# NATURE ONLINE

The Linné Observatory of the Southeast Sweden Universities

## 1 SUMMARY

NATURE ONLINE is a concerted research effort by the three Southeast Sweden Universities to meet Man's grand challenge of ensuring a sustainable development by introducing entirely new on-line, real-time methods of studying and monitoring Nature. This multidisciplinary, synergistic initiative, encompassing fundamental research at all three universities in natural sciences, applied mathematics, computing science, radio science, and complex systems engineering, will develop innovative scientific tools needed to build next-generation, information-rich Earth and space observing infrastructures. These scientific tools will be employed to create the LINNÉ OBSERVATORY, a unique wide-area, multi-sensor array established by connecting and expanding existing and upcoming sensor arrays in the region, interconnected by an adaptive high-performance computing infrastructure. This will allow comprehensive, coordinated first-of-its-kind studies of the Earth, its atmosphere and near space, solar-terrestrial interactions, and astrophysical phenomena. The quantum communication inspired breakthrough radio methods and the versatile data acquisition and processing tools developed by NATURE ONLINE scientists will be powerful and flexible enough to be used in a variety of client information system applications, including such important activities as precision forestry and agriculture, disaster warning and forecasting, monitoring of the marine environment, habitat management, and security. Research results from NATURE ONLINE will help us understand and interact with Nature in fundamentally new ways and, at the same time, pave the way for ubiquitous and pervasive computing and novel radio and radar concepts.

## 2 VISION

The grand challenge for mankind today is to learn how to interact with Nature in a responsible manner so as to ensure a sustainable development. One of the best ways to meet this challenge is to extend the knowledge and awareness of the fundamental principles that control the physical world. This can be achieved in a timely manner by taking advantage of new developments in sensing methodology and the fact that we are entering a new phase of the information and communication technology (ICT) revolution – the connection of information systems directly on line to the physical world – to provide innovative modes of monitoring, studying and controlling Nature. Our vision and long-term goal is that NATURE ONLINE shall become a leading center in the world for such research.

The role of the LINNÉ OBSERVATORY will be similar to the role of new instrumentation developed to support scientific research during the past couple of centuries. Classic examples of the decisive importance of new instruments for studying and understanding Nature more fully are Galileo's telescope and Abbe's microscope.[1] In fact, on the one hand the use of telescopes and microscopes has increased our understanding of Nature. New theories and models have evolved as results of findings using these observing instruments in experiments. On the other hand, analysis and understanding of the inner workings of the new instruments themselves has given rise to new measurement techniques and engineering principles.

## 3 OBJECTIVES

The major, overall objectives of the NATURE ONLINE centre research are:

- To provide new, improved observational techniques for *studying and monitoring of Earth and space and related solar-terrestrial and astrophysical applications*. These techniques will be partly based on entirely new methods, introduced and developed by NATURE ONLINE scientist, that take full advantage of the fundamental physical properties of the electromagnetic medium. Technically, this will be achieved by digital sampling, in space and time, of the complete vector and tensor information embedded in the electromagnetic radiation and the subsequent transport and processing in real time of the on-line digital data. To this end, the LINNÉ OBSERVATORY will be an instrument for improved studies and monitoring of Earth and space.
- To develop, expand, and apply adaptive high-performance sensor and computing technologies to create new powerful and flexible data acquisition and processing tools, which can be used by a variety of wide-area, multi-sensor information systems. A challenge in this context is to *pave the way for ubiquitous and pervasive computing to digest Nature's data*. To this end, the LINNÉ OBSERVATORY will be used as a test bed for future information processing practices and principles.

## 4 POTENTIAL IMPACT

The advances in information and communication technologies that have helped increase dramatically our ability to probe, monitor, and understand the physical world around us will continue: thousands, millions or even billions of such cooperating tiny computers – called 'motes', 'nodes', or 'pods'– will be embedded into the fabric of the real world, including space platforms. This development has been described in the following way: '*The fact that everyday computing is getting exponentially cheaper promises to vastly increase data flows of all sorts and to revolutionize the practice of science*'.[2] The NATURE ONLINE centre will contribute to this impact.

The corresponding adaptive and resilient information processing (*Supervisory Control and Data Acquisition*) system will take advantage of novel system architectures derived from current research and development efforts in the EU and US such as GRID computing[3,4] and the NSF GENI[5] efforts. The fabric of processing sensors and components will act in concert with associated computing and high-performance data transport and processing infrastructures sharing the data that each of them gathers so as to process them into meaningful digital representations of the real world. Climatologists, space physicists, and other scientists will tap into these 'sensor webs' to ask new questions, test hypotheses, or build huge long-term databases of unprecedented scope and detail. The impact of these advances, to which NATURE ONLINE will contribute, can be illustrated by the following

[1] Ian Hacking. *Representing and Intervening. Introductory topics in the philosophy of natural science*. Cambridge University Press, 2005. ISBN-13 978-0-521-23829-8.
[2] Editorial, 2020 Computing Special: Charting the Information Explosion, *Nature*, **440**, p. 383, 23 March, 2006.
[3] http://www.gridcomputing.com
[4] http://www-03.ibm.com/grid
[5] NSR effort on Global Environment for Networking Innovations: http://www.nsf.gov/cise/cns/geni

quotes from a recent article in the *Nature* journal:[6] '*Tiny computers that constantly monitor ecosystems, buildings and even human bodies could turn science on its head. …We will be getting real-time data from the physical world for the first time on a large scale. …This is where computing science hits the tangible, the palpable world. It is the next frontier.*' The LINNÉ OBSERVATORY will be at this frontier, possibly even defining parts of it.

NATURE ONLINE has the potential to provide on-line, real-time access to unique, high-quality environmental information of unprecedented scope and detail for experts and the general public alike. It will thus have an impact on scientific, societal, and human issues. Moreover, the establishment of the LINNÉ OBSERVATORY will invigorate today's ICT, especially sensor web-based technologies and technologies and tools from e-Science, to leap beyond their application to space and Earth observations.

# 5 STRATEGY

The strategy of the NATURE ONLINE centre is to organize the research in terms of five intertwined cross-disciplinary and mutually cross-fertilizing transitional *Research Connections* (see figure below). They connect the physical infrastructure, the LINNÉ OBSERVATORY, to the intellectual infrastructure, the scientist and their collaborative research activities. This will foster a creative atmosphere that facilitates an evolution of new types of fundamental research, observations and experiments. The centre will synergistically exploit, from a holistic perspective, the following five research connections:

- The *Natural Sciences Connection*: Earth and space studies, astrophysics, astroparticle physics and solar-terrestrial physics, including space weather service development and studies of anthropogenic effects on the upper atmosphere.
- The *Computing Science Connection*: Adaptive high-performance computing to ensure optimum operation of on-line sensor webs.
- The *Mathematical Modeling Connection*: Modeling of innovative wave probing techniques by exploiting the classical-quantum correspondence.
- The *Radio Science Connection:* Further development of the innovative, information-rich radio sensor and radar technologies.
- The *Complex Systems Engineering Connection*: Studies of the fundamental system aspects of adaptive high-speed networks of multi-site sensors.

As shown in the figure below, each research connection contributes to the implementation and operation of the LINNÉ OBSERVATORY, by providing the adequate physical and mathematical models as well as the sensor hardware solutions, the software infrastructure, end-user applications, and engineering knowledge to turn these components into a functional whole. At the same time, the LINNÉ OBSERVATORY serves as an experimental platform for pushing the research frontiers in the respective disciplines (*Science Specific Objectives*), each resting on the results of the other sciences. Altogether, the research connections strive to understand and affect the Earth online and to pave the way of ubiquitous and pervasive computing (*Common Grand Challenges*).

