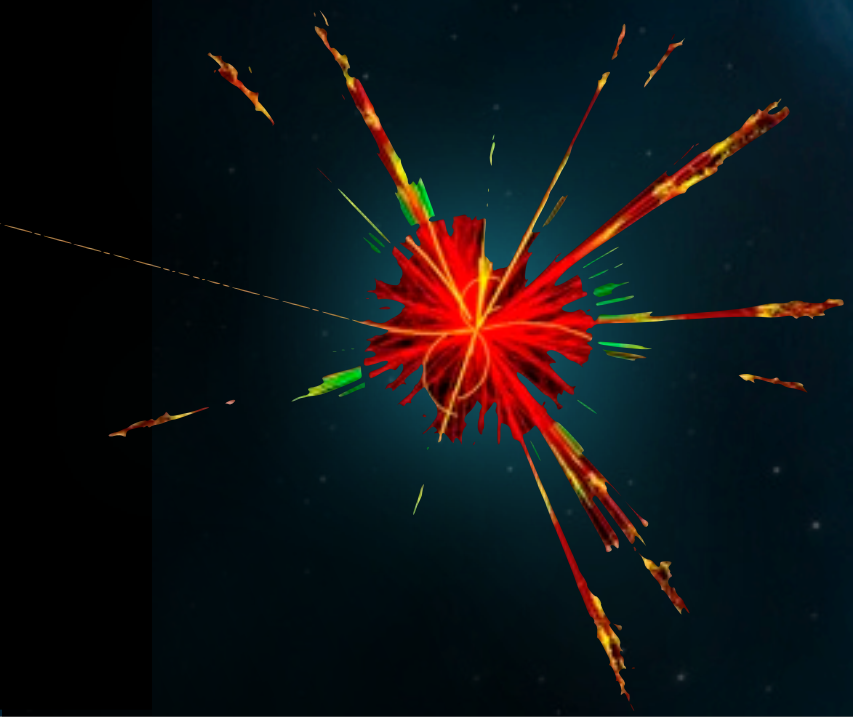
Fra Kvarker til Kvasarer

Plan: Start Her (Partikel Fysik) Slut Her (Kosmologi)



Dr. Peter Skands
CERN - Theoretical Physics Department

Hvem er jeg?

Læste fysik-astronomi på KU
(cand scient: 5 år)

→ Lunds Universitet:
teoretisk fysik (PhD: 3 år)

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(cand scient: 5 år)

→ Lunds Universitet:
teoretisk fysik (PhD: 3 år)

→ Fermilab (Chicago)
"Post Doc": 2 år
"Associate Scientist": 3 år

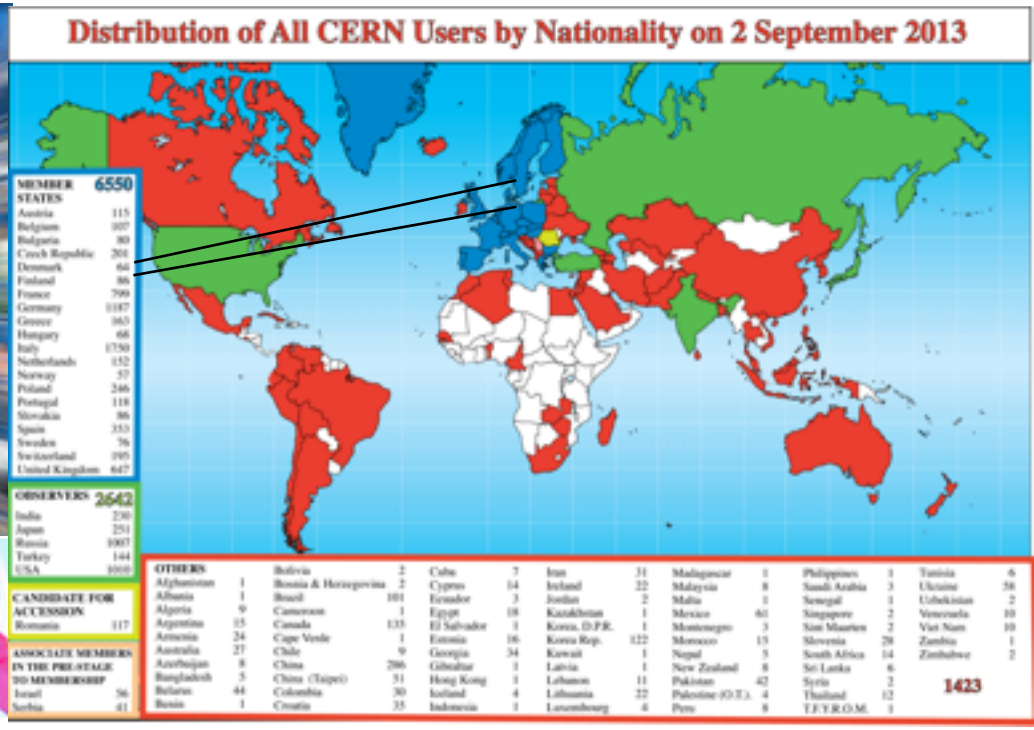
Nu: **CERN** …

CERN: European Organization for Nuclear Research

20 European Member States and around 60 other countries

~ 10 000 scientists work at CERN

Flags of CERN's Member States

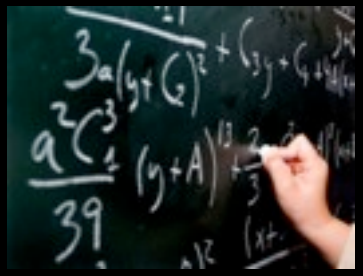


Yearly budget ~ 1 billion CHF ~ 6 mia DKR

What goes on at CERN

LHC Collision at 7 TeV
ATLAS, March 2010

Nutshell



Theory

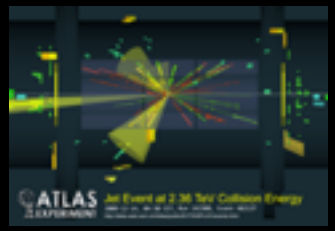
Experiment

Adjust this to agree with this

→ Science

In Practice

• • •



Simulation Codes

→ Simulated Particle Collisions

Experimental Data

→ Published Data Points

signal to background

May 12, 2013

The top 40 physics hits of 2012

The Higgs boson is a popular subject among the most-cited physics papers of 2012, but a particle simulation manual takes the top spot.

