

Virtual Reality Up Close



Discipline of Physics

School of Chemistry and Physics

Faculty of Sciences

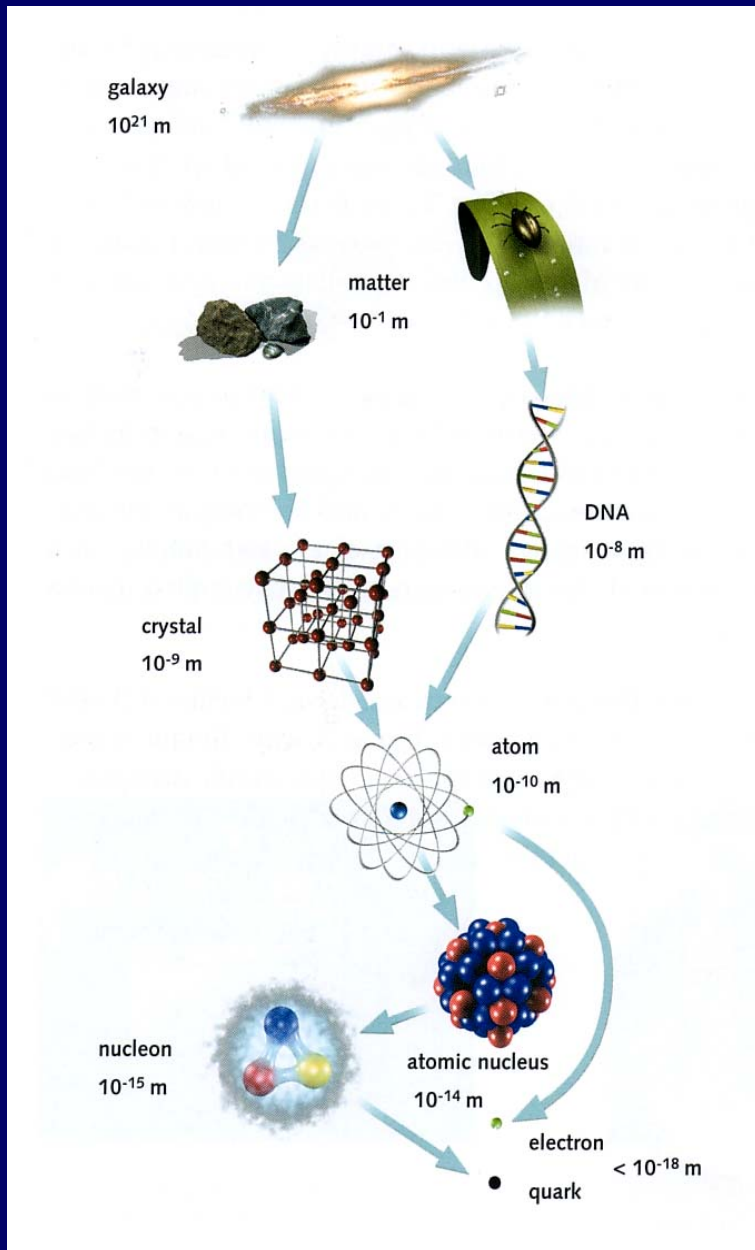
Derek Leinweber

- Professor of Physics University of Adelaide
- Head of School
 - School of Chemistry & Physics
- Deputy Director of:
 - Centre for the Subatomic Structure of Matter (CSSM)
 - South Australian Partnership for Advanced Computing (SAPAC)



Chemistry & Physics

- Astrophysics
- Interstellar Ion Chemistry
- Atmospheric Physics
- Biological Chemistry
- Nano-science & Medical Physics
- Optics and Photonics
- Chemistry
- Nuclear and Particle Physics
- Quantum Field Theory
- Quantum Chromodynamics (QCD)



Programs in the Chemical Sciences

- **BSc (Nanoscience & Materials)**
 - Core training in chemistry enhanced by specialist training in nanoscience
 - Nanoscience – design and manipulation of materials at the molecular level
- **BSc (Ecochemistry)**
 - Core training in chemistry with emphasis on understanding our environment



Programs in the Physical Sciences

- **BSc (Space Science & Astrophysics)**
 - examines the exploration of our Universe from Earth's upper atmosphere to the most distant regions of space
- **BSc (Optics & Photonics)**
 - emphasizes the application of optical physics in the exploration, development, and usage of laser light
- **BSc (High Performance Computational Physics)**
 - focuses on advanced physics, applied mathematics and computer science

Examples of Career Opportunities

- Research
- Patent Attorney
- Journalism
- Mathematical Modelling
- Commerce / Finance Industry
- Mineral Exploration
- Meteorology
- Aviation Research
- Optical communications
- Consulting
- Management
- Satellite Project Scientist
- Defence Industry
- Pharmaceutical companies
- Operations Analyst
- Teaching
- Information technology Industry
- Chemical and Biotechnology Industries
- Environmental Management
- Mining Industry
- Policy Advisors

Fundamental Forces

Everyone knows

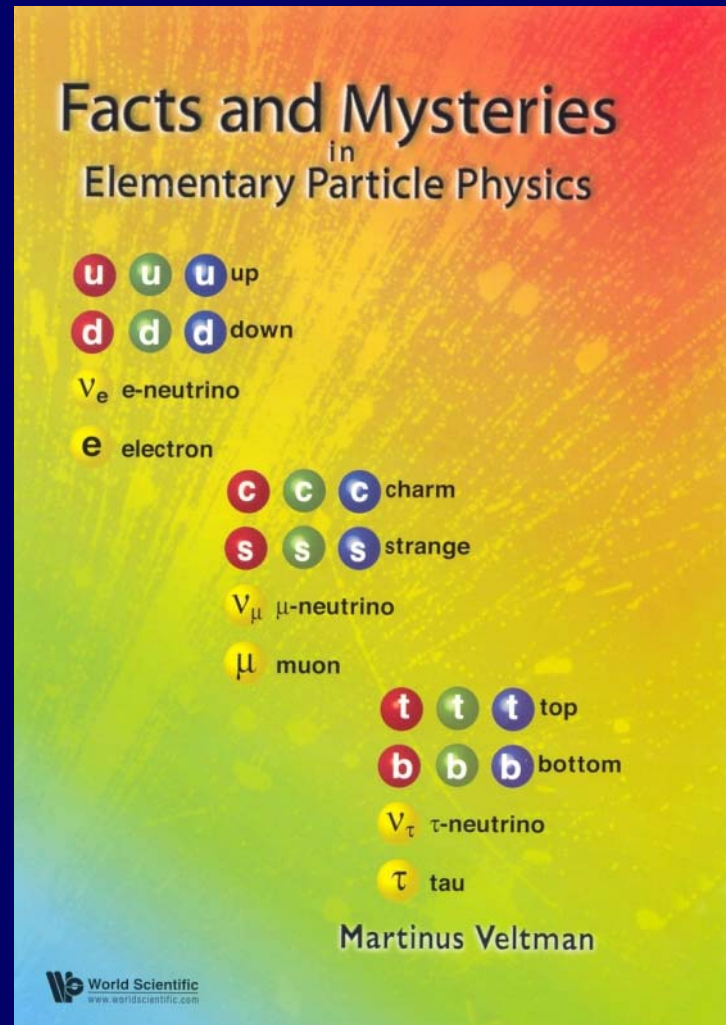
- Opposite electric charges attract
- Same charges repel



How does one charge know the other charge is there?

They exchange particles called photons!

Building Blocks of the Universe



Building Blocks of the Universe

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2

Flavor	Mass GeV/c ²	Electric charge
ν_e electron neutrino	$<1 \times 10^{-8}$	0
e electron	0.000511	-1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	-1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	-1

Quarks spin = 1/2

Flavor	Approx. Mass GeV/c ²	Electric charge
u up	0.003	2/3
d down	0.006	-1/3
c charm	1.3	2/3
s strange	0.1	-1/3
t top	175	2/3
b bottom	4.3	-1/3

- Each quark comes in 3 “colours”: red, green and blue.
- Leptons do not carry color charge and do not see gluons.
- Everything in our universe is made out of these particles!

Force Carriers of the Universe

BOSONS

force carriers
spin = 0, 1, 2, ...

