Opportunities for particle physics experiments in salt caverns

Benjamin Monreal, UC Santa Barbara
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http://hep.ucsb.edu/saltcaverns

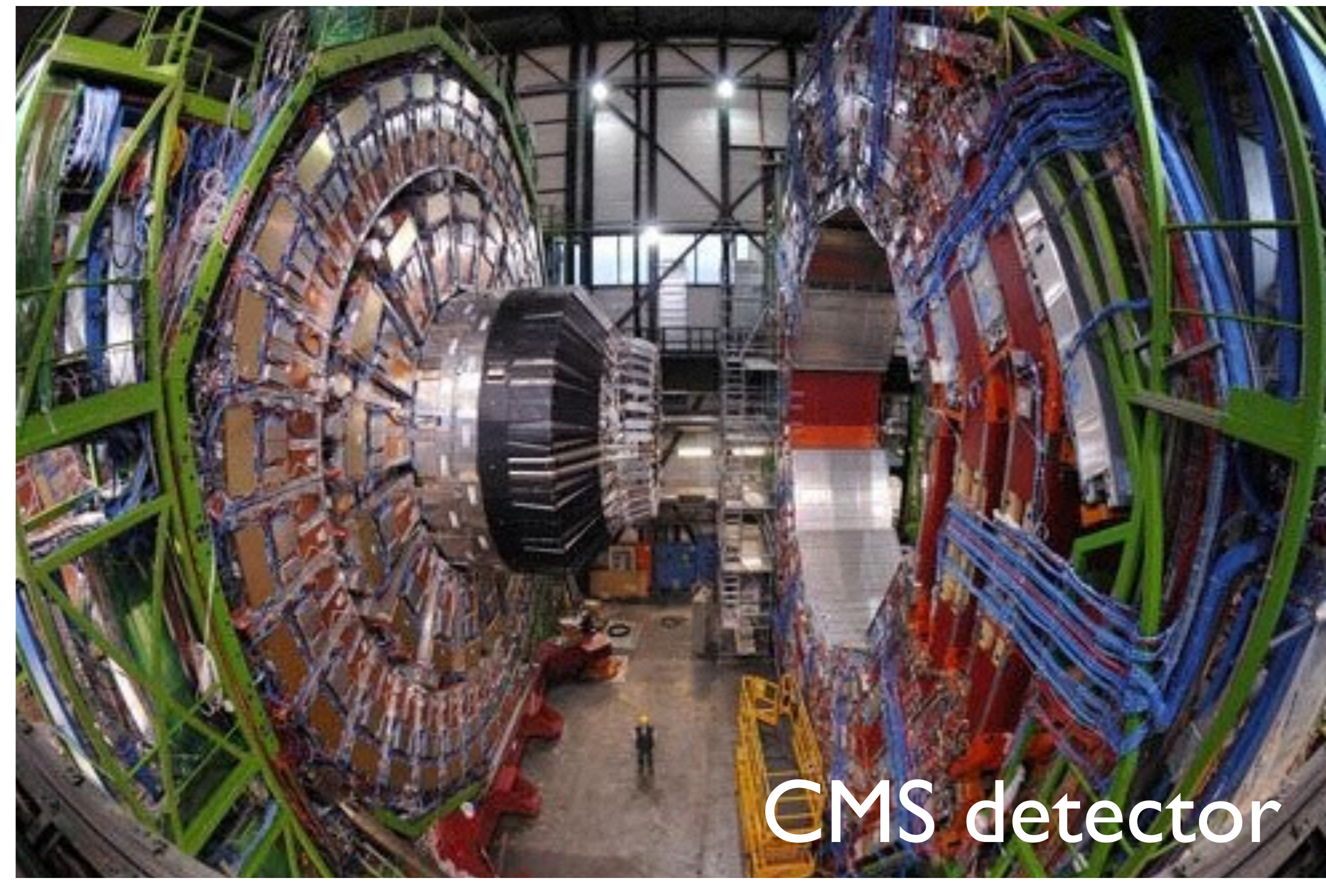
1) Overview of underground particle physics
2) Why I'm interested in salt caverns
3) What kind of detector technologies could we install in a salt cavern?

What do we do aboveground?

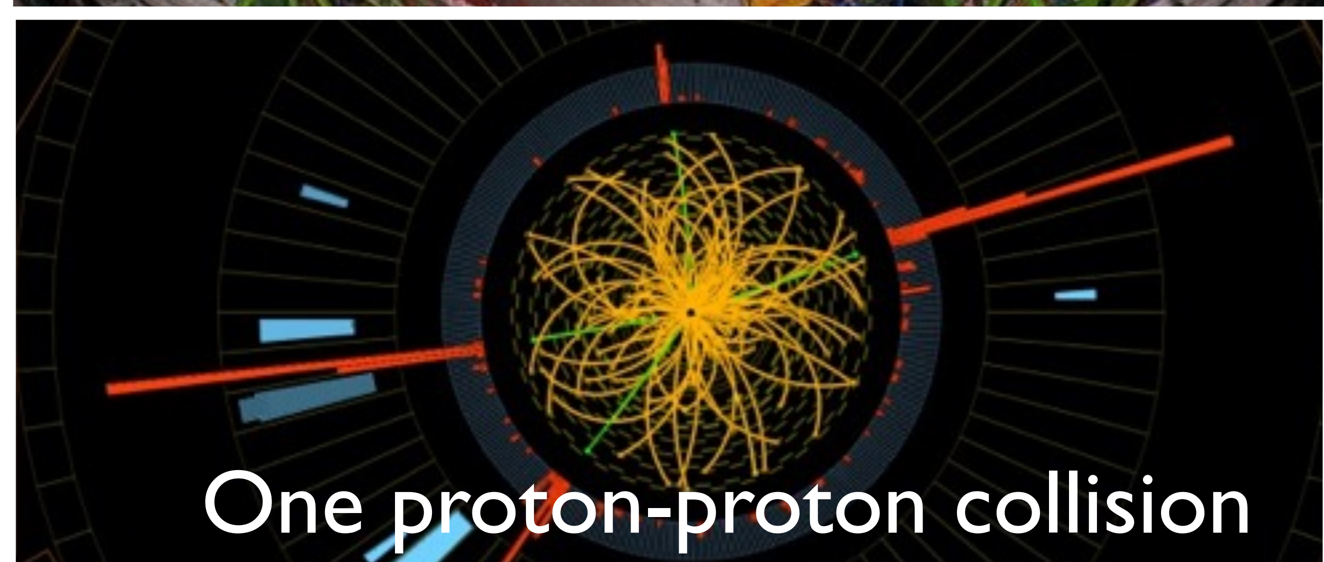
1) Bring particle beams into violent artificial collisions
2) Detect everything that comes out
3) Sift through billions of collisions and look for new phenomena

- 2012: Higgs boson
- 1995: Top quark
- 1983: W,Z bosons
- 1975: Tau lepton
- 1974: Charm quark

Large Hadron Collider, CERN



CMS detector

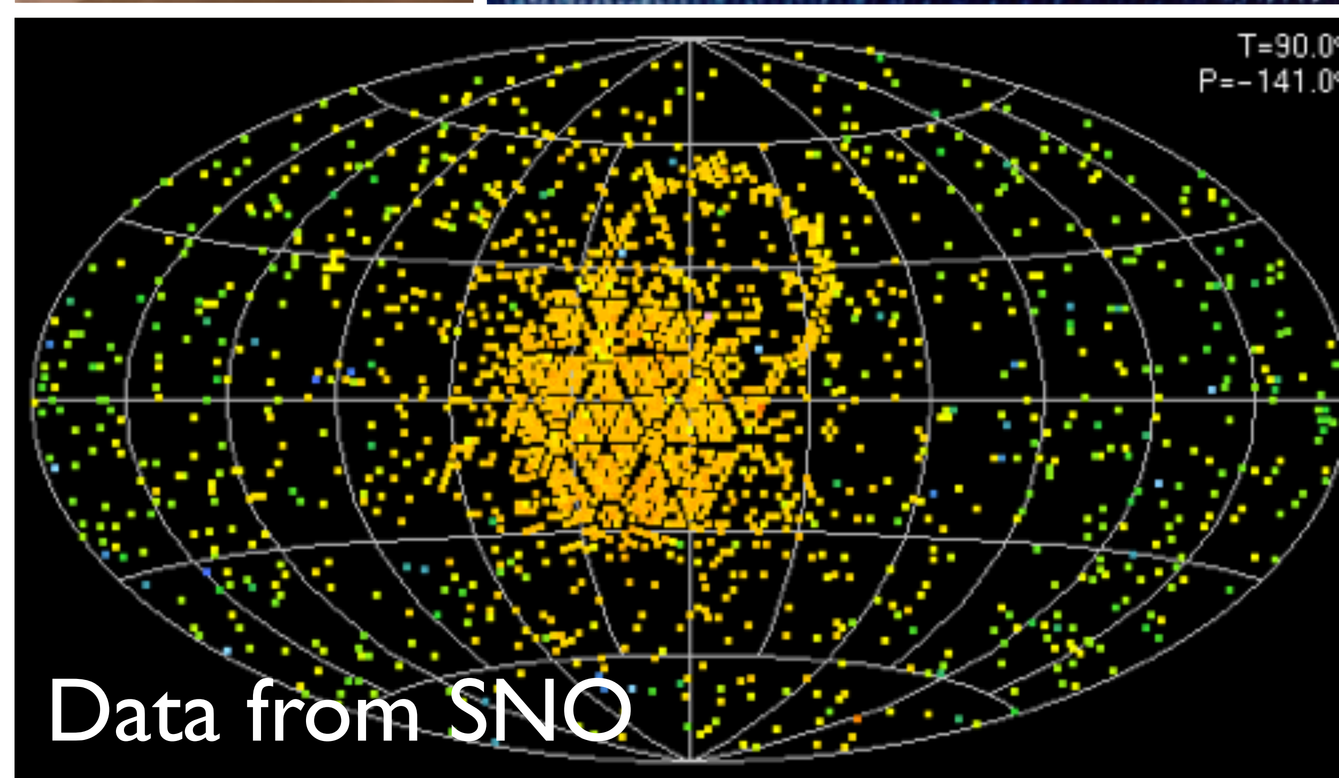


One proton-proton collision

What do we do underground?

1) Build particle detectors in heavily shielded places
    1) escape cosmic rays
2) Detect ultra-rare events from "natural" beams
3) Detect ultra-rare radioactive decay modes

2015 Neutrino flavor change
2002 Cosmic neutrinos
1995 Reactor neutrinos
1988 Neutrino beams



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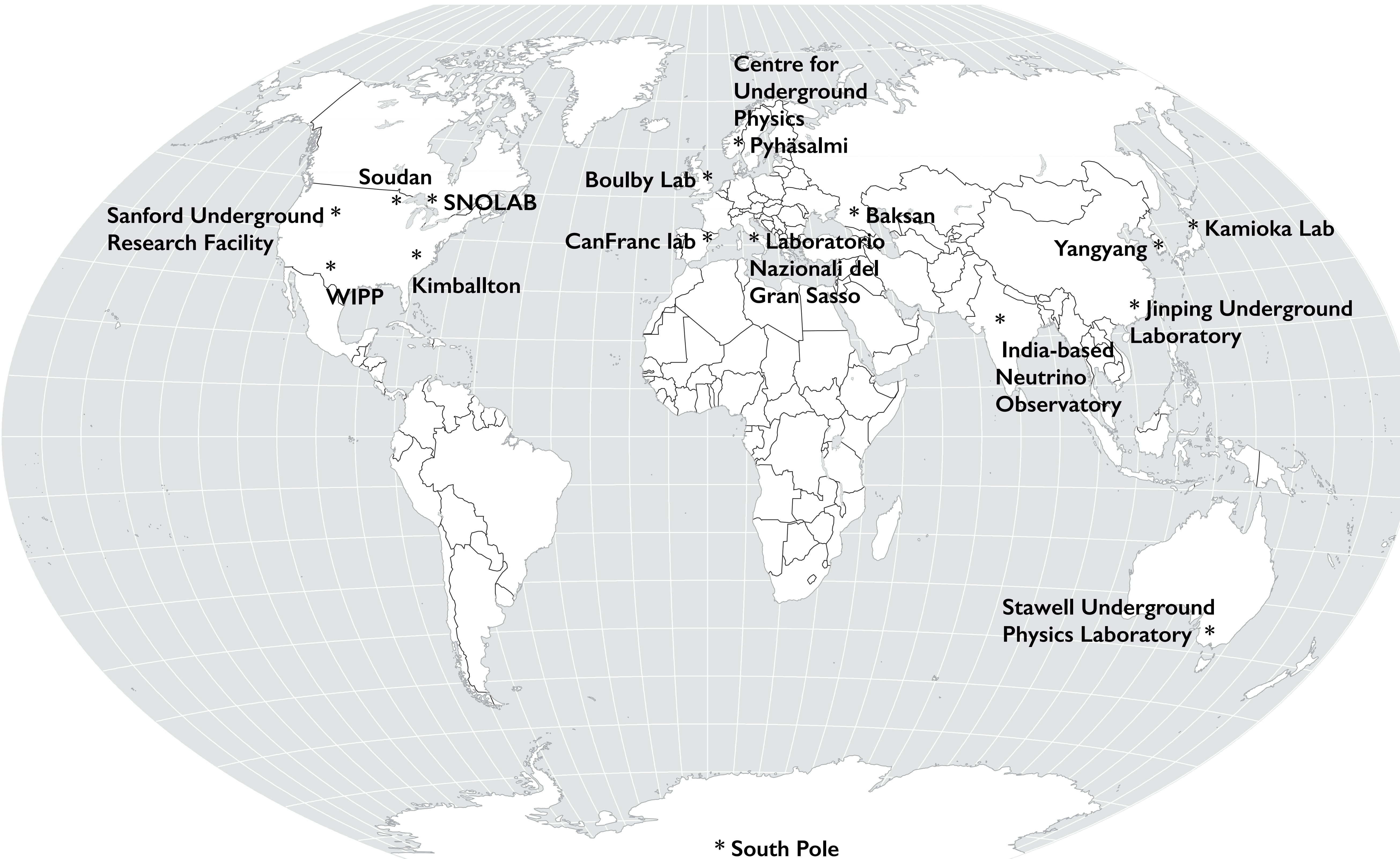

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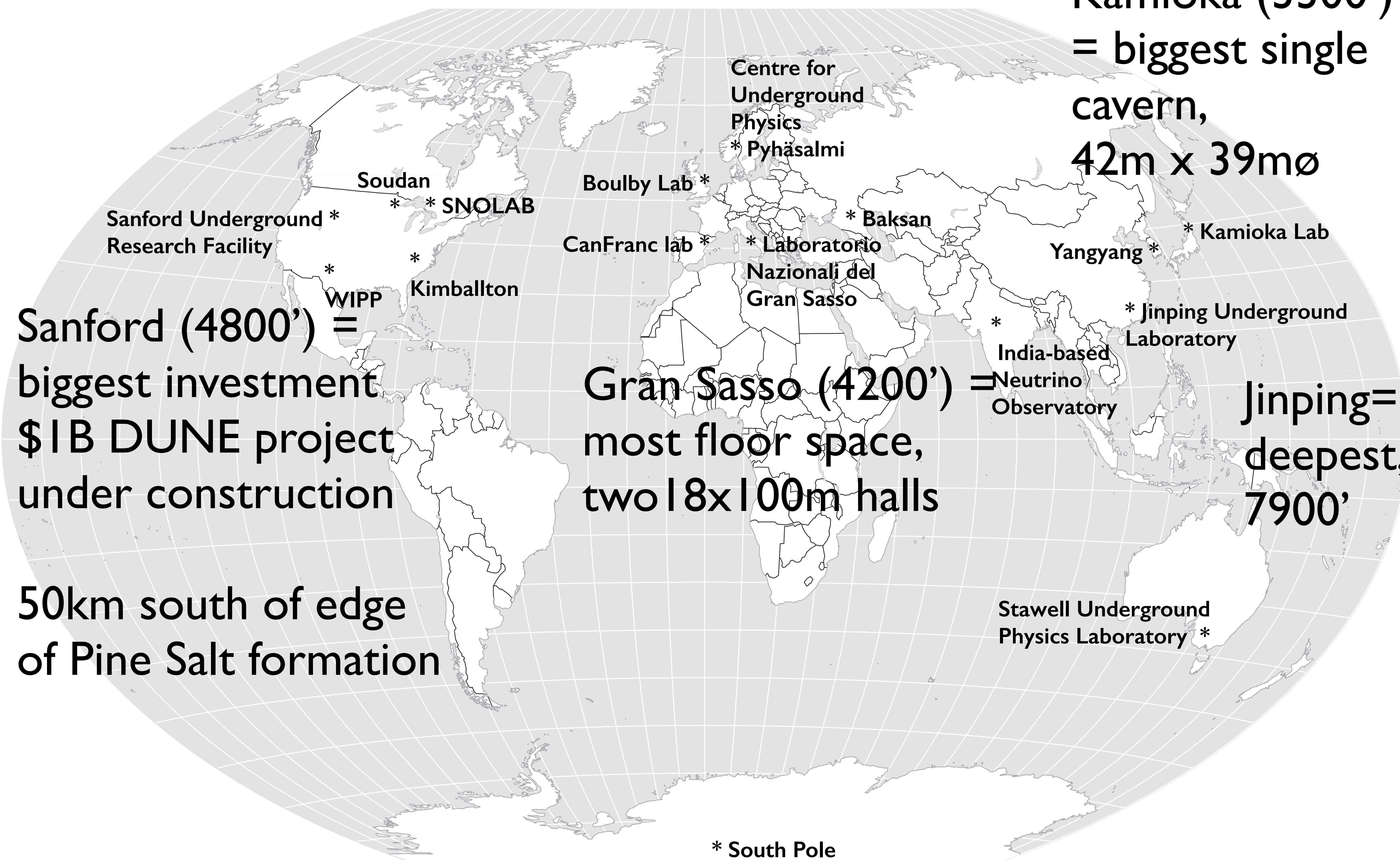


Kamioka (3300’)
= biggest single
cavern,
42m x 39mø

Sanford (4800’) =
biggest investment
$1B DUNE project
under construction

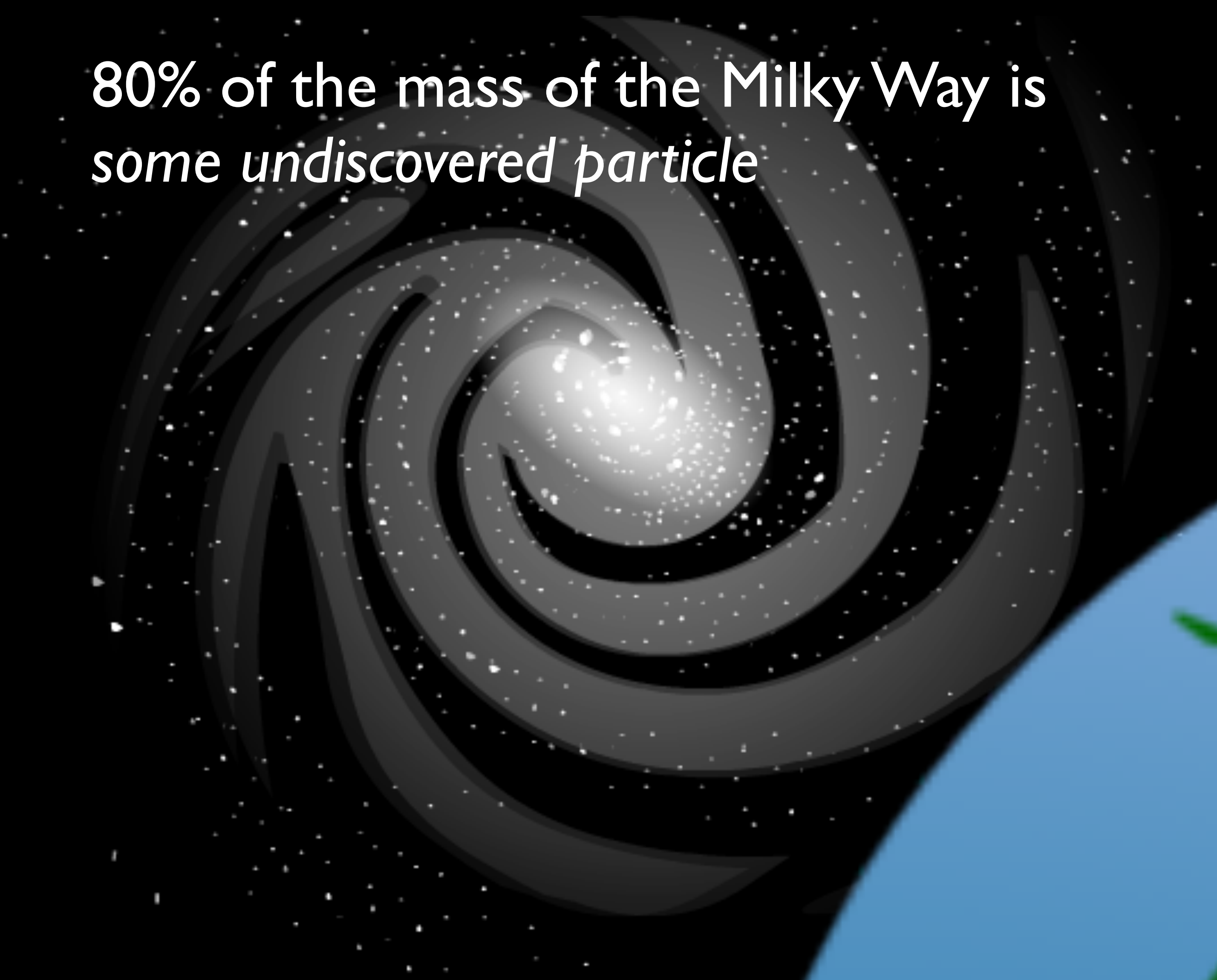
50km south of edge
of Pine Salt formation

