Underground Facilities for Cosmic Frontier (UF2)

J. Cooley*, S. Hertel, H. Lippincott*, K. Ni, E. Pantic
*Liaisons from Cosmic Frontier

Outline

- Key topics in *underground-based* Cosmic Frontier research
- Facilities for particle like dark matter detection
    - Noble liquid detector experiments
    - Cryogenic bolometer experiments
    - Experiments using other technologies
- Status of UF2 Topical Report and Summary
- Discussion

Facilities for noble liquid detector experiments

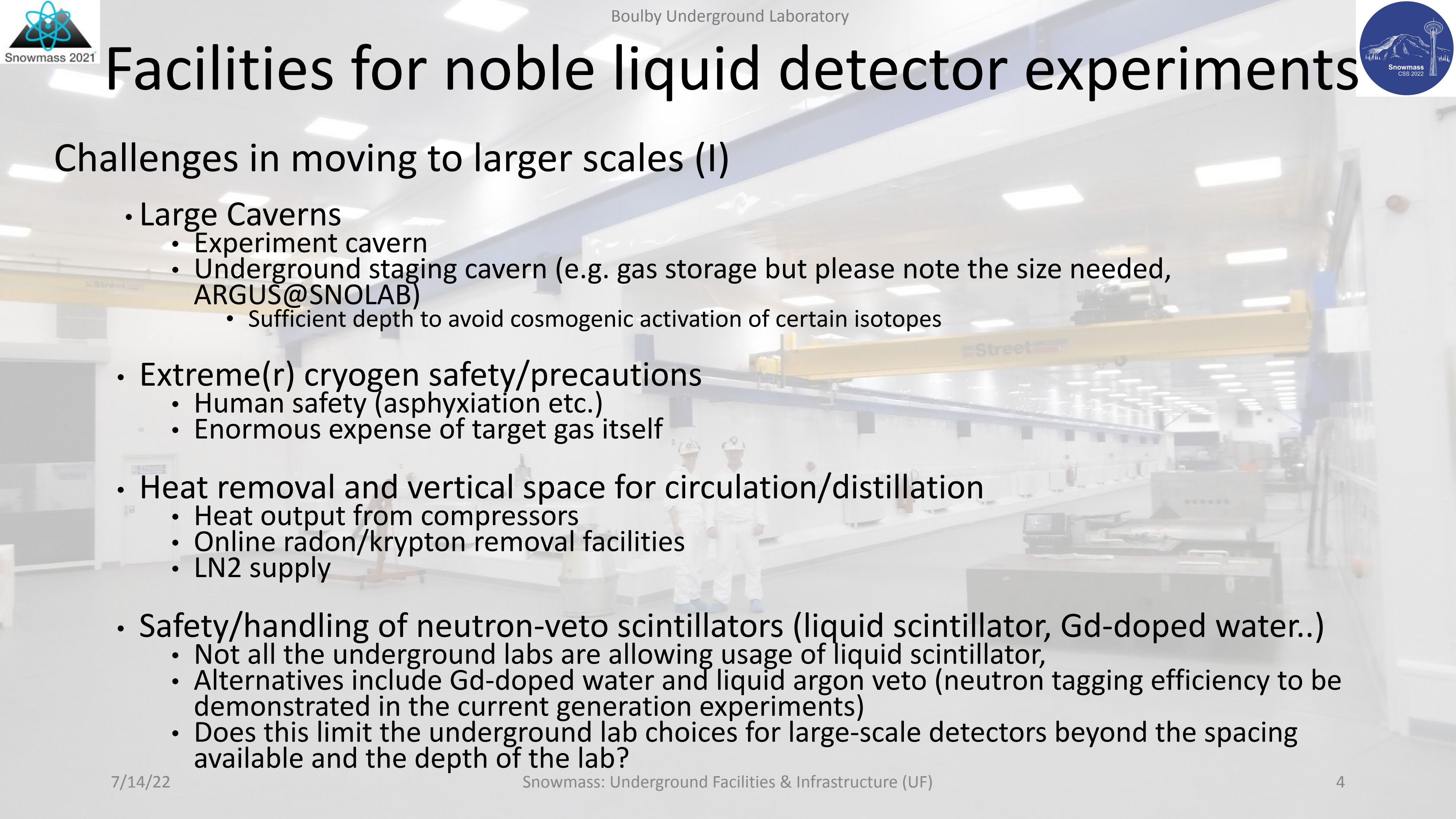
- Physics
  - Primary motivation: GeV-TeV mass DM via nuclear recoils
  - Sensitivity to *many* other other physics questions: sub-GeV DM via ionization-only, ER & migdal, solar neutrinos (both NR and ER), 0vbb, solar axions, hidden photons, etc etc etc…

