Classification of Coronal Mass Ejections and Image Processing Techniques

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Coronal Mass Ejections are known sometimes for their graceful and majestic outflowing from the sun. They are also sometimes characterized by outbursts of great velocity. This paper seeks to classify these CMEs based on a variety of factors. The velocity of the CME is one such factor, as is the structure of the CME itself. The outer edge and the inner core of the CME move at different velocities, and this difference can track the structural evolution of the outburst. Another factor is the angular separation of the "legs" of the CME. All of these factors make it possible to analyze these Coronal Mass Ejections, and to classify them according to certain characteristics.

Introduction and Overview

Coronal mass ejections occur frequently on the sun, with minor ones occurring daily. Using the SolarSoft CME Search provided by NASA and others, CME data can be reviewed. This data was captured by the Large Angle and Spectrometric Coronagraph (LASCO) aboard the Solar and Heliospheric Observatory (SOHO) spacecraft. Stationed at the L1 point, the SOHO spacecraft provides an unobstructed view of solar activity.

Using this data, the database was combed for the most powerful CME candidates for 1998 through 2000 as well as some data from 2005. This provides a glimpse into CME activity during solar minimum as well as maximum. Detailed images were acquired and processed for this collection of powerful CMEs, enhancing details visible in the structure of the CME. Measurements were then taken on these enhanced images, providing height-time data for each CME event.

Using this data, qualities such as velocity and CME depth were derived. The CMEs at this point were classified according to these qualities.

Gathering Raw Images

CME candidates were gathered using the database provided at http://www.lmsal.com/solarsoft/www_getcme_list.html. CMEs are observed using this database, finding those suitable for study. After a list is arrived at of potential CMEs, a second database is called upon, located at http://lasco-www.nrl.navy.mil/cgi-bin/lwdb/lasco/images/form. Raw images are requested through this repository, and downloaded in packages.
**Processing Images**

The raw images provided by the LASCO query form contain information, just not in the right form for the purpose of this study. The brightness of the sun (the disk of which is occulted) peaks just outside the occulting disk. This brightness then falls off incredibly quickly, reaching almost zero brightness in the images. While the brightness can yield interesting results, this study is concerned with the structure of coronal mass ejections. Using previously developed code, the structure is revealed in these raw images.

This process begins outside the occulting disk and works in a radial fashion. It progresses through a series of circles of pixels, normalizing each. The lowest and highest brightness values in each circle are noted, and this narrow range is then scaled up to fill the entire range from black to white in the image. This normalization reveals details that are otherwise lost in the great brightness contrast.

Figures 1 shows the stark difference before and after image processing.

![Unprocessed image (left) and processed image (right)](image_url)

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**Gathering Data**

Code was developed in IDL that allows for the easy tracking of CME structure. The program progresses through the series of images in each CME, presenting each in a window on the screen. The researcher then uses the mouse to select several points on the image simply by clicking directly on the image. The points studied were the outer edge, the inner core, and the two legs of the CME. The program takes these values and outputs the position (in solar radii) and the angle. With these values the structure of the CME can be tracked over time.
Reviewing Data

Figure 2 – Position-time plot for the edge and core of a CME

Figure 3 – Position-time plot for the edge and core of a CME
In the previous figures, the plus symbols represent the position of the edge of the CME, while the diamonds correspond to the core position of the CME. Figure 2 reveals a CME with large velocity. The entire event occurs within a timeframe on the order of five hours. Figure 3, on the other hand, details a CME with a much lower velocity. The CME of figure 3 slowly eases away over the course of 17 hours.

Both figures, however, show the fact that the edge and core seem to progress for the most part together. After gathering data from a number of cases, the edge and core velocities were recorded and compared.

![Edge Velocity versus Core Velocity](image)

*Figure 4 – Core velocity versus edge velocity*

From the data presented in figure 4, a correlation exists between the velocity of the edge and the velocity of the core. This matches with the apparent lock-step movement of the edge and core. However, this correlation is slightly skewed, with a tendency for the edge to move faster than the core.

So what else can the velocities of CMEs reveal? The dataset collected was purposefully chosen to span over a range of years, reaching into both the maximum as well as the minimum periods of solar activity.
The black tick marks of figure 5 represent the edge velocity, while the red serve for the core velocity. For the years from 1998 to 2000 there appears to be an increase in maximum velocity as the years progress. When data collection continued in 2005, the maximum velocity is much larger than in earlier years. It then decreases for the year 2006.
The histogram presented by figure 6 shows the edge velocities in black and the core velocities in red. Both the edge and the core follow a similar distribution. The majority of CMEs are of slower velocity, with the number decreasing with increasing velocity.

**Reviewing Data**

The edge and core of the CME evolve differently with time. They follow a similar path, but with the edge accelerating more quickly than the core. When looking at the distribution of edge and core velocities over time, there seems to be a correlation between maximum velocity and the time period. During solar maximum the CMEs appear slower than in the region of solar minimum. The histogram distribution shows more CMEs in the slower regime, which is curious in that it does not follow a more bell-shaped distribution but rather peaks with slow CMEs.

**Future Work**

Developments in processing techniques allow for the study of images from the C3 camera as well as that of C2. This greatly expands the viewable range, and allows for study of structural evolution far beyond the original limits of the C2 camera. Work can also be continued by expanding the scope of the study to include more data points in the years from 2001 to 2004. This will give more data in general to work with, and will help answer questions concerning how CME strength changes with the solar cycle.