Cold Atoms and Climate Change

An Inter-disciplinary Workshop on Environmental Applications of Quantum Sensors

Origin, Context & Objectives

https://arxiv.org/pdf/2201.07789.pdf

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Alonso et al, arXiv:2201.07789

John Ellis

KING'S College LONDON

Genesis

- NERC funding to King's for activities promoting

  "Discipline-Hopping for Environmental Solutions"

- Quantum sensors using cold atoms offer one possibility

- Proposal encouraged by Physics Department - Ruth Gregory, Chris Lorenz, Malcolm Fairbairn

- Enthusiastic collaboration from Emma Tebbs (Geography)

From our NERC Proposal

- Quantum sensor technologies based on cold atom physics have many applications that are of interest to NERC, including measurements of gravitational fields for monitoring effects of climate change, agriculture and prospecting, as well as sensing magnetic fields.

- These technologies can be integrated into new satellite Earth Observation missions, contributing to novel solutions for monitoring and managing the impacts of climate change and supporting the UN Sustainable Development Goals.

- The King's Physics Department participates] in the AION project funded by UKRI through STFC and EPSRC to employ cold atoms for experiments in fundamental physics.

- We propose a workshop to bring together cold atom physicists, members of the AION Collaboration and experts on the quantum sensors of interest to NERC from King's and elsewhere

The Context (1)

- Earth Observation is key to monitoring and understanding climate change - Emma Tebbs
- The UK has been making substantial investments in Quantum Technology - Peter Knight
- Quantum sensing offers new perspectives in environmental monitoring - Kai Bongs
- The UK has initiated a Quantum Technology for Fundamental Physics programme in which King's Physics is participating - Oliver Buchmueller

The Context (2)

- Natural hazards research at KCL - Bruce Malamud
- Satellite measurements key for monitoring changes in terrestrial mass distribution - Rene Forsberg
- In particular changes in water and ice levels - Fiona Turner
- Quantum measurements from space could take Earth Observation to the next level - Federica Migliaccio

Motivations

- In the Physics Department, we want to use cold atoms to probe fundamental physics, e.g., gravity, dark matter and quantum mechanics
- Our programme envisages a series of experiments of increasing sizes measuring interference effects between atoms
- Our long-term ambition is perform these experiments using satellites
- Many of the technologies are common to those to be used for Earth Observation missions

Motivations

Engaging the next generation: student presentations

- Review of User Requirements for Earth Observation Applications - Gabriella Fasoli
- Atom Gravimetry, Accelerometry & Interferometry - John Carlton

Making Common Cause

- Have collaborated with experts in atomic clocks (next-generation time-keeping and geodesy) and Earth Observation to propose jointly to ESA a road-map for developing and deploying cold atoms in space

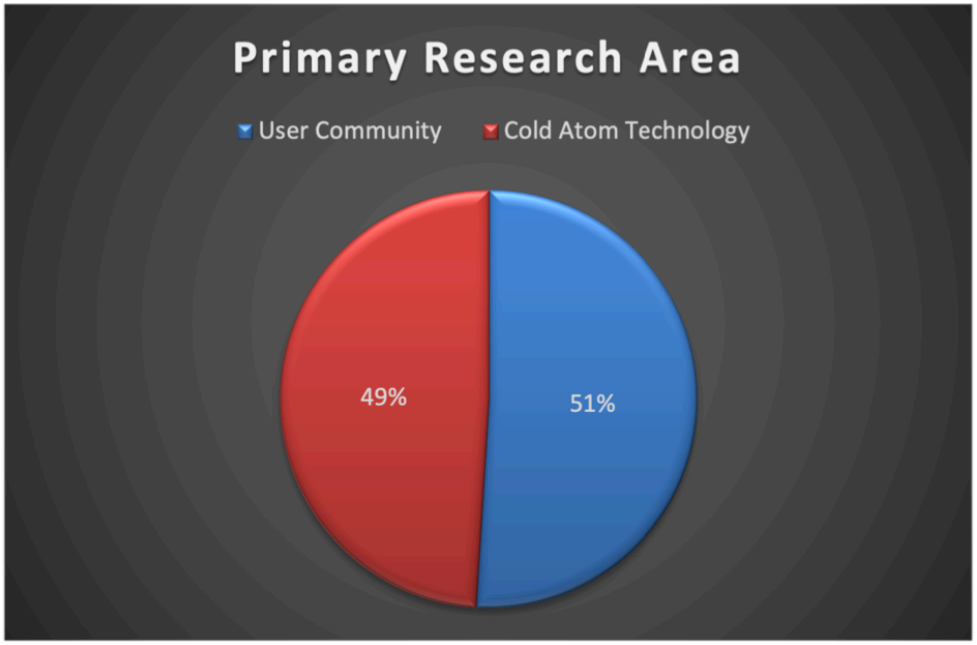
Alonso, …, Badurina, …, JE, …, McCabe et al, arXiv:2201.07789

