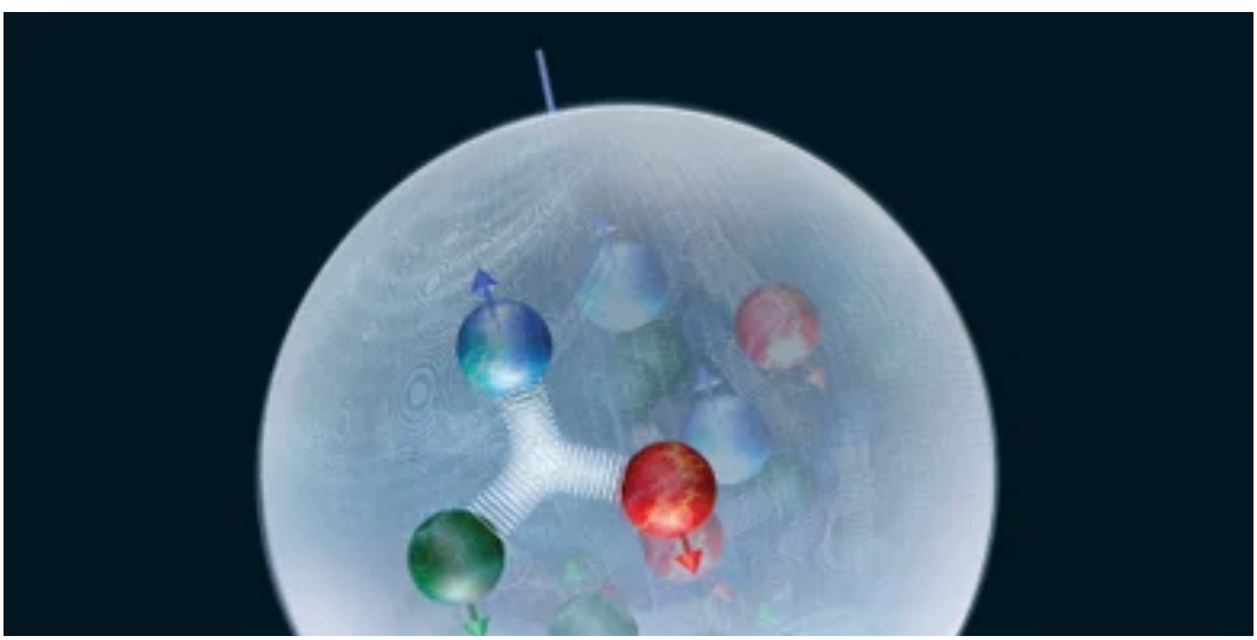
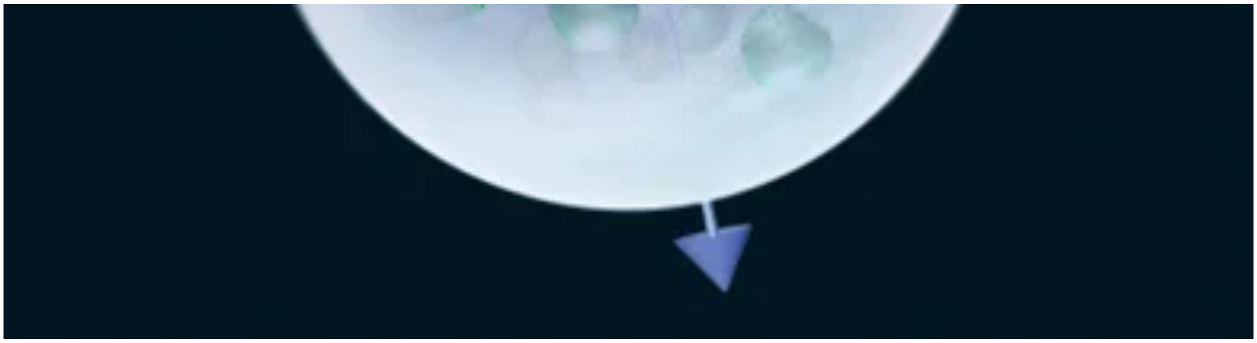
SA Visual

Visualizing the Innards of Subatomic Particles

With a nod to the recently discovered Xi-cc++ particle, here's a look at the quantum foam that lies within

