TRACKING MOVEMENT OF CORONAL HOLES USING MCINTOSH ARCHIVE DATA

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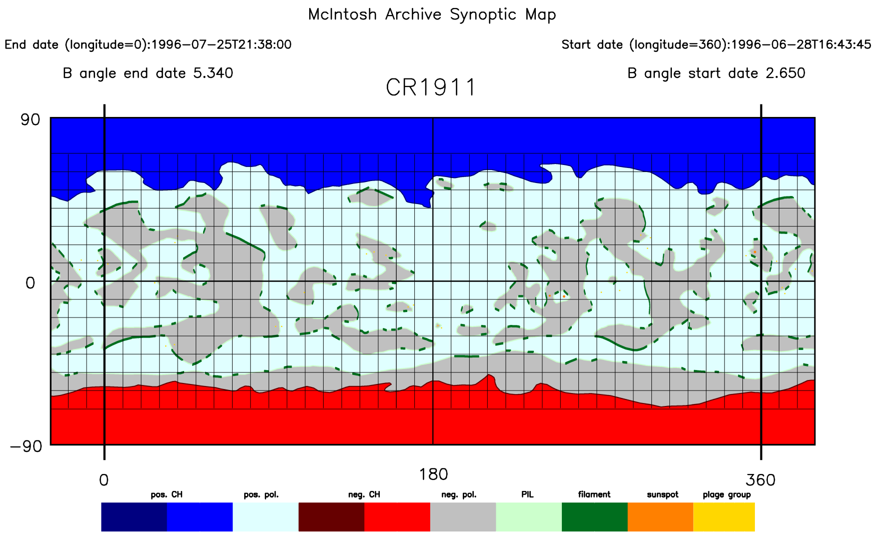
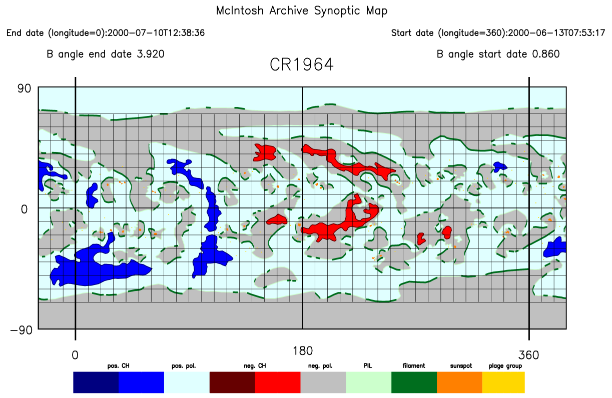
Why Tracking Solar Features are Important

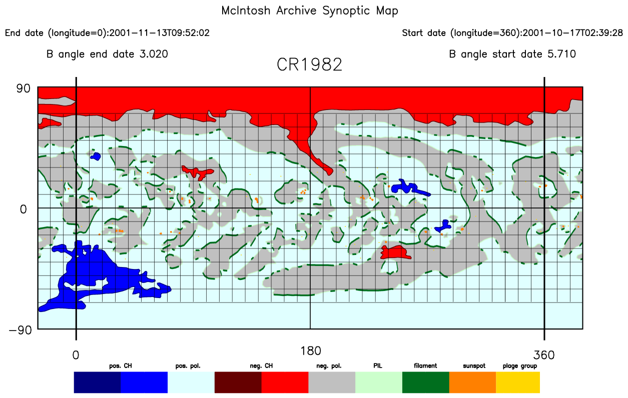
- Tracking solar features will help us better understand how the suns magnetic field works.
- Finding the rotation rates of these features, will help us make deductions of phenomena in the suns interior.
- This will help us learn more about solar weather and possibly help us make better predictions.
- This could help us prepare for potentially dangerous solar storms and help keep our planet safe.

Mapping Suns Magnetic Features

- In 1964, Patrick Mcintosh, a former scientists at NOAA's Space Science Center, started creating hand-drawn maps of the sun's magnetic features.
- Over the course of his life, he made over 45 years (about 4 solar cycles) worth of maps.
- This data gave us a unique record solar activity and the evolution of the suns magnetic field.
- Recently he passed away, and his life's work was in danger of being lost.
- Thankfully, NOAA and NCAR, under the funding of the NSF, have made it their goal to digitalize all these in the McIntosh Archives.

