

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. In addition, we used the manned Skylab EUV, He II 304Å data (Bohlin and Rubenstein, 1975, NOAA, UAG-51) to add coronal holes to 8 maps in 1973 and 1974 at the end of SC20. Magnetograms were used to determine the overall dominant polarity of each region. The maps were produced, with some gaps, into 2009, the start of SC24. 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 517 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 SC22, SC23 and the beginning of SC24 for about 310 CR's. When we have added coronal holes and completed the 42 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 three solar. Our interest is in looking at 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 less than 89 degrees). 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).

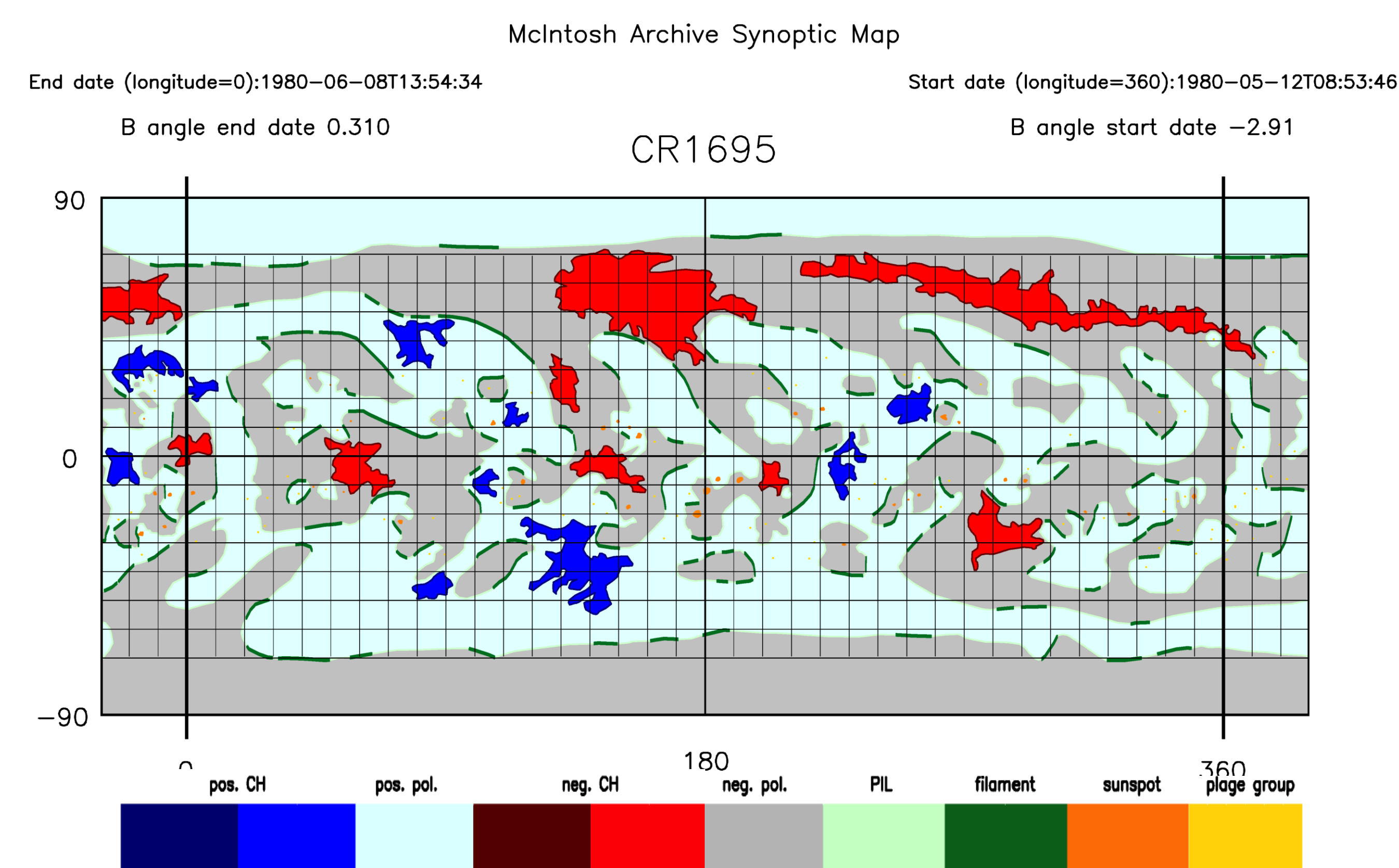


Figure1 LVL3GIF

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.

