Our dynamic Sun: A principal source of new physics*

Bhola N. Dwivedi

Our dynamic Sun provides a principal source of new physics. Among the many exotic objects available for study, the seemingly pedestrian Sun exhibits a variety of phenomena that defy contemporary theoretical understanding. After presenting some history, we address some unanswered questions in coronal physics (e.g. coronal heating and solar wind acceleration) with new results from SOHO. Magnetic energy release on the Sun (explosive events) and coronal mass ejection (key to understanding space weather) are also briefly presented. We conclude with the present scenario and the exciting promise that SOHO holds in the unravelling of some of the known mysteries of our own Sun and in presenting us with some new ones.

'A gaze blank and pitiless as the Sun', was how Yeats evoked faceless doom in his poem *The Second Coming*. The glare of the Sun may still seem pitiless, but it is blank no longer – at least to solar physicists; it is extremely active and dynamic even during its period of minimum activity.

The 20th century has witnessed the transformation of astronomy from celestial mechanics to astrophysics. Not only were various types of stars discovered, but also many kinds of congregates of stars, e.g. globular clusters, galaxies, clusters of galaxies, superclusters and so on. In the latter part of this century, however, astronomy has not only had available optical telescopes but its progress was advanced with instruments that see the entire electromagnetic spectrum such as radio, infra-red, X-ray and gamma-ray telescopes, and even non-photon instruments (e.g. neutrino detectors). These new windows of observation have revealed that there are far more amorphous objects such as nebulae, sheets, filaments, and voids, and constituent astrophysical objects themselves often present violent processes such as flares, shocks, accretion disks, and jets. Our picture of the universe has changed from the quiet to the violent one.

Although there are many exotic objects available for study, the seemingly pedestrian Sun exhibits a variety of phenomena that defy contemporary theoretical understanding. Aside from its intrinsic interest both scientifically and as the source of life on Earth and of the planetary environment, the proximity of the Sun makes it the fundamental testing ground for virtually all astrophysical techniques. The signal-to-noise associated with the collection in one second of solar photons is comparable to that from a similar source at 1 parsec in 1000 years. Hence we are able to analyse solar data (in e.g. the polarimetric, spectral, temporal, or spatial domain) to a very considerable extent. Thus, we can resolve regions on the Sun only 150 km across with the latest spacecraft and ground-based instrumentation. It is these factors which, for example, have resulted in solar physics giving birth to atomic and nuclear spectroscopy in astrophysics, to cosmic magnetometry, to neutrino astrophysics, and to asteroseismology. In addition, since we are, in a sense, embedded in the outer layers of the Sun's atmosphere, and since spacecraft permit a three-dimensional stereoscopic perspective, the Sun is not so strictly 'remotely-sensed' as most cosmic objects, though it is not immune from the problems of remotely-sensed data inversion which permeates astrophysics and stretch our ingenuity to decipher what tricks the Sun is performing.

Some history

Historically it was the motion of planets around the Sun that established the inverse square gravitational force, and centuries later provided the clue, in the precession of the orbit Mercury, that Newton's gravitational theory needed a relativistic correction. The precession, together with the solar deflection of starlight, were then the first quantitative tests of Einstein's general relativity. It was observations of the structure of the solar atmosphere that made it possible to develop the theory of radiative transfer in stellar atmospheres and to discover the element helium. The observed radius and mass of the Sun provided the first clues and ultimate tests of the physics of the stellar interior. The Sun is the principal magnetohydrodynamics (MHD) laboratory for large magnetic

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Reynolds numbers (a measure of turbulence), exhibiting the totally unexpected phenomena of magnetic fibrils, sunspots, prominences, flares, coronal mass ejections, the solar wind, the X-ray corona, and irradiance variations. It is the physics of these exotic phenomena, collectively making up variations of solar activity, with which we are confronted today. The activity affects the terrestrial environment, from occasionally knocking out power grids to space weather and general climate. Not only is there a whole world of scientific mystery there, but the activity affects our living conditions on Earth.

