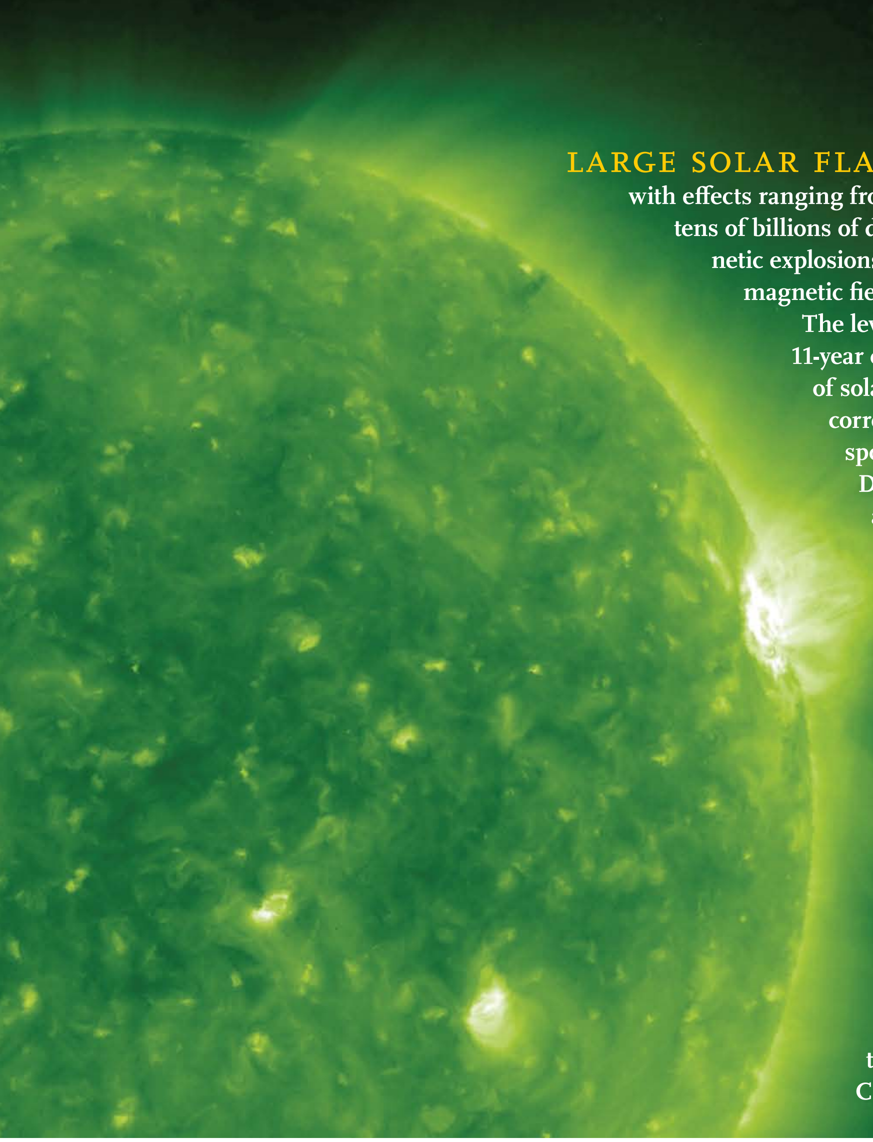
A Sunspot's Tale

An isolated, flaring active region on the Sun has surprised astronomers.

MICHAEL WHEATLAND



SOHO (ESA & NASA) X2

LARGE SOLAR FLARES strongly influence our local space weather conditions, with effects ranging from enhanced (and beautiful) auroral displays to the prospect of tens of billions of dollars of damage to communications satellites. Flares are magnetic explosions in the solar atmosphere, in which energy stored in the intense magnetic fields of sunspot regions is suddenly released.

The level of solar activity on the Sun (including flares) varies with an 11-year cycle, and we have recently experienced an extended interval of solar minimum, with remarkably few sunspots on the Sun, and correspondingly low levels of activity. The year 2008 was the most spot-free on the Sun since 1913, and the last large flare occurred in December 2006. However, 2010 saw the return of spots to the Sun, and the genuine onset of solar cycle 24. This is good news for solar astronomers and just in time for NASA's new major solar satellite, the Solar Dynamics Observatory, but it also portends more dangerous space weather conditions.

In late October of last year, the Sun produced one of the first flaring sunspot regions of the new cycle: active region 11029. This little region emerged on the disk and initially seemed unremarkable, but it proved to be prodigiously flare-productive. The region also appeared to break a basic rule describing how flares are produced.

There are always more small flares than big flares, and the number of events as a function of their size follows a simple rule: a power-law distribution. One measure of the size of flares is their peak flux in X-rays as observed by the GOES (Geostationary Observational Environmental) satellites. The largest flares are X-class events, followed by M- (moderate size) and C-class (small) events. X-class flares have a peak flux ten times that of M-class events, which are ten times bigger than C-class events. The power-law distribution means that the ratio of

Facing Page: Active region 11029, observed at the limb of the Sun in the extreme ultraviolet by the STEREO A (Ahead) spacecraft on 6 November, 2009. This spacecraft is ahead of the Earth on its orbit.

the number of events that are at least M-class to the number that are at least X-class is the same as the ratio of the number that are at least C-class to the number that are at least M-class. This rule is closely observed by flaring active regions, and few deviations from it have been reported since it was identified in the 1950s from radio data. However, we know that it must break down for very large sizes: the strict rule implies a finite probability of a flare of arbitrary size, capable of wiping out life on Earth!

