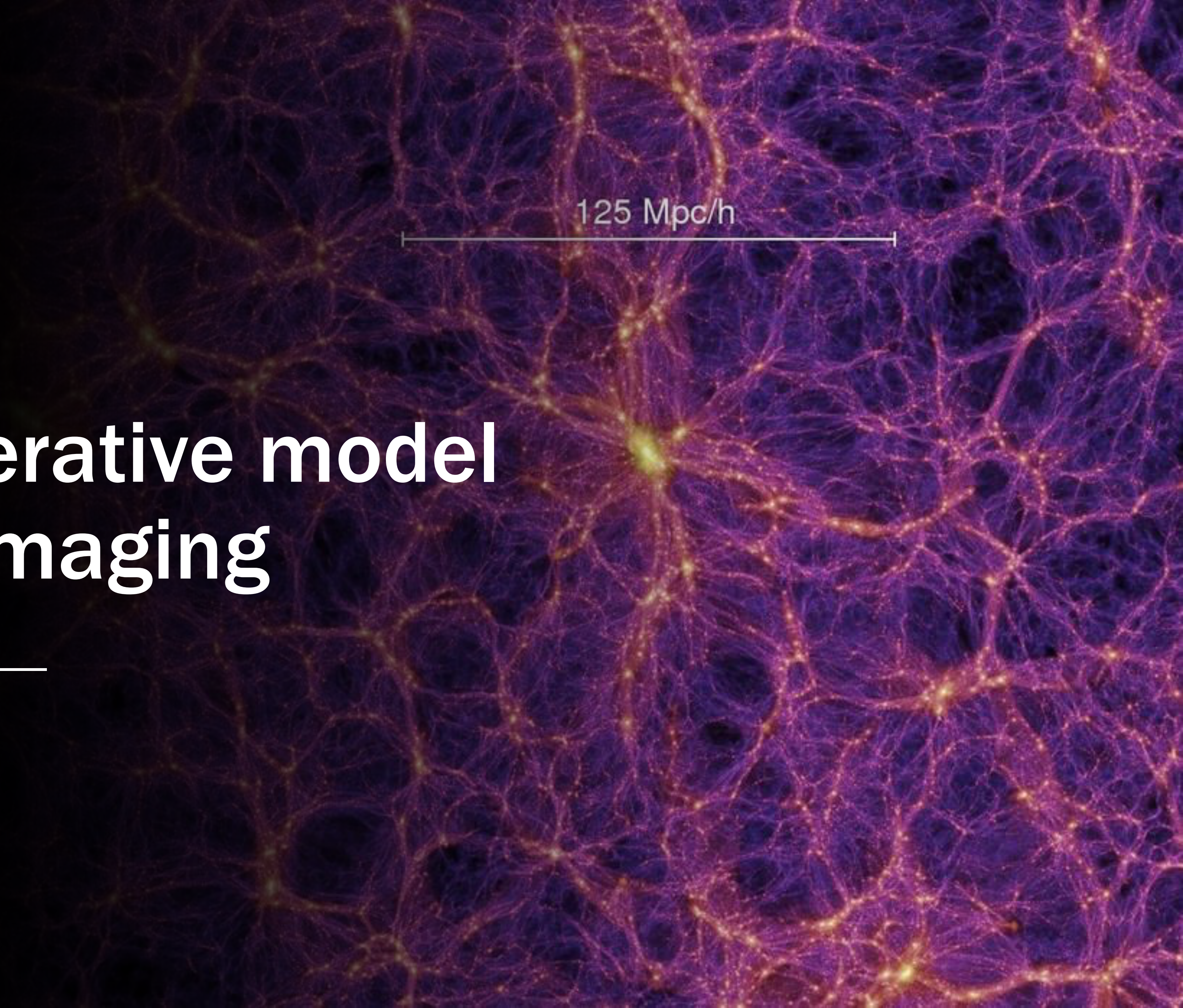


Filament generative model for bayesian imaging

Master thesis(Oct. 2021~)

Jongseo Kim

Supervisor : P.D. Dr. Torsten Enßlin

Contents

Semiclassical path to cosmic large-scale structure

Cora Uhlemann, Cornelius Rampf, Mateja Gosenca, and Oliver Hahn
Phys. Rev. D **99**, 083524 – Published 29 April 2019

A&A 646, A84 (2021)

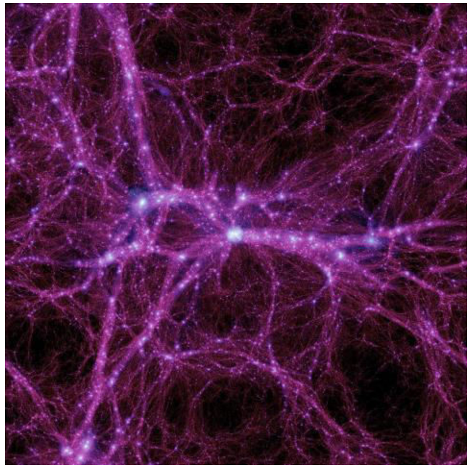
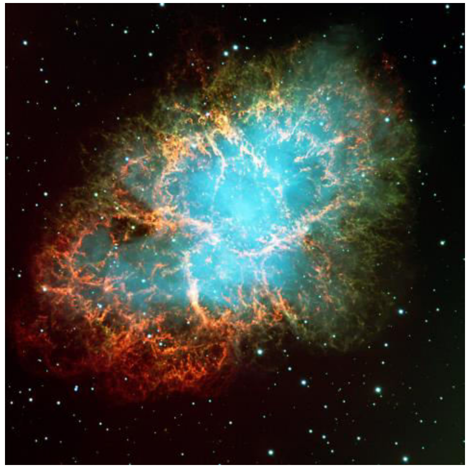
Comparison of classical and Bayesian imaging in radio interferometry

Cygnus A with **CLEAN** and **resolve**

Philipp Arras[1,2,3], Hertzog L. Bester[4,5], Richard A. Perley[6], Reimar Leike[1,2], Oleg Smirnov[5,4], Rüdiger Westermann[3] and Torsten A. Enßlin[1,2]

- Motivation
- **Filament prior model** :
  Derivation of the model
- **Application:**
  Cygnus A at 2052-2MHz
- Summary

Motivation

- In nature, filamentary structures are observed on a wide range of length scales
- What is the simplest **process/algorithm** to generate filaments?
- **A large scale** or **better resolution** can be achieved with the same amount of computational resources

Hydrodynamics

the Euler equation $$\frac{\partial \vec{v}}{\partial t} + (\vec{v} \cdot \nabla)\vec{v} + \frac{1}{\rho}\nabla p + \nabla \Phi = 0 \longrightarrow \frac{\partial \phi_v}{\partial t} - \frac{1}{2}(\nabla \phi_v)^2 = \Phi$$

- Fluid dynamics simulation and N-body simulation can generate filaments but **computationally expensive**
- We can take advantage of **a wave mechanical effective description** to reproduce filaments
- We assume **a curl-free velocity,** $\vec{v} = -\nabla \phi_v$

Derivation of the Schrödinger-like equation

By the transformation, $\Psi = \sqrt{\rho}\,\exp(-i\phi_v/\hbar)$, $\rho = |\Psi|^2$

$$\frac{\partial \phi_v}{\partial t} - \frac{1}{2}(\nabla \phi_v)^2 = \Phi \longrightarrow i\hbar\frac{\partial \Psi}{\partial t} = -\frac{\hbar^2}{2}\nabla^2\Psi$$

We can use **the propagator of free particle** K_0 in QM

$$\Psi_1^x(\vec{x}) = \int d^3q K_0(\vec{x}-\vec{q})\Psi_0^{(ini)}(\vec{q}),\ K_0(\vec{x}-\vec{q}) = N\exp(\frac{i}{\hbar}S_0) = N\exp\{\frac{i}{2\hbar t}(\vec{x}-\vec{q})^2\}$$

By **the convolution theorem,**

$$\Psi_1^x = K_0 * \Psi_0$$

$$\Psi_1^k = K^k\Psi_0^k,\quad K^k = \exp(-i\hbar t k^2/2)$$

Cora Uhlemann et al. Phys. Rev. D 99, 083524 (2019)

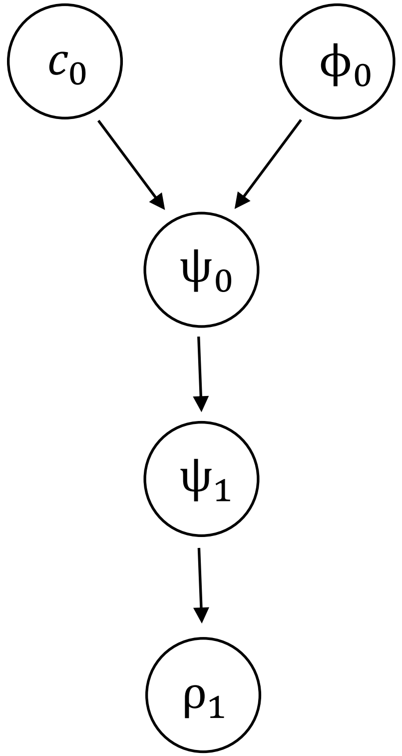
Filament generative model

1. Gaussian random field c0 and phi0

2. $\Psi_0^x = \exp(c_0^x/2 - i\phi_0^x/\hbar)$

3. $\Psi_1^k = K^k \Psi_0^k$

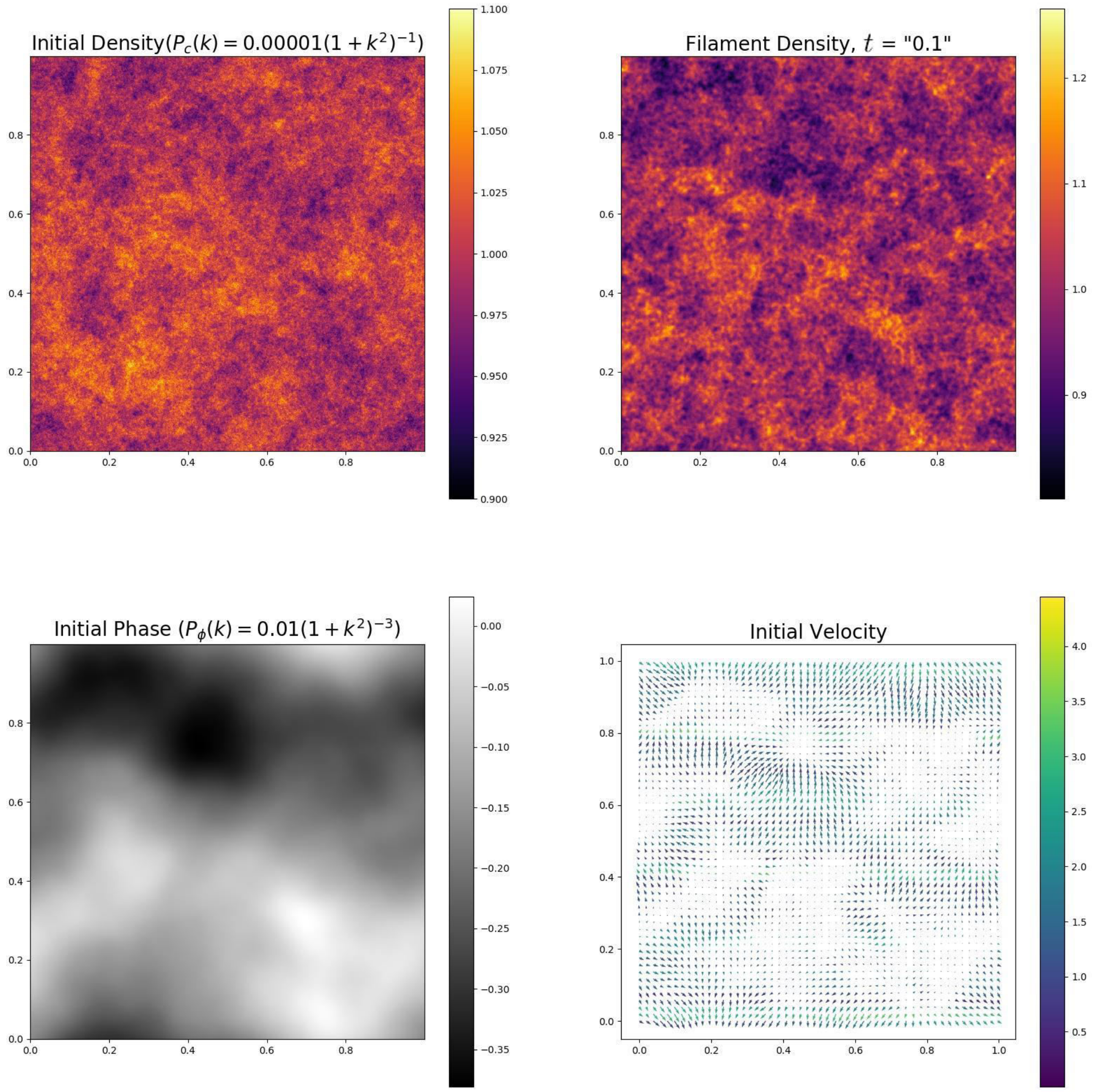
4. $\rho_1 = |\Psi_1^x|^2 = \exp(c_1^x)$



