

Particle Astrophysics Advisory Panel

DMUK meeting

7/1/2025

PAAP:

- *Sergey Burdin (Chair, Liverpool)* - **Direct (particle-like) Dark Matter searches**
- *Garret Cotter (Oxford)* - **Gamma-ray Astronomy**
- *Djuna Croon (Durham)* - **Theory**
- *Ed Daw (Sheffield)* - **Direct (wave-like) Dark Matter searches & Quantum Technology for Fundamental Physics**
- *Tepei Katori (KCL)* - **Neutrino Astronomy**
- *Laura Nuttall (Portsmouth) (on maternity leave, help from Giles Hammond (Glasgow))* - **Gravitational Waves**
- *Blake Sherwin (Cambridge)* - **Cosmic Microwave Background**

Science Board representatives:

- *Francesca Di Lodovico (KCL), Anne Green (Nottingham), Patrick Sutton (Cardiff)*

STFC:

- *Thomas Gray, Georgina Freeman, Melanie Kidd, Jamie Parkin*

Roadmap for UK Particle Astrophysics 2022

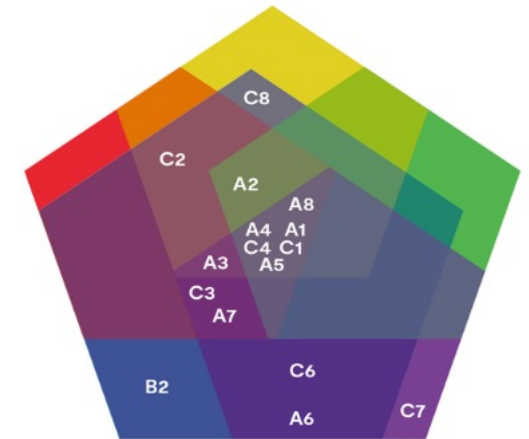


Inputs to the SB PPAN Roadmap

STFC Particle Astrophysics Advisory Panel: Stephen Fairhurst, Sergey Burdin, Ed Daw, Laura Kormos, Jon Lapington, Christopher McCabe, Blake Sherwin.

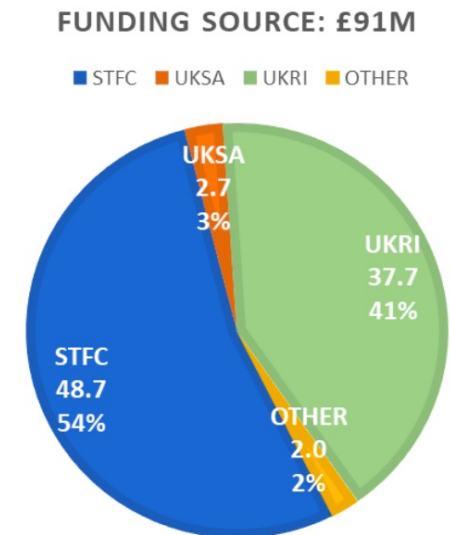
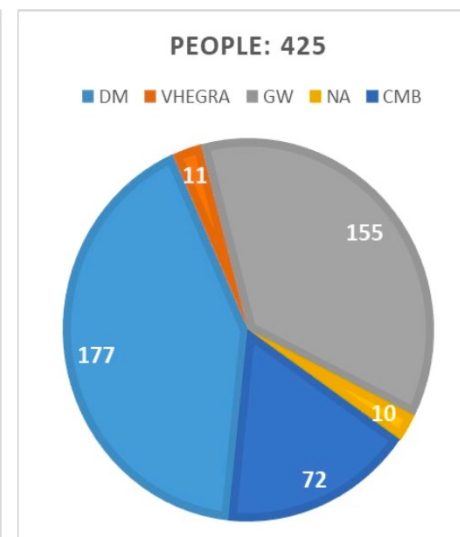
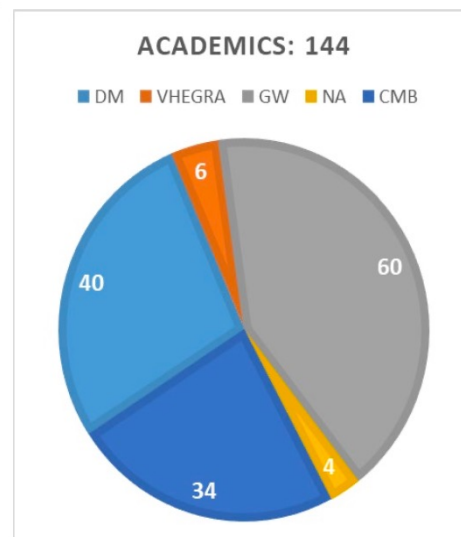
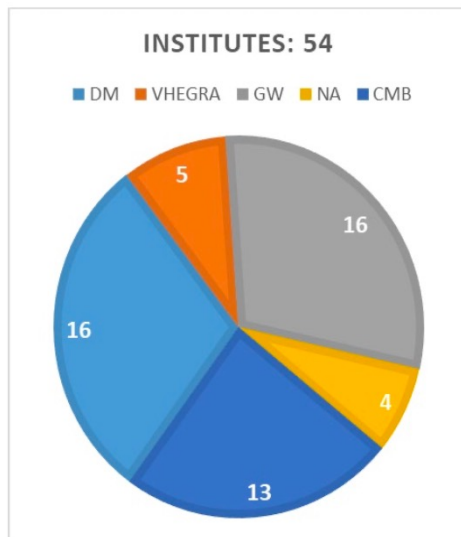
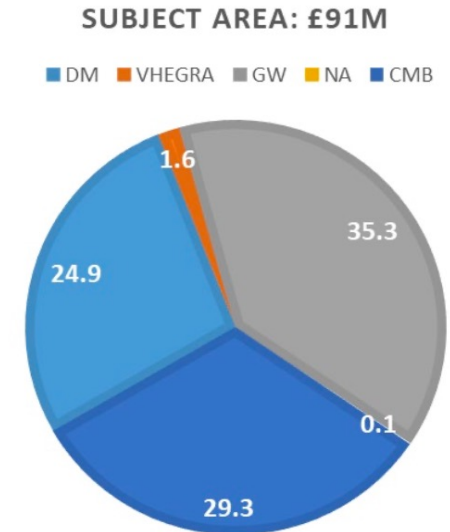


