PATTERNS AND DYNAMICS OF SOLAR MAGNETIC FIELDS AND HeI CORONAL HOLES IN CYCLE 23

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ABSTRACT

H-alpha synoptic charts compiled in Boulder now document large-scale solar activity for 38 years. This set of over 500 charts shows patterns of magnetic polarity in full agreement with Kitt Peak and other magnetic-field synoptic charts. By emphasizing the boundaries between polarities, which are marked with high resolution by structures in the solar atmosphere, we see the dynamics of magnetic fields more clearly than any previous synoptic database. More accurately, we see the dynamics of the sources of magnetic fields. These charts combine filaments, active regions and coronal holes with the magnetic-field patterns, giving new insight to the origin and disappearance of those three fundamental solar phenomena. The most startling revelation by H-alpha charts in Cycle 23 is that our definition of coronal holes as areas of open field lines is incomplete. The motions and evolutions of coronal holes seen with HeI 10830, show behaviors that precede changes in magnetic fields and often without any distinctive change at all in those fields. The changes among coronal holes are coordinated and the changes are synchronized with the solar cycle. These data demand a fresh start to our models of the solar cycle. That model must deal with the dynamics of magnetic field origin and regeneration.

Key words: Sun: magnetic fields, polar crown filaments, coronal holes, large-scale motions, polarity patterns

1. INTRODUCTION

Observations of magnetic fields by magnetographs are essential, but not sufficient, for understanding solar magnetism. It is also essential to learn how convection within a rotating globe of plasma generates streams of charged particles that become electrical currents that then induce magnetic fields. We must focus on the dynamics of MHD guided by evidence of the scale and movement of the convective elements.

Solar cycle models based on dispersion of magnetic fields by surface velocity fields ignore the fact that individual magnetic elements have relatively short lifetimes. These lifetimes are too short for flux elements to survive transport from active regions to even the nearby large-scale patterns of magnetic flux. The lifetimes are obviously too short for flux elements to survive transport to the polar regions and cause the observed polar reversals two years after solar maximum. Paraphrasing the Discussion section of Wilson and McIntosh [1991] "Stenflo [1990] has shown that the turnover time of the large-scale field (i.e. the time in which the individual flux elements decay and are replaced by new elements in the pattern) is of the order two weeks. The Babcock-Leighton model requires two orders of magnitude more time for the evolution of the large-scale fields by active region decay. Stenflo has therefore proposed that the high- or mid-latitude large-scale fields arise primarily as a result of organized small-scale flux emergence rather than active region decay."

The large-scale patterns of magnetic polarity have a law of differential rotation that differs from the differential rotation determined from individual flux elements [Snodgrass, 1983]. The patterns may appear to move as if the flux elements were diffusing or moving with the surface velocity fields; but these behaviors may be explained just as well, and perhaps in more detail, as responses to large-scale velocities below the surface.

There is an understandable preference to use only magnetograms for study of global magnetic fields; but, the emphasis on flux elements, to the exclusion of structures bounding the patterns of magnetic flux, is blinding solar physics to the origin of magnetic fields. This review will show that the form and evolution of large-scale polarity patterns suggest motions that must originate beneath the solar surface. The data on which this review is based are four solar cycles of global maps of large-scale magnetic-field patterns derived from structures observed in the H-alpha line of hydrogen (6563Å). Coronal-hole behavior during the current, 23rd solar cycle includes a sur-

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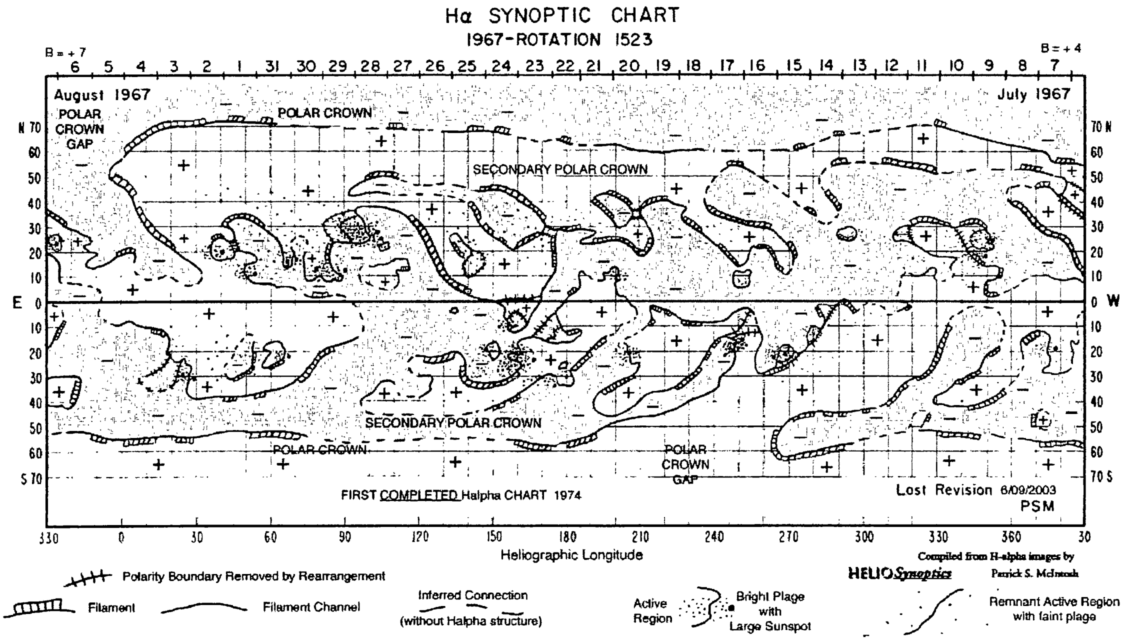

Figure 1. H-alpha synoptic chart for July-August 1967 during the rising phase of Solar Cycle 20. Primary and secondary polar crown polarity boundaries are labeled, as are the polar-crown gaps in both northern and southern solar hemispheres. Dates at the top of the chart correspond to the times of central-meridian passage of the heliographic longitudes labeled along the bottom of the chart directly below those dates. Gray shading distinguishes negative polarity areas from those of positive polarity (white).

prising example that requires a new approach to modeling solar cycles.

