Study of Coronal Hole Lifetimes

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Coronal Hole lifespans over two solar cycles W/The McIntosh Archive

Introduction

In 1964 (Solar Cycle 20), Patrick McIntosh began creating hand-drawn synoptic maps of solar magnetic features, based on Ha images. These synoptic maps were unique in that they traced magnetic polarity inversion lines (PILs) and connected widely separated filaments, fibril patterns, and plage corridors to reveal the large-scale organization of the solar magnetic field (McIntosh, 1979, NOAA, UAG-70). Coronal hole boundaries were later added, primarily from ground-based He I 10830Å images from NSO-Kitt Peak and Sac Peak Solar Observatories. McIntosh briefly used He I 10830Å data for adding coronal holes in 1978 (for 3 rotations), however, he didn't begin using the Helium data consistently until 1981. We have added coronal hole data to the maps of rotations prior to 1981 when available from Kitt Peak Solar Observatory beginning with CR1614 in April 1974. Magnetograms were used to determine the overall dominant polarity of each region. The maps were produced, with some gaps, into 2009, the start of SC 24. The result was a record of ~45 years, ~600 Carrington Rotations (CRs), or over four complete solar cycles of synoptic maps. We are currently completing missing or incomplete maps, as well as digitizing and archiving all of these maps, with the final, searchable versions (Figure 1) publicly available at NOAA's National Centers for Environmental Information https://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-imagery/composites/synoptic-maps/mc-intosh/. Currently 551 of 600 Carrington Rotations have been completed, with coronal holes added or revised to 59 maps, mostly in SC21 (Webb et al.,2018, Frontiers, Astronomy Journal, 5, 23). This study covers most of SC21, SC22, SC23 and the beginning of SC24 for a total of about 310 CR's. When we have added coronal holes and completed the 25 missing and incomplete maps in SC21, we will include them in this study for a paper.

Focus of study

We are looking at coronal hole positions and lifetimes over about three solar cycles. Our interest the relationship between the magnetic cycle and activity cycle, as well as any relationship between the positions and time of appearance of sunspots in relation to the positions and time of appearance of long lived low latitude coronal holes. We subdivide coronal holes into three primary varieties. First we separate those with a polar component (which we define as any coronal hole that has a maximum latitude of above 89 degrees), from non-polar (any coronal hole that has a maximum latitude of 89 degrees or less). Then we further subdivide the non-polar into short lived (they only appear in one Carrington Rotation) and long lived (they appear in approximately the same location on more than one consecutive Carrington Rotation.

