Intro to Particle Physics

Physics 165
Richard Seto

I work at RHIC (PHENIX expt)

I do far too much bureaucracy (money, people...)

I like to think about all kinds of stuff

teaching 165 is part of the stuff I like

The course

- All relevant info on blackboard
  - Book – Particle Physics – Martin/Shaw
  - TA - Shih-Chuan Kao
  - PS 1 is up due….
- Problem sets ~ 1 every 1-2 weeks
- a late midterm
- Presentation
- 5-10 page paper (actually there is not a page limit)

Lectures – Scope of the course

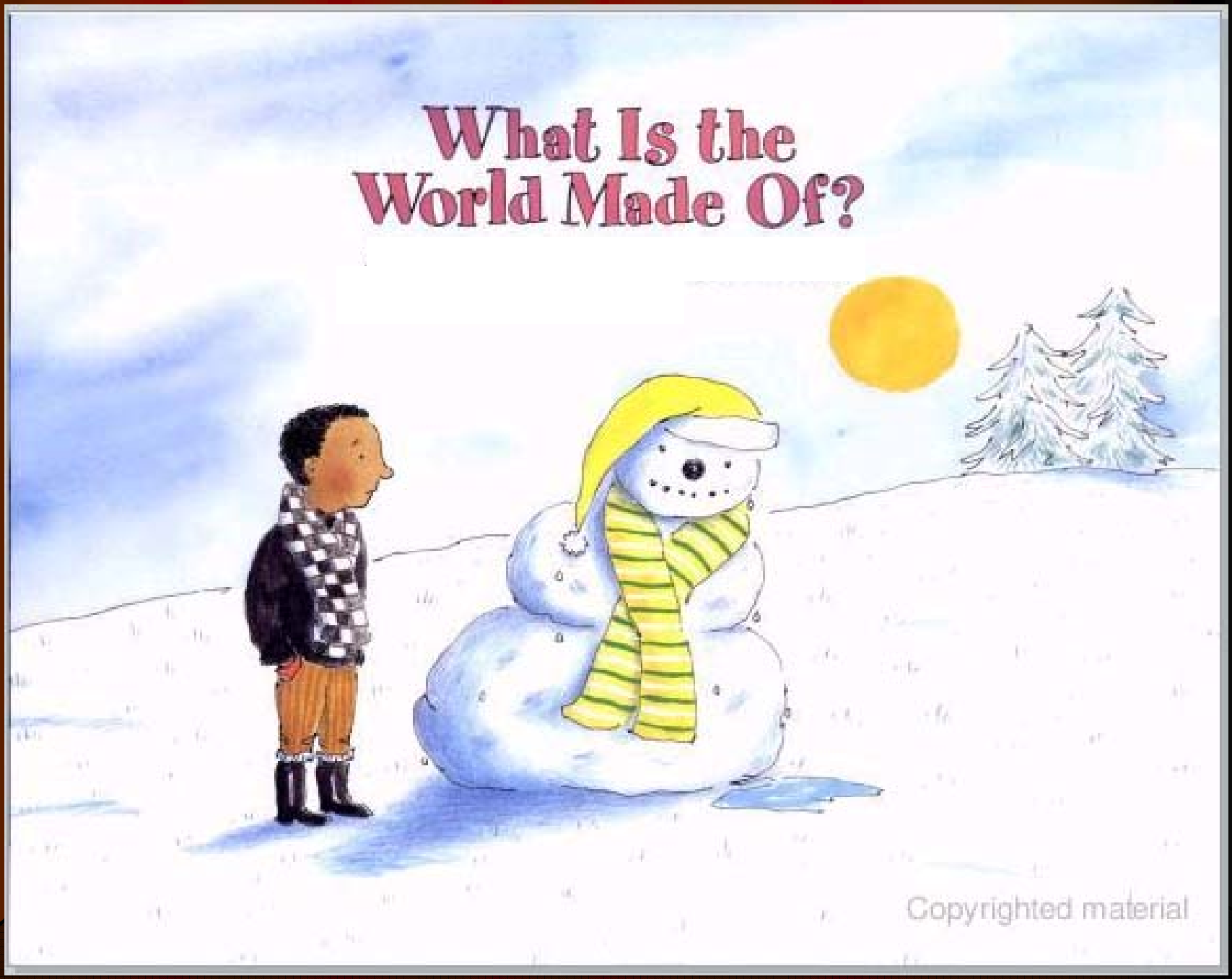
- Lecture and PS – first 2/3 of course
  - Leptons/quarks, forces (our corner of the universe)
  - Particle Detection
  - Field Theory and Symmetries (how we do it)
  - QED and Electo-weak theory
  - Quantum Chromodymamics
  - Grand Unification
  - Dark Energy – The problem
  - Strings and other things

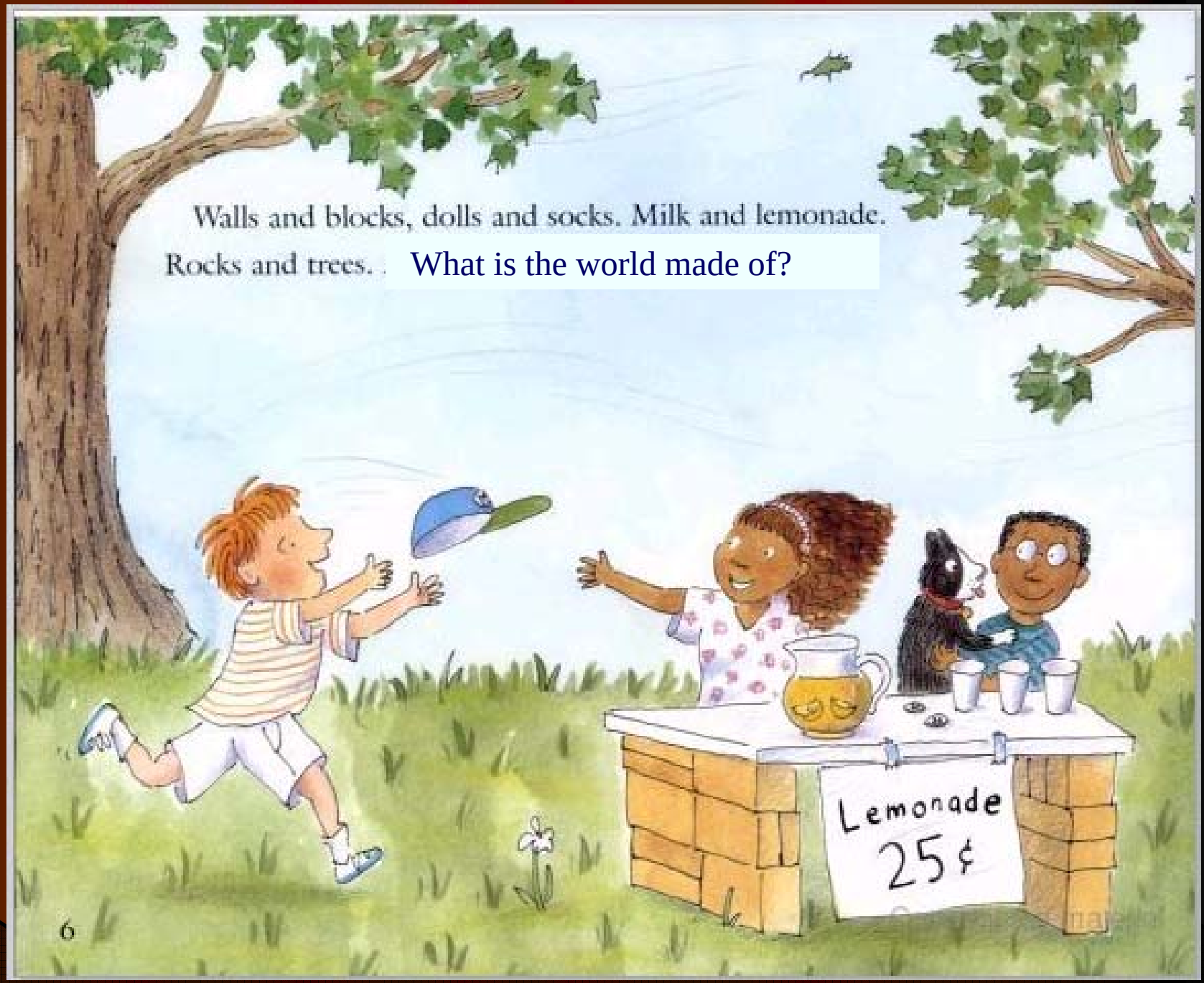
Some possible topics
(not exhaustive)

- The LHC or one of the LHC detectors and what they might see
- Past experiments
- Dark energy
- Dark matter
- Particle Detection techniques (e.g. gas drift chambers, calorimeters, Silicon detectors etc – pick one).
- RHIC and its experiments
- FNAL/CDF/D0
- Space based experiments (e.g. GLAST)
- Underground searches
- Attempts at unification
- For someone with a taste for something tough
  - a real analysis
  - a real theoretical calculation

