Research Article

Implementation of the system II transit point data for investigating the reduction of the rotational speed of the planet Jupiter

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Abstract
From the internal structural study as well as from the graphical analysis, the variations of pressure, temperature, density and viscosity with increasing depth of the planet Jupiter have examined. We have given priority to the property of the constituent material of Jupiter, e.g., the mixture of metallic hydrogen and helium. It appears that the core region of Jupiter contents a relatively high viscosity and due to such high viscous force, the rotational kinetic energy of Jupiter will be lost very slowly causing the planet to slow down with time. In our analysis we have focused on the system II transit point data for getting an experimental evidence of our line of thinking. Considering the monthly data of average rotational period from the year 1997–2017 we find a notable monthly variation of rotational period during this 20 years' time gap. From the equation of the least square fit graph it appears that the slope is 2×10^{-6} s per year, which signifies that Jupiter is getting slow by 2 μs per year. Considering the rate of slow down to be uniform we have calculated the approximate rotational period in the early days of Jupiter life.

Keywords Jovian planet · Metallic hydrogen · Rotational kinetic energy of Jupiter · System II transit point data

1 Introduction

The extensive thick layer of liquid as well as metallic hydrogen and helium mixture [1] in the interior of the planet Jupiter must experience a substantial turbulence because of its very rapid rotation [2]. This turbulence must necessarily convert some rotational kinetic energy into frictional heat energy loss which should have slowed down the rotation of the planet in its extremely long-life time (probably five billion years). Presence of crashing pressure of gravity will make the inner region denser which will effectively increase the viscous force and due to the presence of high temperature in the interior of Jupiter the viscosity will be also enhanced. In this paper, considering the internal structure the variations of pressure, temperature, density and viscosity with increasing depth of the planet is taken into account. We have given priority to system II transit point data, obtained by using the link mentioned in the acknowledgement, for an experimental evidence of our line of thinking. Analyzing the monthly data of average rotational period for the year 1997–2017 and considering the rate of slow down to be uniform we have also calculated the approximate rotational period in the early days of Jupiter life and discussed the possible consequences of such slowing down of this planet.

2 Related works

The proto-cores of the giant planets which are formed outside the snow line, were accreted from both rock and ice so they could become bigger than those planets formed

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inside the snow line and once those cores reach a critical limit (~10 times the mass of Earth) their gravitational force become so strong that they able to pull in material from much farther away [3]. From conservation of angular momentum, it can be said that if a spinning mass starts pulling inward, it spins up and the process continues since it attracts more materials from away making faster to move proto-planetary disc [4]. Jovian planets belong to this group and Jupiter is the largest one of them [5]; Jupiter as well as the other gaseous planets of our solar system are covered with large number of stripes from pole to pole, called zones and belts. To explain the dynamics of Jovian planets a model was proposed in 1976, called Deep Model which suggests that the Jupiter's interior region can be divided into a large number of coaxial cylinders (Fig. 1) each of which has a circulation independent of the others. The latitudes where the outer and inner boundaries of the cylinders intersect can be marked as zones and belts [6]. This type of atmospheric jets is not only observed on the top cloud boundary region but extended to very deep inside the planet [7].

3 Proposed work

Presence of the dynamics of cylindrical layers to very deep interior the planet signifies that the substantial turbulence will also be found in the region where the self-gravity becomes sufficient to convert gaseous hydrogen into liquid as well as metallic [8, 9].

Considering energy gradient theory for Taylor–Couette flow it can be demanded that a flow of viscous fluid between two coaxial cylinders always accompanied by a loss of energy [10, 11]. Two adjacent cylindrical liquid layers of radius r and $r+dr$ are assumed to be rotating with angular velocity (ω), so that the corresponding linear velocities are $v=\omega r$ and $v+dv=\omega(r+dr)$ (Fig. 2). Hence in the interior of the fluid of Jupiter there is a velocity gradient dv/dr which will produce a huge viscous drag between these cylindrical layers to dissipate rotational

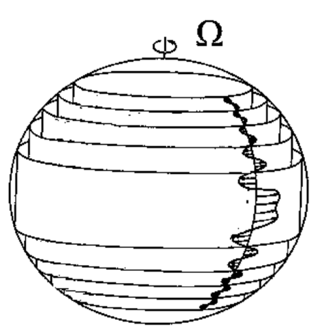

Fig. 1 Internal structure of Jupiter according to deep model

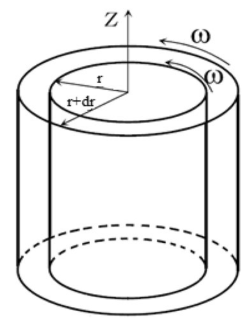

Fig. 2 Two coaxial cylinders of radius r and $r+dr$, rotating with angular velocity ω, producing a velocity gradient

kinetic energy into heat energy. Presence of such velocity gradient is also supported by recent observation of Juno spacecraft by measuring the gravitational harmonics (J_n). Non-vanishing odd gravitational harmonic terms indicate the existence of differential rotation of jets extended to very deep inside the planet [12].