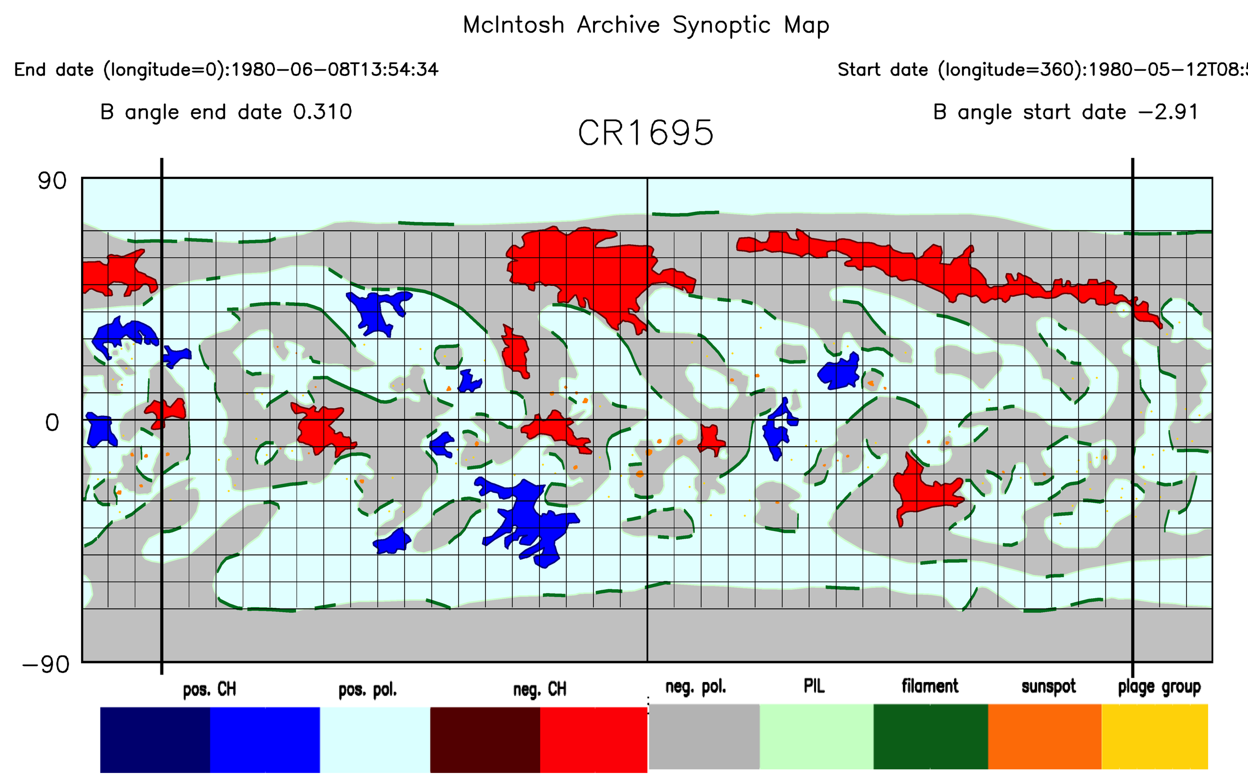

Figure1 LVL3GIF

The McIntosh Archive (McA) synoptic maps are a global representation of the evolving solar magnetic field. This is an example of a processed McA synoptic solar map. Magnetic features are identified by a distinct number or color, as described in the legend.

