

CUME 450
Total points: 80

Overview:

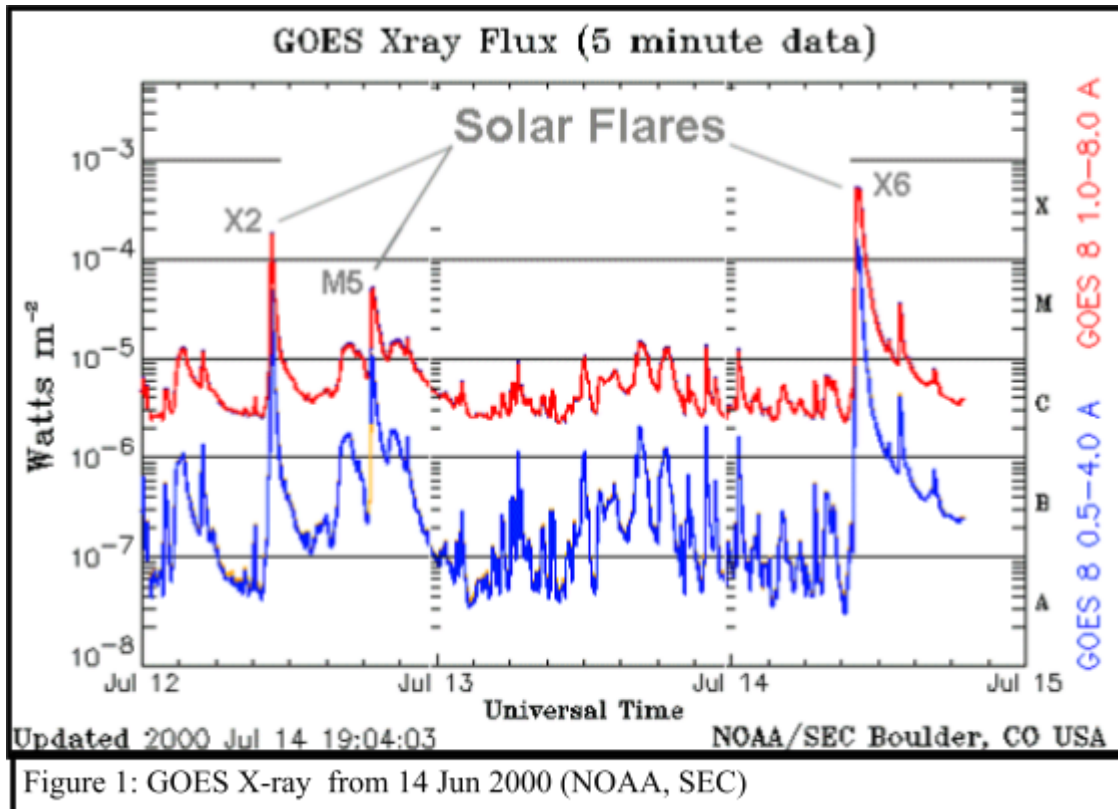
CUME 450 is inspired by the colloquium by Prof Durgesh Tripathi on India's Aditya mission. During the talk Prof Tripathi spoke about fundamental aspects of the Sun and how the Sun affects us on the Earth. Relevant slides are provided for you. You can overview these, and pay special attention to graphs and plots.

To successfully complete the CUME 450, you will need basic understanding of solar physics, stellar spectroscopy and instrumentation.

Instructions:

- 1.) There are four sections to the cume, covering 13 questions. First two sections are based on the details of the solar phenomena that were discussed in the colloquium. These have 25 and 35 points respectively. And the last two sections are based on the mission and cover 10 points each. The guaranteed passing score is 60 points, and the maximum score is 80 points. Passing percentage is 75%.
- 2.) Graphs and plots are provided in most questions for your guidance. Take time to understand these.
- 3.) Solve the cume in order of the questions. Write your thought process. Skip questions that you find difficult and return back. Make sure you finish questions in 90 mins and spend 30 mins rechecking the answers and addressing missed questions.
- 4.) Technical details: You will need pen, paper and calculators.
- 5.) Contact: Via provided Zoom link <https://nmsu.zoom.us/j/99249598194>

Category: Space weather events (25 points)



Space weather relates to the changing environmental conditions in near-Earth space. Space weather effects are caused by turbulence in the space weather, usually caused by the Sun. Auroras are the most common effects observed on the Earth. There were many space-weather events described in the colloquium. We will look at two short term effects and one long term effect in detail.