In the interior of the gas giant the physical parameters like pressure, density, temperature etc. gradually increase which also result some changes in the physical property of its constituent materials. In order to understand the nonlinear dynamics in the interior of Jupiter and how the viscosity affects the motion, we need to study the internal model structure of Jupiter. As there is no direct observation of Jupiter's interior, except Galileo probe at a very shallow region from the cloud top, we have to depend on mathematical modeling and simulation method [13]. For the equation of state and the interior model for Jupiter we would like to examine the pressure, temperature, density profile through the planet [14]. The results of adiabatic show the variation of pressure, temperature, density and viscosity inside the planet with its radius as a parameter. Such a computer-based simulation method is verified by in situ observation of gravitational harmonics (J_n) by Juno spacecraft [15]. We have presented the variations of pressure (green), temperature (red) and density (blue) with increasing radius of Jupiter in Fig. 3 considering the summarized data provided in Table 1. Figure 4 shows the variation of viscosity inside the planet, where we have plotted radius along the X-axis and coefficient of viscosity along the Y-axis. From the internal structural study of Jupiter and from this graphical presentation it is evident that pressure, temperature, density and viscosity gradually increase with the depth. We have also considered the property of the constituent material of Jupiter i.e. the mixture of metallic hydrogen and helium which reveals that the viscosity of the mixture increases almost linearly with temperature though after 10,000 K the variation of viscosity with temperature exhibits some interesting changes, as reported by Bruno et al. [16]. It may, therefore, be concluded that in the core region of Jupiter there will be a relatively high viscosity and due to such high viscous force, the rotational

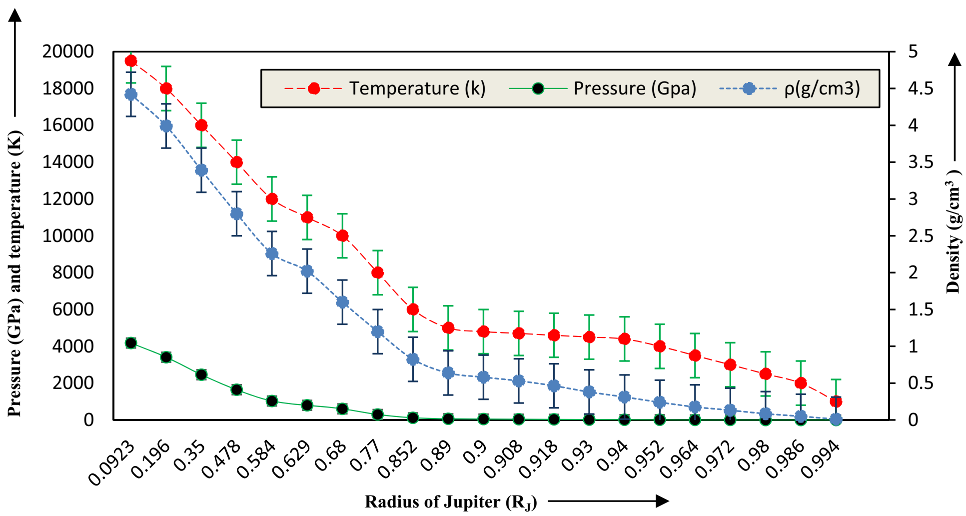

Fig. 3 Interior profile of pressure (green), temperature (red) and density (blue) for the planet Jupiter

Table 1 Thermodynamic and Linear Transport Properties of hydrogen–helium mixture in the interior of Jupiter

