ATTEMPTS TO DETECT EMERGING TWISTED FLUXTUBE

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1. A Proposal for Future Ground-Based Solar Observations

We have been discussing over years about our future plans of ground-based solar observations. I report some points of the discussions and my own proposal of telescope system and observations. Since observations in very high spatial resolution can only be performed in the space, future ground-based observations should emphasize very high precision, long-term observations and systematic determinations of physical quantities which require large instruments. The scientific objectives we consider would be, firstly to study the sun as a star, and secondly to study detailed dynamics of the magnetic fields which causes sun's activities. More specifically, for the first objective, we should start and continue for long period over a 100 year the full-disk measurements of magnetic field vector,velocity field and brightness distribution and monitor large scale magnetic patterns, velocity fields-global convection and circulation and non-uniform rotation, torsional oscillation and their short and long term variations. This kind of observations should be combined with diagnostics of internal structure(particularly convection zone) and its 11 years or any other variations by means of measurements of non-radial and radial pulsations. Long term observations will clarify solar dynamo mechanism and natures of long period activity cycles and their effect on the earth climate and solar system environment. Short term full-disk measurements are also important to examine e.g. energy inbalance due to sunspots,faculae, and coronal hole. Required precisions for these rather routine type observations would be 0.1G for $B_{\parallel}(10^4)$, at least 10G for $B_{\perp}(3\mathrm{x}10^4)$, 0.1-1 m-s for $v_{\parallel}(5\mathrm{x}10^3-5\mathrm{x}10^4)$ and 0.01% for $I(10^4)$. Number in the parenthesis indicate signal to noise ratio required. It is necessary to acomplish measurements of $B_{\parallel},(B_{\perp}),v_{\parallel},I$ simultaneously in a short time to increase data coverage at cloud-rich site.

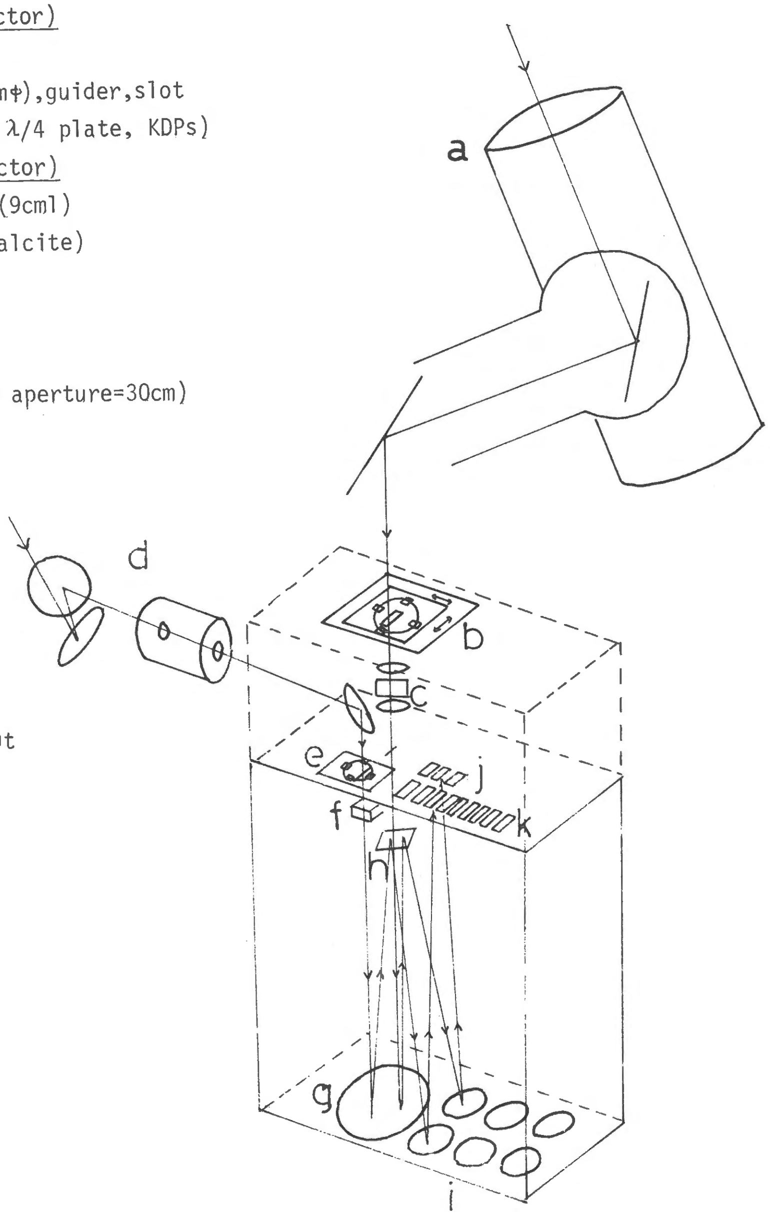
For ultimate understanding of physics of surface magnetic structures or for the second objective, we will need simultaneous determinations with high spatial and time resolutions of three dimentional distributions of velocity, magnetic vector field, density and temperature in each strucrure. Although this should be performed in the space ultimately, perfect determinations even with restriction to visible bands have not been achieved in the ground-based observations. We should obtain two-dimentional maps of v, $\underset{\sim}{B}$, I at least at two photospheric levels and chromosphere simultaneously for each active region or quiet region with time resolutions depending on the purpose (1s-1hr) and good spatial resolution of the order of 1". Requirement of the S/N would be 10^3.

