Line lists for the IRIS far ultraviolet wavelength bands

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This document is not complete but the identifications and wavelengths given in the tables are correct.

Lists of transitions within the IRIS far ultraviolet (FUV) wavebands are given in Tables 1 and 2. For each line the transition information and the reference to the wavelength are given. A key for the wavelength references is given in Table 3. Notes on individual emitting species are given in Section 1.

Every line listed in these tables has been postively identified by the author in IRIS spectra, although many of the lines are only seen in specific solar features such as flares. Some of the lines are only seen in absorption against the strong C II and Si IV lines.

Useful reference spectra in the IRIS wavelength ranges are those of Sandlin et al. (1986) which is a composite of HRTS and Skylab S082B spectra.

1. Discussion of species in wavebands

1.1. C I

The only C I lines are found in the FUV1 channel between 1352 and 1359 Å and are decays to the $2p^2\ ^1D_2$ level from high-lying levels. Johansson (1966) gave calculated values of these wavelengths that are accurate to 0.002 Å. The strongest transition is λ1355.844, and λ1354.288 blends with Fe XXI λ1354.08 during flares.

The formation of λ1355.8 was discussed by Lin et al. (2017), who found that it is dominated by a recombination cascade. They emphasised the value of diagnostics relative to the nearby O I λ1355.6.

1.2. Cl I

λ1351.66 is unusually strong given the very low abundance of chlorine, and this was explained by Shine (1983) as being due to an accidental resonance of Cl I λ1335.73 with the very strong C II λ1335.71 transition. Cl I λ1335.73 and λ1351.66 share the same upper atomic level, and so C II photons absorbed by λ1335.73 can escape through λ1351.66, giving a greatly enhanced intensity for this line.

1.3. O I

The O I λ1355.60 wavelength comes from Eriksson & Isberg (1968) and has an accuracy of 0.5 mÅ. It is an intercombination transition and it does not show any of the optical depth effects of the nearby C I lines.

The line is present in the CHIANTI O I model, however the predictions are likely to be inaccurate based on comparisons with the isoelectronic Ne III model. This model shows that the $2s^22p^33s\ ^5S_2$ level receives significant population through cascading from the $2s^22p^33p\ ^5P_J$ levels, which in turn receive population through cascading from the $2s^22p^33d\ ^5D_J$ levels. None of these levels are currently included in the CHIANTI model due to a lack of available atomic data.

The formation of λ1355.6 was discussed by Lin & Carlsson (2015), who showed that it is dominated by recombination cascades. Lin et al. (2017) highlighted diagnostics possible by comparing λ1355.6 with C I λ1355.8.

1.4. O IV

There is a very rich literature on the O IV intercombination lines both from solar and stellar spectra – see Harper et al. (1999), Keenan et al. (2002) and Keenan et al. (2009) and references therein. The reference wavelengths used here are taken from a stellar spectrum analyzed by Young et al. (2011). The λ1407.375 line is just outside the FUV2 band and is not included in Table 2.

1.5. Si II

A set of seven Si II lines is found in the FUV1 channel and arise from $3s3p^2\ {}^4P_J - 3s3p4s\ {}^4P_{J'}$ transitions. The lines are typically only seen in flares, with λ1348.54 and λ1350.06 found in the 1349 Å window and λ1353.72 in the 1354 Å window. The latter partly blends with Fe XXI λ1354.08 in flare ribbon spectra.

As the Si II lines do not decay to the ground term, then they are optically thin, which is an advantage when studying line profiles in comparison to C II and Mg II.

CHIANTI does not contain any atomic data for the Si II transitions, and recombination (from Si III) may be significant in populating the upper levels.

1.6. S I

Two multiplets give rise to lines in the IRIS FUV2 waveband: decays from the $5s\ {}^3S_1$ and $3p^5\ {}^3P_J$ terms. Wavelengths for these transitions were measured in the laboratory by Kaufman (1982), and we use the Ritz wavelengths calculated from this work. The 1388.436 Å line lies just where the FUV2 channel is vignetted, but can be identified. In the FUV1 channel, two transitions from the $4d\ {}^5D_J$ multiplet are expected at 1333.792 and 1340.851 Å, but the author has not seen clear evidence for the presence of these two lines. The former does partly blend with a known H_2 line, however (Table 1).

1.7. S IV

S IV is similar to O IV in that it gives rise to five intercombination transitions close to 1400 Å. Two of these, λ1416.913 and λ1423.857, are outside the FUV2 waveband and a third, λ1398.066, is too weak to be observed.

1.8. Ca II

Only two lines are found in the IRIS wavebands, at 1341.89 and 1342.55 Å. Both lines are in CHIANTI, and the expected ratio λ1342.55/λ1341.89 is 0.58. λ1342.55 lies partly in the 1343 Å window that is usually observed in IRIS flare observations.

