Ice, neutrinos and radio waves

dylan, RJ, dzb

(borrowing from recruiting talk given to KU grad students)

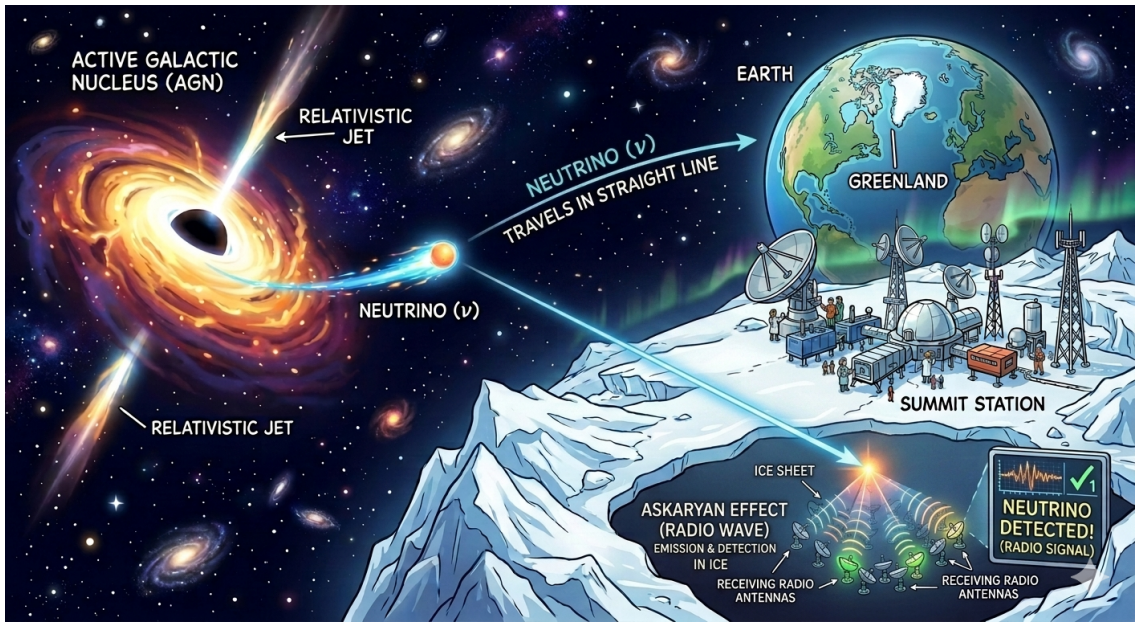
June 21, 2026

Prelude & disclaimers

1. I'll be discussing topics that many of you have more expertise in than myself! Apologies, in advance, for any mis-statements!
2. Please interrupt me if something is unclear! (otherwise, pointless)
3. Thanks to all of **you** for making this possible!
4. And thanks to the Greenlandic govt. and people for letting us work here!

pre-Summary

1. **Distant** sources produce light & 'cosmic rays' (CR), but light absorbed/scattered before can be seen by telescopes; CR neutrinos penetrate!
2. Neutrinos crash deep in polar ice→collision produces radio waves→measure with radio antennas.
3. Our goal: understand how radio waves used to image the neutrino are affected by the ice between neutrino crash-point and our antennas.

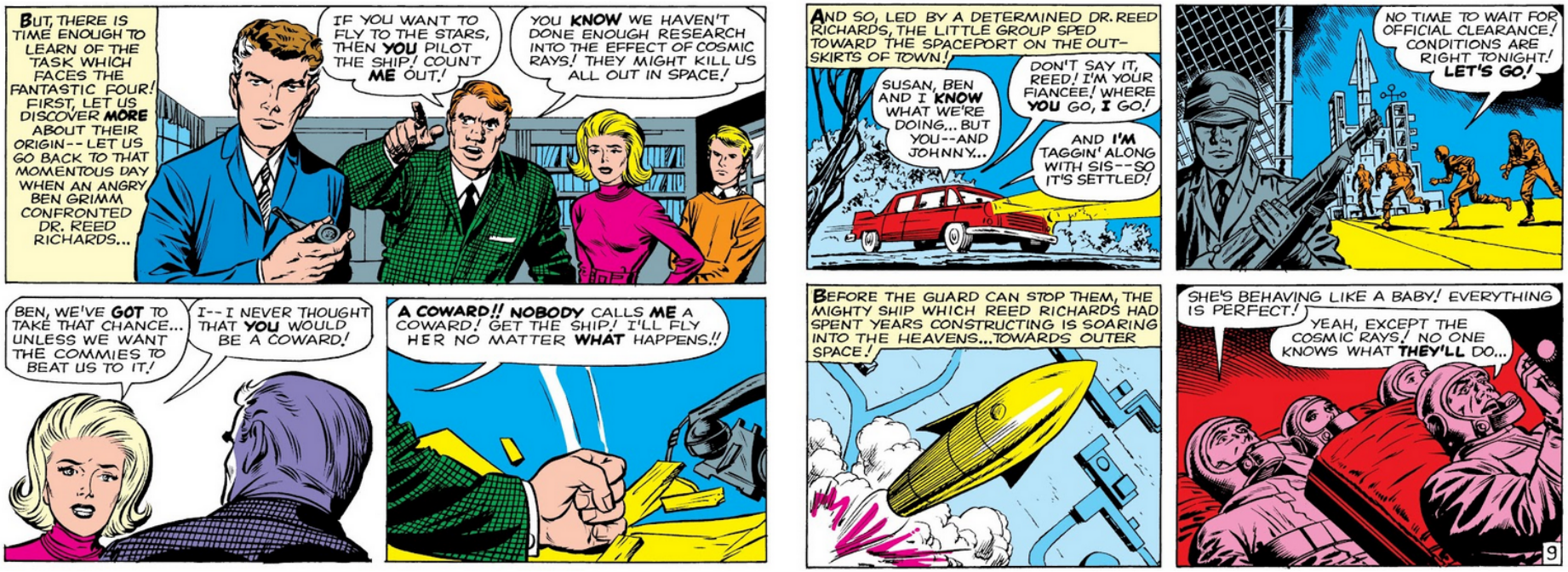


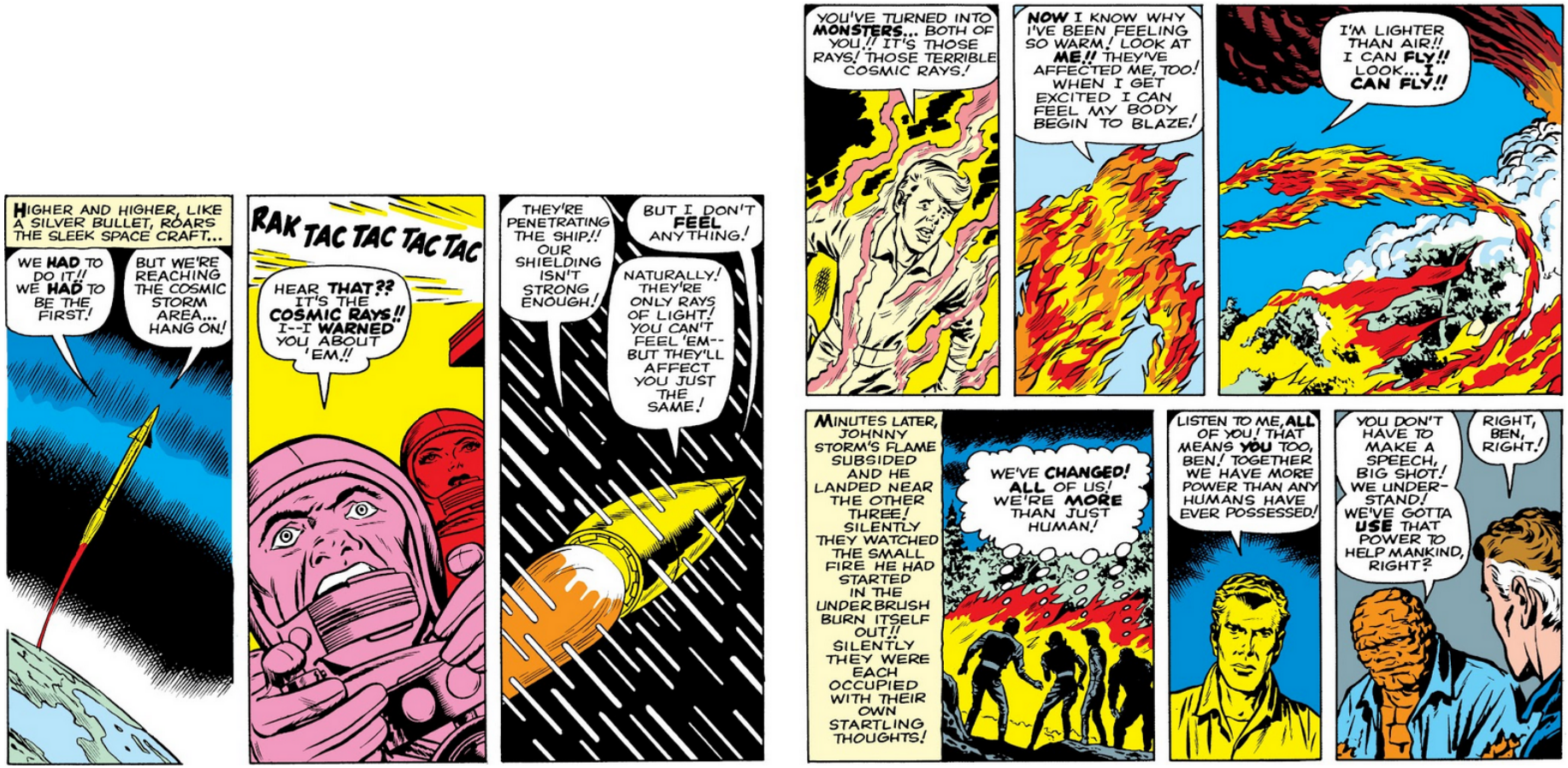
Imagine looking through pure glass block vs. variable-density or dirty glass

