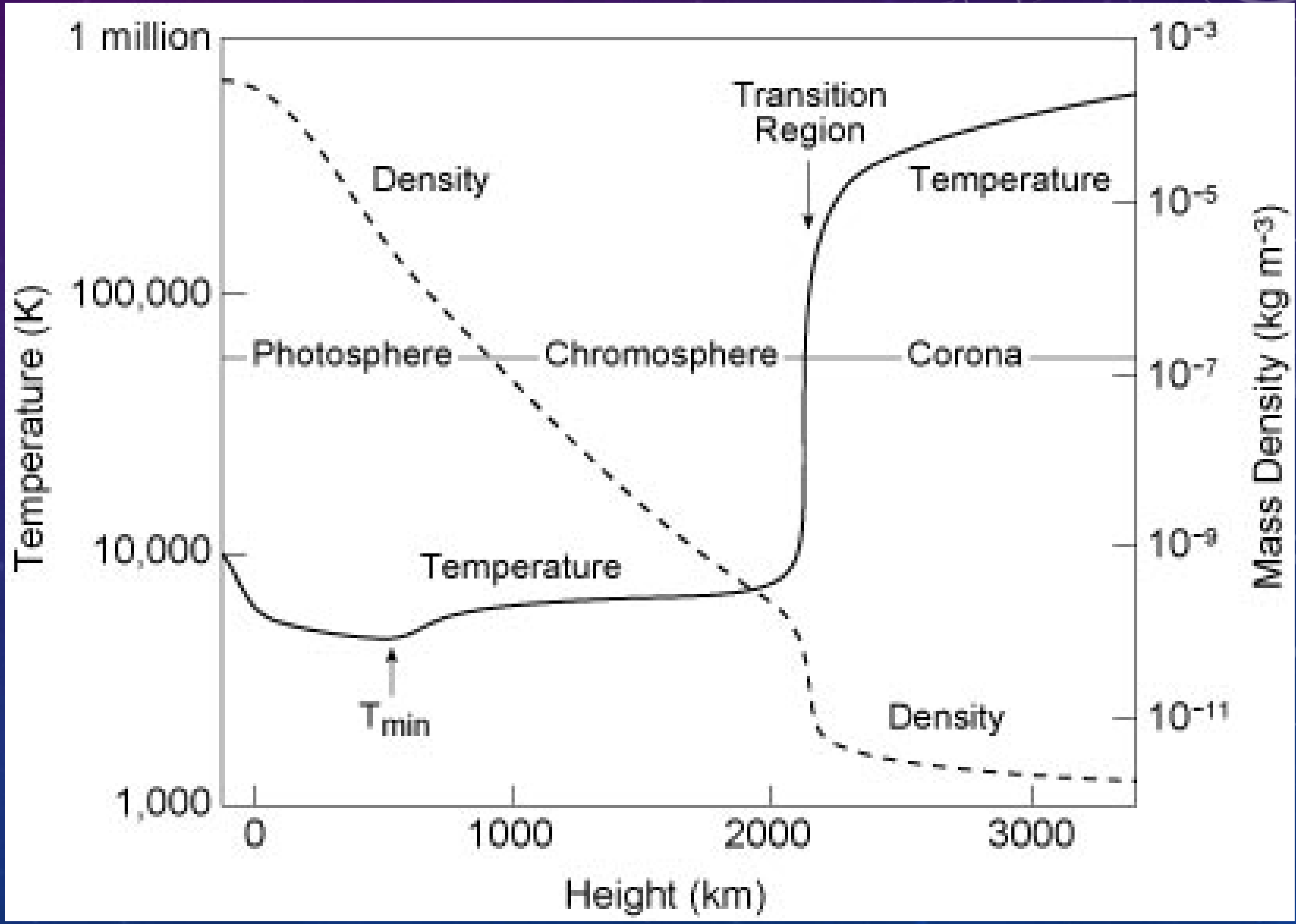
Quantifying Line-of-Sight Effects for Spectroscopic Measurements of Alfvén Waves and Turbulence in the Solar Corona

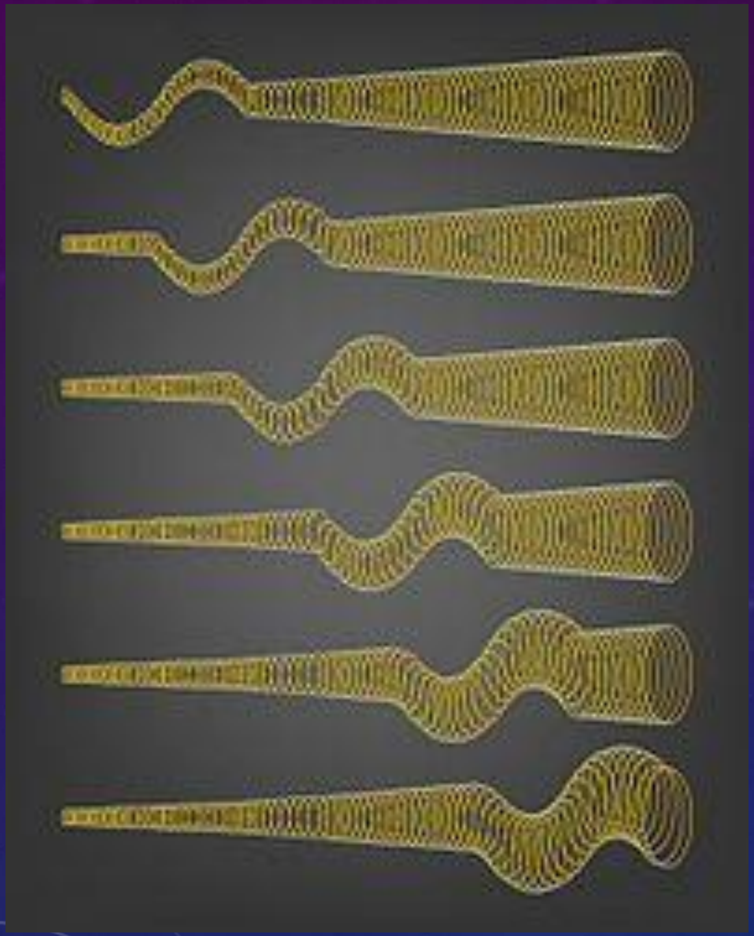
BY CHRIS GILBERT

MOTIVATION: THE CORONA IS UNEXPLAINABLY HOT

- What is the precise mechanism by which the corona is heated?
- Related: How is the solar wind accelerated?
- Two popular ideas:
  - DC: Reconnection (Nanoflares)
  - AC: Alfvén Waves



ALFVÉN WAVES IN THE CORONA

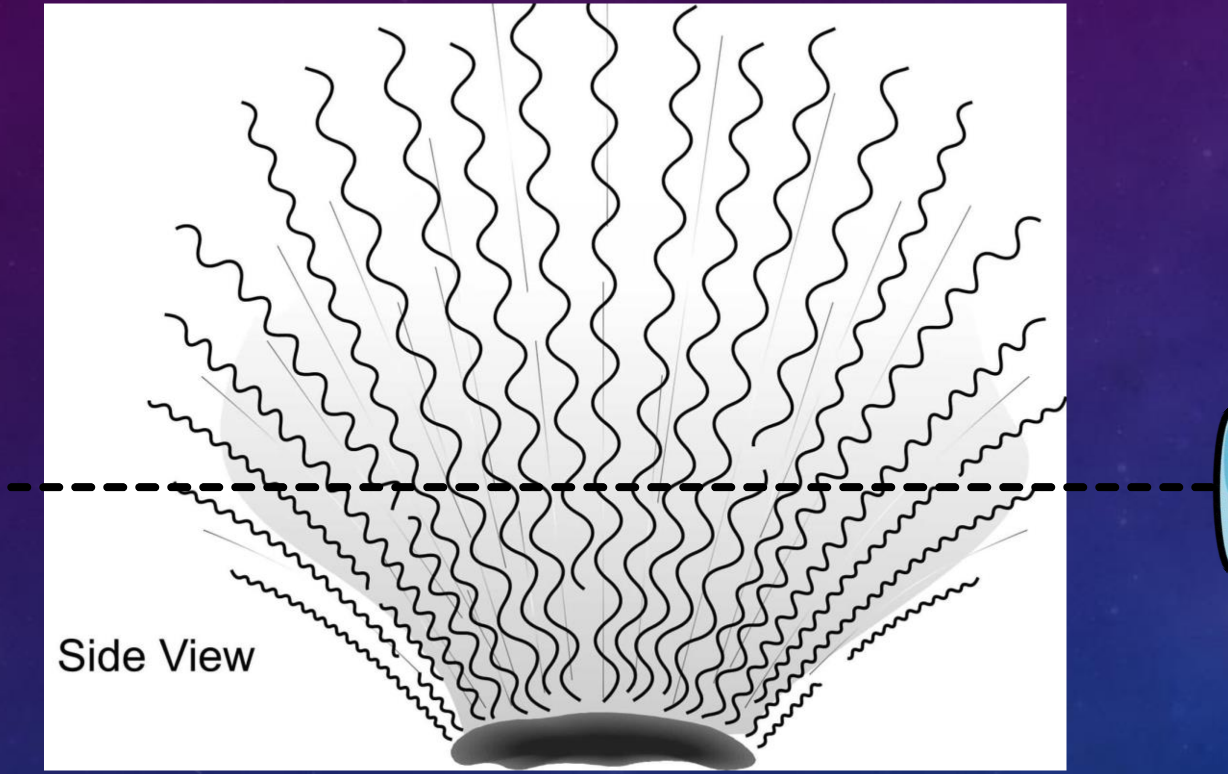


Alfvén waves travel along field lines.

BRAIDS simulation of propagating Alfvén waves

Alfvén waves in open field lines above the Sun’s pole

HOW DO SPECTRA TELL US ABOUT ALFVÉN WAVES?



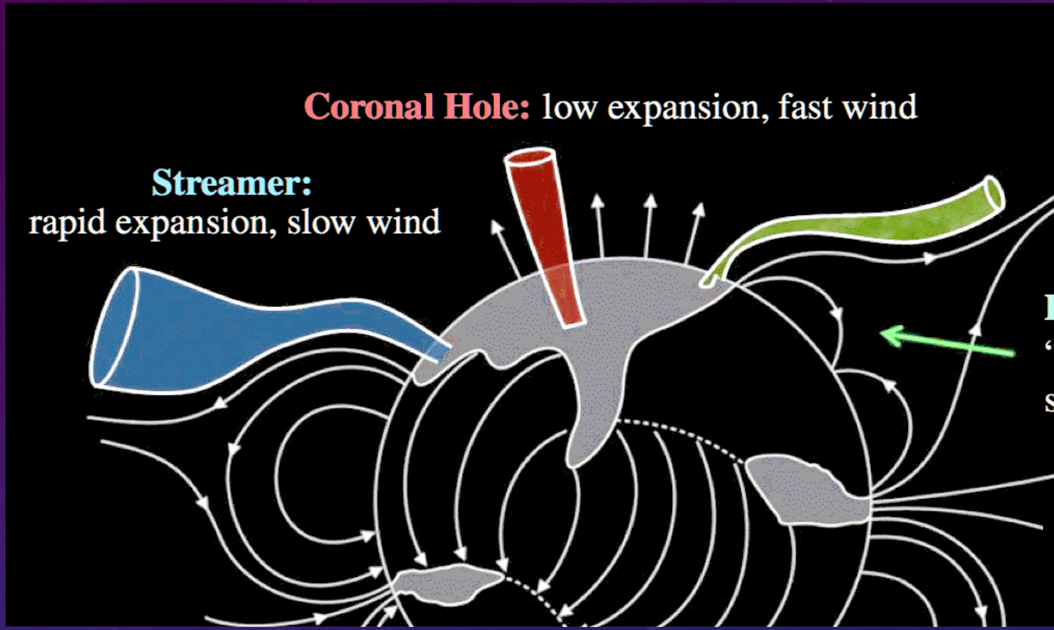
When we make measurements of spectral lines, we are sampling more than one structure in the corona. Each structure will have a Doppler shift due to Alfvén waves.

