SynCOM:

Synthetic Corona Outflow Model for the Heliophysics Community

December, 2021

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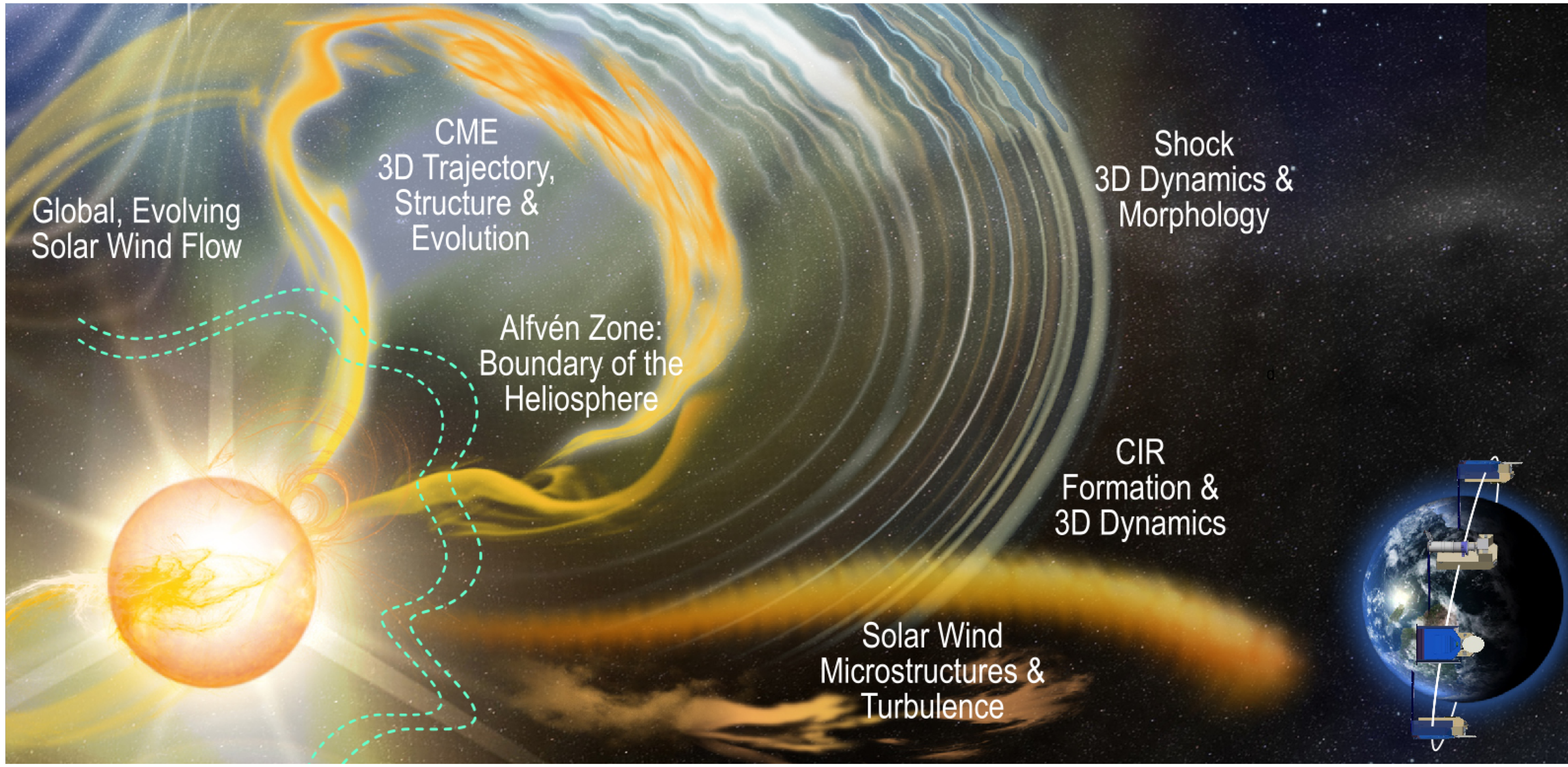
Motivation
PUNCH Mission

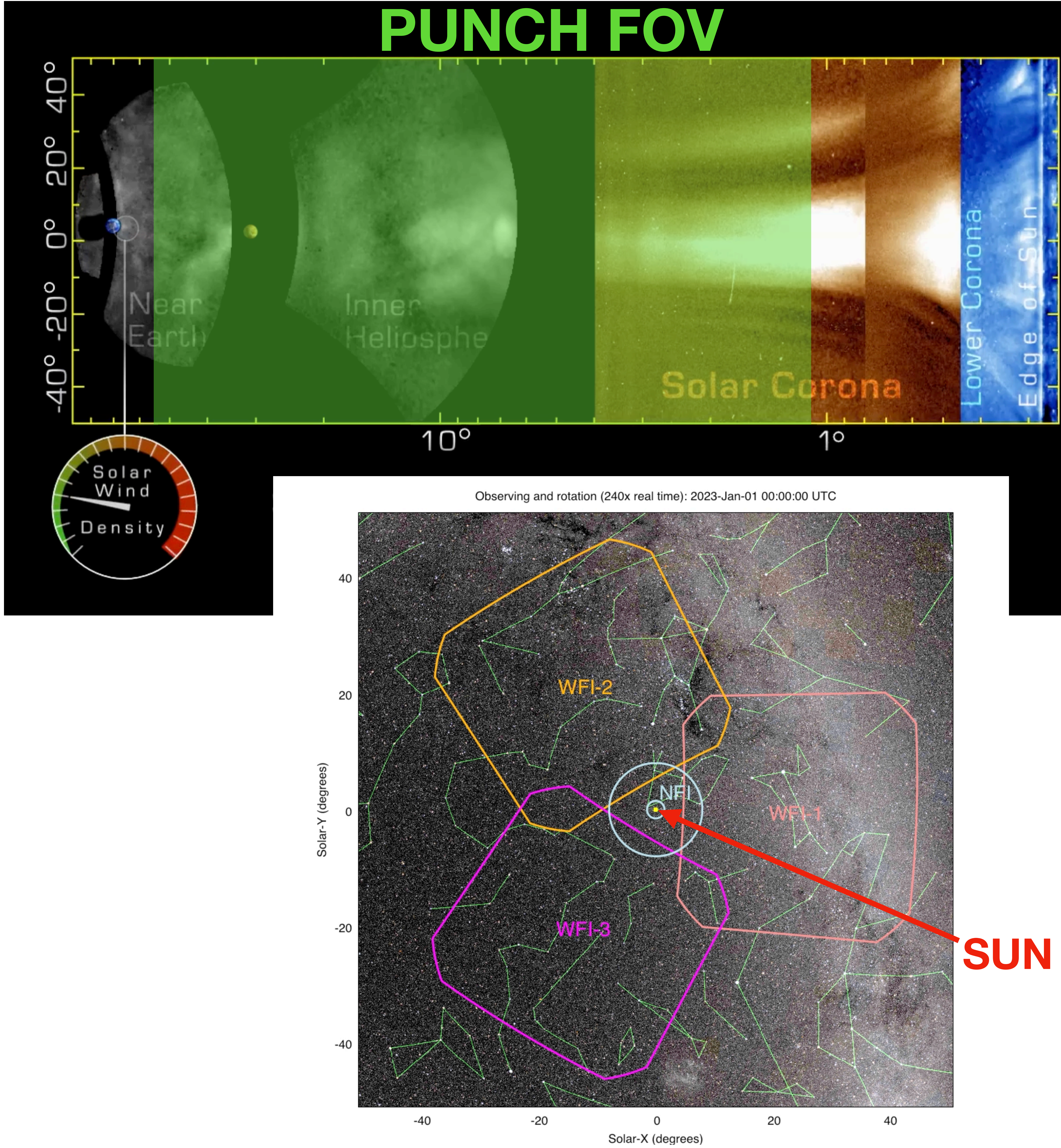
- PUNCH (**P**olarimeter to **UN**ify the **C**orona and **H**eliosphere) mission:

- Science Goal is to comprehend the cross-scale physical processes - from micro-scale turbulence to the evolution of global-scale structures - that unify the solar corona and heliosphere.
    - Understand how coronal structures become the ambient solar wind.
    - Understand the dynamic evolution of transient structures in the young solar wind.



Motivation
PUNCH Mission

- PUNCH FOV: 5 $R_\odot$ (1.25º) to 180 $R_\odot$ (45º)
- PUNCH wind speed measurements:
  - Late phase acceleration
  - Feature speeds
  - Bulk speed via anomalous photometry
  - 3D flow structure
- PUNCH CME evolution measurements:
  - 3D trajectory
- Launch: Oct 2024.



Motivation

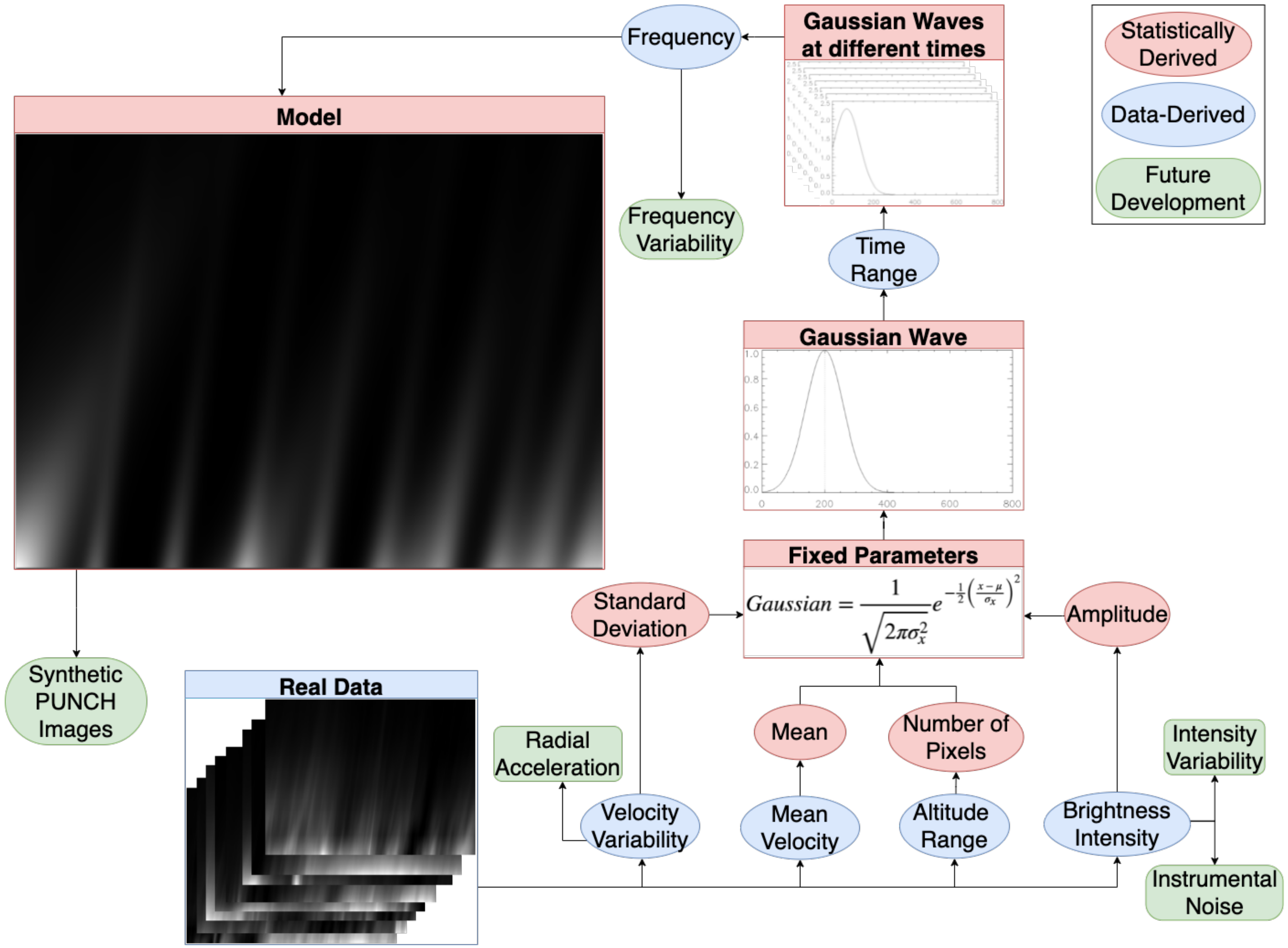
Flow mapping

- In preparation for the PUNCH mission
- Validating and comparing the different algorithms for measuring coronal flow velocities
- Assessing the impact of different types of noise in the algorithm accuracy
- Determining the measurements errors (uncertainties)
- Extrapolating the altitude range of previously operated missions
- Produce synthetic PUNCH images, extending altitude range to ~180 $R_\odot$

Model

Structure

- Gaussian waves as main engine
- Derived of previous solar corona observations
  - Based on statistics of the physical phenomena
- Mimics a transient, quasi-periodical behavior
  - Realistic radial decay of brightness
  - Predefined frequency parameters
  - Predefined velocity parameters
  - Adjustable signal-to-noise ratio



