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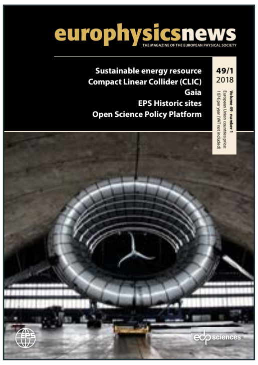
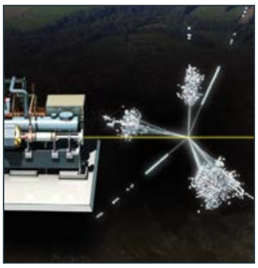


europhysicsnews

Cover picture: © Altaeros. See P.16: The largest renewable, easily exploitable, and economically sustainable energy resource.

▲ PAGE 16

Sustainable energy resource



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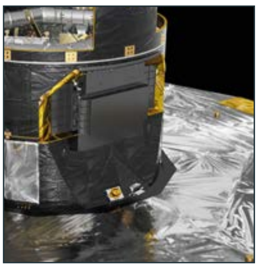
Compact Linear Collider (CLIC)



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Gaia: Science with 1 billion objects in three dimensions

[EDITORIAL]

A new framework on the horizon

The public consultations for the preparation of Framework Programme 9 are an excellent opportunity for the EPS to contribute to the European science policy debate

Past and present Framework Programmes of the European Union have generated substantial added value for Research and Innovation on our continent, and for society at large. Research grants, investments in research infrastructures, the Erasmus Programme and Marie Skłodowska-Curie actions have given a strong boost to cross-border collaboration, have successfully promoted international mobility of students and researchers, and have helped to create a level playing field for scientists from all parts of Europe.

With Horizon 2020 approaching its end, 2018 will be of pivotal importance for the design of its successor, Framework Programme 9 (FP9). An important cornerstone of the FP9 policy debate is the report "LAB-FAB-APP: Investing in the European Future we want" published by the independent "High Level Group on maximising the impact of EU Research and Innovation Programmes" in July 2017[1]. Whereas the recommendations made by the report have, by and large, been well received by the scientific community, they remain general by necessity, and leave room for discussion and interpretation. A remarkably comprehensive and thoughtful response[2] has recently been published by Science Europe, the association of key research organizations and funding agencies from most EU member states. I personally support many of the comments and share many of the concerns expressed in this paper, which should become compulsory reading for all stakeholders involved in the design of FP9 and in the forthcoming consultations: EU funding must complement, not replace national R&D funding systems, which must not lose the "3% of GDP" target out of sight; the proposed doubling of the post-2020 EU research and innovation, while obviously more than welcome, must be protected for civilian research, not invested in defence R&D; continued investment in training, career development and mobility of students and researchers must rely on strong, well-funded national higher education systems; and many more.

Much of the FP9 debate revolves around Recommendations 4 and 5 of the High Level Group (HLG): "Design the EU R&I programme for greater impact" and "Adopt a mission-oriented, impact-focused approach to address global challenges". Predictably, FP9 will be structured around societal, not scientific challenges. This is a legitimate and commendable approach insofar as it encourages enhanced interdisciplinary efforts, including social sciences and the humanities, to tackle the massive challenges which society is facing. However, "mission" and "impact" are buzzwords open to broad interpretation, and there is an obvious risk that mission- and impact-focused funding will lack a long-term vision and lead to a neglect of fundamental research which, as every physicist knows, remains the essential and irreplaceable basis for sustainable applications and technological development. In the language of the Science Europe response: "Excellent frontier and curiosity-driven research and innovation, promotion of internationally outstanding talents, and access to world-class research infrastructures must, therefore, remain cornerstones of EU funding in the future."

Interestingly, HLG Recommendation 5 uses the same language as we do in the EPS for our framing document "Grand Challenges on the Horizon 2050" presently under development (cf .my editorial in the previous edition of EPN). This document is designed to promote a healthy balance and cross-fertilization of fundamental and applied research, and the same principle will guide the participation of our Society in the public stakeholder consultations for the preparation of FP9, which the European Commission has launched in January. Active Participation in all stages of this process is an obvious part of our mission to serve as the top-level representation of the European physics community. The work on drafting first responses has started, and all EPS stakeholders will be invited to comment and to contribute. The LAB-FAB-APP report, the Science Europe response, and other comments all rightly insist that increased EU funding needs to be complemented by increased national funding, and that EU and national investments in R&I need to be better aligned to maximise return and added value. Our member societies will have an important role to play in promoting this vision vis-à-vis national governments and funding agencies.

Similar to – and closely related to – the preparation of our own "Grand Challenges" document, engaging with the European Commission in the design and preparation of Framework programme 9 will be another, excellent opportunity for all EPS stakeholders to work together towards a common and important objective. ■

Rüdiger Voss,
EPS President

[1] http://ec.europa.eu/research/evaluations/pdf/archive/other_reports_studies_and_documents/hlg_2017_report.pdf

[2] http://www.scienceeurope.org/wp-content/uploads/2017/12/SE_Response_LAB-FAB-APP_report.pdf

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EPS HISTORIC SITES

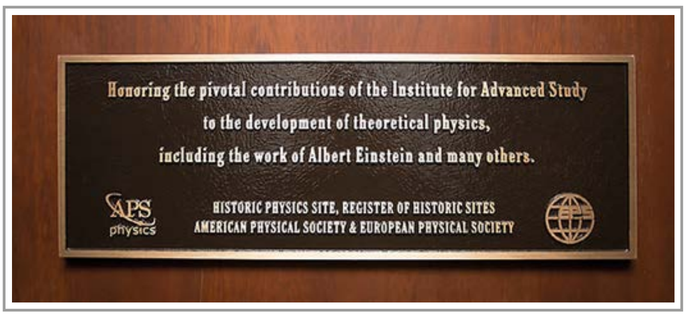
Institute for Advanced Study Princeton,

New Jersey, USA

The Institute for Advanced Study, one of the world's foremost centres for curiosity-driven basic research, was recognised by the American Physical Society (APS) and the European Physical Society (EPS) as their first Joint Historic Physics Site in the United States on 9 November 2016.

The APS-EPS award recognises the Institute's pivotal contributions to the development of theoretical physics, including the work of Albert Einstein, one of the Institute's first professors, who remained there from 1933 until his death in 1955. Also among the Institute's past Faculty are distinguished scientists and scholars spanning a range of disciplines, including Robert Oppenheimer, Clifford Geertz, Kurt Gödel, Erwin Panofsky, Hermann Weyl, Hetty Goldman, Homer A. Thompson and John von Neumann. The APS-EPS Historic Site award puts IAS in the company of the Einsteinhaus, the apartment where Einstein lived in Bern, Switzerland, from 1903 to 1905, and the first European site to receive a joint APS-EPS designation, in September 2015.

"We are very pleased to be partnering with the European Physical Society in the first-ever Joint Historic Site for physics in the United States", said Homer Neal, President of the American Physical Society. *"The Institute for Advanced Study has been one of the premier centres for theoretical physics in the world, hosting physicists in all stages of their careers."*



Christophe Rossel, President of the European Physical Society, added, *"The European Physical Society is particularly pleased to be a partner with the American Physical Society in declaring the famous Institute for Advanced Study as a joint APS-EPS Historic Site. This collaboration, as well as the world's leading researchers hosted by the IAS since 1930, demonstrate that physics is truly international. The APS and the EPS work in their respective regions to promote physics and its societal impact to the general public and policy makers, linking the past to the future for a successful curiosity-driven pursuit of knowledge."*

Robbert Dijkgraaf, Director and Leon Levy Professor of the Institute, said, "We are deeply honoured to be recognised by the American and European Physical Societies, and particularly pleased to be acknowledged for the work of Albert Einstein, who exemplifies the Institute's commitment to curiosity-driven research and academic freedom and their capacity to produce knowledge that results in technological and cultural advances."

The award ceremony was immediately followed by an excellent talk by George Dyson on *"The Institute for Advanced Study: The First 100 Years"*, [a video of the talk is available here: https://www.ias.edu/ideas/2016/dyson-ias-first-100-years].

The Institute for Advanced Study is one of the world's leading centres for theoretical research and intellectual inquiry. The Institute exists to encourage and support curiosity-driven research in the sciences and humanities—the original, often speculative thinking that produces advances in knowledge that change the way we understand the world. Work at the Institute takes place in four Schools: Historical Studies, Mathematics, Natural Sciences and Social Science. It provides for the mentoring of scholars by a permanent Faculty of approximately 30, and it ensures the freedom to undertake research that will make significant contributions in any of the broad range of fields in the sciences and humanities studied at the Institute.

▲ Left to right: C. Rossel, EPS President (2015-2017), H. Neal, APS President (2016), K. Kirby, CEO APS, R. Dijkgraaf, Director IAS Princeton, NJ USA

The Institute, founded in 1930, is a private, independent academic institution located in Princeton, New Jersey. Its more than 6,000 former Members hold positions of intellectual and scientific leadership throughout the academic world. Thirty-three Nobel Laureates and 41 out of 56 Fields Medalists, as well as many winners of the Wolf and MacArthur prizes, have been affiliated with the Institute. ■

David Lee
EPS Secretary General

NAME CHANGE: EPS SPONSORED CONFERENCES ARE NOW EPS RECOGNISED CONFERENCES

As of 1 January 2018, what were formerly known as "EPS Sponsored Conferences" will be called "EPS Recognised Conferences".
EPS "Recognised Conferences are organised independently from the EPS. To obtain the "EPS Recognised Conference label, the EPS Conference Committee applies criteria to ensure the international character, timeliness, and the review procedure for contributions.
The applications should be sent within 6 months before the conference begins.

Recognised Conferences:

- Provide the EPS Secretariat with information regarding the event
- Undertake to place the EPS logo on conference materials
- Provide a report on the conference.

The EPS will publish the conference on its website, and upon request, will advertise the conference in the society's newsletter e-EPS.
For more information, please see: http://www.eps.org/?page=support_sponsored ■

EPS HISTORIC SITES

IBM's Zürich Lab

Rüschlikon, Switzerland

"Teamwork, not only within the borders of a country, but also among countries, has become an imperative necessity of our jet-age era. Advances in the fields of human endeavours are due to a large extent to the cooperation of the best brains and talent available everywhere."

▲ Grand opening of IBM Research in Rüschlikon on 22 May 1963. IBM CEO, Thomas Watson Jr. is speaking.

These words were spoken in 1956 by then IBM CEO Thomas Watson Jr. during the opening ceremony of IBM's Zürich research lab, its first outside of the United States.

In its lifetime, the lab has achieved countless scientific innovations, most notably the scanning tunnelling microscope and high temperature superconductivity. On 26 September 2017 these accomplishments were honored by the European Physical Society (EPS) as a Historic Site, joining other renowned scientific locations including Einstein House Bern and the CERN Synchrocyclotron.

The news was unveiled in a ceremony at the IBM lab with employees and guests. After a short presentation on the history and future of the lab by the current director IBM Fellow Dr. Alesssando Curioni, and department manager, Dr. Walter Riess, and a panel discussion with three former lab directors spanning from the 1960s to today, a plaque was unveiled in front of attendees including several distinguished guests: Rüdiger Voss, EPS President and K.Alex Müller, Nobel Laureate and retired IBM scientist.

Dr. Rüdiger Voss, EPS President, made the official announcement stating, *"This IBM location has achieved many firsts, including the first industrial lab on the EPS Historic Sites List. This will hopefully add some encouragement to industry to keep up their investments in basic research as the ultimate foundation for the progress of science and technology."*

It's not well known that Switzerland wasn't IBM's first choice for its first international lab. In 1955, IBM scientist Arthur Lee Samuel, a pioneer in early computer gaming and artificial intelligence, had narrowed down the list to England, Switzerland and the Netherlands, in this order.

He ultimately recommended Zurich, Switzerland, to IBM CEO Thomas Watson Jr. based on its proximity to talent at ETH Zurich and due to its openness to allow other European scientists to work at the lab. Today, IBM Research - Zürich has employees from more than 45 nationalities working on scientific research scaling from Big data to atoms. ■

■ **Christopher Sciacca**
Communications Manager, EMEA
IBM Research

▼ From left to right, IBM lab director, Alessandro Curioni, Mayor of Rüschlikon Bernard Elsner and Rüdiger Voss, president, EPS. Photo by Thomas Schlund

Open Science and the role of Open Science Policy Platform OSPP

As you might have heard the Directorate General for Research and Innovation (RTD) of the European Commission (EC) published in 2016 a booklet on Open Innovation, Open Science, and Open to the World (the three "O") – A vision for Europe [1]. In the introduction Jean-Claude Juncker writes that "Research and innovation is a key component of thematic policies. It is central to the Digital Single Market, both to enable industry to benefit from digital technologies and to underpin scientific advance through the development of a European Science Cloud". Moreover "Science more generally has a critical role across many areas of policy in providing evidence that helps understand the risks and benefits of different policy choices". For Carlos Moedas, the European Commissioner for research, science and innovation it became apparent that the way science works is changing drastically towards Open Science, a goal that should materialize with the creation of a European Science Cloud either during Horizon 2020 or for the next FP9 program. "Open science (OS) means promoting open access to scientific data and publication alongside the highest standards of research integrity".

To reach its goal the EC created in 2016 three High Level Groups: the Scientific Advice Mechanism (SAM) with 7 members and chaired by Rolf-Dieter Heuer (Former Director-General of CERN), the Open Science Policy Platform (OSPP) with 25 members, chaired by Johannes Vogel (Director of Museum of Natural History, Berlin) and finally the group on Maximising Impact of EU Research and innovation programmes with 12 members, chaired by Pascal Lamy (former Director-General of the World Trade Organisation).

The OSPP was created with the goal to provide advices to the EC. Its members represent different stakeholders from Universities (EUA, LERU, CEASAR, ACEU, YERUN), Research Organisations (EARTO, EMBO, EU-LIFE, ENoLL), Academies and Learned Societies (EPS, EuCheMS, YEAR, GYA), Funding Organisations (Science Europe), Citizen Science associations (ECSA), Publishers (STM, OASPA), Open Science intermediaries (RDA, F1000, OpenAIRE, EGI, DARIAH, GEANT, Business Europe), and Libraries (LIBER) [2].

Among its mandates the OSPP has to function as a dynamic, stakeholder-driven mechanism to identify and address issues of concerns for the science and research community. It advises the EC on how to further develop and implement open science policies, review best practices, draw policy guidelines and encourage their uptake by stakeholders.

The OSPP met already four times, the last time in Tallin (Estonia) on 13 October 2017, to discuss and analyse reports of expert groups on the 8 Open Science priorities and to provide additional recommendations. These priorities are: *Open Access & FAIR Data* [3], *European Open Science Cloud, Future of Scholarly Publishing, Altmetrics, Rewards, Education and Skills, Research Integrity and Citizen Science*. Most of the reports by the expert groups and by the OSPP can be found under https://ec.europa.eu/research/openscience/index.cfm?pg=open-science-policy-platform together with an OS monitor.

