High-Resolution Digital Movies of Emerging Flux and Horizontal Flows in Active Regions on the Sun

K. Topka, S. Ferguson, Z. Frank, T. Tarbell, A. Title (Lockheed PARL)

Abstract

We present high-resolution observations of active regions in many wavelength bands obtained at the Vacuum Tower Telescope of NSO/Sunspot (Sacramento Peak). The SOUP tunable filter (50 - 100 mÅ bandwidth), HRSO 1024 × 1024 CCD camera, and a sunspot tracker for image stabilization were used. Subarrays of 512 × 512 pixels have been processed digitally and recorded on videodisk in movie format. We show movies with 0.5 - 1 arcsecond resolution of the following simultaneous (i.e., interlaced) observations: green continuum, longitudinal magnetogram, Doppler velocity, Fe I 5576 Å line center (mid-photosphere), Hα wings (± 600 mÅ), and Hα line center. The best set of movies show a 90 × 90 arcsecond field-of-view of an active region at S29, W11 (15:05 - 16:25 UT, 8/6/87). When viewed at speeds of a few thousand times real-time, the photospheric movies clearly show the active region fields being distorted by a remarkable combination of systematic flows and small eruptions of new flux. Flux emergence is most easily discovered in line center movies: an elongated dark feature (presumably a horizontal flux tube) appears first, followed soon after by bright points at one or both ends. A brief, strong upflow is seen when the dark feature first appears; downflow in the bright points persists much longer. The magnetic flux appears to increase gradually over this extended period. Some of the flux emergence events have been studied in detail, with measurements of horizontal and vertical velocities and magnetic flux vs. time within one footpoint of the loop.

This work was supported by Lockheed Independent Research Funds and NASA contracts NAS8-32805 (SOUP) and NAS5-26813 (HRSO).

Emergence of Magnetic Flux Tubes

The emergence of new magnetic flux through the photosphere is the first step in the formation of an active region (AR). Many emergence events have been observed at the moderate resolution of Big Bear and Kitt Peak magnetograms. Studies of these have produced a fairly clear understanding of the gross features of AR formation, such as flux emergence rates, rates of polarity separation and areal growth, and distributions of frequency vs. total flux for AR's and ephemeral regions. The early chromospheric development of AR's has been observed even longer by spectroheliograph and filter movie techniques in H-alpha. However, very few if any events have been observed in great enough detail to study the MHD processes actually ocurring during flux emergence. This requires not only very high spatial resolution over an extended period (tens of minutes to hours) but also simultaneous, cospatial measurements of magnetic fields, Doppler shifts, and intensities at several levels.

Theoretical models suggest that horizontal flux tubes should rise through the upper convection zone at speeds representing a balance between buoyancy and drag forces. When they reach the photosphere, the upper portions should expand rapidly into the chromosphere and corona, and the footpoints should become nearly vertical, due to bouyancy. The gas draining from the expanded upper part of the loop may trigger convective collapse, leading to constriction and amplification of the magnetic field strength.

Our observations of 6 August, 1987, show many examples of tiny flux tubes emerging through the surface. Although it is difficult to find one for which the seeing stays good throughout the event, so many events are seen in different phases that some general conclusions can be drawn. The first indications are dark striations in the continuum and line center intensity, suggestive of horizontal field lines rising through the surface; these are typically 1500 to 4000 km long. A strong upflow may be seen for a few minutes in the dark striation just after it appears. Bright points form at one or both ends of the dark feature a few minutes after it appears. Strong downflow and new magnetic flux appear in the bright points. The downflow may persist for an hour or more; the mass flux integrated over this time period would fill a tube roughly 3000 km long at photospheric densities, consistent with the initial footpoint separation. The magnetic flux appears to increase gradually over this whole period, instead of making an abrupt change when the bright point first appears. This result is very tentative, however, because the magnetograms are noisy and the conversion from polarization signal to flux is uncertain and may be time dependent.

Zwaan and Brants have also seen many of these features in an emerging flux region. It is clear that a modest increase in resolution and uniformity of seeing would permit meaningful comparisons with MHD models. Continued observations of this type at excellent sites, with assistance from active optics, or balloon flights of the SOUP instrument could provide such observations in the near future.

FIGURE CAPTIONS

Fig. 1. Snapshots of the active region in (a) continuum near 5576; (b) Fe I 5576, 30 mÅ blue; (c) H-α line center; (d) H-α wing, 600 mÅ red. All images in Figs. 1 and 2 were taken within 80 seconds of each other, in one cycle of the observing sequence. Field-of-view is 90 $\times$ 80 arcseconds, and ticks are at 2 arcsecond intervals.

Fig. 2. Same as Fig. 1, showing (a) Fe I 5576 line center, compensated for the local Doppler shift; (b) Doppler velocity measured from 4 images evenly spaced through 5576 (g=0 line); (c) H-α wing, 600 mÅ blue; (d) magnetogram made in blue wing of Fe I 6302 (g=2.5).