Gran Sasso (4200’) =
most floor space,
two18x100m halls

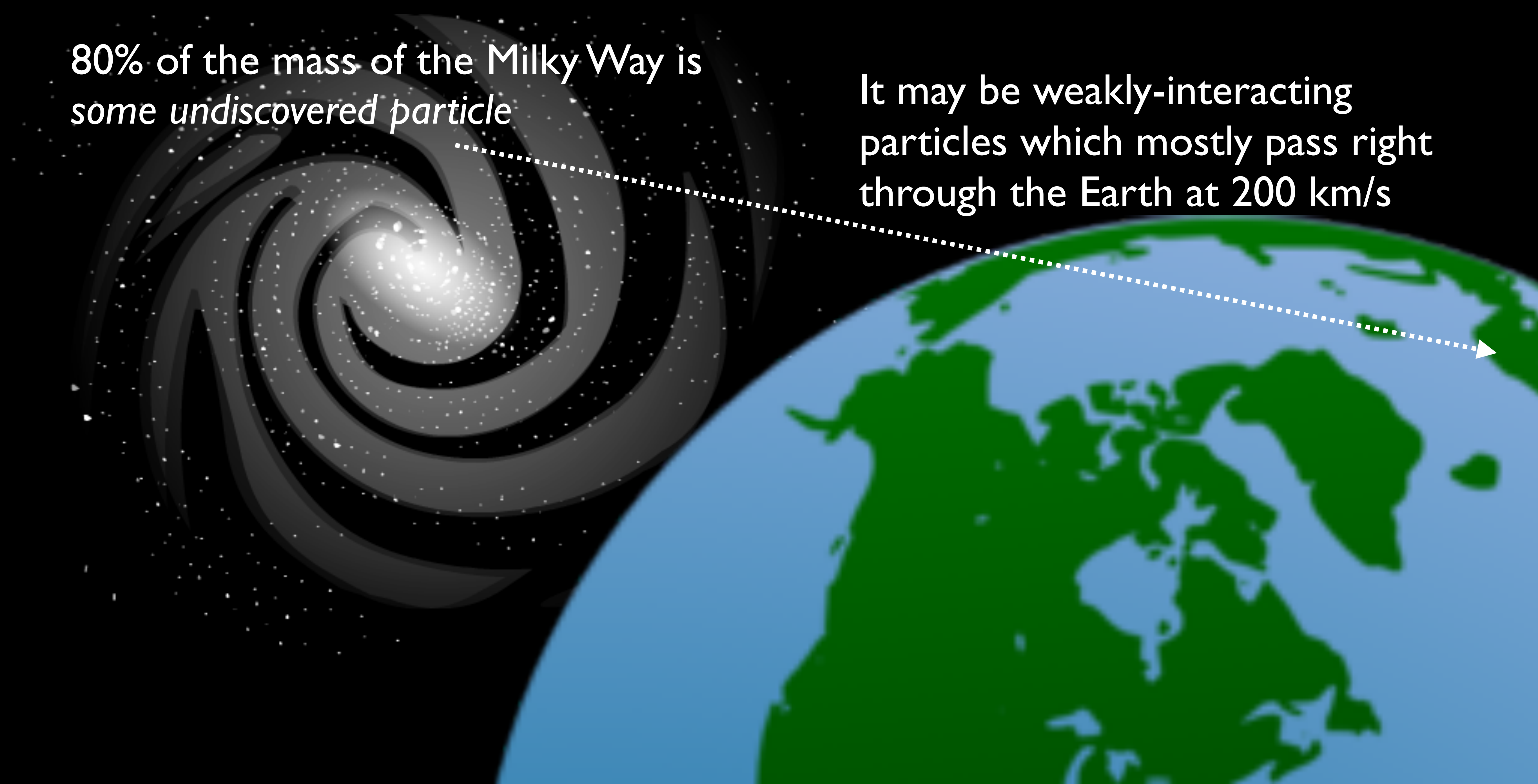
Jinping=
deepest,
7900’

Dark matter

80% of the mass of the Milky Way is
some undiscovered particle



Dark matter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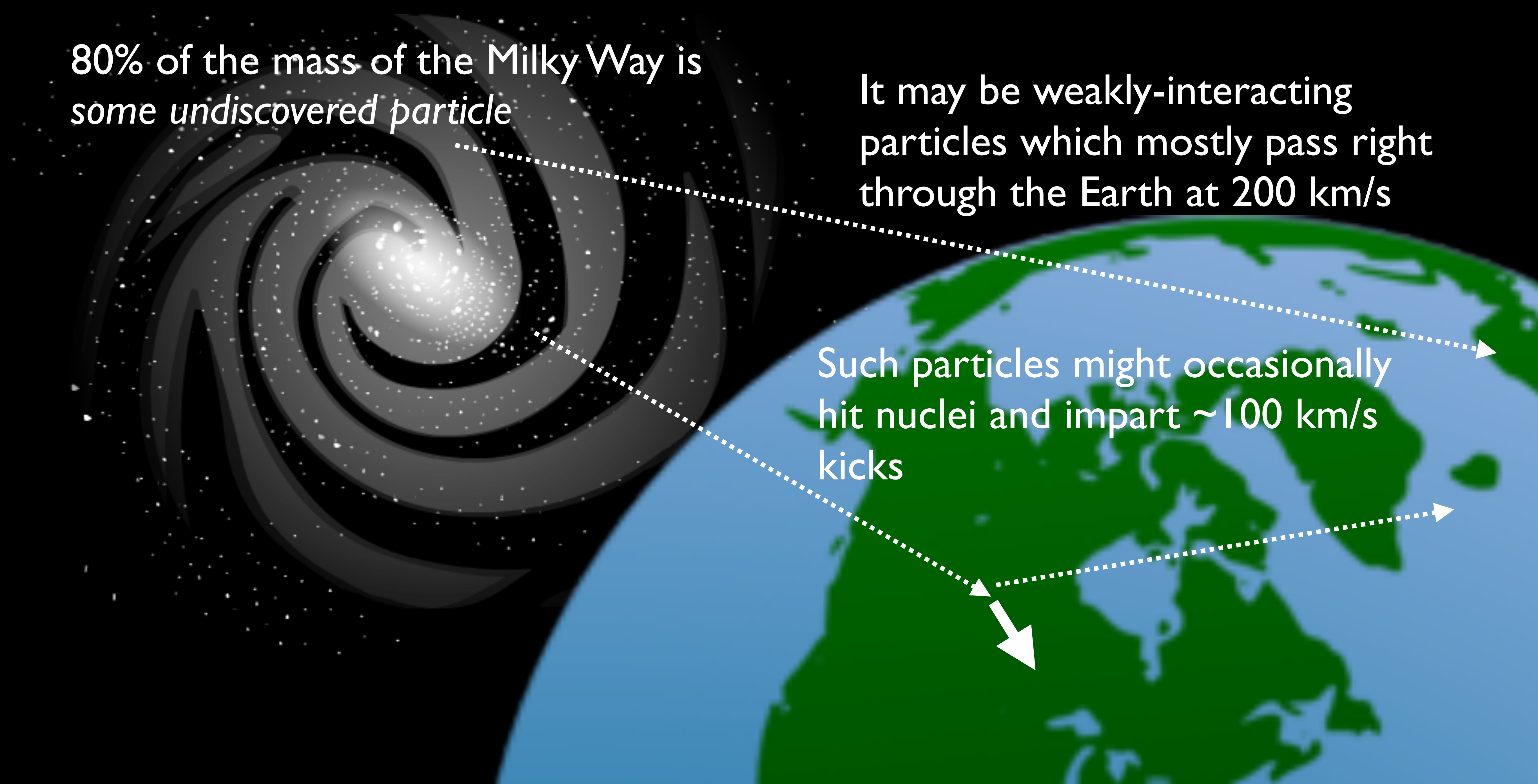
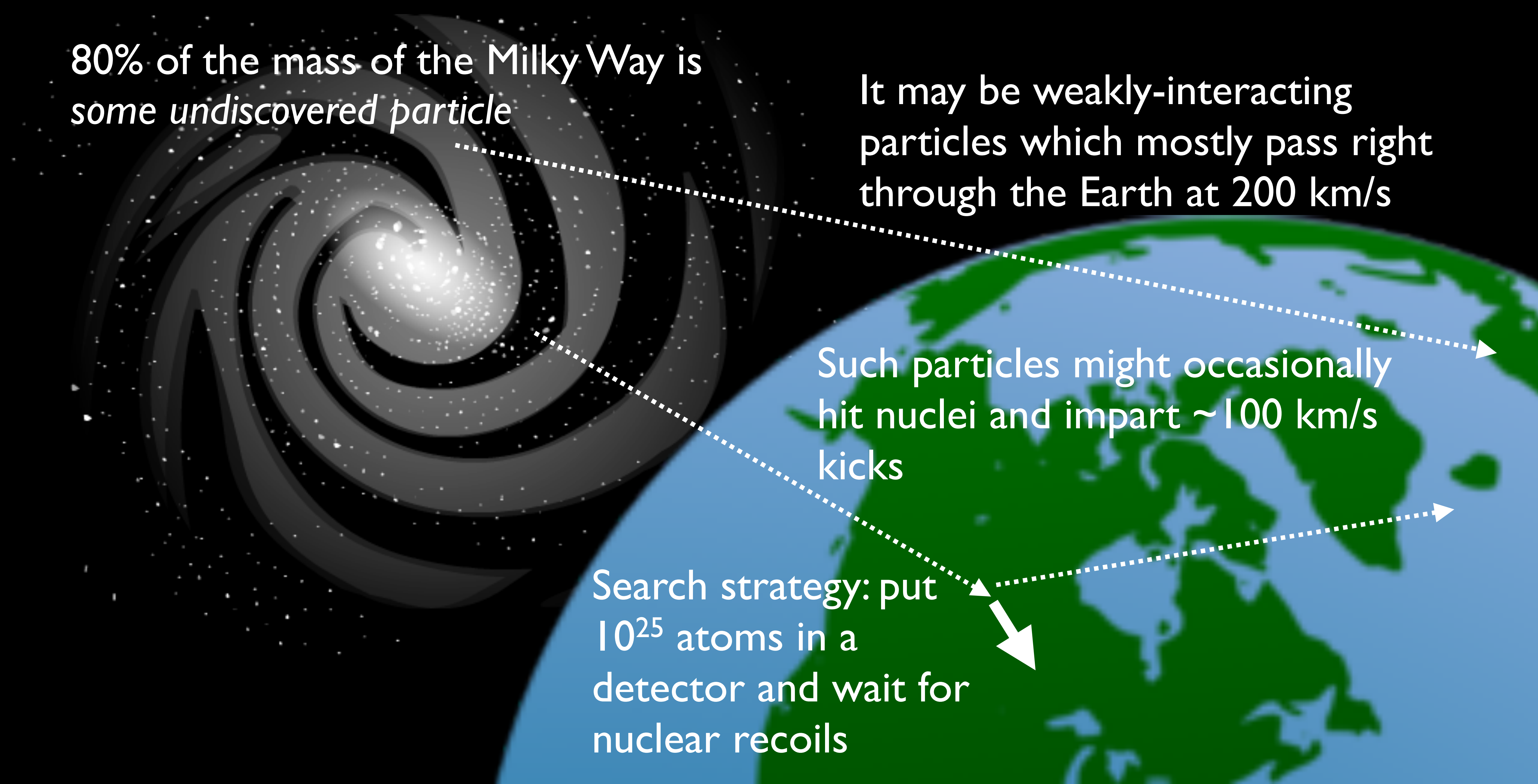


Dark matter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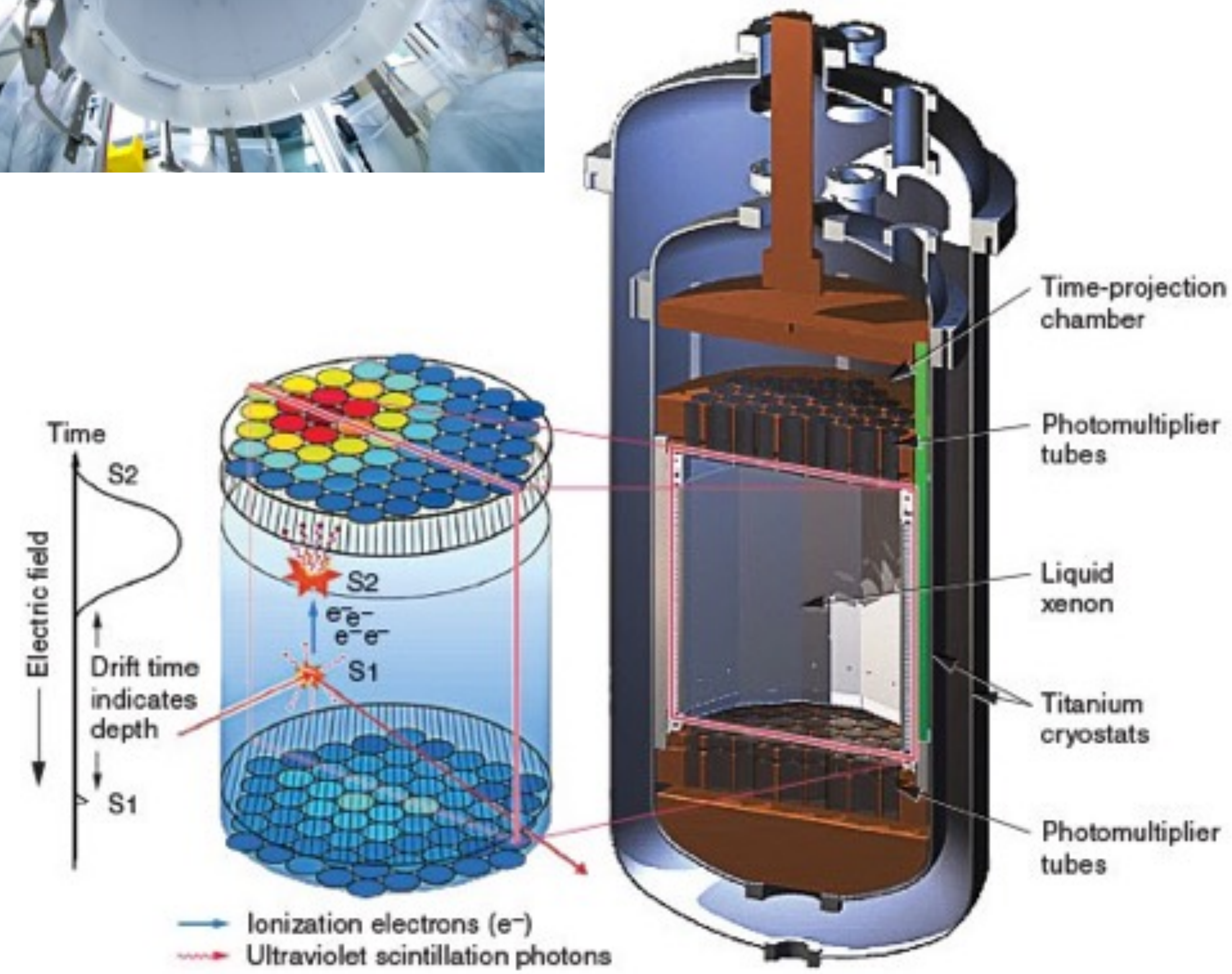
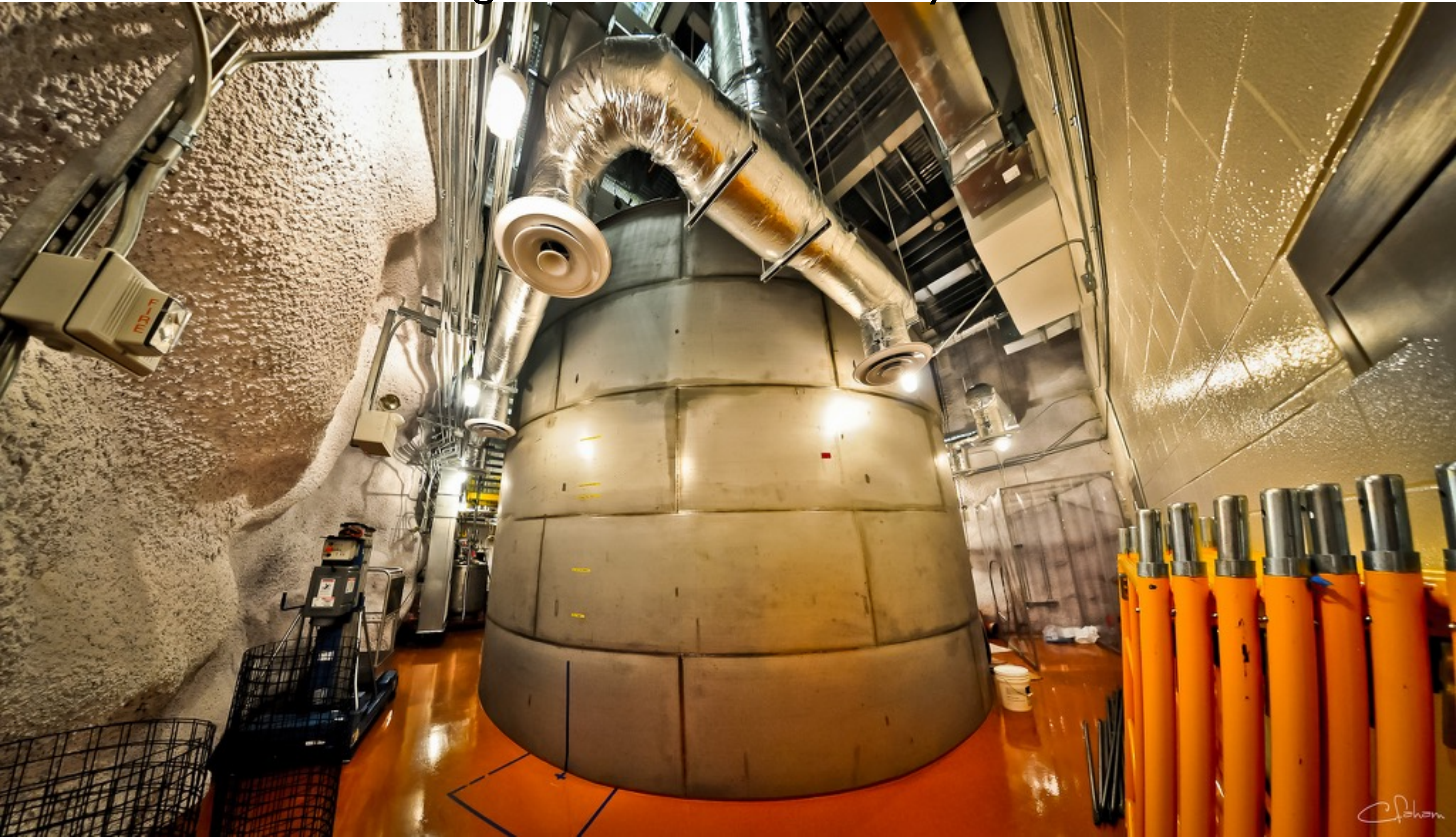
It may be weakly-interacting particles which mostly pass right through the Earth at 200 km/s
Such particles might occasionally hit nuclei and impart ~100 km/s kicks
Search strategy: put 10^{25} atoms in a detector and wait for nuclear recoils

LUX: a typical dark matter search experiment

- 370 kg liquid xenon
- A xenon nucleus, struck by a dark matter particle, would leave a trail of ~100 ionized atoms behind
- Made of copper, titanium, quartz, teflon to minimize radioactivity
- 85 day run in 2013 saw zero events; world-record sensitivity



