Please check our wiki for help on navigating the form.

Horizon 2020

Call: H2020-MSCA-IF-2020

(Marie Skłodowska-Curie Individual Fellowships)

Topic: MSCA-IF-2020

Type of action: MSCA-IF-EF-CAR

(Career Restart panel)

Proposal number: 101028780

Proposal acronym: NuclearRET

Deadline Id: H2020-MSCA-IF-2020

Table of contents

How to fill in the forms

The administrative forms must be filled in for each proposal using the templates available in the submission system. Some data fields in the administrative forms are pre-filled based on the steps in the submission wizard.

1 - General information

Topic	MSCA-IF-2020	Type of Action	MSCA-IF-EF-CAR
Call Identifier	H2020-MSCA-IF-2020	Deadline Id	H2020-MSCA-IF-2020

Acronym: NuclearRET

Proposal title: Nuclear fusion rate enhancement by resonance energy transfer

Note that for technical reasons, the following characters are not accepted in the Proposal Title and will be removed: < > " &

Duration in months: 28

Scientific Area: PHY - Physics (PHY)

Please select up to 5 descriptors (and at least 3) that best characterise the subject of your proposal, in descending order of relevance.

Descriptor 1: Condensed matter, mechanical and acoustical properties, lattice dynamics

Descriptor 2: Quantum electrodynamics

Descriptor 3: Nanophysics: nanoelectronics, nanophotonics, nanomagnetism, nanoelectromechanics, etc.

Free keywords: *resonance energy transfer, phonons, nuclear state transitions*

Please choose the scientific area and descriptors carefully, and in order of importance, since this will guide the REA in the selection of experts for proposal evaluation and the allocation of proposals to experts. To help you select the most relevant area for your proposal, please consult the Guide for Applicants which provides a breakdown of each scientific area into a number of descriptors.

*Abstract**

Enhancing fusion rates could greatly simplify the extremely challenging engineering requirements for nuclear fusion. These challenges are rooted in the physical requirement for high kinetic energy of fusion reactants (which are typically hydrogen nuclei in plasma state) – and therefore high temperatures – believed to be inevitable for achieving substantial fusion rates. Without some form of enhancement, fusion rates are extremely low; for instance, fusion rates for D2 molecules at room temperature have been estimated at about 10^-64/s . In a high-density solid-state system, a rate around 10^-20/s would begin to become technologically interesting. Fusion rate enhancements of about 15 orders of magnitude due to electron screening effects in solid-state environments have previously been demonstrated. For further enhancement, other mechanisms need to be considered. There are encouraging reports of substantial enhancement of state transition rates in quantum systems at the atomic scale due to couplings between resonant subsystems: Kaur et al. 2018 report an 8 order of magnitude enhancement of transition rates in Rydberg atoms; Bang et al. 2019 suggest that such enhancements can be further amplified due to the collective quantum effect of superradiance. If similar enhancement mechanisms can be shown to apply to the nuclear scale – as has been recently proposed and is indicated by related experiments – then enhanced fusion in solid-state environments becomes technologically interesting. The overall objective of this project is to provide a sound theoretical and computational footing for such proposed quantum dynamics-based fusion rate enhancement mechanisms. Demonstrating alternative approaches to enhancing fusion rates would loosen engineering requirements, therefore helping fusion energy to become feasible sooner and possibly in cheaper form. Fusion energy in turn would represent a sustainable, safe, affordable, stable, and highly scalable energy technology.

Remaining characters 12

Has a similar proposal in terms of research objectives been submitted to a Horizon 2020 Marie Sklodowska-Curie Individual Fellowship call? ○ Yes ◉ No

Declarations

1) The applicant (future beneficiary) declares to have the explicit consent of all partner organisations (if applicable) on their participation and on the content of this proposal.	☒
2) The information contained in this proposal is correct and complete.	☒
3) This proposal complies with ethical principles (including the highest standards of research integrity — as set out, for instance, in the European Code of Conduct for Research Integrity — and including, in particular, avoiding fabrication, falsification, plagiarism or other research misconduct).	☒

4) The applicant (future beneficiary) hereby declares:

- it is fully eligible in accordance with the criteria set out in the specific call for proposals; and	☒
- it has the financial and operational capacity to carry out the proposed action.	☒
The applicant (future beneficiary) is only responsible for the correctness of the information relating to his/her own organisation. Where the proposal to be retained for EU funding, the applicant (future beneficiary) will be required to present a formal declaration in this respect.	

Note:

For **multi-beneficiary applications**, the coordinator vouches for its own organization and that all other participants confirmed their participation and compliance with conditions set out in the call. If the proposal is retained for funding, each participant will be required to submit a formal declaration of honour confirming this.

False statements or incorrect information may lead to administrative sanctions under the Financial Regulation 2018/1046.

Personal data will be collected, used and processed in accordance with Regulation 2018/1725 and the **Funding & Tenders Portal privacy statement**.

Please be however aware that, to protect EU financial interests, your data may be transferred to other EU institutions and bodies and be registered in the EDES database. Data in the EDES database is also subject to Regulation 2018/1725 and the EDES privacy statement.

2 - Participants & contacts

#	Participant Legal Name	Country	Action
1	UNIWERSYTET SZCZECINSKI	Poland	

2 - Administrative data of participating organisations

Future Host Institution

PIC	***Legal name***
999851460	*UNIWERSYTET SZCZECINSKI*

Short name: UNIWERSYTET SZCZECINSKI

Address

Street ALEJA PAPIEZA JANA PAWLA II 22 A

Town SZCZECIN

Postcode 71-453

Country Poland

Webpage www.univ.szczecin.pl

Specific Legal Statuses

Legal person .... yes

Non-profit .... yes

International organisation .... no

International organisation of European interest .... no

Secondary or Higher education establishment .... yes

Research organisation ....no

Small and Medium-sized Enterprises (SMEs) ....no

Public body ....yes

Academic Sector .... yes

Department(s) carrying out the proposed work

Department 1

Department name: Institute of Physics

☐ not applicable

☐ Same as proposing organisation's address

Street: ul. Wielkopolska 15

Town: Szczecin

Postcode: PL-70-451

Country: Poland

If the location of the Department carrying out the proposed work is not the same as the location of the Host Institute, please note that although the proposal submission system calculates the budget of the project based on the location of the Host Institute, the budget of the project for the grant agreement will be calculated by using the country coefficient of the location of the Department carrying out the proposed work.

Researcher

The name and e-mail of the Researcher and Supervisor are read-only in the administrative form, only additional details can be edited here. To give access rights and contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Last Name*	Lilley	Last Name at Birth	Lilley
First Name(s)*	Matthew	Gender*	(●) Male ( ) Female
Title	Dr.	Country of residence*	United Kingdom
Nationality*	United Kingdom	Nationality 2	
Date of Birth (DD/MM/YYYY)	08/06/1983	Country of Birth*	United Kingdom
		Place of Birth	Stoke on Trent

Contact address

Current organisation name	Matthew Lilley
Current Department/Faculty/Institute/ Laboratory name	NA

☐ Same as organisation address

Street	20 B Battersea Rise		
Postcode/Cedex	SW11 1EE	Town	London
Phone	+447500252922	Country	United Kingdom
Phone2 / Mobile	+xxx xxxxxxxxx		
E-Mail*	m.k.lilley@gmail.com		

ORCID: *If you have a ORCID number please enter it here (e.g. 9999-9999-9999-999X. where 9 represents numbers and X represents numbe*

Researcher ID: *The maximum length of the identifier is 11 characters (ZZZ-9999-2010) and the minimum length is 9 characters (A-1001-2010).*

Other ID: *Please enter the type of ID here* *Please enter the identifier number here*

Qualifications

Doctorate Date of (expected) award	Select the exact date (DD/MM/YYYY)	01/06/2009
Doctorate start date	Select the exact date (DD/MM/YYYY)	
University Degree giving access to PHD*	Date of award (DD/MM/YYYY)	14/07/2005

Place of activity/place of residence (previous 5 years - most recent one first)

Indicate the period(s) and the country/countries in which you have legally resided and/or had your main activity (work, studies, etc) during the last 5 years up until the deadline for the submission of the proposal.

Please fill in this section without gaps. Short stays (as defined in the Guide for Applicants) shall not be listed in this box.

Period from	Period to	Duration (days)	Country
09/09/2015	09/09/2020	1828	United Kingdom
	Total	1828	

Supervisor

The name and e-mail of the Researcher and Supervisor are read-only in the administrative form, only additional details can be edited here. To give access rights and contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Prof.

