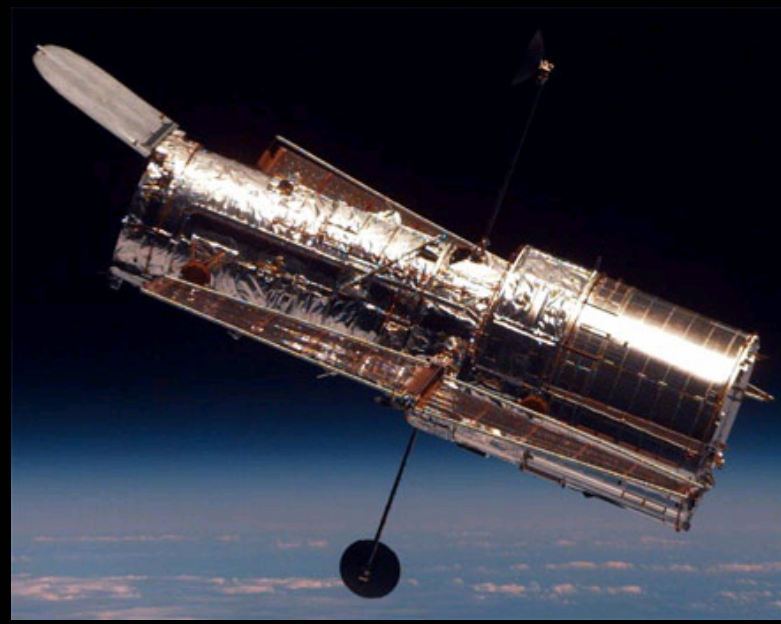
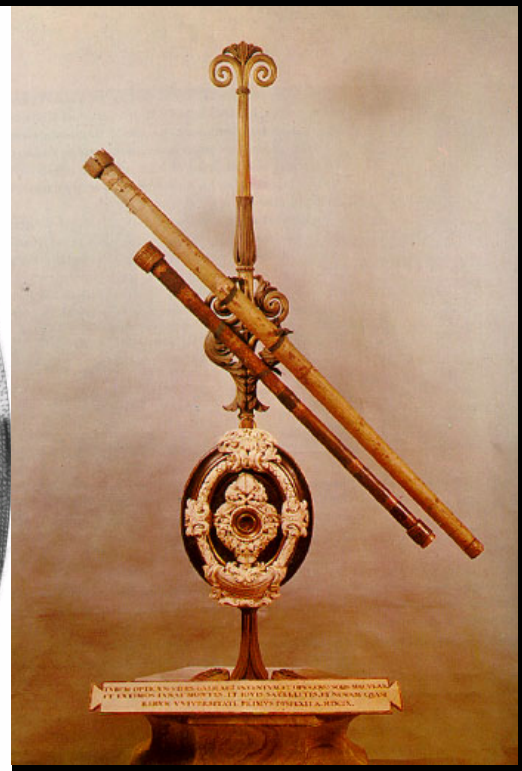
400 Years of Discovery with "Telescopes" & "Microscopes"



Michael S. Turner
Kavli Institute for Cosmological Physics
The University of Chicago

ca 1600: Invention of telescope and microscope

Galileo Galilei



The First Compound Microscope (circa 1595)

Zacharias Janssen (+Hans Janssen & Hans Lippershey)

THE UNIVERSE
YOURS TO DISCOVER

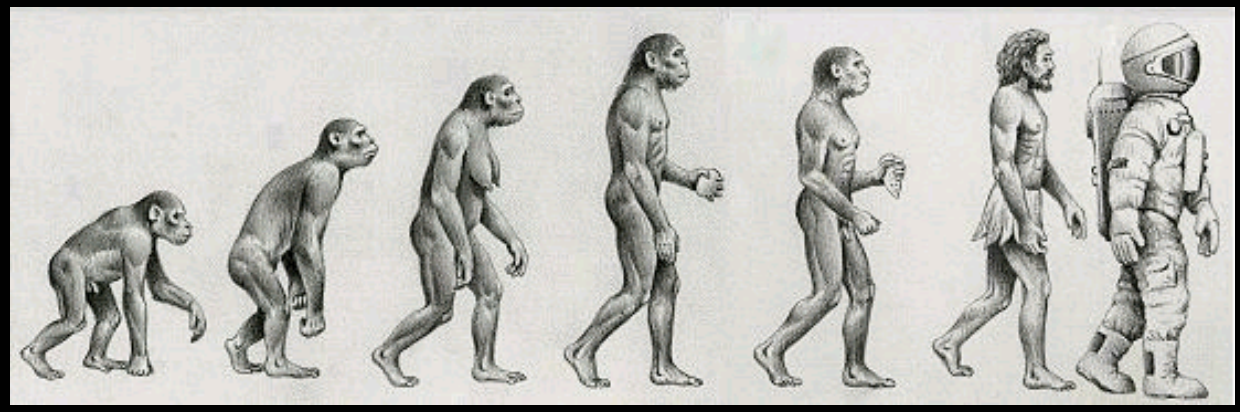
INTERNATIONAL YEAR OF ASTRONOMY 2009

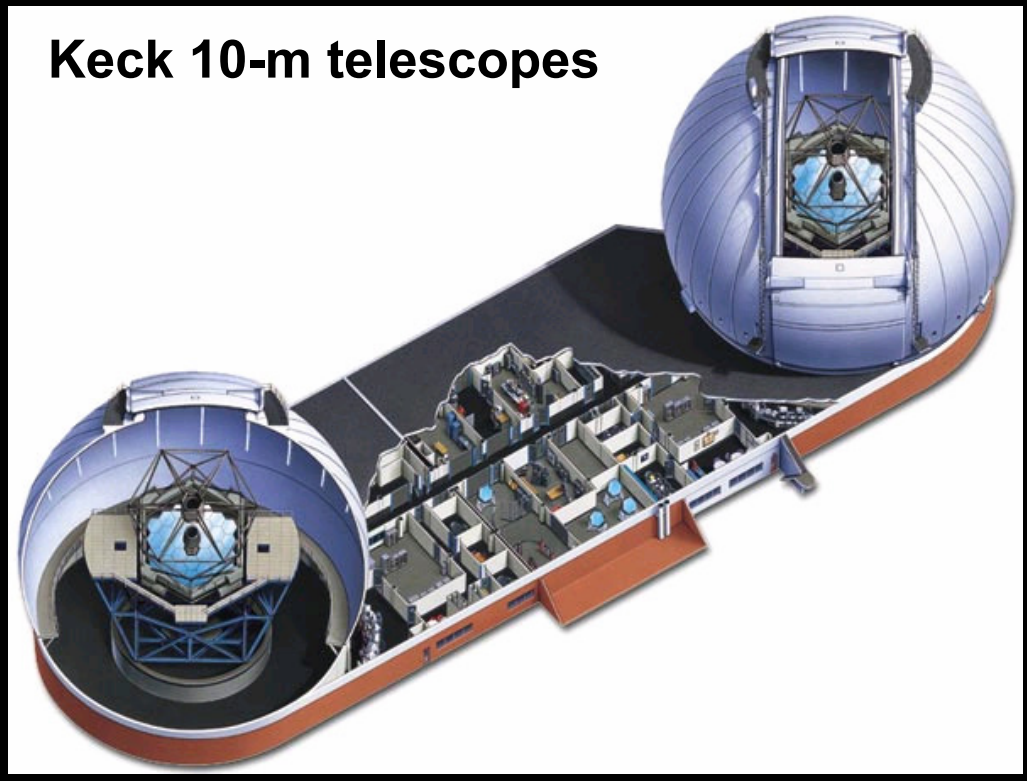
The Birth of Modern Science

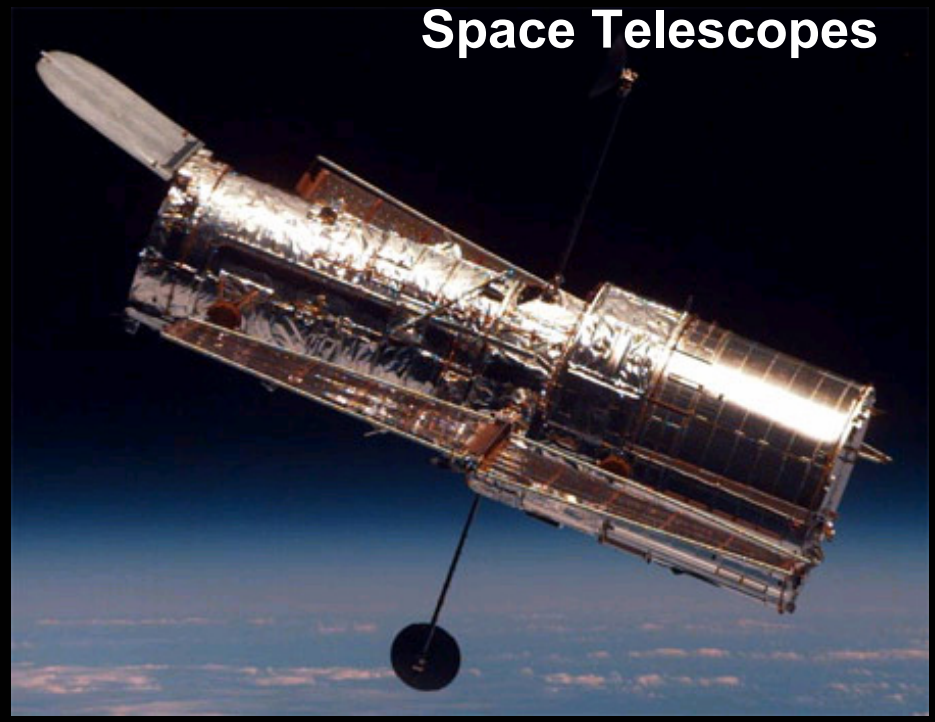
Exploration of the world beyond the reach of our “ordinary senses” with instruments

Beginning of marvelous, but separate, journeys into Inner Space and Outer Space,
with transformative discoveries
and significant spinoffs

400 Years of Intelligent Design

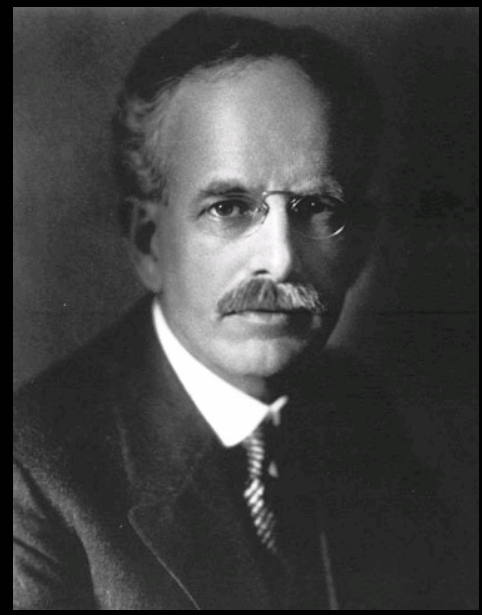






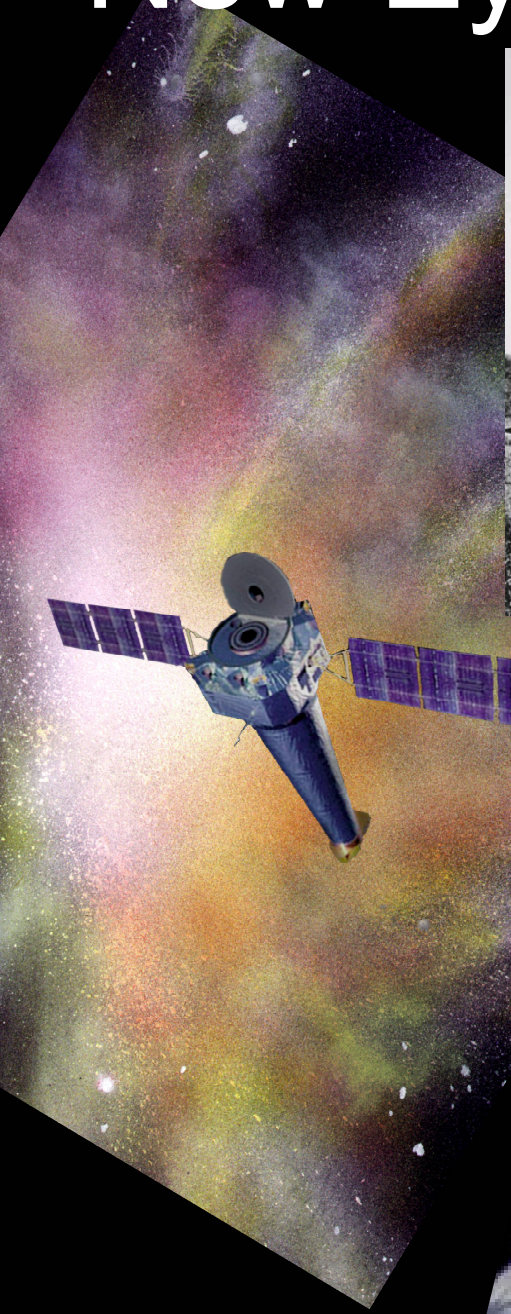
Factor of 10^{10} improvement in sensitivity, with 100x to come (JWST)