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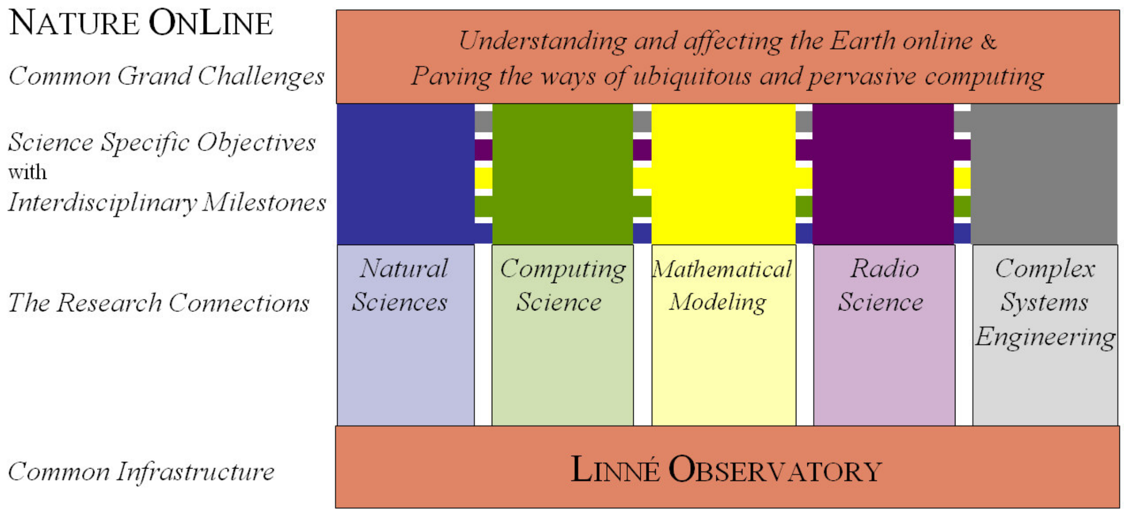
[6] D. Butler, Everything, Everywhere. *Nature*, 440, pp.402–405, 23 March, 2006. (The picture on the front page of the present proposal is taken from this article.)




# 6 WORKING PLAN & MILESTONES FOR THE FIRST TWO YEARS

During the first two years, a prototype of the LINNÉ OBSERVATORY will be made operational. The work is organized in work packages (WPs) – each addressing the necessary research of the contributing main research connections and one additional for integration of results. The individual WPs are described in more detail in Section 4 under each individual *research connection*.

The work package of the *Natural Sciences Connection* (**NS-WP**) will establish and consolidate a novel digital radio method that can extract more physical information from radio emissions than existing methods. This will allow for unprecedented Earth and space observations, including solar-terrestrial interaction and astrophysical applications.

The work package of the *Computing Science Connection* (**CS-WP**) will develop and test an adaptive high-performance computing infrastructure allowing to continuously deploy and un-deploy information components (involving advanced numerical computations) on a high volume data stream.

The work package of the *Mathematical Modeling Connection* (**MM-WP**) will address the open problem of modeling of probing Nature with classical and quantum waves. The results will be adopted by other research connections and NATURE ONLINE as a whole.

The work package of the *Radio Science Connection* (**RS-WP**) will introduce all digital, highly flexible, diversity agile HF/VHF radar and radio techniques to the LINNÉ OBSERVATORY. Before such a system can be put in place, a number of technology developments must be fully mastered and demonstrated, including improved and extended RF electromagnetic theory in this area.

The work package of the *Complex Systems Engineering Connection* (**SE-WP**) will allow integrating the prototype of the LINNÉ OBSERVATORY, using results of the above WPs and existing sensor networks systems, notably the LOIS local array. The objectives of SE-WP are twofold: (i) to implement an integrated system control environment facilitating new applications and sub-systems developed by other work packages, and (ii) to implement interfaces to existing or planned network-based sensor systems.

Further tasks will iteratively improve on the goals of the individual connections. Close integration cycles among the research connections guarantee step-by-step improvements of the LINNÉ OBSERVATORY as a whole.

# 7 THE RESEARCH

The different envisioned contributions from the five research connections to – and requirements on – the LINNÉ OBSERVATORY lead to principal and practical issues that the respective connection needs to address. Our strategy is to align them into a purposeful whole and to break down the general working plan into a workable model that optimally supports innovative observations, experimental research, and development within all contributing research connections.

## 7.1 GENERAL STATE OF THE ART

The origin of the LINNÉ OBSERVATORY is the LOFAR[7] infrastructure currently under construction in the Netherlands and its emerging Scandinavian subsystem LOIS[8] in Southern Sweden, with Växjö as the hub. Primarily, LOFAR/LOIS had its origins in the space sciences and radio astronomy communities, which have concluded that the next generation of their instruments must be based on the technologies of wide-area, adaptive sensor networks supported by software tools, rather than on conventional, costly monolithic facilities. The science of general sensor networks finds broad application across many areas of human activity. The LOIS project builds on the strengths in communication networks and radio research in Sweden, and will enable innovative uses of the sensors developed in Academia, industry and agencies. The huge amounts of data (tens of Tbits/s) transmitted over a combination of wireless/radio channels, fiber and copper networks, will put challenging demands on the data transport and computation facilities and on the collaboration as a whole. It is expected to open new research questions in this area. GRID architectures connecting computational resources of mainframes and PC from different locations may provide the required computational power.

Taking advantage of distributed sensor-rich networks presents a number of challenges regarding data management issues. Current research efforts are underway, exploring the development of novel tools for data management.[9]

## 7.2 THE NATURAL SCIENCES CONNECTION

This research connection targets new types of large-scale, on-line studies of Nature made possible by the breakthrough orbital angular momentum (OAM) radio diagnostic technique invented and introduced by members of the LINNÉ ONLINE team.[10] For this, the other connections serve as enabling research efforts. It will exploit the LINNÉ OBSERVATORY as well as other existing and upcoming European sensor networks to serve as a wide-area sensor infrastructure test-bed for space and environmental sciences.

The objective of this connection is to introduce, establish and exploit new radio and radar methods that rely on the very fundamental physical properties of radio beams.

### 7.2.1 REQUIREMENTS AND CONTRIBUTIONS

Since its discovery fifteen years ago,[11] the OAM method to be used at the LINNÉ OBSERVATORY has been explored in optics and microwaves using opto-mechanical manipulations of the beams. In contrast, at the low radio frequencies used at the LINNÉ

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7 Low Frequency Array, http://www.lofar.org

8 LOFAR Outrigger in Scandinavia, http://www.lois-space.net

9 Balazinska, M., Deshpande, A., Franklin, M. J., Gibbons, P. B., Gray, J., Hansen, M., Liebhold, M., Nath, S., Szalay, A., Tao, V. Data Management in the Worldwide Sensor Web. *IEEE Pervasive Computing*, **6**(2) April, 2007.

10 B. **Thidé** *et al.,* Utilization of Photon Angular Momentum in the Low-Frequency Radio Domain, Physical Review Letters, **99**, 087701, 24 August, 2007.

11 L. Allen, M.W. Beijersbergen, R. J. C. Spreeuw, and J. P.Woerdman, Orbital angular momentum of light and the transformation of Laguerre-Gauss laser modes, Physical Review A, **45**, 8185–8189, 1992.

OBSERVATORY it is possible to use digital techniques to directly sample the instantaneous, local field vectors of the radio beams and manipulate them in software. This goes beyond what is possible today in optics where only second-order quantities (intensities) can be measured and manipulated. To achieve our objective we need to augment the current LOIS test station in Risinge outside Växjö and the upcoming new LOIS test station in Ronneby with sensors, timing and other supporting subsystems and high-speed data transport facilities and to deploy a new LOIS station, supplemented by particle scintillators, on the island of Öland.

