

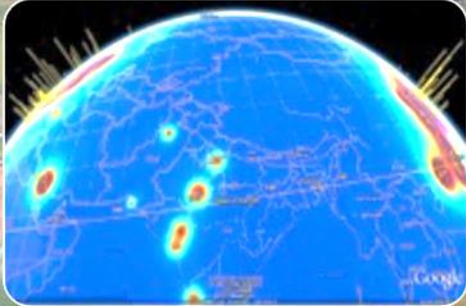
# Deep Science at Boulby Underground Laboratory:

Status and future plans for the UK's deep underground science facility

Sean Paling  
STFC Boulby Underground Laboratory

  STFC Boulby Underground Science

Astroparticle physics & ultra low background studies

 The search for Dark Matter & beyond

Earth and environmental science, astrobiology and planetary exploration

**Latest news from Boulby Underground Laboratory:**  
Status and plans for the UK's deep underground science facility.

 Underground lab @ Boulby

# 0vBB in Xe workshop

## visit 1: 14/9/2026



# Boulby Mine



A working polyhalite and rock-salt mine on the North East coast of England.

Owned by Israel Chemicals Ltd. (ICL-UK). Locally operated as Cleveland Potash Ltd.

Major local employer: ~500 direct staff and 2000 indirect employment.

Polyhalite:  
 $K_2Ca_2Mg(SO_4)$



Ships worldwide for  
agricultural fertiliser



**Deepest mine in  
Britain: 1300km**

The world's first polyhalite mine



12 miles North of Whitby, N. Yorks

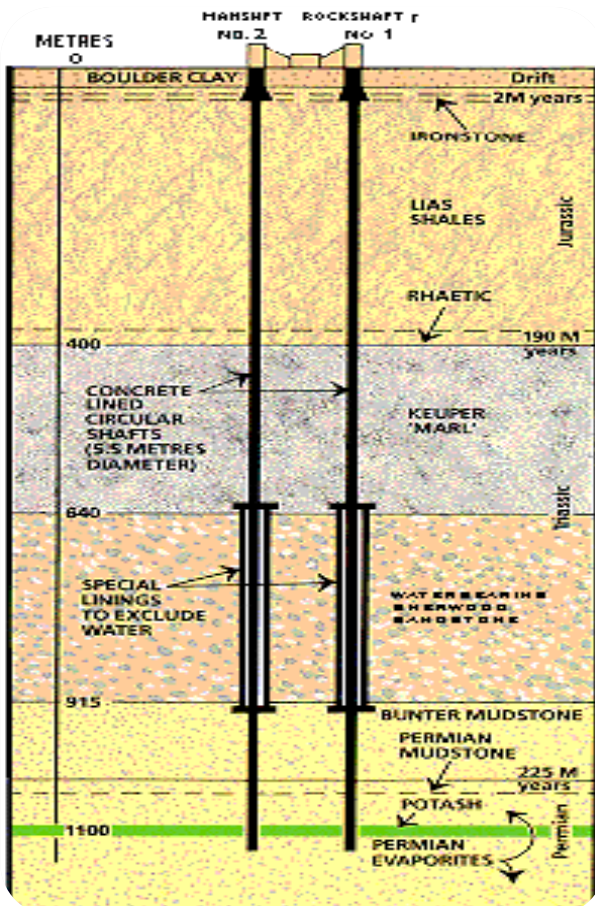


View from Staithes

# Boulby Geology & Mining

Excavations are in Salt (NaCl), Potash (KCl) and Polyhalite ( $K_2Ca_2Mg(SO_4)$ ). Permian evaporite layers left over from the Zechstein Sea (250m.yrs past).

Over 40 kms of tunnel mined each year (now >1,000kms in total), the long-lived roadways being cut in the lower NaCl layer.



Polyhalite



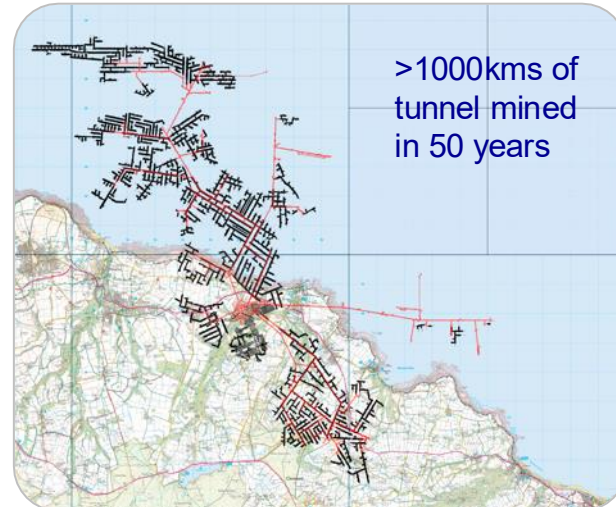
Potash



Rock-Salt



Low activity salt  
U ~67 ppb,  
Th ~125 ppb



Boulby Geology



Typical Boulby Salt Roadway



Zechstein Sea



# Boulby Underground Laboratory

The UK's deep underground science facility operating in a working potash and salt mine.

1.1km depth (2805 mwe). With low background surrounding rock-salt

Operated by the UK's Science & Technology Facilities Council (STFC) in partnership with the mine operators ICL-UK



Outside Experimentation Area (OEA)

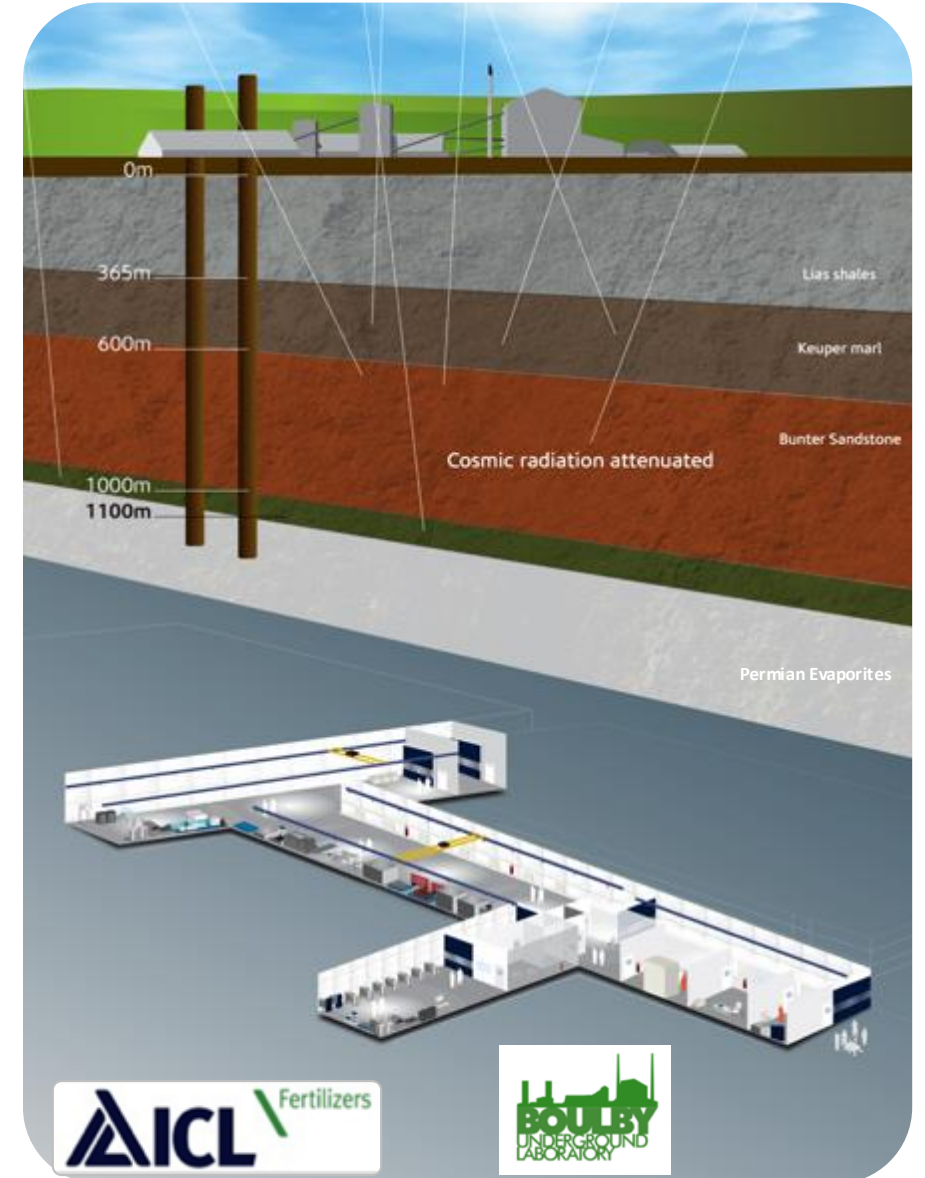


4000m<sup>3</sup> class 10k and 1k clean lab space



Lab entrance

*Factor ~10<sup>6</sup> reduction in cosmic ray flux vs. surface*



A **QUIET** place in the Universe



Surface support and staging building



Office space, chemistry & clean prep lab, storage and staging space, IT room, conference room,

Supported access to surrounding geology & UG environs. Power, wifi/internet.

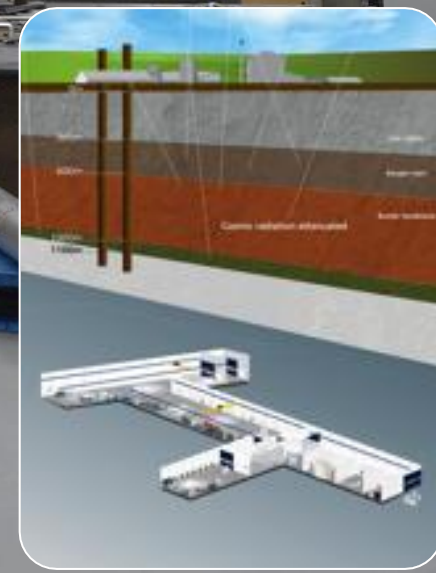


3000m<sup>3</sup> Outside Experimentation Area



BUGS Material screening

**Boulby Underground Lab Facilities 2026:** >4000m<sup>3</sup> class 1k & 10k (ISO 6 & 7) clean room lab space. 10Gb Internet. AC, air filtration, 5T & 10T lifting, LN generation, fume hood & clean prep space. 3000m<sup>3</sup> Outside Experimentation Area (OEA) with power & internet. Supported access to wider mine environs.