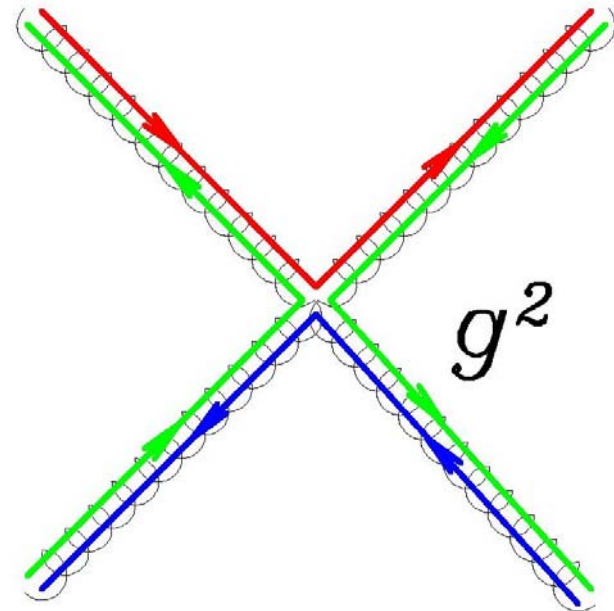
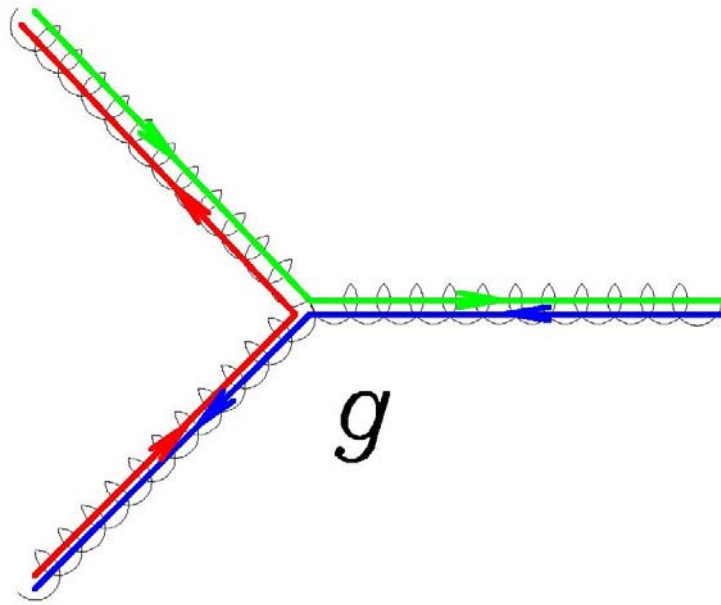
Unified Electroweak spin = 1

Name	Mass GeV/c ²	Electric charge
γ photon	0	0
W^-	80.4	-1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1

Name	Mass GeV/c ²	Electric charge
g gluon	0	0

Gluons carry the colour charge

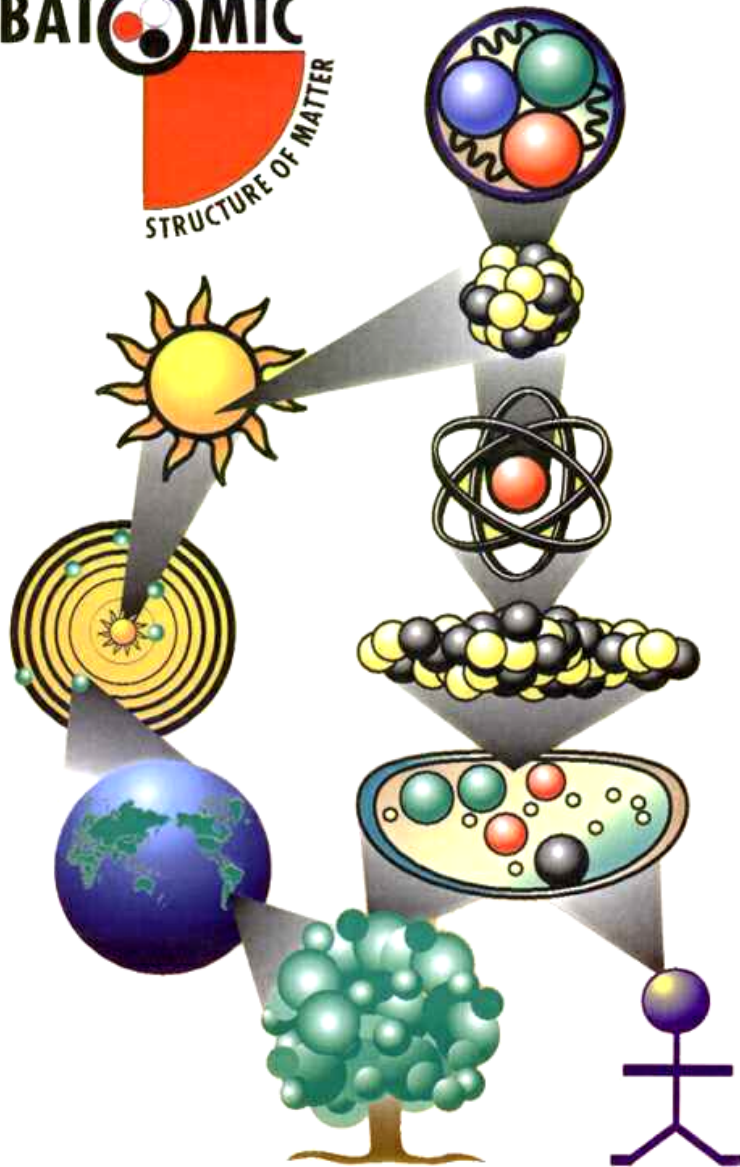


Quantum Chromodynamics (QCD)

- Photons do not carry electric charge.
- Gluons *do* carry colour charge!
- Gluons can directly interact with other gluons!
- The structure of QCD is complex.
- Supercomputer simulations are required to reveal how QCD makes the world around us.



- A red quark emitting a red-anti-blue gluon to leave a blue quark.

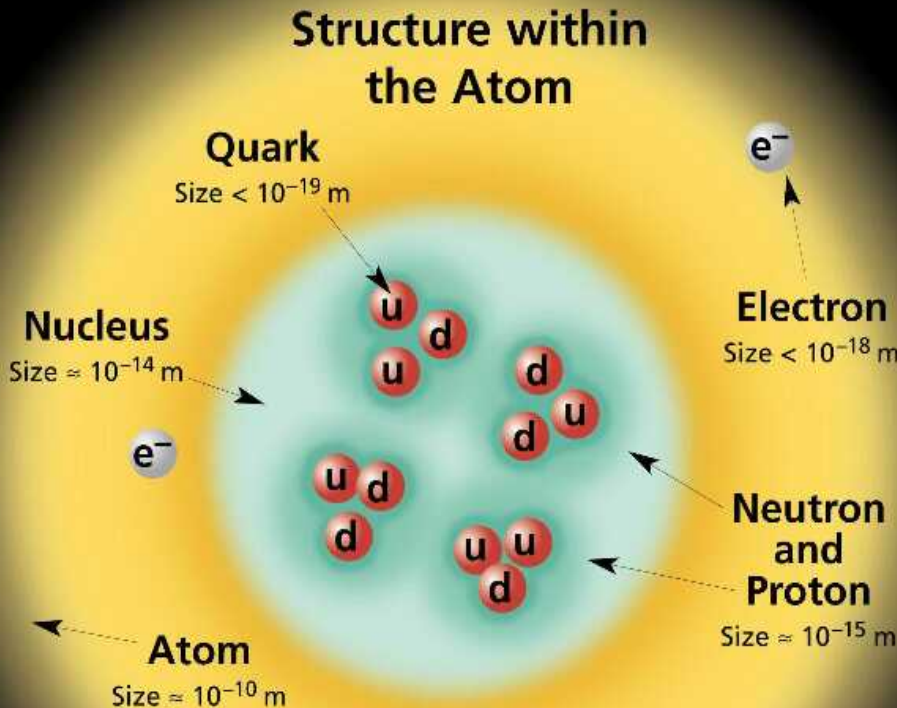


Key Concepts

- Quarks are bound by gluons to form protons and neutrons.
- The theory describing the interactions between quarks and gluons is called **Quantum Chromodynamics (QCD)**.
- Nuclei consist of protons and neutrons bound together by the strong interactions of **QCD**.
- The elements (and thus all of chemistry) are determined by which nuclei are stable.

Atomic Structure

- Warning: Sketch not to scale!
- If the protons and neutrons are 10cm across then
- the nucleus is about 1m across,
- the electrons and quarks are less than 0.1mm across,
- and the atom is the size of Adelaide!