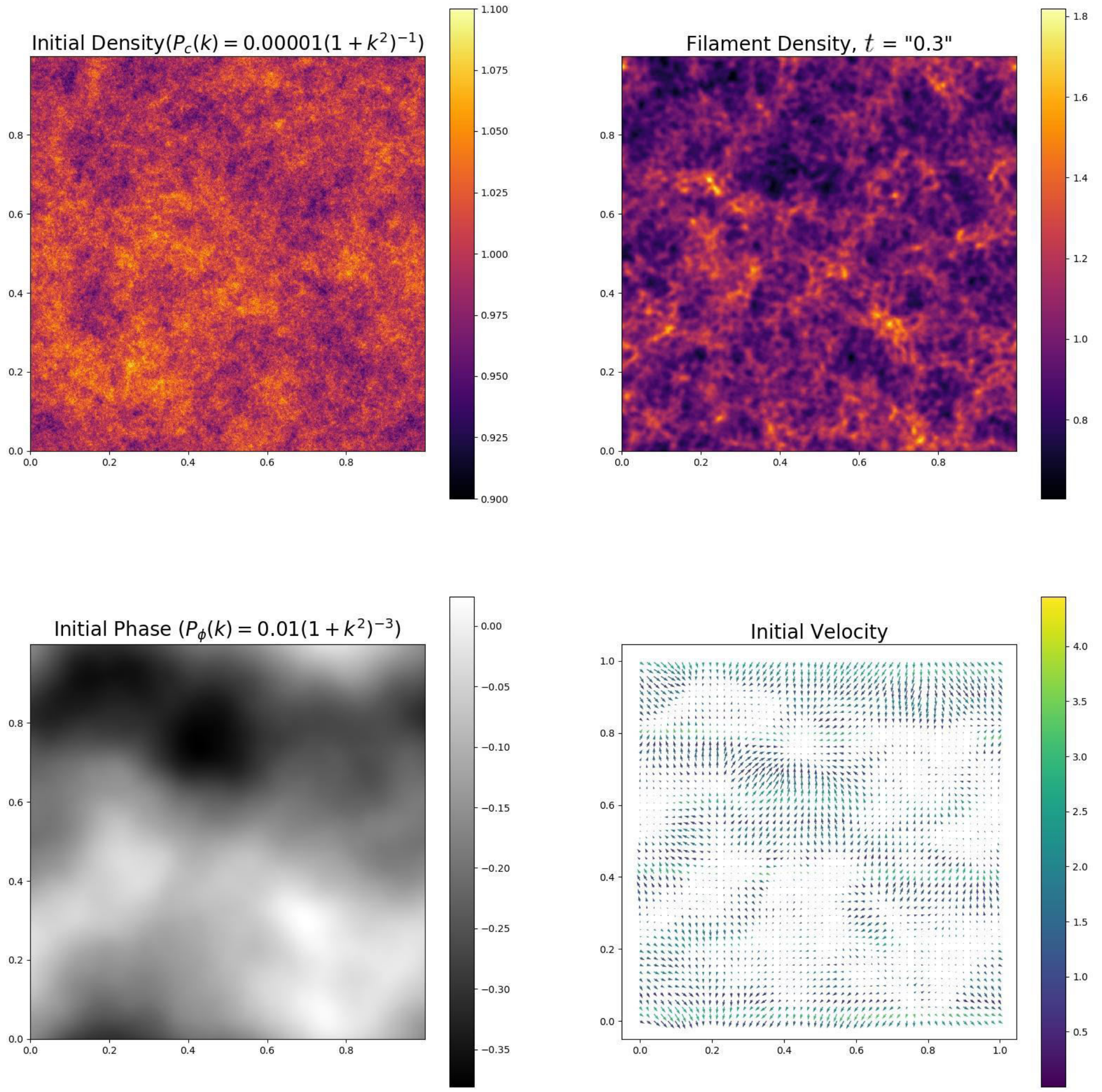
We can produce filamentary structure by **the generative model**

