# Using field-aligned flows to map the coronal magnetic field

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# Overview

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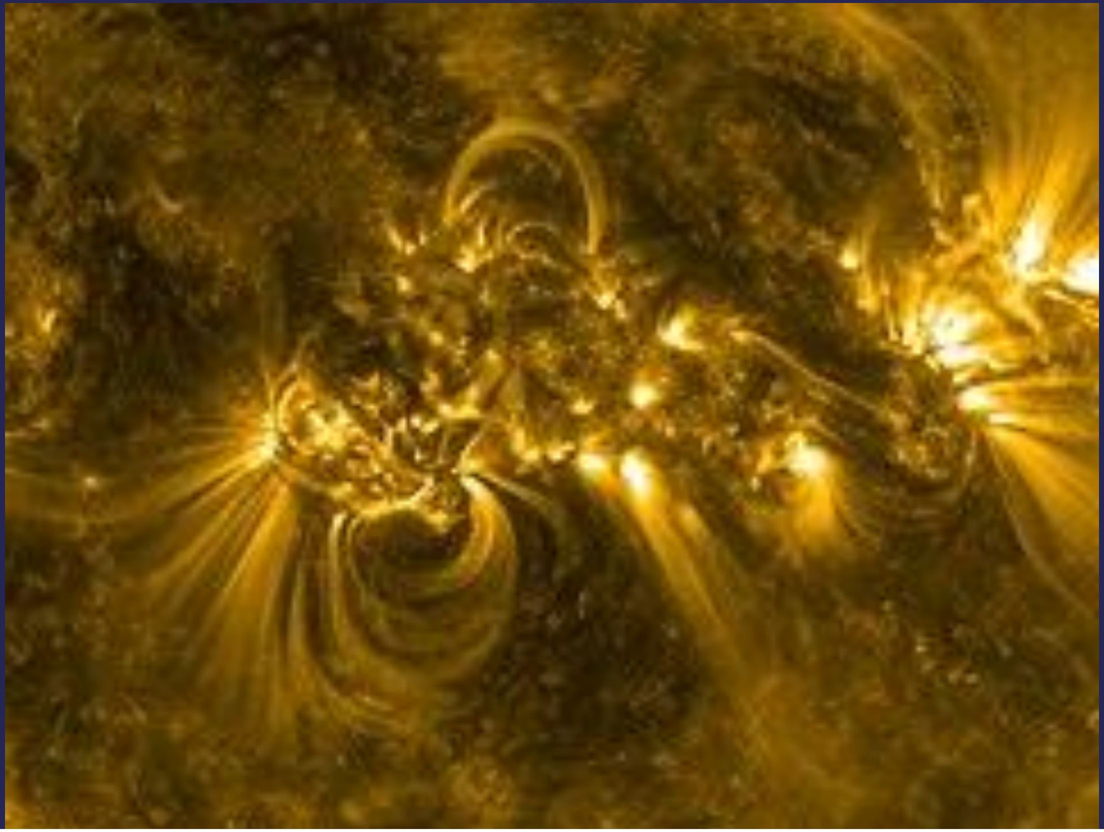
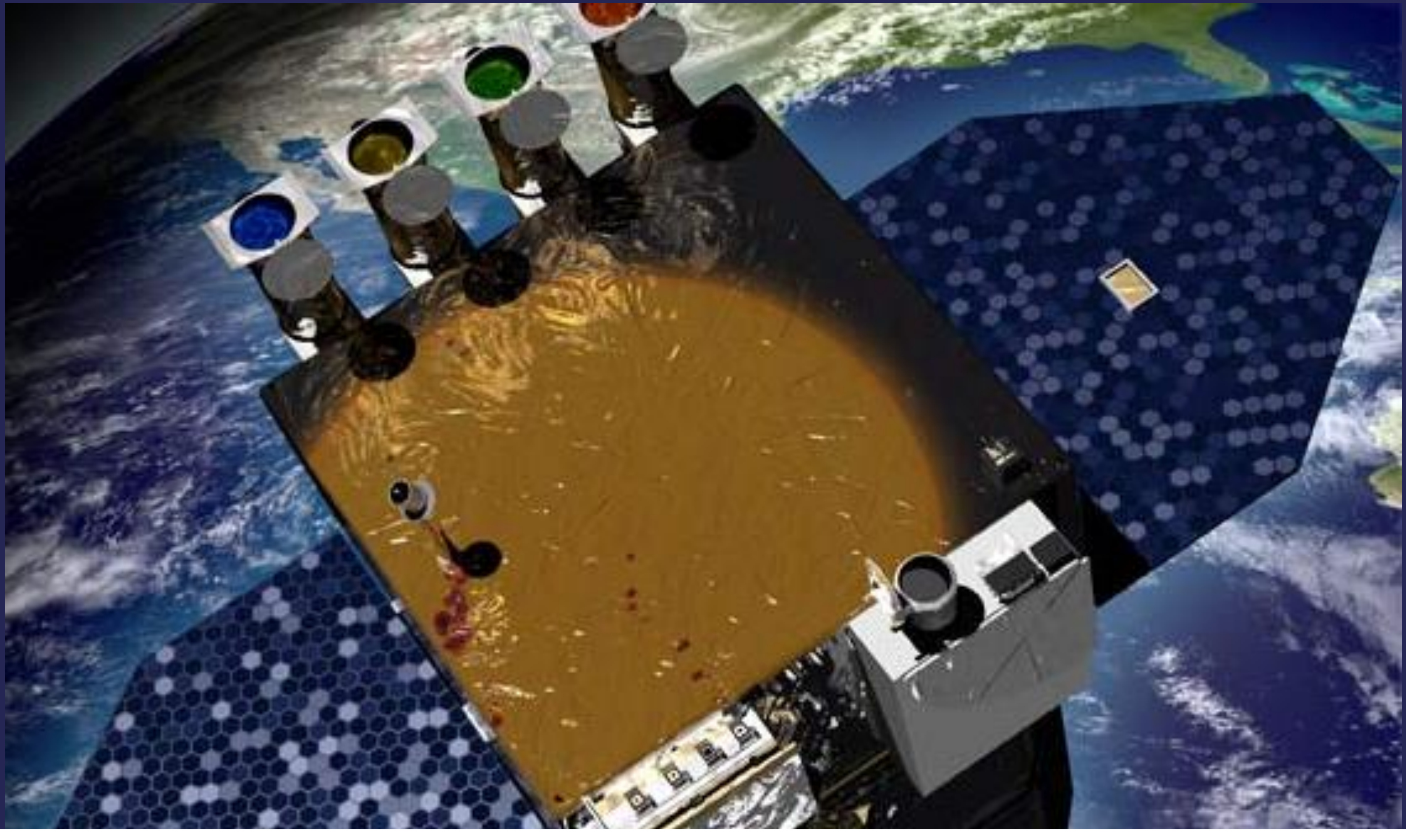




