STRATEGY 2018 – 2022

Embedded globally, strength locally

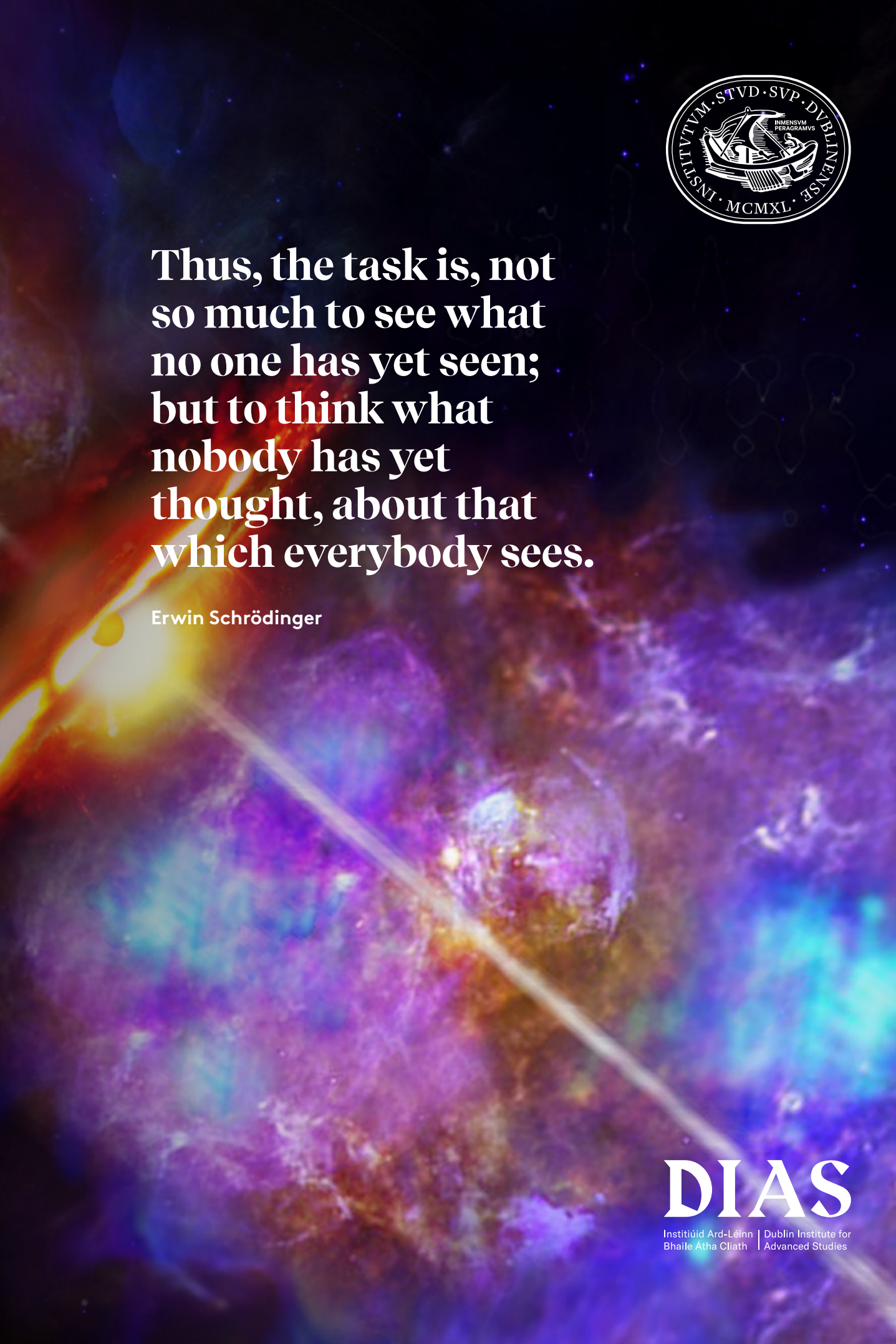
#DIASdiscovers

DIAS

Institiúid Ard-Léinn Bhaile Átha Cliath | Dublin Institute for Advanced Studies

Artist's impression of the accretion burst in the high-mass young star S255IR NIRS 3, by Deutsches SOFIA Institut, University of Stuttgart to accompany the Nature publication by Dr. Alessio Caratti o Garetti, DIAS. (Caratti o Garatti et al. 2017, Nat. Ph. 13, 276)

Contents


INSTITVTVM · STVD · SVP · DVBLINENSE · MCMXL ·
INMENSVM PERAGRAMVS
Thus, the task is, not so much to see what no one has yet seen; but to think what nobody has yet thought, about that which everybody sees.
Erwin Schrödinger
DIAS
Institiúid Ard-Léinn Bhaile Átha Cliath
Dublin Institute for Advanced Studies

Statement from Chairman

DIAS embarks on the next phase of its development at a time of growing geopolitical uncertainty in Europe and worldwide. More critically there is growing concern about the sustainability of our planet and an almost ubiquitous desire to understand our Earth and its natural systems better. The thirst to better understand our universe, our relationship with our sun and to understand everything from a fundamental physical and mathematical perspective has never been greater. Furthermore, the concept of identity and the understanding of our past and ourselves as a people – whether that is on our own island, as part of Europe or as global citizens - are growing themes in national and European discourse.

DIAS in this context has never been more relevant. We are contributing to all these challenging areas for mankind. Continuing the rich legacy of our past, DIAS will continue to make discoveries that will have long term impact. We will be enabled to progress challenging questions through the expertise of our current, and globally acknowledged, excellent team of researchers and scholars. We will contribute understanding and insights by being advanced in our thinking and research, by giving bright minds from home and abroad the space and time to think, and by working in partnership with national and international partners. In terms of the latter we will expand and deepen our partnerships with international collaborators and continue to be an ambassador for excellent Irish research. We will also continue to be a magnet attracting high potential and high calibre researchers and scholars to Ireland, both as visitors and as staff and scholars. We will deepen our role as an intellectual hub for our disciplines over the lifetime of the strategy and we will strengthen our disciplines, associated areas and the relevant research communities nationally. Importantly we will in the coming period identifythrough a strategic process, another area where advanced study is required to benefit mankind.

And so by being a beacon for fundamental research and by leveraging our international reputation, DIAS will strengthen Dublin and Ireland as a home for intellectual leadership, independent critical enquiry and innovative frontier research. We will contribute to the development of local communities through DIAS Dunsink Observatory – a major heritage asset in the Ancient East and nationally. All that we do will contribute to the implementation of national policies and to the betterment of Ireland.

Of course we will not achieve our goals alone. We look forward to engaging with you, our myriad of stakeholders, and having your support, whether directly or indirectly, for our research and advanced study. Or perhaps you will support us by engaging in our growing programme of public events. Watch out for our programme of special events in 2020 when we mark our 80th anniversary.

DIAS is a national and international powerhouse for advanced studies. Our new Strategy 2018-2022: Embedded Globally, Strength Locally ensures continued success for DIAS and the enrichment of human knowledge.

Dr. Vincent Cunnane
November 2018

EXECUTIVE SUMMARY

A Unique Institution, a Proud History and a Continuing Impact

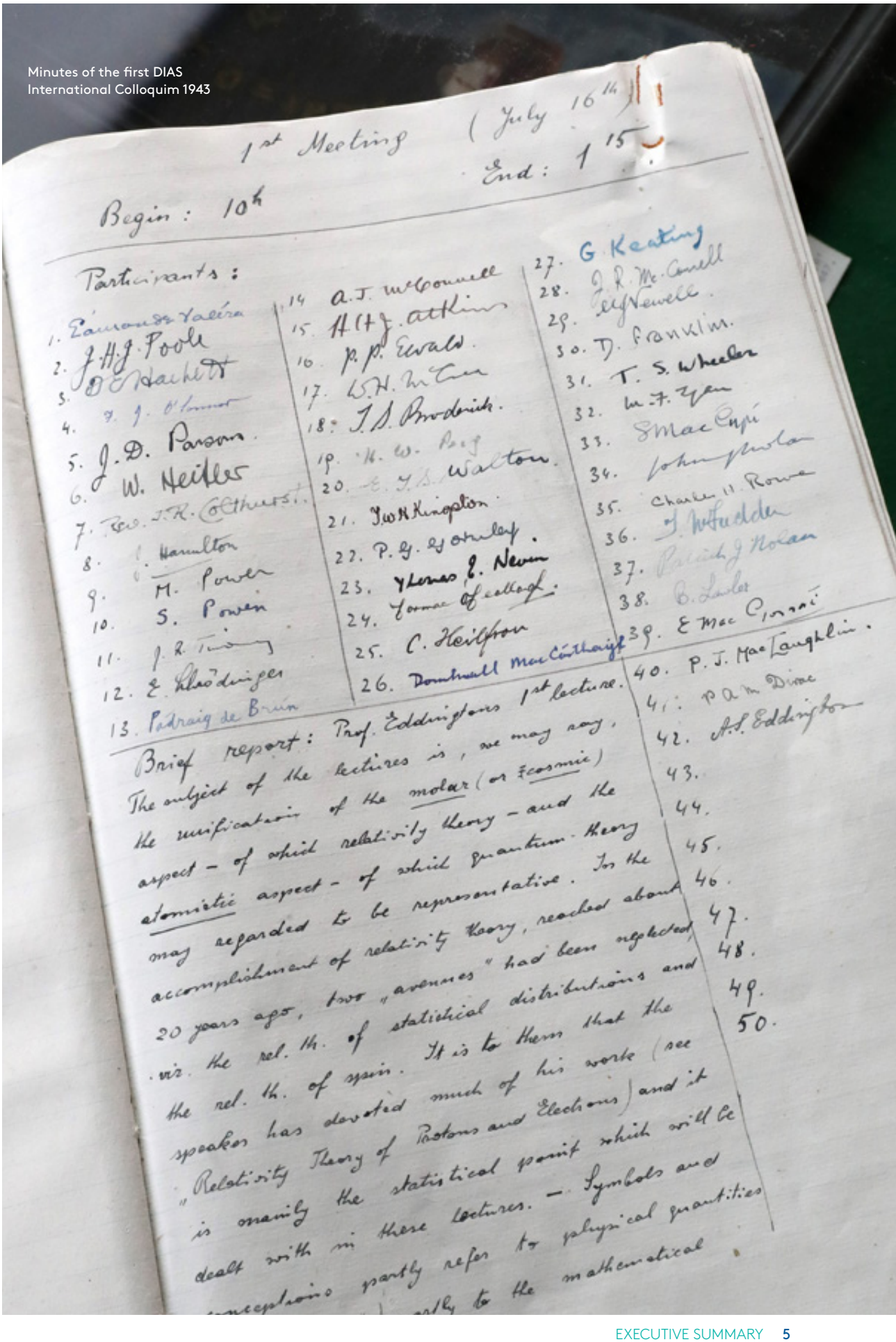
The Dublin Institute for Advanced studies was established in 1940 as the world's second, and Europe's first, such institute with an exclusive focus on research and advanced studies.

The Dublin Institute for Advanced Studies (DIAS) was established in 1940 as the world's second and Europe's first institute with an exclusive focus on research and advanced studies. Our role in Ireland's national higher education and research ecosystem, as a statutory, independent research institute carrying out fundamental research, was reasserted in a comprehensive review of the higher education sector conducted by the Higher Education Authority for the Minister for Education and Skills in 2013.

DIAS is further differentiated in the Irish system by its mandate to focus on fundamental questions and areas of scholarship and as a place that offers researchers the opportunity to study some of the most difficult open questions in our world (set out later in this strategic plan). DIAS mentors and trains early career researchers while rooted and studying in Ireland.

The research work of DIAS is currently organised in three schools: the School of Celtic Studies, the School of Theoretical Physics and the School of Cosmic Physics (encompassing astronomy, astrophysics and geophysics). While in their work, the potential for long-term impact on knowledge is clearly recognised, the schools, in line with broader national policy, are sensitive to activities that may yield short-term impacts and, where these opportunities arise, appropriate steps have been and are being taken in the national interest.

While the previous strategic plan 2012–2017 covered a period of global economic downturn, DIAS continued to deliver on its mandate. It provided support to the disciplines and the research community nationally and internationally in its three broad areas of focus. This current plan sets out a detailed list of specific discoveries and progress during the period, including the instigation of a number of national initiatives and the formation of international partnerships.



Minutes of the first DIAS International Colloquim 1943

1st Meeting (July 16th)

Begin: 10h

End: 1 15

Participants:

1. Éamon de Valera
2. J.H.J. Poole
3. D. Hackett
4. T. J. O'Connor
5. J.D. Parson
6. W. Heitler
7. Rev. J.R. Cotherst.
8. J. Hamilton
9. M. Power
10. S. Power
11. J. R. Twiss
12. E. Schrödinger
13. Pádraig de Brún
14. A.J. McConnell
15. H.(H.)J. Atkins
16. P.P. Ewald
17. W.H. McCrea
18. T.S. Broderick
19. H. W. Berg
20. E.T.S. Walton
21. J.W.H. Kington
22. P.G. Gyorulay
23. Thomas G. Nevin
24. Tomas O Ceallaigh
25. C. Heilfron
26. Domhnall Mac Cárthaigh
27. G. Keating
28. J.R. McCarell
29. Ely Newell
30. D. Franklin
31. T. S. Wheeler
32. W.T. Yen
33. S Mac Cupi
34. John Phelan
35. Charles H. Rowe
36. J. Mitchell
37. Patrick J. Nolan
38. B. Lawlor
39. E Mac Cionnaí
40. P.J. MacLaughlin
41. P.A.M. Dirac
42. A.S. Eddington
43.
44.
45.
46.
47.
48.
49.
50.

Brief report: Prof. Eddingtons 1st lecture.

The subject of the lectures is, we may say, the unification of the molar (or cosmic) aspect – of which relativity theory – and the atomistic aspect – of which quantum theory may regarded to be representative. As the accomplishment of relativity theory, reached about 20 years ago, two „avenues" had been neglected, viz. the rel. th. of statistical distributions and the rel. th. of spin. It is to them that the speaker has devoted much of his work (see „Relativity Theory of Protons and Electrons) and it is mainly the statistical point which will be dealt with in these lectures. – Symbols and conceptions partly refer to physical quantities partly to the mathematical

Part of a Global Network

DIAS is part of a growing global network of institutes for advanced studies and, as such, is a clear demonstration internationally of Ireland's long and continuing commitment to fundamental research. DIAS acts as a 'magnet' for international talent and as an ambassador for Ireland in international research fora. There is a strong international collaborative focus to our work and we have extensive networks of both national and international collaborators.

Our Mission

- To push the boundaries of current understanding in our specialist disciplines and to conduct fundamental research to the highest international standards.
- To enable researchers at all career stages to flourish and fulfill their research potential, and to train talented scholars in advanced research.
- To provide a neutral dedicated research space and a conducive intellectual environment for local and international researchers to conduct advanced studies, explore ideas, and engage in unconstrained thought.

Our Vision

Reflecting our rich legacy and unique mission, DIAS is recognised globally as a force for excellence in fundamental research. Nationally, as the original centre of excellence, we will be acknowledged as an Institute for Advanced Studies leveraging its strong global presence to support its disciplines and the national research community. In this regard, DIAS will be a hub of expertise and a gateway for fostering an international learning community in its disciplines. By attaining a vibrant working environment, both physically and culturally, DIAS will strengthen Dublin and Ireland as a home for intellectual leadership, independent critical enquiry, and innovative frontier research.

Our Values

Our values are excellence in all that we do; freedom and tenacity in the pursuit of understanding; leadership and steadfastness for our disciplines; collegiality and respectful collaboration; openness and social responsibility; integrity and probity, and inclusiveness and diversity.


Descoberta
发现
Հայտնաբերումը
Descubrimiento
Aimsiú
Открытие
Otkriće
اكتشاف
Découverte
Scoperta
#DIASdiscovers
Felfedezés
Darganfod
Ontdekking
Keșif
発見
Entdeckung
Discovery
Ανακάλυψη
Objev

Our Goals

Attainment of our vision will be driven through four overarching strategic goals.

STRATEGIC GOAL 1

Discovery of new knowledge and understanding through excellence and researcher-led endeavour

DIAS will continue to deliver on its mandate and be a beacon for fundamental research and thus deliver social, cultural and economic benefits. In the period 2018–2022, research and advanced study at DIAS will continue to be driven by the desire to gain understanding for the long-term benefit of humanity, Ireland and the world. Our research questions and areas will contribute insights to Celtic society and its legacy, and progress understanding of our island, the universe and the underpinning mathematical principles of nature. In order to deliver on this strategic goal, a number of objectives are set out. These objectives will be attained by the implementation of strategic actions.

STRATEGIC OBJECTIVES

- Implement new research and study themes in our schools. Quantum computing will be an increasing focus in theoretical physics and in astrophysics new themes of solar research and exoplanets research are being added.
- Engage with and support the New Space Technologies Programme, a priority for Project Ireland 2040.
- In recognising the evolution of science and research fields, identify a new area requiring an advanced study focus, within the lifetime of this strategy.

To enable discovery, we will:

- Optimise our facilities and infrastructure so as to provide a stimulating, supportive and accessible environment for advanced studies, and as part of this objective locate in an area designated to foster innovation.
- Leverage the excellence within DIAS to diversify funding sources and increase funding obtained from non-core grant sources.
- Enable progress monitoring by the capture of appropriate information on the quality and impact of DIAS research, building on the already embedded five yearly independent site visit reviews, and drawing on international best practice.
- Preserve the cultural and scientific heritage at DIAS Dunsink and throughout the Institute, and make it more accessible as a public cultural and scientific resource in Dublin City and Fingal County.

STRATEGIC GOAL 2

International research collaboration benefitting Ireland and the world

DIAS stands out as an entity which from its inception is highly internationalised and globally recognised. Critical mass in the research areas in which DIAS is engaged can be achieved only through international collaboration. As a number of our areas involve deep engagement in 'big science', the criticality of access to big science facilities is well understood at DIAS. Conversely, DIAS is highly conscious that as the world-recognised centre for Celtic Studies it must engage internationally to support others in this area.

During the period of this strategy, DIAS will maintain its membership of the international learning community and perform a number of strategic actions to further enhance its function as an ambassador for Irish research internationally and thus accrue benefit for the Irish system.

STRATEGIC OBJECTIVES

- Leverage our international connections to contribute to the implementation of the International Education Strategy of the Department of Education and Skills (DES); for example, Celtic Studies has bilateral relationships with leading global universities.
- Leverage our excellence and international connectedness, and explore opportunities to contribute through research e.g. on Earth System Change, to the Sustainable Development Goals (SDGs).
- Maintain an association and formal collaboration with the current portfolio of international consortia and infrastructures, for example, the High Energy Stereoscopic System (HESS), JWST (successor to Hubble), the European Space Agency (ESA), European Southern Observatory (ESO), and the European Plate Observing System (EPOS).
- In following on from our partnership in the International LOFAR Observatory, and to further strengthen Irish research, promote official Irish participation in the Square Kilometre Array (SKA). We will continue to advocate for Ireland becoming formally associated with CERN.
- Deepen strategic relationships with other institutes for advanced studies and academies, and foster collaboration for the furtherance of frontier research.

STRATEGIC GOAL 3

Attraction and cultivation of research leaders

An opportunity now exists within the changing international landscape to attract world-leading emerging researchers to Ireland, with the potential to revitalise the Irish higher education and research-performing system. Ireland must be recognised internationally both as a leading research performer and as an open high-quality and welcoming environment for research talent. DIAS with its strong international brand and reputation is already a magnet for excellent researchers in each of its specialised branches of knowledge and is globally competitive in attracting talent to Ireland.