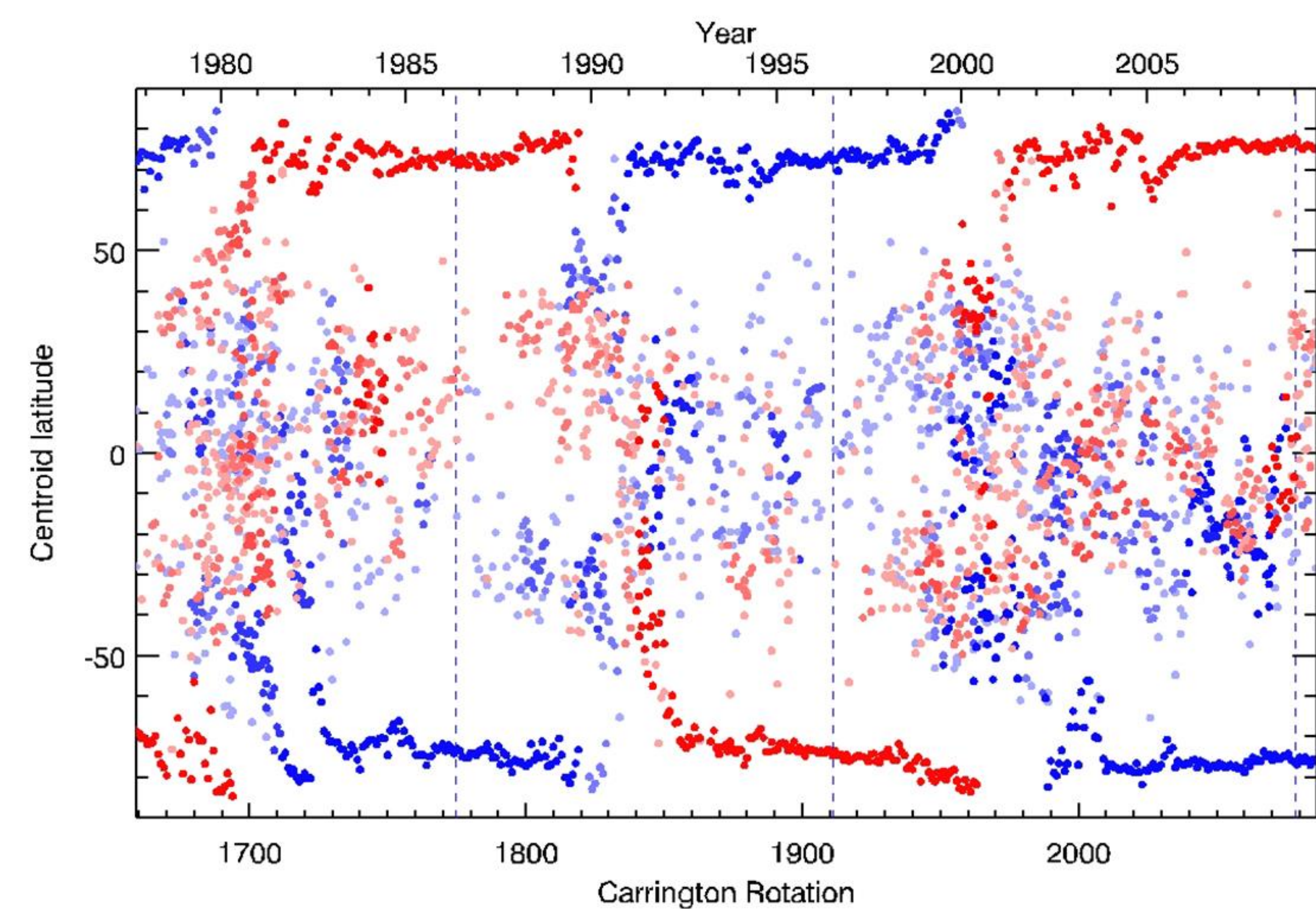


Figure2

All coronal hole centroids are shown in this plot for almost 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. This plot includes gaps of about 15 Carrington rotations near CR1900. 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).

