Short Communication

SCIMEDPRESS

Open Access

Email: aaa@scimedpress.com

Archives of Astronomy and Astrophysics

Application of the Laws of Thermodynamics to Explain the Finite Size of Galaxies

Stabnikov PA and Babailov SP

Institute of Inorganic Chemistry, Siberian Branch, Novosibirsk, Russia

Publication Dates

Received date: November 10, 2025
Accepted date: November 26, 2025
Published date: November 29, 2025

*Corresponding Author

Babailov SP, Institute of Inorganic Chemistry, Siberian Branch, Novosibirsk, Russia, E-mail: stabnik@niic .nsc.ru

Citation

Stabnikov PA, Babailov SP (2025) Application of the Laws of Thermodynamics to Explain the Finite Size of Galaxies. SMP Arch As tron Astrophys 2: 1-7

Abstract

It is proposed to supplement four generally accepted fundamental interactions with two additional potentials that decrease with distance not so sharply as classical gravitation does. The first additional potential of attraction allows explaining the constancy of orbital rates of the stars at the peripheries of galaxies, and the second potential (repulsion) makes it possible to explain accelerated expansion of the universe. The use of two additional potentials allows explaining all the features of motion and structure of material objects at extra-long distances without introducing DM and DE or various modifications of Newton's laws. It is also shown that neither the introduction of DM nor the use of the MOND approach can explain the finite sizes of galaxies, while the application of thermodynamic laws to the motions of stars interacting through an additional attraction force F = GεMmR-1 allows explaining the finite sizes of galaxies.

Keywords: Gravitation; Celestial Mechanics; Galaxy: Kinematics and Dynamics; Dark Matter; Dark Energy

Introduction

To describe the rotation of planets around the Sun, it is sufficient to use the gravitational potential proposed by Newton. However, for longer distances, as determined by (Rubin & Ford 1970), the rates of star rotation at the peripheries of galaxies are almost constant. To explain this anomaly, it is necessary to add something in aid to the gravitational potential. So, various hypotheses have been proposed, and still are being put forward. Three hypotheses will be considered in the present work:

1) The existence of dark matter (DM) [1] and others;

2) Modification of Newton's laws [2] and others;

3) Certain contribution from a weak additional potential decreasing slower than gravitation with distance, but at long distances it becomes decisive [6, 7, 9, 13] and our works.

At present, hypothesis 1 has the largest number of followers. The followers of hypothesis 2 are not numerous. As far as hypothesis 3 is concerned, it has only few followers. In the present work, the possibility to explain the finite size of elliptic galaxies relying on thermodynamic laws is considered.

The Reasons of the Introduction of Dark Matter

The hypothesis of the existence of DM in the space was put forward for the first time in 1937 [14]. That authors was a follower of the stability of the Universe. However, analysis by means of the virial law, carried out for galaxies in the Coma Berenices cluster, has shown that the kinetic energy of galaxies motion with respect to each other is much larger than the potential energy of their attraction. This means that the system is unstable (the galaxies are flying away from each other). Fort his system to become thermodynamically stable, it is necessary to increase the potential energy of attraction between galaxies. This is why Zwicky had proposed the existence of certain DM restricting the galaxies flying away. However, this DM should contribute only into the potential energy of attraction and give no contribution into the kinetic energy of the cluster. If the assumed DM contributes into both the potential and kinetic energy, this supplement would not make the system stable. In other words, DM should possess gravitational mass but should not have any inertial mass. However, Zwicky could interpret the obtained paradoxical data as a confirmation of the expansion of the Universe, because eight years earlier, in 1929, Hubble had determined studying the red shift of light from galaxies that the further away the galaxies, the galaxies were, the higher was their recession rate. So, even so long ago it was unnecessary to rescue the stability of the Universe with the help of DM.

The second coming of DM is related to the authors [8], who had renovated it to explain almost constant rates of star rotation at the peripheries of galaxies. Indeed, it is potentially possible to explain almost constant orbital rates at the peripheries of galaxies with the help of invisible DM. However, to keep orbital rates constant, it is necessary that DM density should ever grow with an increase in the distance from the center it should be noted that there are only indirect data in favor of the existence of DM. No experimental data on its existence have been obtained up to now.

