



Science and
Technology
Facilities Council

Deep Science at Boulby Underground Laboratory: The Search for Dark Matter and Beyond...

Sean Paling
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Science and Technology
Facilities Council

UKRI Science and Technology Facilities Council
Boulby Underground Laboratory

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STFC Boulby Underground Science Facility

Astroparticle physics & ultra low background studies

The search for Dark Matter & beyond

Earth and environmental science, Astrobiology and planetary exploration

**Deep Science at Boulby Underground Laboratory:
The Search for Dark Matter and Beyond....**

Underground lab @ Boulby

Deep Science at Boulby...

What is the Universe made of?

Dark Matter WIMPs

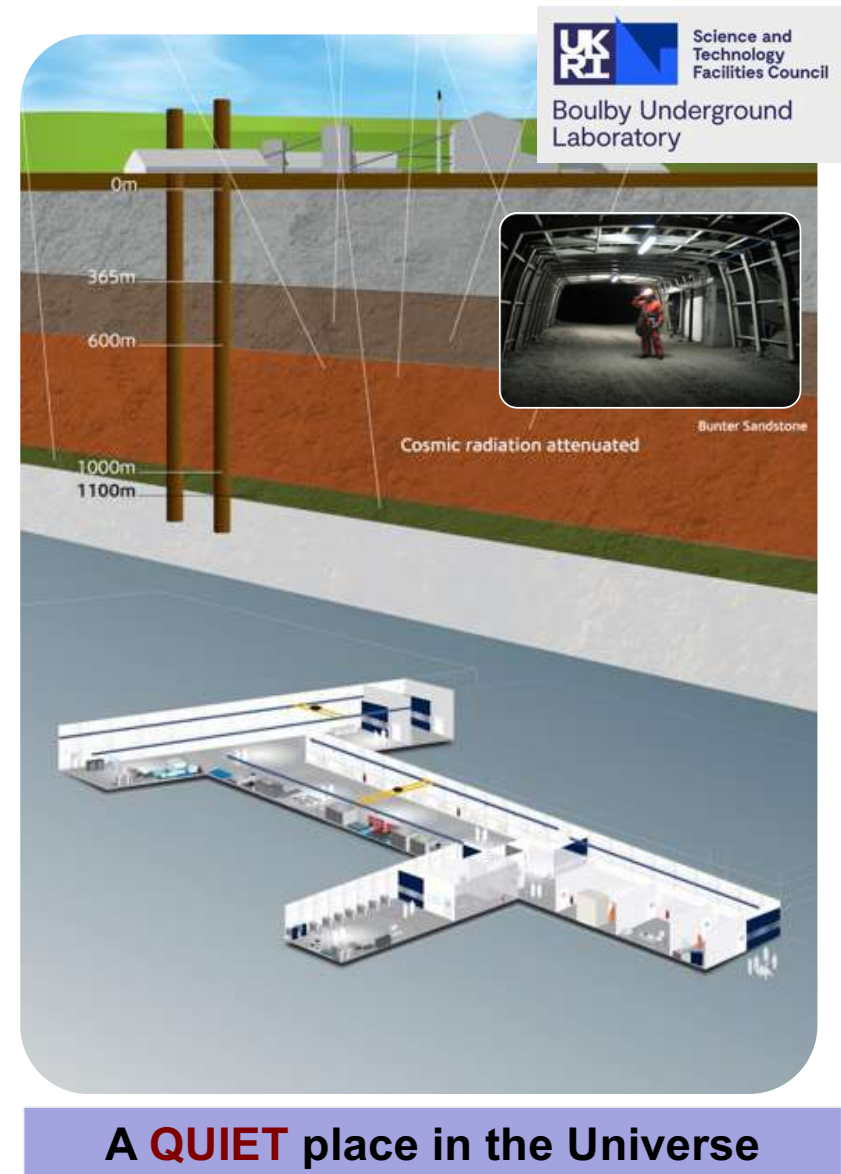
Weakly Interacting Massive Particles

ZEPLIN-III Collaboration:

Imperial College London, Edinburgh,
Rutherford Appleton Laboratory, LIP-Coimbra,
ITEP-Moscow + ..

DRIFT/CYGNUS Collaboration:

Sheffield University, Edinburgh,
Occidental College, University of
New Mexico + ...



Deep Science at Boulby...

The search for Dark Matter and beyond...



**DEEP
SCIENCE**
A DEEP UNDERGROUND SCIENCE AND
ENGINEERING INITIATIVE

sean.paling@stfc.ac.uk

There's lots MORE science you
can do **Underground**...

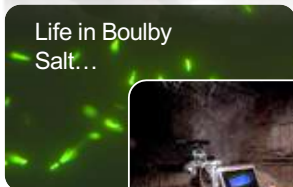
Astro-particle Physics and
Low background Science



Earth and Environmental
Science



Astrobiology and Planetary
Exploration Technology
Development



Life in Boulby
Salt...



October 2023

Deep Science at Boulby...

What we'll cover...

- The Search for Dark Matter....
- Boulby Mine & the Underground Science Facility.
- Latest Dark Matter Search Results ...

And if time...

- Other Science at Boulby: Inc. Astrobiology & Planetary Exploration
- The Future: Towards a MAJOR new facility for Dark Matter and more in the North East of England

Questions?

The Search for Dark Matter...

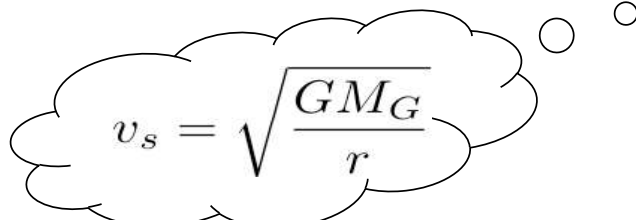
Why do we think it exists?

What is the problem?

Stars, planets & us appear to be only a small part of what is out there – **85% of the matter out there appears to be MISSING**

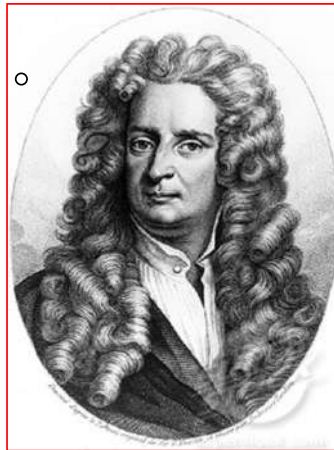
What is the evidence for Missing Mass?

- Dynamics of stars, galaxies, and clusters
- Gravitational lensing
- Large Scale Structure formation
- Analysis of the CMB
- + ...

