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ОБЗОР ЯВЛЕНИЙ СОЛНЕЧНОЙ АКТИВНОСТИ

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OVERVIEW OF SOLAR ACTIVE PHENOMENA

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Аннотация. Солнечная активность обусловлена наличием солнечных магнитных полей. Она проявляется во многих явлениях краткосрочной переменности, причиной которых является солнечное динамо с наблюдаемым устойчивым взаимодействием полоидальных и тороидальных магнитных полей. Механизм солнечного динамо во многом остается неясным, поэтому прогнозировать солнечную активность сложно. В лекции рассматриваются основные процессы солнечной активности, кроме того, глобальная структура Солнца, включая его внутреннее строение и атмосферу. Представлены механизмы и описание различных явлений солнечной активности. Большая часть посвящена солнечным вспышкам и протуберанцам. Даны основанные на последних результатах примеры наблюдений солнечных эрупций, протуберанцев и других активных событий.

Ключевые слова: Солнце, солнечная активность, солнечный цикл.

Annotation. Solar activity is the result of solar magnetic fields. It is manifested by many components of short-term variability, which are generated by the solar dynamo, where the steady interaction between the solar poloidal and toroidal magnetic fields takes place. Solar dynamo is still weakly understood and therefore it is hardly possible to predict solar activity in the future. During my talk, main processes related to the solar activity will be described. In addition the global structure of the Sun will be presented, including the interior as well as the solar atmosphere. The mechanisms and description of different solar active phenomena, including solar active regions, flares and prominences will be given. The most part of my talk will be dedicated to solar flares and prominences. I will present examples of cutting edge observations and analyses of some solar eruptions, prominences, and other active events.

Keywords: Sun, solar activity, solar cycle.

INTRODUCTION

Our Sun is a late-type star, possessing radiative core and convection outer layers. The Sun has also magnetic field and exhibits differential rotation. All these features cause our star to be not completely quiet and constant but showing periodical changes of its radiation level. The period of these changes is approximately 11 years and called solar cycle, and different phenomena occurring during solar cycle constituting solar activity. The main engine which drives solar cycles and activity is located in poorly understood layer called tachocline, which is relatively thin layer (approx. 40 000 km) at the depth of about 200 000 km below the photosphere. During the solar cycle the differential solar rotation converts initially poloidal magnetic field to become stretched in the direction parallel to the solar equator. In this way toroidal magnetic field is strengthened due to solar rotation. Then, the buoyancy force within the convection zone emerges magnetic field towards the solar photosphere in the form of magnetic flux tubes.

When the magnetic field crosses the photosphere the sunspots can appear and create so called active regions. The described above mechanism is called solar dynamo, and it is intensively explored by different scientific groups. Active regions usually consist of a group of two (leading and following) oppositely polarized sunspots, which show an opposite polarity distribution at two solar hemispheres (north vs. south). In the subsequent solar cycle the polarities of leading and following sunspots change the orientation at both hemispheres. Therefore, it is physically more correct to speak about the 22-years cycle, the Hale cycle. Solar cycle is not a purely periodic process; the subsequent cycles may differ in their length and strength. Solar dynamo is still poorly understood and therefore the prediction of the solar activity in future is hardly doable.

Solar activity is manifested by different phenomena observed through the whole cycle, however the most frequently during the maximum of the solar one.

SOLAR ACTIVE PHENOMENA

The solar active events can be observed in the entire solar disk. However, most of them are located close or inside active regions. Except sunspots and surrounding plages, solar activity is manifested mainly by solar flares, coronal mass ejections (CME) and solar prominences.

Solar active regions consist of sunspots and surrounding plages areas (Fig. 1). Sunspots are dark areas with more or less regular shapes, which are visible against the background of the photosphere. Large sunspots usually consist of a dark umbra, surrounded by a slightly brighter penumbra. Only the smallest sunspots, called pores, are devoid of penumbra. The average temperature of the sunspot umbrae is about 4200–4500 K, so there is about 1500 K cooler than the solar photosphere. Diameters of sunspots are 2000–3000 km in case of small pores and over 50 000 km for largest sunspots. Such giant sunspots can be observed even without any optical device, of course using filters, which are necessary to reduce the solar brightness. The diameters of large sunspots are so huge that the entire Earth would