- Future Projects at planning stage
  - Liquid Xenon: a 50-100t observatory XLZD consortium (2028-2033, from CF1)
  - Liquid Underground Argon: a 300t observatory ARGO (2030-2035, from CF1)

?

- Future Projects at concept stage:
  - Liquid Underground Argon or Xe-doped Liquid Underground Argon: a 1.5t detector DarkSide-LowMass (?, from CF1)

- Should any others be included in either class?


Boulby Underground Laboratory

Facilities for noble liquid detector experiments

Challenges in moving to larger scales (I)

- Large Caverns
  - Experiment cavern
  - Underground staging cavern (e.g. gas storage but please note the size needed, ARGUS@SNOLAB)
    - Sufficient depth to avoid cosmogenic activation of certain isotopes

- Extreme(r) cryogen safety/precautions
  - Human safety (asphyxiation etc.)
  - Enormous expense of target gas itself

- Heat removal and vertical space for circulation/distillation
  - Heat output from compressors
  - Online radon/krypton removal facilities
  - LN2 supply

- Safety/handling of neutron-veto scintillators (liquid scintillator, Gd-doped water..)
  - Not all the underground labs are allowing usage of liquid scintillator,
  - Alternatives include Gd-doped water and liquid argon veto (neutron tagging efficiency to be demonstrated in the current generation experiments)
  - Does this limit the underground lab choices for large-scale detectors beyond the spacing available and the depth of the lab?

Canfranc Underground Laboratory

Facilities for noble liquid detector experiments

Challenges in moving to larger scales (II)

- Experiment assembly underground
  - Current generation: Assembled in dedicated low-radon cleanroom, transported underground and installed in clean sealed state
  - Future larger experiments: **more assembly burden shifts underground**
    - Need for large underground low-radon clean room assembly/staging areas
    - Need for multiple cranes to support transport of the assembled detector into its cryostat.
    - Need for vertical space clearance on the order of height of the detector plus the height of cryostat (ceiling height >4m).
    - Need for the enforced floor in the cleanrooms since detectors are getting heavy.

Facilities for cryogenic bolometer experiments

- These experiments are much smaller in facility footprint, but also comparatively sensitive to environmental factors
- Typically based around 3He/4He dilution fridge + shielding/veto
- Primary facility constraints:
  - Vertical Height: Ceiling height of >4m
    - Set by standard commercial DF design geometries
    - Lower cavern heights possible but with increased design complexity
  - Floor vibration: < order-10^-7 g/sqrtHz at all frequencies
    - Set by sensitivity to wire vibration and frictional phonon production
    - Quantitative specification here extremely experiment-specific
    - Some mitigations possible (e.g. seismic platform for SuperCDMS)
  - E&M environment: low backgrounds at all frequencies, inc. DC magnetic fields
    - Extreme sensitivity to both signals and background noise
    - Sources include facility utilities (power, air handling, lighting, etc.) and also neighboring experiments
    - Mitigation via filtering + faraday cage, again adds design complexity
    - DC magnetic field at <100μT (typical earth field, looser requirements after cooldown is complete)

Facilities for cryogenic bolometer experiments

- Low-mass DM is growing in importance/visibility, expect modest growth in the number of cryogenic bolometer experiments

- Some need for R&D in an underground environment
  - Traditional strategy: complete R&D above ground, then deploy underground
  - Current/future considerations:
    - Low-rate ‘heat-only events’ from instrumental effects better constrained in quiet environment
    - Colder experiments: Slower phonon physics, longer event durations and greater pileup-limitations above ground

- Depth/overburden requirements
  - Specific to each experiment, in some cases pending further R&D results

Kamioka

Facilities for cryogenic bolometer experiments

- Future Projects at planning stage
  - NaI Scintillator Bolometer: COSINUS@LNGS (2023, from CF1 report)
- Future Projects at concept stage
  - Multi target Cryo TES: TESSERACT@undetermined (2026, from CF1 report)

- Should any others be included in either class?