By Glenn Roberts Jr.

PDF Download

Related *symmetry* content

Breaking: Physicists, start your searches:

Think of it as a particle physics version of pop radio's "top 40" countdown: INSPIRE, a database of particle-physics publications, has released its annual list of most-cited articles.

Topping the charts in 2012 are articles about the Higgs boson, which made up about 20 percent of the list.

But the most-cited publication of 2012 is a 583-page manual about PYTHIA, a program for simulating particle collisions and their byproducts.

Min Forskning

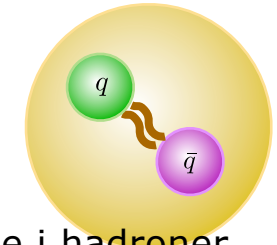
Teorien om den stærke kernekraft: Kvante-Chromodynamik (QCD)

Kvarker og Gluoner + Hadroner = bundne tilstande af kvarker (og antikvarker)

Mesoner (kvark-antikvark): pioner, kaoner, ρ mesoner, …
Baryoner (triple-kvark): protoner, neutroner, hyperoner, …

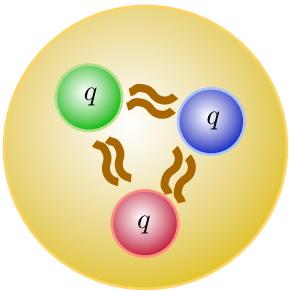
Bremsstrahlung

Når du sparker en kvark, stråler den gluoner
(Jvf elektriske ladninger, der stråler fotoner)



Hadronisering

Når kvarker og gluoner bliver 'kolde' bindes de i hadroner
Der opstår 'gluon-strenge' mellem dem, som bryder op
Den process forsøger vi at modellere og forstå



~ 1fm
= "1 fermi"

"Monte Carlo event generators"

- Kvante-sandsynligheder → tilfældige tal

→ tilfældige begivenheder, som i eksperimentet ~ en 'virtuel accelerator'

- Used by experiments to give "theory predictions", to compare with data
- Used to design and optimize detectors and analysis strategies
- Used by theorists to explore new solutions, new ideas, new physics

Not a computer scientist. But the numerical calculations I (want to) do require a lot of power → distributed computing: farms / GRID / clouds.

LHC@home 2.0

Test4Theory - A Virtual Atom Smasher

LHC Physics Center at CERN

Over 1000 billion simulated collision events

Test4Theory - LHC@home

http://lhcathome.cern.ch/test4theory

LHC@home 2.0 Test4Theory volunteers' machines seen since Sun Nov 17 2013 14:00:00 GMT+1100 (EST) (2804 machines overall)

The LHC@home 2.0 project Test4Theory allows users to participate in running simulations of high-energy particle physics using their home computers.

The results are submitted to a database which is used as a common resource by both experimental and theoretical scientists working on the Large Hadron Collider at CERN.

New: *Citizen Cyberlab* (funds from EU)

Develop an app that lets citizen scientists **learn about, interact with, and optimize high-energy physics simulations**, by **comparing them to real data**

Why ?

the building blocks of Life

The Carbon in our bodies

The Nitrogen

... were made in stars ...

The Oxygen that we breathe

All I know for sure: Nature is a **Fantastic Work of Art**
Where did it come from? What is it? Where is it going?

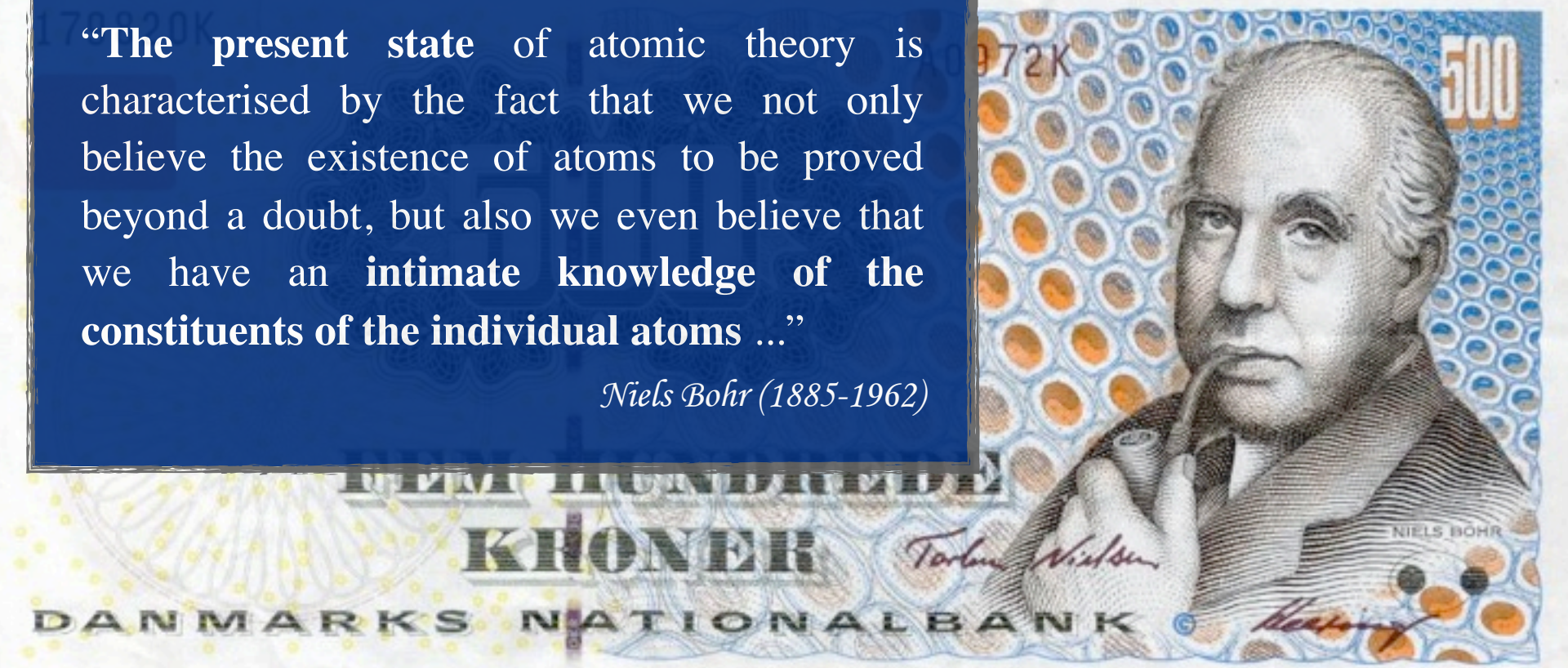
It **inspires us** to think beyond ourselves

