S2 – P10: Studies of Global Solar Magnetic Field Patterns Using a Newly Digitized Archive

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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 - Figure 1a). Coronal hole boundaries were later added, primarily from ground-based He-I 10830Å images from NSO-Kitt Peak. Magnetograms were used, when available, 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, ~570 Carrington rotations (CRs), or nearly four complete solar cycles of synoptic maps. We are currently digitizing and archiving these maps, with the final, searchable versions (Figure 1b) publicly available at NOAA's National Centers for Environmental Information. Here we present preliminary results using the archived maps from SC 21-23. We show the global evolution of closed magnetic structures (e.g., sunspots, plage, and filaments) relative to open structures (e.g., coronal holes), and examine how both relate to the shifting patterns of large-scale positive and negative polarity regions.

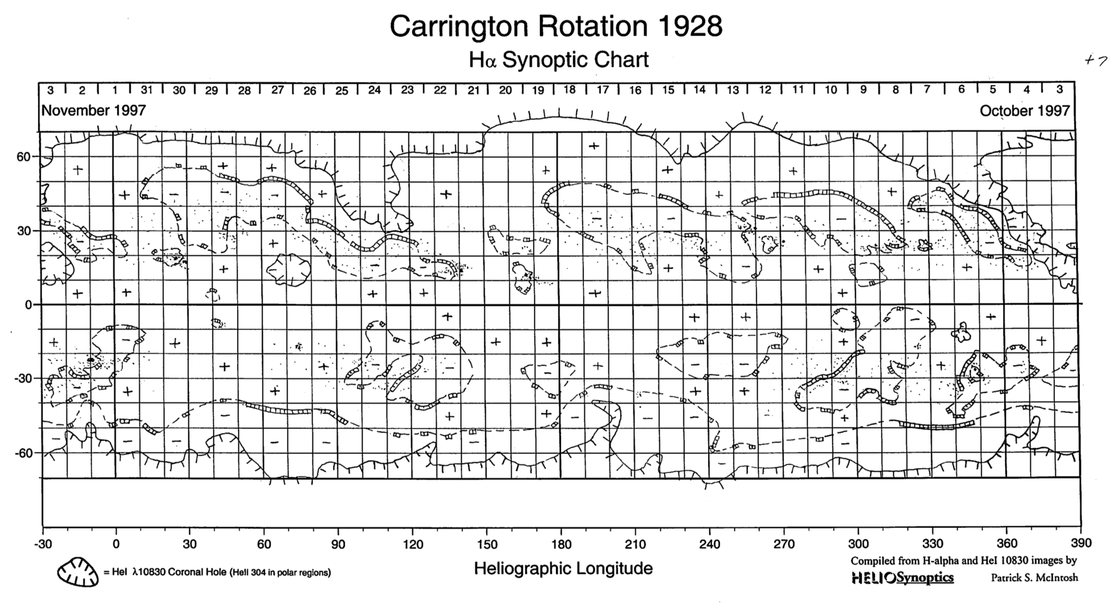

Figure 1a: The McIntosh Archive (McA) synoptic maps are a global representation of the evolving solar magnetic field. Example of original, hand-drawn McA synoptic solar map. Magnetic polarity indicated by +/-; PILs dashed, and filaments are solid parts of the PILs; coronal hole boundaries indicated by hashed lines; plage by light dots, and sunspots by darker dots.

