Antimatter in Science and Film

ANGELS & DEMONS
Lecture Night
THE SCIENCE REVEALED

Victoria

BOB KOWALEWSKI
UNIVERSITY OF VICTORIA
MAY 24, 2011

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FACT OR FICTION?

- CERN –
  - home of mad scientists plotting to attack religion?
  - leading example of open international scientific collaboration?
- Antimatter –
  - a tool in our quest to understand the basic questions of our existence?
  - the ultimate weapon?

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CERN

- European Laboratory for Particle Physics
- Founded in 1954
- 20 member countries
- More than 9,000 scientists
- Over 100 nationalities
- ~150 from Canadian universities and labs

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CERN

Near Geneva, Switzerland

Mont Blanc

Birthplace of the WWW

Not top secret

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THE REAL LHC IS… LARGE

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INSIDE THE LHC

- The world's most powerful particle accelerator
- 27 kilometers around, ~100 meters underground
- Full of superconducting magnets, T = 1.9K

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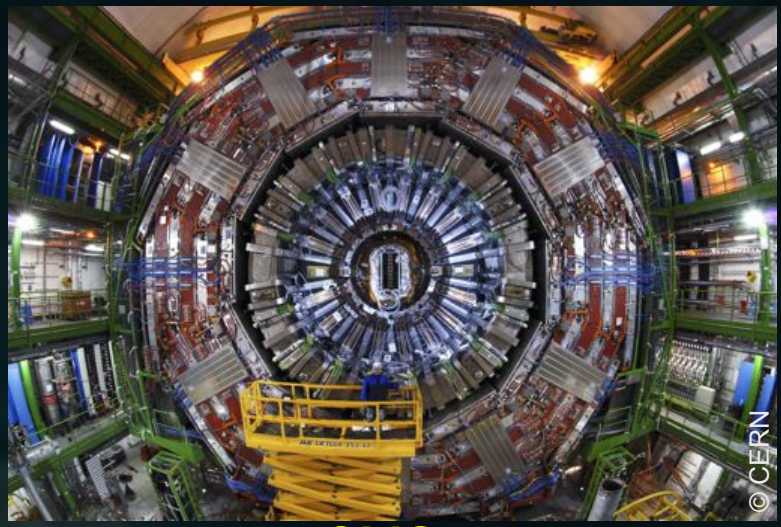
THE LHC

Smashes protons into each other…

…to solve some of the universe's biggest mysteries

ATLAS



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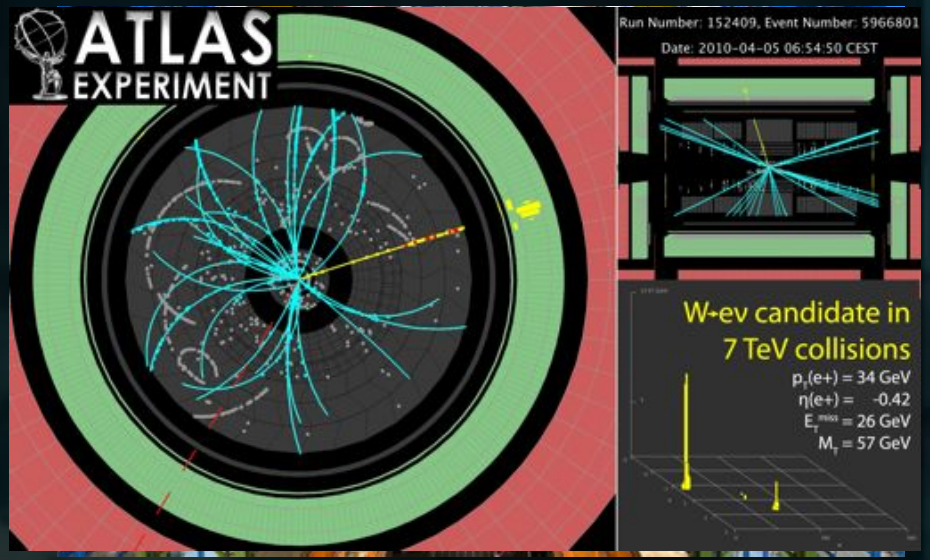
ATLAS EXPERIMENT

ATLAS at a glance

Building the detector

Colliding beams data

- Size of a 7-storey building
- Started R&D in 1991
- Cost: 550M CHF
- Produces many *petabytes* of data per year (millions of gigabytes)



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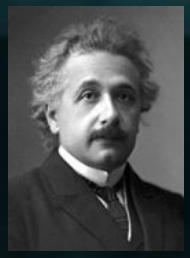
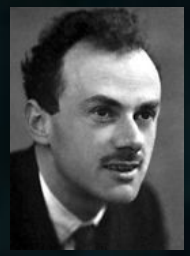
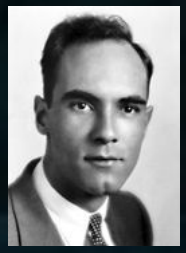
ANTIMATTER HISTORY

- Albert Einstein's theory of relativity (1905) relates energy to mass: $E = mc^2$
- Quantum mechanics is needed to describe the world at atomic and smaller distances
- Paul Dirac reconciled these two theories in 1928 and boldly predicted *antimatter* as a result
- The anti-electron (positron) was first observed by Carl Anderson and collaborators in 1931







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NATURE MAKES ANTIMATTER ALL THE TIME

The positron was discovered in collisions between cosmic rays and atoms

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MATTER VS. ANTIMATTER

Anti-Tom Hanks

Would look very much like

Tom Hanks

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MATTER VS. ANTIMATTER

But were they to meet…

$E=mc^2$

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CAN WE MAKE ANTIMATTER?

Yes! In particle accelerators


SLAC National Accelerator Laboratory

At SLAC (California)… at TRIUMF (Vancouver)…

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CAN WE MAKE ANTIMATTER?