Large-scale patterns of magnetic polarity are recorded in a 38-year collection of H-alpha synoptic charts [e.g. McIntosh 1979, McIntosh, Willock and Thompson 1991, Solar-Geophysical Data 1973-1990]. These charts are distinguished from all earlier solar synoptic charts by the connections between widely-separated filaments based on filament channels and transient, filament-like structures that lie over lines of polarity inversion. The unique qualities of these charts will be summarized. The new phenomena discovered from these charts will be listed and discussed in terms of their implications for solar models and for solar predictions. An appendix following these discussions gives details about making H-alpha synoptic charts, the degree of coverage during the past four solar cycles and the cost and availability of the charts.

2. DATA UNIQUE TO H-ALPHA SYNOPTIC CHARTS

The first chart that contained completed patterns of polarity boundaries is the chart for Carrington Rotation CR1523 displayed in Figure 1. This chart alone is responsible for several new conclusions about large-scale solar magnetic fields. The most distinctive quality of H-alpha synoptic charts is illustrated with this example: Long, uninterrupted polarity boundaries. No other chart has shown these. Only with the recent synoptic maps made from SOHO EUV images have other observers noted the long interconnected filament cavities in the corona. These are identical to the polarity boundaries on H-alpha synoptic charts. This correspondence will be examined in a later publication.

The longest polarity boundary on nearly every synoptic chart consists of the boundary underlying the chain of polar crown filaments. The two polar crowns are usually connected to one another by a polarity boundary extending from either end of a polar crown, dropping to lower latitudes and crossing the solar equator at least twice. This globe-encircling boundary is the true source of the heliospheric current sheet. It may differ from the shape and location of the computed heliospheric current sheet defined by a "source surface", or by the locus of maximum intensity of the white-light corona.

The northern hemisphere shows a series of cellular and peninsular areas bounded by latitudes N20-55. If these were shearing as a result of simple differential rotation there would not be such distinct cellular units pinching off from the original "stream" from the sunspot latitudes. Two of the cells were separating during the disk passage of this rotation, earning the symbols for rearranging polarity boundaries. The narrow connection between the cells and the larger area of negative polarity was a small rectangle. Two sides of this rectangle had to disappear to achieve the rearrangement, and the area within the rectangle changed from negative to positive polarity. There are more than a dozen areas of rearrangements on this chart. These are common events throughout the database of H-alpha synoptic charts.

The very long polarity boundaries underlying the polar crown filament systems in chart CR1523 are seen to continue to lower latitudes at either end of the horizontal segments near the poles. On nearly all H-alpha charts this line meanders around the entire solar globe, crossing the equator at least twice and eventually connects the polar crowns of both hemispheres into one unbroken polarity boundary. This boundary is surely the true source of the heliospheric current sheet that is currently defined by the locus of peak coronal brightness, peak magnetic intensity (with appropriate smoothing), and the origin of the interplanetary sector structure.

3. POLAR CROWN GAPS

The polar crown is not a complete circle around the pole except during a brief period prior to the reversal of the polar polarity. The polar crown is interrupted at one or more longitudes on all synoptic charts but one gap is dominant [McIntosh, 1980]. The primary Polar Crown Gaps (PCGs) in 1967 are particularly distinct in both northern and southern hemispheres [Figure 2]. These PCGs persisted from sunspot minimum in October 1964 to sunspot maximum in January 1969, as illustrated in a stackplot of latitude zones centered on the polar crowns [Figure 3]. The northern high latitude zone (left column) displayed a black (negative polarity) pattern that drifted to the left with respect to heliographic longitude, while the southern stackplot for the same range of latitude (right column) displayed a white pattern with a similar drift. These two patterns include the signature of the PCGs on CR1523 [Figure 2]. What could maintain this long-lived, unipolar feature at high latitudes where there are no active regions? Why did these features persist with such a constant size and systematic movement while the level of solar activity increased from minimum to maximum? It is difficult to imagine how the flux transport model of the solar cycle would create this feature. It is easy to imagine a convective source that organizes and maintains cellular features, one of which is a PCG. The limited data of cycle 20 suggested that coronal holes have something to do with the presence of the polar crown gaps.

Throughout the 12 years of solar cycle 20 there were only primitive data about coronal holes. The first rocket flight with a x-ray imager was in 1966, one year before the chart in Figure 2. The Skylab space station with its solar telescopes operated in 1973, less than three years before the end of cycle 20. The maps of Skylab X-ray coronal holes were placed on H-alpha charts for 1973. The coronal holes coincided with the PCGs of that time. For this review we illustrate this coincidence with synoptic charts from cycle 21.

The sequence of seven charts in Figure 4, from the latter half of 1979, are during the rising portion of cycle 21, the time corresponding to the early part of the stackplot in Figure 3. Digital versions of the 1979 charts were used to attach two charts end-to-end so that the polar

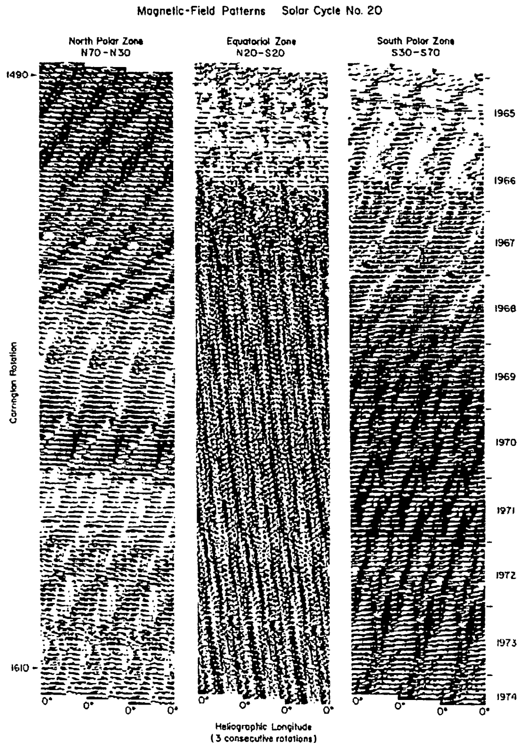

Figure 3. A compressed 10-year time-series of solar magnetic polarity charts for solar cycle #20 divided into three broad zones of latitude. The range of heliographic longitude is tripled to allow perception of patterns that drift through more than 360-degrees of heliographic longitude during ten years. [from McIntosh 1981 and McIntosh and Wilson 1985].