Time complexity **O(N) ~ NlogN** in 2D

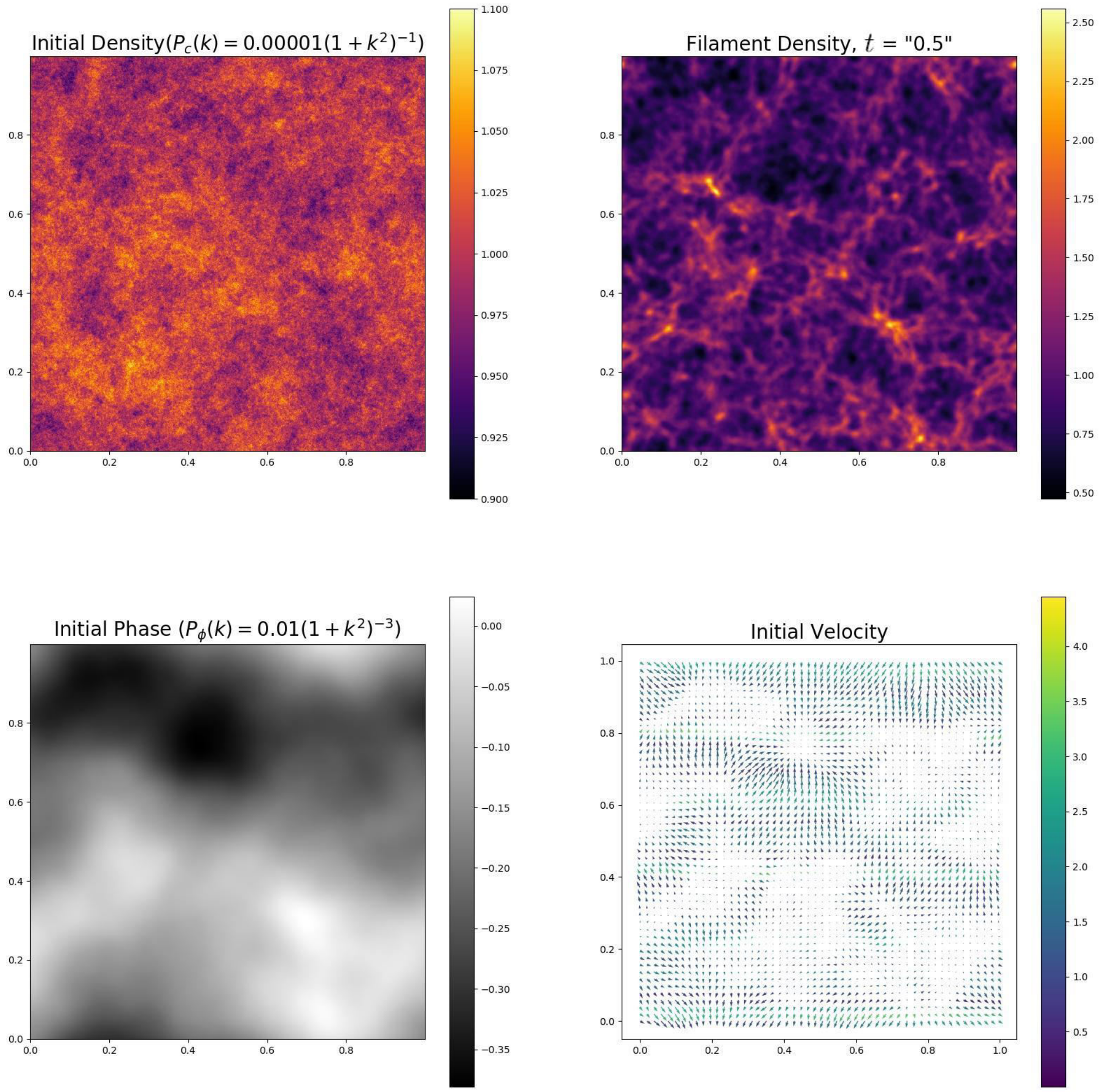
Filament Generative Model



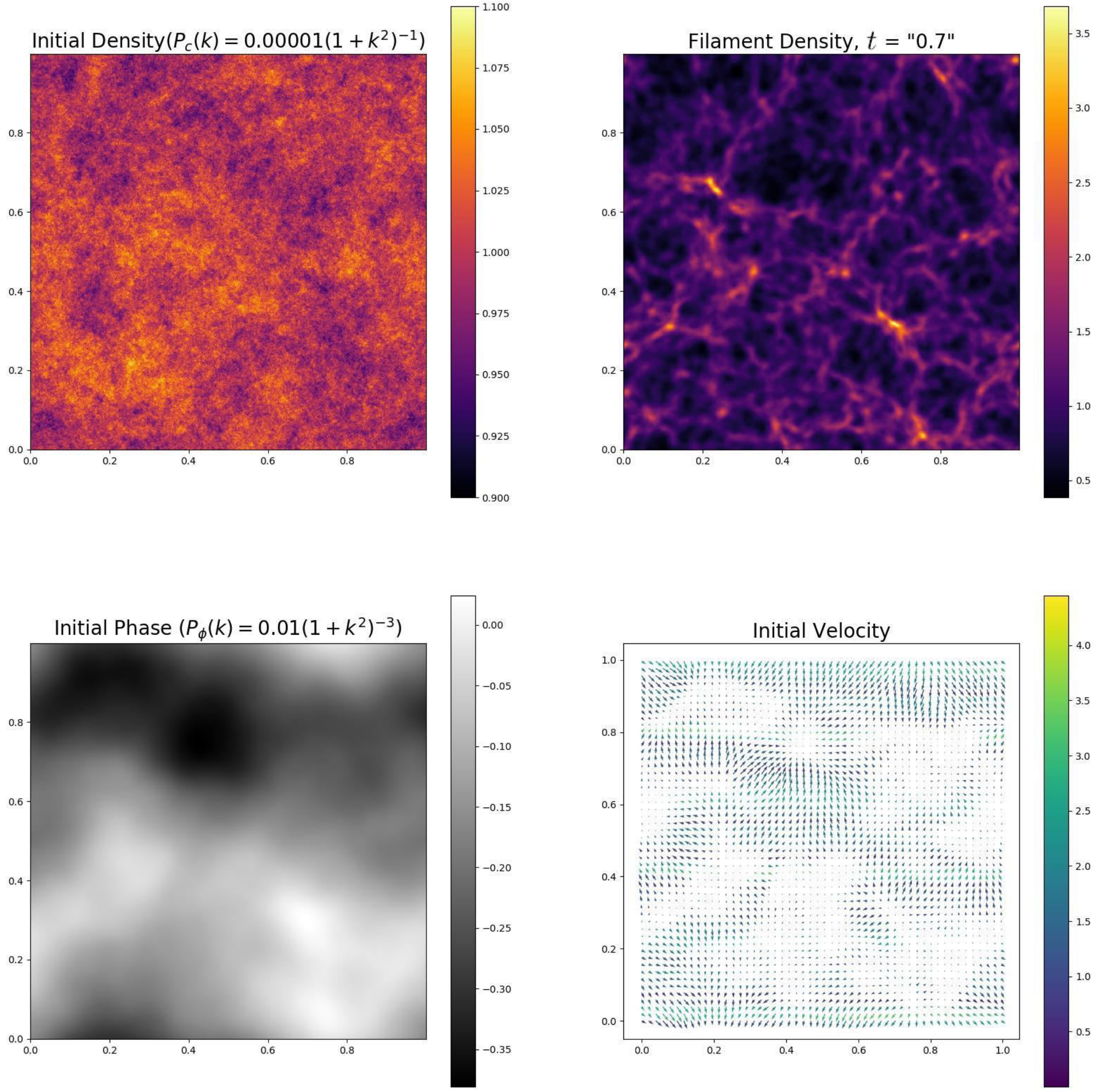
Filament Generative Model



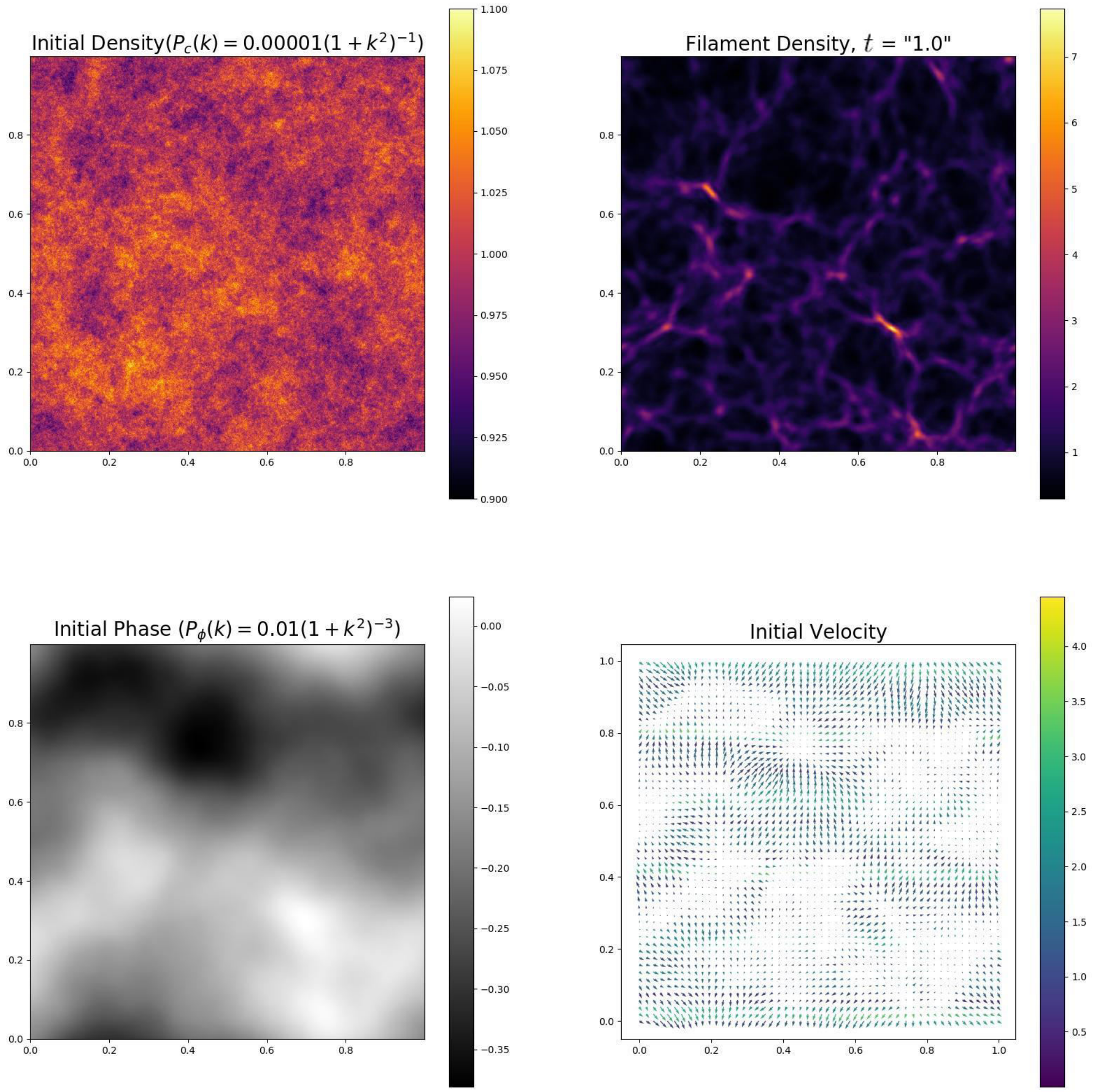
Filament Generative Model



Filament Generative Model



Filament Generative Model



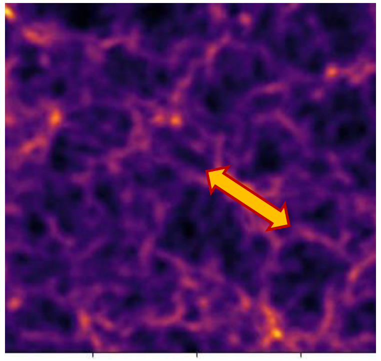
Bayes theorem

$$P(s|d) = \frac{P(d|s)P(s)}{P(d)}, \quad P(s|d)$$: the posterior

- What is the reasonable prior for radio galaxy?

