The Structure of Scientific Knowledge

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Provocation

- Problem: “It’s just a theory”
- Excuse: Popper and Kuhn --
  Current theory could be falsified;
  The better theory could bring in
  new objects and actions.
- Solution: Use only “Certified Theories”
  (which have already been shown false)
  in the domains where they are certified.

Solution

- Define an Certified Theory as one which has
  - Known limits
  - Within which it is certified by better theories as correct and reliable
  - Is in active use by scientists who understand the theories which replace it at its limits,,,
  - And which, in its proper domain, is more insightful than the more cumbersome theories which define its limits.

Challenge and Detour

- But there are many certified theories, and they are defined by their relationships to other theories
- So we need to study relationships between theories
- That occurs within a wide ranging survey of what scientific knowledge can mean.
  - Scientific aims
  - Scientific accomplishments

Multi-Spectral Survey

- Pure Science vs. Applied
- Basic vs. Derived (cf. Chandra)
- Normal or Paradigm Shift (cf. Kuhn)
- Reductionist vs. Emergent (cf. Anderson)
- Accepted vs. Falsified (cf. Popper)
- Cutting Edge vs. Certified

Basic vs. Derived Science

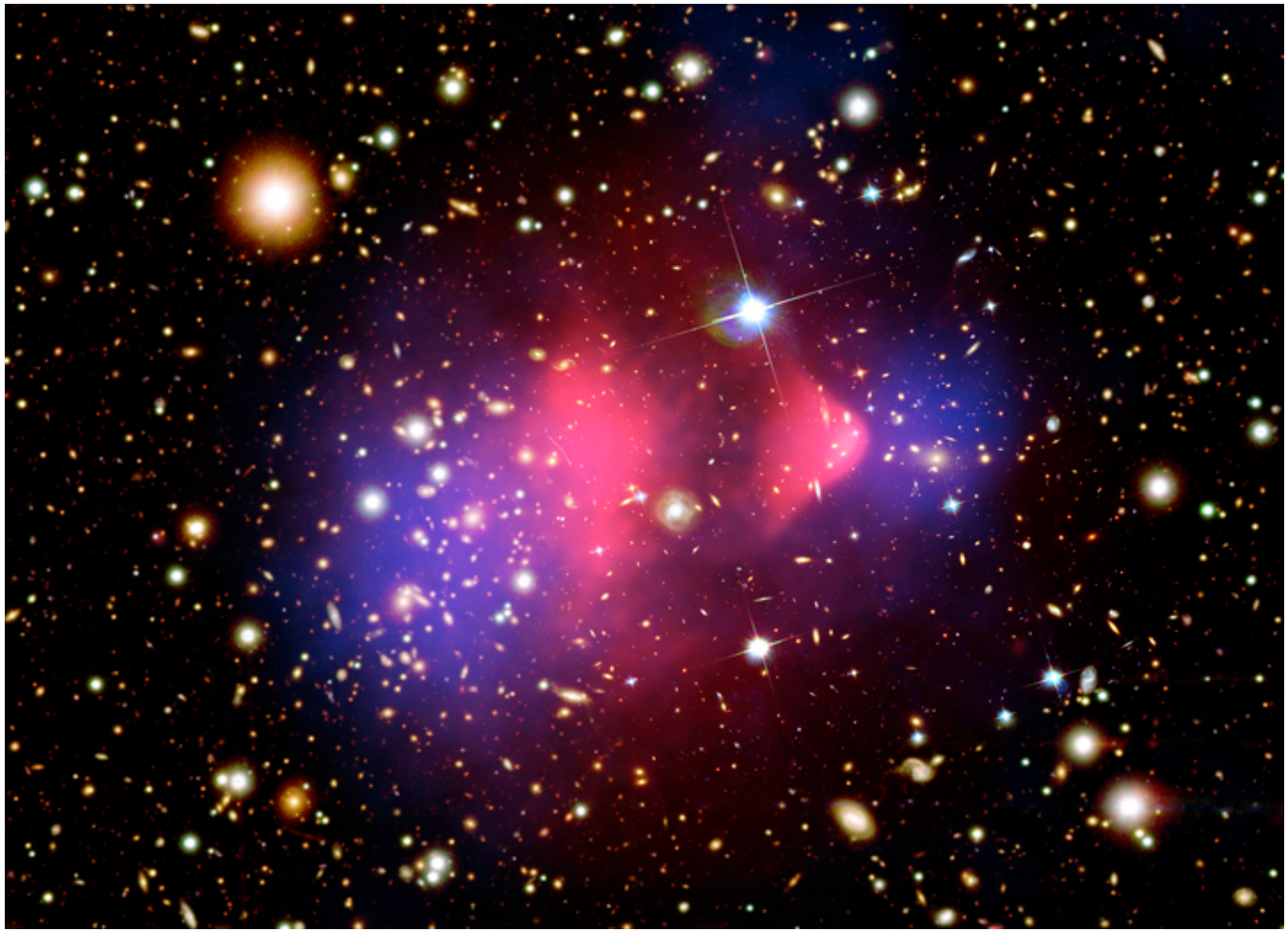
- Basic discoveries
  - Maxwell's equations
  - Dirac equation
  - QCD, etc.
  - Dark matter
- Derived discoveries
  - Chadrasekhar limit for white dwarfs
  - positrons
  - Black Holes

