Fluctuations in solar activity

Our Unsteady Sun

Prof. Janusz Sylwester researches the physics of the Sun and x-ray plasma spectroscopy. The group he directs develops satellite-based devices for studying solar flare plasma

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The Sun, our closest star and source of life, has been under systematic study for only the past several hundred years. Research shows that it is not as stable as once thought, and also not always benign to mankind. Nowadays we keep close tabs on solar activity to try to predict what lies in store for the Earth and its inhabitants

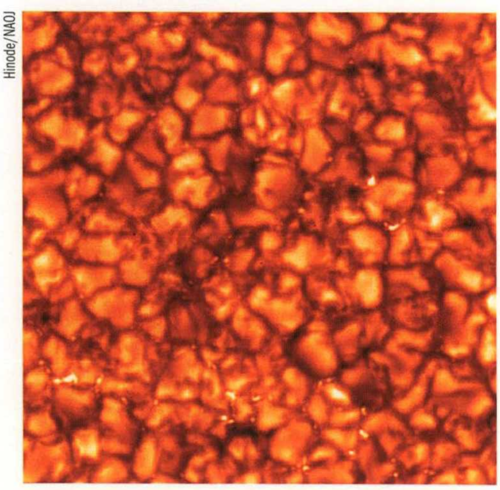
Here's a quick recipe for creating a star plus a solar system: find a large, diffuse cloud of gas and dust, preferably containing traces of heavy elements (debris left behind by previous stars). Under favorable conditions, gravity will cause the cloud to contract and rotate at an increasing rate, forming a disk. The matter pressed into its ever-denser center will heat up until thermonuclear reactions begin. Like in an alchemist's crucible, hydrogen will begin to transform into helium - and from that point onward a long-term balance will be struck between thermal pressure and gravitational forces. The magnetic field of this nascent star will then interact with the disk to cause local gravitational condensations, giving rise to planets, asteroids, and comets.

The history of the Sun

Our own Sun formed some 5 billion years ago, and it will reign over our local area of space until its raging agony some 4 billion years from now. That we know for certain. We also know that the Sun emerged out of cosmic "dust" that was enriched with elements heavier than hydrogen and helium by earlier supernova explosions - i.e. stars with several times the Sun's mass which ended their short, violent lives in explosions. We have likewise known since the times of Galileo and Hevelius that the notion of the Sun being an ideal of stability and perfection is in fact unfounded.

At the core of our Sun lies a "naturally controlled" thermonuclear reactor, where, in keeping with Einstein's well-known formula, some 4 million tons of matter are transformed into radiant energy each second. In this reaction cycle a helium nucleus is synthesized out of four protons, meaning that the hydrogen within the center of the Sun becomes replaced by helium. At present, the Sun still has plenty of nuclear fuel - since our star was formed, i.e. some 4.6 billion years ago, it has consumed more or less 40 percent of its store of hydrogen. For the next 4 billion years the Sun will continue to ensure a relatively stable source of energy for the entire Solar System. Near the end of its evolution it will undergo two short periods as what is called a cool giant, when it will absorb the closer planets, perhaps even including the Earth. Then it will "meet its end" by collapsing, giving rise to a planetary nebula plus an extremely dense white dwarf the size of the Earth.