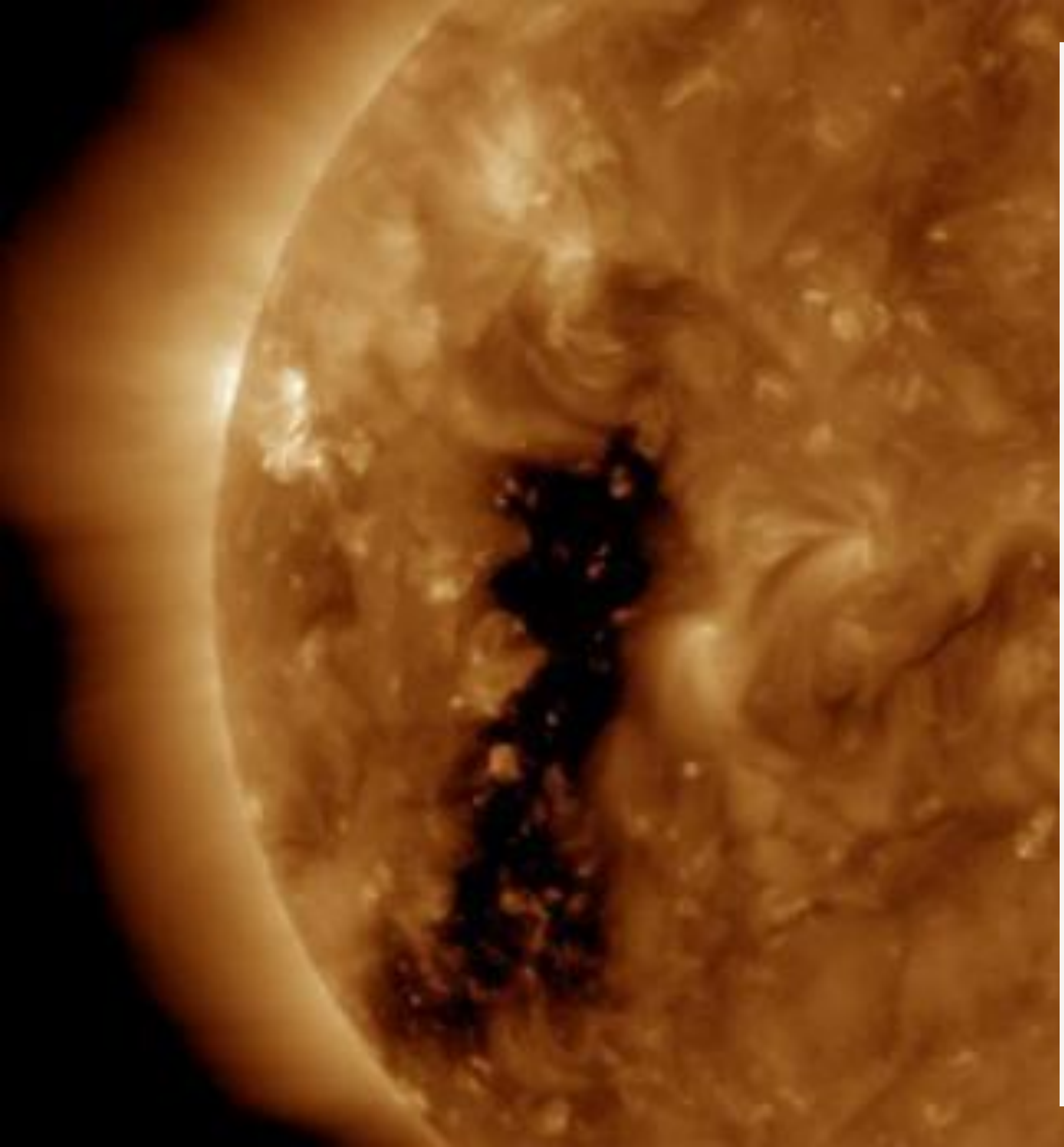






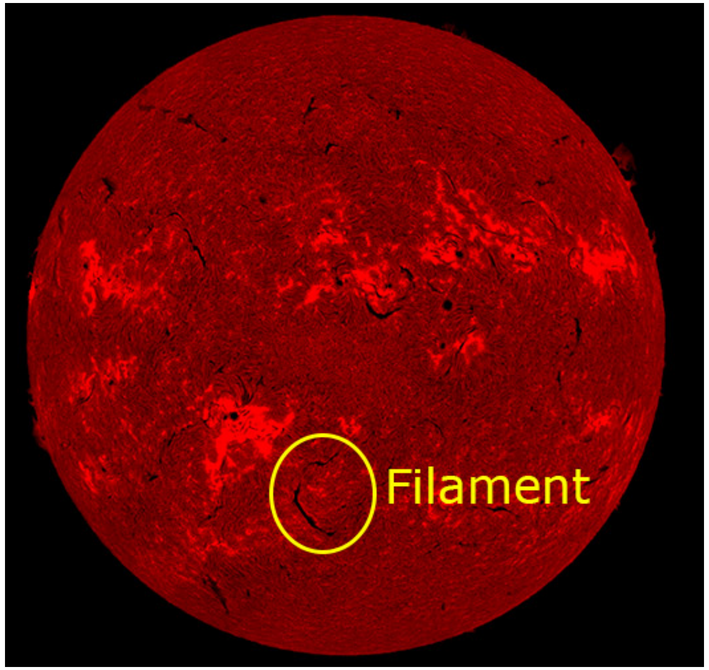
SYNOPTIC MAPS: WHAT ARE THEY?

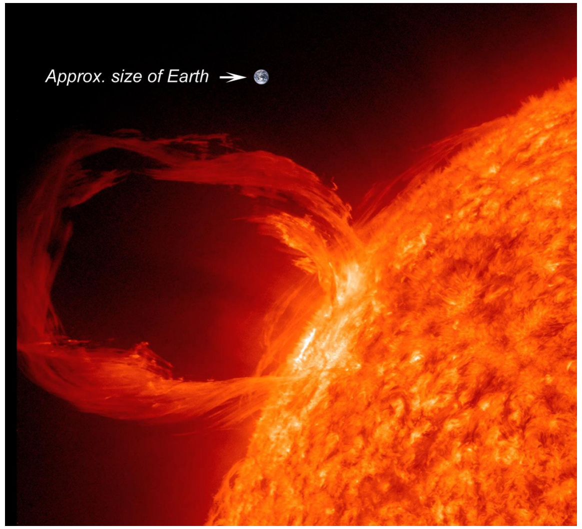
- Map of suns solar features
  - Coronal holes
  - Filaments
  - Magnetic polarity
  - Sunspots
  - Polarity Inversion Lines



Coronal Holes

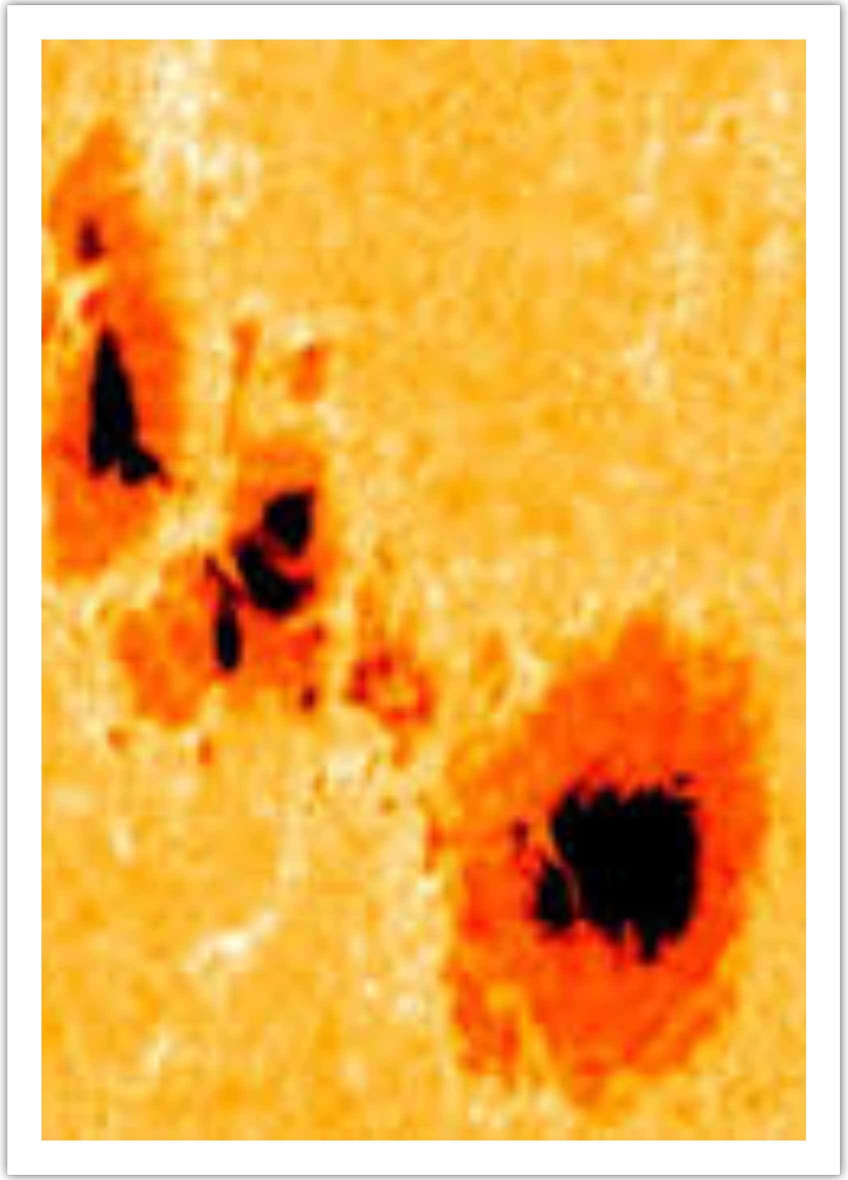
- Coronal holes are regions in Corona that are cooler and less dense than the surrounding plasma.
- They can easily be seen in extreme ultraviolet and soft x-ray images.
- These regions are created from open magnetic field lines from the sun.
- Because the field is open more particles from the corona are free to escape as solar wind, which is why these regions are less dense.





