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Editorial: In Memoriam of Professor Dr. Vojislav V. Mitić (1955–2021): A Distinguished Scholar With Unique Characters in the Fields of Brownian Motion, Fractal Analysis, and Ceramic Chemistry

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Editorial on the Research Topic

Advanced Structures and Properties of Electronic Ceramic Materials

A grievous loss of a close friend and others with pioneering impact on scientific research–Professor Vojislav Mitić have shown an attitude of extraordinary persistence and diligence to his academic works. He made remarkable contributions to the emerging structure analysis of the fracture nature, Brownian motions of ceramic materials, microorganisms, and the related biomolecules. He had considerate, circumspect, and enthusiastic behaviors towards his colleagues.

Prof. Mitić, President of the Serbian Ceramics Society, passed away on 27 September 2021. A week before (September 20–22), he was chairing the Conference "Advanced Ceramics and Applications IX" held in Belgrade. Because of being infected by COVID-19, he was sent to a hospital for treatment afterwards. At that time, his family members, colleagues, friends, and students prayed for him and all wished him back to work soon, to which he was always so devoted. Almost for a week Mitić fought against the deadly disease. Unfortunately, he lost his last battle to SARS-CoV-2. Our life becomes imperfect without him. Nevertheless, we believe that Mitić, a hero of life, would insist us to move on and strive for hardship.

CAREER

Professor Dr. Vojislav V. Mitić was born on March 8 in 1955. He obtained his B.Sc. degree at the University of Nis in 1982, M.Sc. degree at the University of Belgrade in 1990, and Ph.D. degree in Material Science at the University of Nis in 1995. Then he was appointed as a Research Scientist at the Institute of Technical Sciences of the Serbian Academy of Sciences and Arts (SASA). In 1999, he was promoted to Senior Scientific Associate by SASA and elected into the Center for Multidisciplinary Studies, University of Belgrade where his main research was focused on electronic ceramic materials. In 2004, he obtained a position of Scientific Adviser at SASA. Mitić published over 500 scientific articles. In particular, he pioneered applications of fractal geometry and analysis in the studies of ceramic materials, nanotechnology, energy issues, and Brownian motion.

During his academic career, Mitić was invited by many renowned institutes to deliver scientific talks. These included Alfred University, North Carolina Central University (United States), Korean Institute of Science and Technology (South Korea), COMSATS Institute of Information Technology (Pakistan), University of Miskolc (Hungary), Sumy State University (Ukraine), Tomsk State University, Tomsk Polytechnic University, Institute of Strength Physics and Material Sciences of Russian Academy of Sciences (Russian Federation), etc.

Prof. Mitić was elected as the President of the Serbian Ceramics Society and co-founded the Conference "Advanced Ceramics and Applications". Under his leadership, this conference has been operated for a decade long and received international recognition from academic and industrial circles. It has great influence not only on all Balkan countries but also in Western and Asian regions. He also actively participated in many international conferences held in mainland China, Croatia, Germany, Hungry, India, Republic Srpska, Spain, Switzerland, United States, and others. He was invited as a Plenary Lecture at the Presidential Symposium of The 18th Asian Chemical Congress (ACC) held in Taipei, Taiwan (2019).

Being a highly regarded and influential scholar, Mitić became the Chairman of the Chapter of American Ceramic Society, Fellow of American Ceramic Society, General Secretary of International Institute of Science of Sintering, Member of several high-ranked international organizations, including European Academy of Sciences and Arts, World Academy of Ceramics, International Ceramic Federation, International Society for Stereology, European Microbeam Analysis Society, Royal Microscopic Society (United Kingdom), Material Research Society of Japan, IEEE, and Australian Ceramic Society.

Between February and May of 2019, Mitić was invited as a Visiting Professor by National Tsing Hua University. He brought his wife and two sons to Hsinchu, Taiwan for an academic visit for three months, during which he had his 64-year-old birthday. The scenes of Mitić's family members enjoying the local foods and walking together on Tsing Hua campus are engraved in our deep heart.

