

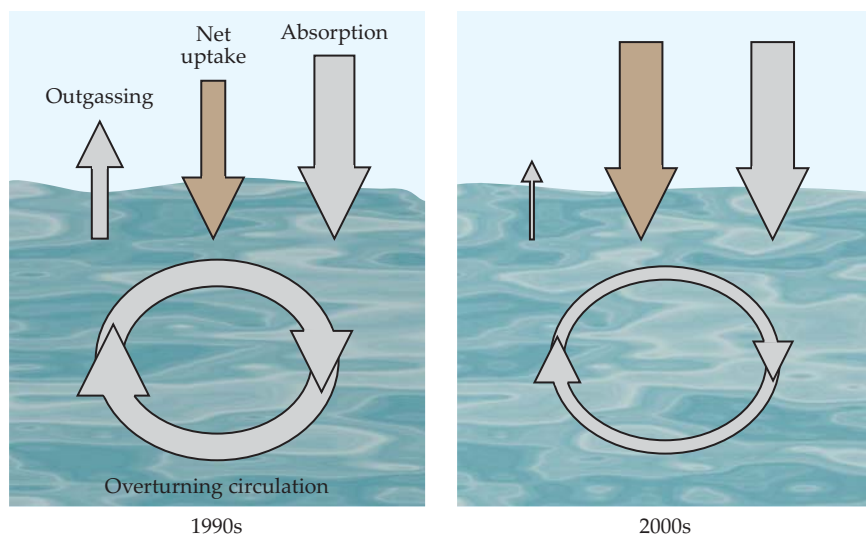


FIGURE 2. CIRCULATION'S ROLE in the ocean's carbon dioxide uptake. The overturning circulation in the upper 1000 m of the ocean transports absorbed atmospheric CO_2 downward but simultaneously brings up natural CO_2 from the deep. Combined with increased atmospheric CO_2 concentrations, weakening overturning circulation in the 2000s resulted in greater net uptake (brown) of CO_2 in that decade. (Adapted from ref. 3.)

(1 Pg = 10^{15} g). The largest reduction occurred in the subantarctic (latitudes 55° S to 35° S), where newly risen deep water in the Southern Ocean encounters the atmosphere.

When the overturning circulation weakened in the 2000s, less anthropogenic CO_2 was sent down to the depths, but even less deep-ocean carbon escaped into the air. On balance, therefore, the

ocean took up more CO_2 than before. That might sound like good news; after all, it means less CO_2 accumulated in the atmosphere. However, coral bleaching and other consequences of ocean acidification make increased CO_2 uptake by the ocean a mixed blessing at best.

Besides, says DeVries, "we think that the effect is going to gradually wear off." The amount of deep ocean CO_2 rising to the surface will eventually plateau even as ever more fossil-fuel CO_2 makes its way into the atmosphere. The balance will tip in favor of reduced ocean CO_2 uptake. Then the slowing ocean overturning circulation will seem to be bad news all around.

Sung Chang

References

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2. P. Landschützer et al., *Science* **349**, 1221 (2015); D. Munro et al., *Geophys. Res. Lett.* **42**, 7623 (2015).
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PHYSICS UPDATE

These items, with supplementary material, first appeared at www.physicstoday.org.

THE UPPER ATMOSPHERE'S NATURAL THERMOSTAT

Occasionally, our sun belches massive plumes of plasma from its corona that stream Earthward. When a fast coronal mass ejection (CME) arrives, it compresses Earth's magnetosphere and can reconfigure the planet's magnetic field lines. The reconfiguration enhances electric currents and energizes charged particles.

