第11卷 第2期
1993年6月

天 文 学 进 展
PROGRESS IN ASTRONOMY

Vol.11, No. 2
Jun., 1993

太阳矢量磁场测量的新进展

叶式煇
（中国科学院云南天文台，昆明 650011）

提 要

本文第一节（引言）论述太阳矢量磁场（主要是横向分量）观测的重要意义、仪器要求和困难实质。第二节先叙述矢量磁像仪的基本原理，然后以北京天文台磁场望远镜和日本冈山天文台矢量磁像仪为例，分别介绍滤光器型和光谱仪型的矢量磁像仪，并比较这两类仪器的优缺点，接着简述仪器定标等问题。第三节以美国高山天文台先后研制的三架仪器为例，讲述斯托克斯参量仪，以及由斯托克斯参量轮廓推求矢量磁场信息的方法。第四节简略介绍斯托克斯偏振量度学的内容。最后在第五节（结束语）中对全文的要点进行简短的总结。

New Advances in the Measurement of Solar Vector Magnetic Fields

Ye Shihui
(*Yunnan Astronomical Observatory, Academia Sinica, Kunming*, 650011)

Abstract

The first Section of this paper (Introduction) describes the important significance of the measurement of the solar vector magnetic fields (in particular the transverse comoponent), the requirements for instrumentation and the basic principles of vector magnetographs. Then it introduces the instruments of birefringent filter-based and spectrograph-based. The Magnetic Field Telescope of the Beijing Astronomical Observatory and the vector magnetograph of the Okayama Astrophysical Observatory are taken as examples, respectively. The merits and shortcomings of these two types of instruments are compared. At the end of this Section the problems including calibration etc. are briefly described. The third Section Presents a short description of the basic principles of Stokesmeters and then describes the methods of derivation of the information of vector magnetic fields with the profiles of Stokes parameters. A brief introduction of the Stokes polarimetry is given in the fourth Section. Finally, the fifth Section is a short summary of the main contents of the present paper.

1992年9月28日收到。

1. Introduction

1. Important Significance

It is well known that magnetic observations are of great importance to solar physics. The sun, billions of stars and extragalactic systems, and interstellar media as well as the ionosphere of the earth are all composed of plasma. Their physical conditions, kinematics and variabilities have close relations with the magnetic fields. E. N. Parkes, a notable American astronomer, remarked that the origin of the disturbances of the universe is magnetic fields, without which the universe would become quiet and monotonially dull. As a matter of fact, a variety of solar activities have inseparable relations with magnetic fields. Since the discovery of the sunspot magnetic fields by G.E.Hale in 1908, a large number of instruments and a series of methods of measuring the solar magnetic fields have been developed by astronomers of several generations.

Nowadays we are in the phase of three-dimensional or vector magnetic field measurements. There have been already sophisticated instruments and methods for the measurement of the longitudinal (or parallel to the line of sight) components. The big task is to measure the transverse (perpendicular to the line of sight) components. The reason why the transverse magnetic field in the solar active regions

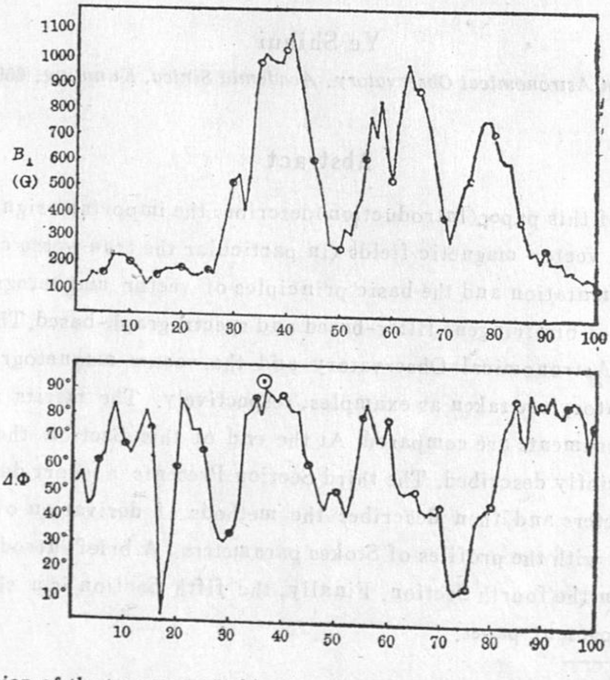

Fig. 1 Distribution of the transverse field intensity and nonpotentiality along the neutral line,

should be measured can be stated as follows.

(1) The relation between flares and magnetic fields

Early in the 1950s, Severny[1] et al. made systematic investigations on the variability of photospheric magnetic fields before and after the occurrence of a flare, and advanced the neutral point theory which, however, led to much controversy[2]. Before long, Hagyard[3] observed vector magnetic fields of four flares using the vector magnetograph of the Marshall Space Flight Center (MSFC). She defined the sheer angle as the difference between the potential field azimuth of the photosphere and the observed transverse azimuth, i. e., $\Delta\Phi \equiv \Phi_P - \Phi_0$, and considered this quantity representing nonpotentiality. Because the potential field is the magnetic field with minimal energy storage, $\Delta\Phi$ can be used to represent the degree of twisting of the magnetic fields and its energy storage. She also found that four flares appared in the vicinity of the neutral line of the magnetic fields, where both $\Delta\Phi$ and the transverse field intensity $B_\perp$ increase to maximum. The values are $\Delta\Phi > 85°$ and $B_\perp \cong 1000$G. The results she obtained for the active region AR 4711 on February 3, 1986 are shown in Figure 1. The abscissa scale in the figure indicates the length of the neutral line of the magnetic field, and ⊙ indicates the place of the flare occurrence.

