MAGNETIC FIELD OBSERVATIONS IN MEUDON OBSERVATORY

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I am going to discuss the problems which are raised in magnetic field observations by describing the French project "THEMIS(1)" and the new photoelectric magnetograph operating in Meudon Observatory since April 1980.

Before that, I would like to discuss two important points for the future in Solar Physics :

1) Why optical Solar Research must be pursued in the future ?
2) Why do we have a need of new ground-based instruments ?

These two points have been discussed recently by C. Zwaan in an European JOSO report :

The sun is the only star that can be observed with sufficient spatial, temporal and spectral resolution to investigate structures and process occurring in parts of its atmosphere which are much smaller than the visible hemisphere. Consequently there is a large class of astrophysical problems which can be studied best or exclusively in the sun.

The advantages of the optical solar research are due to the facts that the deepest part of the solar atmosphere, which is the top of the convection zone, can only be studied in the optical window where the atmosphere is most transparent to continuum radiation.

Structures and process which connect the convection zone with the outer layer can be followed through all the atmosphere by using continuum windows and spectral line profiles.

Many of the problems occur in structures of a very small horizontal extent and many of them are magnetic. The evolution times of the various structures range from seconds to days.

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(1) T.H.E.M.I.S. Telescope Heliographique pour l'Etude du Magnētisme et des Instabilités Solaires.

These considerations lead to the following requirements :

1) High spatial resolution in the horizontal direction

2) Sufficient resolution in height, which requires observations in several spectral lines simultaneously

3) Adequate time coverage to follow the evolution of individual structures

4) Sufficient spectral resolution

5) Accurate polarization measurements.

Observations with a high spatial resolution may be obtained in space. Ultraviolet and Infra-red observations can be only made in plane, balloons, rockets or satellites. However, space instruments are limited in volume, weight and time operation.

Space observations can never replace ground-based observatories ; on the contrary they are complementary but ground-based instruments must be put in the best sites.

Magnetic field is one of the most important physical parameters in star atmosphere. The dimension of individual force tubes is of the order of the scale height of the atmosphere, so as good as the resolution we could hope, in ground-base or in space, the geometrical structures of such features could not be observed directly. The only way to solve the problems is to progress in theoretical model computation in order to be able to obtain good coherence between several simultaneous determinations of the same observed physical parameters with different lines.

The knowledge of such features distribution with solar latitude and the phase of the solar cycle will be of the greatest interest for dynamo theory.

The study of MHD waves in fine magnetic structures is necessary to understand heating mechanism.

The determination of current density (i.e. determination of the vector $\vec{B}$) is essential to study the dynamics of active regions and instability process.

For the future, new solar instruments should be designed in this way. The French project "THEMIS" is a solution.

A perfect magnetograph should allow :

1) Observations of the magnetic vector $\vec{B}$.
2) Simultaneous observations of a great number of lines the profiles of

which depend differently on the physical parameters (temperature, pressure, density...) defining the solar atmosphere at each point.

3) To be used simultaneously with different observational techniques in order to control coherence between several independant determinations of the same parameter.

The first condition requires the instrument to be free of effects due to instrumental polarization. The structure of the instrument and the place of the polarization analyser have been designed so that the instrumental polarization does not interfere with the shape of line profiles.

The second condition is satisfied by a spectrograph predisperser followed by an echelle spectrograph having a useful field corresponding to the free spectral range of the grating. Selective slits situated in the first spectrum allow simultaneous isolation of a great number of lines in a wide spectral range.

The third condition is satisfied by designing the polarization analyser to obtain the whole profiles of the different lines. These profiles will be recorded either on a photographic receiver or on a photoelectric one by using integrated diode arrays. The computer treatment of recorded profiles allows one to define and to change at will and a posteriori the reduction process.

Principle of THEMIS (Figure 1)

A vacuum Cassegrain Telescope pointed to the sun focuses a solar image on the spectrograph slit. Behind it, we put achromatic crystalline plates, a quarter of wavelength for the linear polarization or a modulated electro-optic crystal. The axis of these plates are both parallel and perpendicular to the spectrograph slit. Then we put two quartz crystal the sides of which are cut at 45° of the crystallography axe. In relation one to the other, they are crossed and directed so that the two crosses linear beams they transmit have the same optical length and are polarized at 45° of the entrance slit.