STAFF | By Jen Christiansen on July 10, 2017





Credit: Moonrunner Design

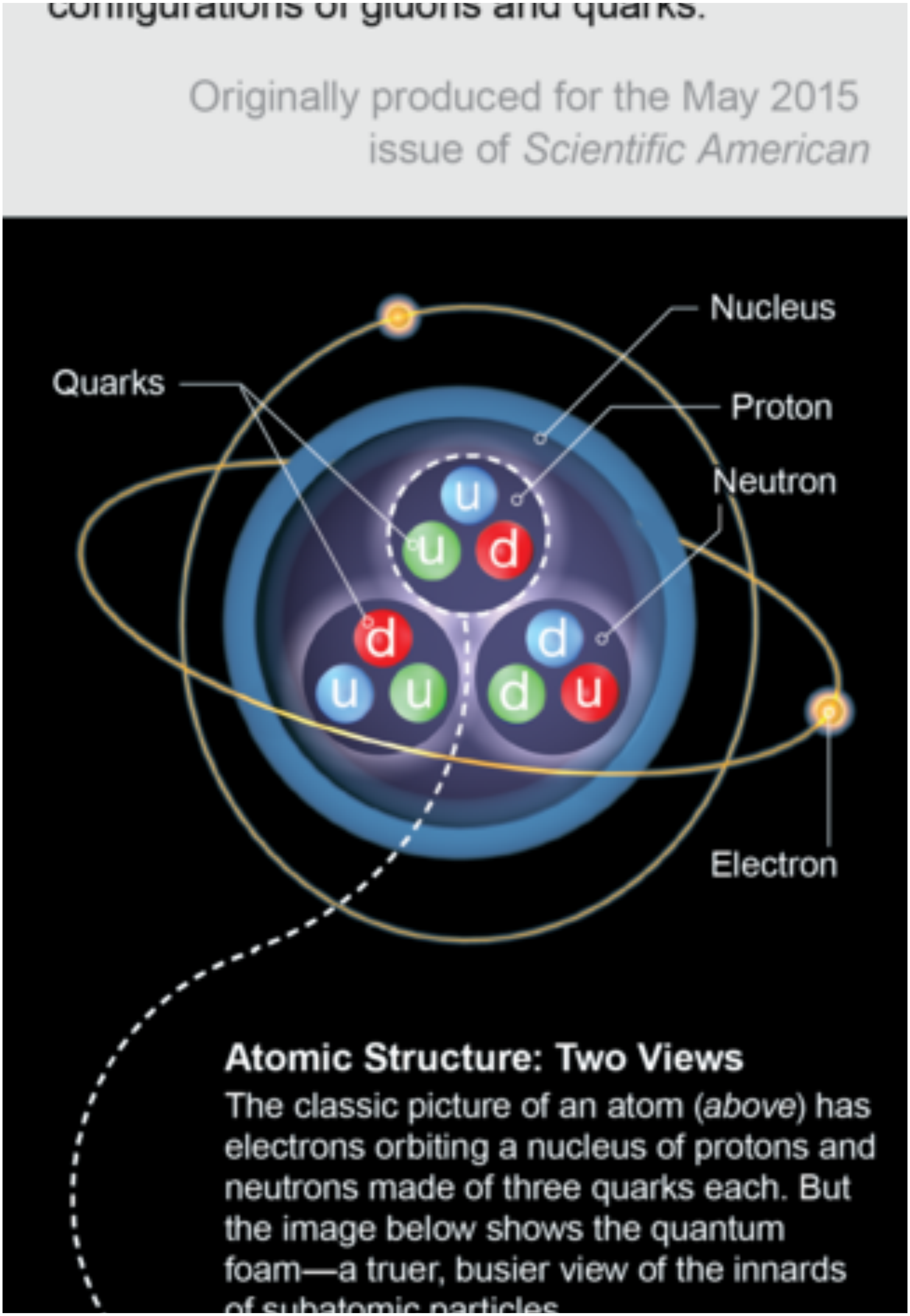
Last week, a new kind of heavy particle was discovered by physicists using the Large Hadron Collider. As reported by my colleague Lee Billings:

> *"The particle, known as Xi-cc++ (pronounced "Ksī-CC plus-plus"), is composed of three smaller elementary particles called quarks—specifically, one lighter-weight 'up' quark like those found in protons and neutrons and two 'charm' quarks, which are a heavier and more exotic variety."*

For context, here's a peek inside a more familiar particle—the proton—and a visual guide to other theoretical quark-gluon combinations. (For more on gluons and quantum foam, check out "The Mysteries of the World's Tiniest Bits of Matter" by Rolf Ent, Thomas Ullrich, and Raju Venugopalan, from the May 2015 issue of *Scientific American*).

