The Solar Slap (75 points)

Please read the general instructions before you start this exam.

Solar Cycle 25 is heating up! It began in December 2019 and will peak in 2025. The start of a new cycle means there will be increasing solar activity until roughly mid-2025. One direct consequence of such activity is the more frequent occurrence of solar flares, which are intense bursts of radiation observed near the Sun's photosphere and low-corona. Solar flares are sometimes accompanied by coronal mass ejections (CMEs), which expel coronal plasma into interplanetary space.

We are living in a golden age for solar astrophysics. In addition to entering a period of high solar activity, we also have new solar telescopes that will allow us to study the Sun as never before. One of these telescopes is the Parker Solar Probe (ParkerSP), the first spacecraft in history to fly into the low solar corona. The ParkerSP has a somewhat eccentric orbit (ε≈0.88) and will approach the Sun as close as 7 million km ($\sim$10 solar radii) on its final orbital perihelion (in 2025).

Just recently, on May 28, 2021, a C-shaped CME was detected by the solar space telescope SOHO (located at a distance of 1.5×10^6 km from Earth, around the Sun-Earth L1 Lagrange point) by means of the onboard LASCO coronographs. The solar eruption generating the CME occurred at 22:19 UTC with an ecliptic traveling angle of 55° (with respect to the Sun-Earth line), heading directly towards the point where ParkerSP was located. Figure 1 shows a sequence of three consecutive images made by NASA, highlighting the evolution of the CME, from the onset to the moment it reaches the ParkerSP.

Assume that all spacecrafts are exactly on the ecliptic plane and the images here show a top view of the ecliptic plane.

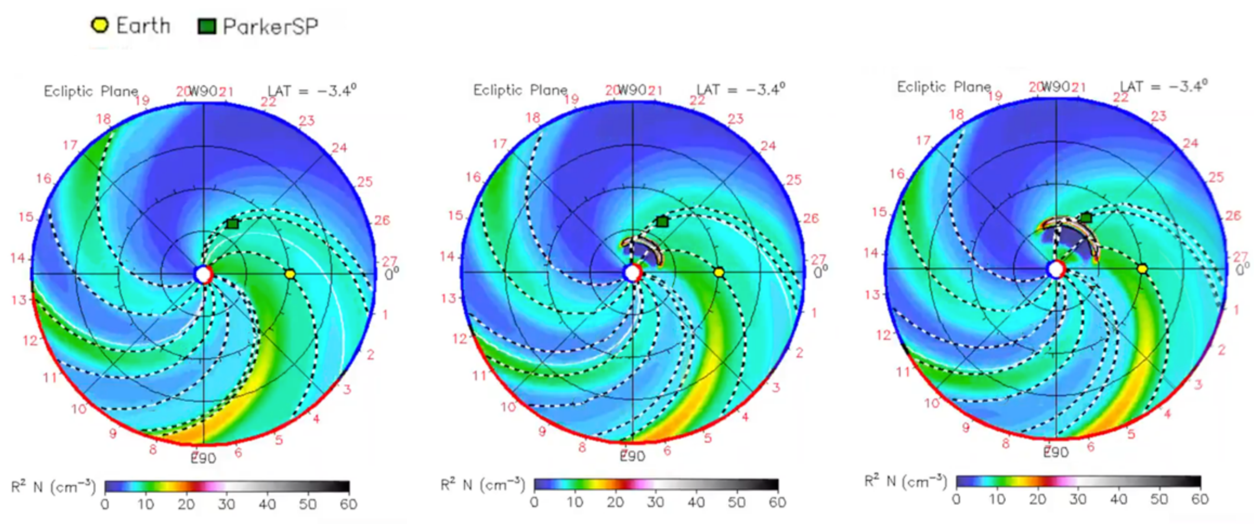

Figure 1: Sequence of images displaying on a heliospheric density map, the evolution of a CME that had its onset on May 28, 2021 at 22:19 UTC. The images show the location of the Sun (center) and of Earth (at 1 AU ≈ 1.5×10^8 km from the Sun) and the spacecraft ParkerSP. Note that the CME front impacts the ParkerSP in the last image of the sequence. The angle formed by Earth-Sun-ParkerSP is 55°.

Part 1 (30 points).

1.1	Using the JHelioviewer software find the CME which occurred on May 28, 2021, by selecting images from the Solar Dynamics Observatory (full disk) and the SOHO-spacecraft coronographs LASCO-C2 (imaging from 2 to 6 solar radii) and LASCO-C3 (imaging from 3.7 to 30 solar radii), as shown in Figure 2. Indicate, in a table, the date and time of each image that you have used.	10.0pt

