

SynCOM:

Synthetic Corona Outflow Model for the Heliophysics Community

December, 2021

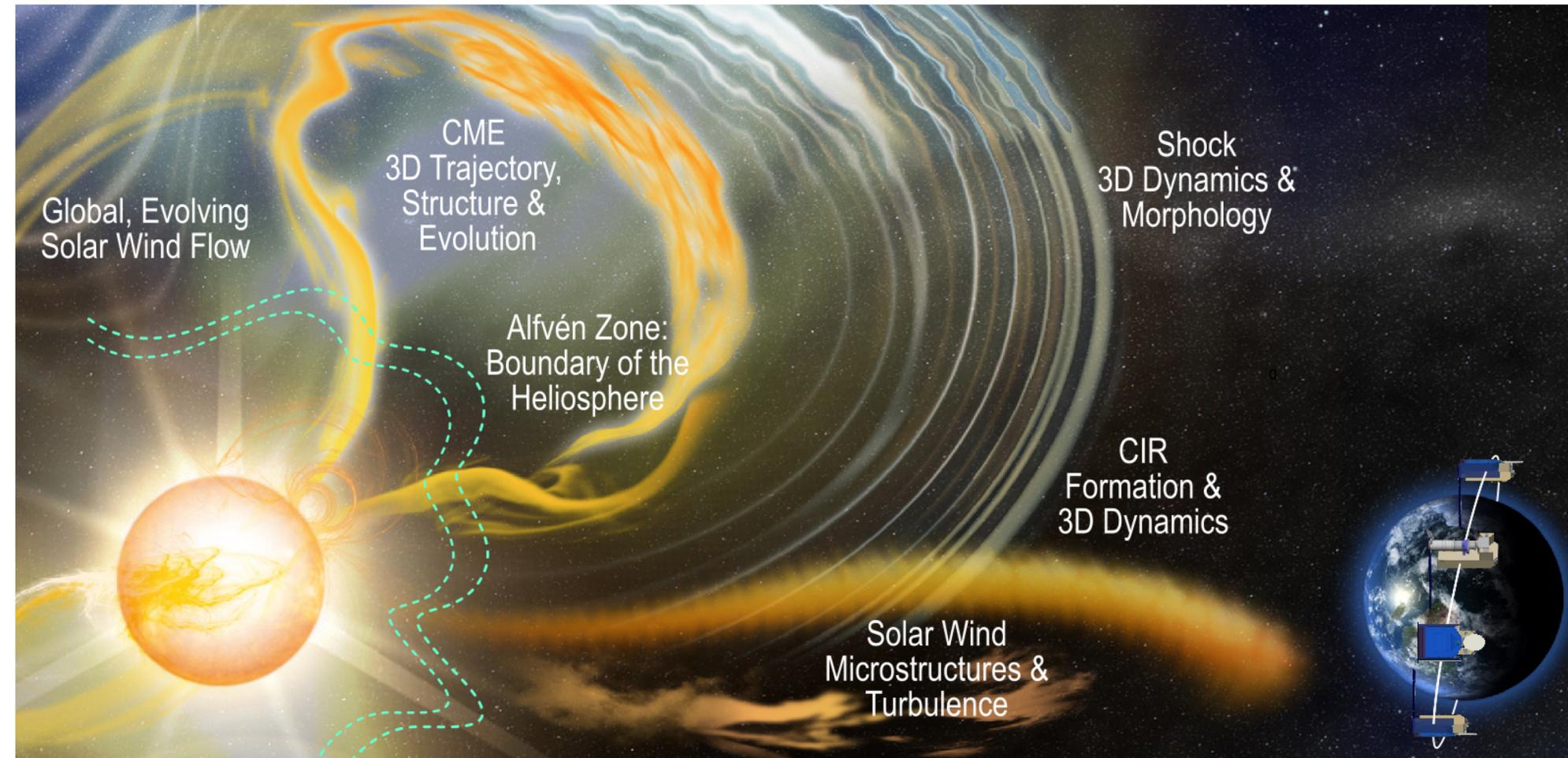
Valmir P. Moraes Filho [1,2], Vadim M. Uritsky [1,2], Barbara J. Thompson [1], Craig DeForest [3]

[1] NASA Goddard Space Flight Center, Greenbelt, MD, [2] Catholic University of America, Washington, DC, [3] Southwest Research Institute, Boulder, CO.

Motivation

PUNCH Mission

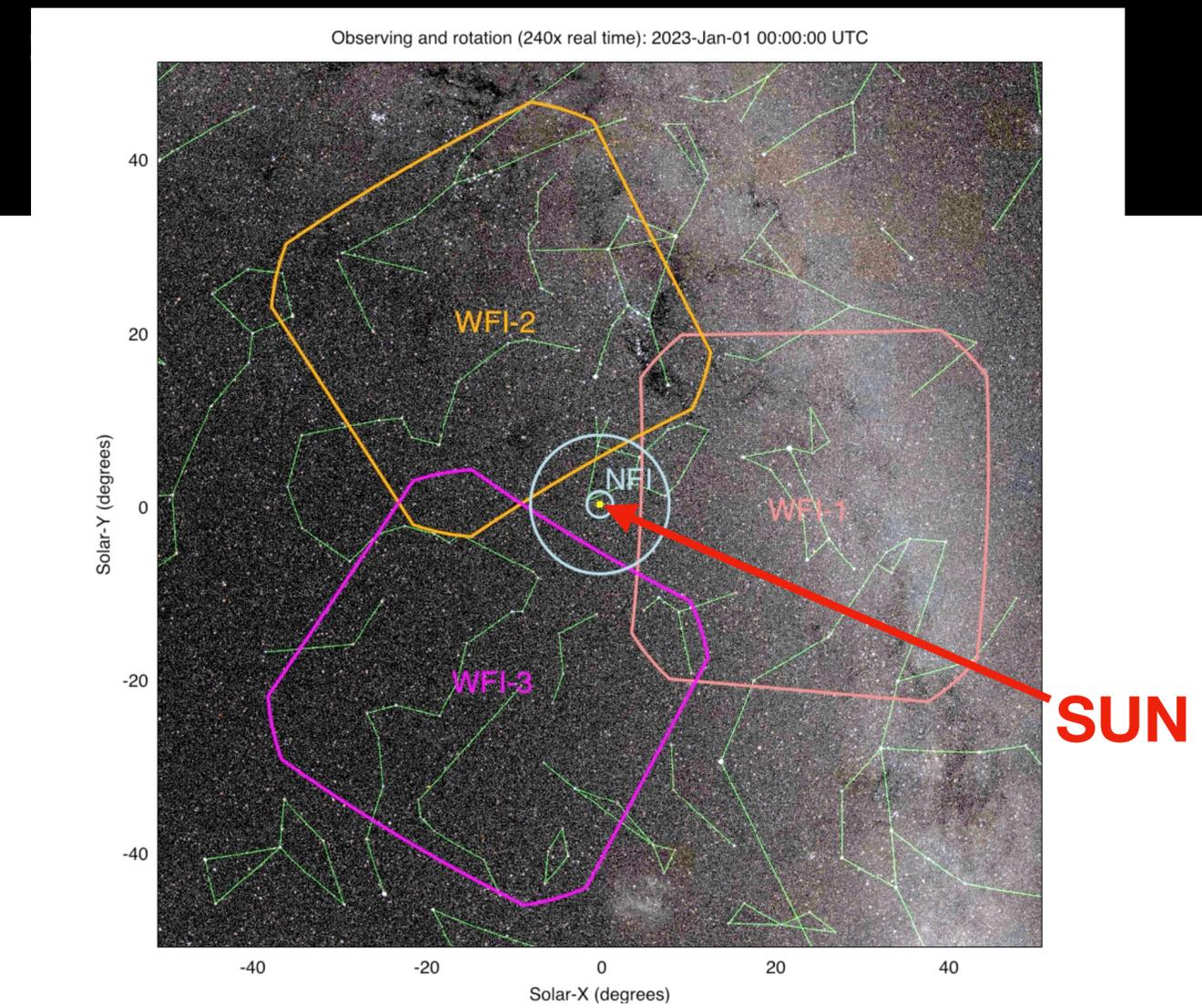
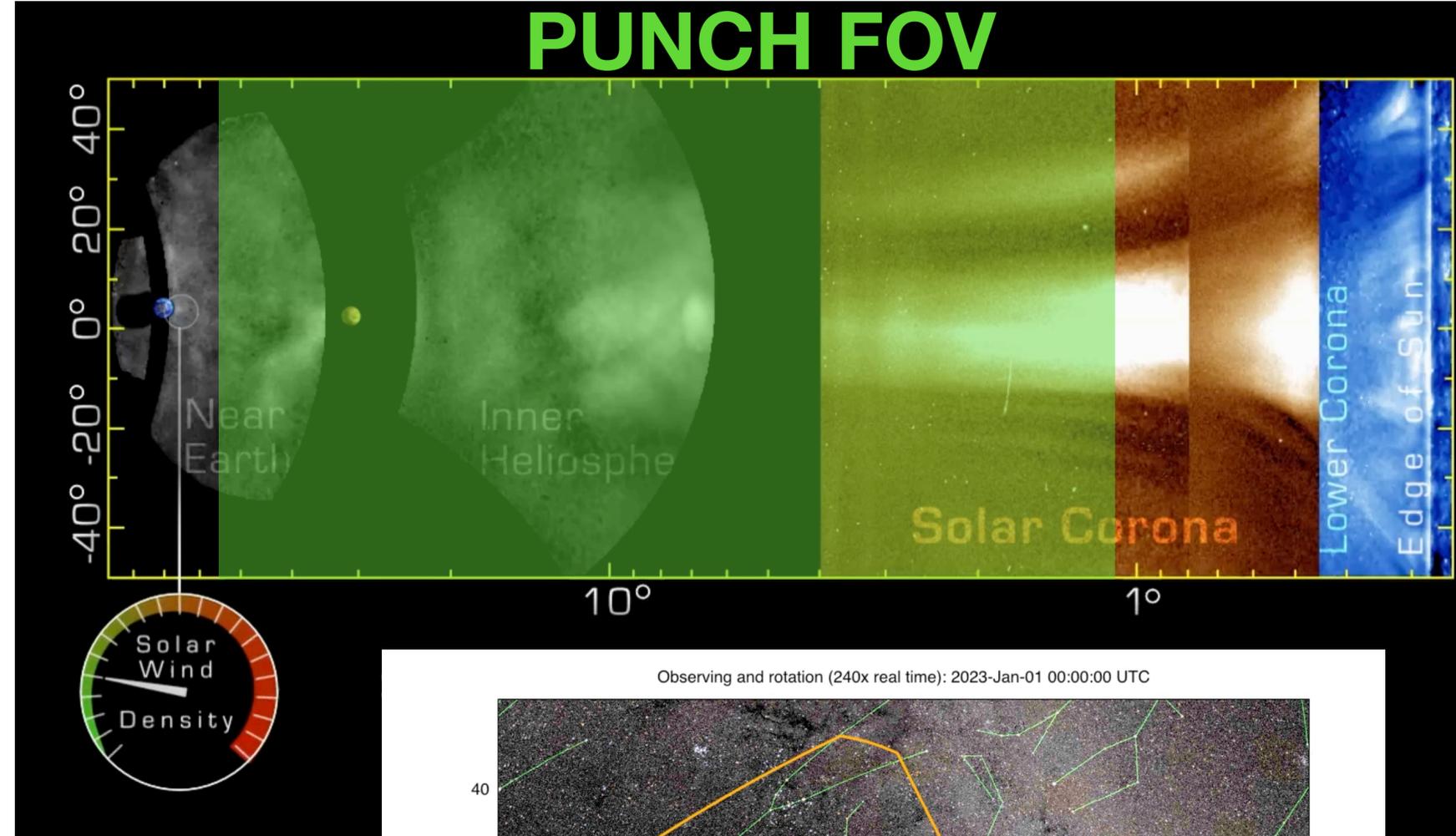
- PUNCH (**P**olarimeter to **UN**ify the **C**orona and **H**eliosphere) mission:
- Science Goal is to comprehend the cross-scale physical processes - from micro-scale turbulence to the evolution of global-scale structures - that unify the solar corona and heliosphere.
 - Understand how coronal structures become the ambient solar wind.
 - Understand the dynamic evolution of transient structures in the young solar wind.



Motivation

PUNCH Mission

- PUNCH FOV: $5 R_{\odot}$ (1.25°) to $180 R_{\odot}$ (45°)
- 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.