Model

Data

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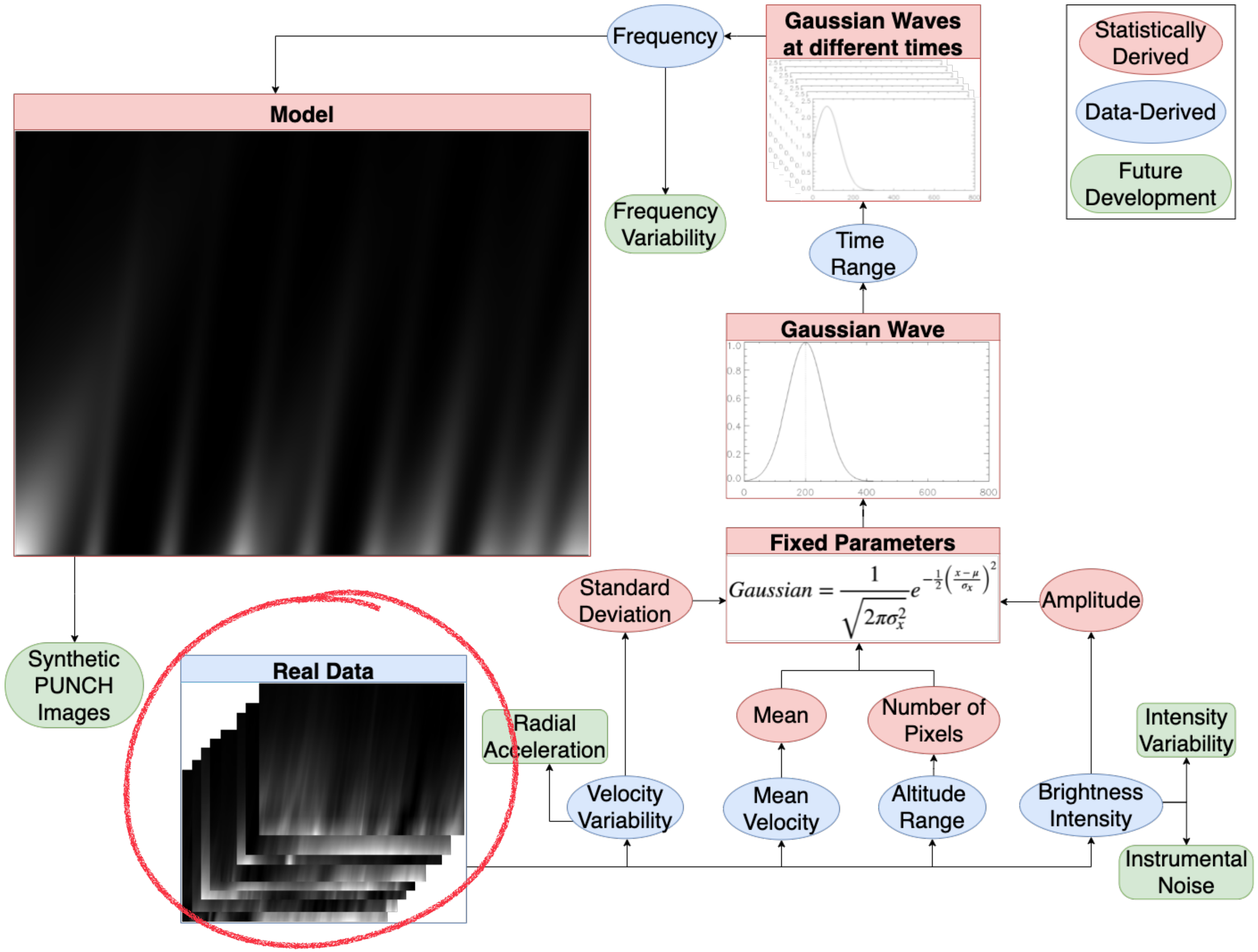
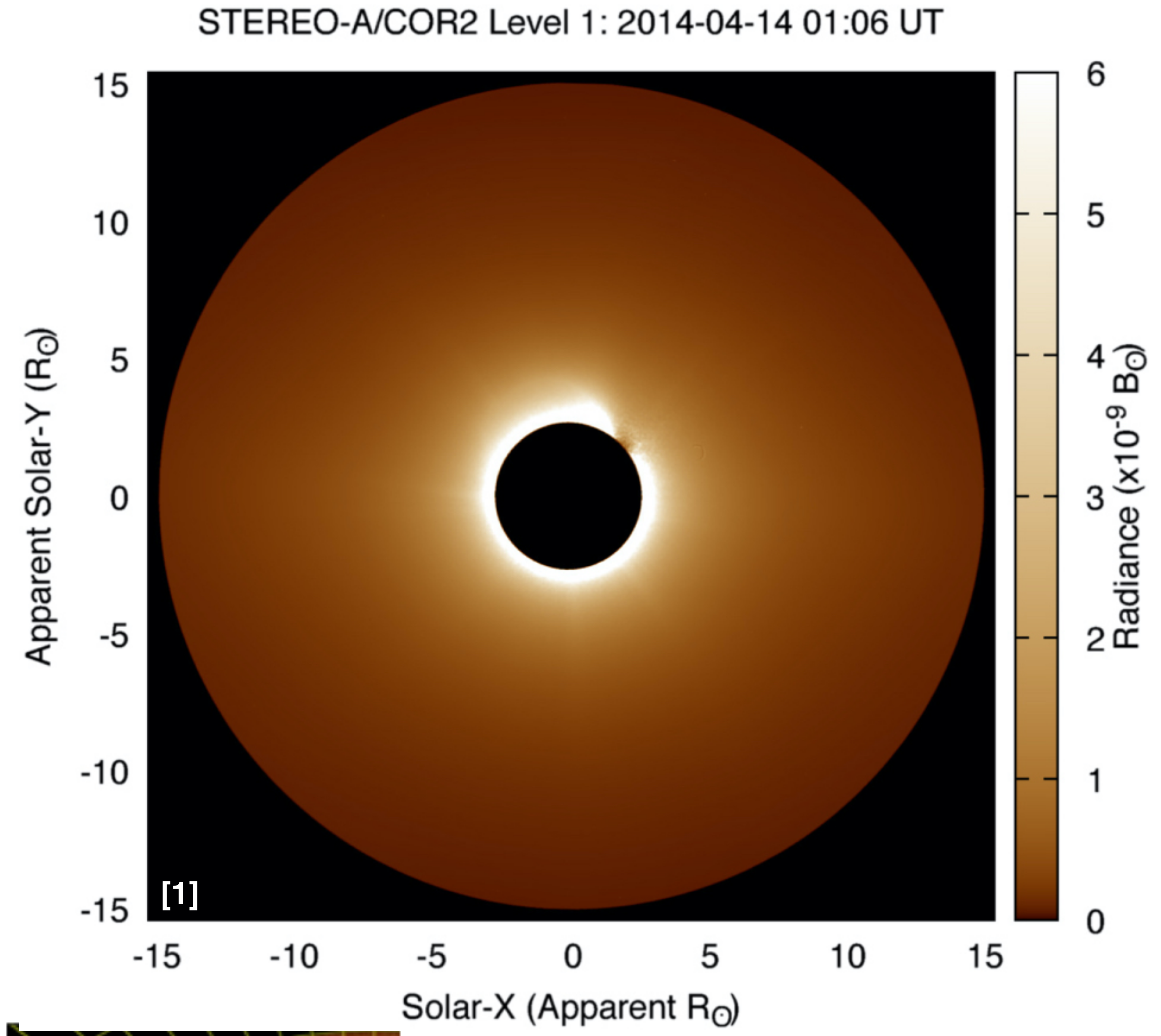
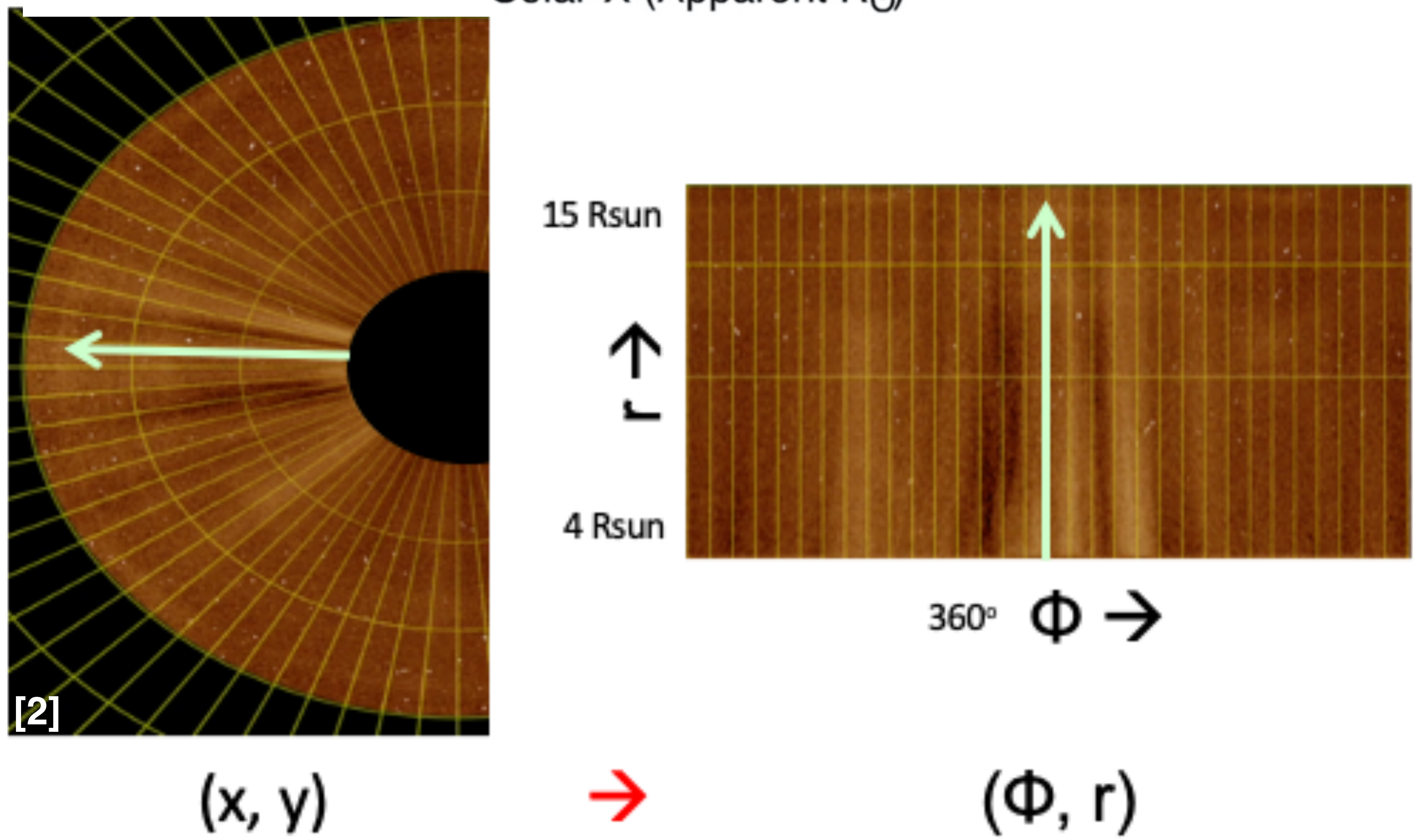


Data
STEREO-A / COR 2

- Special campaign ran in April 2014.
  - Deepest exposure and unpolarized images
  - 36 seconds exposure once every 5 minutes, over 72 hours
- Altitude range from 4 to 15 apparent $R_\odot$
- The raw unpolarized long-exposure coronagraph image received an intense process of preparation by Craig DeForest
  - Images preparation included: coordinate resampling, smooth background and stars removed, and blur reduced.
  - Transforming to a flow-friendly corona image
  - For further details see [1].





[1] DeForest et al., "The Highly Structured Outer Solar Corona", Astrophysical Journal, Vol. 862, 2018.
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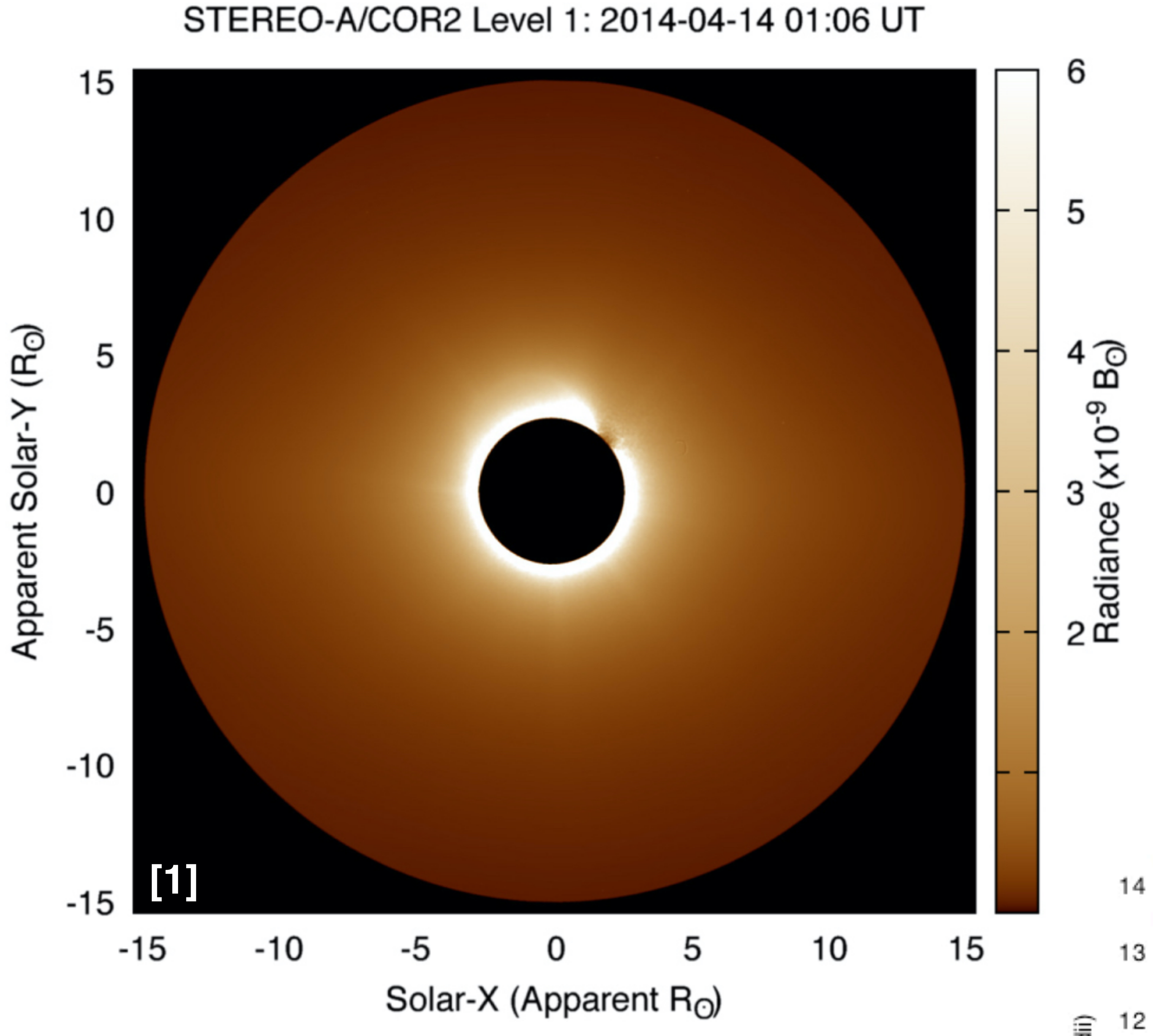