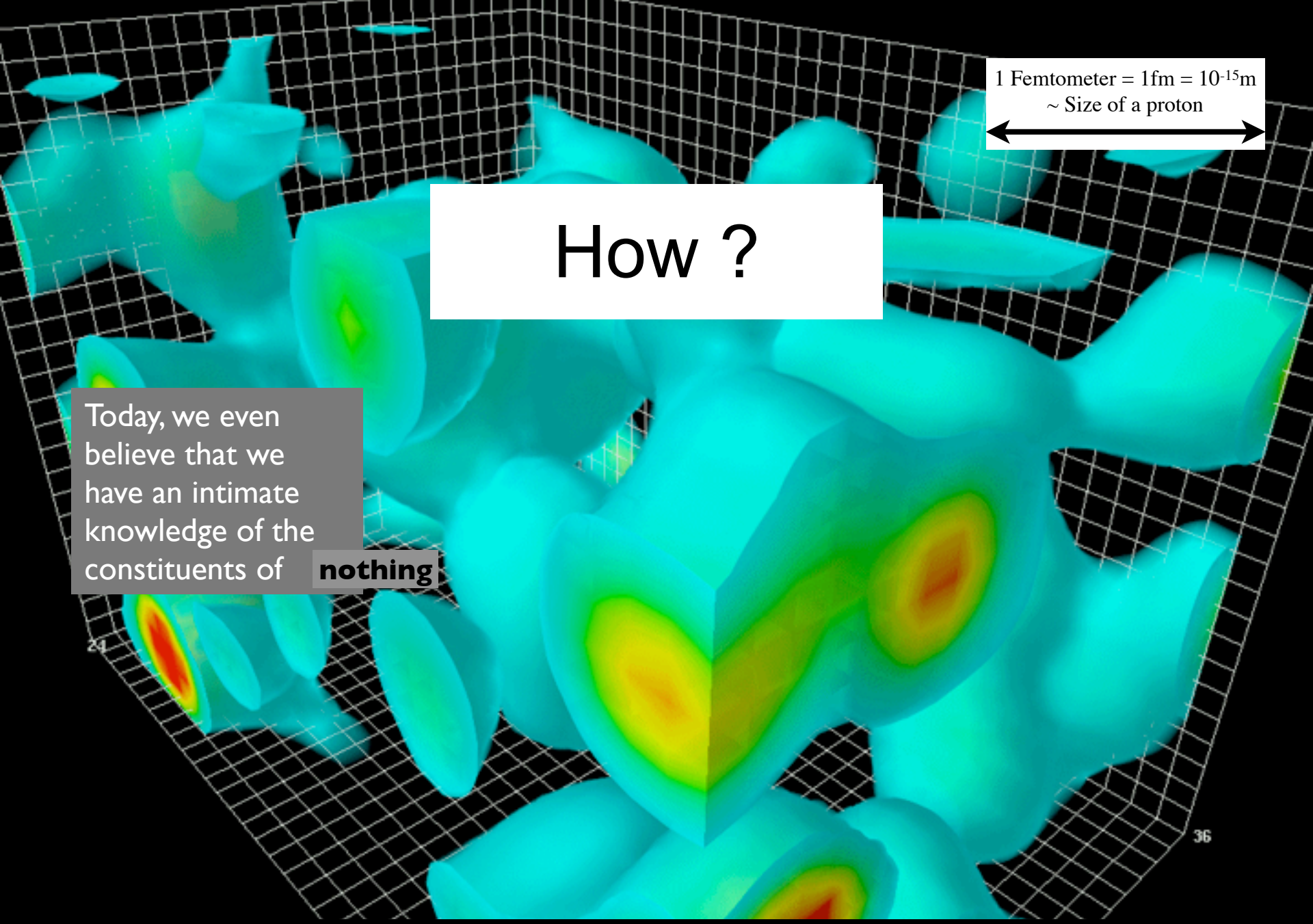
Atomic Theory

Stockholm, 1922

"**The present state** of atomic theory is characterised by the fact that we not only believe the existence of atoms to be proved beyond a doubt, but also we even believe that we have an **intimate knowledge of the constituents of the individual atoms** ..."

Niels Bohr (1885-1962)





http://www.physics.adelaide.edu.au/theory/staff/leinweber/VisualQCD/Nobel

Gluon action density: 2.4x2.4x3.6 fm, Supercomputer "Lattice simulation" from *D. B. Leinweber, hep-lat/0004025*

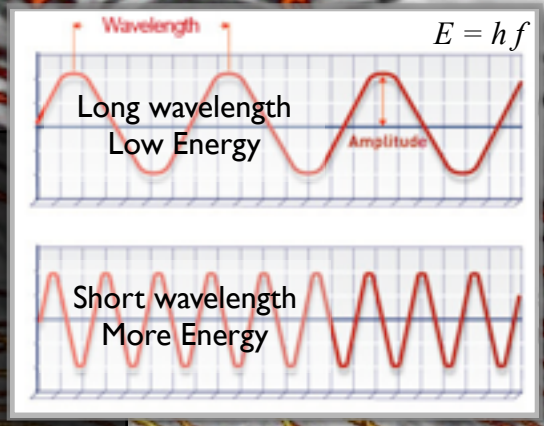
High Energy Physics

The true nature of the **strong nuclear force** is revealed at distances below about 10^{-15}m (= 10^{-6} nm)

To "see" something that small: need very small wavelengths → high energies (E = h f) : kick an electron with 1 billion Volts = 1 Giga-electron-Volt (GeV)

The energy of the Large Hadron Collider at CERN : 8 TeV

In computer simulations, we try to recreate the collisions happening in the LHC in as much detail as mother nature. The clarity of our vision of the **Terascale** depends on their accuracy. *You can help → LHC@home 2.0*



← "the Terascale" !

the real Accelerators

- 1932: Cockroft & Walton built a system that could fire protons, like bullets, into metal targets: p + LiF → Be, He, O, …