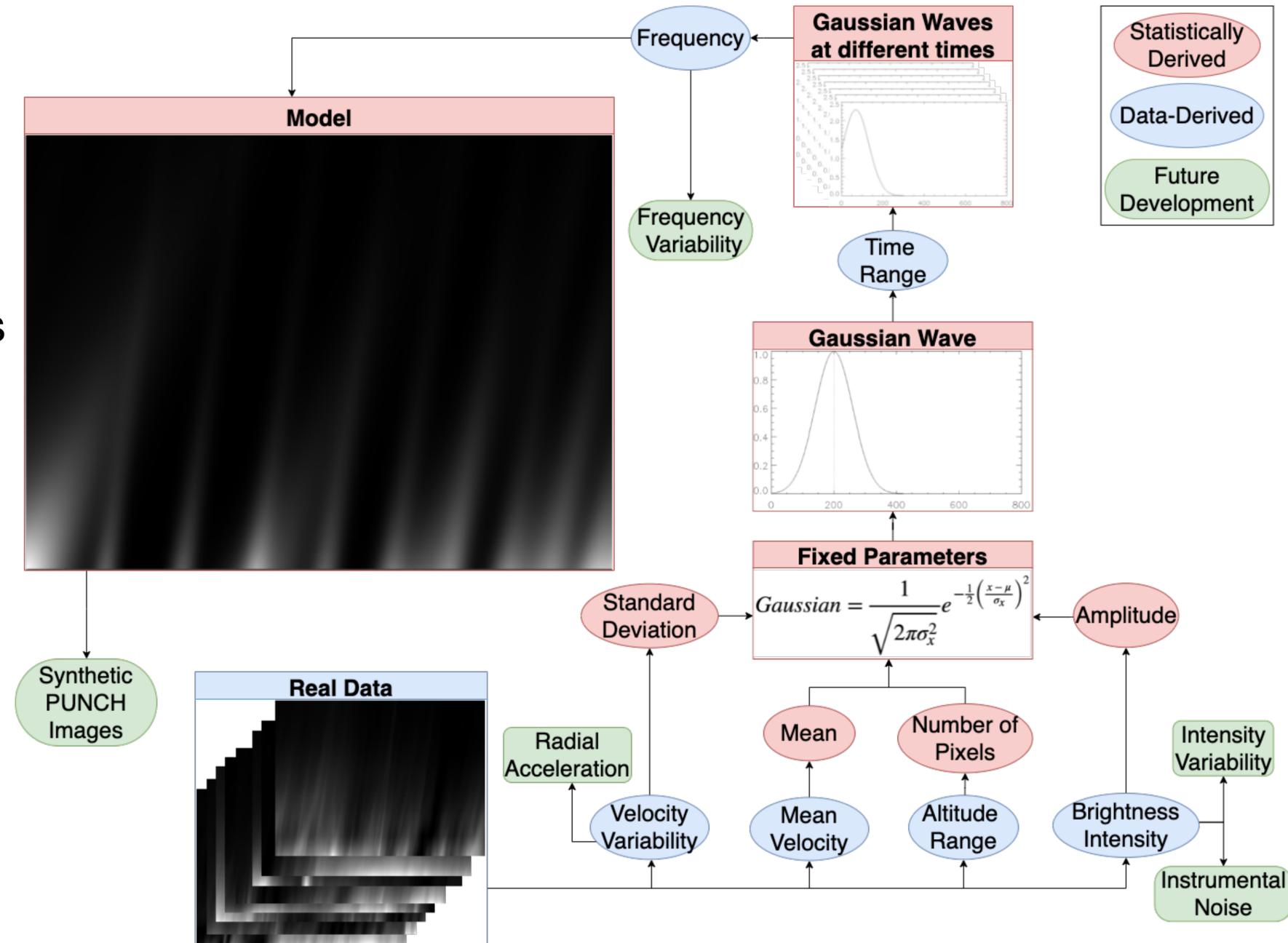
Motivation

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 $\sim 180 R_{\odot}$

Model Structure

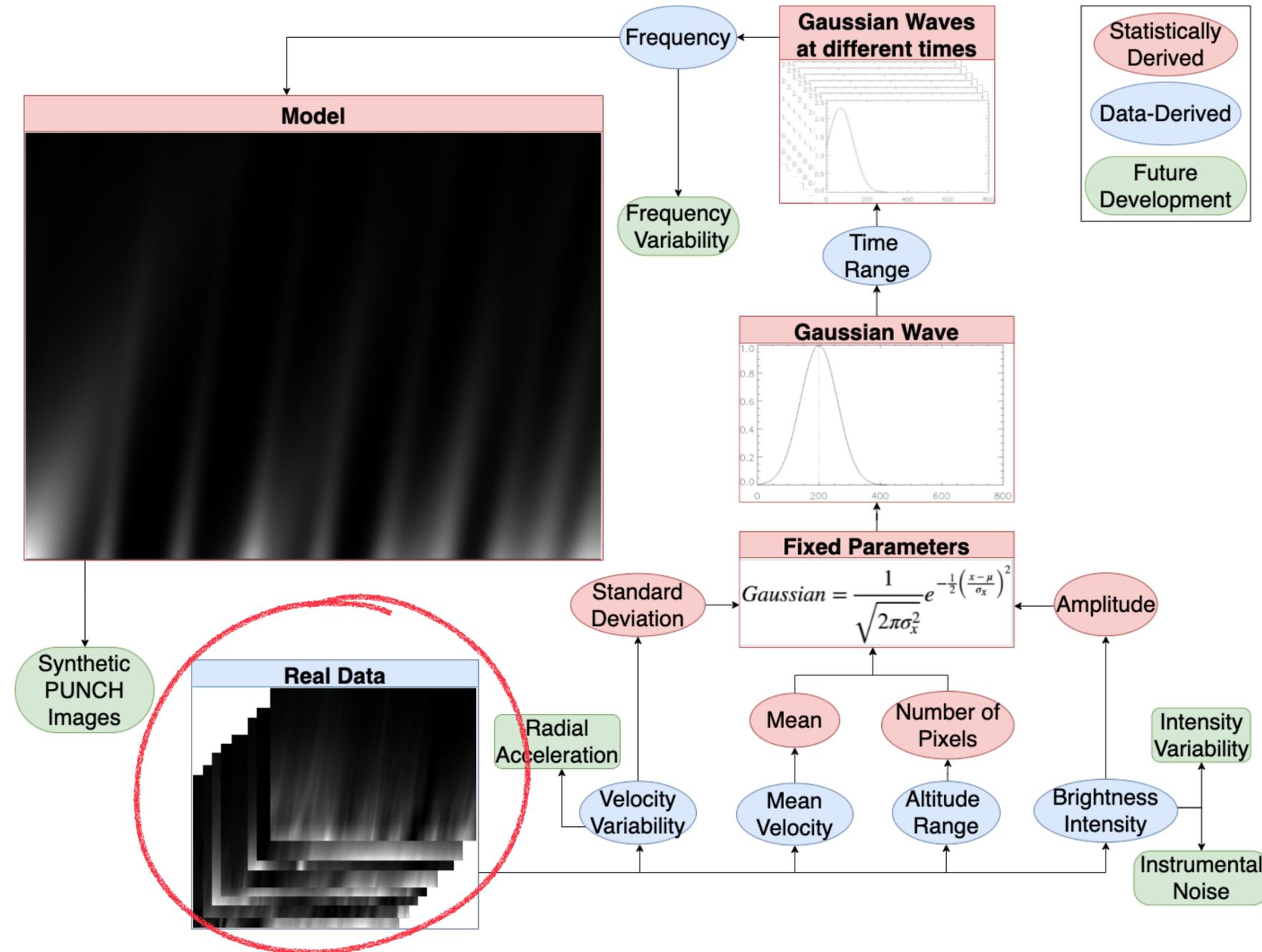
- Gaussian waves as main engine
- Derived of previous solar corona observations
 - Based on statistics of the physical phenomena
- Mimics a transient, quasi-periodical behavior
 - Realistic radial decay of brightness
 - Predefined frequency parameters
 - Predefined velocity parameters
 - Adjustable signal-to-noise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



Model

Data

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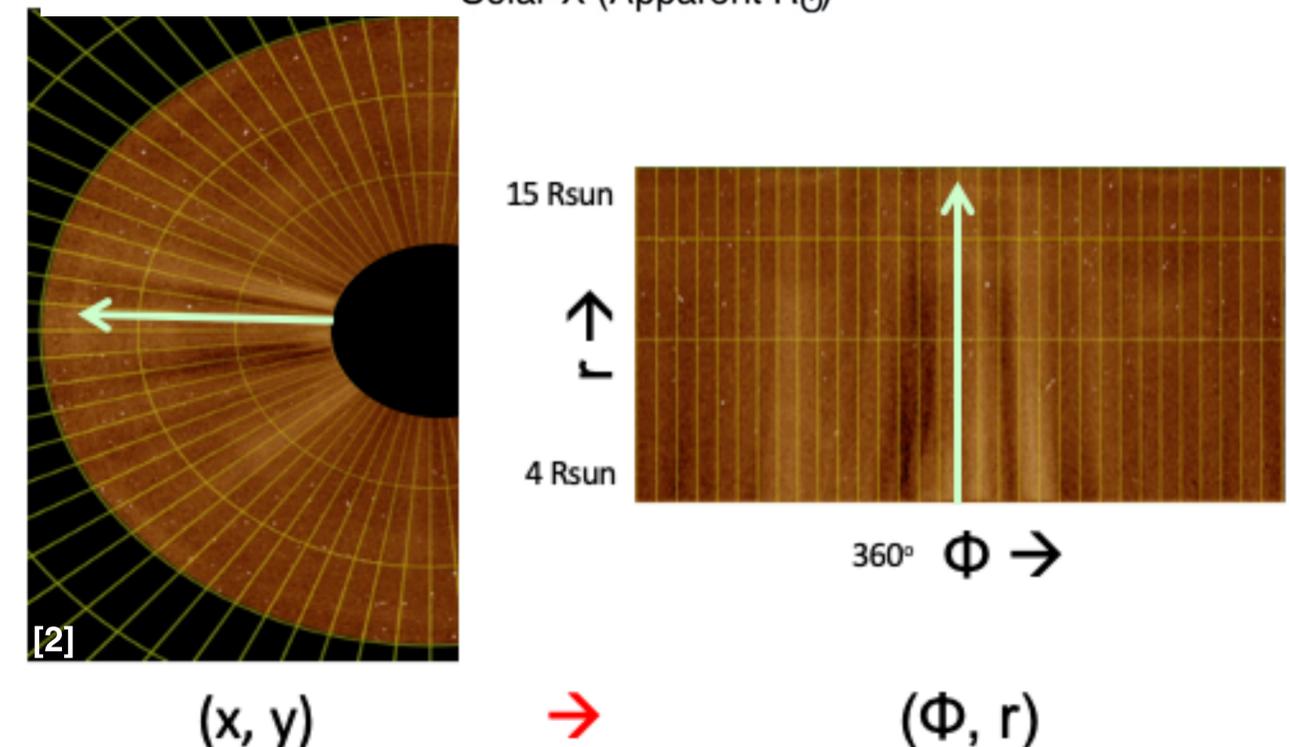
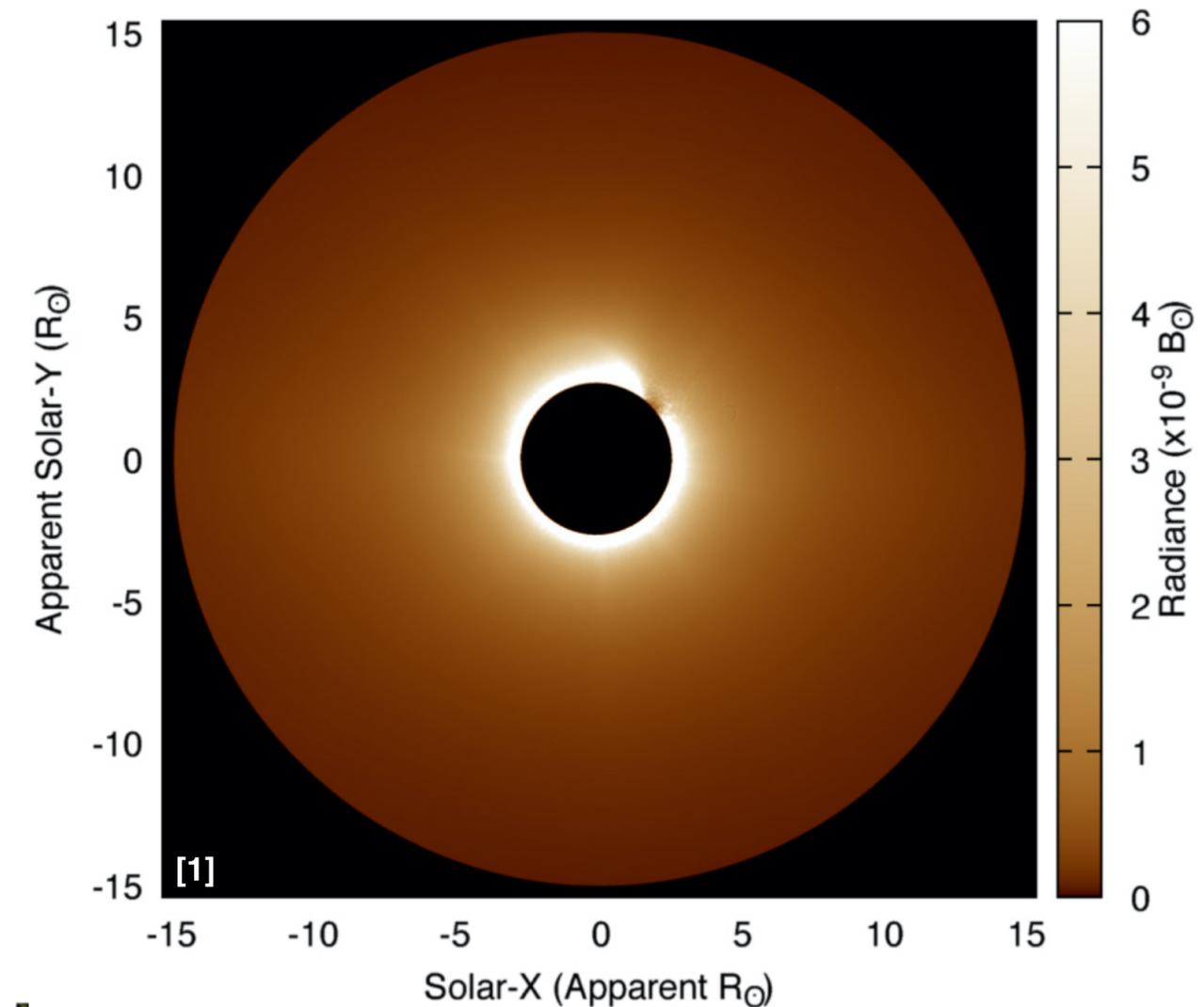


Data

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].

STEREO-A/COR2 Level 1: 2014-04-14 01:06 UT



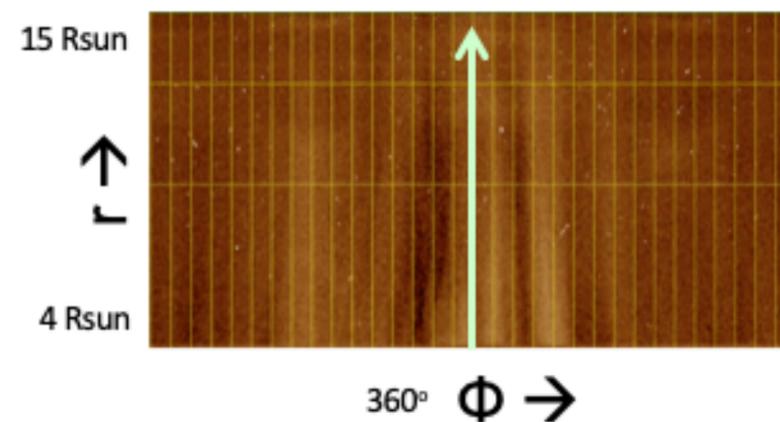
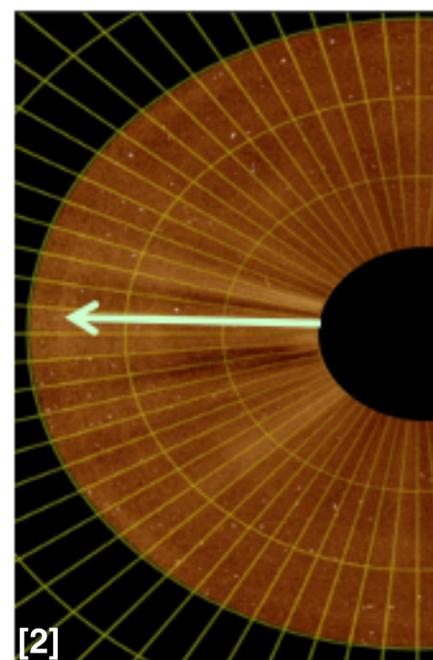
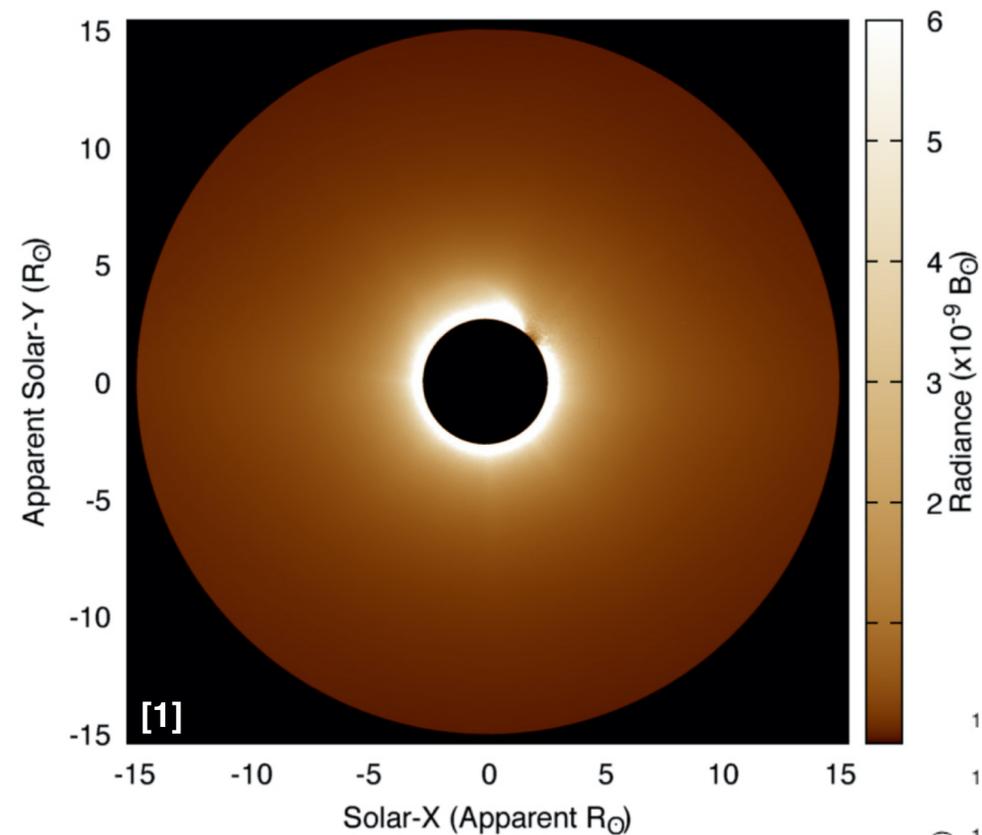
[1] DeForest et al., "The Highly Structured Outer Solar Corona", Astrophysical Journal, Vol. 862, 2018.

[2] Thompson et al., "Tracking Flows and Disturbances in Coronagraph Data", AGU, 2018.

