

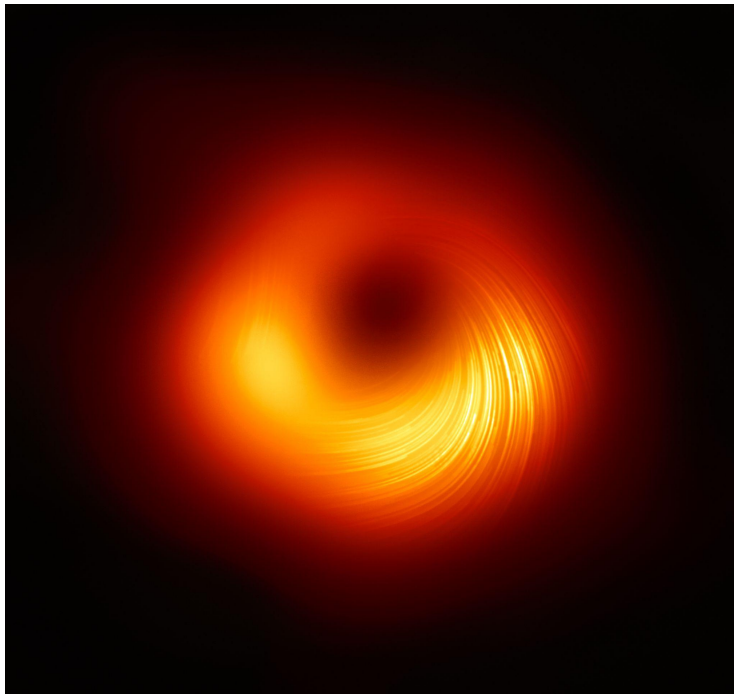
Characterising the Variability of Black Hole Accretion Flows

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Undergraduate

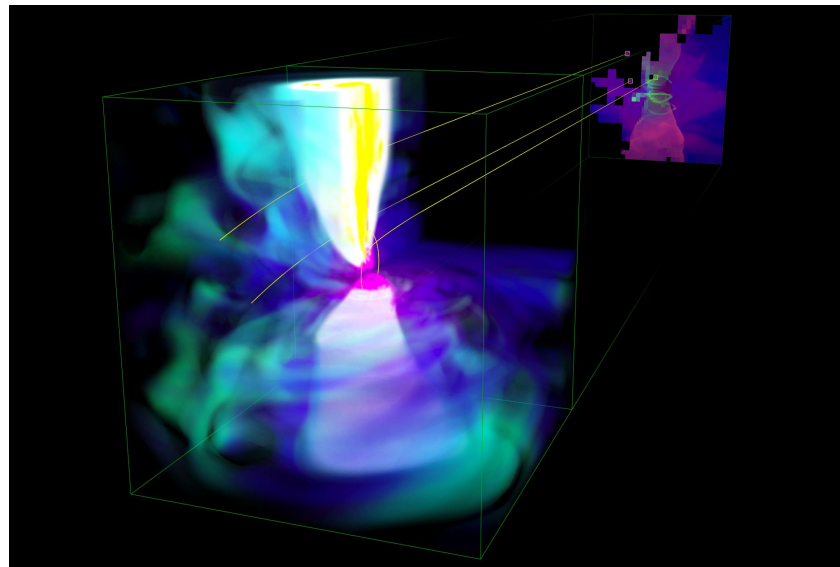


Motivation and Background

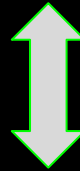
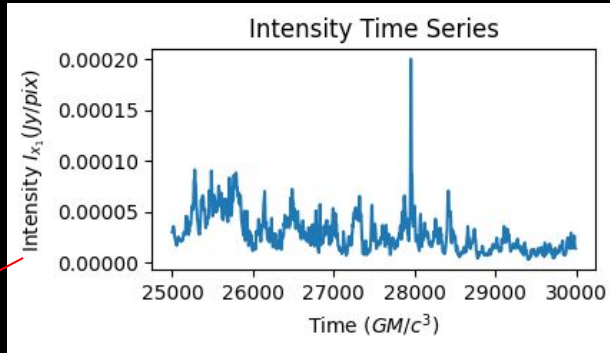


The Event Horizon Telescope (EHT) enables black hole imaging (M87*, Sgr A*).

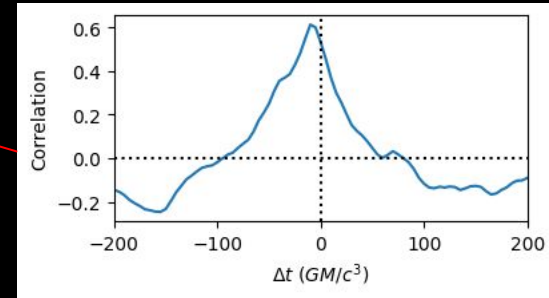
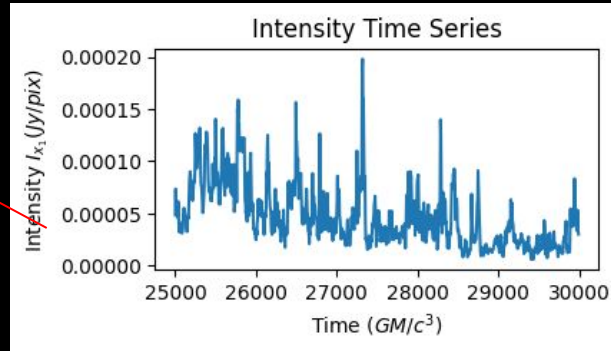
GRMHD simulations are crucial to interpret these observations.