Fermi Laboratory, Chicago, USA, ca. 2000

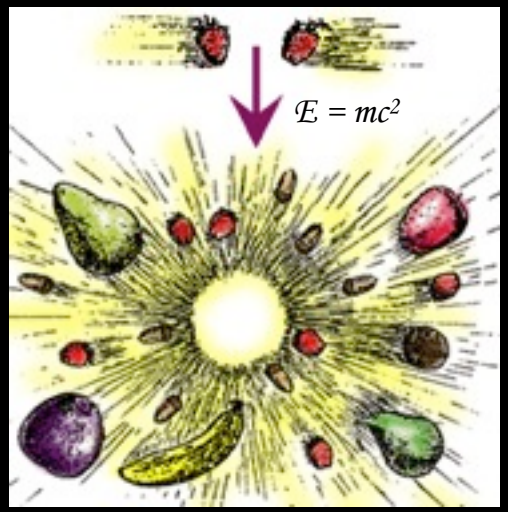
Modern van-de-Graaf

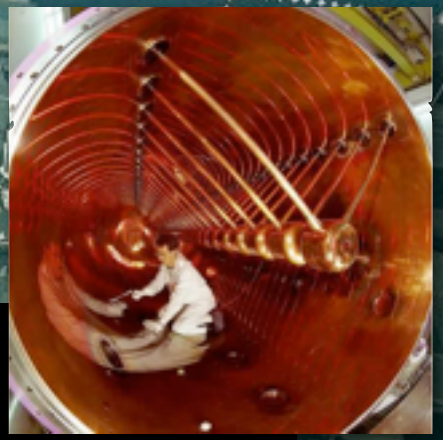
Early van-de-Graaf, ca 1937

(Nobel 1951) "Transmutation of atomic nuclei by artificially accelerated atomic particles"

Particle Accelerators

- The goal:





- Accelerators are 'optical' systems, with
  - Light → charged particles
  - Lenses → magnets
  - Wave length shortening → particle acceleration

So what is "High" Energy ?

Relative to combustion of 1 kg of octane molecules (gasoline) :

100m **Waterfall** : 0.000 025

Burning wood : 0.3

Burning sugar (metabolism) : 0.5

Burning ethanol or coal : 0.75

Burning Beryllium : 1.5

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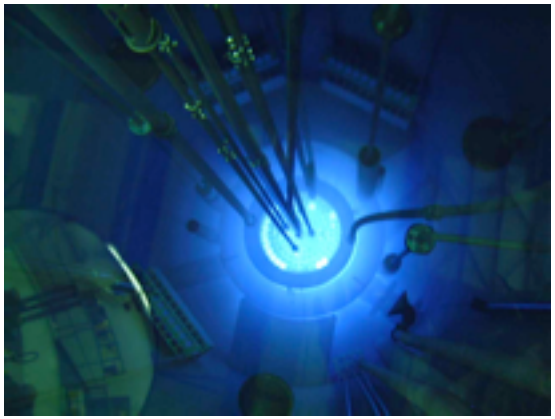
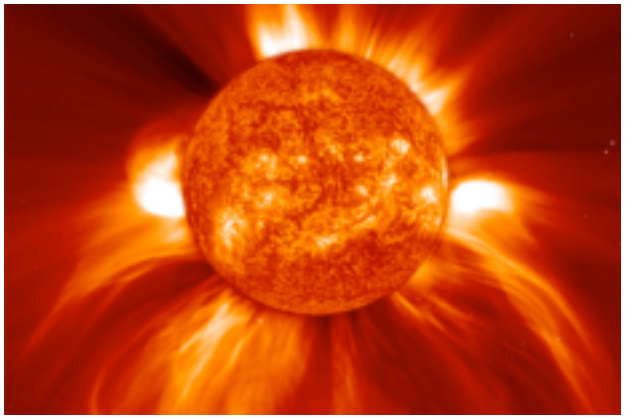
Uranium-235 **Fission** : 2 000 000

Deuterium-Tritium **Fusion** : 10 000 000





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Tevatron collisions : 2 000 000 000 000

LHC collisions: 8 000 000 000 000

FCC collisions: 100 000 000 000 000

Still, Dan Brown exaggerated a bit in "Angels & Demons" …

"If all of the antimatter ever produced at Fermilab had been collected, we would have a couple of nanogrammes …" *Dave Vandermeulen, antimatter expert, Fermilab*

→ Fundamental Science

July 4th 2012:

"Higgs-like" particle seen at CERN

(+ over 500 other published physics papers from LHC so far)

What is "Mass"?

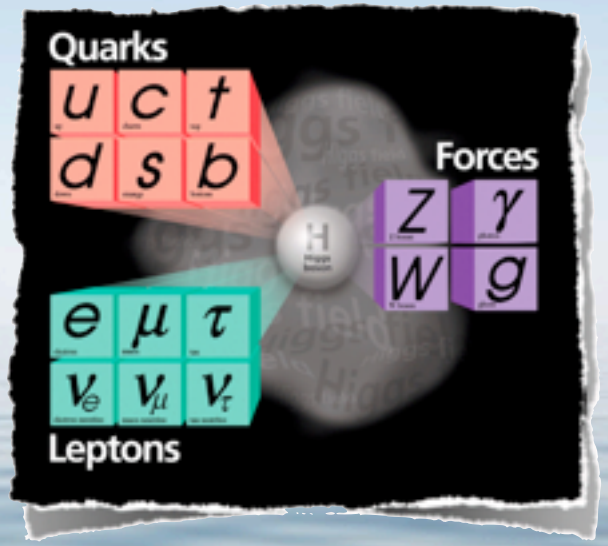
- Consider a 'field' distributed evenly across the Universe, of uniform strength
- Suppose that different particles experience this 'field' as being more or less transparent
  - To a photon (light), the field is completely "translucent"
  - But an electron (or a proton), will interact with it
- Suppose that this field condenses around the particles which couple to it, causing an increased energy density around those particles. Looks like mass ($E=mc^2$).
- We call this field the "H" (or Higgs) Field
- If correct, it should be possible to create waves in the Higgs field itself (though that may require a lot of energy)

The Higgs Particle

- If correct, the Higgs mechanism makes one **spectacular prediction**: it should be possible to excite a wave in the Higgs field itself
- Made out of **pure 'Higgs' stuff**, in particle form this wave is known as the 'Higgs particle' or 'Higgs boson'
- This particle would quickly dissolve (decay) into other particles, but should be **detectable** via its decay products
- The **discovery** of a particle consistent with these properties was announced at CERN on July 4, 2012
- The coming years will see a huge activity trying to determine all the **quantum properties** of this new "H particle"

the Last Piece of the puzzle?

