Bull. Astr. Soc. India (1994) **22**, 59-66

On the unusual surge of 1991 November 16

K. R. Bondal, V. P. Gaur, A. Joshi, W. Uddin and M. C. Pande
Uttar Pradesh State Observatory, Manora Peak, Naini Tal 263 129

Received 1993 March 27; accepted 1993 June 3

Abstract. An unusually 'long' surge of 'short' duration occurred in the NW region of the sun's limb on 1991 November 16, around 04 15 UT. Time-lapse photographic observations employing a Halle H-alpha filter having a 0.5/0.7 Å pass-band were recorded. The instrumentation used is described first, followed by enumeration of the morphological-cum-temporal behaviour of the phenomenon, as well as the possible physical mechanism which may have played a part therein.

Key words : surge—magnetic field—instability

1. Introduction

As a part of the Solar Maximum Year Programme for observing solar activity on a daily basis, a Zeiss coudé refractor with accessories, a Bernhard Halle H-alpha filter and a time-lapse Robot recorder camera with automatic registering facilities were acquired. It was during one of these patrolling hours, that an unusually long surge appeared above the limb on 1991 November 16 around 04 15 UT. At this moment, the first signs of a sharp, straight and then a sword-like brightening emerged out of the sun's limb in the NW region. The phenomenon, which appeared like a surge, was then photographed at short intervals employing the equipment described hereafter.

2. The instrumentation

Recently, studies of the active sun have gained much importance with an objective to investigate the mechanism of occurrence as well as to know the interrelationships of phenomena like sunspots, flares, prominences and surges. The basic prerequisite for the above is, fast registration of the active phenomena using time-lapse photographic techniques.

Prior to the onset of the Solar Maximum period during 1990-92, the Uttar Pradesh State Observatory (latitude +29°22′ N, longitude 79°27′ E, altitude 1951 m above mean sea-level) acquired a 150/2250 coudé refractor from Carl Zeiss Jena, whose primary focus produces a near 22 mm diameter image of the sun, after the beam suffers reflections at two plane mirrors. However, for the purpose of photography this image has been enlarged to a size of

42 mm by interposing a Barlow lens, followed by a prefilter and then the H-alpha Bernhard Halle filter having a dual pass-band facility of 0.5 and 0.7 Å. The filter itself is tunable in the range ±1 Å on either side of the peak H-alpha wavelength. The desired section of the image can then be photographed using a DN-22 Robot recorder, on 35 mm Kodak Tech Pan 2415 film. The recorder has a built-in facility to print date, time and frame number of the film, together with the desired observer's code number. A schematic representation of the equipment used is shown in figure 1.

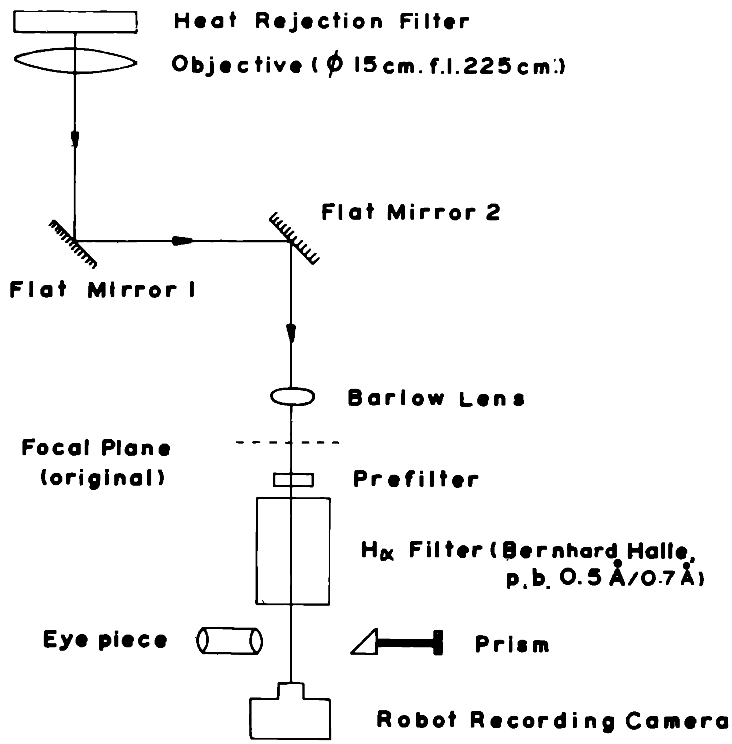

Figure 1. Schematic drawing of the 150/2250 solar coudé refractor of the Uttar Pradesh State Observatory.