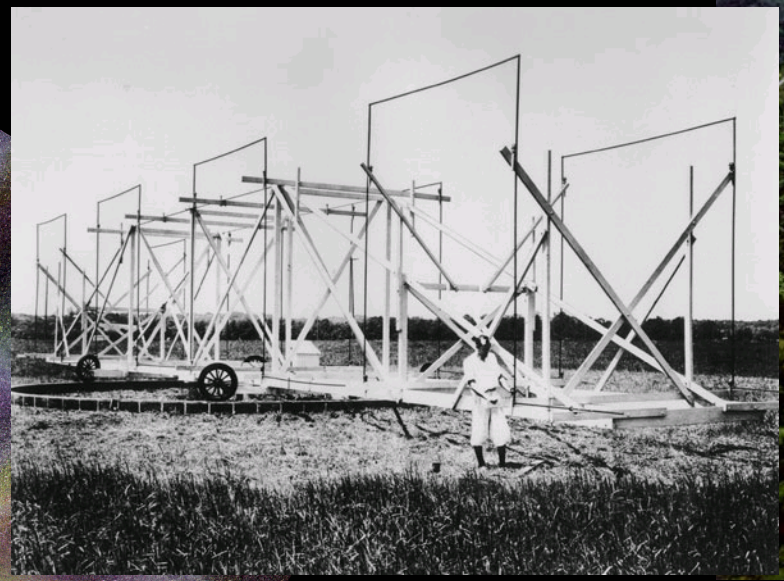
- Refractors to reflectors (Newton, Hale)
- Size: 4 cm to 10 meters (more light)
- High, dry sites with good seeing (better resolution) (Hale)
- Photographic plates
- Electronic detectors (CCDs)
- Spectrographs (Rowland)
- Telescopes in space (NASA)
- Adaptive optics (DoD)

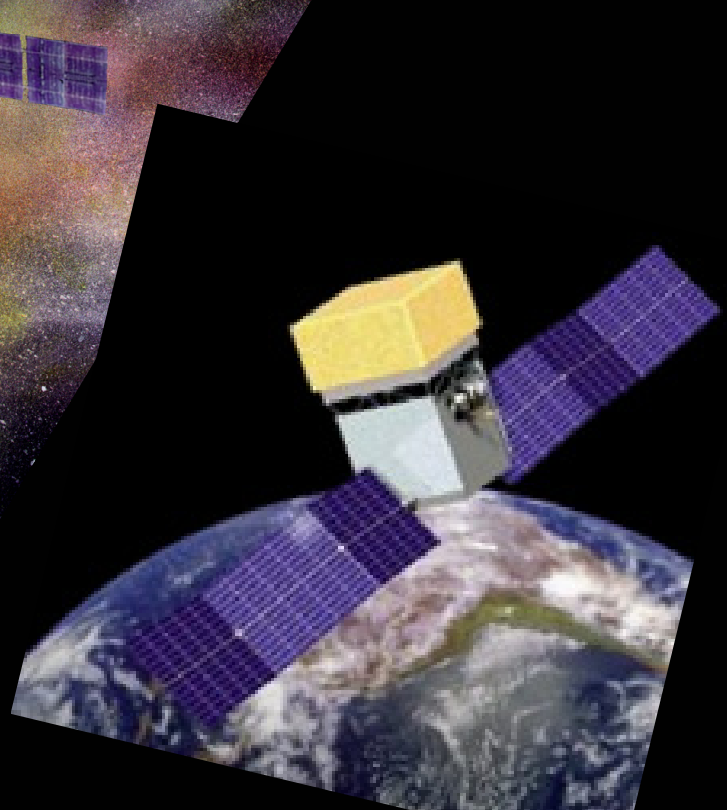


… and “New eyes” (physicists!)