Atoms
Neutrinos
Exotic matter
Antimatter



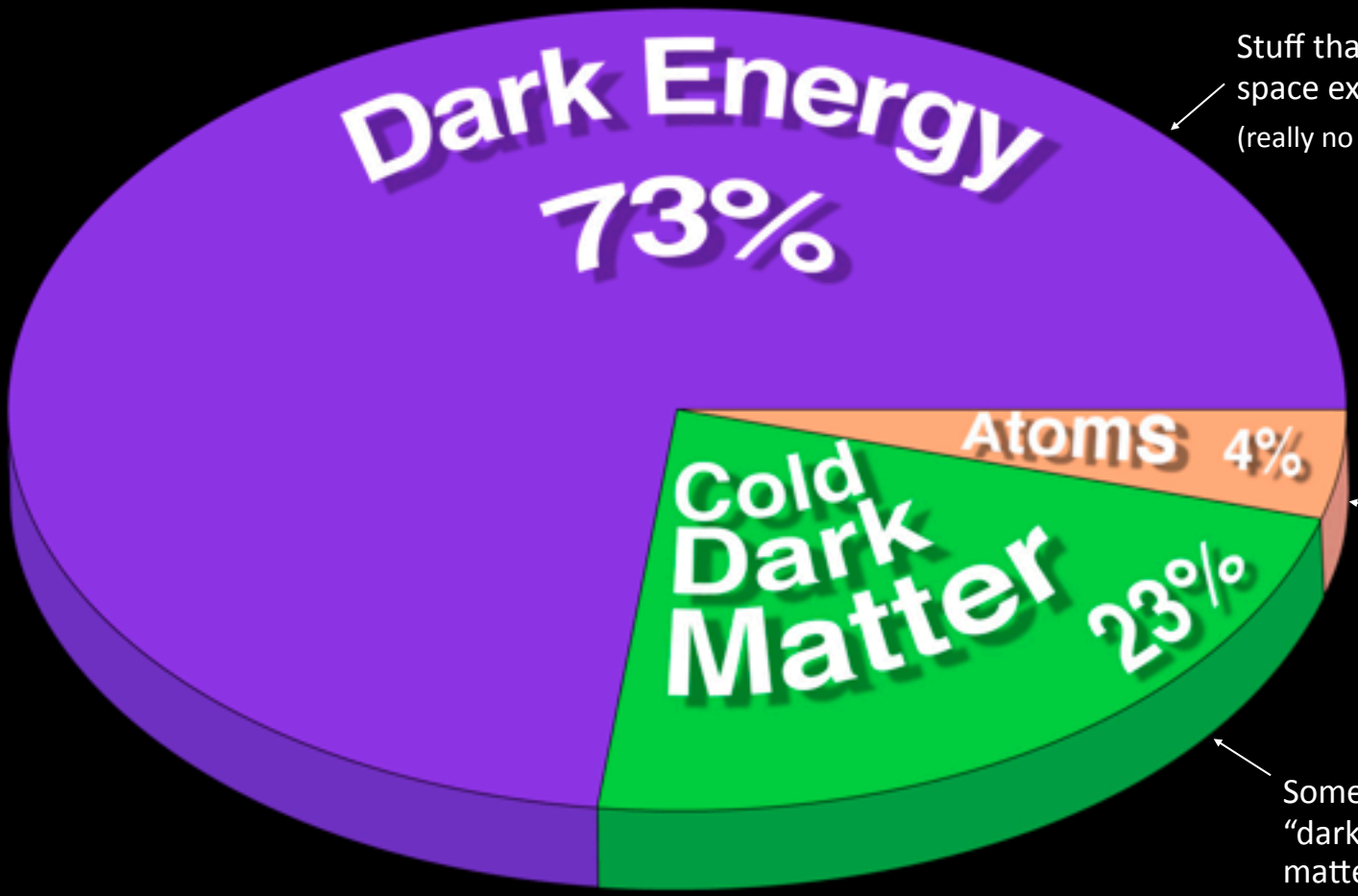
Electromagnetism
The nuclear forces
+ Gravity (Einstein)

+ Mass

Or is there something beyond?

