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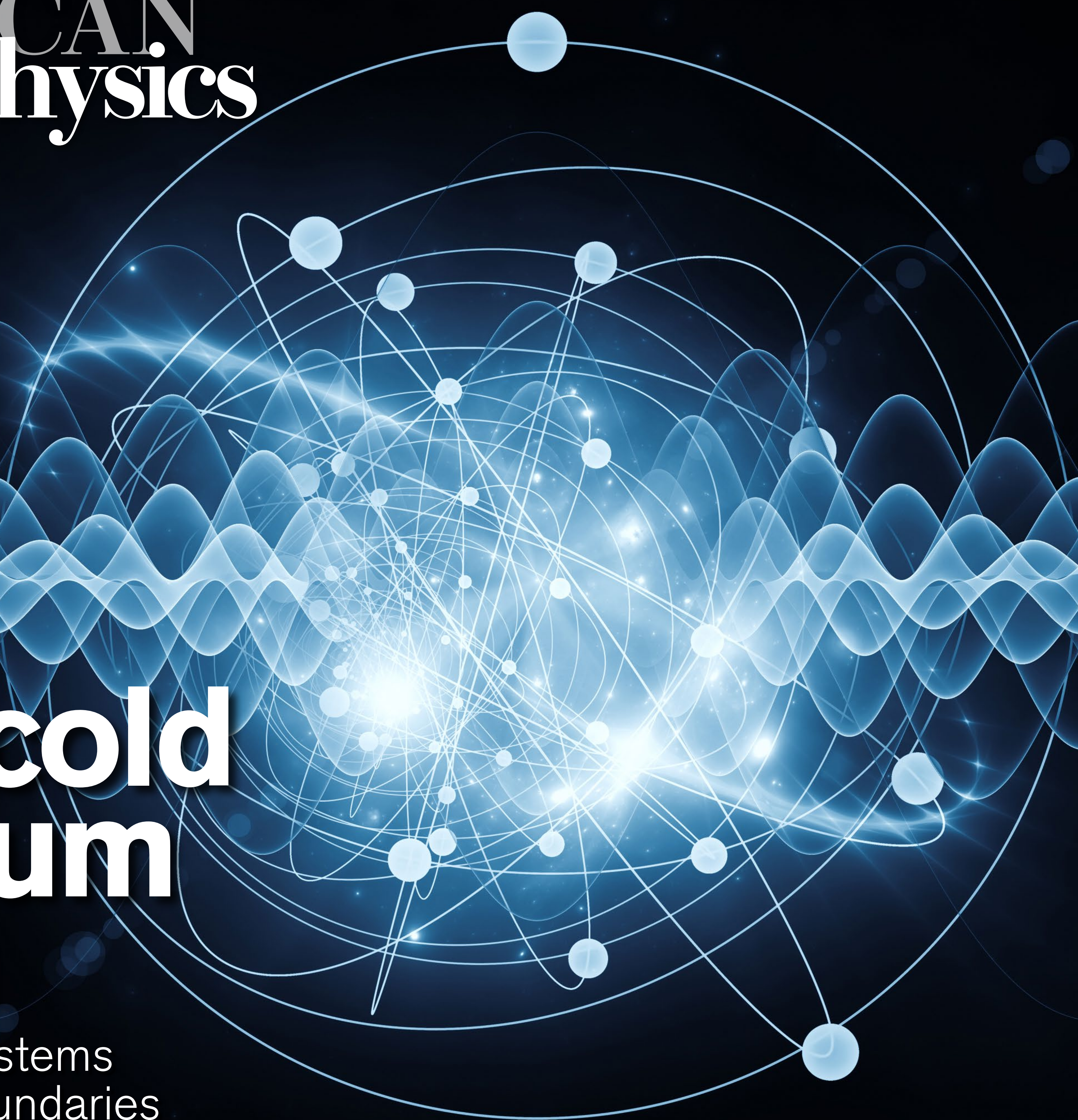

Plus:

WHY WE CAN'T SETTLE ON MARS

MERGING SUPERMASSIVE BLACK HOLES TO SEND OUT A FLARE

STUNNING NEW IMAGES OF OUR SUN

The Supercold Quantum Realm

Ultracold atomic systems are pushing the boundaries of known physics and may even set the stage for quantum computing

WITH COVERAGE FROM nature

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LIFE, UNBOUNDED

Death on Mars

The Martian radiation environment is a problem for human explorers that cannot be overstated

As is the way of news cycles, in recent days we're back to hearing about plans for setting humans up on Mars. A few years ago this idea was in the spotlight because of now defunct efforts such as Mars One, which somehow got 200,000 people to express interest in what would have been a lifelong trip to the Red Planet. We've also seen Elon Musk's vision of how SpaceX would eventually provide a human "backup plan" by permanently settling Mars.

