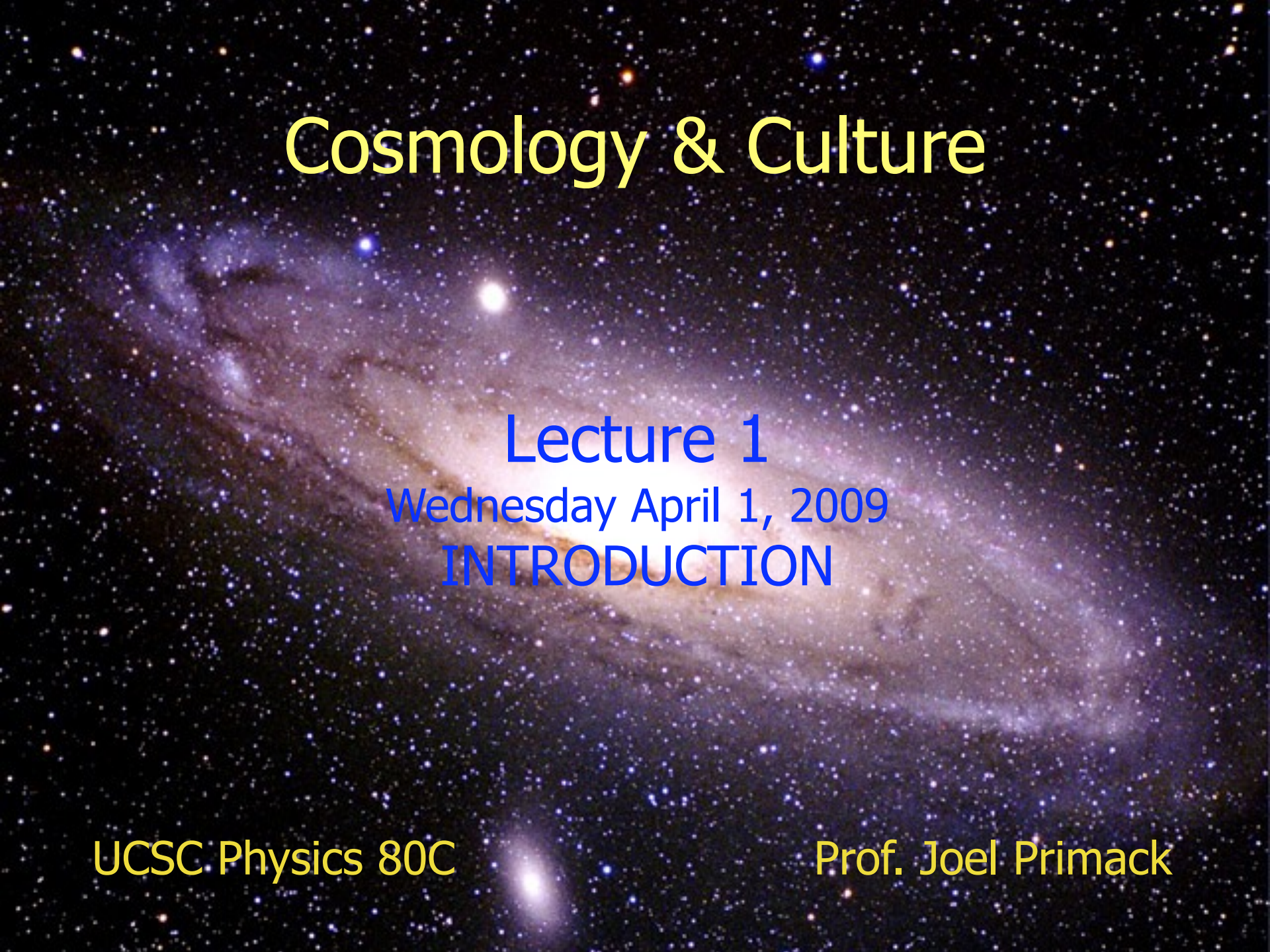


Cosmology & Culture

Lecture 1

Wednesday April 1, 2009

INTRODUCTION

UCSC Physics 80C

Prof. Joel Primack

What this course is about ...

Approaching the New Scientific Picture

What is the universe made of?

How did the universe evolve in time?

How big is it?

Where did it come from, and where is it going?

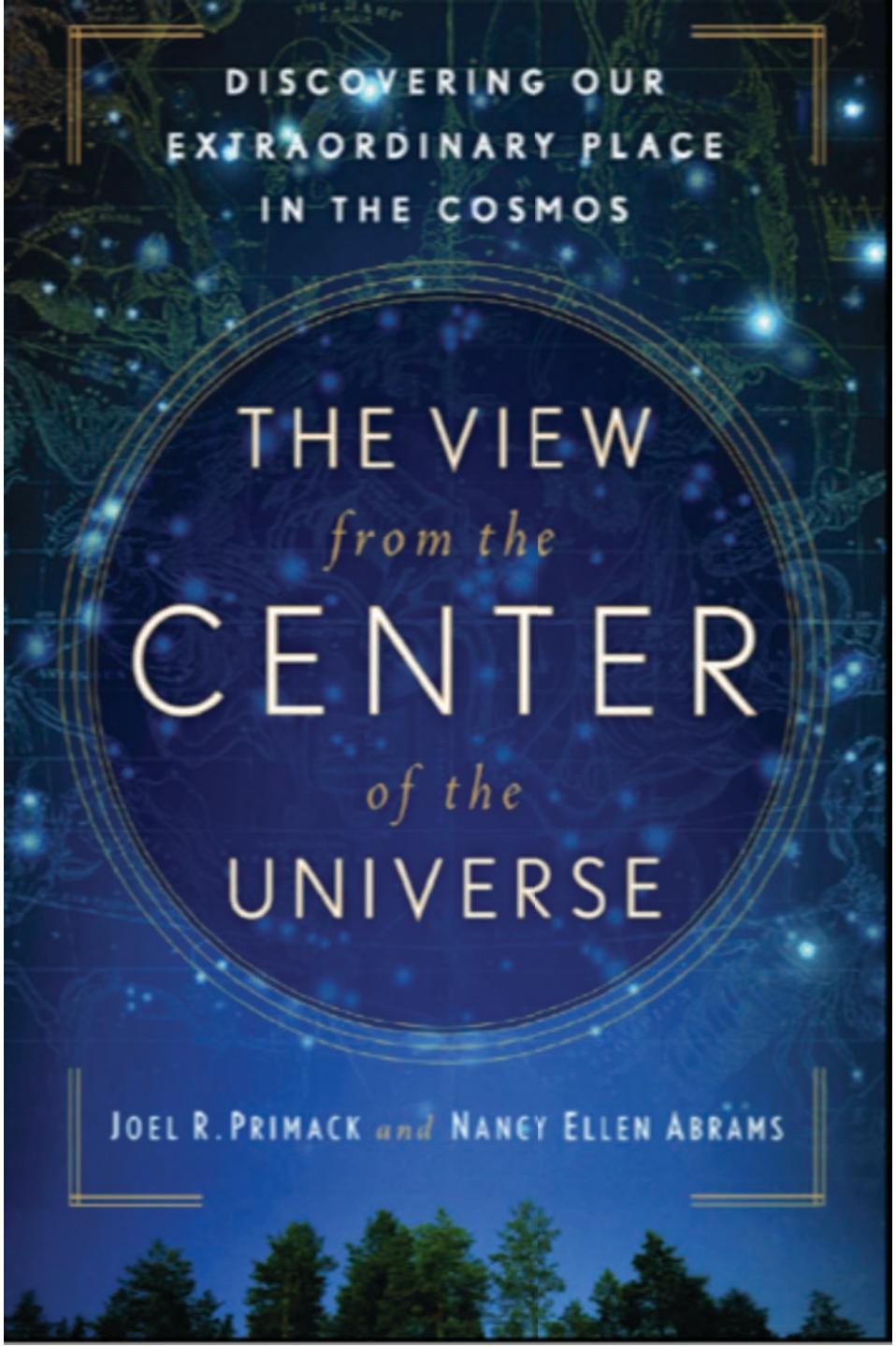
Are we alone?

Big Nonscientific Question

What difference does this all make to *me*?

Textbook for the course

This book grew out of our teaching this course at UCSC for the past decade.



It's available at Bay Tree Bookstore -- and possibly more cheaply at Amazon.com

The public is invited to discuss the book with Nancy and Joel at Bookshop Santa Cruz Thursday April 23 at 7:30 pm

TABLE OF CONTENTS

This book places the scientific meat at the center, sandwiched between the human past and human future. In the first part we look at how earlier cultures saw the universe and how their cosmologies shaped people's sense of what they were and could be. Ancient cosmologies created not only a meaningful mental homeland in the cosmos for their own members but also much of the mythological language, imagery, and questions that still matter today and that continue to inspire artists and thinkers. Although fascinating origin stories have been told around the world, here we focus on those cosmologies in the line of development toward Western scientific culture and on the two great cosmological revolutions that marked the shifts from one universe picture to another. In investigating these early cosmologies, we're looking for time-tested, powerful symbols and other forms of expression and inspiration that touched our ancestors but that also resonate with essential modern cosmological ideas. We will in later chapters reinterpret them in light of modern cosmology so that these new-ancient symbols can represent the mythic power of the new cosmology.

COSMOLOGY AND CULTURE

Physics 80C Spring 2009

1. We will have discussions of each week's readings in class. It is essential that you do the readings before class. Attendance will be taken at most classes.

2. There will be several in-class writing assignments and quizzes on the readings, and/or a quiz on the simple mathematics needed to discuss the wide range of sizes in the universe after we have covered this in class.

3. There will be an in-class, closed-book Midterm Exam on Wednesday May 13.

4. Groups of students will be required to submit proposals, due May 2, for a written or artistic class project or presentation. Some of these projects will be presented in the final class on June 3.

5. Keep an astronomy journal in which you write notes about the appearance of the night sky, especially the moon and planets, with the date and time of each observation. This journal will be due at the class on May 27, and returned at the last class.

6. On a clear moonless night we will have an optional Astronomy Night where we will observe the night sky with the naked eye, and with binoculars and telescopes.

Write your name at the top of a sheet of paper, and take 10 minutes to briefly answer the following questions

1. How do you picture the universe?

2. How do you see yourself fitting in?

3. Have your ideas about these things changed since you were a child? If so, how?

Purpose of this Course

To reveal something unknown to almost everyone, because

Some effort is required to understand it.

Not much has yet been written about it.

Its concepts have not yet been integrated into popular language.

Yet it is one of the most awesome and thought-provoking creations of our species.

At the beginning of the 20th century no human had the slightest idea what the universe really was like. Cosmology - the study of the whole universe - was more metaphysics than astrophysics. But by the beginning of the 21st century, cosmology had become a very successful science with an underlying theory that successfully predicts basic properties of the observable universe that are now being discovered.

To understand the revolutionary nature of the new cosmology, you'll have to learn basic concepts – General Relativity, the Big Bang, Cosmic Inflation, Dark Matter, Dark Energy. Fortunately, we can discuss them without mathematics beyond powers of ten.

Powers of 10: Scientific Notation

Useful in dealing with both LARGE and SMALL numbers.