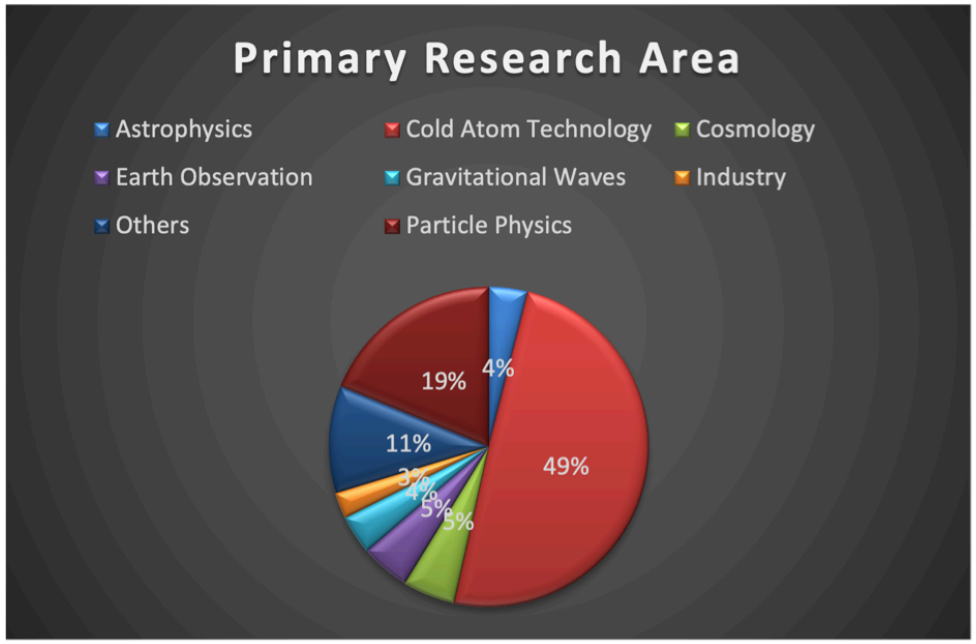
- The road-map starts from existing terrestrial cold-atom projects, and progresses via pathfinder projects towards long-term scientific space missions

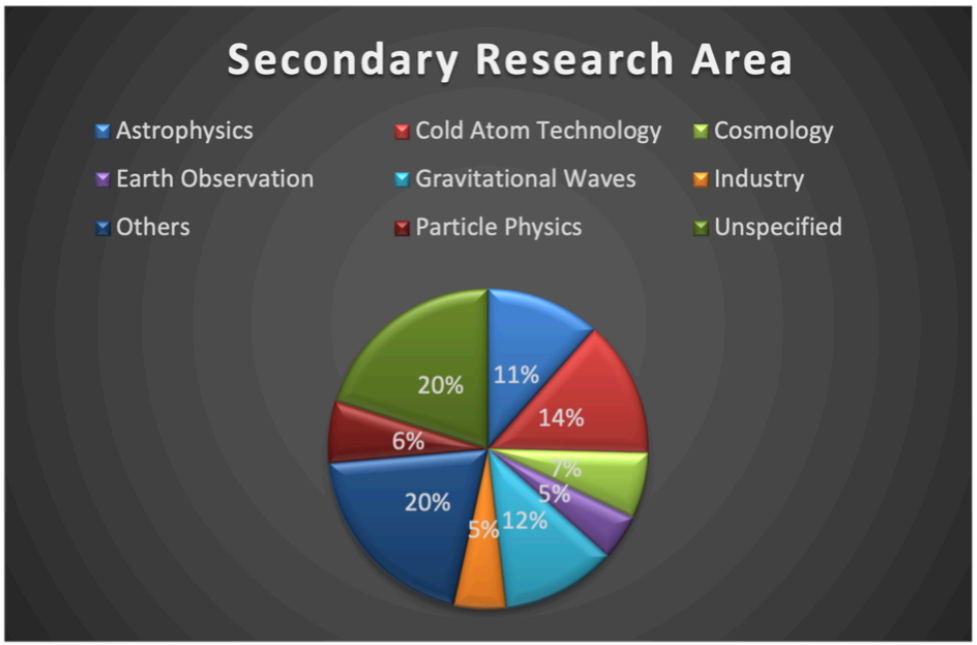
- Aim to develop technological readiness levels of cold atoms and optimize synergies between different scientific missions