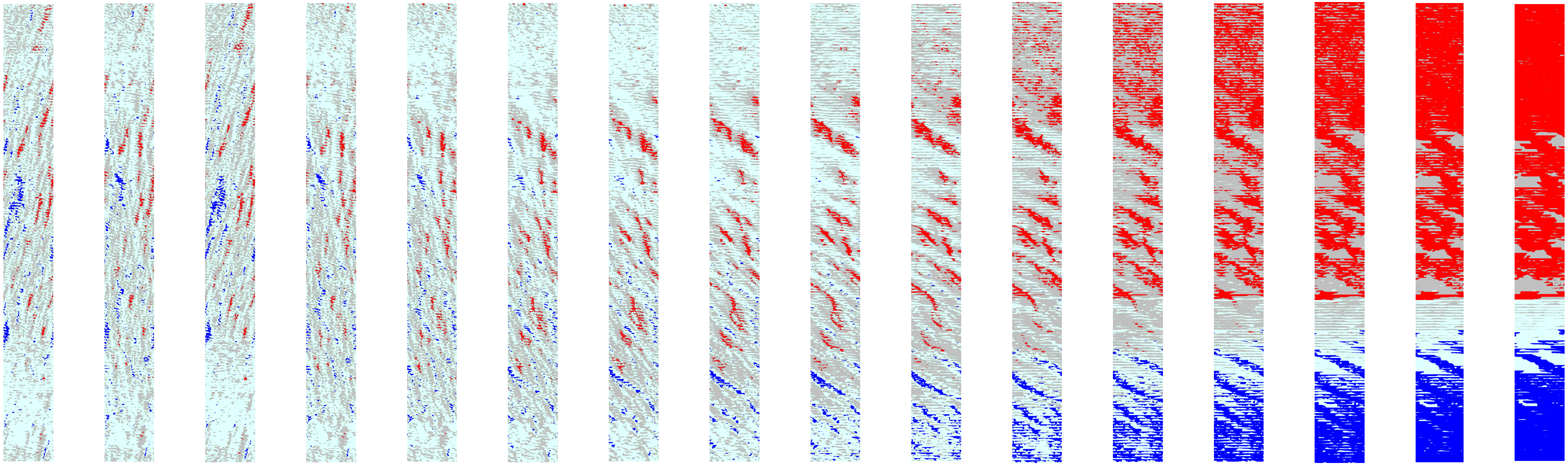
Filaments

- Filaments are large regions of plasma lifted above the photosphere by the suns magnetic field.
- Since this plasma is cooler and less dense than the plasma at the photosphere it also looks dark from a birds eye view.
- However, if seen from an angle you can see large loops of plasma that rise far above the photosphere.
- These are called Prominences.
- Filaments tend to form on magnetic inversion lines.