Distance from the center of Jupiter R (R_J)	Density ρ (g cm^{-3})	Temperature T (K)	Pressure P (GPa)	Shear viscosity η (mPa s)
0.0923	4.42	19,500	4180	1.16
0.196	3.99	18,000	3410	1.06
0.350	3.39	16,000	2460	0.955
0.478	2.80	14,000	1640	0.830
0.584	2.26	12,000	1030	0.666
0.629	2.02	11,000	800	–
0.680	1.60	10,000	600	0.500
0.770	1.20	8000	300	0.410
0.852	0.824	6000	120	0.297
0.890	0.638	5000	64	0.234
0.900	0.581	4800	51	–
0.908	0.531	4700	42	–
0.918	0.464	4600	32	–
0.930	0.380	4500	23	0.140
0.940	0.312	4400	16	–
0.952	0.240	4000	9.6	0.090
0.964	0.177	3500	5.0	–
0.972	0.132	3000	2.7	0.046
0.980	0.0848	2500	1.2	0.033
0.986	0.0497	2000	0.45	0.023
0.994	0.0113	1000	0.0434	–

kinetic energy of Jupiter will be lost very slowly and as a result the planet has to slow down with time.

Thermodynamic properties can be classified into two types, intensive and extensive. Out of the two, intensive is a property independent of the amount of material in the system like temperature, density, viscosity etc. while extensive property depends on the total amount of material in the system. On the other hand, transport properties generally include viscosity, thermal conductivity and diffusivity. These are the molecular properties of a substance that indicate the rate at which specific momentum, heat or mass are transferred. With a view to consider the internal profiles of the Jupiter we have considered some thermodynamic material properties as well as transport properties as listed in Table 1.

3.1 Present observations

It is very much complicated to find the rotational period of Jupiter as the gas giant has no solid surface which can be tracked down to measure the rotation speed. Jupiter has the fastest rotation among all the planets in the Solar System and coincidently Jupiter is also the largest planet in the Solar System; so, it is turning a lot of mass very quickly. The rapid rotation causes the planet's equatorial region to have a greater radius than its polar region which is even visible from ground based telescopic observation [17]. The rotational period depends on what region of the planet is observed as the planet has different speed of rotation at different latitude. Because of such differential rotation the polar region takes about 5 min longer than its equatorial region. There are three different systems to calculate the rotational period of Jupiter [18]. System I is associated with the latitudes up to 10 degrees north and south of Jupiter's equator while System II is for the latitudes greater than 10 degrees north and south in both the hemisphere. In System I and System II the rotation rates are measured by considering how long it takes for a specific storms to come back into view, so both the process is related to the motion of Jupiter's very thick atmospheric region which is extended to very deep inside the planet. The System III (1957) measures the rotational speed of Jupiter's inner

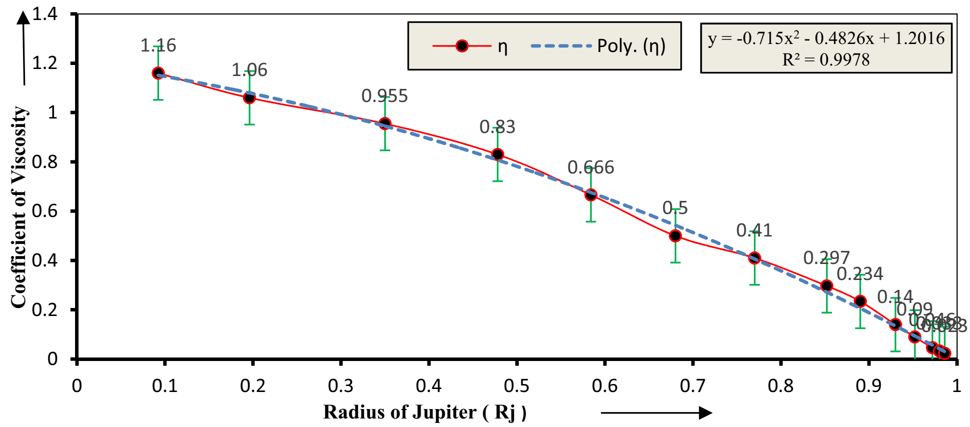

Fig. 4 Variation of coefficient of viscosity with radius in the interior of Jupiter

core using non-thermal radio observations of the planet which is linked to the inner magnetosphere of the planet [19]. The System III was adopted by International Astronomical Union (IAU) according to which the rotational period of Jupiter is 9 h 55 min 29.37 s though it was demanded to be changed slightly over a span of observations because of secular variation of Jupiter's magnetic field [20, 21].

