**QUEST-DMC Joint WP1/WP2 Meeting — Structured Summary (Liverpool, 15–17 Oct) Snapshot**

- **Primary goals:** (i) Real path to **~10 eV** detector threshold (WP1); (ii) Understand/solve the **A→B nucleation puzzle** as an analogue of early-Universe first-order phase transitions (WP2); (iii) Tighten **background modeling**, link **radiation → phase transitions**, and map **DM signal channels** (electrons, nuclei, phonons, heat).
- **Cross-cutting themes:** Baseline/periodicity systematics, cosmic-ray/EM-induced heating, diffusion vs ballistic transport, correlated noise, threshold-less **heat-injection searches**, and **data/MC unification**.

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**Key Outcomes & Decisions**

- **Threshold focus:** Demonstrate a credible route to **10 eV** (WP1) and **~100 eV** triggers for AB transitions (WP2) as near-term funding milestones.
- **Backgrounds:** Cosmic rays dominate many baselines; **correlated acoustic/vibrational modes** confirmed. Modeling must include **copper thermal coupling** and EM effects (eddy currents).
- **Baseline modeling:** Adopt **predictive models** for baseline drift (thermal ODEs, STL decomposition, ICA/PCA for noise). Investigate **~60–100 s** periodicity signatures seen across setups.
- **Data strategy (agreed direction):** Central storage with **versioned HDF5**, **unique run IDs**, **hierarchical levels (L1–L5)** for both **data and simulations**, and **format parity** between MC and data. RAL (Tier-1) proposed; RHUL/Oxford Tier-2 as options.
- **Nanofabrication:** Move forward with **vibrating ribbon resonators** ($Si_3N_4$/Al) and arrays; study **corner/flow-field** effects and frequency control; keep options for **levitating probes** long-term.
- **WP1↔WP2 coupling:** Use **bolometer + PT volume + thin channel** to time-profile **quasiparticle (QP) bursts** from AB transitions; explore **A-phase** for directional response and lower-energy sensitivity.

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**WP1 — Status & Next Steps (Detectors, Backgrounds, Analysis)**
**Status**

- Multiple cells operated; **Gen-1 DM search nearly complete**; big progress on **background models**; identified **missing acoustic** & **correlated** noise pieces.
- **ND3**: long **tracking datasets (~700 h, 75% livetime)**; **SQUID readout** improves SNR; **baseline fluctuations** persist (60–100 s scale).
- **Noise sources:** Eddy currents, vibrational modes, shot noise contributions at thin wires, geophone limits.

**Next steps**

- **Threshold:** Concrete workplan to **10 eV** (electronics, resonator Q, thermal design, shot-noise susceptibility).
- **Baseline/periodicity:** Replicate and analyze ~100 s periodicity (compare F4, ND3; tighten peak removal; test muon-rate modulation).
- **Noise separation:** Deploy **ICA/PCA** pipelines; adopt **complex response** modeling; track progress via **baseline RMS** and **recovery of injected pulses**.
- **Thermal models:** Fit **coupled ODEs (Cu–He Kapitza)** to baseline ramps; include **electron/nuclear/phonon coupling** in copper at low T.
- **Sources & calibration:** Move **Fe-55 source inside the cell** (higher activity, lower attenuation); expand **Geant4** with **true-to-heat partitions** and **correlated-detector** sims.
- **Mini-bolometers:** Evaluate sensitivity/exposure trade-offs; optimize **surface/volume** and **time constants**.

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**WP2 — Status & Next Steps (AB Nucleation, Cosmology Links)**
**Status**

- **AB transition puzzle:** Data consistent with **radiation-triggered hot-blob** diffusion picture; **lifetime vs (T,P,volume)** scaling studied across **five "lakes"**; **non-monotonic** pressure behavior at low P; **Kibble–Zurek** seeding expected in both baked-Alaska and cosmological scenarios.
- **Simulations:** TDGL-based; show **threshold energy** above which PT always succeeds; walls/domains observed; need statistics and refined transport (ballistic + diffusion).
- **Lancaster/RHUL:** Long stable runs (27 months; ~1000 PTs). Macor holder likely radiogenic source; **silicon-powder** holder planned (assay recommended).