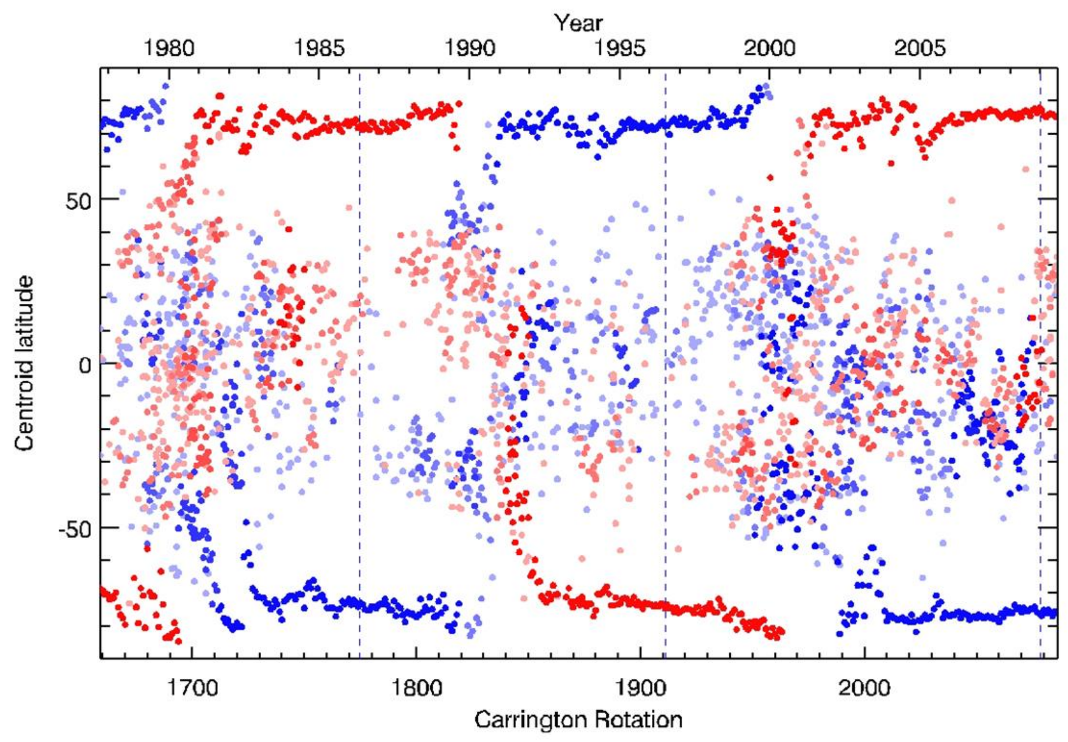

Figure2

All coronal hole centroids are shown in this plot for about 3 solar cycles by Carrington Rotation, year and latitude. Red represents negative polarity and blue represents positive, with the darker shades representing more "lifetimes". We define lifetimes by the number of rotations a given coronal hole recurs. The 11 year magnetic polarity flip as observed by Lowder et al. 2017 is shown here as well as the slight asymmetry of the appearance and evolution of coronal holes at each pole (Webb et al., 1984, Sol Phys., 92, 109).

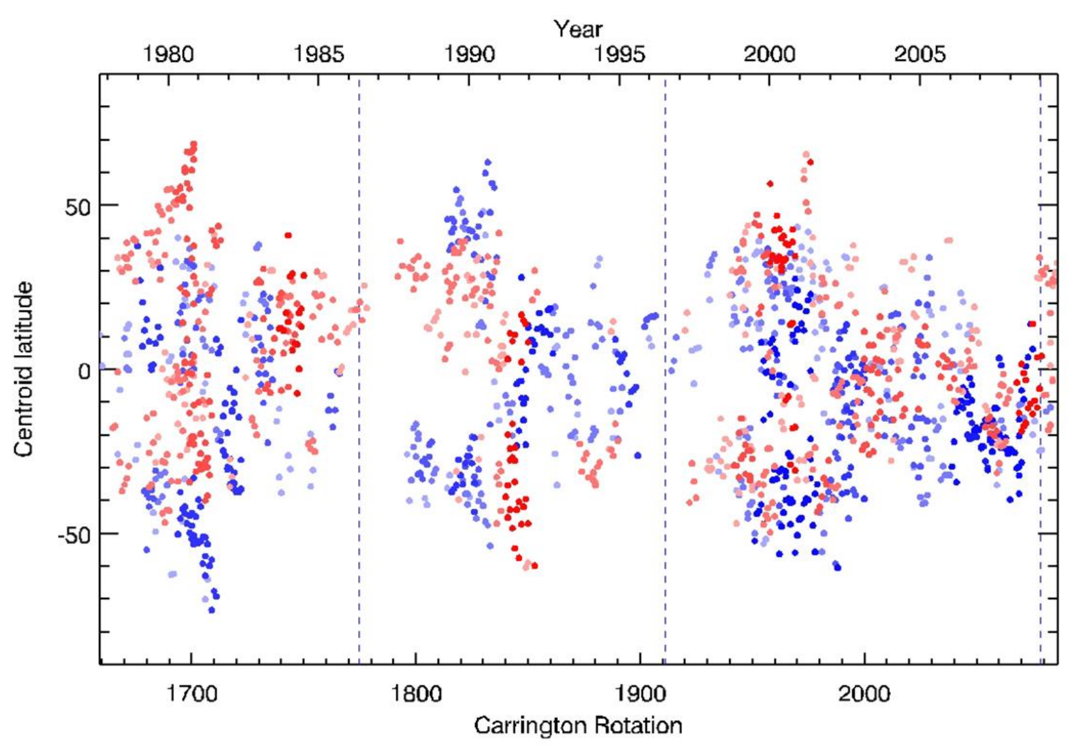

Figure3

This plot is a subset of Figure2 and shows all coronal holes that do not have a polar component that have a lifetime of more than one rotation plotted by centroid. Again, red represents negative polarity and blue represents positive, with the darker shades representing longer "lifespans".