A.) Solar Flares: Solar flares are the sudden releases of energy across the entire electromagnetic spectrum. Solar flares are classified according to their x-ray brightness, which varies in the wavelength range 1 to 8 Angströms.

Figure 1 shows a solar flare x-ray flux chart from GOES satellite obtained from 14 June 2020. Classes of the solar flares are A,B,C,M,X, and are on the right of the plot. Flare of category “A” is the weakest and the flare of category “X” is the strongest. There are three flares identified in Figure 1, these are X2, X6 and M5 flares.

1.) The strongest flare in the past decade was on 6th Sept 2017, an X9.3 flare. Identify the X-ray flux for an X9.3 flare. Estimate the X-ray flux ratios for an X9.3 flare to the flares on the plot shown in Figure 1. (4 points)

2.) Often flares result in down-flows in which plasma travels back to the surface of the Sun.

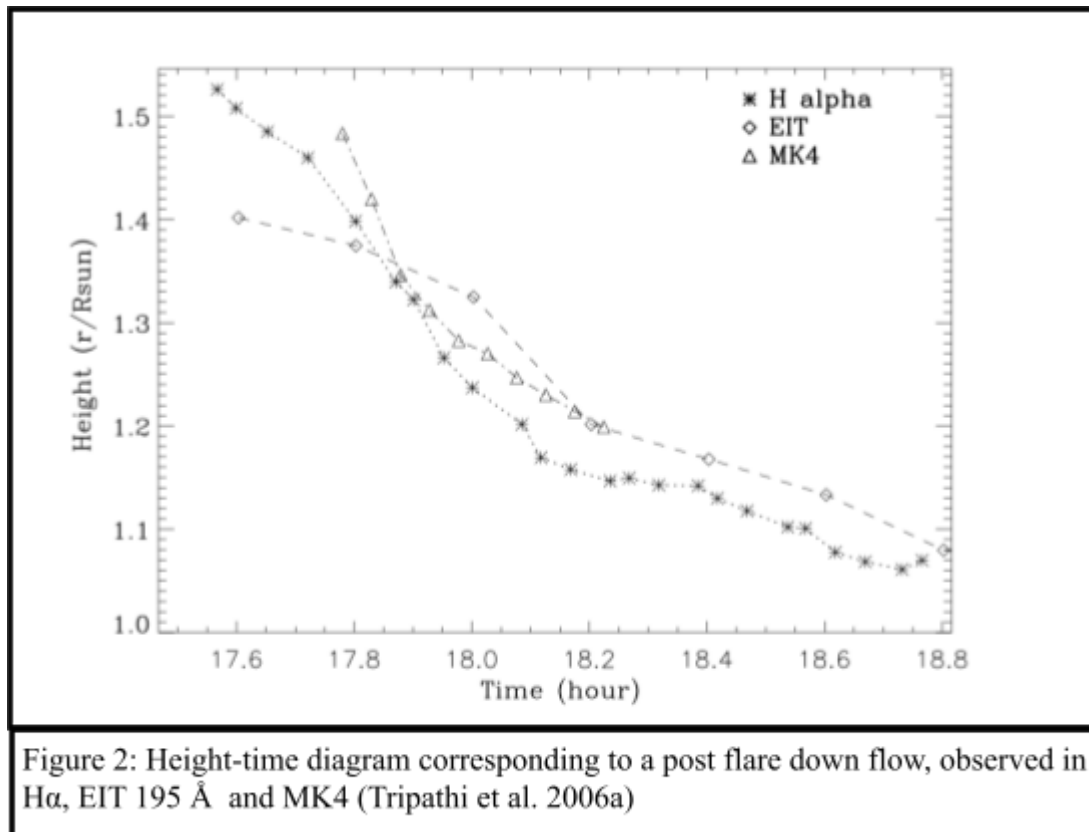


Figure 2 shows a Height-time plot, corresponding to the down-flows after a flare occurrence. These observations are recorded by the H α coronagraph (asterisks), and EIT 195 Å (diamonds), and MK4. $R_{\text{sun}} = 7.0 \times 10^5$ km (Ref: Tripathi et al. 2006a). Estimate the average velocity of the down-flow for the H α and EIT wavelengths. (2 points)