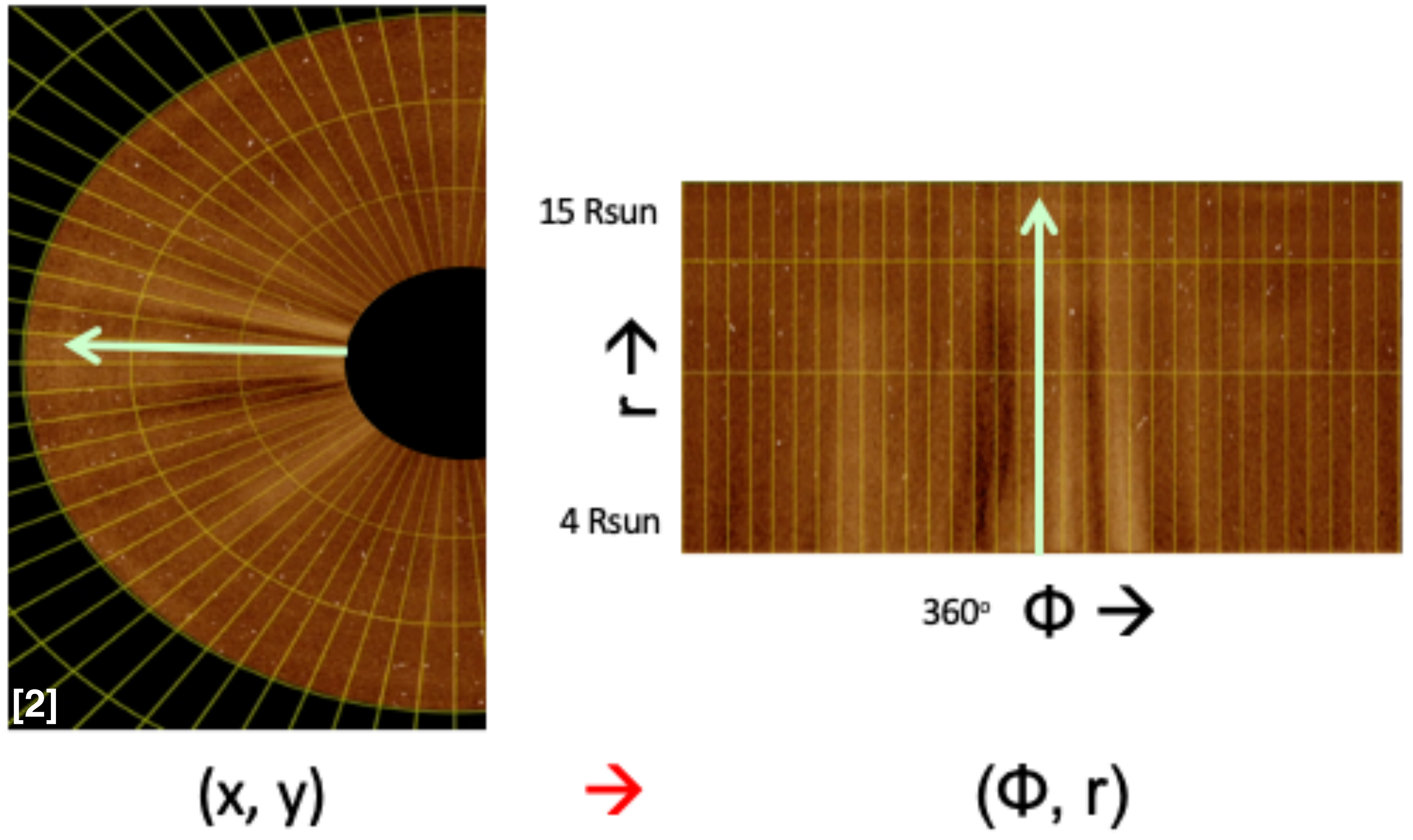

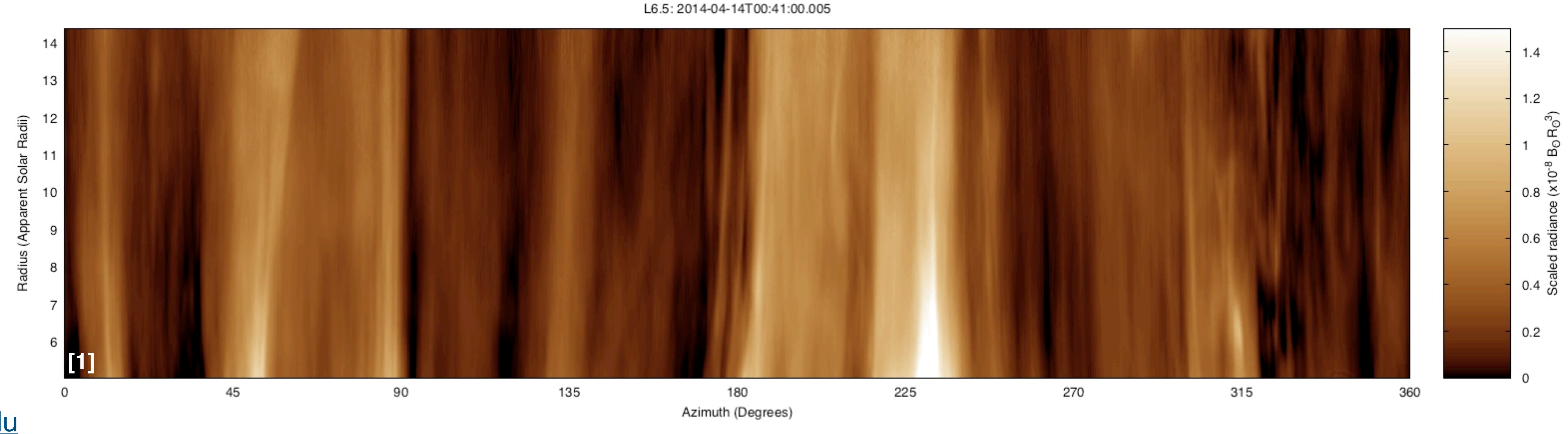

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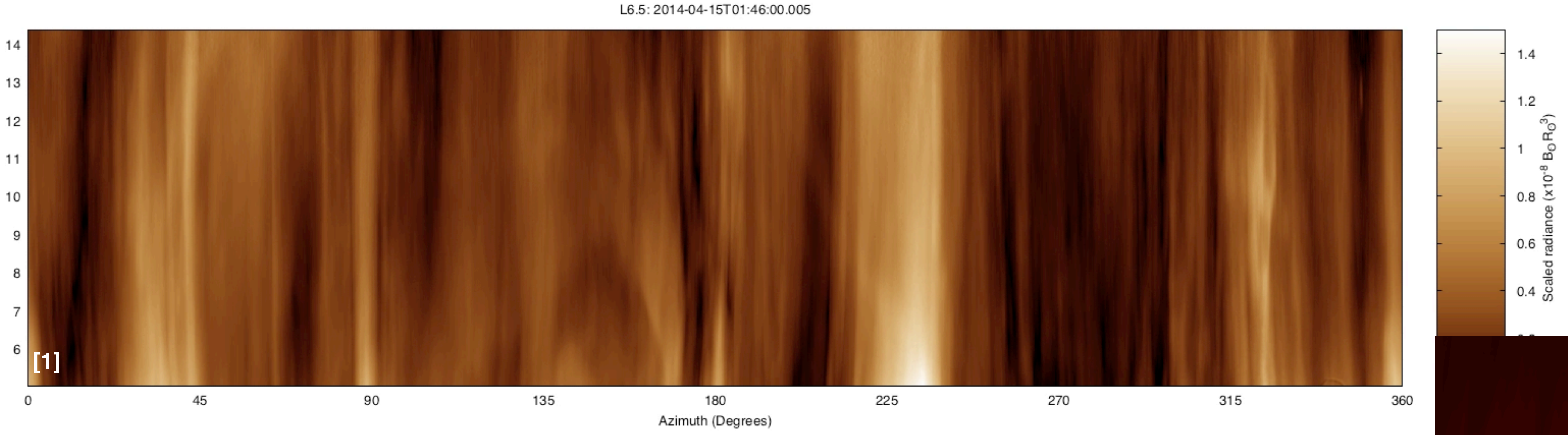
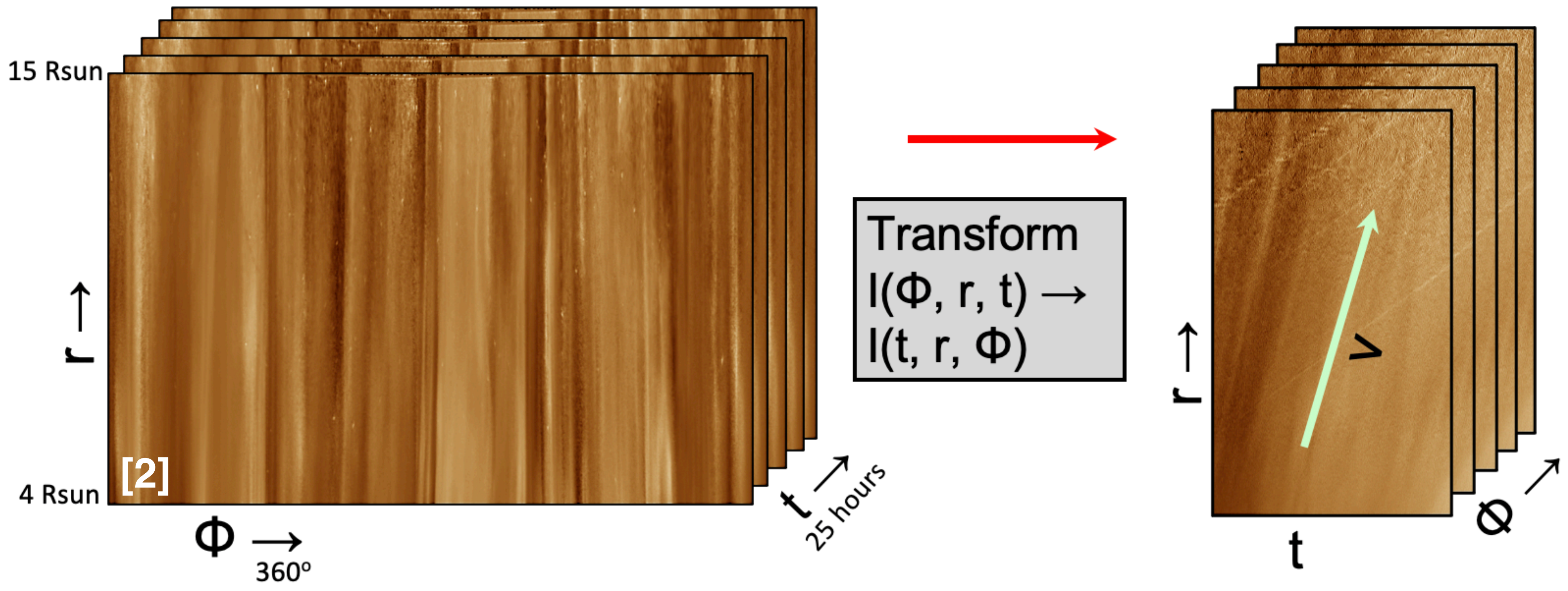
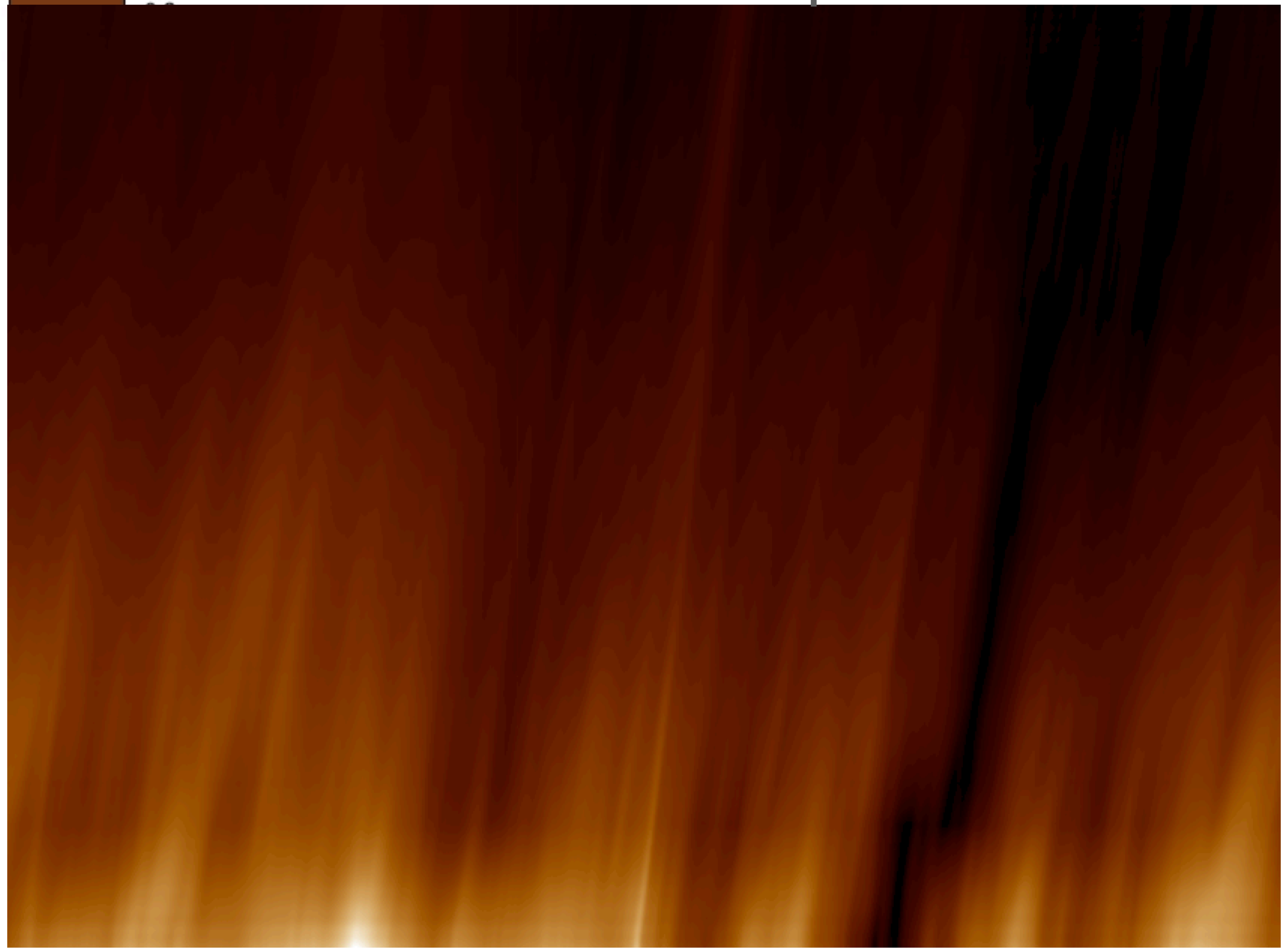
STEREO-A / COR 2





Distance-time plot



Parameters

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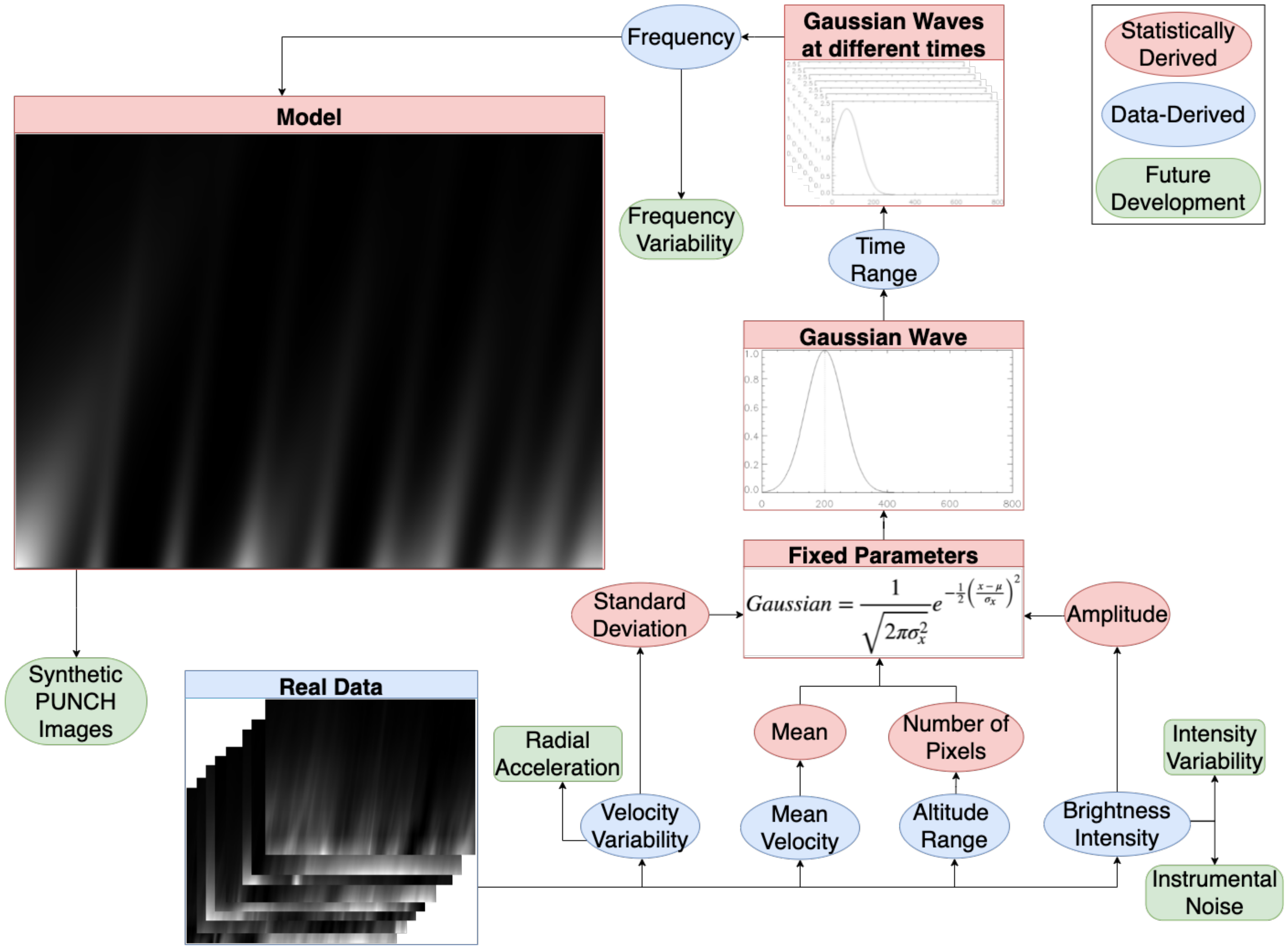
- Derived of previous solar corona observations
  - Based on statistics of the physical phenomena
- Mimics a transient, quasi-periodical behavior
  - Realistic radial decay of brightness
  - Predefined frequency parameters
  - Predefined velocity parameters
  - Adjustable signal-to-noise ratio



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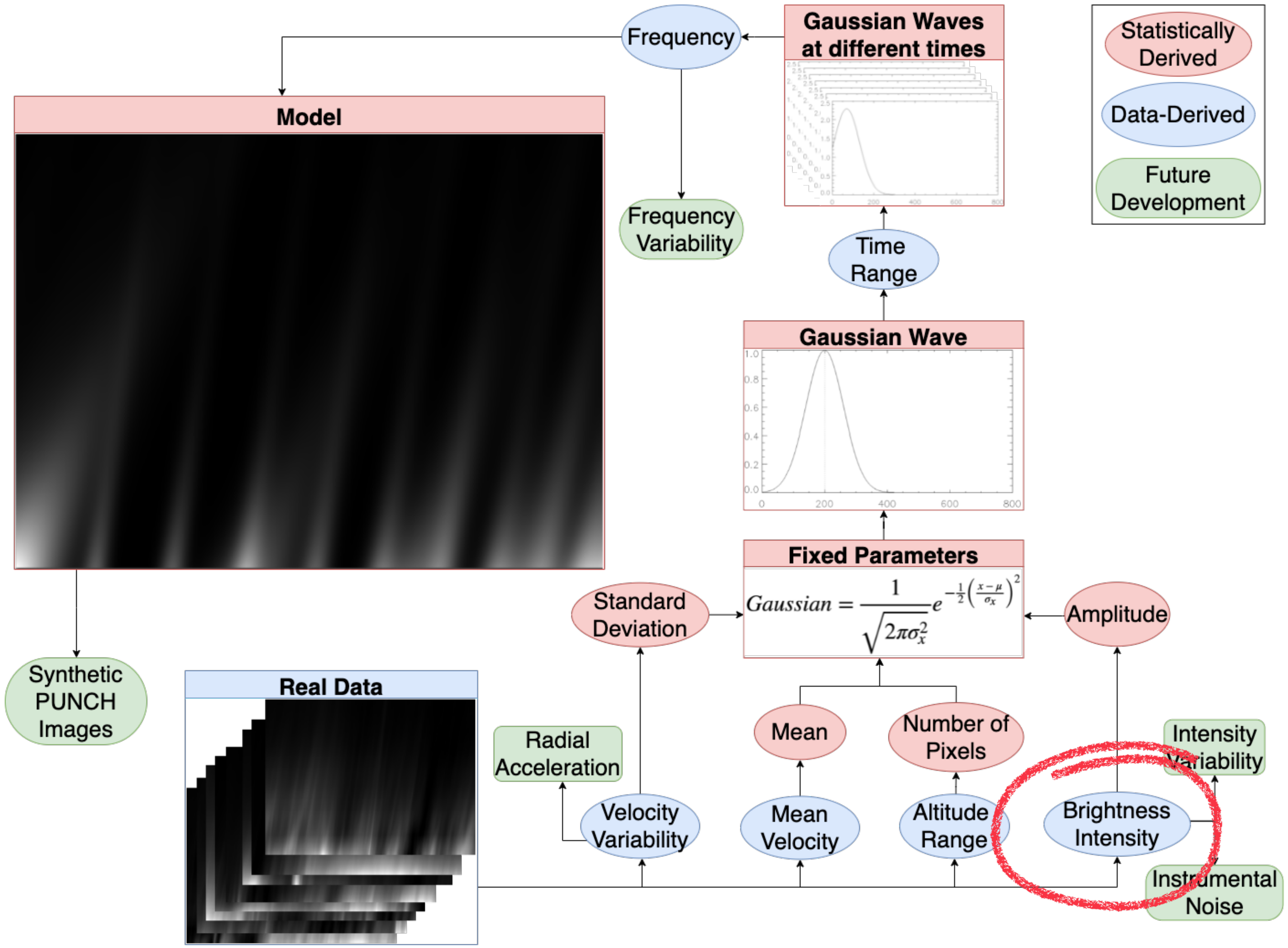
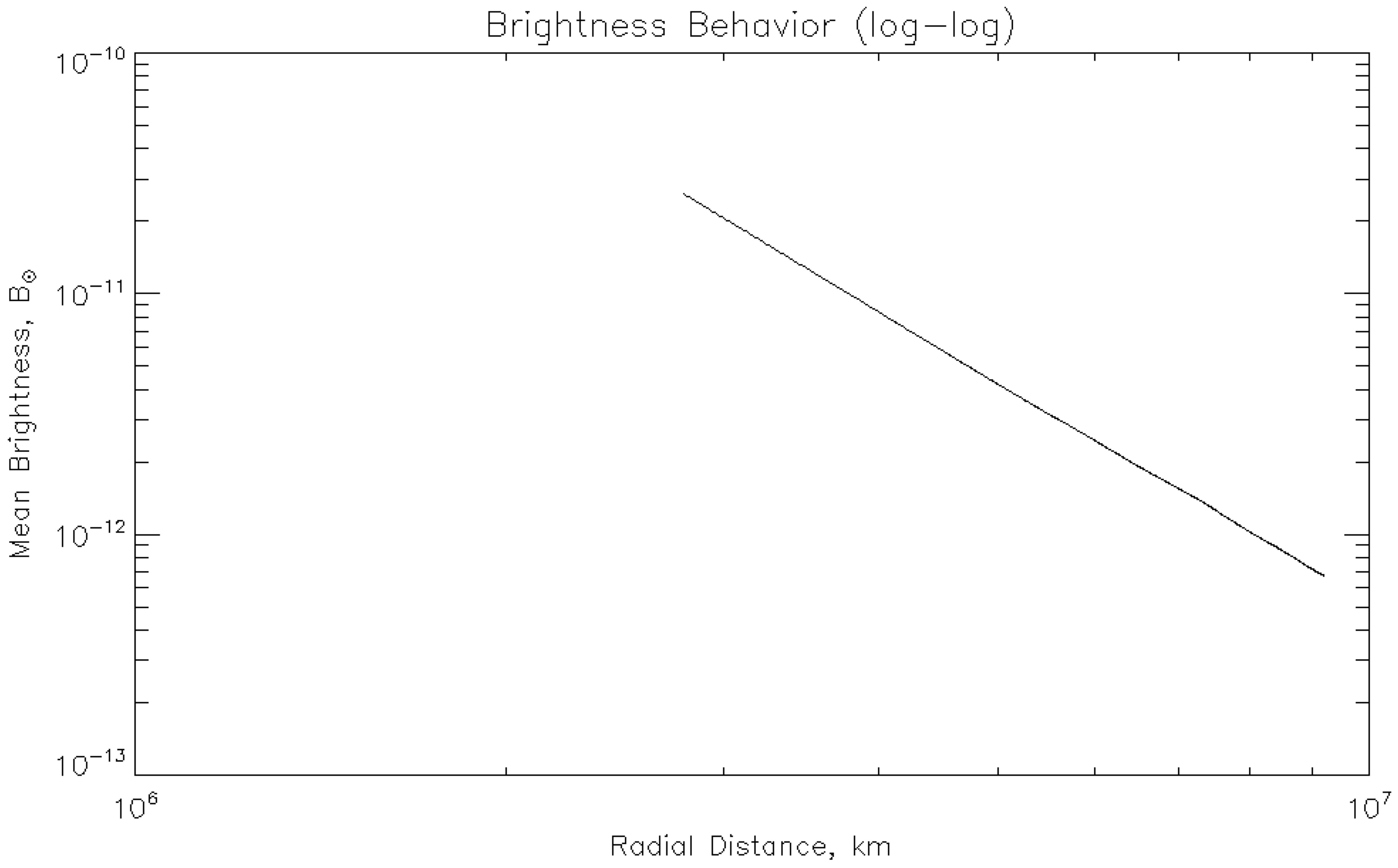