Hagyard emphasized that both $\Delta\Phi$ and $B_\perp$ can be obtained only by means of transverse field observation. Therefore, the relation between flares and magnetic fields is mainly the relation concerning with transverse fields. Hence it is readily understandable that there were a variety of different, and even contrary results concerning the relation between flares and magnetic fields, because only longitudinal fields could be measured by means of the magnetographs in the 1950s. For details see

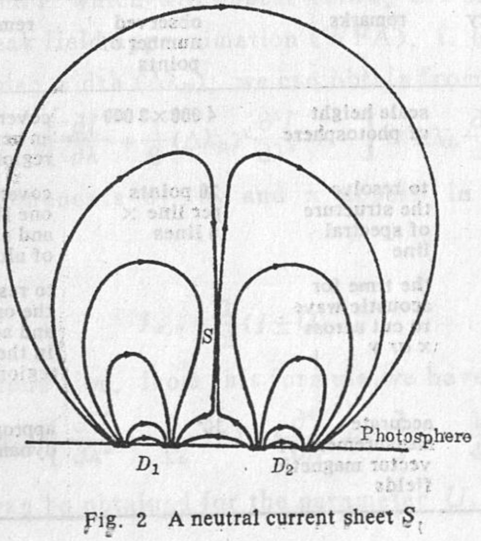

Fig. 2 A neutral current sheet S

reference [2]. As a matter of fact, the energy storage processes, such as the extruding press and sheer of magnetic fields, are related mainly to transverse fields.

(2) The neutral current sheet S and reconnection of magnetic fields

It is shown in Figure 2 that there possibly exists a neutral current sheet S between two dipolar magnetic regions D_1 and D_2. The vertical current intensity can be obtained from formula $j_z = \frac{C}{4\pi}\left(\frac{\partial B_y}{\partial x} - \frac{\partial B_x}{\partial y}\right)$by calculating the transverse components B_x and B_y. Hence it is essential to measure the transverse fields in order to investigate the neutral current sheet and the reconnection of the magnetic fields possibly occurred there[4].

(3) Theory of the force-free field

Low[5] suggested that the linearity or non-linearity of the force-free magnetic fields in solar local regions can be distingushed by means of vector magnetograms.

The important significance of the measurement of the vector magnetic fields (especially transverse components) can be seen from the above-mentioned examples.

2. The Requirements for Instruments

What we have to do is measuring the three elements of the vector magnetic field intensity B, the angle γ between magnetic line of force and line of sight, and the azimuth χ of the transverse field (Figure 3). Harvey[6] suggested at the conference "Measurements of Solar Vector Magnetic Fields" in 1984 that the accuracy of polarization measurements should be 10^{-4} or better if an accuracy of 10G for B and of 0.1 rad, or approximately 6°, for both γ and χ are required. Detailed requirements for instrumentation are listed in Table 1.

Table 1. Instrumentation for the Measurements of Solar Vector Magnetic Fields

Item	accuracy	remarks	observed number of points	remarks	instrumentation
spatial resolution ($\Delta X, \Delta Y$)	0.05	scale height of photosphere	4 000×3 000	covering an active region	telescope >1m
spectral resolution ($\lambda/\Delta\lambda$)	3×10^5	to resolve the structure of spectral line	20 points per line × 6 lines	covering one line and a range of altitude	spectrometer of a large waveband
temporal sensitivity	10s	the time for acoustic wave to cut across x or y	1	to resolve the oscilation and activity in the active region	high sampling rate
sensitivity for $I, Q/I, U/I, V/I$	$\sim10^{-4}$	accurate measurement of vector magnetic fields	10^4	appropriate dynamic range	high sampling rate

Rust and O'byrne[7] repeated these requirements at the conference "Solar Polarimetry" in 1990. They thought that at present no instrument in the world can meet all the requirements, and only LEST and THEMIS now under construction are expected to approach them. In addition, it is considered that an ideal approach is to fly a 1m telescope and vector magnetograph for high-altitude observations on board a spacecraft or balloon.

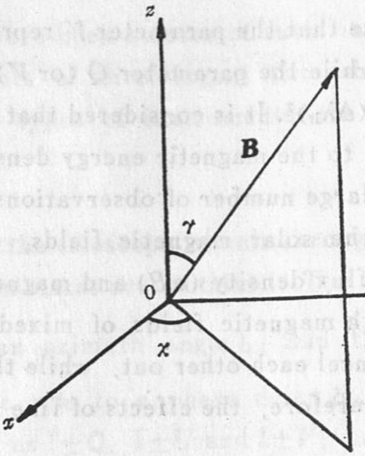

Fig. 3 The magnetic field vector.

3. The Essence of Difficulties

Why is the measurement of vector magnetic fields (especially transverse fields) extremely difficult? There are a variety of causes. Stenflo[8,9] pointed out that the essential reason lies neither in instrumentation nor in theoretical analysis. Actually, there are in the solar magnetic fields fine structures which are by far unresolved by the current instruments and have effects on the longitudinal and transverse measurement in quite different ways. Therefore, it is the effect of fine structures in the vector magnetic field measurement that is very difficult to remove. Here we give the following explanations.

For a spectral line exhibiting the normal Zeeman effect, the intensities of the two circularly polarized components σ_1 and σ_2 in the longitudinal magnetic field are

$$I_{\sigma 1,2}=\frac{1}{2}(I\pm V), \tag{1}$$

where I and V, and Q and V which will appear below, are all Stokes parameters of the spectral line. For weak field approximation (WFA), i. e., for Zeeman splitting ($\Delta\lambda_B$) smaller than Doppler width ($\Delta\lambda_D$), we can obtain from the above formula

$$V=\Delta\lambda_B\left[\frac{\partial I}{\partial\lambda}+\frac{1}{6}(\Delta\lambda_B)^2\frac{\partial^3 I}{\partial\lambda^3}+\cdots\right]\cong\Delta\lambda_B\frac{\partial I}{\partial\lambda}. \tag{2}$$

Three polarized components σ_1, σ_2 and π appear in the transverse magnetic field.

