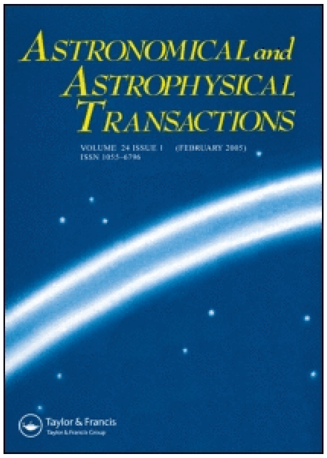

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Galactic status of the Sun

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The so-called theory of stellar orbit diffusion along the Galactic radius is analysed. It is shown that, at present, there is no strong chemical evidence that the Sun was born about 2 kpc closer to the Galactic centre than its current location in the Galaxy. A new mechanism for large and rapid radial wandering of a star due to resonant interaction with the Galactic spiral density waves at the corotation is considered. The influence of spiral arms and the corotation resonance on the evolution of chemical pattern of the Galactic disc is discussed.

Keywords: Sun; Milky Way; Kinematics; Chemical evolution

1. Introduction

The Sun is a standard for both stellar and Galactic studies. That is why investigations of the Sun attract particular attention. These topics were always the focus of interest for P.P. Parenago.

In this paper, we discuss the solar chemical anomaly and the modifications in our ideas on its Galactic status.

For many years the solar chemical anomaly was considered as an unsolvable paradox. Indeed, the solar metallicity (see, for example, [1]) is too high relative not only to the nearby stars with similar ages but also to the youngest objects such as B stars and H II regions (see, for example, [2]). From figure 1 of [2], it is seen that the solar abundance is about 0.2 dex higher than the mean value for the nearby objects. The last result is in conflict with our concepts about the chemical evolution of the Galaxy. Grevese and Noels [1] and Portinari and Chiosi [2] referred to some ideas that could enable us to understand the problem, such as supernovae pollution of the matter from which the Sun was formed, recent metal-poor infall of gas on to the Galactic disc, etc. However, they postponed this problem for future research.

Unlike Portinari and Chiosi [2], Gonzalez [3] exploited this anomaly to support the idea that extrasolar planets have to be searched for near the metal-rich stars.

There was a great response to the paper by Wielen *et al.* (WFD) [4] in which they drew the conclusion that the Sun was born about 2 kpc closer to the Galactic centre than its present location and diffused along the Galactic radius to the current position during its life (this effect

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was called the 'diffusion of stellar orbits'). In spite of the fact that their method cannot be recognized as acceptable, the paper exerted a stimulating influence on studies of both solar and Galactic problems. That is why we would like to analyse it in more detail.

2. Could the Sun have been born far from its present position?

To derive the above result, WFD made several suppositions. First, from the paper by Friel and Janes [5], they adopted a metallicity gradient of $-0.09\,\mathrm{dex\,kpc^{-1}}$. Then, from the data obtained by Eddvardsson *et al.* [6], they found the metallicity–age relation for stars in the solar vicinity:

$$\left[\frac{\mathrm{Fe}}{\mathrm{H}}\right] = 0.05 - 0.048\tau, \tag{1}$$

where τ is the age of a star in gigayears. Then they 'mechanically' combined the above results and wrote the following formula for the time evolution of the radial metallicity distribution in the Galactic disc:

$$\left[\frac{\mathrm{Fe}}{\mathrm{H}}\right] = 0.05 - 0.09(R - R_0) - 0.048\tau, \tag{2}$$

where R is the Galactocentric radius and $R_0 = 8.5\,\mathrm{kpc}$ is the present solar distance from the Galactic centre. Note that WFD believed that the radial metallicity distribution (in a large range of R) is described by a simple linear function and that this abundance pattern does not change with time.

WFD further inverted the last formula and derived the following:

$$R_i - R_0 = -11.11\left(\left[\frac{\mathrm{Fe}}{\mathrm{H}}\right] + 0.048\tau\right) + 0.56. \tag{3}$$

The interpretation of this equation is as follows: for a star with known metallicity and age, the galactocentric radius R_i at which it was born can be found. So, substituting $[\mathrm{Fe/H}]_{\mathrm{e}} = 0\,\mathrm{dex}$ and $\tau_{\mathrm{e}} = 4.5$ Gyears into equation (3), WFD concluded that the Sun was born at $R_i \approx 6.6\,\mathrm{kpc}$.

