

Pathways to Coronal Magnetic Field Energy Storage

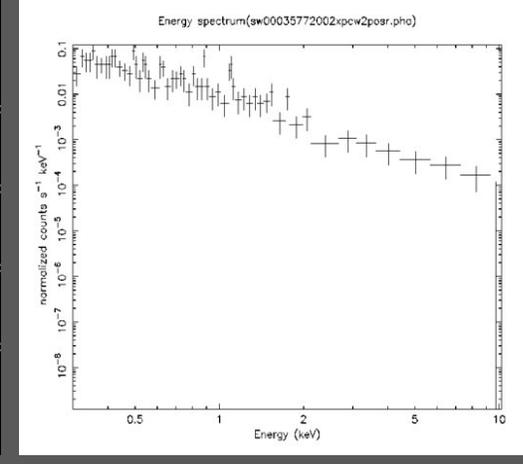
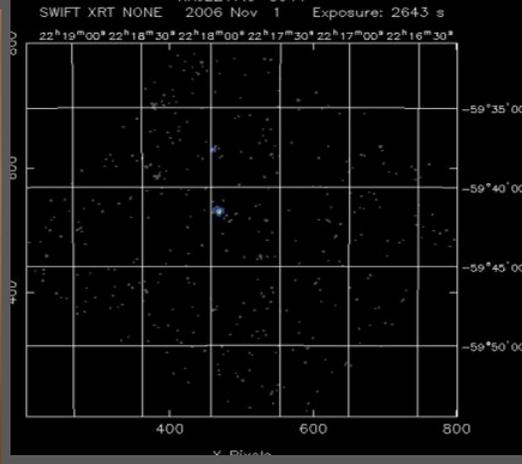
How I learned to coexist with IDL and do analysis in the meantime



NWRA



Alanna Sacra Cavins
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Dr. KD Leka



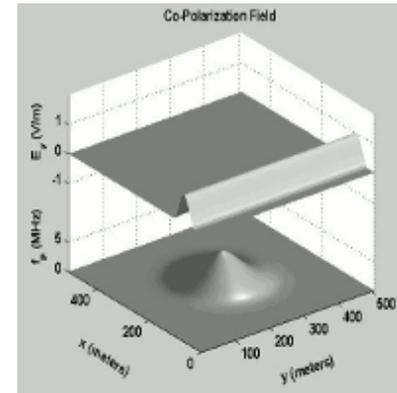
A little bit of my background...

- Alanna Sacra Cavins
- Morehead State University – Rowan County Kentucky
- Class of 2020 2021
- Institute of Stellar Necrology
 - Active Galactic Nuclei– X-Ray analysis - RXJ2217.9-5941
 - 500 source AGN cataloguing project



North West Research Associates

- **What** - is a scientific research organization, owned and operated by its Principal Investigators, with expertise in the space and geophysical sciences.
- **Mission** - to achieve excellence in basic and applied research by providing a working environment designed to support the success of every scientist and engineer.
- **Where**- Research Offices in Boulder, Colorado and in Monterey, California with individual scientists working out of San Diego, CA, Corvallis, OR, and Socorro, NM.
- <https://www.nwra.com/>



NWRA



New Ideas

Traditionally, this analysis was done by looking at the total amount of magnetic energy available in the system

*Where Magnetic Energy is the energy stored in the magnetic field above the photosphere

Instead, look at individual current systems to see what magnetic energy they store

Our hypothesis is that regions which produce large flares must have current systems with large amounts of free energy, and conversely that regions that produce only small flares have only current systems with small amounts of free energy.

*Where Free Energy is the energy that can be released

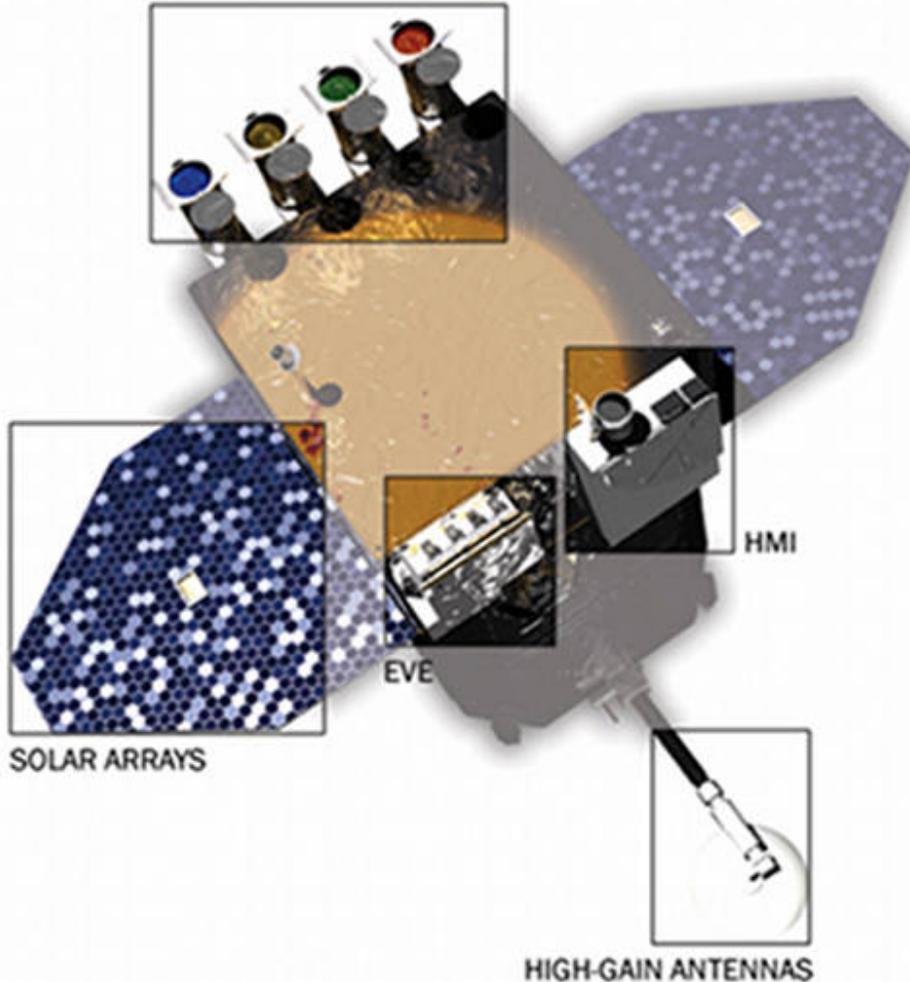
Basic Assumptions

- The Sun follows the laws of physics
- A NLFFF – Non-Linear Force Free Field
 - ¹The coronal field can be considered “force free” because the only forces present at that moment are the balancing electromagnetic forces that the coronal field exerts by itself.

