PH375 Literature Review- Streamer Waves

Kieran Davis and Benjamin Clark

kid4@aber.ac.uk, bec14@aber.ac.uk

Abstract

This literature review gives an overview of the scientific background of coronal streamer waves, including the formation and evolution of streamers. A summary of streamer-CME interaction is then provided, giving an insight into the origins of coronal streamer waves. An outline of the methods used in analysing LASCO C2 and C3 data is also given, with a focus on the application of these analytical methods to the data in question. This results in the ability to produce an approximate calculation of values for different properties of individual streamer waves.

Finally, a discussion is presented detailing some of the limitations of this particular field of solar physics, including a concise case study of issues that haven't yet been fully resolved. This centres mainly on the Kelvin-Helmholtz instability and the proportion of streamer waves affected by this in relation to the 'standard' cause of CME buffeting. Combined, this report gives an accurate review of the current knowledge in the field of coronal streamer waves.

Introduction

The aim for this project is to investigate properties of streamer waves- as such, there is not so much a singular question, but a series of overarching individual questions to answer. These include queries such as, 'What are streamer waves and how do they occur?', 'How are they related to other solar phenomena?' and, 'Are they produced in any other ways?'. In this review, we aim to answer some of the basic questions and provide an insight into the current levels of research on streamer waves, in addition to an envisaged methodology to our project and some of the limitations of streamer wave research in general.

Figure 1- An uncorrected C2 image of the Sun from 1/5/13 00:10:52

The basis for completing this project is purely focused on the analysis of data, and as such requires a fairly straightforward methodology. This involves locating LASCO C2 or C3 data and processing it in a number of different ways to analyse it.

Because the uncorrected images aren't particularly informative to begin with (as shown in figure 1), they must be processed in such a way that it is possible to see the solar processes- such as streamers and CMEs.

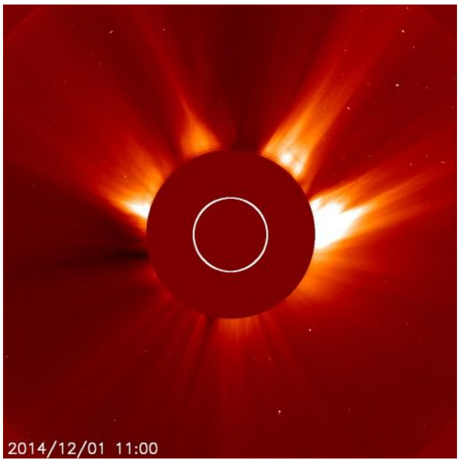

Figure 2- A corrected, time stamped C2 image from SOHO LASCO C2

This is planned to be done using "SAOImage", an astronomical imaging and data visualisation application. The data can then be analysed further by implementing packages in IDL.

This methodology is fairly skeletal, but the bulk of the work lies in the repeated action of processing and analysing data. It is entirely possible that a number of analytical steps will reveal themselves as the investigation proceeds, but at least at the beginning of the project the outline of the method simply involves finding data, processing it, and finally analysing it.

What are streamer waves?

Streamer waves are solar phenomena that can occur when coronal mass ejections (CMEs) interact with coronal streamers. Streamers are large-scale quasi-steady structures that extend from the lower to outer corona (Chen et al. 2010), and are thought to be closely linked to the slow solar wind. There are two types of coronal streamer: helmet streamers and pseudostreamers.

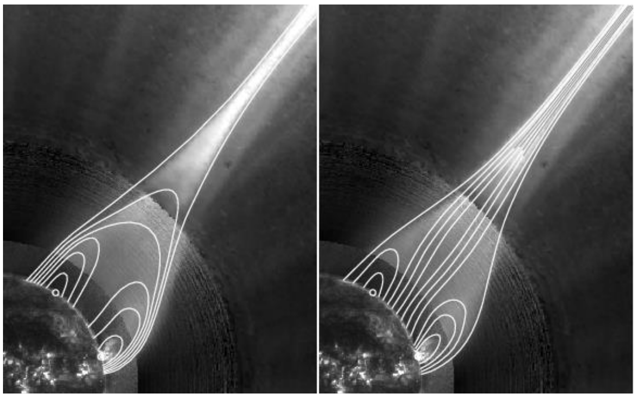
Figure 3- Diagram of a helmet streamer- Morgan and Habbal (2006)

Helmet streamers are one type of coronal streamer (figure 3), and form between coronal holes of opposing magnetic polarity. The individual magnetic fields interact and form an overall field with an onion-like shape. Combining this with the sun's violent surface, the plasma is pushed into space along the magnetic field lines to form a helmet streamer.

