Determination of the solar limb-darkening coefficient through the analysis of intensity profiles derived from solar imaging data

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## Introduction

The Sun, as the only star in the solar system, plays a crucial role due to its significant influence and numerous effects on Earth. In studying the Sun, astronomers commonly rely on solar imaging obtained through cameras and telescopes, which enables the study of key features on the solar atmosphere, such as sunspots. Upon closer examination, however, solar images consistently exhibit a gradual darkening toward the edge of the disk, known as solar limb-darkening. This phenomenon reflects the temperature gradient within the stellar atmosphere, providing valuable information for studying not only the Sun itself but also the atmospheric structures of other stars.

Motivated by this, the project focuses on analyzing daily solar images to determine the solar limb-darkening coefficient. The results are intended to serve as a reference and a useful resource for those interested in studying solar and stellar atmospheric properties.

## Method and Result

1) Solar images were captured using a NIKON D750 camera attached to a 6-inch Dobsonian telescope. A total of 20 solar images were acquired between April 17, 2025 and May 5, 2025, during the period from 14:00 P.M to 15:00 P.M. local time. Obtained images can be explained by using the diagram shown in Figure 1.

2) The acquired images were analyzed for intensity values using ImageJ. First, the images were converted to grayscale, and the oval selection tool was used to draw a circle around the Sun. Then, the previously installed plugin “Radial Profile Angle” was applied to extract the intensity data from the center of the solar disk to its limb as shown in Figure 2.

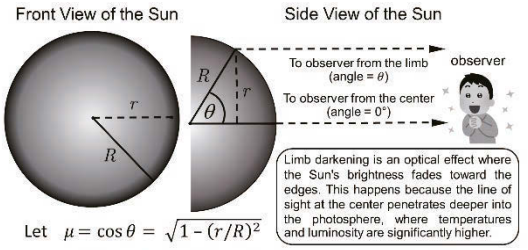
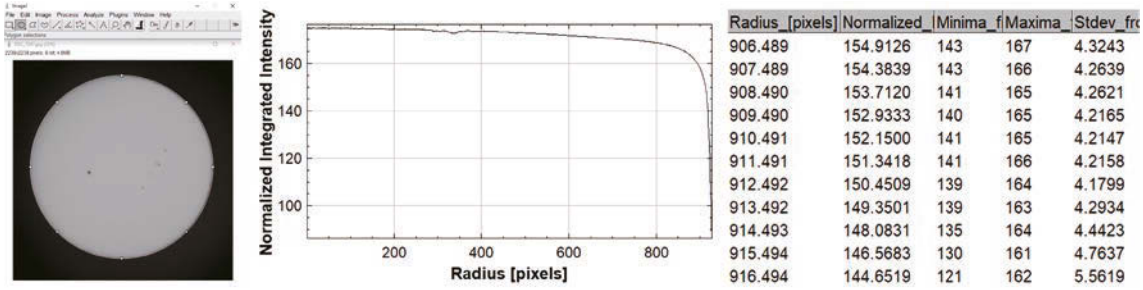



Figure 1. Diagram of a solar limb-darkening




| Radius_[pixels] | Normalized_ | Minima_f | Maxima_ | Stdev_fr |
|---|---|---|---|---|
| 906.489 | 154.9126 | 143 | 167 | 4.3243 |
| 907.489 | 154.3839 | 143 | 166 | 4.2639 |
| 908.490 | 153.7120 | 141 | 165 | 4.2621 |
| 909.490 | 152.9333 | 140 | 165 | 4.2165 |
| 910.491 | 152.1500 | 141 | 165 | 4.2147 |
| 911.491 | 151.3418 | 141 | 166 | 4.2158 |
| 912.492 | 150.4509 | 139 | 164 | 4.1799 |
| 913.492 | 149.3501 | 139 | 163 | 4.2934 |
| 914.493 | 148.0831 | 135 | 164 | 4.4423 |
| 915.494 | 146.5683 | 130 | 161 | 4.7637 |
| 916.494 | 144.6519 | 121 | 162 | 5.5619 |

Figure 2. The image of the Sun converted to grayscale with a circle by using oval selection tool (Left), the intensity graph (Center) and intensity values (Right) after applying the radial profile angle plugin.

3) The obtained intensity values were analyzed by using Microsoft Excel based on the mathematical model proposed by Claret (2014) [1], then linear regression was applied to the linear model and nonlinear regression was applied to the quadratic and logarithmic models based on the least-squares method. The results were then used to generate comparison graphs, which are shown in Figure 3., and to calculate the solar limb-darkening coefficients.

$$\frac{I(\mu)}{I(1)} = 1 - u(1-\mu) \qquad \frac{I(\mu)}{I(1)} = 1 - u_1(1-\mu) - u_2(1-\mu)^2 \qquad \frac{I(\mu)}{I(1)} = 1 - u_3(1-\mu) - u_4\mu\ln\mu$$

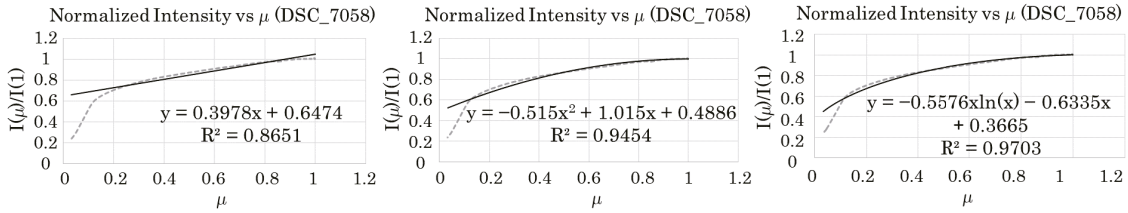



Figure 3. Normalized Intensity vs $\mu$ by linear law (Left), quadratic law (Center) and logarithmic law (Right) (photo code: DSC_7058).

## Data analysis and Conclusion

The analysis of the Sun’s light-intensity profile from photographs using ImageJ and Microsoft Excel shows that the solar limb darkening coefficients can be obtained from regression-based models. The averaged results indicate that, for the linear model, the coefficient u is approximately 0.44. For the quadratic model, $u_1$ and $u_2$ average 0.64 and 0.53, respectively. For the logarithmic model, $u_3$ averages 0.69 and $u_4$ averages 0.67.

These experimental values may be affected by sources of human error, such as measurement or processing inaccuracies, limitations in the equipment used, or atmospheric and dust interference.

## References

[1] A. Claret, D. Dragomir, J. M. Matthews. Theoretical gravity and limb-darkening coefficients for the MOST satellite photometric system. A&A 567 A3 (2014). Retrieved April 15, 2025, from https://doi.org/10.1051/0004-6361/201423515