

**THE ORIGIN OF ROTATION, DENSE MATTER PHYSICS AND ALL THAT:
A TRIBUTE TO PAVLE SAVIĆ**

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SUMMARY: This is a review of the main physical ideas and examples of applicability in astrophysics and pure physics of a semiclassical theory of dense matter proposed by Pavle Savić and Radivoje Kašanin in the early sixties. A hypothesis, advanced by Savić with the aim of solving the problem of the origin of rotation of celestial bodies, will also be discussed. The paper is dedicated to the memory of Pavle Savić, who died recently.

1. INTRODUCTION

Dr.h.c. Pavle Savić, Emmeritus professor of physical chemistry at the University of Beograd, founder and first scientific director of the Institute of Nuclear Sciences in Vinča near Beograd, member and former President of the Serbian Academy of Sciences and Arts, died in Beograd on May 30, 1994. The purpose of this paper is to review some results of his scientific work, and, in an appendix, present the main details of his rich and interesting life. The title of the paper is an analogy with one of the most important books in modern theoretical physics (Streater and Wightman, 1964).

Savić has been scientifically active in the fields of nuclear physics and dense matter physics and astrophysics. In nuclear physics, he co-authored with Irene Joliot - Curie, some of the crucial experiments

which have opened the way to the discovery of nuclear fission. His interest in dense-matter physics was motivated by the problem of the origin of rotation of celestial bodies. Savić formulated a hypothesis (Savić, 1961) which tried to contribute to the solution of this problem. After that, jointly with Professor Radivoje Kašanin, he developed a theory of the behaviour of materials under high pressure (Savić and Kašanin, 1962/65). This paper will present a review of the main ideas and results of their theory (called the SK theory). Readers interested in the "nuclear" activity of Pavle Savić should consult some of the existing excellent reviews of the subject (such as Seaborg, 1980; Savić, 1989). The paper by Savić is especially important, because it gives a "first-hand" account of the conditions and style of work in the famous Institut du Radium in Paris, where he performed his research in nuclear physics.

2. THE SK THEORY

2.1 *The origin of rotation*

The starting point for the development of this theory was a paper by Savić (Savić, 1961), referred to in the following as S61, which had the aim of proposing an explanation of the origin of rotation of celestial bodies. As a result, there emerged the conclusion that rotation is tightly related to the internal structure, and that a correct theory of dense matter was needed.

Considerations of S61 (and, of the whole SK theory) start from a low-temperature cloud consisting of an arbitrary number of chemical elements and their compounds. The life of such a cloud is governed by two physical processes: the mutual gravitational interaction of its constituting particles, and the loss of energy due to radiation. In modern terms, this is a description of a typical interstellar cloud.

Due to the increase of pressure, two important processes occur in the interior of the cloud - the excitation and ionisation of its constituting atoms and molecules. Qualitatively speaking, this is an expected consequence of the perturbation of the electronic energy levels by the external pressure field. The physical possibility of this coupling can be proved even in elementary quantum mechanics, on a solvable system such as a finite potential well. In quantum mechanics increasing the pressure to which a (macroscopic) system is subjected leads to the expansion of the radial part of the electronic wavefunction of the atoms and molecules that make up the system. It is interesting to note that the first fully quantum treatment of excitation and ionisation under pressure in a real solid body has been given only recently (Ma, Wang, Chen et al, 1988), nearly three decades after the concept was used by SK.

At a certain value of the pressure (which is, obviously, a function of the chemical composition of the primordial cloud) a phase transition occurs in the cloud - it passes into the state of a poly-component plasma (two-component in the simplest case). This plasma consists of a randomly moving electron gas and neutral and ionized atoms, molecules. General criteria for the existence of bound and ionized proton-electron pairs in a plasma were recently discussed in detail (Girardeau, 1990; Lebowitz, Macris and Martin, 1992). It has been proved that such an electron gas has a non-zero magnetic field (de Groot and Suttrop, 1972). Owing to a combination of high pressure and low-temperature, the magnetic moments of the ionized atoms and molecules become oriented in parallel, and the resulting torque starts the rotation of the whole system. For a different approach to the problem of the origin of magnetic fields in the early solar system see, for example (Stepinski, 1991, 1992).