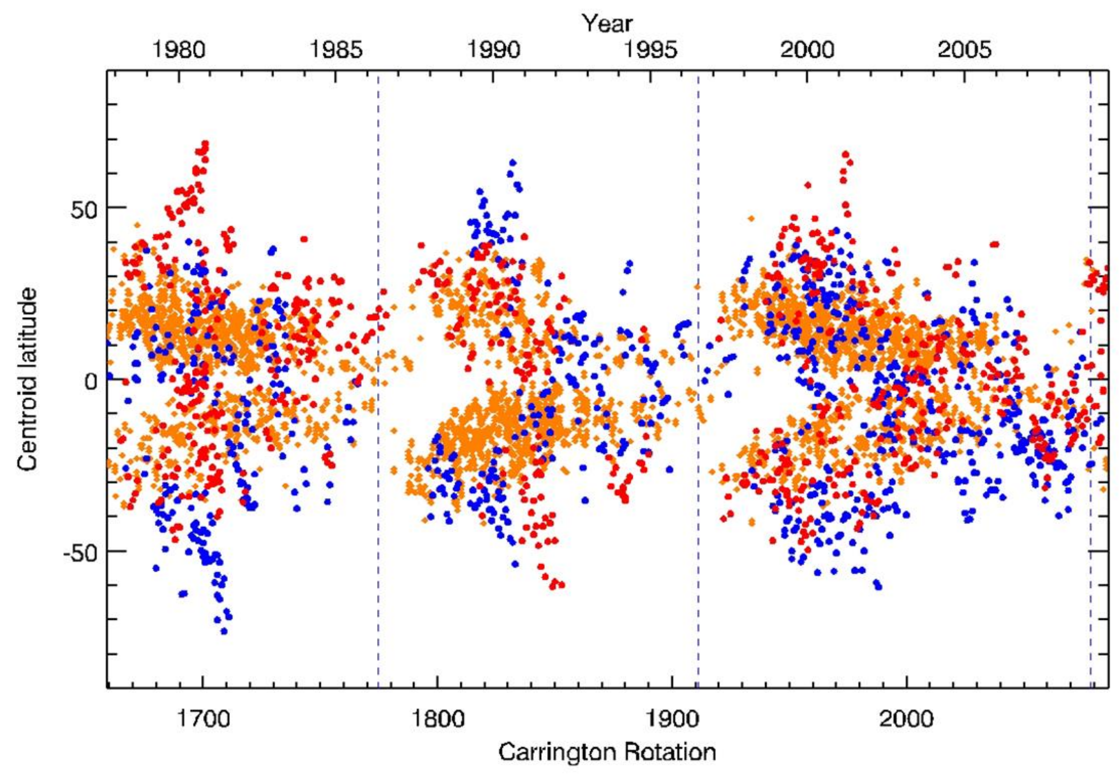

Figure4

This plot shows all coronal holes that do not have a polar component that also have a lifetime of more than one rotation (ie. Figure3 but without shading to demonstrate lifetime information) plus sunspots all plotted by centroid over about 3 solar cycles plus plotted by Carrington rotation, year and latitude. Note the similarity in the butterfly pattern. S. McIntosh et al. (2015, Nature Comm., 6, 6491) have also reported a butterfly structure in temporal evolution of the latitude distribution of coronal hole centroids."

