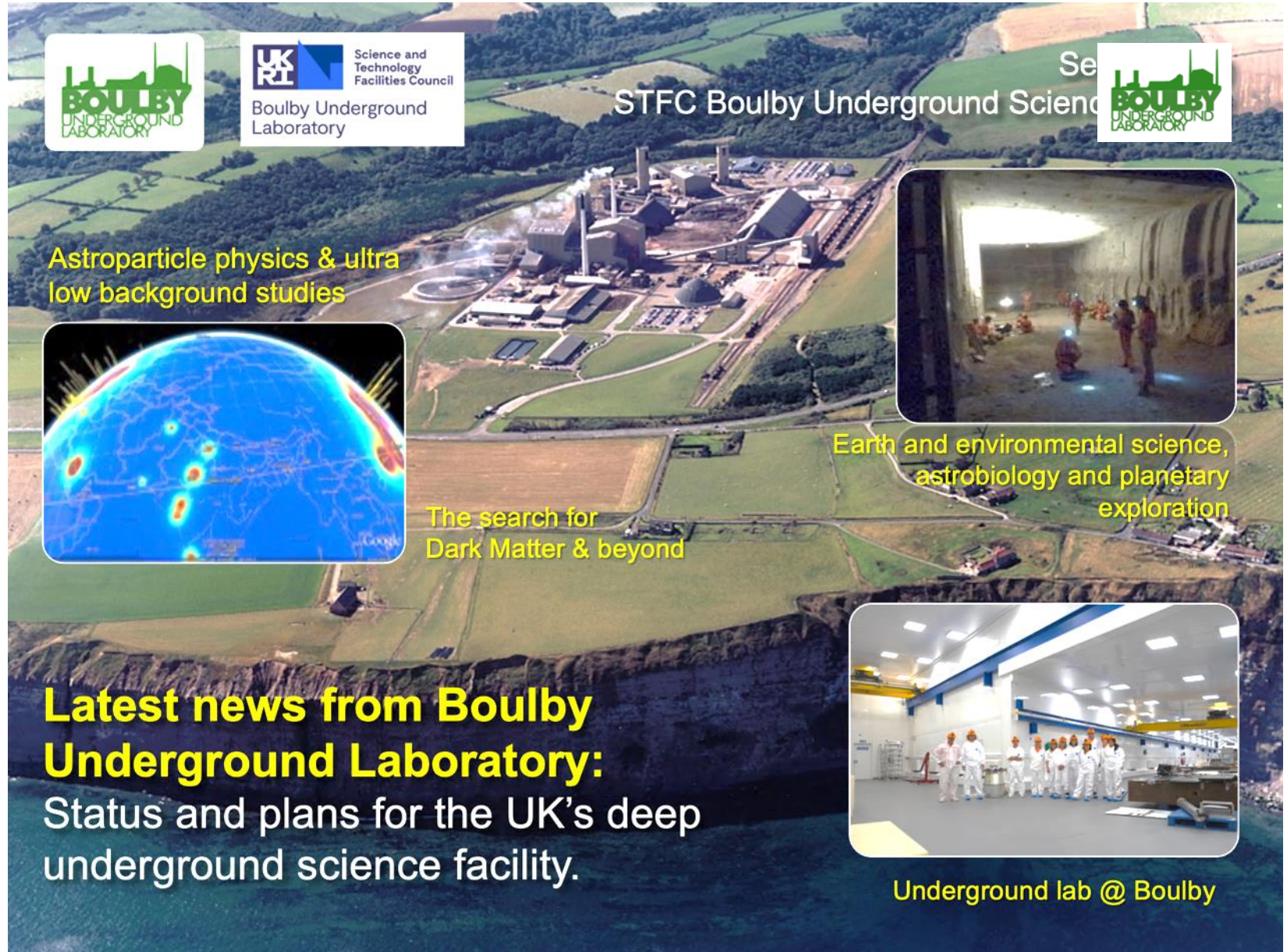


Deep Science at Boulby Underground Laboratory:

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

Sean Paling
STFC Boulby Underground Laboratory



  Science and Technology Facilities Council
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

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

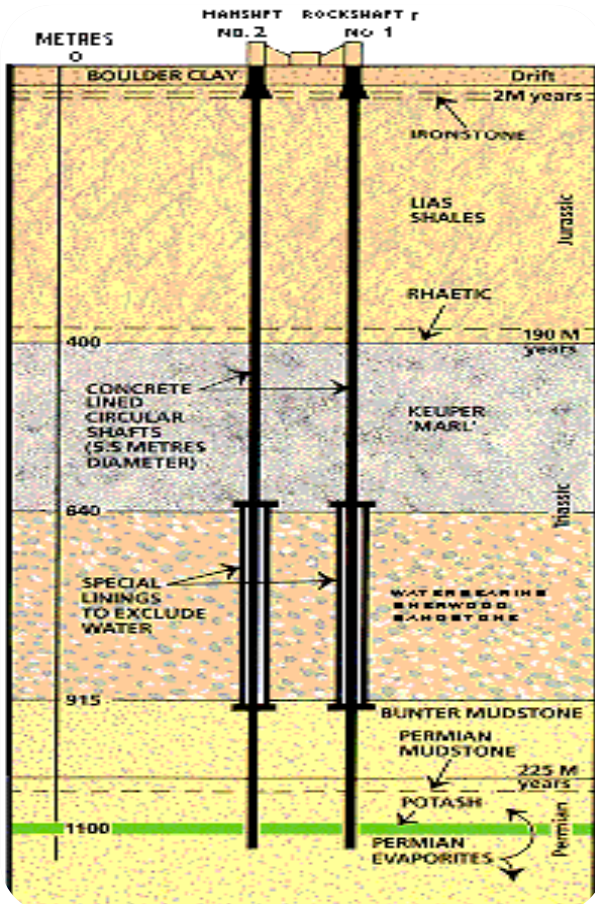


View from Staithes

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



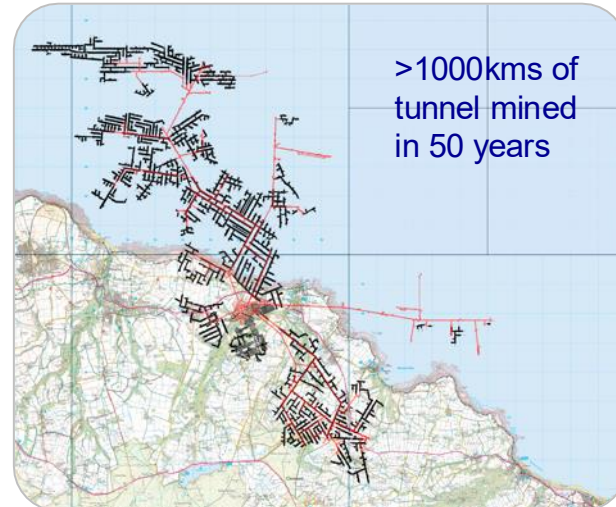
Potash



Rock-Salt



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



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)



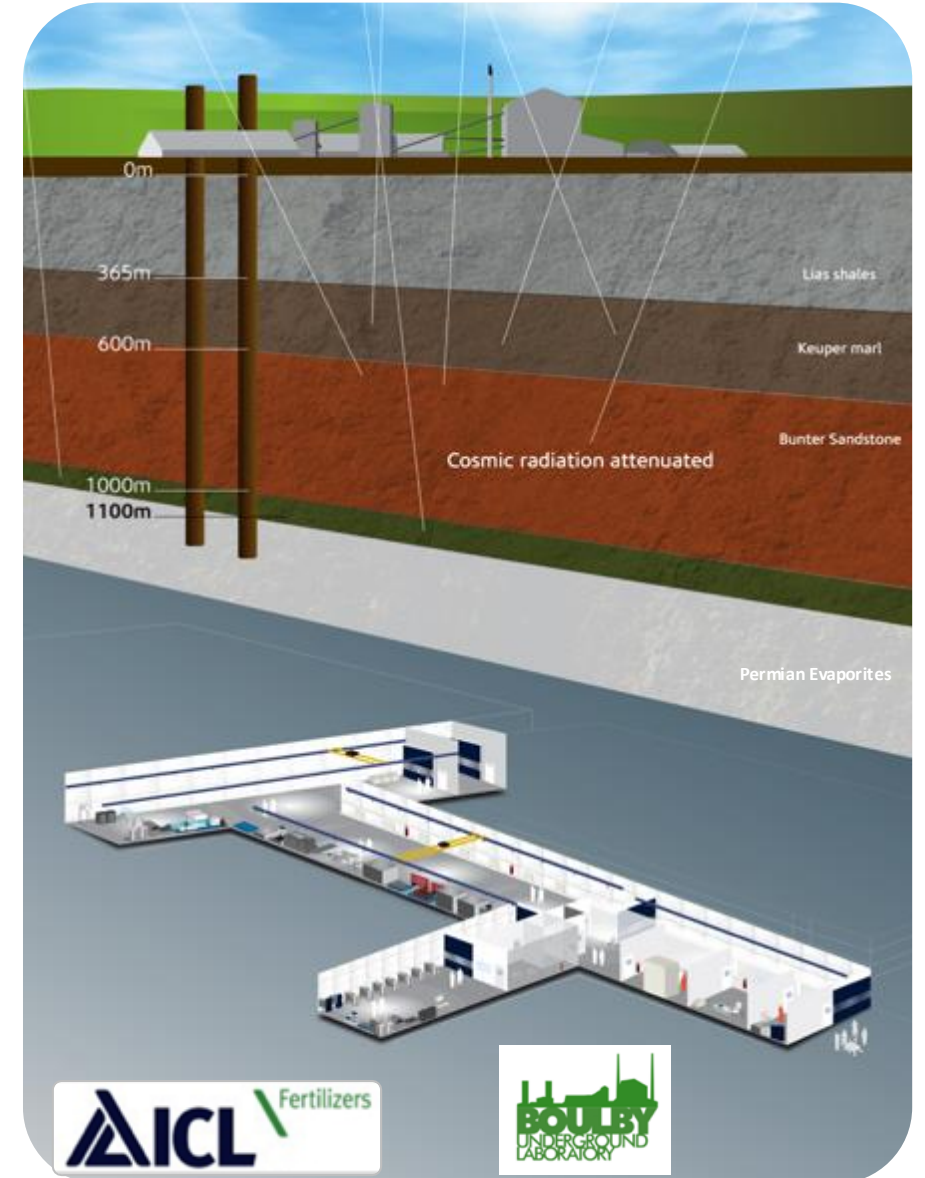
4000m³ class 10k and 1k clean lab space



Lab entrance

Factor ~10⁶ 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.