The solar corona

The solar corona has been observed with the naked eye during a total eclipse for millennia. From the best plates, eclipse observers did produce a synthetic drawing (Figure 1), which represents one of the best observed minimum corona by the Kiev university group. This figure also shows that even at times of a deep minimum of activity, a N–S asymmetry is always present. It has only been in the past 50 years or so, however, that the solar corona was found to consist of hot plasmas with temperatures of a few million degrees, far higher than that of the photosphere. The heating mechanism of the corona still remains one of the challenging puzzles in astrophysics. It is not only the Sun that has a hot corona. It has been revealed by the Einstein Observatory that almost all stars in HR diagram (A graph on which a measure of the brightness of stars, usually their absolute magnitude, is plotted against a measure of their temperature, either spectral type or colour index. The diagram shows how the luminosities and surface temperatures of stars are linked. From a star's position on the diagram, astronomers can estimate its mass and the stage of its evolution.) emit X-rays, implying ubiquitous existence of coronae in these stars (e.g., Rosner *et al.*[1]).

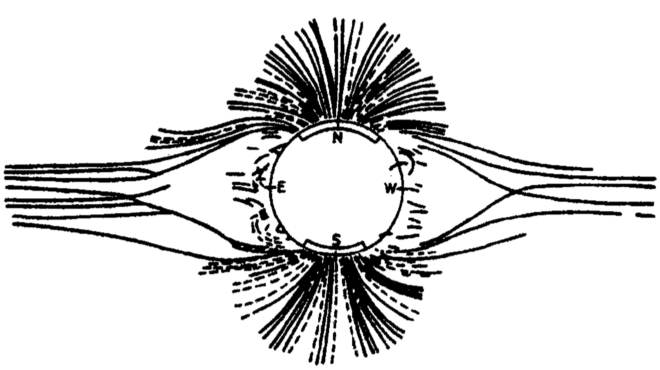

Figure 1. Structured drawing of the eclipse corona of 30 June 1954, made by the Kiev University group, from different plates. The latitude extension of polar coronal hole is drawn inside the disk. Note the asymmetry and the curvature or bending of a part of plumes. 'Dark' space or 'rift' is often observed (dashed lines).

Remarkably, X-ray luminosities from low mass stars are correlated well with their rotational velocities, which suggest that dynamo-generated magnetic fields are the ultimate origin of stellar coronae. Among other tricks of the Sun, it is one of the few places where observations and theoretical considerations may give us insight into a deeper understanding of the effects of magnetic fields. This includes its fascinating attribute that, like a biological form, it can reproduce itself. The complexities of magnetic fields are fascinating: in some cases they serve to refrigerate the gas (sunspots) while in others they serve to heat the gas to millions of degrees (active corona). The magnetic fields seem to be the main cause of unrest in the universe. All the active phenomena on the Sun, e.g. flares, jets, and even the corona itself, are the consequence of strong solar magnetic fields. How and why the magnetic energy is released in these phenomena are central issues in solar physics and plasma astrophysics.

A very brief look at the typical numbers of physical quantities in the corona will be in order. Magnetic field strength and density in the corona are respectively 1–100 gauss and 10^8–10^{10} cm^{-3}. The time scale of active phenomena such as flares is 10–100 sec (of the order of 10–100 t_A), which is longer than the electron–ion collision time $\tau_i \sim 0.01$–1 sec. Here $t_A = L/V_A$ is the Alfvén time, the time for an Alfvén wave to travel a distance L with Alfvén velocity V_A. On the other hand, the typical size for coronal phenomena ranges from $\sim 10^9$–7×10^{10} cm, marginally greater than the electron mean free path $\sim 10^7$–10^9 cm but much greater than the ion gyro radius ~ 100 cm. Hence the MHD approximation holds good in the direction perpendicular to the magnetic field. As for the parallel direction, however, the MHD approximation sometimes breaks down (such as in the flare impulsive phase). The magnetic Reynolds number ($R_m = LV_A/\eta = t_d/t_A$, where t_d is the magnetic diffusion time) is extremely high, of the order of 10^{13}, so that the dissipation process must occur in a small scale, which is of course, governed by a collisionless process, yet a subject of great debate. It should be emphasized here that these properties of coronal plasmas (magnetic Reynolds number >> 1, collisionless dissipation, etc.) are all applicable to astrophysical diffuse plasmas such as hot plasmas in galactic disks/halos and in cluster of galaxies. The plasma β (ratio of gas pressure to magnetic pressure) in the corona is much smaller than unity, i.e. the corona is made up of a low β plasma. Hence the magnetic force dominates the gas pressure force in the corona. The underlying gas layers, e.g. in the photosphere, are high β plasmas. The dynamical coupling between the low β corona and the high beta photosphere through magnetic fields is a key physical process underlying the coronal activity.