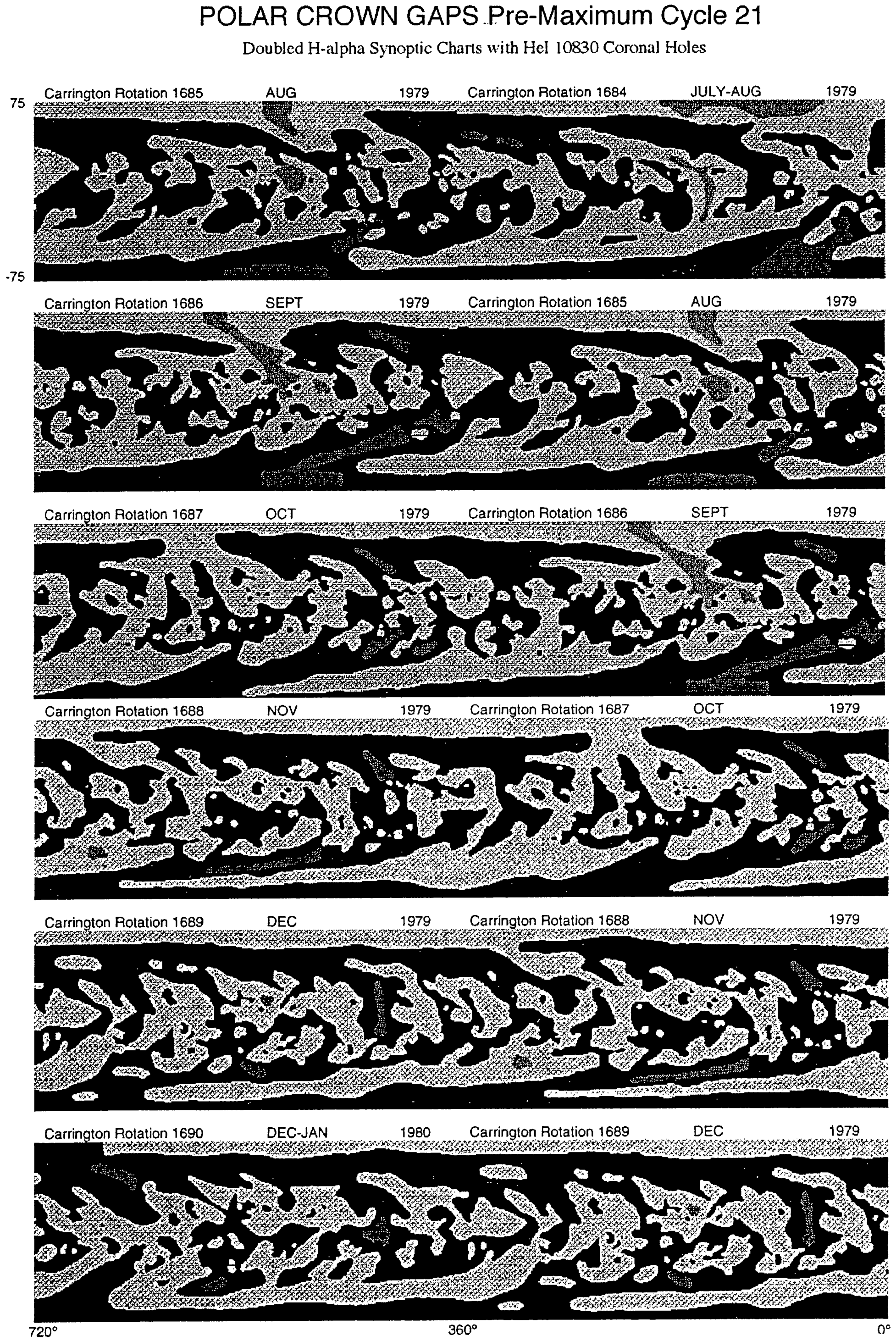

Figure 4. Seven consecutive Halpha synoptic charts in 1979 are displayed as six end-to-end pairs, using digital versions from solar cycle #21. Negative polarity is black, positive polarity is lightest gray and coronal holes are intermediate gray. This format permits viewing the complete polar-crown polarity boundaries at a time in the cylce when they are of maximum longitudinal extent. Coronal holes extend from each pole to lower latitudes through the polar-crown gaps.

crown and its associated features are viewed in their entire lengths, without being truncated by the end of a Carrington Rotation. Polarities are coded as black and light gray, with intermediate gray for coronal holes observed in HeI 10830 spectroheliograms. Throughout this sequence of charts the PCGs are the site of coronal holes that are extensions of the polar coronal holes. These extensions reach to lower latitudes, even crossing the solar equator, by passing through the PCG.

There are other broad areas of unipolarity on the charts of Figure 4 that did not contain a coronal hole; therefore, there are conditions other than the scale of the unipolar area that determine the presence of a coronal hole. The PCG is such a favorable condition. We must search for the distinctive properties of the PCG to understand the necessary conditions for coronal holes.

A closer look at Figure 4 shows that the polar crown is the poleward boundary of an elongated cell that dominates these maps. These high-latitude cells are not as long as they appear, of course. After correcting for latitude these cells are comparable in size to the larger patterns near the solar equator.

The high-latitude cells lay between the primary and secondary polar crowns as labeled in Figure 2. These cells moved as a coherent unit during these seven solar rotations, shifting to the left by approximately 300 degrees of heliographic longitude. The cells also elongate and, in the case of the black northern cell results in the closure of the PCG. In agreement with the polar reversal discussed by Fox, McIntosh and Wilson [1998], the closure of the PCG occurred very near the sunspot cycle maximum in 1979.