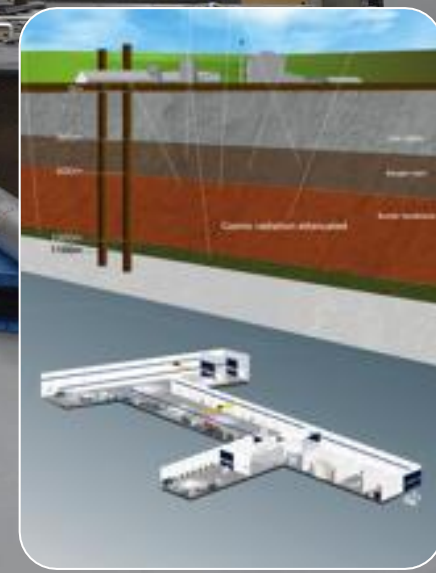


3000m³ Outside Experimentation Area



BUGS Material screening

Boulby Underground Lab Facilities 2026: >4000m³ 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. 3000m³ 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: 30,000m³
 SNO+, SuperCDMS, Deep3600,
 PICO, Next Gen 0vBB (to come?)

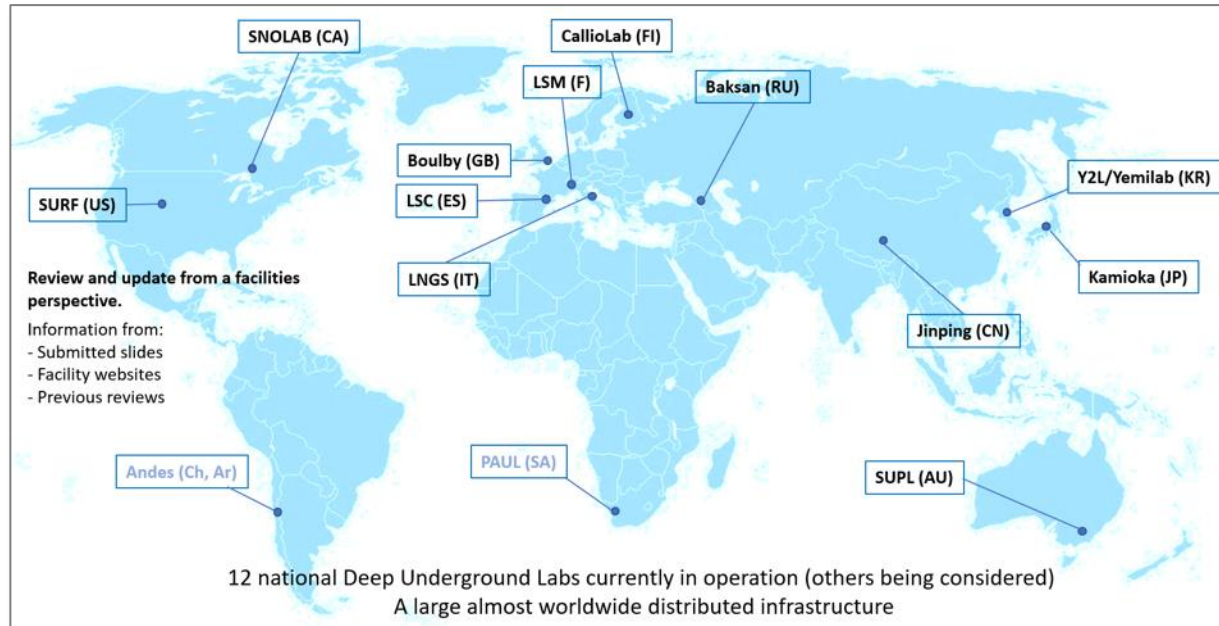


SURF Laboratory (USA)
 Disused Mine, 4200 mwe
 Current vol: 7,100m³
 LZ, MJD, DUNE (to come)



Boulby Underground Laboratory (UK)
 Working Mine, 2850 mwe
 Current vol: 7,200m³
 ZEPLIN+ (past), BUGS, News-G,
 RECON, BUTTON & more...

World Underground Labs



CJPL Jinping (China)
 Hydro power plant, >6000 mwe
 Current vol: 330,000m³
 Panda-X, CDEX, JUNA,
 GeoDEX, JNE and more to come

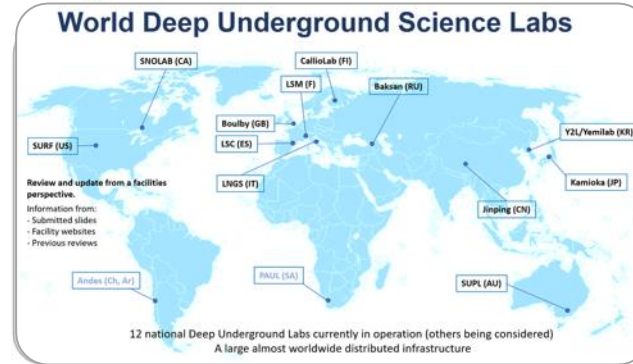


Gran Sasso National Laboratory
 LNGS (Italy)
 Under mountain, 3800 mwe
 Current vol: 180,000m³
 Xenon, Darkside, LUNA, Legend +

Boulby Underground Laboratory (UK)

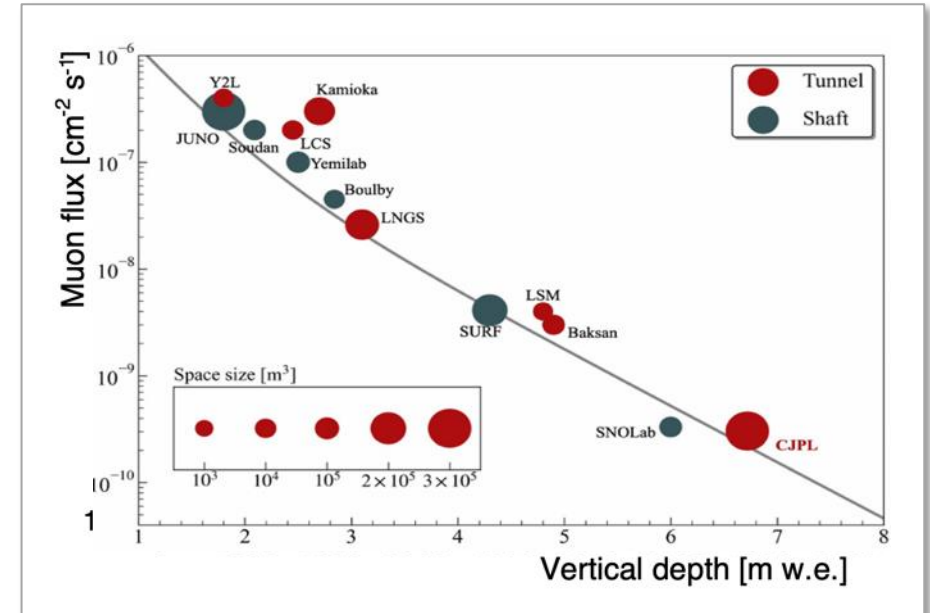
Boulby Facility Details...