**Next steps**

- **Quantify thresholds:** Firm **~100 eV** (typ.) and explore **down to ~10 eV at 0.2 T_c** conditions; measure **latent heat** vs (T,P).
- **Transport & dynamics:** Simulate and measure **QP arrival-time distributions** with **stretched-tube** to bolometer; analyze **vortex contributions** and QP shadows after muons.
- **Environment control:** Reduce radiogenics (holder swap), characterize **magnetic-field** effects on boundary conditions; plan **underground A-phase lifetime** measurements (Boulby?)
- **Cosmology tie-ins:** Extract **phase-boundary speed** & **transition rate** analogues; connect to **LISA-band** GW predictions.

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**Theory & Phenomenology Highlights**

- **DM signal taxonomy:** Sub-threshold **heating** (electrons, nuclei, **Migdal**), **quasiparticle excitations**, **pair-breaking**, and potential **bosonic-field** effects; different operators → different **signal shapes**.

- **Ceiling/attenuation: Diffusion/velocity-loss** frameworks shift sensitivity at low masses; **Earth shadowing** & **daily/annual modulation** to be integrated.
- **Structure functions:** He-3B **quasiparticle S(q,ω)** from BCS/BCS-like formalism: **Pauli blocking** and **gap** enforce thresholds; classical-gas approach valid only at higher q,ω.
- **Threshold-less heat search:** Power injection **P=∫ω(dR/dω)ω dω** with **no explicit readout threshold**; challenges: **where/how** energy is deposited (He vs copper), thermal link pathways; pursue **modulation searches**.
- **A-phase possibilities:** Rich mode spectrum; potential **directional** sensitivity; explore **NMR** as **ultra-low-threshold** readout (limits at lowest T).

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**Talk-by-Talk (very brief)**

- **Jocelyn & Mark (intro):** Roadmap to **10 eV**; background reduction; AB transitions ↔ GW spectra; cosmic-ray rejection long-term.
- **Juri:** Priorities in operators/benchmarks; ceiling & diffusion; **heat-injection** formalism; phonon mass/gap in He-4; He-3 multi-sound modes & DM effects.
- **Dima: Levitating oscillator** achieves **~10 μHz** intrinsic damping; sphere geometry benefits; magnon BEC thermometry path; eddy-current damping & wire-velocity limits.
- **Tania K.: Copper-He thermal model** fits F4 baselines (10–100 pW injections); 100 s periodicity; ~80% cosmic-ray heating estimate; data-access issues flagged.
- **Jack S.: Nuclear recoil vs Migdal** heating; similar power scales; **electron loss function** in Cu is the key unknown → DFT/computational focus.
- **Elizabeth (ND3):** Nanowire behaviors (mode jumps resolved in later runs), **excess noise near resonance**, ops comparisons (pressure, mounts, pot), **FFT + STL** workflow, pulse-shape templating, Fe-55 deployment plan.
- **Lizzie (BG model): NaI gamma mapping** (K-40, Tl-208); dewar attenuation validated; sim/assay mismatches (thickness, materials) under study; implications for ND2.
- **Paolo (ND3 sims): Geant4 + real-noise** synthesis; STL residuals limit peak-find; confusion matrix & PDF fits recover injected rates to **~10%**; roadmap to matched filters.
- **Mark Hindmarsh: Hot-blob diffusion** favored; thresholds vs critical radius/mean-free-path; simulations with anisotropy; domain walls, decay; links to **LISA**.
- **Joe McL.:** Cosmogenic **excimer** tail (~10–15 s) can bias baselines; **PCA/ICA** separates shared noise; metricization via baseline RMS & pulse recovery.
- **Neda D.:** Full **NR-EFT** → SI/SD reductions; dual attenuation frameworks; collider & CPV benchmarks; halo anisotropy extensions.
- **Adam T.: He-3B S(q,ω)** with coherence factors; **Pauli blocking/gap** enforce low-E constraints; bridge to sub-detector heating budget.