Data

STEREO-A / COR 2

STEREO-A/COR2 Level 1: 2014-04-14 01:06 UT

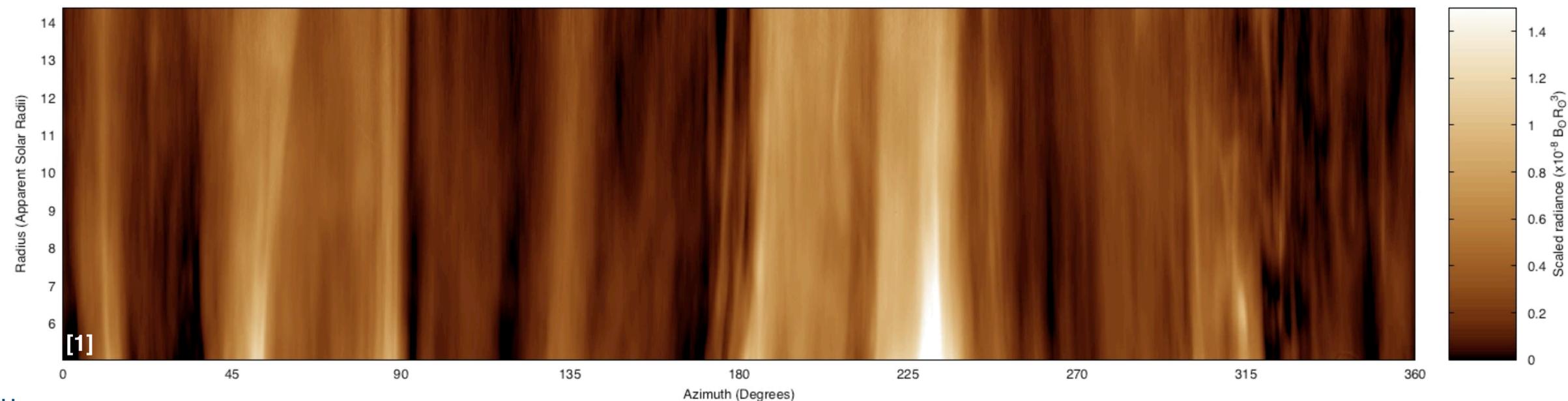


(x, y)



(Φ , r)

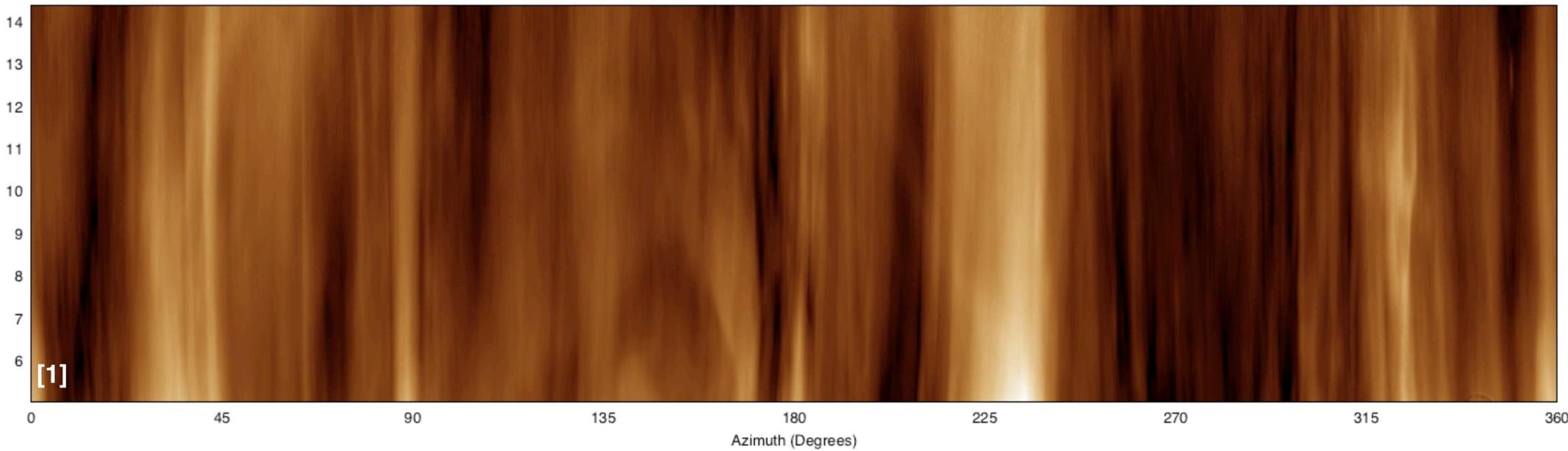
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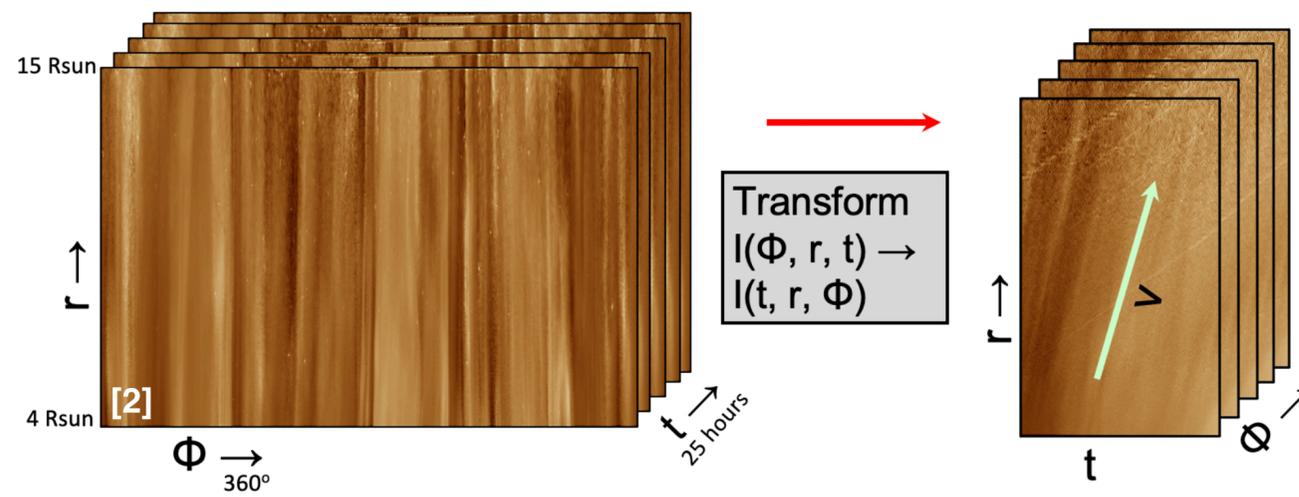
Data

STEREO-A / COR 2

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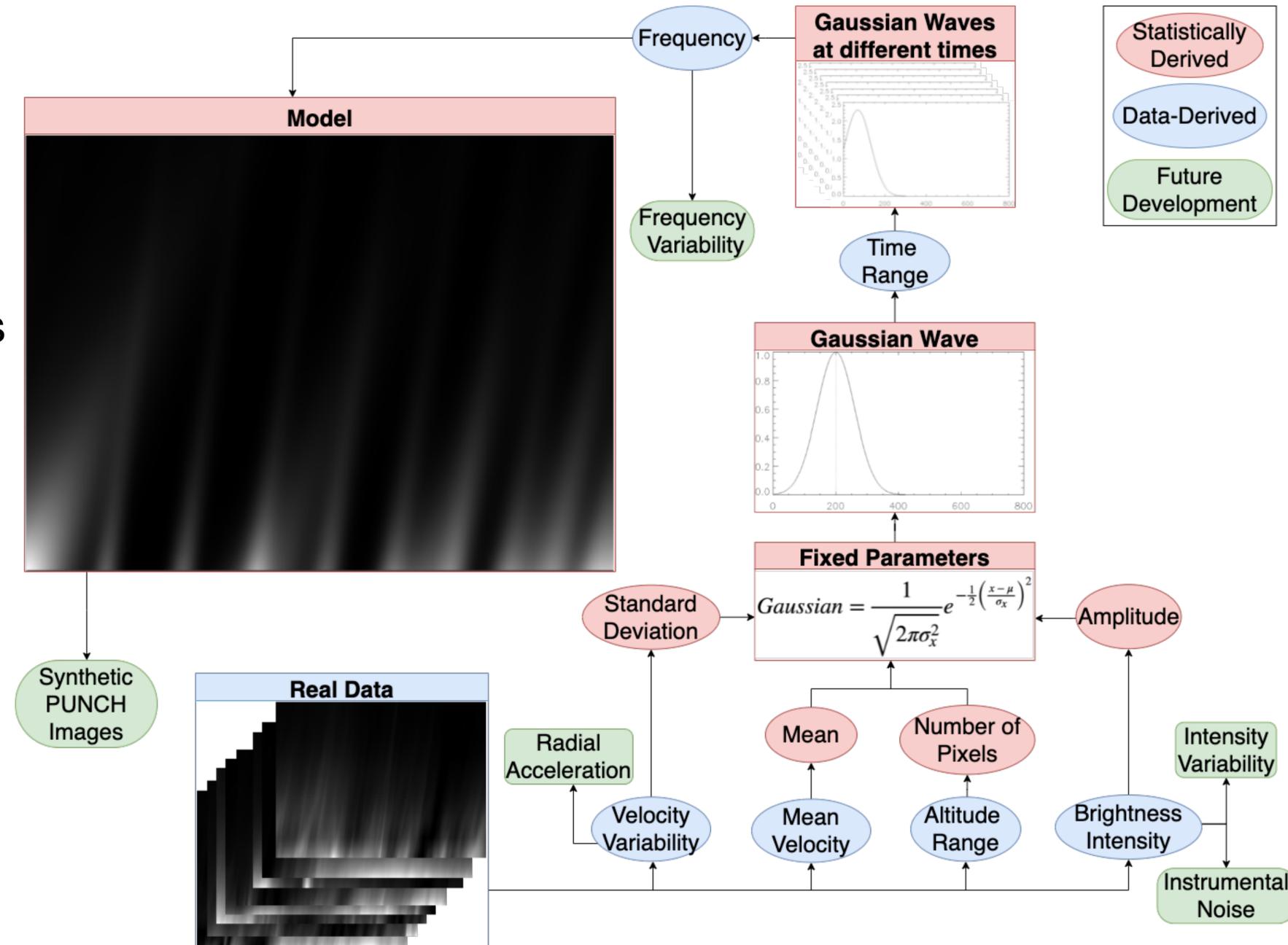