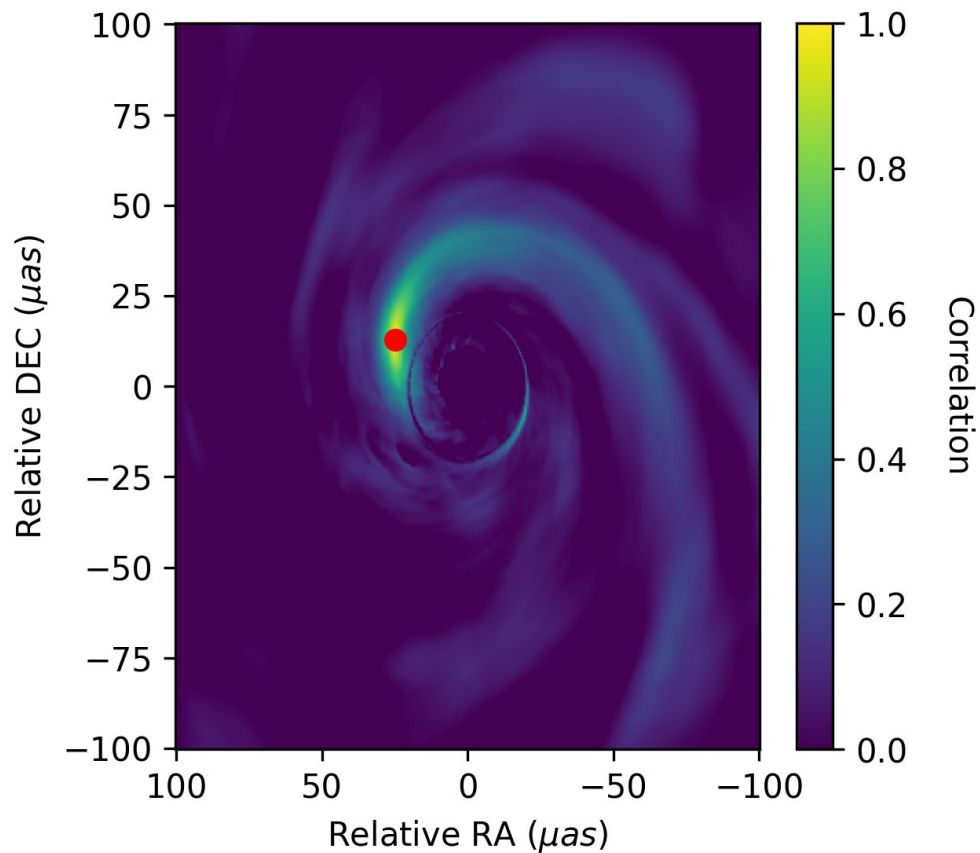
Quantifying the Variability



$$C(x_1, x_2, \Delta t) = \frac{\int I_{x_1}(t) I_{x_2}(t + \Delta t) dt}{\sqrt{\int I_{x_1}^2(t) dt \int I_{x_2}^2(t + \Delta t) dt}}$$

