ARGOS

Conceptual Design Study

Designing a Next-Generation Interferometer for Multi-Messenger Astronomy

Deliverable/Document Title:	**ARGOS Level 0 Science Requirements**
Version:	**1.0**
Release date:	**01.03.2023**
Deliverable number:	**2.1**
Dissemination level:	**Public**
Status:	**Accepted**
Authors:	**ARGOS Consortium**

Funded by the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement ***No 101094354***. The content of this material reflects the opinions of its authors and does not in any way represent the opinions of the European Union

1.1.1 Document history

Version	Date	Content and changes	Edited by
0.1	01.09.2023	First draft created	John Antoniadis
0.2	25.01.2023	Typos corrected	John Antoniadis
0.3	05.02.2023	Typos corrected after internal review	John Antoniadis
1.0	01.03.2023	First release; L0_46 added	John Antoniadis

1.1.2 Peer review history

Partner	Reviewer	Version
FORTH	George Tzagkarakis	v0.1
MPIfR	Ewan Barr	v0.2
CEA	Sammuel Farrens	v0.2
UPRC	Leonidas Marantis	v0.1

1.1.3 Release history

Signed off by	Release Date	Version	Signature
John Antoniadis (FORTH)	01.03.2023	1.0	

1.1.4 Disclaimer

ARGOS-CDS is funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. The European Union cannot be held responsible for them.

1.1.5 Applicable documents

In the event of conflict between the contents of the following documents and this document, the following documents shall take precedence.

1. ARGOS-CDS Grant Agreement (no 101094354): ARGOS_Grant_Agreement_101094354_v1.pdf

1.1.6 Reference Documents

In the event of conflict between the contents of the following document and this document, this document shall take precedence.

1.1.7 Abbreviations and Acronyms

Acronym	Description
ARGOS-CDS	Argos Conceptual Design Study
ASP	Argos Scientific Priorities
CA	Consortium Agreement
DM	Dispersion Measure
DoA	Description of Action (Annex I of the Grant Agreement)
DoW	Description of Work (Annex I of the Grant Agreement)
EC	European Commission
EVN	European VLBI Network
EWG	Engineering Working Group
GA	General Assembly
PC	Project Coordinator
PMC	Project Management Committee
RFI	Radio Frequency Interference
SEFD	System Equivalent Flux Density
SNR	Signal-to-noise ratio
SWG	Science Working Group
TRL	Technology Readiness Level
VLBI	Very-long baseline interferometry
WP	Work Package

1 Background and Scope of this Document

ARGOS is a concept for a leading-edge, low-cost, sustainable European facility that will enable, for the first time, continuous wide-field monitoring of the sky at centimetre wavelengths, while publicly distributing science-ready data and alerts in real time. ARGOS will address multiple fundamental scientific questions, from the nature of dark matter and dark energy to the origin of fast radio bursts and the properties of extreme gravity, satisfying urgent needs of the community.

The facility is currently undergoing its conceptual design phase. The project operates within the Horizon Europe framework and is bound by the Grant Agreement 101094354 with the EC (ARGOS Conceptual Design Study; ARGOS-CDS). The DoW (Annex I of the Grant Agreement) determines the work to be carried out as part of the project. The overarching goal for ARGOS-CDS is to produce a detailed design study that will make the strategic and scientific necessity for such a facility clear and accessible to funding and policy bodies.