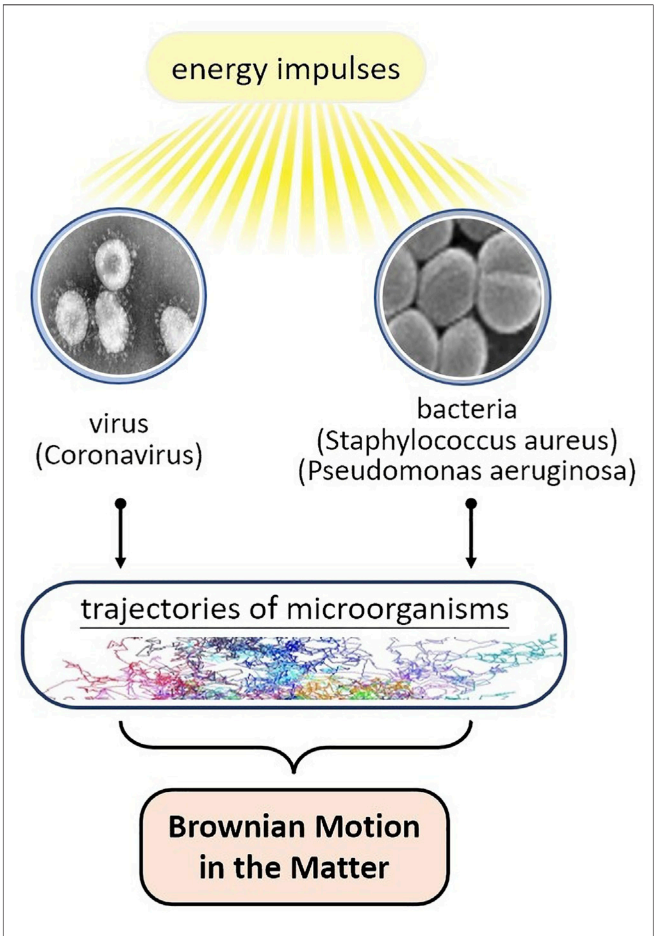


FIGURE 1 | Brownian motion of viruses and bacteria activated by energy impulses.

RECENT CONTRIBUTIONS TO BROWNIAN MOTION AND FRACTAL NATURE

Brownian Motion

The research interests of Prof. Mitić involved ceramic materials, fractals, materials microstructure analysis, graph theory, neural networks, and sintering process. He was a creative scientist with perspectives and had an open vision to discover new fundamental results. Mitić distinguished himself with persistence and enthusiasm to pursue the scientific answers to the questions that there are many open problems. This unique character brought him to a brand-new topic of micro particles in Brownian motion. For instance, there are large technological limitations to make layers thinner and thinner for the demands of microelectronics. Instead of using different microdevices technological integration, he endeavored to open new frontiers in the fields of electronics parameter integrations. Though this scientific and research problem is not easy to tackle, he took a much deeper and more precise approach by investigating the particles motion and their trajectories phenomenal changes. His idea was to establish control over the relation order–disorder on the particles motion and their collision effects by Brownian motion phenomena in the frame of fractal nature matter. He developed mathematical–physics methods to control chaotic motion and transform the controlled structures to the real particles order (Mitić et al., 2020b). The results would explain some processes in the nature of material sciences, especially for ceramic structures.

Mitić was not only productive scientifically but also possessed the magnetic power to drive international scientists and interdisciplinary experts to team up. Under his leadership and together with his colleagues from Taiwan, Ukraine, and the United States, the research team explored the connection between micro particles and microorganisms motion in the nature (Mitić et al., 2020c). They successfully obtained 2D trajectories of fractal analysis and Brownian motion for sub-microorganisms, which were energized by outer impulses (**Figure 1**). Furthermore, the 3D trajectories results confirmed the real images of sub-microorganisms motion in the space. The authors found that there are similar processes between particles motion in the matter and sub-microorganisms motion characterized by fractal nature. This specific idea of biomimetic similarities enables the particles motion from phenomena in the live systems to compare with the particles motion in the inorganic world. It is truly original and leads to understand and recognize the biunivocal different phenomena.