In our analysis we have focused on the system II transit point data to find an experimental evidence of our line of thinking. Considering the monthly data of average rotational period for the year 1997 and 2017 we have drawn Figs. 5 and 6 taking X-axis as month and Y-axis as rotational period. Figure 7 shows a comparison showing a prominent monthly variation of rotational period in the year 1997 and 2017. We have also considered monthly rotational period in different years during the period of 1997 to 2017. Considering the average rotational period and the corresponding standard errors we have graphically represented these data in Fig. 8 taking year along X–axis and average rotational period along Y-axis. Though the period of observation is relatively small, still we note a small increase in the period of rotation. The slope of the graph indicates the slowing down of the planet. As the rate of change of rotational period is too small, the time of observation should be large enough for getting a significant change. From the least square fit graph of Fig. 8, the equation of the line can be expressed as,

$$y = (2 \times 10^{-6})x + 0.4137$$

From the equation of the least square fit graph it appears that the slope of the graph is 2×10^{-6} s per year, which signifies that Jupiter is getting slow by 2 μs per year. Considering that the rate of slowdown remains constant if we go back 10^9. years from present time then it can be

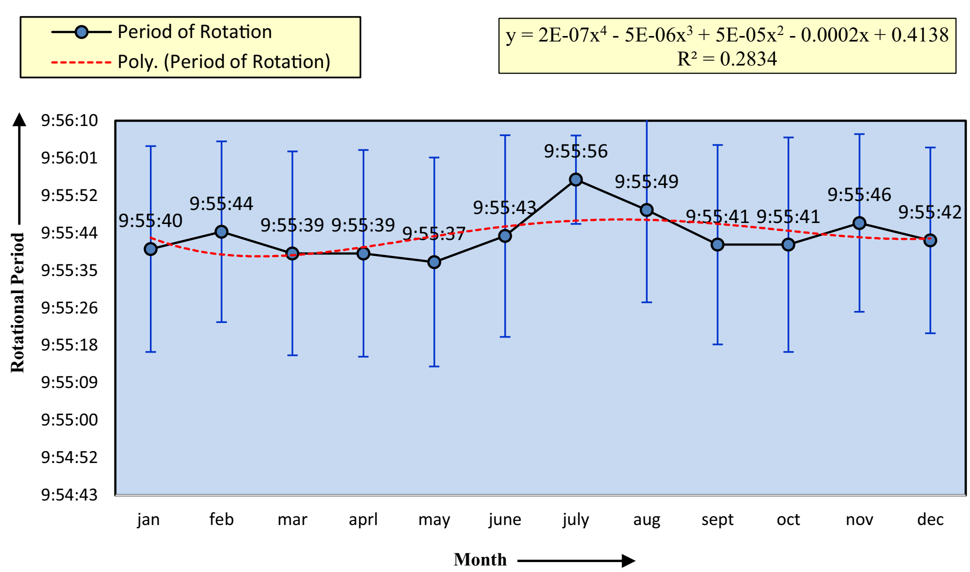

Fig. 5 Variation of rotational period in the year 1997

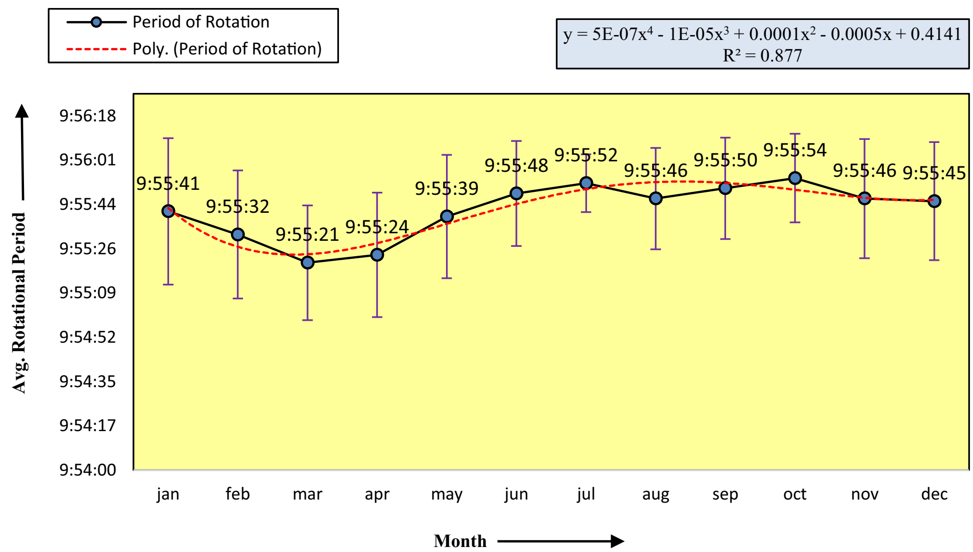

Fig. 6 Variation of rotational period in the year 2017

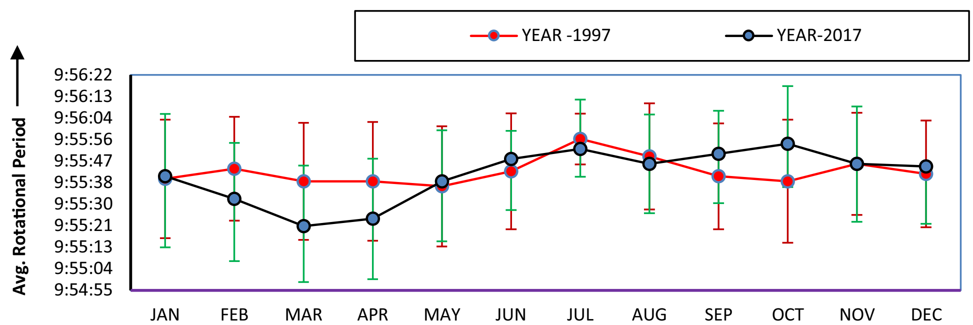

Fig. 7 Monthly variation of rotational period in the year 1997 and 2017

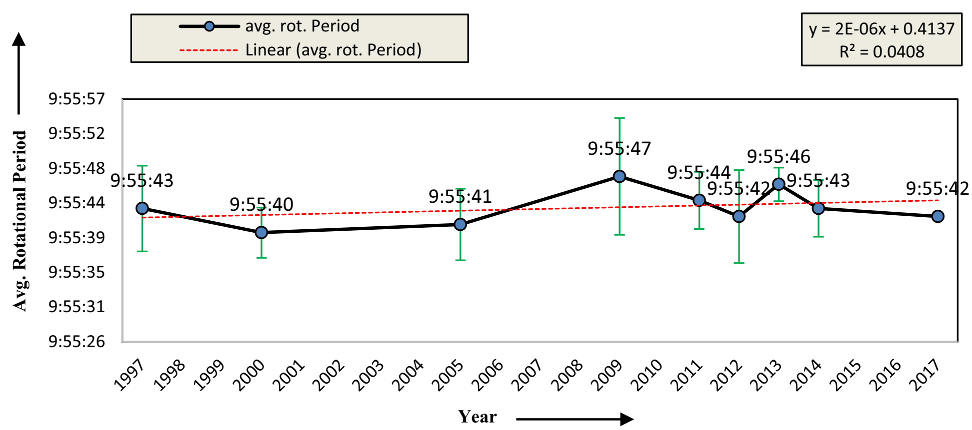

Fig. 8 Variation of rotational period of Jupiter over 20 years of period

found that the planet would have taken 2000s i.e. nearly 33 min less than the recent average period of rotation. Using the slope of the graph and considering the rate of slow down to be uniform we can calculate the approximate rotational period in the early stage of Jupiter life as shown in Table 2.