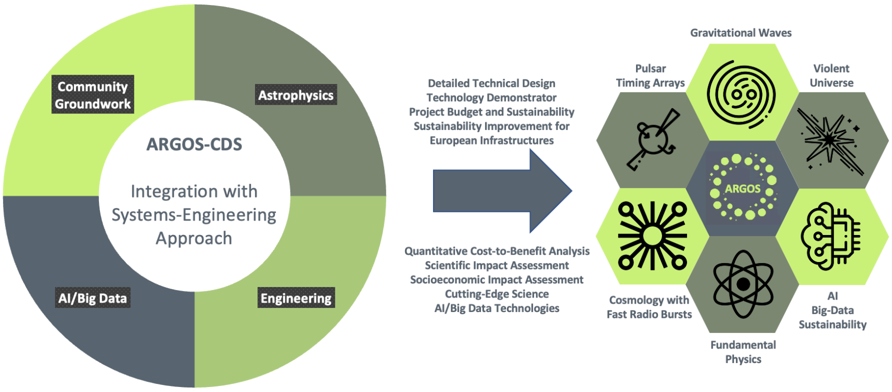

***Figure 1:** ARGOS-CDS overview.*

1.1.1 Background and objectives for ARGOS-CDS

ARGOS-CDS comprises a 3-year project that aims to address all relevant scientific, technological, sustainability and policy-making challenges related to the construction and deployment of ARGOS, following a top-down systems engineering approach. More specifically, with *ARGOS-CDS*, the ARGOS Consortium wishes to achieve the following objectives:

Objective 1: Identify and optimize specific Science Use Cases for *ARGOS* and quantify the corresponding system-wide design requirements to meet these objectives

This will be achieved with input from the *ARGOS* stakeholders who are to be involved in the definition and design processes. Stakeholders include the scientific community, funding, and policy-making bodies (at the regional, national, EU and international levels), as well as the public (industry, students, public).

Objective 2: Produce a comprehensive Technical Design for *ARGOS*

ARGOS-CDS will produce detailed plans for all *ARGOS* subsystems (frontend, backend and software) and their interfacing, as well as sustainability plans for the facility and the required supporting infrastructure. This will include cost estimates for construction, operation, and maintenance, as well as comprehensive risk assessments. The fully costed design, sustainability and roll-out plan reports will advance the project from the conceptual level (TRL2) to the Verification and Prototyping Stage (TRL7).

Objective 3: Characterize the suitability and sustainability of candidate deployment sites

To achieve the objective of characterizing the environment at the main candidate deployment site (Crete, Greece), the prototyping site and alternative sites in Europe, the ARGOS Consortium will undertake site-characterization weather monitoring and RFI measurements). These reports will be complemented by detailed blueprints, environmental and safety studies that will feed into the design study.

Objective 4: Assemble an *ARGOS* prototype for verification, validation and technology pathfinding

Within the context of the design process, we will construct *ARGOS-pathfinder*, a scaled-down prototype of the instrument that will be assembled at the last phase of the project. The main objective of the prototype will be to validate the System Design in a real-world setting and bring all sub-system designs to full maturity (TRL2→7). Beyond its main purpose, *ARGOS-pathfinder* will also serve as a unique testbed for new technologies and solutions, such as optimized and sustainable digital signal processing software and AI-based image reconstruction algorithms, while also producing leading-edge science. These products and science results will be made publicly available and exploited to advance the interoperability of international astronomical facilities.

Objective 5: Enhance the R&I potential of the EU southern periphery in this highly competitive research area and create capacity for lasting scientific and socioeconomic impact beyond the immediate field of Astronomy

Lastly, *ARGOS-CDS* aims to significantly enhance the R&I potential of Europe and Greece, in Astronomy and beyond. This is to be achieved via multiple ways, for instance a) the training of PhD students, scientists and engineers in a highly multidisciplinary and rapidly evolving research area, b) close collaboration with national, European and international consortia and R&I actions, c) participation in European collaborations such as the EPTA, d) the publication of forefront research, and e) the direct involvement of societal stakeholders (students, public, industry) in the design of the instrument and its services, and their training on the use of its products.

1.2 Scope of this document

This document provides an overview of the ARGOS scientific priorities (ASPs), and corresponding level 0 requirements. It is meant to serve as a reference for the ARGOS stakeholders and the Consortium, during the design phase of the facility.

The level 0 requirements are directly derived from the ARGOS Science Priorities (ASPs) that were developed during the first phase of ARGOS-CDS, with input from the scientific community solicited during the ARGOS stakeholders' workshop. The ASPs and level 0 requirements capture the breadth of science that ARGOS will address when it becomes operational.