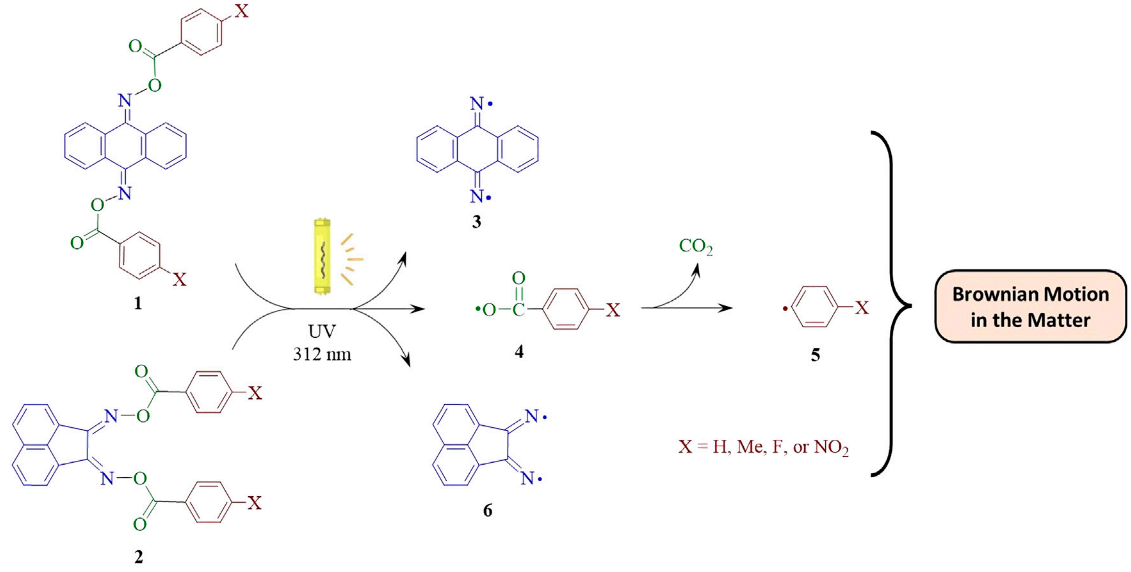
Regarding the intention to connect micromotions in fractalized Brownian motion like electrons and sub-microorganisms world, Mitić practically and actively implemented his ideals to the research plans on alive nature phenomena. One cutting-edge achievement is the establishment of the coronavirus chaotic motion to controlled corona dynamic by fractal nature analysis (Mitić et al., 2021). During the year of 2020, the coronavirus outbreak namely COVID-19 has been drastically gripping the world's attention. At the onset, the scientists were working very hard to understand this new coronavirus (SARS-CoV-2). The problems include what its molecular structure, target receptors, molecular pathogenesis, etc., in particular, why it is so highly transmissible in comparison with other β-CoV genera severe acute respiratory syndrome (SARS) and Middle East respiratory syndrome (MERS). During that period of time, the minimum dose for COVID-19 infection has not yet been clearly found. Some questions about aerosol transmission must be investigated and answered.

A quite new finding is that Mitić and his colleagues successfully combined very rare coronavirus motion sub-microstructures images from worldwide and performed microstructure analysis. *Those images were resolved by time interval method and fractals to give the motion trajectories of viruses.* The obtained diagrams were well defined in a way to control over Brownian chaotic motion as a bridge between chaotic disorder to control disorder. Hence they were able to reconstruct the viruses' trajectories (**Figure 1**). Based on experimental results with viruses, the transformation of their trajectories as a cyclic and progressive dynamic was recognized. The results reported therein are on the way to provide more understanding about this virus motion direction. *It is the first time in the biophysics to disclose results on the coronavirus case by mathematical physical interval fractal analysis.* Mitić opened a very new perspective to lead to complete control of coronavirus cases by a physical, instead of a biological method. Additionally, their results may help scientists to answer questions about aerosol transmission for COVID-19.

Another outstanding work achieved by Mitić and his coworkers included their results on motion of microorganisms within the molecular biology processes (Randjelović et al., 2021). Two special bacteria, *Staphylococcus aureus* and *Pseudomonas aeruginosa*, were chosen as the targets for analysis (**Figure 1**). On the basis of their Brownian motion phenomena, the research team built hierarchy based on molecular-microorganism structures. They developed the analyzed joint parameters between particles in alive and non-alive in biophysical systems. Calculations were performed appropriately by use of discrete mean square approximation. It will be of significance to some biologists and physicists working on the related fields. One week before this paper was accepted for publication, Mitić was in the hospital to fight for his life and battled against SARS-CoV-2. All of the co-authors in this paper share the same grief and sadness though they are working in different institutions.

