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Data Sources

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TABLE I

Filaments and "Disparitions brusques", 1955-1969
From Cartes Synoptiques published by Meudon Observatory

Year	Filaments with importance ⩾ 5		
	Total number	With disparitions brusques Number	%
1955	25	9	36
1956	67	15	22
1957	84	21	25
1958	94	30	32
1959	121	36	30
1960	84	26	31
1961	50	15	30
1962	31	9	29
1963	30	6	20
1964	18	2	11
1965	20	3	15
1966	31	9	29
1967	71	33	46
1968	81	23	28
1969	46	15	33
Total	853	252	30

Eu, La and Sm in sunspot spectra

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Resumen: Se obtuvieron valores de abundancias relativas para Eu, La y Sm a partir de espectros de manchas de alta resolución.

Los resultados son (en la escala $\log \varepsilon^{H} = 12.00$)

	$\log \varepsilon$
Eu	0,70 ± 0,30
La	2,14 ± 0,27
Sm	2,30 ± 0,35

La dependencia de la abundancia con el potencial de excitación del nivel inferior es grande para Eu, menor para La y está ausente para Sm. Esto señala la presencia de errores sistemáticos en los valores de fuerza de oscilador usados para este trabajo.

Se presenta además una lista de nuevas líneas identificadas en el espectro de manchas.

1. *Introduction*

The determination of the relative abundances of heavy elements, specially of those of the Lanthanides, is a straightforward test of the modern theory of nucleosynthesis. This theory assumes these elements are produced by s and r processes and predicts that their relative abundance is inversely proportional to their neutron capture cross-section.

The anomalous behaviour of the Lanthanides in Ap and Am stars and their overabundance in magnetic stars have been the subject of numerous investigations. Pikelner and Kokhlova (1971) and Sargent and Burbidge (1970) discussed possible explanations for these observations. Lines of Lanthanides also show an anomalous behaviour in the solar spectrum occurring in emission on the solar disk in the wings of the H and K lines of Ca II and near the solar limb (see eg. Jenssen and Orrall (1963) and Canfield (1971)). The first determination of the abundance of rare earths was made by Russell (1929) followed by investigations by Wallerstein (1966), Righini and Rigutti (1966) and Grevesse and Blanquet (1969). Most recently Bachmann et al. (1970) have investigated, with improved methods, the abundance of La and Eu from photospheric and sunspot spectra (for details see table 1).

TABLE 1

Zwaan C.: 1965, Roch. Astron. Obs. Utrecht, *17*, part. 4.
A summary of rare earth abundance determinations published so far.

Russell (1929)
Visual estimation of intensities for photospheric lines of many ionized heavy elements. Oscillator strengths from Russell et al. (1928).

Wallerstein (1966)
Curve of growth method for photospheric lines of many ionized heavy elements (adopted excitation temperature: 5.000 K.).

Righini and Rigutti (1966)
Weighting function method computations for ionized heavy elements in the photosphere. Equivalent widths from Utrecht Atlas. Photospheric model: Müller and Mutschlecner (1964). Oscillator strengths: Corliss and Bozman (1962).

Grevesse and Blanquet (1969)
Computation of equivalent widths of many lines of ionized rare earths for different photospheric models. Oscillator strengths from Corliss and Bozman (1962). Equivalent widths from high resolution spectra.

Bachmann et al. (1970)
Line profile computations of either one line of La and Eu in the photosphere and umbra. Isotope effects and hyperfine structure were taken into account. Oscillator strengths from Corliss and Bozman (1962). Observational data: mean profiles obtained photographycally and protoelectrically.

TABLE 2

Newly identified lines of Eu, La, and Sm in the umbra spectrum. The weighting factor g ranges from 1 (ensured identification) to 0.1. Lines with g < 0.1 were rejected for the computations.

