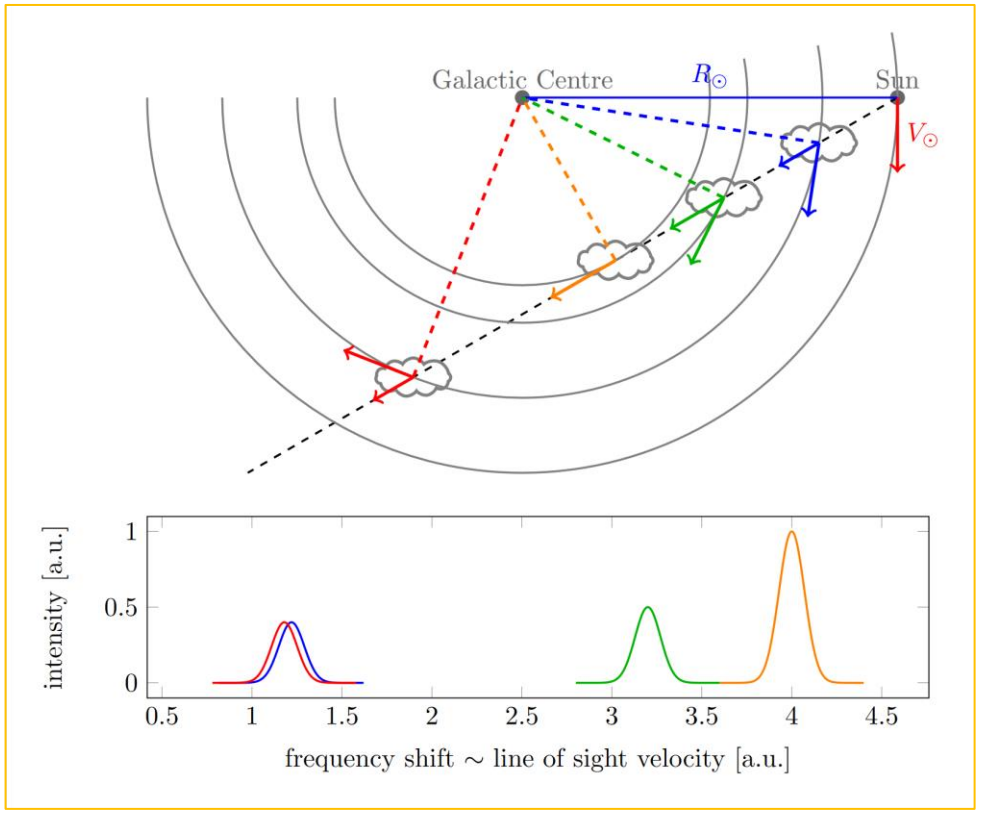
- 21cm fine structure transition
- Doppler shifts from relative motion