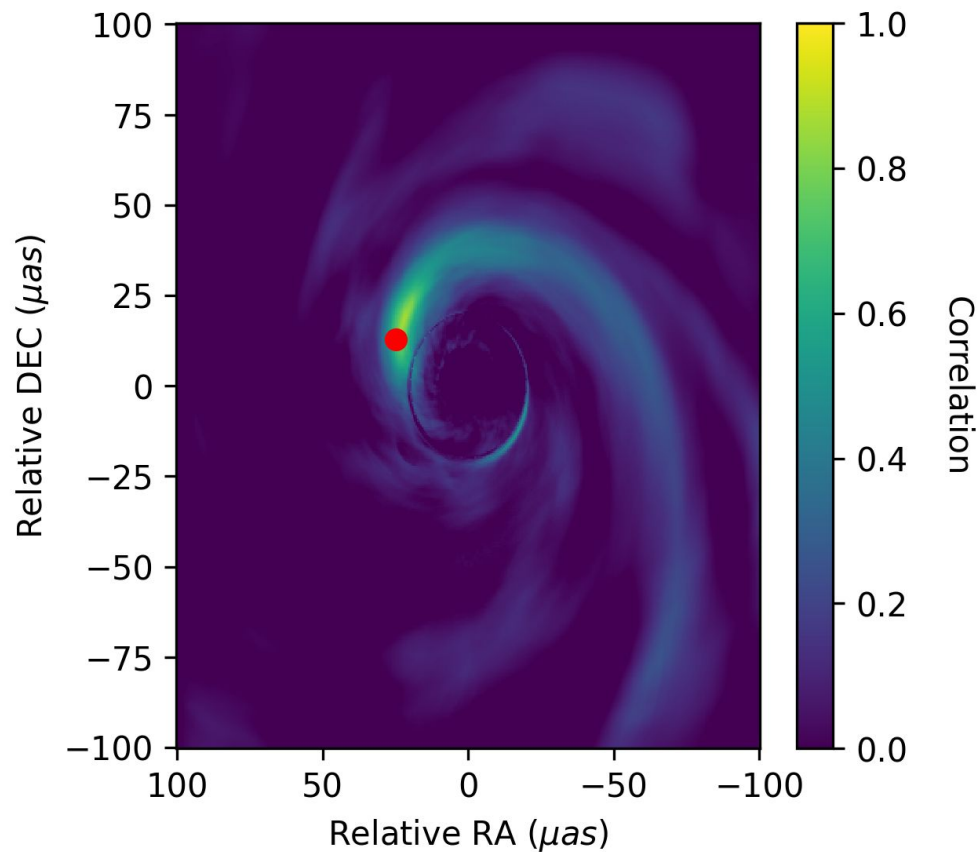


Plotting the Variability with all pixels



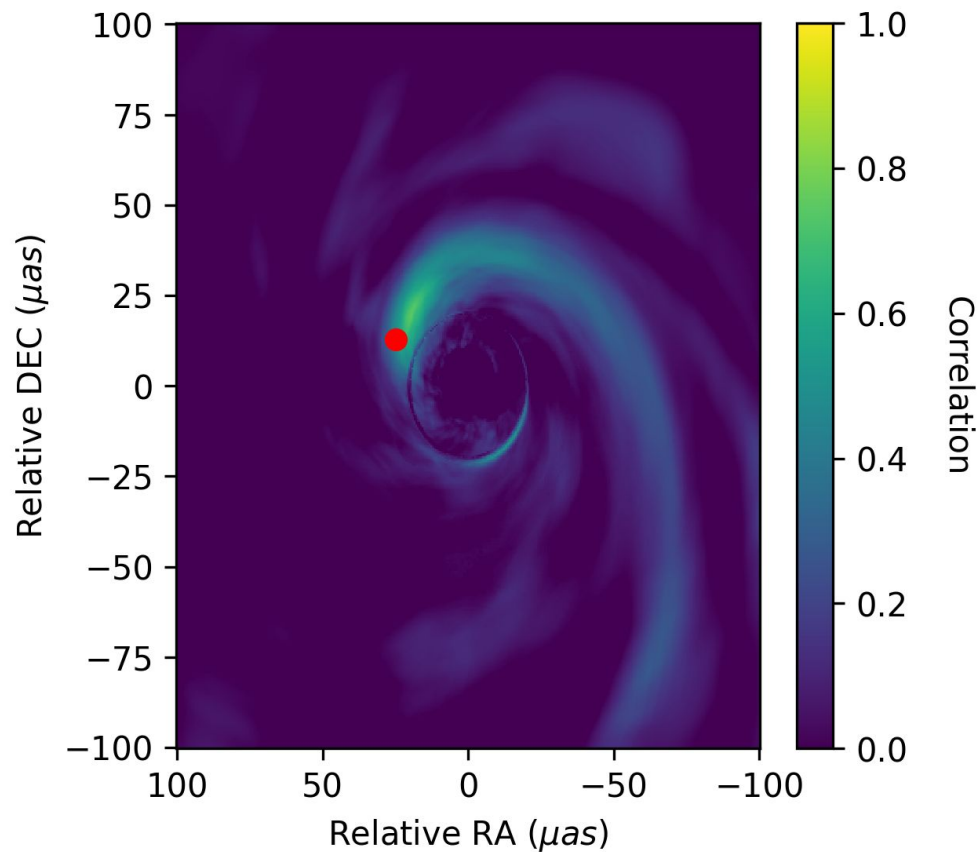
$\Delta t = 0$

Plotting the Variability with all pixels



$$\Delta t = GM/c^3$$

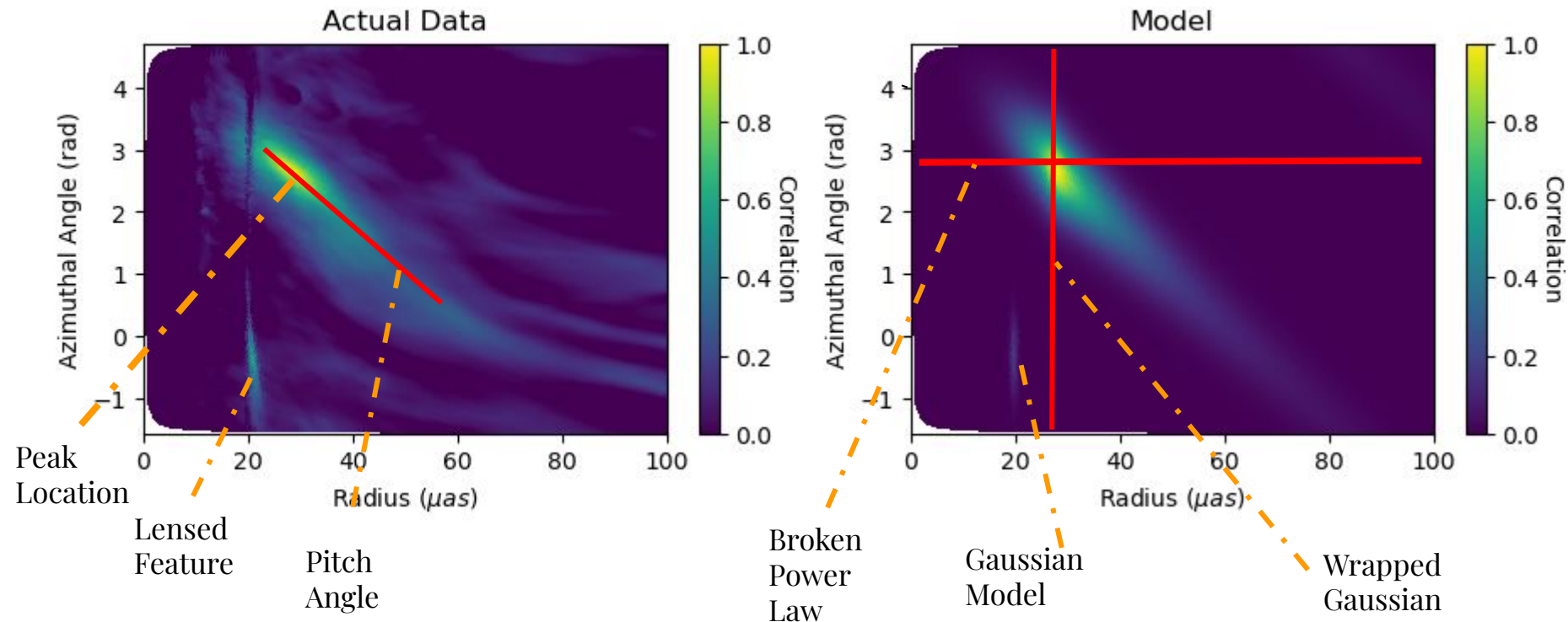
Plotting the Variability with all pixels