Sunspots

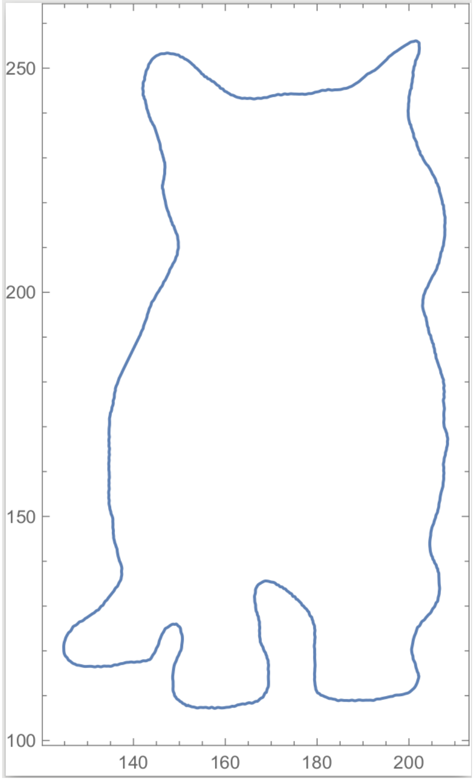
- Sunspots are regions on the photosphere that are cooler than the surrounding plasma.
- These regions are created by intense magnetic flux that prevents convection from occurring.
- Seeing sunspots are more common during solar minimum and less common during solar maximum.
- The number of sunspots increases and decreases through an average cycle of 11 years.

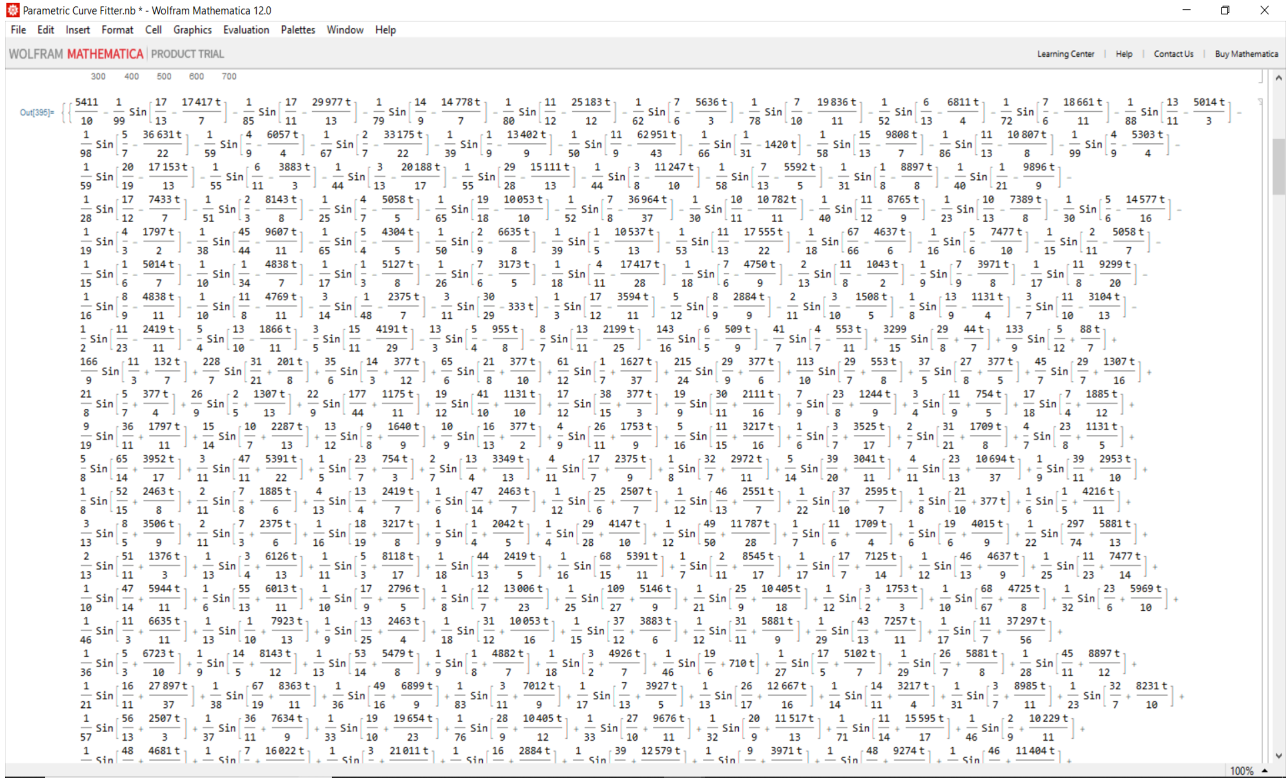


HOW WE TRACK CORONAL HOLES

Calculating the Centroids of Coronal Holes

- Before we can find the slopes of the coronal holes, we must first calculate the centroids of the coronal holes in the stack plots.
- I developed a new method to do this and used Mathematica to implement this method.
- The method can be broken down into a simple two step process.
    1. Mathematically represent the coronal holes.
    2. Use Integration to calculate the x and y coordinates of the coronal holes.

