EMISSION IN ABSORBTION LINES: RESULTS OF THE SL9 L NUCLEUS IMPACT WITH JUPITER

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Abstract. High-resolution spectra of the impact sites and impact of the comet Shoemaker-Levy 9 with Jupiter have been performed at the Pic-du-Midi Observatory. The excitation of several chemical elements (Fe, Ca, Ba, Na, Mn, Mg, etc.) has been identified during the analysis of the L nucleus impact spectra obtained in visible and near-IR. The article presents the atomic lines and the time evolution of nine of them.

Key words: spectroscopy – comets – atomic lines.

1. INTRODUCTION

One of the major astronomical events of 1994 was the impact of the comet Shoemaker-Levy 9 with Jupiter. The astronomical community observed this event within the framework of the coordinated program; several ground-based and space instruments have been involved. SL9/Jupiter impact was a unique event (until now); before the show "live" of the impact SL9 comes inside Jupiter's Roche limit which broken the nucleus in 22 fragments.

The first impact for each nucleus occured on an unfavourable geometry, on the hidden part of Jupiter, not far from the limb. However, relevant data concerning the impacts were collected as soon the impact effects become visible.

2. OBSERVATIONS

The paper presents the spectroscopy in the wavelength range of visible and near-IR (5460-8750 Å) performed for the L impact site. The observations were performed with the 2-meter Bernard Lyot telescope from the Pic du Midi Observatory. The spectra were recorded by a 1024 × 1024 Thomson CCD chip, and

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the spectral resolution was 36 000. The fibber of the spectrograph has 50 microns, which corresponds to a field of view of 2.2" This field of view is small enough to obtain high quality spectra only from the impact site (the apparent diameter of Jupiter is about 38"). The guidance software of the telescope allows both automatic/manual tracking during the exposure.

3. DATA REDUCTION

The pre-treatment of the observed data was performed using MUSICOS software. MUSICOS makes the calibration pixel-wavelength for the intensities spectra. Each spectrum was split in several wavelength intervals (named "orders") which little overlap between the adjacent orders. For the analysis in the absorption line we choose as target on Jupiter the L impact site for July 19/20 at 22:30:55 UT (referred to as S167), and July 20/21(referred to as S213), 1994. As reference, the Jupiter spectrum was taken on July 20/21 (referred to as R216). The spectrum S167 emission lines have already been analysed in several papers (Roos-Serote et al. 1995a,b; Barucci et al. 1995).

The MIDAS software procedures for spectroscopy were employed. The goal of this work was to check the atomic absorption line depth one day after the impact moment and to see the excitation of different atoms of Jupiter-SL9 L impact plume. To reach this goal, all the orders of both spectra of impact site were compared with the reference spectrum R216. Then the results S213/R216 and S167/R216 in each order were compared.

In this treatment, the major problem of the differential rotation of the atmosphere of Jupiter occured. From an order to another, in different spectra, the same atomic line presents a slight shift in wavelength, following the expression:

$$\frac{\Delta\lambda}{\lambda} = \frac{v_{diff}}{c},$$

where v_{diff} denotes the differential speed of Jupiter and c stands for the speed of light.

Thus, an automatic procedure of shift cannot be taken into account. For a good preliminary result in some orders the spectra were rebined. Then, shifting the lines in such a way made the subtraction or division between spectra, so that the minima of the lines are at the same wavelength.

The cosmic ray signatures represented another problem that occured during the treatment. This was skipped manually, each time when the spectrum of Jupiter had no lines in this region, and one given atomic line had an abnormal profile.

At least, we cannot omit the presence of the terrestrial lines, even after a major part of them where eliminated by an automatic procedure. Their presence could alter our qualitative analysis and they were carefully analysed and skipped.

4. RESULTS

The comparison of the L impact site spectra with the unperturbed Jupiter's atmosphere spectrum was made in order to minimize any ambiguity. Then the shifted spectra S167 and S213 were compared in each order. To obtain a good signature for each excited atomic line, the ratio S167/S213 has been analysed. As presented in Fig. 1, only the signatures of atomic lines with amplitude larger than three times the noise amplitude were considered (three sigma relevance).

The analysis reveals orders on which the spectral lines were not perturbed by the impact of the comet (as seen on Fig. 2). At the opposite, there are spectral intervals where almost all of the atomic lines were perturbed.