At this stage the polarimetric analysis of the light is finished so that the polarization state has the least interference with the instrument. Then nothing can change the shape of the line profiles if one can separate completely the two beams given by the analyser at the spectrograph exit. The predisperser characteristics and the echelle spectrograph allow this separation without any pollution. The dispersions of the two spectrograph being correctly choosen by changing the distance between P2 and P3, we are able to do that for any lines and simultaneously for a great number of lines.

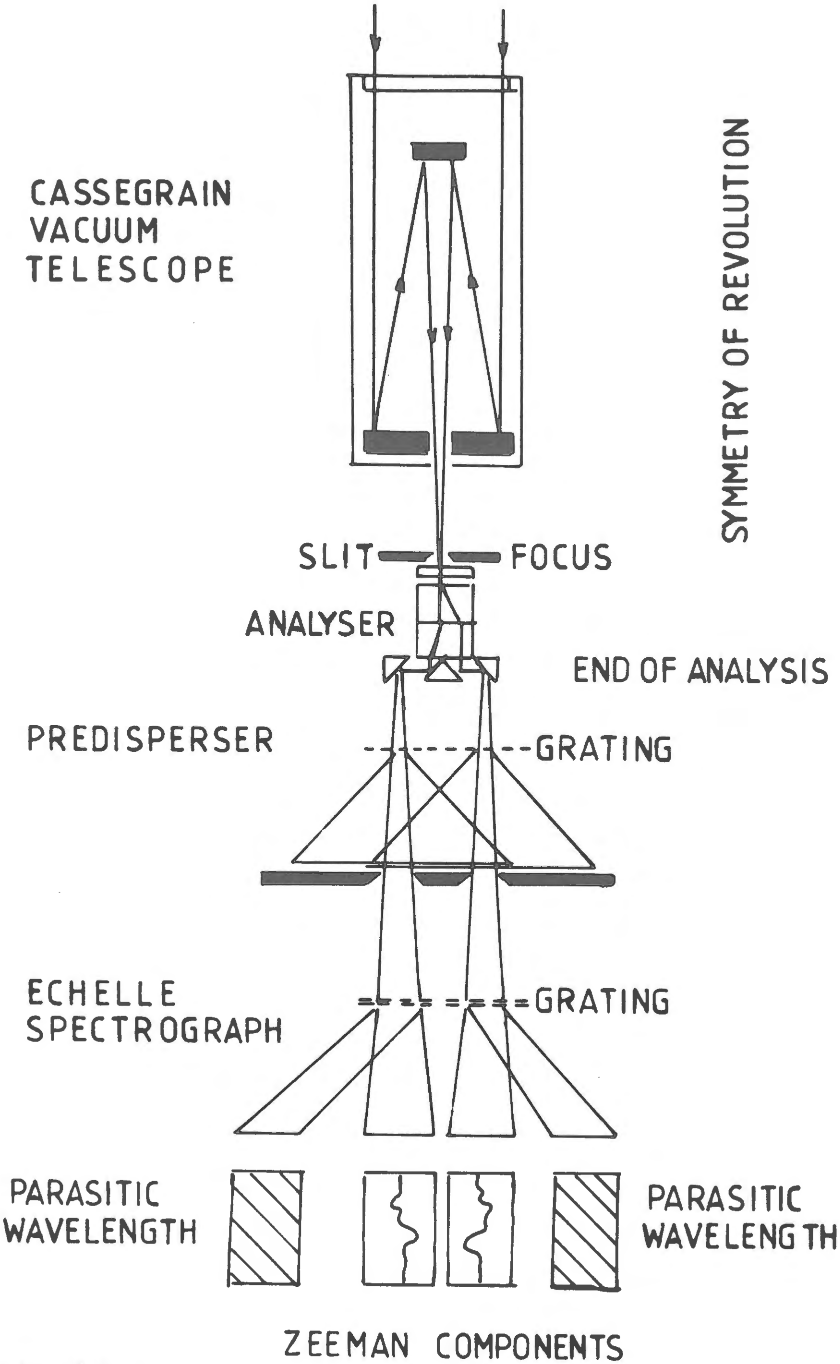

CASSEGRAIN
VACUUM
TELESCOPE
SYMMETRY OF REVOLUTION
SLIT
FOCUS
ANALYSER
END OF ANALYSIS
PREDISPERSER
GRATING
ECHELLE
SPECTROGRAPH
GRATING
PARASITIC
WAVELENGTH
PARASITIC
WAVELENGTH
ZEEMAN COMPONENTS

FIGURE 1

Structure of the instrument

For the framework, several solutions were considered. We adopt an entirely metallic structure both for the instrument and the tower. The vertical spectrographs are stiffly tied to an azimutal mounting which bears the telescope. The aperture of the telescope is 90 cm. It is certainly the largest aperture allowing us to deal with the problems of the entrance window.