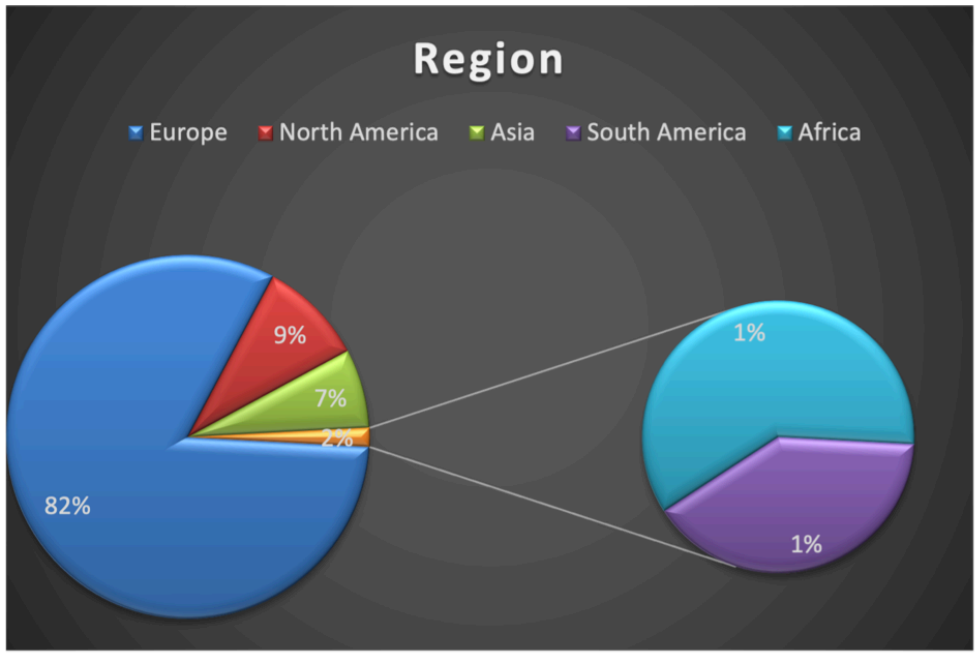
- Joint proposal for cold atom road-map presented to ESA