Fig. 3. Collages of frames from the movies, showing the emerging flux tube measured in Figs. 5 - 8 and many others: (a) 5576 line center; (b) 6302 magnetograms. Each frame is labelled with the time. Field-of-view is 25 $\times$ 25 arcseconds, and ticks are at 1 arcsecond intervals.

Fig. 4. Same as Fig. 3, showing (a) continuum near 5576; (b) Doppler velocity.

Fig. 5 Plot of velocity versus time in a small region between the footpoints of an emerging flux tube. The velocity is the mean in an irregular shaped area covering about 100 pixels of the Dopplergram movie. A strong upflow develops at the beginning of the emergence process and lasts about 200 seconds, suggestive of rising horizontal field lines.

Fig. 6 Plot of velocity versus time in a small region (about 70 pixels) centered on the footpoint of an emerging flux tube. The velocity starts near zero (with fluctuations due to 5-minute oscillations), and then a strong down flow develops that lasts about 1 hour.

Fig. 7 Plot of measured magnetic flux as a function of time in the footpoint of an emerging flux tube (same footpoint as Fig. 6). The data were computed from the magnetogram movie.

Fig. 8 Plot showing the motion of the footpoint of a new flux tube after emergence on the surface of the Sun (same footpoint as in Figs. 6 and 7). Crosses: measurements of the bright point visible on the line center movie. Squares: measurements of the corresponding small magnetic feature visible on the magnetogram movie. The footpoint moves away from its place of origin at 0.8 km/s.

