QCD Visualizations

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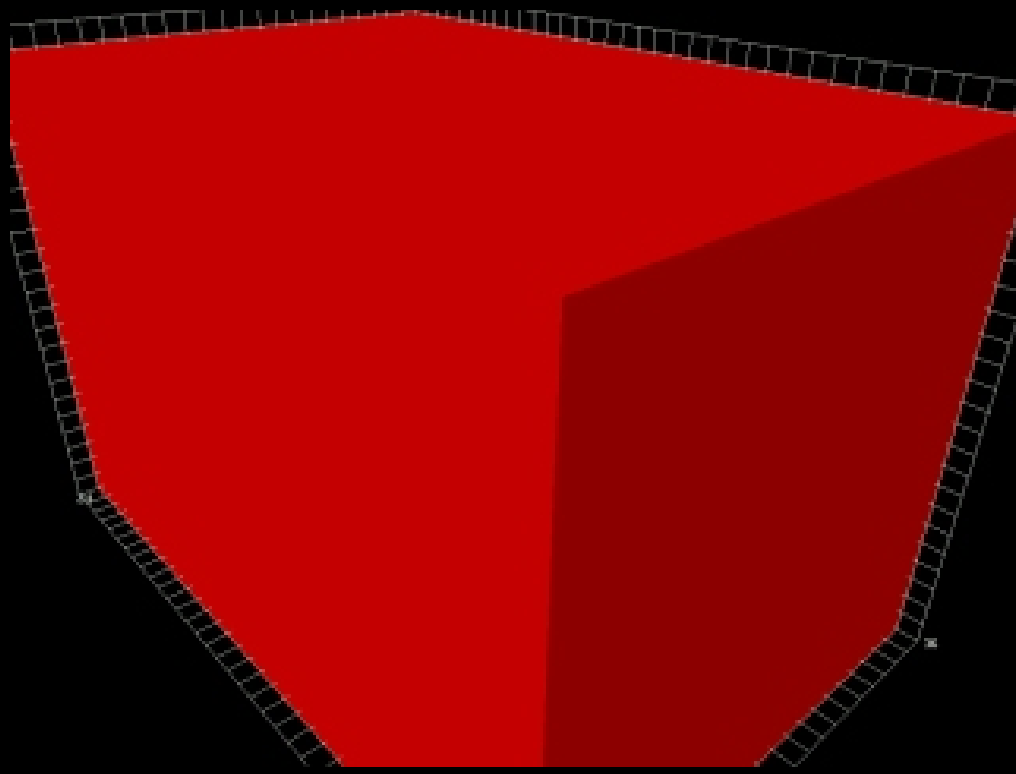
http://www.physics.adelaide.edu.au/theory/staff/leinweber/VisualQCD/QCDvacuum/