In contrast, pseudostreamers separate coronal holes of the same magnetic polarity. The main difference between the two types is that helmet streamers can travel much further, even beyond the range of C2 coronagraphs, whereas only the long stalks (also known as the plasma sheet or streamer belt) of pseudostreamers are visible beyond two solar radii (Wang et al. 2006).

Coronal streamers can be likened to discharges of plasma from the corona due to the electrically charged nature of the plasma and the magnetic properties of the coronal holes that they separate. This is similar to streamers that occur on Earth during thunderstorms (see figure 4)- however, the discharges in this case are electrically-based, rather than driven by magnetism (Ebert et al. 2006). Due to Maxwell's equations, though, we know that electricity and magnetism are closely linked.

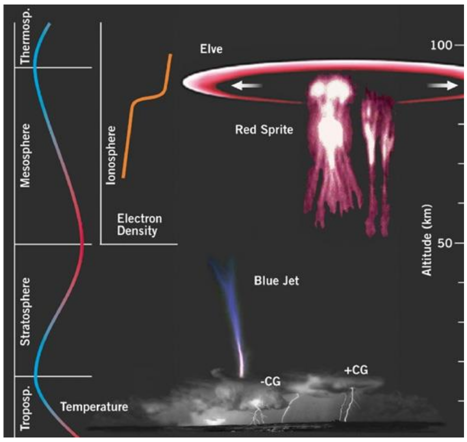

Figure 4- Discharges (sprites) occurring during a thunderstorm- Ebert et al. (2006)

The elemental composition of streamers is similar to that of the coronal region in general- emission lines of H, N, O, Mg, Al, Si, S, Ar, Ca, Fe, and Ni have been detected (Raymond et al. 1997). Of these, though, oxygen ions are the most abundant, and so the relative abundances are given in relation to oxygen rather than hydrogen.

Coronal mass ejections are the largest and most dynamically energetic processes that occur within the corona- a massive burst of energy that ejects solar plasma (in the range of 10^{12}kg) into space, with an energy of around 10^{23} joules. Because of this, close interactions between the CME plasma and streamers can often occur, especially during the active phase of the Sun. During this period, coronal mass ejections and streamers can be found at nearly all altitudes of the Sun (Chen et al. 2010).

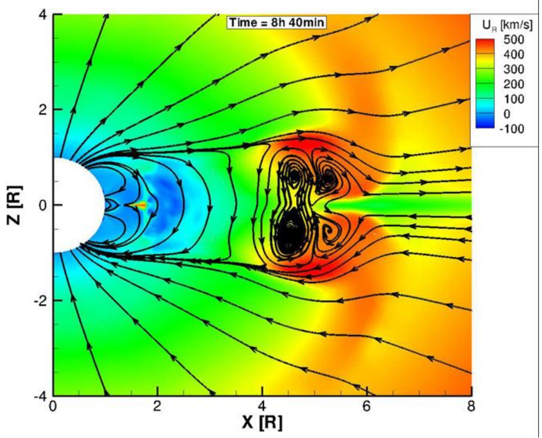

Figure 5- Diagram showing streamer blowout and radial velocities- van der Holst et al. (2009)

Streamer-CME interaction events can be classified in one of two ways. The first occurs when a CME erupts within the streamer interior, resulting in either a streamer blowout (fig. 5) or a streamer puff (van der Holst et al. 2009). The second form of classification comes from the interaction when a streamer is collided with on the side by an expanding CME or by disturbances caused by CMEs, such as shock waves. These collisions can cause oscillation within the streamer, resulting in a fast kink mode carried by the plasma sheet- this is what is known as a coronal streamer wave. The streamer wave propagates outwards with a phase speed consisting of two components- the first is the phase speed of the mode in the plasma rest frame and the second is the speed of the solar wind travelling along the plasma sheet (Chen et al. 2011).