For simultaneous and quick measurements at different lines it is essential to use diode-array type detectors and place them at foci of various lines. Diode-array may be two-dimentional; one for the spatial points along the slit the other for the wavelength points of a line profile. The photon count rate (E) in each pixel of the array reads $E=eD^2/I^2xy\,\eta\Delta\lambda$(e: input photon per $cm^2$and A), D: telescope diameter, I: image size of the sun, x: slit width, y: slit length in each pixel=x, η: efficiency of telescope, spectrograph and detector=0.05 typically, $\Delta\lambda$: wavelength bandpass at the detector=25mA). Taking into account that the measurement is shot-noise limited we obtain $S/N=90D(cm)x('')\sqrt{t(s)}$. To scan a region of L'xL' using slit length equivalent to L' it takes $\Delta t \simeq 9.3\times 10^{-4}L(S/N)^2/(D^2x^3n)$ seconds, where n is number of slits.

To achieve above mentioned observations we propose a system shown in Fig.1. Two telescopes feed two kinds of images on the top of a common vertical spectrograph. One telescope should have an aperture as large as possible and aims measurements of linear polarization and very small $v_{\parallel}$ and $B_{\parallel}$. As an analyzer a rotaing quarter wave plate and KDPs are adopted. Lense system is favored for the primary to avoid instrumental noise produced by the obstacles in the light path. Total noise level including uncancelled instrumental polarization would be less than a few times 10^{-5}. Adopting D=65cm a measurement of a region 8'x8' with $N/S=10^{-4}$ and 2" resolution is fulfilled in 40s. Because of difficulty of quick motion in large telescope and requirement of simultaneous measurement in many lines, a second small and achromatic telescope($D\gtrsim30$cm) is placed horizontally after coelostat and produces 9cm solar image on the 9cm long slit. The full disk measurement at 12 different lines can be performed in 1700/n seconds with the accuracy of 1 ms^{-1} and 0.2G($B_{\parallel}$) and 1" resolution. These lines may be B-sensitive, v-sensitive and T-sensitive lines formed at deep, middle and upper photosphere, respectively

Fig.1 A proposed telescope system

a. telescope 1(refractor)
D ≥ 65cm F/15
b. primary image(10cmΦ),guider,slot
c. analyzer(a rotary λ/4 plate, KDPs)
d. telescope 2(reflector)
e. image(9cmΦ), slit(9cml)
f. analyzer(KDP or calcite)
spectrograph
g. collimator
f=10m, F/30
h. grating(effective aperture=30cm)
i. camera mirrors
detectors
j. two-dim.arrays
(2000x200)
for telescope 1
k. two-dim. arrays
for telescope 2
(12 arrays for
$B_{\parallel}$, $v_{\parallel}$, T measurement
at 4 layers)



and at chromosphere.

A test model of the latter system is under construction at Mitaka. Here a mirror telescope of D=20cm and F/15 makes 2.8cm solar image at the entrance of a horizontal vacuum spectrograph, and line profiles of two circular polarizations are measured for four lines simultaneouly by stepping linear CCDs across line profiles with the smallest step of 1 micron (1.6mA). Calcite block is used as a beam splitter and $\lambda/4$ wave plate. Selection of lines can be achieved by displacing the detectors. Test performances using this system and also the vector magnetograph at Okayama would be the basis to realize proposed observatory in the future.

2. Detection of Emerging Twisted Fluxtubes

One of the specific key problems that belongs to the second objective mentioned in §1 would be the study of magnetic flux emergences. Generally sun's surface activities are initiated by the emergence of bipolar fluxloops. There is a smaller scale version of the flux emergence outside active region known as an ephemeral active region. A third kind of flux emergence which would occur in much shorter and smaller scales may be expected in the quiet region. Eruption of small loops in the quiet region is suggested by recent UV observations by Brueckner. Physical consequence of the flux emergence would be that some extra energy of the magnetic fields which is injected in the convection zone is convected out directly into the corona. Then, it may be conjectured that these extra energies in three different regions are responsible for flares, x-ray bright points and coronal heating in the quiet region, respectively. Although this is still umproved hypothesis, for the special family of spot goups called δ-group in which intense flares occur frequently, there are some observational materials which suggest that the fluxtube constituting δ-group emerges out as it is twisted and that flare occurs in the individual fluxtube which have emerged out as described below.