Sex: (•) Male ( ) Female

First name*: **Konrad**

Last name*: **Czerski**

E-Mail*: **konrad.czerski@usz.edu.pl**

Position in org.: Professor

Department: Institute of Physics

☐ Same as organisation address

Street: ul. Wielkopolska

Town: Szczecin

Post code: PL-70-451

Country: Poland

Website: http://www.usz.edu.pl/

Phone: +48 91 444 1251+

Phone 2: +48 91 444 1226

Fax: +48 91 444 1227

3 - Budget

Is the Researcher eligible for family allowance?* ◯Yes ◉No

Participant Number	Organisation Short Name	Country	Country Coefficient	Number of Months	Researcher Unit Cost			Institutional Unit Cost		Total
					Living Allowance	Mobility Allowance	Family Allowance	Research, training and networking costs	Management and Overheads	
1	UNIWERSYTET SZCZECINSKI	PL	0,755	28	103163,20	16800,00	0,00	22400,00	18200,00	160563,20
Total					103163,20	16800,00	0,00	22400,00	18200,00	160563,20

4 - Ethics

1. HUMAN EMBRYOS/FOETUSES		Page
Does your research involve Human Embryonic Stem Cells (hESCs)?	◯ Yes ◉ No	
Does your research involve the use of human embryos?	◯ Yes ◉ No	
Does your research involve the use of human foetal tissues / cells?	◯ Yes ◉ No	
2. HUMANS		**Page**
Does your research involve human participants?	◯ Yes ◉ No	
Does your research involve physical interventions on the study participants?	◯ Yes ◉ No	
3. HUMAN CELLS / TISSUES		**Page**
Does your research involve human cells or tissues (other than from Human Embryos/ Foetuses, i.e. section 1)?	◯ Yes ◉ No	
4. PERSONAL DATA		**Page**
Does your research involve personal data collection and/or processing?	◯ Yes ◉ No	
Does your research involve further processing of previously collected personal data (secondary use)?	◯ Yes ◉ No	
5. ANIMALS		**Page**
Does your research involve animals?	◯ Yes ◉ No	
6. THIRD COUNTRIES		**Page**
In case non-EU countries are involved, do the research related activities undertaken in these countries raise potential ethics issues?	◯ Yes ◉ No	
Do you plan to use local resources (e.g. animal and/or human tissue samples, genetic material, live animals, human remains, materials of historical value, endangered fauna or flora samples, etc.)?	◯ Yes ◉ No	
Do you plan to import any material - including personal data - from non-EU countries into the EU?	◯ Yes ◉ No	
Do you plan to export any material - including personal data - from the EU to non-EU countries?	◯ Yes ◉ No	
In case your research involves low and/or lower middle income countries, are any benefits-sharing actions planned?	◯ Yes ◉ No	
Could the situation in the country put the individuals taking part in the research at risk?	◯ Yes ◉ No	

7. ENVIRONMENT & HEALTH and SAFETY		Page
Does your research involve the use of elements that may cause harm to the environment, to animals or plants?	◯ Yes ⦿ No	
Does your research deal with endangered fauna and/or flora and/or protected areas?	◯ Yes ⦿ No	
Does your research involve the use of elements that may cause harm to humans, including research staff?	◯ Yes ⦿ No	
8. DUAL USE		**Page**
Does your research involve dual-use items in the sense of Regulation 428/2009, or other items for which an authorisation is required?	◯ Yes ⦿ No	
9. EXCLUSIVE FOCUS ON CIVIL APPLICATIONS		**Page**
Could your research raise concerns regarding the exclusive focus on civil applications?	◯ Yes ⦿ No	
10. MISUSE		**Page**
Does your research have the potential for misuse of research results?	◯ Yes ⦿ No	
11. OTHER ETHICS ISSUES		**Page**
Are there any other ethics issues that should be taken into consideration? Please specify	◯ Yes ⦿ No	

I confirm that I have taken into account all ethics issues described above and that, if any ethics issues apply, I will complete the ethics self-assessment and attach the required documents. ☒

[How to Complete your Ethics Self-Assessment]

5 - Call specific questions

Eligibility Researcher (future fellow)

1. Were you in the last 5 years in military service? ○ Yes ◉ No

2. Did you spend time on procedures for obtaining refugee status (according to the 1951 Geneva Refugee Convention and the 1967 Protocol) in a Member State or Associated Country? ○ Yes ◉ No

3. Did you have a career break in research for a continuous period of at least 12 months within the 18 months prior to the deadline for submission of proposals (i.e. between 10/03/19 and 09/09/20)? ◉ Yes ○ No

Period of career break in research:

From (DD/MM/YYYY) 31/08/2014 To (DD/MM/YYYY) 09/09/2020 Duration (days) 2202

Nature of activities during this period in order to confirm the career break in research:

App coding in my own UK start-up (level 8 ltd). Data science at a private company (Retail Insight). One-on-one maths and physics tuition. Workshop facilitation in a private UK company (Decoded ltd)

Other Questions

1. For communication purposes only, the European Commission REA asks for permission to publish the name of the researcher (future fellow) should the proposal be retained for funding.
Does the researcher (future fellow) give this permission? ◉ Yes ○ No

2. Some national and regional public research funding authorities run schemes to fund MSCA applicants that score highly in the MSCA evaluation but which cannot be funded by the MSCA due to their limited budget. In case this proposal could not be selected for funding by the MSCA, do the researcher and supervisor consent to the European Commission disclosing to such authorities the results of its evaluation (score and ranking range) together with their names and contact details, non-confidential proposal title and abstract, proposal acronym, and host organisation? ◉ Yes ○ No

3. Do you wish to participate to the Widening Fellowships and thus increase your chances of being funded? ◉ Yes ○ No

If you don't reply or if you maintain 'No' as your answer, be aware that your proposal will not benefit from an extra chance of being funded under the Widening Fellowships call in case it cannot be funded under the MSCA-Individual Fellowships call.

The country of the selected PIC belongs to the list of widening countries. A dedicated budget (EUR 7 million) has been set aside under the Work Programme "Spreading Excellence and Widening Participation" to fund EF proposals submitted to the MSCA-IF-2020 call but which cannot be funded under the EF lists of the MSCA-IF-2020 call due to a lack of budget. EF proposals where the host organisation is located in an eligible widening country will be automatically duplicated into the Widening call only if you express your wish to do so. Your decision not to participate in the Widening call will not affect your chances of being funded directly under the MSCA-IF-2020 call.

3. Is there a secondment in Member States or Associated Countries envisaged in Part B of this proposal? ○ Yes ◉ No

Extended Open Research Data Pilot in Horizon 2020

If selected, applicants will by default participate in the Pilot on Open Research Data in Horizon 2020[1] , which aims to improve and maximise access to and re-use of research data generated by actions.

However, participation in the Pilot is flexible in the sense that it does not mean that all research data needs to be open. After the action has started, participants will formulate a Data Management Plan (DMP), which should address the relevant aspects of making data FAIR – findable, accessible, interoperable and re-usable, including what data the project will generate, whether and how it will be made accessible for verification and re-use, and how it will be curated and preserved. Through this DMP projects can define certain datasets to remain closed according to the principle "as open as possible, as closed as necessary". A Data Management Plan does not have to be submitted at the proposal stage.

Furthermore, applicants also have the possibility to opt out of this Pilot completely at any stage (before or after the grant signature). In this case, applicants must indicate a reason for this choice (see options below).

Please note that participation in this Pilot does not constitute part of the evaluation process. Proposals will not be penalised for opting out.

We wish to opt out of the Pilot on Open Research Data in Horizon 2020.	○ Yes	◉ No

Further guidance on open access and research data management is available on the Funding & Tenders portal: http://ec.europa.eu/research/participants/docs/h2020-funding-guide/cross-cutting-issues/open-access-dissemination_en.htm and in general annex L of the Work Programme.

[1] *According to article 43.2 of Regulation (EU) No 1290/2013 of the European Parliament and of the Council, of 11 December 2013, laying down the rules for participation and dissemination in "Horizon 2020 - the Framework Programme for Research and Innovation (2014-2020)" and repealing Regulation (EC) No 1906/2006.*

1. EXCELLENCE

1.1 Quality and credibility of the research/innovation project

Project overview:
Enhancing fusion rates could greatly simplify the extremely challenging engineering requirements for nuclear fusion. These challenges are rooted in the physical requirement for high kinetic energy of fusion reactants (which are typically hydrogen nuclei in plasma state) – and therefore high temperatures – believed to be inevitable for achieving substantial fusion rates. Without some form of enhancement, fusion rates are extremely low; for instance, fusion rates for D_2 molecules at room temperature have been estimated at about 10^{-64}/s[1]. In a high-density solid-state system, a rate around 10^{-20}/s would begin to become technologically interesting. Fusion rate enhancements of about 15 orders of magnitude due to electron screening effects in solid-state environments have previously been demonstrated by the supervisor of this project, Prof. Konrad Czerski[2], as well as others[3,4]. For further enhancement, other mechanisms need to be considered. There are encouraging reports of substantial enhancement of state transition rates in quantum systems at the atomic scale due to couplings between resonant subsystems: Kaur et al. 2018[5] report an 8 order of magnitude enhancement of transition rates in Rydberg atoms; Bang et al. 2019[6] suggest that such enhancements can be further amplified due to the collective quantum effect of superradiance (as will be described below). If similar enhancement mechanisms can be shown to apply to the nuclear scale – as has been recently proposed[7] and is indicated by related experiments[8,9] – then enhanced fusion in solid-state environments becomes technologically interesting. **The overall objective of this project is to provide a sound theoretical and computational footing for such proposed quantum dynamics-based fusion rate enhancement mechanisms.** Demonstrating alternative approaches to enhancing fusion rates – besides extreme temperatures – would loosen nuclear fusion engineering requirements, therefore helping fusion energy to become feasible sooner and possibly in cheaper form. Fusion energy in turn would represent a sustainable, clean, safe, yet affordable, stable, and highly scalable energy technology – technology features that today are highly sought after.

Physics overview: Nuclear fusion – even at relatively high temperatures – involves quantum tunnelling to overcome the electrostatic repulsion between nuclei. Quantum tunnelling was first proposed as an explanation for observed alpha particle emission i.e. in the context of nuclear physics. However, in recent decades, much progress in our understanding of quantum tunnelling has originated from the domains of atomic and molecular physics. This includes tunnelling rate enhancement through the coupling of matching subsystems. Concretely, this project investigates to what extent well-established lessons for tunnelling and transition rate enhancement at the atomic and molecular scales can be applied – with necessary adjustments – to the nuclear scale in order to obtain increased tunnelling probabilities i.e. faster fusion rates, and therefore simpler engineering requirements for future nuclear fusion reactors. The paragraphs below in subsection "Physics details" will review the physics underlying such established tunnelling enhancement mechanisms at the atomic scale and discuss the motivation and feasibility for adopting them to the nuclear scale, and toward fusion rate enhancement in particular.