Sanford Underground Research Facility, 4,850 foot level

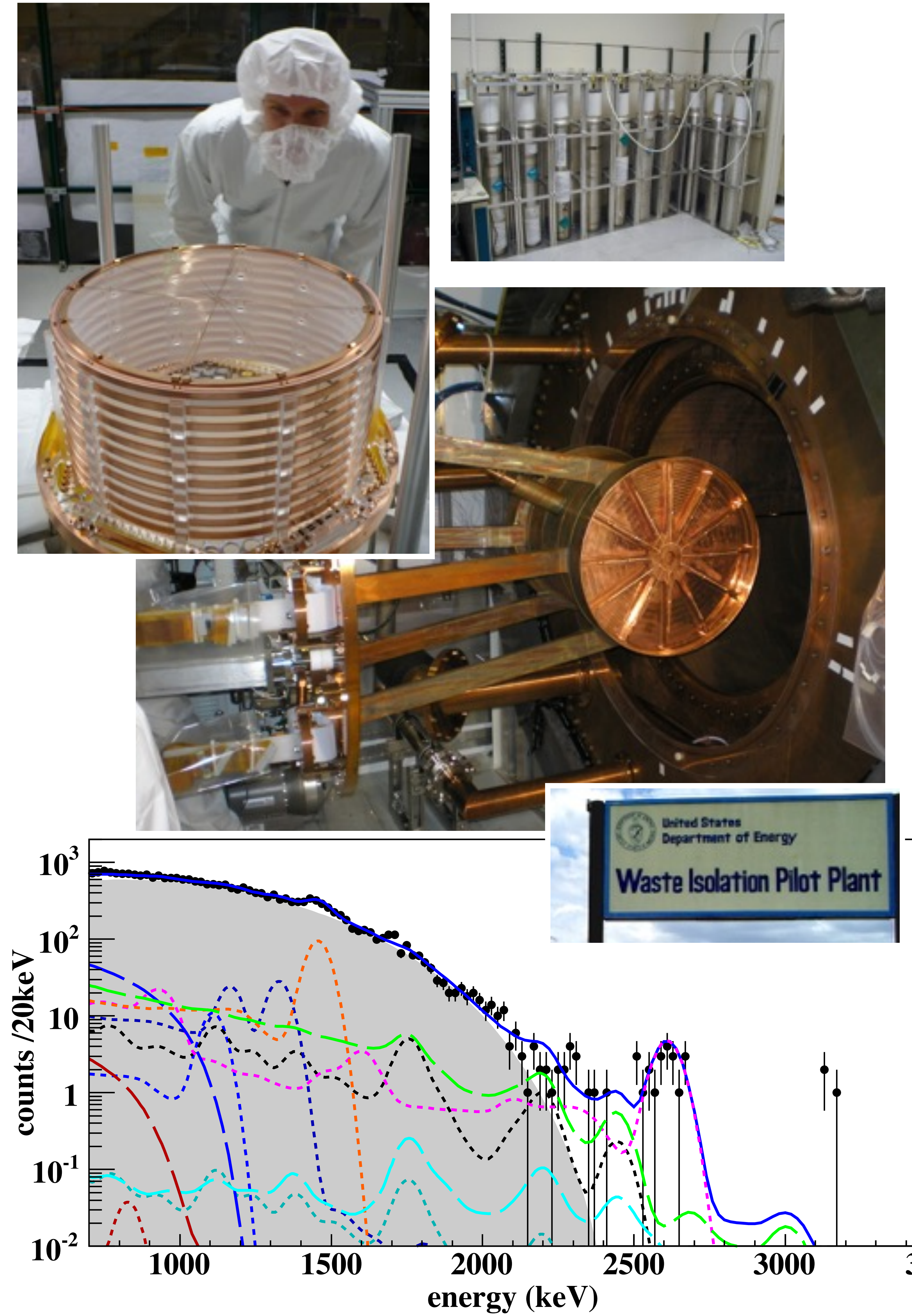


rock, shotcrete include lots of ^{40}K, ^{238}U, ^{232}Th

6m water tank to block neutron and gamma radiation

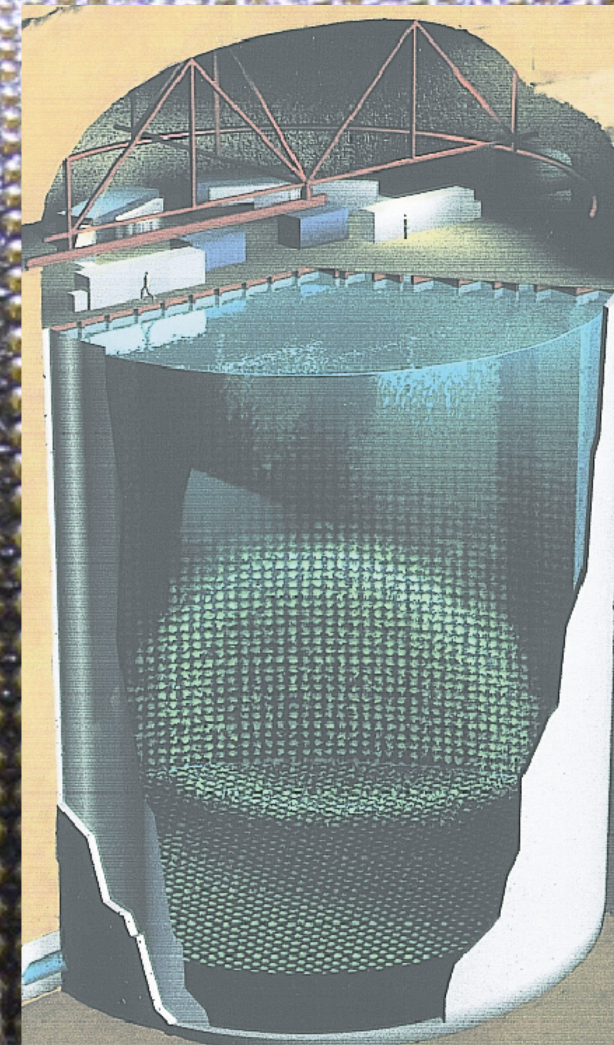
EXO: Searching for the rarest nuclear decays

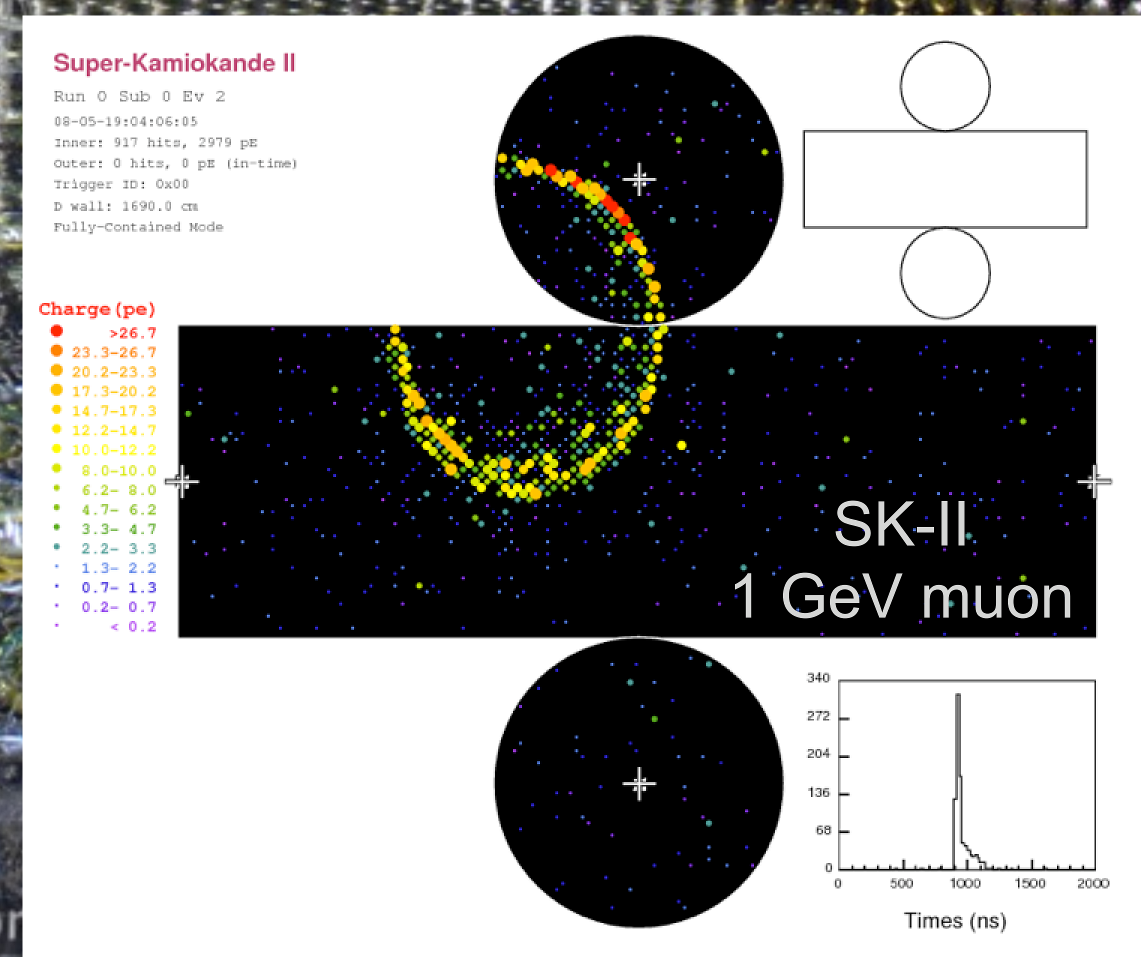
- 200 kg isotope-enriched liquid xenon-136
- "neutrinoless double beta decay" has not yet been observed: $^{136}Xe \rightarrow {}^{136}Ba^{++} + 2e^{-}$
- Easily mistaken for gamma ray
- Huge effort to minimize radioactive materials, maximize shielding … but that's hard to do in a cryostat.

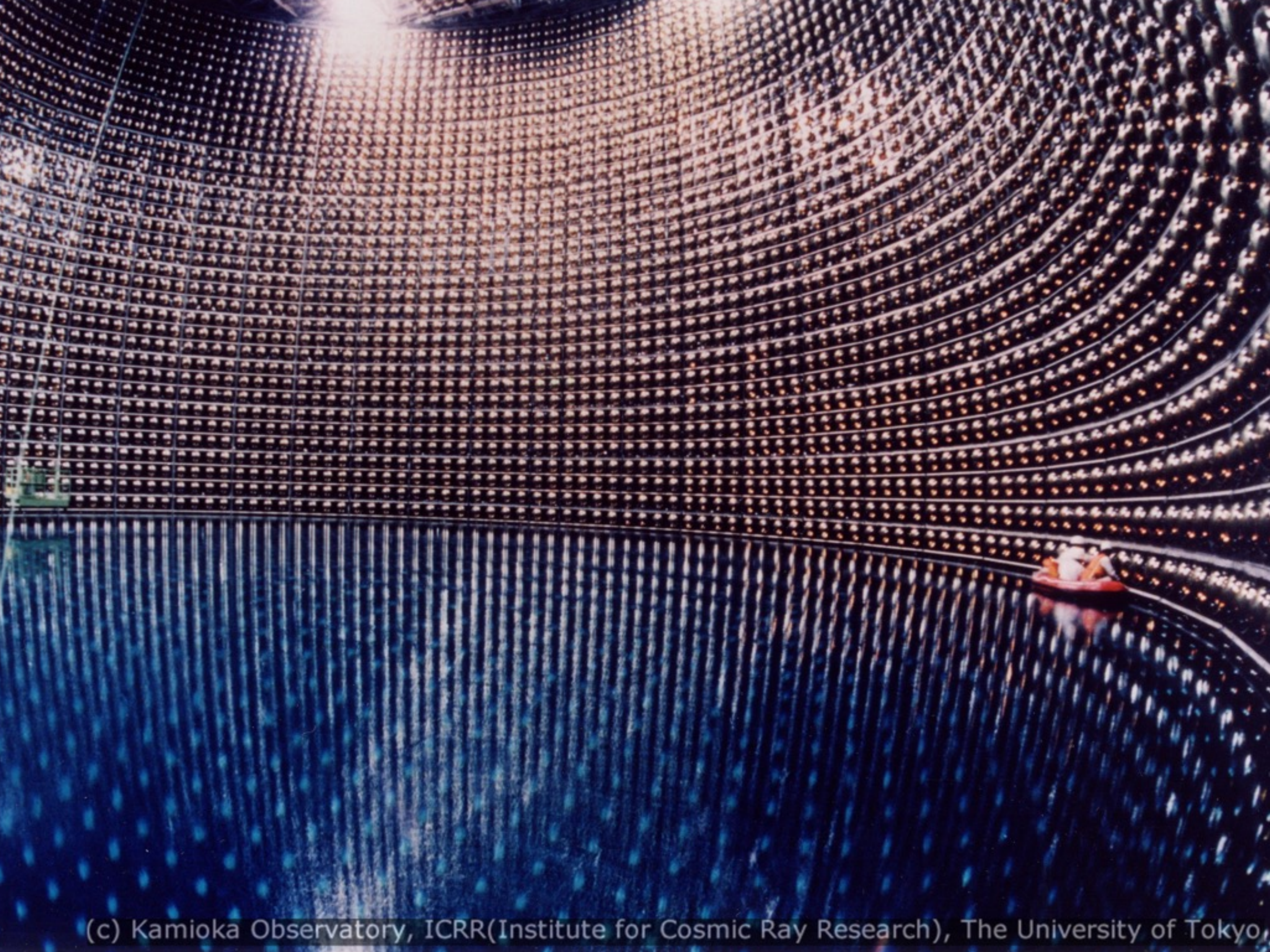


Super-Kamiokande: a large neutrino experiment

- 50 kT water tank 39ø x 42m
- Neutrino from cosmic source collides with water and become a muon; muon track emits cone of light
- 11,000 photomultiplier tubes detect light
- Only ~10 a day
- Neutrino arrival direction and flavor counts revealed new physics (oscillations)







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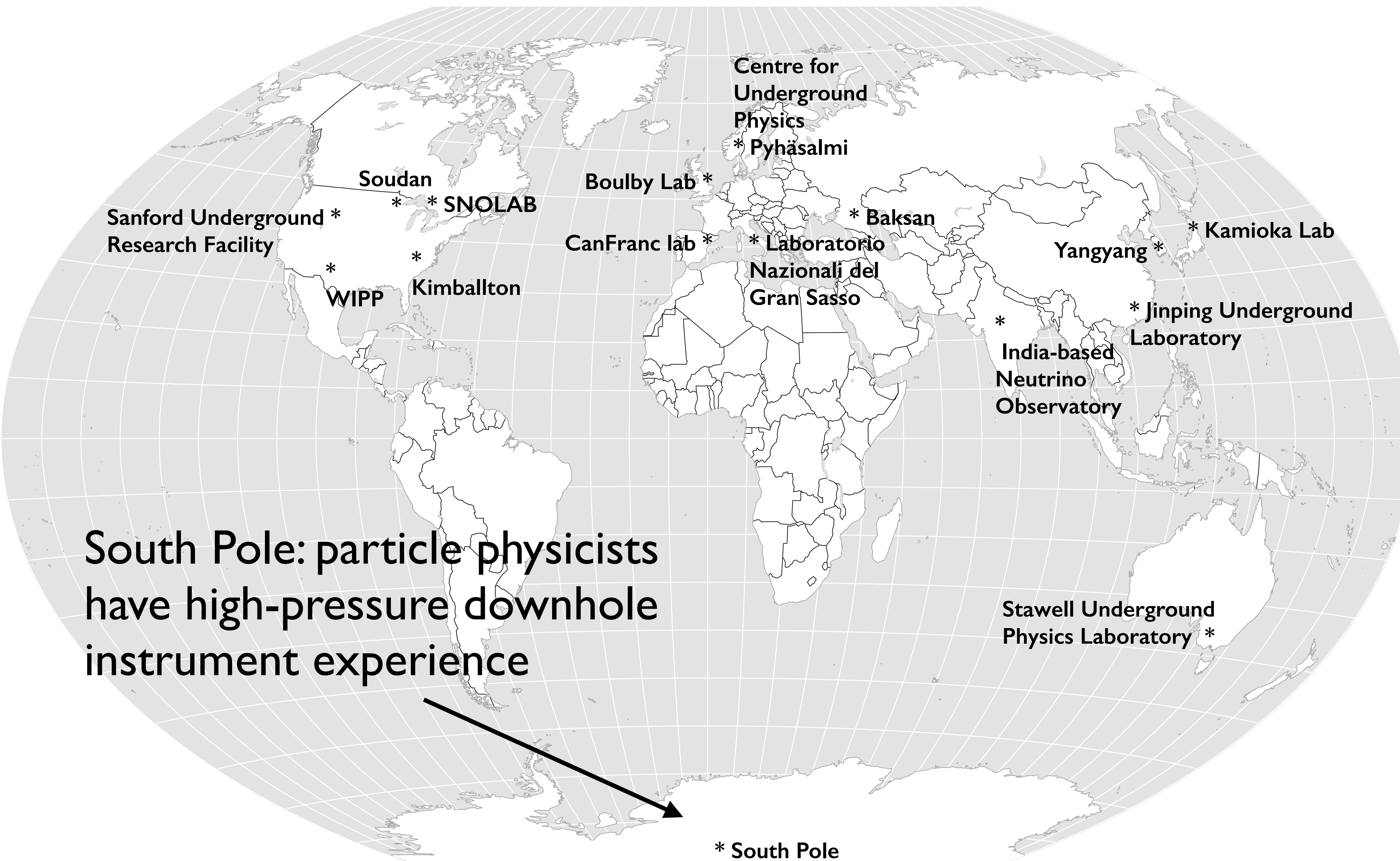
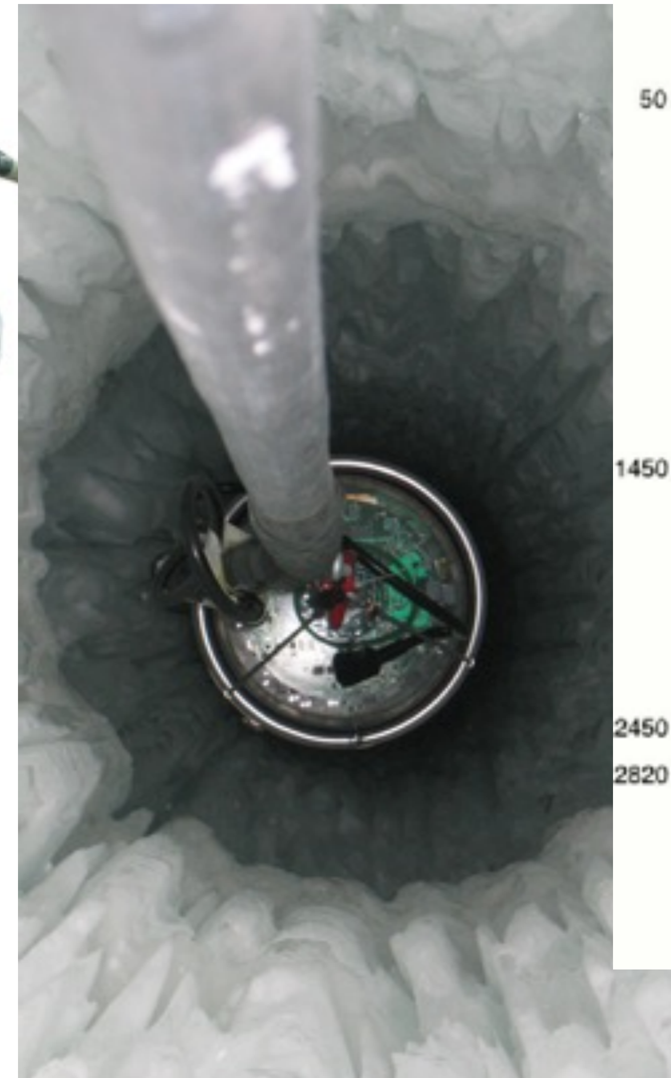
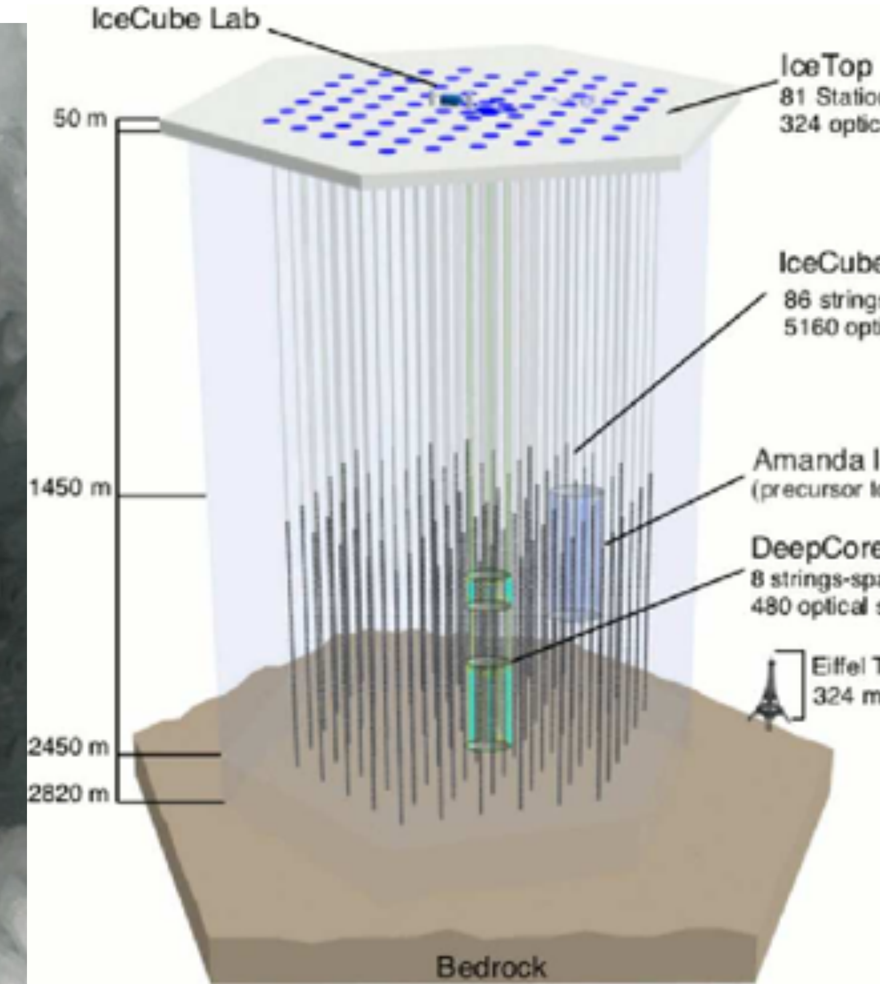
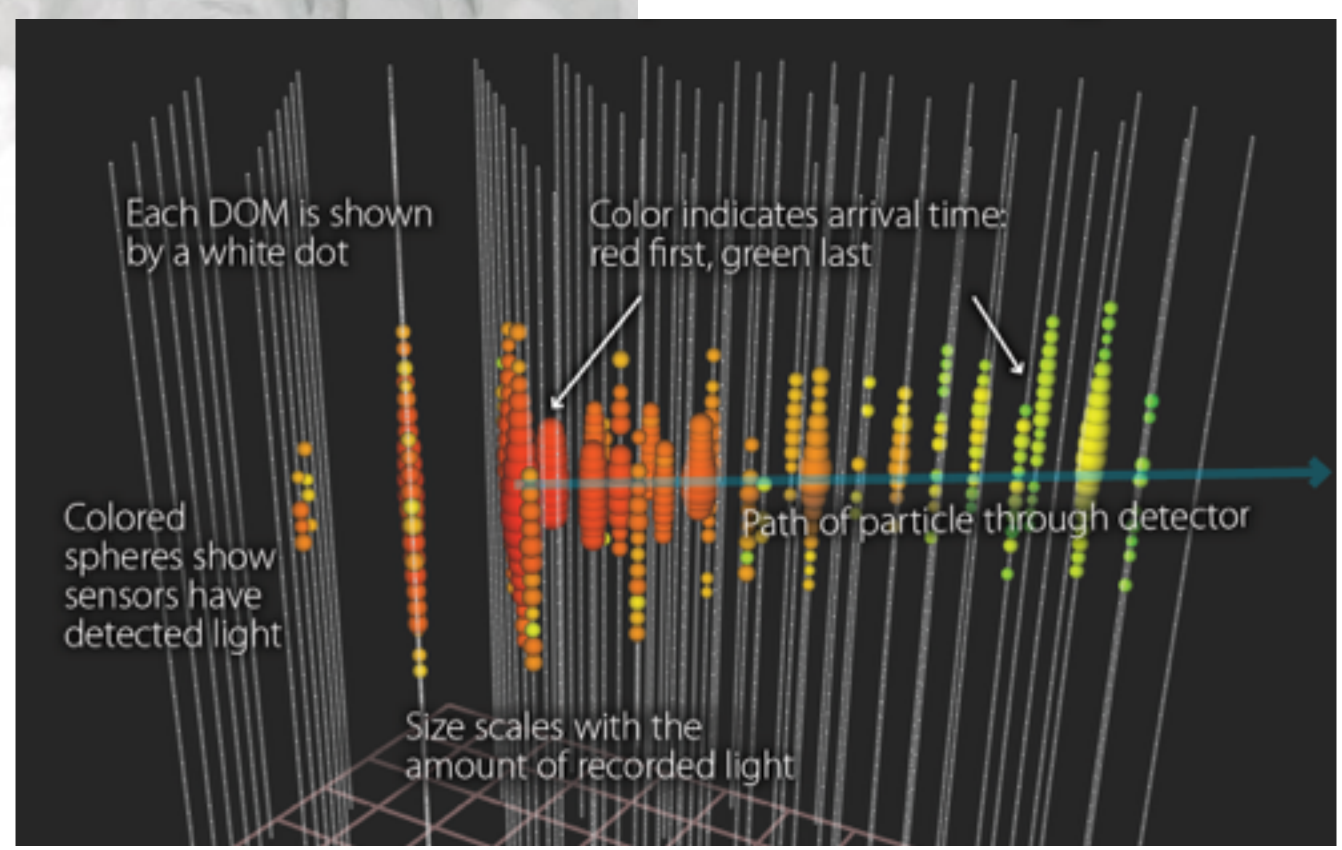


