VECTOR MAGNETOGRAM AND DOPPLERGRAM
OBSERVATION OF MAGNETIC FLUX EMERGENCE AND ITS
EXPLANATION

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Abstract. During 23–28 August 1988, at the Huairou Solar Observation Station of Beijing Observatory, the
full development process of the region HR 88059 was observed. It emerged near the center of the solar disk
and formed a medium active region. A complete series of vector magnetograms and photospheric and
chromospheric Dopplergrams was obtained. From an analysis of these data, combined with some numerical
simulations, the following conclusions can be drawn. (1) The emergence of new magnetic flux from enhanced
networks followed by sunspot formation is an interesting physical process which can be simply described
by MHD numerical simulation. The phenomena accompanying it occur according to a definite law sum-
marized by Zwaan (1985). The condition for gas cooling and sunspot formation seems to be transverse field
strength > 50 G together with longitudinal field strength > 700 G. For a period of 4 to 5 hours, the
orientation of the transverse field shows little change. The configuration of field lines may be derived from
vector magnetograms. The arch filament system can be recognized as an MHD shock. (2) New opposite
bipolar features emerge within the former bipolar field with an identical strength which will develop a
sunspot group complex. Also, arch filament systems appear there located in the position of flux emergence.
The neutral line is often pushed aside and curved, leading to faculae heating and the formation of a current
sheet. In spite of complicated Dopplergrams, the same phenomena occur at the site of flux emergence as
usual: upward flow appears at the location of the emerging and rapidly varying flux near the magnetic neutral
line, and downdraft occurs over large parts of the legs of the emerging flux tubes. The age of magnetic
emerging flux (or a sunspot) can be estimated in terms of transverse field strengths: when 50 G < transverse
field < 200 G, the longitudinal magnetogram and Dopplergram change rapidly, which indicates a rigourously
emerging magnetic flux. When the transverse field is between 200 and 400 G, the area concerned is in middle
age, and some of the new flux is still emerging there. When the transverse field > 400 G, the variation of
the longitudinal magnetogram slows down and the emerging arch becomes relatively stable and a photo-
spheric Evershed flow forms at the penumbra of the sunspot.

1. Introduction

Zwaan (1985) summarized the birth of a new active region and the beginning of flux
emergence as follows: a small compact and very bright bipolar plage appears which
marks the birth of a new active region. Soon the arch filament system (AFS) is observed,
which is seen in the line core of Hα, as a set of roughly parallel dark fibrils connecting
faculae of opposite polarity. Such faculae of opposite polarity move apart and expand
laterally, and their occupied area increases, and eventually a new bipolar sunspot group
forms. At the top of the AFS there is an upward flow having a speed up to 10 km s⁻¹,
while in the legs of the AFS are downdrafts whose speed can reach 50 km s⁻¹. When
their magnetic flux $\Phi$ is below $10^{20}$ mX, the emerging flux regions (EFR) do not develop beyond an ephemeral active region, and only if $\Phi$ exceeds $5 \times 10^{21}$ mX, may a sunspot develop in the EFR (Zwaan, 1985; Bruzek, 1967, 1969; Zirin, 1972, 1974; Harvey and Martin, 1973).

On 23–28 August 1988, the complete development process of an emerging flux region which later formed a medium sunspot group was observed at the Huairon Solar Station. A series of vector magnetograms and Dopplergrams in the photosphere and chromosphere was obtained. Synthesizing and analysing these data, combined with an MHD numerical simulation made for magnetic emergence, we put forward the following concept: (i) Magnetic flux emerging in the original enhanced network in a quiet region to form a small sunspot is a relatively simple process. For a period of a few hours, a chain of phenomena, precisely as indicated above by Zwaan (1985), occur. A suitable model describing such a process is that a strong, small-scale bipolar field floats out from the subphotosphere into a weak, large-scale background field. As the one’s strength sharply overwhelms the other’s, Zwaan’s process will certainly take place quite independently of the special configuration of the original enhanced network (Zirin, 1974; Schoolman, 1973). (ii) Within a pre-existing sunspot active region, a new strong magnetic flux emerges, forming a sunspot-group complex. This is a comparatively complicated process whose physical model may be described as a strong, small-scale bipolar field floating out into a pre-existing strong, large-scale bipolar field. In this case the configuration of the magnetograms and Dopplergrams is no longer unique and simple: in part the picture described by Zwaan still holds. On the other hand, complicated configurations occur such as the colliding of two sunspots. In the following, the observational data will be treated and analysed separately. In the analysis, it is confirmed that sunspots emerge in pairs from the subphotosphere, i.e., $p$-spots and $f$-spots or negative and positive spots come about simultaneously, which was long ago found by Zirin (1972). Through numerical simulation it is realized that emergence in pairs essentially reflects the fact that roughly horizontal field rises from below by the magnetic buoyancy force, and with the top of the arch rising into the chromosphere it leaves behind it a pair of legs in the photosphere, corresponding to negative and positive areas in the magnetogram, while the AFS can be identified as the shock front at the interface of the new and former fields. In Section 3 the simple phenomena of magnetic emergence on 24 August, 1988 is analysed. The complicated phenomena of magnetic emergence on August 25th which forms the sunspot complex is elucidated in Section 4. Successive magnetic emergences on 26–28 August, 1988 are illustrated in Section 5. Some of the typical MHD numerical simulations for magnetic emergence are given in Section 6.

2. Observational Data

The observations for this study were made using the solar magnetic field telescope (SMFT) at Huairou Solar Station of Beijing Observatory. The SMFT system consists of a 35 cm vacuum telescope, a 5 Å birefringent filter with 3 sets of KDP crystal modulators, a CCD camera and an Imaging Technology 151 system controlled by a AST-386