Relying on the assumed distribution of DM over the galaxy, we may conclude that usual matter is attracted to DM, otherwise it would be impossible to explain the constancy of star rates at the peripheries, while DM itself should repel from usual matter, because DM density is permanently increasing with an increase in the distance from a massive center. These are unusual attraction-repulsion properties for DM to possess. In addition, the problem of the maximal galaxy size arises. If DM density increases infinitely with an increase in the distance from the center, the dimensions of the galaxy would also be infinite, which is in contrast to observation data. If DM density beyond the boundaries of a galaxy is equal to zero or decreases slowly, the orbital rates of starts are also to decrease with distance, at a distance longer than these boundaries, similarly to the rates of planets in the Solar system. However, this is not observed at the peripheries of galaxies. In other words, it is impossible to explain the finiteness of galaxy sizes within the hypothesis of DM existence.

Hypotheses Correcting Newton's Laws

Logical difficulties arising from the introduction of DM promoted the formulation of more than 30 alternative models correcting Newton's laws and gravitation at long distances. For instance, Milgrom noted that Newtonian force was confirmed only for relatively high accelerations, and assumed that a slight nonlinearity of acceleration is manifested for interstellar distances, which allows explaining anomalous orbital rates at the peripheries of galaxies [5]. For this purpose, he replaced the equation for the force of uniformly accelerated motion F = mα in Newton's law by F = mα*μ(α/α0), where μ(α/α0) is some function, and α0 is a constant equal to ~10-10 m/s2. This approach has been called MOND hypothesis. However, the dependence of μ(α/α0) on the distance from the center of galaxy is not presented in an explicit form, but the statement is made that for the distances of the Earth's scale and for intra-stellar distances μ(α/α0) ~ 1, while for long distances μ(α/α0) ~ α/α0. Substituting μ(α/α0) value into Newton's law, we readily obtain the independence of the orbital satellite rate of the distance from the center for long distances. However, in this case, a question arises: what μ(α/α0) value is for even longer distances. In this approach, the most important issue is the dependence of μ(α/α0) on R. While this dependence is not represented in an explicit form, it is impossible to state how well this description is in describing the structure and motion of the matter at extra-long distances. Bekenstein proposed a relativistic variant of this approach [2], which was called TeVeS. However, both MOND and TeVeS allow explaining the constancy of orbital rates only for a small selected range of odistances in a galaxy. These approaches are also unable to explain why the sizes of galaxies are finite.

Assessment of Rotation Rates Depending on the Kind of Potential

To provide stable rotation of a body, it is necessary that the forces of attraction to the center are equal to the centrifugal force. For gravitational potential, attraction force is F=γmM/R2, while the centrifugal force is F=mV2/R. By equating these forces, it is easy to see that orbital motion is possible at any distance, even to infinity. For classical gravitation the squared velocities of satellites decrease in inverse proportion to the distance from the center. This agrees with the motion of planets in the Solar system. For the potential with attraction force F=δmM/R1, the rates of orbital motion are V2 = δM, that is, they are constant. However, it is necessary that the interaction forces related to this potential overpasses the gravitation interaction. This can be possible only at long distances.

Thermodynamic Analysis of the Stability of Orbital Motion

In 1870, R. Clausius developed the virial theorem, within which a conclusion on the thermodynamic stability of a system is made relying on the values of its mean kinetic and potential energies. According to the foundations of thermodynamics [3], a system will be stable only if its total energy E is negative. The potential energy U_{pot} can be either negative or positive, while kinetic energy T_{kin} is always positive. The stability of the system is defined by the value of E= U_{pot}. + T_{kin}. For the case when potential energy is a uniform k-power function of radius vector R, the known manual (Landau & Lifshitz 2001) gives equation 2*Tkin= k*Epot. In particular, for gravitational interaction with attraction force F = γMmR^{-2}, k = -1. This is presented in more detail in Table 1.

It follows from Table 1 that stable orbital systems are possible for the potentials of the kind of F ~ Rn, for which n is within the range of ε (-3; -1). For other hypothetic potentials, satellites would fly away or fall onto a massive center. A special case is the potential with n = -3 (F~R-3). In this case, stable circular orbital rotation is possible. The stable orbital velocity decreases in inverse proportion to the distance from the massive center. However, any minimal external action would destroy this system. The satellite would either fly away or fall onto the central body.

