

INFLUENCE OF SPIRAL PATTERNS TO DYNAMICAL EVOLUTION OF GALACTIC DISC

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ABSTRACT. This paper reports on the theoretical investigation of evolution of the Galactic disc, taking in account the influence of spiral patterns. The spiral patterns can be considered as some kind of indicators of the dynamical processes in the disc. We investigate influence of spiral patterns on the surface density of gas, stars and metallicity in time at the solar neighbourhood. We consider the models in the approximation of instantaneous recycling of material. Results of models are compared with observational data, that give possibility to predict correct model for evolution of the Galactic disc. The results of the model predictions differ significantly comparing to the case of the standard Galactic evolutionary model.

Key words: Galaxy:dynamics:spiral pattern.

1. Introduction

At present the very important problem is an investigation of the gas, stars distributions and metallicity in the Galactic disc with an account of the spiral arms. These arms can be considered as some kind of indicators of the dynamical processes in the disc. The dynamics of stars affected by perturbations from both spiral structure and the Milky Way bar (*Quillen, 2002*). The main criteria of the model reliability is a comparison with some observational data (*Boulares, 1989; Gilmore et al., 1990* and others). It is known that spiral arm affect significant the star formation processes. The star formation rate is proportional to parameter k , it is adopted 1 and 1.4 at the solar neighbourhood (see, for example, *Kennicutt, 1998*). As a rule, for the angular velocity of the arm rotation is adopted to be $20 \text{ km s}^{-1} \text{ kpc}^{-1}$ (sometimes the value $27 \text{ km s}^{-1} \text{ kpc}^{-1}$ is used, or $21 \text{ km s}^{-1} \text{ kpc}^{-1}$ is used (see *Vorobyov, 2006*)), while corotation radius is 9 kpc . There are also two specific regions of the *Lindblad* resonances in the disc at 2.8 and 12.8 kpc (*Andrievskiy et al. 2004; Amaral & Lepine, 1997*).

2. Spiral patterns

Spiral patterns – are prominent feature of spiral

galaxies, to which our Galaxy is belonged also.

Occurrence of a wave can be connected either with external indignation or with instability of the disc. Besides waves can be generated by a bar, and also emissions of weights of gas from the central area of the Galaxy.

In difference from stars, braking of gas on the internal party of a pattern occurs not gradually, and jump. Gas of a disk runs to more dense gas in the pattern, stops almost and compressed. If speed of the gas concerning the pattern was more, than full speed of a sound in the gas and amplitude of the spiral wave of density is not too small, there is a shock wave.

The amplitude of the shock wave depends from speed from which gas catches up with the spiral pattern. With removal from the center angular speed of rotation of the Galaxy falls, and for spiral patterns it remains constant. Therefore with removal from the center of the Galaxy relative speed of the gas and a pattern decrease, the amplitude of the wave decreases, on some distance it ceases to be shock. When speed of rotation becomes nearer to speed of the pattern, the pattern comes to an end also.

Compression of the gas in the shock wave and its transition in more dense phase promotes formation of stars. In spiral galaxies the formation of stars occurs not in all galactic plane where interstellar gas is concentrated, and mainly there, where the amplitude of a shock wave in it is great enough.

3. Main assumptions and basic equations

In order to determine the evolutionary model parameters of the Galactic disk (or its selected part) let us consider one element of the disc surface (1 pc^2). For this element we can define the surface gas density, surface stars density and the gas metallicity normalized to the yield of primary elements in the approximation of instantaneous recycling of material. Then the system of equations that describe the evolution of this selected area is the following (all the parameters are adopted for the solar neighbourhood):

$\mu_s, M_\odot \text{ pc}^{-2}$ – is the surface density of stars;

Table 1: Various parameters of the models and computed predictions, $t = 15 \text{ Gyr}$, $C = 0.15$

τ	k_1	ε	μ_g	μ_s	$\frac{z}{y}$	k_2	μ_g	μ_s	$\frac{z}{y}$
5.5	1	0.1	14.1	68.2	1.42	1.4	4.4	77.9	1.4
3.5	1	0.2	6.9	75.4	2.02	1.4	2.1	80.2	1.7
6.5	1	0.2	11.6	70.7	1.43	1.4	4.2	78.03	1.27

$\mu_g, M_\odot \text{ pc}^{-2}$ – is the surface density of gas;
 $\frac{z}{y}$ – is the gas metallicity normalized to the yield of the primary elements;
 $\Psi, M_\odot \text{ pc}^{-2} \text{ Gyr}^{-1}$ – is the star formation rate;
 $f(t), M_\odot \text{ pc}^{-2} \text{ Gyr}^{-1}$ – is the infall rate;
 α – is an inverse characteristic distance for the infall rate in the disc,
 $\frac{1}{\alpha} = 4300 \text{ pc}$;
 $\tau, \text{ Gyr}$ – is the characteristic time of infall;
 M_p – is the present-day mass of the galactic disc,
 $6 \cdot 10^{10} M_\odot$; M_\odot – is the mass of Sun;
 $(1 - R)C$ – is the part of the matter that is created after the *SNe* explosions, C – const, $(1 - R)C = 0.15$;
 t_p – is the age of the Galaxy, $t_p = 15 \text{ Gyr}$;
 R_G – is the galactocentric radius;
 $R_\odot = 7.9 \text{ kpc}$ – is the radius of Sun, which is adopted.