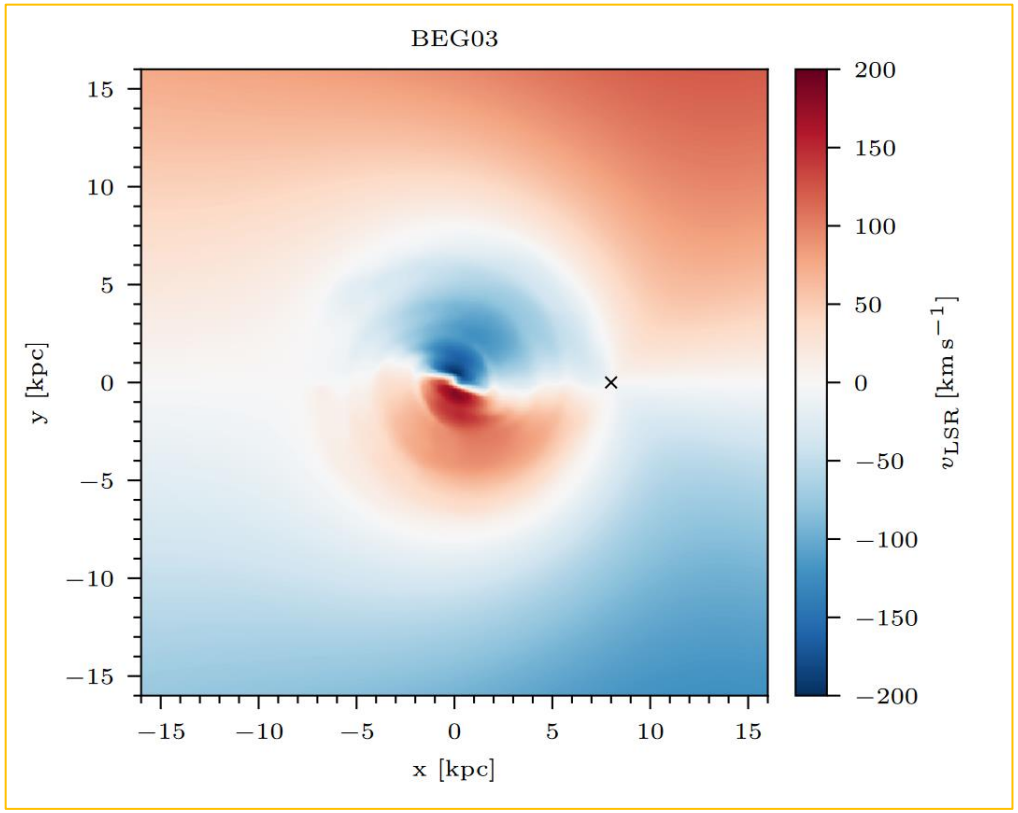
→ Dataset in direction and frequency

→ Inversion problem

Reconstruction

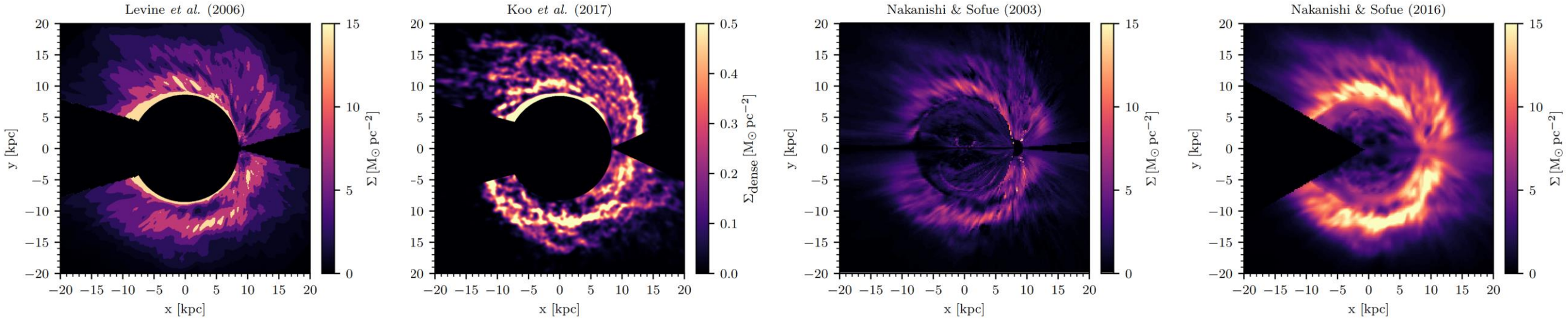
Line-of-sight velocity model + observed frequency shift = distance





Problem: not unique!