4. POLAR CROWN LATITUDE DRIFT

The mapping of all filaments in context with magnetic polarity allows a more precise and meaningful study of polar crown filaments. The important "rush" to the poles by these filament during the rising portion of every solar cycle is recorded for all cycles from the beginning of prominence and filament observation late in the 19th century. The data used to discover and record these poleward migrations were based on averaged latitudes during a solar rotation without knowledge of the arrangement of polarities on either side of the filaments. The H-alpha synoptic charts now show that the chain of polar crown filaments is more continuous, with filaments of the polar crown occurring over a broad range of latitude. In fact, it is impossible to decide at what latitude a filament is no longer a member of the polar crown. On most charts the polar crown is a small portion of a line that lies at a significant angle to lines of latitude and which continues to the equator

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The only reasonable way to record the polar crown latitude drift is to measure from each chart a single point in the polar crown at its maximum latitude. An average of filaments along the boundary has no meaning for the poleward movement.

The shaded versions of H-alpha synoptic charts, as in Figure 1, show that there is a secondary polar crown consisting of the poleward boundaries of the ensemble of cells lying equatorward of the primary polar crown. When the point of highest latitude of this secondary polar crown is added to the history of polar crown latitude drift we get an important surprise. This secondary polar crown drifts towards the poles in synchronism with the primary polar crown. This means that flux of both polarities drifts poleward. That is not expected from the Babcock-Leighton model for dissipation of active-region flux. This is additional evidence that cellular organization of magnetic fields must be controlled by subsurface convective cells.

The separation in latitude between primary and secondary polar crowns during 1979, using maximum latitudes, was about 15 degrees. The large elongated cells in Figure 4 bounded by these two polar crowns have latitudinal widths ranging between 15 and 40 degrees. The poleward motions of the four polar crowns, two in each hemisphere are remarkably identical in Cycles 21 and 22. Figures 4 and 5 together suggest that the elongated cells maintain a constant latitudinal width during their motion poleward. Poleward motions caused by diffusion and meridional flows are unlikely to generate the coherent drifts observed in these H-alpha charts.

The polar crown originates early in a cycle from large-scale unipolar regions that arise near latitude 40. This is also the latitude of the most poleward sunspot groups in a solar cycle, as seen in "butterfly" diagrams that show the equatorward drift of sunspot latitudes through a full solar cycle. The divergent motions between active regions and polar crowns from latitude 40 is an important boundary condition to apply to a new solar cycle model based on convective dynamo activity.

When the primary polar crown reaches the pole and disappears the secondary polar crown stops moving poleward. In Cycle 21 it reverses its motion and moves slow-

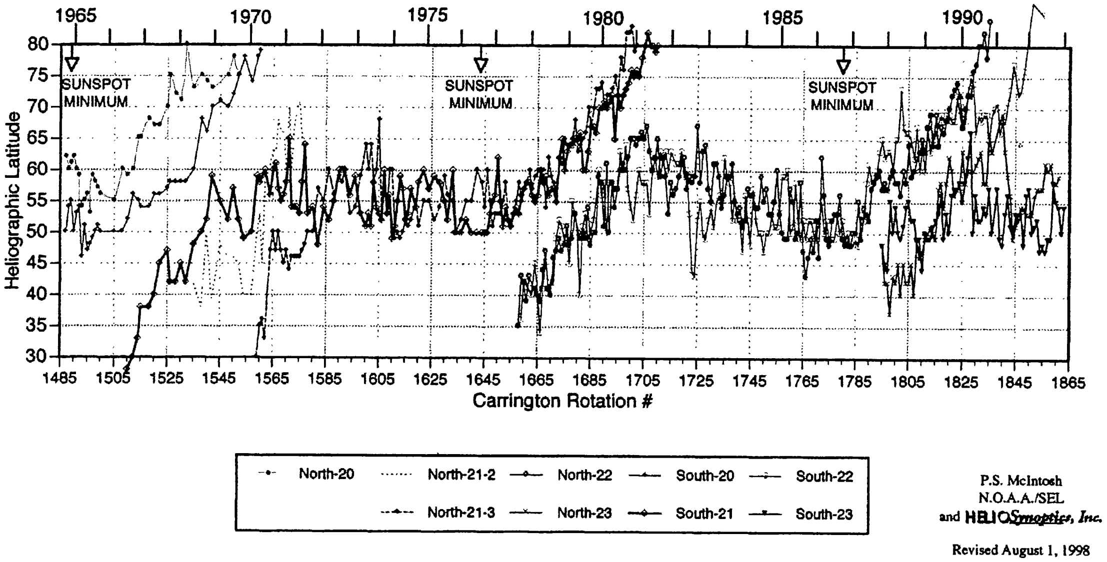

Figure 5. The maximum latitude of the polar crown filaments measured from each Halpha synotic chart for solar cycles #20, 21 and 22. Data from northern and southern hemispheres are superimposed, using different symbols to distinguish between them.

