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Fakulta matematiky, fyziky a informatiky

Roman Nagy

Autoreferát dizertačnej práce

Gravity of the Galaxy and the Motion of the Sun

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Predkladateľ: **RNDr. Roman Nagy**
Katedra astronómie, fyziky Zeme a meteorológie
FMFI UK, Mlynská dolina
842 48 Bratislava

Školiteľ: **doc. RNDr. Jozef Klačka, PhD**
Katedra astronómie, fyziky Zeme a meteorológie
FMFI UK, Mlynská dolina
842 48 Bratislava

Oponenti: ....
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Obhajoba sa bude konať v .... na FMFI UK

Predseda odborovej komisie:
doc. RNDr. Jozef Klačka, PhD.
Katedra astronómie, fyziky Zeme a meteorológie
FMFI UK, Mlynská dolina
842 48 Bratislava

Contents

Introduction

We are interested in a study of distribution of matter in the Milky Way galaxy as well as an effect of the Galaxy on the Sun. We have been especially inspired by Famaey's and Minchev's papers (e.g. Minchev and Famaey 2010, Famaey and Minchev 2010, Minchev et al. 2010). The authors studied a migration of the Sun in the Milky Way galaxy and they also described the distribution of matter in the Galaxy. They presented a model of potential of the Galactic bar, which neglects the symmetric terms (Galactic bulge terms).

Hence we derive the gravitational potential of the Galactic bar, which describes the central region of the Galaxy in a more general way in comparison with the model presented by the authors mentioned above (i.e. we derive a multipolar model of the Galactic bar, including symmetric and asymmetric terms, too). Our approach also differs in expressions of the gravitational potential of the Galactic disc, halo and spiral structure. Subsequently we simulate the Galactic motion of the Sun. We especially focus on the effect of the Galactic bar and the Galactic spiral structure on the radial migration of the Sun (i.e. changes of the Galactocentric distances of the Sun during revolution around the center of the Galaxy).

We simulate the Galactic motion of the Sun in two dimensions (2-D). However, we know that the Sun is placed about 30 *pc* above the Galactic equatorial plane. Thus three dimensional (3-D) models of the Galactic structures are inevitable for the study of the 3-D motion of the Sun. Hence we also derive the 3-D gravitational potential of the Galactic disc from the mass distribution presented by D'Onghia et al. (2013), considering latest observations. We can avoid any approximation using this method. Thus the 3-D model of the Galactic disc makes possible to simulate the motion of the Sun in 3-D. And consequently, the 3-D motion of the Sun will allow to calculate an effect of the Galactic tides on the Solar System.

The results of the radial migration of the Sun in the Galaxy may shed some light on the history and future of the Sun and the Solar System. That is the reason why many authors have been dealing with the Galactic motion of stars, especially of the Sun (e.g. Minchev and Famaey 2010, Famaey and Minchev 2010, Minchev et al. 2010, Bird et al. 2012, Martínez-Barbosa et al. 2015, including us). The knowledge of the motion of the Sun is crucial for better understanding of the origin of the Sun. The last but not least, the study of the Galactic components may help us to reveal true nature of the physical processes shaping our own galaxy, which are still not well understood.

Chapter 1

Results

The dissertation is divided in 8 chapters. The first five chapters are basically focused on a general discussion on galaxies, the Milky Way galaxy and various models of the Galactic components. Chapter 1 presents well-known properties of galaxies and the Milky Way galaxy, too. The next 3 chapters provide a overview of models of the Galactic structures published in scientific journals. Chapter 2 shows models of the Galactic disc. Chapter 3 deals with the Galactic bar and bulge and finally, chapter 4 presents models of the Galactic halo. Chapter 5 shows a comparison of rotation curves of the Galaxy for various models of the Galactic halo. Chapter 6 presents main objectives of the PhD dissertation.