ORIGINAL PAGE IS
OF POOR QUALITY

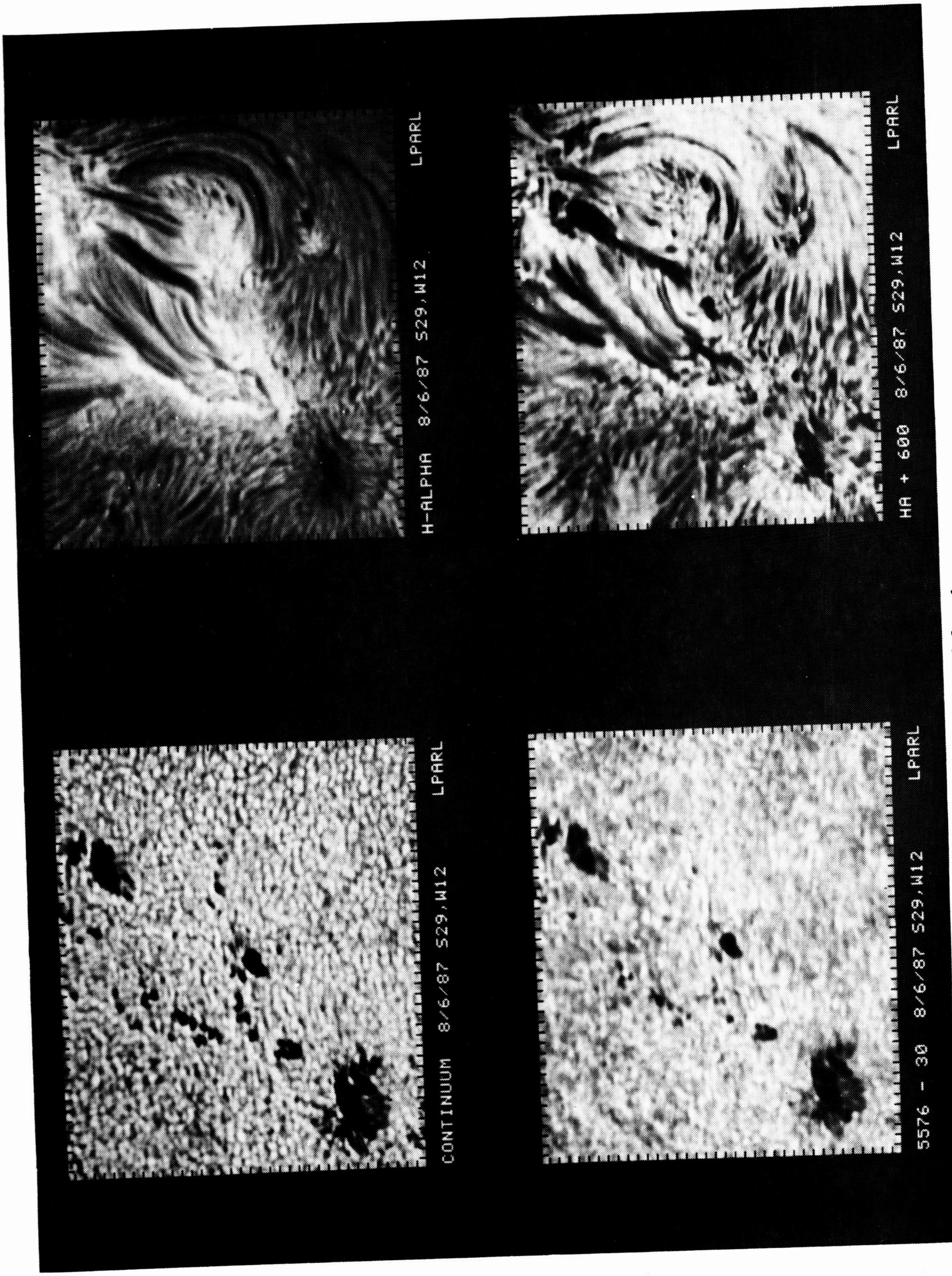

FIG. 1

ORIGINAL PAGE IS
OF POOR QUALITY

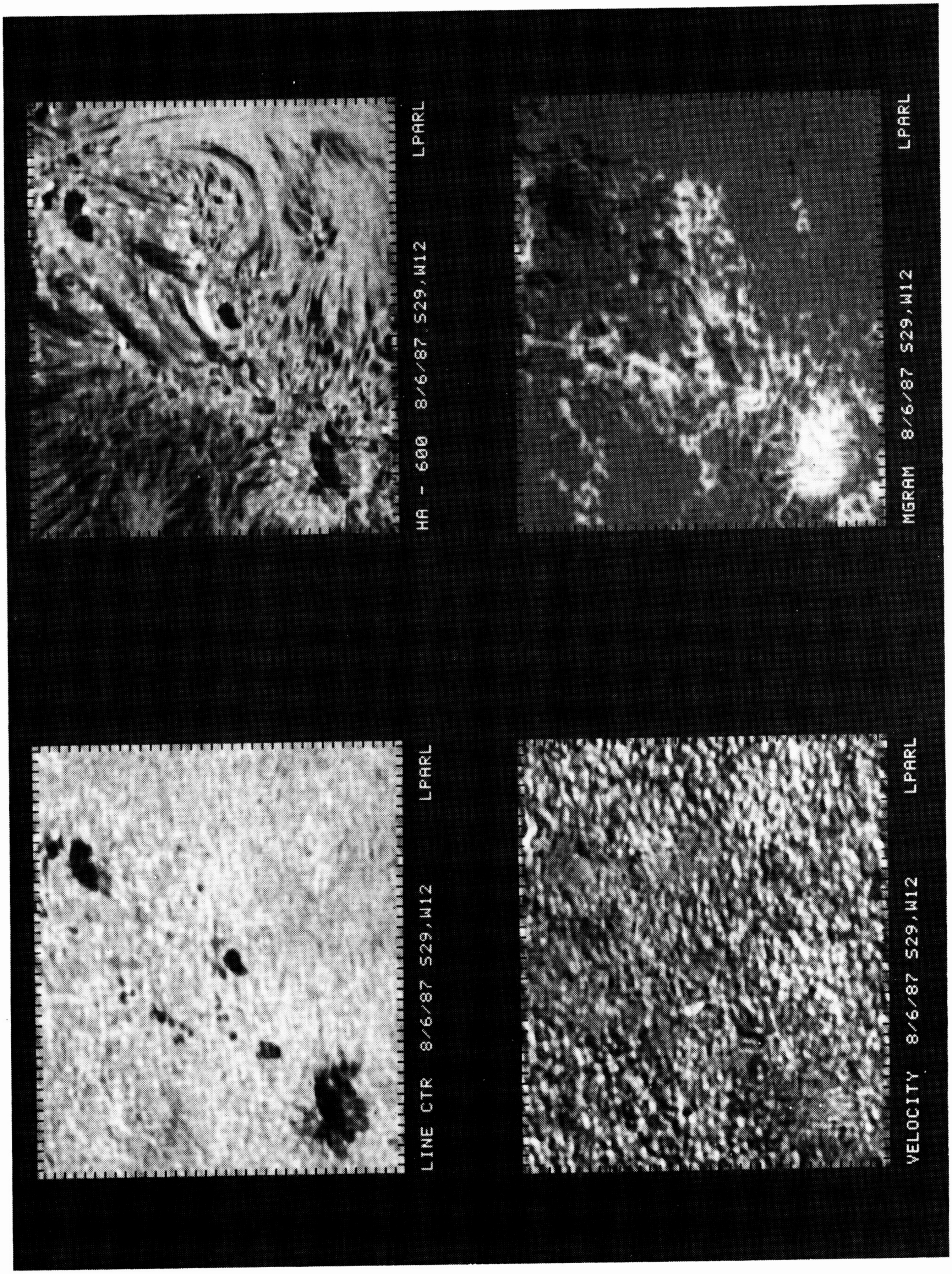