The efforts of Mitić in Brownian motion were broadened to biomolecules like DNA (Aleksić et al., 2021; Hwu et al., 2021). In collaboration with Hwu and Tsay, series of bis-oxime ester conjugates were designed and synthesized (**Scheme 1**). They bear special intercalating moieties, including 9,10-anthraquinone, acenaphthylene-1,2-dione, and indane-1,3-dione. These oxime ester conjugates were found to cleave DNA upon UV irradiation at room temperature for 2.0 h. The results of gel electrophoresis show that certain conjugates containing an anthraquinone or an acenaphthylenedione intercalator (i.e., **1** and **2**, respectively, in **Scheme 1**) exhibit appealing DNA nicking potency. Both of them with a nitro substituent on the benzoyl moieties cleave DNA at concentrations as low as 37 and 6.5 μM, respectively, when the (form II)/(form I) ratio is 1.0.

DNA scissions by organic compounds may proceed through a radical process. Such compounds are of great value in photodynamic therapy and gene therapy. Certain organic radicals, such as hydroxyl radical, other oxygen-centered radicals, nitric oxide radical, other nitrogen-centered radicals, carbon-centered radicals, etc., have been proved that they participate in DNA cleavage (Hwu et al., 1994; Sugiura and Matsumoto, 1995; Hwu et al., 1997; Hwu et al., 2009). Based on the EPR and trapping experiments, the bis-iminyl radical (i.e., **3** and **6**), benzoyloxy radical **4**, and phenyl radical **5** are formed during the photolysis of the oxime esters (**Scheme 1**). Moreover, results from photolytic fragmentation studies reveal that the benzoyloxy radicals and their degraded aryl radical intermediates are essential to DNA scission rather than the bis-iminyl radicals. The goal of this study was to identify the species that are responsible for the DNA cleavage. Their specificity of individual reactant movement, including its rate, would affect the reaction. The future research planned by Mitić was to establish the radicals' movement modeling. *He anticipated that the stochastic movement of each radical may have certain specificity or regularity, which is associated with fractional Brownian motion. It could be characterized by its fractal dimension.* We will continue his idea to



SCHEME 1 | Brownian motion of radicals generated by photolysis with UV light.

establish an ordering of radicals, which he suggested to be related to their capacity in DNA cleavage.

Fractal Analysis

As early as ~1996 (Mitić et al., 1996a) Mitić had made significant contributions to the development of methods related to the fractal nature analysis in reconstruction of the material structures. It is now regarded as one of the novel and reliable procedures, which are used for characterization of microstructure of various materials in the form of grains or pores. His research targets were focused on barium titanates and ceramics. The established methods can also be applied to refractory, silicates, and other materials. On the basis of the fractal analysis of grains and perimeters, his group has shown many times with success that their reconstruction can be accomplished by use of the Richardson's method of a changeable yardstick. Mitić's application of frontiers were based on the fractal nature of material structure. In practice, it turns to be an important natural necessity in the triad contact point. A variety of material reconstruction and characterization entails the prediction of microstructure properties within the miniaturization frame (Mitić et al., 2010a; Mitić et al., 2011; Mitić et al., 2013a; Mitić et al., 2015a).

In the modern world, a number of new and practical scientific approaches are constituted by the relationship between the structure analysis of the fractal nature and electronics. These include the essential nanoscience and technology, electronic ceramic materials as well as various perovskites. Organometal halide perovskites are playing a vital role on solar cells and regarded as highly promising materials for energy conversion with cost-effectiveness. Nowadays the real structural nature of intergranular capacities can be applied to realize the capacity phenomenon.

Mitić's research team employed statistical method to determine the influence caused by the temperatures at different levels of sintering. Among a number of conducted experiments, one outstanding example was at high temperatures between 1,320 and 1,380°C applied on the size of contact area for $BaTiO_3$ (with a cubic perovskite structure) doped with different additives (Mitić et al., 2010b; Mitić et al., 2012a; Paunović et al., 2012). All of the steps involving the use of fractals were new methods related to the grain and pore structure characterization. Through a unique approach, he successfully combined the Voronoi model and fractals. The evidence between the terrestrial surface morphology observed from outer space and the observation of grain surface structures on microstructure level constitutes the basis for applications of the Voronoi model. Mitić noticed the morphological shape properties and thus used the method of Voronoi tessellation for grain surface modeling. Consequently, a much more realistic approximation to physically advanced technology structures than Euclidean geometry was obtained. These results indicate that procedural parameter likely exhibits fractal behavior, such as the fluctuations of particle energy and Brownian motion.