We measure this with spectrometers like COMP or EIS as a broadening of the spectral line.

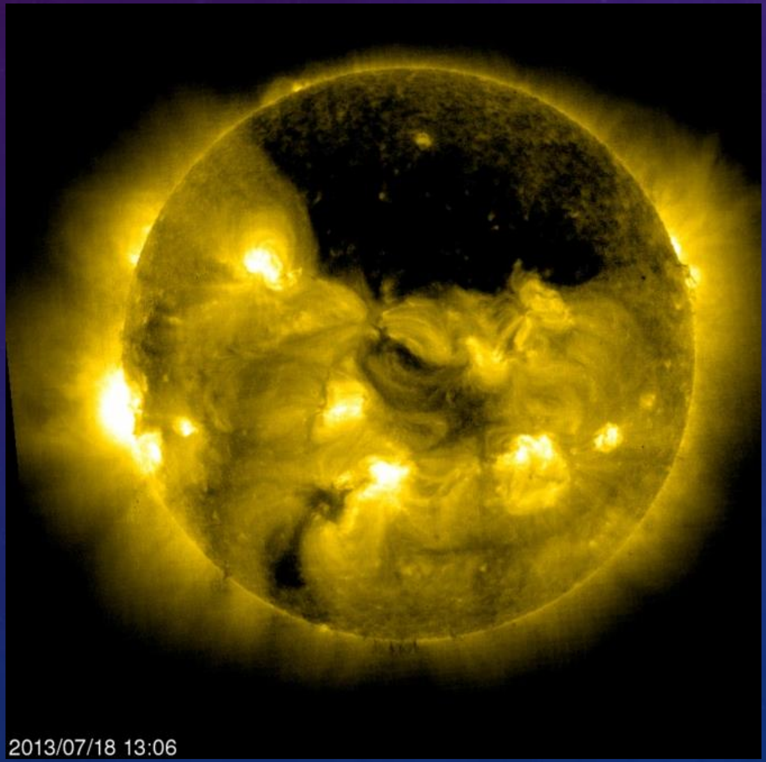
The goal of this research is to simulate these observations using forward modeling to better understand the distribution of Alfvén waves in the corona.

LETS STUDY SOME CORONAL HOLES!

- There are two types of solar wind, fast and slow
  - Slow wind occurs near the equator, and has complex structures, like helmet streamers
  - Fast wind comes from the holes, and is nice and radial

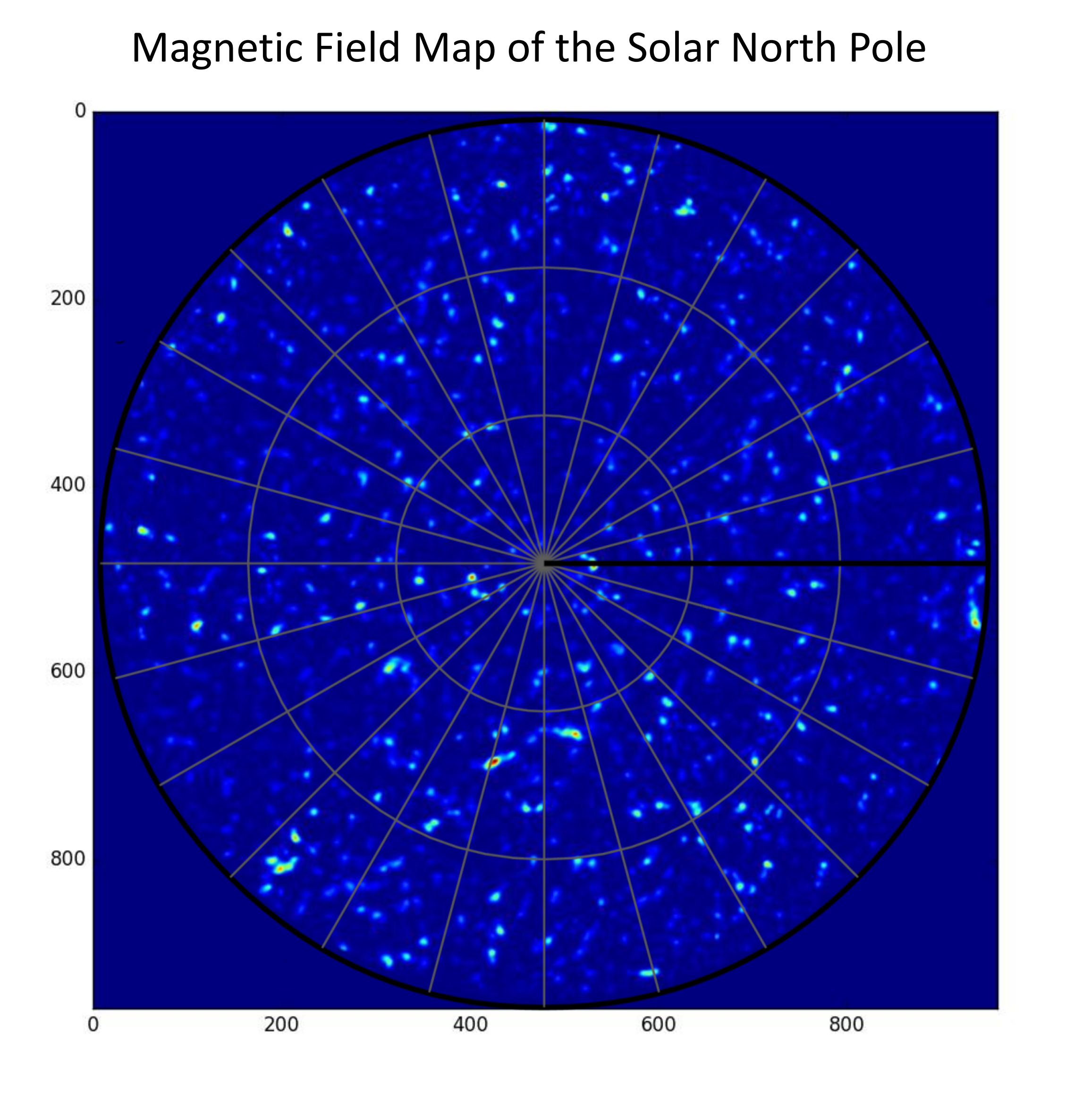


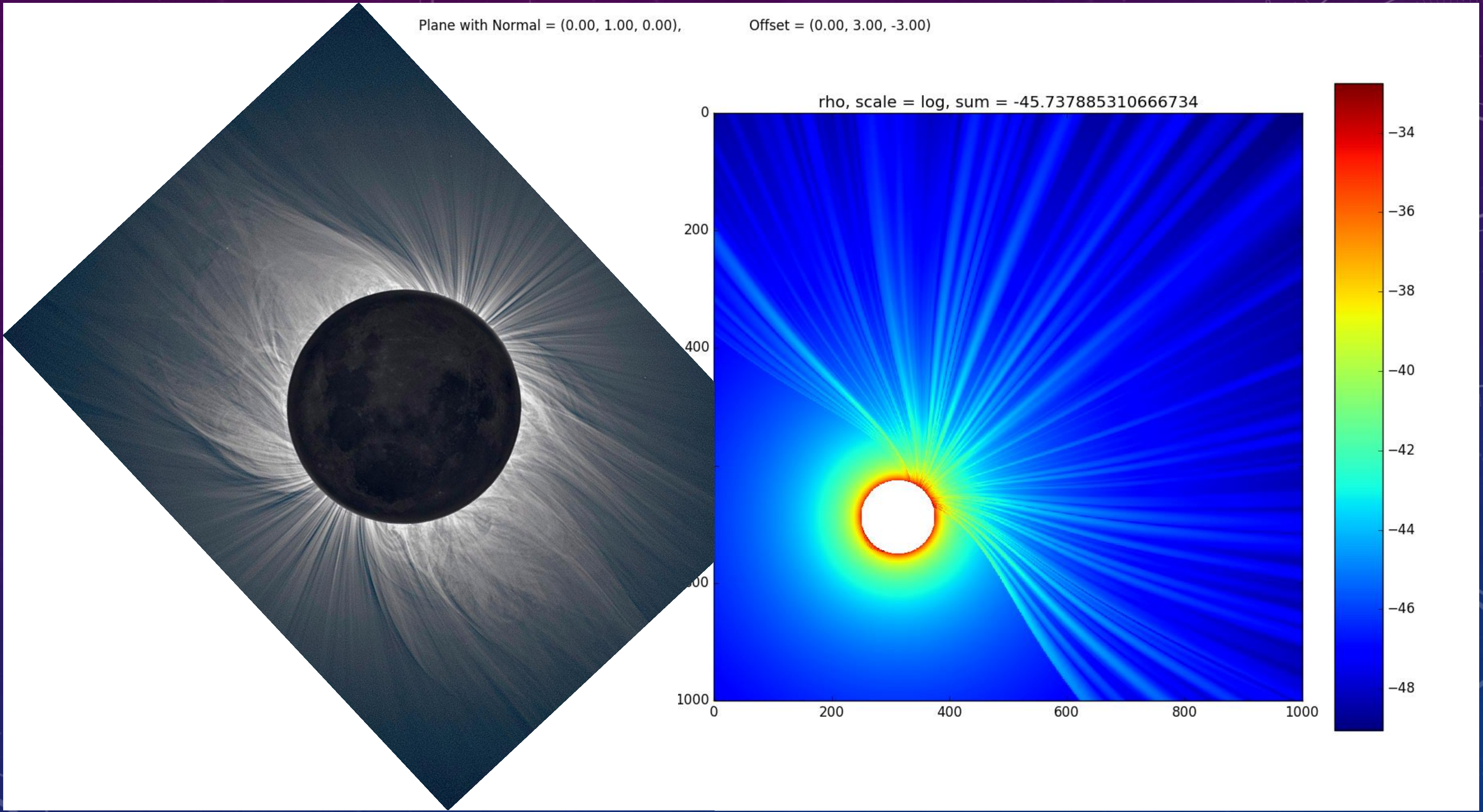
Original image:
J. Luhmann



SIMULATION ENVIRONMENT

- This object contains the properties that define the environment in which spectral lines will be simulated
  - Magnetic Field Map
    - $\rho \propto \left(\frac{B}{B_{thresh}}\right)^{0.5}$
  - Background Plasma Properties: f(r)
    - Density
    - Wind Speed
    - RMS Alfvén Speed
    - Alfvén Profiles
    - Temperature
  - Fundamental Constants
    - Kb, C, etc.