Their intensities are

$$I_{\pi,\sigma}=\frac{1}{2}(I\pm Q). \tag{3}$$

Again under the WFA condition, from this formula we have

$$Q=-\frac{1}{4}(\Delta\lambda_B)^2\left[\frac{\partial^2 I}{\partial\lambda^2}+\frac{1}{12}(\Delta\lambda_B)^2\frac{\partial^4 I}{\partial\lambda^4}+\cdots\right]\cong-\frac{1}{4}(\Delta\lambda_B)^2\frac{\partial^2 I}{\partial\lambda^2}. \tag{4}$$

A similar formula can be obtained for the parameter U. From (2) and (4) we can realize that the parameter V representing the circular polarization is propotional to $\Delta\lambda_B$, while the parameter Q (or V) representing the linear polarization is propotional to $(\Delta\lambda_B)^2$. It is considered that V is proportional to the magnetic flux density and $Q(U)$ to the magnetic energy density because $\Delta\lambda_B$ is propotional to B. In recent years, a large number of observations show that there are very complex fine structures in the solar magnetic fields, which have distinctly different effects on the magnetic flux density (αB) and magnetic energy density (αB^2). (For instance, in a region with magnetic fields of mixed polarities, the magnetic flux densities may mostly cancel each other out, while the magnetic energy densities will remain the same.) Therefore, the effects of fine structures on V and Q (or U) will also be different.

Furthermore, under the WFA condition, the longitudinal field intensity ($B_\parallel \equiv B\cos\gamma$) can be derived from V and the transverse field intensity and azimuth χ can be derived from Q and U. In doing so, the following formulae can be used[10]:

$$Q = C_Q\,(B\sin\gamma)^2\cos 2\chi\frac{\partial^2 I(\lambda)}{\partial I^2},$$

$$U = C_U\,(B\sin\gamma)^2\sin 2\chi\frac{\partial^2 I(\lambda)}{\partial\lambda^2}, \tag{5}$$

$$V = C_V(B\cos\gamma)\frac{\partial I(\lambda)}{\partial\lambda},$$

where C_Q, C_U, and C_V are constants, which can be determined by calibration. It can be seen from the above expressions that the effects of fine structures on the longitudinal and transverse field measurements are different. Hence these effects are difficult to remove.

It is also worth mentioning that from (2) and (4) we have $V \propto \Delta\lambda_B$, while Q (or U) $\propto (\Delta\lambda_B)^2$. Therefore, the measuring error for Q (or U) is much larger than that for V. As a result, the measuring error for the transverse fields is much larger than that for the longitudinal one. In addition, both angles γ and χ should be determined for measuring the transverse fields. The variability of χ should be considered because of the effect of Faraday rotation. The direction of the transverse magnetic force line can not be judged directly from observation, and that is the so-called 180-degree ambiguity. In a word, the measurement of transverse fields is much more difficult than that of longitudinal fields. What is the most difficult is just the most important. This can be said to be the challenge of the nature to the mankind.

2. Vector Magnetographs

Since the first vector magnetograph of the Crimean Astrophysical Observatory[11,12] was constructed in early 1960, there have been a dozen of such instruments in use. They can be divided into instruments of birefringent filter-based and spectrograph based. The principles of these two types of instruments are similar, although their performances are quite different.

1. Principles

When the light of a solar image formed by the telescope travels through a polarizing analyzer, beams of different polarization states are obtained. The light axis of the $\frac{1}{4}$-wave plate in the analyzer has an azimuth angle δ, and the voltage changes of the modulating crystal (KD*P) give rise to a phase delay δ. Different combinations of the Stokes parameters, such as $I \pm Q$, $I \pm U$ and $I \pm V$, can thus be obtained by changing Q and δ. Then all the parameters can be determined by these combinations, and the three elements B, γ and χ can be evaluated simultaneously by using (5) or other similar formulae. By doing so, on point-by-point basis on the solar image vector magnetograms can be mapped by computer.

The Magnetic Field Telescope[13] of the Huairou Solar Observation Station of Beijing Astronomical Observatory uses a filter to separate the emission in megneto-sensitive spectral lines. The half width of transparency of FeI λ 5324 and H_β are 0.15Å and 0.12Å, respectively. The vector magnetograph[14] of the Okayama Astrophysical Observatory in connection with a spectrograph with focal length of 10 meters are used for observation in FeI λ 5250. These two instruments are filter-based and spectrograph-based, respectively. Besides, the vector magnetograph at the Big Bear Solar Observatory, MSFC and Johns Hopkins University (JHU) of the United States are all filter-based. While the vector magnetograph of Mees Solar Observatory (MSO) of Hawaii University in the United States, Potsdam Observatory in Germany, Sayan Observatory in Russia, and the modified instrument at Crimean Astrophysical Observatory are all spectrograph-based. These two types of instruments have merits and shortcomings themselves, because different methods are adopted of intercepting the radiation of magneto-sensitive line from a wide range of spectral wavelength range.

2. Comparison Between the Two Types of Instruments

The merits and shortcomings of the two types of instruments are: (1) The filter-based instrument can take a complete magnetogram over a large range of region on the solar disk at a time, while the spectrograph-based instrument needs scanning point-by-point (or scanning various regions of the solar disk using the full height of a slit). Therefore, the temporal resolution of the former is much better than that of the latter; (2) The fact that the bandwidth of transparency of the filter is not nar-

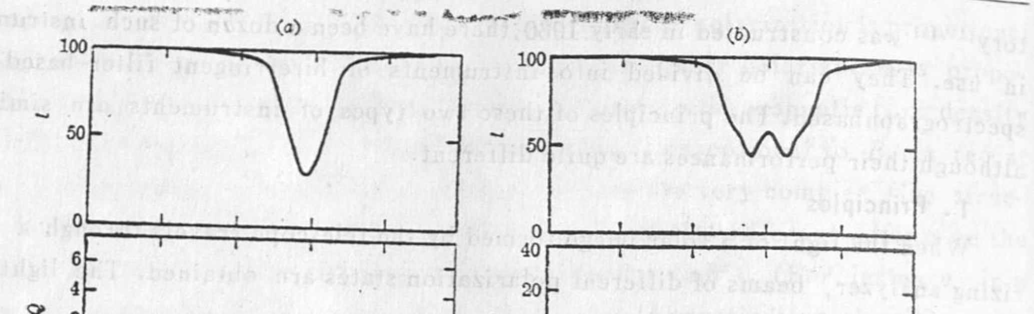

Fig.4 Two sets of profiles of the Stokes parameters of CaIλ6122.

