Application for affiliate membership of NLSI International Partners Program

The Netherlands lunar science community would like to apply for affiliate membership of the NLSI International Partners Program. In this document we provide the background to this application, give an overview of current and planned national research activities related to lunar science, and detail several specific areas in which the Dutch lunar science community can complement and extend the expertise of NLSI's US and other international partners.

Background

Planetary science in general, and lunar science in particular, are relatively young, fast-growing areas of scientific research in The Netherlands. The Netherlands has a long, distinguished track record in (radio-)astronomy research, with major contributions to both instrument development, space missions, and fundamental research. This research has recently included lunar research. The Netherlands Institute for Radio Astronomy (ASTRON) has been actively involved in conducting a number of studies on lunar landers and their use for erecting a radio telescope on the Moon, and is studying an orbiting radio antenna array around the Moon. A national academic consortium (NuMoon) recently completed an initial test confirming that the Moon can be used as a giant high-energy particle detector, by observing it with the Dutch Westerbork Synthesis Radio Telescope (WSRT). NuMoon is planning further Moon observations with the LOFAR (LOw Frequency ARray) radio telescope which is in the commissioning phase. Because of the very large baselines covered with this telescope these new measurements will be important for planetary science as well as for detecting ultra-high energy particles.

In 2006, planetary science research received a significant impetus by the development of a government-sponsored dedicated planetary science support funding scheme. In the same year, a personal grant awarded by the European Science Foundation injected additional funding aimed specifically at fundamental lunar science. In total, an estimated 5 M€ was invested into planetary science over the past three years, with 1.5 M€ focused specifically on lunar science.

Further illustrations of the growing importance of planetary and lunar science in the Netherlands include

- the upcoming appointment of a dedicated planetary science professorship at VU University Amsterdam (the first such professorship in the country, which will be taken up by Prof. Bernard Foing, former project scientist for ESA's SMART-1 lunar mission, and executive director and past president of the International Lunar Exploration Working Group (ILEWG).
- the appointment of a Netherlands Royal Academy of Arts and Sciences (KNAW) Visiting Professor in planetary science in 2009 (Prof. Carl Agee, Institute of Meteoritics, University of New Mexico, USA)
- the award of a European Union (EU) 'ERC Advanced grant' (the most prestigious personal grant in the EU) to Prof. Heino Falcke (ASTRON / Radboud University) who is a member of the Exploration Definition Team of the ESA lunar cargo lander, previously participated in the science definition team of the MoonNEXT study, and is an international member of the NLSI astrophysics node "LUNAR" led by Jack Burns.

In parallel to these developments at academic institutions, sections of the national space instrumentation industry have become very active in the pursuit of commercial approaches to lunar and planetary science ('Space 2.0'). This is illustrated by the widely publicized recent signing of a Letter of Intent by a national consortium aiming to place a combined Raman/LIBS instrument on the lander of Odyssey Moon, one of the Google Lunar X PRIZE contestants.

In light of this recent growth of interest and focus, and in view of the rapidly expanding number of other space-faring countries intent on developing lunar science it is vital for the Dutch lunar science community to develop excellent international contacts. Our membership of the NLSI would constitute a major step in this direction.

Organizational nature of the proposing group

The proposing group listed below is a consortium consisting of (1) academic researchers based in the Netherlands that are active in lunar science, with backgrounds ranging from astroparticle physics to geochemistry; (2) members of the national space industry community involved in designing instrumentation specifically suitable for lunar missions (both in orbit and on the surface). In addition, a representative of the recently founded Netherlands Space Office (NSO), the government institution which coordinates space science and technology activities is included.

The consortium is led by lunar researcher dr. Wim van Westrenen (VU University Amsterdam, expert in experimental lunar interior research), who plans to manage a Dutch NLSI partner lunar science web portal and coordinate contact between the consortium and NSLI. The members of the proposed Dutch NLSI node cover a wide range of lunar research activities detailed in the next section.