	λ (Å)	umbral Wλ (mÅ)	g
EuII	5818.74	18	0.5
	5953.82	8.5	0.5
	6049.50	7	0.1
	7426.65	5	0.1
SmI	4397.38	26	0.25
	4463.90	6.5	0.1
	4480.34	14	0.25
	4532.40	7.5	0.1
	4533.80	20	0.5
	5550.38	13	1.0
	5659.86	15	1.0
	5802.84	6	1.0
LaI	4486.10	17	0.25
	4567.92	22	0.5
	4770.40	17	0.5
	4850.82	11	0.25
	5304.00	13.5	0.25
	5357.86	15	0.1
	5761.82	14	0.1
	5769.08	20	0.25
	5821.96	17	0.1
	6394.26	19.5	0.5
	6455.94	15.5	0.5
LaII	4636.44	10	1.0
	5303.52	5	1.0

From the lower temperature in sunspot umbrae (as compared with the photosphere) one expects that not only lines of EuII, LaII and SmII but also numerous lines of neutral atoms should be present which may then be used for more comprehensive analysis (only a few ionized lines in the blue region have been used by former investigators). However, this advantage is partially compensated by uncertainties due to scattered light and by the more severe problems of blends and continuum level determination in an umbral spectrum.

2. *Observations and Reductions*

Highly resolved photoelectric sunspot spectra (Wöhl (1970) and Wöhl et al. (1970)) have been used for this analysis. The region 4000 Å ≤ λ ≤ 7000 Å has been searched for lines of EuI and EuII, SmI and SmII as well as of LaI and LaII using the tables of Meggers et al. (1961). A weighting factor g was assigned to every line under consideration; the factors entering into g were: a) the wavelength difference $\lambda_{lab} - \lambda_{spot}$, b) the probability of the line being blended by other lines (atomic lines from the table of Harrisson (1969), molecular lines from a tape prepared by Wöhl (1970)), c) the shape of the line profile in view of the strong hyperfine structure of the rare earth lines, d) the presence of unidentified photospheric lines in the vicinity. Only those lines for which g was higher than a minimum acceptable level and which showed a linear dependence of the measured equivalent width on the intensity-index of Meggers' tables (1961) were used for the final analysis.

Lines of Eu, La and Sm which have been newly identified in the sunspot spectrum are presented in table 2. Details concerning the method used to obtain the abundance are summarized in table 3.

The line-broadening due to the hyperfine splitting, isotope effects and Zeeman-splitting (abreviated for shortness to HFS in the following) is of great importance for the determination of the abundance from the measured equivalent width, Wλ, since these effects are not negligible for Eu, La and Sm. The influence of these effects on the abundance determination have very recently been rediscussed by Wolffram (1972). Since the HFS-broadening of the lines under study are nearly unknown we considered this effect on the logarithmic abundance (log ε) by introducing an "HFS-microturbulence". As shown in figure 1 (this is one of the few lines with known HFS) the "HFS-broadening" dominates over the temperature- and-solar microturbulence-broadening. For lines on the linear part of the curve of growth (most of the lines used here belong to this group) the halfwidth is proportional to the "HFS-microturbulence", ξ. From the halfwidth (HW) measured in sunspot-spectra we determined ξ from the relation

$$HW = 1.66\,(\lambda/c)\,\xi$$

and introduced ξ into our computations of Wλ.

TABLE 3

Details concerning the determination of abundances in this work

Investigated elements	LaI, LaII, SmI, SmII, EuII
Oscillator strengths and partition functions	Corliss and Bozman (1962)
Adopted stray-light amount and correction procedure	5 % in photospheric units Zwaan (1965)
Models used for computation and test	Umbra: Henoux (1969), Stellmacher and Wiehr (1970), Zwaan improved (1965). Microturbulence empirically determined for each line (see text). Photosphere (for tests): Holweger (1967)
Equivalent width range of used lines in the umbra (in mÅ). In brackets total number of lines used for computations.	LaI: 11-42 (12) LaII: 5-120 (7) SmI: 6-26 (8) SmII: 5-39 (13) EuII: 5-50 (7)

