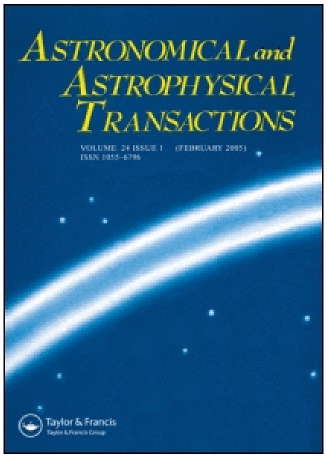

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MASS EJECTIONS AND LARGE-SCALE MAGNETIC STRUCTURES ON THE SUN IN MARCH 1989

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Mass ejections have been investigated using Hα filtergrams taken on March 11, 1989 during two consecutive X-ray flares. Magnetic field topology in the active region and its environs has been analysed. Magnetic field structure reconstruction is discussed.

KEY WORDS **Sun, flares, mass ejections, magnetic field**

1 INTRODUCTION

H_α and X-ray irradiance variations and EUV line emission are often accompanied by mass eruptive phenomena on the Sun. Sometimes mass ejections are related only to radio type II or III bursts and X-ray enhancement without H_α-brightening, qualified as solar flares. We have investigated matter ejections associated with H_α flares. Plasma ejections from the solar surface have an appreciable mass with velocities and energies ranging over orders magnitude and seem to be associated with periodic processes of energy storage and magnetic field reconstruction in active regions (AR). The ejection material partly leaves the Sun and (or) some material falls back on to the solar surface along the same trajectory.

Solar mass ejections have been extensively studied. Their morphology, physics, kinematic features, interaction of processes, observed in H_α, EUV, X-rays and radio waves are investigated. The influence of magnetic field structures, affect of the initial velocity and of the orientation of the ejection relative to the gravity forces on the fate of the ejection and its instability are examited (see, for example, Kovács and Dezső, 1990; Mouradian *et al.*, 1983; Schmieder *et al.*, 1984, 1987, 1994; Song *et al.*, 1987; Svestka *et al.*, 1990). Up to now the nature of solar mass ejections and their role in flare phenomena has not been known in detail. In this paper we analyse repetitive events associated with X-ray flares occurring in the region of an emergent magnetic flux in the AR. We investigated ejections observed in March 1989 in AR

NOAA 5395. It was an extraordinarily flare-prolific active region which showed an unusually complex activity. During a single disc passage the AR produced an unprecedented 11 X-class and 49 M-class X-ray flares, 23 optical flares of greater than unit importance, huge surges and geomagnetic effects. The emergence of new magnetic flux by its manner and location was out of the ordinary. New spots, which emerged in penumbra, were not round and moved together in the direction parallel to the bipole inversion line (Tang and Wang, 1993). The emergence of new flux in the midst of strong magnetic fields and shear motions near the neutral line seems to cause the AR flare productivity.

2 OBSERVATIONS AND THE METHOD OF TREATMENT

Observations were obtained on the High Altitude expedition of the Sternberg Astronomical Institute near Alma–Ata on the coude-refractor Opton using scanning H_α-filter with a passband of 0.25Å. The AR was crossing the solar disc from March 6 to 19. Systematic mass ejections with different velocities and trajectories were observed. In the period from March 10 to 13 the flare activity of AR was highest. Selected sequences of H_α-filtergrams taken at time intervals when two X-ray flares occurred on March 11 were used for the investigation. Series of filtergrams obtained in the H_α line centre and wings up to ± 3Å allowed us to determine full space velocities of the ejections and their orientations relative to the solar surface.

In Figure 1 schematic drawings of the AR on March 11, 1989 at different time moments are shown. The spot polarities are ascribed. On March 11 a N-polarity spot group was surrounded by a chain of mainly small S-polarity spots. All the spots were immersed in an extensive penumbra. On March 13 the group structure significantly changed and became more complex. On the magnetogram of March 11 it is seen that the large N polarity occupying the central part of the AR, was surrounded by the U-shaped curved neutral line and S-polarity elements (Figure 1). The region was stretched along the longitudinal direction. The main configuration of the neutral magnetic line was preserved for the disc passage of the AR.

The magnetograms, obtained on March 11 at the Beijing Astronomical Observatory (Wang *et al.*, 1991), show, that near the spot N1 an emergent magnetic flux was observed and one of the closest pairs of small spots, forming a δ-configuration. In the vicinity of this location from March 7 to 11 four X1–X4 class flares and many other X-ray flares occurred (Solar Geophys. Data, 1989, No. 541, Pt. 2). Later this location became less active.

