REPORT UAG-79

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# for
# Solar-Terrestrial Physics

## SOLAR OBSERVATIONS DURING SKYLAB
## APRIL 1973-FEBRUARY 1974
## I. CORONAL X-RAY STRUCTURE
## II. SOLAR FLARE ACTIVITY

December 1980

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J.M. Hanson
Department of Aeronautical Engineering, University of Michigan
Ann Arbor, Michigan

E.C. Roelof and R.E. Gold
Applied Physics Laboratory, The Johns Hopkins University
Silver Spring, Maryland

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# CONTENTS

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Silver Spring, Maryland

## I. CORONAL X-RAY STRUCTURE

ABSTRACT

Large-scale (~ 10°) emission features visible in soft X-ray photographs from the American Science and Engineering, Inc. (AS&E) spectrographic telescope S-054 on Skylab have been superposed on Hα Synoptic Charts [*McIntosh, 1975*] for Carrington Rotations 1601 through 1610. The charts identify loop arcades and loop complexes associated with strong magnetic fields, as well as coronal holes and areas devoid of emission loops. Although not adequate for the study of the geometry of individual features, the charts convey a global sense of coronal structure which is often difficult to obtain from individual (disk) images.

### 1. INTRODUCTION

The interest of our group at the Johns Hopkins University/Applied Physics Laboratory in the American Science and Engineering, Inc. soft X-ray images of the solar corona began with the first association of a solar wind stream with a coronal hole photographed on a rocket flight in 1970 [*Krieger et al., 1973*]. Later, the AS&E Skylab data from the S-054 X-ray spectrographic telescope allowed us to extend the associations between coronal X-ray structure and solar wind streams [*Krieger et al., 1975; Nolte et al., 1976a, Mitchell et al., 1980*] and to include energetic particles from 300 keV to > 3 GeV [*Gold et al., 1975a, b; Roelof et al., 1975a, b; Roelof, 1976*]. These studies related interplanetary observations to large-scale X-ray features, e.g., coronal holes or large complexes of loop-like structures. We decided that the next logical step was to make more detailed comparison with the loop-like structures which spanned 5° or more of heliographic longitude or latitude.

We have therefore prepared an atlas of X-ray features from the S-054 Skylab data covering Carrington Rotations 1601 - 1610 (May 29, 1973 to January 31, 1974). In order to facilitate comparison with other Skylab data, we have mapped the X-ray features onto synoptic charts in heliographic longitude and latitude which overlay the Hα Synoptic Charts of *McIntosh* [*1975*]. We caution the user that, since we were initially interested in coarse (∿ 10°) structure, we worked from positive prints made from 70-mm negatives available from the National Space Science Data Center. These are of significantly lower quality than that available from AS&E internegatives, as we document below. Even though individual loop locations and configurations cannot be considered exact, we intend to use these X-ray synoptic charts as indicators of the general characteristics of regions of about 20° x 20° in area. In other words, these charts can adequately identify loop arcades, loop complexes associated with strong fields, and areas devoid of emission loops, but they are inadequate for any study of the geometry of individual loops. We regard their main utility to be in conveying a global sense of coronal organization which is difficult to gain from individual (disk) images. These charts are in Appendix A.

### 2. SYNOPTIC CHARTS OF X-RAY FEATURES FROM THE SOFT X-RAY PHOTOGRAPHS TAKEN BY THE SKYLAB EXPERIMENT S-054 (AMERICAN SCIENCE AND ENGINEERING, INC.)

The basic data set was the 70-mm microfilm, (National Space Science Data Center, No. 73-027A-0513), from which 8" x 10" glossy prints were made at two different exposures. These photographs covered Carrington Rotations 1601 - 1608, and those used are listed in Table 1 by numbers between 1 and 163. On rotations 1609 - 1610, the S-054 images were partially obscured by a defective filter wheel, but usable images were provided on 8" x 10" negatives by J. T. Nolte of AS&E. The out-of-focus image of the deformed filter wheel was clearly identifiable and seriously affected only a portion of the image. Contact prints were made of these negatives, and those used are listed by a 5-digit number in Table 1. A "montage" of the useful portions of the X-ray images from rotations 1609 and 1610 was published by Mitchell et al. [*1980*].

In order to use the photographs, the north and south poles of the Sun had to be located in each photograph. The roll angle ($\gamma_{RR}$) for the time when each picture was taken was found in the "Skylab X-Ray Telescope Film Image Catalog" provided by NSSDC with the documentation of the microfilm. Using a transparent overlay on the photographs, the poles were easy to locate. By centering the solar disk and aligning the lines with fiducial marks on the left side of the photographs, $\gamma_{RR}$ located the north pole. In some photographs, fiducial marks did not exist on the left side. In this case the marks on the right side were aligned with the result that $\gamma_{RR}$ gave the south pole of the Sun.

From the time of the day when the picture was taken, the heliographic longitude of central meridian could be calculated. These longitudes are listed (by photograph number) in Table 1. Stonyhurst Sun disks (transparent overlays) for integer values of the inclination ($B_0$) of the solar equator were laid over the photograph and the latitudes and longitudes read directly.

For each area of the Sun during rotations 1601 - 1608, photographs were examined and those in which the region of interest was most clearly shown were chosen. This choice generally included two or three photographs taken before and two or three taken after the main photograph. The different photographs made it possible to view the area of interest in the corona from many different angles. Viewing different photographs made it possible to discern what three-dimensional loops existed and to pick out many that were not visible in the central photograph. Only the central photographs are listed in Table 1.

TABLE 1

PRINCIPAL X-RAY PHOTOGRAPHS USED FOR CHARTS

| Photo No. | Carrington Rotation | Heliolongitude of CM (deg) | Time of Photo (day:hr:min) |
|---|---|---|---|
| 1 | 1601 | 46 | 149:07:06 |
| 5 | 1602 | 352 | 153:07:59 |
| 7 | 1602 | 263 | 160:01:21 |
| 11 | 1602 | 210 | 164:01:20 |
| 17 | 1602 | 120 | 170:20:41 |
| 20 | 1602 | 85 | 173:12:32 |
| 24 | 1602 | 32 | 177:13:00 |
| 28 | 1603 | 339 | 181:11:42 |
| 33 | 1603 | 272 | 186:13:16 |
| 38 | 1603 | 206 | 191:12:53 |
| 44 | 1603 | 128 | 197:18:06 |
| 46 | 1604 | 314 | 209:16:44 |
| 52 | 1604 | 239 | 216:06:47 |
| 56 | 1604 | 176 | 221:01:10 |
| 63 | 1604 | 77 | 228:13:33 |
| 73 | 1605 | 312 | 238:00:39 |
| 81 | 1605 | 206 | 246:01:12 |
| 91 | 1605 | 73 | 256:02:00 |
| 97 | 1606 | 353 | 262:03:11 |
| 99 | 1606 | 327 | 264:03:20 |
| 101 | 1606 | 288 | 267:01:10 |
| 105 | 1606 | 235 | 271:01:29 |
| 106 | 1606 | 222 | 272:00:44 |
| 115 | 1606 | 104 | 281:00:32 |
| 116 | 1606 | 90 | 282:01:25 |
| 120 | 1606 | 37 | 286:01:53 |
| 125 | 1607 | 332 | 291:01:26 |
| 127 | 1607 | 298 | 293:14:06 |
| 136 | 1607 | 186 | 302:01:40 |
| 144 | 1607 | 81 | 310:02:12 |
| 149 | 1607 | 15 | 315:01:53 |
| 153 | 1608 | 303 | 320:12:14 |
| 155 | 1608 | 262 | 323:14:46 |
| 163 | 1608 | 164 | 331:01:43 |
| 050048 | 1609 | 140 | 360:05:23 |
| 051039 | 1609 | 96 | 363:13:41 |
| 051544 | 1609 | 17 | 4:12:37 |
| 052095 | 1610 | 285 | 11:14:03 |
| 053275 | 1610 | 207 | 17:14:39 |
| 054996 | 1610 | 154 | 21:12:08 |
| 056362 | 1610 | 75 | 27:14:12 |
| 056542 | 1610 | 22 | 31:13:05 |

During rotations 1609 and 1610, the out-of-focus image of a bent filter wheel caused part of each photograph to be obscured. For this reason, the procedure was modified slightly. Starting with the earliest chosen photograph, loops seen on each photograph were extracted. These loops were checked with the other photographs. The photographs were studied in the order of when they were taken.

For the entire period, the loops chosen were those in which both footpoints could be seen. When both footpoints were apparent, they were located by dots and connected with a dashed line. If both footpoints could not be determined accurately, the minimum observed extent of the loop was shown by a dotted line. This was done so that at least an idea of the structure involved could be obtained (e.g., Rotation 1609).

After the loops were picked out, they were traced on transparent acetate which was placed over the central photograph. If the loops could be seen on the central photograph, they were drawn directly on the acetate. If not, the Stonyhurst disks made it possible to find the latitudes and longitudes involved on adjacent images and to relocate the loops on the drawing. In this manner, as many loops as possible were extracted from within 60° of the sub-terrestrial point in the central photograph.

Using Stonyhurst disks, the footpoints of the loops were transferred from the acetate tracings to the Hα Synoptic Charts from the Skylab Atlas by *McIntosh* [*1975*]. They were marked by dots and connected by lines to show what loops exist. Again, if the exact locations of the footpoints are in question, the loops were indicated by dotted lines. Certain areas of rotations 1603, 1608, and 1609 contain no data because of gaps in the X-ray photographs.

Many possibilities for error exist in determining the loops. The error in locating the north and south poles was less than 1/2 degree and was considered insignificant. The error in determining the longitude was at most 1/10 degree for rotations 1601 - 1608 and 1/2 degree for 1609 - 1610. The error from approximating $B_0$ is less than 1/2 degree for rotations 1601 - 1608, and less than one degree for 1609 - 1610. These errors are small and random in nature. There are larger possibilities for error. Near central meridian, the error for locating footpoints which can be seen is less than two degrees. Near the limb, however, the cosine projection effect translates a small error in locating a loop into an error as large as five degrees in longitude near the limb, although latitude is unaffected. Such near-limb images were used only as a last resort due to missing data.

There are also many subjective factors in defining the X-ray structures. Four examples of configurations which could be misinterpreted are shown in Figure 1A, and the resulting drawings in Figure 1B. The chances of these misinterpretations were minimized by using many photographs for the same region. This enabled the structures to be viewed from different angles, reducing the chances for error. In example (i) of Figure 1, two small loops, if unresolved, may be drawn as a single larger loop. On the other hand, a long loop (example ii) whose top is not visible in emission may be drawn as two shorter loops. Example (iii) is a dark X-ray filament channel which sometimes overlies a large Hα filament. Since high-lying loops are often faint, continuity could be suggested and the full loops drawn, or conversely, the dark gap could be discernible with the same result as example (ii). Finally, if there are loops near high latitudes which extend over the limb but are not fully illuminated (example iv), only their lower segments may appear in the drawing.

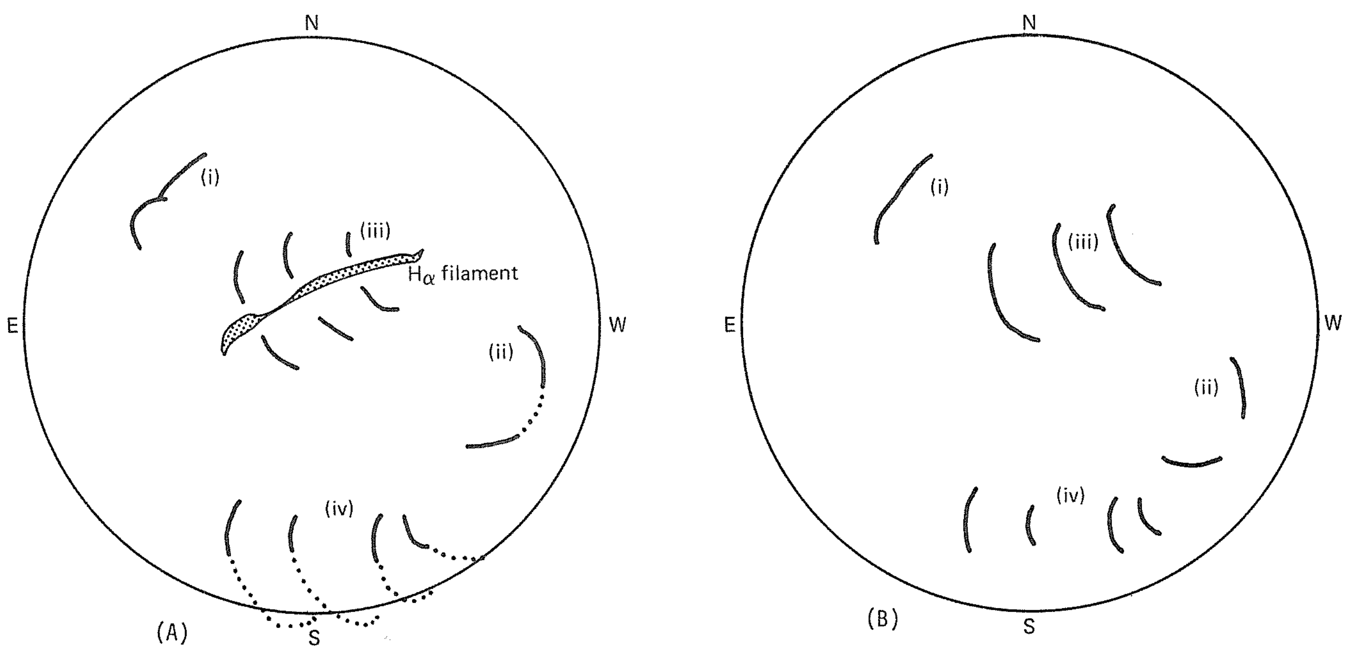


Fig. 1. (A) shows four X-ray structures likely to be misinterpreted. (B) shows the resulting drawings. In (i) two unresolved loops were combined; in (ii) the top of a loop is unseen and is drawn as two loops; in (iii) a dark X-ray channel is interpreted as three complete loops; in (iv) unlit parts of a loop on the limb are missed.