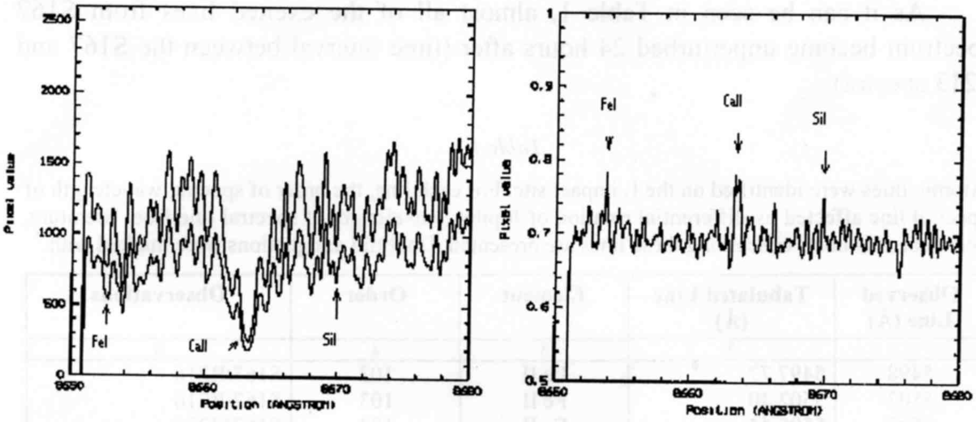

Fig. 1 – Left: Spectra of the 65-th order of R216, and S213 (upper and lower spectrum, respectively). On the center of this order the Paschen $n = 13$ absorption line of Ca II ion. Right: Signatures of Ca II, Fe I, and Si I after the S213/R216 computation.

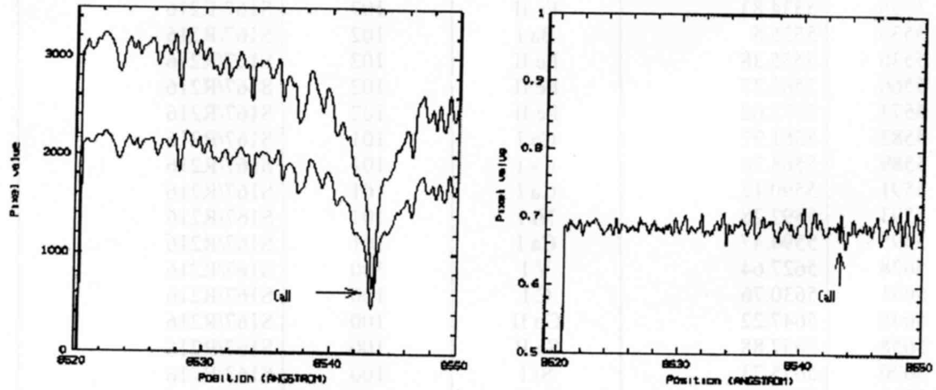

Fig. 2 – "Quiet" order. Spectra of the 66-th order of R216, and S213 (upper and lower spectrum, respectively) containing Paschen line $n = 15$ of Ca II ion (left plot). The result of the S213/R216 computation (right plot).

For the S213, almost of the orders are "quiet". At the opposite, the S167 spectrum presents high differences for several atomic lines (Fig. 3). Thus, the Fe I, II, and III lines are excited on almost all of orders as well as the representative lines of Ca I, and II ions.

Table 1 lists the excited lines. In a first time the line identification was made taking as origin the profile of spectral lines from *The High Resolution Spectral Atlas of the Solar Irradiance* by Beckers, Bridges and Gilliam (1976), and *The Solar Spectrum from λ 6000 to λ 13495* by Babcock and Moore (1947). Then our identification was refined using the articles of Morton (1991, 2000), Morton and Noreau (1994), and the VizieR database of atomic lines (http://vizier.u-strasbg.fr), Reader and Corliss, and Hirata catalogues.

As it can be seen in Table 1, almost all of the excited lines from S167 spectrum become unperturbed 24 hours after (time interval between the S167 and S213 spectra).