Name	*Institution*	*Expertise*	*Position*
Prof. Gareth Davies	VU University Amsterdam	Geochemistry	Permanent staff
Prof. Heino Falcke	Radboud Univ. / ASTRON	Astroparticle physics	Permanent staff
Prof. Bernard Foing	VU University Amsterdam	Remote sensing techniques	Permanent staff
Prof. Olaf Scholten	KVI / Groningen Univ.	Astroparticle physics	Permanent staff
Erik Laan	TNO Science & Industry	Instrument development	Permanent staff
Dr. Martijn Smit	SRON	Gravity and seismics	Permanent staff
Dr. Bert Vermeersen	TU Delft	Gravity field analysis	Permanent staff
Arno Wielders	Space Horizon	Mission development	Permanent staff
Dr. Arie van den Berg	Utrecht University	Thermal evolution	Permanent staff
Dr. W van Westrenen	VU University Amsterdam	Experimental lunar science	Permanent staff
Dr. Amin Aminai	Radboud University	Lunar radio-antenna	Postdoc
Dr. John Kelley	Radboud University	Astroparticle physics	Postdoc
Dr. Maaijke Mevius	KVI / Groningen Univ.	Astroparticle physics	Postdoc
Dr. Nachiketa Rai	VU University Amsterdam	Experimental lunar science	Postdoc
Dr. Kalpana Singh	KVI / Groningen Univ.	Astroparticle physics	Postdoc
Dr. Elodie Tronche	VU University Amsterdam	Experimental lunar science	Postdoc
Linjie Chen	Radboud University	Moon antenna	PhD student
Mirjam van Kan	VU University Amsterdam	Experimental lunar science	PhD student
Jellie de Vries	VU University Amsterdam	Planetary thermal evolution	PhD student
Josepha Kempl	VU University Amsterdam	Metal core formation	PhD student
Sander ter Veen	Radboud University	Astroparticle physics	PhD student
Dr. Rolf de Groot	Netherlands Space Office	Director Science and Tech	Permanent staff

Current activities in lunar science

Current national activities in lunar science are in many ways complementary to the work being pursued by the first seven US NLSI Teams announced earlier this year. As such, we think both the NLSI and the Dutch lunar science community would benefit greatly from increased interaction that would undoubtedly stem from an affiliate membership. National expertise of specific interest to the NLSI can broadly be divided into three areas: (a) Experimental lunar interior science (b) (Radio)astronomy-related research on and off the Moon (c) Instrument development aimed at both institutional lunar missions and upcoming commercial missions.

(a) *Experimental lunar interior science.*

Since 2007, VU University Amsterdam houses a high-pressure laboratory that is exclusively dedicated to lunar interior research. This laboratory was built with funding from a European

Science Foundation (ESF) European Young Investigator (EURYI) award to dr. Wim van Westrenen. The lunar research team currently holds 5 full-time positions, making it one of the largest research groups focusing on the lunar interior in the world. The project involves close collaboration with Utrecht University's geophysics department. The aim of this research is to develop a fully consistent, complete physical and chemical model for the origin and evolution of the Moon.

To reach this aim, the group is obtaining novel constraints on the physical properties and compositions of the materials forming the lunar crust, mantle and core using a multidisciplinary approach. Systematic high-pressure, high-temperature experiments on lunar compositions are used to quantify the distribution of elements between minerals and melts in the Moon's interior. Densities of these phases are being measured as a function of pressure and temperature for the first time, using new in situ measurement techniques using synchrotron X-ray radiation.

These experimental data are combined with the latest surface compositional data from lunar space missions as well as computer simulations (thermochemical convection modeling) of the dynamics of the early lunar interior. Surface compositional data are obtained in collaboration with ESA. It's research headquarters (ESTEC) is located in the Netherlands, and several MSc students have pursued their BSc and MSc research projects at ESTEC.

The direct combination of measurements of the physical and chemical properties of the lunar interior with thermochemical convection modeling is highly complementary to existing expertise within the NLSI. In particular, the experiments we perform are complementary to the experiments performed by the group of Prof. Tim Grove who is a member of the NLSI team led by Prof. Carle Pieters. Obviously our group would benefit from stronger interaction with, e.g. the NLSI teams led by Pieters (for integration between our experiments and the latest remote sensing data) and Bottke (to bridge the gap between thermal evolution models and lunar formation models).

(b) (Radio)astronomy-related research.

As mentioned in the introduction, The Netherlands Institute for Radio Astronomy ASTRON has been conducting a number of studies together with EADS Astrium on lunar landers and their use for erecting a Low Frequency Array (LOFAR)-like radio telescope on the Moon, as well as using it for geophysical measurements (seismology). Currently ASTRON are conducting a study for an orbiting radio antenna array around the Moon under contract from ESA.