STRATEGIC OBJECTIVES

- Recruit leading researchers in our specialist fields and assure a sustainable structure by reinstating posts at different career stages; to accomplish this the number of active researchers on site will increase (primarily a mix of externally funded positions and longer-term visitors.)
- In line with a key function of DIAS, accommodate excellent individuals from Ireland or abroad who wish to access a location where their time can be dedicated to research (including sabbaticals).
- Develop and implement an Associated Faculty structure for the Institute.
- Enhance professional and career development opportunities for staff and scholars, mindful of particular needs of early career researchers.
- Enhance gender balance at DIAS and attain Juno accreditation, followed by Athena SWAN Bronze accreditation.

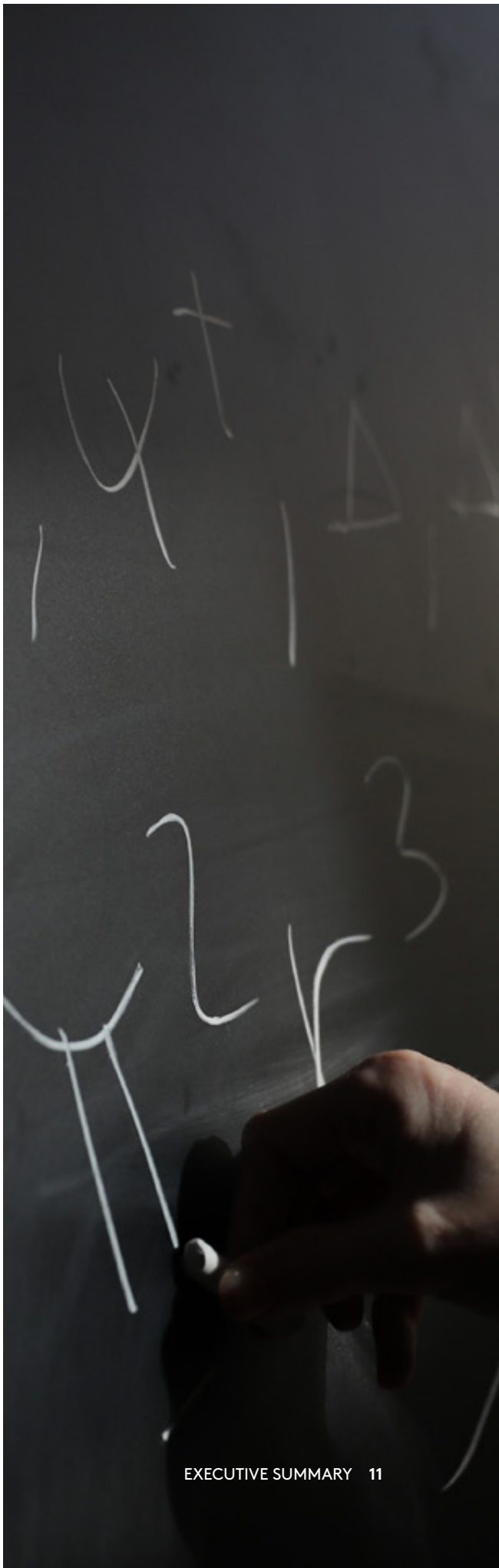
STRATEGIC GOAL 4

Strengthening disciplines and research communities nationally

At DIAS, we believe we have a responsibility and duty to our disciplines and by extension the associated communities. This strategy reflects this view and hence in the national interest this responsibility and duty will become an area of major focus for DIAS in the lifetime of this strategy.

STRATEGIC OBJECTIVES

- Expand the provision of specialist material to students (undergraduate and postgraduate) within the higher education system through structured initiatives and in partnership with other national Higher Education Institutions (HEIs).
- Establish an International Visitor Lecture series for the benefit of the national community.
- Establish a programme of DIAS International Summer Schools across the entire Institute (open to national and international participants).
- Shape the direction of research in Ireland through statements. Develop roadmaps for the strengthening of our disciplines nationally.
- Strengthen and expand DIAS's contribution to national research centres, other initiatives, and national policies. In that regard, continue to develop collaboration with other national academic and non-academic stakeholders for those domains in which we engage.
- Enhance and expand outreach activities to the public and so increase understanding of those areas, and increase the interest of citizens in research in science, technology, engineering and mathematics (STEM) and in the Arts, Humanities and Social Sciences (AHSS).



DIAS 1940-2018: Some Highlights[1]

1943
E. Schrödinger (first Director of Theoretical Physics at DIAS and Nobel Prize winner) delivers his famous "What is Life?" series of public lectures in TCD. Acknowledged by Crick, Watson and Wilkins to have inspired their discovery of DNA

1946
Publication of first volume of 'Celtica' - from that day to this the seminal journal worldwide for Celtic Studies

1947
School of Cosmic Physics established and Dunsink Observatory becomes part of DIAS

1957
The first all-island gravity survey completed and published by T. Murphy

1959
Publication of Volume 1 of H. Wagner's Linguistic Atlas and Survey of Irish Dialects (1959-1969), a key reference document to this day

1960
J.L. Synge publishes his 'Relativity: The General Theory' and for more than a decade DIAS becomes the leading world centre for research in general relativity

2017
T. Ray awarded ERC advanced grant (only one of seven in Ireland since 2013)

2018
Marking 40 years leading the Irish National Seismic Network - a key international resource which detects earthquakes and other seismic activities

1 See also Appendix A

1972
DIAS fly first ever Irish experiment in space and onto the lunar surface (NASA Apollo 16 mission)

1965
The O'Raifeartaigh Theorem published to wide acclaim

1978
Publication of Binchy's 'Corpus Juris Hibernia' - the key work on Brehan Laws to this day

1987
B. Jacob demonstrates that the Irish continental shelf extends out through the Porcupine and Rockall basins thereby enlarging Ireland's zone of economic interest by a factor of ten

The H.E.S.S. collaboration of which F. Aharonian is a leader - is awarded EU Descartes prize for outstanding trans-national research

2007

2013
W. Nahm awarded the Max Planck medal of the German Physical Society

2000
J. Lewis of DIAS founds Corvil - now a major network analytics company

2001
DIAS has the first Irish experiment on the International Space Station (one of ten experiments on board)

DIAS is the world's foremost academic publisher in the field of Celtic Studies. 400 books have been published.

SECTION I

A Distinct Role Contributing to a Diverse Higher Education and Research System

DIAS: The World's Second and Europe's First Institute for Advanced Studies

To promote Ireland's reputation for intellectual endeavour, the Irish Government, led by Taoiseach Éamon de Valera, established DIAS in 1940[2]. As the second institute for advanced studies established worldwide and Europe's first at the time, it was specifically set up to have an exclusive focus on research and advanced studies and much like the first institute, in Princeton, USA, to have no undergraduate teaching mission.[3] It is thus a postgraduate institution, where the world-renowned Nobel Prize-winning physicist, Erwin Schrödinger, was its first director.[4] Internationally, the number of institutes for advanced studies continues to grow and DIAS is part of this global network.[5] It is a clear beacon to the international arena of Ireland's commitment to fundamental research be it exploratory, longer-term, often non-programmatic and high risk/high gain.

DIAS's presence in Ireland, although unique in the Irish context, strengthens the national objective for a diverse – but coherent – research-performing landscape. The specific contribution of DIAS was recognised following a comprehensive review of the higher education sector and its institutions, conducted by the Higher Education Authority for the Minister for Education and Skills in 2013. DIAS was approved to remain a statutory, independent research institute carrying out fundamental research.[6]

> **The primary purpose is the pursuit of advanced learning and exploration in fields of pure science and high scholarship to the utmost degree that the facilities of the institution and the ability of the Faculty and students will permit. The establishment of the Institute is founded on the belief that there is at present little or no lack of schools and colleges for the training of young men and women ... [and] ... there is never likely to be an over-abundance of opportunities for men and women engaged in the pursuit of advanced learning in the various fields of human knowledge.**
>
> Louis Bamberger and Caroline Bamberger Fuld on the organisation and purpose of the Institute for Advanced Study, Princeton[7]

2 DIAS is an independent statutory corporate body which reports to the Oireachtas, and engages with Government through the Office of the Minister for Education and Skills.

3 DIAS does not award degrees and thus does not currently charge fees or have fee income.

4 Schrödinger was director of the School of Theoretical Physics.

5 Examples include the Perimeter Institute (Canada) and the Korean Institute for Advanced Study.

6 For further information on the review, see http://hea.ie/assets/uploads/2017/04/Report-to-the-Minister-2013.pdf; and https://www.education.ie/en/Publications/Policy-Reports/HEA-Report-to-the-Minister-for-Education-and-Skills-on-Irish-higher-education-Response-Letter-.pdf.

7 L. Bamberger and F. Fuld (1930), Institute for Advanced Studies Bulletin No. 1.

Ireland's Only Institute for Advanced Studies

DIAS is differentiated in the Irish education system not only by virtue of its mandate to focus on research and advanced studies, but also by its mandate to focus on fundamental questions and areas of scholarship. It therefore focuses on excellence and intellectual capital as the key output from its endeavours. Importantly, in order to cultivate independent research leaders and experts with critical thinking and creative minds for the future, it also mentors early stage career researchers.[8] It does so at a stage in their careers where independent research is important for their intellectual development. Importantly, it is a place which offers researchers the opportunity to study some of the most difficult open questions in our world, and to train early career researchers while rooted and studying in Ireland.

DIAS, in addition to its distinct focus, also specialises in terms of research areas. Its research work is currently organised into three schools: the School of Celtic Studies, the School of Theoretical Physics and the School of Cosmic Physics (encompassing astronomy, astrophysics and geophysics).[9] Structures are optimised to support the unique research-focused mission of the organisation. While the schools operate in different areas of human thought and experience, they have the common purpose of extending the boundaries of knowledge and understanding, in addition to fostering critical analysis. The potential for long-term impact on knowledge is clearly recognised, but in line with broader national policy, there is a sensitivity to activities that may yield short-term impact; and where these opportunities arise, as has happened in the past,[10] appropriate steps are taken in the national interest.[11]

8 DIAS awards highly internationally competitive scholarships and fellowships, in addition to mentoring individuals funded through competitively won research grants.

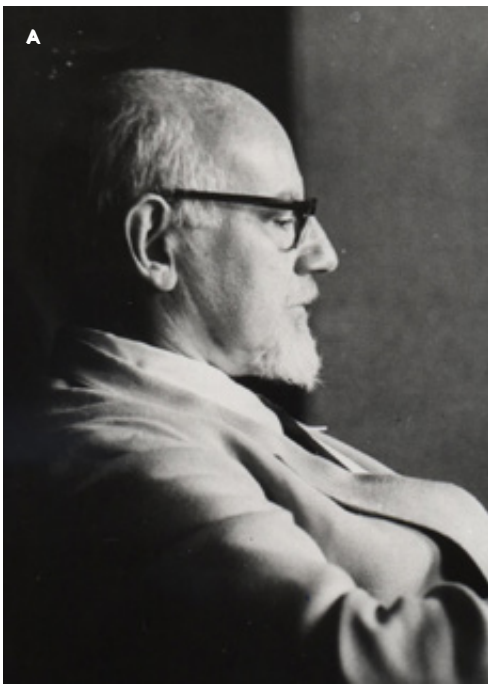
9 Each school is overseen by an independent governing board of the highest distinction. A council provides a common legal identity for DIAS and is the overarching governance structure. Each school has a Director, with a Registrar/CEO responsible for overall corporate administration.

10 In 2000, Corvil Networks – now a major network analytics company – was established by Professor John Lewis from the study of the foundations of statistical mechanics and the relation of entropy to information; the ideas were applied to telecommunications and the high-tech start-up company was established to exploit resulting intellectual property.

11 DIAS is a member of Dublin Region Innovation Consortium, and has access to the knowledge-transfer capabilities at Dublin Institute of Technology (DIT).

Prof E. Schroedinger (left) welcoming Prof P. Dirac at Dublin Airport

Our Physics and Mathematics Eponyms



Erwin Schrödinger
DIAS 1940 - 1957

- Co-founder of quantum mechanics
- The Schrödinger equation

Huan Wu Peng
DIAS 1941 - 1947

- The Heitler–Peng integral equation

Walter Heitler
DIAS 1941 – 1949

- Co-founder of Theoretical Chemistry
- The Heitler–Peng integral equation

John Lighton Synge
DIAS 1948 – 1995

- Synge's theorem

Cornelius Lanczos
DIAS 1952 – 1974

- The Lanczos method
- The Lanczos potential
- The Lanczos algorithm
- The Lanczos resampling
- The Lanczos kernal

Lorcan O'Raifeartaigh
DIAS 1956 – 2000

- O'Raifteartaigh theorem
- The O'Raifteartaigh model
- The O'Raifteartaigh mechanism

John Trevor Lewis
DIAS 1963 - 2001

- The Lewis–Dalgarno method

Werner Nahm
DIAS 2002 - present

- The Nahm equations
- The Nahm transform

The Ward–Takahashi Identity

- John Clive Ward & Yasushi Takahashi (DIAS 1957 - 1960)

The Nolan–Pollak Counter

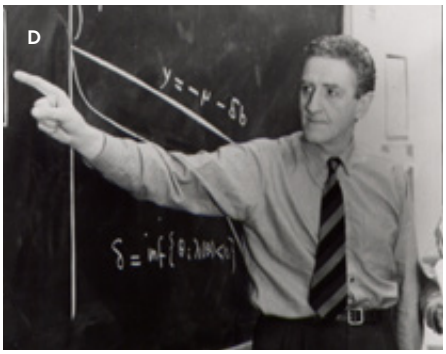
- Leo W Pollack (DIAS 1947 - 1963); an early pioneer of big data

A Prof. John Lighton Synge

B From left: President De Valera, Prof. J.A. Wheeler and Prof. C. Lanczos

C From left: Prof. Lorcan O'Raifeartaigh, Prof. Stephen Hawking and Prof. Ernest Walton

D Prof. John T. Lewis in School of Theoretical Physics, DIAS



Our Mission

Our mission as an Institute for Advanced Studies is to push the boundaries of current understanding in our specialist disciplines and to conduct fundamental research to the highest international standards; to enable researchers at all career stages to flourish and fulfil their research potential, and to train talented scholars in advanced research; to provide a neutral dedicated research space and a conducive intellectual environment for local and international researchers to conduct advanced studies, explore ideas, and engage in unconstrained thought.

Enhancing the Scientific, Cultural and Economic Life of Ireland

By virtue of its areas of expertise and the small community in these areas nationally, DIAS has a strong international collaborative focus and therefore extensive networks of both national and international collaborators. It has long been associated with new perspectives, approaches and paradigms – many of which have stood the test of time, some indeed in unexpected ways. In addition to impacts already presented (pages 12 and 13), Impacts for 2012-2017 are presented in Chapter 3 Enhancing Ireland's Global Reputation. Further examples of impactful individuals and the legacy of research work are presented in Appendix 1.

SCHOOL OF CELTIC STUDIES (SCS)

The field of Celtic Studies is highly international, with the school at DIAS being the first dedicated centre. In broad terms, however, it has been said that for the School of Celtic Studies 'its stature as the paramount world-centre of the discipline is shown by the fact that virtually all scholars of international repute currently active in Europe and further afield have links to the School or have received some of their training in DIAS'.[12,13] The school is the acknowledged world-leading centre for research in the Celtic languages and literatures and the foremost academic publisher in the field with research conducted on Celticism in Ireland and continental Europe. A key priority is the provision of reliable editions of hitherto unpublished material and texts, previously accessible only to scholars consulting the manuscripts.[14] Through its pioneering projects in the digital humanities, its contributions are now globally accessible on the internet.[15] The Ogham in 3D project is an example of a project making a significant contribution to the preservation of our culture. The library at SCS has the most comprehensive and accessible collection of books and journals on Celtic Studies on the island of Ireland.

SCHOOL OF COSMIC PHYSICS (SCP)

In the science field, DIAS, through its engagement in global research projects addressing internationally recognised fundamental questions about our planet and the universe, has long been a research ambassador for Ireland. The School of Cosmic Physics is currently functionally structured into two divisions: one focused on the interior and surface of the Earth (Geophysics section[16]) and the other focused outwards (Astronomy and Astrophysics section). The school is a leader of national activity in these areas and is highly respected internationally for the depth, breadth and quality of its activities. It is currently involved in, for example, the building of the successor to the Hubble Space Telescope, the James Webb Space Telescope, which will be the largest telescope ever made.

DIAS developed hardware and is currently engaged in developing software. The school carried out the first gravity survey of Ireland[17] and through off-shore geophysical research enabled the extension of Ireland's ocean territory by tenfold.[18] DIAS is now a world leader in studies of the global structure of the Earth's crust and mantle, and in volcano studies around the globe. As the last land mass on the edge of the European land mass for measuring seismic activity, DIAS – home of the Irish National Seismic Network – contributes significantly to the study of national, European and world seismology.

SCHOOL OF THEORETICAL PHYSICS (STP)

The School of Theoretical Physics investigates the fundamental mathematical structures in which the laws of physics find expression. This research has profound, if long-term, implications not just for our understanding of the structure and origin of the universe, but, through quantum information theory, for the future of computing and the limits of what is computable. Quantum theory and relativity – two basic applications of mathematics to physics – permeate almost every advance in modern science and technology. In theoretical science, the mutual interaction between mathematics and physics is flourishing. Mathematical concepts and analysis are particularly important in understanding and developing physical theories and, at the same time, ideas from physics have stimulated many new developments in modern mathematics. Work at the school has contributed to these developments: 'The STP of the Institute has a very distinguished history and continues to play a vital role in nurturing research in mathematical and theoretical physics both nationally and internationally'.[19]

12 Independent External School Review, 2014.

13 Examples include Professor Thomas Charles-Edwards, Professor of Celtic, Oxford; Professor James McCloskey, University of California, Santa Cruz; Professor Neil McLeod, Professor of Law, Murdoch University, Australia; Professor Tomás Ó Cathasaigh, Professor of Irish Studies, Harvard University.

14 Researchers require advanced linguistic, palaeographical, literary, and general philological expertise to edit and comment on medieval texts, to make phonetic transcriptions of spoken language, and to deal with the complicated linguistic issues that will confront them.

15 The Irish Script on Screen, flagship project.

16 According to the Independent External School Review, 2014, 'even though the permanent staff of the Geophysics section is not large, it is the strongest concentration in Ireland, with more than 50% of staff geophysicists, most of the postdoctoral fellows and more than two-thirds of postgraduate students'.

17 Thomas Murphy, DIAS, 1957.

18 Professor Brian Jacob and collaborators, 1987.

19 The Independent External School Review, 2014.

The Irish Script on Screen, has digitised 400 manuscripts, and has in excess of four million hits annually from over 150 countries.

20 Co-funded by the Geological Survey Ireland since 2017.

ENHANCING IRELAND'S RESEARCH INFRASTRUCTURES

DIAS has played a key role nationally in the establishment of research infrastructures (see Table 1). It led the genesis of high-performance computing infrastructure on behalf of the system; its leadership of inter-institutional consortia in this area culminated in the establishment of the Irish Centre for High-End Computing (ICHEC). DIAS was advanced in promoting this area for investment. Project Ireland 2040 now supports participation in the European Union (EU) High Performance Computing (HPC) programme.

