

# What is the Universe Made of?

## •Materials

Magnetic Car and track set up with two weights and several thin boards

## •Introduction

### Protons, Neutrons and Electrons: The Stuff of Life

You, this computer, the air we breathe, and the distant **stars** are all made up of protons, neutrons and electrons. Protons and neutrons are bound together into nuclei and atoms are nuclei surrounded by a full complement of electrons. Hydrogen is composed of one proton and one electron. Helium is composed of two protons, two neutrons and two electrons. Carbon is composed of six protons, six neutrons and six electrons. Heavier elements, such as iron, lead and uranium, contain even larger numbers of protons, neutrons and electrons. Astronomers like to call all material made up of protons, neutrons and electrons "**baryonic matter**".

Until about twenty years ago, astronomers thought that the universe was composed almost entirely of this "baryonic matter", ordinary stuff. However, in the past decade, there has been ever more evidence accumulating that suggests there is something in the universe that we can not see, perhaps some new form of matter.

### The Dark Matter Mystery

By measuring the motions of stars and gas, astronomers can "weigh" galaxies. In our own solar system, we can use the velocity of the Earth around the Sun to measure the Sun's mass. The Earth moves around the Sun at 30 kilometers per second (roughly sixty thousand miles per hour). If the Sun were four times more massive, then the Earth would need to move around the Sun at 60 kilometers per second in order for it to stay on its orbit. The Sun moves around the **Milky Way** at 225 kilometers per second. We can use this velocity (and the velocity of other stars) to measure the mass of our Galaxy. Similarly, radio and optical observations of gas and stars in distant galaxies enable astronomers to determine the distribution of mass

in these systems.

The mass that astronomers infer for galaxies including our own is roughly ten times larger than the mass that can be associated with stars, gas and dust in a Galaxy. This mass discrepancy has been confirmed by observations of gravitational lensing, the bending of light predicted by Einstein's theory of general relativity.

### HST Image of a gravitational lens



By measuring how the background galaxies are distorted by the foreground cluster, astronomers can measure the mass in the cluster. The mass in the cluster is more than five times larger than the inferred mass in visible stars, gas and dust.

### Candidates for the Dark Matter

What is the nature of the "dark matter", this mysterious material that exerts a gravitational pull, but does not emit nor absorb light? Astronomers do not know.

There are a number of plausible speculations on the nature of the dark matter:

- **Brown Dwarfs:** if a **star's** mass is less than one twentieth of our Sun, its core is not hot enough to burn either hydrogen or deuterium, so it shines only by virtue of its gravitational contraction. These dim objects, intermediate between stars and planets, are not luminous enough to be directly detectable by our telescopes. Brown Dwarfs and similar objects have been nicknamed **MACHOs** (MASSive Compact Halo Objects) by astronomers. These MACHOs are potentially detectable by gravitational lensing experiments. If the dark matter is made mostly of MACHOs, then it is likely that baryonic matter does make up most of the mass of the universe.

- **Supermassive Black Holes:** these are thought to power distant **quasars**. Some astronomers speculate that there may be copious numbers of black holes comprising the dark matter. These

black holes are also potentially detectable through their lensing effects.

- New forms of matter: particle physicists, scientists who work to understand the fundamental forces of nature and the composition of matter, have speculated that there are new forces and new types of particles. One of the primary motivations for building “supercolliders” is to try to produce this matter in the laboratory. Since the universe was very dense and hot in the early moments following the **Big Bang**, the universe itself was a wonderful particle accelerator. Cosmologists speculate that the dark matter may be made of particles produced shortly after the Big Bang. These particles would be very different from ordinary baryonic matter. Cosmologists call these hypothetical particles WIMPs (for Weakly Interacting Massive Particles) or “non-baryonic matter”.

### WMAP and Dark Matter

By making accurate measurements of the **cosmic microwave background fluctuations**, WMAP is able to measure the basic parameters of the Big Bang model including the density and composition of the universe. WMAP measures the density of baryonic and non-baryonic matter to an accuracy of better than 5%. It is also able to determine some of the properties of the non-baryonic matter: the interactions of the non-baryonic matter with itself, its mass and its interactions with ordinary matter all affect the details of the cosmic microwave background fluctuation spectrum.