Consortium member Prof. Falcke organized two workshops (sponsored by ASTRON, EADS, and RadioNet - a EU network of radio astronomers), entitled "Towards a European Infrastructure for Lunar Observatories" and co-corganized two conferences, called "To Moon and Beyond" in Bremen, Germany. Funding by the KNAW is used to develop a prototype for a lunar radio antenna. This project is performed in synergy with antenna developments for the AUGER cosmic ray detector which is funded by NOVA (the national Astronomy Research School). Scientific goals of the prototype antenna, which is targeted to fly with the first ESA moon lander, are to measure - among others - the lunar radio environment, cosmic ray (and potentially meteorite) impacts, and the lunar ionosphere.

A recent project by consortium members from KVI and ASTRON called "NuMoon" uses the Moon as a giant particle detector, by observing it with (Dutch) radio telescopes (first the Westerbork Synthesis Radio Telescope/WSRT, to be followed shortly by LOFAR). The experiment has just produced the best limit on the existence of ultra-high energy neutrinos and was featured in New Scientist, see http://www.newscientist.com/article/dn17561-moon-used-as-giant-particle-detector.html. This experiment links up with research activity (a) mentioned above, as knowledge of the structure of the Moon is of high relevance, and as the interaction of neutrinos happens underneath the lunar regolith (tens to hundreds of meters below the surface). As part of this research, data will be gathered on the reflectivity and emissivity of the lunar surface at radio wavelengths between 15 and 240 MHz with very good spatial resolution.

(c) *Instrument development aimed at institutional lunar missions and upcoming commercial missions.*

Since the early beginnings of space exploration in the sixties, Dutch institutes and companies have been strongly involved in the development of scientific instrumentation for

astronomy and Earth observation missions. Astronomy missions such as Ans, IRAS, XMM, ISO and Herschel and Earth observation missions such as ERS-2, Envisat and EOS-AURA all carried Netherlands-built instruments and led to significant scientific discoveries.

Coinciding with the start of ESA's Aurora programme, national instrumentation expertise is now also directed to planetary exploration missions with contributions to the development of a Raman/LIBS spectrometer, a Life Marker Chip and SEIS, an instrument for seismic measurements. Concerning lunar science and exploration in particular, a TNO-led initiative called Moon4You now aims to place a Raman/LIBS instrument to fly to the Moon in 2012 on Odyssey Moon's MoonOne mission. The Raman/LIBS instrument is a fundamental, next-generation instrument for mineralogical and elemental (atomic) characterisation of lunar soil and rock samples. It uses an Optical Head to illuminate samples with laser light that generates physical phenomena (Raman shift and plasma for the LIBS) with light emission. Emitted light is collected and relayed to a spectrometer using optical fibres to record a spectrum on a CCD for sample identification.

The main science objective of the Moon4You instrument onboard a lunar mission would be to determine the mineralogical and elemental composition of the lunar surface, to (1) provide details on the geological and geochemical evolution of the Moon (2) perform detailed in-situ mapping of lunar material of interest for lunar exploitation means and the realization of a future lunar base (3) demonstrate and validate technology for future planetary exploration missions and terrestrial spin-offs.

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Specific areas where productive near-term exchanges/partnerships are anticipated

As mentioned above, we feel Dutch lunar science complements and extends the work done by NLSI US institutions in several respects. This complementary nature leaves significant scope for productive synergetic exchanges / partnerships.

The Dutch node could assist in the training of the next generation of lunar scientists, by offering and supervising MSc and PhD research projects on lunar science, specifically aimed at the evolution of the lunar interior and the use of the Moon in (radio)astronomy research. One example of specific expertise that is not currently actively pursued in the US includes our capability to measure in situ the physical properties of lunar melts and minerals, in collaboration with the European Synchrotron Radiation Facility (ESRF), Grenoble, France. We envisage exchange visits by researchers to our lunar research laboratories, and intend to actively pursue the possibilities of allowing US-based students to perform part of their research at ESA's ESTEC location in the Netherlands.

A second area of potential near-term partnerships concerns the integration of remote sensing data with high-pressure experiments. We already have some experience with trying to use SMART-1 data to constrain the composition of near-side and far-side basalts. This experience could be combined with the experience of the Pieters team to provide new experimental constraints on the origin of the differences between the lunar near and far sides.

Members of our consortium already attend the Lunar and Planetary Science meeting, and plan to become actively involved in the new annual NLSI-sponsored Lunar Science Conference.

In the area of outreach, we note that many members of our consortium are also members of the Dutch Platform for Planetary Science (NPP). One of the main tasks of the NPP is organizing outreach activities, and the NPP intends to actively assist in publicizing the activities of the NLSI to a wider audience. The NPP also organizes a yearly scientific meeting in the Netherlands which will raise the national profile of lunar research.

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