- Long-term, 10y timescale: convergence with QIS needs
  - As coherence times lengthen, QIS will increasingly benefit from underground facilities
  - *Possibility* of QIS-motivated many-DF facilities, economy of scale (or not! Lots of uncertainty in the direction of QIS over 10y timescale).   Perhaps large in floor space and relatively shallow.

- Two models: dedicated to single collaboration vs shared user facilities
  - User facility model, is it working? At least partial examples include CUTE, NEXUS, and in the future the SuperCDMS cryostat

Facilities for other dark matter detection technologies

The main goal here is to complement CF1 efforts to encourage support for multiple experimental techniques spanning the wide range of direct dark matter masses.

Bubble chambers are leading the field in sensitivity to spin-dependent couplings between dark matter and protons.

- Beyond PICO-500 there does not seem to be any other larger-scale experiment utilizing bubble chamber as technology.
- PICO-500 is planned (currently in the stage of design) detector in Cuber Hall in SNOLAB. SNOLAB also houses PICO-40L.
- The major challenges for any other experiment beyond PICO-500 as reported in the SM white paper are new materials and surface treatments for the vessel, acoustic bubble sensing without imaging and active veto. But it is not clear if any of these developments directly depend on the status of underground facilities.
- We are not aware of any other specific (not common) underground facility challenges associated with PICO-500 or future bubble chambers. Please could you provide feedback if there are some?

Facilities for other DM detection technologies

The main goal here is to complement CF1 efforts to encourage support for multiple experimental techniques spanning the wide range of direct dark matter masses.

Scintillating bubble chambers are blind to electronic recoils, can achieve 100eV energy thresholds and are planning to explore dark matter down to spin-independent neutrino fog at around 1 GeV.

- The SBC@SNOLAB is the only detector listed under the concept category in the table within CF1 WG report.
- The SBC detector will be a large scale (1 tonne) when compared to other bubble chambers and hence there might be some specific needs to the UG facilities, but it is not clear if those needs could be specified right now given that the development and testing on the smaller scales is still ongoing. We would love to hear about those underground facility needs.
- The SBC effort might extend beyond coming decade.
- Scintillating bubble chambers are operated at high pressure and cryogenic temperatures so SNOLAB facilities will have to address safety measures related to that combination.
- Does SBC have any requirements on the floor vibrations?
- SBC has a specified timeline with a phased approach.

Facilities for other DM detection technologies

The main goal here is to complement CF1 efforts to encourage support for multiple experimental techniques spanning the wide range of direct dark matter masses.

CCD skipper detectors detect single ionized electrons and have the potential to significantly extend nuclear recoil sensitivity for DM masses near 1 MeV.

- The DAMIC-M 1kg@LSM and SENSEI 100g@SNOLAB are listed under running or under construction in the table within CF1 WG report.
- Oscura@SNOLAB is the only detector listed under the concept category in the table within CF1 WG report.
- The detectors need to be cooled to about 120K but do to their internal structure their needs probably match the needs of cryogenic detectors for the floor vibrations and E&M shielding.
- Is vertical height clearance also a concern for this technology?
- Experiments utilizing CCD skipper detectors have a phased approach visible in the CF1 report.

Snowmass 2021

Facilities for other DM detection technologies

The main goal here is to complement CF1 efforts to encourage support for multiple experimental techniques spanning the wide range of direct dark matter masses.

Directional gas detectors (low-density gas drift chamber/TPC) capable of direct recoil imaging

- CYGNO@LNGS and CYGNUS@multiple sites are the detectors listed under the concept category in the table within CF1 WG report. (CYGNO experiment is a CYGNus module with optical readout and is part the CYGNUS proto-collaboration which aims at constructing a network of underground observatories for directional DM search.)
- We would love to hear about the underground facility needs of directional gas detectors and their timeline for the construction of the network.
- We expect that the footprint of directional gas detectors is going to be large and hence main question will be about the space available.
- Is vertical height clearance also a concern for this technology?

Other technologies in the planning/concept stage:

SABRE, COSINE-200, CDEX-100, SNOWBALL, ALETHEIA, Windchime (from CF1 report).