The temperature of the Sun's outer atmosphere (the corona) exceeds that of the solar surface by about two

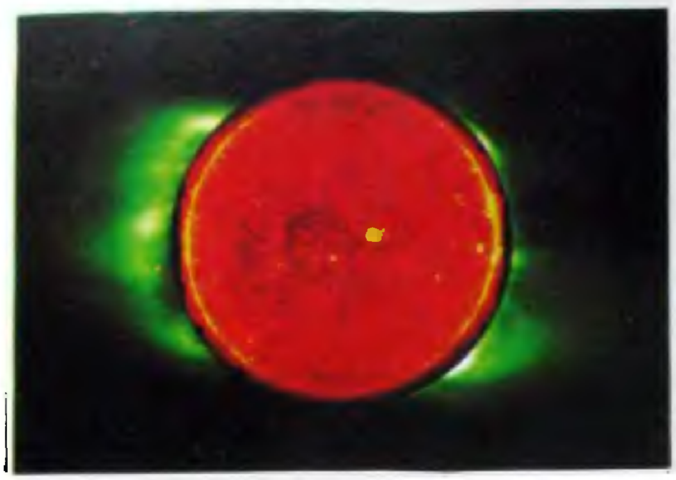

Figure 2. Hot extended corona seen in the 'green line' (Fe XIV 5303 Å) emission (LASCO/SOHO) with neon sign: 600,000 K gas on the Sun shows up in the EUV light from highly ionized neon (Ne VIII 770 Å) taken from SUMER/SOHO.

orders of magnitude, but the nature of the coronal heating has long been a mystery. The corona is a magnetically dominated environment, consisting of a variety of plasma structures including X-ray bright points, coronal holes and coronal loops. There seem to be several mechanisms at work: magnetic reconnection has been shown to heat X-ray-bright points, large scale diffuse loops may probably be heated in an MHD turbulent manner (e.g., Priest *et al.*[2] and references therein). How small loops and coronal holes are heated, is not known.

The solar wind

It is now well established that the high-speed solar wind is associated with coronal holes which are well-defined regions of strongly reduced EUV and X-ray emission (see, e.g. Zirker[3]). The speed of the fast wind is about 800 km/s, much greater than that of the normal solar wind (~ 400 km/s). The slow wind is transient, filamentary and not in equilibrium with the coronal base. The origin of the fast wind still remains a puzzle. Ever since the white-light eclipse images, providing the first evidence of magnetic field lines in coronal holes extending away from the Sun[4,5], the connection between polar plumes and fast wind streams remained intractable. This provides ground for debate whether the fast wind originated from the bulk volume of coronal holes, from polar plumes, or from both. High resolution EUV observations from the SUMER (Solar Ultraviolet Measurements of Emitted Radiation) on the spacecraft SOHO (Solar and Heliospheric Observatory) provide a special opportunity to investigate plasma parameters in coronal holes up to a distance of about 430,000 km above the limb or $r = 1.6$ $R_{\odot}$ from the centre of the disk. Analyses and interpretations of several polar coronal holes observed by SUMER have already provided important clues concerning the coronal hole plasmas[6–8]. The most surprising result that emerges from the analysis of the line width of solar ions observed by UVCS[9] as well as SUMER[10] is the large value of T_i required to fit the observations. So, there are cool electrons but very hot ions in coronal holes. It is quite clear from these observations that the fast and the slow winds originate and are accelerated in completely different ways. Observing the polar plumes, which are ray-like structures aligned along open magnetic field lines in polar coronal holes, suggest that the fast solar wind emanates from the dark inter-plume lanes. The inference of electron and ion temperatures and densities has recently been investigated from these regions[11]. For it must be recalled that any solar wind model is extremely sensitive to the input parameters, such as electron, proton and ion temperatures, electron density, element abundances, wave velocity amplitude and magnetic field. This called for high-resolution EUV observations that SUMER provides.