The mechanism just described may seem, at first sight, highly qualitative. However, when elabo-

rated in detail (Savić and Kašanin, 1962/65; Savić, 1981), it gives values of the magnetic fields and the allowed intervals of the speed of rotation of the Sun and the planets which are in good agreement with the observations. For example, the observed speed of solar rotation in the equatorial zone is $\omega = 2.9 \cdot 10^{-6}$ rad/s, while the physically allowed interval according to the SK theory is $(1.2 \leq \omega \leq 44.7) \cdot 10^{-6}$ rad/s. The SK theory gives a value of 10-14 Gauss for the magnetic field of Jupiter, while the measured value is 14 Gauss (Savić, 1981).

An obvious question emerges at this point - why does the SK theory give the physically permitted interval and not a single value for the speed of rotation of a celestial body? This is due to the fact that the speed of rotation is calculated via the estimate of the work, done per atom, by the external pressure in expulsing the electrons from the energy levels in the atoms and molecules that make up the material. As the pressure is related to the density, and it has a lower and upper limit in every phase, the consequence is that the theory provides only the limits of the physically possible interval of the values of the speed of rotation.

It would be an interesting problem in theoretical plasma physics to reformulate this part of the SK theory, so as to narrow the limits of the interval, or even transform it in a single value. Another important question concerns lunar rotation. It is a known fact that the Moon rotates with a period equal to its orbital period. On the other hand, one often hears that, according to SK (Savić, 1972), the Moon should not rotate. The discrepancy seems to be obvious and serious, but it actually has a simple solution. Rotation of a body is, in the framework of SK, a consequence of pressure ionization of atoms and molecules in its interior. The realizability of this process in a given celestial object depends on its mass and chemical composition. When they calculated a model of the internal structure of the Moon, SK have determined the mean atomic mass of the chemical mixture that the Moon is made of ($A = 71$), and the chemical elements which enter into its composition (B, Be, C, O, F, Ca, Mg, Al, Si, Ti, V, Se, Y, Zr, Sb, Te, La and the rare earths). On the other hand, it has been estimated in SK that the central pressure in the Moon is too low to ionize any of the chemical elements present there, which led to the theoretical conclusion that the Moon should not rotate. However, in their calculation, SK did not take into account the possibility that the Moon can contain molecules as well as pure elements, and that the ionization potentials of the molecules are often smaller than the ionization potentials of the pure atoms. This difference can be ascribed to the polarization of surrounding molecules and, in some cases, intermolecular band formation (Seki, 1989). For example, ionization potentials of Ca, F and CaF are 6.113 eV, 17.422 eV and 5.8 eV, respectively. It follows that it is easier to ionize CaF by subjecting it to high pressure, than to achieve the same goal for

pure Ca and F. Reasoning in this way (that is, starting from the chemical elements proposed by SK for the composition of the Moon, forming molecules from them and then determining the ionization pressure), one could show that at least some of these molecules can be ionized in the interior of the Moon and that lunar rotation can be accommodated within the SK theory.

2.2 Materials under high pressure

The study of materials subjected to high pressure is important in a variety of situations in physics, astronomy and related sciences. These include the early Universe and phase transitions which occurred in it (Satz, 1993, 1994), heavy-ion collisions in accelerators (Angert, Bourgairel, Brouzet et al, 1993; Geiger, 1994; Schukraft, 1994), the internal structure of stars, planets and satellites (Zharkov and Trubitsyn, 1980; Čelebonović, 1990; Lindblom, 1992; Weber and Glendenning, 1993; Sedrakian, Blaschke, Ropke and Schulz, 1994 and numerous other publications), but also experiments performed in diamond-anvil cells (such as Savić and Urošević, 1987), the synthesis of high-temperature superconductors (Hiroi and Takano, 1994) and spectral-line broadening studies.