In addition, there will be one rather obvious situation where no loops will appear on the charts, although they are likely to be present on the Sun. On the 64-second exposure negatives used for this study (NSSDC-73-027A-05C/D), active region X-ray plages (which often overlie Hα plages) are strongly over-exposed. Therefore, end points of loops leading into plages were not identifiable, nor were loops lying completely within large plages. Consequently these charts depict only large-scale loops with at least one footpoint well away from bright X-ray plage regions.

An independent problem was that in many cases there was evolution of the loop structure from day-to-day. The result of this is that specific loops have to be chosen on a given photograph, while a day later the structure may appear different on another photograph. This was especially apparent for parts of rotations 1609 and 1610.

The result of all these inherent and subjective errors is that the results must be viewed as approximate. This fact can be easily seen if one compares drawings showing photographs 105 and 106 at central meridian as shown in Figure 2. The difference in central meridian is 12.8°. There are many similarities, but also many differences, even though the photographs were taken only one day apart.

The photographs were fourth-generation prints. For photograph #63 and adjacent photographs, second-generation prints were obtained from American Science and Engineering, Inc. As can be seen from Figure 3, which compares the drawing made from (A) NSSDC 70-mm microfilm #63 with the drawing made from (B) AS&E 8" x 10" second-generation negatives, the loop structure seen is more complex in the higher quality prints than in those used to make these charts. However, the large scale structure is similar, and this was our main objective.

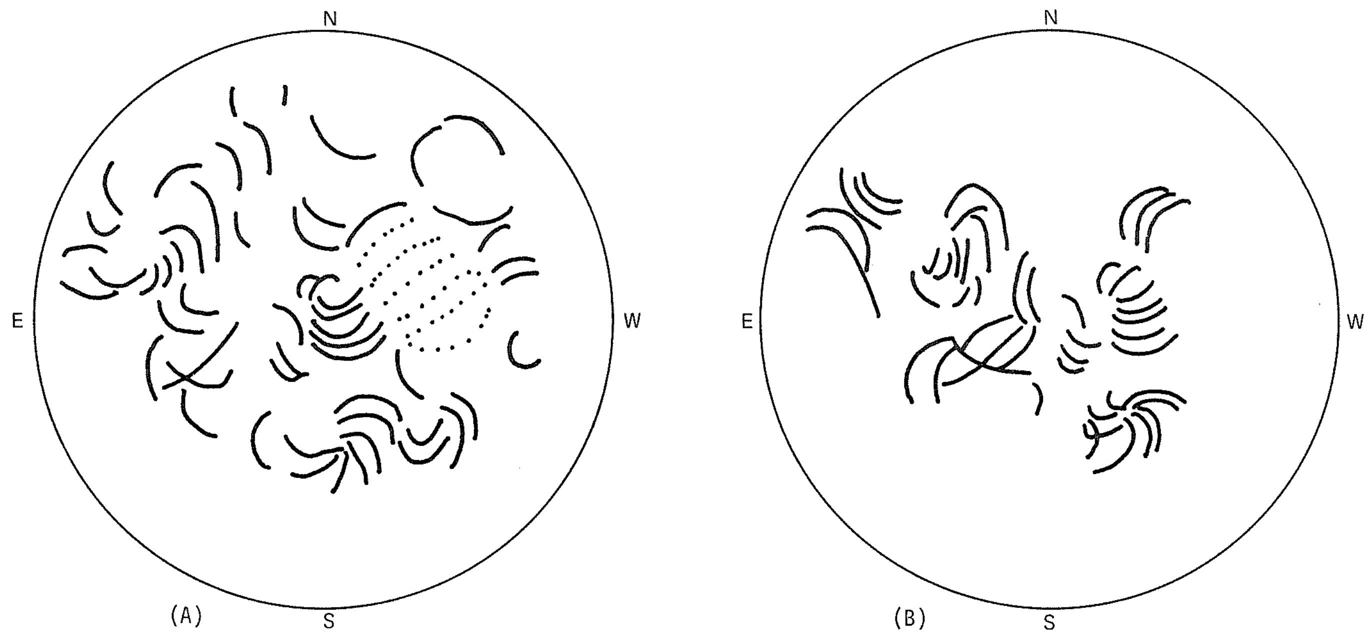


Fig. 2. Drawings of photograph 105, in (A), and 106, in (B), are compared. They have central meridians of L=235.3° and L=222.5° respectively. Though taken only one day apart, the interpretations are different.

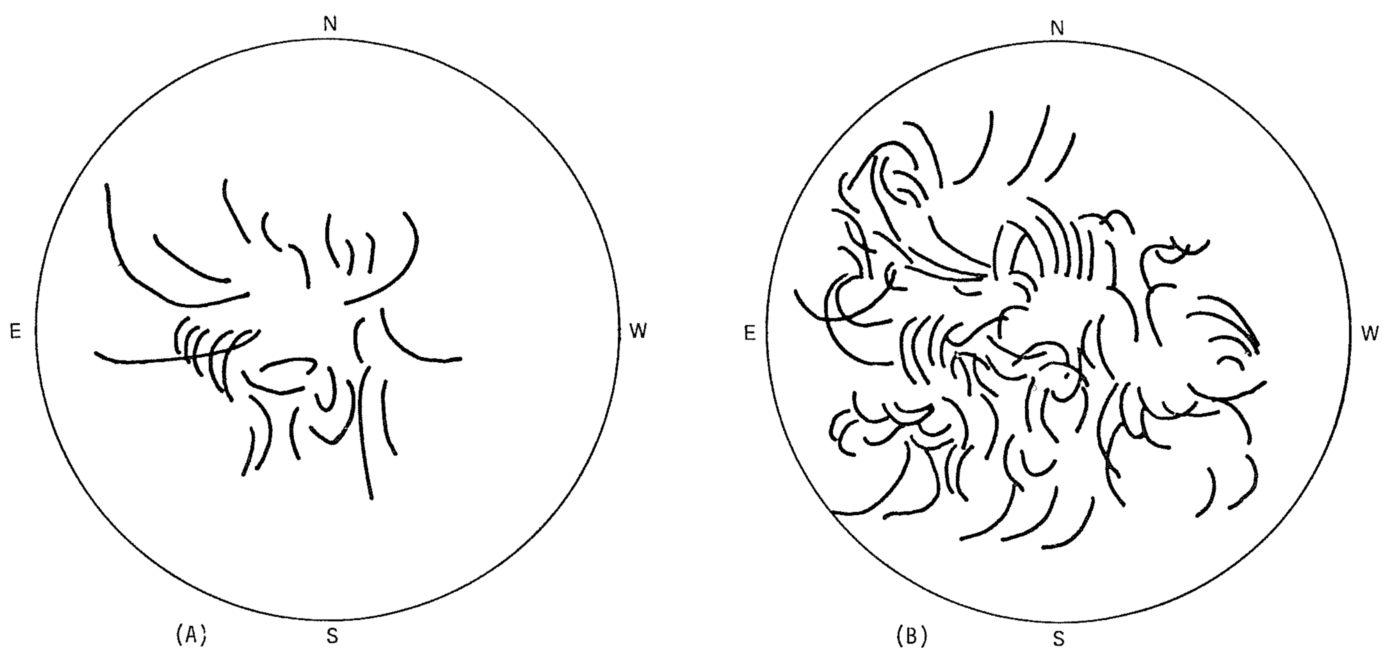


Fig. 3. Drawings of X-ray structures made from NSSDC 70-mm microfilm #63, (A), and an 8" x 10" second-generation negative of the same region, (B), show that although (A) shows fewer details, the large scale patterns are similar.

The X-ray structures, as drawn on a rectangular heliographic latitude and longitude grid, are printed in color and overlaid on the Hα Synoptic Charts. When both loop footpoints were apparent, they were located by dots and connected with a dashed line. If both footpoints could not be determined accurately, the minimum observed extent of the loop was shown by a dotted line (as on rotation 1609).

The image resolution on rotation 1610 was also low, but for clarity, the loop connections are shown simply as dashed lines. The strongly over-exposed images of X-ray plages (where no loops can be resolved) are indicated by regions diagonally striped in color. The regions stippled in color are the coronal holes CH 1 through CH 6, taken from *Nolte et al.*, [*1976b*]. Boundaries for coronal holes not covered by that publication were taken from *Bohlin and Rubenstein*, [*1975*]. Areas not covered by either publication show no boundary data. The boundary of one particularly extensive hole, extending from the south pole up past the equator in the eastern hemisphere on rotation 1610 was estimated by *Mitchell et al.* [*1980*] from the same soft X-ray photographs listed in Table 1 and is shown on the chart.

All-in-all, we believe that if the Synoptic Charts of X-ray features are regarded as what the eye perceives in the X-ray photographs (and therefore as indicative only of the approximate location and nature of the actual emission features), they will be useful as a representation of large-scale coronal structures. The synoptic charts should be considered as preliminary, but sufficiently accurate for use as they stand, within the guidelines set down in the Introduction. *Note added in Proof*: Final cross-checking of the printed charts revealed two regions of systematic misalignment, aside from isolated minor plotting errors (the great majority of which were less than 2° in position). On rotation 1605, all footpoints west of 310° should be shifted 2° toward the east, and on rotation 1608, all footpoints between 120° and 350° should be shifted 2° to the west. These misalignments are noted on the two charts.

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These charts constituted part of a senior thesis presented by JMH to the Department of Physics and Engineering of Loyola College (Baltimore). Full-sized originals of the Hα Synoptic Charts were provided by P. S. McIntosh of the Space Environment Laboratory, NOAA/ERL. We appreciate the helpful comments of A. S. Krieger and J. T. Nolte of American Science and Engineering, Inc. who also provided unpublished negatives to complement the National Space Science Data Center 70-mm film record. Work at JHU/APL was supported by the National Aeronautics and Space Administration under Grant NSG-7077 and by the Air Force Geophysics Laboratory via Task ZF10 of Contract N00024-78-C-5384 with the Department of the Navy.

# II. SOLAR FLARE ACTIVITY

## ABSTRACT

Charts of time versus longitude for each of Carrington Rotations 1600 - 1611 depict: 1) Hα importance, brightness, and location of confirmed flares; 2) peak flare X-ray flux 1-8 Å; 3) peak flare decimetric radio intensity; and 4) flux of 1.8 - 4.5 MeV protons plotted at their high coronal emission longitude estimated from simultaneously measured solar wind velocity.

## 1. INTRODUCTION

These Solar Activity Charts are a compilation for the Skylab period of selected indices of optical solar flares, radio bursts, soft X-rays, and energetic particles in a concise form. The charts were initially designed to complement studies of the coronal and interplanetary distribution of energetic solar particle populations, although their compact representation of spatial and temporal relationships has been of assistance in a wide variety of solar-terrestrial studies. The charts show the Hα importance and brightness of confirmed flares, the 1-8 Å peak X-ray flux and a spectral average of decimetric radio emissions related to the optical flares. Full disk coverage extends from April 13, 1973 through February 24, 1974. See Appendix B.

The energetic particle fluxes are represented on the charts as a continuous swath centered on the estimated high coronal connection longitude of the large scale interplanetary field line from Earth. The width of the swath is proportional to the logarithm of the ~ 3 MeV proton flux measured at Earth. The charts are organized in heliographic longitude versus time so it is easy to follow the development of an active region throughout its disk passage on a given solar rotation as well as its recurrences over several rotations, since all the activity from a given region falls on a straight vertical line. Conversely, all the flares and related radio and X-ray bursts on the disk at a given time are distributed along a horizontal line. The charts also indicate directly the distance between an active region and the longitude where energetic protons (associated with activity in that region) were injected onto the interplanetary field lines leading to the Earth.

## 2. PROCEDURE FOR DRAWING SOLAR ACTIVITY CHARTS

On the Solar Activity Charts for Carrington Rotations 1600 - 1611, time is measured on the vertical axis and heliographic longitude on the horizontal axis. Time progresses upward and is measured in day of year on the left and day of month on the right. Thus the locus of each limb progresses from lower right to upper left. The format follows that introduced by *Gold et al.* [*1974*].

The data on the activity charts are accurate to approximately one degree and to two hours. The confirmed visible flares, their X-ray data and their radio data were all found in *Solar-Geophysical Data (Comprehensive Reports)*. The importance of the Hα flares is shown by the size of the circle. Bright flares are solid, while normal and faint ones are open. The flares shown range in importance from importance (-) to importance 3. If more than one flare occurred in the same active region within a two-hour interval, only the flare of highest importance was plotted.

The number of the McMath Plage Region (MPR) containing the activity is indicated along the bottom of the chart, with northern and southern latitude regions listed on two separate lines. Where more than one MPR occupies the same longitude each additional region is coded with a different non-circular symbol.

The radio burst peak intensities are indicated by diagonal dashes emanating from each flare symbol. The radio data considered were those from the essentially identical instruments at Sagamore Hill (Massachusetts), Manila, the Canary Islands, and Athens. The frequencies used were 1415, 2695, 4995, and 8800 MHz. If the radio data peaked within 10 minutes of the flare's Hα peak, they were considered. The radio flux shown on the activity charts is the average over the four frequencies of the highest flux observed among the four observations at each frequency. The flux is in $W/10^{22}m^2Hz$.

The 1-8 Å X-ray fluxes were measured by the Solrad 9 or Solrad 10 spacecraft and reported in *Solar-Geophysical Data*. The peak fluxes are indicated by horizontal or vertical dashes emanating from the flare symbol. They are associated with a given flare if the peak in Hα and X-ray occurs within five minutes. Flux units are $ergs/10^4cm^2s$. The three X-ray levels on the charts correspond to Boulder classifications M1-M4, M5-X4, and ≥X5.