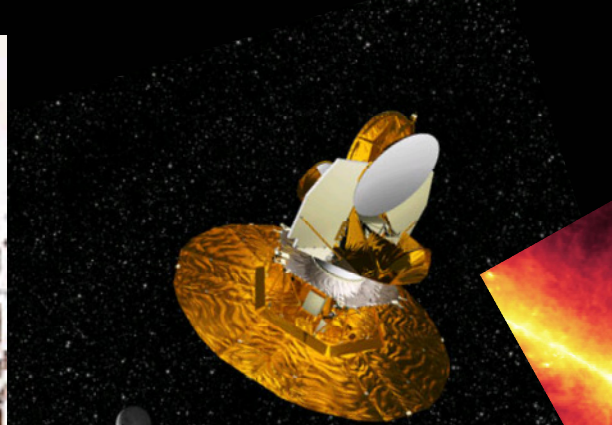
New Eyes 1

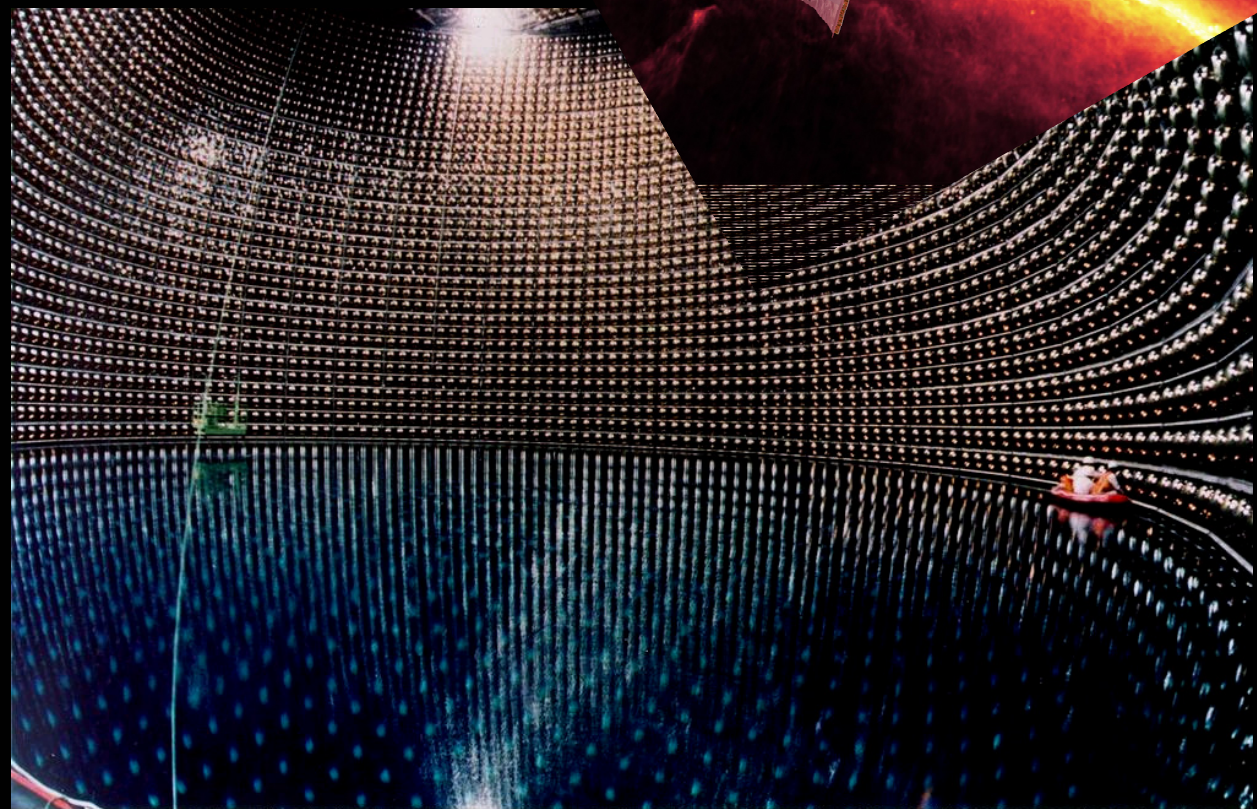




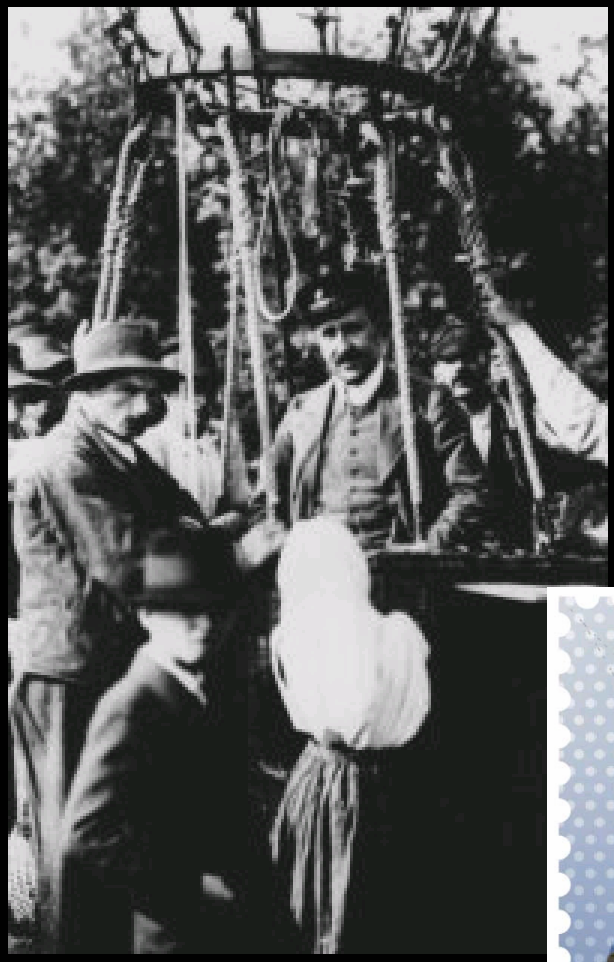


New Eyes 2

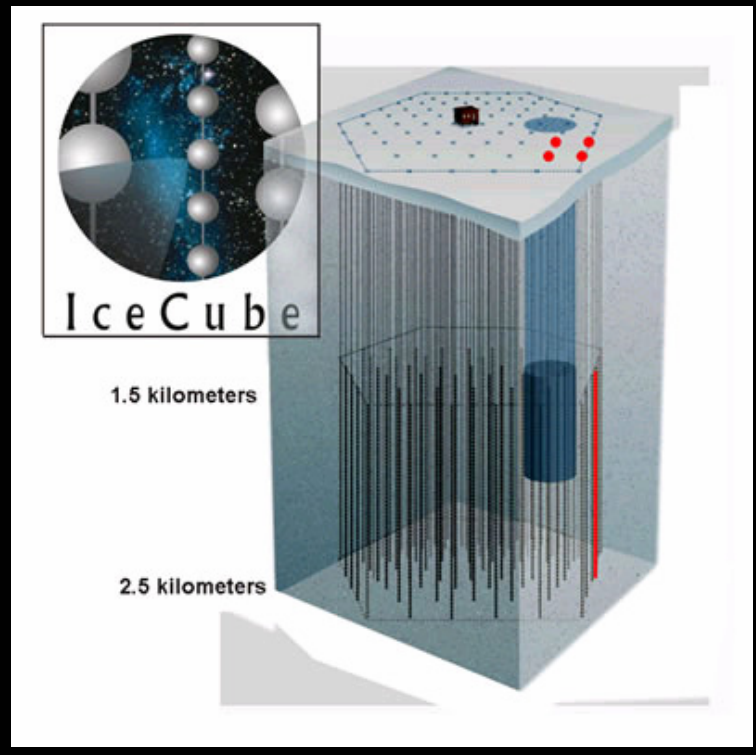




New Eyes 3

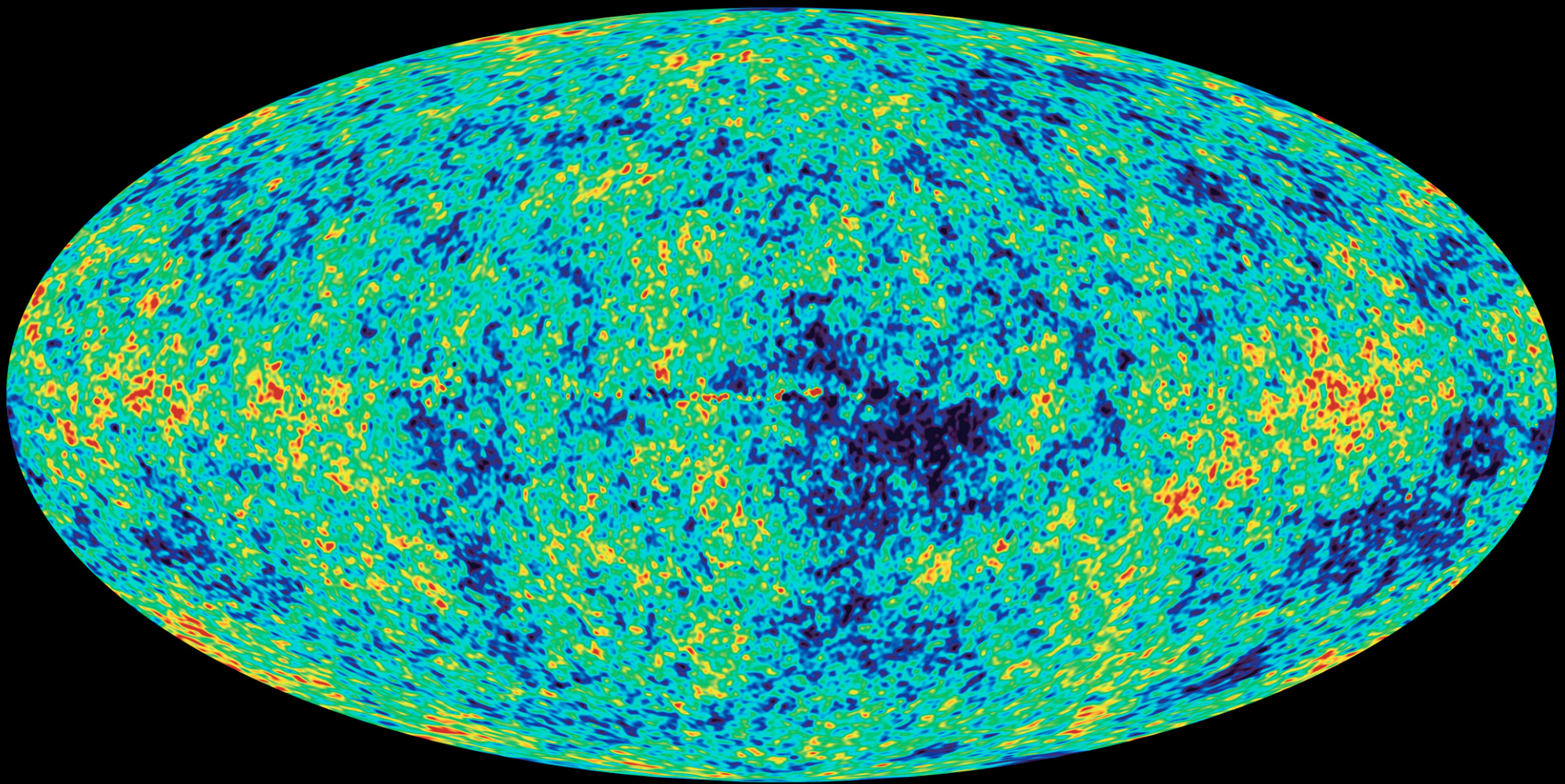



75 c
10 20 ev
OBSERVATORIO
PIERRE
AUGER
MALARGÜE
MENDOZA
ARGENTINA
REPÚBLICA ARGENTINA
CORREO OFICIAL
2007

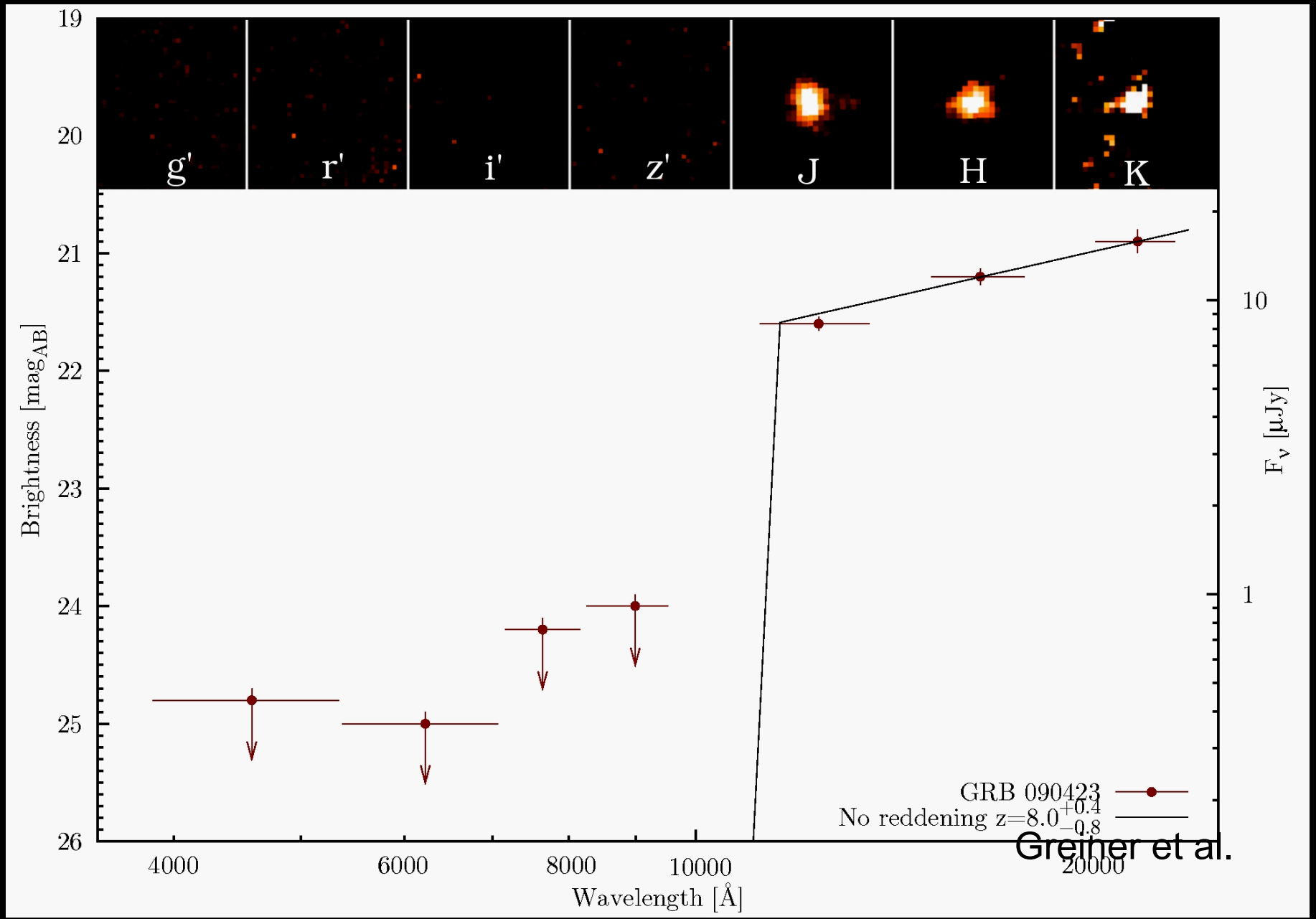

IceCube
1.5 kilometers
2.5 kilometers

Birth of Galaxies

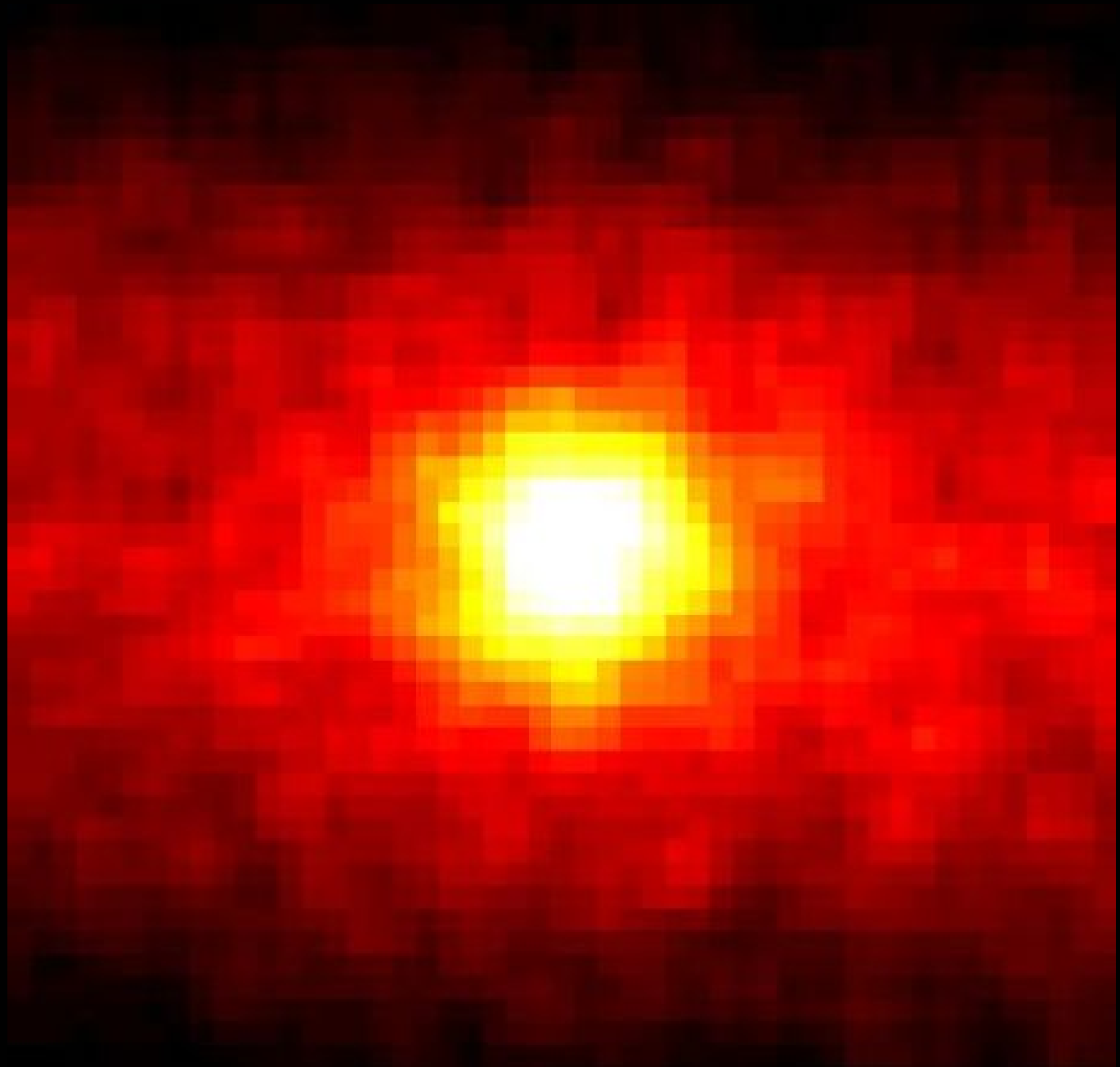
The Universe at 380,000 yrs



Swift GRB 090423 z = 8.2 GROND photo-z
Birth of a Black Hole at the Edge of the Universe



Center of sun (neutrinos)



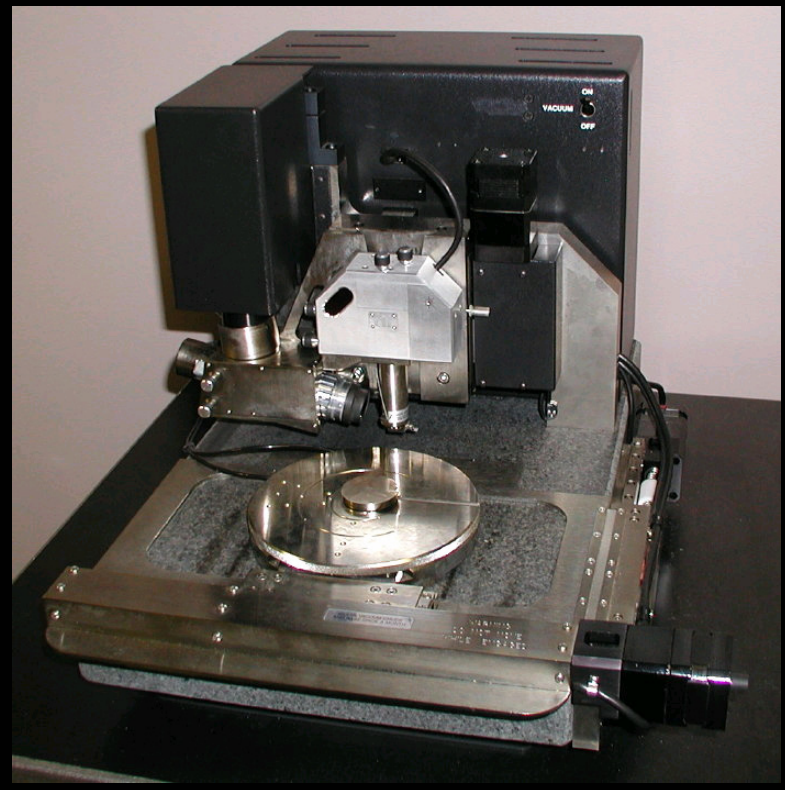
Telescopes Discoveries

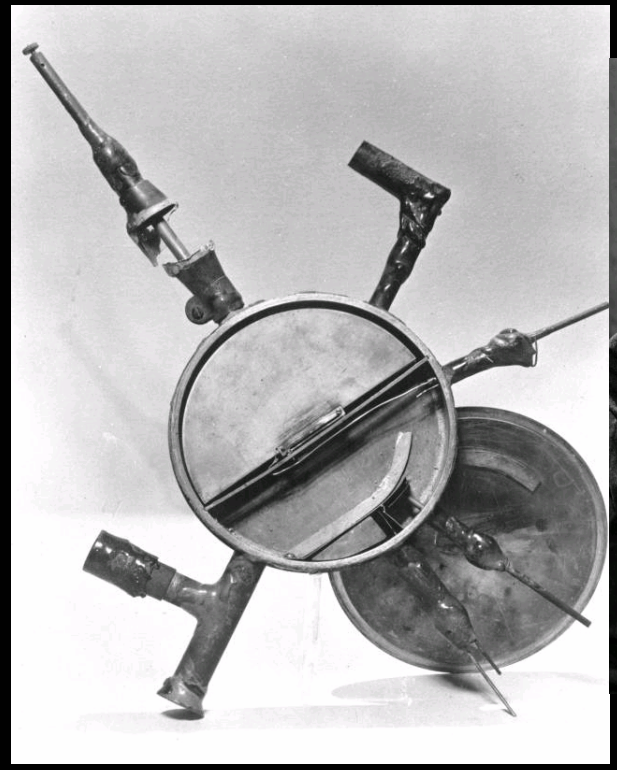
- Evidence for heliocentric Universe (phases of Venus) and nature of Milky Way (stars)
- Universal laws of physics (gravity, spectra)
- Hot big-bang beginning
- Helium, antimatter, muon, …
- Black holes
- Exoplanets (343 and counting)
- Dark Matter
- Absence of antimatter in the Universe
- Dark Energy
- Neutrino mass/oscillations