On the best filtergrams one can see fine dark threads beginning in front of spot N1 and stretching for extensive distances from the AR, i.e. continuous matter flows along magnetic lines could have occurred for minutes. The matter was ejected with large velocities from the location near the spot N1, where the flare kernels, visible in H_α wings, were situated. Ejected material clouds and matter flows falling back to the solar surface were seen simultaneously (Figure 1: A, B, C). The ejection dimensions ranged from 20 to 160 and more arcsec.

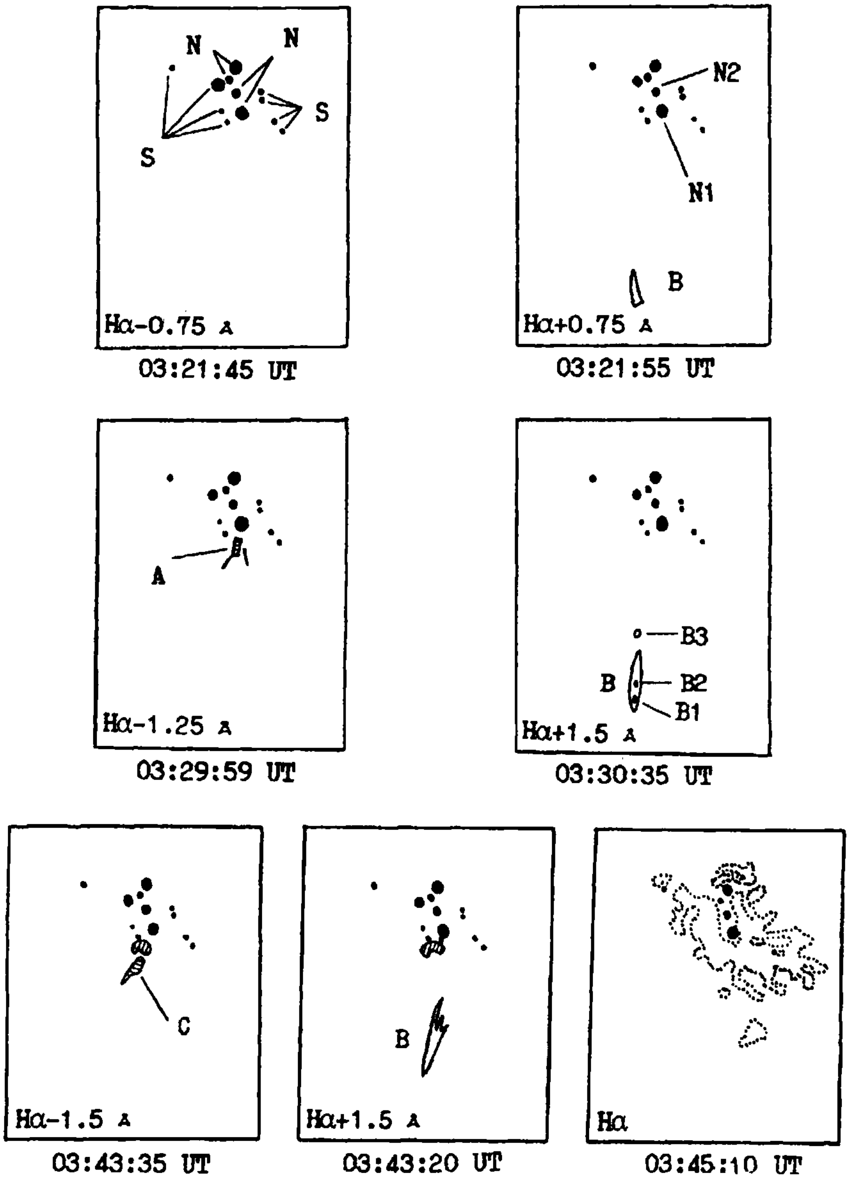

Figure 1 The events, observed on March 11, 1989 in NOAA 5395 during two consecutive flares. The ejections bases are spatially correlated with a strong shear zone in the vicinity of the souther part of the U-shaped magnetic neutral line. The material backflow B descending to the solar surface with a velocity of about 120 km s^{-1} (1N/M2.0), 03:33 UT) and the matter outflow D ascending with a velocity of about 60 km s^{-1} appear to move along trajectories with similar spatial orientation. North is upward, west to the right. The positions of the front edge of surge B are shown at different moment: t1 03:22 UT, t2 03:29 UT, t3 03:31 UT, t4 03:39 UT, t5 03:43 UT. *1*, spots; *2*, flare; 3, flare kernels; 4, blue surge; 5, red ejection; 6, neutral magnetic; 7, penumbra boundary; 8, transverse field lines (Beijing Astronomical Observatory, private communication).