Yes! In particle accelerators

And at CERN's LHC

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ANTIMATTER CAN'T BE USED FOR

- **Destroying the Vatican**
- **Generating Power**
  - More energy required than is produced
- **Spaceships (sorry, trekkies…)**

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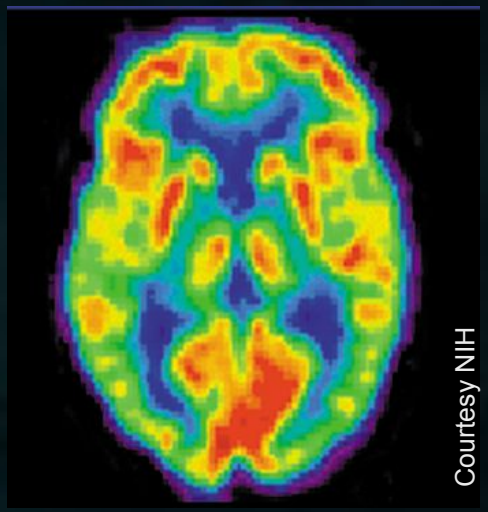
ANTIMATTER CAN BE USED FOR

PET Scans

(P = positron)



Functional imaging

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ANTIMATTER CAN BE USED FOR

- Solving some of the biggest mysteries in science

- Q1: Why are we made of matter, not antimatter?
- Q2: Why do we have mass?
- Q3: What is most of our universe made of?

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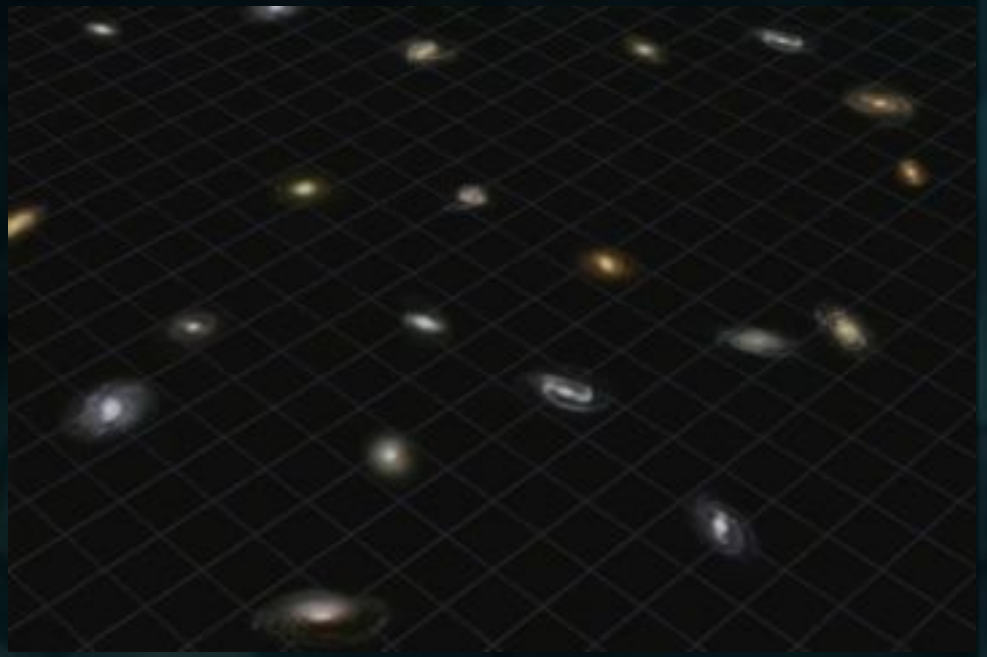
Q1: THE MYSTERY OF ANTIMATTER

- We can exist because there is almost no antimatter around
- It wasn't always that way



NASA/STScI/G.Bacon

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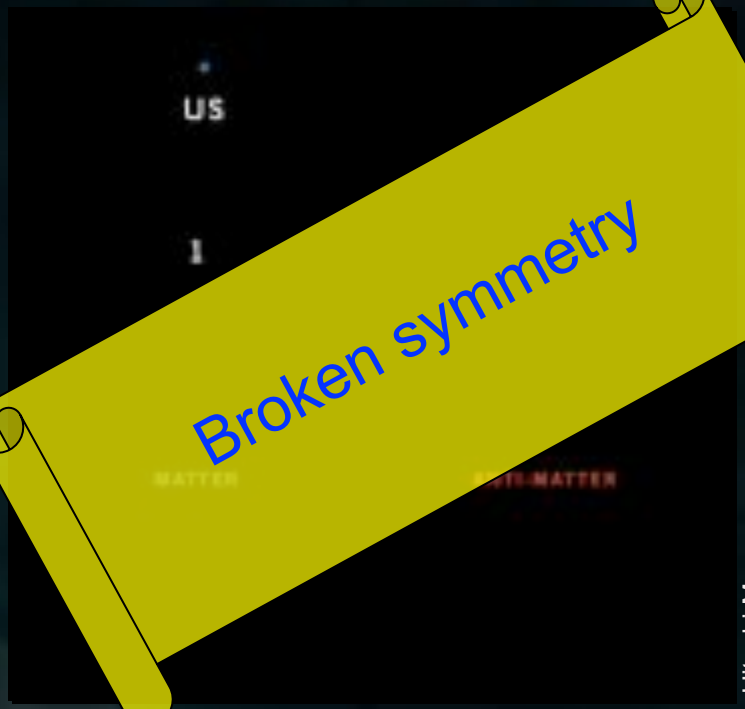
THE BIG BANG

- 14 billion years ago, the Big Bang produced matter and antimatter in equal amounts
- Everything should have annihilated.
- Instead…
- Some reactions differ for particles and antiparticles – we call this an *asymmetry*



