Updates to the SUMER Spectral Atlas

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Received: 16 September 2022 / Accepted: 19 October 2022 / Published online: 9 November 2022
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Abstract

We present a reworked version of the SUMER spectral atlas (Curdt et al., 2001). New identifications are given for more than 100 emission lines; entries were corrected or added to the list. The solar emission curve – spectral radiance versus wavelength – in the SUMER spectral range is now available in digital format as electronic supplementary material. To reveal the true solar emission, second-order photons from the Lyman continuum have been discarded near the long wavelength section in the first order of diffraction.

Keywords Line:atlas · Line:identification · Line:formation · Sun:sunspots · Sun:transition region · Sun:UV radiation

1. Introduction

In the SUMER Spectral Atlas of solar-disk features (Curdt et al., 2001), we have published our most up-to-date knowledge of the solar spectrum in the range from 668 Å to 1611 Å. We communicated the full spectral emission curve that the SOHO-SUMER instrument can assess in graphical representation and a list of emission lines with and without identifications.

We re-used in these updates the observations of the SUMER Spectral Atlas and are confident that they represent the typical emissions of solar disk features observed in 1996, 1997
as well as 1999. We added new insights that accumulated over two decades in Section 2. This updated atlas is by no means a comprehensive inventory of solar emission in the SUMER spectral range. We refer to the 2001 article on the observations in quiet Sun regions, in a coronal hole, and in a sunspot, along with details of the instrument. Moreover, we did not find any reason to change the data processing described step by step in Curdt et al. (2014) and the established radiometric calibration (Wilhelm et al., 2002).

From a discussion with Juan Fontenla (private communication), we learned that the long wavelength edge of the published emission curve conflicts with solar atmospheric models (Fontenla et al., 2006), which is a potential problem when used in astrophysical applications. In this spectral range, photons of the Lyman continuum observed in the second order of diffraction progressively intermix with first-order emission. Different from strong second-order lines, e.g., Ne VIII at 770 Å, that can easily be separated from background emission, intermixed continua cannot easily be decomposed. Since the true solar emission of continua is relevant for astrophysical applications, we treat this problem in Section 3.

Over the years, not only observations by SUMER and other instruments but also theoretical work led to new insights about excitation processes and resulted in the identification of emission lines, thus updating the 2001 line list. It is time to communicate these new insights before the data are deposited in the archives.

2. Line Identification

The list of emission lines published in 2001 was compiled to the best of our knowledge at that time. New insights emerged from SUMER off-disk observations and numerous data sets from sunspots and sunspot plumes. Above sunspots, a group of lines is observed in the solar atmosphere, which Tian et al. (2009) dubbed ‘peculiar lines’. These are mainly forbidden lines, intersystem lines, possibly non-dipole transitions. Some of the lines observed off-disk (Kink, Engström, and Feldman, 1999; Curdt, Landi, and Feldman, 2004) or listed in the prominence atlas (Parenti, Vial, and Lemaire, 2005) and in the Tian atlas (Tian et al., 2009) are also observed on disk, but remained unidentified in the 2001 article. They are referenced here as updates. Emission lines unidentified in our 2001 atlas were later on identified as Fe VIII (Ekberg and Feldman, 2003b), Si VIII and S X (Kink, Engström, and Feldman, 1999), and Fe IX (Landi and Young, 2009). Other Fe VIII lines were reported by Landi and Young (2010). But, none of these lines could be identified in disk spectra because of close and complex blends. However, in deep exposures in the corona we observed the strong 1062.45 Å Fe VIII line (Curdt, Landi, and Feldman, 2004). The puzzling spectral features around 1170 Å (Wilhelm et al., 2005) were finally identified as S I autoionization lines (Avrett, Kurucz, and Loeser, 2006).

