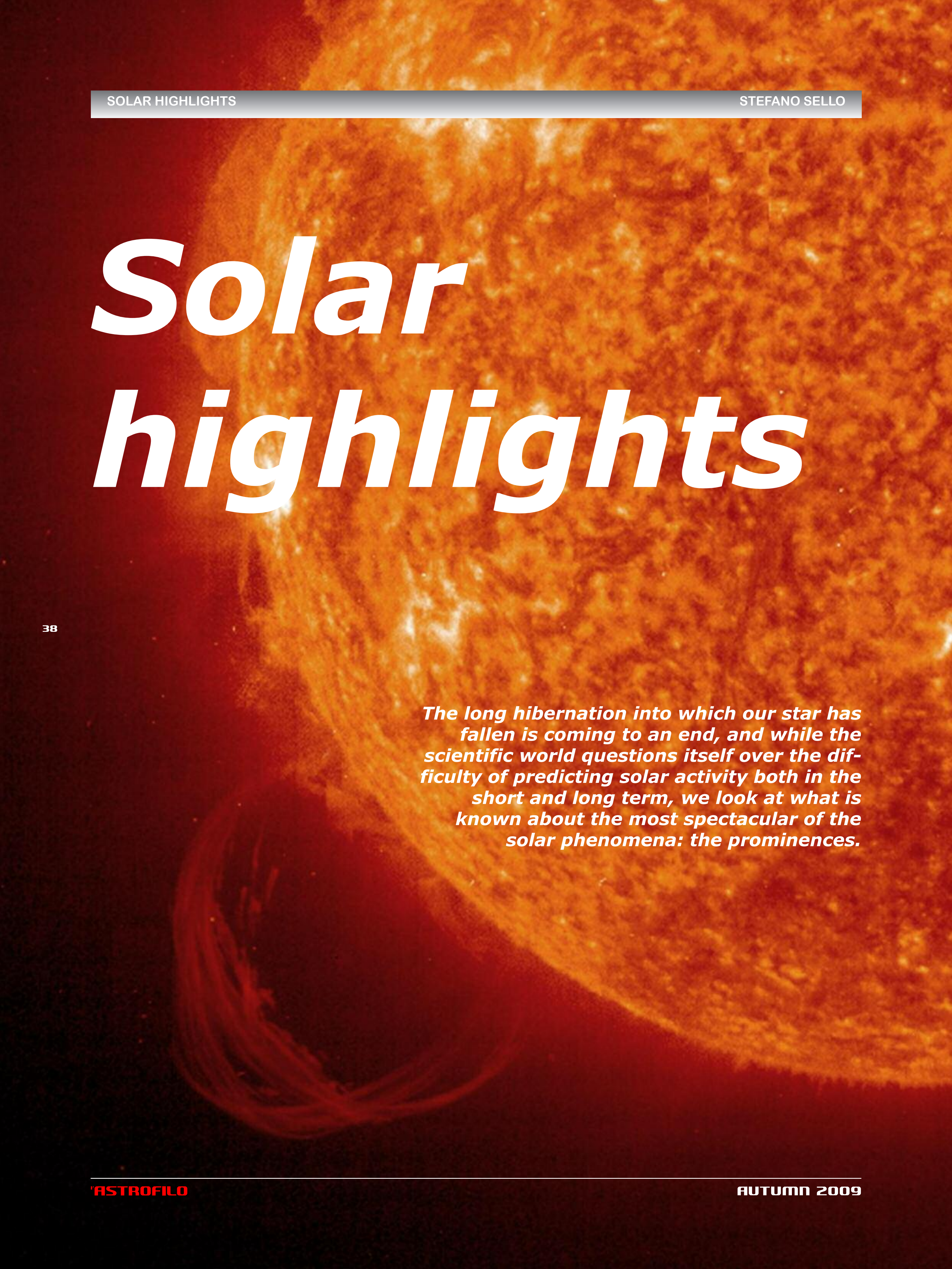
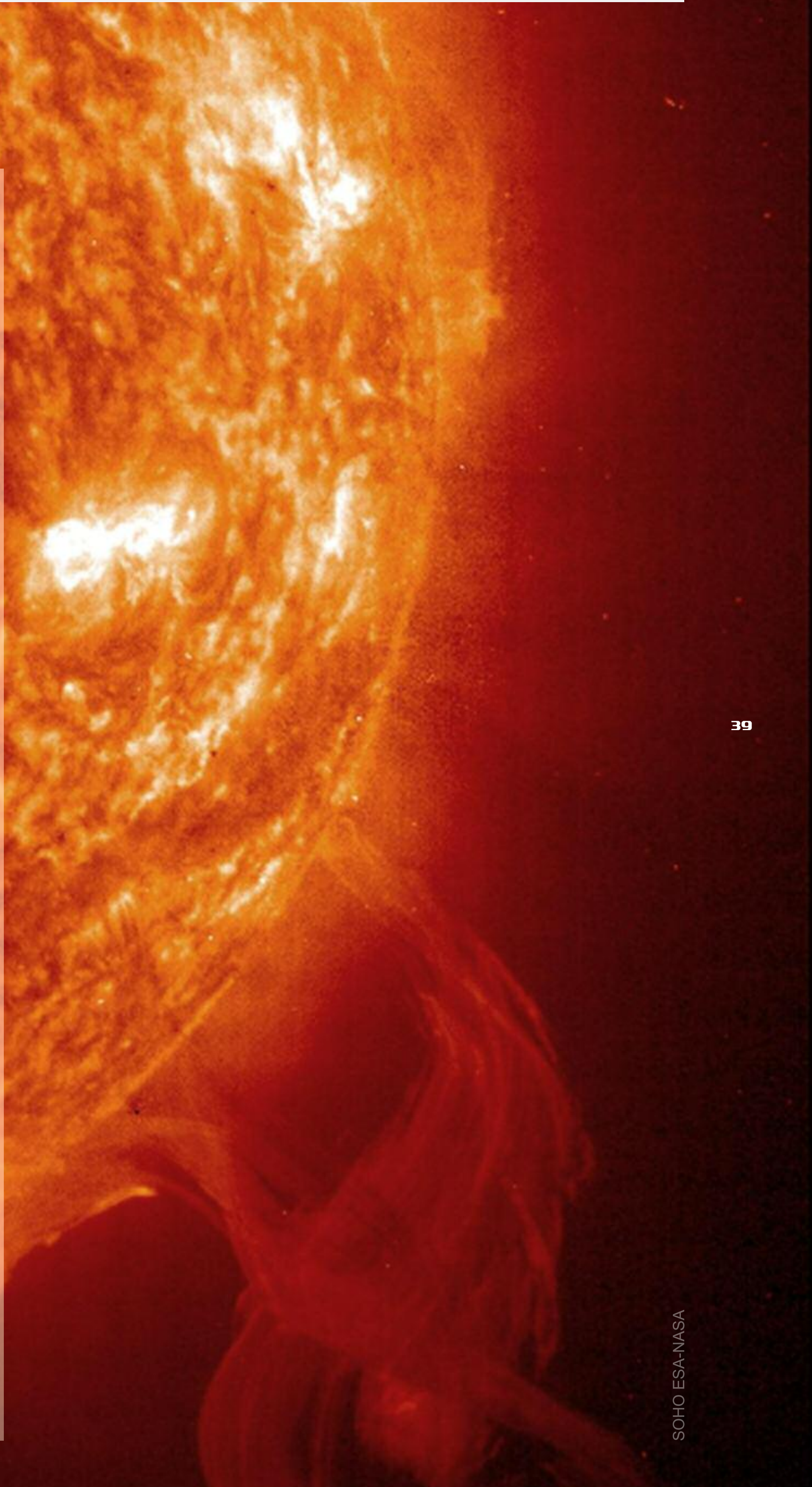


