Characterisation of solar limb darkening from NOMAD-UVIS observations

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Limb darkening

The phenomenon of solar limb darkening describes the effect where regions on the sun's surface with greater radial separation from the centre are observed to emit correspondingly less total radiance.

The region **A** in the schematic below resides at a lower depth (hence higher average temperature) than region **B**, but they both lie at a distance **L** from the surface in the direction of the line of sight parallel with this distance vector.

If the optical depth is unity over this path length then the column along the vector **L** provides for a lesser total integrated luminosity to the observer the greater the radial separation this point is from the centre

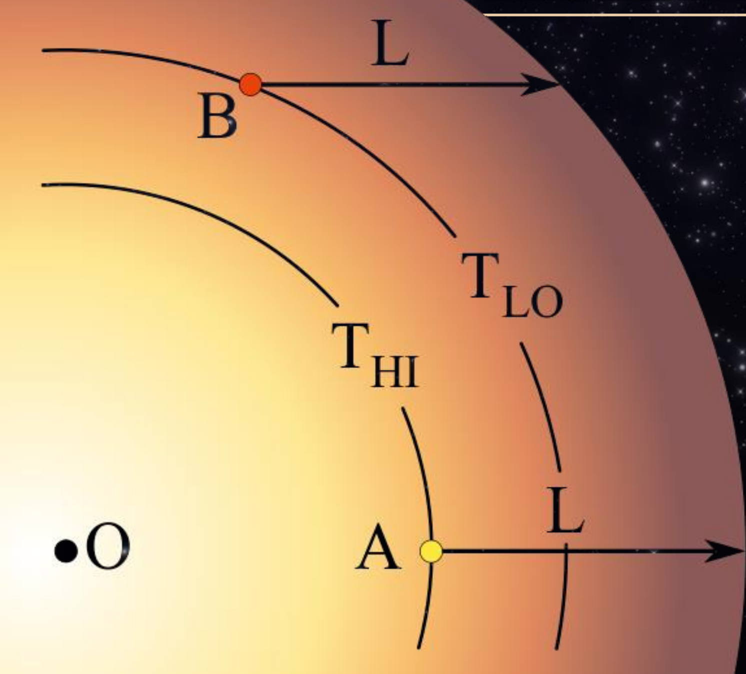
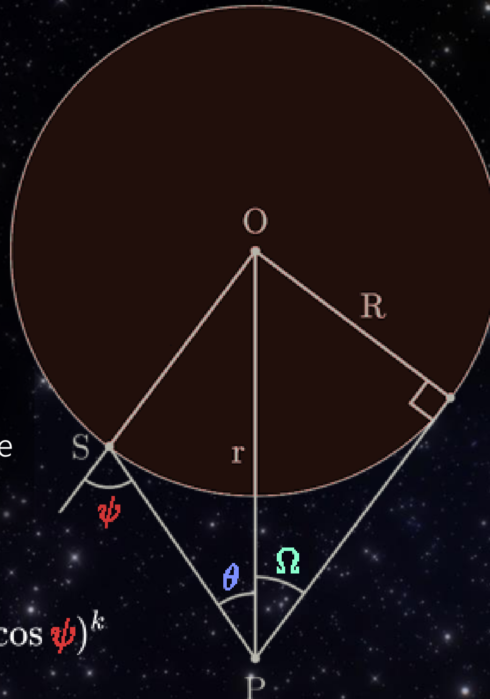


Image: wikipedia

Observational geometry

- ***R*** – Solar radius
- ***P*** – Observer location
- ***S*** – Observed surface point
- ***ψ*** – LoS/Surface normal angle
- ***ϑ*** – Observed/central LoS angle
- ***Ω*** – Solar angular radius



$$\text{(1)} \quad \frac{I(\psi)}{I(0)} = 1 + \sum_{k=1}^{N} A_k (1 - \cos\psi)^k$$

$$\text{(2)} \quad \cos\psi = \frac{\sqrt{\cos^2\theta - \cos^2\Omega}}{\sin\Omega} = \sqrt{1 - \left(\frac{\sin\theta}{\sin\Omega}\right)^2}$$

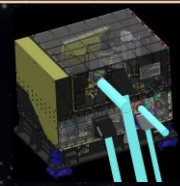
Darkening models

The solar limb darkening is defined by the ratio of the observed intensity in the line-of-sight to the peak central intensity, $I(\psi)/I(0)$ (Eq. 1). This ratio can be modelled using a set of **limb darkening coefficients, A_k**. [4]

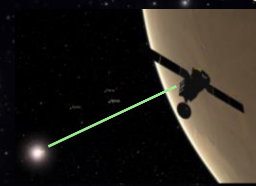
The angle from and the surface normal. This in turn can be expressed purely in terms of observables (Eq. 2), namely the radial angle of the observed point and the angular radius of the sun.