  -> smooth field under **homogeneity and Isotropy**

  -> lognormal sky to enforce **positivity**

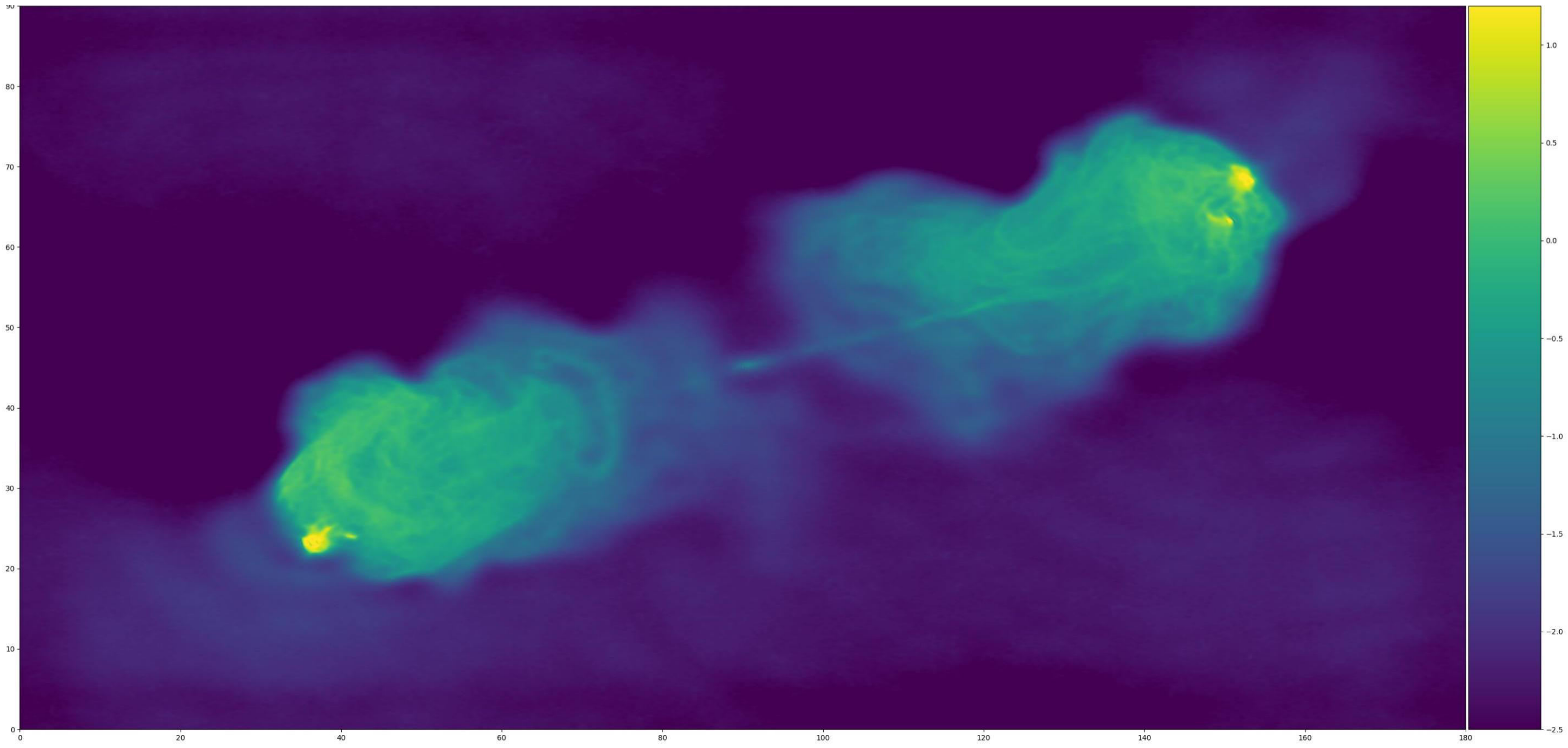


- Filaments and jets have **directional correlation**

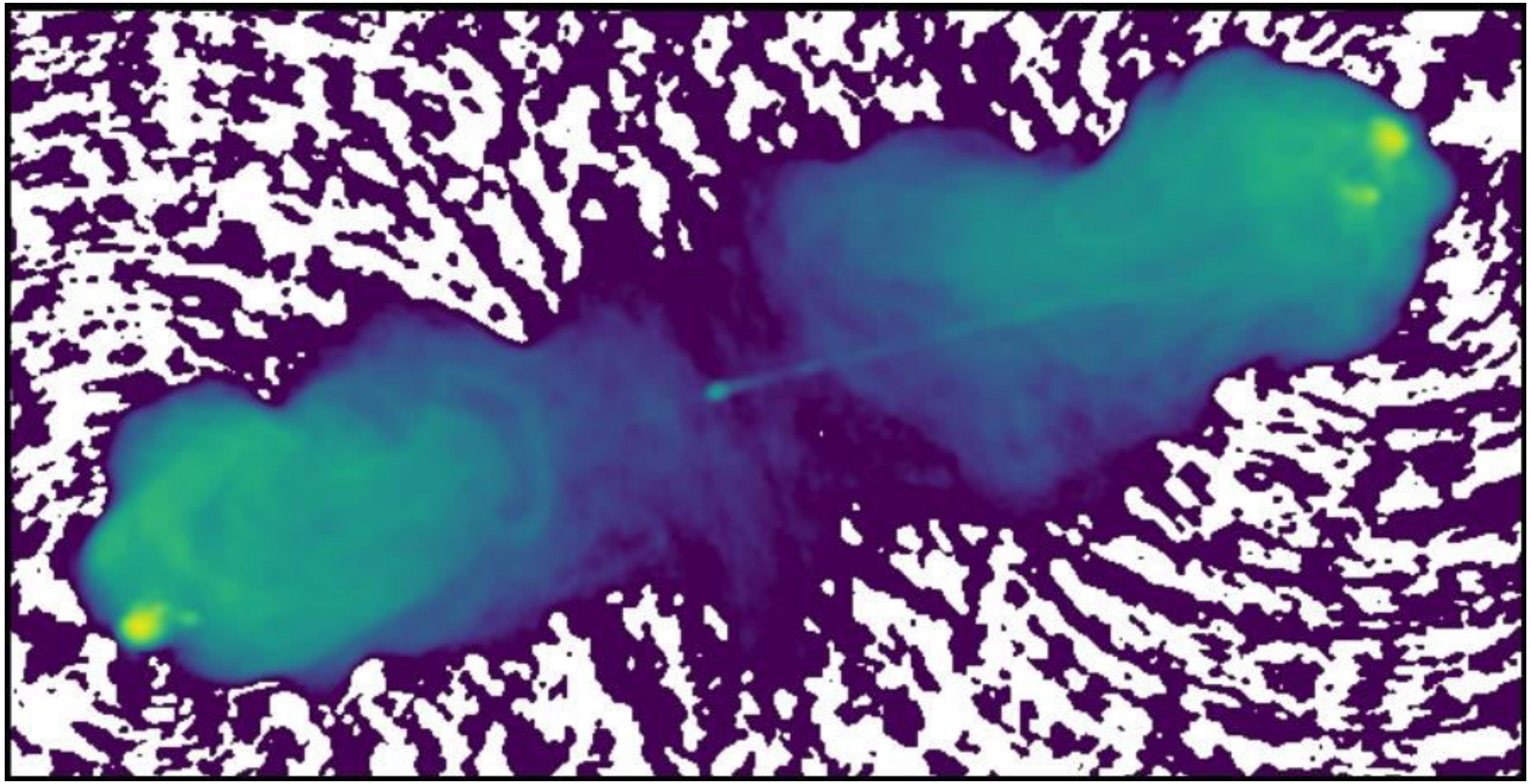
  -> **local anisotropy** is encoded in the filament prior model

Let's use the real data with Bayesian imaging algorithm RESOLVE

Cygnus A image by filament prior

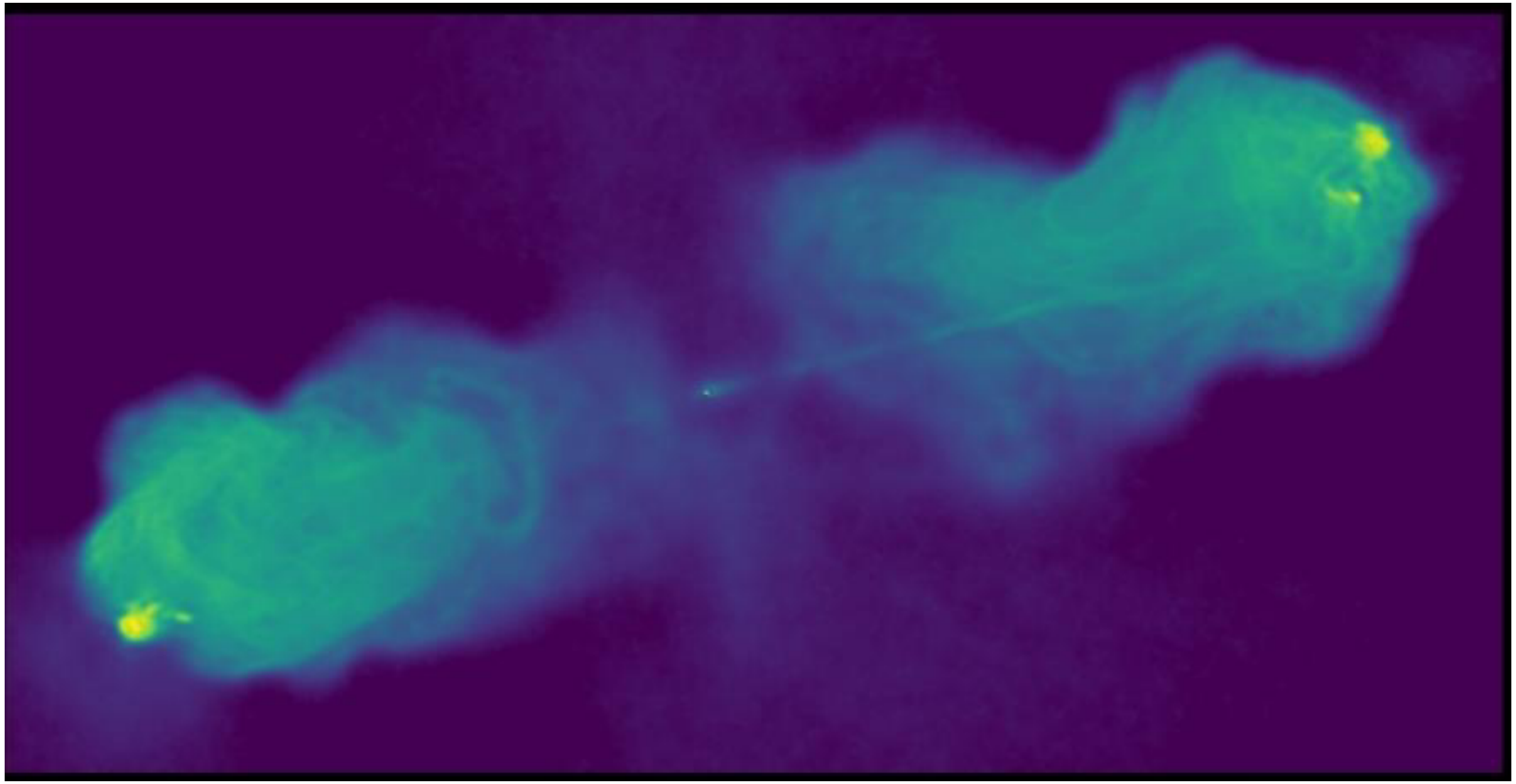


Cygnus A image by CLEAN



Philipp Arras et al. A&A, 646, A84 (2021)

Cygnus A image by a density field



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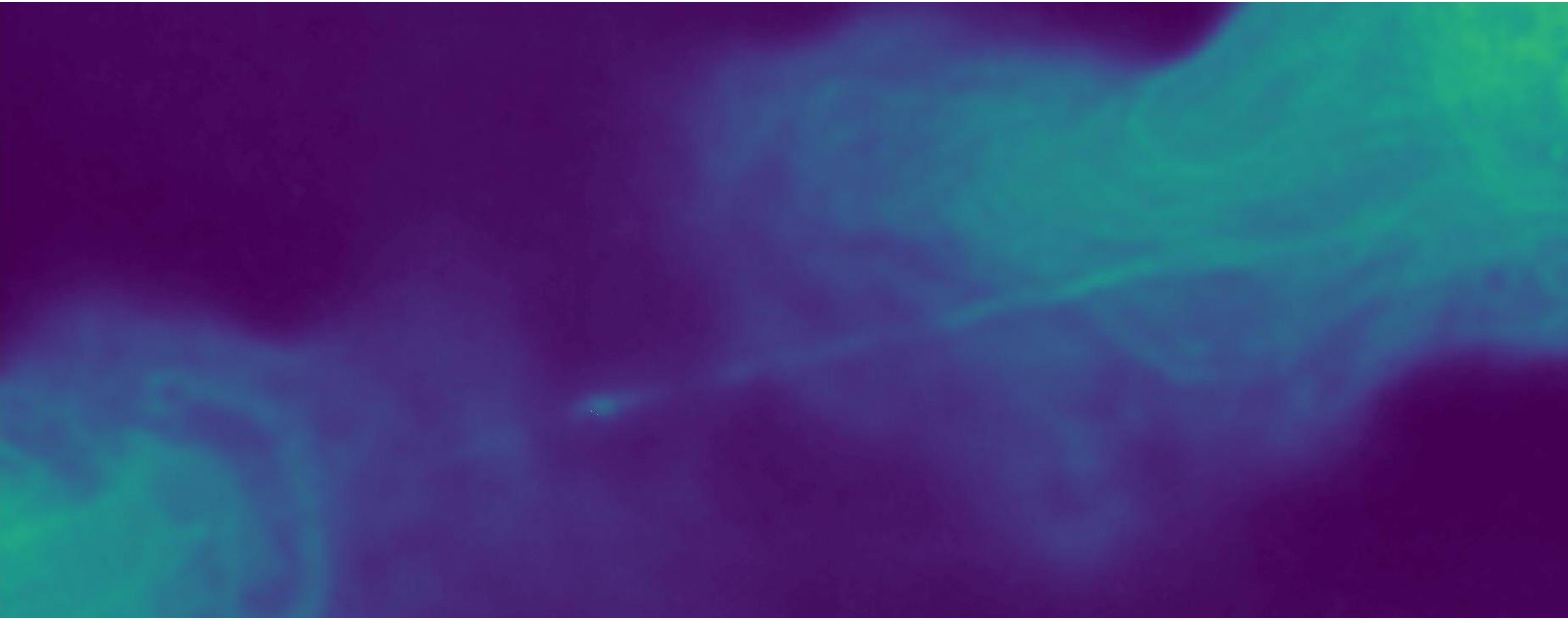
Jets (Previous work)