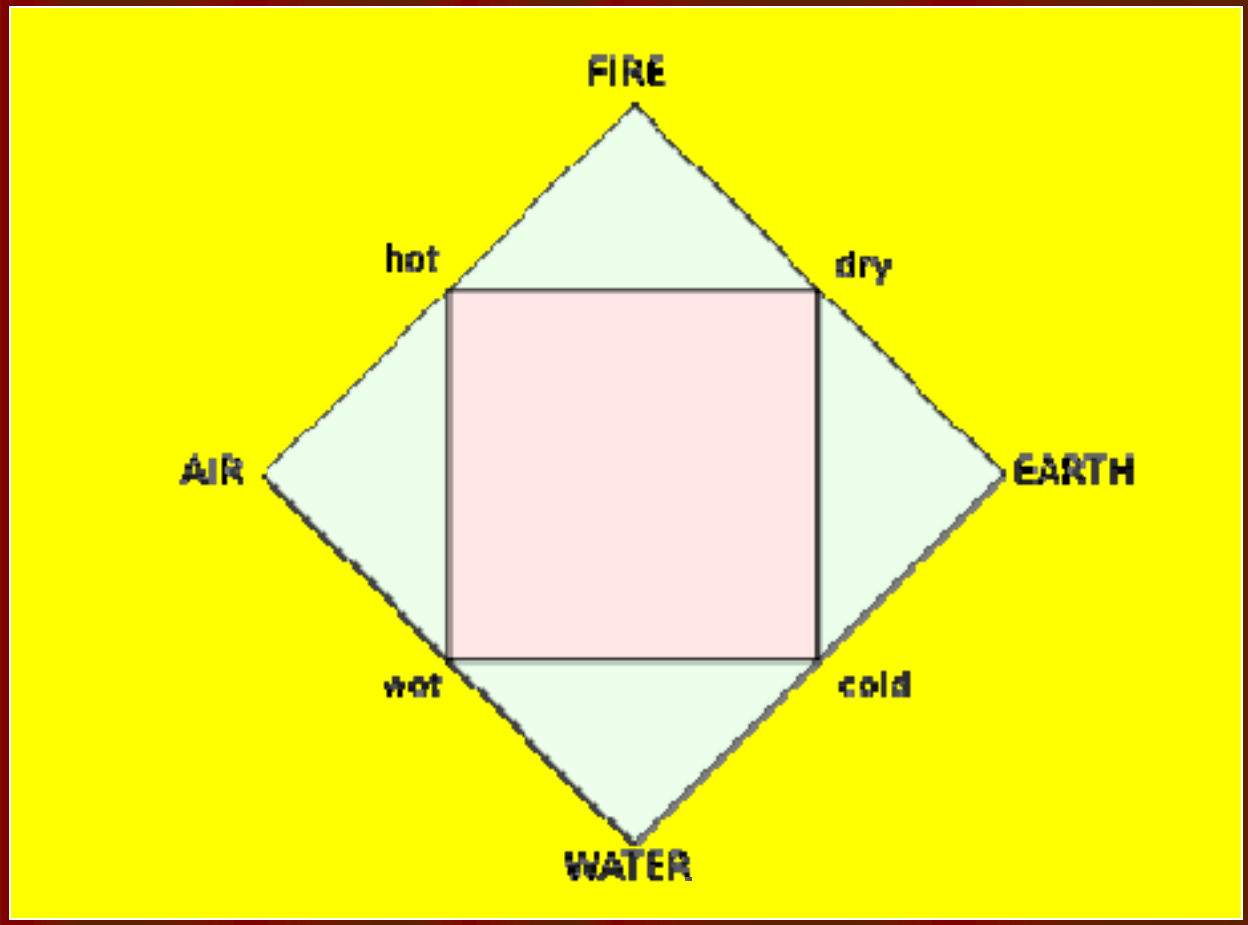
- Sources
  - Folks at UCR
  - Folks at other universities
  - Scientific American
  - Journal articles
  - The web
  - Your brain
  - Books at the library

What Is the World Made Of?



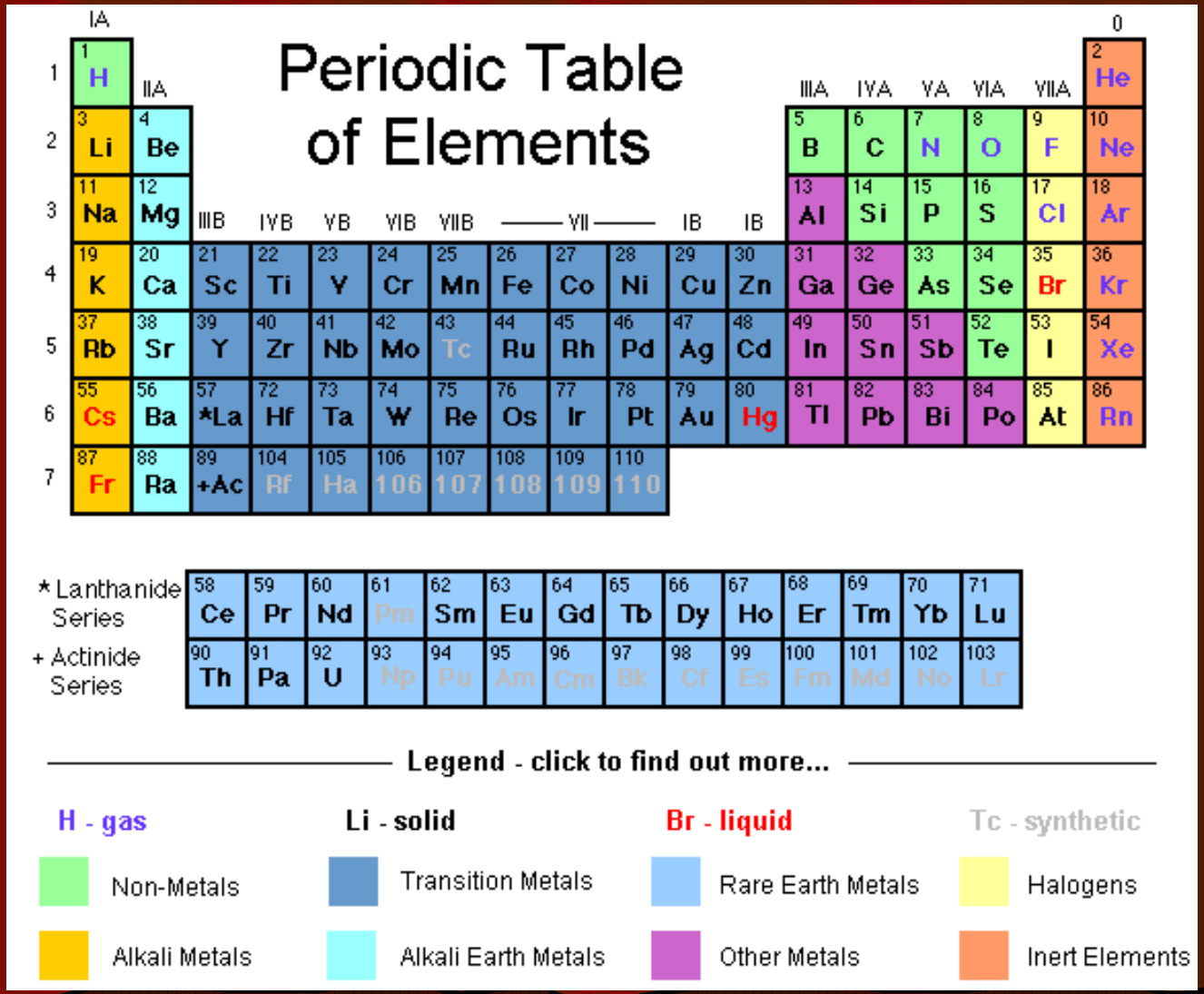

Walls and blocks, dolls and socks. Milk and lemonade.
Rocks and trees. .
What is the world made of?
Lemonade
25¢
6