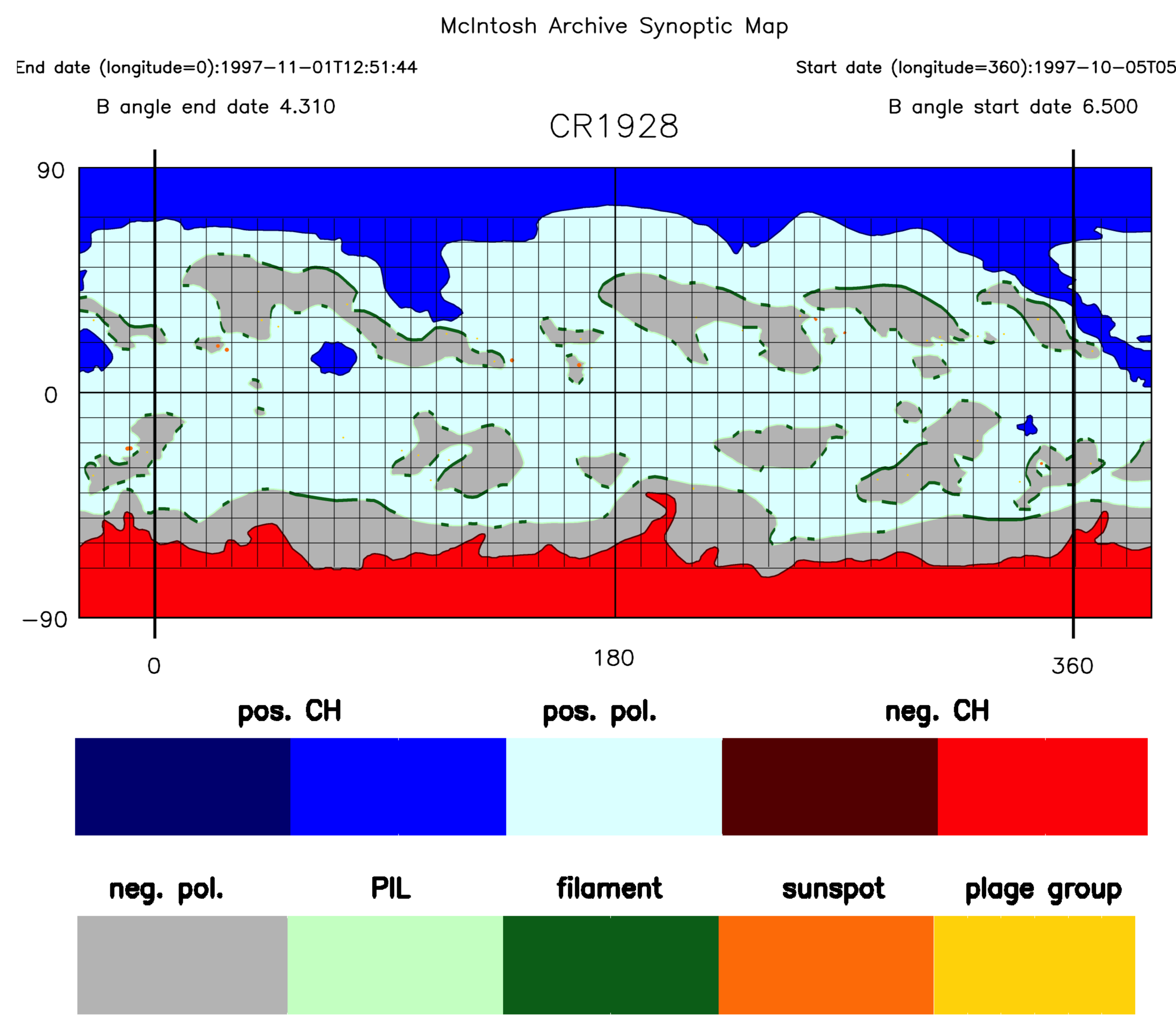

Figure 1b: Example of processed McA synoptic solar map for the same Carrington rotation. Magnetic features identified by a distinct number or color, as described in the legend. Thus far ~70% of the maps have been processed.