If the protons and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

QCD and the Origin of Mass

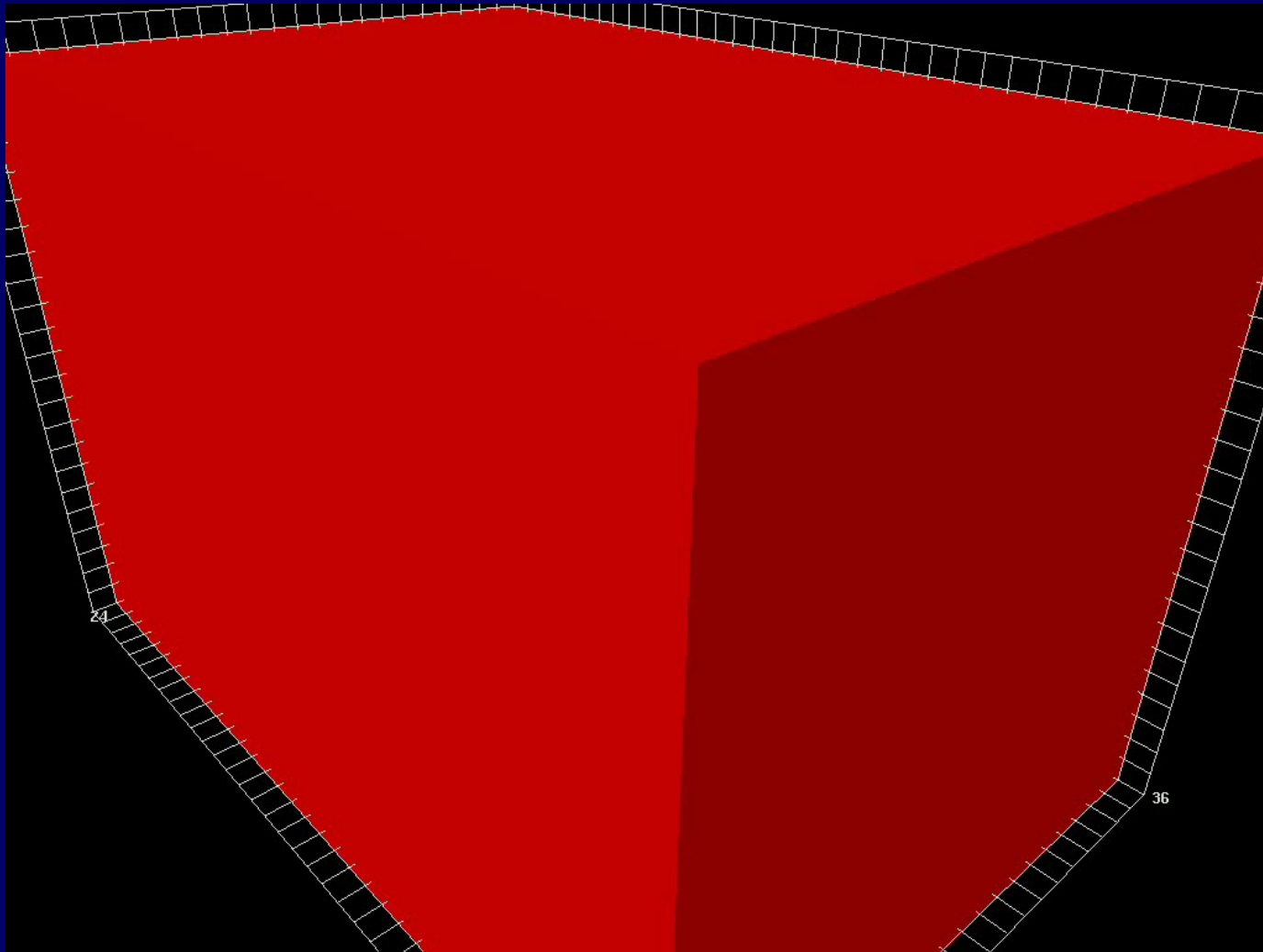
$$\begin{array}{rcll} & u & + & u & + & d & = & \text{proton} \\ \text{mass:} & 0.003 & + & 0.003 & + & 0.006 & \neq & 0.938 \end{array}$$

Where does the rest of the proton mass come from?

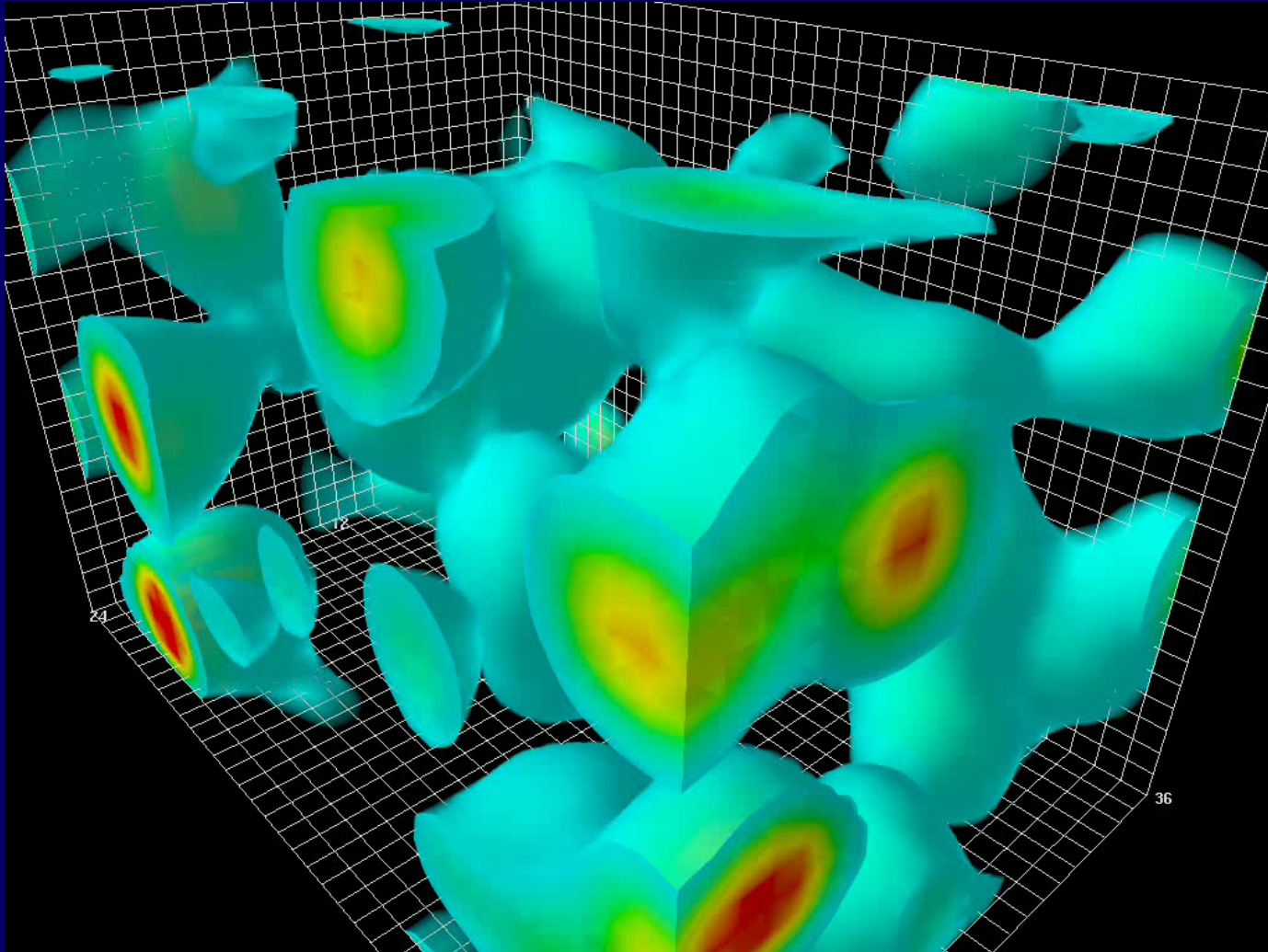
Think $E = m c^2$ or

$$m = E / c^2$$

The QCD Vacuum



The QCD Vacuum



Physics



Frank Wilczek
The Nobel Prize in Physics 2004

Nobel Lecture

Asymptotic Freedom: From Paradox to Paradigm



Frank Wilczek held his Nobel Lecture December 8, 2004, at Aula Magna, Stockholm University. He was presented by Professor Sune Svanberg, Chairman of the Nobel Committee for Physics.

See a Video of the Nobel Lecture

Presentation

50 sec.

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Nobel Lecture

35 min.

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Lecture Slides

Pdf 2.30 MB

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QCD Lava Lamp

Animation 518 kB

The Lecture in pdf-format

Pdf 983 kB

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Printer Friendly

Comments & Questions

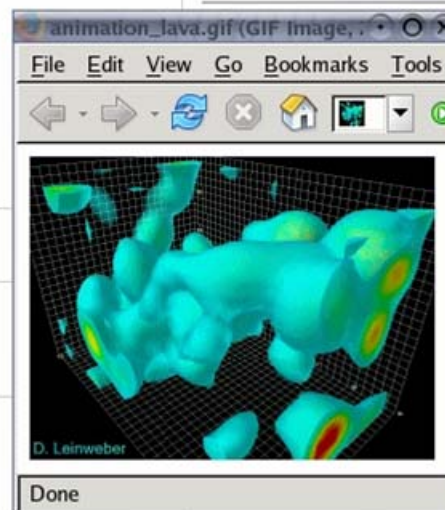
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The 2004 Prize in:

Physics

Prev. year Next year

The Nobel Prize in Physics
2004



H. David Politzer

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Orion Supercomputer



- Sun Technical Compute Farm
- Fastest computer in Australia in 2000
- 160 processors
- High-speed Myrinet network
- 160 Gbytes RAM
- 144 Gflops
- 1 Gflop = 1,000,000,000 calculations per second
- Exclusively dedicated to Lattice QCD

Hydra Supercomputer



- IBM eServer 1350 Linux cluster
- Installed in 2003
- Ranked 2nd in Australia
- Ranked 106 in the world
- 256 Intel Xeon (2.4 GHz) procs.
- High-speed Myrinet 2000
- 256 Gbytes RAM
- 1200 Gflops = 1.2 Tflops
- Serves SA Researchers