2 Scientific Priorities for ARGOS

2.1 Background

The ARGOS Scientific Priorities (ASPs) comprise a series of science themes and open questions that ARGOS will directly address when it becomes operational. They were developed iteratively, first during the preparation of the ARGOS-CDS Horizon proposal, and later during the conceptual and definition phase of the design study. The ASPs have their basis on literature reviews and original research. Importantly, they also include input from the scientific community and the ARGOS stakeholders. This input was mostly collected during the ARGOS Stakeholders workshop, which took place in Heraklion, Crete, between October 24-27, 2023. The workshop brought together over 90 experts from various fields of astronomy to discuss the scientific potential and challenges of a future European wide-field radio interferometer.

To collect input for the ASPs, the workshop participants were given a set of general constraints and capabilities for the facility (Section 2.2), as well as a preliminary set of specifications (e.g., total collecting area, frequency coverage, field-of-view, number of dishes, sensitivity). They were then asked to contribute and discuss potential science priorities that would be uniquely addressed by such a facility.

Following the conference, the proposed science priorities were evaluated by the ARGOS SWG against the following list of criteria.

1. How fundamental is this scientific question? Is it going to lead to a significant advance in the field?
2. How urgent is this scientific question? Is it something that should be addressed in the next five years to decade?
3. What is the importance of radio measurements for the envisioned result? Can this scientific question be addressed by measurements at other wavelengths?
4. How necessary is the ARGOS contribution for achieving this result? Can it be achieved by other radio facilities?
5. What is the fractional ARGOS sensitivity required to fully address this scientific question?
6. How important is a synergy between existing facilities and ARGOS to address this scientific question?
7. Is there an established method/technique for producing the scientific product required for this result?
8. Have the methods for extracting the required measurements from the scientific product been established?
9. Are there risks related to uncertainties in our understanding of the underlying physical phenomena and/or astrophysical sources?

A concise overview of these priorities is captured in the four broad themes presented in the remainder of the document, as well as the related level 0 science requirements. A more detailed presentation of the science priorities that were established via this process will be provided in the ARGOS White Paper, to be prepared by the Consortium following the Preliminary Design Review.

2.2 General Considerations

To consider the needs and desires of ARGOS non-science stakeholders, as well as the spirit and rules of the Horizon Europe call under which ARGOS-CDS is funded, the technical design should try to respect the following constraints:

- **Low-cost**: The total cost for hardware (antennas, RF, electronics, compute notes) shall not exceed 60 million Euro in 2023 prices. These numbers refer to an observatory with a total collecting area of ~30,000 m^2.
- **Scalability**: The unit cost – defined as the total hardware cost for the full array, divided by the number of elements – shall not exceed 50,000 Euros in 2023 prices.
- **Modularity**: In the context of ARGOS-CDS, the Consortium has agreed to develop three science pipelines for *pulsar timing, imaging, and commensal FRB searches*. However, the technical design should allow for possible future upgrades with new backends, ideally without affecting existing modules. This could be achieved, for instance, by having all backends subscribe to the same data stream (that is, the correlator/beamformer output) as is done in MeerKAT
- **Private sector involvement**: To the extent that it is possible, the technical design should provide incentives for the involvement of private companies. Similarly, the ARGOS-CDS should prioritise the development of software and technologies that could have spill-over benefits. In practice, this means incorporating COTS components in the design wherever possible, prioritising the development of algorithms that could be adopted for commercial applications (e.g. AI algorithms for image reconstruction and anomaly detections, optimization of data processing methods, etc.), testing and developing low-cost hardware fabrication methods, etc.

- **Environmental constraints:** The technical design should strive to minimise energy consumption and the overall environmental impact. Decommissioning of the instrument should leave no observable impact to the deployment site.

2.3 Complementarity to other facilities

ARGOS is being designed to deliver state-of-the-art, science-ready data to the scientific community, seconds after capture. Public data products will include prompt transient alerts and light curves for FRBs, supernovae and GW sources, daily ultra-sensitive sky images with unprecedented sensitivity and resolution, and high-cadence pulsar timing data (see below). By opening the dynamic radio sky for exploration, ARGOS will be a valuable counterpart to next-generation multi-wavelength public surveys such as the *Zwicky Transient Facility, Vera C. Rubin Observatory and DSA2000,* and will complement the science envisioned for next-generation radio facilities such as the *SKA.*
To maximize its long-term impact, ARGOS should be complementary to flagship facilities that pursue relevant science goals in terms of its location, sensitivity, frequency coverage and overall capabilities.