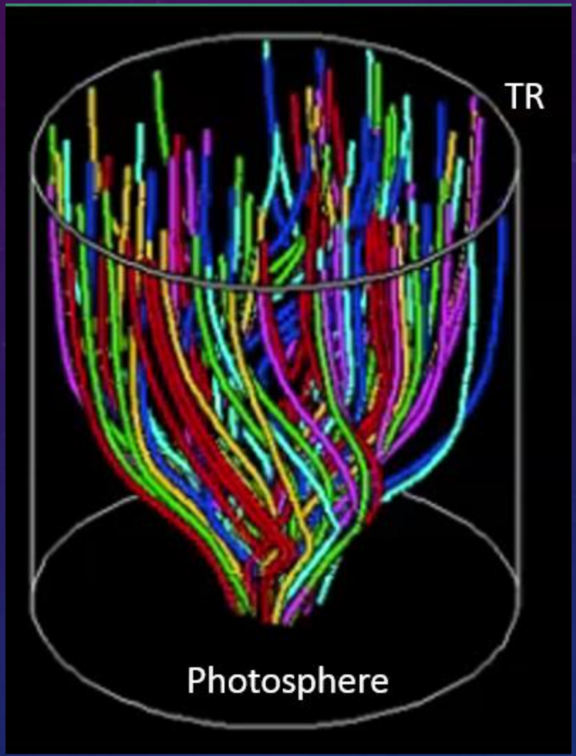


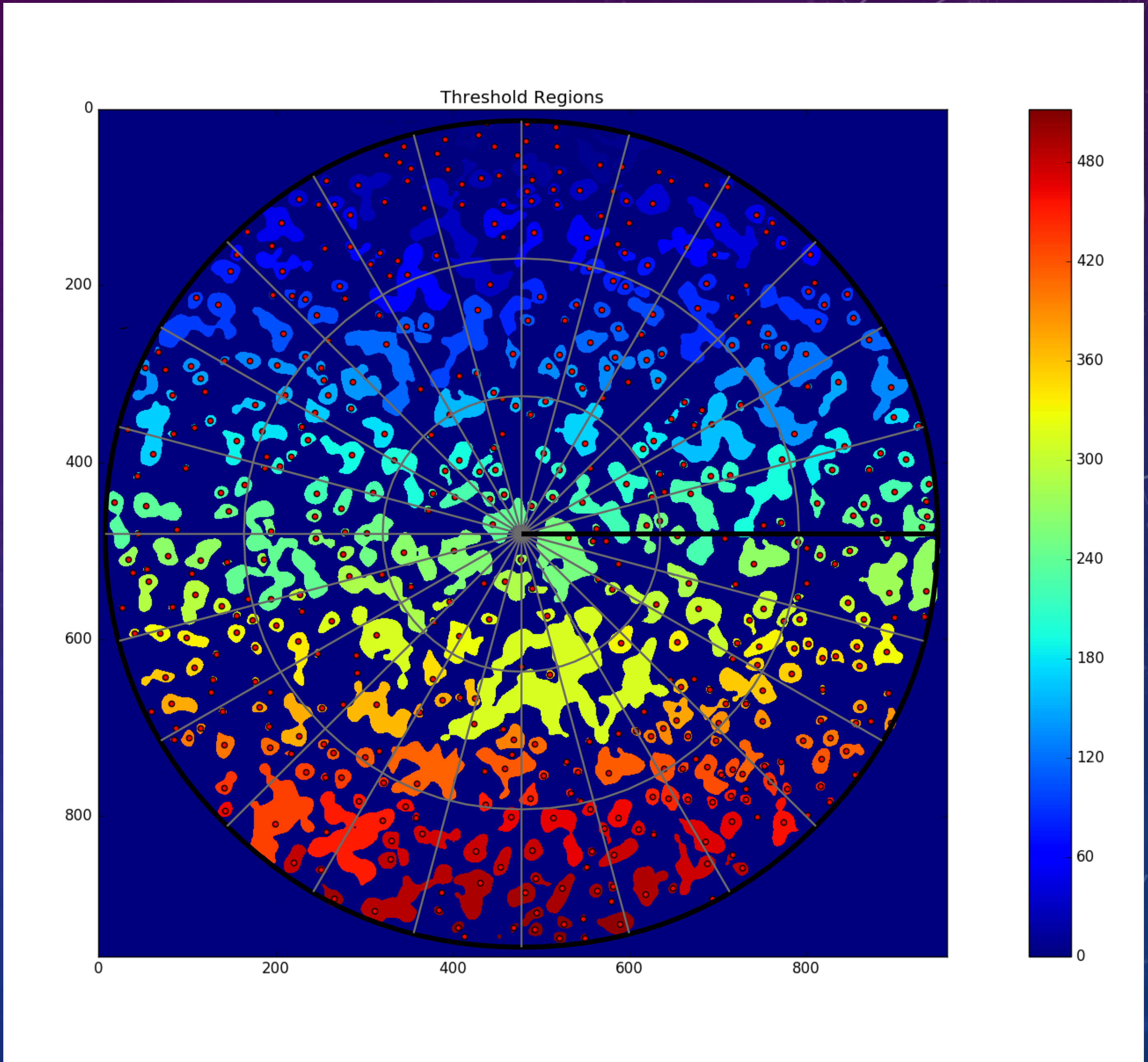


The magnetic field map causes density enhancements that look like the real solar coronal holes!

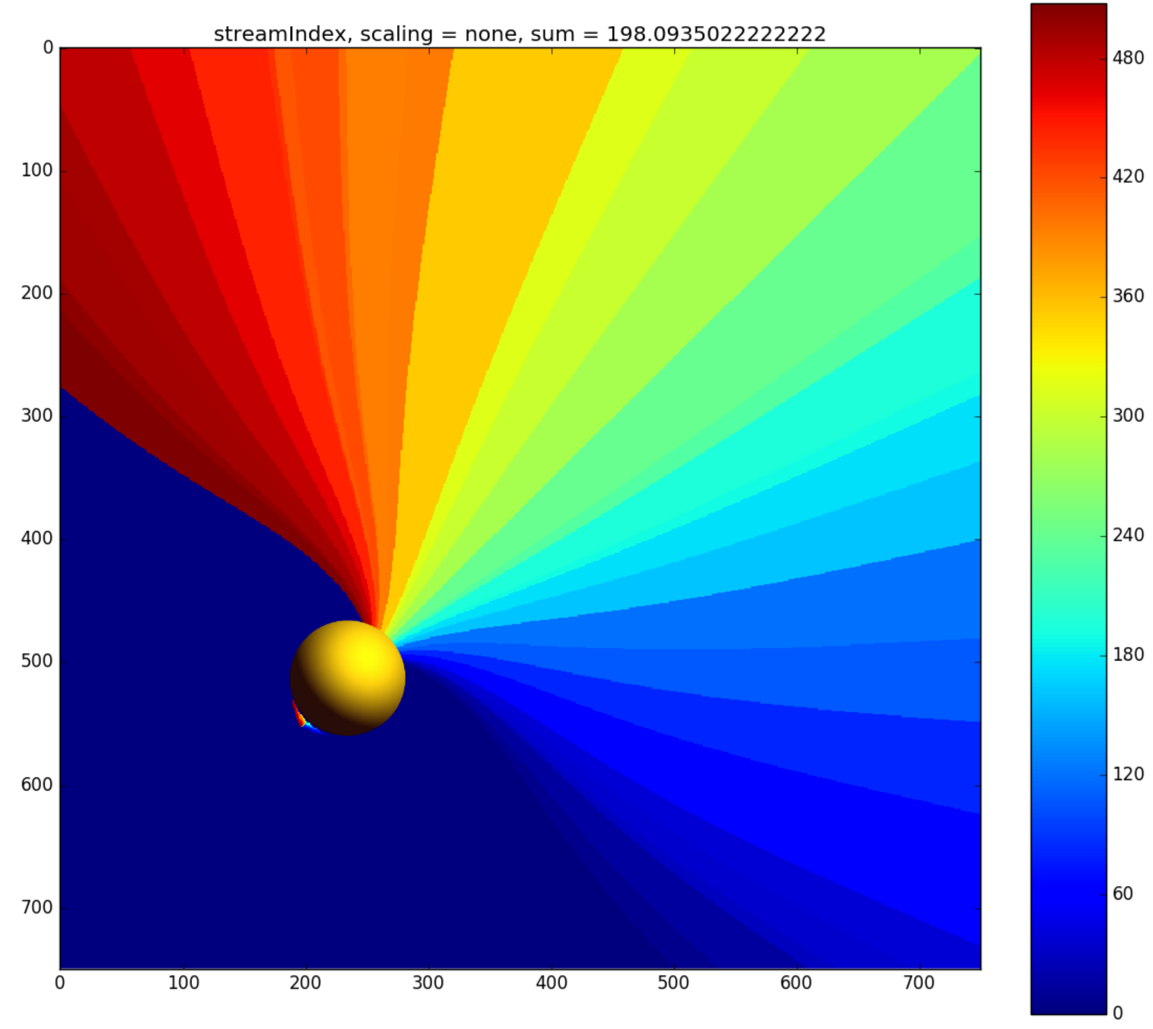
PROCESSING THE BMAP

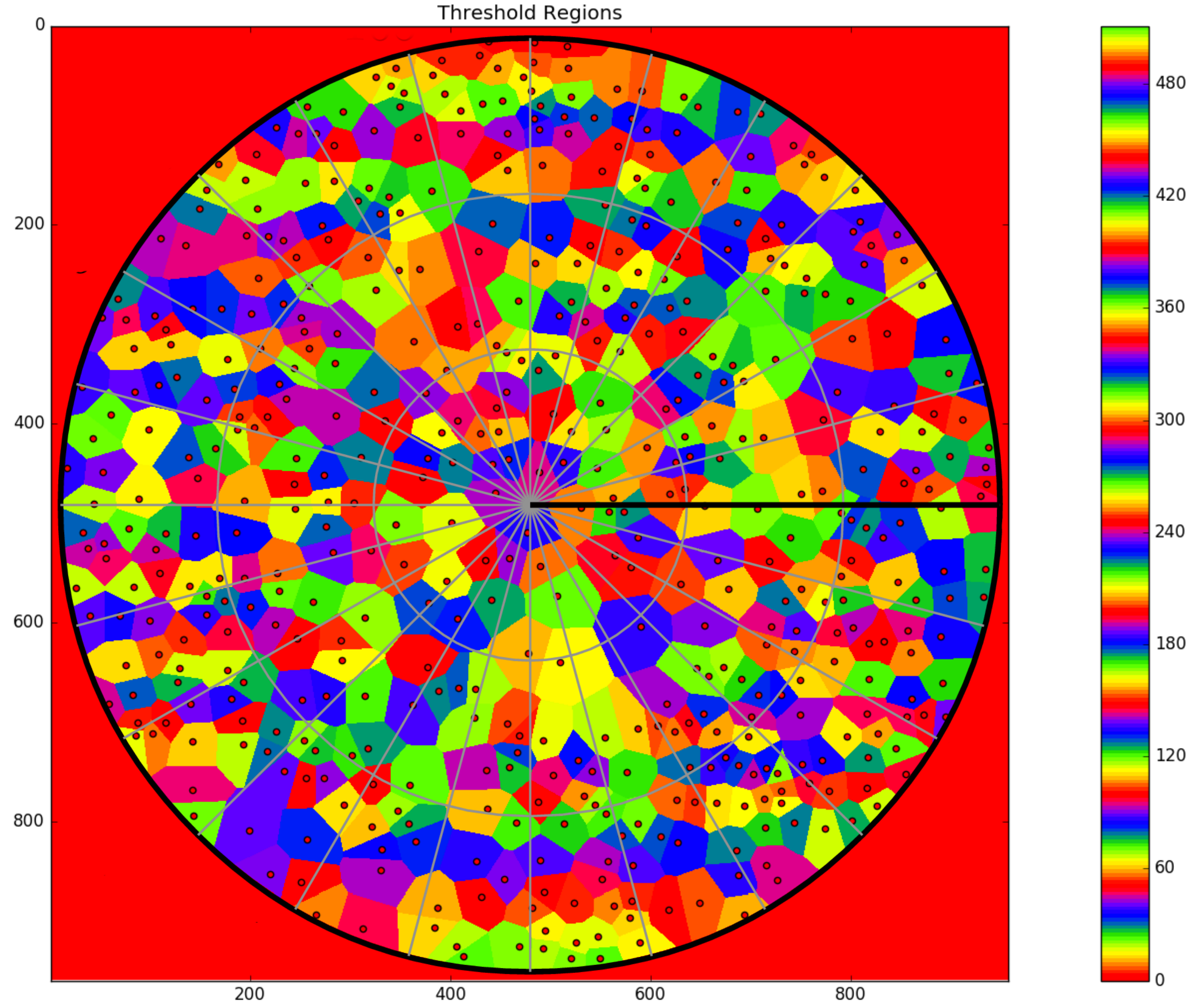
We want many different sources of waves (supergranuale scale)





The streams are indexed to group coherent regions into a single wave source.