Life Impact – Sciences



Aquila Supercomputer



- SGI Altix 3000
- Installed in 2004
- 160 Intel Itanium 2 processors
- NUMAlink network
- 160 Gbytes RAM
- 830 Gflops
- Serves SA Researchers

Life Impact – Sciences



APAC Supercomputer



- **SGI Altix 3700 Bx2 cluster**
- **Installed in 2005**
- **Ranked 26th in the World**
- **1680 Intel Itanium 2 processors**
- **NUMAlink network**
- **3.2 Gbytes/s**
- **3360 Gigabytes RAM**
- **11,000 Gflops = 11 Tflops**
- **Serves Australia**

Corvus Supercomputer

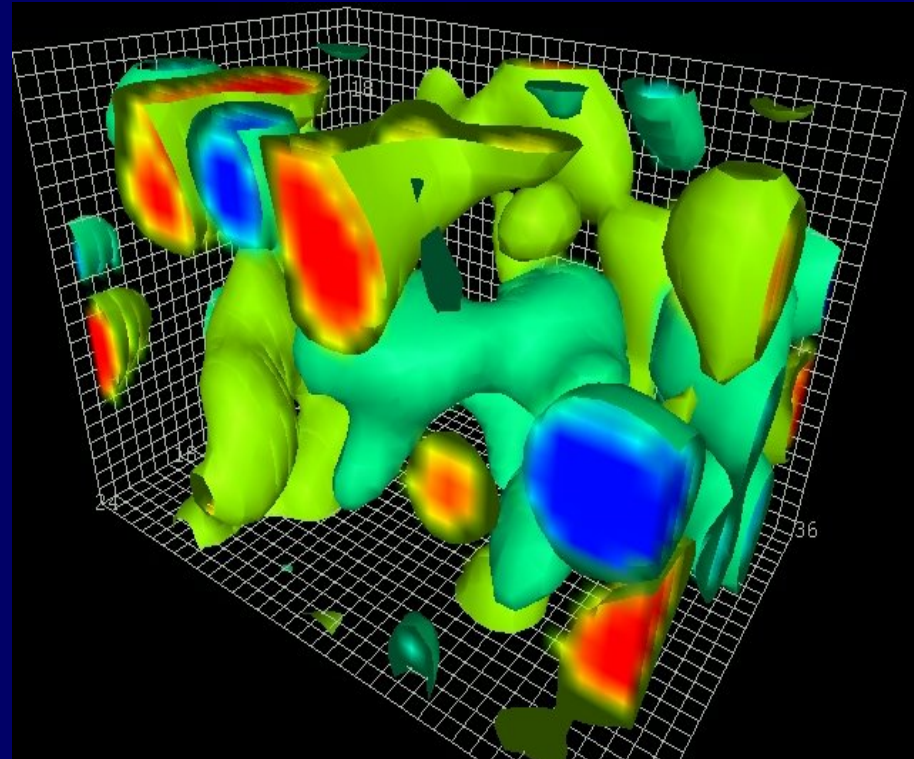
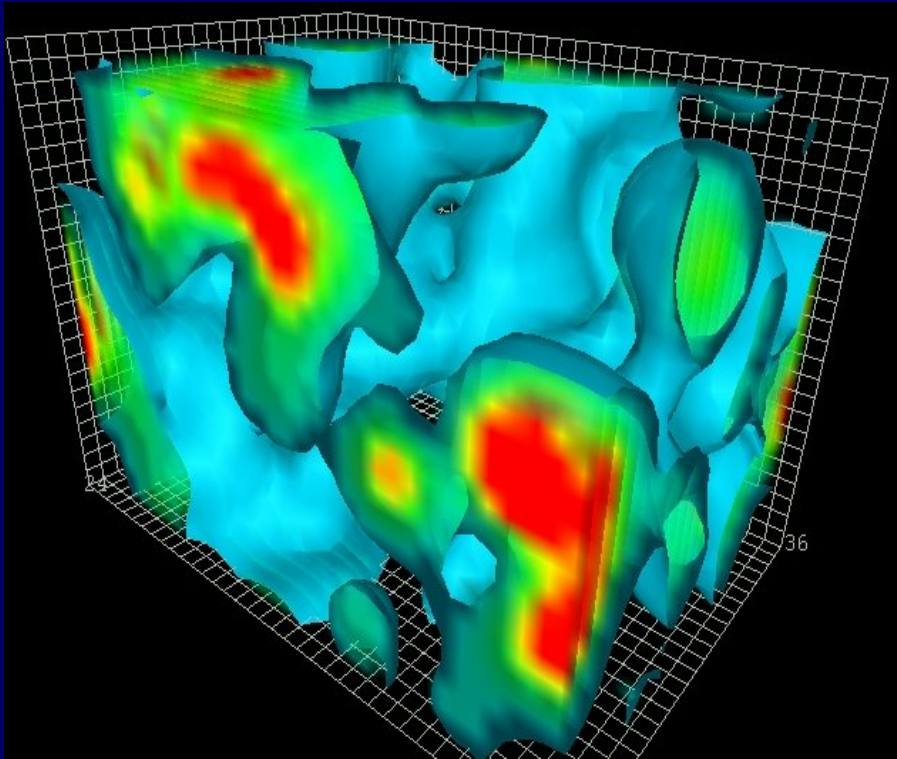


- New SGI Altix XE1300
- Installed in May 2007
- 136 Intel “clovertown” processors
- 544 computational cores
- 1,088 Gbytes RAM
- High-speed InfiniBand network
- Ranked 2nd R&D in Australia
- Equivalent to 166 in top 500
- 6 Tflops = 6,000,000,000,000 flops
- 70,000 Gbytes Data Storage
- Serves SA Researchers