Solar highlights

The long hibernation into which our star has fallen is coming to an end, and while the scientific world questions itself over the difficulty of predicting solar activity both in the short and long term, we look at what is known about the most spectacular of the solar phenomena: the prominences.



SOHO ESA-NASA

Of all the phenomena observable on the Sun, the prominences are certainly among the most spectacular and fascinating for their morphological richness and dynamical evolution.

Although the first correct interpretations of prominences as "clouds in the solar corona" go back to about the mid eighteen hundreds, their documented scientific observation goes back to medieval times, where, however, there was no lack of exotic, to sat the least, explanations.

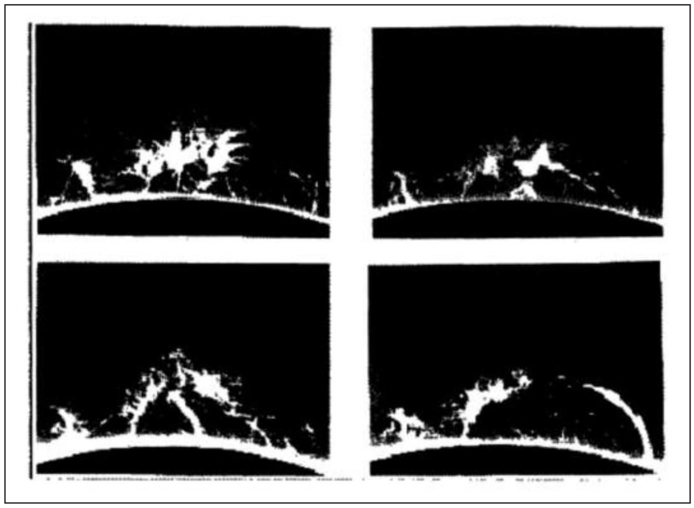
The history of study of the prominences we tend, for convenience, to sub-divide into three periods: 1) speculative, pre 1860, 2) photographic and spectroscopic, between 1860 and 1960, 3) polarimetric, after 1960 (Tandberg-Hanssen, 1995, 1998).

During the speculative period it is clear that the only way to observe the solar prominences was during total solar eclipses. Chistyakov's research on historic eclipses lead to date the first annotations of a possible prominence to 1375 B.C. in Chinese engravings.

More cautiously, Wang and Siscoe, studying various archaeological Chinese records, suggest that the period between 1339 and 1280 B.C. is likely to have seen the first phenomenological description of the solar corona and/or prominences. According to Littman, Wilcox and Espenak, the first certain record of prominences is more recent and dates from 334 A.D. and was due to Giulio Firmicio di Siracusa.

Secchi, in 1875, describes an observation by Muratori in 1239 during an eclipse in which he describes a "flaming hole" in the corona, that very probably was nothing else but a prominence, may be within a cavity. Vyssostky, in 1949, reports that various Russian chronicles from the Medieval era cite phenomena that could be associated with prominences. Sviatsky, in fact, in 1923 cites as the first reliable description of prominences that in the Novgorod chronicle of the eclipse on 1st May

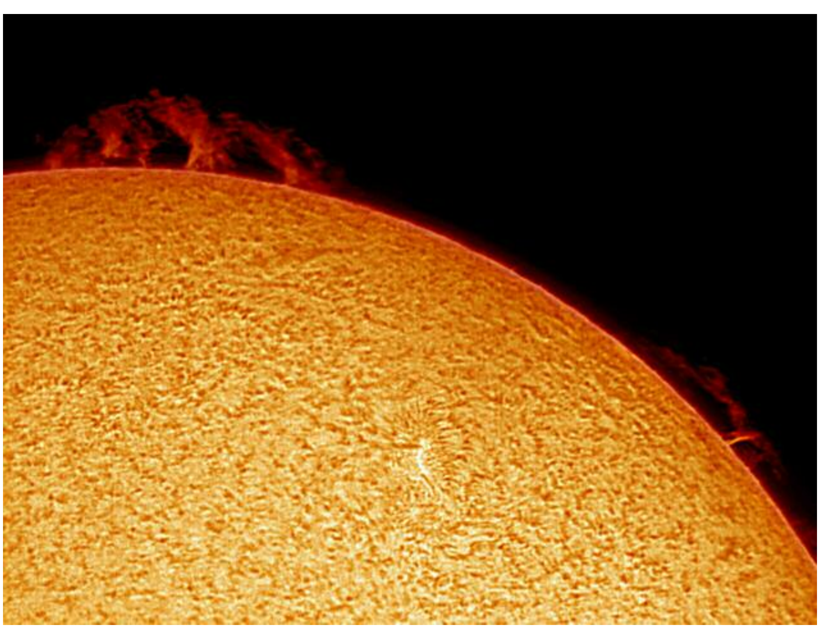
1185. But historians agree that the first description on a scientific basis goes back to the eclipse of 2nd May 1733 in Gothenberg in Sweden. On that occasion, Vassenius observed three or four prominences completely separated from the lunar disk, interpreting them as "reddish clouds in the lunar atmosphere", a plausible explanation at the time, bearing in mind also the circumstances of the observation. Secchi (1875) reports that *"...of all the ancient observations the most detailed is that which Vassenius made in Gothenberg on 2nd May 1733. In the corona, that he attributed to the lunar atmosphere, he saw various fluctuating red clouds; one of these seemed larger than the others and appeared to be composed of three separate superimposed masses, completely separated from the lunar disk"*. In 1778 Ulloa, from an unspecified location, describes the observation of an active prominence, interpreting it as a "hole in the Moon".