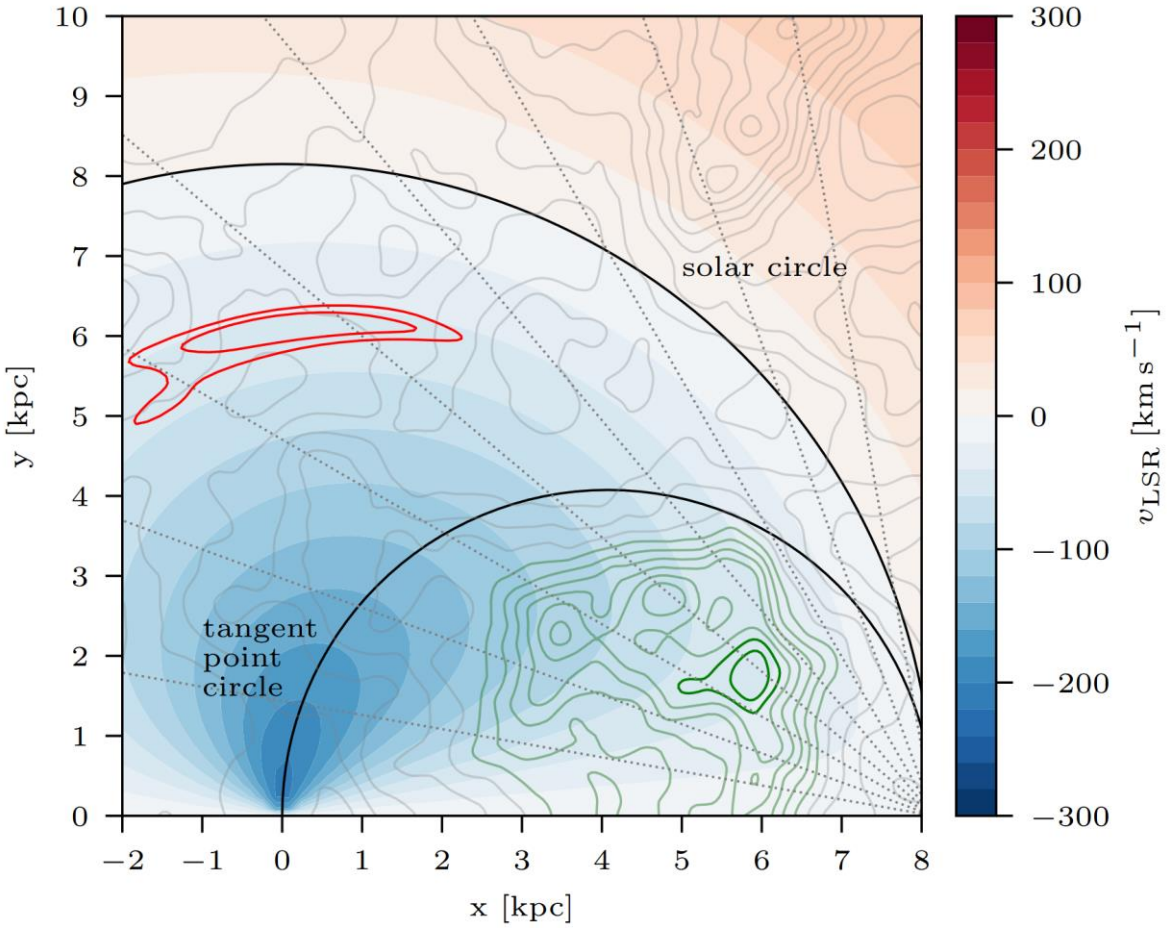
Previous Maps



Commonality: Treating every line-of-sight independently!

Need to exploit correlations between neighbouring line-of-sights!

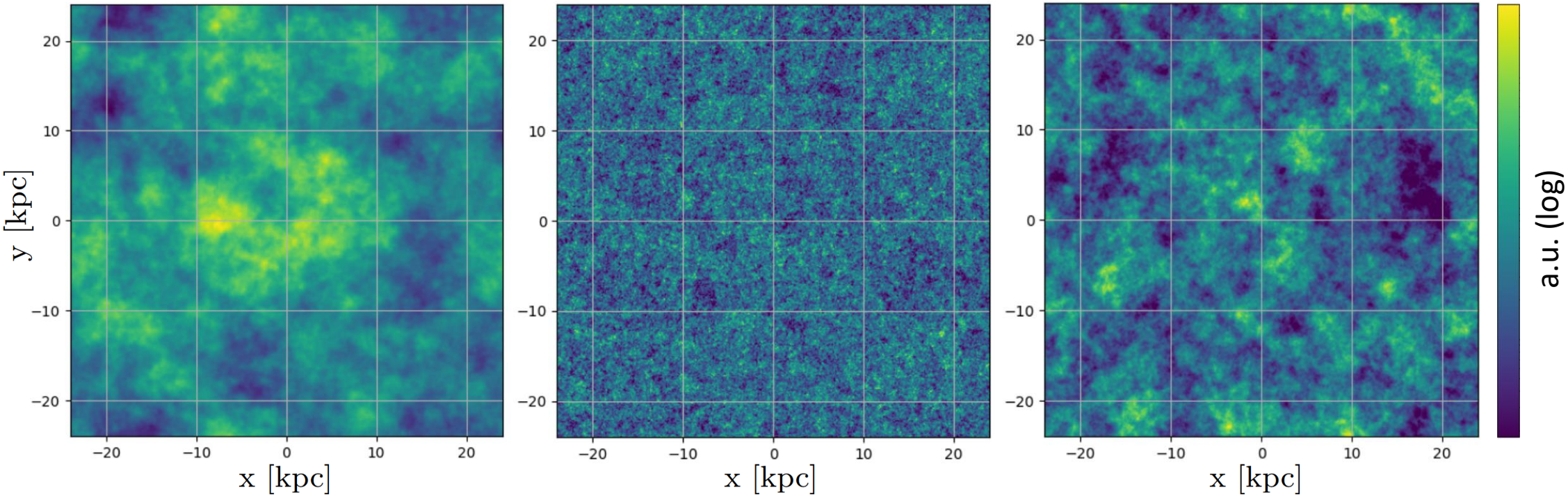
Regularisation 1



- Near-by line-of-sights are not independent of each other!
- Structures should look “undistorted”