# of Quarks and Gluons

Every proton or neutron inside an atom contains three primary quarks held together by gluons. In addition to the main three quarks, extra pairs of quarks and their antimatter counterparts constantly appear and disappear, along with phantom gluons that arise and vanish, creating a so-called quantum foam that continuously alters the landscape inside protons and neutrons. This cacophony complicates a number of fundamental questions, such as how quarks and gluons can account for the masses and spins of their parent particles and how exactly gluons do the work of containing quarks in stable configurations. One way physicists attempt to resolve these mysteries is by considering the theoretical properties of, and even trying to create, unusual configurations of gluons and quarks


Originally produced for the May 2015
issue of *Scientific American*
Nucleus
Quarks
Proton
Neutron
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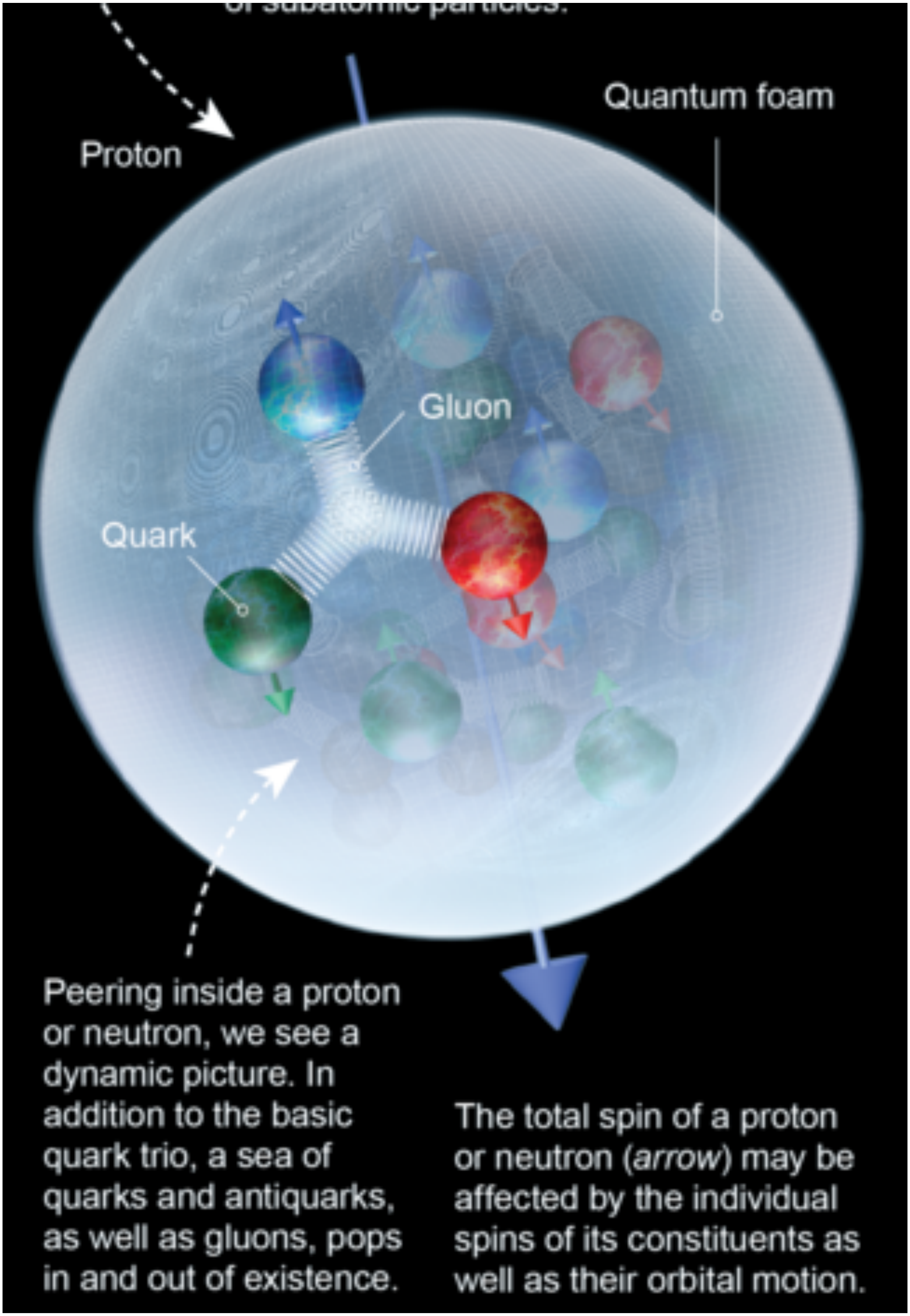
Electron
Atomic Structure: Two Views
The classic picture of an atom (*above*) has
electrons orbiting a nucleus of protons and
neutrons made of three quarks each. But
the image below shows the quantum
foam—a truer, busier view of the innards