Parameters

Brightness Behavior

- Linear fit of the mean brightness by the distance
- The data behaves like a power law
- Indicating a clear decay with distance: $a = -3.04$
- Easily reproduced to our model



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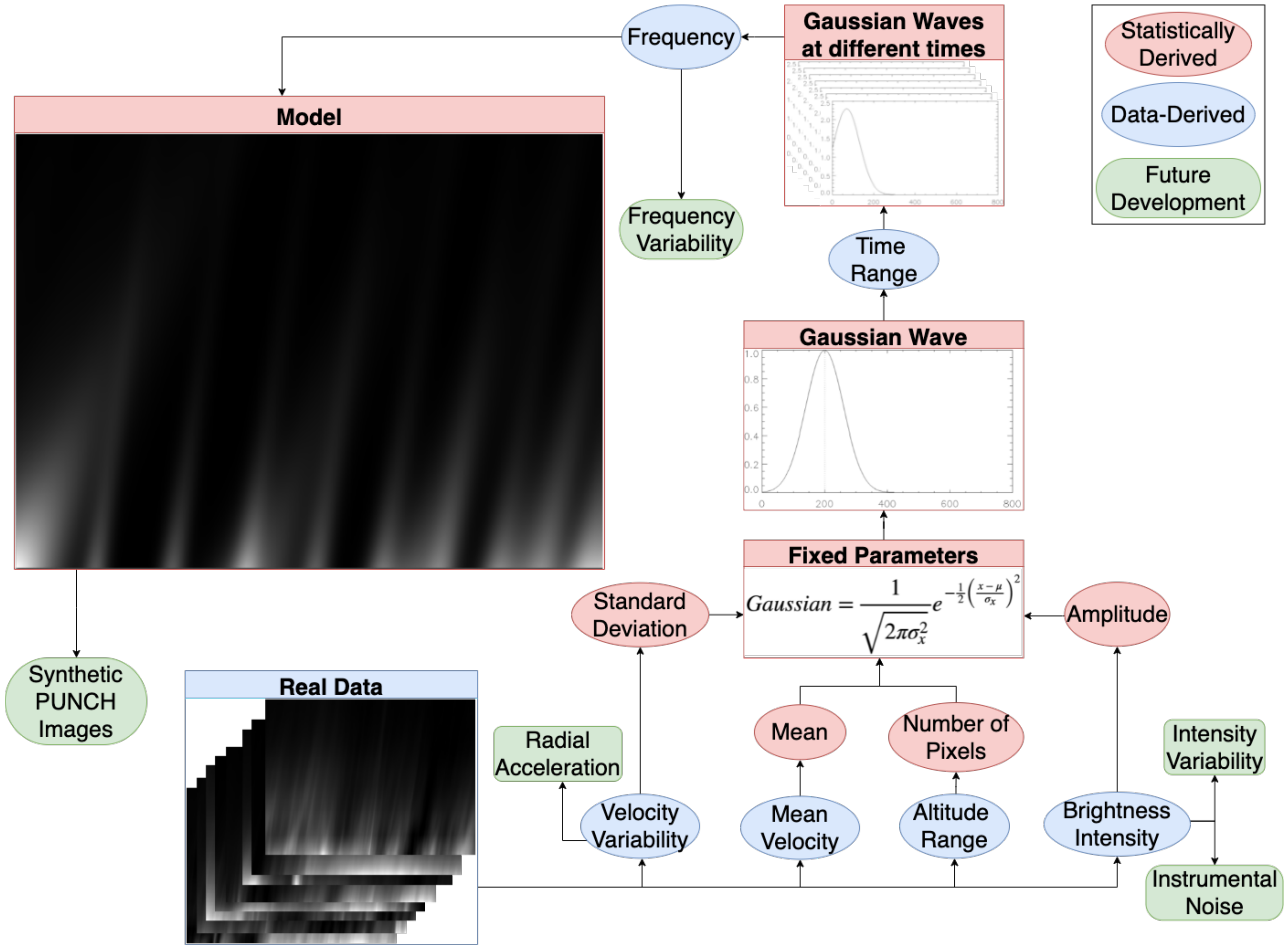

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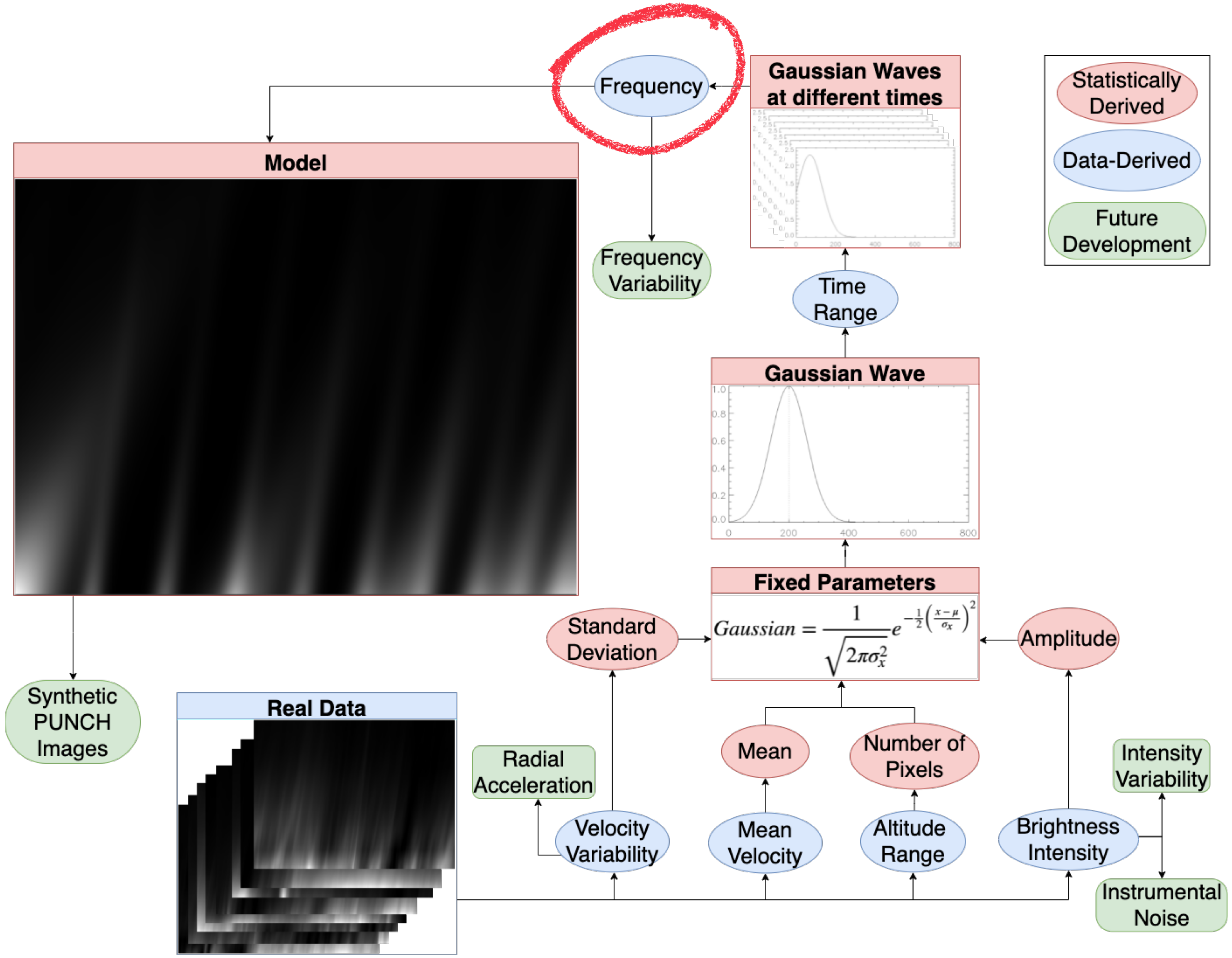
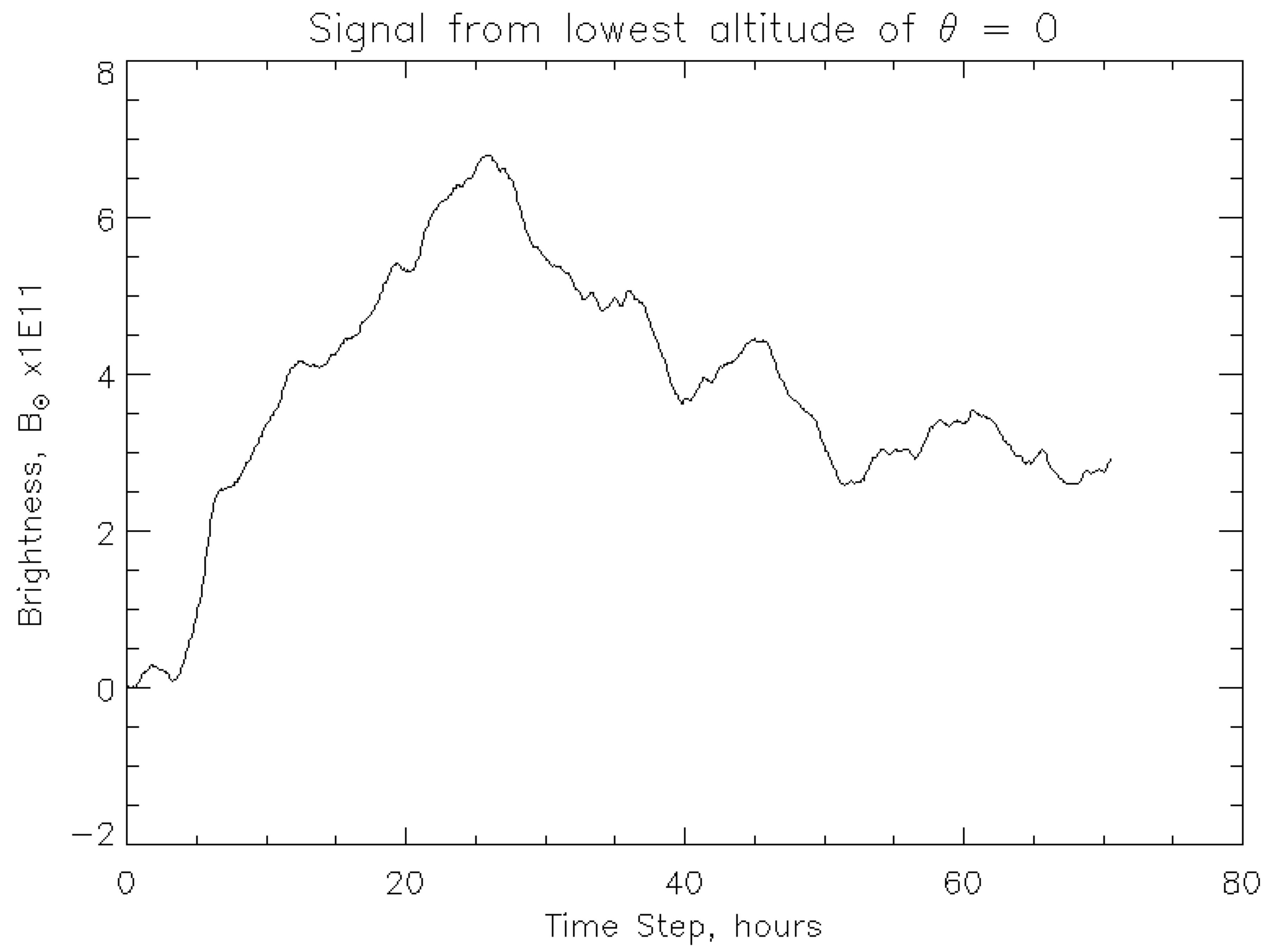
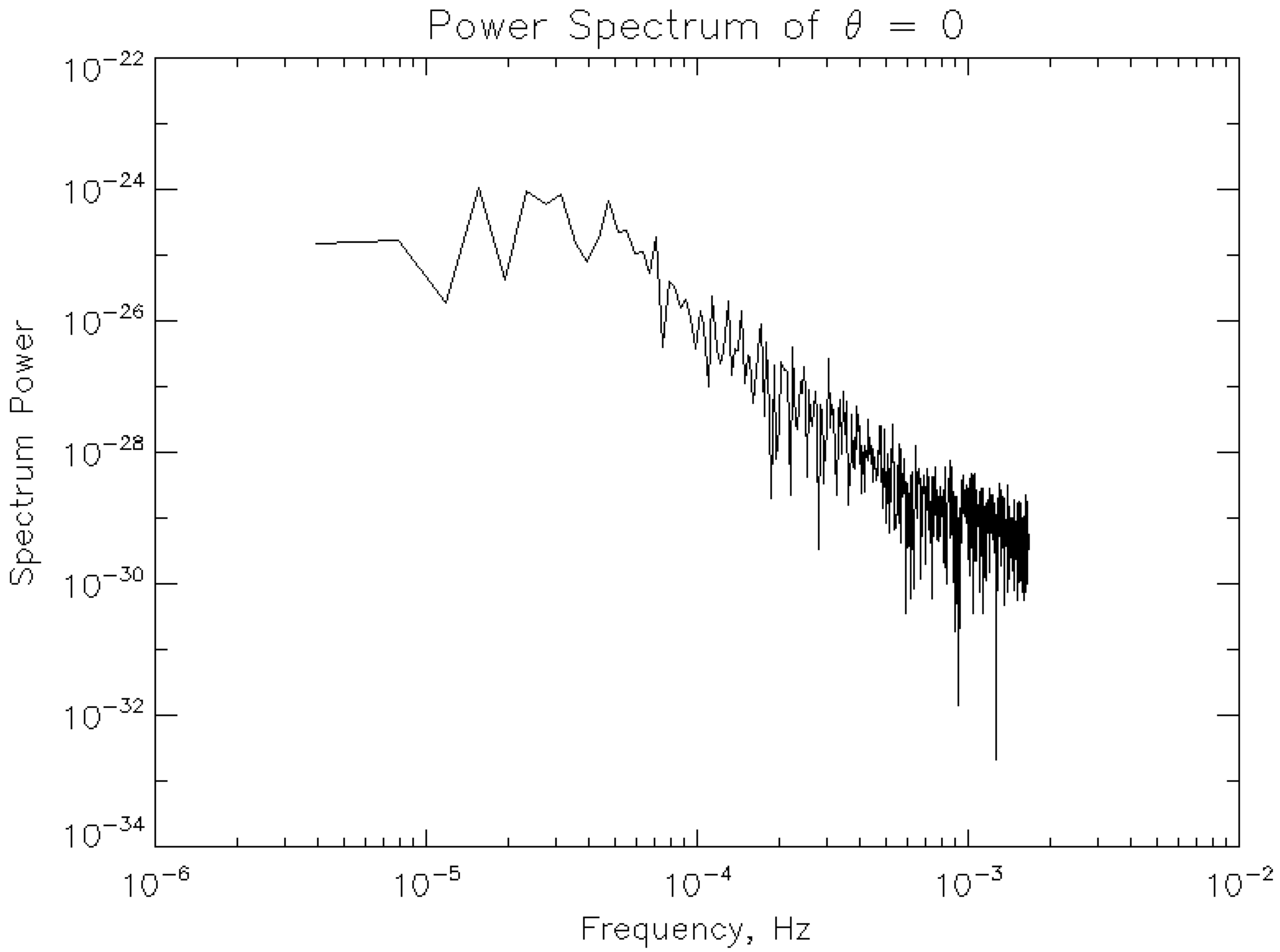


Parameters
Frequency

- **Signal taken from lowest altitude** at all times from each position angle
    - Sampling time: 300 seconds
- The second highest peak in the power spectrum contains the signal’s frequency
- This frequency contains information on the amount of features launches at a certain position angle.
- The statistical measurements was taken within a given power threshold.