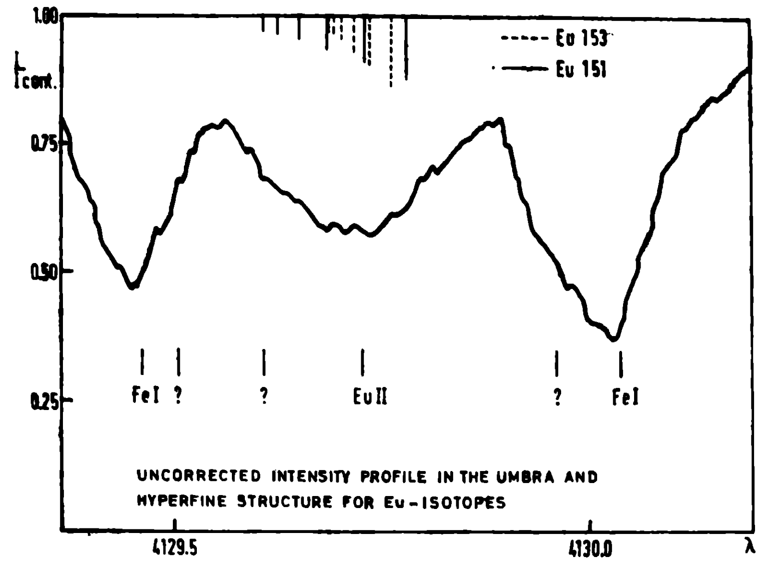

Fig. 1 — A sample of the used sunspot spectrum showing Rowland Table identifications. Note the large HFS-pattern of both Eu isotopes as compared with thermal — and microturbulence — broadening.

3. *Results and Discussion*

The results are shown in figure 2 and 3 and in table 4. There is no remarkable dependence of log ε on the equivalent width which is obvious since we determined the dominant "HFS-microturbulence" empirically.

TABLE 4

Results of this investigation compared with those of other authors

Weight g	λ (A)	χ^{L}_{rs} (eV)	umbral $W\lambda$ (mA)	log ε ($\log^{H}\varepsilon = 12.00$) Model 1	Model 2	Model 3
1.0	4129	0.00	50	0.70	0.62	0.45
0.5	5818	1.23	18	3.30	3.27	3.03
0.5	5953	1.27	8.5	3.70	3.65	3.40
0.1	6049	1.27	7	2.50	2.42	2.22
1.0	6437	1.31	30.5	2.90	2.87	2.63
1.0	6645	1.37	8	1.80	1.77	1.52
0.3	7426	1.27	5	2.10	2.04	1.80

Model 1 Stellmacher and Wiehr (1970)
Model 2 Henoux (1969)
Model 3 Zwaan Improved (1965)

Samarium

SmI and SmII show (see figure 2) a nearly insignificant dependence of log ε on the lower excitation potential χ^{L}_{rs}. For all sunspot models used in this paper no significant difference in log ε between SmI and SmII is found. The final abundance of Sm, as computed from both neutral and ionized lines, shows no difference between Henoux's (1969) and Stellmacher-Wiehr's (1970) models. These models presently give the best representation both of continuum observations and line profiles in sunspot umbrae. Hence, the