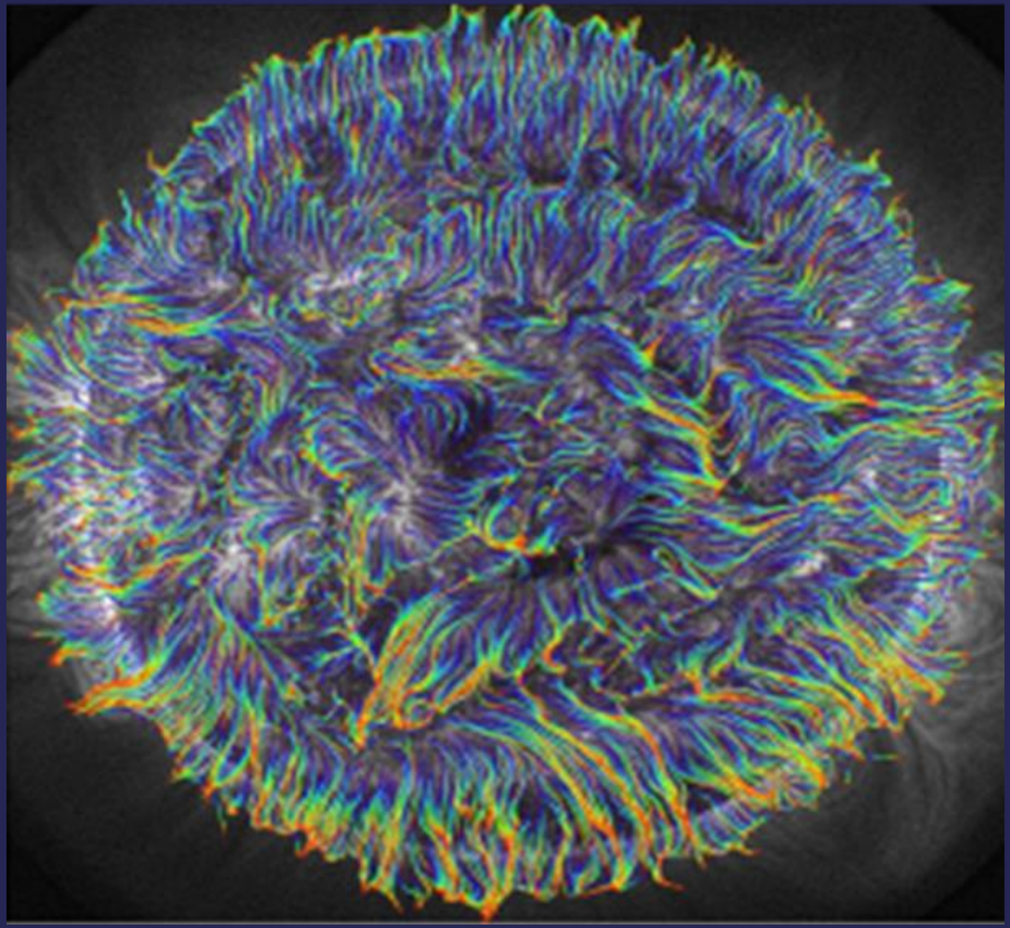
# Introduction

- In EUV loops are seen in the corona.
- The loops are magnetic in nature.
- The shape of the loops can give us valuable information.

RQ: How can a method be established to model the low-coronal magnetic field using new constraints gained from tracking faint field-aligned motions in EUV?

# Motivation

- Develop accurate models: The main motivation is to create precise models of the Sun's coronal magnetic field. This is crucial to enhance our understanding of physical processes in the solar atmosphere.
- Improve forecasting: Accurate models of the coronal magnetic field aid in forecasting the solar wind in interplanetary space. This is vital for predicting and preparing for potential space weather events.
- Interpret measurements: The project aims to provide models that incorporate observational constraints from both the photosphere and the corona. This will enable better interpretation of coronal remote and in situ measurements.
- Address central problems: By developing two complimentary models constrained by observed data, the project seeks to address central issues in the field, including the magnetic topology of the quiet-Sun atmosphere, radial magnetic field height, and the sources of high-density, slow solar wind.



