The Prominence- and Chromosphere Spectrum of the Sun

Recorded with the DADOS Spectrograph
at Buelach Observatory

Richard Walker, CH-Rifferswil
richiwalker@bluewin.ch

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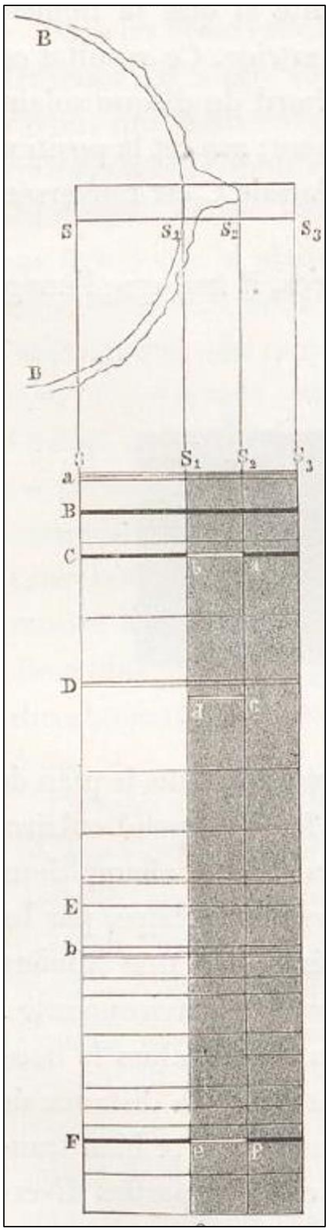
Father Angelo Secchi, 1818 – 1878,
The "Father of modern astrophysics "

1 On the Tracks of Angelo Secchi



The Jesuit Father Angelo Secchi, 1818 - 1878, as head of the Vatican Observatory not only explored the solar corona, but also developed the first classification system for stellar spectra. He is therefore often called the "father of modern astrophysics". In his French-language book "Le Soleil" [1] of 1875, he describes among other things with a sketch (fig. right) and the following text, how with a prism spectrograph at the disk edge of the sun, an emission spectrum of the prominences can be observed. At that time, he had recorded the results only in drawings. The upper part of his sketch shows half of the solar disk (B - B), as well as the position and orientation of the slit, relative to a prominence (S − S1 − S2 − S3). The most prominent spectral lines are labeled here exclusively with Fraunhofer designations A, B, C, D, E, b, and F. The following text is a rudimentary translation from (Old) French, with explanatory additions, according to current knowledge (in red).

If the (dark) slit section S1 – S3 (outside the solar limb) meets a prominence in the background, three bright (emission) lines immediately appear in the strip of S1 – S2. The first in the red region of the spectrum, in the extension of C (Hα), the second (D3, He) near D (sodium D1, D2) and the third in the extension of F (Hβ). You might even see a line at G (Hγ). If there are no prominences in the background, these lines will be very short and thus difficult to see. If there is a flare or a spot at the edge of the sun, one can move the slit to this spot, and align it perpendicular to the sun's edge. The spectral lines will then allow characterization of the prominence....

The white emission sections at C, D and F are just faintly visible in Secchi's sketch. Further he describes other tactics, e.g. how to scan a prominence vertically with the slit oriented tangentially to the edge of the sun.