The above approach has several flaws. First, it is well known from statistics [7] that inverse regression cannot be directly derived from equation (2) by means of simple inversion if the correlation coefficient is not exactly equal to 1. For this, a new regression (R versus [Fe/H]) must be constructed. We used the same data from [5] that were exploited by WFD and derived the new slope in the last regression. It happens to be equal to $-5.20\,\mathrm{kpc\,dex^{-1}}$ in contrast with the work of WFD (see equation (3)). Normalizing the inverse relation so that, at $\tau = 0$ and $[\mathrm{Fe/H}] = 0$, the initial galactocentric distance R_i is equal to R_0, we obtain

$$R_i = -5.20\left(\left[\frac{\mathrm{Fe}}{\mathrm{H}}\right] + 0.048\tau\right) + 8.5. \tag{4}$$

From the last equation we find that the Sun was born at $R_i \approx 7.4\,\mathrm{kpc}$ instead of 6.6 kpc as in the work of WFD. An estimation for the error of solar displacement from its present position made by means of numerical experiments shows that the displacement is of the order of the error. Hence, there is no strong statistical evidence based on the solar abundance anomaly (if it really exists; see below) that the Sun was born sufficiently far from its present position.

Another criticism of the WFD method was made by Twarog *et al.* [8]. They noticed that all open clusters considered in [5] are situated at $R \geqslant 8\,\mathrm{kpc}$. However, in order to 'move' the Sun far inside its present position, WFD had to extrapolate the linear radial metallicity distribution into the corresponding region of R with the same gradient. On the basis of their new data, Twarog *et al.* showed that the abundance distribution in the Galactic disc is not described by a simple linear function with a unique gradient. So, WFD's extrapolation is not justified.

Starting with the paper of Andrievsky *et al.* [9] (see also subsequent papers by these workers), it is clear the radial metallicity distribution in the Galactic disc is bimodal, i.e. there is a sufficiently large (negative) gradient inside about 7 kpc and a plateau from 7 to about 10–11 kpc (of course, we exclude from consideration the central part and the edges of the Galaxy).

A similar bimodal abundance structure over the Galactic disc can be traced on planetary nebulae [10].

Nevertheless, the representation of the metallicity distribution in the Galactic disc by a linear function has been very popular until now (see the paper by Daflon and Cunha [11] who approximated the distribution by a linear function with a unique gradient in spite of the fact that their own observations show a clear depression of the abundance near the solar position). What makes researchers treat the metallicity distribution in such a way? Perhaps, the intuitive reason is as follows: the heavy-element output is proportional to some power of the star formation rate; on the other hand, the star formation rate is proportional to some power of the gas density. Since, in the first approximation, the gas density distribution in the Galactic disc can be described by an exponential function, the resulting radial abundance distribution (on a logarithmic scale) is expected to be linear (in the range of R under consideration).

In reality, the chemical evolution of the Galactic disc is a very complicated process. Besides nucleosynthesis, there are several competitive processes that play important roles in the formation of the final chemical pattern, such as recycling of matter from the gas to the stellar phase and backwards, the infall of external matter on to the Galactic disc, turbulent mixing, spiral arm influence, etc.

In our opinion, it is impossible to reconstruct the chemical evolution of the Galactic disc without taking into account Galactic spiral arms. We see at least two effects of spiral arms on the chemical abundance pattern, both of which are connected with the *corotation resonance*.