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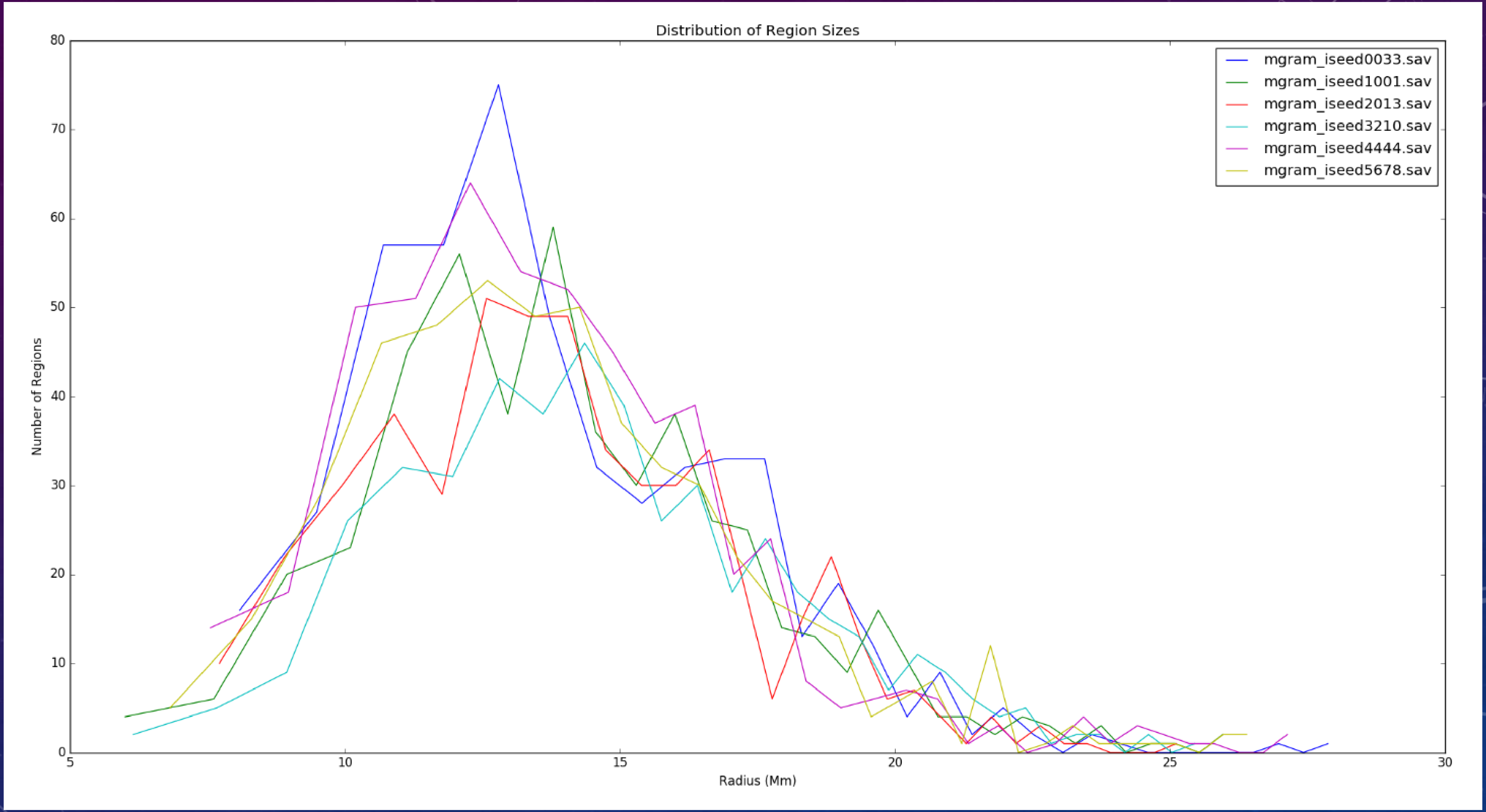
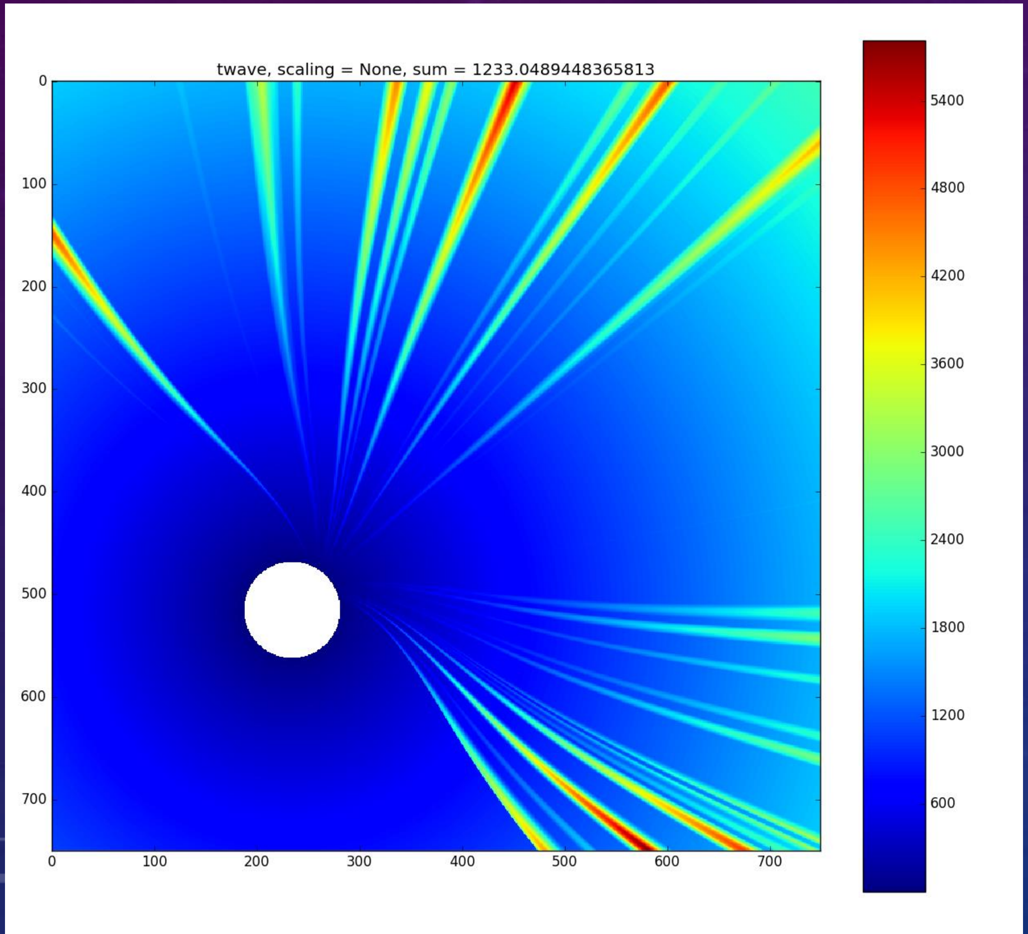


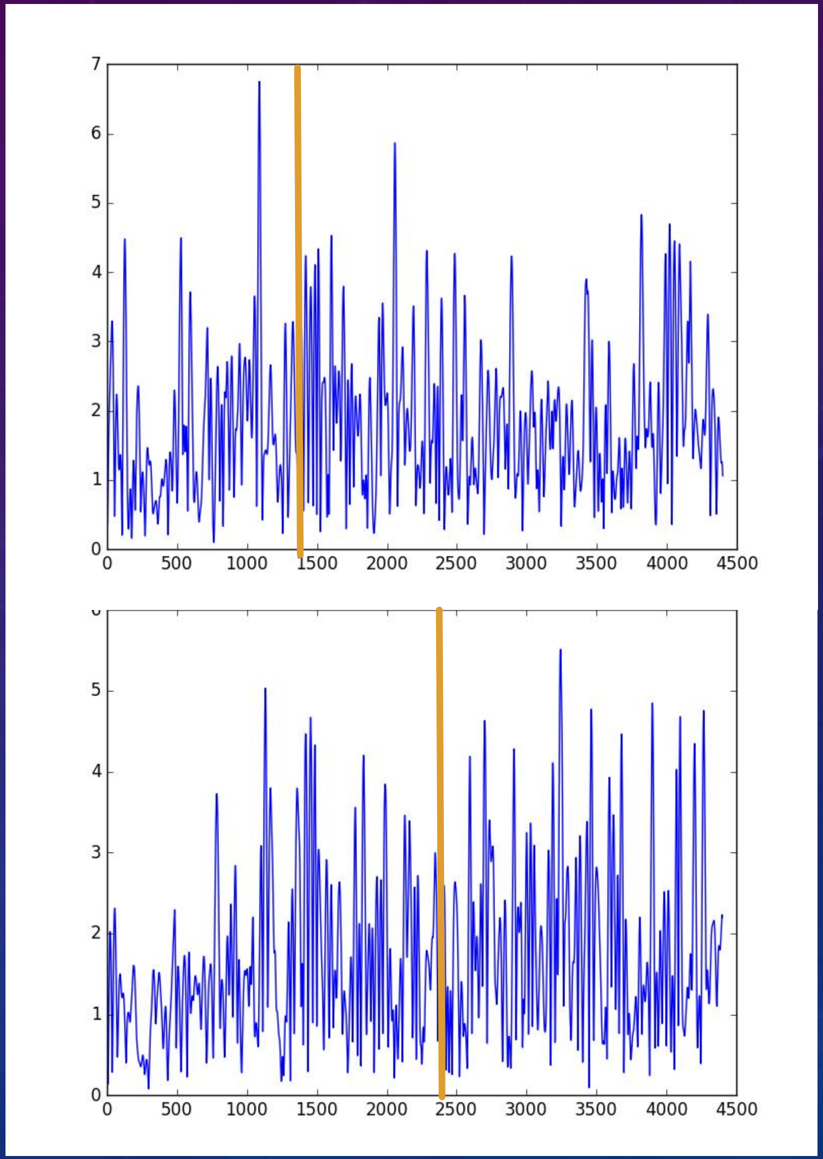
The sizes of the coherent regions are tuned to match supergranule cell sizes on the Sun.