Table 1

Atomic lines were identified on the L impact site. For each line, the order of spectra, wavelength of spectral line affected by differential rotation of Jupiter, wavelength of spectral line from literature, element, and notes concerning these lines are presented. Doubtful assignations were marked with *

Observed Line (Å)	**Tabulated Line (Å)**	**Element**	**Order**	**Observations**
1	2	3	4	5
5498	5497.77	Fe II	103	S167/R216
5502	5502.30	Fe II	103	S167/R216
5507	5506.44	Fe II	103	S167/R216
5511	5512.98	Ca I	103	S167/R216
5511	5510.61	Cr I	103	S167/R216
5527	5526.8	Sc II	102	S167/R216
5533	5535.05	Mo I	102	S167/R216
5535	5534.83	Fe II	102	S167/R216
5536	5535.5	Ba I	102	S167/R216
5536	5535.38	Fe II	102	S167/R216
5566	5565.37	Fe II	102	S167/R216
5573	5572.62	Fe II	102	S167/R216
5582	5581.97	Ca I	101	S167/R216
5589	5588.76	Ca I	101	S167/R216
5591	5590.12	Ca I	101	S167/R216
5593	5592.28	Ni I	101	S167/R216
5595	5594.47	Ca I	101	S167/R216
5628	5627.64	V I	100	S167/R216
5631	5630.76	C I	100	S167/R216
5648	5647.22	Co II	100	S167/R216
5658	5657.88	Sc II	100	S167/R216
5676	5675.73	Si I	100	S167/R216
5710	5708.93	Fe II	99	S167/R216
5737	5736.75	Ca I	99	S167/R216
5788	5787.9	Cr I*	98	S167/R216

Table 1 (continued)

Observed Line (Å)	Tabulated Line (Å)	Element	Order	Observations
1	2	3	4	5
5853	5853.45	Fe II	97	S167/R216
5858	5857.45	Ca I	97	S167/R216
5863	5862.89	Fe I	97	S167/R216
5890	5889.95	Na I	96	S167/R216
5896	5895.92	Na I	96	S167/R216
5915	5914.97	Fe II	96	S167/R216, S213/R216
5984	5983.86	Fe II	95	S167/R216
6014	6013.5	Mn I	94	S167/R216
6017	6016.6	Mn I	94	S167/R216
6066	6065.83	Fe II	93	S167/R216
6123	6122.22	Ca I	92	S167/R216
6142	6141.72	Ba II	92	S167/R216
6163	6162.17	Ca I	92	S167/R216
6176	6176.05	N II	92	S167/R216
6210	6209.73	Fe I	91	S167/R216
6226	6225.92	Cr II*	91	S167/R216
6243	6242.87; 6242.9	Ca I*; Mn I*	91	S167/R216
6245	6244.47	Si I	91	S167/R216
6319	6318.66	Fe II	90	S167/R216
6359	6358.76	Fe II	89	S167/R216
6439	6439.07	Ca I	88	S167/R216
6451	6449.81; 6450.24	Ca I+Co I	88	S167/R216
6472	6471.66	Ca I	87	S167/R216, S213/R216
6494	6493.78	Ca I	87	S167/R216
6496	6495.78	Fe I	87	S167/R216, S213/R216
6498	6498.75	Ba I	87	S167/R216, S213/R216
6501	6499.65	Ca I	87	S167/R216, S213/R216
6563	6562.85	H I	86	S167/R216
6574	6572.78	Ca I	86	S167/R216
6679	6678.9	Fe II	85	S167/R216
6708	6707.91; 6707.76	Li I	84	S167/R216 (double)
6978	6978.48	Cr I	81	S167/R216
7289	7288.88	Fe II	78	S167/R216
7290	7290.26	Si I	78	S167/R216
7326	7326.15	Ca I	77	S167/R216, S213/R216
7327	7325.51	Mn I	77	S167/R216, S213/R216
7853	7852.86	C I*	72	S167/R216
7858	7858.09	Fe III	72	S167/R216
7938	7938.06	Fe II	71	S167/R216
8095	8094.93	Fe I	70	S167/R216
8187	8186.97; 8186.99	F III*, Mn II*	69	S167/R216
8195	8194.70	Fe I	69	S167/R216
8405	8404.77; 8404.84	Mn III*, Fe II*	66	S167/R216
8415	8414.89; 8414.95	Fe II*, F I*	66	S167/R216, S213/R216
8664	8662.14	Ca II	65	S167/R216, S213/R216
8683	8683.4	N I	65	S167/R216, S213/R216
8710	8710.03	Fe I	65	S167/R216, S213/R216
8737	8736.02; 8736.48	Mg I, Mn I	65	S167/R216
8790	8789.34	Fe I	65	S167/R216