First and foremost, ARGOS shall position itself as a *SKA follow-up instrument* that will enable long-term monitoring of pulsars and time-varying sources.
At the same time, ARGOS shall also significantly enhance the capabilities of other flagship European infrastructures (in particular LOFAR2.0 and the EVN), while also complementing next-generation multi-messenger facilities such as the Vera-Rubin Observatory and the Einstein Telescope, in terms of sky coverage, resolution and instantaneous field-of-view.

Requirement ID	Description
L0_01	ARGOS shall be deployed at a location in Europe that allows access to at least 40% of the SKA and Rubin Observatory fields.
L0_02	ARGOS shall have a total collecting area to within 20% of the SKA-MID 1 collecting area.
L0_03	The Galactic centre shall be visible from the ARGOS deployment site for a minimum of three hours per day.
L0_04	ARGOS shall provide access to elevation angles between 15 and 90 degrees, and to azimuthal angles between 0 and 360 degrees
L0_05	Argos shall provide a half-power beam width of at least 2.3 deg at the lower edge of its band.
L0_06	ARGOS shall cover the frequency range between 1 and 3 GHz to allow follow up of time-varying SKA discoveries such as pulsars and FRBs, and to provide a high-frequency counterpart to LOFAR2.0.
L0_07	All final data products shall have a noise level degraded due to RFI by no more than 10% in respect to the thermal noise of the array. The latter refers to the noise of an observatory compatible with the requirements listed above, scaled by the number of elements used when the data are being captured.
L0_08	Argos shall provide an angular resolution of at least O(5”) at the upper end of its band
L0_09	Argos shall provide an effective bandwidth of no less than 95% of the frequency coverage enabled by its receivers (~2 GHz) centred around 2 GHz), for both orthogonal polarization states.

L0_10 Argos shall capture and process (correlate, beamforming, pulsar timing, VLBI) data over its entire effective bandwidth, in both polarizations and in real time

L0_11 To enable the potential better coverage of SKA bands in the future, ARGOS reflectors should be sensitive to frequencies up to 8 GHz.

L0_12 ARGOS shall provide continuous sidereal tracking of single targets and/or celestial positions (from few seconds to continuous 24/7 monitoring for circum-polar targets)

L0_13 ARGOS shall be capable of tracking celestial objects moving with speeds from 0 to 20 times the sidereal rate up to 85 degrees elevation, to enable fast drift-scan surveys and monitoring of near-Earth objects.

L0_14 ARGOS shall be compatible with the EVN

L0_15 To position itself as a SKA follow-up instrument and a Vera Rubin counterpart, ARGOS shall provide at least four observing modes: pulsar timing, imaging (fast cadence/accumulation), single burst transient search, and VLBI. To enable commensal FRB searches, the transient search mode should be provided simultaneously with at least one of the other two.

2.4 Pulsar Timing

Gravitational waves with frequencies below a few microhertz are a critical messenger from the early universe and a key observational benchmark for cosmological structure formation theories. These signals correspond to spacetime perturbations with wavelengths much larger than the Solar System and are therefore impossible to detect with human-made detectors. Nature provides an alternative probe: radio millisecond pulsars (MSPs) have such stable rotational properties that allow them to be used as the kiloparsec-separated arms of a Galactic-scale detector array (pulsar timing array; PTA) sensitive to low-frequency GWs.
PTAs search for GWs by monitoring the pulse arrival times (TOAs) from a suit of MSPs. As GWs propagate through the Galaxy, they perturb the local spacetime near the Earth and the pulsars. Near-earth perturbations induce correlated TOA variability between pulsars, which can be used to separate GW signals from other sources of noise. The sensitivity of a PTA to GWs depends on the observing cadence, the duration of the experiment, and the properties of the pulsars observed. There are currently five long-running PTA experiments, EPTA, the North American Nanohertz Observatory (NANOGrav), and the Parkes Pulsar Timing Array (PPTA), the MeerKAT Pulsar Timing Array (MPTA) and the Chinese Pulsar Timing Array (CPTA). Together, these regional PTA experiments form the International Pulsar Timing Array (IPTA) consortium. With baselines spanning a few decades and a typical observing cadence of a few weeks, these PTA experiments are currently sensitive to nanohertz GWs. These consortia recently announced the detection of a signal consistent with a nanohertz GW background, a milestone that represents the culmination of many decades of effort to open a completely new window to the universe.