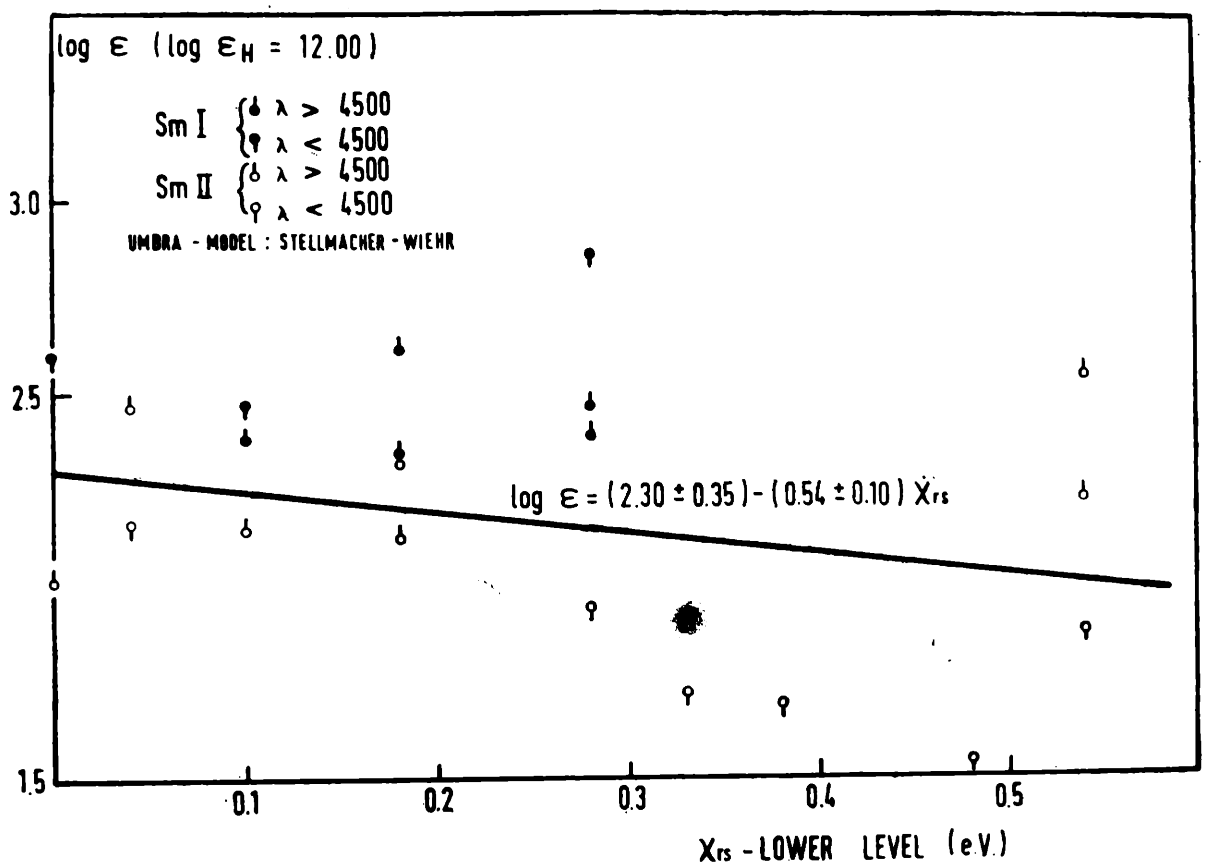

Fig. 2 — The abundance for Sm as a function of excitation potential. Used gf-values: Corliss and Bozman (1962).

above result is not surprising, since the temperature profiles of these models agree very well in those layers where the lines under investigation are formed. This is not the case for the Zwaan improved model (Zwaan (1965)) as can be seen from the following results of a weighted least square fit of the measurements for these three models:

$$\begin{aligned}
&\log {}^{Sm}\varepsilon \ \text{(Stellmacher-Wiehr)} =\\
&\log {}^{Sm}\varepsilon \ \text{(Henoux)} =\\
&\log {}^{Sm}\varepsilon \ \text{(Zwaan improved)} =\\
&\qquad = (2.30 \pm 0.35) - (0.54 \pm 0.10)\ \chi^{L}_{rs}\\
&\qquad = (2.31 \pm 0.39) - (0.62 \pm 0.12)\ \chi^{L}_{rs}\\
&\qquad = (1.92 \pm 0.28) - (0.32 \pm 0.08)\ \chi^{L}_{rs}
\end{aligned}$$

A check of these figures by computing the equivalent width of these lines in the photosphere confirms the "resonance-level" value of log ε. Only SmII could be used for this test, since no SmI lines are identified in Rowland's Tables.

Lanthanum

A significant difference between the abundance of La I and La II does not occur for all models. However, as can be seen in figure 3, there is a strong dependence of log ε on χ^{L}_{rs} especially for neutral La. Systematic errors in the gf-values by Corliss and Bozman (1962) could, among other effects, explain this effect. Again, the abundance derived from Zwaan's improved model is significantly lower than that obtained from the model by Henoux and Stellmacher-Wiehr, the latter two showing no difference in log ε at all:

$$\begin{aligned}
&\log {}^{La}\varepsilon \ \text{(Stellmacher-Wiehr)} =\\
&\log {}^{La}\varepsilon \ \text{(Henoux)} =\\
&\log {}^{La}\varepsilon \ \text{(Zwaan improved)} =\\
&\qquad = (2.14 \pm 0.27) + (0.79 \pm 0.14)\ \chi^{L}_{rs}\\
&\qquad = (2.14 \pm 0.29) + (0.78 \pm 0.15)\ \chi^{L}_{rs}\\
&\qquad = (1.84 \pm 0.22) + (0.71 \pm 0.11)\ \chi^{L}_{rs}
\end{aligned}$$

The photospheric check of La II lines confirms also the "resonance-level" abundance as obtained from sunspot spectra.