State of the art of fusion research: Nuclear fusion research today is highly focused on magnetically confined fusion and to a lesser degree on inertially confined fusion. Freeman Dyson, one of the fathers of quantum electrodynamics, emphasised the need in science "to stay flexible and avoid premature commitment to rigid programs"[10]. Since conventional approaches to nuclear fusion continue to run into technical difficulties and delays, my supervisor, our collaborators, and I consider it prudent to contribute research on promising alternative approaches that potentially offer greater simplicity in implementations and hence reduced cost and greater speed toward application. Calls for research on alternative approaches to nuclear fusion have recently been voiced by a number of commentators[11] as well as by a Horizon 2020 funding call[12] (which resulted in the CleanHME project led by the supervisor of this

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[1] Koonin, S. E., & Nauenberg, M. (1989). Calculated fusion rates in isotopic hydrogen molecules. Nature, 339.
[2] Czerski, K., et al (2001). Enhancement of the electron screening effect for d+ d fusion reactions in metallic environments. *EPL (Europhysics Letters)*, *54*.
[3] Raiola, F., et al (2004). Enhanced electron screening in d (d, p) t for deuterated metals. *The European Physical Journal A-Hadrons and Nuclei*, *19*.
[4] Schenkel, T., et al (2019). Investigation of light ion fusion reactions with plasma discharges. *J. Appl. Phys.*, *126*.
[5] Kaur, M., et al (2018). Dynamics of resonant energy transfer in one-dimensional chain of Rydberg atoms. *The European Physical Journal D*, *72*.
[6] Bang, S., et al (2019). Superradiance and symmetry in resonant energy transfer. *ArXiv Preprint ArXiv:1912.05892*.
[7] Hagelstein, P. L., & Chaudhary, I. U. (2017). Coupling between the Center of Mass and Relative Degrees of Freedom in a Relativistic Quantum Composite and Applications. J. Cond. Mat. Nucl. Sci, 24.
[8] Metzler, F., et al (2018). Observation of non-exponential decay in X-ray and γ emission lines from Co-57. *J. Cond. Mat. Nucl. Sci*, *27*.
[9] Chumakov, A. I., et al (2018). Superradiance of an ensemble of nuclei excited by a free electron laser. *Nature Physics*, *14*.
[10] Dyson, F. (2013). "Six Cautionary Tales for Scientists" in *From Eros to Gaia*. Pantheon.
[11] See for instance Tennenbaum, J. (2020, April 27). Fusion power enters world of 'extreme light.' Asia Times. Waldrop, M. M. (2014). Alternative Fusion Technologies Heat Up. Scientific American.
[12] Call: H2020-EIC-FETPROACT-2019 (EIC Pathfinder: FET Proactive - Boosting emerging technologies).

project, Prof. Czerski). It may also be the case that different lines of fusion research will over time cross-pollinate, converge, and benefit from one another.

Methodology: At the core of this project are the development and computational implementation of quantum mechanical models that capture the dynamics of coupled nuclei under realistic conditions. The starting place is an existing toy model that the author already implemented[13] using Python's QuTiP library and which exhibits expected features of excitation transfer and enhanced transitions between coupled subsystems. As part of the project, this model will be extended to match experimental conditions and results from experiments already conducted by a collaborating group at MIT (see references and details in experimental section below). These experiments have been reported to exhibit phonon-mediated transfer of nuclear excitation in samples of coupled Fe-57 nuclei. After validating my extended model by comparing inputs and outputs with the experimental configuration, the model will be deployed to simulate behaviour (i.e. nuclear transition rates such as fusion rates) in a novel context (metal-hydrogen systems with candidate dopants as acceptor nuclei). The goal of this final part is to inform promising experimental configurations that can exhibit macroscopic effects from phonon-mediated nuclear fusion rate enhancement in solid-state environments (see below for details).

Interdisciplinary aspects: This project is highly interdisciplinary as it is located at the intersection of nuclear physics, solid-state physics, as well as atomic, molecular, and optical (AMO) physics. The project involves the development of computation as well as theory and also requires relevant insights from materials science and nuclear engineering. More specifically, the project is located at the intersection of quantum dynamics, nanostructured materials, and nuclear energy research.

Gender aspects: Due to this project being a physics project, gender aspects are limited. However, it may be mentioned that I created an open science internet platform (IDA, see projectida.org) for the discussion of research in the emerging field of solid-state nuclear science. The name of the platform – IDA – is a tribute to Ida Noddack, a nuclear physicist of the early 20th century who first proposed the possibility of nuclear fission in 1934, four years before the official discovery of fission. In part because Dr. Noddack was a woman, her suggestions remained ignored. Naming the platform after Ida Noddack, is a late tribute to such pioneering women scientists.

Physics details:

Nuclear fusion as a transition in a two-state system: Nobel laureate Julian Schwinger identified in 1991[14] that the nuclear fusion process can be expressed in a typical framing of quantum electrodynamics (QED): a two-state system. For instance, the D+D → He-4 reaction is then viewed as a two-state system where the excited state $|D_2>$ in the form of a deuterium molecule can decay to a lower-energy ground state |He-4> with the simultaneous release of 24 MeV of energy (from the mass defect). In Schwinger's framing of the fusion process as a two-state system, where the fusion event represents a state transition, well-known toolsets of QED can be applied.

Accelerated transitions at the atomic scale: The framing of nuclear fusion as a state transition draws our attention to physics where state transitions have been shown to undergo acceleration. A widely studied example is the transfer of energy between molecules of chlorophyll in close proximity inside plant cells[15]. Instead of a single excited chlorophyll molecule |e> transitioning to its ground state |g> on the nanosecond timescale, a coupled pair of molecules described by |e,g> (first excited, second ground) can transition to |g,e> (the excitation gets transferred) on the picosecond timescale without the radiation of photons. This radiationless process, known as resonance energy transfer (RET)[16], has been known experimentally since 1922[17] and has been placed on a firm QED footing since the 1980s[18]. More recently, in experiments involving Rydberg atoms, state transition rates have been increased by several orders of magnitude[19]. In these configurations, the RET processes – and therefore transition rates – are further enhanced due to a many-body quantum effect known as superradiance. Superradiance theory predicts that, when a large number of quantum states (N) is coherently excited, transition rates can be accelerated by a factor of N^2 [20]. To evaluate whether such mechanisms also apply at the nuclear scale, what needs to be considered is the nature of the couplings between

[13] Lilley, M.K. (2020) "Excitation transfer" in *Two State Quantum Systems*. https://github.com/project-ida/two-state-quantum-systems/
[14] Schwinger, J. (1991). Nuclear Energy in an Atomic Lattice—Causal Order. *Progress of Theoretical Physics*, *85*.
[15] Fassioli, F. (2014) Photosynthetic light harvesting: excitons and coherence. Journal of the Royal Society Interface 11.
[16] Jones, G. A (2019) Resonance Energy Transfer: From Fundamental Theory to Recent Applications. Frontiers in Physics, 7.
[17] Carlo, G. (1922) Über Entstehung wahrer Lichtabsorption undscheinbare Koppelung von Quantensprüngen. Z Phys. 10.
[18] Andrews D. L. (1989) A unified theory of radiative and radiationless molecular energy transfer. Chem Phys. 135.
[19] Brekke, E.G, (2009). Stimulated Emission Studies of Ultracold Rydberg Atoms, Thesis, University of Wisconsin-Madison.
[20] Dicke, R.H. (1954). Coherence in Spontaneous Radiation Processes, Physical Review, 93.

interacting molecules as well as the possible existence of alternative but comparable couplings at the nuclear scale. This will be discussed next.

Accelerated transitions at the nuclear scale: Searching for couplings similar to those that enable RET on the atomic scale would mean looking for electromagnetic couplings via the dipole/quadrupole moments of nuclei. These are the kinds of couplings that are exploited in Mössbauer spectroscopy to determine the chemical environment of nuclei in solids. Nucleus-nucleus couplings of this kind are however vanishingly small. When the dynamics of the lattice in which nuclei are embedded are considered, other possibilities come to sight. Since the 1930s, scientists have known that nucleon-nucleon interactions are momentum-dependent[21] – which forms the basis of nuclear spin-orbit coupling[22]. Although uniform motion affecting nucleons can be transformed away, the backwards and forwards motion characteristic of vibrational motion cannot. Such motion can then be thought of as a (weak) Lorentzian boost to existing spin-orbit splitting (a centre-of-mass momentum component that gets added to each nucleon's relative momentum). Consequently, nuclear states can become weakly coupled with those of nearby nuclei through a coherent vibrational field (i.e. coherent phonons). In practice, theoretical estimates of such couplings are still small compared to nuclear transition energies but are nevertheless orders of magnitude larger than the well-known but miniscule dipole/quadrupole couplings[23]. However, even small couplings are relevant in this context. This is because: (1) as shown in the RET literature[24], even small couplings can enable transfer of comparatively large excitation in case of highly resonant states i.e. well-matched energy levels between donor and acceptor subsystems; and (2) couplings can be further amplified due to superradiance.

Preliminary experimental evidence: Recent experiments at MIT have shown spatially delocalised gamma radiation from macroscopic samples of radioactive Co-57 undergoing high-frequency (THz) vibration[25,26]. In these experiments, Co-57 continuously populates 14.4 keV excited states |Fe-57*> which are then coupled to |Fe-57> ground states of nearby stable nuclei via coherent phonons. Our MIT collaborators estimate up to 100,000 excitation transfers occurring within the state lifetime of about 100 ns, implying an acceleration of the state transition Fe-57* → Fe-57 by about 5 orders of magnitude. Such observations are believed to be possible due to sufficiently substantial phonon-nuclear coupling resulting from a combination of a large number, N, of participating nuclei in the phonon coherence domain[27] and nuclear superradiance. Specifically, for a coherence length L, the number of nuclei N scales as L^3 and – because superradiance enhancements scale as N^2 – coupling strengths and therefore rate enhancements can be expected to scale as L^6. When combined with reports of macroscopic phonon coherence domains[28] and recent observations of nuclear superradiance in Fe-57 experiments[9] at the European Synchrotron, DESY, and RIKEN, it is conceivable that phonon-nuclear couplings could indeed result in observable rate enhancements of nuclear state transitions.