For the case of n = -2 (a system with the classical gravitational interaction γ, F~R-2) stable rotation of a body over a circular orbit is possible at any distance from the center because the total energy of the system E = Upot + Tkin = ½ Upot is negative. Moreover, this system has got a definite safety margin. For instance, if a definite amount of the kinetic energy is added to a satellite or subtracted from it, the satellite would change its circular orbit for elliptical one, but the system would not be destroyed. If we add kinetic energy, more than ½ Upot, to the satellite, the system will be destroyed, and the satellite will fly away.

For the case of n = -1, (the system with additional interaction δ, F~R-1), the rates of the steady rotation of stars around a center are constant (Tables 1), which is observed at the peripheries of elliptical galaxies. It should be stressed that the logarithmic function changes its sign with an increase in R/Rz. For R/Rz = 0, 60653, the logarithm is equal to -0,5, then the sum of Tkin and Upot is equal to zero. This is the critical value. For R/Rz<0,60653 the total energy of the system is E<0, and steady rotation is possible For R/Rz>0.60653, E>0, and orbital motion is impossible according to the laws of thermodynamics.

Table 1: Expressions for potential, kinetic and total energy of orbital motion depending on the forces of attraction.

k	n	attraction force	$U_{pot.}$	$T_{kin.}$	$V^2 =$	Virial theorem	E
3	2	$F_2 = G_2 mMR^2$	$G_2 mMR^3/3$	$G_2 mMR^3/2$	$G_2 MR^3$	$3U_{pot} = 2T_{kin}$	>0
2	1	$F_1 = G_1 mMR$	$G_1 mMR^2/2$	$G_1 mMR^2/2$	$G_1 MR^2$	$2U_{pot} = 2T_{kin}$	>0
1	0	$F_0 = G_0 mM$	$G_0 mMR$	$G_0 mMR/2$	$G_0 MR$	$U_{pot}. = 2T_{kin}.$	>0
*	-1	$F_{-1} = \delta mM/R$	$\delta mM[Ln(R/Rz)]$	$\delta mM/2$	δM	$U_{pot} = 2Ln(R/Rz)T_{kin}.$	**
-1	-2	$F_{-2} = \gamma mM/R^2$	$-\gamma mM/R$	$\gamma mM/R/2$	γMR^{-1}	$-U_{pot}. = 2T_{kin}.$	<0
-2	-3	$F_{-3} = G_{-3} mM/R^3$	$-G_{-3} mM/2R^2$	$G_{-3} mMR^2/2$	$G_{-3} MR^{-2}$	$-2U_{pot.} = 2T_{kin}.$	0
-3	-4	$F_{-4} = G_{-4} mM/R^4$	$-G_{-4} mM/3R^3$	$G_{-4} mMR^3/2$	$G_{-4} MR^{-3}$	$-3U_{pot.} = 2T_{kin}.$	>0

M and m – mass of the star and satellite; k – exponent (Rk) in the expression of energy, n – exponent (Rn) in the expression of the force of attraction (n = k-1).

E is the total energy of the system. If E < 0, then the system is stable. If E > 0, then the system is not stable. The relations for which the system is unstable are highlighted in red,

* - Upot expression. For n= -1 is given in [11].

** – stable rotation is possible close and impossible far from the center. Everything depends on the value of Ln(R/Rz).

The dependence of the potential energy of attraction on distance R from the massive center for the additional attraction potential with force F = δMmR-1 is shown in Figure 1.