The connection longitude of the 1.8-4.5 MeV omnidirectional proton flux is shown on the activity charts. The flux was measured by the JHU/APL energetic particle experiments on the IMP-7 and 8 spacecraft and is indicated at the estimated high coronal "connection longitude". The connection longitude is the estimated source longitude of the interplanetary plasma and "frozen in" interplanetary magnetic field, estimated using observed (1 hr. avg.) solar wind velocities provided by the National Space Science Data Center from the MIT and LASL plasma instruments on the same spacecraft [*Nolte and Roelof, 1973*]. The flux of the ∿ 3 MeV protons is indicated by the width of the bar centered on the connection longitude path. It is measured to the nearest decade in $particles/cm^2s$ sr MeV.

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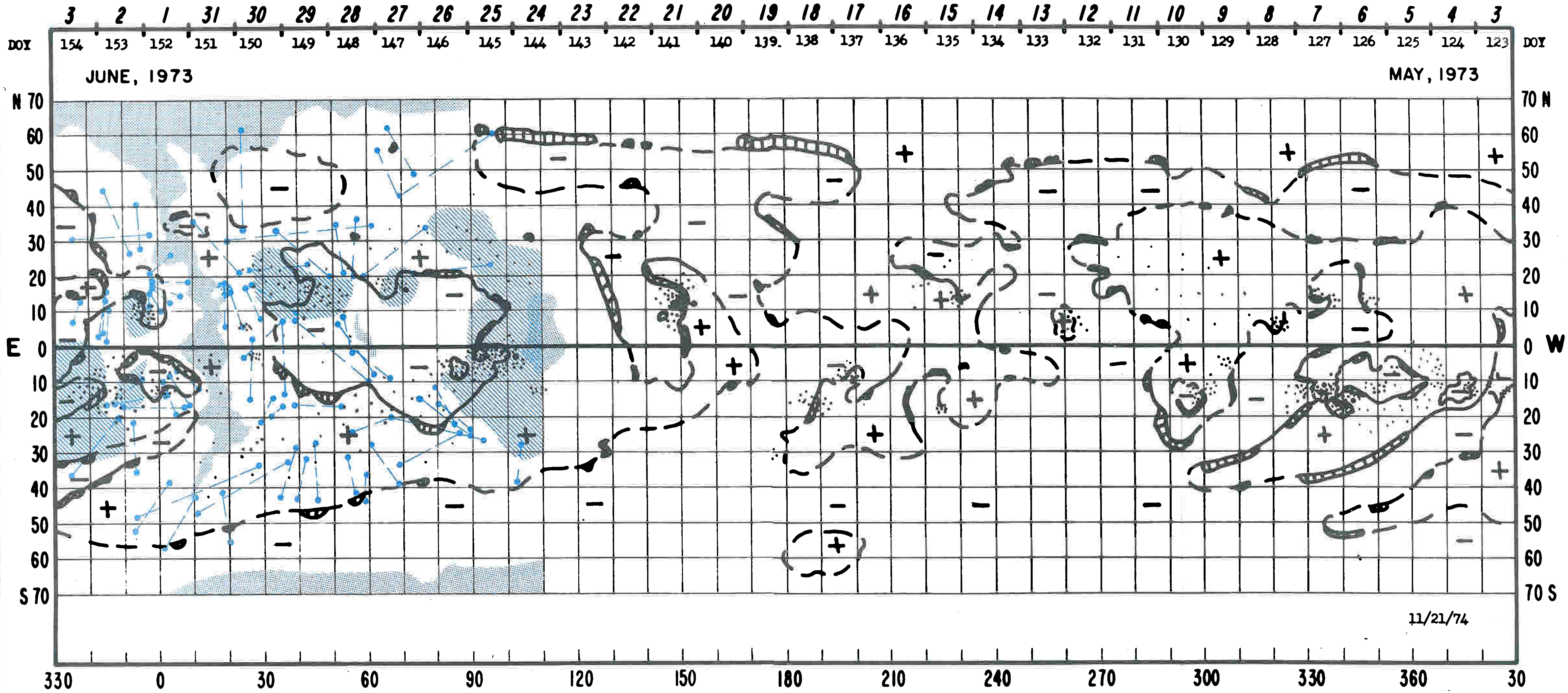
# APPENDIX A