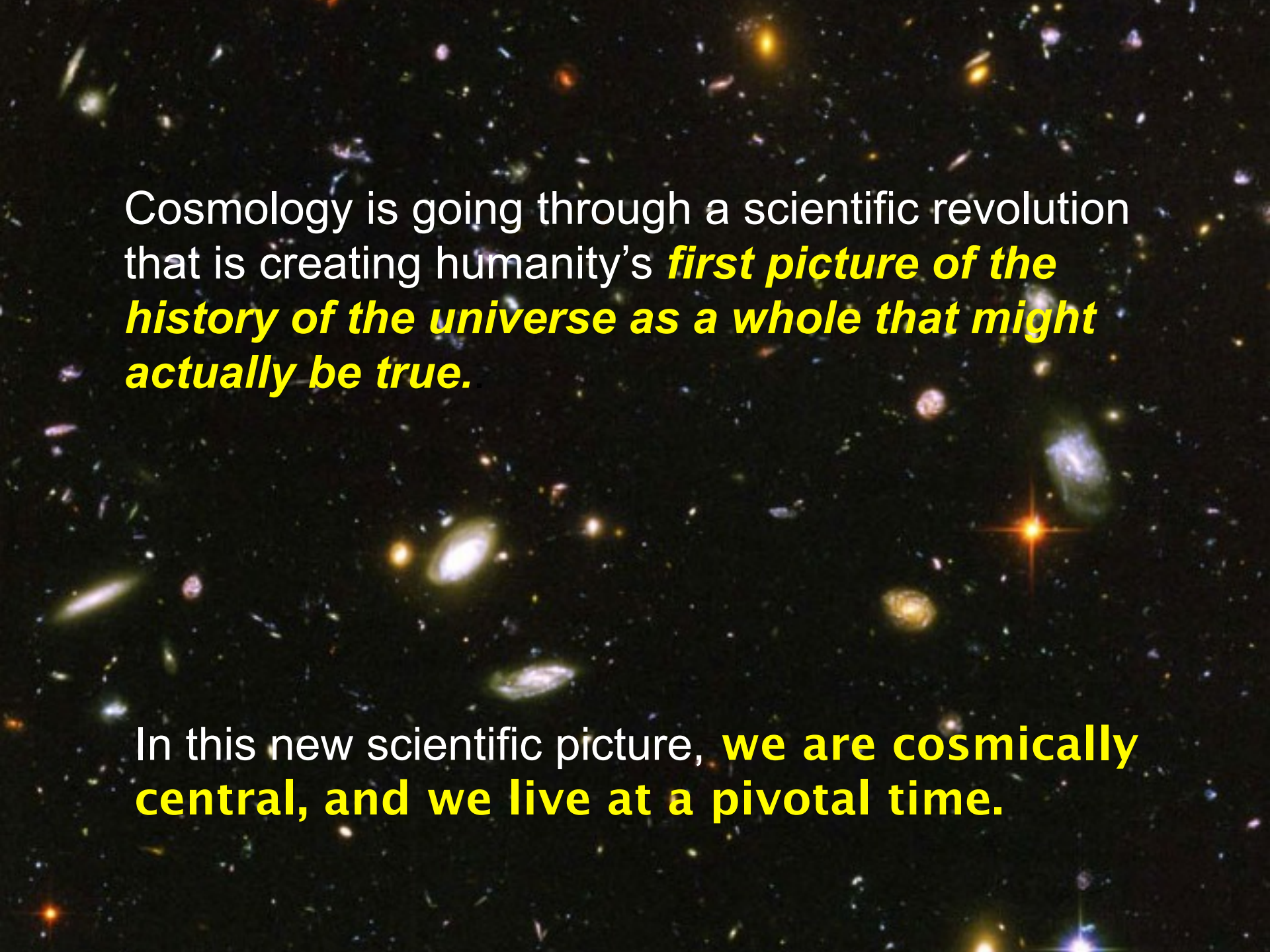
Examples: $200 = 2\times10^{2}$ $50{,}000 = 5\times10^{4}$ $0.003 = 3\times10^{-3}$

Bill Gates may want to use scientific notation in his banking:
\$40 billion = \$40,000,000,000 = $\$4\times10^{10}$

Multiplication: $10^{a} \times 10^{b} = 10^{(a+b)}$ $(2\times10^{2})\times(3\times10^{-3}) = 6\times10^{-1}$

light year = (speed of light)(length of year)
$= (3\times10^{10}\ \text{cm/s})(3.16\times10^{7}\ \text{s}) \approx 10^{18}\ \text{cm}$

size of a galaxy $\approx 10^{5}$ light years $= 10^{23}$ cm
$= 100{,}000{,}000{,}000{,}000{,}000{,}000{,}000$ cm



Cosmology is going through a scientific revolution that is creating humanity's ***first picture of the history of the universe as a whole that might actually be true.***

In this new scientific picture, **we are cosmically central, and we live at a pivotal time.**

Traditional cosmologies since ancient Egypt have taught that human actions uphold the order of the universe, and without humans performing those actions, the chaos that existed before the beginning would return – and that therefore you matter to the cosmos.

But reacting to the limited knowledge about the universe in the Newtonian cosmology, people have often thought that human beings are isolated individuals tossed into a cold, hostile universe, and there is no meaning or purpose except for what we can each create -- an existential view.

The new cosmology challenges this view!

Cosmology & Culture Syllabus

Week

1 **INTRODUCTION**

Part I COSMOLOGICAL REVOLUTIONS

1 **Chapter 1 Wrapping Your Mind Around the Universe**
2 **Chapter 2 From the Flat Earth to the Heavenly Spheres**
3 **Chapter 3 From the Center of the Universe to No Place Special**

Part II THE NEW SCIENTIFIC PICTURE OF THE UNIVERSE

4 **Chapter 4 What Is the Universe Made of?** ***The Cosmic Density Pyramid***
5 **Chapter 5 What Is the Center of the Universe?** ***The Cosmic Spheres of Time***
6 **Chapter 6 What Size is the Universe?** ***The Cosmic Uroboros***
7 **Chapter 7 Where Do We Come From?** ***The Cosmic Las Vegas***
8 **Chapter 8 Are We Alone?** ***The Possibility of Alien Wisdom***

Part III THE MEANINGFUL UNIVERSE

9{ **Chapter 9 Think Cosmically, Act Globally**
Chapter 10 Taking our Extraordinary Place in the Cosmos

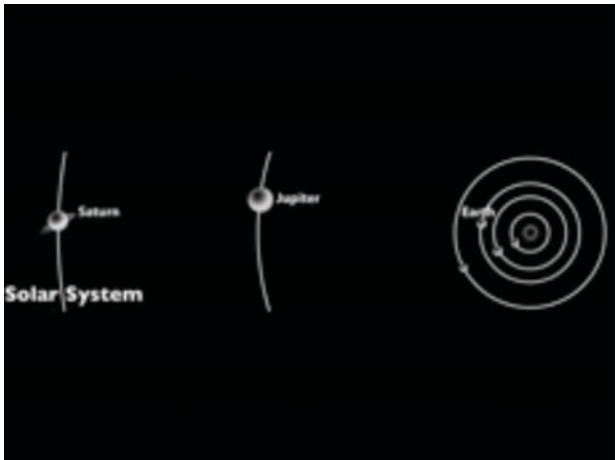
10 Reports on student projects & summary of course

Changing Cosmologies

Biblical

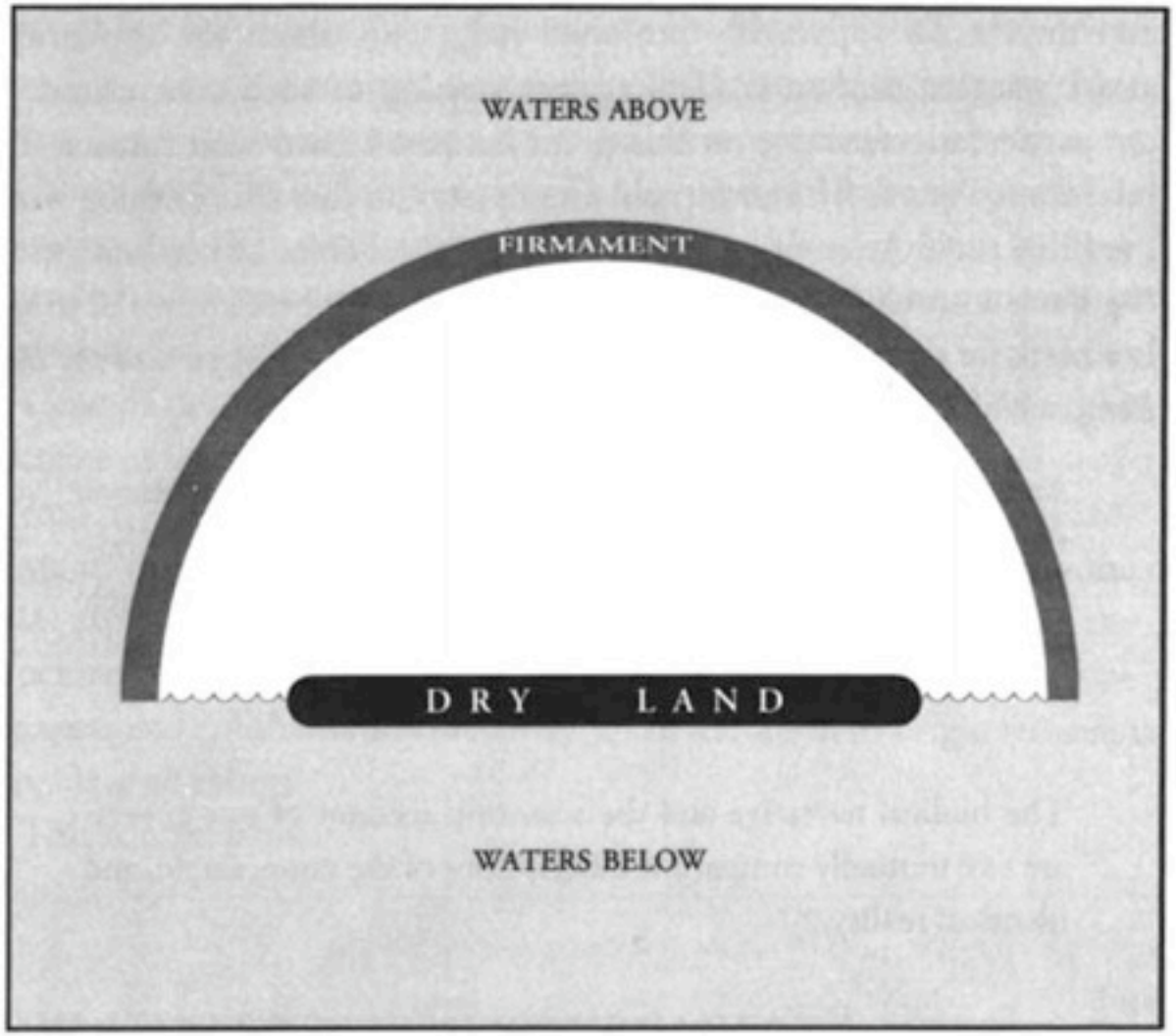
Greek/Medieval

Newtonian



Changing Cosmologies

Biblical



Changing Cosmologies

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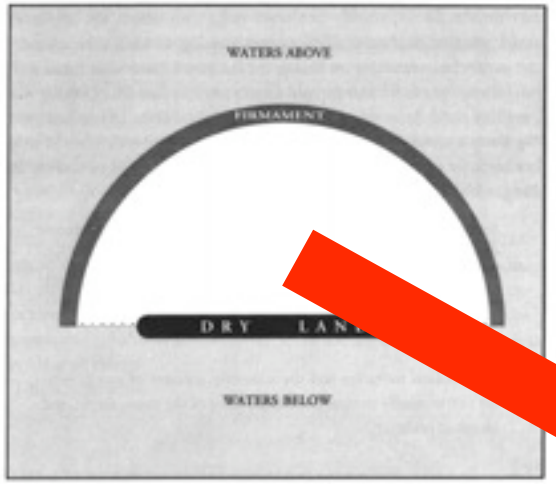
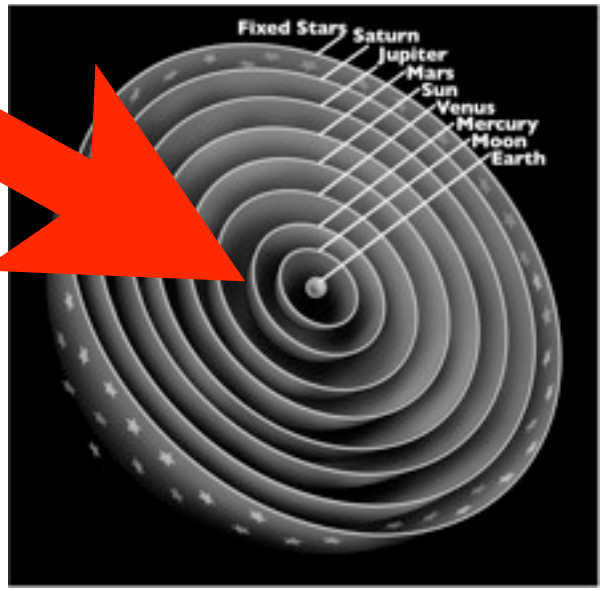
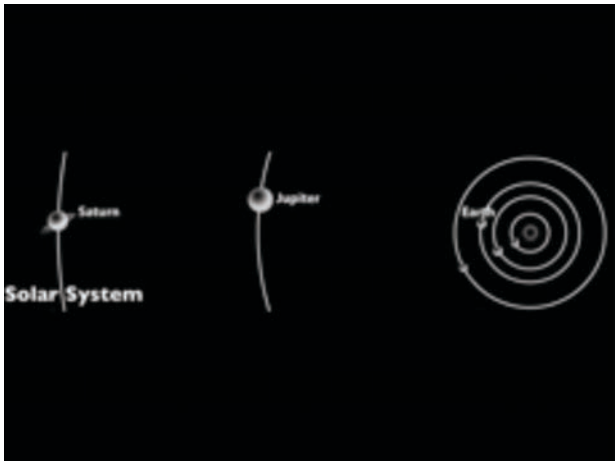