- 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/m³)
- Diverse science programme.
- Science and Industry partnership



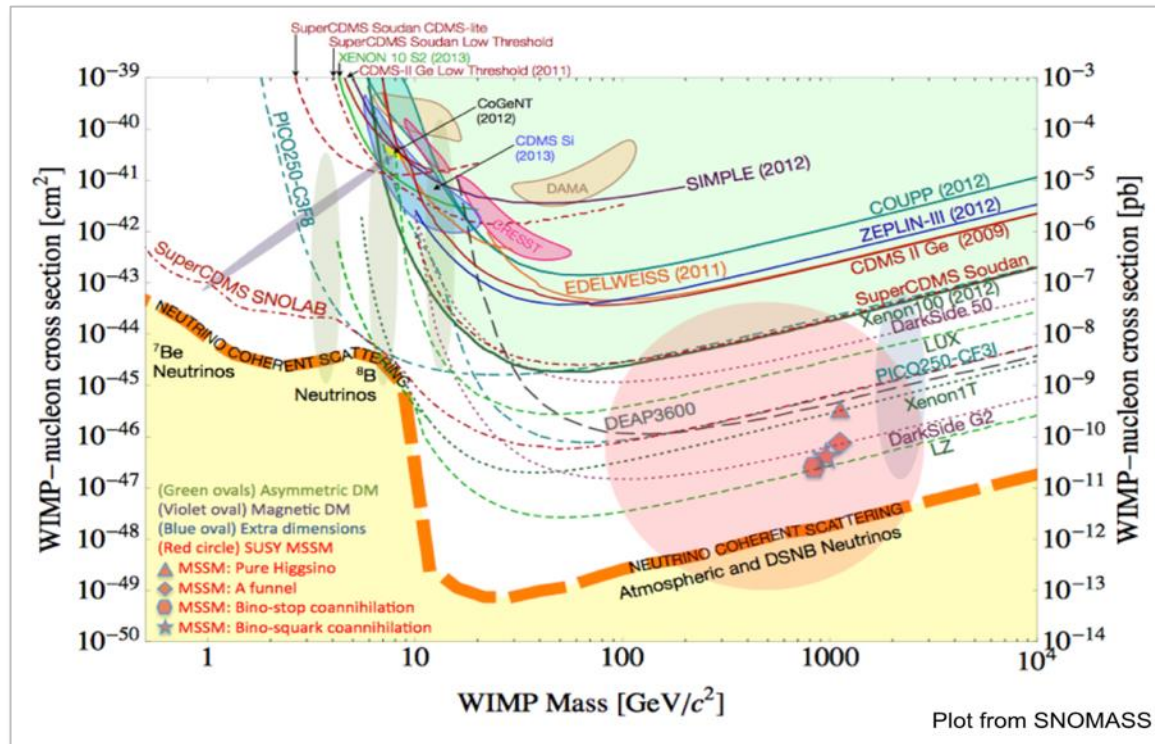
Science Programme Status and Plans.

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

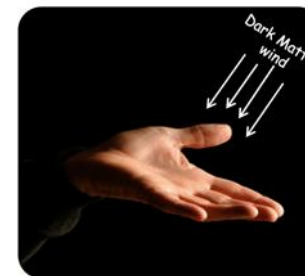
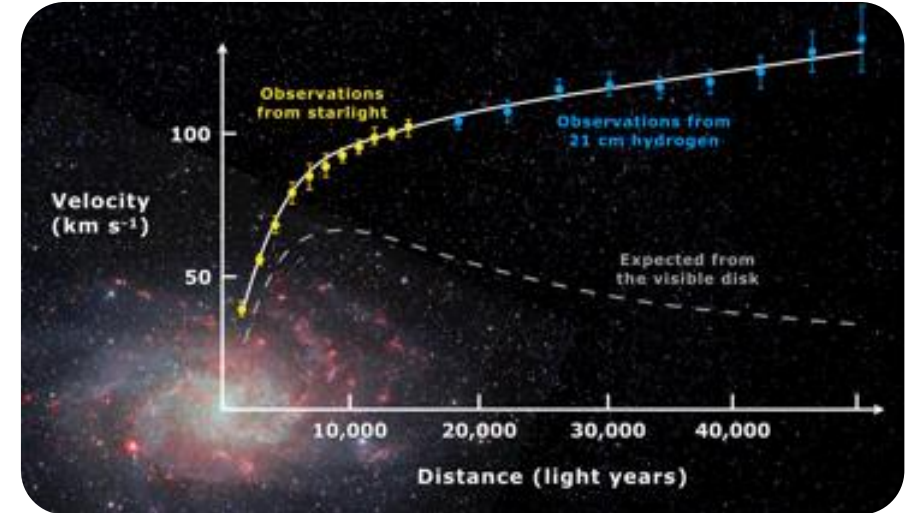
Boulby Dark Matter Studies...

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

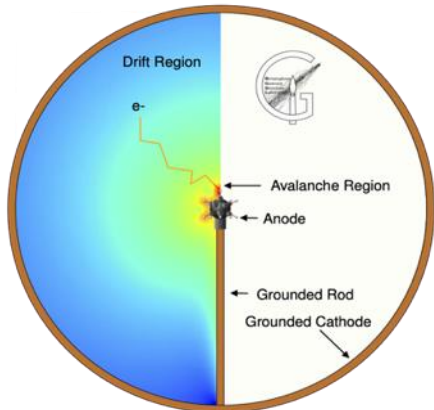
DarkSPHERE

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

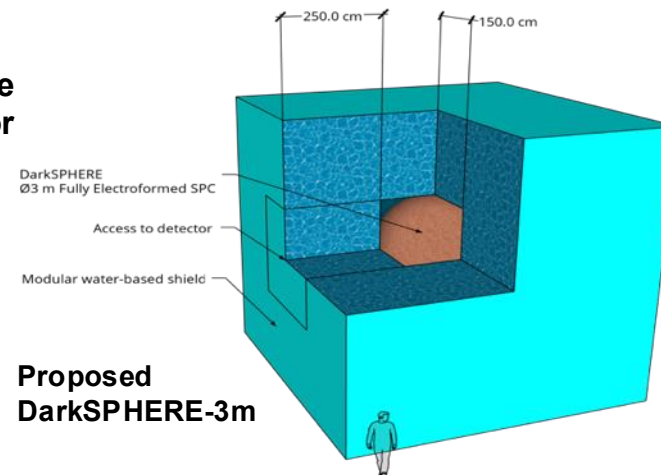
- Instrumentation developments
 - Multi-anode sensor
 - Gas filtration
 - Rate effect studies
- Neutron spectroscopy (with N₂ gas)
 - Neutron background surveys
 - Industrial applications
- High-purity copper electroformation
- **Towards scaled-up, electroformed, detector at Boulby, 3m diam. 5 bar**
He:CH₄H₁₀ **DarkSPHERE**



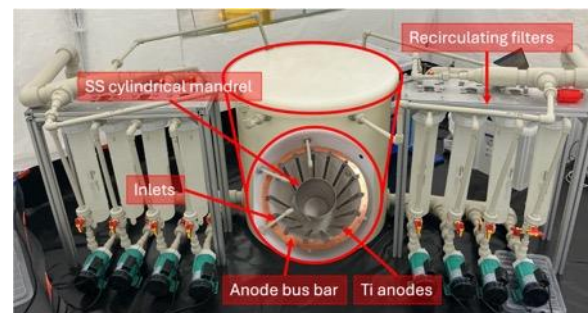
SPC concept: Variable target
Low E_{th}, Low mass sensitivity



11-anode
sensor



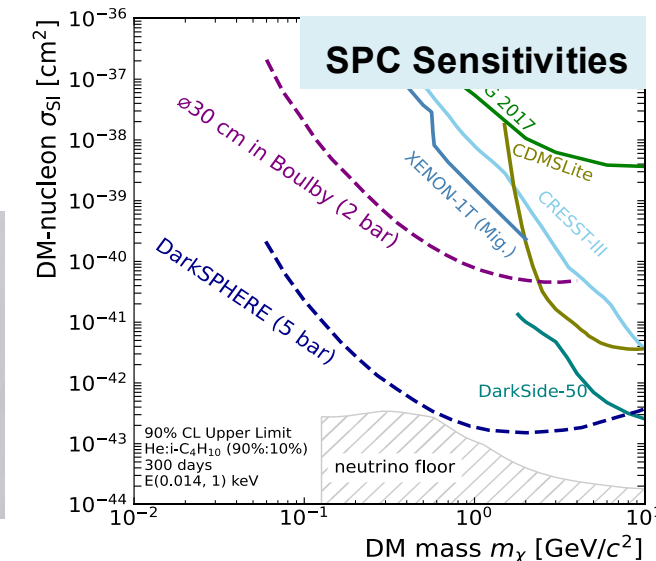
AI-S30 R&D Detector



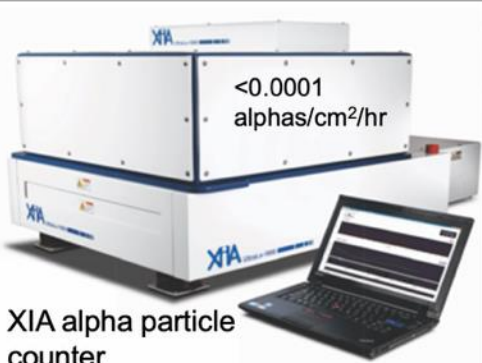
Copper electroforming at Boulby



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



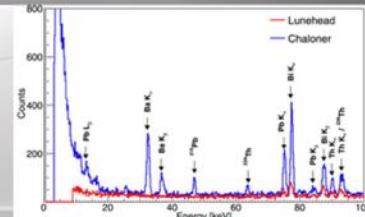
Ultra Low Background Material Screening @ Boulby (**BUGS**)



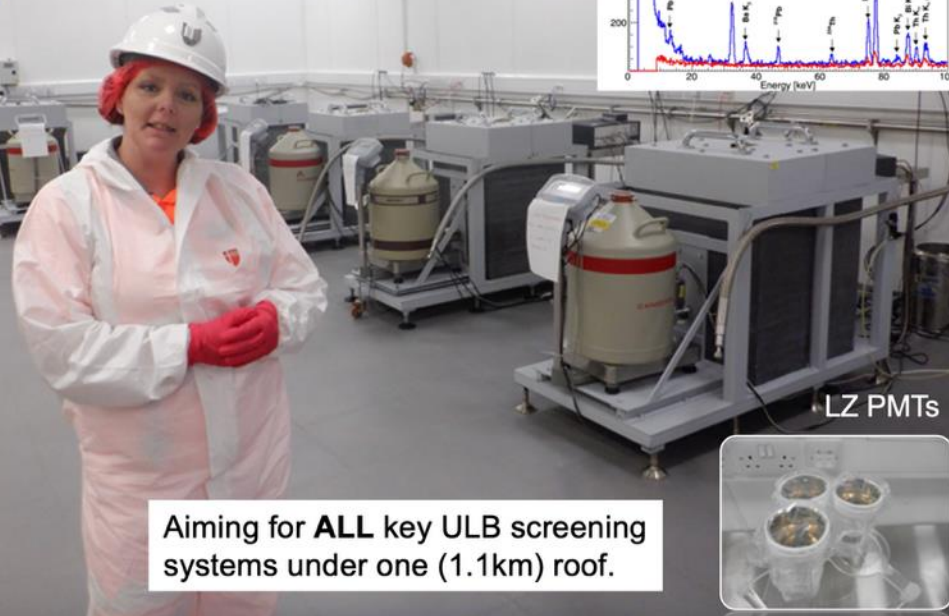
XIA alpha particle counter



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.