A strict agenda has been drafted to foster Open Science, generate debates at the national and European levels and to remove barriers to the acceptance of OS by developing specific incentives on evaluation criteria (altmetrics [4], rewards and skills), open peer review and collaborative science, for example. Developing research infrastructures for OS is also of great importance to implement open data sharing principles (FAIR data, protocols, methodologies) and long term storage and preservation platforms. Finally, embedding OS in society requires to foster stronger relations between science and public as well as business actors. This can be achieved by setting up knowledge coalitions and Joint OS Initiatives (JOSI) to address the common societal challenges under H2020 and beyond. The integrated advice on all 8 OS ambitions should be finalized at the next OSPP meeting in March 2018 and ready for presentation at the Competitiveness Council, end of May 2018.

The EPS is calling on your feedback on the available reports and would welcome any constructive remarks or recommendations from the physicists' community. You can forward your comments to the EPS General Secretary David Lee and to Christophe Rossel, EPS Vice-president and member of the OSPP.

An opinion *Survey on Open Science & Career Development for Researchers 2017-2018* is now available online under https://ec.europa.eu/eusurvey/runner/EPSOS. Created by EPS in collaboration with EURODOC (European Council of Doctoral Candidates and Junior Researchers) and OSPP, this survey is aimed at all types and stages of researchers in Europe but particularly encourages early-career researchers to respond. Please fill it and share it within your network in order to reach enough responses for valid statistics and thus help EPS in contributing efficiently to the general debate. ■

■ C. Rossel
EPS Vice-president

References

[1] Open innovation, open science, open to the world – A vision for Europe (May 2016). See https://publications.europa.eu/en/publication-detail/-/publication/3213b335-1cbc-11e6-ba9a-01aa75ed71a1

[2] For an explanation of the acronyms, see the official list of members at https://ec.europa.eu/research/openscience/pdf/ospp_nominated_members.pdf#view=fit&pagemode=none

[3] FAIR stands for 'Findable, Accessible, Interoperable, and Reusable, see www.nature.com/articles/sdata201618

[4] The word altmetrics will be replaced by the more consensual term of next generation metrics

Highlights from European journals

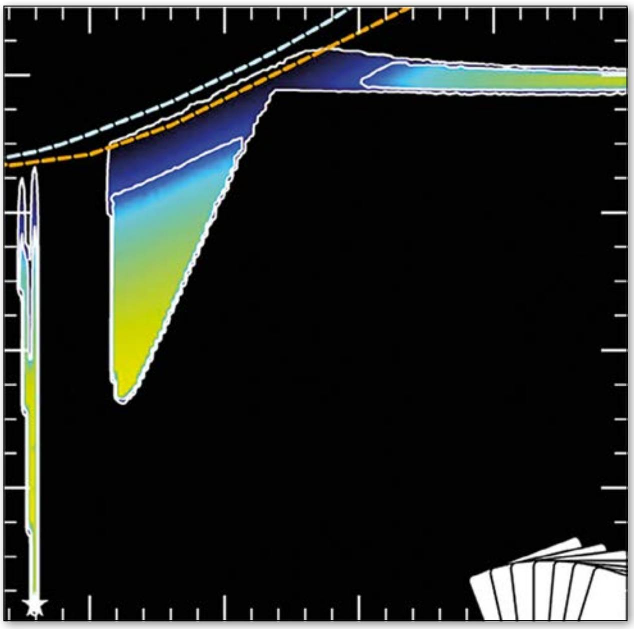
THEORETICAL PHYSICS

Combining experimental data to test models of new physics that explain dark matter

The most statistically consistent and versatile tool to date is designed to gain insights into dark matter from models that extend the standard model of particle physics, rigorously comparing them with the latest experimental data.

In chess, a gambit refers to a move in which a player risks one piece to gain an advantage. The quest to explain dark matter, a missing ingredient from the minimal model that can describe the fundamental particles we have observed (referred to as the standard model of particle physics), has left many physicists eager to gain an advantage when comparing theoretical models to as many experiments as possible. In particular, maintaining calculation speed without sacrificing the number of parameters involved is *a priori*ty. Now the GAMBIT collaboration, an international group of physicists, has just published a series of papers that offer the most promising approach to date to understanding dark matter. The collaboration has developed the eponymous GAMBIT software, designed to combine the growing volume of experimental data from multiple sources—a process referred to as a global fit—in a statistically consistent manner. Such data typically comes from astrophysical observations and experiments that collide subatomic particles, such as those involving the Large Hadron Collider (LHC), based at CERN in Geneva, Switzerland.■

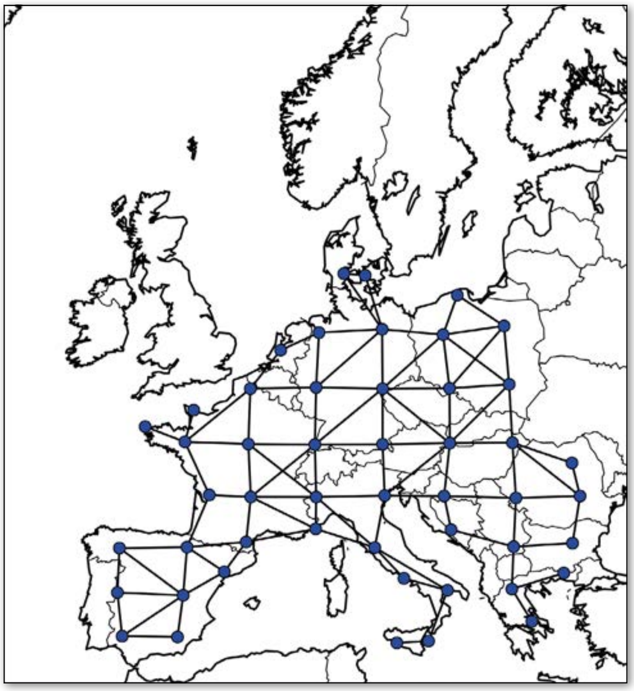
▴ Likelihood of scattering, from the scalar singlet model and experimental data comparison.



■ **The GAMBIT Collaboration**, 'Status of the scalar singlet dark matter model', *Eur. Phys. J. C* **77**, 568 (2017)

COMPLEX SYSTEMS

Spatial scales in electricity system modelling



▾ Coarse-grained network representation of the European electricity grid.

Models of large-scale electricity systems often only incorporate a certain level of spatial detail regarding the distribution of generation and consumption. This coarse-graining due to constrained availability of data or computational limitations also applies to the representation of the power grid. In particular, the network topology as well as the load and generation patterns below a given spatial scale have to be aggregated into representative system nodes. But how does this coarse-graining affect what simulations tell us about the system? This important question has been addressed using a simplified, but spatially-detailed model of the European electricity system with a high share of renewable generation. Applying a clustering algorithm, the transmission needs of the system are derived on various spatial scales. Surprisingly, it turns out that the transmission infrastructure costs only vary weakly under the coarse-graining procedure. This can be understood using an analytical approach, which yields approximate spatial scaling laws for measures of transmission infrastructure in electricity system models. ■

■ **M. Schäfer**, **S. B. Siggaard**, **K. Zhu**, **C. R. Poulsen** and **M. Greiner**,
'Scaling of transmission capacities in coarse-grained renewable electricity networks', *EPL* **119**, 38004 (2017)

HISTORY

How theoretical particle physicists made history **with the Standard Model**

The personal recollections of a physicist involved in developing a reference model in particle physics, called the Standard Model, particularly in Italy.

▲ Luciano Maiani, Pucci de Stefano, and their child Camilla at the Theory Division picnic, CERN 1985.

Understanding the Universe requires first understanding its building blocks, a field covered by particle physics. Over the years, an elegant model of particle physics, dubbed the Standard Model, has emerged as the main point of reference for describing the fundamental components of matter and their interactions. The Standard Model is not confined to particle physics; it also provides us a guide to understanding phenomena that take place in the Universe at large, down to the first moments of the Big Bang, and it sets the stage for a novel cosmic problem, namely the identification of dark matter. Placing the Standard Model in a historical context sheds valuable light on how the theory came to be. In a remarkable paper published recently, Luciano Maiani shares his personal recollections with Luisa Bonolis. During an interview recorded over several days in March 2016, Maiani outlines the role of those researchers who were instrumental in the evolution of theoretical particle physics in the years when the Standard Theory was developed. ■

■ **L. Maiani** and **L. Bonolis**,
'The Charm of Theoretical Physics (1958-1993) Oral History Interview', *Eur. Phys. J. H* **42**, 611 (2017)

PARTICLE PHYSICS

Observational constraints and astrophysical uncertainties **in WIMP detection**

Weakly Interacting Massive Particles (WIMPs) are one of the best candidates for the exotic dark matter that makes up 80% of the matter in the Universe. They are predicted to exist in extensions of the standard model of particle physics and would be produced in the Big Bang in the right amount to account for the dark matter. Lab-based direct detection experiments aim to detect WIMPs via their rare interactions with normal matter. The signals expected in these experiments depend on the local dark matter density and velocity distribution. An accurate understanding of these quantities is therefore required to obtain reliable constraints on the WIMP particle physics properties, *i.e.* its mass and interaction cross sections. This paper reviews the current status of observational constraints on the local dark matter distribution and also numerical simulations of Milky Way-like galaxies, before discussing the effects of uncertainties in these quantities on the experimental signals. It concludes with an overview of various methods for handling these astrophysical uncertainties, and hence obtaining accurate constraints on the WIMP mass and cross-sections from current and future experimental data. ■

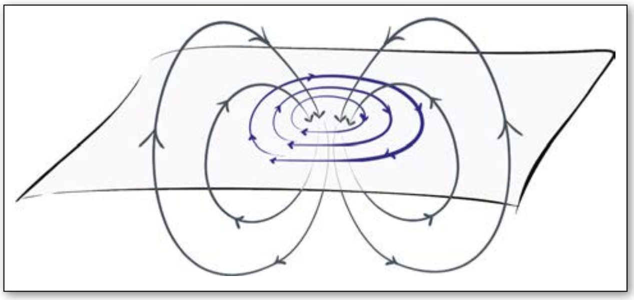
■ **A. M. Green**,
'Astrophysical uncertainties on the local dark matter distribution and direct detection experiments',
J. Phys. G: Nucl. Part. Phys. **44**, 084001 (2017)

CONDENSED MATTER

Weyl states mean **magnetic protectorates**

Electrons in conductors are basically free particles subject to residual collisions, a picture first proposed by Paul Drude in 1900 and later developed by Arnold Sommerfeld in 1927 with quantum concepts. The Drude-Sommerfeld assumption that in between any two collisions the electrons move freely is only approximate since electrons transport charge.

While in motion they give rise to an electric current that creates a magnetic field able to influence each other's trajectories. In the Drude-Sommerfeld scenario this small magnetic field interaction among electrons is simply discarded. However this magnetic field can lead to topologically protected states in case the electrons move in a layer no matter its strength assuming residual collisions. The magnetic field streamlines, created by the electronic motion, form loops that pierce the layer twice. These magnetic field loops are a consequence



▲ Pictorial view of a Weyl quasi-particle state and its magnetic field loops.

that electrons occupy Weyl states and yet live in the parabolic band of the Drude-Sommerfeld scenario. Indeed this residual magnetic interaction brings these Weyl states to a higher energy since they acquire magnetic energy. Nevertheless they fall in magnetic protectorates forbid to decay into a lower energy state. ■

■ **M. M. Doria** and **A. Perali**,
'Weyl states and Fermi arcs in parabolic bands',
EPL **119**, 21001 (2017)

MATERIAL SCIENCE

Resolving tension
on the surface of polymer mixes

A new study finds a simple formula to explain what happens on the surface of melted mixes of short- and long-strand polymers.

Better than playing with Legos, throwing polymer chains of different lengths into a mix can yield surprising results. In a new study published recently, physicists focus on how a mixture of chemically identical chains into a melt produces unique effects on their surface. That's because of the way short and long polymer chains interact with each other. In these kinds of melts, polymer chain ends have, over time, a preference for the surface. Now, the authors have studied the effects of enriching long-chain polymer melts with short-chain polymers. They performed numerical simulations to explain the decreased tension on the surface of the melt, due to short chains segregating at the surface over time as disorder grows in the melt. They found an elegant formula to calculate the surface tension of such melts, connected to the relative weight of their components. ■

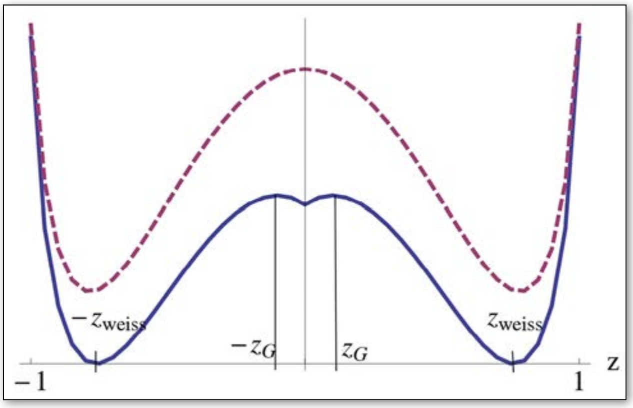
▼ Polymers. Credit iker-urteaga via Unsplash.

■ **P. Mahmoudi** and **M.W. Matsen**,
'Entropic segregation of short polymers to the surface of a polydisperse melt', *Eur. Phys. J. E* **40**, 85 (2017)

STATISTICAL PHYSICS

How small does your rice pudding need to get
when stirring jam into it?

New study shows that two seemingly diverging theories of ever-increasing disorder, known as entropy, can be tested against each other experimentally in the smallest possible systems.



▲ Gibbs (full lines) and Boltzmann (dashed lines) free energies.