ALFVÉN WAVES AND TURBULENCE

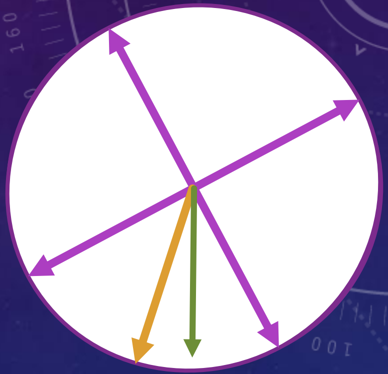
Wave travel time



Wave Profiles

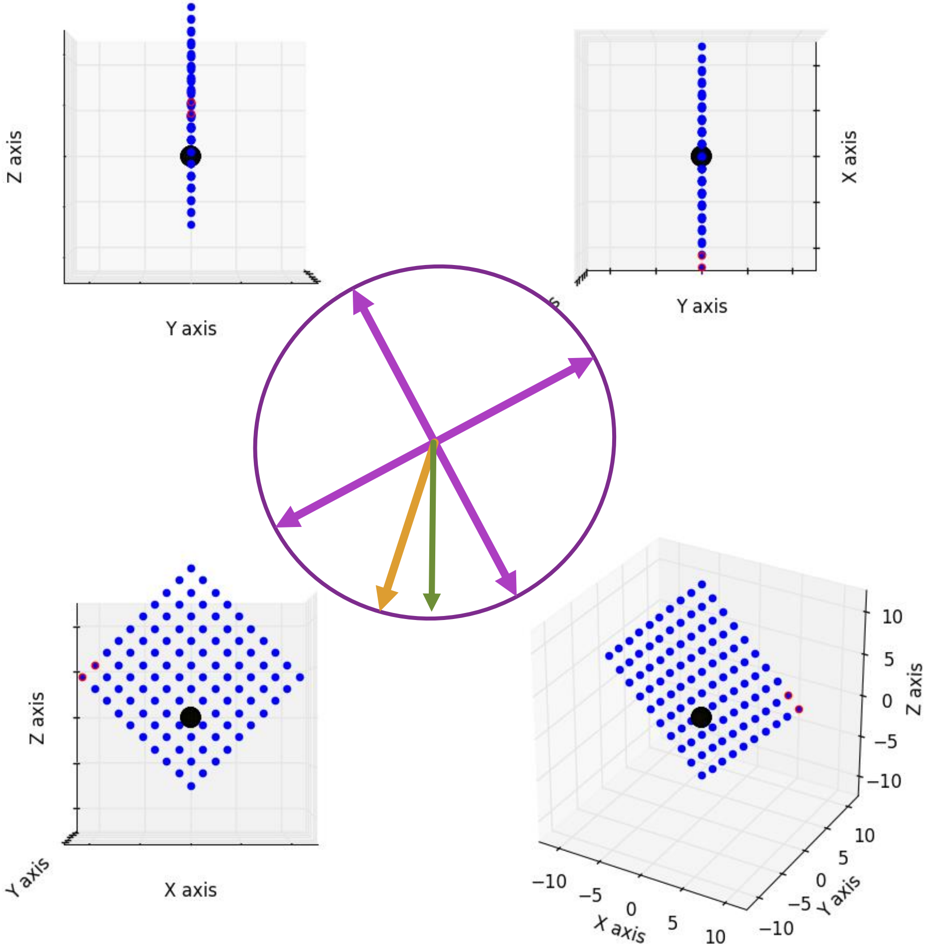


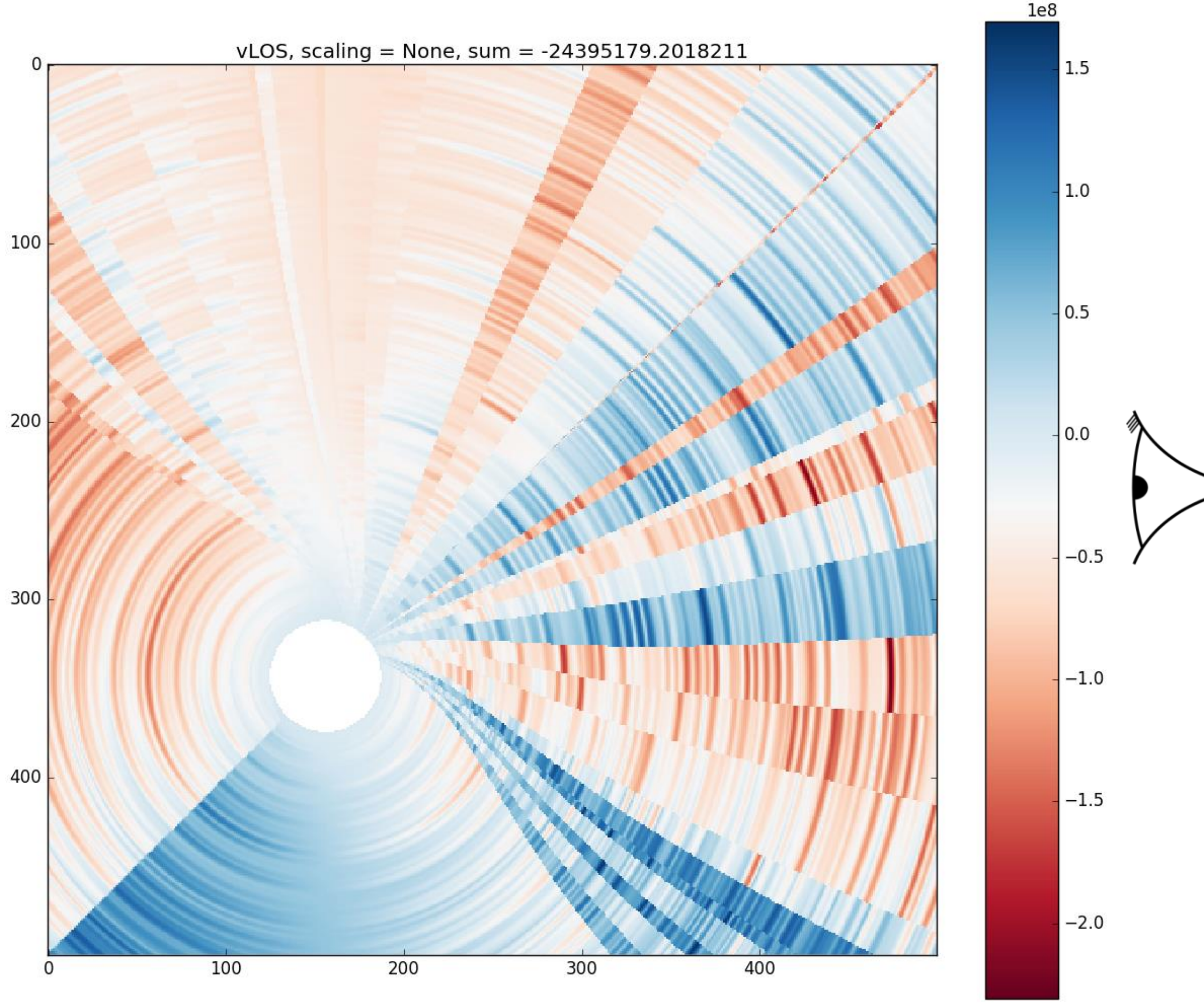
Cross-section of a single streamer



Alfvén wave profiles are generated by the BRAIDS code and imported to my simulation

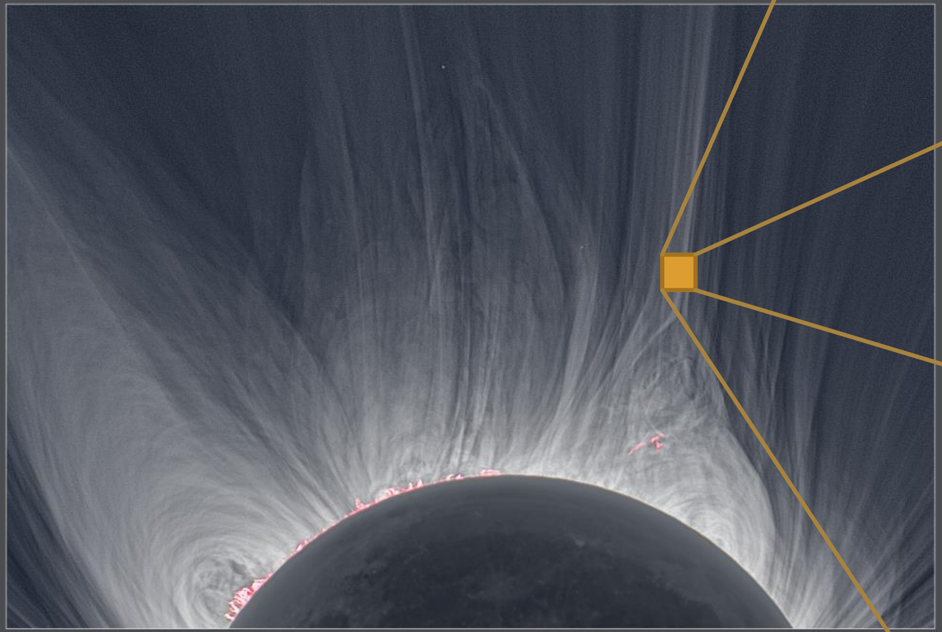
Plane with Normal = (0.00, 1.00, 0.00), Offset = (0.00, 3.00, -3.00)





LEVEL 0: SIMPOINT

Every point in the simulation is an object, which has the all of these properties.