Magnetic energy release on the Sun

The universe abounds with examples of explosive energy release that can heat plasma to extreme temperatures and accelerate particles to relativistic velocities. In many cases, a magnetic field is the only source of energy available to power these cosmic explosions. This is the case with solar flares and many other less energetic solar phenomena. While the existence of a large reservoir of solar magnetic energy is well established, the reason for its sudden release is still debated. The widely accepted explanation is a process known as magnetic reconnection. This involves the cutting and reattachment of magnetic lines of force. Many argue that reconnection has a sound observational and theoretical basis but others counter that there is not yet definitive proof that reconnection actually occurs on the Sun. It is precisely for this reason that the new results of Innes *et al.*[12] are so important. They provide the best evidence to date for the existence of bi-directional outflow jets, a fundamental part of the standard reconnection model. Figure 3 *a* shows sequence of the Si IV 1393 Å profile obtained during two 90 min observing periods on the 21 and 23 June 1996. We see an explosive event lasting about 4 minutes. In the first 60 seconds, broad profiles with a distinct blue asymmetry are seen at just three scan positions. After 90 s the Doppler shifts have reached a maximum and the event size has almost doubled in the E–W direction. Now the profiles change from predominantly

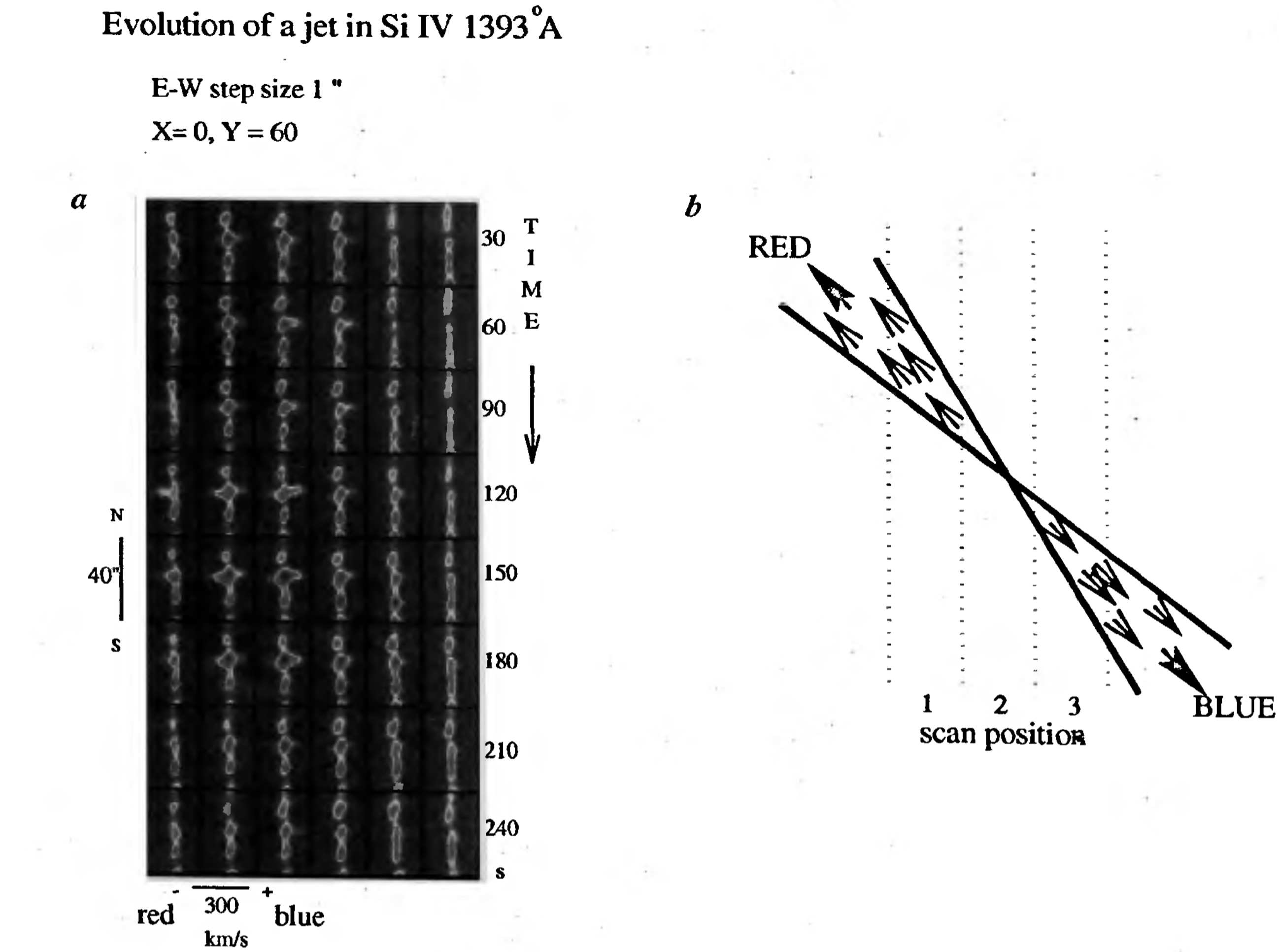

Figure 3. *a*, The jets' evolution in the Si IV 1393 Å line profiles obtained with high-resolution spectrometer SUMER on the spacecraft SOHO. Each unit in this figure shows a 40 arcsec (1 arcsec = 715 km on the Sun) section of a spectrum along the slit for Doppler velocities from – 150 km/s (red) to + 150 km/s (blue). Red shifts are to the left and blue shifts are to the right. Each row shows a single spatial raster with step size corresponding to a 1.1 arcsec displacement of the slit in the E–W direction. Time increases from top to bottom. The time between rows is 30 s. The event starts, and is centred at, column 3. The jet has propagated ~ 1 arcsec to the left and right in the 30 s between taking rasters in rows 