WMAP determined that the **universe is flat**, meaning it is neither open nor closed, but right between. A closed, or elliptical, universe experiences a continuous cycle of a Big Bang, expanding a finite amount, and falling back on itself. On the other hand, an open, or hyperbolic, universe will expand to infinity quickly. It takes a flat universe, as ours is, an infinite amount of time to extend to infinity. A universe will be elliptical, flat, or hyperbolic based upon its energy density. Remember, matter is energy:  $E=mc^2$ . Of the total energy density of the Universe, we now know the breakdown to be:

- \* 4% Atoms, 23% Cold Dark Matter, 73% Dark Energy. Thus 96% of the energy density in the universe is in a form that has never been directly detected in the laboratory. The actual density of atoms is equivalent to roughly 1 proton per 4 cubic meters.

- \* Fast moving neutrinos do not play any major role in the evolution of structure in the universe. They would have prevented the early clumping of gas in the universe, delaying the emergence of the first stars, in conflict with the new WMAP data.

- \* The data places new constraints on the Dark Energy. It seems more like a “cosmological constant” than a negative-pressure energy field called “quintessence”. But quintessence is not ruled out.

For more information about dark matter and dark energy, see the WMAP website:

<http://map.gsfc.nasa.gov/>

### •Procedure

In this lab, you will explore a model for the Universe where you can change the mass and “dark energy” of the system. The mass in the model corresponds to the mass of the Universe, both baryonic and non-baryonic. The incline of the track corresponds to the dark energy. Dark energy is the energy that is pushing the universe outward. As stated above, dark energy acts like negative pressure, like the air in the balloon in the *Expansion of the Universe* lab. Due to conservation of energy, we know that all of the Universes’ energy (atoms, cold dark matter, and dark energy) was present at the Big Bang. We refer to the energy which is expanding the Universe as “dark” because we have no idea what it is!

It is useful to think about dark energy in terms of anti-gravity. If there is a **great abundance** of dark energy in a universe, then the universe will be **open** - it will expand to infinity in less than an infinite amount of time. This is due to the great amount of energy pushing the matter outward. In a **closed** universe, the amount of dark energy is **small** enough that gravity will eventually take over, pulling the matter back together and creating another Big Bang. The situation directly in-between, a flat universe, has just the perfect amount of dark energy that the universe takes an infinite amount of time to expand to infinity. In our model, if the track the car runs on is at such an incline that the car **runs right past** a marked point, then the car/track universe is **open**. If the track has a greater incline and the car **stops before** the marked point, the universe is **closed** and will fall back on itself. If the car stops right at the mark, then the model universe is flat. You will also be able to change the mass of the car to see the effect

of mass on the model universe.

- 1) Designate someone on your team for each of the following jobs:
  - a. The car launcher. You will obtain more consistent results by having the same person launch the car each time.
  - b. The stopper. This person makes sure the car doesn't run off the end of the track.
  - c. The observer. The observer will call out the farthest reached position of the front of the car using the ruler on the track.
  - d. The recorder. This person will record each of the measurements in the chart below.
- 2) Start with the front of the car at a good number, like 200 cm. Record this value. Do this with no incline on the track and no weight in the car. Have the car launcher do a few practice launches so the technique is consistent. Make sure the car doesn't crash off the end of the track!
- 3) Once you have an idea of how far the car goes with no incline and no weight (this will be the farthest the car goes), decide on a reference mark somewhere between the starting value and the value of the farthest travel distance. The model car/track universe that has the exact amount of mass and incline to be "flat" will stop here. *Note: it will be tough to get the experiment exactly flat; you'll just get as close as you can. This is true of the actual Universe as well. As far as we can tell (5% accuracy), the Universe is flat. However, it is basically impossible for the Universe to be EXACTLY flat.*
- 4) Repeat each of the cases in the chart below five times and record the average in the chart. You will need to decide how much incline you need to try based upon your selected mark.

•Questions

- 1) True or False: In this model universe, a larger incline corresponds to more dark energy. Explain.
- 2) How much more dark energy is in *our* Universe as compared to energy from matter?
- 3) What does your answer to 2) say about the accuracy of the model?
- 4) What seemed to have a greater effect in the model, incline or mass?
- 5) What other aspects of the model are inaccurate?
- 6) Summarize what the model helped you learn about the composition of the Universe.

**For credit, each member of the team needs to turn in a copy of the filled-in chart and answers to the questions.**

mark = ____ cm	No incline	Incline 1, = ____ cm	Incline 2, = ____ cm	Incline 3, = ____ cm	Incline 4, = ____ cm	Incline 5, = ____ cm
no added mass blocks						
one added mass block						
two added mass blocks						