Attempting the study of a material subjected to high pressure and/or temperature is a difficult, interesting but solvable problem. Experimental investigations encounter various kinds of technical problems (such as filling a diamond-anvil cell, or measuring the electrical conductivity of a specimen in a cell). On the theoretical side, a specimen of a material is an example of a typical many-body system, whose Hamiltonian can be expressed as

$$H = \sum_{i=1}^N -\frac{\hbar^2}{2m} \nabla_i^2 + \sum_{i=1}^N V(\vec{x}_i) + \sum_{i,j=1}^N v(|\vec{x}_i - \vec{x}_j|) \quad (1)$$

All the symbols in Eq. (1) have their customary meanings. By using the standard approach of statistical mechanics, one should introduce some form of the interparticle potential $v(|\vec{x}_i - \vec{x}_j|)$ in Eq. (1), calculate the partition function which is defined by ($Z = \text{tr} \exp(-\beta H)$), and from it the free energy and all the other required thermodynamic potentials (for example, Ruelle, 1969). Instead of embarking on such a complicated calculation, Savić and Kašanin have founded their theory on a set of 6 experimentally founded premisses supplemented by a microscopic selection rule.

The mean interparticle distance a is defined by the relation

$$N_A (2a)^3 \rho = A \quad (2)$$

where N_A denotes Avogadro's number, ρ is the mass density and A is the mean atomic mass of the material. After thus introducing a , one can define the "accumulated" energy per electron as

$$E = e^2/a \quad (3)$$

One might expect that a relation such as (3) should contain the ionic charge Z . It can be shown (Leung, 1984) that a , as defined in (2) is a multiple of the Wigner-Seitz radius, which actually contains Z .

The basic premisses of the SK theory are the following statements (Savić and Kašanin, 1962/65; Čelebonović, 1989 d):

1. The density of a material is an increasing function of the pressure to which it is exposed.

2. With increasing density, every material undergoes a sequence of phase transitions. The phase ending at the critical point is denoted as the zeroth phase. For every phase, indexed by i , there exist two limiting values of the density, such that

$$\rho_i^0 \leq \rho_i \leq \rho_i^* \quad (4)$$

$$(1/\alpha_i)\rho_i^* \leq \rho_i \leq \rho_i^* \text{ with } \alpha_i > 1.$$

3. The maximal densities of two successive phases are related by

$$\rho_{i+1}^* = 2\rho_i^* \quad (5)$$

which can be derived from the results of S61. It was shown in that paper that the mean densities of the planets can be fitted by the expression

$$\rho_i = \rho_0 2^{\varphi_i} \quad (5a)$$

where $\rho_0 = 4/3$ stands for the mean density of the Sun, and values of the exponent φ_i have to be chosen for each planet. The density of a material is a consequence of its composition and the equilibrium between the attractive and repulsive forces which exist in it. Values of φ_i are a function of these equilibrium conditions and their changes under high external pressure. (5) follows from (5a) by assuming $\varphi_{i+1} - \varphi_i = 1$.

4. It is assumed that

$$\frac{E_i^*}{E_i^0} = \frac{E_{i+1}^0}{E_i^*} \quad (6)$$

Some form of a link between the accumulated energies in successive phases was needed in order to render the calculations possible, and (6) was accepted because of its simplicity. After some algebra, one gets that $\alpha_i \alpha_{i+1} = 2$, and that

$$\alpha_i = \begin{cases} 6/5 & i = 1, 3, 5, \dots \\ 5/3 & i = 2, 4, 6, \dots \end{cases} \quad (6a)$$

5. The final density of the zeroth phase is

$$\rho_0^* = \frac{A}{3\bar{V}} \quad (7)$$

which is approximately equal to the critical density in the van der Waals theory. \bar{V} denotes the molar volume of the material at $T = 0$ K; in the terminology of the van der Waals theory, $\bar{V} = b$.

6. Using assumption 3., it can be shown that

$$\frac{A}{\bar{p}} = \frac{1}{2} \left(\frac{A}{\rho_1^*} + \frac{A}{\rho_2^*} \right) \quad (7a)$$

where \bar{p} denotes the density at the zero-point, defined as $\bar{p} = A/\bar{V}$.