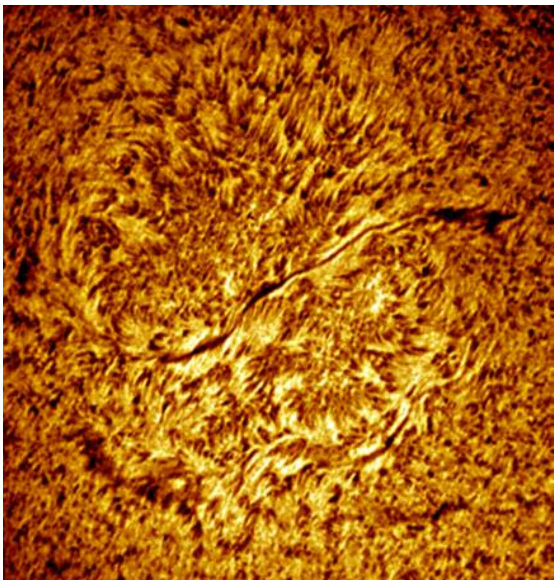
Photographs of prominences taken by Lyot with his coronograph in 1937. [Paris Observatory, Meudon]

All of these early observations of solar prominences were forgotten in the following years, until the observation of the famous eclipse on 8th July 1842, visible in France and Italy. Finally, the observations by Baily, Airy, Arago, Struve and others lead to the correct interpretation of the prominences as solar phenomena, but the consensus was anything but general, due to the inaccurate description of the shape and position of the prominences, mainly due to the fact that the spectacle was completely unexpected.

Secchi (1875) reports: *"During the eclipse of 8th July 1842, the astrono-*



CCD image made on 23rd April 2006 of a quiescent (left) and active (right) prominence using narrow-band interference filters centred on the H-α line. [HASO - Pisa]



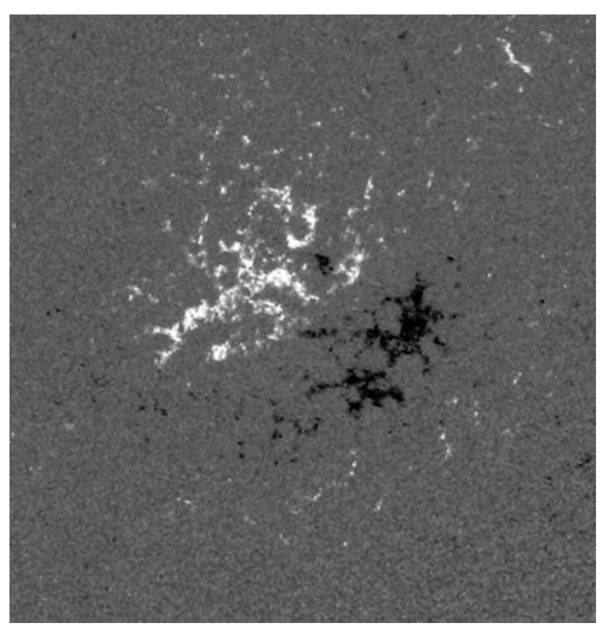
Enormous "active" prominence (intermediate type) (> 555,000 km, just under 0.8 Rs) seen on the solar disk as a filament on 10th October 2005, associated with the large active region AR10808 after its decaying phase.
These images enable the study of the properties of the chromosphere in the vicinity of filaments. [HASO - Pisa]

mer's attention was drawn by prominences that emanated from around the Moon like gigantic pink flames [...] *The surprise that this unexpected phenomenon caused did not allow precise observations to be made, creating a complete disagreement between the different reports*". Many, in fact, maintained that the prominences were lunar phenomena, like clouds or mountains (Grant, 1852). Only with the eclipse of 28th July 1851, observed in Norway and Sweden by Airy and Carrington, does an interpretation emerge that will later be confirmed: "the prominences are solar nebular formations". The physical nature of these clouds was naturally yet to be determined. In this same year the first image of a total solar eclipse was made; a daguerreotype by Berkovski.

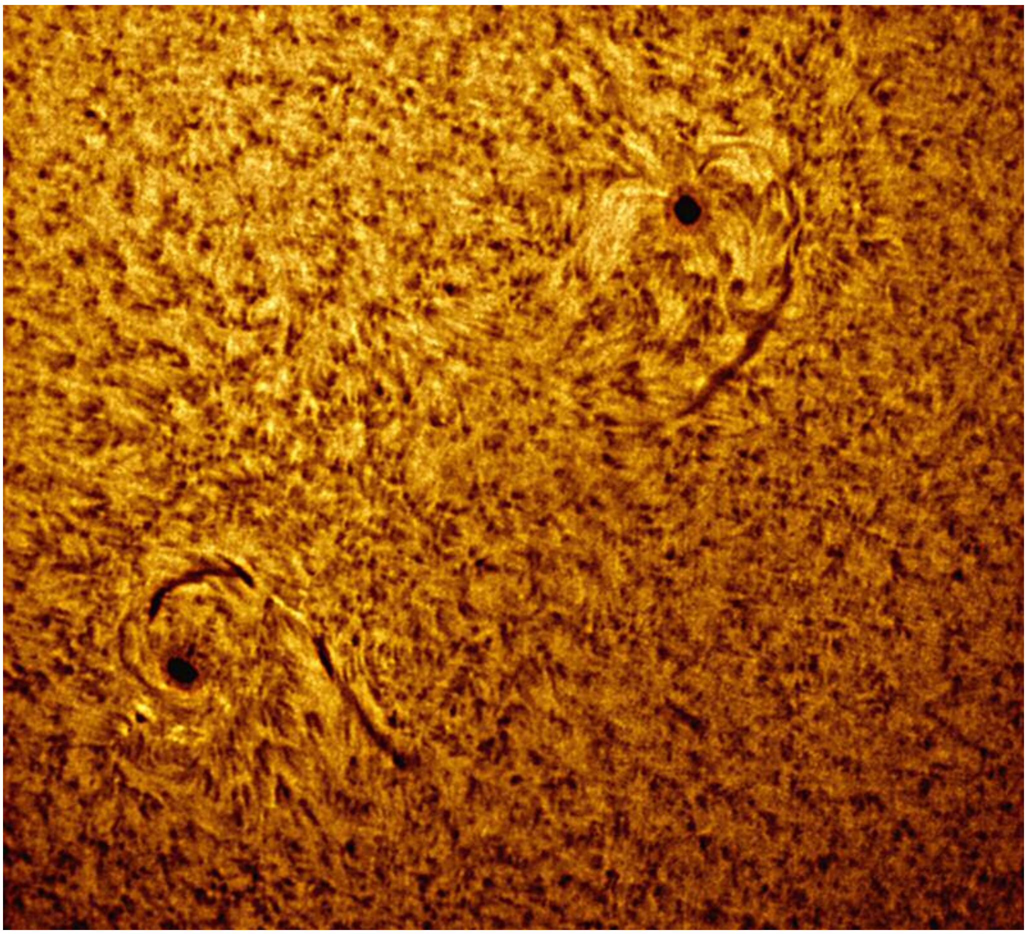
1860 represented a turning point in the study and interpretation of solar prominences with the introduction of photography during the 1860 eclipse in Spain.