Our own work led to many new identifications, among others, lines of Si V and sulfur in different ionization stages, including S I. We intensely employed the atomic databases CHIANTI (Del Zanna et al., 2021) and NIST (Kramida, Ralchenko, and Reader, 2021) for coherency checks and plausibility tests. Moreover, stellar spectra (Young, Feldman, and Loebel, 2011) and spectra recorded by other instruments provided valuable information. The spectral overlap with SUMER and higher spectral resolution of the instrumentation of the IRIS spacecraft (De Pontieu et al., 2014) spawned our understanding of the fluorescence excitation of molecular hydrogen present in sunspot and flare spectra (Jaeggli, Judge, and Daw, 2018). Spectral lines of molecular hydrogen are very narrow, without any flows, and with sharp boundaries of small sections along the slit and therefore relatively easy to identify. This supports the model assuming a small volume of cold gas at rest sitting above a
Figure 1. The detection ratio of first- and second-order photons as derived from the radiometric calibration. Photons observed in the second order of diffraction appear overlaid to the first-order emission and have to be discarded for studies of the first-order emission. The relevance of this correction starts at about 1400 Å (cf. Section 3 for details).

sunspot that is illuminated by UV photons from above (Jaeggli, Judge, and Daw, 2018). We found many other cases of excitation by optical pumping. For instance, photons of the bright 1335 Å C II line excite atoms of the low-abundance element chlorine from the ground state into the $^2P_{1/2}$ level, thus pumping the prominent Cl I line at 1351.7 Å (Shine, 1983), as the Ly-$\alpha$ line does for the P I line at 1411.30 Å. We assume that photo resonance excitation is a common process in stellar atmospheres.

Theoretical work of atomic spectroscopy scientists established among others the contributions of the species Mn VI and Fe VII (Ekberg and Feldman, 2003a), Mn VII and Fe VIII (Ekberg and Feldman, 2003b; Landi and Young, 2010), and Si VIII (Kink, Engström, and Feldman, 1999). We also mention that Jordan (2011) questioned the identification of the strong emission line at 1319.8 Å as N I. This line is now listed as N I or S I with a question mark.

After recompilation, the line list contains 1119 spectral lines, and 147 entries are new identifications or modifications of the original content. We also discarded those entries from the previous list, of which we doubt whether they are spectral lines at all. Question marks denote identifications that are still uncertain. The updated information is presented twice, the new 147 entries are shown in Table 1. Table 2 is a comprehensive list of all lines in the spectral range from 668 Å to 1611 Å identified in SUMER disk spectra so far. It is not a replacement of Table 1 in Curdt et al. (2001), but a simplified list highlighting the modifications marked by hashtags. This table is only available as online material. References indicating the source of new identifications are given in both tables.

Table 2. List of all emission lines observed in SUMER on-disk reference spectra so far (status 2 April 2022). It extends the line list given in Curdt et al. (2001). This table is available at DOI.

3. Second Order Removal

Lines are observed in first and second order of diffraction in SUMER spectra. Second-order lines are overlaid to the first-order spectrum. The spectral range from 668 Å to 743 Å in the first diffraction order is also observed by the B-detector from 1336 Å to 1486 Å in the second order.
Table 1 List of newly identified emission lines observed in SUMER on-disk reference spectra (status 5 September 2022). It extends the line list given in Curdt et al. (2001). Most line blends are denoted with the last three digits of the literature wavelength in Å. Second-order lines are indicated by /2. References for line identifications are given in the last column: Ekberg and Feldman (2003a) – (1a); Ekberg and Feldman (2003b) – (1b); Kink, Engström, and Feldman (1999) – (2); Jaeggli, Judge, and Daw (2018) – (3); Jordan (2011) – (4); Young, Feldman, and Lobel (2011) – (5); Landi and Young (2009) – (6); Curdt, Landi, and Feldman (2004) – (7); Parenti, Vial, and Lemaire (2005) – (8); Tian et al. (2009) – (9); Avrett, Kurucz, and Loeser (2006) – (10); own work – (11) (for which transitions are given, if available). The line of interest in blends is preceded by an asterisk (*).