Table 1: Advanced studies through provision of research infrastructures

Name	Function	Leader or key partner
Irish National Seismic Network	Detects earthquakes and other seismic activity – part of European and global network	Leader and operator[20]
Meamram Páipéar Ríomhaire / Irish Script on Screen (ISOS)	Creation of digital images of old Irish manuscripts; images freely available online. Contains >400 manuscripts – a unique resource with >4 million hits in 2017	Leader
Bibliography of Irish Linguistics and Literature (BILL)	A catalogue of thousands of publications relevant to Celtic Studies	Leader
iMARL	A national ocean bottom listening infrastructure – precursor to a tsunami warning system	Leader
National CTBTO Office	Comprehensive Nuclear-Test-Ban Treaty Organization	Hosted at request of Department of Foreign Affairs and Trade
I-LOFAR	The new national radio-telescope infrastructure	Key partner
ICHEC	The national high-performance computing infrastructure	Key partner

CONTRIBUTING TO THE DELIVERY OF NATIONAL POLICY

In addition to the impacts and the beneficial infrastructures set out above for DIAS, the reputation and track record[21] of the organisation since its inception has been key in attracting the expertise of outstanding scientific researchers from abroad to work in Ireland. In modern parlance, DIAS has always been a 'talent magnet'.[22] Also by virtue of its persistent engagement in the international arena, DIAS is a respected and well-connected ambassador for Irish research and scholarship. This has been reflected in the profile of candidates for competitively funded research positions at DIAS.[23] In line with our mission, DIAS provides a neutral forum within which staff and scholars from national and international higher education institutions and research-performing bodies can meet and work together.

Despite no formal International Visitors programme in place at DIAS due to funding constraints over the past number of years, self-funded international visitors continued to request time, of varying durations, at DIAS.[24] DIAS has also led inter-institutional, national postgraduate research education and training initiatives. In these ways and others, DIAS has made a major contribution to Ireland's intellectual life and international prestige.

In policy terms, these activities and outputs specifically contribute to the delivery of Innovation 2020, the National Strategy for Higher Education to 2030,[25] and the Action Plan for Education.[26] DIAS contributes significantly to the conduct of frontier research and to attracting world-leading research professors and future research leaders to Ireland.

DIAS draws down funding from Horizon 2020[27] and has supported the Irish Government in the discussion on joining the European Southern Observatory (ESO). Collaborative research projects between enterprise and DIAS have emerged particularly in the cosmic physics domain. In overall terms, DIAS strengthens the national research performance as assessed internationally by the EU and OECD in terms of excellent public research, and global competitiveness in particular.[28]

Furthermore, DIAS is also contributing to the implementation of other national policies such as the Geological Survey Ireland Research Roadmap, and the Harnessing Our Ocean Wealth: An Integrated Marine Plan for Ireland.[29,30] It is contributing to the delivery of The Global Island: Ireland's foreign policy for a changing world,[31] in terms of its international connectedness and in terms of its role as the national office for the CTBTO.

DIAS is proud of its role and how it contributes to Irish and global research endeavours, while constantly being aware of its cultural and scientific legacy. DIAS will mark its 80th anniversary in 2020.

21 As an example, in 2016, DIAS received one of only seven European Research Council (ERC) Advanced Grants obtained in Ireland since the start of Horizon 2020; in 2016, DIAS had five Nature publications. DIAS has 19 permanent academic staff.

22 Through international competitive processes (2004–2016 inclusive), 17% of Schrödinger/Bergin Fellow appointments were Irish nationals; 39% of fellows are now based in Ireland.

23 Research staff profile is 32% Irish, 33% rest of EU and 35% rest of world.

24 There were 115 research visitors from 20 countries in 2016.

25 Innovation 2020 (DJEI, 2012); National Strategy for Higher Education to 2030 (DES, 2011).

26 Published by the Department for Education and Skills, the Action Plan for Education 2016–2019 sets the ambition: 'To become the best higher education system in Europe and position Ireland as a Global Innovation Leader'.

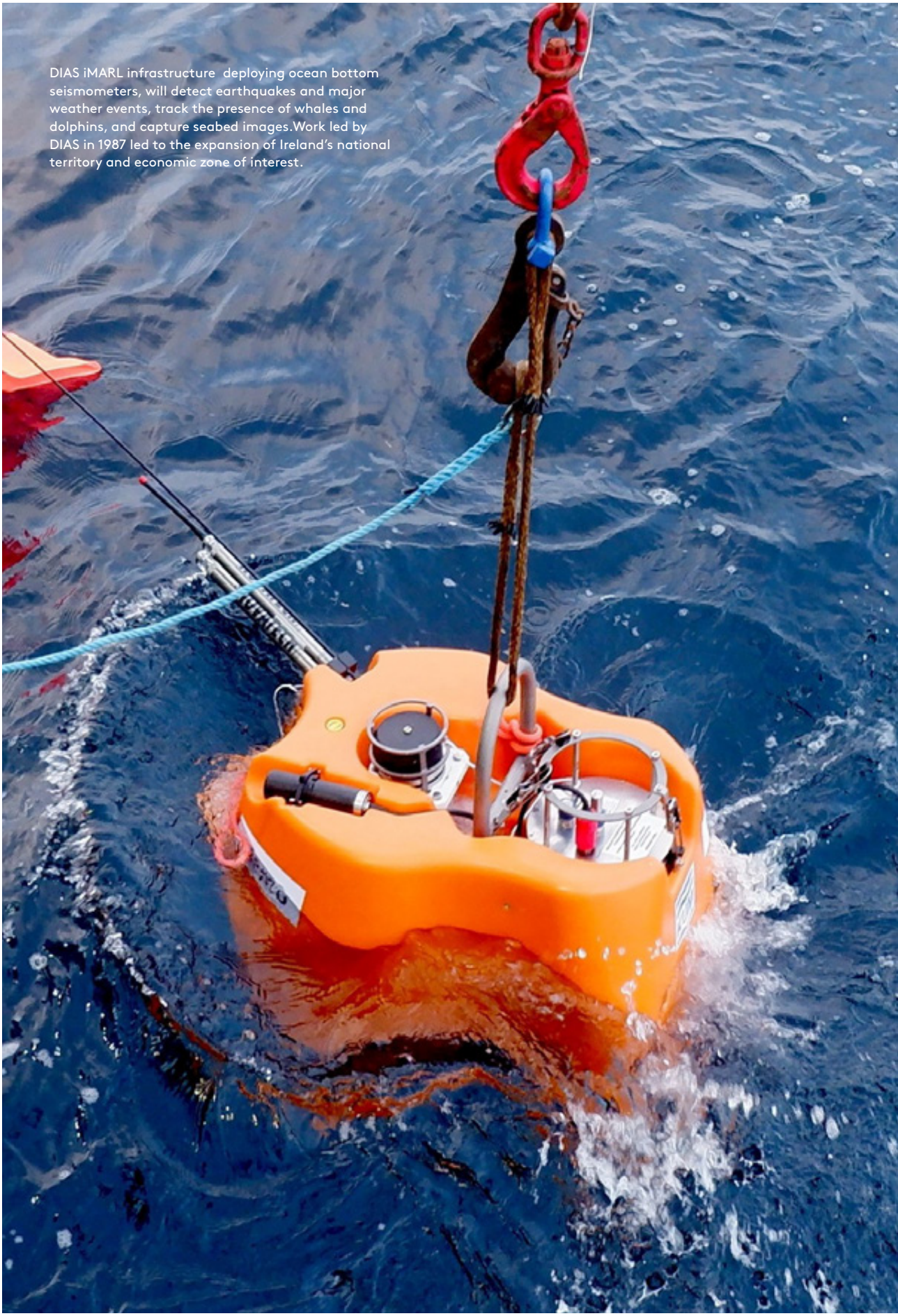
27 Some 15% of DIAS competitively won funding in 2017 was from Horizon 2020.

28 Thomson Reuters' InCites Essential Science Indicators Reports; EU InnovationScorecard; OECD Education at a Glance; OECD Science, Technology & Innovation Reports.

29 Geological Survey Ireland Research Roadmap (2016).

30 Harnessing Our Ocean Wealth: An Integrated Marine Plan for Ireland (Government of Ireland 2012).

31 The Global Island: Ireland's foreign policy for a changing world (Government of Ireland 2017).

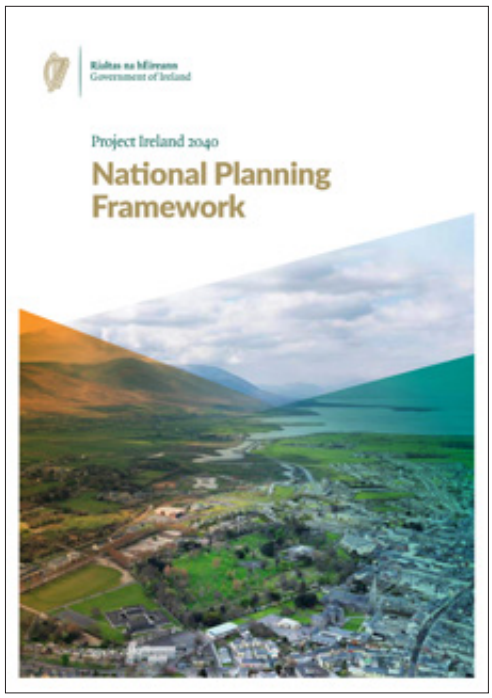


DIAS iMARL infrastructure deploying ocean bottom seismometers, will detect earthquakes and major weather events, track the presence of whales and dolphins, and capture seabed images.Work led by DIAS in 1987 led to the expansion of Ireland's national territory and economic zone of interest.

SECTION II

Contributing to the Future of Ireland

Current Context: Project Ireland 2040



In setting out the future vision for DIAS, its statutory responsibilities must remain central to its activities. However, it is also recognised that there has been a fundamental change in the research environment in Ireland and internationally in the period since DIAS's foundation, and more especially in recent years. This strategic plan is set for a period following the global economic downturn, a downturn that has been particularly acute in Ireland. Yet, simultaneously, society expects all State-funded entities to deliver more, in terms of output, economic and/or societal impact and relevance, and this trend will continue.

As mentioned earlier, DIAS is already contributing to the implementation of a range of national strategies and roadmaps – Innovation 2020, the National Strategy for Higher Education 2030, the Action Plan for Education, the Geological Survey Ireland Roadmap, the Harnessing our Ocean Wealth Roadmap, and the Global Island policy. In addition to these individual plans, Ireland has at this juncture, at an overarching level, set down ambitions for the country in Project Ireland 2040 (Government of Ireland 2018). DIAS has a contribution to make to achieving the goals therein, in particular in the context of achieving 'A Strong Economy, Supported by Enterprise, Innovation and Skills'. The Investment Action 'Strengthen International Science, Technology and Innovation Collaboration' is one where DIAS has already engaged on behalf of Ireland. The global interconnectedness of DIAS should be leveraged to progress this area, as it is currently been done for example in the context of Ireland's engagement with the European Southern Observatory (ESO), and the European Plate Observing System (EPOS). DIAS in view of its expertise can contribute to the proposed priority New Space Technologies Programme,[32] in addition to contributing to 'developing North–South research and innovation capability'. DIAS is already active on an all-island basis in the areas of astronomy, astrophysics, Celtic Studies and geophysics.[33]

As the originator of Ireland's high-performance computing infrastructure, DIAS very much welcomes the Government's intention to participate in the EU High Performance Computing Programme.

DIAS generates very significant amounts of data and is a significant utiliser of current national capacity.

In the context of Project Ireland 2040, it is also noteworthy that DIAS Dunsink Observatory is a national heritage asset and would contribute to the objectives under 'Enhanced amenity and heritage'. The Observatory was designated as an historic site of significant importance by the European Physical Society in 2018.

Furthermore, whilst DIAS has a national role, it is based in Dublin and contrbutes to the city. It has much to offer in the context of the Dublin City Development Plan[34] and the objectives to develop the city centre as a national resource for innovation. Three 'differentiators' to give the city an international competitive edge have been set out: (a) an internationally competitive location for talent attraction, (b) place making: a vibrant capital city, enhancing the city as a place to live, invest, grow a business, and nurture innovation, (c) a connected world-leading research and innovation system.[35]

If DIAS is to continue to deliver for Dublin and Ireland, it must expand the scale of its activities and the resource base. Crucially, DIAS must act in accordance with its core values and legislated mandate. In this way, it will contribute in its unique way to a strong diverse system, in addition to supporting aforementioned national strategies and policies.

32 DIAS has a rich legacy in space technology development. Currently, in Astrophysics, DIAS has a detector development group, is developing hardware for the ARIEL satellite mission, and is collaborating to develop hardware and software for the James Webb Space Telescope.

33 The first ever cross-border agreement between Dublin and Stormont was signed to enable the Armagh-Dunsink-Harvard Telescope to be developed. DIAS continues to have a strong collaboration with the Armagh Observatory and Planetarium.

34 See Dublin City Development Plan (2016–2022)

35 A 'Policy Statement on Foreign Direct Investment in Ireland' from the Department of Jobs, Enterprise and Innovation (2014).

Our Vision

Reflecting our rich legacy and unique mission, DIAS is recognised globally as a force for excellence in fundamental research. Nationally, we are the original centre of excellence, and we will be acknowledged as an Institute for Advanced Studies that is leveraging its strong global presence to support its disciplines and the national research community. In this regard, DIAS will be a hub of expertise and a gateway for fostering an international learning community in its disciplines.

By attaining a vibrant working environment both physically and culturally, DIAS will strengthen Dublin, and Ireland, as a home for intellectual leadership, independent critical enquiry, and innovative frontier research.

Our Strategic Goals

Attainment of our vision will be driven through four overarching strategic goals:

- **Goal 1:**
  Discovery of new knowledge and understanding through excellence and researcher-led endeavour
- **Goal 2:**
  International research collaboration benefitting Ireland and the world
- **Goal 3:**
  Attraction and cultivation of research leaders for Ireland
- **Goal 4:**
  Strengthening disciplines and research communities nationally

The objectives underpinning these goals are set out later in this document. A strategic action plan, which will be reviewed annually by the DIAS Council, has been prepared.

Our Values

- Excellence in all that we do
- Freedom and tenacity in the pursuit of understanding
- Leadership and steadfastness for our disciplines
- Collegiality and respectful collaboration
- Openness and social responsibility
- Integrity and probity
- Inclusiveness and diversity

From the ISOS collection,
School of Celtic Studies

An incandescent vision, a wildness of imagination, sensibility to sound and colour and form … human passion, love, sorrow and anger.

Myles Dillon (DIAS, 1948–1968) on the enduring qualities of the literature of early Ireland

Our Schools

SCHOOL OF CELTIC STUDIES

Advancing the understanding of the Celtic legacy, Ireland's national identity, history and cultural individuality both past and present.

The school is charged with the investigation and editing of literary, historical, legal and technical manuscript materials in the Irish language; the study and elucidation of Old, Middle and Modern Irish grammar, lexicography and philology; and the recording and linguistic analysis of the living speech of Irish dialects. Other particular areas of interest include Early Irish law; medieval and modern literature and texts; annals; bardic poetry; Welsh grammar; Breton literature and language; Irish dialect monographs; and Hiberno-Latin. The Irish Script on Screen (ISOS) flagship initiative aims to provide a virtual library of unique medieval manuscripts from the seventh to the nineteenth centuries (with the cooperation of libraries in Ireland and abroad). Publications from the school are in constant use in Celtic Studies courses throughout the world.[36] Our wide range of publications traverses much of the field of Celtic Studies: editions of Medieval and Modern Irish texts (several series), prose narratives, law texts, verse texts, family poem-books, etc. A substantial number of Welsh, Breton and Hiberno-Latin texts have also been published as have language studies, grammars, dialect studies, lexicography, and literary studies.

The school conducts the Triennial International Summer School in Celtic Studies and the annual colloquium, Tionól, is a key event in the national calendar for academics and researchers. Celtica is its highly respected biennial journal and one of the most prominent platforms for the publication of research findings in the field. DIAS is at the heart of the international field of Celtic Studies.

36 The school has published almost 400 books since its establishment.

It is a well-known experience that the only truly enjoyable and profitable way of studying mathematics is the method of 'filling in the details' by one's own efforts.

Cornelius Lanczos (DIAS, 1954–1968)

SCHOOL OF THEORETICAL PHYSICS

Investigating the mathematical principles of the laws of nature and advancing the future of computing.

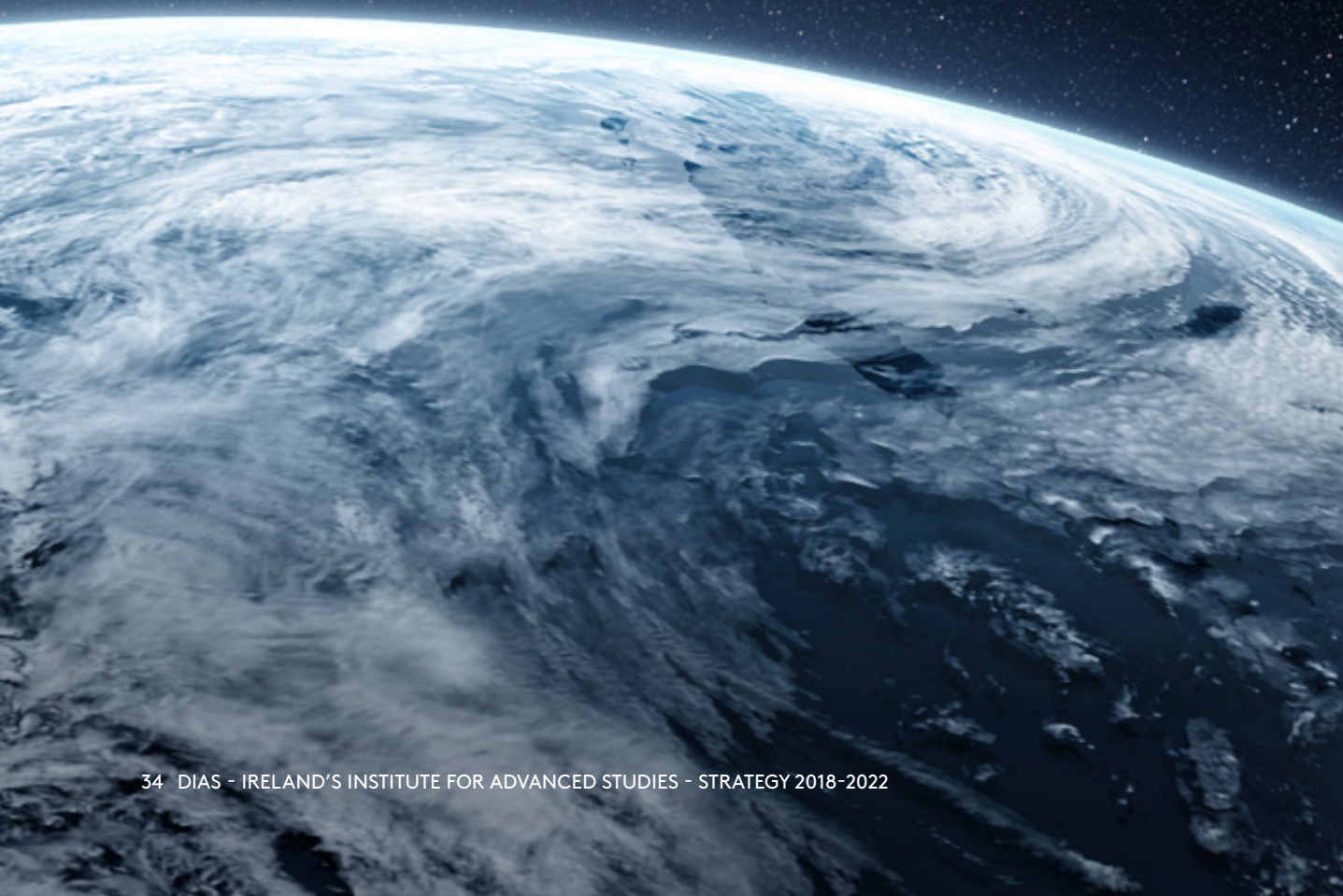
According to the Institute for Advanced Studies Act 1940 and the School of Theoretical Physics Establishment Order of 1940, the duties of the school are to undertake and publish research into the mathematical principles of natural philosophy and the application of those principles to physics, as well as the training of advanced students.