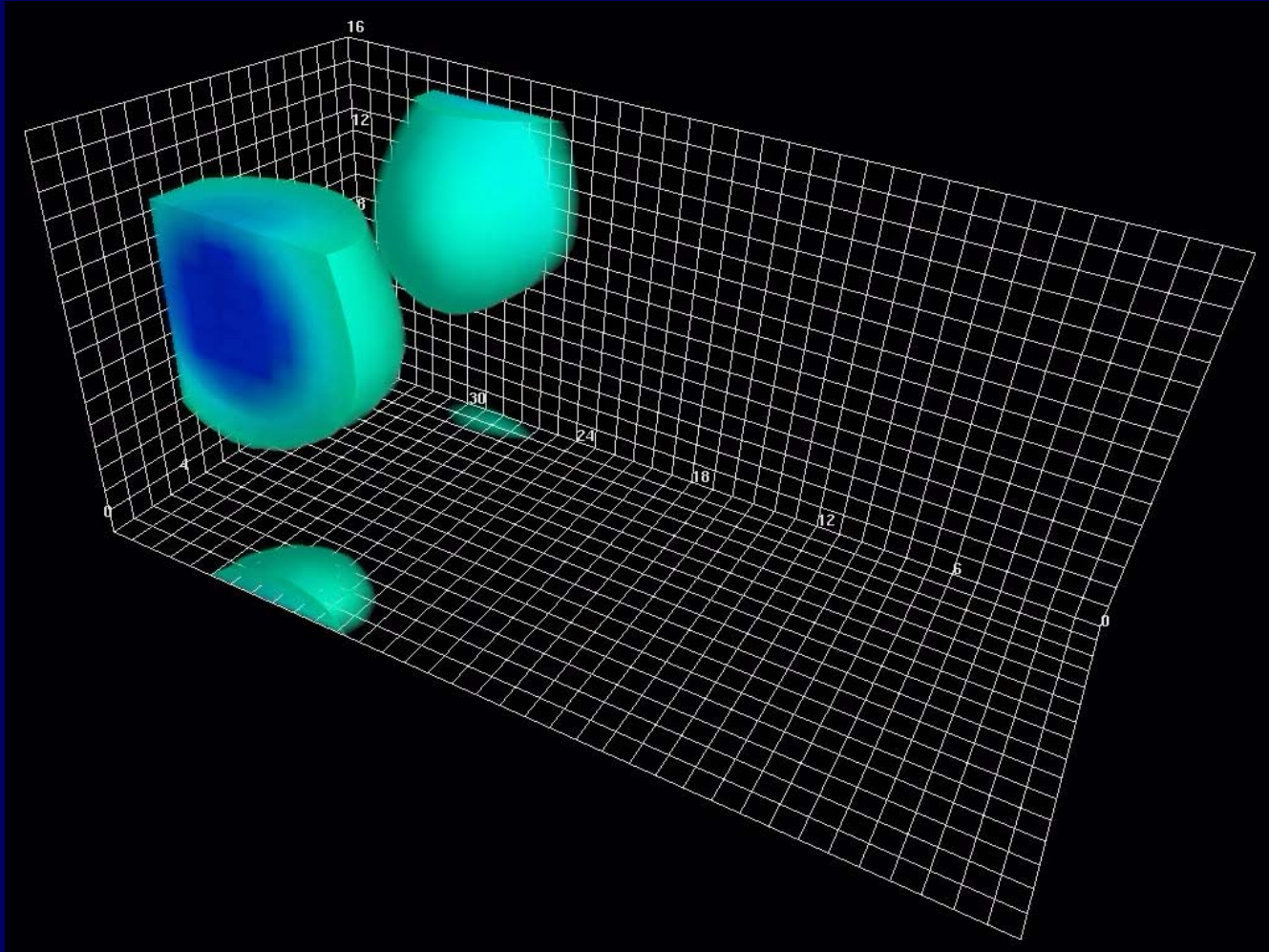
Life Impact – Sciences



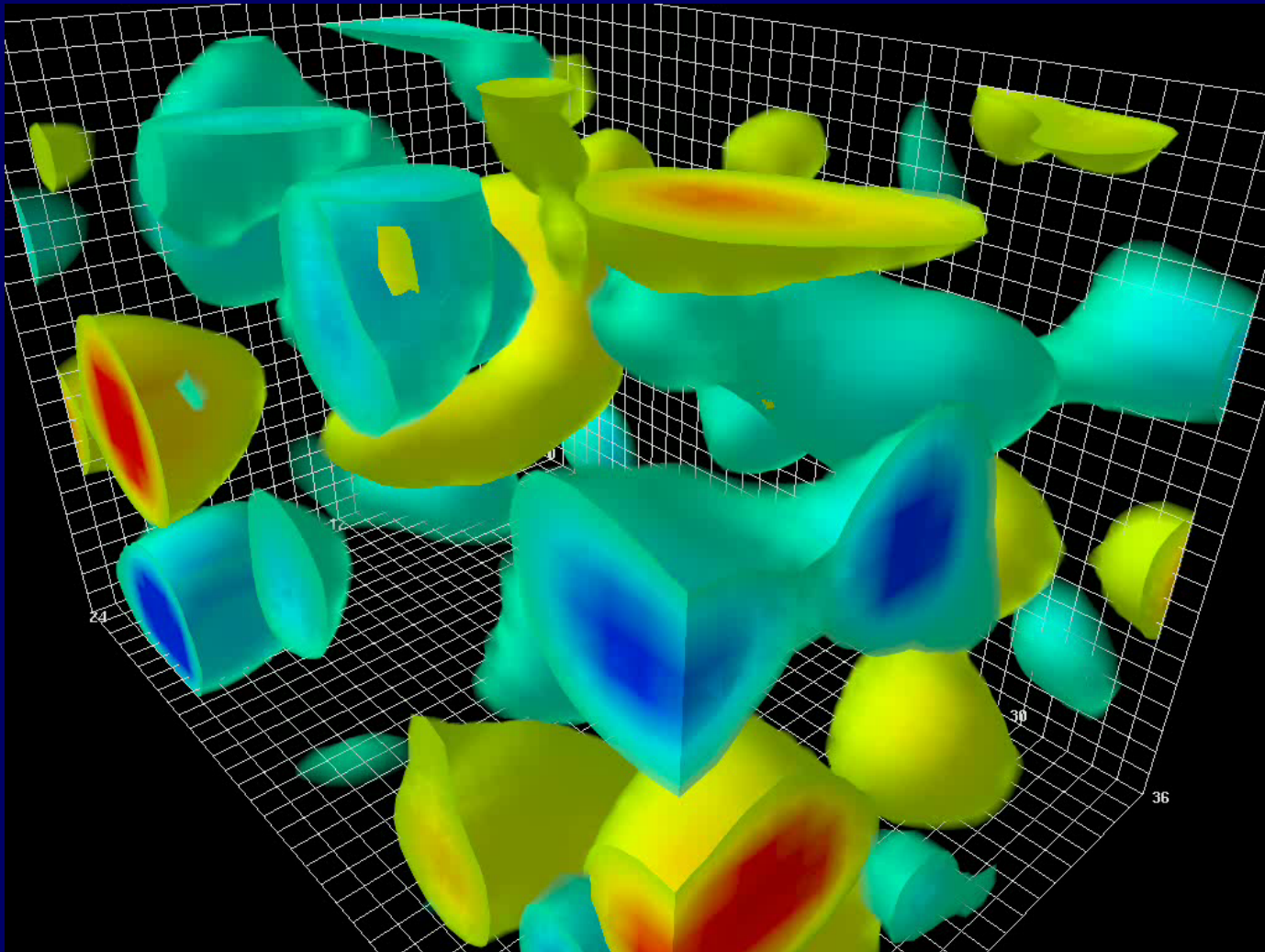
The QCD Vacuum



Instantons



Gluon field winding



Bound States of Quarks

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

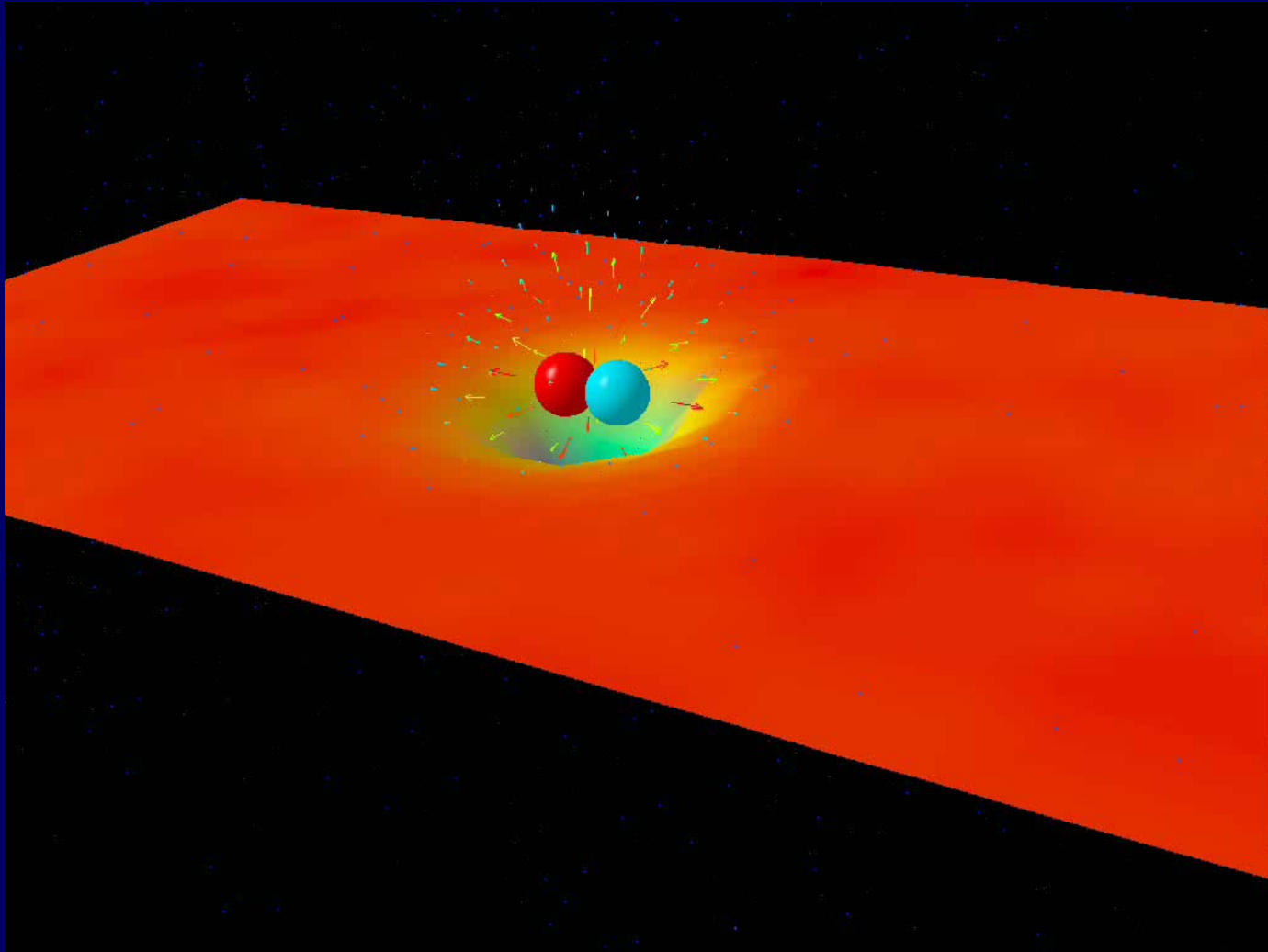
Baryons are fermionic hadrons.
There are about 120 types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	uud	1	0.938	1/2
\bar{p}	anti-proton	$\bar{u}\bar{u}\bar{d}$	-1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	-1	1.672	3/2