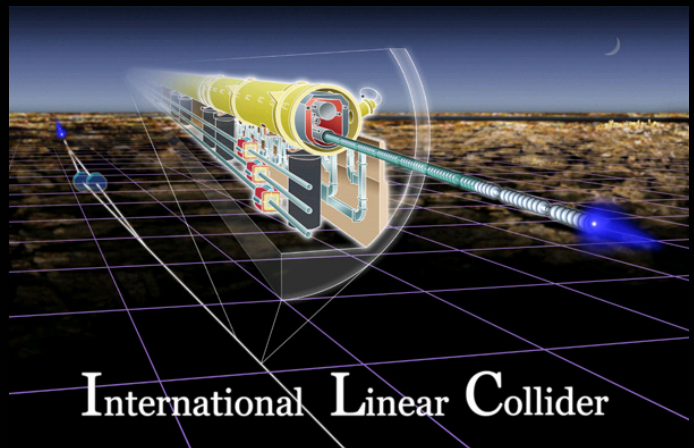
Factor of 10^{12} improvement in resolution in space: from eV to TeV

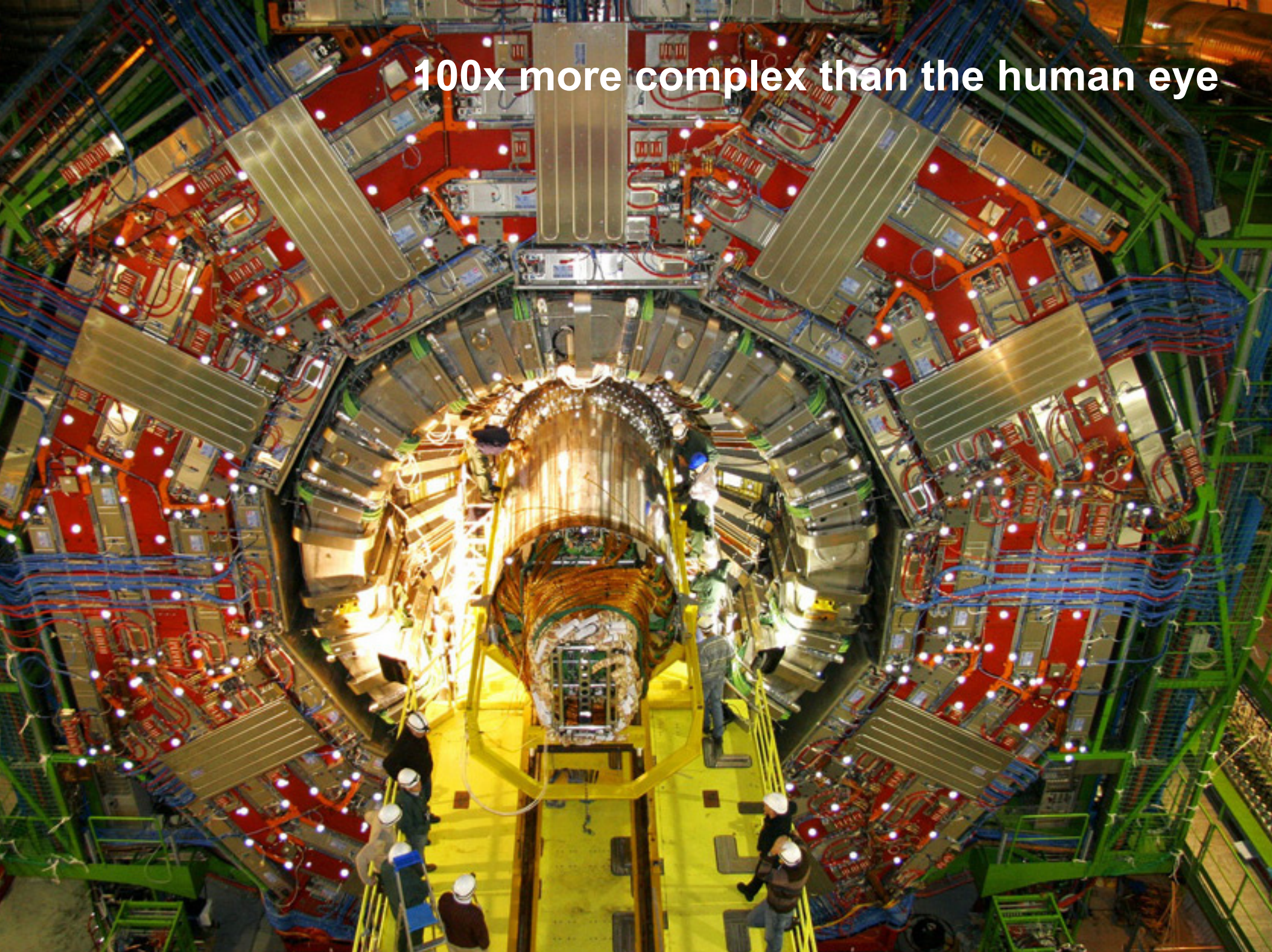
- Compound optical microscopes
- Electron microscopes
- Atomic Force Microscope
- Cathode ray tubes
- Cyclotrons/synchrotrons
- Linear accelerators
- Colliders (circular and linear)
- Detectors!!


Fig: 5.
Fig: 6.


VACUUM
ON
OFF

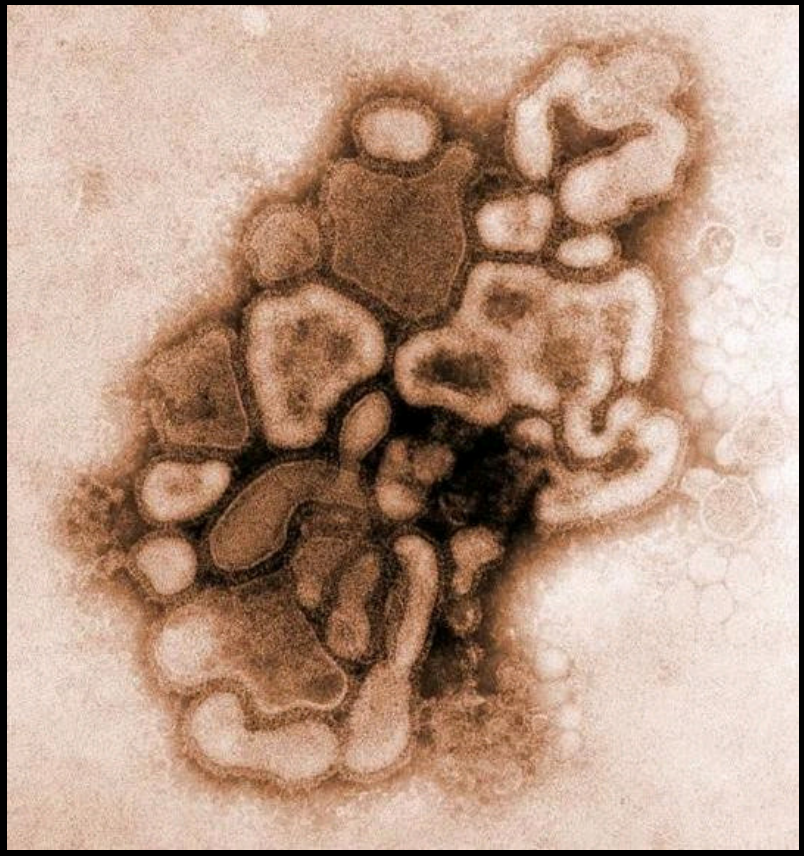


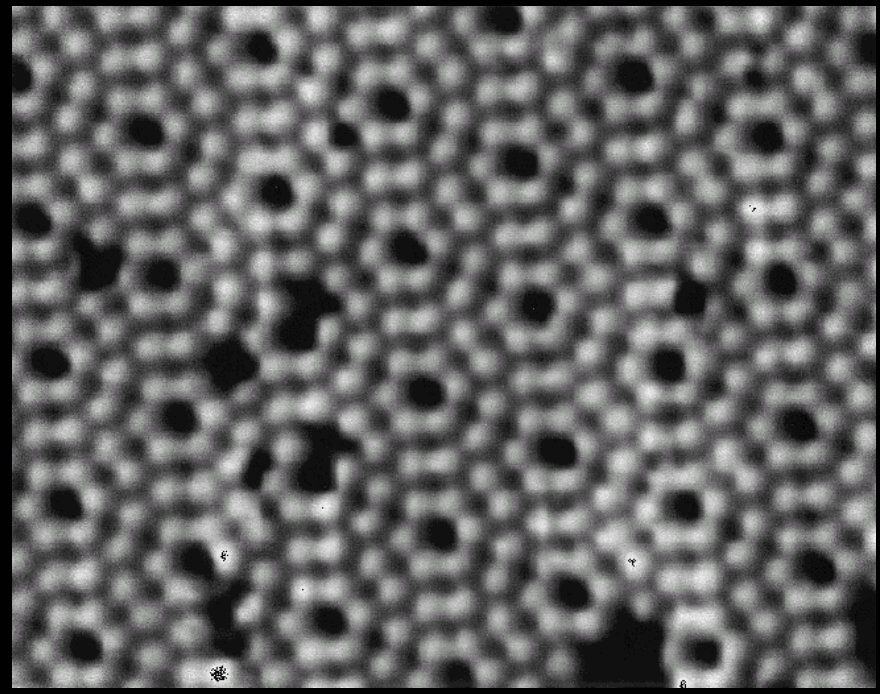

International Linear Collider

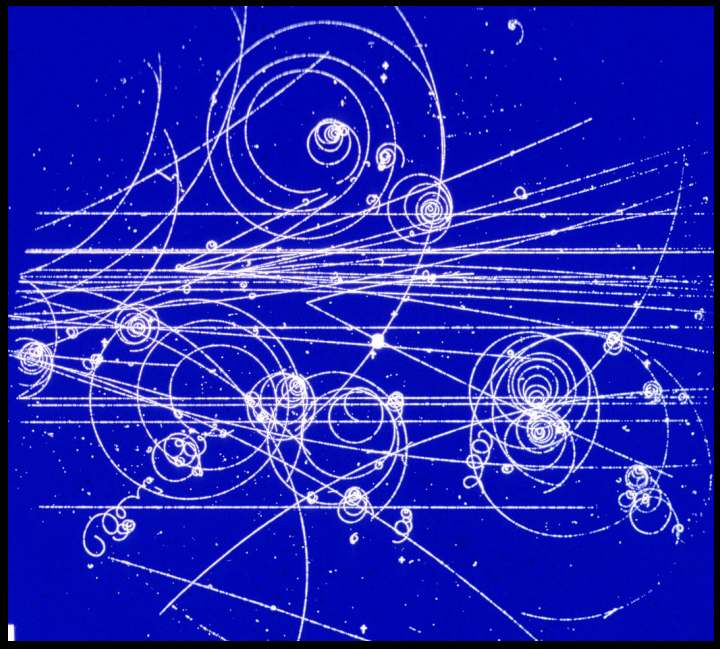

100x more complex than the human eye

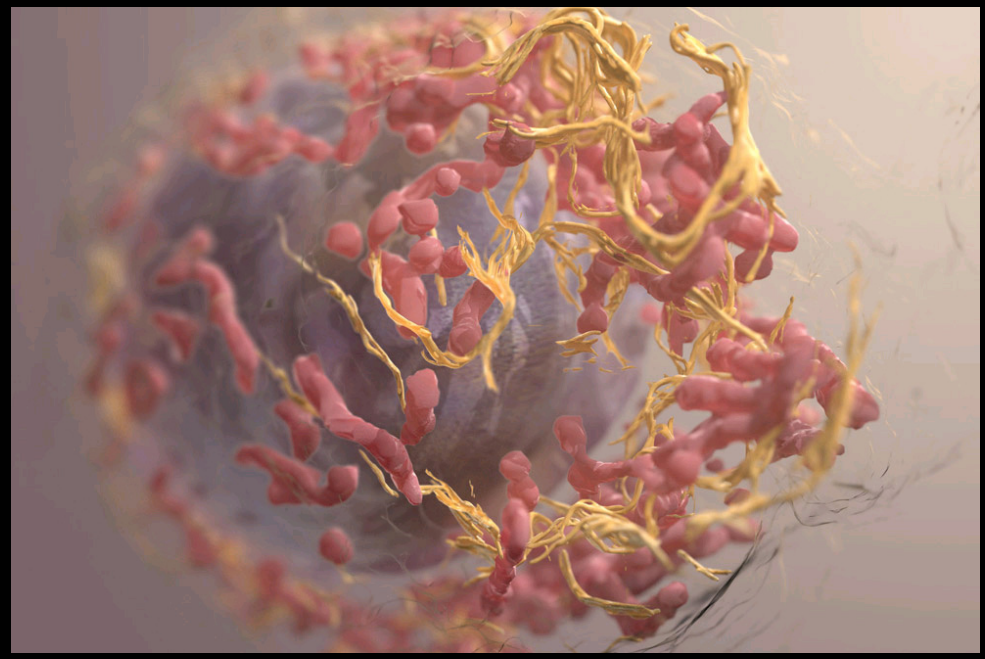
“Microscope Discoveries”

- Microbial world: cells, viruses, DNA, …
- The pieces of the atom: p, n and e
- Nuclear physics: from new elements to quark/gluon plasma
- Subatomic and subnuclear particles
- 3 Quarks, 4 Leptons, W/Z/Gluons
- Standard Model (and soon, beyond!)









