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METHOD OF DIGITIZATION AND ANALYSIS OF K CROMOSPHERIC FILTERGRAMS IN A SOLAR ROTATION STUDY.

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Abstract. The data analysis procedure, relative to a study of solar rotation at cromospheric level, is described. Daily cromospheric filtergrams in the K line of Ca II, covering the interval 1972-1973, are digitized. Then the digitized data, expressed as functions of time and heliolatitude, are analyzed to evaluate the cromospheric synodic rotation period. This work has been performed with the use of the SADAF flying-spot photometer controlled by a PDP/8/I computer, at the IEI of Pisa.

In this paper we present a study of solar rotation at cromospheric level and we describe mainly the method of analysis of solar filtergrams, with the use of computer controlled scanning techniques, which appear th most appropriate in this case. For physical reasons it is required to get an evaluation of cromospheric rotation, without selecting a specific cromo spheric feature as a rotation tracer. This is accomplished by analyzing ir the frequency domain the cromospheric emission, registered as a function time at a given heliolatitude. For a significant frequency analysis of a tim series, a large number of solar filtergrams should be scanned and digitize High spacial resolution of scanning is desirable to correct filtergrams fo orientation. Both reasons suggest as an appropriate method of analysis th digitization of filtergrams, using a fast scanning procedure, which has been carried on with the use of the SADAF computer controlled flying-spot photometer of the IEI of Pisa.

Recent evidences suggest that solar rotation is not independent of time. More precisely the differential rotation of the solar atmosphere (name the dependence of solar rotation rate on heliolatitude) varies through the solar cycle. In the periods of declining solar activity, the rotation rate, whi is usually decreasing with increasing heliolatitude, increases out of the solar equator, approaching the equatorial rotation rate. This has been verif ed during the declining solar activity phases of two solar cycles, at corona height (Antonucci and Svalgaard, 1974). Observations of coronal hole rota ion, studied by means of detectors on satellites, can be interpreted as confirming such results (Wagner, 1975; Timothy et al., 1975). In Figure 1 th coronal rotation periods, corresponding to the declining phase of solar cyc are displayed as a function of heliolatitude(white squares and dark triangl and they can be compared with those measured during years of higher sol activity (dark squares). This unexpected behavior of coronal rotation could be very important to understand the dynamics of the solar atmospher and the origin of the cyclic behavior of solar activity, that should arise from the interplay of rotation and convection of the external solar layers. Now the question is whether other deeper layers of the solar atmosphere, such as cromosphere, do show the same rotational characteristics through the solar activity cycle. For these reasons daily cromospheric observation covering two years during the declining phase of last solar cycle, 1972-1973, have been examined to estimate the solar rotation rate (or, in other words, to test the degree of differential rotation at cromospheric level).

Solar rotation measures are usually obtained by selecting a specific solar feature as a tracer;namely the rotation period is evaluated on the basis of the motion of the selected feature. Moreover the tracer is often related to solar activity phenomena and therefore it provides a biased test of the behavior of the solar atmosphere during low activity. Therefore it is more appropriate a method which allows to take into account the total behavior of the solar atmosphere (at cromospheric level in our case). This is possible studying the recurrence tendency of the cromospheric emission, observed daily, at a given heliolatitude. In fact, a cromospheric feature, lasting more than one solar rotation period, should contribute to a recurrence tendency of the cromospheric emission data series with period equal to its synodic period of rotation. And cromospheric emission as a time function can be easily obtained by digitizing the daily cromospheric filtergrams.

The cromospheric filtergrams in the K line of Ca II, covering the period 1972-1973, have been kindly provided by Prof. K. O. Kiepenheuer of the Fraunhofer Institut of Freiburg. They have been digitized and analyzed according to the following procedure.

A densitometric measure of the filtergrams, representing the sun in the K line of Ca II as a disk of 21 mm of diameter on film, is performed by means of the SADAF flying spot photometer, controlled by a PDP/8/I computer. Over a scanning area of 24 X 24 mm^2, 1024 X 1024 points are measured, using the highest spacial resolution of the photometer. The densitometric resolution is of 64 gray-levels in the density range 0.05-2.2.