Starting from these premisses, the following set of relations can be derived:

$$\begin{aligned} \rho_1^* &= 2^i \rho_0^* & \rho_1^0 &= \frac{\rho_1^*}{\alpha_i} \\ V_0^* &= 3\bar{V} & V_1^0 &= \alpha_i V_1^* 2^{-i} & V_1^* &= 2^{-i} V_0^* \\ r_0^* &= (15/4N_A \times 10^{-23})^{1/3} \bar{V}^{-1/3} \\ r_1^* &= 2^{-i/3} r_0^* & r_1^0 &= r_1^* \times \alpha_i^{1/3} \end{aligned} \quad (8)$$

The SK theory has an inherent limitation - it can successfully treat only first order transitions. It is presumed in the theory that a discontinuous change of volume $V_1^* \rightarrow V_{i+1}^0$ occurs at the phase transitions pressure. Second order transitions can be considered as a special case, for which $V_1^* - V_{i+1}^0 \rightarrow 0$

The value of the pressure at which a phase transition will occur in a given material can be calculated by considering the work done by the external pressure in compressing the material,

$$\Delta W = p_i^* (V_1^* - V_{i+1}^0) = p_i^* V_1^* (1 - 1/\alpha_i) \quad (9)$$

and equating it to the change of the accumulated energy

$$\Delta W = \Delta E = N_A (E_{i+1}^0 - E_i^*) \quad (10)$$

After some algebra, manipulating equations (8) to (10), one arrives at the following expression for the maximal internal pressure in phase i of a material having zero-point volume \bar{V} :

$$p_i^* = 1.8077 \beta_i (\bar{V})^{-4/3} 2^{4i/3} \text{ Mbar} \quad (11)$$

where

$$\beta_i = 3 \frac{\alpha_i^{1/3} - 1}{1 - 1/\alpha_i} \quad (11a)$$

The value of external pressure needed to induce a phase transition from phase i to phase $i + 1$ is, finally, given by

$$p_{tr} = p_i^* - p_i^0 = p_i^* \left(1 - 2^{-4/3} \frac{\beta_{i-1}}{\beta_i} \right) \quad (12)$$

which can be reduced to

$$p_{tr} = \begin{cases} 0.5101 p_i^* & i = 1, 3, 5, \dots \\ 0.6785 p_i^* & i = 2, 4, 6, \dots \end{cases} \quad (13)$$

with p_i^* determined by (11).

Expression (13) represents a simple mathematical algorithm for the calculation of a sequence of possible phase transition pressures in a given material. Those values of pressure at which a phase transition is physically possible according to SK are selected with the following criterion (Savić and Kašanin, 1962/65):

$$E_0^* + E_i = E_i^* \quad (14)$$

E_i denotes the ionisation potential, E_0^* and E_i^* can be calculated by (3) using (8) and the transformation $a = r \times 10^{-8}$ cm.

This procedure has recently been applied to a set of 19 materials of different chemical nature, with experimentally known phase transition points (Čelebonović, 1992 c). The unique criterion for the choice of the materials was the easy availability of experimental data. It was found that the agreement between the experimental and theoretical values of phase transition pressures is very encouraging - the relative differences vary between practically zero and 30 - 40%. It may seem that the upper limit is very high, but it is actually of the same order of magnitude as the results of some quantum-mechanically founded calculations (Čelebonović, 1992c and references given there). The possible causes of the differences were analyzed in some detail. They include the contribution of various factors, such as the exact form of the inter-particle potential in the material and the effects of temperature. For details, see (Čelebonović 1992c).

Apart from the calculation of the value of phase transition pressure for a given material, another interesting (and partially open) problem in the SK theory concerns the establishment of the equation of state (EOS) of dense matter. In its original formulation, this theory aims at proposing a representation of the so-called cold-compression curve, and the problem of the behaviour of dense matter with $T \neq 0$ has been just touched in it. A form of the EOS in the $\rho - T$ plane has been proposed starting from the SK theory (Čelebonović, 1991b). It was derived by comparing the expression for the accumulated energy unit volume with the result for the total energy per unit volume of a solid body, which is known in solid state physics. As a test, this EOS was applied to the interior of the Earth, and the results were in good agreement with geophysical data.