Participants in Community Workshop







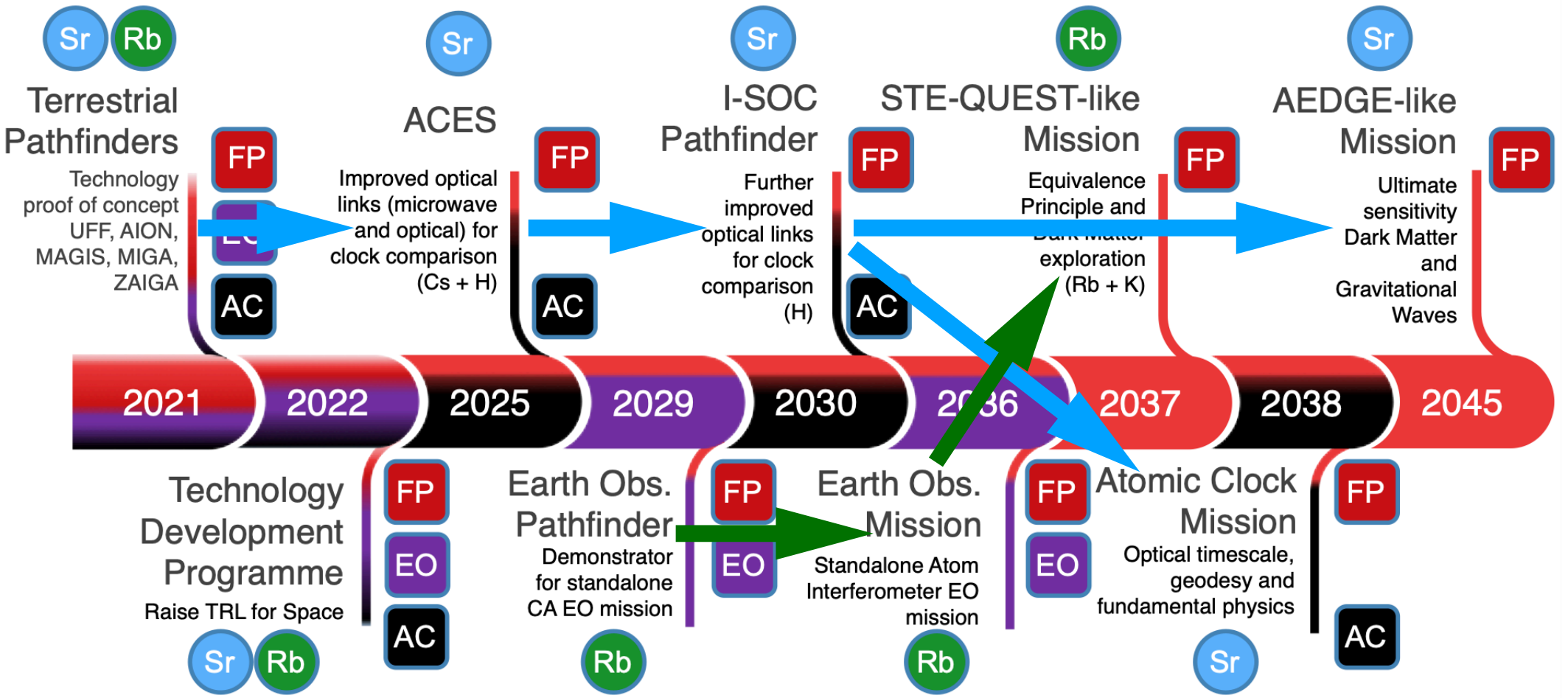


Common Technologies

- Preferred cold atom species: strontium & rubidium
- Strontium: atomic clocks and interferometric detectors for dark matter and gravitational waves - AION & AEDGE
- Rubidium: technology more advanced, preferred for Earth Observation and space-borne probe of equivalence principle, dark matter and quantum mechanics using Bose-Einstein condensates - STE-QUEST

Alonso, …, Badurina, …, JE, …, McCabe et al, arXiv:2201.07789

Community Proposal for ESA Road-Map for Cold Atoms in Space



Legends:

Main Cold Atom Species

Sr Strontium

Rb Rubidium

Areas of Relevance

EO Earth Observation

AC Atomic Clocks

FP Fundamental Physics

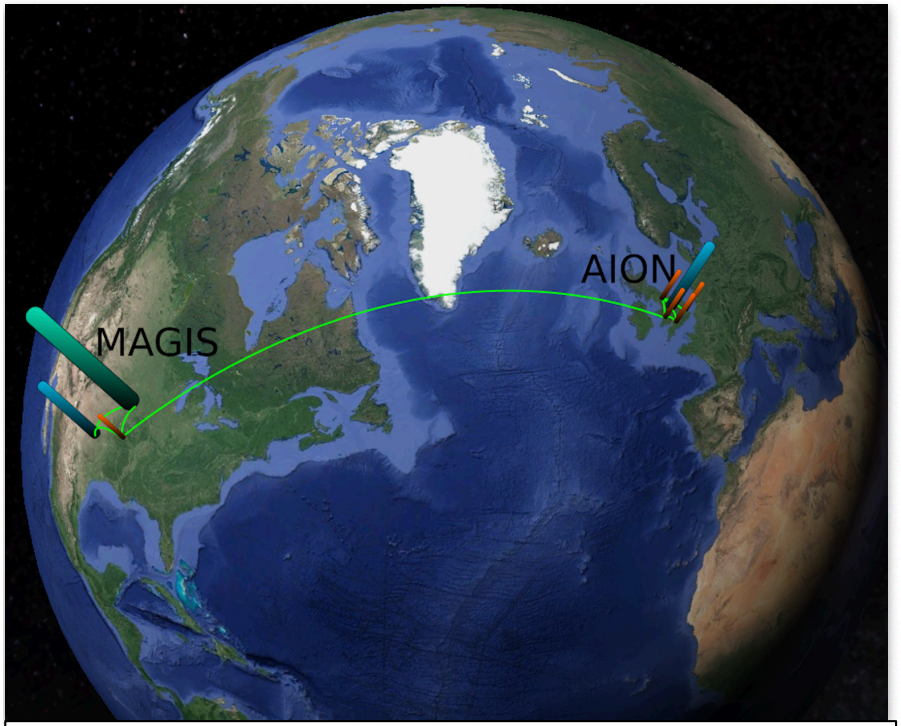
Main Milestone Area (colour coded)

2045 Example: Fundamental Physics

AION Collaboration

L. Badurina[1], S. Balashov[2], E. Bentine[3], D. Blas[1], J. Boehm[2], K. Bongs[1], A Beniwal[1], D. Bortoletto[1], J. Bowcock[5], W. Bowden[6,*], C. Brew[2], O. Buchmueller[6], J. Coleman[2], J. Carlton[1], G. Elertas[1], J. Ellis[1,&], C. Foot[3], V. Gibson[7], M. Haehnelt[7], T. Harte[7], R. Hobson[6,*], M. Holynski[1], A. Khazov[2], M. Langlois[4], S. Lellouch[4], Y.H. Lien[4], R. Maiolino[7], P. Majewski[2], S. Malik[6], J. March-Russell[1], C. McCabe[1], D. Newbold[2], R. Preece[3], B. Sauer[6], U. Schneider[7], I. Shipsey[3], Y. Singh[1], M. Tarbutt[6], M. A. Uchida[7], T. V-Salazar[2], M. van der Grinten[2], J. Vossebeld[4], D. Weatherill[3], I. Wilmut[7], J. Zielinska[6]

[1]Kings College London, [2]STFC Rutherford Appleton Laboratory, [3]University of Oxford, [4]University of Birmingham, [5]University of Liverpool, [6]Imperial College London, [7]University of Cambridge



Network with MAGIS project in US

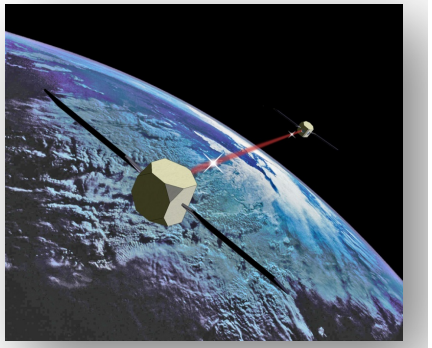
MAGIS Collaboration (Abe et al): arXiv:2104.02835