### 7.2.2 PRINCIPAL AND PRACTICAL QUESTIONS INCLUDING SPECIFIC STATE OF THE ART

*Solar-Terrestrial Interactions and Space Weather*: By utilizing OAM radio methods and the long experience of our partners to lay the foundation for a future netted space probing radar of European dimensions, we hope to make a significant contribution to the development of European Space Weather research and prediction capabilities. Space Weather refers to transient events of intense solar activity which directly affect the Earth and near-Earth space. Such events are known to have a potentially damaging effect on critical space-borne and ground-based technology systems and on biological systems, including human beings.

*Radio Emission from Cosmic Ray Air Showers and Astroparticle Physics*: Ultrahigh energy ($\sim 10^{20}$ eV) cosmic rays (UHECR) and neutrinos (UHECυ) interacting with matter produce short lived cascades of elementary particles that emit radio pulses which can be sensed by radio antennas as demonstrated by the LOPES collaboration.[12] They also detected highly inclined air showers, which is the case for neutrino induced air showers.[13] For neutrino astronomy, the low UHECυ rate of an estimated 1 neutrino/($km^2$yr) requires detectors with large effective detection areas. Thus, the Earth's atmosphere, the Antarctic glacier and the deep sea have been used to develop neutrino detector techniques. Another interesting possibility that has been proposed is to utilize the Moon.[14] The AMANDA neutrino telescope[15] at the South Pole in Antarctica commenced taking data in the early 1990's and the physics group at the University of Kalmar has been involved in the experiment since the beginning. Because the universe never before has been studied through the neutrino radiation, many new results are expected from this new field of research. To further develop the experimental techniques in order to extend the field of neutrino astronomy into radio emission, this is a task of high importance and relevancy. In the atmosphere, the neutrino induced air showers will emit synchrotron radiation. In solid detectors, such as ice or the lunar regolith, a so called Askaryan radio pulse is emitted as a result of coherent Cherenkov emission.[16] Both of these types of radiation are characterized by their polarization properties. Measuring this property and the orbital angular momentum of the electromagnetic field, are two of the major experimental objectives of the LINNÉ OBSERVATORY as a new technical enterprise. The LINNÉ OBSERVATORY thus offers a remarkably well suitable installation both for air shower detection in the atmosphere and for targeted lunar UHECυ observations.

*Radio Astronomy and Observational Radio Sciences*: In radio astronomy the analysis and description of the polarization characteristics of the radiation field has so far relied completely on a 2D projection of the Poynting vector onto the detector aperture. The

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[12] H. Falcke *et al*., Detection and imaging of atmospheric radio flashes from cosmic ray air showers, *Nature*, **435**, 313-316, 19 May, 2005.

[13] J. Petrovic *et al*., Radio emission of highly inclined cosmic ray air showers measured with LOPES. Journal of Physics, **39**, 471-474, 2006.

[14] O. Stål, J. Bergman, B. **Thidé**, L. K. S. Daldorff, and G. Ingelman. Prospects for Lunar Satellite Detection of Radio Pulses from Ultrahigh Energy Neutrinos iIteracting with the Moon. Physical Review Letters, **98**(7):071103, 16 February, 2007.

[15] **AMANDA**: http://www.amanda.uci.edu/collaboration.html

[16] P. W. Gorham *et al*., Observation of the Askaryan Effect in Ice. Physical Review Letters, **99**, 171101, 25 October, 2007.

introduction of 3D characteristics of the radiation field has severe implications for the interpretation of the observed radiation signatures from the near-Earth environment but also for astronomical observations of powerful radiation processes in stars and galaxies. A 3D signature of the radiation processes will require a renewed look at the observed radiation from these sources in order to re-interpret the physics of the emission region.

*Analysis of existing radio astronomy data*: Existing radio astronomy data may already contain the 3D signature. Powerful emission systems in radio pulsars and quasars could have been emitting partly in an $l=1$ orbital angular momentum (OAM) mode. Re-analysis and re-interpretation of existing data of radio pulsars and quasars and BL Lac systems with radio jets pointing at the observer may accommodate an interpretation and verification of the OAM states of the emission regions.

*Equipping new generation radio telescopes for 3D*: Two major new-generation radio telescopes are being built and designed. LOFAR is a distributed network sensor telescope that is the first of its kind with its core in The Netherlands but with outstations distributed throughout northern Europe, including the UK, France, Germany, Poland, and Sweden. The radio astronomy segment of LOFAR operates from 30 to 80 MHz and from 110 to 240 MHz and will consist of 50 (and increasing) stations composed of two fields of isolated antennas. After local processing the station data will be transferred to a central (super-computer) processing system using fiber optical cables. While LOFAR has already some stations in operation, the science program will start in 2009. The Square Kilometer Array (SKA) telescope will also be a networked radio telescope operating from 200 MHz to 25 GHz and will be located in either Southern Africa or Australia. SKA will start Phase-I operation in 2012 and be fully operational in 2018. The sensors for both LOFAR and SKA will be independent units that are controlled individually by local processors. As a result the network of sensors can be flexibly programmed to be sensitive to $l=1, 2,$ etc. OAM signals. Once OAM has been recognized in astronomical signals, the LOFAR and SKA systems can be specifically tuned to observe the OAM of astronomical sources. Since both LOFAR and SKA will operate in a region range that is of interest for ionospheric studies and for space research, these instruments are also particularly well equipped for these research areas.

In general, the use of Jones matrices will be applicable for implementing the modifications to the data handling. When OAM is taken into account these matrices go from being 2×2 to be $2(l+1)\times2(l+1)$, where $l$ is a (possibly very large) integer, reflecting the fact that the number of radio degrees of freedom may increase dramatically when angular momentum is included in a proper way.[17]

*Analysis of new and existing ionospheric data*: Existing ionospheric data may contain a 3D signature that has not yet been recognized. Re-evaluation of ionospheric data will lead to the recognition of an extended parameter related to 3D photon signatures. Known radio emissions may have more information about the emission process and its parameter space that is embedded in their radiation and that has not been recognize. Radio beam OAM (beam vorticity) will be used in an attempt to develop an ionospheric plasma vorticity and turbulence imaging technique.[18]

[17] L. Allen, J. Courtial and M. J. Padgett, Matrix formulation for the propagation of light beams with orbital and spin angular momenta, Physical Review E, **60**(6), 7497–7503, 1999.

[18] B.**Thidé**, Nonlinear physics of the ionosphere and LOIS/LOFAR, *Plasma Physics and Controlled. Fusion*, **49**, in press, October, 2007.

#### 7.2.3 Working Plan & Milestones for the Next Two Years and Long-Term Plans

There are three main applicants (á 25% of fulltime employment) and three PhD students (á 80%) contributing to the Natural Sciences connection summing up to ~78 Person Months (PM) to utilize in the first two years.

**NS-WP 1** – *Solar-Terrestrial Interactions and Space Weather* [18 PM] considers the establishment of the Ronneby LOIS test station, its integration into the Linné Observatory infrastructure and its use for 3D vectorial radio studies of solar storm events and their impact on the ionosphere.

**NS-WP 2** – *Radio Emission from Cosmic Ray Air Showers and Astroparticle Physics* [9 PM] considers the establishment of a third LOIS station on the island of Öland, supplemented by scintillators, for air shower detection and integration into the Linné Observatory infrastructure.

**NS-WP 3** – *Interpretation of existing Radio astronomy data* [9 PM] considers the current electromagnetic formalism for polarization in a 3D picture and re-evaluates the available radio astronomy data.