FIG. 2

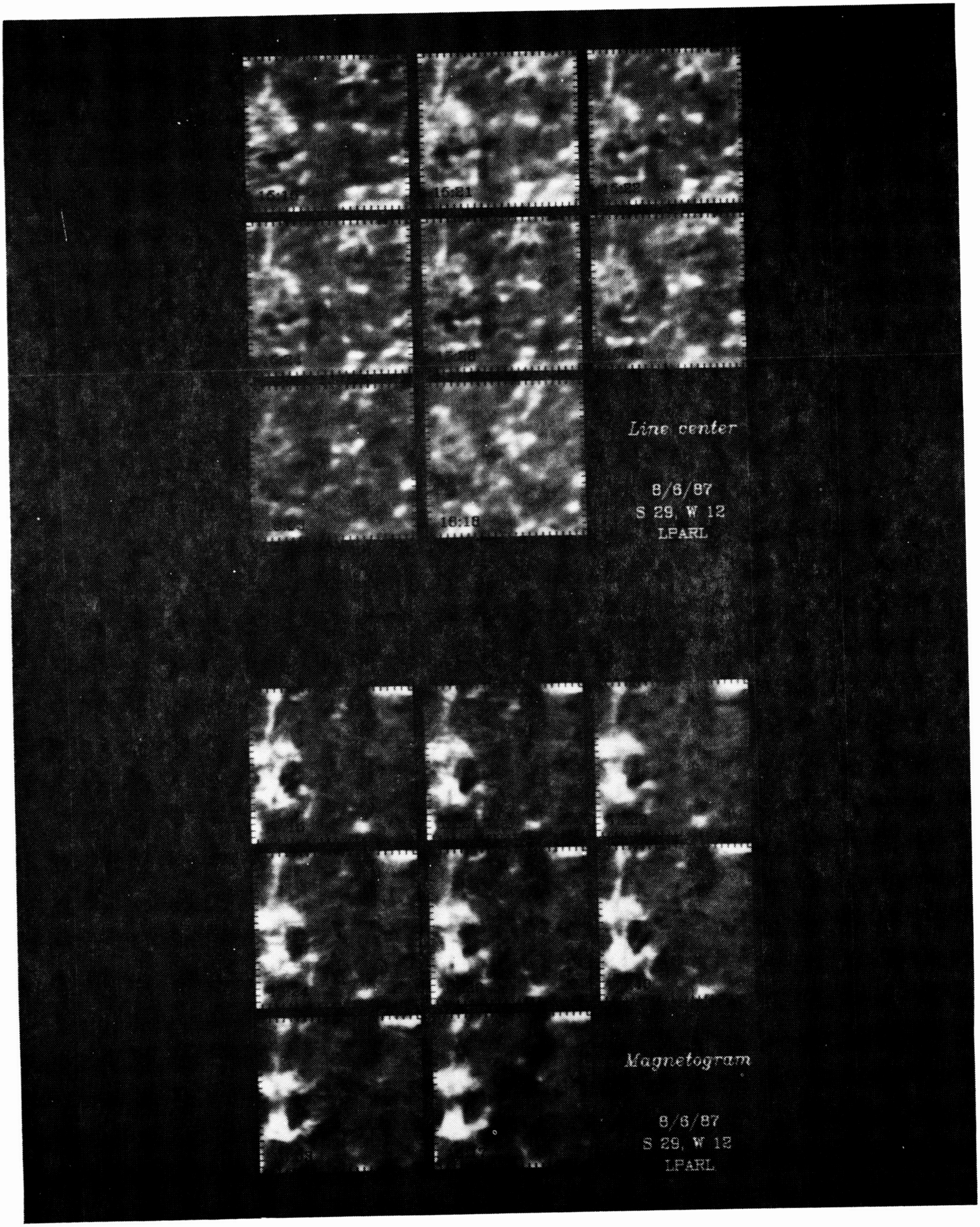
16:18
Line center
8/6/87
S 29, W 12
LPARL
Magnetogram
8/6/87
S 29, W 12
LPARL