Gravitational waves
 Very High Energy Gamma
 Neutrino
 Direct Dark Matter
 Cosmic Microwave Background



Current Status of UK Particle Astrophysics

- Over 400 people in 54 institutes
 - 144 academics
 - Large communities: Dark Matter, Gravitational Waves, CMB Cosmology
- Significant growth in key areas in the last decade
 - Gravitational Waves ~3x, Dark Matter ~2x
- Total funding over ~5 years: £91M
 - Major funding from UKRI Infrastructure Fund: GW, Simons, XLZD



Thanks to Henrique Araújo for collating the information

PAAP answers to questions from SB PPAN

1) Have there been any significant changes or developments that would cause the panel to alter the recommendations in their current roadmap?

- We endorse recommendations in the PAAP Roadmap with some comments outlined below and in Q5
- PAAP notes changes in the STFC governance structure and establishment of SB PPAN with the long-term prioritised roadmap across all PPAN research areas, which opens opportunities to re-balance the overall STFC science portfolio and address recommendation 3.1.
 - **Recommendation 3.1.** *We recommend re-balancing the overall STFC science portfolio to allow increased levels of funding for Particle Astrophysics. This will ensure continuing UK leadership within existing experiments, while also increasing the breadth and depth of Particle Astrophysics research.*
- Development of Boulby Underground Laboratory which could accommodate a range of big/medium/small scale experiments requiring very low background and potentially host the next generation dark matter search experiment is an important development addressing recommendation 3.2.
 - **Recommendation 3.2.** *We recommend that STFC should provide large, strategic investment in future Particle Astrophysics observatories and experiments to ensure continuing UK leadership in the long term.*
- Rapid development of GPUs and AI, increase in data volumes and complexity will require novel approaches to digital infrastructure and resources. The heterogeneity of PAAP leads to diversity of requirements within PAAP remit. Communication with the Digital Research Infrastructure was established and the central approach to licensing (Europractice) and pooled resources was discussed.

2) Have there been any major scientific developments within the field since the roadmap was last updated that should affect STFC's consideration of future support of relevant UK research?

- A short overview of different PAAP areas is given in the next slides

Gravitational Waves

Main projects

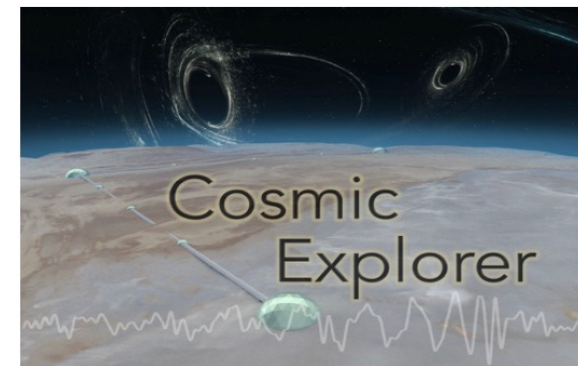
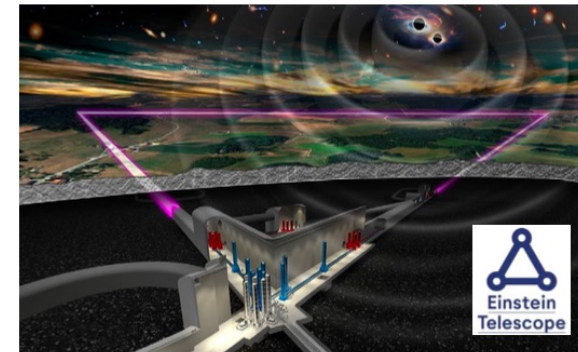
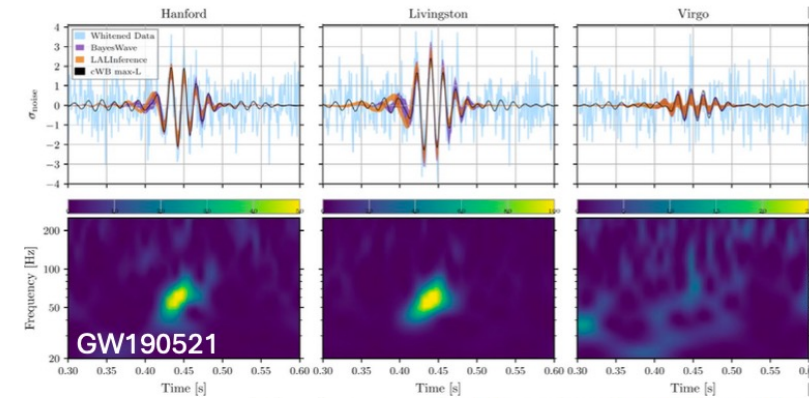
- aLIGO, aLIGO-Virgo-KAGRA (LVK) network → Advanced LIGO plus (A+)
- LISA Pathfinder → LISA (ESA “L-mission”) approved by UKSA
- Pulsar Timing Arrays