Connecting back to fusion: Schwinger's framing of the fusion problem D+D → He-4 as a state transition from |D_2> (treated as |He-4*>) to |He-4> allows for a direct connection between the above-mentioned experimental results suggesting accelerated nuclear state transitions. Accelerated state transitions then equate to enhanced nuclear fusion rates. It should be noted that repeated excitation transfer between D_2 and He-4 four-nucleon clusters would not be expected to yield experimentally observable results directly because the energy would remain contained within the (closed) coupled system. However, like in atomic and molecular RET, in the presence of suitable acceptor subsystems in the coupled system, transferred energy can be subdivided in the course of transfer[29] which – by the time decoherence occurs – would lead to alternative decay, including decay via particle emission. Depending on which nuclear isotopes are present as acceptor nuclei (preferably whose energy levels, or multiples thereof, are close matches with the donor subsystem), this subdivision process can lead to the emission of observable alpha particles triggered by previous fusion processes – a conjecture that is also supported by preliminary experiments[30].

Summary of objectives: The objectives of the proposed project include:

[21] Breit, G. (1937). Approximately relativistic equations for nuclear particles. *Physical Review*, *51*.
[22] Goeppert Mayer, M. (1950). Nuclear Configurations in the Spin-Orbit Coupling Model. I. Empirical Evidence. Physical Review, 78.
[23] Hagelstein, P. L. (2016). Quantum composites: A review, and new results for models for Condensed Matter Nuclear Science. J. Cond. Mat. Nucl. Sci, 20.
[24] Andrews, D. L. (2009). *Resonance energy transfer: Theoretical foundations and developing applications*. SPIE Press: Washington.
[25] Metzler, F., Hagelstein, P., & Lu, S. (2018). Observation of non-exponential decay in X-ray and γ emission lines from Co-57. J. Cond. Mat. Nucl. Sci, 27.
[26] Metzler, F. (2019). Experiments to Investigate Phonon-Nuclear Interactions (Thesis). Nuclear Science and Engineering Department, MIT, Mass.
[27] Lim, J., et al (2014). Phonon-induced dynamic resonance energy transfer. New Journal of Physics, 16.
[28] Pettit, R. M., et al (2019). An optical tweezer phonon laser. Nature Photonics, 13.
[29] Andrews, D. L. (2009). *Resonance energy transfer: Theoretical foundations and developing applications*. SPIE Press: Washington.
[30] Forbes S. (2019), Initial report on low-energy ion beam experiments with various metal targets [Conference presentation]. ICCF22, Assisi, Italy.

- Implementing the described computational quantum electrodynamics model with the goal of simulating realistic phonon-mediated RET events between atomic nuclei. The author has already implemented basic versions of such models (known as spin-boson type models)[13] which need to be extended.
- Validating the computational model using the experimental conditions and outcomes from the described Fe-57 experiments[25, 26].
- Application of the validated model to a novel context – rate enhancement of the fusion reaction $D_2 \rightarrow$ He-4 – and subsequent identification of promising experimentally accessible configurations from which macroscopically observable effects of fusion rate enhancement are expected.

The overarching objective of this research is to articulate realistic upper and lower bounds for the possibility of enhancing fusion rates via resonance energy transfer (RET) at the nuclear scale; and to identify experimental configurations that promise large versions of the effect, ideally large enough versions to become relevant for future technology development. As such, the proposed research seeks a transition from TRL 1 to TRL 2 on the Technology Readiness Level (TRL) scale.

1.2. Quality and appropriateness of the training and of the two way transfer of knowledge

What new knowledge will the researcher contribute: Having spent nine years working in a nuclear fusion research in the UK, I developed deep technical expertise related to key issues in this domain; and I developed a wide network of nuclear fusion researchers. I look forward to contributing my technical expertise to the research at USZ as well as providing access to researchers in my network. Moreover, I developed strong communication skills during my career break as I frequently taught workshops on technical subjects to business leaders during that time. As a co-founder of a company, I also benefited from exposure to the tech startup world. In this context, I gained various kinds of IT expertise, for instance the use of modern open source and collaborative ways for building and reviewing computational work with the help of a community (using GitHub and related tools). I have already applied these skills to my own continued physics work in pursuit of an open science approach to research. This involves writing computational essays, Python notebooks, blog posts, and educational science videos on YouTube. Such skills are not typically taught in a research environment and yet they are essential both for building public support for research and for effective interaction with specialised audiences[31]. I will contribute my communications and IT expertise to the work at USZ throughout my interactions with group members. Specifically, I plan to collaborate with fellow group members on blog posts and similar outreach materials. This is also a good way to transfer knowledge about open science practices to USZ researchers. I will also propose to migrate to a modern online system such as GitHub for code management and collaboration. I have previously held workshops on such tools and will provide such training to fellow researchers at USZ (events that can be open to the larger USZ community). Since 2019, I have operated a YouTube channel called "Casual Physics" where I regularly provide educational physics videos[32]. I will offer to also disseminate research updates of the Czerksi Group in novel ways such as via interviews to reach wider and more diverse audiences. Finally, on subject-oriented matters, I expect my presence at USZ to be a valuable contribution to the host organisation, particularly since my research is aligned with the objectives of the CleanHME Horizon 2020 consortium which Prof. Czerski leads, leading to synergies and ample opportunities for technical knowledge transfer.

What new knowledge will the researcher gain: Since my career goal involves providing leadership to the emerging solid-state fusion field, I need to hone my academic strategy and management skills. An experienced researcher and academic administrator such as my supervisor Prof. Czerski is an ideal mentor to this end. I seek to learn more from Prof. Czerski about thinking strategically about planning long-term research campaigns, publication sequences, and grant applications. We will discuss such matters in our biweekly meetings. Since Prof. Czerski is the coordinator of the Horizon 2020 consortium CleanHME, I also look forward to learning more about managing cross-institutional and cross-cultural collaborations. I plan to take on certain responsibilities in the context of the CleanHME project such as liaising with some of the 12 consortium members, especially those whose expertise is close to my research such as the Hagelstein Group at MIT. Finally, I look forward to learning more about applied nuclear physics research from other team members such as the ion beam accelerator work led by Dr. Targosz-Ślęczka. I expect that frequent discussions with Prof. Czerski and Dr. Targosz-Ślęczka may lead to new ideas for experimental configurations to be computationally explored and tested by my models and simulations.

Training that will be offered: Training will be primarily training-through-research. I aim to work through the proposed work packages as independently as possible with regular status updates and feedback to and from Prof. Czerski as well as other team members such as Dr. Targosz-Ślęczka. Other close collaborators will include members of Prof. Czerski's research network, especially Dr. Metzler at MIT and Dr. Galvanetto at UZH who I have already

[31] Beck, S., et al (2020). The Open Innovation in Science research field: A collaborative conceptualisation approach. Industry and Innovation, 0.
[32] See for example "Can a plant teach nuclear new tricks?" youtu.be/gvZj6LBvH80

been interacting with. Intermediate results will be shared with researchers in the Czerski Group, in the collaborative network with MIT and UZH, and in the CleanHME Horizon 2020 consortium to provide commentary and validation. Experts from these networks will also be consulted in cases where I encounter difficulties. A major part of the training comprises dealing with strategic and tactical research decisions as the research campaign evolves: this depends critically on input from an experienced researcher such as Prof. Czerski. Questions tackled in close coordination with Prof. Czerski and Dr. Targosz-Ślęczka include: When met with difficulties, how to respond to them? Which alternative approaches ought to be explored? How much time ought to be budgeted to this end? When should external experts be consulted? I expect to benefit from receiving guidance on tackling such questions. Another training element relates to the institutional setting of a research university: How to think about the impact of results and implications for follow-on research? How to think of the research project as part of a larger research program? How to obtain follow-on funding and continue development of the new knowledge area, ideally with an expanded network of collaborators? Here, too, guidance from an experienced scientist and administrator such as Prof. Czerski will represent an important training element. An important vehicle for knowledge transfer will be frequent meetings which include one-on-one meetings, group meetings, as well as on-demand meetings with collaborators (see implementation section). Another training element concerns career planning. I have developed a career plan which I will continue to discuss with other researchers in the group, especially those in similar phases of their research careers. This includes discussions on publication portfolios, job market requirements for research careers, networking opportunities to that end, as well as effective communication and presentation of one's research, including practice seminars.

1.3. Quality of the supervision and of the integration in the team/institution

The University of Szczecin (USZ) is one of the largest universities in Poland and a global leader in the emerging field of solid-state nuclear science. The supervisor of this proposed MSCA project, Prof. Konrad Czerski, was the Dean of the Faculty of Mathematics and Physics until 2019. Prof. Czerski continues to be the Head of the Department for Nuclear and Medical Physics and the eLBRUS Laboratories at USZ. Prof. Czerski has also been a long-term affiliate of the Technical University of Berlin (TUB) where he obtained his PhD and habilitation and served as a professor before joining USZ. Prof. Czerski is well known internationally for his pioneering experimental and theoretical works in the field of accelerated fusion rates in solid-state environments and the discovery of the enhanced electron screening effect (see Czerski et al. 2001 below). His main research interests are related to studies on the edge between nuclear and atomic physics, nuclear astrophysics, plasma physics and medical physics. In recent years, many of his publications were devoted to search for innovative nuclear energy sources based both on fusion and fission nuclear reactions. He published more than 100 scientific papers in international journals, supervised 10 PhDs in physics. Prof. Czerski's main responsibilities today include leadership of the Horizon 2020 consortium CleanHME which aims to demonstrate feasibility of accelerated nuclear fusion in solid-state environments such as in hydrogen-loaded metals. As the coordinating organisation of this consortium, USZ is the central node in a network of 12 consortium members and partners across Europe and North America. The following is a selection of the most outstanding papers and international projects of the supervisor with relation with this proposal.