Context:'Cosmic Ray Astronomy'

1. Telescope has been standard tool of astronomy for 400 yrs.
2. In addition to visible light, distant sources produce other particles that contain information about those sources ('Cosmic Rays')
3. CR include protons, gamma-rays, iron nuclei, neutrinos
4. Constantly bombarding Earth (and you!); supernova in our own galaxy produces about 10^{19} neutrinos passing through our bodies
5. CR relatively unstudied until seminal journal publication (`Lee & Kirby, Nov. 1961`) documented cumulative (and potentially tragic) biological consequences of cosmic rays on metabolism (**ISBN** 978-0785114864, **DOI:**, 10.1080/21504857.2021.1918737) of earliest astronauts

the originals: Richards, Richards, Richards, and.... Grimm



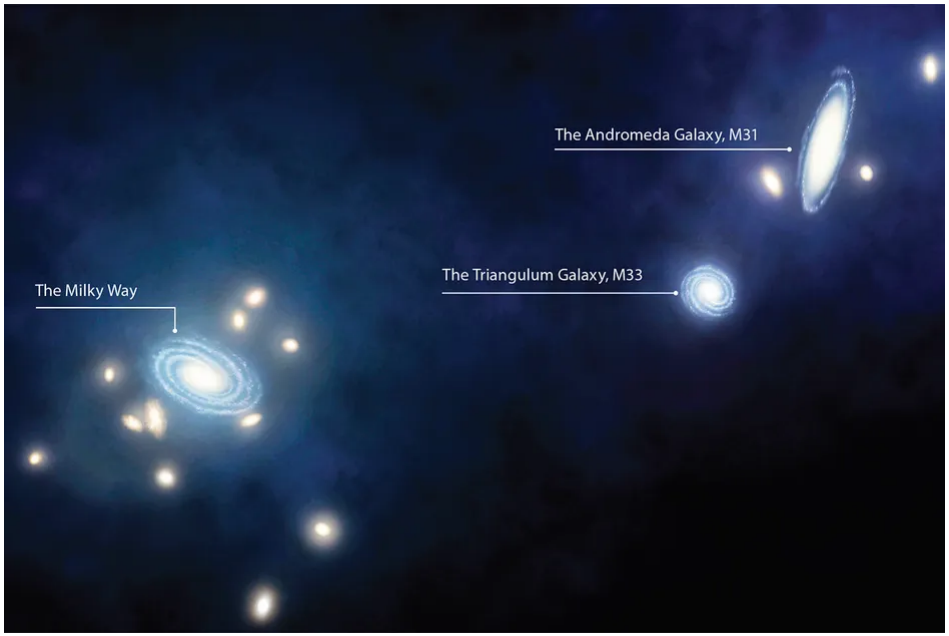


The moral for Ben Grimm: don't get into cars with strangers

- not-so-kooky: If there were an X-class solar flare (20/yr), Martian astronauts would receive an immediately lethal radiation dose

Astronomical sources we study with light & CR?

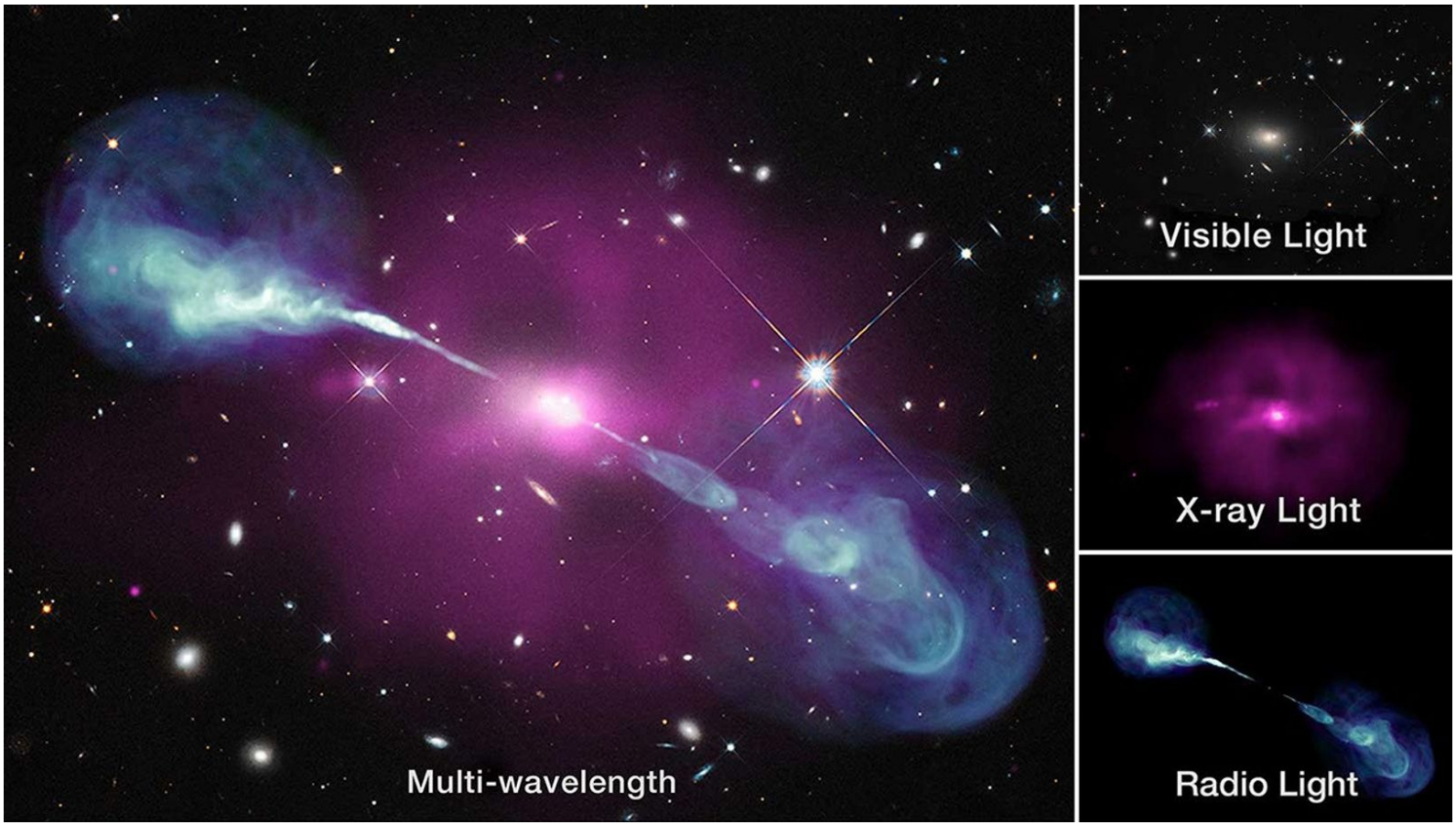
Cosmic scales: Milky Way→Andromeda∼0.8 Megaparsecs



Zoom out: radius of visible universe about 28500 Megaparsecs!
-For sources further than ∼10 Mpc, increasingly harder for light to penetrate intergalactic 'fog' before reaching our Earth-borne telescopes!
-Cosmic Ray neutrinos are more (much more) penetrating than light.