Key results

- aLIGO: UK leadership in operation, upgrade & exploitation
- The European Pulsar Timing Array had its second data released, and announced evidence for discovery of a gravitational wave background based on its analysis
- Leading contributions to GW science
 - Most up-to-date LVK catalogue of GW observations (GWTC-3)
 - First clear discoveries of neutron star – black hole binaries (GW200105, GW200115)
 - First confirmed observation of an intermediate-mass black hole (GW190521)

Future Projects

- Next-generation observatories to realise transformative potential of GW astronomy:
 - Einstein Telescope & Cosmic Explorer: the UK is uniquely well-placed to contribute to both
- Next-Gen GW project



Gamma-Ray Astronomy

Main Projects

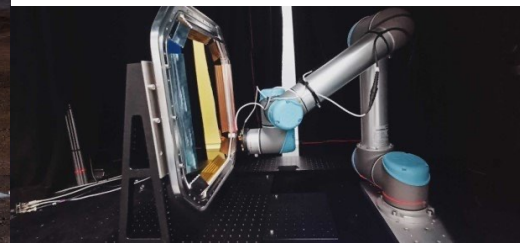
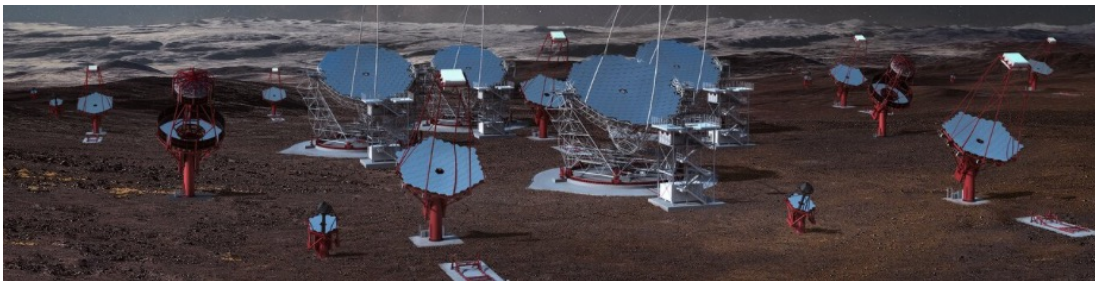
- HESS, (MAGIC, VERITAS) → CTA design and construction (camera for Small-Sized Telescopes @CTA-South)
- Limited involvement in Southern Wide-field Gamma-ray Observatory (SWGGO)
- Science exploitation of Fermi and HESS funded mostly from non-STFC sources

Key results

- Successful production/deployment of the first fully-operational camera for SSTs (Sicily, 2019)

Future Projects

- **CTA** is the priority for the UK community



Neutrino Astronomy

Main Projects

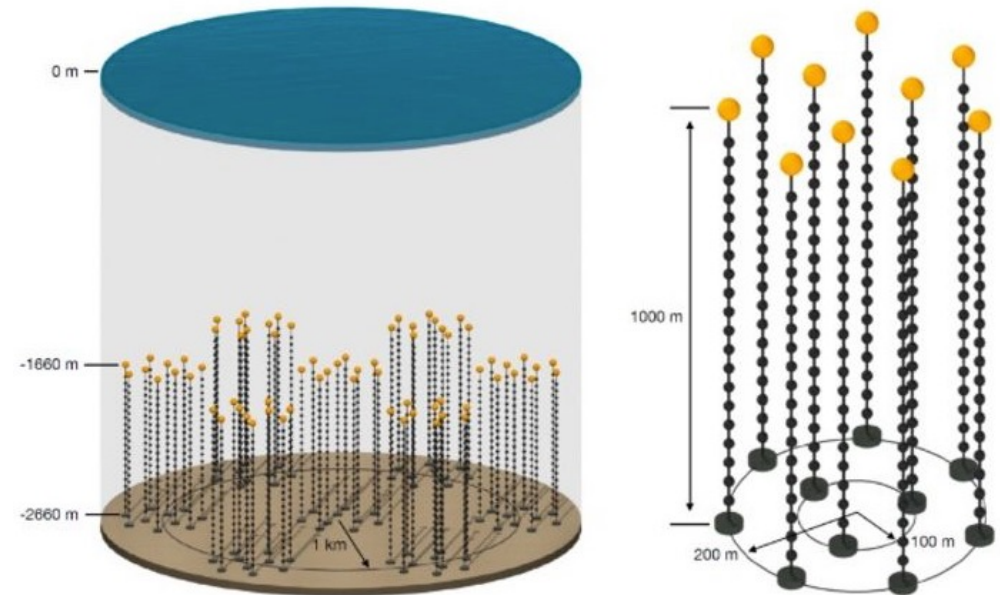
- IceCube/IceCube-Gen2, ANITA/PUEO, P-ONE, KM3NeT, Trinity – small involvements, mostly non-STFC funded
- UK High-Energy Neutrino (UHEN) consortium is working towards consolidating the UK effort to achieve critical mass in one project