During this phase of analysis the filtergrams are corrected for orientation. In fact the North-South solar axis varies its inclination with respect to a fixed reference (the terrestrial axis orientation, corresponding to the vertical direction on the images of Figure 2) on the film, for each filtergram, depending on the day of observation of the solar disk. Therefore in order to memorize on magnetic tape equal-oriented digitized solar images, the scanning has been performed perpendicularly to the solar axis, taking into account the daily value of P, inclination between the solar and terrestrial axes. For each filtergram the contour, the radius and the centre of the solar disk are found by computer program. Referring to the images of Figure 2, the density along a horizontal line is compared with the backgro density, measured at the four corners of the scanned area (corner spots in Figure 2). When the value of density exceeds the background density value and in the same time its derivative along the horizontal direction exceeds a fixed value (to account for standard deviation of the background density), the disk limb is intersected. Any horizontal line will intersect twice the limb and the diameter is the perpendicular through the mid-point of these segments. The centre and the radius of the disk are computed, as well as the circumference. The solar axis passes through the centre with inclination P_o with respect to the vertical direction. Then the scanning is performed perpendicularly to it inside the circumference; outside the densit is leveled to its lowest value. Figure 2 a shows a partial scanning (superimposed to a previous complete scanning) of a filtergram, transver to the vertical reference direction, on the computer display. Figure 2b represents the same solar image scanned perpendicularly to the solar axis direction, inclined of $P_o=26^{\circ}$ with respect to the vertical direction (7 October 1972). At this point the digitized images (oriented with respect t the solar axis) are memorized on magnetic tapes, ready to be analyzed.

The second step of the analysis consists of expressing the cromospheric emission as a function of time and heliolatitude. On each digitized solar image, a longitudinal sector, ± 5° wide, is selected around the solar central meridian (coinciding with the solar rotation axis, on the disk image Then the central longitudinal sector is divided in 30 latitudinal zones of equal amplitude in sin (φ, heliolatitude), therefore near the equator the zones are 4° wide and their amplitude (in degrees) increases towards th poles. The density measured in each latitude zone, in the central longitudinal sector, is normalized by subtracting the average density value, measure over the whole solar disk. Then, for each latitude, the daily normalized density values, ordered in time sequence, represent the cromospheric emission as a function of time.

The synodic period of rotation can be evaluated testing the recurrence tendency of such time series around the period of 27 days

(average synodic period of rotation of the whole sun). Power spectra of the cromospheric emission are obtained for each latitude zone by means of the Hewlett-Packard Fourier Analyzer System 5451A. In Figure 3 power spectra, averaged over three consecutive latitude zones, corresponding respectively to the latitude ranges: 90°-53° N, 53°-37° N, are represented. They show a clear peak in correspondence to the expected rotation frequency of the sun. The synodic rotation period can be determined and in both cases its value is 28 days. We do not want to give a detailed discussion of these results, that will be discussed elsewhere. We just want to point out that, over a wide range of latitude (about 50°), there exist cromospheric features living more than one solar rotation (otherwise they would not contribute to determine the recurrence tendency of cromospheric emission) that rotate with a synodic period independent of latitude within the experimental uncertainty. To represent this result a horizontal straight line should be drawn in Figure 1, in correspondence to P=28 days in the latitude range 90°-37° N. But, for example on the basis of the estimates obtained studying solar magnetic spots (dashed line in Figure 1), we should expect, for such high latitudes, values increasing from 29 days (value at 40° N) with increasing latitude. Then the so-far accepted estimates of solar rotation rates as a function of latitude can not be assumed as correct through the whole solar cycle. They are probably valid for high activity periods (in fact they are based on tracers characteristic of activity). While for low activity periods the rotation rate has to be computed on the basis of techniques taking into account the total solar emission, including the quiet structures of solar atmosphere.

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Figure Captions.

Figure 1. The synodic periods of rotation of green corona (dark and white squares) by Antonucci et al., 1974, magnetic spots (dashed line) by Newton et al., 1951, weak photospheric magnetic fields (dots) by Wilcox et al., 1970, and EUV coronal holes (triangles) by Wagner, 1975, are plotted versus heliolatitude.