- **Petri H.:** WP2 progress; multi-lake stats; non-monotonic pressure behavior; **ballistic+diffusive** simulation; hardware upgrades (holder).
- **Samuli (mini-bolometers):** Sensitivity gain vs exposure loss; surface heat capacity dominance; geometry/time-constant considerations.
- **Lev (nano-ribbons): $Si_3N_4$/Al ribbons** (10 μm×100 nm), flow-field & Andreev reflections, corner effects; arrays & dual-holes geometry; fabrication yield/controls.

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**Risks / Unknowns**

- **Baseline drift & periodicity** origins (cosmics vs control loops vs EM/flow).
- **Copper electron-loss function** at low energies (sets Migdal heating).
- **Shot noise & thin-wire limits**; **corner/flow-field** non-linearities for ribbons.
- **Thermal partitioning** (He vs copper vs walls), **TLS** contributions, vortex/QP **afterpulses**.
- **Data fragmentation** without central HDF5/ID/version discipline.

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**Action Items (owner → action)**

- **WP1 team:** Define and publish **10 eV** threshold roadmap (electronics, resonators, thermal design, noise budget).
- **Tania K. & BG subgroup:** Replicate/diagnose **~100 s** baseline periodicity; re-run fits with **stricter peak cuts**; compare across cells.
- **Joe McL. & Analysis:** Operationalize **PCA/ICA** pipeline; set **quantitative metrics** (baseline RMS, injected-pulse recovery).
- **Elizabeth + ND3 ops:** Deploy **Fe-55 inside cell**; complete **18 bar/10 bar** comparison and **STL parameter scans**; document demag-cycle effects.
- **Lizzie (BG model):** Close **sim↔assay** gaps (thickness/materials/superinsulation); take **ND2** measurements when warm.
- **Paolo (sims):** Add **correlated-detector** and **forward-smeared drift** models; implement **matched-filter** and **data-pulse templates**.
- **Dima & Lev (hardware):** Validate **levitating-probe** damping claims inside fridge; prototype **ribbon arrays**, study **corner rounding** and **45° beams**.
- **Petri/Mark/Juri (WP2):** Expand **ballistic+diffusive** TDGL sims; quantify **trigger thresholds** vs (T,P); plan **A-phase lifetime** tests underground.
- **Data WG (Tania lead):** Draft **HDF5 schema**, run-ID convention, **L1–L5** levels, and **MC/data format parity**; evaluate **RAL Tier-1** + backups.
- **Theory WG (Juri/Neda/Adam):** Publish **operator/benchmark** set per paper; finalize **heat-injection** formalism with **S(q,ω)** for He-3/He-4; include **modulations** and **attenuation**.

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**Near-Term Milestones**

1. **Data/MC schema v1** and centralized storage plan agreed.
2. **Baseline-model report** (periodicity, cosmic fraction, ICA/PCA gains).

3. **ND3 Fe-55-in-cell** results + low-energy selection criteria.
4. **Sim pack v2:** correlated detectors, matched filters, forward smearing.
5. **WP2 sim note:** threshold maps vs (T,P), hot-blob vs critical radius, domain statistics.
6. **Hardware note:** ribbon resonator design space & first cryogenic tests.

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**Collaboration & Logistics**

- **Working groups:** WP1 split (theory, analysis, hardware); WP2 sim/exp subgroups; **Data WG** constituted.
- **Common timetable:** Maintain an **accessible meeting calendar**; ensure **version control** and **backwards compatibility** across repos and datasets.