Galactic corotation as a principal "driver" for the bimodal abundance radial distribution formation in the disk of our Galaxy

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Abstract

A theory of a unified mechanism for the formation of the bimodal radial distribution of iron and oxygen in the Galactic disk is developed. The underlying cause for the formation of the fine structure of the radial abundance pattern is the influence of spiral arms, specifically the effect of the corotation resonance.

I. What is the bimodal radial abundance pattern?

It is an unexpected fine structure with a steep gradient in the inner part of the galactic disk (for r < 7 kpc) and rather flat plateau-like distribution in the outer part (for r > 7 kpc and up to about 11 kpc) with a bending of the distribution at $r \approx$ 7 kpc (Fig. 1).

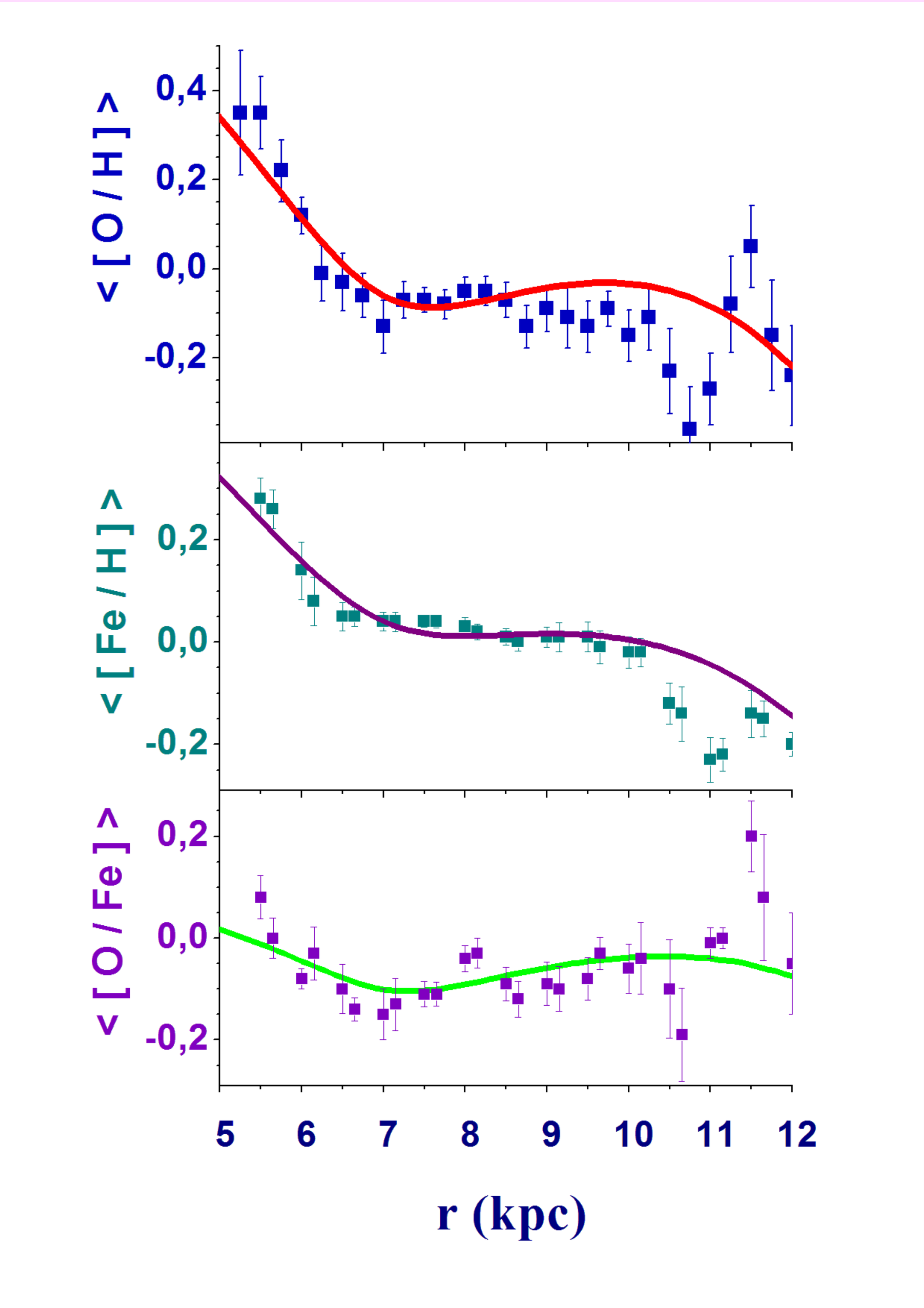

Fig. 1. The bimodal radial distribution of oxygen and iron in the galactic disk derived by means of spectroscopic data over Cepheids (Andrievsky et al., 2002 – 2004). To do the fine structure more clear the original data were averaged over the bins of 0.5 kpc width (squares, Acharova et al., 2010). The bending of the distribution at $r \approx$ 7 kpc is seen.

The similar bimodal radial distribution is demonstrated by regions of ionized hydrogen, as well.