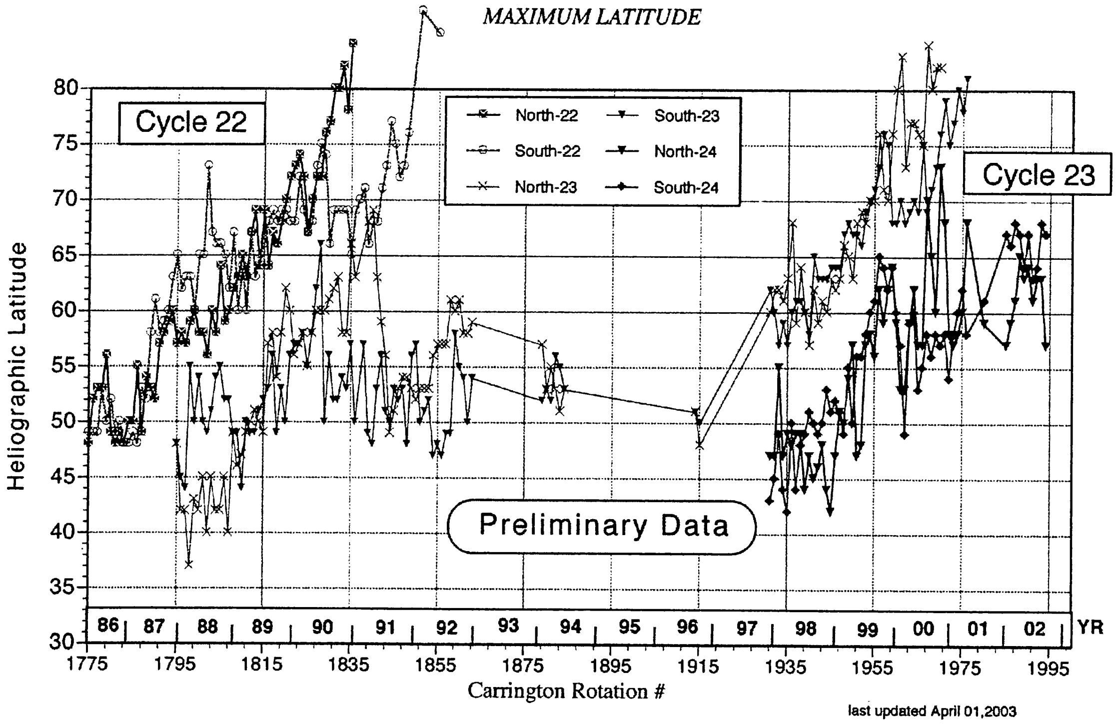

Figure 6. Maximum latitude of polar crown filaments for solar cycles #22 and 23, with significant data gaps due to unprocessed or missing solar images. Additional data are preliminary. Data from northern and southern hemispheres are superimposed, using different symbols to distinguish between them.

ly toward the equator through tthe remainder of the solar cycle. In Cycle 20 the secondary polar crown stopped its poleward motion near latitude 55 and held that latitude for the remainder of the cycle. During the past two solar cycles the secondary crown exhibited a more complicated motion; however, the post-maxium phase of both of those cycles is not represented with complete and accurate data at this time.

The secondary crown consists of a series of polarity cells separated by gaps that vary in longitudinal extent. As either polar crown, primary or secondary, moves poleward the gaps between polarity cells narrow and one cell after the other merge to reduce the number of cells containing a portion of the polar crown.

5. AN ENCOUNTER BETWEEN A POLARITY CELL AND A CORONAL HOLE

The excellent digital solar images during the current Cycle 23 permitted unprecedented accuracy in mapping all data on Halpha synoptic charts, bringing into sharper view the relationships among the structures. The coronal holes appeared more and more interesting as data accumulated for Cycles 21 and 22, but the appearances and motions of the coronal holes in Cycle 23 are simply remarkable. Figure 7 presents an outstanding event that challenges the present definition of a coronal hole.

In July 1999 a large coronal hole (CH) appeared at N45 in an area that was void of active regions but which was mapped as a dividing positive-polarity cell. The CH moved eastward by 45 heliographic degrees during the next solar rotation(CR1952), a unusual slow rate of solar rotation for latitude 45. The CH "approached" a cell of positive polarity at a similar latitude That cell that had moved eastward no more than 15 degrees since the previous chart. On CR1953 the CH was observed to approach the cell at a pace that could be noticed day by day. During the disk passage of these two features, the polarity cell shear so rapidly that it was mapped as two outlines, one for the earliest form and the other for the shape and position ten days later. The coronal hole had accelerated its motion (slowed its eastward drift) while the polarity cell was decelerating rapidly to the identical rate the coronal hole displayed prior to the encounter with the cell. It is as if the two features traded their momenta, like colliding billiard balls. After the encounter the coronal hole became stationary in heliographic longitude and developed an extension equatorward. The polarity cell continued to shear to tthe point of dividing into two and moving and rearranginng so fast that double mapping continued for CR1954 and CR1955.

This puzzling encounter seems to indicate that this coronal hole was not just an open magnetic field feature, but an entity with momentum different than its surroundings. It must be rooted in a subsurface velocity field that is anomolous and which swept up the plasma in whichh the polarity cell originated and deformed and decelerated the cell.

Figure 8 displays the full synoptic chart CR1956 so that this moving CH is placed in context with the entire globe. Now it is obviously a member of a complex cluster of like-polarity coronal holes that were spread over mand entire hemisphere and in association with the south polar CH. These coronal holes and the negative-polarity 'sea' in which they lay defined a polarity sector that surely was the source of an interplanetary sector of negative polarity. It appears that as the moving CH developed extensions toward the south pole, a sysem of narrow coronal holes develop equatorward and westward from the south pole. This suggests there is a circulation in a counterclockwise direction in terms of coronal hole evolution/migration. There are latter observations that lend credence to this idea, and which add another chapter to the involvement between coronal holes and the polar reversals reorted by Fox et al[1998].

6. CLOSING THOUGHTS

Perceptions of patterns and the examination of forms, morphologies, evolution and degrees of complexity are central to understanding and predicting solar activity. The reason is that they reveal dynamics on and below the solar surface. Convection and large-scale patterns of flows are central to atmospheric phenomena on planets, and surely these occur in the atmospheres of stars. Solar patterns and their movements are the weather of the sun. These ever-changing morphologies are boundary conditions for solar cycle theory. They are difficult to quantify but they can be quantified with digital forms of global maps of the sun.

The connections between solar activity and the Earth environment require that we approach research and its applications in two ways at the same time. Our basic research must examine multiple hypotheses with a high standard for the truth rather than just accepting the first "reasonable" explanation of the sun and its effects. There are aspects of the complex and long-term changes in the sun that cannot be modeled well enough until we accumulate data for a very long time. The need for timely and effective predictions of solar influences demands we apply imperfect understanding in a careful blend of theory and empirical relationships. Climate change, possible influences on short-term weather, and established serious effects from geomagnetic storms and solar energetic particles call for predictive services.