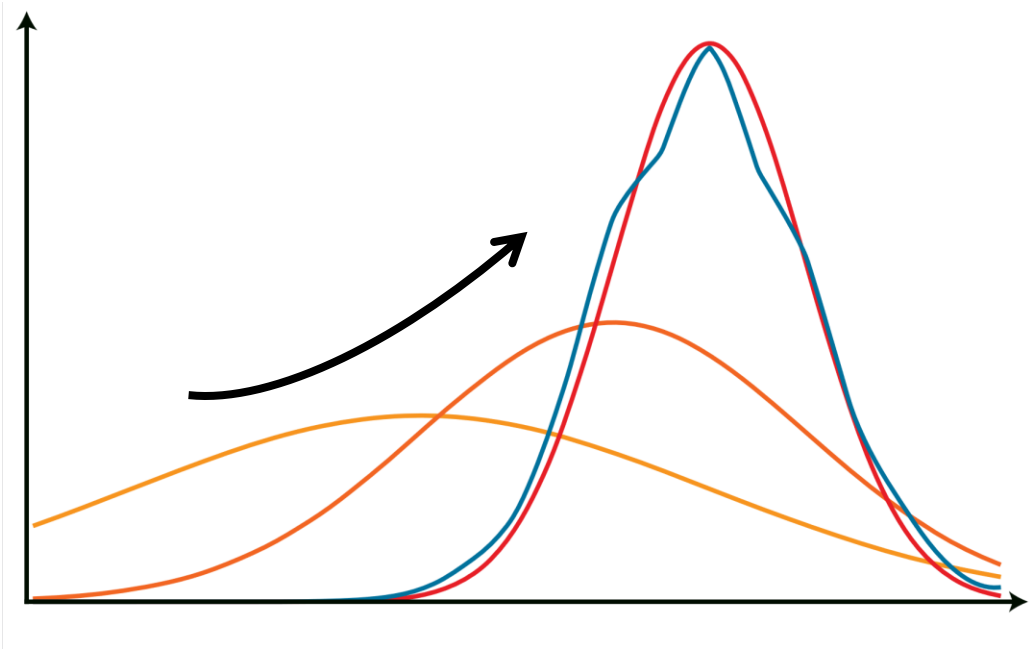
Regularisation 2

Gas distribution as realisation of correlated lognormal random field!



Reconstruct correlation structure together with the gas density!

Method: Metric Gaussian Variational Inference



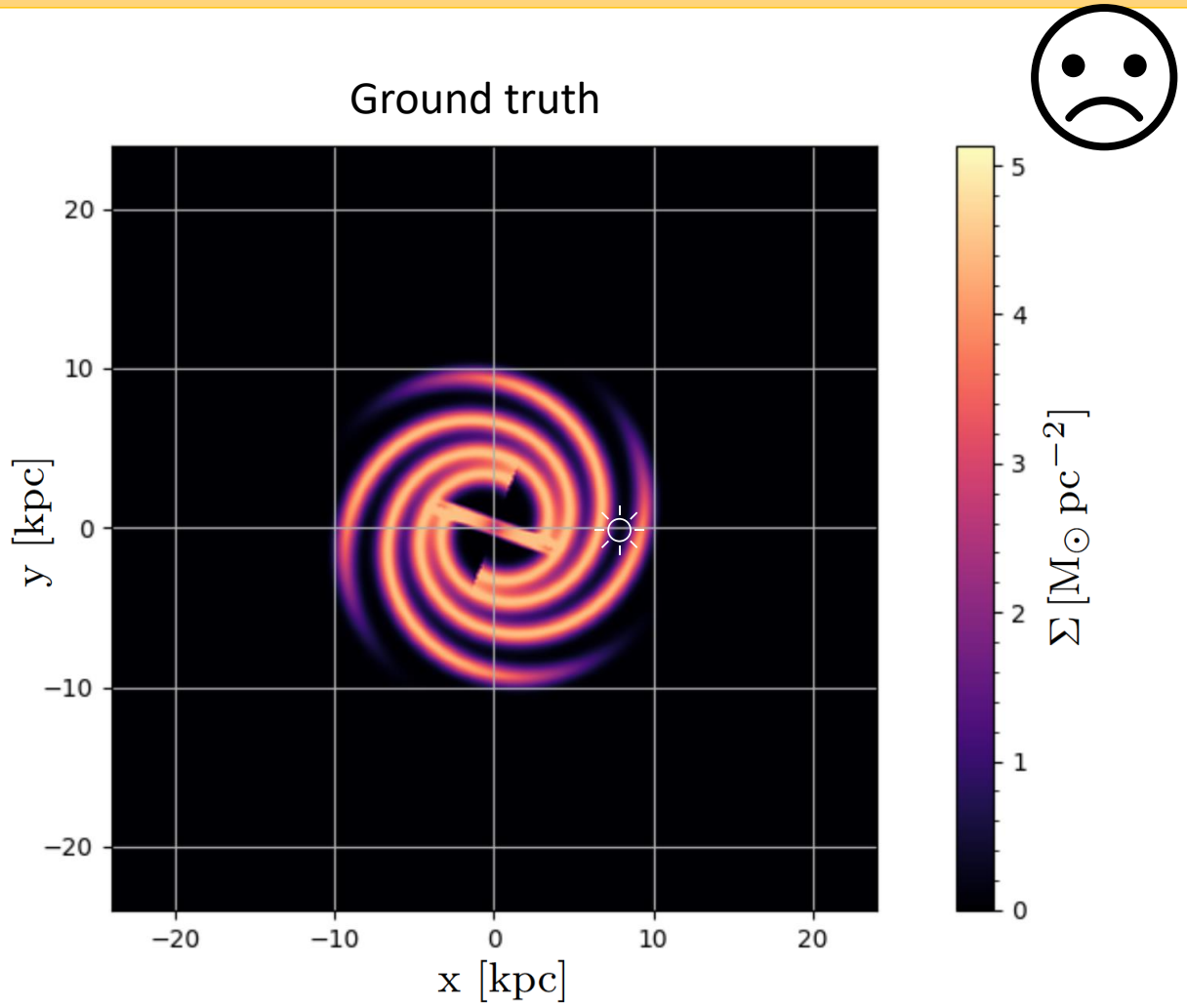
Bayes' theorem:

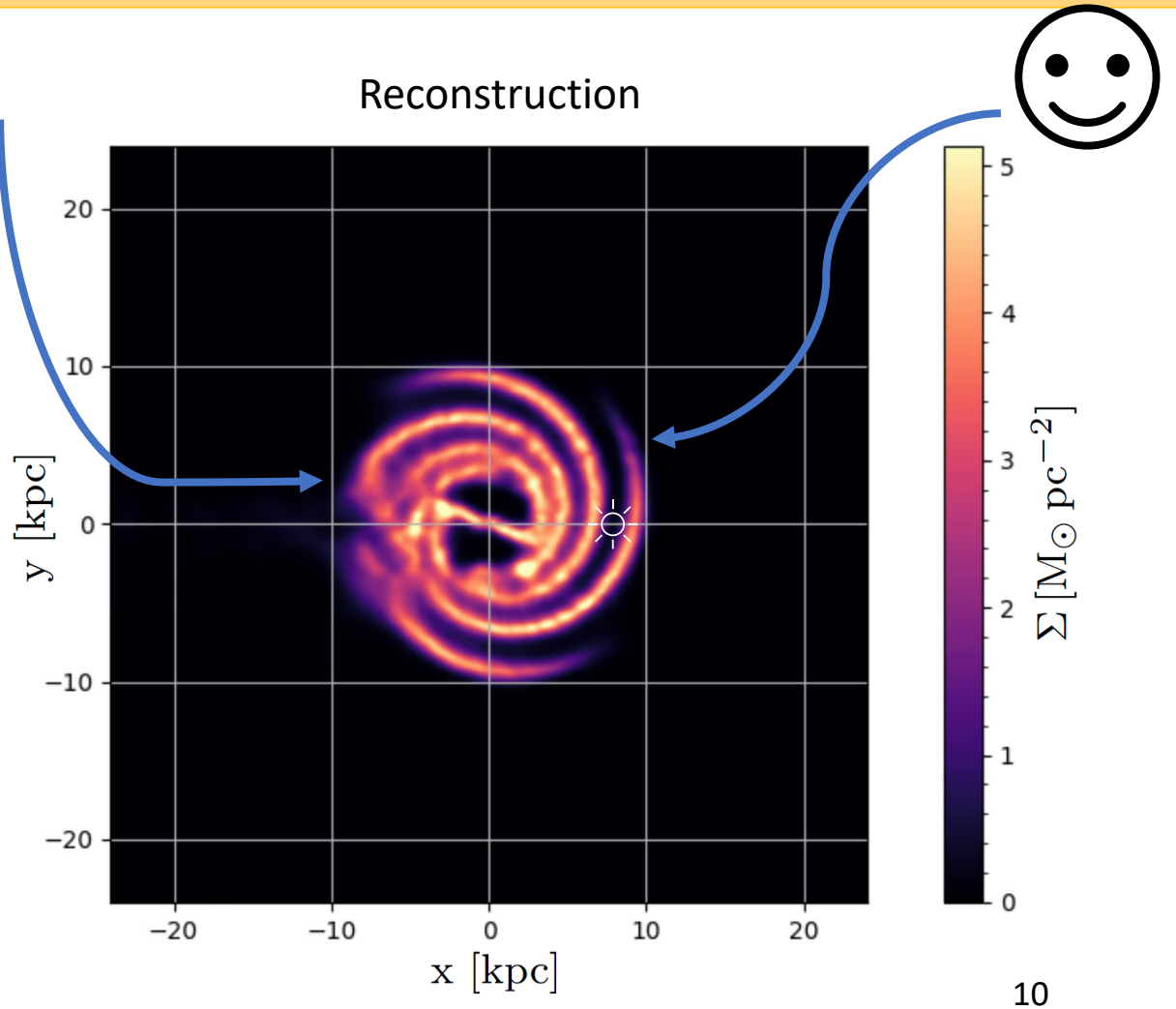
$$\underbrace{p(\text{3D}-\text{Gas}|\text{data})}_{\text{Posterior}} \propto \underbrace{p(\text{data}\,|\text{3D}-\text{Gas})}_{\text{Likelihood}}\,\underbrace{p(\text{3D}-\text{Gas})}_{\text{Prior}}$$

1. Adopt parametric distribution for posterior
2. Estimate "distance" from true posterior via Kullback-Leibler-Divergence
3. Approximate covariance matrix with Fisher matrix
4. Update posterior estimation
5. Repeat

