

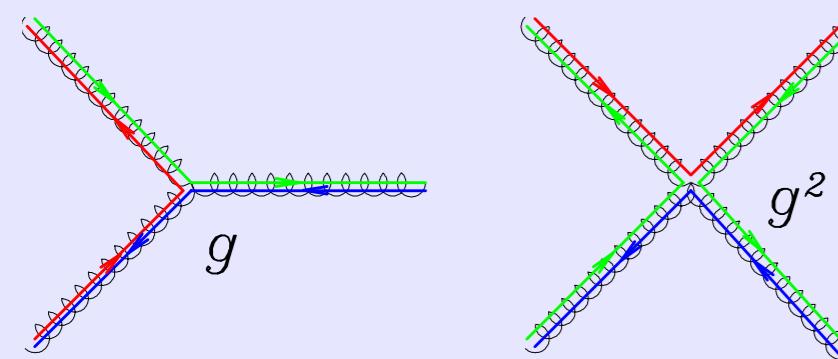
Emergent Structure of QCD

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Empty Space is not Empty

- Quantum Chromodynamics (QCD) is the fundamental relativistic quantum field theory underpinning the strong interactions of nature.
- The gluons of QCD carry colour charge and interact directly



- Gluon self-coupling makes the empty vacuum unstable to the formation of non-trivial quark and gluon condensates.
- 16 chromo-electric and -magnetic fields compose the QCD vacuum.
- One of the chromo-magnetic fields is illustrated at right.

Vortices in the Gluon Field

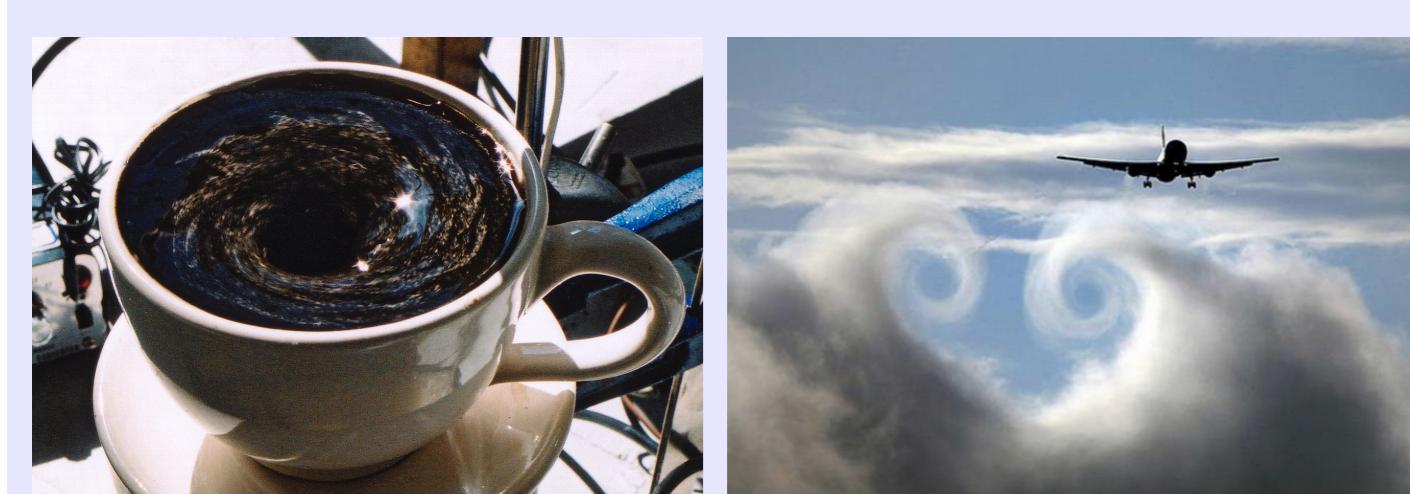
What is the most fundamental perspective of QCD vacuum structure that can generate the key distinguishing features of QCD

- The confinement of quarks, and
- Dynamical chiral symmetry breaking and associated dynamical-mass generation.