**NS-WP 4** – *Equipping new generation radio telescopes* [14 PM] concentrates on the evaluating and redesigning the antenna control and data analysis software for LOFAR in order to adapt it to OAM measurements. This work package will result in a software design and an estimate of the time required for implementation. The actual software effort of rewriting the control software will need to be covered by a future work package.

**NS-WP 5** – *Interpretation of existing ionospheric data* [9 PM] considers the current electromagnetic formalism for polarization in a 3D picture and re-evaluate the available ionospheric data for OAM signatures.

**NS-WP 6** – *RFI suppression in radio data* [9 PM] With access to the entire (3D van Cittert-Zernike matrices) vector field it is possible to make a better (than with 2D matrices) assessment of the RFI components and provide a better isolation of the RFI and other OAM quantities. This work package will provide an assessment of the effort of implementing the 3D formalism into current RFI mitigation methods. The actual software development effort needs to be implemented in a separate effort.

Additional efforts of this connection [10 PM] are planned for global system integration and will contribute to the corresponding work package of the Complex Systems Engineering connection (SE-WP 3).

#### 7.2.4 Potential Impact

The 3D analysis of electromagnetic signals provides a complete description of the emission processes causing these emissions. These 3D aspects will provide new insights into the physical mechanisms that govern these processes. In particular, the re-interpretation of existing observational data may allow correcting existing interpretations and removing inconsistencies between theoretical predictions and observations. This approach strongly impacts and changes the interpretation of radio astronomy and ionospheric observations. It also paves the way for future observing systems that sample *all* the information embedded in the radiation.

### 7.3 The Computing Science Connection

This research connection addresses problems of adaptive, high-performance, highly programmable stream-computing. Since the Linné Observatory will produce aggregate data rates of several hundreds of Gigabits per second, this connection will also develop technologies for distributing the data for exploitation.

The objective of this connection is to develop the theoretical and practical premises for a high-performance and highly adaptive middleware infrastructure, allowing application domain scientists – not only computer scientists – to develop information processing components with the necessary performance provided to the end user.

### 7.3.1 REQUIREMENTS AND CONTRIBUTIONS

Digital radio and radar sensor networks must accommodate a massive amount of real-time data streaming at extremely high speeds. It will be neither possible nor desirable to physically store and process all data at storage nodes. Instead, the data streams may be processed as they move through the network. The processing on the data streams must be fast enough to keep up with the stream volume in order to detect phenomena and produce scientific indicators immediately when such phenomena are detected. We envision $10^2$ – $10^3$ sensors each producing 1–10 *Gbits/s* resulting in a total system data rate of 100 *Gbits/s* –10 *Tbits/s*. Various numerical algorithms are applied in real time on these data streams before the data is further delivered for visualizations, storage, and other processing. For example, unusual transients and signal patterns can be detected, noise can be removed, and differences between different data streams detected. Such operations require high-performance numerical algorithms optimized w.r.t. their data throughput. Therefore, the middleware and information processing components require high-performance computing.

Each sensor is equipped with a custom processor of 1-10 *Gflops* deployed with an operating system. Four of them are clustered around a custom PC which, in turn, is interconnected via a high-speed network with others clusters and with a dedicated server. This server maps data streams to services accessible online. This leads to a distributed computing power of 100 *Gflops*-10 *Tflops* in the sensors alone, which is doubled by the computing power in the backbone computer network. In principle, the distributed computing power of the LINNÉ OBSERVATORY facilitates high-performance computing.

The LINNÉ OBSERVATORY cannot be deployed at once. Instead it has to be built up by adding new sensor- and computer-nodes step by step. Moreover, over the lifetime of the LINNÉ OBSERVATORY certain nodes will fail and need to be replaced. Finally, the numerical applications, as well as their interconnection, their non-functional requirements and the basic computation and communication resources, change over time. All this necessitates automatic and dynamic adaptation in the underlying processing system, including re-scheduling and re-optimization of the system. A high-speed dynamic architecture responds to the above change requests in real-time and uses novel on-line scheduling and optimization models and algorithms.

Users and developers of the observation components are scientists and, hence, the complexity of *distributed*, *adaptive* and *high-performance* computing should be transparent to them.

### 7.3.2 PRINCIPAL AND PRACTICAL QUESTIONS INCLUDING SPECIFIC STATE OF THE ART

*Machine Models* abstract from concrete computing infrastructures to make such complex systems manageable, i.e., allow for optimization and code generation. We need to develop a machine model (i) *complex* enough to captures the properties of the LINNÉ OBSERVATORY relevant for performance, *i.e.*, models of a heterogeneous network of distributed heterogeneous computers and sensors possibly changing over time. At the same time, it must be (ii) *simple* enough to generate efficient code for, *i.e.*, allowing for automated scheduling and rescheduling of tasks of the observatory components.

*Programming Models* push the level of abstraction even further in order to hide properties that are automatically manageable by compilers and only expose those necessary to define the functional and non-functional behavior or the applications. Currently, a simple yet sufficient programming model for parallel stream applications does not exist. Starting from a HPF-like model,[19] widely accepted in the scientific computing community, we need to develop such a model that is (i) explicitly parallel since automated parallelization leads to suboptimal performance, (ii) provides explicit constructs and data structures for stream operations and for application reconfiguration, (iii) is efficiently and effectively translatable to our machine model.

*Translations and optimizations* schedule independent computation tasks to computation nodes.[20] A close to optimal scheduling is a necessity to cope with the high-performance requirements of the information processing components. We need to adopt existing[21] and develop new optimizations regarding the novel machine model of the LINNÉ OBSERVATORY. Due to the adaptivity requirement, we additionally face an online scheduling problem: computational tasks and infrastructure components are added and removed online. Hence, scheduling and re-scheduling ought to rearrange the executed code accordingly without stopping the LINNÉ OBSERVATORY in its entirety. Additionally, re-scheduling should react on changes in the applications as soon as possible and, hence, the performance of the scheduling algorithms is an optimization goal in itself. Recently, we suggested automated online composition of parallel computation components,[22] which we need integrate with the novel optimizations to develop.

S*oftware architecture* inhibits or enables quality properties in applications and supports the requirements of systems.[23] As our requirements – adaptability, high performance, and programmability – are conflicting, the software architecture also defines a compromise and trade-off between them. This challenge is strongly related to the design of a middleware infrastructure as required/developed by the Computing Science connection.

Recently, we suggested an architectural pattern called Dynamic Model Driven Architecture (DMDA)[24] capturing all three requirements. It maps programs defined in the program model to code executable on the machine model. It adapts both models reacting to changing infrastructure and application situations. Evaluating and adopting DMDA and setting the balance among a set of multi-dimensional requirements is an experimental exercise to take.

### 7.3.3 WORKING PLAN & MILESTONES FOR THE NEXT TWO YEARS AND LONG TERM PLANS

There is one main applicant (á 25%) and one PhD student (á 80%) contributing to the Computing Science connection summing up to ~26 PM to schedule in the first two years.

**CS-WP 1** – *Initial specification of a middleware* [5 PM / Month 1–5] defines the interfaces to the hardware infrastructure and the runtime environment for the initial setup of the LINNÉ OBSERVATORY. Milestones include after Month 3: specification and after Month 5: simulator implementation of the middleware with test application.