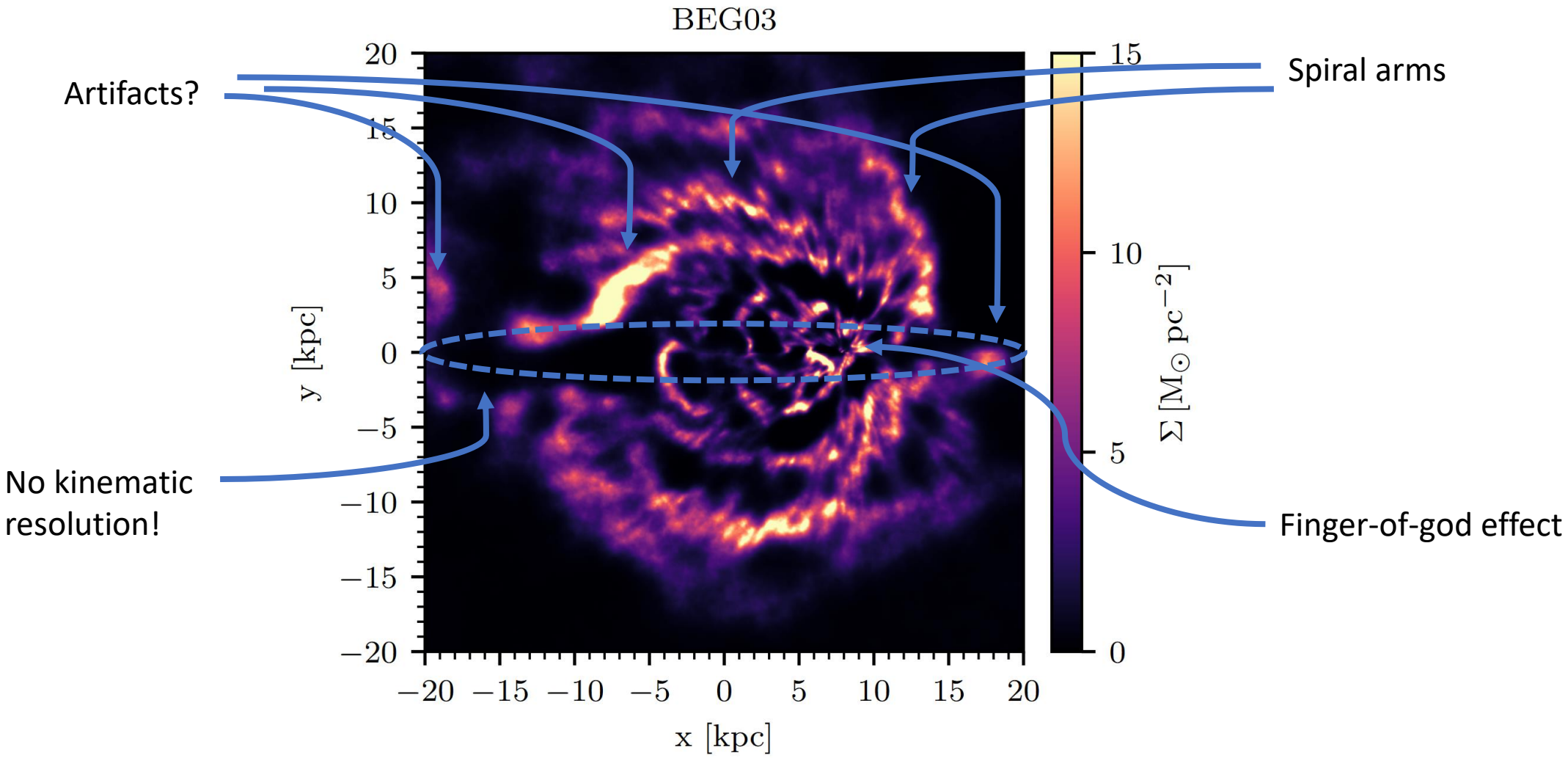
(Knollmüller and Enßlin (2019))

