

The question of life and death of sunspots

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One of the most important problems in solar physics is understanding the sun's magnetic cycle. In this phenomenon, the active regions are the main ingredients. Sunspots were observed in the pre-historic era by Chinese scholars¹. They were the first extraterrestrial objects found to harbour a magnetic field². Yet, their physical nature and relation with the sun's cyclic magnetic activity is poorly known. The recent high-resolution observations and computational techniques have led to the revelation of the secrets of these cool objects in a hot environment.

A well-developed spot has a dark core called umbra and less dark, filamentary structured penumbra as shown in Figure 1. Sunspots are observed in various different sizes and shapes with complex internal structure. At times, the dark umbra is divided by light bridges. Although the scientific observations of sunspots with telescopes³ began as early as 1610, the additional properties of magnetic field and mass motion came only after about 300 years^{2,4}. Observation of Zeeman effect by George Hale, in USA, on sunspots showed that these are the regions of intense magnetic field on the sun. The Evershed effect, observed in Kodaikanal Observatory in India, is essentially the Doppler-shifted photospheric absorption lines which have asymmetric line profile towards the blue and red wavelengths in the sun centre and limb direction of the penumbral region of a spot. The Evershed effect disappears as the sunspot is observed near the disk centre, indicating that these effects are produced due to the horizontal plasma motion from the sunspot to its surroundings.

The application of specially developed optical tomography technique⁵ to simple sunspots showed that the magnetic field all around the spots was inclined at an angle $> 90^\circ$ and was therefore directed back into the sun. It also showed the mass motion in the penumbral region in terms of Doppler velocities of -3 to 1.5 km s^{-1} towards the sun centre and $+3 \text{ km s}^{-1}$ towards the limb. The flow continued beyond the penumbra and highly correlated with magnetic field inclination, as would be

expected from the 'freezing' of plasma to magnetic field lines of force. Blue-shifts (upflows) are located at the middle of the penumbra where the magnetic field points upward and red-shifts (downflows) in the outer penumbra, coinciding with the downward pointing fields. These flows are transient with a time-scale of 10–15 min (ref. 6). They can be understood in terms of siphon flow mechanism, in which the pressure difference at the end points of the tube drives and sustains the plasma motion along tube⁷. For example, a flux tube originating in the penumbra and connecting the photosphere may have field strengths 1424 G at the upstream foot-point and 1439 G at the downstream. This difference in magnetic field is maintained even at the upper layers. As the total pressure (gas pressure plus magnetic pressure) in the penumbra equals the gas pressure in the photosphere everywhere, the difference in gas pressure at two points drives

the flow. However, using a single, photospheric, magnetic sensitive line it is not possible to observe the field at the same height inside and outside the spot due to the Wilson effect. So, the applicability of siphon flow mechanism to Evershed effect is not satisfactory. Sunspots are dark because the magnetic field inhibits the convective energy transport from the underlying layers⁸. Consequently, it is observed that the blocked energy shows up as bright rings extending at least one sunspot radius out from the penumbra, which is about 10 K warmer than the surrounding photosphere. About 10% of the missing energy is emitted through these bright rings where the vertical flux tubes are absent⁹. Although such rings were observed earlier using photographic techniques¹⁰, the present observations with modern electronic detectors show that they are much more extended.