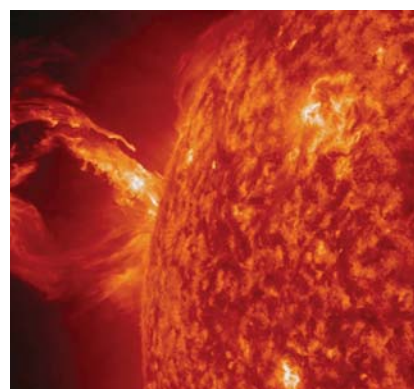
Those currents and particles heat

the tenuous atmosphere—hundreds of kilometers in altitude—which then expands outward. Low-orbiting satellites should thus experience more drag. But measurements of their orbital decay reveal that the drag from CMEs isn't always as great as expected. Researchers led by Delores Knipp (University of Colorado Boulder) now explain why. Under some circumstances, the same CME that heats the upper atmosphere also triggers chemical reactions that quickly cool it. Charged particles with energies greater than about 10 keV split molecular nitrogen, and the free N atoms react with oxygen to produce nitric oxide. The NO molecules, often created in a vibrationally excited state, spontaneously radiate in the IR. The upshot is that they remove energy from the heaving atmosphere and thereby cool and contract it.

From an archive of satellite data, the researchers analyzed the IR flux from NO as it responded to nearly 200 isolated CMEs that struck Earth between 2002 and 2014. They found that the fastest CMEs—ones whose speeds exceeded 500 km/s and produced shock waves ahead of the ejected plasma—led to early and copi-

ous NO production and emission. The shock-led CMEs transferred so much energy into the upper atmosphere that they generated more than twice the IR flux as non-shock-led storms. Knipp and her colleagues are hopeful their analysis will offer new insights for atmospheric modelers and satellite-drag forecasters trying to plan and track orbits that avoid collisions with space debris. (D. J. Knipp et al., *Space Weather*, doi:10.1002/2016SW001567.)

—RMW



NASA/GODDARD/SDO

HELIUM COMPOUND MAY FORM UNDER PRESSURE

Helium doesn't play well with others. Beyond its noble gas designation on the periodic table, it has the lowest electron affinity—zero—among the elements, and the highest ionization energy. Scientists have managed to mechanically pack He atoms with other elements, but the He has little effect on those compounds' characteristics.

Now an international team has presented evidence for a compound whose electronic structure and thus its physical properties are influenced by its He components. Researchers led by Artem Oganov ran a crystal structure prediction algorithm to play matchmaker for He and found that the compound Na_2He should form at high pressures. The researchers shared their prediction

with Alexander Goncharov and colleagues, who loaded He gas and solid sodium into a diamond-anvil cell at the Carnegie Institution for Science. After increasing the pressure to 140 GPa and heating the sample, Goncharov's team noticed a marked shift in material properties. New peaks appeared in x-ray diffraction patterns, and the sample's melting point rose to more than 1500 K; pure Na melts at about 550 K.

The scientists say they have created a novel insulating ionic crystal in which He atoms take residence inside cube-shaped voids present in the lattice of Na atoms; in doing so, the He atoms force Na electrons out into neighboring voids. Though the He atoms do not form bonds, they facilitate a new stable arrangement in which each non-He-occupied cube shares a pair of electrons.

Andreas Hermann, a materials scientist who was not involved in the research, is impressed by the theoretical analysis but says that "follow-up experiments seem necessary" to confirm the Na_2He interpretation. He notes that the x-ray diffraction pattern includes the peaks predicted for Na_2He but also some unexplained extra ones. And Hermann would like to see more details supporting the researchers' claim that the compound Na_2HeO should also prove stable.

Assuming Na_2He has formed between the diamond tips at Carnegie, scientists will want to explore the possibility that helium is crushed into compounds inside the cores of gas giant planets. (X. Dong et al., *Nat. Chem.*, in press.)

—AG

A GRAVITATIONAL-LENSING MEASUREMENT OF THE HUBBLE CONSTANT

In 1929 Edwin Hubble confirmed that galaxies are receding from us with a speed proportional to their distance: $v = H_0 d$. As late as the mid 1990s, the value of the proportionality constant H_0 , the Hubble constant, was known only to be somewhere between 50 and 90 km/s per megaparsec (see the article by Mario Livio and Adam Riess, *PHYSICS TODAY*, October 2013, page 41). With the help of space-based observatories, H_0 can now be determined with a precision of about 1%. The value obtained from a

detailed map of the cosmic microwave background (CMB) is 66.93 ± 0.62 km/s/Mpc. But that determination is in tension with the value of 73.24 ± 1.74 km/s/Mpc derived from standard candles (Cepheid variables and type Ia supernovae, whose luminosities are known).