C:\Windows\system32\cmd.exe

```
CoronaSim!
Written by Chris Gilbert
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Simpoint Properties
T  :  1310737.60627
alfAngle  :  4.57865702357
alfT1  :  3457.94710927
alfT2  :  3659.89747228
alfU1  :  13811943.0702
alfU2  :  26507005.3113
cPos  :  [0.1, 0.1, 1.5]
cU  :  [-5663120.2818389349, -5663120.2818389349, 9327469.3867232278]
deltaLam  :  0.0131763193129
densfac  :  1
env  :  <coronasim.environment object at 0x000000006B75208>
f  :  2.46597992741
findT  :  True
footB  :  2.47998936927
foot_cPos  :  [0.042071133845158301, 0.042071133845158301, 1.0082460212636426]
foot_pPos  :  [1.01, 0.058942607346144732, 0.78539816339744828]
grid  :  <gridgen.plane object at 0x0000000006388390>
intensity  :  2.6274647402e-13
lam  :  200
lam0  :  200
lamLos  :  -0.0707134596973
lamPhi  :  1.32823263089e-11
nGrad  :  [ 0.70710678  0.          -0.70710678]
pPos  :  [1.5066519173319364, 0.094003033807577033, 0.78539816339744828]
pU  :  [7745042.880189077, -17222896.031280585, 24428732.145663504]
qt  :  1
rho  :  4.44765790341e-18
rx  :  1.50665191733
streamIndex  :  916
twave  :  162.737715173
twave_fit  :  136.991254914
twave_rat  :  1.18794236374
uPhi  :  24428732.1457
uTheta  :  -17222896.0313
ur  :  7745042.88019
ux  :  -5663120.28184
uy  :  -5663120.28184
uz  :  9327469.38672
vAlf  :  288802488.557
vLOS  :  -10599947.6086
vPh  :  296547531.438
vRms  :  9609079.52005
```
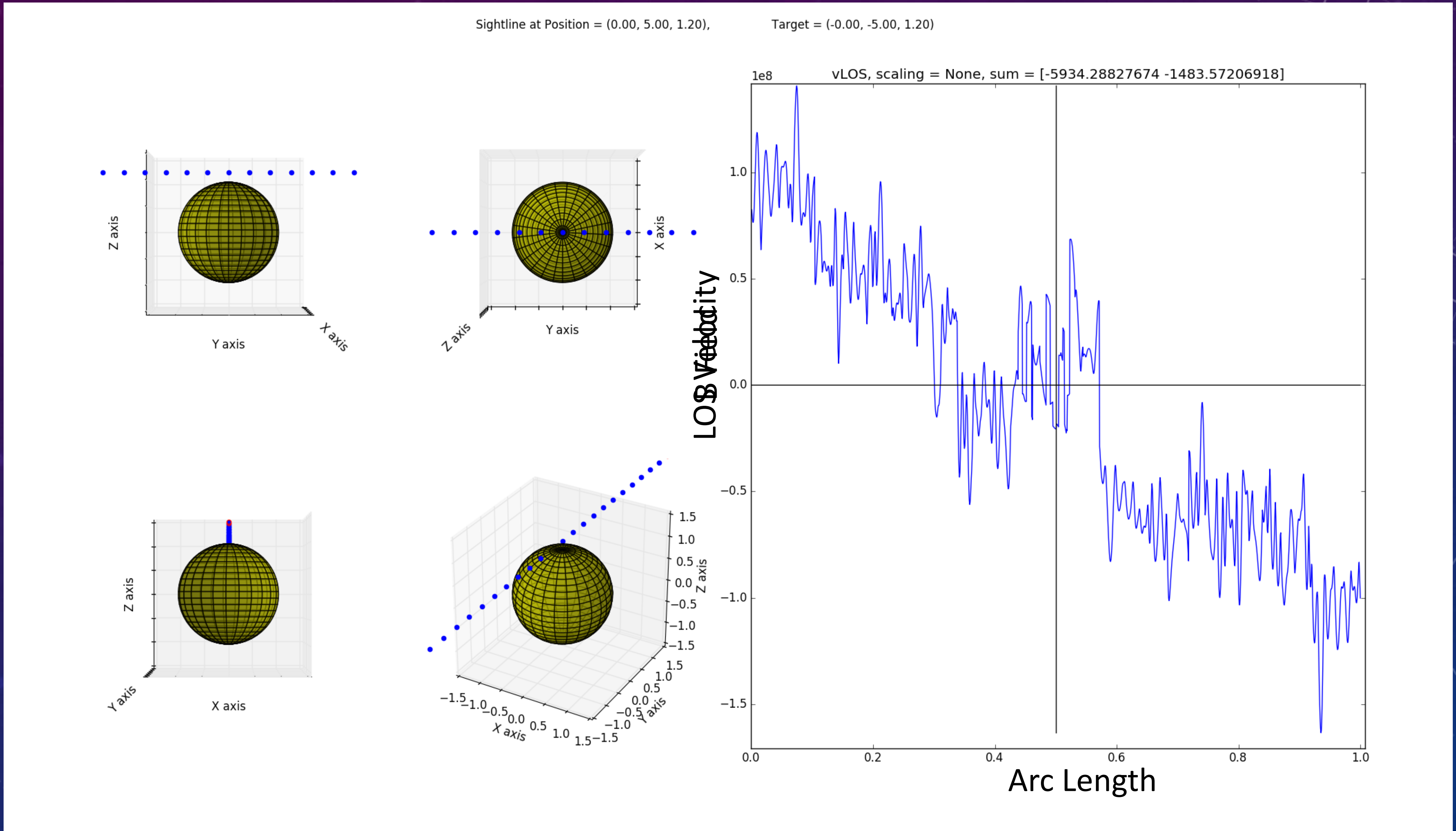
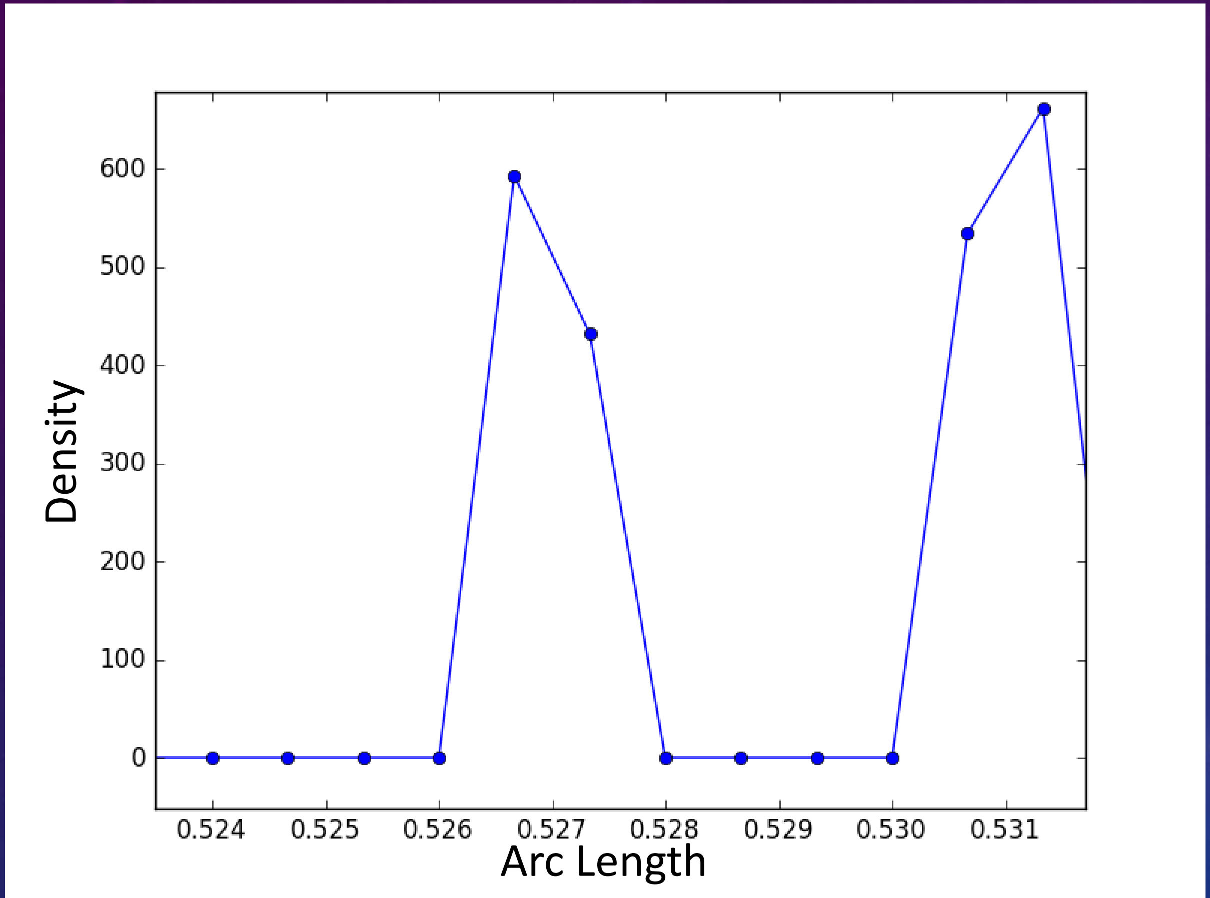
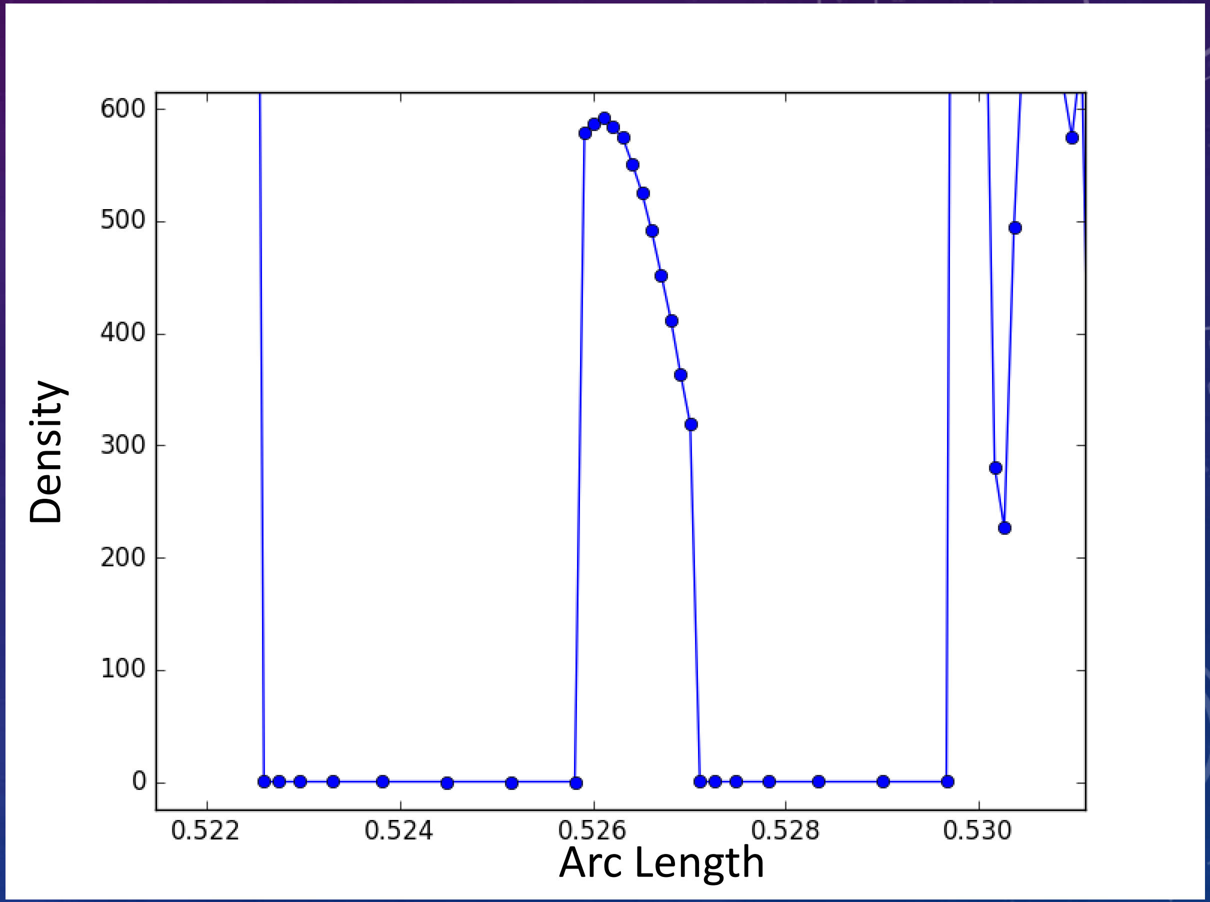

LEVEL 1: SIMULATION OF A SINGLE SIGHTLINE



Plasma properties are simulated along a line-of-sight. This can then be used to generate a spectral line.

ADAPTIVE MESH!





The program adapts the step size to investigate regions of higher density. This drastically reduces the computation time required.