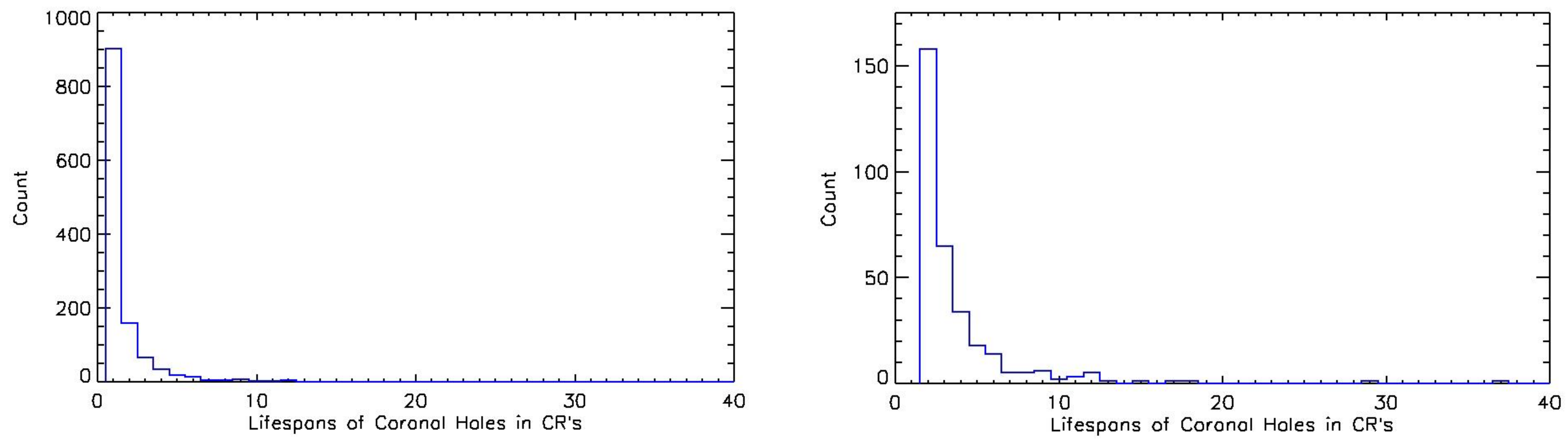

Figure5a and 5b

These plots show the numbers of non-polar coronal holes by the number of Carrington Rotation lifetimes experienced by each coronal hole or group of them if they tend to divide. The one on the right does not include the single rotation lifetimes but they are otherwise the same.