If there are some specific underground facilities needs we would like to hear about them.

Modane Underground Laboratory

Comments in common to all experiments

Underground material assay facilities continue to be essential to the field (see UF4)

Underground material production, purification, distillation, etc. (see UF4)

Obvious, but needs mentioning: *facility personnel* are hugely important (Management, planning, safety and safety oversight can all make or break an experiment)

Robust onsite computing infrastructure.

New Underground Spaces coming online

The LBNF Module of Opportunity is the primary new underground space coming online in the next few years

- @SURF 4850 level, half of one LBNF detector cavern
- Dimensions: 73m long, 20m width, 28m height
- LBNF excavation now 34% complete
- Infrastructure outfitting for LBNF scheduled to end in May 2024

Is this info correct?

Are we missing something?

SURF is advocating for additional space be excavated immediately after LBNF excavation ends

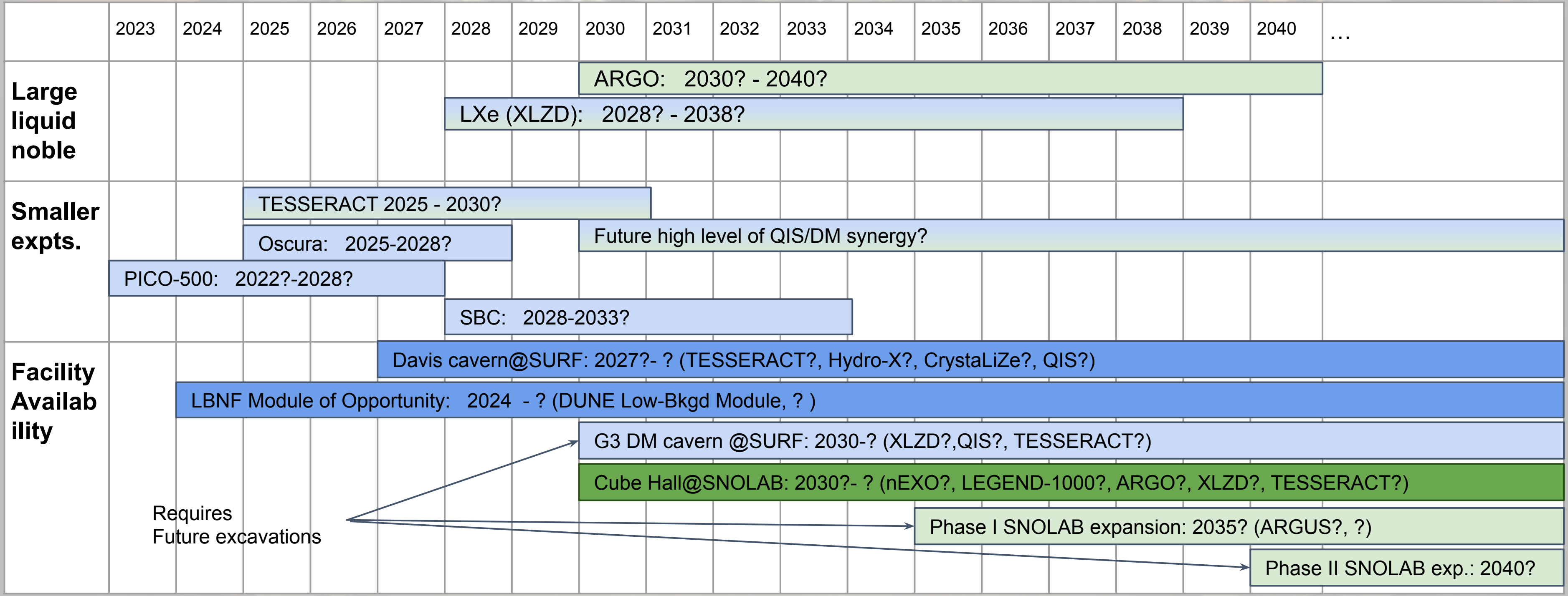
- Proposals at both 4850 and 7400 foot levels
- Excavation for the smaller space for hosting large-scale DM detector could begin ~2027, and be completed by ~2030.
- SURF Long-Term Vision Workshop, Sep. 2021 (https://indico.sanfordlab.org/event/26/)

SNOLAB also has plans for significant expansion

- Proposals for both for the storage space (ARGUS project) and experimental space.
- Each expansion will take about 5yr and work would be organized as two phased expansions.
- Intermediary storage for the fraction or all of ARGUS 400t of underground argon possible at the lesser depths.

