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National Aeronautics and Space Administration
Goddard Space Flight Center
Contract No.NAS-5-12487

ST-ISA-CR-10659

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GPO PRICE	$
CFSTI PRICE(S)	$
Hard copy (HC)	3.00
Microfiche (MF)	

ff 653 July 65

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18 OCTOBER 1967

ST – SA – CR – 10659

ON LITHIUM CONTENT IN THE SPECTRA OF STARS OF T TAURUS TYPE AND IN COSMIC RAYS*

Doklady A.N. SSSR,
Astronomiya
Tom 176, No.2, 291-294
Izd-vo "NAUKA", 1967.

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SUMMARY

On the basis of earlier findings about the presence of lithium in T Tau-type stars the author establishes that the total number of lithium atoms in their atmospheres is at least $1 \cdot 10^4$ times greater than in that of the Sun. Drawing a parallel with the high lithium content in cosmic rays, it is hinted that T Tau-type stars may be lithium suppliers for the interstellar medium. To verify this, a line of study is suggested for determining the isotopic composition of cosmic rays, particularly in relation to the Sun.

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*   *

A resonance duplet of neutral lithium, 6708 Li I, of substantial intensity, was first observed by Hunger [1] in the spectra of two stars of the T Taurus type: T Tau and RY Tau. Subsequently, Bonsak and Greenstein [2], while corroborating Hunger's observations, established the presence of this line in three more stars of the same type: SU Aur, GW Ori and RW Aur, its intensity being very high. The amount of lithium in these stars was found to be 50 to 400 times greater than in the Sun. At present nearly 20 stars of the T Tau type are known for which the lithium to metals ratio exceeds by two orders this ratio for the Sun. At the same time there are no observed proofs of the presence of lithium in standard dwarf stars of later type (later than KO) [3]. Under-such conditions the fact of anomalous lithium content in the T Tau-type stars acquires a particular significance.

As is well known, lithium belongs to the number of elements which cannot exist in star interiors; at temperatures above $3 \cdot 10^{6\circ}$ lithium vanishes rapidly, combining with hydrogen and forming helium. This is why the presence of lithium in the atmosphere of a star is usually considered as the proof of the possibility, in principle, of formation of certain elements directly in the atmospheres of stars as a consequence of some nuclear processes. If this is so, the abundance

(*) O SODERZHANII LITIYA V ZVEZDAKH TIPA T TEL'TSA I V KOSMICHESKIKH LUCHAKH of lithium in the atmospheres of stars of the type T Tau must be considered as evidence of exceptional activity of nuclear processes in them.

Attempt was made in [4] to show that the anomalous lithium content in the T Tau stars has a direct bearing on the continuous emission phenomenon. The fast electrons responsible for this emssion appear in the atmosphere of T Tau stars as a result of β-decay of helium isotope $He_2{}^6$, and the lithium isotope $Li_3{}^6$ appears in them as a product of decay. Contrary to the typical flare stars, the process of continuous emission yield, and consequently the very β-decay has in T Tau stars a more or less constant character. Thus, the process of constant lithium accumulation in their atmospheres is also inescapable and this should apparently be the explanation of its observed abundance.

It could, however, be shown that the real number of lithium atoms in the atmospheres of T Tau stars is much greater than what follows from the Bonsak's and others'observations. The fact is that the absorption line 6707 Li I belongs to neutral lithium and arises at transition from the ground state 2s to the nearest 2p level. Meanwhile in the atmospheres of flare stars lithium must be present mainly in a singly ionized state, and this by virtue of the fact that the intensity of nonthermal radiation beyond the lithium frequency threshold (shorter than 2300 A) during star flare is significantly greater than the intensity of thermal (Planck) emission beyond the same threshold in a normal star of the same type or in the Sun. This follows if only from the very fact of the presence of hydrogen emission lines in the spectra of T Tau stars, which could not be excited without the presence of a sufficiently powerful emission in the shortwave region of their spectrum.