(a) B=1 000G, γ=30°, X=0; (b) B=3 000G, γ=67°, X=30°.

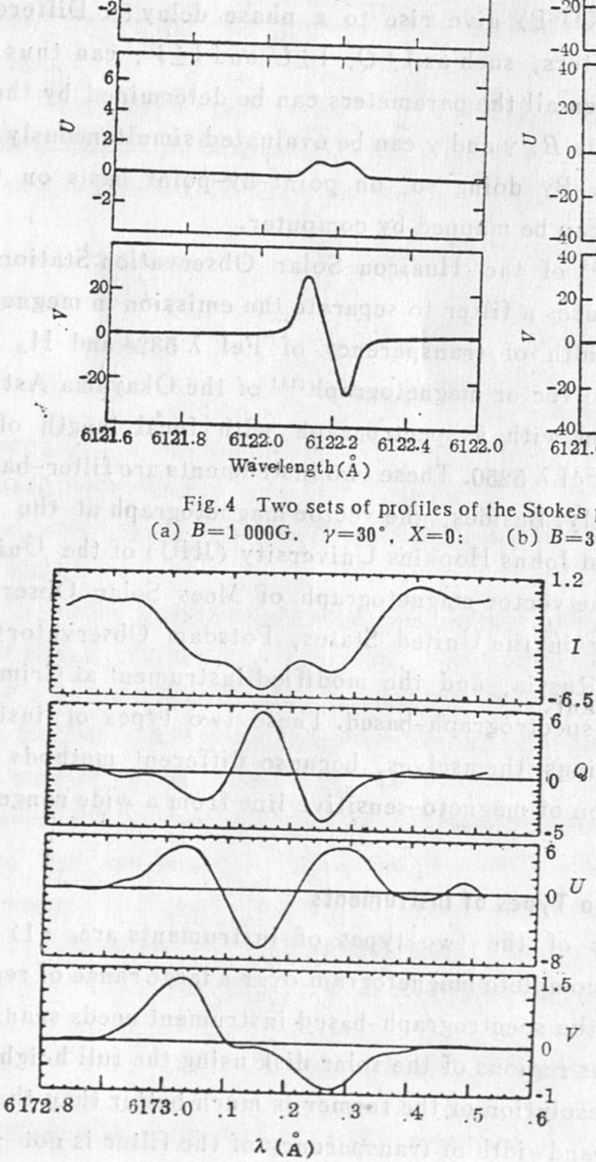

Fig.5 Two sets of profiles of the Stokes parameters passing through a filter of JHU vector magnetograph.

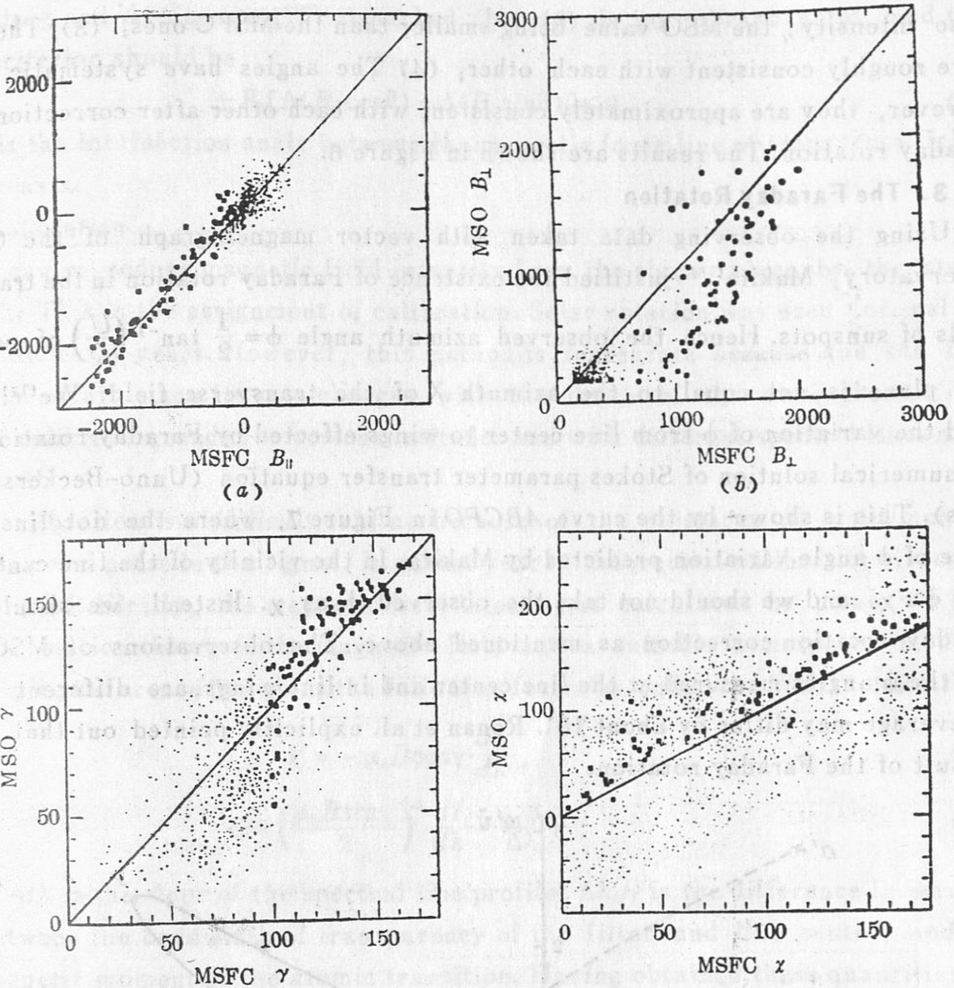

Fig.6 A point-to-point comparison of MSFC and MSO.

row enough results in a large deformation of the profiles of the Stokes parameters, and the intensity decreases significantly. Hence the former instrument is not good for accurate and quantitative observations. This case can be shown by the two sets of profiles of CaI λ 6122 in Figure 4. Figure 5 shows the deformation of the profiles and the decrease of the intensity caused by the filter of the JHU vector magnetograph. The cause is readily understandable. The half bandwidth of transparency of the filter is $0.167\,\text{Å}$. Taking this value as the half-width of the instrumental profile, the spectral resolution is only 3.7×10^4 for the above-mentioned spectral line. However, solar spectrographs generally have a spectral resolutions of some $10—30\times10^4$.