**CS-WP 2** – *Initial Machine Model* [5PM / Month 6–10] defines an initial parameterized machine model for the initial setup of the LINNÉ OBSERVATORY. It ports the initial middleware to the actual sensor network hardware, e.g., the LOIS core, measures parameters like communication delay, bandwidth and overhead, and validates the appropriateness experimentally. Milestones include after Month 6: initial machine model selected, after

[19] D. B. Loveman: HPF. *IEEE Parallel & Distributed Technology: Systems & Technology*, **1**(1), 1993.
[20] H. Zima, B. ChaMan. Supercompiler for parallel and vector computers. Frontier, Series, *ACM Press*, 1990.
[21] W. Zimmermann, W. **Löwe**: Foundations for the integration of scheduling techniques into compilers for parallel languages. *International Journal of Computational Science and Engineering* 1(3/4), 2005.
[22] Ch. Kessler, W. **Löwe**: A Framework for Performance-Aware Composition of Explicitly Parallel Components. To appear in C. Bischof et al. (eds.): Parallel Computing: Architectures, Algorithms and Applications, *IOS Press*, 2008.
[23] L. Bass, P. Clements, and R. Kazman. Software Architecture in Practice. Addison-Wesley, 1997.
[24] J. Andersson, M. Ericsson, W. **Löwe**: DMDA - A Dynamic Service Architecture for Scientific Computing. In: *Fifth IEEE/IFIP Working Conference on Software Architecture (WICSA05)*, 2005.

Month 7: simulator ported and parameters measured, and after Month 10: parameters validated/adjusted in dummy test application.

**CS-WP 3** – *Initial Programming Model* [5PM / Month 6–10] extends Java[25] with data-parallel and stream processing constructs to create an initial programming model and implement test applications. Milestones include after Month 7: constructs defined and added to Java, mapped to core Java using Recoder[26] meta-programming, after Month 10 source test programs naively mapped to and executable on the simulator.

**CS-WP 4** – *Integration* [5PM / Month 14–19] integrates results of CS-WP 1—3. Milestone after Month 15: source test programs executable on the initial middleware.

Additional, efforts of this connection [6 PM] are planned for global system integration – after CS-WP 2/3 and after CS-WP 4. They contribute to the corresponding work package of the Complex Systems Engineering connection (SE-WP 3).

Further steps will iteratively add heterogeneity to the machine models, replace the naïve mapping with more advanced scheduling-based optimization techniques, improve on the programming models, and address adaptability of software to changed application requirements, hardware, and even events in Nature by generalizing DMDA.

### 7.3.4 Potential Impact

Programmers will soon be faced with hundreds of hardware threads on a single-processor chip. Exploiting them efficiently is the only way to keep up with the performance potential they provide. This makes parallel computing and adequate programming and machine models and optimizations inevitable even in mainstream computing.

The advances in information and communication technologies including information-rich sensor technologies brings us closer to the vision of ubiquitous computing. An enormous amount of information needs to be processed online by distributed computation units. Stream processing becomes a major computing paradigm in the future.

Technologies for managing fast streams of high-volume data are expected to have a major impact on the way future high-bandwidth networks will be used for high-definition multimedia, on-demand services, remote medical diagnostics and treatment, etc. This will contribute to the drive for new networking standards and create market opportunities.

## 7.4 The Mathematical Modeling Connection

The problems addressed concern the development of models and methods for the efficient extraction of information from radio and radar observations. This information is initially carried by waves and later transformed to signals via sensors and information processing system and sent to the end users.

The objective of the mathematical modeling connection is to develop new models (as well as to test existing ones) for propagation of radio signals in inhomogeneous and fluctuating media with the purpose of extracting information and to explore the analogy between mathematical methods for classical and quantum waves (as far as possible). From the mathematical modeling perspective the Linné Observatory is an e-Science instrument providing unique possibilities for testing both existing and newly developed models and methods.

[25] Java: http://java.sun.com/j2se/1.5.0

[26] Recoder: http://recoder.sourceforge.net

### 7.4.1 Requirements and Contributions

The medium in radio signals propagate are in general inhomogeneous and fluctuating. Therefore, sufficiently sophisticated mathematical models for the wave propagation should be applied. The number of antennas is huge and they are distributed in space. The modeling of interaction of radio waves (having the same source, *e.g.*, the Sun) with such a large number of antennas and receivers is a complicated mathematical problem. Therefore, some simplifications reducing the size of the problem should be invented.

To use a similarity between mathematical models for quantum and classical waves is an attractive project that can provide both increased understanding of the physical mechanisms and numerical efficiency. However, quantum waves have a number of distinguishing features (e.g. entanglement). A corresponding comparative analysis of quantum and classical waves is thus required. Increased physical knowledge and improved calculation efficiency can be achieved by exploiting all symmetries present in the problem for which modern group analysis provides suitable methods.

The main problem in extracting information from the sensor system is to optimize the signal to noise ratio that means optimization or regularization of the constructed models. Super resolution can be achieved by combining mathematical physics with methods from statistical signal analysis.[27]

So far there are no results on conservation laws for perturbed Maxwell's equations. Our approach will be based on the concept of approximate transformation groups and approximate symmetries of differential equations affected to small perturbations. This concept was suggested in an article co-authored by a Nature OnLine scientist in 1987.[28] The theory has not yet been applied to the Maxwell equations. This is one of the tasks of the mathematical modeling connection.

### 7.4.2 Principal and Practical Questions including Specific State of the Art

Open research questions concern the modeling of classical and quantum waves. To describe the propagation of the radio waves is a difficult problem: the medium is inhomogeneous and fluctuating. In combination with a very large system, an efficient modeling would be required. One important tool is to utilize all available symmetries by using modern group analysis methods. Furthermore, analogies with quantum mechanical waves methods have proved to be efficient and stable.

In comparison with the direct description above of the propagation of waves, the reverse description, or so called inverse problem, is much more difficult. It concerns the determination of the sources and the medium in which the wave is propagating. That this problem is non-linear is a minor obstacle compared to the ill-posedness of the formulation. To achieve useful information or sufficiently sharp pictures a regularization or optimization is required.

The Maxwell equations in vacuum have a rich set of symmetries. In particular, the orbital angular momentum (OAM), which can be used in radio and radar probing techniques, is one of those conserved quantities manifesting fundamental symmetries of the Maxwell's equations. Research into the optimum mathematical base functions for OAM radio will be useful from the practical point of view. However, the assumption on empty space is too restrictive. It would be physically more realistic to be able to find conservation laws for electromagnetic waves in 'almost empty space'.

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[27] S. **Nordebo**, M. Gustafsson and B. Nilsson 2007 Fisher information analysis for two-dimensional microwave tomography. *Inverse Problems* 23 (2007) 859-877

[28] V.A. Baikov, R.K. Gazizov and N.H. **Ibragimov**, Approximate symmetries of differential equations with a small parameter, Preprint, Keldysh Institute of Applied Mathematics, 1987.

The main problem is to construct models with sufficient efficiency for a very complicated system allowing extraction of information with sufficient quality. The models are therefore based on fundamental physical principles and investigated with sufficient mathematical rigor.

A systematic treatment of super-resolution in imaging and inverse scattering is one specific objective to accomplish. The following topics are of interest: resolution and super-resolution analysis based on the Fisher information measure; Bayesian estimation and statistically optimal exploitation of a priori information for inverse problems; information fusion and hybrid inversion algorithms adopted to specific measurement phenomena; experimental verification of the results on information extraction.

The principal question in applications of the quantum-classical analogy is how far we can proceed by using this analogy. Since both types of wave equations can be written as systems of Hamilton equations,[29] one can apply Lie group analysis and explore all advantages of the group method. It is also clear that, since the Maxwell's equation can be written (using the Riemann-Silberstein vector) in the form of the Schrödinger's equation, one can represent classical wave solutions in the form of Feynman integrals. One of the greatest unsolved problems is the problem of classical-quantum connection.[30] The project provides a unique possibility for such studies in an essentially applied framework.