Chapter 7 presents the paper Klačka, Nagy and Jurči (2012) published in Mon. Not. R. Astron. Soc. We have been especially inspired by Famaey's and Minchev's papers (e.g. Minchev and Famaey 2010, Famaey and Minchev 2010, Minchev et al. 2010). The authors study a migration of the Sun in the Milky Way galaxy and they also describe the distribution of matter in the Galaxy. They present model of a potential of the Galactic bar, though the model neglects the symmetric terms (Galactic bulge terms). We found a model of the central part of the Milky Way galaxy, the Galactic bar (i.e. we derived a multipolar model of the Galactic bar, including symmetric and asymmetric terms, too). We also concentrated our attention on a precise description of the other Galactic structures. We found, that the significant radial migration of the Sun did not occur, if the Sun was under the action of the Galactic halo, disc and Galactic bar. In this case, the Galactic bar model was based on the *COBE* observations (Freudenreich 1998, model S) and the Galactocentric distance varied just ± 1 percent around the current Galactocentric distance of the Sun R_0.

On the other hand, a mutual effect of the Galactic bar, disc, halo, together with the Galactic spiral structure, yielded the significant radial migration of the Sun. If we considered the initial values of $v_0 = 220$ $km\ s^{-1}$ and $R_0 = 8.0$ kpc, IAU recommendation, the four-armed spiral structure and the Galactic bar model based on the *COBE* observations, the Galactocentric distances lied within interval $R \in \langle 7.86, 8.11 \rangle$ kpc and it was not influenced by the value of the spiral structure strength. If we replaced the two-armed spiral structure with the two-armed spiral structure, the interval of the radial migration of the Sun was $R \in \langle 7.55, 8.90 \rangle$ kpc and the results were strongly influenced by the value of the spiral structure strength; lower value generates narrower interval of the Galactocentric distances. A mutual effect of the higher value of $\epsilon_s = 0.060$ and the corotation resonance between the spiral structure and the Sun might generated more significant radial migration of the Sun $R \in \langle 4.18, 15.15 \rangle$ kpc. However, the resonance showed up at the time $T > 3 \times 10^9$ years and the migration yielded $R \in \langle 7.17, 9.21 \rangle$ kpc during $T < 3 \times 10^9$ years.

Chapter 8 shows results of the improved model of the Galaxy. The chapter is focused only on the two-armed spiral structure. The models of the Galactic bar and spiral arms corresponded to Klačka et al. (2012), on the other hand, an alternative model of the spiral structure was considered, too. Evaluated values of the spiral structure strength were in accordance with other authors. We also altered models of the Galactic disc and halo. We took the model of the Galactic disc in form presented by Dauphole and Colin (1995). If we considered the value of $v_0 = 239$ $km\ s^{-1}$ and the value of $R_0 = 8.3$ kpc, the radial migration of the Sun yielded $R \in \langle 8.0, 8.9 \rangle$ kpc. We also found a significant dependence on the value of the spiral structure strength. The lower value generated narrower interval of the Galactocentric distances. We could see, that using the model of the Galactic disc in form presented by Dauphole and Colin (1995) increased the radial migration of the Sun, $R \in \langle 8.0, 8.9 \rangle$ kpc, in comparison with the case presented in chapter 7 (however, the same initial conditions had to be taken into account).

We improved our understanding of the Milky Way galaxy and galaxies in general, although we can still make models more realistic. A major part of models in literature considers the motion of the Sun in the equatorial plane of the Galaxy, including our own. However, the Sun is not situated in the Galactic equatorial plane, its position is about 30 pc above the Galactic equator. Thus it is crucial to create a 3-dimensional (3-D) model of the Galaxy, in order to simulate the motion of the Sun properly. Therefor, we derived the 3-D gravitational potential of the Galactic disc without using any approximation. We used the mass distribution considering latest observations defined by D'Onghia et al. (2013) and the result is presented in chapter

9. We derived the gravitational potential of the Galactic disc by using Fourier and Hankel transformations. The found potential differs from the approximative formula used by D'Onghia et al. (2013) and it better describes gravitational field of the Galactic disc. As is known, close approaches of the nearby stars and the Galactic tides dramatically effect the Öpik-Oort cloud as well as the Solar System itself. Thus the 3-D model will be used in a study of the 3-D motion of the Sun and, consequently, it will allow us to calculate an effect of the Galactic tides on the Solar System and it will help us to better understand a past and future of the Galaxy and the Solar System.