In January, Musk brought the idea up again, in typically provocative fashion, by talking about sending one million people to Mars by 2050, using no fewer than three Starship launches per day (with a stash of 1,000 of these massive spacecraft on call). He also raised the possibility of giving Martian-wannabe settlers loans to enable them to pay for the opportunity. Naturally, for many observers this also provoked discussion of indentured servitude for those "seeking a new life in the off-world colonies," to paraphrase a famous line from the 1982 movie *Blade Runner.*

But whatever you think about Musk's pronouncements or about his businesses, there are some very serious scientific hurdles to setting humans up on Mars (and in full disclosure, I own a few Tesla shares, and I greatly admire his vision and drive for terrestrial change, as well as the space-launch business, but I'm also somewhat wary of people being taken seriously just because they have amassed a lot of cash).

One of those hurdles is radiation. For reasons unclear to me, this tends to get pushed aside compared with other questions to do with Mars's atmosphere (akin to sitting 30 kilometers above Earth with no oxygen), temperatures, natural resources (water), nasty surface chemistry (perchlorates) and lower surface gravitational acceleration (one third of that on Earth).

But we do have good data on the radiation situation on Mars (and in transit to Mars) from the Radiation Assessment Detector (RAD) that has been riding along

NASA, JPL-CALTECH AND MSSS

with the Curiosity rover since its launch from Earth.

The bottom line is that the extremely thin atmosphere on Mars and the absence of a strong global magnetic field result in a complex and potent particle radiation environment. There are lower-energy solar wind particles (such as protons and helium nuclei) and much higher-energy cosmic-ray particles crashing into Mars all the time. The cosmic rays, for example, also generate substantial secondary radiation—crunching into Martian regolith to a depth of several meters before hitting an atomic nucleus in the soil and producing gamma rays and neutron radiation.

An analysis by Donald M. Hassler and his colleagues, published in 2014 in *Science*, noted that a human expedition with 360 days total in interplanetary space plus 500 days on Mars itself would expose astronauts to just over one sievert of radiation. Now, statistically that's not too awful. It would increase your odds of getting fatal cancer by some 5 percent over your lifetime.

But if we consider just the dose on Mars, the rate of exposure averaged over one Earth year is just more than 20 times that of the maximum allowed for a Department of Energy radiation worker in the U.S. (based on annual exposure).

And that's for a one-off trip. Now imagine you're a settler, perhaps in your 20s, and you're planning on living on Mars for at least (you'd hope) another 50 Earth years. Total lifetime exposure on Mars? Could be pushing 18 sieverts.

Now that's kind of into uncharted territory. If you got eight sieverts all at once, for example, you would die. But getting those eight sieverts spread out over a couple of decades could be perfectly survivable—or not. The RAD measurements on Mars also coincide with a low level of solar-particle activity, and they vary quite a bit as the atmospheric pressure varies (which it does on an annual basis on Mars).

Of course you need not spend all your time above surface on Mars. But you'd need to put a few meters of regolith above you or live in some deep caves and lava tubes to dodge the worst of the radiation. And then there are risks not to do with cancer that we're only just beginning to learn about. Specifically, there is evidence that neurological function is particularly sensitive to radiation exposure, and there is the question of our essential microbiome and how it copes with long-term, persistent radiation damage. Finally, as Hassler et al. discuss, the "flavor" (for want of a better word) of the radiation environment on Mars is simply unlike that on Earth, measured not just by extremes but by its makeup, comprising different components than on Earth's surface.

To put all of this another way: in the worst-case scenario (which may or may not be a realistic extrapolation), there's a chance you'd end up dead or stupid on Mars. Or both.

There is also a real difference between a small group of astronauts being constantly monitored, advised and trained to optimize their time on Mars (whether brief or long term) and a million settlers eager to be pioneers. The old trope of "what could possibly go wrong?" springs to mind.

Obviously no one, not even an emboldened SpaceX, is going to plop humans down on Mars en masse without worrying about all of this. But I think it's an open question as to just how big a challenge the radiation hurdle turns out to be, along with all the other hurdles.