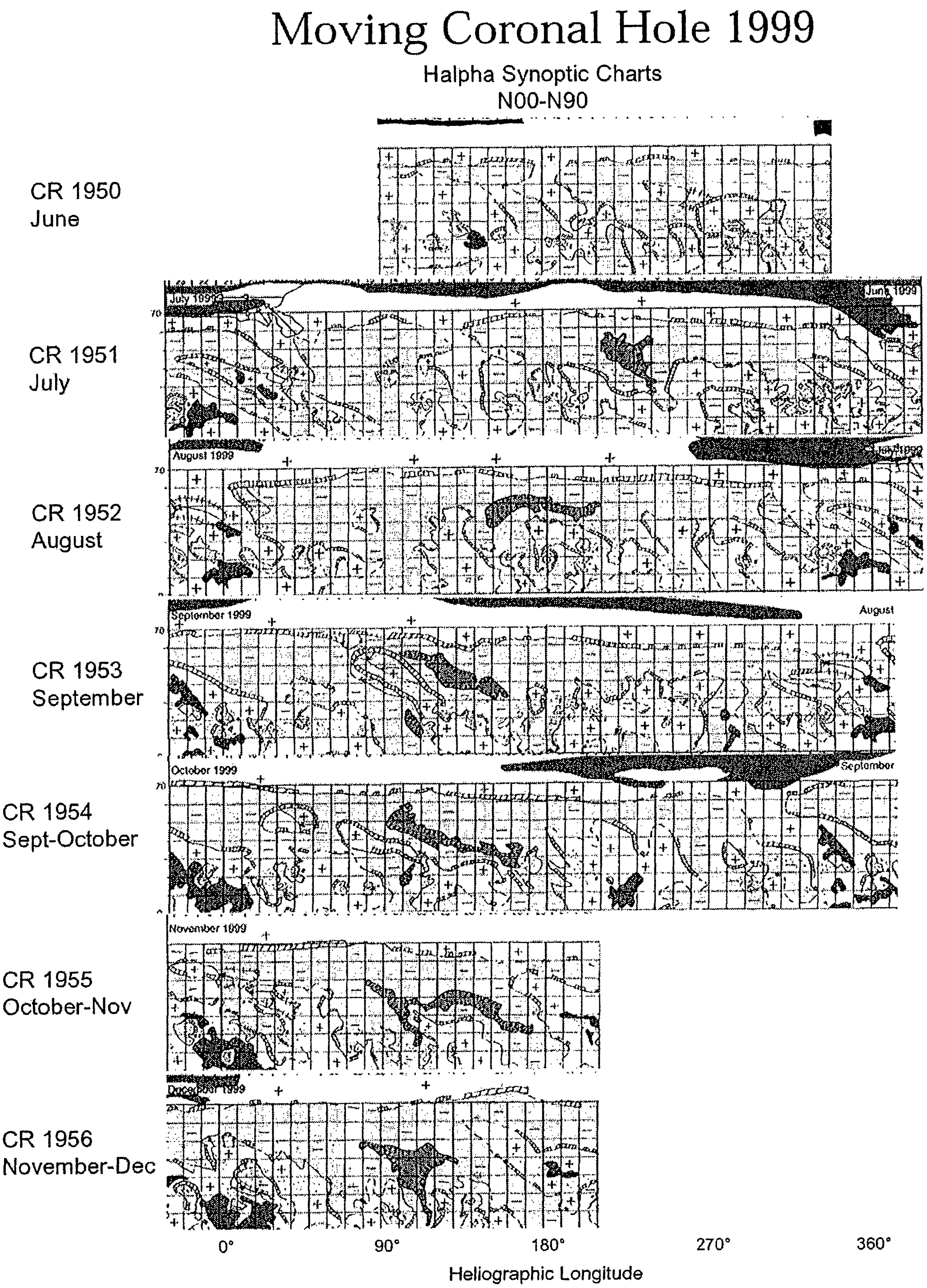

Figure 7. Northern hemisphere portions of Halpha synoptic charts during the second half of 1999 show an unusual encounter between a mid-latitude coronal hole and a cell of positive polarity at the same latitude.

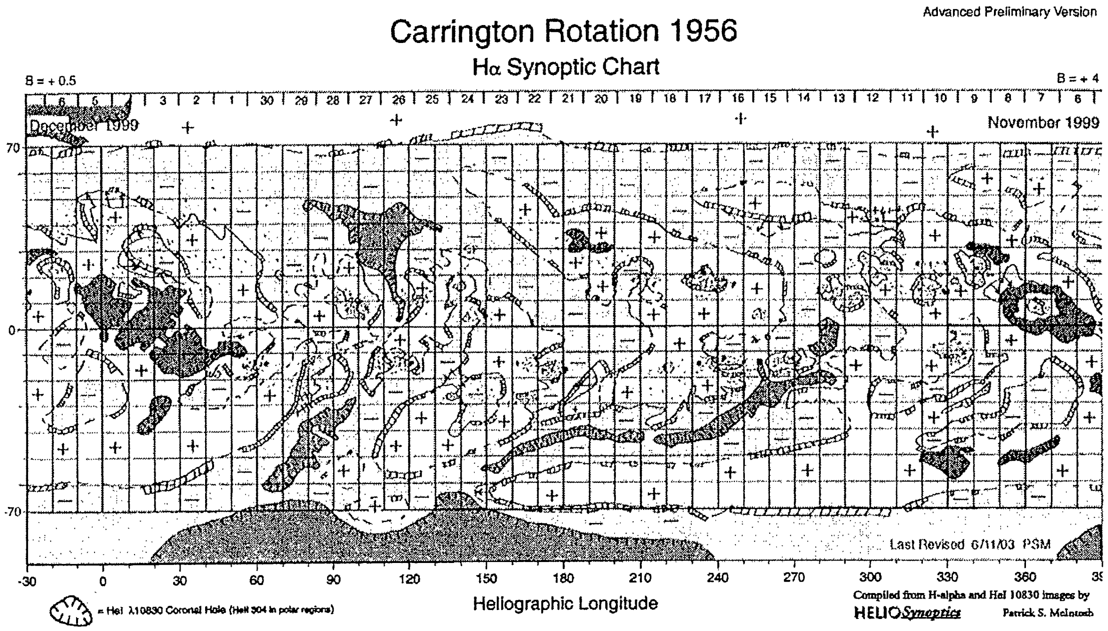

Figure 8. The entire synoptic chart for the last frame in Figure 7 shows the coronal hole at N35 and L=110 was part of a large network of coronal holes of like polarity that dominated half of the entire sun.