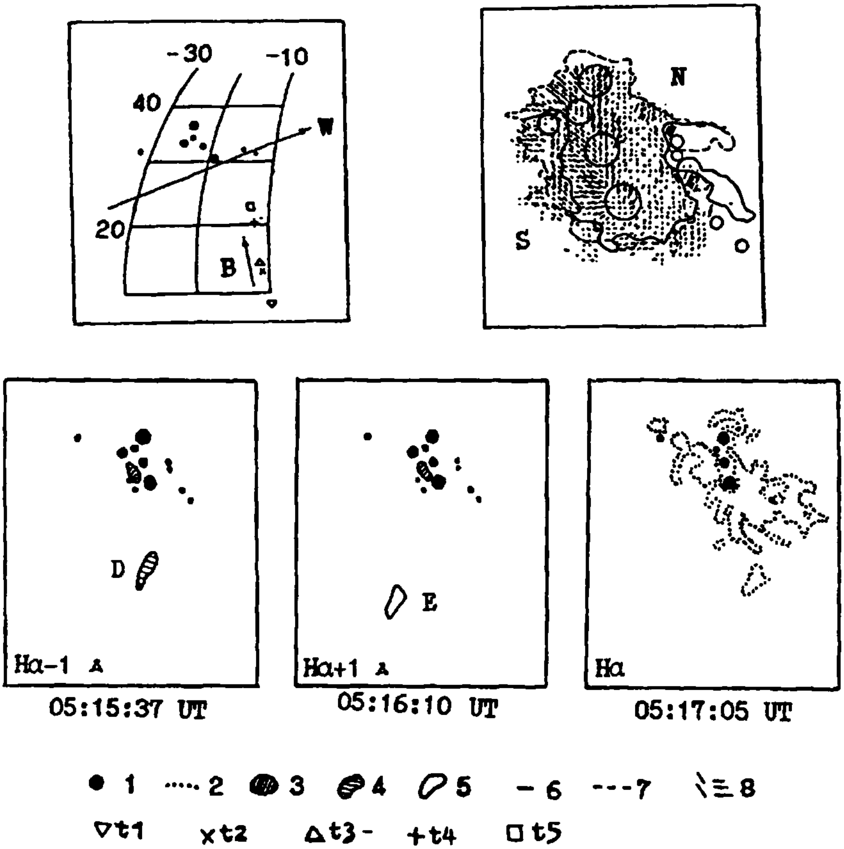

Figure 1 Continued.

Some mass ejections (like A on Figure 1) showed a sharp image of a cylindrical shape while others were irregular and bizarre (like B on Figure 1), became diffused and then disintegrated. The first type of ejection seemed to be confined by their own magnetic field which was stronger than the surrounding field. Most of the phenomena observed by us were of the surge type.

It was possible to trace an ejection trajectory in the picture plane using the motion of the front or back edge of the ejection or the motion of the centre of the ejection bulk. Sometimes during several minutes we could follow the motion of a concrete knot in the ejection bulk.

In the investigated cases the observed trajectories in the picture plane could be considered approximately as rectilinear ones (Figure 1). Hence, directly from the observations we obtained the magnitude and orientation of the velocity of the ejection, projected on the picture plane (V_{ph}). Besides having scans of the H_α profile we could evaluate the line-of-sight velocity V_{ls} from the maximum contrast of the ejection intensity. Knowing V_{ph} and V_{ls} and using the mathematical method described below we determined the full velocity $\mathbf{V}$ and its space orientation. The full velocity $\mathbf{V}$ was decomposed in to two components: one parallel to the solar surface ($\mathbf{V}_{\|}$) and the other perpendicular to the solar surface ($\mathbf{V}_{\perp}$).

The orientation of the full velocity vector relative to the solar surface was defined by two angles β and α. The β angle was between the velocity $\mathbf{V}$ and the vertical $\mathbf{N}$ to the solar surface at the O point with heliographic coordinates ϕ and λ. The α angle was between $\mathbf{V}_{\|}$ and the tangent to the circle of latitude at the O point. The latter was chosen near the spot N1.