Proton
Quantum foam
Gluon
Quark
Peering inside a proton or neutron, we see a dynamic picture. In addition to the basic quark trio, a sea of quarks and antiquarks, as well as gluons, pops in and out of existence.
The total spin of a proton or neutron (*arrow*) may be affected by the individual spins of its constituents as well as their orbital motion.

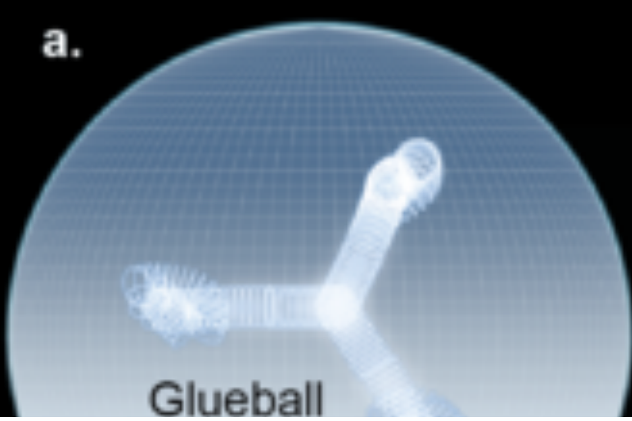
Exotic States of Matter

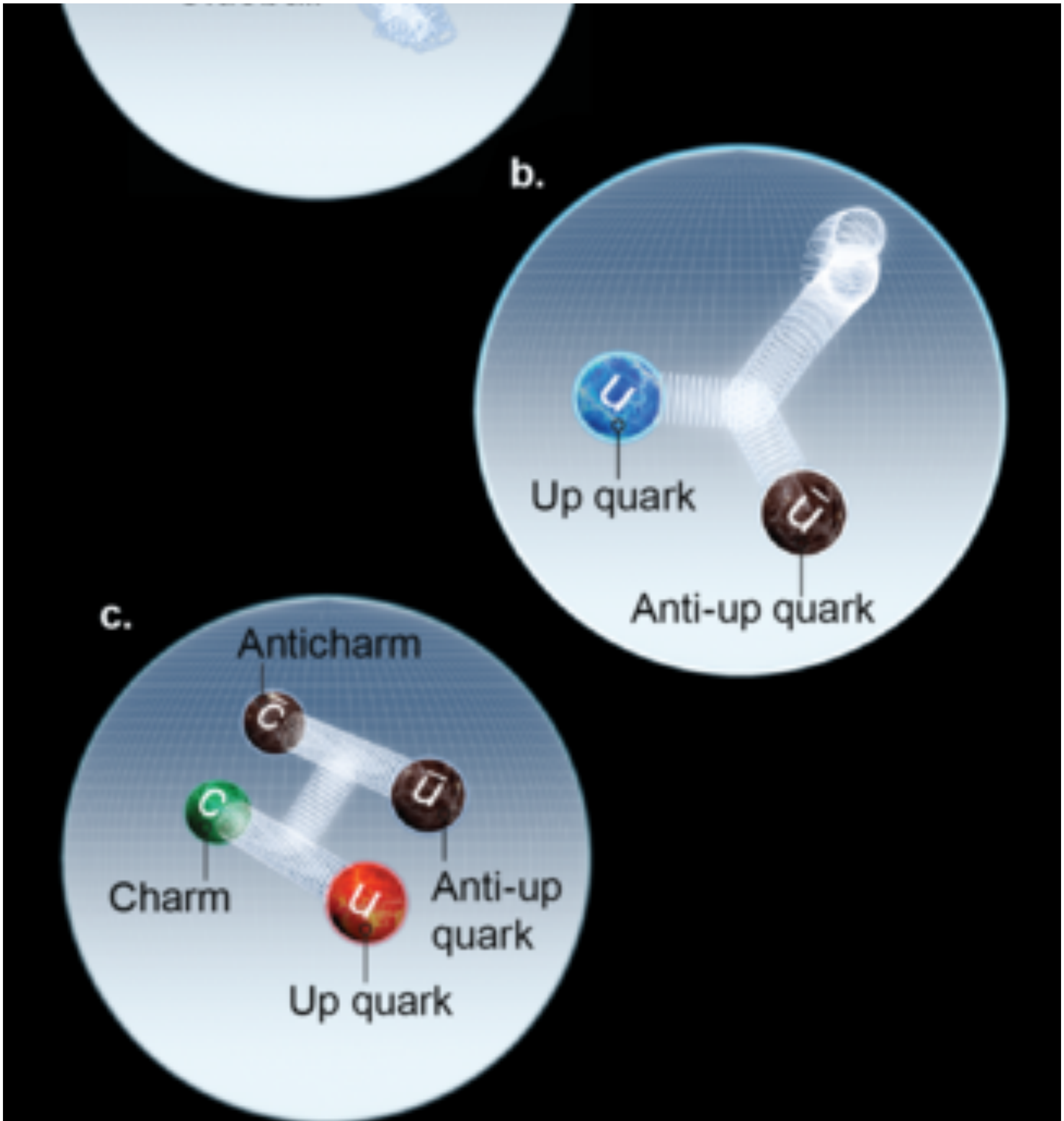
Physicists have theorized and, in a few cases, created unusual combinations of quarks and gluons beyond the familiar protons and neutrons. These exotic states offer new possibilities for studying the