Selection of research articles & national and international research projects:

1 - W7-X Team (K. Czerski) 2018. Magnetic configuration effects on the Wendelstein 7-X stellarator, *Nature Physics* 14. **2 - K. Czerski, D. Weißbach, A. I. Kilic, G. Ruprecht, A. Huke, M. Kaczmarski, N. Targosz-Ślęczka, K. Maass. 2016.** Screening and resonance enhancements of the 2H(d,p)3H reaction yield in metallic environments. *Europhys. Lett.* 113. **3 - G. Schiwietz, K. Czerski, M. Roth, P. Grande, V. Koteski, F. Staufenbiel. 2010.** Evidence for an Ultrafast Breakdown of the BeO Band Structure Due to Swift Argon and Xenon Ions. *Phys. Rev. Lett.* 105. **4 - K. Czerski, A. Huke, P. Heide, G. Ruprecht. 2001.** The 2H(d, p)3H reaction in metallic media at very low energies. *Europhys. Lett.* 68. **5 - K. Czerski, A. Huke, A. Biller, P. Heide, M. Hoeft and G. Ruprecht. 2001.** Enhancement of the electron screening effect for d+ d fusion reactions in metallic environments, *Europhys. Lett.* 54.

2020-2024, CleanHME Horizon 2020 project. **2015-2019**, grant at the Joint Institute for Nuclear Research, Dubna, Russia, "Induction and repair of chromosomal damage in peripheral human blood lymphocytes and human tumor cell line induced by radiation of different quality". **2017-2019**, grant of German Ministry of Industry, "Study on partitioning of nuclear waste by fractionated distillation. **2012-2015**, grant of Polish National Science Centre, "Research on deuteron fusion reactions in metallic media at low energies". **2010-2014**, EU supported project, Foundation of the eLBRUS laboratories at the University of Szczecin, construction of ultra-high vacuum accelerator for study of nuclear reactions at very low energies. **2008-2012**, grant of Polish Ministry of Science and Higher Education, "Branching ratio of deuteron fusion reactions in metallic environment at very low energies".

Integration in the team/institution: Prof. Czerski's team at USZ spans ten members, most of which are PhD holders. The most senior member of the team is Natalia Targosz-Ślęczka. Dr. Targosz-Ślęczka received her PhD in Nuclear

Physics for experimental and theoretical study of low-energy nuclear reactions in metallic environments and has been a long-term collaborator of Prof. Czerski's. She will be my main point of contact in the Czerski Group. I have lived abroad for extended periods, including a 24-month stay as a Research Associate in Sweden, and expect no difficulties in adjusting to the new environment. Both myself as well as Dr. Targosz-Ślęczka and Prof. Czerski have been part of the same collaborative research network around the subject of nuclear reactions in solid-state environments. Other members of this collaborative research network include Dr. Florian Metzler and Prof. Peter Hagelstein at MIT and Dr. Nicola Galvanetto at University of Zurich (UZH). Due to such shared contacts and research partners I expect integration into the Czerski Group to be seamless.

1.4. Potential of the researcher to reach or re-enforce professional maturity / independence

Fusion energy is a lifelong passion of mine. Throughout the first part of my nine-year research career spanning PhD, Postdoc and Junior Research Fellow at major research institutions (Imperial College; Culham Centre for Fusion Energy) I was striving to push boundaries of fusion science and technology. Aside from my five first-author publications (two of which are Physical Review Letters) and ten invited talks on theoretical, computational and experimental aspects of nuclear fusion, I was most interested in exploring novel compact plasma configurations as a path to more economical fusion power. This resulted in a collaboration with the UK's first fusion start-up, Tokamak Energy, where I secured a gift of £1M toward the development of a compact high-temperature superconducting tokamak – the first of its kind in the world. Although there was (and still is) much to learn about basic plasma physics and materials science through the operation of high temperature fusion plasmas, I grew increasingly concerned over the extreme technical requirements in thermonuclear fusion and their implications for commercialisation timelines and economic viability. In 2014, I took a step back from academia to help gain perspective and take a broader look at nuclear fusion, especially in view of other, rapidly developing areas of physics – a path that led me to identify solid-state nuclear science as a particularly promising approach. Here, at the intersection of nuclear reactions, quantum dynamics, and nanostructured materials, is where I focused my continued intellectual development and where I built connections to leading researchers in the emerging field (including to my supervisor Prof. Czerski). This is where I see my long-term career. In my time outside academia, I have gained valuable skills that I can now bring back to the scientific enterprise: particularly professional code development, data science, one-on-one teaching, and workshop facilitation. My diversity of experience has helped me develop an ability to conduct research across multiple domains, at various levels of depth, and in collaborative settings. Aside from the obvious need to be skilled in administrative and organisational aspects, I believe a mature researcher is "T-shaped" – they create ideas by making connections between different areas and can also go deep to begin concretely developing these ideas and interface with relevant experts. My path towards T-shaped maturity will be reinforced in this project as its strong technical dimension will deepen my existing physics expertise and computational skills; and its interdisciplinary orientation will broaden my exposure across related technical domains as well as to crucial strategy and management issues. My personal objective for the coming years is to lay the foundation for becoming a leading researcher in the emerging field of solid-state nuclear science. I am convinced that my path to date has contributed to this goal and that the proposed project will help me further consolidate and reinforce this development.

2. IMPACT

2.1 Enhancing the future career prospects of the researcher after the fellowship

This research promises to contribute a solid theoretical foundation to the emerging field of solid-state nuclear science and as such may catalyse a large amount of follow-on research in basic and applied domains. Presently, the largest research networks in this area include two Horizon 2020 projects (CleanHME and HERMES), a Google-led initiative[4] in the US, a program at NASA ("Lattice Confinement Fusion")[33], and a Toyota- and Nissan-led initiative in Japan. As of today, I already have contacts in each of these research networks. Due to the scope and diversity of research needed in this field, research will continue to span a wide range of institutions and geographies. My long-term career objective is to be a Europe-based researcher in a leadership role at a research organisation (such as one of the participating organisations in the above-mentioned networks) who can act as a central network node, a thought leader, and coordinator for efforts in this emerging field. Such activities require deep technical expertise (which I continue to develop), communication skills, as well as management and strategy acumen (which I seek to enhance and further develop through this project). Alongside my professional development, I have created an open science platform (IDA, see projectida.org) with the explicit goal of creating a hub for knowledge exchange and coordination of research efforts in solid-state nuclear science. Already today IDA is used by several leading researchers in this field for publishing codes and for providing literature reviews and learning materials. As part of my research project, I seek to grow and promote IDA as well as open science practices more generally. In the long run, it is my goal that IDA

[33] See Steinetz, B. M., et al (2020). Novel nuclear reactions observed in bremsstrahlung-irradiated deuterated metals. Physical Review C, 101.

and my continued professional development as a researcher will be mutually beneficial to one another. To conclude, I expect the project to be highly impactful for my career as it will allow me to deepen relationships to researchers in the emerging field of solid-state nuclear and it will greatly increase my visibility, especially as I disseminate results and share updates on ongoing work. I expect resulting publications to draw much attention and become discussed widely. I am convinced that the reputational gains will be particularly valuable in shaping my career after the action.

2.2. Proposed measures to exploit and disseminate the project results

I expect that the results of this research will place nuclear RET and the resulting acceleration of fusion rates in solid-state environments on a firm theoretical footing. There is already much interest in such results from academic groups engaged in solid-state nuclear science such as the programs in Europe, the US, and Japan mentioned in the previous paragraph. My existing connection to these groups makes it appropriate to disseminate results via a series of talks and workshops among such audiences. In the course of last year, I already attended a meeting organised by the International Society for Condensed Matter Nuclear Science and gave a seminar talk during an invited visit to MIT. I also anticipate these results to be of interest to a much wider physics audience. To disseminate the results among scientists and researchers I will take a four-pronged open science approach:

1 - Open Access papers in top-tier international journals. Specifically, I plan to publish two papers in Physical Review X (Open Access). I expect the first paper to describe the results after WP2 and the second paper to describe the results after WP3. I aim to complement these long-form papers with two short letters in PRL (where I have previously published on my nuclear fusion research as a first author).
2 - Talks and conferences. I will give talks at several international conferences such as the annual APS March Meeting where I expect to have the additional opportunity to disseminate my work through detailed post-talk discussions with researchers from different subfields.
3 - Open source dissemination of codes. The code from WP1 will be published on GitHub where I expect to receive open peer review on the code details through GitHub's "issues" feature.
4 - Regular online content for diverse physics audiences. I will continue to publish specialist research posts and computational essays on my work via the open science platform that I created as a hub for solid state nuclear science (projectida.org).

Intellectual Property (IP) issues: Since this research can be largely classified as basic research, I expect IP implications to be minimal. Neither principles of science nor computational models as such can be patented. Computer codes can be copyrighted; however, due to my commitment to open science, I will publish all codes under an open source license. There may be IP implications toward the end of the project when simulations are undertaken for identifying suitable experimental configurations: in principle, such simulations may point the way toward useful material combinations and nanostructures – which can be patented. If such possibilities shall, I will follow standard procedures for IP generated at USZ. As the holder of several patents, Prof. Czerski will be a knowledgeable point of contact in such a situation.