Table 1: The interior of the Earth

depth (km)	0 - 39	39 - 2900	2900 - 4980	4980 - 6371
ρ_{max} (g/cm ³)	3.0	6.0	12.0	19.74
P_{max} (Mbar)	0.25	1.29	2.89	3.7
T_{max} (K)	1300	2700	4100	7000
		$A = 26.56$		

However, proposing within SK a suitable form of the EOS of a thermo-mechanical system in the $P - \rho - T$ space of thermodynamical variables is currently an open problem.

We have so far reviewed the applications of the SK theory in laboratory high-pressure work. It can be used in astrophysics, where it gives the possibility of modelling the internal structure of celestial bodies. As input data it demands just the mass and radius of the object under study.

Starting from these data, it provides the number of layers which exist in the interior of the object and their thickness, the distribution of pressure, density and temperature with depth under the surface, the strength of the magnetic field and the interval of the physically allowed values of the speed of rotation. It is very important that the SK theory gives the mean atomic mass of the chemical mixture that the object under study is made of.

The theory has so far been applied to the Sun, all the planets except Saturn and Pluto, the Moon, the Galileian satellites, the satellites of Uranus, Neptune's satellite Triton and the asteroids 1 Ceres and 10 Hygiea. The results are scattered in the literature, but, generally speaking the agreement with experiments and calculations performed by other methods is good. For example, it was calculated that the depth of the Moho layer in the Earth is 39 km, while the experimental value is 33 km. Tables 1 and 2 contain data on the interiors of the Earth and the Moon calculated within the SK theory (Savić, 1972, 1981):

Table 2: The internal structure of the Moon

depth (km)	0 - 338	338 - 1738
ρ_{max}	3.32	6.64
P (Mbar)	0.015	0.089
T (K)	529	793
	$A = 71$	

The values of T in table 2 were calculated by using eq. (7) of (Čelebonović, 1991b) and assuming $Z = 1$.

Parameters of the interiors of various Solar System bodies calculated within the SK theory can not be compared to any direct experiments, but only to the consequences of these results on the visible layers of these objects. On the other hand, observationally verifiable conclusions can be drawn from an analysis of the mean atomic masses, $\langle A \rangle$, of the chemical mixtures making up objects in the planetary system. A review of all the currently available

values of $\langle A \rangle$ determined within the SK theory is presented in the following Table. The symbols J_i ($i = 1, \dots, 4$) and U_k ($k = 1, \dots, 5$) denote the satellites of Jupiter and Uranus.

Table 3: the chemical composition of some Solar System bodies

object	$\langle A \rangle$	satellite	$\langle A \rangle$
Sun	1. 4	Moon	71
Mercury	113	J1	70
Venus	28. 12	J2	71
Earth	26. 56	J3	18
Mars	69	J4	19
1 Ceres	96	U1	38
Jupiter	1. 55	U2	43
Saturn	/	U3	44
Uranus	6. 5	U4	32
Neptune	7. 26	U5	32
Pluto	/	Triton	67

It can easily be seen from the preceding Table that the planetary system is chemically inhomogeneous; the well known division on the terrestrial and jovian planets is clearly visible. The asteroid 1 Ceres, whose orbit is currently between those of Mars and Jupiter is, by its chemical composition, similar to Mercury (Čelebonović, 1988b). Physically, this could imply that "once upon a time" it originated close to Mercury, but that their orbits later diverged (chaos ??). Using the value of $\langle A \rangle$ calculated for 1 Ceres within SK, the mass of the asteroid 10 Hygiea was calculated, and the result is in excellent agreement with the experimental value known in celestial mechanics.

A similar case exists in the Neptune - Triton system; their respective values of $\langle A \rangle$ differ by almost an entire order of magnitude (Čelebonović, 1986). This can be interpreted as a consequence of the fact that Triton is a captured body. A similar conclusion follows from the analyses of its motion.