LZ PMTs



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)

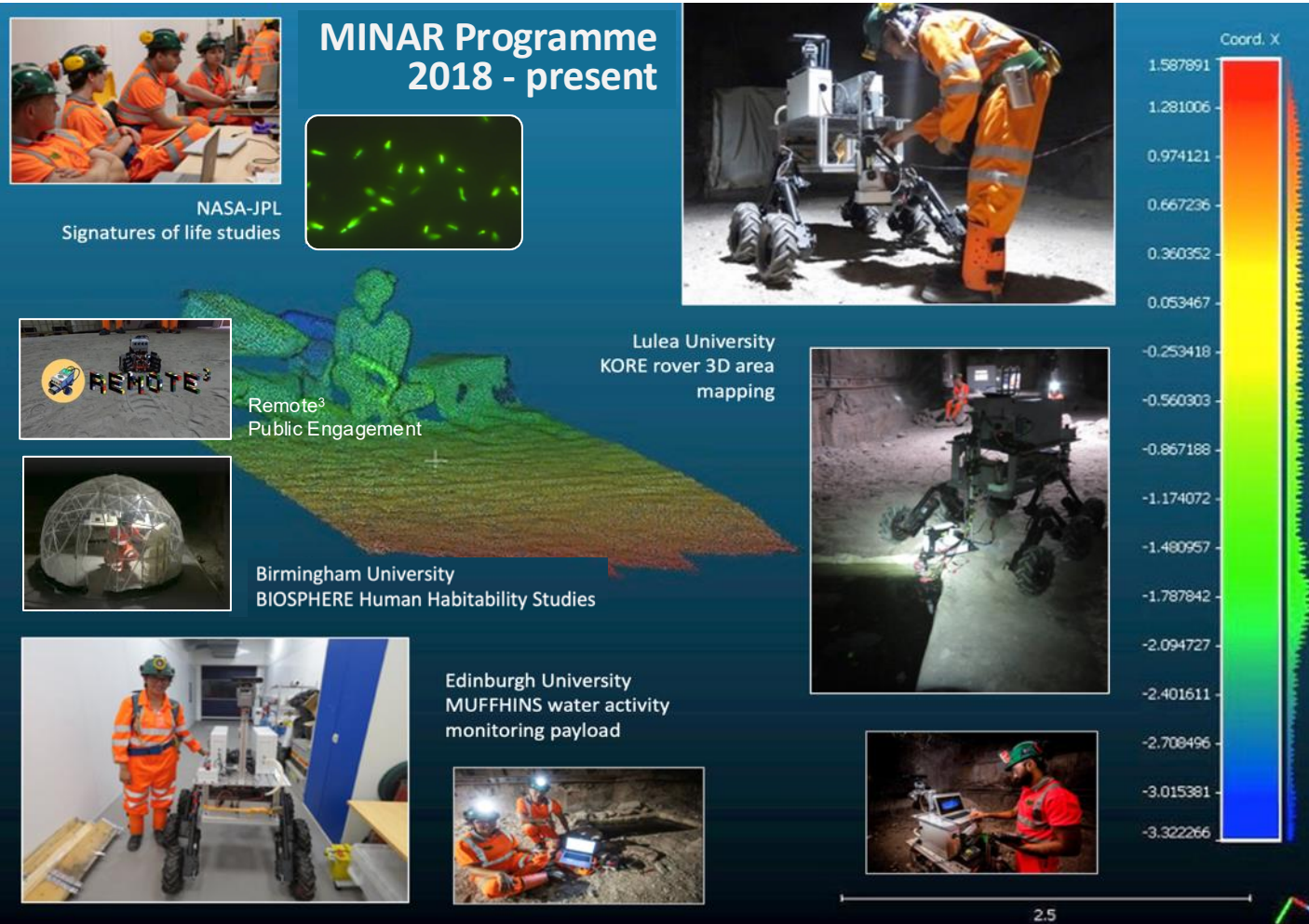
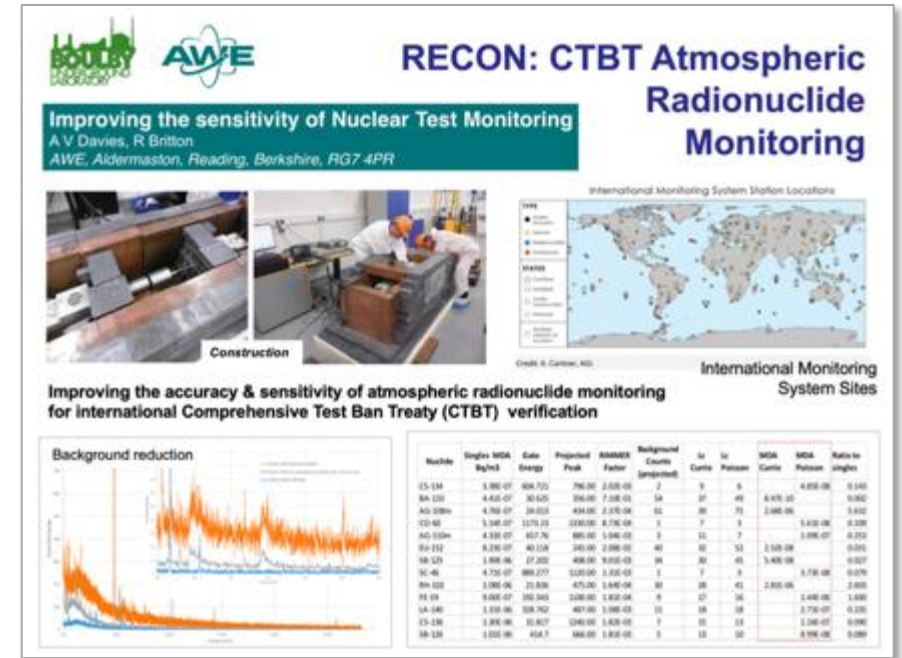
- ULB Germanium (8)
- XIA: Surface alphas (2)
- Radon Emanation (2)
- ICPMS-QQQ * All now in operation

Multidisciplinary Science

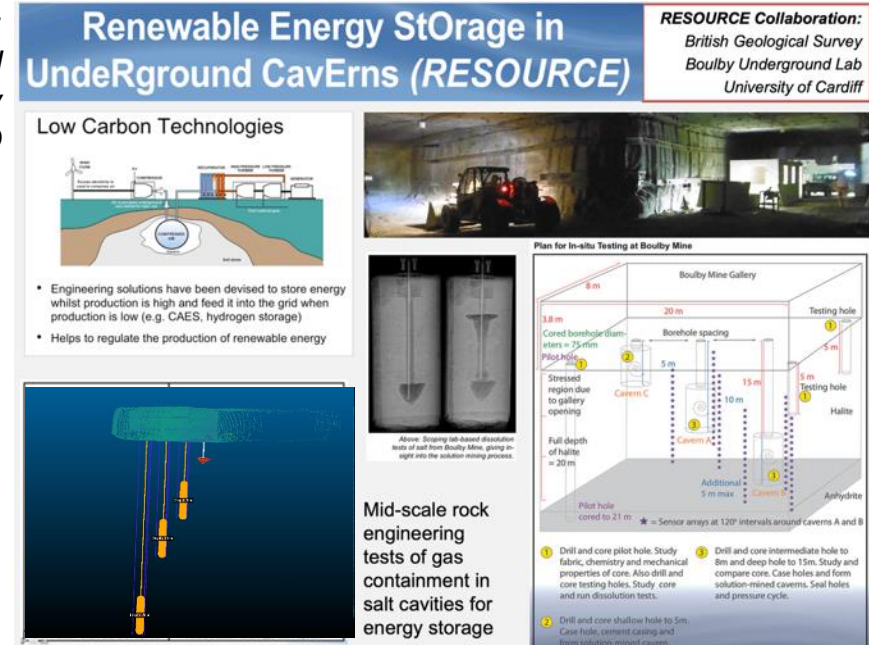
Applied low background particle physics, Earth and Environmental science, Astrobiology & Planetary Exploration Technology Development.