# World deep underground laboratories...



**SNOLAB (Canada)**  
Active Mine, 5890 mwe  
Current vol: 30,000m<sup>3</sup>  
SNO+, SuperCDMS, Deep3600,  
PICO, Next Gen 0vBB (to come?)

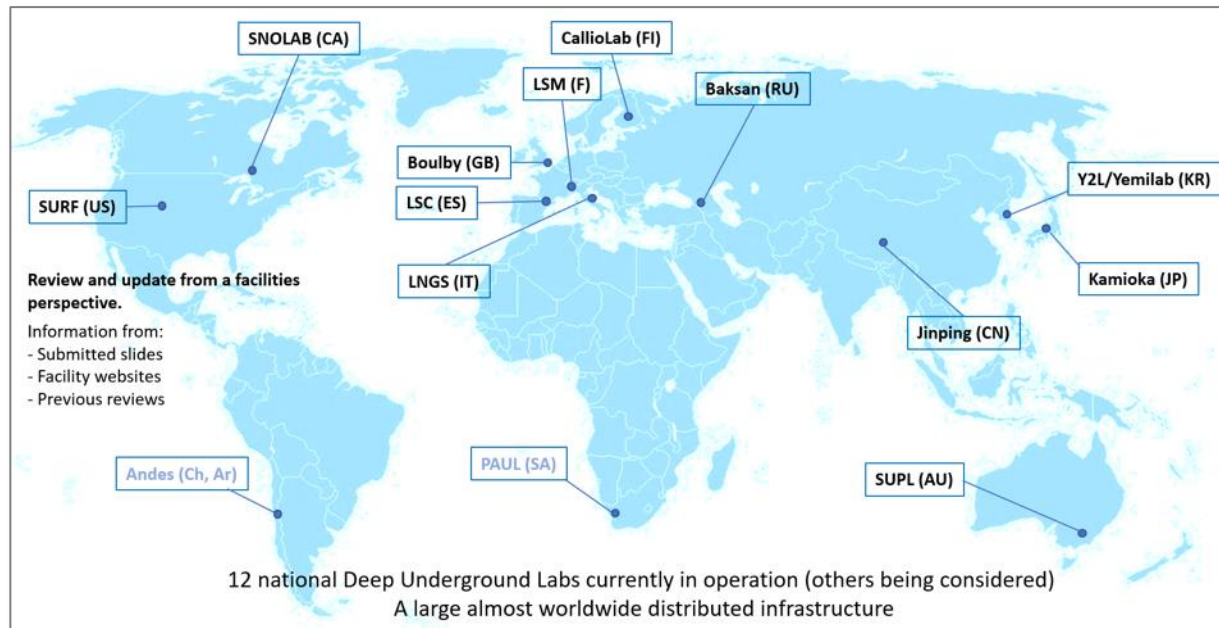


**SURF Laboratory (USA)**  
Disused Mine, 4200 mwe  
Current vol: 7,100m<sup>3</sup>  
LZ, MJD, DUNE (to come)



**Boulby Underground Laboratory (UK)**  
Working Mine, 2850 mwe  
Current vol: 7,200m<sup>3</sup>  
ZEPLIN+ (past), BUGS, News-G,  
RECON, BUTTON & more...

## World Underground Labs



**CJPL Jinping (China)**  
Hydro power plant, >6000 mwe  
Current vol: 330,000m<sup>3</sup>  
Panda-X, CDEX, JUNA,  
GeoDEX, JNE and more to come



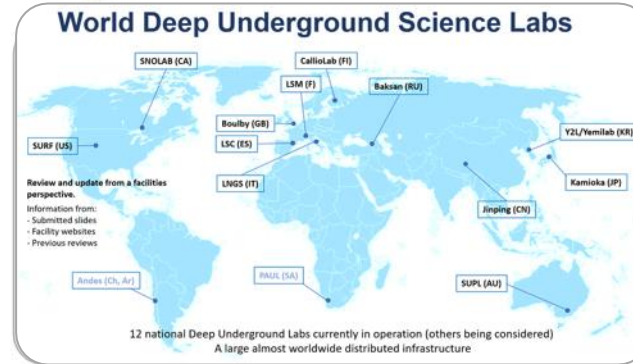
**Gran Sasso National Laboratory**  
LNGS (Italy)  
Under mountain, 3800 mwe  
Current vol: 180,000m<sup>3</sup>  
Xenon, Darkside, LUNA, Legend +

# Boulby Underground Laboratory (UK)

## Boulby Facility Details...

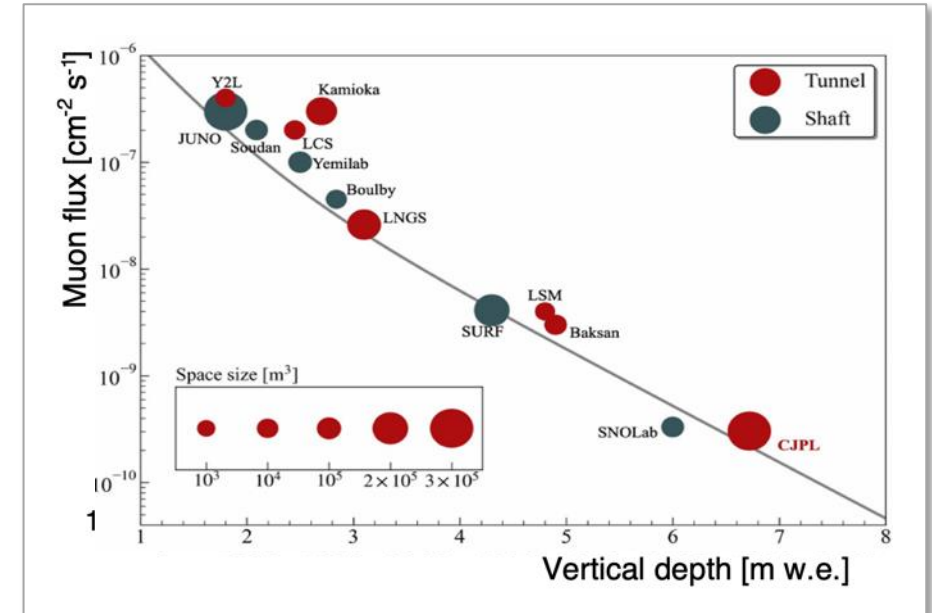


- The UK's deep underground science facility. One of 5 in Europe, <15 in the world.
- Supports work of >10 collaborative projects (astrophysics to climate, geology, environment etc), >60 institutions, >250 scientists & students.
- Facility funded and operated by the Science & Technology Facilities Council (STFC).
- Operations, H&S & science programme managed by 23 onsite staff and supported by Rutherford Appleton Lab (PPD).
- Mine operators ICL-UK provide wide-ranging operational & high level support.



### How does Boulby Compare?

- Low Radon levels (3 Bq/m<sup>3</sup>)
- Diverse science programme.
- Science and Industry partnership



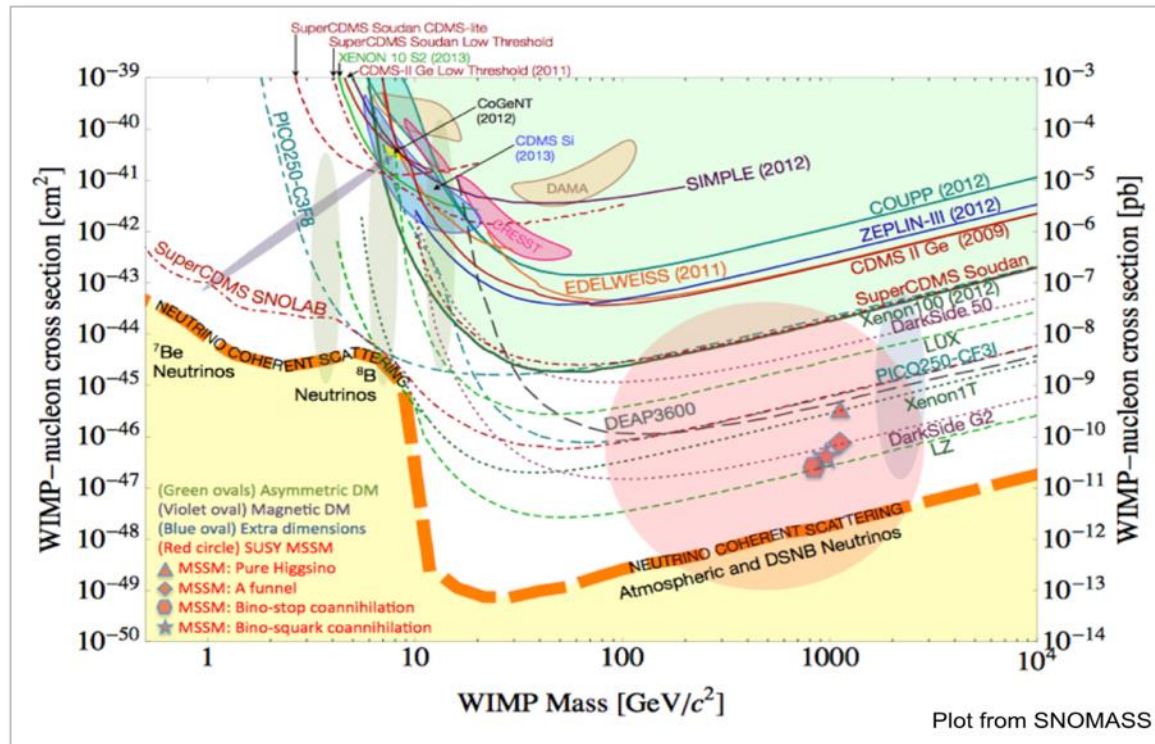
## Science Programme Status and Plans.