Now the H0LiCOW (H_0 Lenses in COSMOGRAPHY's Wellspring) collaboration has presented a comparably precise measurement based on its observations of three gravitationally lensed quasar systems. The H0LiCOW result, $H_0 = 71.9 + 2.4 - 3.0$ km/s/Mpc, agrees with the standard-candle determination, but it is about 2 standard deviations distant from the CMB-derived value.

When light traveling from a quasar to Earth passes by a sufficiently massive galaxy, the galaxy can act as a lens that bends the quasar light. As a result, Earthbound astronomers see multiple images of the quasar as shown in the figure. At times the brightness of the quasar flickers, and those fluctuations at the source are observed in the lensed images too. But since each image corresponds to a slightly different path length from quasar to telescope, the flickers appear at slightly different times for each image. The H0LiCOW team carefully measured those time delays, which are inversely proportional to H_0 .

The Hubble constant determination from the CMB assumes, among other things, that the universe is flat and that dark energy is characterized by Einstein's cosmological constant. If the conflicting values suggested by standard candles and lensed quasars hold up, some of the assumptions of cosmology's now-standard model may need to be revised. (V. Bonvin et al., *Mon. Not. R. Astron. Soc.* **465**, 4914, 2017.)

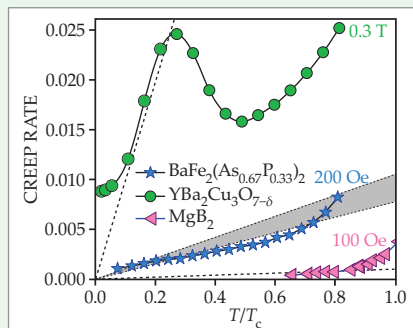
—SKB



ESA/HUBBLE, NASA, SUYU ET AL.

UNIVERSAL LOWER BOUND ON THE DISSIPATION OF SUPERCONDUCTORS

Despite their name, not all superconductors have zero resistance below their transition temperature T_c , at least when placed in a sufficiently strong magnetic field. For so-called type 2 superconductors—a class that includes high-temperature cuprate, iron-based, and magnesium diboride superconductors—the field penetrates and forms a lattice of vortices. Each vortex is an eddy of supercurrent that encircles a quantized amount of magnetic flux. Crystal defects, often intentionally introduced, will tend to pin the vortex lattice in place, but a sufficiently high current will force the vortices to move. That motion dissipates energy and manifests itself as a finite resistance. For currents slightly below the threshold, thermal fluctuations can provide the extra kick needed to knock the lattice free. Known as creep, thermally activated vortex mo-



tion can limit the operating range in applications such as high-field magnets and power transmission. The discovery of iron-based superconductors a decade ago challenged the understanding of vortex creep: The materials' observed creep rate was significantly higher than expected. Serena Eley (Los Alamos National Laboratory) and colleagues now report on their

study of $\text{BaFe}_2(\text{As}_{0.67}\text{P}_{0.33})_2$. The research did not explain the high creep rates in iron superconductors—indeed, the team observed the lowest rate yet seen for those materials. But the researchers did find a universal lower bound for the low-temperature creep rate, one that depends only on the ratio of temperature to T_c and on the square root of the Ginzburg number, which parameterizes the scale of thermal fluctuations with respect to the superconductor's magnetic properties. The figure shows how the derived limits (dashed lines) compare with measured creep rates for different superconductors. The researchers conclude that any new high- T_c superconductor will have high creep; the work may also help guide materials design for superconductor applications. (S. Eley et al., *Nat. Mater.*, in press, doi:10.1038/nmat4840.)

—RJF