IceCube

- Antarctic ice cap is incredibly pure, transparent ice. Turn 1km^3 block into a detector
- Custom hot-water drill bores holes to 2450m
- "String": 60 photosensors in Benthos pressure vessels on a cable
- ~ $300M project cost
- Science goal: neutrinos from distant galaxies







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Why I'm interested in salt caverns

Affordable space:

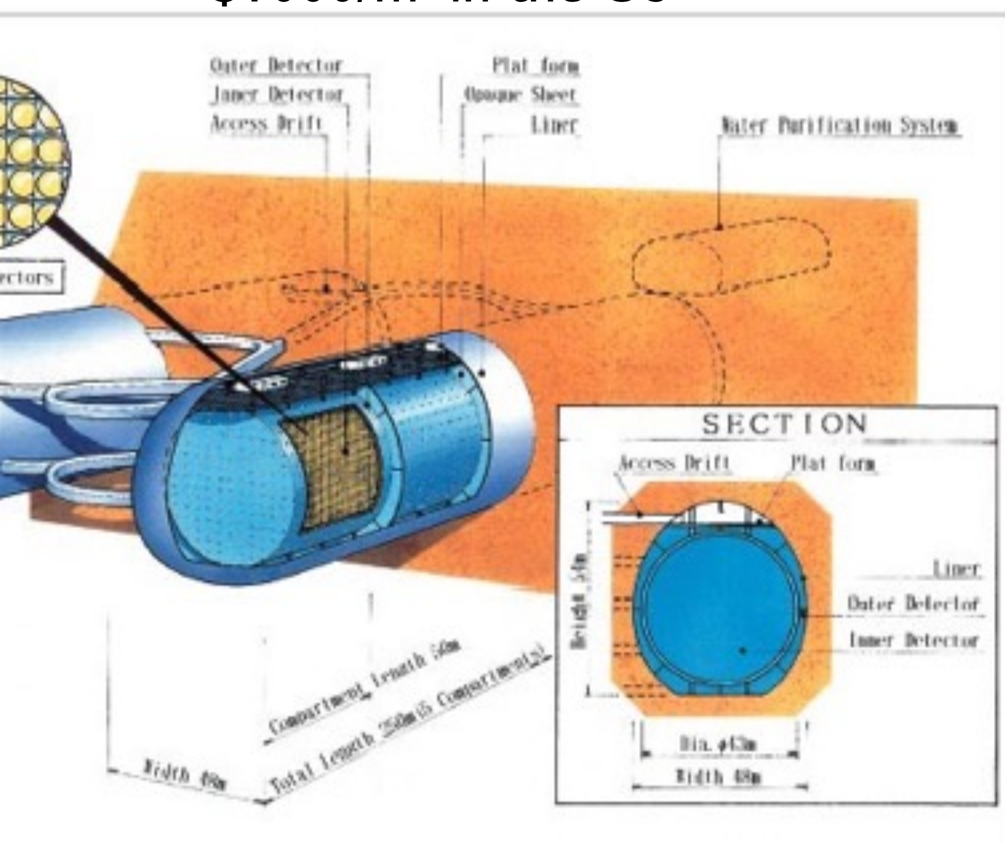
1) Small experiments want thicker water shielding
2) Some physics goals demand megaton targets
3) Mine development costs \$1000/m^3 in the US

High pressure:

1) High-pressure xenon is often a better ionization medium than liquid xenon
2) Pressure-vessel engineering is too hard (mass, cost, radioactivity)

Access to flammable gases:

1) CH_4 and H_2 targets for antineutrino experiments
2) $\bar{\nu} + H \rightarrow e^+ + n$
3) Prohibitive safety issues in conventional labs



\$900M Hyper-Kamiokande proposal
500 kT water in two large halls

NEXT-100: 1000 kg steel vessel to hold 100 kg Xe at 15 bar

BEBC, the last (?) large H_2-based experiment, decommissioned 1984

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3) What kind of detector technologies could we install in a salt cavern?

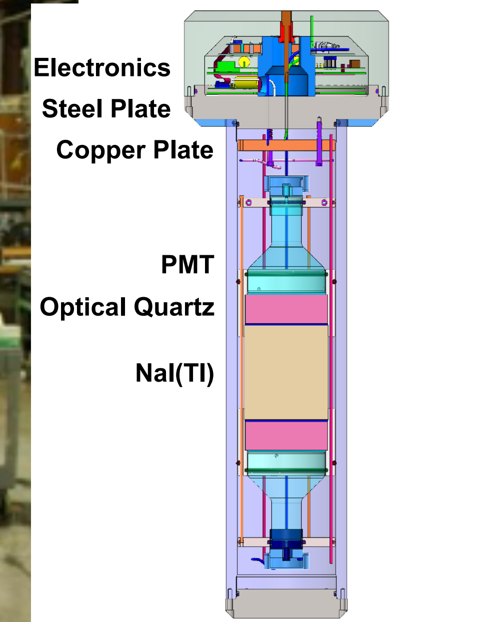
What kind of detector technologies could we install in a salt cavern?

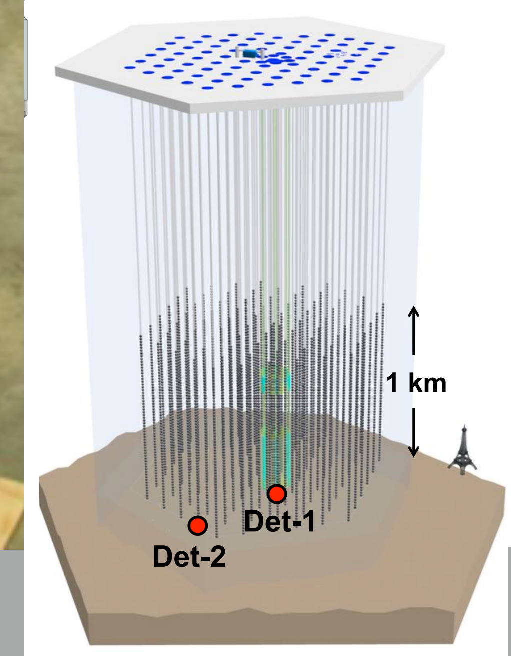
- We have brainstorming-level ideas, not real engineering designs
- Some of these ideas are probably unrealistic
- That's part of why I am here

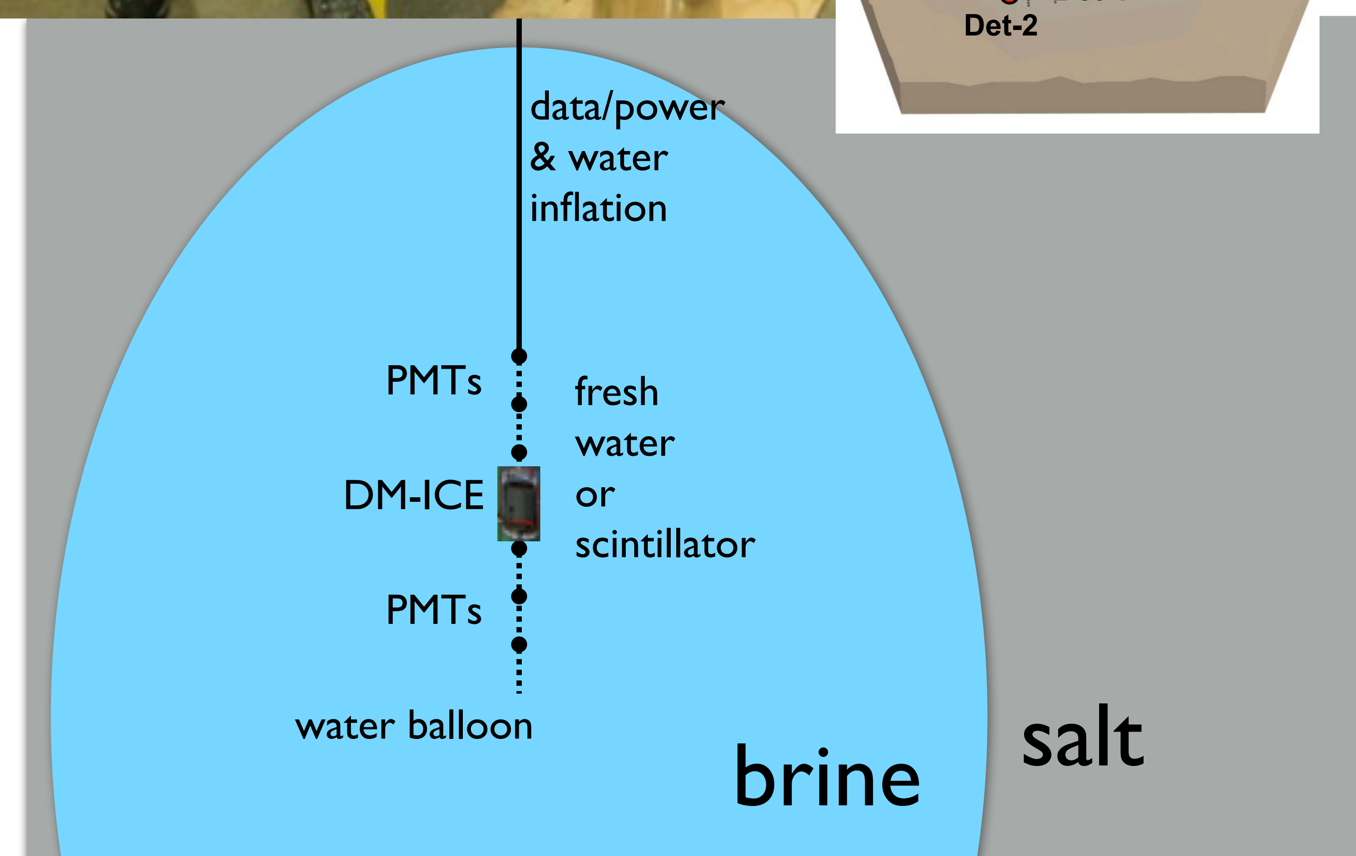
Simple: DM-ICE

- 17kg scintillating crystal, sensitive to dark matter
- Pressure-hardened! Two units already using deep polar ice as low-background environment
- Salt cavern with some muon veto = lower background, easier logistics
- Existing hardware fits down 14" borehole
- Design studies for 250kg upgrade with 27" bore

Question #1: what constrains bore diameters?







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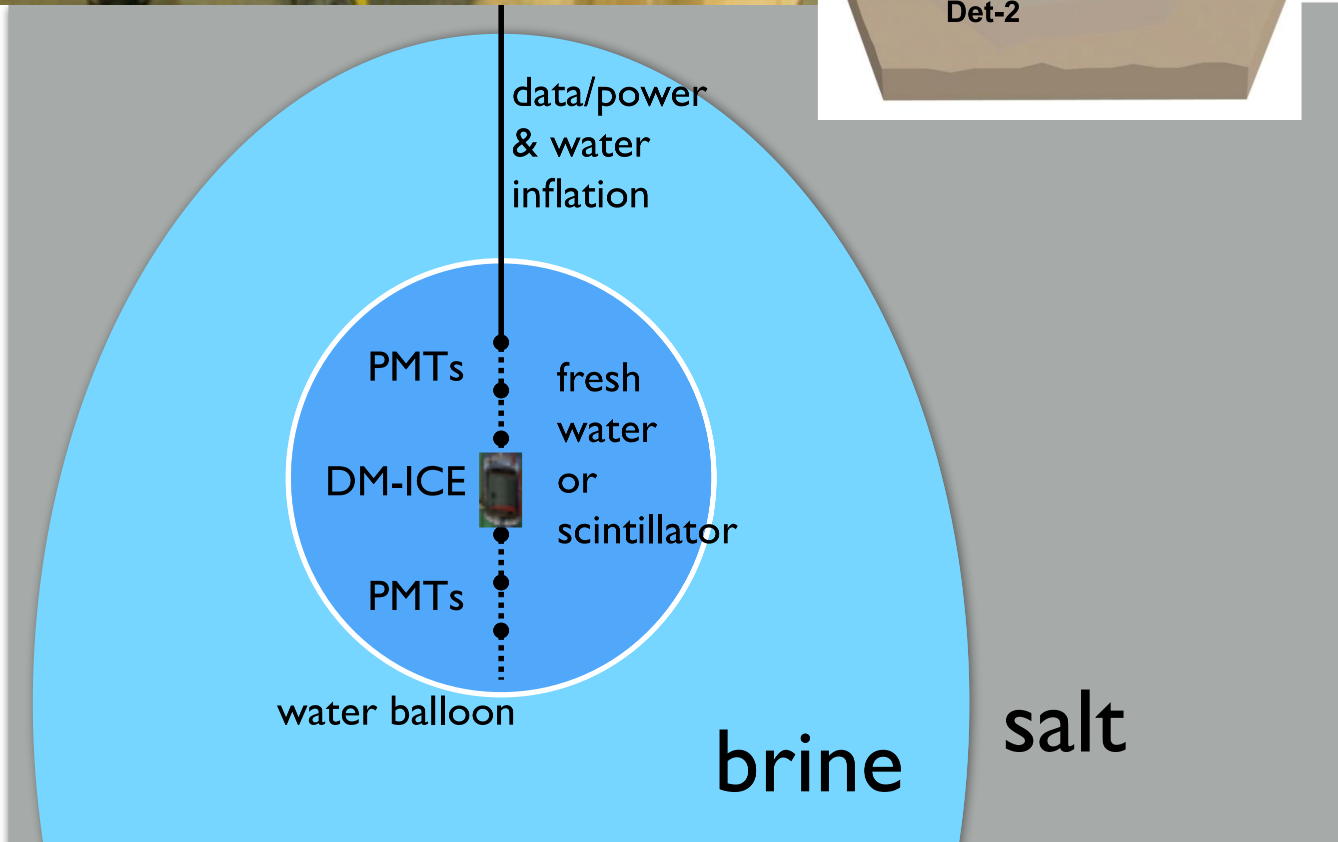
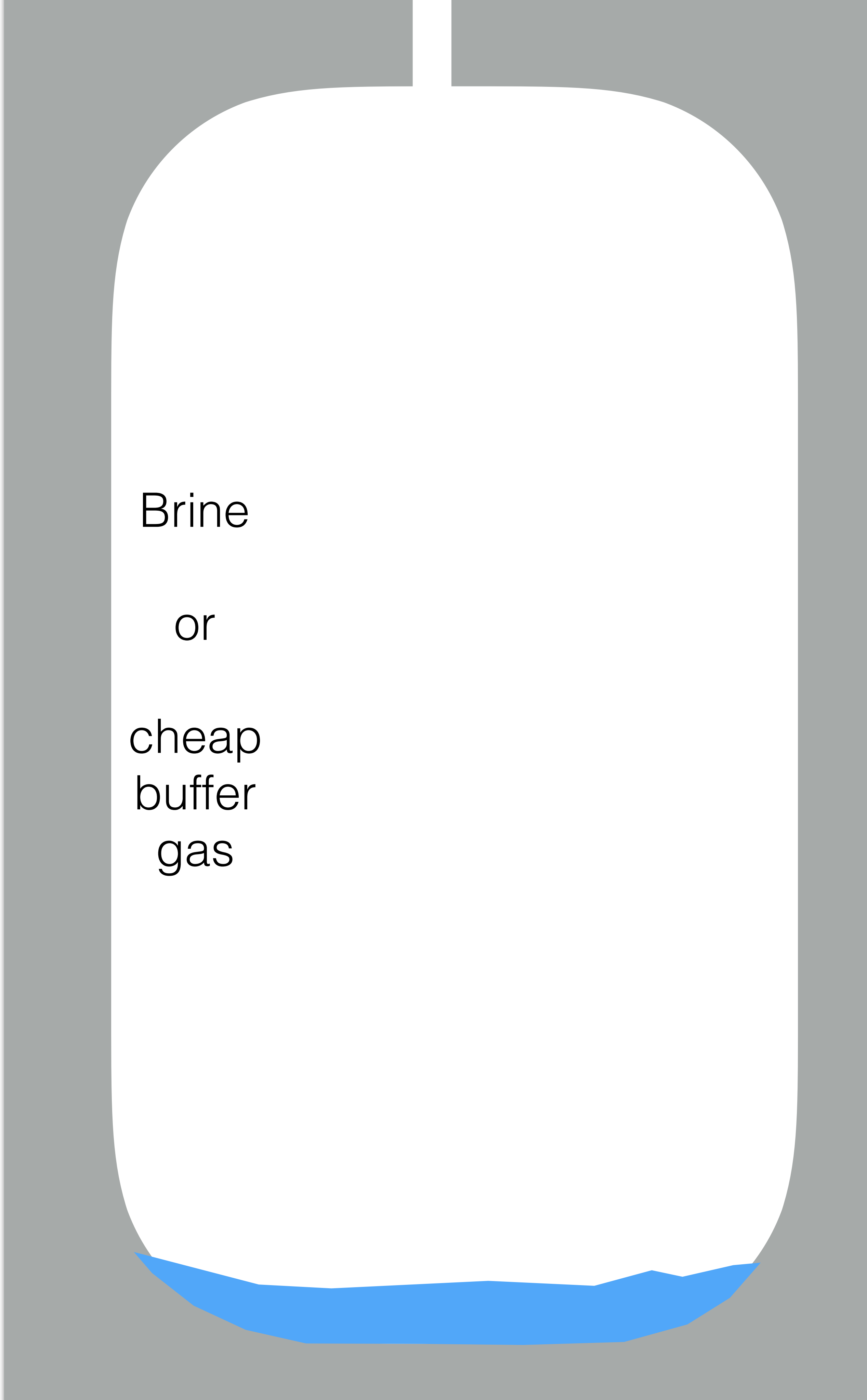


Medium complexity: inflatable drift chamber

- How do we use cavern volume at diameters larger than the borehole?
- "inflatable" drift chamber
  - cylindrical balloon w/ conductive surface
  - (complex) anode cylinder in center at +100 kV
  - Particle events in gas lead to signals on anode
- $R_{cathode} < 20x\ R_{anode}$
- Brine fill: hydrostatic gradient along balloon
- Gas fill: more complicated string, shoe, plug? Rockfall?