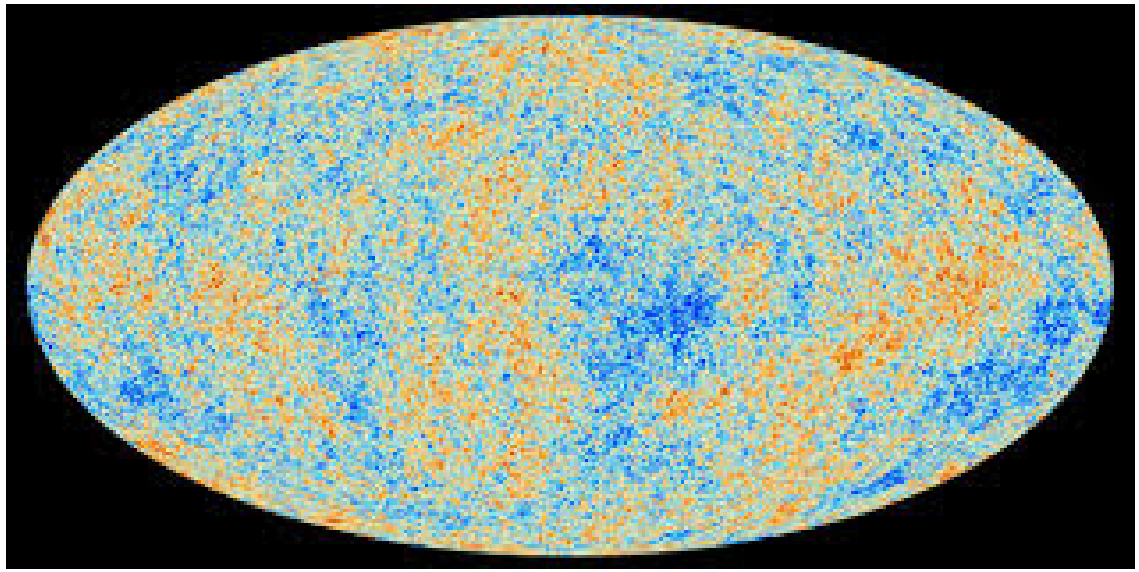
‘Active Galactic Nucleus’ is one such source

Billion-solar-mass **black-hole** spitting out light and particles (note lobes)
-Harder to see light, the further the source, because of...



the Cosmic Microwave Background fog

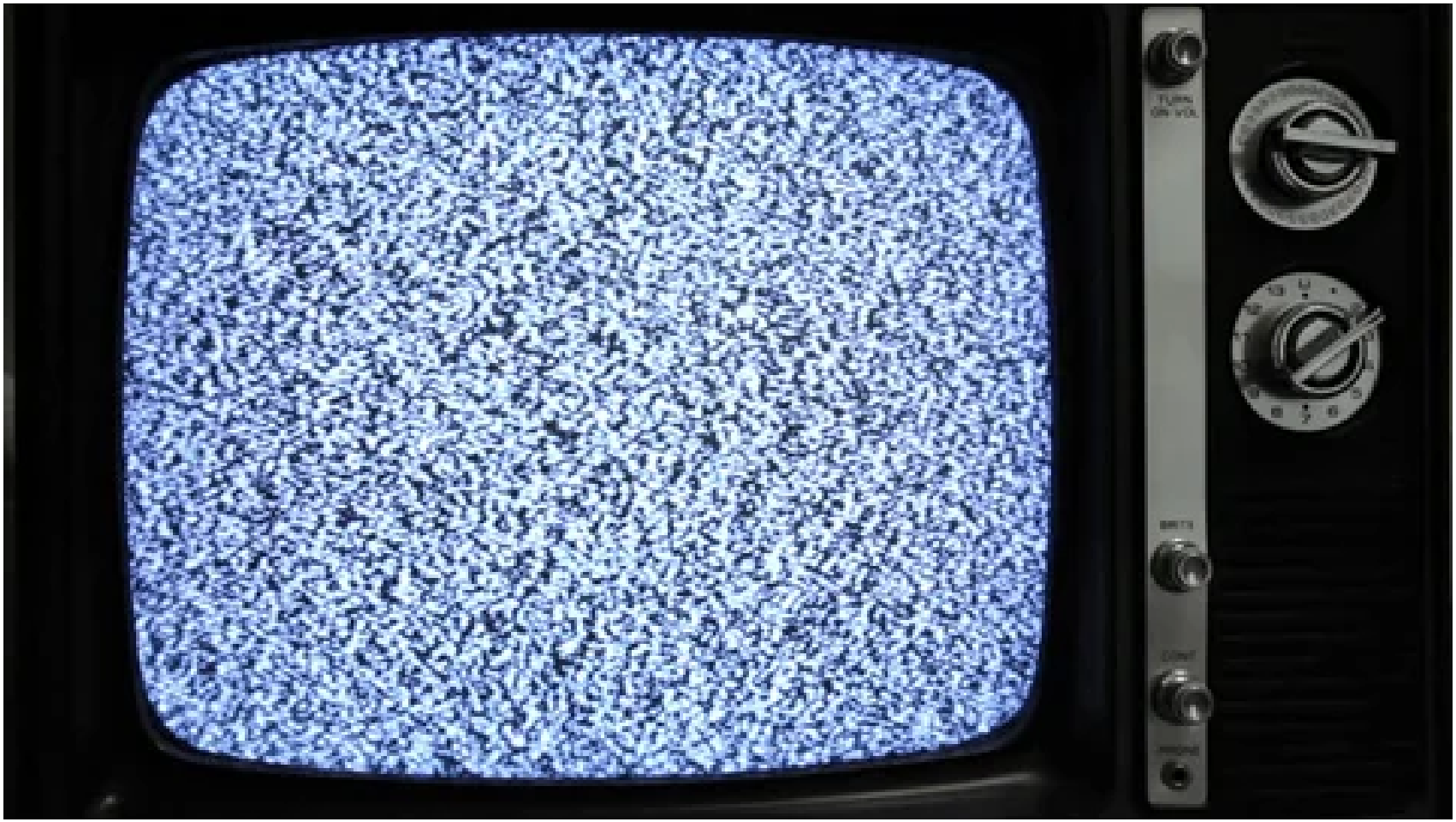
What would the sky look like if our pupils were 5-10 m in size (therefore sensitive to wavelengths 20000× that of sun)?



• Cosmic Microwave Background (CMB); Big Bang afterglow! Photons produced 28500 Mpc away; 400 photons/cc (each 13.4B yrs old)
• Coming from all directions⇒Universe has no center!!
• energy of CMB photons $\sim$ 1/40000 that of sun-tan photons; hot/cold difference about 1 ppb ('grew' into galaxies!)

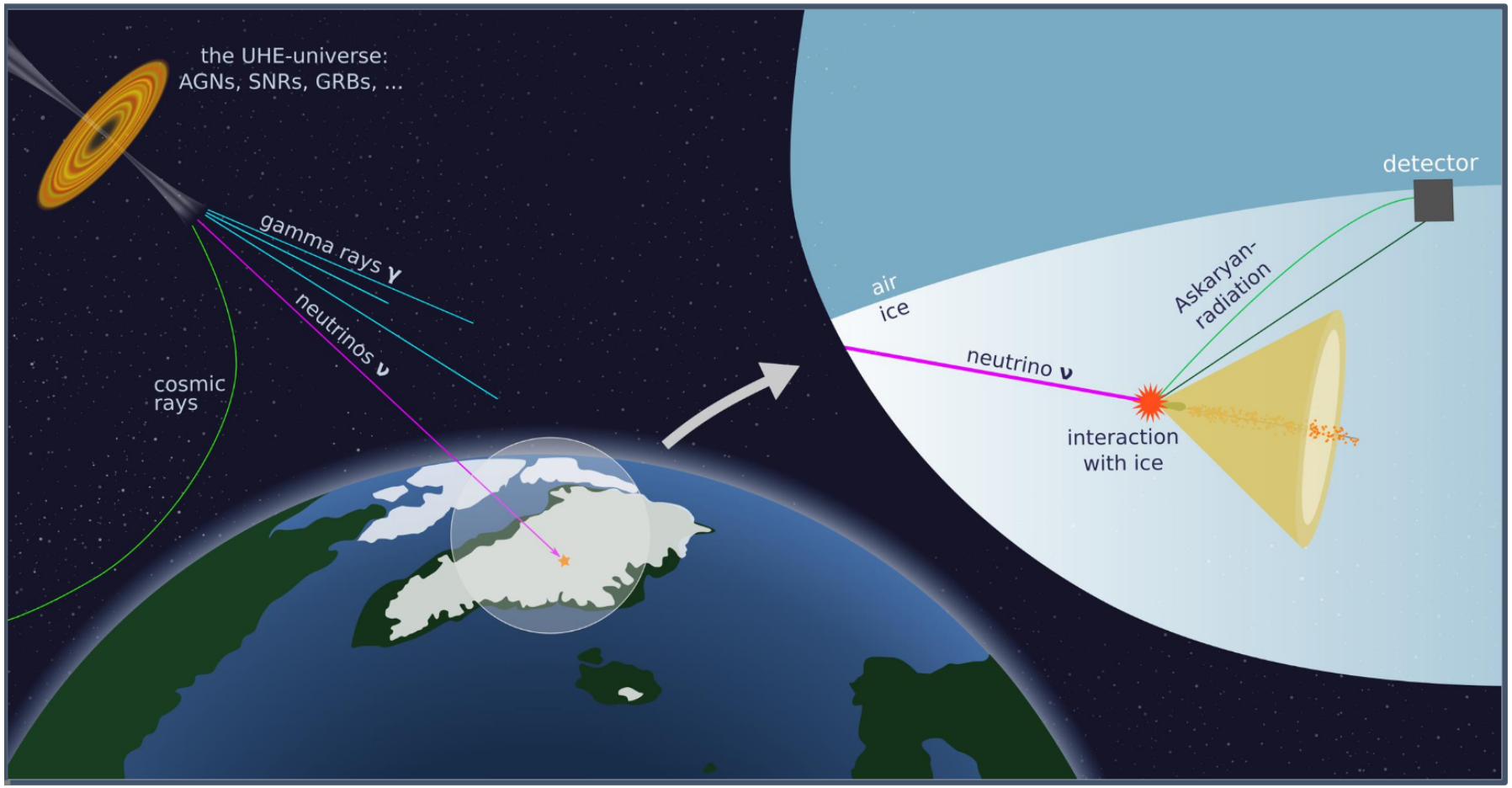
B&W TV set to Ch. 3 in Newark, NJ (1968)

about 10% of this image ('snow') is antenna pickup of CMB!