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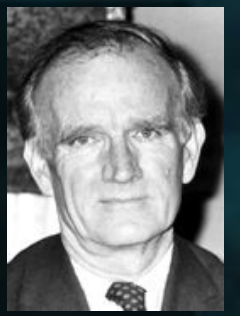
THE ANTI-WORLD LOOKING GLASS IS CRACKED

- An asymmetry between matter and antimatter was discovered in 1964
- A theoretical mechanism that could produce this asymmetry was proposed in 1973
- This prediction was verified recently, leading to the 2008 Nobel Prize in Physics


Cronin


Fitch


Kobayashi


Maskawa

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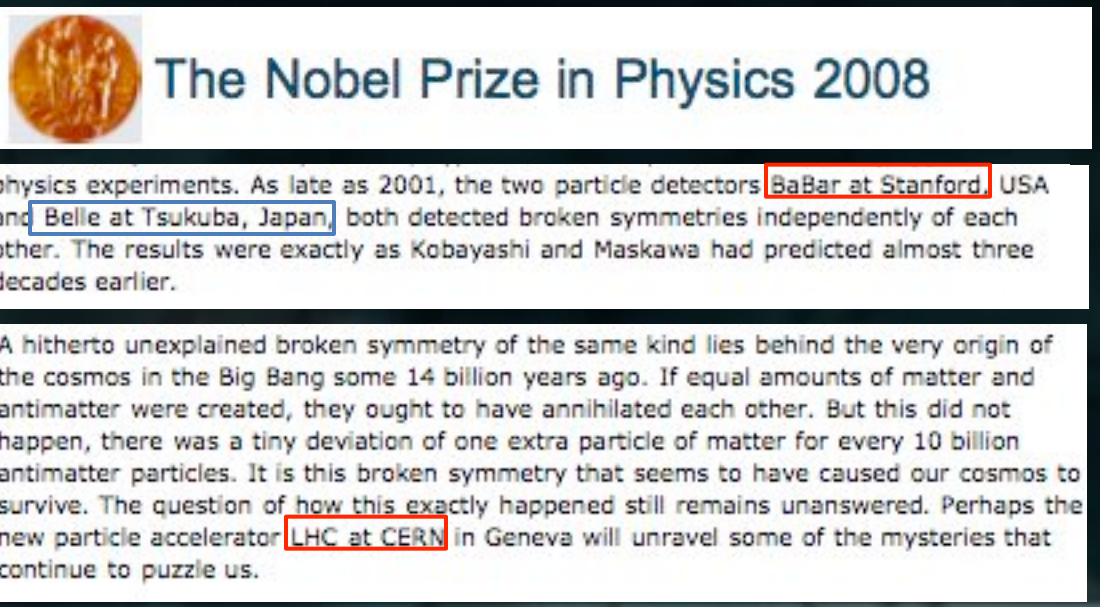
BABAR EXPERIMENT NAMED IN NOBEL CITATION

- Predictions were put to test by experiments in California and Japan



The Nobel Prize in Physics 2008

physics experiments. As late as 2001, the two particle detectors BaBar at Stanford, USA and Belle at Tsukuba, Japan, both detected broken symmetries independently of each other. The results were exactly as Kobayashi and Maskawa had predicted almost three decades earlier.

A hitherto unexplained broken symmetry of the same kind lies behind the very origin of the cosmos in the Big Bang some 14 billion years ago. If equal amounts of matter and antimatter were created, they ought to have annihilated each other. But this did not happen, there was a tiny deviation of one extra particle of matter for every 10 billion antimatter particles. It is this broken symmetry that seems to have caused our cosmos to survive. The question of how this exactly happened still remains unanswered. Perhaps the new particle accelerator LHC at CERN in Geneva will unravel some of the mysteries that continue to puzzle us.

BABAR Collaboration at UVic, May 2002

UVic faculty and students involved from the start

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Q1: WHAT HAPPENED TO THE ANTIMATTER?

- The differences predicted by Kobayashi and Maskawa and measured in BaBar are very slight – not enough to explain the cosmic absence of antimatter
- There must be another explanation

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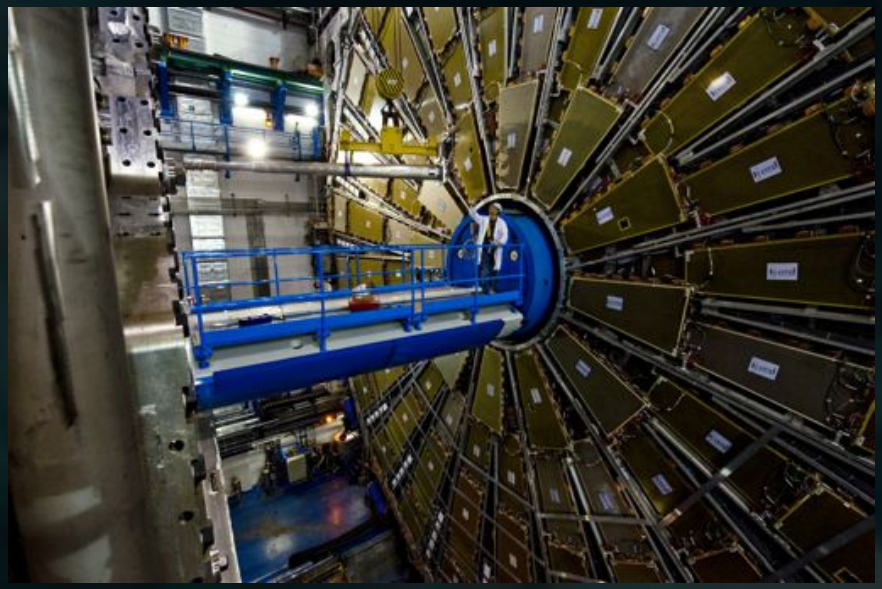
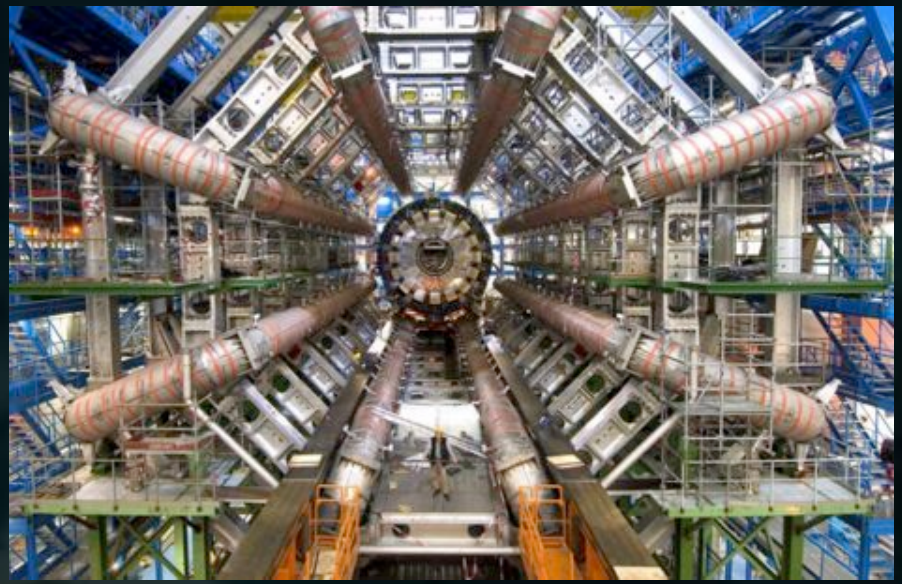
SOLVING THE MYSTERY