Facility Needs Timeline

This table only lists future planned/concept experiments that publicly designated through SM process, SURF or SNOLAB as their possible labs. We identified that is where the space is “full”.



Any line or number here is FUZZY.

SURF
SNOLAB

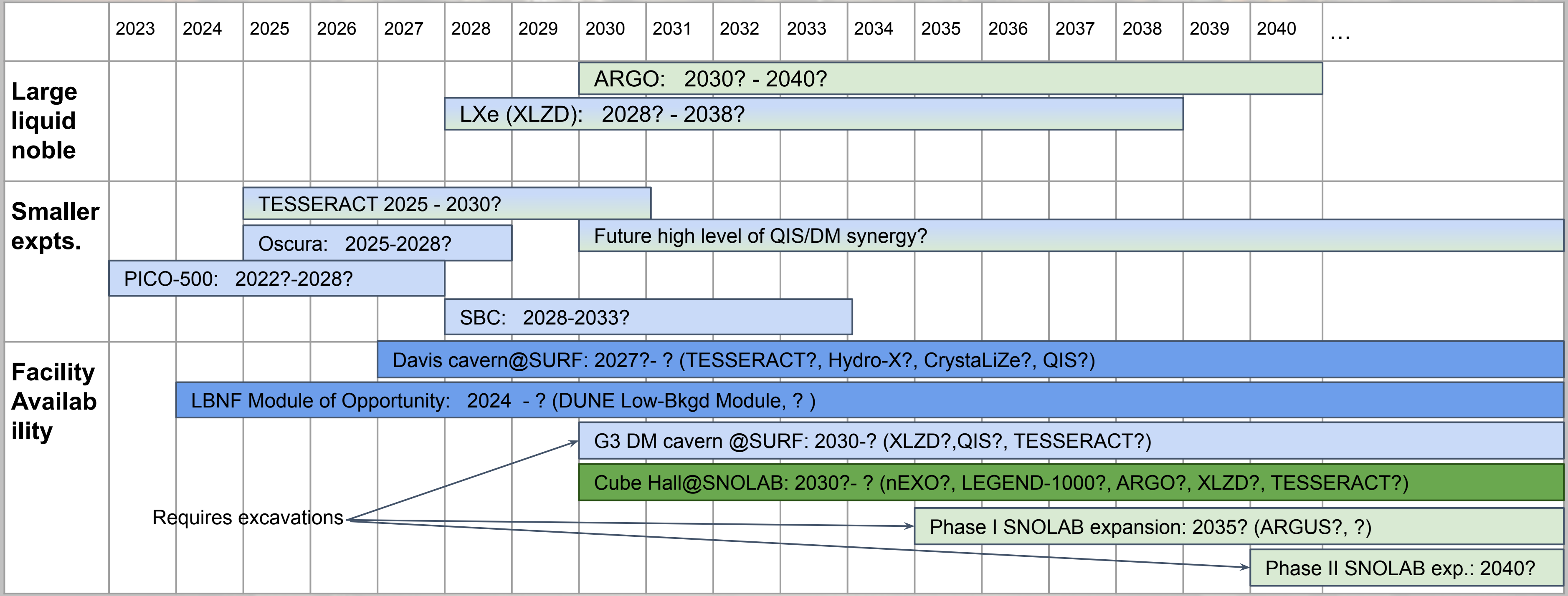
Modane Underground Laboratory

Facility Needs Timeline

Is this info correct?