II. What is the problem in explanation of the above bimodal abundance pattern formation?

The problem is as follows: both the sources of oxygen – SN II – and other basic galactic parameters, like the density of ISM, or the rate of gas falling onto the galactic disk, etc., do not have any features in their radial distribution close to r = 7 kpc .

So, the nature of origin of the bimodal radial distribution of heavy elements is determined by some nontrivial effects.

To explain the above problem we develop the idea of influence of spiral arms, specifically the corotation resonance, first proposed by Oort (1974).

Oxygen is mainly synthesized by SN II which are strongly concentrated in spiral arms. We believe that this element is a most pure indicator of spiral arms influence on formation of bimodal radial distribution. The result of our theory for oxygen is shown in the upper panel of Fig. 1 (red line).

III. What is the corotation resonance?

Spiral arms represent spiral density waves which rotate in the galactic plane as a <u>solid body</u> with the angular rotation velocity Ω_P = *const*, whereas the galactic matter of the disk rotates differentially, i.e. Ω is a function of *r*. The distance r_c where both the velocities coincide($\Omega(r_c) = \Omega_P$) is called the ***corotation resonance*** (Fig. 2).

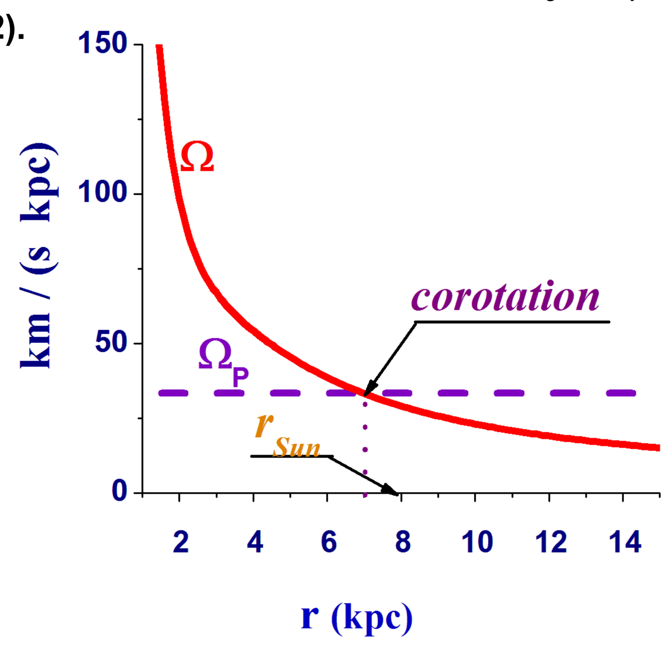

Fig. 2. Angular rotation velocities for the galactic disk *Ω (r) and for the spiral density wave Ω_P*. The corotation is the distance where both the velocities coincide.

IV. How does the corotation resonance enable to explain the formation of the bimodal radial distribution of oxygen?

The enrichment rate E of ISM by a heavy element is described by the expression:

$E = \eta PR$, where P is the mass of the element ejected per SN explosion,

R is the rate of SN events.

Considering oxygen synthesis we have to bear in mind that it is produced by SN II which are strongly concentrated in spiral arms. Hence, an any volume of ISM is only enriched by oxygen when the volume happens to be close to nucleosynthesis sites, i.e. to spiral arms. The more frequently the volume passes an arm, the higher the rate of its enrichment (Oort, 1974). Since the frequency of the volume entering a spiral arm is proportional to $|\Omega - \Omega_P|$ following to Oort (1974) we suppose:

$\eta = \beta |\Omega(r) - \Omega_P|$, β is a constant.

From this representation and Fig. 2 it is seen that in the vicinity of the corotation resonance, r_C, where $\Omega \rightarrow \Omega_P$, a gap in the radial distribution of oxygen to be formed. The combine effect of the corotation resonance and turbulent diffusion in ISM will lead to the bimodal radial distribution of oxygen (Fig. 1).

V. The similar bimodal radial distribution of iron is the most striking discover (Fig. 1).

The problem is as follows: oxygen and iron are produced by different sources.

- oxygen: mainly by SN II;
- iron: ~ 30% by SN II, ~ 70% by SN Ia

For a long time it was widely believed that SN Ia progenitors are old → they do not concentrated in spiral arms → spiral arms and corotation may not influence the radial distribution of iron !

VI. 2 sub-populations of SN Ia progenitors (Mannucci et al., 2006) .

- short-lived with ages < 100 Myrs ("prompt");
- long-lived with ages > 100 Myrs ("tardy");

Short-live – prompt – SN Ia progenitors are concentrated in spiral arms, long-lived – tardy – progenitors are not concentrated in arms. Hence, the rate for ISM enrichment by iron may be represented as follows:

$$E_{Fe} = (\beta P^{II}_{Fe} R^{II} + \gamma P^{Ia}_{Fe} R^{Ia}_{P}) \,|\, \Omega(r) - \Omega_P \,|\, + P^{Ia}_{Fe} \zeta R^{Ia}_{T}$$

γ and ζ are constants, sub indices "P" and "T" refer to prompt and tardy progenitors.

The results explaining the simultaneous formation of the bimodal radial distribution of oxygen and iron and their relation superimposed on the observed abundance patterns are shown in Fig. 1.