### 7.4.3 Working Plan & Milestones for the Next Two Years and Long Term Plans

There are three main applicants (á 25%) and three PhD students (á 80%) contributing to the Mathematical Modeling connection summing up to ~78 PM to utilize in the first two years.

**MM-WP 1** [19 PM] applies mathematical methods of quantum mechanics (via Schrödinger-like representation of Maxwell's equations) to modeling and numerical simulation of propagation of radio signals.

**MM-WP 2** [19 PM] performs systematic treatment of super resolution in imaging and inverse scattering in combination with tools and methods from statistical Radio communication such as the Fisher information and Bayesian estimation.

**MM-WP 3** [40 PM] attempts to find conservation laws for electromagnetic waves in "almost empty space".

All above work packages, especially MM-WP 3, are strongly coupled to the Natural Sciences Connection, and, hence, contribute to the integration of the results of the Mathematical Modeling connection with the other connections.

Even future activities will be realized consistently with corresponding packages of the other connections.

### 7.4.4 Potential Impact

The models and tools developed for an efficient extraction of information with high quality such as resolution from the received radio signals form an important basis for the research of the other participants in the consortium. Moreover, these models and tools are expected to have an essential impact on non-destructive investigations in other areas such as medicine, engineering prospecting for natural resources that should get increased significance in the future.

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[29] A. **Khrennikov**,. Nonlinear Schrödinger equations from prequantum classical statistical field theory, Physics Letters A, 357, N 3, 171-176 2006.

[30] A. **Khrennikov**, A pre-quantum classical statistical model with infinite-dimensional phase space. J. Phys. A: Math. Gen., 38, 9051-9073, 2005.

## 7.5 THE RADIO SCIENCE CONNECTION

These problems concern the interconnection of novel information-rich radio and radar sensors at the low radio frequency (long wavelength) limit connecting the analogue to the digital. Compared to conventional technologies involving large mechanically maneuverable antenna structures, NATURE ONLINE centre's software observatory technique is considerably more flexible and cost-effective.

The objective is to jointly utilize the multitude of diversity gains supported by the unique radio signal composition of the distributed radio sensor backbone of the LINNÉ OBSERVATORY to investigate novel radio transmission and radio access techniques for probing and communications purposes. These techniques would cater for higher data rates, increased resource efficiency and light-weight practical realization. As a prerequisite, an in-depth characterization and modeling of the radio channel including the novel transmission resource of rotational frequency will be performed.

### 7.5.1 REQUIREMENTS AND CONTRIBUTIONS

The radio signal composition and radio sensor backbone of the LINNÉ OBSERVATORY will offer a unique framework for formulating the theoretical concepts as well as verifying the aforementioned generalized diversity gains in a physical system. Firstly, the underlying vector representation of the electromagnetic waves may provide a basis for a generalized formulation of the multi-input multi-output paradigm accounting for a variety of diversity mechanism and no longer be restricted to conventional antenna arrays. This would also be an attractive feature for practical relations in mobile terminals as power dissipation and implementation size may be conserved. Secondly, the multi-level structure of the radio signals used in the LINNÉ OBSERVATORY would allow for researching into reliable and secure communication links that use non-binary sequences and channel codes. In the former case, lower maximum nontrivial correlations can be achieved compared to the best binary sequences, while non-binary channel codes promise better error rate performance compared to their binary counterparts. Thirdly, as the considered radio signals carry orbital angular momentum (OAM), a radio resource that can be viewed as a rotational frequency, a generalization of the ambiguity function towards a multi-dimensional variant may lead to a breakthrough in guiding location-related needs of objects within the radio sensor network.

### 7.5.2 PRINCIPAL AND PRACTICAL QUESTIONS INCLUDING SPECIFIC STATE OF THE ART

*Multi-dimensional radio channel measurement and modeling*: The radio channel in the LINNÉ OBSERVATORY deploys vector antennas and offers rotational frequency as additional resource. This novel medium needs to be understood prior to designing radio transmission and access schemes for radio communications. The same applies for its use in Earth and space observations as well as ranging and location-based services. Specifications need to identify the scenarios to be measured with respect to the distributed multiple link system, mobility scenarios and parameters such as conventional and OAM/rotational carrier frequencies, bandwidth, delay resolution, and dynamic range. On this basis, a measurement campaign needs to be conducted to clarify behaviors such as the propagation phenomena, scattering mechanisms, temporal, spatial, and rotational correlation between different frequencies bands on the conventional and rotational frequencies. This campaign and the clarification of key characteristics including delay spread, angular spread, and rotational spread will pave the way for modeling the multidimensional radio channel comprising of vector antennas and rotational spread and essentially support link layer and system simulations.

*Signal modulation and detection:* The modulation and detection schemes have to account for both radio communications signals as well as natural signals from Earth and space. Although OFDM has gained significant interest in recent years, it is also known to be susceptible to weather conditions as its evolutions in digital video broadcasting has revealed[31]. As such, novel spreading modulation approaches based on combination techniques and interference free window (IFW) sequences will be considered to facilitate multi-access to the transmission medium[32]. In particular, large area sequences, classified for the first time by Cresp *et al.*[33] can be combined in many ways with polyphase, complementary or loosely synchronous sequence to design large area synchronous sequences that offer an IFW subject to system constraints. The concept of combination and inherent use of mutually orthogonal complementary sets of sequences supports signal detection through fast correlation. The availability of OAM/rotational frequencies can be viewed as an expansion of the frequency domain into a second dimension and may allow for higher date rates in point-to-point communications. Potential leakage between rotational frequency bands may be alleviated by the use of permutation sequences. Given spreading modulation is used, a link to ranging applications is readily obtained, while the correlation receiver structures could be reused in passive or active techniques for Earth and space radio and radar diagnostics.

*Non-binary turbo encoding and iterative detection*: A posteriori probability decoding algorithms play an important role in decoding turbo codes as they process soft information. There has been increased recent interest in non-binary computing, promoting the use of codes over such fields and rings.[34] It is also interesting to note the recent research on decoding of general low-density parity-check (LDPC) codes over prime and extension fields. These works are motivated by the observation that bit error performance of LDPC codes can be improved for moderate code length by increasing the order of the associated field. The multifaceted structure of the radio signals in the LINNÉ OBSERVATORY may provide a vehicle to develop and deploy novel non-binary channel coding along with iterative decoding algorithms given the radio channel is understood.

### 7.5.3 WORKING PLAN & MILESTONES FOR THE NEXT TWO YEARS AND LONG TERM PLANS

There is one main applicant (á 25%) and one PhD student (á 80%) contributing to the Radio Science connection summing up to ~26 PM to schedule in the first two years.

**RS-WP 1** [3 PM] defines system specifications to facilitate the channel measurement campaign and development of radio signal processing algorithms for radio communications and observation applications.

**RS-WP 2** [6 PM] conducts a measurement campaign to reveal the channel characteristics in light of the unique radio signal composition and radio sensor network of the LINNÉ OBSERVATORY.

**RS-WP 3** [9 PM] develops the non-binary spreading modulation, detection, and access techniques for radio communications and natural signal processing. Commence research on non-binary turbo coding and corresponding iterative detection schemes for providing reliable radio links.

**RS-WP 4** [3 PM] integrates results of RS-WPs.

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31 H.-J. **Zepernick**, A. Finger, Pseudo Random Signal Processing: Theory and Application, John Wiley & Sons, 2005.

32 H.-H. Chen, The Next Generation CDMA Technologies, John Wiley & Sons, 2007.

33 G. Cresp, H.-J. **Zepernick**, and H. H. Dam, On the Classification of Large Area Sequences, IEEE Int. Workshop on Information Theory, Bergen, Norway, July 2007, pp. 153-157.