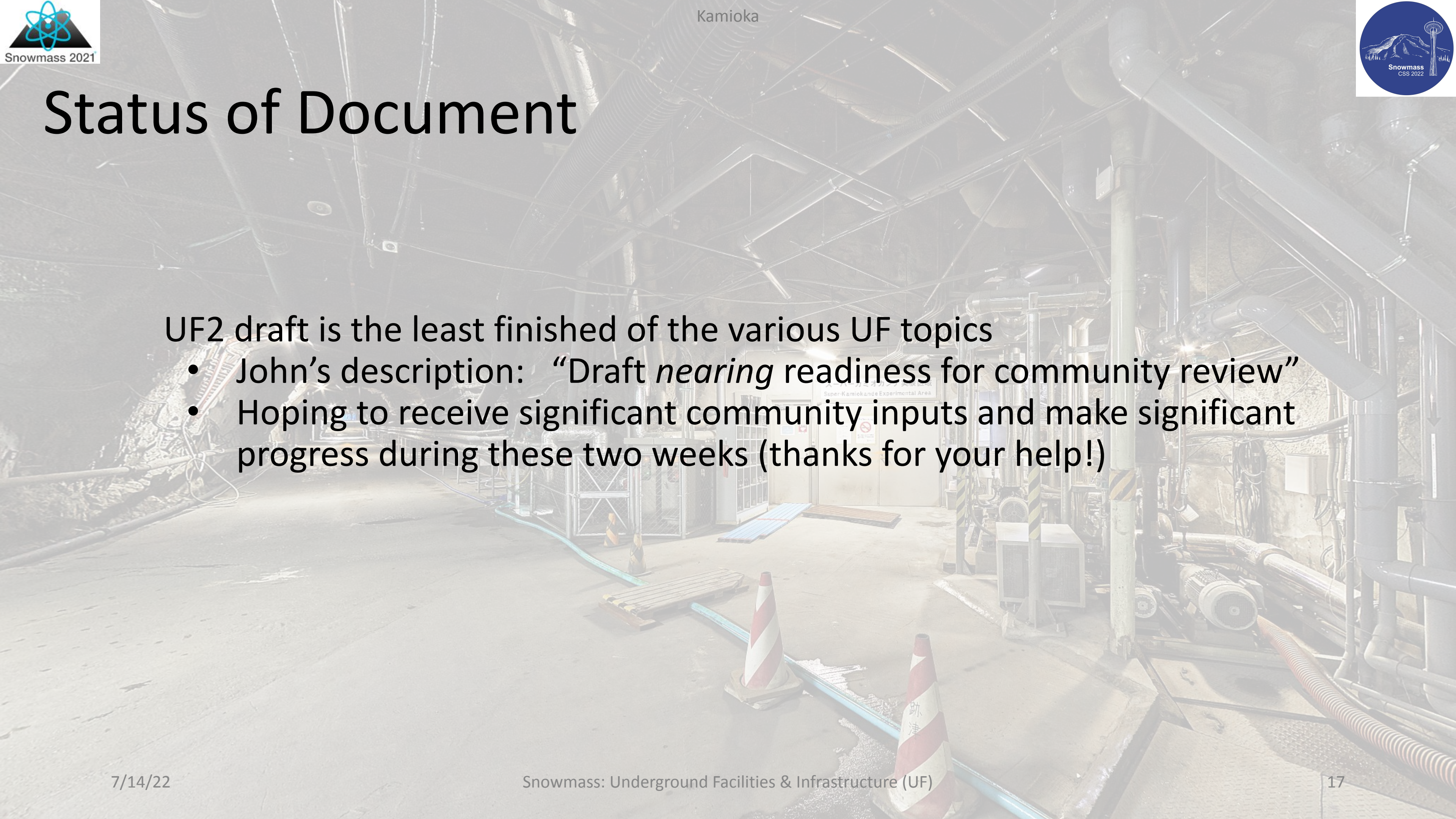
Are we missing something?

This table only lists future planned/concept experiments that publicly designated through SM process, SURF or SNOLAB as their possible labs. We identified that is where the space is “full”.



Any line or number here is FUZZY.

SURF SNOLAB



Kamioka

Status of Document

UF2 draft is the least finished of the various UF topics

- John’s description: “Draft *nearing* readiness for community review”
- Hoping to receive significant community inputs and make significant progress during these two weeks (thanks for your help!)

Key Take-aways

- Multiple new DM experiments are expected and being planned, while facilities are currently ‘full’. We heard this explicitly from SURF yesterday. Clear need for more underground space, tailored to future needs.

- This underground space should specifically include
  - Both large spaces for large experiments (liquid noble) and small spaces for smaller experiments (cryogenic, ‘other’)
  - Large radon-free clean rooms for detector assembly and installation for the next generation experiments
  - Large areas for staging (e.g., gas storage) and experiment utilities (e.g. pumps, distillation)

- Discussion