The “Easy 7 Step” Analysis Process

- 1) Observations
- 2) Inversion process (very technical)
- 3) Remapping
- 4) Partitioning
- 5) CFITS
- 6) Biot Savart Law
- 7) Energy Estimates

The SDO Spacecraft

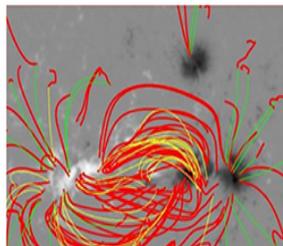
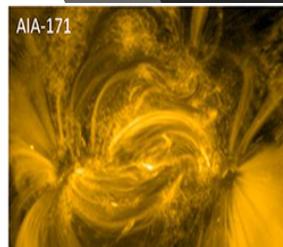
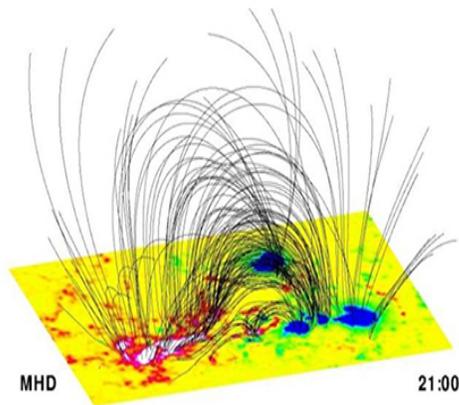
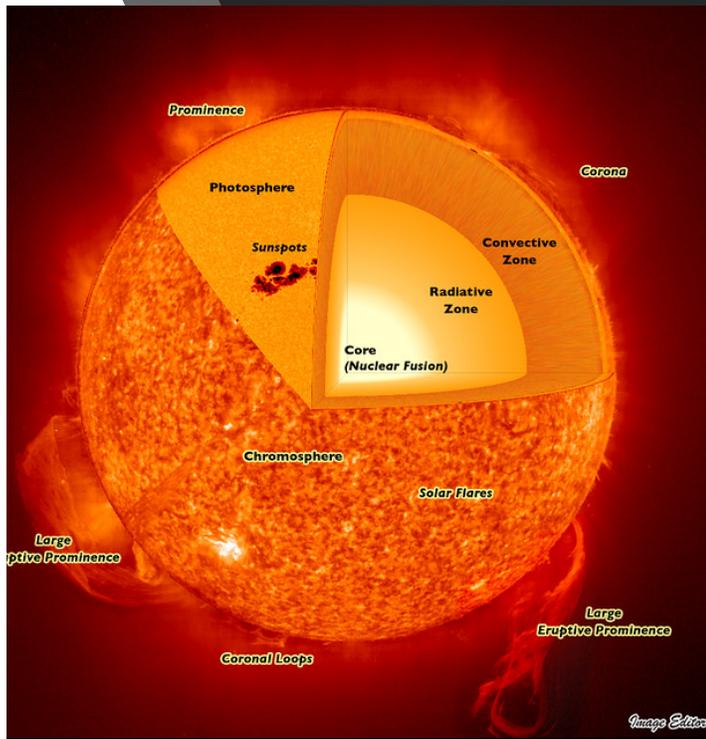


HMI on the SDO

- The Solar Dynamics Observatory (SDO) will be taking a closer look at the Sun, the source of all Space Weather.
- The Helioseismic and Magnetic Imager will use a technique called "helioseismology" to gaze through the sun at internal processes.
- The imager was built by Stanford University and the Lockheed Martin Solar Astrophysics Laboratory, Palo Alto, California
- https://www.nasa.gov/mission_pages/sdo/spacecraft/index.html

SDO Observes Here

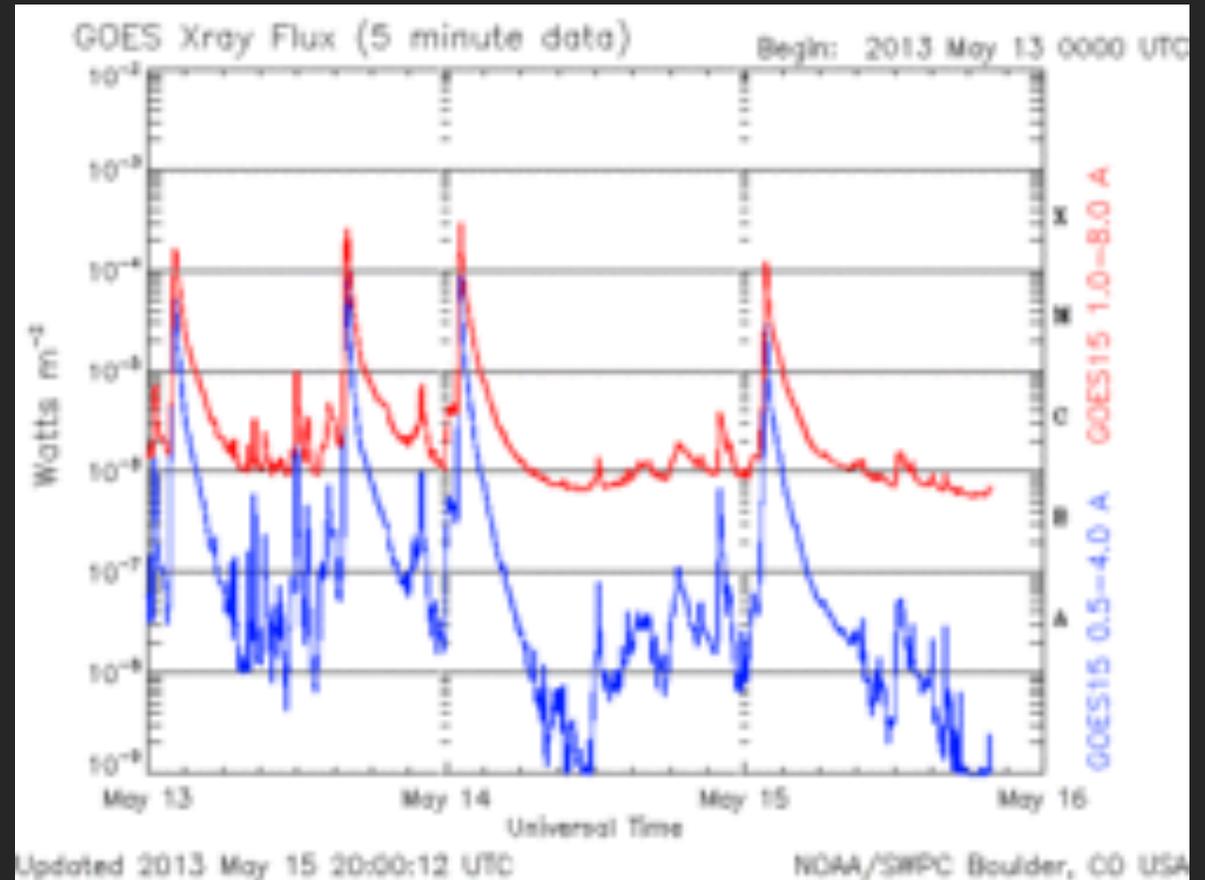
- Photosphere – the layer of the sun where photons escape – we can see this
- Corona – above the photosphere – where magnetic reconnection probably occurs
 - * Close to the photosphere
- Reconnection = change in connection of magnetic field lines
- This causes a release of magnetic energy. (Reservoir)
 - We cannot see the actual lines we are seeing plasma
- Note: It is generally accepted that this can lead to solar flares



Classification of Flares [W/m²]

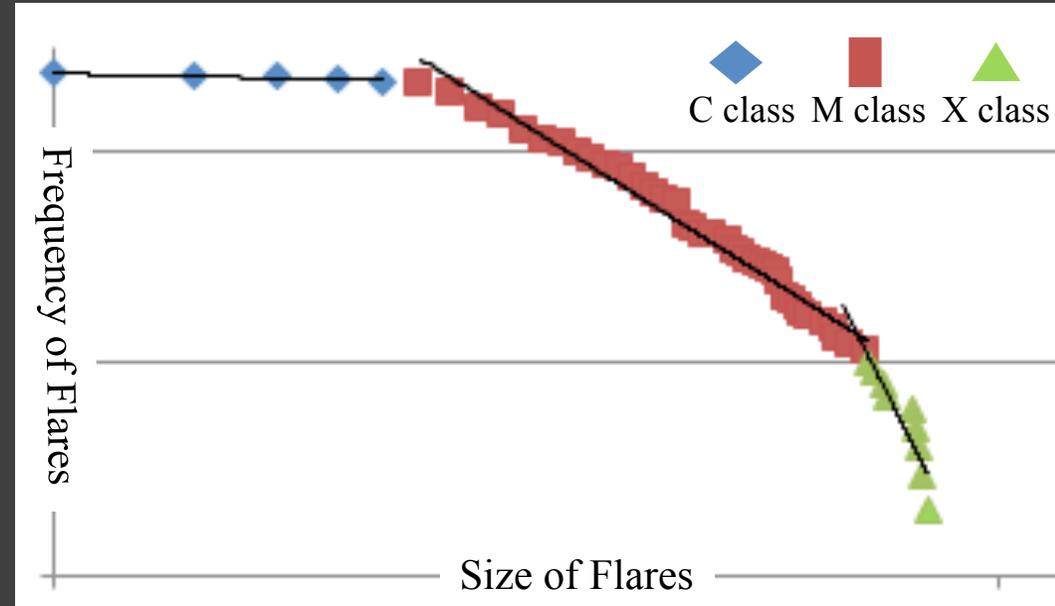
- A - 10⁻⁸ - Very hard to see next to background and noise
- B - 10⁻⁷ - Hit or miss but still not easy to see
- C - 10⁻⁶ - Small
- M - 10⁻⁵ - Medium
- X - 10⁻⁴ - Large