Bound States of Quarks

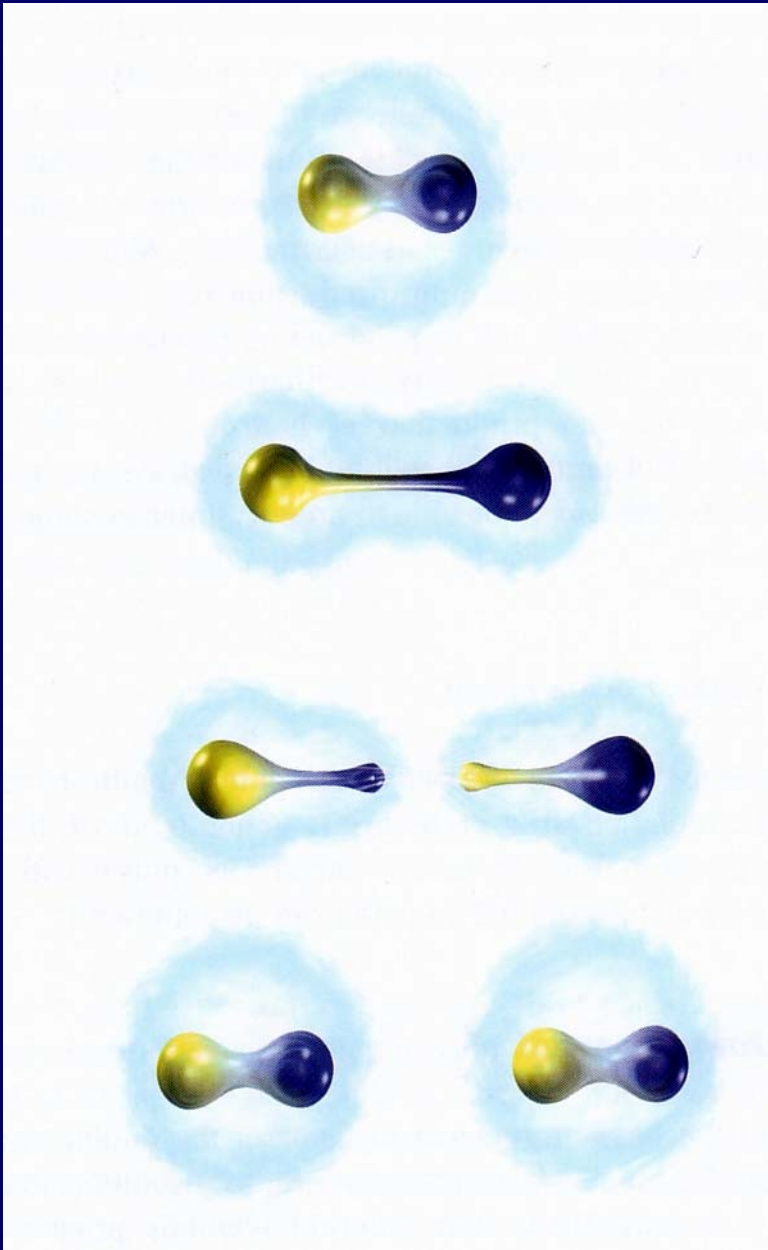
Mesons $q\bar{q}$					
Mesons are bosonic hadrons. There are about 140 types of mesons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	-1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2.980	0

Gluon flux tubes

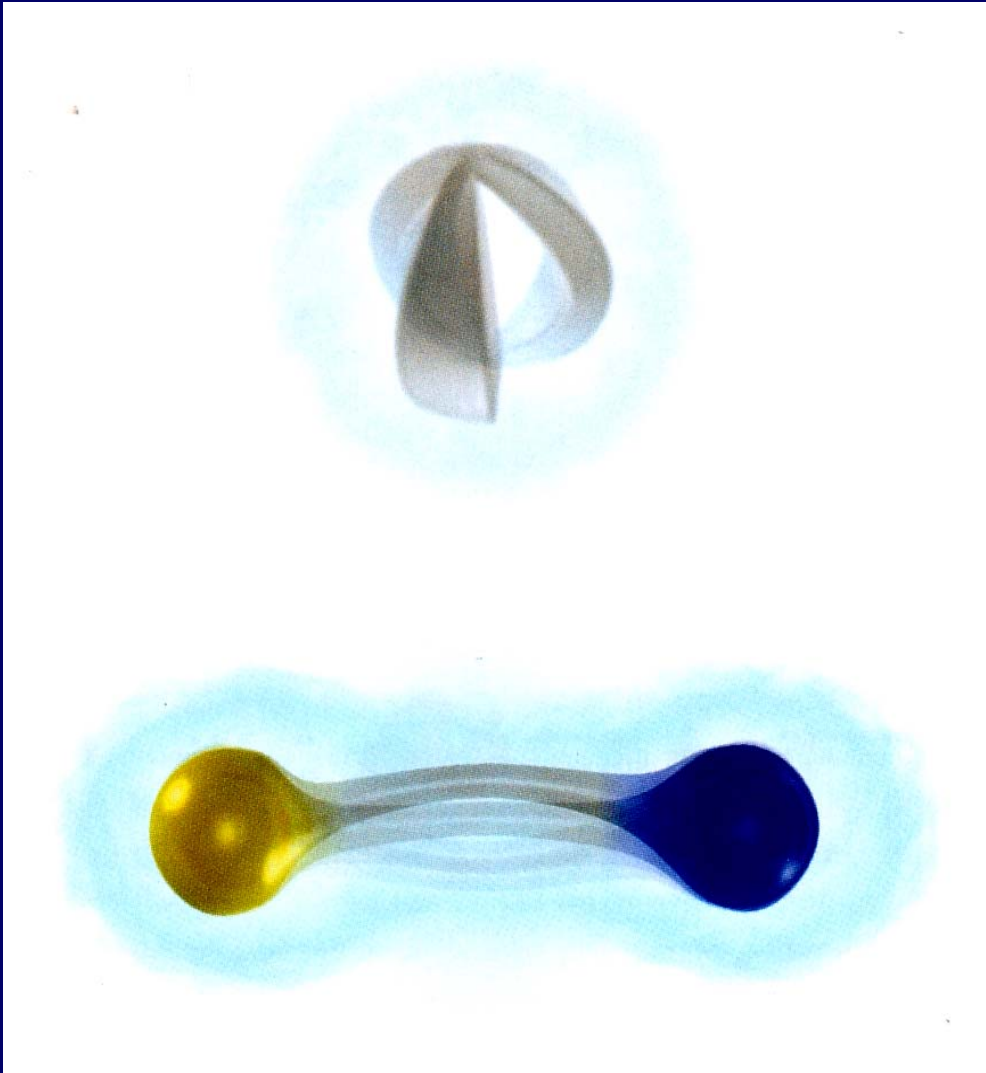


Confinement

- It is impossible to isolate a quark.
- Quarks are “*Confined*”

