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# The Heliosphere in the Local Interstellar Medium: Into the Unknown

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The first International Space Science Institute (ISSI) book in the *Space Sciences Series of ISSI* was “The Heliosphere in the Local Interstellar Medium: Proceedings of the First ISSI Workshop 6–10 November 1995, Bern, Switzerland” edited by R. von Steiger, R. Lallement, and M.A. Lee and published in 1996. In 1995 Voyager 1 was at 60 AU and Voyager 2 at 46 AU; the first crossing of the termination shock was 20 years away and the first HP crossing 27 years in the future. The Voyagers continued outward. New Horizons was launched with more modern instrumentation and explored low-latitude regions of the outer heliosphere. Energetic neutral atoms observed by IBEX and CASSINI allowed exploration of the heliosphere over the whole sky. By 2016 entirely new regions of space had been explored. The Voyagers had both crossed the termination shock and observed the heliosheath region. V1 had crossed the heliopause and observed the interstellar medium. Clearly it was time for an ISSI update on the outer heliosphere.

An ISSI Forum on ‘Future outstanding questions for solar system planetary science, and associated key representative space missions, in the context of a H2061 foresight exercise’ was led by Dr. Michel Blanc. In this forum, an invited talk was given by Dr. Veerle Sterken, ‘The heliosphere and its Interaction with the Local Interstellar Cloud’. This talk was the

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basis for an ISSI workshop proposal, 'Heliospheres and Astrospheres', submitted by Veerle Sterken in 2016 and re-submitted by John Richardson in 2017 as "The Heliosphere-LISM interaction". This proposal was accepted as a stand-alone ISSI workshop. After many COVID related delays, the workshop 'The heliosphere in the local interstellar medium' took place at ISSI from 8–12 November 2021. After the long and isolated Corona period, the real-life interaction was scientifically stimulating and new ISSI equipment for hybrid meetings allowed remote participation. This workshop followed a different format due to the Covid delays; already advanced draft chapters were presented at the workshop, with discussions centered on adding missing science and reducing overlaps. The resulting manuscripts describe the status of all aspects of outer heliospheric science, the puzzles that remain, and plans for future work.

An advantage of these delays was that V2 crossed the heliopause in 2018 and entered the LISM, giving two complete transits of the heliosphere. The initial reconnaissance of the heliosphere and very local interstellar medium (VLISM) is complete with in situ measurements, observations of energetic neutral atoms (ENAs), neutral VLISM H and He, UV emissions, and interstellar dust. This book reviews the current state of knowledge of the heliosphere's interaction with the VLISM.

Zank et al. give a history of outer heliosphere research after 1996. Richardson et al. describe in situ observations of the outer heliosphere, heliosheath, and VLISM. Kleimann et al. discuss theoretical progress in understanding the data and modeling the global heliosphere. Baliukin et al. discuss the UV data and models. Galli et al. describe neutral atom observations at energies below 10 keV. Dialynis et al. review the structure of the global heliosphere as seen by in-situ ions from the Voyagers and remotely sensed ENAs from Cassini. Zirnstein et al. discuss in situ observations of interstellar pickup ions from 1 au to the outer heliosphere. Sokol et al. present an overview of theory and modeling of interstellar neutrals, pickup ions, and ENAs throughout the heliosphere. Giacalone et al. review anomalous cosmic rays and heliospheric energetic particles in the heliosphere. Rankin et al. discuss galactic cosmic rays throughout the heliosphere and in the VLISM. Engelbrecht et al. describe the theory of cosmic ray transport in and near the heliosphere. Perri et al. review theoretical and observational developments in particle acceleration at shocks. Mostafavi et al. describe shocks and magnetic field observations in the VLISM. Fraternali et al. discuss the turbulence in the outer heliosphere and VLISM. Linsky et al. describe inhomogeneities in the LISM and its relation to the heliosphere. Sterken et al. describe observations and models of dust in and near the heliosphere. Herbst et al. compare observations and models of the astrospheres of planet-hosting cool stars. Finally, Brandt et al. discuss futures missions and observations needed to fully understand our heliosphere.

**Dedication:** The present collection of papers is number 88 in the *Space Sciences Series of ISSI*, forming a nice pair together with the first collection mentioned above, which appeared more than a quarter century ago. Hence it is a good time to pause and reflect on how the series, and ISSI as a whole, came into being. Back in the 1980s, when the six missions to comet 1P/Halley were successfully coordinated by the Interagency Consultative Group (IACG), Johannes Geiss (1925–2020) realized the potential of a new kind of space science institute. Such an institute would not be preoccupied with the design and construction of the next generation of space experiments, but rather provide a platform where space scientists could meet to contribute to a deeper understanding of the results of present and past space missions, thus adding value to those results through multi-disciplinary research in a framework of international cooperation. With his characteristic, unrelenting enthusiasm and perseverance Johannes Geiss managed, together with a small group of Swiss scientists, to

convince first the Swiss authorities and then ESA to providing the necessary funds such that the International Space Science Institute could open its doors in 1995. Realizing that this new kind of institute needed to generate a product other than new space experiments, he immediately began to convene the first workshop and reached an agreement with Kluwer (now Springer) to publish the results as a carefully crafted series of review papers that were to reflect the status of the chosen theme in a concise manner. The theme of that first workshop, the Heliosphere in the Local Interstellar Medium, was a role model for all future ISSI workshops in the sense that these bring together space scientists who study a subject (here the heliosphere) using different tools and techniques such that they not normally get into direct contact or cooperation at ordinary conferences. But even Johannes Geiss with his optimism probably would not have thought it possible that ISSI would prosper such that 27 years later it would have interacted with a sizeable fraction of the space science community at large, and its publication series would soon reach one hundred collections. Sadly, he did not live to see the return to the theme of the first workshop implemented and presented here. It is therefore our sincere wish to dedicate this volume to the memory of Johannes Geiss, founding father and *spiritus rector* of ISSI.

## Declarations

**Competing Interests** The authors declare no competing interests.

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