B.) Coronal Mass Ejections: A Coronal Mass Ejection (CME) is an eruption that results in release of plasma and magnetic field from the Corona. CMEs are often associated with solar flare eruptions and filament eruptions. A CME structure consists of the core and a leading edge (LE), and is often associated with a down flow (see left panel of Figure 3). Plasma properties of LE are different from the core, the core being more denser. Figure 3, right panel, shows a Height-time diagram of a CME that was triggered by a Filament eruption (Tripathi et al. 2006b).

3.) Estimate the velocities for the leading edge of the CME, the core of the CME, and the down flow. Why do you think the leading edge of the CME moves faster than the Core of the CME? (5 points)

4.) Name two effects of short term space weather events that we experience on the Earth. (5 points)

C.) Long Term Space Weather Events: Total solar irradiance (TSI) is a measure of the solar power over all wavelengths per unit area incident on the Earth's upper. TSI changes by a small fraction as the solar cycle or Sun's magnetic cycle goes from a period of high

activity to a period of low activity. The period of high activity is called the Solar Maximum and the period of Low activity is called the Solar Minimum.

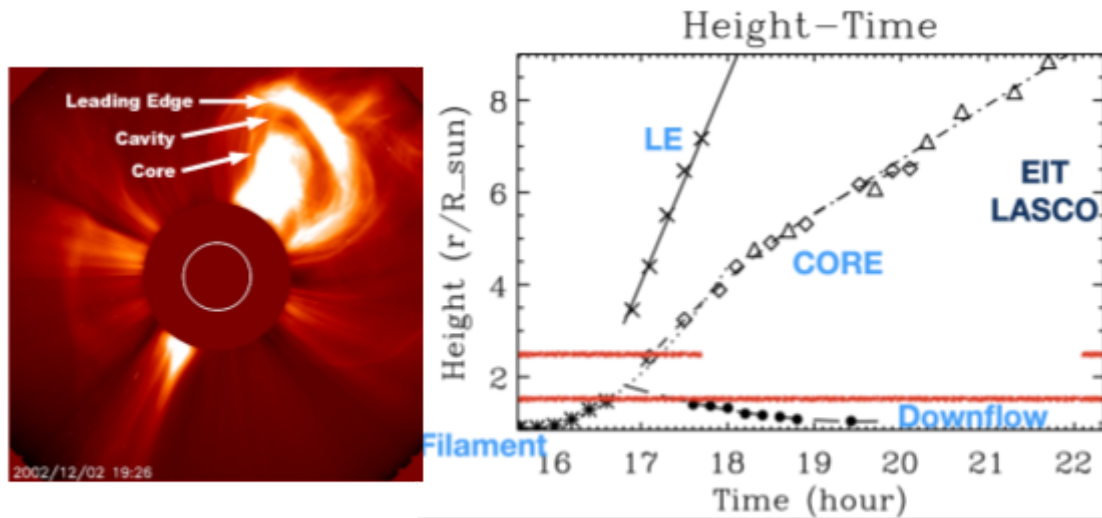
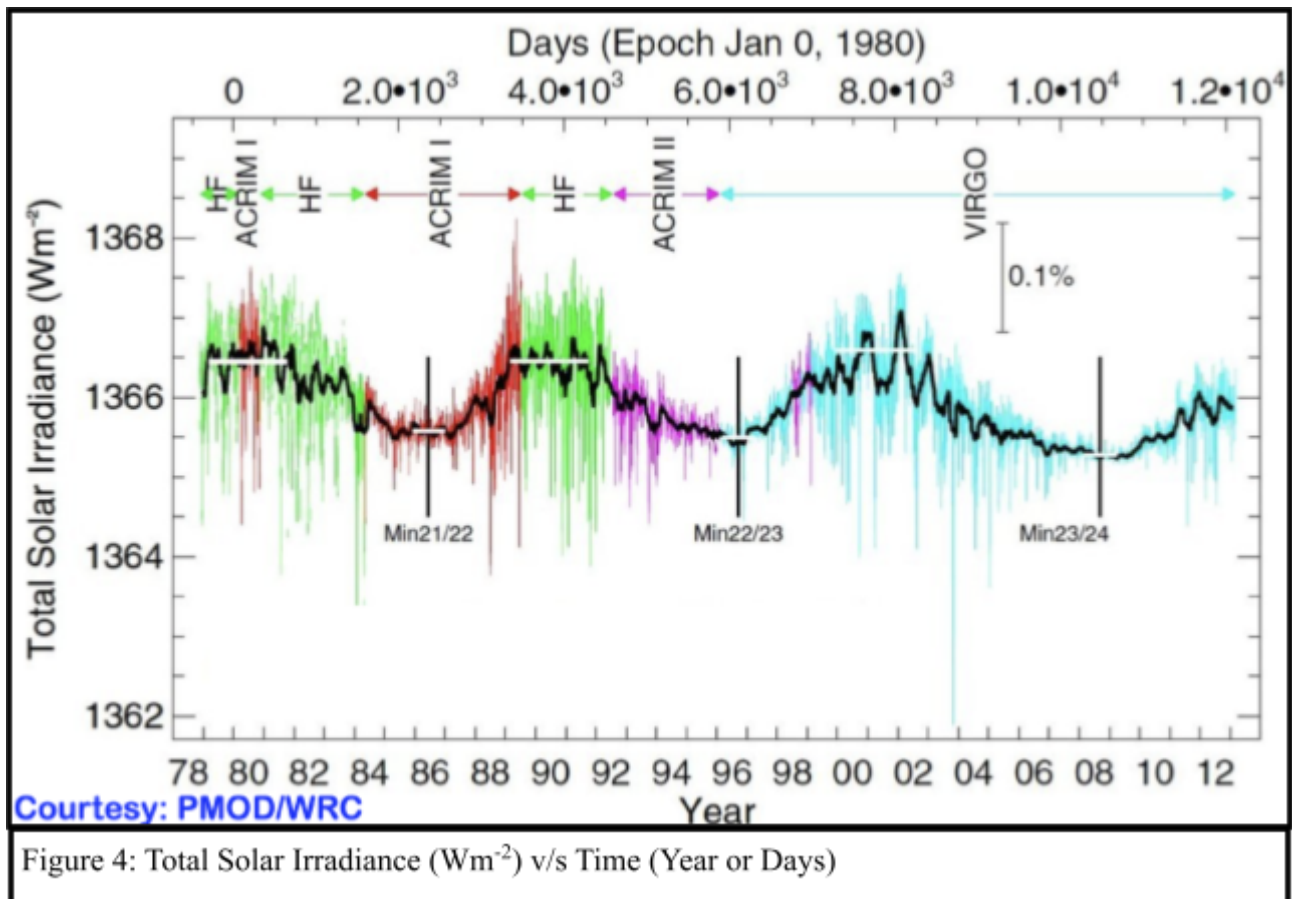


Figure 3: Left panel shows CME with its components (Colaninno et al. 2012). Right panel shows CME evolution after a filament eruption (Tripathi et al. 2006b)

5.) Figure 4 from PMOD/WRC shows TSI (Wm^{-2}) v/s Year or Days. It covers the maxima of solar cycles 21, 22, 23 obtained from different satellites and the minima between solar cycles 21/22, 22/23 and 23/24.