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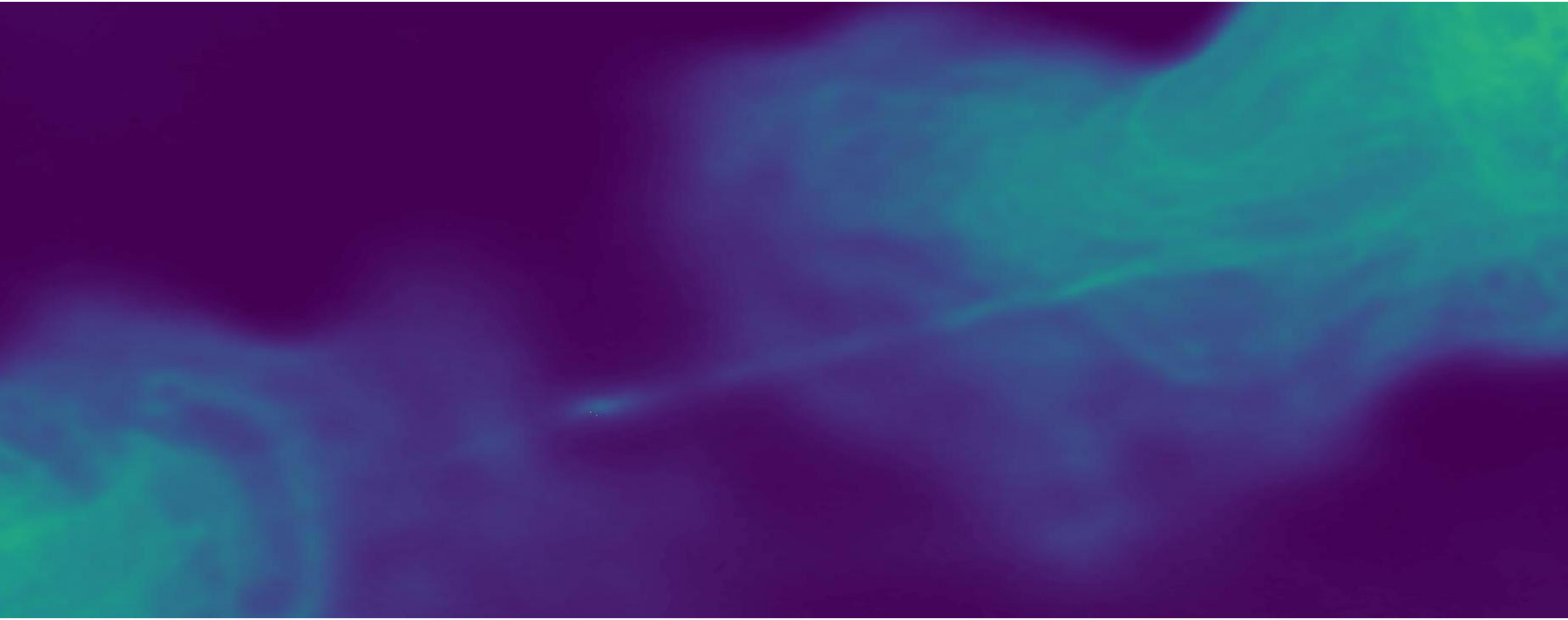
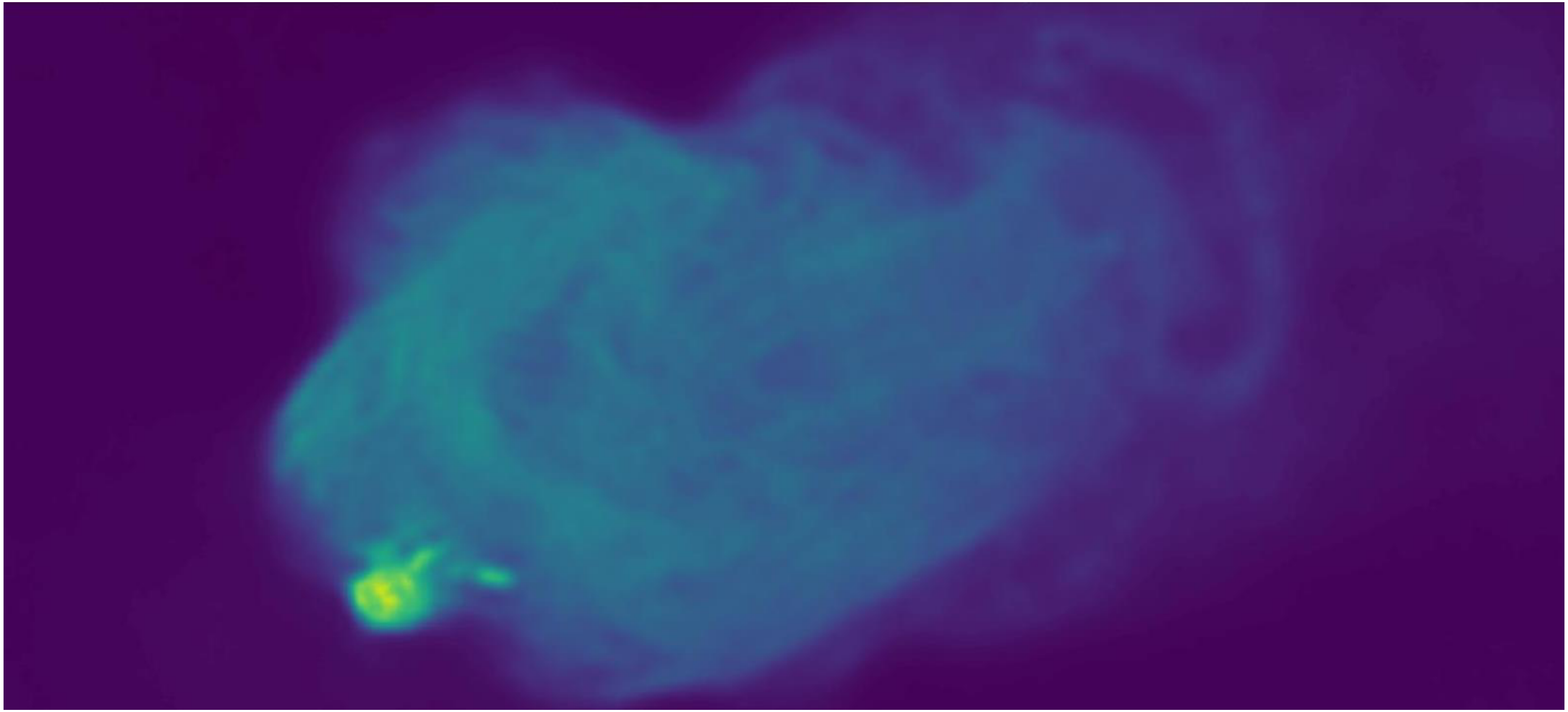
Jets with filament prior model



Left lobe (Previous work)



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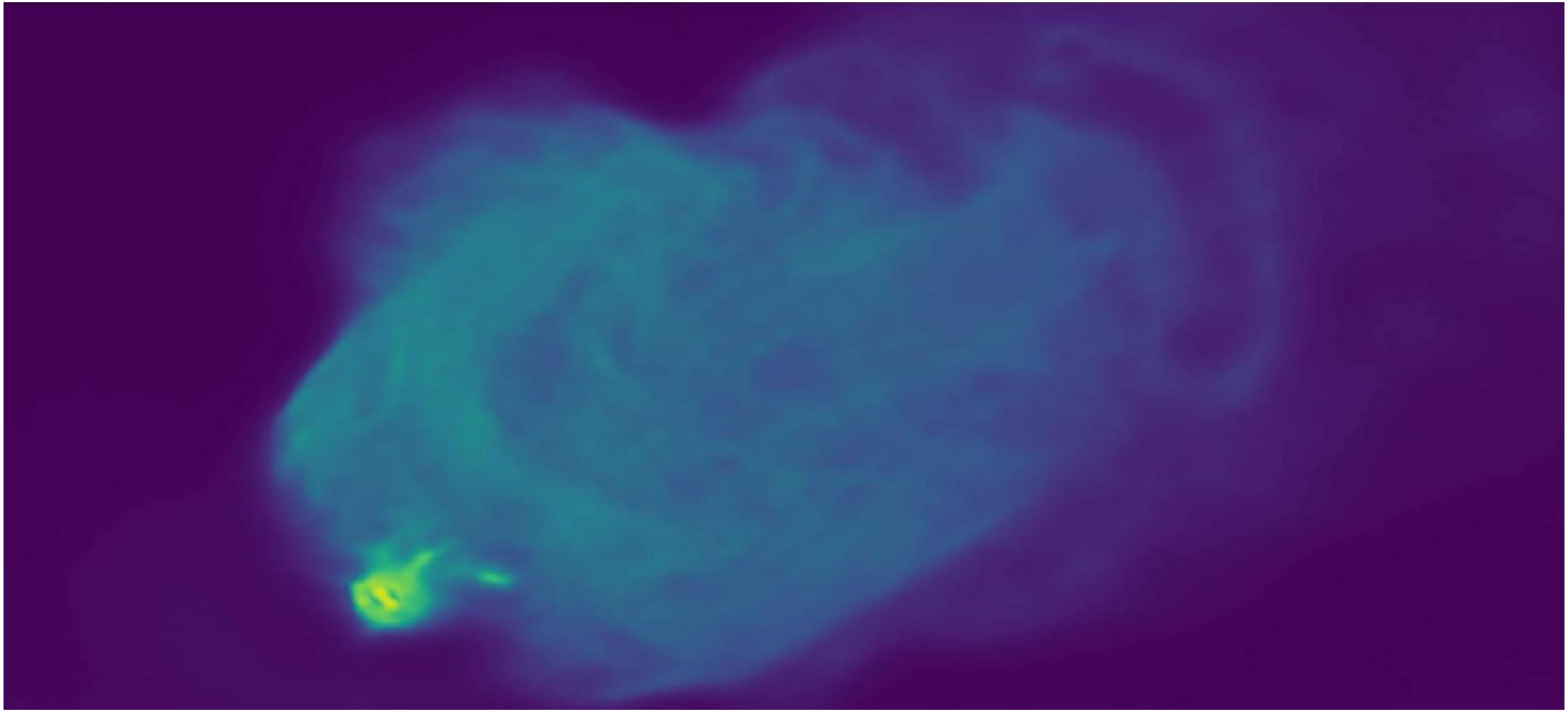
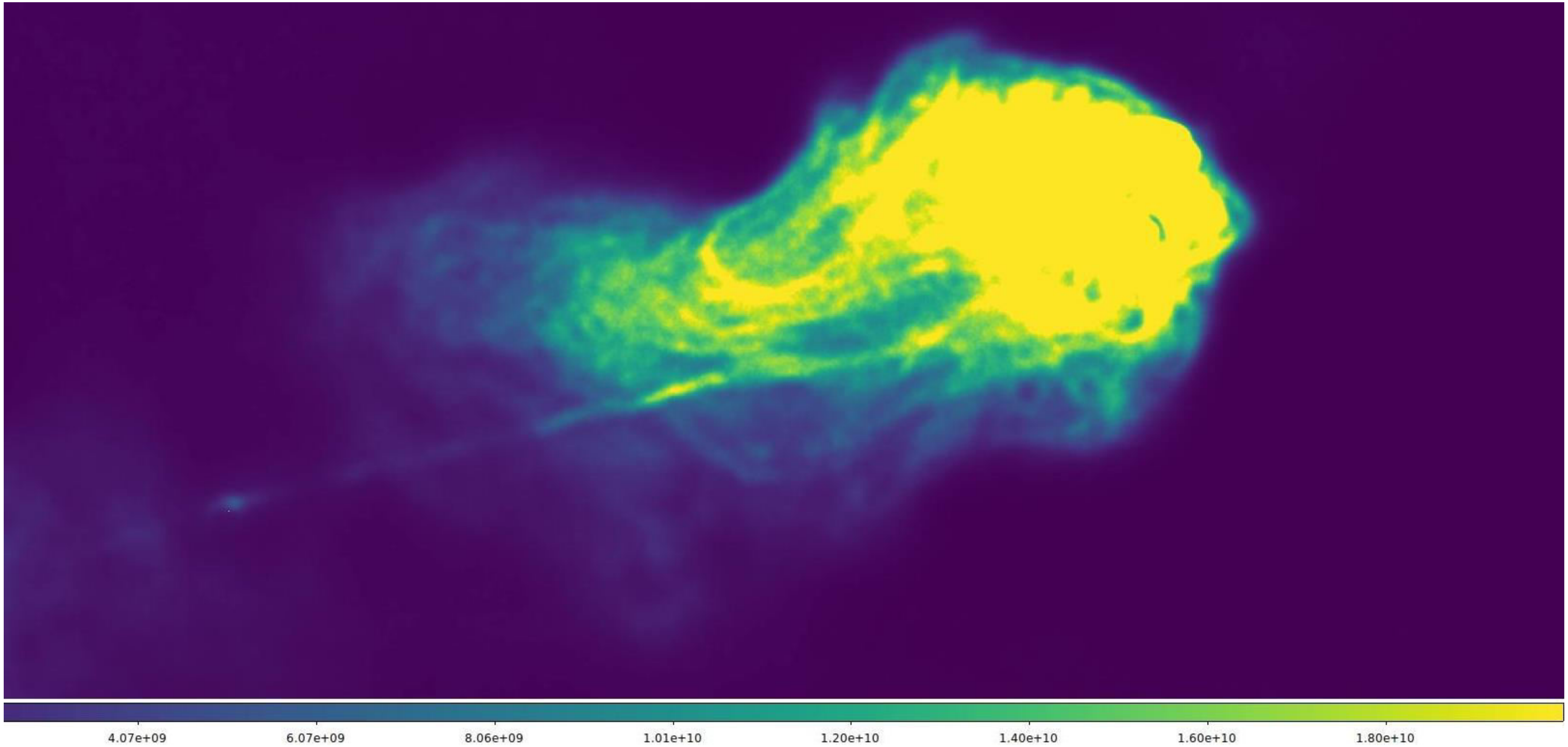
Left lobe with filament prior model