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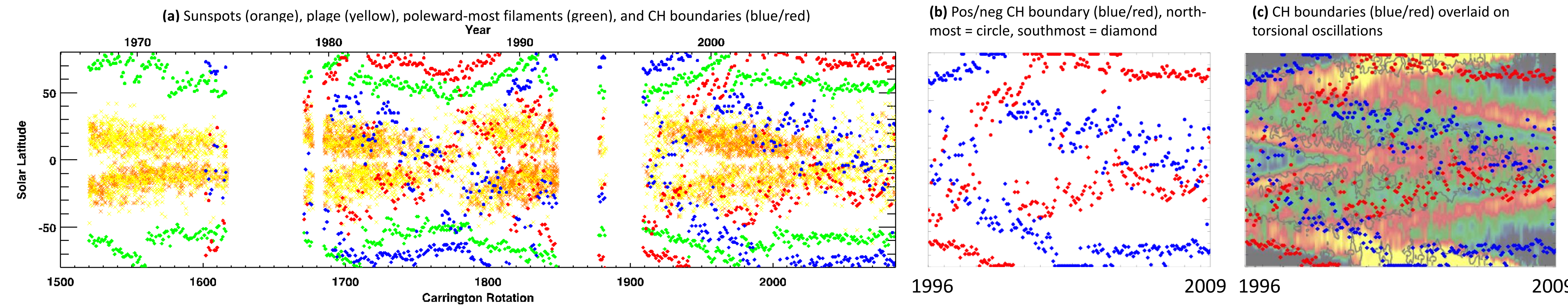

Figure 3: Open vs. closed magnetic field evolution over SC 23. **(a)** Classic butterfly-type plots of all of the McA data processed to date starting with 1967 and ending in 2009. The locations of sunspots (orange), plage (yellow), and the poleward-most filament for each CR (green) are shown, the latter indicating the "rush to the poles" and polarity reversals (e.g., McIntosh, 1992). Such filament patterns have recently been traced as far back as SC 14 (e.g., Li et al., 2008; Tlatov et al., 2016; Chatterjee et al, 2017). After 1972 coronal hole boundaries (red=negative, blue=positive; furthest north per CR=circles, furthest south=diamonds) are plotted. For most CRs (other than at maximum): a polar and a low-latitude coronal hole boundary extent is shown, for both polarities, creating a double-helix pattern (S. McIntosh et al., 2014); see also Webb et al., 1984; Harvey & Recely, 2002; Bilenko & Tavastsherna, 2016; Fujiki et al., 2016). **(b)** Plot of coronal hole boundaries only for SC 23, 1996-2009. **(c)** The same coronal hole plot overlaid on a plot of the zonal flows (torsional oscillations) of the near-surface (0.99R) magnetic field from GONG, MDI, and HMI data, covering the period for SC 23 (from Howe, 2016; prepared by R. Komm).