The centre vortex perspective of the QCD vacuum provides a single fundamental mechanism based on the centre of the $SU(3)$ gauge group, *i.e.* the three values of $\sqrt[3]{1}$.

Plotting a Vortex

Vortex Lines: Consider the line running down the centre of a vortex.



This line is plotted in the right-hand figures as a red or blue jet. They show the directed flow of centre charge $z = e^{2\pi i/3}$ through spatial elementary squares (plaquettes).

Branching Points or Monopoles: In $SU(3)$ gauge theory, 3 vortex lines can merge into or emerge from a single point. Their prevalence is surprising.

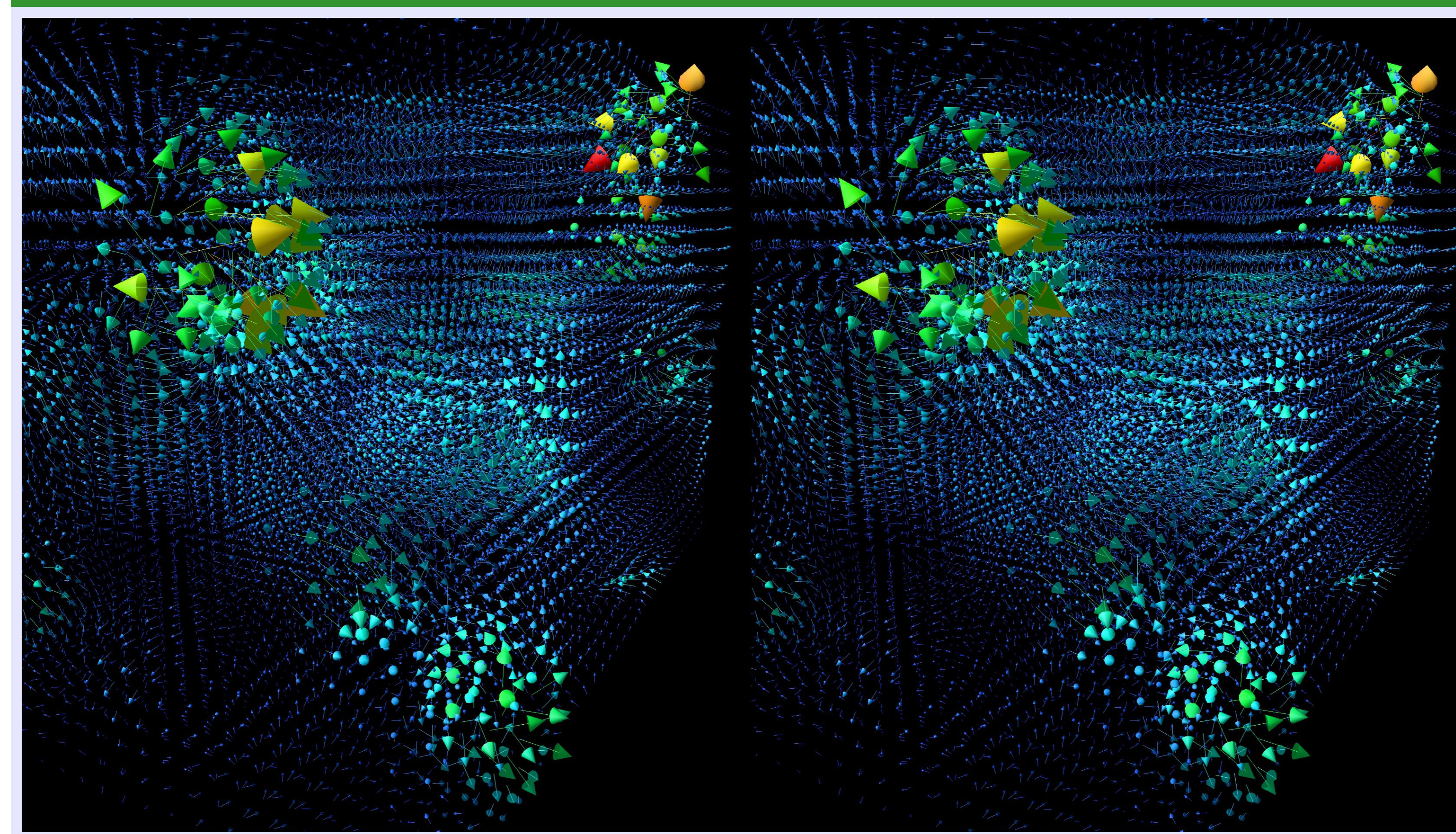
Vortex Sheet Indicator Links: As the vortex line moves in time, it creates a vortex sheet in 4D spacetime. This movement is illustrated by arrows along the links of the lattice indicating centre charge flowing through a space-time plaquette.