Key results

- Neutrinos are only high-energy particles to explore the deep universe
- IceCube observations:
 - TXS0506+056: a nearby blazar
 - NGC1068: a nearby galaxy

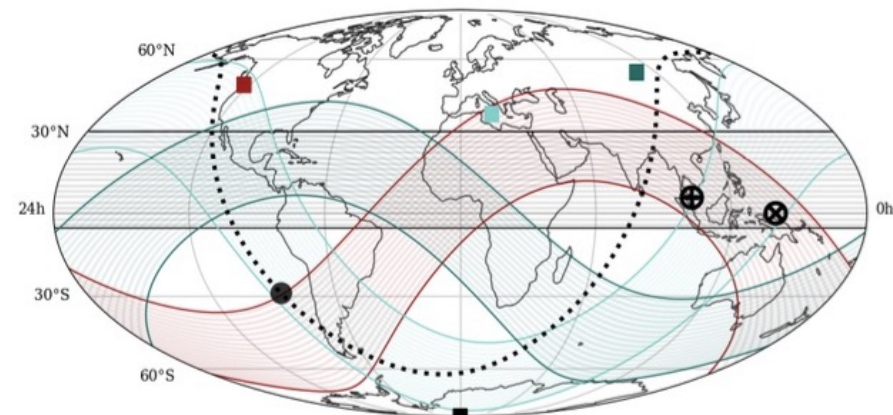
Future Projects

- Consolidation of the UK community is in progress
 - P-ONE?
- **Neutrino Astronomy is an important part of development of multi-messenger astronomy in the UK**



P-ONE configuration

- | | | |
|-------------------------|-----------|--------------|
| ⊕ TXS 0506+056 | ■ IceCube | ■ KM3NeT |
| ⊗ NGC 1068 | ■ P-ONE | ■ Baikal-GVD |
| ● Galactic center/plane | | |



Direct Dark Matter (Particle-like) Searches

Main Projects

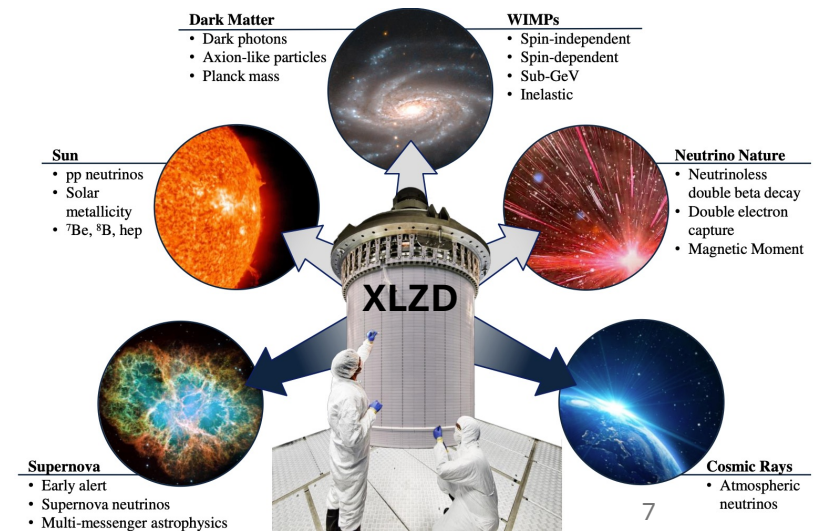
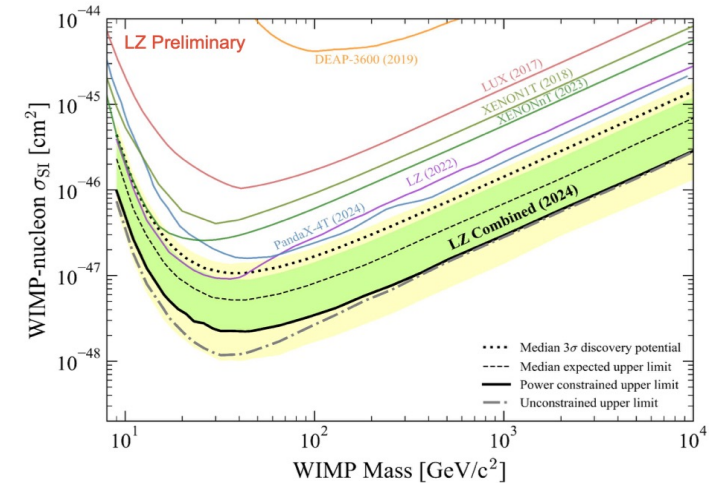
- LXe programme: ZEPLIN @Boulby → LUX @SURF → LUX-ZEPLIN (LZ) @SURF
- LAr programme: DEAP-3600 @SNOLAB → DarkSide-50, DarkSide-20k @LNGS
- Gas detectors: NEWS-G @SNOLAB; MIGDAL @RAL
- QUEST-DMC – superfluid ^3He particle-like dark matter detector, nanowire readout.