34 T. Lestable and M. Ran (Eds.), White Paper – Error Control Coding for Next Generation Wireless Systems, WWRF/WG4/Subgroup on Channel Coding, WG4 Meeting #17, Nov. 2006.

Additional, efforts of this connection [5 PM] are planned for integration and contribute to the corresponding work package of the Complex Systems Engineering connection (SE- WP 3).

Further tasks will iteratively improve on radio channel characterization, obtaining a good performance complexity tradeoff for the radio transmission and access techniques, and facilitate radio resource management to fully utilize system capacity. Close integration cycles with the other research connections in NATURE ONLINE guarantee step-by-step improvements of the LINNÉ OBSERVATORY as a whole.

### 7.5.4 POTENTIAL IMPACT

Sensing methods in the radio regime inspired by quantum optics can be a valuable contribution to wireless communications by introducing ideas on entirely new modulation schemes for information-rich, resource-saving radio and microwave communication systems, which in turn may introduce new telecommunication standards. Moreover, the inexpensive, yet flexible and versatile, new digital methods developed will facilitate the invention of cost-effective huge aperture radio and netted radar systems for the commercial and non-commercial sectors alike.

By amalgamating these novel approaches, which are supported by the unique radio signal composition and radio sensor network of the LINNÉ OBSERVATORY, commercially viable radio transmission techniques and radar signal processing algorithms are envisaged to be developed. The benefits of these approaches are seen in increased spectral efficiency, providing for satisfactory coverage, increased reliability, and significantly reduced costs for the implementation of diversity concepts. The practical applications may include multimedia communications, delivery of location-based services, precise guidance of emergency teams, as well as monitoring and timely communication of environmental changes or natural disaster warning.

## 7.6 THE COMPLEX SYSTEMS ENGINEERING CONNECTION

This connection addresses the non-trivial integration of components that are complex in themselves: The LINNÉ OBSERVATORY establishes a time-synchronous, flexible, robust, secure, auto-configuring, scalable and extensible sensor network connected to high-performance computing infrastructure for observing Nature. For the successful outcome the more applied activities must be supported by physical and mathematical modeling.

The objective is to design and implement a sustainable and flexible infrastructure supporting experiments at the LINNÉ OBSERVATORY. As such, the activities of this connection support a systemic view of the LINNÉ OBSERVATORY.

### 7.6.1 REQUIREMENTS AND CONTRIBUTIONS

The LINNÉ OBSERVATORY aims at increasing our understanding of selected aspects of Nature, relevant to, for instance, climate change or other environmental challenges. To that end we need to develop mathematical models supporting explanations or predictions. A challenge is now to identify suitable parameters and corresponding key thresholds, *cf*. Natural Science and Mathematical Modeling connections. Instrumentation and reading of sensors as well as processing and monitoring data, information and the state of models are mainly concerns of the Computing Science and Radio Science connections. Identifying and pursuing systemic requirements such as adaptability, high-performance, usability/programmability – at a later stage even resilience, dependability, scalability, conformance, trustworthiness and other qualities – are the main responsibilities of the Complex Systems Engineering connection.

Contributions from this activity are mainly related to advancements of current GRID-based infrastructures related to e-science towards virtual laboratories, semantic-based services, and context dependant middleware related to scientific topics addressed by the LINNÉ OBSERVATORY.

### 7.6.2 PRINCIPAL AND PRACTICAL QUESTIONS INCLUDING SPECIFIC STATE OF THE ART

Open research questions concern design, implementation and maintenance of the experimental infrastructure and the integration of the results of the other connections.

The first major challenge relates to the system architecture. For the overall system architecture, we will adopt ideas and suggested solutions from the NSF GENI project.[35] Specifically, we will evaluate and adopt the basic ideas of *Abstractions*, *Interfaces*, *Security*, and *Implementation*. Furthermore, we will design and implement programmable nodes and operator portals as well as researcher portals to facilitate setting up and running dedicated experiments. To that end we will also implement suitable system services and user services as well as instrumentation tools and data repositories. Here the current state-of-the-art, besides the GENI project, is given by several EU funded projects such as the Enabling Grids for E-science projects.[36]

Integral parts of the system architecture will be the software architecture as required/developed by the Computing Science connection and the architecture of the system facilitating the radio channel measurements as required/developed by the Radio Science connection. Hence, this challenge is strongly related to the design of the software middleware infrastructure and the experimental system for radio communication and observation applications.

The second challenge relates to development of suitable models for measurements and analysis of system related data including the *machine models* as required/developed by the Computing Science connection. Present day models have clear and identified shortcomings including predictions of performance of data traffic, understanding of the behavior of the network or behavior of end users. Furthermore we need to develop new kinds of protocols that are more supportive of diagnosis tasks.

We identify a third challenge of transforming low level information carried by data streams into packages that fills in selected parameters of selected models (data filters combined with data fusions/data abstractions) in the information processing network. The user-centric and domain dependant transformation of the data packages of the information processing network into meaningful and semantically correct information to the end-users involves several still open research questions. Our approach with selected domains and concurrent development of tools supporting experimentation is a way to for incremental development of our understanding of those topics.

### 7.6.3 WORKING PLAN & MILESTONES FOR THE NEXT TWO YEARS AND LONG TERM PLANS

There are two main applicants (á 25%) and two PhD students (á 80%) contributing to the Complex Systems Engineering connection (~52 PM). Additionally, this connection receives integration support from the other connections (~21 PM). Altogether, there are ~73 PM to schedule in the first two years.

We are planning three work packages for the activities of the Complex Systems Engineering connection in the first two years. The activities of the work package are intervened with activities of the other connections.

**SE-WP 1 –** *Reference architecture* [17 PM / Month 1–9] identifies a suitable reference architecture, including software architecture, for the LINNÉ OBSERVATORY. Milestones

[35] GENI: http://www.geni.net
[36] EGEE-I and EGEE-II: http://public.eu-egee.org

include after Month 6: generic architecture supporting key experiments at the LINNÉ OBSERVATORY, and after Month 9: a generic architecture supporting models and instrumentation of the LINNÉ OBSERVATORY.

**SE-WP 2 –** *Requirements for a prototype* LINNÉ OBSERVATORY [27 PM / Month 6–20] specifies a selection of systemic requirements supporting trustworthy operations at the observatory. Milestones after Month 12: selection of suitable systemic requirements, after Month 20: instrumentation supporting trustworthy operations at LINNÉ OBSERVATORY.

**SE-WP 3 –** *Integration with work packages of other connections* [29 PM / Month 1–24] especially with practical results from the Computing Science and Radio Science connections. Milestones after Month 14: assessments of the integration process, first iteration, after Month 22: assessments of the integration process, second iteration, and after Month 24: assessments of the prototype of LINNÉ OBSERVATORY.

Also the further activities of this connection will follow a risk-driven iterative process model. Close integration cycles with the other connections guarantee step-by-step improvements of the LINNÉ OBSERVATORY as a whole.

#### 7.6.4 POTENTIAL IMPACT

The work of the Complex Systems Engineering connection is closely following standards and results (middleware and tools) from related international e-science projects. The specific focus of the LINNÉ OBSERVATORY will enable impact to international e-science projects as well as within the connection areas within the project.

# 8 COMPETENCE AND RESOURCES

This section describes the *scientific* competence and resources of the mobilized and required. For the organizational resources, we refer to *Appendix* U.