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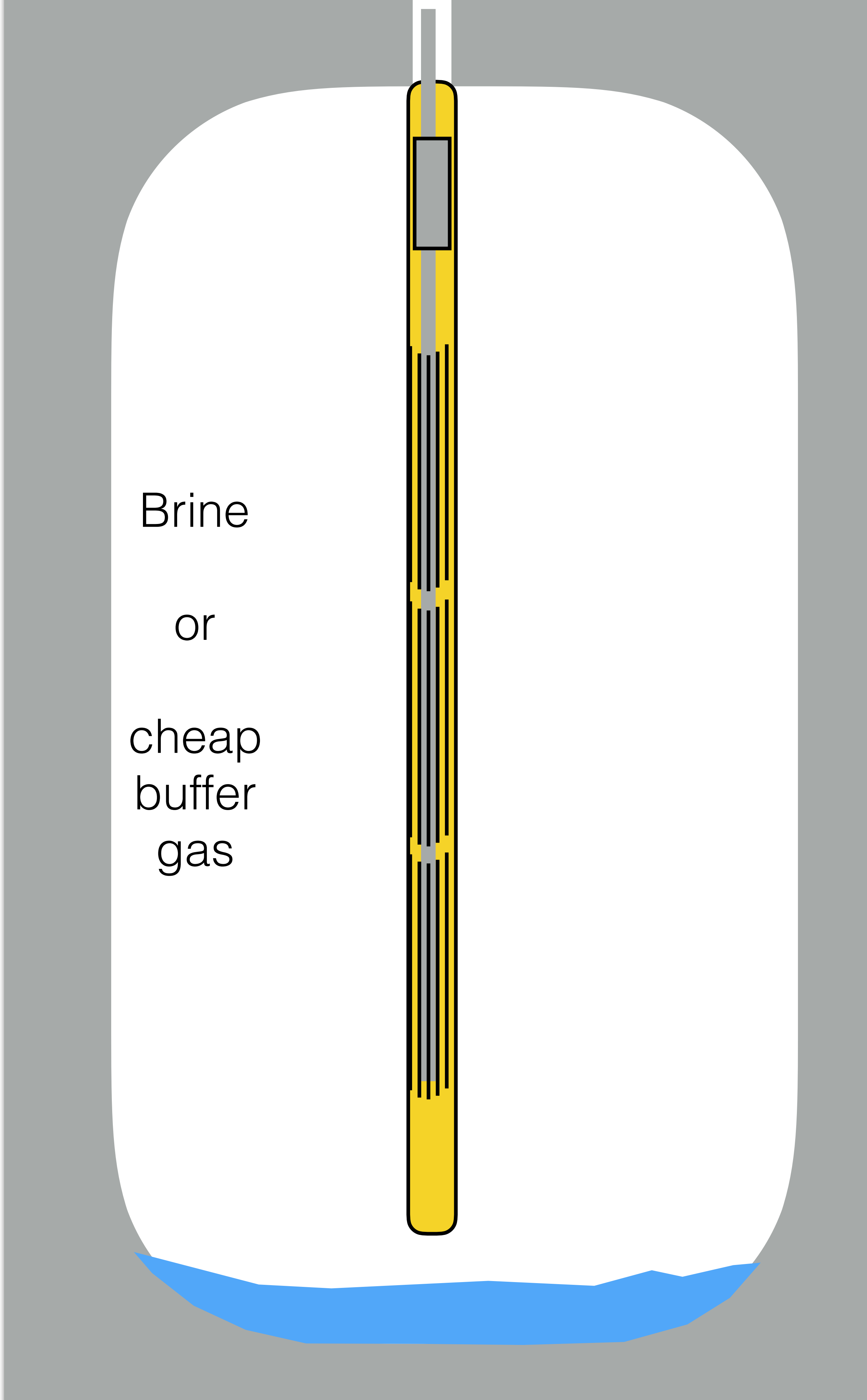

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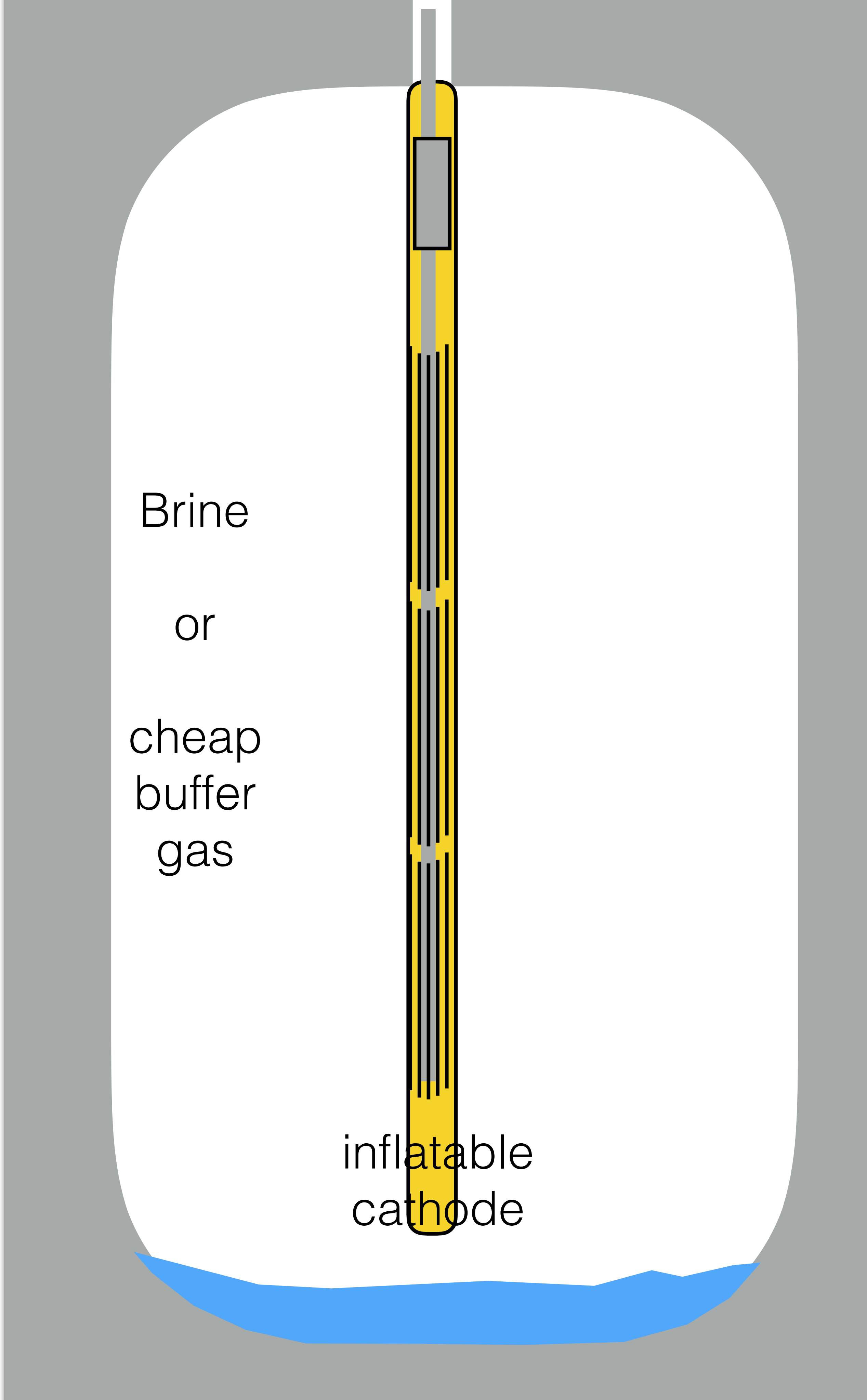

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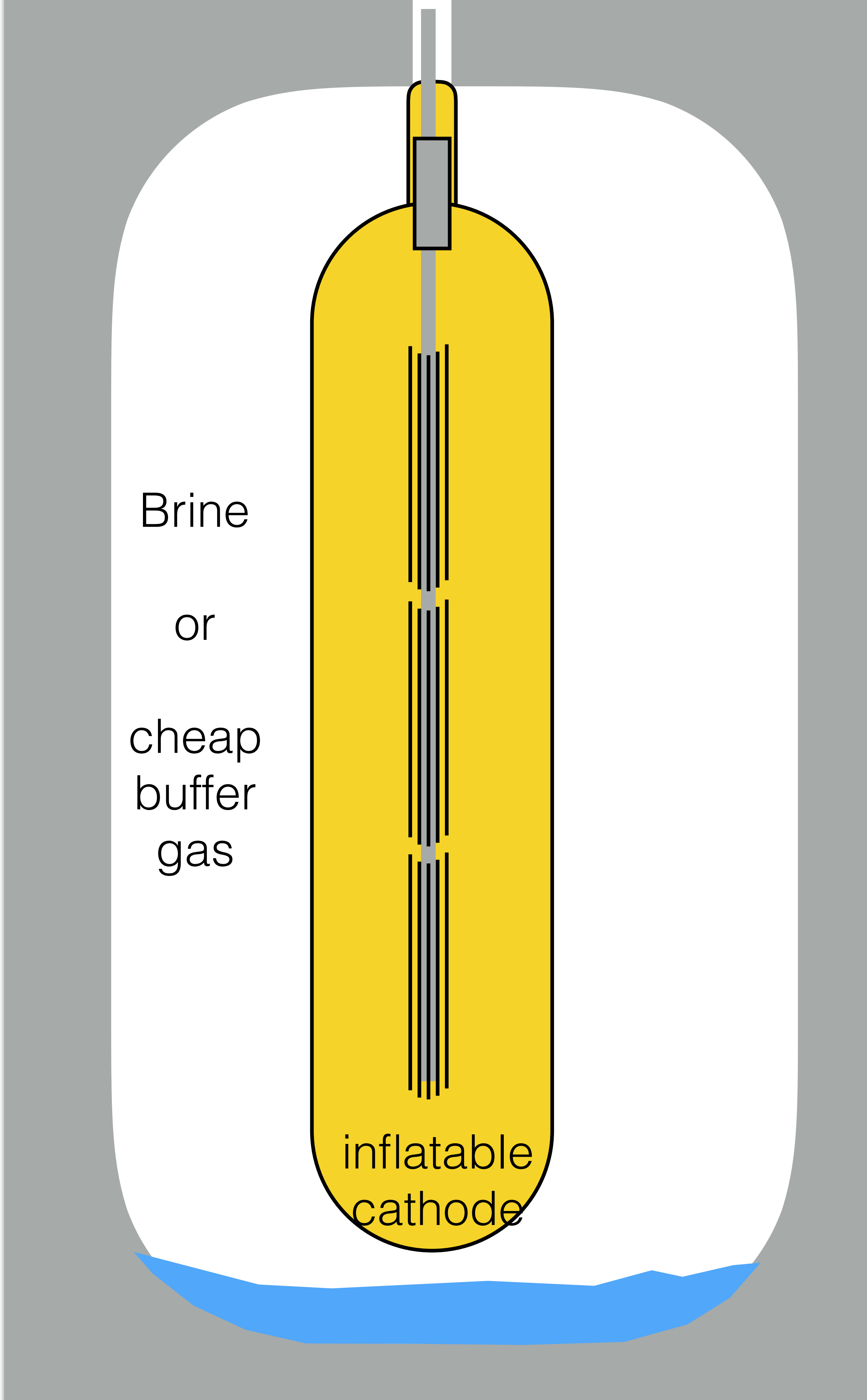

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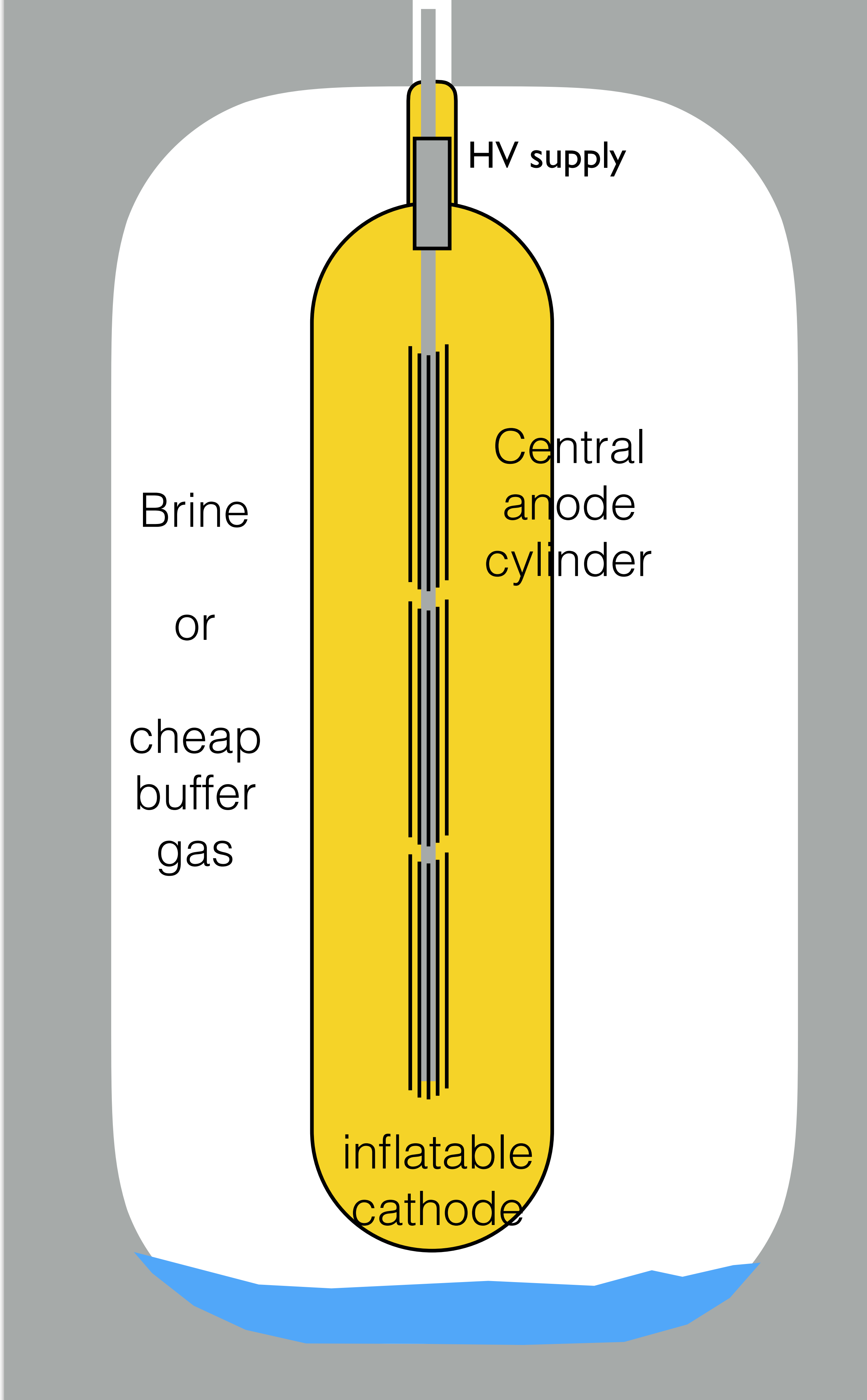