In order to compare the two types of vector magnetographs, Ronan et al.[15]. made a point-to-point comparison of the observational data for the same active region obtained at the same time with the two instruments of MSFC and MSO, which belong to two types respectively. The results indicate: (1) The longitudinal field intensities are in good consistency; (2) There are systematic errors in the transverse intensity, the MSO value being smaller than the MSFC ones; (3) The angles γ are roughly consistent with each other; (4) The angles have systematic errors. However, they are approximately consistent with each other after correction for the Faraday rotation. The results are shown in Figure 6.

3. The Faraday Rotation

Using the observing data taken with vector magnetograph of the Okyama Observatory, Makita[18] justified the existence of Faraday rotation in the transverse fields of sunspots. Hence the observed azimuth angle $\phi=\frac{1}{2}\tan^{-1}\left(\frac{U}{Q}\right)$ of polarization plane is not equal to the azimuth χ of the transverse field. We[17] calculated the variation of ϕ from line center to wings effected by Faraday rotation using the numerical solution of Stokes parameter transfer equation (Unno–Beckers' equations). This is shown by the curve *ABCPO* in Figure 7, where the dot line is the curve of ϕ angle variation predicted by Makita. In the vicinity of the line center, we have $\phi \gg \chi$, and we should not take the observed ϕ as χ. Instead, we should make Faraday rotation correction as mentioned above. The observations of MSO show that the ϕ angles measured at the line center and in line wings are different and on the average may differ by about 10°. Ronan et al. explicitly pointed out that this is a result of the Faraday rotation.

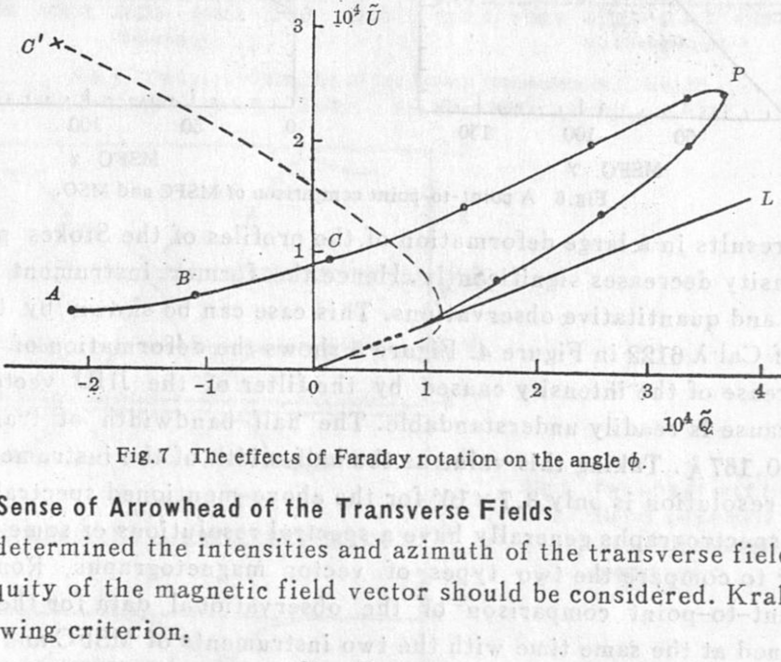

Fig.7 The effects of Faraday rotation on the angle ϕ.

4. The Sense of Arrowhead of the Transverse Fields

Having determined the intensities and azimuth of the transverse fields, the 180-degree ambiquity of the magnetic field vector should be considered. Krall[18] suggested the following criterion:

$$B_\perp \cdot \nabla B_2 < 0, \tag{6}$$

This impies that the directions of increase and decrease of $B_\perp$ and ∇B_2 are the same.

Wu Linxiang and Ai Guoxiang[19] remarked that (6) is not always valid, and the correct criterion should be

$$\pm B_2[\Delta(B_\perp\cos\theta)+\Delta(B_\perp\sin\theta)]\leqslant 0, \tag{7}$$

where θ is the intersection angle between the magnetic force line of transverse fields and the x-axis.

5. Calibration

How can we reduce magnetic field intensity from the signals given by the magnetograph? This is the assignment of calibration. Solar rotation was used for calibration in the early years. However, this method is inaccurate because the sun has differential rotation and its rate changes with the depth of the atmosphere. The results of calibration made for various latitudes and with different spectral lines may differ greatly.

The calibration is a difficult subject because of the existence of instrumental polarizition and noise in the signal. In recent years, theoretical calibration is currently adopted. Firstly, the magnetic field intensity is calculated by means of the spectral formation theory in the magnetic field and a suitable atmosphere model. For example, reference [7] gives the following formulae under the WFA condition

$$V=-\mu_\lambda B\cos\gamma\frac{dI}{d\lambda}, \tag{8}$$

$$Q=\left(\frac{\mu_\lambda B\sin\gamma}{2}\right)^2\frac{dI}{d\lambda}\quad\frac{3}{\Delta\lambda_{off}}, \tag{9}$$

where $dI/d\lambda$ is the slope of the spectral line profile, $\Delta\lambda_{off}$ is the difference in wavelength between the bandwidth of transparency of the filter and line center, and μ_λ is the magnetic moment of the atomic transition. Having obtained these quantities, the relation between $V\sim B_\parallel$ and $Q\sim B_\perp$ can be established, and that is the calibration. This method takes into consideration the actual observation and uses relatively accurate theoretical calculations, and so it is comparatively reliable.