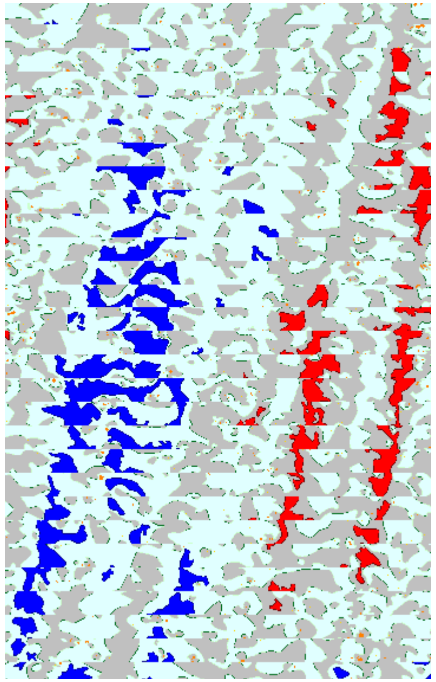


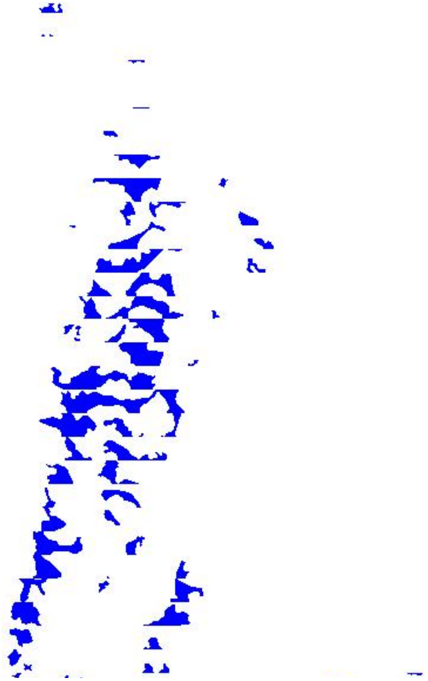


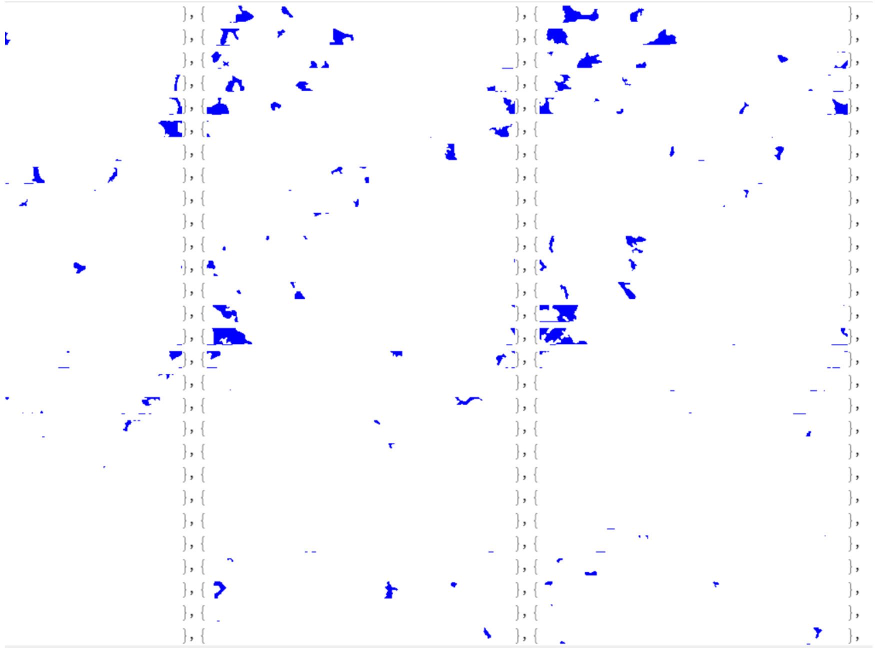
PARAMETRIZING ANYTHING

How These Equations are Made

- Images of the stack plots are put through a color filter to isolate the positive and negative coronal holes.
- Each stack plot image is split into smaller images, showing the latitude bands during each Carrington rotation.
- Mathematica then extracts the pixel coordinates at the edges of each of the coronal holes and performs Fourier transformations on these points.
- This creates pairs of trigonometric equations for the x and y values.
- Together these equations create curves that model the contours of the coronal holes.