FIG. 3

ORIGINAL PAGE IS
OF POOR QUALITY

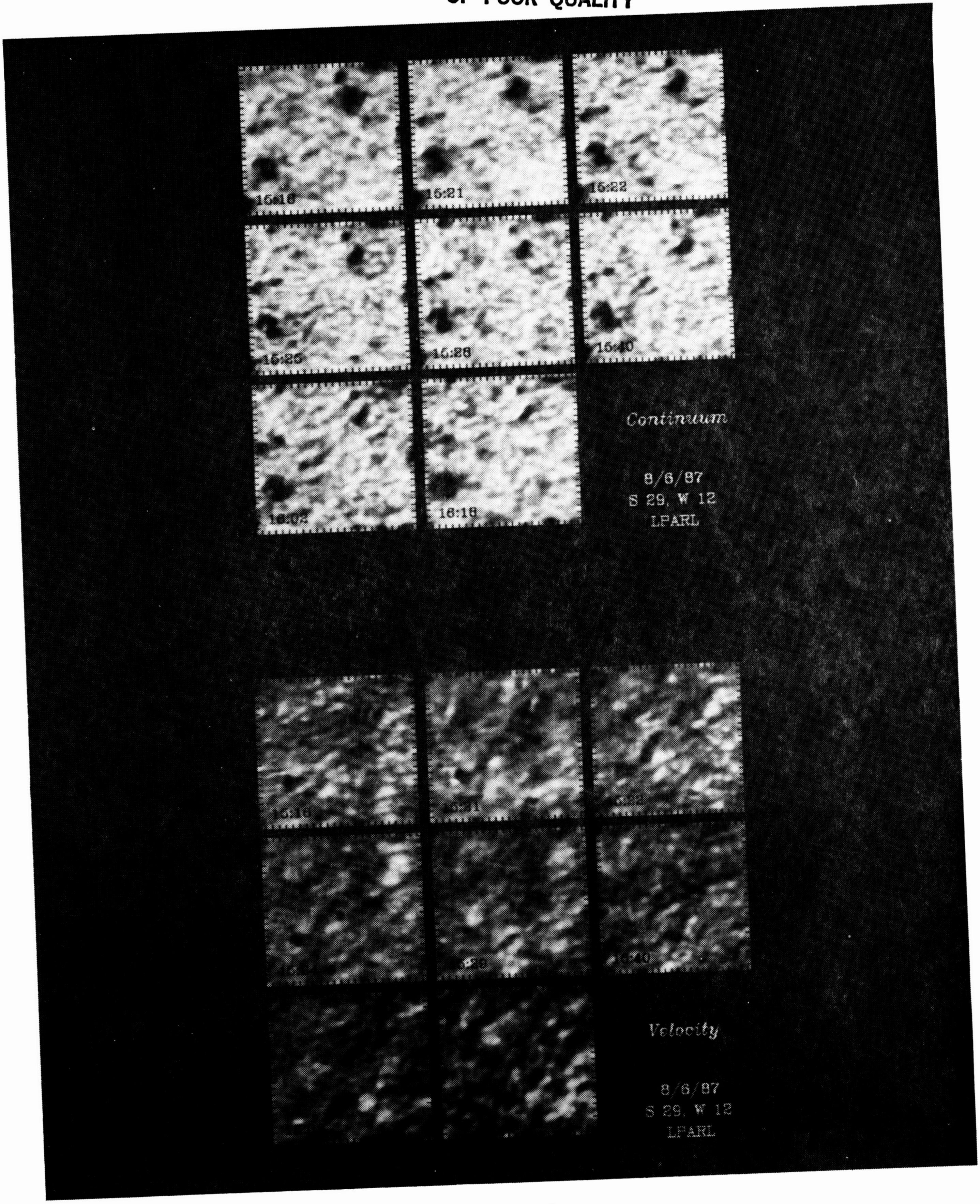

FIG. 4

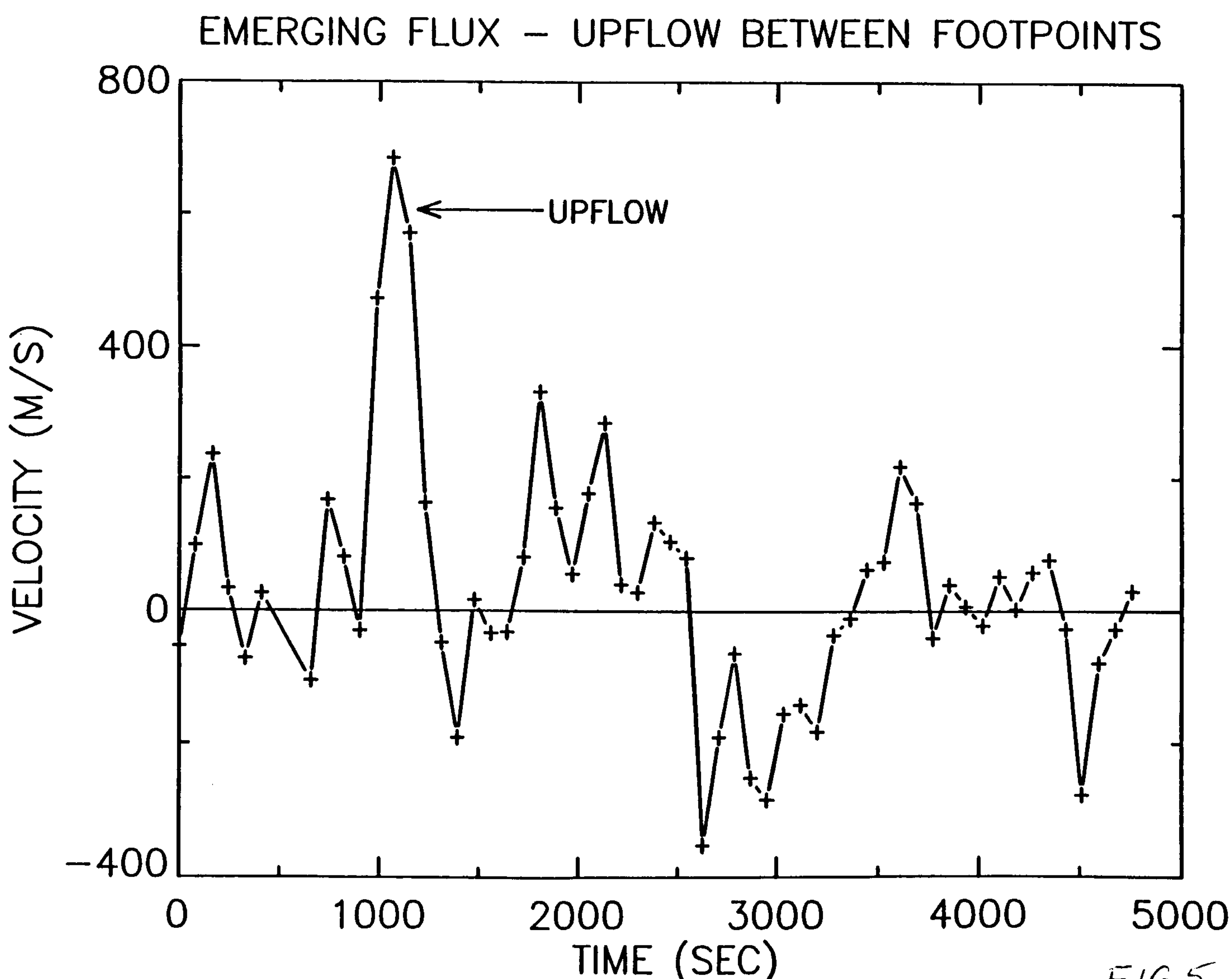
EMERGING FLUX – UPFLOW BETWEEN FOOTPOINTS
UPFLOW
VELOCITY (M/S)
800