2.3. Proposed measures to communicate the project activities to different target audiences

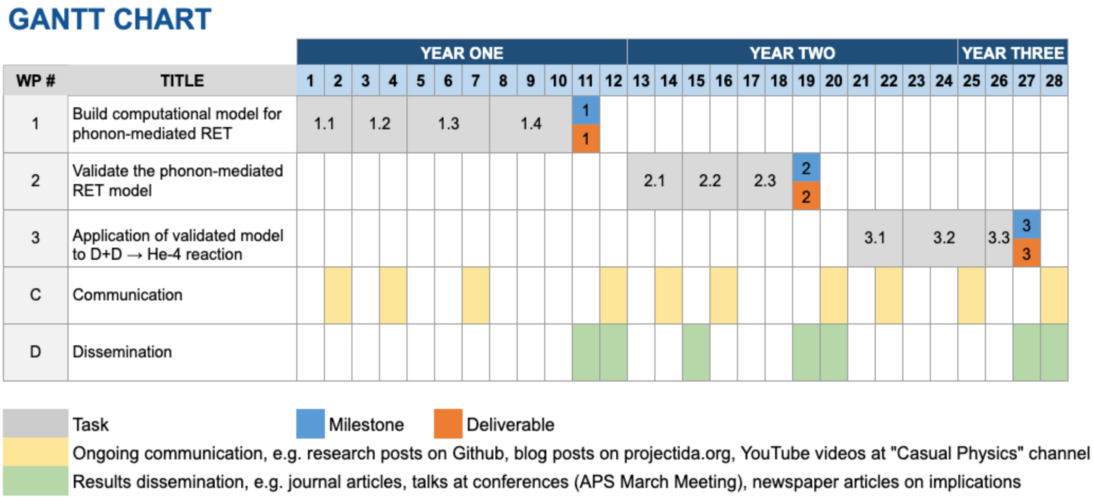
Research carried out in this project may point the way to alternative pathways and implementations of commercial nuclear fusion. Given the urgent need for clean and safe sources of power, communication of such results and their implications to general audiences is important. In particular, broad public outreach can aid in creating support for subsequent research efforts needed for further development towards technologies and applications. I believe I am well equipped to convey complex scientific results and implications in the context of my research effectively and concisely to a wide range of audiences. Specifically, I have four years of work experience as an educator where I provided training to diverse audiences on complex science and technology related issues. I am passionate about explaining and illustrating science in understandable and tangible ways, as demonstrated by my video logs and science blogging activity. Audiences that I aim to reach with my content include policy makers, industry leaders, journalists, and citizen scientists – as well as the general public more widely. I will target these audiences through a number of avenues:

1 - Research updates and summaries as blog posts. I will regularly publish research updates and summaries of my work in accessible language and with supporting learning materials on my open science platform projectida.org. On the website I use tags to identify content suitable for background levels "beginner", "intermediate", and "advanced".
2 - Educational YouTube videos. I will continue to create educational YouTube videos on my science channel "Casual Physics"[32] with varying levels of detail to cater to different audiences, including 5 min summaries, 10 min intros and 20 min deep dives.

3 - Twitter networking. I will publish ultra-short snippets of my work via Twitter on a regular basis as a way to provide insight into the process of science in addition to highlighting ongoing results.
4 - Talks for popular audiences. Using my experience as a technology education facilitator, I will create and deliver live talks/workshops with Q&A sessions via YouTube live streaming and Zoom. My close collaborator at MIT, Dr. Metzler, is part of the Google-led network on solid-state nuclear science which may lead to opportunities of presenting at Google (such as the "Google Talk" format).
5 - Newspapers and online news outlets. Through my network, I have access to contacts at major European and international newspapers, including DIE ZEIT, Der Spiegel, Wall Street Journal, and the New York Times. Together with collaborators, I seek to publish opinion pieces about the potential of innovative approaches to nuclear fusion. After each journal article publication, I will work with the USZ public relations office to issue a press release. I will also contact online outlets such as phys.org for additional coverage.

3. IMPLEMENTATION

3.1 Work plan



WP1 - Build computational model for phonon-mediated RET: To simulate RET, I will build on the paradigm of the spin boson model that captures the physics of cavity QED, where a single two-state system (TSS) interacts with a single mode of that cavity and is isolated from its environment. I have already implemented and open sourced[13] the simplest version of this model that is capable of simulating idealised RET between two TSS and a single phonon mode. The goal of this WP is to extend this computational model to include a number of effects to make physically realistic RET. Tasks for this WP include:

Task 1.1 - Handling an arbitrary number (N) of TSS: Essential for studying the extent to which superradiance affects RET. The computational intensity of the simulations will be managed by working in the Dicke basis – this reduces computational load from a scaling of 2^N to N^2.
Task 1.2 - Spatial dependence of the phonon modes: Essential to explore macroscopic phonon coherence domains.
Task 1.3 - Handling a spectrum of phonon modes: Essential for understanding the sensitivity of the RET rates to mode frequency. Spectra of phonon modes will be taken from the literature.
Task 1.4 - Coupling to the environment: Essential for modelling the competition between incoherent decay and RET. Environmental effects will first be included by adding dissipation using Brillouin–Wigner theory[34] and secondly by taking a density matrix approach by using well understood permutational invariant approaches to efficiently solve the Lindblad equation appropriate for open quantum systems [35].
Milestone 1: A computational model that can simulate a large number of nuclei (TSS) and their interactions via phonon-nuclear coupling in a lattice excited by a realistic spectrum of phonon modes with competing coherent and incoherent processes.
Deliverable 1: A collection of Python codes that contain the model will be uploaded to GitHub; several Python Notebooks will be created to illustrate key results and characteristics of the model with plots and animations. Experts will be invited to comment on and critique the implementation.

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34 Hagelstein, P. L. (2011). Energy Exchange In The Lossy Spin-Boson Model, J. Condensed Matter Nucl. Sci. 5.
35 Shammah, N. (2019). Open quantum systems with local and collective incoherent processes: Efficient numerical simulation using permutational invariance https://arxiv.org/abs/1805.05129v5

WP2 - Validate the phonon-mediated RET model: In WP2, the model that was extended in WP1 to match realistic conditions will now be compared with experimental conditions and results from the Fe-57 nuclear excitation transfer experiments at MIT[25,26]. This will be done in collaboration with the MIT researchers. The comparison with experimental parameters serves as a way to validate the model and to fine-tune model parameters. The goal of this WP is for the model to exhibit comparable outcomes from comparable input parameters as in the Fe-57 experiments.

Task 2.1 - Obtain estimates for phonon-nuclear coupling strengths: Calculations of phonon-nuclear coupling strengths have been undertaken for coupled Fe-57* → Fe-57 nuclei, Ta-181* → Ta-181 nuclei, and for D+D → He-4 nuclei[36]. To validate the model from WP1, the given Fe-57 phonon-nuclear coupling strength will be used as a starting point. Prof. Czerski, a nuclear physics expert, will be consulted to validate phonon-nuclear coupling strength calculations by Prof. Hagelstein at MIT. This calculation itself is based on recent (velocity-dependent) models of nucleon-nucleon interactions via chiral-effective field theory[37] and is beyond the scope of this project.
Task 2.2 - Determine model input parameters from experiment: phonon characteristics, i.e. spectrum and spatial distribution, coherence length: The model will then be stimulated with THz phonons (which in the Fe-57 experiments are caused by applied mechanical stress and corresponding dislocation movement). Expected phonon modes from dislocation movement in an iron lattice, as used in the experiments, are documented in Marian 2006[38].
Task 2.3 - Simulation, comparison with experiment, and sensitivity analysis: Finally, the modelled system is simulated in its entirety and results are compared to the Fe-57 experiments. Key experimental inputs in the experiments are: the number of Fe-57* nuclei (available from the number of Co-57 nuclei and decay rate) on the sample; the number of Fe-57 nuclei; the density and therefore proximity distribution of each; and applied mechanical stress. Key output parameters are the range of delocalisation of observed emission i.e. the range of excitation transfer. The range has been estimated as around 1 mm which would translate into 100,000 subsequent transfers assuming a phonon coherence length of 10 nm and the Fe-57 14 keV state lifetime of about 100 ns.
Milestone 2: The extended model from WP1 with experimentally validated parameters and behaviour.
Deliverable 2: The codes on GitHub from Deliverable 1 will be complemented with files that show simulation results corresponding to the Fe-57 experiments and their experimental parameters; a first paper will be produced to report findings from WP1 and WP2 and submitted to PRX (after publishing a preprint).

WP3 - Application of validated model to D+D → He-4 reaction: simulation of accelerated nuclear fusion as RET-enhanced state transition in a two-state system: After the model and key input parameters have been validated in WP2, in the context of a simple but not necessarily useful experiment (Fe-57 experiments), the model will now be put toward in a more interesting context: instead of transition rate enhancement from Fe-57* → Fe-57, I will consider transition rate enhancement from D_2 → He-4 i.e. accelerated fusion rates.