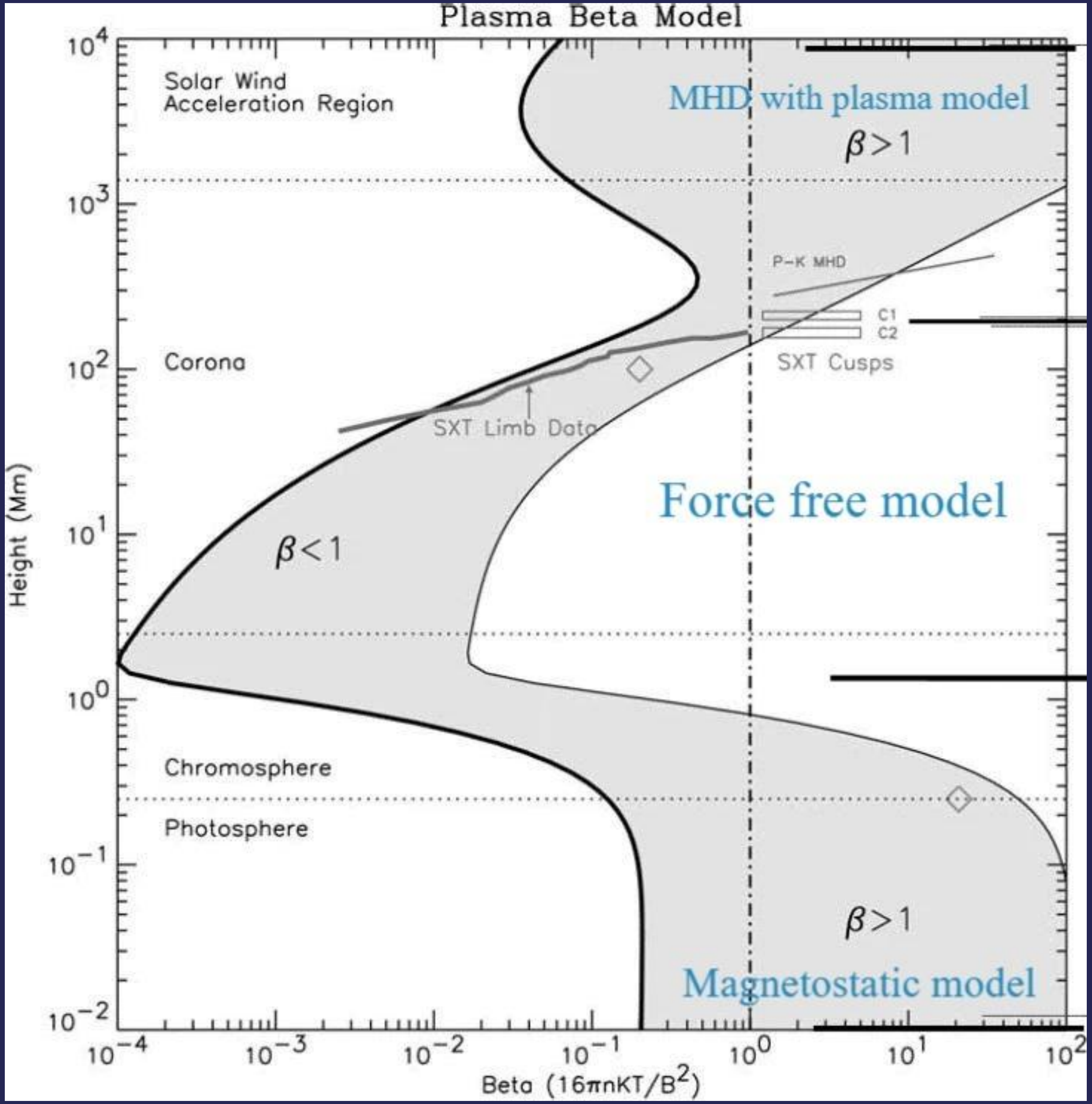
The vector field gained from tracking faint motions in time series of images in the Atmospheric Imaging.

How to associate the twist of a magnetic loop with its inherent magnetism?

Answer: **Force-Free field** $\alpha$ represents the twist for given field line; it provides a quantitative basis for the topology of a field line.

From the equation of motion of Solar MHD

- Pressure Force (plasma)
- The Lorentz Force
- Force due to Gravity

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# Force free magnetic field

MHD equation of motion:

$$\rho \frac{dv}{dt} = -\nabla p + (j \times B) + pg$$

Since magnetic field is in equilibrium,

net force in zero:

$$-\nabla p + (j \times B) + pg = 0$$

Lorentz term dominants the corona:

$$(j \times B) = 0$$

From Amper's law:

$$\nabla \times B = \mu_0 j \quad or \quad j = \frac{1}{\mu_0} \nabla \times B$$

Substituting for $j$ gives us:

$$\left( \frac{1}{\mu_0} \nabla \times B \right) \times B = 0 \quad or \quad (\nabla \times B) = \alpha B$$