400
0
−400
0
1000
2000
3000
4000
5000
TIME (SEC)

FIG 5

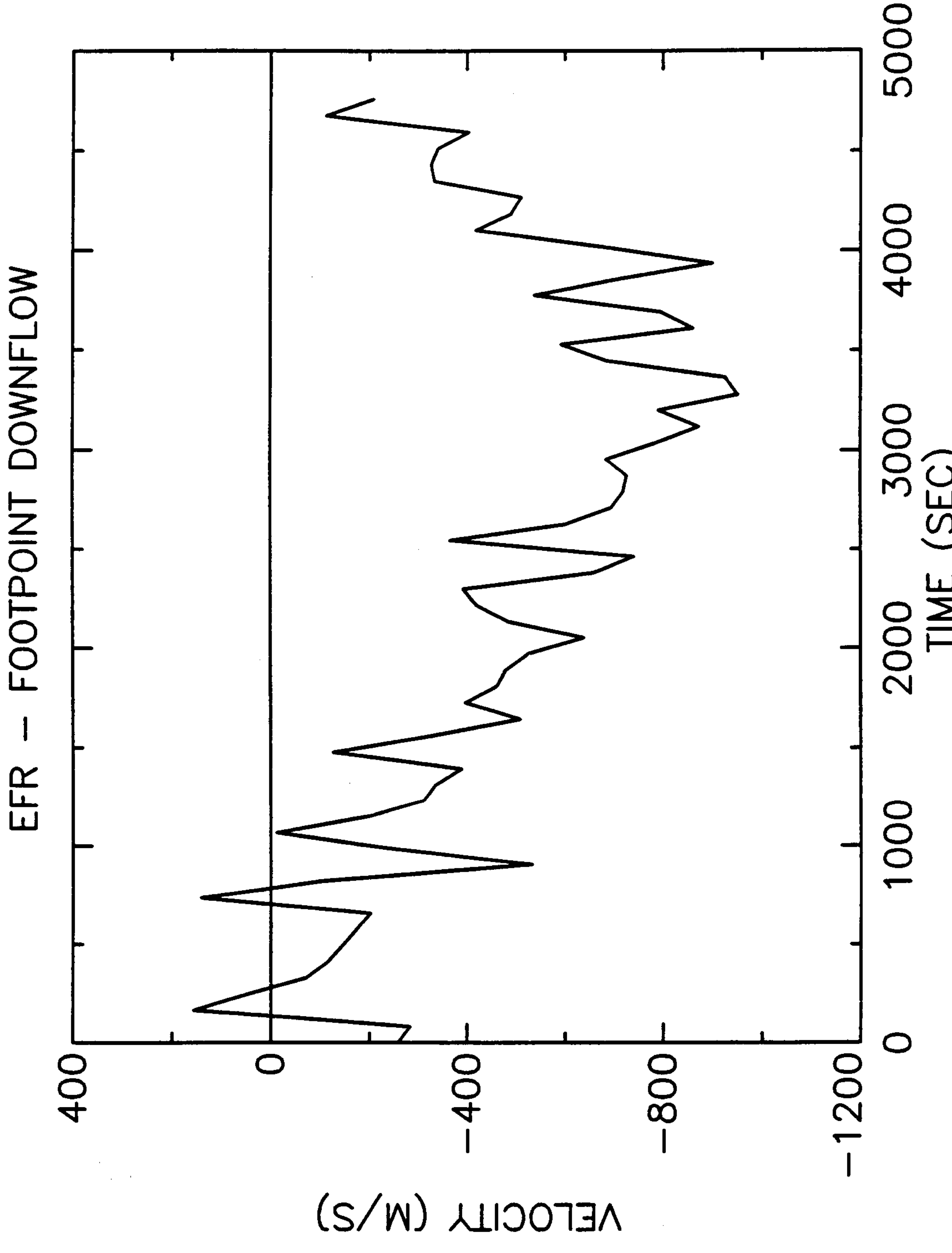
EFR – FOOTPOINT DOWNFLOW
VELOCITY (M/S)
400
0
−400
−800
−1200
0
1000
2000
3000
4000
5000
TIME (SEC)