On the other hand it may be shown that the concept of inverse Compton effect may not explain the emergence of emission lines in the spectra of T Tau stars and analogous objects even for energies of fast electrons $E \sim 1.5 \cdot 10^6$ ev.

In connection with this it is of interest to determine the real content of lithium atoms in the atmospheres of T Tau stars by comparison with the Sun; to that effect it is necessary to consider the problem of lithium ionization in the conditions of these stars' atmosphere. However, not being in possession of observation data on energy distribution in the continious spectrum of these stars in the region shorter than 3000 A, we utilized for the operational hypothesis the results brought out in [5], i. e., we shall consider that the nonthermal radiation ionizing lithium, emerges on the atmosphere of the star as a result of inverse Compton effect.

The condition of stationary state between the photoionization processes from neutral lithium's ground state and the recombination processes of singly ionized lithium atoms with free electrons will be the initial condition. We have

$$n_1 \int_{\nu_0}^{\infty} \varkappa_{1\nu} \frac{I_\nu(\mu, \tau, T_*)}{h\nu}\, d\nu = n^+ n_e C_{Li}(T_e), \tag{1}$$

where n_1 and n^+ are respectively the concentrations of neutral and singly ionized lithium atoms; ν_0 is the frequency of neutral lithium ionization;

$\kappa_{1\nu}$ is the continuous absorption coefficient from the ground state of neutral lithium; n_e is the concentration of thermal electrons; $C_{Li}(T_e)$ is the aggregate recombination coefficient of lithium ion with an electron; $I_\nu(\mu, \tau, T_*)$ is the intensity of the radiation ionizing lithium, which, for example, in case of monoenergetic electrons is given by the relation [5] :

$$I_\nu(\mu, \tau, T_*) = B_\nu(T_*) C_\nu(\mu, \tau, T_*), \tag{2}$$

where $B_\nu(T_*)$ is the Planck function for the effective temperature T_* of the star and

$$C_\nu(\mu, \tau, T_*) = C_x(\mu, \tau, T_*) = \left(1 + \frac{1}{4\pi} \frac{1}{\mu^4} \frac{e^x - 1}{e^{x\mu^2} - 1} \tau\right) e^{-\tau}, \tag{3}$$

where $x = h\nu / kT_*$, $\mu = E / mc^2$, τ is the effective optical thickness of the layer of fast electrons above the photosphere on Thompson scattering processes.

In the case of normal star or of the Sun the stationary state condition gives analogously (1),

$$N_1 \int_{\nu_0}^{\infty} \kappa_{1\nu} \frac{B_\nu(T_*)}{h\nu} d\nu = N^+ N_e C_{Li}(T_e), \tag{4}$$

where N_1, N^+ and N_e are the same quantities as n_1, n^+ and n_e, but related to a normal star.

For lithium's continuous absorption coefficient $\kappa_{1\nu}$ we have [6]:

$$\kappa_{1\nu} = 3{,}7 \cdot 10^{-18} (\nu_0 / \nu)^2 \text{ cm}^2. \tag{5}$$

The recombination coefficient of $C_{Li}(T_e)$ is generally not very sensitive to the electron temperature (at least for hydrogen). By the same token the difference in electron temperatures between the atmosphere of a flare star and that of a conventional star may be ignored. Then, from (1) and (4), we may write for the ratio $z_*/z_\odot$, where $z_* = n^+ / n_1$ is the degree of lithium ionization in the atmosphere of a flare star, and $z_\odot = N^+ / N_1$ is the same for the Sun

$$\frac{z_*}{z_\odot} = \frac{N_e}{n_e} \frac{T_*}{T_\odot} e^{h\nu_0/kT_\odot} \int_{x_0}^{\infty} \frac{C_x(\mu, \tau, T_*)}{e^x - 1} dx. \tag{6}$$