The first effect is attributed to the elements, e.g. oxygen, that are mainly produced by type II supernovae. The point is that type II supernovae are strongly concentrated on spiral arms. Having very young ages, they are not displaced far from their birthplaces. Hence, the enrichment of a given interstellar gas volume by heavy elements only takes place when the volume occurs close to the element sources, i.e. inside spiral arms. Since the Galactic matter rotates around the centre (in the Galactic plane) differentially with the angular rotation velocity Ω which is a function of R and the spiral wave pattern rotates as a solid (the angular rotation velocity $\Omega_{\mathrm{P}} = \text{constant}$) the rate of enrichment depends not only on the star formation rate but also on the frequency at which the volume of interstellar medium enters the spiral arms, i.e. the difference $|\Omega(R) - \Omega_{\mathrm{P}}|$. Thus, near the corotation radius R_{C} (where $\Omega(R_{\mathrm{C}}) = \Omega_{\mathrm{P}}$), the effectiveness of nucleosynthesis will be depressed. This depression is smoothed out by the turbulent diffusion in the interstellar medium [10, 12, 13].

The second feature of the spiral arm influence on the abundance pattern is due to dynamic effects of the corotation. Indeed, the resonant interaction of stars with the gravitational field of Galactic density waves at the corotation causes them to wander greatly over a large part of the Galactic radius, about 2–3 kpc for a time period of the order of 1 Gyear or even less. This is a more rapid mechanism for radial stellar displacement than the stellar orbit diffusion considered by WFD. As was shown in [13], such stellar wandering will transform the initial linear radial abundance distribution into a bimodal-like distribution for a time of about 3–5 Gyears. This effect can be observed over planetary nebulae or open clusters [14, 15].

Finally, the real radial Galactic abundance distribution is not described by an oversimplified representation of equation (2) with a unique (over a large part of the disc) gradient which, in turn, does not vary with time as was assumed by WFD. Unlike the work of WFD and of the above-cited researchers, the abundance pattern is represented by a bimodal function with different gradients in various regions of the Galactic disc, the shape of the pattern varying in time.

Perhaps, we should close the discussion by considering the paper by Asplund *et al.* [16] (and other papers by these workers). They constructed a new model for the Sun which takes into account three-dimensional hydrodynamic time-dependent simulations of turbulence and derives a much lower abundance for the Sun, so that

$$\left[\frac{Z}{\mathrm{H}}\right]_{\mathrm{new}} - \left[\frac{Z}{\mathrm{H}}\right]_{\mathrm{old}} \approx -0.16\,\mathrm{dex}, \tag{5}$$

where the subscripts old and new correspond to [1] and [16] respectively and we assumed that the mean atomic weights are similar for both determinations. Since the error in the abundance for the Sun is of the order of ± 0.5 dex, the above bias is statistically significant.

Thus, the strong solar abundance anomaly and the chemical basis for the WFD theory of stellar orbit diffusion have disappeared.

3. The end of the history?

In spite of the fact that the theory of stellar orbit diffusion along the Galactic radius has lost its chemical basis, the paper by WDF stimulated more refined research of the Galaxy and the Sun.

Note here the paper by Sellwood and Binney [17] who showed that the resonant interactions of stars with transient spiral density waves break the age–metallicity relation in the Galactic disc.

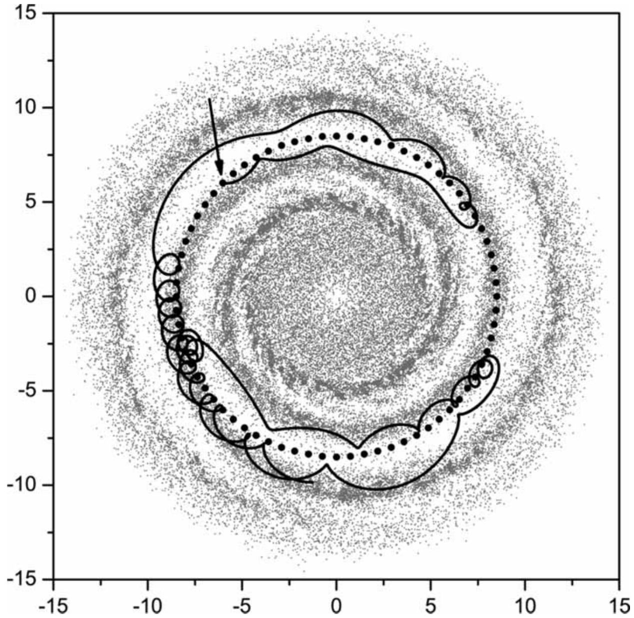

Figure 1. An example of a stellar trajectory perturbed by the gravitational field due to Galactic spiral density waves. The location of the corotation circle is shown by solid bold circles. The place where the star starts is indicated by the arrow.