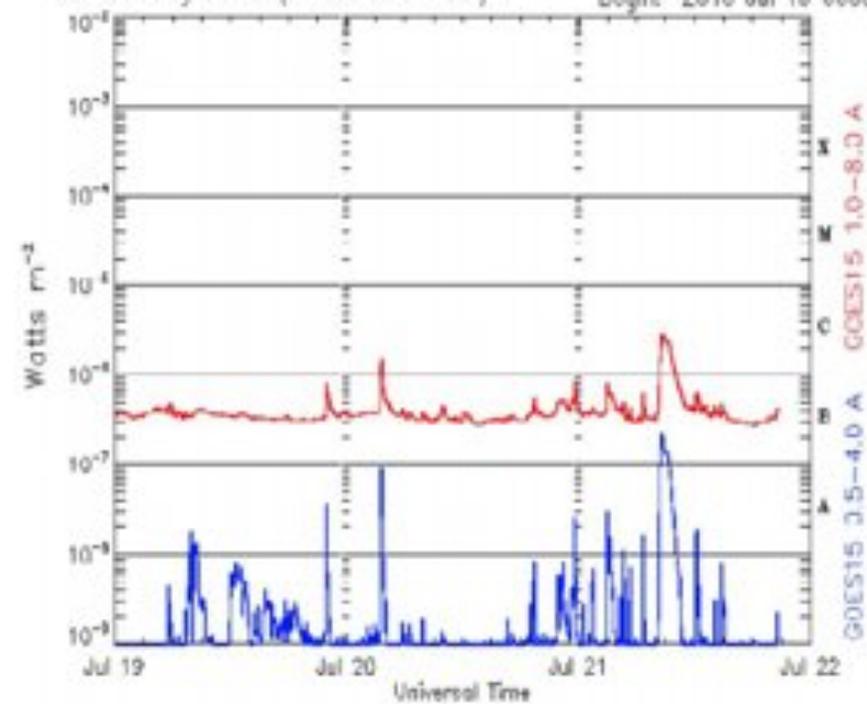
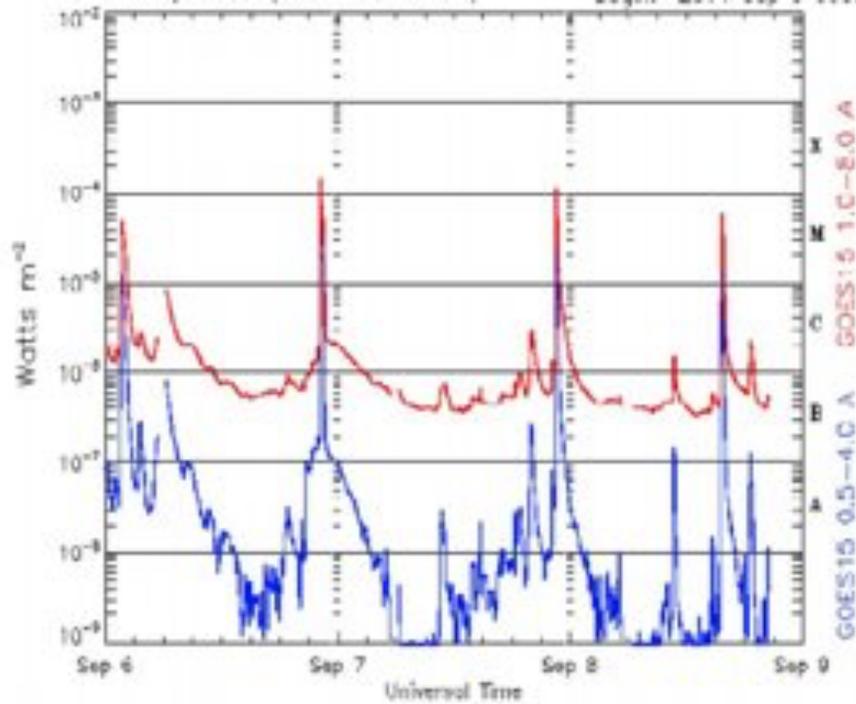
*Note size is based off soft x-ray peak flux



Over a long period of time...

- "Power law Distribution"
 - Majority fall into C and M classes with a few X class
 - Decreasing with a few outliers





On Individual Active Regions

- May not be the case
- Some areas with larger flares don't exhibit many small ones
- Vice Versa

The “Easy 7 Step” Analysis Process

1) Observations

The result is: photons!

2) Inversion process (very technical)

