**the mass of a coronal mass ejection:**

Our lesson:

lets talk about scattering.  Scattering is a process that occurs when an electromagnetic wave collides with a particle. That collision removes energy from the incident wave and re-radiates the energy and that means it is scattered.  It is scattered because the electric and magnetic components of the incident wave accelerate the particle which emits radiation.   Thomson scattering is an important phenomenon in plasma physics and was first explained by the physicist sir John Thomson. The main cause of the acceleration of the particle is due to the electric field of the incident wave. The particle will move in the direction of the oscillating electric field, resulting in electromagnetic radiation. As a hint the moving particle radiates most strongly in a direction perpendicular to its motion and that radiation will be polarized along the direction of its motion. Therefore, depending on where an observer is located, the light scattered from a small volume-element may appear to be more or less polarized.''

As the energy of a photon is inversely proportional to its wavelength, symbolised by the greek letter lambda λ… the Compton scattering or the Compton effect, explains the decrease in energy (increase in wavelength λ) of a high energy (X – or γ (gamma) – ray) photon, as it interacts with a free electron. More important for astrophysics, is the existence of the Inverse Compton scattering. In Compton scattering the photon gains energy (decrease in wavelength) upon interaction with a high energy electron. The amount the wavelength changes by, is called the Compton shift. Although nuclear Compton scattering also exists, what is meant by Compton scattering usually is the interaction involving free electrons.

On chapter 3 and also in this chapter we learnt about the mean free path. As photons are scattered in random directions, i.e. random walk in which each step is the mean free path  which mathematically is described as the mean free path. The equation is described with words on chapter 3 so here we will have only the grapheme and you may use the hyperlink to go to the chapter where it is.  So the mean free path  is graphemically equal to  λ = 1 σT ne. Do not forget that.  Now,  Imagine  that the celestial sphere is an imaginary sphere of immense radius surrounding you the multi-sensorial observer. The plane of the sky would be a plane that  touches the celestial sphere, but do not cross it, that means it is tangent to the celestial sphere and perpendicular to something wrongly defined as the line of sight. A good analogy, Imagine you are at the center of a beachball and that a flat sheet of paper is extended over the beachball. The celestial sphere is the ball around you.The plane of the sky is the piece of paper.  The line of sight is a straight line that goes from your eyes to the point of interest.  Lets use the CARDIS, find the x,y,z axis,  take the z-axis to run along the line facing the  object or extending to the object(people call it the line of sight), then the plane of the sky will be the plane slicing throught the x-y plane note that the way the x,y, axis connect to the z axis is perpendicular to the z-axis. In the case of many spacecrafts acquiring images like LASCO, measured distances in solar radii are actually called measurements of elongation, where elongation is the angle between a line from Sun to Earth  and a line from the Earth to the point where were  the measurement is taken. We will call that point P.  That elongation is converted to distance with the application of two assumptions:

1. Light from the point P, which is the measured point, is Thomson scattered such that the line from the Earth to P ( the measured point) is at right angles to the line from the Sun to P. This approximation can be expressed as  R which is approximately the sine of the elongation or in graphemic form:

R∼ sin ε ( greek letter careful for nemeth or duxburry or mathML…the letter greek is for elongation and the elongation as explained above is the angle between two lines)

in that equation R is the distance from the Sun to P in astronomical units and assumes that the mass of the Coronal Mass Ejection (CME) is localized in the plane of the sky, and if the  intensity of the integrated line of sight is equal to the CME intensity at the point P being measured.

2. Elongation angles or angle between the two perception lines, or between two point objects as perceived from an observer are small, such that the sine of the elongation approximates the size of the elongation in graphemic form (sin ε ∼ ε), then  R is approximately the same as the elongation in graphemic form (R∼ ε).

Then , even though we know this does not apply in all cases and only under those two assumptions, we may use Thomson scattering to approximate the mass of a coronal mass ejection or CME.  A CME is a tremendously accelerated flow of particles ejected from the Sun but the interstellar media is filled with particles. The electric and magnetic components of the wave crashing on those particles in the interstellar media accelerate the particle. As it accelerates, it, emits radiation and the incident wave is scattered this means that the incident wave causes further vibration in the electrons in the interstellar media and those electrons will emit light in all directions. The main cause of the acceleration of the particle will be due to the electric field component of the incident wave. The moving particle radiates most strongly in a direction perpendicular to its motion and that radiation will be polarized ( restricted to a plane ) along the direction of its motion. Therefore, depending on where an observer is located, the light scattered from a small volume element may appear to be more or less polarized.

