Report on molecular hydrogen lines seen by IRIS during flares

Peter Young (peter.r.young@nasa.gov)
NASA Goddard Space Flight Center
Version 1.1

1. Introduction

Much of the early work on FUV H_2 emission was based on high resolution spectra from Skylab and HRTS, and the identifications are summarized in Bartoe et al. (1979). The IRIS spectra contain transitions from the H_2 Lyman band and energy levels for this band were published by Abgrall et al. (1993). A recent paper discussing H_2 lines in solar UV spectra is by Jaeggli et al. (2018).

2. Spectrum types

The 2013 October 11 23:54 UT data-set is an important reference data-set as it is a large-format, full-CCD raster that includes several types of interesting features, including flares and supersonic loop flows.

Schmit et al. (2014) highlighted an interesting example of a H_2 emission line spectrum seen in X-pixel 309. In a region around Y-pixel=719, the Si IV lines become quite weak and we see many narrow lines, many of which are H_2. We refer to this spectrum as "X309". Interestingly, it seems to be a sub-set of the lines seen in flare spectra. For example there are two lines at 1333.475 and 1333.797 that are normally strong in flare spectra, but 1333.475 is barely measurable in the X309 spectrum whereas 1333.797 is strong. Also, there are two lines at 1338.35 and 1338.55 that are seen in flare spectra, but 1338.35 is not seen in the X309 spectrum. The line 1344.0 is also strong in flare spectra, but disappears in the X309 spectrum.

It appears, based on SJI images, that the X309 spectrum is being fluoresced by a flare occurring some distance away.

X-position 67 shows a typical flare H_2 spectrum in the Y-pixel region 550–650, and we refer to this as the X67 spectrum. Y-pixel 648 is interesting as it shows a very compact brightening for which the transition region lines are narrow, thus it may be useful for comparing examples of H_2 spectra where the fluorescing lines are narrow or broad.

3. Notation

The IRIS H_2 transitions mostly come from the Lyman sequence, and individual states 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 an *upward* transition from $J = 2$ to $J = 3$ and P1 indicates a transition from $J = 1$ to $J = 0$.

4. Excitation process

If we use the notation (v, J) to refer to states, then we consider an excitation from a lower state (v'', J'') to an upper state (v', J').

As an example of the fluorescence process responsible for the IRIS emission lines, we consider a H_2 transition at 1393.719 Å that is a R0 0–5 transition, i.e., $(5, 0)$ to $(0, 1)$. This transition can be excited by Si IV λ1393.76. The upper state can decay to states in the P-branch: $(0, 2)$, (1, 2), (2, 2), etc. These correspond to 0–0 P2, 0–1 P2, 0–2 P2, 0–3 P2, etc, with wavelengths 1112.495, 1166.254, 1221.958, etc.

The upper state can also decay along the R-branch to states (0, 0), (1, 0), (2, 0), etc. These correspond to 0–0 R0, 0–1 R0, 0–2 R0, etc., with wavelengths 1108.127, 1161.692, 1217.208, etc.

If we check Bartoe et al. (1979) we see that the 0–4 R0, 0–4 P2, and 0–5 P2 transitions at 1333.475, 1338.565 and 1398.954 Å were observed by *Skylab* in a flare spectrum. All three of these lines are observed by IRIS. No other transitions from the two sequences are within the IRIS passbands (except the excitation channel line λ1393.719).

In Table 1 we list a number of other examples of H_2 lines fluoresced by strong emission lines.

Table 1: H_2 fluorescent lines in the IRIS wavebands.

Exciting line	Fl. channel	Branch	Member	Wavelength	IRIS?
Si IV 1393.76	0–5 R0, 1393.719	R0	0–4	1333.475	Y
			0–5	1393.719*	–
		P2	0–4	1338.565	Y
			0–5	1398.954	Y
Si IV λ1402.77	0–5 P3, 1402.648	P3	0–4	1342.257	Y
		R1	0–4	1333.797	Y
			0–5	1393.961	Y, bl
C II λ1334.53	0–3 P10, 1334.501	P10	0–4	1393.451	Y
		R8	None		
H I λ1215.67	1–2 P5, 1216.071	P5	None		
		R3	None		
C II λ1335.71	1–4 P6, 1335.581	P6	1–5	1393.732	bl
		R4	None		
C IV λ1548.19	1–6 P16, 1548.352	P16	None.		
		R14	1–3	1344.033	Y
			1–4	1398.900	?, bl 1398.954

5. Overview

Table 2 contains H_2 lines within the IRIS bands that were identified by Bartoe et al. (1979) and Sandlin et al. (1986). The wavelengths for each line have been computed from the energies of Abgrall et al. (1993).