Greek/Medieval



Newtonian



Changing Cosmologies

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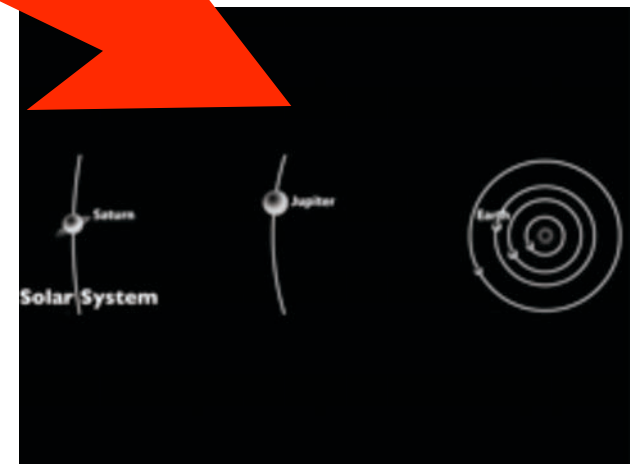
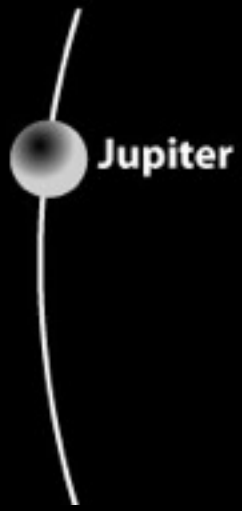
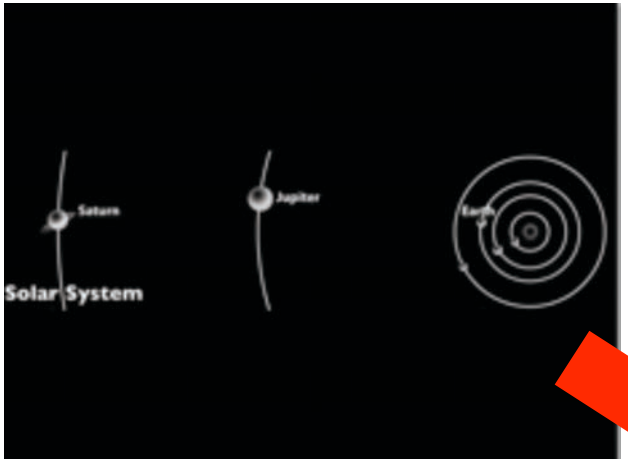


Changing Cosmologies

Newtonian



Changing Cosmologies



Changing Cosmologies

Size R Age T Center	Composition	Unifying Ideas	God's role?

Medieval Cosmos

Finite R Finite T Geocentric	Sublunary: Earth, Water, Air, Fire Heavens: Ether	Circular motion Great Chain of Being	Prime mover, Hierarch, Saviour

Newtonian Cosmos

Infinite R? Infinite T? No center	Atoms, Void Ether?	Deterministic mechanics Universal gravitation	Clockmaker

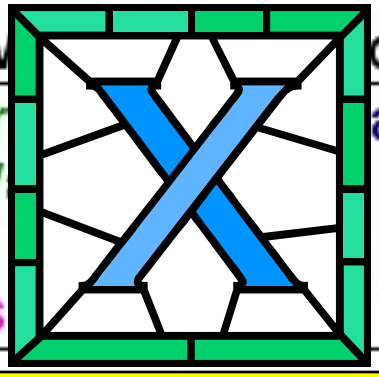
Modern Cosmos

R = 10^{28} cm T = 10^{10} yr Homogeneous & Isotropic	Atoms quarks, electrons Radiation Dark Matter Vacuum	Gravity = space curvature Nondeterministic quantum theory Evolution	Before the Big Bang? Immanent?

After the Copernican-Newtonian Revolution, the Medieval Cosmos was taught only as history, never again as scientific truth

M…os

Finite R Finite T Geocentric	Sublunar Earth, W… Air, Fire Heavens	…ar motion Chain of	Prime mover, Hierarch, Saviour

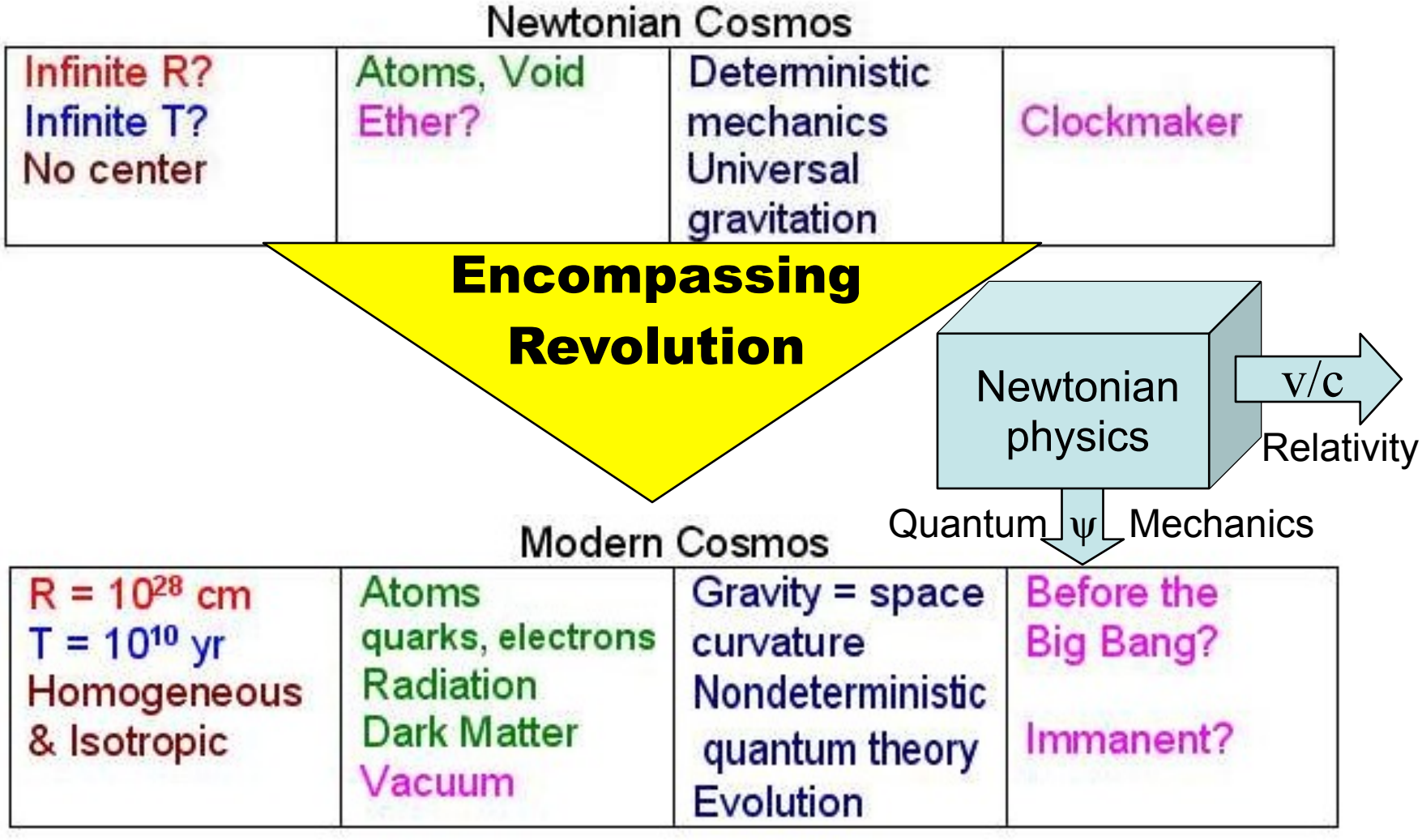


Overthrowing Revolution

Newtonian Cosmos

Infinite R? Infinite T? No center	Atoms, Void Ether?	Deterministic mechanics Universal gravitation	Clockmaker

But since Newton, all scientific revolutions in physics have been encompassing revolutions



Encompassing Revolutions

Einstein's Theory of Relativity makes the same predictions for motion as Newton's theory whenever the speeds are slow compared to the speed of light, and gravity is not too strong. All the planets in the solar system move very slowly compared to the speed of light, and gravity is relatively weak. Therefore relativity makes the same predictions for the motions of the planets as Newton's theory, except for some very small differences in the motions of the fastest planets that orbit closest to the sun. Relativity encompasses Newtonian physics.

A new scientific theory ENCOMPASSES an old one when the new theory is valid for a wider class of phenomena, and
the two theories make the same predictions (to some specified accuracy) for a significant range of phenomena.
(We can then say that the new theory reduces to the old one for a subset of these phenomena.)

The highest grade of truth

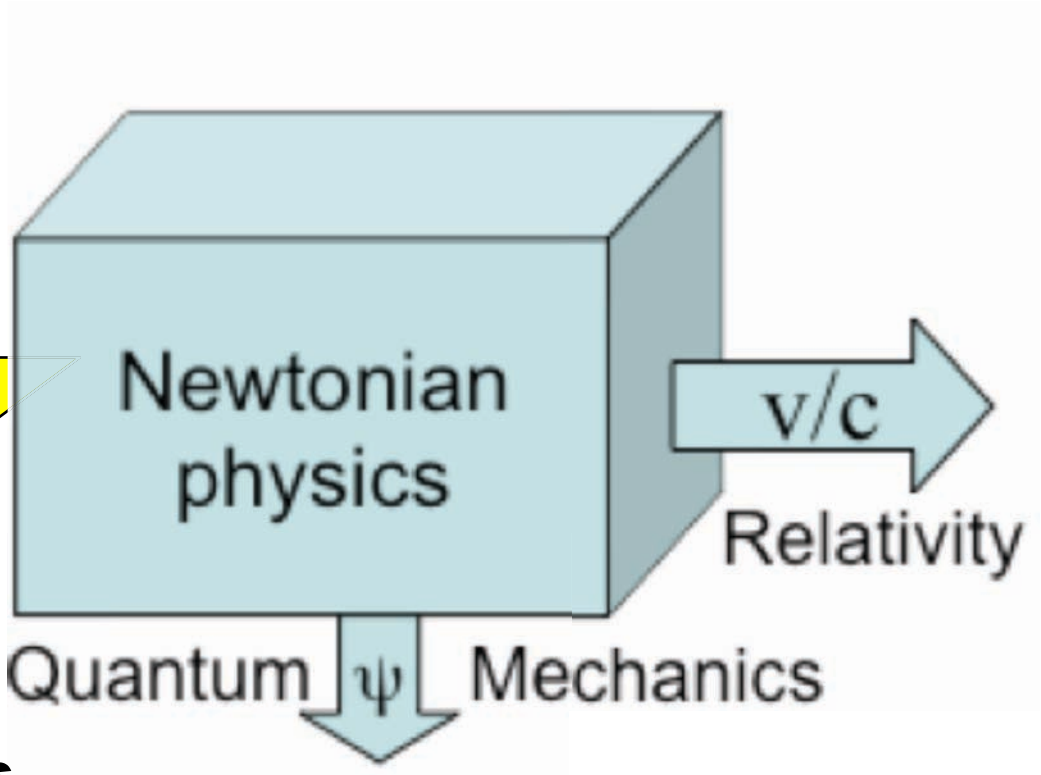
Charles Misner has pointed out a deep insight about scientific truth: **the only sort of theory we can know to be "true" is one which has been shown to be false – in the sense that its limitations are known**. As philosophers of science from Hume to Popper have emphasized, we can never prove that a scientific theory is true, since there is always the possibility that new data will be discovered that disprove it. But when a scientific theory has been encompassed by a more comprehensive theory that itself has been well tested, we can have considerable confidence that the encompassed theory is "true" within its known limits. This is the highest grade of scientific truth that is available.