Secchi, following the photographic observations and the visual observations of the 1851 eclipse, concludes as follows: 1) the prominences are not due to some optical illusion: they are real phenomena and originate from the Sun; 2) the prominences are masses of luminous material with great vivacity and remarkable photogenic activity; 3) there are masses of prominence material suspended and isolated like clouds in the atmosphere; 4) as well as the prominences there is a layer of the same material that completely surrounds the Sun (here Secchi was referring to the chromosphere); 5) the number of prominences is incalculable; 6) the height of the prominences is remarkable (2 or 3 arc minutes, or about 90,000 to over 130,000 km).

Spectroscopic techniques, combined with photography were used by the same Secchi and de la Rue, who applied spectroscopic observations for the first time during the eclipse of 18th August 1868 in India and the Malay peninsula, with the



Magnetogram taken on the same day as the previous image, in which it can be seen how the filament divides the region into opposite magnetic polarities (black areas have negative, and white areas have positive polarity). [SOHO MDI ESA-NASA]

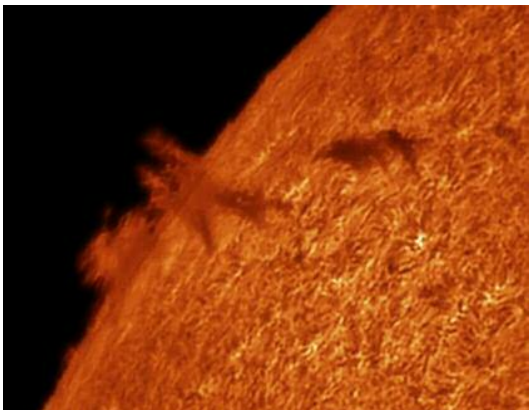


Filaments associated with the active regions AR10940 and AR10941, taken on 4th February 2007. In the lower left filament there is a clear region seen in emission, more luminous than the surrounding chromosphere. [HASO - Pisa]

aim of studying "the chemistry of the prominences". The main result obtained was that the spectra of the prominences consist of bright lines, which supported the physical interpretation of these as masses of luminous gas.

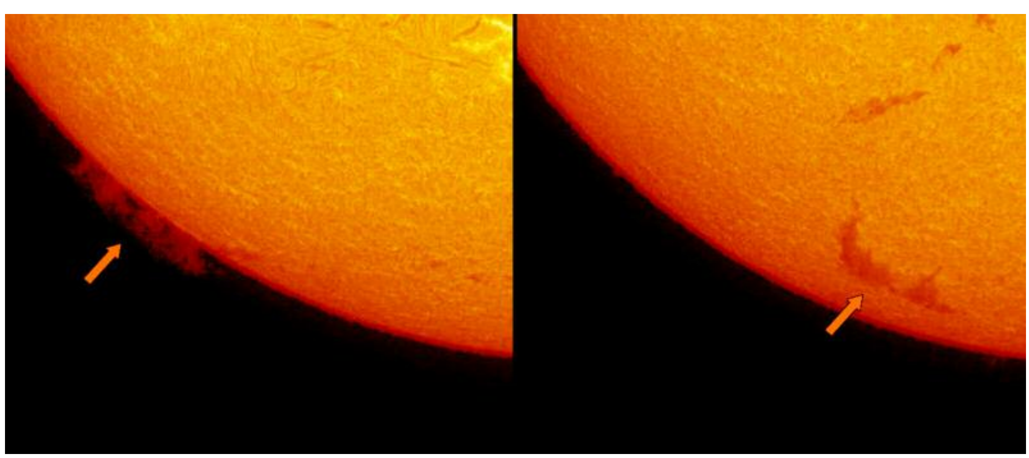
A fundamental development followed this eclipse: Janssen realized that the emission lines were bright enough to be detected even outside eclipses. The day after the eclipse, he positioned the slit of his spectrograph beyond the limb of the Sun and observed the emission lines from the prominences in full daylight. Independently and contemporaneously the same kind of observation was carried out by Lockyer, that in the same year published the famous 2-part article "Spectroscopic Observations of the Sun", where, besides, he coins with Sharpey the term "chromosphere", to indicate the dynamic and brightly coloured envelope that surrounds the Sun, above the photosphere, until its outer boundary with the corona, already noted by Secchi in 1851.