COSMIC CONVERGENCE

Merging of the Frontiers of Particle Physics, Astrophysics and Nuclear Physics

Neutrinos and how they shape the Universe

Origin of baryons in the Universe

Origin of the periodic table

Identification of Dark Matter

Understanding of Dark Energy

Origin of the Universe

Nature of Space, Time, Matter and Energy

“Telescopes” and “Microscopes” Cosmic Complementarity

Heavenly Laboratory: tremendous range in space, time, energy, and fields

Earthly Accelerators: control of conditions and high precision

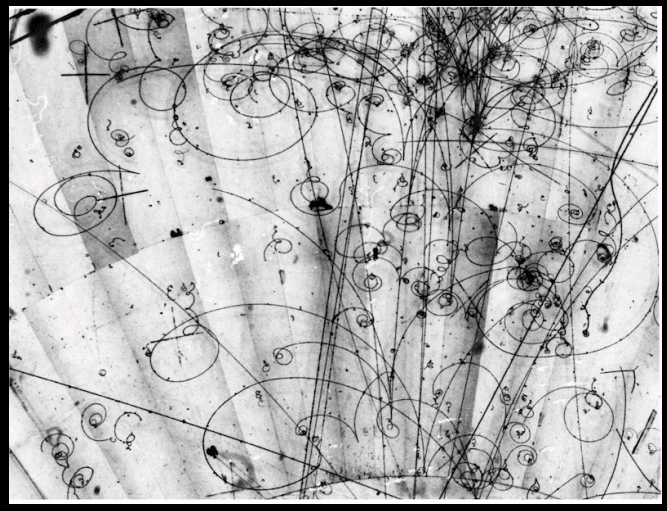
Three Examples

Antimatter

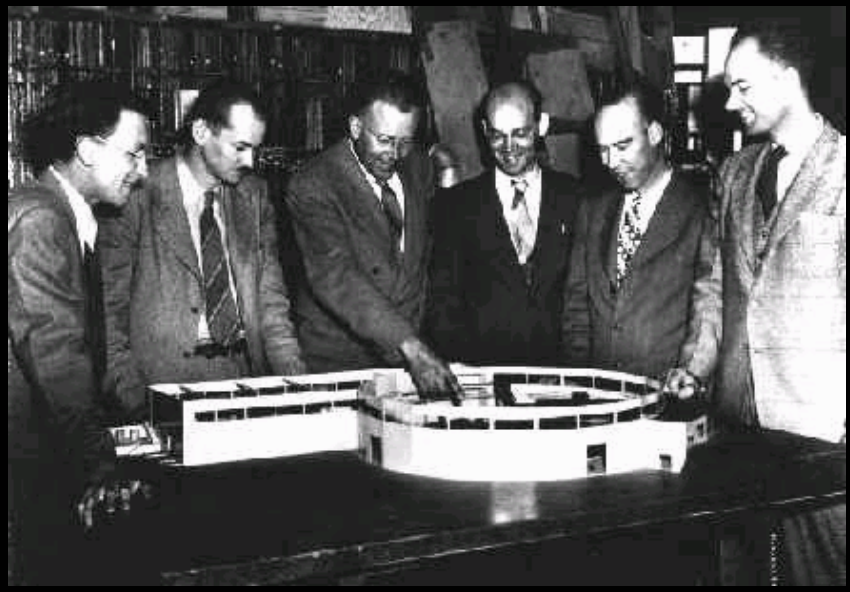
Dark Matter

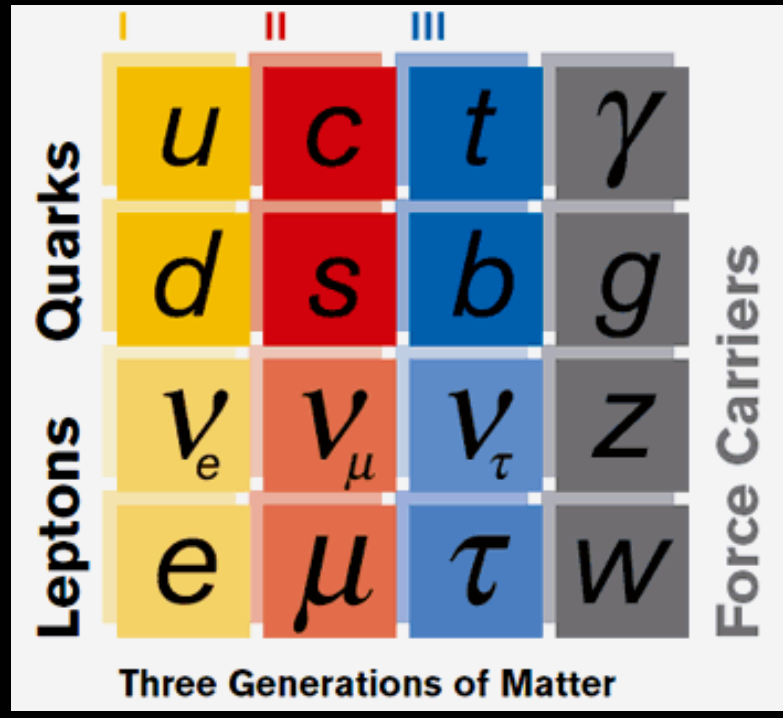
Dark Energy

Discovery of antimatter and muon with CR telescope



Followed up with accelerators





DON'T LET THE BRIGHT LIGHTS FOOL YOU

THE DARK SIDE CONTROLS THE UNIVERSE

OUR UNIVERSE

STARS: 0.5%

DARK MATTER: 33%

DARK ENERGY: 66%

DARK MATTER HOLDS IT TOGETHER

DARK ENERGY DETERMINES ITS DESTINY

The Dark Side of the Universe

Universe Census

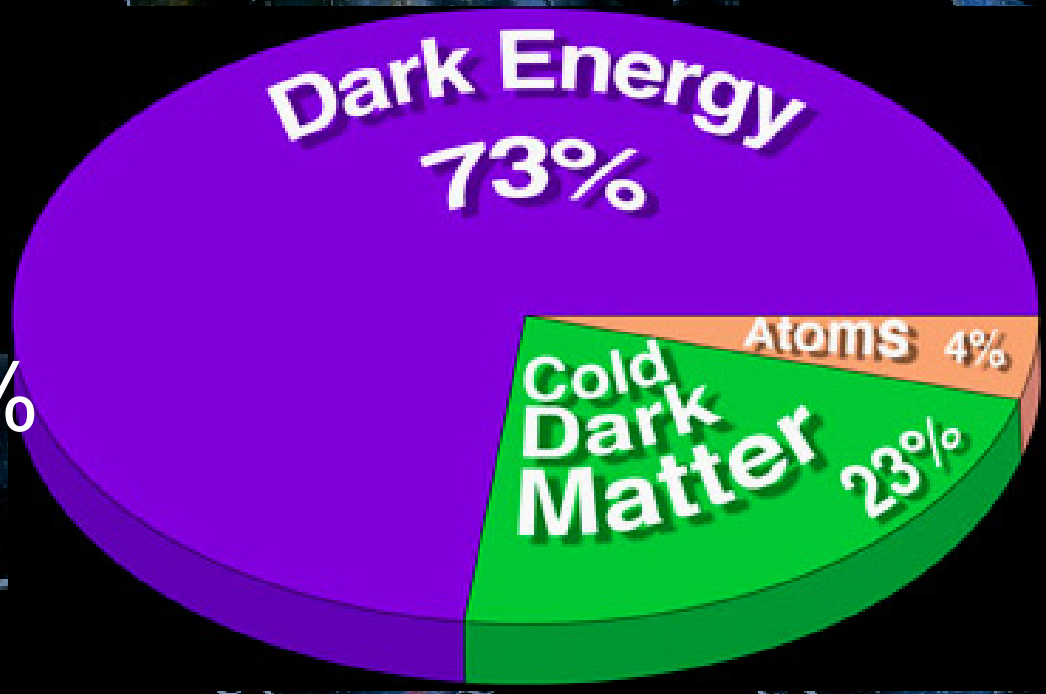
Stars: 0.5%

Hot Atoms: 4.0%

Exotic Dark Matter: 24%

(Neutrinos: 0.2% to 2%)

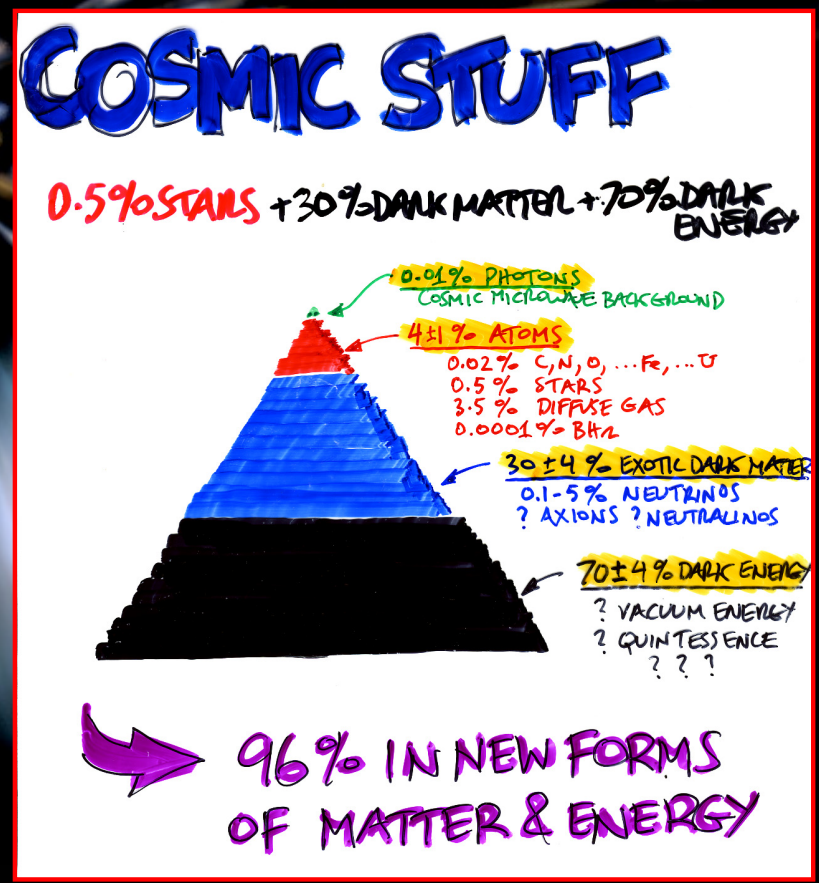
Dark Energy: 71%

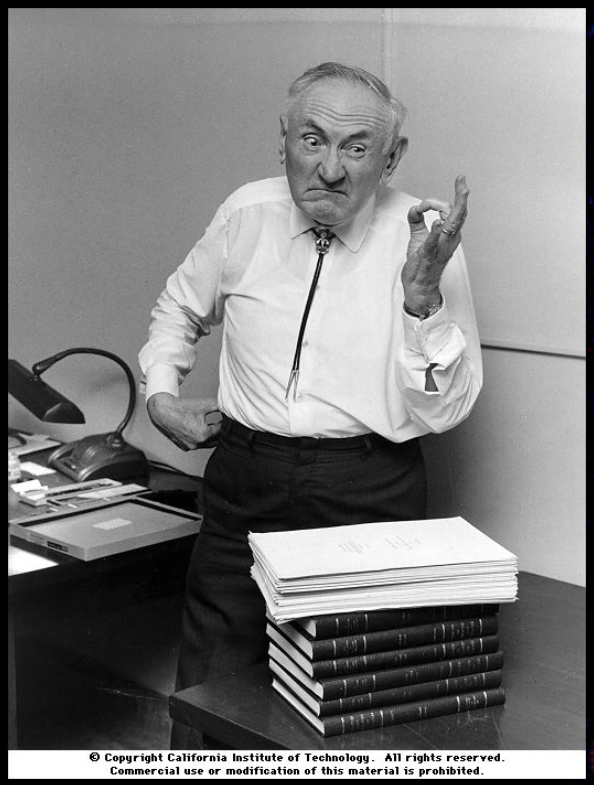


"Consensus Cosmology"

precision cosmology not an oxymoron!