$$\Delta t = 2GM/c^3$$

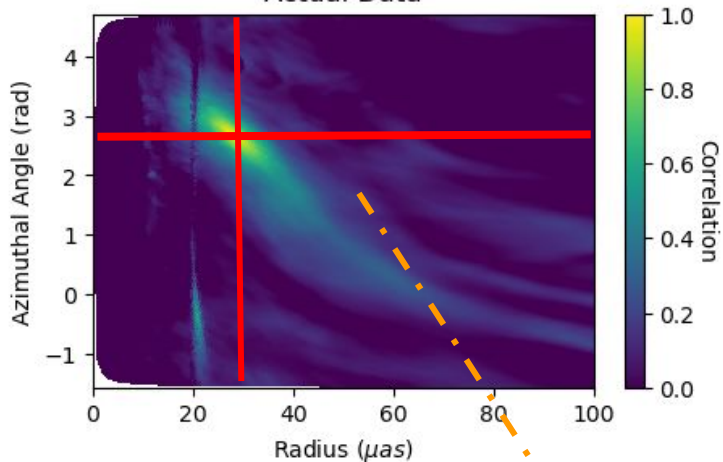
Modelling this Structure

Parameters: Peak Location, Lens Location, Pitch Angle

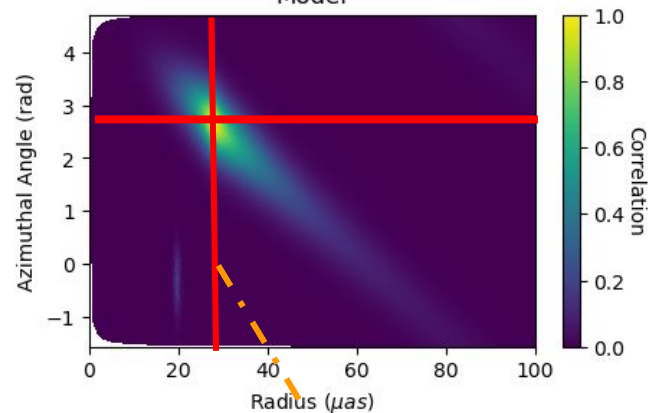


Modelling this Structure

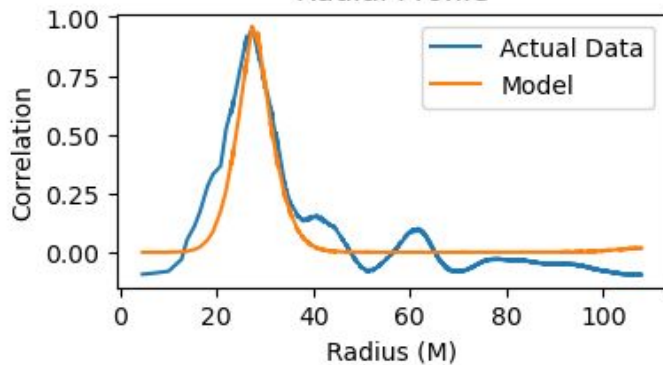
Actual Data



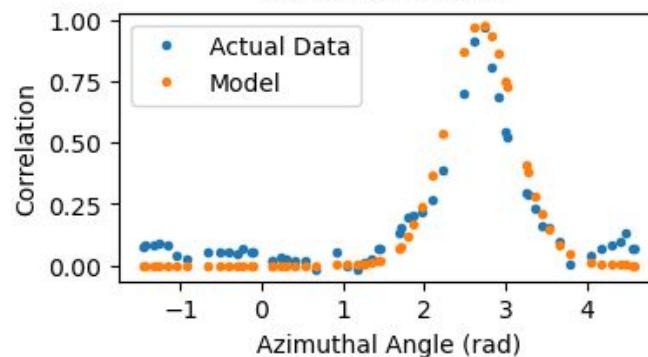
Model



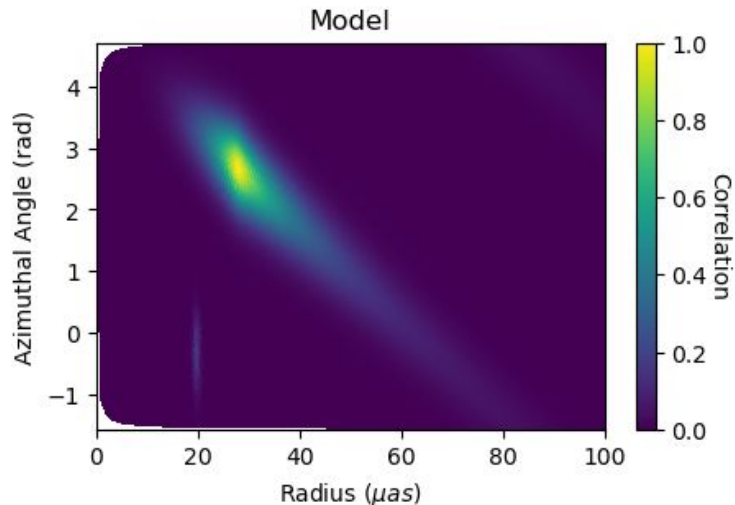
Radial Profile



Azimuthal Profile



Conclusion

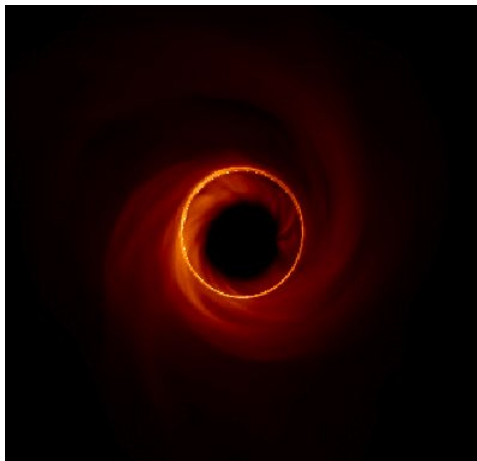


Use of GRMHD simulations to characterise the variability and obtain a Broken Power law and Azimuthal Wrapped Gaussian model