Known H_2 lines in the IRIS spectra are given in Table 2, which is mostly compiled from the list of Sandlin et al. (1986). Wavelengths are obtained from the energy compilation of Abgrall et al. (1993).

They key transitions for the IRIS bands belong to the 0–4 and 0–5 Lyman series.

The Lyman 0–4 R-series is only seen for J=0,1 and higher numbers are not seen. The P-series is more complete, however, with J=2–5 seen in the FUV1 band. $J = 1$ is expected at 1335.866 Å, but this is in the wing of C II λ1335. Only the $J = 10, 11$ members of the P-series fall within the FUV2 band, and both are seen but $J = 10$ lies in the wing of Si IV λ1393.

The Lyman 0–5 P-series has three strong members in the FUV2 band, corresponding to $J = 1 - 3$.

6. Outstanding issues

The 1338.565 line is a good ID, but alongside it is a line at 1338.35 that is almost as strong in some conditions. The Roncin & Launay (1994) line list gives a line at 1338.379 Å, corresponding to 5–6 P2. We then expect to see 5–7 P2 at 1389.799, which is present in the X67 spectrum. However, 1338.35 disappears in the X309 spectrum, whereas 1389.799 remains present.

In addition, we expect to see 5–6 R0 at 1333.893 Å, but there is no sign of this line in either spectrum. In conclusion, the 1338.379 Å ID is not supported by the other lines in the spectra.

References

Abgrall, H., Roueff, E., Launay, F., Roncin, J. Y., & Subtil, J. L. 1993, A&AS, 101, 273

Bartoe, J.-D. F., Brueckner, G. E., Nicolas, K. R., Sandlin, G. D., Vanhoosier, M. E., & Jordan, C. 1979, MNRAS, 187, 463

Jaeggli, S. A., Judge, P. G., & Daw, A. N. 2018, ApJ, 855, 134

Roncin, J.-Y., & Launay, F. 1994, J. Phys. Chem. Ref. Data Monograph Series, 4, 1

Sandlin, G. D., Bartoe, J.-D. F., Brueckner, G. E., Tousey, R., & Vanhoosier, M. E. 1986, ApJS, 61, 801

Schmit, D. J., Innes, D., Ayres, T., Peter, H., Curdt, W., & Jaeggli, S. 2014, A&A, 569, L7

A. Document history

Version 1.1, 5-May-2020 Updated title; some minor text changes.

Table 2: H_2 lines from Bartoe et al. (1979) and Sandlin et al. (1986).

Wavelength	Transition	Reference
1333.475	0–4 R0	B79, S86
1333.797	0–4 R1	B79, S86
1334.486†	3–5 R5	B79
1334.501†	0–3 P10	B79
1335.549†	3–5 P4	B79
1335.581†	1–4 P6	B79
1337.469	0–4 R3	B79
1338.565	0–4 P2	B79, S86
1340.795	0–4 R4	B79, S86
1342.257	0–4 P3	B79, S86
1342.892	1–4 P7	B79, S86
1345.051	2–5 R0	B79
1345.090	0–4 R5	B79
1346.911	0–4 P4	B79
1352.504	0–4 P5	B79, S86
1356.488	0–4 R7	B79
1356.857	4–6 R2	S86
1393.451	0–4 P10	B79, S86
1393.719	0–5 R0	B79
1393.732†	1–5 P6	B79
1393.901	0–5 R1	B79
1395.199	0–5 R2	B79, S86
1396.221	0–5 P1	B79, S86
1397.420	0–5 R3	B79, S86
1398.954	0–5 P2	B79, S86
1400.612	0–5 R4	B79, S86
1402.648	0–5 P3	B79
1403.381	2–6 R2	S86
1403.982	0–4 P11	B79, S86
1404.750	0–5 R5	B79

† – blended with C II or Si IV.

Table 3: Parameters used for computing spectra.

Index	File data	Rast. no.	Xpix	Ypix	Comment
1	11-Oct-2013 23:54	0	309	716:723	H_2 lines particularly strong; not many other lines