## 8.1 MOBILIZATION OF RESOURCES

### 8.1.1 PEOPLE INVOLVED

Research will be conducted by the applicants and senior researchers and graduate students in their respective groups. The main applicants include: *Natural Sciences Connection*: Willem **Baan**, Staffan **Carius**, Bo **Thidé**. *Computing Science Connection*: Welf **Löwe** and Baan, Gustavsson, Milrad, Thidé. *Mathematical Modeling Connection*: Nail **Ibragimov**, Andrei **Khrennikov**, Sven **Nordebo** and Thidé. *Radio Science Connection*: Hans-Jürgen **Zepernick** and Nordebo, Thidé. *Complex Systems Engineering Connection*: Rune **Gustavsson**, Marcelo **Milrad** with direct support of Löwe, Baan, Thidé, Zepernick.

### 8.1.2 EXISTING INFRASTRUCTURES

NATURE ONLINE will utilize existing sensor network infrastructures and experimental labs in Sweden (LOIS) and in Europe (LOFAR). The LOIS infrastructure includes:

- The LOIS test station installation in Risinge, near Växjö, including high-speed optical fibre connections. This can be seen as the core installation of the LINNÉ OBSERVATORY.
- A 56-core IBM Blade Server with very high I/O capacity (due to two Shared University Research grants from IBM) is a central resource dedicated to heavy stream processing tasks.
- The Ångström Laboratory antenna chamber, Uppsala University (due to a shared funding from the Wallenberg Foundation) will allow controlled OAM radio sensor experiments.

### 8.1.3 EMBEDDING IN THE NATIONAL AND INTERNATIONAL RESEARCH COMMUNITIES

All research connections are embedded in national and international research communities which have contributed significantly to the state of the art in the respective fields.

The *Natural Sciences Connection* is embedded in the research communities of:

- Theoretical Physics, Cosmological imprints on cosmic radio emissions: Profs Danielsson and Lindström. Theoretical Particle Physics, UHECR: Prof Ingelman., Electricity and Lightning Research, Sprites: Prof Cooray. Signals and systems, Antenna chamber: Prof Ahlén; OAM radio and Space Physics: Dr Bergman. (Uppsala University, Sweden)
- Space Weather: Swedish Institute of Space Physics and the Space Weather Regional Warning Centre, Lund, Ass.prof Henrik Lundstedt.
- CsI calorimeter detectors for GLAST: Prof. N. Johnson, Prof. E. Grove (NRL, Washington, US), Prof. Benoît Lott (CENBG, Bordeaux Gradignan, FRANCE) and others of the GLAST collaboration.
- Primary electronic signal performance analysis for the AMANDA neutrino telescope: Prof. Hallgren (Uppsala University, Sweden) and others of the AMANDA/IceCube collaboration.
- Distributed observing and data acquisition systems of the European VLBI Network.
- ASTRON technology and system development for radio and optical astronomy and infrared space astronomy. Interference management and data processing: Dr. Boonstra (ASTRON, NL), Prof. Ellingson, (Georgia Tech, USA), Dr. Sault (Swinburne University, Melbourne, AUS)

The *Computing Science Connection* is embedded in the research communities of:

- Parallel task and task graph scheduling: Prof. Middendorf (Uni Leipzig, Germany), Prof. Trystram (IIMAG, France), Prof. Zimmermann (Uni Halle, Germany),
- Software composition: Prof. Assmann (Uni Dresden, Germany), dynamic composition of scientific components: Prof. Kessler (PELab, Linköping University),
- High-volume, high-performance data stream processing: Dr's. Amini and Elmegreen (IBM Research, USA), Prof. Risch (Database Lab, Uppsala University).
- High-speed data transport, distributed and central computing for astronomy: Dr. Szomoru (JIVE, Dwingeloo, NL) and Dr. Nijboer (LOFAR), Dr. Tzioumis (ATNF/CSIRO, AUS), Dr. Whitney (Haystack Observatory, USA), Dr. Romney (NRAO Soccoro, NM, USA).

The *Mathematical Modeling Connection* is embedded in the research communities of:

- Quantum foundations: Prof. ´t Hooft (Uni Utrecht, the Netherlands), Nobel Prize in Quantum Field Theory, Prof. Nieuwenhuizen (Uni Amsterdam, the Netherlands), Prof. Manko (Lebedev Phys. Institute, Moscow, Russia), Prof. Volovich (Steklov Math. Institute, Moscow, Russia).
- Quantum information and quantum probability: Prof. Accardi (Uni Rome, Italy), Prof. Albeverio (Uni Bonn, Germany), Prof. Svozil (Uni Vienna, Austria), Prof. Jaeger (Boston Uni, USA), Prof. D'Ariano (Uni Turin, Italy), Prof. Grib (Friedmann Lab. St-Peterburg, Russia), Prof. Belavkin and Prof. Hudson (Nottingham, UK).

The *Radio Science Connection* is embedded in the research communities of:

- Channel measurements and modeling: Dr. Suzuki (CSIRO, Australia and ITU-R Chairman of Subgroup 3K-3), Dr. Sharp (CSIRO, Australia), Dr. Weber (Qualcomm, Germany).

- Radio transmission and access techniques: Prof. Finger (Uni Dresden, Germany), Prof. Vary (RWTH Aachen, Germany). Prof. Farkas (Slovak University of Technology, Slovakia), Prof. Matolak (Ohio University, USA), Prof. Wysocki (University of Nebraska-Lincoln, USA), Prof. Nordholm (Curtin University, Australia).
- Pre-standardization and EU networks: Wireless World Research Forum, EU Network of Excellence EuroFGI (Future Generation Internet) and its successor EuroFN (Future Networks).

The *Complex Systems Engineering Connection* is embedded in research communities of:

- GRID computing and critical infrastructures: Prof Hadjsaid (General Director IDEA-GIE INPGrenoble, France and former President of CRIS), Prof Deconnink (ESAT/ELECTA K.U. Leuven, Belgium), network of The Institute of Critical Infrastructures, consortia of EU funded projects INTEGRAL and GRID.
- Semantics and knowledge intensive systems: Prof. Akkermans (Business Informatics, Free Uni Amsterdam, Holland), Prof. Clark (Dep't Computing, Imperial College, London, UK).
- Ubiquitous Computing Architectures and Applications Prof. Hoppe (Department of Computer Science, Uni Duisburg-Essen, Germany) Prof. Hiroaki Ogata (Dept. of Information Science and Intelligent Systems, Tokushima University, Japan)
- Architectures and instrumentation: PhD Mellstrand (Sony-Ericsson, MIB Group, Lund).

## 8.2 REQUIRED RESOURCES

The key persons Bo Thidé and Willem Baan, who will lead NATURE ONLINE will contribute with 100% and 50% of their working time, respectively. The remaining main applicants – employed on faculty funding already – will contribute with 25% each. For persuading short term research goals, we need ten PhD students (80%), each supervised by one of the main applicants.

Additionally, we need resources for the close collaboration between the connections, which is crucial for NATURE ONLINE. Costs include the organization of kick-off and closing meetings, workshops and further planning meetings over the lifetime of NATURE ONLINE, the organization of the graduate education for the PhD students involved, and expenses for bilateral visits and conference travels.

Finally, we require equipment and instrumentation hardware and software to further develop the existing and emerging LOIS sensor networks towards the LINNÉ OBSERVATORY as envisioned by NATURE ONLINE. The instrumentation hardware includes radio sensors, calibrated boxed connection racks, GPS positioning equipment, PCs etc. We also need to account for deprecation of hardware and software for installation and operation expenses.

Altogether, we require resources worth on average **~14 MSEK/year** with major investments in the first two years. We apply for a Linneaus grant of 7 MSEK/year. Co-funding by The Southeast Sweden Universities covers the remaining ~7 MSEK/year and guarantees the investments of the first two years. Refer to *Appendix* U for details.