Results 1: Verification of the Algorithm





Results 2: Application to HI4PI-Dataset

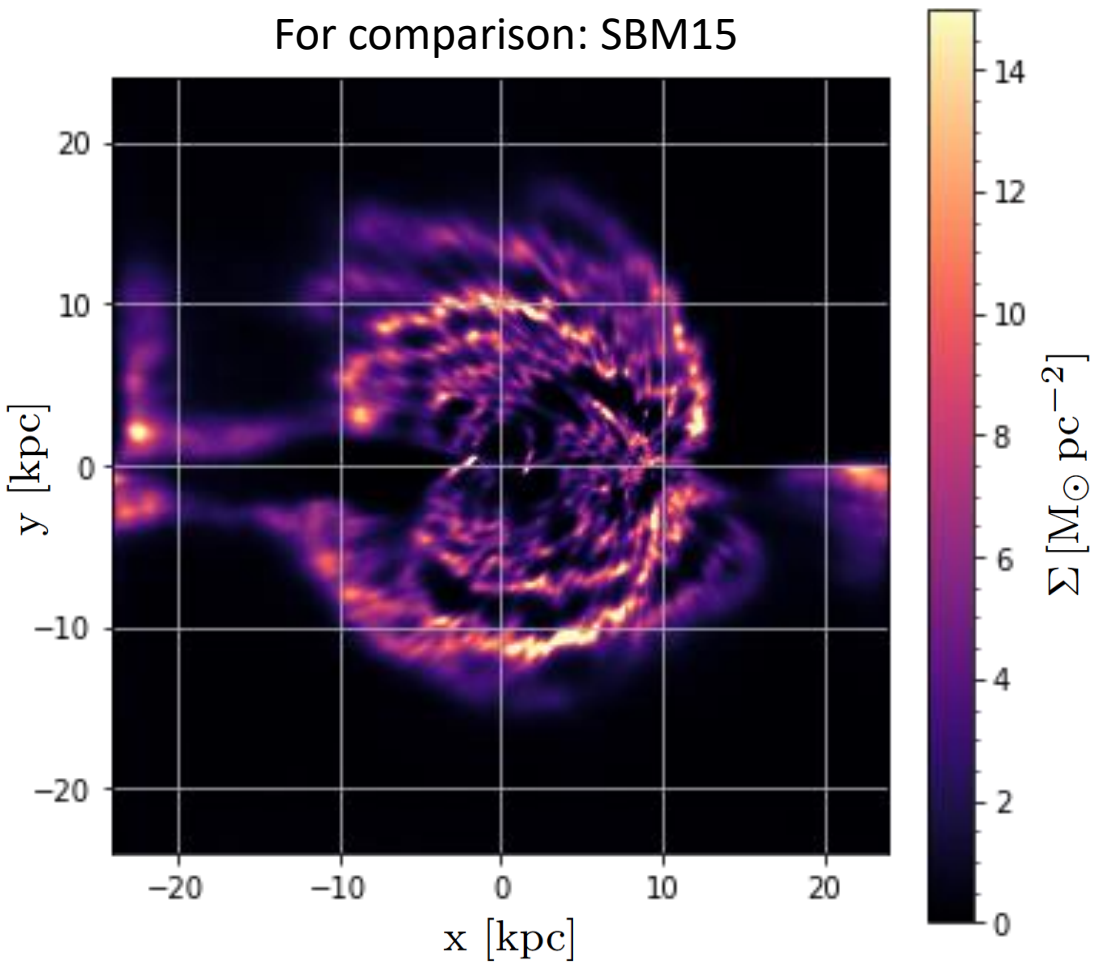


Biggest Problems and Prospects

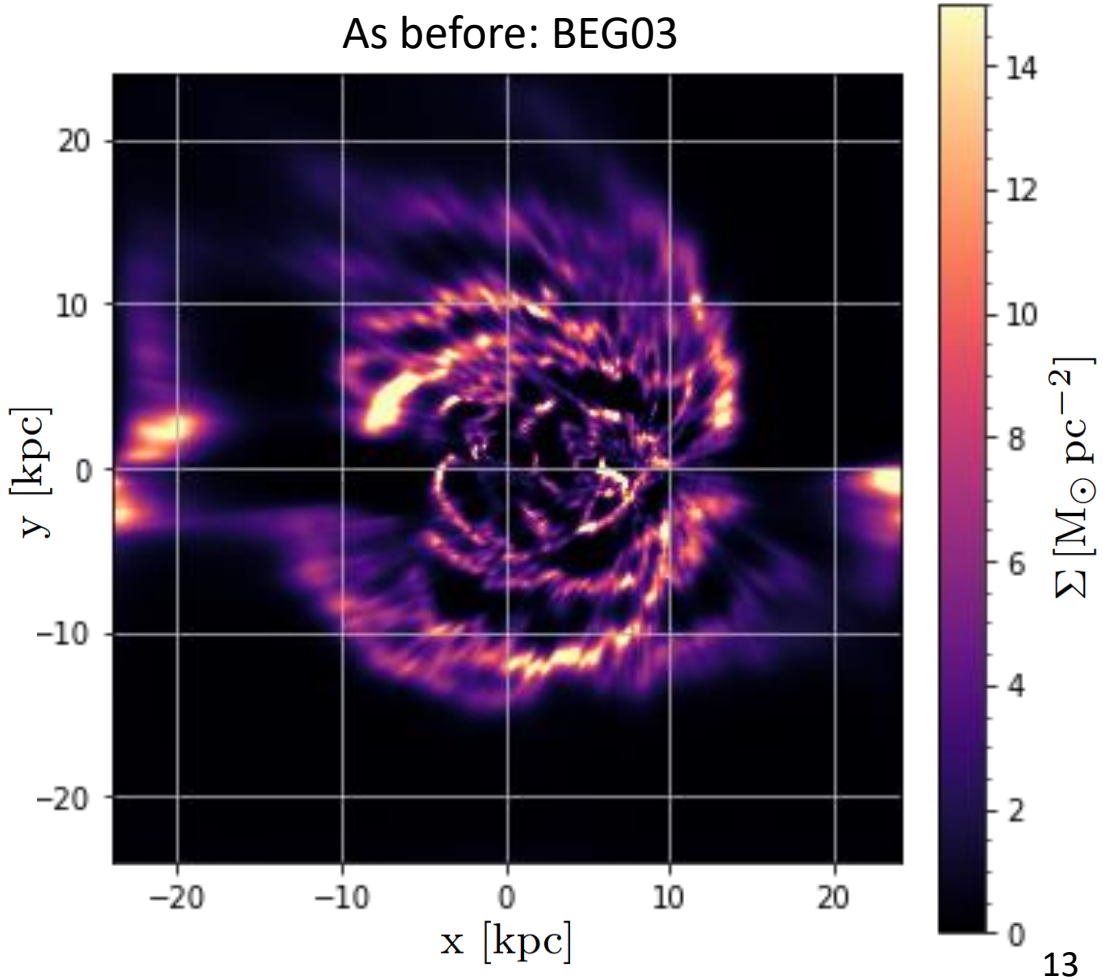
Assumed limit of optically thin gas	Include absorption effects → more gas in high-intensity regions
Assumed fixed velocity field / Ignored peculiar motions	Set prior distribution for velocity field as well and reconstruct it together with the gas density field
This may be too much freedom / data is not constraining enough	Use complimentary data, e.g. parallax measurements of galactic masers or correlations with dust in the galaxy

