Binary pulsars as tool for testing galaxy models

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Overview

1. Introduction
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3. Galactic effect
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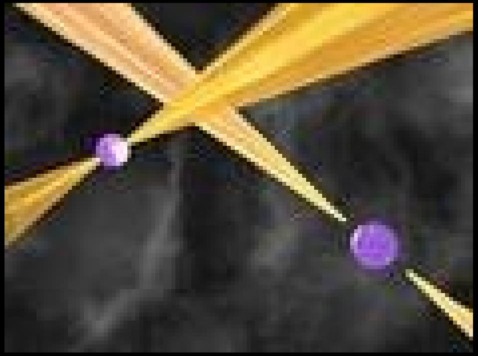
Introduction

Binary pulsar is binary system consisting of pulsar and usual star or two neutron stars.



The first binary pulsar PSR B1913+16 has been discovered in 1974 (Hulse & Taylor).

Statistics of binary pulsars

About 100 objects (not X-ray) in Galactic field.

About 150 objects in globular clusters.

Derivatives of orbital period have been measured for more than 20 objects.

The reasons for orbital period variations

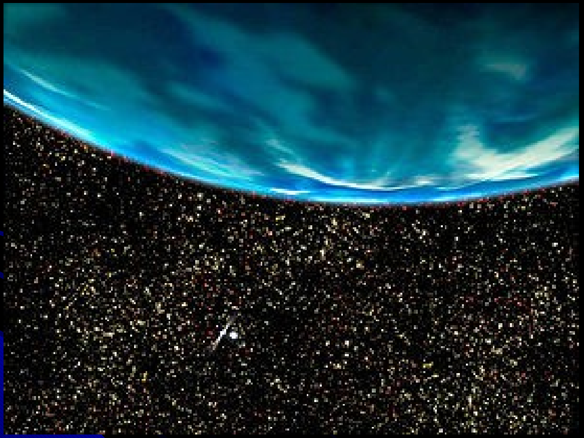
1. Mass loss or mass transfer in close binary.
2. General relativity effect (gravity waves).
3. Relative acceleration in Galaxy field with respect to Sun.
4. Shklovskii effect (proper motion of pulsar).
5. Effects of gravity from nearby massive objects (e.g., stars)

X-ray binary pulsars

We do not consider them due to accretion. It is rather difficult to take into account this effect.

Binary pulsars in globular clusters

The gravitational potential of a cluster has a great effect. It is difficult to take it into account, because we do not know an actual position of pulsar in cluster. So we do not consider such objects.



PSR B1620-26 with a planet in globular cluster M4.

Binary pulsars in Galactic field

Basic effects:

$$\left(\frac{\dot{P}}{P}\right)_{obs} = \left(\frac{\dot{P}}{P}\right)_{GR} + \left(\frac{\dot{P}}{P}\right)_{Gal+\mu}$$

Gravitational wave effect (GW),

Galactic acceleration effect (Gal),

Shklovskii effect (proper motion) (μ).

General relativity effect

$$\left(\frac{\dot{P}}{P}\right)_{GR} = -\frac{192\pi}{5} T_{\odot}^{5/3} \left(\frac{P_b}{2\pi}\right)^{-5/3} \frac{1}{(1-e^2)^{7/2}} \times$$
$$\times \left(1 + \frac{73}{24} e^2 + \frac{37}{96} e^4\right) \frac{M_p M_c}{(M_p + M_c)^{1/3}} ,$$

where $T_{\odot} = GM_{\odot}/c^3 = 4.925490947$ ***μs,***

M_p and M_c are the masses of pulsar and its companion,

e is orbital eccentricity,

P_b is orbital period.

Galaxy acceleration and Shklovskii effects (Damour & Taylor, 1991)

$$\left(\frac{\dot{P}}{P}\right)_{Gal+\mu} = \boldsymbol{n}_{10} \cdot (\boldsymbol{a}_1 - \boldsymbol{a}_0) + \frac{\mu^2 d}{c},$$

where $\boldsymbol{a}_1$ *and* $\boldsymbol{a}_0$ *are vectors of accelerations near pulsar and near the Sun,* $\boldsymbol{n}_{10}$ *is unit vector directed from the Sun to pulsar,* μ *is pulsar proper motion,* d *is the pulsar heliocentric distance.*