What is the world made of? 1



Ancient Greeks

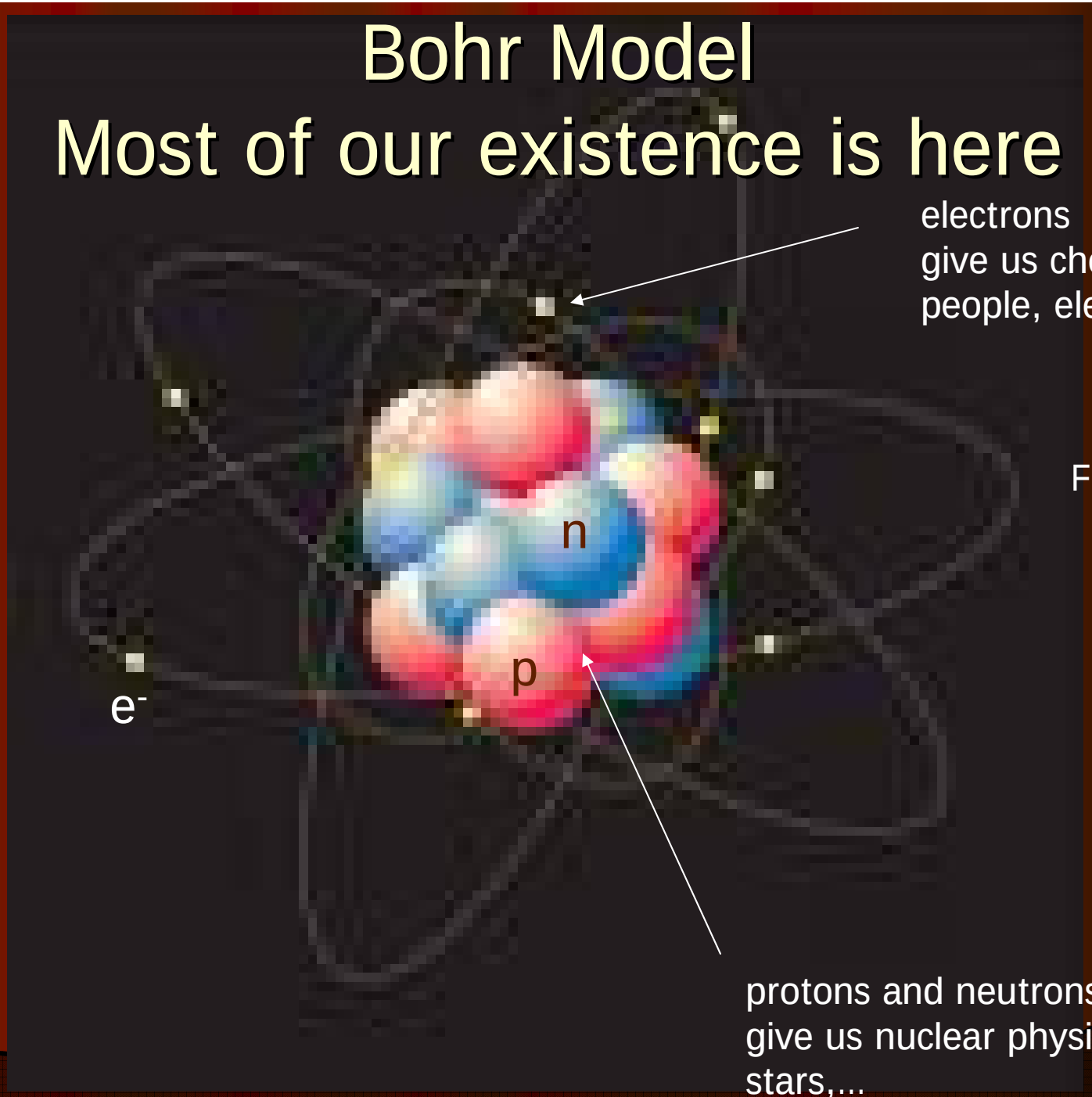
What is the universe made of? 2



But why?
Fundamental?

Mendelev

Bohr Model
Most of our existence is here

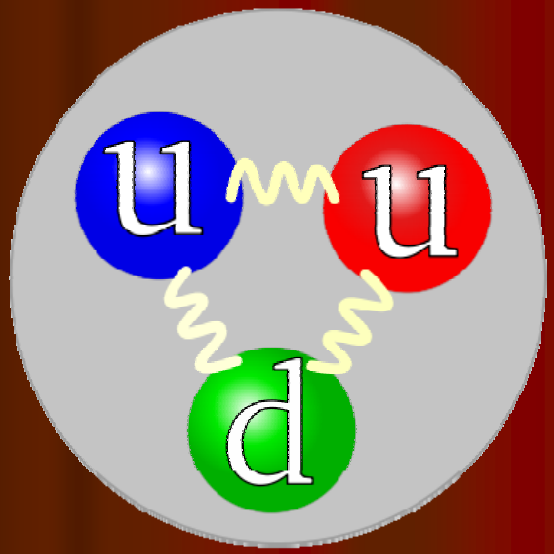


electrons
give us chemistry!
people, elements

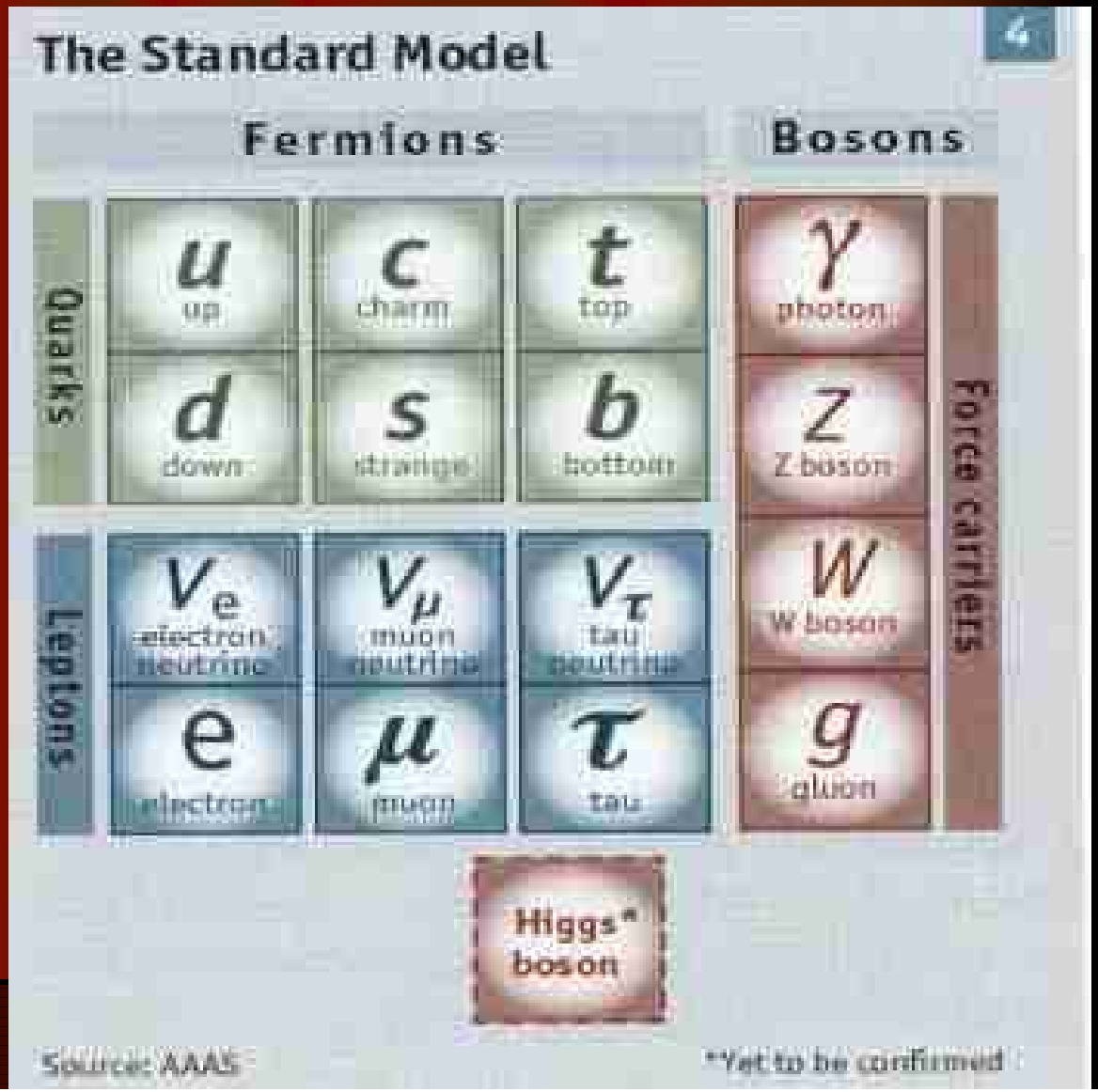
Fundamental?

protons and neutrons
give us nuclear physics, energy, stars,...