Subatomic cosmic-ray 'neutrinos' can penetrate the fog!

- light-year of lead required to stop one solar neutrino!



- But need a HUGE neutrino target! Must be uniform, dense, support deployment of sensors⇒ Earth icecaps!

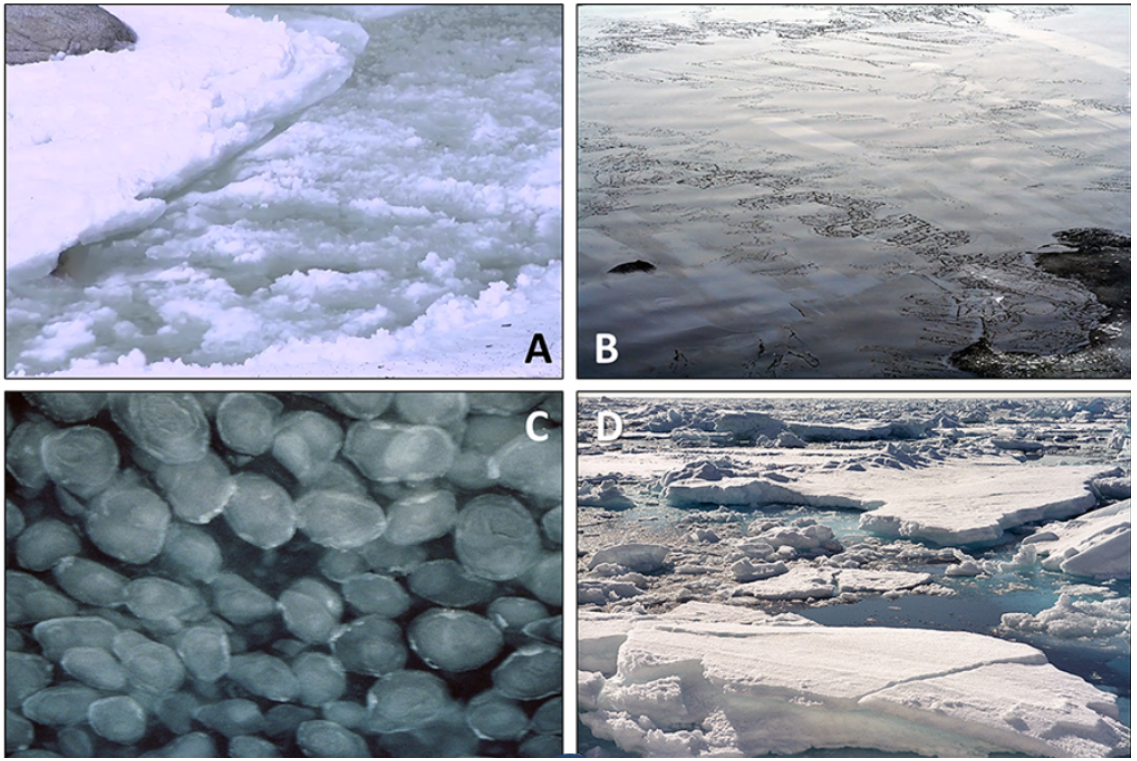
Neutrino factoids and detection scheme

• 300 Big Bang Neutrinos per cc, each 13.7B yrs old (300,000 yrs older than CMB)
• 0.01% of potassium is radioactive ^{40}K; each person emits ∼100 million neutrinos/day
• Solar ν, 50 trillion/body/second: On average, only one will be stopped by biomass per lifetime (aside: 2/3 of these neutrinos are different types of neutrinos than those produced by sun!)

• *Small interaction probability⇒need BIG target transparent to radio waves: Earth icecaps, e.g.*
• Antennas detect radiowaves from debris following neutrino-ice collision!
• **Our research task: determine how ICE either absorbs or scatter radio wave signals before reaching our antennas!**

Ice oddities

- Chemistry: it gets bigger when it freezes!
- Biology: Stuff lives in it in ice cores!
- Astrobiology: Is there life in the ice sheet of Enceladus (Saturn's moon)?
- Climatology: Albedo and Negative feedback (Snowball Earth - for 750 M yrs, Earth was enveloped in ice sheet)
- Astrophysics: Clear at optical and also radio frequencies, so Ice=good neutrino target

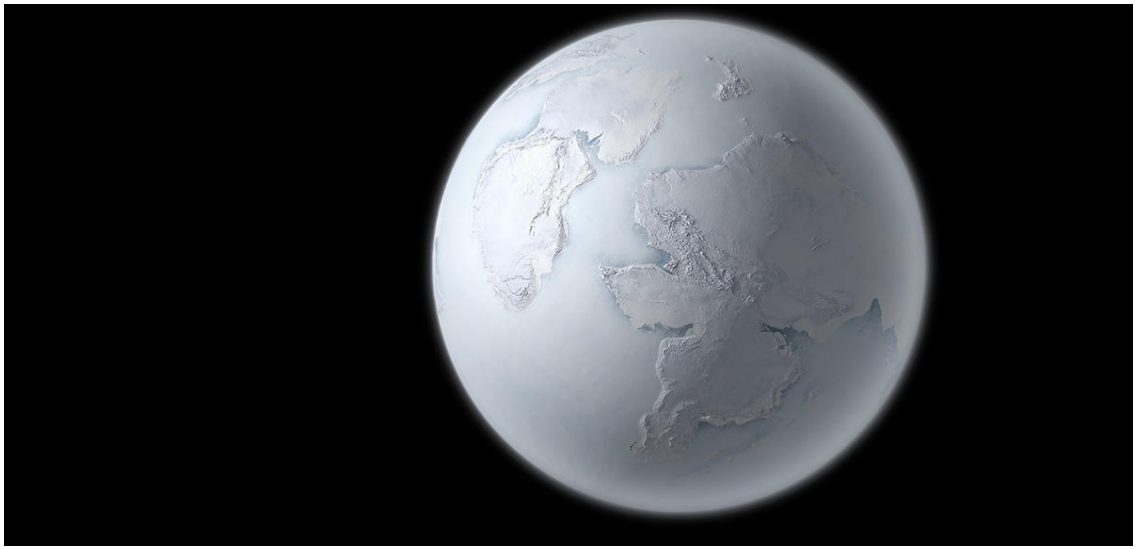


Google says 40–80 words for ice in Greenlandic

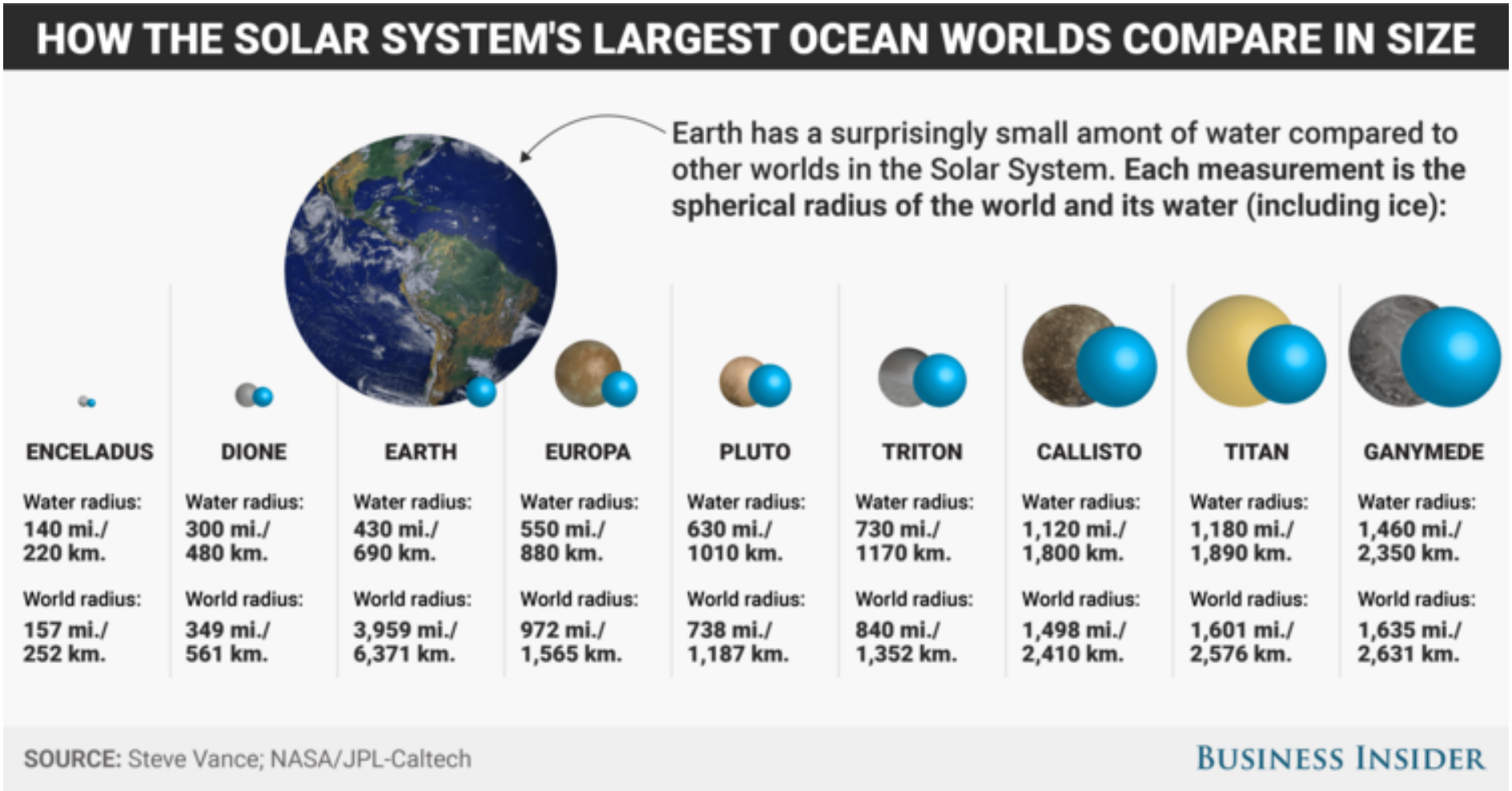
Snowball Earth (750Ma) - but, how?

