THE Crafoord PRIZE

Crafoord *Days* 2019

13–15 MAY
IN LUND, SWEDEN

PHOTO: ALAN SILFEN

SALLIE W. CHISHOLM

The Crafoord *Prize* in Biosciences

Abstracts and Programme

Anna-Greta and Holger Crafoord Fund

THE FUND WAS ESTABLISHED in 1980 by a donation to the Royal Swedish Academy of Sciences from Anna-Greta and Holger Crafoord. The Crafoord Prize was awarded for the first time in 1982. The purpose of the fund is to promote basic scientific research worldwide in the following disciplines:

- Mathematics
- Astronomy
- Geosciences
- Biosciences (with particular emphasis on Ecology)
- Polyarthritis (e.g. rheumatoid arthritis)

Support to research takes the form of an international prize awarded annually to outstanding scientists and of research grants to individuals or institutions in Sweden. Both awards and grants are made according to the following order:

year 1: Mathematics and Astronomy
year 2: Geosciences
year 3: Biosciences (with particular emphasis on Ecology)
year 4: Mathematics and Astronomy
etc.

The Prize in Polyarthritis is awarded only when the Academy's Class for medical sciences has shown that scientific progress in this field has been such that an award is justified.

Part of the fund is reserved for appropriate research projects at the Academy's institutes. The Crafoord Prize presently amounts to 6 million Swedish krona.

The Crafoord Prize is awarded in partnership between the Royal Swedish Academy of Sciences and the Crafoord Foundation in Lund. The Academy is responsible for selecting the Crafoord Laureates.

Content

PROGRAMMES

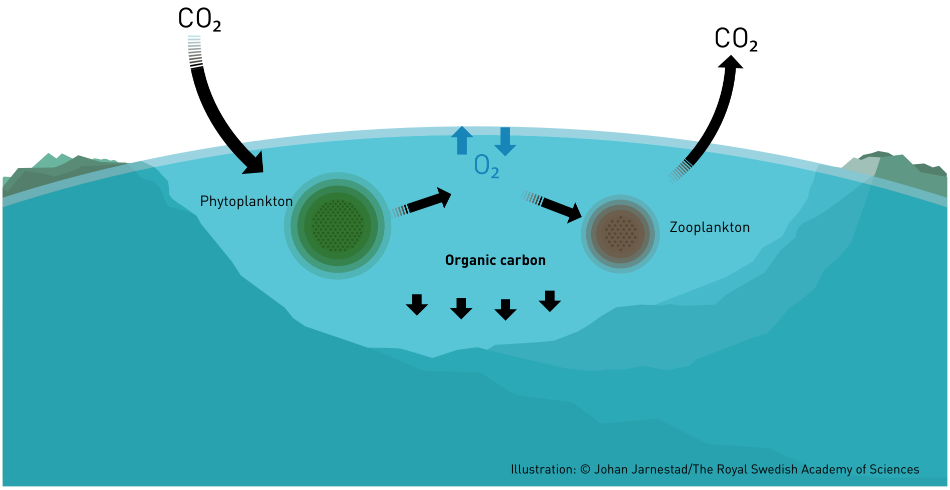
The Crafoord Laureate in Biosciences 2019

PHOTO: ALAN SILFEN

SALLIE W. CHISHOLM
MASSACHUSETTS INSTITUTE OF TECHNOLOGY, MIT, MA, USA

Sallie W. Chisholm, Massachusetts Institute of Technology, MIT, MA, USA, *"for the discovery and pioneering studies of the most abundant photosynthesising organism on Earth,* Prochlorococcus".

The Crafoord *Prize* in Biosciences



A miniscule organism of huge importance

The *Prochlorococcus* cyanobacteria is the smallest and most common oxygen-producing organism in the world. It dominates large areas of the World Ocean and is responsible for a considerable share of the photosynthesis on Earth, yet was entirely unknown until the 1980s. Sallie Chisholm is awarded the Crafoord Prize 2019 for her discovery of and research into this incredible organism.

Microorganisms in the world's seas and oceans perform a large part of all photosynthesis on Earth. In the multitude of thousands of different species, there is one that is unique: *Prochlorococcus* cyanobacteria, which is the world's smallest and most common photosynthesising organism. It is about half of a micrometre in diameter, and there can be 100 million of them in a single litre of water.

