Rethinking the Nebra Sky Disk

The June 2020 issue of PHYSICS TODAY features an image of the Nebra Sky Disk as the illustration for a book review by Bernie Taylor (page 53). The sky disk is one of the earliest depictions of recognizable astronomical objects and relationships. Researchers have analyzed the disk extensively and debated about when it was created and where it was found. The disk had been used for generations, and elements were added to it over the years.[1]

The 30-centimeter disk originally featured elements that appear to be stars, the Sun or a full Moon, and a crescent Moon. Two golden arcs (one of which is now missing) were later added to the rim, which may have changed the disk's function. It has been posited that those arcs represent the distances the sunrise and sunset travel between solstices at the latitude where the disk was purportedly found in 1999 near Nebra, Germany.

Added later to the disk was another arc with two distinct lines along its length and many shorter ones radiating from its sides. Some have interpreted the object to be a mythical boat that ferries the Sun across the sky, with the short engraved strokes representing the oars.[2]

Images of the disk are often oriented so that the third arc is on the bottom, emphasizing the possibility that the symbol represents a boat. But if the two side pieces indeed represent the extent of sunrises and sunsets throughout the year, then the disk is meant to be viewed as though the edge represents the horizon, as with modern overhead sky charts. If that is the case, the disk's iconography might be interpreted differently.

The disk could be depicting the star cluster nearly midway between the side arcs—often thought to be the Pleiades—in the sky to the south, as it would sometimes appear from the area around Nebra. The object often thought to be a Sun boat then would be a fuzzy swath, low in the sky and to the north. I propose that it was intended as a representation of the aurora borealis, which would have made periodic appearances in Nebra. That would agree with the observational nature of the rest of the disk.


The Nebra Sky Disk

References

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3-2-1 Contact: Scientists at the writers' table

Ingrid Ockert's article "S is for Science: The making of *3-2-1 Contact*" (PHYSICS TODAY, January 2021, page 26) ably portrays the pioneering roles viewer research and innovative programming played in the landmark series. But as a former curriculum developer at the Children's Television Workshop, which produced *3-2-1 Contact*, I'd like to point out that the article omits mention of a less obvious way in which the show broke new ground.

Rather than relying solely on outside content advisers, the Children's Television Workshop adopted the novel strategy of also bringing people with scientific expertise in-house to collaborate on the day-to-day making of *3-2-1 Contact*. After the show's maiden year, that responsibility fell to the biologist Ed Atkins, who went on to oversee all the science in the series. He was perhaps the first scientist invited into the intricacies of television production on this scale.

He was an inexhaustible source of ideas for episodes and a conduit for the many other scientists who contributed to the show in front of the camera or behind the scenes. In his work with writers, animators, editors, and producers, Atkins touched every science-related image and idea that appeared on screen and essentially established the role of content director in science television thereafter.

That so many in the scientific community today think back to *3-2-1 Contact* and smile is a wonderful testament both to the soundness of the Children's Television Workshop's vision of melding content with production in the development of the series and to Atkins's unique gifts in that arena.

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▶ **Ockert replies:** Ralph Smallberg brings up an excellent point. While some 1970s shows had science advisers, the Children's Television Workshop was one of the first production companies to give them a seat at the writers' table. In 1977 the company launched a three-day workshop in Glen Cove, New York, bringing together leading scientists and educators—including MIT physicist Philip Morrison—to brainstorm topics for what became *3-2-1 Contact*. From there, the Children's Television Workshop formed a formal science advisory committee for the show, intentionally including scientists from Black, Hispanic, and Asian American communities.

As I note in the article, the first content director of *3-2-1 Contact* was Charles Walcott, a biologist at the State University of New York at Stony Brook, who did a wonderful job of facilitating the collaborations between the scientists and the production staff. Likewise, Ted Ducas, a physicist at Wellesley College, deserves credit for his role in cowriting the show's excellent first season.