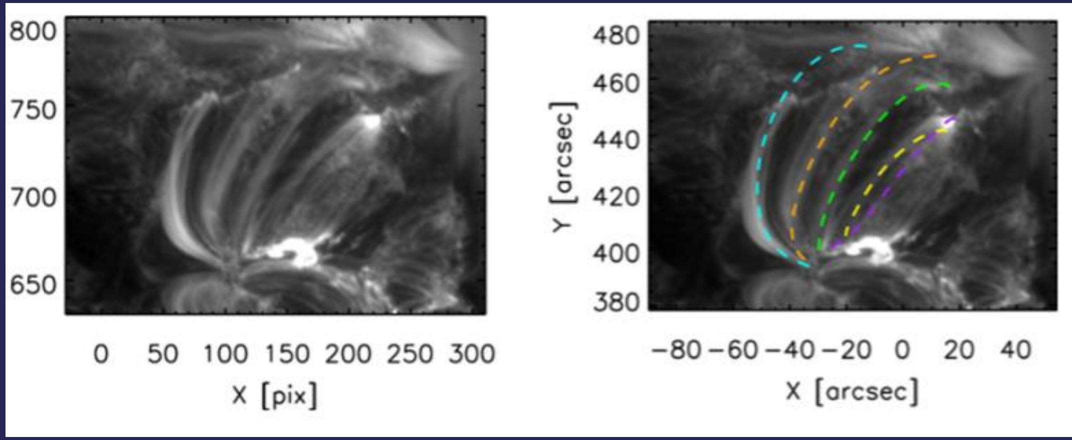
NLFF equation

- $\alpha$ represents the twist for a given field line; it provides a quantitative basis for the topology of a field line.
- $\alpha$ can be written as $\alpha = 4\pi n$, where n is the number of turns per unit length.
- $\alpha$ has units of inverse length accentuating its inherent connection to spatial dimensions.
- $\alpha$ and $j$ are related.
- $\alpha$ can also provide information about the current density, $j$, in the loops.

# Procedure

- From the loops very little can be known about the actual magnetic field lines.
- The idea is to draw the loops on a computer screen and comparing these curves with the shape on the field lines with a range of different alphas.
- The best fitting line, for a given loop, would give the best estimate of alpha for that loop;.

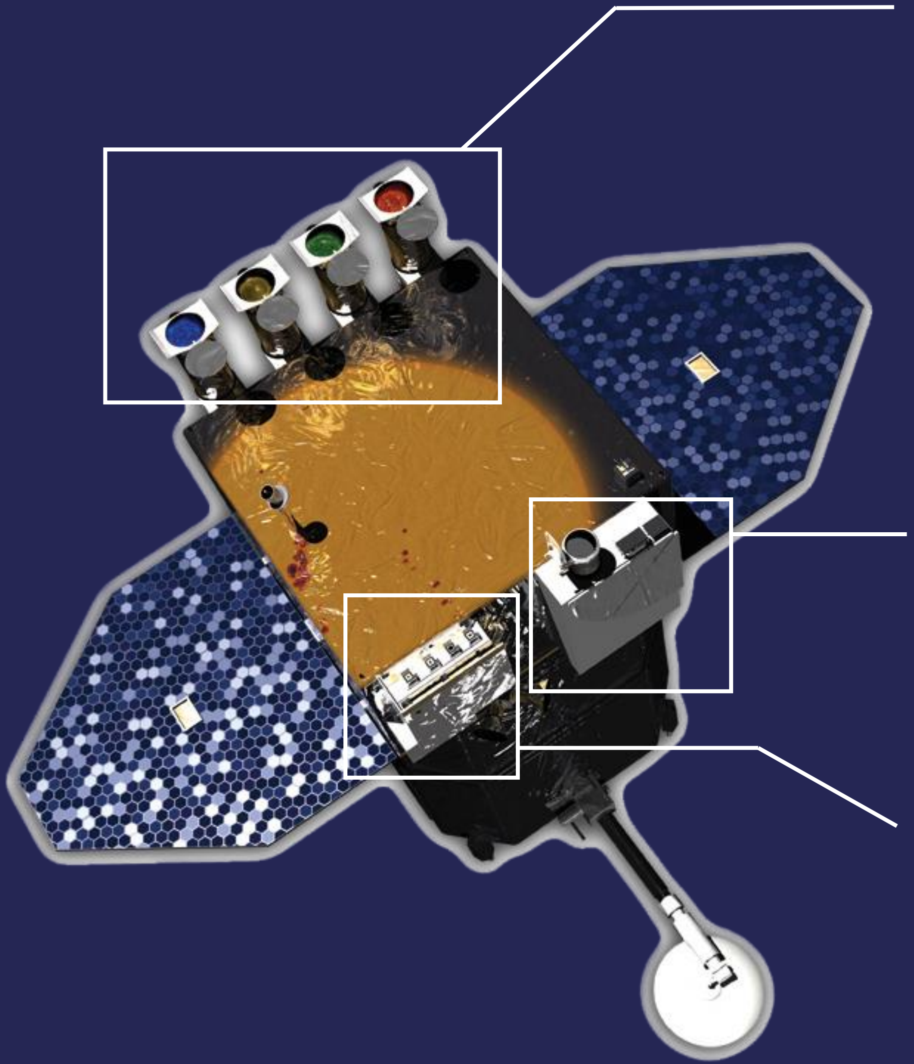
- For a given α and a photospheric flux distribution, Bz, the solution can be obtained using Green's Function (Chiu and Hilton, 1977).
- The Green's Function is a function of α; for different alphas we have different Green's Function.




The α–h fitting method of Malanushenko
Knowing the magnetic field enables the plotting of field lines

Data-observed By SDO → Applying TNOF → Computing the Magnetic field → Tracing the Loops in EUV → Manual fit Auto fit

# SDO - Data



**AIA (Atmospheric Imaging Assembly):**

Multi-Wavelength Images: High-resolution images of the solar atmosphere in various extreme ultraviolet (EUV) wavelengths (171, 193, 304).