To transform an ensemble of MSPs into an inertial GW detector, one first needs to account for a wide range of effects that influence the observed pulse arrival times. The strongest nanohertz GW signals induce a TOA structure of a few tens of nanoseconds over several years. Therefore, the smaller the rms of a timing solution, the easier it becomes to identify a GW signal in the timing residuals. There are now approximately 30 MSPs with timing models precise enough to predict TOAs to within a few hundreds of nanoseconds. These pulsars make it obvious that, at this level, there is additional stochastic variability that cannot be attributed to GWs nor can be accounted for by deterministic timing models. This variability can be astrophysical (for example, pulsar magnetospheric activity, low-amplitude glitches, and interstellar turbulence), dynamical (for example, uncertainties related to the Solar System mass distribution and the Earth's rotation) or instrumentational (clock noise or changes in the observing setup) in nature. In addition, because timing solutions are continuously refined by minimising the rms of the residuals, the GW signal may be partially absorbed in the timing solution, due to its resemblance (i.e., correlation) to the signature of long-term deterministic effects. These issues now pose the most significant barrier that the characterisation of GWs with PTAs.

The recent PTA results make it obvious that a breakthrough in the precise characterization of timing noise can be achieved with systematic, high-cadence monitoring of pulsar variability (profile changes and glitches), dispersion-measure variations, and telescope performance.
Similarly, individual close massive binaries may soon be detected if the PTA response improves at high frequencies. PTAs are sensitive to systems with periods shorter than the characteristic length of their datasets, which emit above ~5 nanohertz (at twice their orbital frequency). A 10-fold improvement compared to current state-of-the-art around this frequency will directly confront the most realistic theoretical predictions. A comparable improvement at higher frequencies (up to a few microhertz) will enable significantly deeper searches, even for highly eccentric binaries. Finally, extending the PTA response to higher frequencies, where contributions of various GW sources (SMBHBs, cosmic strings, etc.) exhibit the highest diversity will play a critical role in characterise the low-frequency GW landscape.

ARGOS will become the most sensitive instrument of the EPTA. In addition, it will provide high-cadence (nearly daily), high-SNR observations of all PTA pulsars. By covering a frequency window above 2 GHz that is less severely affected by propagation effects, ARGOS will play a critical role in the characterization of the stochastic nHz GW background.

In addition to PTA science, ARGOS will be able to provide precise observations of faint radio pulsars out to large distances. This will become particularly important in the next couple of decades as the SKA telescope is expected to provide a complete census of the galactic radio pulsar population. Long-term (>5 yr) follow-up observations of these discoveries -crucial for astrophysical studies- will require dedicated long-term observations that will not be possible with the SKA itself due to time limitations. ARGOS will fill an important gap that will maximize the scientific impact of SKA – a ~2-billion-Euro investment – in this field. Pulsar timing observations are crucial for addressing a broad range of fundamental questions, from the nature of gravity to the properties of dense matter. To address the aforementioned science drivers, the following requirements should be respected.

Requirement ID	Description
L0_16	In timing mode, ARGOS shall synthesize in real time at least sixteen full-stokes coherent tied-array beams using all available elements of the array.
L0_17	All time-domain products shall have a fractional error in absolute flux ($\Delta F/F$) measured against an established celestial flux standard, better than 2%
L0_18	All time-domain products shall have a fractional error in polarization degree and polarization angle, measured against an established celestial polarization standard, better than 1%
L0_19	ARGOS shall provide real-time coherent de-dispersion and pulsar folding for at least one tied-array beam per subarray, and for dispersion measures up to 1000 pc cm^3.