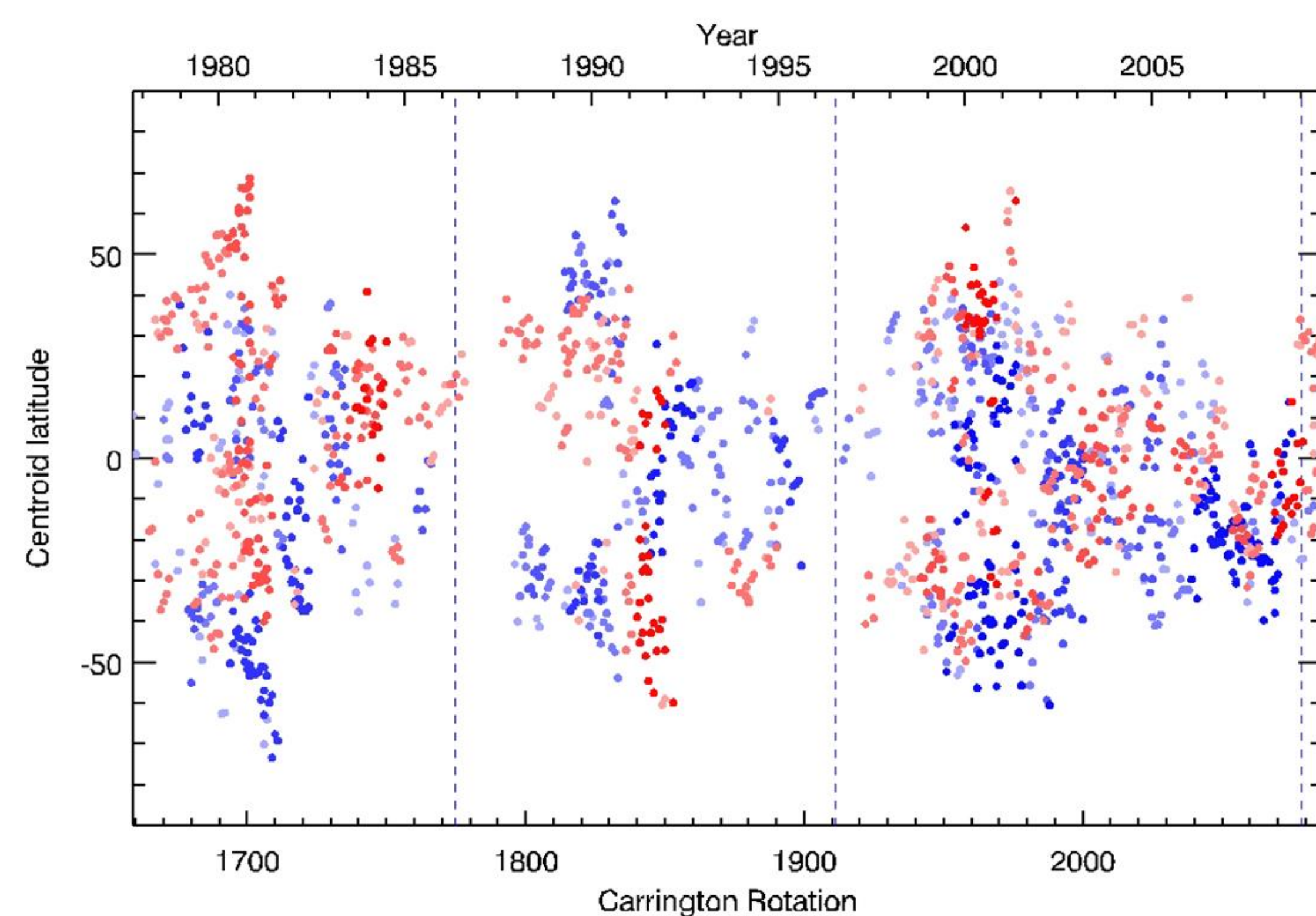


Figure3

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

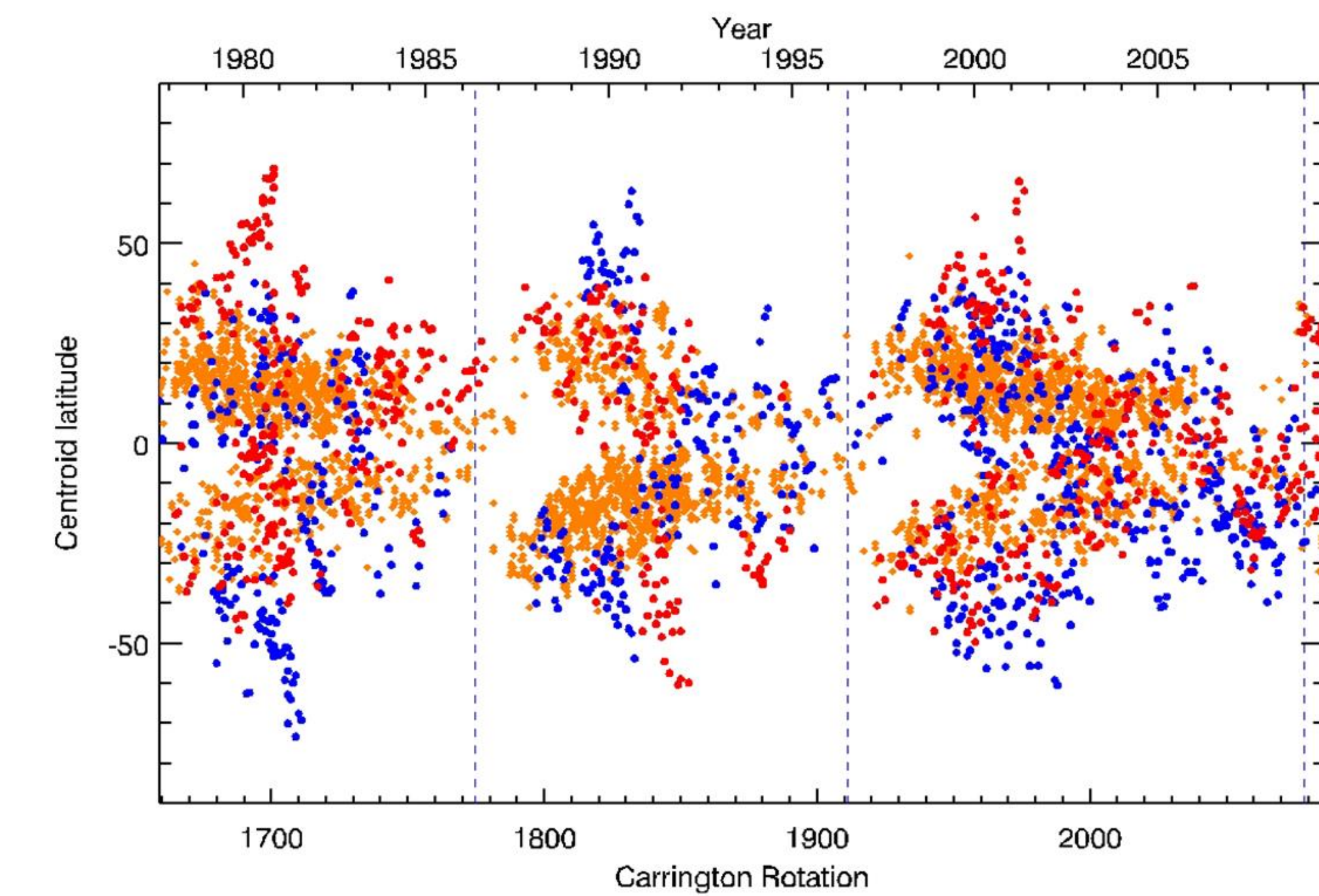


Figure4