To calculate the α and β angles we developed a computer program (Delone *et al.*, 1989) based on the method of the reconstruction of three-dimensional structure of loops observed in a projection on the solar disc (Loughhead *et al.*, 1984). Three coordinate systems were used. All these systems are turned each other on known angles. To transform coordinate systems, multiplications of the direction cosines matrix were used. Knowing from the observations $\mathbf{V}_{\mathrm{ph}}$ and $\mathbf{V}_{\mathrm{ls}}$ we calculated $\mathbf{V}$, the β angle between $\mathbf{V}$ and $\mathbf{N}$, the horizontal and vertical relative to the solar surface components $\mathbf{V}_{\|}$ and $\mathbf{V}_{\perp}$ and the α angle, defining the azimuth of the horizontal component of the full velocity $\mathbf{V}$.

3 RESULTS

The kinematic features of the ejections observed on March 11, 1989 were investigated at time when two X-ray flares occurred. The results are given in Table 1. The following information is given in it: observation time interval, line-of-sight velocity $\mathbf{V}_{\mathrm{ls}}$ (Å), velocity $\mathbf{V}_{\mathrm{ph}}$ in the picture plane, full velocity $\mathbf{V}$, horizontal and radial relative to the solar surface velocities $\mathbf{V}_{\|}$ and $\mathbf{V}_{\perp}$, α and β angles, describing the space orientation of $\mathbf{V}$, the maximum ejection dimension in arcsec. According to the chosen coordinate system value $\mathbf{V}_{\mathrm{ls}}$ is positive when directed to an observer, $\mathbf{V}_{\perp}$ is positive when $\mathbf{V}_{\perp}$ is directed outside from the solar surface, $\beta < 90°$ if an ejection moves from the solar surface and $\beta > 90°$ if material returns to the Sun, $\alpha > 0$ or < 0 dependening on the position of $\mathbf{V}_{\|}$ to the north or the south from the tangent to the circle of latitude at the 0 point.

On March 11 near the maximum of the 1N/M2.0 flare (N27°, E18°, 03:30–03:33–04:00 UT) from the region of the small S-spots, plasma clouds (A and C in Figure 1) were ejected that were visible in far-blue H_{α}-line wings. The estimated velocities of the A-type ejections were several hundreds of km s^{-1} and in some cases seemed to reach values near to, or greater than, the escape speed. We could not determine their full velocities because we scanned only to H_{α}-2.5Å but the line-of-sight velocities of the A-type ejections appeared to be more than 150 km s^{-1}. For example, at 03:38–03:44 UT picture plane velocities $\mathbf{V}_{ph}$ of $\sim$ 500–620 km s^{-1} were measured.

Between 03:21 and 03:45 UT a large dark cloud B (Figure 1) was observed descending into the chromosphere with a velocity of $\sim$ 120 km s^{-1}. Its motion was investigated in more detail. Its trace in projection on the solar disc was stretched

Table 1. Mass ejections on March 11, 1989 in NOAA 5395

Parameters	EVENT							
	B ejection		*Condensations*			*C eject.,*	*D surge,*	*E cloud,*
	front edge	*center*	*N1*	*N2*	*N3*	*centre*	*centre*	*front edge*
Beginning–end, UT	0321 0343	0328 0345	0329 0331	0329 0331	0329 0331	0329 0338	0516 0525	0516 0525
Line-of-sight velocity $\mathbf{V}_{ls}$ (Å)	+1.5	+1.5	+1.5	+1.5	+1.5	−3	−1	+1
Direction of motion	To AR	To AR		To AR		From AR	From AR	To AR
Velocity in picture plane $\mathbf{V}_{ph}$ (km s^{-1})	123	100	52	63	72	33	39	30
Full velocity $\mathbf{V}$ (km s^{-1})	141	121	86	93	99	141	60	55
Horizont. component $\mathbf{V}_{\parallel}$ (km s^{-1})	140	119	75	86	94	116	59	49
Radial component $\mathbf{V}_{\perp}$ (km s^{-1})	−12	−21	−41	−37	−32	80	9	25
Azimuthal angle $\alpha°$	106	106	107	105	116	−63	−65	100
Inclinat. angle $\beta°$	95	100	119	113	109	56	81	109
Maximum dimension (arcsec)	165						70	70
Flare: importance Coordinates Time interval (UT)		1N/M2.0 N27°E18° 03:30–03:33–04:00					1B/M2.3 N31°E22° 05:14–05:31–06:15	

from ~ 5° to ~ 30°. The motion of the front edge, of the central part and two condensations inside the cloud were followed. The velocities of these features happened to differ from each other (Table 1), e.g. the ejection did not move as united whole.