In unemployed nano-sized domains, the $BaTiO_3$ and other ceramic materials have fractal configuration nature based on three phenomena. First, ceramic grains have fractal shape looking as a contour in cross section or as a surface. Second, the "negative space" is made of pores and intergranular space. Third, fractal Brownian motion within the material, during and after sintering, is in the form of micro particles (i.e., ions, atoms, and electrons) to flow. Mitić et al. (2019) extended the Coble's model by fractal nature correction along with already-generalized Euclidean geometries for studies of ceramic materials and the associated energy (Mitić et al., 2015d). These triple factors were found to make the very peculiar microelectronic environment electro-static/dynamic combination. The stress was set on inter-granular micro-capacity in function of higher energy harvesting and storage. Application of the constructive fractal theory can be applied to identify the micro-capacitors with fractal electrodes. The approach was based on the iterative process of interpolation, which is compatible with the grain model itself. Inter-granular permeability was taken by Mitić as the fundamental thermodynamic parameter function of temperature and enthalpy (Gibbs free energy).

Another outstanding project carried out by Mitić was the ceramic microstructure consolidation prognosis from the viewpoint of the fractal aspects (Mitić et al., 1996b). He explored the possibility of gaining a better insight to the internal properties associated with intergranular micro capacity of electro-ceramics. The overall energy distribution would be dependent on effects of ceramic grain surface fractality and material particle dynamics. His theoretical–experimental model clarified the relationship between energy and fractality. This turns out to be the mainspring in the final prognosis of material properties. His research outcome with high prevision of the applied fractal nature mathematics indeed opens new perspectives to evaluate the intergranular capacity and understand the micro-impedance spatial distribution better. It is beneficial to the developments of electronic circuit integration and miniaturization in the future.

With these new concepts in Mitic's mind, he proceeded towards advanced components and device packaging. He foresaw the current semiconductor technology already-limited in certain extend and envisioned the needs of some theoretical and experimental advances. Further investigation in the area of fractal nature domain and material structure analysis were moving forward and going deeper. It turns out of importance for a more precise surface contact in the energy storage and material consolidation for different battery systems. The outgrowth confirmed the shape of grains as microstructure constituents, which were resulting from the reconstruction of possibilities that are involving the application of Brownian motion particles. These accomplishments represent scientific research over a long term in Mitić's life, which merges into the field of electronic material fractal analysis (Mitić et al., 2012a; Mitić et al., 2015b; Mitić et al., 2020a).

Introduction of fractal correction function related to basic electrochemical and thermodynamic parameters is an original contribution of Mitić to the field of electrochemistry. It nurtures a new approach towards intergranular capacity. The outcomes are of significance to the energy storage aspect and provide the fundamentals to the future applications (Mitić et al., 1996b). These include creation of perspectives and solutions for advanced miniaturization, electronic parameters multilevel integration, unprecedented solutions for better components and electronic circuit packaging, as well as characteristics of circuits, components, and materials.

The fractal nature phenomena were stressed by Mitić in the form of a correction factor α that was added as a multiplicative constant for the ceramic material relative permittivity. His inventive approach was to establish the α value by deriving it from the outline fractal dimension or a ceramic grain/pore surface. Then he developed further by involving the Brownian motion of particles. He presented a frontier idea about microstructure morphology in relation with various material properties (Mitić et al., 2012b).

Numerous methods for microstructure modeling grain geometry and grain boundary surface were also developed by Mitić. The results are vital to the optimization of a variety of electric properties. Most of these methods were based on the calculation of contact surfaces in the prescribed volume of the ceramic samples. His prime perception for the Voronoi approach was on the basis of the evident similarity between the terrestrial surface morphology observed from outer space and the grain surface on a microstructure level (Mitić et al., 2012a; Mitić et al., 2015c).