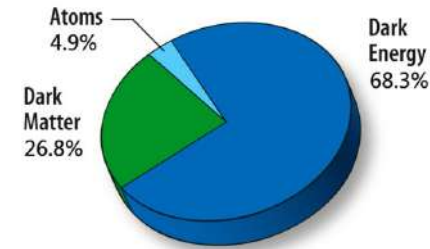

$$v_s = \sqrt{\frac{GM_G}{r}}$$

Faster = heavier

Isaac
Newton

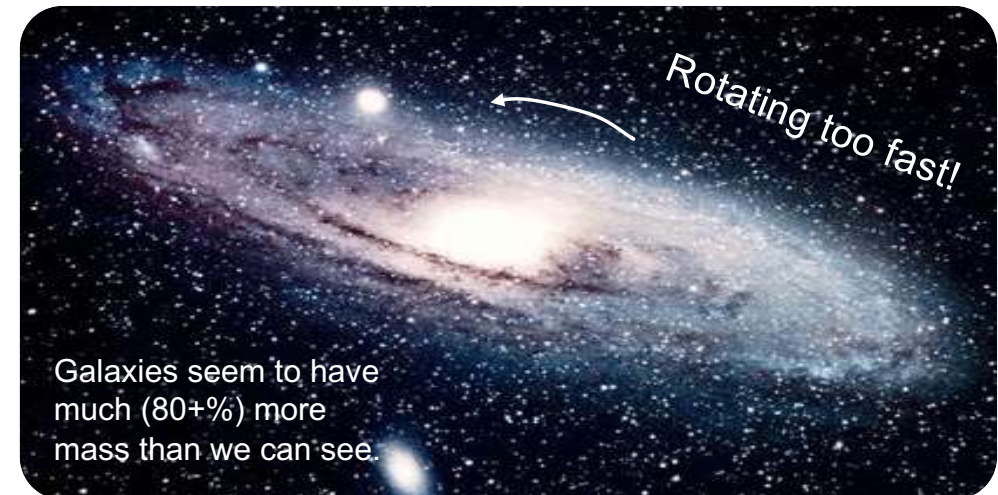
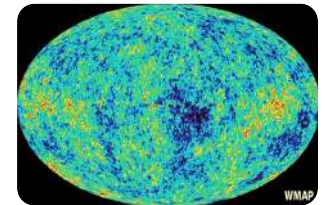


Vera
Rubin



85% of the **MATTER** in Universe is MISSING

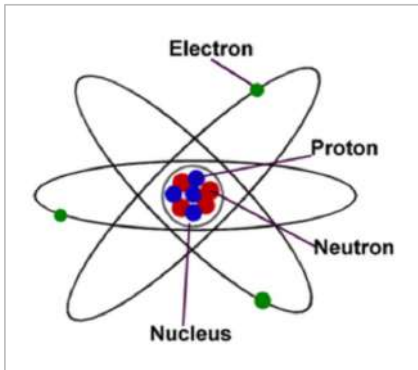
Cosmic
Microwave
Background
(CMB)



The Search for Dark Matter...

What IS Dark Matter???

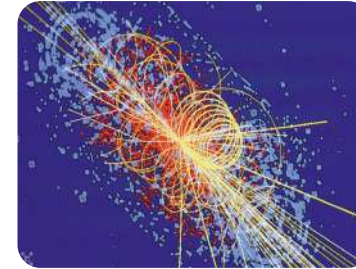
Evidence suggest Dark Matter is NOT big but small things (particles)



	1 st	2 nd	3 rd		
Quarks	u up	c charm	t top	γ photon	H Higgs Boson
	d down	s strange	b beauty	W^{\pm} W boson	
Leptons	e electron	μ muon	τ tau	Z^0 Z boson	
	ν_e neutrino electron	ν_{μ} neutrino muon	ν_{τ} neutrino tau	g gluon	
				Gauge Bosons	

Known particles that make up the 'Standard Model'....

We now know a lot about particles in nature...



Particle Physics @ the LHC



Could DM be 'normal matter'?

No... Evidence suggests favoured candidate is some form of 'new' **Weakly Interacting Massive Particles ('WIMPs')**

Likely behaviour: *heavy, no charge, interacts 'weakly'*

Likely Mass: *10-1000 × mass of H atom*

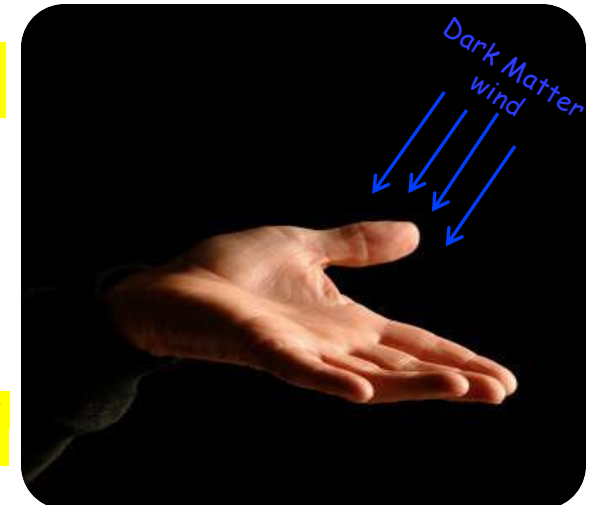
Particle Physics even suggests new particle possibilities...

χ

Neutralino?

Expect ~ 20 million / hand / second

<1 per month hit!



The Search for Dark Matter...

Dark Matter in nutshell...

**85% of the
Matter in the
Universe is
missing!**

Weakly Interacting Massive
Particles (**WIMPS**) are a
favoured candidate...

It is out there and all around us
but we can't see it...

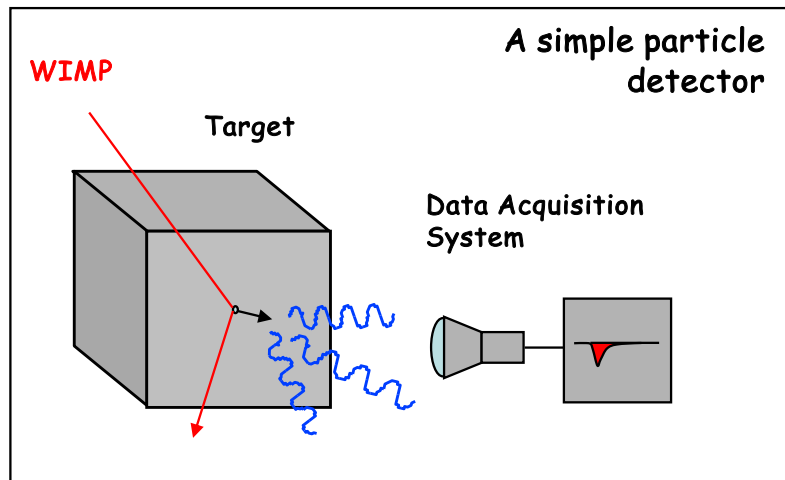


Does Dark Matter matter??

- It holds the universe together
- Is the dominant stuff governing the evolution of the Universe up to today.

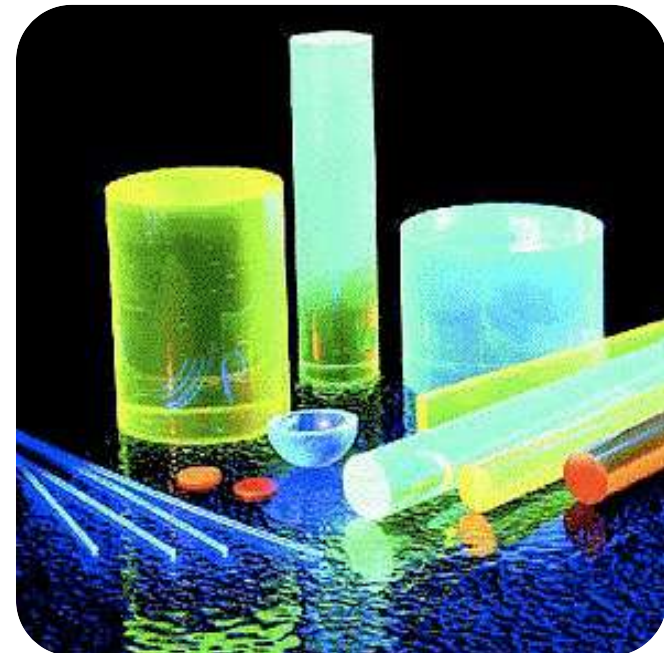
Is this all true??

How to detect Dark Matter Particles?