Two hours later we succeeded in observing two mass clouds D and E during the 1B/M2.3 class flare (N31, E22, 05:14–05:31–06:15 UT). The general appearances of two flares, observed in the centre of the H_α line on March 11, 1989 at 03:30 UT and 05:30 UT, were similar, although the flare kernels were situated differently as can be seen distinctly in the H_α wings (Figure 1), namely, near spots N1 and N2, respectively.

The E formation was descending to the solar surface with a velocity of about 55 km s^{-1} and the D surge was ejected with a speed of about 60 km s^{-1} along a trajectory which appeared to be very similar to the trajectory of cloud B, observed during the previous flare 1B/M2.3 at 03:30 UT (see Figure 1 and Table 1), the motions of the D and B clouds were opposite in terms of their directions, B was descending to the AR and 2 h later D was ascending from the solar surface almost along the same trace.

The similarity of the B and D trajectories is seen by a direct superposition of the picture plane traces and is confirmed by the calculations using our program. In this case the calculated parameters α and β describing the space orientation of the trajectories give the relation $|\alpha_{as}| + |\alpha_{des}| \approx 180^\circ$ and $\beta_{as} + \beta_{des} \approx 180^\circ$, keeping in mind that the signs and values of α and β depend on the direction of the cloud velocity, i.e. B and D moved along the same trace in opposite directions.

The spatial similarity of the trajectories of two matter flows B and D seems to be an evidence that no global reconstruction of magnetic structure of the AR occurred between 03:30 UT and 05:30 UT on March 11, 1989, i. e. ejections did not disrupt the magnetic field. This is proved by the appearance resemblance of two flares.

A comparison of the H_α filtergrams with magnetograms (SGD) has shown that the ejection trajetories like B and D were stretched along boundaries of large-scale magnetic structures. A large magnetic arch appears to exist extending from the AR towards the solar equator. This arch became visible when ejected plasma filled it.

4 DISCUSSION

As discussed in Wang (1994), a strong magnetic shear developed on March 11 along the eastern and southern parts of the neutral line. The magnetic shear is evident from the vector magnetic field observations and is obvious on the best photographs from the morphology of the H_α fibrils which are drawn up in parallel with the neutral line. The strong shear might be created by the new flux emergence, which collided with the pre-existing surrounding magnetic field and might be the reason for the noticeable motion of the spot N1, what in turn generated a very strong shear in the southern part of the neutral line. A lot of important flares and large surges occurred on March 11 in the vicinity of the shear zone. Such a shear was not observed in this part of the AR earlier or later. We have analysed repetitive ejections associated with X-ray flares and spatially correlated with the sourthern part of the shear zone.

So the ejection kinematic features on March 11, 1989 NOAA 5395, visible in a projection on the solar disc, have been investigated. The ejections were observed for 6–23 min and had dimensions of 20–170 arcsec and velocities in the range from 50 to 270 km s^{-1}. In some cases the velocities were near to, or greater than, the escape speed. The greatest speeds seemed to be during the flare peak. The velocities of the front edges, central point and separate mottles were examined. Different ejection elements have been established to move with different velocities. The ejections reached heights of 15–30 $\times$ 10^3 km above the solar surface and their velocities were inclined to it at angles not greater than 45°. Knowing the dimensions of the surges in the picture plane and assuming their symmetry relative to magnetic lines and the mean density of the order of 10^{-11} cm^{-3}, the ejections masses were calculated to be 10^{15}–10^{16} g, and energies were 10^{23}–10^{30} erg.

Our results for the highest ejection velocities agree with similar data obtained by Den and Kornienko (1993) from their fine spectral observations of this AR.

Some ejections like the B cloud seem to move along large magnetic arches stretching from the AR to the solar equator. These arches appear to exist for many days.

The traces of the ejections from the active point in the AR occurred at different moments divided by noticeable time intervals, and proved to have an identical spatial orientation. Such a case occurred during two consecutive X-ray flares of approximately the same importance on March 11 (B cloud at 03:30 UT, 1B/M2.3 and D surge at 05:30 UT, 1N/M2.0), which might be interpreted as relative stability of large-scale magnetic structures. We think that observed flares and ejections did not strongly disrupt the overlying magnetic field. Ejections along a large magnetic arch were also observed by us on March 13.

So investigations of the surge spatial trajectories help us to understand the magnetic situation in the AR and its evolution. We hope that our surge investigations provide some additional information to the numerous scientific literature about this interesting unusual flare-prolific active region.

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