Singular Points: When the vortex sheet spans all four space-time dimensions, it can generate topological charge. Lattice sites with this property are called singular points and are illustrated by spheres. The sphere colour indicates the number of times the sheet adjacent to a point can generate a topological charge contribution.

Topological Charge Density: Non-trivial topological charge is often associated with instanton-like field configurations which dynamically generate the mass the proton and other hadrons.

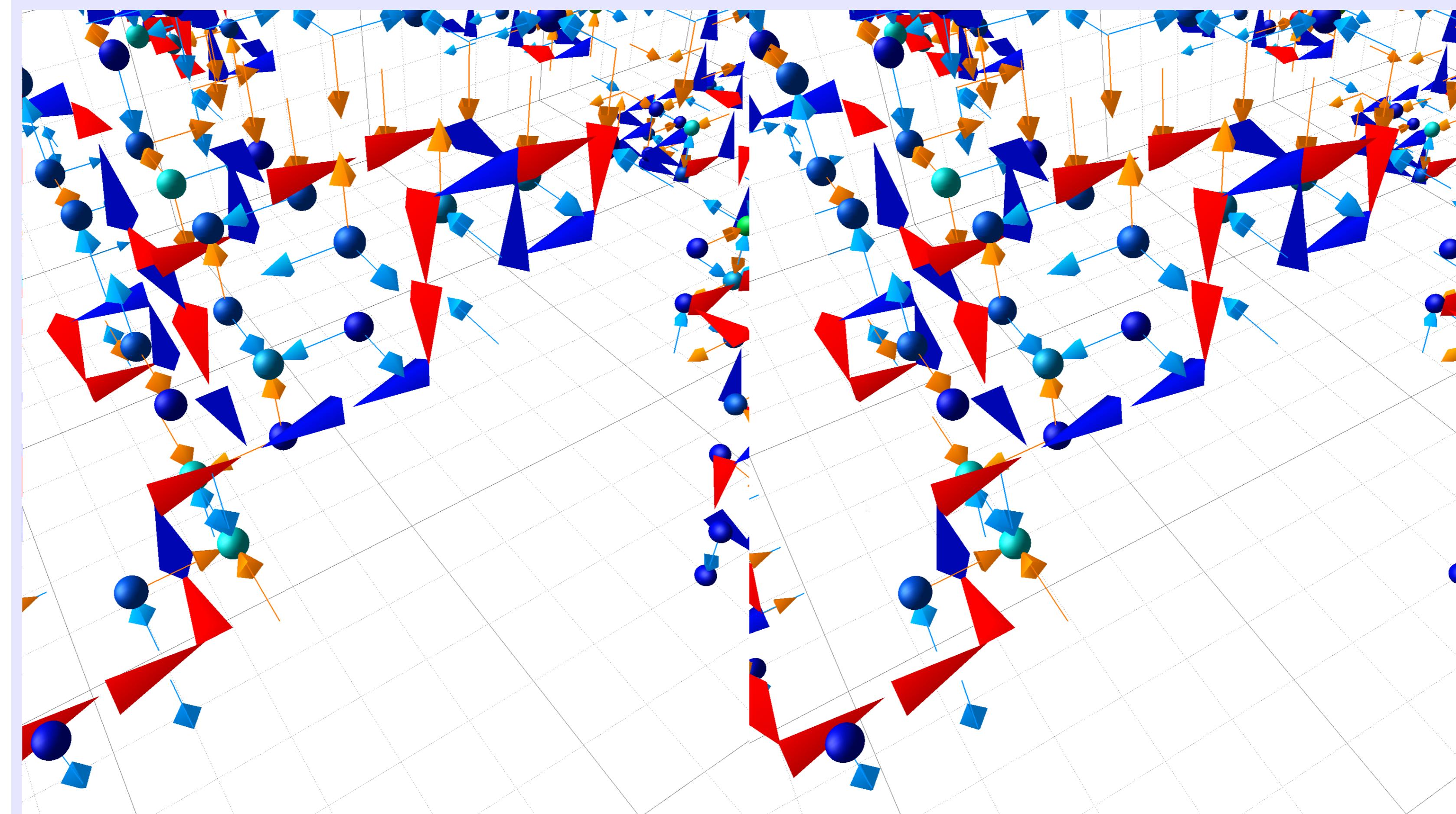
Vortices & Topological Charge: Vortices are somewhat correlated with the positions of significant topological charge density, but not in a strong manner. However, the percolation of vortex structure is significant and the removal of these vortices destroys most instanton-like objects.