Photomultiplier tube

Scintillators

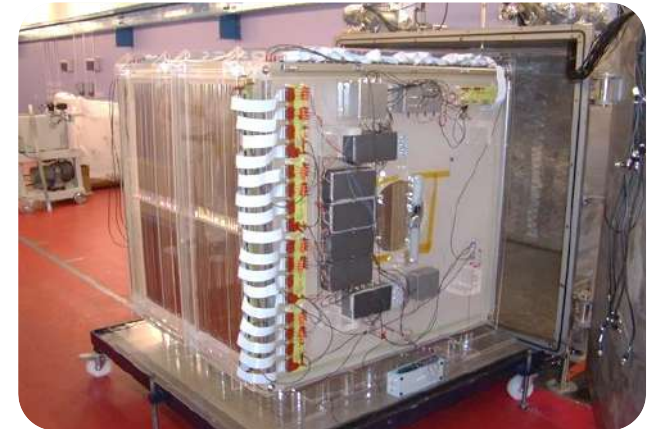
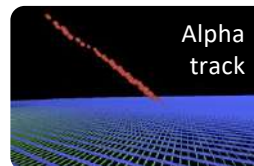


Boulby Dark Matter Detectors



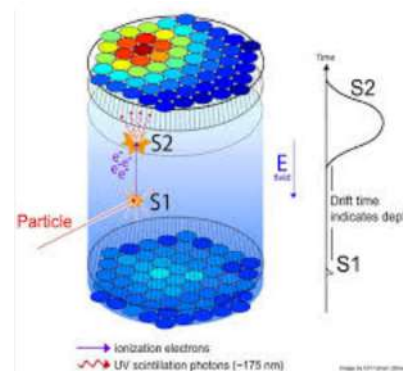
ZEPLIN-III:
2-phase
Xenon
Detection
(Completed
2011)

DRIFT/CYGNUS
Low-pressure gas
negative ion drift
TPC (R&D since
2010)



High purity
copper
cryogenics
and PMT
mount

8kg liquid
Xenon target



ZEPLIN-III: Imperial College, Edinburgh,
RAL, LIP-Coimbra, ITEP-Moscow, + ..

DRIFT-II
shielded
operation

DRIFT-II : Occidental
Collage, U. New Mexico,
Colorado State , Hawaii,
Wellesley Collage,
Sheffield, Edinburgh +...



Why Go Underground?

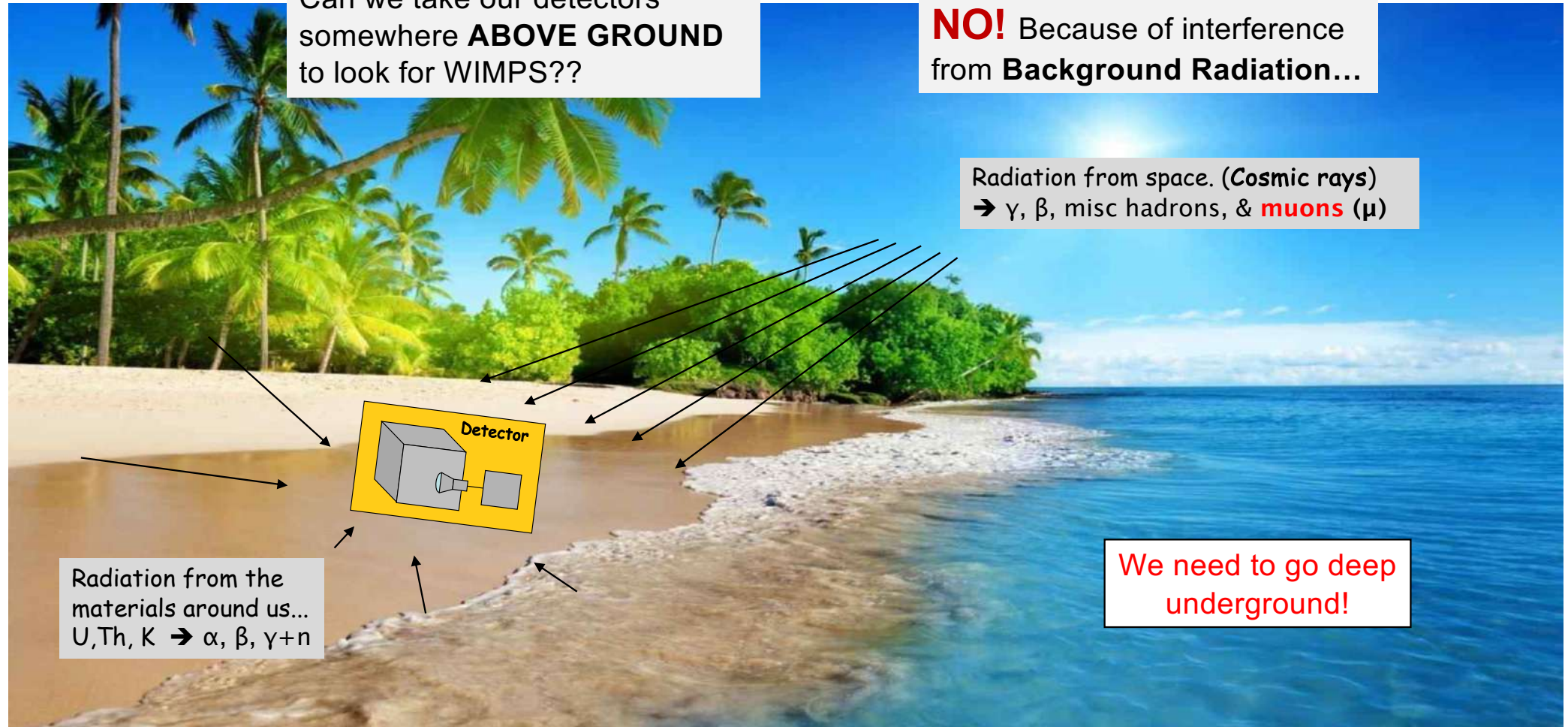
Can we take our detectors somewhere **ABOVE GROUND** to look for WIMPS??

NO! Because of interference from **Background Radiation...**

Radiation from space. (**Cosmic rays**)
→ γ , β , misc hadrons, & **muons** (μ)

Radiation from the materials around us...
U, Th, K → α , β , $\gamma+n$

We need to go deep underground!



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



12 miles North of Whitby, N. Yorks



UKRI Science and Technology Facilities Council
Boulby Underground Laboratory



View from Staithes

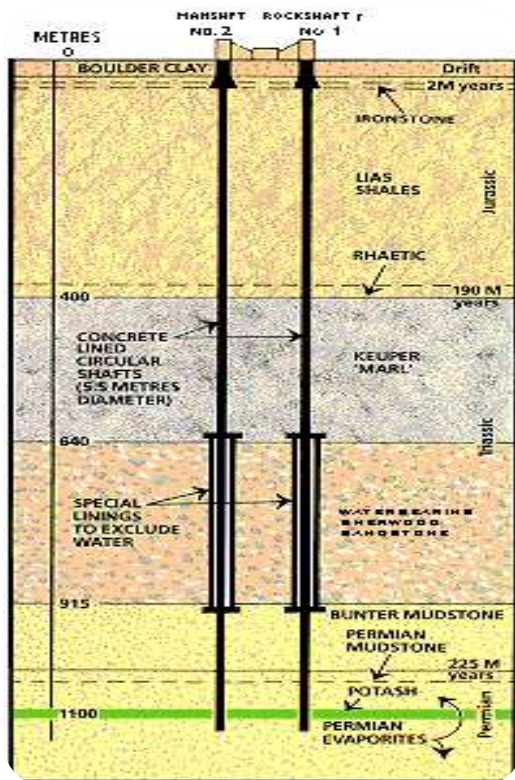
**Deepest mine in
Britain: 1300km**

The world's first polyhalite mine

Boulby Geology & Mining

Excavations are in Salt (NaCl), Potash (KCl) and Polyhalite ($K_2Ca_2Mg(SO_4)_4$). 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.