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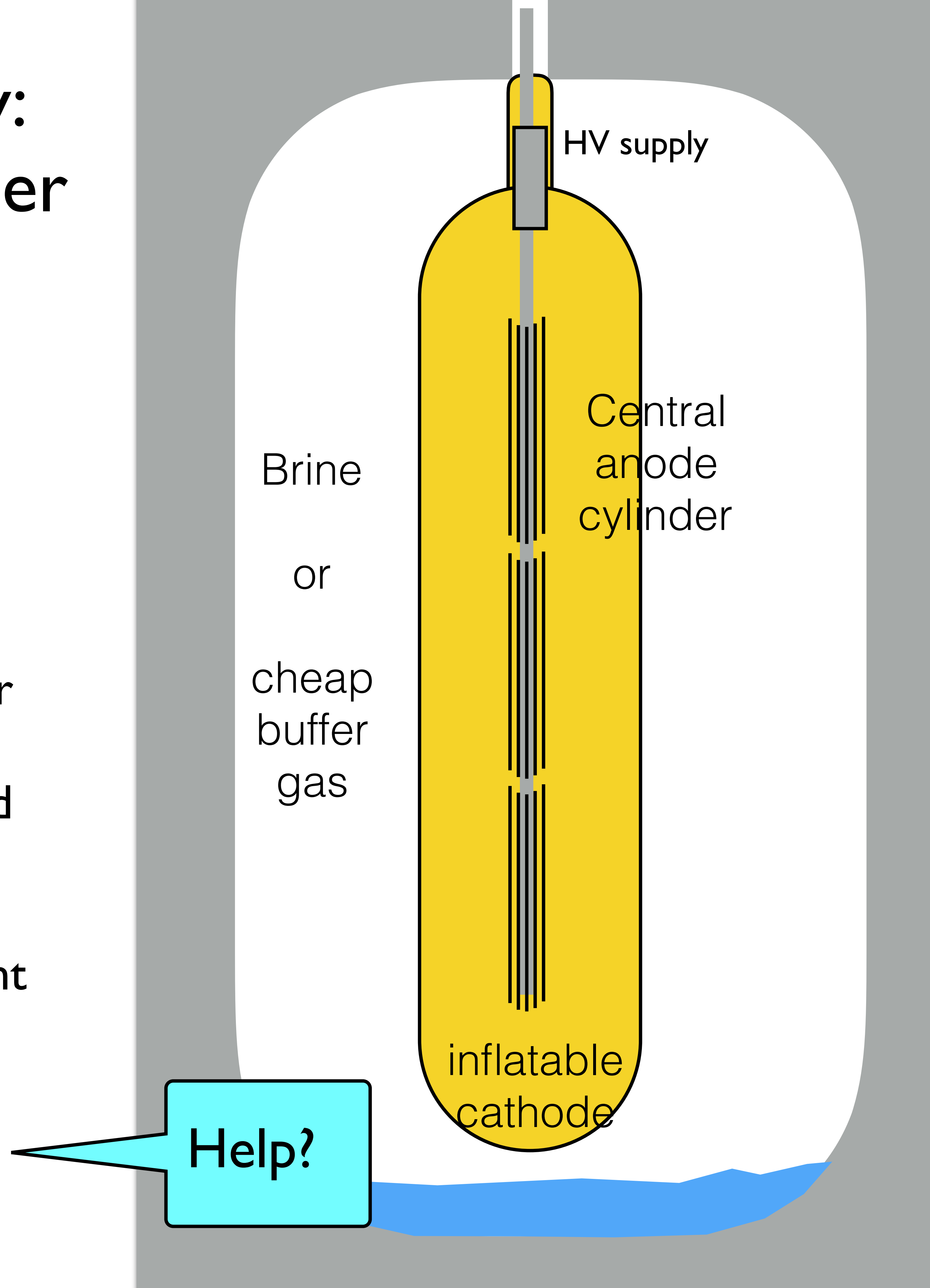
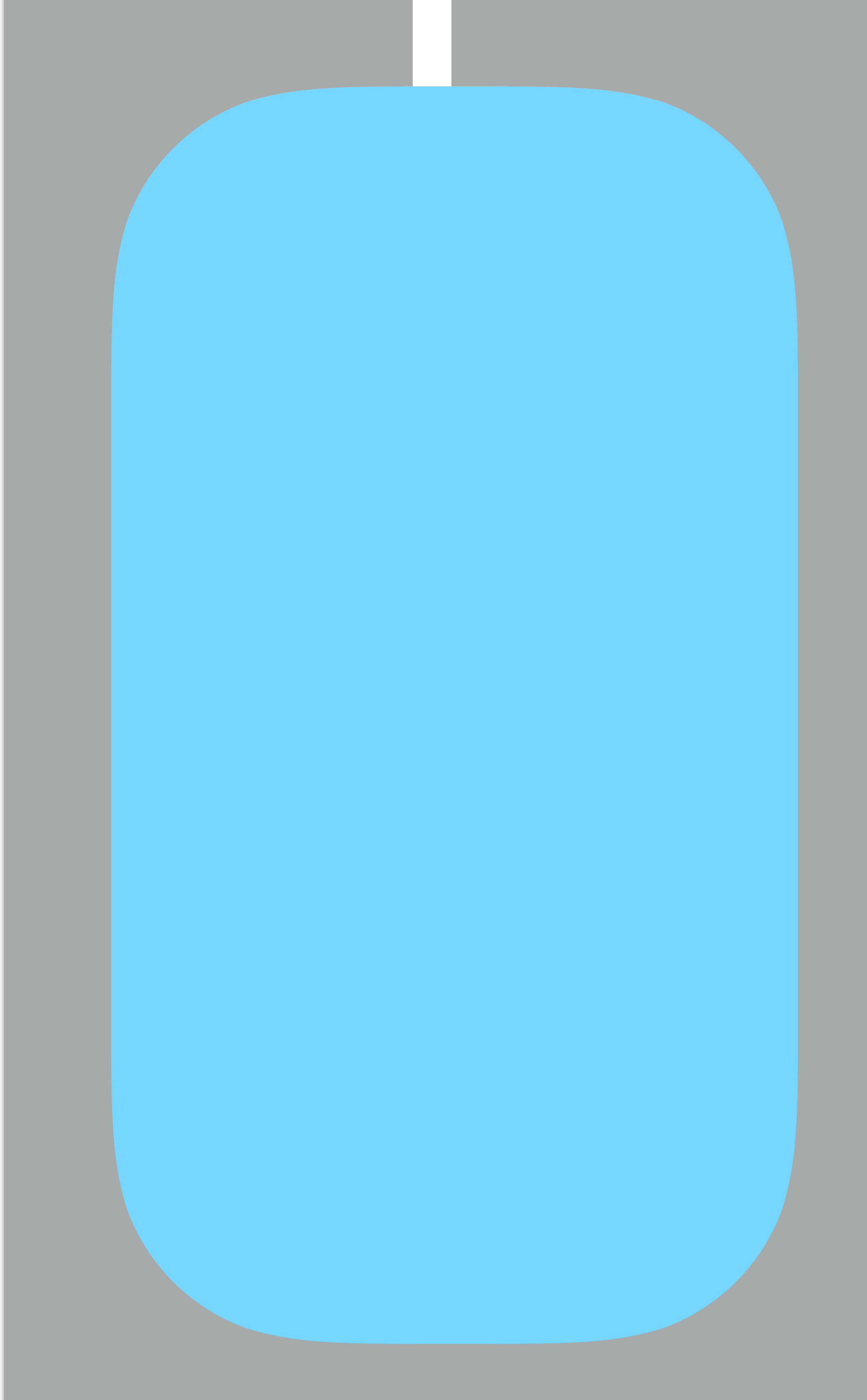


High complexity: Fully lined cavern, in-cavern construction

- Can we instrument megaton-scale volumes?



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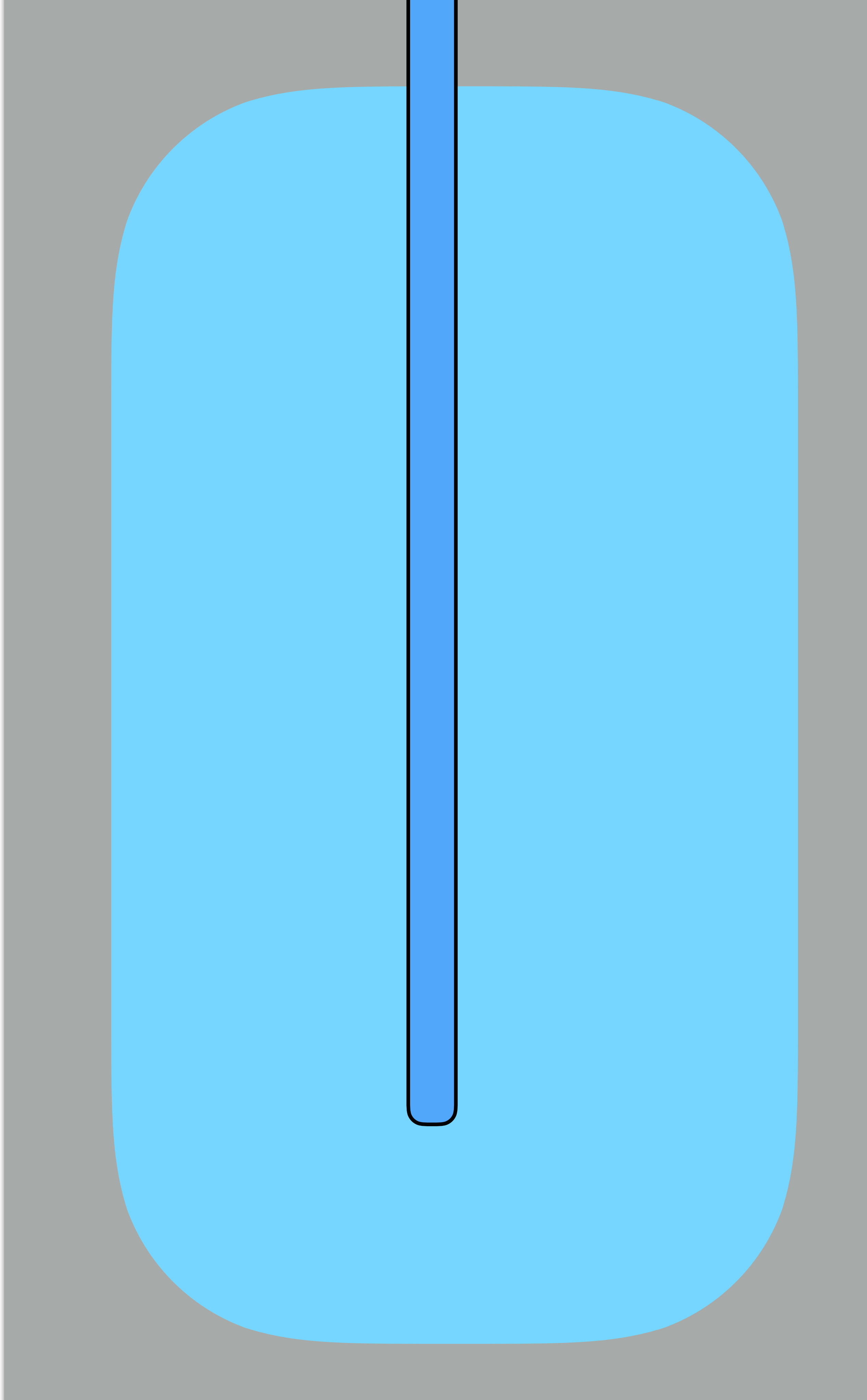

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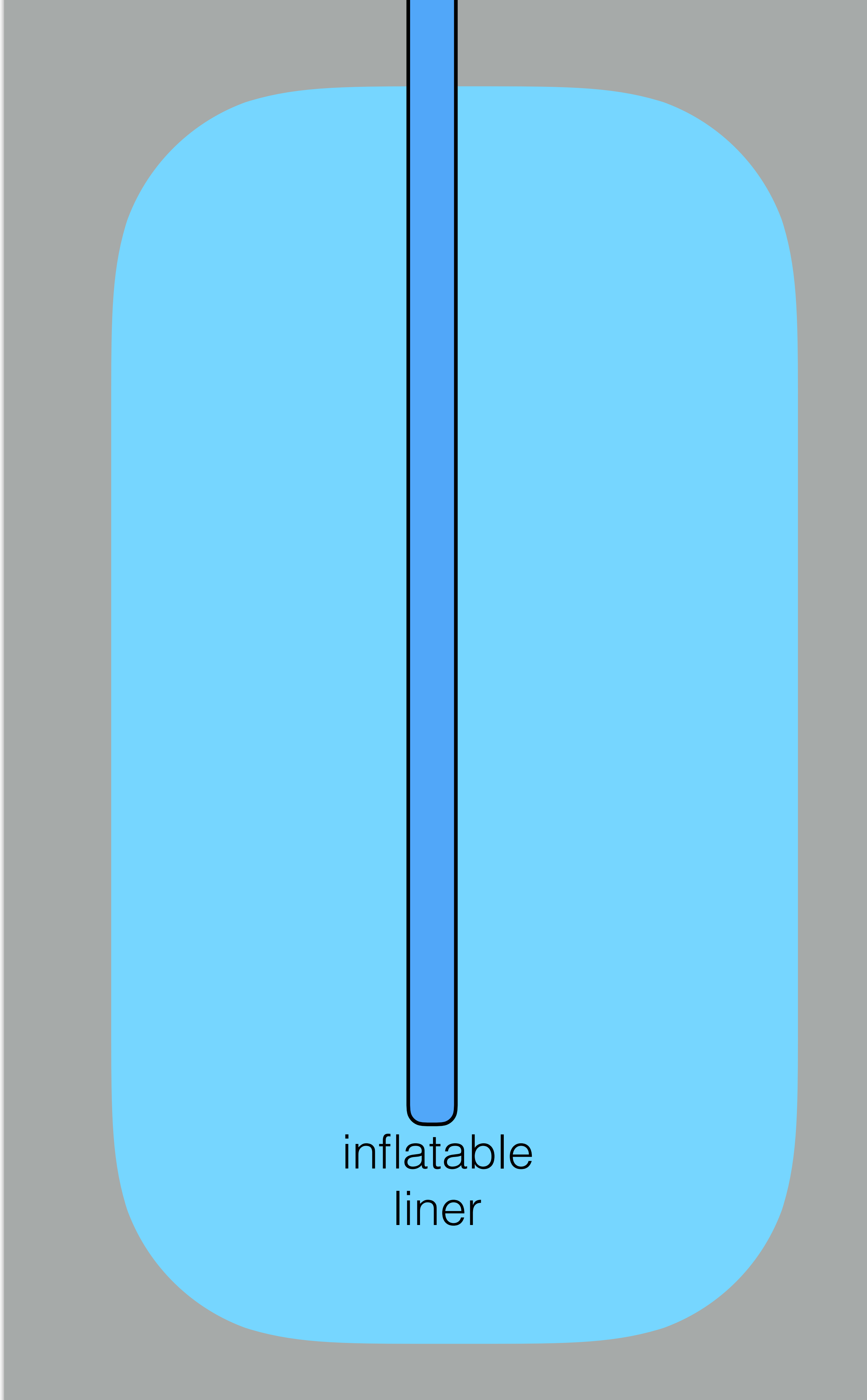

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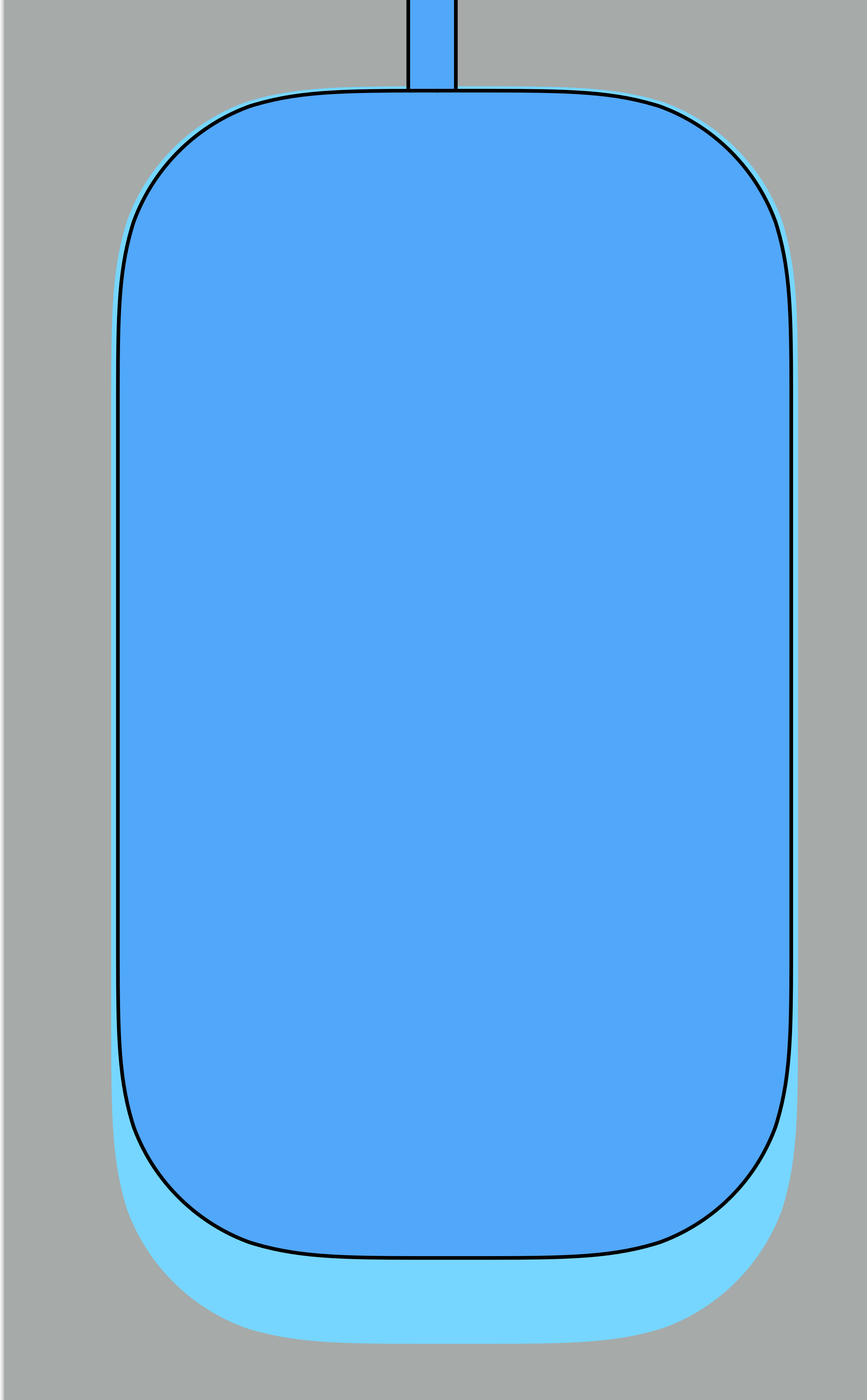

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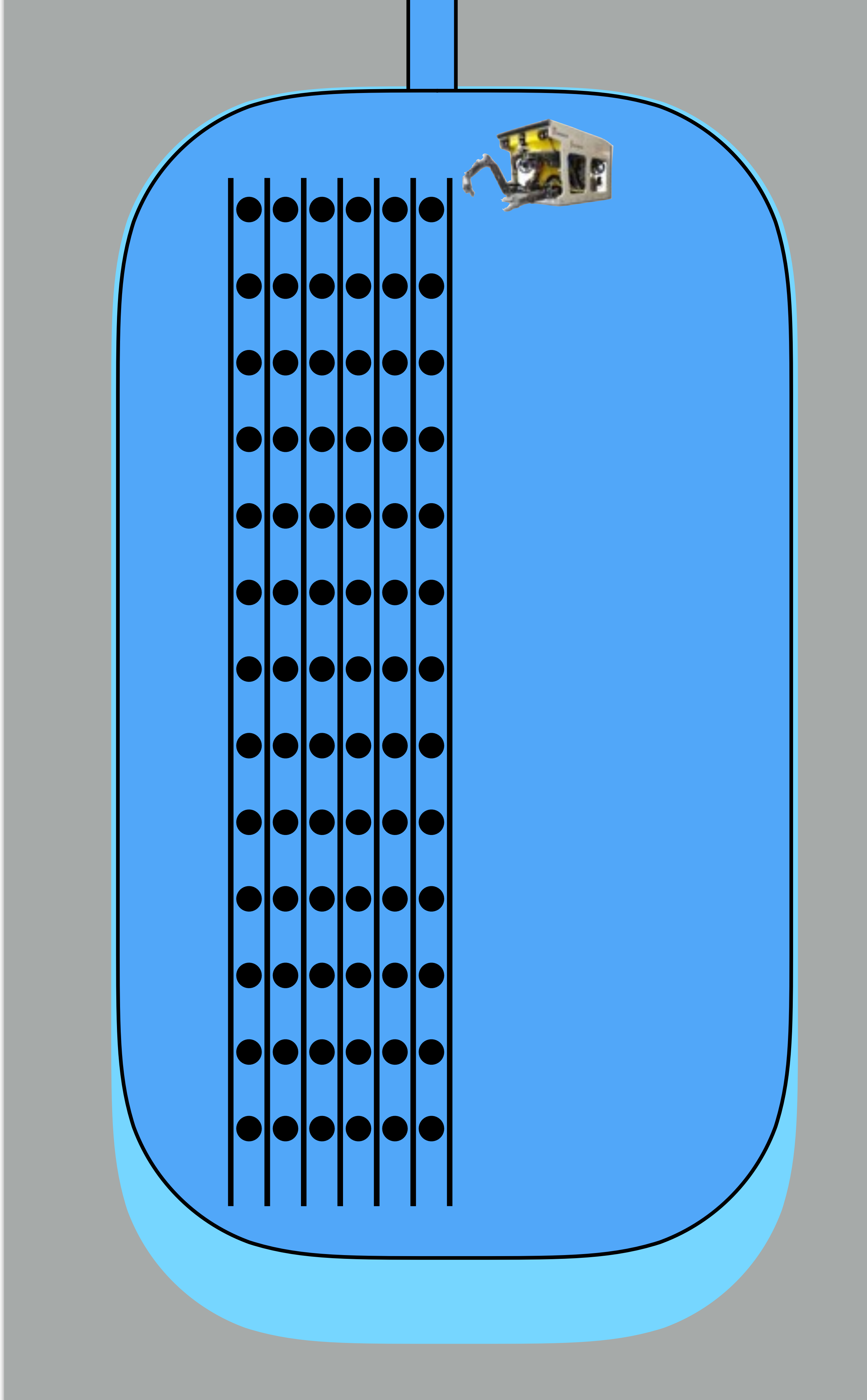