Distance-time plot



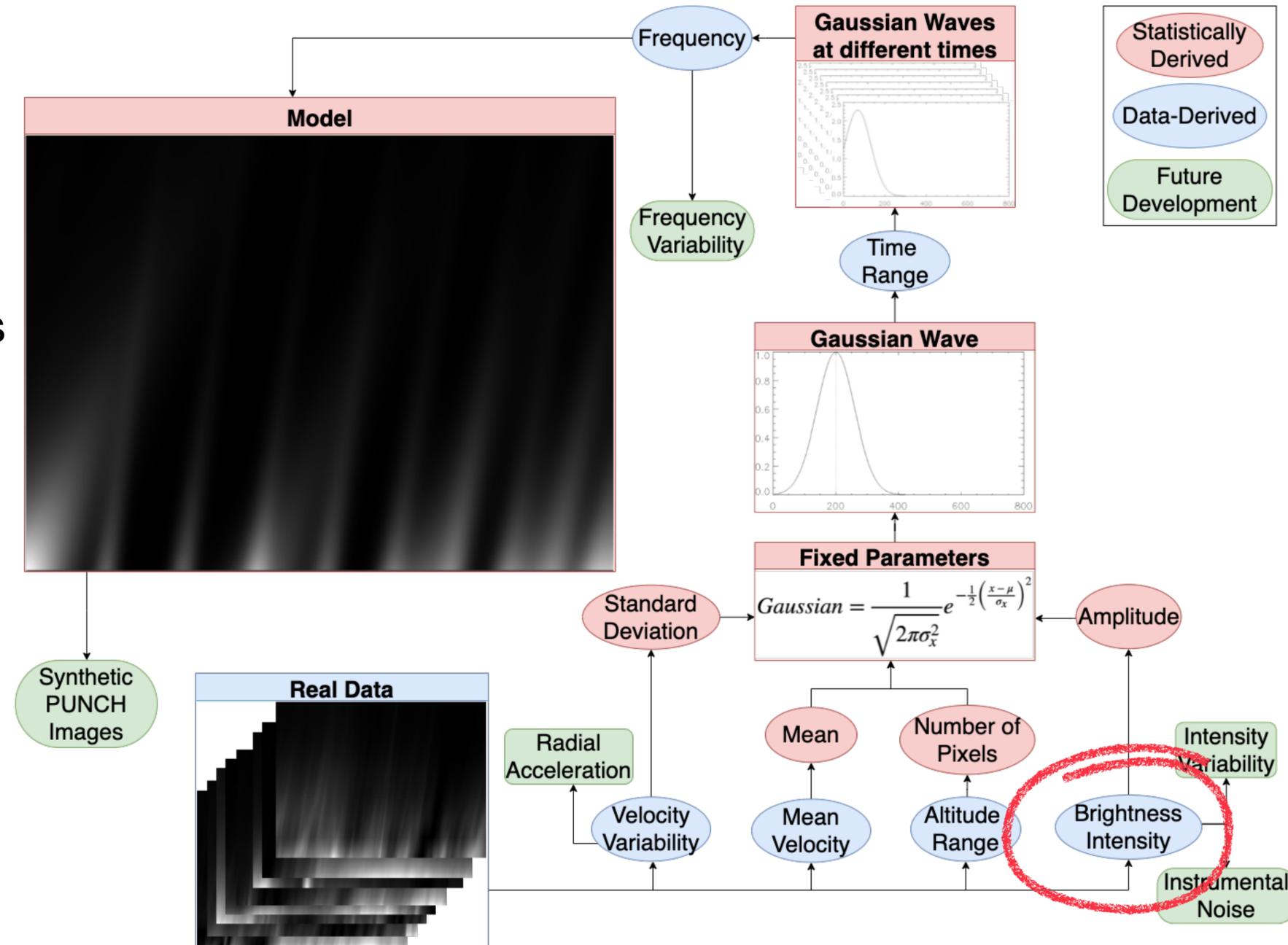
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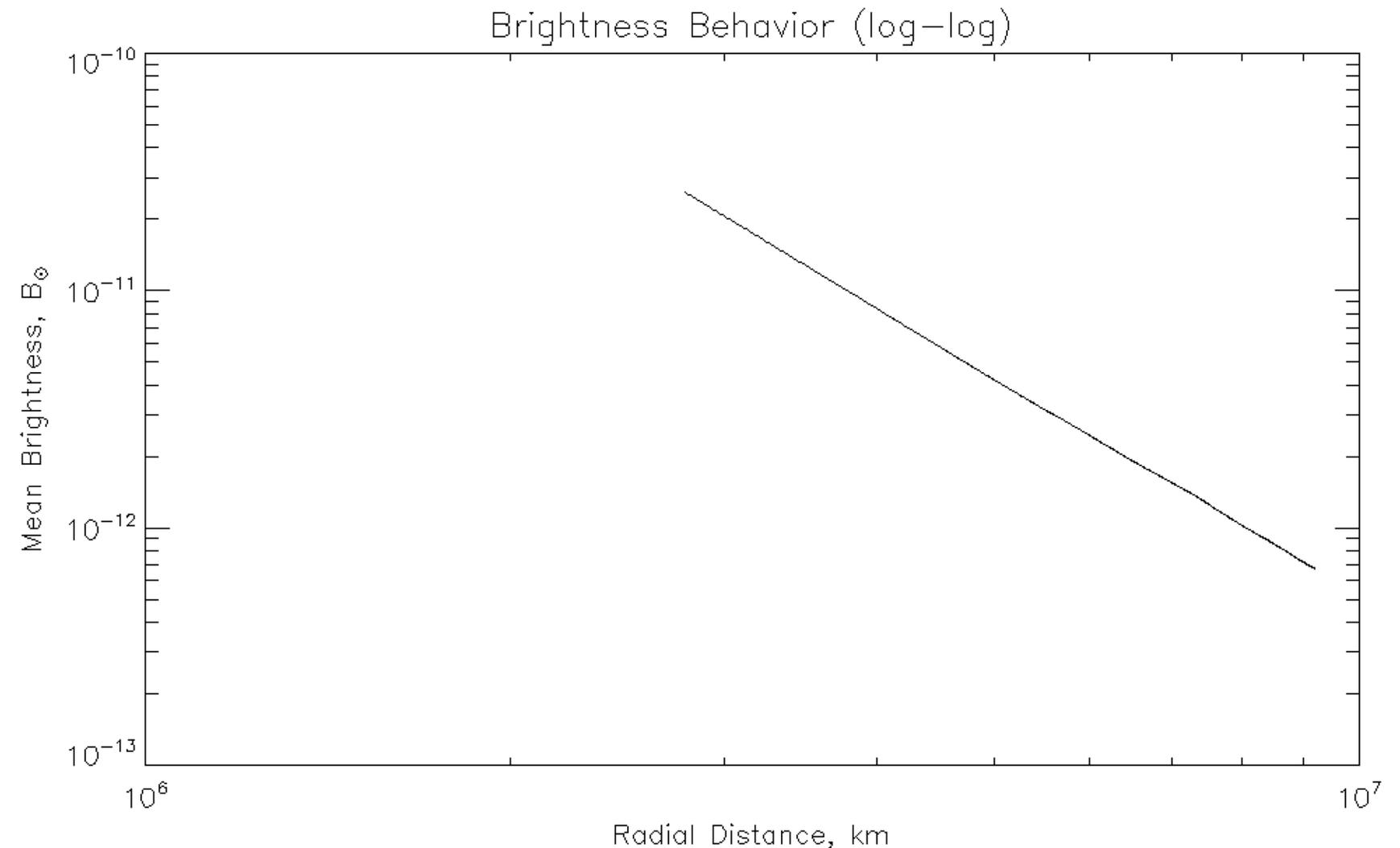
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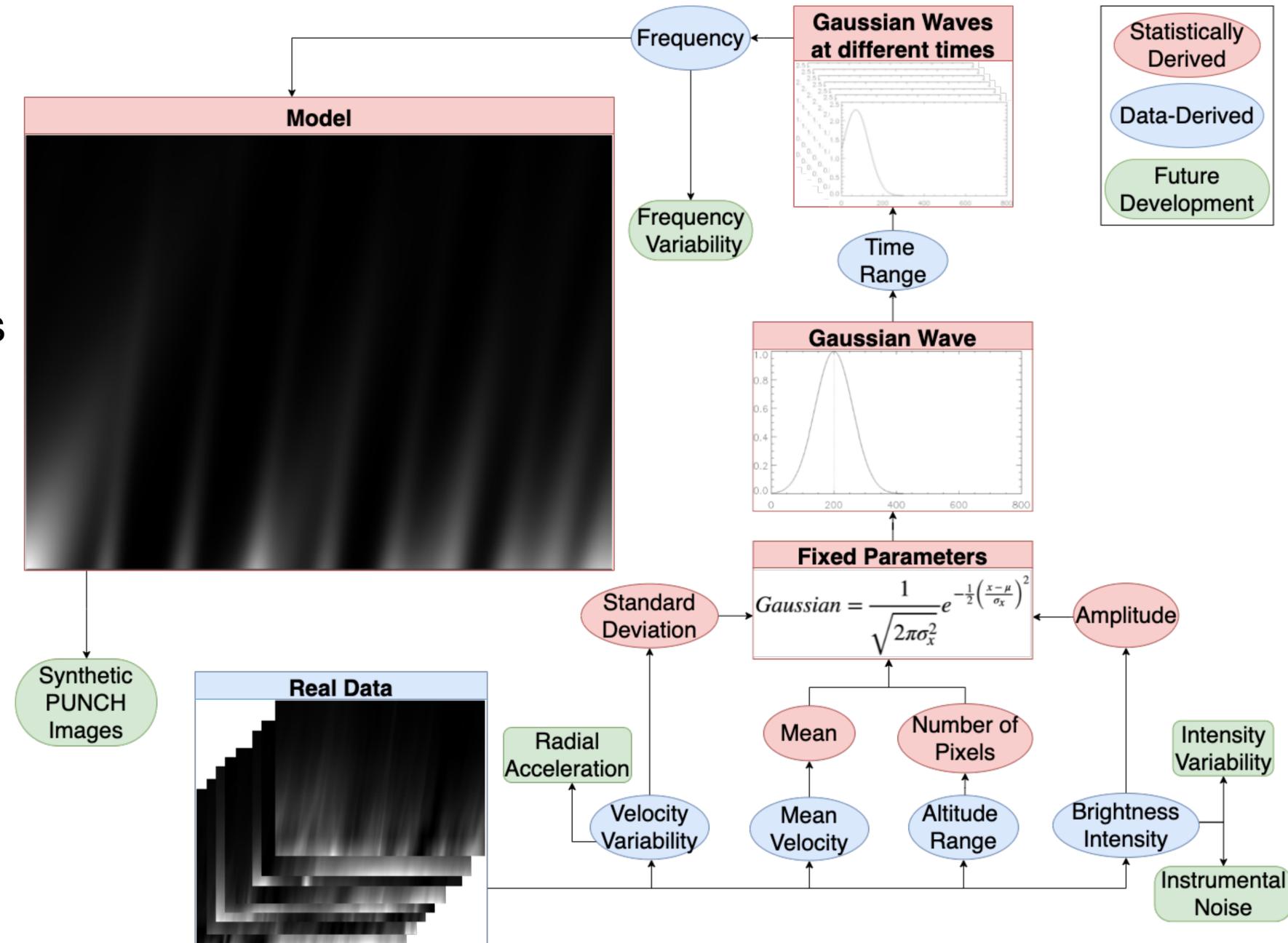
Brightness Behavior

- 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



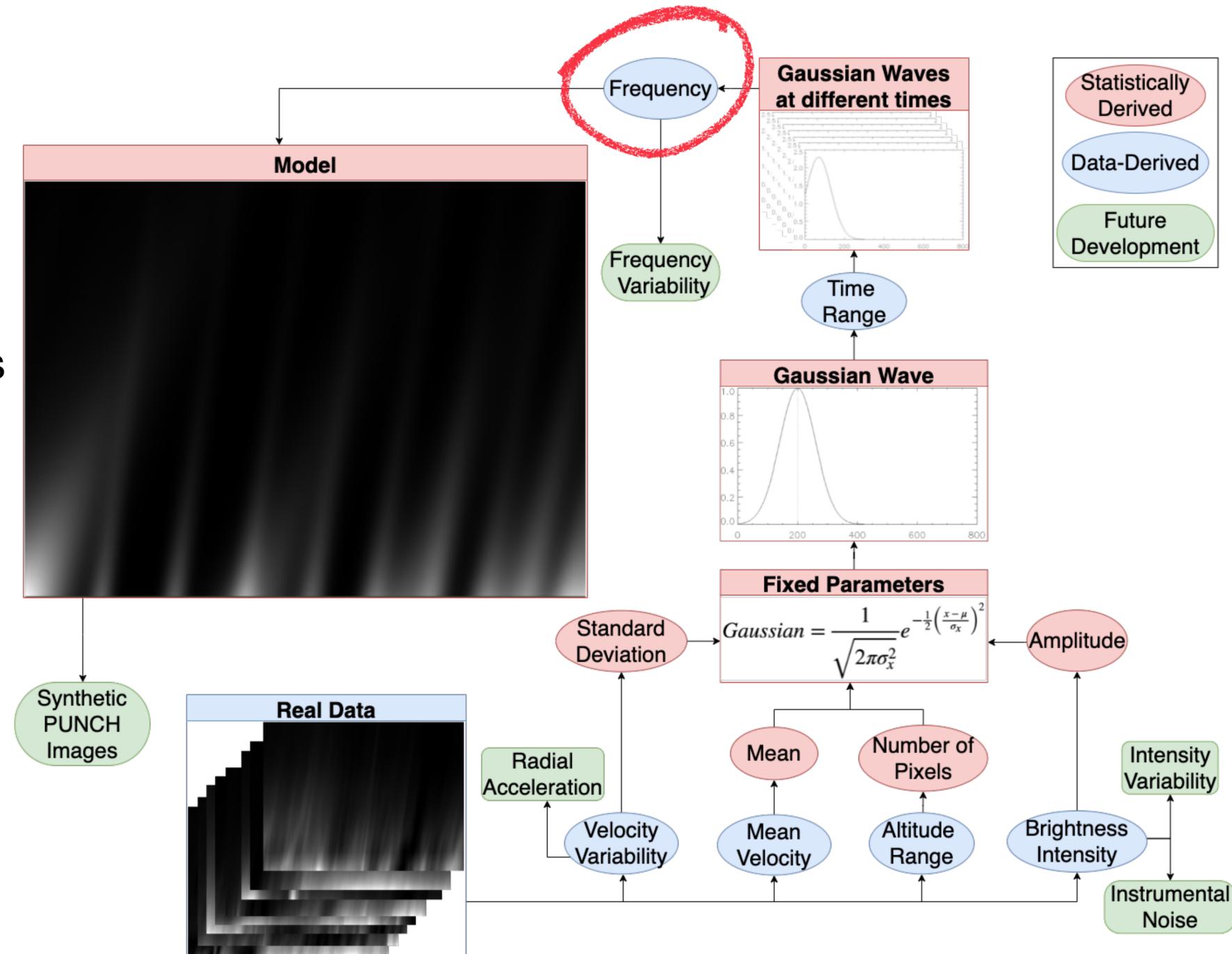
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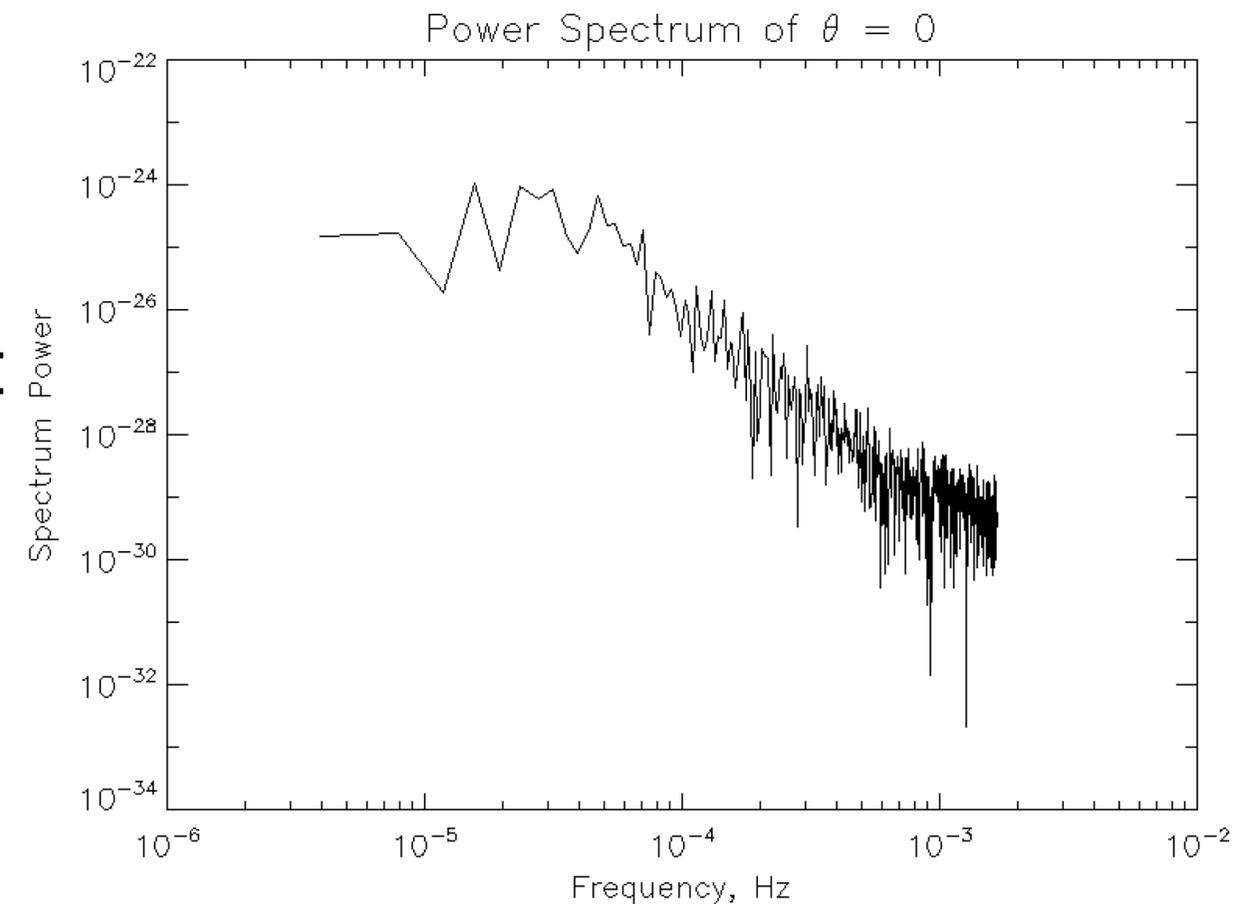
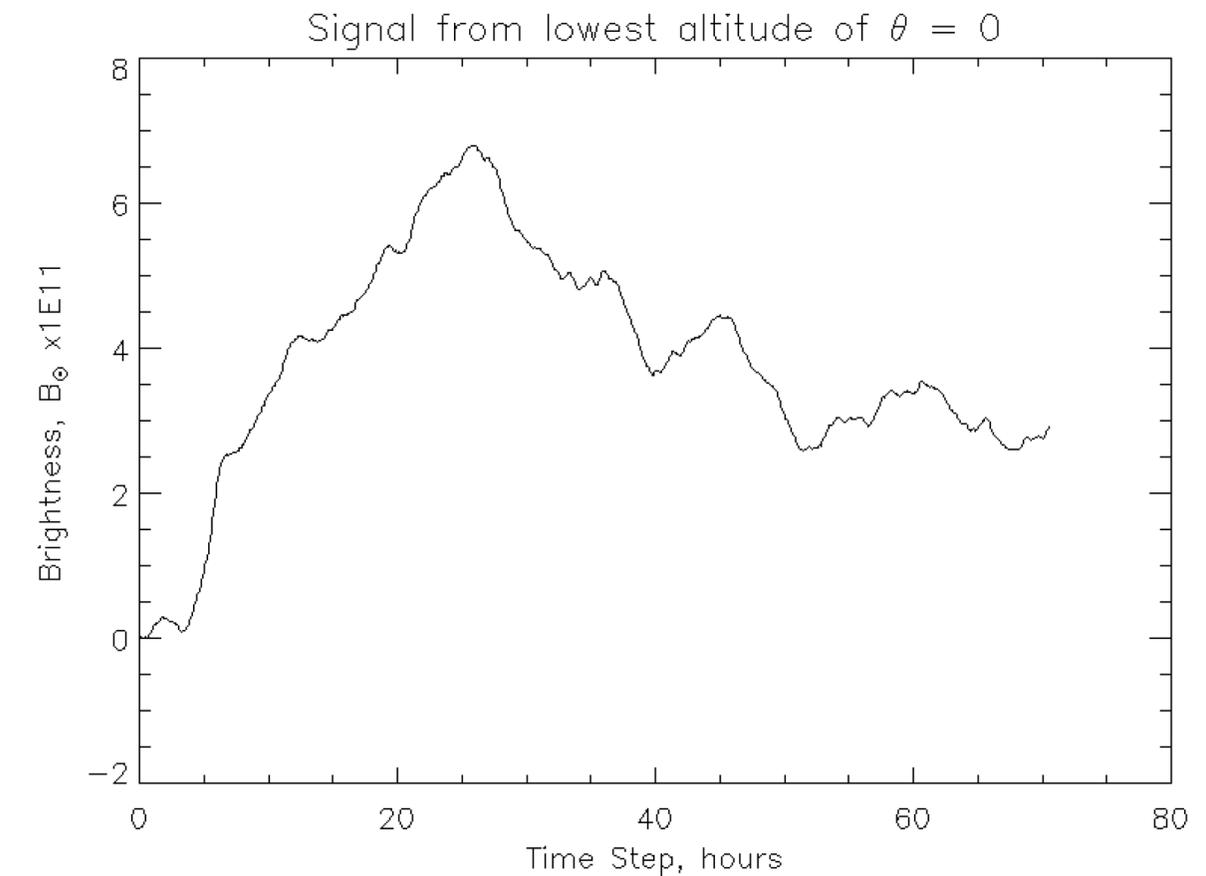
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Parameters