interactions that can occur between quarks and gluons—potentially helping to resolve some basic mysteries of matter.

Glueballs and Their Kin

Theoretical simulations suggest that quarks and gluons can combine to create other particles beyond protons and neutrons. For example, "glueball" particles (*a*) made exclusively of gluons may exist, as well as "hybrid" particles made of quark-anti-quark-gluon bound states (*b*), or "tetra quark" states where two antiquarks are bound to two quarks (*c*). There is now increasing evidence that tetra quarks have been found, although glueballs and hybrids remain to be discovered.

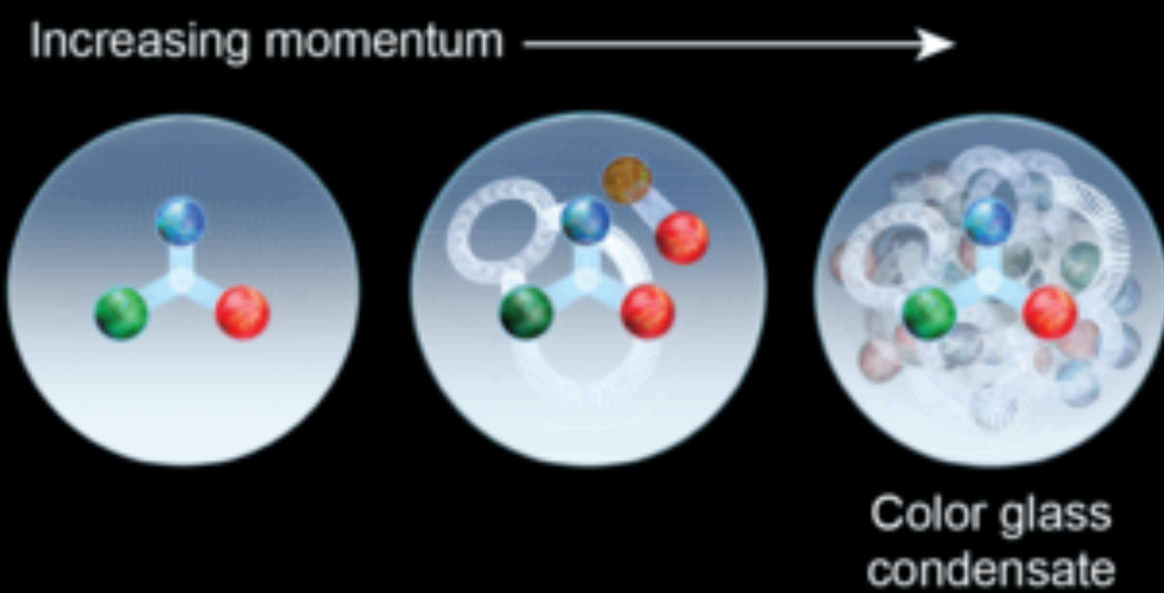
a.