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 I
Outreach/ Education: General Public, Schools +	A

Long Term (Current lab plus major new lab)		
Particle Physics and Low Background Science: Dark Matter: Major Next Gen Experiments: • Xenon (XLZD) • Argon (SOLAIRE+) • Gas (DarkSPHERE+) • ULT technologies for DM • Quantum Technologies for DM Neutrinos: • BUTTON-100+ • DATUM (LEGEND Support), • SoLAR +.... Mat screening & LB Techniques: A world's best facility: • Ge, XIA, RnEm, ICPMS, Cleanliness & Engineering R&D • RECON+ - Nuclear Security Gamma spec		Target projects for a major new UK underground facility / campus
Earth & Environmental Science: • Sustainable Energy R&D (Gas Storage, Geotherm, CCS) • Local/Global Seismology Observatory • Geological Repositories R&D • Misc geology / Geophysics R&D		
Astrobiology & Planetary Exploration: • Extremophile R&D • Astrobiology / life beyond Earth R&D • Human habitation R&D • Planetary exploration technology development • Mining and industry application development.		
Quantum Sensors and Computing: • AION-20/100/100 – Atomic Interferometry • Quantum Sensor and Computing Technology R&D		
Outreach and Education: • A National Centre for Science and technology outreach and education.		

Boulby Future Earth and Environmental Science

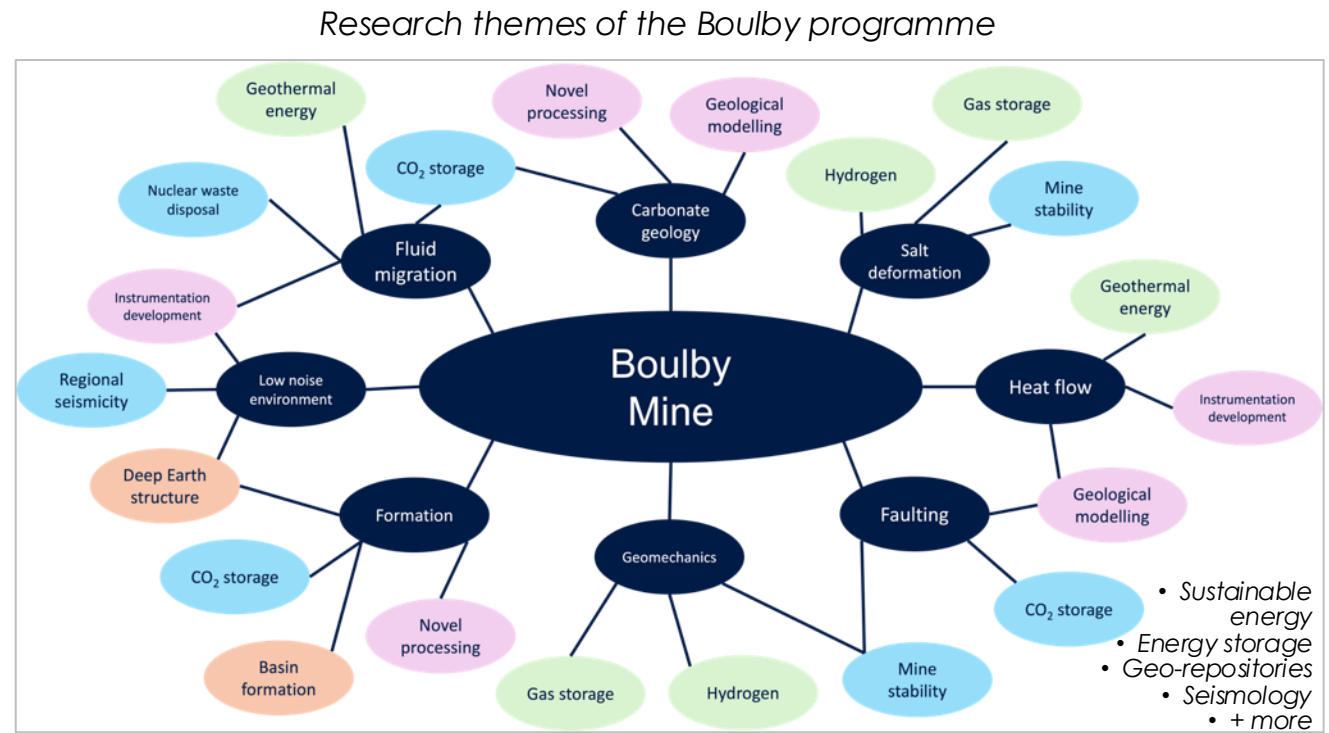
Developing program of Earth science research at Boulby by a consortium of UK universities and industry.

Earth science at Boulby workshop August 2024

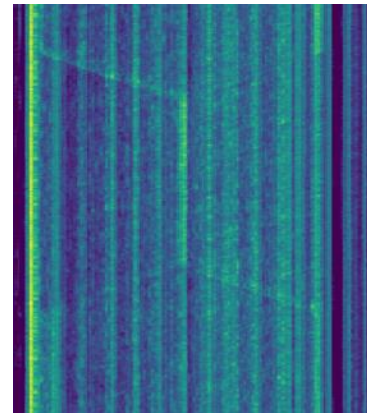
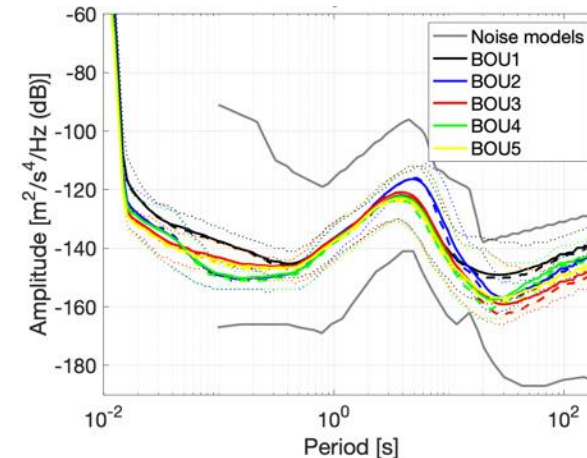


Workshop of 17 universities and 4 companies has led to a proposal of an integrated program of Earth science research, currently being considered by NERC.

NERC
scoping
study
proposal

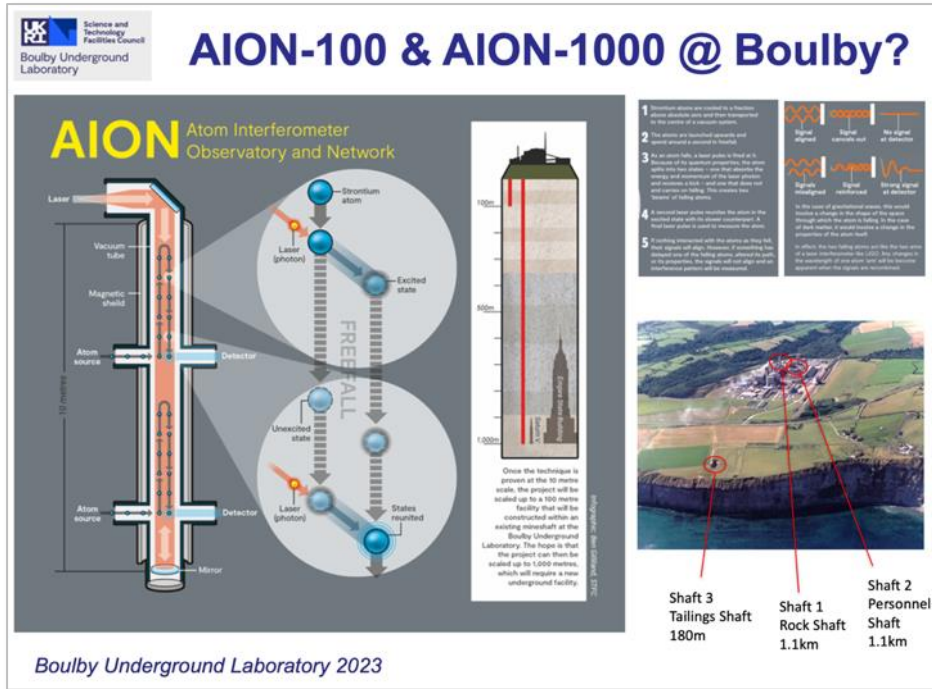


Developing a community coordinated programme of Earth Science @ Boulby



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...