Frequency

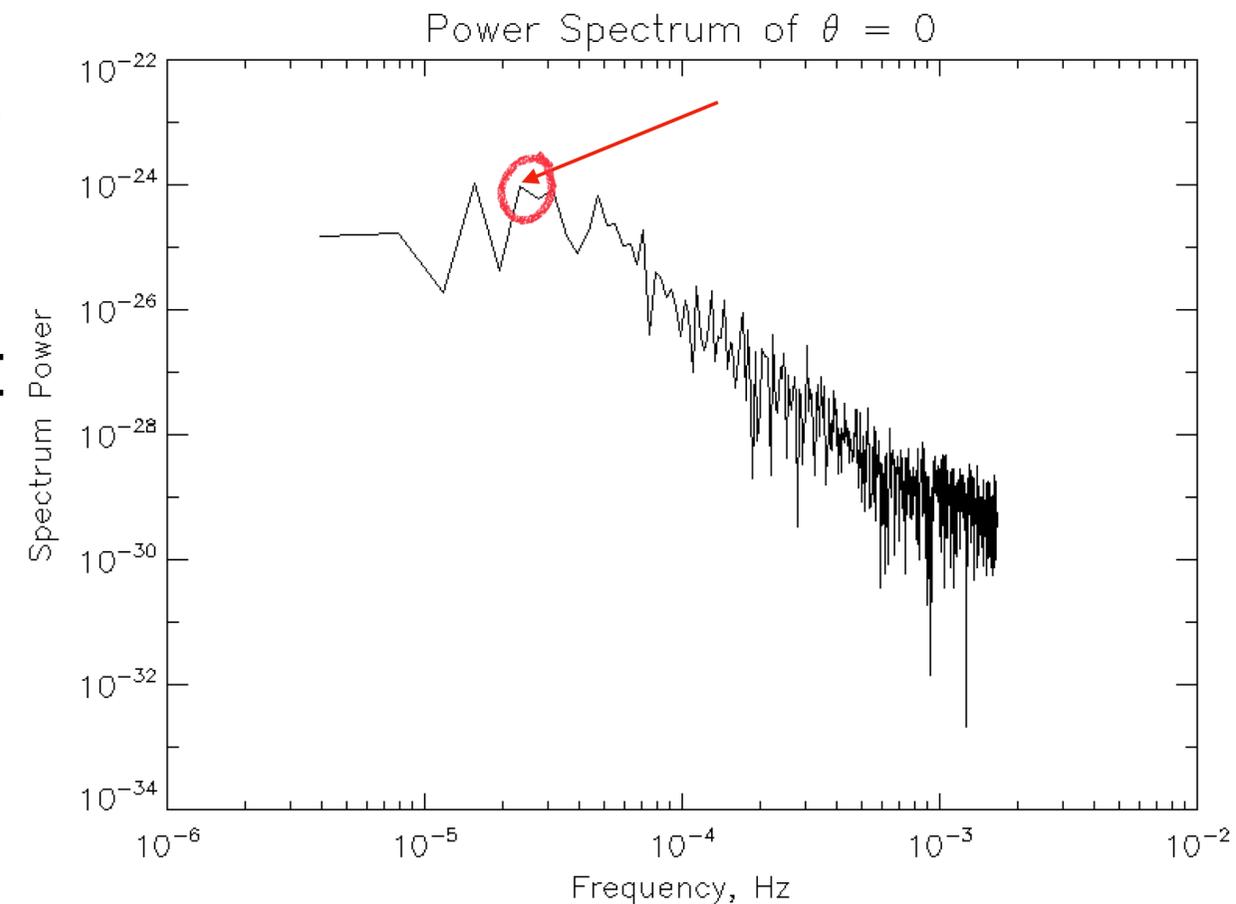
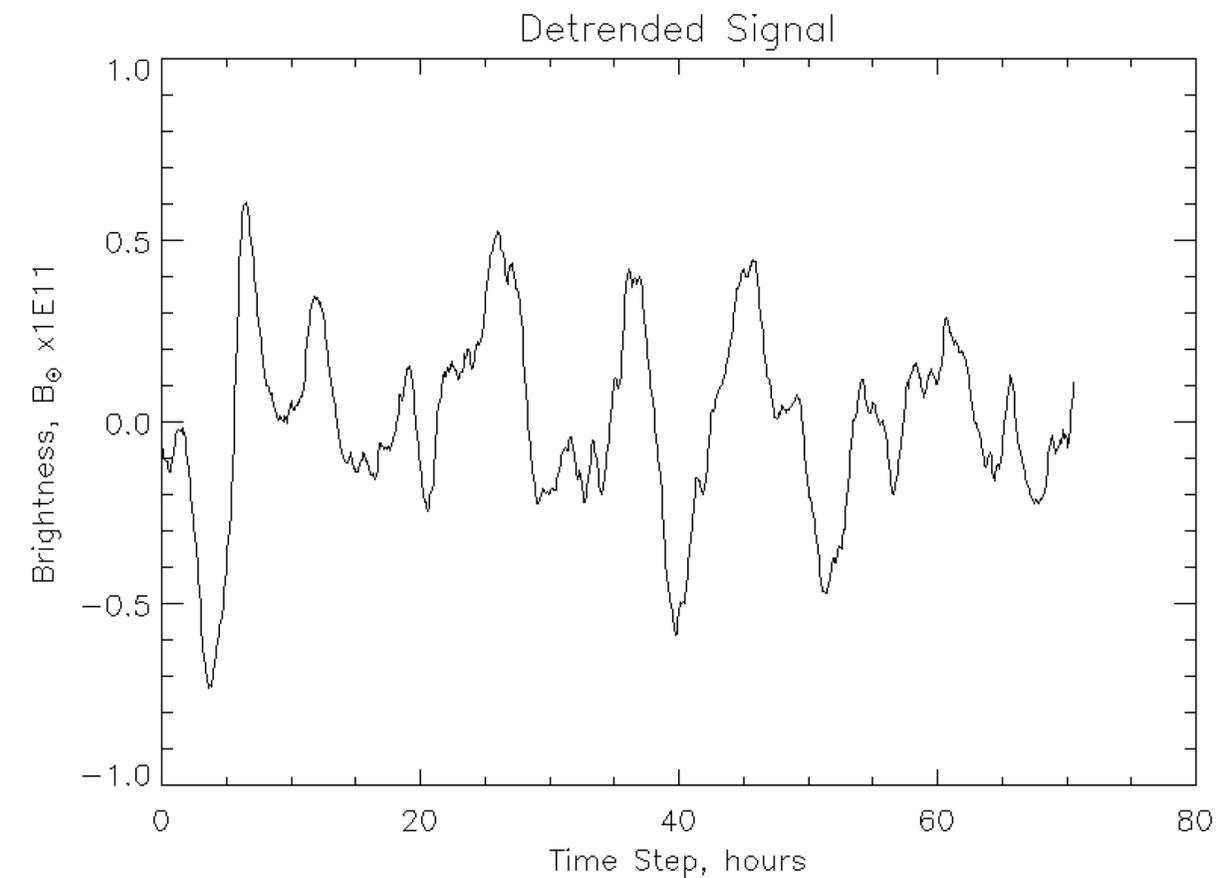
- **Signal taken from lowest altitude** at all times from each position angle
 - Sampling time: 300 seconds
- The second highest peak in the power spectrum contains the signal's frequency
- This frequency contains information on the amount of features launches at a certain position angle.
- The statistical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