Newtonian Cosmos

Deterministic mechanics

Universal gravitation

Encompassing Revolution



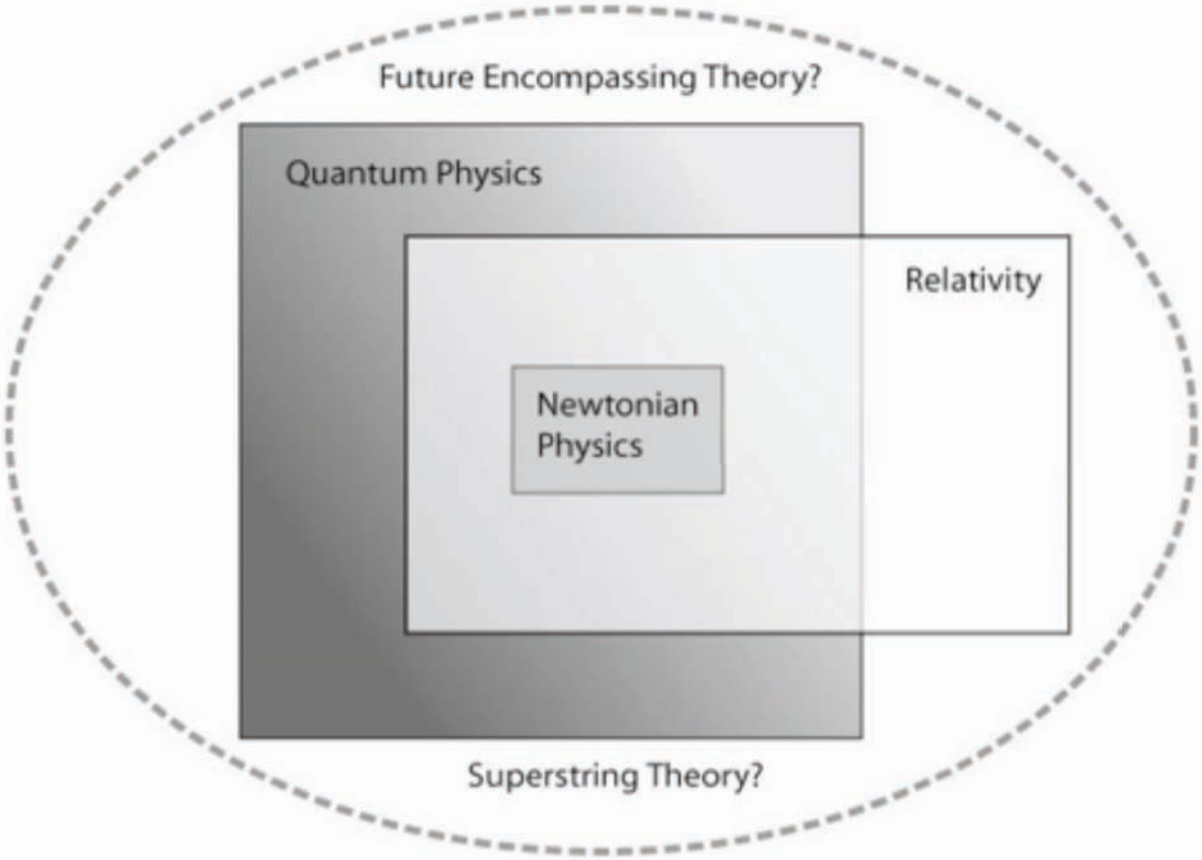
21st Century Cosmos

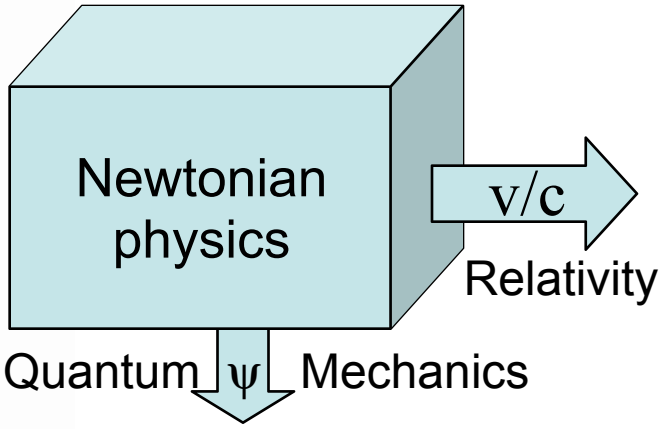
Nondeterministic quantum mechanics

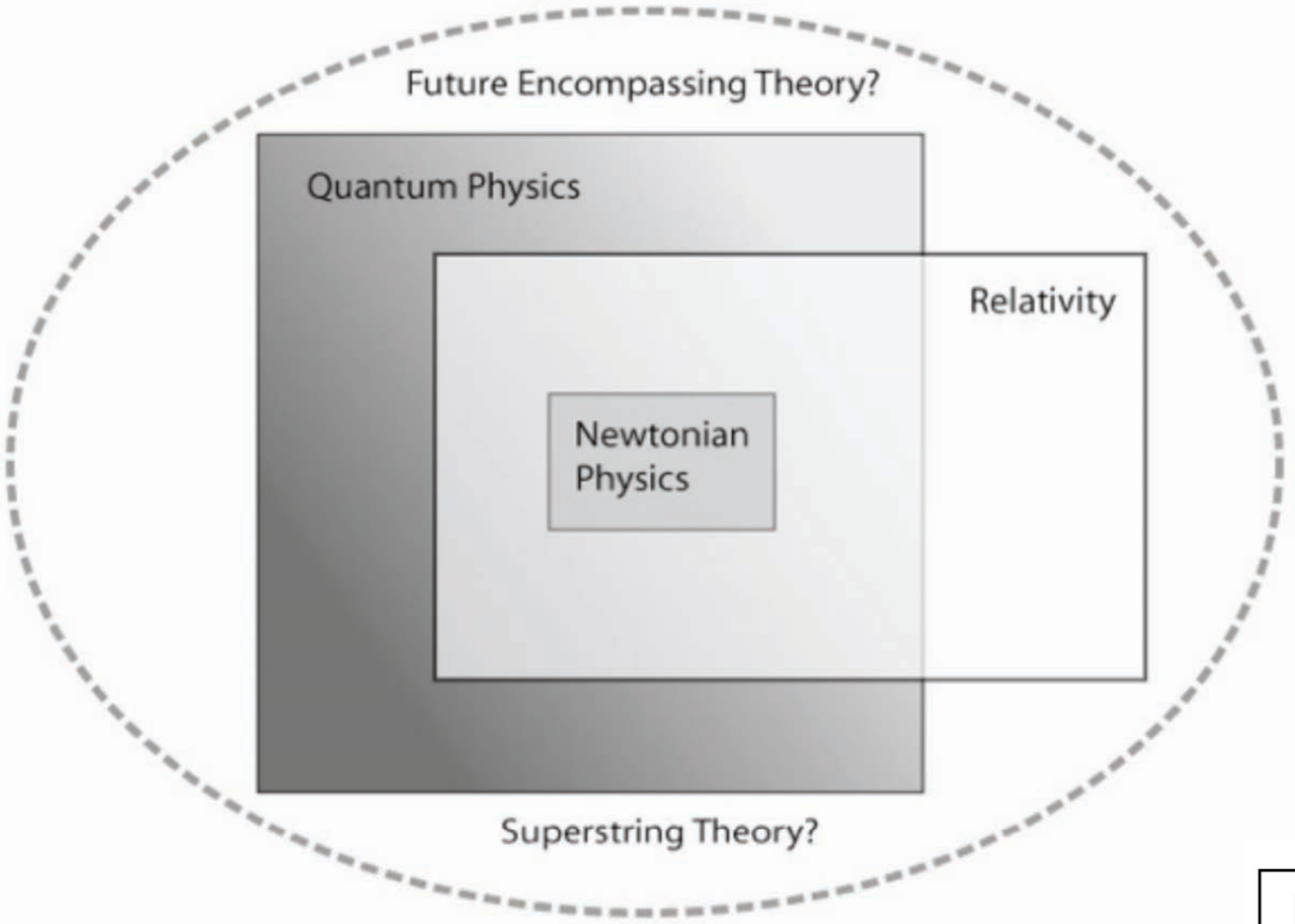
Gravity = space-time curvature

Evolution

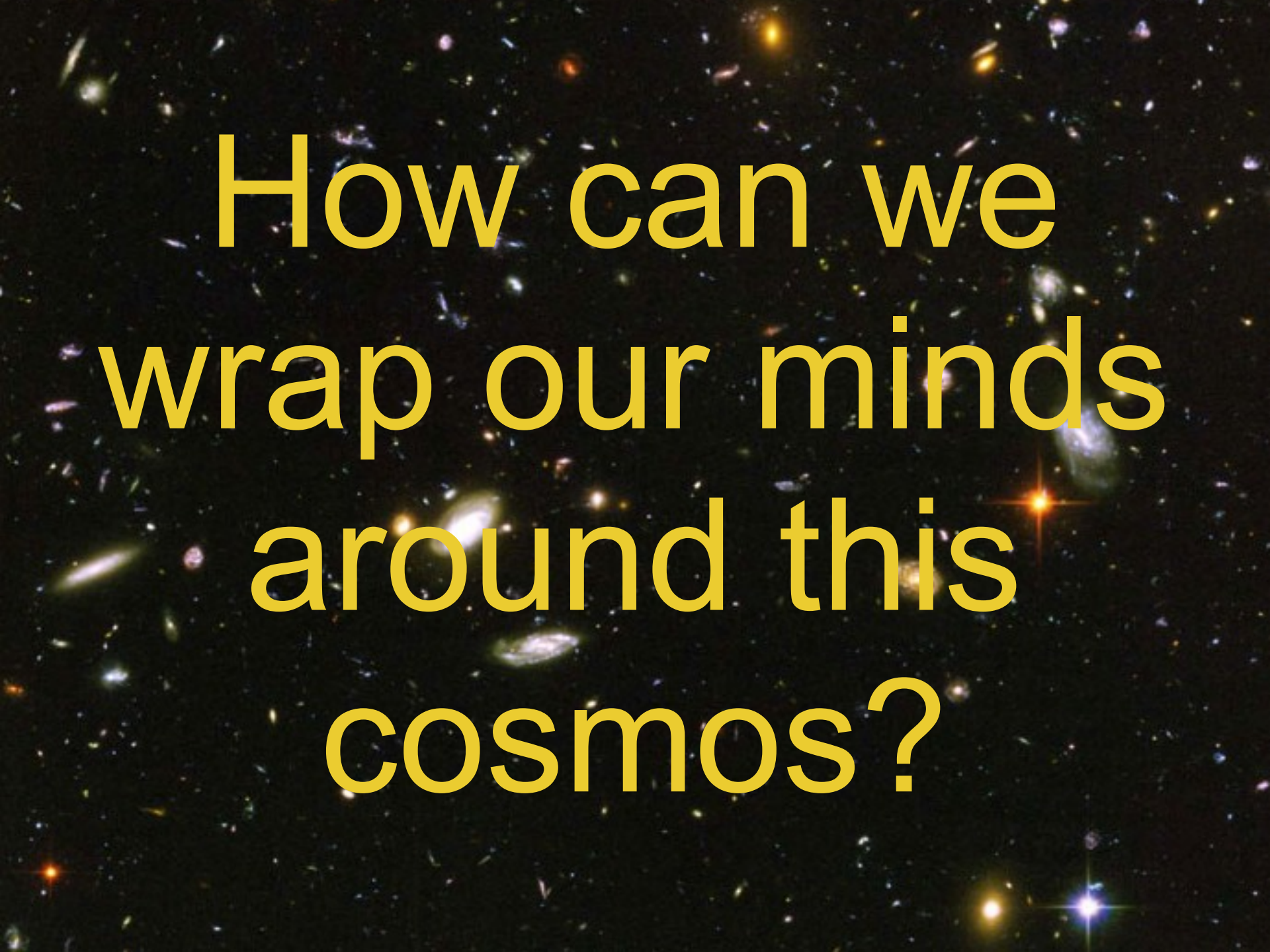
Encompassing Scientific Revolutions

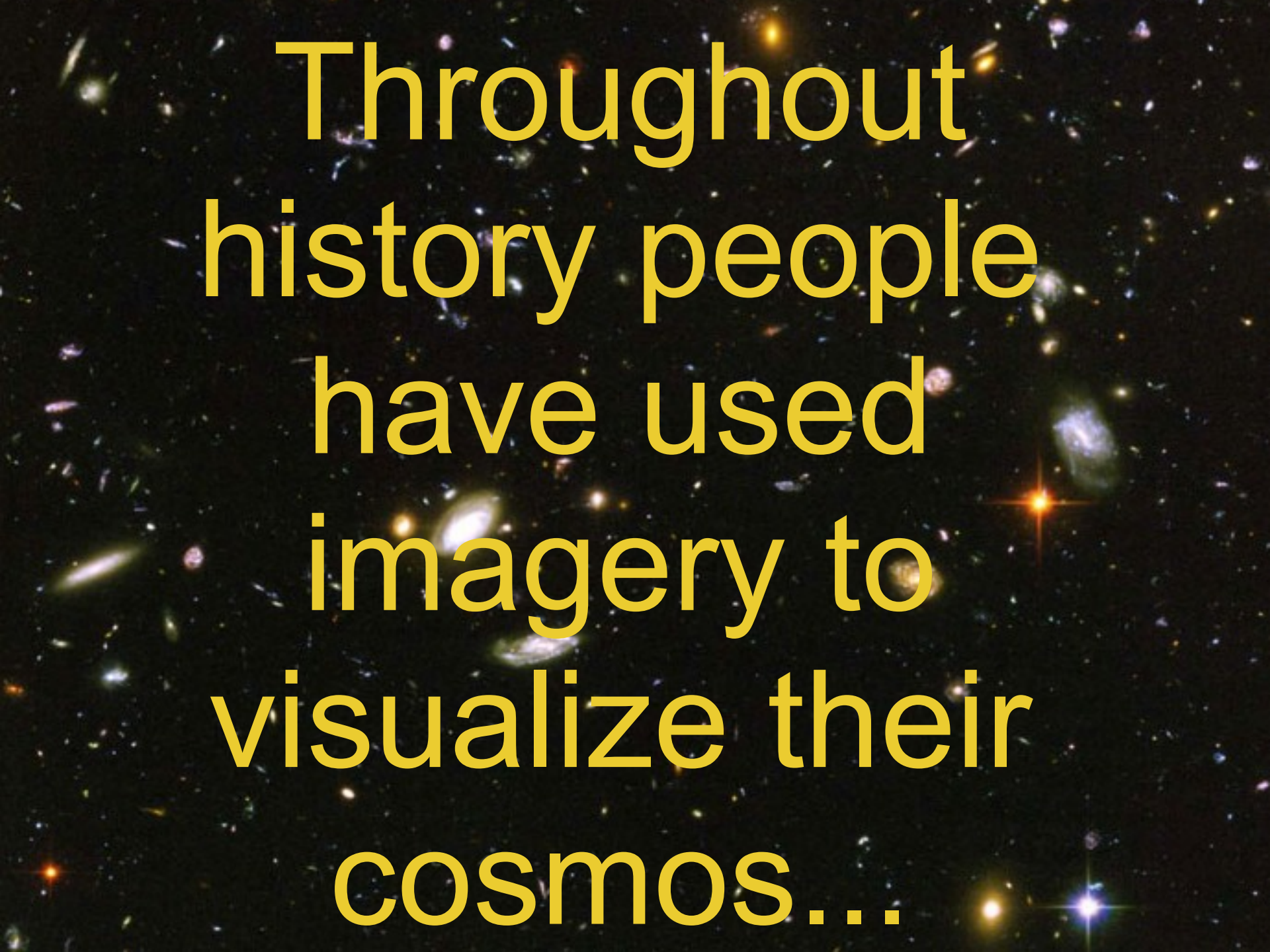





Future Encompassing Theory?
Quantum Physics
Relativity
Newtonian Physics
Superstring Theory?

mini-icon


How can we wrap our minds around this cosmos?


Throughout history people have used imagery to visualize their cosmos…


Here's a lightning
overview of
the images
we propose
for our cosmos

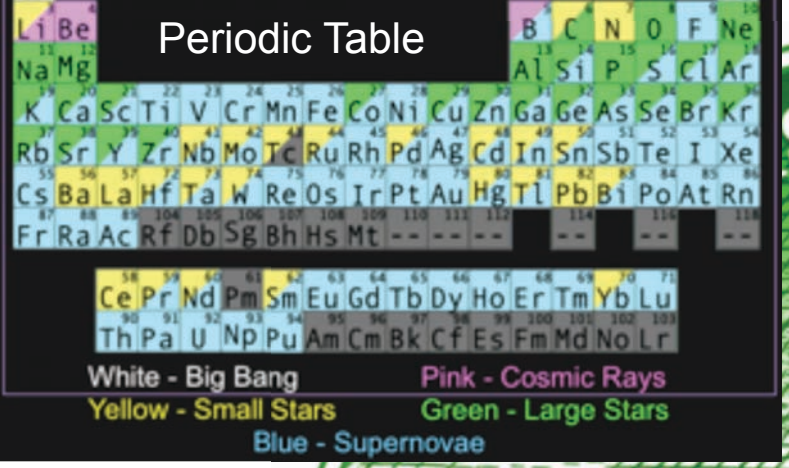
The Cosmic Recipe

- We now know the cosmic recipe. Most of the universe is invisible stuff called "nonbaryonic dark matter" (25%) and "dark energy" (70%). Everything that we can see makes up only about 0.5% of the cosmic density, and invisible atoms about 4%. The earth and its inhabitants are made of the rarest stuff of all: heavy elements (0.01%).

- The ΛCDM Cold Dark Matter Double Dark theory based on this appears to be able to account for all the large scale features of the observable universe, including the details of the heat radiation of the Big Bang and the distribution of galaxies.

- Constantly improving data are repeatedly testing this theory. The main ingredients have been checked several different ways. There exist no convincing disagreements, as far as I can see. Possible problems on subgalactic scales may be due to the poorly understood physics of gas, stars, and massive black holes.

- But we still don't know what the dark matter and dark energy are, nor really understand how galaxies form and evolve. There's lots more work for us to do to figure all this out.