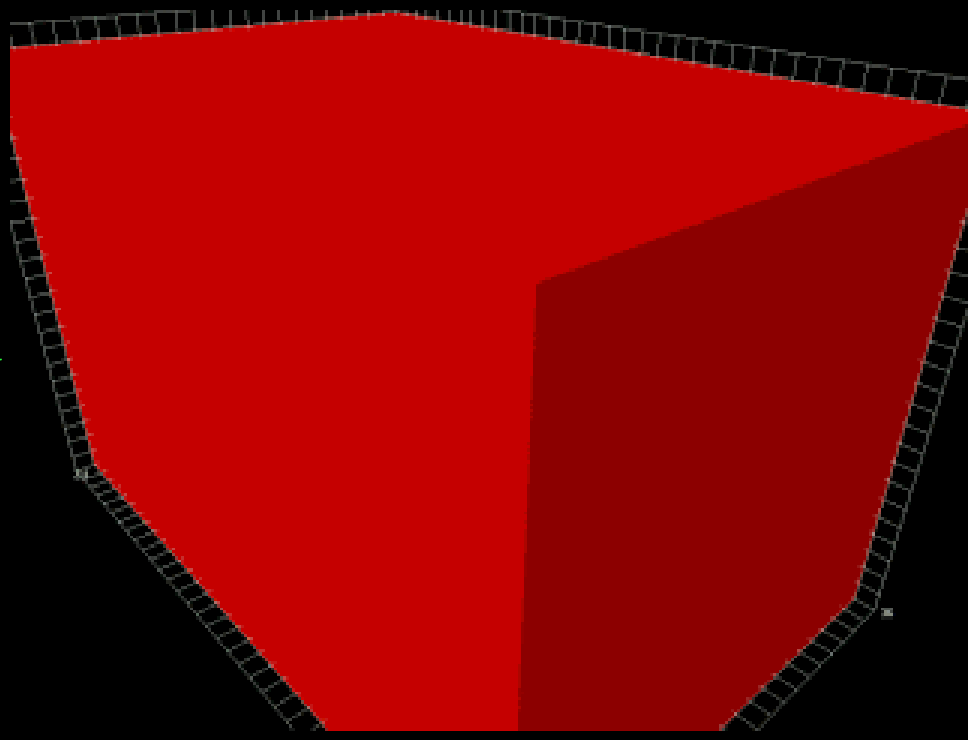
The QCD Vacuum

- If you could see the glow of gluons in what you thought was empty space, you would see something like this:
- Just as a magnet has a magnetic field in its lowest energy state, the QCD vacuum has a chromo-magnetic field in its lowest energy state.
- Both short distance and long distance gluon fluctuations occur.



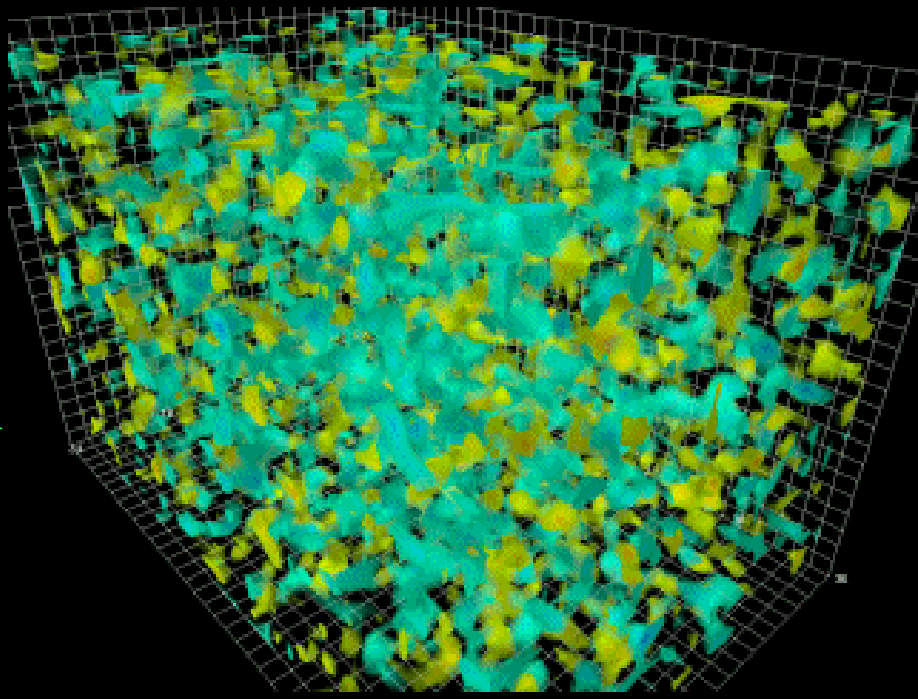
Revealing Structure in the Gluon Field

- Using an algorithm to remove short-distance noisy fluctuations, the smooth long-distance structure of gluons can be revealed.
- Hot spots marked by red show where the energy of the gluon field is strong.
- The isolated lumps surviving the smoothing process are associated with a knotted-winding behavior in the gluon field.



