# XLZD: A next generation observatory for Dark matter and rare events

Hugh Lippincott on behalf of XLZD Collaboration UCSB







### Liquid xenon detectors: the definitive search for "high-mass" WIMPs

### Projected sensitivity and current limits



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  - ER/NR discrimination
  - Low energy threshold
  - 3D position self-shielding, singles/ multiples





S2 light pattern gives x-y position (~few mm resolution)

Drift time gives z position (~0.5 mm resolution)

S1

Incoming

Particle

E.

### Cathode

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  - High density, large A<sup>2</sup>, many isotopes (SI, SD, NR-ETF, inelastic)





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## Liquid Xenon Dual Phase TPCs

- Calibration is key e.g.:
  - LZ High stats of ER (background) distribution using dispersed tritium (CH<sub>3</sub>T) - ~160k events!
  - <u>LZ</u> and <u>XENON</u> have now used YBe to calibrate low energy NR
- Allows for precise modeling in final analysis, enables discovery



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### • Searching for WIMPs into the "fog"

- Nearly indistinguishable background from astrophysical neutrinos
- Sensitivity rapidly falls 20% flux uncertainty
- Systematic limit (1000 tonne-year exposure)
   = practical limit of ~100-tonne detector
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### A Liquid Xenon Observatory with a broad science program

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### **Dark Matter**

WIMPs Sub-GeV Inelastic Axion-like particles Planck mass Dark photons

### <u>Supernovae</u>

Early alert Supernova neutrinos Multi-messenger astrophysics



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### Neutrino nature

Neutrinoless double beta decay Neutrino magnetic moment Double electron capture



### <u>Sun</u>

pp neutrinos Solar metallicity <sup>7</sup>Be, <sup>8</sup>B, hep

*arXiv:<u>2410.17137</u>, <u>2203.02309</u>* 



### non Observatory with a broad science program





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arXiv:<u>2410.17137</u>, <u>2203.02309</u>





### non Observatory with a broad science program







## XLZD:A Unified Community to build the definitive experiment Consortium MOU signed in July 2021 by XENONnT, LUX-ZEPLIN, DARWIN Collaboration agreement signed in Sept 2024

- XENONnT and LZ: ongoing science programs, technology progenitors
- DARWIN: initiated R&D and design studies with significant ERC support







First annual XLZD meeting ay KIT in Karlsruhe, Germany (June 2022)

### XLZD Collaboration formed $\rightarrow$ establish international project



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- XENONnT and LZ: ongoing science programs, technology progenitors
- DARWIN: initiated R&D and design studies with significant ERC support
- Recent / ongoing activities
  - Design and sensitivity reports posted
  - Working groups: science, technical, siting
  - UK Pre-construction & Boulby development
  - Annual gatherings: KIT 2022, UCLA 2023, RAL 2024, LNGS 2025
  - <u>xlzd.org</u>



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## Design Heritage: technical foundation from LZ and XnT

- Rich heritage from two successful programs
- Deep bench of expertise in key areas, including:
  - Radioactivity, including extensive Rn screening programs
  - High voltage electrodes and delivery
  - Low-background PMTs w/Hamamatsu
  - Purification and cryogenics



LZ Grids



### XnT Kr distillation







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- Multiple design approaches to draw from:

LZ	XnT
Woven grids and HV delivery system	Strung wire grids
All poly HV cable, and side entrance geometry	Top entrance HV cab
Compressor driven gas phase purification and storage	Liquid phase purifica
Chromatographic Kr and Rn removal	In-line distillation Rr
Distillation based impurity sampling	Chromatography bas
Gd-LS outer veto + Xe skin	Gd-water outer veto
Low radioactivity Ti vessel	SS vessel
Multiple weir liquid level control	Bell jar liquid level o



LZ Grids



### XnT Kr distillation

- ation and storage
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- and shield
- control







## R&D to mitigate top technical risks

Highest risks that require early R&E		
Establish Electric Fields	Control Detector Bac	
<ul> <li>Key requirements:</li> <li>f grid size</li> </ul>	<ul> <li>Key requirements:</li> <li>intrinsic background fr</li> </ul>	
• 1 cathode HV	accidentals (↑ surface)	
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- Studies of accidentals, detector effects in LZ/XnT data
- Investments across XLZD groups in medium and large scale test platforms
- Possible definitive performance testing using existing shielded underground infrastructure



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### Combined team's track record establishes technical foundation and capabilities for making the necessary advances



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### Possible sites for XLZD

- Completing a study of siting options
- Key considerations include
  - Depth impact on backgrounds, particularly for DBD
  - Ability of host site and country to provide suitably outfitted space compatible with project timeline and separate from project cost
  - Accessibility & transport large sub-assemblies, vessels
  - Underground fabrication and staging where required
- Key contenders shortlist
  - Boulby new 1300 meter lab being proposed
  - LNGS middle of Hall C
  - SNOLAB CryoPit under evaluation
  - SURF "Module of Opportunity" cavern or new excavation

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### More on site considerations

- How do we build this detector underground?
  - 4+ meter diameter cryostats
  - 3+ meter diameter TPC components
    - Fabricated in clean, low radon environment
  - Xenon handling
    - Online krypton/radon distillation columns
    - Neutron shielding for xenon that leaves water tank (activation)
  - Xenon recovery (capacity for 60-80t of xenon)
  - Liquid scintillator plant for outer detector





## Key endorsements & roadmaps

### **P5** Recommendation

2. Construct a portfolio of major projects that collectively study nearly all fundamental constituents of our universe and their interactions, as well as how those interactions determine both the cosmic past and future.