Sallie (Penny) Chisholm and her research colleagues discovered *Prochlorococcus* on expeditions in the Atlantic and Pacific Ocean during the second half of the 1980s. The group had the idea of using a flow cytometer – an instrument that had so far mainly been used in medical research – to study microorganisms in seawater. Results from the instrument showed a weak signal that was initially interpreted as background noise. However, additional research showed that this signal came from something living – an extremely small, photosynthesising bacteria. This discovery was published in 1988, but *Prochlorococcus* was not named until 1992.

Sallie Chisholm has dedicated much of her research to studying *Prochlorococcus*. It is found in all oceans and seas and is the dominant photosynthesising organism in all nutrient-poor, relatively warm waters. This is a significant proportion of the Earth's surface, so the global population of this type of bacteria is estimated at about $3*10^{27}$ (3,000,000,000,000,000,000,000,000,000) individuals.

Genetic studies have shown that *Prochlorococcus* has exceptionally few genes – but also very many. One individual can have as few as 1,700 genes, the fewest of all known photosynthesising organisms. However, there is great variation between different populations and, in total, the species has around 80,000 different genes – approximately four times more than humans. A thousand or so of these genes are common to all individuals.

Prochlorococcus is interesting in itself, but may also contribute to better understanding of the truly significant phases in the development of life on Earth. As a relative of the organisms that, a few billion years ago, began to deliver oxygen to the atmosphere, it can help us understand this decisive stage. *Prochlorococcus* is also extremely relevant to our understanding of how seas and oceans will change in the future because of ongoing climate change.

The power of diversity: *What* Prochlorococcus *can teach us about life*

CRAFOORD LAUREATE 2019 **SALLIE W. CHISHOLM**, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, MIT, MA, USA

There are an estimated 10^{27} *Prochlorococcus* cells in the global ocean, collectively fixing billions of tons of carbon each year. These tiny cyanobacteria are ubiquitous in the tropical and subtropical oligotrophic oceans, often reaching concentrations of more than 10^8 cells liter^{-1}. They are the most abundant photosynthetic cells on Earth, yet they were not known to exist until about 30 years ago.

The global *Prochlorococcus* "collective" is composed of amazingly diverse lineages, each with different light and temperature optima, nutrient acquisition systems, stress responses, secondary metabolites etc. While each cell has roughly 2000 genes, it only shares about half of these – the core genome – with all other *Prochlorococcus*. The remainder are part of an enormous pan-genome that continues to grow with every cell we sequence – appearing almost boundless in its diversity[1]. Studies of the distribution of ecotypes and genes in different environments give us clues about the selection pressures shaping this diversity, and studies of cultured isolates continue to reveal novel biological properties of these cells. This cross-scale approach, focused on a single organism, has given us a window into the vast complexity of marine ecosystems and the features that contribute to their resilience. It has also provided us with a lens through which to view forces that have shaped the very nature of our planet over evolutionary time.[2]

[1] Biller, S.J., P. Berube, D. Lindell, and S.W. Chisholm (2015). *Prochlorococcus*. The structure and function of collective diversity. *Nature Reviews Microbiol.*, 13: 13–27, doi: 10.1038/nrmicro3378.

[2] Braakman, R., M.J. Follows, and S.W. Chisholm (2017). Metabolic evolution and the self-organization of ecosystems. *PNAS USA*, 114 (15), E3091–E3100, doi: 10.1073/pnas.1619573114.

Going where the wild things are: understanding microbial interactions in the sea

ALEXANDRA Z. WORDEN, GEOMAR HELMHOLTZ CENTRE FOR OCEAN RESEARCH KIEL, GERMANY

Microbial eukaryotes (protists) are diverse and play multiple roles in marine ecosystems, yet many key taxa remain uncultured. These unicellular organisms have a penchant for engulfing other cells – indeed the rise of photosynthesis in eukaryotes came from an endosymbiosis event in which the engulfed cyanobacterium ultimately became the chloroplast, the photosynthetic organelle within eukaryotic cells. Throughout evolutionary time subsequent events have resulted in gain or loss of photosynthetic capabilities in different protistan lineages, and some protists have lost the ability to phagocytose other microbes. Unfortunately, most methods for observing ocean communities, even widespread molecular approaches, do not resolve the interactions that occur between wild protists and other biological entities – leaving us with the knowledge that marine protists are exceptionally diverse, but with little possibility for translating this knowledge into concrete understanding of the roles performed by individual lineages.