| λ<sub>obs</sub> Å | Line | 1<sup>st</sup>, 2<sup>nd</sup> or 3<sup>rd</sup> Blends | Ref. |
|-------------------|------|------------------|-----|
| 669.00            | Al IX |                                | 9   |
| 671.57            | K VII |                                | 11  |
|                   |      | $3s^23p^2p_{3/2}^0 - 3s3p^22D_{5/2}$ |     |
| 671.98            | N II  | *S VIII           | 2   |
| 674.10            | S IV  |                                | 11  |
|                   |      | $3s3p3d_4^0 F_{7/2} - 3s3p4f_4^0 G_{7/2}$ |     |
| 674.41            | S IV  |                                | 11  |
|                   |      | $3s3p^2 2 D_{5/2} - 3s3p3d^1 G_{7/2}$ |     |
| 675.20            | S VIII |                               | 2   |
| 684.04            | Na VI |                                | 9   |
| 686.33            | N III | 6.44 *Fe VIII, 6.41 *S VIII | 1b, 2 |
| 688.68            | Fe VIII |                             | 1b  |
| 697.14            | Fe VIII |                             | 1b  |
| 709.21            | Ar V  | *S IX                     | 7   |
| 710.94            | S III |                                | 11  |
|                   |      | $5s5d_3^3D_3 - 5p5d_1^1 D_2^0$ |     |
| 717.00            | S IV  |                                | 11  |
|                   |      | $3s3p^2 2 D_{5/2} - 3s3p3d^2 D_{5/2}^0$ |     |
| 717.69            | Fe IX |                                | 6   |
| 721.23            | Fe VIII |                            | 1b  |
| 723.75            | Fe VIII |                            | 1b  |
| 728.10            | Fe VII |                                | 1a  |
| 735.42            | Fe VII |                                | 1a  |
| 738.87            | Fe VII |                                | 1a  |
| 740.03            | *Fe VII |                    0.11 Ar VIII | 1a  |
| 740.90            | Fe VII |                                | 1a  |
| 741.14            | Fe VII |                                | 1a  |
| 745.38            | Fe VII |                                | 1a  |
| 745.55            | Fe VII |                                | 1a  |
| 747.37            | Fe VII |                                | 1a  |
| 749.91            | Fe VII |                                | 1a  |
| 752.90            | Fe VIII |                              | 1b  |
| 757.15            | Fe VII |                                | 1a  |
| 775.25            | O I   |                                | 11  |
|                   |      | $2s^22p_4^3 P_2 - 2s^22p_3^3 F_5 D_1^0$ |     |
| 784.52            | Fe VII |                                | 1a  |
| \( \lambda_{\text{obs}}/\text{Å} \) | Line | 1st, 2nd or 3rd Blends | Ref. |
|---|---|---|---|
| 784.81 | Mn VII | Fe VII | 1b, 1a |
| 792.77 | Fe VII | | 1a |
| 795.23 | Ne VII | | 9 |
| 799.11 | Fe VII | | 1a |
| 801.69 | Fe VII | | 1a |
| 803.46 | Fe IX | | 6 |
| 804.16 | Fe VII | 4.14 S X | 1a, 2 |
| 811.55 | Mn VII | | 1b |
| 822.56 | S III | | 11 |
| 864.03 | Na VII | \( 3s^23p^2 3p_2^2 - 3s^23p^3d^3 F_3^0 \) | 11 |
| 873.78 | Si V | \( 2s^22p^2 P_{1/2} - 2s^22p^4 P_{3/2} \) | 11 |
| 877.92 | Ar VII | | 9 |
| 880.33 | Na VII | | 9 |
| 946.65 | Mg II | 6.32 *S X | 2 |
| 955.45 | N I | | 8 |
| 962.44 | O III | | 8 |
| 966.68 | Si V | | 11 |
| 967.20 | Si V | Fe III | 11 |
| 974.58 | S V | *Si VIII , 4.56 N II | 2 |
| 975.85 | Si V | | 11 |
| 980.40 | Si V | \( 2s^22p^53p_1^3 P_1^0 - 2s^22p^53d^3 D_3^0 \) | 11 |
| 987.91 | Si V | \( 2s^22p^53p_1^1 D_2 - 2s^22p^53d^1 F_3^0 \) | 11 |
| 997.18 | Ne VI | 7.40 Si III, *Mg XI | 7 |
| 1013.88 | H₂ | | 11 |
| 1014.68 | O III/2 | | 11 |
| 1016.40 | O III/2 | \( 2s^22p^2 3p_0^3 - 2s^2p^3 3s_1^0 \) | 11 |
| 1028.95 | Na VII | Fe V ? | 11 |
| 1045.53 | Fe VIII | \( 2s^22p^3d^4 P_{3/2}^0 - 2p^23s^4 P_{3/2} \) | 1b |
| 1045.75 | S I | | 11 |
Table 1 (Continued)