Another fundamental step in the study of prominences is made in 1892, when Hale develops the spectroheliograph and makes it available the following year to Deslandres. But 1936 is probably the decisive year for the modern study of prominences, with the introduction by Lyot of bi-refringent filters and the coronograph, that make possible systematic and continuous observations of prominences. On page 40 (top) some of the first observations of Lyot are shown from June 1937, collected later in the famous review of



Quiescent prominence seen simultaneously projected onto the disk (in absorption) and on the limb (in emission). Narrow band H-α image (<0.5 A) from 1st May 2008. [Pete Lawrence, Selsey, West Sussex, UK]

d'Azambuja in 1948, student of Deslandres and pioneer of the modern study of prominences.
The following polarimetric period begins in 1961 when the solar physicists Zirin and Severny measure the magnetic field in a prominence for the first time, using the well-known effect of the doubling of spectral lines in magnetic fields, called the "Zeeman effect". In fact, already in 1908, Hale, using the same principle measured the magnetic field within active sunspot regions, but only thanks to the polarization characteristics of the Zeeman effect was he also able to measure the weaker magnetic fields of the prominences, that vary from a few Gauss for quiescent prominences to a few hundred Gauss for the active ones.

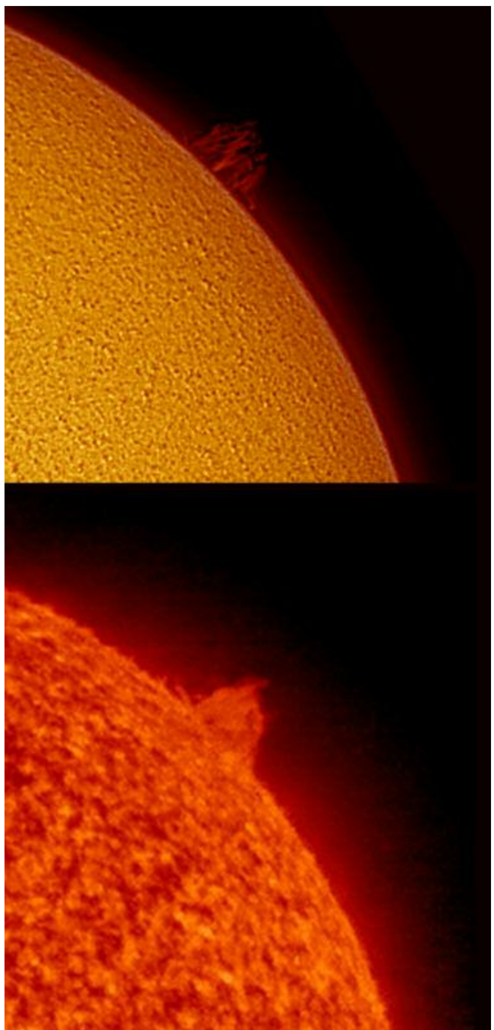


Quiescent prominence seen on the solar limb (left) and projected onto the disk (right) 4 days later. H-α images of 26th and 30th August 2001. [Big Bear Solar Observatory]

The nature of prominences

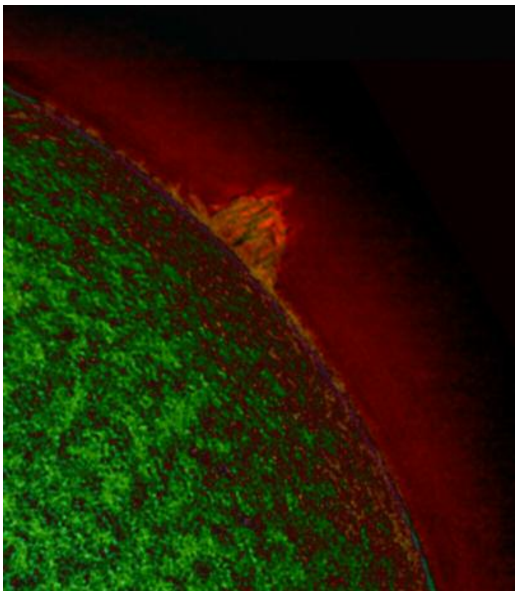
Starting in 1951 interpretation and modeling of the physical nature and principal characteristics of prominences began. We cite the first model of Menzel that shows how a magnetic field can support a prominence in equilibrium with gravity. More refined models followed, like that of Dangey in 1953, that of Kippenhahn-Schluter in 1957 and others, aimed at explaining on the basis of the observed magnetic fields, the support of the prominences in the chromosphere and corona. Contemporaneously, another area of study was aimed at understanding the nature of the plasma in the prominences, initially ignoring the presence of magnetic fields and considering only the factors of temperature, density and velocity (Jager, 1959, Jefferies & Orrall, 1963).
The most recent models try to understand the internal structure and the thermodynamics of the prominences, considering also magnetic support within three dimensional models. These are able to reproduce the observed dynamics via, for example, processes of magnetic reconnection (important for explaining solar flares), intimately connected to the large-scale magnetic structure of the solar corona.
Following Tandberg-Hanssen (1995) we can summarize the three essential cha-

racteristics of the prominences: 1) there is no well-defined canonical prominence with which to compare others, even though in general terms a prominence can be defined as a region of the chromosphere or corona that is denser and colder than the surrounding environment; 2) no structure can be considered as isolated from its surroundings, but will have strong connections and interactions with the chromosphere and corona, and 3) no prominence has a uniform and homogeneous structure, and further, all prominences are dynamical structures even if on different spatial and temporal scales.
Even bearing in mind the above limitations, it is still useful for the study of the physical nature of the prominences to divide them into two general classes, common amongst the various classifications proposed: quiescent prominences, or those associated with calm regions chromospheric regions, and active ones, or those associated with active photospheric and chromospheric regions (Pettit, 1925-1932; Newton, 1934; Menzel & Evans, 1953; Severny & Khoklova, 1953; de Jager, 1959; Zirin, 1966).
A separate discussion, instead, is reserved for a third class, that of the eruptive prominences (quiescent or active structures that become unstable, are ejected on short time-scales and disappear, diffusing into the corona), to which the explosive, transient coronal phenomena called (Coronal Mass Ejections, CME) belong.