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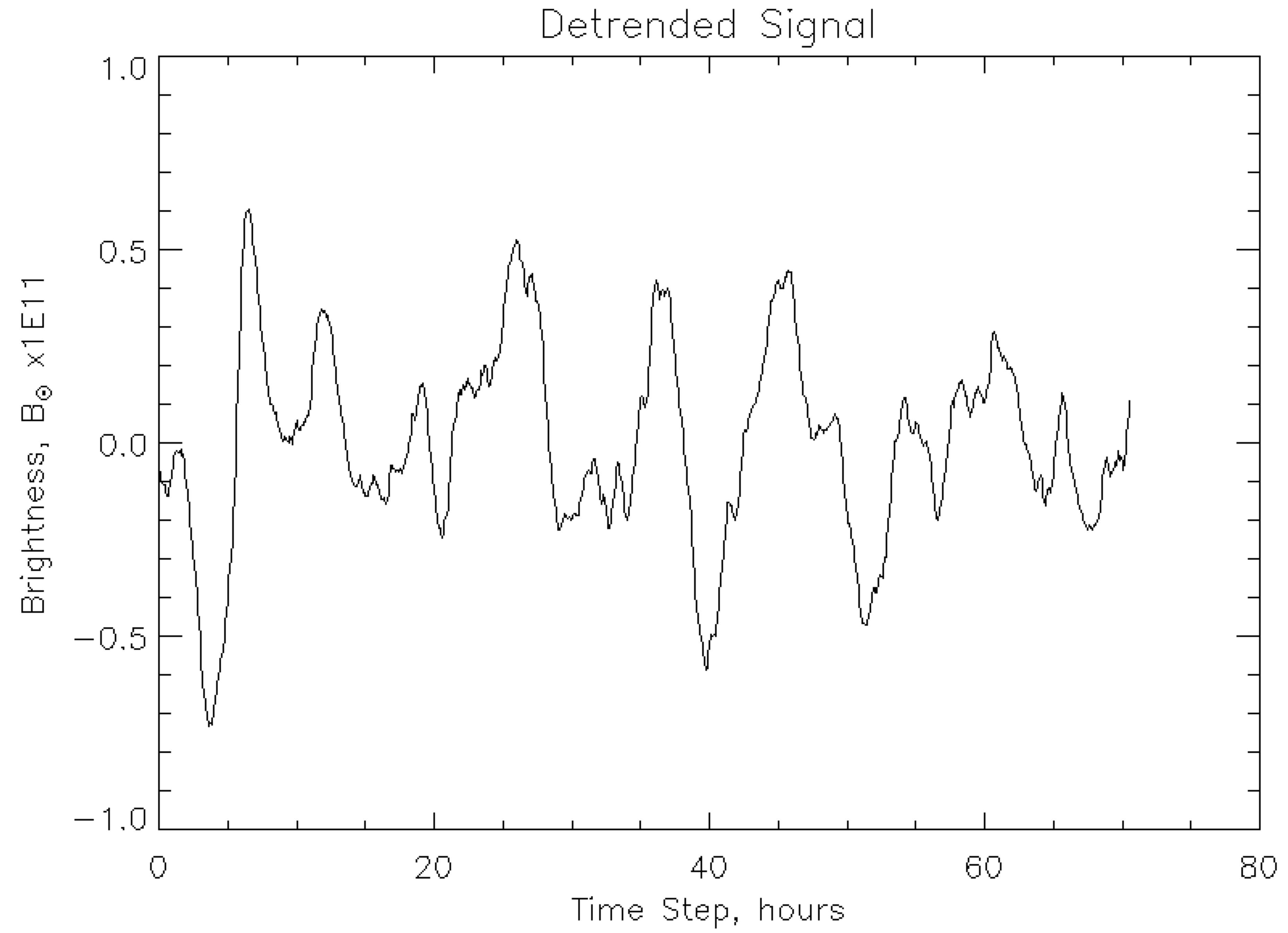

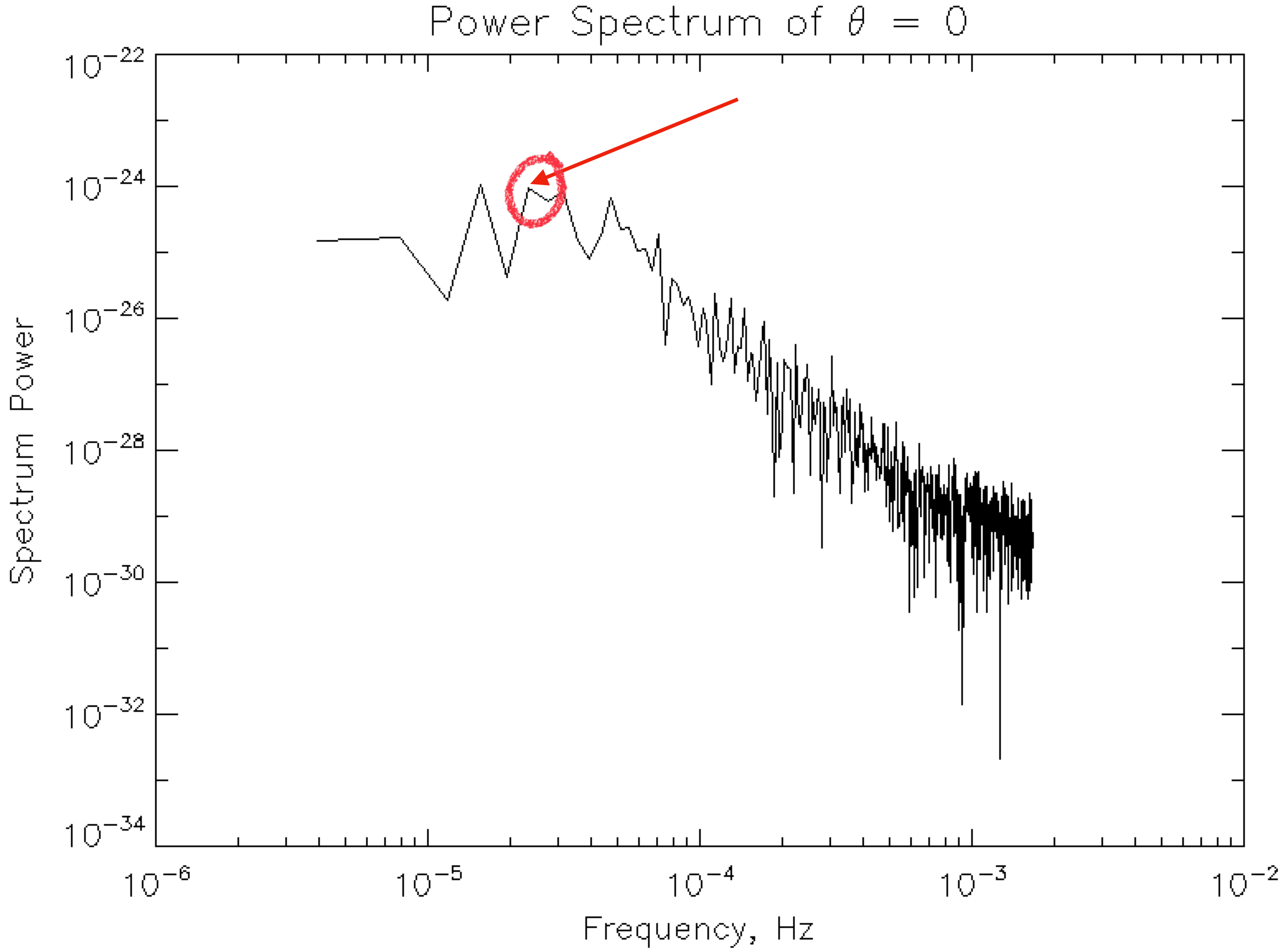

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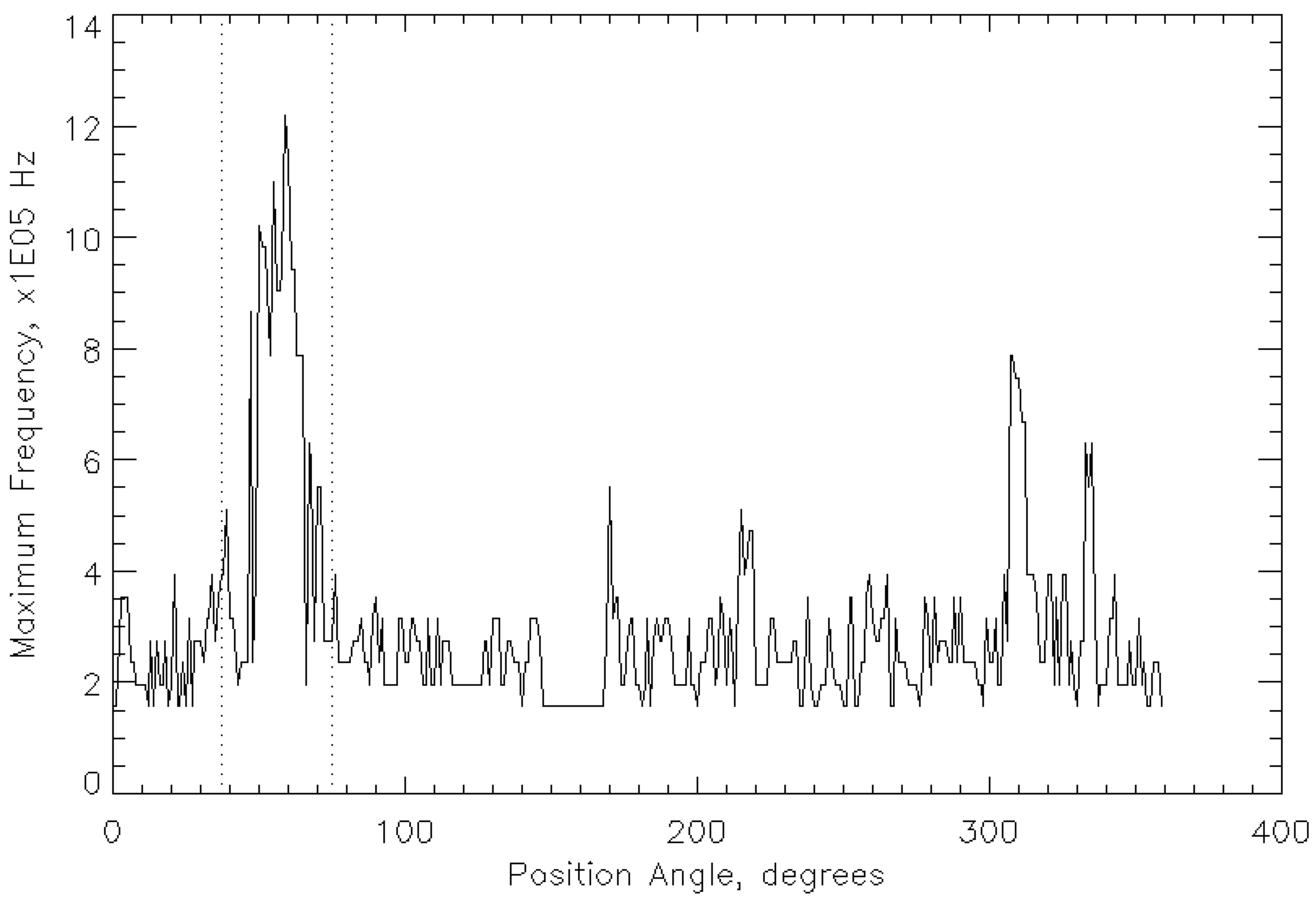