Have you ever tried turning the spoon back after stirring jam into a rice pudding? It never brings the jam back into the spoon. This ever-increasing disorder is linked to a notion called entropy. Entropy is of interest to physicists studying the evolution of systems made up of multiple identical elements, like gas. Yet, how the states in such systems should be counted is a bone of contention. The traditional view developed by one of the fathers of statistical mechanics, Ludwig Boltzmann — who worked on a very large number of elements — is opposed to the seemingly disjointed theoretical perspective of another founding scientists of the discipline, Willard Gibbs, who describes systems with a very small number of elements. In a new study published recently, the author demystifies this clash between theories by analysing the practical consequences of Gibbs' definition in two systems of a well-defined size. He speculates about the possibility that, for certain quantities, the differences resulting from Boltzmann's and Gibbs' approach can be measured experimentally. ■

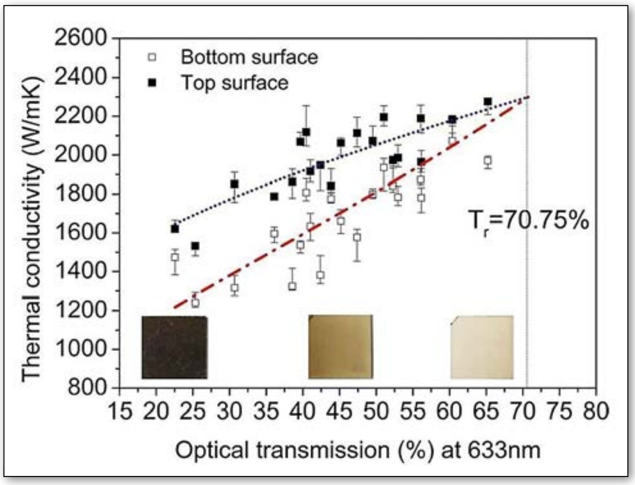
■ **L. Ferrari**,
'Comparing Boltzmann and Gibbs definitions of entropy in small systems', *Eur. Phys. J. Plus* **132**, 487 (2017)

MATERIAL SCIENCE

Polycrystalline diamond: thermal conductivity versus optical defects

With development of technologies, diamond can be produced in big amount and various qualities. With the continuing advances in production of synthetic diamonds, diamond is feasible for more applications such as heat sink for electronics. In this work, the authors have worked together with one of the largest synthetic diamond company (Ila Technologies Pte. Ltd. Singapore). The authors have systematically studied the influence of various optical active defects on thermal conductivities for synthetic polycrystalline diamonds. It is found that the top surface, which shows higher thermal conductivity compared to the bottom surface (where growth nucleation started), also shows lower densities of defects than the bottom surface. The influence from non-diamond carbon phase and C-H stretch for top surface is not significant because of the low concentration of these defects on the growth surface. However the heat transport is still limited by the presence of Ns^0 defect, which is the main contributor lowering the thermal conductivities on the top surfaces. For the bottom surface, non-diamond carbon phase, Si vacancy, C-H stretch and Ns^0 defects all lead to an obvious reduction in the thermal conductivity. Furthermore, a well fitted equation was given to quickly estimate the thermal conductivity by optical transmission, and the equation was demonstrated to be valid at any wavelength in visible region. This enables a fast and reasonable estimation of thermal conductivity by visual inspection. ■

▾ Thermal conductivity of polycrystalline diamond versus optical transmission (%) at 633 nm.

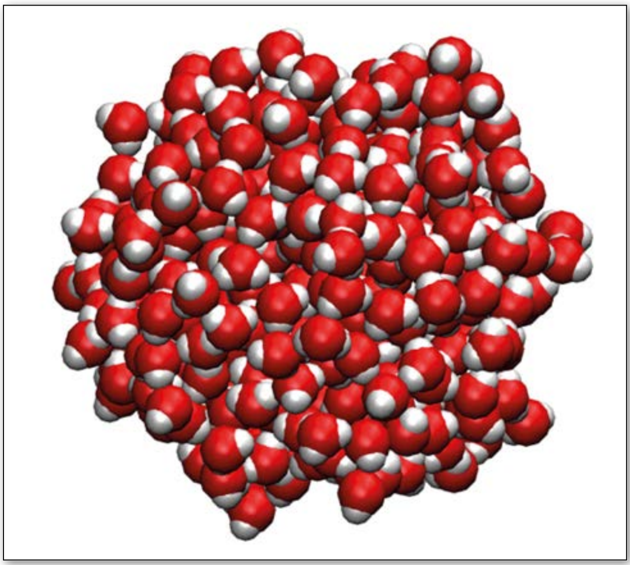


■ **Q. Kong**, **A. Tarun**, **C. M. Yap**, **S. Xiao**, **K. Liang**, **B. K. Tay**, **D. S. Misra**,
'Influence of optically active defects on thermal conductivity of Polycrystalline diamond', *Eur. Phys. J. Appl. Phys.* **80**, 20102 (2017)

COMPLEX SYSTEMS

Swarm-based simulation strategy proves significantly shorter

New method creates time-efficient way of computing models of complex systems reaching equilibrium.



▴ Water droplets we used as a test case in this paper.

When the maths cannot be done by hand, physicists modelling complex systems, like the dynamics of biological molecules in the body, need to use computer simulations. Such complicated systems require a period of time before being measured, as they settle into a balanced state. The question is: how long do computer simulations need to run to be accurate? Speeding up processing time to elucidate highly complex study systems has been a common challenge. And it cannot be done by running parallel computations. That's because the results from the previous time lapse matters for computing the next time lapse. Now, the authors have developed a practical partial solution to the problem of saving time when using computer simulations that require bringing a complex system into a steady state of equilibrium and measuring its equilibrium properties. These findings have been recently published. One solution is to run multiple copies of the same simulation. In this study, the authors examine an ensemble of 1,000 runs—dubbed a swarm. This approach reduces the overall time required to get the answer to estimating the value of the system at equilibrium. ■

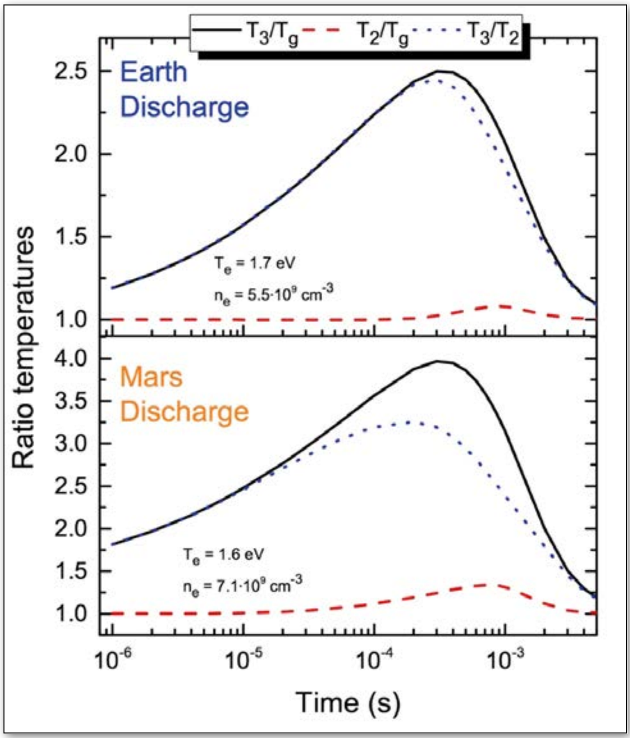
■ **S. M. A. Malek**, **R. K. Bowles**, **I. Saika-Voivod**, **F. Sciortino**, and **P. H. Poole**,
'Swarm relaxation: Equilibrating a large ensemble of computer simulations", *Eur. Phys. J. E* **40**, 98 (2017)

PLASMA PHYSICS

Making oxygen on Mars thanks to plasma technology

Sending a manned mission to Mars is one of the next major steps in space exploration. Creating a breathable environment, however, is a substantial challenge. Plasma technology could hold the key to creating a sustainable oxygen supply on the red planet, by converting carbon dioxide directly from the Martian atmosphere. Low-temperature plasmas are one of the best media for CO_2 decomposition, both by direct electron impact and by transferring electron energy into vibrational excitation. It is shown that Mars has excellent conditions for In-Situ Resource Utilisation (ISRU) by plasma. Indeed, the pressure and temperature ranges in the Martian atmosphere mean non-thermal plasmas can be used to produce oxygen efficiently. Besides the 96% carbon dioxide atmosphere, the cold surrounding atmosphere may induce a stronger vibrational effect than that achievable on Earth. The method offers a twofold solution for a manned mission to Mars. Not only would it provide a stable, reliable supply of oxygen, but a source of fuel as well, as oxygen and carbon monoxide have been proposed to be used as a propellant mixture in rocket vehicles. ■

▾ A pulsed plasma induces a higher vibrational excitation on Mars.

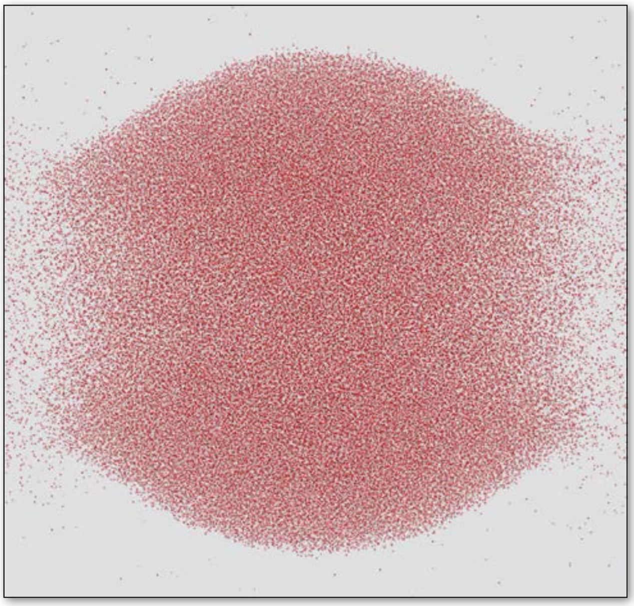


■ **V. Guerra** and **8 co-authors**,
'The case for in situ resource utilisation for oxygen production on Mars by non-equilibrium plasmas', *Plasma Sources Sci. Technol.* **26**, 11LT01 (2017)

BIOPHYSICS

Droplet explosion by shock waves, relevant **to nuclear medicine**

Ion beam cancer therapy could be improved if ion-induced shock waves are discovered. A new study explores how these predicted waves can be observed.



▴ Simulation of a disintegrating droplet.

An arrow shooting through an apple, makes for a spectacular explosive sight in slow motion. Similarly, energetic ions passing through liquid droplets induce shock waves, which can fragment the droplets. In a study published recently, the authors have proposed a solution to observe the predicted ion-induced shock waves. They believe these can be identified by observing the way incoming ions fragment liquid droplets into multiple smaller droplets. The discovery of such shock waves would change our understanding of the nature of radiation damage with ions to cancerous tumour. This matters for the optimisation of ion-beam cancer therapy, which requires a thorough understanding of the relation between the physical characteristics of the incoming ion beam and its effects on biological tissues. The predicted shock waves significantly contribute to the thermomechanical damage deliberately inflicted on tumour tissue. Specifically, the collective flow intrinsic to the shock waves helps to propagate biologically harmful reactive species, such as free radicals, stemming from the ions. This mechanism increases the volume of tumour cells exposed to reactive species. ■

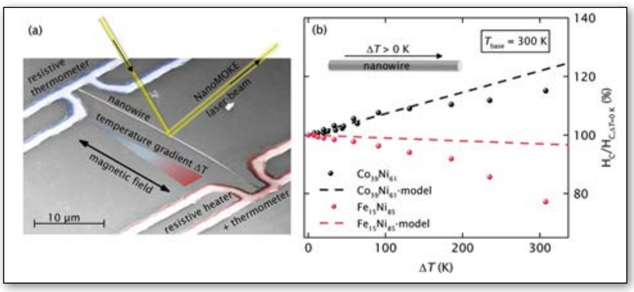
E. Surdutovich, **A. Verkhovtsev** and **A. V. Solov'yov**, 'Ion-impact-induced multifragmentation of liquid droplets', *Eur. Phys. J. D* **71**, 285 (2017)

MATERIAL SCIENCE

Temperature gradients influencing the hysteresis of **ferromagnetic nanostructures**

For future data storage technology, in which downscaling of magnetic bit unit sizes is crucial, heat-assisted magnetic recording (HAMR) is one key technology to ensure the writability for magnetic bits. It relies on a laser heating pulse to lower the coercive field H_C of the magnetic bit unit. Here, we investigated the temperature- and temperature gradient-dependent switching behaviour by H_C measurements of individual, single-domain CoNi and FeNi alloy nanowires via measurements of the magneto-optical Kerr effect. While the switching field generally decreased under isothermal conditions at elevated temperatures, temperature gradients (ΔT) along the nanowires led to an increased switching field up to 15 % for $\Delta T = 300$ K in $Co_{39}Ni_{61}$ nanowires. We attribute this enhancement to a stress-induced contribution of the magneto-elastic anisotropy that counteracts the thermally assisted magnetization reversal process. Our results demonstrate that a careful distinction between locally elevated temperatures and temperature gradients has to be made in future HAMR devices. ■

▼ **(a)** Nanowire device used for magneto-optical Kerr effect (MOKE) measurements. **(b)** Normalized coercive fields $H_C/H_{C,\Delta T=0K}$ for $Co_{39}Ni_{61}$ and $Fe_{15}Ni_{85}$ nanowires as a function of the temperature gradient ΔT. Increasing H_C with increasing ΔT for $Co_{39}Ni_{61}$ nanowires contradict the basic concept of heat assisted magnetization reversal (HAMR).

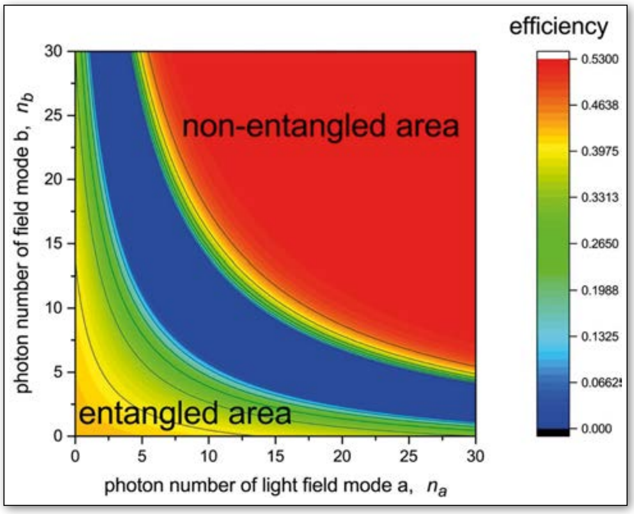


A.-K. Michel and **12 co-authors**, 'Temperature gradient-induced magnetization reversal of single ferromagnetic nanowires', *J. Phys. D: Appl. Phys.* **50**, 494007 (2017)

QUANTUM PHYSICS

Quantum manipulation power for quantum information processing gets a boost

Improving the efficiency of quantum heat engines involves reducing the number of photons in a cavity, ultimately impacting quantum manipulation power. Traditionally, heat engines produce heat from the exchange between high-temperature and low-temperature baths. Now, imagine a heat engine that operates at quantum scale, and a system made up of an atom interacting with light (photons) confined in a reflective cavity of sub-atomic dimensions. This setup can either be at a high or low temperature, emulating the two baths found in conventional heat engines. Controlling the parameters influencing how such quantum heat engine models work could dramatically increase our power to manipulate the quantum states of the coupled atom-cavity, and accelerate our ability to process quantum information. In order for this to work, we have to find new ways of improving the efficiency of quantum heat engines. In a study published recently, the authors show methods for controlling the output power and efficiency of a quantum thermal engine based on the two-atom cavity. ■



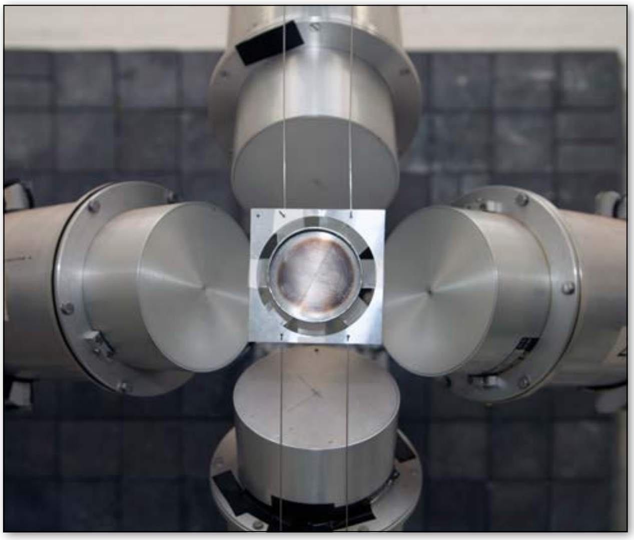
▲ Relationship between the output power and the number of photons.