3. Observations

To observe the surge, the Halle filter was put on its 0.7 Å passband mode and tuned to +0.5 Å (redward) of the H-alpha line centre for best appearance of the features. The exposure times were, to start with, 2 secs and then increased to 3 for the rest of the observations. To photograph the 'active' disc in the vicinity of the surge, an exposure time of 0.5 sec was given. Good observations were however marred by malfunctioning of the time registration unit of the Robot recorder, as well as by power failure, preventing some frames from being taken during the decay phase of the event. Hence, in our analysis, only those frames on which the time marks could be deciphered (with some difficulty) have been used for the analysis.

Visual inspection of the filtergrams did not reveal any helical structure in the surge as is sometimes seen (Verma 1983). Instead, the surge initially originated as a bright spike, radially from the limb, gradually increasing in length and in brightness. The maximum height (above the solar limb) attained by the surge was found to be nearly 1.3×10^5 km with the maximum length (along its trajectory) of the same order. The measurements on the film were made using a seven-fold magnifying eyepiece equipped with a graduated scale (grid) of least count 0.1 mm.

We have estimated the velocity of the surge in terms of height increase of the tip of the surge by measuring the radial distance between the tip and the photosphere. A plot of the velocity (in km s^{-1}) versus height is shown in figure 2. The upper part of the figure shows the velocity during the ascending phase while the lower shows the velocity during the

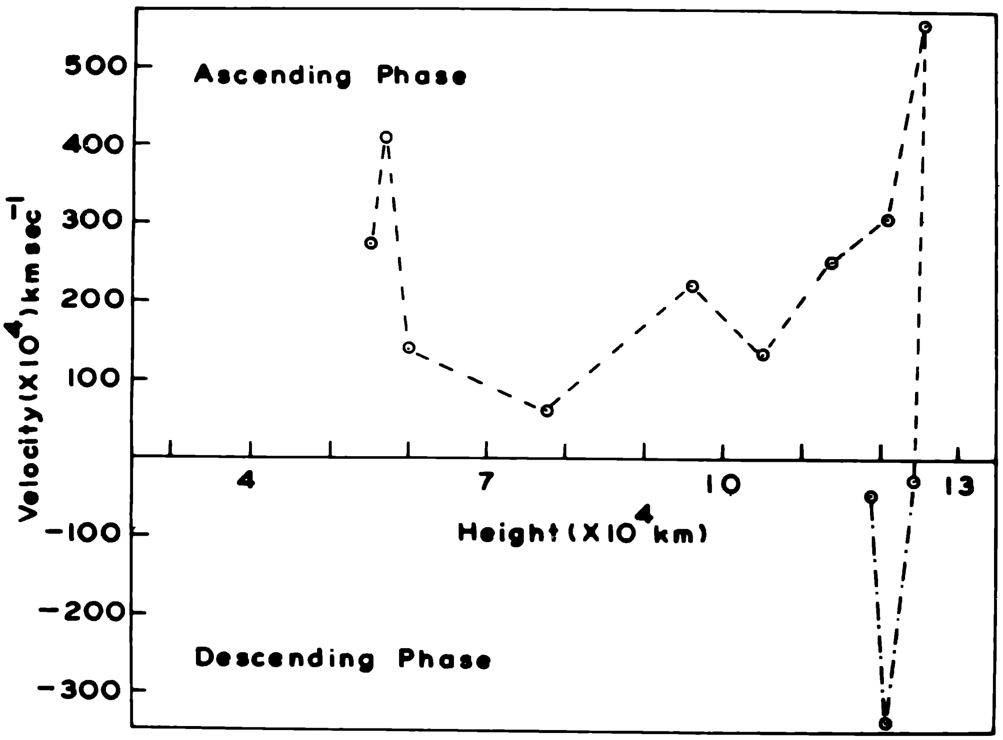

Figure 2. The variation of velocity with height for the surge.

descending phase, indicated by negative values. Figure 3 depicts the height variation with time. Figure 2 shows that the velocity increases in the beginning, followed by an alternate decrease and increase, suggesting a superposition of two or more accelerating stages for the surge. The increase in height with time as shown in figure 3, indicates a variation from a very steep in the beginning, to a less steep later on, then steady, followed by constancy to a final decline during the decay phase.