Boulby Geology

Polyhalite



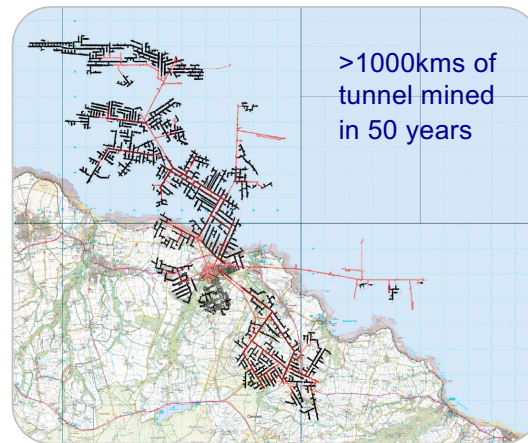
Potash



Rock-Salt



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



Typical Boulby Salt Roadway

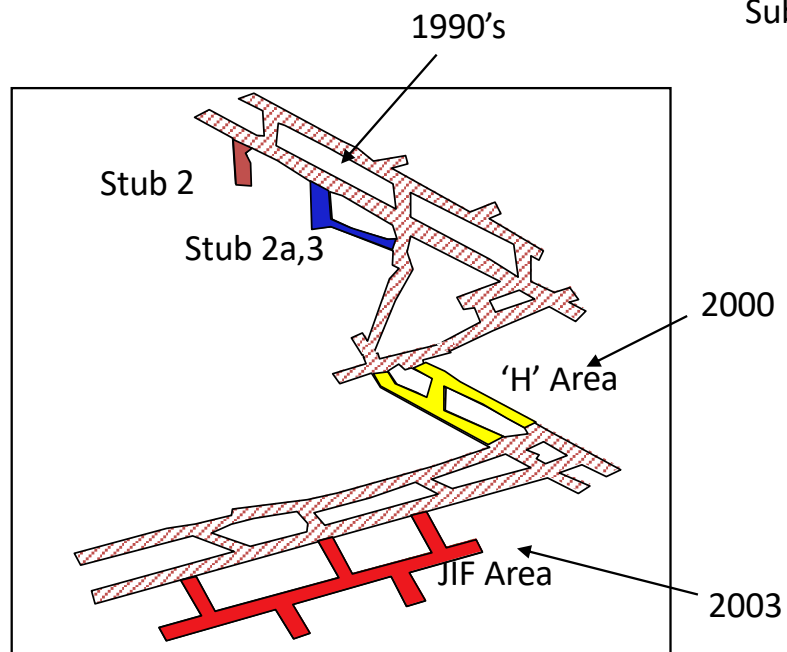


Zechstein Sea



Boulby Underground Laboratory

Boulby Infrastructure Evolution



Map of the Dark Matter research areas



Sub2



Stub 2a



JIF Area
2003-2015



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)



A **QUIET** place in the Universe

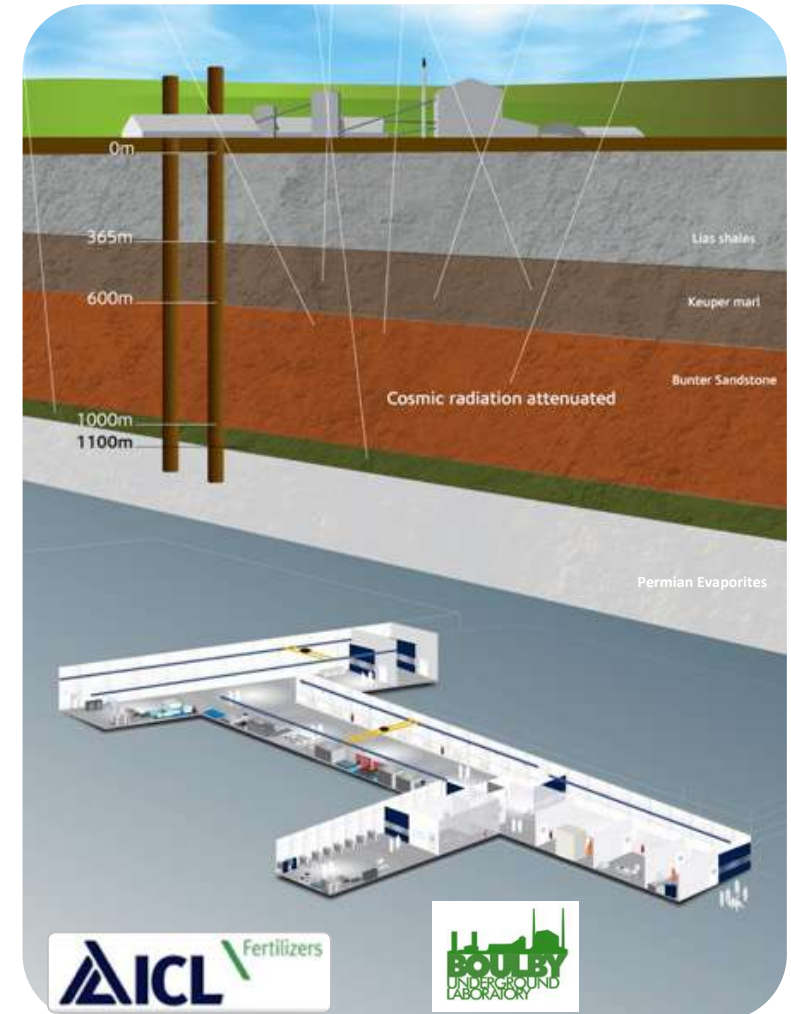


4000m³ class 10k and 1k clean lab space



Lab entrance

Factor ~10⁶ reduction in cosmic ray flux vs. surface





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.

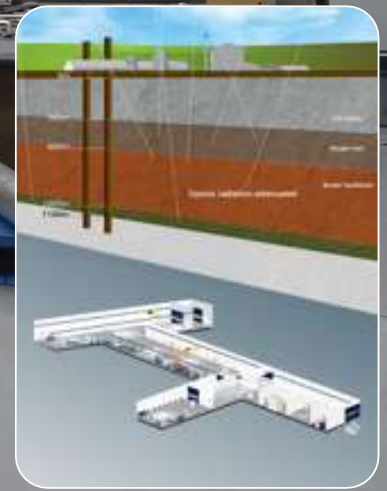


3000m³ Outside Experimentation Area

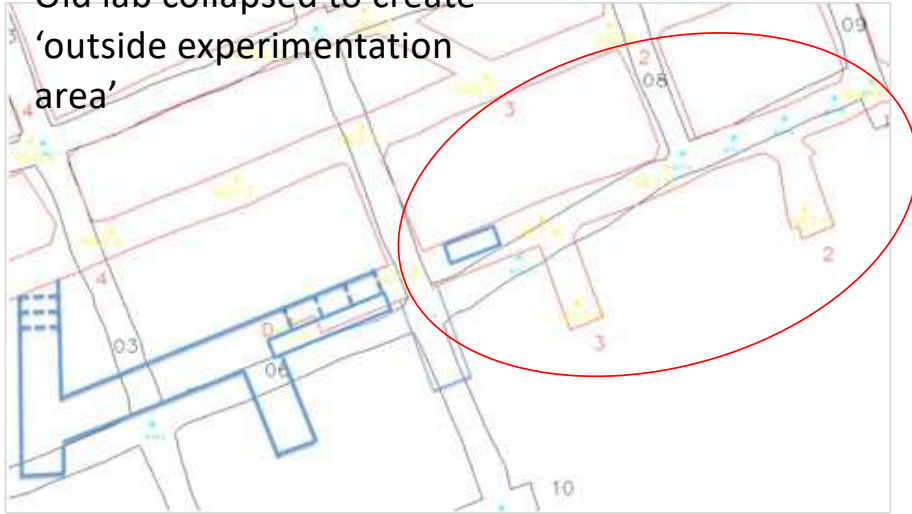


BUGS Material screening

Boulby Underground Lab Facilities 2023: >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.