L0_20 ARGOS shall produce full-stokes coherently de-dispersed pulse profiles with a frequency resolution of 20 kHz and a time resolution of at least 1 μs.

L0_21 To enable precision pulsar timing, the timing accuracy of the observatory clock should be better than 10 ns over 10 years with respect to NIST

L0_22 ARGOS shall record coherently de-dispersed pulse profiles (integrated over frequency and time) with a SNR > 1000 in Stokes I, for MSPs with flux-densities > 1 mJy, within one hour of total integration time

L0_23 ARGOS shall observe the 25 brightest EPTA pulsars with a median cadence of no more than 3 days and an integrated SNR > 500, in under 33% of the observing time.

L0_24 ARGOS shall provide full-stokes, 50 MHz sub-banded times of arrival as part of its regular processing pipeline.

L0_25 As part of its regular processing pipeline, ARGOS shall flag statistically significant pulse profile changes in respect to a reference profile.

L0_26 ARGOS shall provide updated timing ephemerides for all its pulsar targets. The timing ephemerides shall be updated with a cadence of less than 24 hours.

L0_27 ARGOS shall provide alerts for glitches, strong scattering events, and other timing irregularities for all its pulsar targets

L0_28 ARGOS shall provide a minimum of 4 sub-array (multi-pointing) timing modes

2.5 Imaging

ARGOS aspires to conduct high-sensitivity searches for radio transients that vary with timescales ranging from few seconds to weeks. These surveys will also provide daily high-resolution (<15”) images of a ~1000 deg^2 area, reaching a sensitivity of <7 μJy/beam per visit, leading to the discovery of millions of supernovae, gamma-ray bursts (GRBs), white dwarfs, neutron stars, black holes, active galaxies and nearby stars (Figure 1.2). These high-quality datasets will uniquely address a broad range of fundamental open astrophysical questions, from the properties of accreting compact objects to the physics of cosmic explosions and the nature of supernova progenitors. The prompt distribution of public transient alerts will enable unpresented multiwavelength studies of the dynamic universe, making *ARGOS* a valuable counterpart to future public surveys such as the *Vera Rubin Observatory*. For neutrino astronomy, *ARGOS* will identify candidate counterpart events to detected astrophysical neutrinos, providing the critical timing information that is necessary for a field that operates in the single-neutrino-per-source regime. For TeV gamma-ray astronomy, *ARGOS* will similarly provide triggers for targeted observations of variable sources such as blazars, which may only be detectable during their active states. Finally, by enabling immediate follow-up of rare events such as ultra-high-energy cosmic rays, *ARGOS* will provide key information on the origin of the highest-energy particles in the Universe.
Offering a large FoV and high sensitivity, *ARGOS* will be able to search the typical 50-100 deg^2 credible localization regions of LIGO events in under a day, detecting double neutron star mergers out to

distances of 200-500 Mpc. Following an initial detection, *ARGOS* will be uniquely positioned to follow up the evolution of the radio light-curves over long periods of time, complementing efforts at other wavelengths and radio frequencies.

Requirement ID	Description
L0_29	ARGOS shall point at any direction on the sky in less than 3 minutes.
L0_30	ARGOS shall offer a survey speed figure-of-merit of at least 10^7 deg^2 m^4 MHz K^{-2}
L0_31	All image-domain products shall have an absolute photometric accuracy of at least 5%
L0_32	All image-domain products shall have an absolute astrometric accuracy (fractional error in the position of a point source relative to the adopted celestial reference frame) of at most 10% of the synthesised beam.
L0_33	ARGOS shall provide a frequency accuracy of at least 10^{-11} over 10 years
L0_34	All image-domain products shall have an accuracy in absolute polarization degree and angle, measured against an adopted celestial polarization standard, better than 2% across the entire field of view of the primary beam
L0_35	For unresolved sources, ARGOS shall provide a peak intensity to background intensity rms ratio (brightness dynamic range) of 40 dB at 25 arcsecond spatial and 1 MHz frequency resolution.
L0_36	For unresolved sources, ARGOS shall provide a polarization dynamic range (peak intensity to instrumental polarized response) of 30 dB at 25 arcsecond spatial and 1 MHz frequency resolution.
L0_37	ARGOS shall provide full Stokes real time imaging over its FoV with a time resolution of at least 1 second.
L0_38	ARGOS shall provide real-time detections and astrometric positions for all point sources detected with a significance greater than 10 sigma
L0_39	ARGOS shall be capable of switching between imaging and time-domain modes within less than 30 seconds
L0_40	ARGOS shall provide a minimum of 4 multi-pointing imaging modes