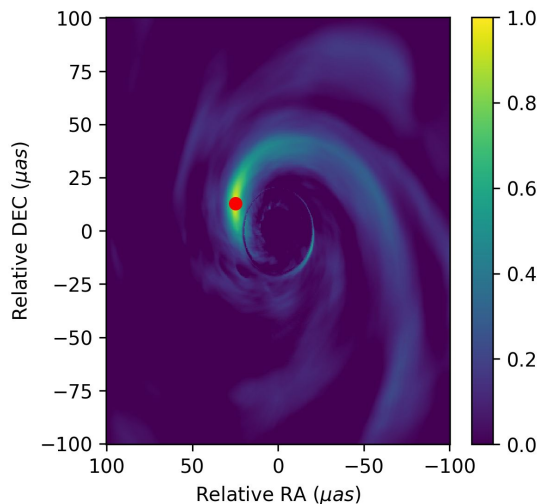
What's next

- Apply this model to more GRMHD simulations
- Use this model to characterize turbulence and disentangle it with the mean image.
- Application to real data and upcoming EHT movies.

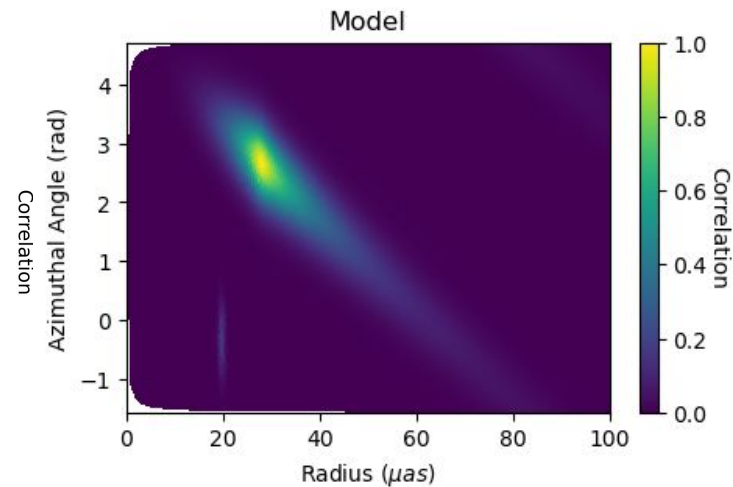
Conclusion



Use of GRMHD simulations to characterise the variability



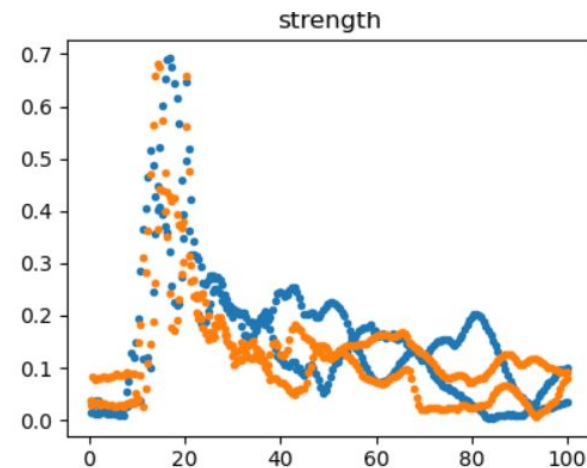
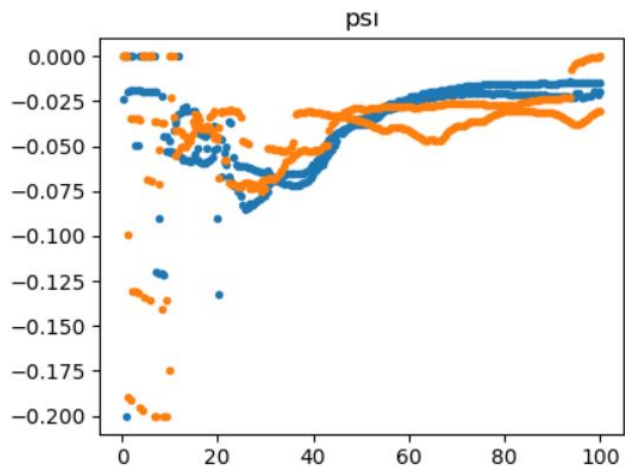
Correlation across all pixels