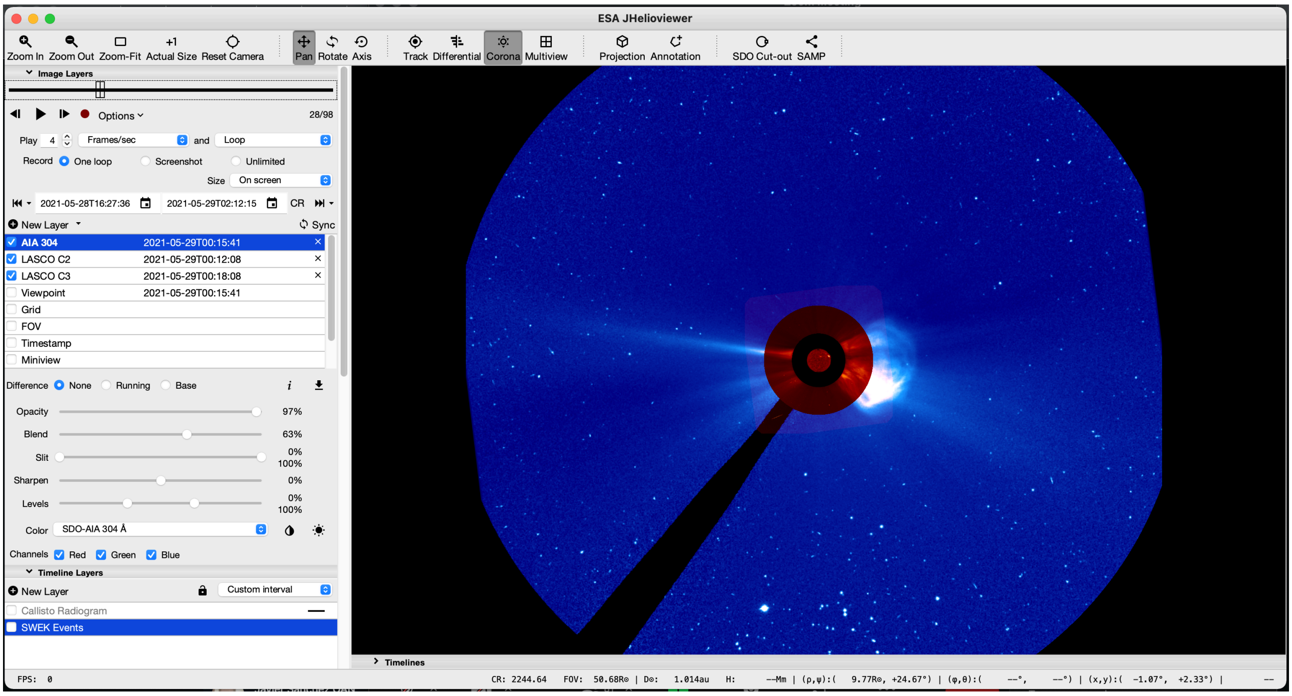

Figure 2: Exploration of solar data for May 28, 2021 with JHelioviewer.

1.2	Use a selection of images to measure the distance of the CME front from the Sun in km.	10.0pt

1.3	Extend the table of data (that you constructed in previous part) to include • Date and time (as reported in 1.1) • Distance of CME front from the Sun in km (as reported in 1.2) • Cumulative velocity in km/s (e.g. if you are at the 4th image, the mean velocity between onset of CME until the time of the 4th image), • Velocity per time interval in km/s (e.g if you are at the 4th image, the mean velocity of CME between the times of the 3rd and 4th image). Make this table in the working sheet.	10.0pt

Note: Both the velocities are to be calculated with respect to the Sun.

Do not forget to label each of the columns of your table accordingly.

Part 2 (15 points).

2.1	Make distance-time and velocity-time graphs (for both cumulative and velocity per time interval) using the measured and calculated data from your table.	15.0pt

Part 3 (10 points).

3.1	Considering that the CME moves at constant speed for distances larger than 30 solar radii, estimate the velocity (in km/s) of the CME front when it impacts the ParkerSP, and the time (in hours) it takes to do so from its onset.	10.0pt

Part 4 (10 points).

From the following statements, mark which are TRUE and which are FALSE.

4.1	If we keep decreasing the time interval between successive images, the precision of measurements of the evolution of the CME and the calculated physical parameters will always keep increasing.	2.0pt
4.2	A more accurate analysis and measurements of the CME evolution should consider the differential rotation of the Sun, and therefore the calculated velocities will be affected.	2.0pt
4.3	Any software (numerical) misalignment among the images when creating the mosaic will have direct effects on the precision of the calculations.	2.0pt
4.4	The different assumptions made in order to construct the model displayed in a heliospheric density map in Figure 1, may affect the estimation of the Sun-ParkerSP distance.	2.0pt
4.5	The interaction of the CME-front with the remnant dust left by the 2019 Borisov comet broadens and diffuses the images. This reduces the contrast in the images, substantially increasing the uncertainty in determining the CME-front and its propagation.	2.0pt

Part 5 (10 points)

5.1	The CME front carries a large number of protons and alpha particles. Calculate the energy (in eV) of a single proton and a single alpha particle as measured by the Solar Wind Electrons Alphas and Protons (SWEAP) instrument on board the ParkerSP. Consider only the mechanical energy of the particles resulting from the propagation of the CME front, neglecting all other forms of energy.	10.0pt

Tools:

The JHelioviewer software (https://www.jhelioviewer.org/download.html) can be used to explore solar data from several solar telescopes as shown in Figure 2. Using the graphic interface, you can select an observing data (Observation Date) and upload multiple solar images by adding layers (AddLayer). Using the option, you can inspect a sequence of images to study the evolution of an eruptive event. By moving the cursor you get the information about the coordinates where you are located (in arcseconds) with respect to the center of the Sun (x:0” y:0”).