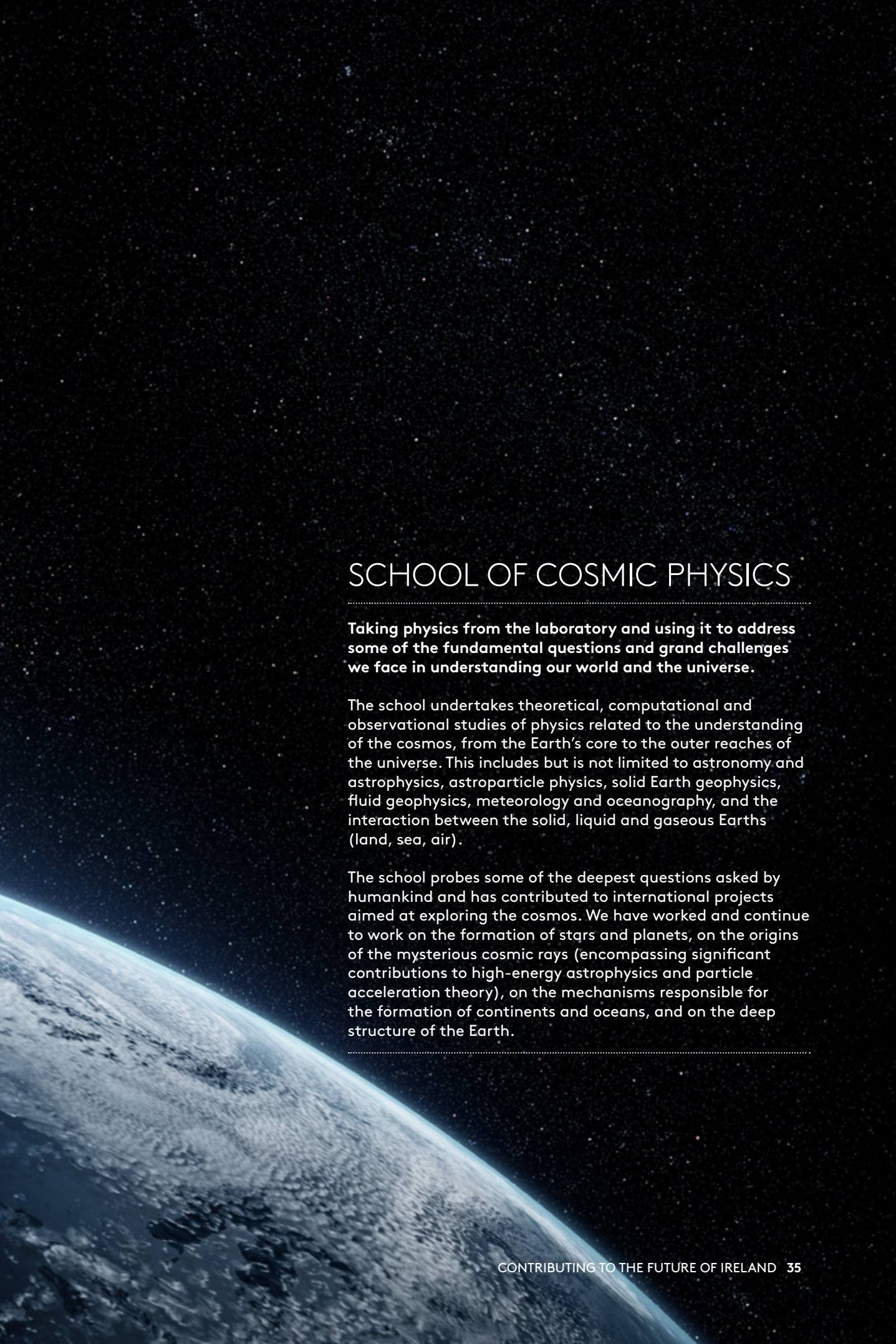
The school is highly regarded internationally for work on quantum field theory, string theory, and quantum information. Groundbreaking research on the deep structure of quantum fields and related physical structures, and the development of new mathematical tools for their study, in addition to work on the theory of quantum information and the emergence of geometry out of a world of quantum fluctuations, are current areas of focus. The reconciliation of Einstein's theory of relativity (gravity) and quantum physics – a key global question – and the fundamental physics of phase transitions are also current areas of interest.

The school has an extensive national and international network, and has a Research Associate programme. It provides facilities for university professors and lecturers on leave of absence from their academic duties and it organises seminars, conferences, and lectures.

I would say that the prime motivation has been an alliance of national pride with that thirst for natural knowledge which we have come to accept as part of the life of civilized man. One might say that the purpose of the scientific schools of the Institute is to play a small but effective part in trying to satisfy man's insatiable desire to understand how nature works.

J.L. Synge (DIAS 1948–1972)



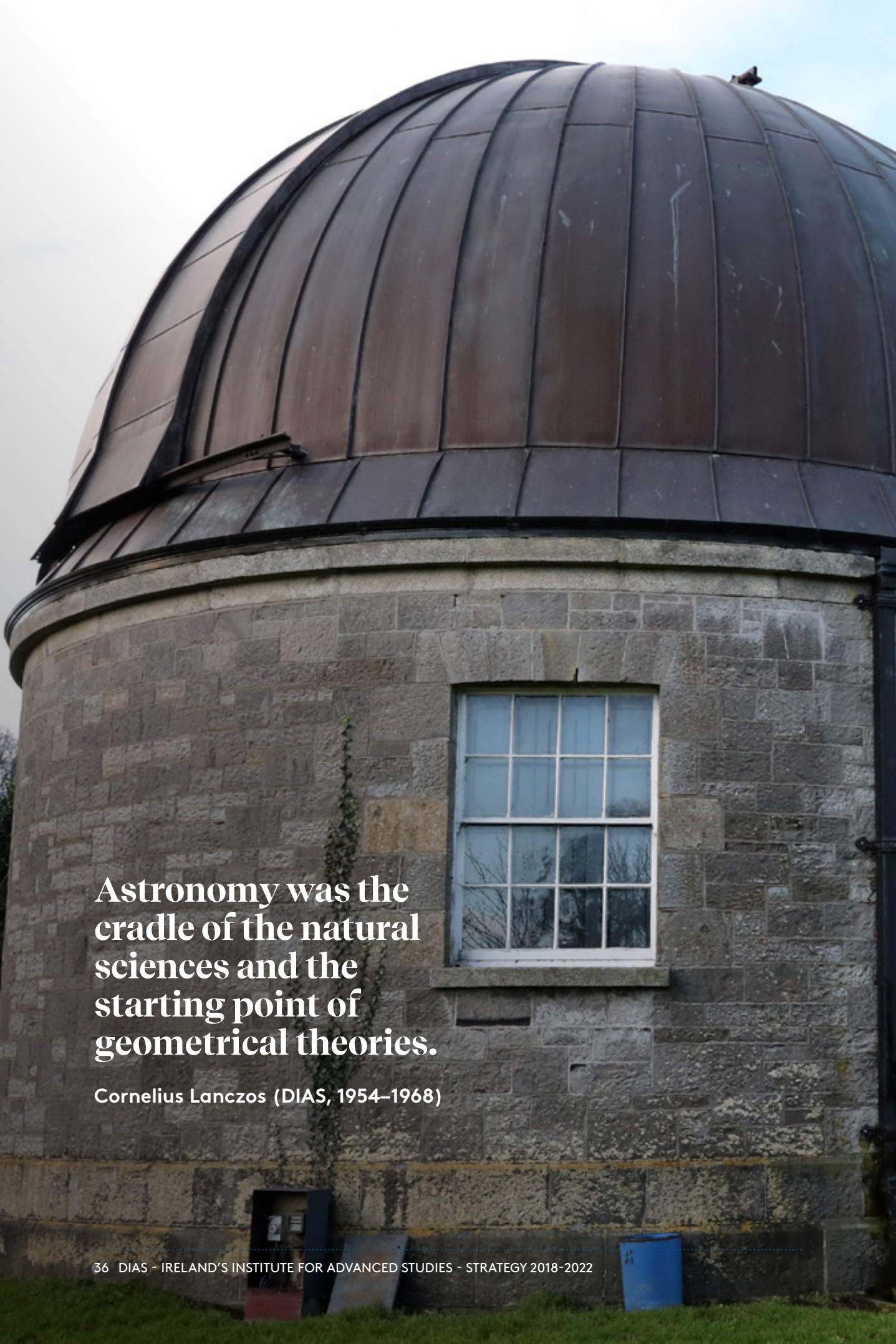


SCHOOL OF COSMIC PHYSICS

Taking physics from the laboratory and using it to address some of the fundamental questions and grand challenges we face in understanding our world and the universe.

The school undertakes theoretical, computational and observational studies of physics related to the understanding of the cosmos, from the Earth's core to the outer reaches of the universe. This includes but is not limited to astronomy and astrophysics, astroparticle physics, solid Earth geophysics, fluid geophysics, meteorology and oceanography, and the interaction between the solid, liquid and gaseous Earths (land, sea, air).

The school probes some of the deepest questions asked by humankind and has contributed to international projects aimed at exploring the cosmos. We have worked and continue to work on the formation of stars and planets, on the origins of the mysterious cosmic rays (encompassing significant contributions to high-energy astrophysics and particle acceleration theory), on the mechanisms responsible for the formation of continents and oceans, and on the deep structure of the Earth.



Astronomy was the cradle of the natural sciences and the starting point of geometrical theories.

Cornelius Lanczos (DIAS, 1954–1968)

DIAS DUNSINK OBSERVATORY

Dunsink Observatory is part of the School of Cosmic Physics and was the first building in Ireland constructed specifically for scientific research. It was the workplace and residence of Ireland's greatest ever mathematician and scientist, Sir William Rowan Hamilton. It is forever associated with his discovery of quaternions. It houses some magnificent examples of the work of the Dublin firm, Grubb, world leaders in the construction of telescopes in the late nineteenth century. As a building, it primarily stands as a monument to a different era in science, part of the history of the tentative steps towards an understanding of the universe, and right up to the 1980s it was engaged in solar activity research. It is integral to the Irish Astronomy Trail, a cross-border initiative instigated by DIAS in 2012. Other sites on the trail include Birr Castle and Armagh Observatory. Dunsink is the oldest and longest running science outreach centre in Ireland with several thousand visitors per year (>5,500 in 2016).[37] Its future role will be grounded in this latter role as a more public institution and a heritage asset, stimulating the tradition of astronomy in Ireland and cultivating physics and mathematics in national cross-institutional education initiatives. The site was designated as an historic site of significant importance by the European Physical Society in 2018.

37 DIAS Dunsink Observatory is not currently an open site and visits are made by appointment. Open nights are held in the October–March timeframe.

The oldest scientific building in Ireland and longest-running science outreach facility on the island of Ireland; the second oldest observatory in Ireland and the United Kingdom


DIAS: Insights into our
island, past and present

SECTION III

Enhancing Ireland's Global Reputation

Strategy 2012–2017: Progress

The previous strategy was prepared and implemented at a time of global economic downturn. Furthermore, the focus of national funding shifted to nearer-term projects with foreseeable economic impact and relevance. Despite these challenges, DIAS continued to deliver on its legislated mandate.

The provision of support to the disciplines and the research community nationally and internationally continued to be an imperative for researchers at DIAS. A number of specific developments took place reflecting this outlook. Demonstrating leadership of the community, the School of Theoretical Physics, for example, led the instigation of the Irish Quantum Foundations, supported by Maynooth University. The following partnerships have also been established:

- DIAS now leads a Spoke in the Irish Centre for Research in Applied Geosciences (iCRAG).
- DIAS instigated the development of a national ocean-bottom listening infrastructure – a precursor to a tsunami warning system, attaining funding for the iMARL initiative from Science Foundation Ireland (SFI).
- DIAS is a key partner for the new national I-LOFAR (radio-telescope) infrastructure.

Provision of shared infrastructure and online resources became a key area of focus. For example, the manuscripts digitisation project Irish Script on Screen continued to be expanded.

In this timeframe, DIAS lobbied for access to international infrastructures on behalf of the community. One such example is DIAS being to the fore in advocating for Ireland's membership of the European Southern Observatory (ESO).

Furthermore, many of the areas of research in DIAS involve engagement with international and global projects by necessity. Despite the lack of dedicated funding and budget adjustments at DIAS, the Institute continued to play a role on behalf of Ireland in the international arena. In addition to engagement with the James Webb Space Telescope,[38] other national, regional and global geophysics work progressed.

38 DIAS's engagement with the development of the biggest telescope ever to be put in space, the James Webb Space Telescope (JWST), through the MIRI European consortium, of which DIAS is a lead member.

39 Evidence for the acceleration of protons to PeV energies in the centres of our galaxy was found recently by DIAS researchers. The first-time specific astronomical site in our galaxy has been linked to particle acceleration to these energies and has important implications for the origin of cosmic rays as well as, potentially, the high-energy neutrinos reported by the ice cube experiment.

40 CTA is the Cherenkov Telescope Array, the next generation ground-based observatory, composed of over 100 telescopes all over the globe, for gamma-ray astronomy at very high energies. KM3NeT (Cubic Kilometre Neutrino Telescope) is research infrastructure housing the next generation of neutrino telescopes.

The HESS Radio Telescope Array in Namibia

For example, DIAS became a key partner in the European Network of Observatories and Research Infrastructures for Volcanology (EUROVOLC) developing the next generation of European volcanological infrastructure.

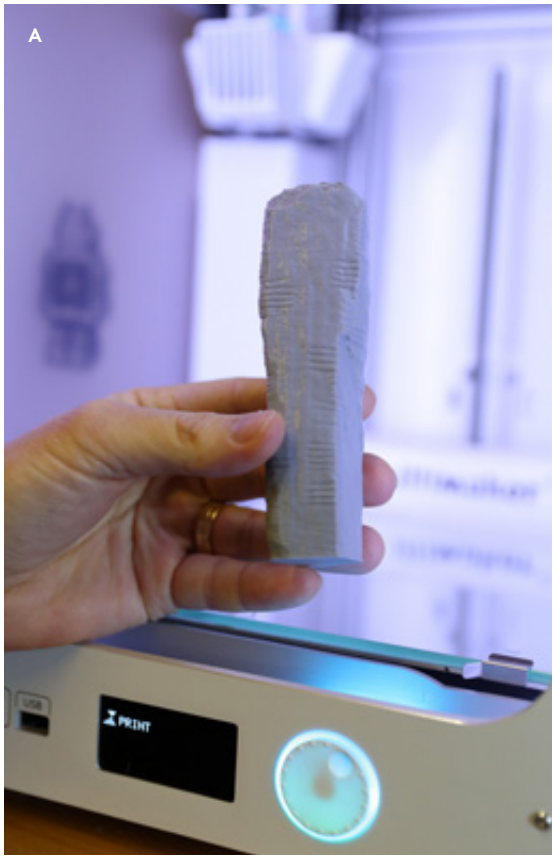
Participation over the period by DIAS in the following international infrastructures and collaborations resulted in significant publications on:

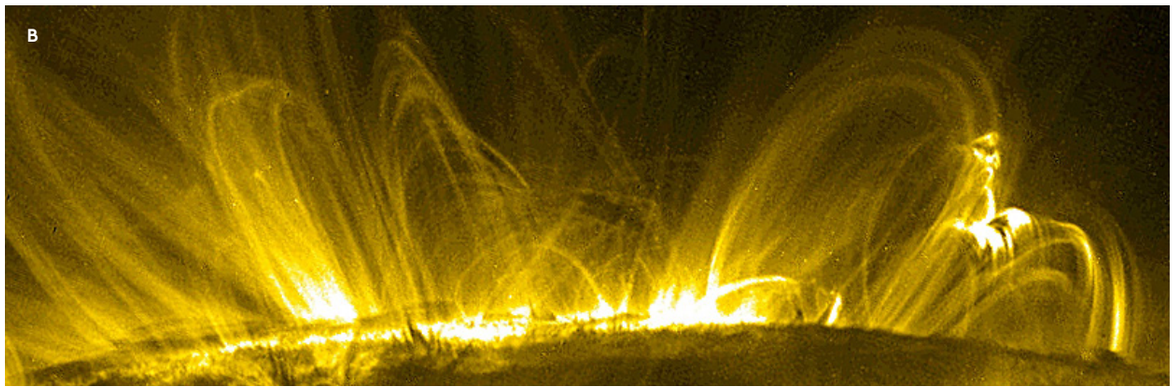
- HESS, the European collaborative project to operate a system of high-energy gamma-ray telescopes in Namibia.[39]
- KM3NeT and CTA,[40] major projects on the European Strategy Forum on Research Infrastructures (ESFRI) Roadmap. DIAS acts as an adviser and observer on these projects.

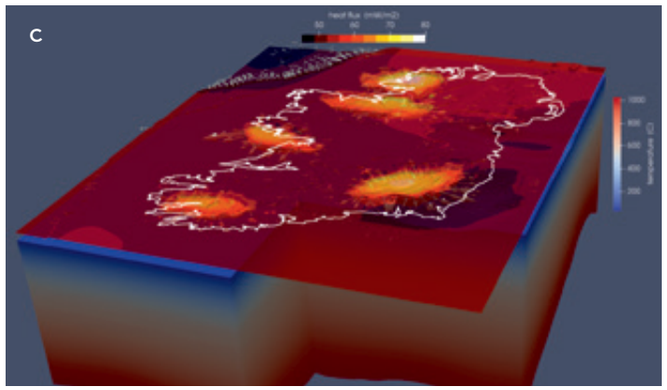
Some Specific Discoveries and Progress

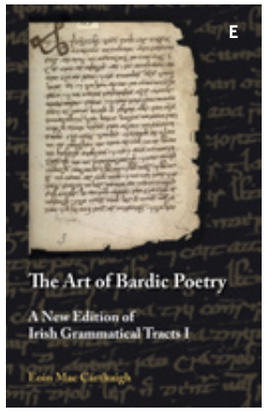
2012

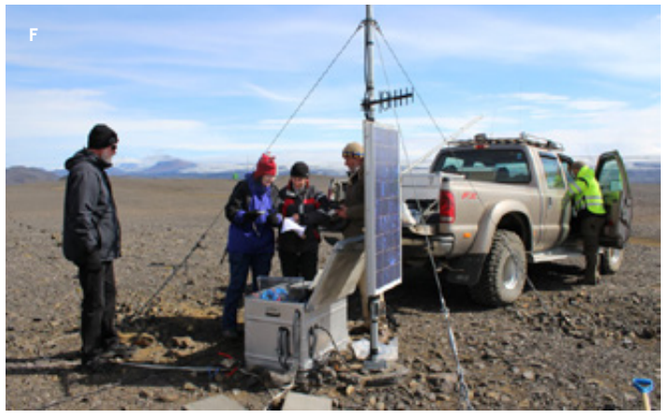
- DIAS is appointed by the Minister for Foreign Affairs as the Irish National Data Centre for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO).
- A new model for estimating water in the Earth's mantle is published in an American Geophysical Union journal.
- ESA and NASA declare the Mid-Infrared Instrument (MIRI) ready for delivery to NASA's Goddard Space Flight Center. DIAS is involved in the development of a pioneering camera and spectrometer so sensitive that it could see a candle on one of Jupiter's moons.
- The Centre for Astroparticle Physics and Astrophysics (CAPPA) is established, following the decision to establish it in 2011. The first DIAS Summer School in Astrophysics is hosted by University College Dublin (UCD) in 2015.
- A pilot for the Ogham in 3D project is initiated; it involves the 3D scanning of Ogham stones. Subsequently, it is rolled out as a full project. The second phase incorporates a major 'citizen science' dimension with members of the public identifying the location of stones. In the region of 140 stones are screened and catalogued over the duration of the previous strategy **(A)**.
- Fergus Kelly is awarded the Derek Allen Prize in Celtic Studies from the British Academy.
- The Calculus Course for Leaving Certificate students, run by the School of Theoretical Physics, is launched. Comprehensive lecture notes on Large Deviation Theory are provided. Courses in mathematics for upper second-level students and third-level university students are held.
- The Irish Astronomy Trail is launched by DIAS, which links all the key astronomy sites on the island of Ireland, and is a cross-border initiative with the Armagh Observatory.











