Let's try to solve the puzzles together.
Thinking of Our Universe
How do we measure the content of the Universe?

We look at the oldest light which set out on its journey long before the Earth or even our galaxy existed.

This light forms the background of the Universe: Cosmic Microwave Background (CMB)

Measurement of this light tells us the story of the Universe.

CMB was emitted when the Universe was only 380,000 years old.
Today, I take you to the Dark Matter world.

The 23% is still unobserved in the laboratory. (This new matter can not be seen visually!) We call this Cold Dark Matter.
Existence of Dark Matter

We know the dark matter exist.

- Collision of the galaxies
- Rotation curves of the galaxies

Cosmic Collision of 2 Galaxy Clusters
splitting normal matter and dark matter apart

- Another Clear Evidence of Dark Matter – (8/21/06)

Ordinary Matter
(NASA’s Chandra X Observatory)

Dark Matter
(Gravitational Lensing)

Approximately the same size as the Milky Way
Old observation: Rotation Curves of the Galaxies

But we have a few clues. Let’s check what we know.

Dark Matter Sandwich

"I can’t tell you what’s in the dark matter sandwich. No one knows what’s in the dark matter sandwich."
What is Cold Dark Matter?

It’s Doesn’t Matter.
Right, it doesn’t shake hand with anyone easily. Two dark matter clusters (blue balls) are just passing each other.

It’s a Cold Matter.
Yes, it is a “relativistically” slowly moving (“cold”) object.

It’s a Charge-less Matter.
Right, it doesn’t respond to your flash light. This means it is a neutral object.

So, It’s a Cold Dark Matter.
Right, it is a neutral and long-lived (stable) object.

Can it be one of the known particles?
Let’s check what we know.

Known Matter Particles

How many?
**12 Particle-Zoo Animals**

The 12 elementary particles are fundamental building blocks of matter.

All masses in MeV.
ANIMAL MASSES SCALE WITH PARTICLE MASSES

**4 Zoo Keepers**

- **g**'s (gluons) → strong force
  - Quarks experience them.
  - Protons & neutrons are stick together.

- **γ**'s (photons) → electromagnetic force
  - Quarks, leptons (other than neutrinos) experience this force.

- **W**'s (weak bosons) for weak forces
  - Quarks, leptons experience this force.

**NOTE**: Graviton (G) (∅ not found) carries gravitational force.
Exercise 1: “Weak” Reaction

Complete the decay diagram.

\[ d \rightarrow u + e + \nu \]

Exercise 1: Answer

Complete the decay diagram.

\[ d \rightarrow W + u \]
\[ W \rightarrow e + \nu \]
Exercise 2: “Weak” Reaction

Complete the decay diagram.

$t \rightarrow b \, e \, \nu$

Theory of Unification

All reactions are explained by a single description (= theory).
[100 points] The Standard Model describes all these particles and 3 of 4 forces by paring two elementary particles. We have confirmed the existence of those in the laboratory experiments. Choose a candidate for the Dark Matter particle. Explain why.

Solutions for Exam 1

Quarks, electron, muon, tau particles, and force carriers can not be the dark matter, since their interactions are stronger than what we expect.

Neutrinos can, but they have other problems.

We need a new model.
**New Idea**

We need an idea, based on a new symmetry.

*Supersymmetry* or *SUSY*

**Supersymmetrizing the Standard Model**

*Neutal-ino*

This new charge-less (neutral) particle is the leading candidate for the dark matter.

1) What is the new model?
2) Attractive?
3) Can the neutralino be detected and consistent with the dark matter content of the Universe?
Supersymmetric Reflection

But, one of them is neutralino. This is the lightest SUSY particle and stable.

Lots of new particles!!!

Exam 2: The “SUSY Model”

Complete the decay diagram. Hint: The decay of any SUSY particle ends with the Standard Model particle decay plus a lightest neutralino (neutral and long-lived) by keeping the SUSY nature. Namely,

\[ t_{\text{SUSY}} \rightarrow W_{\text{SUSY}} + b \]
\[ W_{\text{SUSY}} \rightarrow \chi_{\text{SUSY}} + e \nu \]

Compared to:

\[ t \rightarrow W + b \]
\[ W \rightarrow e \nu \]
Solutions for Exam 2

The SUSY nature will be preserved through the entire decay chain. We graphically show this by yellow lines from the beginning to the ending.

Attractive?

YES. Physicists always dream about unification of all the forces.

We can construct a SUSY model with a stable neutralino to have the grand unification of the forces.
When Were the Dark Matter Particles Created?

Now

~380,000 years CMB

~0.0000001 seconds

Thinking of Dark Matter Detection

My Universe
How Can We See Them in the Lab?

One type of experiment: in deep underground

(*) The TAMU group is one of leading institutions in the US.

Fruit Smasher

One promising way: In collisions

(*) The TAMU group is one of leading institutions in the US.
Particle Smasher

One promising way: In particle collisions

➔ Tevatron and Large Hadron Collider

Physics Magic: Ping-pong balls → Steel Balls

\[ E = mc^2 \]

Proton and antiproton collision can produce the Standard Model particles like heavy top quarks (~180 times heavier than a proton!)
Proton ($p$) and Antiproton ($\bar{p}$) at Tevatron

**Top Discovery**

[Tevatron] proton and anti-proton collide and produce the Standard Model particles as well as New Particles. In 1995, the CDF(*) and D0 collaborations co-discovered the top quark in ~4 trillion (4,000,000,000,000) collisions.

**Q** We have 100 trillion collisions today. Can the Tevatron produce the neutralinos?

**A** May not ☹️

[The neutralinos can be heavier. See the next slide.]

(*) The TAMU group is one of charter members of the CDF collaboration.
The SUSY grand unification is possible if the neutralino mass is 100~500 times heavier than the proton mass.

The LHC at CERN, scheduled for the first proton-proton collisions in 2007 in Switzerland, will have the smashing power of 14 Tera electron Volts (14,000,000,000 eV) - far larger than any other machine ever built.

Two experimental groups, called ATLAS and CMS\(^*\), will record the first collisions by the end of 2007.

\(^*\) The TAMU group is a member of the CMS collaboration.
Collisions as We Imagine …

We study blue and red dots and yellow lines to figure out what happens in the collision!

Wanted Young Sherlock Holmes

Here is one of the key reactions to discover the neutralinos at the LHC

We have to extract this reaction out of many trillion pp collisions.
How do you know that the neutralinos (we will observe) at the collider are responsible for the dark matter content?

We measure the masses \((m)\) of the particles at the LHC.

We calculate the dark matter content \((\Omega)\) in the new model of the Universe.

\[
\Omega = x(m) \times y / z + g \times h(m) - p(m) / q + r(m) \times 45 / 100 + 60 \times u_r(m) \times t_v + d \times s(m) + j(m) \times p(m) = 0.23
\]

March 24, 2007 Dark Puzzles of the Universe

Conclusion

So far in the laboratories we have seen the particles responsible for 4% of the universe.

The upcoming experiments will try to probe the nature of 23% of the universe: dark matter.

Challenge:

73% of the universe is still a major puzzle. Not yet understood theoretically!
So far in the laboratories we have seen the particles responsible for 4% of the universe.

The upcoming experiments will try to probe the nature of 23% of the universe: dark matter.

73% of the universe is still a major puzzle. Not yet understood theoretically!

Conclusion

TO HELP SOLVE THE PUZZLE OF THE UNIVERSE.

Any Questions?