Comparison between two simultaneous images of a quiescent prominence taken in the visible H-α (top) and in the ultraviolet HeII (bottom) on 26th August 2008 at 07:19 UT. [HASO - Pisa, SOHO ESA-NASA]

The main characteristics that define the first two classes are: the dimensions, large in the case of quiescent prominences (from 60,000 to 600,000 km in length and from 4000 to 15,000 km in width); the temperature, lower for the quiescent class (from 5000 to 8000 K); the magnetic field, lower in the quiescent case (from 4 to 50 G); the plasma velocities lower for quiescent (from 0.5 to 5 km/s or from 10 to 20 km/s).
On page 40 (bottom) we see an H-α image in which both quiescent and active prominences are present simultaneously, while on page 41 (top) we see an example of an enormous active prominence (or intermediate according to Zirin) imaged on the solar disk (a filament) in October 2005. This was associated with the active region AR10808, one of the largest and most dynamic of the recently ended cycle 23.
Comparing H-α images of the solar disk with the corresponding magnetograms, it

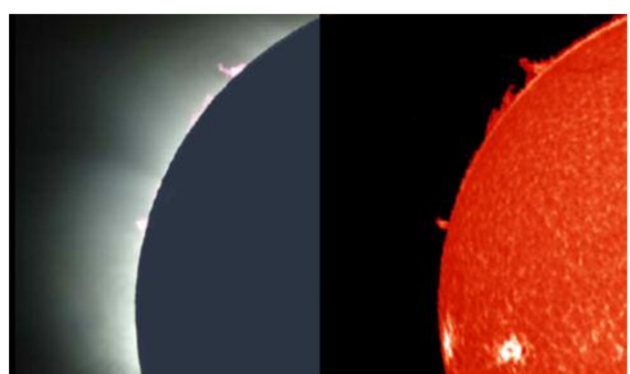


Digital manipulation that shows the difference between the two previous images, giving information on the spatial distribution of temperature and density within the prominence. The image is black in regions where there is no difference. [HASO - Pisa, SOHO ESA-NASA]

has been possible to determine that filaments and prominences generally follow lines in the magnetic field that have a null longitudinal component, that have the special property of dividing and separating regions of opposite magnetic polarity. Filaments projected onto the solar disc appear dark, in absorption, with respect to the surrounding chromosphere. Only rarely does a filament associated with a large active region appear in emission, and therefore brighter, when projected onto the disk, as happens with flares. An example of this kind is shown on page 42, where two large active filaments can be seen associated with and curved around the large regions AR10940 and AR10941, imaged on 4th February 2007. A significant part of one of the filaments appears in emission, this phenomenon has a relatively brief lifetime with respect to that of a filament. The extraordinary image, almost with a 3D effect, at the top of page 43 shows instead how a prominence projected onto the solar disk normally appears dark, in absorption; while the same one, if viewed at the same time on the limb appears bright, that is, in emission.
Another nice example of how prominences appear bright if seen at the solar limb, but dark if seen on the disk is shown again on page 43 (bottom), where the shift and the change of appearance of a large quiescent prominence is seen over the course of four days.

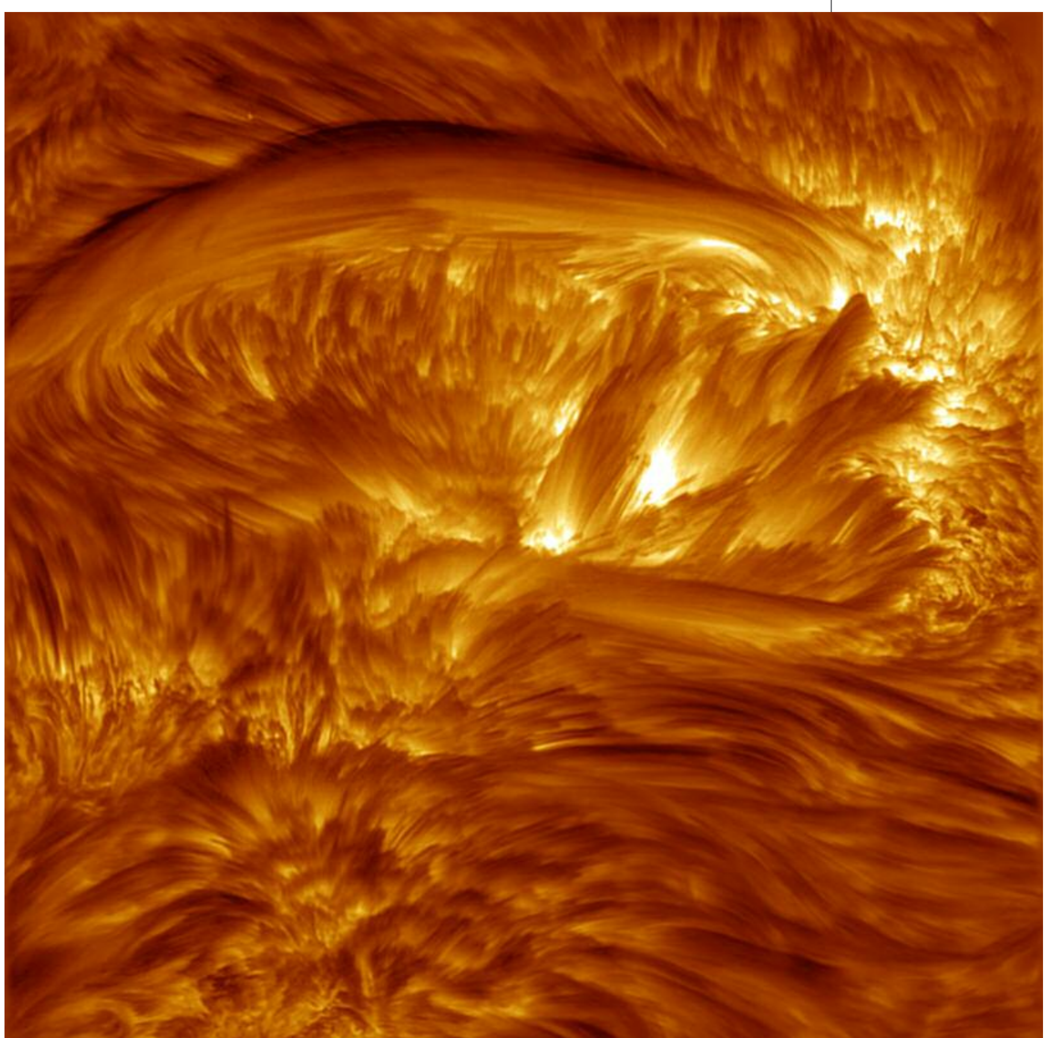
Principal physical characteristics

An effective diagnostic of the prominences must take account of the fact that they have temperatures hundreds of times lower than the surrounding corona and densities hundreds or thousands of times greater. By far the best diagnostic spectral lines are H-α in the visible at 656.28 nm (line C of Fraunhofer or first transition of the Balmer series), that forms at temperatures around 10,000 K, and HeII in the ultraviolet at 30.4 nm, that forms at temperatures between 60,000 and 80,000 K in the highest parts of the chromosphere. Skylab observations in the 70s, with 5 arc second resolution (about 3600 km), showed that the dimensions of the prominences remained practically unchanged if observed in lines that form in the temperature range 10,000 to 300,000 K, whereas above this temperature the prominences start to diffuse, merging with the corona. Recent studies at the Big Bear Solar Observatory (BBSO) and GSFC-NASA, comparing images of quiescent and eruptive prominences in the above spectral lines have instead demonstrated significant differences in the morphology and dynamics of prominences, showing evidence of strong dishomogeneities in the plasma temperature, and that a given prominence need not have both hot and

