



Space, time, and motion in the universe





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Simulation from Greg Bothun University of Oregon





HST Picture of the Antennnae Galaxies (NGC 4038/4039) 63 million light-years away in the southern constellation Corvus.



Hubble Deep Field









2 million light years - 90,000 mph





The VIRGO Project



Galaxies: Building blocks of the (visible) universe



Dark Matter



Absol ute space, in its own nature, without relation to anything external, remains al ways similar and immovable.

Isaac Newton 1686 *Principia*



Space and time are related.

Albert Einstein 1905

Space is dynamical (curved, warped, bent, etc.).

> Al bert Einstein 1915



Space expands.

Edwin Hubbl e 1929



The University of Chicago



1909 National Champions

The universe is hot.

Arno Penzias Robert Wil son 1965





GIT

ন্থ

T = 3K = -454 F = -270 C







(10 nonlinear partial differential equations)



Fermi National Accelerator Laboratory



Particle Accelerator-Telescope-Time Machine

Galileo Pisan Accelerator Laboratory



FERMILAB PRIMORDIAL SOUP





4X10⁻¹² seconds 0.000 000 000 004 seconds

3x10¹⁵ degrees 3,000,000,000,000,000°



FERMILAB PRIMORDIAL SOUP

FERMILAB PRIMORDIAL SOUP

Caution !!! Condensed

50 Earth masses in matter 50 Earth masses in antimatter

+ extra mountain of matter

HOT

64 billion years of energy output of sun

CONTENTS

elementary particles and antiparticles

FERMILAB PRIMORDIAL SOUP

KNOWN INGREDIENTS:

56% QUARKS
16% GLUONS (STRONG FORCE)
9% ELECTRON-LIKE PARTICLES
9% W's AND Z's (WEAK FORCE)
5% NEUTRINOS
2% PHOTONS (ELECTROMAGNETIC FORCE)
2% GRAVITONS (GRAVITATIONAL FORCE)
1% HIGGS BOSONS

SECRET INGREDIENT: DARK MATTER





atoms form

nuclei form

neutrons protons form

primordial soup

HORS D'OEUVRES BEFORE SOUP ?

At time zero:

- infinite temperature
- infinite pressure
- infinite density
- infinite curvature

At time zero:

- spacetime singularity
- physical law breaks down
- no predictions possible
- here be dragons!

BEFORE PRIMORDIAL SOUP?

NOTHING!!! (vacuum)

MUCH ADO ABOUT NOTHING:

NOTHING is something

NOTHING has energy

NOTHING can change



Quantum Uncertainty

Nothing has energy: The Higgs potential

- The vacuum has a "Higgs potential"
- Interaction with the Higgs potential gives mass to particles



Every cubic inch of space is a *MRACLE !* - Walt Whitman

- background radiation
- virtual particles
- Higgs potential

Nothing can change

- Today the density of nothingness is less than 10⁻³⁰ grams per cc
- Before primordial soup the density of nothingness may have been larger than 10⁺³⁰ grams per cc
- The primordial soup came from vacuum discharge (inflation)

"For every complex natural phenomenon there is a simple, elegant, compelling, wrong explanation."

- Tommy Gold



Chicago at night



The microwave sky $T = 2.728^{\circ} K$ (-454° F)









EVERYTHING IN THE UNIVERSE

MICROWAVE RADIATION PATTERN SUPERCLUSTERS OF GALAXIES **CLUSTERS OF GALAXIES STARS** PLANETS PEOPLE POODLES PIGEONS PETUNIAS POND SCUM **KATHERINE HARRIS** FROM THE QUANTUM VACUUM!



BEFORE NOTHING ?

NOTHING HAD A BEGINNING:

- quantum creation of space, time, vacuum from less than nothing.
- nothing is unstable -- emergence of the universe is *inevitable*.



IMAGINARY TIME



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NOTHING IS ETERNAL:

- universe is still inflating.
- on largest scales, universe is unchanging -no beginning and no end.



Universe has no beginning. .no end

Each bubble grows to cosmological size









When one tugs at a single thing in nature, he finds it hitched to the rest of the universe.

– John Muir



The Quantum and the Cosmos

www-astro-theory.fnal.gov/Personal/rocky/