The result is: a photospheric current system image

3) Remapping

The result is: coordinates on the longitude and latitude scales

4) Partitioning

5) CFITS

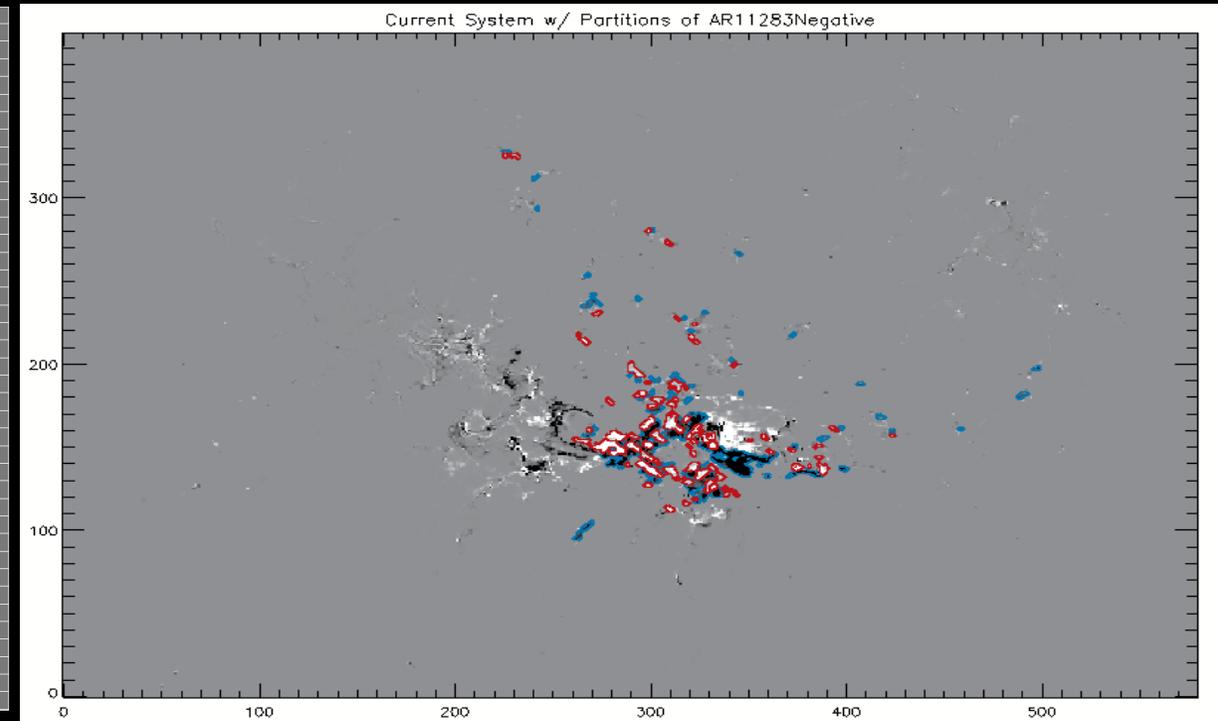
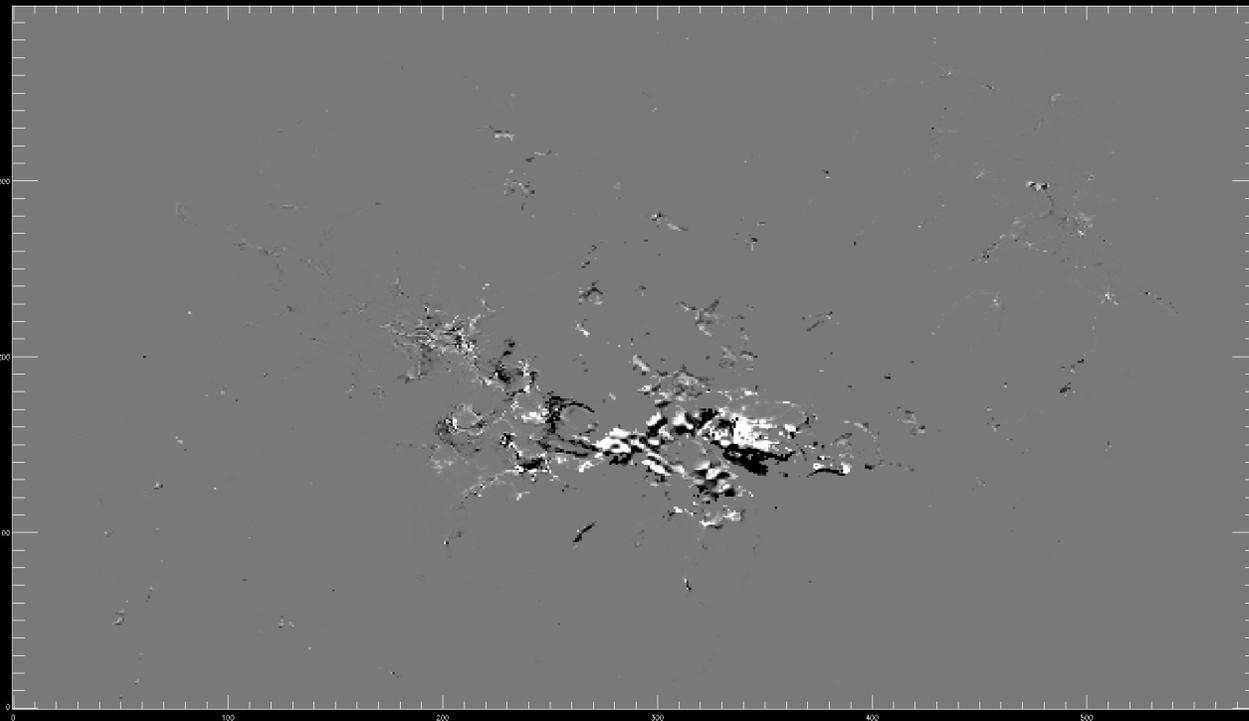
6) Result: Mask Array

6) Biot Savart Law

7) Energy Estimates

Parameter Selection is IMPORTANT

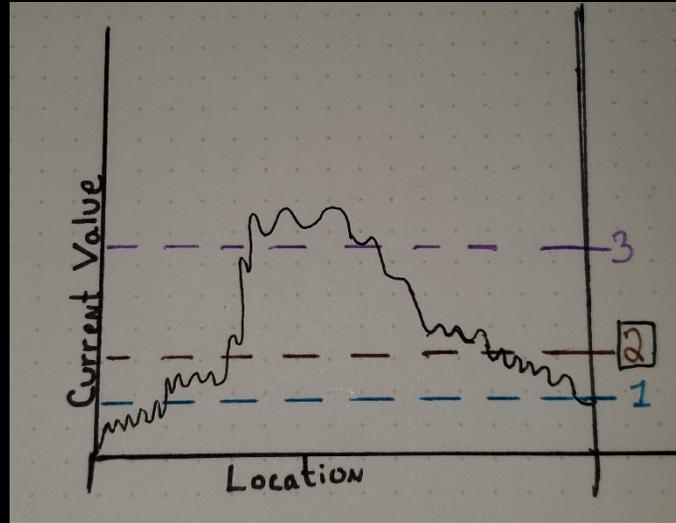
- Images are of the mask array
- On the same min and max scale



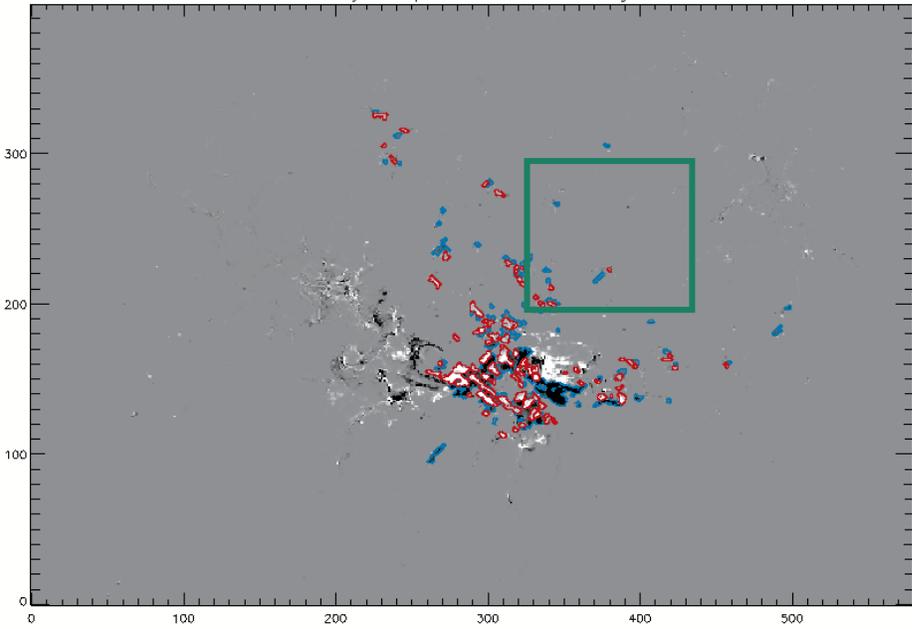
Selecting Parameters – J Threshold

The level at which we observe from the photosphere.