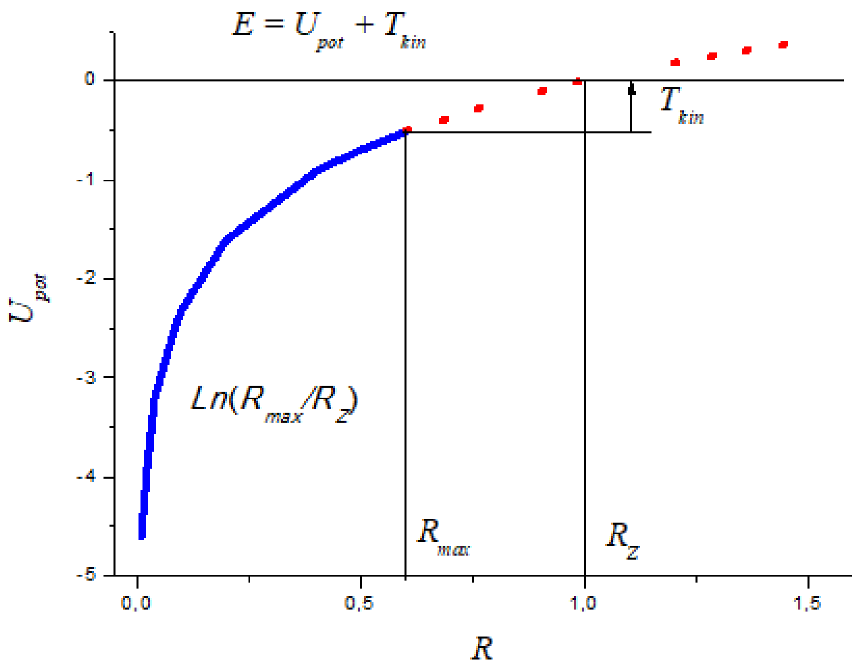


Figure 1: Dependence of potential energy Upot. from the distance to the massive center for attraction with force F = δMmR-1. The solid line indicates the possibility of stable orbital motion, the dash red line indicates the impossibility of stable orbits.

It follows from 1 that the orbital motion of starts is possible up to a definite maximal distance. At a longer distance, according to the laws of thermodynamics, either a stellar system or anybody with the tangential velocity V2 = δM cannot be held by the massive center.

Thus, the attraction potential with the force F = δMmR-1 allows us to explain the constancy of star rates at the peripheries of galaxies, the sizes of galaxies, and the uniform expansion of the Universe for even longer distances.

Estimation of the Constants of Additional Potentials

For the additional interaction to have almost no effect on the dynamics of rotation in the Solar system, δ should be substantially smaller than γ ($\gamma = 6{,}67428\ 10^{-11}\ H\times\ell^2\times kg^{-2}$, where H is force unit (Newton), and ℓ is length unit, m). Proceeding from these considerations, A.A. Rimsky-Korsakov assumed in 2003 [7] that $\delta \sim 1.710^{-31}\ H\times\ell\times kg^{-2}$. To fit star rotation in 60 galaxies, V.A. Puga used the expression for attraction forces: $F = Mm(\gamma R^{-2} + G2R^{-1} + G_1)$ [6]. The values obtained by fitting were: $G2 = (2.7\pm0.4)10^{-31}\ H\times\ell\times kg^{-2}$, $G_1 = (3.0\pm1.0)10^{-51}\ H\times kg^{-2}$. In our works, we used the value δ = G2 for the additional potential, and to explain the accelerated expansion of the Universe, we propose repulsion potential with the force F = -MmεR-0.5.

Conclusion

In the present work, the logical and thermodynamic analysis of hypotheses proposed for explaining the motion of matter at extra-long distances is carried out. The main feature of all fundamental interactions is their invisibility, similar to the hypothetical DM and DE. So, we suppose that this fact will allow replacing these entities by two additive potentials.

Why the method of additive potentials has not yet gained general recognition in astrophysics? In our opinion, the reason is htat the thermodynamic analysis of the possibility of orbital motion has not been carried out yet for different potentials.

Acknowledgments

The work was supported by the Ministry of Science and Higher Education of the Russian Federation (research project 121031700321-3).

References

1. Babailov SP, Stabnik PA (2023) Astrophysics & Aerospace Technology. Short Communication Volume 11, Issue 4.

2. Bekenstein J (2004) Relativistic gravitation theory for the modified Newtonian dynamics paradigm. Phys. Rev. D. 70, 083509.