Backup 1: Comparison of velocity models

For comparison: SBM15

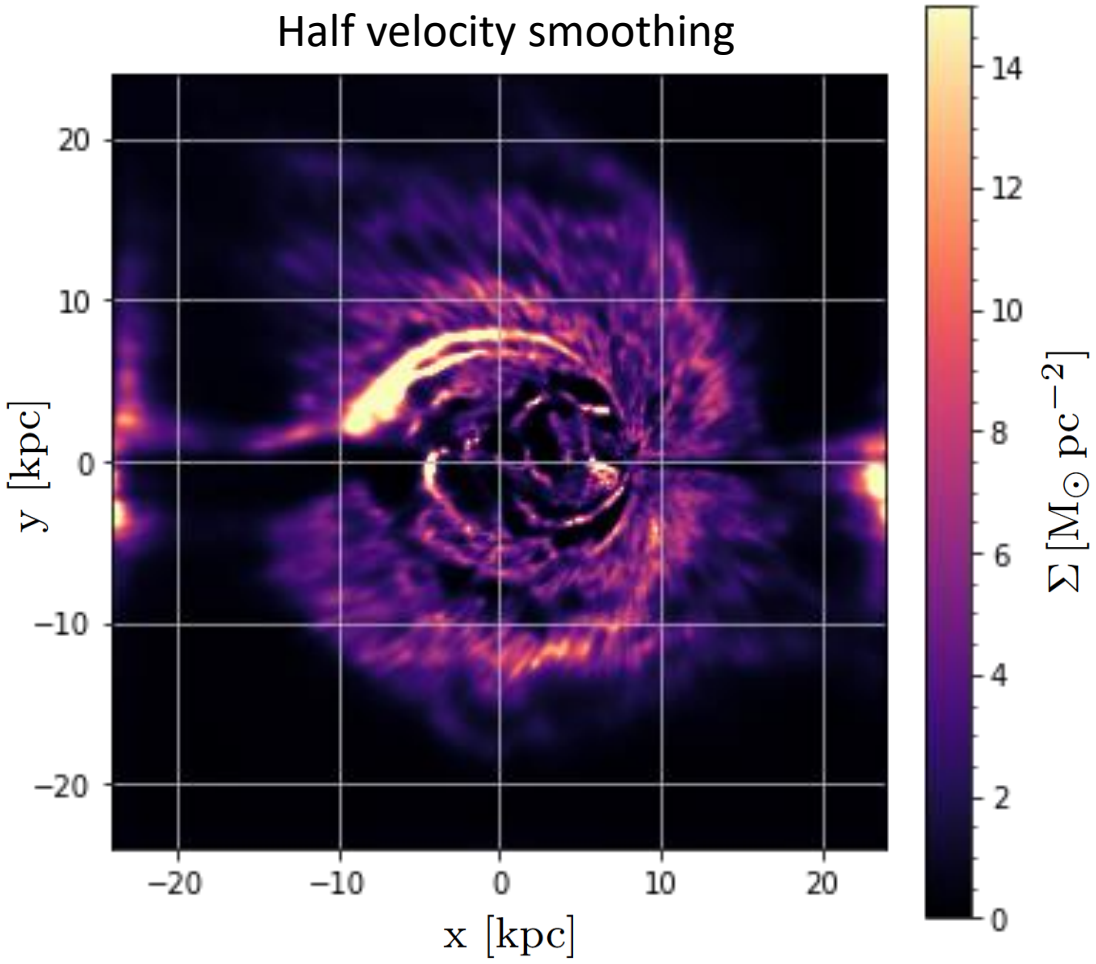


As before: BEG03



Backup 2: Comparison of velocity smoothing

Half velocity smoothing



Double velocity smoothing