Old lab collapsed to create
'outside experimentation
area'



Lighting, 240/110V power, Internet
/ WIFI. Ventilation, doors, MINAR
Base Station Hut

'Outside Science'
Geology &
Geophysics
Astrobiology,
MINAR, Mars
Analogue space



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Outside Experimentation Area (OEA)



October 2023

Boulby Underground Laboratory (UK)



Boulby Facility Details...



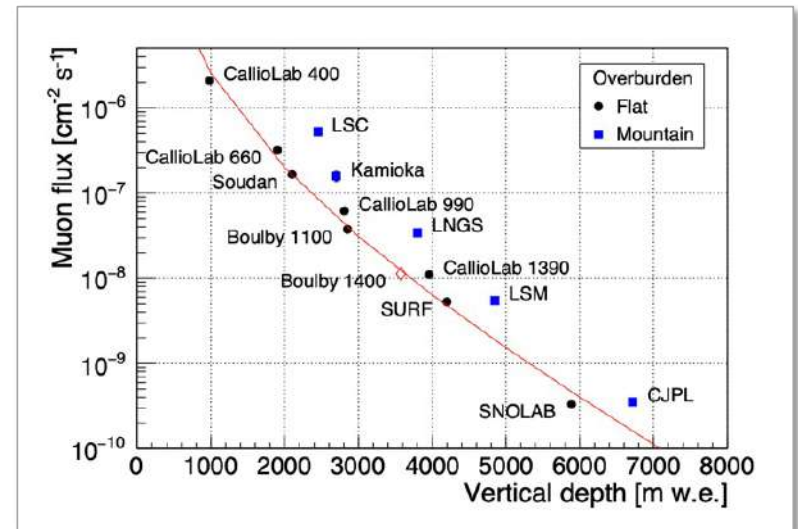
- The UK's deep underground science facility. One of 5 in Europe, <15 in the world.
- Supports work of >10 collaborative projects (astrophysics to climate, geology, environment etc), >40 institutions, >170 scientists & students.
- Facility funded and operated by the Science & Technology Facilities Council (STFC).
- Operations, H&S & science programme managed by 17 (+2) 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



And more...



Science Programme Status & Plans.

- Astroparticle & Low Background Science
- Earth & Environmental Science
- Astrobiology & Planetary Exploration Studies
- Outreach & Education

Find out more:
@BoulbyLab
www.stfc.ac.uk/boulby

Boulby Underground Laboratory 2023



Working alongside Mining @ Boulby

STFC-Boulby Lab responsibility:

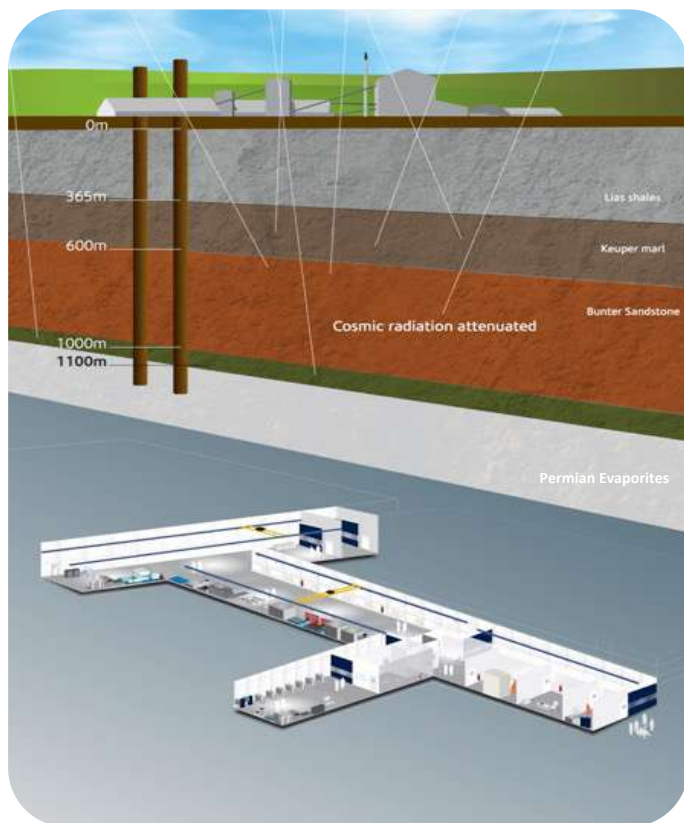
Run and maintain the lab
Facilitate / Support Science
Health & Safety
Operations Impact
Outreach & Media

CPL/ICL support us:

Keep the mine operating and safe
Emergency H&S
Materials transportation
High level support



Going Underground



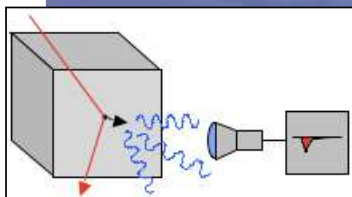
The Search for Dark Matter...

Searching for WIMPs?

WIMPs

Remaining
Backgrounds

Dark Matter
search
detectors



Dark Matter Detectors
need to be...

- a) Big
- b) 'Low background'
- c) '**Discriminating**'

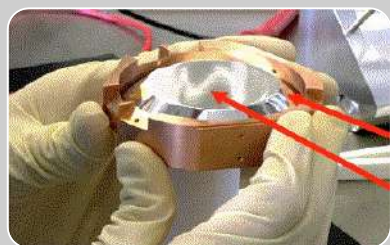
The World Dark Matter search effort...



CRESST
(Gran Sasso, IT)



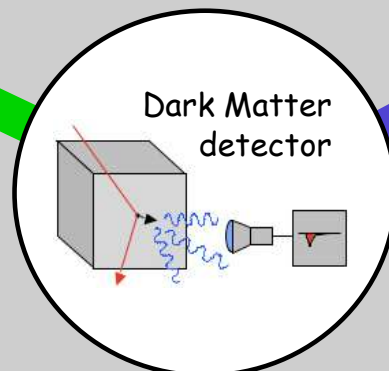
DAMA/LIBRA
(Gran Sasso, IT)



EDELWEISS
(Modane, Fr)

Phonons

Scintillation



SuperCDMS
SNOLab, Canada)



ZEPLIN III
(Boulby)



LUX
(SURF, USA)

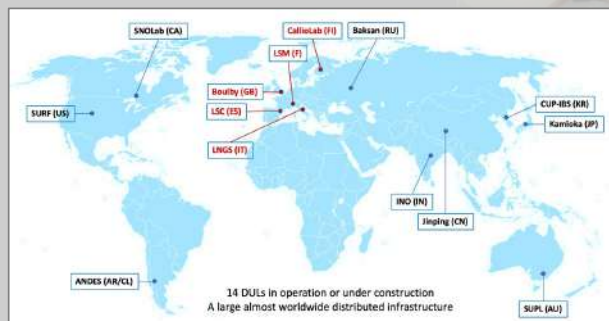


CYGNUS
(Boulby, UK)

Ionization



XENON 100, IT
(Gran Sasso, IT)