UVIS is an ultraviolet and visible spectrometer that is a part of the **NOMAD** instrument on board ESA's Trace Gas Orbiter (**TGO**) spacecraft in orbit around Mars [3]

TGO



NOMAD

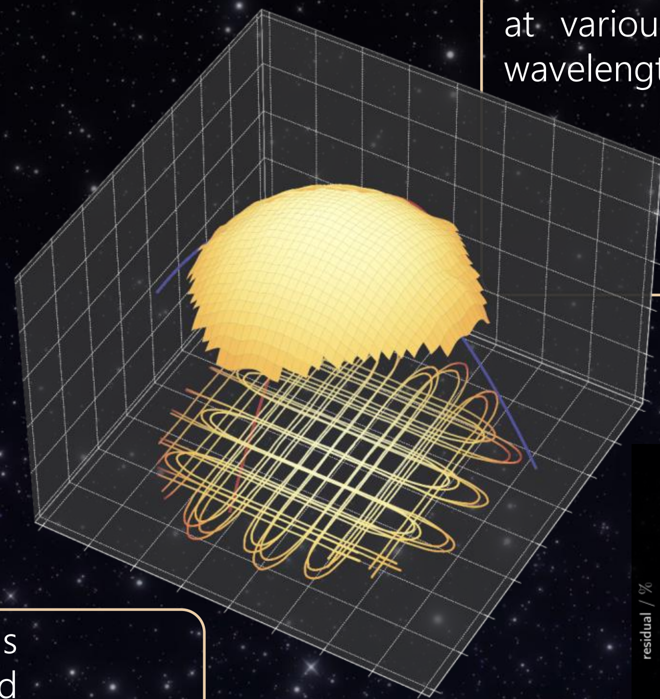


Scan geometry

Surface radiance maps

The observational linescan data was interpolated to create a set of radiance maps of the solar surface normalised to the central peak intensity at various wavelengths throughout the UVIS wavelength band.

A 2-dimensional implementation of a low order **Savitsky-Golay filter** was used to smooth these constructed surface radiances.

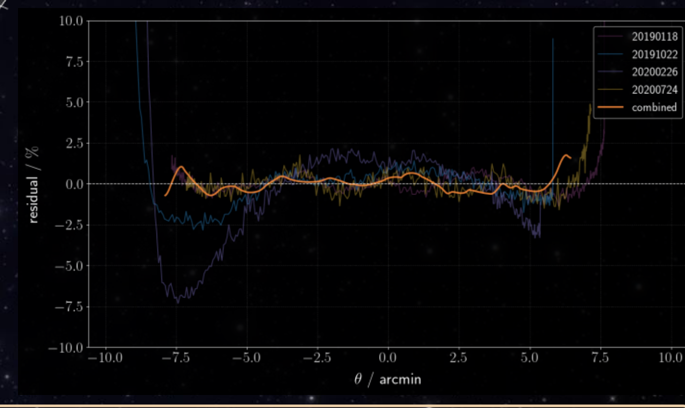


Solar scans

Over a period of approximately 18 months the NOMAD-UVIS spectrometer conducted a series of 4 pairs of scans of the solar surface (in both X & Y dimensions).

Temporal distribution of solar scans (2019/01 – 2020/07)

These independent solar radiance observations were transformed into a uniform instrument reference frame to allow them to be combined into an overall 'global' radiance scan.



Model fits

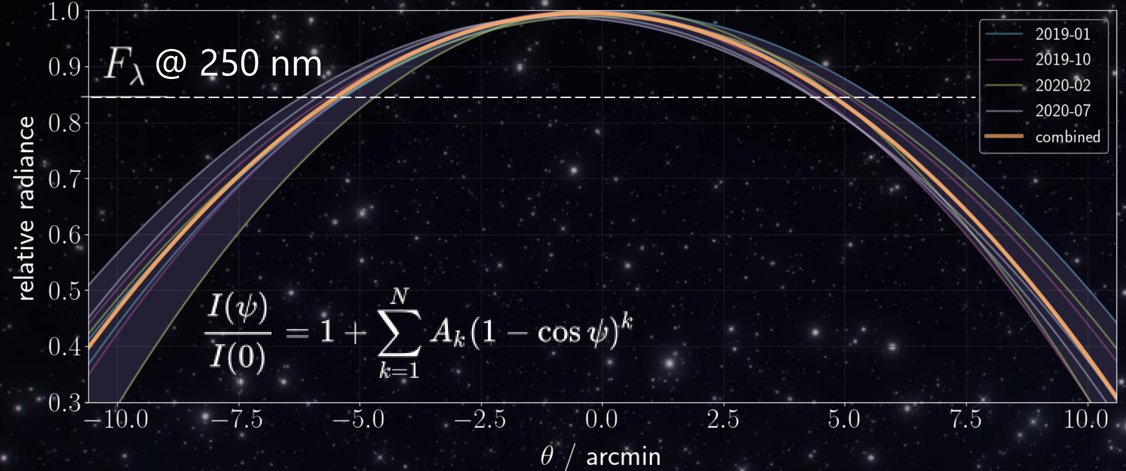
The limb darkening models were fit to the resultant final maps in order to extract a collection of coefficients which characterise the darkening effect at each wavelength.