Let us write the following differential equations for the gas, stars surface densities and metallicity (the system of differential equations was decided by numerical method of *Runge – Kutta of fourth order*).

$$\begin{aligned} \frac{d\mu_s}{dt} &= (1 - R) \Psi \\ \frac{d\mu_g}{dt} &= -(1 - R) \Psi + f(t) \\ \mu_g \frac{d\frac{z}{y}}{dt} &= (1 - R) \Psi - f(t) \frac{z}{y} \end{aligned}$$

As it was showed by *Andrievsky et al.* (2004) some characteristics can be written as follows:

$$\begin{aligned} \Psi &= C \mu_g^k \\ f(t) &= \frac{\alpha^2 M_p \exp(-\alpha R_G - \frac{t}{\tau})}{2\pi\tau \left(1 - \exp\left(-\frac{t_p}{\tau}\right)\right)} \end{aligned} \quad (2)$$

Rather like test was considered in R.Thon, H.Meusinger, 1998.

If we consider the spiral arms, then the function of the star formation rate can be modified:

$$\begin{aligned} \Psi &= C \mu_g^k (1 + \Delta) \\ \Delta &= \varepsilon \theta \frac{|\Omega_D - \Omega_P|}{C_s} R_G \end{aligned}$$

Table 2: Observational data

	Authors	data
μ_g	<i>Gordon, Burton, 1976</i>	6.5
μ_g	<i>Haywood, Robin, 1997</i>	10
μ_g	<i>Dickey, 1993</i>	7.5
μ_g	<i>Kuijken, Gilmore, 1991</i>	12.7
μ_g	<i>Boulares, 1989</i>	14
μ_s	<i>Gilmore, 1990</i>	35 ± 5
μ_s	<i>Andrievsky, 2004</i>	54.8
$\frac{z}{y}$	<i>Andrievskiyet.al., 2002b</i>	1.122

ε – is the factor which define an efficiency of the star formation;

θ – is the cut-off factor, it is required, because the self-sustained Galactic density waves are known to exist only in so-called wave zone between inner *Lindblad* resonance, and outer *Lindblad* resonance. $\theta = 0$ for $R_G < 3 \text{ kpc}$, $\theta = 1$ for $3 < R_G < 13 \text{ kpc}$, $\theta = 0$ for $R_G > 13 \text{ kpc}$;

Ω_D – angular speed of rotation of disc of the Galaxy, $\Omega_D = \Omega_D(R_G)$, hence (see *Andrievskiyet.al.*, 2004):

$$\begin{aligned} \Omega_D &= -0.069 \left(\frac{R}{1000}\right)^3 + 0.447 \left(\frac{R}{1000}\right)^2 + \\ &5.601 \left(\frac{R}{1000}\right) + 181.844 \text{ km s}^{-1} \end{aligned}$$

Ω_P – angular speed of the rotation of the spiral pattern, which determines the range of the spiral modes and fixes the location of resonances. Determinations of Ω_P from observations using different methods have given values of Ω_P around $20 - 30 \text{ km s}^{-1} \text{ kpc}^{-1}$. We adopt $\Omega_P = 20 \text{ km s}^{-1} \text{ kpc}^{-1}$ (recall that the spiral pattern rotates as a solid body, i.e. $\Omega_P = \text{const}$, whereas the Galactic disk rotates differentially).

C_s – is the speed of the sound in the interstellar environment, $C_s = 20 \text{ km s}^{-1}$.

Below we give the set of parameters of our models and computed results of models taking into account the spiral arms (Table 1), and more over then we give the comparative table with observational data (Table 2) (*Dickey, 1993*; *Kuijken&Gilmore, 1991*; *Boulares, 1989*; *Gordon&Burton, 1976* and so forth).

3. Conclusions

It is showed that:

1. the given research comprises construction of the theoretical models describing dynamic evolution of a disk of the Galaxy with different variations of parameters, which are included into the system of differential equations;

2. models consider influence of spiral patterns on surface density of stars, gas and the gas metallicity normalized to the yield of primary elements;

3. comparison of results of numerical modelling with results of observational data shows, that the certain models give good agreement with observational data.

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