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Cosmic Neutrinos: Much ado about nearly nothing

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Special points of interest:

Neutrinos: light stuff..

Triton Fun stuff

Superfluous questions

Our universe is awash in neutrinos. The sun sends 60 billion of them each second through every square centimeter of your outstretched hand. Neutrinos are extremely small, almost massless elementary particles created in stellar processes. Supernovae release unimaginable numbers of them. Yet there's even more to the story: At this very moment, the space your body occupies is shared by 10,000,000 *relic* neutrinos from the Big Bang itself. Because they haven't interacted with anything since they "decoupled" from the rest of creation a mere second after the Big Bang, these cosmic neutrinos could give us a new window on the first moments of our universe—if we could find a way to "see" them!

This "cosmic neutrino background" started forming a mere 0.18 seconds after the Big Bang, at a time when temperatures exceeded 30 billion degrees Kelvin and particles whizzed around with energies of 3 million electron volts. Half a ton of mass crammed every cubic centimeter of space, and weak interactions between the closely packed particles spawned equal numbers of *electron neutrinos, muon neutrinos* and *tau neutrinos*—the three known flavors. The universe was now expanding wildly outward like a big balloon in each microsecond and cooling down dramatically in the first second of its existence.

As the one-second mark approached, the plummeting temperatures and densities were causing the *weak nuclear force* to lose its influence on matter. Particles were fleeing too quickly to be affected by this slow-acting force. Neutrinos—which respond primarily to the weak force--ceased interacting with other particles. Particles started to precipitate out of this hot gaseous mix. Tau and muon neutrinos froze out of the mix first. Electron neutrinos froze out less than a second later, when the energies dropped to ~ 2 million electron volts. In the brief moment between those two events, temperatures had dropped 10 billion degrees Kelvin !

Another 100 seconds would elapse before deuterium and helium began forming. A whopping 380,000 years beyond that, the microwave background energy started travelling through the universe and was detected by the microwave instruments of Penzias and Wilson in Holmdel, New Jersey. (Arno Penzias and Robert Wilson were the discoverers of the 3 degree cosmic microwave background (CMB) radiation from the early universe which confirmed the Big Bang and later garnered them the Nobel Prize in Physics.)

The universe has cooled considerably in the last 13.7 billion years of its existence. Today, those neutrinos have cooled down to 1.94 deg Kelvin, a mere 0.167 of an electron volt. That amounts to a redshift of about 12 billion!

Why are the 1.94 K cosmic neutrinos even colder than the 2.725 K cosmic microwaves? The furiously energetic particle soup from which neutrinos emerged was peppered with photons spontaneously tearing themselves apart into *electron-positron* pairs, and those pairs combining back into photons. At the ripe old age of one second, photon energies dropped below 1 million electron volts, the minimum needed to forge an electron-positron pair. Photons were stuck being just photons, and an excess number of them accumulated, dumping their energy and entropy back into the expanding plasma. This brief thermal pulse reheated the universe by 35% —

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Neutrinos: ***continued***
Photos/Info: Symmetry magazine/Fermilab/SLAC/BooNE/Super-K

--but the (almost) completely decoupled neutrinos were bypassed, left out in the multi-billion-degree "cold".

This is a wonderful story, but can it be verified? Neutrinos, never sociable, interact even less at low energy. Cosmic neutrinos (or "relic" neutrinos, from the Big Bang) run a factor of millions below our detection threshold, making their solar-generated cousins look positively gregarious! When Wolfgang Pauli predicted the existence of neutrinos in 1930, he apologized for postulating a particle that was, at the time, undetectable. Had he predicted Big Bang neutrinos, he would have been disconsolate!

As it turns out, detection may just be possible, and indirect verification has already been achieved. Neutrinos affect the expansion rate of the universe, and that alters the abundance of helium-4, (a heavier isotope of the helium atom) which we can measure.

The "ripples" in the Cosmic Microwave Background are also affected by neutrinos. Dark Energy accounts for about 74% of the mass-energy in our universe and neutrinos, a modest 0.3%. But when the Cosmic Microwave Background formed, and space was orders of magnitude more compact, Dark Energy was negligible (well under 1%) and neutrinos were fully 10% of the total mass-energy of the universe.

Can we even hope for direct detection of any of these neutrinos? The number of relic neutrinos is vastly exceeded by neutrinos from the sun (and from nearby nuclear reactors!). But the 300 kilometer per second motion of the earth through the Cosmic Neutrino Background creates a wind, and the pressure from relic neutrinos at small energies actually exceeds that from the others, which have a vast energy range. This makes them more detectable.

Of course, we could go back to older ideas, like an accelerator wrapping all the way around the earth (expect one detection every 100 years), or a lead shield thicker than the known universe. All this confirms the old saying that "neutrinos induce courage in theorists, and perseverance in experimenters."

Element abundances and microwave "ripples" tell us about how neutrino mass affected the expansion of the universe and give us confidence that there are just three flavors of ordinary, low mass neutrinos. The direct detection of these older neutrinos would confirm the effect of the weak force interactions themselves and reveal exotic types of neutrinos that characterized the first second of time—and likely shaped the universe we see today.

Just as the lowly pawn is pivotal in chess, the ghostly neutrino plays a key role in the unfolding story of our universe. Once neutrinos decoupled, neutrons could be locked into nuclei, forging the early elements as space cooled. As Pauli himself put it, neutrinos "let the stars shine in peace." For a particle that's nearly nothing, neutrinos are really something else.

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References:

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   (the Japanese neutrino experiment):
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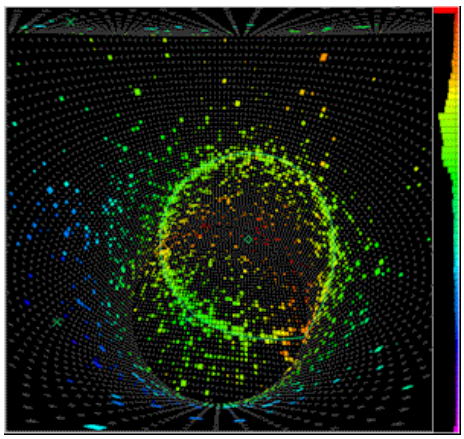
Particles, particles, everywhere
Neutrinos seen in cloud chambers



Neutrino ring of light

Path of an electron neutrino observed by the Čerenkov radiation (light) it causes when it impacts an electron; this occurs when neutrinos interact with water deep underground in the Super-Kamiokande experiment in Japan

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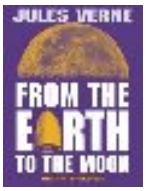

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Superfluous Questions:

1) In the TV show *I Dream of Jeannie*, Tony Nelson's best friend is *who* ?

a) Col. Bellows b) Gen. Petersen c) Maj. Healey d) Gen. Schaffer

2) In the TV show *Bonanza*, what real-life lake bordered the Ponderosa Ranch ?

a) Lake Arrowhead b) Lake Merced c) Lake Shasta d) Lake Tahoe

3 What state contains *all* of these cities: *Arco, New Plymouth, Grangeville, Sugar City* ?

a) Alabama b) Vermont c) Colorado d) Idaho

4) What does the symbol *omega*, Ω , signify in astronomy ?

a) vacuum energy b) density parameter c) temperature d) central Comptonization

—> ANSWERS in next months issue of the Science Newsletter ! <——-

** ANSWERS to July's Superfluous Questions: 1. d) Mars 2. c) Bengie Molina 3. d) 1960 4. b) Southern Cross