On the other hand, if the spiral pattern is a quasistationary structure (say, for the time period of several billion years) the trajectory of a star starting near the corotation radius is very tangled. It covers a large part of the Galactic disc. As seen from figure 1, the star visits both the Centaurus and the Perseus arms. This result changes our idea on stellar trajectories in the Galaxy according to which stars move along quasicircular, slightly oscillating (owing to epicyclic oscillations) orbits. This can be very important for the fate of our Sun since, as was first proposed by Marochnik *et al.* [18], the corotation resonance is situated close to the Sun position (see also [19]). Moreover, such irregular trajectories do not allow us to derive the abundance gradient over stars in the solar (corotation) vicinity by means of the method of stellar motion in a regular Galactic field such as that used in [6].

Finally, the new method in [16] was mainly applied to constructing the solar model. However, a question arises: can intensive applications of this method to other stars reduce their abundance? In this case, the Sun will again become an anomaly star and the problem of solar chemical anomaly will return.

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References

[1] N. Grevesse and A. Noels, *Cosmic Abundances*, Astronomical Society of the Pacific Conference Series, volume 99, edited by S.S. Holt and G. Sonneborn (Astronomical Society of the Pacific, San Francisco, California, 1996), p. 117.

[2] L. Portinari and C. Chiosi, Astron. Astrophys. **350** 827 (1999).

[3] G. Gonzalez, Mon. Not. R. Astron. Soc. **308** 447 (1999).

[4] R. Wielen, B. Fuchs and C. Dettbarn, Astron. Astrophys. **314** 438 (1996).

[5] E.D. Friel and K.A. Janes, Astron. Astrophys. **267** 75 (1993).

[6] B. Eddvardsson, J. Andersen, B. Gustafsson *et al.*, Astron. Astrophys. **275** 101 (1993).

[7] K. Überla, *Faktorenanalyse* (Springer, Berlin, 1977).

[8] B.A. Twarog, K.M. Ashman and B.J. Anthony-Twarog, Astron. J. **114** 2556 (1997).

[9] S.M. Andrievsky, V.V. Kovtyukh, R.E. Luck *et al.*, Astron. Astrophys. **381** 32 (2002).

[10] I.A. Acharova, J.R.D. Lèpine and Yu.N. Mishurov, Mon. Not. R. Astron. Soc. **359** 819 (2005).

[11] S. Daflon and K.Cunha, Astrophys. J. **617** 1115 (2004).

[12] Yu.N. Mishurov, J.R.D. Lèpine and I.A. Acharova, Astrophys. J. Lett. **571** L113 (2002).

[13] I.A. Acharova, J.R.D. Lèpine and Yu.N. Mishurov, Astron. Rep. **49** 354 (2005).

[14] J.R.D. Lèpine, Yu.N. Mishurov and I.A. Acharova, Astrophys. J. **589** 210 (2003).

[15] I.A. Acharova, J.R.D. Lèpine and Yu.N. Mishurov, *Milky Way Surveys: the Structure and Evolution of our Galaxy*, Astronomical Society of the Pacific Conference Series, volume 317, edited by D. Clemens, R. Shah and T. Brainerd (Astronomical Society of the Pacific, San Francisco, California, 2004), p. 355.

[16] M. Asplund, N. Grevesse and A.J. Sauval, *Cosmic Abundance as Records of Stellar Evolution and Nucleosynthesis*, Astronomical Society of the Pacific Conference Series, volume 336, edited by T.G. Barnes III and F.N. Bash (Astronomical Society of the Pacific, San Francisco, California, 2004), p. 25.

[17] J.A. Sellwood and J.J. Binney, Mon. Not. R. Astron. Soc. **336** 785 (2002).

[18] L.S. Marochnik, Yu.N. Mishurov and A.A. Suchkov, Astrophys. Space Sci. **19** 285 (1972).

[19] J.R.D. Lèpine, Yu.N. Mishurov and S.Yu. Dedikov, Astrophys. J. **546** 234 (2001).