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

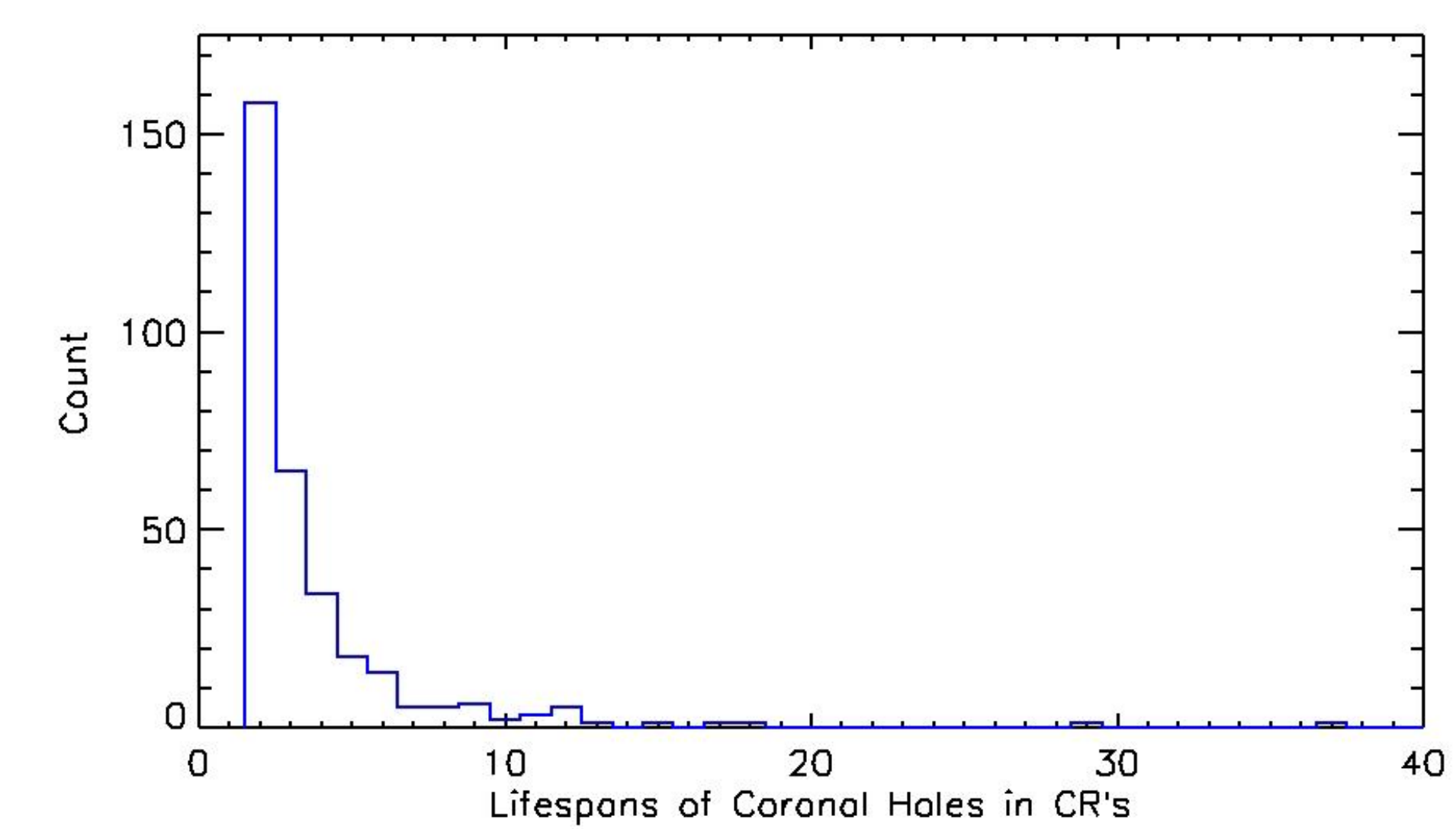


Figure5

This plot shows the proportions of long lived (more than one rotation) non-polar coronal holes by the number of Carrington Rotation lifetimes experienced by each coronal hole group over two solar cycles.