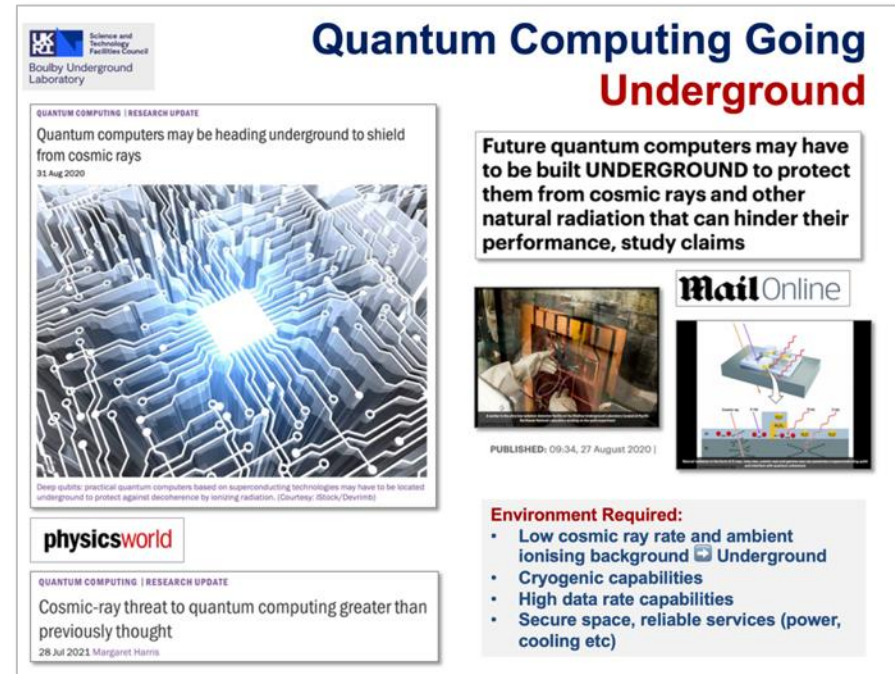


AION-20, 100 & 1000: Atomic interferometry for GW and light DM studies

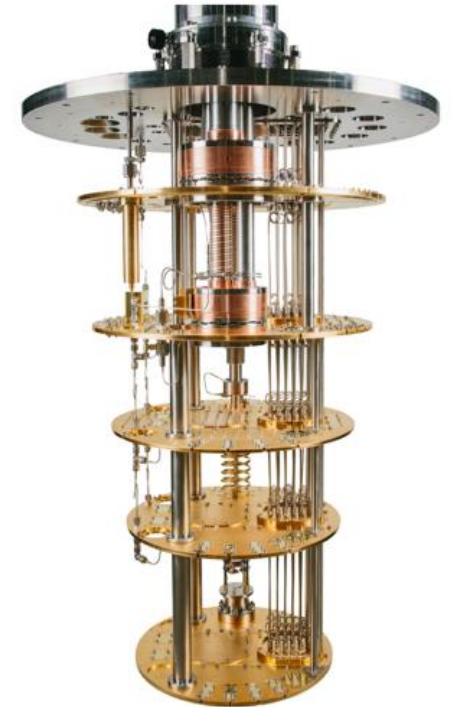
A growing Quantum @ Boulby community:

- 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



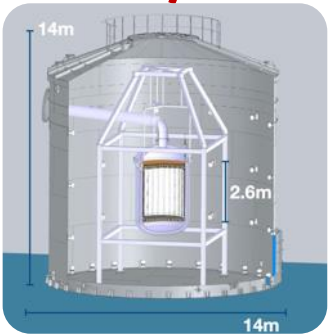
LZ: 10T 2-phase Drk Matter detector operating in SURF lab, USA. Early 2-phase Xe technology developed in the UK. STFC/UK investment continues.



Xenon-nT
LNGS, Italy



DARWIN
(Proposed)

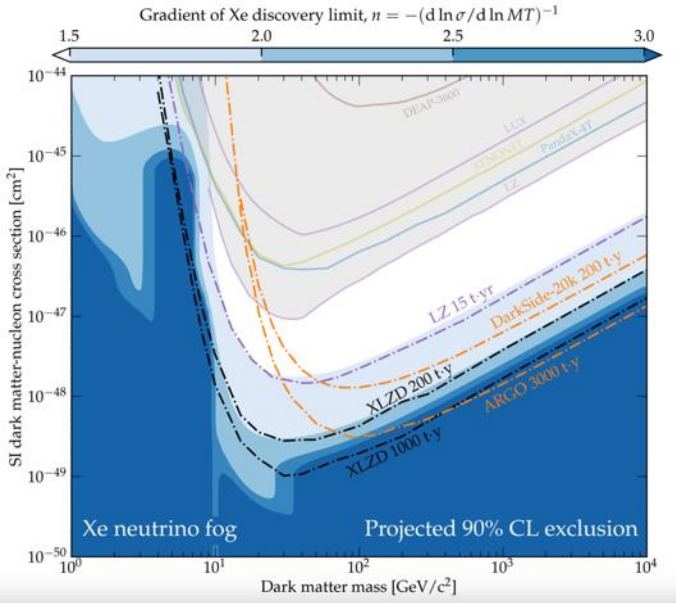


XLZD
2021 merging
of LZ, Xenon
and DARWIN
teams

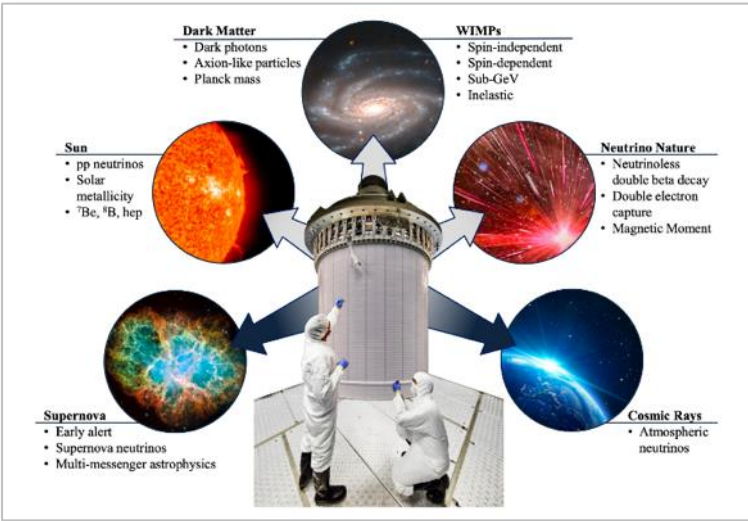
XLZD
50-100T LXe
Operation 2032+
Site evaluation
underway

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

Projected
sensitivity
(Akerib P5
town hall
mtg 2023)

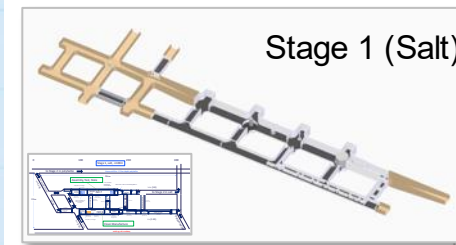
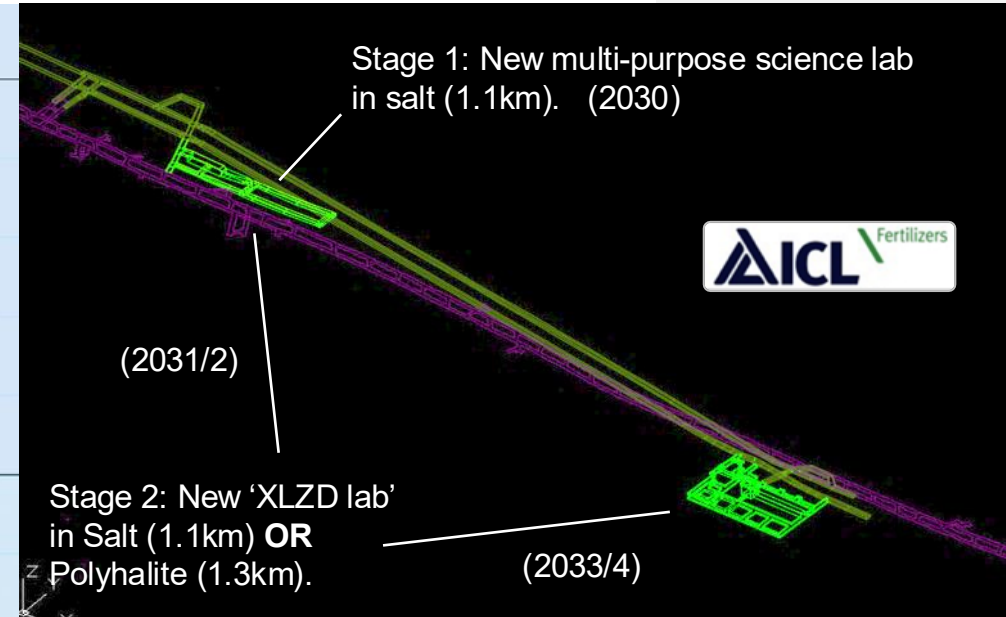
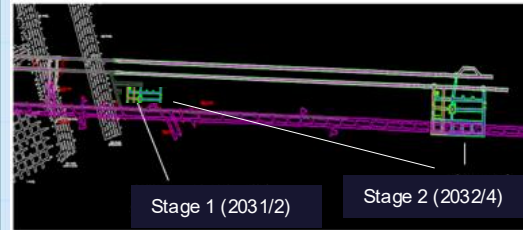
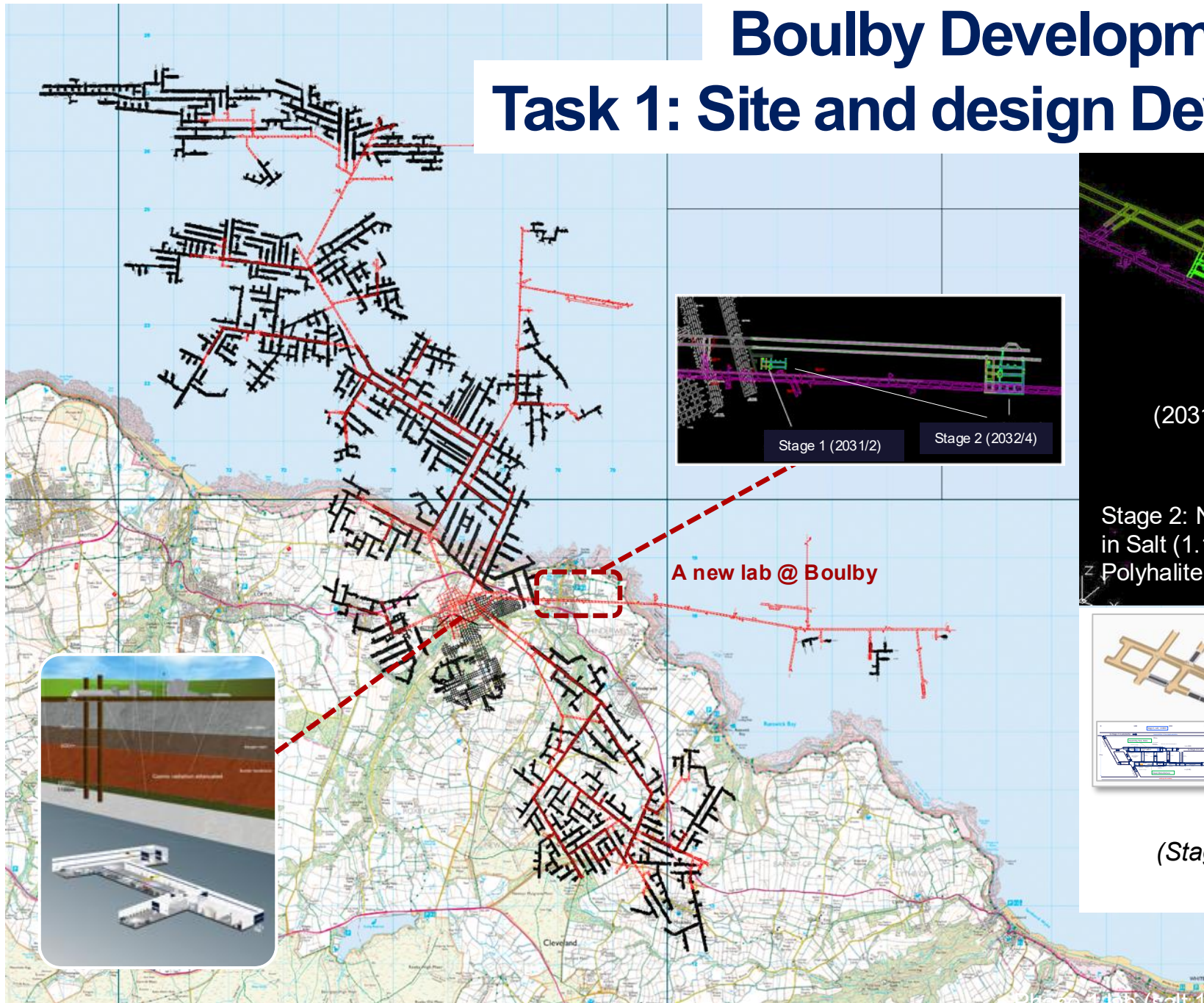