4. Results and discussions

It is known that surges eject out from strong magnetic regions. Our observations show that in the initial stage, the velocity of the surge was much higher than in the later, indicating the dominance of magnetic energy present in the active region. A physical explanation for the lowering of the velocity could be that the surge, while moving through the corona, traverses a medium having a finite energy density due to the thermal pressure of the gas.

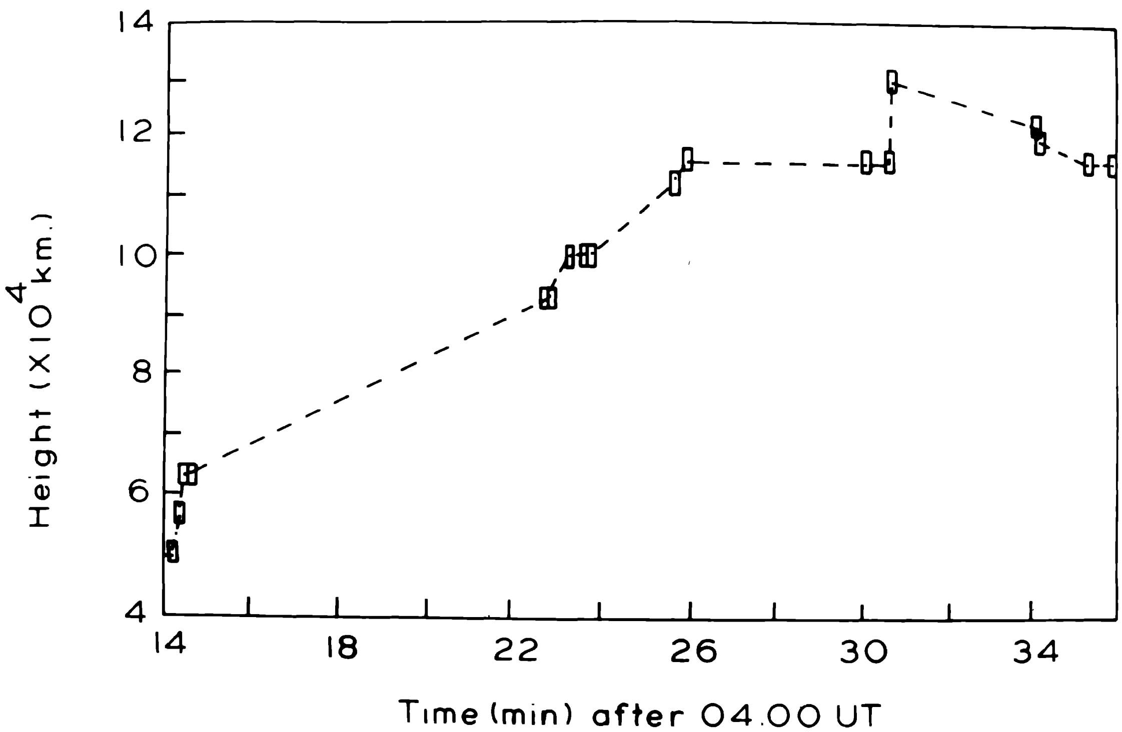

Figure 3. The variation of height with time for the surge.

This gas pressure in the corona provides a resistance to slow down the moving material of the surge. The material at the very end of the surge trajectory gets compressed by the coronal gas pressure and at the same time 'evaporating' due to the higher ambient temperature of the corona (Roy 1973). Due to the foreshortening near the limb, the exact location from where the surge erupted was not visible. A strong possibility however exists that the surge was ejected from the boundary of the active region.

In the ascending phase, the maximum height attained by the surge was calculated to be about 1.3×10^5 km, indicating it to be of class 1 importance (Westin 1969). The initial velocity of rise was estimated at nearly 276 km s^{-1}, increasing to a maximum of about 552 km s^{-1}. During the decay or descending phase it was as low as 46 km s^{-1}. In other words, the surge had a slow initial acceleration, rapidly increasing at a few thousand kilometers above the limb.

Surges are known to occur in the vicinity of active spot groups on the sun. The presence of a possible flare nearby helps in 'accelerating up' the surge material, though Kleczek *et al.* (1971), from numerous observations, indicated that the two are independent phenomena. However, several other observations have shown that they are manifestations of the same process, via the same cause, due to the magnetic field variation (Roy 1973).