Here, we will discuss recent advances in understanding the trophic roles of wild, uncultured protistan groups and their physical interactions with other cells and viruses in the sea. Collectively, these studies are critical for understanding the evolution and ecology of marine protists. Importantly, aspects of their cell biology are flexible; for example, some perform both photosynthesis and predation. Hence, where the bulk of their activity lies along the spectrum from photosynthesis to predation dictates whether they act predominantly as a primary producer, responsible for uptake of CO_2, or a heterotrophic consumer with very different impacts. As scientists grapple with ecosystem change, understanding the biology of the diverse protistan groups in the sea as well as how they participate in ecosystem processes, and how their activities may shift, has become increasingly urgent. Using integrative approaches for elucidating microbial interactions in the wild, we are identifying intriguing relationships and exchanges that modify how we think about microbial food web links and carbon flow in ocean ecosystems.

The ecological importance of marine viruses

CORINA P.D. BRUSSAARD, NIOZ ROYAL NETHERLANDS INSTITUTE FOR SEA RESEARCH AND UNIVERSITY OF AMSTERDAM, THE NETHERLANDS

The seas and oceans are numerically dominated by microorganisms (e.g. the photosynthetic prokaryotic *Prochlorococcus*) that form the base of most marine pelagic food webs. Particularly in a time of global climate change it is vital to understand their population dynamics and community structure. Whereas these microorganisms depend on the physicochemical environment for their production, their standing stock is the resultant of gross growth and losses. The traditionally dominant loss factor is grazing by zooplankton; however, viruses are increasingly recognized as important mortality agents. Viruses are typically host-specific and differ in their ecological impact from predators. In the lytic reproductive mode, they are responsible for shunting the flow of organic carbon and nutrients upon host cell lysis from particulate to the dissolved organic matter pool. My research focusses on elucidating the ecological roles of marine viruses, the still poorly known connection between marine viruses and biogeochemistry and the influence environmental conditions have on virus-host interactions. Here I will present and discuss the quantitative relevance of viruses in marine microbial mortality, in particular for phytoplankton, and illustrate how host growth conditions impact virus proliferation. In summary, I will demonstrate how viruses rule the marine realm and consequently advocate to include viral activity in global marine ecosystem models.

One drop of seawater, one million organisms

RAMUNAS STEPANAUSKAS, BIGELOW LABORATORY FOR OCEAN SCIENCES, ME, USA

Marine microorganisms have been playing essential roles in global biogeochemistry, ecosystem functioning, and the health of multicellular organisms for billions of years. Improved understanding of their roles and trajectories in the changing oceans is one of the current frontiers in biosciences. The staggering diversity and abundance of microorganisms have been challenging the scientific inquiry and motivating advances in research technology. In a recent study, we employed novel tools to sequence the genomic blueprints of six thousand bacterial and archaeal cells from a 0.4 mL sample from the Sargasso Sea. We found that this tiny parcel of ocean water contained at least 12 taxonomic phyla, including several lineages of "microbial dark matter". Every sequenced cell was genomically unique, and only 0.1% of cell pairs shared enough similarity to be considered the same species. We found that the majority of the coding potential of marine bacterioplankton resides in the most abundant lineages, despite the streamlined genomes of their individual members. In addition to cellular genomes, the applied techniques also recovered genomes of cell-infecting agents and enabled measurements of cells' physical sizes, thus opening cultivation-unbiased windows into the viral-host interactions and genome-to-phenome relationships. Surprisingly, a larger fraction of the global prokaryoplankton metagenomes could be mapped on single cell genomes from this 0.4 mL seawater sample than on metagenomic bins produced from global datasets. Collectively, these findings indicate effective dispersal on the global scale, limited clonality and enormous pangenomes among planktonic Bacteria and Archaea of the surface ocean. These characteristics have important implications for the functioning and evolution of the marine microorganisms, as well as for the suitability of contemporary research tools to adequately represent the complexity of global microbiomes.