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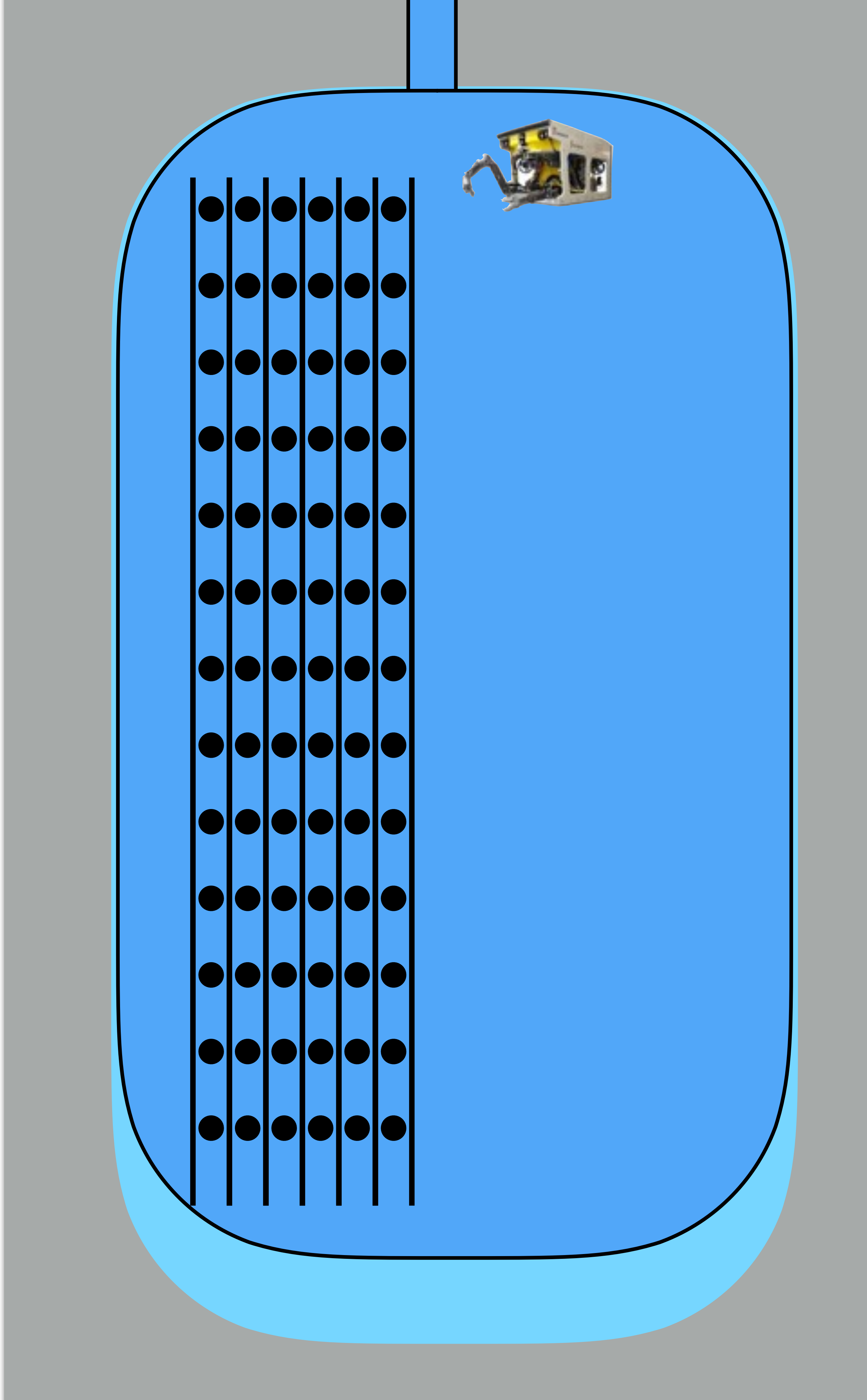

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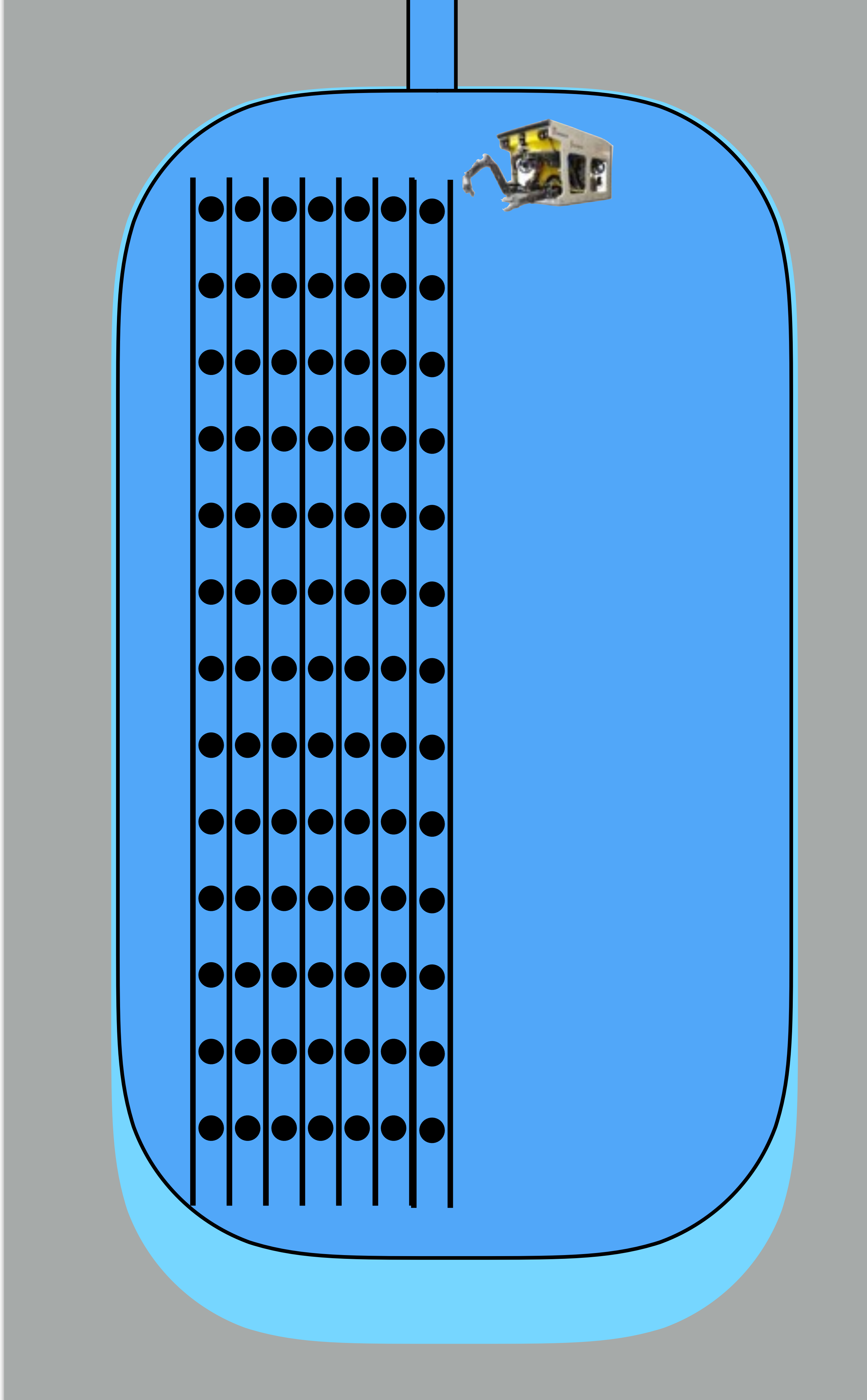

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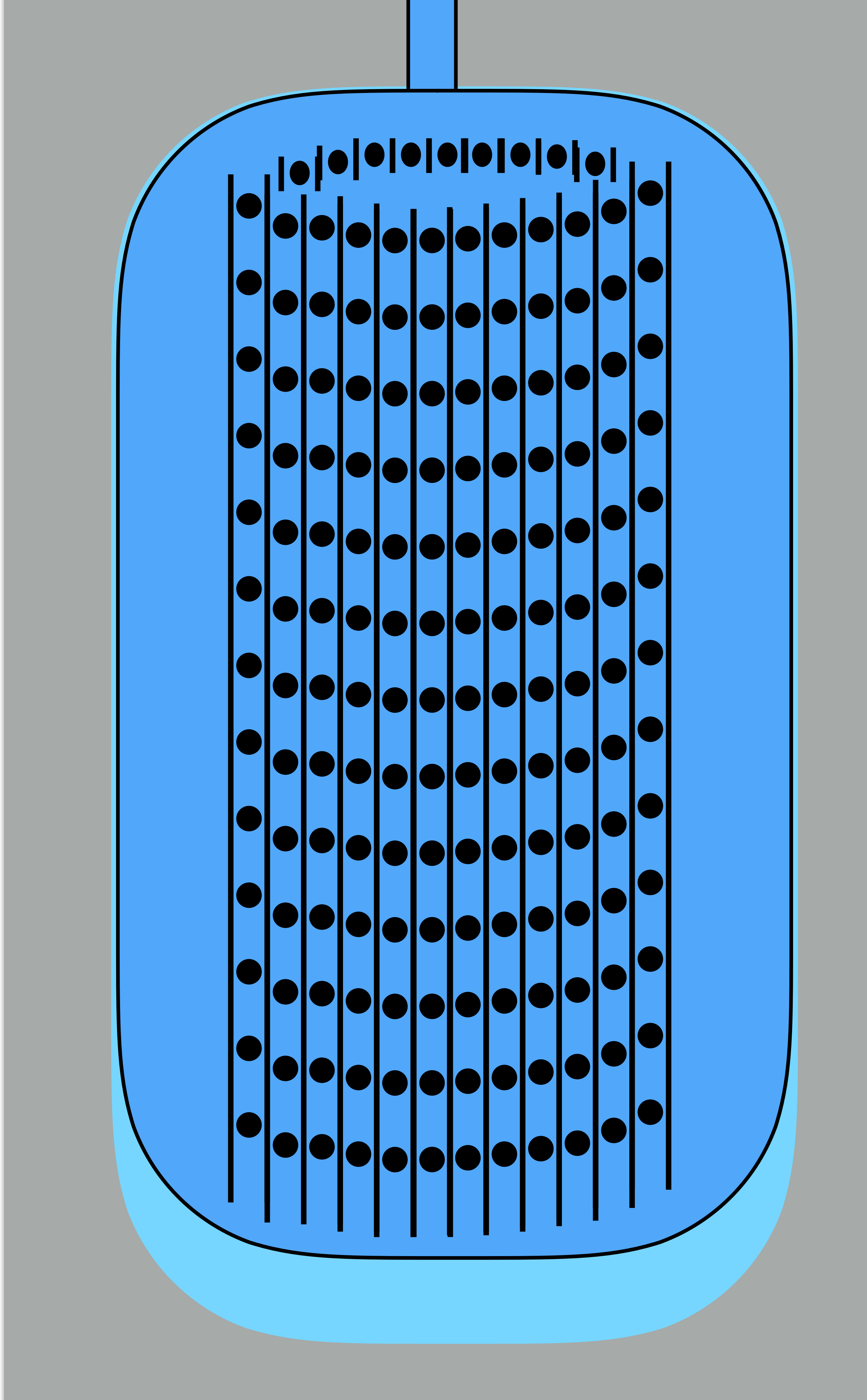
- Standard-ish tech
  - PMT strings in pressure hulls = "standard" detector tech from IceCube
  - Remote sub/crane operations
- Low-risk cavern design: open well, halmostatic pressure, well diameter not critical
- Biggest novelty: cavern lining
- If this sounds hard remember that we are accustomed to $1B project estimates for facilities half this size



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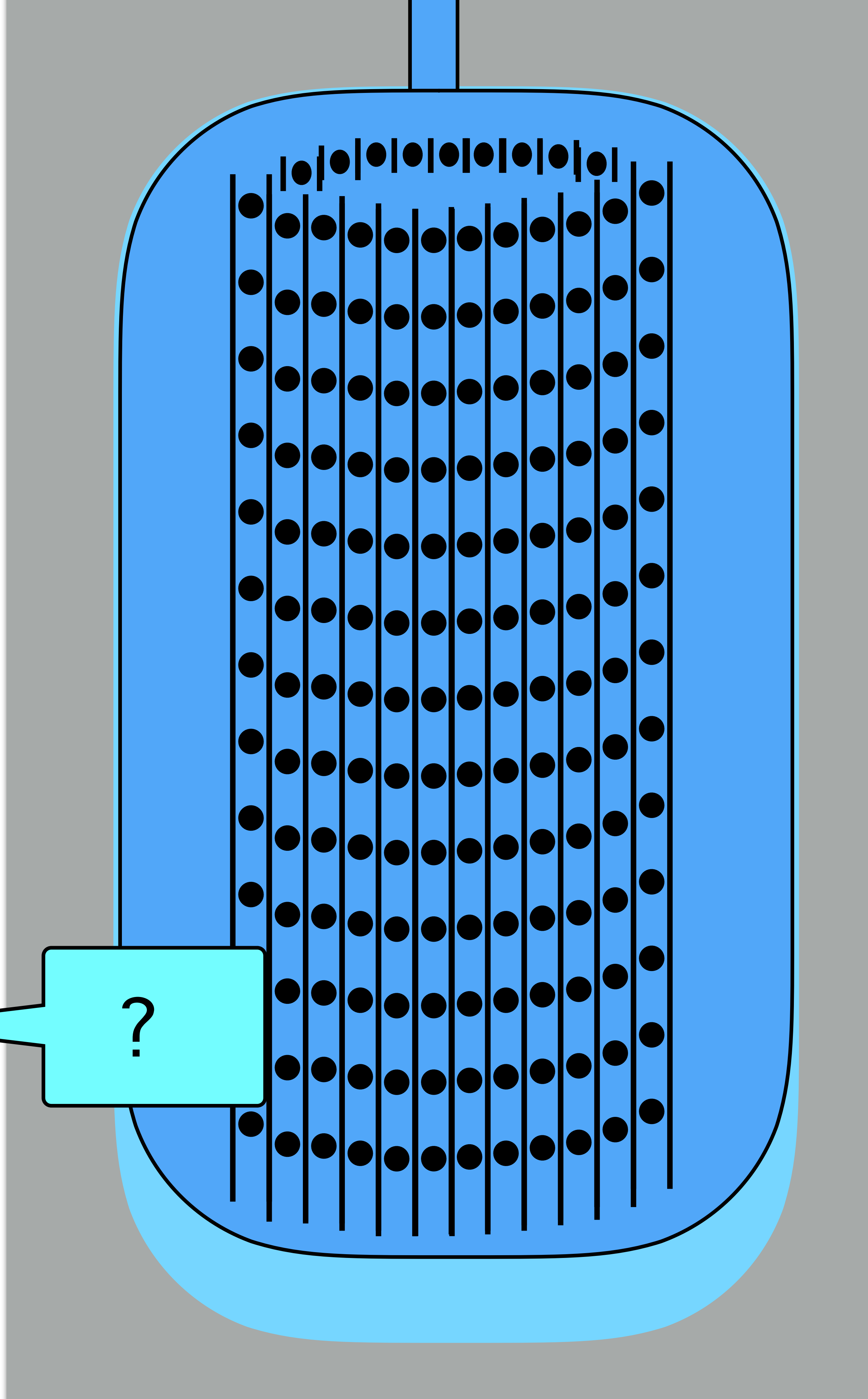
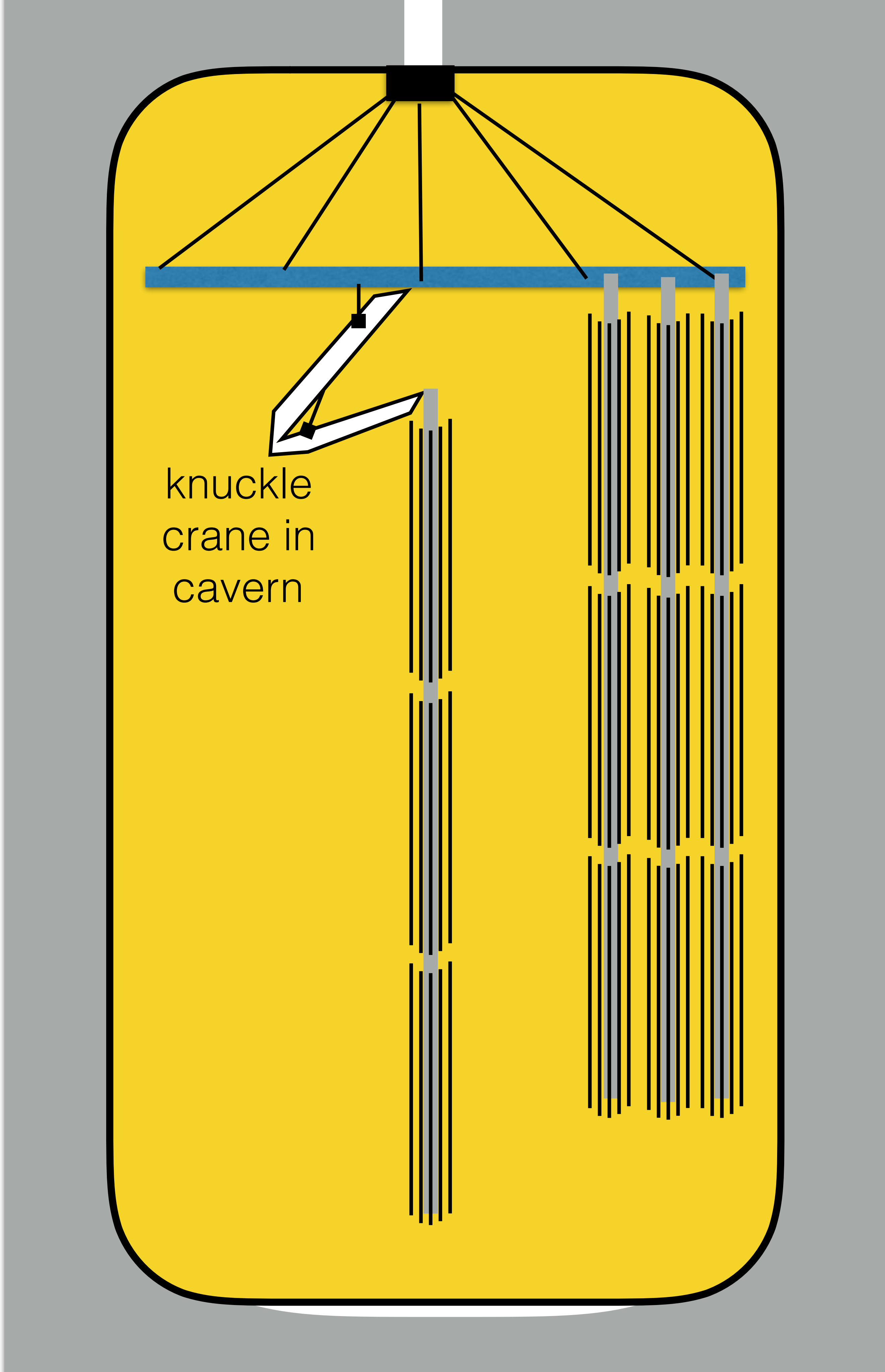


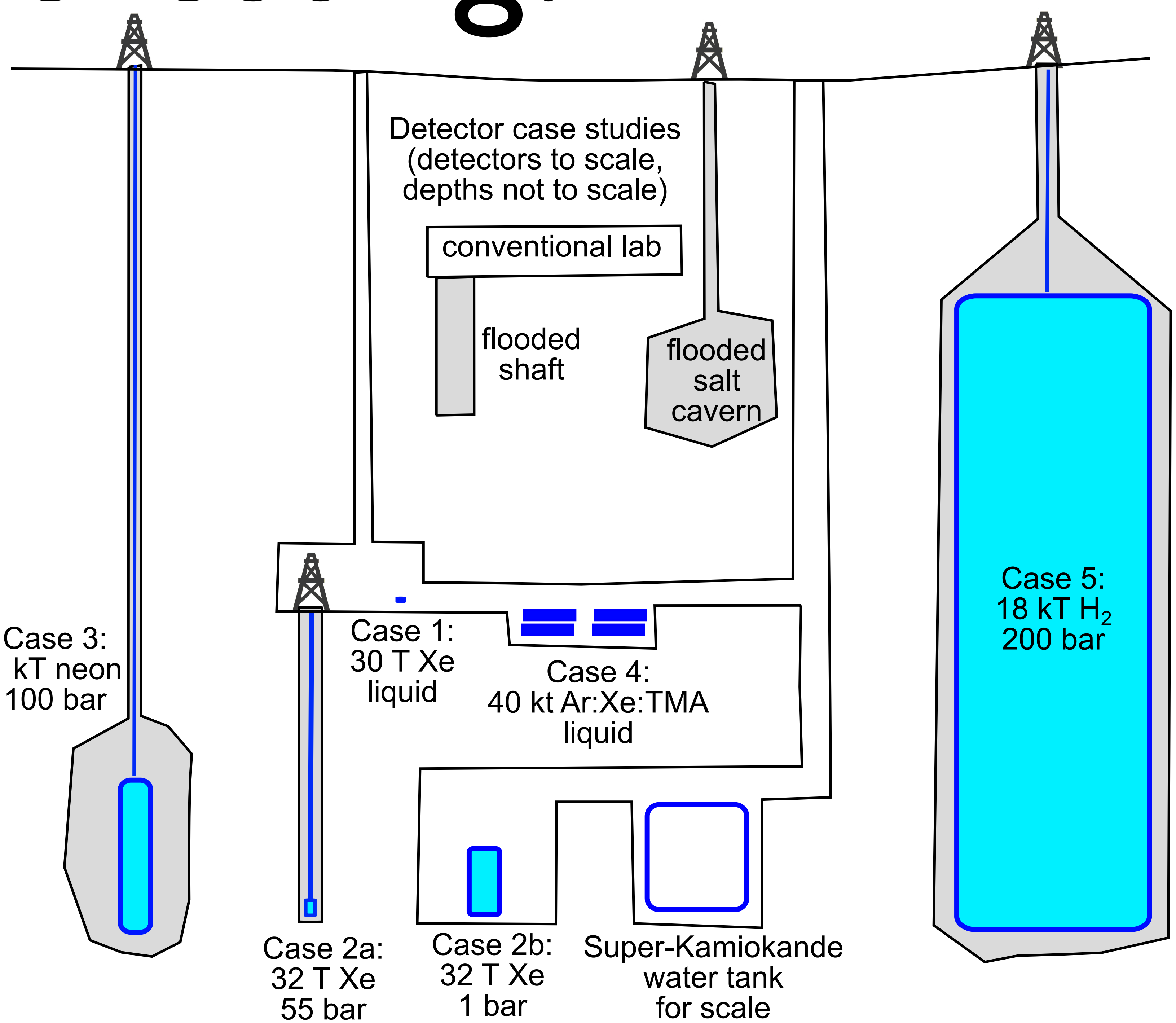
How far can we push?