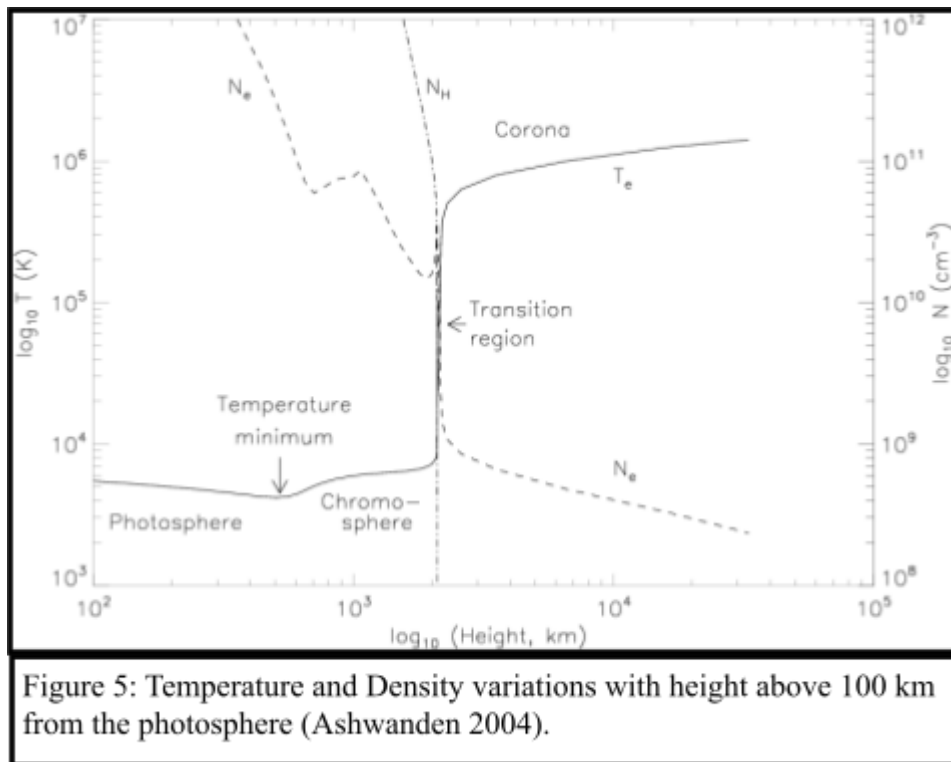
5.a.) Estimate the average TSI at the maxima and average TSI at the minima for all cycles in the plot. (3 points)

5.b.) How much does the TSI vary between maximum and minimum of each solar cycle. (3 points)



5.c.) The slides talk about the TSI being dependent on the wavelength. How can solar physicists improve their estimation of TSI? (3 points)

Category: Solar Atmosphere: (35 points)



The solar atmosphere is extremely dynamic as one goes from the photosphere (the surface of the Sun) to the solar corona. The regions in the solar atmosphere are the photosphere, the chromosphere, the transition region and the corona.