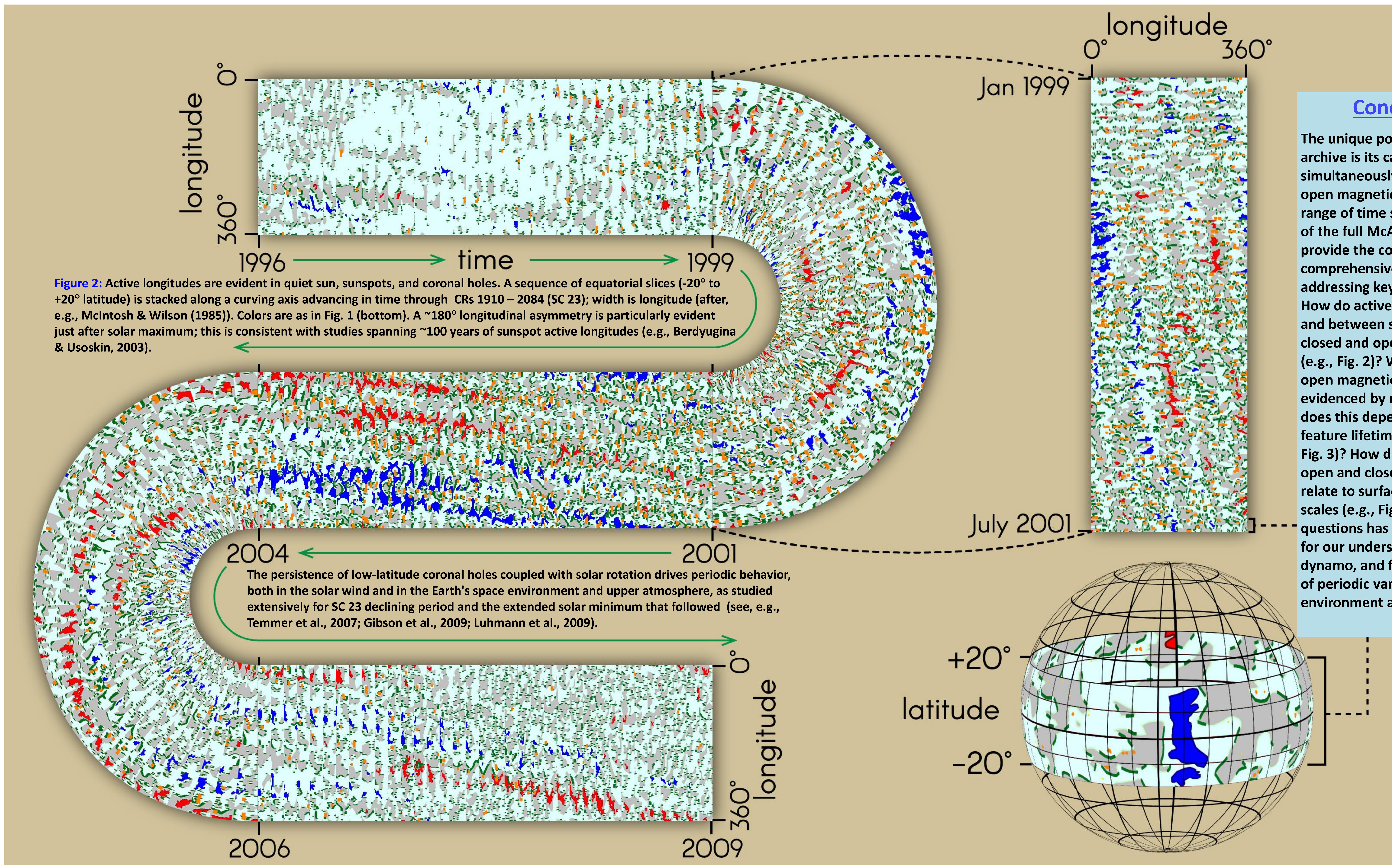

Figure 2: Active longitudes are evident in quiet sun, sunspots, and coronal holes. A sequence of equatorial slices (-20° to +20° latitude) is stacked along a curving axis advancing in time through CRs 1910 – 2084 (SC 23); width is longitude (after, e.g., McIntosh & Wilson (1985)). Colors are as in Fig. 1 (bottom). A ~180° longitudinal asymmetry is particularly evident just after solar maximum; this is consistent with studies spanning ~100 years of sunspot active longitudes (e.g., Berdyugina & Usoskin, 2003).

The persistence of low-latitude coronal holes coupled with solar rotation drives periodic behavior, both in the solar wind and in the Earth's space environment and upper atmosphere, as studied extensively for SC 23 declining period and the extended solar minimum that followed (see, e.g., Temmer et al., 2007; Gibson et al., 2009; Luhmann et al., 2009).

Conclusions

The unique power of the McIntosh archive is its capability to simultaneously represent closed and open magnetic structures over a range of time scales. The completion of the full McA digitization will provide the community with a comprehensive resource for addressing key questions including: How do active longitudes vary within and between solar cycles, for both closed and open magnetic features (e.g., Fig. 2)? Where are closed and open magnetic features rooted (as evidenced by rotation rate), and how does this depend on SC phase, feature lifetime, and latitude (e.g., Fig. 3)? How does the evolution of open and closed magnetic features relate to surface flows on SC time scales (e.g., Fig. 3)? Answering these questions has important implications for our understanding of the solar dynamo, and for our interpretation of periodic variations of Earth's space environment and upper atmosphere.

The McIntosh Archive is available at:
https://data.noaa.gov/dataset/solar-imagery-composites-synoptic-maps-mcintosh/

We dedicate this project to Pat McIntosh, who passed away in October 2016. We are grateful to his daughter, Beth Schmidt for permission to use Pat's original data. We thank Don Kolinski for graphics assistance. This work is supported by NSF grants #1540544 and #1722727, and by NCAR, which is funded by NSF.