Chapter 2

Future work

However, still plenty of unsolved mysteries left in the Milky Way galaxy. The Galactic spiral structure and its nature is still not satisfyingly understood. There are two competing theories explaining the origin of the spiral structure. The theory, postulated by Lin and Shu (1964), claims that a density wave propagating through the Galactic disc results into long-lived spiral arms. On the other hand, Julian and Toomre (1966) presented the theory, in which a short-lived spiral structure is created by growing local instability. Recently new papers on Galactic spiral structure have appeared, e.g. D'Onghia et al. (2012), Grand et al. (2012), etc. The papers show another way how the long-lived as well as short-lived spiral structures come to exist. We will focus on better understanding of the spiral structures and we will study their effect on the motion of Sun and other bodies in the Galaxy in the future.

We used the model of the spiral arms describing the two- and four-armed spiral structure. But latest observations suggest, that the Milky Way galaxy has more complex spiral structure - two more dense arms and two less dense secondary arms. Moreover, the recent observations of the Galactic central region also revealed complex doubled structure of the Galactic bar (e.g. Gonzalez et al. 2011). We will also take into account this complexity of the Galactic central region in our future work. Further studies are therefore necessary to determine the effects of the Galaxy on the Solar System.

Abstrakt

RNDr. Roman Nagy. Gravitácia Galaxie.

[dizertačná práca]

Univerzita Komenského v Bratislave.

Fakulta matematiky, fyziky a informatiky.

Katedra astronómie, fyziky Zeme a meteorológie.

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Dizertačná práca skúma gravitáciu našej Galaxie a jej vplyv na pohyb Slnka. V rámci práce sme detailne odvodili multipólový rozvoj gravitačného potenciálu galaktickej priečky. Následne sme simulovali pohyb Slnka okolo stredu Galaxie pod vplyvom všetkých galaktických častí, menovite galaktického hala, disku, galaktickej priečky a špirálových ramien. Zistili sme, že samostatné pôsobenie galaktickej priečky nespôsobuje výraznú radiálnu migráciu Slnka ($\pm$ 1 okolo súčasnej galaktocentrickej vzdialenosti Slnka R_0), pričom model priečky bol založený na pozorovaniach družice *Cosmic Background Explorer* (*COBE*) (Freudenreich 1998, model S) a pôsobenie špirálovej štruktúry bolo zanedbané.

Taktiež sme v rámci našej práce zvážili rôzne modely galaktického hala a disku. V prípade, že sme použil vzťah pre potenciál galaktického hala z prác Dehnena (2000) alebo Mincheva a Famaeyho (2010) v mierne pozmenenej forme a na popis disku sme využili model prezentovaný v práci Daupholea a Colina (1995), tak sa radiálna migrácia Slnka nachádzala v intervale $R \in \langle 8.0, 8.9 \rangle$ kpc, pričom sme použili hodnoty počiatočnej rýchlosti $v_0 = 239$ km s^{-1} a polohy R_0 = 8.3 kpc. Tiež bola zistená závislosť migrácie od parametru charakterizujúceho silu špirálovej štruktúry.

V dizertačnej práci sme zo vzťahu pre rozloženie hmoty v galaktickom disku prezentovaného v práci D'Onghiaovej a kol. (2013) odvodili trojrozmerný gravitačný potenciál disku, pričom sme sa nedopustili žiadnych zanedbaní a zjednodušení. Takto odvodený presný gravitačný potenciál využijeme v našej ďalšej práci na skúmanie pohybu Slnka v troch rozmeroch a následnú aplikáciu na študovanie vplyvu galaktických slapov na našu slnečnú sústavu.

Keywords: gravitácia - Galaxia: kinematika a dynamika - Galaxia: štruktúra

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