Key results

- LZ leads search for both spin-independent and spin-dependent interactions above 10 GeV
- DarkSide-50 leads on SI interactions in low-mass region $\sim 1\text{-}3$ GeV
- NEWS-G leads on SD (proton) interactions in 0.2-1 GeV

Future Projects

- **Major new underground facility at Boulby** is the paradigm-shifting opportunity
- **XENON+LUX+ZEPLIN+DARWIN = XLZD**: Rare Event Observatory for DM & ν physics
 - Xenon Futures (R&D) → XLZD@Boulby (UKRI Infrastructure Fund)
- Further opportunity for mid-class projects under review
 - SOLAIRE – LArTPC with Silicon photosensors
 - DarkSPHERE – Next-generation NEWS-G
 - QUEST-DMC – QTFP project



Direct Dark Matter (Wave-like) Searches

Main Projects

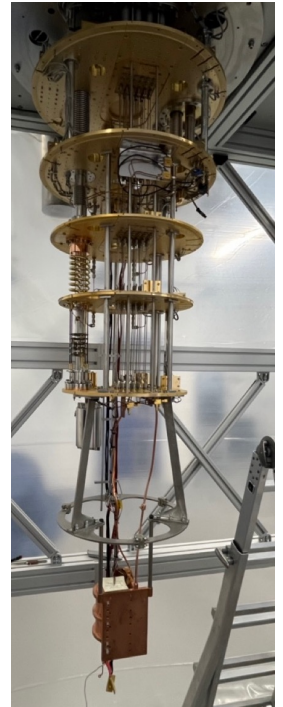
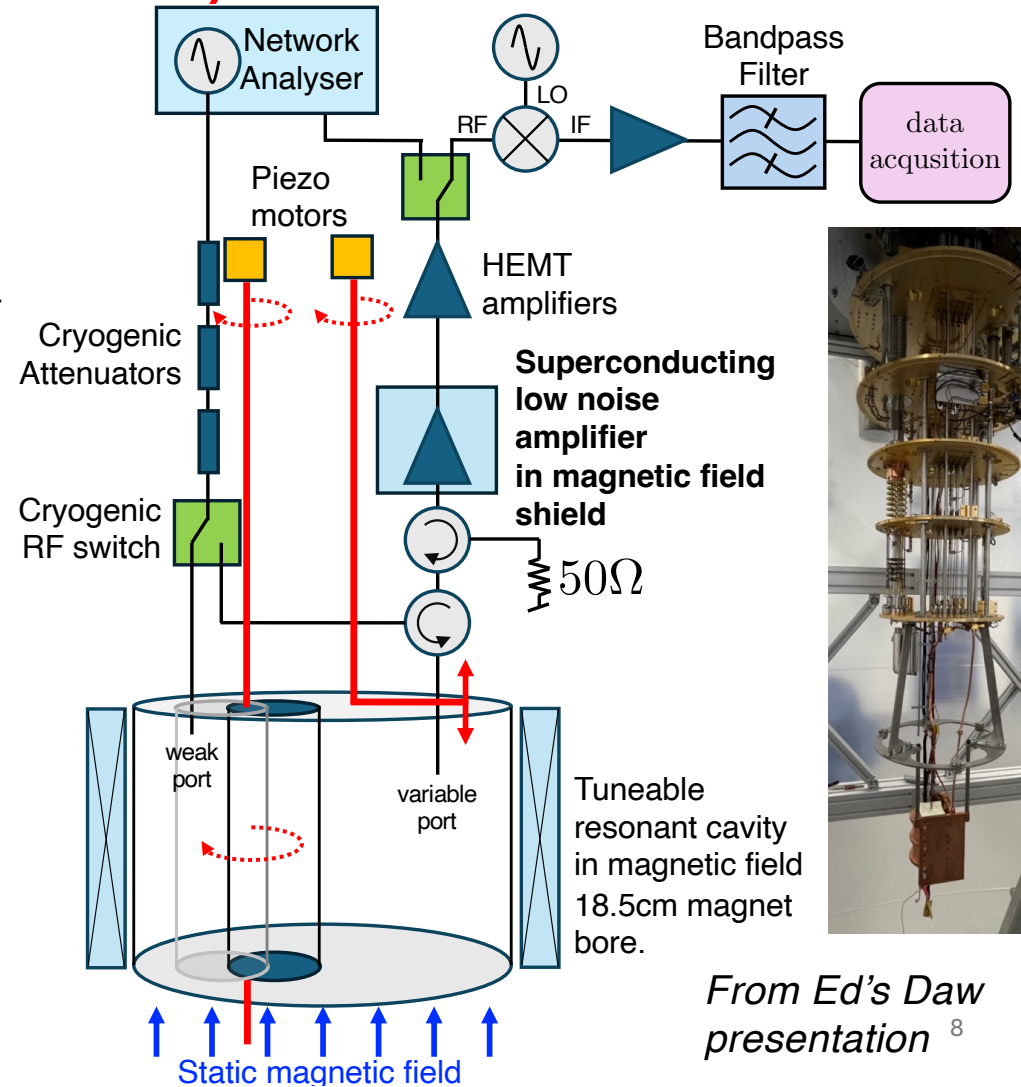
- **QSHS** – ultra-low-noise search for **QCD axion / wave-like dark matter**.
- **AION** – atom beam interferometry for **ultra-light axion / mid band gravitational waves**.
- **QI** – precision optical and squeezed light interferometry for **ultra-light halo or produced axions/ALPS**, probes of semiclassical gravity and quantum gravity.