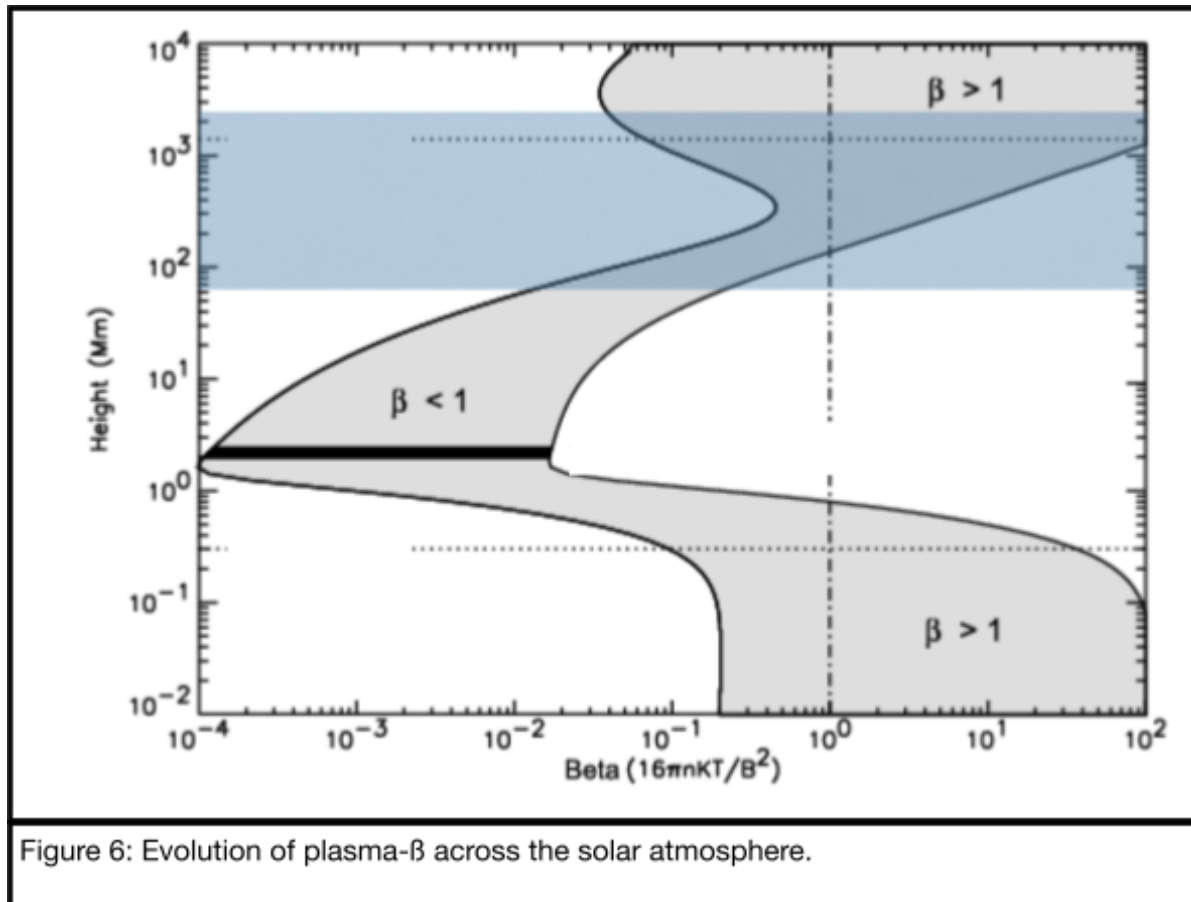
6.) Variations of plasma properties: Figure 5, is from the Ashwanden 2004 book “Physics of the Solar Corona. An Introduction”. It shows the relation of plasma parameters such as the temperature and the density as a function of the solar atmosphere. The solid lines refer to the temperature, which is labelled on the left vertical axis, while the dashed line marks the density. N_e is the electron density. N_H is the Hydrogen density. The plot shows a sudden temperature rise in the solar atmosphere.

6.a.) A transition between the photosphere and the chromosphere corresponds to a temperature minimum region. Beyond this region the solar temperature rises. Compute the rate of temperature increase in the solar chromosphere as a function of height. (1 point)

6.b.) The transition region in the solar atmosphere covers approximately a few hundred kilometres. What other physical changes occur over this height in the solar atmosphere? (3 point)

6.c.) How does the pressure behave in the transition regions? (3 points)

7.) Plasma- β : Solar plasma is often dictated by the magnetic fields. Plasma- β , is the ratio of plasma (gas) pressure to magnetic pressure. Plasma- β , gives us an idea about how the plasma and magnetic field interact. Figure 6 from Gary (2001), shows evolution of plasma- β along the solar interior and solar atmosphere. We focus on regions above the photosphere.



Notice the trend changing in plasma- β . The solid lines enclose the range of plasma- β at that height. Use the upper-bound of this range to answer the questions below. The dark-dashed-dot line corresponds to $\beta = 0$ region.

7.a.) Describe how the plasma- β changes in the chromosphere (shaded in blue). (Answer in 2-3 sentences, 3 points).

7.b.) Where is the transition region in Figure 6? (1 point)

7.c.) What happens to plasma- β in the transition region? (1 point)

8.) Observational aspects of the solar atmosphere: Figure 7 is a Val-C 1-D model of the solar atmosphere observed associated with a quiet Sun region., developed by Vernazza et al 1981. This model shows the relation of temperature and height across the solar atmosphere, and also temperature and density. For this cume, a quiet-Sun is a region void of any sunspots or strong concentrations of magnetic fields.

