A WHALE'S VIEW

Q: DO WHALES HAVE ASTRONOMY CLUBS? A WHALE'S EYE IS LARGER THAN MOST BINOCULARS; WHAT WOULD IT SEE WHEN SURFACED?

***John Henderson,** Mojave, California*

Bigger eyes let an animal see more stars. A whale's large pupil might enable it to see more than twice as many stars as a human. RENACAL1/ISTOCK/THINKSTOCK

A: Just as with a big optical telescope, it is the size of the eye's aperture (i.e., pupil) that determines how many stars are seen — the bigger the pupil, the more light is captured from each star. Even extremely dim stars are visible with a large telescope. This is equivalent to saying that a larger telescope lens allows one to see stars of higher magnitude.

The same is true of eyes. In all eyes, the pupil functions as the aperture through which photons reach the light-sensitive cells of the retina. On a moonless starry night, human pupils reach a maximum width of 8 millimeters. With such a diameter, we are able to discern stars with a magnitude as faint as 6.5, allowing us to see over 9,000 stars in the entire night sky.

What about whales, basking on a starlit ocean surface at night? Remarkably, despite the often gigantic sizes of whales, their eyes are not as large as one might think. Even the largest whale eyes studied are only around 70 millimeters across (compared to around 25 millimeters for the human eye), but these eyeballs have thick outer layers of muscles and insulating fat. The actual eye itself, embedded within these layers, is typically only around 40 millimeters across. The pupil is only half as large again as our own pupil — around 12 millimeters wide in the dark (as measured in southern right whales, gray whales, and bowhead whales), so nothing near as large as the objective lenses of typical binoculars! Assuming similar exposure times and that the photoreceptors of whales are as efficient at absorbing photons as our own eyes are (which is amazingly only around 5 to 10 percent), whales would be able to see stars almost one magnitude fainter than we can (around 7.4).

This would allow them to see some 2½ times as many stars, in fact around 22,500! While this number does seem impressive and would give whales a superior view of the night sky compared to our own, imagine the number of stars that would be seen by the giant deep-sea squid *Architeuthis dux* if it were ever to come to the surface. With eyes almost 30 centimeters across and with pupils 9 centimeters wide, this squid could potentially see stars as faint as magnitude 12, which is truly staggering!

Eric Warrant
University of Lund, Sweden

The ringed planet's shadow blocks out the Sun in this 140-image mosaic of Saturn's surroundings captured by NASA's Cassini mission. NASA/JPL-CALTECH/SSI

Q: HOW ARE SATURN'S RINGS REPLENISHED? WILL THE PROCESS SHUT DOWN?

Doug Kaupa
Colorado Springs, Colorado

A: The age, origin, and evolution of Saturn's bright icy rings are some of the biggest mysteries in the solar system. Most theories have the main rings forming from the partial or total destruction of an icy moon (roughly 250 to 3,000 miles [400 to 5,000 kilometers] in diameter) some 3.8 to 4.5 billion years ago. We would expect the constant influx of micrometeoroids to have substantially darkened the rings over time, but their nearly pure white appearance leads to a paradox: The rings are likely old, but they look young!

One way to solve this paradox is to recycle the rings. If micrometeoroid contamination is limited to the ring particles' surfaces, it is possible that when particles collide and re-accrete, or when large particles are broken up by meteoroid impacts, the pristine interior ice is exposed, making the particles look new again. Also, if the dense B ring has much more mass than expected, the ring can act as a reservoir for fresh ice, replenishing the entire ring system over time.

The mass of the B ring is unknown. The Cassini mission's "Grand Finale" orbits in 2017 will place the spacecraft between the rings and Saturn and allow, for the first time, a direct measurement of the rings' mass. This may help solve the paradox once and for all.

Recycling and replenishment use material already in the rings. Even though it may take billions of years to destroy them, the lifetime of Saturn's rings is still finite.

Finally, we do know where two rings come from. The enormous faint E ring is produced from ice particles emitted by geysers on the moon Enceladus, while dust from the surface of the tiny moon Aegaeon replenishes the G ring.

Robert French
SETI Institute
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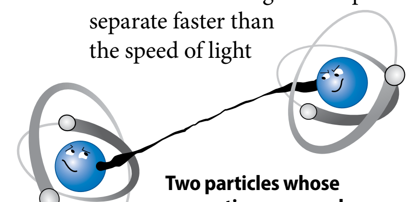
Q: COULD QUANTUM ENTANGLEMENT BE A RESULT OF THE BIG BANG?

Eldon Alden
Howe, Oklahoma

A: If accelerated inflationary expansion occurred in the early universe, inflation itself is what puts the "bang" into the Big Bang. During inflation, the universe likely contained a chaotic soup of exotic high-energy fields. When inflation eventually ended, the energy in these fields was converted into the usual zoo of familiar particles like protons and electrons in a process called reheating.