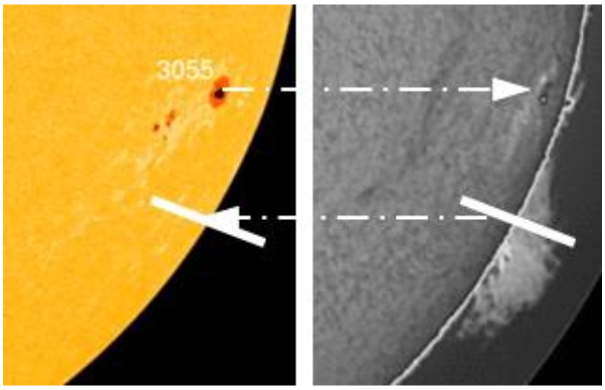
2 Preliminary Experiments

The main motivation was to reproduce Secchi's experiment with modern 21st century means. Therefore, the initial failures were all the more surprising (and embarrassing). The first experiments were performed, albeit with low solar activity, using the low-resolution 200 lines/mm grating and the highest-resolution 25 µm slit of the DADOS spectrograph. The spectral resolution yields thus about R ≈ 600 (λ/Δλ). The available background prominences were rather small. On the spectral recordings, so outside the solar limb, no emissions were visible. The reasons could be either the insufficient density of the prominence, an unfavorable position of the slit, and/or a too low spectral resolution. These emission lines correspond to the most intense of the so-called flash spectrum, which can be photographed at the beginning and end of the totality phase of a solar eclipse [3]. Thus, the French astronomer Jules Janssen discovered the first evidence of the element helium with the "yellow" emission line already during the solar eclipse of 1868 [4]. According to M. Waldmeier, the spectral lines of the chromosphere correspond, at least qualitatively, largely to those of the prominences [2].

3 The "Buelach Secchi Experiment"

On Sunday July 17, 2022 Stefan Meister, Martin Huwiler, Carsten Ziolek, Jonas Schenker and the author met at the Buelach observatory [5]. Later Peter Salvi from the AGZU joined them. The purpose was, beside the exchange of experiences, the solar observation, as well as testing and comparing different equipment and accessories. Impressive was among other things the demonstration of the Lunt calcium K filter by Martin Huwiler and Jonas Schenker. But also in the Hα- and white light range a pleasantly active sun with various spot groups and flare areas was shown. In the afternoon the attempt to record a prominence spectrum in "Secchi manner" should take place.

3.1 Positioning of the Slit



An intense, large-scale prominence at the SW edge of the solar disk proved to be a stroke of luck. In the immediate vicinity was the activity region AR 3055, which as a reference facilitated the positioning of the slit in front of the prominence. The graphic on the right shows the required interaction of white light (Spaceweather.com) and Hα-image (Gong, Mauna Loa). The mirror effects of the optics and accessories still need to be taken into account. The slit should be reasonably perpendicular to the solar limb and about half its length in front of the prominence.

3.2 Instruments and Setup

The telescope applied was the Apo refractor TEC 140 with 980 mm focal length. At the Buelach Observatory it sits piggyback on the Officina Stellare Pro RC 360 [5] astrograph. A Herschel wedge was placed upstream of the Dados spectrograph as an energy protection filter. The resulting 90° mounting angle by the way improved the leverage at the eyepiece tube of the telescope. The flip mirror, which is usually placed in front of the DADOS, had to be removed, because it was not possible to focus on the slit mirror. This was of no consequence here, because in this experiment the flip mirror was neither needed to find the object, nor to feed the external calibration light.

The flip mirror was not observed with a separate camera, but via an eyepiece with the corresponding DADOS supplementary optics.

The camera used was the ZWO ASI 1600MM Pro.

3.3 Resolution of the Spectrograph

In analyzing the first failed experiments, Secchi's spectral sketch was used to estimate the resolution of his spectrograph. The sodium double absorption appears narrowly resolved there, which is not the case with the 200L/mm grating. Therefore, the 900L/mm grating was mounted, which is also able to resolve the D-double line and thus generates a comparable resolution. The spectral resolution thus achieved is R ≈ 4000 ($\lambda/\Delta\lambda$). The contribution of this measure to the later success of the experiment is still unclear.

3.4 Mounting of the Spectrograph

Iterative adjustment of the mounting angle with the goal to finally get the slit at the solar limb with about half of the length, perpendicular in front of the prominence...

...with repetitive control by the slit optics and the spectral image on the screen

Setting the spectral range, adjusting the grating angle of the DADOS spectrograph. Here the control on the screen compared to the 900L solar spectrum in the Spectral Atlas [6].

Finally, the setup ready for recording with telescope, spectrograph and camera. Thus, it was possible to record the entire range as sketched by Secchi, i.e. from ~Hα (C) to Hβ (F), corresponding to ca. 4800 – 6600 Å, with one single exposure.