Pairing up in the Plankton: evolution, ecology and activity of cyanobacteria symbiosis

RACHEL A. FOSTER, STOCKHOLM UNIVERSITY, SWEDEN

Some of the most enigmatic components of the marine plankton are the microalgal (protists) groups, which carry intimately associated cyanobacteria as symbionts. In the sunlit zone of the ocean where dissolved nutrients are largely limiting, cyanobacteria pair up with a diverse group of protists. In hosts that have lost the capacity to photosynthesize, the hosts presumably rely on their cyanobacterial partners for carbon (C). These relationships resemble the ancient symbiotic event that led to chloroplasts and are thus interesting systems to study. In other hosts, such as a few genera of diatoms, that have retained photosynthesis, the cyanobacteria are N_2 fixers, and therefore can fix di-nitrogen (N_2) and provide reduced nitrogen (N) to their respective hosts. The diatom symbioses are broadly distributed in the world's oceans, and contribute to global N and C cycles due to high fixation and sinking rates. Despite their ubiquitous distribution and biogeochemical significance, our understanding of the intimate nature between the partners remains poor.

Recently we identified a continuum of symbiont integration in the diatom-cyanobacterial symbiosis, where the symbiont cellular location is tightly coupled to genome size and content – specifically the number and types of transporters – and the timing of the partnerships. Time-calibrated phylogenetic trees dated the appearance of diatom cyanobacterial symbiosis from 100–50 Mya and were consistent with the symbiont cellular location: recently evolved symbionts are located external to their hosts, and possess higher numbers of transporters. Internal symbionts have fewer transporters for nitrogenous substrates, and several carbon transporters appear to be incomplete, or missing. Using a variety of methodologies, including confocal microscopy, comparative genomics, gene complementation, and secondary ion mass spectrometry, we have begun to identify several intriguing aspects for these planktonic partnerships.

The evolution of modes of nutrition in forest fungi – from wood decay to symbiosis

FRANCIS M. MARTIN, INRA FRENCH NATIONAL INSTITUTE FOR AGRICULTURAL RESEARCH, FRANCE

Within the plant microbiota, mycorrhizal fungi are striking examples of microorganisms playing crucial roles in nutrient acquisition. They have coevolved with their hosts since the raise of land plants and the recent development of calibrated phylogenies, linked with the growing understanding of fungal genomes, provides remarkable insights into the evolutionary histories of mycorrhizal symbioses.

The comparison of 100+ genomes from mycorrhizal fungi, wood decayers and soil decomposers has revealed several independent lifestyle transitions from saprotrophism to mutualism in fungal lineages. In addition to reconstructing the evolution of mycorrhizal symbioses, our growing ability to use reference genomes for profiling differentially-expressed transcripts, for instance, is helping us to identify hundreds of symbiosis-related genes. I will discuss recent genomic studies that have revealed the adaptations that seem to be fundamental to the convergent evolution of ectomycorrhizal fungi, including the loss of some metabolic functions, such as plant cell wall degrading enzymes, and the acquisition of small secreted effector-like proteins that facilitate the accommodation of symbiotic fungi within their host plants. Finally, I will consider how these insights can be integrated into a model of the development of ectomycorrhizal symbioses and pave the way to a better understanding of their role in carbon cycling in forest ecosystems.

Station ALOHA: a proving ground for microbial oceanography

DAVID M. KARL, UNIVERSITY OF HAWAII AT MANOA, HI, USA

Microbial oceanography is a relatively new discipline that integrates the principles of marine microbiology, microbial ecology and oceanography to study the role of microorganisms in the biogeochemical dynamics of natural marine ecosystems. A general goal of microbial oceanography is to observe and understand microbial life in the sea well enough to make accurate ecological predictions, for example, of the impact of climate variability on microbial processes in the global ocean. Since October 1988, interdisciplinary teams of scientists from the University of Hawaii and around the world have conducted research at Station ALOHA (22.75 N, 158 W), a site chosen to be representative of the expansive North Pacific Subtropical Gyre. Numerous scientific discoveries from Station ALOHA, including novel microorganisms, unprecedented metabolic pathways and complex interactions, have transformed our understanding of microbial life in the sea. The uncertain nature of future climate change and the potential impacts on the structure and function of marine ecosystems demands a comprehensive description and understanding of the sea around us. Sustained research of marine microbes is vital, so continued field observations and experimentation at Station ALOHA is both timely and important. After three decades of intensive study, we now have a new view of an old ocean, with revised paradigms built on the strength of high-quality time-series data, insights from the application of -omics techniques and observations from autonomous gliders. The pace of new discovery, and the importance of integrating this new understanding into predictive models, is an enormous contemporary challenge with great scientific and societal relevance.