One hypothesis (based on evidence that CO_2 concentration precipitously dropped at that time):

- Following pangea break-up, more 'interior' acid rain exposes basalt rocks
  - Basalt⇒Major CO_2 sink, so reverse greenhouse effect
  - Cooling + increased Greenland/Antarctic glaciation⇒⇒ *albedo* ↑⇒ *cooling* ↑



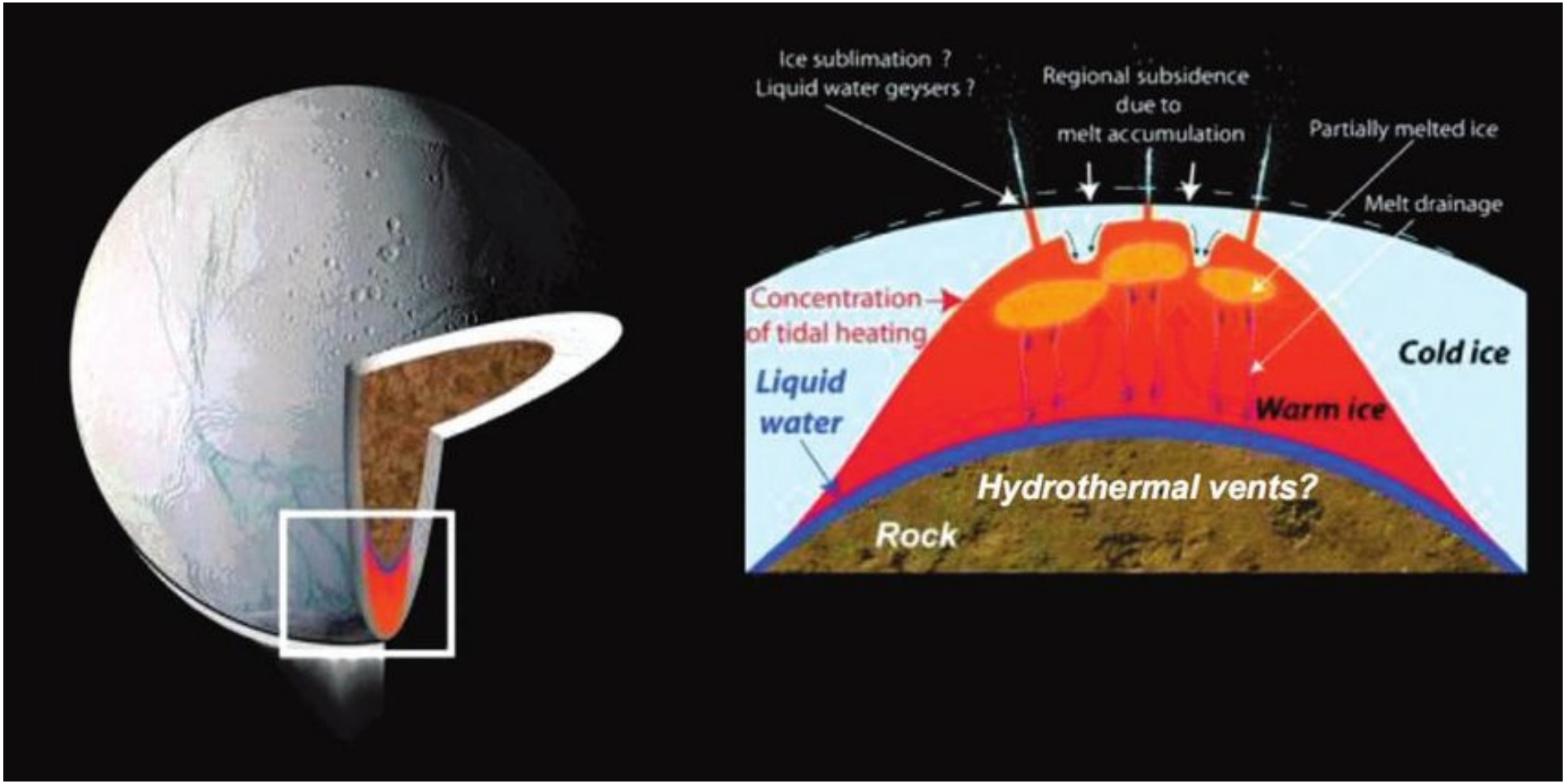
Earth has (only) some water/ice



Europa: 2× Earth water

Ganymede: 39×Earth water

Enceladus interesting watery moon (of Saturn)



Enceladus: 10-50 km thick ice crust over water

Tidal forces from Saturn so large that generated heat prevents complete freezing; speculate life in water below ice crust

Enceladus-esque subglacial polar lakes?

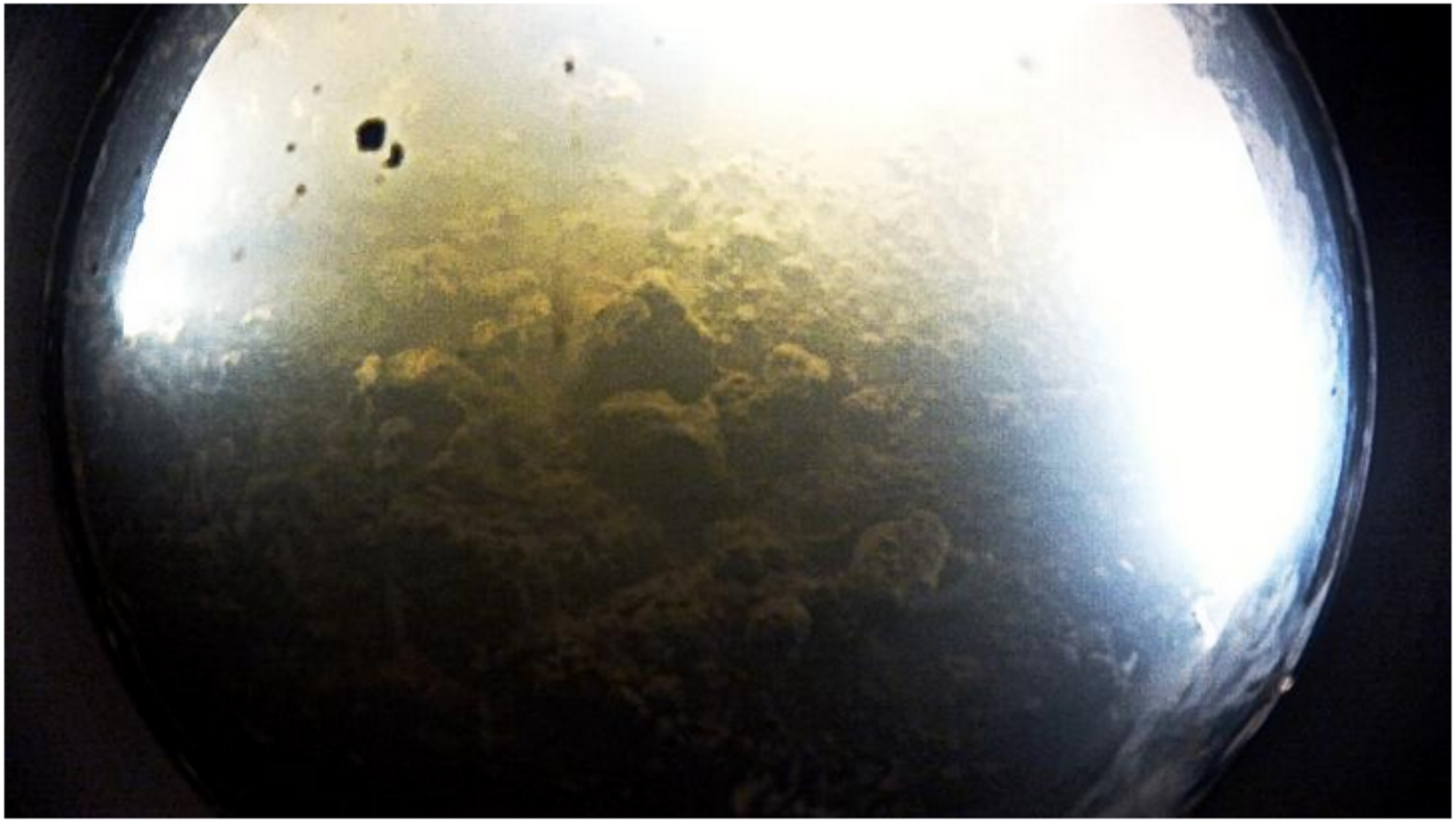
https://salsa-antarctica.org/
Retrieve 1067 m deep sample from Mercer Sub-glacial lake 500 km from SP!