| $\lambda_{\text{obs}}/\AA$ | Line     | 1st, 2nd or 3rd Blends | Ref. |
|------------------------|----------|------------------------|------|
|                        |          | Transition             |      |
| 1048.22                | Ar I     | $3s^2 3p^6 1S_0 - 3s^2 3p^5 4s^2 P^o_1$ | 11   |
| 1057.79                | Al VIII  | Mg IX                  | 7    |
| 1063.58                | Ar VII   |                        | 11   |
| 1066.65                | Si IV    | 6.66 *Ar I             | 11   |
| 1071.44                | N I      |                        | 8    |
| 1074.06                | He t/2   | 4.01 *Fe VII           | 1a   |
| 1087.86                | Ne IV/2  | 7.86 *Fe VII           | 1a   |
| 1095.37                | Fe VII   |                        | 1a   |
| 1098.92                | S IV     |                        | 11   |
| 1099.45                | S IV     | $3s^3 p^2 2D_{3/2} - 3p^3 2D^o_{3/2}$ | 8    |
| 1117.24                | Ne VI/2  | 7.24 Ca V/2, 7.58 *Fe VII | 1a   |
| 1118.90                | Si V     |                        | 11   |
| 1133.68                | Ca XIII  |                        | 7    |
| 1141.45                | Fe VII   |                        | 1a   |
| 1155.00                | Fe VII   |                        | 1a   |
| 1163.85                | H$_2$    | 3.90 *Fe VII           | 1a   |
| 1166.18                | Fe VII   |                        | 1a   |
| 1167.20                | S I      |                        | 10   |
| 1170.18                | Al VI?   |                        | 11   |
| 1170.70                | S I      |                        | 10   |
| 1171.95                | Si V     |                        | 8, 11|
| 1172.75                | S I      | $2s^2 2p^5 3s^3 P^o_1 - 2s^2 2p^2 3p^1 D_2$ | 10   |
| 1189.00                | C I      | *Si VIII               | 2    |
| 1201.47                | O II     |                        | 11   |
| 1202.00                | O II     | $2s^2 2p^2 3s^4 P_{3/2} - 2s^2 2p^2 6p^4 D^o_{5/2}$ | 11   |
| 1202.00                | S I      | $2s^2 2p^2 3s^4 P_{5/2} - 2s^2 2p^2 6p^4 D^o_{7/2}$ | 11   |
| 1202.61                | S I      | $3s^2 3p^4 3 P_2 - 3s^2 3p^3 18d^3 D^o_3$ | 11   |
| 1203.41                | S I      | $3s^2 3p^4 3 P_2 - 3s^2 3p^3 17d^3 D^o_3$ | 11   |
| 1207.00                | S I      | $3s^2 3p^4 3 P_2 - 3s^2 3p^3 16d^3 D^o_3$ | 11   |
| 1208.38                | Fe VII   | 8.32 Si XI/2           | 1a   |
Table 1 (Continued)