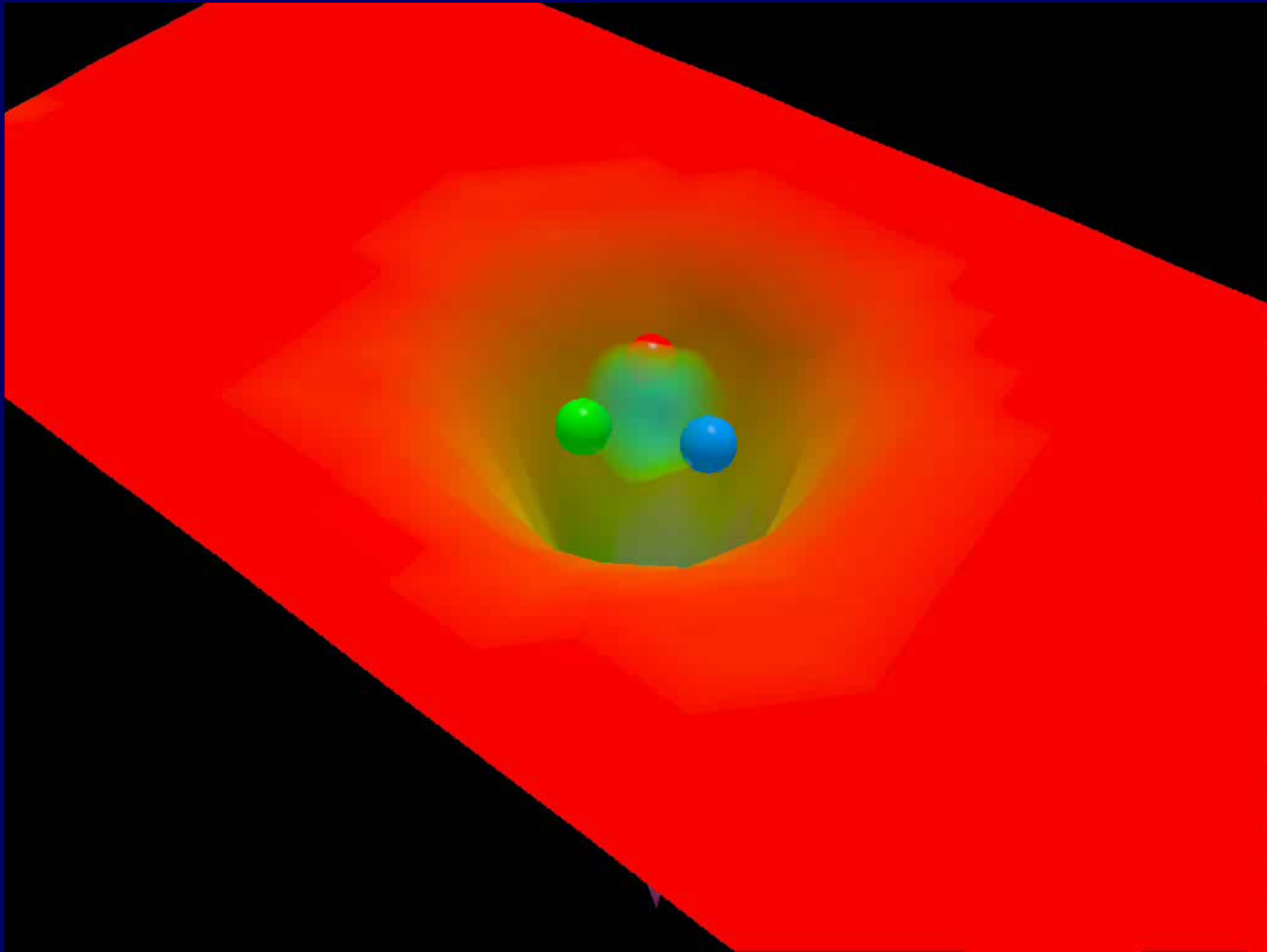


Exotic States of Matter

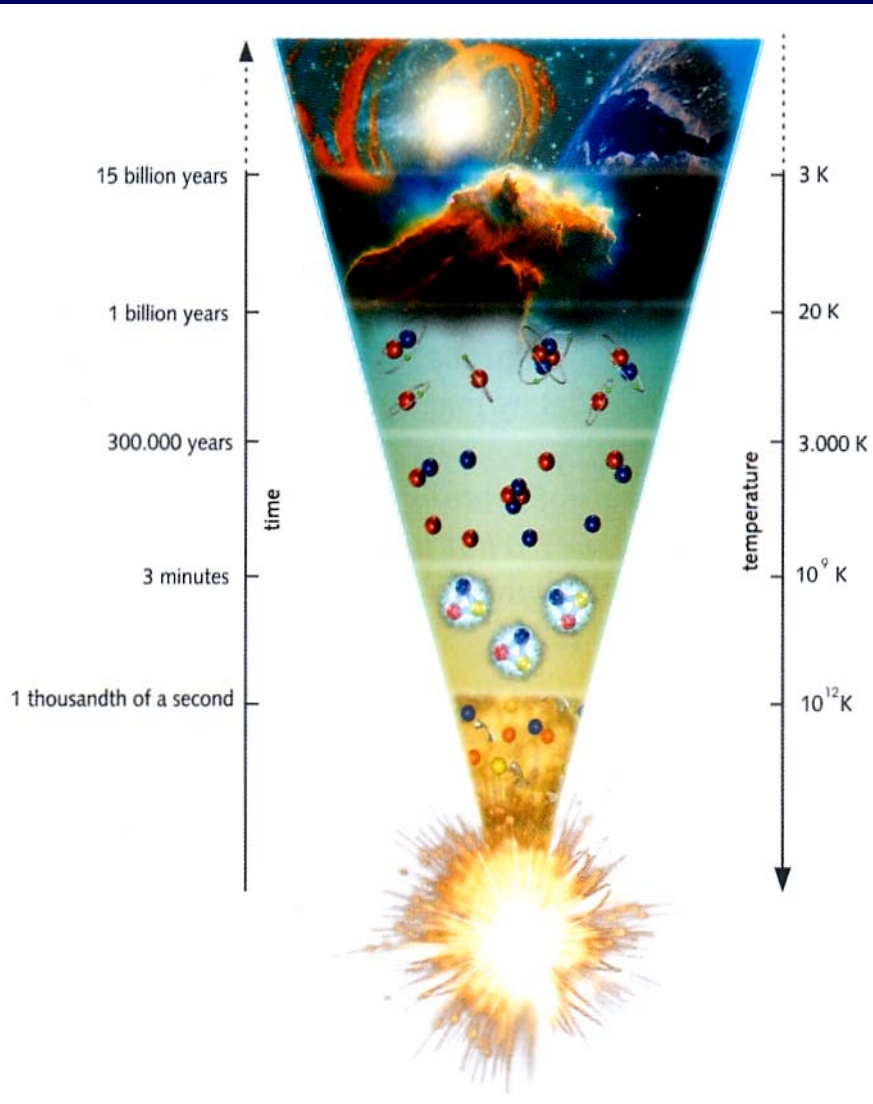


- QCD predicts the existence of exotic mesons.
- Glueballs are mesons dominated by pure self-interacting gluons stuck together.
- Other exotics involve the excitation or vibration of gluons.

Gluon flux tubes



Time



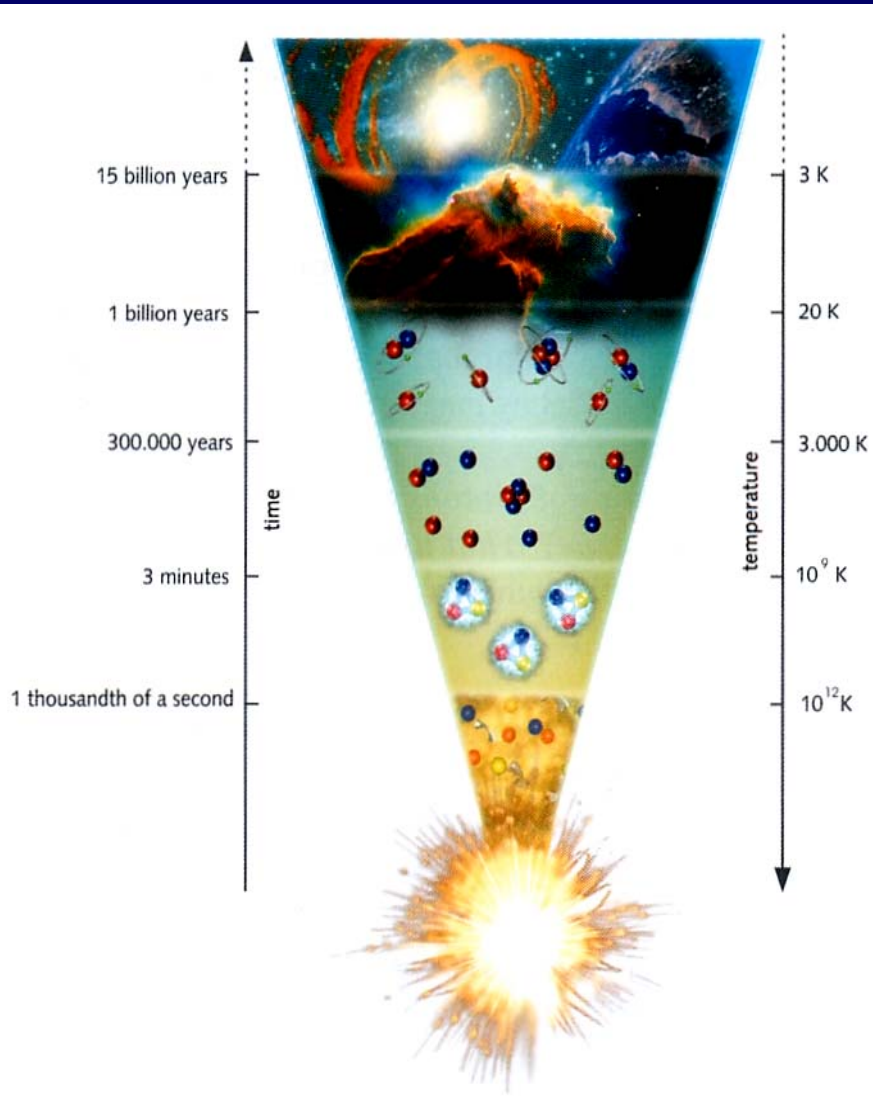
- Supernova & Star Dust
- Star Formation
- First Atoms
- First Nucleii
- First Protons and Neutrons
- Quark Gluon Plasma
- Big Bang