Entrance window problems

For a vacuum telescope the entrance window is subject to :

1) Mechanical stresses, beacuse of the difference in pressure between its two sides and the reactions of its supports and the air-tight joint.

2) Thermal stresses, because of the local difference of temperature due to radiation (sun, sky, structure),conduction and convection (ambient air).

These local stresses, according to Brewter's Law introduce variations of glass index and hence optical phase retardation which are proportional to them. Only the mechanical reaction of the joint and the radial gradient of temperature introduce polarization. The main results are the following (Figure 2) :

1) The local mechanical or thermal polarization is equal to zero in the center and maximal on the rim.

2) The total mechanical or thermal polarization is equal to zero for a revolution symetry distribution of the local stresses.

High resolution scanning of the sun surface

For many astrophysical problems we need good maps of the space or time derivatives of the observed parameters. The inertia of telescope introduces a loss of efficiency of the drive mechanism to scan the solar image with high accuracy and low time constant.

Optical scheme of "THEMIS" has been designed so that such effects would be as less as possible. High accuracy scaning is obtained by moving the spectrograph slit in the focal plan of the telescope. A servo controlled flat mirror holds the beam on the predisperser optical axe.

R = 30 cm

R = 30cm

FIGURE 2

LOCAL POLARIZATION

MECHANICAL

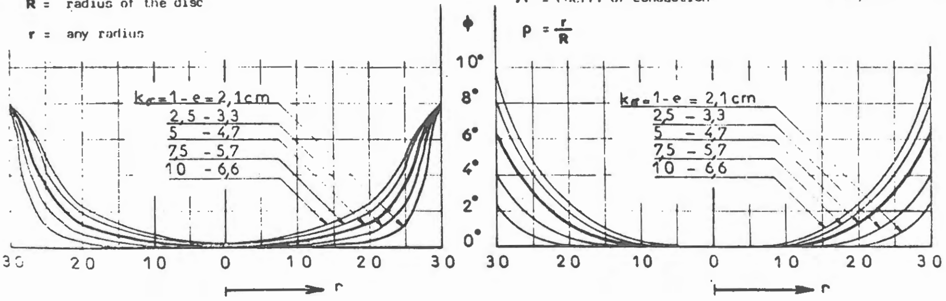
$$\phi^{\circ} = \frac{360}{2\pi} \cdot \frac{C.p}{\lambda} \cdot \frac{R}{1+\left(\frac{R-r}{e}\right)^2}$$

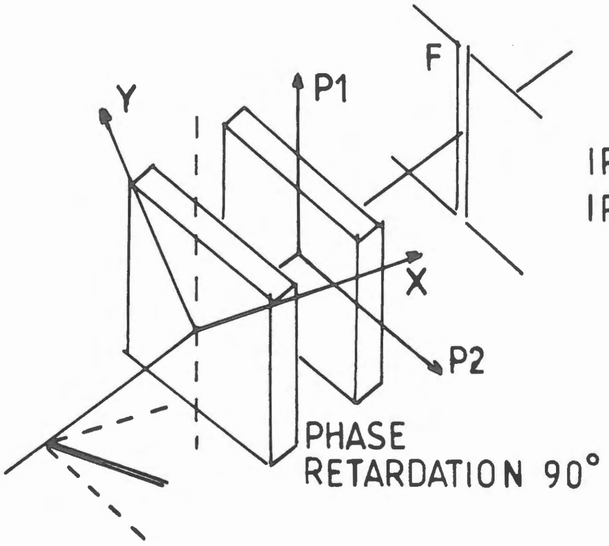
C = Brewster's constant = $2,78.10^{-7} cm^2/kg$
p = atmospheric pressure = $1 kg/cm^2$
λ = wavelength = $6.10^{-5} cm$
e = thickness of the disc
R = radius of the disc
r = any radius

THERMAL

$$\phi^{\circ} = \frac{720.E.\alpha.T_R.C.e}{\lambda} \cdot \frac{\sum_{n=1}^{\infty} \frac{n}{2n-1} \cdot \frac{1}{(n!)^2} \cdot \left(\frac{R^2.K}{4.e.\Lambda}\right)^n \cdot \rho^{2n}}{\sum_{n=1}^{\infty} \frac{1}{(n!)^2} \cdot \left(\frac{R^2.K}{4.e.\Lambda}\right)^n \cdot \rho^{2n}}$$