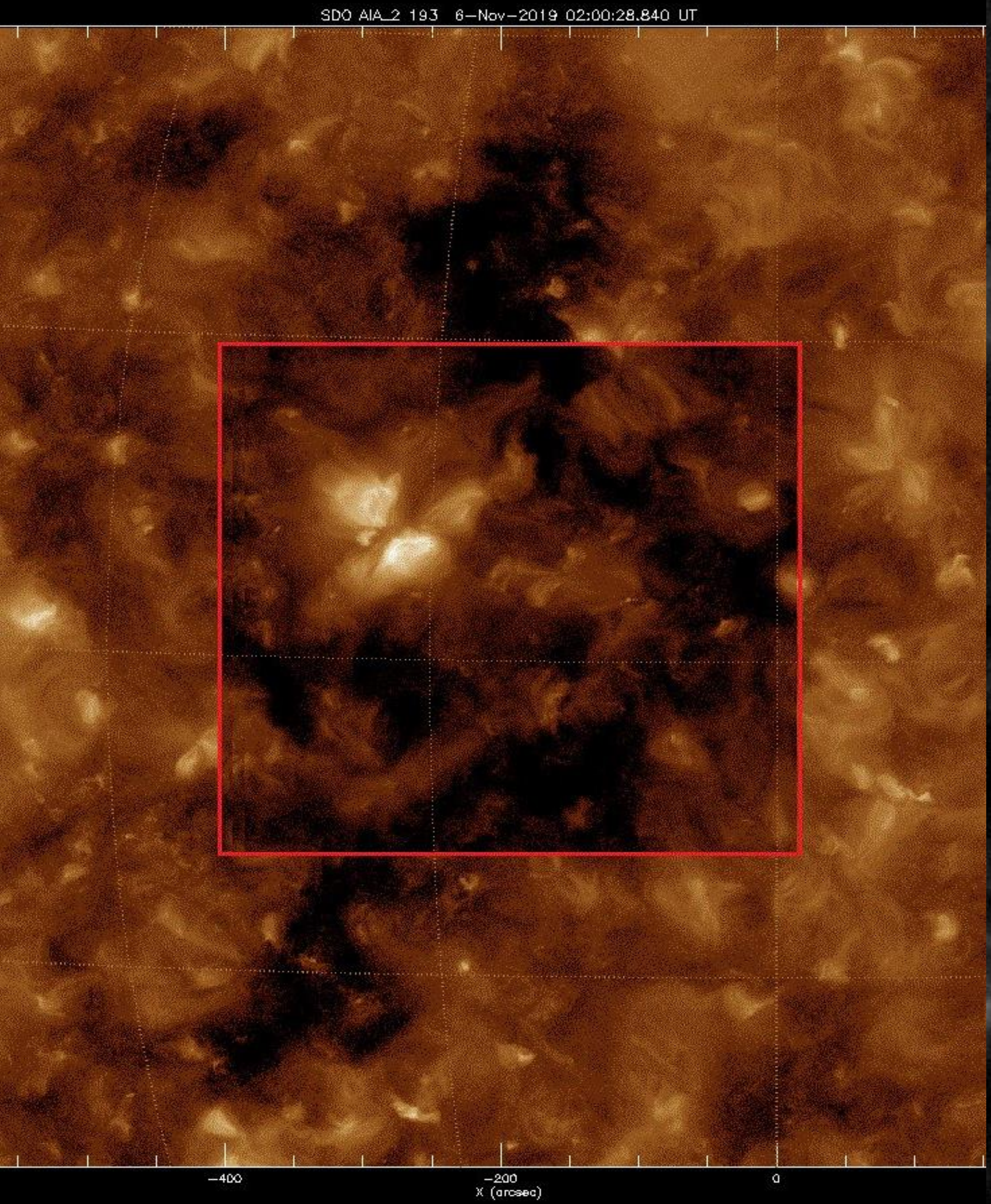
Coronal Imaging: Observations of the corona's outer layers, including the transition region, which aid in studying temperature variations and structures.

**HMI (Helioseismic and Magnetic Imager):**

Photospheric Magnetic Field: Precise measurements of the Sun's magnetic field strength and polarity in the photosphere.

