SOLAR ACTIVITY - II

Small-scale solar activity

Flares, microflares, nanoflares

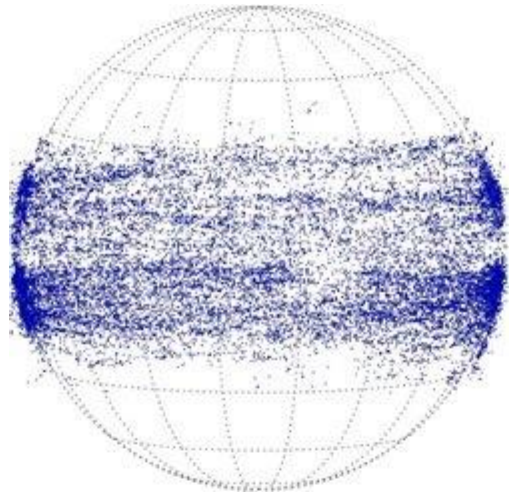

Figure 6: Spatial distribution across the solar surface of five years' worth of microflares observed by RHESSI.

Flare-like activity extends to smaller scales and to lower energies. The weakest events - nominally of order 10^{-6} of the energy of a major flare - are the *microflares*. Parker proposed the term *nanoflare* for still weaker events hypothetically associated with the formation of current sheets and their dissipation. The sticking and slipping of the coronal plasma between these temporary static equilibria, the *nanoflares*, would then constitute the heating mechanism involved with the extraction of magnetic free energy in the coronal magnetic field stressed by random footpoint motions. The nanoflares would be essentially too numerous to recognize individually, and perhaps not surprisingly no unambiguous evidence for their existence has yet appeared. The microflares, however, are easy to observe by a variety of techniques because of their isolated spatial and temporal distributions.Figure 6 shows their spatial pattern for a five-year interval of time, establishing their strong association with the sunspotregions. The occurrence distribution function for solar flares and microflares, and for stellar flares, tends to follow a flat power law in peak flux F, such as $F^{-1.8}$. Its flatness implies that the most energetic events dominate the total flux of all flares taken together, rather than the more numerous smaller events.

X-ray bright points

The last image in the sequence of Figure 1 (the rightmost one) shows a solar-minimum corona. The obvious X-ray emission comes from only a few *X-ray bright points*, phenomena originally discovered with the Skylab soft X-ray telescopes and their rocket-borne predecessors. The bright points tend to have a uniform and timeinvariant distribution across the solar surface, as expected from magnetic fields associated with the surface convective flows (the supergranulation of the quiet photosphere) rather than with the active-region fields responsible for sunspot fields.

Activity in the lower atmosphere

In addition to the flare-like phenomena, small-scale activity takes other forms. In the lower atmosphere the jet pattern persists, though "true" flares appear to require coronal conditions. Thechromosphere contains a great deal of dynamic activity that is being sorted out by high-resolution observations; the topics include spicules as well as jets and may not involve the high temperatures (above a few 10^6 K) that characterize flares. Many names are associated with this small-scale activity: jets, turbulent events, network flares, blinkers, explosive events, X-ray bright points, Ellermann bombs, evanescent active regions, etc.

Finally, at the very base of the solar atmosphere and in fact embedded into the photosphere, one finds the G-band bright points and the faculae. These are bright elements resulting from the*hot walls* of granulation adjacent to intense magnetic flux tubes. This effect results from the reduced opacity created by the substitution of magnetic pressure for gas pressure within the flux tube. There is a tight relationship between photospheric faculae and chromospheric plage, but the hot-wall model does not comment on this and the actual physics remains unclear.