AION

AEDGE:
Atomic Experiment for Dark Matter and Gravity Exploration in Space

Beyond LISA

Yousef Abou El-Neaj,[1] Cristiano Alpigiani,[2] Sana Amairi-Pyka,[3] Henrique Araújo,[4] Antun Balaž,[5] Angelo Bassi,[6] Lars Bathe-Peters,[7] Baptiste Battelier,[8] Aleksandar Belić,[5] Elliot Bentine,[9] José Bernabeu,[10] Andrea Bertoldi,[8,*] Robert Bingham,[11] Diego Blas,[12] Vasiliki Bolpasi,[13] Kai Bongs,[14,*] Sougato Bose,[15] Philippe Bouyer,[8,*] Themis Bowcock,[16] William Bowden,[17] Oliver Buchmueller,[4,@] Clare Burrage,[18] Xavier Calmet,[19] Benjamin Canuel,[8,*] Laurentiu-Ioan Caramete,[20,*] Andrew Carroll,[16] Giancarlo Cella,[21,22] Vassilis Charmandaris,[23] Swapan Chattopadhyay,[24,25] Xuzong Chen,[26] Maria Luisa Chiofalo,[21,22] Jonathon Coleman,[16,*] Joseph Cotter,[4] Yanou Cui,[27] Andrei Derevianko,[28] Albert De Roeck,[29,30,*] Goran Djordjevic,[31] Peter Dornan,[4] Michael Doser,[30] Ioannis Drougkakis,[13] Jacob Dunningham,[19] Ioana Dutan,[20] Sajan Easo,[11] Gedminas Elertas,[16] John Ellis,[12,32,33,*] Mai El Sawy,[34] Farida Fassi,[35] Daniel Felea,[20] Chen-Hao Feng,[8] Robert Flack,[15] Chris Foot,[9] Ivette Fuentes,[18] Naceur Gaaloul,[36] Alexandre Gauguet,[37] Remi Geiger,[38] Valerie Gibson,[39] Gian Giudice,[33] Jon Goldwin,[14] Oleg Grachov,[40] Peter W. Graham,[41,*] Dario Grasso,[21,22] Maurits van der Grinten,[11] Mustafa Gündogan,[3] Martin G. Haehnelt,[42,*] Tiffany Harte,[39] Aurélien Hees,[38,*] Richard Hobson,[17] Bodil Holst,[43] Jason Hogan,[41,*] Mark Kasevich,[41] Bradley J. Kavanagh,[44] Wolf von Klitzing,[13,*] Tim Kovachy,[45] Benjamin Krikler,[46] Markus Krutzik,[3,*] Marek Lewicki,[12,47,*] Yu-Hung Lien,[15] Miaoyuan Liu,[26] Giuseppe Gaetano Luciano,[48] Alain Magnon,[49] Mohammed Mahmoud,[50] Sarah Malik,[4] Christopher McCabe,[12,*] Jeremiah Mitchell,[24] Julia Pahl,[3] Debapriya Pal,[13] Saurabh Pandey,[13] Dimitris Papazoglou,[51] Mauro Paternostro,[52] Bjoern Penning,[53] Achim Peters,[3,*] Marco Prevedelli,[54] Vishnupriya Puthiya-Veettil,[55] John Quenby,[4] Ernst Rasel,[36,*] Sean Ravenhall,[9] Haifa Rejeb Sfar,[29] Jack Ringwood,[16] Albert Roura,[56,*] Dylan Sabulsky,[8,*] Muhammed Sameed,[57] Ben Sauer,[4] Stefan Alaric Schäffer,[58] Stephan Schiller,[59,*] Vladimir Schkolnik,[3] Dennis Schlippert,[36] Christian Schubert,[3,*] Armin Shayeghi,[60] Ian Shipsey,[9] Carla Signorini,[21,22] Marcelle Soares-Santos,[53] Fiodor Sorrentino,[61,*] Yajpal Singh,[14,*] Timothy Sumner,[4] Konstantinos Tassis,[13] Silvia Tentindo,[62] Guglielmo Maria Tino,[63,64,*] Jonathan N. Tinsley,[63] James Unwin,[65] Tristan Valenzuela,[11] Georgios Vasilakis,[13] Ville Vaskonen,[12,32,*] Christian Vogt,[66] Alex Webber-Date,[16] André Wenzlawski,[67] Patrick Windpassinger,[67] Marian Woltmann,[66] Michael Holynski,[14] Efe Yazgan,[68] Ming-Sheng Zhan,[69,*] Xinhao Zou,[8] Jure Zupan[70]



White paper submitted to ESA Voyage 2050 Call

Abou El-Neaj, …, JE et al: arXiv:1908.00802

Voyage 2050

Final recommendations from the Voyage 2050 Senior Committee

Large missions:

- Moons of the Giant Planets
- Exoplanets
- New Physical Probes of the Early Universe: Fundamental physics and astrophysics

Possible Medium missions:

- … QM & GR (cold atoms?)