E = Young's modulus = $8,3.10^5 kg/cm^2$
α = coeff. of thermal expansion = $7,1.10^{-6}$
T_R = differ. of temperatures rim-center = 0.1 °K
K = coeff. of linear exchange = $1,8.10^{-3} W/cm^2.°K$
Λ = coeff. of conduction = $11,1.10^{-3} W/cm.°K$
$\rho = \frac{r}{R}$





$IP1 = 1/2\,(I + V)$
$IP2 = 1/2\,(I - V)$

FIGURE 3

How take out magnetic field from observed profiles ?

With a circular analyser of polarization (Figure 3) we obtain the stokes parameters I and V.

1. Unsaturated line and weak field

In this case we can use the linear approximation

$$I \approx P(\lambda)$$
$$V \approx G\Delta\lambda H \cos\psi \frac{dP}{d\lambda}$$

where P(λ) is the profile of the undisturbed line (H = 0) ; ψ the angle between $\vec{H}$ and the line of sight ; G the landé factor of the line and $\Delta\lambda H$ the displacement of the Zeeman component for the magnetic field H with G = 1.

Babcock magnetograph :

This instrument measures the variations of the V Stokes parameters at :

$$\lambda = \lambda o + \Delta\lambda VR + \Delta\lambda$$

where λ_o is the wavelength of the line, ΔλVR the Doppler shift for the radial velocity VR and Δλ the half Doppler width of the line.

Leighton magnetograph

With this technique we measure the variations of V at $\lambda = \lambda o + \Delta\lambda$(no correction for VR)

With these two techniques some difficulties occur :

- the profile P(λ) of the undisturbed line is unknown at any point where a magnetic field is present. (Problems of calibration)

- saturation effect if $\Delta\lambda H > \Delta\lambda$

Center of gravity **method** (Semel)

$$CG = \frac{\int_{-\infty}^{+\infty} \lambda P(\lambda)\, d\lambda}{\int_{-\infty}^{+\infty} P(\lambda)\, d\lambda}$$

Observed through a circular analyser of polarization the displacement of the center of gravity of the blend of the Zeeman components equals $G\Delta\lambda H\cos\Psi$, and this result is independent of the line profile $P(\lambda)$. It is a consequence of the Zeeman effect.

Lambdameter technique : DZA Sacramento Peak
Meudon magnetograph

Gives the same results as the center of gravity method for an adequate choice of the slit.

2. Strong magnetic field and saturated line

It is necessary to solve the transfer equations to calibrate the observations. We can used :

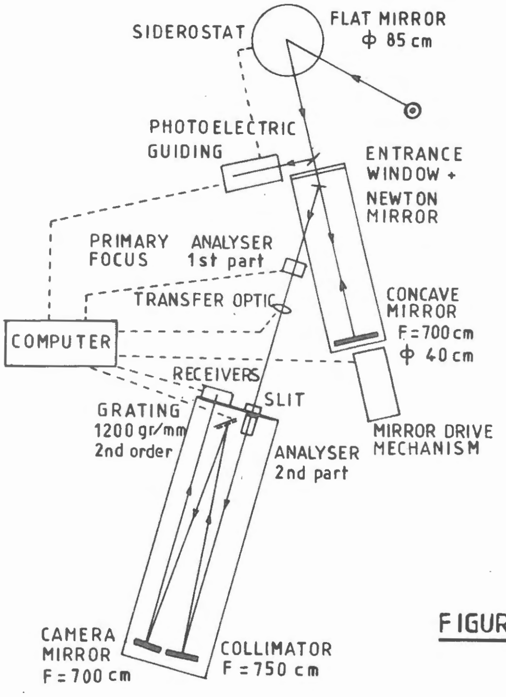
- Either the analytical solutions given by Unno
- or numerical integrations of the transfer equations if we want to take into account the variations with depth of the physical parameters.

3. Unresolved fine structures

It is necessary to observe simultaneously a great number of lines the profiles of which depend differently of the physical parameters (temperature, pressure, density...) inside and outside the magnetic regions. The center of gravity method gives the true average field (Rees-Semel).