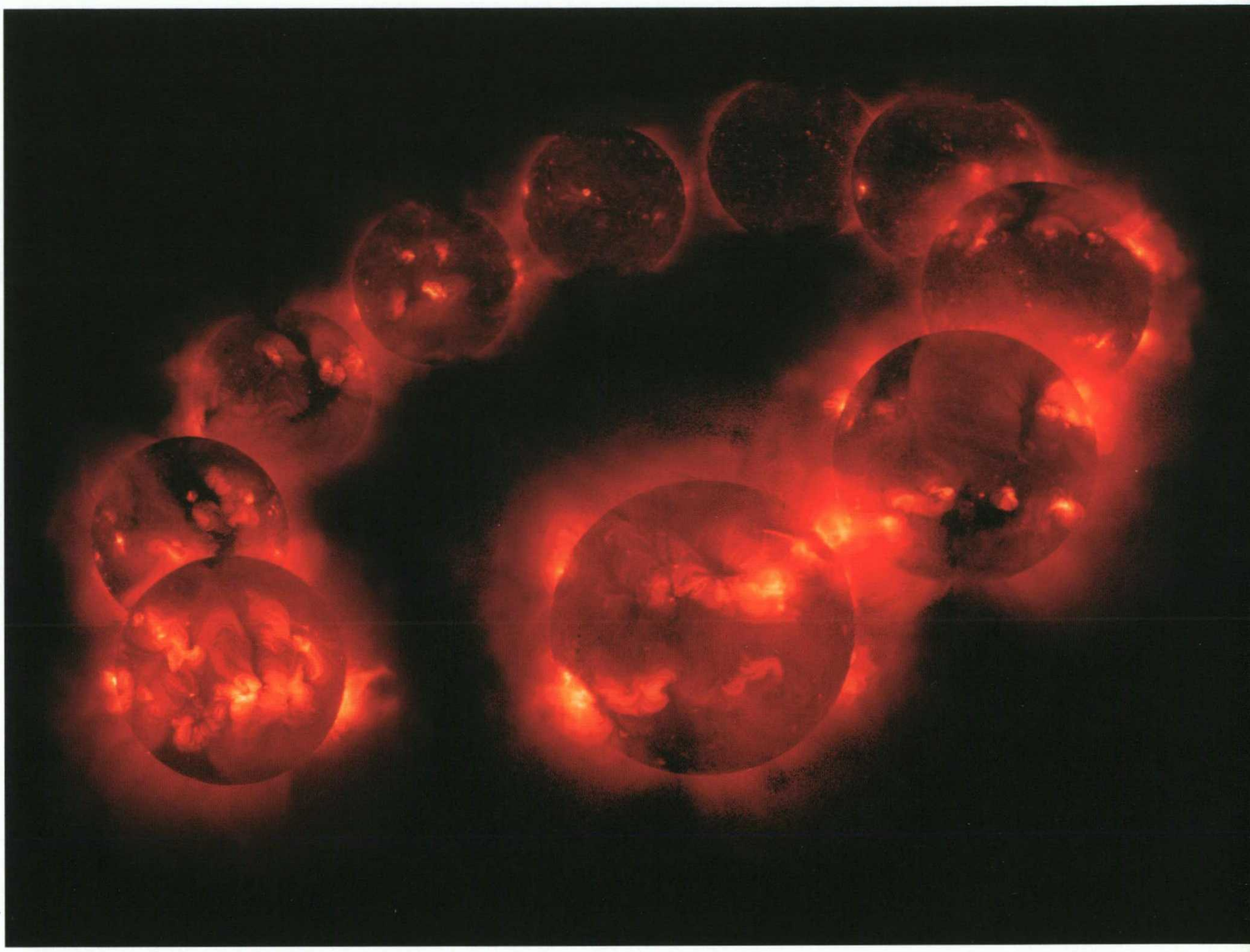
Heliophysics, the physics of the Sun, is a branch of astrophysics that studies the structure, properties, and activity of our star - the source of energy for the biosphere and for our civilization. Drawing upon knowledge from many fields of physics plus advanced methods



Hinode/NAOJ

Aside from sunspots, the photosphere's brightness is also non-uniform in a way that is highly reminiscent of the surface of boiling oil. These so-called granules (several hundred km across) result from convection currents drawing energy up to the surface of the star. In the dark inter-granule areas, plasma falls back towards the interior

A depiction of variability in the Sun's radiation in the x-ray range, using selected images taken by the SXT x-ray telescope (aboard the Japanese satellite *Yohkoh*). These images were taken approximately each year from 1991–2000, ranging from a maximum to a minimum and back to a maximum of activity. The fluctuation in radiation levels is clearly visible in the x-ray range



Yohkoh/ISAS i NASA

of computation, we can nowadays anticipate the future evolution of the Sun and analyze its history with considerable precision. For instance, we know that the Sun has gradually increased in brightness since its formation (so far by some 30%). Due to this trend, some 1.2 billion years from now the Earth is set to experience a gigantic greenhouse effect, causing the evaporation of the oceans and the annihilation of multi-cellular life.

Why does the Sun shine?

The majority of the energy released within the Sun takes the form of gamma ray quanta, which do not have any simple route to the surface. Instead, they become repeatedly reabsorbed, a process whereby they become "broken down," as the average energy of such quanta diminishes while their number grows proportionally. The quanta filter through to the surface over tens of thousands of years, in the final stage penetrating through the external convection layer, 200,000 km thick. On the other hand, a small portion of the energy does permeate outside the Sun almost immediately, in the form of a stream of neutrinos which can also be detected on the Earth using refined detectors situated within deep mine corridors. This enables us to monitor on an ongoing basis - let's say once a month - the current pace of processes within the Sun's core. It is stable (on our time scale).