- Low background Particle and Nuclear Physics
- Earth & Environmental Science
- Astrobiology & Planetary Exploration Studies
- Quantum Sensors and Computing (new)
- Outreach & Education

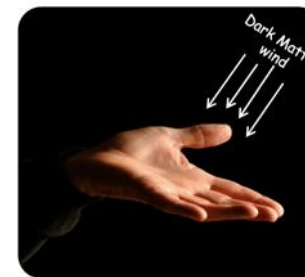
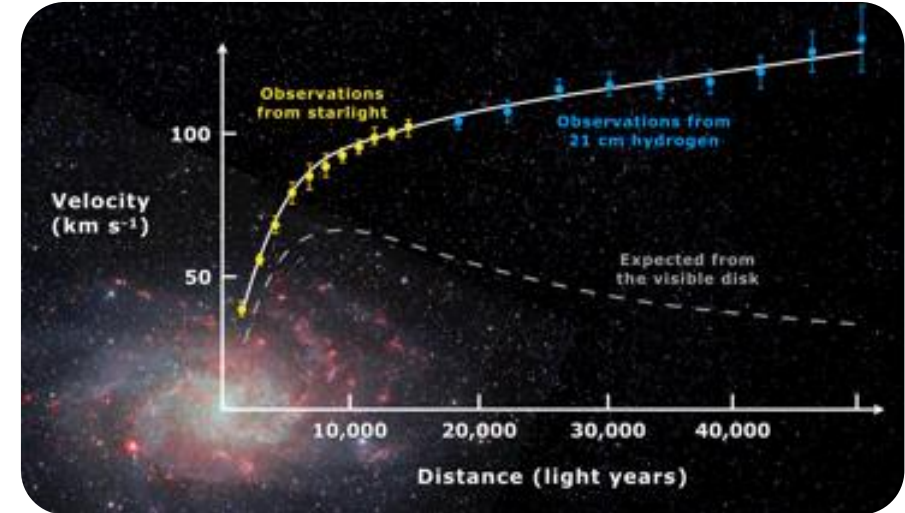
# Boulby Dark Matter Studies...

Boulby has hosted **Dark Matter search** studies for over two decades. Including the **NAIAD, DRIFT & ZEPLIN** experiment programmes.

Boulby now hosts CYGNUS directional DM programme, NEWS-G / Dark-Sphere R&D and providing ULB material screening for other studies, inc **LUX-ZEPLIN (LZ)**



Galactic rotation curves



World DM particle search limits and future projections

**ZEPLIN-II & III:**  
The world's first 2-phase Xenon dark matter detectors  
(Finished 2011)



ZEPLIN-III @ Boulby

# Spherical Proportional Counters (SPC) at Boulby

## NEWS-G

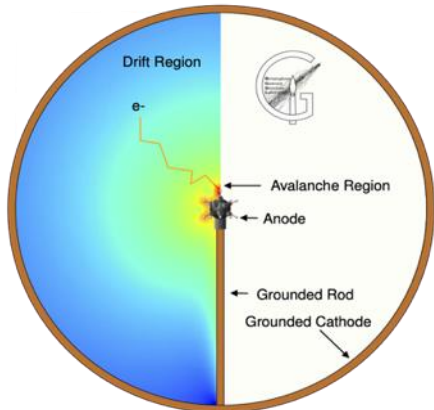
## DarkSPHERE

K. Nikolopoulos, P. Knights, L. Millins,  
G. Rogers, D. Spathara, P. Walters  
University of Birmingham  
and international NEWS-G  
Collaboration (France, Canada,  
Greece, USA)



### NEWS-G Activities at Boulby

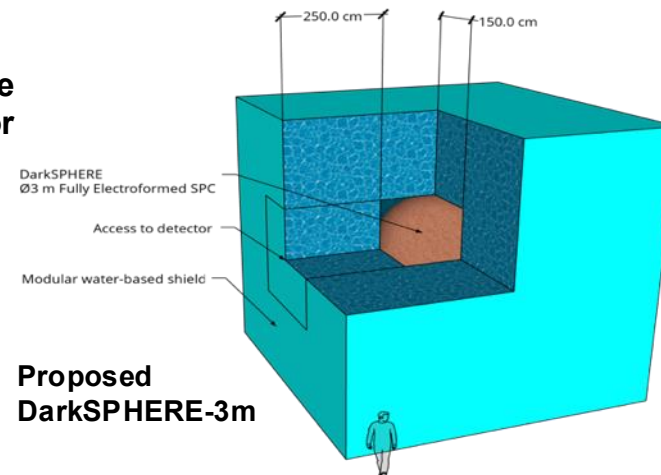
- Instrumentation developments
  - Multi-anode sensor
  - Gas filtration
  - Rate effect studies
- Neutron spectroscopy (with N<sub>2</sub> gas)
  - Neutron background surveys
  - Industrial applications
- High-purity copper electroformation
- **Towards scaled-up, electroformed, detector at Boulby, 3m diam. 5 bar**  
He:CH<sub>4</sub>H<sub>10</sub> **DarkSPHERE**



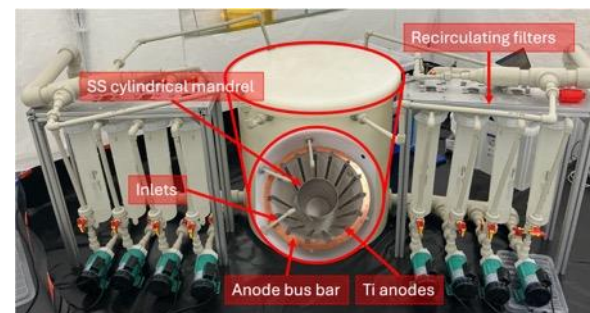
SPC concept: Variable target  
Low E<sub>th</sub>, Low mass sensitivity



11-anode  
sensor



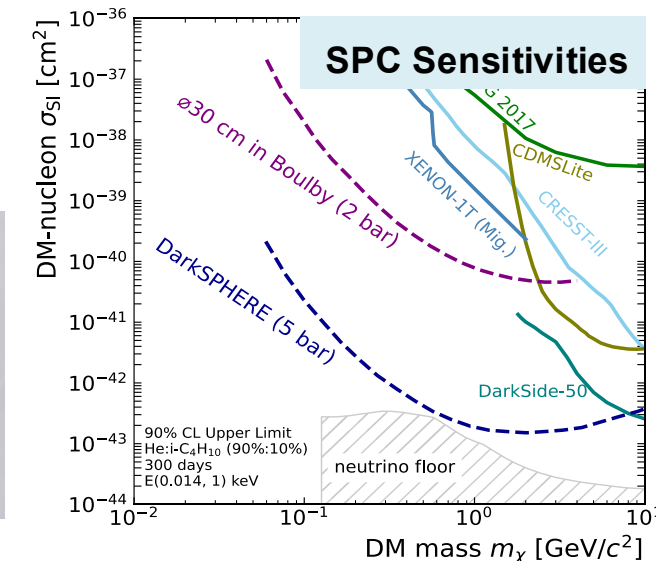
AI-S30 R&D Detector



Copper electroforming at Boulby



Selected as top in STFC's Medium  
Scale Dark Matter Fund bid (2025)



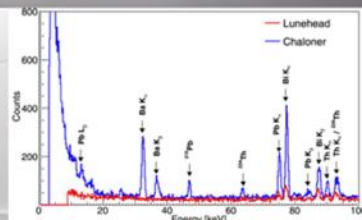
# Ultra Low Background Material Screening @ Boulby (**BUGS**)



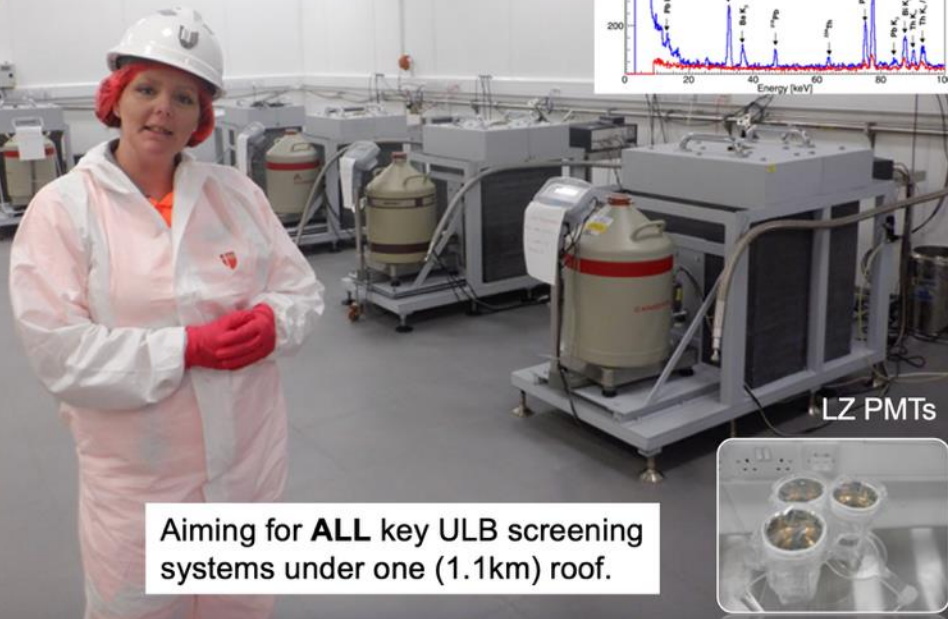
XIA alpha particle counter



8 ULB Ge detector systems, 2 XIA alpha counters, 2 Rn emanation systems, ICPMS



**BUGS (Boulby UnderGround Screening).** World-class material screening for current and future ULB experiments. Towards PPT sensitivity for G3 DM and Neutrino experiments



Aiming for **ALL** key ULB screening systems under one (1.1km) roof.



**BUGS (UG):** A range of HPGe detectors and *alpha particle detectors* for intrinsic and surface radioactivity measurements.