2012, 2013

- The highest resolution global models of seismic shear wave structure for the top 300km in the Earth are created. Two Geophysical Journal International student prizes are awarded to DIAS students, one in each year.

2013

- DIAS move to the development of software for the MIRI/James Webb Space Telescope.
- Professor Werner Nahm receives the internationally prestigious Max Planck Medal;[41] he subsequently receives the RIA Gold Medal in 2015.
- DIAS engages with a new initiative, the Festival of Curiosity, which is Dublin's annual international festival of science, arts, design and technology. During Science Week, DIAS hosts a training week on Astronomy for national school teachers and instigates the Astronomy Watch initiative.

2014

- GRAVITY, the new instrument for the VLT interferometer development, is completed; it will allow for the measurement of positions and motions of astronomical objects on scales far smaller than is currently possible. It will study not only the black hole at the centre of the Milky Way but also the birth of stars and planets, which is of primary interest to DIAS.

2015

- A new reference frame for the absolute motions of tectonic plates is published. This global solution integrates all the observations of relative motions of tectonic plates, particularly of spreading at mid-oceanic ridges revealed by seismic anisotropy measurements.
- The Grubb coelostat used by Eddington to verify Einstein's prediction of the gravitational deflection of light by the sun is restored and put on display in Dunsink Observatory.

2016-2017

- This is a peak year for visitors at Dunsink Observatory with in excess of 5,500 visitors (primarily through Open Nights in the winter).
- Three scientist from DIAS contributed to the breakthrough discovery and interpretation of gravitaional waves from the merging of two neutron stars.

2012-2017

- The Irish Script on Screen project – a joint initiative with Marsh's Library, Kings Inns, the Royal Irish Academy (RIA) and the National Library of Scotland – is in operation. Work continues in adding manuscripts from the National Library of Ireland and Trinity College Dublin (TCD). A key addition in the period is the addition of the TCD copy of the Annals of the Four Masters. The number of manuscripts in ISOS increased to 383 manuscripts by 2016.
- Sixteen books are published in the period, plus nine reprints.

41 This medal is awarded by the German Physical Society; past recipients include Einstein, Heisenberg, Schrödinger, Fermi and Dirac. There has only ever been three holders on the island of Ireland – all three being based at DIAS.

A 2017: 3D model of a DIAS catalogued Ogham stone. In the region of 155 stones are screened and catalogued by period end.

B In 2017, DIAS astronomers and collaborators may have discovered why the sun's outer corona is so much hotter than the sun's surface.

C Work by DIAS geophysics - a 3D temperature distribution in Ireland.

D In July 2017, I-LOFAR, the Irish radio telescope, switched on in Birr. DIAS is a funding and research partner. I-LOFAR is part of the international LOFAR network.

E One of the 16 books published by DIAS Celtic Studies 2012-2017.

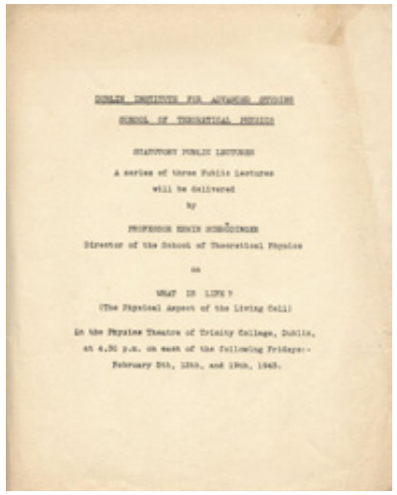
F Significant discoveries and insights were made by DIAS in 2016-2017. Key papers in Nature Geoscience and Scientific Report demonstrated that the upper 2 km of the Earth's crust is substantially weaker than previously thought. This results in a new interpretation of pre-emptive seismic signals on volcanoes.

- Interpolation of data from the Porcupine Basin occurs as part of the Petroleum Infrastructure Programme.
- New methods to use satellite magnetic field data are developed to study ocean circulation currents.
- The Irish Geoscience Graduate Programme (all-Ireland virtual graduate school) is implemented, led by DIAS, who delivers seven of 15 short courses.
- DIAS is the key driver in the establishment of ICHEC, the national high-performance computing infrastructure, leveraging the previous national DIAS-led computing initiative – e-INIS.
- The Seismology in Schools (Seismeolaíocht sa Scoil) programme continues to expand, in secondary schools, geoparks and IT colleges, also incorporating schools from Northern Ireland. Initial discussions with other European partners take place, also regarding the involvement of schools in the InSight Mars experiment currently under way.

Over the 2012-2017 period a number of key advances were made in the following areas of theoretical physics:

- Mathematical possibilities for the origin of space and time were investigated, taking into account that there is no sign for the existence of either before the Big Bang. An origin within a more general structure might be reflected in a subtle fuzziness of spacetime at small scales. Matrix models for the study of fuzzy spaces were developed and their phase transitions investigated. It was found that ensembles with four dimensions have special properties.
- Superstring physics was studied in its M-theory version, which includes membranes for mathematical consistency. Strong support was found for recent conjectures in gauge/gravity duality.
- Deep relations between gravity and the other forces were discovered that continue to sharpen the conceptual and mathematical tools for the study of quantum fields. This line of research has lasting value, though no signs of string physics and supersymmetry were found at CERN.
- The duality between behaviour in the bulk and on the boundary that was developed in a string theoretic context was used in other areas of physics, for the quark–gluon plasma and for exotic quantum states in condensed matter. For quarks, a persistent diamagnetic response similar to that for quantum dots and nanotubes was discovered. Also, persistent boundary currents in advanced condensed matter systems could in principle transport net charge.
- It was found that supergravity can be understood as a square of Yang–Mills theories, in a way related to the Freudenthal–Rosenfeld–Tits magic square discovered in mathematics.
- Working with quantum information will transform our technology, with the double challenge of efficient transmission and of quantum computation. New statistical concepts for the description of quantum information and new results on its transmission through noisy channels were obtained.
- For quantum computation, particle-like excitations of matter in new quantum states will be essential. Much of the corresponding current research is focused on Majorana fermions. In contrast to previously held ideas, it was found that their multi-particle content is important for the analysis of their experimental features.
- Work in more classical areas of physics concerned slit diffraction, light beams in carbon nanotubes, and the thermodynamics of black holes. In mathematics, new theorems for positive vector bundles were proven and efficient mathematical methods for certain quantum field theories on arbitrary Riemann surfaces were developed.

In 1943, Erwin Schrödinger, DIAS, delivered a series of lectures which are acknowledged by the discoverers of DNA to have inspired their thinking.


DUBLIN INSTITUTE FOR ADVANCED STUDIES

SCHOOL OF THEORETICAL PHYSICS

STATUTORY PUBLIC LECTURES

A series of three Public Lectures
will be delivered
by

PROFESSOR ERWIN SCHRÖDINGER
Director of the School of Theoretical Physics

on

WHAT IS LIFE?
(The Physical Aspect of the Living Cell)

In the Physics Theatre of Trinity College, Dublin,
at 4.30 p.m. on each of the following Fridays:-
February 5th, 12th, and 19th, 1943.

CASE STUDY

Engaging in Unconstrained Thought

1943 – the physicists' approach to 'What is Life?'... 2018 – the physicists' approach to historical climate change...

The preparations for and investigation of climate change and rare geophysical events need both science and historical studies. Neglecting the studies of a Japanese tsunami in 869 AD had catastrophic consequences when another tsunami of similar magnitude hit the same area in 2011, causing many thousands of deaths, 25 trillion Yen damage, and global consequences for the nuclear industry. Concerning climate, the ongoing increase of carbon dioxide in the atmosphere is leading not only to a predictable increase of temperature but also to greater unpredictable weather fluctuations, potentially causing disasters. Prevision of the consequences of climate change can be helped by historical studies.

There are no historical precedents for climate changes of comparable magnitude in the past 2000 years, as the fluctuations in the aftermath of the last Ice Age died off over a period of 10,000 years. The last major fluctuations still however affected the civilizations of Ancient Egypt and Mesopotamia. What happened in terms of agriculture, health and migrations may be comparable to what must be expected now.

The ancient history of Egypt and Mesopotamia is marked by three dark periods when states collapsed. For example, the last decades of the seventeenth century BC were marked by the abandonment of all cities in southern Mesopotamia and by large-scale migrations. What happened next is largely unknown, since most of the record-keeping ceased. For the current study of these events, the most important question is whether they were caused by climate fluctuations or not. As a first step, we need a precise correlation between the palaeoclimatic data obtained by scientists and the historical events.

The current large uncertainties in the historical dates of events have hindered studies on historical climate change and consequences. Ten years ago, in 2008, no solution seemed to be in sight. However, a consensus is now emerging due in large part to new studies of cuneiform texts with astronomical data by Professor W. Nahm from DIAS. This work has been published over the past five years and new developments in radiocarbon dating appear to support his conclusions. The resulting simultaneity of events and major societal and political disruption in Egypt and Mesopotamia points to climate change as a common cause. The work of Professor Nahm has opened up this field for further study.

SECTION IV

Future Impact: Strategic Goals and Objectives

Strategic Goal 1

Discovery of new knowledge and understanding through excellence and researcher-led endeavour

As part of the global research landscape, with an internationally recognised track record in advanced studies and research, DIAS will continue to deliver on its legal mandate and be a beacon for fundamental research[42] and thus deliver social, cultural and economic benefits. In the period 2018–2022, research and advanced study at DIAS will continue to be driven by the desire to gain understanding for the long-term benefit of humanity, Ireland and the world. A number of our focal science research areas have been identified as 'the biggest unanswered questions' for humankind.[43,44,45,46] A key target outcome is to further enhance DIAS's position as a leading contributor to fundamental frontier research and to expand scholarly publications.

Our research questions and areas will contribute insights to Celtic society and its legacy, and progress understanding of our island, our planet, the universe and the underpinning mathematical principles of nature. The focus of our research and advanced study areas and questions are set out from page 57.

In order to deliver on this strategic goal, a number of objectives are set out. Strategic objectives will be attained by the implementation of strategic actions as agreed by the DIAS Council.

STRATEGIC OBJECTIVES:

- Implement new research and study themes in our schools. Quantum computing will be an increasing focus in theoretical physics and astrophysics new themes of solar research and exoplanets research are being added.
- Engage with and support the New Space Technologies Programme, a priority for Project Ireland 2040.
- In recognising the evolution of science and research fields, identify a new area requiring an advanced study focus, in the lifetime of this strategy.

To enable discovery we will:

- Optimise our facilities and infrastructure so as to provide a stimulating, supportive and accessible environment for advanced studies, and as part of this objective locate in an area designated to foster innovation.[47,48]
- Leverage the excellence within DIAS to diversify funding sources and increase funding obtained from non-core grant sources.
- Enable progress monitoring by the capture of appropriate information on the quality and impact of DIAS research, building on the already embedded five yearly independent site visit reviews,[49] and drawing on international best practice.
- Preserve the cultural and scientific heritage at DIAS Dunsink and throughout the Institute, and make it more accessible as a public cultural and scientific resource in Dublin City and Fingal County.

New themes of research of DIAS include sun-earth connections, searching for exoplanets and partnering on satellite development. DIAS had the first ever Irish experiment in space.

42 See A.J. Salter and B.R. Martin (2001) The economic benefits of publicly funded basic research: a critical review, Research Policy, 30 (2001): 509–532.

43 See http://www.sciencemag.org/site/feature/misc/webfeat/125th/–Top 25 Unanswered Science Questions (2005), Science Online; The Top 25 questions facing science over the next quarter century (2005).

44 The Big Questions in Science: The Quest to Solve the Great Unknowns, Andre Deutsch, 2013.

45 https://www.newscientist.com/round-up/physics-questions/

46 https://news.nationalgeographic.com/2016/02/160218-dark-energy-matter-universe-gravity-mysteries-space/

47 See Dublin City Development Plan (2016–2022): 'CEE5 (i) To recognise that cities are crucibles of innovation and that the city centre Z5 zoned area and inner city area including the Docklands is the crucial metropolitan and national resource for innovation, promoting the proximity and diversity of uses that foster innovation.'

48 Dublin City Development Plan (2016–2022): Key economic zones include – [SDRA 6] Docklands and Wider Docklands Area; [SDRA 8] Smithfield/Grangegorman; [SDRA 7] Heuston and Environs; [SDRA 16] Liberties (including the Digital Hub); and [SORA] Earlsfort Terrace.

49 The quinquennial external review process is an important factor in assisting each school to deliver globally significant contributions in its niche areas of research. These independent reviews benchmark DIAS research against global standards and provide a rigorous and exacting assessment of quality.

This exceptional (for Ireland) level of external scrutiny by international peers has proven a very valuable instrument in ensuring quality and adherence to mission.

Strategic Goal 2

International research collaboration benefitting Ireland and the world

50 EPOS is designated a high-priority ESFRI initiative by the EU Council of Ministers.

51 SKA wavelength coverage complements what is available from the ground through ESO and LOFAR, and from space through Irish membership of ESA.

DIAS stands out as an entity which from its inception is highly internationalised and globally recognised. DIAS has retained this orientation, both on its own behalf and on behalf of the Irish research community. When we consider those areas for advanced study in which DIAS has a focus, and the global nature of many of these areas, it is clear that international collaboration and cooperation are critical.

Critical mass for those research areas in which DIAS is engaged is achieved not solely nationally but internationally through collaboration. In the lifetime of the previous Strategic Plan 2011–2017, due to the economic downturn, the national priority was not on engagement in global endeavours. Nonetheless, DIAS engaged and continued to be an ambassador for Irish research and science.

As a number of our research areas involve being deeply engaged in 'big science', the criticality of access to big science facilities is well understood at DIAS in the context of what is required to enable researchers in Ireland work on the big research questions.

DIAS support for Ireland joining CERN is illustrative of this. Conversely, DIAS is highly conscious that, as the world-recognised centre for Celtic Studies it must engage internationally to support others in this area.

In this strategy, DIAS will maintain its membership of the international learning community and perform a number of strategic actions to further enhance its function as an ambassador for Irish research in the international area, and thus accrue benefit for the Irish system.

Our International Research Collaborations*:

* Project based, does not include European and global infrastructure partners

STRATEGIC OBJECTIVES:

- Leverage our international connections to contribute to the implementation of the International Education Strategy of the Department of Education and Skills (DES); for example, Celtic Studies has bilateral relationships with leading global universities (such as Cambridge, Oxford, and Harvard).
- Leverage our excellence and international connectedness, and explore opportunities to contribute through research, e.g. in Earth Systems Change, to the Sustainable Development Goals (SDGs).
- Maintain an association and formal collaboration with the current portfolio of international consortia and infrastructures, for example, HESS, JWST (successor to Hubble), ESA, ESO, and EPOS.[50]
- In following on from our partnership in the International LOFAR Observatory, and to further strengthen Irish research, promote official Irish participation in the Square Kilometre Array (SKA).[51] We will continue to advocate for Ireland becoming formally associated with CERN.
- Deepen strategic relationships with other institutes for advanced studies and academies, and foster collaboration for the furtherance of frontier research.

Strategic Goal 3

Attraction and cultivation of research leaders

An opportunity now exists within the changing international landscape to attract world-leading and excellent emerging researchers to Ireland. This opportunity has the potential to revitalise the Irish higher education and research-performing system following a difficult period. The vision now is for Ireland to be recognised internationally both as a leading research performer and as an open high-quality and welcoming environment for research talent. DIAS, with its strong international brand and reputation, is already a magnet for excellent researchers in each of its specialised branches of knowledge.

A key indication of the latter – i.e. the interest among the early career cohort internationally to be mentored by DIAS experts – is the fact that approximately 70% of DIAS scholars/fellows are from the international research community.[52] Furthermore, a proportion of those individuals remain in the Irish system. DIAS is globally competitive at attracting talent to Ireland, and the model for DIAS is attractive in that it enables 'researcher-led' scholarship.

DIAS will perform a number of strategic objectives to further enhance its function as a magnet for talent, nationally and internationally.

Our Team from All Over the Globe…

STRATEGIC OBJECTIVES:

- Recruit leading researchers in our specialist fields and assure a sustainable structure by reinstating posts at different career stages; to accomplish this the number of active researchers on site will increase. (primarily a mix of externally funded positions and longer-term visitors.)
- In line with a key function of DIAS, accommodate excellent individuals from Ireland or abroad who wish to access a location where their time can be dedicated to research (including sabbaticals).
- Develop and implement an Associated Faculty structure for the Institute.
- Enhance professional and career development opportunities for staff and scholars, mindful of the particular needs of early career researchers.
- Enhance gender balance at DIAS and attain Juno accreditation, followed by Athena SWAN Bronze accreditation.

52 This is approximately 35 countries.

Strategic Goal 4

Strengthening disciplines and research communities nationally

DIAS supports its own research and that of the national community and Ireland through leveraging its reputation and strong international connections. DIAS strengthens the disciplines nationally, so as to enable the community reach its full potential and to ensure future sustainability.