Europium

Only 7 lines of ionized Eu could be used for this analysis. Surprisingly we did not find any linear relation between umbral Wλ — values and Meggers' (1961) intensity scale for EuI lines although many coincidences occur between absorption features in the umbral spectrum and some wavelengths of this table. As table 4 shows, the line at λ 4129 (the only resonance line used) gives the lowest abundance value. All other (excited) lines lead to higher values of log ε. Grevesse and Blanquet (1969) obtained the value 1.12 from this line which was confirmed by Bachmann et al. (1970) who obtained the value 1.0. We searched for other EuII lines with different excitation potentials in the sunspot spectra and found them blended or even not present. From a study of the lines which are not present in the spectra an upper limit to the abundance could be derived. This procedure confirms a strong dependence of log ε on χ^{L}_{rs}, stronger than that obtained for the other two ele-

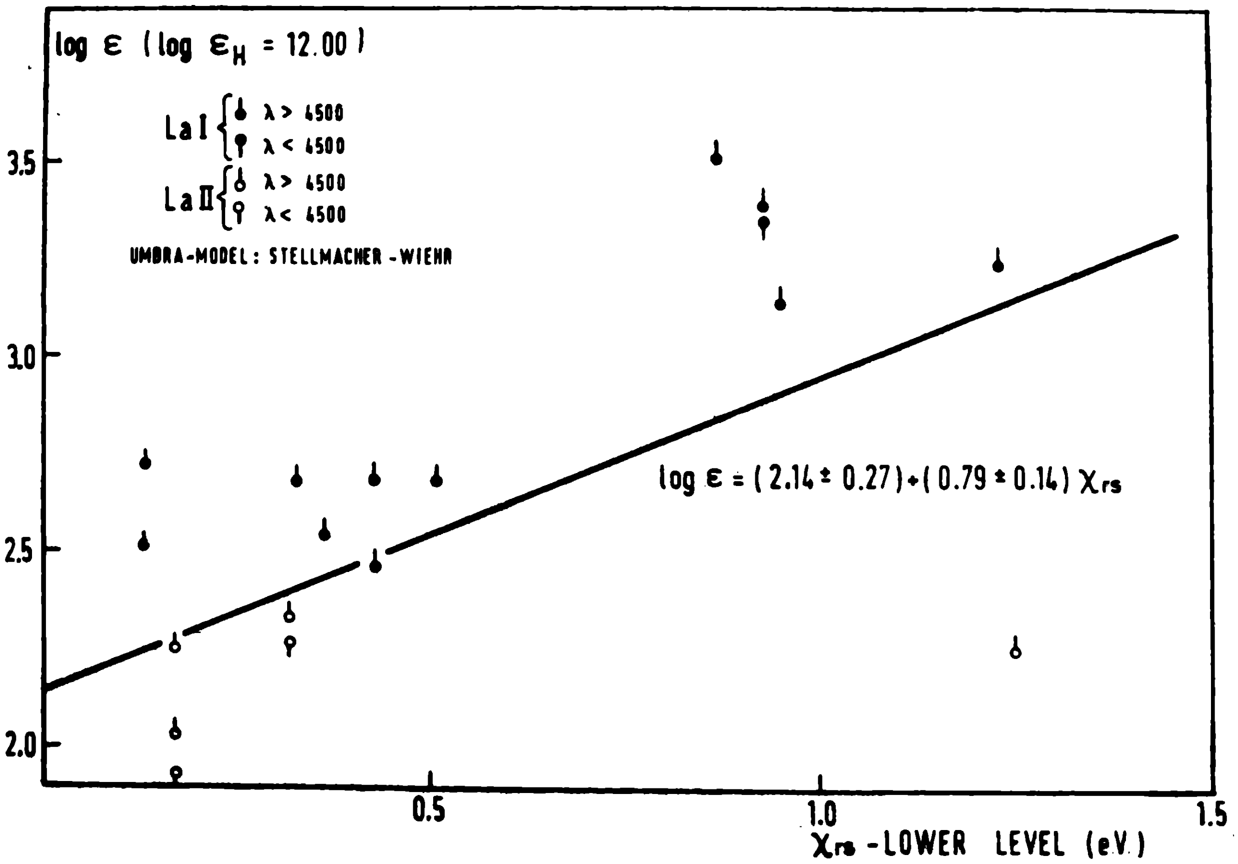

Fig. 3 — The abundance for La as a function of excitation potential. Used gf-values: Corliss and Bozman (1962).