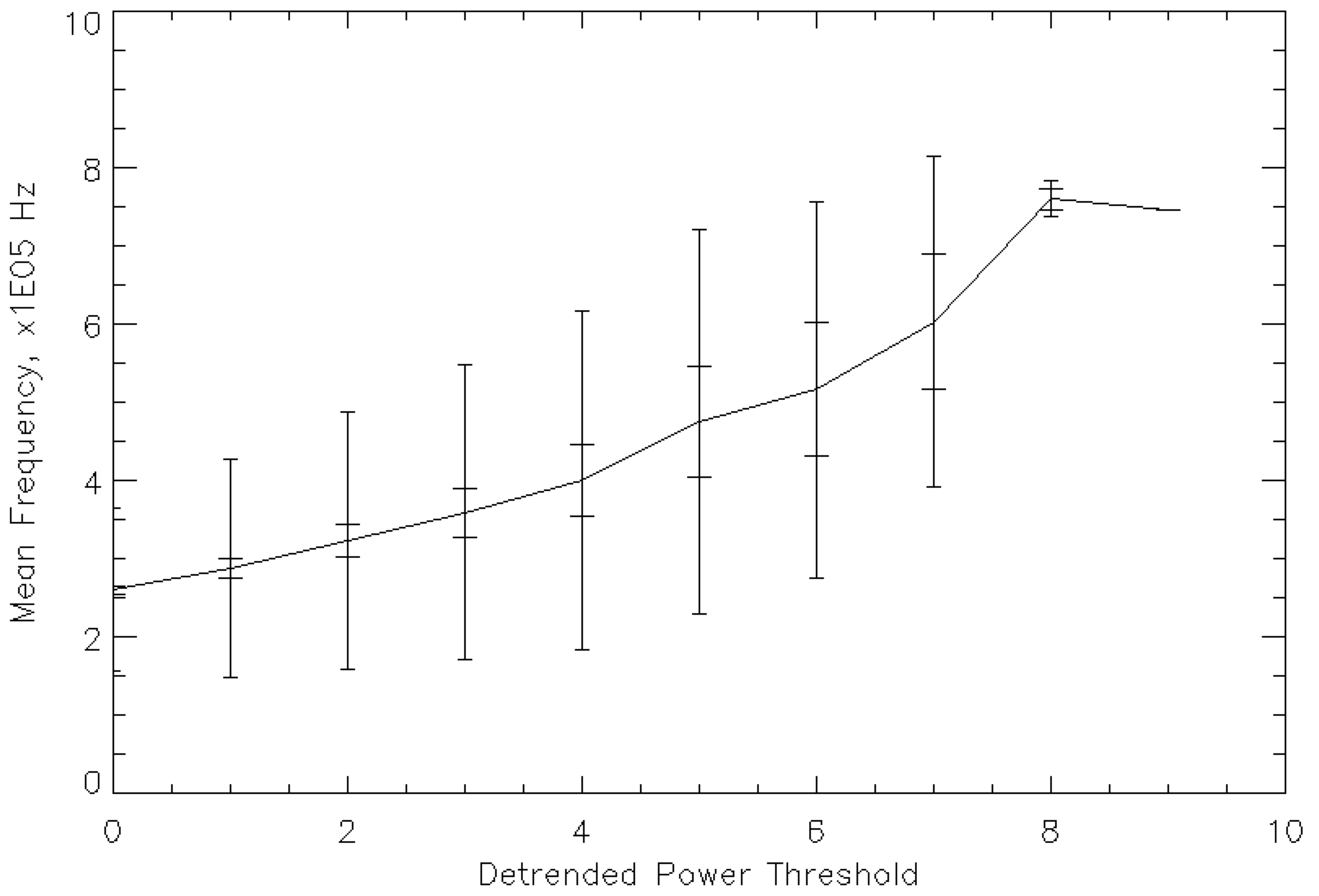

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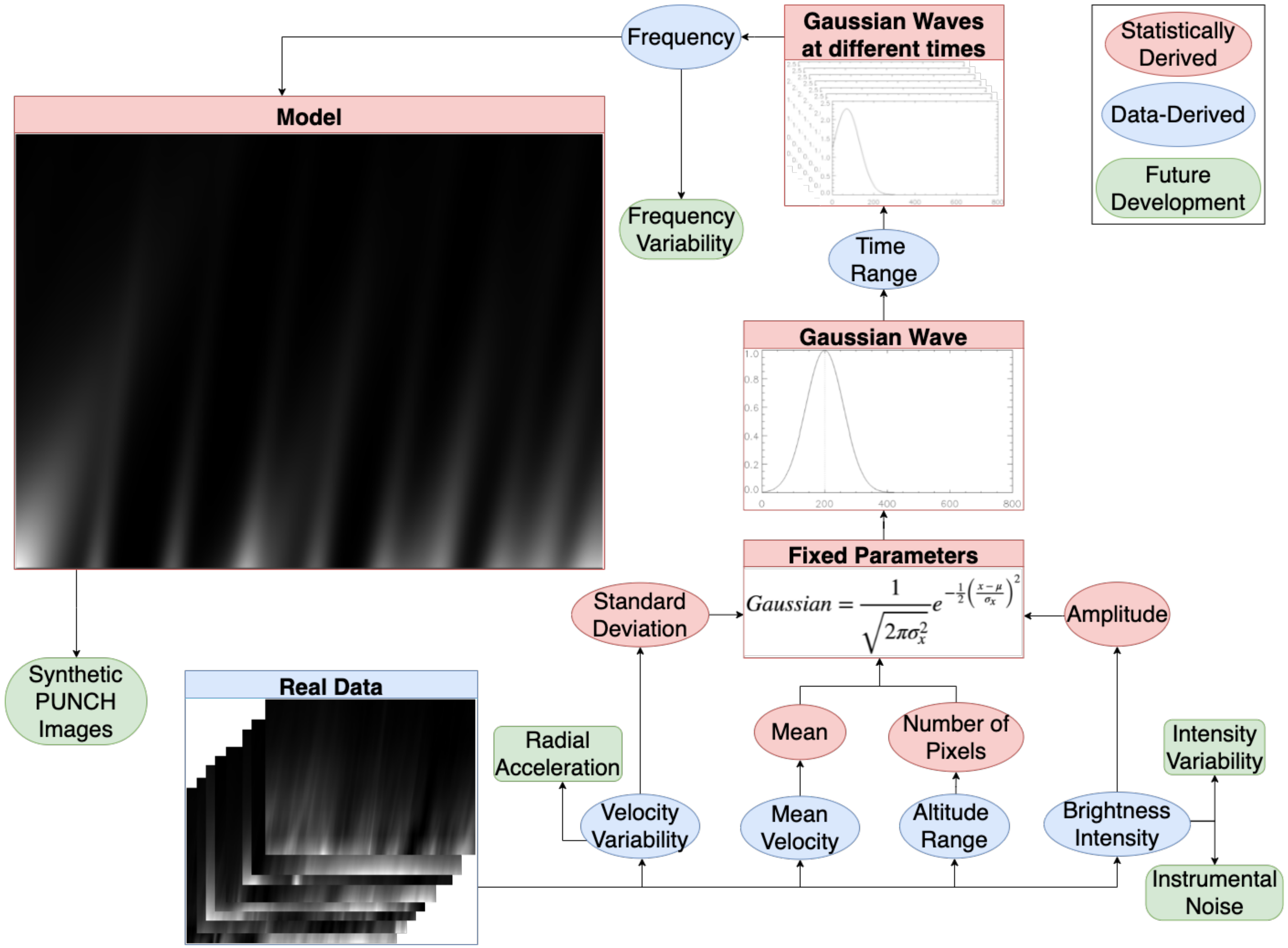

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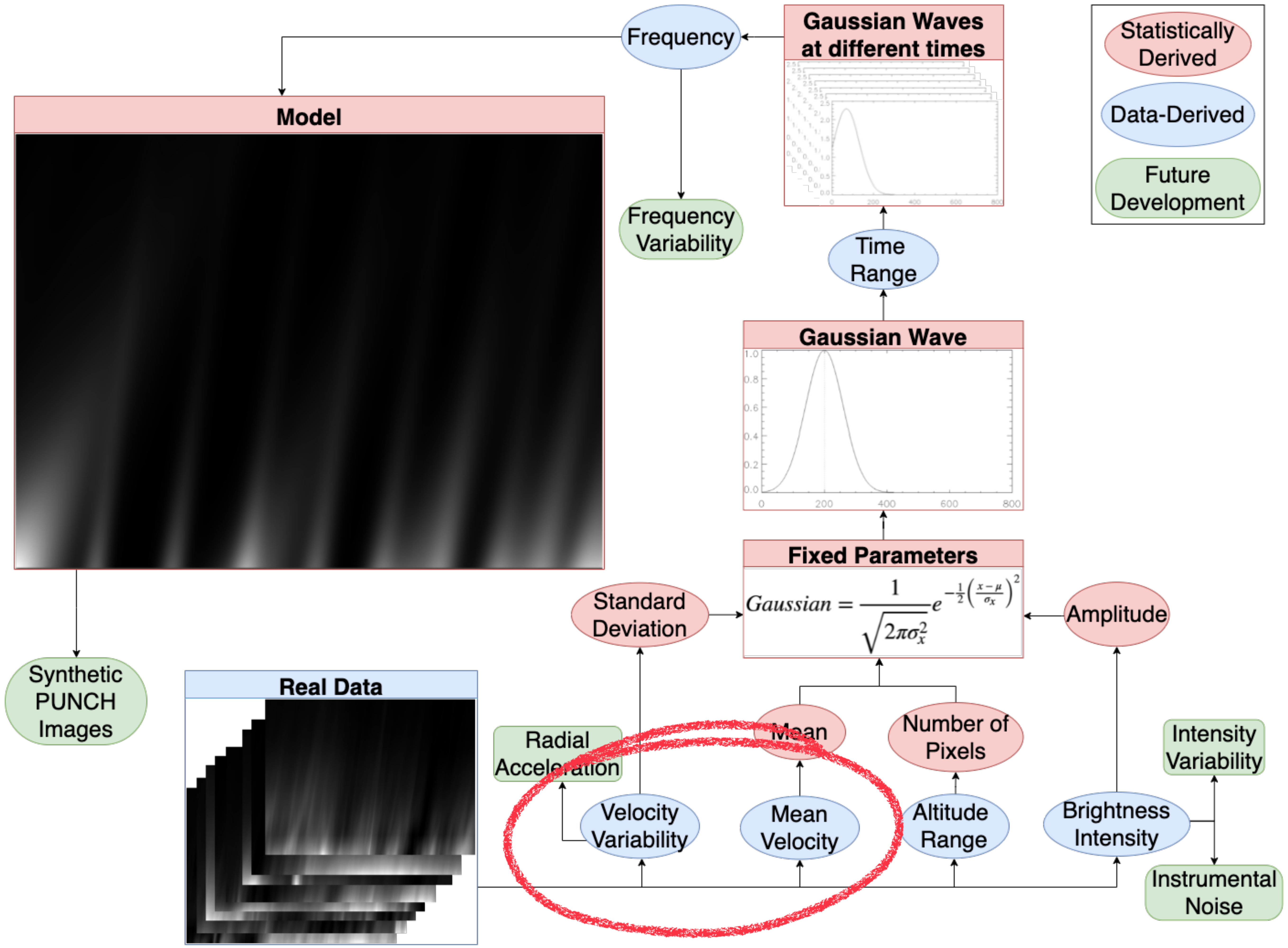
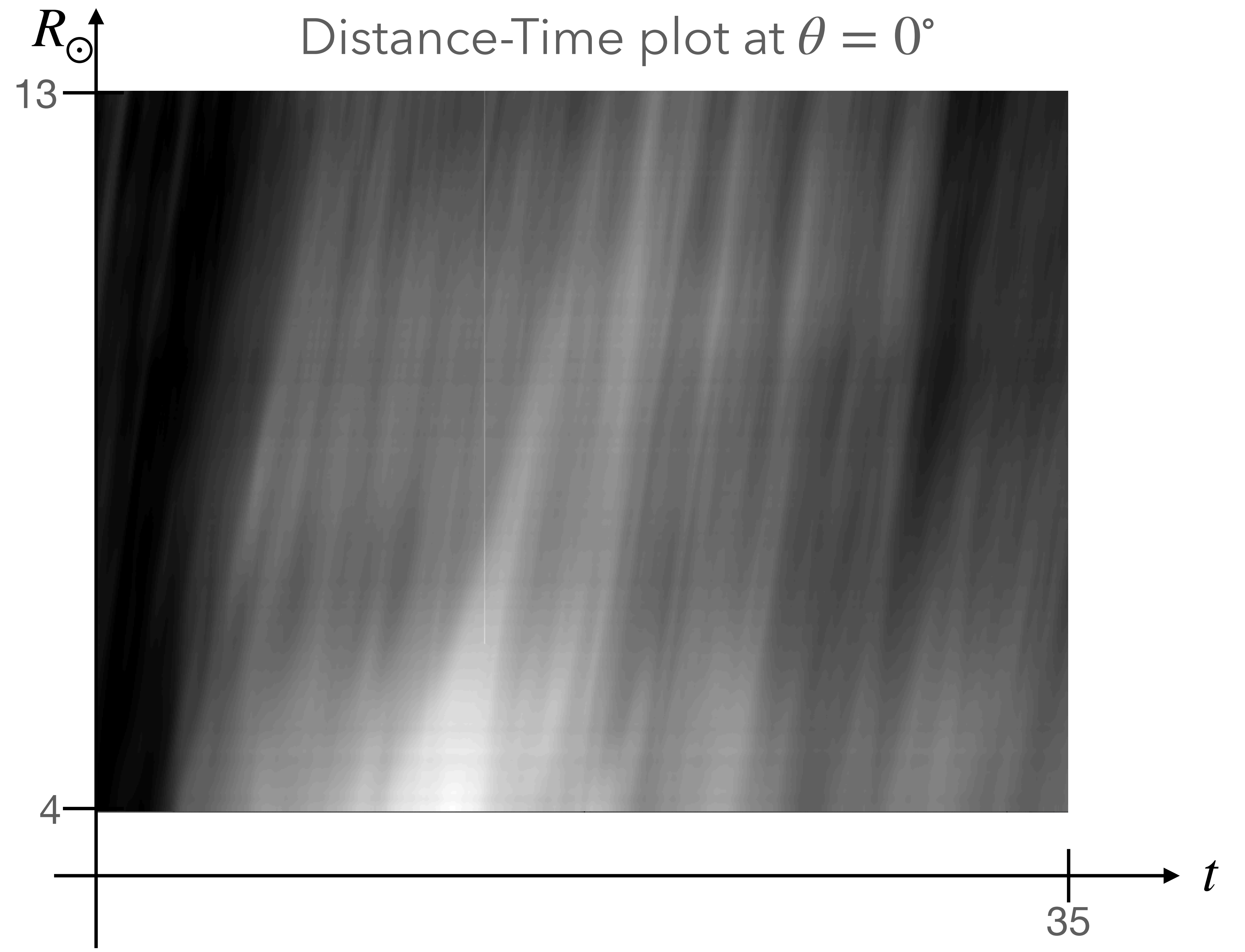
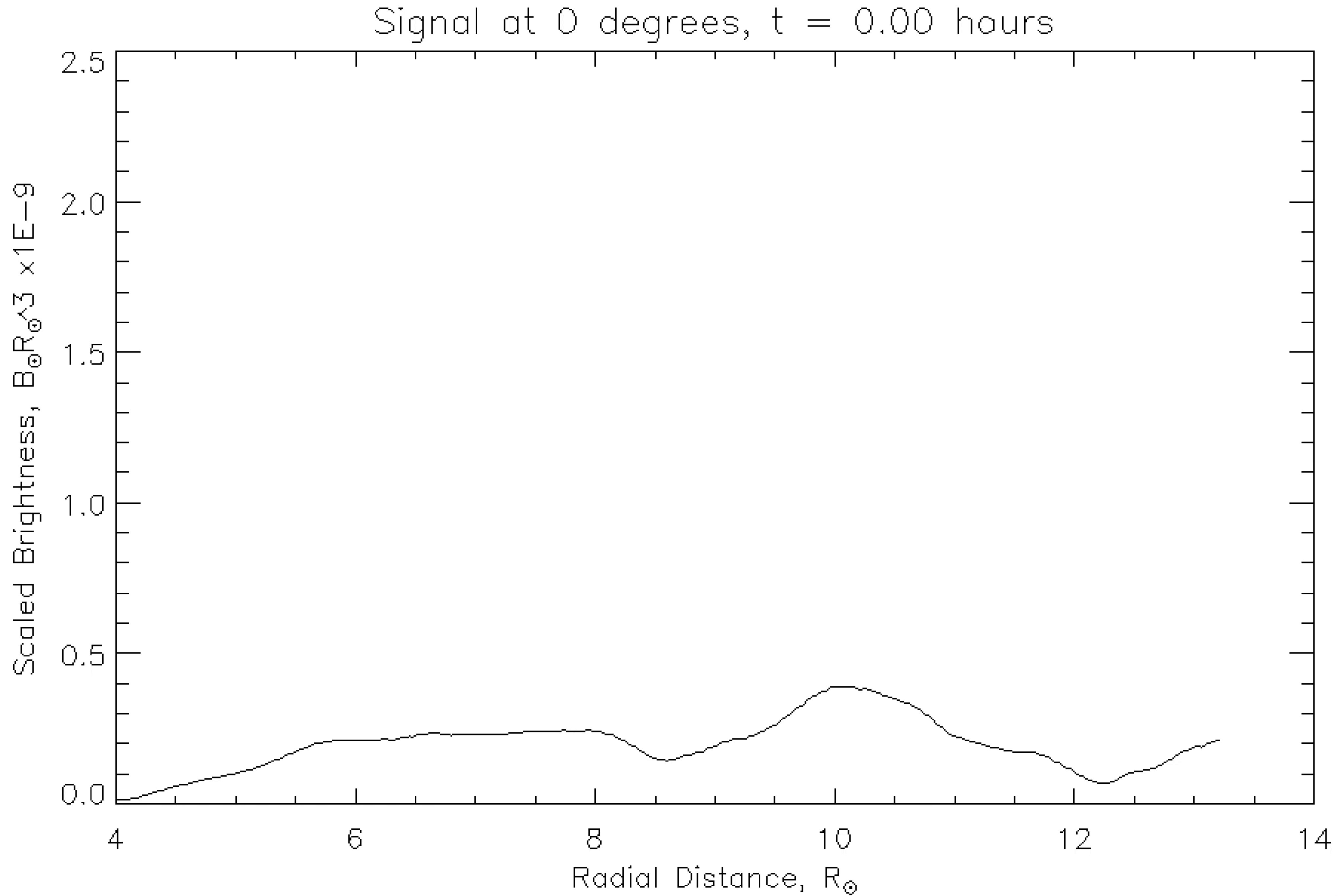


Parameters

Velocity

- **Distance-time plot**: contains a collection of signals for each time step
- **Signal attenuates with distance** but base level remains the same
- Flow tracking algorithm chosen cross-correlation of 1-D signal
- Evaluates the maximum correlation coefficient and locates its corresponding spatial lag
- Velocity could be provided by any which method.





