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PHYS 454

Professor Hedberg

HW#4

Question 1 – Limb Darkening

a) From NASA's SDO (Solar Dynamics Observatory) [1], the HMI (Helioseismic and Magnetic Imager) intensitygram of the sun [2] will be used to investigate the drop in brightness from its center to the outer radius/disk. This is known as *Limb Darkening*. The HMI intensitygram is shown in **Figure 1**.

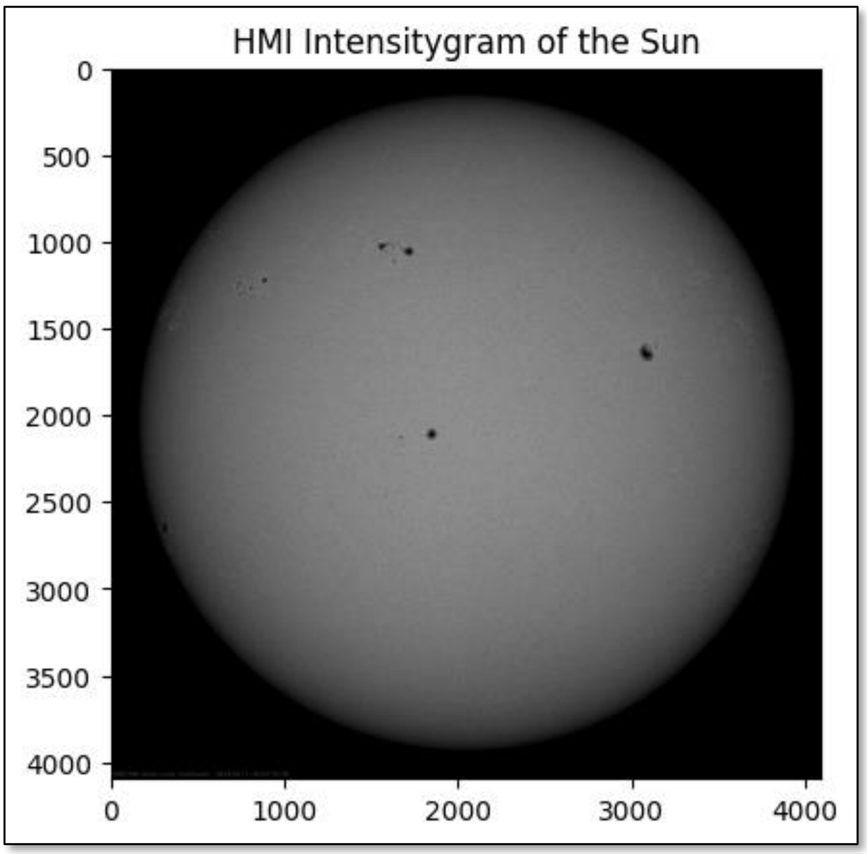

Figure 1: HMI Intensitygram of the Sun, displayed using python. The x and y axis are positions in pixels (4096 x 4096)

A line profile was extracted from this image. Since the only the distance from the center to the edge radius is needed, the image was cropped in half. Additionally, the intensities of the brightnesses were normalized. **Figure 2** shows the cropped image and the graph of normalized intensity as a function of the distance from the center of the sun (in pixels).