The Meudon Solar Magnetograph

Sice April 1980, a new type photoelectric solar magnetograph using two 256G Reticon integrated diode arrays (Figure 4), is operating at Meudon Observatory. The Newton-Gregory telescope (equivalent focal length 23 m) receives the solar beam from a Foucault Siderostat. In front of the entrance window, a flat mirror deflects a part of the beam to a photoelectric guiding. The analyser of polarization is of the "THEMIS" type. The controlled temperature quarter wave plate



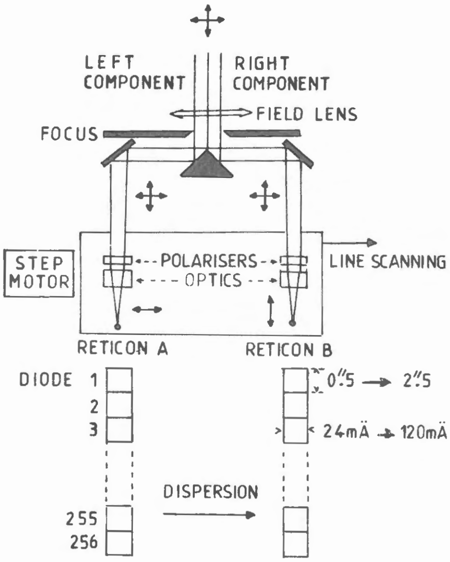
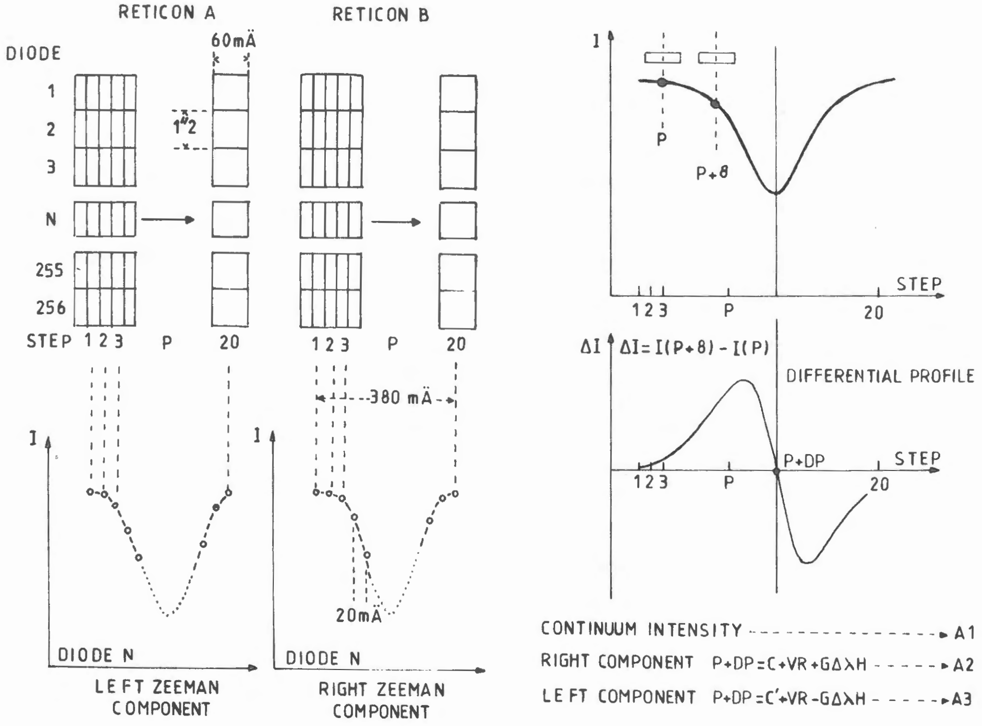