Like: Quantum Gravity? Higgs Origins? Grand Unification? Extra Dimensions? …

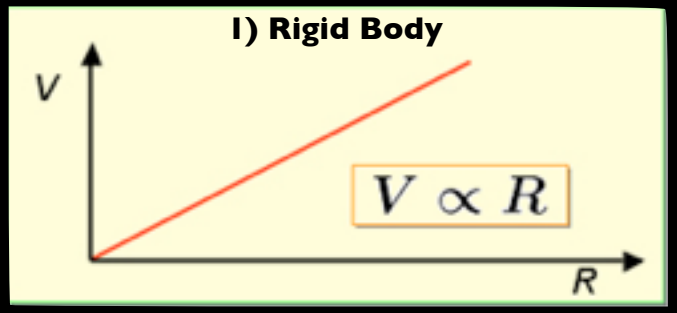
The Dark side of the Universe

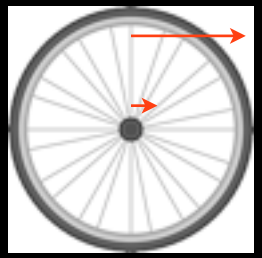


Dark Matter: 23%

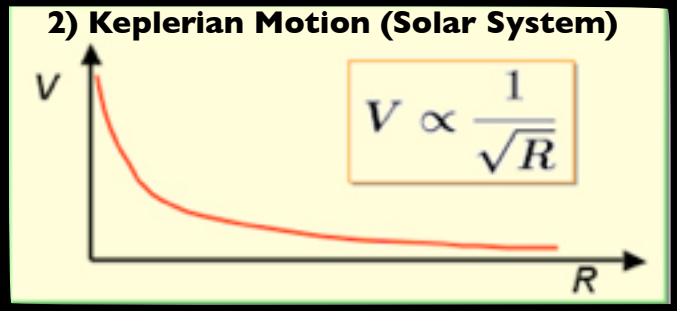
Rotation Curves

1) Rigid Body



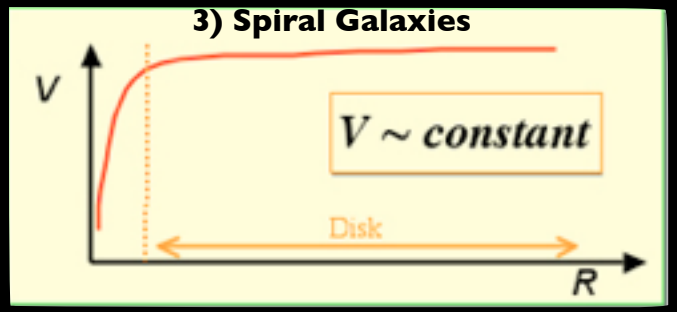


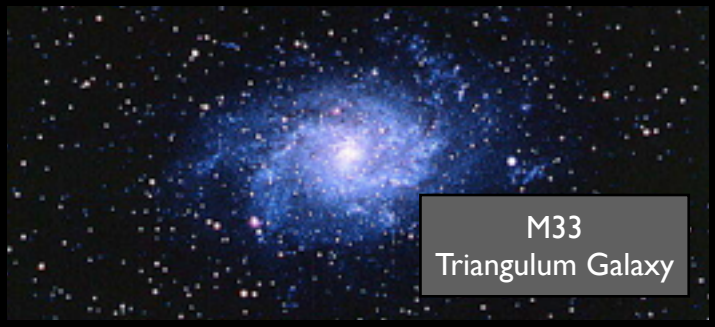
2) Keplerian Motion (Solar System)



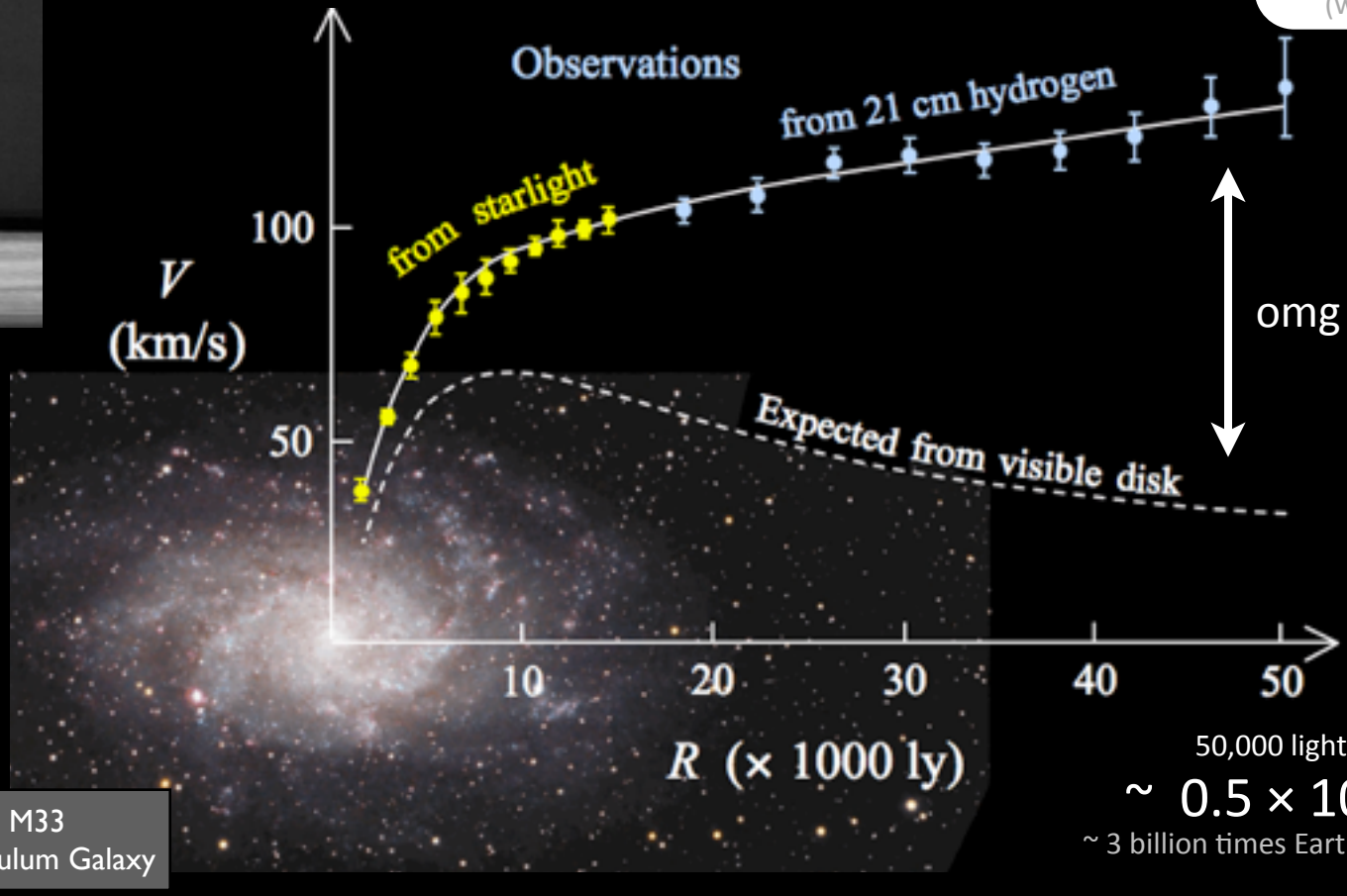
Mercury: 48 km/s Earth: 30 km/s Neptune: 5 km/s

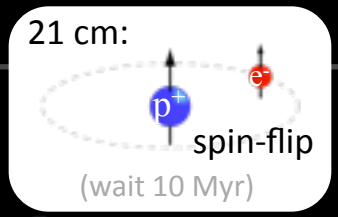
3) Spiral Galaxies





Rotation Curves of Galaxies
(and of Galaxy Clusters)