K.W. Sun, **R. Li** and **G.-F. Zhang**, 'A quantum heat engine based on the Tavis-Cummings model', *Eur. Phys. J. D* **71**, 230 (2017)

NUCLEAR PHYSICS

From experiment to evaluation, **the case of n+^{238}U**

Evaluated nuclear data represent the bridge between experimental and theoretical achievements and final user applications. The complex evolution from experimental data towards final data libraries forms the cornerstone of any evaluation process. Since more than 90% of the fuel in most nuclear power reactors consists of ^{238}U, the respective neutron induced cross sections are of primary importance towards accurate neutron transport calculations. Despite this significance, the relevant experimental data for the ^{238}U(n,γ) capture reaction have only recently provided for a consistent description of the resonance region. In this work, the ^{238}U(n,γ) average cross sections were evaluated in the energy region 5-150 keV, based on recommendations by the IAEA Neutron Standards projects and experimental data not included in previous evaluations.



▲ Experimental set-up for capture measurements at the Joint Research Centre in Belgium.

A least squares analysis was applied using exclusively microscopic data. This resulted in average cross sections with uncertainties of less than 1%, fulfilling the requirements on the High Priority Request List maintained by the OECD-NEA. The parameterisation in terms of average resonance parameters maintained consistency with results of optical model and statistical calculations. The final deliverable is an evaluated data file for ^{238}U, which was validated by independent experimental data. ■

■ **I. Sirakov**, **R. Capote**, **O. Gritzay**, **H.I. Kim**, **S. Kopecky**, **B. Kos**, **C. Paradela**, **V.G. Pronyaev**, **P. Schillebeeckx**, and **A. Trkov**,
'Evaluation of cross sections for neutron interactions with ^{238}U in the energy region between 5 keV and 150 keV',
Eur. Phys. J. A **53**, 199 (2017)

ASSOCIATE MEMBERS UPDATE

The European Physical Society provides a forum for physicists from all sectors to come together to discuss common issues in physics. The EPS counts among its members 42 National Physical Societies, over 3000 Individual Members, and more than 40 Associate members. Associate Members are typically universities, European and International research institues, publishers and companies that wish to contribute to the strength of the European physics community.EPS Associate Membership is an exclusive opportunity to showcase Associate Members' sustainability vision for strategies and practices. Associate Members benefit from a unique EPS platform to create partnerships with key stakeholders, industry insiders and leading decision makers in physics, technology, sustainable development, culture and education. In the renewed AM policy, EPS still preserves the possibility of joining our Society as regular Associate Member, but two new statuses are proposed in order to attract various supporters' profiles. These can now directly support prestigious actions during leading conferences welcoming the broadest audiences in Europe and the world's largest trade fairs in technology. Specific actions are planned to highlight AM's international leadership by funding and presenting international awards to the highest-level scientists.EPS Associate Members will be provided with customised packages of benefits, highlighted prominently at all levels through the numerous EPS channels (award ceremonies, conferences, publications, web advertisements *etc.*), and publicly acknowledged for their major commitment. To enjoy these benefits, the EPS proposes three levels of Associate Membership and Sponsorship, namely, (i) The EPS 'Prestige' Sponsorship(ii) The EPS Sponsorship for 'Societal Challenges'(iii) The EPS regular Associate MembershipMore information on how you can join the EPS as an Associate Members can be found here: http://www.eps.org/?page=membership_am ■

THE LARGEST RENEWABLE, EASILY EXPLOITABLE, AND ECONOMICALLY SUSTAINABLE ENERGY RESOURCE

Giancarlo Abbate[1] and Eugenio Saraceno[2] – DOI: https://doi.org/10.1051/epn/2018101

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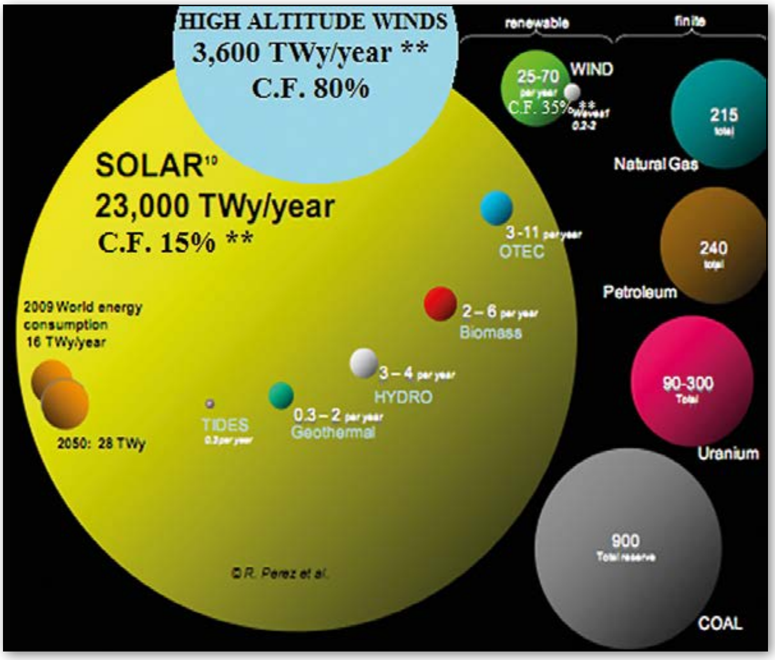
Sun, the ultimate energy resource of our planet, transfers energy to the Earth at an average power of 23,000 TW. Earth surface can be regarded as a huge panel transforming solar energy into a more convenient mechanical form, the wind. Since millennia wind is recognized as an exploitable form of energy and it is common knowledge that the higher you go, the stronger the winds flow. To go high is difficult; however Bill Gates cites high wind among possible energy miracles in the near future. Public awareness of this possible miracle is still missing, but today's technology is ready for it.

Tropospheric Wind Energy or High Altitude Wind Energy (HAWE), also known as high-wind energy, is a vast and well-known kinetic energy resource. The atmospheric stationary regime is powered by a percentage of the total mean solar radiation (230 W/m^2 after reflection to space) around 2%. Gustavson in 1979 [1] estimated the power needed to maintain the stationary regime of the atmosphere as huge as 3,600 TW.

Of the 3,600 TW figure, the near-surface wind resources available to wind turbines are in the range 25-70 TW, see figure 1.

Near-surface wind and solar technologies also deal with low capacity factors. The most efficient solar technology, solar photovoltaics, suffers from a tradeoff between capital cost and capacity factor. Availability only during daylight hours and weather variability are also drawbacks needing expensive power backup and storage to assure a reliable supply. Wind turbines deal with the lack of good sites that must have strong and constant winds to harness. Offshore installations deal with the strong increase of capital cost. This is reflected by the persistent need for subsidy by the solar and wind power investments to be profitable. In figure 2.a, a real example [3] is shown, where the power curve reaches its nominal value only in the queue of the wind speed distribution, resulting in a quite low capacity factor[1].

High-wind resources around 1-2.5 km above ground level, on the other hand, enjoy a much higher mean speed, as shown in figure 2.b [4], being more constant and intense. Consequently, High Altitude Wind Energy System (HAWES) capacity factor can reach values more than twice the one exhibited by a best-class wind turbine [see Figure 4]. In a big and fundamental work of 2008, Archer and Caldera [5] showed that at high altitude, say beyond 500-800 m above ground level, strong winds are present almost everywhere around the globe and almost always. Thus, for a HAWES not only the issue of capacity factor but also "the lack of good sites" has been eliminated or at least drastically reduced (see, for instance, the work of Yip, Gunturu, and Stenchikov for the Middle East resource [6]).



▲ **FIG. 1:** Power and energy resources [2].

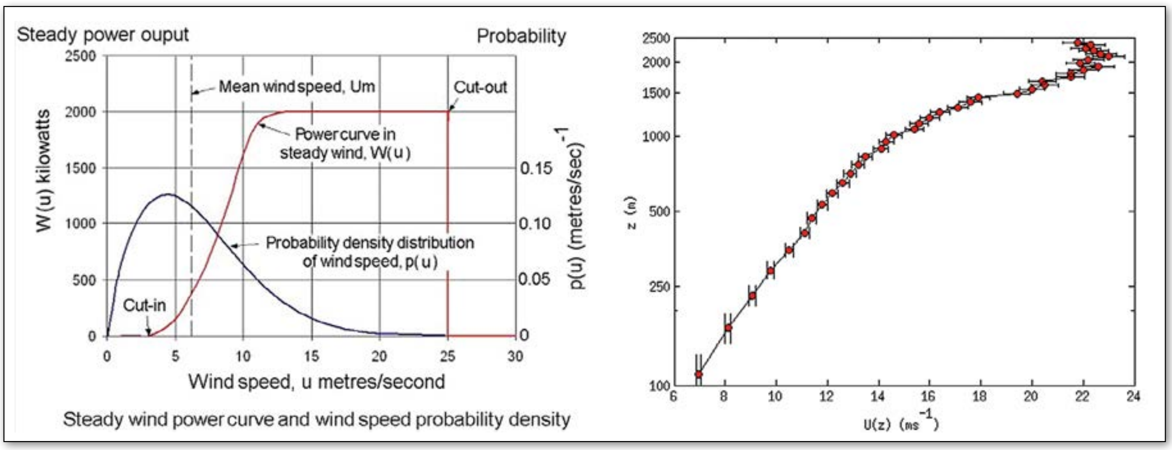
Now, the opportunity is to develop HAWES by means of an economically sustainable technology, in order to harvest the most productive available resources. In this way, it will be possible to reduce the production cost and increase the amount and the quality of the renewable energy supply (*i.e.* no or minimal intermittency).

HAWES technology development

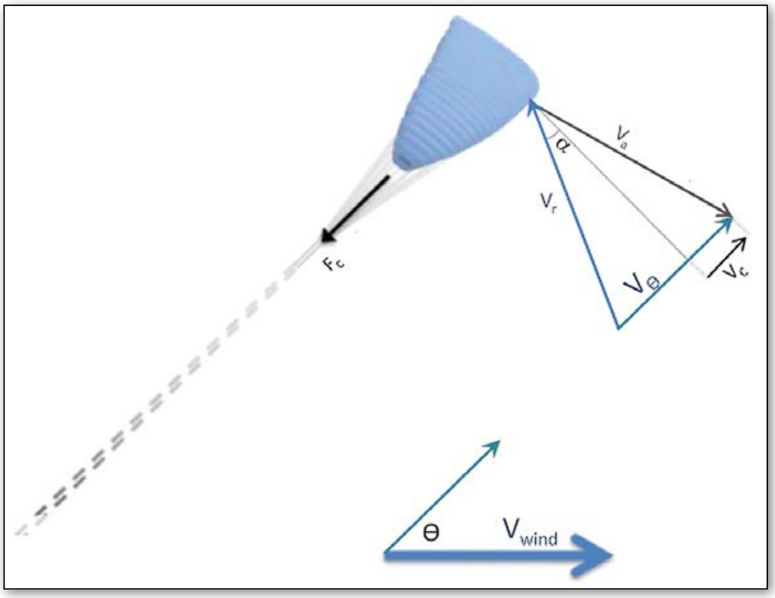
In the last decade, HAWE technologies promised to overcome the windmills drawbacks by three main drivers:

- Reach for higher altitudes, where winds are stronger and constant
- Dematerialization: lighter devices to reduce capital and maintenance costs
- Harvest a wider area than the windmill blades can do.

Although the high wind resource exploitation had been investigated since the 19th century by G.Pocock [7] and later by the theoretical work of Loyd [8], no relevant technological development was performed up to the early 2000s.



◄ **FIG. 2: (a)** Wind speed probability (blue line) and power curve (red line) for a Vestas 90m 2MW wind turbine [3]; **(b)** Measured mean wind speed *vs.* altitude over Greater London using a Doppler Lidar.[4]



▲ **FIG. 3:** Schematic of force and velocities for a tethered kite where V_a is the wing absolute speed and V_r is the wing relative speed.

Then, the availability of new light materials featuring high stress resistance, like ultra-high molecular weight polyethylene fibers (UHMWPE), or composite carbon/Kevlar materials, together with advances in computer science and control techniques, changed the scenario. Several private companies, universities, and public research centres were able to realize and control some small-scale High Altitude Wind Energy Systems. The first HAWES prototype that successfully produced some energy, using a 5 m^2 sport kite controlled by a truck-mounted engine, was a device called MobilGen, by the Italian company KiteGen Research S.r.l.. In the following years, many players succeeded in realizing kW class HAWES prototypes using kites or drones. Among others, we cite: KiteGen 2006 [9], TU Delft 2007 [10], Makani Power 2009 [11], Swiss kite power 2009 [12], Windlift 2010 [13], TU Delft 2012 [14], NASA 2012 [15], KiteGen 2012 [16], TWINGTECH 2013 [17].

A quite comprehensive review of HAWES technologies can be found in a recent paper by Cherubini et al [18]. Many different technologies were proposed for the exploitation of high altitude wind, divided in two main classes, with electric generation at a ground station (groundgen), and with onboard generation (flygen). In the following, we shall focus on groundgen technology, because it appears the most viable, especially from an economic point of view. The working principle of a groundgen machine is very simple. A kite, tethered by one rope (or two) to a ground station, flies crosswind and exerts a lift force on the rope(s). The rope tension is transmitted to alternators, through a pulley and a drum, around which the rope is wrapped. Unwrapping of the rope let the alternators generate electric energy.

Taken for granted the proof of concept of the feasibility of HAWES energy production, as all those players were able to confirm, there have been since then some research debates that need to be solved. Scalability of the concept, from the kW class of the prototypes to the MW class, has to be assessed. At the same time, also economical sustainability of HAWES technologies should be proved, and the two issues are related to each other. In fact, it is easily shown that a HAWES kW class power plant is not able to pay for the hourly wage of a supervisor or maintenance operator.

We shall base the following discussions mainly taking into account the technological developments made by KiteGen Research[19], in particular because it appears the only, or at least the most advanced, player oriented towards large-scale HAWES.