NEWS · 18 JANUARY 2019

EXCLUSIVE: Tiny animal carcasses found in buried Antarctic lake

The surprise discovery of ancient crustaceans and a tardigrade emerged from a rare mission to drill into a lake sealed off by a kilometre of ice.

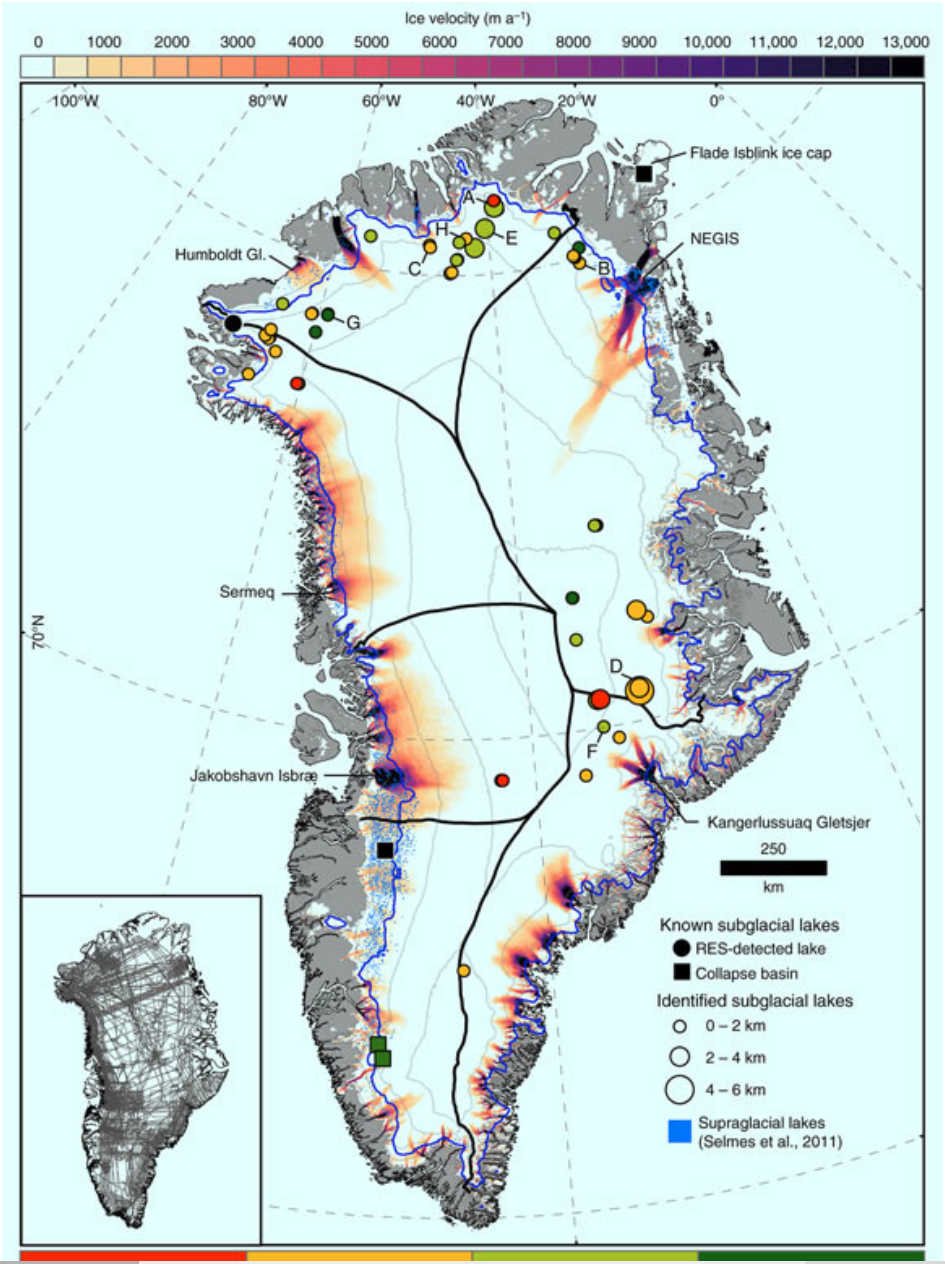
Life traces @z=-1 km



Sediments crumble as an underwater camera touches the bottom of Whillans Lake in Antarctica.

IMAGE COURTESY ALBERTO BEHAR, JPL/ASU, AND NSF/NASA

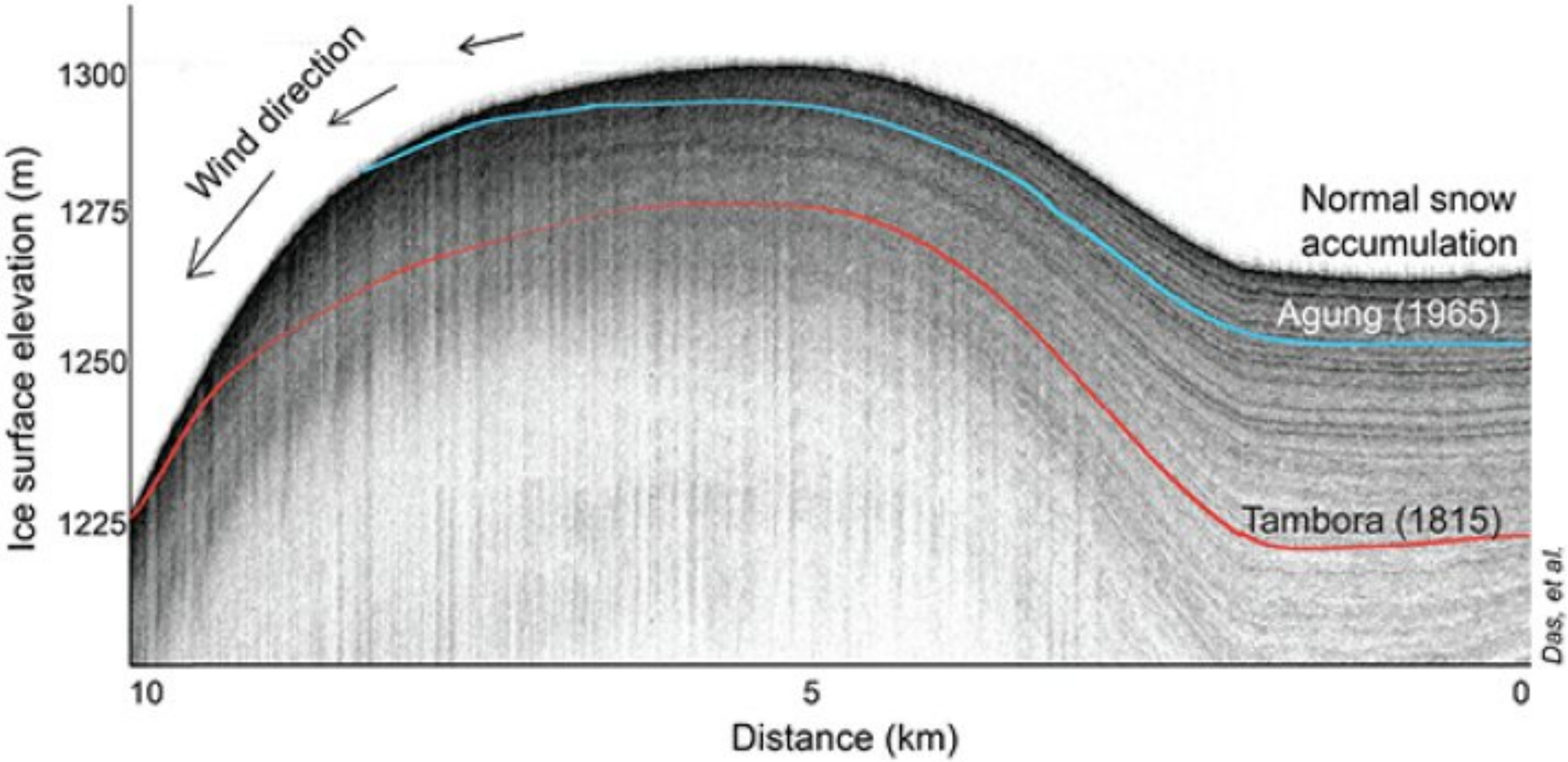
Lakes also under Greenland ice sheet!