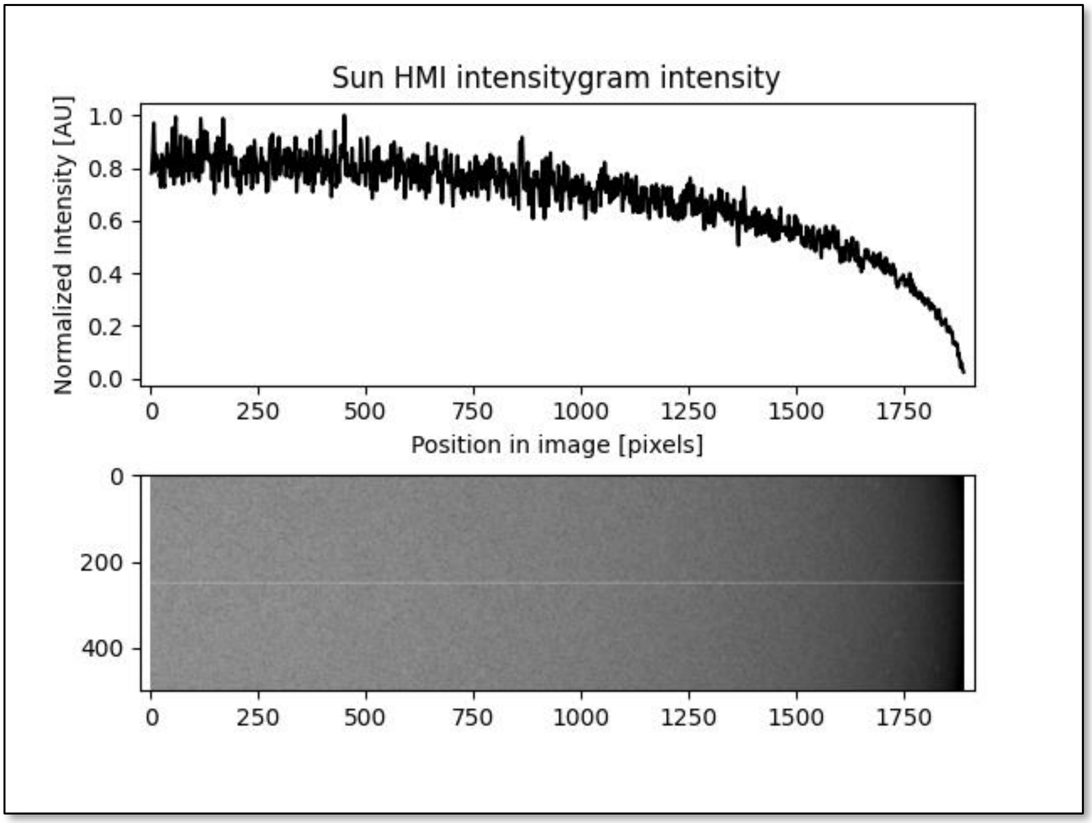

Figure 2: Normalized Intensity graph from center of sun to edge

b) From Chapter 9 of Intro to Modern Astrophysics [3], Limb Darkening can be estimated as a function. This approximation, known as the theoretical Eddington approximation of solar limb darkening, is shown in **Equation 1**.

$$\frac{I(\theta)}{I(\theta = 0)} = \frac{a + b\cos(\theta)}{a + b} = \frac{2}{5} + \frac{3}{5}\cos(\theta) \tag{1}$$

where I is the intensity, a and b are wavelength-dependent coefficients, and θ is the angle from the line of sight toward the center of the sun and the line of sight a distance away from the center of the sun perpendicular to the surface of the sun. The right-hand side of the equation is the simplified equation. The angle θ is visualized in **Figure 3**.

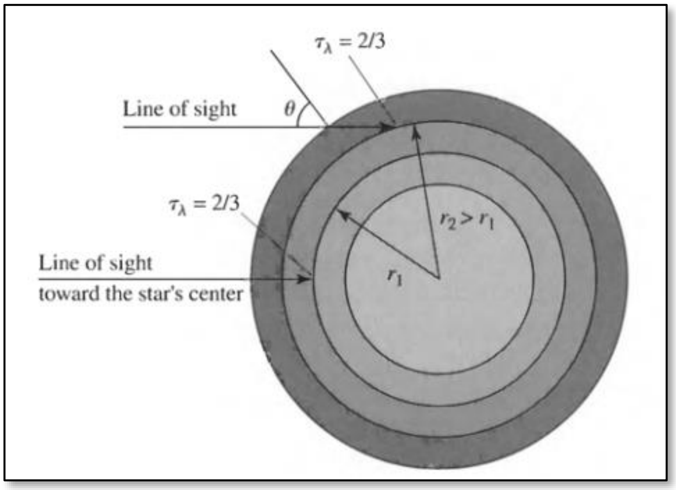

Figure 3: Line of sight of sun and angle from a perpendicular on the surface of the sun

However, this is assuming we know the angle. We can transform the equation to be dependent on another variable by relating θ and d, the distance from the center of the sun. Using basic trigonometry, we can obtain **Equation 2**.

$$\theta = \sin^{-1}\left(\frac{d}{\text{radius of sun}}\right) \tag{2}$$

The maximum value for d is the radius of the sun, which should theoretically be the darkest (minimum intensity). **Figure 4** shows the Eddington approximation with respect to the variables θ and d.