Issue1: inconvenience of Loyd model

According to the paper of M.L.Loyd [8], the following equations describe the behaviour of a tethered kite wing:

$$V_c \approx V_\theta - \sqrt{\frac{2F_C}{\rho K_{PF}}}\,;\; F_C \approx \frac{1}{2}\rho(V_\theta - V_C)^2 K_{PF}\,;\; P \approx \frac{1}{2}\rho V_C(V_\theta - V_C)^2 K_{PF}\,;$$

where V_c is the reel-out speed of the ropes, V_θ is the component of the speed of the wind parallel to the ropes, F_c is the load on the ropes and P is the output power, ρ is the air density. In Loyd's equations, K_{pF}, the Kite Power Factor, is defined as $K_{pF} = SE^2C_L = S\frac{C_L^3}{C_D^2}$, where S is the kite surface area, C_L and C_D the lift and drag coefficient, and E is the lift to drag ratio, also known as aerodynamic efficiency. Figure 3 geometrically shows these relationships.

Loyd calculated that the optimum of the power can be obtained when $V_c \approx ⅓ V_\theta$. It can be easily shown (see the red dashed curve in figure 4) that, following this optimization, if the Kite Power Factor is higher than the one of a sport kite, with aerodynamic efficiency ranging from 5 to 10, the force on the rope raises sharply and becomes unmanageable, as the wind speed exceeds 12-15 m/s. This event is very frequent at altitudes over 500 m. Consequently, this is a main critic to HAWES, as it negatively affects the capacity factor.

The control theory, however, has a different point of view and it is used to safeguard the system instead of seeking the optimum performance. In the following the given equations are used to calculate the power curve, shown in figure 4, as function of the natural wind speed. There are three productive phases, corresponding to three areas of the curve:

1. B: wind speed is above the minimum (*i.e.* beyond cut-off area A) but not enough to exert the maximum force; the force is exploited to increase the altitude and find more wind. A little amount of power can also be produced as the rope is reeling out. During this phase, forces are still low and some Loyd optimization may be performed by the control system trying to maintain $V_c \approx ⅓ V_\theta$.

2. C: wind speed is enough to exert the maximum force. Electronic control, hardware and software, is performed in order to maintain the force constant, while the ropes reel out at a proper, variable speed. Since force is constant, a power proportional to the reel-out speed is produced. This strategy means that the Loyd optimization curve has been abandoned to safeguard the system, while wind speed increases.
3. D: wind speed reaches and passes the maximum possible for phase 2, because reel-out speed cannot be increased any more. To keep constant both maximum force and maximum reel-out speed, the electronic control displaces the ropes by an angle φ, driving the kite out from the centre of the power window. In this phase, the power output is damped to P_{Max}. Notice that P_{Max} is greater than the nominal power, to compensate the energy consumed during the passive phase of the production cycle (*i.e.* when the rope is completely extended and must be recovered).

Let us provide some values of physical parameters, reasonable for a large-scale HAWES, to give an estimated power curve. (Notice that most of them are taken from the design, or actual realization, of a KiteGen prototype).

- Max generator power P_{Max}=4 MW
- Nominal generator power 3 MW
- Wing surface S=150 m^2
- Wing Lift factor C_L=1.2
- Wing Drag factor C_D=0.04
- Wing Aerodynamic efficiency E=30
- Wing weight 287 kg
- Max load 20 tons for each rope for a total $F_{c,Max}$=400 kN
- Rope diameter 22 mm (Dyneema SK75)
- Rope length 3536 m
- Rope weight 1948 kg
- Minimum operative altitude 2100 m
- Maximum altitude 2500
- Working angle θ=45° (rope vs ground)
- Maximum reel-out speed $V_{c,Max}$=10 m/s
- Maximum reel-in speed 20 m/s
- Cycle time 1 min-10 min
- These parameters are used for the calculation of force and power.

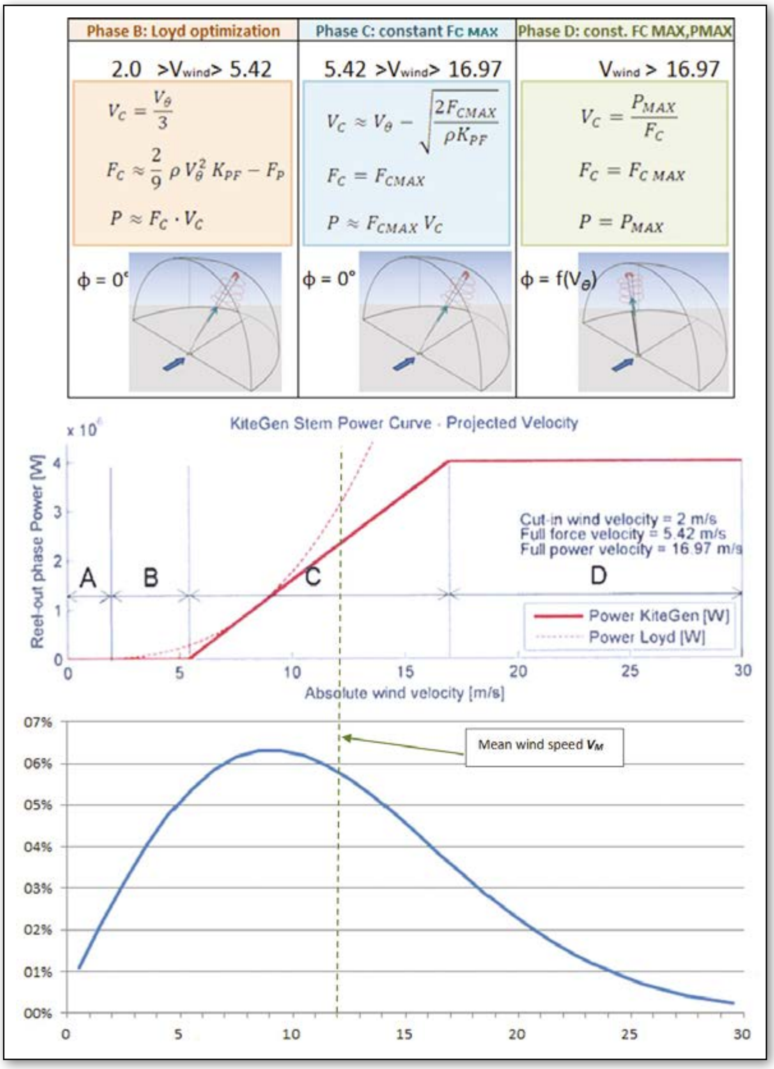
Figure 4, courtesy of KiteGen Research, shows the power curve, the three operative areas and the related equations given the speed and force constraints for a KiteGen Stem unit. At the bottom of Figure 4 is also shown the probability density distribution for wind velocity at the altitude of 2300 m a.g.l., in the same horizontal scale of the power curve.

It can be seen that the 3-phase control strategy allows exploiting winds that are well stronger than the Loyd optimization strategy would have made possible. In other words, the criticism to HAWES, founded upon Loyd optimization model, is not consistent because, when there is excess of available power, there is no need to reach the highest power with the actual wind; it is more advisable wasting some power to increase the capacity factor and the safety of the system. A comparison of Figure 4 with Figure 2a makes clear immediately how much larger the CF for a HAWES can be than for the standard wind turbine.

Issue2: importance of the aerodynamic efficiency

As seen, aerodynamic efficiency plays a quadratic role in the force exerted by the flying device. This means that it is as important as the wind speed. Higher efficiencies allow working with lower wind speed and having kites of smaller surface. High efficiency kites for power production are a totally new concept, because this feature is not useful for sport and leisure kites and would be harmful for people using them. HAWES developers are realizing several different concepts of high efficiency kite or drone (Makani, Twingtech tensarity wing, KG power wing). Generally, rigid or semi-rigid

▾ **FIG. 4:** (From top to down) Relevant equations for power generation; power curve for a 3MW HAWES (red); Weibull probability density distribution for wind velocity @ 2300 m a.g.l. with V_M=12 m/s [20]



materials have been preferred for this scope, and also to more safely host sensor devices that could be damaged because of the fluttering phenomena associated with flying devices made of flexible materials. Given its relevant role in the power generation of HAWES, the aerodynamic efficiency must be accounted very accurately in analytical modeling and simulation, and in experimental measurements. In the 3-phase power curve simulation shown above, the authors used a value E=30, close to the value obtained in the experimental tests by his company. In a very important paper [21], by Argatov and coworkers, the authors introduced a larger value E=37, but then used in their numerical simulation an *"effective"* glide ratio equal to 10, by the following argument. The kite is tethered to the ground station by a rope that moves through the air and is subject to a drag force; this drag affects the aerodynamic efficiency decreasing its value to the estimated *"effective"* glide ratio. We shall come back to the rope drag problem in the next paragraph, however we should emphasize now that, in a careful design, between the rope and the kite there is a mechanical coupling that allows the top of the rope to be always aligned with the tension provided by the kite. Thus, no aerodynamic effect by the rope drag can be envisaged. Instead, the rope drag force can change the flight direction of the kite, possibly forcing the kite out of the centre of the power zone. In the last case, the electronic control drives the kite along a corrected path to reach again the high-power spot.

Issue 3. The rope drag problem, weakness of the Argatov model

In a number of articles [21-23], Argatov and coworkers made an upgrade and a refinement of the old Loyd's work of 1980, with the aim to estimate the energy output of a HAWES based on the pumping kite technology, the same described in the present paper. These works appeared at the right moment, when several experimental demonstrations of HAWES feasibility were performed in different countries, and there was a real need of a theoretical analysis and estimations based on more realistic and accurate basis. However, the problem is very complex from an analytic point of view, involving continuous variables interacting with each other. Thus, the authors made several approximations, even though they released few of them in the last paper. Unfortunately, some of the maintained assumptions have proved to be unrealistic letting a large uncertainty in the final results, especially the quantitative ones.

We notice that Argatov and coworkers afforded the problem in a correct way, but probably they underestimate the strong quantitative, and in some cases also qualitative, influence of the approximations involved in their analysis. We also underline that one of their most important conclusion, namely that *"actually during the kite's cross-wind motion only the upper part of the tether will contribute into the equivalent air resistance of tether"* [21], appears correct and in agreement with the experimental findings.

However, their final quantitative conclusion, and the corresponding numerical simulation on a HAWE system considered typical by them, is in striking contrast with their previous sentence, showing that the longer is the rope, the less efficient is the extraction of mechanical energy. This result, if correct, would have been a heavy drawback for HAWES. In fact, the operative altitude should have been reduced and consequently the quality and speed of the available wind resource.

First, in Argatov's model, the rope is treated as a rigid body, even when sag is considered. Propagation phenomena along the rope and transversal deformations are neglected. Secondly, in the pumping kite technology the rope tension is kept constant, but not its length as assumed in the model. The consequence is an unrealistic rigid shape of the moving rope, and an overestimation of its drag that is added to the unnecessary decrease of the glide ratio. Last, the rope tension is assumed uniform along the rope in the calculation of the drag that, in turn, reduces the tension: this is an evident inconsistence of the model. All these assumptions go in the same direction of reducing more and more the system efficiency, when the kite flies higher and higher, so damping the power curve at height less than 1000 meters. Finally, in the worked-out simulation shown to test their model, Argatov and coworkers used parameter values taken from Fagiano (2009) [24], including a kite surface area of 10 m^2 that is 13-14 times less than the actual value of the design and experimental realization of the present technology. Since in the Argatov's model the kite area affects strongly the value of its effective glide ratio, we can conclude that, even in the frame of its assumptions, that simulation and related suggestions are outdated and have no real meaning, at present.

A recent thesis work by F. Roselli [25] is devoted to the same problem of evaluation of the rope drag, but considering the rope flexible and with a variable length, as it is. A numerical computation shows that, for ropes longer than 900 m, there is a significant deviation from the Argatov's model, and the drag tends asymptotically to a lower value. Summarizing here, the rope drag is not an issue because it only affects the cut-in wind speed, slightly raising it. The energy wasted by the ropes is paid by a speed offset of the reeling out due to the envelope of the bending, counter bending and swing behaviour. However it brings other advantages like an expansion

COMPANY	SHORT DESCRIPTION	STATE OF ART	DRAWBACKS	PICTURE
Makani Power USA	FlyGen concept. Generator on board. The tether carries energy from the kite to the grid, connecting it to the ground station.	30 kW prototype. Recently shifted from flexible to rigid airfoils.	- Conducting tethering cables instead of insulating ropes as in KiteGen. - Harnessing propellers which add drag thus limiting the aerodynamic efficiency of the system. - Risk of total investment loss should a crash occur	
KiteGen Research Italy	Two tether Groundgen concept with composite sensorized Power Wing. Mechanical energy brought to ground alternators using ropes.	100 kW prototype first produced energy in 2006. Composite Wing designed and realized. 3MW double stem generator industrialization ongoing	- Rope doubled to solve safety and piloting issues adds more drag. - Big wing needs careful handling	
Altaeros USA	Tethered airborne platforms designed to lift a lightweight wind turbine up to 600m above ground.	First functional BAT prototype launched in 2012. The company is claiming to work on the first commercial scale BAT.	- Need of helium (non renewable source). - The trigonometric ratio between buoyancy force and wind drag vectors excludes them from the category of tropospheric wind.	
X-Wind Germany	Combines automatically steered kites, grounded rail systems and cable car technology on linear or circular track.	A 400m linear test track is in operation since 2011. Closed loop prototype is under construction.	- No relevant patent coverage, they patented a blimps rail generator. - Rail concept presumably developed in infringement with KiteGen Carousel patent.	
Sky Wind Power Germany	Flying electric generator with rotors that both lift the vehicle and convert the kinetic energy into electricity.	Small prototype tested in December 2011 flying with additional safety tethers through a limited range of the required maneuvers.	- Conducting tethering cables - Heavy structure suitable for jet streams exploitation only.	
Amphyx Power Netherlands	PowerPlanes flying repetitive cross-wind patterns, attached with a cable to a ground-based generator.	10 kW scale prototype with rigid airfoils.	- No patent coverage - Lack of scalability due to the flat wing that require a heavy longeron to sustain the wind force.	
Sky Sails Germany	Ship traction using crosswind power. Traction power-kite with flying actuators.	50 kW prototype already sold to pilot customers.	Patent coverage for ship traction but not for energy production.	

▲ **TABLE 1:** State of the art of HAWES technology developed by some representative companies.

of the wind power window spot in combination with the flying path that is called "exo-phanic lemniscate". It is obvious that this behaviour could only appear with a model that computes and describes a full flying cycle including the wing attitudes and the rope discretizing, a simplified snap of an instant is meaningless.

Still there are important features missing in current analysis, as for instance the coupling between rope and kite without rotational constraints discussed in the previous Section. However, it seems that slowly a realistic model of pumping kite power generation is being settled, and most of interested scientists and active players do believe there is room for optimization of energy extraction from wind in the sky region up to at least 3000 m a.g.l. (see, for instance, [26] and [27])

State of the art and last developments

We want to underline once again that the different technologies of HAWES are still in their infancy and significative developments towards industrialization have been performed only in the second decade of the century. Nevertheless, as said above, many players were able to give experimental demonstrations of their feasibility. Table 1 shows the state of the art of technical developments achieved by some representative, even though not exhaustive, industrial players.