Figure 2. Cromospheric filtergram in the K line of Ca II, observed October 7, 1972, scanned perpendicularly to a) the reference vertical axis (corresponding to the terrestrial rotational axis), b) the solar rotational axis, inclined by $P_o = +26^\circ$ with respect to the fixed reference.

Figure 3. Power spectra of the cromospheric emission evolution during 1972. The synodic rotation period, evaluated on the basis of the frequency peak, is 28 days for both ranges of heliolatitude : 90°-53° N and 53°-37° N.

SOLAR ROTATION - SYNODIC PERIOD

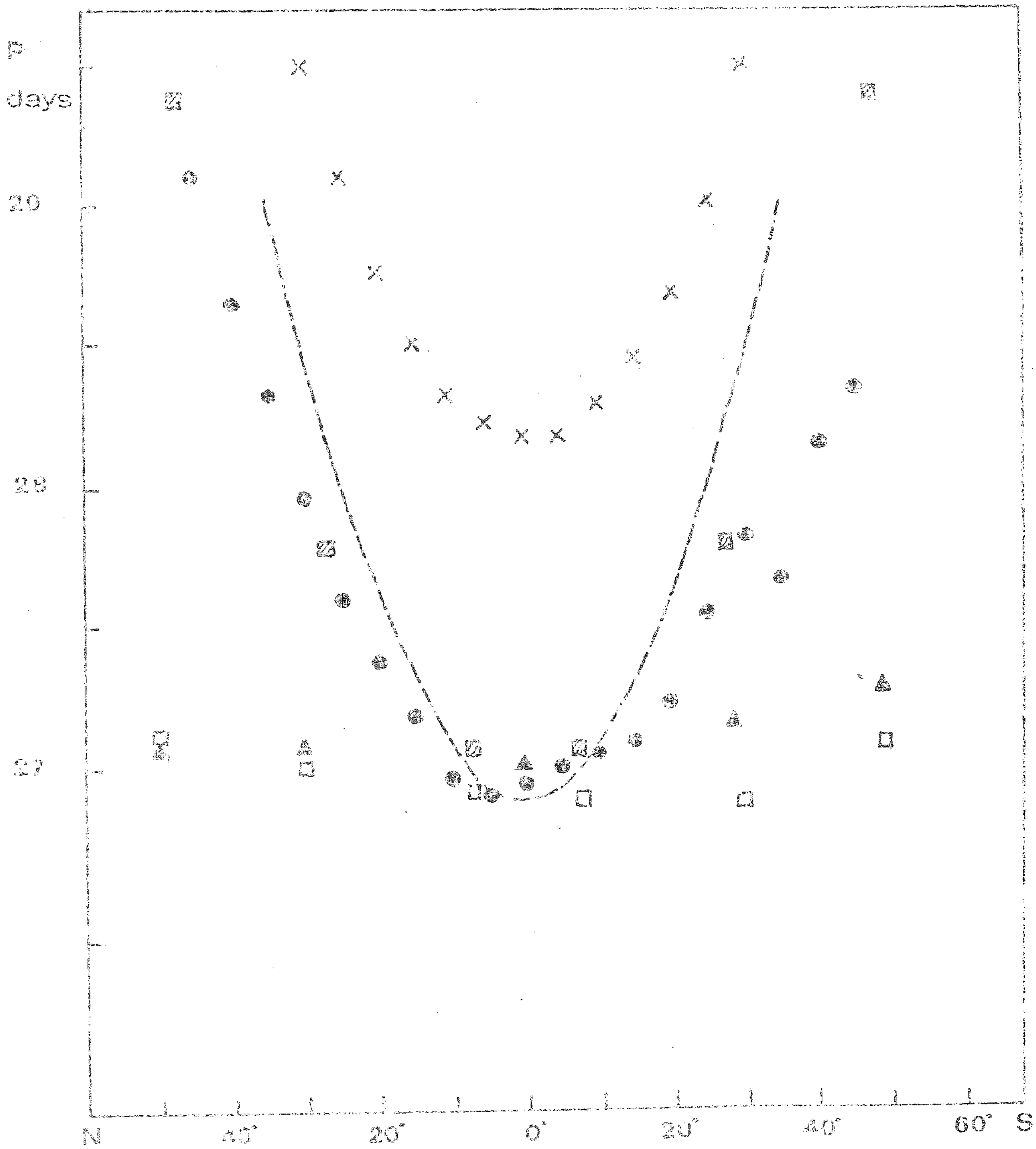
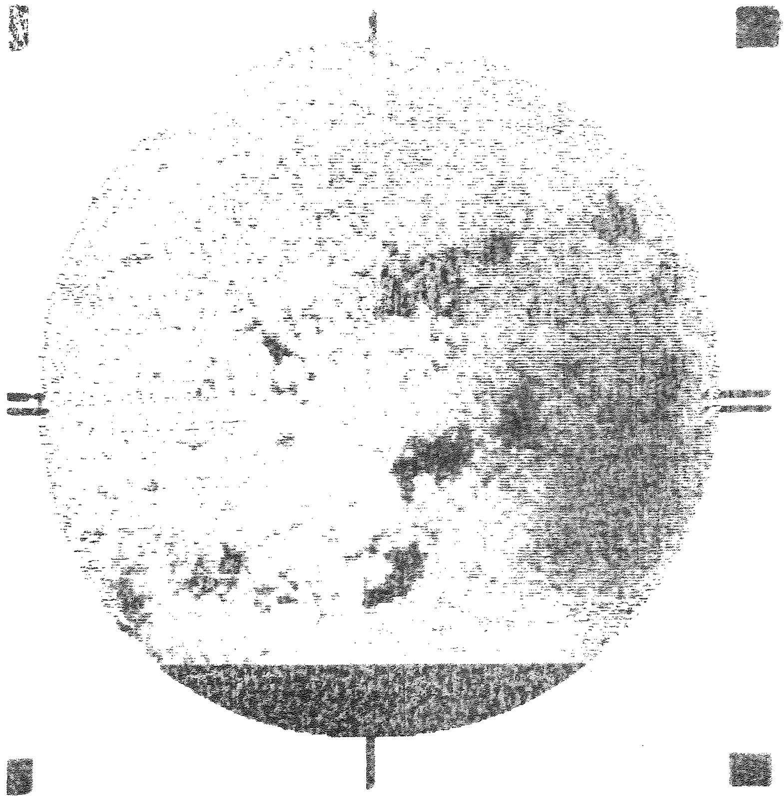