FIG 6

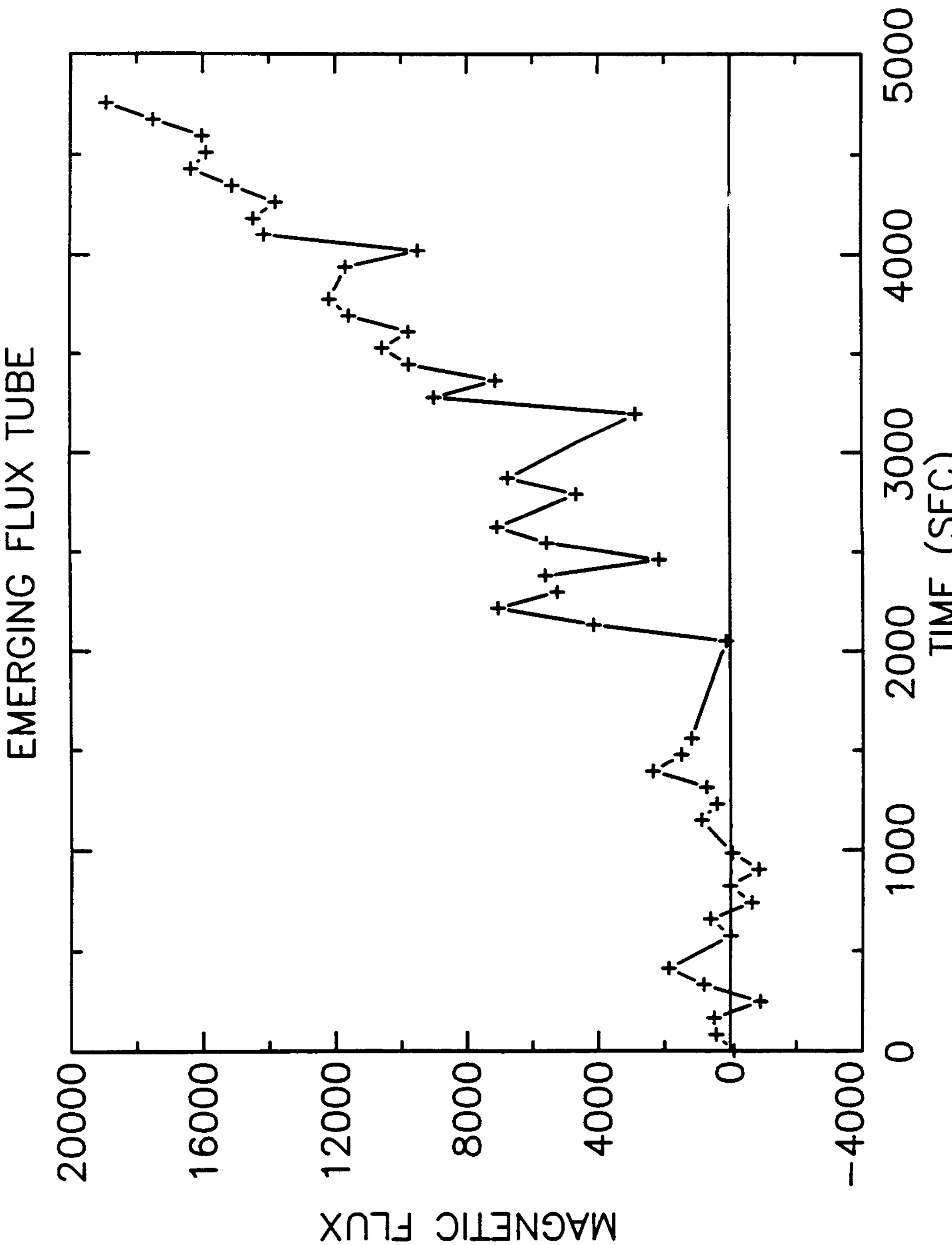
EMERGING FLUX TUBE
MAGNETIC FLUX
20000
16000
12000
8000
4000
0
−4000
0
1000
2000
3000
4000
5000
TIME (SEC)