Calculating Centroids Using Line Integration

- To calculate the centroid of 2-D objects it is common to use double integration.
- However, these integrals are not compatible with parametric equations.
- Fortunately, it is possible to use line integrals as a substitute.
- All we need to do is convert between the two.
- This can be done with using Greens Theorem.

Calculating Centroids Using Line Integration

- $\bar{x} \to \frac{M_y}{m} \to \frac{\iint_R x\rho(x,y)\, dA}{\iint_R \rho(x,y)\, dA} = \frac{\rho(x,y) \iint_R x\, dA}{\rho(x,y) \iint_R dA} = \frac{1}{A} \iint_R x\, dA$
- $\bar{y} \to \frac{M_x}{m} \to \frac{\iint_R y\rho(x,y)\, dA}{\iint_R \rho(x,y)\, dA} = \frac{\rho(x,y) \iint_R y\, dA}{\rho(x,y) \iint_R dA} = \frac{1}{A} \iint_R y\, dA$
- $\oint_R \vec{F} \cdot \overrightarrow{dr} = \oint_C P\, dx + Q\, dy = \iint_R curl\left(\vec{F}\right) dA = \iint_R \frac{\partial Q}{\partial x} - \frac{\partial P}{\partial y}$
- Converting $\bar{x}$ to a line integral.
  - For what force field does $\frac{\partial Q}{\partial x} - \frac{\partial P}{\partial y} = \mathrm{x}$
  - If $\frac{\partial Q}{\partial x} = x$ and $\frac{\partial P}{\partial y} = 0$ then the force field $\vec{F} = \left\langle 0, \frac{1}{2}x^2 \right\rangle$
  - So $\bar{x} = \frac{1}{A} \oint_C \frac{1}{2}x^2\, dy = \frac{1}{2A} \oint_C x^2\, dy$

Calculating Centroids Using Line Integration

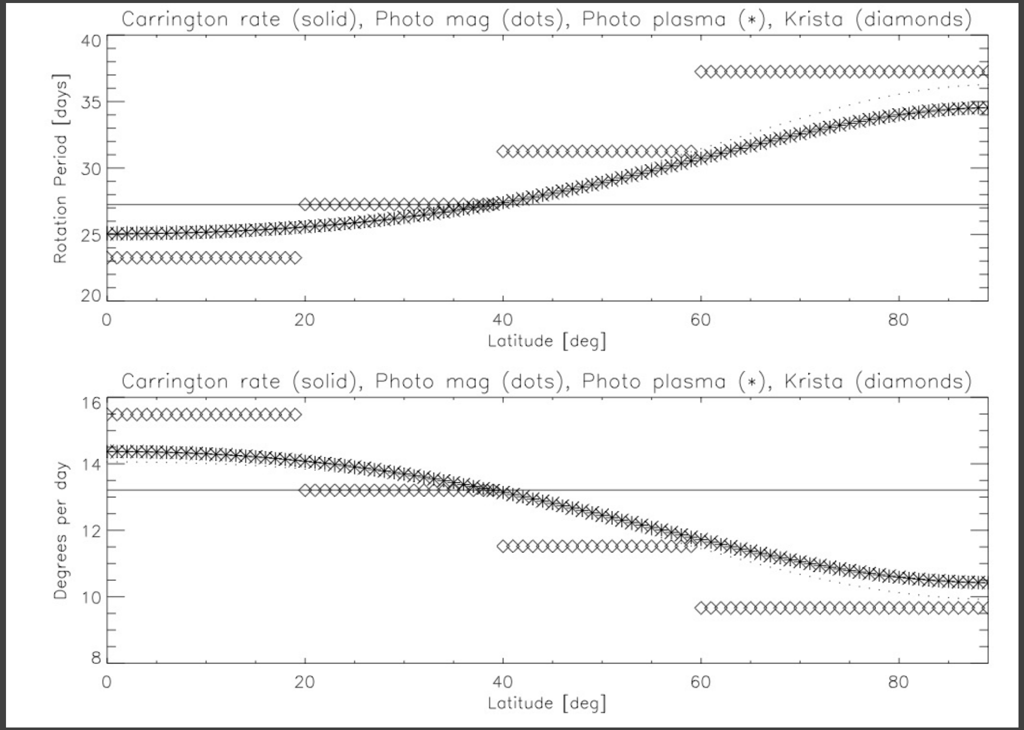
- Converting $\bar{y}$ to a line integral.
  - For what force field does $\frac{\partial Q}{\partial x} - \frac{\partial P}{\partial y} = \mathrm{y}$
  - If $\frac{\partial Q}{\partial x} = 0$ and $\frac{\partial P}{\partial y} = -y$ then the force field $\vec{F} = \left\langle -\frac{1}{2}y^2, 0 \right\rangle$
  - So $\bar{y} = \frac{1}{A}\oint_C -\frac{1}{2}y^2\,dx = -\frac{1}{2A}\oint_C y^2\,dx$
- So the two line integrals
- $\frac{1}{2A}\oint_C x^2\,dy$ and $-\frac{1}{2A}\oint_C y^2\,dx$ calculate the x and y component of the centroid point $(\bar{x}, \bar{y})$ respectively.