Parameters

Frequency

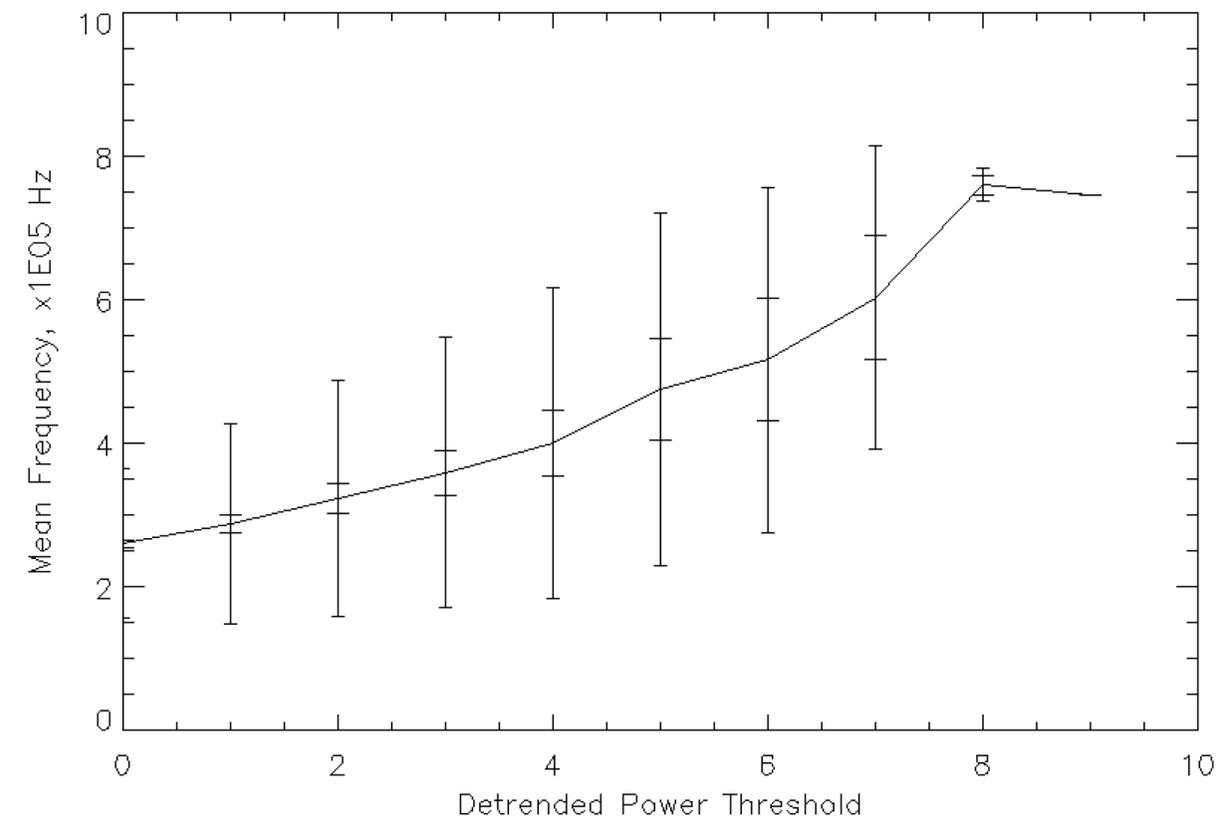
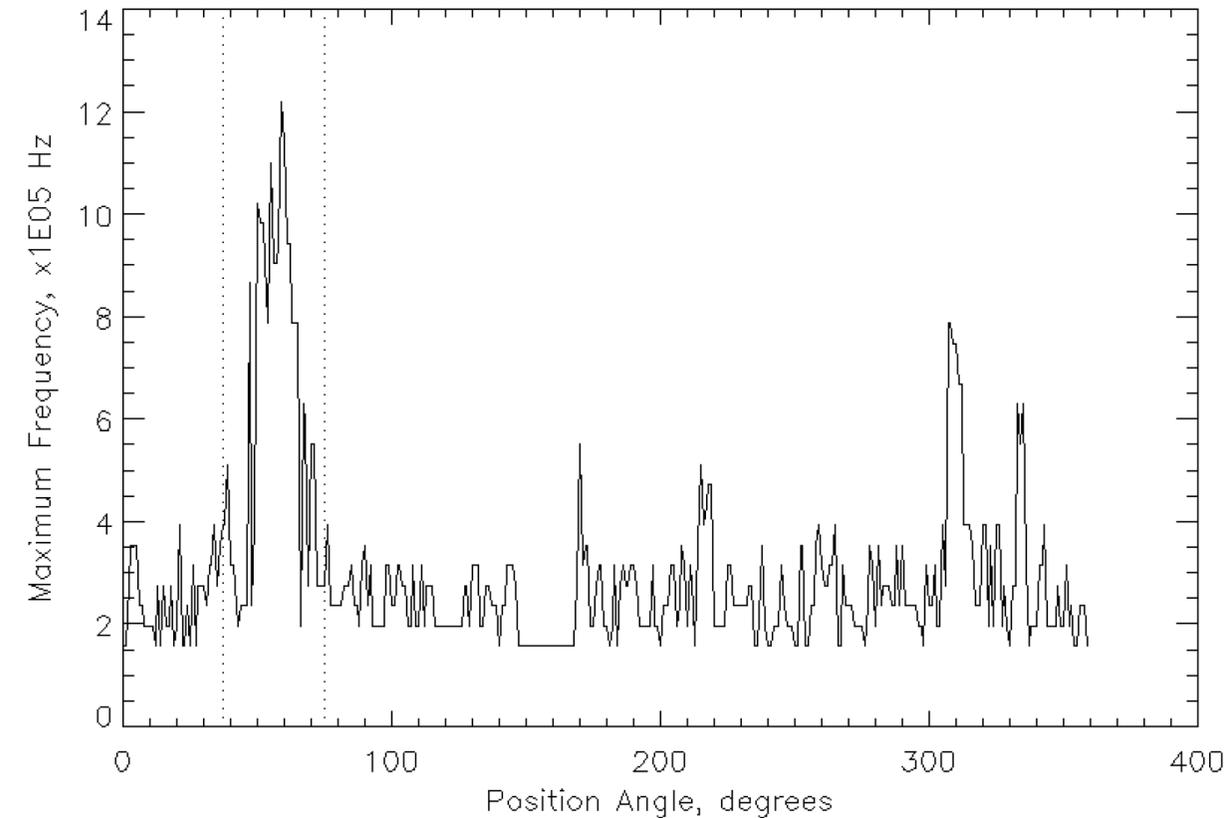
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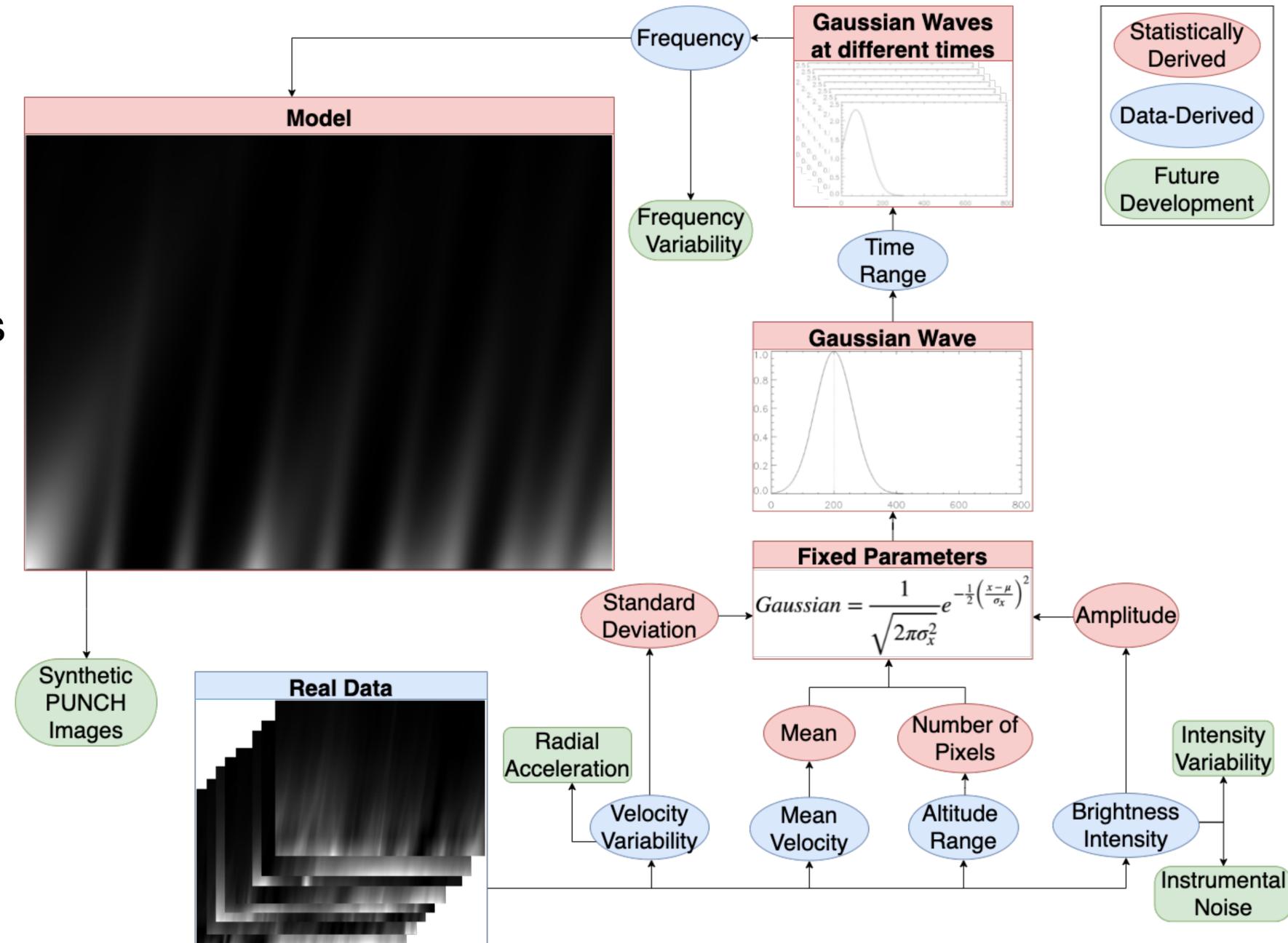
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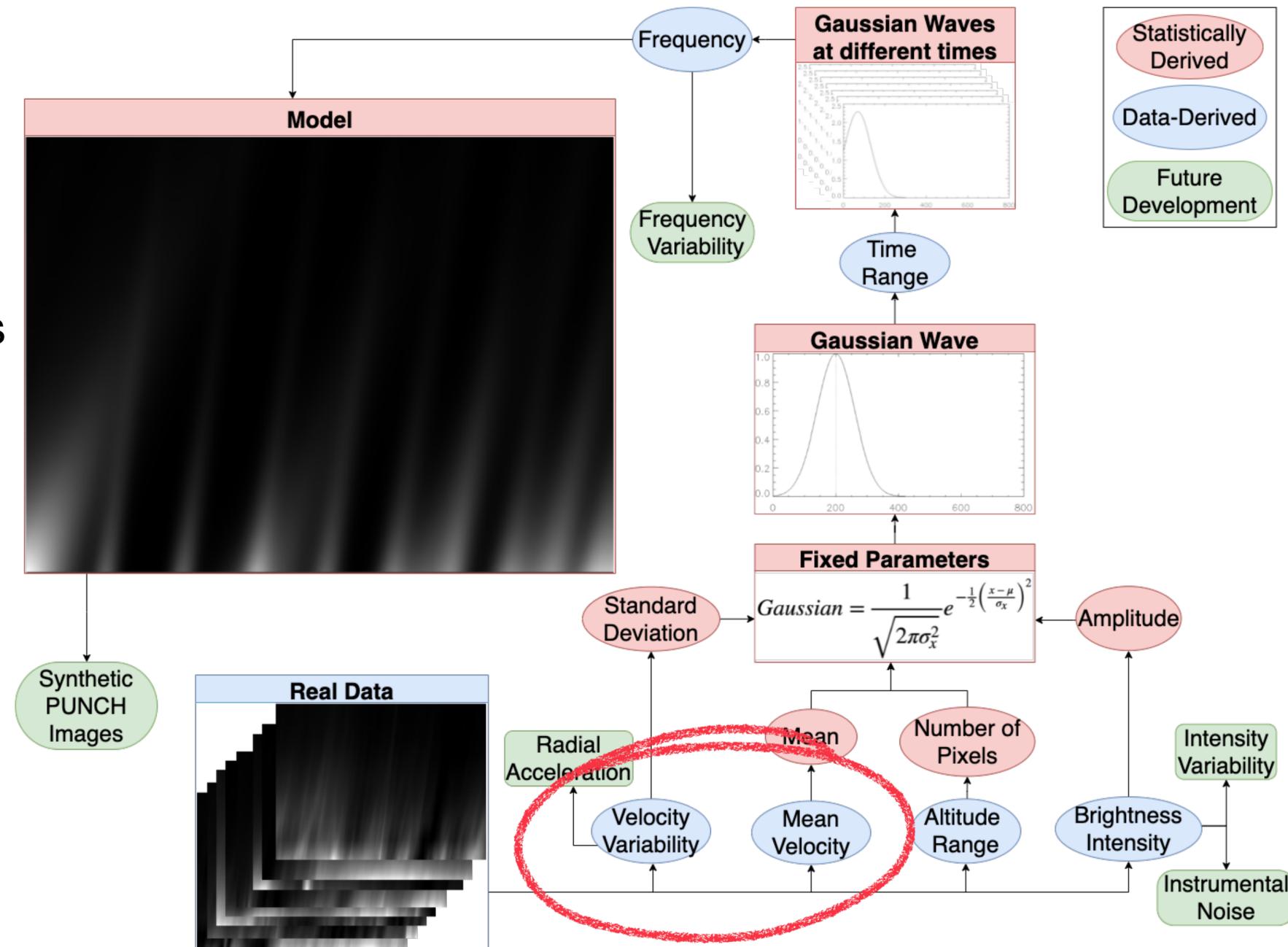
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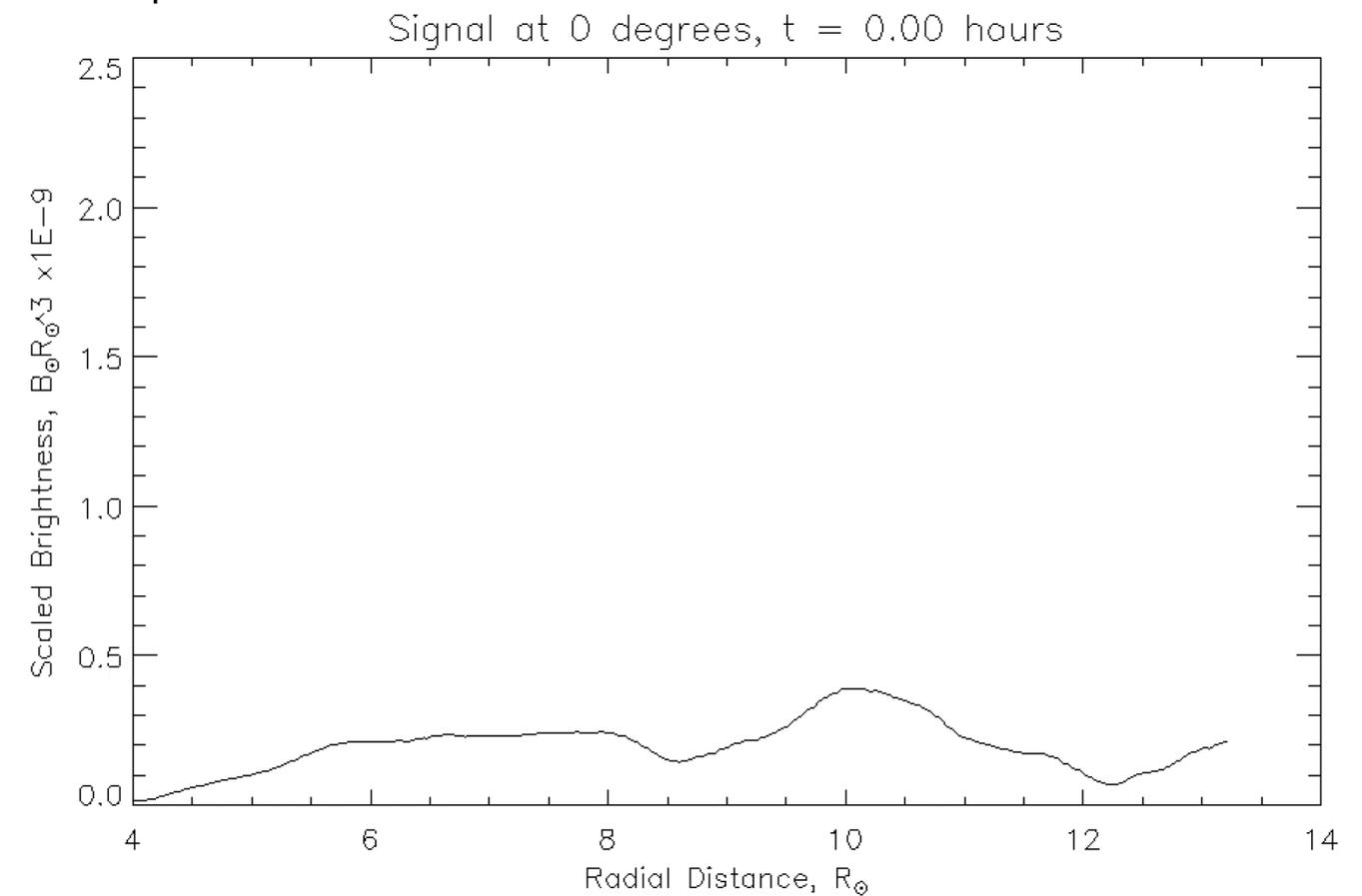
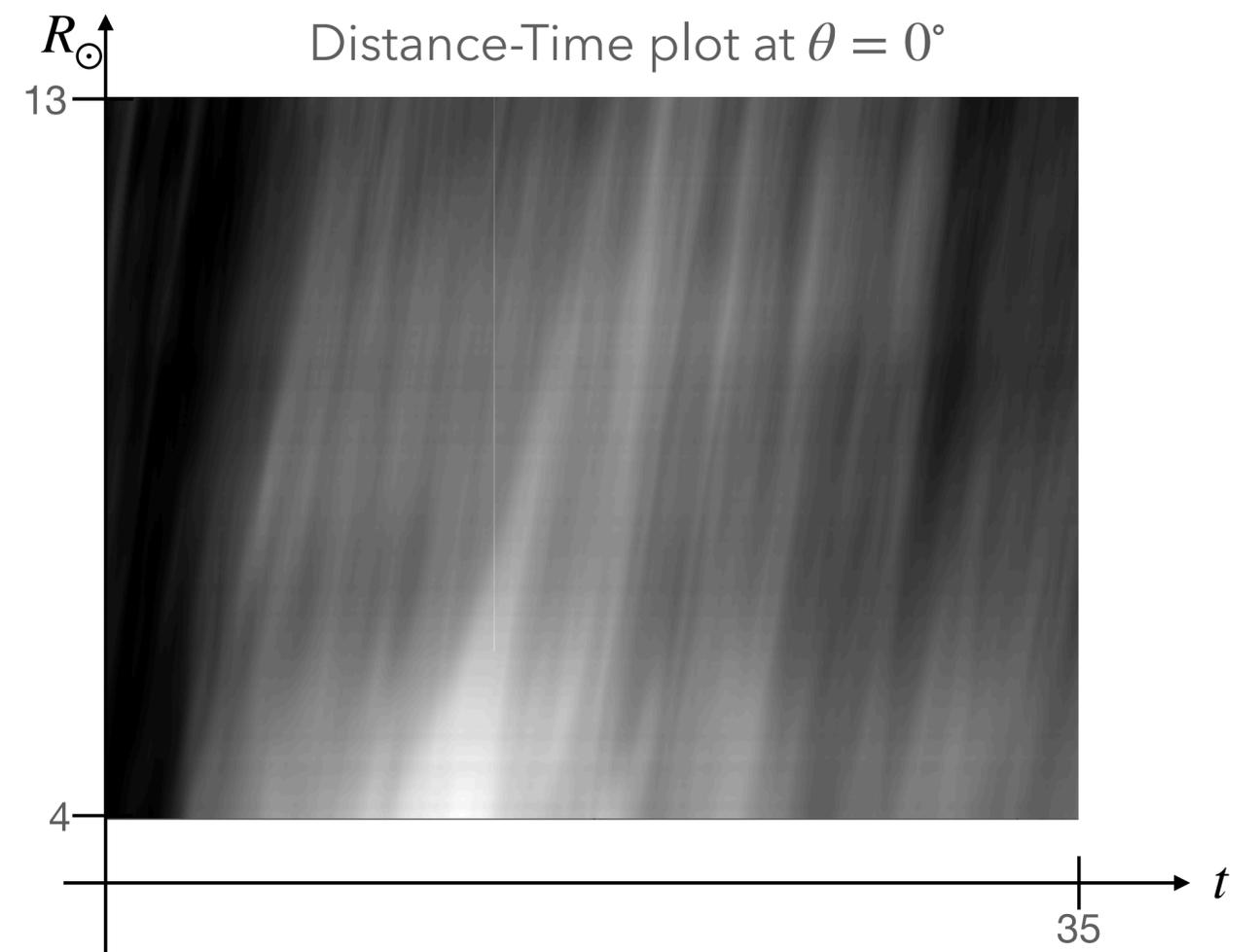
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Parameters

