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SURO-LC - Low Frequency Radio Astronomy at Lagrangian Point 2

Willem Baan*[(1)(2)], Albert-Jan Boonstra[(1)]
(1) Netherlands Institute for Radio Astronomy, ASTRON, Dwingeloo, The Netherlands
e-mail: baan@astron.nl, boonstra@astron.nl
(2) XinJiang Astronomical Observatory, Urumqi, XinJiang, PR China

Proposals for a SURO-LC mission have been proposed in 2012 as an S-Class mission to the European Space Agency. Although the proposal was not accepted, the concepts and principles proposed for this mission still remain relevant at this time.

The Low Cost Space-based Ultra-long wavelength Radio Observatory (SURO-LC) would be the first high-sensitivity and high-resolution telescope for the very low radio frequencies that can only be observed from space. It would bring unique access to the frequency spectrum hidden from earth-based observations, to a multi-disciplinary science community to make new discoveries in both the nearby and distant universe. SURO-LC will produce essential data for extra-galactic astronomy, 21-cm neutral hydrogen cosmology of the Dark Ages of the Universe, Galactic astronomy, heliophysics, space weather, and studies of radio planets. SURO-LC operates at frequencies between 0.1 and 70 MHz, of which the 0.1 – 30 MHz range is mostly inaccessible from Earth because of ionospheric blocking and man-made radio frequency interference (RFI). SURO-LC will generally operate in an all-sky imaging mode and may switch into a rapid monitoring mode in response to rapid solar and Galactic events, and for observing transient radio events and variable planetary emissions. SURO-LC consists of a low-maintenance formation of nine slowly moving spacecraft, eight spherically distributed daughters, each equipped with 3 orthogonal dipole antennas, form the elements of an interferometric radio telescope; together with an offset mothership for data acquisition, digital signal processing, and communication with the ground. All nine satellites can operate for a minimum 2 years in a Lissajous orbit around the second Lagrange point (L2), at 1.5 million km distance from Earth, in order to provide a low relative-drift orbit and a radio clean environment with strongly reduced terrestrial RFI. The SURO-LC facility delivers unique science using unique innovative exploitation of established high TRL and low-cost small spacecraft engineering solutions, to fully reflect the spirit of the call for low cost science missions while observing all the constraints.

SURO-LC has Science Objectives that strongly supported the science objectives of the ESA Cosmic Vision 2015-2025 Programme. Operating at low radio frequencies (LF), which are partly inaccessible from the ground due to the Earth ionosphere and man-made RFI, SURO-LC serves as a highly efficient radio-imaging instrument that can address unique science objectives and contribute to understanding the early evolution of the Universe and its constituents, and new physical aspects of the Solar system and the Galaxy. The science cases for low-frequency observations with SURO-LC addressed many issues that are remain relevant:
(1) for Extragalactic Source Populations it is the evolutionary history of source populations at high redshifts and the effect of feedback on the growth of accreting black holes and the nuclear star formation activity,
(2) for the Dark Ages and the Epoch of Reionisation the 21-cm spin temperature of neutral hydrogen will determine the onset of star formation, and the formation of the first black holes,
(3) for Heliophysics studies and Space Weather the monitoring will provide LF imaging of flares and of Coronal Mass Ejections far out into the Solar system,
(4) Planetary Radio Emissions will explore planetary and exo-planetary emissions at inaccessible frequencies and discover unexplored magnetic field and magnetospheric/atmospheric properties,
(5) for pulsars and transient radio sources observations will provide the first measurements of pulse shapes and spectral properties at low frequencies, and
(6) for the Galactic Interstellar Medium observations will determine the structure of the local Warm Interstellar Medium and provide diagnostic tools forthe local Interstellar Medium.

The (then) proposed payload of SURO-LC was distributed between 8 daughter satellites and a mothership. The daughters' antennas receive low frequency radio waves and transmit the digitised data over inter-satellite links (ISL) at 60 Mbps to the mothership for digital signal processing and further downlinking to Earth. The multi-satellite SURO-LC mission follows from two ESA pre-Phase A studies, FIRST (2009) and DARIS (2010), both of which independently demonstrated feasibility of a low-frequency free flying instrument. The daughter and mothership spacecraft are adaptations of flight proven designs, making best use of small satellite developments with high Technological Readiness Levels (TRL). The SSTL SNAP-1 nano-satellite was proposed as a baseline for the daughter spacecraft. A simplified LISA Pathfinder (PF) bus and main propulsion was a baseline for the mothership combined with the VEGA launcher for delivery to L2. The Cost at Completion would be Md' 99.5 plus up to 20% margin. The telescope imaging capability strongly benefits from a slowly evolving/drifting configuration of spacecraft in orbit at L2. While accurate knowledge of the separation and relative orientation of the spacecraft to a fraction of the observing wavelength (>4 m) is required, no precise formation control is needed. Multi-lateration data-fusion metrology algorithms, developed from high performance aerospace measurement applications, give consistent, reliable, high precision ranging and relative orientation derived from coarse radio ranging. The positional information will be used for imaging of the astronomical data, configuration maintenance, collision avoidance, and for maintaining the data link configurations between daughters and mothership. Directed high- gain antennas maintain the high-speed data link margin between daughters and mothership. Processing at the mothership uses proven terrestrial radio interferometry techniques, uniquely adapted for all sky viewing, to produce science meta-data for using standard downlinking protocols.

The SURO-LC team had support from the global low-frequency radio astronomy community from Europe, USA, Australia, India, Japan, and China. A wider science community contributed to the science and engineering design, and benefits will flow to the solar and space physics, and the terrestrial radio communication and ranging communities, from data and concepts used in SURO-LC.

The reasons for non-acceptance included perceived low TRL levels, with passive/loose formation flying being a new concept and sparse antenna imaging concepts not yet demonstrated in space.

Related literature follows below.

References

[1] Baan, W.A. et al, June 2012, SURO-LC, A Very Low Frequency Distributed Aperture Space Observatory, S-Call proposal ESA.

[2] Blott, Richard, Baan, Willem, Boonstra, A.-J. , Bergman, J. et al., 2013, Space-based ultra-long wavelength radio observatory (low cost) - SURO-LC. 279, (request at: https://www.researchgate.net/publication/260725483)

[3] Rajan, R.T., Boonstra, A-J., Bentum, M., Klein-Wolt, M, et al. , Space-based aperture array for ultra-long wavelength radio astronomy, 2016, Exp. Astron. 41, 271

[4] Bergman, J.E.S., Blott, R.J, Forbes, A.B., Humphreys, D.A, et al, 2009. FIRST Explorer – An innovative low-cost passive formation-flying system, astro-ph: arXiv: 0911.0991