**ICP-MS (Surface):** Newly installed system for trace element analysis and isotopic ratio measurements.

**BUGS Facility:** (Boulby Under-Ground Screening)

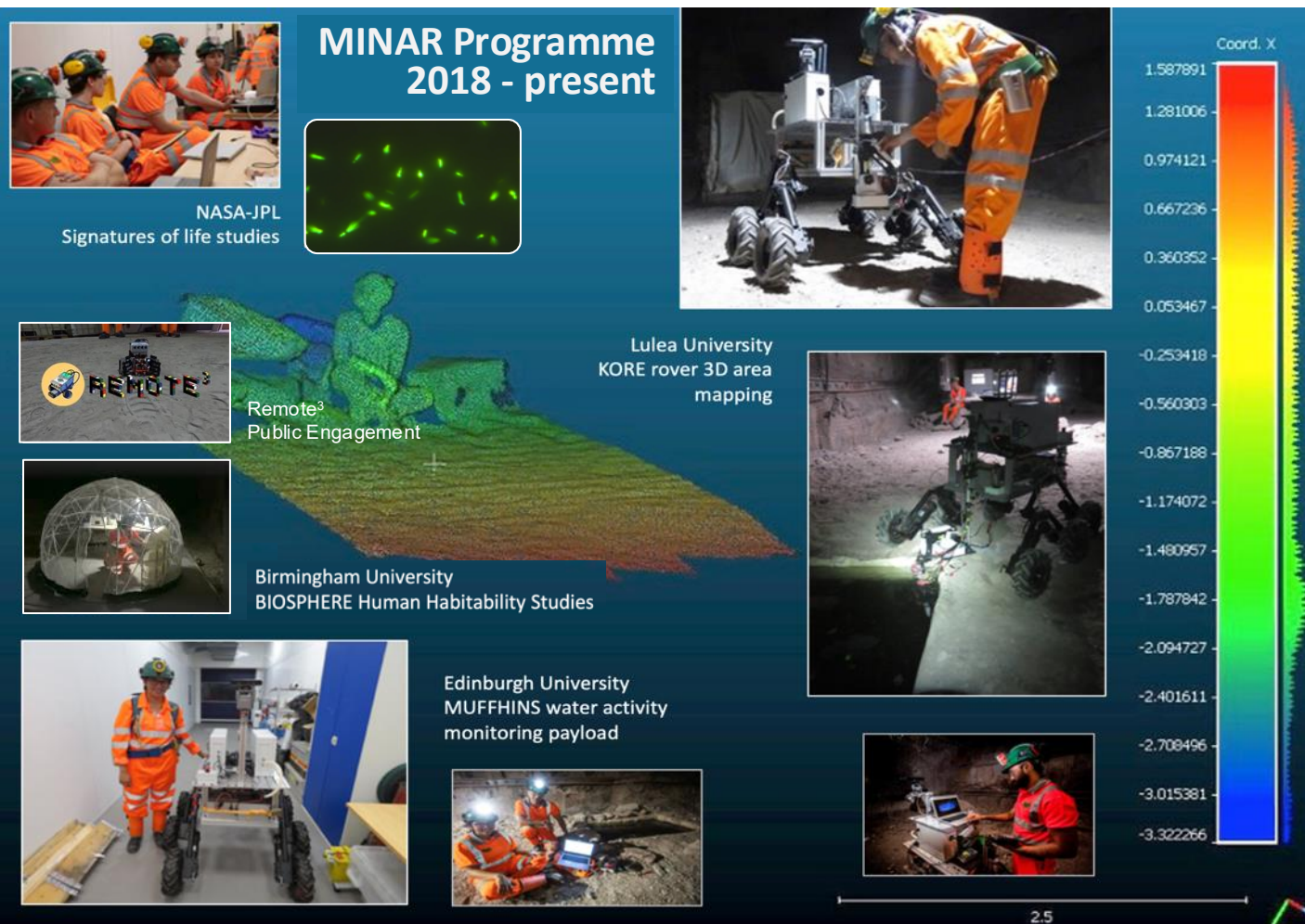
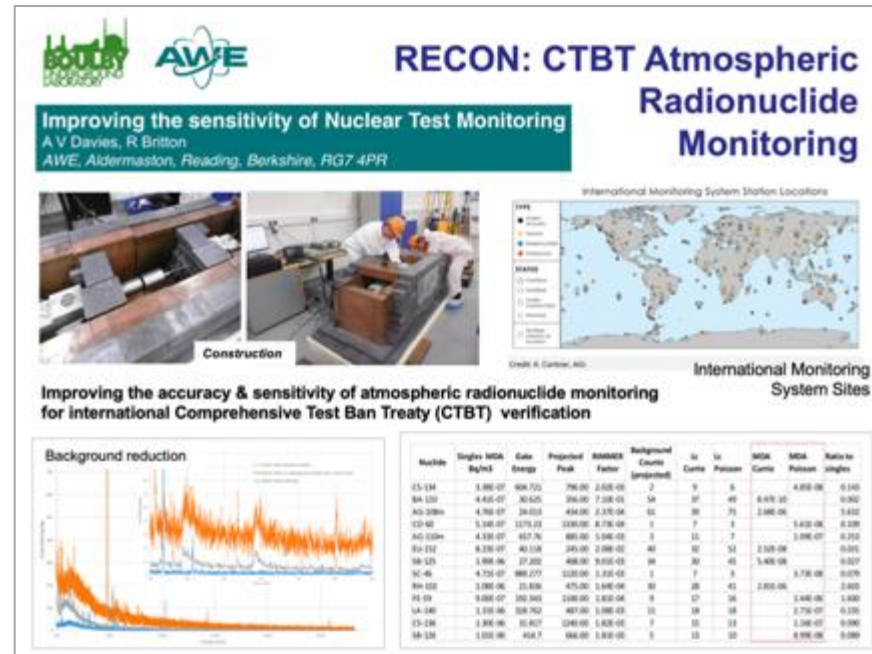
- ULB Germanium (8)
- XIA: Surface alphas (2)
- Radon Emanation (2)
- ICPMS-QQQ \* All now in operation

# Multidisciplinary Science

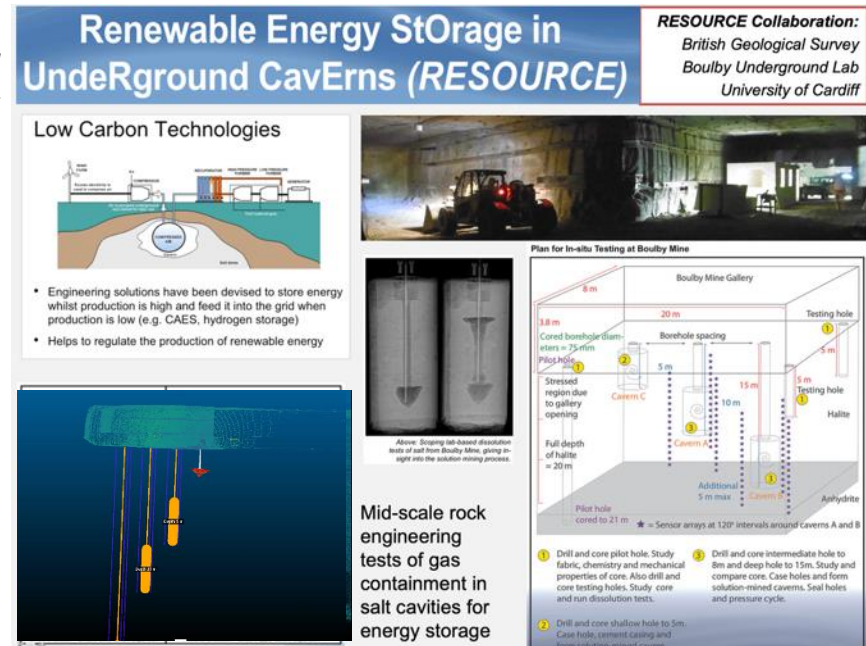
Applied low background particle physics, Earth and Environmental science, Astrobiology & Planetary Exploration Technology Development.

**RECON:**  
Atmospheric  
monitoring for  
nuclear  
security

**MINAR:**  
Astrobiology and planetary exploration technology development



**RESOURCE:**  
Compressed  
gas energy  
storage R&D



# Boulby Science Activities Now and Potential Future

|                                      | Now                                                  |        |
|--------------------------------------|------------------------------------------------------|--------|
|                                      | Current Projects                                     | Status |
| Particle Physics & Low Background    | CYGNUS - DM R&D                                      | E/P    |
|                                      | News-G - DM R&D                                      | A      |
|                                      | BUGS: Ge, XIA, RnEm - Material Screening             | A      |
|                                      | RECON - Nuclear Security R&D                         | A      |
|                                      | BUTTON – Nuclear security R&D                        | A      |
| Earth & Environmental                | Muon Tomog – CCS & undersea Geoimaging R&D           | A      |
|                                      | RESOURCE – Energy store R&D                          | A      |
|                                      | Seismology/AION R&D                                  | A      |
| Astrobiology & Planetary Exploration | BISAL – Biology/Astrobiology                         | A      |
|                                      | MINAR – Planetary Exploration Tech development       | A      |
|                                      | Misc. Other. SELLR, C14, BIO-SPHERE...               | A/I    |
|                                      | Outreach/ Education - Misc events, progs, Remote3... | A      |

Status: A = Active, P = Paused, E = End, I = Interest confirmed

| 2023-2030                                                                 |        |
|---------------------------------------------------------------------------|--------|
| Medium Term (Current Lab + mods)                                          | Status |
| BUGS: Ge, XIA, RnEm, ICPMS - Material Screening                           | A      |
| BUTTON-30 – Nuclear security R&D                                          | A      |
| RECON+ - Nuclear Security R&D                                             | A/I    |
| DarkSPHERE, SDMS, SOLAIRE, UltraDark, MechQSDM – DM Search                | I      |
| DATUM – Neutrino Tech R&D                                                 | I      |
| SoLAr – Neutrino R&D                                                      | I      |
| Seismology Array – Geosurvey R&D                                          | I      |
| RESOURCE+ – Energy store R&D                                              | A/I    |
| Muon Tomog – CCS & undersea Geoimaging R&D                                | A/I    |
| BISAL+ – Biology/Astrobiology                                             | A/I    |
| MINAR+ – Planetary Exploration Tech development                           | A/I    |
| Misc. Other. AION R&D – Atomic Interferometry Quantum Computing Tech R&D? | A<br>I |
| Outreach/ Education: General Public, Schools +                            | A      |

| Long Term (Current lab plus major new lab)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |  |                                                                                    |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|------------------------------------------------------------------------------------|
| <b>Particle Physics and Low Background Science:</b><br>Dark Matter: Major Next Gen Experiments: <ul style="list-style-type: none"><li>• Xenon (XLZD)</li><li>• Argon (SOLAIRE+)</li><li>• Gas (DarkSPHERE+)</li><li>• ULT technologies for DM</li><li>• Quantum Technologies for DM</li></ul> Neutrinos: <ul style="list-style-type: none"><li>• BUTTON-100+</li><li>• DATUM (LEGEND Support),</li><li>• SoLAR +....</li></ul> Mat screening & LB Techniques: A world's best facility: <ul style="list-style-type: none"><li>• Ge, XIA, RnEm, ICPMS, Cleanliness &amp; Engineering R&amp;D</li><li>• RECON+ - Nuclear Security Gamma spec</li></ul> |  | Target projects<br>for a <b>major new<br/>UK underground<br/>facility</b> / campus |
| <b>Earth &amp; Environmental Science:</b> <ul style="list-style-type: none"><li>• Sustainable Energy R&amp;D (Gas Storage, Geotherm, CCS)</li><li>• Local/Global Seismology Observatory</li><li>• Geological Repositories R&amp;D</li><li>• Misc geology / Geophysics R&amp;D</li></ul>                                                                                                                                                                                                                                                                                                                                                             |  |                                                                                    |
| <b>Astrobiology &amp; Planetary Exploration:</b> <ul style="list-style-type: none"><li>• Extremophile R&amp;D</li><li>• Astrobiology / life beyond Earth R&amp;D</li><li>• Human habitation R&amp;D</li><li>• Planetary exploration technology development</li><li>• Mining and industry application development.</li></ul>                                                                                                                                                                                                                                                                                                                         |  |                                                                                    |
| <b>Quantum Sensors and Computing:</b> <ul style="list-style-type: none"><li>• AION-20/100/100 – Atomic Interferometry</li><li>• Quantum Sensor and Computing Technology R&amp;D</li></ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                           |  |                                                                                    |
| <b>Outreach and Education:</b> <ul style="list-style-type: none"><li>• A National Centre for Science and technology outreach and education.</li></ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |  |                                                                                    |