Some surges reveal a helical structure, which plays an important role particularly during its decay phase by introducing a screw-type instability (Golant *et al.* 1980). The surge observed by us however did not have such a structure.

In our observations a peculiar feature of the surge was, that during the growth or rising phase, it showed alternate compression and expansion of the plasma (figures 4b-4h). At least two frames (when seen on the negative) indicated 'funnelling' out of the material along the

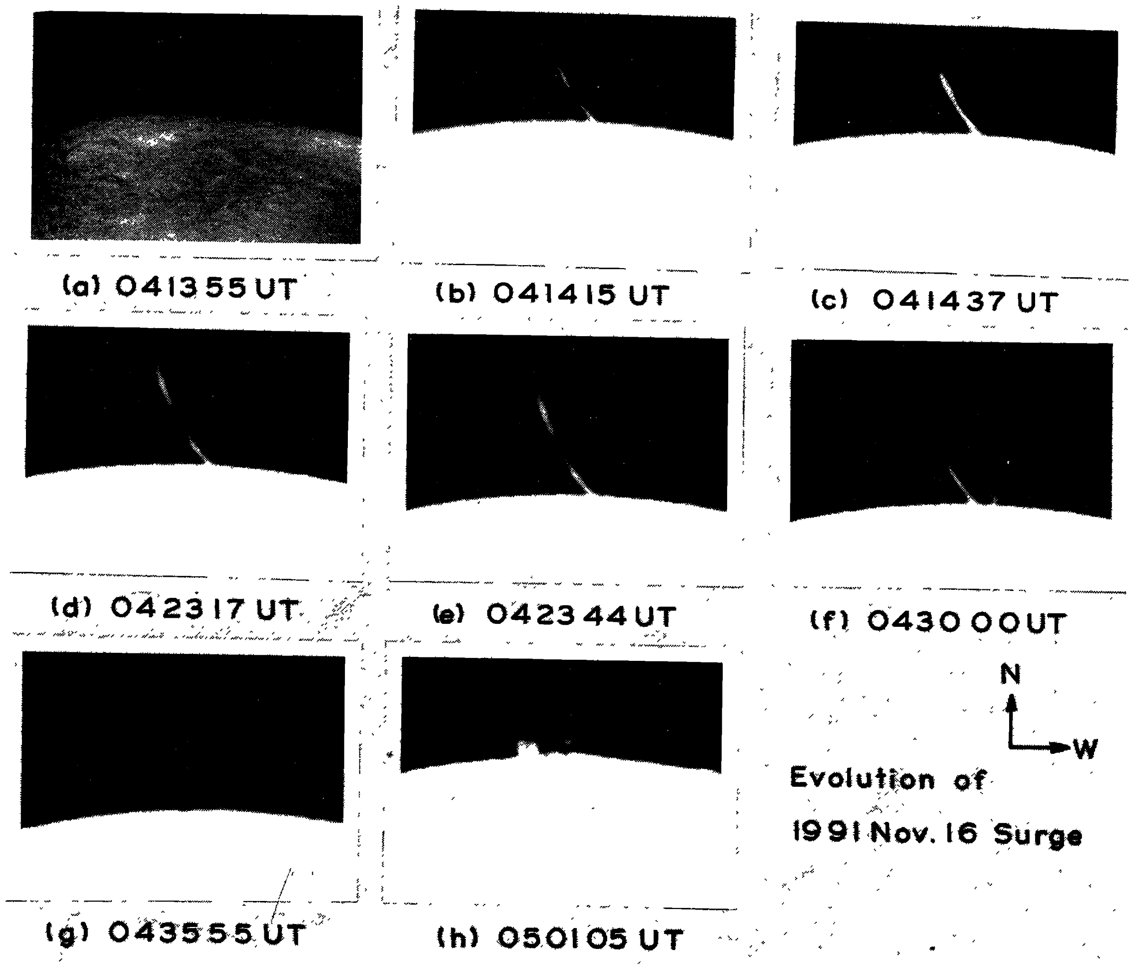

Figure 4. Selected H-alpha filtergrams showing the surge evolution and the alternate compression and expansion of the plasma.