50,000 light years

~ 0.5×10^{18} km

~ 3 billion times Earth-Sun distance

Something unknown is making galaxies spin like crazy

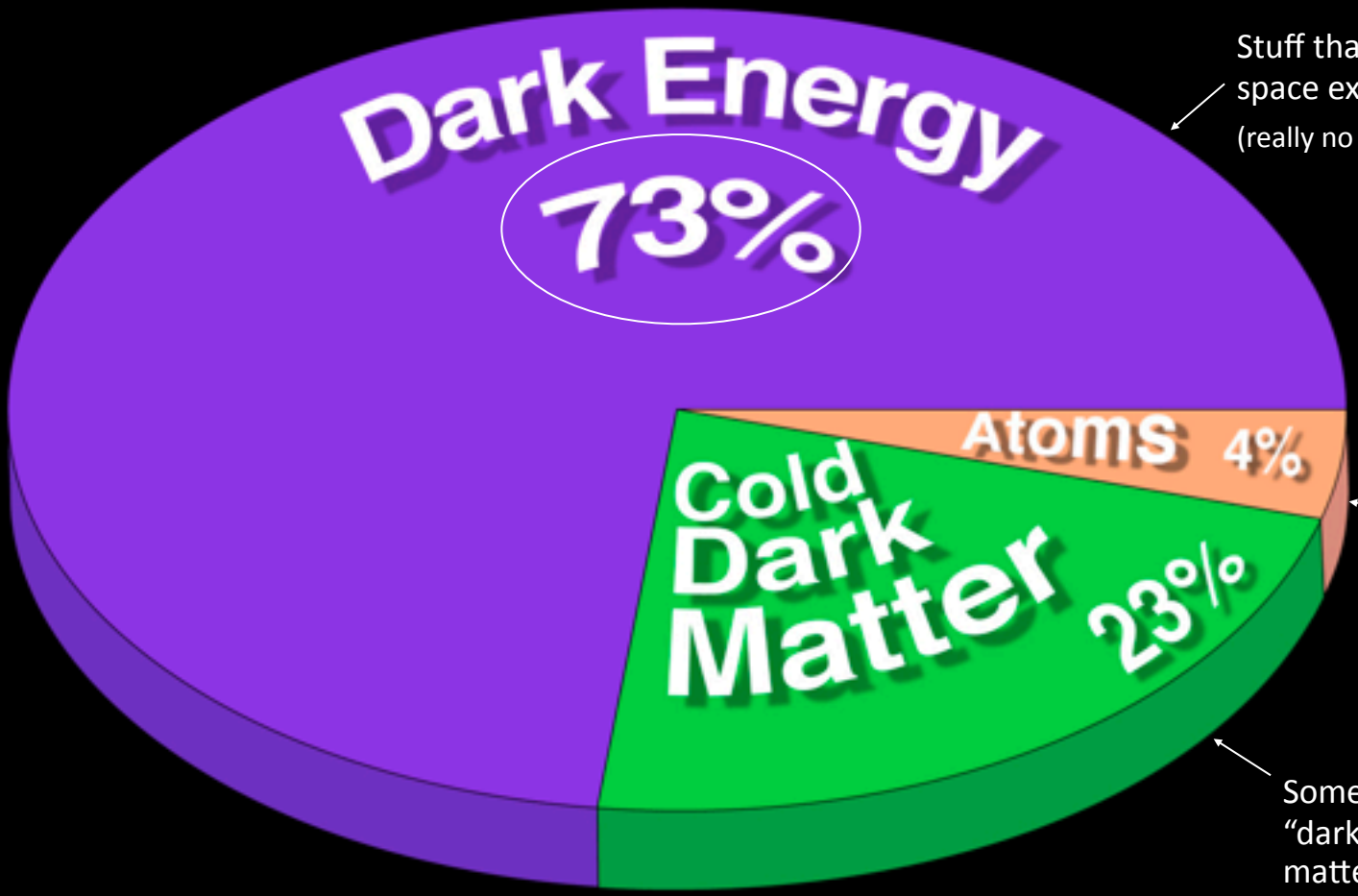
When Galaxies Collide

- August 2006: Clowe et al.: "A direct empirical proof of the existence of dark matter"

But we still don't know what "it" is
Maybe we can make it in the LHC ?
Or "see" it in space or on Earth?
Stay tuned…

Astrophysical Journal 648 L109-L113 (2006)