- Standard Hot Big Bang of the 1970s
- Flat, accelerating Universe
- Atoms, exotic dark matter & dark energy
- Consistent with inflation
- Precision set of cosmological parameters
  - $\Omega_0 = 1.005 \pm 0.006$ (uncurved)
  - $\Omega_M = 0.280 \pm 0.013$ (matter)
  - $\Omega_B = 0.045 \pm 0.0015$ (atoms)
  - $\Omega_\Lambda = 0.72 \pm 0.015$
  - $H_0 = 70 \pm 1.3$ km/s/Mpc
  - $t_0 = 13.73 \pm 0.12$ Gyr
  - $N_\nu = 4.4 \pm 1.5$





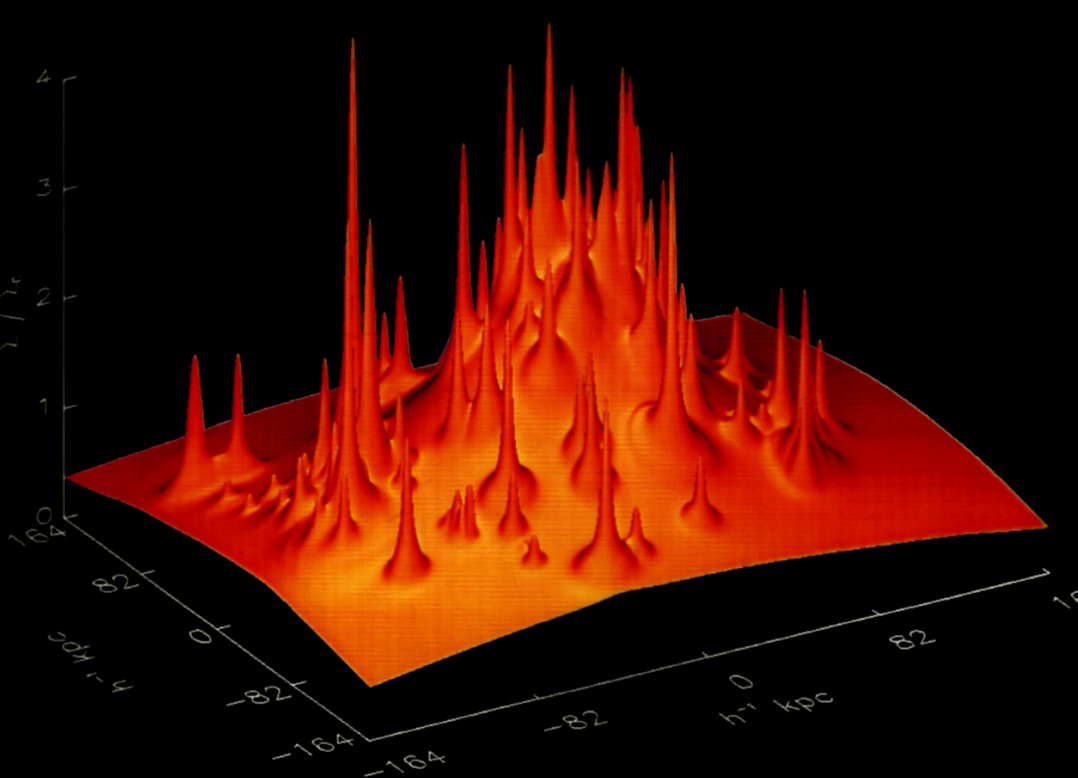
Imaging Dark Matter

Gravitational Lens
Galaxy Cluster 0024+1654

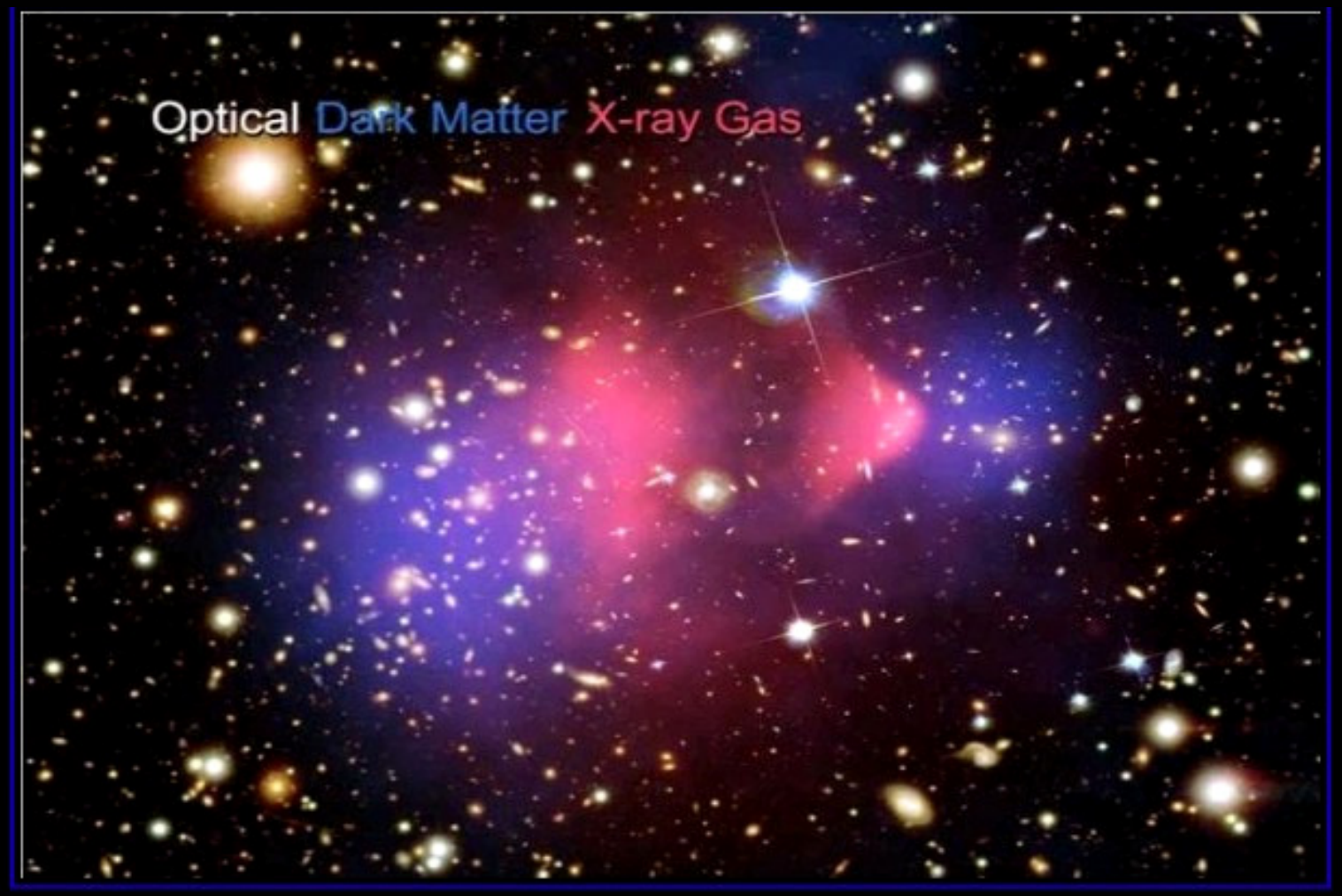
HST · WF

PRC96-10 · ST ScI OPO · April 24, 1996
W.N. Colley (Princeton University), E. Turner (Princeton University),
J.A. Tyson (AT&T Bell Labs) and NASA

PROJECTED MASS DENSITY: CLOO24



The Bullet Cluster



DARK MATTER

Most of the universe can't even be bothered to interact with you.