Normal or Paradigm Shift

- Normal science (correct the details)
  - Dark Energy (in GR normal, not in QFT)
  - Dark Matter (no change to Einstein's equations needed)
  - Allow for small neutrino masses
- Paradigm Shift
  - Go from 4D to 11D ?
  - Æther to Special Relativity Vacuum
  - Fixed spacetime to dynamically curved spacetime
  - Empty vacuum to quantum virtual particle æther

Normal or Paradigm Shift

- Recent success “Dark Matter Telescope”



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After more than 50 years of experiments our present understanding of the Universe

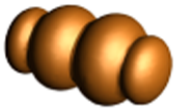
Leptons

Electric Charge

Tau	-1	0	Tau Neutrino
Muon	-1	0	Muon Neutrino
Electron	-1	0	Electron Neutrino

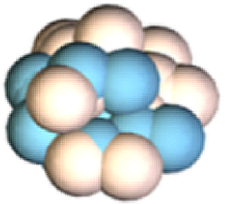
Strong

Gluons (8)



Quarks

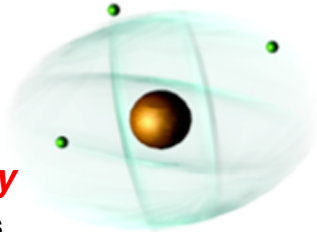
Mesons
Baryons



Nuclei

Electromagnetic

Photon



Atoms
Light
Chemistry
Electronics

Quarks

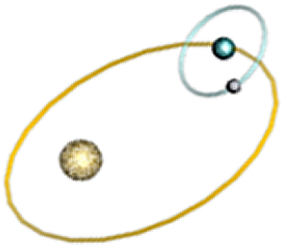
Electric Charge

Bottom	-1/3	2/3	Top
Strange	-1/3	2/3	Charm
Down	-1/3	2/3	Up

each quark: R, B, G 3 colours

Gravitational

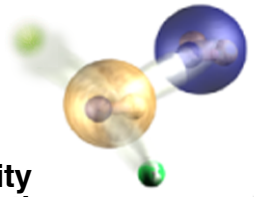
Graviton ?



Solar system
Galaxies
Black holes

Weak

Bosons
(W,Z)



Neutron decay
Beta radioactivity
Neutrino interactions
Burning of the sun

Reductionist Chemistry

Equation to Solve in *ab initio* Theory

$$H\Psi = E\Psi$$

Known exactly:

3N spatial variables

(N # of electrons)

To be approximated:

1. variationally

2. perturbationally

Reductionist Chemistry

Hamiltonian for a Molecule

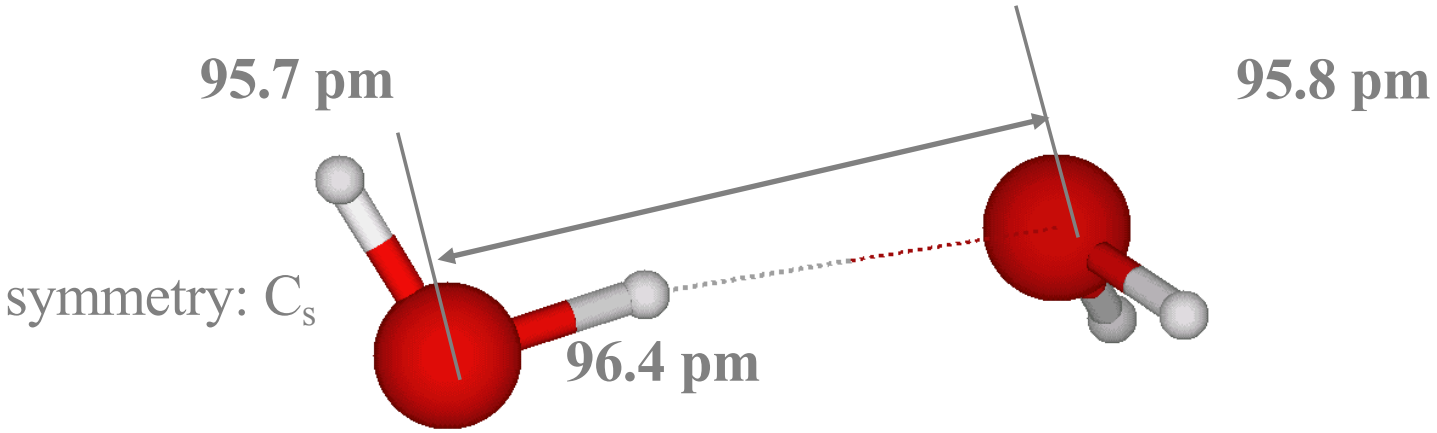
$$\hat{\mathbf{H}} = \sum_{i}^{electrons} \frac{-\hbar^2}{2m_e}\nabla_i^2 + \sum_{A}^{nuclei} \frac{-\hbar^2}{2m_A}\nabla_A^2 + \sum_{i}^{electrons}\sum_{A}^{nuclei} \frac{-e^2 Z_A}{r_{iA}} + \sum_{i>j}^{electrons} \frac{e^2}{r_{ij}} + \sum_{A>B}^{nuclei} \frac{e^2 Z_A Z_B}{R_{AB}}$$

- kinetic energy of the electrons
- kinetic energy of the nuclei
- electrostatic interaction between the electrons and the nuclei
- electrostatic interaction between the electrons
- electrostatic interaction between the nuclei

Reductionist Example

Equilibrium structure of $(H_2O)_2$

W.K., J.G.C.M. van Duijneveldt-van de Rijdt, and
F.B. van Duijneveldt, *Phys. Chem. Chem. Phys.* **2**, 2227 (2000).



Experimental [J.A. Odutola and T.R. Dyke, *J. Chem. Phys* **72**, 5062 (1980)]:

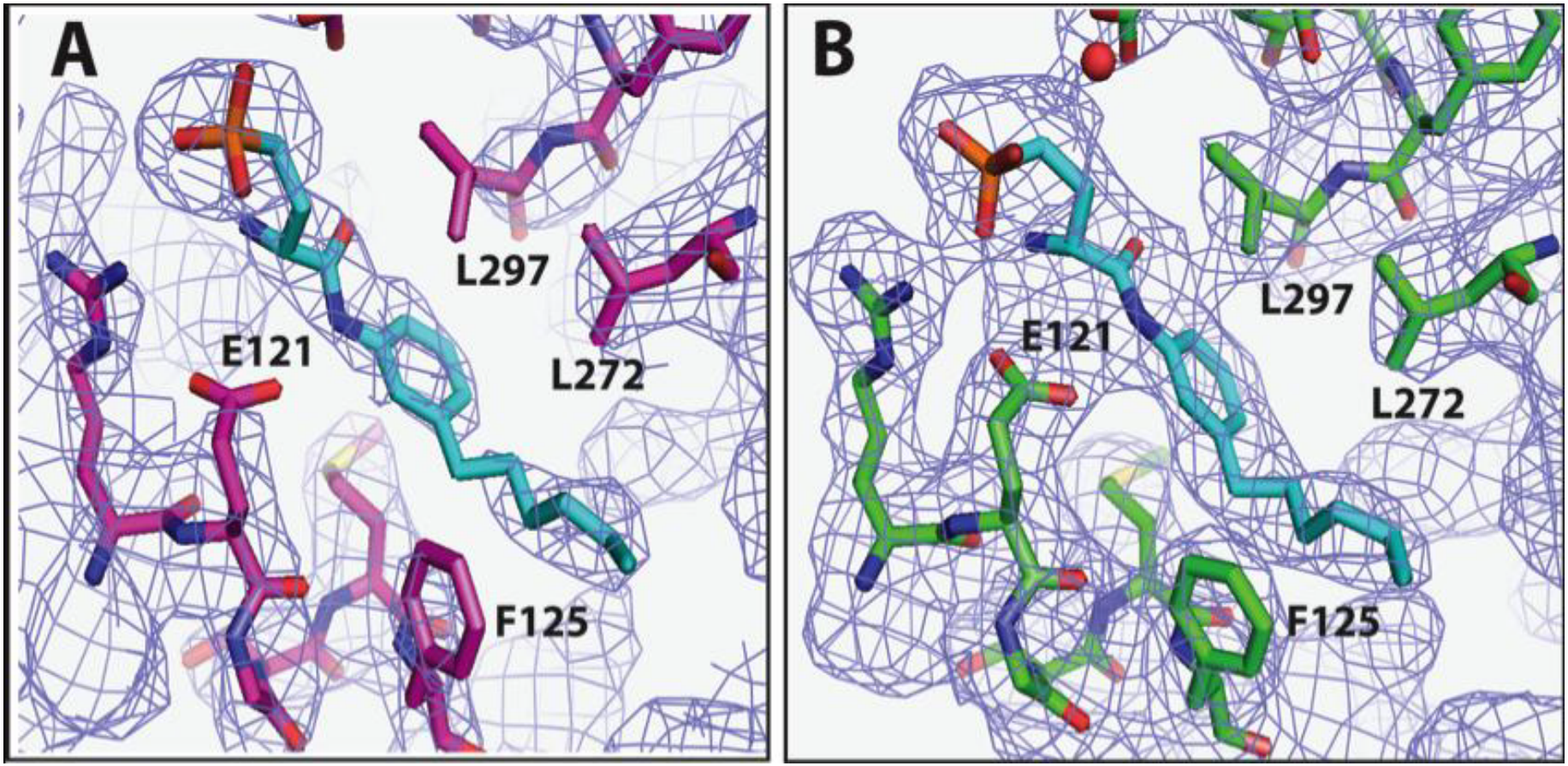
$$< R_{OO}^{-2} >^{-½} = 297.6 \pm 0.4 \text{ pm}$$

SAPT-5s potential [E.M. Mas *et al.*, *J. Chem. Phys.* **113**, 6687 (2000)]:

$$< R_{OO}^{-2} >^{-½} - R_{OO,e} = 6.3 \text{ pm} \rightarrow R_{OO,e}(\text{exptl.}) = 291.3 \text{ pm}$$