As is shown by calculations, sufficiently strong hydrogen emission lines in the flar star spectra may already appear for $\mu^2 \sim 10$. Having also assumed $T_* \approx 3000°$ K and $\tau \sim 1$, we shall find from (6)

$$z_* / z_\odot \approx 10^2 N_e / n_e. \tag{7}$$

In the atmosphere of a flare star the greatest uncertainty resides in the electron concentration n_e. Obviously during star flare n_e rises strongly first of all on account of strong hydrogen ionization. However, by its order of magnitude n_e cannot be greater than the total concentration of hydrogen atoms in the atmosphere of the star (the fast electrons will not participate in the recombination processes). Thus, assuming $N_1 \sim 10^{12}$ cm^{-3} (for the Sun) and $n_e \leqslant N_e$, we shall have

$$z_* / z_\odot \gtrsim 100.$$

In this way the degree of lithium ionization in the atmospheres of T Tau stars must be at least by 2 orders higher than the degree of lithium ionization in the atmosphere of the Sun. But, as was shown above, there is 100 times more lithium in the T Tau stars than in the Sun. Hence it follows that the total number of lithium atoms in the atmospheres ot T Tau stars must be at least $1 \cdot 10^4$ times greater than in the Sun.

The last conclusion may characterize to the full extent the whole singularity and at the same time the exceptional power of processes taking place in the atmospheres of T Tau stars and objects analogous to them. A very high Li content in the atmospheres of these stars may, moreover, serve as a complementary argument in favor of the hypothesis on the possibility of He^6 β-decay in the atmospheres of stars and, in the final account, in favor of the concept of fast electrons.

The necessity and the importance of the above analysis follows, in particular from the fact that all the lines of singly ionized lithium are in the far ultraviolet (soft X-ray region) and this is why, in principle, the ionized lithium can not be detected in star spectra.

The above conclusion of high lithium content in stars of the T Tau type may acquire a particular interest in connection with the fact of anomalously high content of light elements, including lithium, in the composition of cosmic rays. For example, the ratio Li/H is of the order 10^{-11} for the Sun, while for cosmic rays it is of the order 10^{-3}. It is generally considered that lithium is a fragment of heavy nuclei splitting taking place in the interstellar medium during their encounter with protons. However, this assumption requires the presence of a quite considerable amount of heavy nuclei in the sources of cosmic rays, exceeding by 1 to 2 orders their natural abundance (for details see [7]).

Nor is excluded the possibility that the anomalous lithium content in cosmic rays has a direct relationship with the anomalous lithium content in the stars of T Tau type and that these stars, alongside with the objects similar to them, are suppliers of lithium for the interstellar medium. If indeed the flare of a star is induced by β-decay of He^6 nuclei, part of Li^6 nuclei, being fragments of this decay, will leave the star, finding itself in the interstellar space with initial energy of the order 10^6 ev. At the same time their number is very large; the total number of Li^6 nuclei, which may be liberated during a single very powerful flare, is equal to the total number of fast electrons and of the order $10^{45} - 10^{46}$ [5]. Part of them (which one, it is difficult to say), accelerating in magnetic fields of the interstellar space, passes into the composition of cosmic rays.

Apparently, the above can be verified by analyzing the isotopic lithium composition in cosmic rays; for the validity of the hypothesis brought forth the number of Li^6 nuclei must greater than the number of Li^7 nuclei, i. e. a relation should take place, that would be inverse to that observed in the Sun and in stars.

Unfortunately, we have not succeeded in finding any kind of data on the isotopic composition of cosmic rays. Thus it is of interest to conduct special experiments by way of installing instrumentation on Earth's artificial satellites and altitude rockets. Particular interest may be offered by the results of such experiments set up in relation to the Sun. The nature of chromospheric flares in the Sun and the nature of flares in stars is the same, as this seems to us, the difference being only in the scale of the events. This is why the fact of lithium presence in the composition of the solar component of cosmic rays during solar flares may in itself contribute a great deal in the way of clues.

***** THE END *****

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Manuscript received on
5 December 1966

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CONTRACT No.NAS-5-12487
VOLT TECHNICAL CORPORATION
1145 - 19th St. NW
WASHINGTON D.C. 20036.
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Translated by ANDRE L. BRICHANT

on 17 October 1967