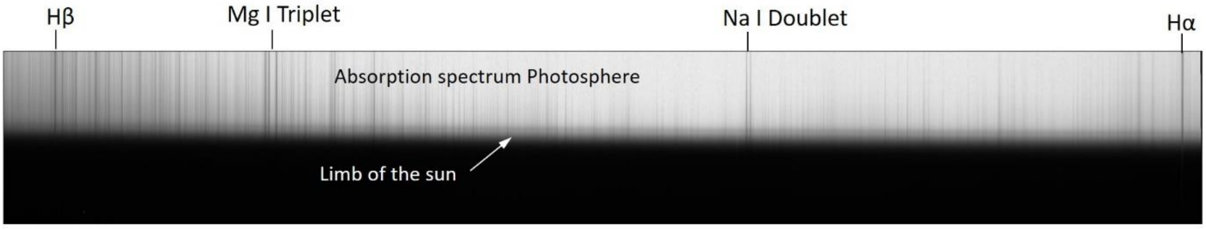
3.5 Recordings

A total of 5 images with exposure times of 1.4 – 4.0 s were taken. The sampling of the camera ZWO ASI 1600 mm Pro is optimized in the basic mode for astrophotography, but proved to be too large for the later evaluation with the IRIS software (oversampling). Therefore, in the future, images should already be taken in a hardware or software binning mode. Consequently, during processing with IRIS the recordings had to be reduced, applying the *Geometry/Resample* function by a factor of 0.35 in the X and Y directions.

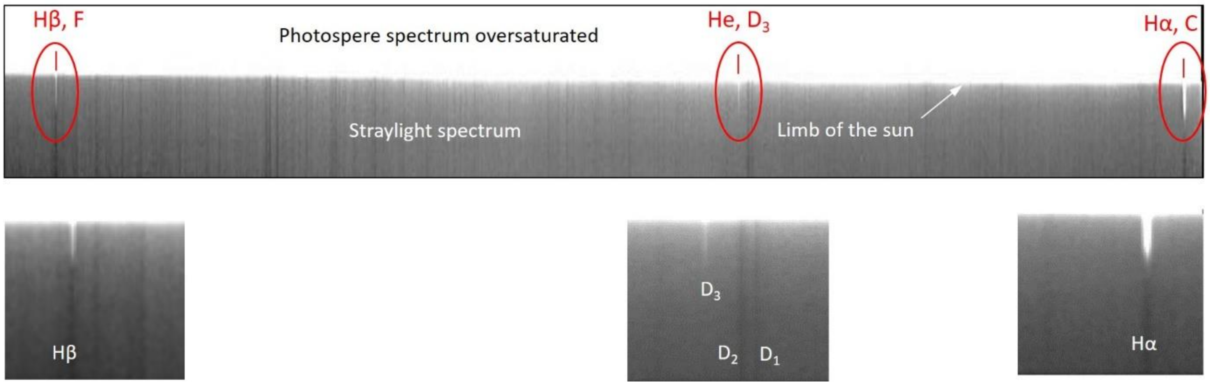
Further recommendation for the repetition of this experiment: Create a larger series of exposures with strongly different exposure times, also with somewhat overexposed images – furthermore at slightly different slit positions.

3.6 Processing of the Recordings

The data reduction was made, somewhat adjusted, according to [8], i.e. without subtraction of the stray light or sky background. Only one image was processed, showing the emissions most significantly. In normal exposed images, with the solar absorption spectrum at the solar limb, the three "Secchi emissions" Hα, He I and Hβ are just very faintly visible. Interesting is here still the brightness drop at the sun's limb.



But if the solar limb spectrum is oversaturated by the brightness slider, a scattered light spectrum appears outside the solar disk, quasi as a welcome reference, which is superimposed with three, now clearly visible emissions.