Fig. 1



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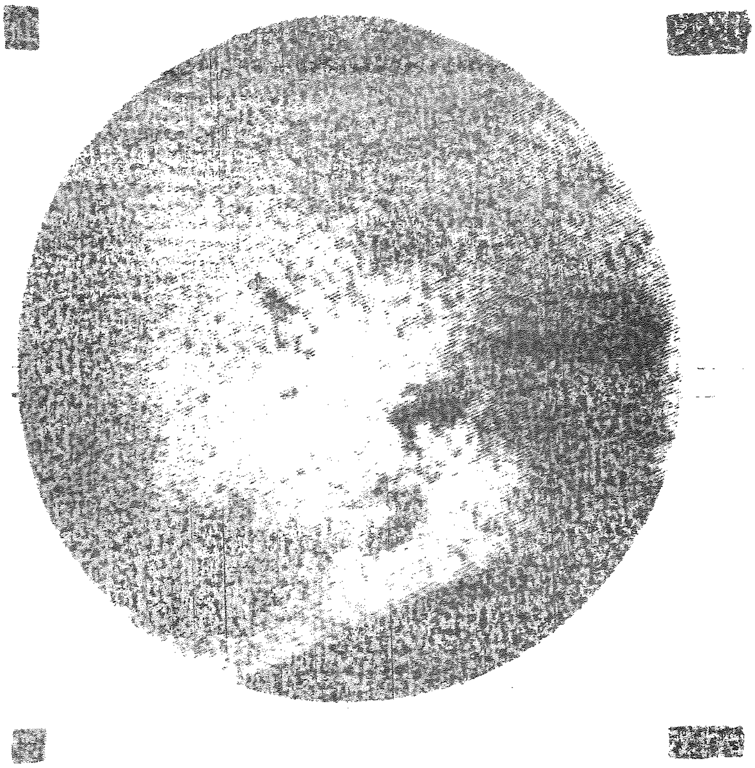