Emergent Chemistry

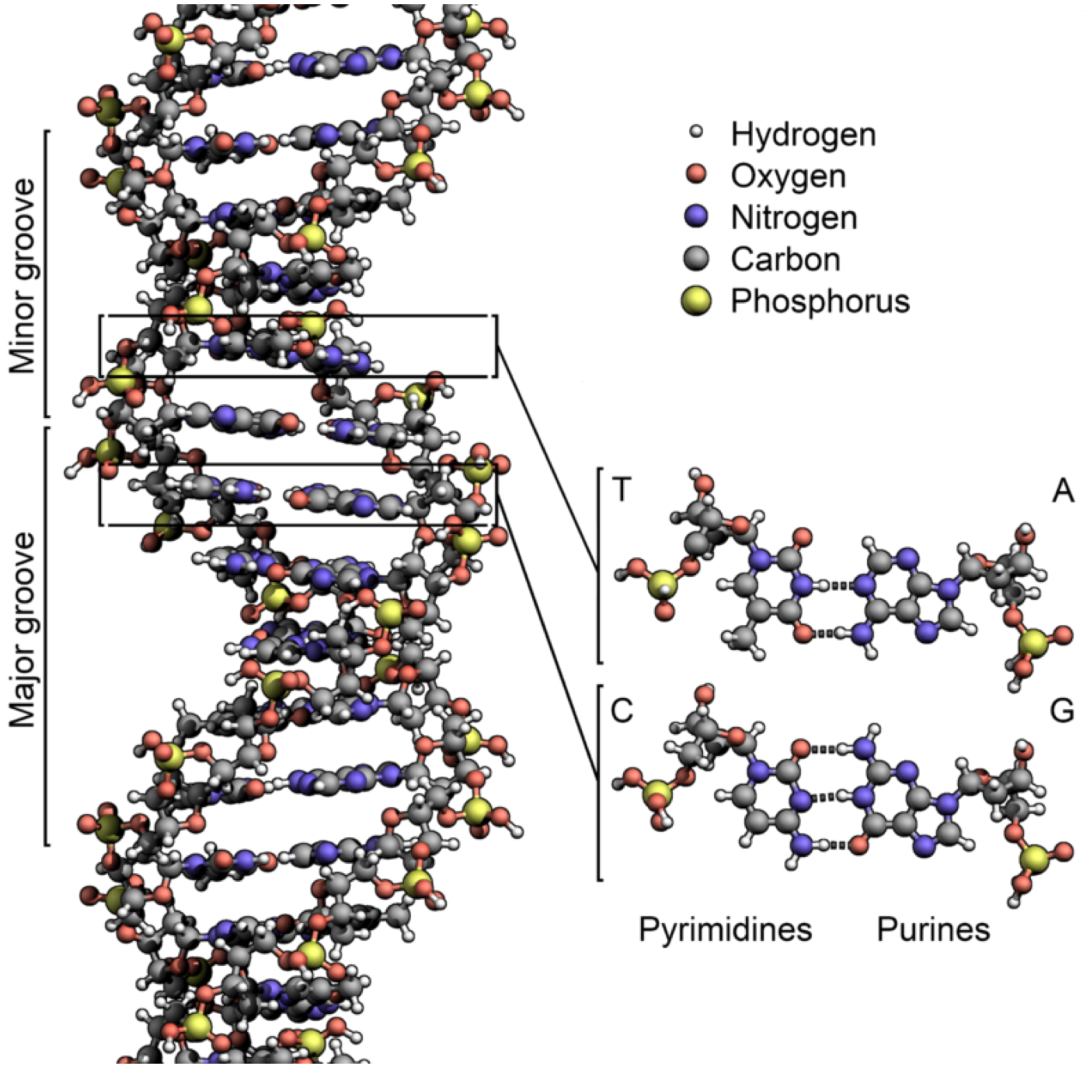
From Hanson et al., Science v335, p851, SOM p 22



Emergent Chemistry

In DNA even the atoms, much less individual electrons, are barely noticed.

The base pairs are the basic unit.



Emergent Chemistry

- As a simpler example of reductionist vs. emergent concepts in chemistry consider the "More is Different" (Ph. Anderson) view of the Carbon Atom as a building block.
- Is there anything *visible* in the Schrödinger equation view of the carbon atom that would lead to both
  - Diamond, and
  - Graphite

  as possible quasistable many-particle equilibria?