In our class we will spend most of our time here



Proton

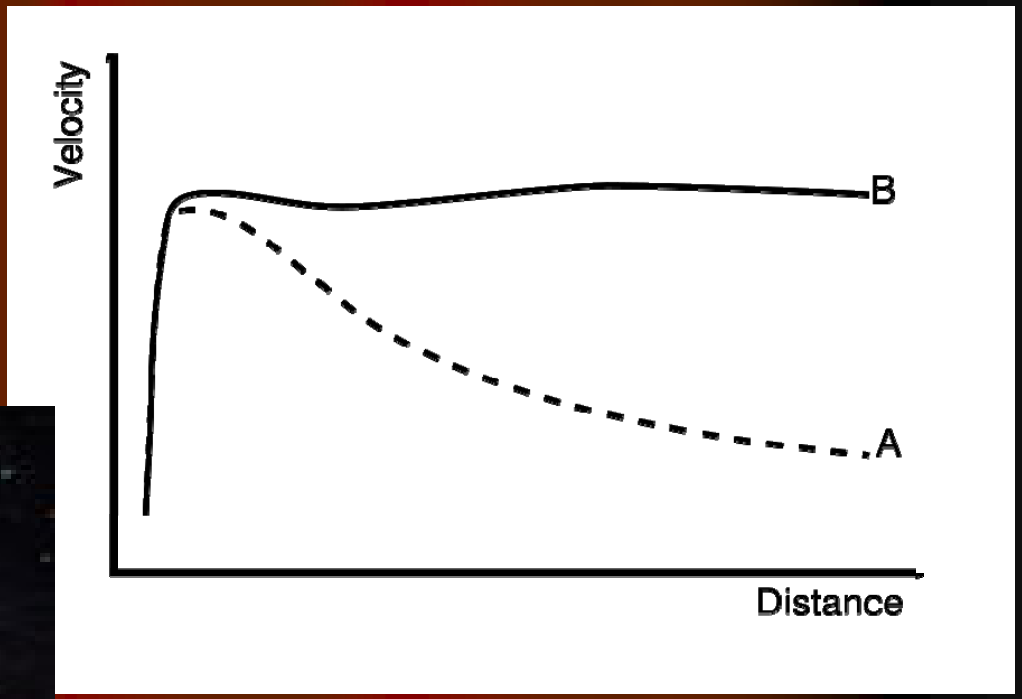


Is this all there is?
Is it fundamental

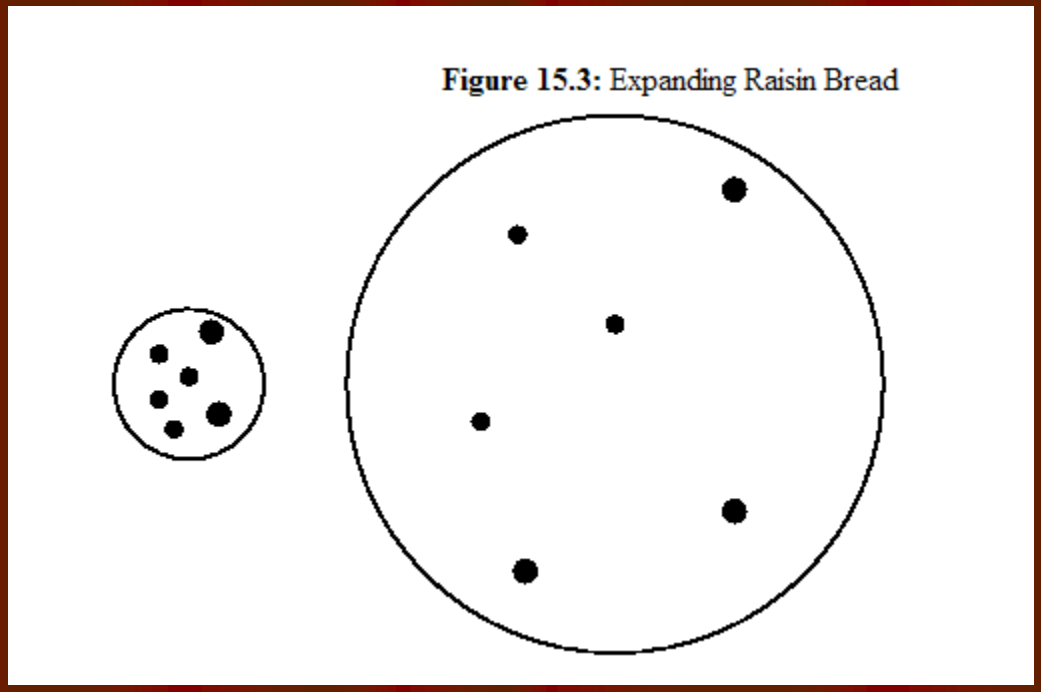
Standard Model

- Probably best tested Theory of all time.
- Drives physicists nuts
  - EVERYTHING WORKS
- Are we done?
  - Why are the masses what they are
    - e.g. why don’t you weigh twice what you do?
  - Why are the strengths of the interactions what they are
    - Why isn’t gravity 1% stronger?

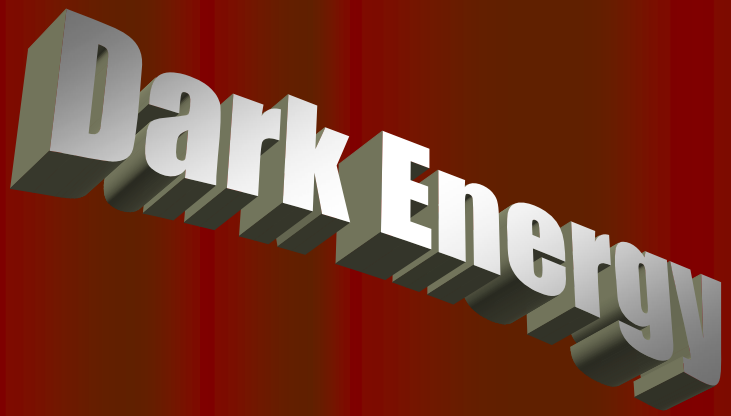
Problems... problems... problems...



Universe expansion is Accelerating!

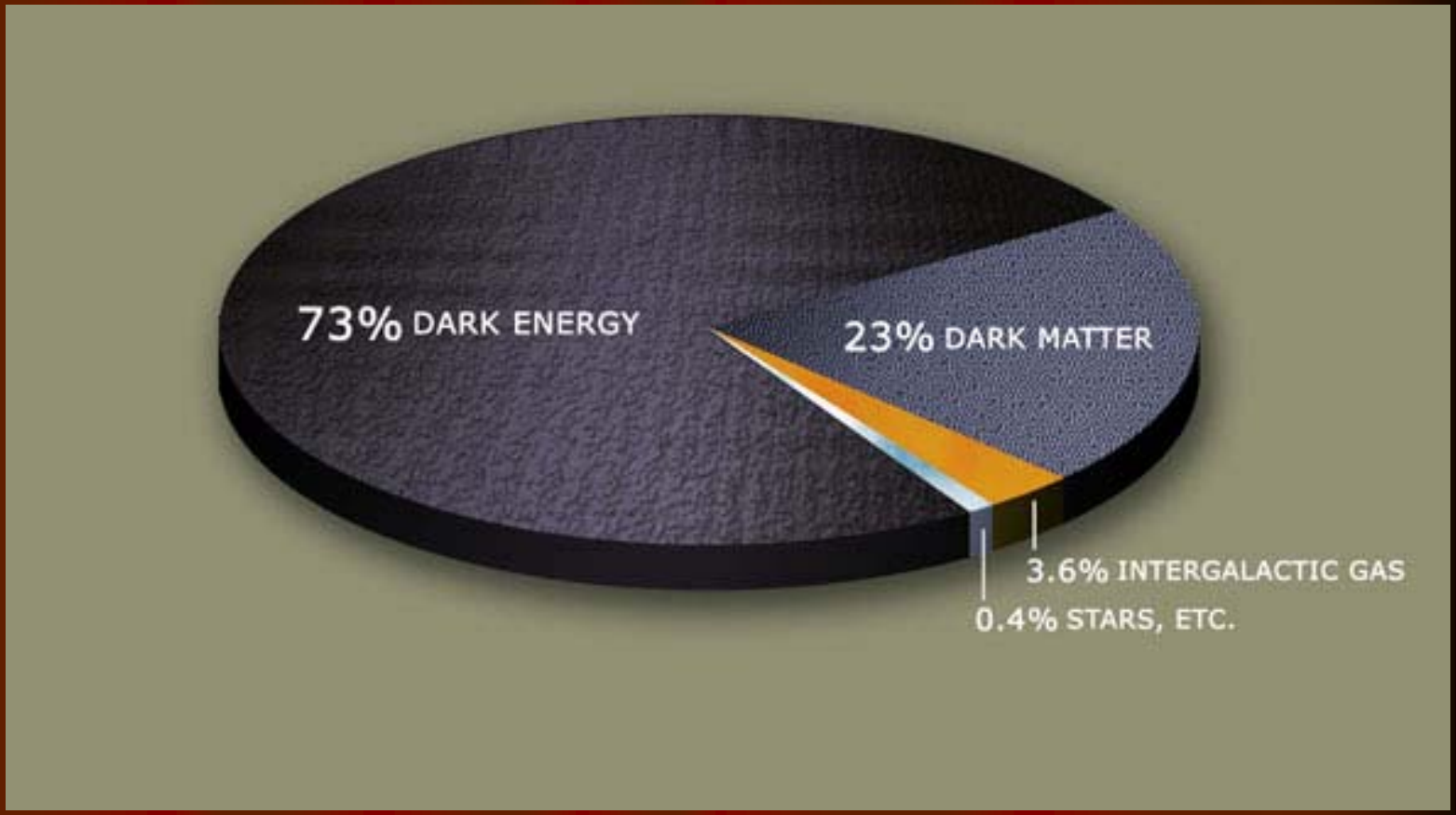


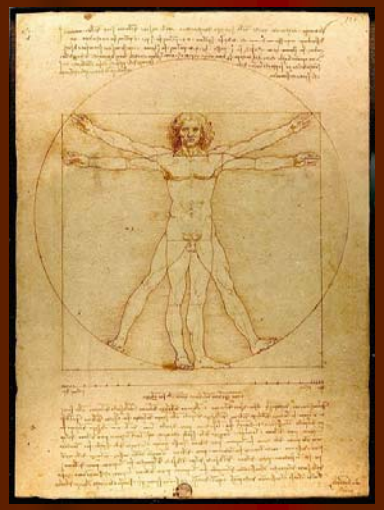
Why?



repulsive gravity (aka anti-gravity)
vacuum energy
  Note – a quick calculation from what we know gets this wrong by
    ~ 120 orders of magnitude
quintessence

What is the universe made of? Is that all there is?





Is that all there is?

Supersymmetry?

Wimp? Dark matter?