The most common way to produce entangled states — where two particles remain mysteriously correlated regardless of distance — is when particles or fields interact or are created together. Since we believe quantum mechanics would hold during inflation, entanglement between different degrees of freedom in these exotic fields would be a natural outcome. It is an open question whether inflationary-era entanglement could survive the chaotic process of reheating.

Purely considering causality, inflation makes regions of space separate faster than the speed of light (this is allowed in general relativity). So today, regions once in causal contact during inflation are now out of causal contact, beyond each other's so-called cosmic horizons.



Two particles whose properties are somehow connected are "entangled." ASTRONOMY: ROEN KELLY

The main question is whether any entanglement set up during inflation could survive and persist to somehow produce observable effects today. The answer is that we don't know. We probably require a full theory of quantum gravity to even formulate such a question precisely. But even without knowing the details, cosmic scale tests of quantum mechanics are probably the best way to look for any strange effects. It certainly would be wonderful if the early universe left us such clues because it could let us use local measurements of space-time to test questions about parts of the universe that seem inaccessible in principle.

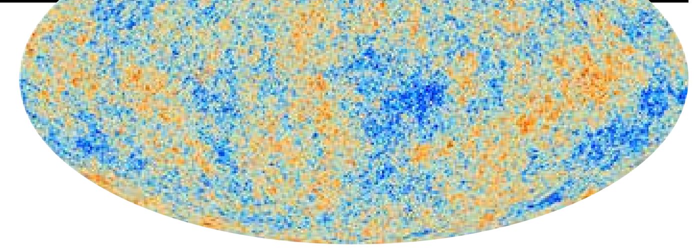
Andrew Friedman
Massachusetts Institute of Technology, Cambridge

Q: A WHITE DWARF PULLS MATTER FROM ITS BINARY AND EXPLODES IN A NOVA. YET WHEN THE MASS HITS A CERTAIN LIMIT, THE STAR BURSTS IN A TYPE IA SUPERNOVA AND IS DESTROYED. WHY THE DIFFERENCE?

Suzanne Farkas
Amherst, Ohio

A: A nova is a relatively small surface explosion from a white dwarf below the Chandrasekhar limit of 1.4 solar masses. Novae can recur on timescales as short as a year. Large telescopes have been around for only about a century, limiting our ability to measure recurrent nova timescales; nova explosions could well recur after thousands or millions of years.

A type Ia supernova explosion occurs when the white dwarf pulls enough material from its companion star to reach 1.4 solar masses. A likely mechanism is a small thermonuclear flame near the center that propagates so fast that the entire white dwarf incinerates before it can expand and cool. So far there is no clear consensus on how a type Ia (or nova) explodes. A type Ia explosion easily can burn more than half of the white dwarf into iron, so next time you fry something in an iron pot, a good chunk may have synthesized in such explosions over billions of years. Another oddity is that while most of the energy is released in a few seconds, the peak brightness occurs three weeks later!



Astronomers are putting great effort into mapping the cosmic microwave background, our universe's oldest light. ESA/THE PLANCK COLLABORATION

This delay is because the ejected material is so dense after the explosion that photons can barely escape. Over time, the rapidly advancing ejected material moving at about 22 million mph (10,000 km/s) becomes less dense and more photons escape, resulting in an observable "rise time." Finally, note that "core collapse" supernovae, the natural evolutionary end for large stars, are much more common than type Ia, but the type Ia are spectacularly bright and seen over much larger distances.

Richard Kessler
University of Chicago

Q: IS THE COSMIC MICROWAVE BACKGROUND A SHELL AROUND US? OR ARE THE MICROWAVES EVERYWHERE IN THE UNIVERSE?

Barry Berman
Sparks, Maryland

A: The cosmic microwave background (CMB) radiation fills the universe and travels in all directions. As we see it from here in satellite maps, it is about equally bright in all directions, and that's one of the main reasons we know it's cosmic. The Greek word is *isotropic*, which means the same in every direction.

Assuming we are not at a special spot, that also means that the radiation is the same brightness in all locations throughout the universe, at least if you could take a measurement at the same time at each location (13.8 billion years after the Big Bang). The maps we make of the CMB brightness show it as it is now arriving here from everywhere else, but if you wait a billion years, there still will be radiation arriving from everywhere else.

There is one sense in which we see the CMB coming from an apparent shell around us. The universe became fairly suddenly transparent when it was about 380,000 years old and the temperature was down to about 3,000 kelvins. So we see each CMB photon as coming from the last place it bounced off an electron. It's a little like looking at the Sun. We see the Sun's light coming from features on what seems to be a surface, but the Sun doesn't have a surface — it is gaseous. Right now we are receiving light that escaped from the Sun 500 seconds ago, and if we wait a day we will still be receiving light from the Sun that has taken 500 seconds to arrive. It's like that with the CMB too, except it has taken 13.8 billion years for the light to arrive here instead of 500 seconds.

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Send us your questions

Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.