Characterizing δ-sunspots and an introduction to 'Degree of δ'

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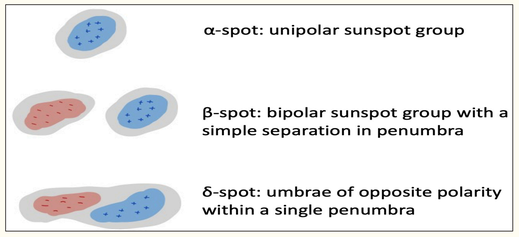
Abstract

A new quantity, the degree of δ (DoD), is introduced to characterize the fraction of active region umbral flux that is participating in the δ-configuration. For sunspot groups in Solar Cycle 24, we analyze Spaceweather HMI Active Region Patches (SHARPs) to calculate the temporal variations of DoD, magnetic flux, flux emergence rate, polarity footpoint separation, rotation and tilt angle for δ-spots and a control group of sunspots that are not in a δ-configuration. We report the calculated quantities at the time the region is at the maximum DoD and also at the time of maximum magnetic flux.

By isolating the umbrae involved in the δ-configuration, our measured parameters depict the dynamics of participating flux tubes more accurately than assuming a total bodily emergence of the active region. On average, δ-spots spend 63% of their time on the disk in a δ-configuration, meaning that the δ-configuration is not present during the entire time such active regions are observed. δ-spots rotate more, separate less and emerge faster than other sunspots. When isolating the δ-portion of the spot, 74% of Solar Cycle 24 δ-spots are in either an Anti-Hale or Anti-Joy configuration compared to 17% of the control group of sunspots. Finally, maximum flare energy, which has implications for space weather prediction capabilities, is correlated to the umbral flux isolated in the δ-regions.

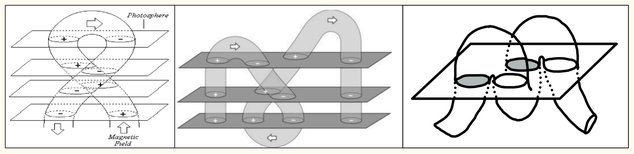
An introduction to δ-sunspots



Characteristics of δ-sunspots:

→ umbrae of opposite polarities within 2° of one another, contained in a single penumbra
→ short-lived compared to same size non δ-sunspots
→ anti-Hale
→ polarities do not separate

Flux tube geometries that could lead to δ-sunspot formation:



[kink instability, inverted kink instability, multi-segment buoyancy]

Motivations for studying δ-sunspots

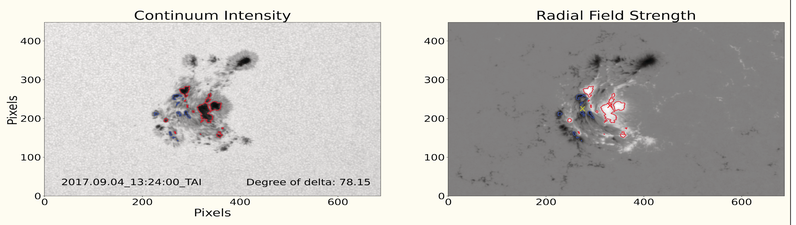
~8% of Solar Cycle 24 spots were in δ-configuration
(133 δ of 1657 active regions obs. by HMI)
~10% of delta spots produce X class flares
~80% of X-class flares originate in δ-regions

δ-sunspots are the source of many geo-effective space weather events

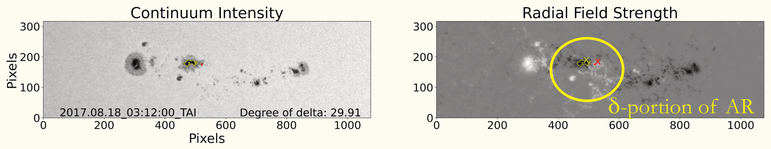
Defining Degree of δ

Degree of δ: the sum of unsigned umbral flux participating in the δ-configuration divided by the sum of total unsigned umbral flux of the active region.