SIBLE MATTER

ALL OTHER VISIBLE ATOMS

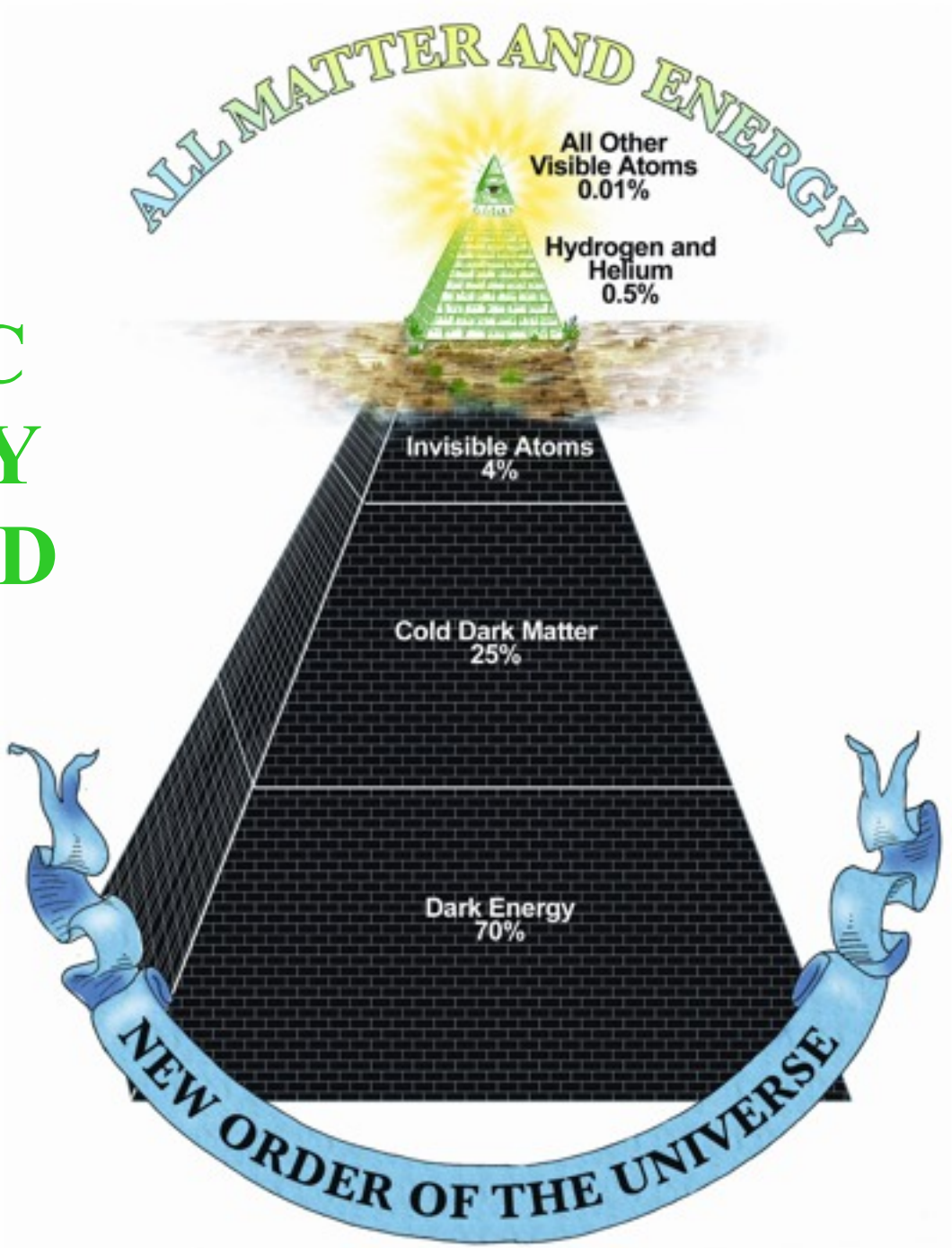
stardust

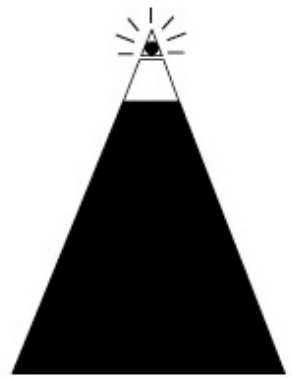
HYDROGEN AND HELIUM

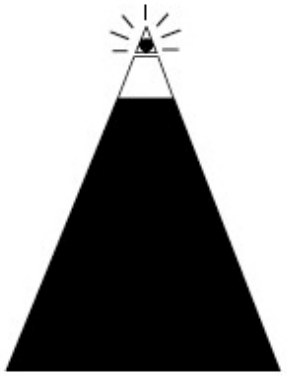
stars

NOVUS ORDO SECLORUM

COSMIC DENSITY PYRAMID

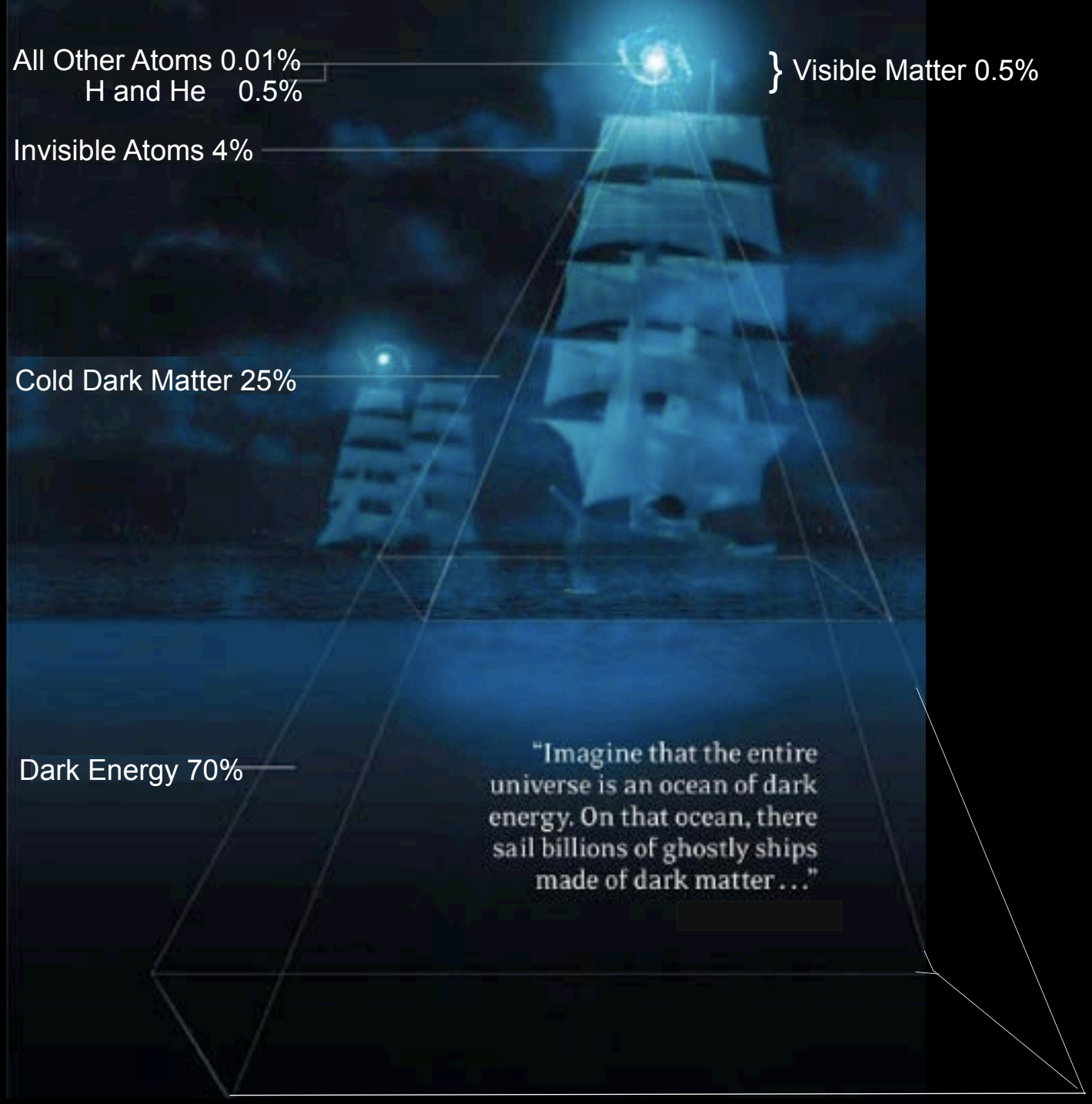


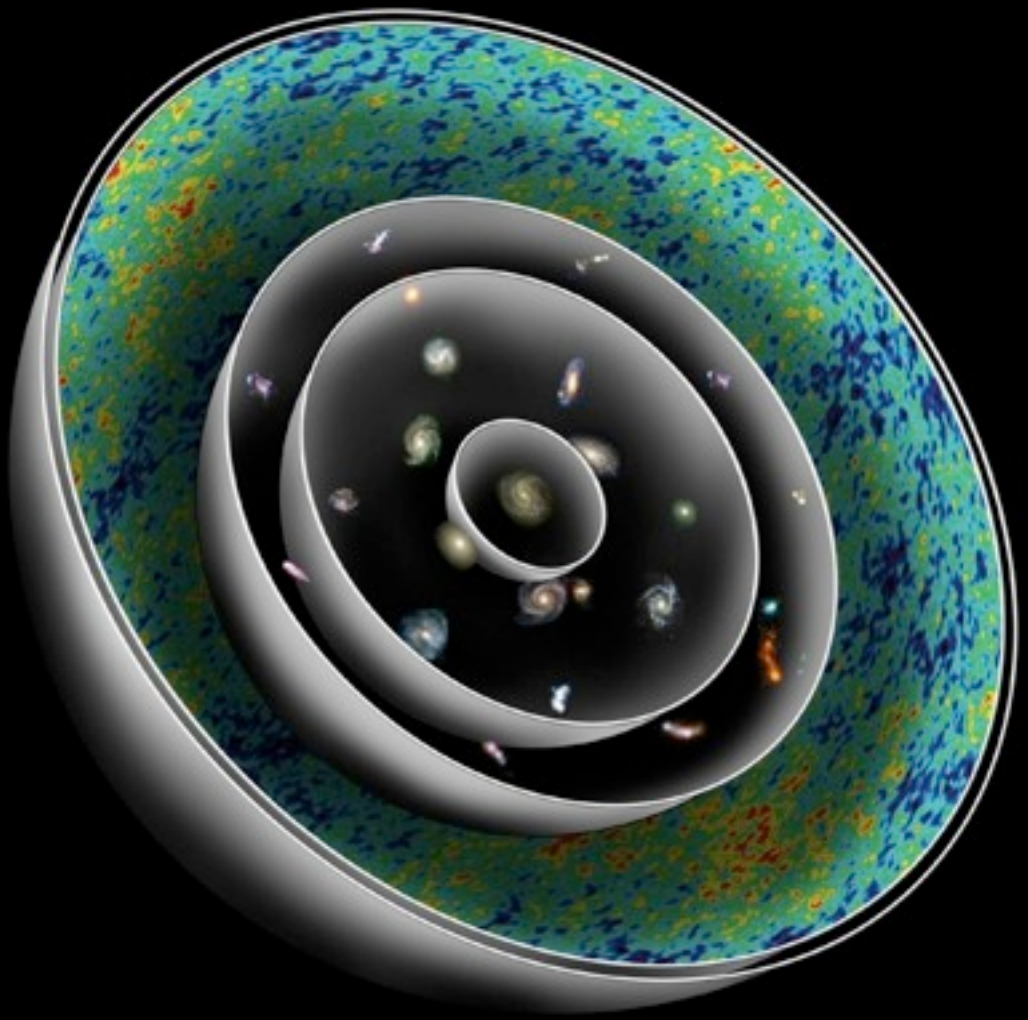




Cosmic Density Pyramid

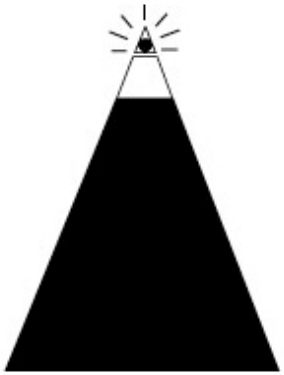
1) We are made of the rarest material in the universe: stardust.


All Other Atoms 0.01%
H and He 0.5%
} Visible Matter 0.5%
Invisible Atoms 4%
Cold Dark Matter 25%
Dark Energy 70%
"Imagine that the entire universe is an ocean of dark energy. On that ocean, there sail billions of ghostly ships made of dark matter . . ."



Looking out in space
is looking back in time

2) We live at the center of our Cosmic Spheres of Time, because every place is the center of its own cosmic spheres of time. The finite speed of light makes this inevitable in a uniformly expanding universe.



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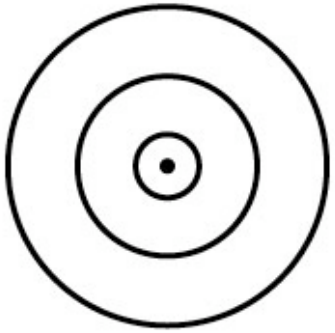

Cosmic Spheres of Time

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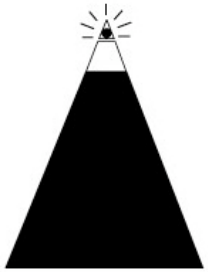

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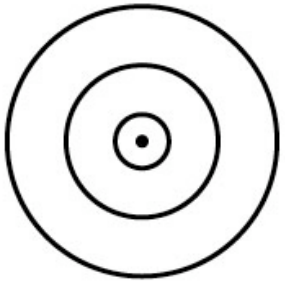

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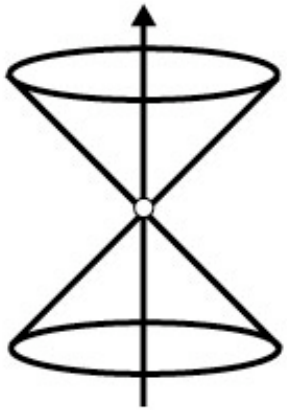
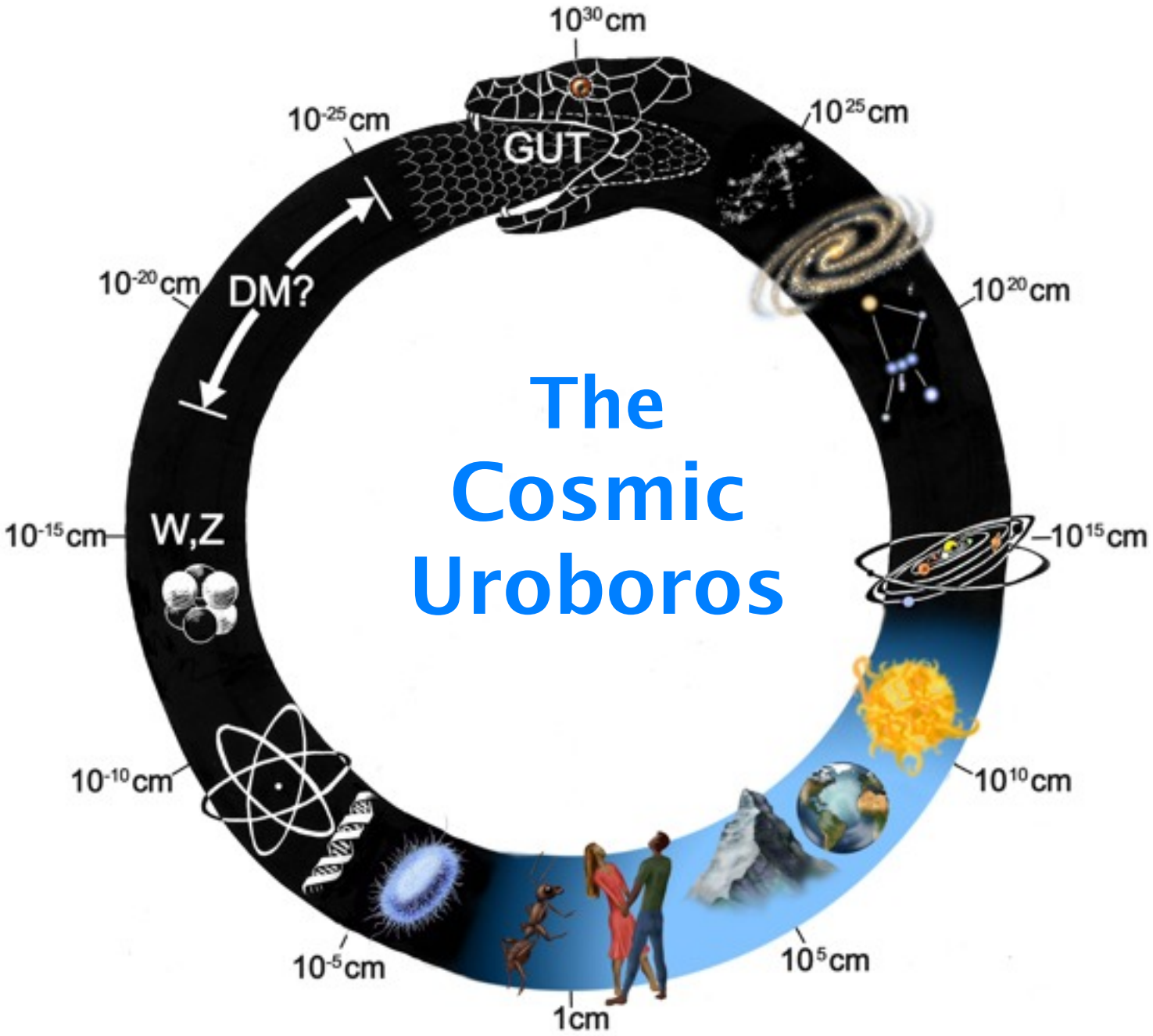


Light Cone

3) We live at the midpoint of time, which is also the peak period in the entire evolution of the universe for astronomical observation. Most nearby galaxies are middle aged, past their violent youths but not yet senescent and finished with star formation. The most distant galaxies – which we have *just* acquired the technological