Commonly used spectral lines used for solar observations are over plotted on the graph. Amongst these Mg II k spectral line is the hottest line and the Lyman- α is the coldest. E.g: if our task is to observe hot-plasma in the Transition region, we will use the Mg II k line.

Based on Figure 7, let's design some observational strategies. Use only named-spectral lines to answer the questions below. You may want to use Figure 5 as a reference to overview different regions of the solar atmosphere.

8.a.) Find where the photosphere lies in Figure 7. What is the temperature range in this region? Briefly describe two ways to measure the temperature of the solar photosphere? (5 points)

8.b.) Can you use $H\alpha$ wings to observe the photosphere? Justify your answer considering the temperature and altitude of the $H\alpha$. (2 points)

8.c.) I am looking at solar jets that have temperature ranges between 8000 K and 20000 K. Plasma in these jets travels between the heights of 1500 km and 2500 km. Suggest two spectral lines that can be used for comparing plasma properties. Justify your selection by

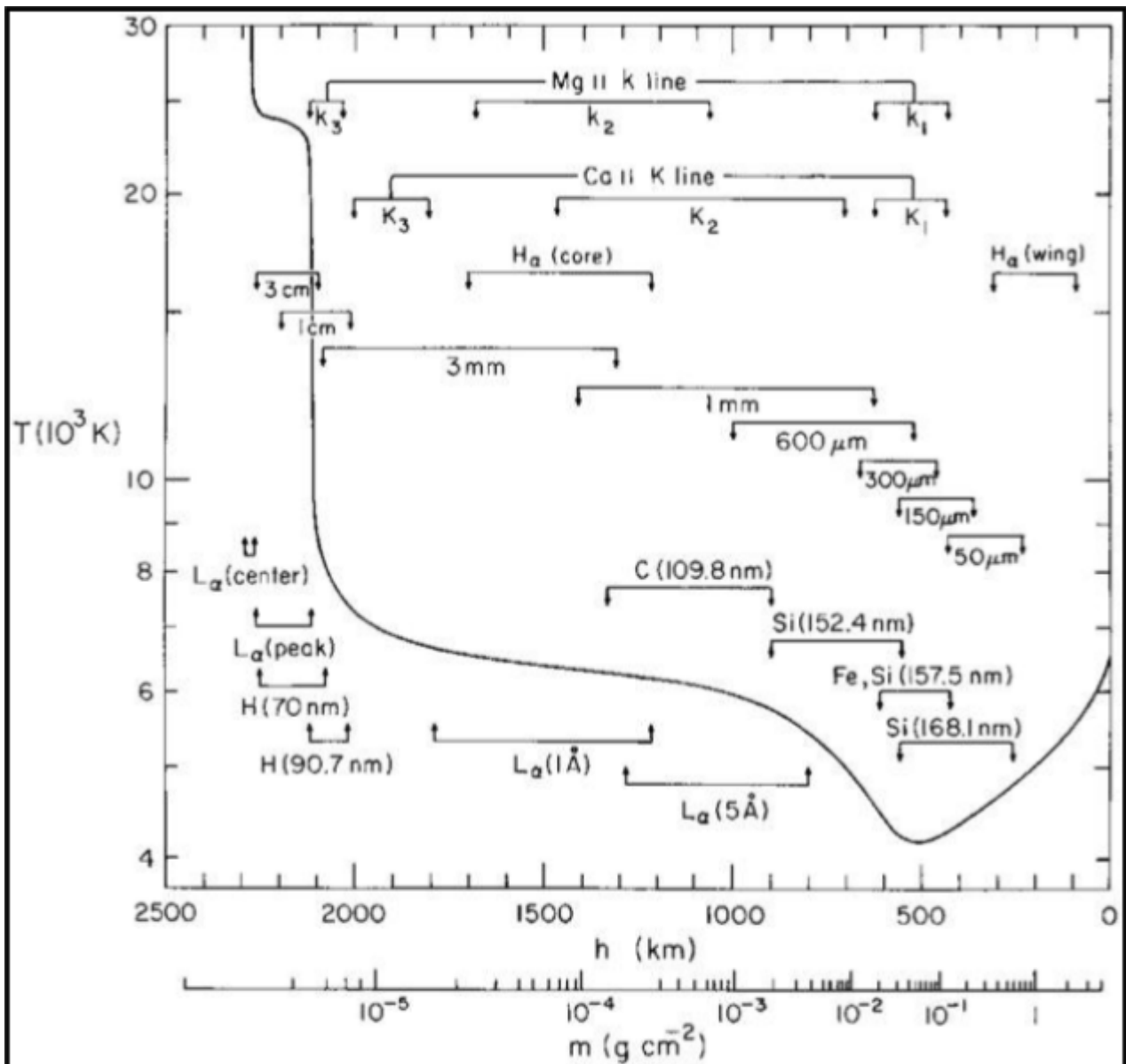


Figure 7: Val-C model of the solar atmosphere above a quiet Sun by Vernazza et al. 1981.

explaining how the temperature and altitude of the jets led to your choice? (5 points)

8.d.) I am looking at a sunspot, which lies between 5000 K and 6000 K. I want to investigate how waves from the sunspot travel across the solar atmosphere. Which two spectral lines can I use for comparison? Justify your selection. (5 points)

9.) General overview of the solar atmosphere based on a combination of sections above:

9.a.) What would be my observing strategy if I wanted to select two spectral lines to continuously observe the solar atmosphere between 500 km and 2500 km. (3 points)

9.b.) Why do CME down-flows have different velocities at different wavelengths? (3 point)