Gluon Field in the non-trivial QCD Vacuum



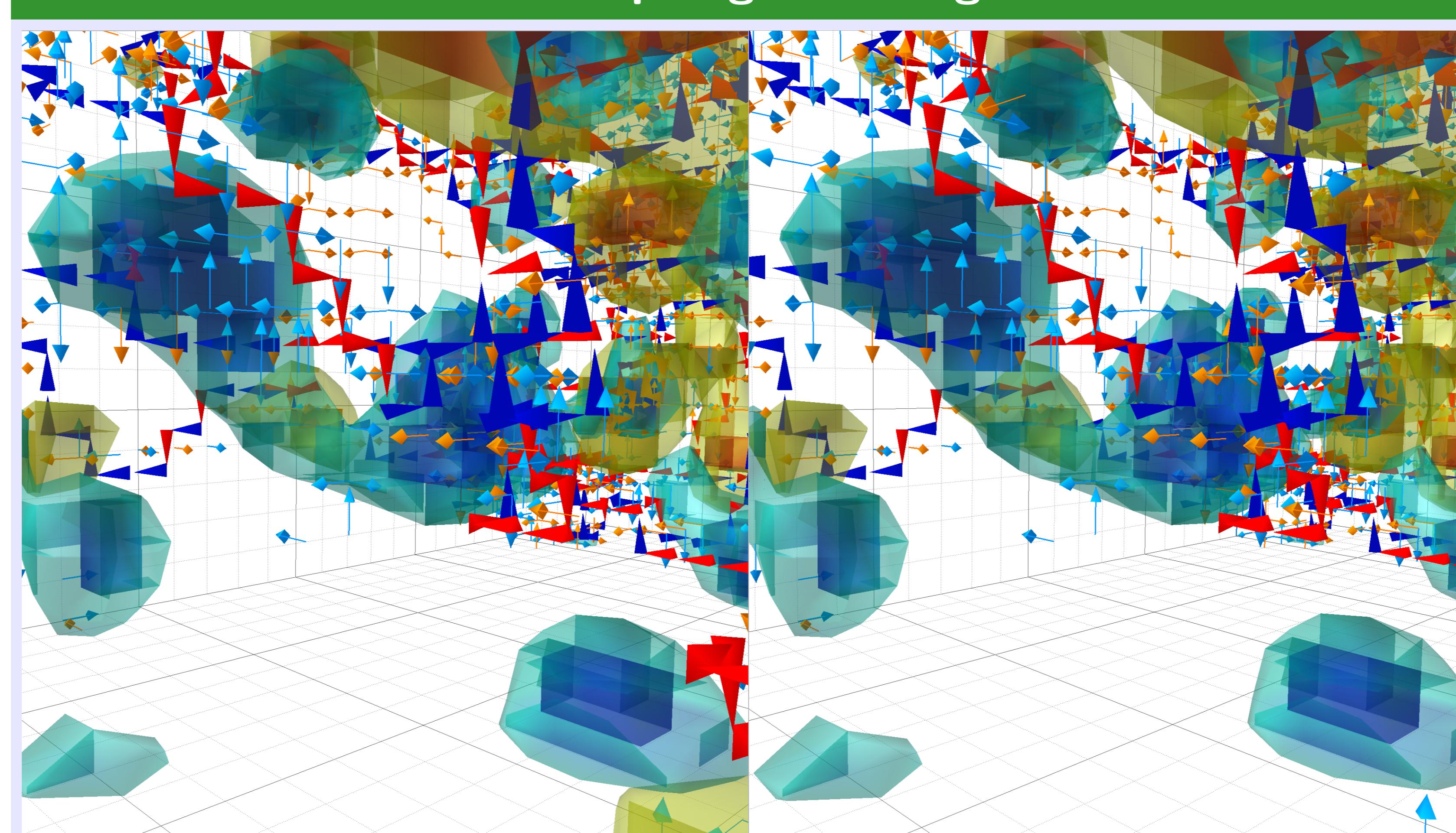
Stereoscopic image of one the eight chromo-magnetic fields composing the nontrivial vacuum of QCD.