PROGRAMME

Crafoord *Days* 2019

Overview programme Crafoord *Days* 2019

Monday 13 May 10:30

Prize Lecture

Held by the Crafoord Laureate **Sallie W. Chisholm**.

BLÅ HALLEN, ECOLOGY BUILDING, SÖLVEGATAN 37, LUND

Registration at www.crafoordprize.se or www.kva.se

Tuesday 14 May 09:00

Prize Symposium
How Microbes Rule the World

Lectures by the Crafoord Laureate **Sallie W. Chisholm** and invited speakers.

GRAND AUDITORIUM, LUX, HELGONAVÄGEN 3, LUND

Registration at www.crafoordprize.se or www.kva.se

Wednesday 15 May 16:30

Prize Award Ceremony

By invitation only.

LUND UNIVERSITY MAIN AUDITORIUM, UNIVERSITETSHUSET, PARADISGATAN 2, LUND

Detailed programme

THE CRAFOORD PRIZE IN BIOSCIENCES 2019

The Crafoord *Prize* Lecture in Biosciences

10:30

BLÅ HALLEN, ECOLOGY BUILDING, SÖLVEGATAN 37, LUND

Open to the public and free of charge, but registration is required for all participants. Limited number of seats. For registration and further information visit: www.kva.se/crafoordprizelecture2019

Monday 13 May

10:30	Registration and coffee	
11:00	Presentation of the Crafoord *Prize* and the Crafoord Laureate	Ove Eriksson, Chairman of the Crafoord Prize Committee in Biosciences, the Royal Swedish Academy of Sciences
11:10	*Tiny cell, global impact: A journey of discovery with a microbe from the sea*	CRAFOORD LAUREATE 2019 Sallie W. Chisholm, Massachusetts Institute of Technology, MIT, MA, USA
11:45	Questions from the audience	
12:00	LUNCH	Lunch is served outside the lecture hall and is included for registered participants

Detailed programme

THE CRAFOORD SYMPOSIUM IN BIOSCIENCES 2019

How Microbes Rule the World

09:00

GRAND AUDITORIUM, LUX,
HELGONAVÄGEN 3, LUND

Open to the public and free of charge. Seating is limited.
For registration and further information visit:
www.kva.se/crafoordsymposium2019

Tuesday 14 May

09:00	Registration	
	MORNING SESSION	CHAIR: **Daniel Conley**, Member of the Royal Swedish Academy of Sciences
09:20	Opening address	**Göran K. Hansson**, Secretary General, the Royal Swedish Academy of Sciences
09:25	Introduction of the Crafoord Laureate	**Jarone Pinhassi**, Member of the Royal Swedish Academy of Sciences
09:30	*The power of diversity: What* Prochlorococcus *can teach us about life*	**CRAFOORD LAUREATE 2019** **Sallie W. Chisholm**, Massachusetts Institute of Technology, MIT, MA, USA
10:20	COFFEE BREAK	
10:40	*Going where the wild things are: understanding microbial interactions in the sea*	**Alexandra Z. Worden**, GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany
11:20	*The ecological importance of marine viruses*	**Corina P.D. Brussaard**, NIOZ Royal Netherlands Institute for Sea Research and University of Amsterdam, the Netherlands
12:00	LUNCH	(Included for registered participants)
	AFTERNOON SESSION	CHAIR: **Lars Tranvik**, Member of the Crafoord Prize Committee
13:20	*One drop of seawater, one million organisms*	**Ramunas Stepanauskas**, Bigelow Laboratory for Ocean Sciences, ME, USA
14:00	*Pairing up in the plankton: evolution, ecology and activity of cyanobacteria symbiosis*	**Rachel A. Foster**, Stockholm University, Sweden
14:40	COFFEE BREAK	
15:10	*The evolution of modes of nutrition in forest fungi – from wood decay to symbiosis*	**Francis M. Martin**, INRA French National Institute for Agricultural Research, France
15:50	*Station ALOHA: a proving ground for microbial oceanography*	**David M. Karl**, University of Hawaii at Manoa, HI, USA
16:30	Closing remarks	**Lars Tranvik**, Member of the Crafoord Prize Committee

Anna-Greta and Holger Crafoord

HOLGER AND ANNA-GRETA CRAFOORD

Holger Crafoord (1908–1982) was prominent in Swedish industry and commerce. He began his career with AB Åkerlund & Rausing and devoted a larger part of his working life to this company. In 1964, Holger Crafoord founded Gambro AB in Lund, Sweden, where the technique of manufacturing the artificial kidney was developed. This remarkable dialyser soon became world famous. Since then, a series of medical instruments has been introduced on the world market by Gambro.