# Boulby Future Earth and Environmental Science

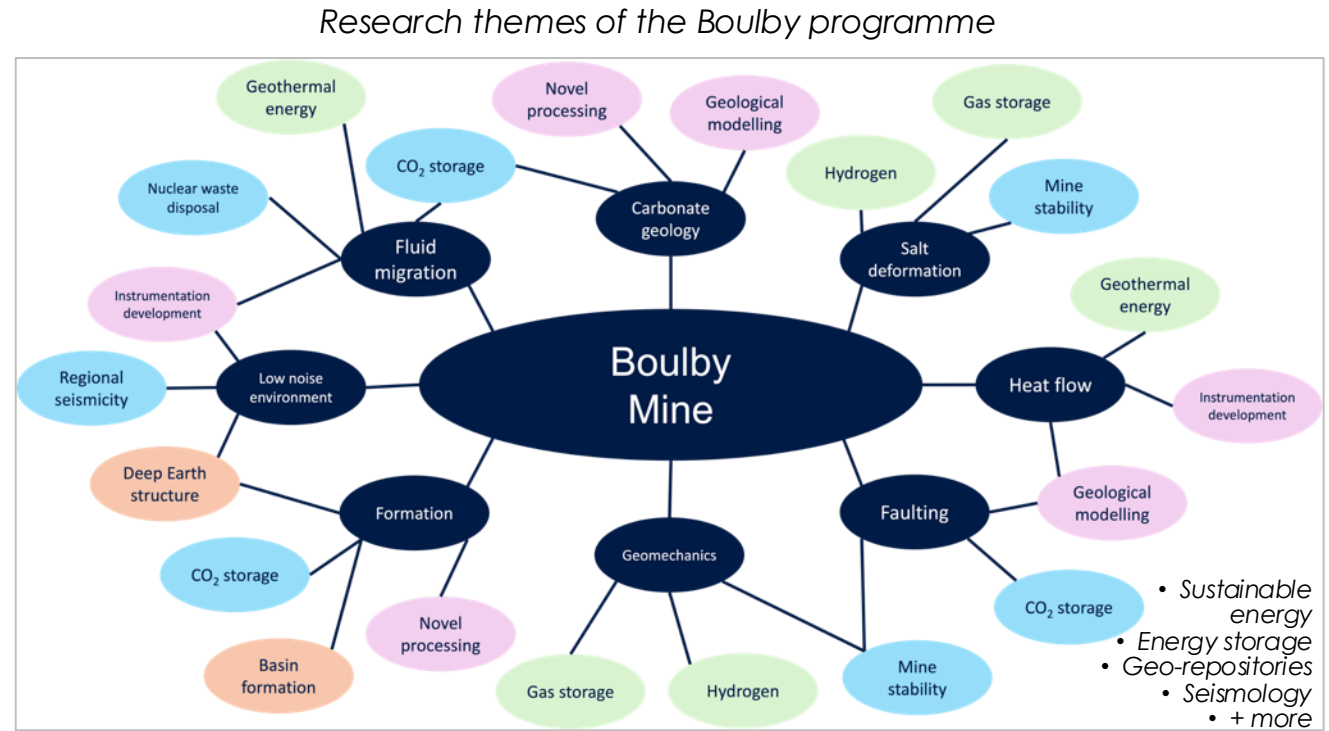
Developing program of Earth science research at Boulby by a consortium of UK universities and industry.

## Earth science at Boulby workshop August 2024

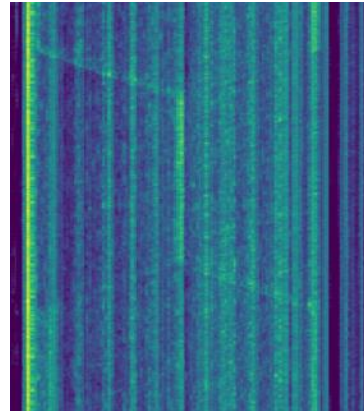
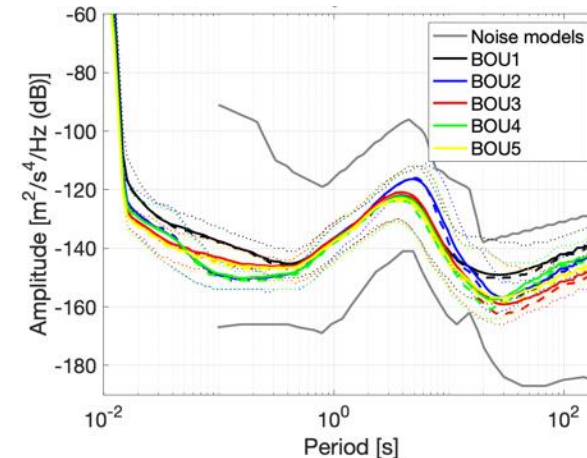


Workshop of 17 universities and 4 companies has led to a proposal of an integrated program of Earth science research, currently being considered by NERC.

NERC  
scoping  
study  
proposal

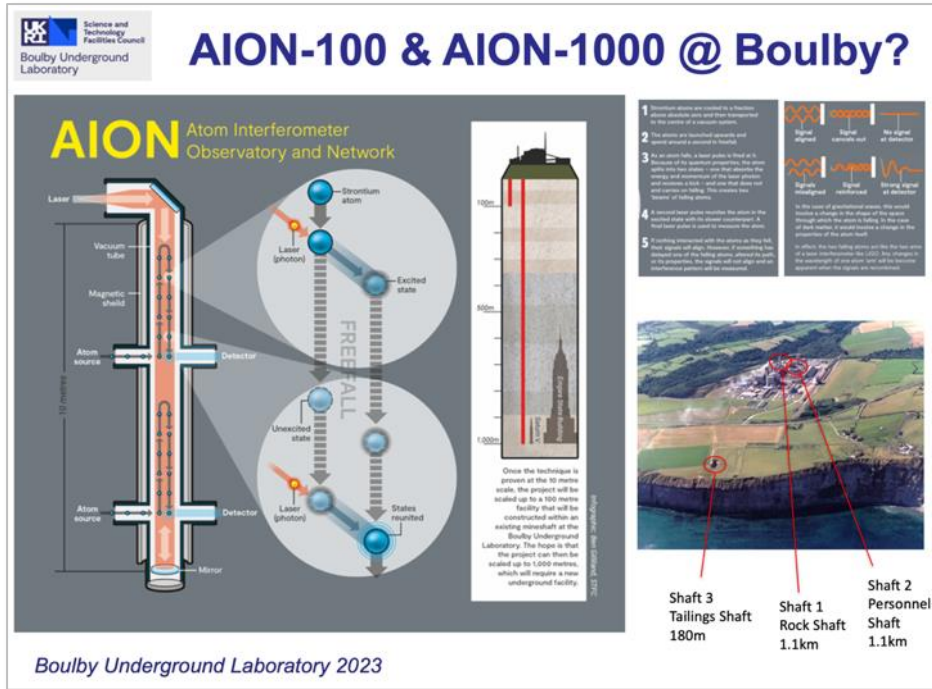


## Developing a community coordinated programme of Earth Science @ Boulby



Seismometers and fibre optic acoustic sensors deployed to baseline vibration levels for AION experiment and North Sea regional earthquake monitoring.

# Quantum Sensors and Computing @ Boulby...

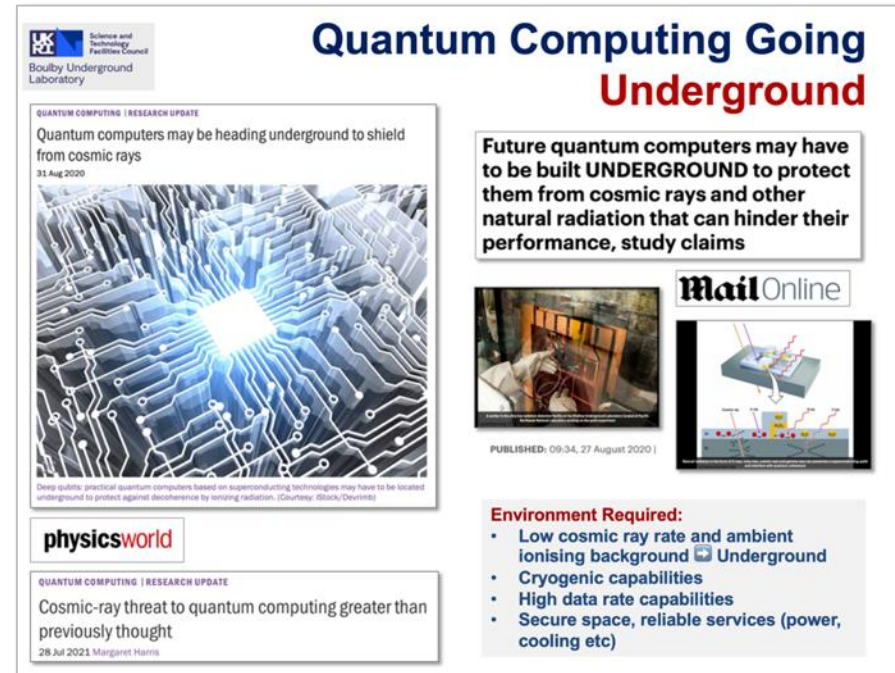


AION-20, 100 & 1000: Atomic interferometry for GW and light DM studies

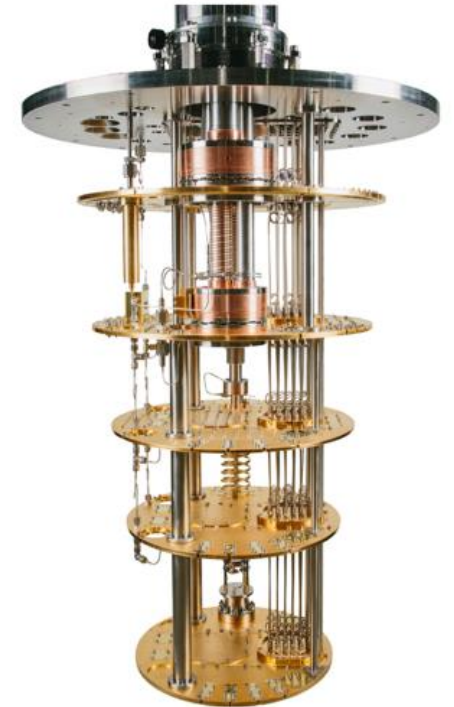
## A growing Quantum @ Boulby community:

- Planning future quantum sensors and computing R&D and operation
- Helping to specify technical infrastructure needs for a future hosting facility
- Community meetings held Sept 24, October 25
- **Durham laser cold atom project (QuASAR) being installed @ Boulby (3/26).**

Quantum Computing in Ultralow background environment?



**Coming to Boulby v.soon!**  
Oxford Instruments  
Proteox MX Dilution Fridge



In collaboration with **National Quantum Computing Centre (NQCC)**.  
Will be available for use by wider community.

# Next Generation Xe Dark Matter(+) Detector (XLZD)

Lux-ZEPLIN (LZ). SURF, S. Dakota, USA



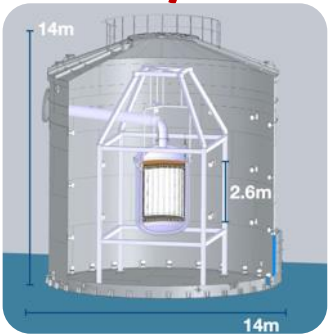
LZ: 10T 2-phase Drk Matter detector operating in SURF lab, USA. Early 2-phase Xe technology developed in the UK. STFC/UK investment continues.



Xenon-nT  
LNGS, Italy



DARWIN  
(Proposed)

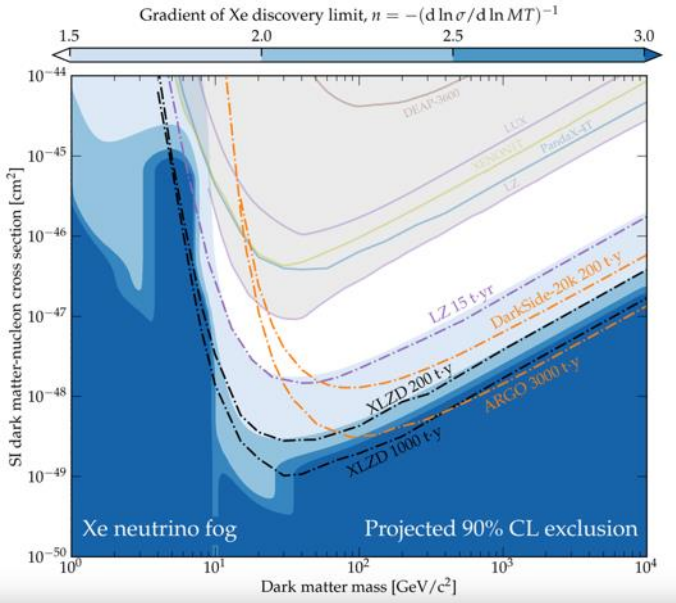


**XLZD**  
2021 merging  
of LZ, Xenon  
and DARWIN  
teams

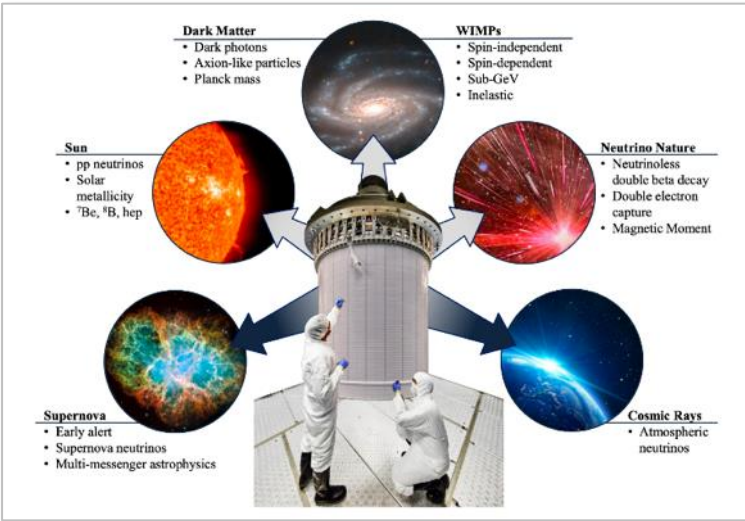
**XLZD**  
50-100T LXe  
Operation 2032+  
Site evaluation  
underway

**Could XLZD be  
constructed  
and operated at  
Boulby 2030+?**

Projected  
sensitivity  
(Akerib P5  
town hall  
mtg 2023)

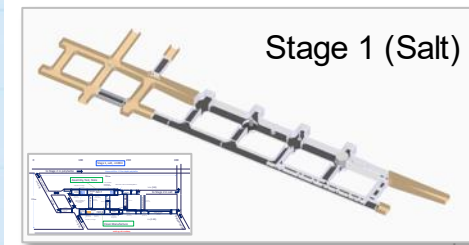
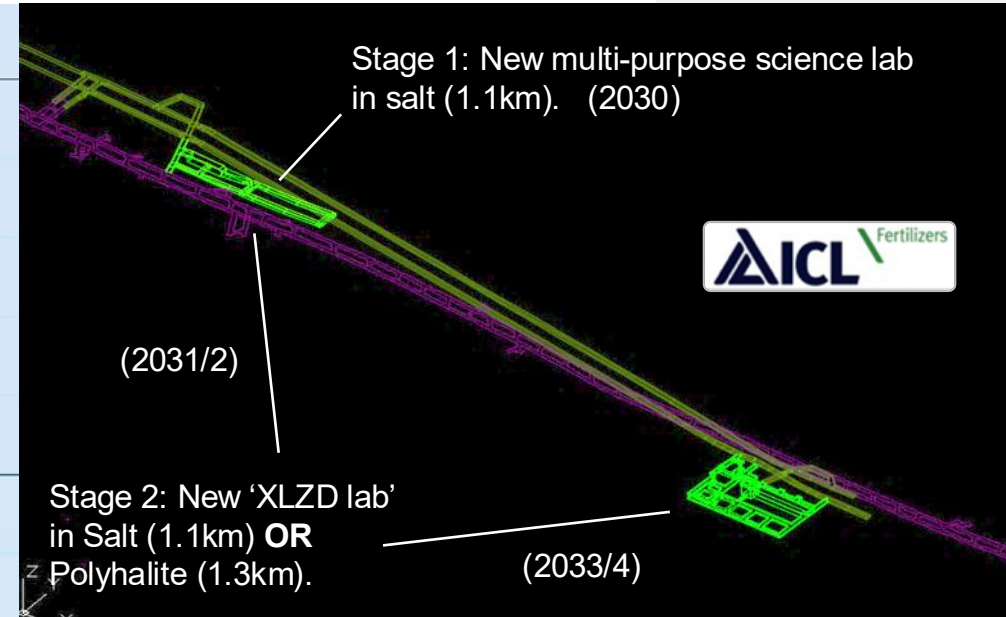
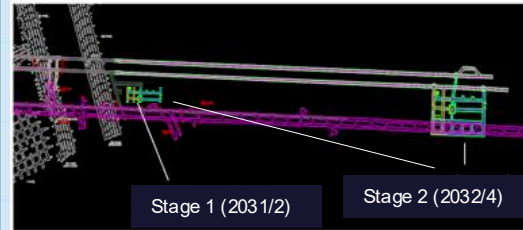
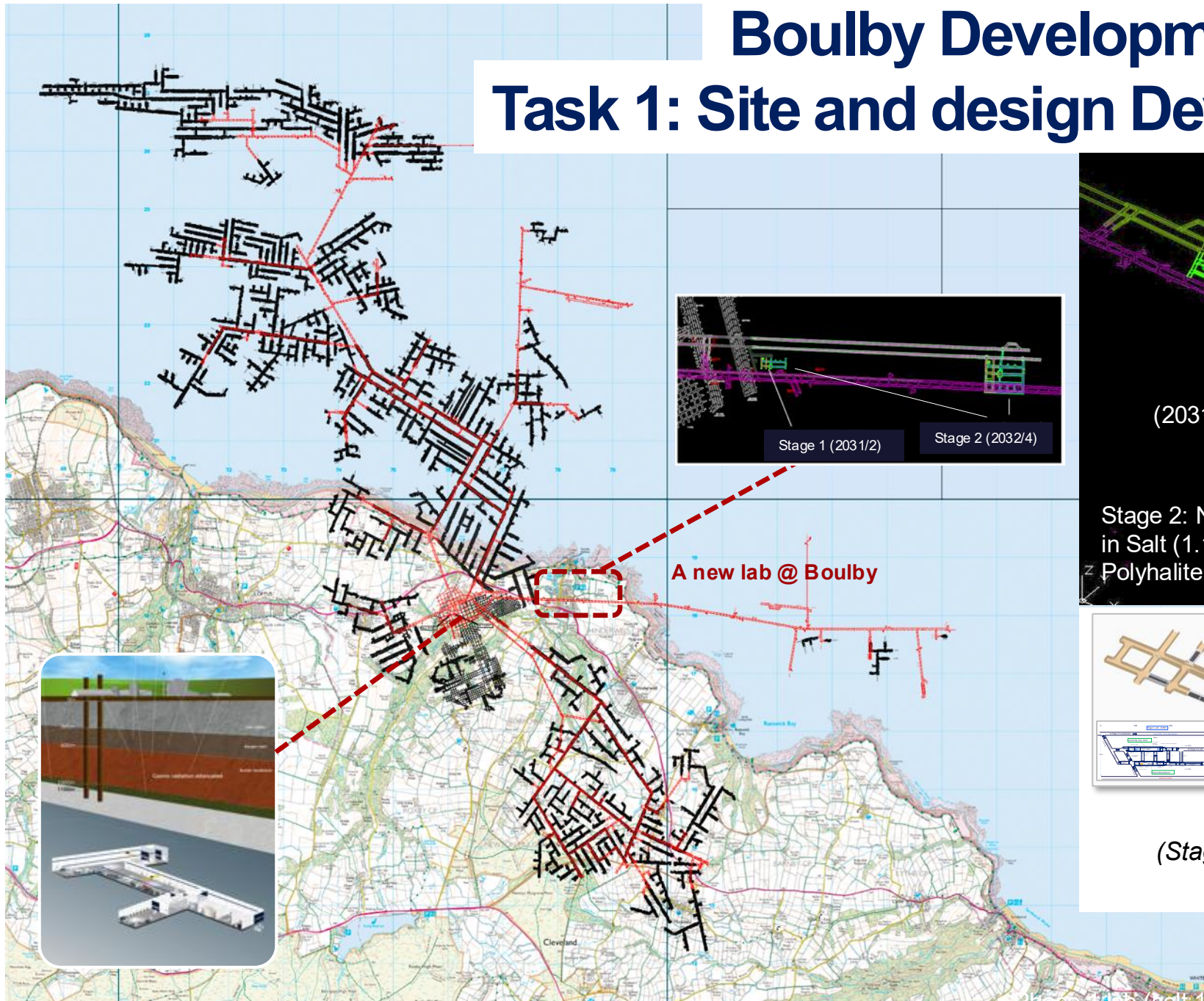