| $\lambda_{\text{obs}}$/Å | Line       | 1st, 2nd or 3rd Blends Ref. Transition | Ref. |
|-----------------------|-----------|--------------------------------------|-----|
| 1209.20               | S I       | $3s^2 3p^4 3p_2 - 3s^2 3p^3 12d^3 D_3^o$ |     |
| 1241.95               | Fe XII    | 1.90 *S I                             |     |
|                      |           | $3s^2 3p^4 2p_2 - 3s^2 3p^3 8s^3 S_1^o$ |     |
| 1249.00               | C I       | 9.23 *O IV /2                         |     |
|                      |           | $2s^2 p^2 4 p_{1/2} - 2p^3 4 S^o_{3/2}$ |     |
| 1250.26               | *O IV/2   | 0.09 Si I                             |     |
|                      |           | $2s^2 p^2 4 P_{3/2} - 2p^3 4 S^o_{3/2}$ |     |
| 1251.48               | Si V      |                                      |     |
|                      |           | $2s^2 2p^5 3s^3 P^o_1 - 2s^2 2p^5 3p^3 P_1$ |     |
| 1251.70               | O IV/2    | 11                                    |     |
|                      |           | $2s^2 2p^2 4 P_{3/2} - 2p^3 4 S^o_{3/2}$ |     |
| 1251.76               | Si V      |                                      | 8   |
|                      |           | $2s^2 2p^5 3s^3 P^o_1 - 2s^2 2p^5 3p^3 P_1$ |     |
| 1257.24               | H$_2$     |                                       | 3   |
| 1269.06               | ? /?      | *H$_2$ ?                             | 3   |
| 1269.21               | S I       |                                       |     |
|                      |           | $3s^2 3p^4 3 P^o_1 - 3s^2 3p^7 7s^3 S^o_{1}$ |     |
| 1282.30               | H$_2$     |                                       | 3   |
| 1283.06               | Fe II     | 3.25 H$_2$                           | 3   |
| 1285.49               | Si V      |                                       |     |
|                      |           | $2s^2 2p^5 3s^3 P^o_1 - 2s^2 2p^5 3p^3 D_1$ |     |
| 1285.69               | H$_2$     |                                       | 3   |
| 1286.43               | H$_2$     | 6.20 Ca V/2                          | 3   |
| 1293.10               | Ca V/2    |                                       |     |
|                      |           | $3s^2 3p^4 3 P^o_2 - 3s^2 3p^5 3 P^o_{2}$ |     |
| 1293.88               | H$_2$     |                                       | 3   |
| 1311.36               | C I       | *Fe III ?                             |     |
| 1313.46               | C I       | 3.39 C I, ?/2                       |     |
| 1318.98               | N I or S I?|                                       |     |
| 1319.76               | S V/2     | 9.68 N I, *Si V                      |     |
|                      |           | $2s^2 2p^5 3s^1 P_{1}^o - 2s^2 2p^5 3p^1 D_2$ |     |
| 1322.24               | *Mn XII   | 2.26 H$_2$                           |     |
|                      |           | $3s^2 3p^2 3 P^o_1 - 3s^2 3p^2 1 S^o_0$ |     |