1.9. Fe II

A commonly-used shorthand for Fe II transitions assigns letters to the terms, with letters a, b, c etc. assigned to even parity terms and letters z, y, x etc. assigned to odd parity terms. The lowest energy terms are all even parity. This notation is used here and the reader is referred to the NIST atomic database for complete transition information. Not all terms are assigned letters and so for these the complete term description is given.

λ1399.9605 partly blends with O IV λ1399.766 in some circumstances (Young, 2015).

The λ1403.1002 line is sometimes seen as an absorption line against a broadened Si IV λ1402.770 profile.

1.10. Fe XXI

The wavelength of this line is somewhat uncertain, and Table 1 gives the wavelength from Feldman et al. (2000) which has an uncertainty of 0.020 Å based on off-limb SUMER observations. From IRIS spectra, Young et al. (2015) derived a wavelength of 1354.106 ± 0.023 Å and Brosius & Daw (2015) derived 1354.0714 ± 0.0108 Å, both of which were derived from on-disk flare spectra.

1.11. Molecular hydrogen

The wavelengths are computed using the energy levels of Abgrall et al. (1993). All lines in the IRIS wavebands are from the Lyman sequence, and the notation used in the tables is as follows. The individual states of H_2 are identifed by their vibrational (v) and rotational (J) quantum numbers. Transitions between v states are given as, e.g., 0–4, which corresponds to a transition from a lower state $v = 4$ to an upper state $v = 0$. For transitions between J states, the possibilities are for J to increase by 1 or decrease by 1. These possibilities are identified as R and P branch transitions, respectively. For example, R2 indicates a transition from $J = 2$ to $J = 3$ and P1 indicates a transition from $J = 1$ to $J = 0$.

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A. Update history

Version 1.4 Updated sections of C I and O I; added a Si II line.
Version 1.3 Added sections on Ca II and Si II.
Version 1.2 Updated the O I section, and added a section on Cl I.
Version 1.1 Updated the S I wavelengths and added a section on S I.

Table 1: Lines in the FUV1 1331.7–1358.4 Å channel.

Species	$\lambda_{\rm ref}$	Ref.	Transition
H_2	1333.475	8	0–4 R0
H_2	1333.797	8	0–4 R1
C II	1334.5323	2	$2s^22p\ ^2P_{1/2} - 2s2p^2\ ^2D_{3/2}$
Ni II	1335.203	2	$3d^9\ \mathrm{g}^2D_{3/2} - 3d^8(^1G)4p\ ^2F_{5/2}$
C II	1335.6627	2	$2s^22p\ ^2P_{3/2} - 2s2p^2\ ^2D_{5/2}$
C II	1335.7077	2	$2s^22p\ ^2P_{3/2} - 2s2p^2\ ^2D_{3/2}$
H_2	1338.565	8	0–4 P2
Ca II	1341.890	5	$3p^64s\ ^2S_{1/2} - 3p^66p\ ^2P_{3/2}$
H_2	1342.257	8	0–4 P3
Ca II	1342.554	5	$3p^64s\ ^2S_{1/2} - 3p^66p\ ^2P_{1/2}$
H_2	1344.033	8	1–3 R14
Si II	1346.873	2	$3s3p^2\ ^4P_{3/2} - 3s3p(^3P)4s\ ^4P_{5/2}$
Ni II	1348.333	2	$3d^8(^1D)4s\ ^2D_{5/2} - 3d^74s4p\ \mathrm{z}^4D_{5/2}$
Si II	1348.543	2	$3s3p^2\ ^4P_{1/2} - 3s3p(^3P)4s\ ^4P_{3/2}$
Fe XII	1349.400	5	$3s^23p^3\ ^4S_{3/2} - 3s^23p^3\ ^2P_{1/2}$
Si II	1350.057	2	$3s3p^2\ ^4P_{5/2} - 3s3p(^3P)4s\ ^4P_{5/2}$
Si II	1350.520	2	$3s3p^2\ ^4P_{3/2} - 3s3p(^3P)4s\ ^4P_{3/2}$
Si II	1350.658	2	$3s3p^2\ ^4P_{1/2} - 3s3p(^3P)4s\ ^4P_{1/2}$
Cl I	1351.656	1	$3s^23p^5\ ^2P_{1/2} - 3s^23p^4(^3P)4s\ ^2P_{1/2}$
Si II	1352.635	2	$3s3p^2\ ^4P_{3/2} - 3s3p(^3P)4s\ ^4P_{1/2}$
C I	1352.751	3	$2s^22p^2\ ^1D_2 - 2s^22p(^2P)4d\ ^3P_1$
C I	1352.988	3	$2s^22p^2\ ^1D_2 - 2s^22p(^2P)4d\ ^3P_2$
Fe II	1353.0218	1	$3d^6(^3P_2)4s\ \mathrm{b}^4P_{5/2} - 3d^5(^4P)4s4p(^3P)\ ^4P_{3/2}$
Si II	1353.718	2	$3s3p^2\ ^4P_{5/2} - 3s3p(^3P)4s\ ^4P_{3/2}$
Fe II	1354.0131	1	$\mathrm{b}^4P_{5/2} - 3d^5(^4P)4s4p(^3P)\ ^6P_{5/2}$
Fe XXI	1354.064	9	$2s^22p^2\ ^3P_0 - 2s^22p^2\ ^3P_1$
C I	1354.288	3	$2s^22p^2\ ^1D_2 - 2s^22p(^2P)4d\ ^1P_1$
Fe II	1354.7434	1	$\mathrm{a}^2I_{13/2} - 3d^5(^2I)4s4p(^3P)\ ^2H_{11/2}$
O I	1355.5977	4	$2s^22p^4\ ^3P_2 - 2s^22p^3(^4S)3s\ ^5S_2$
C I	1355.844	3	$2s^22p^2\ ^1D_2 - 2s^22p(^2P)4d\ ^1F_3$
C I	1357.134	3	$2s^22p^2\ ^1D_2 - 2s^22p(^2P)5s\ ^1P_1$
C I	1357.659	3	$2s^22p^2\ ^1D_2 - 2s^22p(^2P)4d\ ^3D_3$
C I	1357.857	3	$2s^22p^2\ ^1D_2 - 2s^22p(^2P)4d\ ^3D_2$
C I	1358.188	3	$2s^22p^2\ ^1D_2 - 2s^22p(^2P)4d\ ^3D_1$