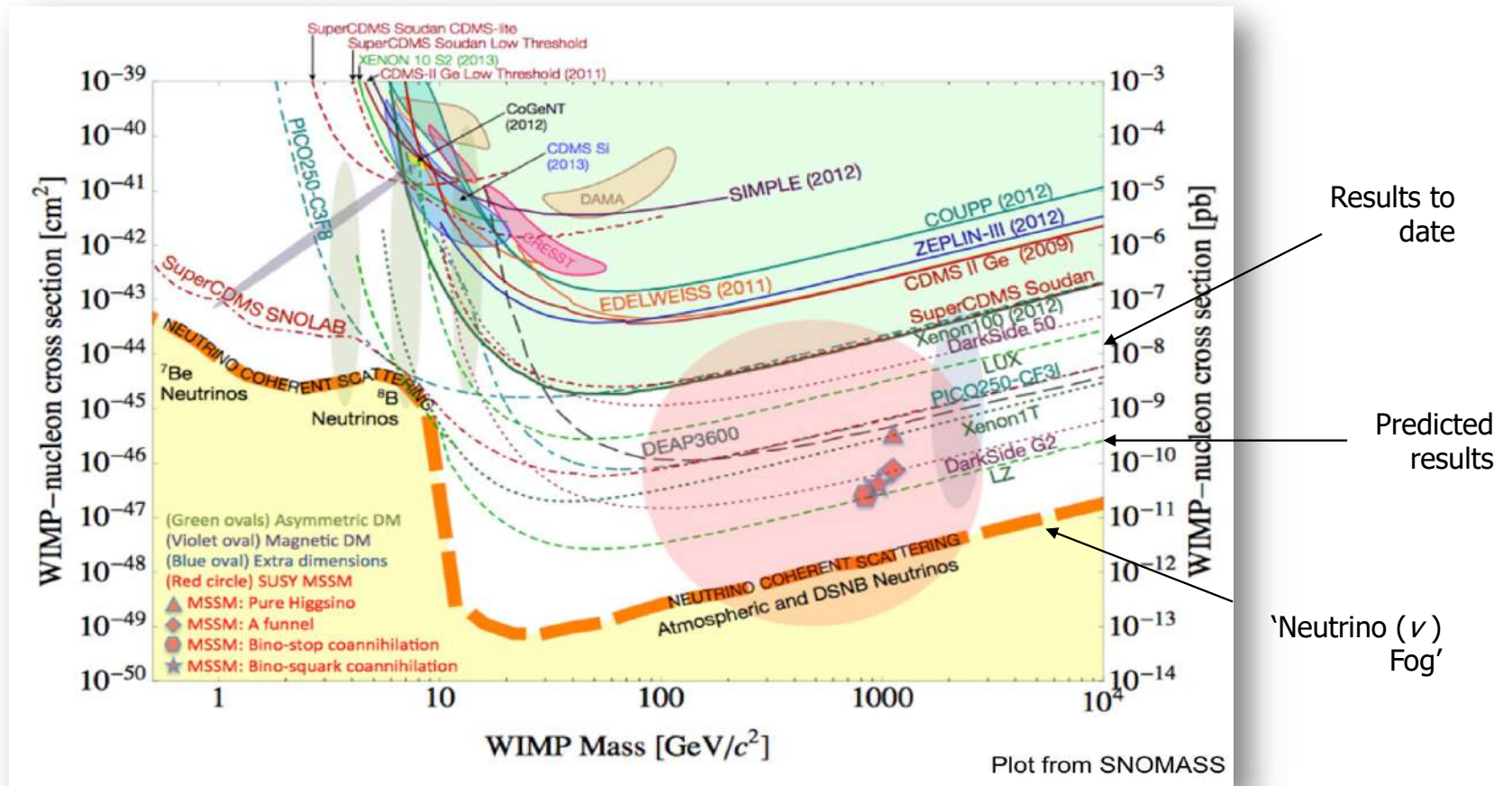
Predictions of particle physics theory

Results so far: 'Have we found it yet?'

The Longer View...

We might find it soon, or we'll start to hit the 'neutrino fog' (where it gets even harder).

But we'll keep going...



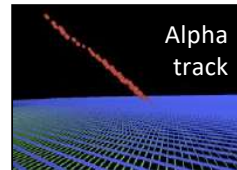
Dark Matter Studies @ Boulby.

DRIFT/CYGNUS: R&D for DIRECTIONAL Dark Matter detection.

STATUS: Programme operating at Boulby since 2001. Currently limit-setting and conducting system performance & scale-up R&D. Plans for further R&D & expansion / collaboration (**CYGNUS**).

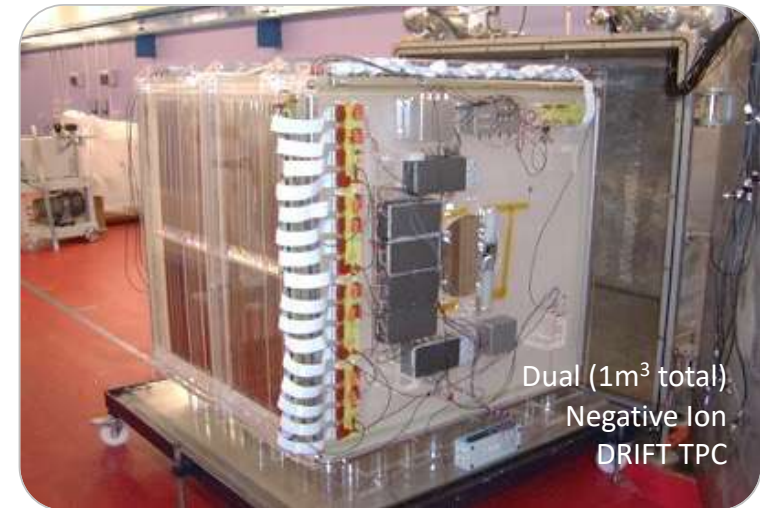


DRIFTII-d limit setting and R&D exploring issues and technologies for scale up - CYGNUS



Low-pressure gas Time Projection Chamber (TPC)

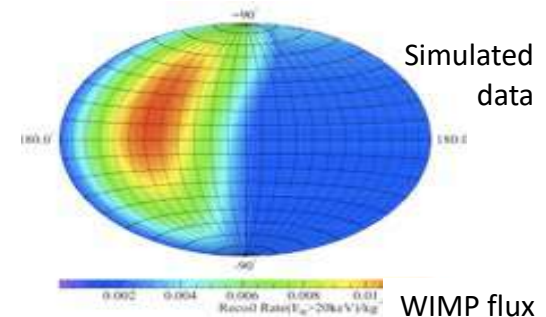
*Occidental College,
New Mexico,
Colorado State,
Hawaii, Wellesley,
Sheffield,
Edinburgh, Boulby*



DRIFT-II-d @ Boulby

Dual (1m³ total)
Negative Ion
DRIFT TPC

Directional detection



Simulated data

WIMP flux

Directional Dark Matter detection – providing probably
THE most powerful direct detection signature

Spherical Proportional Counters (SPC) at Boulby

NEWS-G

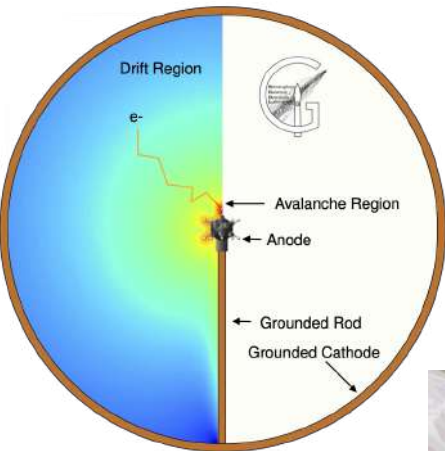
K. Nikolopoulos
P. Knights, I. Manthos, L. Millins,
T. Neep, G. Rogers, R. Ward
University of Birmingham
and international NEWS-G Collaboration



NEWS-G Collaboration Meeting
Boulby 2023

NEWS-G Activities at Boulby

- Instrumentation developments
 - Multi-anode sensor
 - Gas filtration
 - Rate effect studies
- Neutron spectroscopy (with N_2 gas)
 - Neutron background surveys
 - Industrial applications
- Towards scaled-up, electroformed, detector at Boulby, 3m diam. 5 bar $He-CH_4H_{10}$:
DarkSPHERE