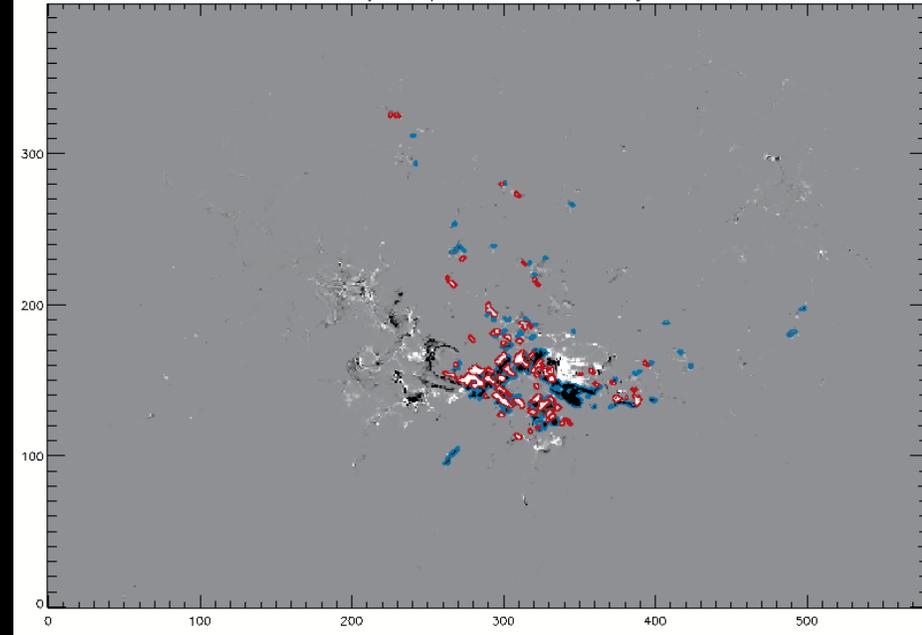
**Major noise reduction
Square



Current System w/ Partitions of AR11283Negative

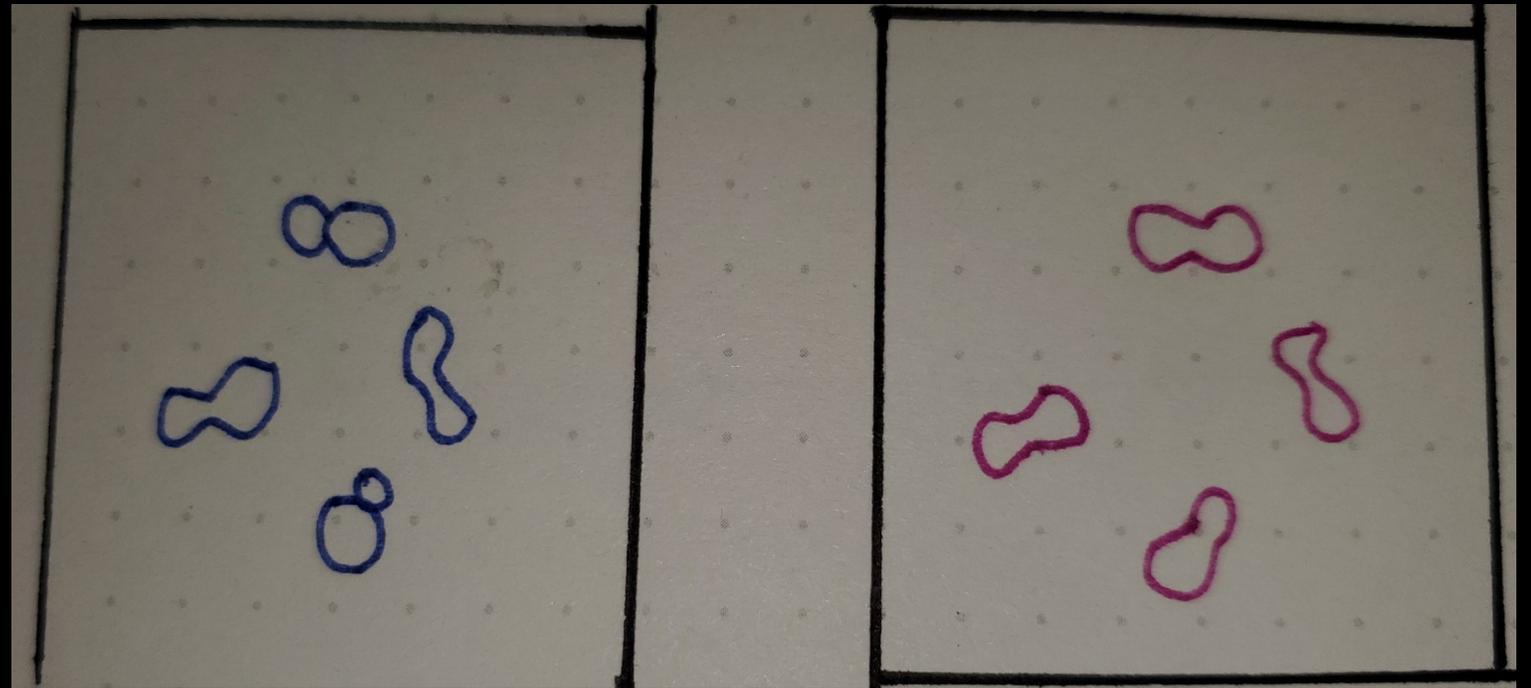
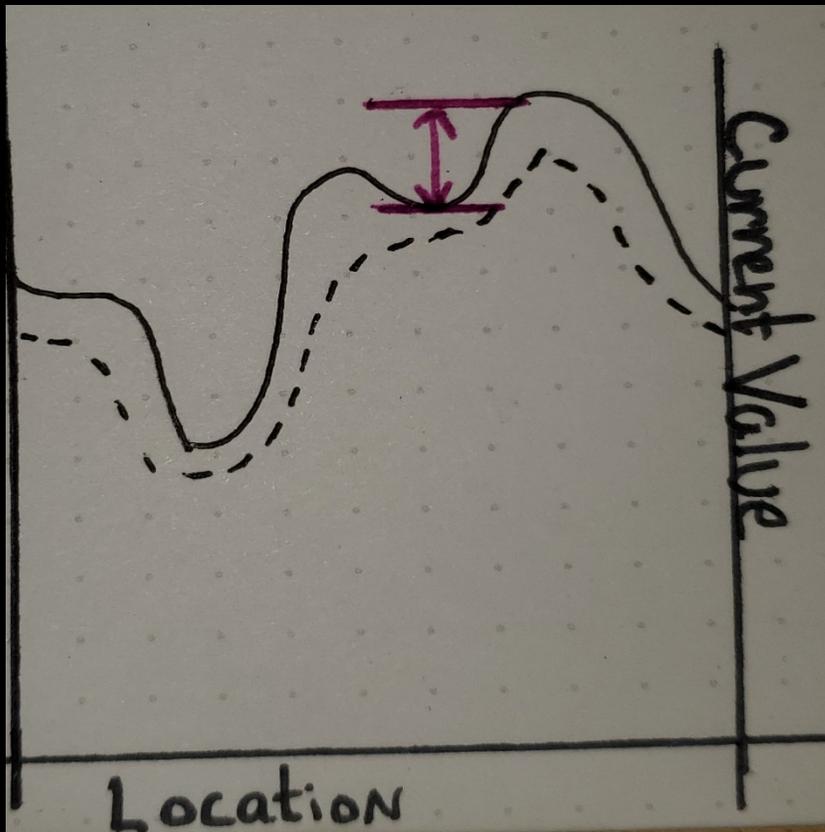


Current System w/ Partitions of AR11283Negative



Selecting Parameters – Saddle Point

If two peaks are near each other a saddle point would cause them to merge into one larger peak.