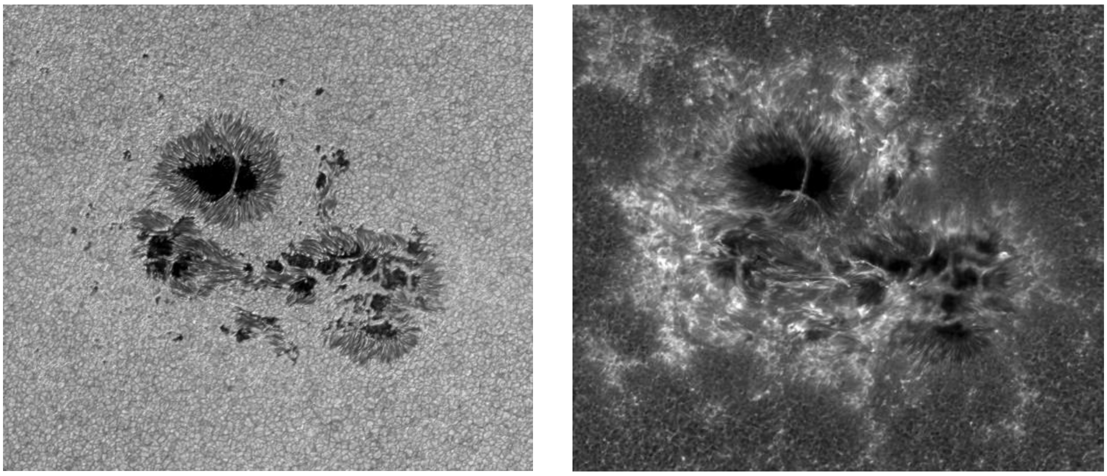


Figure 1. Example of active region with plage areas. Left: white light image. Right: Ca II image Figure 1

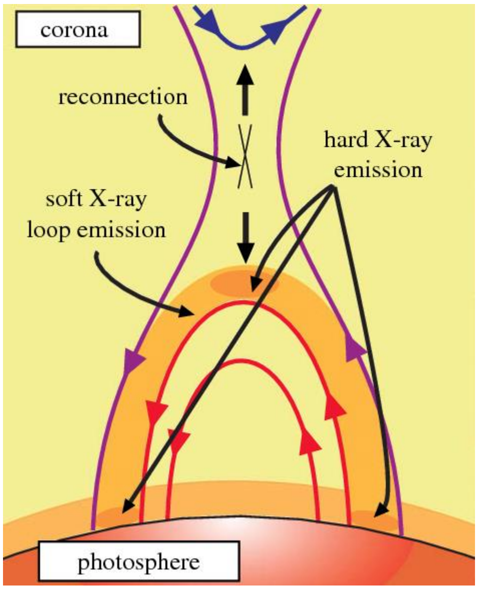


Figure 2. Scheme representing the processes during solar flares

easily fit into their umbrae. The sunspots lifetime ranges from several hours for the smallest features to many months for the largest sunspots. Sunspots usually occur in clearly distinguished groups. The number of sunspots in the group, their distribution, the stage of development reflect changes in the local magnetic fields and are the easiest to observe signatures of the evolution of active regions. The solar observers describe the basic morphological and evolutionary features of groups of sunspots using different classifications; the most popular is the McIntosh classification. Solar active regions are usually surrounded by the plage areas (faculae, Fig. 1) — brighter region visible in the photosphere and the chromosphere. They possess enhanced temperature due to the stronger magnetic field of the active regions. Solar plages significantly affect solar total irradiance (solar constant).

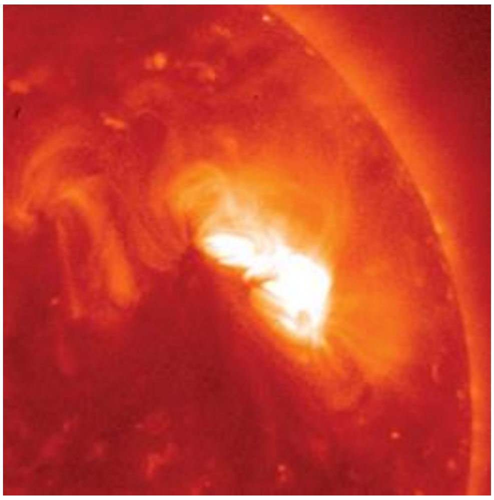
The most energetic solar active phenomena are solar flares. Solar flare is an extremely complex set of phenomena and processes caused by the sudden release of enormous energy due to reconnection process in the atmosphere of the Sun (even up to E~10^{25}–10^{27} J in a single flash), previously accumulated in magnetic fields of active regions (Fig. 2).