The filamentary structure is also observed in the umbral region which connects

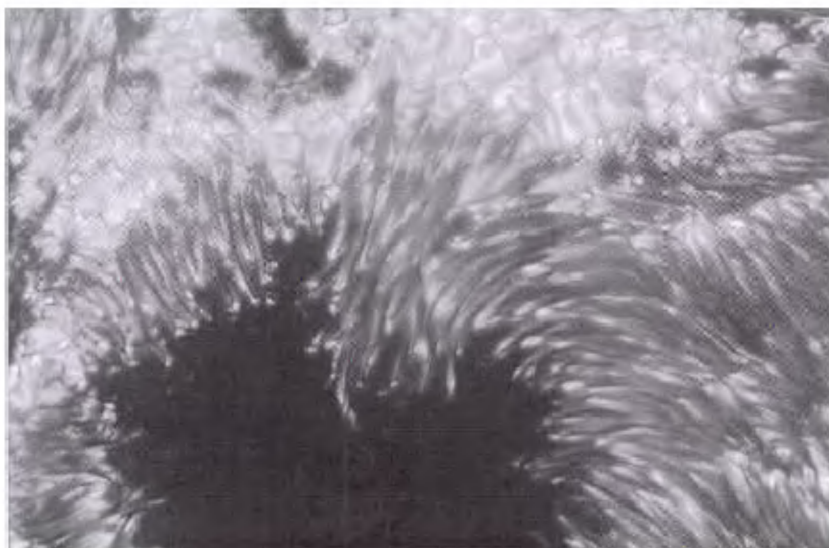


Figure 1. Part of the largest sunspot in Active Region 10030 recorded on 15 July 2002 with the Swedish 1-m Solar Telescope on La Palma. This image was post-processed with the so-called Phase-Diversity Technique, making it the highest-resolution solar image ever. The tickmarks around the edge of the image show the scale. The distance between two ticks is 1000 km. The central part of the sunspot (the umbra) looks dark because the strong magnetic fields there stop upwelling hot gas from the solar interior. The thread-like structures surrounding the umbra make up the penumbra. Dark cores are clearly visible in some of the bright penumbral filaments that stick out into the umbra. The Swedish 1-m telescope belongs to The Royal Swedish Academy of Sciences.

the penumbra along with featureless voids. This suggests that there exist two types of fields in the umbra, one with inclined field lines and the other perpendicular to the surface, originating from the voids¹¹. The dynamical events in the form of flashes of bright light extending over 2000–3500 km are observed in the umbral region. They last for about 1.5 min in the interval of 2.5 to 3 min. The time series observation of intensity (I) and circular polarization (V) Stokes profiles¹² in the photospheric and chromospheric lines showed that the dynamical character of an asymmetric spot is different from the symmetric one¹³. The symmetrical spots do not show the umbral flashes, but the line profiles exhibit 2.5 min oscillation. In contrast to their photospheric counterpart, the chromospheric Stokes-V profiles show periodic anomalous behaviour. In case of the spot with light bridges, active behaviour of Stokes-I is observed. The chromospheric Stokes-V profiles become strikingly asymmetric during the flash events. These observations show that the umbral flashes can be produced either by injecting the photospheric material, thereby increasing the chromospheric opacity leading to a shift in optical depth scale, or by an upward wave propagation in a down-flowing plasma leading to the generation of shocks.

The finer structures in the fibril have now been observed with large modern telescopes¹⁴. It shows that the 100 km long, stable penumbral fibril connects the dark umbra with the surrounding photosphere. It consists of a dark elongated core of about 100 km size surrounded by a bright envelope of similar size. Many of the fibrils are observed to be twisted. Surrounding these objects, there are fine dark structures in the form of hair and canal, whose true nature is not known. The bright envelope of the fibrils cannot be produced by surface current or topological dissipation. Similarly, the dark features on a bright background are unsustainable due to Rayleigh–Taylor instability, if these objects are dense. At the outer edge of the penumbral boundary the field lines are kept submerged outside the spot by turbulent, compressible convection of the order of 1000 km size, which is dominated by strong, coherent, descending plumes¹⁵. This downward plumbing of magnetic flux explains the origin of the interlocking–comb structure of the penumbral magnetic field, and

other properties such as the moving magnetic features near the sunspot with speeds of $0.5\text{--}3\text{ km s}^{-1}$. This downward pumping transports the flux to sub-photospheric layers against magnetic buoyancy.

The sunspots are produced by two processes. One, when the magnetic flux protrudes through the convection zone in the form of an Ω -shape, the cross-section at the photosphere manifests as sunspots. Two, they are formed through the coalescence of small pores without the penumbra. In either case, as the total magnetic flux increases either by vertical emergence of the Ω loop or by increased size of the pore due to coalescence, the force balance demands that the outermost magnetic field lines become more nearly horizontal. As the field lines attain a critical angle, convectively driven filamentary instability sets in, bringing the flux ropes to the solar surface. At this point, they are grabbed and pumped downwards by granular convection. The interaction of convective photosphere and the sunspot boundary is important as it affects both its stability and decay. Parker suggested a cluster model of sunspots, in which the loose cluster of magnetic flux tubes are held together by a down draft beneath the sunspot¹⁶. Such converging flows of $\sim 1\text{ km s}^{-1}$ at a depth of several megametres have been found by recent time–distance helioseismology investigation¹⁷.

At this point of time, what is known is that the sunspots are dark, cool regions with intense magnetic field. The penumbral flux ropes bend and fall on the solar surface, where they become subjected to the prevailing convective hot medium. The high-resolution fibril structures with 100 km dark core may be a portion (visible in white light) of these falling flux tubes. When the gas pressure difference is established at two ends of these tubes, the Evershed flow sets in episodically. In course of time, it is observed that the two sunspot polarities diffuse and decay, perhaps mainly influenced by the photospheric turbulent medium. So, the turbulent flow acts both for the stability (life) and decay (death) of the sunspots. It is, therefore, important to distinguish these two separate ingredients in the flow. The key to this problem is to observe the interaction mechanism of the flux tubes with the surrounding turbulent medium by measuring the velocity and magnetic field at such resolutions. The nature of

umbral flux is also not known, as it propagates upwards¹⁸, which can be observed with simultaneous multi-line magnetography.