The Dark side of the Universe: 2

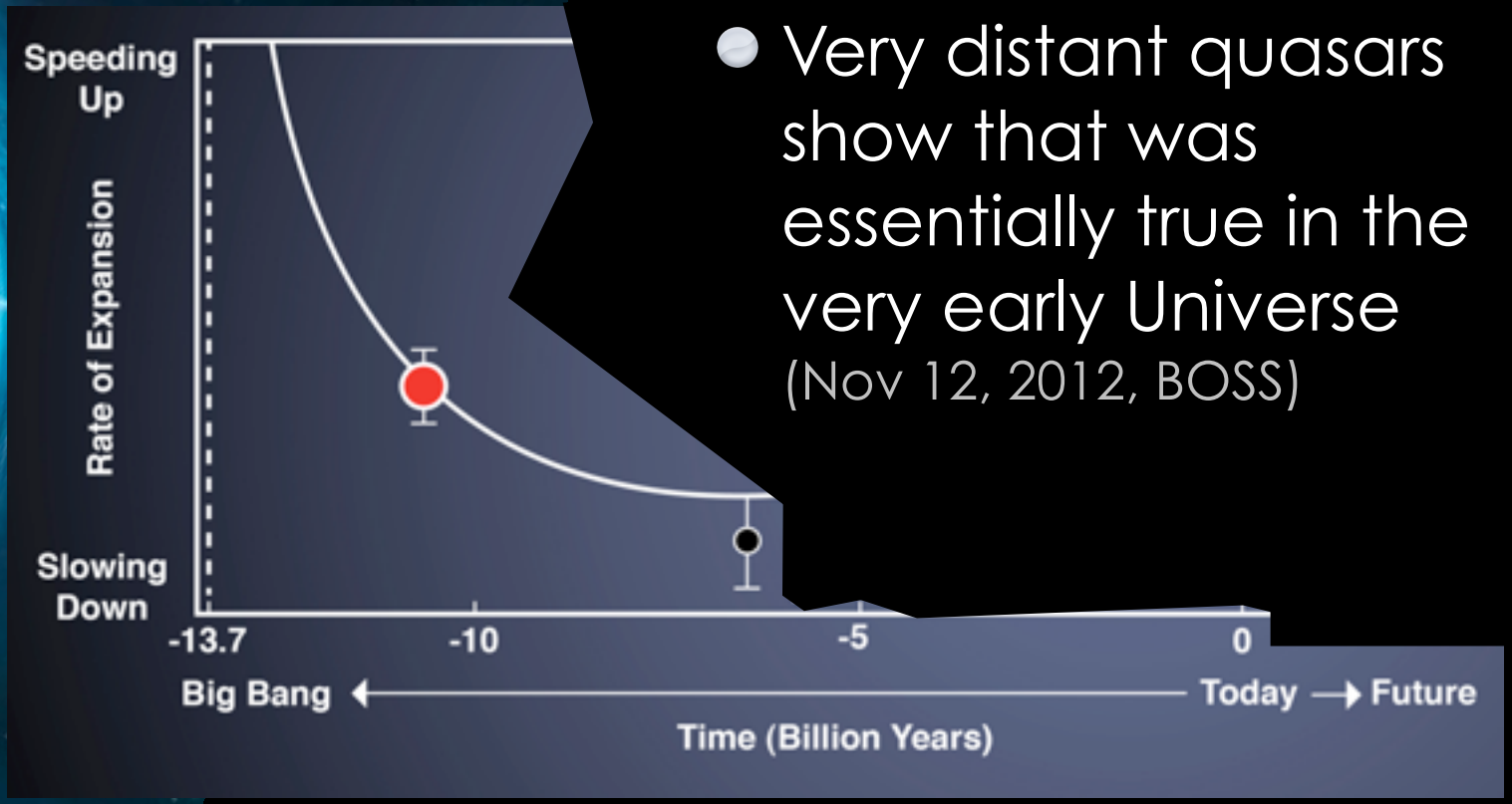


Quasars

- Extremely far away → appear point-like ("Quasi-Stellar" → Quasar)
- The most luminous objects in the Universe → we can see them even when they're very, very far away (~ 10 billion light years) …
- … when the Universe was younger

Quasars

- Gravity slows down expansion of Universe
- Very distant quasars show that was essentially true in the very early Universe (Nov 12, 2012, BOSS)



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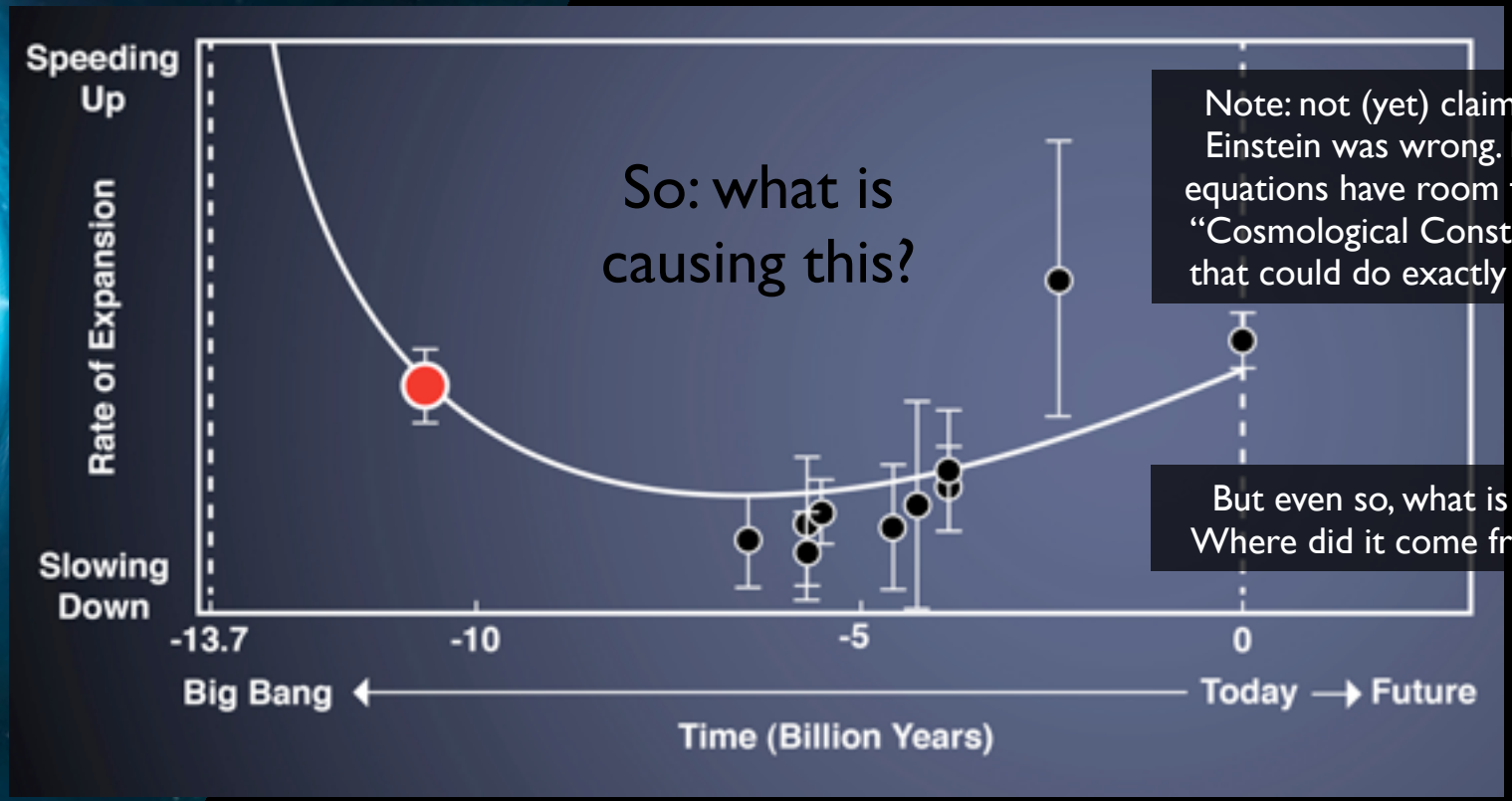

Questions (for you?)

- What are Dark Matter and Dark Energy? Are they new "stuff" that obeys known laws, or are they new laws unto themselves? Or both?
- How well can ***you*** solve Quantum Field Theory? Without assuming things that aren't true? Fluctuations within fluctuations within fluctuations within fluctuations ...
- Is 4 dimensions all there is? If more, how do they look? Is holography relevant?
- Where did the Higgs potential come from? How is it stable? What determines how particles couple to it? Is it fundamental? Are there more Higgs fields?
- Why does normal matter have heavier 'exotic' cousins? I.e., the other quarks and leptons. Do they play a role in some grander pattern?
- Why 4 fundamental forces? Are there more? Or are they really one?
- Why is there a bit more matter than antimatter around? (e.g., us)
- Also, what *is* quantum gravity? Superstrings? Or something else?
- Ideas are not enough. ***How to test! How to calculate!***