3. Stokesmeters

This is a new type of instrument and also known as the Stokes polarizer. The instrument firstly uses a polarized light analyzer to get the intensities of four Stokes parameter, and then the four profiles of Stokes parameters can be obtained by rotating a grating and scanning in a range of a certain magneto-sensitive line. Figure 8 shows a set of profiles observed. The complete information of vector magnetic fields can be obtained by analyzing these profiles.

Nowadays the best Stokesmeters in the world are Stokes-I[20], Stokes-II[21] ,and

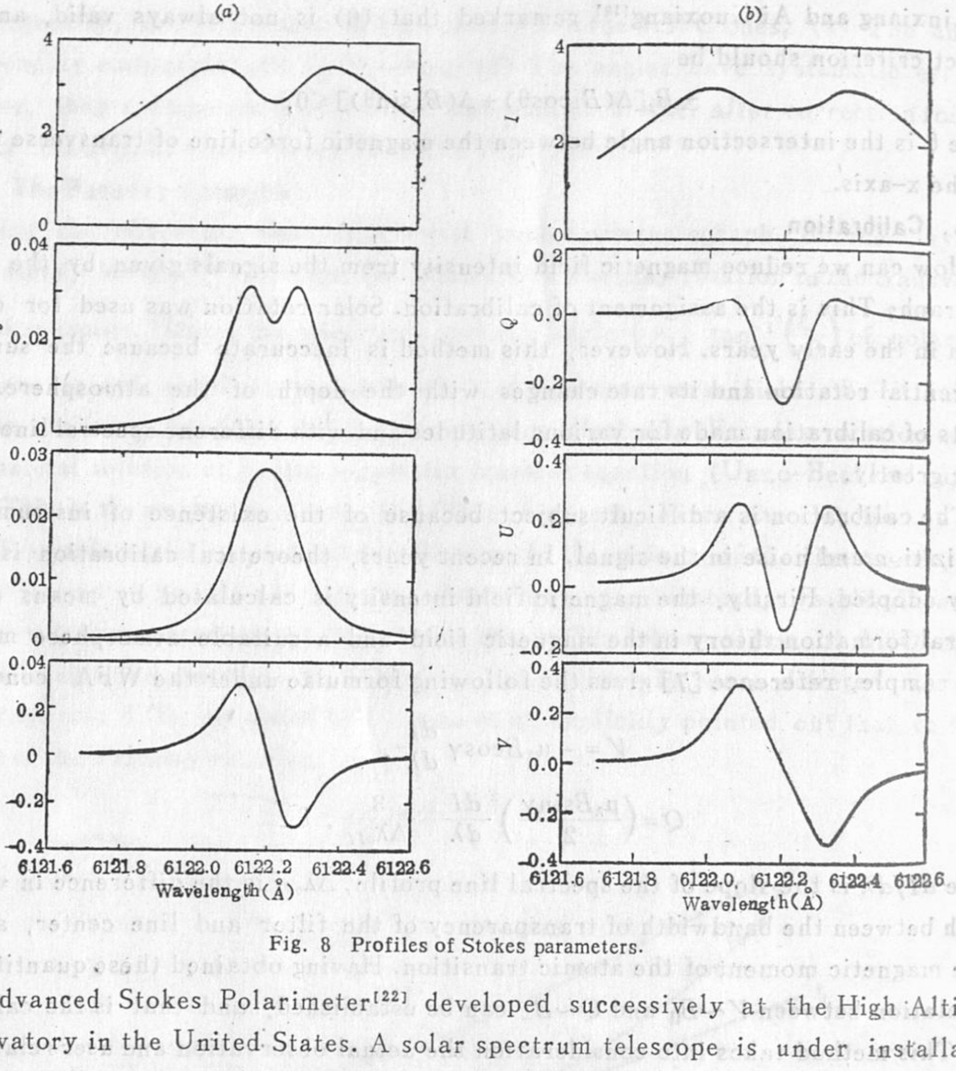

Fig. 8 Profiles of Stokes parameters.

the Advanced Stokes Polarimeter[22] developed successively at the High Altitude Observatory in the United States. A solar spectrum telescope is under installation at Yunnan Astroniomical Observatory, and it is also a Stokesmeter.

It is quite a formidable task to derive vector magnetc field information from the profiles of Stokes parameters. The reason is that the profiles are formed by the polarized radiation in the solar atmosphere through a complex transfer process. A variety of factors should be treated, such as the inhomogeneity of atmosphere and magnetic fields, re-emission mechanism of radiation, magneto-optical effect, and deviations from thermodynamic equilibrium etc. There has been a long period of investigation on these problems by scientists at the High Altitude Observatory. Early in 1977, Auer, Heasley and House[23] suggested the AHH program. They fit the observed profiles of Stokes to the Unno algebraic solution and selected values of magnetic field intensity and direction. In other words, they derived the magnetic field information from observed profiles by inversion. Landolfi, Landi Degl'Innocenti and Arena[24] improved the method, because Unno's algebraic solutions is rather crude. They took into account the magneto-optical effect,line wing damping, inhomogeneity of magnetic field etc. and established the ALL program. Using the method, Arena[25] investigated the megnetic and velocity fields of sunspots. He used (1) the ratio of absorption coefficient of line center to continuum absorption coefficient, (2) $\Delta\lambda_B$, (3) $\Delta\lambda_D$, (4) γ, (5) χ (6) damping constant, (7) source function and (8) wavelength of line center, all togather eight parameters, to evaluate the values of the parameters at various places in the spots with observed profile and the least square inversion.

Landi Deg'Innocenti[26] summarized six methods of the evaluation of vector magnetic field from Stokes profiles, one of which was founded by us[27]. He called it "technique of characteristic quantity". It contains three steps: (1) evaluating B from the difference between the maximum of V profile ($V_{\max}$) and the wavelength of line center, (2) evaluating γ from $V_{\max}$, and (3) evaluating χ from the value of Q profile at line center. We have obtained fairly good results in processing the observed data from Okayama Astrophysical Observatory. For details see[28].