Table 2 Rotational period in the early stages of lifetime of Jupiter

Year	Period of rotation
1×10^9	9 h 22 m 23 s
2×10^9	8 h 49 m 03 s
3×10^9	8 h 15 m 43 s
4×10^9	7 h 42 m 23 s
5×10^9	7 h 09 m 03 s

4 Conclusions

From our observation of system II transit point data, we predicted that the time period of Jupiter has increased to 9 h 22 m 23 s from 7 h 09 m 03 s in its lifetime of five billion years which signifies that the planet had a faster rotation in its early life and have slowed down gradually. The same logic may also be applicable for the planetary bodies and similar systems containing viscus fluid in the interior and suffering from differential rotation. The Sun is an appropriate example of such body which might have slowed down more rapidly in comparison to Jupiter. Therefore, we may comment that both Jupiter and Sun had initially similar rotational period and both have slowed due to the frictional energy loss, but the Sun was affected more. This could be an approximate explanation for why the Sun currently rotates very slowly (almost once in a month). The decrease in rotational speed of Jupiter definitely reduces centrifugal force which will effectively increase the self-gravitational pressure on the interior hydrogen to convert more gaseous hydrogen into liquid hydrogen; therefore, it gives rise to the possibility of change in magnetosphere of the planet. Again, the conservation of angular momentum points out clearly that any change in rotational speed will either result a change in size of the planet or a change in radial distribution of mass inside the gas giant. All the changes occur so slowly that observation over a large time scale is required to obtain a considerable change. The satellite data in future may give us more clues to reveal the story of the mysterious gas giant.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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