Completely new particles





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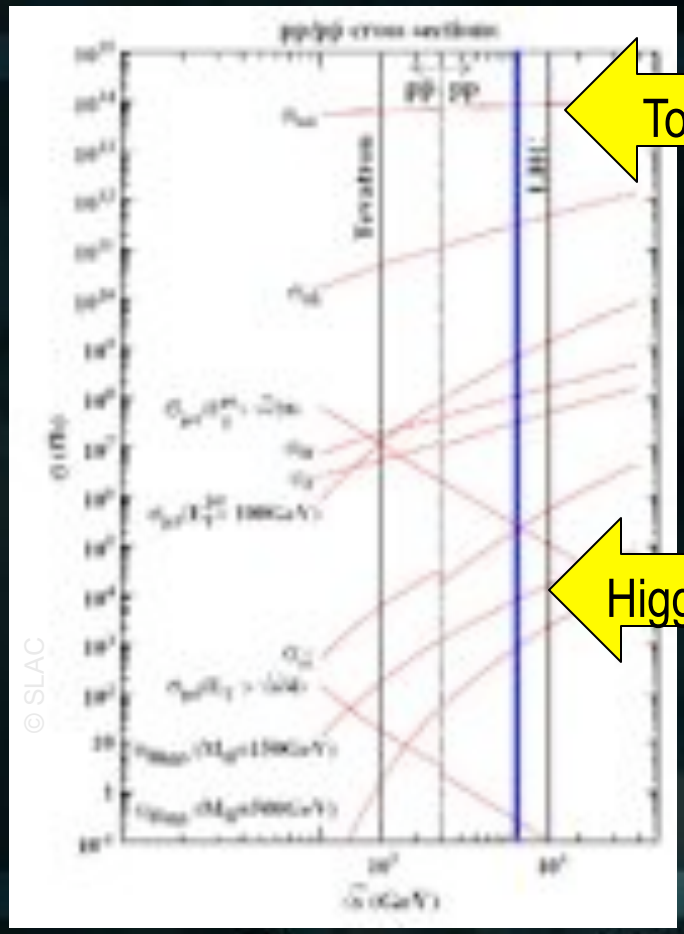
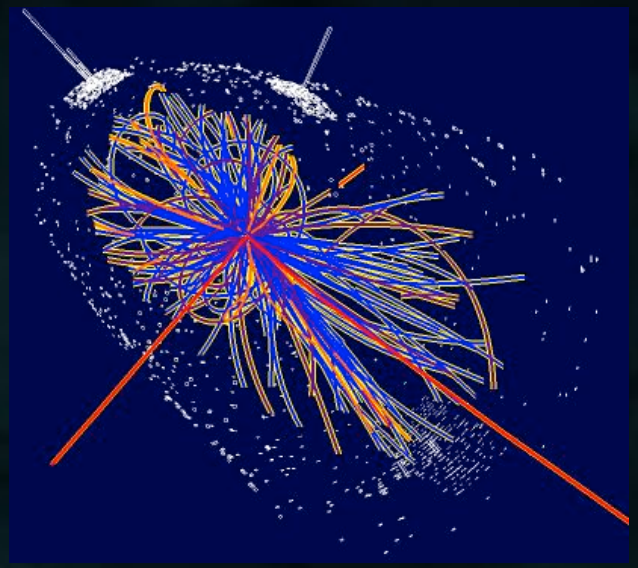
THE SEARCH FOR THE HIGGS BOSON



Large Hadron Collider



Needle in a *big* haystack ($1/10^{11}$)