Ice Cores and (fuzzy) WAIS psychrophiles

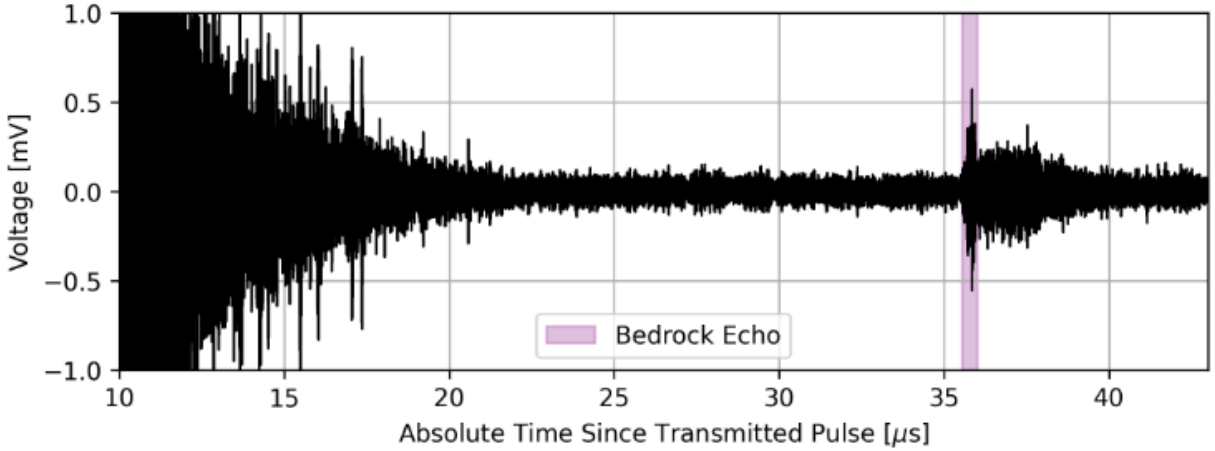
Radar shows ice layers: chronicle Volcanic past

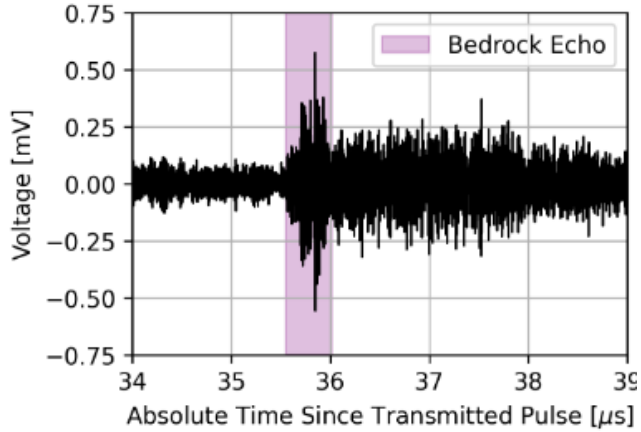
but these layers will also mess up radio waves from cosmic ray neutrino collisions, before they reach our sensors

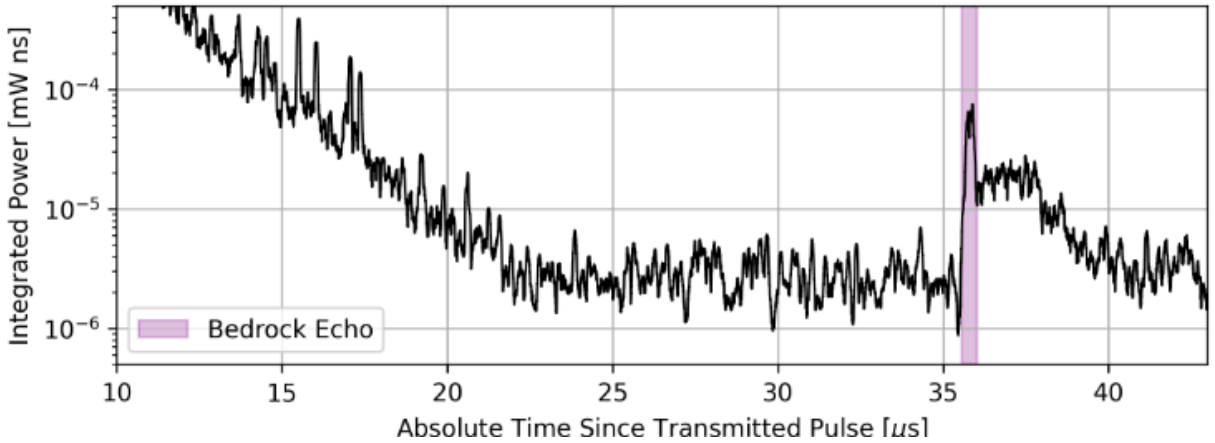


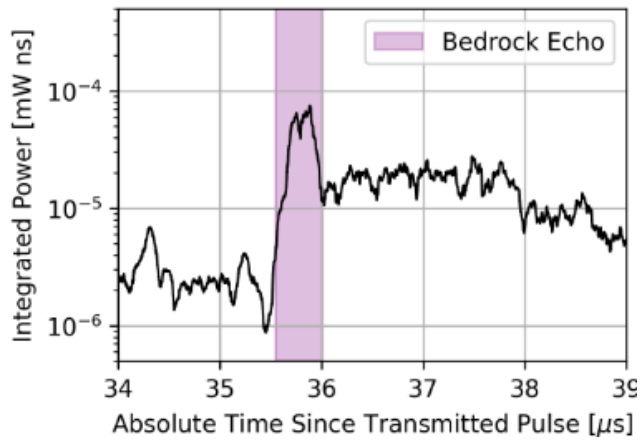
8/21 Summit radar: echoes visible through 6 km of ice!!

But also internal layers; typically due to volcanic ash deposition





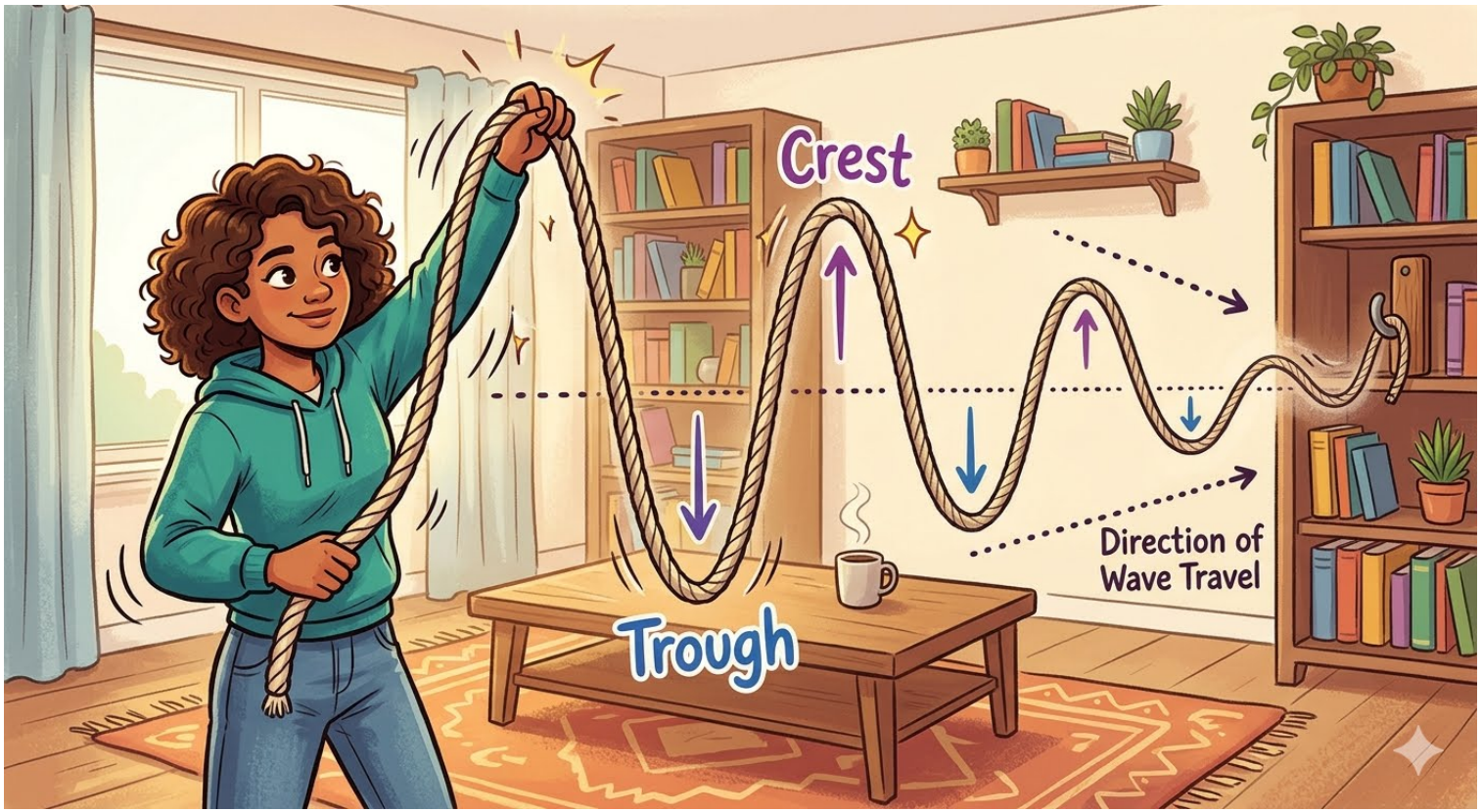




Ice Likes to Move

Birefringence!