INTENSITY AS FUNCTION OF WAVELENGTH

Emission Intensity

$$I(\lambda) = \rho^2 \ * \Phi(\lambda)$$

Line Profile Function

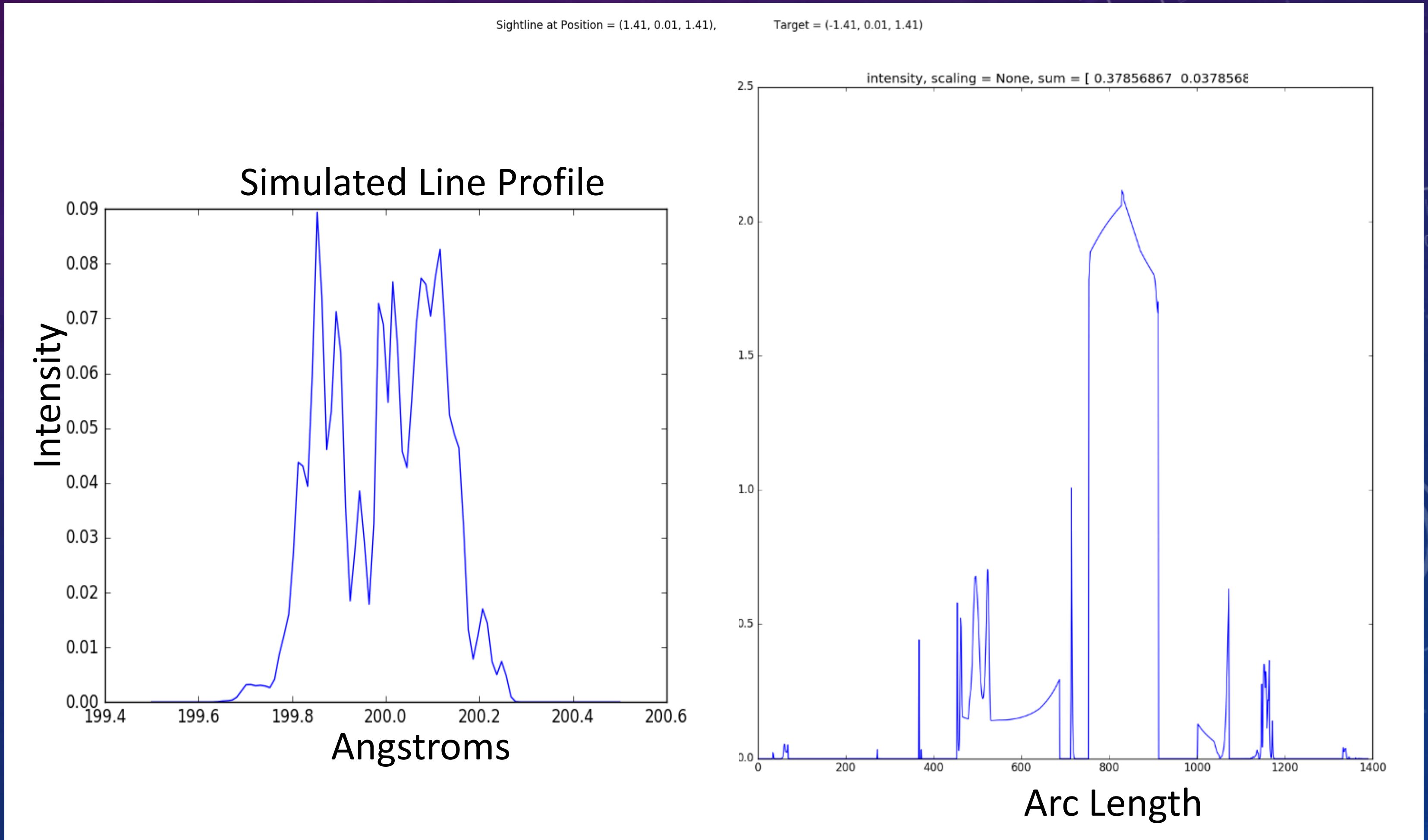
$$\Phi(\lambda) = \frac{1}{\Delta\lambda\sqrt{\pi}} e^{-\left(\frac{\lambda - \lambda_0 - \lambda_{LOS}}{\Delta\lambda}\right)^2}$$

Thermal Width

$$\Delta\lambda = \frac{\lambda_0}{c}\sqrt{\frac{2k_bT}{m_i}}$$

Doppler Shift

$$\lambda_{LOS} = \frac{v_{LOS}}{c}\lambda_0$$



LEVEL 2: MULTISIM

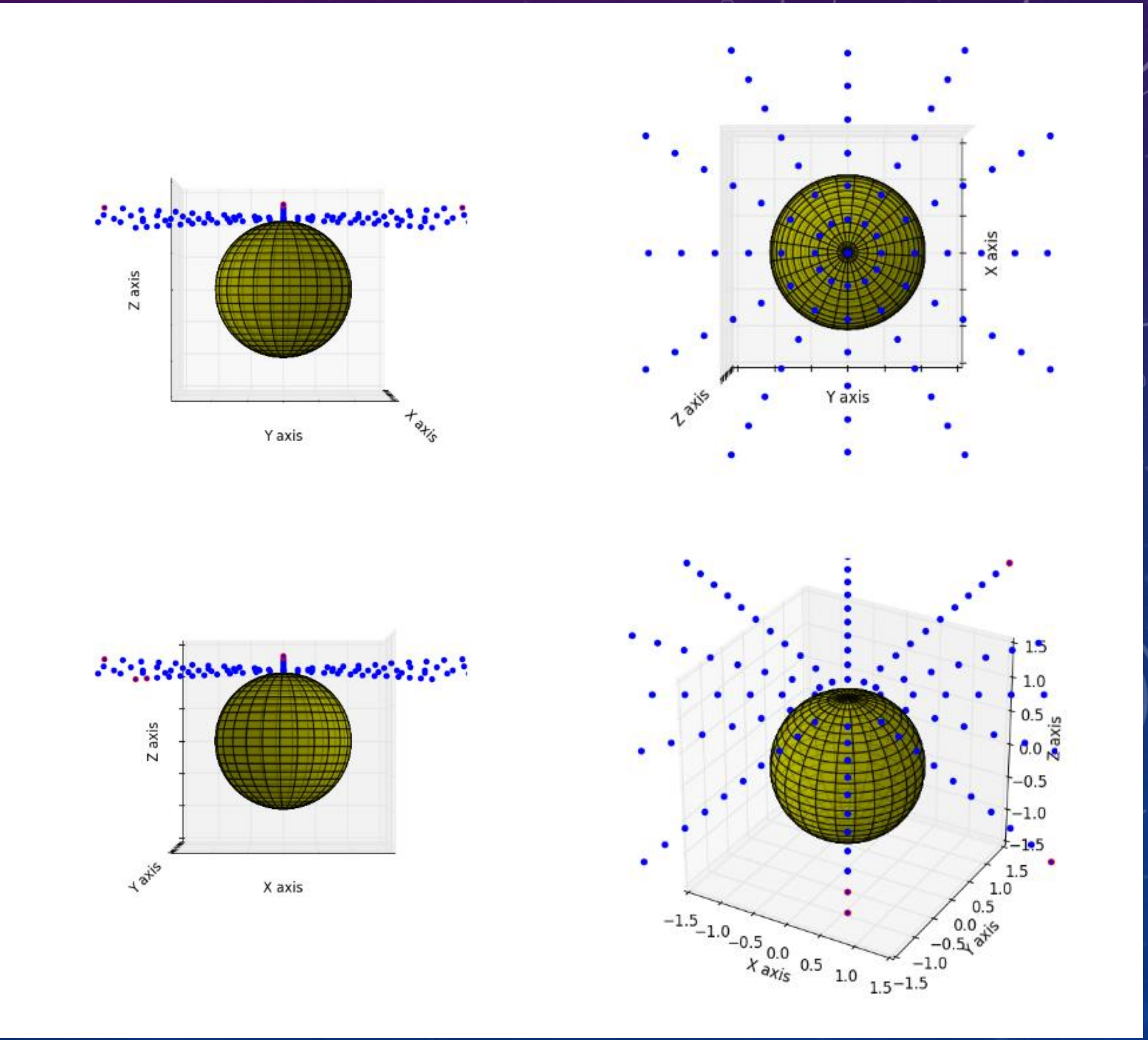
Generate many sightlines at a given impact parameter, in order to get statistics on spectral line properties.

Each line is simulated at a random time.

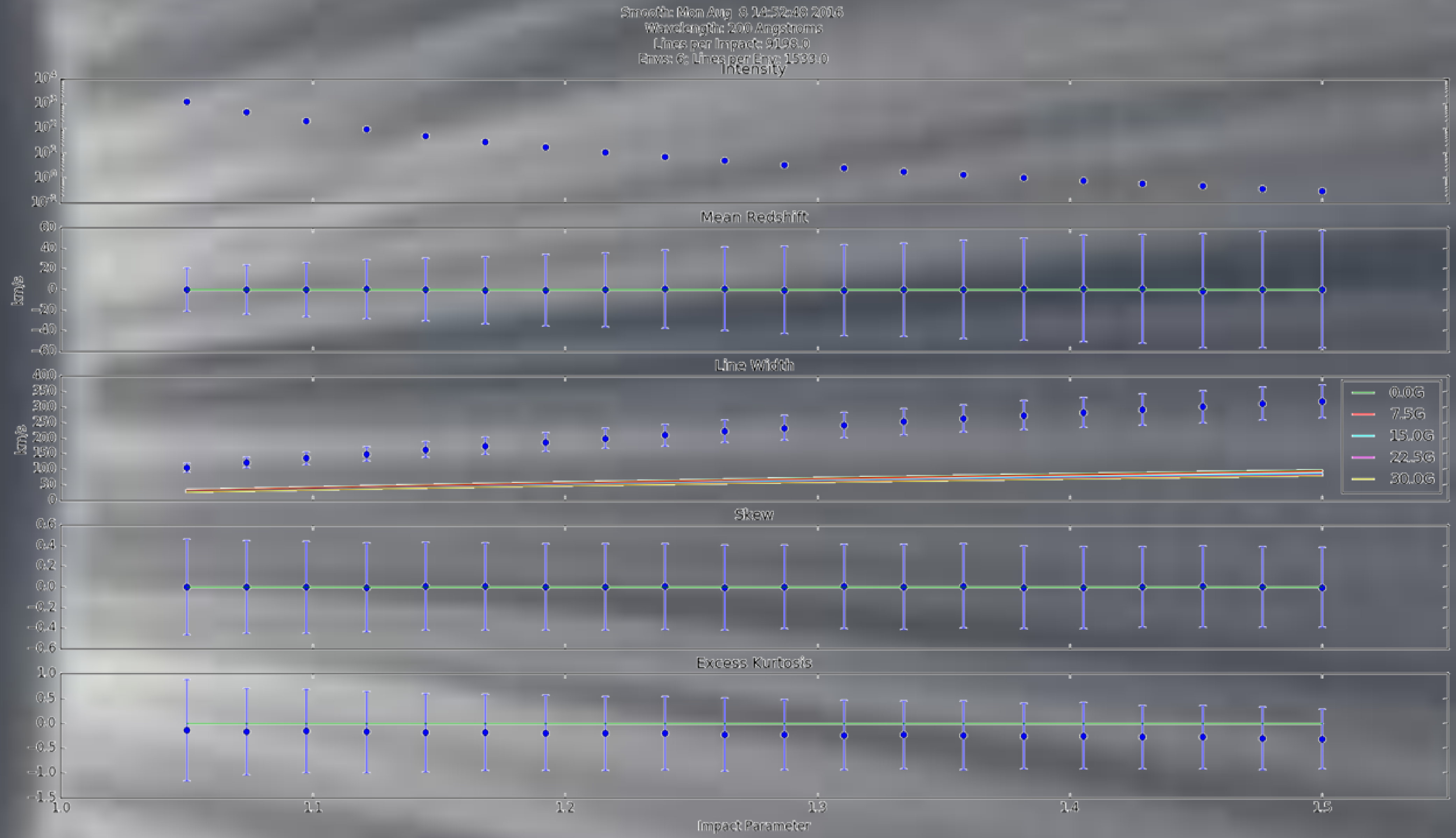
A typical run generates about 10,000 spectral lines, using 6 different magnetic field maps.