Right lobe (Previous work, linear scale)



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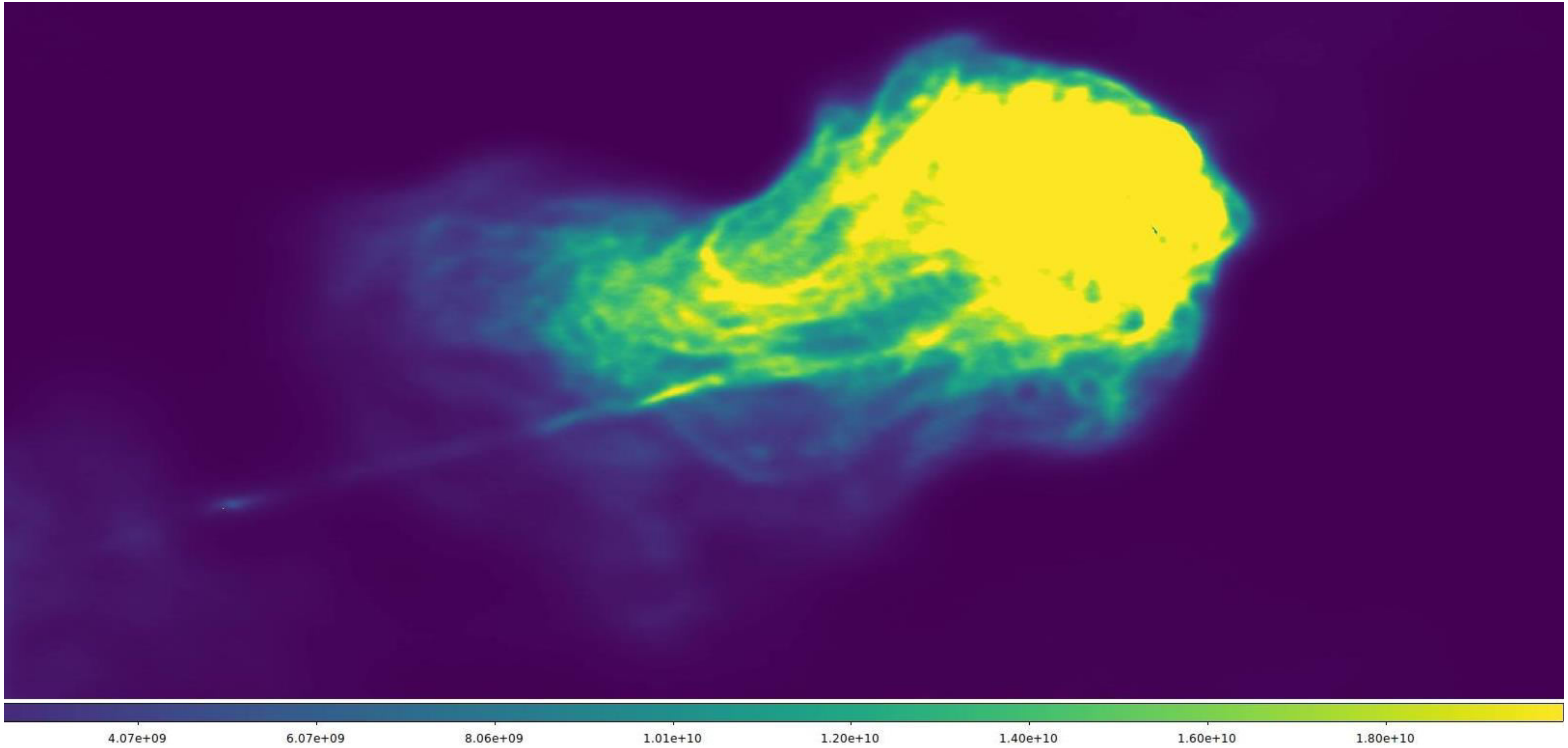
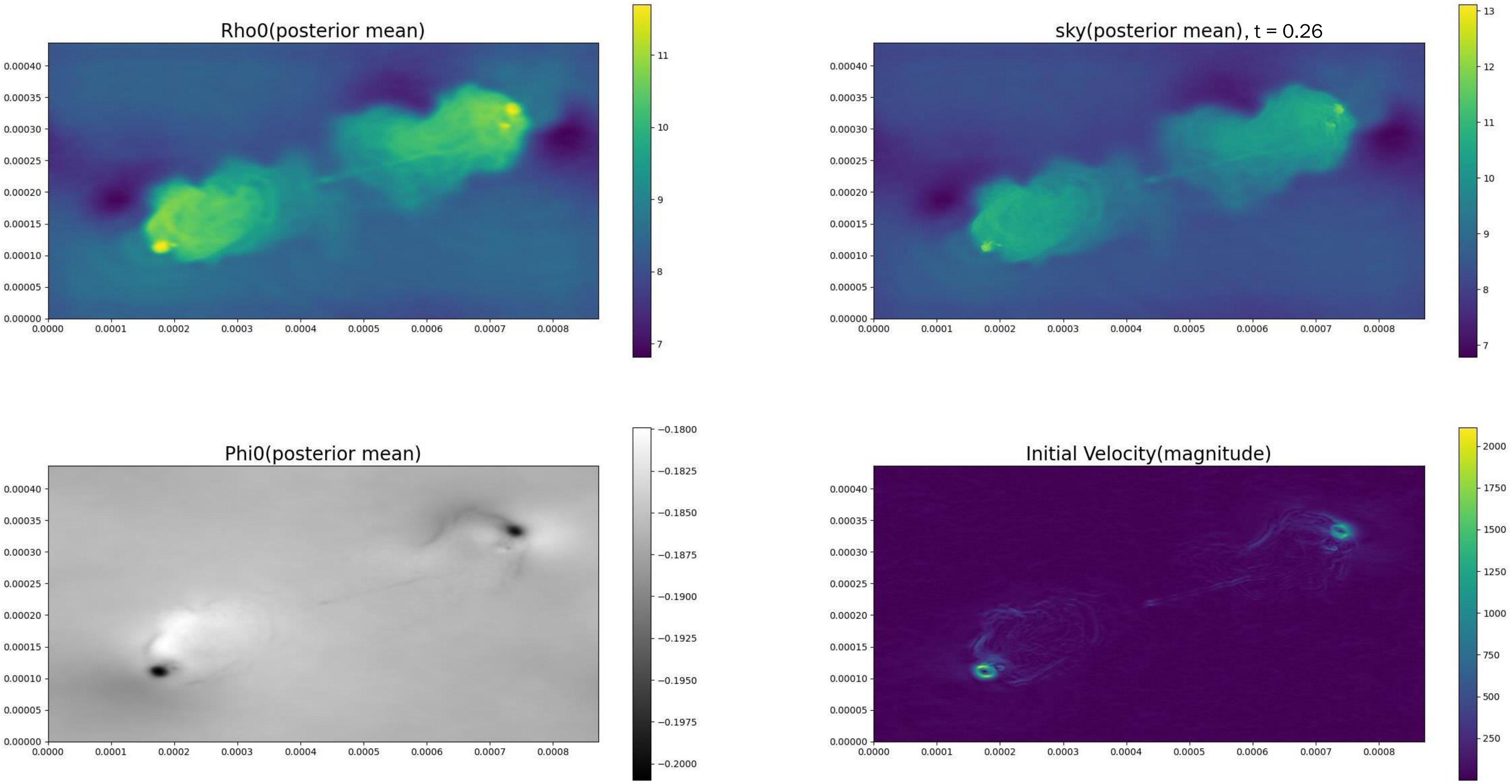
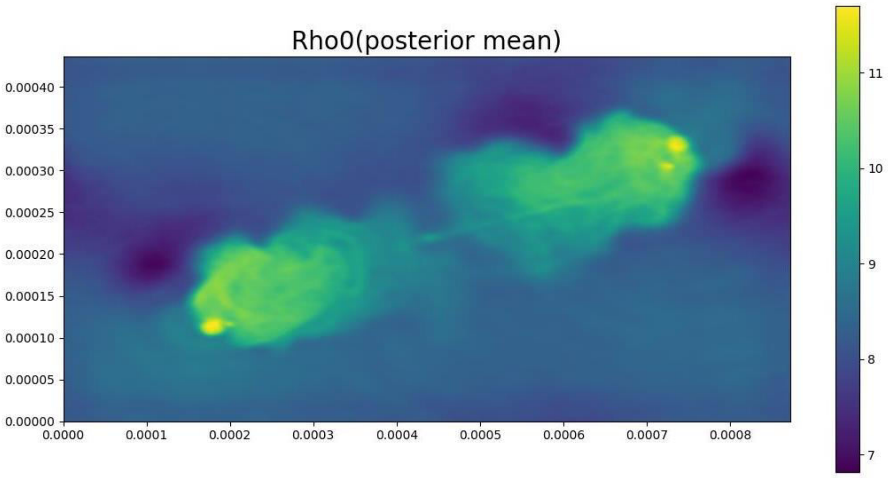
Right lobe with filament prior model