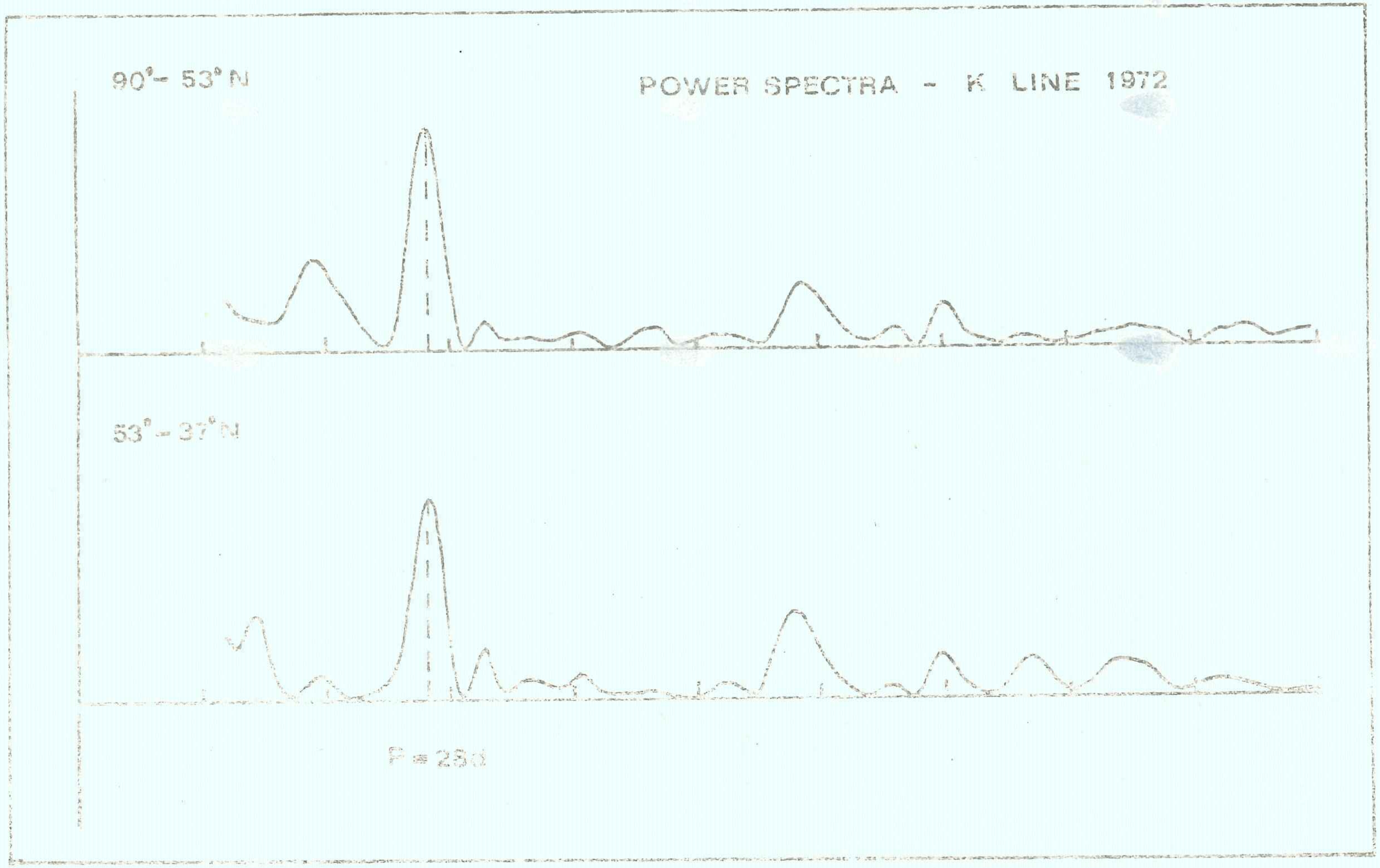

Fig. 3