Key results

- An important demonstration of the feasibility of sensor technologies at or around the quantum limit in sensitivity and allowing to probe phenomena that do not produce high energy by-products detectable in conventional general purpose particle detectors.
- Part of the Quantum Technologies for Fundamental Physics initiative
- **The QTFP community grew significantly since the initial funding and became an important part of the UK scientific landscape.**

Future Projects

- As part of the Quantum Technologies for Fundamental Physics initiative these projects depend on future funding of this initiative
- **It is essential to identify sources for its continuous funding and support within the STFC core program.**



From Ed's Daw presentation ⁸

Cosmic Microwave Background

Main Projects

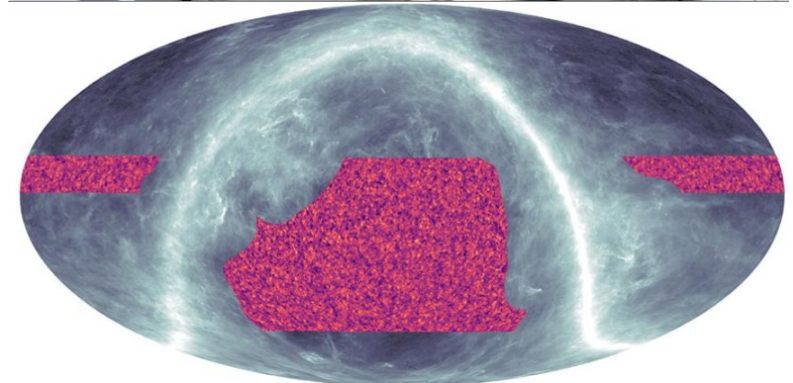
- Significant UK involvement has been funded by UKRI Infrastructure Fund into the Simons Observatory
 - Two small-aperture telescopes (SATs) in 2026
- New involvement in Japanese-led LiteBIRD satellite (inflationary GW), initial funding from the UKSA
- Atacama Cosmology Telescope (ACT)

Key results

- The analyses of CMB power spectrum and lensing spectrum with Planck and AdvACT
 - Precise tests of Λ -CMD and inflation
 - Tightest bounds on neutrino masses
 - UK-led ACT lensing analysis
 - Simons Observatory
 - Two SATs are taking data
 - 3rd SAT and LAT are due soon

Future Projects

- LiteBIRD
- CMB-S4: significant uncertainty due to recent issues with NSF polar operations



ACT lensing map

Theory

Large and prominent community in astroparticle theory

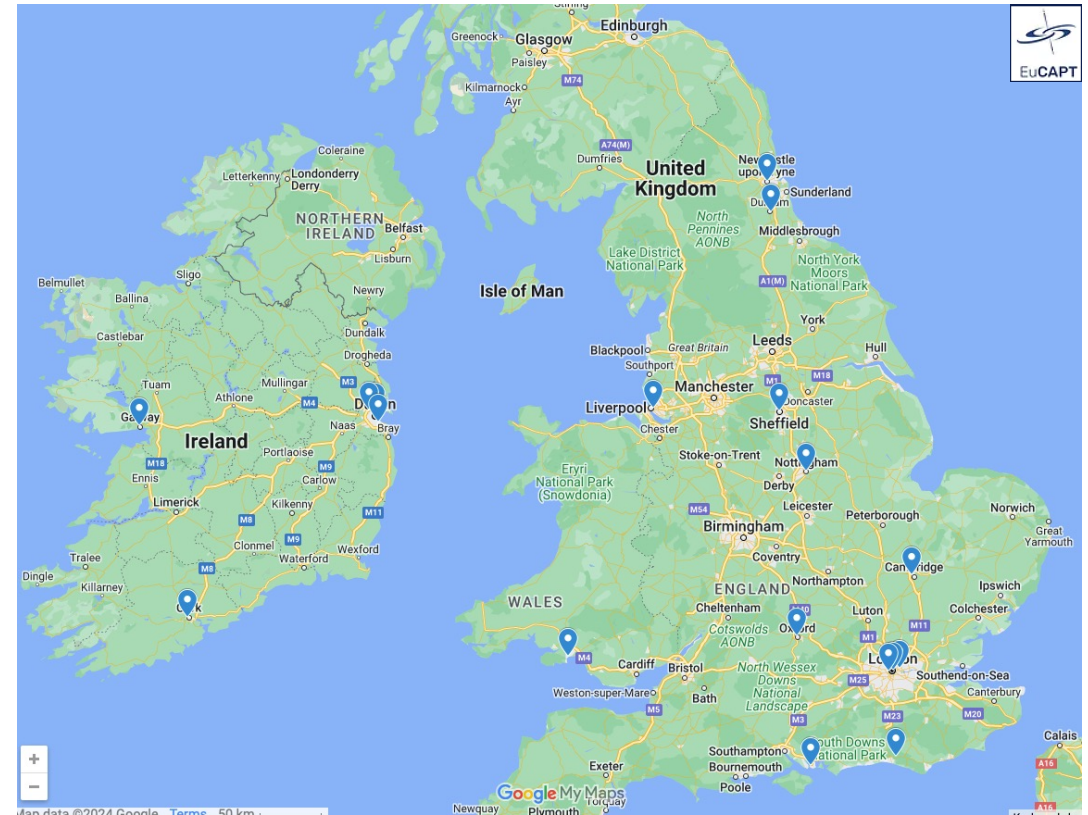
- 16 UK institutes in European Consortium for Astroparticle Theory (EuCAPT)
- Areas: Particle phenomenology and cosmology, cosmic-rays, neutrinos, gravitational waves, general relativity