**EVE (Extreme Ultraviolet Variability Experiment):**

Capturing detailed spectral data to study variations in EUV emission lines from the solar corona.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-400
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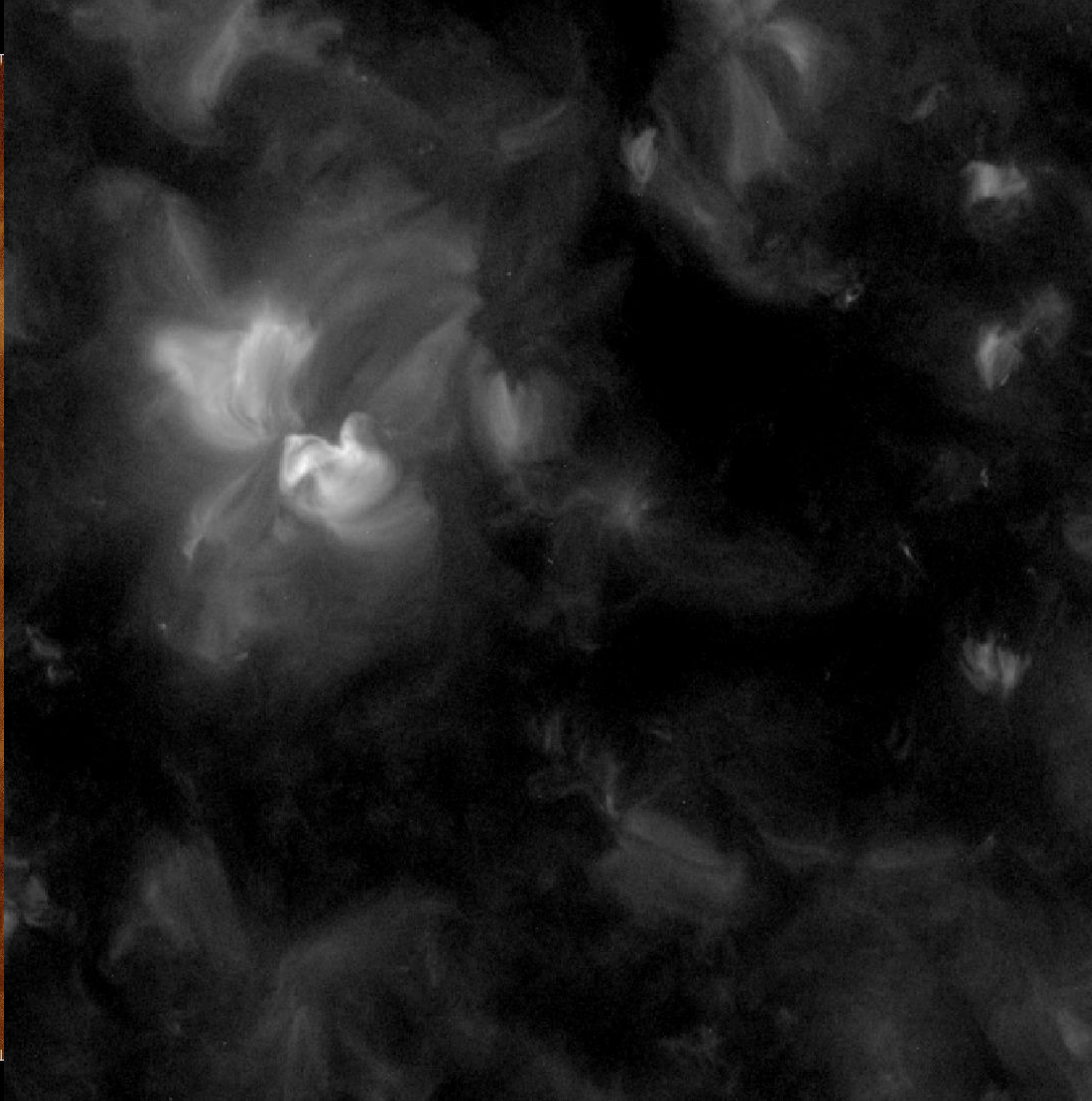
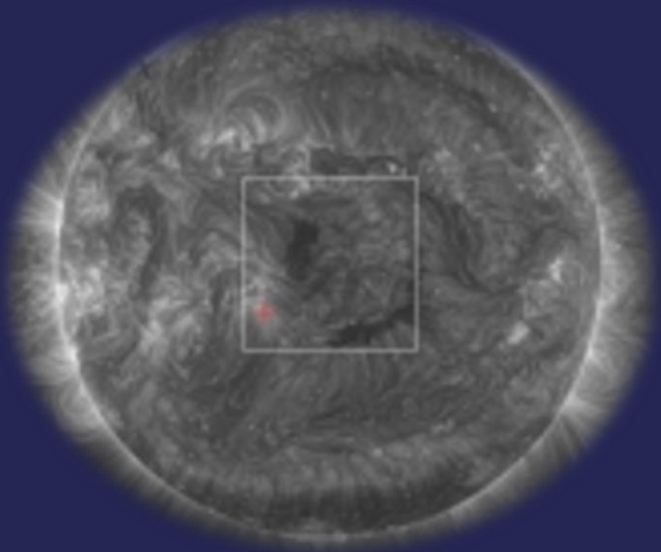
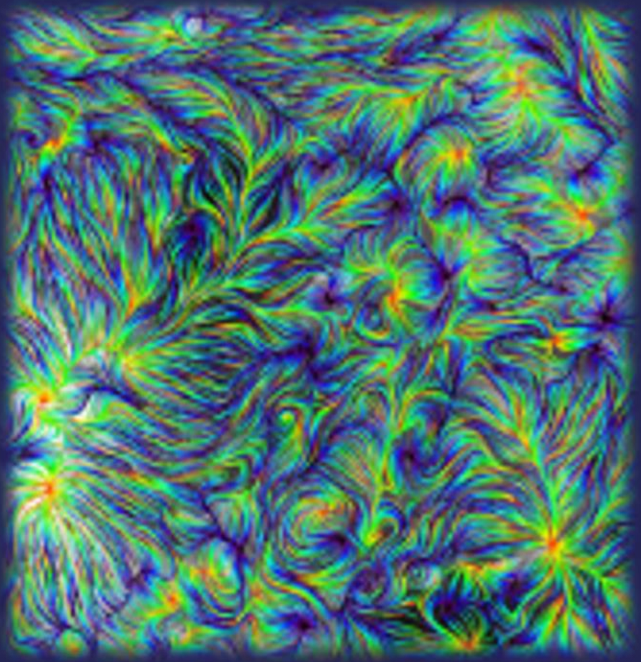


# TNOF- Time-Normalised Optical Flow

- TNOF is a processing technique used to track faint coronal propagating disturbances (CPDs)
- It involves normalizing the time axis of the image sequence, which removes the spatial variations in intensity and reveals the faint propagating disturbances.
- An optical flow algorithm is then applied to track the motion of these disturbances over time.
- It is a computer vision technique that tracks the movement of objects in an image sequence by analysing the changes in pixel intensity between frames.
- By applying TNOF to define EUV images of the solar corona, we can reveal continuous propagating faint motions throughout the corona, with amplitudes typically 2% of the background intensity.
- The motion vector field generated by TNOF describes large-scale coherent regions that converge at narrow corridors, and large-scale vortices can also be seen.