Table 2: Lines in the FUV2 1389–1407 Å channel.

Species	$\lambda_{\rm ref}$	Ref.	Transition
S I	1388.436	11	$3s^23p^4\ ^3P_2 - 3s3p^5\ ^3P_2$
S I	1389.154	11	$3s^23p^4\ ^3P_1 - 3s3p^5\ ^3P_1$
Fe II	1390.3162	1	b $^2H_{9/2}$ – $3d^6(^1G)4p\ ^2H_{11/2}$
Fe II	1392.1480	1	a $^2H_{11/2}$ – u $^2G_{9/2}$
S I	1392.589	11	$3s^23p^4\ ^3P_0 - 3s3p^5\ ^3P_1$
Fe II	1392.817	7	a $^2H_{9/2}$ – u $^2G_{7/2}$
H_2	1393.451	8	0–4 P10
H_2	1393.961	8	0–5 R1
Ni II	1393.330	2	$3d^9\ ^2D_{5/2} - 3d^8(^3P)4p\ ^2D_{5/2}$
Si IV	1393.755	1	$3s\ ^2S_{1/2} - 3p\ ^2P_{3/2}$
S I	1396.113	11	$3s^23p^4\ ^3P_1 - 3s3p^5\ ^3P_2$
H_2	1396.221	8	0–5 P1
O IV	1397.198	10	$2s^22p\ ^2P_{1/2} - 2s2p^2\ ^4P_{3/2}$
H_2	1398.954	8	0–5 P2
Ni II	1399.026	7	$3d^9\ ^2D_{3/2} - 3d^8(^3P)4p\ ^2P_{3/2}$
O IV	1399.766	10	$2s^22p\ ^2P_{1/2} - 2s2p^2\ ^4P_{1/2}$
Fe II	1399.9605	1	b $^4P_{1/2}$ – $3d^5(^4D)4s4p(^3P)\ ^6D_{3/2}$
O IV	1401.158	10	$2s^22p\ ^2P_{3/2} - 2s2p^2\ ^4P_{5/2}$
S I	1401.514	11	$3p^4\ ^3P_2 - 3p^3(^4S)5s\ ^3S_1$
Fe II	1401.7766	1	b $^4F_{7/2}$ – w $^4G_{9/2}$
Si IV	1402.770	1	$3s\ ^2S_{1/2} - 3p\ ^2P_{1/2}$
Fe II	1403.1002	1	a $^4F_{7/2}$ – w $^2G_{7/2}$
Fe II	1403.2537	1	b $^4F_{7/2}$ – w $^4G_{7/2}$
H_2	1403.982	8	0–4 P11
Fe II	1404.1191	1	a $^4F_{9/2}$ – w $^2G_{9/2}$
O IV	1404.779	10	$2s^22p\ ^2P_{3/2} - 2s2p^2\ ^4P_{3/2}$
S IV	1404.826	10	$3s^23p\ ^2P_{1/2} - 3s3p^2\ ^4P_{1/2}$
Fe II	1405.6081	1	a $^4F_{9/2}$ – x $^2F_{7/2}$
Fe II	1405.7986	1	b $^4F_{5/2}$ – w $^4G_{7/2}$
S IV	1406.043	10	$3s^23p\ ^2P_{3/2} - 3s3p^2\ ^4P_{5/2}$

Table 3: Sources of reference wavelengths.

Index	Reference
1	NIST
2	Kelly & Palumbo (1973)
3	Johansson (1966)
4	Eriksson & Isberg (1968)
5	CHIANTI
6	Brekke et al. (1997)
7	Sandlin et al. (1986)
8	Abgrall et al. (1993)
9	Feldman et al. (2000)
10	Young et al. (2011)
11	Kaufman (1982)