The duration of flares fluctuates from a dozen or so minutes for the weakest phenomena up to several-dozen hours for the strongest events. The phenomena that create a solar flare run together in all layers of the solar atmosphere, even partially in the low-lying photosphere.

During solar flares, huge amounts of energy are emitted in the form of electromagnetic spectrum (from gamma to radio) and streams of particles (electrons, protons, ions) at speeds up to 70 % of the speed of light. Usually the solar flare exhibits several phases, the most important is so-called impulse phase, during which the rapidly generated energy of magnetic fields causes a sudden (in seconds to minutes) increase in the intensity of electromagnetic radiation. Another phase is the decay phase, when the energy released from magnetic fields decreases and the solar flaring plasma gradually cools down. Usually, during strong flares, there is a significant reconstruction of local magnetic fields, which is associated with the formation of magnetic loops arcades, eruptions of prominences, coronal mass ejections, etc. Solar flares are observed in the whole range of the electromagnetic spectrum - from radio to gamma waves. In X-rays we can observe the coronal parts of solar flares, where the plasma temperature reaches 2×10^7 K (Fig. 3 left). The chromospheric component of solar flares has a temperature of around 10 000 K and the emission is observed mostly in chromospheric spectral lines, e.g. in Hα hydrogen line (Fig. 3 right).

Solar flares are sometimes associated with Coronal Mass Ejections (CME). During these events the huge amount of plasma is ejected in the form of large bubble that may span angular size up to about 90° (Fig. 4).

The plasma leaves the Sun with the velocities of the order of tens of km/s but it is then accelerated to 200–2500 km/s. Some events can be also connected with the prominence eruption. Then, inside CME we observe the dense prominence structures, which are ejected together with CME. The CMEs carry solar magnetic field along that tends to fill the heliosphere — the magnetically closed region around the solar system. Only some of CMEs (called halo CMEs) are ejected towards the Earth. They can reach the Earth's surroundings, and then



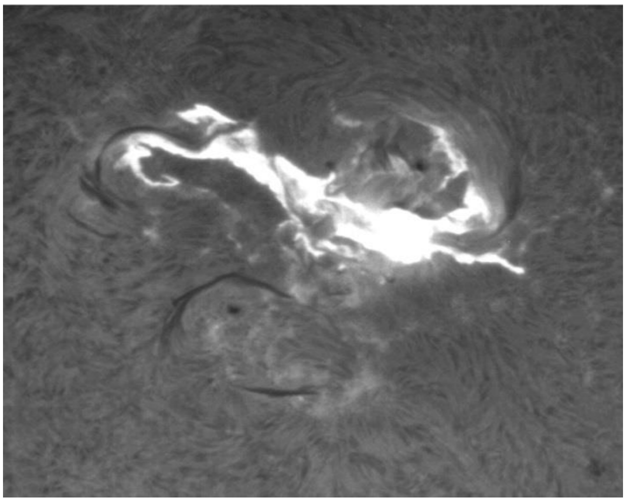


Figure 3. Left: image of solar flare observed in X-ray radiation (Credit: Hinode JAXA/NASA/PPARC); Right: solar flare as visible in the chromospheric Hα line (Credit: Astronomical Institute, University of Wroclaw, Poland)

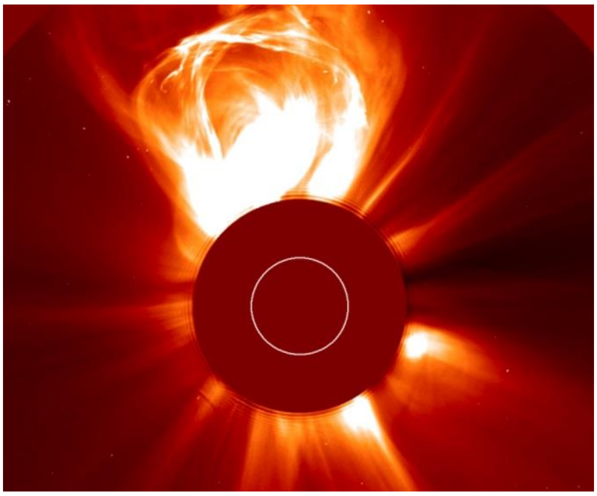


Figure 4. Coronal mass ejection observed in the form of large bubble (Credit: SOHO Consortium, ESA, NASA)