It has been observed that both the wavelength and phase speeds of coronal streamer waves can gradually change at greater distances- the wavelength increases and the phase speed decreases, while the period remains constant, and even the wave amplitude can increase slightly over time (Chen et al. 2010, Feng et al. 2013). This can be attributed to the Kelvin-Helmholtz instability (KHI) of the coronal streamer, which occurs at a neutral sheet in a fluid wake (Feng et al. 2013). This suggests that streamer waves do not only occur when interacted with by a CME, but can oscillate due to the intrinsic instability of the streamer.

How are they analysed?

As mentioned above, the raw data (C2 or C3 coronagraphs) can be processed into a more manageable form by using any number of image processing programs. However, the application we aim to use for at least the initial investigation is "SAOImage" as stated earlier.

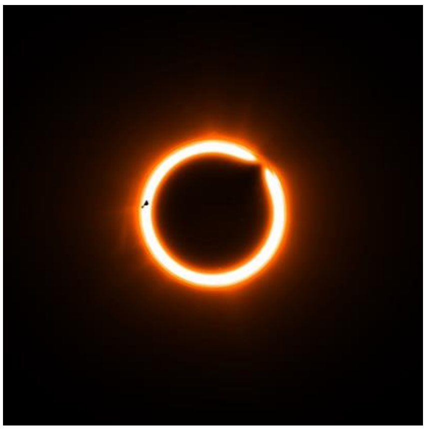
Figure 6- The same image as fig. 1, but processed slightly to show more information.

The data can be processed in a number of ways, depending on the program used. One method is to view the data using different colour filters to find the most contrasting image when the foreground and background are compared (see figure 6).

Using "SAOImage", each co-ordinate of the image contains a value of intensity. This can be used to create a form of image contrast by taking an ambient intensity value of the image background and using it to normalise the rest of the image. This makes it much easier to view the coronal structures on C2 and C3 coronagraphs. However, the drawback to this method is that by changing the values of the points within the image, a certain amount of the information is lost. Therefore, one must make sure to use the processed image only for viewing the structures produced in the coronal area or to use the processed image values in relation to itself. This, then, would likely be in the form of a ratio.

After the images have been processed to greater show the coronal structures (in this case, coronal streamers), there are a number of different steps to calculate the properties of the structure. For example, if you take the spatial resolution of the image (C2: 11.9 arcsec/pixel) and measure the length of wave propagation on the image, then one can calculate the approximate wavelength of the streamer wave. Similarly, by taking multiple consecutive images with a constant time resolution (usually around 12 minutes) one can estimate the time period for the wave. Using these two values, it is possible to work out a number of different properties of the streamer wave such as the phase speed, wave number and Alfvén speed. These will only be approximate values, however, as the waves are subject to turbulence from numerous sources and so will not exhibit ideal behaviour. In addition to this, the Kelvin-Helmholtz instability of the streamer (as noted above) may well be responsible for the modification of the wave's properties as it propagates through the medium, changing the wavelength and phase speed. Ideally, this can be accounted for by splitting the chosen wave into sections that have constant values for these properties. Additionally, it may even be possible (if the Kelvin-Helmholtz instability has a constant-valued effect on the streamer) to map the instability as a function of propagation distance.

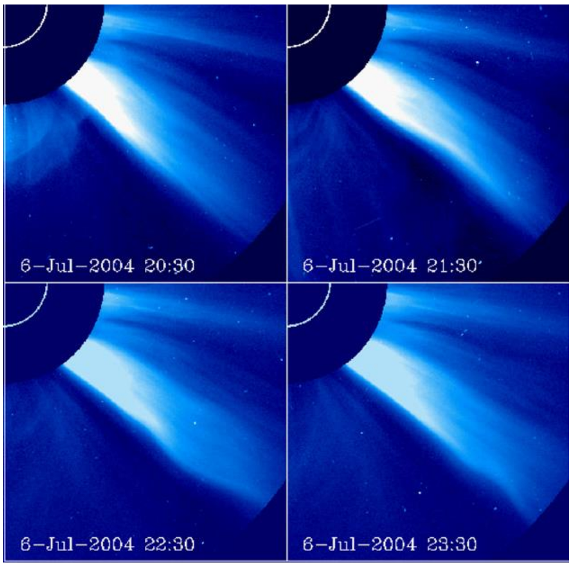

Figure 7- Wavelike motion of a streamer stalk- Chen et al. (2010)

For this to occur, it is imperative that a streamer be chosen that meets a number of prerequisites. For example, the wave must propagate perpendicularly to the field of view (FOV). This will make calculating the individual properties much simpler as it will not be necessary to factor the angle into calculations for the wavelength. Another necessity for an ideal streamer wave to study is that it be taken from the equatorial region of the solar corona- this is because it will be more representative of other streamer waves as they are most likely to be found in that region. As mentioned above, during solar maxima streamers and coronal mass ejections can occur at nearly any helioaltitude, but at other times they are much more likely to be found in the equatorial region (as shown in fig. 8).