| 1333.47               | H$_2$     |                                       | 3   |
| 1333.79               | S I       | *H$_2$                               | 3   |
| 1337.84               | H$_2$     |                                       | 3   |
| 1342.28               | H$_2$     |                                       | 3   |
| 1342.90               | *O IV     | 2.76 *Cl VI/2                       |     |
|                      |           | $2s^2 p^2 2 P_{3/2} - 2p^3 2 D^o_{3/2}$ |     |
|                      |           | $2p^6 3s^2 1 S^o_0 - 3s^3 p^1 P_{1}^o$ |     |
| 1343.64               | O IV      |                                       |     |
|                      |           | $2s^2 p^2 2 P_{3/2} - 2p^3 2 D^o_{3/2}$ |     |
| \( \lambda_{\text{obs}}/\text{Å} \) | Line | 1st, 2nd or 3rd Blends | Ref. |
|----------------|--------|------------------------|------|
| 1345.16        | H\(_2\) |                        | 3    |
| 1345.51        | S IV/2 |                        | 11   |
|                 |        | \( 2s^2p3d^4F^o_{3/2} - 3s3p4f^4G^o_{5/2} \) |      |
| 1347.06        | H\(_2\) |                        | 3    |
| 1372.90        | Fe VIII /2 |                  | 1b   |
| 1373.00        | H\(_2\) |                        | 3    |
| 1380.23        | H\(_2\) |                        | 3    |
| 1384.71        | H\(_2\) |                        | 3    |
| 1394.28        | Fe VIII/2 |                | 1b   |
| 1397.22        | H\(_2\) |                        | 3    |
| 1398.06        | S IV   |                        | 5    |
| 1411.30        | P I    | pumped by Ly-\(\alpha\) | 11   |
|                 |        | \( 3s^2p^3d^2D^o_{3/2} - 3s^2p^3d^2D_{1/2} \) |      |
| 1423.86        | S IV   |                        | 5    |
| 1426.49        | H\(_2\) |                        | 3    |
| 1431.03        | H\(_2\) |                        | 3    |
| 1439.11        | H\(_2\) |                        | 3    |
| 1440.79        | *Si VIII | Fe II   | 2    |
| 1442.54        | Fe VIII /2 |             | 1b   |
| 1444.09        | C O ? |                        | 11   |
| 1446.12        | H\(_2\) |                        | 3    |
| 1453.08        | H\(_2\) |                        | 3    |
| 1456.13        | C I    | 6.23 *Fe VII/2          | 1a   |
| 1458.14        | H\(_2\) |                        | 3    |
| 1465.60        | Si V ? |                        |      |
|                 |        | \( 2s^2p^53s^3P^o_0 - 2s^2p^53p^3S^o_1 \) |      |
| 1467.09        | H\(_2\) |                        | 3    |
| 1467.40        | C I    | 7.27 Ni II, 7.42 *P IV | 5    |
| 1477.80        | Fe VII/2 |                     | 1a   |
| 1480.22        | Ar VIII/2 |                   | 1a   |
| 1481.76        | C I    | 1.68 S I, 1.62 *Fe VII/2 | 1a   |
| 1442.36        | *Fe VII/2 |                      | 1a   |
| 1574.90        | *S X/2 |                        | 2    |