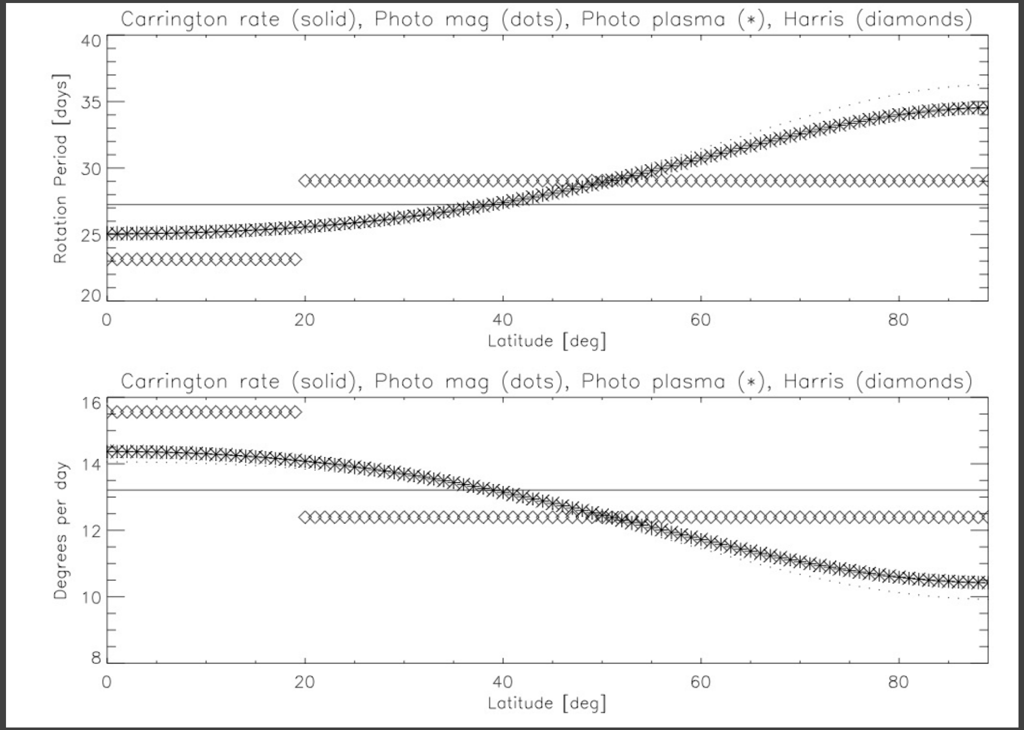
Problems with Centroid Method

- Most of the time the centroid method is accurate.
- However the x or y values of the centroids are sometimes way off and not even on the coronal hole.
- This seems to happen for small coronal holes.
- Fortunately, this doesn’t happen very often and there are plenty of coronal hole pattern to observe at each central latitude.

Finding the Slopes

- After the centroids of the coronal holes were calculated the coordinates the x values were converted to longitude.
- The longitudes were then plotted on a Longitude vs. Time graph.
- Then to get the slopes we found the line of best fit.
- For four central we chose a long-lived coronal hole pattern to find the slope of.
- Ideally if we had more time we would have found more for each latitude and took the average.





RESULTS: CARRINGTON ROTATION RATES VS DIFFERENTIAL ROTATION

Conclusions

- Seeing how much the rotational rates of these coronal holes differs from the differential rotation will tell us how much its movement is being influenced by other phenomena.
- One of the biggest causes of coronal hole movement other than the differential rotation is Rossby waves.
- After we get more and better data of the coronal holes rotation rates at different latitudes, this will be the focus of our research.
- Learning more about these waves could possibly help us make better predictions of coronal mass ejections.
- Better predictions, would help us better prepare for natural disasters caused by these events.

QUESTIONS