Next generation **world's best** Dark Matter (+) detector. **Expected 2030+**



Boulby Development Project

Task 1: Site and design Development.



Total volume
(Stage 1 + stage 2)
~120,000m³

DRAFT: 2-stage design

~(30m)³ main cavity

Stage 2
(Polyhalite?)

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.

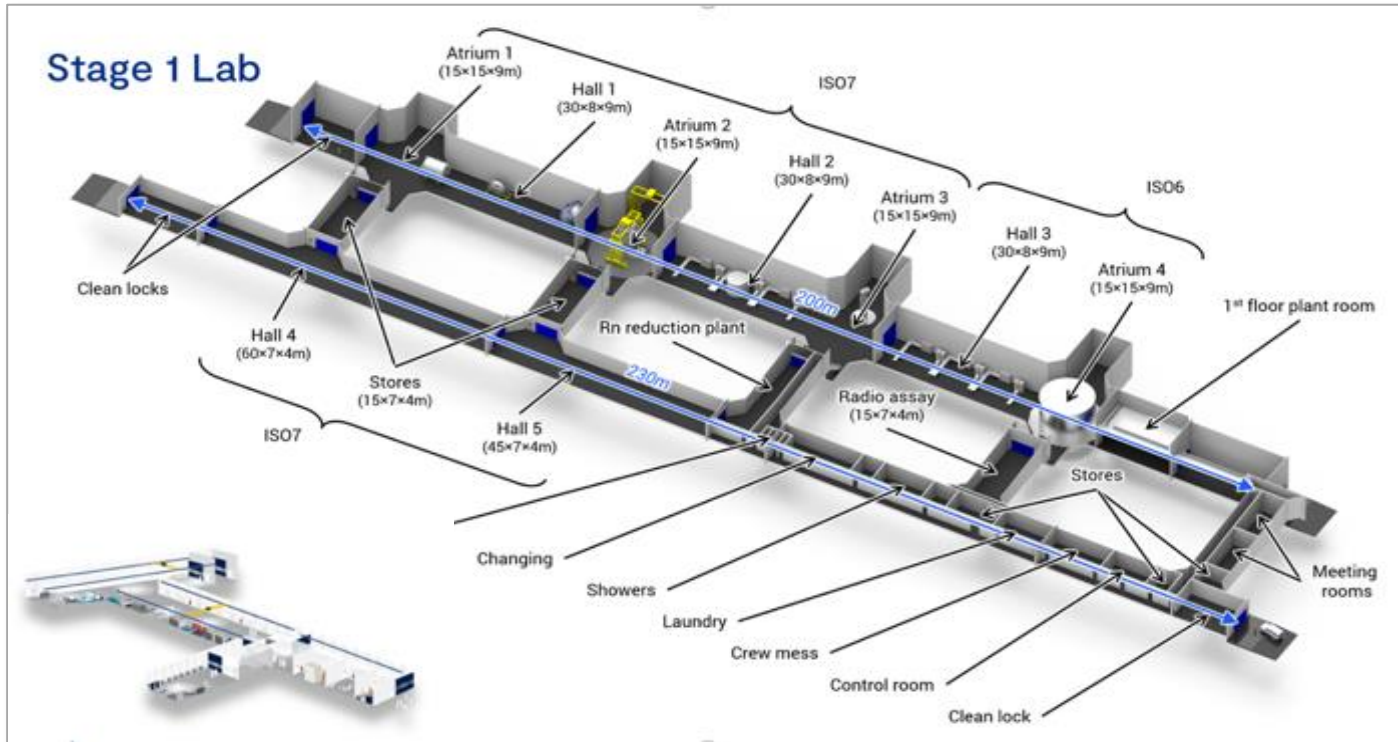


Image Credit: A Ball, J Elmer, C Kinahan, J Hill et al.

EXCAVATION NOW COMPLETE.
Planning for laboratory outfitting now underway



Stage 1 Outfitting

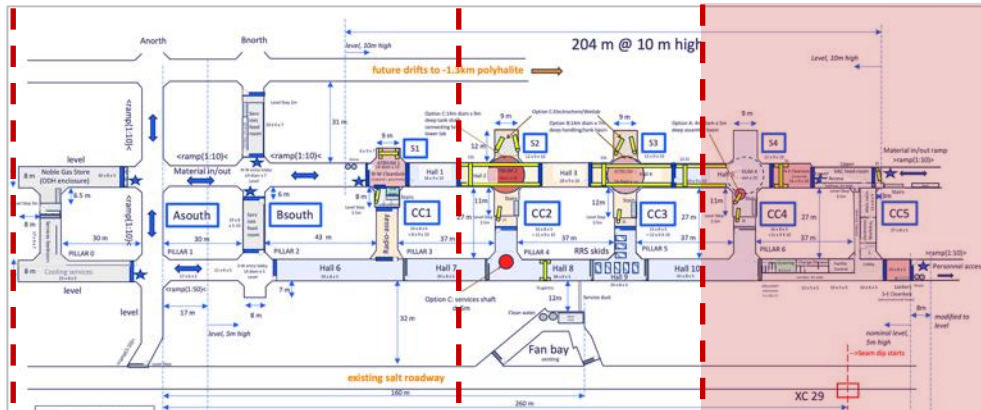
A new, world-class multidisciplinary science facility, complementing and succeeding the current Boulby laboratory



Stage 1 Lining Options

Possibility for single shot or staged outfitting

Staged outfitting phases (SOPs)