2 and 3. The shift from red to blue line asymmetry is clearly visible in rows 4 and 5. *b*, A schematic sketch of a bi-directional jet. The expected Doppler shifts change as the spectrometer scans across the jet structure. The vertical lines indicate the line of sight at three arbitrary scan positions of the spectrometer slit during E–W raster. (From Innes *et al.*[12]).

red shifts on the left to predominantly blue shifts on the right. Over the final 90 s, the event seems to fade uniformly along its extent. The observed emission-line asymmetries are those expected from a bi-directional jet whose flow axis is directed at some angle to the line of sight, as sketched in Figure 3 *b*. Incidentally, we[13] observed a dynamic event in the solar corona as shown in Figure 4. Our results indicate knots of cold plasma forming in the corona above an active region. These knots, which are far from any observable loop, flow with velocities 100 km/s in several directions away from their formation site. This and similar results of this kind will lead to a better understanding of how the Sun's magnetic energy feeds its hot corona and the solar wind.

Coronal mass ejections

Observations made with white light coronagraphs flown on OSO-7 and Skylab in the early 1970s convincingly demonstrated that large quantities of material (10^{15}–10^{16} g) are sporadically ejected from the Sun into interplanetary space (see, for instance, Gosling[14] and references therein). Such transient ejections of material are known as coronal mass ejections (CMEs). The nature and cause of CMEs is a fundamental, yet unsolved problem in solar physics. They are often times associated with prominence eruptions and/or solar flares. We show in Figure 5, a fast CME seen as a bright intense loop on 9 May 1998 by LASCO/SOHO (Large-Angle Spectroscopic Coronagraph on board the SOHO spacecraft).

Bad weather in outer space is caused by electromagnetic storm when a blast of solar gas slams into the Earth's magnetic field at supersonic speed. CMEs generate magnetic storms on Earth, sometimes strong enough to shut down electrical power systems and interfere with communications. Modern societies, with their cellular phones and satellite navigation and communication systems, are more vulnerable than ever to electronic