- Can we imagine a cavern-spanning gas ionization detectors?
  - Ar, CO_2, or CH_4 based
  - 100-200 bar
  - Elaborate mech. eng.
- Speculative mining tech:
  - Stringent materials specs on huge liner
  - Assemble under 1 bar air?
  - Hang 1000 t weight from casing?
- At stake: at 500kT scale, factor of 100 boost in search for proton decay and "grand unified theory"



What scales are interesting?

- Solid-state detectors < 1 t
- Xenon at 1—30 tons, especially with P < 50 atm
- Neon at 1 kT
- Argon at > 20 kT
- H_2 at >10 kT
- Water at 200–1000 kT



Questions

From physicists

- "Can't we send miners in? Or divers? Wait, no."
- "Is such a cavern predictable/stable enough to entrust $100M worth of detector hardware to it?"
  - They're used to scaled, bolted, shotcreted roofs

From me

- "How would you build a cavern if it was required to spend 2y at zero pressure?"
- "How big a borehole can we get?"
- "What would plug/BOP/DHSV operations look like?"
- "When/where do we start?"

What’s next

- UCSB engineer working on design of inflatable-cylinder detector
- In contact with DM-ICE collaborators who have quickly-deployable hardware
- Would like to open discussion/collaboration with engineers, owners, etc.
- Visit hep.ucsb.edu/saltcaverns and join a discussion group

Funded by DOE Office of High Energy Physics
under DE-SC0013892.

SNOLAB

Salt Cavern Detector Intere ×

hep.ucsb.edu/saltcaverns/

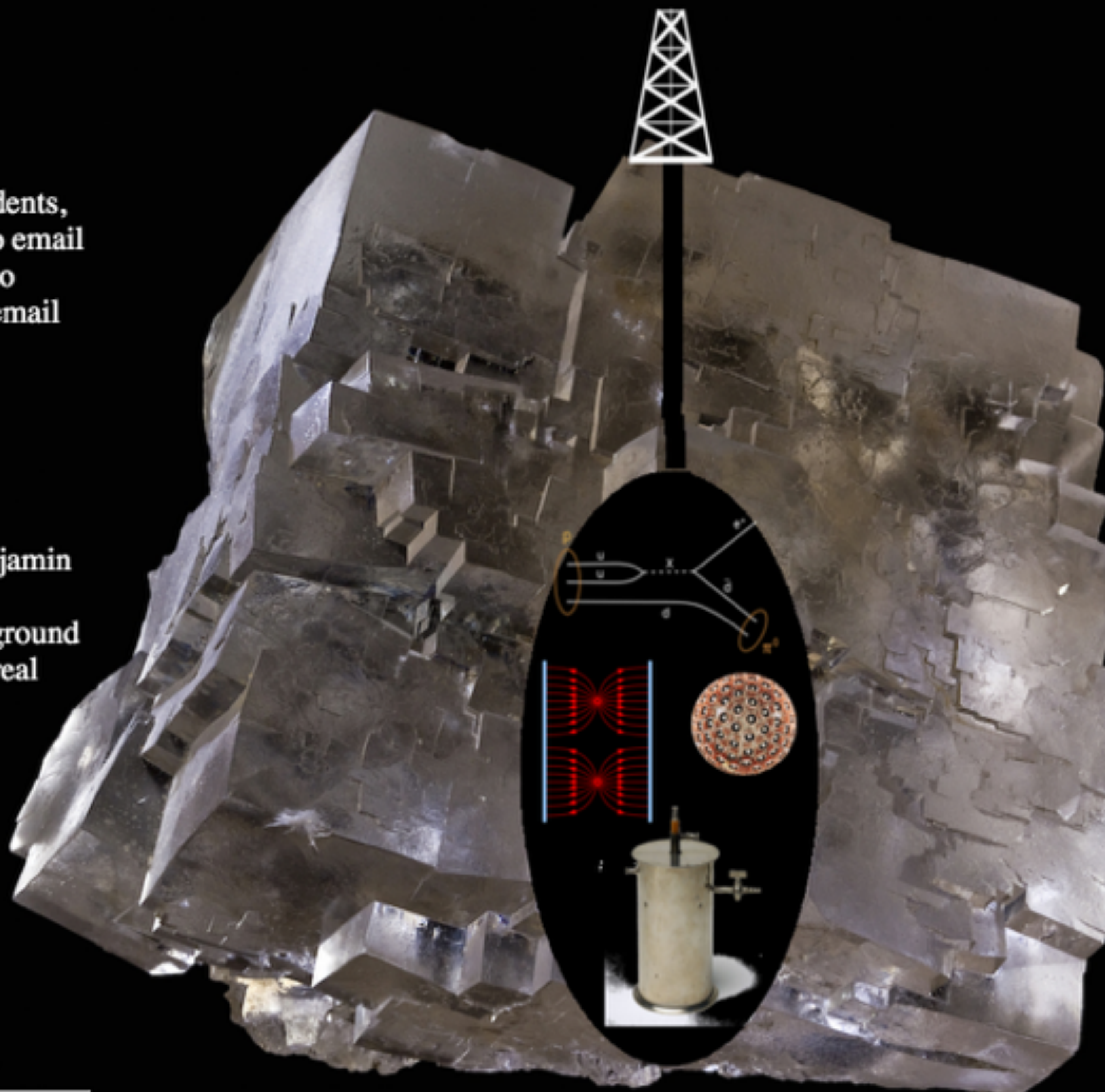
Apps | Welcome to BSCW S | Frequency Modulatio | LL Player Profile: Mo | Tandem Press (Suza | University of Washin | » | Other Bookmarks

Salt Cavern Detector Interest Group

We are a group of physicists interested in solution-mined salt caverns as deployment sites for future experiments in nuclear and particle physics.

Internal site

Our internal discussion forum is hosted on Basecamp. Please join us! Students, postdocs, PIs, engineers all welcome. Site access requires an invitation, so email scdig_request@hep.ucsb.edu to get one. (Doing so is not a committment to anything---work, email, teleconferences, etc. You'll just get an invitation email from Basecamp.)



References

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2. http://arxiv.org/abs/1410.0076 Underground physics without underground labs: large detectors in solution-mined salt caverns. Benjamin Monreal

Contact

All interest is welcome! Contact Ben Monreal via scdig@hep.ucsb.edu.

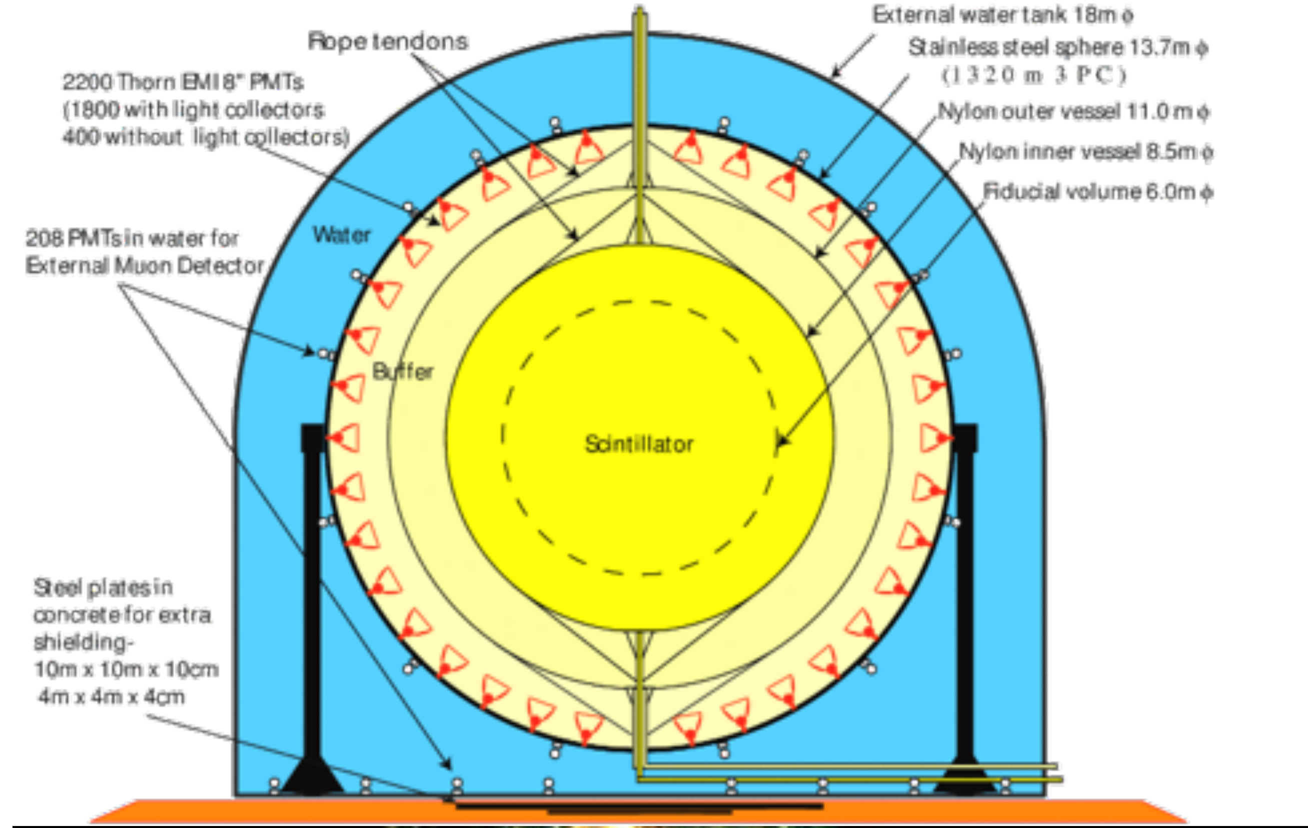
Credit

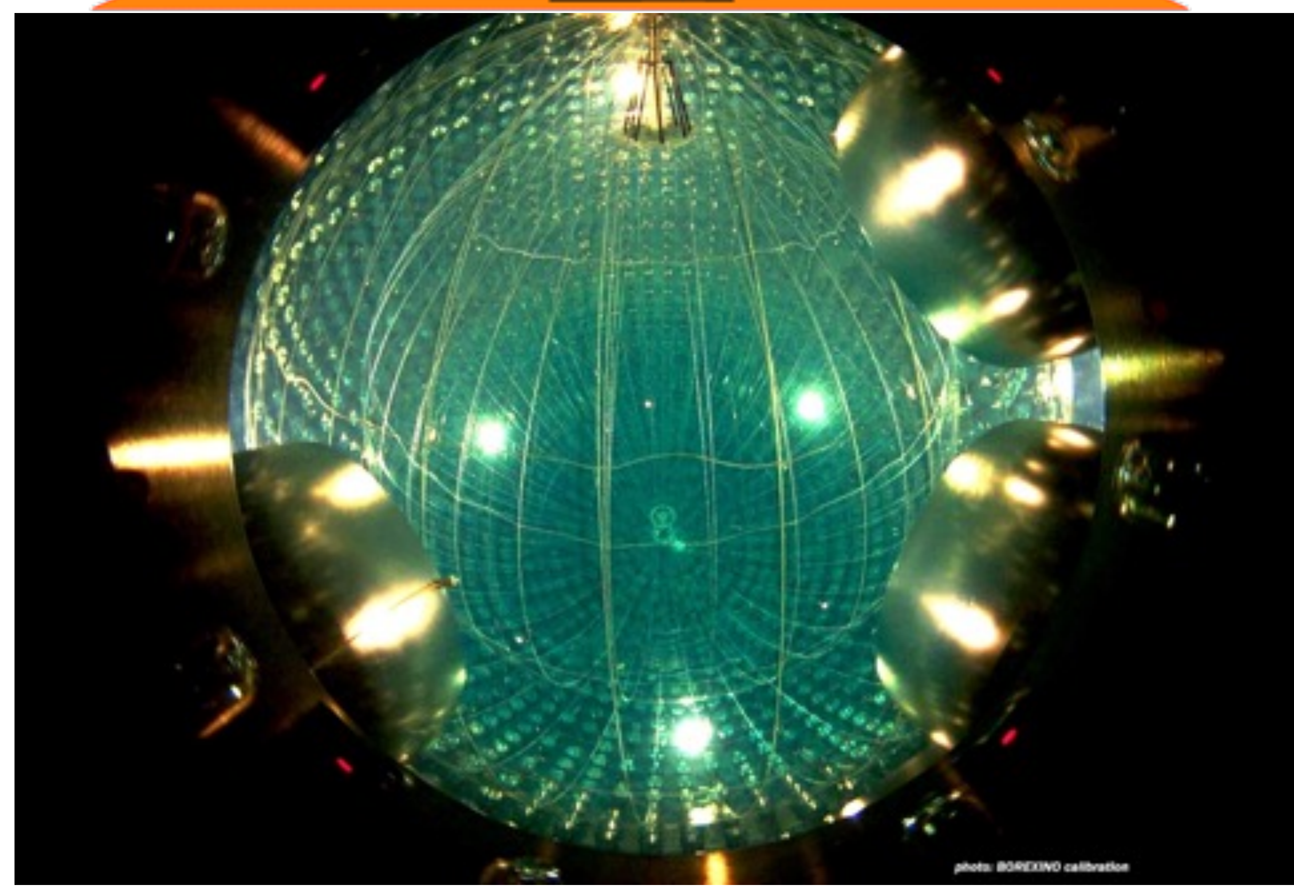
This research is funded by the Department of Energy under grant DE-SC0013892. Salt crystal and detector images from Wikimedia Commons.

Last modified: Thu Jan 21 16:37:42 PST 2016

Borexino: a onion-like scintillator detector

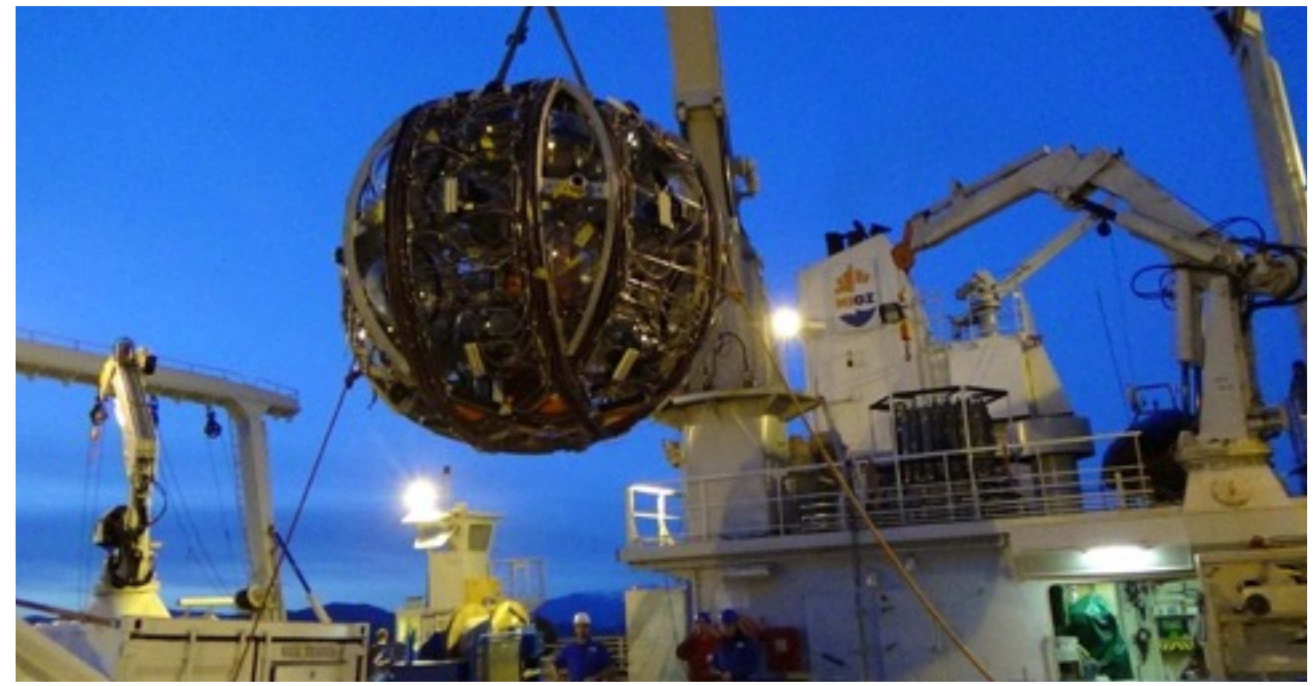
- Nested spheres:
  - 18m: water tank
  - 14m: photodetector sphere
  - 11m: high-purity oil balloon
  - 8.5m: particle-sensitive scintillator balloon
- Complex inflation, calibration sequence controlled through "neck"
- Observables:
  - 200/y neutrinos from Sun
  - 5/y antineutrinos from Earth

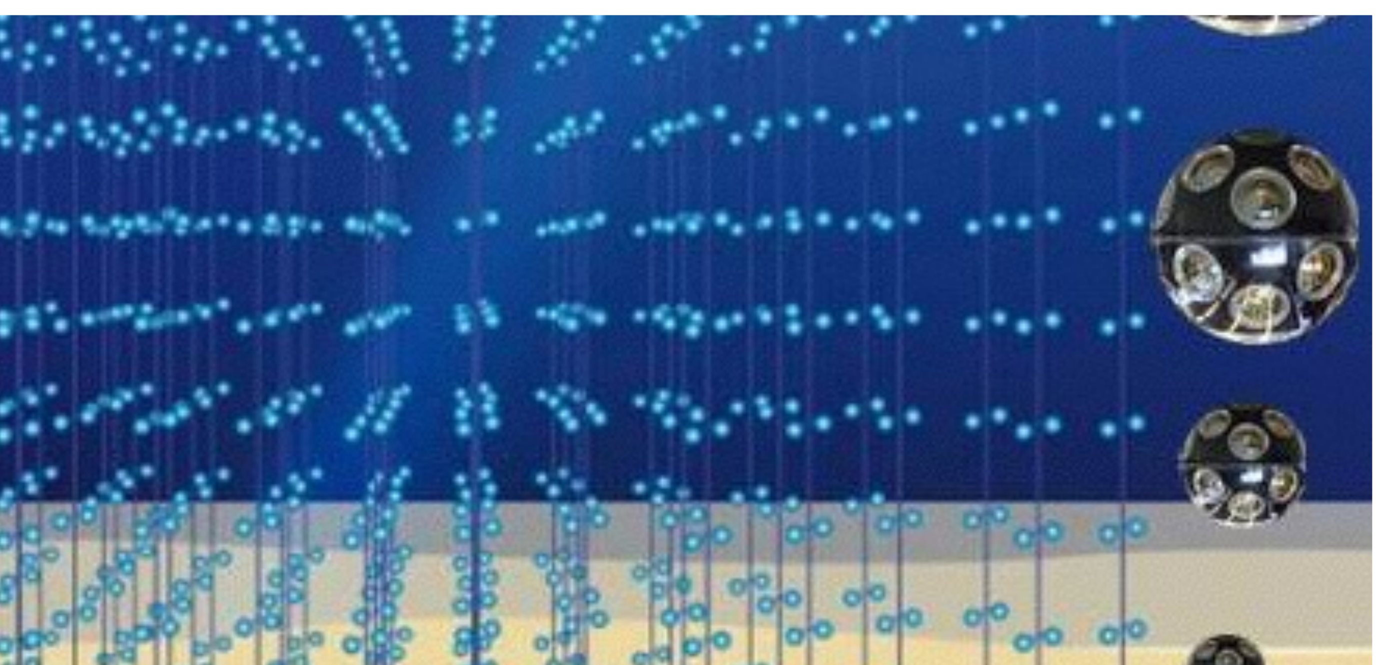




KM3NeT

- Like IceCube, but in the deep Mediterranean
- Buoyant strings deployed and cabled by ROV
- Three sites under construction





DUNE

- 30 kT liquid argon target in membrane cryostats
- Neutrino beam travels 1300km Fermilab - SD
- Construction has begun