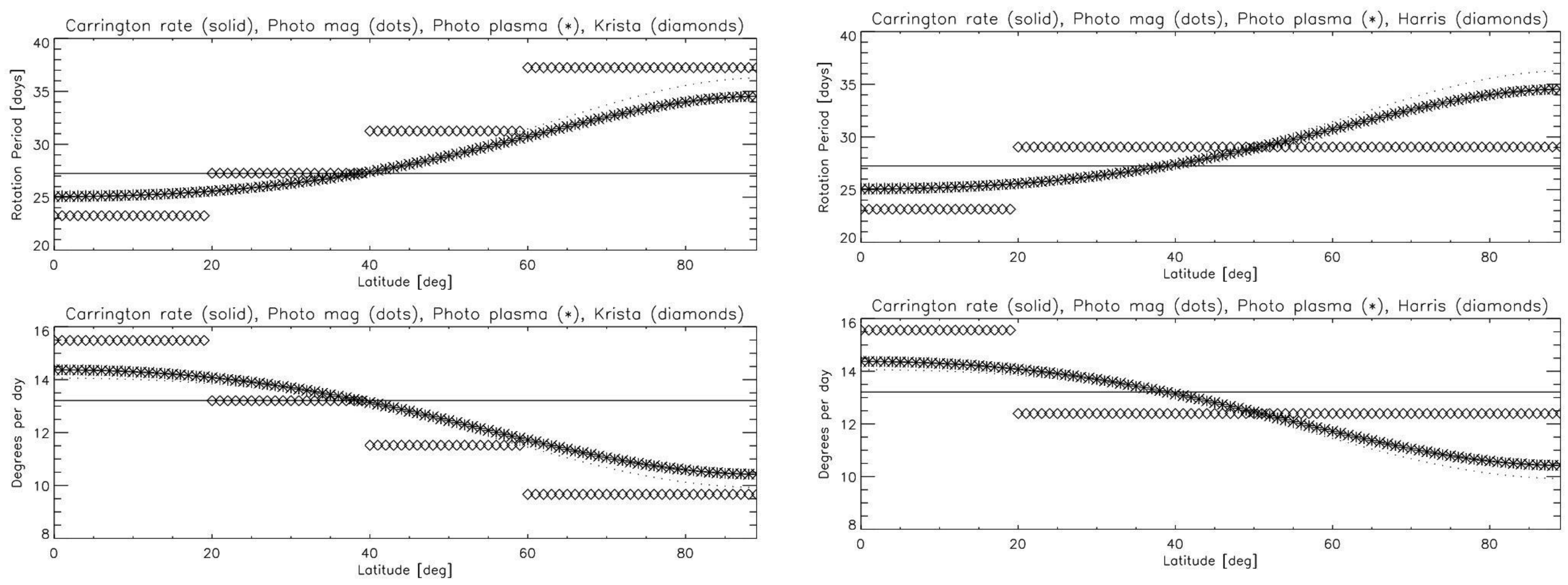

Figure6a and 6b

These plots show differential rotation of various features versus the Carrington Rate. The Carrington rate, used in the McA synoptic maps, is the flat line representing approximately 13.3 degrees rotation per day regardless of Latitude and a fixed rotational rate of approximately 27.2 days. We used the Photospheric plasma rotation rate, seen here as the continuous line of stars, to track our coronal holes from rotation to rotation. The left plot has a rotational rate of coronal holes found by Krista et al. (2018) which shows minor deviation from the plasma rate for the three year period studied. Harris (a visiting REU student) began a study of differential rotation rates of coronal holes that found a similar rotation rate as Krista et al. did for lower latitudes. We hope to continue work with Harris to establish this rate with the McA and then apply it to our data in the manner we used the photospheric plasma rate for these plots.