Velocity

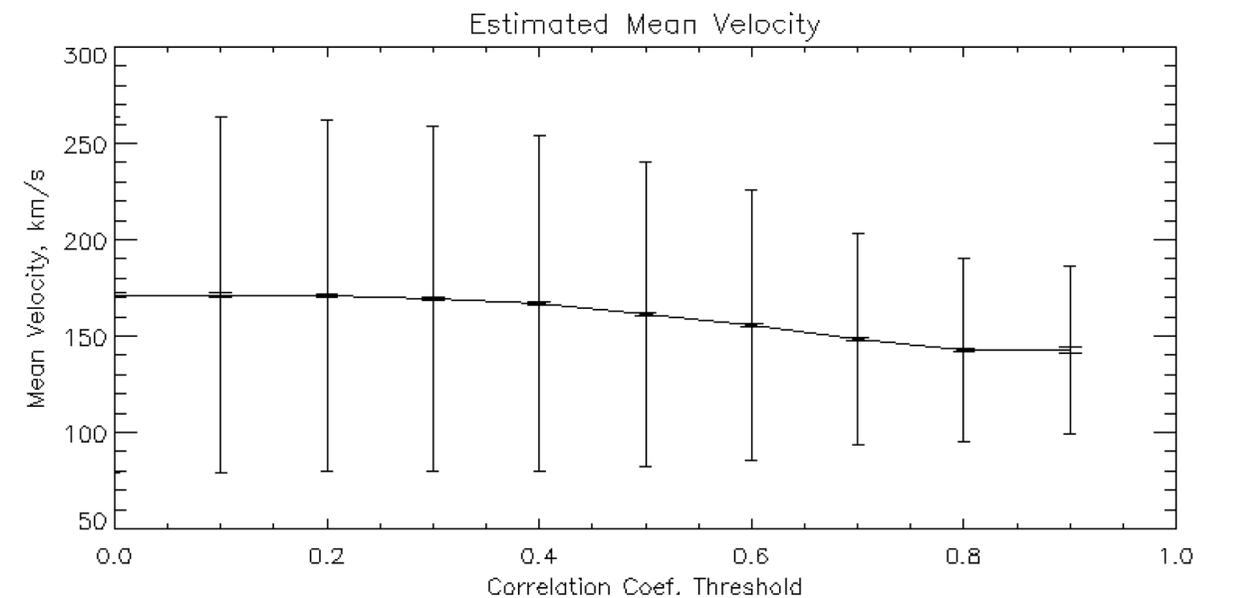
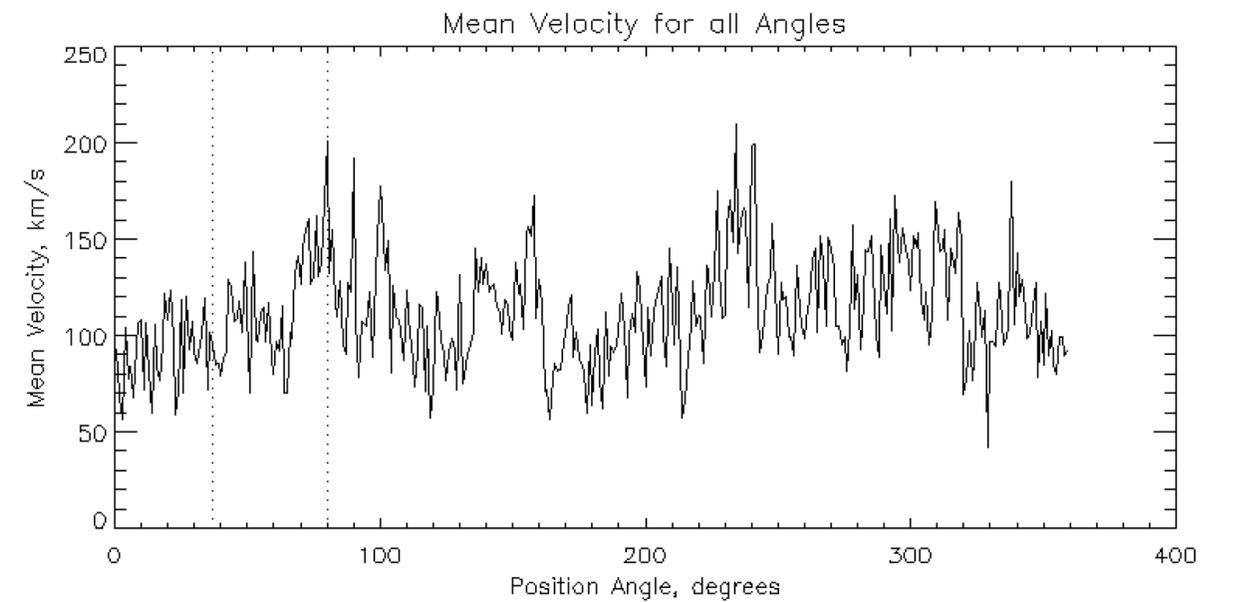
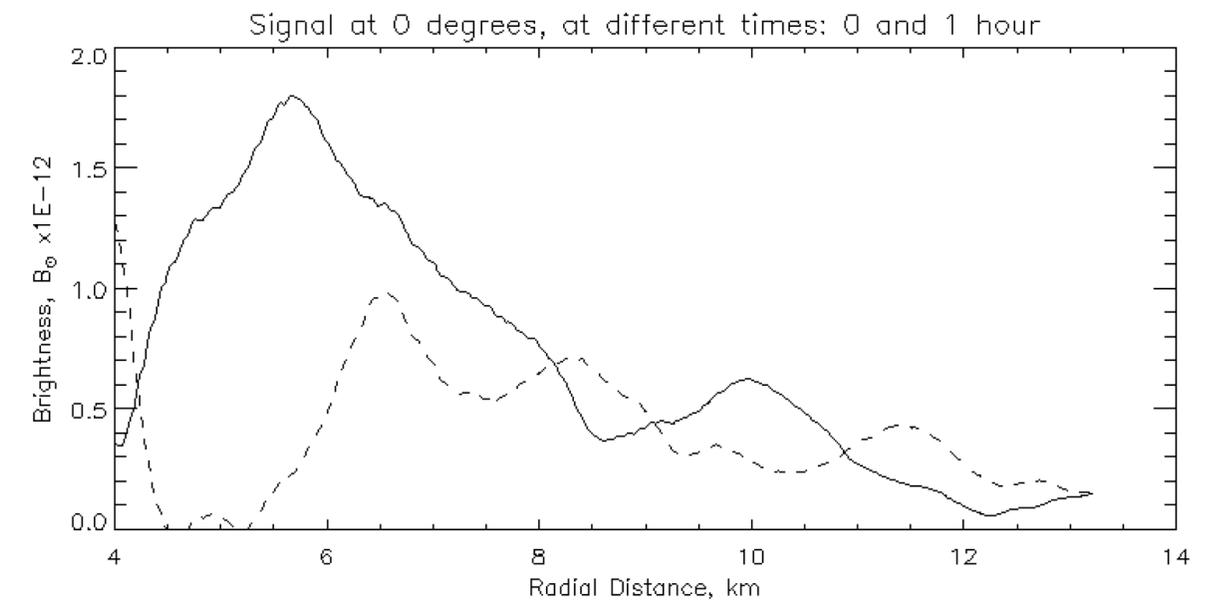
- **Distance-time plot:** contains a collection of signals for each time step
- **Signal attenuates with distance** but base level remains the same
- Flow tracking algorithm chosen
cross-correlation of 1-D signal
- Evaluates the maximum correlation coefficient and locates its corresponding spatial lag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



Parameters

Velocity

- Distance-time plot: contains a collection of signals for each time step
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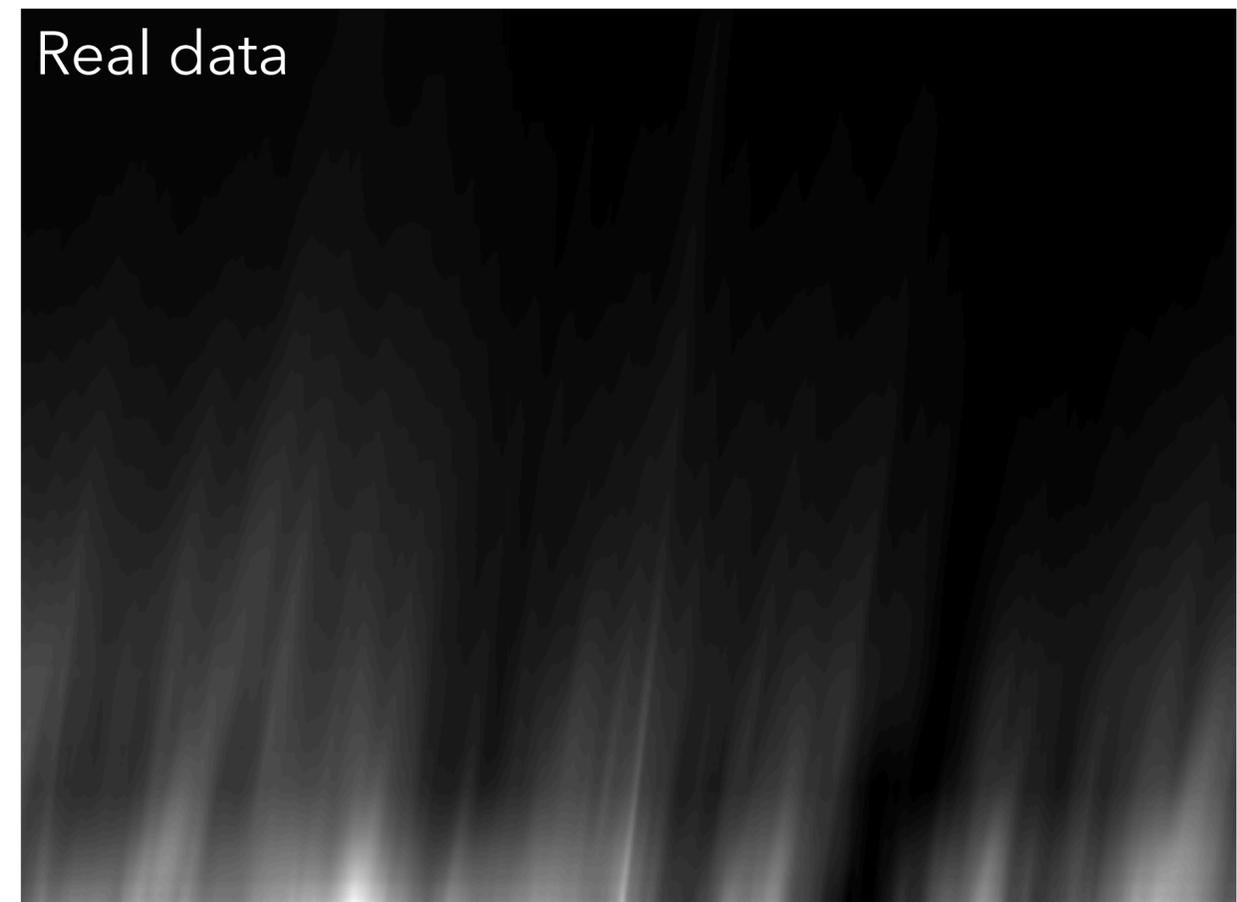