So for our sky plane assumption, the CME mass (m) is calculated by measuring the integrated intensity across a selected area on a running difference image βobs.  To calculate Bobs you take the CME image from any satellite ( LASCO, SDO, etc) SOHO  for example  divide the area by the pixel calibration (um/pixel), which is available in the Image Info or metadata. Note that there are free softwares online that  calculate the integrated intensity (sum) first, then divides by the number of pixels to get the average intensity.  We invited you to use the images from LASCO instrument C in which the resolution is 1024 × 1024 multiply those two numbers and you will get the pixelation.  Then we need to calculate the area of the image.  Using your orchestar or if using. a mobile light detector hold the image over a piece of light. In my case I use a  deep pot and inside i put another telephone or one of those souvenir key holders that come with the light on or a tiny flashlight like the ones from a keyholder.  Then on the top of the pot i extend the CME image which should be on a gridded paper. If you are using an orchestra you may do this directly on the cardis.   Take the orchestar or the mobile sensor and by listening to the high and low pitches you may map with tape or pushpins the form of your CME. If the CME is more or less circular find the centre , you may even marcate the whole perimeter you heard with clear tape and marcate the centre then measure the radius with a tactile string or ruler use the area of the circle equation to calculate the area. Now multiply the pixels by the area and you will get Bobs…. We have not finished and you should save that number: Bobs

For our purposes CME mass (m) is calculated by measuring the integrated intensity across a selected area on an image βobs which we have but we need to include the angle of the line going from the Sun to the point and the plane of the sky. That is included by an equation that says that the sin of omega is equal to the cosine of the that multiplied b the radius. In graphemic form 𝑠𝑖𝑛𝛺 = 𝑐𝑜𝑠𝜃 𝑅0 . Omega is calculated by dividing the area between the radius.Where (θ) is the angle of the line SP to the plane of the sky. Here, Be (θ), known as the Thomson scattering function, is given by: A (𝑅) = 𝑐𝑜𝑠Ω 𝑠𝑖𝑛2Ω

𝑠𝑖𝑛𝛺 = 𝑐𝑜𝑠𝜃 𝑅

The Thomson scattering function, is given by:  ( i know i need to say it in words)

B  = − 1 8 [ 1 − 3 𝑠𝑖𝑛2Ω − 𝑐𝑜𝑠2Ω ( 1+3𝑠𝑖𝑛2𝛺 𝑠𝑖𝑛𝛺 )ln( 1+𝑠𝑖𝑛𝛺 𝑐𝑜𝑠𝛺 )]

C = 4 3 − 𝑐𝑜𝑠𝛺 − 𝑐𝑜𝑠2 𝛺 3

D  = − 1 8 [ 5 + 𝑠𝑖𝑛2𝛺 − 𝑐𝑜𝑠2𝛺 ( 5−𝑠𝑖𝑛2𝛺 𝑠𝑖𝑛𝛺 ) ln ( 1+𝑠𝑖𝑛𝛺 𝑐𝑜𝑠𝛺 )]

 𝐵𝑒 (𝜃) = 𝜎𝜋 2 [2(𝐶 + 𝑢(𝐷 − 𝐶)) 𝑐𝑜𝑠2𝜃(𝐴 + 𝑢(𝐵 −𝐴))]

A is area!

here omega or ( greek letter please) is a measure of the amount of the field of view from some particular point that a given object covers. That is, it is a measure of how large the object appears to an observer looking from that point. and it is calculated by omega equals the spherical surface of the sphere divided by the squared radius of that sphere.  In graphemic form it is written (we need help with the image of this tiny equation and i know i did not tell them this in a reality is  a solid angle..)

In the equations above  (θ) is the angle between the line Sun to measured point P and the plane of the sky. To make it easier you may plot it on the cardis. it means that line sun to the point we are interested makes an angle to the plane of the sky and that angle is that greek letter (θ)

then the mass is the result of the multiplication of that B(obs) I told you to remember, multiplied by Bsube multiplied by 1.97 evated to the -27 or in graphemic form

𝑚 = 𝐵𝑜𝑏𝑠 𝐵𝑒(𝜃) × 1.97 × 10−27 𝐾𝑔

first calculate omega, then using omega substitute it on the equations for A, b, c, d . then substitute the values calculated for ABCD on the equation for b(e) and then substitute bobs and Be on the equation for the mass.   you should get an approximate value to the mass of the coronal mass ejection. The result will be in kilograms but if you may you may change it to sola rmasses  using that one kilogram is equal to 5.02785e-31

Observe clearly that the equations above list how to calculate Bobs and Be.

before we continue please observe that this equations consider the following:

1.σ (what letter this?) is the scattering cross section, 7.95 × 10−26 per  steradian  u limb darkening

2. µ (nu) = 0.63

why did we use thomson? because Mass measurements are very dependent on angle θ an it is necessary to perform calculations with θ equal to the direction of propagation of the CME.