Technology development recommendations for Cold Atom Interferometry

- for gravitational wave detectors in new wavebands …, detectors for dark matter candidates, sensitive clock tests of general relativity, tests of wave function collapse ….
- must reach high technical readiness level, be superior to classical technologies
- start with atomic clocks, on free-flyer or ISS?
- M-mission?

In parallel: ESA Call for M, F-Class Science Missions

call for missions 2021

esa

Call for missions 2021 » Home

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- Phase-1 proposal
- Workshop
- Phase-2 proposal
- Endorsement letters
- Q & A

CALL FOR A MEDIUM-SIZE AND A FAST MISSION OPPORTUNITY IN ESA'S SCIENCE PROGRAMME

Update 3 February 2022: A Q&A page has been added with answers to questions posed after the briefing meeting.

Update 13 January 2022: The presentation from the briefing meeting is available to download here (pdf).

Issue date: 13 December 2021

The ESA Director of Science solicits the scientific community in ESA's Member States for proposals for both a "Fast" mission opportunity (to be launched in the 2030-2031 timeframe) and for a Medium mission opportunity (to be launched around 2037).

The new long-term scientific plan Voyage 2050, for the Science Programme of the European Space Agency (ESA), has been issued in June 2021, following a broad consultation of the scientific community and a peer review process, with final recommendations issued by an independent scientific Senior Committee.

The plan includes three Large (L) missions in selected science themes (Moons of the Giant Planets, From Temperate Exoplanets to the Milky Way, and New Physical Probes of the Early Universe) and a set of Medium (M) and Fast (F) missions.

The definition of the F and M space missions is based on a competitive, peer-reviewed selection process. Even though the Voyage 2050 plan identifies a set of possible themes for the Medium missions, proposals in all fields of space science will be considered, with no prejudice.

DOCUMENTATION

Letter of Invitation from the Director of Science (pdf)

Call for a Medium-size and a Fast mission opportunity in ESA's Science Programme (pdf)

Technical Annex for this Call (pdf)

Voyage 2050 Senior Committee Report (pdf)

Added 13 January 2022: Presentation from the briefing meeting

Added 3 February 2022: Q & A page with answers to questions posed after the briefing meeting.

STE-QUEST Proposal

STE-QUEST
Space Time Explorer and QUantum Equivalence principle Space Test

A M-class mission proposal in response to the 2022 call in ESA's science program

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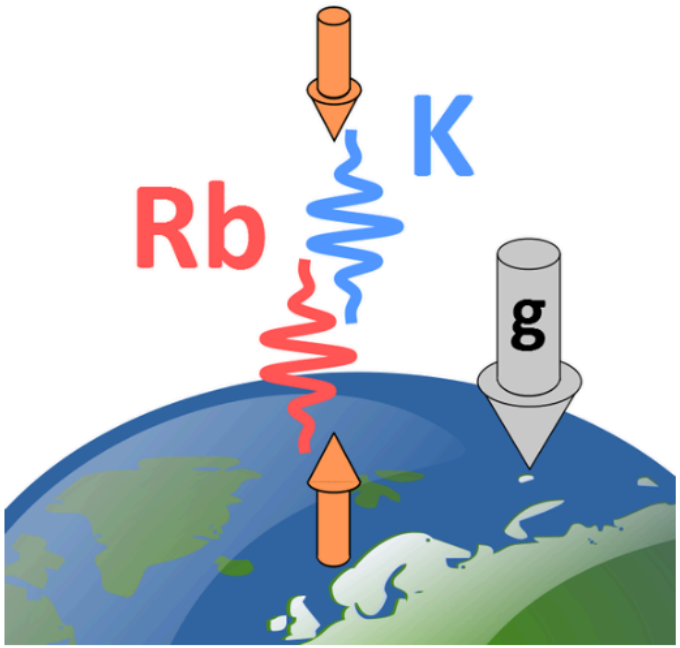
February 15, 2022



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Potential Outcomes from this Workshop

- Establish contacts between physicists, geographers and climate experts at King's and elsewhere
- Identify possible joint actions at King's and with external partners: London, UK, international
- Joint master's/doctoral students?
- Potential diversification of departmental research activities?
- Summary report to King's hierarchy