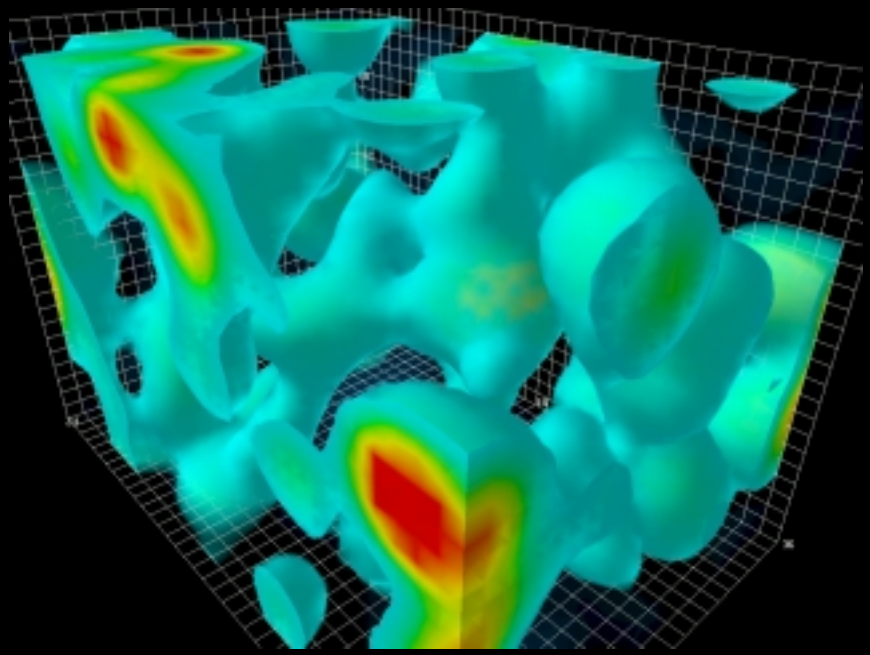
The Winding of the Gluon Field

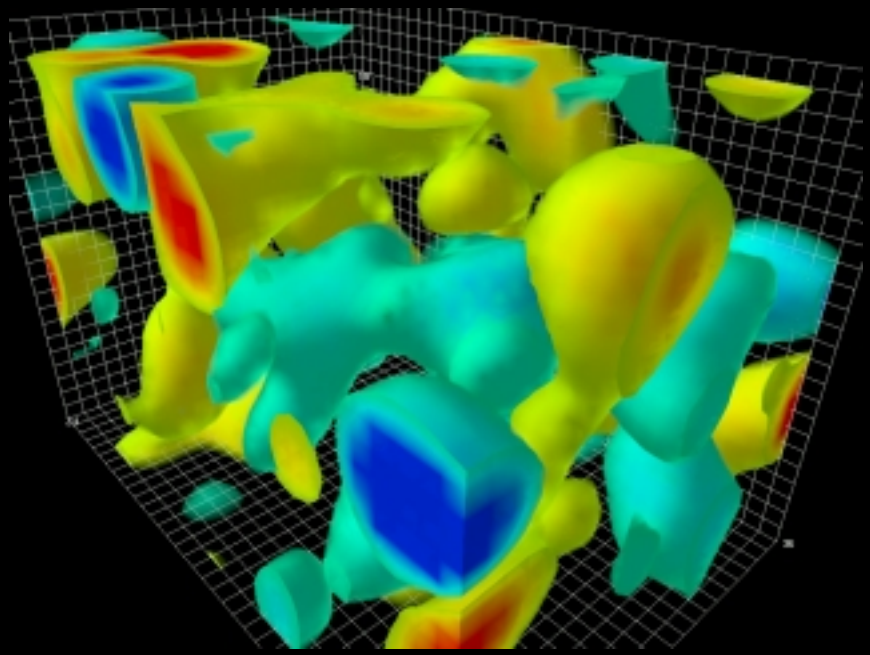
- Using the same smoothing algorithm, the winding of the gluons can be revealed.
- Just as water can swirl down a drain in clockwise and counter-clockwise directions, gluons can wind in positive (red to yellow shading) or negative (blue to green shading) directions.
- Opposite windings next to each other can wipe each other out (annihilate). Watch the upper left corner!



Energy and Winding

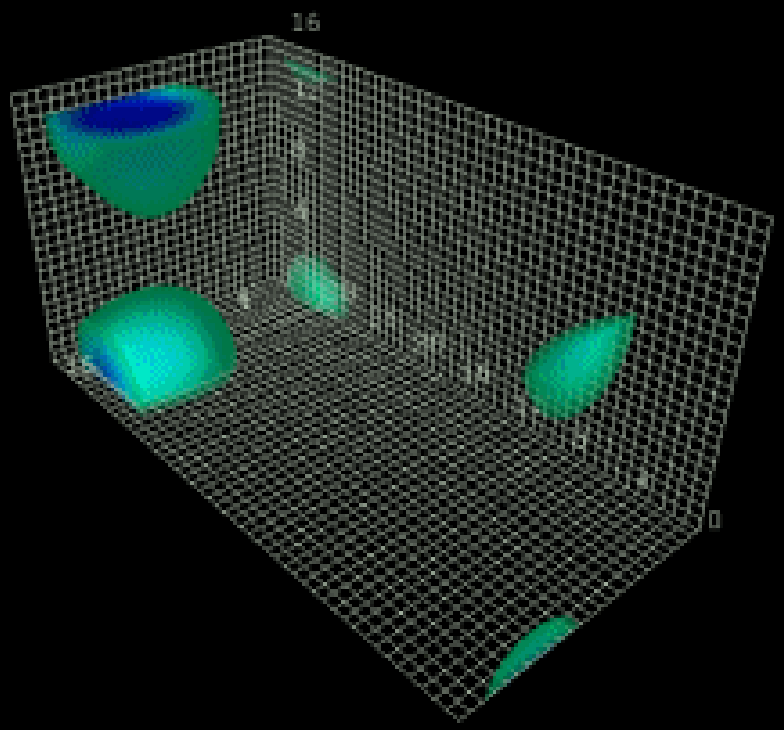
Each localized energy fluctuation in the gluon field corresponds to localized winding in the gluon field.