Radial Broken Power law
and Azimuthal Wrapped
Gaussian Function

Applying across the images

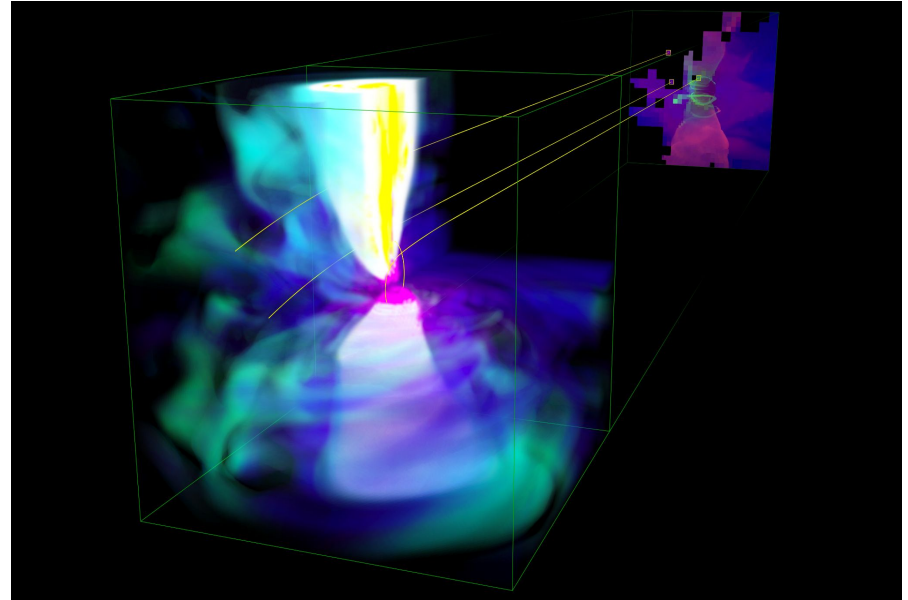
- Model applied pixel-by-pixel to entire frames
 - Reveals how variability parameters change with radius
- Enables radial profiling of dynamic behavior.



GRMHD Simulations

- GRMHD = General Relativistic Magnetohydrodynamics
- Simulates:
 - General relativity (gravity)
 - MHD (magnetic plasma)
- Captures time-dependent accretion flows behavior

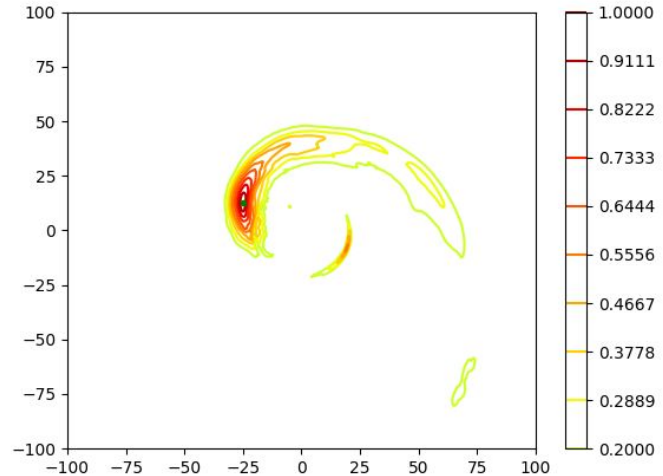
General Relativistic Ray Tracing (GRRT) turns plasma configuration from GRMHD to image.



Quantifying the Variability

- Captures how intensity varies across space/time in simulation images
- Detects patterns, turbulence, and coherence

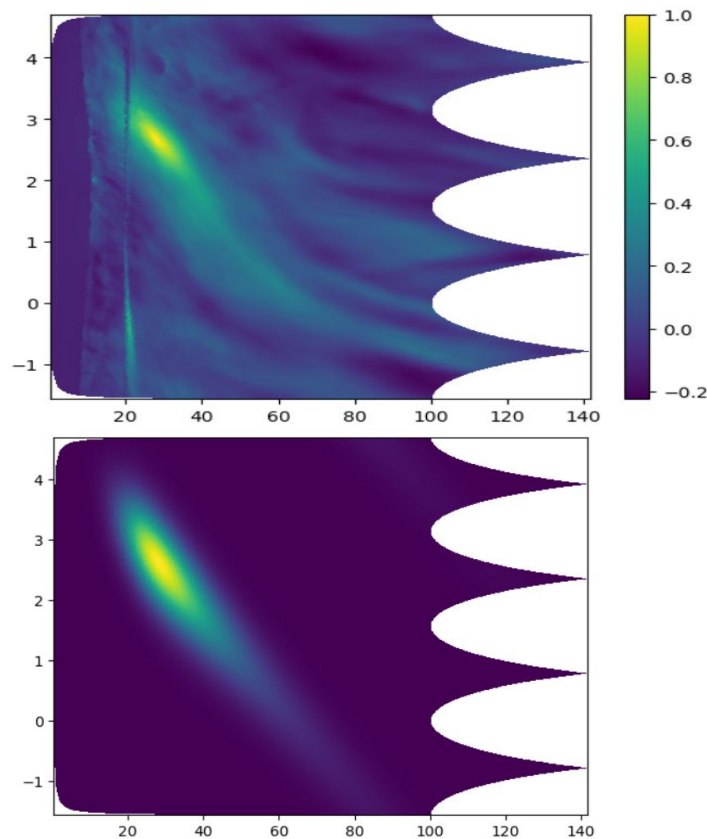
We calculate pixel-to-image correlations to reveal structure.