axis. This again shows that the surge had an axial magnetic field, and not a helical one. The alternate bulging and contracting segments indicate the presence of sausage instability, while the visibility of alternate bending in the same shows that 'kink' mode instability also seemed to be present. The surge can be approximated to an isolated thin flux tube embedded in a field-free stratified medium (Durrant 1988). Such a thin tube has three modes of oscillations: a torsional or Alfvénic wave which propagates as a horizontal twist in the tube, a longitudinal wave in which vertical motions lead to successive compressions and expansions of the gas and of the field and a transverse wave in which horizontal displacements produce vertically propagating kinks in the tube. It is however interesting to note that in the vicinity of the surge, there was another small and short-lived surge which clearly revealed a helical structure. This has been brought out in the line drawings (figure 5), made after enlargement of the image on the film using a spectrum projector. The funnelling out of the ionised matter, caused the current flow along the axis of the surge tube presumably giving rise to sausage instability, due to 'pinch' effect. While the whole motion is affected by gravity also, the magnetic field in the active region during the initial stages of the surge formation accelerated up the plasma. The gravity caused the bending, producing the curvature.

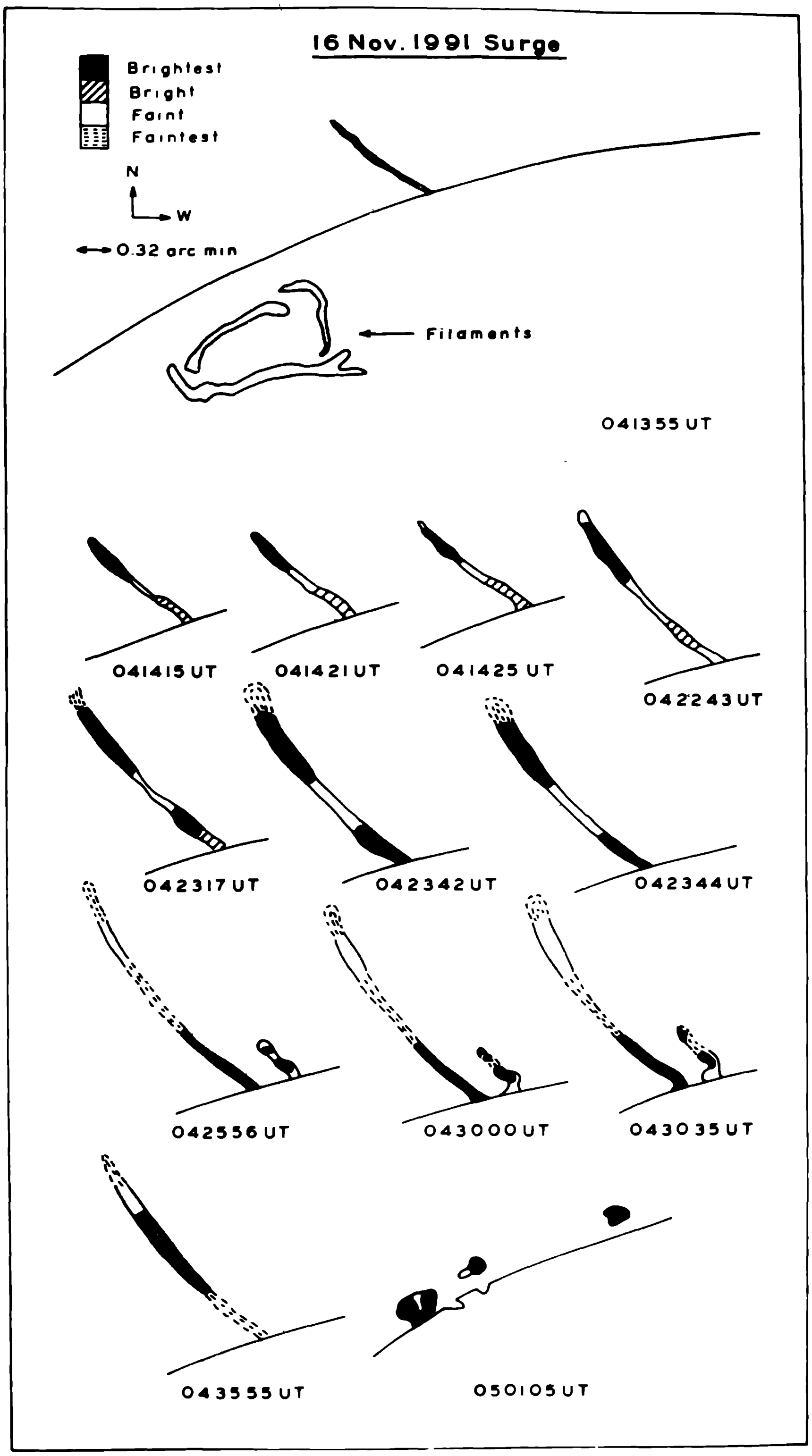

Figure 5. Hand-drawn contours for the surge to show 'funnelling out' of matter and to depict the 'kink' and 'pinch' effect.