Top: region near disk center, observed by AIA 193Å during 21 March 2015. Bottom: The TNOF velocity vector field for AIA 193Å. Colour indicates the propagation direction, blue to red.

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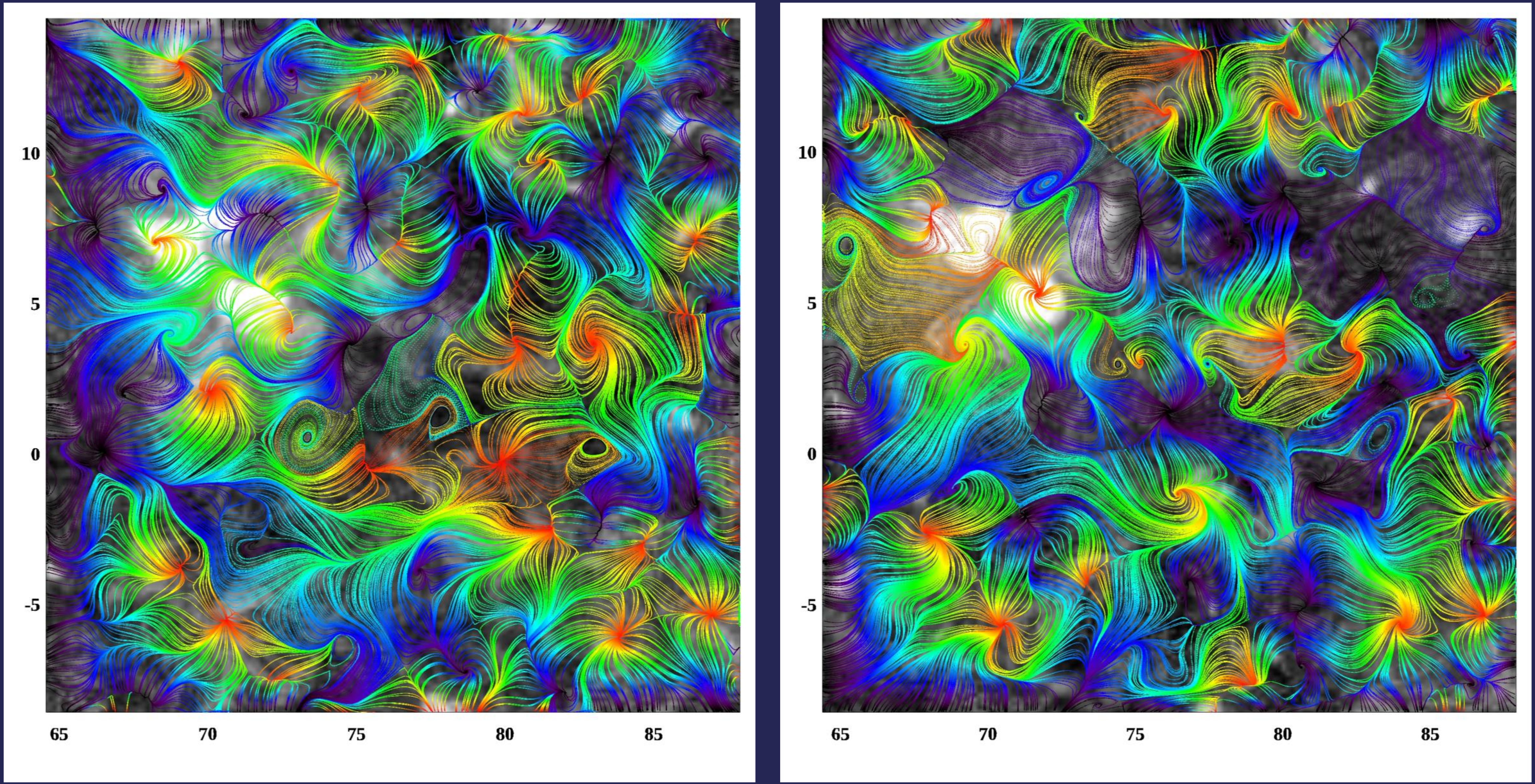