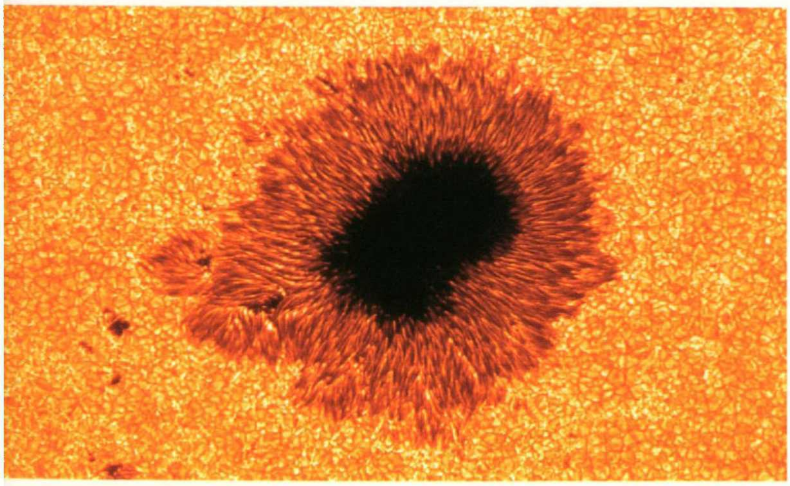
Spotted star

It is significantly more intriguing to study the visible portion of the Sun, called the photosphere, which emits 99.9% of the energy. Here sunspots appear periodically, a phenomenon that was systematically studied by Galileo. Sunspots are grouped on the surface into localized "active regions." Their appearance is well studied observationally, yet its theoretical interpretation remains problematic. Describing these active phenomena is a task for magnetohydrodynamics, the discipline of physics which investigates the behavior of ionized gas in the presence of a magnetic field.

Inside each sunspot is a darker region, called the umbra, at a temperature about 1,500 degrees lower than its neighborhood, surrounded by a lighter, extremely dynamic penumbra. The penumbra comprises a set of animated fibres whereby magnetized plasma (ionized gas) heads in a direction set by the local magnetic field. Most of the sunspots, which are on average about the size of the Earth, change over time. They may "live" for several days to several months.

Aside from sunspots, the photosphere's brightness is also non-uniform in a way that is highly reminiscent of the surface of boiling oil. Brighter areas, called granules, are caused by plasma convection currents which draw energy from inside up to the surface. The dimensions of the darker intergranular areas, tens of kilometers across, lie at the current limit of our observation resolution.

Reliable observations of the numbers of sunspots have been recorded for several hundred years now, although there is historical data (mainly from China) describing spots observed on the Sun thousands of years earlier. Analyzing the timing and location of sunspots has shown that the Sun's activity is cyclical, each cycle lasting approximately 11 years. The spots of a new cycle appear far away from the Sun's equator, but with time they begin to emerge closer to the equator. The true periodicity is in fact 22 years, since the magnetic polarity of the sunspots switches after 11 years.



The best image of a sunspot so far obtained, taken using the SOT telescope on board the Japanese satellite Hinode, launched into orbit in autumn 2006. This sunspot is 50,000 km in diameter

Hinode/NAOJ

"Spotting" is the natural reaction of our Sun's atmosphere to a complicated physical situation, in which a highly conductive ionized ball of gas (i.e. a star) rotates within a steady interstellar medium. Individual cycles of solar activity demonstrate varying amplitude. We are currently at a minimum, awaiting the start of cycle 24, which is somewhat delayed.

The regularity of the cycle, however, remains in question. In the 16th and 17th century, following the initial sunspot observations by Galileo and Hevelius, no sunspots were observed over a period of decades, and the related polar aurora phenomenon was also not then noted. In the history of solar activity this period is called the "Maunder minimum." During this time, coinciding with the Swedish Deluge era in Poland, the Sun's activity diminished for reasons that remain unexplained.

Precise modern measurements indicate that greater solar activity does slightly boost the stream of energy reaching us from the Sun (i.e. by some 0.1%). During the Maunder minimum, this small albeit long-term downturn in the amount of incoming energy probably sufficed to cool down the Earth's climate enough to enable fairs to be held on the frozen Thames, and to freeze the Baltic sufficiently to allow troops to cross on foot (as mentioned in the memoirs of Jan Chryzostom Pasek). It is highly likely, therefore, that there is a long-term link between the Earth's climate and the level of solar activity.

The significance of the global warming problem, therefore, makes studying variations in the energy supplied by the Sun of top-rank importance.