The recent observations of the sunspots are made at $\sim 100\text{ km}$ resolution using adaptive optics systems with 19 mirror elements. Such systems with 24 and 80 elements are being developed for solar studies, which might lead to finer resolutions. The space-based Solar-B will give 0.5 arc-sec resolution in 2005. It is not known now, what exactly is the limit for the fine features that can be observed with high-resolution techniques at this time. The photon mean free path in the solar photosphere is about $50\text{--}70\text{ km}$. But the sophisticated radiative transfer calculations show that fine structures as small as few kilometres should in principle be directly observable¹⁹. Also, theoretical arguments suggest that there exist magnetic structures on scales as small as a kilometre or less. The high-resolution instruments have just started functioning and will reach new heights by the end of this decade. It is therefore the decade that will witness many important findings having direct bearing for understanding the life and death of the sunspots, which are the main ingredients of the solar activity cycle.

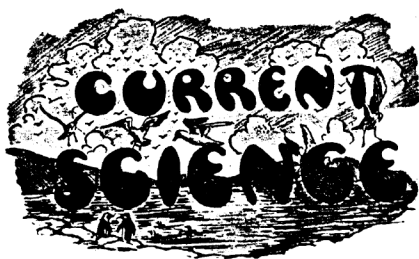
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FROM THE ARCHIVES



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Automobile Industry in India

The question of establishing an automobile factory in India is just a part of the general scheme of industrialising the country, and, if it is agreed that the development of all the available material resources of this great sub-continent is desirable and necessary for the promotion of the prosperity and the well-being of the Empire, it is inconceivable why the modest proposals for the inauguration of a motor factory in Bombay were discouraged. It will be remembered that in connection with framing the outline of the project, Sir M. Visvesvaraya had investigated the possibilities of this new venture in all its detail, by visiting a large number of automobile factories in Europe and America, and by consulting with their directors and technical experts. The report that he prepared after exhaustive enquiry, revealed the fact that practically all the experts consulted favoured the project, by offering active support and co-operation. It was a grave misfortune

that, while the report was being sympathetically considered by the promoters of the scheme, they appear to have been suddenly seized with a spirit of pessimism in respect of the success of the proposals formulated in the report, and that they were almost inclined to believe the misleading doctrine that India would do better to buy foreign motor vehicles than build them in her own factories. The establishment of a large industry, such as the one Sir M. Visvesvaraya was contemplating, must necessarily affect vested interests and must even provoke a certain measure of hostility, but what is puzzling is that the hard-headed business men, who take a practical and a long-range view of industrial concerns, should succumb to the blandishments of false and futile economic philosophy. In 1936, efforts were made to enlist the sympathy and the active support of the Government of Bombay and the Government of India. The Government of India were profuse in their sympathy, but adhered to the policy of discriminating protection for Indian industries; enunciated by the Fiscal Commission of 1921–22 and in pursuance of this policy the Imperial Government could offer no assistance to ‘an industry that was not started’ and could therefore make no promise for the purchase of its products. The Congress Ministry, then in power in Bombay, however, offered provisionally a guarantee of 3 or 3.5 per cent interest on a capital issue of Rs 150 lakhs for the industry for a period of ten years. Before the concession could

be finally sanctioned, the Congress Government went out of office. . . .

It is not surprising that the Government have dealt with the proposal in their traditional grand style. In war, more particularly in its acute phases, such as those in which we find ourselves at the present moment, it might be supposed that temporary make-shift arrangements are what are most urgently required, and some may even be disposed to think that the time is inopportune for the inauguration of large-scale industries. According to such views, it would be safest for all concerned to follow traditional methods of thought and action. But wars shatter traditional methods because they introduce into our political, social and economic institutions unfamiliar and devastatingly new problems. It is only on a basis of quantitative knowledge that industrial problems can be formulated and that the need for the institution of new industries can properly be determined. The problem presented by Sir M. Visvesvaraya’s brochure is definite and simple, and it is hoped that the Governments, to which appeals for support and encouragement for the projected factory have been preferred, will not be lacking either in ability or willingness to remove delays of industrial advancement and economic development in India. ‘Policies’ are sacred, and they acquire more sanctity by furthering the industrial prosperity of the People. ‘Vested interests’ are serious and they earn better respect by not injuring national interests.