Hα Synoptic Charts, Rotations 1601-1610

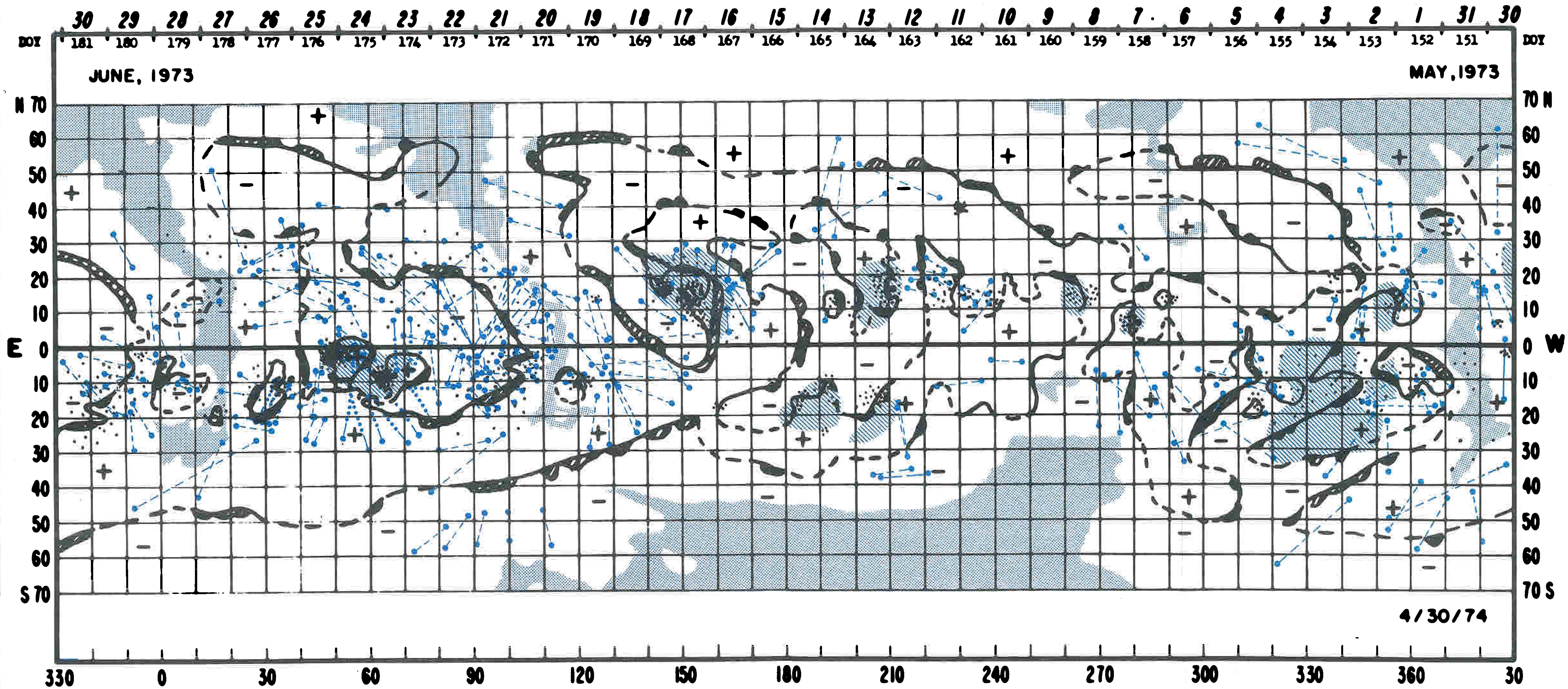
# Hα SYNOPTIC CHART

## 1973 - ROTATION 1601



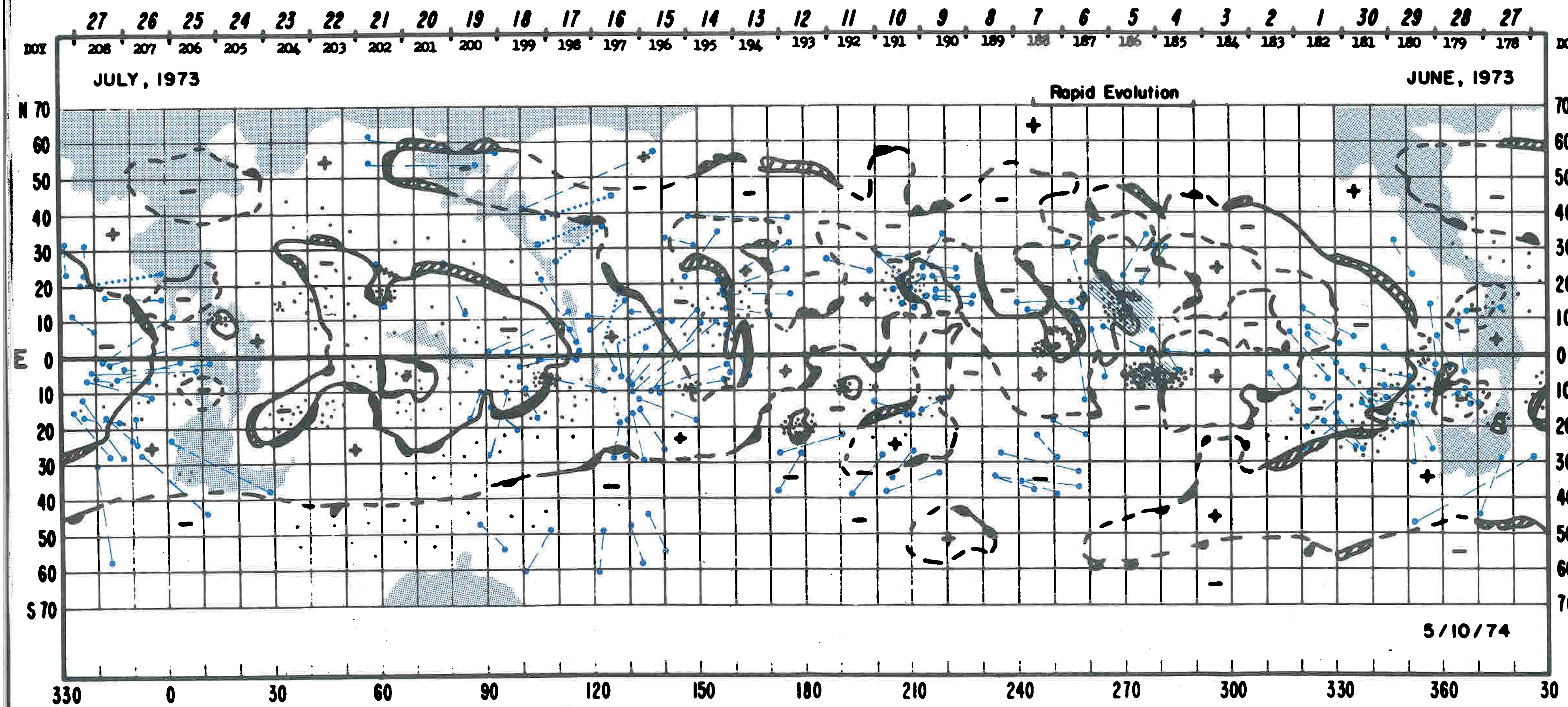
# Hα SYNOPTIC CHART

## 1973 - ROTATION 1602

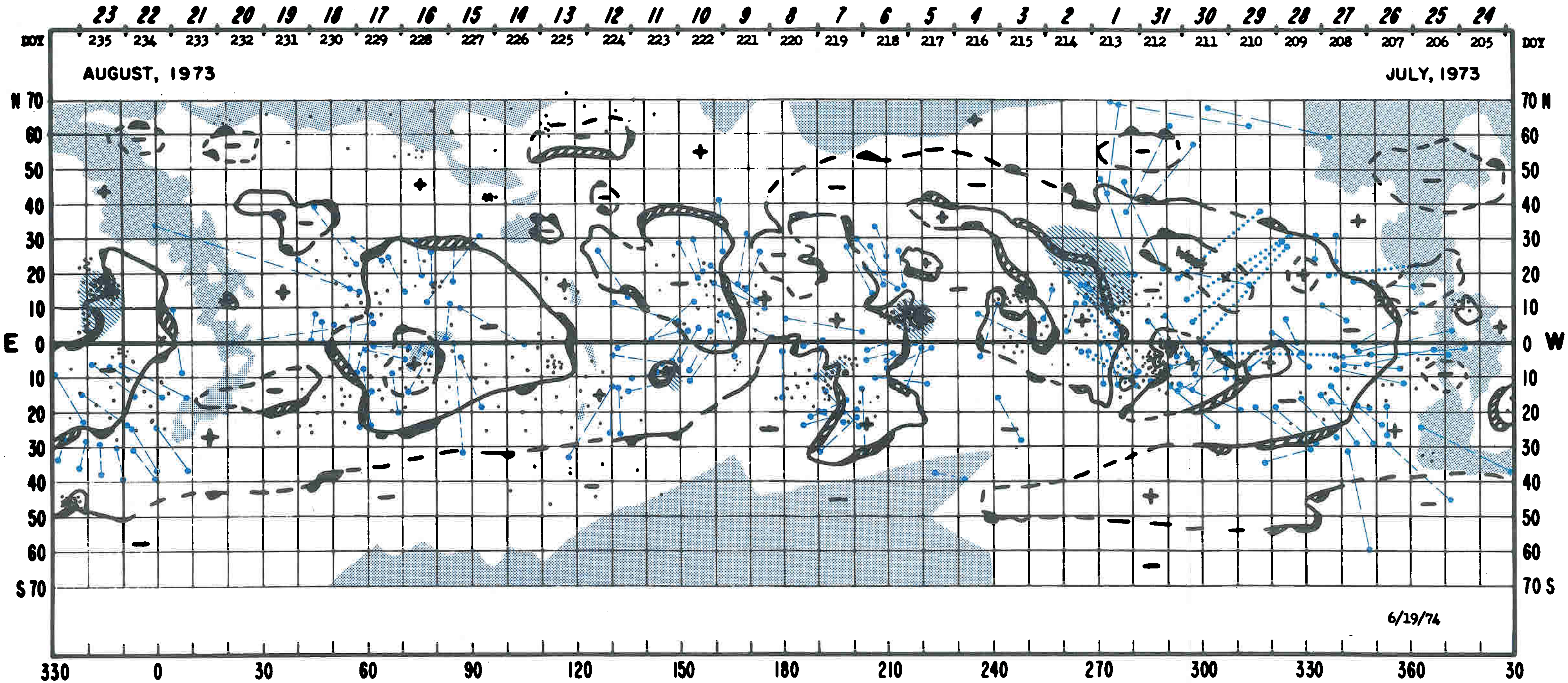


# Hα SYNOPTIC CHART

## 1973-ROTATION 1603

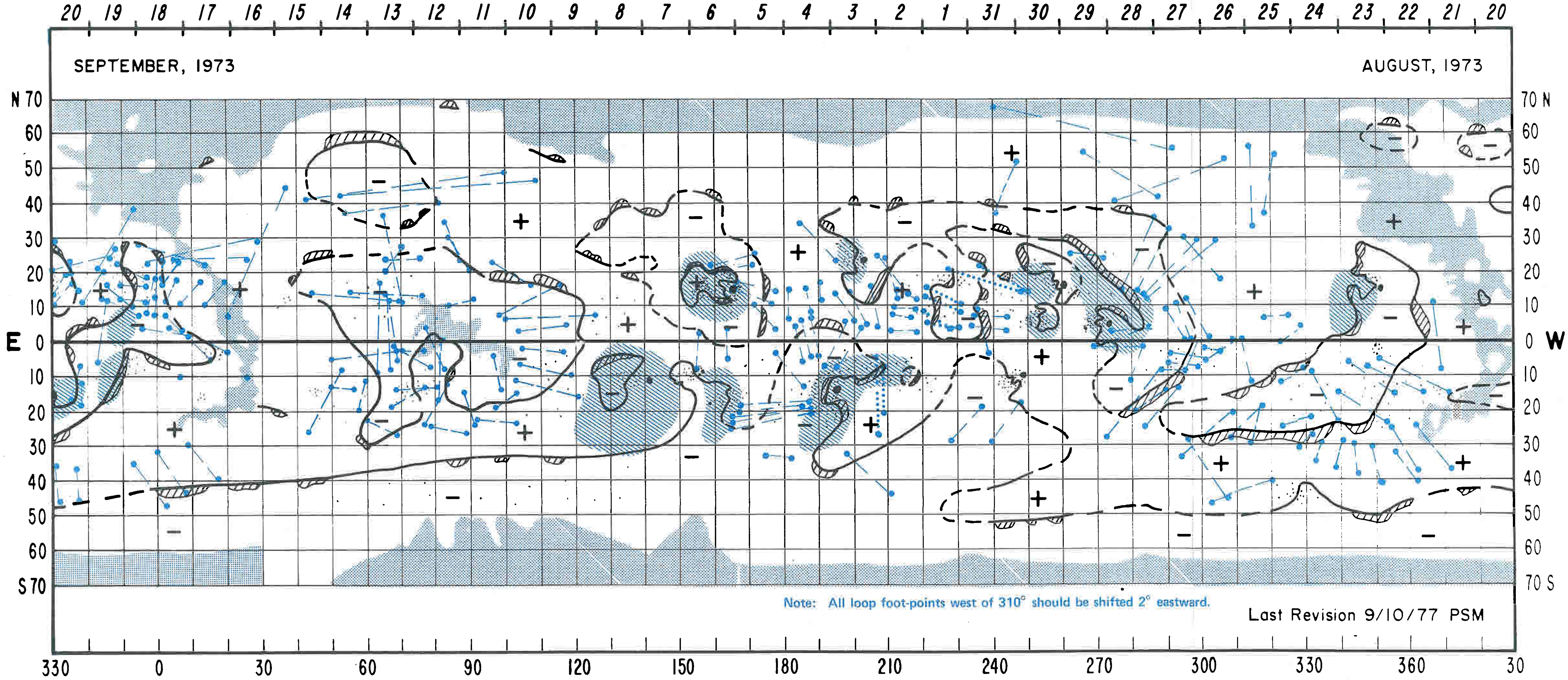


# Hα SYNOPTIC CHART
## 1973 - ROTATION 1604

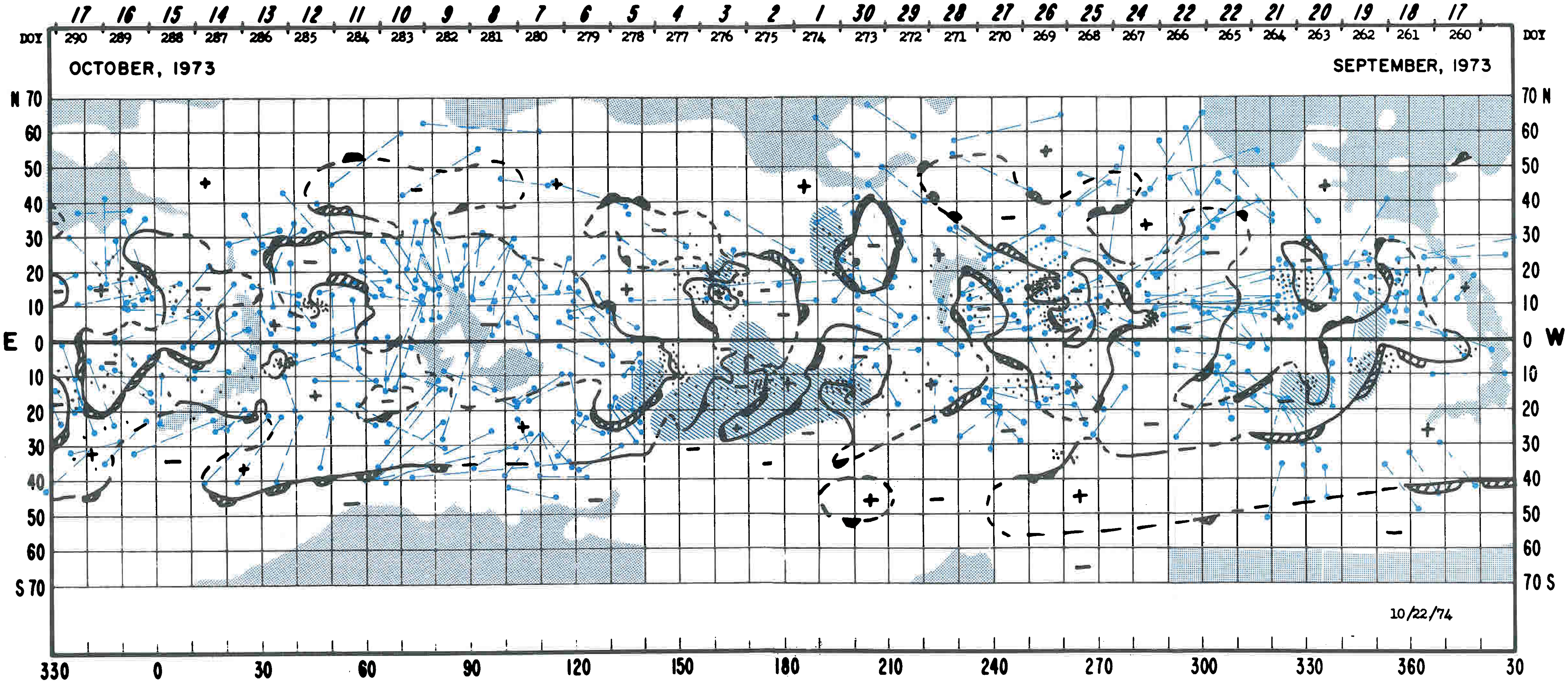


# Hα SYNOPTIC CHART

## 1973 - ROTATION 1605

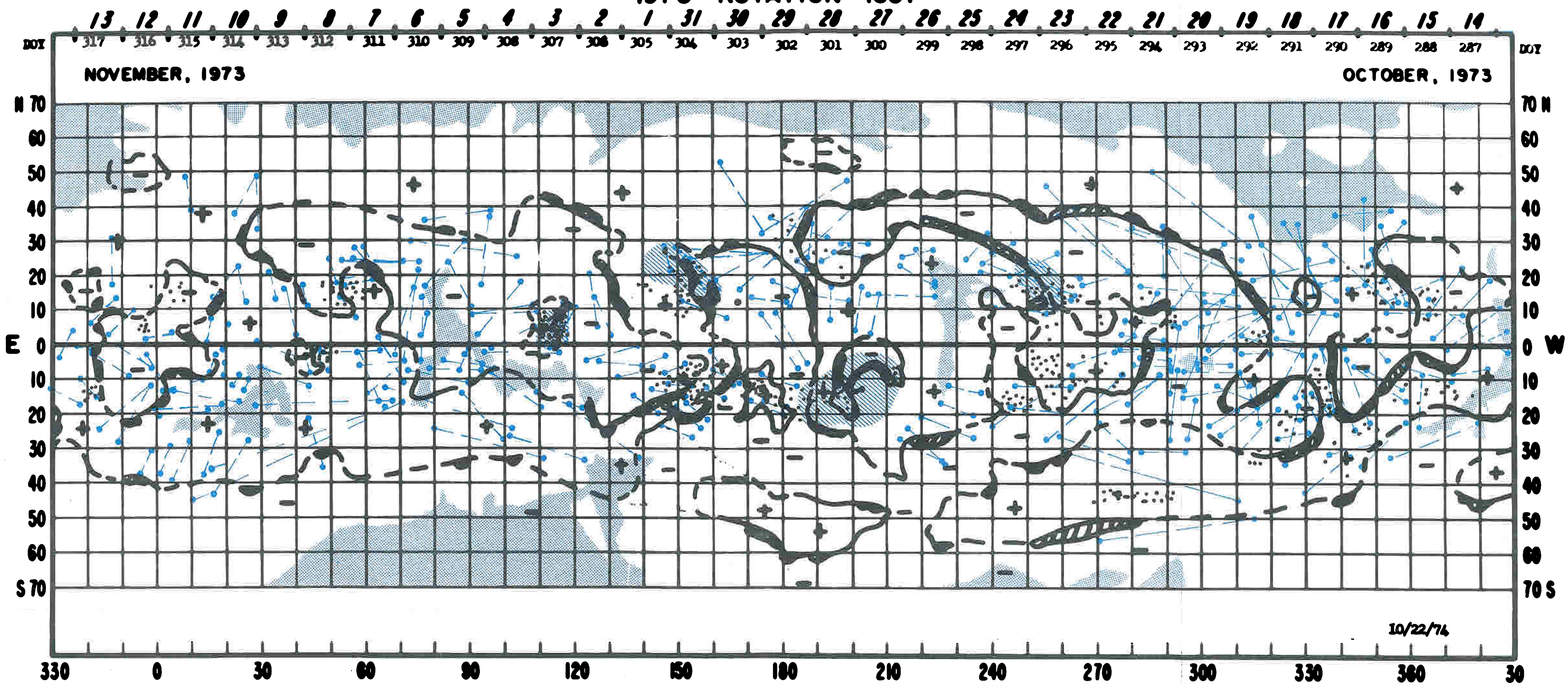


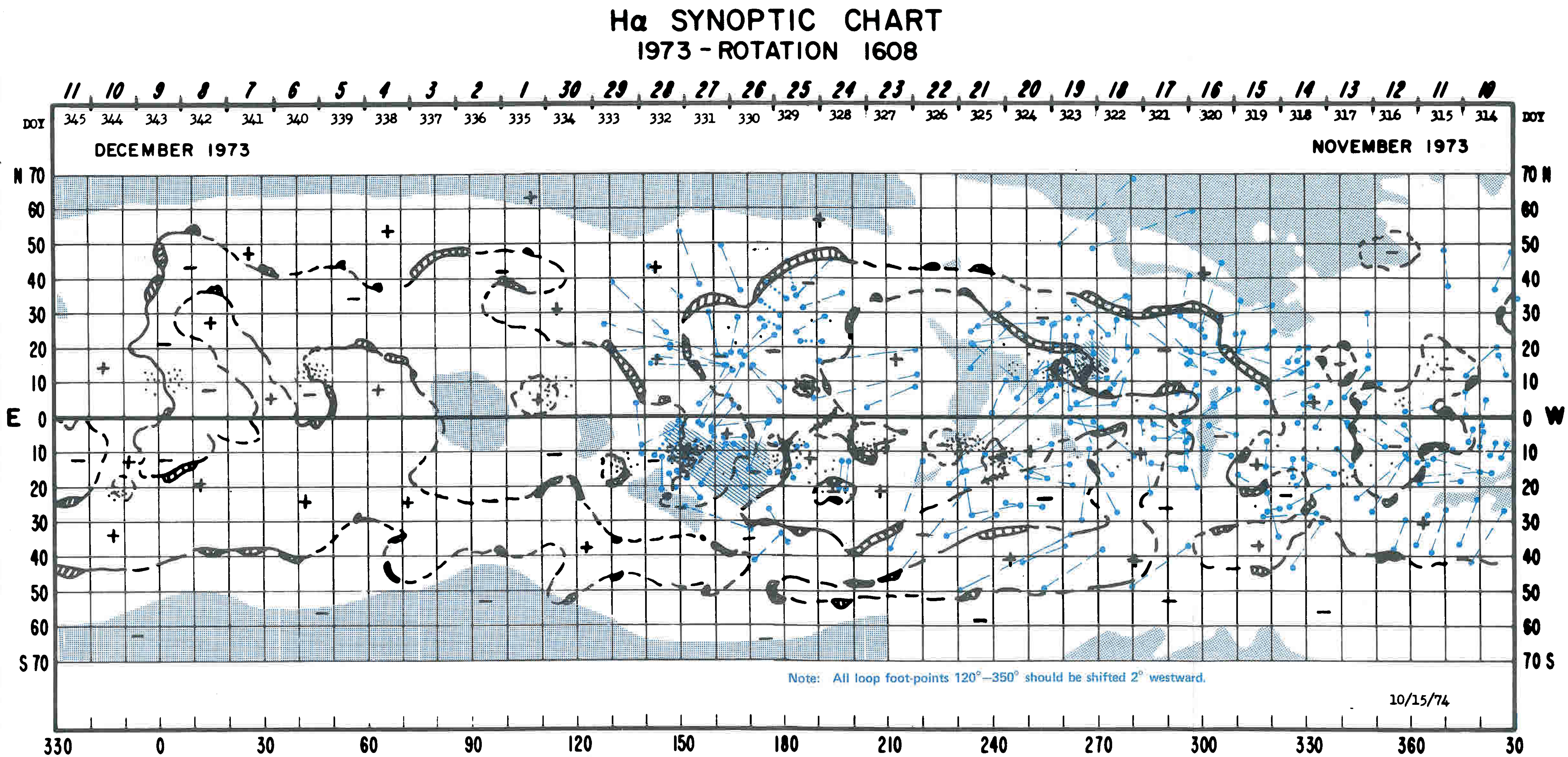
# Hα SYNOPTIC CHART
## 1973 - ROTATION 1606