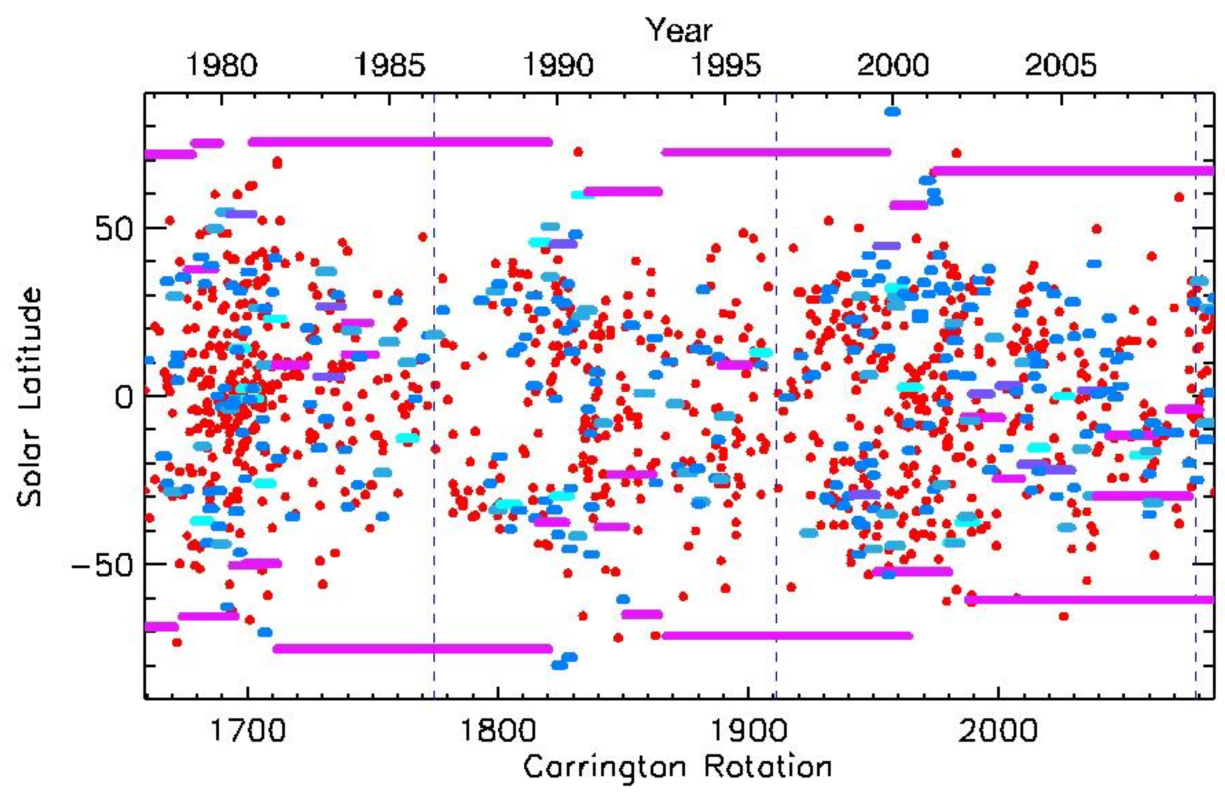

Figure7

This plot is another way to look at the positions of low latitude coronal holes and their lifespans by latitude and time. Each coronal hole is shown by heliographic longitude and lifespan over the two solar cycles, with color representing lifespan by rotation. Red represents 1 rotational lifetime, Blue 2 – 3 lifetimes, medium blue 4-5, light blue 6-7, cyan 8-9, purple 10-11, magenta 12+. A similar plot was created by Krista et al. (2018, Astron. J., Vol 155, Number 4, Figure 5b).

Conclusions: As we are missing the beginning of SC21 at this point some of our early lifetimes will be skewed. We find that the majority of low latitude non-polar coronal holes last less than one rotation and that less than one percent last for over 10 rotations. Krista et al. (2018, Astron. J., Vol. 155, Number 4), found that coronal holes within 10 degrees of the equator tend to show prograde movement, between 10 and 20 degrees they demonstrate both eastward and westward drift, however, above 20 degrees they predominantly show eastward movement. Our findings agree. The polar coronal holes are more prevalent than the low-latitude coronal holes in solar minimum. The polarity at the poles switches during solar maximum resulting in coronal holes of the opposite polarity appearing at each pole after solar maximum (Lowder et al. 2017, Sol Phys, 292, 18). The mid- and low-latitude coronal holes are on average short-lived and found at most latitudes in the ascending phase of the solar cycle, but are most prevalent and expansive in latitude at solar maximum (Mazumder et al., 2017, arXiv:1810.02133 [astro-ph.SR]). In solar maximum and the descending phase of the solar cycle, the mid- and low-latitude coronal holes are relatively long-lived, where new coronal holes appear closer to the equator in time, similar to the movement of sun spots and other solar structures in the famous 'butterfly' pattern as commented on by Mazumder et al., 2017, arXiv:1810.02133 [astro-ph.SR]) and S. McIntosh et al. (2015, Nature Comm.,6, 6491).

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Bohlin and Rubenstein, 1975, NOAA Report UAG-51
Krista, L.D. et al., 2018, Astronomical Journal, Vol. 155, Number 4
Lowder, C., et, al. 2017, Sol Phys 292: 18
Mazumder, R. et al., 2017, arXiv:1810.02133 [astro-ph.SR]
McIntosh, P. S., 1979, NOAA Report UAG-70
McIntosh, S. et al., 2015, Nature Comm., 6, 6491
Webb, D.F. et al., 2018, Frontiers, Astronomy Journal, 5, 23