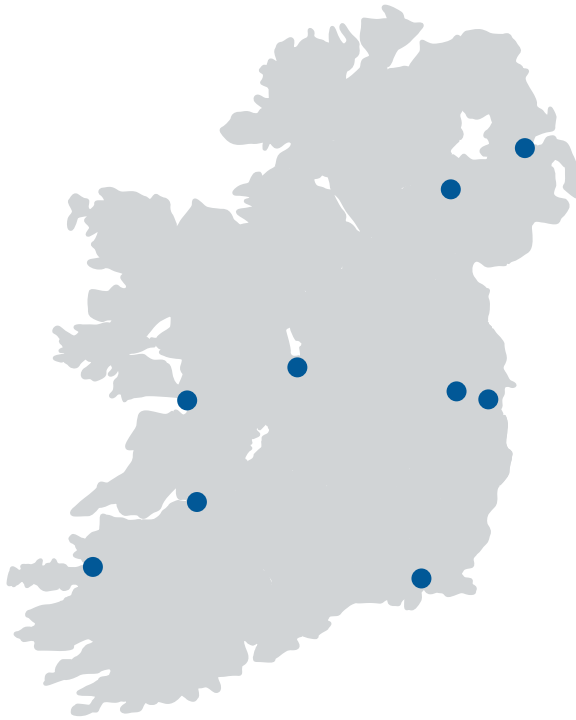
Reflecting track record and history, DIAS is a natural national hub for its disciplines. It has a key role in providing a backbone for its disciplines in the system through provision of specialist expertise and resources. The provision of space for research associates and research visitors to enable them spend dedicated time on research has already been mentioned. We will continue to mentor and train early stage researchers and provide opportunities for engagement with experts at the highest level.

Furthermore, as a research and advanced studies entity, we can continue to perform an important role in galvanising collaboration nationally and internationally. Historically and currently, we perform an important role in this regard. We are also freer to input to national and European consultation processes on policy, reflecting primarily disciplinary considerations. For example, the future of pure mathematics in Ireland is of concern to us.[53]

53 For example, in the future it is possible that computer science departments will be no longer be able to call on the expertise of pure mathematicians in teaching cryptography.

For these reasons, we believe we have a responsibility and duty to our disciplines and, by extension, the associated communities strengthening the system. We will directly contribute to the goal of the Action Plan for Education: 'To become the best higher education system in Europe and position Ireland as a Global Innovation Leader'. Our strategy reflects this view and, in the national interest, reflecting our collegial and collaborative values, this goal will become a major focal area for DIAS in the lifetime of this strategy.

Our National Academic and/or Research Collaborations:



NUI Glaway (NUIG)

Trinity College Dublin (TCD)

University Colllege Dublin (UCD)

University College Cork (UCC)

Dublin City University (DCU)

Maynooth University (MU)

Royal Irish Acedemy (RIA)

Queens University Belfast (QUB)

University of Limerick (UL)

Dublin Institute of Technology (DIT)

Waterford Institute of Technology (WIT)

Athlone Institute of Technology (AIT)

Irish Astronomical Society

The Discovery Programme

Armagh Planetarium

National Library of Ireland

IT Tallaght

IT Tralee

STRATEGIC OBJECTIVES:

- Expand the provision of specialist material to students (undergraduate and postgraduate) within the higher education system through structured initiatives and in partnership with other national HEIs.[54]
- Establish an International Visitor Lecture series for the benefit of the national community.
- Establish a programme of DIAS International Summer Schools across the entire Institute (open to national and international participants).
- Shape the direction of research in Ireland through statements. Develop roadmaps for strengthening of our disciplines nationally.
- Strengthen and expand DIAS's contribution to national research centres, other initiatives, and national policies.[55] In that regard, continue to develop collaboration with other national academic and non-academic stakeholders for those domains in which we engage.[56]
- Enhance and expand outreach activities to the public and so increase understanding of those areas, and increase the interest of citizens in STEM and AHSS research.

54 DIAS currentlyhas memoranda of understanding (MOUs) with DCU, TCD and UCD. Other MOUs will be put in place.

55 DIAS is contributing to the implementation of the Geological Survey Ireland Research Roadmap. and to the Harnessing Our Oceans Wealth Strategy. It will continue to engage with and support ICHEC, iCRAG, I-LOFAR, etc.

56 For example, the Department of Foreign Affairs and Trade; Geological Survey Ireland; the National Library, etc.

DIAS researchers, in studying the Earth System, work in diverse and challenging terrains: Iceland 2018

Delivering the strategy

Factors for success

The factors that have contributed to the success of DIAS to date are summarised below, and also the key potential barriers at this juncture to future success.

In setting out our objectives and more specifically in preparing our action plan, it is planned to maintain those positive factors which have contributed to our success, while in parallel addressing, or minimizing, the potential barriers.

KEY FACTORS FOR SUCCESS TO DATE

Reputation and track record: Bringing advanced understanding to major scientific and cultural questions.

Human resources: World-leading researchers based at DIAS and the ability to attract and retain leading experts.

Focus: Freedom to focus on scholarship and research.

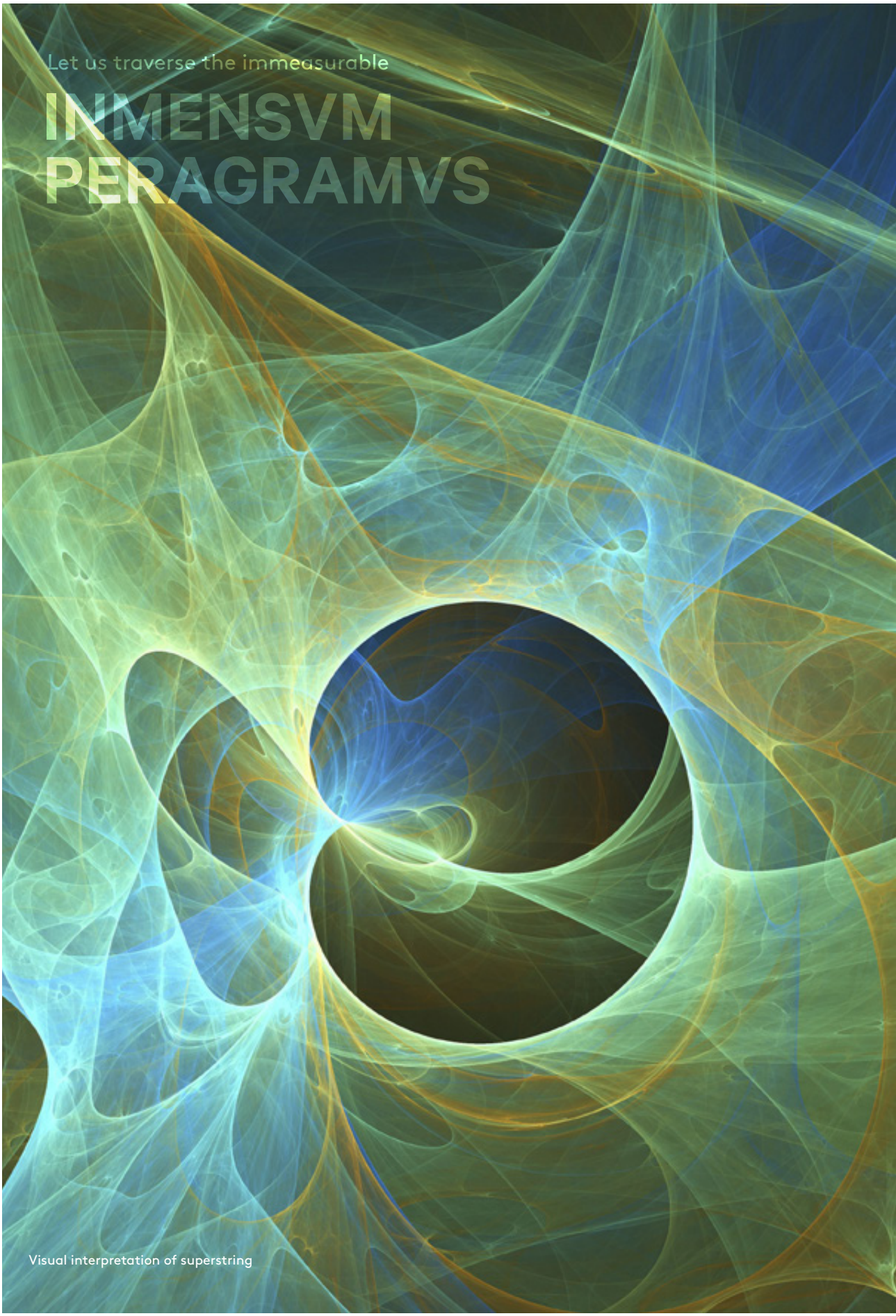
Research excellence as the driver: Strategic and targeted engagement with other research performers, nationally and internationally, driven by the desire to excel further in knowledge creation and understanding.

POTENTIAL BARRIERS TO SUCCESS

Strategic: Communication: A broader understanding and recognition of DIAS's role, contributions and how it can add further value is needed. A greater focus on communication to all its stakeholders is required.

Human resources: In order to fully leverage DIAS's international reputation, a 'fit for purpose' framework to facilitate the attraction and retention of excellent researchers to DIAS is required. Enhanced funding support from a range of sources (public, private, plus core and competitive) required.

Facilities: There is a requirement for capital investment to enhance current facilities, and provide one location for our expanding schools, so as to create an optimal environment for advanced studies.

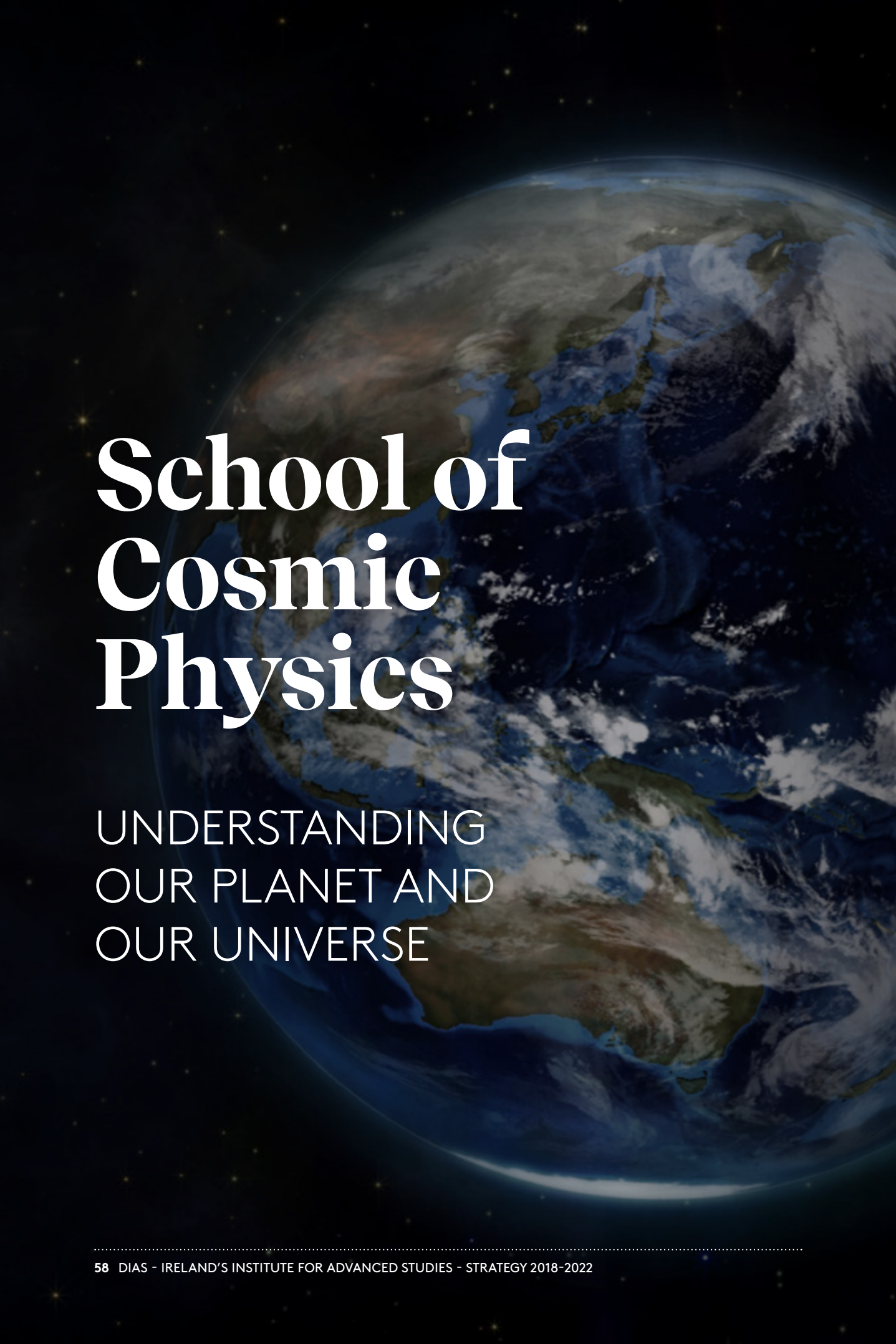


Visual interpretation of superstring

SECTION V

Our Research Questions and Areas

The following section outlines the broad research and advanced study areas for each school in the lifetime of the strategy and considers the work in a broader context.



School of Cosmic Physics

UNDERSTANDING OUR PLANET AND OUR UNIVERSE

How unusual is planet Earth?

One of the great discoveries of the last decade has been that our solar system is not unique and that most stars appear to have planets in orbit around them. However, many of these systems appear to be very different to our own and it is still an open question as to how common Earth-like planets are, and how exactly the formation of planets fits into the broader picture of star formation.

Ultimately, of course, the key question we would like to answer is whether there are other Earth-like planets with signatures of life and how common they are. DIAS has been studying star formation since the 1980s and our observational facilities are now so good that we are beginning to study planet formation also.

Exoplanets, as planets around stars other than our own Sun are called, will form an increasingly important aspect of our research in the future and DIAS is involved in two major space projects, both of which will contribute to this. We are partners in the European Space Agency's ARIEL mission, which will study the atmospheres of exoplanets in unprecedented detail, and also in NASA's James Webb Space Telescope, the successor to the Hubble Space Telescope, which is expected to deliver a wealth of information about star and planet formation. Interpreting these observations, as well as ones made from the ground using the telescopes of the European Southern Observatory and other facilities, such as the European radio-telescope LOFAR, will utilise sophisticated numerical modelling using high-performance computing facilities of the type provided by ICHEC, which DIAS helped establish.

Our study of the origin of exoplanets will also be enhanced by the establishment of a new optical/near-infrared detector group. The type of detectors being developed, Microwave Kinetic Inductance Detectors (MKIDs), are ideal exoplanet hunters. Moreover, the cryogenic laboratory facilities established for the detector group will also be used to test hardware we are developing for the ARIEL satellite mission in which DIAS is a co-principal investigator.

How does nature beat CERN?

High-energy charged particles appear to be very common in the universe. We have known for over a century that the Earth is constantly bombarded by relativistic charged particles, the so-called cosmic rays, and that some of these have energies way beyond anything that we can achieve even in the Large Hadron Collider at CERN.

In addition to the direct evidence of the arriving cosmic rays, we also have increasing amounts of indirect evidence, for example, from gamma-ray astronomy, that in many astrophysical systems charged particles are very efficiently accelerated, in some cases at rates that push the limits of what is thought to be physically possible. But how exactly this happens, and what allows nature to beat CERN, is only imperfectly understood.

The study of cosmic rays has been one of the key research topics of the School of Cosmic Physics since its establishment in 1947 and now forms part of the broader field of high-energy non-thermal astrophysics and astroparticle physics.

One of the big advances in the field has been the development of ground-based gamma-ray astronomy using the imaging atmospheric Cherenkov technique, most notably by the HESS collaboration, of which DIAS is a member. However, the field is intrinsically multi-wavelength (from radio to gamma-rays) and multi-messenger (neutrinos and gravitational waves) requiring inputs from all areas of modern astronomy as well as theoretical and numerical modelling.

Planet and universe formation

Understanding the Sun–Earth connection

The Sun is an active star that can produce eruptions of hot gas threaded by magnetic fields. From time to time, these solar storms can impact the Earth's magnetosphere and upper atmosphere, producing spectacular auroral displays. These phenomena can also have technological impacts, damaging satellites, interrupting radio communications and navigation systems, and causing fluctuations in electrical power grids. Using images from NASA's Solar Dynamics Observatory (SDO) spacecraft, we are developing image-processing and machine-learning algorithms to detect and characterise the complex magnetic fields associated with sunspot groups. Measurements are giving us a new insight into how the properties of sunspot magnetic fields relate to flaring and how they can be used to improve forecasting of solar activity. Once a solar storm has been launched, we use images from SDO and ESA/NASA's Solar and Heliospheric Observatory to understand a plethora of associated phenomena, such as plasma waves and oscillations, mass ejections, and shocks. Radio observations are of particular interest to us due to the insight that they can provide into shock waves and particle acceleration. We therefore lead the operation of the Irish Low Frequency Array (LOFAR) at Birr Castle and are engaged in a Horizon 2020 design study to upgrade the International LOFAR Telescope network to better monitor solar activity and space weather.

At Earth, X-ray and extreme ultraviolet (EUV) emission from solar flares can cause increased ionisation in our upper atmosphere, which we continue to monitor using Very Low Frequency (VLF) antennas. We are using these measurements to understand how closely coupled the Earth's ionosphere is to small-scale fluctuations in solar X-ray and EUV emission. The geomagnetic field of the Earth can also be impacted by solar storms. The solar group working with DIAS Geophysics and EirGrid plc have deployed a network of magnetometers in Ireland (MagIE) to monitor geomagnetic storms. MagIE, when coupled with our comprehensive model of the Irish electrical power grid, is modelling how the Irish power grid responds to day-to-day and worst-case geomagnetic variability.

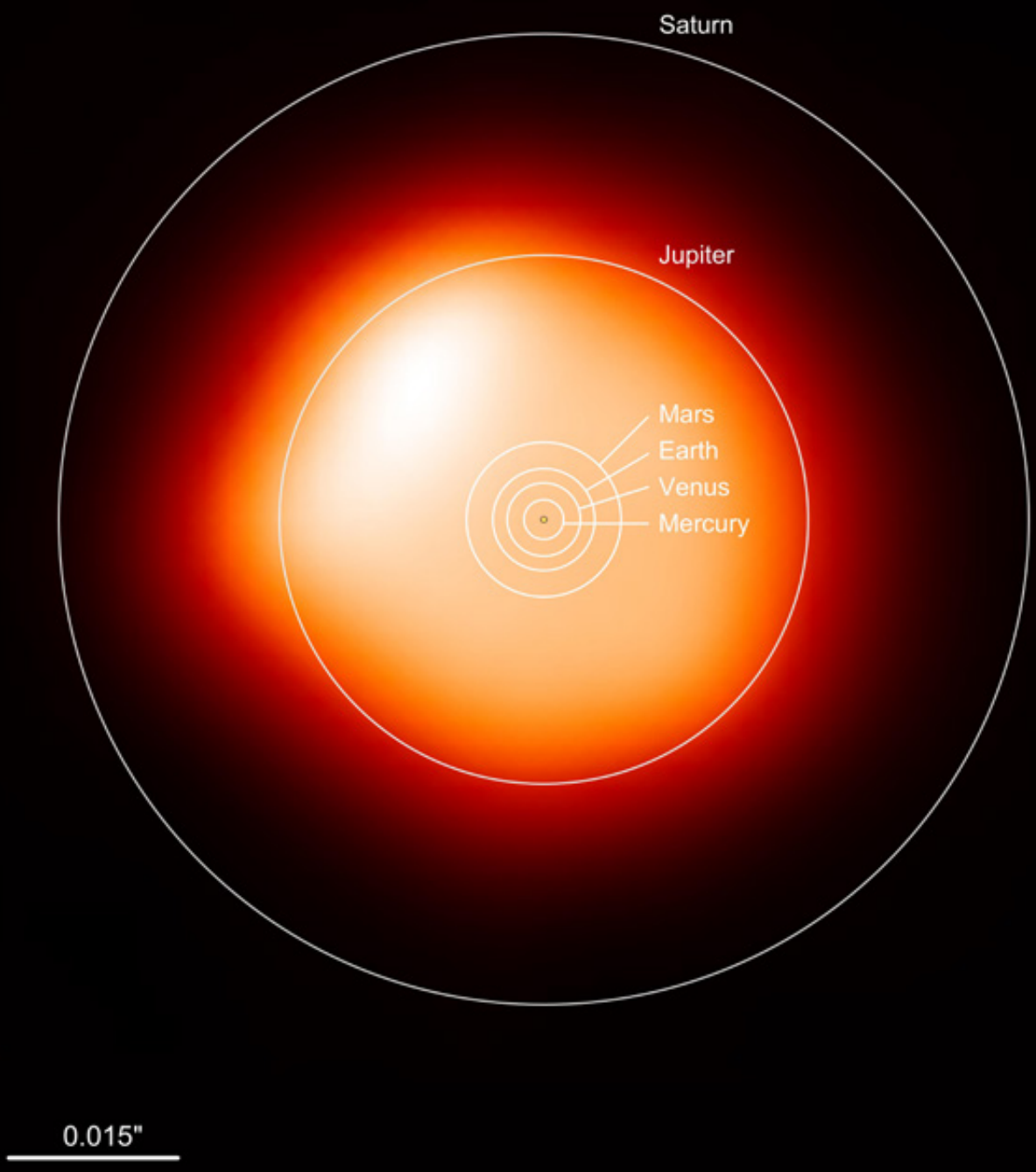
A more complete understanding of the Sun–Earth connection will soon be available to us with the launch of ESA's Solar Orbiter spacecraft by NASA in February 2020. Supported by ESA PRODEX, we are developing software for the Spectrometer Telescope for Imaging X-rays (STIX) and are involved in coordinating observations from the suite of instruments that will be flown on Solar Orbiter.