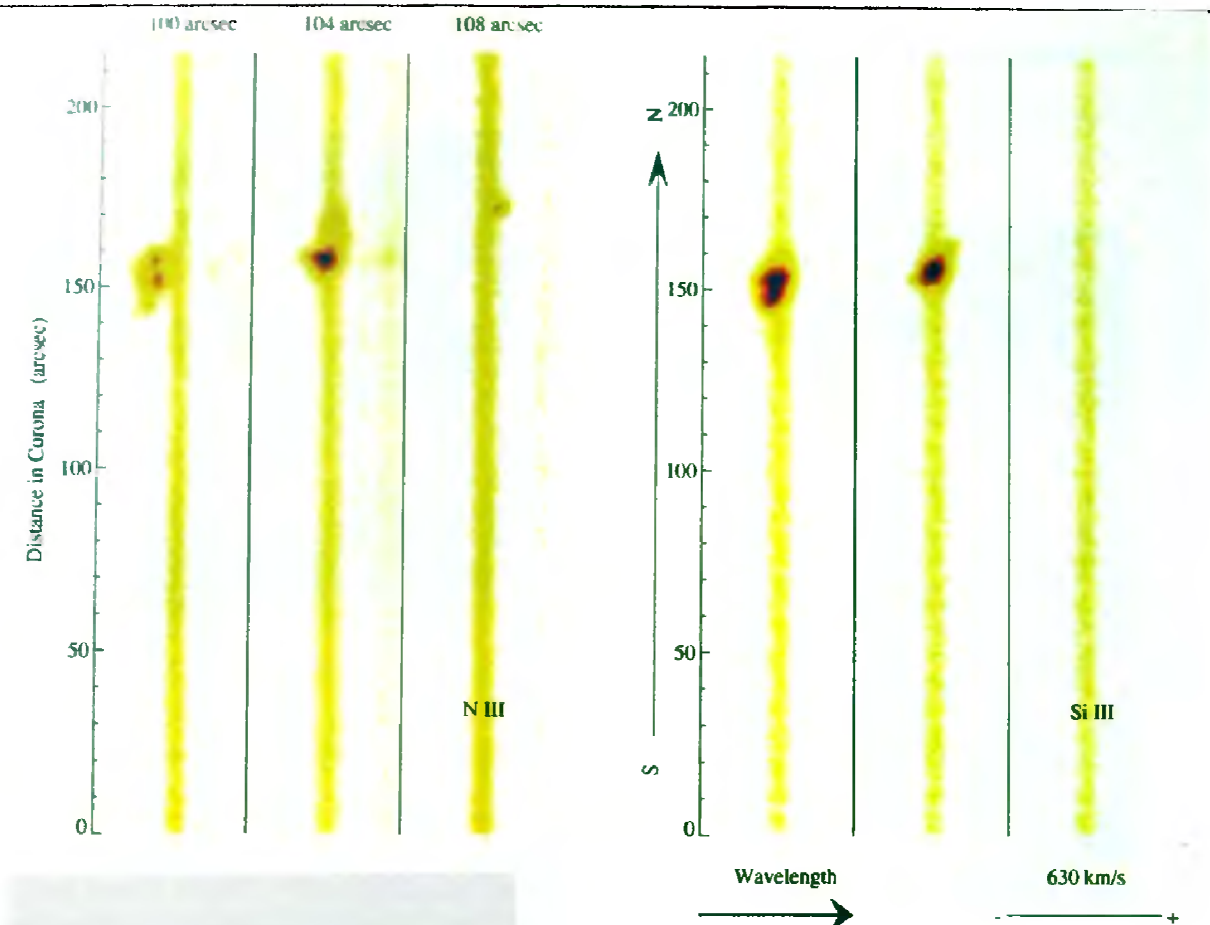

Figure 4. N III 992 Å and Si III 1207 Å emission lines along the spectrometer slit at and around the site of a dynamic event in the solar corona. Note that the emission outside the events stems purely from scattered light, and provides good indications of the rest wavelengths (From Dwivedi *et al.*[13]).

