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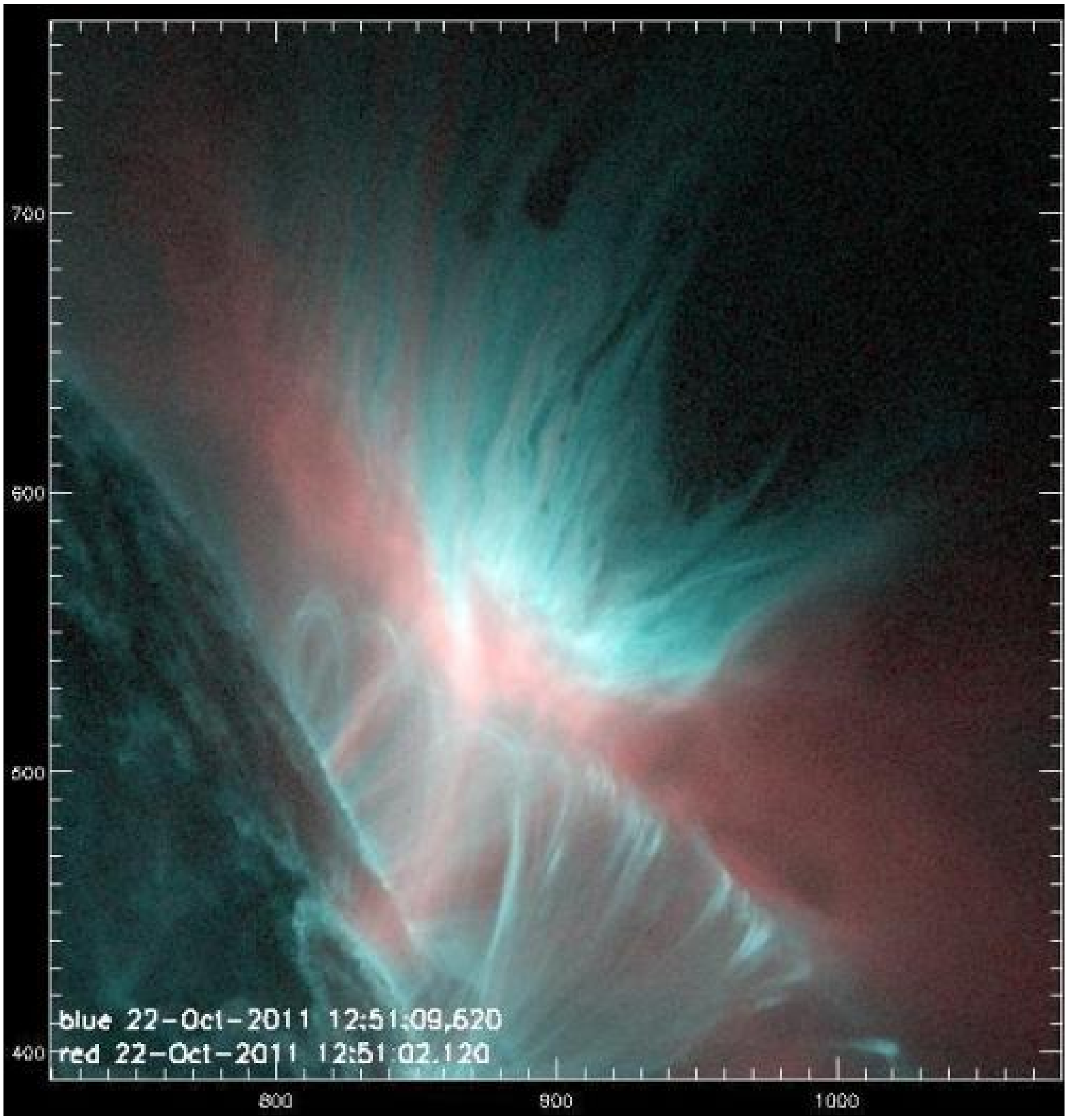
The dark fingers of the solar atmosphere

December 8 2014



A witch's cauldron in the solar atmosphere: The image originates from the AIA instrument of the American SDO satellite and shows the ultraviolet radiation from part of the corona on 22 October 2011. It was taken at a wavelength of 13.1 nanometres (shown in blue) and 9.4 nanometres (red). The dark finger-like structures of the Rayleigh-Taylor instability at the top of the image can be clearly distinguished from the blue plasma. Credit: NASA / SDO / MPS