Task 3.1 - Determine the phonon-nuclear coupling strength: Like in WP2, first, the phonon-nuclear coupling strength, in this case for the D_2 → He-4 reaction, estimated by Prof. Hagelstein at MIT will be validated by Prof. Czerski at USZ, a nuclear physics expert. These assessments will result in a value with an upper and a lower bound across which can be scanned in simulations. In contrast to the phonon-nuclear coupling strength between Fe-57* and Fe-57 which is a constant, the phonon-nuclear coupling strength between D_2 and He-4 is a function of distance between the deuterium nuclei (and therefore dependent on the lattice configuration).
Task 3.2 - Parameter space scan to determine regions of high enhanced fusion rate: Next, the dynamic behaviour of a typical idealised lattice configuration is simulated while undergoing stimulation by THz phonons. With octahedral interstitial site occupation of deuterium nuclei in a metal lattice such a Pd, interatomic distances are on the order of 200 pm or more and even substantial tunnelling enhancement would not lead to observable effects. However, other lattice configurations can be tested such as lattices with vacancies that allow for simultaneous octahedral and tetrahedral site occupation and molecule formation. The goal is then to see how many orders of magnitude can the fusion rate be accelerated if coupling to nearby He-4 nuclei is achieved via phonon-mediated RET.
Task 3.3 - Proposal of experimental configurations that can yield observable fusion rate enhancement: The parameter scans from Milestone 3.2. can be turned into an optimisation problem where maximised fusion rates are determined as a function of realistic model input parameters (such as realistic lattice configurations and resulting interatomic distances and phonon-nuclear coupling strengths).
Milestone 3: The final milestone is the identification of promising configurations that are accessible experimentally and that would yield macroscopically observable results indicative of accelerated fusion.

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[36] Hagelstein, P. L., & Chaudhary, I. U. (2013). Central and tensor contributions to the phonon-exchange matrix element for the D2/4He transition. J. of Cond. Matt. Nuc. Sci., 15. Hagelstein, P. L. (2018). Calculation of the Boosted Spin–orbit Contribution to the Phonon–Nuclear Coupling Matrix Element for 181 Ta. J. of Cond. Matt. Nuc. Sci., 29.
[37] Machleidt, R., & Entem, D. R. (2011). Chiral effective field theory and nuclear forces. *Physics Reports*, *503*, 1–75.
[38] Marian, J., & Caro, A. (2006). Moving dislocations in disordered alloys: Connecting continuum and discrete models with atomistic simulations. Physical Review B, 74.

Deliverable 3: The codes on GitHub from Deliverables 1 and 2 will be complemented with files that show simulation results for the $D_2 \rightarrow$ He-4 reaction in different proposed experimental configurations (lattice configurations); a second paper will be produced to report findings from WP3 and submitted to PRX (after publishing a preprint).

3.2 Management structure and procedures, including risk management

The management structure involves Dr. Targosz-Ślęczka (the most senior member of the Czerski Group) as a peer as well as Prof. Czerski as the supervisor. Interaction with Dr. Targosz-Ślęczka will be almost daily in person and through messaging software. On this level, many operational issues will be discussed and minor issues informally resolved. Biweekly meetings with Prof. Czerski represent the next layer in the management structure. These meetings serve as opportunities to summarise recent results and monitor progress in accordance with the timeline. This is also the platform to address larger challenges encountered such as modelling challenges. If such challenges cannot be resolved between myself and Prof. Czerski, I can involve domain level experts from our network, including Prof. Hagelstein at MIT, Prof. Andrews in Norwich, or Prof. Chenu at Ikerbasque (all of whom are quantum dynamics experts). **Financial management** of the project will be handled by Prof. Czerski's administrative staff. The same staff already handle financial management of the CleanHME Horizon 2020 project of which Prof. Czerski is the coordinator. **Administrative risk** that might endanger the action include the possibility of another Covid outbreak or other events that prevent freedom of movement. This could also include Brexit-related issues since I am a UK citizen. However, since the large majority of the proposed action comprises modelling and computational work as well as coordination and interaction with collaborators that are remote anyways, the action should not be jeopardised in case there are travel constraints. **Research risks** include unexpected challenges encountered in the modelling process, especially when a match with the Fe-57 experiments at MIT is sought. Early theoretical issues with the model and simulations can be resolved by consulting domain level experts in our network, as laid out above. Mismatch with experiment is more challenging. However, such risks would only occur later in the project i.e. towards the end of WP2. This means that much of the action would have already been completed in the form of an extended model for nuclear RET that is matched to experimental inputs. In case, experimental and computational results differ, the estimated parameters (such as expected phonon characteristics and estimated phonon-nuclear coupling strengths) need to be revisited and possibly adjusted to see whether a match with experiment can be achieved within a reasonable range of these parameters. If still no match with experiment is achieved, the model itself needs to be revisited and revised, in close collaboration with experts in our network (see above). Even if such a model cannot match the results of the Fe-57 experiments, it would still represent a substantial contribution worthy of a publication. Such a publication could then serve as a basis for discussion among a wider community to identify problems with the models or with the Fe-57 experiments. As such the action would lead to new scientific insight one way or another. Moreover, even in case of mismatch with the Fe-57 experiments, the model and simulations can be used to predict simpler experimental configurations that allow for a better match between experimental and computational results. For instance, among our collaborators are groups that work with ultrafast lasers that can provide more deliberate phonon stimulation than the mechanical stress experiments at MIT. In summary, I am confident that the action will lead to a substantial scientific contribution despite existing research risks.

3.3 Institutional environment (infrastructure)

Since the majority of work is theoretical and computational in nature, the requirements on physical infrastructure are limited. The most relevant physical infrastructure is computational infrastructure. Here, I already have guaranteed access to cloud-based high-performance computing resources (MIT Supercloud) via our collaborators at MIT (which are part of Horizon 2020 CleanHME project led by Prof. Czerski). Besides computational resources, what is most important to my project is the social and intellectual infrastructure. In this regard, being part of the CleanHME project is a major advantage as it guarantees frequent exchange with a range of experts directly relevant to my research. Another relevant aspect are the close ties of Prof. Czerski's team to the Greater Berlin area (which is only about 1.5 hours from Szczecin). Prof. Czerski himself and several team members live in Berlin (commuting to Szczecin) and have close ties with a number of relevant institutions there, including the Technical University of Berlin, Humboldt University, and the Institute for Solid-State Nuclear Physics. In coordination with Prof. Czerski and Dr. Targosz-Ślęczka, I will be able to participate in interactions with Berlin-based institutions, team members, and collaborators. The Czerski Group's local network is beneficial in a number of ways, especially since the region hosts many leading academics in quantum dynamics such as Prof. Volkhard May (author of an authoritative textbook relevant to this project), the Dahlem Center for Complex Quantum Systems, and leading research centres – which provide ample international networking opportunities. Particularly relevant centres include the Berlin-based Max-Born-Institute for Nonlinear Optics and Short Pulse Spectroscopy (MBI) and the Paul Drude Institute for Solid State Electronics (PDI) as well as the nearby Helmholtz-Zentrum Dresden-Rossendorf (HZDR). Prof. Czerski and Dr. Targosz-Ślęczka offered to introduce me to researchers with matching interests in such relevant institutions.

4. CV OF THE EXPERIENCED RESEARCHER

Dr. Matthew Lilley

https://mattlilley.com | info@mattlilley.com

Plasma physicist with extensive experience working in a collaborative multidisciplinary research environment, primarily on non-linear phenomenon, instabilities and dynamical systems. Passionate about pursuing fusion as a sustainable energy source for the future.

Education and Training:

1st October 2005 – 1st June 2009
Imperial College London, PhD in Plasma Physics

1st October 2001 – 14th July 2005
University of Warwick, MPhys 1st Class (89%, top of class) in Mathematics and Physics

Research Experience:

Imperial College London, UK
Junior Research Fellow
1st September 2011 - 31st August 2014
Research focus - Fusion energy: Nonlinear modelling of plasma instabilities driven by energetic particles, electrostatic confinement and particle dynamics in systems with discrete symmetry.

Achievements:

- Published 7 peer-reviewed articles in collaboration with national and international laboratories, including an Editor's Highlight Physical Review Letter [8-14]
- Discovered a new class of high frequency Compressional Alfvén eigenmode instability on MAST [14]
- Built PIC version of the bump-on-tail (BOT) fast particle code I created during my postdoc
- Optimised BOT (written in Matlab) and re-coded in Fortran, increasing speed by a factor of 4, allowing an investigation of long-time evolution of beam-driven nonlinear waves
- Invited to lecture at York University [F] and UCL [G] and to present invited talks at national [H] and international [I,J] conferences on the non-linear evolution of a fast-particle driven waves.
- Fostered collaboration with industrial partner, Tokamak Energy, securing a gift of a £1M experimental device
- Constructed and costed a research proposal worth £1.6M involving negotiations with multiple stakeholders
- Coordinated experiments with scientists at CCFE and the International Tokamak Physics Activity panel to gather data on fast particle instabilities.

Responsibilities:

- Manage a personal research budget of £25,000 and a student research budget of £12,000
- Supervise research of a PhD student, 2 Masters students and 1 third-year student
- Manage and execute a personal research programme
- Train postgraduates: lectures in advanced mathematical methods

Chalmers University of Technology, Sweden
Research Associate
1st September 2009 - 31st August 2011
Research focus - Fusion energy: nonlinear modelling of plasma instabilities

Achievements:

- Built open source MatLab software – BOT (https://github.com/mklilley/BOT) – now used by several laboratories to study fast particle instabilities.
- Published 2 peer-reviewed articles [6,7]
- Invited to give a summer school lecture [C] and present invited talks at two international conferences [D,E]
- Received a highly competitive Junior Research Fellowship position at Imperial College

Responsibilities:

- Manage and execute a personal research programme
- Mentoring and informal supervision of a PhD student
- Training masters students: lectures in electromagnetic waves

Imperial College London, UK
PhD student
1st September 2005 - 1st June 2009
Research focus - Fusion energy: Compressional Alfvén eigenmodes in spherical tokamaks

Achievements:

- Published several peer-reviewed articles on both theoretical and experimental topics, including a Physical Review Letter [1-5].
- Presented prize-winning poster and oral presentations [A] at national and international conferences. Was invited to lecture at the Culham theory meeting [B].
- Organised the 2008 Institute of Physics conference on plasma physics.
- Engaged with MP to promote the importance of fusion to the public.