The most important parameter is the distance d between the Sun and pulsar

$$\left(\frac{\dot{P}}{P}\right)_{Gal+\mu} = \boldsymbol{n}_{10}\cdot(\boldsymbol{a}_1-\boldsymbol{a}_0)+\frac{\mu^2 d}{c},$$

where $\boldsymbol{a}_1$ *and* $\boldsymbol{a}_0$ *depend essentially on* d*, as well as the Shklovskij effect too. The pulsar heliocentric distance is critical parameter. The measurements of this value are critically depend on Galactic model of ionized gas distribution.*

Dependence on galactic model

$$\left(\frac{\dot{P}}{P}\right)_{Gal} \approx \left(\frac{\dot{P}}{P}\right)_{obs} - \left(\frac{\dot{P}}{P}\right)_{GR} - \left(\frac{\dot{P}}{P}\right)_{\mu}$$

for comparison

$$\boldsymbol{n}_{10}\cdot(\boldsymbol{a}_1 - \boldsymbol{a}_0)$$

the uncertainty

$$\sigma = \sqrt{\sigma_{obs}^2 + \sigma_{GR}^2 + \sigma_{\mu}^2}.$$

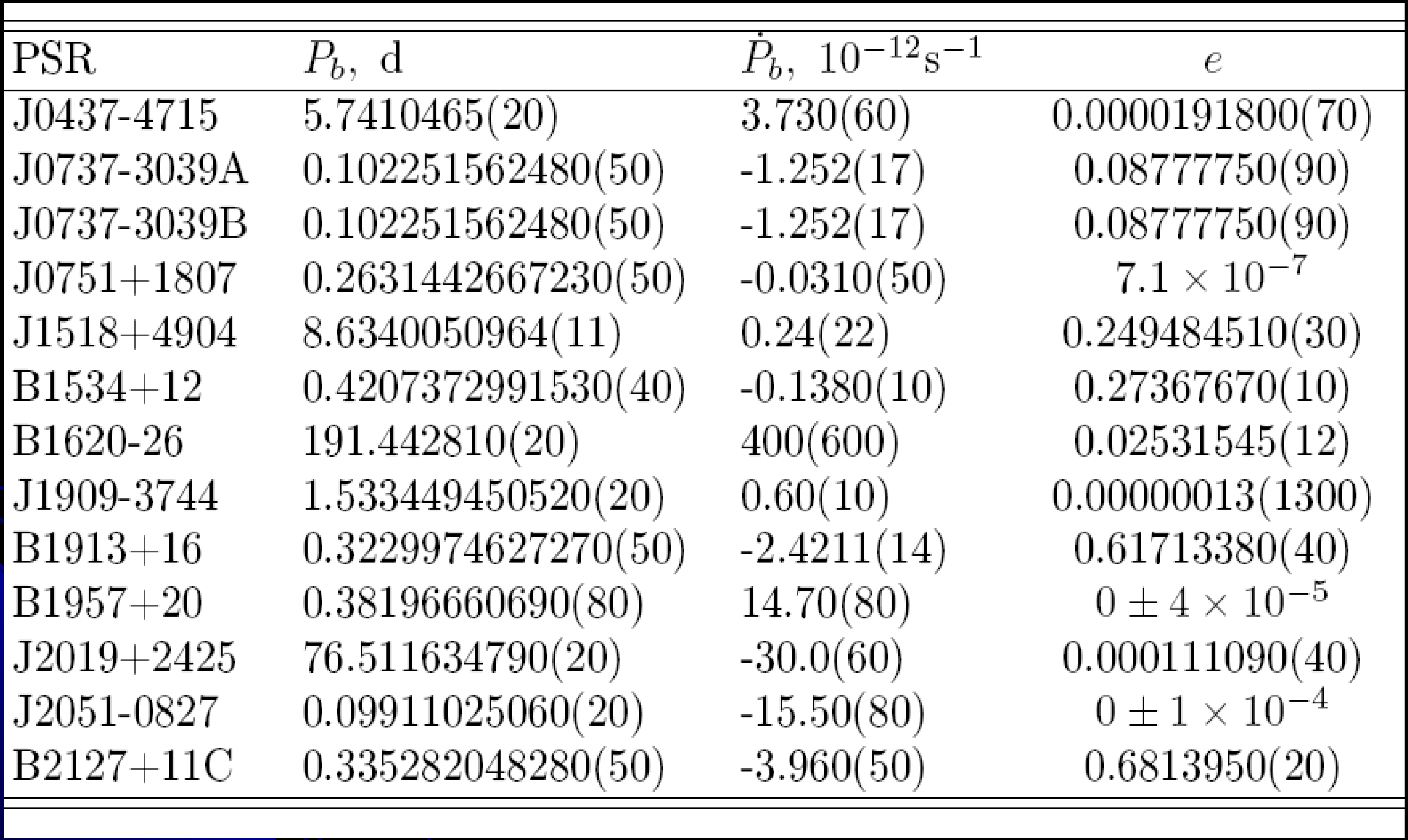
Binary pulsars under consideration

We have used ATNF Pulsar Catalogue

http://www.atnf.csiro.au/research/pulsar/psrcat/expert.html

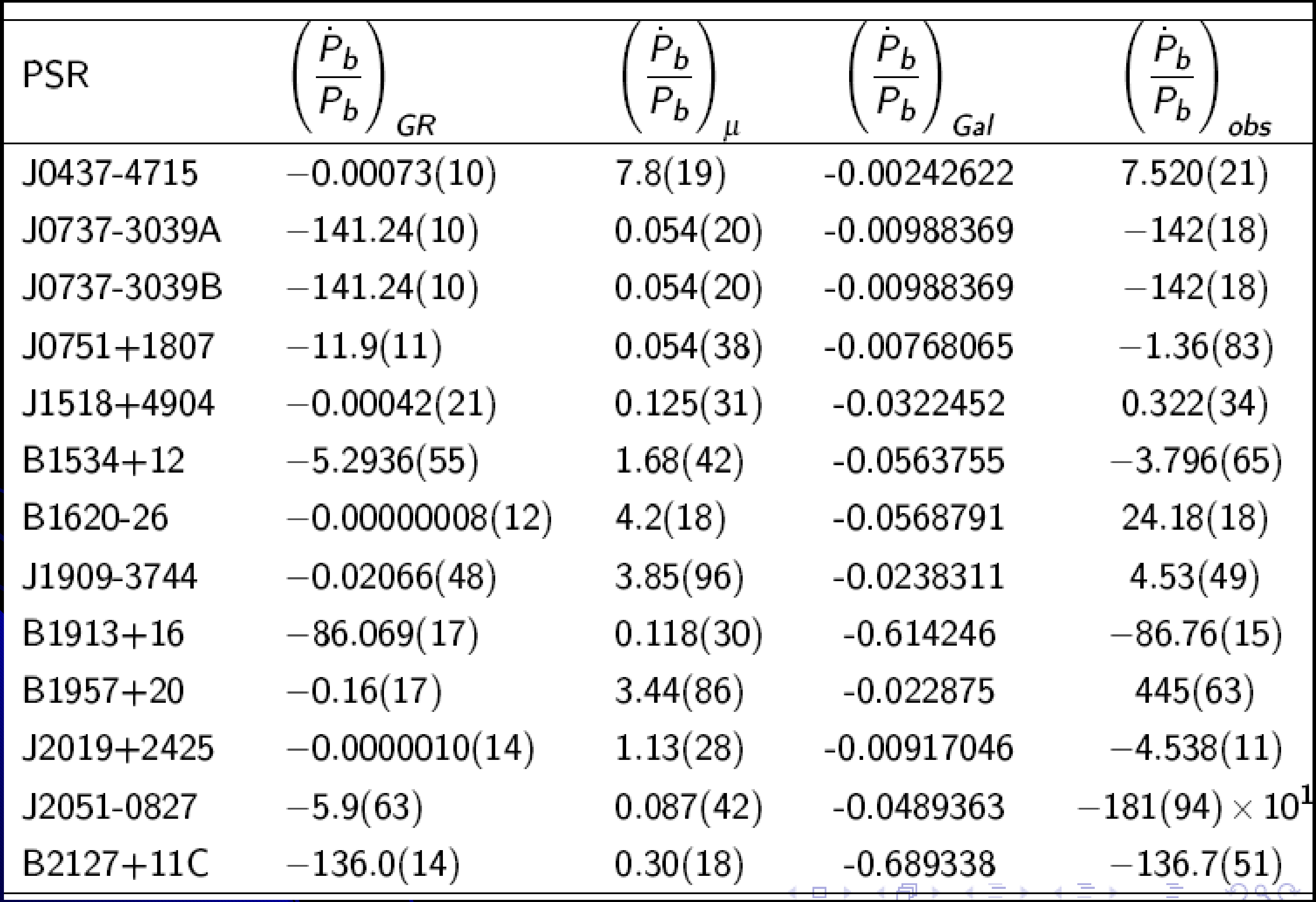
We have chosen binary pulsars in Galactic field with measured derivatives of orbital periods, distances, and proper motions.