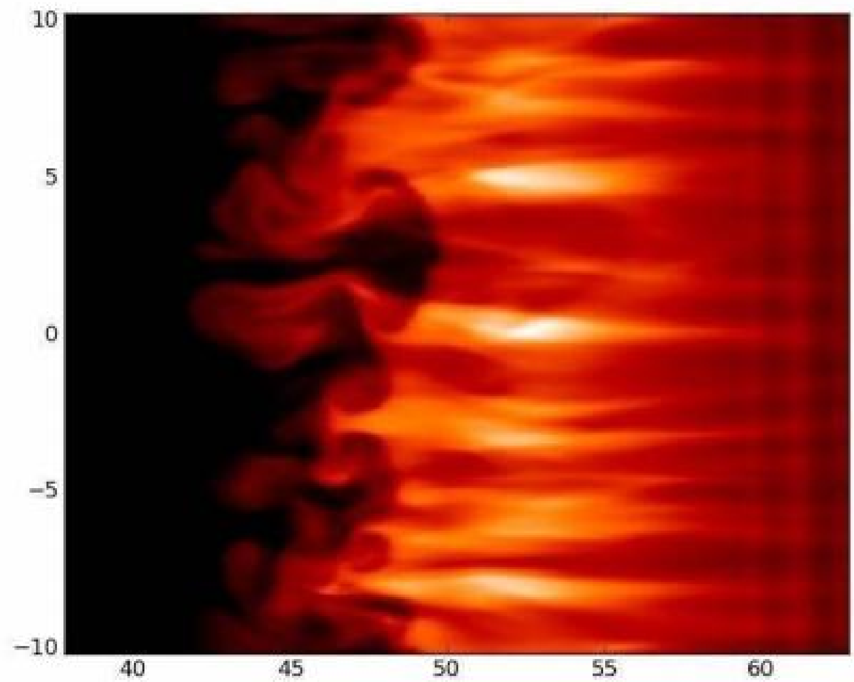
The Sun is bubbling, forming mysterious finger-like plasma structures in its gaseous envelope, the corona. A German-American team headed by the Max Planck Institute for Solar System Research has now succeeded in explaining these filigree-like forms. In their new theory, the scientists make use of a long-known natural phenomenon which can be observed in very different situations – in the distant cosmos as well as in a cup of tea at home.

Energy conversion is in full swing in the solar corona. Magnetic and electrical energy are converted into immense heat, and the temperatures shoot up to ten million degrees Celsius. This can lead to so-called eruptive flares in the vicinity of sunspots: gas masses separate from the surface of the Sun and are ejected high into the corona.

In the process, strange, elongated plasma structures emerge, which are usually visible for only a few minutes in the upper part of the flares. Since their discovery around 15 years ago, solar researchers have been mystified as to the cause of these dark structures; they form a clear contrast to the enfolding bright plasma which emits ultraviolet light.

Owing to their shape and wavy movements these dark structures sometimes called "tadpoles" in researcher jargon. "Before, we were literally groping in the dark as far as their interpretation was concerned, because all attempts to explain them were unable to satisfactorily explain the observations," says Davina Innes from the Max Planck Institute for Solar System Research.

Together with colleagues, she evaluated flare photos from the Solar Dynamics Observatory (SDO) of the US space agency NASA and the likewise American STEREO mission (Solar TErrestrial RElations Observatory). Both probes can observe the Sun at several wavelengths of ultraviolet light.