Ongoing developments include the search for a fully automated flight control, performed by many public research organizations and private companies; sensors and radio communication device fit-out to assure a maximum safety level; an educational and communication strategy to increase the working expertise in this sector and public awareness of the paramount importance of this energy resource.

Despite the short development time, many important results have been achieved until now, so that the scientific community must consider high wind exploitation more than a promise, rather a real opportunity. However, apart from some exceptions represented by a small number of universities and the US organization NASA, public involvement, funding, and acknowledgement of HAWE technologies have been very shy or even absent. This fact appears in evident contradiction with global energetic, economic, and environmental needs, and with public declarations of most of governmental bodies around the world. ■

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TOWARDS TEV-SCALE ELECTRON-POSITRON COLLISIONS

COMPACT LINEAR COLLIDER (CLIC)

Steffen Doebert and Eva Sicking – DOI: https://doi.org/10.1051/epn/2018102

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The Compact Linear Collider (CLIC), a future electron-positron collider at the energy frontier, has the potential to change our understanding of the universe. Proposed to follow the Large Hardron Collider (LHC) programme at CERN, it is conceived for precision measurements as well as for searches for new phenomena.

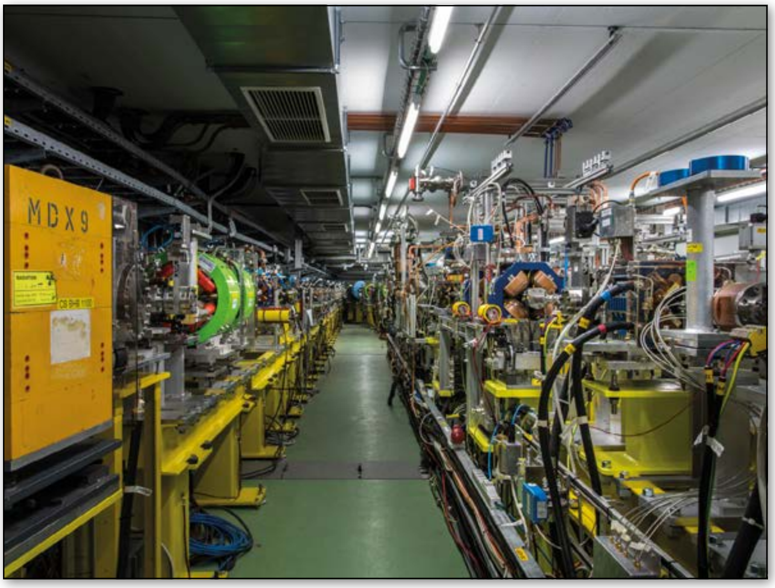
The Higgs boson, the last pillar of the Standard Model of Particle Physics (SM), was discovered at the Large Hadron Collider (LHC) in 2012. Up to now, no direct signs for new physics beyond the Standard Model (BSM) were found at the LHC. Yet there are phenomena such as the matter-antimatter asymmetry, governing mechanisms at the early universe, or dark matter that cannot be explained within the existing SM. With the recently approved High-Luminosity upgrade of the LHC (HL-LHC), which will record collision data until ~2038, more than 10 times more statistics can be collected such that signs of potential new physics could still be revealed in the coming years. Following a complementary approach, several future collider projects using collisions between electrons and positrons instead of collisions between protons are currently proposed for the time after the HL-LHC. These colliders focus on precision measurements of the Higgs boson and the top quark. Here, new physics could manifest itself via deviations from SM expectations. The Compact Linear Collider (CLIC) is one of these proposed future colliders. CLIC would provide a guaranteed physics programme of precision measurements of the Higgs boson and the top quark, the heaviest particle in the SM. CLIC would also be a powerful tool to perform both direct and indirect searches for new physics processes, complementary to the HL-LHC programme. CLIC is conceived as a staged machine with centre-of-mass energies ranging from 380 GeV up to 3 TeV, with a corresponding accelerator length from 11 to 50 km, respectively. The collision energy of CLIC can be

▼ ©CERN

adapted easily to investigate potential future discoveries at either LHC or CLIC. CLIC is a global project of more than 70 institutes in more than 30 countries. It consists of two collaborations: the CLIC accelerator study and the CLIC detector and physics collaboration (CLICdp) [1, 2]. They are studying the possibility of building CLIC in the area around Geneva, across the Swiss-French border, with CERN as the host laboratory, although the technology could equally well be deployed at another location.

Precision measurements in a clean environment

The proton (p) is a compound object comprising several elementary particles, so-called partons: 3 valence quarks, gluons and sea quarks. This substructure limits the knowledge of the underlying processes taking place in an individual proton-proton (pp) collision. For instance, it is *a priori* unknown which parton takes part in the collision or which fraction of each proton's energy is carried by the colliding partons. Furthermore, more than one pair of partons can collide in the same pp collision. In electron-positron (e^+e^-) collisions, both incoming particles are elementary, without substructure. Therefore, the colliding particles and the collision energy are well defined, and their polarisations can be controlled. This superior knowledge about the colliding system in e^+e^- collisions enables one to interpret the data with higher precision than in pp collisions. Moreover, high rates of QCD (Quantum Chromo-Dynamics, the theory of the strong interaction) background events may hide the few interesting physics events in pp collisions, while e^+e^- collisions provide a cleaner experimental environment as well as lower radiation levels than in pp collisions.

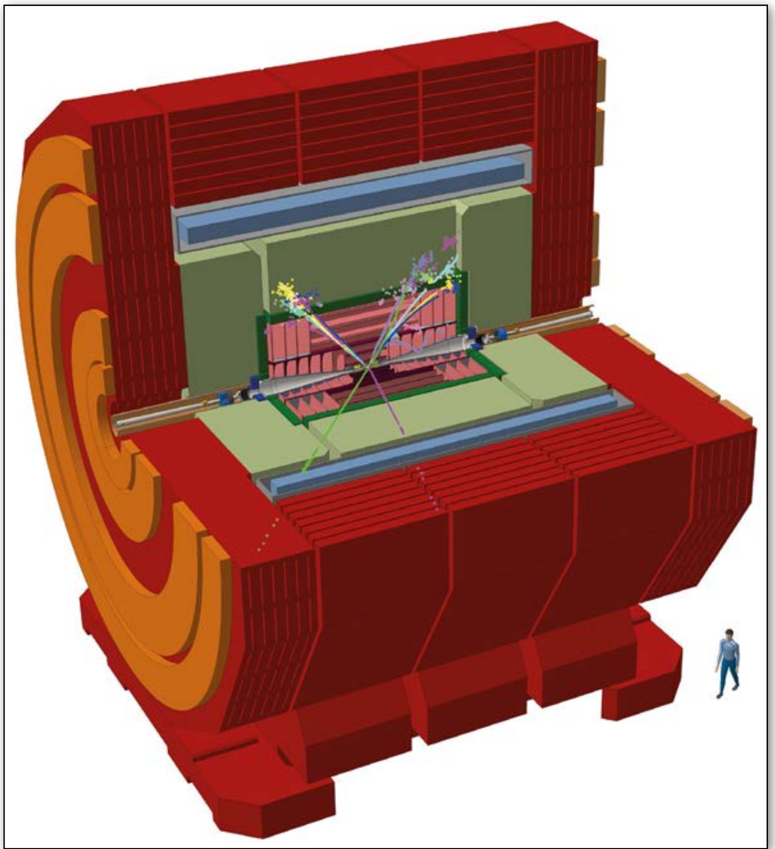


▲ **FIG. 1:** The CLIC Test Facility (CTF3). Using the two-beam acceleration technique, acceleration gradients of up to 150 MV/m have been obtained. ©CERN

Revealing the mystery of the Higgs boson

For the first energy stage of CLIC with a total accelerator length of 11 km, a centre-of-mass energy of 380 GeV is foreseen [3]. This energy will enable precision measurements of the Higgs boson and the top quark. These are the heaviest particles of the SM and were both discovered in pp collisions. Measuring their properties for the first time in e^+e^- collisions would provide more detailed insight into the SM and could potentially challenge it.

In e^+e^- collisions at 380 GeV, Higgs bosons can be precisely measured in two different production processes: by being radiated off a Z boson, a process called Higgsstrahlung ($e^+e^- \to ZH$) and by the fusion of two W bosons ($e^+e^- \to H\nu_e\bar{\nu}_e$). For a comprehensive study of the Higgs boson at a single energy stage,



▲FIG. 2: The CLIC detector concept with a diameter of 13 m and a side length of 11.5 m. The detector consists of layers of cylinders and endcaps of different detector technologies and it hermetically surrounds the collision point located in the centre of the detector. Energy deposits of an example $e^+e^- \rightarrow ZH$ event at 380 GeV centre-of-mass energy are shown, where the Z boson decays into a pair of muons and the Higgs boson decays into a pair of quarks resulting into jets. ©CERN

such access to more than one Higgs-boson production process is advantageous, because a combined analysis leads to a better precision on the width of the Higgs resonance [4]. The width is the intrinsic spread of the Higgs-boson mass, which is wider the faster the Higgs boson decays. The Higgs-boson mass and width can be measured, as well as the Higgs-boson couplings to most other elementary particles at the percent-level of precision independently of any assumed model. This is possible due to measurements of the Higgsstrahlung process, where the Higgs boson is measured through its recoil against the Z boson, independently on the exact decay mode of the Higgs itself. Thanks to the low backgrounds in e^+e^- collisions, the coupling of the Higgs boson to charm quarks can also be studied, a process so far not accessible at the LHC due to larger background levels.

Discovered at Fermilab in 1995, the top quark is still of big interest in the particle physics community. At 380 GeV the probability of the top-quark pair production is close to its maximum, resulting in a large sample of top-quark pairs. A high-statistics threshold scan around the onset of the pair production near 350 GeV can provide a theoretically well-defined top quark mass measurement with unprecedented precision, about one order of magnitude better than expected at the HL-LHC. With the good precision of the Higgs-boson mass achieved at the LHC, the uncertainty on the top-quark mass is currently the leading uncertainty in tests of the SM vacuum stability.

The CLIC scheme: Two beams are better than one

The highest centre-of-mass energy in electron-positron collisions so far –209 GeV – was reached at the circular LEP (Large Electron Positron) collider at CERN. In a circular collider, the circulating particles emit synchrotron radiation and the energy lost needs to be replaced by a powerful radio-frequency (RF) system. Energy loss by synchrotron radiation scales with the fourth power of the energy/mass ratio. In LEP 3% of the beam energy was lost at each turn. Therefore, a circular accelerator option is not feasible for TeV-scale electron-positron collisions. Instead, CLIC follows the linear collider approach with two linear accelerators facing each other and beams colliding head-on in a central detector. This scheme has inherent consequences. Linear accelerators have to transfer the full energy to the particles in a single pass. Therefore, extremely high accelerating fields are required in order to limit the overall length and cost of the facility. CLIC is based on an unprecedented accelerating field of 100 MV/m leading to a very compact accelerator. Since the particle beams only collide once in a linear collider, they have to be very intense and focused to a minimal beam size at the interaction point in order to achieve the necessary event rate (luminosity) for the experiments. In CLIC the beams will be focused to a tiny rectangular spot size of 1 nm × 40 nm (the smallest dimension is about 10000 times smaller than a human hair) and will carry a total instantaneous beam power of ~ 14 MW per beam at full energy. The overall energy efficiency has been a key parameter for the optimisation throughout the design of the accelerator.

CLIC uses normal conducting travelling-wave accelerating structures, operating at a high electric field of 100 MV/m, which results in a site length of 50 km for 3 TeV centre-of-mass energy. For comparison the LHC has a circumference of 27 km. To reach high accelerating gradients the CLIC structures are operating at a high frequency of 12 GHz using very short, powerful RF pulses of 240 ns duration. To create such high RF peak power for the accelerating structures distributed all along the main linear accelerator, CLIC uses a so called two-beam acceleration scheme. In this scheme, a second beam, the so-called drive beam, runs parallel to the main beam. The drive beam is a high current (100 A), low-energy (2.4 GeV) electron beam with a bunch repetition rate of 12 GHz. This beam passes through Power Extraction and Transfer Structures (PETS), inside which it decelerates and thereby generates the powerful RF pulse at 12 GHz. For collision energies above several hundred GeV such a two-beam acceleration scheme becomes more efficient and less costly than a classical RF powering scheme with klystrons.

The drive beam is generated efficiently at lower RF frequency (1 GHz). Long bunch trains of 140 μs are created in a fully loaded normal conducting accelerator converting 95% of its input energy into particle acceleration, exceeding the typical efficiency of a superconducting linear accelerator. Subsequently beam bunches are interleaved in the injector complex comprising a delay loop and two combiner rings to arrive at the final 240 ns bunch trains with 12 GHz bunch separation. The feasibility of the entire two-beam concept including beam combination, efficiencies and accelerating gradient has been demonstrated successfully in the CLIC Test Facility (CTF3) at CERN shown in Figure 1 and documented in the Conceptual Design Report (CDR) published in 2012 [5].

Extremely high beam quality needs to be maintained throughout the accelerator complex with an unprecedented small final focus at the interaction point. To reach these objectives beamline elements have to be aligned to micron accuracy and some of the focusing elements have to be stabilised against vibrations and ground motion at the nanometre level. To this end the CLIC study developed and demonstrated sophisticated alignment procedures as well as sub-nanometre stabilisation of the final focus quadrupoles.

A detector for CLIC

The design and the technology choices for the detector are driven by the requirements of the high-precision physics programme as well as by the accelerator conditions, such as the bunch repetition rate and the abundance of beam-induced backgrounds. The CLIC detector concept, shown in Figure 2, is based on ultra-light vertex and tracking detectors as well as fine-grained calorimeters, optimised for particle-flow analysis (PFA) techniques [6]. PFA aims at improving the energy measurement of so-called jets, bundles of particles originating from one initial quark or gluon. For each of the particles in the jet, the detector sub-system with the most accurate measurement of the particle is used: the tracking system for charged particles, the electromagnetic calorimeter for photons, and the hadronic calorimeter for neutral hadrons. Several technology demonstrators for the most challenging detector elements have been developed and tested (see Figure 3 for an example). The research and development on the detector concepts for future linear colliders has had a significant impact also on other projects such as the HL-LHC detector upgrades, where for instance the fine-grained calorimeters will find a first large-scale application.