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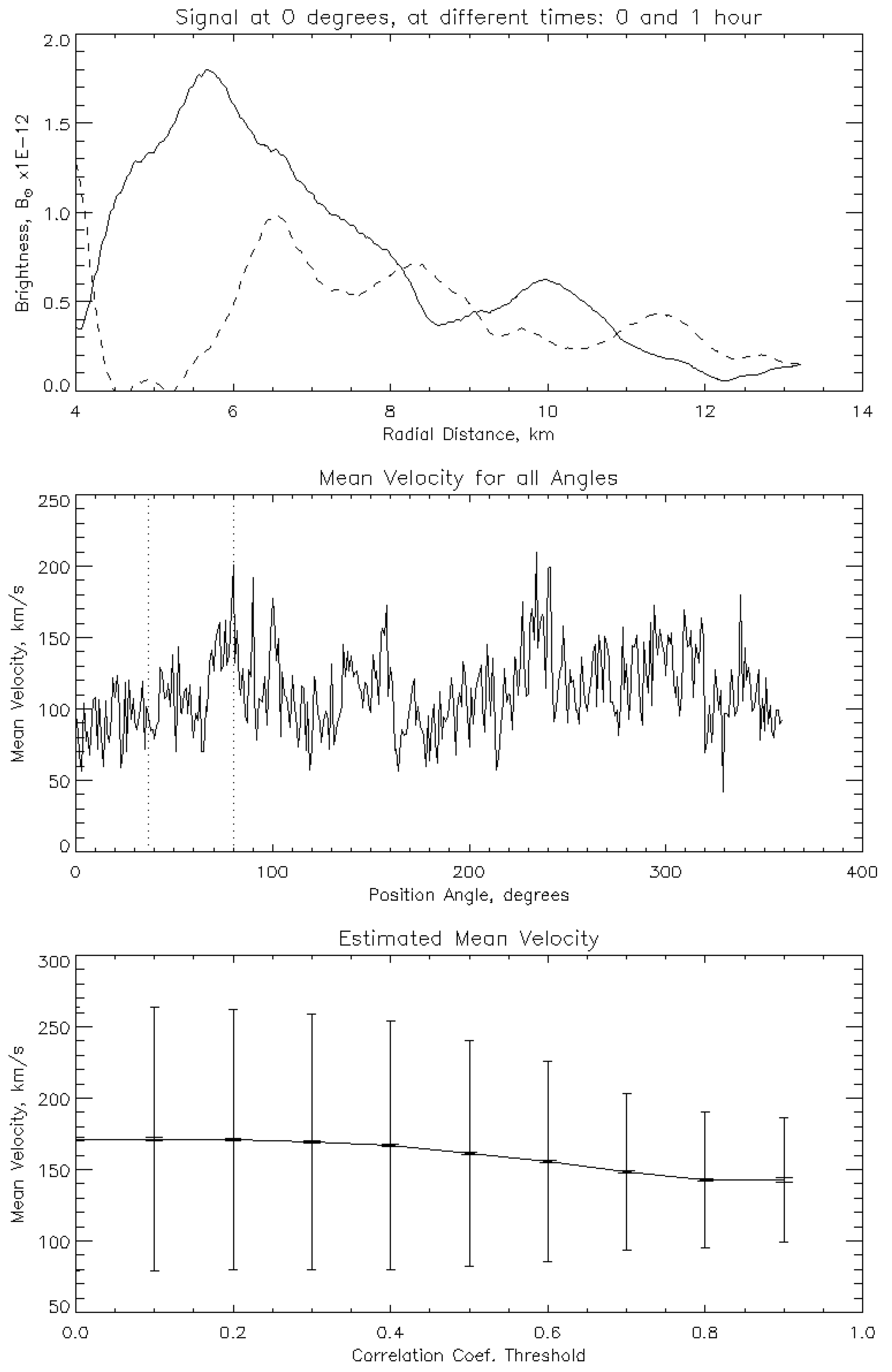
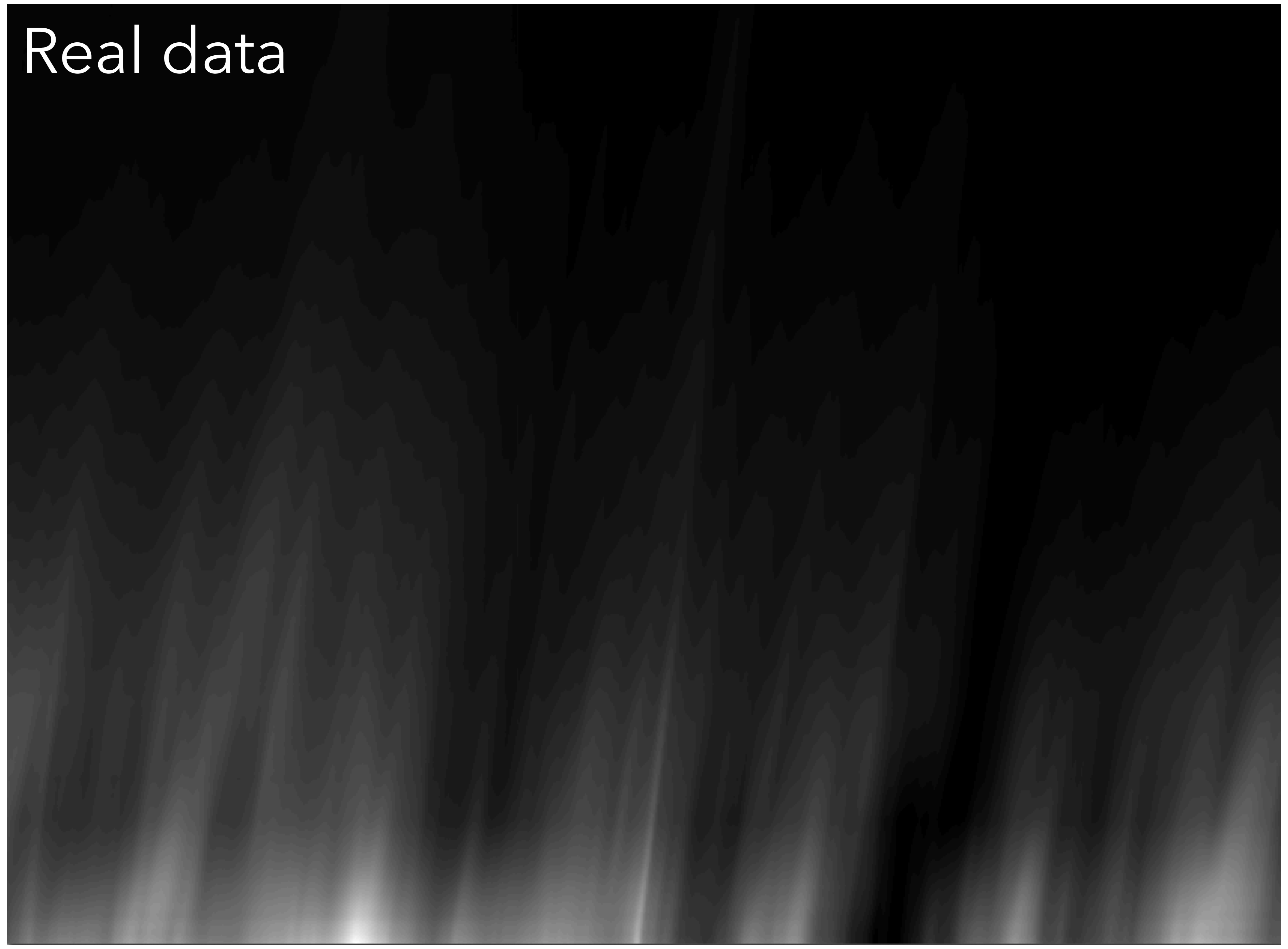
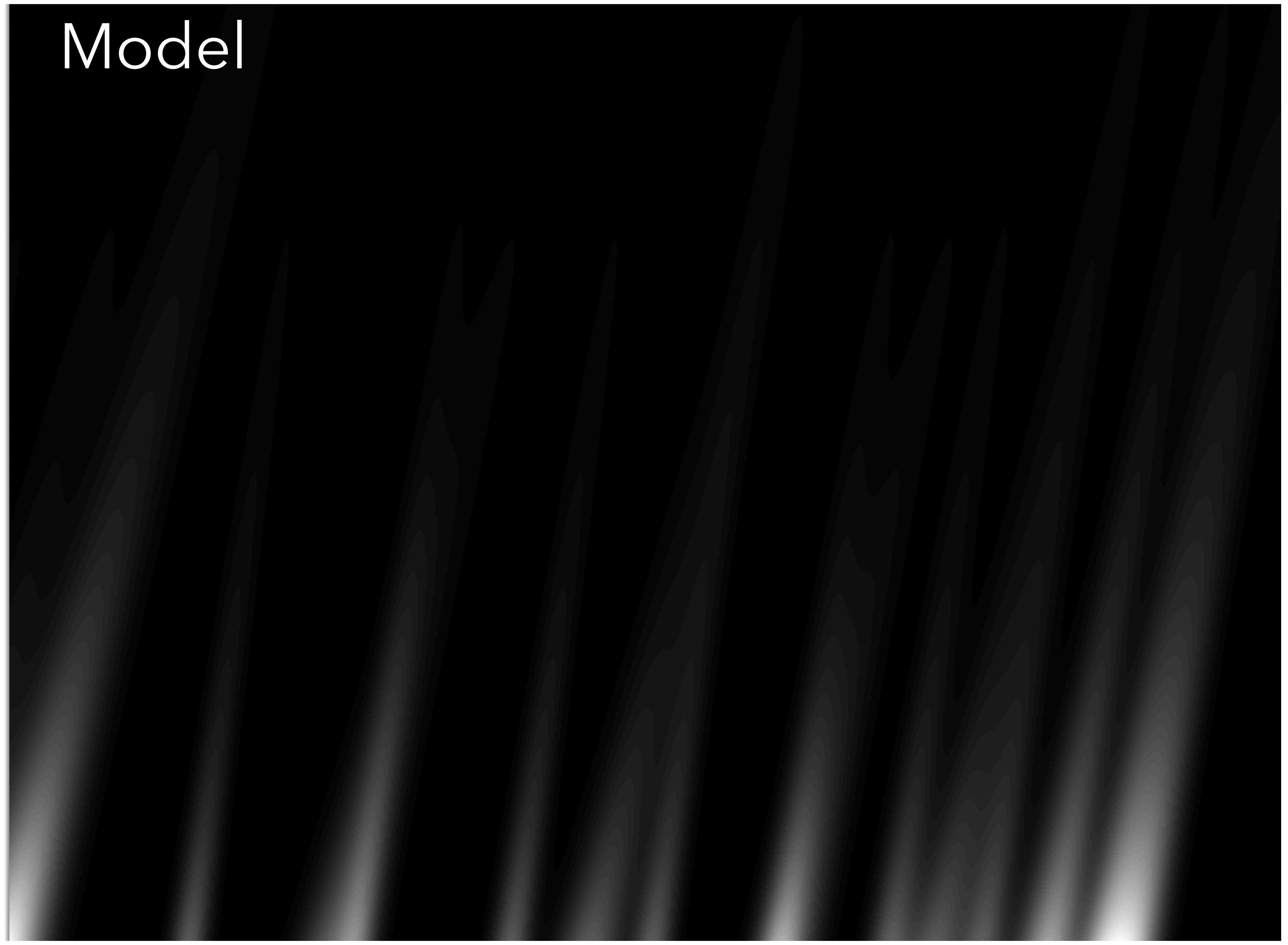


Model

Distance-time plots

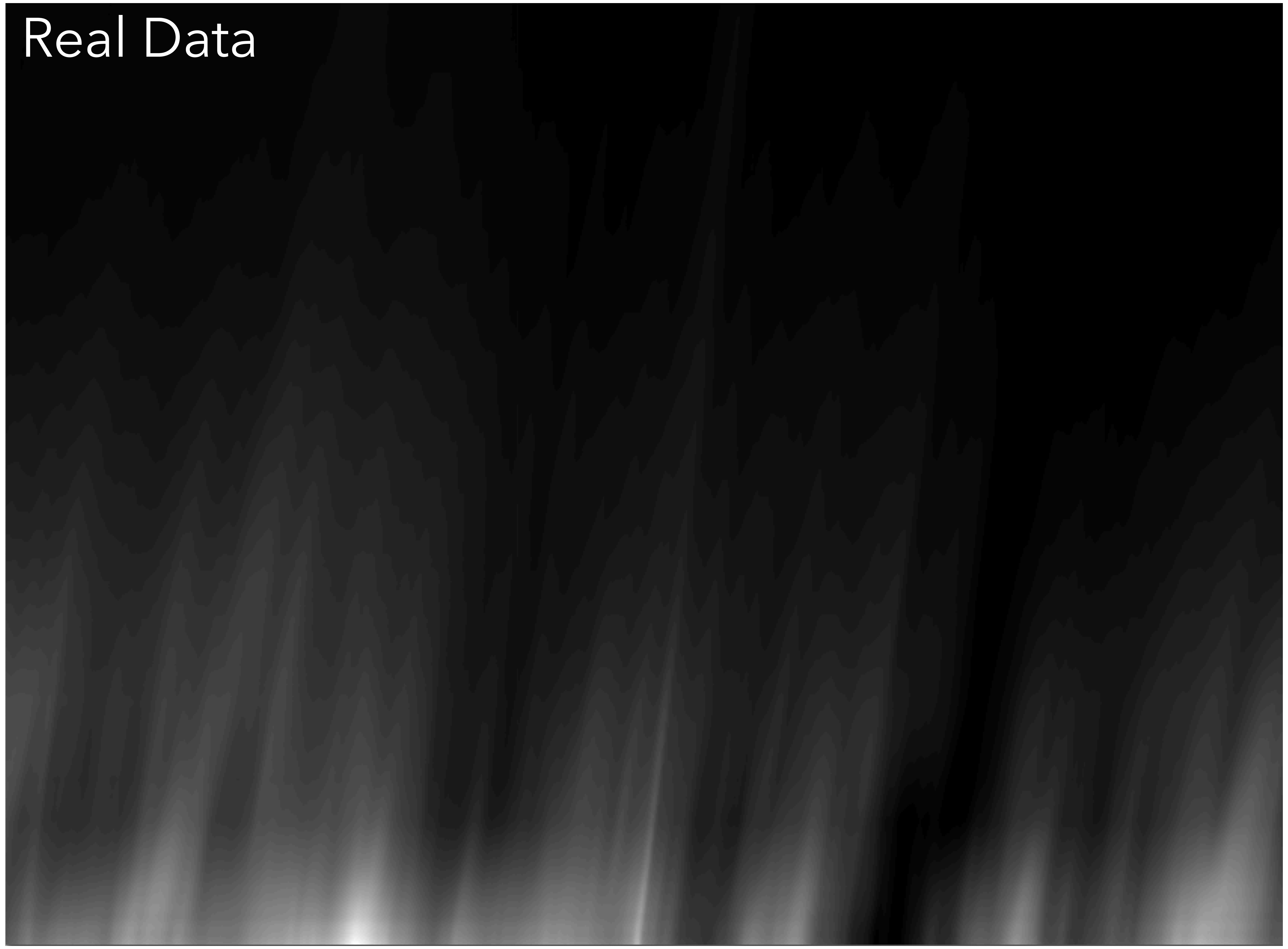
- Parameters control aspects of the image
  - Frequency: how often features appear
  - Velocity: inclination of features
  - Velocity standard deviation: width of features
- Radial behavior mimics brightness attenuation with distance
- Noise level is adjustable and is generated by a random seed