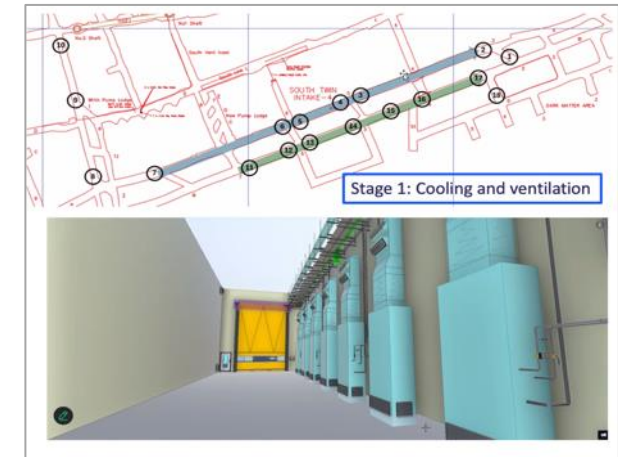
SOP3

SOP2

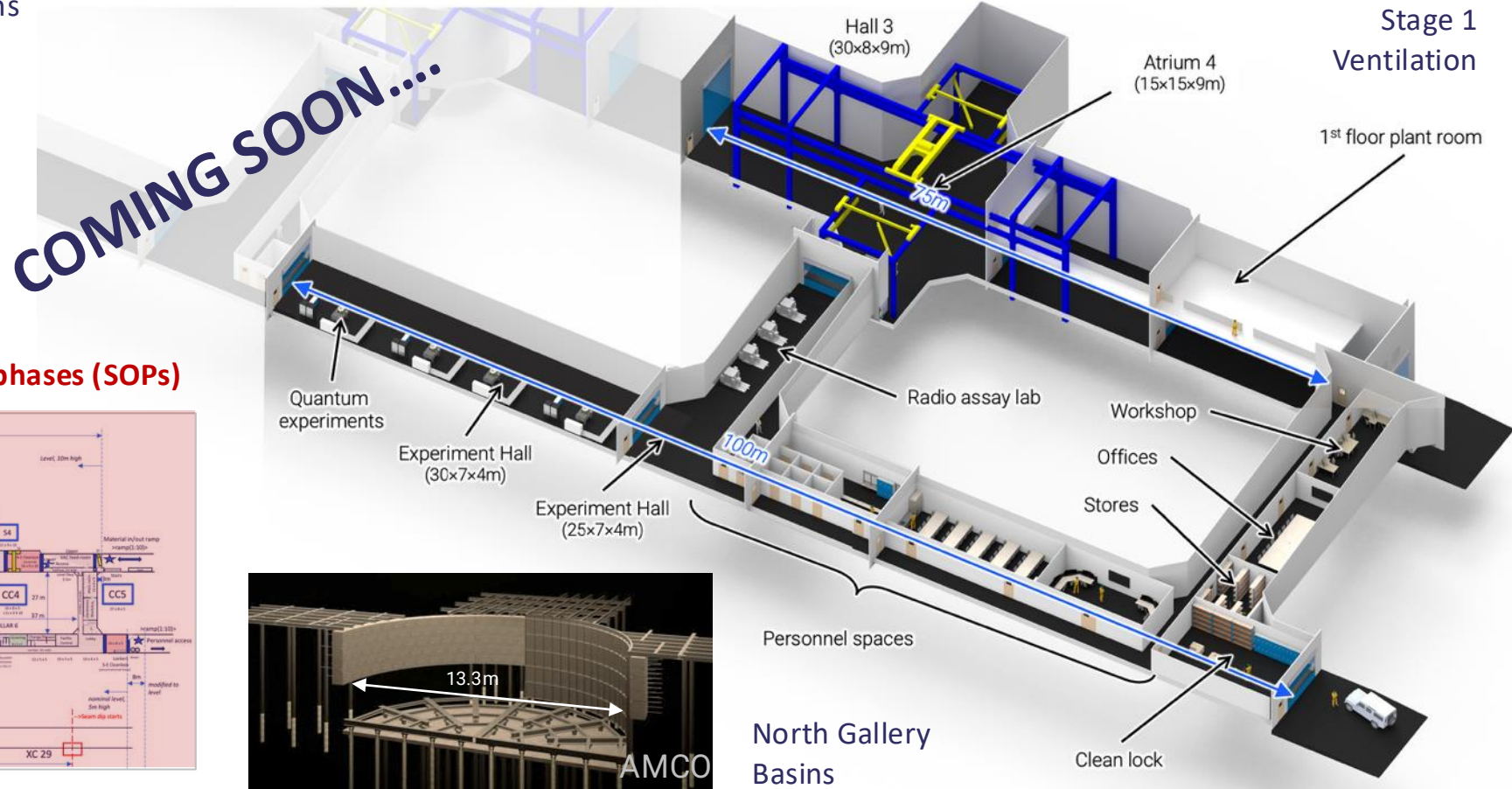
SOP1



Surface Building Development



Stage 1 Ventilation



North Gallery Basins

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)**

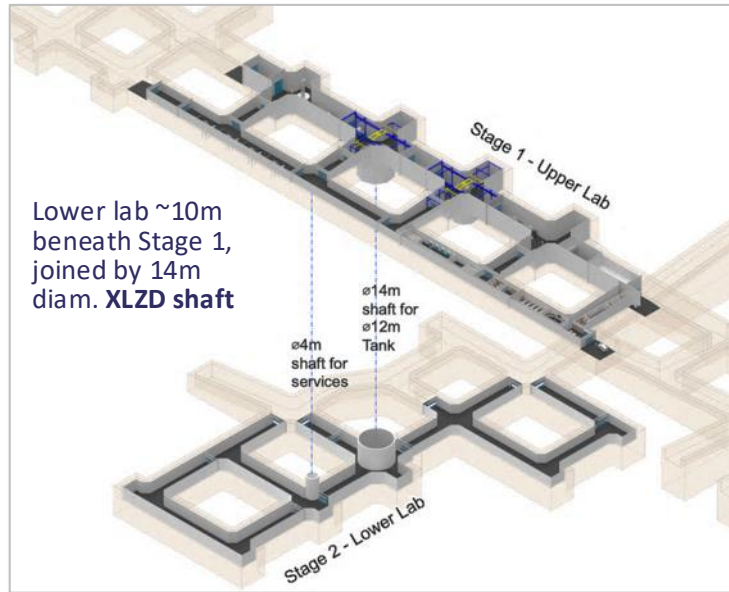
Decision factors:

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

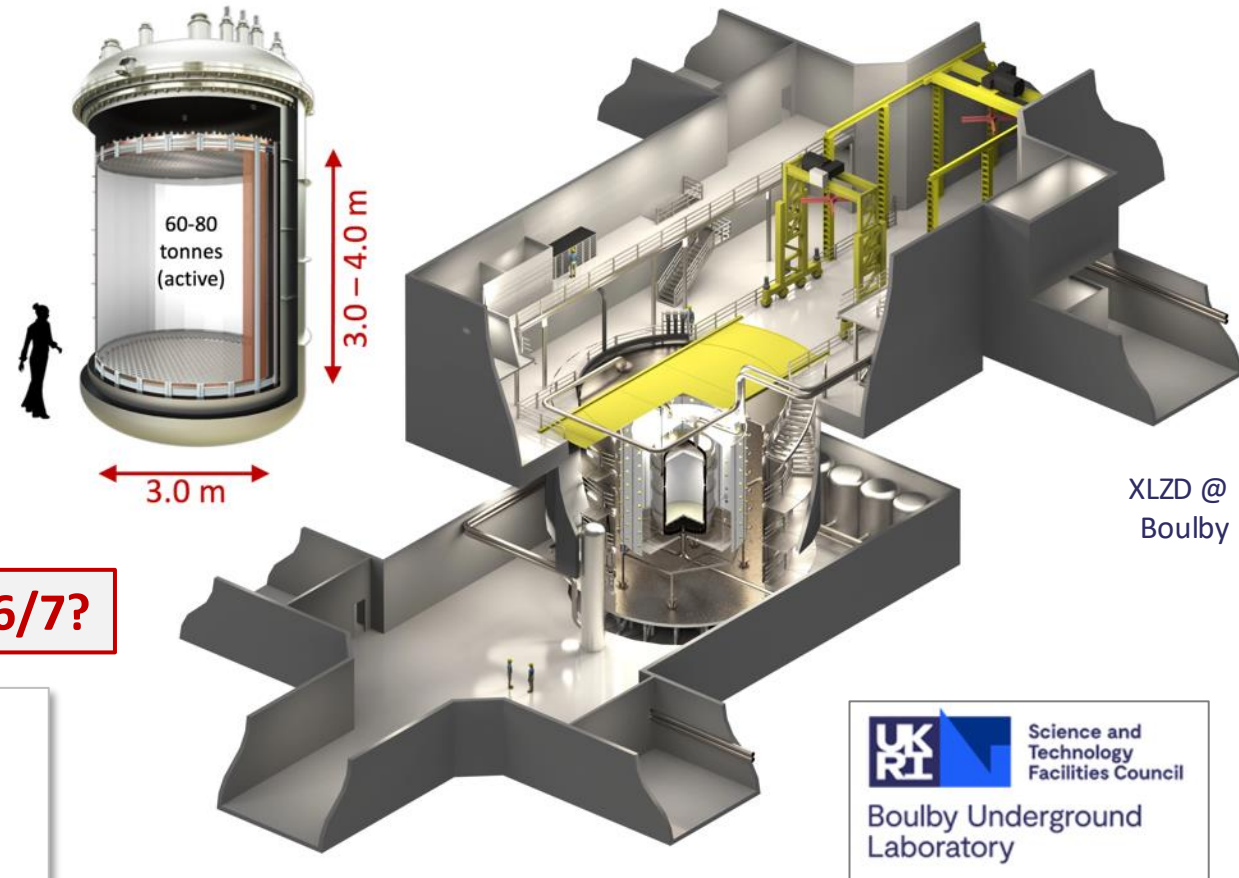
Host site Decision... 2026/7?

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.

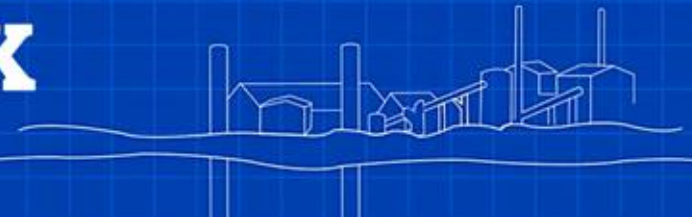


Stage 2 & Stage 1 in Salt



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

XLZD-UK



Summary...

Boulby Underground Lab Status:

- The UK's deep underground science facility
- A rich & varied science programme in low BG science, Earth & environmental science, astrobiology & planetary exploration, quantum sensors & computing.

Future plans:

- We are expanding facilities at Boulby to accommodate future projects across all science themes, inc major future rare event projects, such as XLZD
- Delivery of Stage 1 (of a possible two-stage) facility expansion – is now underway.
- Future BIG expansions also possible – in salt (1.1km) or Polyhalite (1.3km).
- Water (liquid) transportsystems already in place and well used at Boulby mine.
- **Come and visit us!**