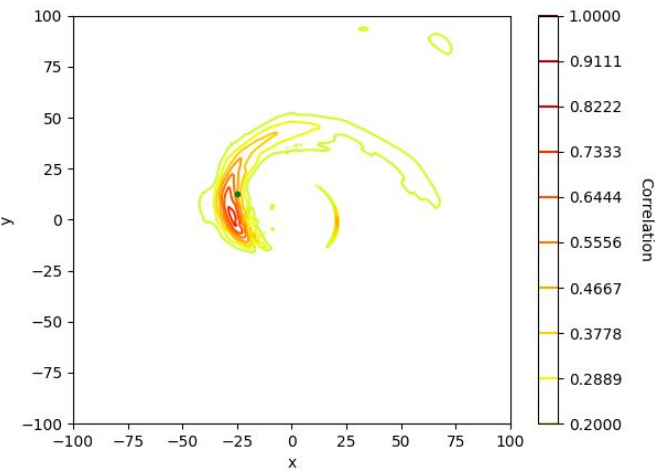
Modelling this Structure

Correlation structure modeled using Bayesian statistics:

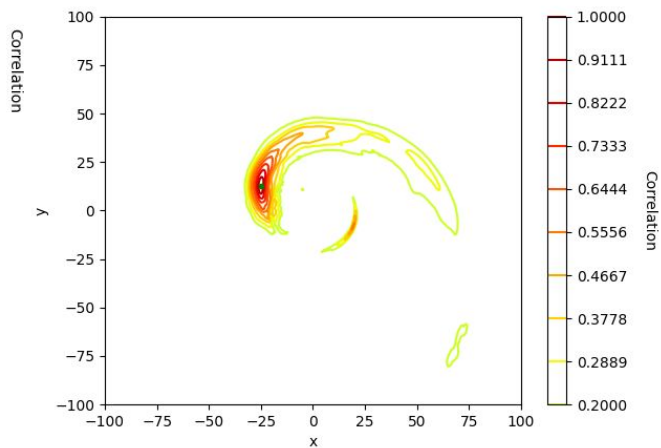
- Radial: Broken power-law
- Angular: Exponential cosine
- Parameters: Peak location, Pitch angle, Feature strength, Peak width, lensed feature strength,



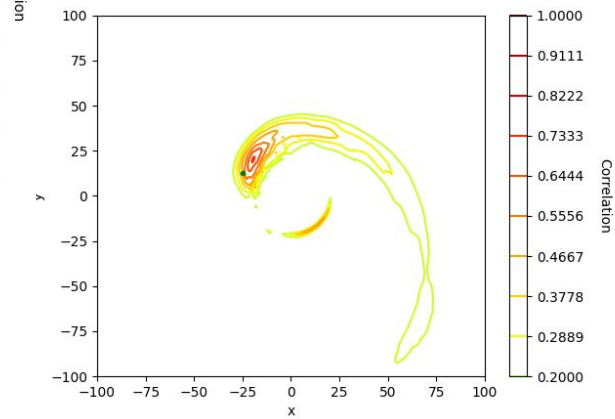
Plotting the Variability with all pixels