FIG 7

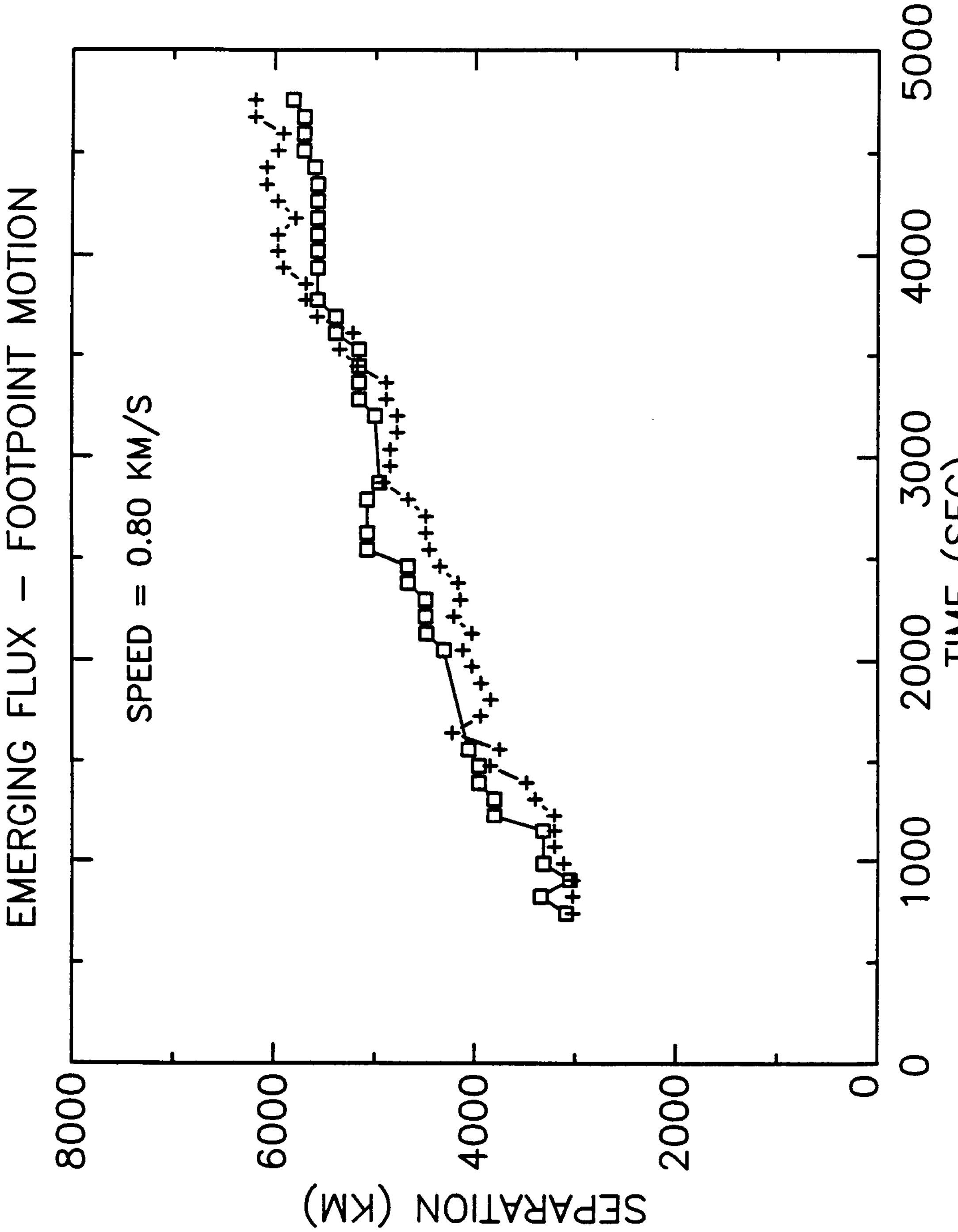
EMERGING FLUX – FOOTPOINT MOTION
SPEED = 0.80 KM/S
SEPARATION (KM)
TIME (SEC)
0
2000
4000
6000
8000
0
1000
2000
3000
4000
5000

FIG 8