Gradients in $\langle A \rangle$ visible in the jovian and uranian satellite systems have been interpreted as a result of various transport processes in the respective circum-planetary accretion disks (Čelebonović, 1987; 1989).

The problem of the origin of the Earth's satellite Moon has been considered within the SK theory (Savić and Teleki, 1986). Indications were presented in favour of the common origin of the two bodies.

Instead of a conclusion

At the end of this review of the theory of dense matter proposed by Pavle Savić and Radivoje Kašanin, a few general comments are in order.

Distinct advantages of their theory are its physical and mathematical simplicity, which were made possible by a careful choice of the starting assumptions. For those accustomed to the language of modern theoretical physics, the SK theory can be described as a mean field type theory based on the Coulomb interaction, and supplemented by a microscopic selection rule. The simplicity of the theory necessarily induces a certain amount of coarseness in its results. One such example is the fact that the theory does not give a unique value for the speed of rotation of the celestial object under study, but, instead an interval of physically allowed values. Some work aimed at refining the theory is already under way. It is hoped that this review will motivate (at least some of) the readers to get acquainted with the details of the SK theory and try to perform some calculations of their own.

APPENDIX: some biographical notes on Pavle Savić

Pavle Savić was born on January 10, 1909 in Thessaloniki (Greece), where his father was an employee of the Customs service of the Kingdom of Serbia. At the age of 23, he majored in physical chemistry at the University of Beograd, where he became a teaching assistant. His first scientific publication, written in 1931, with his professor Dragoljub Jovanović, dealt with the methods of measurements of γ rays. In 1935 he was awarded a French Government scholarship for a 6 months visit to the Institut du Radium in Paris, one of the world's best centers for research in nuclear physics at that time. Instead of 6 months, he stayed for 4 years and contributed, with Irene Joliot-Curie, to some of the historic experiments which have led to the discovery of nuclear fission. He was "asked to leave French territory" because of the sensitive pre-war political situation in France. When war began in Yugoslavia, he joined the partizan movement and was assigned various important positions in the General Headquarters.

After the war, in 1945., he became a professor of physical chemistry at the University of Beograd, and a year later was elected a corresponding member of the Serbian Academy of Sciences (as it was then called). As an important act, Savić initiated the founding of the Institute for the study of the structure of matter in Vinča near Belgrade. He assured the scientific direction of the Institute until 1960., and remained at the University until 1966. For 10 years, starting in 1971., he was President

of the Serbian Academy of Sciences and Arts, and managed, during that time, to completely modernize its functioning. Prof. Savić gave the impulse to the foundation, in the Institute of Physics, of a high-pressure physics laboratory. He remained scientifically active (within the limitations imposed by his age and health) literally until the end of his life. His final publication (Savić and Čelebonović, 1994), appeared a few months after his death.

Pavle Savić was a scientist who managed to combine strict knowledge, bold original ideas and an intuitive "sense" of nature, an excellent teacher and a trusted friend. He will be remembered and missed by all those who knew him.

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REFERENCES

- Angert, N., Bourgarel, M. P., Brouzet, E., Cappi, R., Dekkers, D., Evans, J. et al: 1993, *CERN Heavy-ion facility design report*, CERN 93-01.
- Čelebonović, V.: 1986, *Earth, Moon and Planets*, 34, 59.
- Čelebonović, V.: 1987, presented at the II Workshop "Astrophysics in Yugoslavia", (Astronomical Observatory, Belgrade, September 8.-10.) and published in the book of abstracts, p. 41.
- Čelebonović, V.: 1988b, *Earth, Moon and Planets*, 42, 297.
- Čelebonović, V.: 1989d, *Earth, Moon and Planets*, 45, 291.
- Čelebonović, V.: 1989, *Bull. Obs. Astron. Belgrade*, 140, 47.
- Čelebonović, V.: 1990, *High Pressure Research*, 5, 693.
- Čelebonović, V.: 1991b, *Earth, Moon and Planets*, 54, 145.
- Čelebonović, V.: 1992c, *Earth, Moon and Planets*, 58, 203.
- de Groot, S. R. and Suttrop, L. G.: 1972, *Foundations of Electrodynamics*, North Holland Publ. Comp., Amsterdam.
- Geiger, K.: 1994, *preprint CERN-TH. 7429/94*.
- Girardeau, M. D.: 1990, *Phys. Rev.*, A41, 6935.
- Hiroi, Z. and Takano, M.: 1994, *preprint, to appear in Physica C* (proceedings of the Grenoble M2S - HTSC IV Conference).
- Lebowitz, J. L, Macris, N. and Martin, P. A.: 1992, *J. Stat. Phys.*, 67, 909.
- Leung, Y. C.: 1984, *Physics of Dense Matter*, Science Press/ World Scientific, Beijing and Singapore.
- Lindblom, L.: 1992, *Astrophys. J.*, 398, 569.