order. For the A-detector this corresponds to a range from 778 Å to 805.5 Å in the first order and 1556 Å to 1611 Å in the second order. Second-order lines can be classified as the second-order emission by their bare/KBr photocathode response ratio (Wilhelm et al., 1995, 2002) and separated from first-order emissions by subtracting the first-order background or by multi-Gauss decomposition. However, there is a problem with the intermixed continua observed at longer wavelengths since there is no easy way to separate first-order photons from second-order photons. We propose a calculation employing the radiative calibration of the instrument to transpose first-order counts into the second order and to subtract them.
from the overall emission. If the number of first-order photons at a given wavelength is known, then the radiometric calibration can be applied to calculate their spectral radiance if they appear in the second order. This allows us to transpose the effect of short wavelength photons into the second order and to discard their contribution. Such a correction has – in principle – to be applied for each data set with no change of target and close in time.

In order not to introduce additional uncertainties, we only employ spectral information recorded on the KBr-coated section of the photocathode. Therefore, a potential problem exists for the range from approximately 1471 Å to 1572 Å that is only observed by the A-detector in the first order with no suitable photons in the low-wavelength counterpart that can only be observed by the B-detector. Switching detectors is a complex procedure and was no option. However, empirical evidence has shown that in the quiet Sun, variations of the Lyman continuum do not normally change the slope of the curve. For the 2001 paper, we selected a spectral scan of the A-detector matching the continua of the B-detector curve. We assume that also for the proposed correction this pair of spectral scans is appropriate, and the Lyman continuum observed by the B-detector can be applied for the second-order removal in both data sets. In the long wavelength range, the radiance of the Lyman continuum observed in the second order is continuously rising, while the sensitivity for first-order photons decreases. The combination of both effects is demonstrated in Figure 1. At 1600 Å, every second count represents Lyman continuum photons in the second order.

This algorithm cannot be applied for second-order spectral lines, in particular, for those from higher ionization stages, e.g., Ne VIII, since temporal excursions introduce unacceptable uncertainties, in addition to the high relative standard uncertainty of the radiometric calibration at the long wavelength edge of 30% (Wilhelm et al., 2002). Therefore, second-order emission lines beyond 1400 Å have been manually removed by interpolation.

The solar spectral radiance of the quiet Sun in the full spectral range of the instrument is displayed in Figure 2. The graph is a composite with a section from 668 Å to 1400 Å taken from Curdt et al. (2001) and the section from 1400 Å to 1600 Å as described in this work. Enlarged subsections at much higher resolution can be produced from the data provided as online material (cf., Section 4).

**4. Data Retrieval**

The solar emission curve – spectral radiance versus wavelength – is displayed in Figure 4 of the 2001 atlas, and the spectral lines are marked with line identification information. This graphical representation is very useful for practical purposes since it provides a first look overview and comprehensive orientation in newly recorded spectra. Quantitative information of the spectral radiance was extracted and is given in Table 4 of the 2001 atlas together with atomic transition details. The original vector variables used for the graphical representation and quantitative information of the spectral radiance in the range from 1400 Å to 1600 Å without the second-order emission as displayed in Figure 2 are now available in computer-readable form and can be downloaded with a standard FITS-reader from the file SUMER_DISC_SPECTRA.FITS available at DOI rounding up this article.

**5. Conclusion**

Any photon coming from the Sun carries information about the atomic system of the emitting source and the physical environment leading to the excitation processes. If we are able
Figure 2  Spectral radiance of the quiet Sun in the range from 668 Å to 1600 Å composed from data of both detectors. Second-order counts have been discarded in the wavelength range from 1400 Å to 1600 Å. After subtraction of the second-order photons the blue curve represents the emission in the first order. The peak of the Ly-α line is out of range.

to reveal and interpret this information, we have a powerful tool and enormous potential to enhance our understanding of the solar atmosphere. However, even for the so-called quiet Sun, \( \approx 10\% \) of the lines in online Table 2 are still unidentified, and this percentage is much higher for the active Sun. Future work is needed to understand the excitation processes of these lines and we have to conclude that even with this update, our project is far from complete.

Supplementary Information  The online version contains supplementary material available at https://doi.org/10.1007/s11207-022-02078-2.

Acknowledgments  The authors thank Bernhard Fleck for motivating us and Dietmar Germerott for his technical support throughout the project. Our work to update the information on SUMER spectra is based on both atomic databases CHIANTI (Del Zanna et al., 2021) and NIST (Kramida, Ralchenko, and Reader, 2021) and greatly benefited from constructive remarks of an anonymous referee. SUMER is part of SOHO, the Solar and Heliospheric Observatory, of ESA and NASA.

Author contributions  A.B.E wrote the main manuscript text. B.C. wrote the radiometric calibration section. A.B. prepared the figures. A.D.F. contributed to the line identification. All authors reviewed the manuscript.

Funding Note  Open Access funding enabled and organized by Projekt DEAL.

Declarations

Competing interests  The authors declare no competing interests.

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