SM Particle type	Particle	Symbol	Spin	R-Parity	Superpartner	Symbol	Spin	R-parity
Fermions	Quark	q	$\frac{1}{2}$	+1	Squark	$\tilde{q}$	0	-1
	Lepton	ℓ	$\frac{1}{2}$	+1	Slepton	$\tilde{\ell}$	0	-1
Bosons	W	W	1	+1	Wino	$\tilde{W}$	$\frac{1}{2}$	-1
	B	B	1	+1	Bino	$\tilde{B}$	$\frac{1}{2}$	-1
	Gluon	g	1	+1	Gluino	$\tilde{g}$	$\frac{1}{2}$	-1
Higgs bosons	Higgs	h_u, h_d	0	+1	Higgsinos	$\tilde{h}_u, \tilde{h}_d$	$\frac{1}{2}$	-1

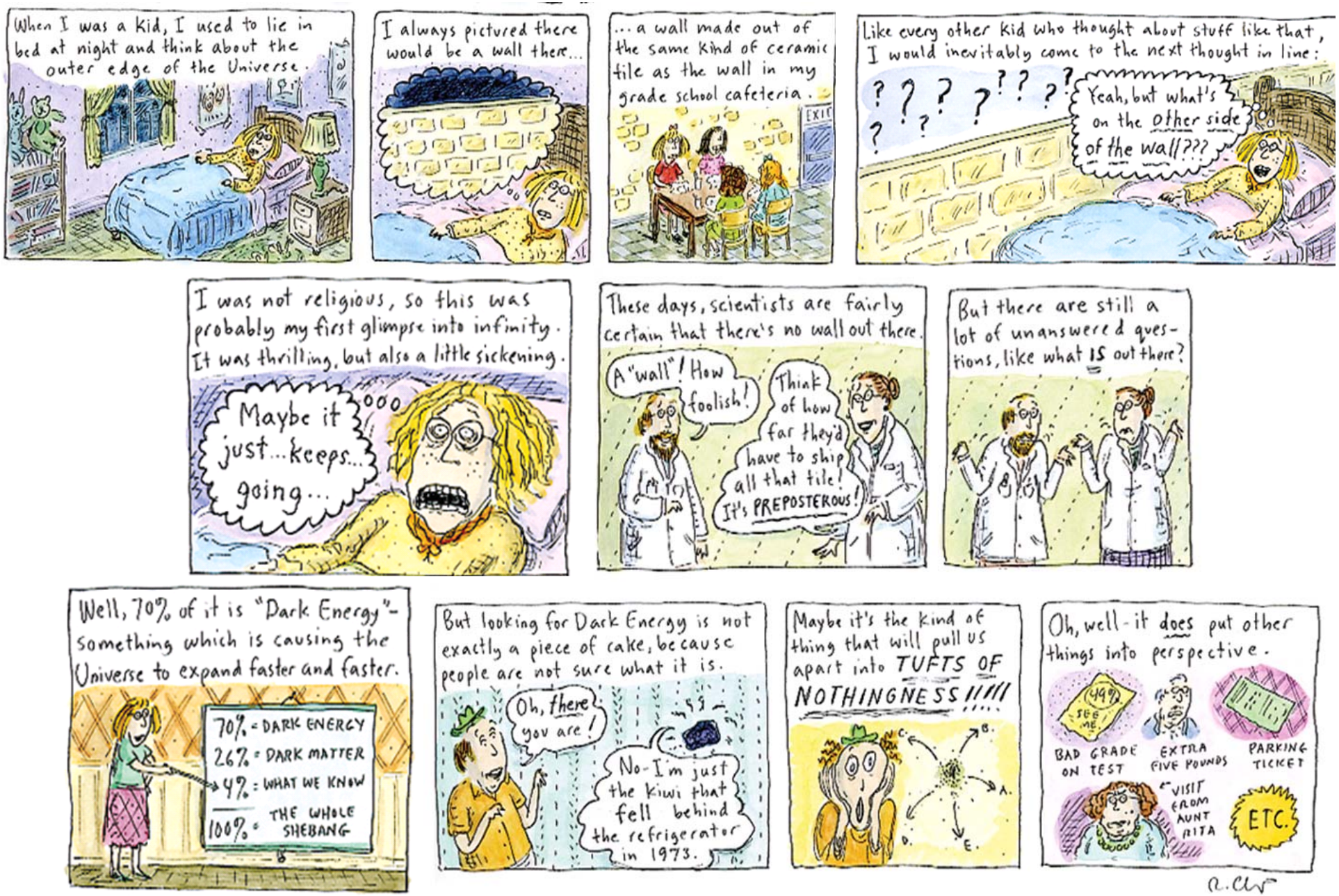
Is it fundamental??
In fact why do we want to work in only 4-D?

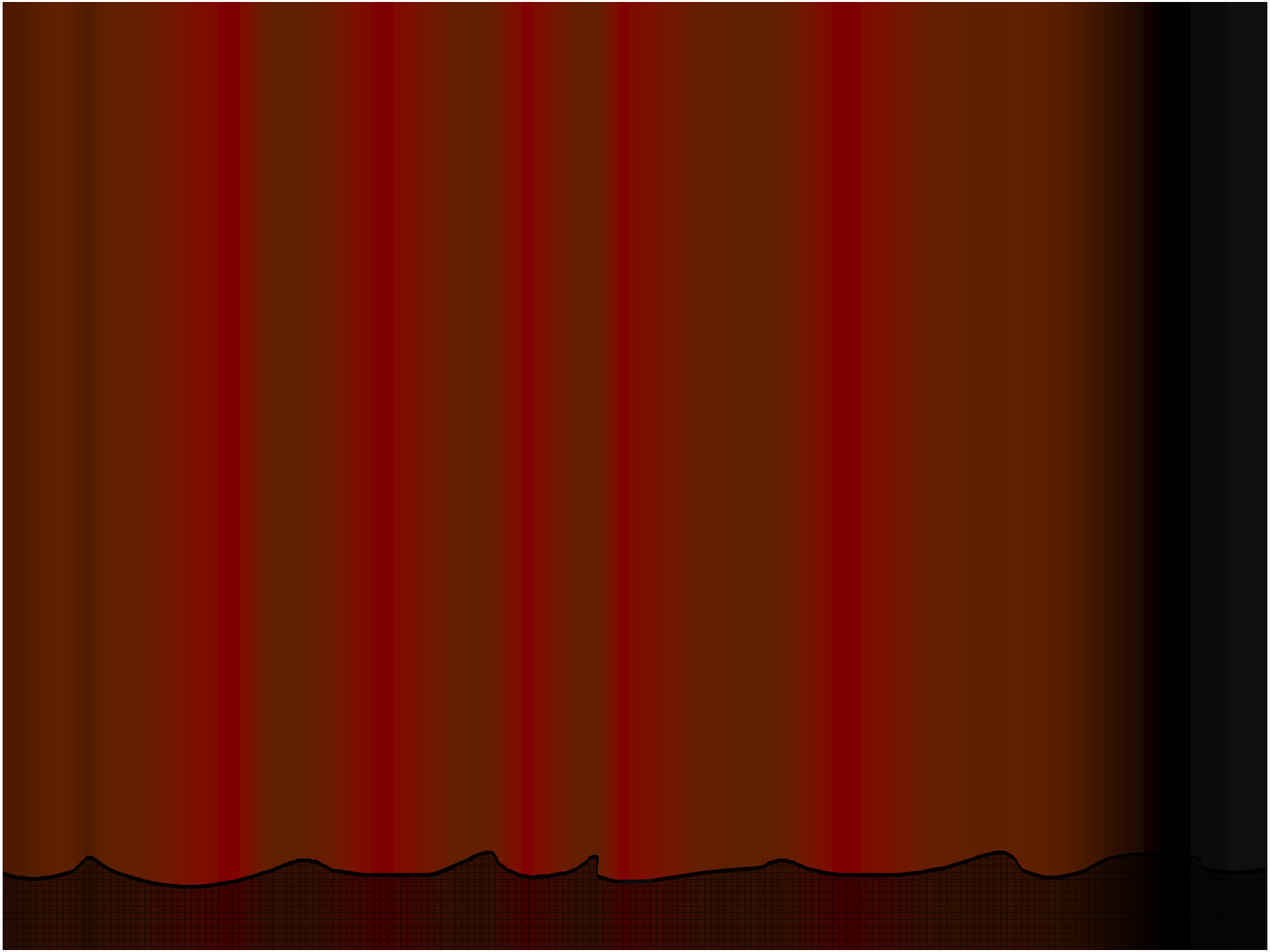
- Go to 11-D

Other questions

- why does time go forward? what defines forward in time?
- Why do we think symmetries govern everything?
- can we understand field theory/QM?
- Are the “fundamental” constants really fundamental or is it just like the direction of “down”
- Why are the fundamental constants where they are?
- Why are we here?