# Hα SYNOPTIC CHART

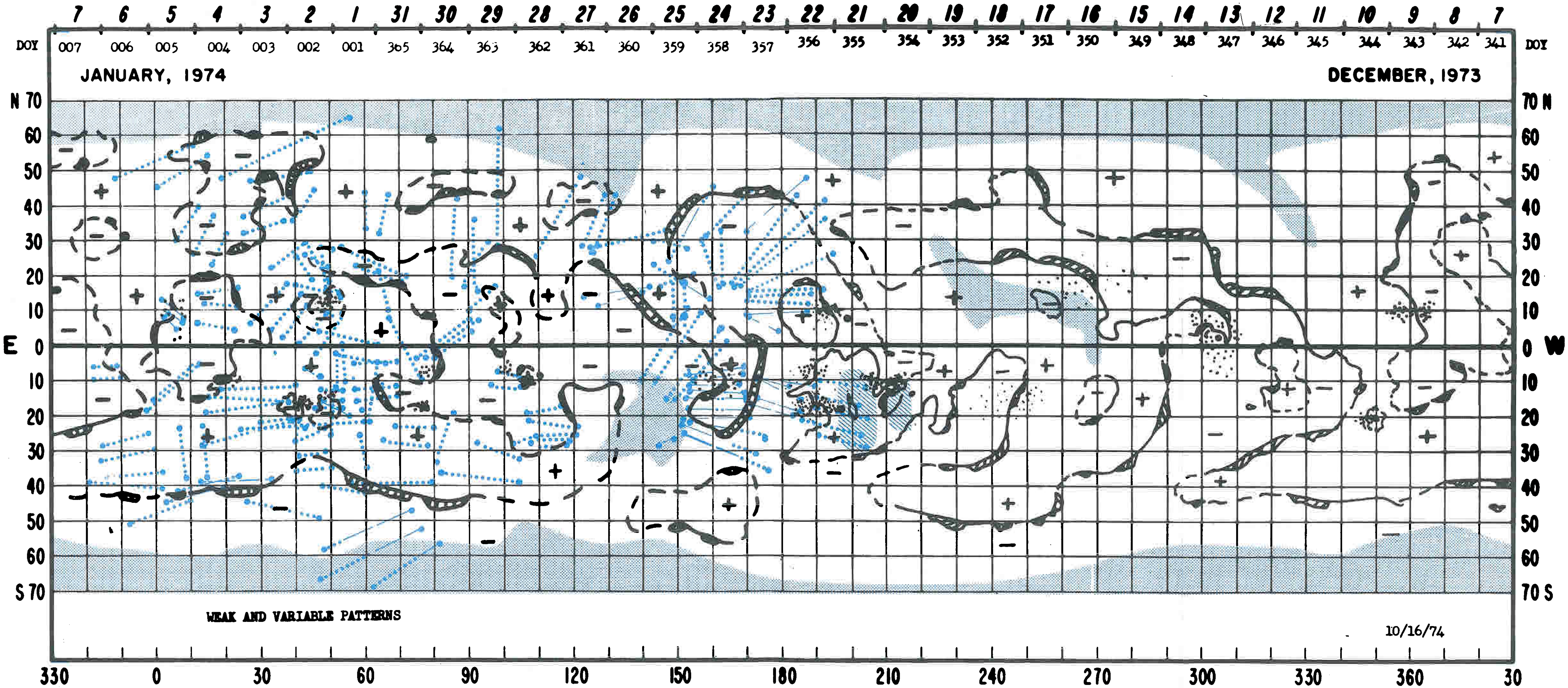
## 1973 - ROTATION 1607

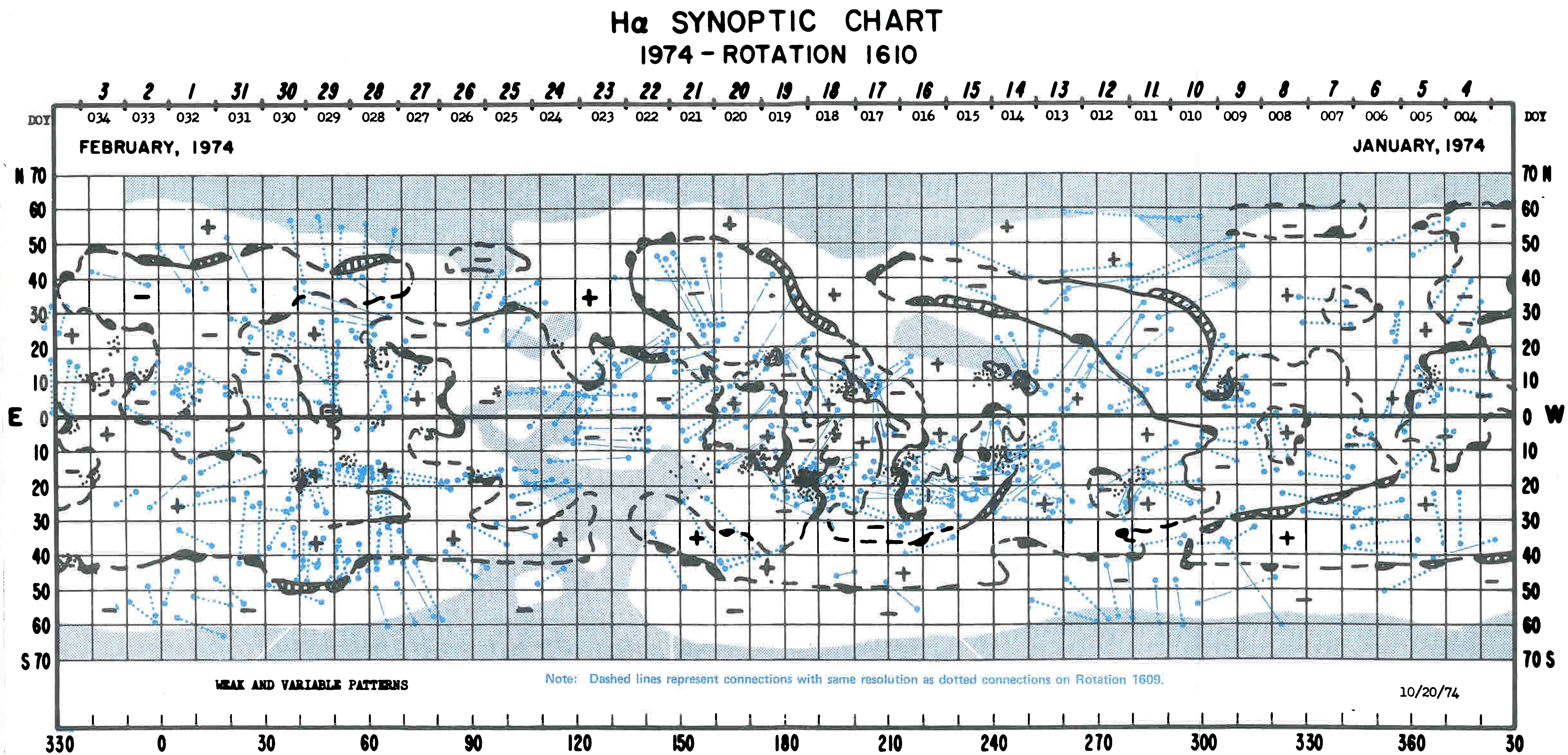



Hα SYNOPTIC CHART
1973 - ROTATION 1608
DECEMBER 1973
NOVEMBER 1973
DOY
E
W
Note: All loop foot-points 120°—350° should be shifted 2° westward.
10/15/74

# Hα SYNOPTIC CHART

## 1973, 1974 - ROTATION 1609



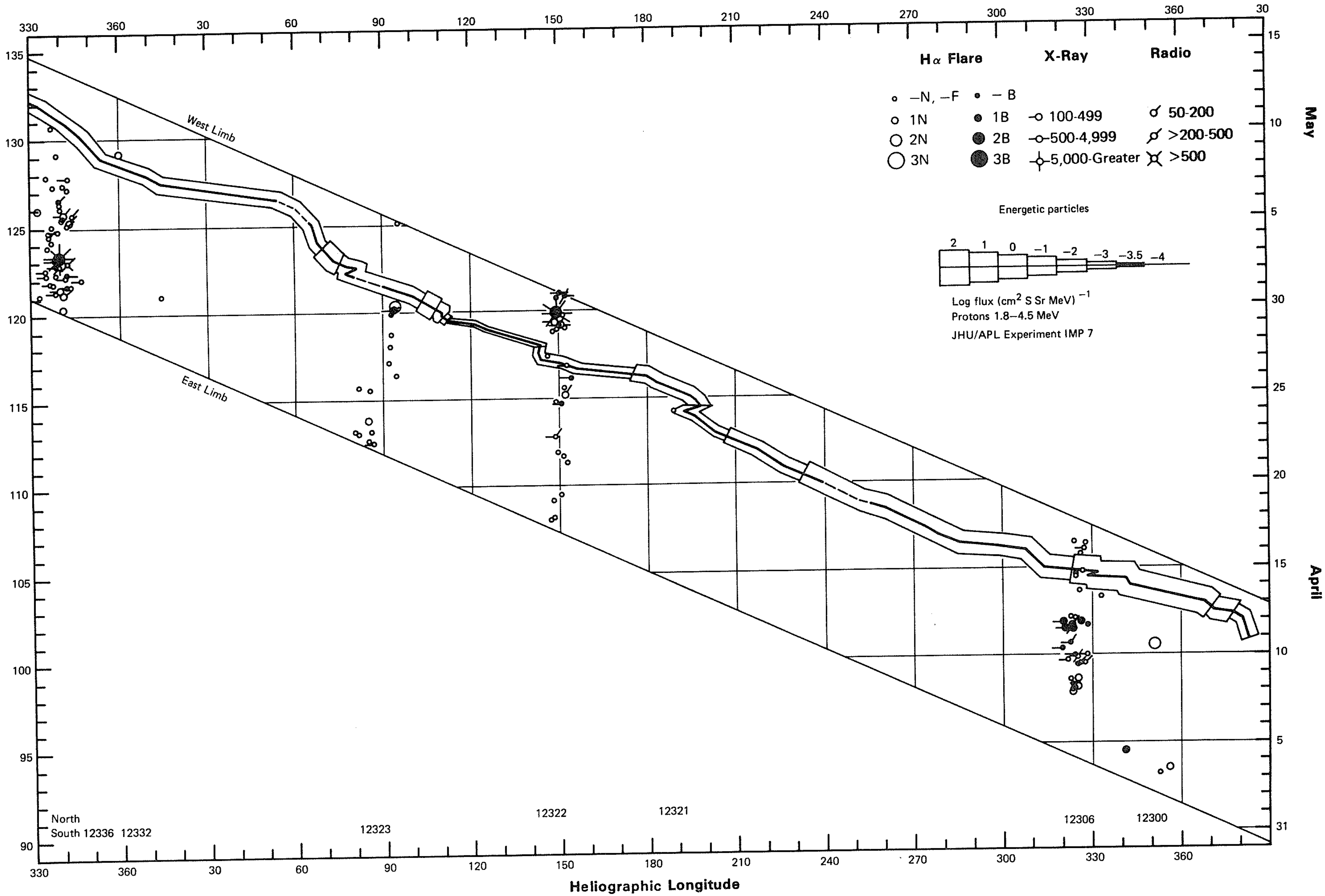

Hα SYNOPTIC CHART
1974 - ROTATION 1610
DOY
FEBRUARY, 1974
JANUARY, 1974
E
W
WEAK AND VARIABLE PATTERNS
Note: Dashed lines represent connections with same resolution as dotted connections on Rotation 1609.
10/20/74