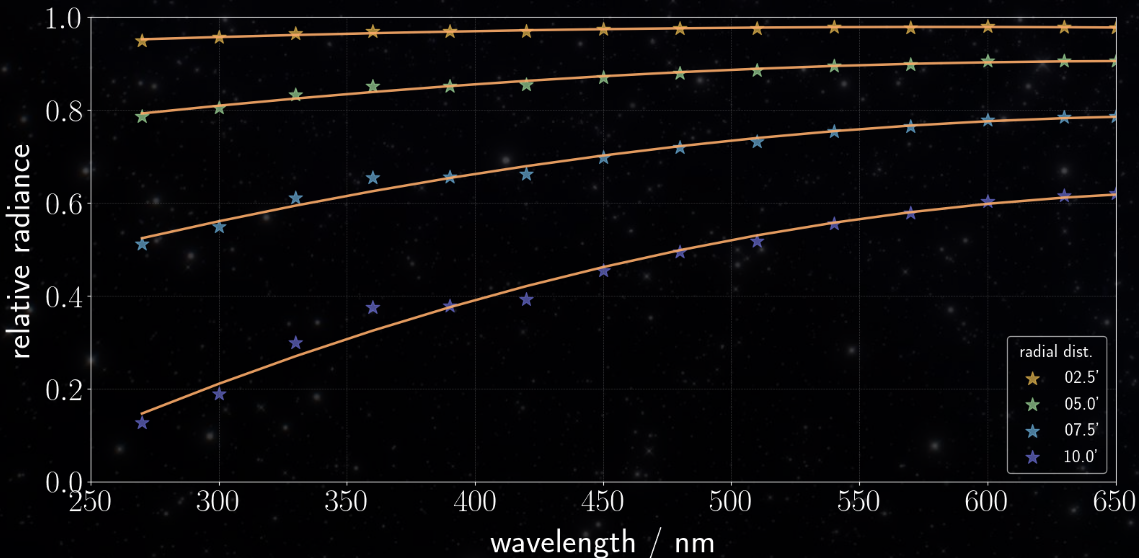
The model residuals show that a combined aggregated map performs better than individual scan data, due to a lack of coverage in the individual cases caused by imperfect pointing.

The magnitude of limb darkening is more pronounced in the UV than the visible spectrum. An example profile across the radial diameter of the sun is shown below for the most extreme case in the UVIS band (250 nm), along with the derived mean surface radiance. This characterisation of the solar output is defined relative to the peak radiance, a very good approximation can be expressed with the three primary extracted darkening coefficients (where $A_{1,2,3}$ = A, B, C)[5].

$$\frac{F_\lambda}{I_\lambda(0)} = A + C + \frac{2}{3}B - 2C(\frac{2}{3}\ln 2 - \frac{1}{6})$$

The limb darkening as a function of wavelengths for different radial distances from the centre is shown below.





Future work

A set of linescans are currently being conducted by the instrument providing an extended grid covering the entirety of the solar surface allowing for the construction of more robust radiance maps. Analysis of these maps will enable better precision of limb darkening coefficients in addition to improved UVIS science data accuracy. A paper is also currently in preparation describing the analysis presented here.

References

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Acknowledgements

The NOMAD experiment is led by the Royal Belgian Institute for Space Aeronomy (IASB-BIRA), with Co-PI teams in the United Kingdom (Open University), Spain (IAA-CSIC) and Italy (INAF-IAPS). This work was enabled through UK Space Agency grants ST/V002295/1, ST/V005332/1, ST/S00145X/1 and ST/R003025/1, and this project acknowledges funding by the Belgian Science Policy Office (BELSPO), with the financial and contractual coordination by the ESA Prodex Office (PEA 4000103401, 4000121493), by Spanish Ministry of Science and Innovation (MCIU) and by European funds under grants PGC2018-101836-B-I00 and ESP2017-87143-R (MINECO/FEDER), as well as by the Italian Space Agency through grant 2018-2-HH.0. This work was supported by the Belgian Fonds de la Recherche Scientifique – FNRS under grant number 30442502 (ET_HOME). The IAA/CSIC team acknowledges financial support from the State Agency for Research of the Spanish MCIU through the 'Centre of Excellence Severo Ochoa' award for the Instituto de Astrofísica de Andalucía (SEV-2017-0709). US investigators were supported by the National Aeronautics and Space Administration