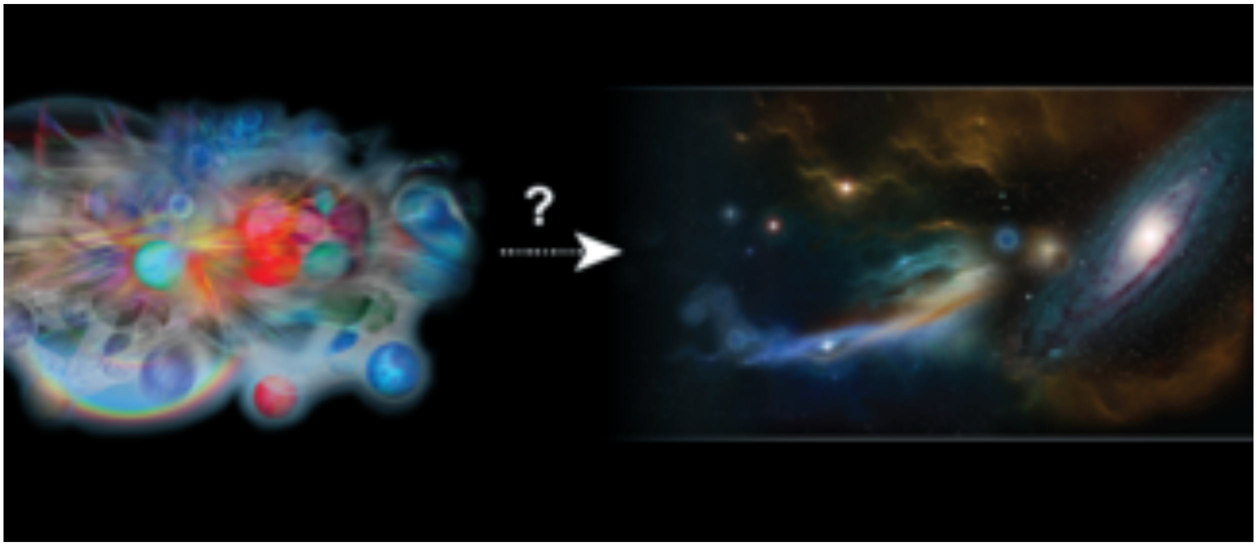
Saturated State

When protons and neutrons are accelerated to extreme speeds, the gluons inside them multiply. At high speeds the proton's energy increases and gluons split into daughter pairs, each with slightly less energy than the original. The new gluons, in turn, create more daughter gluons with even less energy. Eventually the proton reaches a "maximum occupancy" limit where no more gluons can fit inside—a theorized state called a color glass condensate. Strong hints of such a state have appeared in particle accelerators, but no firm proof exists so far.



Mimic of the Infant Universe

When the cosmos was young, it was too hot for atoms or even stable protons and neutrons to form. Quarks and gluons buzzed around freely in a roiling swarm. Accelerators on Earth recently succeeded in replicating this state, called a quark-gluon plasma (artist's conception, below left), by smashing atomic nuclei together at near light speed. By studying the plasma as it cools, physicists can learn not just about the behavior of quarks and gluons but also about the early evolution of our universe.



Credit: Moonrunner Design

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