Search for the unknown

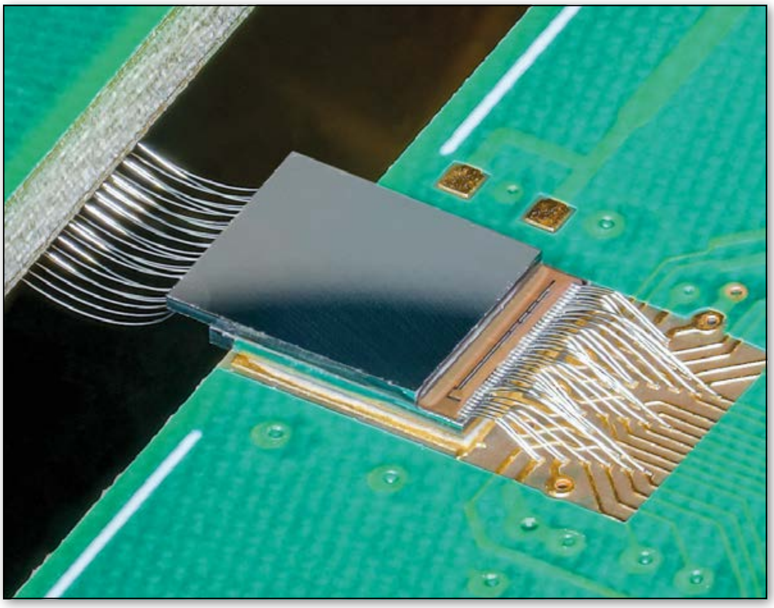
CLIC is currently foreseen to have three energy stages as shown in Figure 4. At each stage, collision data are taken for 5-7 years interleaved with 2 years for accelerator upgrade, leading to a physics programme spanning over two decades. The second and third energy stages are planned to be at 1.5 TeV and at 3 TeV. The energy choices for these stages can be adapted following discoveries from the HL-LHC. The higher energy stages will provide the best reach for direct and indirect searches for physics beyond the Standard Model.

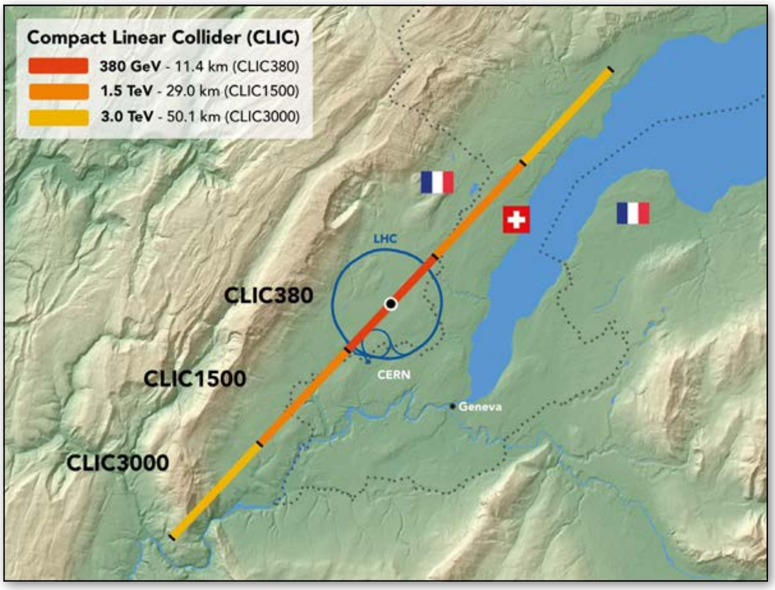
CLIC will push the boundaries of particle physics and search for physics effects that are not explainable by the Standard Model. Significant deviations from the SM observed in precision measurements would indicate new physics. Such measurements can probe energy scales far beyond the actual collision energy. In this way a 3 TeV CLIC accelerator could probe energy scales up to several tens of TeV.

CLIC also aims at direct detection of new particles, reaching particle masses up to 1.5 TeV for particles produced in pairs. Compared to hadron collisions, electron-positron collisions offer superior sensitivity to electroweak states. Taking Supersymmetry (SUSY) theory as an example, CLIC offers excellent sensitivity to Charginos, Neutralinos and Sleptons as well as to additional heavy Higgs bosons.

At the higher energy stages of CLIC, large samples of Higgs bosons produced in WW fusion enable the measurement of extremely rare Higgs-boson decays. The higher energies also give access to Higgs bosons produced together with a pair of top quarks ($t\bar{t}H$) or two Higgs bosons produced in the same collision event. Especially the double Higgs-boson production is a key process as it reveals the Higgs self-coupling, a central parameter for understanding the Higgs field [4]. Besides CLIC, several other e^+e^- colliders are being proposed, showing the strong interest in e^+e^- collisions. The International Linear Collider (ILC) is currently under consideration for construction in Japan. Its first energy stage is proposed at 250 GeV, where the Higgsstrahlung process is at its maximum. Later possible upgrades to 350 GeV and 500 GeV are being considered. In addition, two circular e^+e^- colliders are currently under study, the Compact Electron Positron Collider (CEPC) in China and the Future Circular Collider e^+e^- (FCC-ee) at CERN [7]. Both have a circumference of around 100 km. As they are circular, they are limited in e^+e^- energy reach due to synchrotron radiation. The proposed energies

▼FIG. 3: A silicon pixel detector prototype currently under study for the innermost detector surrounding the collision point. The detector is made of a High-Voltage CMOS sensor (top) and a CLICpix2 readout chip (bottom) that are glued to each other. Both parts have a size of 3.3×4.0 mm^2 and consist of an array of 128×128 pixels of 25×25 µm^2 size each. ©CERN





▲ **FIG. 4:** The CLIC accelerator with energy stages of 380 GeV, 1.5 TeV and 3 TeV. The accelerator could be built close to Geneva in the border region of Switzerland and France. ©CERN

range from 91 GeV to 350 GeV, covering the Z peak, WW production, Higgs-boson and top-quark physics. Among these projects, CLIC offers the only technology for multi-TeV e^+e^- collisions, resulting in the strongest discovery reach beyond the Standard Model.

CLIC technologies: New ideas, not only for particle physics

The CLIC team is developing specific technologies due to the unique two-beam approach and the luminosity requirements. The focus of the technology developments is on high-gradient normal-conducting accelerating and decelerating structures, ultra-precision alignment and component stabilisation as well as high-efficiency power converters. For example, the CLIC collaboration has developed reliable accelerating structures capable of operating at a field gradient of 100 MV/m, and power production structures delivering 135 MW of peak power at 12 GHz (more than a million light bulbs of 100 W each switched on for a tiny fraction of a second). These are very attractive technologies facilitating the design of cost-effective and compact accelerators for industrial and medical applications. The CLIC team works with a number of partners to promote these technologies for user applications such as compact X-ray sources and free electron lasers to study materials, molecular or biological processes or for cancer therapy. Sophisticated alignment systems for CLIC accelerator components have demonstrated that precisions better than 10 microns can be achieved over several hundred metres. Moreover, solutions were found to stabilise final focus quadrupoles including feedback against ground motion to a sub-nm level. These techniques are meanwhile used in other accelerator projects such as the LHC. There is also a strong effort to develop high-efficiency power converters to reduce energy consumption. In collaboration with industry the CLIC team has focused on developing multi-beam klystrons which reach an efficiency of over 70%, to power the drive beam. Such developments are attractive for all future particle accelerators.

An option for the future

Over the last 20 years, the CLIC team has developed a mature design for a TeV-scale linear e^+e^- collider. In particular the first stage at 380 GeV with its evident physics case exploring Higgs-boson and top-quark physics is an attractive option for the future of CERN and is ready to be launched. The priorities for future particle accelerators are set through the European Strategy for Particle Physics (defined by the CERN council). This strategy is foreseen to be updated in spring 2020. In case of a go ahead, the CLIC team and technology are ready to contribute to unravelling the intriguing open questions in particle physics. ■

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Steffen Doebert is a senior scientist working for more than 15 years on linear collider technologies at CERN and Stanford. He is a member of the CLIC Steering Committee and responsible for several hardware development projects within the CLIC study.

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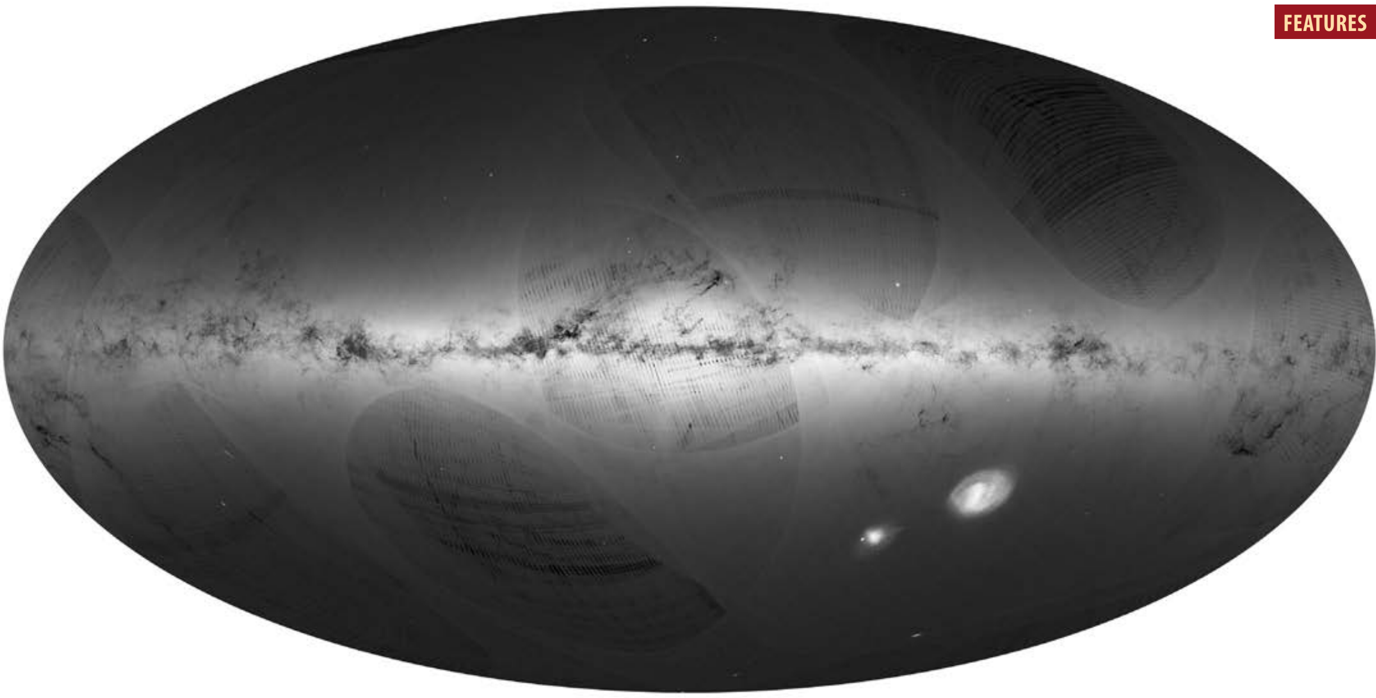

GAIA: SCIENCE WITH 1 BILLION OBJECTS IN THREE DIMENSIONS

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Gaia is an operational satellite in the ESA science programme. It is gathering data for more than a billion objects. Gaia measures positions and motions of stars in our Milky Way Galaxy, but captures many asteroids and extragalactic sources as well. The first data release has already been made and exploitation by the world-wide scientific community is underway. Further data releases will be made with further increasing accuracy. Gaia is well underway to provide its promised set of fundamental astronomical data.

Gaia is a cornerstone mission in the science programme of the European Space Agency (ESA). The fundamental scientific goal of Gaia is to reveal the structure and formation of our Milky Way Galaxy. This is achieved by measuring the position and motion of more than 1 billion stars. It is building on the heritage of its predecessor Hipparcos, an ESA mission that mapped the positions, distances and motions of more than 100,000 stars in the Solar neighbourhood. With respect to Hipparcos, Gaia improves thus in number of objects, but even more so in accuracy. Furthermore, Gaia is doing not only astrometry, measuring positions and motions, but provides also photometry and spectroscopy. While measuring the positions over the operational 5 year period it is possible to deduce the motion on the plane of the sky, but for the radial velocity component spectroscopy, based on the Doppler effect, is required. Therefore the title of the article is in fact too humble: Gaia provides data in 6 dimensions. Furthermore the photometry and spectroscopy can be used to deduce astrophysical properties of the stars detected by the satellite. By knowing temperature and brightness of stars, astronomers can get a hold on ages and masses, which are essential to understand the formation and evolution of the Milky Way.

While stars are the primary targets of Gaia, the mission will make a major contribution to solar-system and extragalactic studies as well. This is thanks to the observing strategy of Gaia. The satellite has no knowledge of the sky in advance. It has a detection system on-board based on magnitude threshold and gathers data of any bright enough point source. Although the majority of objects are stars most asteroids and many galaxies look also point-like to Gaia and observations are made. The precise position measurements of asteroids allow determination of the orbital elements to higher accuracy than is possible from ground-based measurements. This, combined with taxonomic information from photometry, allows more detailed studies between relations of orbital families of small bodies in the solar system and their physical characteristics. With extragalactic sources it is possible to provide fundamental

▲ The first Gaia all-sky view based on star counts. Brighter areas on the map means higher concentration of stars. Credit ESA/Gaia/DPAC relations between radio and optical reference systems. This is important because a large number of quasars used to define the reference frame based on radio observations are also visible to Gaia. The overarching aim of the Gaia mission is to contribute to fundamental astronomy across many scientific disciplines.

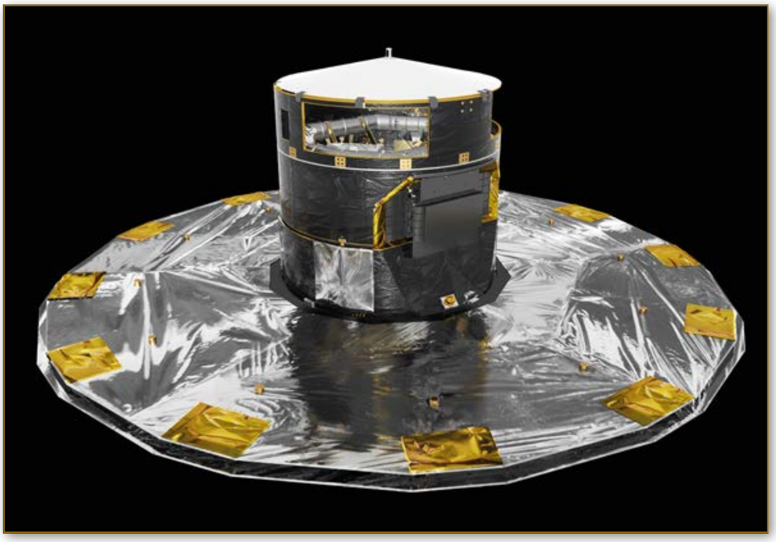
Spacecraft

The Gaia satellite was built by Astrium, Toulouse (now 'Airbus Defence and Space') as the prime industrial contractor. Unlike most ESA science missions, which have scientific instruments built in institutes in member states, in Gaia the payload was constructed by the prime industrial partner too. This was done due to the system approach needed to ensure stability across the satellite. The design driver in Gaia was the extreme stability needed to achieve the high accuracy required for astrometry. Any and all thermal connections to and in the payload had to be understood and minimised. Additionally, during science operations there are no moving parts in the satellite. An illustrative example of the level of detail required in design is read-out electronics. Reading out a small amount of data from the detector creates a small amount of heat. When scanning dense stellar fields there are more objects thus creating more heat than in sparse fields. This is not acceptable and therefore Gaia does 'fake reading' in regions with less stars so that the amount of reading activity is always constant.