Next generation **world's best** Dark Matter (+) detector. **Expected 2030+**



# Boulby Development Project

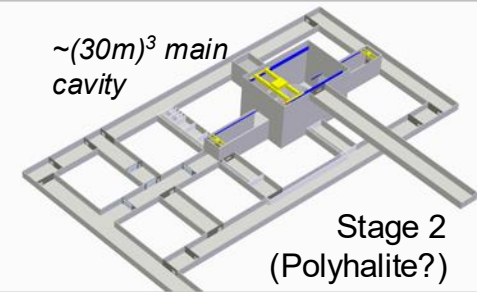
## Task 1: Site and design Development.



Total volume  
(Stage 1 + stage 2)  
~120,000m<sup>3</sup>

*DRAFT: 2-stage design*

~(30m)<sup>3</sup> main  
cavity



**Excavations for stage 1 of expansion  
by ICL-UK began in mid-2024.**

# Stage 1: A new world-class multi-disciplinary deep underground science facility.

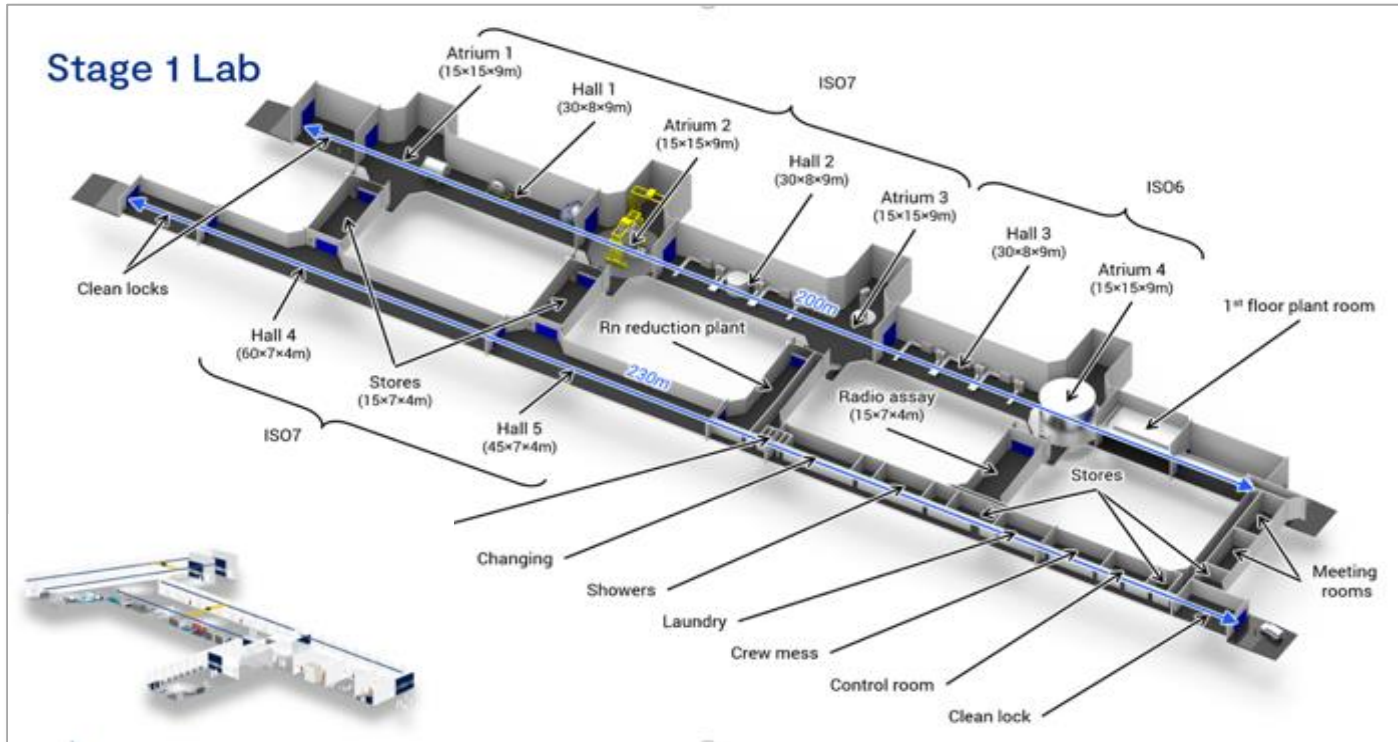


Image Credit: A Ball, J Elmer, C Kinahan, J Hill et al.

**EXCAVATION NOW COMPLETE.**  
**Planning for laboratory outfitting now underway**



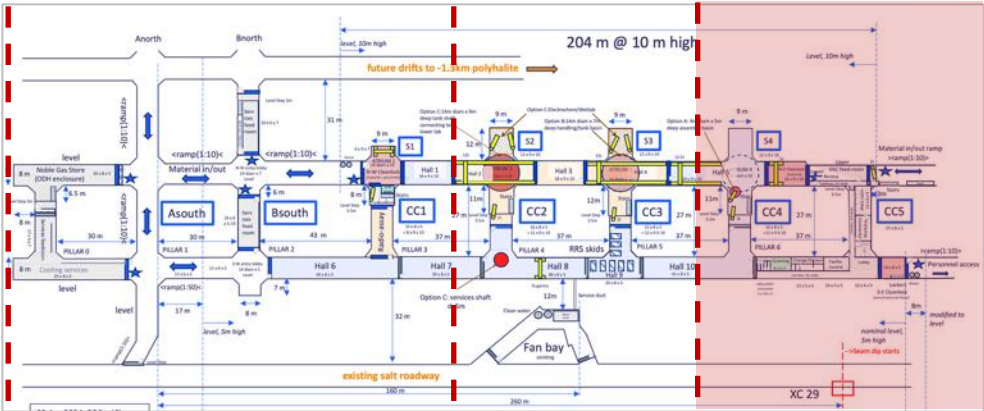
# Stage 1 Outfitting

A new, world-class multidisciplinary science facility, complementing and succeeding the current Boulby laboratory

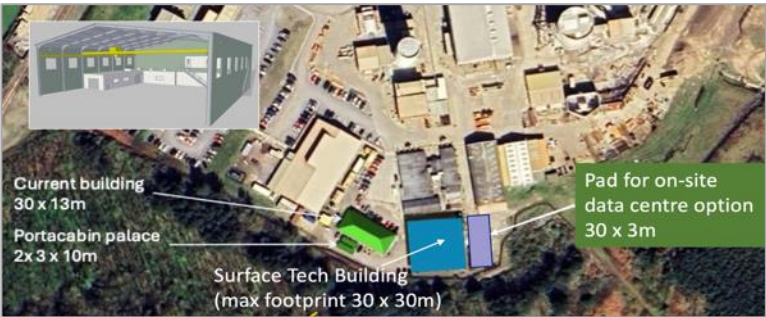


Stage 1 Lining Options

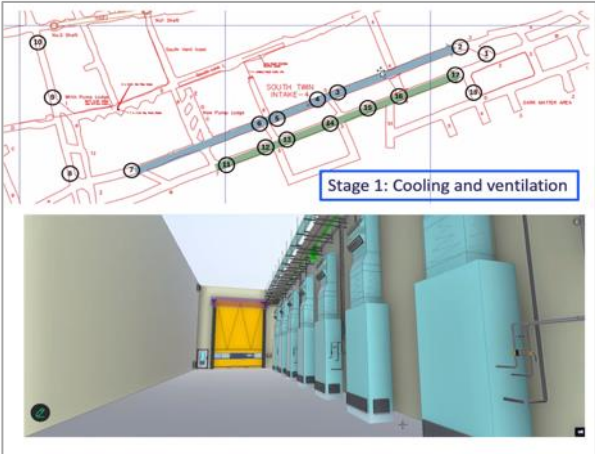
Possibility for single shot or staged outfitting