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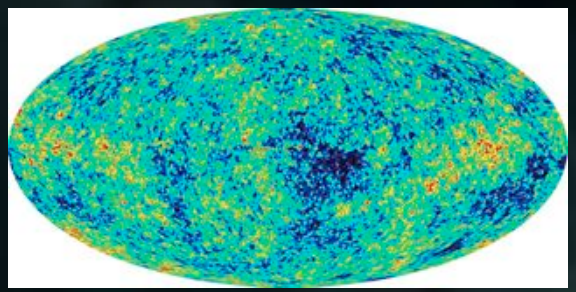
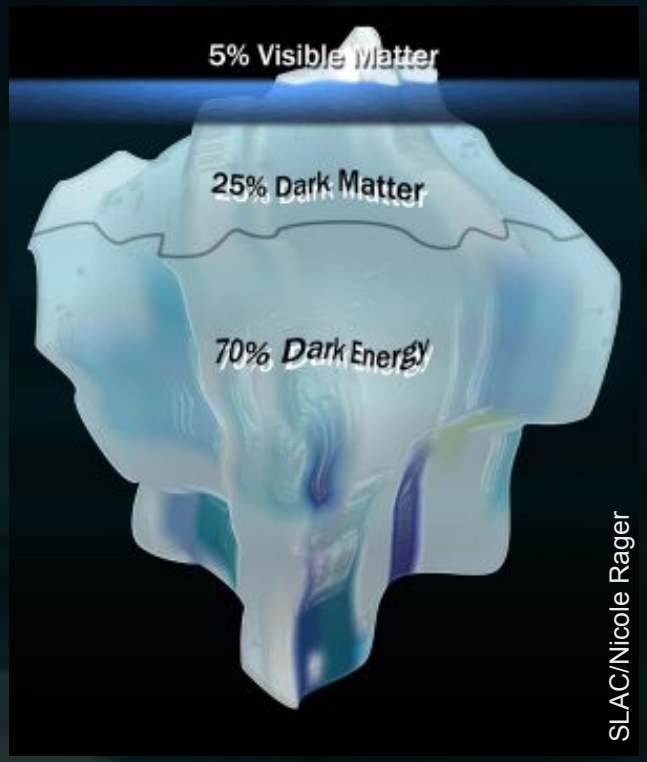
Q3: WHAT'S OUT THERE?

- Astronomy tells us:
- The matter we know is 5% of the universe
- The rest is dark matter
- And dark energy



map.gsfc.nasa.gov



SLAC/Nicole Rager

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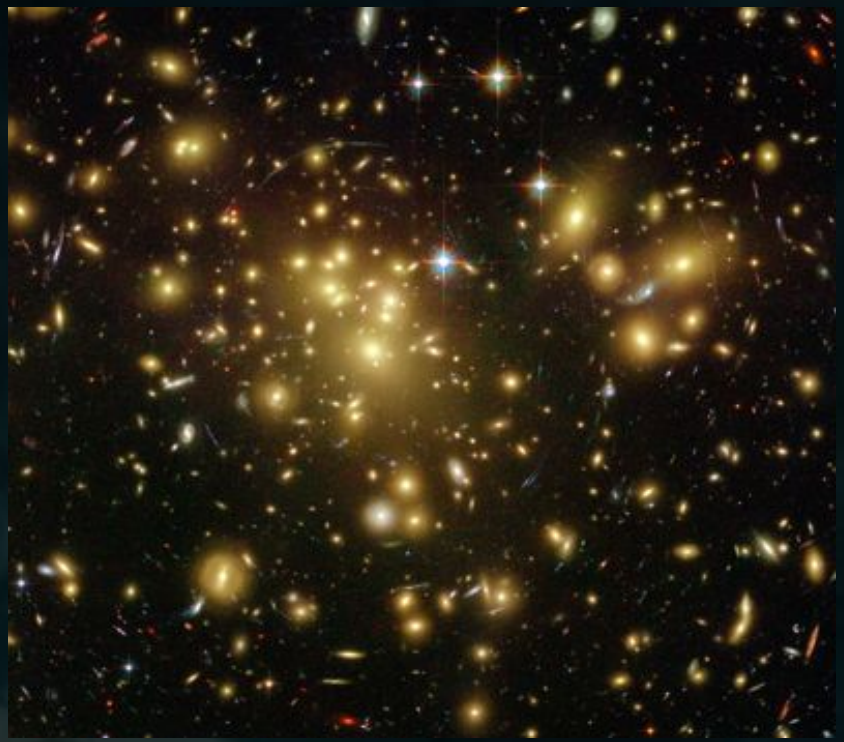
Q3: DARK MATTER

- "Dark" because it doesn't give off radiation (light)
- Can tell it's there from gravitational effects on galaxies
- Could be made of undiscovered particles



hubblesite.org cluster Abell 1689

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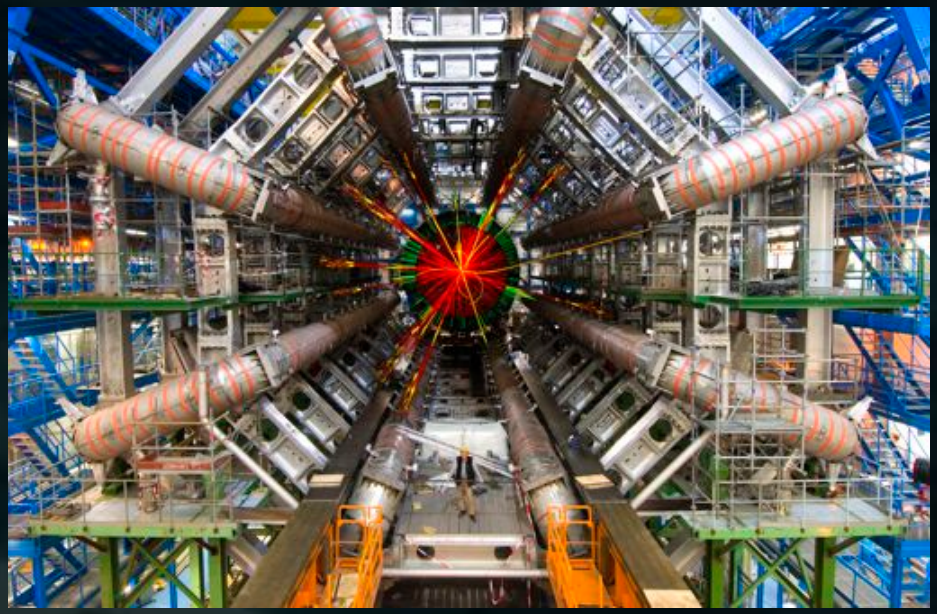
MAKING DARK MATTER – AND ANTIMATTER