Key results

- Major UK involvement at leadership level to EuCAPT
- New theoretical effort in the QTFP programme
 - E.g., DM, GW

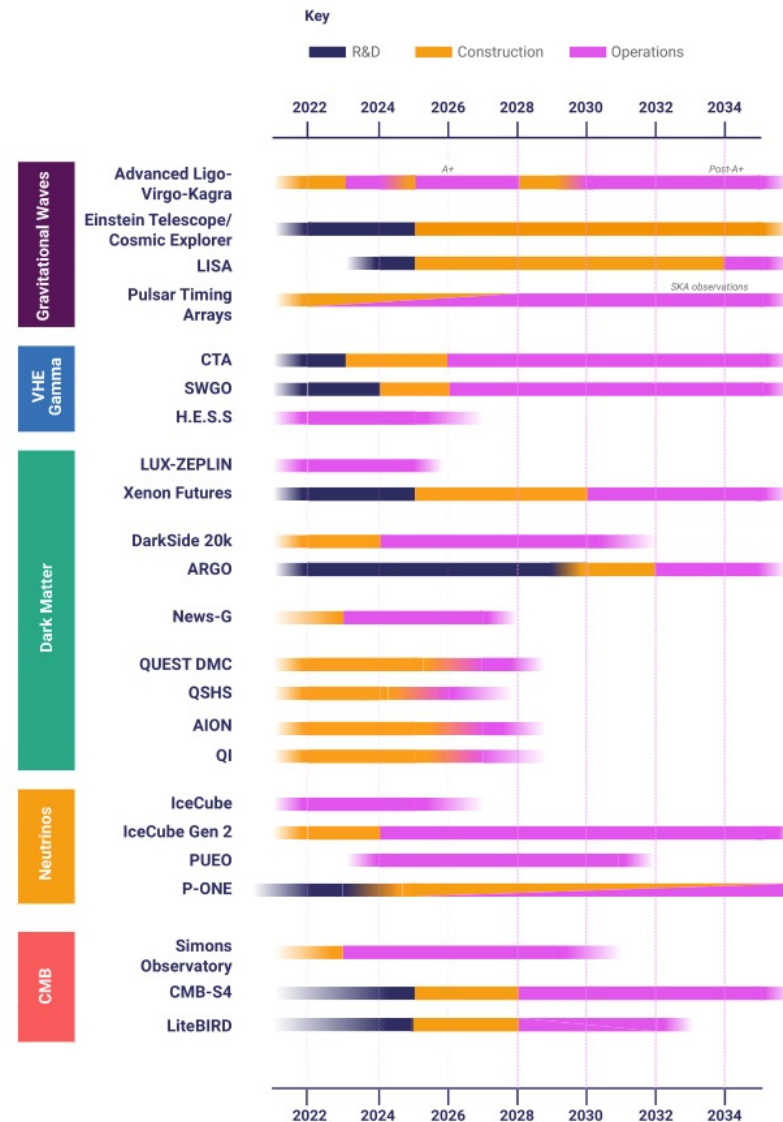
Future Projects

- A strong theory community and links with experiments are essential for success of the UK experimental programme

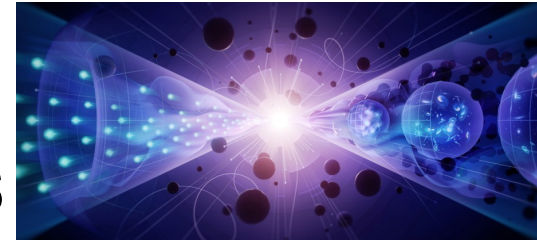


Timeline

- Timeline as presented in the PAAP roadmap 2022 must be updated
- The process started but still many inputs are needed
 - In general, 1-2 years overoptimistic in terms of starting operations



PAAP answers to SB PPAN questions



3) Where applicable, have there been any significant updates to relevant international roadmaps?