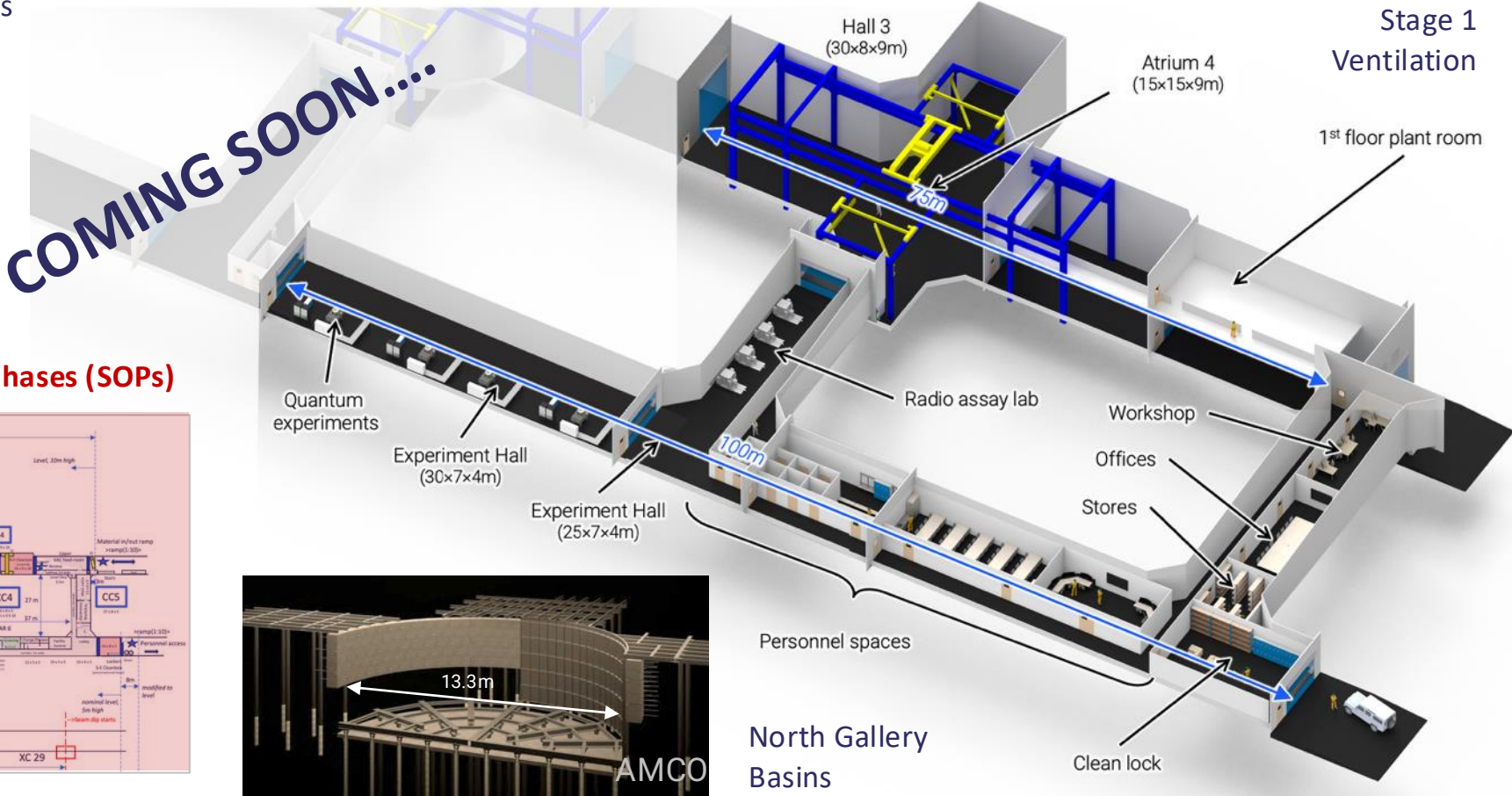
SOP3                      SOP2                      SOP1



Surface Building Development



Stage 1 Ventilation



# What about XLZD?

The international XLZD collaboration are looking at 4 potential Underground Labs to host the project:

- SURF (USA)
- SNOLAB (Canada)
- LNGS (Italy)
- **Boulby (UK)**

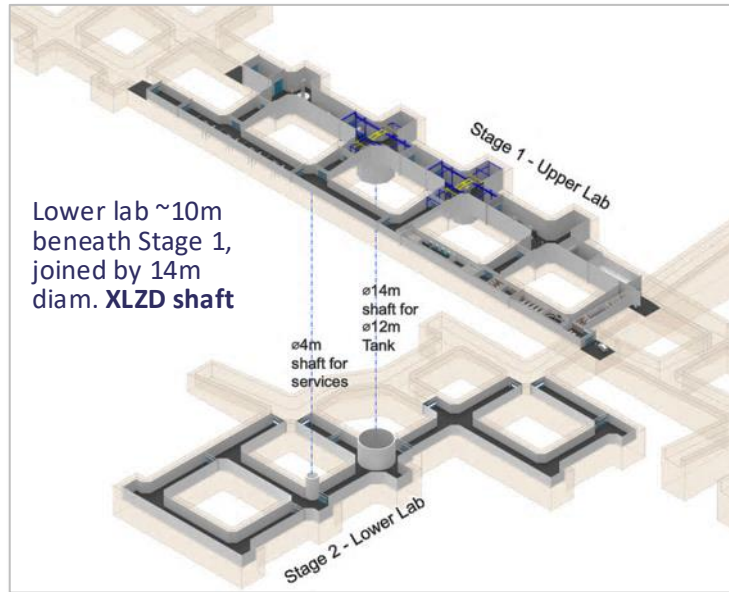
## Decision factors:

- Physical/practical suitability
- National science capability
- Local political & financial support

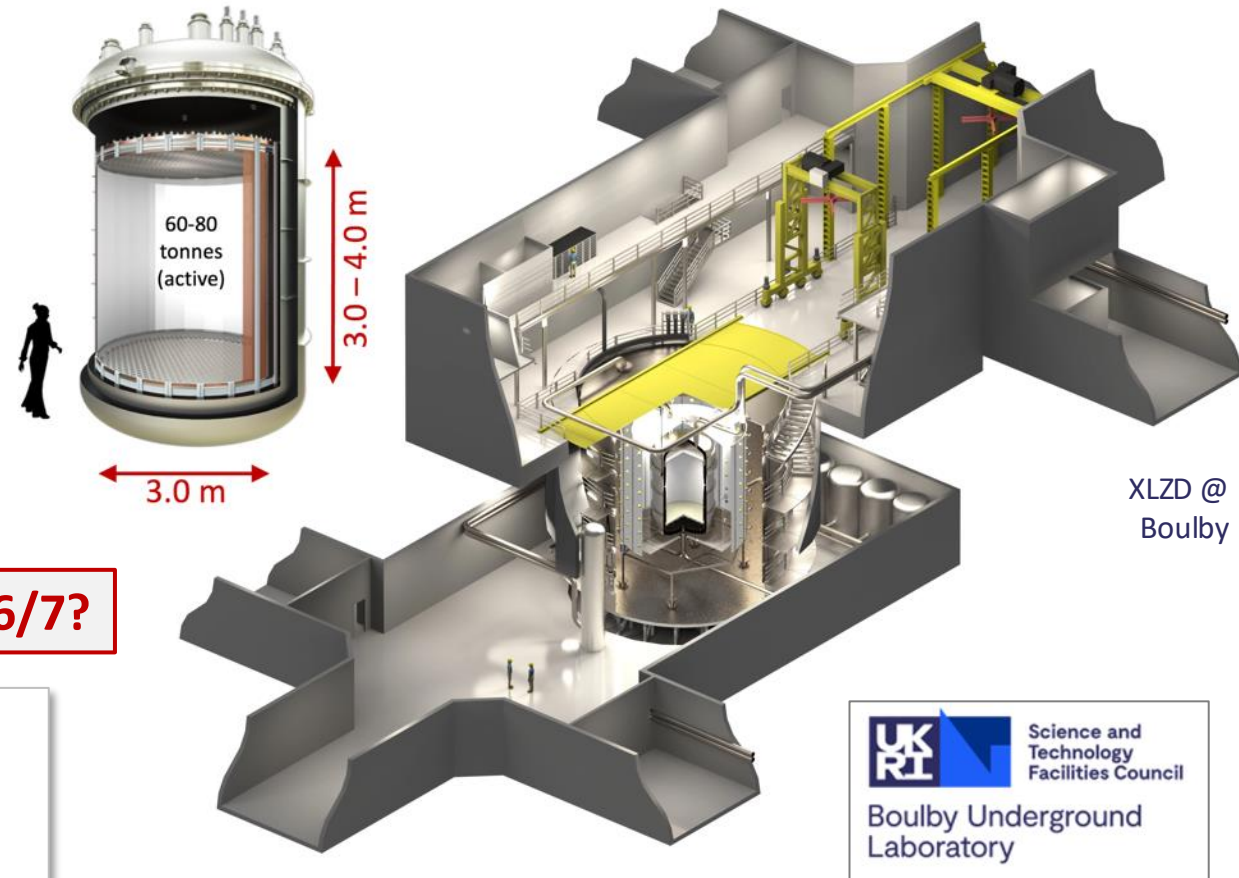
**Host site Decision... 2026/7?**

## Latest news from XLZD-UK:

- New simulations show 1.1km depth is fine for XLZD science ambitions
- **Stage 2 in SALT is now Boulby Plan A.**
- **QUICKER** and **CHEAPER** to deliver and operate
- Lab(s) in the Polyhalite layer are also still an option.

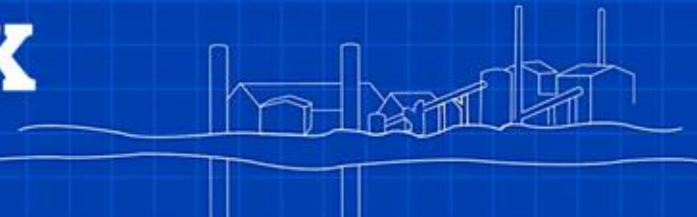


Stage 2 & Stage 1 in Salt



**Ongoing design & planning efforts for the XLZD Dark Matter & Rare-Event detector coming to Boulby**

**XLZD-UK**



# Deep Science at Boulby Underground Laboratory: Status & plans for the UK's Deep Underground Science Facility.

## Summary...

### Boulby Underground Lab Status:

- The UK's deep underground science facility
- Nationally and Internationally important. With a strong history in Dark Matter tech. development
- Now a rich & varied science programme in pure & applied low background science, Earth & environmental science, astrobiology & planetary exploration, quantum sensors & computing.

### Future plans:

- We are expanding facilities at Boulby with a flexible outfitting strategy to accommodate future projects across all science themes, inc. the major Dark Matter(+) study XLZD.
- Delivery of Stage 1 (of a possible two-stage) facility expansion – is now underway.
- **Come and visit us!**