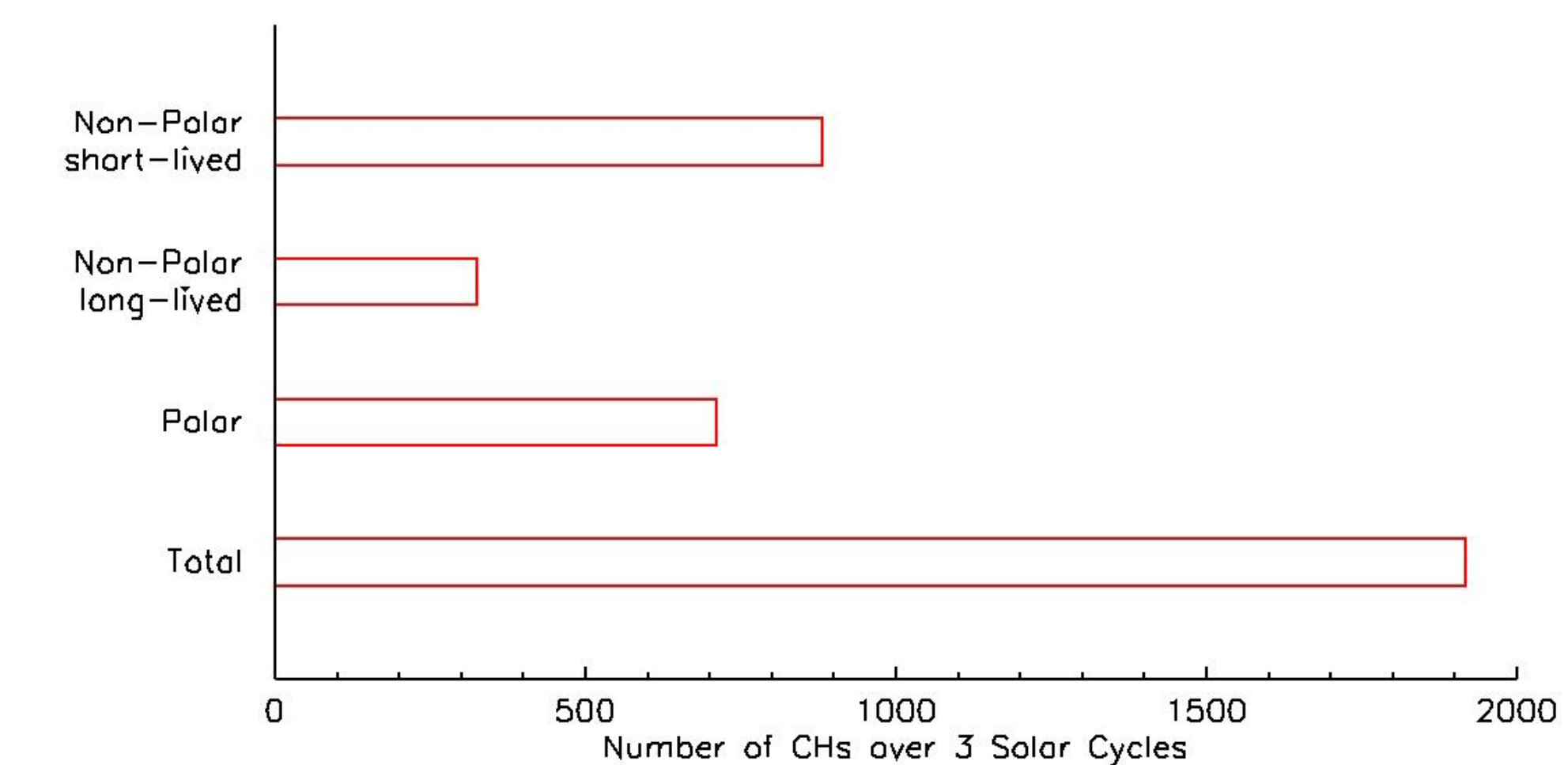


Figure6

This plot shows the proportions of the different types of coronal holes as compared to the total number of all coronal holes for the two solar cycles. Total numbers of low latitude coronal holes that last only one lifetime are plotted against low latitude coronal holes that live longer than one rotation. The polar coronal holes, which tend to last many rotations, are also plotted.