Lines are analyzed for

- Total Intensity
- Mean Doppler Shift
- Line Width
- Skewness
- Kurtosis



LEVEL 3: LINE STATISTICS AS A FUNCTION OF IMPACT PARAMETER



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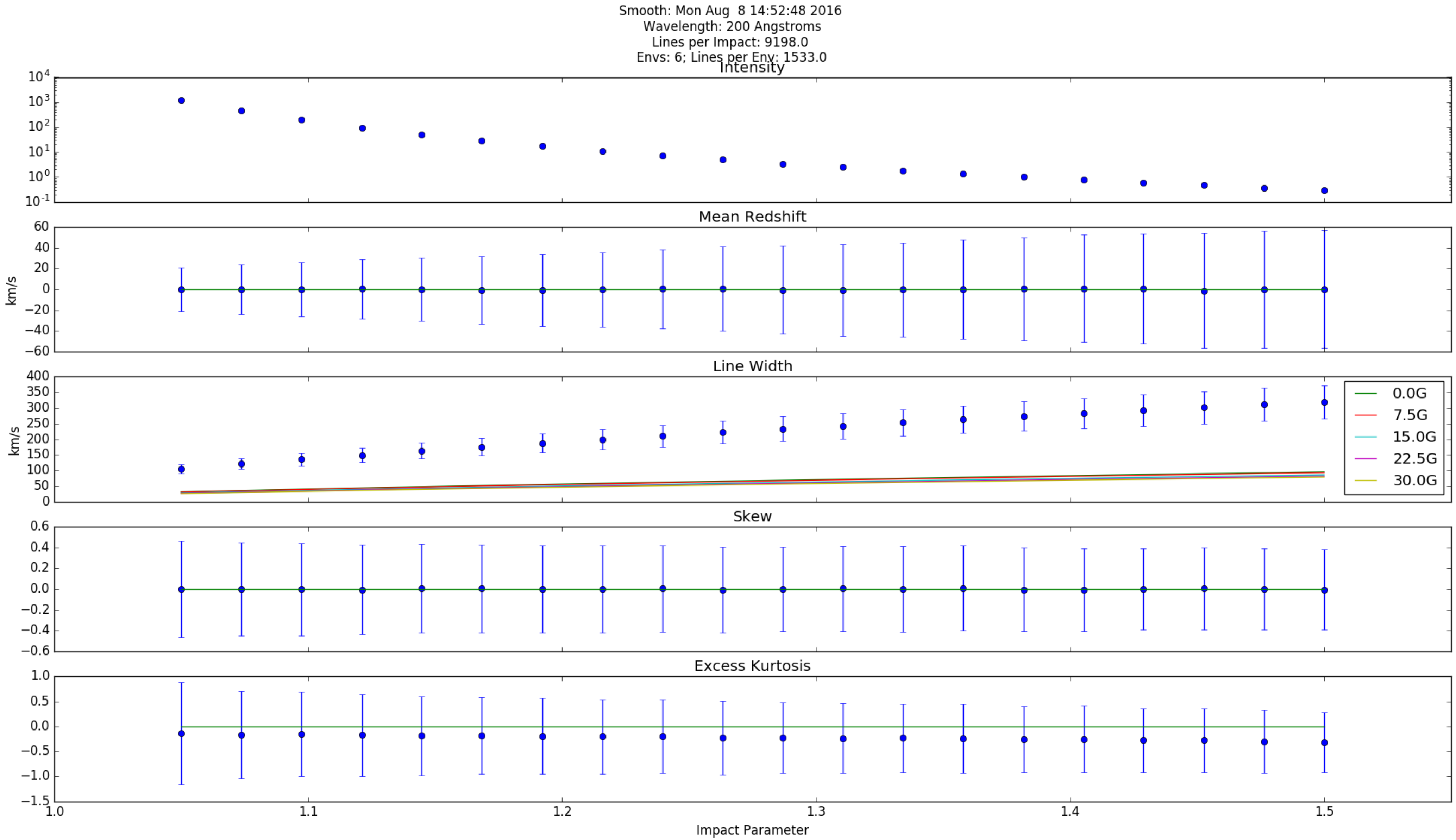
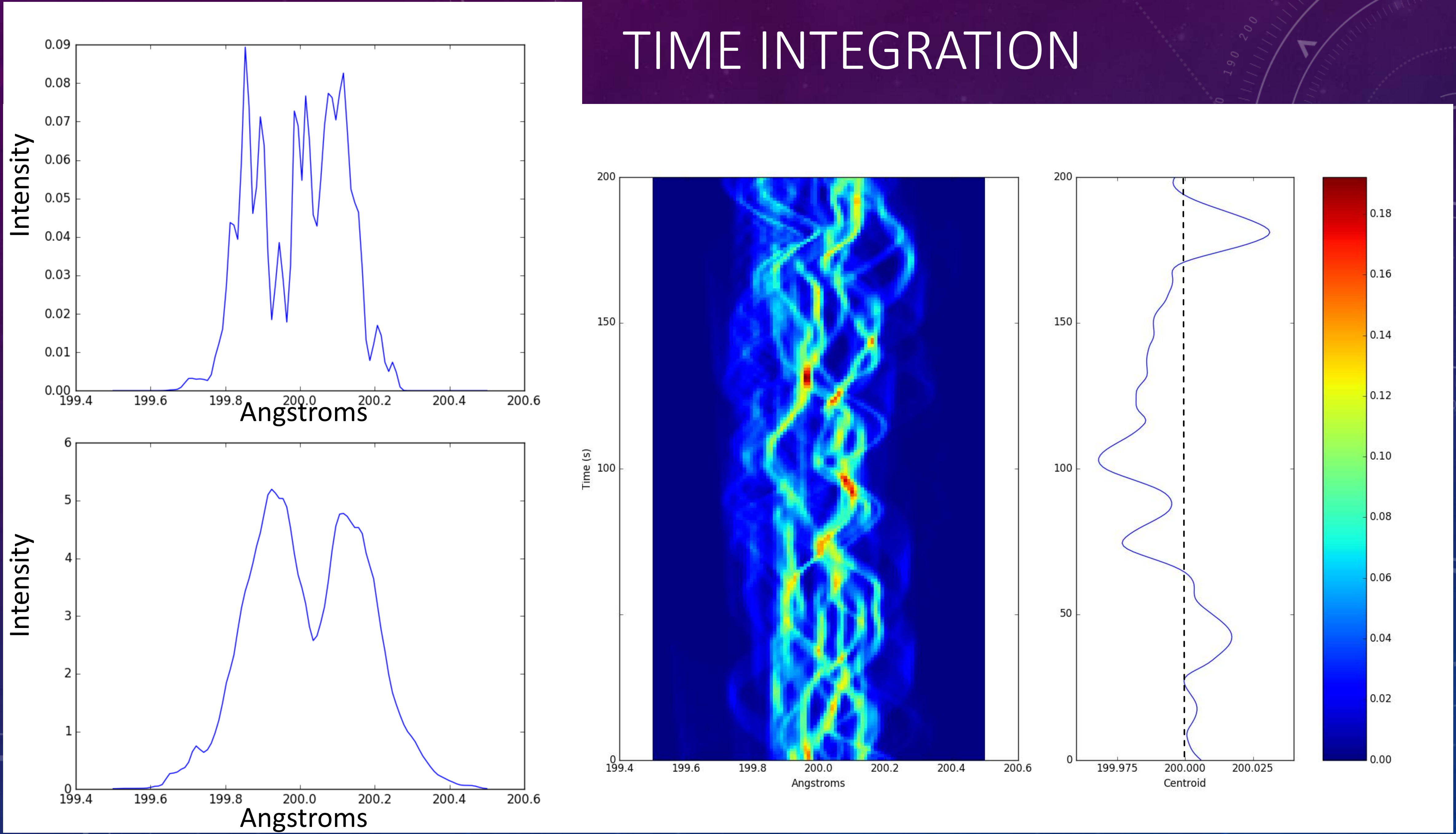


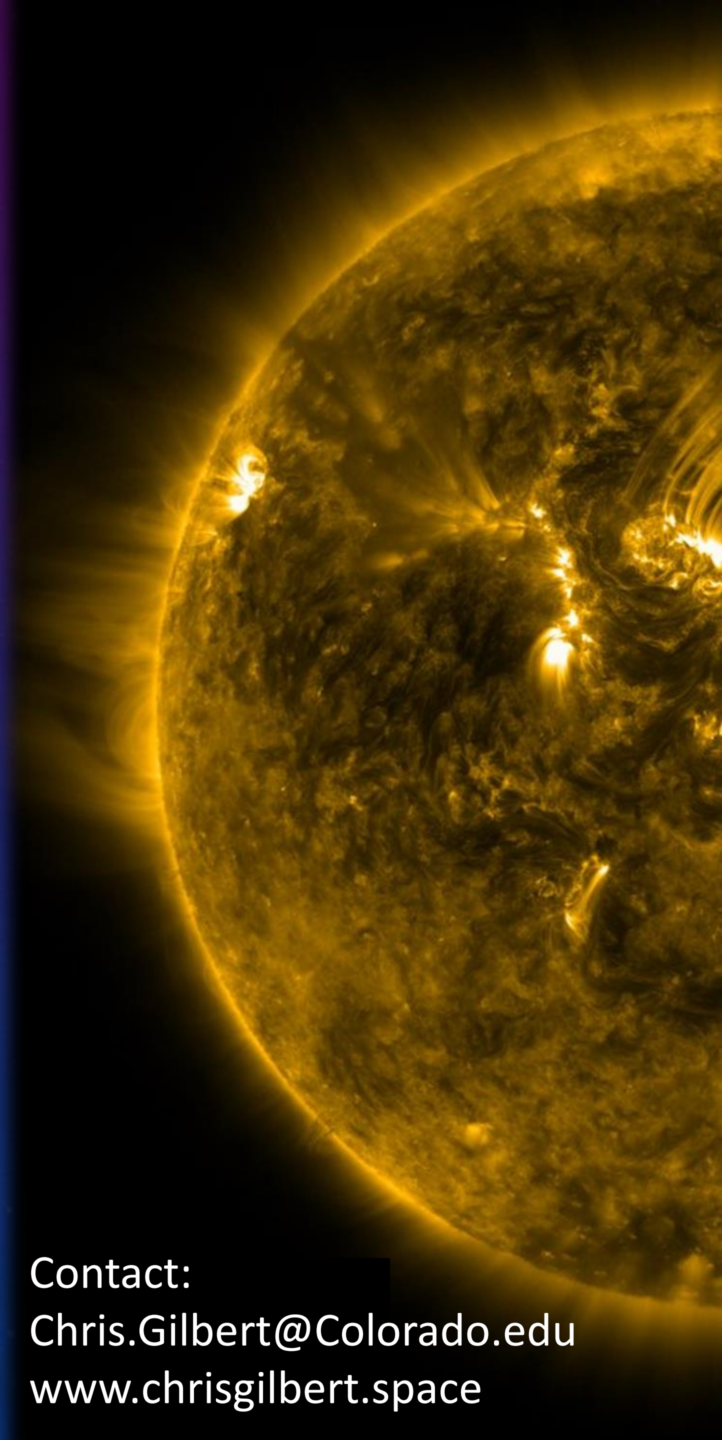
TIME INTEGRATION



LOOKING FORWARD

- The simulation works, now we just need to make it match the observations.
  - Vary the model parameters and continue refining the physics until it matches observations from instruments like EIS, COMP
  - Learn to invert the observations to find V_{RMS}
- Parameter study of cell size
  - Test the hypothesis that the residual redshift observed decreases as $\frac{1}{\sqrt{N}}$

QUESTIONS?



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