Centre Vortices in the Gluon Field



Vortex features including vortex lines (jets), branching points (3-jet combinations), crossing points (4 jets), indicator links (arrows) and singular points (spheres) are described in the discussion of the left-hand column.

Vortex Correlation with Topological Charge



Correlation of topological charge density in the gluon field with the positions of centre vortices. Positive charge density is rendered red through yellow and negative charge density is rendered blue through green.

Looking for More . . .



Read our paper on
Centre Vortex
Structure



Watch Veritasium's
“Empty Space is
Not Empty”



Explore CSSM
Visualisations on
YouTube



See Nobel Prize
Lecture QCD
Visualisations



Learn why “Your
Mass is Not from
the Higgs Boson”

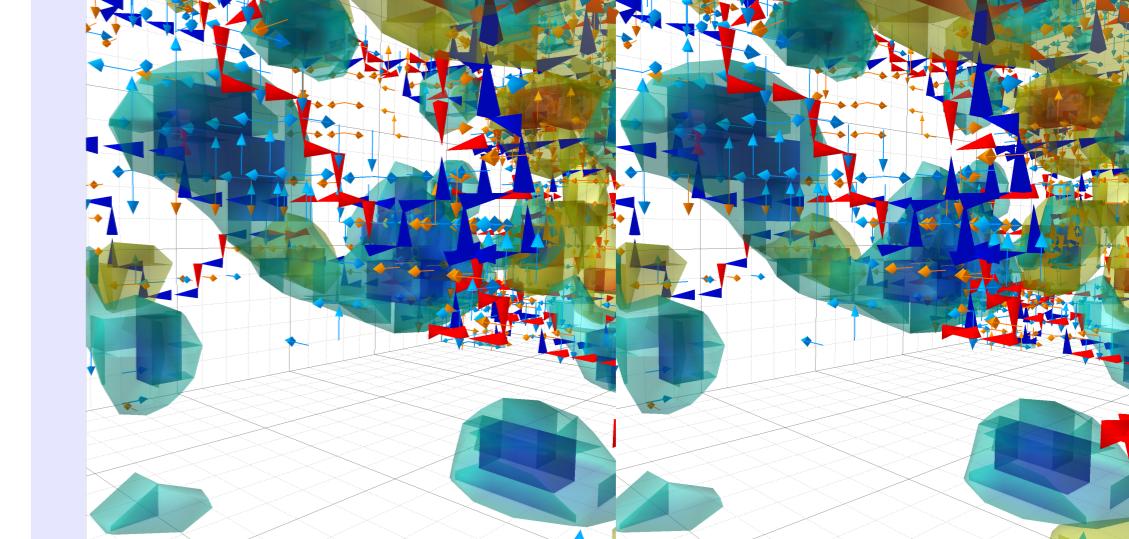
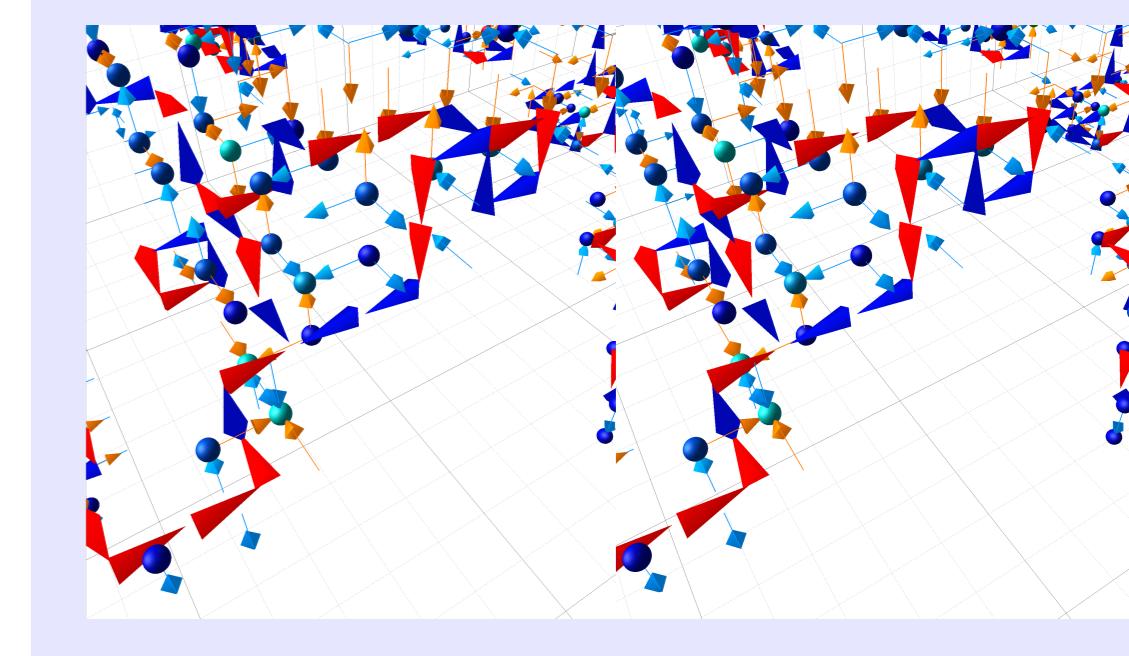
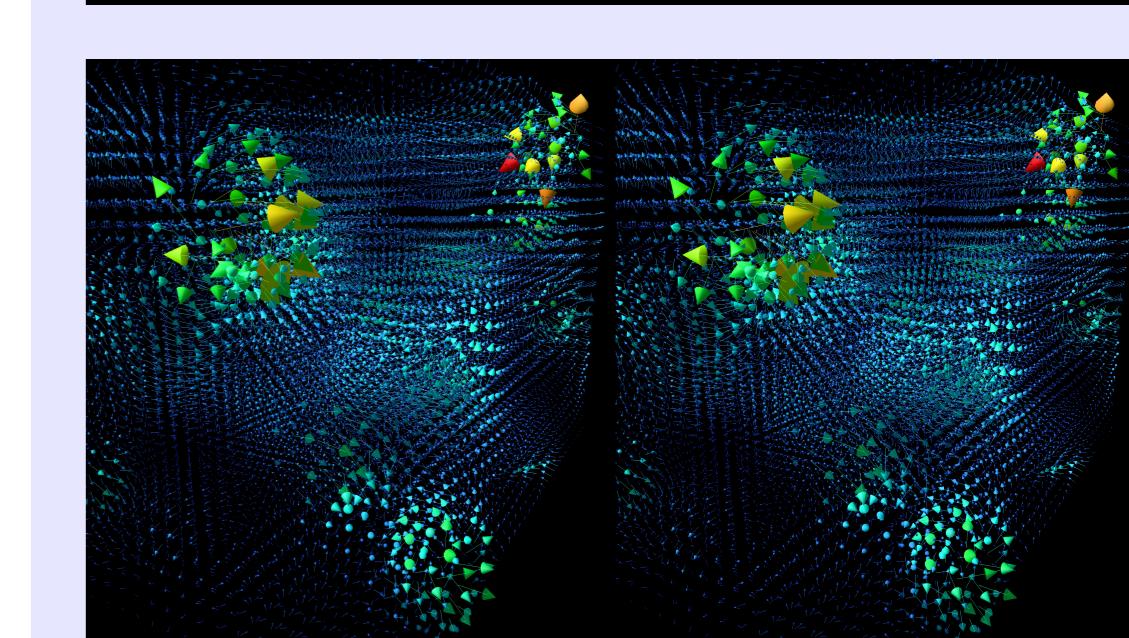
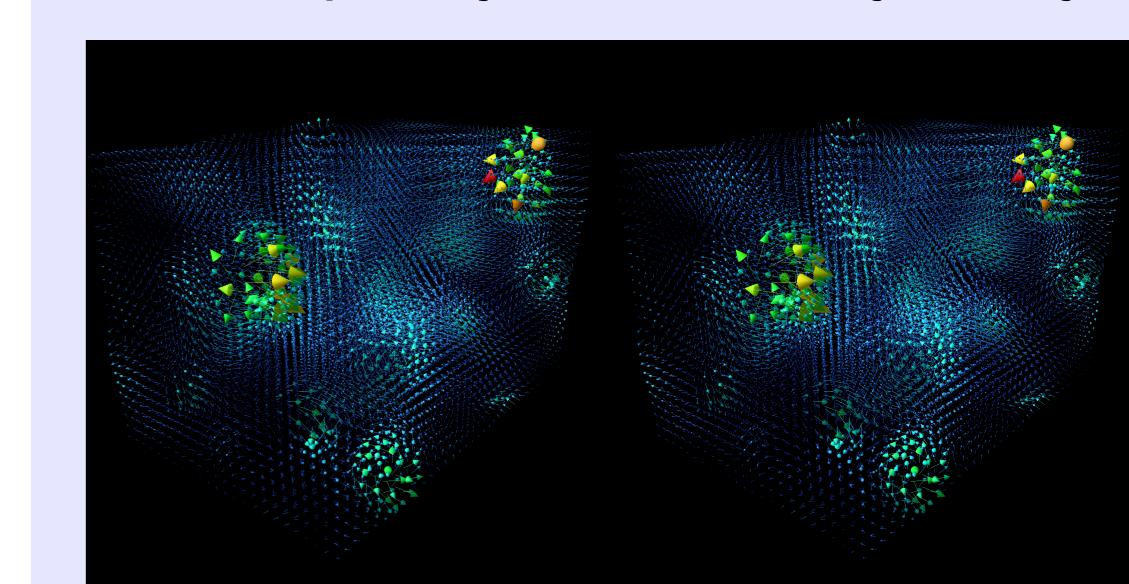
Viewing Stereoscopic Images

Remember the *Magic Eye*® 3D illustrations? You stare at them cross-eyed to see the 3D image. The same principle applies here. Try this!

1. Hold your finger about 5 cm from your nose and look at it.
2. While looking at your finger, take note of the double image behind it. Your goal is to line up those images.
3. Move your finger forwards and backwards to move the images behind it horizontally.
4. Tilt your head from side to side to move the images vertically.
5. Eventually your eyes will lock in on the 3D image.

Can't see the stereoscopic view? Try these!

The stereoscopic images below don't require you to cross your eyes.



Follow these steps:

1. Bring your eyes really close to one of the image pairs.
2. Close your eyes and relax.
3. Open your eyes and allow the (blurry) images to line up.
4. Move back slowly until your eyes are able to focus.

Augmented Reality

This poster features Josh Charvetto's augmented reality app for lattice QCD. Get the app and see a whole new view of this poster through the camera's eye.



Android



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