PROSPECT

Prof. Mitić was a distinguished scholar with profound vision, broad knowledge, and great leadership. He possessed an exceptional character with high devotion to flourish our societies and benefit mankind. In May 2020 he co-published a paper to address *the Global Leadership Challenge in the 21st Century with an integrated and strategic perspective in science, engineering, and technology* (Fiorini et al., 2020) At that point, the COVID-19 as a pandemic was devastatingly threatening our lives and disrupting our societies. To respond this outbreak, Mitić acted and exercised his expertise to conduct the research projects related to SARS-CoV-2.

Till now, SARS-CoV-2 has already infected over 261,435,768 people, killed more than 5,207,634 in total as of 30 November 2021 reported by World Health Organization. Moreover, COVID-19 has already been affecting 216 countries and territories around the world. Mitić and his coworkers has opened up a new frontier to understand and predict the Brownian motion nature of coronavirus (Mitić et al., 2021). Their findings resulting from the mathematical–physical–biological multidisciplinary dimension provide a new prospective on the complexity of coronavirus. It was anticipated by him that these results could be helpful for further analysis of the level microbiology and clinical studies in infective medicine and epidemiology. The ultimate goal of his idea is to recognize the kinetic direction of viruses within organ cells.

Throughout the entire career, Mitić has also devoted very much of his efforts on the illustration of different features among the Euclidean geometry, Voronoi model, and the fractal nature of matters with related geometry. He used many examples to demonstrate and explain the varieties emerging from alloys, electro-ceramics, and bio-ceramics (Mitić et al., 1996c; Mitić et al., 2010b; Mitić et al., 2013b; Mitić et al., 2020c). He proved what was possible to be done by applying the Voronoi model and fractals. Use of the Voronoi model led to faster microstructure reconstructions while by fractals came up a more precisely reconstructed and predicted morphology structure. Furthermore, he highlighted the advantages by applying the joint approach and model that involved the use of the Voronoi model and fractals together. Mitić showed an original approach both in theory and practice.

The unique approach with the combination of the Voronoi model and fractals offer a much more natural approximation of physically advanced technology structures than Euclidean geometry. Therefore, the procedural parameters would have fractals in nature with energy changing and Brownian walk (Mitić et al., 2020c; Aleksić et al., 2021; Hwu et al., 2021; Mitić et al., 2021; Randjelović et al., 2021). With regard to the necessity of future miniaturization, it is of importance to come up with new methods for the prediction of microstructure morphology that could be faster and more precise (Mitić et al., 2013a). All of these concerns lead to the essential point of morphology prediction (Mitić et al., 2015d). In this era and times, Mitić has illuminated a new direction and opened the frontiers for future research.

In the late 20th century, artificial neural networks applications in science and technology has quickly drawn great attentions worldwide. Extensive research on the topics of biomimetic and biophysical phenomena have been continuously conducted and carried out. The outcomes lead to understanding of certain functions of neurons in living organism nerve system. These basic element processes produce signals by a simple algorithm. The input signals are massively parallel processed; the output presents the superposition of all parallel processed signals. On the basis of these principles, Mitić started to work on artificial neural networks for solving various problems, such as pattern recognition, clustering, and functional optimization (Mitić et al., 2020c). His research team analyzed thermophysical parameters of samples based on Murata powders and consolidated by sintering processes. Among different physical properties, he applied the neural network approach on grain sizes distribution as a function of the sintering temperature higher than 1,100°C (Mitić et al., 2022).

Furthermore, Mitić continued to apply neural networks to prognose structural and thermophysical parameters. Consolidation sintering process is crucial to prognose; yet its design requires many parameters (Mitić et al., 2020c; Mitić et al., 2021). To avoid long and even incorrect experiments that are wasting time, materials, and energy, he introduced an artificial neural network method (Mitić et al., 2020a). He provided a very efficient procedure in projecting the parameters and assisted the production of ceramic samples with success. These results are valuable in prediction and design of microstructure parameters for advanced microelectronic miniaturization development in the future (Mitić et al., 2020c). The work of Mitić was original and practical for real microstructure projecting, especially on the phenomena within the thin films coating around the grains. He paved a new way in the advancement of fractal microelectronics.

It is too sudden for Mitić to leave us as there are still many brilliant ideals and projects anticipated by him. All of his colleagues and friends will remember his hearty smiles. In particular, the spirit of profound perception and continuous innovation is Prof. Mitić's greatest legacy to us.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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