- Ma, D., Wang, Y., Chen, J. and Zhang, Y.: 1988, *J. Phys.*, C21, 3585.
- Ruelle, D.: 1969, *Statistical Mechanics*, W. A. Benjamin Inc., London.
- Satz, H.: 1993, preprint CERN - TH. 7064/93.
- Satz, H.: 1994, preprint CERN - TH. 7410/94.
- Savić, P.: 1961, *Bull. de la classe des Sci. Math. et natur. de l'Acad. Serbe des Sci. et des Arts*, XXVI, 107.
- Savić, P. and Kašanin, R.: 1962/65, *The Behaviour of Materials Under High Pressure I-IV*, Ed. by SANU, Beograd.
- Savić, P.: 1972, *C.R. des seances de la Soc. Serbe de Geologie pour 1968.- 1970*, p. 279.
- Savić, P.: 1981, *Adv. in Space Res.*, 1, 131.
- Savić, P. and Teleki, G.: 1986, *Earth, Moon and Planets*, 36, 139.
- Savić, P. and Urošević, V.: 1987, *Chem. Phys. Lett.*, 135, 393.
- Savić, P.: 1989, in: *50 years with nuclear fission*, ed. by J. W. Behrens and A. D. Carlson, p. 20, Ed. by the American Nuclear Society Inc., La Grange Park, IL 60525 USA.
- Savić, P. and Čelebonović, V.: 1994, in: *Proc. of the 1993. Joint AIRAPT/APS Con. on High Pressure Sci. and Technol.*, AIP conference proc., 309, p. 53, AIP Press, New York.
- Schukraft, J.: 1994, preprint CERN - PPE/94-139.
- Seaborg, G. T.: 1980, in: *Collection of papers devoted to Pavle Savić on the occasion of his seventieth birthday*, ed. by M. Garasanin, p. 39., Ed by SANU, Beograd.
- Sedrakian, A. D., Blaschke, D., Ropke, D. and Schulz, H.: 1994, *Phys. Lett.*, B338, 111.
- Seki, K.: 1989, *Mol. Cryst. Liq. Cryst.*, 171, 255.
- Stepinski, T. F.: 1991, *Publ. Astron. Soc. Pacific*, 103, 777.
- Stepinski, T. F. 1992, *Icarus*, 97, 130.
- Streater, R.F. and Wightman, A. S.: 1964, *PCT, spin and statistics and all that*, Benjamin, New York.
- Weber, F. and Glendenning, N. K.: 1993, *Lawrence Berkeley Lab.*, preprint LBL- 34783.
- Zharkov, V. N. and Trubitsyn, V. P.: 1980, *Physics of Planetary Interiors* (in Russian) Nauka Publ. House, Moscow.

ПОРЕКЛО РОТАЦИЈЕ, ФИЗИКА ГУСТЕ МАТЕРИЈЕ И СВЕ ОСТАЛО:
У СПОМЕН НА ПАВЛА САВИЋА

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Прегледни чланак

У раду су приказане основне физичке идеје и примери применљивости у астрофизици и физици семикласичне теорије густе материје коју су почетком шездесетих година предложили Павле Са-

вић и Радивоје Кашанин. Детаљно се говори и о Савићевој хипотези о пореклу ротације небесних тела. Рад је посвећен Павлу Савићу који је недавно преминуо.