OVER THE EDGE

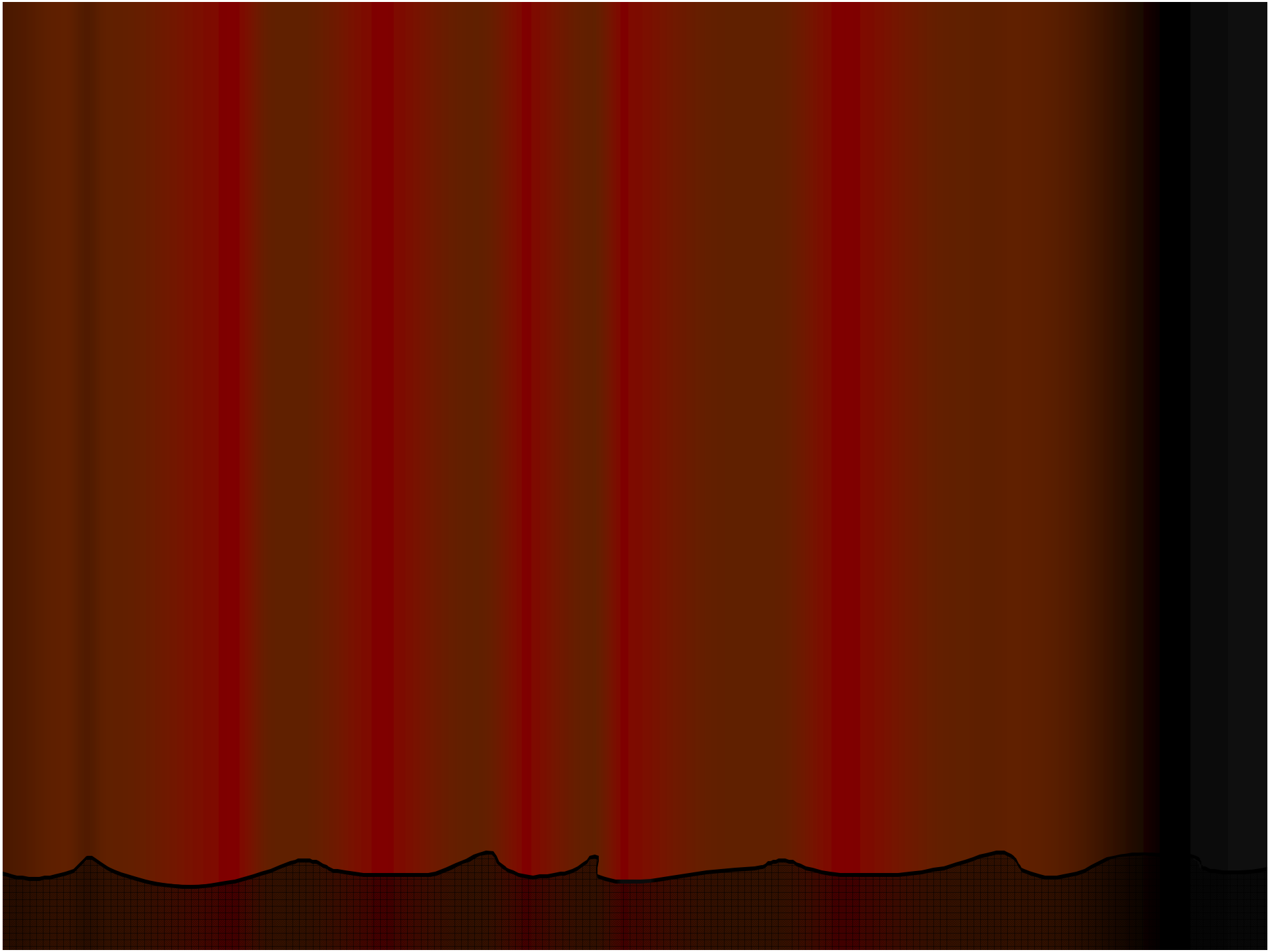


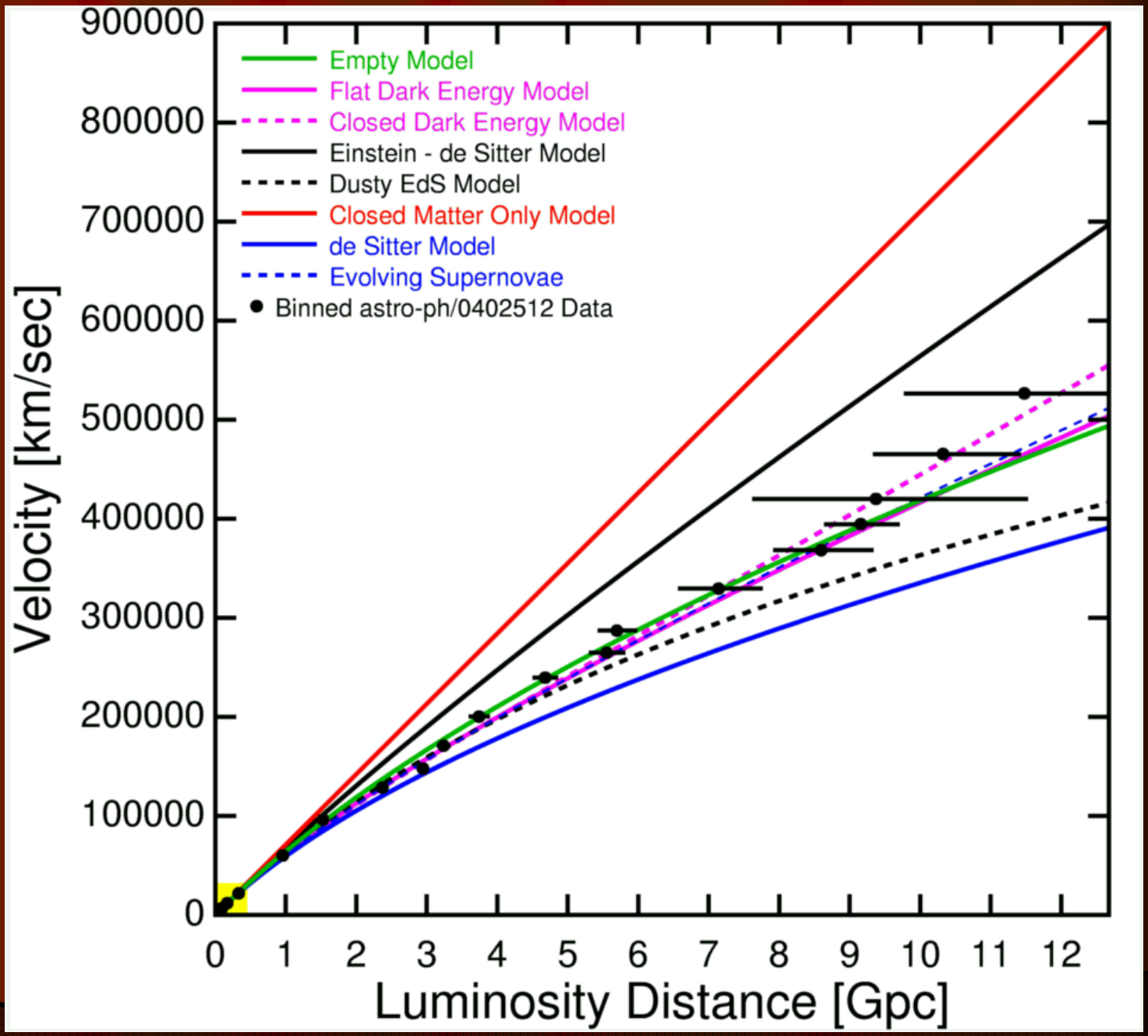



OVER THE EDGE
When I was a kid, I used to lie in bed at night and think about the outer edge of the Universe.
I always pictured there would be a wall there...
...a wall made out of the same kind of ceramic tile as the wall in my grade school cafeteria.
EXIT

The presentation and paper

- Pretend you are a researcher (actually – no need to pretend – you are!)
- Give a talk, write it up
- Purpose
  - Learn deeply about a topic
  - Teach your friends about it
  - Learn to prepare a presentation/write a paper
    - clarity
    - interest
- Format
  - you choose a topic – you see me to discuss it
  - a practice talk in class (We all interrupt, criticize etc)
  - A real talk in class (I keep my mouth shut – Students can ask questions)
    - use last several weeks+exam date
  - turn In paper during exam week




Empty Model
Flat Dark Energy Model
Closed Dark Energy Model
Einstein - de Sitter Model
Dusty EdS Model
Closed Matter Only Model
de Sitter Model
Evolving Supernovae
Binned astro-ph/0402512 Data
Velocity [km/sec]
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
0 1 2 3 4 5 6 7 8 9 10 11 12
Luminosity Distance [Gpc]

Particles

Leptons

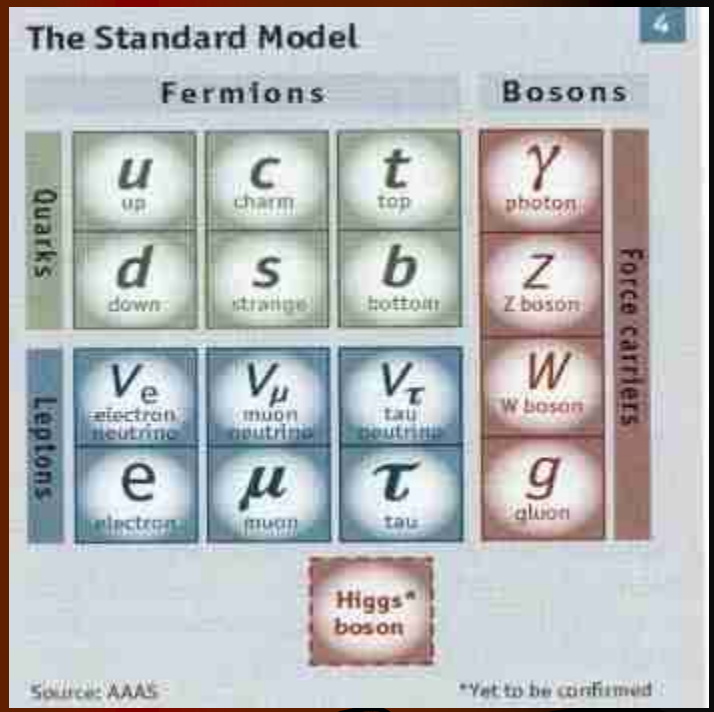
	Electric Charge		Electric Charge
Tau	-1	Tau Neutrino	0
Muon	-1	Muon Neutrino	0
Electron	-1	Electron Neutrino	0

Quarks

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

each quark: ●R, ●B, ●G 3 colors

The particle drawings are simple artistic representations



Standard Model of

FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model is a quantum theory that summarizes our current knowledge of the physics of fundamental particles and fundamental interactions (interactions are manifested by forces and by decay rates of unstable particles).