# APPENDIX B

## Solar Activity Charts, Rotations 1600-1611

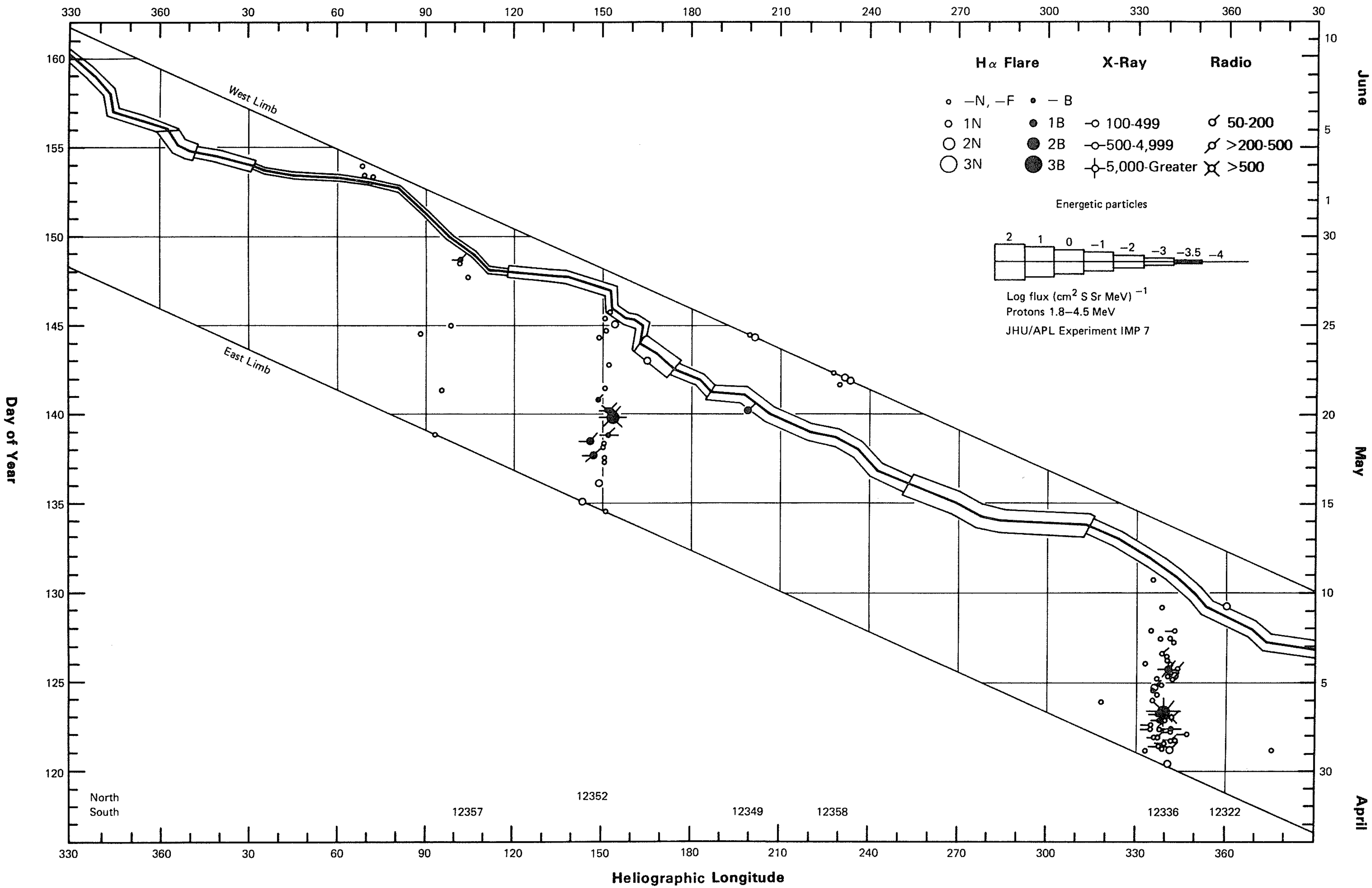
# SOLAR ACTIVITY CHART

## 1973 — ROTATION 1600



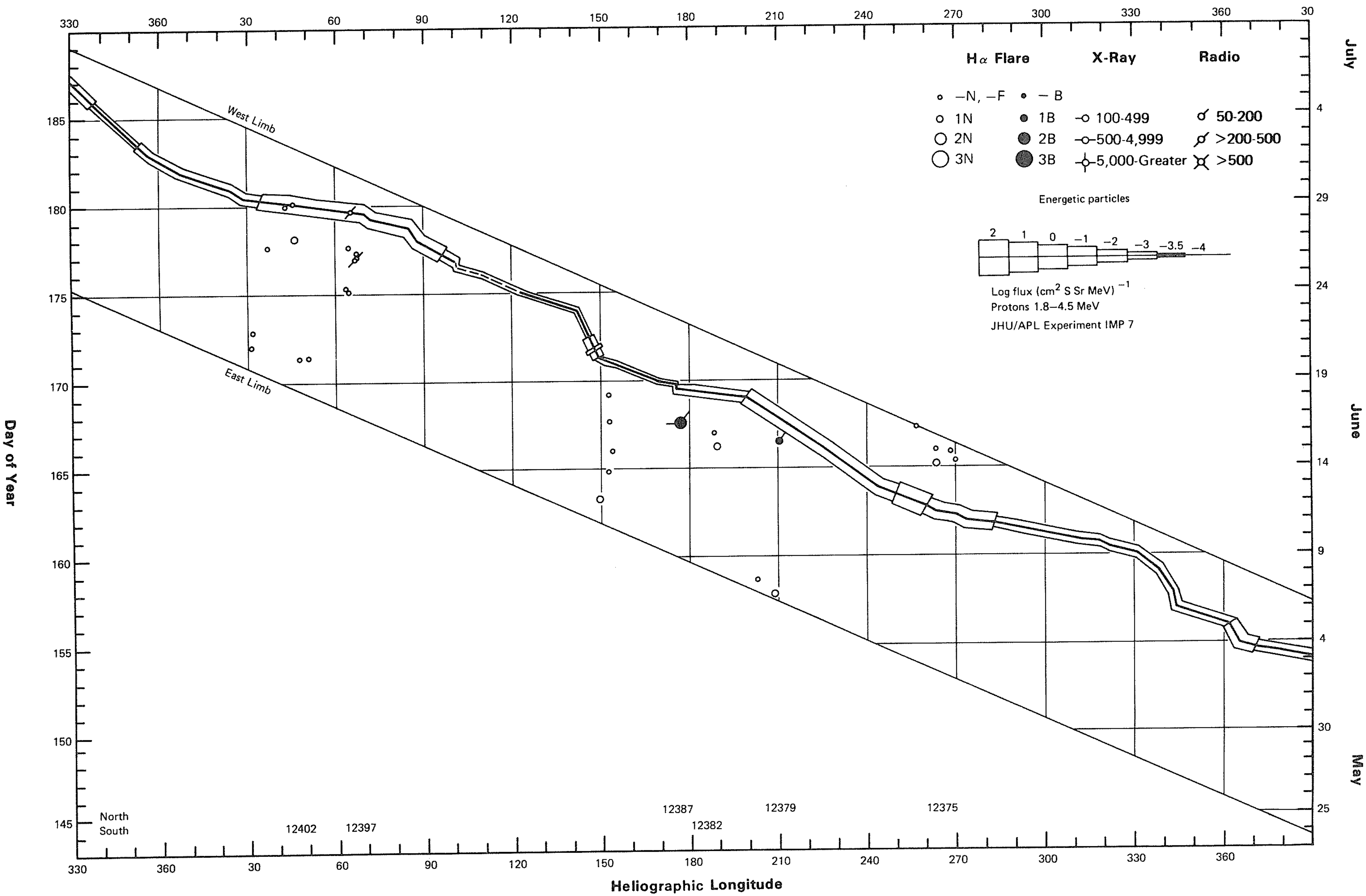
# SOLAR ACTIVITY CHART

1973 — ROTATION 1601



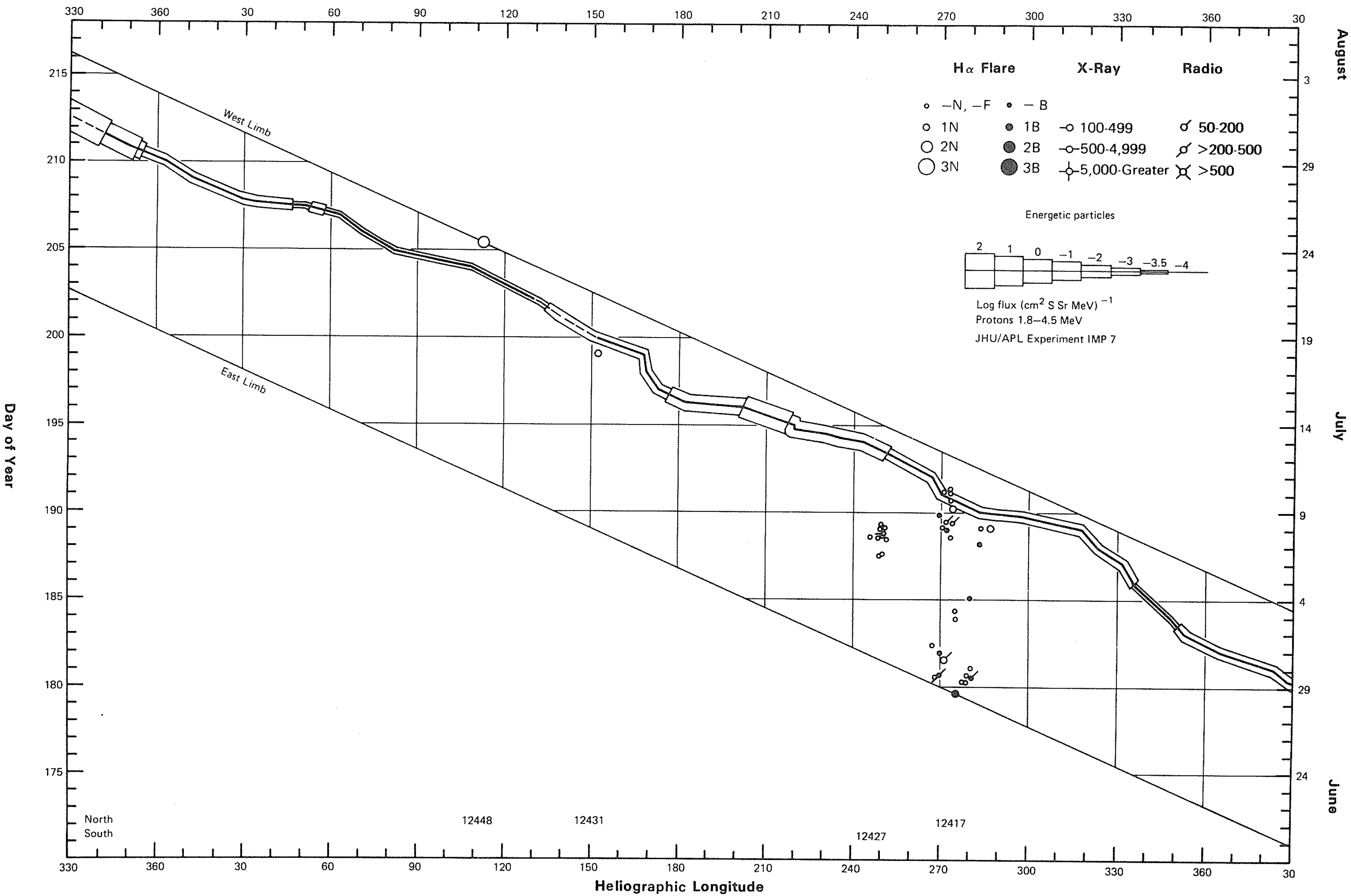
# SOLAR ACTIVITY CHART

## 1973 — ROTATION 1602



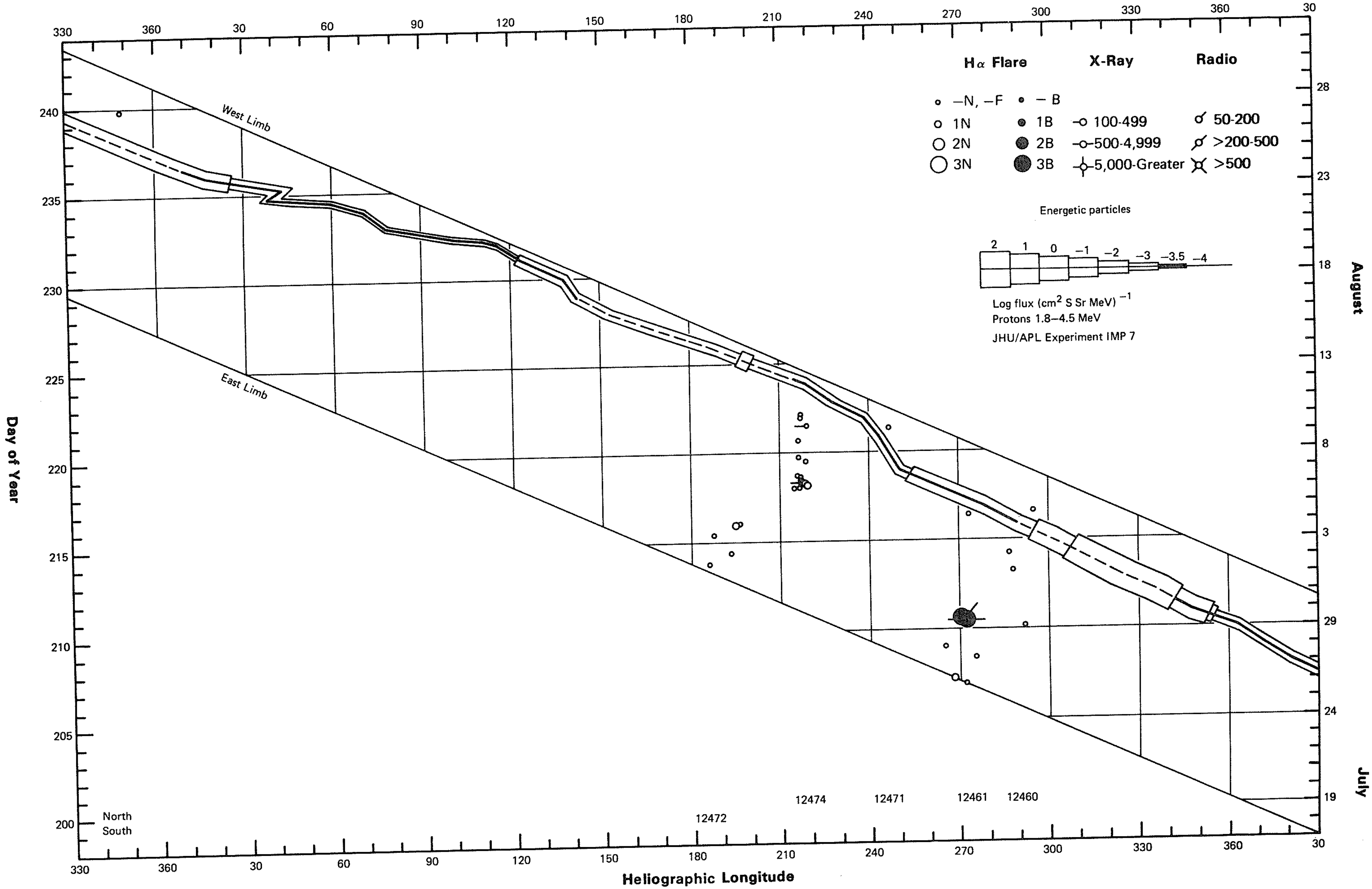