ability to see – are beginning to disappear over the cosmic horizon now that the once-slowing expansion of the universe has begun instead to accelerate. The universe *as we are observing it today* will truly become mythic, since it will become the lost Golden Age. Our distant descendants will know that our fabulously rich sky actually existed but will never be seen again.


10^30 cm
10^-25 cm
GUT
10^25 cm
10^-20 cm
DM?
10^20 cm
The
Cosmic
Uroboros
10^-15 cm
W,Z
10^15 cm
10^-10 cm
10^10 cm
10^-5 cm
10^5 cm
1cm

Cosmic Uroboros

4) We live at the middle of all possible sizes – in Midgard, where the possibility of tremendous variety and complexity coming in small packages keeps life interesting. Life of our complexity could bloom on no other size scales of the Cosmic Uroboros.

Biggest size = Size of visible universe = 10^{29} cm
Smallest size = Planck length = 10^{-33} cm

$1 = 10^0$ $10 = 10^1$ $100 = 10^2$ Our size scale is $\sim 10^2$ cm.

10^3 = thousand 10^6 = million 10^9 = billion 10^{12} = trillion

$0.1 = 10^{-1}$ $0.01 = 10^{-2}$ $0.001 = 10^{-3}$ = thousandth

Cosmic Uroboros

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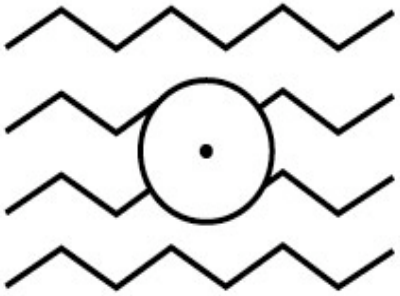
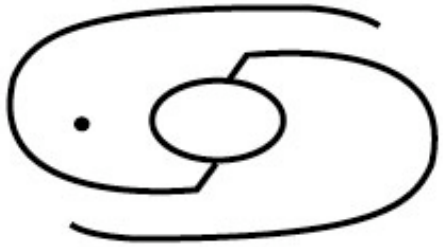
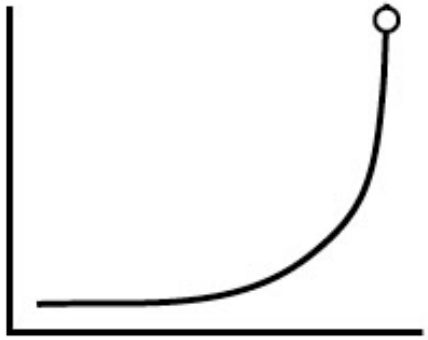


Our Cosmic Bubble

5) We live in a universe that may be a rare bubble of spacetime in the infinite, seething cauldron of the eternal superuniverse. Outside our absolutely unique and isolated bubble, which we call the Big Bang, there is neither space nor time as we know it. But here inside, there is time for evolution and history, and there is space across which connections can form and structures can develop. We are not geographically central in eternal inflation, but we are very special.