At particle accelerators like the Large Hadron Collider



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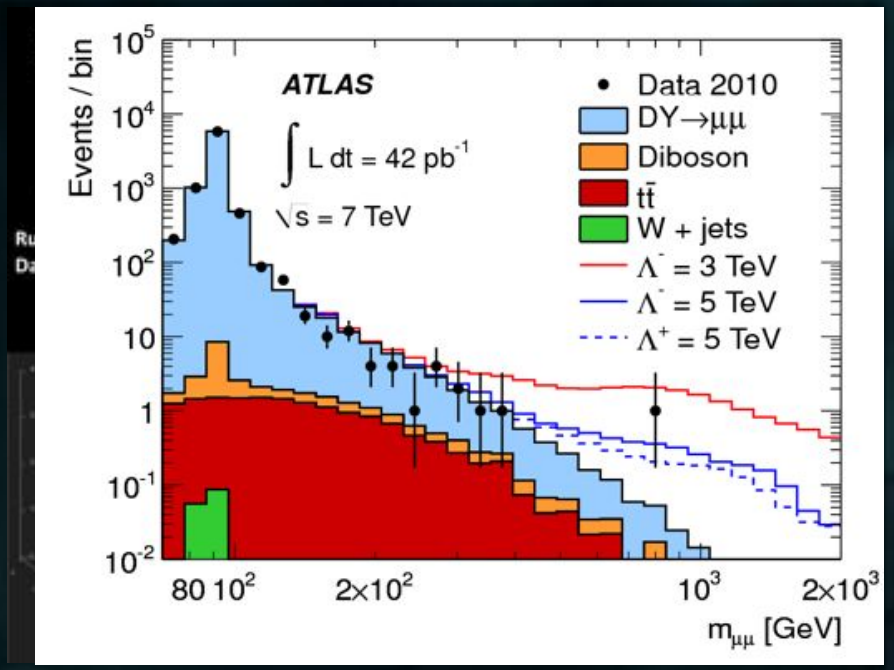
STAY TUNED

- The LHC is colliding beams; the first scientific results came out last summer, but it's still early days
- We're poised to make new discoveries about nature



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THANK YOU
For more information
www.phys.uvic.ca
www.triumf.ca
www.cern.ch
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SEARCHING FOR ANSWERS INTERNATIONALLY

- High energy frontier

Europe

- Study of elusive neutrinos

T2K

$\nu_\mu \rightarrow \nu_e$

Japan

- High intensity frontier (precision, rare decays)

USA

- Theoretical physics

$$\Gamma(b \to q\ell\nu) = \frac{G_F^2 m_b^5}{192\pi^3}|V_{qb}|^2(1 + A_{ew})\ldots$$

Global

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SEARCHING FOR ANSWERS IN VICTORIA

- Large, active UVic group
  - 9 faculty
  - 7 adjunct faculty
  - 10 research associates
  - 25 graduate students
  - Joint faculty with TRIUMF and Perimeter Institute
  - $2M/year research funding
- International reputation
  - Build detectors used in USA, Japan, Europe
  - Fill leadership roles in flagship experiments in USA, Japan, Europe
  - Former PhD students are faculty at McGill (3), SFU, Carleton (2), Lancaster (UK – 2)

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EXPERIENTIAL LEARNING

- Training of students and post-doctoral researchers is a primary goal
  - Some stay in academia
  - Some move into industry
  - All are highly skilled in using sophisticated, modern tools to solve problems

- UVic student during installation of ATLAS at CERN

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BONUS MATERIAL

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HOW MUCH DOES THIS ALL COST?

- The LHC and associated detectors cost about $10 billion
- Canada's contributions, over 17 years, total ~$100 million
  - puts Canadian researchers at the forefront
  - hundreds of students trained on the project
  - Canadian industry built important high-tech components
- The cost of one Hollywood movie (e.g. the Da Vinci Code) exceeds Canada's total investment in LHC science

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WHAT'S A HIGGS BOSON?

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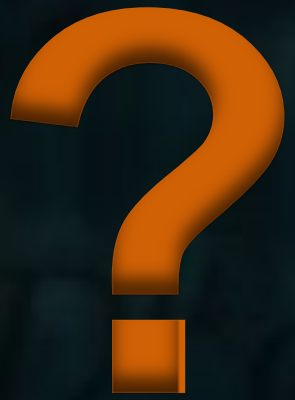
DARK ENERGY

- Fills empty space
- Causes the universe to expand faster and faster
- Being studied on earth and in space

- Still a complete mystery



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HOLLYWOOD'S CERN

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THE MOVIE

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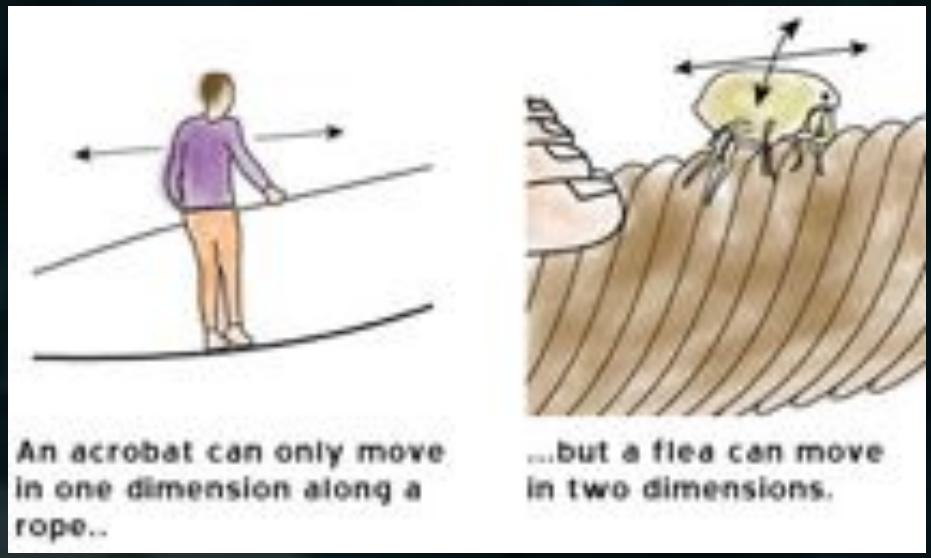
NEW DIMENSIONS OF SPACE?