4. Stokes Polarimetry

This is a new field of research under rapid development in recent years. It deals with Stokes profile, tackles the nature of unresolved fine structures in the magnetic fields (i.e., magnetic element or magnetic tubes), and characterizes their parameters (for instance, filling factor, true magnetic field intensity, the temperature density and velocity of the motion of material within the magnetic the tubes) and their variations with the depth. Combined analysis of two or more lines arerequired for reducing and even eliminating the effects of the atmosphere model etc.

An important method is the "line ratio technique". It uses two selected lines with similar formation process,for instance FeI λ 5 247.06 and λ 5 250.22. They are both from the first multiplet of the neutral iron atom with similar intensities and excitation potentials. The only distinct difference is the Lande splitting factors, which are g = 2.0 and 3.0, respectively. According to formula (2) and the principles of Zeeman effect, we have $V_{5250}:V_{5247}=3:2$. However, V profiles taken by scanning a bright plage indicate that the ratio is nearly unity. The reason is that the magnetic fields in the plage are stronger, and hence the approximate formula (2) under WFA condition is no longer true. Therefore, more terms should be taken in the Taylor expansion for more accurate calculation. Stenflo took a series of values of B,

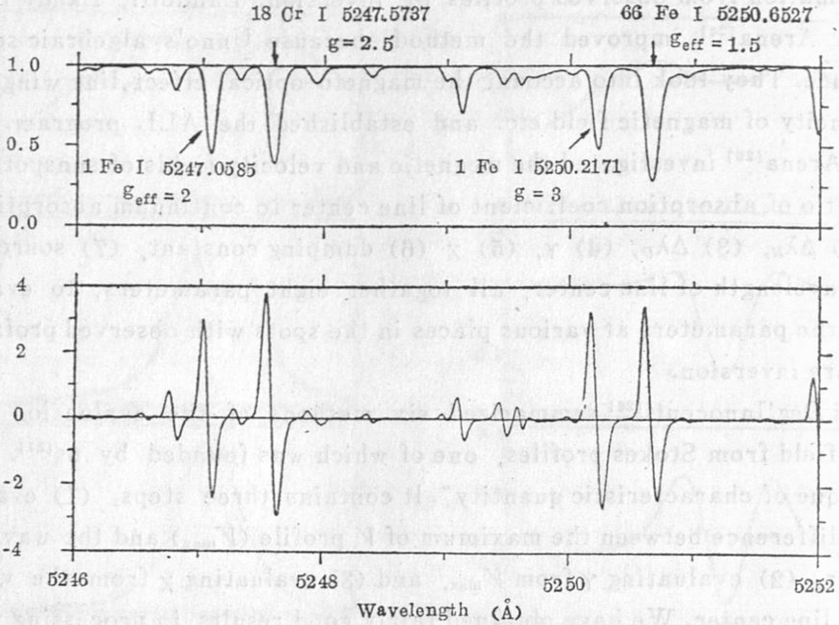

Fig.9 Profiles of I and V of Fe I 5247Å and 5250Å.

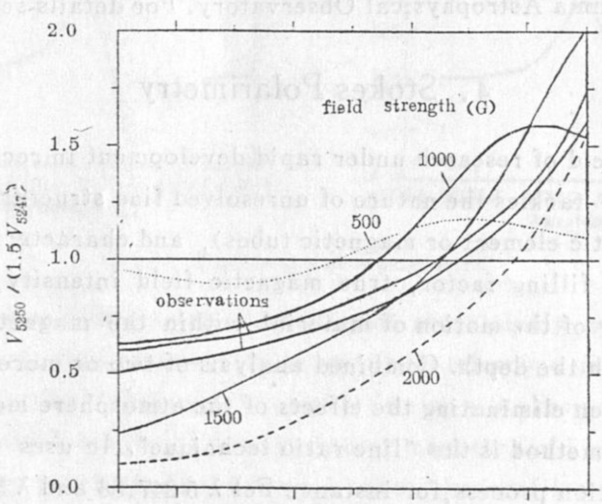

Fig.10 Distribution of the ratios of $V_{5250}/1.5V_{5247}$ in the range of the spectral line for different magnetic field intensities.

and calculated the ratios of theoretical V parameters using a lot of different values of $\Delta\lambda$. A comparison of these ratios with the observed results are shown in Figure 10. It follows that the magnetic field intensity is some 1500G, much larger than the value usually adopted. The essential point of this method is to evaluate B by means of the ratio of V parameter of two lines and thus the effects such as filling factor are canceled out.

In recent years, Title et al[29]. carried out high spatial resolution observations of the solar magnetic fields by using adjustable filter developed at Lockhead Laboratory, with the highest resolution of 0.3—0.5 arcsecond. We mention here only their polarization diagram of active region on the solar disk for two lines of λλ 5 247 and 5250. Using the above-mentioned line ratio technique, they acquired that the intensity of magnetic elements in the line formation region is approximately 1 000G, while in the region of continuum spectrum 2 000G. For detail see reference[30].

Stenflo et al. derived the change with altitude of B in the magnetic flux tube from the variations of twin-peak distance of the V profile. He also determined the direction of the motion of material in the magnetic flux tube from the change of the asymmetry of V profiles on the solar disk. For details see references [8]and[9].

The essence of difficulties for vector magnetic fields measurements is the unresolved fine structures in the solar magnetic fileds, as described in the first section of the text. The effect of such structures on the I radiation is difficult to remove. However, it is reasonable to consider that the polarization radiation represented by parameters Q, U and V are originated in magnetic elements and has in principle no relation with the intermediate region. Hence analyzing the profiles of I, Q and V, especially comparing the lines with approximately similar formation conditions, the above-mentioned difficulties could mostly be overcome. This is just the advantages of the polarimetry. We believe that this new branch of science is promising.

Now that we have given a brief description of Stokes polarimetry, the following is some complementary remarks about it.