How did stars and galaxies form?

When we look at the night sky, the first thing we see are the stars, but if we look deeper with powerful telescopes then we start to see that the universe is full of galaxies similar to our own Milky Way, themselves composed of stars. Modern cosmology gives a good account of the formation of large-scale structures in the universe, and once stars are formed we have a good understanding of their structure and evolution. What is not so well understood is the critical step in between, the formation of galaxies and of stars out of primordial gas. Massive stars are thought to play a key role in this process because their rapid evolution and strong radiation allows them to have a regulatory feedback effect. A key technique to understanding high-mass star formation, and also the formation of galaxies, is detailed numerical modelling of the ultraviolet radiation fields associated with these stars and the complex circumstellar environments produced by their time-varying winds and outflows.

These models can be compared with observations of massive stars in our own galaxy and then used to extrapolate to similar phenomena in the early universe at the time the first stars were formed and the galaxies as we know them today began to take shape. By looking back in time to see galaxies in the early universe, the James Webb Space Telescope – for which DIAS has developed hardware and is now writing software – will provide important observational clues and advances in computing power and will allow much more sophisticated numerical models to be calculated.

Betelgeuse, the Red Supergiant located in the constellation Orion, captured by DIAS Astronomer in 2017 using the world's largest radio telescope, ALMA. Designated by ESO as the most detailed image of another start - other than our sun - ever generated. Internationally acclaimed photo of the "Star Betelgeuse" (taken by Dr. O' Gorman, DIAS)



Our Sun and star formation

How do the Earth's tectonic plates form and evolve?

Ancient cores of the Earth's continents formed billions of years ago, but today the continental lithosphere continues to be formed, reworked and reshaped. Oceanic lithosphere is formed at mid-ocean ridges and then cools and thickens with age, but this cooling can be disrupted by interaction with hot patches in the underlying asthenosphere. The lithosphere in the North Atlantic, for example, cools slower than average due to the heating by the Iceland Hotspot, as research at DIAS has shown, and it is these disruptions by hot currents in the Earth's mantle that probably give rise to dramatic geological events, such as volcanic eruptions that formed Ireland's Giant's Causeway and other geological landmarks. The evolution of the lithosphere (which makes up the Earth's tectonic plates) determines the evolution of topography on Earth and the distribution of natural subsurface resources, and yet it is poorly understood. Understanding this is the grand challenge in Earth science. Research on this is pursued vigorously at DIAS, at scales from global to North Atlantic to Ireland and its offshore.

How much water is there on planet Earth?

Most people are well aware of the water cycle of evaporation and precipitation yet, surprisingly, we still do not know how much water there is on planet Earth. Vast quantities of water exist underground – some is free to move as 'groundwater' flowing through cracks and fractures in the shallow subsurface, while some is 'locked up' in the Earth's mantle as ions within mineral crystals. Groundwater changes with the season and is intimately related with the end-members of both drought and flooding events, worldwide. We will attempt to 'weigh' time-varying groundwater at a national scale in Ireland using high-precision satellite gravity data from the GRACE mission – yielding information on Ireland's total water budget. Mantle water affects the flow, seismic and electrical properties of rocks. Through integrated modelling of the effects of water on rock properties and a comparison with observations, we will also address the task of assessing the distribution of water in the Earth's mantle.

How do volcanoes work?

Volcanoes are complex objects that emit a range of geophysical and geochemical signals as they transition through various stages of unrest. Inverting these signals to gain a clear understanding of the physical processes that generate them is challenging because multiple different processes can generate similar signals leading to a range of possible interpretations. Furthermore, data networks used for monitoring volcanoes are often too sparse to provide data that can be used to answer fundamental research questions. We have designed and installed bespoke research networks on several volcanoes throughout the world (e.g. Italy, Iceland, Cost Rica, Peru). Analysis of these data has led to new models for low-frequency seismic signal generation on volcanoes, and is leading to a new understanding of how volcanoes behave. We will build on that work with multidisciplinary acquisitions jointly using DIAS seismic and electromagnetic capabilities with the aim of gaining a better understanding of the physical causes of precursory changes prior to eruptions.

'Deeper' understanding of sedimentary basin

Sedimentary basins are regions on the planet where vast quantities of sediments accumulate. They are the main hosts for hydrocarbon resources and deposits within these basins and also hold vital information about past climates in both recent and deep time. Broadly, sedimentary basins form when the Earth's crust is stretched though tectonic processes; however, the details of controls on their evolution are still uncertain.

DIAS is building on its long history in the study of sedimentary basins through combining new multiscale offshore seismic experiments in the NE Atlantic using the iMARL ocean bottom infrastructure (recently awarded to DIAS) with industry data. New high resolution data inversion methods applied to these datasets and supported by very large-scale numerical simulations of seismic wave propagation in offshore regions are leading to a new understanding of basin structure and evolution. These findings have implications for our understanding of geo-resource distributions and past climates in the NE Atlantic region.

How do oceans interact with the solid Earth?

Ocean interaction with the solid Earth is not confined to the coastal zone. Terrestrial seismometers throughout the world record continuous background low-frequency ground vibrations called microseisms. It is now known that one flavour of these microseisms is generated by ocean waves interacting with the deep ocean floor, well offshore. This has far-reaching consequences for our understanding of the 'Earth System'.

As ocean waves are driven by wind, this means that atmospheric disturbances are coupled to the solid Earth, globally – not merely in areas of terrestrial exposure. This leads to unanswered questions about the potential for atmospheric disturbances to trigger underwater landslides and even possibly trigger earthquakes as they 'stress' the sea floor. Employing arrays of terrestrial seismic stations, ocean-sensing infrastructure available through iMARL, and supported by high-end numerical simulations, we are using the stormy NE Atlantic as a test bed for investigating the detailed mechanisms associated with ocean–land coupling at regional scales. The aim is to lead to a better understanding of the 'Earth System'.

Other questions such as 'What is supporting the topography of the surface of the Earth', and the 'Modelling of global sea level change in past and present' may be found on our website: www.dias.ie

Understanding Earth System Change – key for global sustainable development

School of Theoretical Physics

UNRAVELLING THE UNDERPINNING MATHEMATICAL PRINCIPLES OF NATURE

How do we unify gravity with quantum physics – the big question in physics?

Superstring theory is the best developed attempt to unify gravity with the rest of physics, but there are others. One idea was to bend special relativity by reviving action-at-a-distance and imbuing the fields of the standard model with some non-local behaviour. The simultaneous electromagnetic and gravitational observation of the neutron star collision supports locality to a high degree, however. Thus, we can imagine locality pushed to the extreme. If one can change space at an arbitrarily small scale, local fields can be extracted. Einstein obtained the energy-momentum field in this way. He only considered continuous changes, but it might be possible to change space by attaching a very small wormhole. This must yield other fields beyond gravity.

At DIAS, we showed that the idea works beautifully in two dimensions. In three or four dimensions it might fail, but nobody knows yet. Does the standard model still work when wormholes are present? Another path taken here and in collaboration with Imperial College London is the following. The quanta of gravitational waves have spin two, those of the other known forces have spin one. Maybe one can get gravity by convoluting two copies of the latter kind? Technically, the idea seems to need supersymmetry, but not necessarily at an energy that accelerators can reach. A third path uses computer calculations where space is modelled by something like ten thousand points and one looks for dynamical laws that will approximate the smooth behaviour of Euclidean geometry or gravitational waves. Obviously, we will try quantum computers as early as we can. Some paths will merge, others will lead into blind alleys, but we share Faraday's conviction that the quest will succeed.

Superstring theory has shown that gravity and quantum physics can fit together smoothly. At the very least it has ended the period when most particle physicists just ignored gravity. But could it be that the standard model can be combined with gravity without superstrings? Perhaps no, but we do not know for certain. If the combination works, a new mathematical structure has to be uncovered, like Galileo's invariance, or the theory of spacetime curvature. We probably have the tools to find it, though a quantum computer might make it much easier.

What is the microstructure of spacetime?

This question is usually posed in the context of a search for a quantum theory of gravity but one can explore the question more generally. Spacetime is the scaffolding on which all spacetime events occur. The macroscopic structure we observe is locally the Minkowski spacetime of special relativity. On larger scales it is described by Einstein's theory of general relativity. But can this Minkowski spacetime be an emergent structure from something more primitive? And what are the possibilities for this more primitive structure? Could spacetime be fundamentally discrete with only primordial events existing and our perceived continuum spacetime their large-scale manifestation? Could it be that the coordinates of spacetime are non-commutative objects so that the order in which we multiply them matters? Perhaps spacetime is not four dimensional (three space plus time) as we perceive it in our everyday lives, but has more spatial dimensions yet undetected. The School of Theoretical Physics has a long tradition in addressing questions associated with the quantum realm, going back to its founding director Edwin Schrödinger and followed by Professors Walter Heitler, James R. McConnell, Lochlainn O'Raifeartaigh and John T. Lewis. It has been a pioneer in research into fundamental questions associated with gravity, especially under the influence Professors John L. Synge and Cornelius Lanczos. The school is exploring all of the above questions.

What is quantum gravity?

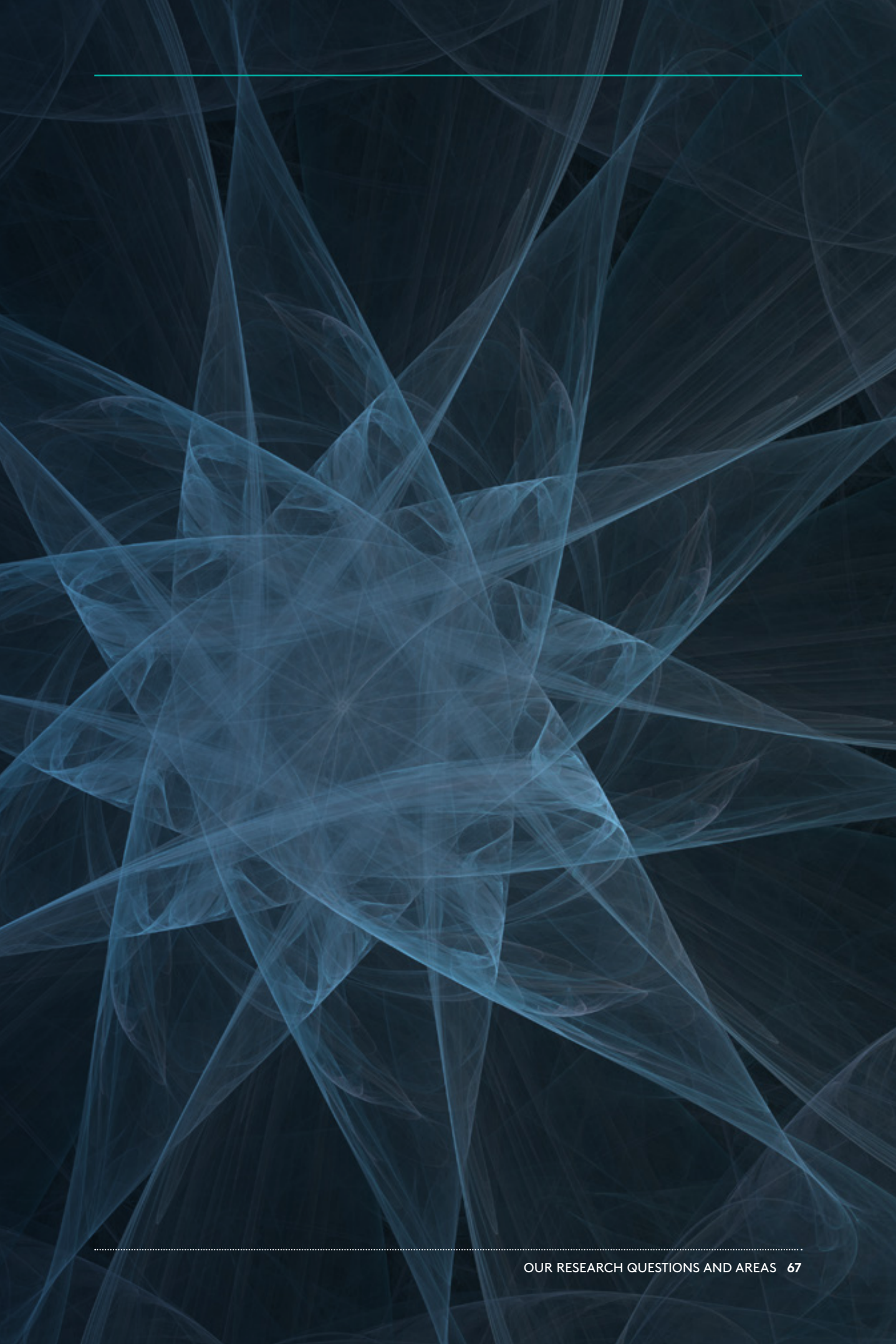
Is it described by continuum or atomistic physics? Is quantum mechanics compatible with an atomistic description or does quantum gravity require some more profound reformulation of our notions of quantum dynamics that goes beyond quantum mechanics?

In pursuing the continuum hypothesis, we at DIAS are investigating if the fundamental degrees of freedom might be extended exotic objects known as M-branes, which are supersymmetric membranes and are themselves built from interacting fundamental degrees of freedom, sometimes called D0-branes. These are then described by matrices which in turn describe non-commutative coordinates in an embedding space. In this approach, time is a continuum entity but the notion of space is emergent. To address the discrete hypothesis, we, in contrast, assume that spacetime is fundamentally atomistic yet causal and is described by partially ordered sets called causets.

An example of a partially ordered set of this type is family relationships, as in A is a daughter of B, B and C are unrelated. It has been shown that discrete causal order allows for the reconstruction of the metric of a spacetime, if, for example, the causet is sprinkled, by a Poisson process, into a known spacetime. A suitable quantum dynamics is not yet known in this formulation but a causet version of the Einstein–Hilbert action has been found and we are exploring this as a possible formulation of quantum gravity.

What causes phase transitions of materials?

The most common phase transitions are the liquid–gas and solid–liquid transitions. These take place at very sharply defined temperatures at a given pressure. As these transition temperatures are crossed, the structure of the material changes. This must be due to the forces between the constituent atoms or molecules. However, the precise relation between the nature of these forces and the occurrence of a phase transition is still poorly understood. Already more than a century ago, van der Waals proposed a simple model for the liquid–gas transition in which he suggested that the force on a given molecule be replaced by an average of the forces due to all others. This so-called mean field theory gives rise to a prediction for the transition temperature, which was useful at the time in the effort to liquify hydrogen and helium. However, this model is otherwise not very satisfactory, not just quantitatively, but also qualitatively. For example, it does not predict a second transition for liquid to solid. A better understanding was obtained for other phase transitions. Ferromagnetic materials exhibit a magnetic phase transition: at high temperatures the magnetisation disappears, also abruptly. A very simple model for such magnetic transitions was proposed by Ising. He represented the elementary magnetic atoms as arrows pointing either up or down, where neighbouring arrows tend to point in the same direction due to a force between them. Peierls showed in 1936 that there is indeed a phase transition in this model. However, he used a special property of this model, namely a symmetry between up and down arrows. In 1987, Pirogov and Sinai extended his analysis to cases where this symmetry is absent. Nevertheless, this still only applies to cases where the arrows can only have a finite number of discrete directions. At DIAS, we are working on extending this further to continuous cases as well as to quantum-mechanical transitions. Examples of the latter are the Bose–Einstein phase transition, and the superconducting phase transition.



Is spacetime an emergent concept?

And if so did the universe undergo a phase transition in which spacetime is emergent from some more fundamental theory?

Phase transitions are ubiquitous in nature. The most familiar ones are those of water in our everyday experience, that is, its freezing and thawing or its boiling and liquefying. But there is a vast number and variety of such phase transitions. So it is natural to ask what phase transitions the universe underwent in its evolution and did it emerge in its current form as a phase transition from something more primitive. DIAS is exploring the idea that the universe emerged in a primordial phase transition by examining models where a specific space or spacetime has been found as a low temperature phase in simplified and idealised models. In models where a specific geometry has been found as emergent, we have observed that there is typically a low temperature geometric phase and a high temperature non-geometric phase with the phases separated by a phase transition. When the fundamental degrees of freedom of spacetime are taken to be supersymmetric membranes, quantised as D0-branes which propagate on an 11 dimensional parallel-propagation wave (pp-wave), the resulting model is known as the Berenstein–Maldacena–Nastase (BMN)-matrix model. It is conjectured that this model may provide a microscopic definition of M-theory, which in turn describes string theory and is hoped may provide a quantum theory of gravity.

The BMN-model has potentially many phases and it is possible if the universe began in a very hot thermal state, that it underwent a phase transition to something similar to a Robertson–Walker universe, that is, the theoretical description of our universe, as it cooled. We at DIAS are currently mapping the phase structure of the BMN-model as a function of temperature.

Transmission of quantum information – how can it be optimised?

In the digital age, information is transmitted in digital form, that is, binary format: a series of zeros and ones. This in highly efficient because computers are able to manipulate binary numbers very fast. However, this is essentially a classical (non-quantum) representation, whereas physical systems are in principle quantum-mechanical in nature.

In principle, in should be possible to transmit information in the form of quantum states. This would have advantages. First of all, quantum states have higher information density, and, secondly, whereas classical information can be intercepted, quantum states cannot.

Namely, a quantum state is changed upon interception, and this can be detected by the receiver if certain provisions are made. This same property of quantum states makes them also very fragile, however, because they are changed as a result of any external disturbance.

The information states therefore need to be protected against external disturbances by building in redundancies. How to do this efficiently is a subject of research at DIAS.