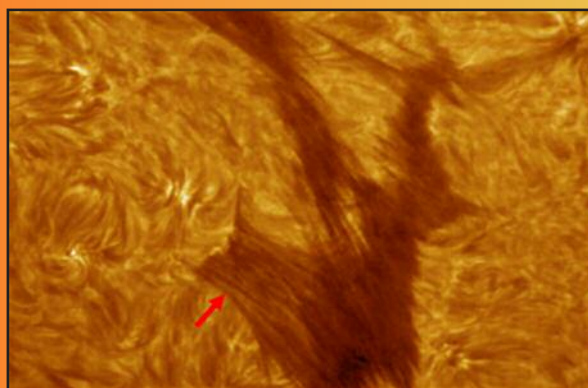


Comparison between almost simultaneous images of prominences taken during the total solar eclipse of March 29th 2006: white light on the left and narrow-band H-α on the right. [NAO Rozhen]

cold regions. On page 44 we find a comparison between two simultaneous images of an imposing quiescent prominence taken on the 26th August 2008, one in the H-α band (HASO - Pisa) and the other in the HeII band (EIT telescope on board the SOHO probe). As is clear from the images, the morphology reflects the different temperature and density distribution of the prominence, characteristic of the two observing bands.
The direct multiband comparison between images such as these will allow ever deeper studies into the physical conditions in the various types of prominence. As an example, on page 45 (top), a digitally processed image made from the previous images is shown that highlights the differences between the two images, allowing the distribution of temperature and density to be determined.
Until now we have described and classified prominences taking account of morphological aspects and of their physical and dynamical properties. We have yet to answer one fundamental question. How do prominences form? We know that the most important parameter in the study of prominences is the magnetic field that governs the behaviour of the plasma. Despite the systematic observations of the last ten years, the physical mechanisms behind the formation of prominences are still not completely understood. In particular, there is no theory that explains their stability in a low density, high temperature environment. We can say, for brevity, that there are at least two principal formation mechanisms: one from above, with its ori-



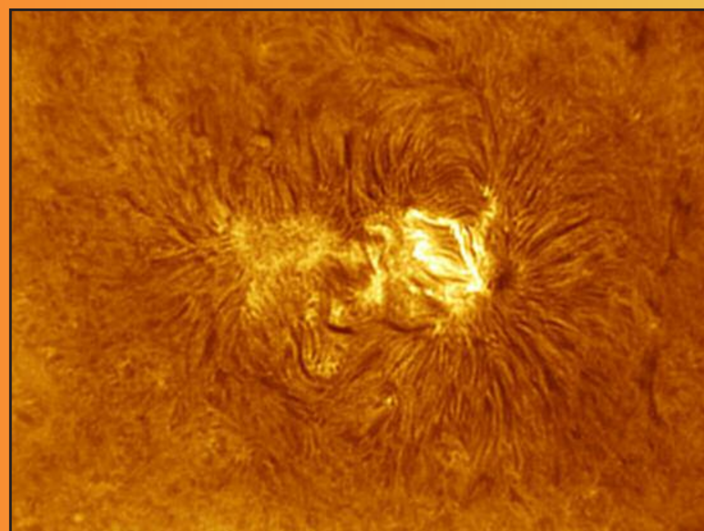
Impressive image of the filaments in an active region immersed in the fine structure of the chromosphere. H-α image taken on the 4th October 2005 with the Swedish Solar Telescope (Lin & Engvold). [Institute for Solar Physics of the Royal Swedish Academy of Sciences in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias]



Quiescent filament at high spatial resolution observed in H-α on 25th August 2003 with the Swedish Solar Telescope (Lin et al. 2005). The arrow indicates a peculiar "barb" structure, a lateral filament appendage, aligned with the magnetic field lines and bending downwards, in which chromospheric material flows. [Institute for Solar Physics of the Royal Swedish Academy of Sciences in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias]

gin in the corona (the condensation process), and one from below, governed by the magnetic fields of the photosphere and chromosphere (injection process) (Tandberg-Hanssen, 1995).
Since it is thought that the magnetic field plays the leading role in the formation, stability and also the possible appearance of instabilities that lead to eruptive phenomena, most effort is being put into the detailed study of the structure and dynamics of the magnetic fields, via sophisticated experimental techniques such as spectropolarimetry.
Using the optical and spectropolarimetric instruments on board the Hinode satellite, a joint group of American and Japanese researchers has investigated the formation of active prominences, studying the dynamics of both the photosphere and chromosphere within the active region AR10953.
The evolution of the photospheric magnetic field suggests that the appearance of helical flux tubes could always be associated with the formation and maintenance of prominences in active regions.
When we know the complete 3D topology of the magnetic field within the solar prominences we will be able to answer with greater accuracy the unresolved questions on the physical mechanisms that regulate their formation in the chromosphere and corona.
One question, only apparently trivial, is the following: what colour are the prominences? We know that if we observe in the the strong H-α emission line the prominences appear bright red, but when observed during a total solar eclipse, in white light, they look pinkish. Recent studies have shown that the emission in white light of most prominences is due to a Thomson scattering process (or diffusion) of the radiation coming from the solar disk by free electrons in the plasma of the prominence. The pink coloration is therefore the result of a mix of red H-α emission and scattered white light (an example is shown on page 45). The true colour can depend anyway on other factors: white light emission from the corona from behind and in front of the prominence necessarily overlay the internal emission; also blue emission from the H-β line can contribute to the integrated emission.
The most recent studies of the fine structure of the prominences (and filaments) reach a spatial resolution of 70-100 km (0.15"), thanks to the new SST (Swedish 1-m Solar Telescope) equiped with adaptive optics. The study of these extraordinary images (see pages 46 and above) will allow a deeper understanding of the internal magnetic morphology and structure of prominences.
For the dynamics we await the homogeneous time sequences with the same res olution produced by SOT (Solar Optical Telescope) aboard the Japanese satellite Hinode. The first SOT images showing the structure and dynamics of the prominences are extraordinary, like for example the ring-shaped quiescent polar prominences that are forcing a revision of current ideas and theories on the role of magnetic fields in prominence formation and dynamic behaviour. Concerning this, of particular interest are some recent results in the study of so-called prominence seismology, a powerful diagnostic tool to

AR1029: the largest active region of the year and of the new solar cycle.