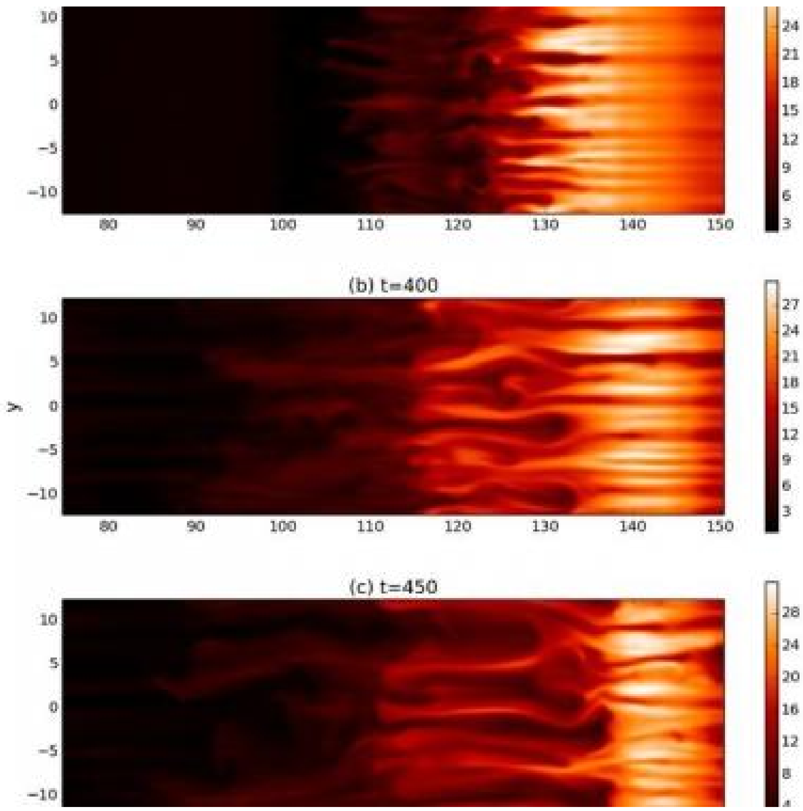


Streaming gas in the corona: Here a typical result of the new simulation computation based on magnetohydrodynamics. As in the observations, the dark finger-like structures indicate the Rayleigh-Taylor instability. Credit: MPS

The high-resolution images originate from flare eruptions during 2011 and 2012 and capture even small details measuring less than 800 kilometres. A particular feature of the SDO images is that they show the solar events several times per minute. They are therefore ideal for investigating the usually short-lived mysterious coronal "tadpoles". "It turned out that these structures are instabilities that form when plasmas of different densities encounter each other," says Innes.

In a second study, which was headed by Max Planck researcher Lijia Guo, computer models were used to simulate the same processes. These three-dimensional MHD computations – MHD stands for magnetohydrodynamics – are based on a theory which physicists use to describe electrically conducting fluids; by way of approximation, the solar plasma can also be computed with this.

The results of the complex computations are in striking agreement with the observations. It is surprising that the structures which have puzzled the solar physicists for many years are explained by an old acquaintance on the basis of the current model computations: "We've been able to prove that the processes are caused by the Rayleigh-Taylor instability, a fundamental process in fluid dynamics," says Guo. This instability occurs, for example, between two fluids of different density when they are accelerated with respect to each other.



Solar snapshots: Three time-lapse excerpts from the new simulation computation based on magnetohydrodynamics. The evolution of the dark finger-like structures, which indicate the Rayleigh-Taylor instability, can be clearly seen. Credit: MPS

Instabilities can even occur in a cup of tea into which a drop of milk is introduced, as the milk, which is heavier than the tea, is subject to terrestrial gravity acceleration. The briefly visible, mushroom-shaped evaginations at the tea-milk interface are a typical sign of the instability. These also occur in flowing gases. "Rayleigh-Taylor instabilities can also be observed in the cloud surrounding exploding stars. The finger-like structures in the gas masses of the Crab nebula, which was formed by a supernova explosion, can be explained in this way," says Lijia Guo.

The two studies undertaken by the Max Planck researchers have now also led to a more detailed understanding of the processes in the corona. In addition to the Rayleigh-Taylor instability, there is also a high-energy process where the magnetic field leaps into a different configuration, called reconnection. Like a rubber band which is twisted so much that it snaps, the energy stored in the magnetic field is released suddenly during the flares.

In the corona, the magnetic field lines take on the role of the rubber band. When the field lines suddenly regroup, a beam of thin plasma forms: a jet. This is accelerated from the site of the reconnection towards the solar surface. Further down, the jet meets up with denser plasma. Dense and thin plasma thus meet at the head of the jet – the Rayleigh-Taylor instability takes its course.

"Our observations are the first to provide clear proof of these reconnection jets, which have to date been described only in theory," says Davina Innes. The results obtained by the two researchers will surely also meet with interest outside the community of solar physicists: "Reconnection, Rayleigh-Taylor instability, jets – our studies have hit upon a few phenomena that could also benefit other fields of physics," says Lijia Guo.

More information: "Rayleigh-Taylor type Instabilities in the Reconnection Exhaust Jet as a Mechanism for Supra-Arcade Downflows." *Astrophysical Journal Letters*, Vol. 769,Nr. 2 (1 December 2014) DOI: 10.1088/2041-8205/796/2/L29

D. E. Innes, L.-J. Guo, A. Bhattacharjee, Y.-M. Huang, D. Schmit, Observations of Supra-Arcade fans: Instabilities at the Head of Reconnection Jets, *Astrophysical Journal*, Vol. 796, Nr. 1 (20 November 2014) iopscience.iop.org/0004-637X/796/1/27

Provided by Max Planck Society