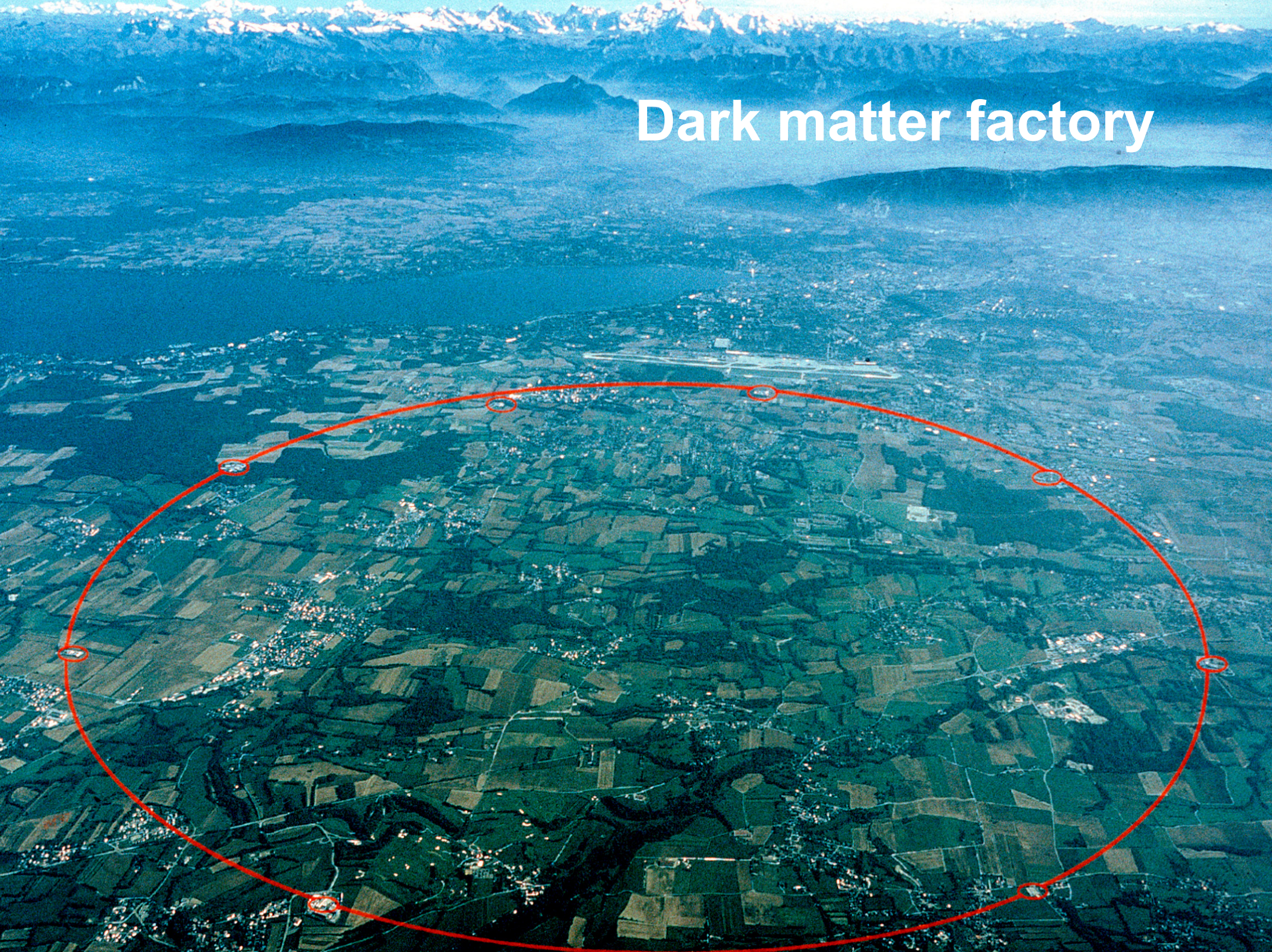
Galaxies have dark halos

MOOSE DIAGRAM of DARK MATTER CANDIDATES

MIT '90

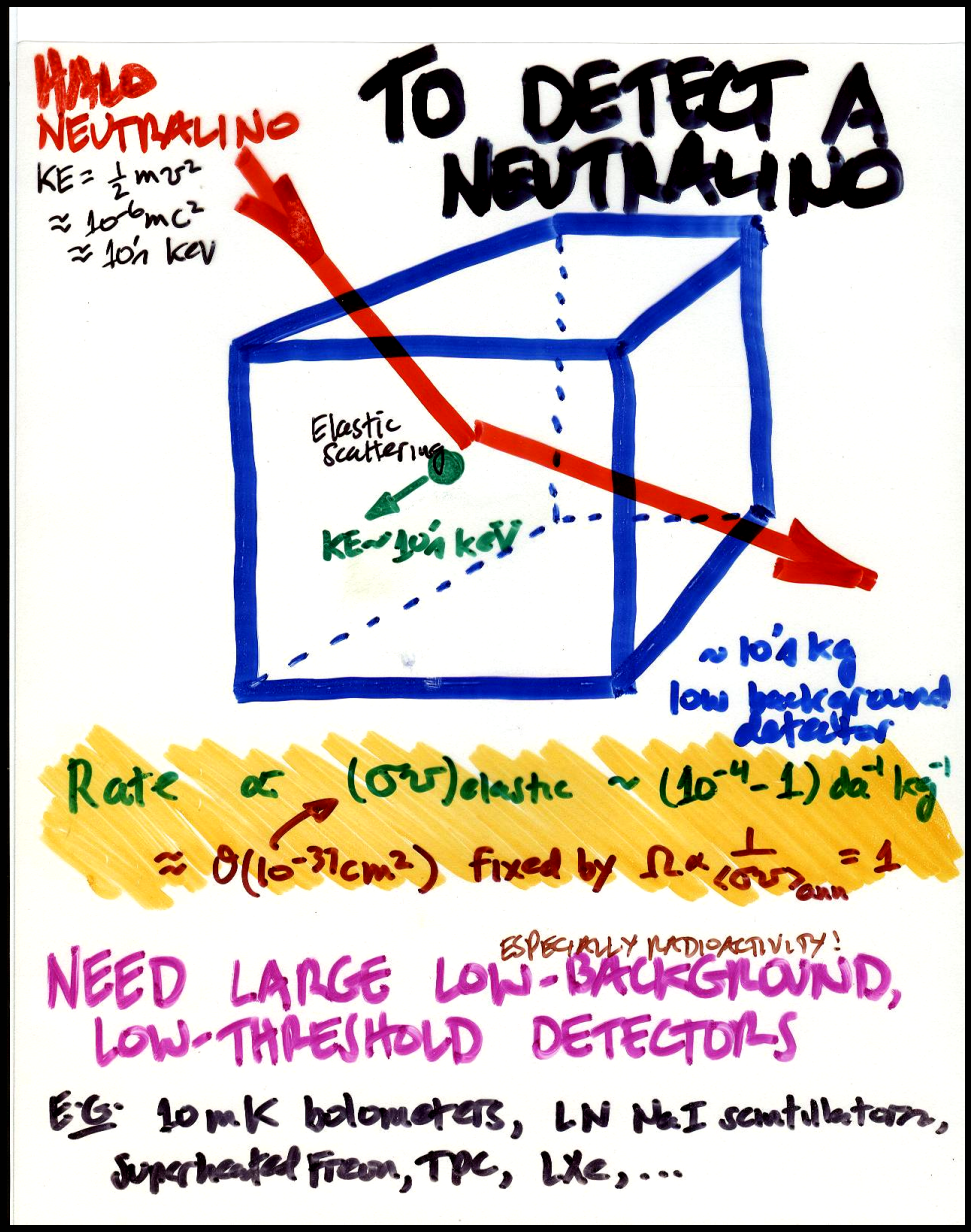
Full Court Press!

- Direct Detection in Halo
- Produce at accelerator (LHC)
- Halo annihilation (photons, positrons): FGST, Pamela
- Solar annihilation (neutrinos)

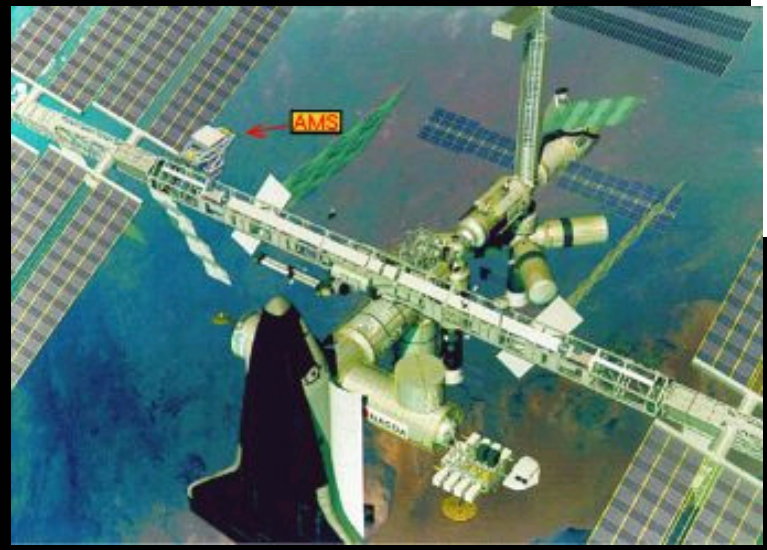

Dark matter factory

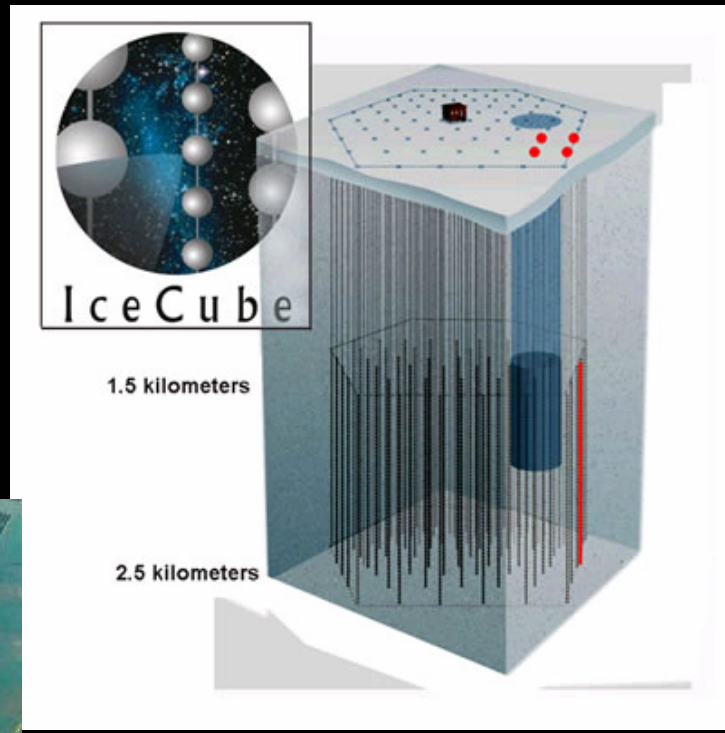
Soudan Mine
Dark Matter Search

CDMS Collaboration



Dark Matter annihilating in our halo produces positrons, neutrinos and gamma rays





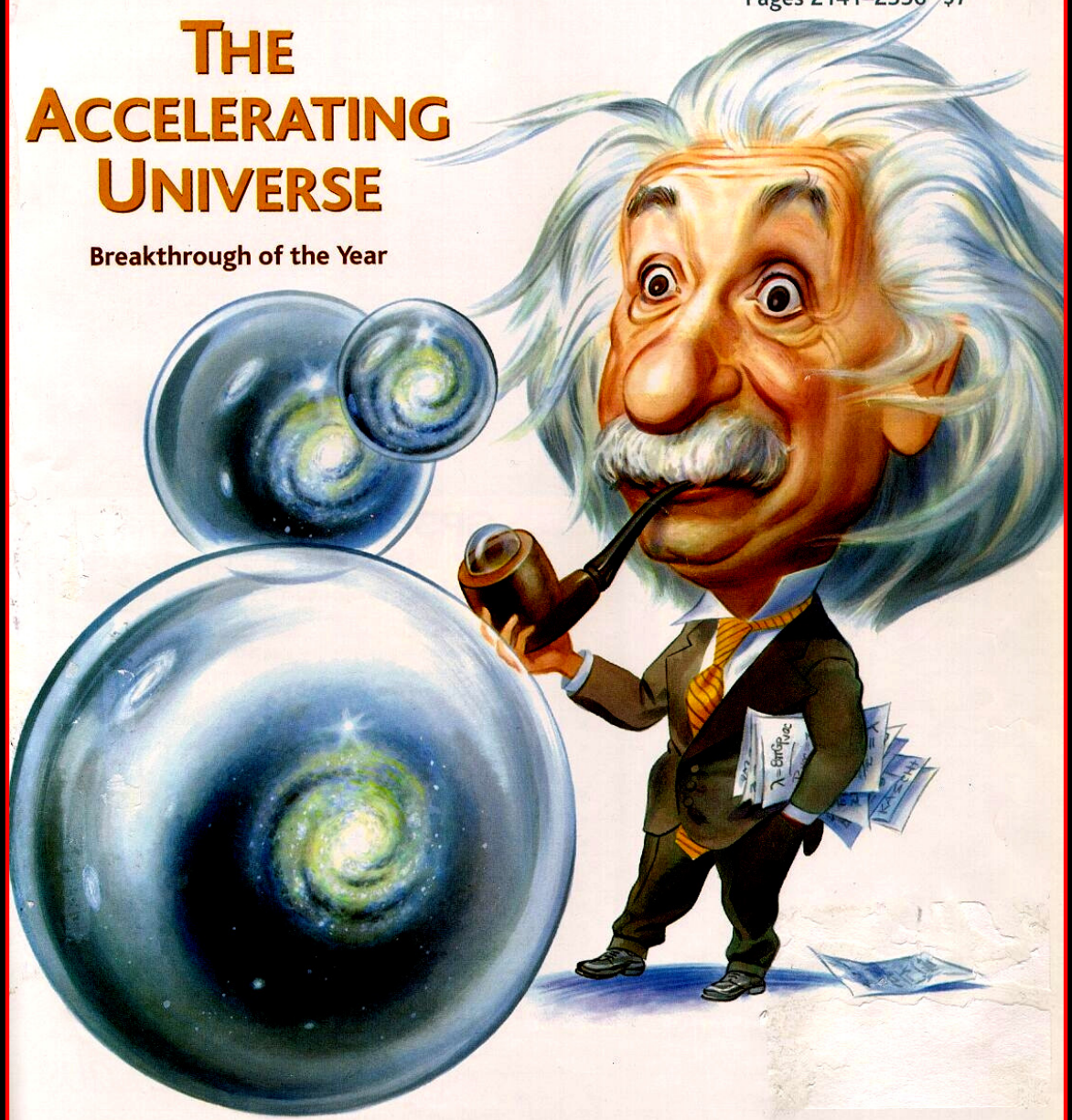
18 December 1998

Science

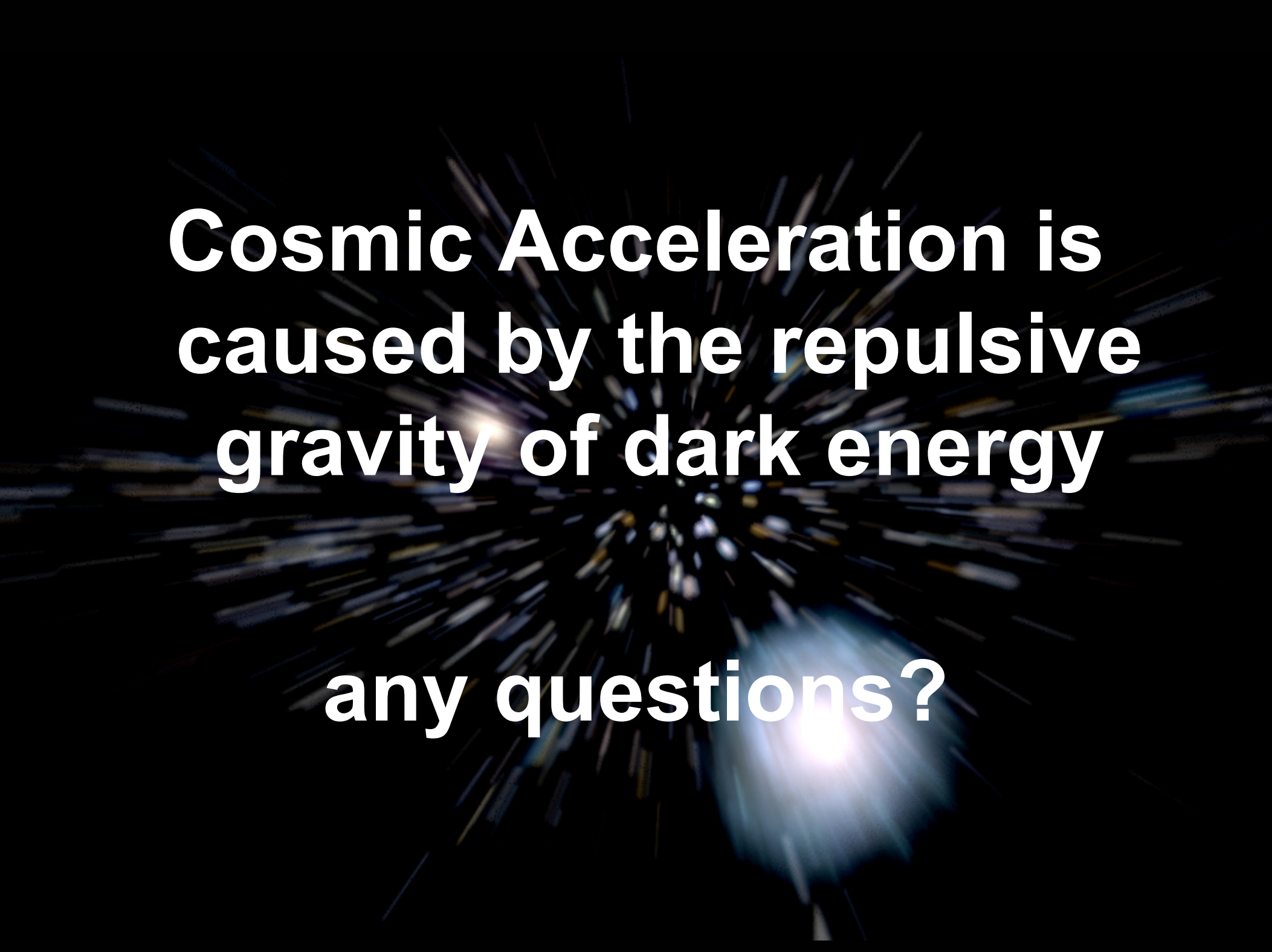
Vol. 282 No. 5397
Pages 2141–2336 $7

THE ACCELERATING UNIVERSE

Breakthrough of the Year



AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE


Cosmic Acceleration is caused by the repulsive gravity of dark energy
any questions?