Periodic Table of the Elements

1 IA New Original												C Solid		13 IIIA		14 IVA		15 VA		16 VIA		17 VIIA		18 VIIIA	
Alkali metals												Br Liquid												He Helium 4.002602	
Alkaline earth metals												H Gas												Ne Neon 20.1797	
Transition metals												Tc Synthetic												Ar Argon 39.948	
Lanthanide series																								Kr Krypton 83.798	
																								Xe Xenon 131.293	
																								Rn Radon (222)	
																								At Astatine (210)	
																								Po Polonium (209)	
																								Bi Bismuth 208.98038	
																								Pb Lead 207.2	
																								Tl Thallium 204.3833	
																								Sn Tin 118.710	
																								In Indium 114.818	
																								Cd Cadmium 112.411	
																								Ag Silver 107.8682	
																								Pd Palladium 106.42	
																								Rh Rhodium 102.90550	
																								Ru Ruthenium 101.07	
																								Tc Technetium (98)	
																								Mo Molybdenum 95.94	
																								Nb Niobium 92.90638	
																								V Vanadium 50.9415	
																								Cr Chromium 51.9961	
																								Mn Manganese 54.938049	
																								Fe Iron 55.845	
																								Co Cobalt 58.933200	
																								Ni Nickel 58.6934	
																								Cu Copper 63.546	
																								Zn Zinc 65.409	
																								Ga Gallium 69.723	
																								Ge Germanium 72.64	
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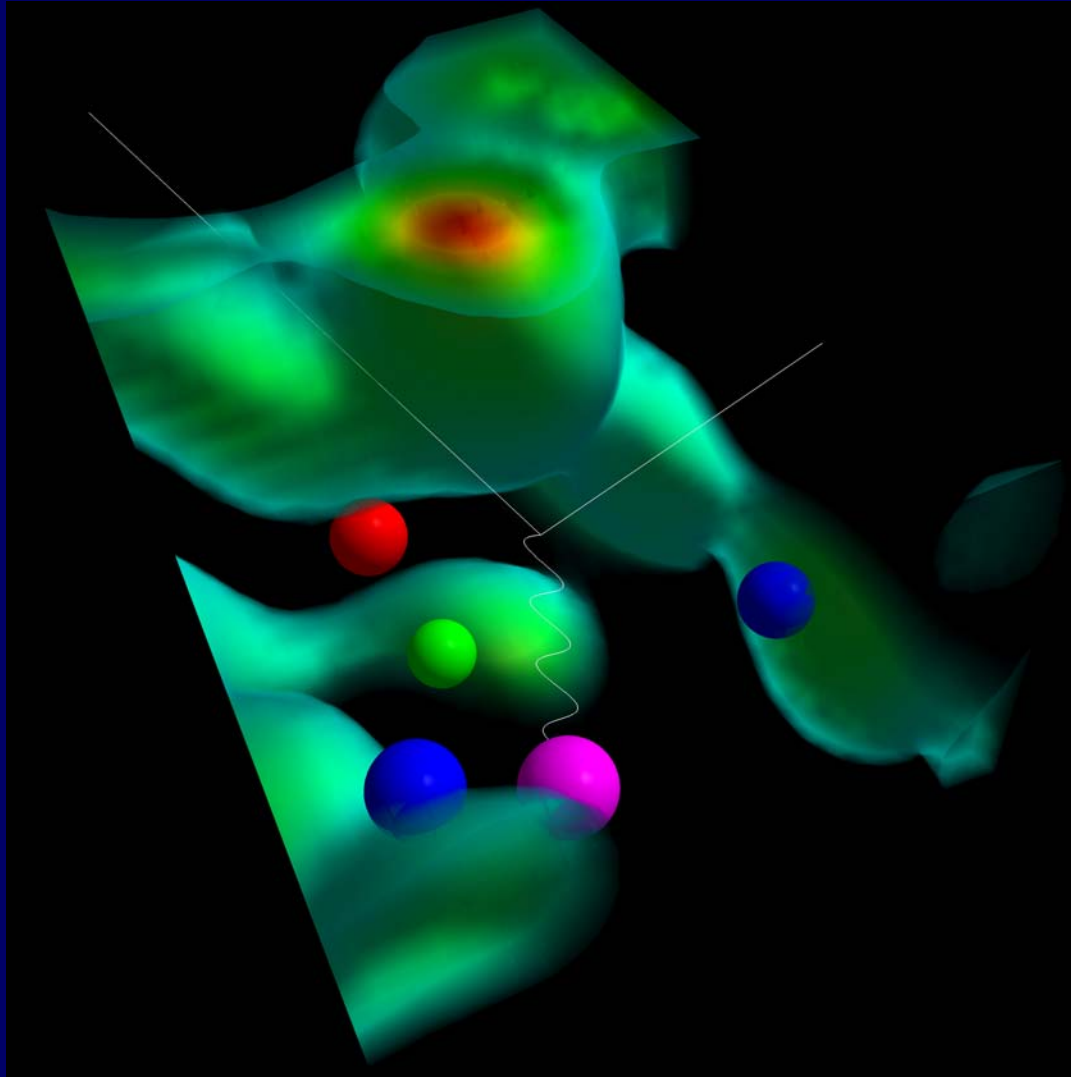
Note: The subgroup numbers 1-18 were adopted in 1984 by the International Union of Pure and Applied Chemistry. The names of elements 112-118 are the Latin equivalents of those numbers.

Time

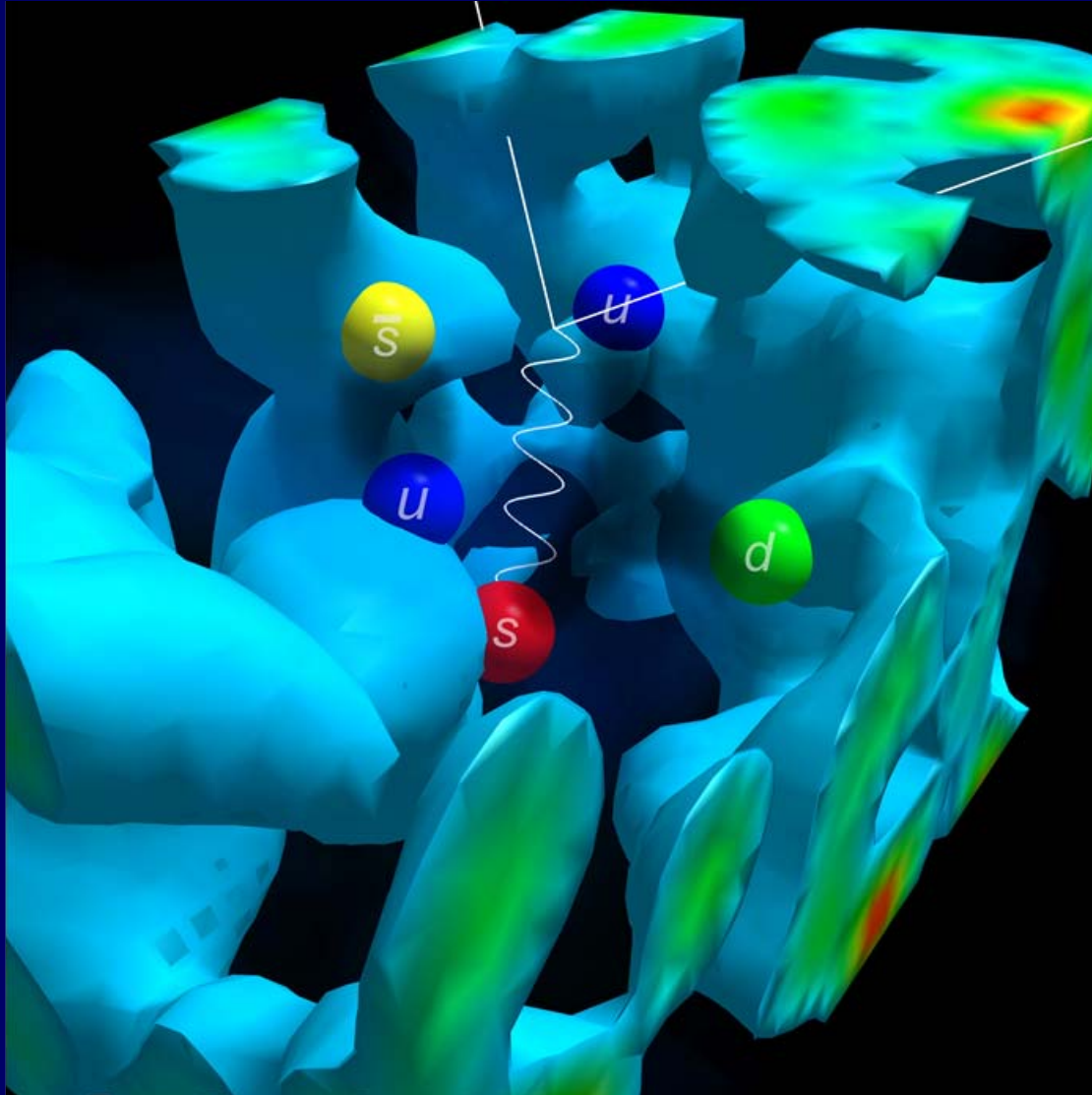


- Supernova & Star Dust
- Star Formation
- First Atoms
- First Nucleii
- First Protons and Neutrons
- Quark Gluon Plasma
- Big Bang

Proton Structure



Strangeness in the Proton



Pre-requisites

BSc

Two science subjects, one chosen from
Chemistry, Maths Studies, Specialist Maths, Physics
& one from
Biology, Chemistry, Geology, Physics

Specialist Programs with Physics

- Physics,
- Maths Studies *and*
- Specialist Maths

Further Information

Visit the web and explore

- Visual QCD or
- The Origin of Mass

at

- [www.physics.adelaide.edu.au/
theory/staff/leinweber](http://www.physics.adelaide.edu.au/theory/staff/leinweber)