(1) The results of investigation on solar magnetic fields using the new branch of science by Stenflo et al. has given rise to some controversy. In interpreting the magnetograms diagram taken from Big Bear Solar Observatory, Zirin argued that there indeed exist fine structures in the solar magnetic fields, but the magnetic elements are not so small as Stenflo says,and also the magnetic fields are not so strong. Zirin concluded in a book[31] "After we have criticized the Stenflo's model, on quatitative grounds, there is no doubt that qualitatively it is correct,and it was this model that focussed our interest on the discrete magnetic elements." We should also mention that in the international conference on "The Magnetic and Velocity Fields of Solar Active Regions" held in September 1992, Stenflo and Zirin had interesting and friendly face-to-face debates. As a result, they had fundamentally consistent points of view on the fine structures of solar magnetic fields. The large quantitative difference of their results is only caused by different ways of investigation, with emphysis on observation or on theoretical analysis.

(2) The discussions in our text are solely based on the Zeeman effect. However, in recent years, the theory of the Hanle effect has gradually matured and begun to play an eminent role in the measurements (for instance see[32]), and begun to be known in the measurements of solar vector magnetic fields. The Hanle effect originates in resonant scattering of bound electrons in the magnetic field and the radiation of solar prominences is just the scattered radiation of solar solar photosphere. This is the reason that not a few solar physicists have obtained some interesting results by measuring the vector magnetic fields of solar prominences on the basis of Hanle effect. Because of the limited space, we only present an important question raised by Leroy, the so-called "vertical structure paradox". The fine structures of quiescent prominence mainly appear vertically, while the magnetic vector of prominence lies in the horizon, that is, parallel to the solar disk. According to magnetohydrodynamics, if the plasma of the prominence is frozen in the magnetic field, the distribution of the fine structures of prominence should be in consistency with the magnetic fields, and therefore the phenomenon described above is difficult to understand. It is considered that there may be something mysterious with the magnetic fields in prominences.

5. Summary

1. Both the importance and difficulties of the measurment of the solar vector magnetic fields are concentrated in the measurement of the transverse fields.

2. The essence of difficulties is that the fine structures of the solar magnetic fields are unresolvable by the current instruments. These structures have different effects on the longitudinal and transverse fields.

3. The approach to overcoming the difficulties is to develop Stokesmeters and to undertake the research on Stokes polarimetry.

References

[1] Severny, A. B., *Izv. Krym. Astrofiz. Obs.* 20 (1958), 22; 24 (1960), 28.
[2] 叶式煇，天体的磁场，§5.3.科学出版社，(1978).
[3] Hagyard, M.J., *Mem. Soc. Astron. Ital.*, 61 (1990), 337.
[4] Tandberg-Hanssen, E. and Emslie, A. G., in The Physics of Solar Flares, p. 150, Cambridge (1988).
[5] Low, B. C., in Measurements of Solar Vector magnetic Fields, ed. by M. J. Hagyard, NASA CP—2374, p.49. (1985).
[6] Harvey, J., in Measurements of Solar Vector Magnetic Fields, ed. by M.J. Hagyard, NASA CP—2374, p.109, (1985).
[7] Rust, D.M. and O'Byrne, J.W., in Solar Polarimetry, ed. by L.J.November, NSO/Sac peak, p.74, (1991).
[8] Stenflo, J. O., in measurements of Solar Vector Magnetic Fields, ed. by M.J, Hagyard, NASA CP-2374, p. 263, (1985).

[9] Stenflo, J.T., *Solar Phys.*, 100 (1985), 139.
[10] Jefferies, J.T., Lites, B. W. and Skumanich, A., *Ap.J.*, 343 (1989), 920.
[11] Stepanov, B.E. and Severny, A.B., *Izv. Krym. Astrofiz. Obs.*, 28 (1962), 166.
[12] Severny, A.B., *Izv. Krym. Astrofiz. Obs.*, 31 (1964), 126.
[13] 艾国祥，胡岳风，天文学报，27 (1986), 173.
[14] Makita, M., *Astrophys. Space Sci.*, 118 (1986), 163.
[15] Ronan, R. S, et al., *Solar Phys.*, 138 (1992), 49.
[16] Makita, M., *Solar Phys.*, 103 (1986), 1.
[17] Ye shi-hui and Jin Jie-hai, *Solar Phys.*, 112 (1987), 305.
[18] Krall, K,R, et al., *Solar Phys.*, 79 (1982), 59.
[19] 吴林襄，艾国祥，天体物理学报，10 (1990), 371.
[20] Raur, T.C. et al., *Solar Phys.*, 65 (1980), 111.
[21] Baur, T.C. et al., *Solar Phys.*, 70 (1981), 395.
[22] Lites, B.W., in Solar Polarimetry, ed. by L.J. November, p.3, NSO/Sac Peak, (1991).
[23] Auer, L.H. et al., *Solar Phys.*, 55 (1977), 47.
[24] Landolfi, M. et al., *Solar Phys.*, 93 (1984), 269.
[25] Arena, P., *Solar Phys.*, 129 (1990), 259.
[26] Landi Degl′Innocenti, M., in Measurements of Solar Vector Magnetic Fields, ed. by M.J. Hagyand, NASA CP-2374, p.279, (1985).
[27] 叶式煇，金介海，天文学报，24 (1983), 119.
[28] 叶式煇，紫金山天文台台刊，5 (1986), 175.
[29] Title, A.M. et al., in Solar Photosphere: Structure, Convection and Magnetic Fields, ed. by J. O. Stenflo, p. 49, Kluwer Acad. Publ., (1990).
[30] Keller, C.U. et al., *Astron. Astrophys.* 236 (1990), 250.
[31] Zirin, H., Astrophysics of the Sun, Cambridge Univ. Press, (1988).
[32] Stenflo, J.O., in The Hanle Effect and Level-Crossing Spectroscopy, ed. by G. Moruzzi and F. Strumia, p. 237, Plenum Publ. Corp., (1991).
[33] Leroy, J. L., in Dynamics and Structure of Quiescent Solar Prominences, ed. by E. R. Priest, p.77, Kluwer Acad. Publ., (1988).