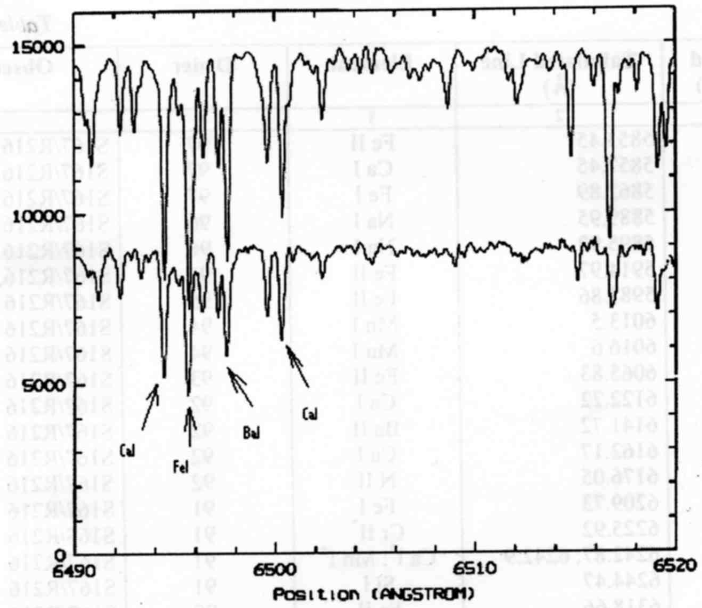

Fig. 3 – Order 87 on S167 (top), and R216 (bottom) spectra. We can distinguish the perturbed lines of Fe I, Ca I, and Ba I lines (marked by arrows).

However, some excited lines are present in both spectra (S167 and S213). In order to have their temporal evolution, casually the orders of a third spectrum were analysed. This spectrum (S166) was taken on July 19/20, 1994, just at the moment that L impact site and plume appeared on the Jupiter visible hemisphere. Table 2 presents such an evolution in the case of some important lines. The percentage values given by the last three columns of Table 2 are computed only from the geometrical consideration, taking into account the depth of the line in the R216 spectrum.

Table 2

The evolution of some spectral lines in three analysed spectra. The spectral line contains the differential rotation shift imposed by Jupiter's rotation.

Element	Wavelength (Å)	S166/R216	S167/R216	S213/R216
Ca I	6472	26%	25%	7%
Ca I	6494	13%	20%	–
Fe I	6496	26%	29%	13%
Ba I	6498	16%	20%	1%
Li I	6708	3%	24%	–
Ca II	8664	84%	70%	10%
N I	8683	15%	33%	13%
Fe I	8790	44%	35%	–
Mg I, Mn I	8737	16%	25%	–

We have paid a special attention to the hydrogen quadrupolar momentum lines. We have searched for the S(0) – S(3) H signatures (6270.24 Å, 7959.77 Å, 8150.67 Å, and 8272.67 Å, respectively), but our search has not provided positive results.

5. DISCUSSION

The greatest part of the absorption atomic lines of the solar spectrum (of our spectral interval) remained unperturbed after the reflection on Jupiter. The Jovian atmosphere does not present metallic compounds on the analysed spectral interval, the profile of Jupiter's spectrum reproduces the solar spectrum. The perturbed spectra come from the L impact site. Therefore, we can formulate the conclusion that the most significant part of this excitation was released by the cometary material.

Various mechanisms could be responsible of the presence of the atom excitation. The perturbation of atomic lines could be explained as the effect of such a mechanism (or several such mechanisms). As long as the goal of this article is to present the qualitative results of spectra analysis, these mechanisms will be only remembered. However, the author intimate conviction is that different excited lines could be explained only by individual theories.

The main known mechanisms are: the resonant fluorescence, the thermal collision (if we consider the temperature on the impact site and plume greater than 1000 K), and the electronic recombination. The resonant fluorescence mechanism is unanimously accepted as the responsible of the presence of metallic lines on the cometary's spectra as well as for the presence of molecular bands. The thermal collisions could contribute to atomic lines only if the collision rate of atoms is high enough to produce transitions between the corresponding energy levels, and the electronic recombination could be efficient for the excitation of atoms in metastable states.

6. CONCLUSIONS

The analysis of the L impact spectra reveals several excited atomic lines. Alkaline lines (Li, Na, Ba, Ca, Mg) as well as line of transition metals (Fe, Cr, Ni, Co, Mn) are listed in Table 1. Nitrogen (N) and maybe flour (F) and carbon (C) lines are presented and rest to be confirmed by further analysis and astronomical observations. The major part of the atomic lines disappear 24 hours after the impact instant, which shows the efficiency of the de-excitation mechanism and energy dissipation on Jupiter's atmosphere.

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