3. Karno S, Klausius R, Tomson W, et al. (2009) Ed. A.K. Timiriazev. Moscow. URSS. P. 312

4. Landau LD, Lifshitz EM (2001) Mechanics, Pergamon Press, Moscow v.1. (Book, in Russian)

5. Milgrom M (1983) Astrophys J. 270: 365.

6. Puga VA (2014) JETP 146: 500.

7. Rimsky-Korsakov AA (2003) Proceedings of the Radium Institute. Khlopin. St. Petersburg. 10: 65-9.

8. Rubin V, Ford W (1970) Astrophys. J 159: 379.

9. Sanders R (1984) Astronomy and Astrophysics 136: L21-3.

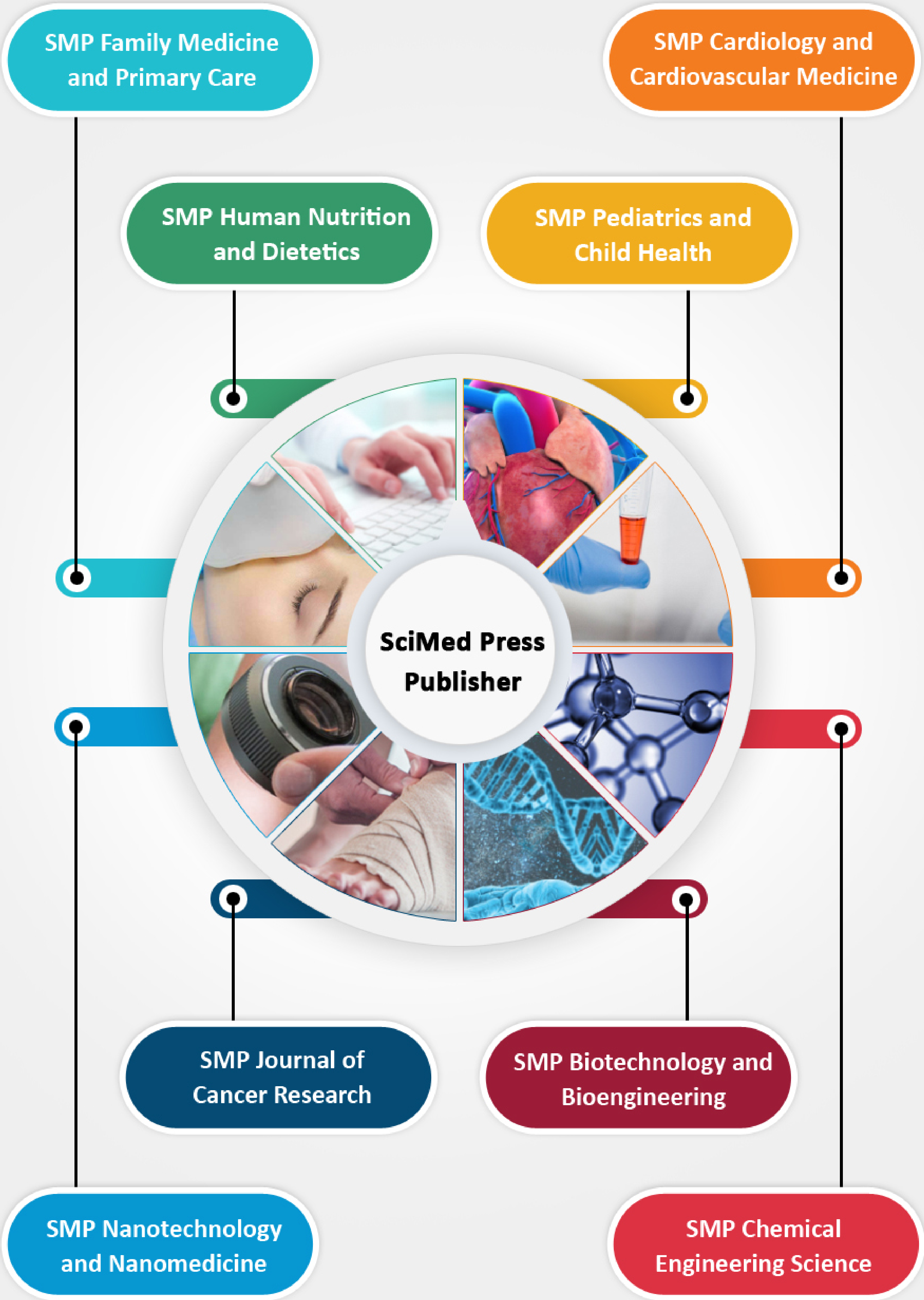
10. Stabnikov P, Babailov S (2015) Astrobiol Outreach, 3: 4.

11. Stabnikov PA, Babailov SP (2017) J. Astrophys. Aerospace Technol. 5: 1-4.

12. Stabnikov PA, Babailov SP (2021) Intern. J. Astronaut Aeronautical Eng. 6: 50.

13. Tohline J (1982) Proceedings of the Symposium, Besancon, France, A83-49201 24-89.

14. Zwicky F, (1937), Astroph J. 86: 217.


SMP Family Medicine and Primary Care
SMP Cardiology and Cardiovascular Medicine
SMP Human Nutrition and Dietetics
SMP Pediatrics and Child Health
SciMed Press Publisher
SMP Journal of Cancer Research
SMP Biotechnology and Bioengineering
SMP Nanotechnology and Nanomedicine
SMP Chemical Engineering Science