DYNAMIC PHENOMENA IN THE VISIBLE LAYERS OF SUNSPOTS*

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Abstract. The empirical properties of the various dynamic phenomena are reviewed and interrelated with emphasis on recent observational results. The topics covered are:

1. Introduction
2. Aperiodic Phenomena
   - 2.1. Externally Driven Phenomena
     - 2.1.1. Umbral Flares
     - 2.1.2. Inverse Evershed Flow
   - 2.2. Internally Driven Phenomena
     - 2.2.1. Penumbra
       - 2.2.1.1. Penumbral Grains
       - 2.2.1.2. Evershed Flow
     - 2.2.2. Umbra
       - 2.2.2.1. Umbral Dots
       - 2.2.2.2. Inhomogeneity of the Umbral Magnetic Field
       - 2.2.2.3. Umbral Turbulence
3. Oscillations and Waves
   - 3.1. Chromosphere
     - 3.1.1. Umbra: Oscillations and Flashes
     - 3.1.2. Penumbra: Running Waves and Dark Puffs
   - 3.2. Photosphere
4. Overview

It is proposed from the observations that umbral dots and penumbral grains are essentially the same phenomenon, and that the observational goal of highest priority with respect to both the origin of the periodic phenomena and the problem of the missing heat flux is to better determine the nature of these elementary bright features.

1. Introduction

This paper reviews the present observational knowledge of dynamic phenomena in the photosphere and chromosphere in sunspots. The dynamic phenomena discussed are features or events which display spectral evidence for mass motion or which change appreciably in brightness or position on time scales less than about one hour. The scope is limited to dynamic phenomena which are observed in stable, symmetric sunspots; those dynamic phenomena associated with emerging flux, polarity reversals, or strong shear in the magnetic field within a sunspot or group of spots, e.g.,

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Ellerman bombs, surges, certain photospheric bright points (Zirin and Moore, 1980), are ignored. This still leaves an impressive array of dynamic phenomena which occur in sunspots regardless of the large-scale magnetic complexity.

The observed dynamic phenomena fall into two classes: periodic and aperiodic. The aperiodic phenomena, in turn, are of two distinct types: those driven by conditions or events external to the sunspot and those driven from within the spot. There are two externally driven dynamic phenomena, both chromospheric: umbral flares and the inverse Evershed flow in the superpenumbra. The internally driven aperiodic dynamic phenomena, on the other hand, are all photospheric; these are the Evershed flow, penumbral grains, umbral dots, and umbral turbulence. The periodic dynamic phenomena are all driven from within the sunspot. At chromospheric levels these consist of umbral velocity oscillations, umbral flashes, running penumbral waves, and penumbral dark puffs. In the spot photosphere, in addition to the photospheric components of the chromospheric oscillations and waves, several other velocity oscillations have been observed.

In the following sections, the observed properties of each of the above dynamic phenomena are summarized and illustrated with selected examples of the best observations to date. This review serves to update previous reviews of most of the same phenomena by Zwaan (1968) and by Beckers (1969, 1975). The present review includes more recent observational results, especially for umbral dots, penumbral grains, photospheric umbral oscillations, and oscillations and waves at the edge of the umbra.

From the empirical results, we point out certain correspondences and probable connections between several of the dynamic phenomena. In particular, we conclude:

(1) Umbral dota and penumbral grains are essentially the same phenomenon.

(2) The magnetic field in umbral dots is much weaker than in the dark surroundings, but probably has the same polarity. The observed upflow velocity of a few kilometers per second in dots could then produce the signature of *apparently* reversed weak field observed in the circular polarization profiles of magnetically split spectral lines.

(3) Non-oscillatory convection in umbral dots may well contribute strongly to umbral turbulence as presently observed. This would substantially reduce the allowable amplitude of Alfvén waves in the umbral photosphere. Spatial resolution sufficient to resolve umbral dots ($\ll 1''$) is probably required to observationally determine whether any significant fraction of the missing heat flux in sunspots is converted to Alfvén waves.

(4) All of the periodic dynamic phenomena in the chromosopheric layers of sunspots (chromospheric umbral oscillations, umbral flashes, penumbral dark puffs, running penumbral waves) are driven by velocity oscillations in the umbral photosphere. These photospheric oscillations, in turn, are probably excited by subphotospheric oscillatory convection in the umbra.