- Theories of “extra dimensions” try to explain why gravity appears so weak compared with the other forces
- Extra dimensions might be curled up into loops
- Experimental signature could be a series of new particles at LHC



particleadventure.org

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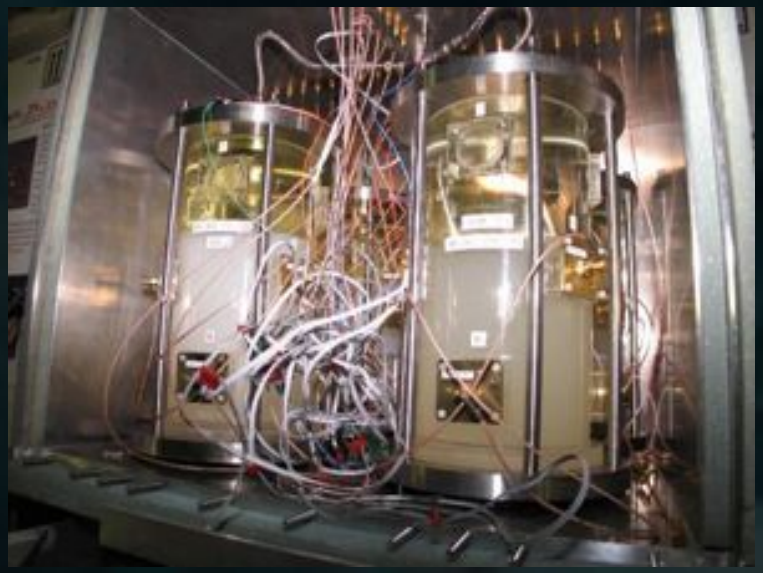
SEARCH FOR NATURALLY OCCURRING DARK MATTER

Deep underground



PICASSO, SNOLAB

In space

PAMELA satellite

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THE PLOT

- Antimatter is stolen from CERN's Large Hadron Collider and hidden in Vatican City
- Countdown to Vatican annihilation begins
- Race through Rome to avert death and destruction

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HOLLYWOOD'S LARGE HADRON COLLIDER

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ANTIMATTER

- It's real
- It's produced at the Large Hadron Collider
- Enough of it could destroy Rome
- What is it?

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WHAT IS MATTER?

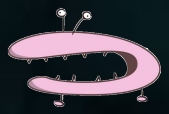
Particles in various combinations

Quarks


up


down

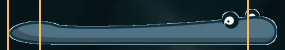
light


charm


strange

medium


top


bottom

heavy

Leptons


electron

light


muon

medium


tau

heavy


electron neutrino


muon neutrino


tau neutrino

extremely light

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BUILDING A UNIVERSE

electron

proton

neutron

Multiply by a whopping big number (like 10^{100} a *googol*)

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BUILDING A UNIVERSE

NASA, ESA/JPL-Caltech/B. Mobasher (STScI/ESA)

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WHERE DOES ANTIMATTER FIT?

For every particle


up


electron


down


electron neutrino

There is an antiparticle


anti-up


positron


anti-down


Anti-electron neutrino

Particles and antiparticles have opposite properties (e.g., charge)

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ANGELS & DEMONS & ANTIMATTER

- Rome is threatened by ¼ gram of antimatter
- Annihilation of ¼ g matter + ¼ g antimatter = 10 kilotons of TNT
- More than enough to destroy the Vatican
- 100% efficient: all mass → energy
- Should we all be worrying about anti-matter proliferation?

¼ gram

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ANTIMATTER'S NO THREAT

- We make *very* little antimatter
- Fermilab stores (for ~1 day each) 2 nanograms of antiprotons per year – enough to boil 2/3 cup of water

- It would take 109 million years to make ¼ gram

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ANTIMATTER'S NO THREAT

- It's not portable in large quantities

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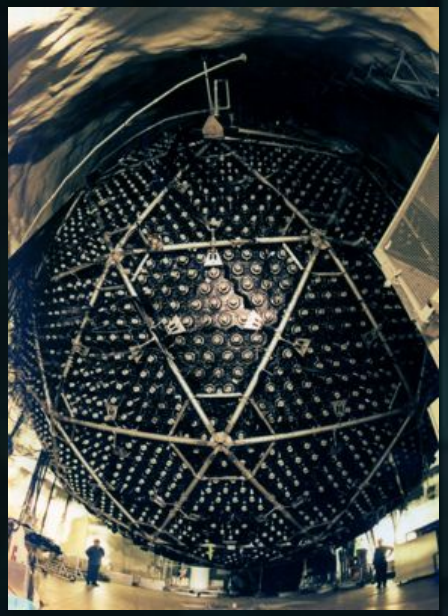
SOLVING THE MYSTERY

With neutrinos

- Neutrinos come in three types (generations)
- They can spontaneously switch (oscillate)
- Could provide answers
- Investigation underway

T2K experiment (Japan)



Sudbury Neutrino Observatory

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ANGELS & DEMONS
Lecture Night
THE SCIENCE REVEALED

Q2: HOW DO WE ACQUIRE MASS?