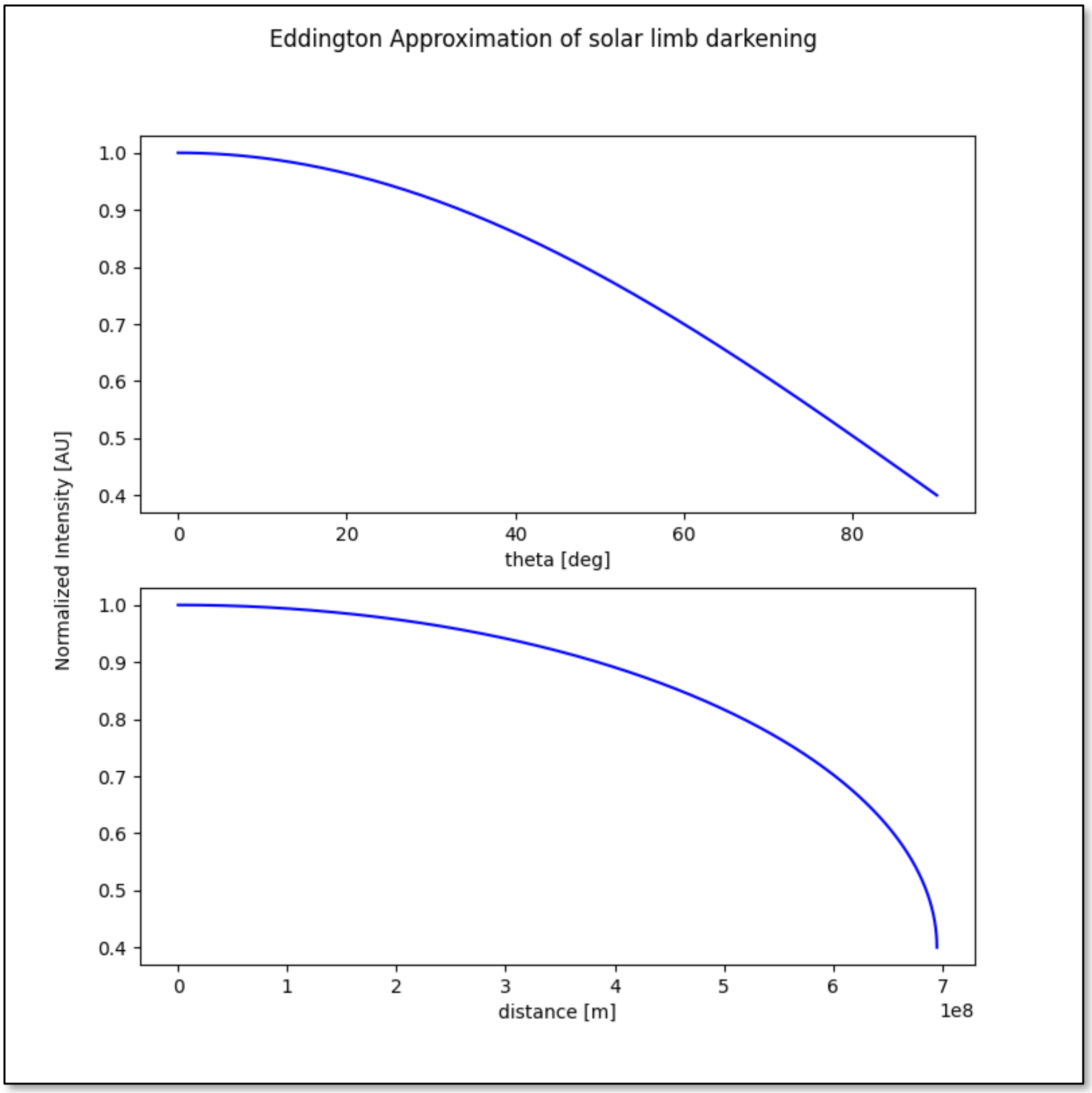

Figure 4: Eddington approximation of limb darkening w.r.t. theta angles (top) and distance from center of sun (bottom)

c) Since the Eddington approximation from part b) is in units of meters and the normalized intensity graph from part a) is in units of pixels, we need to convert both to the same units. **Figure 5** shows the Eddington approximation superimposed onto the Sun HMI intensitygram graph. Although the approximation does not fall within most of the data, the slope and downwards trend is very similar. This shows that the Eddington approximation of limb darkening is a good estimation, but not perfect.