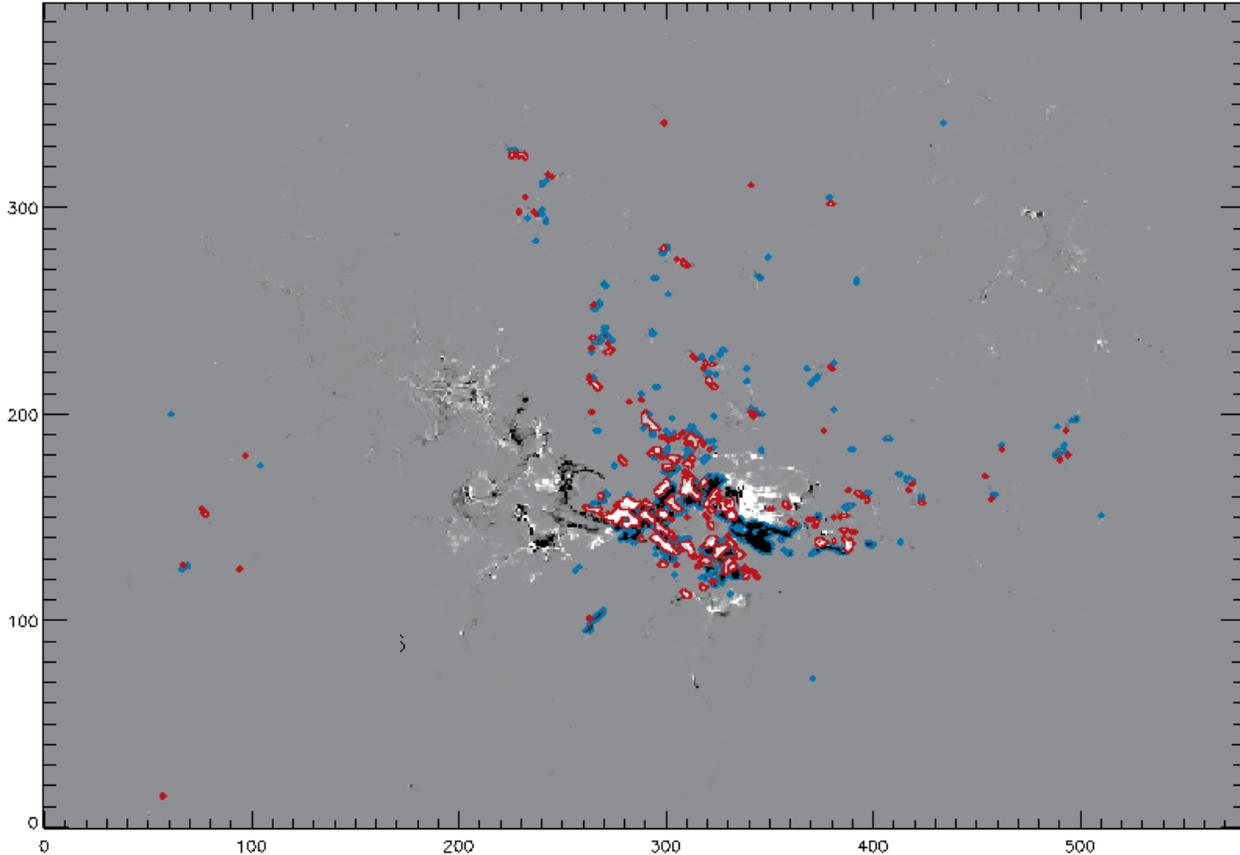
Issues with Saddle Point?

- You would expect smaller islands to merge into a larger one..
- That did not happen
- Quasi Maximum value of 1000
- Minimum should be around 1 for our purposes

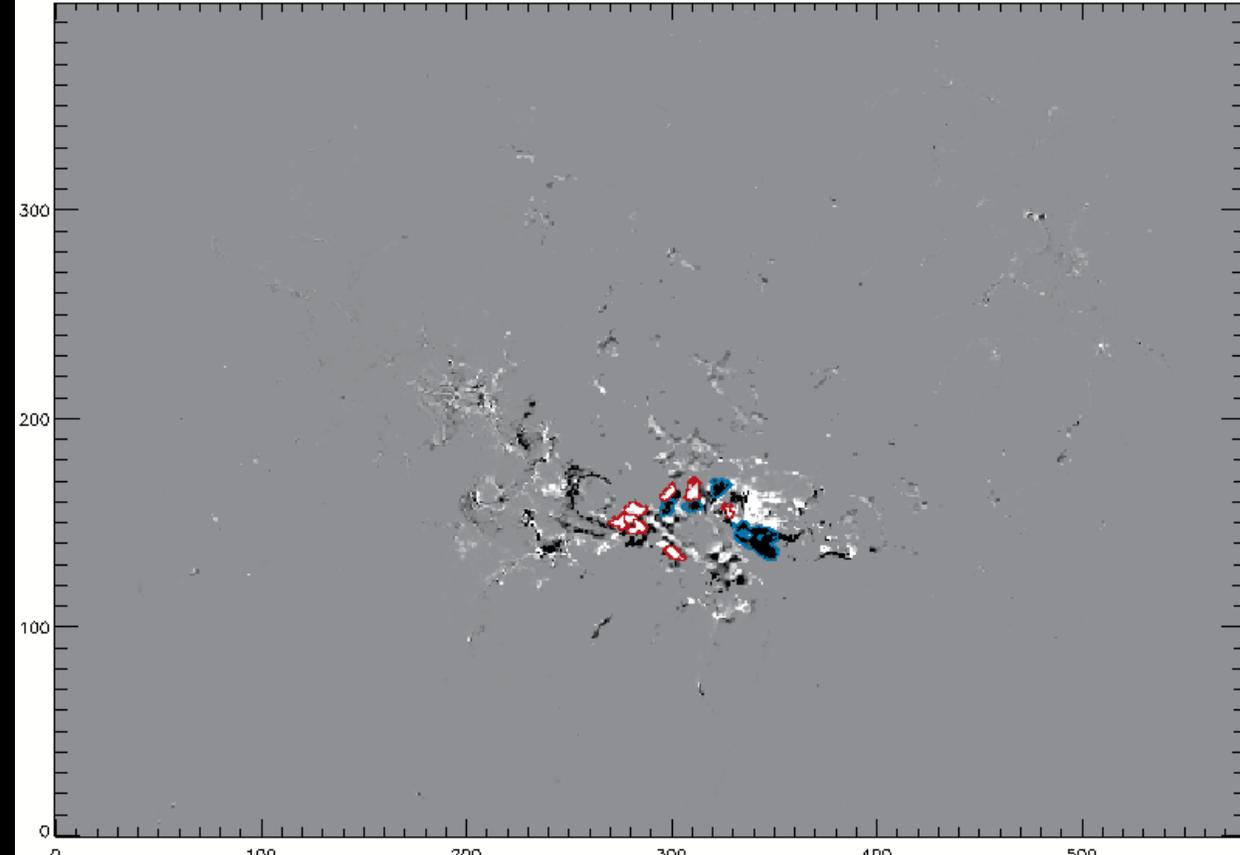
Selecting Parameters - Minimum Size

- 1) If the “current system” is below a certain value ignore it
- 2) Good for large scale structures