Most of the arts, as painting, sculpture, and music, have emotional appeal to the general public. This is because these arts can be experienced by some one or more of our senses. Such is not true of the art of mathematics; this art can be appreciated only by mathematicians, and to become a mathematician requires a long period of intensive training. The community of mathematicians is similar to an imaginary community of musical composers whose only satisfaction is obtained by the interchange among themselves of the musical scores they compose.

Cornelius Lanczos (DIAS, 1954–1968)
quoted in Howard Eves's Mathematical
Circles Squared (Boston 1972)

School of Celtic Studies

INSIGHTS TO CELTIC SOCIETY AND LEGACY

We pursue a 'blue-skies' research agenda. There are widely different issues and research questions to be addressed right across its range. Within the areas covered at present by the school, our broad remit will be to provide scholarly editions of texts; to confront and address the myriad linguistic, literary and historical problems found in these sources; to identify and address the many research questions that arise; to continue with our ISOS and other online initiatives; to act as academic conduit and publisher for the very best work being carried out in Celtic Studies, both at DIAS and in other institutions.

The school carries out advanced research in many areas of the languages and literatures of the Celtic countries, with particular emphasis on Irish.

Background to Celtic Studies

Prior to the rise of the Roman Empire much of Central and Western Europe was occupied by a people we nowadays call the Celts. This designation is primarily linguistic and refers to people whose language belonged to the Celtic branch of the Indo-European linguistic family, Celtic being one of the main branches of this family. Following the rise of the Roman Empire, the Celts lost their foothold in Continental Europe, enduring only in Britain and Ireland down to the present day. Despite this, their contribution to Europe's heritage has been immense.

RESEARCH AREAS

Irish Script on Screen

Our manuscript legacy 'What it tells us about our past...'

A project of particular importance, entitled the Irish Script on Screen (ISOS) project, provides a strategic focus for SCS research (www.isos.dias.ie). The aim of the project is to create digital images of Irish manuscripts and to make these, together with relevant academic commentary, accessible on a website. The purpose of doing so is to provide an electronic resource which will:

- Provide exposure on the internet for a vital part of Ireland's cultural heritage.
- Place these primary materials at the disposal of scholars and students.
- Contribute to the conservation of these valuable documents by creating images of high-resolution detail, thereby reducing the need to handle the artefacts themselves.

Medieval Irish manuscripts are national treasures and each is a unique document. While printing made possible the production of multiple identical copies of a book, each manuscript is a unique product.

Irish manuscripts survive from the sixth century onwards, and the loss of any one of them is an irreplaceable loss.
Our earliest manuscripts are written on vellum. This was a very expensive commodity and, as a result, in writing their texts the scribes made use of a wide range of abbreviations and symbols to ensure they were able to accommodate as much text as possible on each page. Interpreting these symbols and tracing the development of the system of writing is a very challenging task and one that can be carried out only by highly trained readers of mediaeval manuscripts (palaeographers).

The value of replicating manuscripts was recognised as early as the nineteenth century. Significant time and effort were invested in the production of facsimiles, such as Lebor na hUidre (1870), An Leabhar Breac (1872–76), the Book of Leinster (1880), the Book of Ballymote (1887), etc. Therefore, while the ISOS project represents a new departure in terms of technology, it renews a tradition of concern for the conservation and replication of our primary sources, thereby providing for their wider availability.

This will lead to the preservation of important manuscripts and to the development of new insights into Ireland's cultural history. The school is committed to utilising modern technology to promote global access to primary materials, thereby facilitating worldwide research in Celtic Studies.

Irish contribution to the formation of Medieval Europe

In the period after the fall of the Roman Empire, Ireland emerged as an intellectual powerhouse in Western Europe. Its monasteries held extensive libraries, scriptoria and workshops, and its scholars were famed through their writing, artwork and teaching. A substantial body of literature and learning, in Irish and in Latin, has been transmitted to us from Medieval Ireland. The publication and analysis of this material, in print and through digital image, is a central area of endeavour in the school.

History and development of Celtic languages

A primary goal of Celtic Studies is establishing the relationship of the Celtic languages to each other, ancient and modern, and how they sit within the broader framework of the Indo-European family to which they belong. The development of each language is also traced through a study of its different stages of attestation, from earliest times down to the spoken languages of the present day. Research includes the recording and investigation of the modern dialects of the Celtic languages.

Language and culture: a window to Celtic society

The designation Celtic Studies encompasses not only the linguistic study of Irish, Scottish Gaelic, Manx, Welsh, Breton and Cornish, in all their stages of development, but also the study of ancient Continental Celtic languages (e.g. Gaulish, Celtiberian) found only in inscriptions and other such fragmentary sources. The associated literature and culture of these languages is also studied in depth as are many aspects of the societies in which they came into being (laws, history, societal organisation, religion, mythology, folklore, etc.). The study of Medieval Latin, the language of the Church, is also central. Related fields of study, such as archaeology, onomastics and numismatics, are also highly important for our understanding of early and medieval society.

Literature and society

The extensive body of literature in the Celtic languages transmitted to us from medieval times is one of the most important parts of Europe's cultural inheritance from the medieval period. In it we have detailed accounts of how medieval societies were organised, both socially and politically. The study of this, particularly through the editing and analysis of the legal texts that have been transmitted to us, is a central objective of the school.

Celtica, the seminal international journal for Celtic Studies, was founded and published by DIAS since 1946.

Some forthcoming publications:

- An edition of Amra Choluim Chille (which will be the first in a new series of medieval Irish texts)
- Buchedd Beuno (Welsh)
- A major study of the Irish of West Kerry
- An edition of an Early Irish law text
- An edition of Johannes Scotus Eriugena's Periphysion
- An edition of the poetry of Maonas Ó Ruairc

Corpus Iuris Hibernici

The foundation for modern studies of the Brehon Laws.

An example of the value of the research pursued by the school is the six-volume edition of the Brehon Laws, the Corpus Iuris Hibernici (CIH), published by DIAS in 1978. It represents the fruit of 30 years of work by Professor D.A. Binchy, a senior professor in the School of Celtic Studies, and its impact is demonstrated by the renaissance in the study of the Brehon Laws which has taken place since its publication.

These challenging texts, written in a very early form of Irish, are now at last yielding their secrets, and present evidence that is detailed and quite unique for the organisation of society in Europe following the fall of the Roman Empire. Binchy's work has become the foundation for the study of this unique early medieval legal system, and will remain so for a long time to come. Since the publication of CIH, scholars have been editing, interpreting, and translating many of these challenging texts. To date, eight volumes in DIAS's Early Irish Law Series have appeared. This work is an example of open-ended research pursued by the school.

APPENDICES

Appendix A

A Legacy of Discovery and Impact

The value to Ireland of DIAS's unique mission has been demonstrated over the last 75 years. It has greatly enhanced DIAS's profile and reputation internationally, augmented the pool of human capital and skills in the country, and delivered serendipitous discoveries with economic impact.

The Institute for Advanced Studies Act was enacted in 19 June 1940, and the first meeting of the Council of DIAS took place in the Taoiseach's office on 15 October 1940.

The timeline below sets out key output and impact dates for DIAS since its inception.

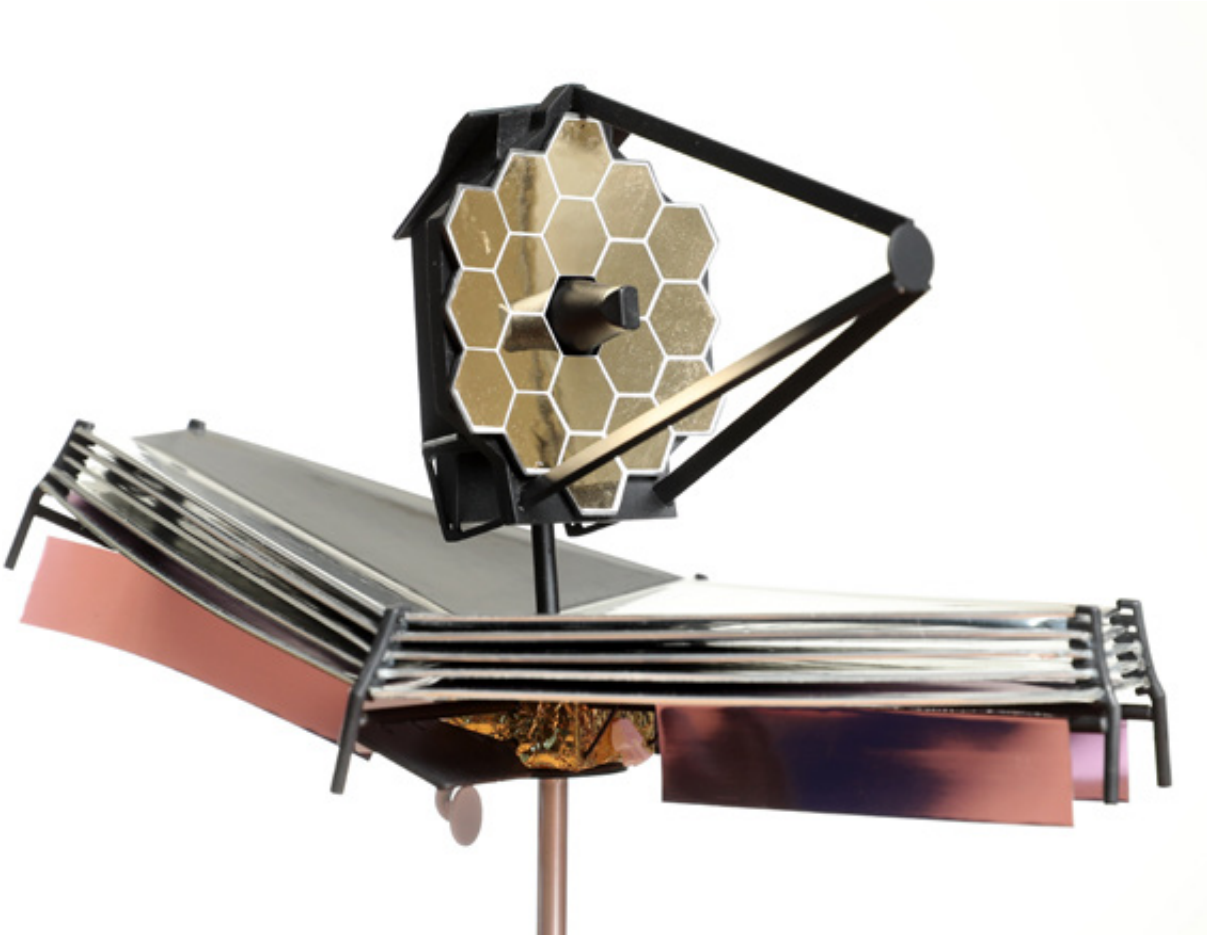
1942	T.F. O'Rahilly delivers his statutory public lecture 'The Two Patricks' in TCD, subsequently immortalised by the writer Flann O'Brien with his joke about DIAS showing that there is 'no God but two St Patricks'.
February 1943	E. Schrödinger delivers his famous 'What is Life?' series of public lectures in TCD. These are reproduced in book format and are acknowledged publicly by Crick, Watson and Wilkins to have significantly influenced and inspired their discovery of DNA.
July 1943	DIAS hosts its first Theoretical Physics International 'Summer Colloquium' attended by, among others, Nobel Prize-winner Dirac and world renowned physicist Eddington.
1944	The Union of the Three Fundamental Fields (Gravitation, Meson, Electromagnetism) is published by E. Schrödinger.
1946	Publication of the first volume of Celtica, henceforth the seminal journal for Celtic Studies worldwide.
1946	The Final Affine Field Laws is published by E. Schrödinger. This work is subsequently overtaken by renormalisation theory by Feynman, Schwinger and Tomonaga.
March 1947	The School of Cosmic Physics is established and Dunsink Observatory becomes part of DIAS.

August 1947	The first ever cross-border (international) agreement between the two jurisdictions on the island of Ireland is signed, so as to enable the establishment of the Armagh-Dunsink-Harvard telescope in South Africa.
1955	The Ninth International Astronomical Union General Assembly is held in Dublin and hosted by DIAS.
1956	C. Lanczos publishes Applied Analysis, which is a highly original and influential compilation of ideas and results in numerical analysis.
1957	The first all-island gravity survey is completed and published by T. Murphy.
1959	Volume 1 of H. Wagner's Linguistic Atlas and Survey of Irish Dialects (1959–1969) is published, a key reference document to this day.
1959	The First International Congress for Celtic Studies is organised in Dublin under the aegis of DIAS.
1960	J.L. Synge publishes Relativity: The General Theory, emphasising its geometrical aspects, and for the next decade DIAS becomes the leading world centre for research in general relativity. The full impact of Synge's marriage of geometry and relativity was not appreciated until several decades after his work, but it had a profound influence on the subsequent work of Penrose and Hawking on black holes and the geometry of the universe.
1965	The Ward–Takahashi Identity is published, which is an important contribution to the area of generalised conservation laws.
1972	DIAS (collaborating with the University of Berkeley) fly the first ever Irish experiment in space and onto the lunar surface on the NASA Apollo 16 mission. DIAS pioneered space physics in Ireland with this important step. Also of note are experiments on Apollo 17, and on the Long Duration Exposure Facility launched into orbit by Challenger in 1984; in all there are 16 experiments on space missions over the subsequent 40 years.
1972	K. Imaeda publishes A New Formulation of Classical Electrodynamics, which is an insightful and important contribution to this area.
1975	L. O'Raifeartaigh publishes A Supersymmetry Breaking Mechanism, now regarded by the international physics community to be the one most likely realised in nature; L. O'Raifeartaigh is also known worldwide for the O'Raifeartaigh Theorem, a result in unification theory.
1978	D.A. Binchy's Corpus Iuris Hibernici is published in six volumes. This key publication – the fruit of 30 years of work on Early Irish law texts (the Brehon Laws) – laid the foundation for the study of this area and profoundly changed perceptions and understandings on all aspects of Early Irish history and society. They also contribute to the study of the organisation of society in Europe following the fall of the Roman Empire.
1978	The Irish National Seismic Network is established, which is a key national resource that detects earthquakes and other seismic activity, in addition to being the western-most unit of the European network, and thus is contributing significantly to world seismicity.

1979	The 'La Palma' agreement is signed, giving access by Irish astronomers to observing facilities in the Canary islands by the then National Board for Science and Technology (NBST), DIAS and the UK Science Research Council (SRC).
1987	The B. Jacob-led project (involving colleagues from the University of Hamburg and other institutions) 'unequivocally' demonstrates that the Irish continental shelf extends out through the Porcupine and Rockall Basins, thereby enlarging Ireland's zone of economic interest by a factor of ten. This started as fundamental work, initiated in the early 1980s, on the formation of the North Atlantic Ocean, which showed that the Irish continental shelf is twice as large as previously thought. This represents a huge expansion of the area over which Ireland has now substantial rights under the Law of the Sea, that is, these areas now form part of Ireland's national territory. The work was subsequently confirmed with more sophisticated equipment by the Marine Institute and Geological Survey Ireland (GSI).
1988	F. Kelly's Guide to Early Irish Law is published.
1991	DIAS hosts the International Cosmic Ray Conference at which Jim Cronin and Alan Watson initiate discussions of what was to become the International Pierre Auger Observatory.
1997	F. Kelly publishes Early Irish Farming.
2000	J. Lewis of DIAS founds Corvil, now a major network analytics company. The unexpected economic advantage related to the study of the foundations of statistical mechanics and the relation of entropy to information led to the realisation that similar ideas could be applied to telecommunications, and thus a successful high-tech start-up company was established to exploit the resulting intellectual property.
2000	The Wigner Medal is awarded to Lochlainn O'Raifeartaigh by the Group Theory and Fundamental Physics Foundation.
2001	DIAS has one of the first 10 (and first Irish) experiments on the International Space Station after an extremely competitive international selection process.
2003	DIAS heads the CosmoGrid consortium funded by PRTLI-3, which leads to the establishment of the national high-performance computing infrastructure, ICHEC, in 2005.
2007	The HESS collaboration, of which DIAS is a member, is awarded the EU Descartes Prize for outstanding transnational collaborative research.
2010	Professor F. Aharonian, with two other individuals, wins the Rossi Prize of the American Astronomical Society for the HESS project.
2011	The Fourteenth International Congress of Celtic Studies is held in Ireland under the aegis of DIAS (hosted at Maynooth University).
2012	F. Kelly is awarded the Derek Allen Prize in Celtic Studies by the British Academy.

2013	W. Nahm is awarded the Max Planck Medal by the German Physical Society. Professor Nahm subsequently is awarded the RIA Gold Medal in 2015.
2014	F. Aharonian is awarded the Viktor Ambartsumian International Science Prize.
2016	T. Ray is awarded a European Research Council (ERC) advanced grant for his work on star formation.

A model of the James Webb Space Telescope, the successor of Hubble, and the largest telescope ever built. DIAS has developed hardware and is now writing software for this major global project.



Acronyms

AHSS	Arts, Humanities and Social Sciences
BILL	Bibliography of Irish Linguistics and Literature
BMN	Berenstein–Maldacena–Nastase
CAPPA	Centre for Astroparticle Physics and Astrophysics
CERN	Conseil Européen pour la Recherche Nucléaire [European Organization for Nuclear Research]
CIH	Corpus Iuris Hibernici
COST	European Cooperation in Science and Technology
CTA	Cherenkov Telescope Array
CTBTO	Comprehensive Nuclear-Test-Ban Treaty Organization
DCU	Dublin City University
DES	Department of Education and Skills
DIAS	Dublin Institute for Advanced Studies
DJEI	Department of Jobs, Enterprise and Innovation
e-INIS	The Irish National e- Infrastructure
EPOS	European Plate Observing System
ERC	European Research Council
ESA	European Space Agency
ESA PRODEX	European Space Agency Programme de Développement d'Expériences Scientifiques
ESFRI	European Strategy Forum on Research Infrastructures
ESO	European Southern Observatory
EU	European Union
EUROVOLC	European Network of Observatories and Research Infrastructures for Volcanology
EUV	Extreme Ultraviolet
GSI	Geological Survey Ireland
HEI	Higher Education Institution
HESS	High Energy Stereoscopic System European Collaborative Project to Operate a System of High-Energy Gamma- Ray telescopes in Namibia
HPC	High Performance Computing
ICHEC	Irish Centre for High-End Computing
iCRAG	Irish Centre for Research in Applied Geosciences
I-LOFAR	Irish Low Frequency Array
iMARL	Insitu Marine Laboratory for Geosystems Research
ISOS	Irish Script on Screen
IT	Institute of Technology
JWST	James Webb Space Telescope
KM3NeT	Cubic Kilometre Neutrino Telescope
MagIE	Network of Magnetometers in Ireland
MIRI	Mid-Infrared Instrument
MU	Maynooth University
NASA	National Aeronautics and Space Administration
NBST	National Board for Science and Technology
OECD	Organisation for Economic Co-operation and Development
QSPACE	Quantum Structure of Spacetime
RIA	Royal Irish Academy
SCP	School of Cosmic Physics
SCS	School of Celtic Studies
SDGs	Sustainable Development Goals
SDO	Solar Dynamics Observatory
SFI	Science Foundation Ireland
SKA	Square Kilometre Array
STEM	Science, Technology, Engineering and Maths
STIX	Spectrometer Telescope for Imaging X-Rays
STP	School of Theoretical Physics
TCD	Trinity College Dublin
UCD	University College Dublin
UK SRC	United Kingdom Science Research Council
VLF	Very Low Frequency
VLT	Very Large Telescope

Design: reddog.ie

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