We have estimated the mass, magnetic field, magnetic and kinetic energy density of the surge material.

Mass : To estimate the mass, we selected two frames, one taken at the earlier phase, and the other at a somewhat intermediate phase, when the surge had acquired the maximum length. Using the eyepiece, measurement of the length and width were made, to calculate the volume of the surge material. Taking the shape to be that of a cylinder, the total mass of the surge was calculated, making the assumption that the average mass density of the surge material is of the order of 10^{-12} gm cm^{-3} (Roy 1973). The mass in the two stages turned out to be 2.6×10^{15} and 3.0×10^{15} gm respectively, agreeing well with the values quoted by several authors (Bruzek 1965; Engvold 1980).

Magnetic field : A lower limit of the magnetic field was calculated, based on the equipartition principle (Ballester & Kleczek 1984) using

$$B^2 = 8\pi\rho g_{\odot} h_{\max},$$

where $g_{\odot}$ is the gravitational acceleration on the sun's surface and $h_{\max}$ the maximum height attained by the surge. The value of B finds itself of the order of 65 gauss, in close agreement with the values obtained by several authors (Harvey 1969; Engvold, 1980).

Magnetic energy density : Using the above value of the magnetic field strength, the magnetic energy density comes out to be of the order of 168 erg cm^{-3}.

Kinetic energy density : Due to the short duration of the surge phenomenon and because of its dynamic nature, the surge exhibited a wide range in velocities. The kinetic energy density therefore also varied considerably. For the typical case seen here, for a velocity of 2.76×10^7 cm s^{-1}, the kinetic energy density comes out to be about 380 erg cm^{-3}, and for a velocity 5.52×10^7 cm s^{-1}, it turns out to be 1524 erg cm^{-3}.

5. Conclusion

Some of the characteristic features of the surge observed here are :

(i) The surge did not show any helical structure which is sometimes seen.

(ii) The surge attained a maximum height of 1.3×10^5 km, and a maximum velocity of 552 km s^{-1}.

(iii) The surge had a maximum mass of 3.0×10^{15} gm, an estimated magnetic field of 65 gauss at its maximum height and a magnetic energy density of 168 erg cm^{-3}. The magnetic field is perhaps the lower limit.

(iv) The geometry exhibited by the surge indicated the presence of both sausage and kink instability modes operating from within.

(v) The result (iv) above could have been caused by the funnelling out of the ionised material into the corona, as seen in some frames.

Acknowledgement

The authors are thankful to an anonymous referee for useful comments.

References

Ballester J. L., Kleczek J., 1984, Solar Phys., 90, 37.

Bruzek A., 1965, in : Flare Associated Optical Phenomena : Solar Flares and Space Research, eds C. De Jager & Z. Svestka, North-Holland Publishing Co., pp. 66-69.

Durrant C. J., 1988, The Atmosphere of the Sun, Adam Hilger, Bristol and Philadelphia, p. 60.

Engvold O., 1980, in : Solar and Interplanetary Dynamics, eds M. Dryer &E. Tandberg-Hanssen, IAU Symp. 91, p. 175.

Golant V. E., Zhilinsky A. P., Sakharov I. E., 1980, Fundamentals of Plasma Physics, John Wiley and Sons, pp. 374-385.

Harvey J. W., 1969, Magnetic Fields Associated with Solar Active Region Prominences, Ph.D. Thesis, University of California.

Kleczek J., Kleczekova H., Kvicala J., 1971, Bull. Astr. Inst. Czech., 22, 347.

Roy J-Rene, 1973, Solar Phys., 32, 139.

Verma V. K., 1983, Bull. Astr. Soc. India, 11, 70.

Westin H., 1969, Solar Phys., 7, 393.