Comparing Coronal Hole Properties During the Descending Phases of Solar Cycles 23 and 24

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Background

Coronal holes. — The Sun’s corona has a temperature of about a million Kelvin (MK) that emits strongly in the extreme ultraviolet (EUV; a few hundred Å) wavelength. Above active regions (ARs) where sunspots reside, the coronal plasma can be hotter (a few MK) due to interactions with strong magnetic field (several thousand Gauss). There are also regions with cooler temperature (sub-MK) and lower density known as coronal holes (CHs). They appear dark in EUV observations (Figure 1).

The coronal structures are determined by the magnetic field configuration. For example, CHs are associated with unipolar, open magnetic field of a few G on average at the photosphere that extends all the way into the interplanetary space. They are the source of fast solar wind (up to 800 km s\(^{-1}\)) that can produce space weather disturbances including aurora.

Cyclic magnetic fields. — The solar activity and magnetic field undergoes 11-year cycles. We have routine measurements of magnetic field in the photosphere and can describe the field mathematically using spherical harmonics.

1. During the maximum phase, the Sun’s lower latitudes (below 30°) are covered by ARs. In high-latitude regions (above 60°), the mean field is weak and close to zero. The higher order (larger \(l\)) are important.

2. During the minimum phase, the lower latitudes become quiet and the polar regions has a mean field of several G. Magnetic field can be approximated by a dipole (\(l = 1\)). From one minimum to the next, the dipole changes sign.
The descending phase refers to the period between the activity maximum and the next minimum when the ARs decay away. The dipole/high-latitude field grows stronger as remnants of the AR field get carried poleward by meridional flow. High-order components become weaker.

The ascending phase refers to the period between the minimum and the next maximum.

**CH during descending phase.** — During a typical minimum phase, the strong axial dipole component ($l = 1, m = 0$) ensures that the polar region magnetic field is open. The polar regions become large CHs. Fast solar wind comes only from these regions and can rarely impact the Earth. However, for the minimum phase between Cycles 23 and 24 (2004-2006), the equatorial dipole ($l = 1, m = 1$) and quadrupole components ($l = 2$) were relatively strong. There were many low-latitude CHs directly facing the Earth; aurorae were more frequent. Such structures are related to a weaker upcoming Cycle 24 is.

**Project description**

The maximum phase of Cycle 24 occurred around 2014. We start to see huge CHs covering almost half of the Sun (Figure 1) during the current descending phase. We wish to ask the following questions.

1. What are the size and location of the CHs during the descending phase of Cycle 24 (2016-2018)?
   How do they compared to those of the previous Cycle (2004-2006)?

2. What is the magnetic field inside CH like? What are the dipolar and quadrupolar components of the solar magnetic field of the two descending phases? How are they related to the CH properties?

3. How well can we model the size and location of the CHs?

This is a relatively large project. The questions should be worked on sequentially. For a single-student, ten-week program, the expectation is to work on Q1 and part of Q2 only.

For Q1, we will analyze the EUV images taken by the Atmospheric Imaging Assembly (AIA) on board of the SDO spacecraft for Cycle 24, and those taken by the Extreme Ultraviolet Imaging Telescope (EIT) on board the SoHO spacecraft for Cycle 23. We will retrieve these images using SunPy, determine the boundary of the CHs, and measure their location/size.

For Q2, we will analyze photosphere magnetic maps taken by the Helioseismic and Magnetic Imager (HMI) on SDO for Cycle 24, and the Michelson Doppler Imager (MDI) on SoHO for Cycle 23. We will perform spherical harmonic decomposition and compare results from Q1 and Q2.

For Q3, we will use the potential field source surface (PFSS) model, which takes the magnetic maps as the lower boundary and infer the coronal magnetic field. We will find the foot points of the open magnetic field lines as the location of modeled CHs. The modeled CH will be compared with observation.

**Getting Started**

1. Install the SunPy package. Check out AIA/HMI images on the SolarMonitor/Helioviewer website. Retrieve one AIA 193 Å and one HMI magnetogram for a particular time. Inspect and plot the images using ds9/Python.
2. Figure out the center of the solar disk, its radius, the latitude and longitude of each pixel of your selected image.

3. Identify regions you think are CHs. Compute the mean value for a small patch inside CH and compare it with a quiet Sun region nearby.

Reference & Software

SunPy: http://sunpy.org/
SolarMonitor: https://solarmonitor.org
Helioviewer: https://www.helioviewer.org
ds9: http://ds9.si.edu/site/Home.html