A list of binary pulsars under study



PSR	P_b, d	$\dot{P}_b$, $10^{-12}\mathrm{s}^{-1}$	e
J0437-4715	5.7410465(20)	3.730(60)	0.0000191800(70)
J0737-3039A	0.102251562480(50)	-1.252(17)	0.08777750(90)
J0737-3039B	0.102251562480(50)	-1.252(17)	0.08777750(90)
J0751+1807	0.2631442667230(50)	-0.0310(50)	7.1×10^{-7}
J1518+4904	8.6340050964(11)	0.24(22)	0.249484510(30)
B1534+12	0.4207372991530(40)	-0.1380(10)	0.27367670(10)
B1620-26	191.442810(20)	400(600)	0.02531545(12)
J1909-3744	1.533449450520(20)	0.60(10)	0.00000013(1300)
B1913+16	0.3229974627270(50)	-2.4211(14)	0.61713380(40)
B1957+20	0.38196660690(80)	14.70(80)	$0 \pm 4 \times 10^{-5}$
J2019+2425	76.511634790(20)	-30.0(60)	0.000111090(40)
J2051-0827	0.09911025060(20)	-15.50(80)	$0 \pm 1 \times 10^{-4}$
B2127+11C	0.335282048280(50)	-3.960(50)	0.6813950(20)

The results for binary pulsars



PSR	$\left(\frac{\dot{P}_b}{P_b}\right)_{GR}$	$\left(\frac{\dot{P}_b}{P_b}\right)_{\mu}$	$\left(\frac{\dot{P}_b}{P_b}\right)_{Gal}$	$\left(\frac{\dot{P}_b}{P_b}\right)_{obs}$
J0437-4715	−0.00073(10)	7.8(19)	-0.00242622	7.520(21)
J0737-3039A	−141.24(10)	0.054(20)	-0.00988369	−142(18)
J0737-3039B	−141.24(10)	0.054(20)	-0.00988369	−142(18)
J0751+1807	−11.9(11)	0.054(38)	-0.00768065	−1.36(83)
J1518+4904	−0.00042(21)	0.125(31)	-0.0322452	0.322(34)
B1534+12	−5.2936(55)	1.68(42)	-0.0563755	−3.796(65)
B1620-26	−0.00000008(12)	4.2(18)	-0.0568791	24.18(18)
J1909-3744	−0.02066(48)	3.85(96)	-0.0238311	4.53(49)
B1913+16	−86.069(17)	0.118(30)	-0.614246	−86.76(15)
B1957+20	−0.16(17)	3.44(86)	-0.022875	445(63)
J2019+2425	−0.0000010(14)	1.13(28)	-0.00917046	−4.538(11)
J2051-0827	−5.9(63)	0.087(42)	-0.0489363	$-181(94) \times 10^{1}$
B2127+11C	−136.0(14)	0.30(18)	-0.689338	−136.7(51)