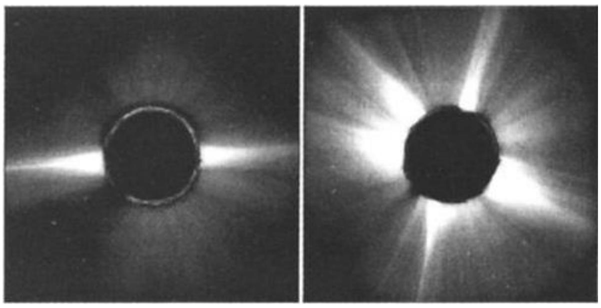
Figure 8- Polarised white light images of the corona at solar minimum (left) and maximum (right)- Wang et al. (2000)

One more factor to take into account is that it is necessary to survey more than one streamer wave- through this method, it should be possible to work out at least some form of average streamer size/intensity for the area and factor out any unusual streamers produced if needed. Surveying multiple waves may even make it possible to model some form of pattern between waves of different amplitudes and possibly even calculate a scaled value for the instability of each streamer.

Why do people study streamer waves?

Streamer waves have not been extensively researched to date, whereas coronal streamers themselves have been well documented throughout the years, and their behaviour increasingly analysed in various papers and journals (see references). This makes it a difficult area to conduct original investigations due to the distinct lack of specific literature on the subject. However, because streamer waves are produced within coronal streamers and are formed through interaction with other solar material (or through intrinsic instability), it isn't difficult to apply the current level of knowledge and research about streamers and the overarching field of plasma physics to this scarcely-researched phenomenon, making this a prime candidate for further study. Also, by studying streamer material it is possible to learn more about the magnetic field (B field) in the corona- this is enormously helpful because beyond 1.2-1.5 solar radii the magnetic field becomes too weak to measure directly (Chen et al. 2011).

Coronal streamers propagate to several solar radii and emit radiation in the visible and UV spectrums (Parenti et al. 2000), making them easy to spot compared to background radiation. Coronal streamers also tend to be one of the most long-standing structures in the solar corona- they can remain visible for up to several months (Chen et al. 2009) and are therefore easy to study for extended periods of time. As mentioned above, they also occur very frequently- especially at solar maxima- and so can be extensively studied without having to wait until the right time of month/year.

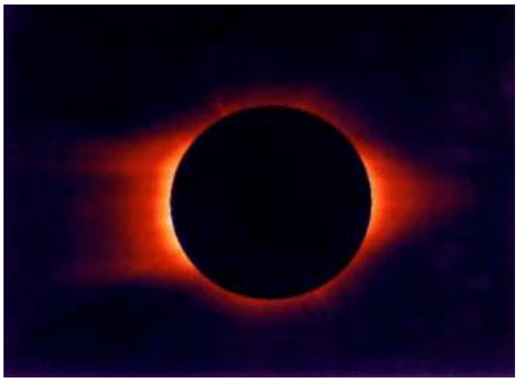

Figure 9- Image of the corona in O VI- Raymond et al. (1997)

The fact that streamers remain stable for so long means they can interact frequently with other solar occurrences in the solar corona. This means that coronal streamer are usually closely linked with other scientific points of study in the corona- such as coronal holes (and therefore coronal hole jets), coronal mass ejections, magnetic reconnection, and the slow solar wind. Therefore, having knowledge about coronal streamers can grant a great deal of insight into the other goings-on in the solar atmosphere. As detailed above, streamer waves can occur when a coronal steamer is buffeted by a coronal mass ejection (CME), causing the streamer to oscillate. This interaction between distinct solar events can give us a great deal of insight into the behaviour of dynamic plasma. Not only that, but the observation of streamer waves when no CMEs were close in either space or time (as detailed in Feng et al. 2013) is suggestive of the inclusion of the Kelvin-Helmholtz instability (KHI) of the wave, and so open up another branch of research to pursue, making coronal streamer waves a highly attractive prospect to investigate in the scientific community.