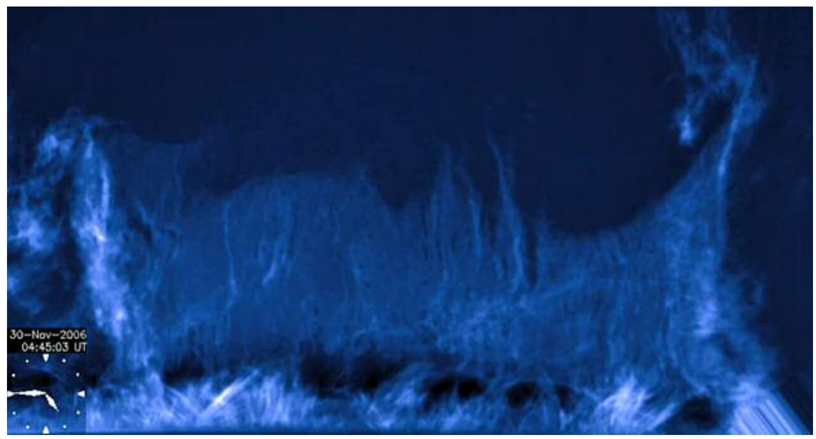


One of the first H-α images of the active region AR1029, taken on 25th October 2009 by Paul Haese - Blackwood, South Australia.

At the end of September 2009 one could basically sum up solar activity as follows: during the year the Sun has produced only 18 sunspots, often so small that many observers questioned the real presence of photospheric spots within the indicated active regions. By then we were used to the regime of extremely low solar activity during a historic minimum, with very few exceptions like the "extraordinary" active region AR 1024, that in the first week of July delighted solar observers by quickly becoming the largest active region for two years. This region reached a size of 230 mes (millionth of a solar hemisphere; 1 mes is about 3 million square kilometres) had a bipolar magnetic configuration (beta) and produced class B and C solar flares. The magnetic polarity of AR1024 classified it as belonging to the new cycle 24. After this show all returned to normal... or almost. A new surprise arrived at the end of October: during the weekend of the 24th, a new region, AR1029, suddenly emerged, making itself noticed by class B and C flares. Its dimensions and structure were already interesting, but during its evolution it reached 380 mes, on 29th October, with a relatively complex magnetic configuration (beta-gamma type). After five days of growth and continuous activity, AR1029 was the biggest and most active region of the year, with a linear extension of 50,000 km that produced 10 class C flares, more than three times the number of flares of this type identified during the rest of the year. The magnetic polarity of AR1029 also classified it as belonging to the new solar cycle. May be these are the signals of the awakening solar activity in cycle 24 for which we were waiting.

derive information not obtainable in other ways, on magnetic configuration, plasma parameters and stability mechanisms in active, eruptive and quiescent prominences. This branch of solar physics now makes use of the best observations available in H-α, EUV and microwave bands, obtained with the various probes (SOHO, Hinode and STEREO), as well as the most sophisticated non-linear time series analysis (such as wavelet analysis). The idea behind this approach is to study the internal structure and dynamics of prominences via large amplitude oscillations (from 2 to 40,000 km of movement over 20 km/s) induced principally by the interaction with shock waves produced by large, distant solar flares (Tripathi et al., 2009).
The high spatial and temporal resolution studies of the morphology and dynamics of prominences will allow the refinement of theoretical models and current diagnostics; not forgetting, however, Heinzel's

observation made at a recent convention on the physics of the chromosphere (Coimbra, 2007) where he cited Tandberg-Hannsen from his splendid monograph, in which it is underlined how, after 130 years, the comments of Secchi are still valid: *"The prominences present themselves in such bizarre and capricious forms that it is absolutely impossible to describe them with a certain exactness"* (Le Soleil, 1877).



Spectacular image of a quiescent polar ring prominence taken in the line of ionized calcium, CaII, by the Solar Optical Telescope (SOT) on the Hinode probe. [JAXA/NASA]

Conclusions

The possibilities for amateur astronomers to observe solar prominences (and more generally the solar chromosphere) have improved hugely in recent years. This is largely due to the diffusion of high quality, commercially available, narrow band (<0.7 Å) filters of various types, most centred on the hydrogen H-α line (656.28 nm), and systems for CCD imaging developed specifically for planetary and solar imaging. How much the process of imaging and subsequent digital analysis of solar prominences has been simplified is evident simply by comparing with the techniques that were used, for example, in the early nineties. Looking through the various amateur articles of that period where the reader was introduced to the fascinating world of prominence photography, it is obvious how, at the time, not so long ago after all, that obtaining a reasonable image was no easy task and a considerable familiarity with specialized observational techniques (useful in taking the image with highly specialized instrumentation) and, perhaps above all, with the treatment of photographic plates and film in the darkroom was needed. It is clear then, that the digital techniques now available have greatly simplified the process of image and film making. Although the study of the chromospheric and coronal phenomena of the Sun remains a rather specialized discipline, above all because of the need for highly sophisticated, purpose built equipment, the technological evolution of the last ten years now allows anyone who is seriously motivated to observe and produce high quality images of the solar prominences in all their majesty, morphological complexity and dynamism.

Stefano Sello was born in 1959 in Codogno (Milan). He graduated from the University of Parma in 1986 where he studied mathematical physics. From 1987 to 1998 he was a researcher at CISE, Milan, where he worked on numerical models of continuous media. Since 1998 he has been a senior researcher in the department of Physical and Mathematical Models at the ENEL research centre in Pisa, concerned in particular with the development of advanced numerical methods for the study and characterization of complex dynamical systems. In the astronomical field he is concerned mainly with solar physics, studying the characterization and prediction of solar cycles.