FERMIONS matter constituents spin = 1/2, 3/2, 5/2, ...

Leptons spin =1/2

Flavor	Mass GeV/c^2	Electric charge
ν_L lightest neutrino*	$(0–0.13)\times10^{-9}$	0
e electron	0.000511	–1
ν_M middle neutrino*	$(0.009–0.13)\times10^{-9}$	0
μ muon	0.106	–1
ν_H heaviest neutrino*	$(0.04–0.14)\times10^{-9}$	0
τ tau	1.777	–1

Quarks spin =1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.002	2/3
d down	0.005	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	173	2/3
b bottom	4.2	–1/3

*See the neutrino paragraph below.

Spin is the intrinsic angular momentum of particles. Spin is given in units of ħ, which is the quantum unit of angular momentum where $\hbar = h/2\pi = 6.58\times10^{-25}$ GeV s $=1.05\times10^{-34}$ J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The energy unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c^2 (remember $E = mc^2$) where 1 GeV = 10^9 eV $=1.60\times10^{-10}$ joule. The mass of the proton is 0.938 GeV/c^2 = 1.67×10^{-27} kg.

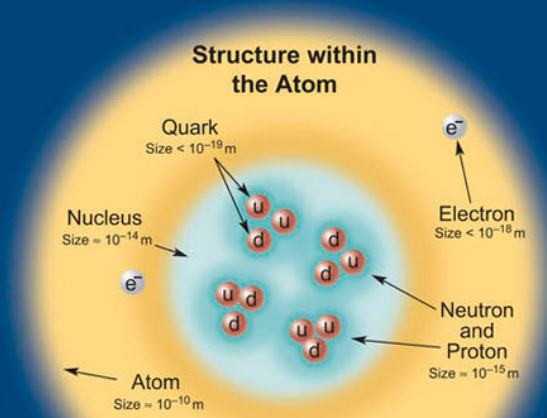
Neutrinos

Neutrinos are produced in the sun, supernovae, reactors, accelerator collisions, and many other processes. Any produced neutrino can be described as one of three neutrino flavor states ν_e, ν_μ, or ν_τ, labelled by the type of charged lepton associated with its production. Each is a defined quantum mixture of the three definite mass neutrinos ν_L, ν_M, and ν_H for which currently allowed mass ranges are shown in the table. Further exploration of the properties of neutrinos may yield powerful clues to puzzles about matter and antimatter and the evolution of stars and galaxy structures.

Matter and Antimatter

For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or – charge is shown). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0, γ, and $\eta_c = c\bar{c}$ but not $K^0 = d\bar{s}$) are their own antiparticles.

Structure within the Atom



If the proton and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

BOSONS force carriers spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.39	–1
W^+ W bosons	80.39	+1
Z^0 Z boson	91.188	0

Strong (color) spin =1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Color Charge

Only quarks and gluons carry "strong charge" (also called "color charge") and can have strong interactions. Each quark carries three types of color charge. These charges have nothing to do with the colors of visible light. Just as electrically-charged particles interact by exchanging photons, in strong interactions, color-charged particles interact by exchanging gluons.

Quarks Confined in Mesons and Baryons

Quarks and gluons cannot be isolated – they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs. The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge.

Two types of hadrons have been observed in nature **mesons** $q\bar{q}$ and **baryons** qqq. Among the many types of baryons observed are the proton (uud), antiproton ($\bar{u}\bar{u}\bar{d}$), neutron (udd), lambda Λ (uds), and omega Ω^- (sss). Quark charges add in such a way as to make the proton have charge 1 and the neutron charge 0. Among the many types of mesons are the pion π^+ ($u\bar{d}$), kaon K^- ($s\bar{u}$), B^0 ($d\bar{b}$), and η_C ($c\bar{c}$). Their charges are +1, –1, 0, 0 respectively.

Properties of the Interactions

The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

Property	Gravitational Interaction	Weak Interaction (Electroweak)	Electromagnetic Interaction	Strong Interaction
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge
Particles experiencing:	All	Quarks, Leptons	Electrically Charged	Quarks, Gluons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons
Strength at 10^{-18} m	10^{-41}	0.8	1	25
Strength at 3×10^{-17} m	10^{-41}	10^{-4}	1	60

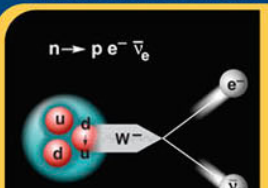
Visit the award-winning web feature *The Particle Adventure* at

ParticleAdventure.org

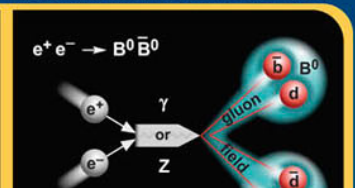
This chart has been made possible by the generous support of:
U.S. Department of Energy
U.S. National Science Foundation
Lawrence Berkeley National Laboratory

Particle Processes

These diagrams are an artist's conception. Blue-green shaded areas represent the cloud of gluons.



A free neutron (udd) decays to a proton (uud), an electron, and an antineutrino via a virtual (mediating) W boson. This is neutron β (beta) decay.



An electron and positron (antielectron) colliding at high energy can annihilate to produce $\bar{B}^0$ and B^0 mesons via a virtual Z boson or a virtual photon.

Unsolved Mysteries

Driven by new puzzles in our understanding of the physical world, particle physicists are following paths to new wonders and startling discoveries. Experiments may even find extra dimensions of space, mini-black holes, and/or evidence of string theory.

Universe Accelerating?

The expansion of the universe appears to be accelerating. Is this due to Einstein's Cosmological Constant? If not, will experiments reveal a new force of nature or even extra (hidden) dimensions of space?

Why No Antimatter?

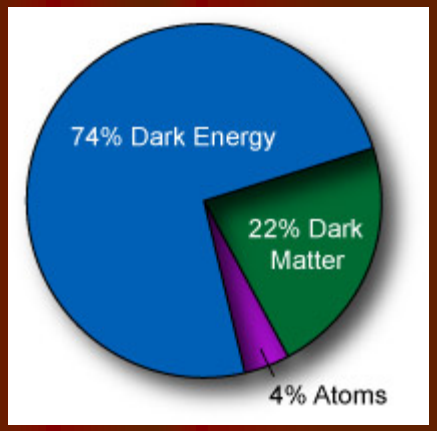
Matter and antimatter were created in the Big Bang. Why do we now see only matter except for the tiny amounts of antimatter that we make in the lab and observe in cosmic rays?

Dark Matter?

Invisible forms of matter make up much of the mass observed in galaxies and clusters of galaxies. Does this dark matter consist of new types of particles that interact very weakly with ordinary matter?

Origin of Mass?

In the Standard Model, for fundamental particles to have masses, there must exist a particle called the Higgs boson. Will it be discovered soon? Is supersymmetry theory correct in predicting more than one type of Higgs?