Responsibilities:

- Manage and execute a personal research programme
- Running problem-solving classworks for undergraduates
- Mentoring a student with learning difficulties

Other Professional Experience:

Project IDA, UK
Founder
10th February 2020 – Present

- Founded an open science internet platform (https://www.project-ida.org) for the discussion of research in the emerging field of solid-state nuclear science
- Wrote computational essays on quantum dynamics, in the form of Jupyter notebooks, which I open sourced on GitHub (https://github.com/project-ida/two-state-quantum-systems) and made accessible on the research section of IDA (https://www.project-ida.org/research-codes).

Decoded, UK
Product Developer / Freelance facilitator
22nd February 2017 – 30th September 2018 / 10th January 2019 – Present

- Creating new, and enhancing existing, educational experiences in the area of technology, e.g. blockchain, machine learning, data, code and quantum computing
- Create hands-on tools to help bring tech concepts to life
- Delivering the courses to non-technical audiences

Retail Insight, UK
Senior Analyst - Decision Science

1st July 2015 – 15th December 2015

- Created an algorithm in python to optimise price reductions and times in order to minimise supermarket waste
- Provided informal training for employees to introduce mathematical rigour into their data analysis techniques
- Presented results to clients

Level 8 Ltd, UK
Founder
21st October 2013 – 3rd January 2020

- Founded a company with 2 fellow physicists in order to fund our fusion energy ideas
- Created a hybrid app called Squidler (https://squidler.com) using Ionic, ActionHeroJS, Redis and MongoDB

Self-employed, UK
Freelance Physicist, Tutor & Developer
1st September 2014 - Present

- Published a peer-reviewed article with international collaborators [15]
- Taught maths and physics to students with a variety of abilities
- Designed and created a brand http://mattlilley.com for my services and for others (http://rchapmanharris.com)
- Became Chief Technology Officer for The Curtain Works (https://thecurtainworks.com/). Added new and extended existing features to flesh out the initial site design and took the site live.

Publications – Peer Reviewed:

[15] Eriksson F, Nyqvist R M, **Lilley M K**, 2015, Kinetic theory of phase space plateaux in a non-thermal energetic particle distribution, **Physics of Plasmas**, Vol: 22, 092126

[14] Sharapov, S E, **Lilley M K**, et.al, 2014, Bi-directional Alfvén Cyclotron Instabilities in the Mega-Amp Spherical Tokamak, **Physics of Plasmas** Vol:21, 082501

[13] **Lilley M K**, Nyqvist R M, Formation of Phase Space Holes and Clumps, 2014, **Physical Review Letters**, Vol:112, 155002 **- Editor's Highlight**

[12] Meyer H, et.al, 2013, Overview of physics results from MAST towards ITER/DEMO and the MAST Upgrade, **Nuclear Fusion**, Vol:53, 104008

[11] Sharapov S E, et.al, 2013 Energetic Particle Instabilities in Fusion Plasmas, **Nuclear Fusion**, Vol:53, 104022

[10] Gryaznevich M, Svoboda V, Stockel J, et al., 2013, Progress in application of high temperature superconductor in tokamak magnets, **Fusion Engineering and Design**, Vol:88, 1593

[9] Nyqvist R M, **Lilley M K**, Breizman BN, 2012, Adiabatic description of long range frequency sweeping, **Nuclear Fusion**, Vol:52, 094020

[8] **Lilley M K**, Breizman B N, 2012, Convective transport of fast particles in dissipative plasmas near an instability threshold, **Nuclear Fusion**, Vol:52, 094002

[7] Lloyd B, Akers RJ, Alladio F, et al., 2011, Overview of physics results from MAST, **Nuclear Fusion**, Vol:51, 094013

[6] **Lilley M K**, Breizman B N, Sharapov SE, 2010, Effect of dynamical friction on nonlinear energetic particle modes, **Physics of Plasmas**, Vol:17, 092305

[5] Meyer H, Akers RJ, Alladio F, et al., 2009, Overview of physics results from MAST, **Nuclear Fusion**, Vol:49, 104017

[4] **Lilley M K**, Breizman B N, Sharapov SE, 2009, Destabilizing Effect of Dynamical Friction on Fast-Particle-Driven Waves in a Near-Threshold Nonlinear Regime, **Physical Review Letters**, Vol:102, 195003

[3] Zhang Y, Heidbrink WW, Zhou S, et al., 2009, Doppler-shifted cyclotron resonance of fast ions with circularly polarized shear Alfven waves, **Physics of Plasmas**, Vol:16, 055706

[2] Gryaznevich M P, Sharapov S E, **Lilley M**, et al., 2008, Recent experiments on Alfven eigenmodes in MAST, **Nuclear Fusion**, Vol:48, 084003

[1] **Lilley M K**, Sharapov S E, 2007, Compressional Alfven and ion-ion hybrid modes in the deuterium-tritium plasma of a spherical tokamak power plant**, Physics of Plasmas**, Vol:14, 082501

Invited Talks:

[K] Research Laboratory of Electronics, MIT, Experiments in metal hydrogen systems, 2019

[J] 55th Sherwood Fusion Theory Conference, On the Formation of Phase Space Holes and Clumps, 2014

[I] European Physical Society Plasma Physics Conference, Energetic Particle Modes from bump on tail to tokamak, 2012

[H] Institute of Physics Plasma Physics Conference, Nonlinear wave-particle interactions in plasmas, 2012

[G] UCL, Feeling the Fusion Burn, 2013

[F] York Plasma Institute, Dynamics of a nonlinear resonance, 2011

[E] European Fusion Theory Conference, Nonlinear energetic particle modes: from bump on tail to tokamak, 2011

[D] 12th IAEA TCM on Energetic Particles in Magnetic Confinement Systems, Nonlinear energetic particle modes: from bump on tail to tokamak, 2011

[C] ITER Summer School, Nonlinear energetic particle modes: from bump on tail to tokamak, 2011

[B] Culham Theory Meeting – January, Destabilizing effect of dynamical friction on fast particle driven waves, 2009

[A] 50th Sherwood Fusion Theory Conference, Destabilizing effect of dynamical friction on fast particle driven waves – PRIZE WINNER, 2009

5. CAPACITY OF THE PARTICIPATING ORGANISATIONS

List of participating organisations

Participating organisations	Legal Entity Short Name	Country	Supervisor	Role of partner organisation
University of Szczecin	USZ	Poland	Prof. Konrad Czerski	Beneficiary

University of Szczecin - USZ - Poland

General description	University of Szczecin (USZ) founded 30 years ago, is a dynamically developing institution with over twenty thousand students being educated in 44 major courses. It is engaged in cooperation confirmed by bilateral agreements with over 135 universities and research institutions.
Academic organisation	Yes
Role and profile of key persons (supervisor)	Supervisor - Prof. Konrad Czerski, Head of Department for Nuclear and Medical Physics and eLBRUS laboratories at the University of Szczecin; till Sep 2019 also Dean of the Faculty of Mathematics and Physics.
Dept./Division / Laboratory	Czerski Group at the Department for Nuclear and Medical Physics at the Faculty of Mathematics and Physics of USZ.
Key research facilities, Infrastructure and Equipment	The proposed project requires mostly computational resources which are already guaranteed through the bilateral cooperation between USZ and MIT. However, experimental facilities at USZ and close interaction experimental researchers operating these facilities can be helpful in informing relevant modelling and simulation cases. To this end, the following facilities are of particular interest: ● ultra-high vacuum accelerator system for low energy ion bombardment and ion implantation, specifically of deuteron ions into metal targets ● diagnostic systems for AES, low-level spectroscopy, mass spectroscopy, NMR spectrometer, optical diagnostic systems ● HP Germanium, NaJ and semiconductor detectors, nuclear electronics
Independent research premises?	Yes – USZ facilities are all independent.
Previous and current involvement in research and training programmes	2020-2024, CleanHME Horizon 2020 project. 2015-2019, grant at the Joint Institute for Nuclear Research, Dubna, Russia, “Induction and repair of chromosomal damage in peripheral human blood lymphocytes and human tumor cell line induced by radiation of different quality”. 2017-2019, grant of German Ministry of Industry, “Study on partitioning of nuclear waste by fractionated distillation. 2012-2015, grant of Polish National Science Centre, “Research on deuteron fusion reactions in metallic media at low energies”. 2010-2014, EU supported project, Foundation of the eLBRUS laboratories at the University of Szczecin, construction of ultra-high vacuum accelerator for study of nuclear reactions at very low energies. 2008-2012, grant of Polish Ministry of Science and Higher Education, “Branching ratio of deuteron fusion reactions in metallic environment at very low energies”.
Relevant publications and/or research/innovation products	1 - W7-X Team 2018. Magnetic configuration effects on the Wendelstein 7-X stellarator, Nature Physics 14. 2 - K. Czerski, et.al. 2016. Screening and resonance enhancements of the 2H(d,p)3H reaction yield in metallic environments. Europhys. Lett. 113. 3 - G. Schiwietz, et.al. 2010. Evidence for an Ultrafast Breakdown of the BeO Band Structure Due to Swift Argon and Xenon Ions. Phys. Rev. Lett. 105. 4 - K. Czerski, et.al 2001. The 2H(d, p)3H reaction in metallic media at very low energies. Europhys. Lett. 68. 5 - K. Czerski, et.al 2001. Enhancement of the electron screening effect for d+ d fusion reactions in metallic environments, Europhys. Lett. 54.

6. ETHICS ISSUES

There are no special ethics issues associated with this project. No human subject, regulated substances, or proprietary information are involved. All Project activities will be undertaken within the clear boundaries of national and EU legal frameworks.