Dark Energy

Defining features:

- Large negative pressure, $p \sim -\rho$, so that $(\rho + 3p) < 0$
- $w = p/\rho$ (equation-of-state parameter) ~ -1
- Smoothly distributed
- **Not particulate (dark matter has $p \sim 0$)**

Simplest example:

- Energy of the quantum vacuum: $w = -1$

Quantum Nothingness Has Repulsive Gravity!

How Repulsive?

Just About Right -- Give or Take 10^{55}

DARK ENERGY

MAY BE THE MOST PROFOUND PROBLEM IN ALL OF SCIENCE TODAY

Youbetcha Katie, I believe in Dark Energy – we can see it from Alaska!

Two Big Dark Questions

(worthy of Swedish Gold)

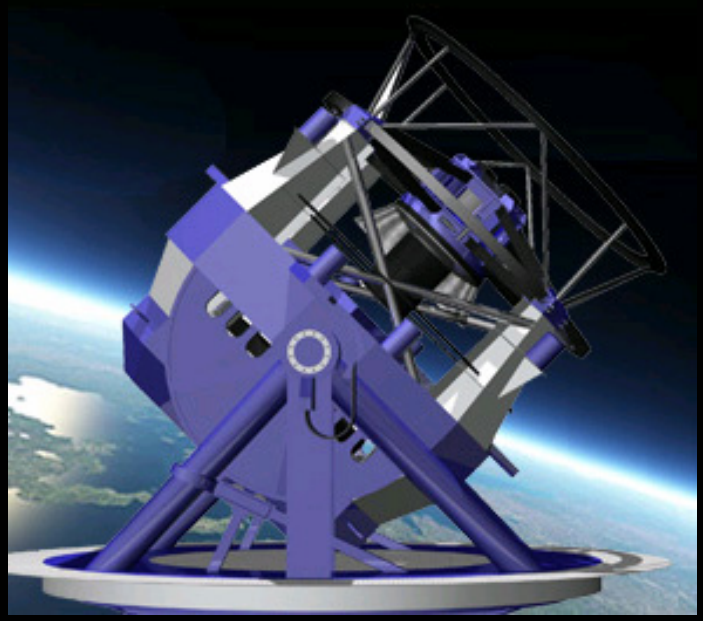
Does dark energy change with time (i.e., is it vacuum energy)?

No, at the 10 to 20% level

Do we need to go beyond General Relativity to describe cosmic acceleration?

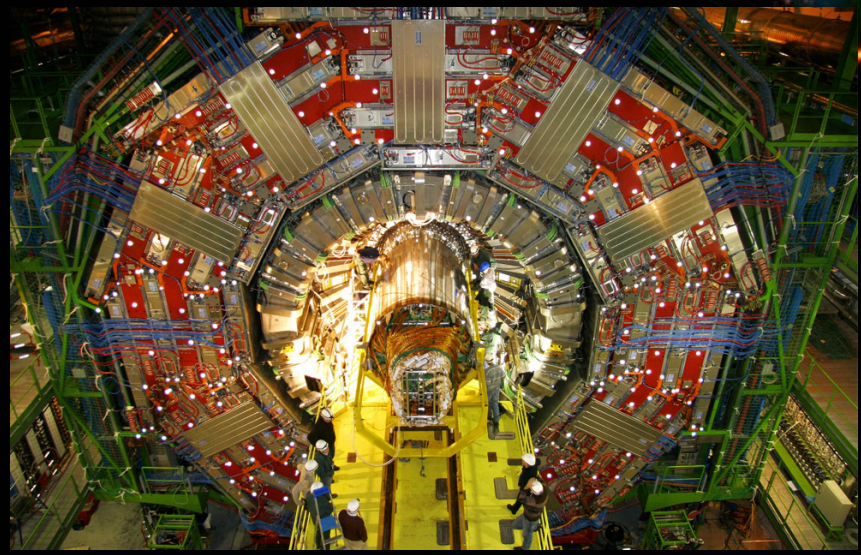
Not well tested

Probes of Dark Energy: Telescopes and Accelerators



LSST: Probe Dark Energy by Measuring the Evolution of Structure in the Universe

SNAP/JDEM: Probing Dark Energy by Measuring the Past Expansion Rate



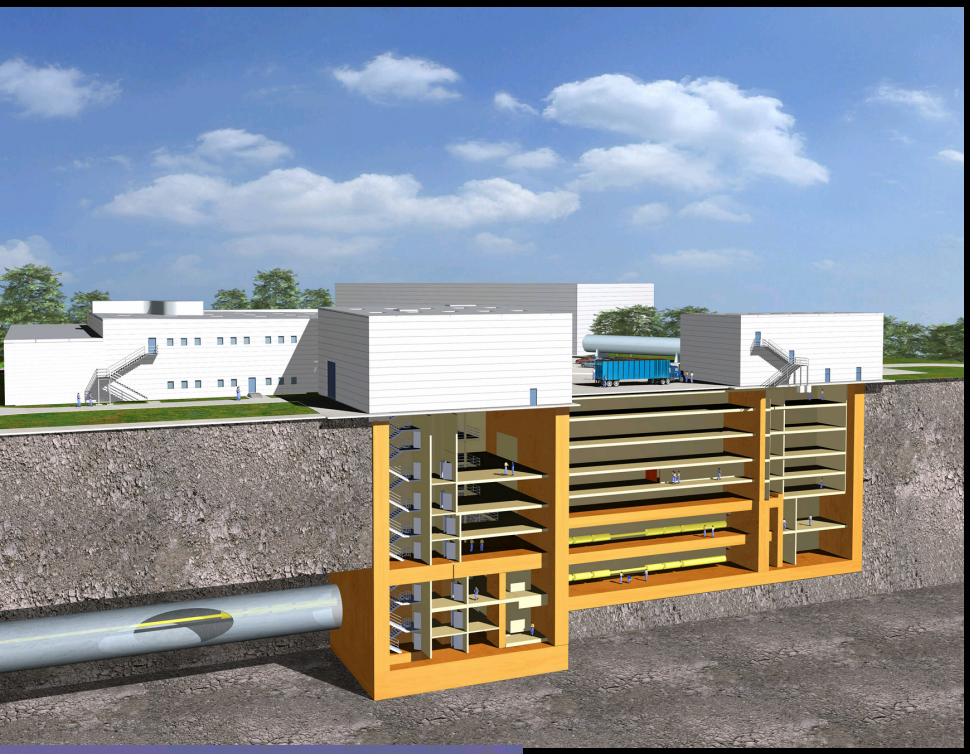
LHC: Probing Dark Energy by Searching for SuperSymmetry

Accelerators are not just for particle physics, nuclear physics and cosmology

Imaging with neutrons and intense x-rays

SNS@Oak Ridge

APS@Argonne



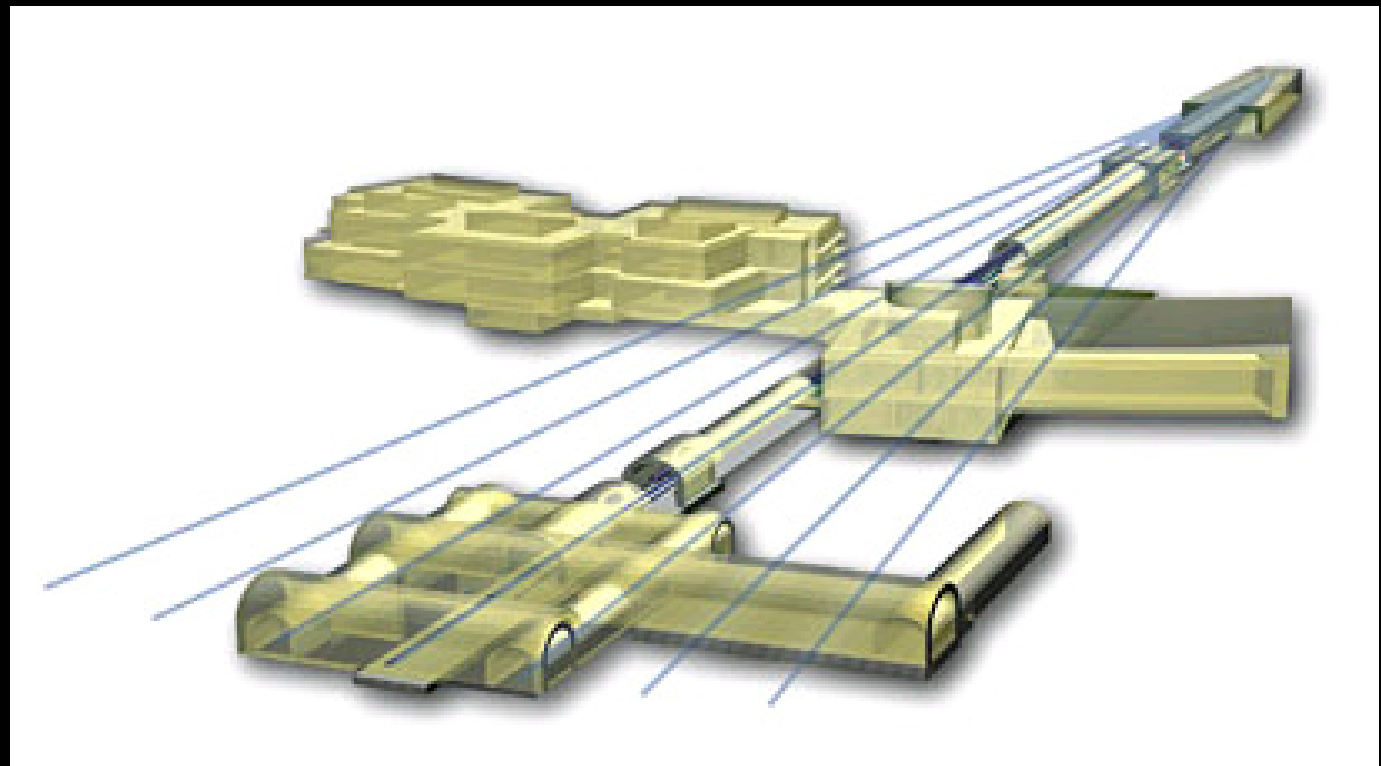
Coherent Light Sources

a new era in imaging in time and space

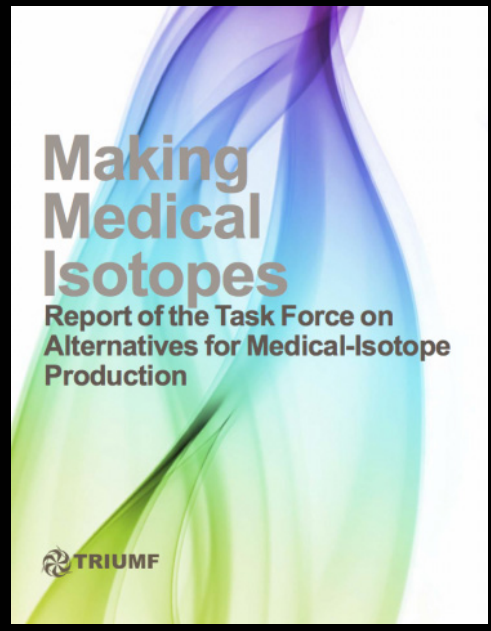
15 GeV Electrons — LCLS — 1.5 Å X-Ray

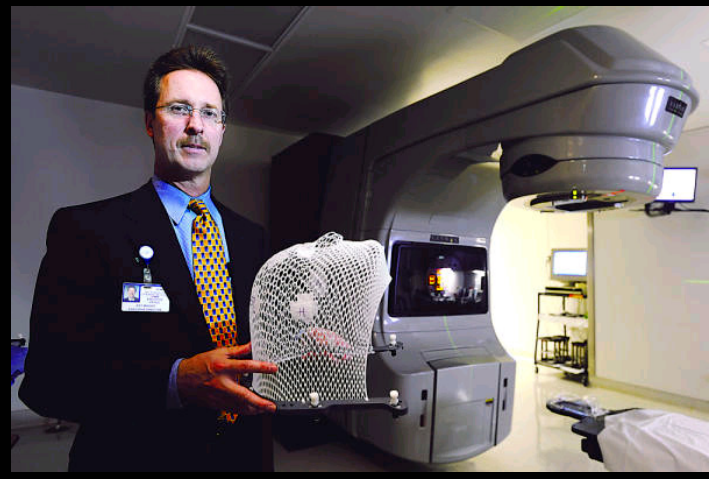
Linac Coherent Light Source

DESY XFEL X-Ray Free-Electron Laser



Medical and industrial applications





… and at the Movies!