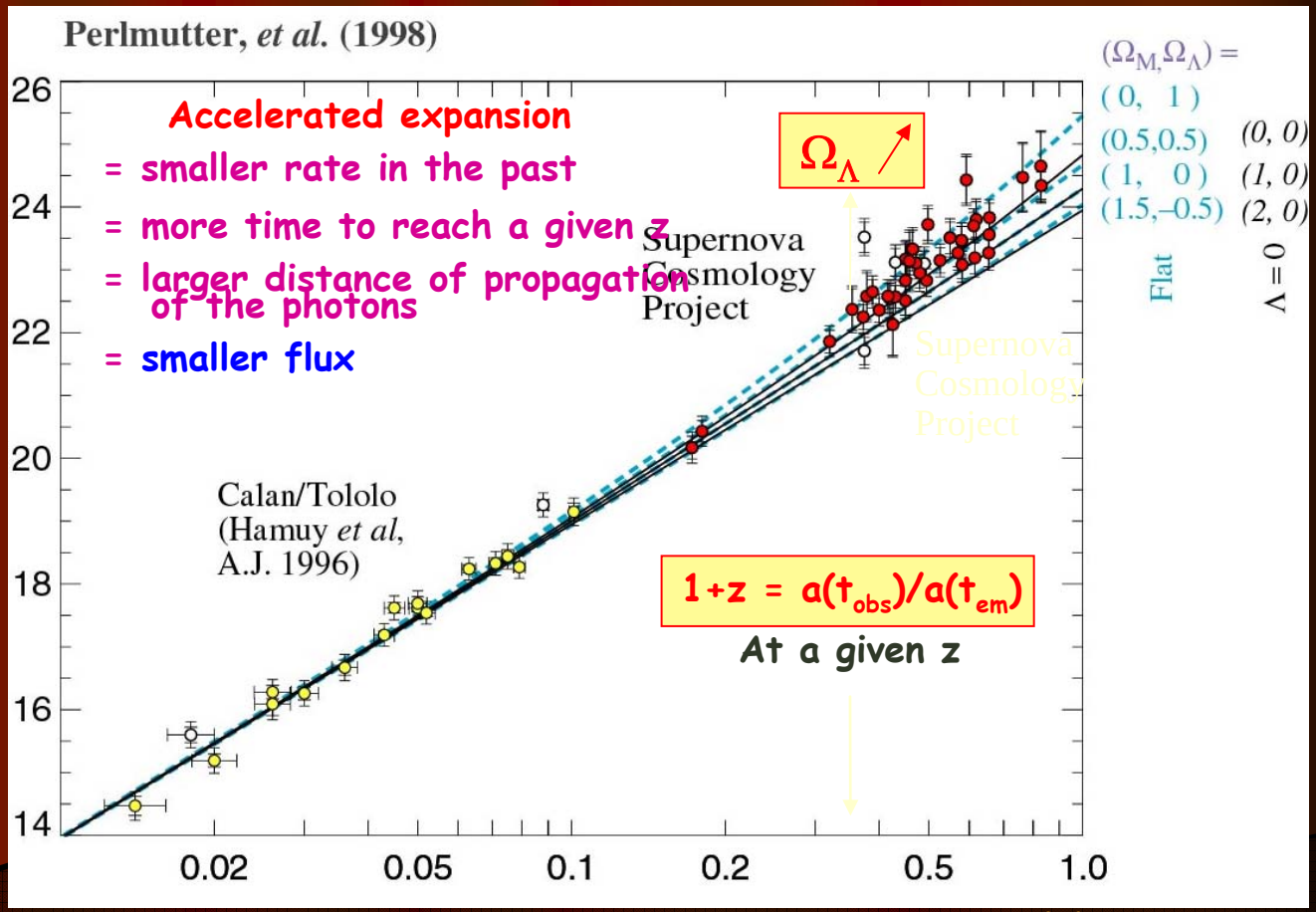

74% Dark Energy
22% Dark Matter
4% Atoms

Hubble diagram:

$m = -2.5 \log F + cst = 5 \log (H_0 D_L) + M - 5 \log H_0 + 25$

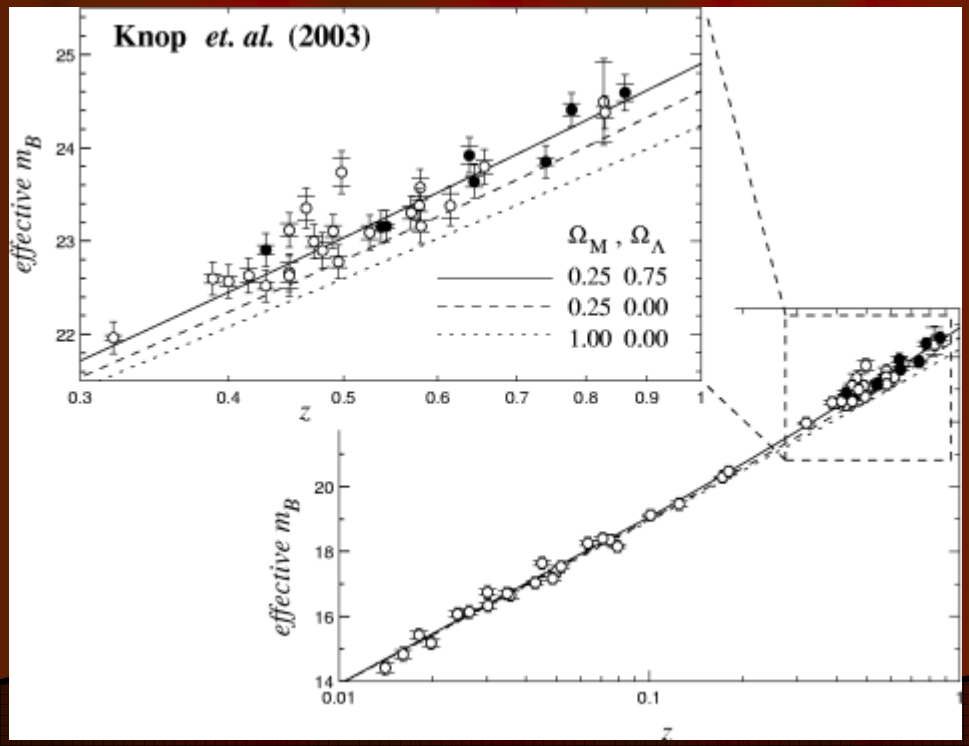
$H_0 D_L \longrightarrow cz$ (z → 0) ⟹ measure of H_0

Large z : measure of Ω_m, Ω_Λ



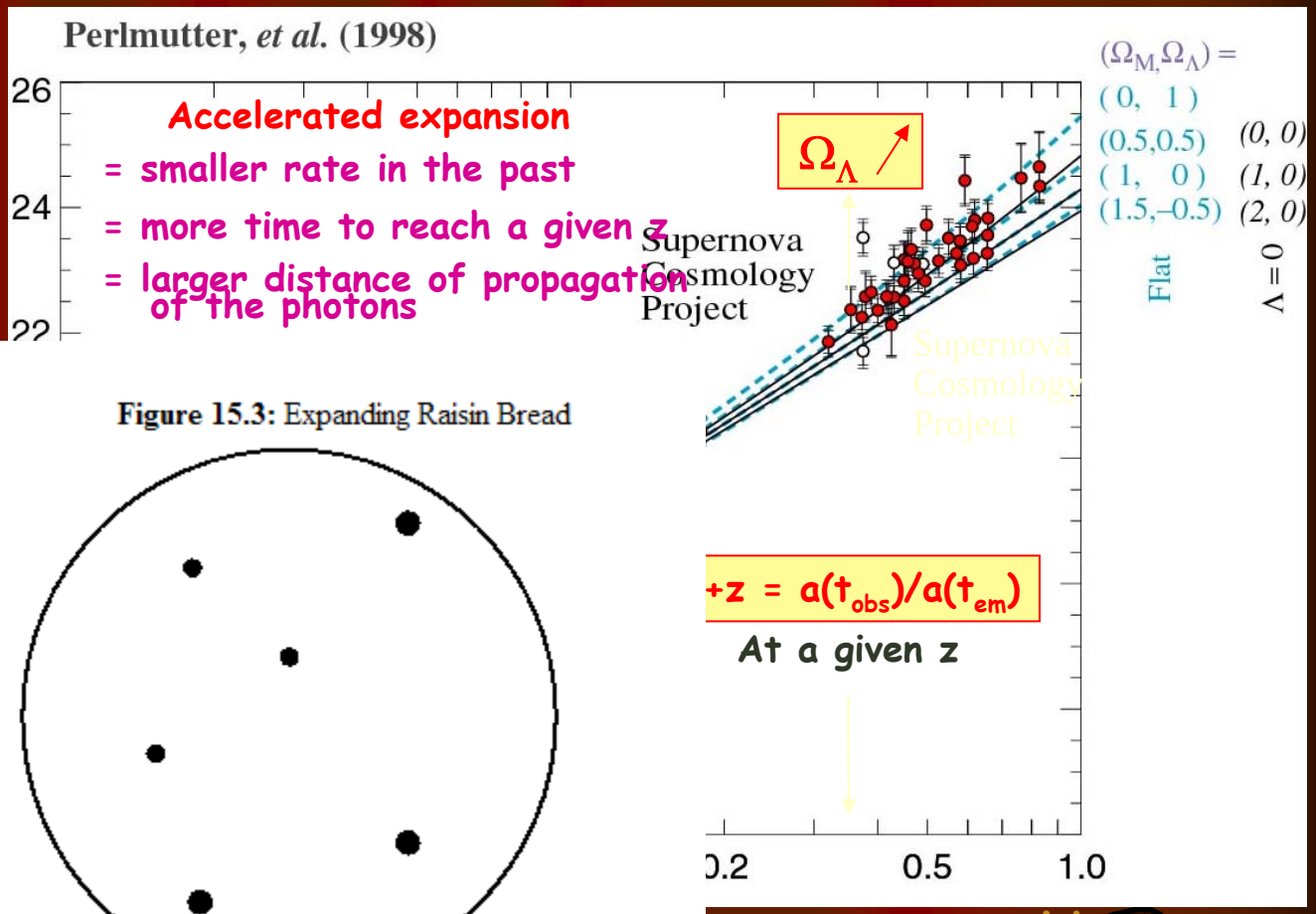
Magnitude m → fainter

Redshift z → older


Knop et. al. (2003)
effective m_B
z
Ω_M , Ω_Λ
0.25 0.75
0.25 0.00
1.00 0.00

further away

fainter



older

Older, receding faster