In 1980, Holger Crafoord founded the Crafoord Foundation, which annually contributes greatly to the Anna-Greta and Holger Crafoord Fund.

Holger Crafoord became an honorary doctor of economics in 1972 and in 1976 an honorary doctor of medicine at Lund Univeristy.

Anna-Greta Crafoord (1914–1994) took, as Holger Crafoord's wife, part in the development of Gambro AB. Through generous donations and a strong commitment in the society around her, she contributed to the scientific and cultural life. In 1986 she founded the Anna-Greta Crafoord foundation for rheumatological research and in 1987 Anna-Greta Crafoord became an honorary doctor of medicine at Lund Univeristy.

Over the years, the Crafoords have furthered both science and culture in many ways and it is noteworthy that research in the natural sciences has received an important measure of support from the Anna-Greta and Holger Crafoord Fund.

THE ROYAL SWEDISH ACADEMY OF SCIENCES was founded in 1739 and is an independent non-governmental organisation, whose overall objective is to promote the sciences and strengthen their influence in society. The Academy has a particular responsibility for natural science and mathematics, but its work strives to increase interaction between different disciplines. The activities of the Royal Swedish Academy of Sciences primarily focus on:

- being a voice of science in society and influencing research policy (policy for science)
- providing a scientific basis for public debate and decision-making (science for policy)
- recognizing outstanding contributions to research
- being a meeting place for science, within and across subject boundaries
- providing support for young researchers
- stimulating interest in mathematics and natural science in school
- disseminating knowledge to the public
- mediating international scientific contacts
- preserving scientific heritage

THE ACADEMY has around 460 Swedish and 175 foreign members who are active in classes, committees and working groups. They initiate enquiries, consultation documents, conferences and seminars. The Academy has General Meetings eight times a year. Open lectures are held in association with these (read more at www.kva.se/kalendarium). They can also be watched via www.kva.se/video.

THE ACADEMY´S institutes offer unique research environments in ecological economics, botany, the history of science and mathematics.

Every year, the Academy awards a number of prizes and rewards. The best known are the Nobel Prizes in Physics and Chemistry and the Sveriges Riksbank Prize in Economic Science in Memory of Alfred Nobel (the Prize in Economic Sciences). Other major prizes are the Crafoord Prize, Sjöberg Prize, Göran Gustafsson Prizes, Söderberg Prize and the Tobias Prize. The Göran Gustafsson Prizes are awarded to outstanding young researchers and are a combination of a personal prize and research funding. Since 2012, the Academy of Sciences has been one of the academies involved in implementing the Wallenberg Academy Fellows career programme, which provide long-term funding to the most promising young researchers. As well as a comprehensive range of scholarships, the Academy is also involved in appointments to research posts in a number of programmes funded by external foundations.

Through its working groups and committees, the Academy also works to promote sustainable, science-based societal development in the area of energy and the environment, among others. Issues relating to education and conditions for teachers are another major interest. The Academy organises Science Meetups, holiday schools at which recent arrivals to Sweden and Swedish upper-secondary school pupils learn more about natural science together. In the 1990s, the Academy and the Royal Swedish Academy of Engineering Sciences founded one of Sweden's biggest school development programmes, NTA – Naturvetenskap och teknik för alla (Science and Technology for all).

THE CRAFOORD PRIZE IS AWARDED IN PARTNERSHIP BETWEEN THE ROYAL SWEDISH ACADEMY OF SCIENCES AND THE CRAFOORD FOUNDATION IN LUND. THE ACADEMY IS RESPONSIBLE FOR SELECTING THE CRAFOORD LAUREATES.

WWW.CRAFOORDPRIZE.SE

KUNGL. VETENSKAPS-AKADEMIEN

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