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



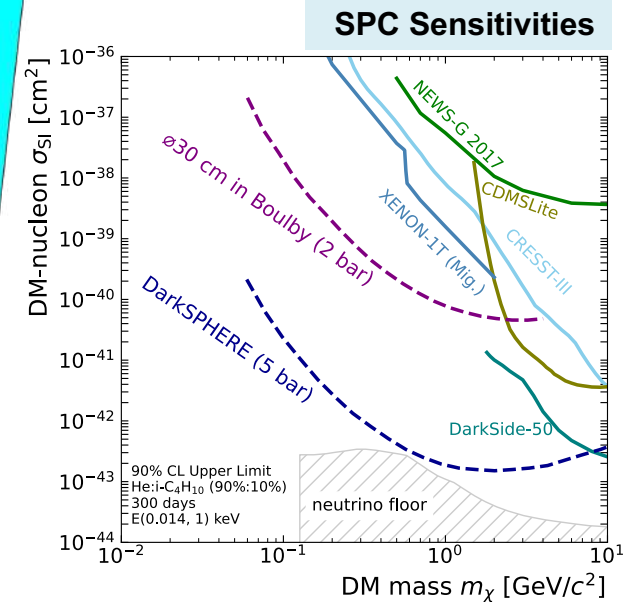
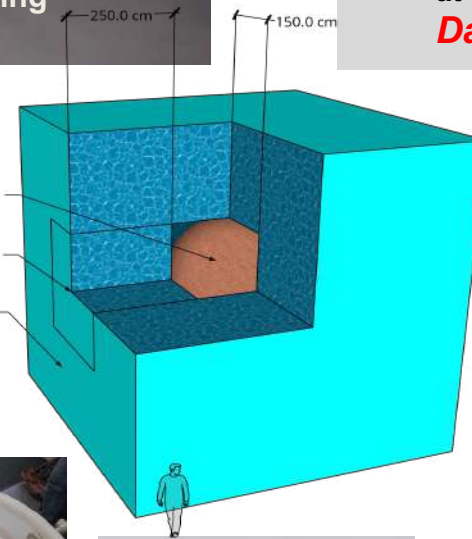
11-anode sensor



AI-S30 R&D Detector



Copper electroforming at Boulby



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



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

sean.paling@stfc.ac.uk



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 *
- ICPMS * * Commissioning

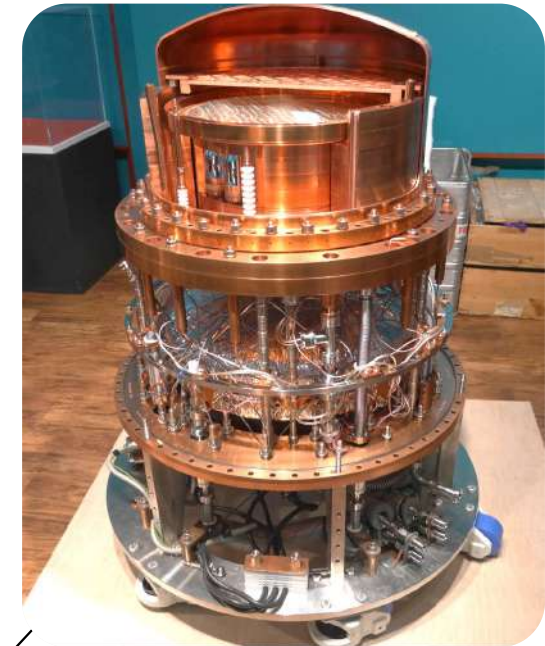
October 2023

Summary So Far....

- ❑ Evidence suggests **DARK MATTER is out there!** It is likely to be particles – up there and all around us.
- ❑ We have NOT directly detected Dark Matter yet. The race to find Dark Matter is still **very much ON**. We are continuing to narrow the search.
- ❑ We are leading the UK search effort at Boulby with
 - **DRIFT/CYGNUS** and **NEWS-G** R&D projects
 - Material Screening with **BUGS**
 - More to come??

Please support your local Dark Matter search studies...

Can we get a future
ZEPLIN-type
detector at Boulby?



ZEPLIN-III Dark Matter
Detector @ Whitby
Museum

Other Science Studies at Boulby **and** What next?

Wider Science @ Boulby

- ❑ Astro-particle and Low Background Science
- ❑ Earth and Environmental Science
- ❑ Astrobiology and Planetary Exploration

Boulby Wider Science Studies



ERSaB: Gamma spectroscopy & low background counting environmental radioactivity studies

Boulby, Scottish Universities Env. Research Ctr (SUERC), Atomic Weapons Estab. (AWE)

RESOURCE: Rock engineering feasibility study of salt cavity compressed gas sustainable energy storage



Boulby, British Geology Survey (BGS), Cambridge, Manchester.

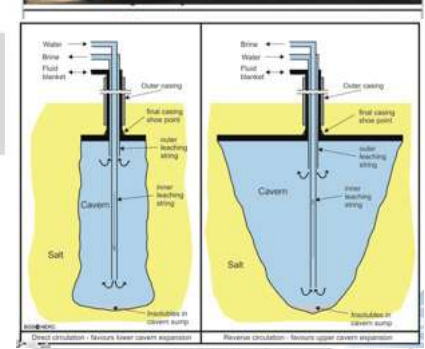
Low Background Science, Earth & Environment Science, Astrobiology & Planetary Exploration...



MINAR: Space Technology Development

Boulby, Edinburgh, Aberdeen, York, Birmingham NASA, York, ICL etc.

Plus Misc. Geology & Geoscience (& more to come)...



Life in Boulby Salt...



BISAL: Astrobiology / Geo-microbiology. Studies of life in salt, life on Earth & beyond

Astrobiology & Planetary Exploration

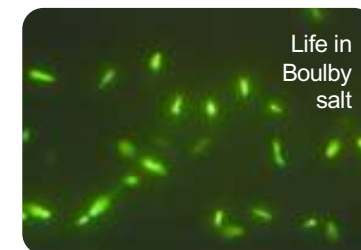


Sampling life in Boulby Brine



Subsurface Astrobiology Laboratory

MINAR MINE Analogue Research



Life in Boulby salt

ALSO: An important 'Mars Analogue site' – with geology & conditions to allow explorations & astrobiology technique & instrumentation development



MINAR - Pancam

Mining & extraplanetary exploration instrumentation development



Studies of life in Boulby rock – studies of limits of life on earth and on other planets



MINAR - CLUPI

Boulby,
Edinburgh,
Aberdeen, York
Birmingham
NASA, York, ICL
etc. etc.

Boulby and Instrumentation for Earth and Space Exploration



MINAR V. 9th to 20th October 2017

MINAR 5

Overall objectives:

- To test instruments and methods for the subsurface exploration of the Moon and Mars.
- To develop new educational material.

Main accomplishments:

- Testing of life detection equipment and planetary exploration instruments from: NASA JPL, NASA Ames, University of Leicester, Space-X Institution, University of Newcastle, University of Edinburgh, Luleå University of Technology.
- Development of education materials on planetary exploration at primary and secondary school level.
- Training of ESA Astronaut, Matthias Maurer.
- Life links from Boulby with up to 38,000 views.
- Live link with Kalam Centre, India



MINAR – Pac Man, HABIT & many more



Live from Mars!

Join our live feed from 1 km underground in Boulby mine, UK - an extreme, Mars-like environment where scientists are preparing for the exploration of space!