6) We live at more or less the midpoint in the life of our planet. It formed, along with the sun and other planets, about four and a half billion years ago. It has about six billion more years to go before it is roasted when our sun swells into a red giant star. We also live in the middle of the billion year period during which Earth is most hospitable to complex life. From the point of view of our species, whose recorded history is a mere 5000 years, today is late enough to have evolved to our present abilities while early enough still to have a potential future so vast it beggars the imagination.



7) We live at a turning point for our species. From the point of view of the generations alive at this moment, it is late enough that we are sobering up to the scale of our problems, but not so late that we have lost all chance to solve them. This is a very special time that will never come again.

Cosmology & Culture Syllabus

Week

1 **INTRODUCTION**

Part I COSMOLOGICAL REVOLUTIONS

1 **Chapter 1 Wrapping Your Mind Around the Universe**
2 **Chapter 2 From the Flat Earth to the Heavenly Spheres**
3 **Chapter 3 From the Center of the Universe to No Place Special**

Part II THE NEW SCIENTIFIC PICTURE OF THE UNIVERSE

4 **Chapter 4 What Is the Universe Made of?** ***The Cosmic Density Pyramid***
5 **Chapter 5 What Is the Center of the Universe?** ***The Cosmic Spheres of Time***
6 **Chapter 6 What Size is the Universe?** ***The Cosmic Uroboros***
7 **Chapter 7 Where Do We Come From?** ***The Cosmic Las Vegas***
8 **Chapter 8 Are We Alone?** ***The Possibility of Alien Wisdom***

Part III THE MEANINGFUL UNIVERSE

9{ **Chapter 9 Think Cosmically, Act Globally**
Chapter 10 Taking our Extraordinary Place in the Cosmos

10 Reports on student projects & summary of course

COSMOLOGY AND CULTURE

Physics 80C Spring 2009

1. We will have discussions of each week's readings in class. It is essential that you do the readings before class. Attendance will be taken at most classes.

2. There will be several in-class writing assignments and quizzes on the readings, and/or a quiz on the simple mathematics needed to discuss the wide range of sizes in the universe after we have covered this in class.

3. There will be an in-class, closed-book Midterm Exam on Wednesday May 13.

4. Groups of students will be required to submit proposals, due May 2, for a written or artistic class project or presentation. Some of these projects will be presented in the final class on June 3.

5. Keep an astronomy journal in which you write notes about the appearance of the night sky, especially the moon and planets, with the date and time of each observation. This journal will be due at the class on May 27, and returned at the last class.

6. On a clear moonless night we will have an optional Astronomy Night where we will observe the night sky with the naked eye, and with binoculars and telescopes.

SIGN THE CLASS ROLL

NOW BEING CIRCULATED

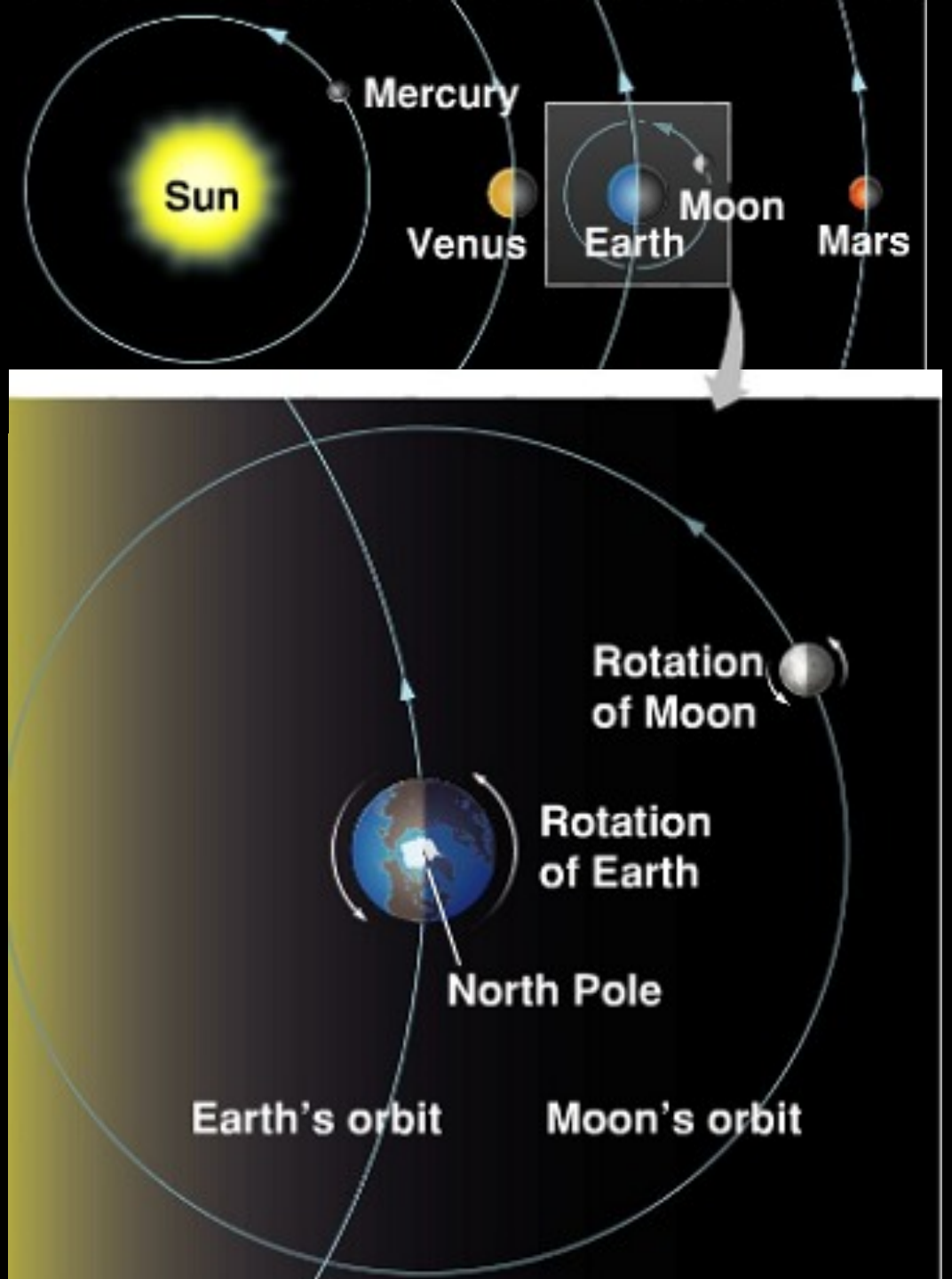
IF YOU WANT TO TAKE

PHYSICS 80C

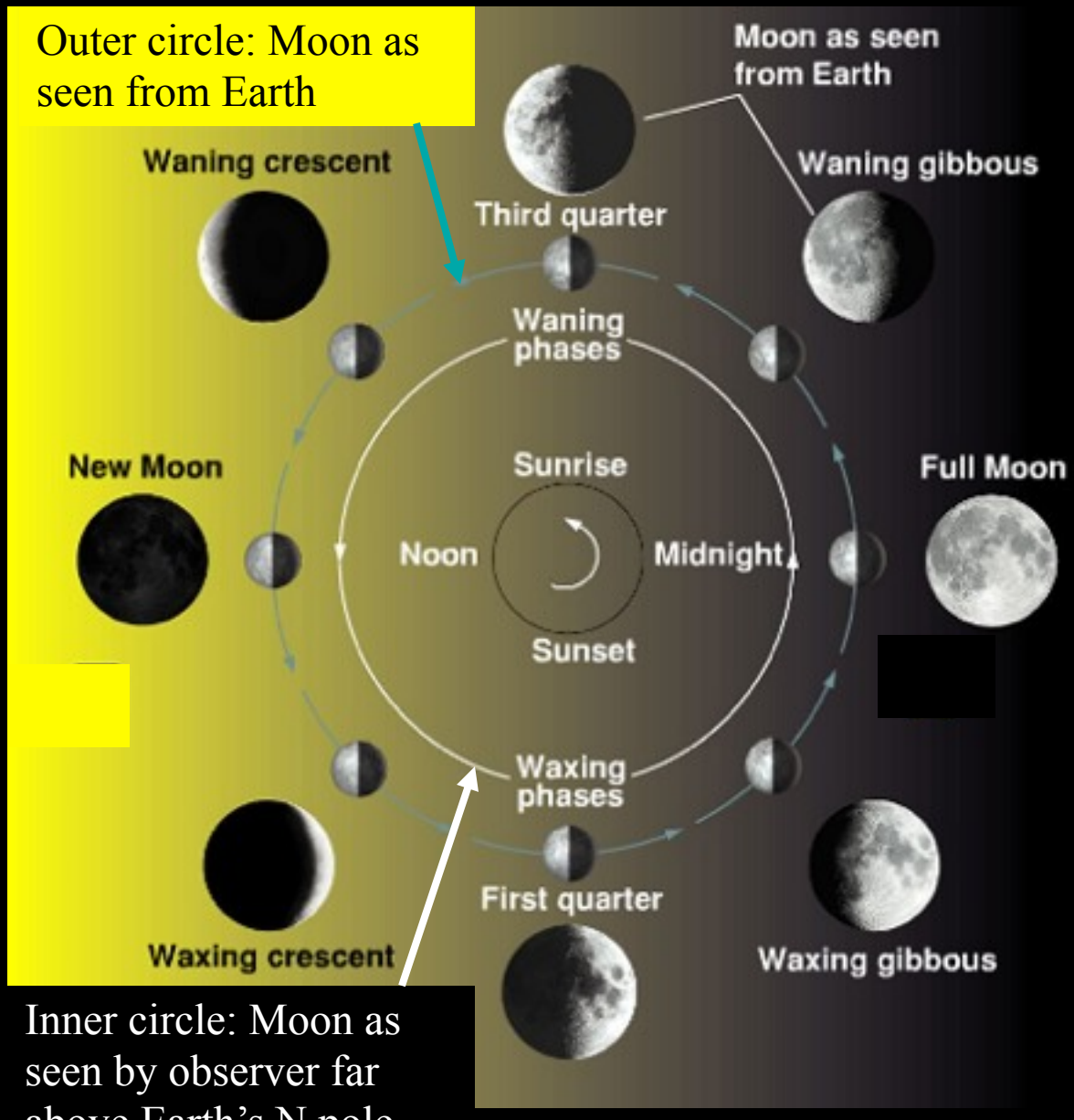
THERE WILL NOW BE A

20 MINUTE BREAK

Earth, Moon, Solar System



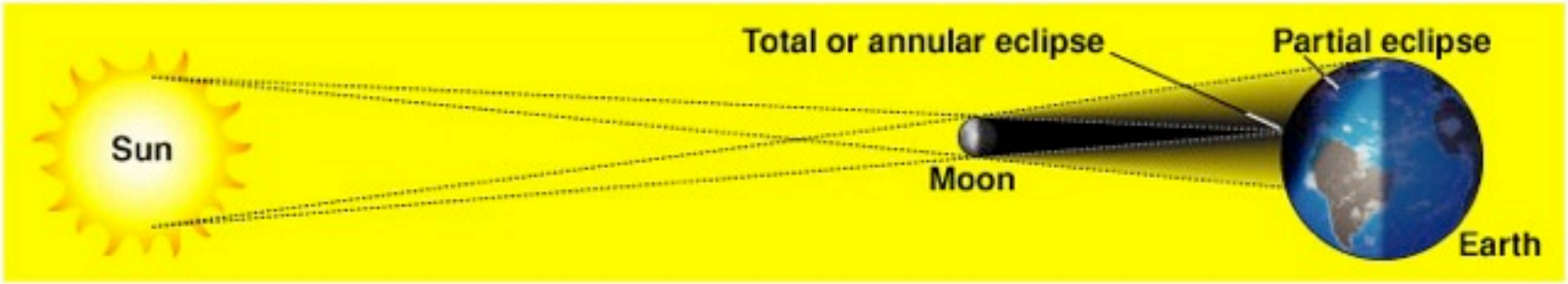
Phases of the Moon



The crew of Apollo 8 captured this image of Earth rising over the surface of the Moon in 1968.