Gaia has many unique features in its design. First of all Gaia has two telescopes looking at two fields of view 106.5 degrees away from each others. These two views are required to be able to do absolute astrometry. The fields of view are projected on a single focal plane with 106 Charge Coupled Devices (CCDs). The CCDs are operated in a specific mode taking into account the fact that Gaia is constantly scanning the sky. The way to keep the images sharp is to move the charge *i.e.* to move the images on the CCDs at exactly the same speed as the satellite is spinning. Thus Gaia is making constantly a picture of the sky where the width is the width of the detector, but the length has no limitation as it simply continues along the scanning of the spacecraft. It would be wonderful to get this Hubble Space Telescope resolution image of the full sky back to the Earth for analysis, but there is no way to transmit all data down. Therefore Gaia sends data only of pixels which have bright enough point sources in them. This is the case not only for astrometry, but also for photometry and spectroscopy.

Photometry in Gaia is achieved with two prisms. The light of a star is simply spread along the scanning direction and recorded on dedicated photometry CCDs. Spectroscopy follows the same principle, but for high resolution it is necessary to guide the light through a specific optical assembly (Radial Velocity Spectrometer) before recording the data. While photometry is done to all objects for which astrometry is done, spectroscopy can only be done to some 150 million brightest objects.

▾ **FIG. 1:** Gaia spacecraft. © ESA



Operations

Gaia was launched 19 December 2013 from Kourou with a Soyuz rocket. The travel time to its operational point, L2 (the second Lagrange point in the Sun-Earth system), took about a month. The commissioning period was successfully completed in half a year and since summer 2014 Gaia has been performing its routine science programme. An orbit around L2, which is beyond the Earth, was chosen for operations as there Gaia can turn its shield to hide not only to the Sun, but also toward the Earth and the Moon. The telescopes thus always look at the dark sky.

As already mentioned Gaia is constantly scanning the sky. However, the requirement is to cover the full sky as homogeneously as possibly. Furthermore, every point of the sky should be scanned with differing scanning angles to prevent any systematic effects creeping into the measurements. The scanning law followed by Gaia is a compromise between technical and scientific requirements. A technical requirement, for example, is that for thermal reasons the spin axis of Gaia is always precisely 45 degrees to the Sun. With this constraint the homogeneity of scanning is best achieved by combining the scanning with a slow precession of the spin axis of the spacecraft to the natural movement of L2, and Gaia thereby, around the Sun in a year.

Despite on-board processing done in Gaia, the amount of data transmitted to the Earth is enormous. Three ESA ground stations in Spain, Australia and Argentina are used to get the data down. When the scanning direction is along the Galactic plane, Gaia is producing so much data that essentially full time coverage is needed (and even then not everything can be sent); normally less than 10 hours per day is required for the downlink. Now more than three years in operations Gaia is truly in routine phase. Gaia is occasionally disturbed by micro-meteoroids, but it recovers autonomously typically in few minutes. All in all an amazing 10^{12} measurements have been collected so far.

Data processing

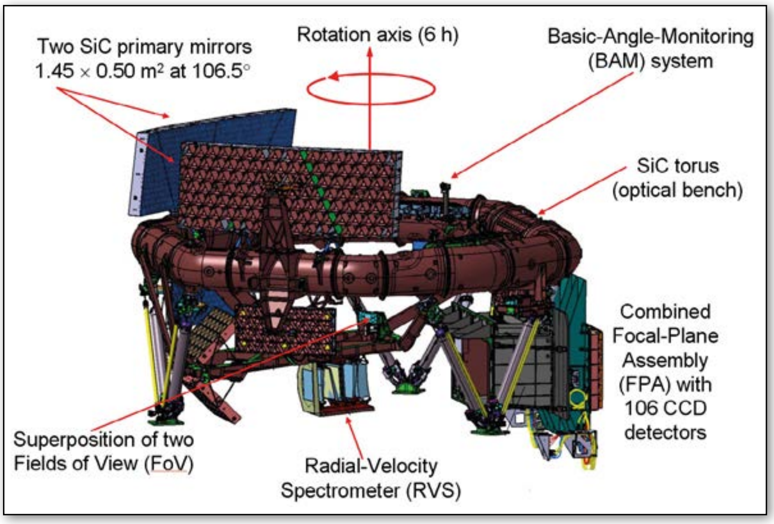
The huge amount of data collected by the spacecraft requires a major data processing effort. For Gaia, Data Processing and Analysis Consortium (DPAC) was chosen for the task. DPAC has about 500 members, scientist and engineers, working full or part time in research institutes and universities all over Europe. The consortium brings together experts of specific scientific topics working in a structure of coordination units producing code running in six data processing centres. While it is necessary to combine the expertise residing across institutes in Europe, the distributed data processing approach poses also challenges. A lot of attention had to be spent on ensuring good information flow throughout the consortium so that integration of the algorithms led to working code in data processing. After several years of preparations the pipelines needed still a major revision as the true data always have features not anticipated. Nevertheless, DPAC managed the challenge and the first data release (Gaia DR1) was achieved in September 2016.

Gaia DR1 is considered to be a taster for what is to come. That may be too humble a statement. Gaia DR1 increased the number of trigonometric distance measurements from 100,000 to above 2 million. In comparison to the 1 billion to come this is a small number, but a huge step in comparison to Hipparcos. Additionally Gaia DR1 contained position and brightness for more than 1 billion sources. The most accurate sky map produced ever. For about 3,000 variable stars also the light curves of the first year of observations were produced. Purely from operational perspective Gaia DR1 was an excellent training for future releases, but also scientifically the data have been used extensively.

Science results

Since Gaia DR1 some 250 refereed articles using Gaia data have been published. Although the distances estimates are not yet good for sources far away, the data set allowed to look further and more precisely in the Solar neighbourhood. Many marginal Hipparcos results were addressed and controversies were resolved. Also new questions were raised. In recent years asteroseismology has made major progress and Gaia DR1 allowed to test the results. First it appeared that distances between asteroseismological work and Gaia do not match, but later studies indicated much less discrepancy. This is clearly a topic that will be extensively addressed in future Gaia releases where the errors in distances will become significantly smaller.

Gaia DR1 has been used often in combination with ground-based data from spectroscopic surveys. Addressing the interplay of Milky Way stellar components is best done when the position and motion information is combined with the knowledge of astrophysical properties of stars based on spectroscopic analysis. In future releases this area of Milky Way research will receive a huge boost with the increased number of stars observed by Gaia with small errors.



▲ **FIG. 2:** Gaia Payload Module. ©ESA

Gaia DR1 also allowed to conduct the first comparison of quasar positions in radio and optical wavelengths. Quasars are known to have jets and purely from astrophysical perspective it is possible that the optical position *i.e.* the visible light centre does not coincide with the radio position where the jet may play a more important role. In the first instance generally the discrepancies are small, but this work will continue when the accuracy of Gaia position measurement is bound to match that already achieved at radio wavelengths.

Future

At the moment the Gaia focus is fully on the second data release. Gaia DR2 is scheduled for April 2018. This will be a major milestone not only for Gaia, but for astronomy in a wider context. Gaia provides fundamental information on which further research can be based. Yet Gaia DR2 is not the end, but more products and higher accuracy can be expected in Gaia DR3 and DR4 anticipated for 2020 and 2022. The nominal end of mission was planned for summer 2019, but today we know that the satellite has consumables to continue until mid 2024. The first step in the process of funding the operation in this extended period has been achieved. ESA has made the initial extension approval till the end of 2020. We are convinced that the science provided by Gaia will be so compelling, that the future extensions will be granted as well. We are well underway producing a set of fundamental astronomical data for decades to come.

About the Author

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Opinion: make the difference!

Petra Rudolf, University of Groningen

In Physics, the atmosphere for minorities has improved a lot in the last 20 years, thanks to an increase in awareness. But the road to a workplace where differences in culture, gender, social background and physical conditions are truly accepted, is still long. In the following I list some actions, which our Physical Societies, institutions and funding agencies can impose, but also things every single one of us can do to improve inclusiveness:

- All physicists: sign up for bias awareness training; all of us are biased but only when we realize we are, our rational side can keep control over our irrational bias.
- All physicists: whenever you organize a conference or a workshop, make sure that the number of female speakers is representative of the field. There are enough good women in each field, and one token woman as plenary speaker is not enough.
- Employers: make bias training mandatory for all committees taking decisions about money and people, and make sure that these committees are representative. Numerous studies have shown that committees with two women are far more effective than those with only one. When recruiting and promoting make sure that the way you evaluate academic excellence is not gendered[1].
- Employers: compare salaries, workspace and teaching load (take the "A Study on the Status of Women Faculty in Science at MIT"[2] as example) and adjust - like the University of Exeter and the London School of Economics did for salaries to close the gap for minorities[3].
- Employers: automatically increase the duration of temporary contracts (PhD students, postdocs, junior professors) if the employee has been on maternity leave.
- Physical Societies: explicitly include a statement on the status of women and minorities in your Ethical Statements as the American Physical Societies does[4] and make sure that your country has a charter which recognizes institutions for their efforts in the advancement of gender equality like the Athena Swan in the U.K.[5]
- Physical Societies: offer child care at each event you organize or sponsor.
- Physical Societies: make sure that your country has a "Come back fellowship" for physicists who have been out of research for caring tasks; examples are the Welcome Trust Career Re-entry Fellowship[6], or the Daphne Jackson Fellowships[7]. The M.Hildred Blewett Fellowship (U.S.A.) is similar but provides only one year – too short to make a complete re-entry.
- Funding agencies: request a proof of commitment to women's careers in STEM a prerequisite for funding: take example from the U.K. National Institute for Health Research's BRC/BRU where funding will require a minimum silver Athena Swan award[8], which can only be obtained following a submission to the Equality Challenge Unit (ECU).
- Funding agencies: consider effective working time in research in award criteria (see EU's ERC grants) for all personal grants (postdoc fellowships, junior professorships *etc.*) and make these grants available also for part-time employment (60% min) for a longer time; *i.e.*, a 5-year grant can be used over 7 years if the awardee works 70% instead of full time.

Make sure that your country has a charter which recognizes institutions for their efforts in the advancement of gender equality

- Funding agencies: include special financing for childcare during travel for collaborative experiments, conferences in all research grants, and offer extra funding for child care for young investigators who move abroad for extra experience (see grants offered by the Christiane Nüsslein-Volhard Foundation[9]).
- Funding agencies: set up special programmes to encourage the appointment of more women to assistant professorships (like the Dutch MEERVOUD[10]) and to tenured positions (like the Dutch ASPASIA[11]).
- Funding agencies: support universities and research institutions with special funds for positions for partners to solve two-body-problems. ■

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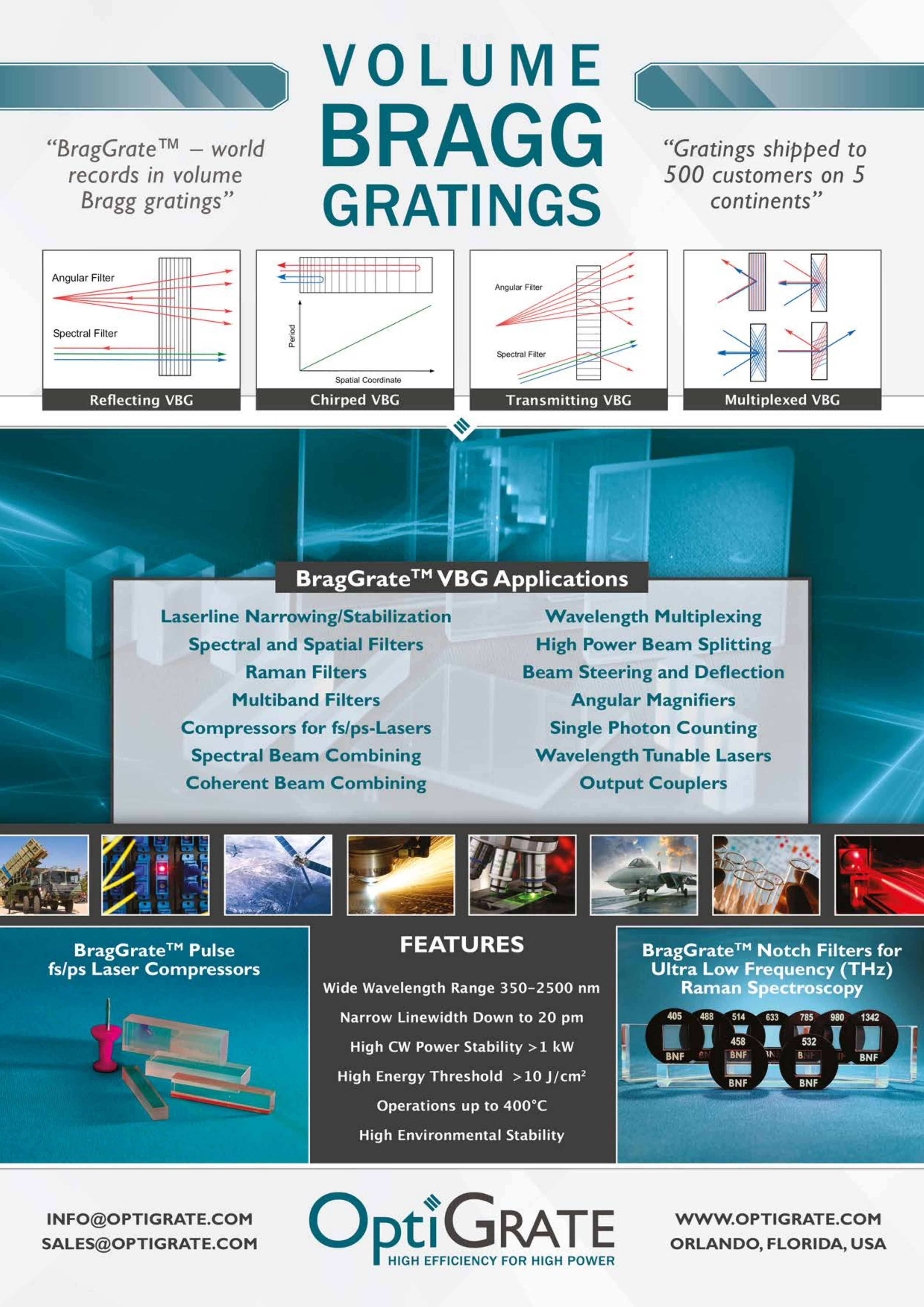
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