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Another look at the proton sea

Johanna Miller nicely summarizes the current experimental situation with the puzzling asymmetry of the proton's antiquark "sea" in the May 2021 issue of PHYSICS TODAY (page 14). She describes the SeaQuest experiment, which found that there are about 50% more $\bar{d}$ antiquarks than $\bar{u}$ antiquarks. The result is surprising, since the traditional mechanism generating the sea was commonly expected to be mediated by gluons, which are "flavor blind" and cannot tell $\bar{u}$ from $\bar{d}$.

Miller's report mentions two theoretical ideas proposed to explain the asymmetry. One is that the presence of two u valence quarks leads to "Pauli blocking" of sea u quarks, the twin brothers of $\bar{u}$ antiquarks. But quarks have six states available: three colors × two spin orientations. In addition, valence and sea quarks overlap little in momentum space. Pauli blocking is therefore way too small to explain the data. (I'll turn to the second idea—the contribution of the pion cloud—at the end.)

Unfortunately, Miller does not mention a third idea that has been put forth, which is more nontrivial and seems likelier to explain the puzzling asymmetry. It started with an observation by Alexander Dorokhov and Nikolai Kochelev[1] that the so-called 't Hooft effective four-quark Lagrangian[2] is "flavor nondiagonal," leading to processes $u \to u(\bar{d}d)$ and $d \to d(\bar{u}u)$ but not to $u \to u(\bar{u}u)$ and $d \to d(\bar{d}d)$.

In a way, the effect is also due to the Pauli exclusion principle, but at a different level. Topological tunneling events, known as instantons, create fields so strong that they fix the color and spin states of participating quarks uniquely. Instead of six possibilities, there remains only one, thus a complete blocking. Since the proton has two valence u quarks and only one valence d quark, that mechanism would suggest $\bar{d}/\bar{u} = 2$ rather than 1.

Recently I made the first attempt to evaluate that effect quantitatively, by calculating the wavefunction of the five-quark $uudu\bar{u}$ and $uudd\bar{d}$ sectors of the proton induced by the 't Hooft Lagrangian.[3] The results approximately match the data, in magnitude and momentum dependence.

How can one test that idea further? If that explanation is true, the sea of Δ^{++} baryons, which have three up quarks, would have only $\bar{d}$ antiquarks (at corresponding momentum fraction x). It is hardly possible to check that experimentally, but it can be tested numerically, via lattice gauge theory.

A second test is related to the other explanation Miller mentions, the pion cloud. While pions can indeed generate asymmetry in the isospin of the sea, they will not do so for the spin, since pions have spin zero. The 't Hooft Lagrangian, on the other hand, leads to strict predictions for the quark polarizations. For example, a left-handed up quark u_L can produce only a 100% polarized $\bar{d}_R d_L$ pair. Therefore, a key to the sea's antiquark asymmetry should come from future theoretical and experimental investigations that relate isospin and the spin asymmetry.

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Rare earths in space communications

I have enjoyed reading several items on the rare-earth elements in PHYSICS TODAY over the past few years. David Kramer's most recent piece focused on the topic (February 2021, page 20) was about neodymium-based rare-earth magnets, but readers might be interested to learn of another class of rare-earth magnets based on samarium. Among their applications are traveling wave tubes (TWTs), which form the backbone of the world's entire space communications system.

The core feature of most TWTs is a stack of samarium–cobalt ($SmCo_5$ or Sm_2Co_{17}) magnetic rings, each magnetized in opposition to its neighbor. One design uses a 25 cm stack of 16 rings that are 4 cm in diameter. The tubes can amplify and transmit millimeter waves in frequency ranges of 300 MHz to 50 GHz. They have bandwidths as high as two octaves, power gains of 40–70 dB, and output powers of a few watts to megawatts. TWTs also exhibit excellent reliability. *Voyager 1*, launched in 1977, has a SmCo TWT produced by Watkins-Johnson that is still broadcasting from more than 23 billion kilometers away from Earth!