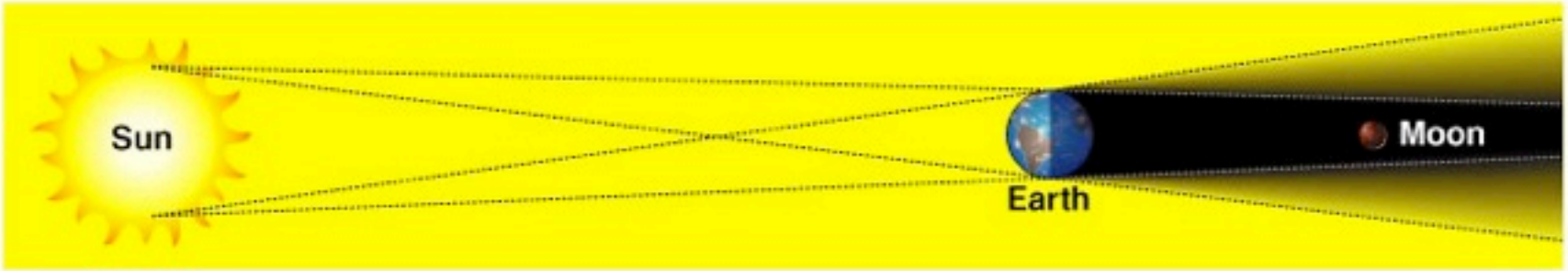
Eclipses

(a) Solar eclipse geometry (not to scale)



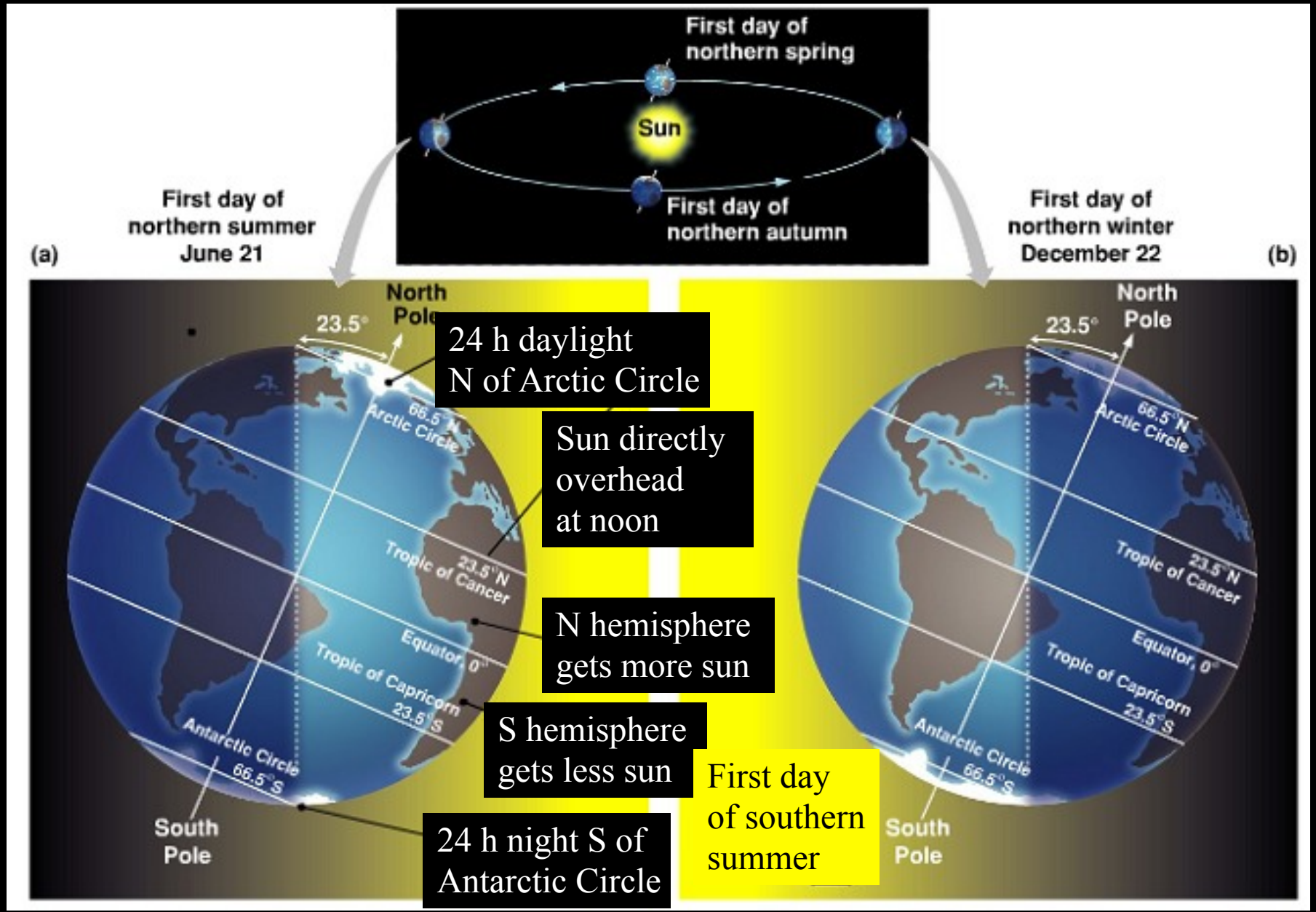
(b) Solar eclipse to scale

(c) Lunar eclipse geometry (not to scale)

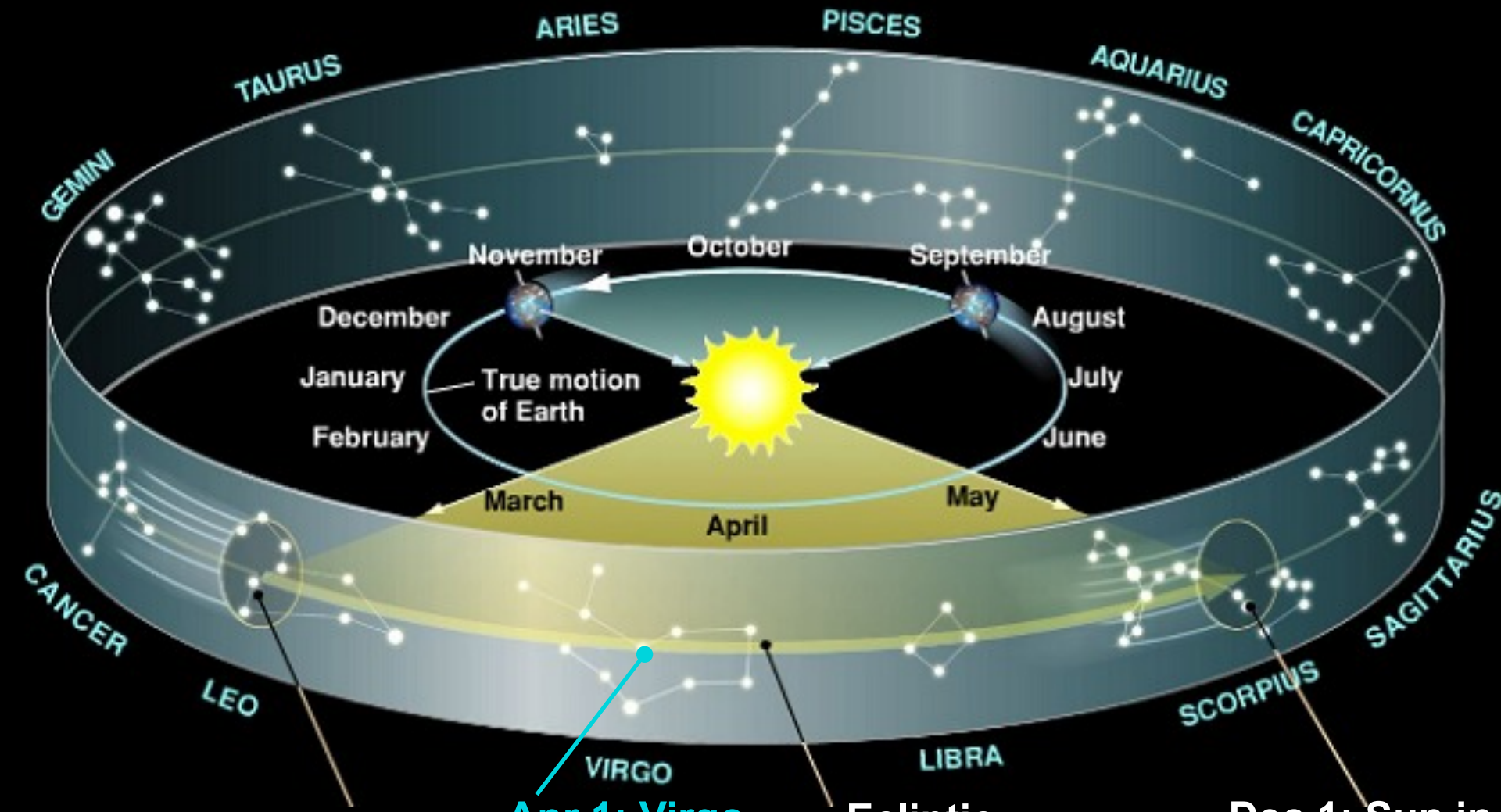


(d) Lunar eclipse to scale

Seasons


First day of northern spring
Sun
First day of northern autumn
First day of northern summer June 21
First day of northern winter December 22
(a)
(b)
North Pole
23.5°
66.5° N Arctic Circle
23.5° N Tropic of Cancer
Equator, 0°
Tropic of Capricorn 23.5° S
Antarctic Circle 66.5° S
South Pole
24 h daylight N of Arctic Circle
Sun directly overhead at noon
N hemisphere gets more sun
S hemisphere gets less sun
24 h night S of Antarctic Circle
First day of southern summer

The Sun Moves Against the Stars



Sept 1: Sun in direction of Leo as seen from Earth

Apr 1: Virgo is high in sky at midnight

Ecliptic (apparent path of the Sun)

Dec 1: Sun in direction of Scorpius

Mini-Quiz

Q1. The reason there are seasons is that

A. The earth is closer to the sun in summer than in winter
B. The earth's axis is tilted

Q2. When it is summer (the warmest season) in the N hemisphere

A. It is also summer in the S hemisphere
B. It is winter in the S hemisphere

Q3. Match correctly:

A. Solar eclipse	1. Full moon
B. Lunar eclipse	2. New moon

Mini-Quiz

Q1. The reason there are seasons is that

A. ~~The earth is closer to the sun in summer than in winter~~

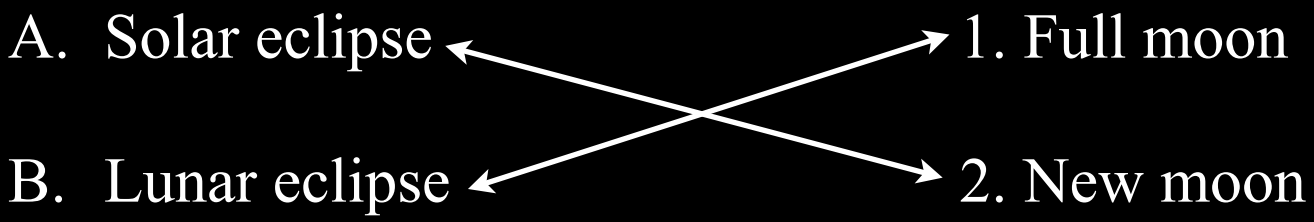
B. The earth's axis is tilted

Q2. When it is summer (the warmest season) in the N hemisphere

A. ~~It is also summer in the S hemisphere~~

B. It is winter in the S hemisphere

Q3. Match correctly:



One approach to challenging intuition is what we call "contemplations." These are brief meditations on what it might feel like to experience the scientific ideas you're learning about. Here is an example to help get a feeling of how the planet turns.

Imagine it is late afternoon and you are lying on your back in soft grass, looking up at the sky, your feet toward the south. You lazily spread out your arms and legs and feel the warm earth below you. There is nowhere you need to go. You are just a part of the earth. Slowly turn your head to the right and look west toward the orange sun. You can feel your patch of earth turning away from the sun, heading into night. Just as the horizon on your right rises to meet the sun, you turn your head all the way left, and there you see on the eastern horizon the moon appearing at the same moment. Tonight is the night of the full moon, when sun and moon are opposite and in perfect balance. Now feel your patch of earth moving slowly toward the huge, orange moon. The moon appears to rise and become whiter because you are seeing it through less and less atmosphere. It seems smaller, but only because it is no longer near the horizon where your mind compares it with familiar objects in the earthly landscape. Time passes. The earth carries you around until the last glow of sunlight disappears and stops masking the stars. It is cold now. You have traveled into night on your planet. You are the face of the planet that is traveling into night.

IF YOU WANT TO TAKE
PHYSICS 80C
BE SURE YOU ARE
ON THE CLASS ROLL

IF YOU WANT TO TAKE PHYSICS 80C
BUT YOU AREN'T YET REGISTERED
SUBMIT A SHORT ESSAY ON WHY
YOU WANT TO TAKE THE COURSE
BY EMAIL TO joel@physics.ucsc.edu
Include information about your year and major, and explain how this course fits into your academic program and personal plans.