Radio Waves moving up/down through ice, parallel to ice flow, move slightly (0.2%) faster than side-to-side!



Impact on radio-detection-of-neutrino experiments?

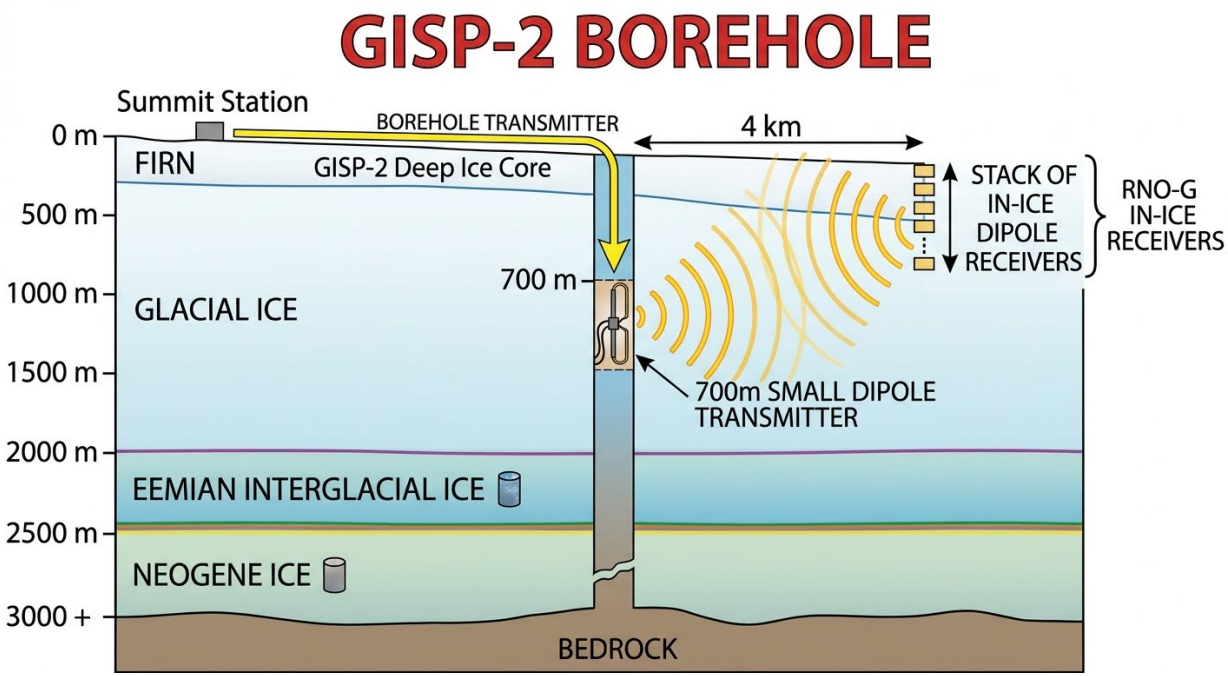
Thus far, radio-wave signals from neutrinos have never been observed. However, we know from 'control' experiments (send radio signal from pulser in the 1700-m deep SPICE hole at South Pole to radio receivers 2–5 km distant) that there are unexpected effects, for example:

1. At some transmitter depths, SPICE signals are very weak; moving transmitter by only 10–20 m up/down yields very strong signals.
2. In some cases, we send out a wave going up-down and, in the ice, it rotates to a wave going side-to-side (with a time delay)!
3. In some cases, there are 'density inversions' - ice density at 6 m greater than at 12 m!?

We want to understand why this happens; almost certainly, calculations of expected science results are overly optimistic since they exclude such effects!

Our (aspirational) field work:

1. Drill holes into ice (8 cm OD; 15–20 m deep); Analyze cores for density, impurities (salt) and 'internal layers'
2. Place a radio transmitter 700 m into the GISP-2 borehole (reached bed in 1993) and measure signal loss/scattering in distant RNO-G receivers.



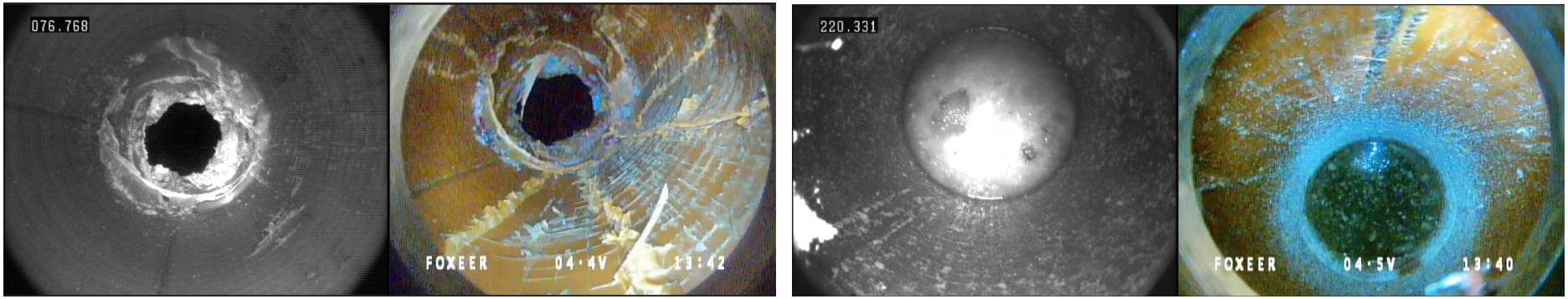
So far...

Internal ice layer (16Jun26):

Other clear anomalies - deeper ice sometimes less dense than ice above it!

GISP-2: 2007 v. 2026

L: 31-m casing / R: top-of fluid (3 hrs ago; obstruction 1–2 m in)

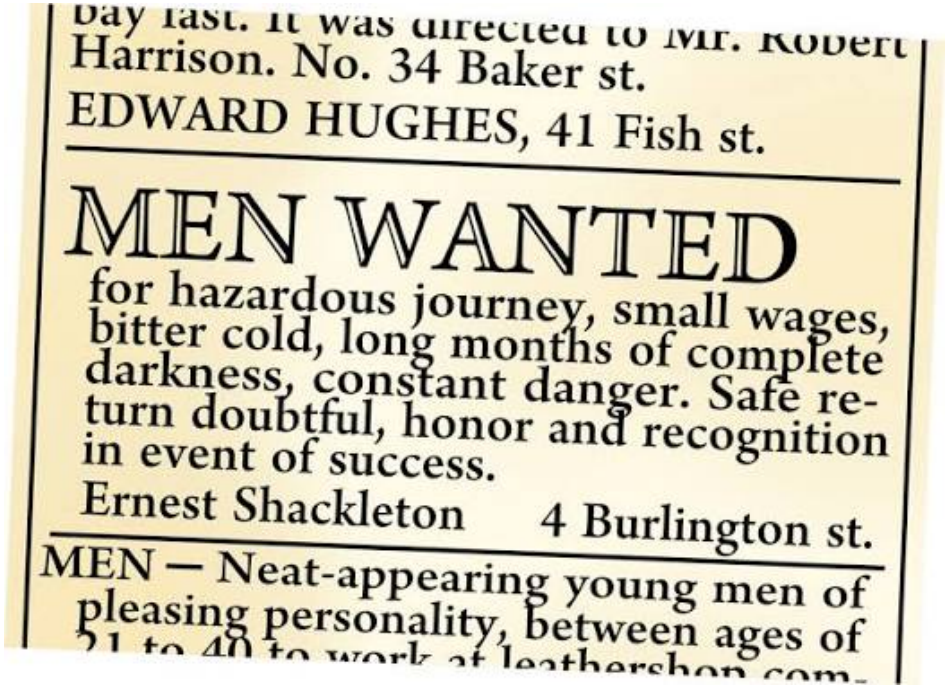


Battering ram a la' DISC hole 2021?
2026 top of fluid=2007 top of fluid (accounting for accumulation)⇒unlike DISC hole, no hole closure!

post-Summary

1. Owing to their inertness, neutrino 'astronomy' offers a new Window on Universe
2. Detect neutrinos indirectly, via radio-waves created after neutrino crashes into ice molecule
3. Here: want to characterize how ice can distort or alter radio signals before detection - broadcasts from GISP-2 would be big

(from recent grad recruiting talk) If this stuff interests you...


day last. It was directed to Mr. Robert
Harrison. No. 34 Baker st.
EDWARD HUGHES, 41 Fish st.

MEN WANTED
for hazardous journey, small wages, bitter cold, long months of complete darkness, constant danger. Safe return doubtful, honor and recognition in event of success.
Ernest Shackleton 4 Burlington st.

MEN — Neat-appearing young men of pleasing personality, between ages of 21 to 40 to work at leathershop com-

Acknowledgments

Thanks to the entire Summit community for making this such an enjoyable and productive place to work, incl.:

1. Cooks and kitchen staff for feeding us
2. Cargo for getting all our hardware here
3. Electrical, carpentry, machinery ops for providing hardware and infrastructure support
4. Station and field coordinators for their preternatural patience for entertaining random requests (at random hours)
5. Medical for keeping us healthy
6. anyone else I may have forgotten!

and thanks for listening!

Voodoo Child (slight return)

if anyone interested, RJ/Dylan will show video of camera going into GISP-2 hole