# SOLAR ACTIVITY CHART

## 1973 — ROTATION 1603



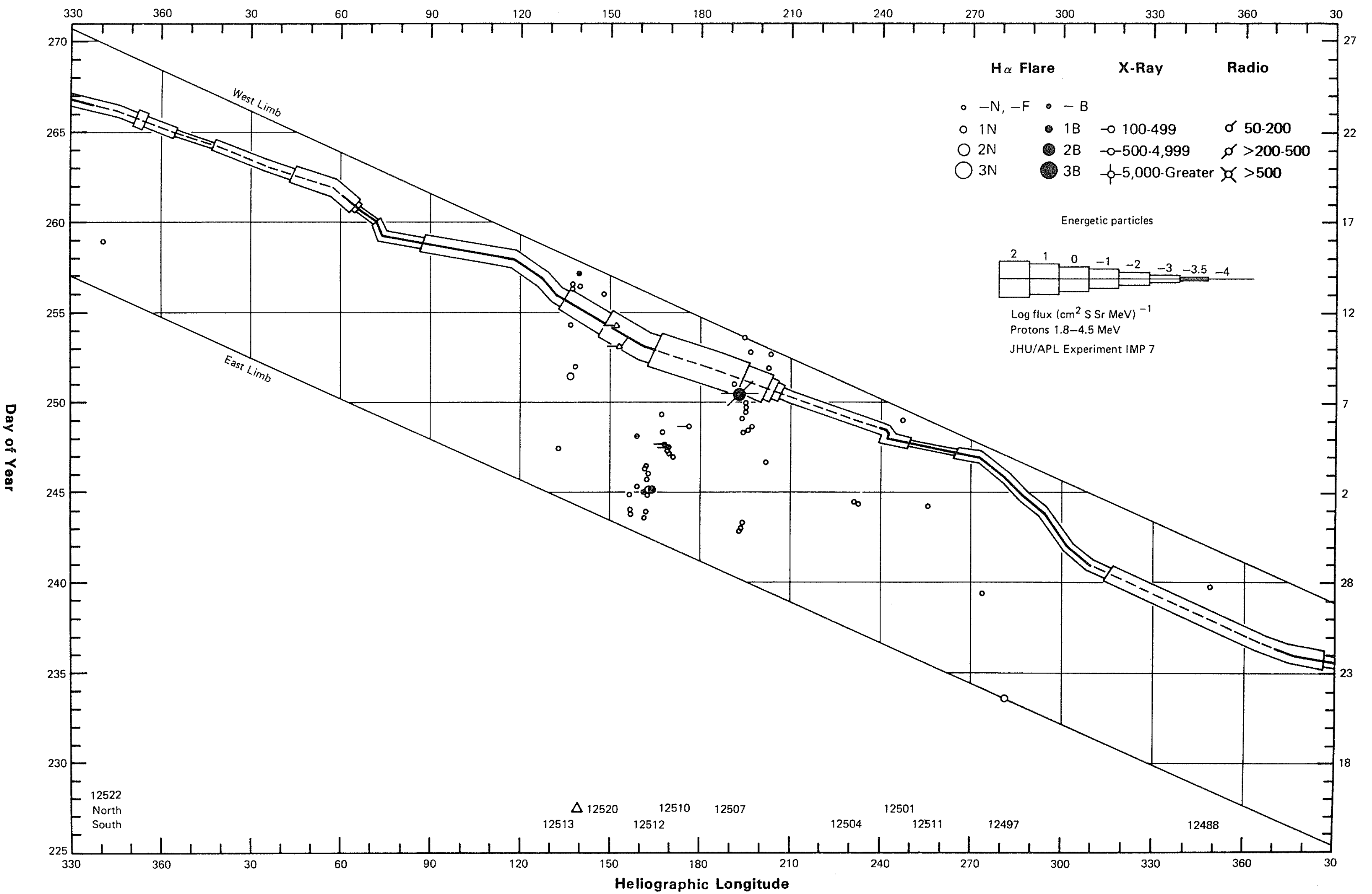
# SOLAR ACTIVITY CHART

## 1973 — ROTATION 1604



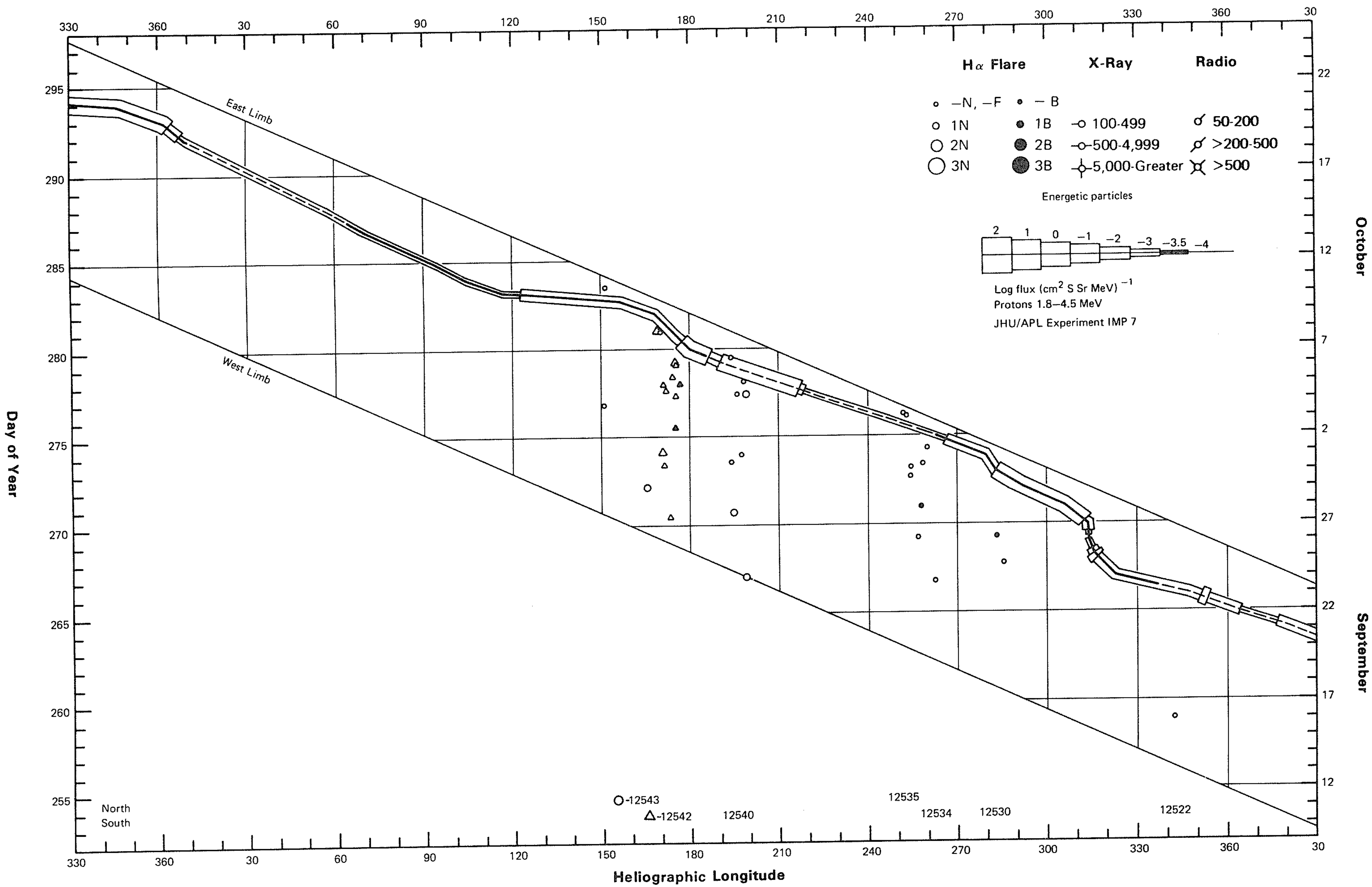
# SOLAR ACTIVITY CHART

1973 — ROTATION 1605



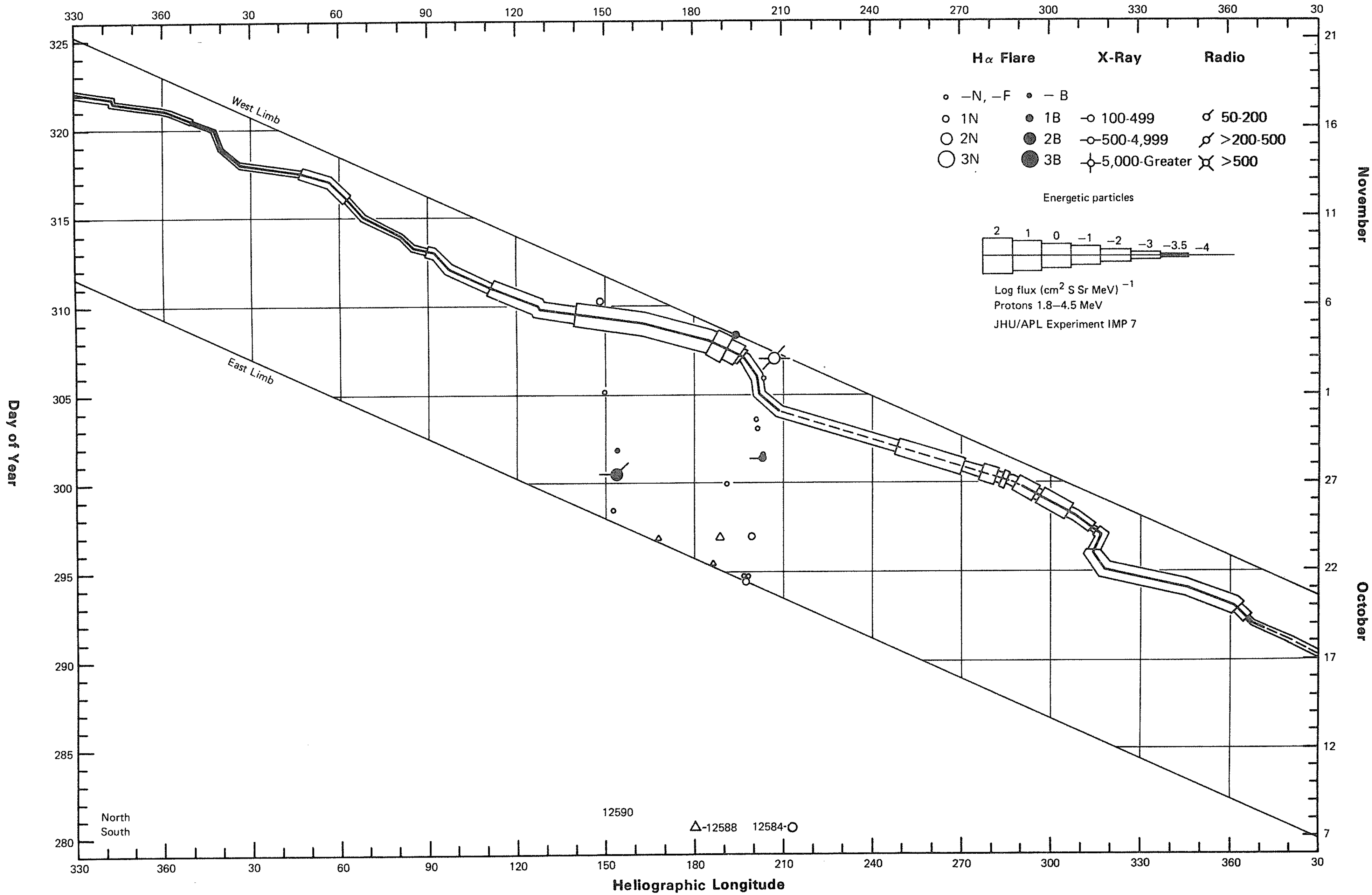
# SOLAR ACTIVITY CHART

1973 — ROTATION 1606



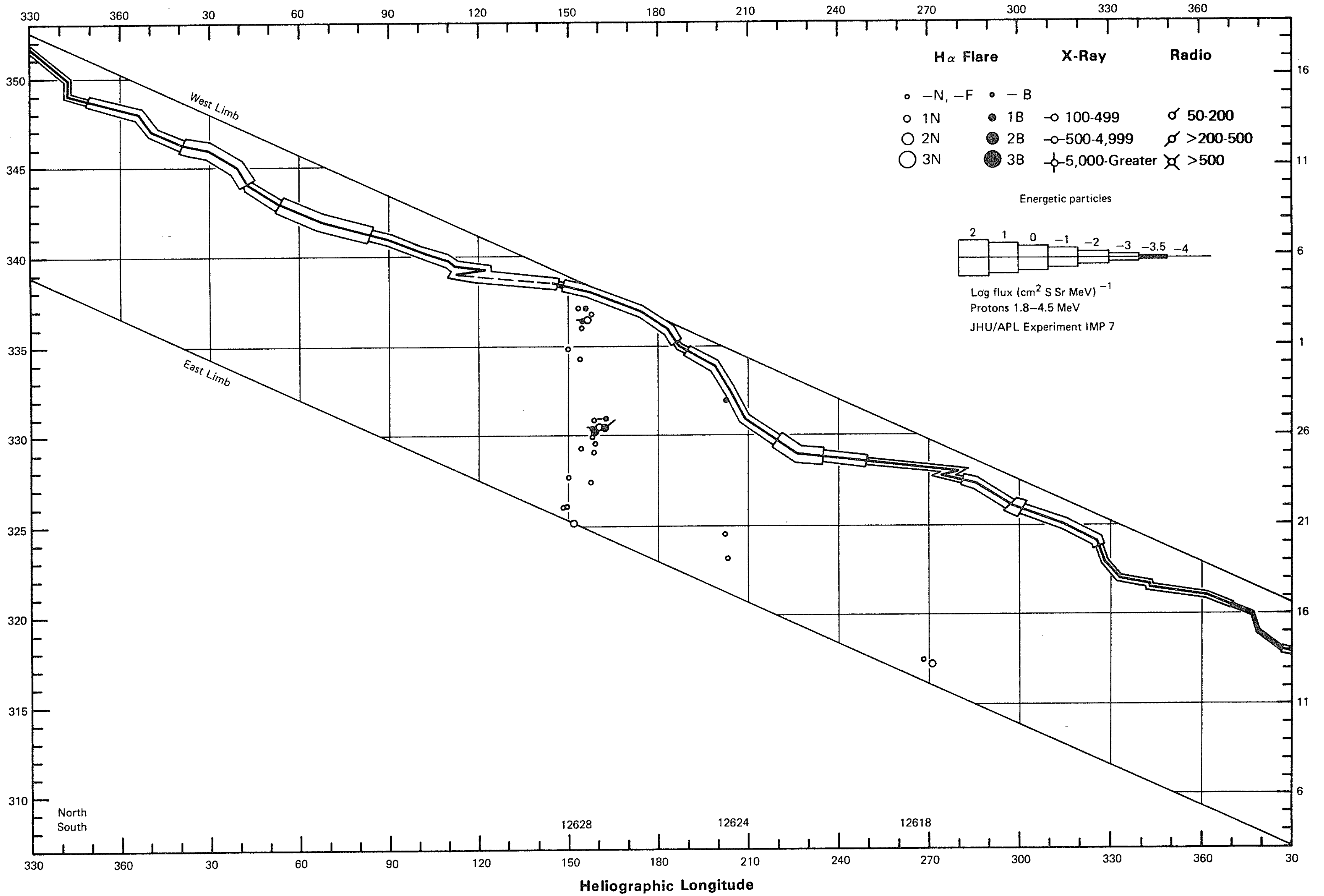
# SOLAR ACTIVITY CHART

## 1973 — ROTATION 1607



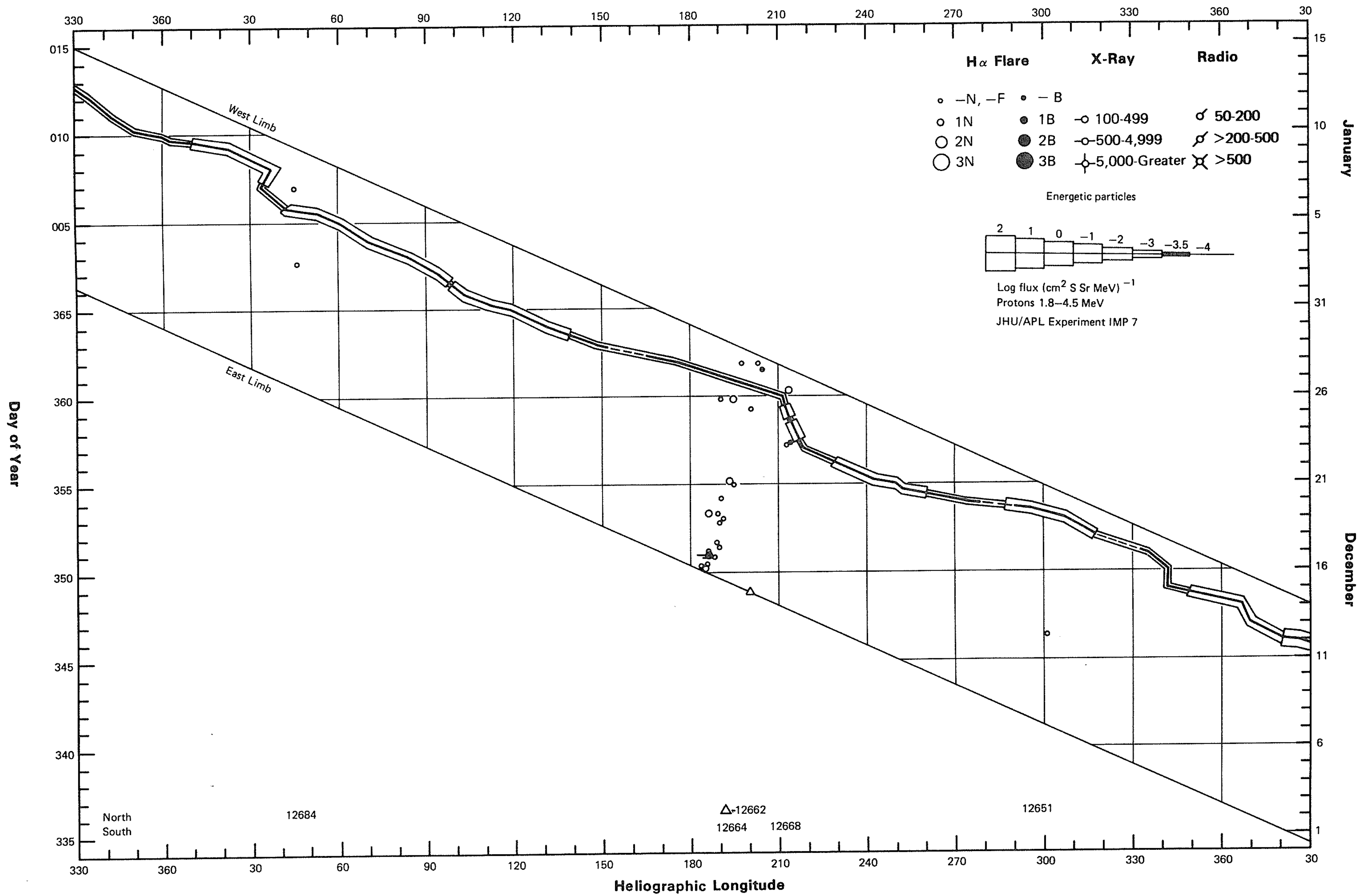