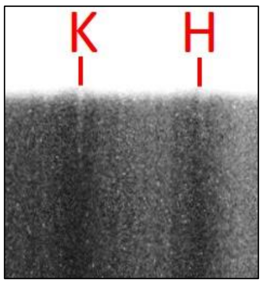


3.7 Results and Discussion

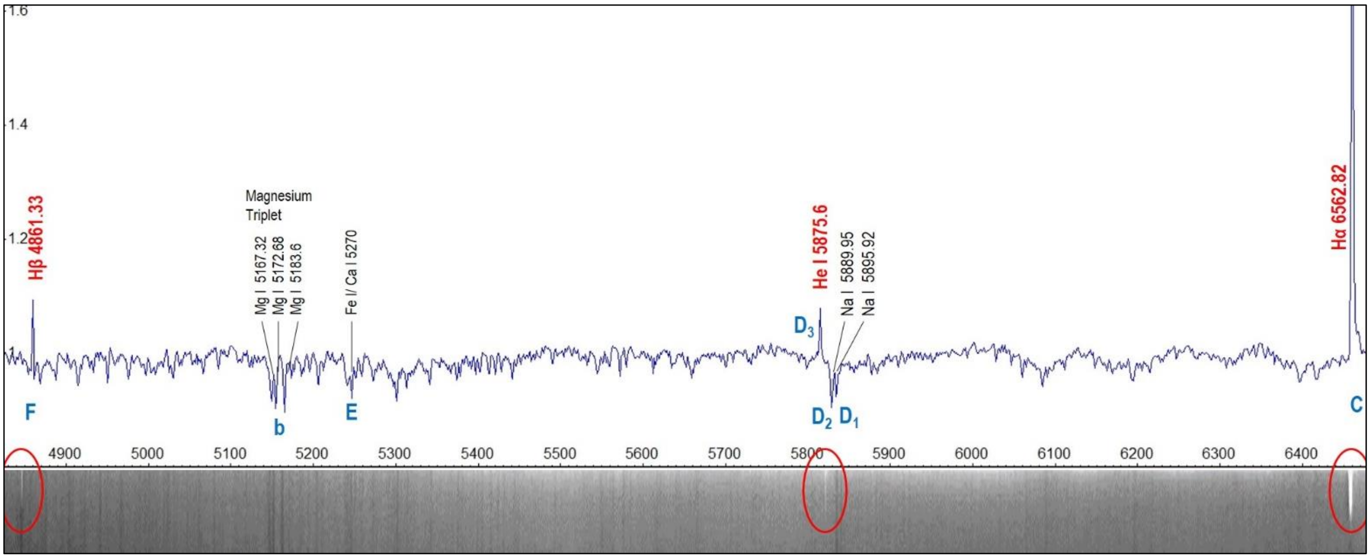
The emission of Hα appears most intense, followed by Hβ and He I. These elements comprise the bulk of the photosphere composition with H ≈ 92.1% and He ≈ 7.8%. Absorption and emission lines are coincident for Hα and Hβ. The helium line appears just somewhat left of the sodium double absorption, but remarkably without any corresponding absorption section. This caused headaches for a long time, because until the beginning of the 20th century it remained unknown that the temperature in the photosphere of ~5800 K is too low for the absorption of the neutral helium line He I at 5875.6 Å. But in the outer region of the overlying, ~2000 km thick chromosphere, the necessary excitation temperature of ~10'000 K is reached.

Unaware of these effects, this line and the causing element was named after the sun god Helios "Helium", because this signature was only visible in the solar chromosphere spectrum at that time. Because it appears in the immediate vicinity of the sodium double absorption D_1/D_2, it was designated as D_3.

The length of the sections appearing in emission, is the same for all lines, because it depends just on the height of the prominence in the slit region. The emission at Hγ (Fraunhofer G), mentioned by A. Secchi to occur occasionally, is not detectable here. However, with close inspection and strong zoom, very weak emission can be seen in the cores of the ionized calcium H and K lines (Ca II λλ 3968.47, 3933.66). This means that particularly strong and hot prominences should also be visible in the calcium region.



In addition, here follows the profile of the scattered light spectrum generated in Visual Spec with the three superimposed emission lines and rectified continuum. For display reasons the intensity of the Hα emission is strongly truncated here. The profile is calibrated based on known lines (Hα, D_2 and Hβ). Therefore, we see a small offset to the original, non-linear spectral image. The most prominent lines are still labeled here in blue with the Fraunhofer designations.



3.8 Conclusion

With this setup it is easy to reproduce A. Secchi's historical attempt, i.e. to qualitatively display the emission line spectrum of prominences. Further analysis options are currently not apparent, except of the influence of solar surface conditions on the appearance of these emission lines. For the imaging, measurement and analysis of prominences, much more efficient means are available today, e.g. with the Hα-filters.

4 Literature and Internet

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