- > See planetary scientists at work
- > Explore an underground astrobiology laboratory
- > Learn about preparations for planetary exploration

Monday 16th October 10-11 am BST
- in collaboration with the Kalam Centre, India

Wednesday 18th October 10-11 am and 3-4 pm BST
- live with ESA astronaut Matthias Maurer

Log on to:
<https://www.facebook.com/UKCentreForAstrobiology/> for live feed
Send your Mars exploration questions in advance to UndergroundAstrobiology@ukcf.ac.uk

Logos: UK Centre for Astrobiology, Science & Technology Facilities Council, BISAL, Kalam Centre, etc.



Boulby Underground Laboratory shared UK Centre for Astrobiology's live video. ...

Published by Emma Meehan (?) · 17 October ·

14,955 Views

UK Centre for Astrobiology was live.

UK Centre for Astrobiology

Science and Technology Facilities Council

Boulby Underground Laboratory



NASA-JPL
Signatures of life
studies



MINAR VII to IX. 2018 - 2022



Lulea & Aberdeen
University
KORE rover 3D area
mapping



COMING Soon: MINAR X1- Nov 2023
Inc. BIOSPHERE: Human Habitability Studies



Edinburgh University
MUFFHINS water activity
monitoring payload



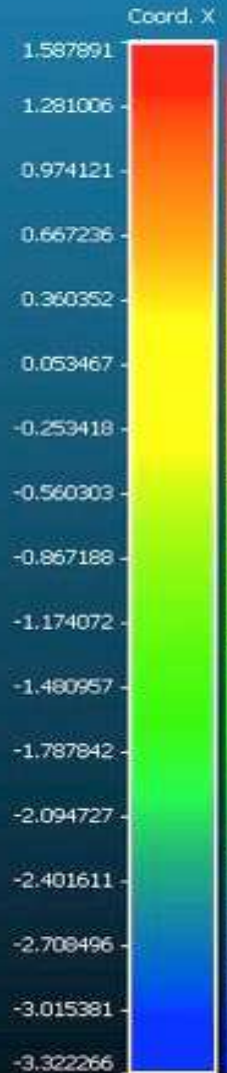
MINAR - CLUPI

REMOTE-3 Coding &
Robotics outreach



MINAR - MUFFHINS

KORE 3D Mapping



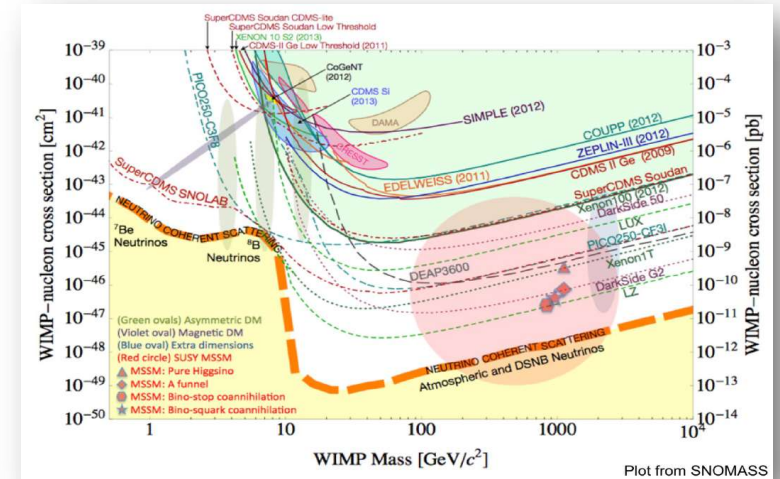
2.5

What next for Dark Matter(+) @ Boulby?

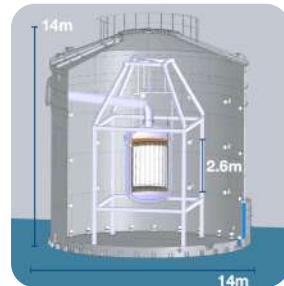
Lux-ZEPLIN (LZ). Operating NOW



SURF underground lab, S. Dakota, USA



Xenon-nT. LNGS, Italy. Operating NOW



DARWIN. Proposed future project



Coming soon! 'XLZD'.
50-100T Liquid Xenon Dark Matter Detector. Expected 2032+

Could the next World's-Best Dark Matter detector (+more) come to the UK?

Some BIG new international science projects are going to need a home...

- **XLZD**: 2-Phase Xenon Dark Matter
- **DARKSPHERE+**: Light Dark Matter
- **AION-100,1000**: Atomic Interferometry for Grav Waves and light Dark Matter
- **BUTTON 100+**: Neutrino Detection technology for nuclear security
- **+ more...**

The Boulby New Laboratory Study (Bo

A new lab
@ Boulby?

Results: *It IS FEASIBLE, well motivated and timely*



FEASIBILITY STUDY
FOR DEVELOPING THE BOULBY UNDERGROUND LABORATORY
INTO A FACILITY FOR FUTURE MAJOR
INTERNATIONAL PROJECTS

Supported by the STFC Opportunities Call 2019

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Boulby-FS: Academic-led new lab
feasibility study undertaken 2020/1

Towards a major **new** multi-disciplinary Underground Lab in the UK...

Plans now being developed for a major new multi-disciplinary Deep Underground Science Facility in the UK.



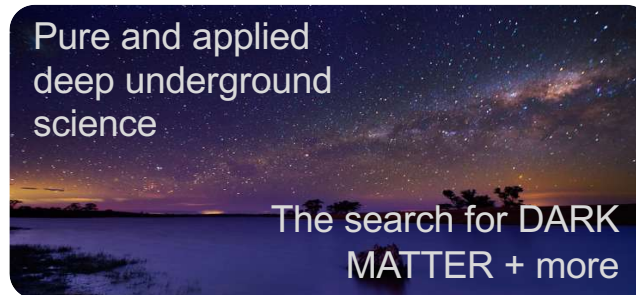
A world-leading UK deep underground science facility hosting next-generation science 2030+

- **Searches for Dark Matter**
- Neutrino studies
- Quantum Sensors, Quantum Computing
- Pure & applied low background particle physics
- Earth and Environmental Sciences
- Astrobiology & planetary exploration.
- Outreach, Education and more...

Boulby Development Project (BDP)
3-year study (2022-25). Tasks:

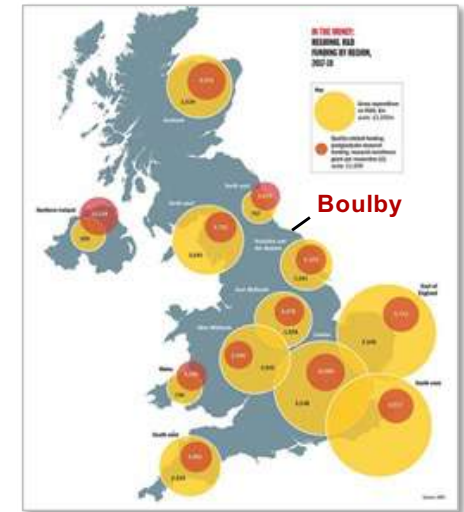
- Location & site next level design
- Business case development / submission
- Science Case development
- Stakeholder liaison

Pure and applied
deep underground
science



The search for DARK
MATTER + more

Regional R&D
Spending 2017-18



A new UK facility will bring:

- HIGH-impact, world-leading science
- LARGE multi-national collaborations
- BIG fundamental science questions
- MAJOR local & national investment, employment, impact and visibility.

Government 'fit': *Levelling Up, Strength in Places, UK Science Superpower...*



Science and
Technology
Facilities Council

Deep Science at Boulby Underground Laboratory: The Search for Dark Matter and Beyond...

Sean Paling
Boulby Underground Lab
Science and Technology
Facilities Council

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Sean Paling
STFC Boulby Underground Laboratory

Thank You....



Please Contact us...

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