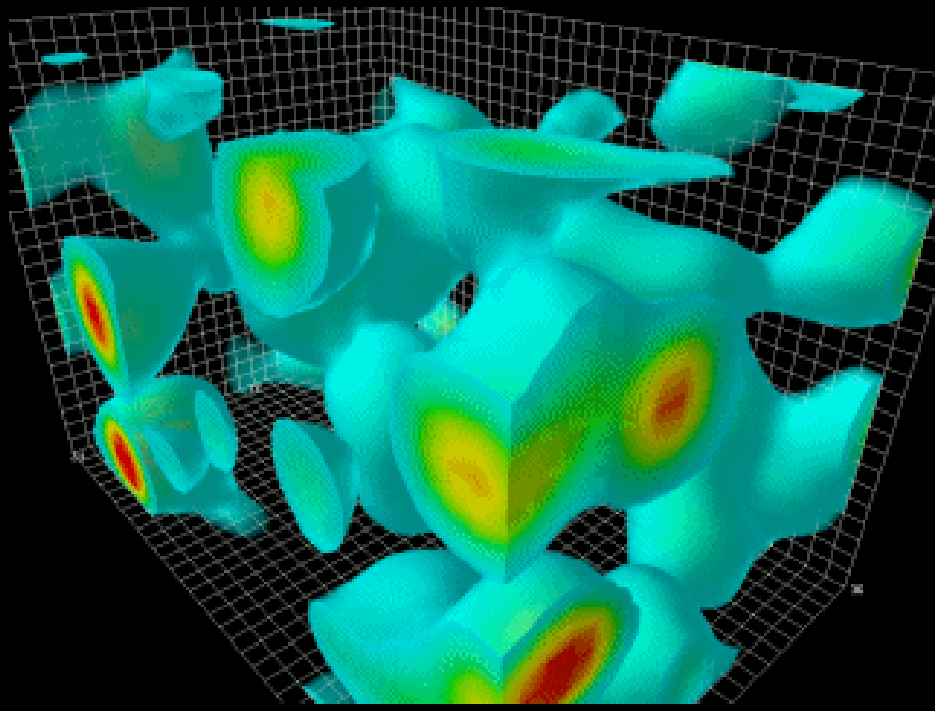
Instantons

- These localized objects are often called *Instantons*.
- They are short-lived (Instant) objects as can be seen in this animation which loops over time.
- Instantons are four-dimensional spheres. The yellow sphere in the foreground is what you would see if a four-dimensional sphere visited our world.