(1) Configurations of δ-group

Any complex configuration of δ-group can be decomposed into sets of compact bipoar spots in which two poles are closely located, large horizontal fields exist in between the two poles, and spiralled penumbral structure surrounds the two spots. This photospheric configurations (Fig.2a) suggest a compactly twisted magnetic knot as shown in Fig.2b.

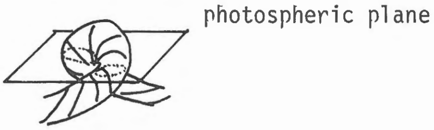


Fig.2a

Fig.2b

Fig.2a Typical bipolar configuration element in δ-group

Fig.2b A twisted magnetic knot and its photospheric cross section as sunspots

(2) Characteristic evolution patterns

A bipolar part of the complex δ-group or a single bipolar δ-group develope in the pattern of mode A (Fig 3a) : two spots grow rapidly with penumbral filaments connecting straightly, then there occurrs a relative motion between the two spots (shear motion) together with the filaments showing curls, finally well-developed spirall appears. In the decay phase of a complex group a mode B evolution (Fig.3b) is seen : one growing spot approaches one of the bipolar pair which showed modeA evolution, the neutral line between the two spots is dominated by a part of the curled filaments which developed in mode A. As the new spot (f) approaches, these filaments become less curled and connected to the two spots at the ends. Finally filaments connect straightly the two spots similar to the initial stage of mode A and one of the spot shrinks rapidly. Since photospheric fields would represent the field configuration of high beta region, these peculiar evolution can be explained by the continuous emergence of a twisted knot like the one shown in Fig.3c considering that photospheric spot configuration is an intersection of the fluxtube with a horizontal plane.

Fig.3a
Mode A

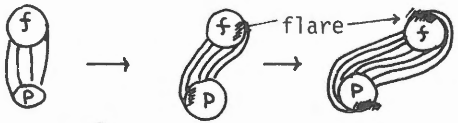
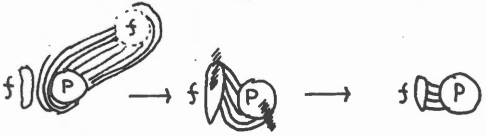


Fig.3b
Mode B



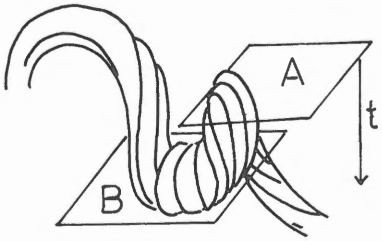


Fig.3c A magnetic knot whose continuous emergence explains mode A and mode B evolutions of sunspots.

(3) A general law of configuration and motion

All the cases after 1969 show a rule shown below concerning direction of the magnetic axis, helicity of the penumbral spiralls and direction of the shear motion, for the mode A evolution. This is easily explained by an emergence of the twisted knot.

magnetic axis	helicity	shear motion
p/f(p-spot north of f-spot)	left-hand twist	f-spot-- east
f/p(f-spot north of p-spot)	right-hand twist	p-spot--west

(4) Anomalous velocity field

There have been observed in the last stage of mode B evolution a large blue shift (>1kms) at the neutral line consisting of strong horizontal fields. The two spots on the sides of the neutral line showed continuous shear motion and disappeared gradually (Fig.4) since this group is close to the disk center, this motion probably manifest the last stage of the flux emergence in which a tube concave to the surface emerges out (Fig.3 c).

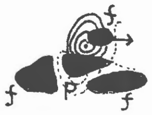


Fig.4 Velocity contours superimposed on spot configuration(1974 July 4). Thick line for blue shift.

(5) Evolution of the flare site

In course of Mode A and B evolution Hα flare sites successively shift to the new positions which correspond to the feet of the newly developed penumbral filaments. This suggests that flare occurs in the individual twisted tube which has emerged out.

(6) Energetics of flares

Energy input evaluated under the assumption that flare energy is directly supplied to corona by emergence of the twisted part of the flux tube agrees quite well with the energy output of flares evaluated from soft x-ray flux and interplanetary shock wave flux (Tanaka, Smith, and Dryer 1978 IAU Symp.91)

Whether this model applies to other flares than occur in δ-group may be tested by measuring magnetic field vector structure in the flare region outside sunspots. The measurement of the velocity field at several levels would be important to distinguish vertical flow associated with the flux emergence of the knot from usually dominant horizontal flow. Transient loop eruption in the quiet region occurs in a short time (20s), thus high time resolution measurement with high sensitivity magnetograph is essential to detect it. These observations may, hopefully, be enabled by the proposed instrument.