I have studied flare statistics for a number of years, applying methods of Bayesian probability to the task of counting flares. Bayesian probability is a powerful approach to scientific inference (the determination of the parameters of a model and testing of the model based on observational data) based on Bayes' theorem, introduced by the Reverend Thomas Bayes in a posthumous paper in 1763. Pierre-Simon Laplace developed Bayesian methods, and in 1818 applied them to accurately determine the mass of Saturn from contemporary data.

There have been many prominent Bayesians, including the economist John Maynard Keynes, but the theory was largely out of favour prior to the first half of the 20th century. It has enjoyed a resurgence with the advent of computers permitting Bayesian calculations previously considered intractable, and is now popular in many fields including astronomy and astrophysics.

Active region 11029 presented a unique opportunity for a careful study of flare statistics because the region produced flares when there was no other activity on the Sun, so the flares from the region could be counted and measured free from background effects. The region produced more than 70 flares as counted by the GOES satellites, but all were small: there were no M-class events. This immediately piqued my interest. Did the region follow the ubiquitous power law?

I applied Bayesian methods to the problem, and found that active region 11029 does not follow the power law: there are too few large events given the observed number of small events. A Bayesian hypothesis test (model comparison) indicates that a model with an upper departure from the power law is about 200 times more probable than the simple power law, given the data. This result represents the first strong evidence for departure from the power law for an individual active region, and a paper presenting the analysis appeared in the 20 February, 2010 issue of the *Astrophysical Journal.*

Active region 11029 was small and highly flare-productive, an unusual combination. Its small size means that it has a limited amount of magnetic energy available for flaring, and its rate of flare production suggests that it should be using up that energy rapidly (although the energy is subsequently replenished by distortion of the magnetic field by photospheric motions and emergence of new magnetic flux). The appearance of a departure from the power-law distribution most likely reflects the region attempting to produce a flare with more energy than is available at a given time. This is an unusual occurrence: most highly flaring active regions are large and have more energy available than the biggest flares they produce. Correspondingly, they do not show a departure from the power law.

The result may have a practical use: the size of the departure from the power law reflects the total magnetic energy available for flaring, and hence indicates a maximum possible flare energy. This sets a limit to the space weather damage that a region can cause. Similar careful studies of flare statistics for other regions may permit determination of this quantity, with resulting advantages for solar flare prediction and space weather forecasting. The tale of active region 11029 may prove telling. ✦

THE SUN WILL RISE

Laplace also famously used Bayes' theorem to estimate the probability that the Sun will rise tomorrow. His estimate was $(N+1)/(N+2)$, where N is the number of days the Sun has already been observed to rise.

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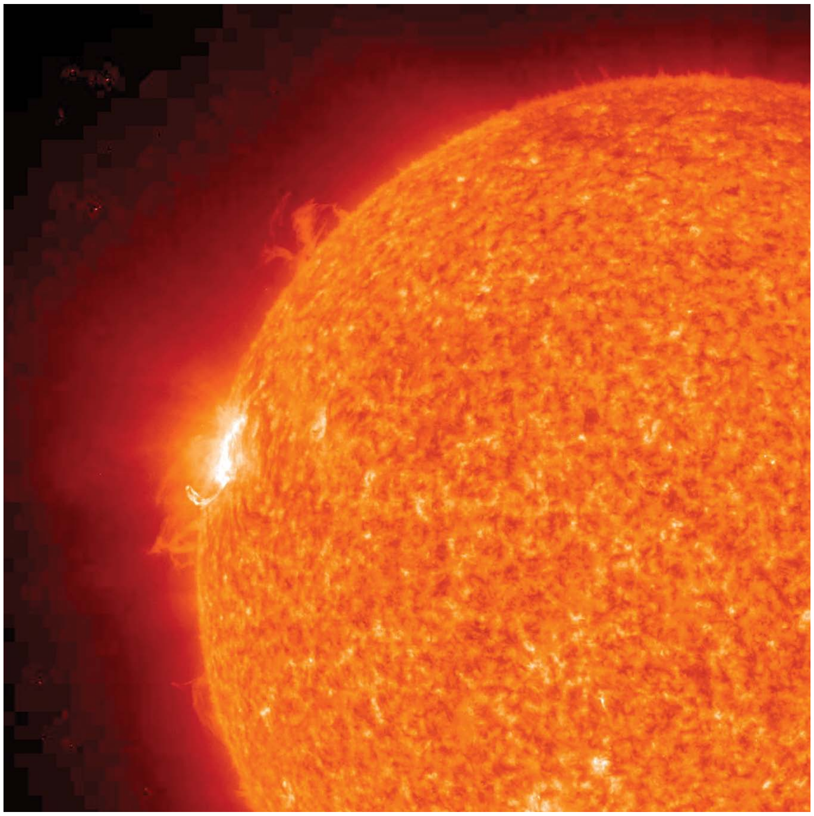

Sunspot region 11029 made a second transit of the disk of the Sun starting on 13 November, 2009, but was no longer flare productive. It is observed here in the extreme ultraviolet by the SOHO spacecraft rotating into view at the east limb.