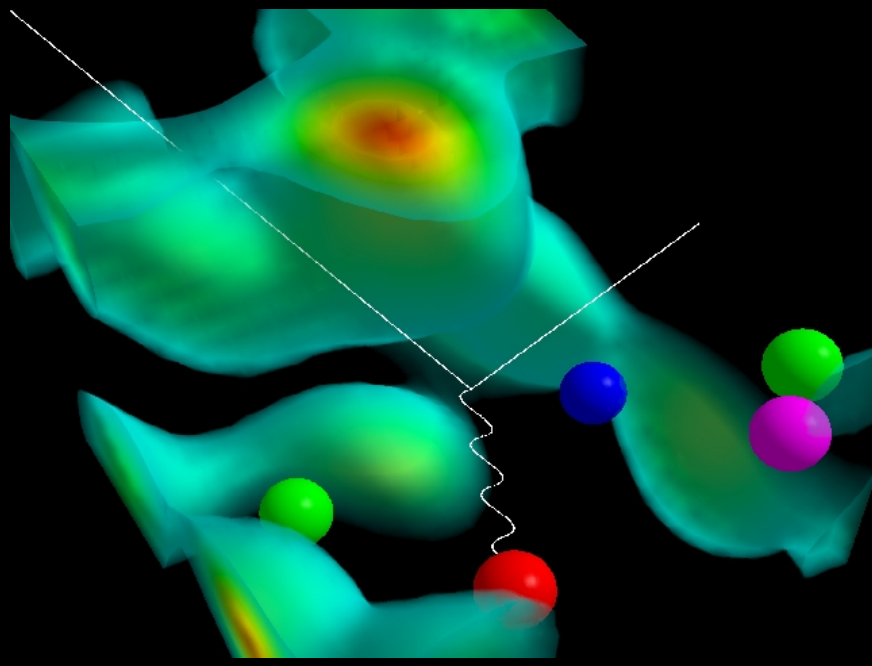
The Complex Structure of Gluons

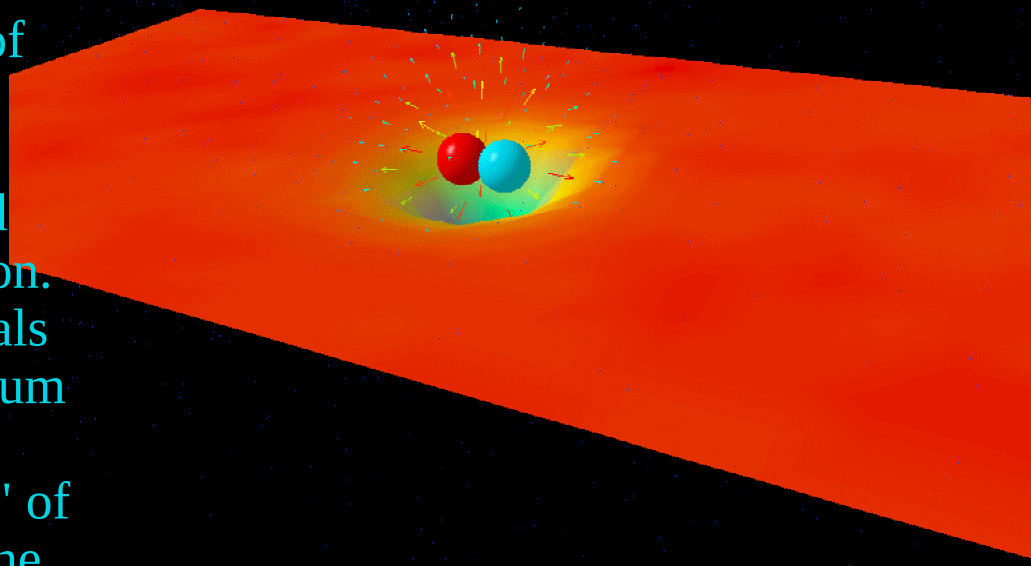
- The gluon structure of the QCD vacuum is very rich and complex.
- The short-lived instantons, displayed here by their localized energy, act to bind low-energy quarks to their locations.
- Quarks are thought to hop from instanton to instanton as they fluctuate in and out of the vacuum.



Artist's Rendition of a Proton

- Three quarks indicated by red, green and blue spheres (lower left) are localized by the gluon field.
- A quark-antiquark pair created from the gluon field is illustrated by the green-antigreen (magenta) quark pair on the right. These quark pairs give rise to a *meson* cloud around the proton.
- The masses of the quarks illustrated in this diagram account for only 3% of the proton mass. The gluon field is responsible for the remaining 97% of the proton's mass and is the origin of mass in most everything around us.
- Experimentalists probe the structure of the proton by scattering electrons (white line) off quarks which interact by exchanging a quantum of light (wavy line) known as a photon.



The QCD “Flux Tube”

- This animation shows the expulsion of the QCD vacuum from the region between a quark-antiquark pair illustrated by the colored spheres. The surface plot illustrates the reduction of the vacuum action density in a plane passing through the centers of the quark-antiquark pair. The vector field illustrates the gradient of this reduction. The tube joining the two quarks reveals the positions in space where the vacuum action is maximally expelled and corresponds to the famous "flux tube" of of QCD. As the separation between the quarks changes the tube gets longer but the diameter remains constant thus explaining the linear confinement potential felt between quarks.