- Too much of this…

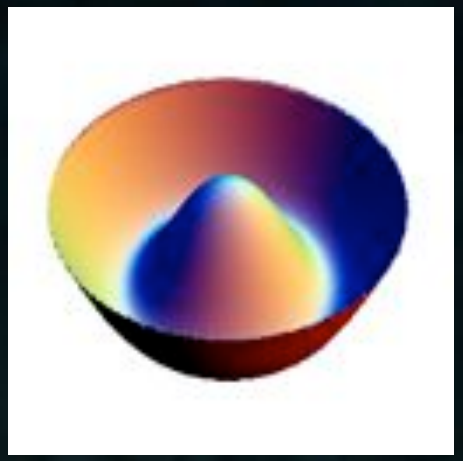
- Not enough of this…

ANGELS & DEMONS
Lecture Night
THE SCIENCE REVEALED

Q2: HOW DO FUNDAMENTAL PARTICLES ACQUIRE MASS?

- Still a mystery
- One possibility: Higgs field
- Predicted in 1964
- Still unconfirmed

- Can prove it by finding the Higgs Boson (the "God particle" referred to in the Angels and Demons film clip)



Broken symmetry

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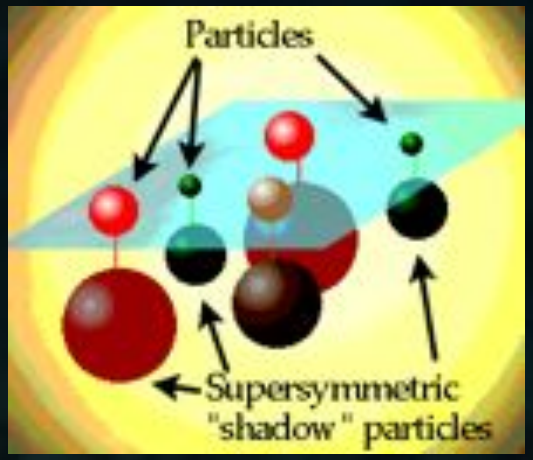
YET ANOTHER MIRROR?

- With the discovery of antimatter, the number of fundamental particles doubled
- A beautiful theoretical idea – Super-symmetry –predicts that each particle has a "super-partner"
- Dark matter candidate
- LHC may discover these



"sparticles"

Susy09, the *17th International Conference on Supersymmetry*

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SEARCHING FOR ANSWERS

- At particle physics laboratories around the world

ANGELS & DEMONS
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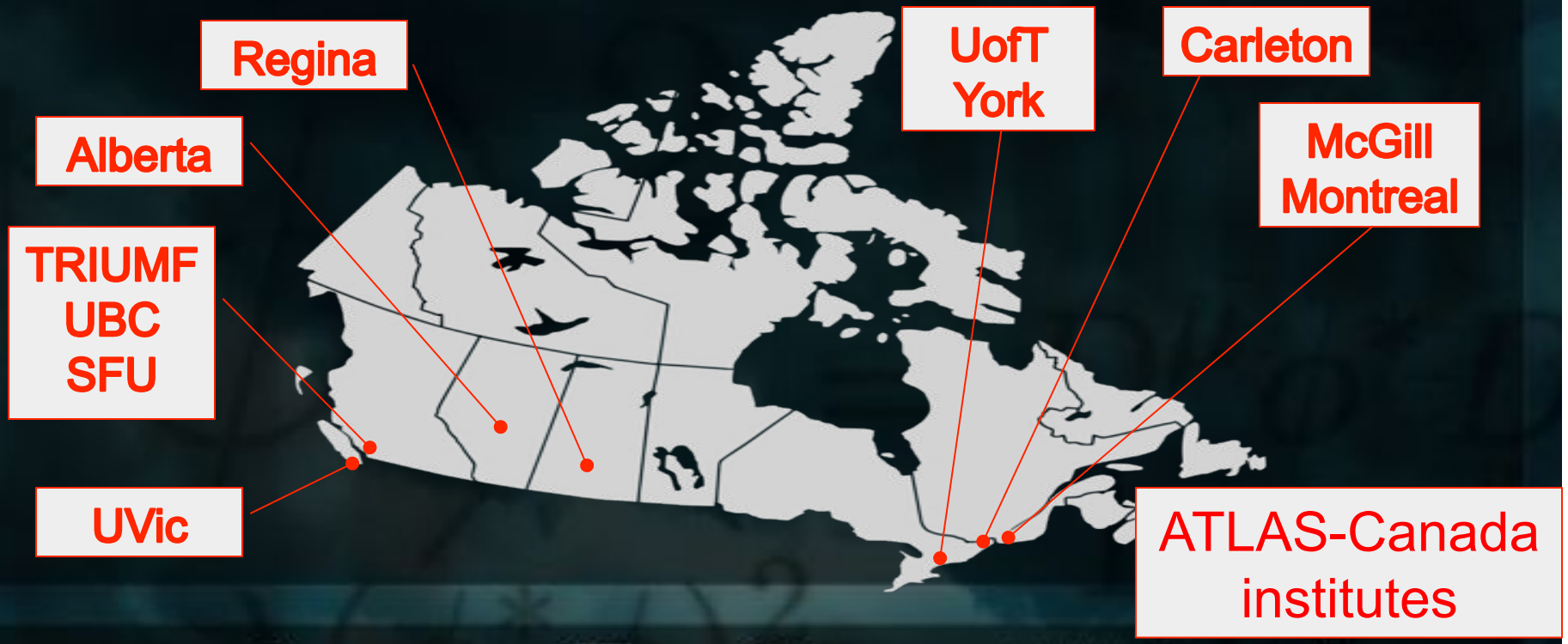
THE SCIENCE REVEALED

SEARCHING FOR ANSWERS

- At universities and laboratories across Canada



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