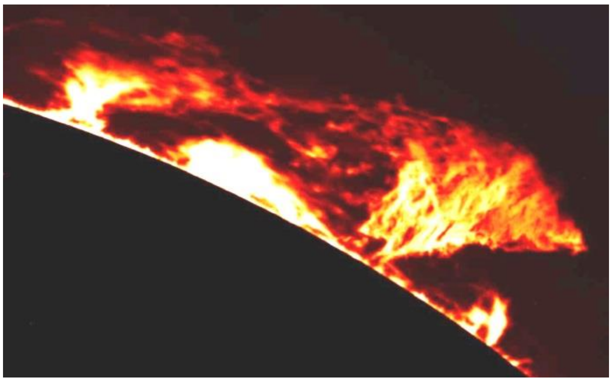


Figure 5. Solar prominence observed with the Large Coronagraph in the Hα line. (Credit: Astronomical Institute, University of Wroclaw, Poland)

cause disturbances of the Earth's magnetosphere and generate auroras (northern lights). Such phenomena are important for better understanding the Sun-Earth relations.

The quietest solar active phenomena are solar prominences. They are associated with the topology of the

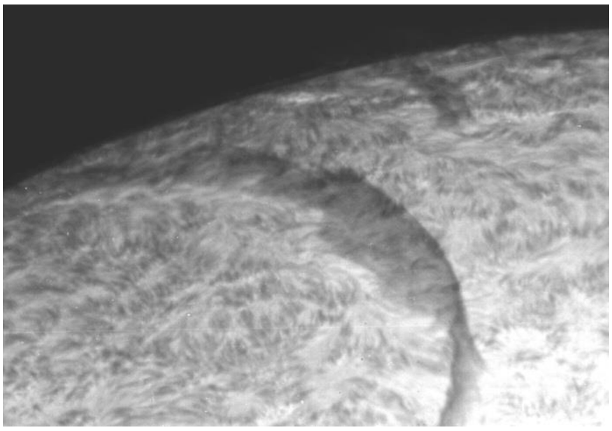


Figure 6. Solar filament observed in the H-alpha line with the Large Coronagraph. (Credit: Astronomical Institute, University of Wroclaw, Poland)

magnetic field generated by active regions. However, quiescent solar prominences can appear also far from active regions. Solar prominences are observed above solar limb using ground-based or space coronagraphs (Fig. 5). Then we see bright structures of the temperature around 10 000 K on the dark background. These structures supported by the magnetic field, which can form special structures (dips) in the shape protecting the plasma to fall down. It is interesting that due to very weak thermal conduction between the prominence and corona and due to large radiative losses, the plasma of the prominences is much cooler than the surrounding corona. Solar prominences can be also observed in the solar disk, in particular in chromospheric Hα line, as dark thin structures. Such features are called solar chromospheric filaments (Fig. 6). Solar prominences are divided into two main groups: active and quiescent. Active prominences (flare loops, eruptive prominences, surges, sprays) are much more dynamic, related with active regions and have shorter lifetime. They are more connected with the solar activity than quiescent prominences, which may form long-living (days to weeks) huge clouds with the fine structures observed with high-quality instruments (Fig. 7).

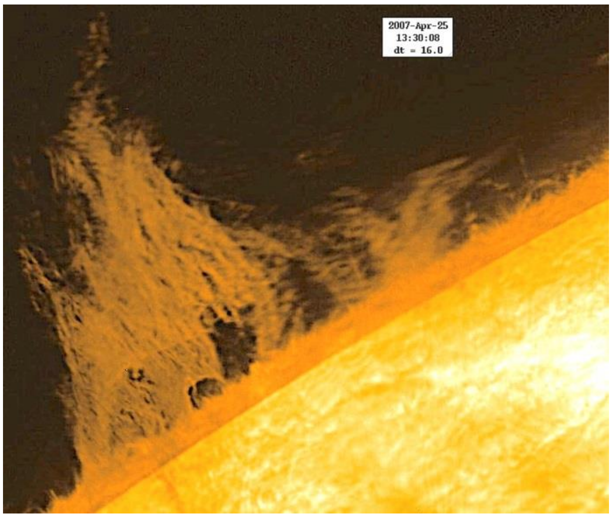


Figure 7. Solar quiescent prominence observed in the Hα line with the Large Coronagraph. (Credit: Hinode JAXA/ NASA/PPARC)

All active phenomena cause the Sun — our day star — to be not just a quiet disk, which is visible every day, but to be an interesting active star, where many different processes take place in all parts of its atmosphere. These processes can be observed even by amateur astronomers who are intensively involved into investigation of solar activity.