Current System w/ Partitions of AR11283Negative



Current System w/ Partitions of AR11283Negative



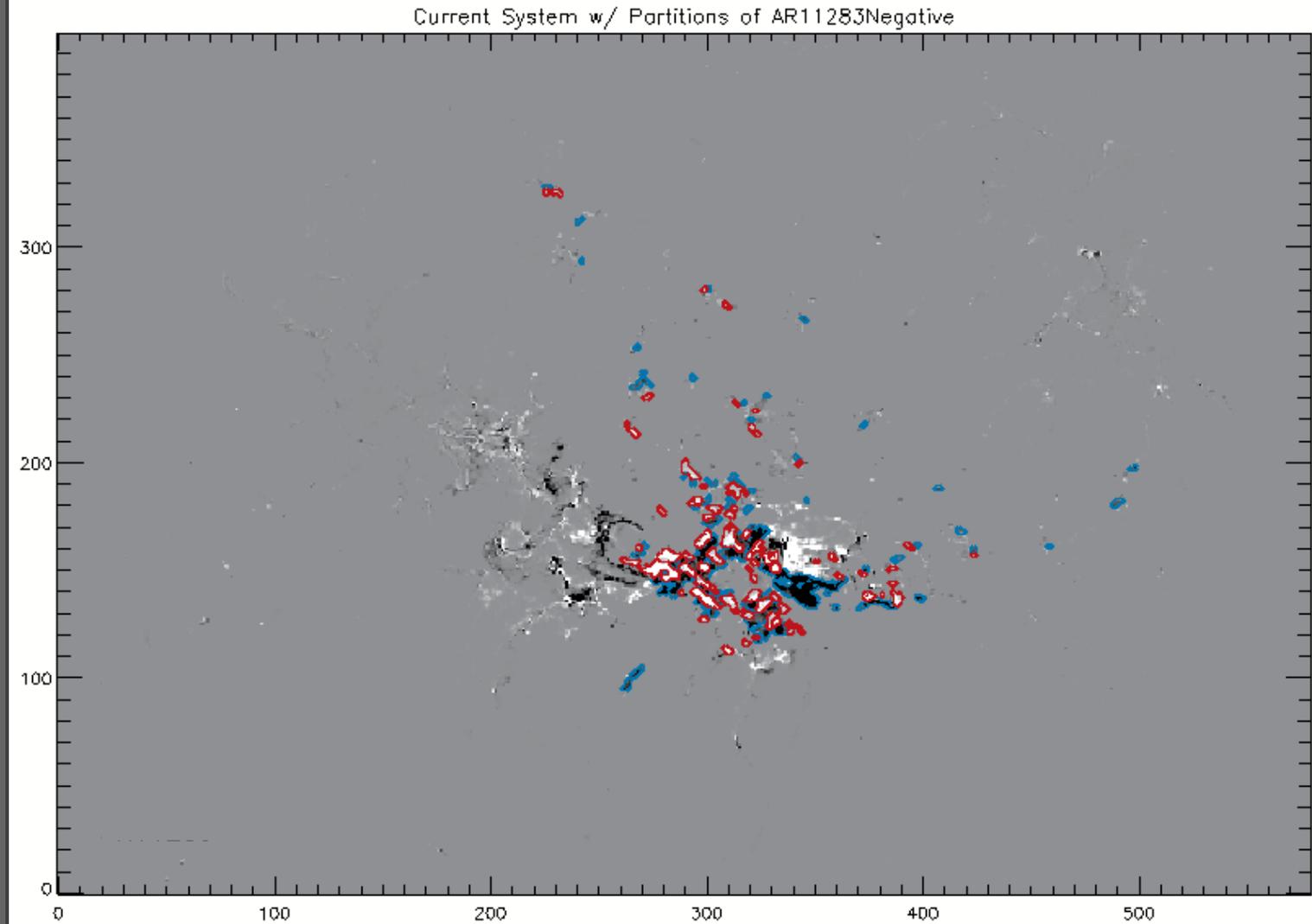
Selecting Parameters – Final Picture

J Threshold = 350

Minimum Size = $2e18$

Saddle Point = 0 **

Polarity = Negative



The “Easy 7 Step” Analysis Process

- 1) Observations
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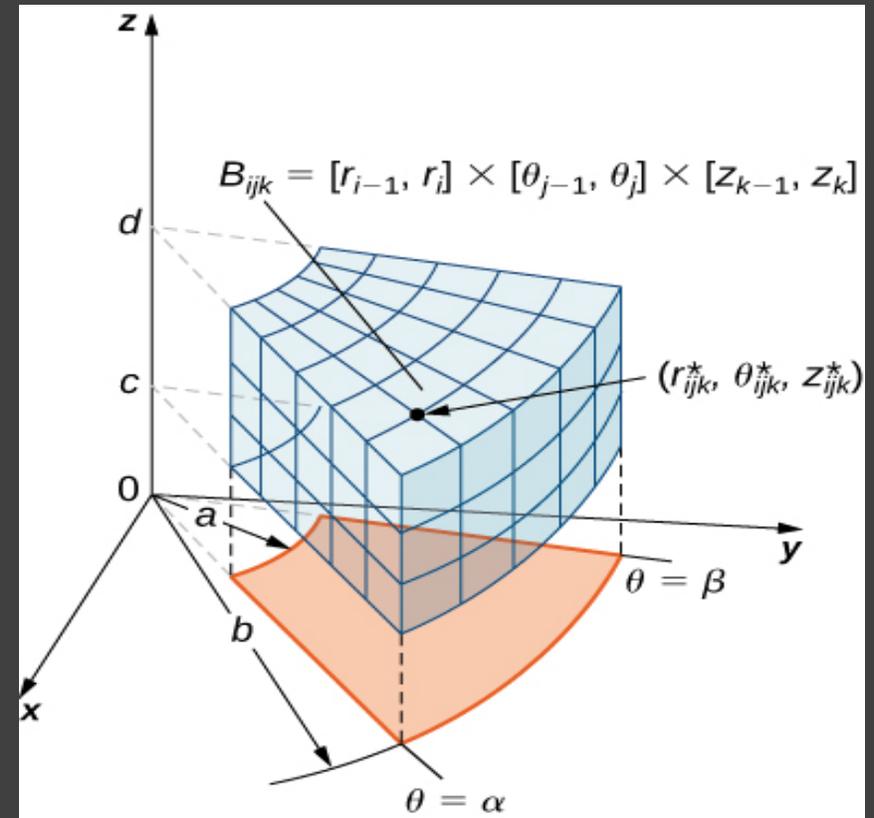
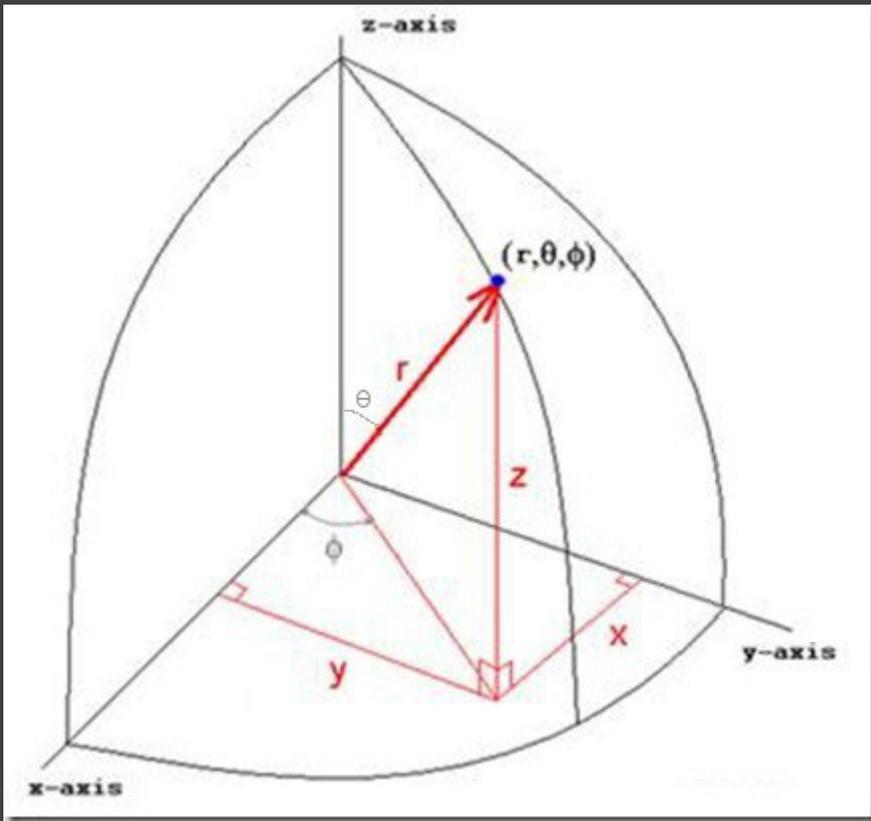
This results in: an official set of parameters we use

- 5) CFITS
- 6) Biot Savart Law
- 7) Energy Estimates

CFITS

- CFITS = Current Field Iteration in Spherical
- Spherical Coordinates
- In Omega, Phi, and R

Not looking at the whole sun
but something more
specialized so we get a shape
like this:



The “Easy 7 Step” Analysis Process

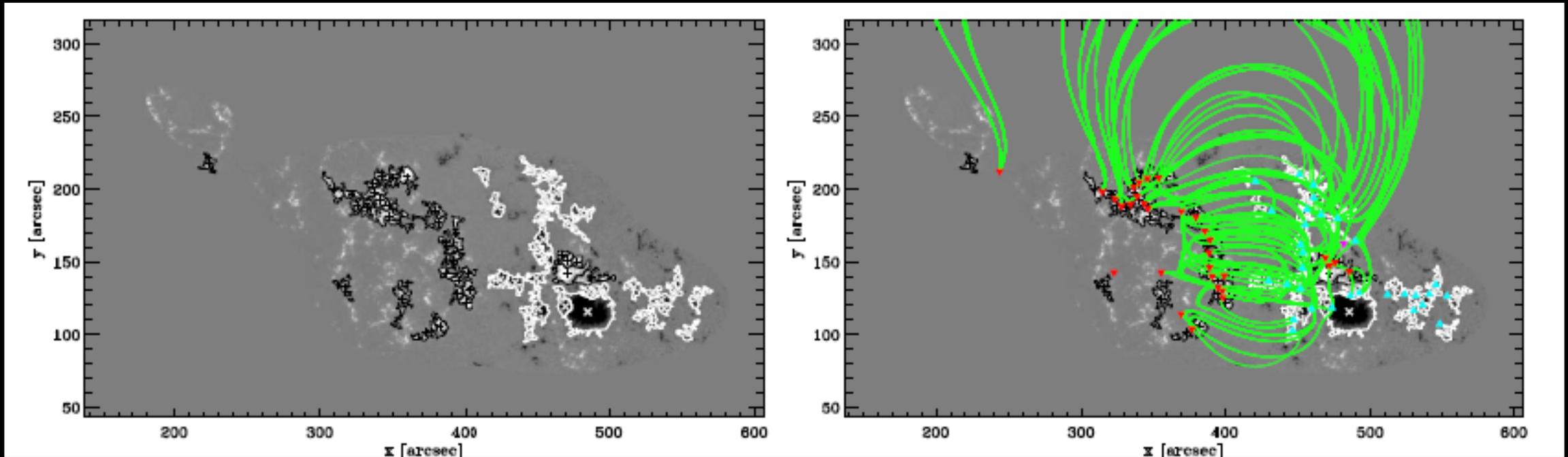
- 1) Observations
- 2) Inversion process (very technical)
- 3) Remapping
- 4) Partitioning
- 5) CFITS

This results in: a mask array

- 6) Biot Savart Law
- 7) Energy Estimates

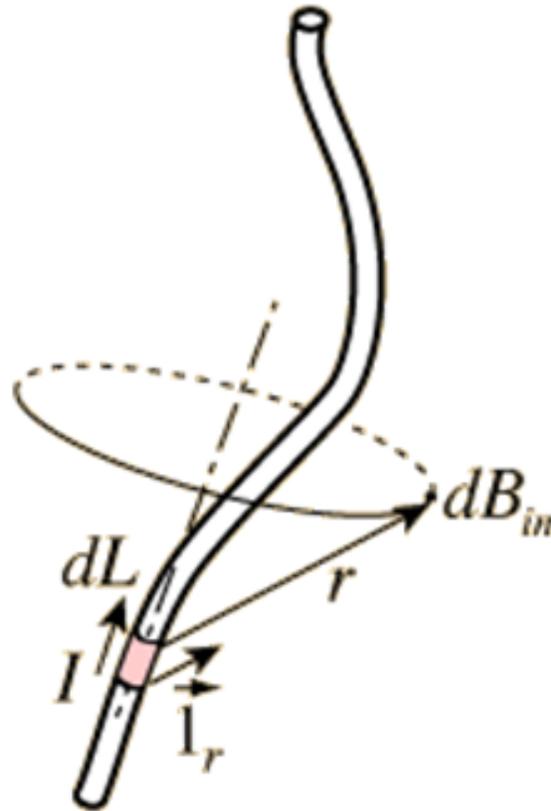
Field Line Propagation

- Going from the current footprints into the 3 dimensional space in increments



Enactment of the Biot Savart Law

We can not change
the laws of physics



Magnetic field
of a current
element

$$d\vec{B} = \frac{\mu_0 I d\vec{L} \times \vec{1}_r}{4\pi r^2}$$

where

$d\vec{L}$ = infinitesimal length of conductor
carrying electric current I

$\vec{1}_r$ = unit vector to specify the direction
of the the vector distance r from
the current to the field point.

The “Easy 7 Step” Analysis Process

- 1) Observations
- 2) Inversion process (very technical)
- 3) Remapping
- 4) Partitioning
- 5) CFITS
- 6) Biot Savart Law

This results in: a field line file

- 7) Energy Estimates

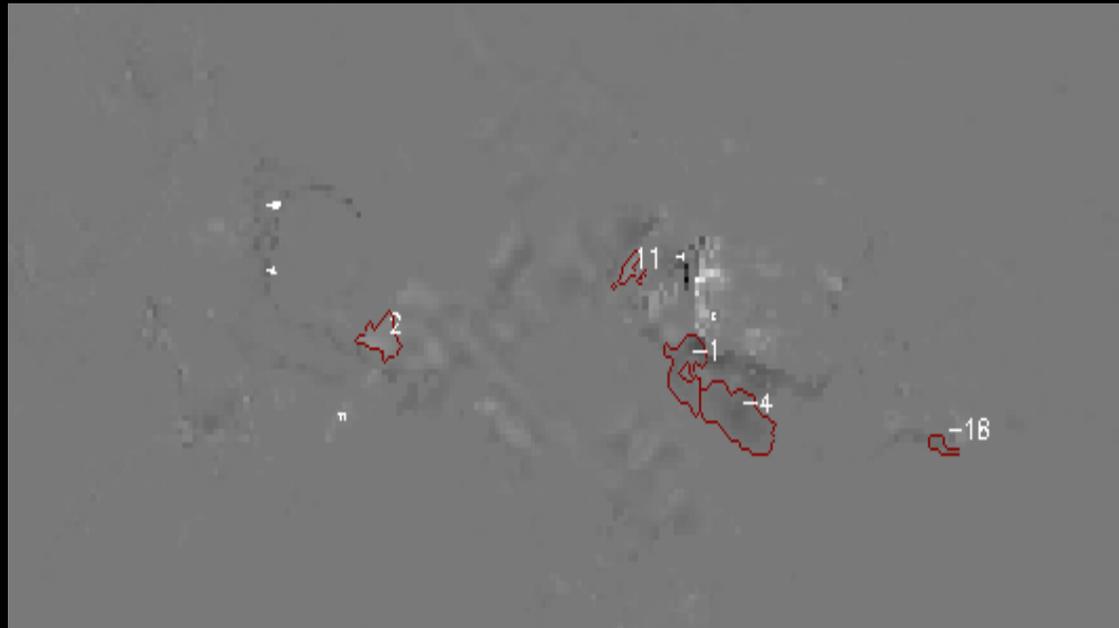
NOAA AR11283

- This region was seen from September 02, 2011 to September 06, 2011. The specific images shown are based off the observations from the HMI/SDO instrumentation. The investigation focused on NOAA AR11283 at central meridian on 2011.09.06.
- Produced LARGE flares (even a CME)

Current Systems and Magnetic Energy

Current Systems:	Magnetic Energy (ergs):
N004	1.01E+30
N001	2.57E+29
P002	1.74E+29
P011	3.52E+28
N018	2.19E+28

- We note that -4 has the greatest footprint and the most energy.
- We also note that +11 has a smaller footprint but a longer field line



Final Statements

- We were correct in our hypothesis?
- Largest Energy found in my region was N004 with 10^{31} ergs
- Parameters can be subjective and the selected ones for this project should not be used for EVERY region ever

What next?

- The results I have are based on one day for the active region.
- The next step is to analysis the rest of the observations for AR11283 to investigate current system evolutions (beginning Fall semester as my senior thesis)



Acknowledgements

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