ments under investigation. Computations of $\log \varepsilon$ for those Eu II lines observed in the photospheric spectrum tend to the "resonance level" abundance. However, a (certainly weaker) dependence of $\log \varepsilon$ χ^{L}_{rs} cannot be ruled out in view of the small number of lines at our disposal. In order to have some information about the behaviour of Eu I we made tests of some resonance lines of neutral Eu using reliable gf-values by Komarovskii et al. (1968). In this manner we obtained upper values for the abundance that confirm both in the umbra and in the photosphere, the lower figures.

The great scatter in the obtained values in figure 2 and 3 is probably due to: a) errors in the gf-values by Corliss and Bozman (1962), b) unknown blends of atomic and molecular origin in at least some of the lines, c) uncertainties in the adopted continuum level for each line.

The systematic dependence of the abundance on χ^{L}_{rs} is at first glance evident when comparing our results with many works dealing with corrections to Corliss and Bozman's oscillator strengths. But it has to be pointed out that these authors propose a negative correction of the gf-values of excited lines, while our results need a positive correction in order to decrease the abundances for lines of high excitation potential. Hence in the case of these elements the temperature of the arc used by Corliss and Bozman has been overestimated. The correction might be absent for Sm, the abundance of which looks independent on χ^{L}_{rs}, and strongest for Eu, which shows the most striking χ^{L}_{rs} — dependent results to the investigated elements.

The need for a wavelength-dependent correction for the gf-values used was pointed out by many authors and is evident if one compares these values for EuI with the ones by Komarovskii et al. (1968). However, no information about this correction for the lines investigated here could be found and it is dangerous to extrapolate the data from other elements, so no corrections in this sense were made.

Final results and comparison with other authors are shown in table 5. Improved laboratory data are needed in order to ensure the abundance values of heavy elements, since these values for the sun can be determined with an accuracy of only a factor of 3 to 5. No statement can be made about neutron capture processes due to this great inaccuracy. The strong dependence of $\log \varepsilon$ on excitation potential, especially in the case of Eu II, and the absence of any correlation between sunspot $W\lambda$ — values and Meggers' intensity scale for Eu I lines indicates the possibility of strong temperature dependent errors. The influence of these errors should be rediscussed in view of the "overabundance" of heavy elements in A stars. As long as this effect has not been clarified, any conclussions on the behaviour of these elements in magnetic fields seem to be premature.

TABLE 5

			$\log \varepsilon$ ($\log^{H} \varepsilon = 12.00$)						Abundance relative
A	Z	El	R	W	RR	GB	Meteor.	This work	to Sm ($\log^{El} \varepsilon - \log^{Sm} \varepsilon$)
139	57	La	2.3	1.92	--	1.81 ± 0.27	1.11	2.14 ± 0.27	—0.16
152	63	Eu	1.9	0.97	0.96	0.49 ± 0.14	0.51	0.70 ± 0.30	—1.60
153	62	Sm	2.0	1.27	1.62	1.66 ± 0.21	0.91	2.30 ± 0.35	

R : Russell (1929)
W : Wallerstein (1966)

RR : Righini and Rigutti (1966)
GB : Grevesse and Blanquet (1969)

From neutron capture theory predicted relative abundances ($\log^{El} \varepsilon - \log^{Sm} \varepsilon$) (Seeger et al. 1965)

	s-process	r-process
$\log^{La} \varepsilon - \log^{Sm} \varepsilon$	+ 0.5	+ 0.02
$\log^{Eu} \varepsilon - \log^{Sm} \varepsilon$	— 1.0	— 0.34

ACKNOWLEDGEMENTS

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