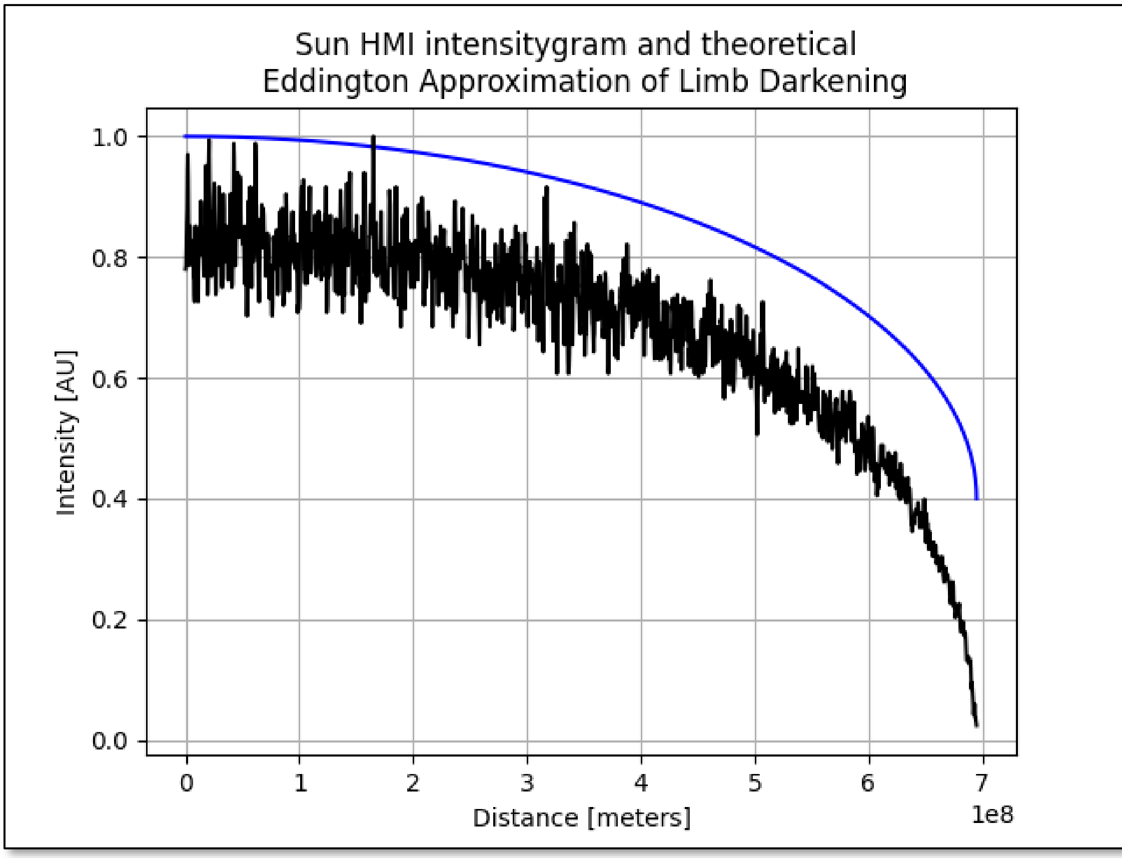

Figure 5: Eddington approximation superimposed on normalized intensity graph of sun

Question 2 – Balls of Gas

A GMC (Giant Molecular Cloud) is the Orion Nebula of the Orion molecular cloud complex, shown in **Figure 6**.

Figure 6: The Orion Nebula of the Orion molecular cloud complex

Containing mostly hydrogen, the Orion Nebula has a radius of approximately **12 light years** and a mass of **2000 solar masses**. The time for free fall collapse is not determined by size, but the density of the cloud. To get average density, we need to find the mass and the volume. Given the radius of the cloud and the mass in terms of solar masses, we can obtain the average density of the Orion Nebula to be about **$6.49*10^{-19}$ kg/m^2**. The free fall collapse time can be calculated from **Equation 3**.

$$t_{ff} = \left(\frac{3\pi}{32G\rho_0}\right)^{1/2} \tag{3}$$

Where G is the gravitational constant. The calculated free fall time of the Orion Nebula is **$2.615*10^6$ years**, or **2.615 million years**.

Question 3 – Eclipse

a) **Figure 7** is the view from CCNY of the April 8th eclipse at 2:55 PM. Unfortunately, I could not get an image of crescent shadows. This image was taken with the solar glasses over the lens of my phone.

Figure 7: Partial Eclipse taken with the selfie camera of a Google Pixel 6 with solar glasses over the lens.

b) *Phenomena*

What exactly are we watching?

Is it the sun or the moon?

Is it the sky when it darkens?

Or is it everyone, including you?

Usually Mondays are quiescent and shallow

but April 8th produced crescent shadows

The influx of people increased and widened

While the sun's light lessened and narrowed

The eclipse was truly a sight to behold

The moon covers the sun, as we have been told

After I looked up, I then looked at my surroundings

So many humans gathered, this is the phenomena that's astounding.

References

[1] https://sdo.gsfc.nasa.gov/data/

[2] https://sdo.gsfc.nasa.gov/assets/img/latest/latest_4096_HMII.jpg

[3] https://hedberg.ccnysites.cuny.edu/PHYS454/SPRING-2024/assignment-4/limb-darkening.pdf

[4] Source Code –

https://colab.research.google.com/drive/1BRtMB-_6uEroiuI6VvAss4s7QySyHuA1?usp=sharing