The most successful solar predictions are those based on images that have recorded patterns, morphologies and evolutions for the past century, the white-light and H-alpha synoptic patrol images.

It is distasteful to depend on qualitative, statistical or correlative relationships when we possess powerful computers on which to run physical models and to automate the practical applications of those models. The trained observer-scientist is adept at perceiving patterns and their changes more accurately and certainly more quickly than computer expert systems. We cannot throw away the knowledge of experienced observers as we attempt to evaluate and predict solar activity. We can easily add this wisdom and acute perception to the computer models and predictive algorithms, and me must do so for the sake of expedient and effective space weather services.

A stark reality about our subject is the length of the solar cycle and the variety among the solar cycles. The activity centers that produce the most damaging eruptive events are rare, occurring only 10 times in a 10-year solar cycle. The statistics of such regions are insignificant, at least in terms of "modern" measurements. This situation warns that our theories and our models based on data from one or two solar cycles may contain premature dogma. Prudence advises to add data as much as possible from the synoptic patrol imagery and from the knowledge and experience of the observer-scientists who have watched the sun closely for most of their lifetimes.

APPENDIX

COMPILATIONS OF H-ALPHA SYNOPTIC CHARTS

A detailed description of the content and constructtion methods for H-alpha synoptic charts appeared in a recent paper on coronal holes and the polar field reversals [Fox, McIntosh and Wilson, 1998]. Additional information appears below, with some duplication of the above reference.

H-alpha synoptic charts [Figure 1] are distinguished from all earlier solar synoptic charts by the connections between widely-separated filaments based on filament channels and transient, filament-like structures that lie over lines of polarity inversion. In addition, important inferred connections were found by reasoning with the distribution of measured magnetic polarities and considering systematic motions and "typical" behaviors of polarity patterns in a sequence of charts before and after the chart needing inferences to complete patterns. These charts are the first to reveal the organization of large-scale fields into distinct cells, peninsulas and large sectors of unipolarity. These are the first charts to combine the magnetic-field polarities with all filaments, active regions and, since 1975, coronal holes detected by intensity and fine structure in HeI 10830 spectroheliograms frrom the Kitt Peak station of the National Solar Observatories.

H-alpha synoptic charts are compiled at a price, however. Their compilations require more than 100 hours per chart because each solar image is mapped by hand rather than with automated image processing and coordinate transformation software. This is necessary because the complexity and great variety of forms in high-resolution H-alpha filtergrams defy, so far, automated feature recognition. It is necessary to be an expert in the interpretation of these images in order to identify the true polarity boundaries from these structures, and to alThe polarity patterns are mapped with assistance from, but independent of, magnetograms and with an intentional preference for defining boundaries by structures visible in high-quality H-alpha filtergrams. The synoptic magnetic field data are line-of-sight data. The polarity boundaries away from active regions are broad bands without significant vertical fields, an expected situation in view of the large-scale arcades of magnetic fields that span those boundaries. Why should anyone insist that the measured magnetic-field data are primary for defining boundaries to the polarity patterns? If we want to detect the scale and motions of large-scale elements of the solar atmosphere we need narrow structure instead of vague bands as our tracer of the motions and our definition of scales among these patterns. Only the Halpha synoptic charts give information of this nature on a time-scale of multiple solar cycles.

so account for elevated and active structures. Because of the great and rapid changes in many features during a 14-day transit across the solar disk there has to be subjective judgements applied to representing each feature in a static chart. The filaments are accumulated throughout the disk passage of a polarity boundary so that the most precise position is obtained and so that there is a comprehensive account of all sections of polarity boundaries that formed filaments. This requires examination of each image on which an area appears, repeated for every one of hundreds of features that may occur on a single chart. Each active region and coronal hole is represented by its largest manifestation, without giving preference to the central-meridian appearances. These maximum aspects give an appropriate representation of the importance of each feature.