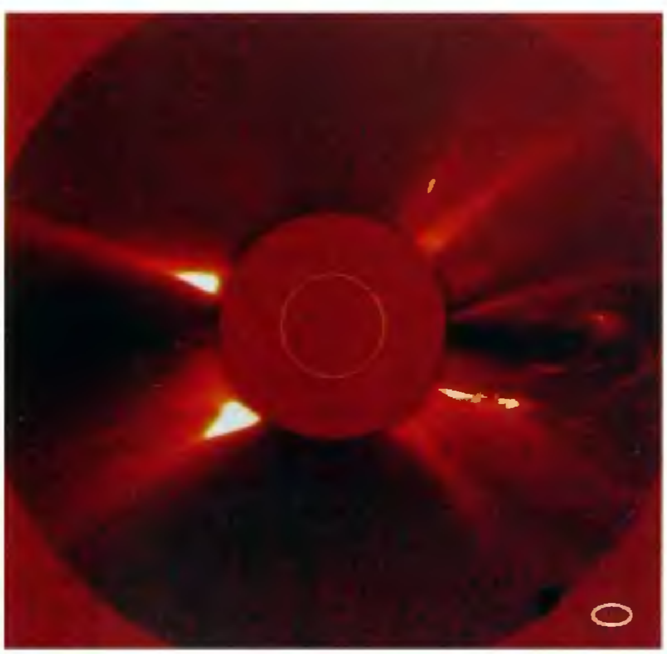

Figure 5. A fast coronal mass ejection is seen as a bright intense loop at 21:06 UT on 9 May 1998 at the S–W limb of the Sun in the white-light, observed by LASCO/SOHO. In this image, the disc of the Sun is shown by white rim while the occulter of the C2 coronagraph (observed from 1.7 to 6 solar radii) by outer circle.

disruptions. Like tethers on a hot air balloon, smaller magnetic fields hold back a larger field until the tethers break and a huge chunk of the Sun erupts into space, taking with it a huge coiled magnetic field. If the Earth's magnetic field is properly aligned, the Earth makes a magnetic contact with the Sun. And when they contact, it allows solar wind energy to get into the near-Earth environment and make storms: we are then wired to the Sun.

Concluding remarks

The SOHO generation of high-resolution observations seem to provide some clues to why Nature does it that way. SOHO's coronal instruments have yielded a bonanza of observations of a quality far superior to their predecessors[15], generating both new results and confirmations of hitherto hard-to-establish conjectures on the solar atmosphere. These observations have already substantially improved our insights into the physics of the Sun itself as well as how the solar wind and solar coronal eruptions influence the near-Earth environment.

The quakes on the Sun, tornadoes on the Sun or the storm-tossed Sun will throw light on space weather.

Engineers and scientists warn that storms in space like hurricanes and earthquakes could have a devastating impact on society. A new generation of satellites is expected to monitor space meteorology in the same way as its terrestrial counterpart. The scientific future of solar physics offers exciting prospects for the simple reason that the Sun presents more and more mysteries representing opportunities to learn new physics. And as Yeats says elsewhere, 'I will... pluck till time and times are done... the golden apples of the Sun', the objective of enthralled SOHO scientists is to unlock the secrets of our dynamic Sun.

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Groundwater contamination and health hazards by some of the most commonly used pesticides

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The groundwater contamination and health hazards by some of the most commonly used pesticides have been discussed. The persistence of pesticides in food chain has been evaluated and various factors responsible for the leachability of pesticides in groundwater have been discussed. Maximum and most possible preventions from the pesticide health hazards have been suggested.

WATER is a very important constituent of our ecosystem and so we have to preserve and improve its quality. Among various organic and inorganic water pollutants, pesticides are very dangerous and harmful because of their tissue degradation and carcinogenic nature[1]. Pesticides are bioaccumulative and relatively stable, as well as toxic/carcinogenic, and, therefore, require close monitoring. The EEC Directive[2] concerning the quality of water for human consumption, established the maximum concentration of each pesticide at 0.1 µg/l and the total pesticides concentration at 0.5 µg/l (ref. 3). A list of most commonly used pesticides with acceptable daily intake[4] is given in Table 1. The WHO has classified the pesticides into five groups on the basis of their (LD_{50} values) hazardous nature. The EPA[5] elaborated the list of properties of pesticide which indicate their groundwater contamination potential (Table 2).

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Sources of pesticide pollution

The major sources of pesticide pollution are industries, agriculture, forestry and domestic activities. However, pesticide pollution through air has also been reported. The dust particles in the air adsorbed the pesticides (due to pesticides spray in agriculture, forestry and domestic use) and then contaminate water bodies, sediments and soil through rain water[6]. The possible rout of water pollution due to pesticides is shown in Figure 1.