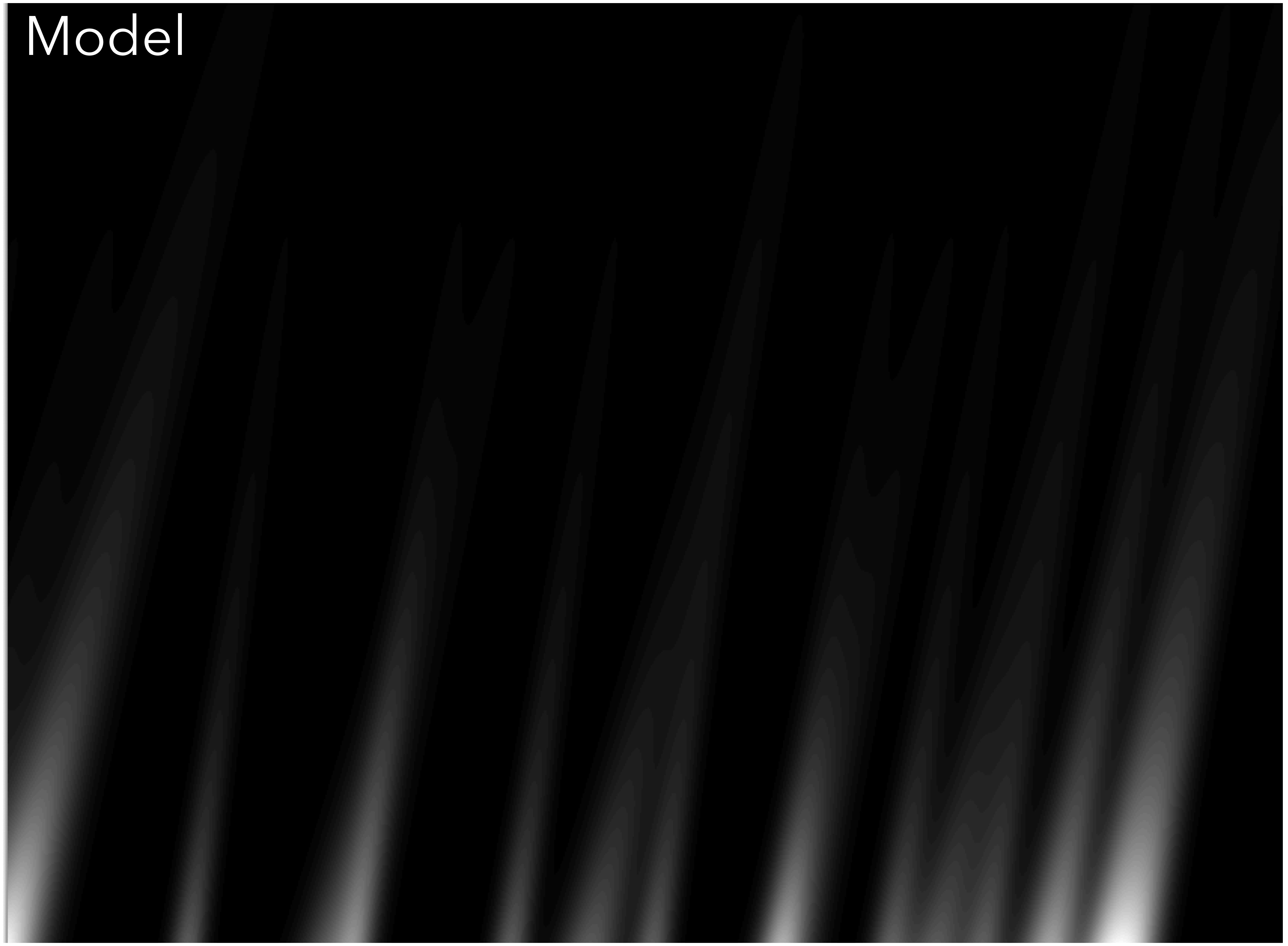




Model

Distance-time plots

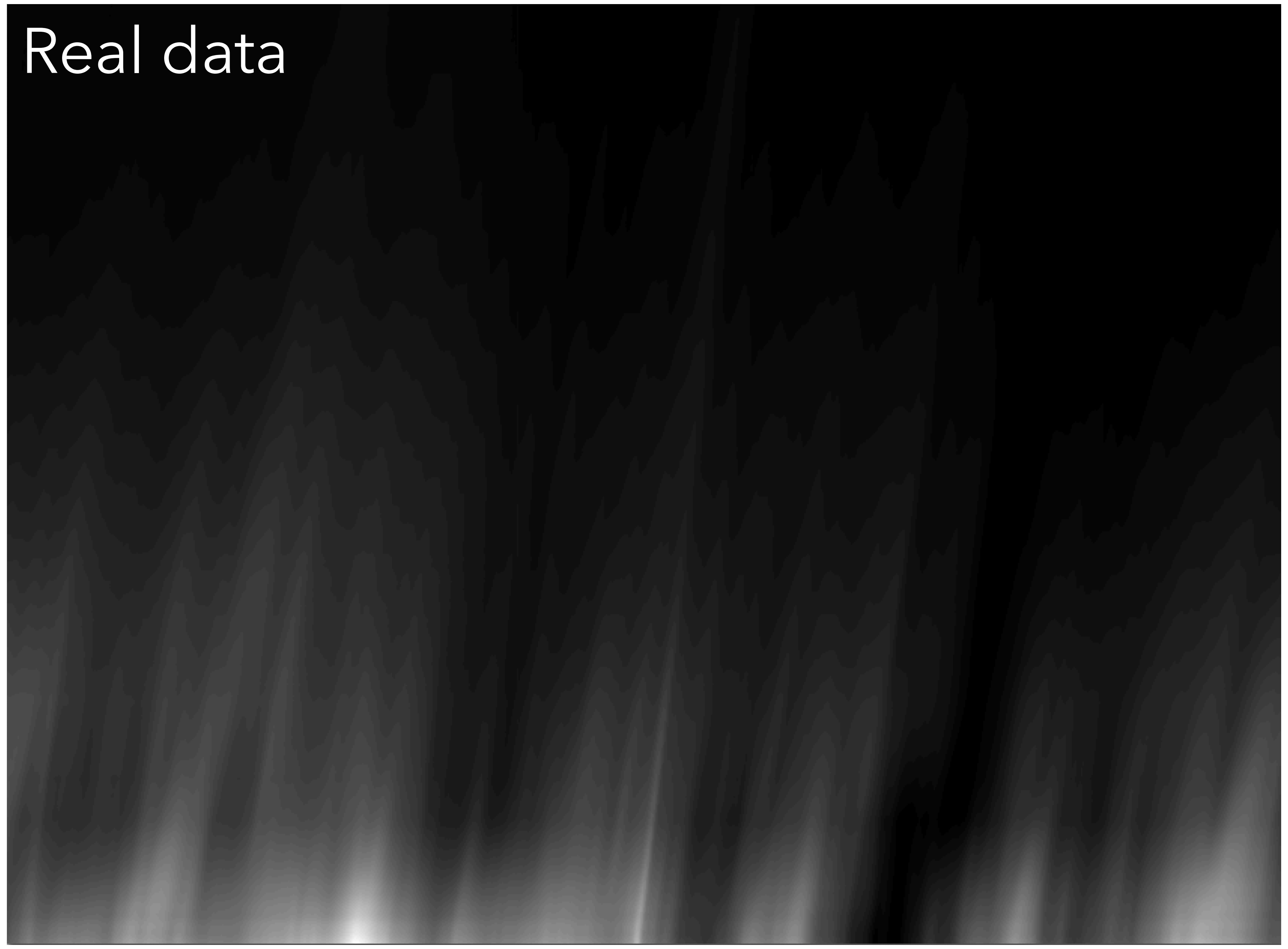


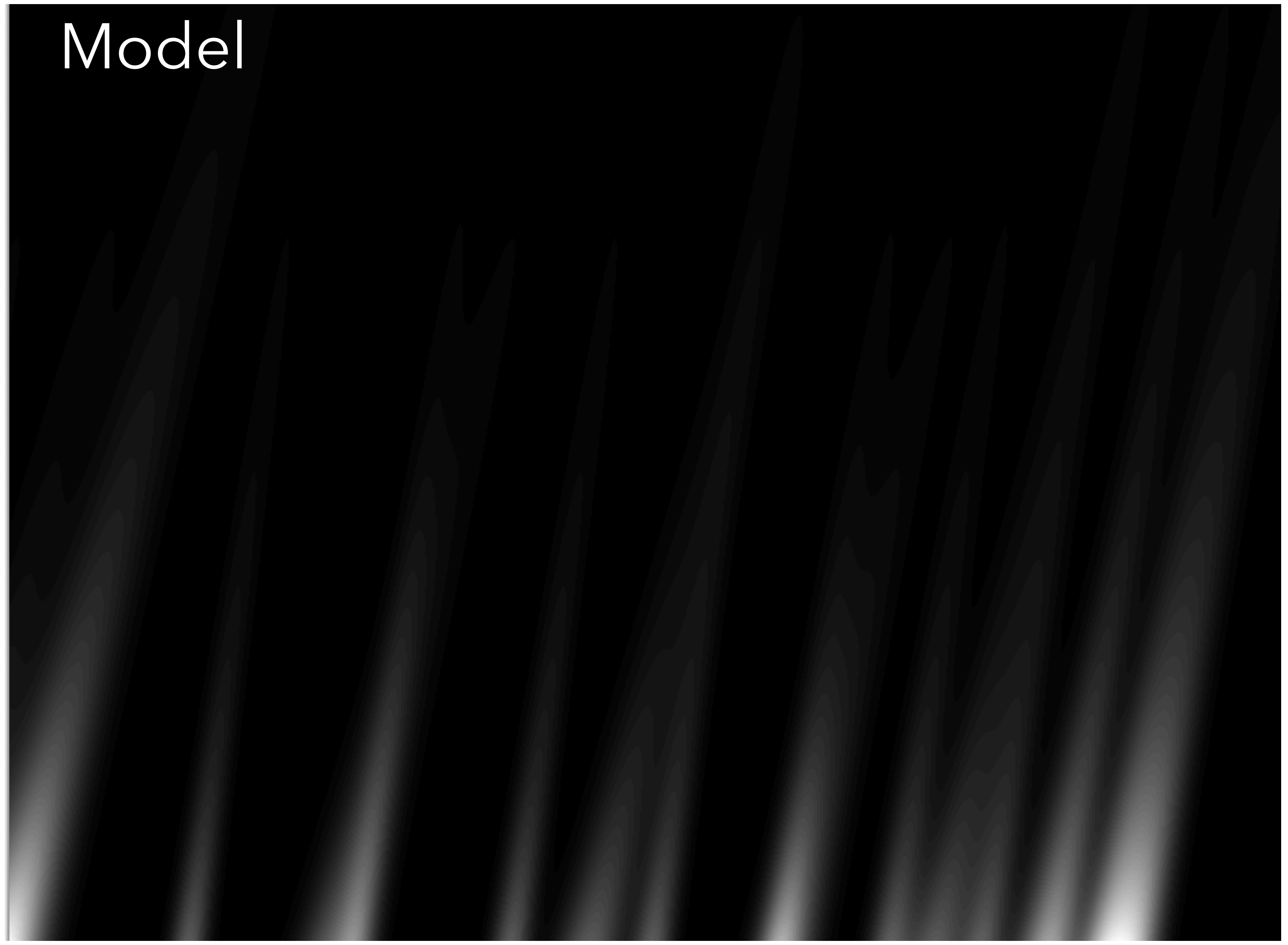


Model

Overview

- Gaussian waves with fix parameters
- Parameters control aspects of the image
  - Derived from real observations
- Statistically similar to real data
- SynCOM will serve to calibrate the different flow tracking techniques
  - Due to its predefined parameters

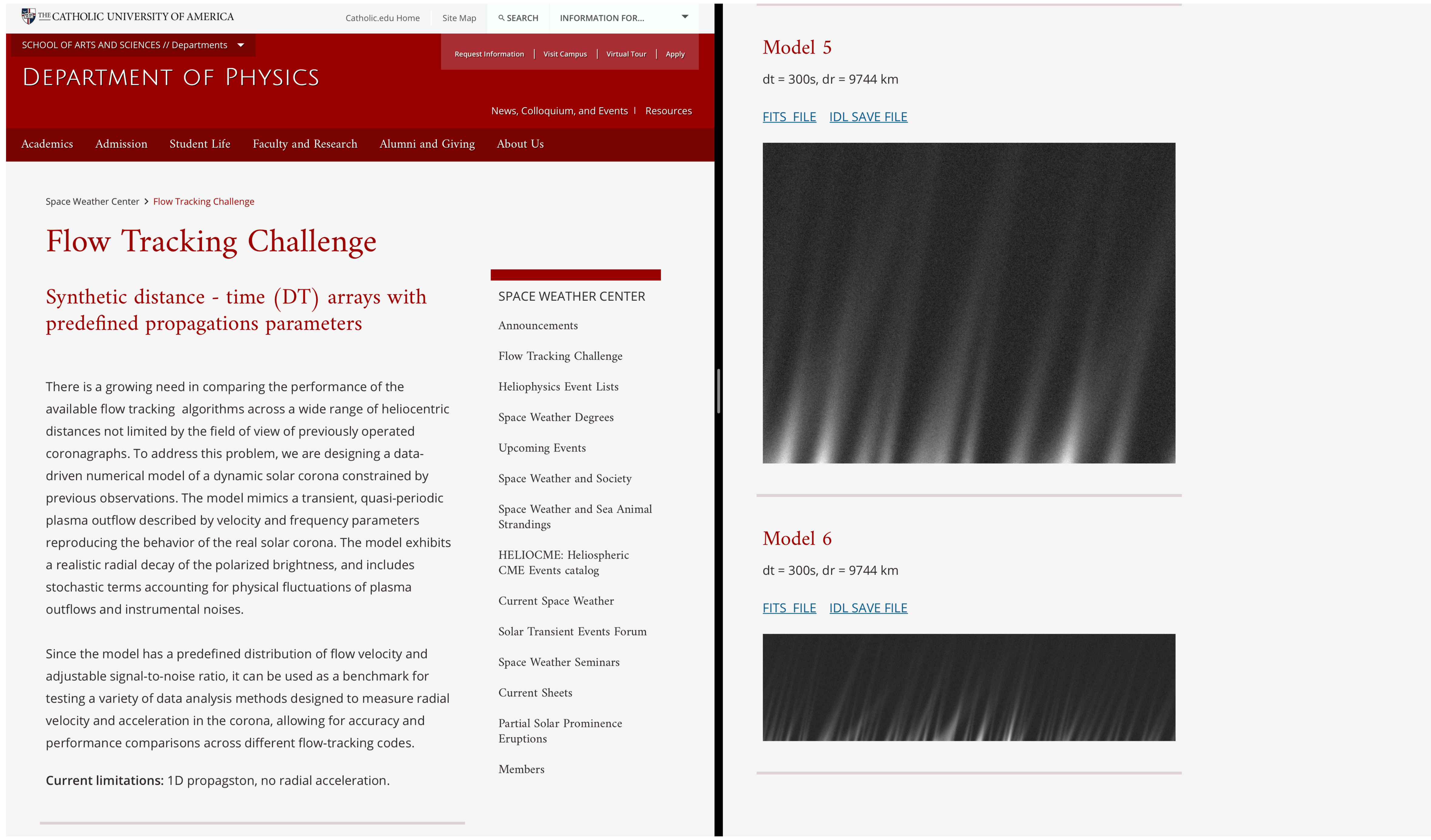




On-Going

Flow tracking Challenge

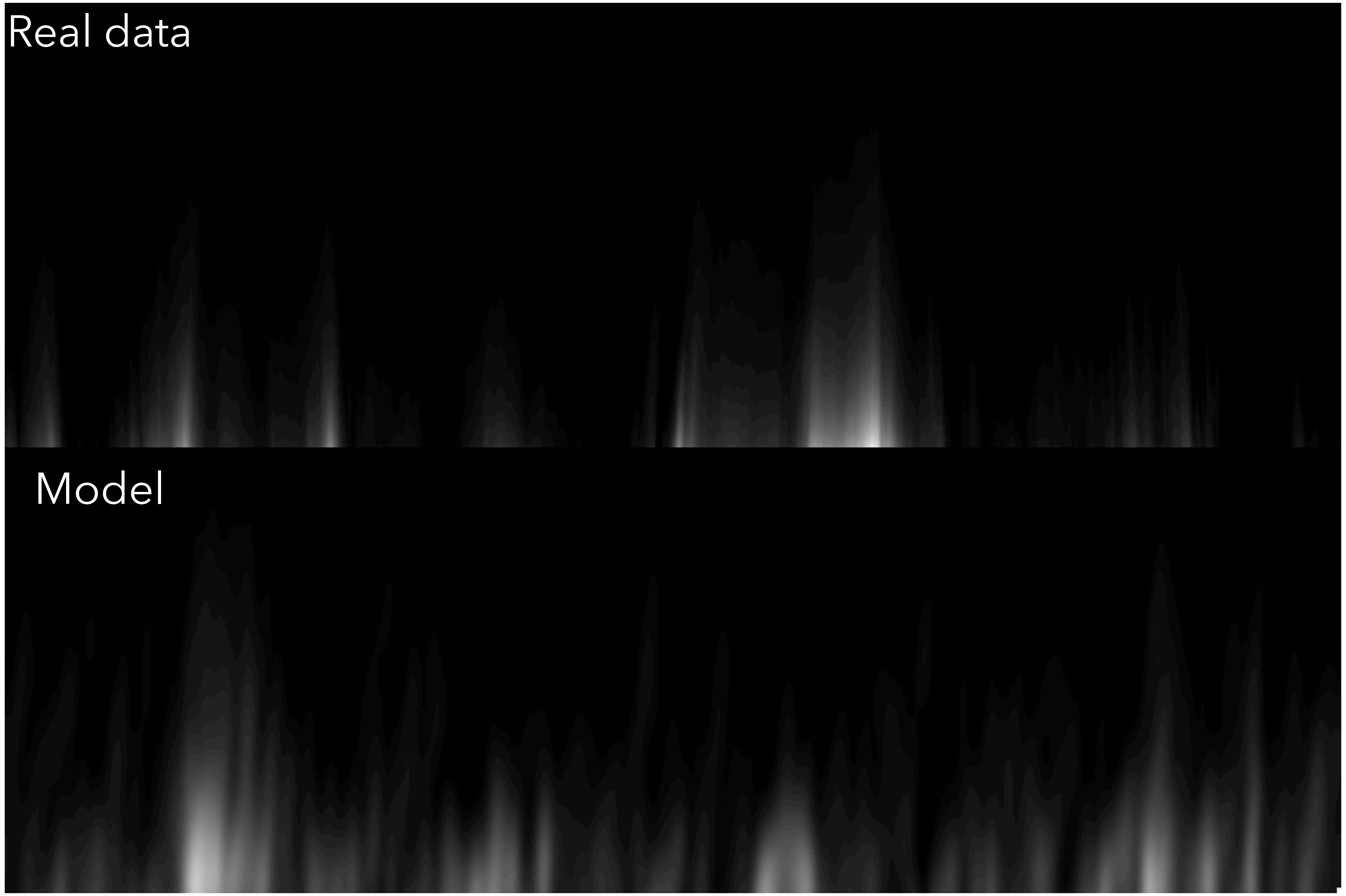
- 2nd Flow tracking workshop, June 2021
  - Effort produce algorithms to measure apparent flows with uncertainties
  - Flow tracking mini-challenge
- Open invitation to all flow-trackers and enthusiasts to test their algorithms using our synthetic images.
- Heliophysics community participation will be crucial.



In Development

Synthetic Corona Images

- Spatial-spatial $(r\ vs.\theta)$ images:
  - Some algorithms rely on this type
- Controlled parameters:
  - Frequency for each position angle
  - Radial and angular velocities
  - Velocities standard deviations
- Under work:
  - Geometry of the outflow more reminiscent with real data.



Conclusions

- We created a model that simulates a pattern that is statistically similar to the real data
  - Model is capable of incorporating radial acceleration
- The SynCOM objective is to serve as a calibrator of the different flow tracking methods
  - Initial results of our flow tracking challenge presented a great success on testing different algorithms
- Initial analysis of spatial-spatial images show great promise on emulating the solar corona outflow.
  - Next steps: fix known problems, such as the geometry of the features

Thank you for watching!

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