Category: Aditya-L1 in a nutshell. (10 points)

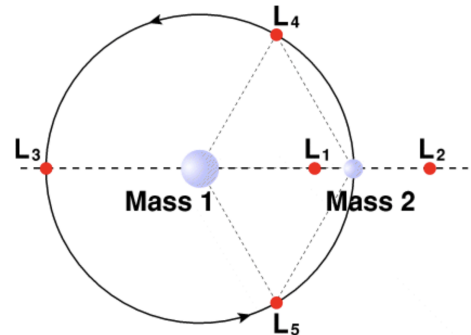
Aditya-L1 mission focuses on:

- a.) Space weather
- b.) Heating of the upper atmosphere.
- c.) Spatially resolved solar spectral irradiance
- d.) Solar Wind particle distribution and composition.

10.) How does being at L1, a the Lagrangian point between the Sun and Earth, assist the science goals of the mission? Describe one advantage and one disadvantage of L1 over L4 or other points.

(5 points)

11.) What are the challenges in data transmission faced by ADITYA-L1? How can ADITYA-L1 overcome this? (5 points)



Category: Solar Ultraviolet Imaging Telescope: (10 points)

SUIT is designed to investigate coupling between different regions of the solar atmosphere. Here are some of the technical details:

- Detector - 4096 x 4096 - 48'
- FOV - 33' - enough margin for alignment with VELC
- Pixel size — 0.7''
- effective angular resolution — 1.4''
- 11 science filter
- 8 narrow-band - solar atmospheric dynamics
- 3 broad-band - Sun-climate relationship
- Synoptic as well as PI driven observational sequence possible - joint observing programs with others observatories

(1'' = 750 km)

SUIT has three observational programs, in mode:

- Full disk 4kx4k in all 11 filters — where images are obtained every 30 mins
- Full disk Mg II — 2kx2k — where images are obtained every min.
- Partial disk — 700'' x 700'' — where images are obtained every 4 to 40 s

12.) A jet on the Sun is 6000 km in height, 150 km in width and has a lifetime of 2 mins. Choose an appropriate observing program from the three mentioned to observe this jet and justify your selection. (5 points)

13.) This jet oscillates in the transverse direction, and has an oscillating amplitude of 200 km, and a period of 2 s. But SUIT has a pixel size of 0.7''. Could SUIT data be used to resolve such higher-frequency oscillations? Justify your answer? (5 points)