$\Delta t = -2$

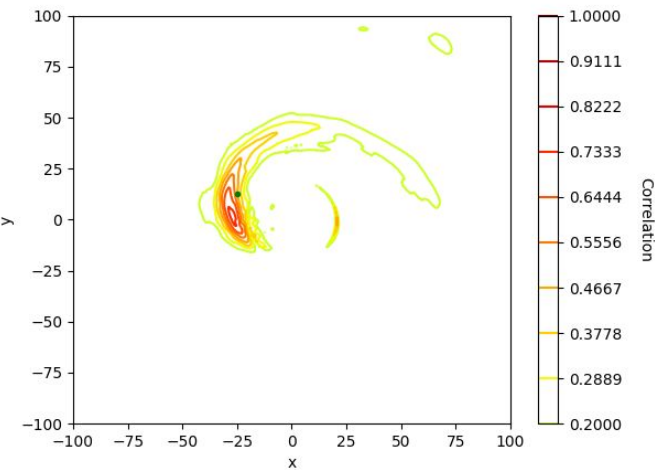


$\Delta t = 0$

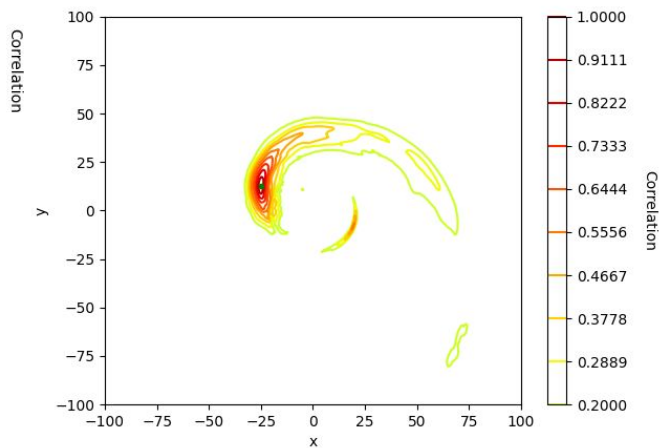


$\Delta t = 2$

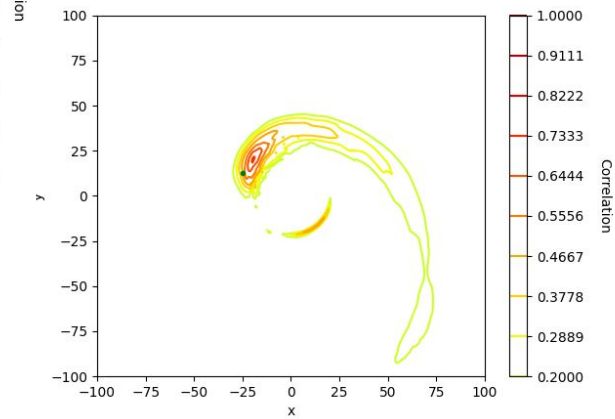
Plotting the Variability with all pixels



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$\Delta t = 0$

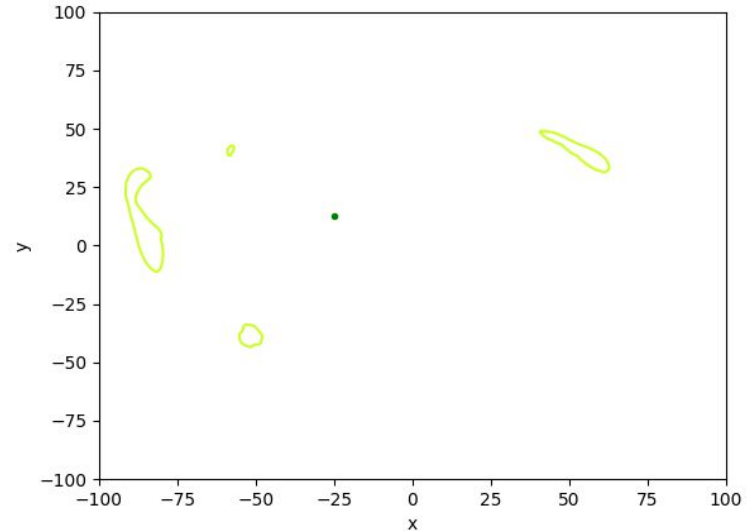


$\Delta t = 2$

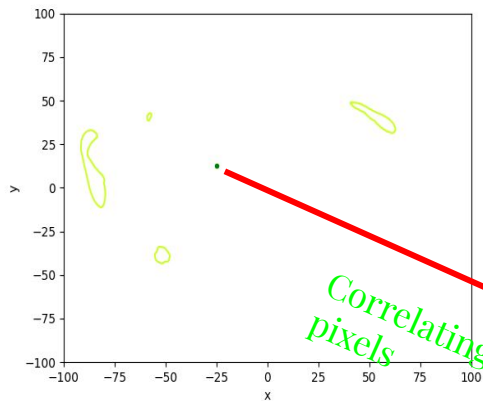
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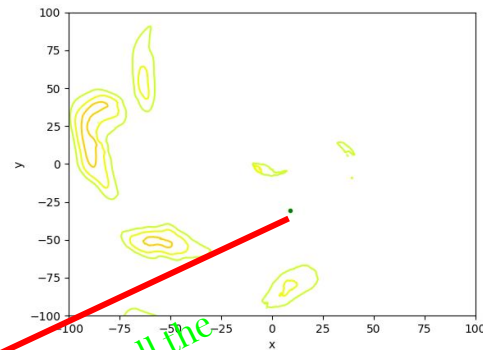
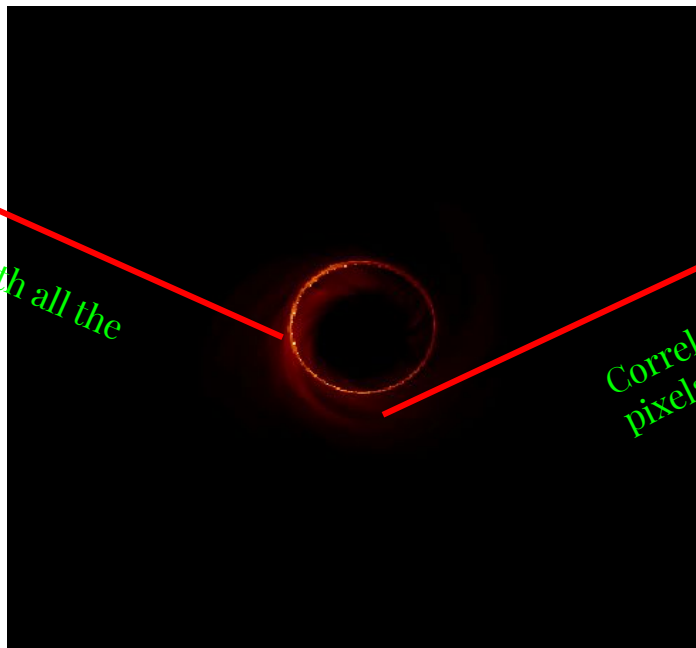
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Plotting the Variability with all pixels



Correlating with all the
pixels



Correlating with all the
pixels