# SOLAR ACTIVITY CHARTS

1973 — ROTATION 1608



# SOLAR ACTIVITY CHART

1973 — ROTATION 1609



# SOLAR ACTIVITY CHARTS

## 1973-1974 — ROTATION 1610

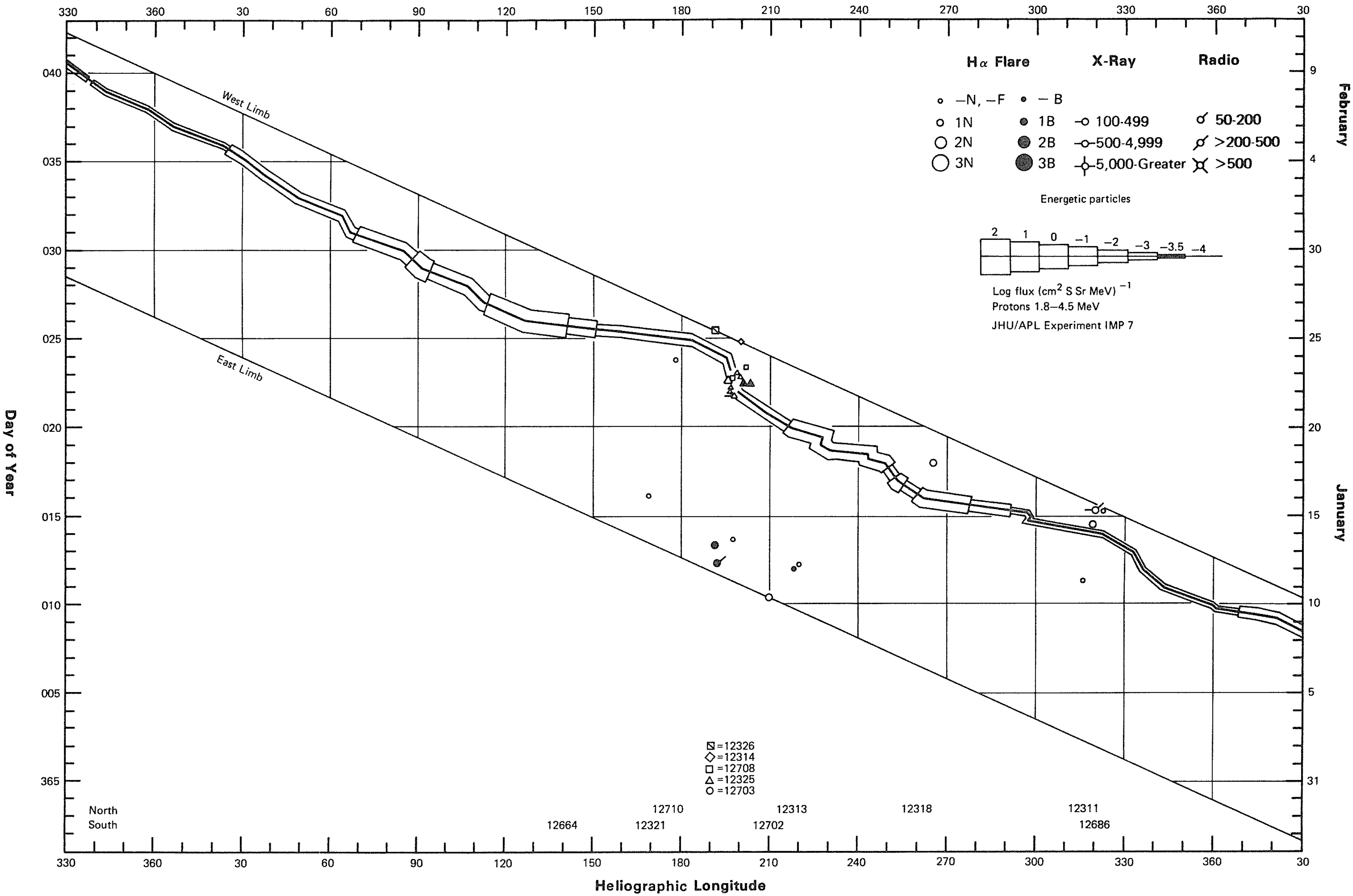
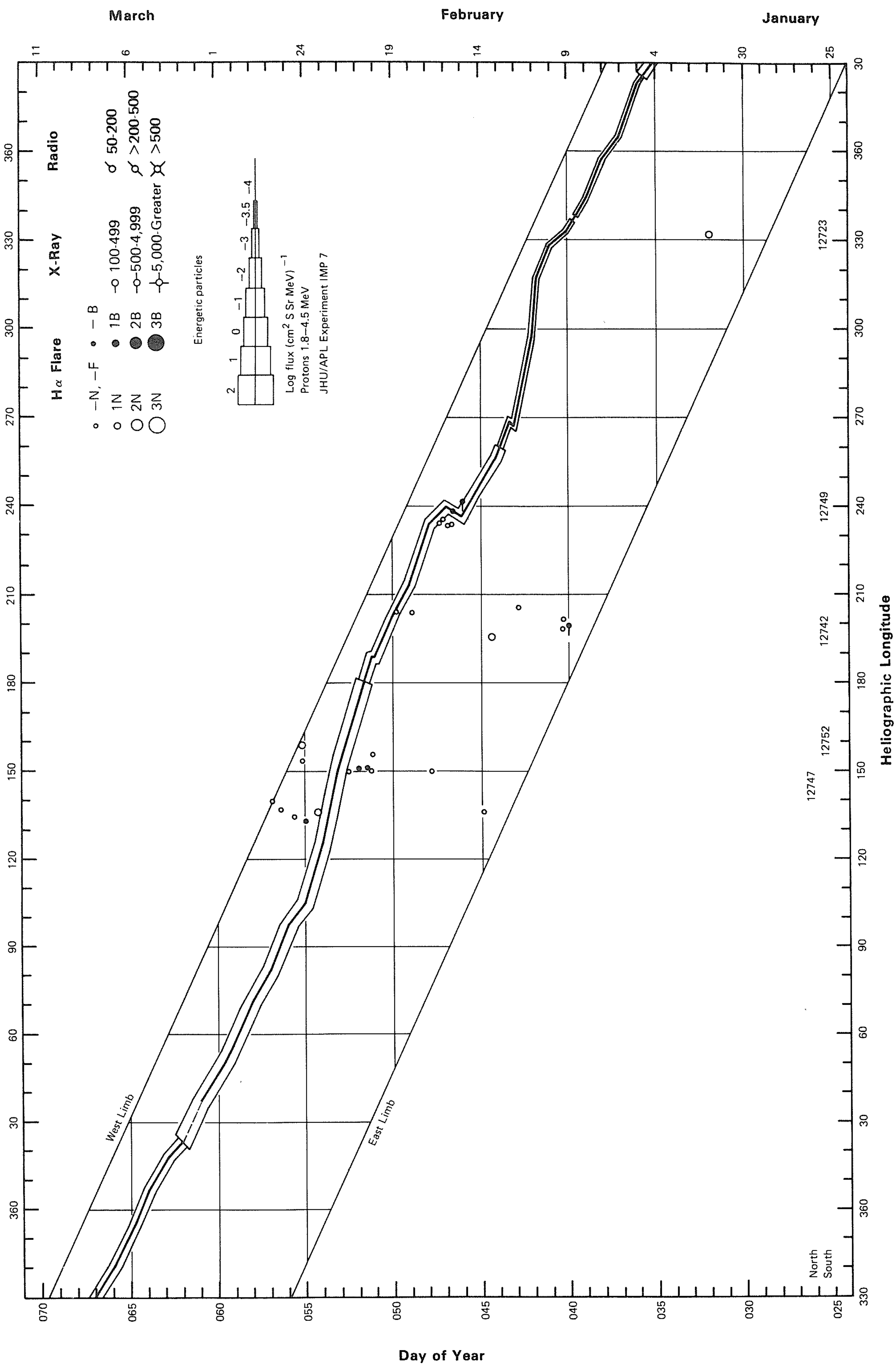



FIGURE 2

# SOLAR ACTIVITY CHART

## 1974 — ROTATION 1611



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