The excess luminosity of faculae alters the total solar irradiance subtly but detectably, as do the sunspots. In more extreme stars this effect can be much larger, and interestingly can reverse the phase of the cyclic brightness variations relative to the solar pattern, where sunspot area maximum corresponds somewhat non-intuitively to the phase of maximum brightness. At solar maximum the Sun is some 0.1% brighter than its solar-minimum level. In more active stars the magnetic activity may have substantial impacts on basic stellar parameters, such as the luminosity, and probably therefore have substantial effects on the stellar structure itself.

Particle acceleration, magnetic reconnection, and energetics

Media:Solar activity cme.mpg

Particle acceleration forms an integral part of solar magnetic activity, in the sense that the corona exhibits the sudden transient effects (flares, CMEs, jets) described above. In most cases the release of energy does not involve *heating* as such, but rather *particle acceleration*, in which the distribution function of the plasma becomes highly anisotropic and non-Maxwellian. The movie to the right (click to activate) shows the results of strong particle acceleration by a CME, probably associated with thecollisionless shock wave driven ahead of it into the solar wind. In general the acceleration of high-energy particles dominates flare energetics, even on the small scales of the microflares.

The flare component of a major event (i.e., its electromagnetic radiations) and the CME component (its mechanical effects) can each consume as much as 10^{32} ergs in extreme cases. The relatively low Alfvén speed in the photosphere precludes any sudden injection of energy from this reservoir, and so in general terms we know that the energy of the event must come from a slow accumulation in the coronal magnetic field, followed by a sudden release and partition into the observed forms. We are sure that magnetic reconnection describes some of the important effects, we do not presently understand the physics of the instability that results in the flare and/or CME. Note that the coronal plasma has a low plasma beta, meaning that non-magnetic forces such as gravity cannot play a significant role in the energetics.

Analogs

Stellar activity

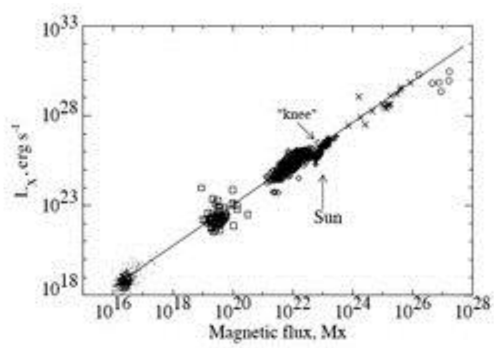

Figure 7: Correlation of X-ray brightness and magnetic flux, from solar features through M dwarf stars and T Tauri stars.

Generally solar-type stars have the combination of rotation and convection necessary for the existence of complex surface magnetic fields, and hence stellar activity. This stellar magnetism then leads to solar-type activity, including starspots, stellar flares, and presumably other analogous and also unique forms of energy release. Related activity can also take place in various binary stellar systems and during the early life of newly formed stars; during the T Tauri phase there may be rapid rotation and an accretion disk, and activity occurs at levels much higher than the current solar level. The occurrence of related forms of magnetic activity across a broad spectrum of astronomical objects complements studies of solar activity, for which it is impossible to vary the rotation or gravity, for example, as a means of empirical understanding of the dynamo mechanism.Figure 7 shows the generality of the correlation between activity, as measured by X-rays, and magnetic flux.

Aurorae

Weaker forms of plasma activity occur in planetary magnetospheres. The terrestrial aurora and its linkage with the magnetosphere and itsgeomagnetic tail provide several often-discussed analogies to flares and CMEs. The drivers of geomagnetic activity include themagnetopause and the ionosphere. Note that these structures do not have strict analogs in the solar case. More importantly than the analogies, though, *space plasmas* provide a laboratory for the *in-situ* study of important plasma-physics concepts involving conditions (such as collisionless shock waves) that are difficult to reproduce in the laboratory. The microphysics is of course completely impossible to study in solar or stellar environments by remote-sensing techniques, but not so to spacecraft capable of measuring particles and fields within these space plasmas directly down to the Debye scale. In the domain of space plasma physics, one can in principle obtain full measurements of the particle distribution function and the 3D structure of the plasma.

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