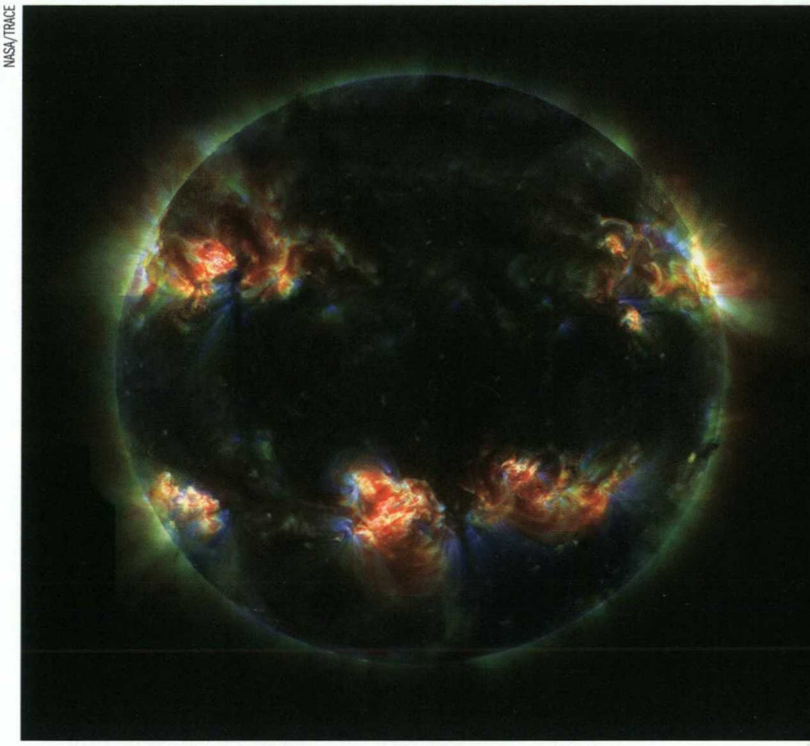
Flaring up

These days we no longer study the Sun just in the visible spectrum, which the human eye can perceive and for which the earth's atmosphere is transparent. Devices operating high above our atmosphere can now record observations in the ultraviolet and x-ray ranges, where the phenomenon of magnetic activity is visible in all its glory.

The structure of the Sun's atmosphere is very non-uniform, with areas of various densities and temperatures immediately adjacent to one another, and the situation changes not only from hour to hour, but even from one second to the next. From our standpoint, the most important changes are solar flares, when a small magnetized area of the solar atmosphere emits a quantity of energy equivalent to a million-megaton explosion in the course of one minute. The Sun's brightness in the x-ray range then increases a million times, when the plasma heats up to millions of degrees and mainly gives off x-ray radiation. This cases a strong additional ionization of the outer layers of the Earth's atmosphere, blocking radio communications on many frequencies and interfering with GPS system readings. The Sun thrusts out a cloud of plasma, millions of tons in mass (called a coronal mass ejection), usually accompanied by a flare. If the Earth happens to lie along its path we have cause for alarm, since it puts us "in the eye of the hurricane" of cosmic weather, i.e. a magnetic storm. On the Earth's surface essentially nothing changes. But in 1859, for example, soon after the first telegraph lines were laid in the United States, the cables suddenly burnt out over extensive areas. Nowadays we know that this failure was the result of electric current induced in the cables by a strong deformation of the Earth's magnetic field, caused by such a cloud of solar plasma. In 1989, in turn, half of the province of Québec experienced a power failure caused by a significantly weaker solar flare. Such flares can significantly deform our Earth's defensive shield - the magnetic field that guides compass needles. Such deformations have sometimes led to satellite failures (approximately 10 having been lost in 2000 alone), telecommunications problems, or pipeline malfunctions. Without a doubt, these streams of solar particles pose a great threat to the health and even life of astronauts traveling on planned flights to the Moon and Mars, since the protection of the Earth's magnetic field simply does not extend that far.

It is essential, therefore, to constantly monitor solar activity so as to do our best to predict the current threat of active phenomena in the solar atmosphere, and thus to minimize their impact. This is the basic objective of what is called the space weather research program. Space weather centers have been operational for many years at the NOAA (in Boulder, Colorado), in Russia, in Belgium, and also in Poland at the Space Research Center of the Polish Academy of Sciences.

NASA/TRACE



The solar corona during a period of increased activity, visible in the extreme ultraviolet on 20 July 1999. The color scheme here is linked to temperature - ranging from 1 million degrees (blue) to 2-3 million degrees (red)

It is crucial for such heliophysics research to be continued since despite many papers published and thousands of analyses made, we still do not understand the basic physical mechanisms underpinning the sudden release of energy during solar flares, and we cannot predict with sufficient precision when one might occur and how large it will be.

Poland has become actively involved in the program of space-based solar research, chiefly in studying the x-ray radiation of solar flares. The research devices being developed at the Solar Physics Division of the Space Research Center, in collaboration with international centers, are currently the best in their class, measuring x-ray spectra at a resolution that permits the temperature and quantity of the heated plasma to be identified. An x-ray photometer now under construction (the SphinX project) will make it possible to register the x-ray spectra of solar flares more than 10 times a second, much more frequently than previously possible. ■

Further reading:

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