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Preface: High-resolution space-borne radio astronomy

This Special Issue presents a brief overview of the state of affairs in high-resolution space-borne radio astronomy. A high angular resolution can be achieved in radio astronomy by employing interferometry, in particular – its "ultimate" incarnation, Very Long Baseline Interferometry (VLBI). The timing of this publication appears to be very appropriate: the year of 2019 will be remembered in the history of radio astronomy by two milestones relevant to the topic of this Special Issue.

First, the second and so far the last dedicated Space VLBI mission, the Russia-led *RadioAstron* (Kardashev et al., 2013) has completed its in-orbit life after 7.5 years of successful operations. This mission, together with its two predecessors, the first demonstration Orbital VLBI with the NASA's Tracking and Data Relay Satellite System (OVLBI–TDRSS) in 1986–1988 (Levy et al., 1986) and the first dedicated Space VLBI mission, the Japan-led VSOP/HALCA (Hirabayashi et al., 1998), constitute the first examples of VLBI systems with baselines exceeding the Earth diameter. The RadioAstron mission, some results of which are presented in this Special Issue, provided the highest angular resolution at its observing wavelengths. A review of the RadioAstro results, together with complementary ground-based studies and some topics on RadioAstron operations, are presented in this Special Issue in the papers by Bayandina et al., Bruni et al., Edwards et al., Gabuzda et al., Jauncey et al., Kovalev Yu.A. et al., Kovalev Y.Y. et al., Kravchenko et al., Richards et al., Shakhvorostova et al., Shatskaya et al., Zakhvatkin et al., and Zensus et al.

Second, the year of 2019 marked the beginning of the era of direct imaging studies of super-massive black holes and their relativistic "shadows". A ground-breaking result has been demonstrated by the global Earth-based VLBI observations at 230 GHz conducted by the Event Horizon Telescope (EHT) Collaboration (2019). However, further studies of black holes' shadows with linear resolution comparable to their event horizons require even sharper vision. This could be achieved either by observing at sub-millimeter wavelengths, shorter than demonstrated in the recent EHT observations at the wavelength of 1.3 mm, or employing even longer than the current EHT baselines – or a combination of these two recipes. Both these options, sub-millimeter wavelengths and longer baselines, require space-borne systems, which are the focus of several papers presented in this Special Issue (Fish et al., and Linz et al.).

But a drive toward higher angular resolution is topical not only at short, millimeter and sub-millimeter waves. It is influencing the radio astronomy agenda for cosmological and astrophysical studies at the opposite end of the radio domain of the electromagnetic spectrum, at ultra-long wavelengths (ULW), longer than the ionosphere cut-off of about 30 m (the paper by Bentum et al.). First indicative results of observations at ultra-long wavelengths might be achieved as early as 2019 in several experiments deployed by the Chinese Lunar mission *Chang'E-4*. The family of ultra-long-wavelength experiments on this mission included the ULW experiments on the *Longjiang-2* microsatellite, the Netherlands-China Low-Frequency Experiment deployed on the relay satellite *Queqiao*, and the ULW experiment on the *Chang'E-4* lander positioned on the Moon's far side. The paper by An et al. in this Special Issue gives a brief overview of a broad range of Space VLBI developments in China across the electromagnetic spectrum, including the ULW domain.

One paper, by Nunes et al., is somewhat outside of the "high-resolution" theme of this Special Issue. It presents a promising attempt of using a Space VLBI instrumentation for fundamental physics, namely, verification of the Einstein Equivalence Principle.

Finally, one contribution in this Special Issue is rather atypical for professional science journals. David Jauncey, one of very few active participants of all three Space VLBI missions implemented to date and the only co-author of all three main publications representing each of these missions, OVLBI–TDRSS, VSOP/HALCA and *RadioAstron* (Levy et al., 1986; Hirabayashi et al., 1998; Kardashev et al., 2013, respectively), offered a series of his sketches made at numerous Space VLBI meetings around the globe over the past several decades. This series would help the readers of the Special Issue to get a

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sense of the spirit of truly global and collaborative science of VLBI.

Advances in Space Research presents a Special Issue dedicated to Space VLBI not for the first time: the first such publication took place in 2000 (Hirabyashi et al., 2000). In a way, that publication marked the beginning of the first generation dedicated Space VLBI missions, which had started with the launch of VSOP/HALCA in 1997. The current, the second Space VLBI Special Issue marks the end of the first generation era with the completion of the *RadioAstron* mission in 2019.

Over the past decades a number of international meetings devoted to the science case, engineering developments, in-orbit operations and observational results of high-resolution space-borne radio astronomy systems took place at various locations around the world. Most of them were "self-standing", but some have been conducted under the umbrella of major international scientific unions, such as the Committee for Space Research (COSPAR), International Astronomical Union (IAU) and International Radio Science Union (URSI). They played an important role in amalgamating the international efforts in support to the high resolution radio astronomy.

The guest editor expresses his gratitude to all authors of this Special Issue and more than 60 peer-reviewers. Together, they made this Special Issue a comprehensive compendium of modern high-resolution space-borne radio astronomy. Invaluable assistance in preparation of the papers for publication was provided by the Journal Managers Cari Bottois and Henna Hakala. Special thanks go to Margaret (Peggy) Ann Shea, the past Chief Editor of *Advances in Space Research,* who not only led the overall editorial work and handled several papers in this Special Issue (as well as in the Space VLBI Special Issue of *Advances in Space Research* 26(4), 2000), but patiently taught the layman guest editor some essentials of the editorial work.

Implementation of high-resolution radio astronomy in Space as operational missions involved thousands of people in many countries. But as in any massive scientific endeavour, Space VLBI came about owing to the pioneering impact of just a few. One of those few was Nikolai Kardashev. He was one of the initiators of VLBI as a powerful radio astronomy technique, the founder of the *RadioAstron* project and simply one of the greatest minds in the radio astronomy of the past seven decades. This Special Issue carries two papers, by Kovalev Y.Y. et al. (p. 705) and Kovalev Yu.A. et al. (p. 745), which have been worked on with active Nikolai's participation. The guest editor of this Special Issue was privileged to work closely with Nikolai Kardashev for forty years. Sadly, Nikolai Kardashev passed away in August 2019. On behalf of many friends and colleagues of Nikolai Kardashev, the guest editor dedicates this Special Issue on space-borne high-resolution radio astronomy, the field of science in which Nikolai Kardashev made many pivotal contributions, to his memory.

Nikolai Kardashev
1932 – 2019

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