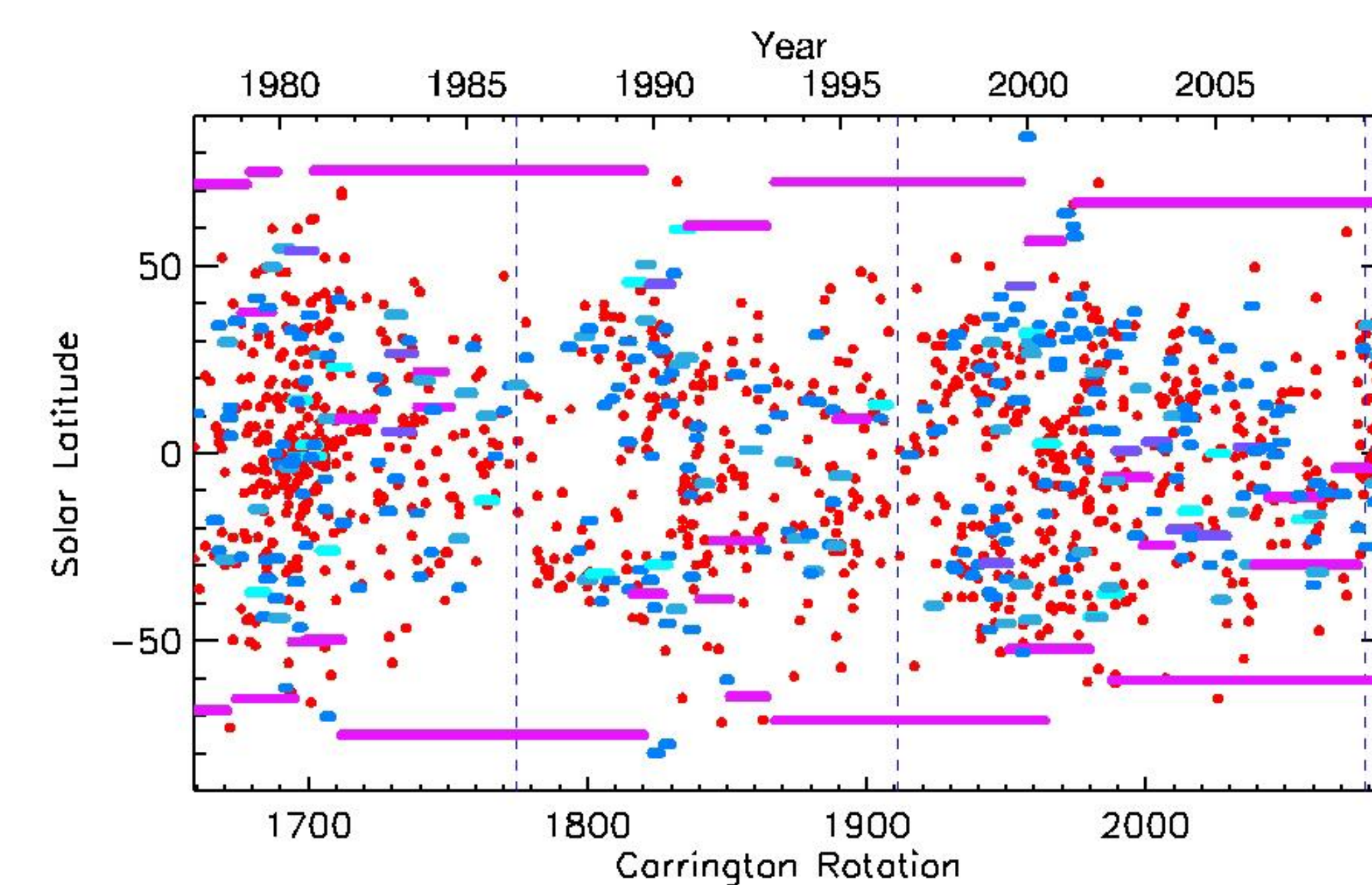


Figure7

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: We acknowledge that 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. 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 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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