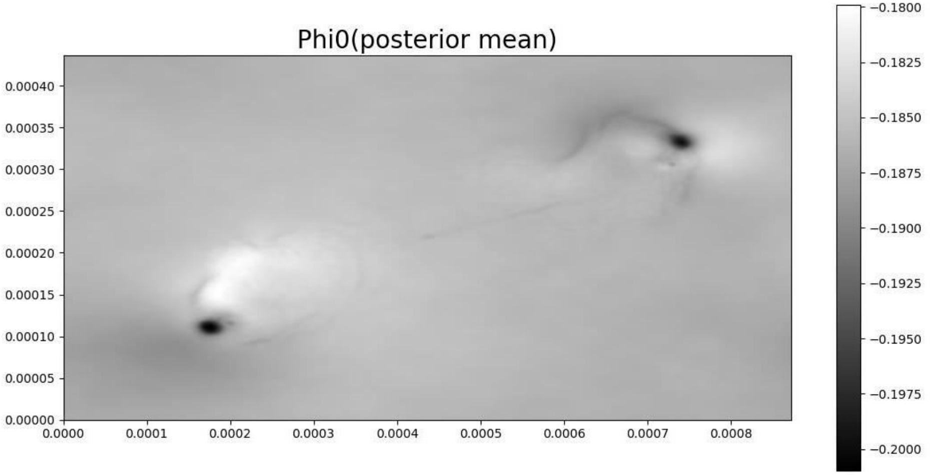


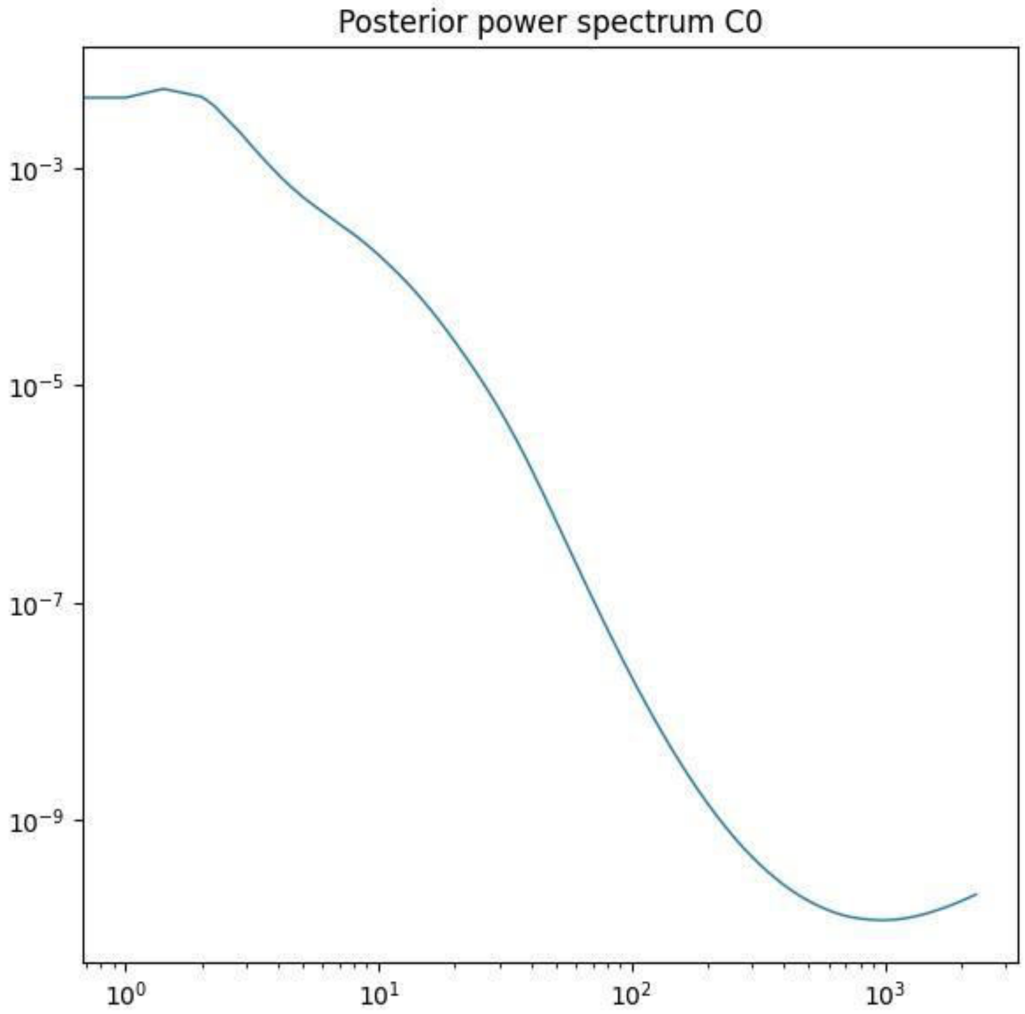
Density, phi0, velocity plots



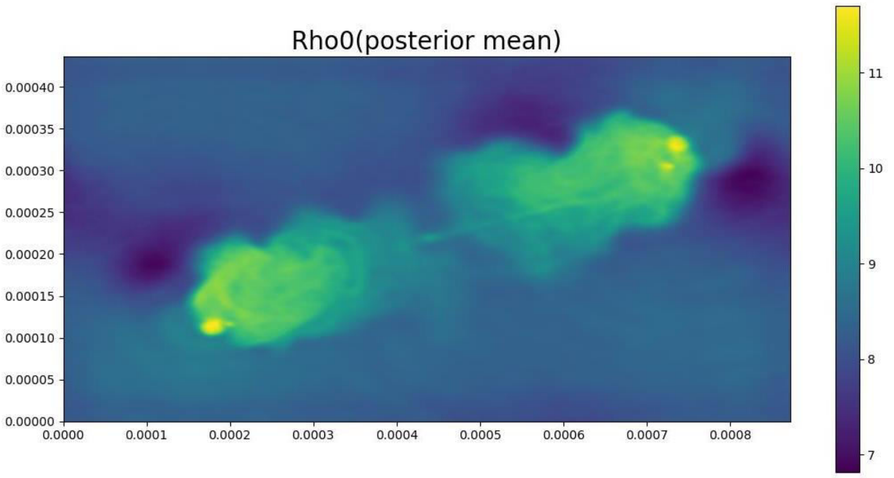
Density, phi0, velocity plots

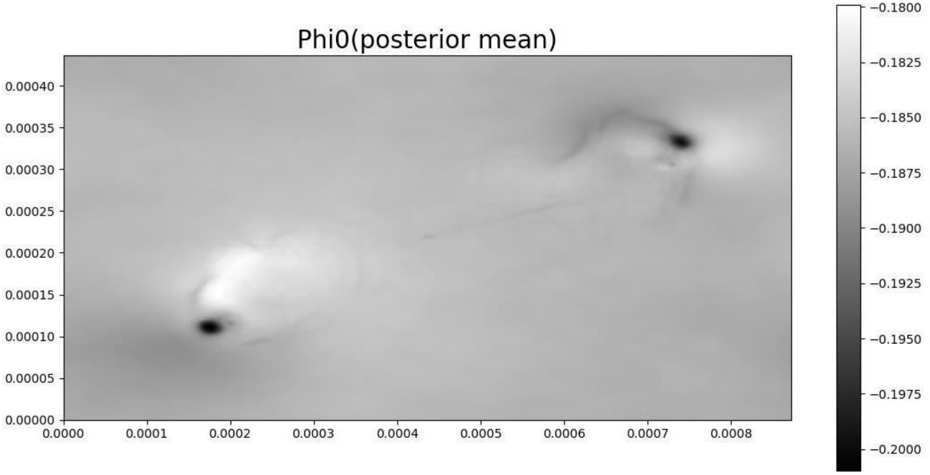


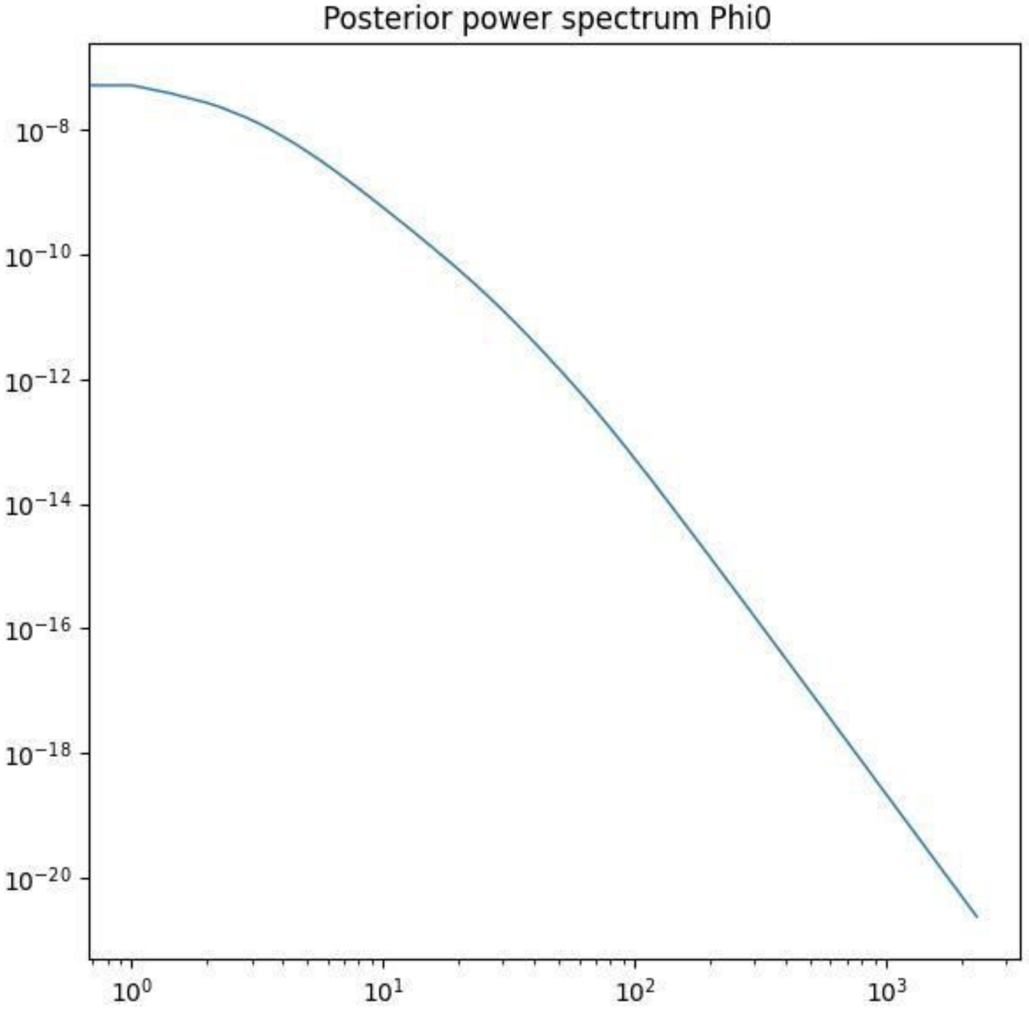




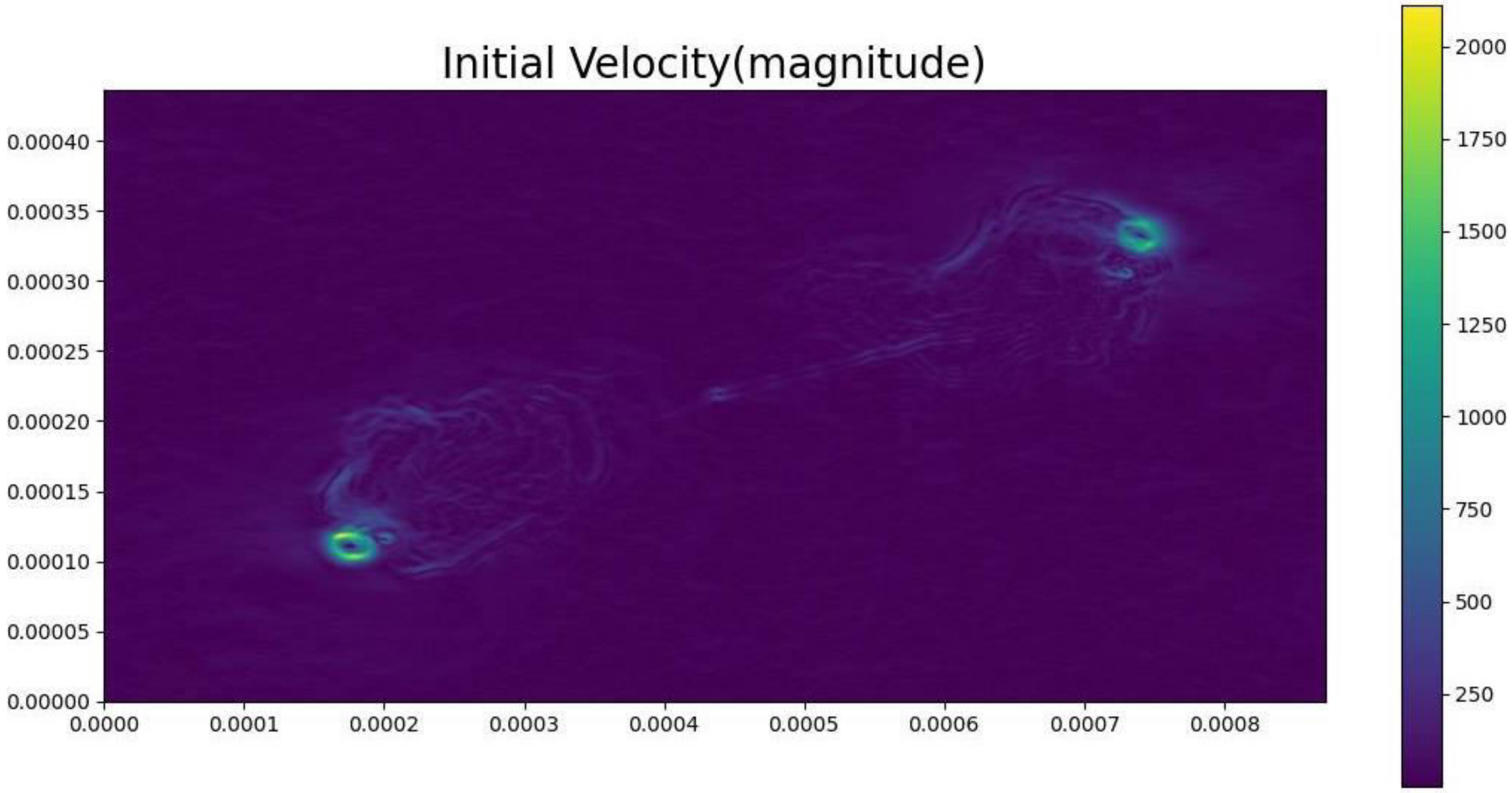
Density, phi0, velocity plots



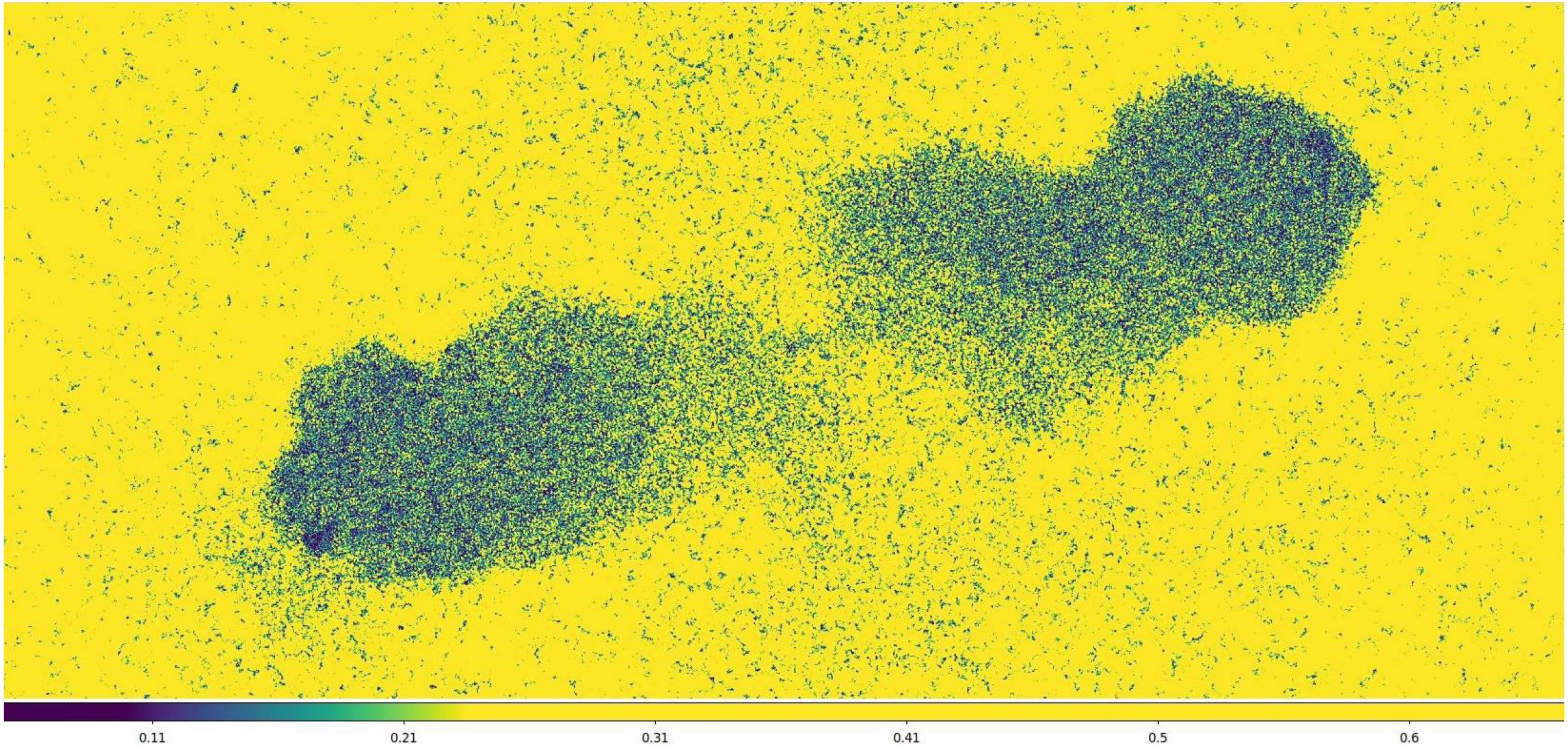




Initial velocity plot



relative uncertainty map (previous work)



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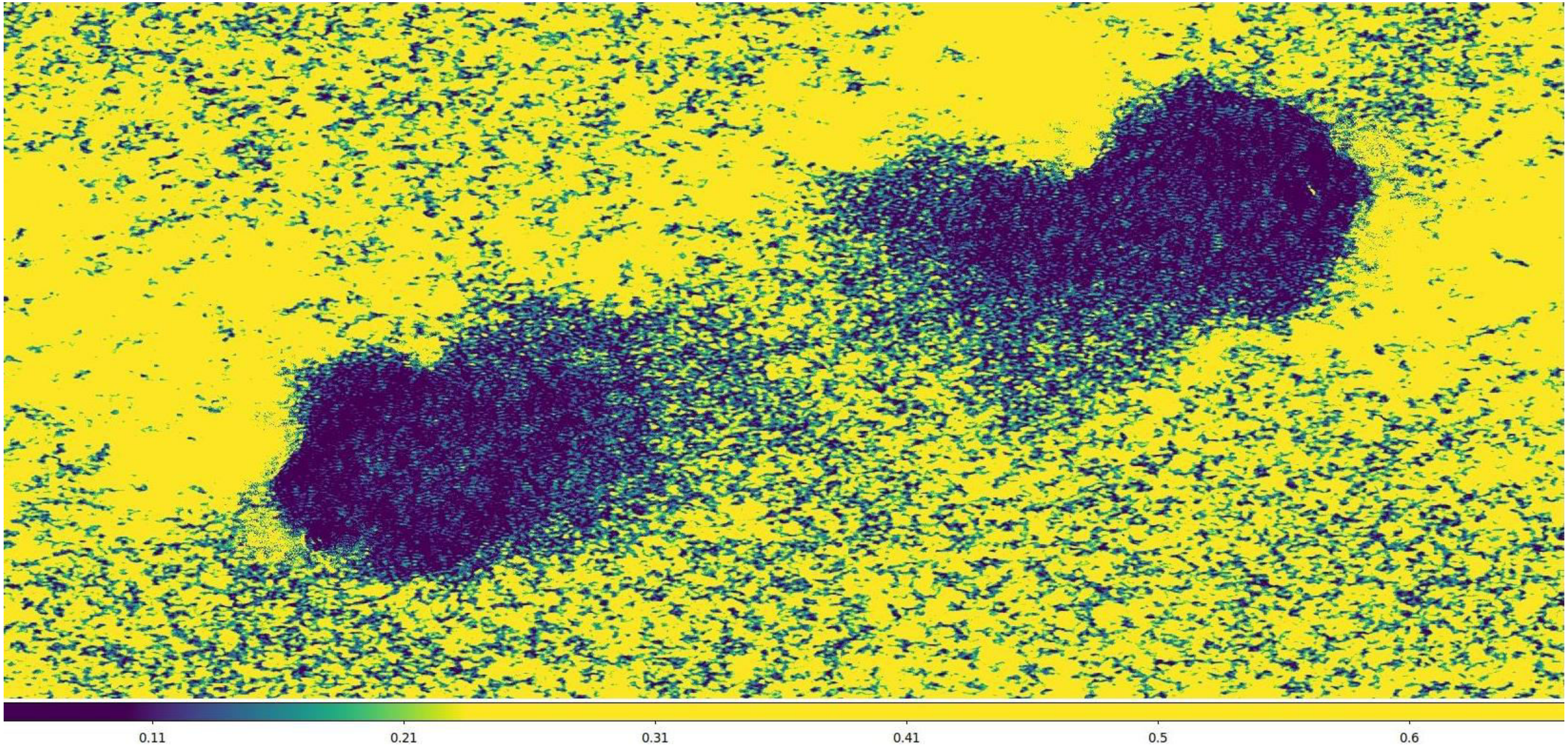