FIGURE 4

EXIT PART OF THE SPECTROGRAPH



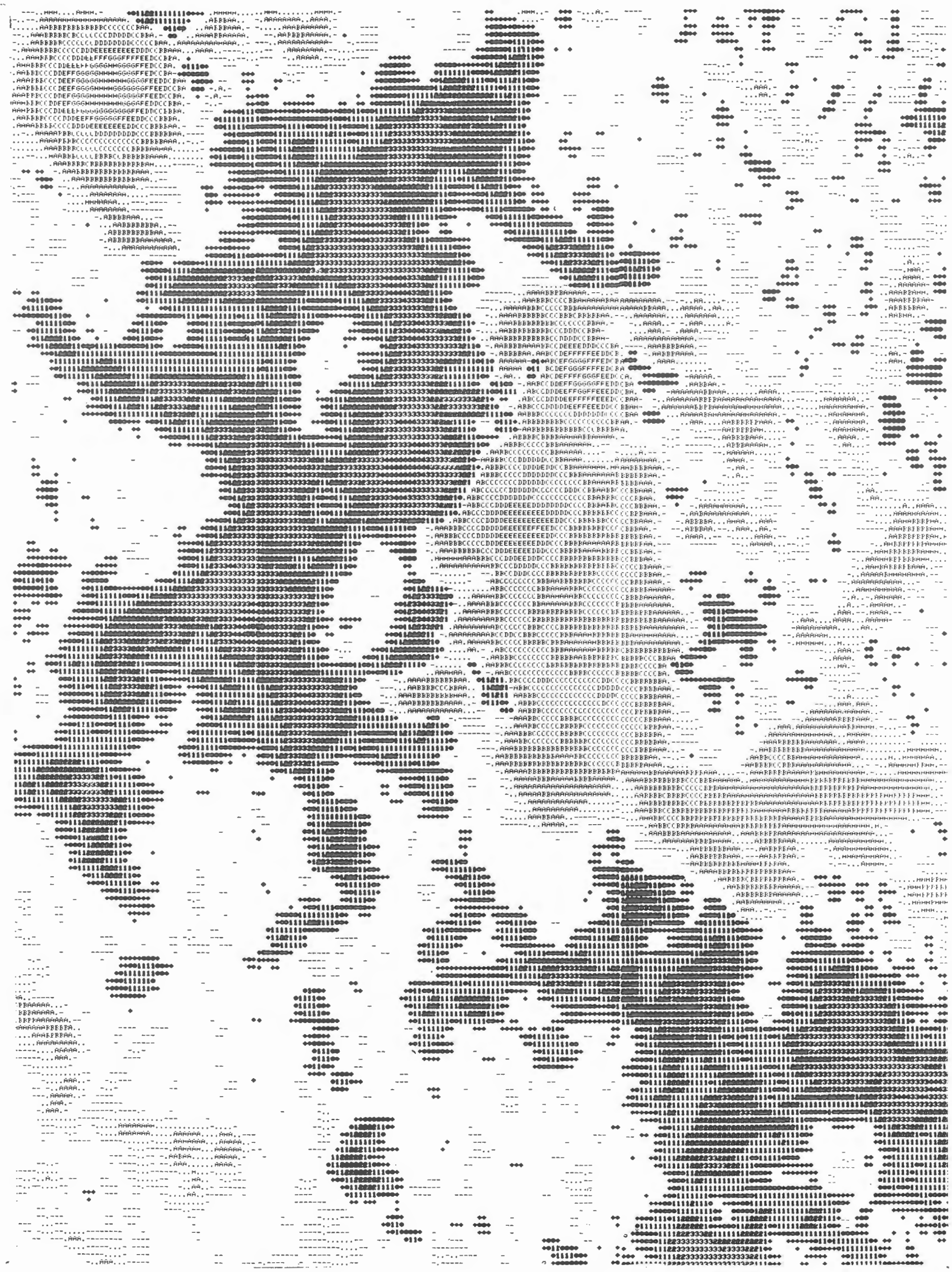


FIGURE 5 : MAGNETIC FIELD

(Analyser 1st part) is put in the telescope primary focus. Behind the entrance slit of the spectrograph, a calcite plate (Analyser 2nd part) transmits simultaneously the right and left Zeeman components which are separated in the exit part of the spectrograph. A microcomputer TEXAS 990/4 controls all the active parts of the instrument and data acquisition. The two Reticon diode arrays, perpendicular to the spectrograph dispersion are shifted to scan the Zeeman components. For each diode the differential profile I(P+8)-I(P) and the line position P+DP are computed in real time (Figure 4). The three parameters A1, A2 and A3 are stored on standard IBM 3740 "floppy disk". About six minutes are sufficient to scan an active region with a resolution of 1.2" x 2". From the A1, A2 and A3 values we are able to obtain maps of the longitudinal magnetic field, the radial velocity and isophote continuum.

Figure 5 shows an example of magnetic map. (Black numbers for North polarity and grey letters for South polarity). The intensity of the longitudinal component is given by the following symbols :

0	10	20	40	100	200	400	600	800	1000	1500	2000	2500	3000
white	-	x	1	2	3	4	5	6	7	8	9	0	#
	+	.	A	B	C	D	E	F	G	H	I	J	$