Three most reliable objects

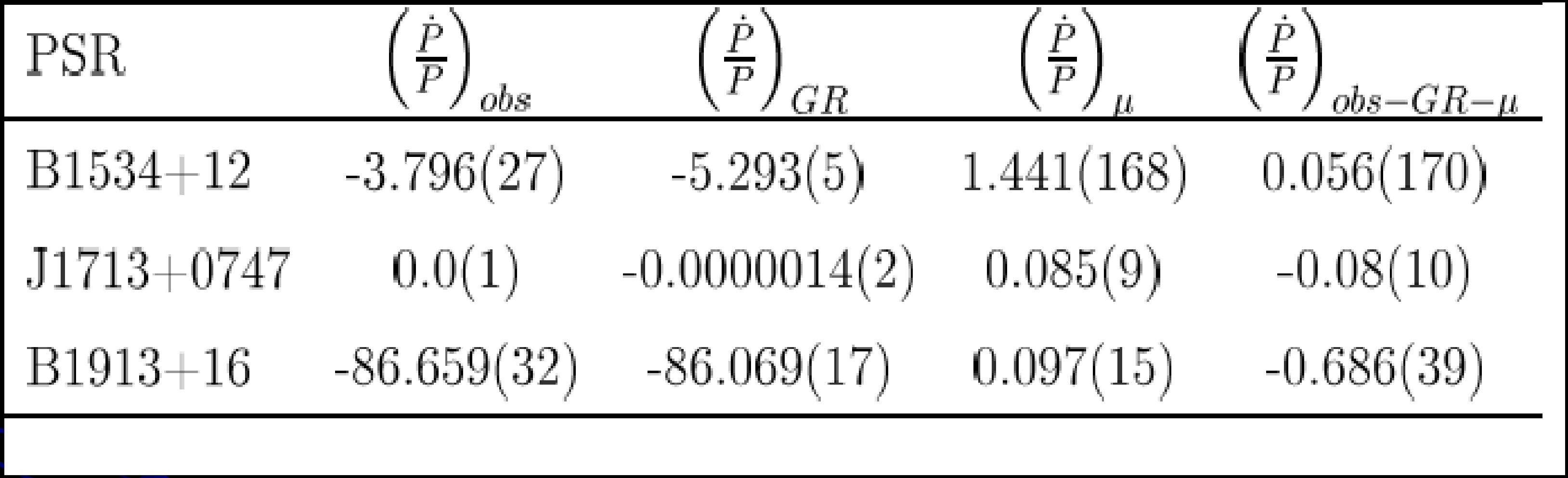
PSR B1534+12

PSR J1713+0747

PSR B1913+16

(Nobel Prize)

Results for three binary pulsars



PSR	$\left(\frac{\dot{P}}{P}\right)_{obs}$	$\left(\frac{\dot{P}}{P}\right)_{GR}$	$\left(\frac{\dot{P}}{P}\right)_{\mu}$	$\left(\frac{\dot{P}}{P}\right)_{obs-GR-\mu}$
B1534+12	-3.796(27)	-5.293(5)	1.441(168)	0.056(170)
J1713+0747	0.0(1)	-0.0000014(2)	0.085(9)	-0.08(10)
B1913+16	-86.659(32)	-86.069(17)	0.097(15)	-0.686(39)

Galactic models

- Flat rotation curve
- Kutuzov-Ossipkov (1989)
- Allen-Santillan (1991)
- Flynn et al. (1996)
- Dehnen & Binney (1998)

Parameters for comparison

$$k_1 = \frac{1}{\sum_i p_i}\sum_i (p_i\lambda_i), \quad k_2 = \underset{i}{max}(p_i\lambda_i),$$

$$k_3 = \sum_{i=1}^{n}(p_i\lambda_i).$$

Here

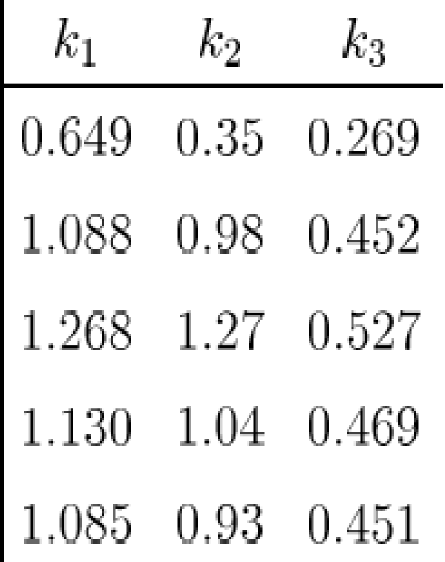
$$\lambda_i = \frac{|(\dot{P}/P)_{obs-GR-\mu} - (\dot{P}/P)_{Gal}|}{\sigma_i}$$

$$p_i = \frac{\sigma_{max}^2}{\sigma_i^2}$$

is weight of the value λ_i.

Minimum k_i corresponds to the best model

The values of k_i for three binary pulsars under study



Model	k_1	k_2	k_3
Flat rotation curve	0.649	0.35	0.269
Kutuzov-Ossipkov (1989)	1.088	0.98	0.452
Allen-Santillan (1991)	1.268	1.27	0.527
Flynn et al. (1996)	1.130	1.04	0.469
Dehnen & Binney (1998)	1.085	0.93	0.451

Conclusions

We have suggested a new method for testing the models of regular galactic field using the binary pulsars as tool.

The first test using the most reliable three pulsars has shown that the simple model with flat rotation curve in the solar neighborhood gives a slightly better agreement with respect to four other models.

Perspectives

The next steps of our work are as follows:

- Choosing of a larger amount of the binary pulsars with measured orbital period derivatives;
- Probing other Galaxy models;
- Developing of criteria for comparison of different models.