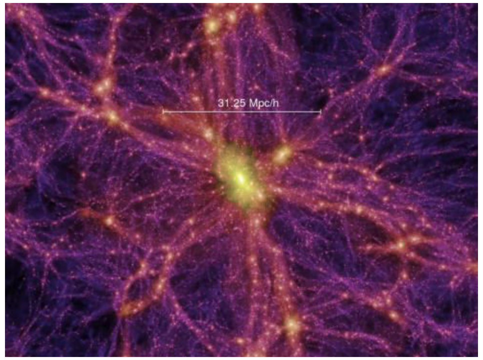
relative uncertainty map (with filament prior)

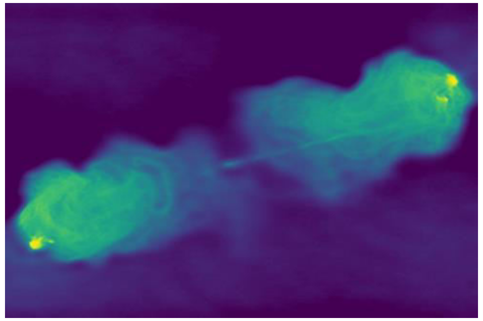


Summary

- **Filament generative model:**
  Simple mechanism is encoded to generate filament



- **Cygnus A** by the **filament** prior:
  Reveal **jets and edges** in the radio galaxy with uncertainty estimation



- **Filamentary structure in Astrophysics:**
  The model can be used as **a prior model** for various astronomical objects


Thank you for your attention!