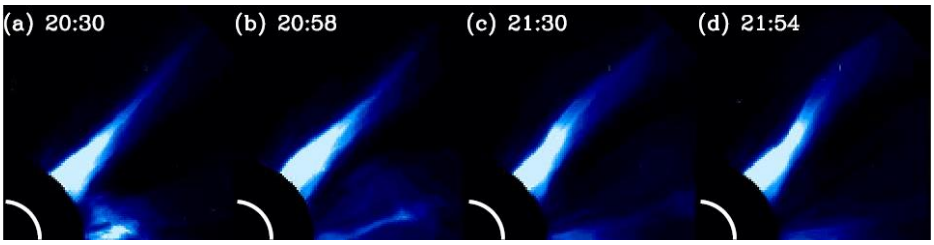

Figure 10- White light images of the CME-streamer interaction by LASCO C2 on 5/6/03- Feng et al. (2011)

What are the limitations of research and what is there yet to be explained?

When observing the sun to find examples of streamer waves, it is found that beyond around 1.2-1.5 solar radii the magnetic field is too weak to directly observe, and therefore it is incredibly difficult to accurately model the effect of the magnetic field on coronal streamers from this point outwards. There are a number of indirect methods to measure the field, mostly involving numerical extrapolation or the use of radio techniques (Chen et al. 2011). However, the weakened magnetic field should only prevent magnetic reconnection from occurring in the streamer and so should not greatly affect the macroscopic effect of the coronal streamer wave propagation.

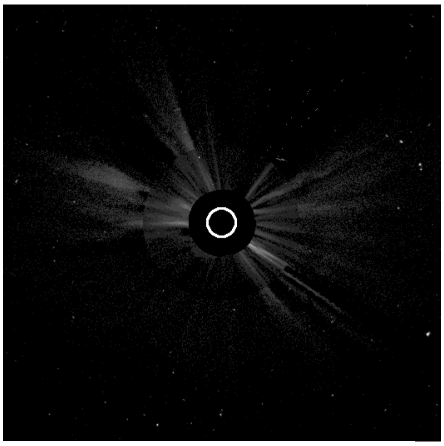

Figure 11- Oscillating streamer observed in C2 and C3- Feng et al. (2013)

As described above, the field of researching coronal streamer waves is surprisingly exclusive, and so very few papers have been written on this specific topic. This means that a number of factors in the coronal processes have yet to be sufficiently explained. These include a quantitative evaluation of the effect on streamers when buffeted by side-on coronal mass ejections and the effect that the Kelvin-Helmholtz instability has on the wave compared to other, external factors. It was stated earlier that streamers can begin to oscillate if there are no CMEs nearby due to the intrinsic instability of the streamer itself, but whether this is a rare case or whether it is a much more common occurrence has yet to be concluded. Therefore, during the project the different causes of streamer waves will be categorised into two sections- those caused by CMEs and those that occur as a result of the Kelvin-Helmholtz instability. From this, it should be relatively straightforward to work out how common each of the different forms of propagation are, compared to each other. For example, the instability form may be an extremely rare occurrence- however, it may also be a constant factor, affecting every single streamer, although perhaps less violently than CMEs. This question is one that should be answered in order to give a better understanding on the properties of streamer waves.

Concluding Remarks

This literature review has given an overview of the scientific background of coronal streamer waves, including the formation and evolution of streamers themselves and the initiation of propagation due to a number of factors. In addition, a summary of streamer-CME interaction was provided, giving an insight into the origins of the propagation of coronal streamer waves. An outline of the methods used in analysing LASCO C2 and C3 data has also been given, with a focus on the application of these analytical methods to the data in question. This results in the ability to produce an approximate calculation of values for different properties of individual streamer waves.

Finally, a discussion was presented detailing some of the limitations of this particular field of solar physics, including a concise case study of issues that haven't yet been fully resolved. This centred mainly on the Kelvin-Helmholtz instability and the proportion of streamer waves affected by this in relation to the 'standard' cause of CME buffeting. Combined, this report gives an accurate review of the current knowledge in the field of coronal streamer waves.

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