- a. **CMB-S4**, which looks back at the earliest moments of the universe,
- b. Re-envisioned second phase of DUNE with an early implementation of an enhanced 2.1 MW beam and a third far detector as the definitive long-baseline neutrino oscillation experiment,
- c. Offshore Higgs factory, realized in collaboration with international partners, in order to reveal the secrets of the Higgs boson,
- d. Ultimate Generation 3 (G3) dark matter direct detection experiment reaching the neutrino fog,
- e. IceCube-Gen2 for the study of neutrino properties using non-beam neutrinos complementary to DUNE and for indirect detection of dark matter.
- Astroparticle Physics European Consortium (APPEC) mid-term roadmap
- Helmholtz roadmap (DE)
- UKRI funds to develop XLZD
- SERI roadmap (CH)



of Dark Matter

"This improvement in reach would provide coverage of important benchmark WIMP models, such as most remaining potential dark matter parameter space under the constrained minimal supersymmetric extension to the Standard Model."

"APPEC strongly supports the European leadership role in Dark Matter direct detection, underpinned by the pioneering LNGS programme, to realise at least one next-generation xenon (order 50 tons) and one argon (order 300 tons) detector, respectively, of which at least one should be situated in Europe. APPEC strongly encourages detector R&D to reach down to the neutrino floor on the shortest possible me scale for WIMP searches for the widest possible mass range."







## G3 Dark Matter

- From P5 Recommendation 2, Priority 4 out of 5 :
  - An ultimate Generation 3 (G3) dark matter direct detection experiment reaching the neutrino fog, in coordination with international partners and preferably sited in the US.
- DOE response and actions:
  - At the present time, based on the Snowmass Community Summer Study, there have been two proposals for G3 Dark Matter detectors : XLZD and ARGO
  - P5 recommended a domestic site for the experiment in the higher funding scenario and an international site in the lower funding scenario.
  - Start with site independent R&D as we understand the funding that will be available.
     Engage with partners who are interested in hosting.
  - DOE will entertain proposals by U.S. groups for pre-project R&D.



### DOE response to P5 (May 2024)





## DARWIN R&D

- R&D for next-generation liquid xenon detector
- Several large-scale demonstrators in operation (3 ERCs)
- Photosensors, TPC design, large-scale purification, Rn removal, Gd-loaded water, etc.





Xenoscope at UZH L. Baudis et al., JINST 16, 2021, EPJ-C 83, 2023





Established by the European Commission



Pancake in Freiburg A. Brown at al., JINST 19, 2024



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## Supporting XLZD project to host world-leading dark matter experiment

The Technology Department will provide vital engineering expertise to the XLZD project to demonstrate that STFC can host the world's most advanced dark matter detector at Boulby Underground Laboratory.

The XLZD Consortium combines three worldleading collaborations, Xenon, Lux-Zeplin and Darwin, to design and build a single dark matter experiment.

Several locations internationally are being considered to host this experiment, with the UK developing plans to potentially house the detector at STFC's Boulby Underground Laboratory.

The UK consortium, led by Imperial College





### **Related Sections**

Projects and Mechanical Engineering (RAL)

### **Related Content**

HP Highlights

• WIMP science - potential for major discovery



- WIMP science potential for major discovery
- Scientific breadth exciting additional goals



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iscovery goals



- WIMP science potential for major discovery
- Scientific breadth exciting additional goals
- XLZD is timely
  - Proven technology / merger of expert teams
  - International planning underway



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If WIMPs exist above the systematic limit of astrophysical neutrinos, XLZD will observe them.

## The XLZD Collaboration

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Imperial College London King's College London Royal Holloway, University of London STFC Daresbury Laboratory STFC Rutherford Appleton Laboratory University College London University of Bristol University of Edinburgh University of Liverpool University of Oxford University of Sheffield University of Chicago University of Sussex University of Texas, Austin University of Wisconsin LPNHE

Subatech/IN2P3

Brookhaven National Laboratory LIP-Coimbra **Brown University Bucknell University** Columbia University Pennsylvania State University Purdue University University of Alabama University of Maryland University of Massachusetts University of Michigan University of Rochester

Rice University

University of Coimbra

University of Barcelona

### Countries: 17 Institutions: 76 Members: 440+

Black Hills State University

South Dakota School of Mines

SURF

xlzd.org

Lawrence Berkeley National Laboratory

Lawrence Livermore National Laboratory

SLAC National Accelerator Laboratory

University of California, Los Angeles

University of California, Santa Barbara

University of California, San Diego

University of California, Berkeley

University of California, Davis

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Vinca Institute of Nuclear Sciences

INAF Osservatorio Astrofisico Torino **INFN-LNGS** Weizmann Institute SISSA University and INFN Bologna University of Ferrara University of L'Aquila University of Naples "Federico II"



2nd XLZD Meeting - UCLA, April 2023

Kobe University Nagoya University The University of Tokyo

Institute for Basic Science

The Chinese University of Hong Kong, Shenzhen Tsinghua University Westlake University

The University of Melbourne