The following shows the intensitygram and magnetogram of a sunspot (NOAA #12673) at a time where 78.15% of its total umbral flux is oppositely signed and contained within a single penumbra; DoD = 78.15%



• By isolating emerging regions of interest, we can determine
→the time that the δ-portion of these sunspots is formed
→lifetime in a δ-configuration
→ other parameters of interest without assuming a synchronous total bodily emergence
→ highlights potential flare-producing, shearing regions inside of larger active regions



Intensitygram and magnetogram of NOAA #7107 with the δ-region outlined

Data & Analysis

• Data collected via the Helioseismic and Magnetic Imager (HMI) on board the Solar Dynamics Observatory (SDO)
• 126 ARs observed in a δ-configuration

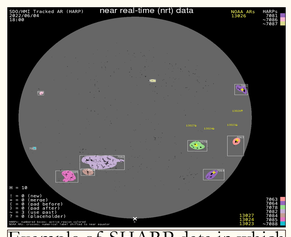
To analyze these ARs:

• Remove limb darkening, and constrain ARs to 55°
• Umbral-penumbral-quiet sun boundaries were set via I_c and B_r as recorded by HMI

Characterize ARs at two times

Time 1: values using the entire AR when the region is at its maximum flux

Time 2: values using only the δ-portion of the AR at its maximum DoD



Example of SHARP data in which active region data is cut-out from the full-disk image.

Measured Observables:

• DoD
• Tilt angle, anti-Hale (AH), anti-Joy (AJ)
• Flux and Flux Emergence
• Footpoint separation
• Flare energy (maximum and total)

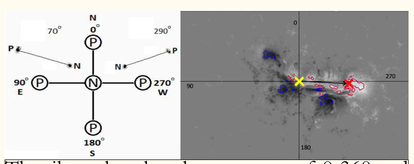
Samples:

Small sample of 18 δ-sunspots and 12 β-sunspots (control)

→ analyze δ-sunspots at Times 1 & 2 and β-sunspots at Time 2

Large sample of 126 δ-sunspots

→ analyze for more limited values (AH/ AJ, DoD, umbral flux, flare energies)



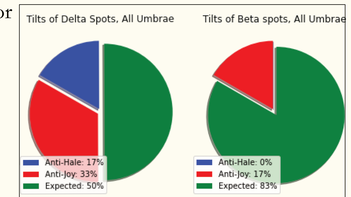
The tilt angle values have a range of 0-360 and are defined by putting the centroid of the negative polarity at the origin.

Results

The behavior of δ-spots can be described as follows

1. Compare δ-spots (total umbrae) to β-spots:

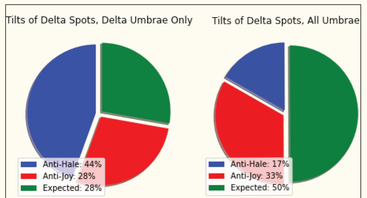
• δ-spots are 3 x more likely to be in AH or AJ tilt-configurations
• δ-spots have 3 x the max umbral flux
• Equal footprint separation at max flux
• δ-spots have 4 x rotation rate
• δ-spots experience ¼ the separation
• δ-spots last 1.5 x longer
• δ-spots produce 60 x more flare energy



Tilt configurations for δ-spots (left) and β-spots (right) from small sunspot sample groups.

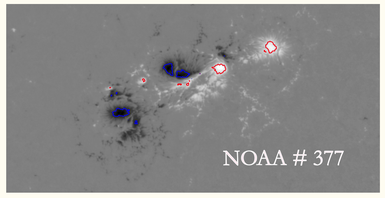
2. Compare isolated 'δ-umbrae' to umbrae in entire active region:

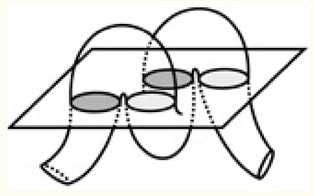
• δ-umbrae are 1.44 x more likely to be in AH or AJ tilt- configurations
• δ-umbrae have ¼ the max umbral flux
• δ-umbrae have half the footprint separation at max flux
• δ-umbrae have > 2 x the rotation rate
• δ-umbrae converge over time
• δ-umbrae are short lived



Tilt configurations for isolated δ-umbra (left) and total δ-spot umbra (right) from small sunspot sample groups.

Classifying δ-spot Geometries





Of the small sample of δ-spot ARs:

• 4 had observational signatures consistent with a kink instability
• 3 had observational signatures consistent with interacting active regions
• 6 had observational signatures consistent with multi segment buoyancy, or quadrupole
• 4 had observational signatures consistent with inverted kink instability

Conclusions & Discussion

The importance of isolating the delta-portion of the AR are as follows.

→ Tilt angles and other observables are vastly different when calculated using the delta umbrae than when calculated using the entire AR.

→ The kink instability acts on a smaller spatial scale than the entire AR.

→ Isolating the flux involved in the delta allows us to more precisely examine the twist and other conditions that allow a delta spot to form.

The importance of classification are as follows.

→ We have an automated process for 10+ observables for δ-spots which can be mapped to a likely formation process of the δ-spots.

→ Classifying δ-spots allows for a greater understanding of instabilities acting on flux tubes as they emerge into the solar atmosphere.