2.6 Fast transients and commensal modes

ARGOS will perform a commensal real-time survey for transients varying with timescales shorter than a second. The unique combination of large collecting area, wide field-of-view (FoV) and high spatial resolution (Section 1.2) will enable the discovery and precise localization of thousands of FRBs per year. ARGOS will significantly extend the sensitivity and frequency coverage of envisioned FRB surveys with the CHIME, DSA and ASKAP, covering a frequency window above 2 GHz that is 10—50 times less affected by smearing due to propagation effects. This will enable routine identification of FRBs at a sustainable cost, as the detection of highly dispersed FRB signals requires expensive computations. FRB alerts will be distributed publicly in real time, allowing the prompt multi-messenger follow-up of events. ARGOS will also enable the discovery of FRBs associated with extreme environments and over much greater cosmological distances. Its large frequency bandwidth of 2 GHz will allow precise measurements of frequency-dependent propagation effects, revolutionizing our knowledge of Cosmic magnetism and FRB host environments. Finally, the combination of high detection rates and reduced influence of dispersive smearing will enable, for the first time, the discovery of gravitationally lensed FRBs, which will revolutionize precision cosmology. FRBs originating at large cosmological distances are influenced by the gravitational attraction of intervening material. The most important gravitational lenses are galaxies and their dark-matter halos. These sources can cause arrival delays of several days between lensed images of the same FRB event. Because the intrinsic width of an FRB is much smaller (a few fractions of a ms), these time delays can be measured with extremely high accuracy (few parts in a billion). As a comparison, current measurements of strong gravitational lensing with quasars and supernovae reach typical precisions of a few percent. The identification of strongly lensed FRBs with delays ranging from days to weeks would require a network of telescopes distributed around the globe at similar latitudes, to continuously monitor the same sky region with high sensitivity and resolution. A facility such as ARGOS (in Europe) together with CHIME (Canada), and DSA (US) would be the only path forward to realize this objective. The detection of only 10 strongly lensed FRBs by an ARGOS/CHIME/DSA synergy would result in a 1% measurement of the Hubble constant and a 0.5% constraint on the cosmic curvature. These measurements would directly test the validity of the cosmological principle and dark energy. Besides intervening galaxies, objects with much lower masses may also act as gravitational lenses. An existing possibility is that dark matter is made up of massive compact halo objects (MACHOs): primordial black holes and/or exotic compact stars with masses between few earths to few hundreds of solar masses. Such objects would result in gravitational lensing events with delays of a few milliseconds, orders of magnitude shorter than what present lensing surveys targeting quasars and supernovae are able to probe. ARGOS will be uniquely positioned to search for lensed FRBs with delays down to ~0.1 ms, thereby probing the entire parameter space for MACHOs.

Requirement ID	**Description**
L0_41	ARGOS shall provide a real-time tied-array beam mode for single burst transient searches over its entire half maximum power beam width.
L0_42	ARGOS shall provide a real-time de-dispersion and transient search mode, for dispersion measures up to 3000 pc cm^{-3}
L0_43	ARGOS shall provide low-latency (<1 min) alerts for time-domain transients with flux, DM, polarization and positional information.
L0_44	ARGOS shall store channelized voltage data for up to 10 time-domain bursts for offline processing.
L0_45	ARGOS shall have no more than 10% SNR loss compared to ideal matched filtering when searching for transients of minimum widths of 0.1 ms between DMs 0 and 3000 pc/cm^{-3}
L0_46	ARGOS shall record frequency-resolved, Stokes-I timeseries with a minimum frequency resolution no greater than 250 kHz and minimum time resolution no greater than 30 µsec, for a minimum of 16 beams