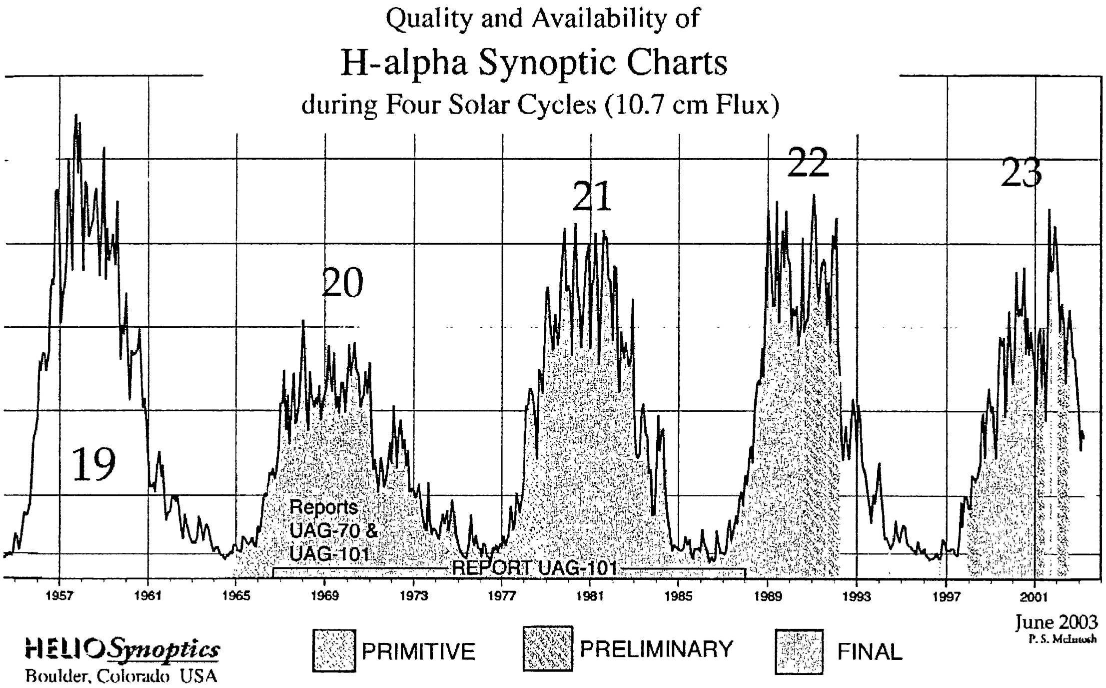

Figure 9. H-alpha synoptic charts are available for the years shaded within a plot of the monthly mean radio flux at 10.7cm wavelength. The lighter tones of gray indicate charts compiled from few or low-quality H-alpha images(PRIMITIVE) and those compiled with no significant gaps in the daily sequence of H-alpha or magnetogram images, but are incomplete in details and/or unverified(PRELIMINARY).

Significant time is given to maping difficult areas, such as centers of high activity that often consist of multiple bipolar sunspot groups overlain with brilliant, complex chromospheric structures. It required many years to see sufficient variety in such active areas and learn how to find the paths of polarity boundaries in the maze of multiple regions.

It is just as difficult to map the dashed-line connections between distinct features. Dashed lines mean there were no H-alpha structures showing a connection; yet, the distribution of polarities indicated there must be a connection. These connections can lie in large expanses of quiet, weak magnetic fields where magnetograms are a confusion of "salt and pepper", a mix of polarities that changes throughout the disk passage. Patient work with subtle details and comparisons with the same coordinates on charts of the previous and subsequent solar rotations usually allow inferred connections that are consistent through a series of charts.

2.2 Coverage and Quality of H-alpha Chart Database

H-alpha synoptic charts were constructed back to the beginning of solar cycle 20 and mapping has continued into 2002 as of this writing. Figure 9 represents the coverage of completed charts as of July 2003. Data gaps occurred with irregular support and lack of time, as well as from a reduction in data from patrol observatories after April 1994. Coverage greatly improved for solar cycle 23 with the advent of the World Wide Web and digital imaging, giving access to images from numerous observatories and spacecraft.

Charts in the earliest years of Cycle 20 are incomplete and less accurate than later charts. There was an absence of magnetograms, a dependence upon images from only a few patrol observatories that often had poor observing conditions, and there was insufficient experience for interpreting solar images. Computer assistance was limited to creating grids with appropriate date lines. Photographic prints of solar images were measured by manually overlaying Stonyhurst grids of solar latitude and central-meridian distance and drawing the interpreted polarity boundaries onto graph paper. The image scale varied from print to print depending on the skill of the darkroom technicians and, therefore, grids often did not match the size of the images. Nonetheless, methods were devised to minimize coordinate errors, including the overlaying of data from different days to detect unacceptable offsets from the averaged positions.

The detection of coronal holes, the accuracy of their boundary locations (and, therefore, their areas) all depend upon the size of the images, the accuracy of the fit between the image and the Stonyhurst disk and the exposure and contrast of the photograph or digital image. Only in the charts for the 23rd solar cycle were digital methods able to control all these factors. It is easily apparent that there are few small and narrow coronal holes in the charts prior to Cycle 23. Coronal holes in earlier cycles often intruded into polarity patterns, indicating possible errors in area and/or location. Understandably, the data for Cycle 23 permits more careful analyses than do data in earlier cycles.

Most charts are not perfectly complete due to limited time for editing and reviewing all images for filaments and active regions omitted. It is possible that many of the rapid changes during a disk passage are not yet entered on the charts. In view of the importance of rapid changes as a predictor of CMEs these areas of change must be completed.

This author compiled most of the early charts and he is presently the only person who can review and edit charts to the level of FINAL or archival quality. Support from the U.S. Air Force Geophysical Laboratory and from E. C. Roelof of The Johns Hopkins University provided assistants to finish charts for cycle 20 and publish the first atlas of H-alpha charts [Mcintosh 1979]. The use of assistants led to inhomogenities in data quality, but an increase in the length of the database.

Near the center of the solar disk the coordinate accuracy is often ±1 degree, but decreases slightly with distance from disk center. Positional accuracy varies more seriously with the character of the solar structures and, of course, with worsening atmospheric conditions at the grround-based observatories. Data accuracy increased during cycles 21 and 22 with the use of larger image scale and more control over the printing of the images.

The quality of the cycle 23 charts is superior tothe earlier cycles because of digital imaging and the use of computer software to control all aspects of image qualit., Computer-assisted mapping is now more capable, but presently unaffordable.

2.3 Availability and Costs of Charts

The H-alpha charts are not yet in the public domain because they have been funded by HelioSynoptics' private funds or purchased by two research institutions who presently are the only groups with permission to use the data. Their purchases do not cover the full cost of making the charts. If at least four additional institutions make purchases of the entire Cycle 23 collection of chart the costs of production will be met and the charts will then become available through an FTP site on a web page. Until then purchase orders are encouraged for individual charts or complete years of 13 charts. Please send an email to Patrick S. McIntosh for purchase order details.

Prices of individual charts or sets of charts for a full year depend on the number of purchasers expected. The cost of producing a single chart has risen to $4000 US due to the labor intensive methods necessary for recognizing complex structures and accounting for motions and evolutions during a disk passage. The 100+ hours includes at least 50 hours of professional-level attention. Preparation of high-quality graphics and publications add significant costs.

The best situation for everyone is to obtain federal funding that will support filling all data gaps from 1964 to 2004 and revising older charts with use of digital copies of photographic solar images for the years prior to use of CCDs. All charts should be digitized with software that creates computable data bytes. Such a database for the entire four cycles of charts would allow fast and thorough anlyses that may generate the necessary boundary condtions for a new dynamo-like solar cycle model.

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