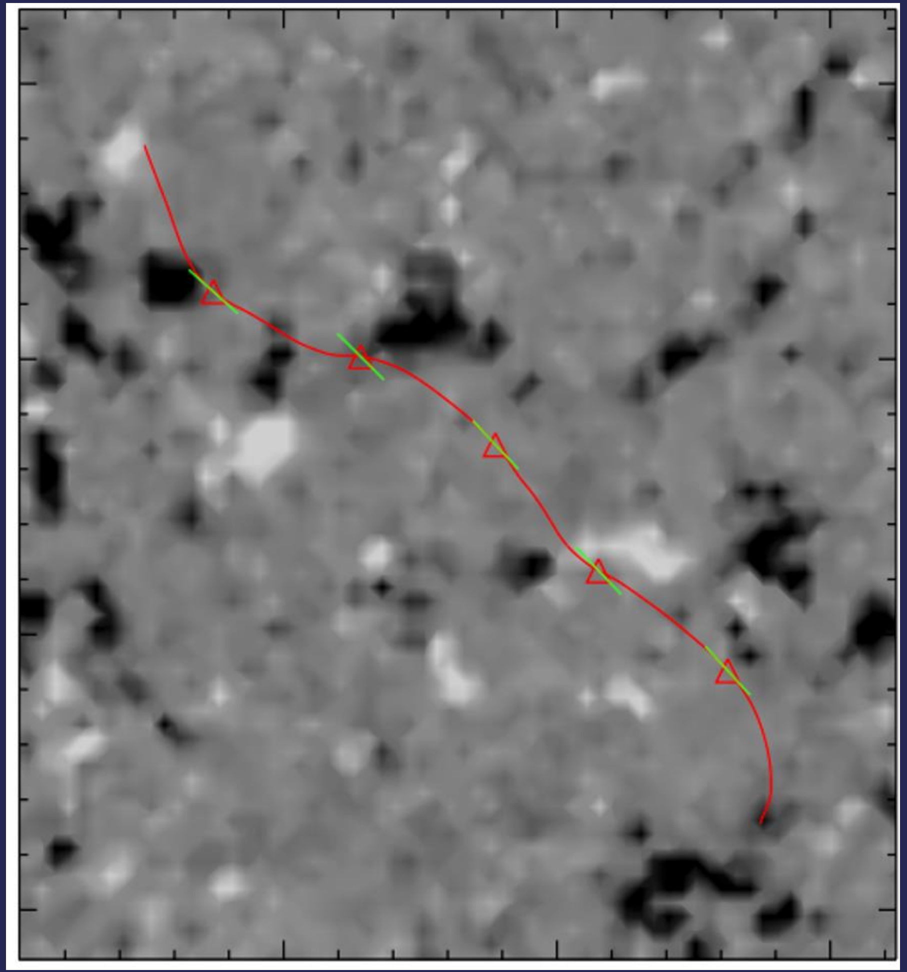

(Left) A velocity vector field was obtained by tracking faint motions in the time series of AIA 193 channel images 01:00-03:00. (Right) The same region of the disk, 13:00-15:00

# Main Results

- The TNOF method is employed to track magnetic waves, and through comparisons, it corroborates the alignment of magnetic field, B. Additionally, the TNOF velocity provides valuable constraints on the non-linear force-free field (NLFF).

- The parameter $\alpha$ also offers insights into the current density, j, within the loops. These combined observations yield broad constraints on the behavior of the solar corona.

- The optimal values found for the TNOF method are α=0.06 and h=1.12 Rs.



Optimal fit of a NLFF magnetic model at 5 selected points (green segments) to one of the TNOF flow paths (red)

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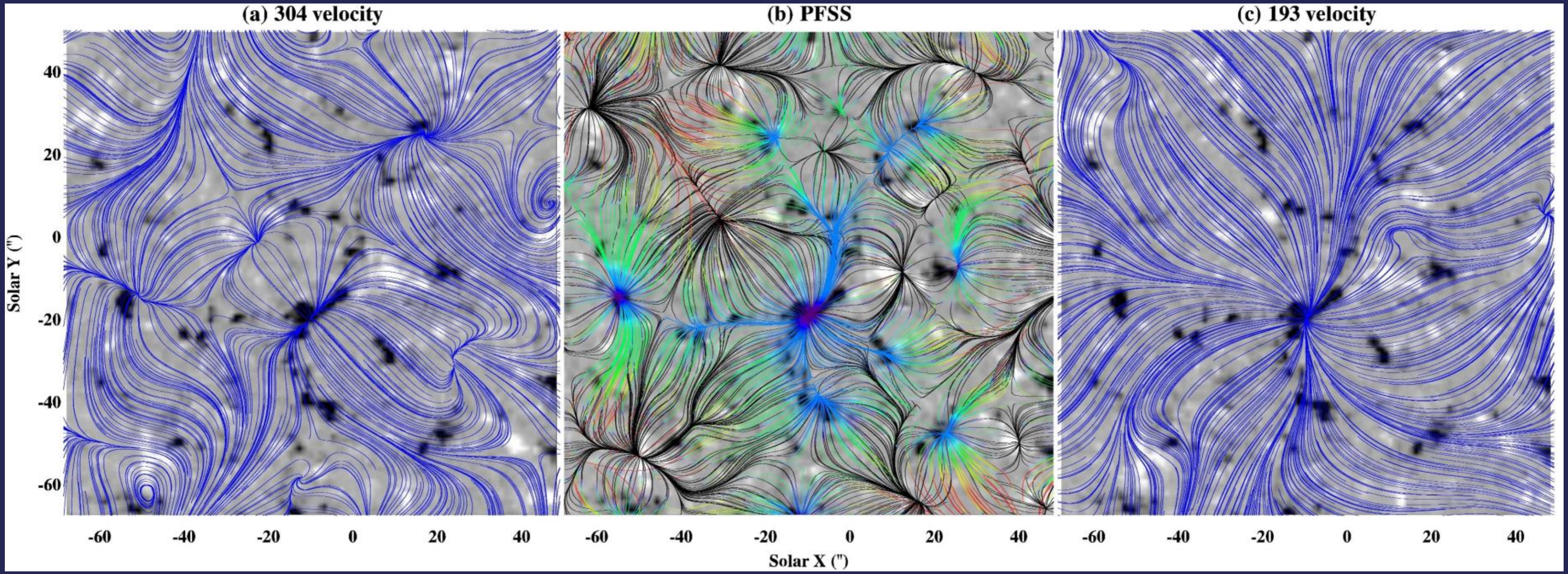
# Future work

The next steps in this project involve implementing the two independent methodologies and applying them to a range of coronal observations. The resulting magnetic models will be compared to existing models and in situ measurements to assess their accuracy and improve our understanding of the Sun’s coronal magnetic field.




Comparison of the velocity fields of the (a) 304 and (c) 193 channels, with (b) field lines traced from a potential field extrapolation, for a small region near disk center. The extrapolated field lines are coloured according to height, with black being very low-lying lines, followed by blue, green, yellow and red. The background image is the HMI magnetogram observed at 2018 October 27 13:00UT.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Diolch! Thank you!