Emergent Theories

- P. W. Anderson, “More is Different”, *Science*, Vol. 177, pp. 393—396 (1972)

- Philip W. Anderson, Chapter 3 in *More and Different* (World Scientific, 2011) ISBN 978-981-4350-13-6

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Scientific Aims

Agreement with experiment & observation. But

- Extrapolation is not enough (e.g. tide tables)
- Reductionist theme is prominent
  - Explain reality by its underlying constitutents, e.g. “Theory of Everything”
  - Needs both basic science and derived science (see Dyson at Chandra100)
- Emergent laws and properties are essential
  - Thermodynamics, Hydrodynamics, Chemical bonds, … (see Philip Anderson)

Scientific Aims

- The best current theories are subject to change.
- Ambitious scientists are working to find where they are wrong, which could win them a prize.

Scientific Accomplishments

- Theories get falsified – Popper
  - A statement is not scientific if one can't imagine an experiment of observation that might prove it wrong.
  - This has happened previously; why not again?
- Scientific revolutions – Kuhn
  - Not only the rules change
  - Even the vocabulary/concepts may be entirely novel

Scientific Accomplishments

The growing lode of permanent knowledge:

- Don't rely on the best current theories – look elsewhere.
- But the trash bin of falsified theories doesn't look inviting at first. Phlogiston anyone?
- But the reusables shop is full of good stuff!
- With Newtonian mechanics as a prime example, we look for "Certified Theories"

Structure of Sci. Knowledge

- The core set of Certified Theories with their mutual relationships and their relationships to other theories
- The active troposphere of cutting edge theories, the best we know in any given area
- The stratosphere of speculative theories, representing plausible directions toward better theories.

Definition

- Define an Certified Theory as one which has
  - Known limits
  - Within which it is certified by better theories as correct and reliable
  - Is in active use by scientists who understand the theories which replace it at its limits,,,
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Famous Certified Theories

- Pre-Ptolemaic motion of celestial objects
- Kepler's laws
- Newtonian Mechanics
- Heisenberg-Schrödinger quantum mechanics
- Maxwell-Lorentz classical electrodynamics
- Schwinger-Feynman-Dyson electrodynamics

Certified Theories

A tool needed for recognizing certified theories is the collection of relationships theories may have with each other:

- Correspondence principles
- Emergent laws and concepts
- Evanescent laws and concepts

Correspondence Principles

- Quantum theory gives classical mechanics when quantum numbers are large
- General Relativity reduces to special relativity when curvature is negligible
- GR reduces to Newtonian gravity for weak fields and slow motions
- Special relativity gives Newtonian mechanics for slow motions
- Electroweak YM gives QED at low energies

Evanescent Laws

- A law or property can be called Evanescent when in some domain either
  - It becomes irrelevant or useless
  - It is indefinable or misleading
  - Its normal consequences can be evaded
  - It (rarely) is incorrect in some domain
- I could (Oppurg) make the evanescence case for energy and entropy on the cosmological scale.

Evanescent Laws

- Examples
  - Conservation of QCD color charge as one moves into atomic physics
  - Coulomb law as one calculates the motions of solar system planets
  - Schrödinger equation in molecular genetics
  - *Energy on cosmological scales*
  - *Entropy in large self-gravitating systems*

Structure of Sci. Knowledge

- The expanding lode of reliable scientific knowledge is contained in the core set of Certified Theories
- Some applications of this viewpoint:
  - Crackpot theories
  - “theory-laden observations”

Crackpot Theories

- Defined: a theory which, while explaining (?) some phenomenon, cannot produce by correspondence principles the certified theories which show that centuries of past data make sense.

"Theory-laden"

- Some philosophers worry that if we need a bubble chamber to see cosmic rays, that data assumes the theory it is trying to support.
- Worst case: If Archimedes could be resurrected and flown from Syracuse to Geneva then, given full access to CERN, could he see quarks there?
- Response: Even CERN detectors are mainly interpreted using Certified Theories.

Speculation vs. Reliable Sci.

Projects many scientists find implausible have supporters who treat inconvenient scientific facts as “just a theory”

The viewpoint I present here is provided as background for scientists talking to journalists and politicians.

This presentation here is too technical for direct delivery to a nonscientific public.

It is most applicable in fields with clearly defined theories such as physics, chemistry, genetics.