Model

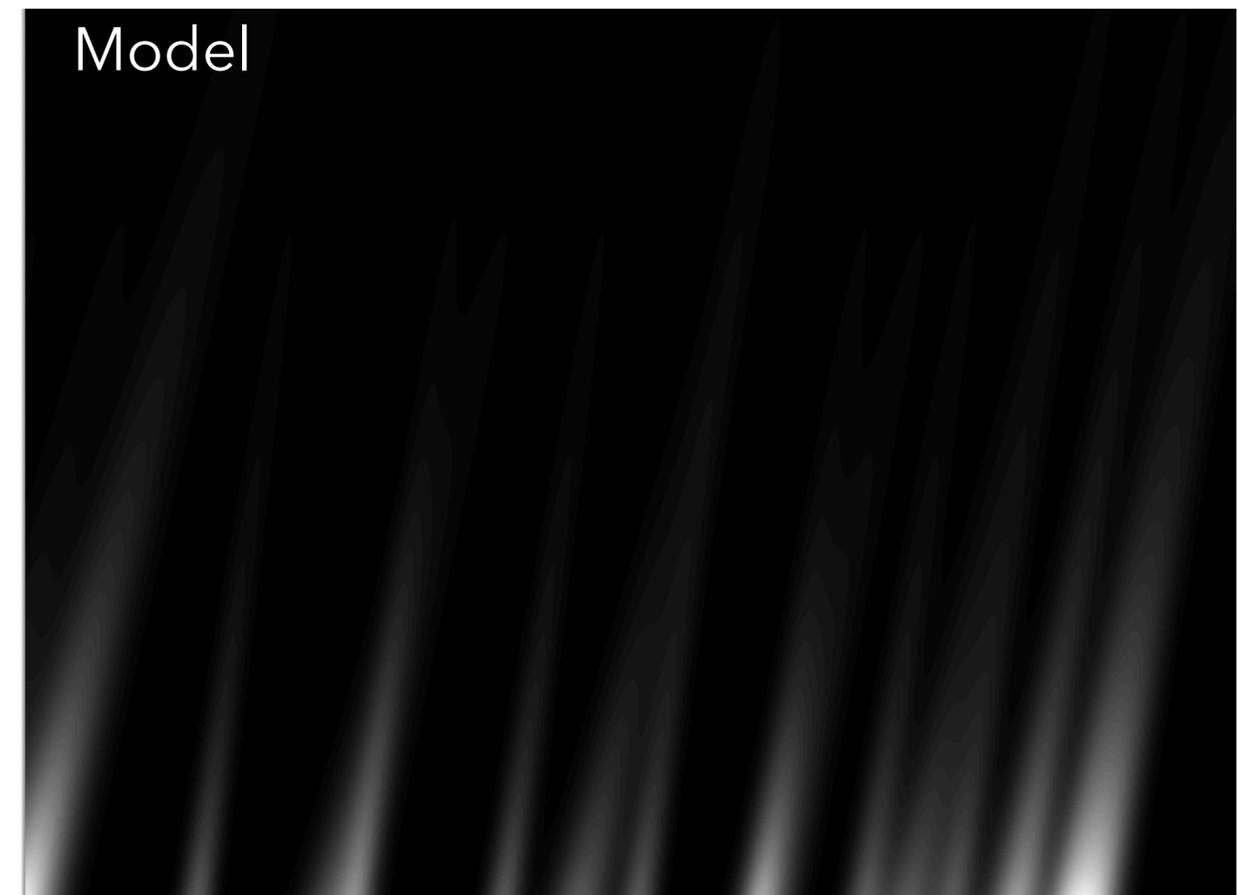
Distance-time plots

- 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

Real data



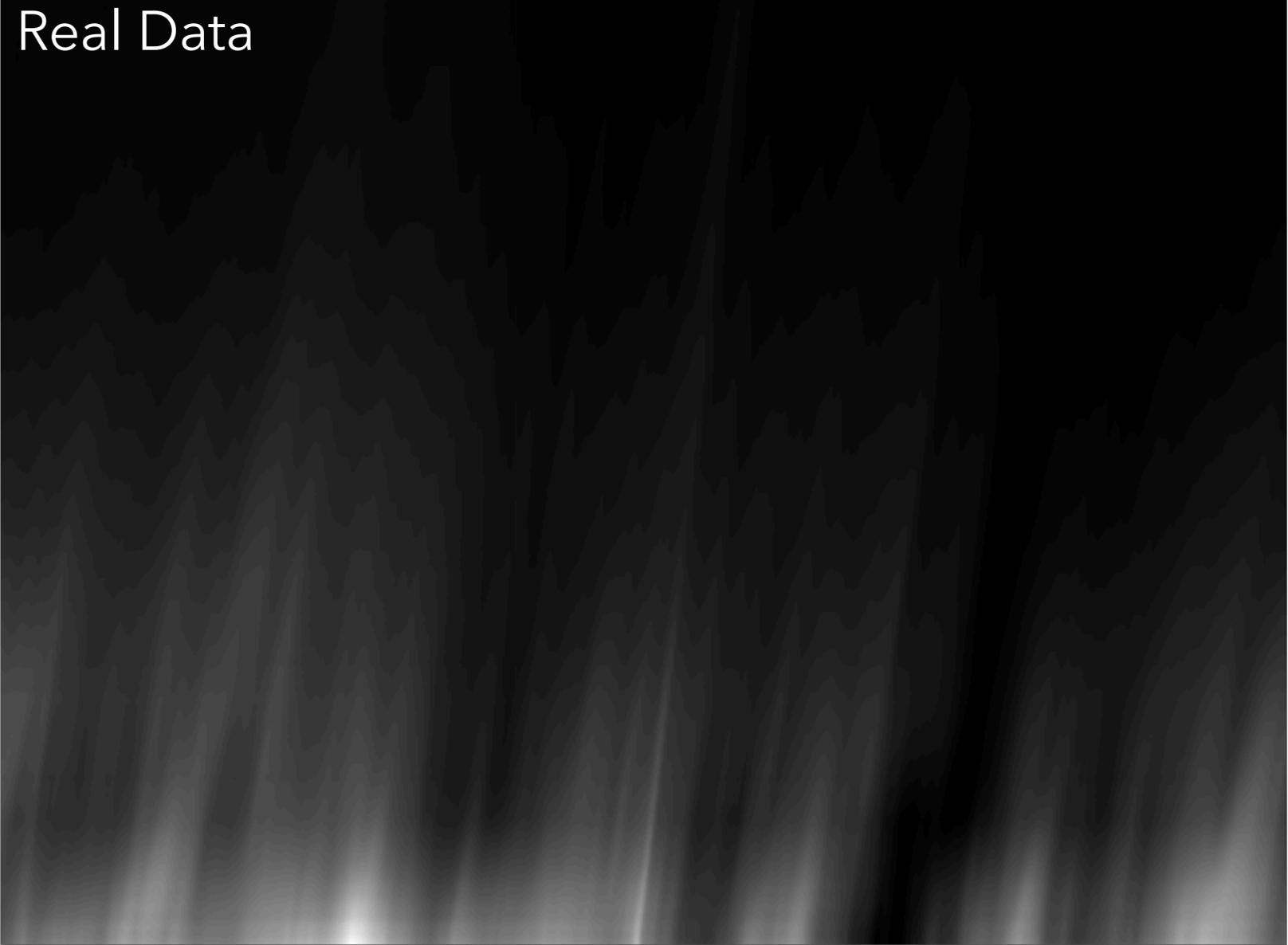
Model



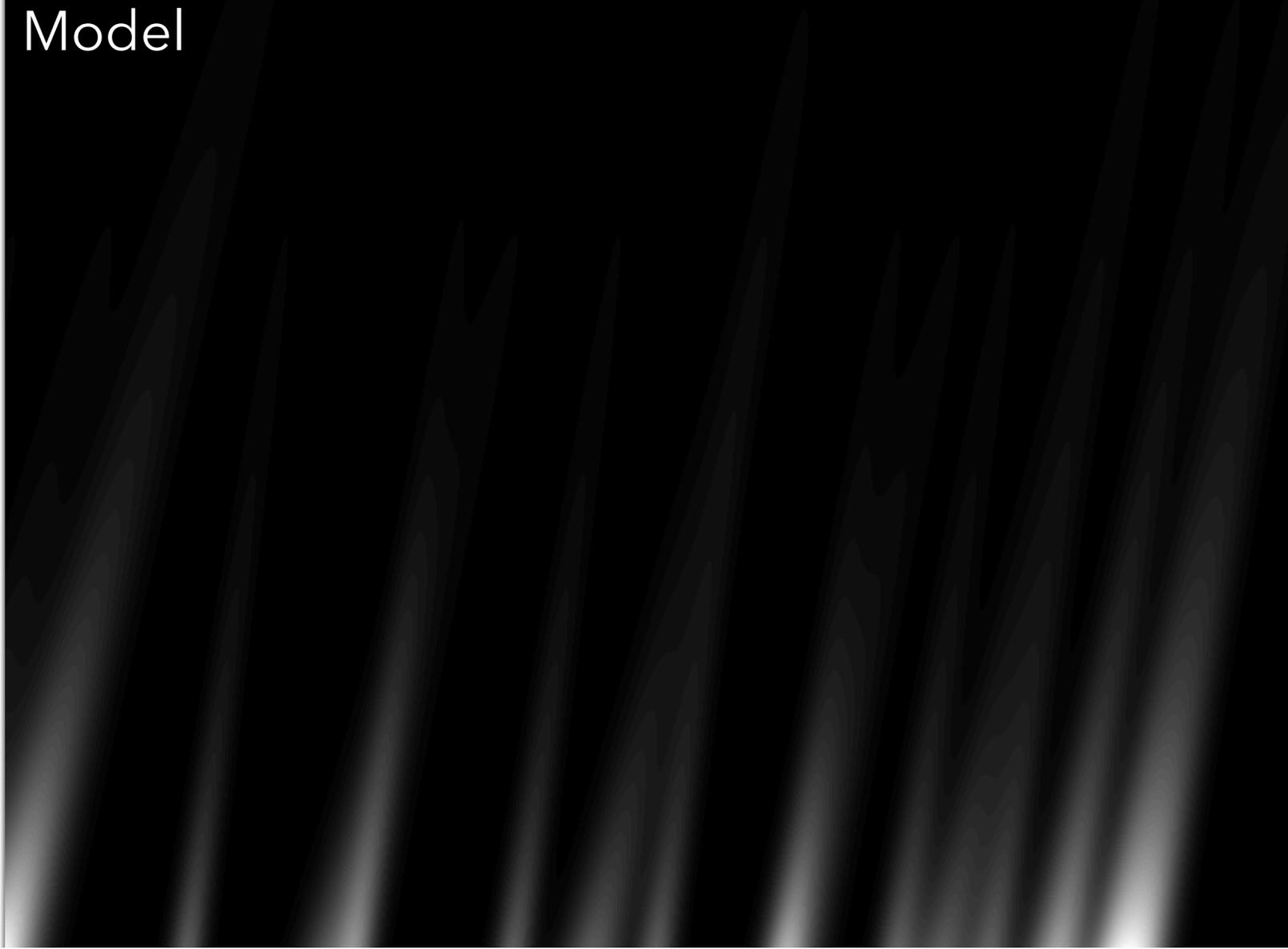
Model

Distance-time plots

Real Data



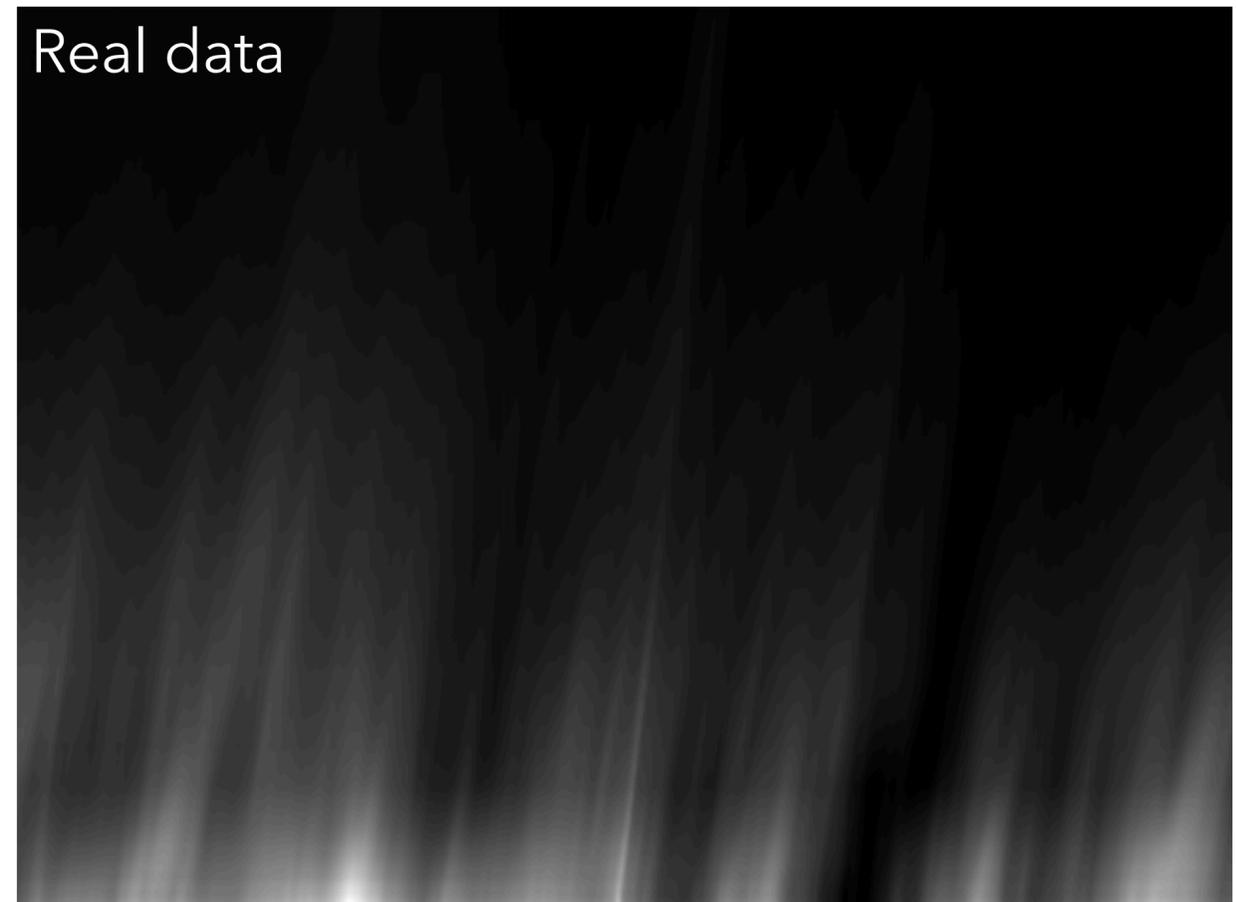
Model



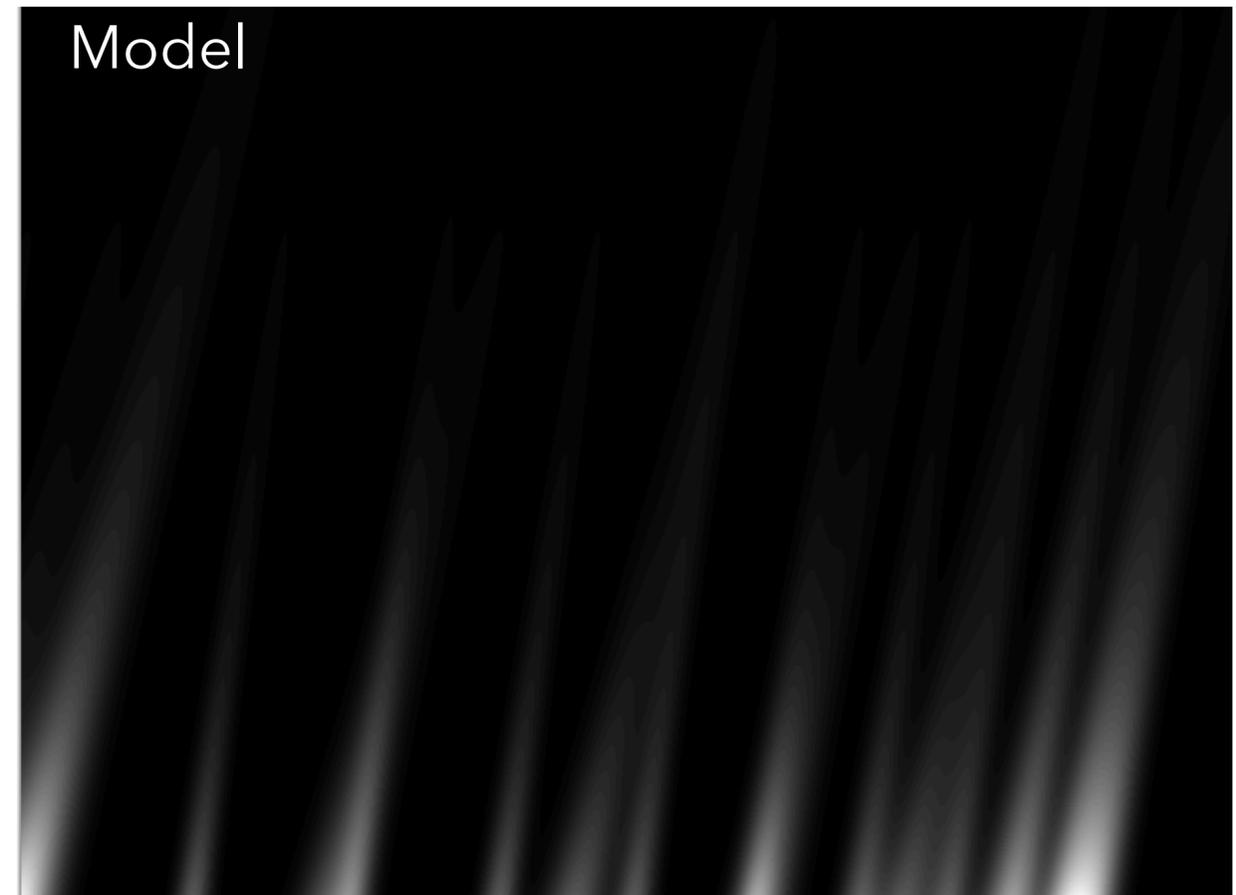
Model Overview

- 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

Real data

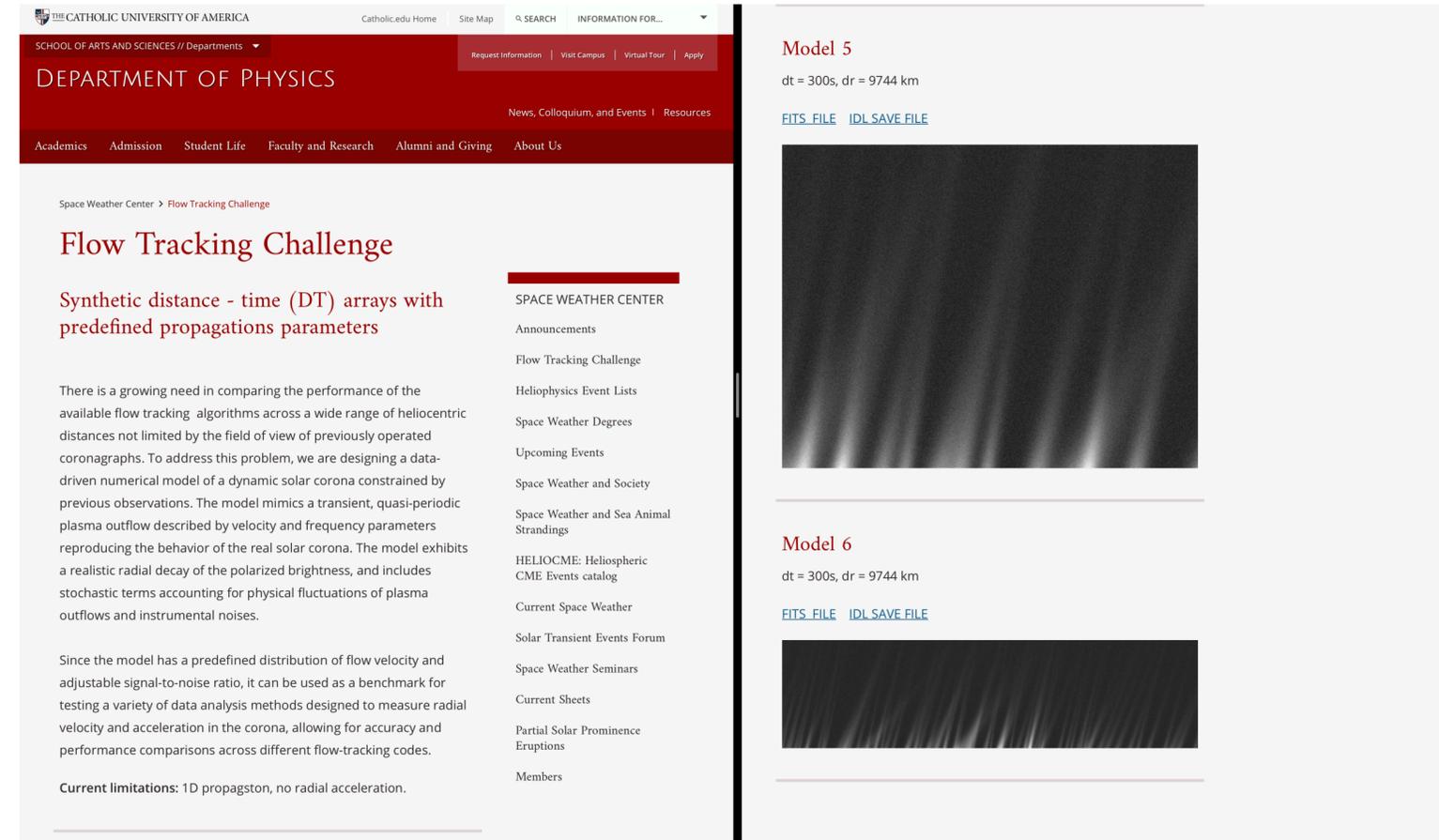


Model



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.



Space Weather Center > Flow Tracking Challenge

Flow Tracking Challenge

Synthetic distance - time (DT) arrays with predefined propagations parameters

There is a growing need in comparing the performance of the available flow tracking algorithms across a wide range of heliocentric distances not limited by the field of view of previously operated coronagraphs. To address this problem, we are designing a data-driven numerical model of a dynamic solar corona constrained by previous observations. The model mimics a transient, quasi-periodic plasma outflow described by velocity and frequency parameters reproducing the behavior of the real solar corona. The model exhibits a realistic radial decay of the polarized brightness, and includes stochastic terms accounting for physical fluctuations of plasma outflows and instrumental noises.

Since the model has a predefined distribution of flow velocity and adjustable signal-to-noise ratio, it can be used as a benchmark for testing a variety of data analysis methods designed to measure radial velocity and acceleration in the corona, allowing for accuracy and performance comparisons across different flow-tracking codes.

Current limitations: 1D propagation, no radial acceleration.

SPACE WEATHER CENTER

- Announcements
- Flow Tracking Challenge
- Heliophysics Event Lists
- Space Weather Degrees
- Upcoming Events
- Space Weather and Society
- Space Weather and Sea Animal Strandings
- HELIOCME: Heliospheric CME Events catalog
- Current Space Weather
- Solar Transient Events Forum
- Space Weather Seminars
- Current Sheets
- Partial Solar Prominence Eruptions
- Members

Model 5
dt = 300s, dr = 9744 km
[FITS FILE](#) [IDL SAVE FILE](#)

Model 6
dt = 300s, dr = 9744 km
[FITS FILE](#) [IDL SAVE FILE](#)



In Development

Synthetic Corona Images

- Spatial-spatial (r vs θ) 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.

Real data



Model



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!**