- The 2023 P5 report outlines several recommendations relevant to astroparticle physics, including support for:
- **Neutrino Experiments:** IceCube and IceCube Gen-2
- **Dark Matter Research:** ADMX, DarkSide-20k, LZ, SuperCDMS, XENONnT. Plan and start an ultimate **G3 dark matter direct detection experiment**. Start the construction of experiments from the **Dark Matter New Initiatives**.
- **Cosmic Evolution Studies:** Back the Vera C. Rubin Observatory for LSST and DESI for cosmic evolution
- **Cosmic Microwave Background:** Plan and start **CMB-S4**
- **Infrastructure Development:** Invest in R&D for advanced detection instruments and cyberinfrastructure, including AI/ML and quantum computing integration
- Funding for US contributions to **CTA** is recommended for dark matter N.B. NSF funding has already commenced with an award for the CTA medium-sized telescopes.
- Enhance research in **theory** to propel innovation, maximize scientific impact of investments in experiments, and expand our understanding of the universe.



PAAP answers to SB PPAN questions

- The APPEC 2023 mid-term update makes several recommendations aligned with the PAAP roadmap including:
 - **High Energy Gamma Rays:** Clear endorsement for construction and operations for **CTA**, and support for construction of **SWG0**. We also note that in ASTRONET, **CTA** is the top-ranked new ground-based facility
 - **High Energy Neutrinos:** Endorsement of **KM3NeT** collaboration with the possibilities of additional neutrino telescopes located off the coasts of Canada (**P-ONE**). Support of **IceCube Upgrade and IceCube-Gen2**.
 - **GW:** Support of participation in **ET** (recently included in the ESFRI roadmap) and **Cosmic Explorer**, building the bridge between second and **third-generation detectors**, which will access all cosmological scales back to the early universe. **LISA** and the **Pulsar Timing array** will open a window to observations at lower frequencies, making gravitational-wave emission from yet unobserved astrophysical and cosmological sources detectable for the first time.
 - **Dark Matter:** Support of **at least one next-generation xenon (order 50 tons)** and **one argon (order 300 tons)** detector and detector R&D to reach down to the neutrino floor on the shortest possible time scale for WIMP searches for the widest possible mass range.
 - **Axions and ALPs:** Support of the unique European-led efforts for axions and ALPs detection in mass ranges complementary to the established cavity approach and R&D efforts to improve experimental sensitivity and extend the accessible mass range.
 - **CMB:** Encouragement of European contributions to **LiteBIRD**, **CMB-S4**, and R&D towards other, next-generation, ground-based experiments.
 - **Theory:** Support of a **theory programme in the field of astroparticle physics**, with special attention focused on adjacent disciplines such as particle physics, astronomy and cosmology.

PAAP answers to SB PPAN questions

- **4) Have any significant new opportunities or risks emerged for the health of discipline that are not included in the current roadmap, or that need to be expanded upon in more detail?**
 - See SWOT table
- **5) Do any of the recommendations in the roadmap require a significant update or revision?**
- **Recommendation 3.6.** 100% agency contribution is needed for early-stage research funding.
- **Recommendation 4.2.** Change the last sentence to: *We recommend that STFC work with the GW community to develop a strong business case for a future bid to the UKRI Infrastructure Fund, in support of next generation GW Observatories.*
- **Recommendation 4.3.** *We strongly endorse the continued UK participation in LISA, funded by UKSA. STFC support for the preparation of science exploitation activities should be increased to be commensurate with the UK commitments and leadership roles in the mission hardware and science ground segment subsystems, supported by UKSA. As highlighted in the current funding clarification, “STFC Support for Gravitational Waves Research”, this would likely be via the Astronomy Grants Panel or a Statement of Interest to Science board.*
- **Recommendation 6.2.** This recommendation should be revised to support XLZD at Boulby.
- **Recommendation 6.4.** STFC should continue to support searches for light, wave-like dark matter such as axions and other hidden sector phenomena, beyond the end of the initial QTFP scheme.
- **Recommendation 7.1.** Mention P-ONE as a longer-term large-scale experiment.

PAAP answers to SB PPAN questions

- **6) What do you consider to be your key skills gaps that need addressing?**
 - More engineering and project management personnel are needed for large scale experiments, especially those based in the UK
- **7) Are there any trends across skills needs (for example, regional, career stage) that are notable within your particular area?**
 - Difficult to compete with industry for the graduates and PDRAs leaving for industry jobs (that's good but we still need to be competitive).
 - Career pathways for non-academic staff remain a weak point.
- **8) What do you anticipate will be the future skills needs?**
 - New directions, like quantum technology and AI, and requirements, like sustainability, will require dedicated expertise in these areas.

Inputs are based on PAAP Survey

- 32 inputs
 - 15 from collaborations/institutions
 - XLZD-UK
 - University of Liverpool
 - UK LISA
 - Trinity Neutrino Telescope
 - QTFP
 - DarkSide-UK
 - QuaDMOS
 - QI (QTFP)
 - KM3NeT
 - CTA-UK
 - Cardiff Gravity Exploration Institute
 - Institute for Gravitational Research, University of Glasgow
 - Armagh Observatory and Planetarium
 - LIGO
 - QSHS (QTFP)
 - 12 from tenured faculties
 - 4 from PDRAs
 - 1 from PhD student
- **The SB PPAN Roadmap process is ongoing**
 - **Version 1 in Spring 2025**
 - **The community feedback and input are important**