AST 9.002

Introduction to Astronomy I
Workbook

Arvind Borde

This workbook contains work done by: ______________________________

Signature: ______________________________

Introduction to Astronomy I

(1) What is the solar system?

(2) What are the names of some types of solar system bodies?

1

Questions about the solar system

- What are the solar system bodies (including the sun) made of?
- What holds the system together?
- Planets revolve around the sun, moons revolve around planets: is revolution necessary?

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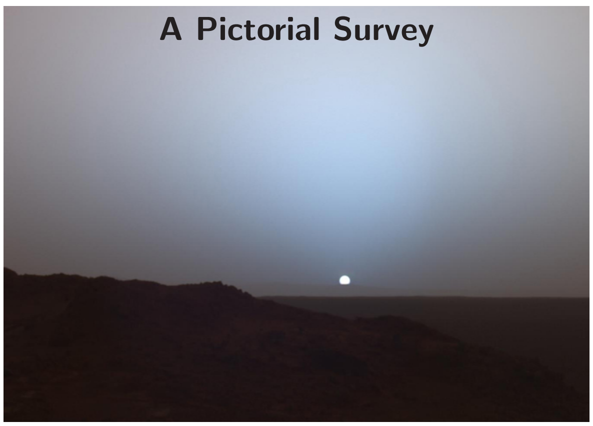

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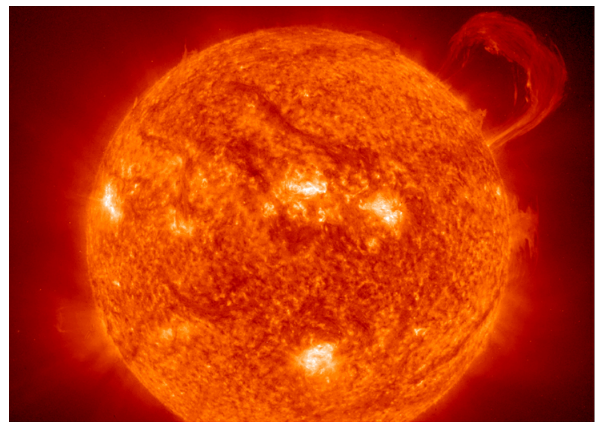

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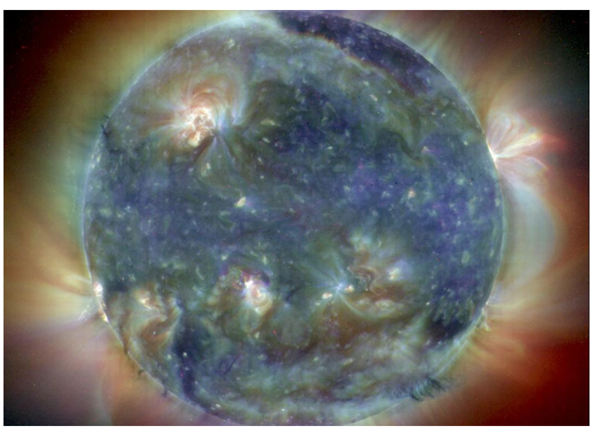

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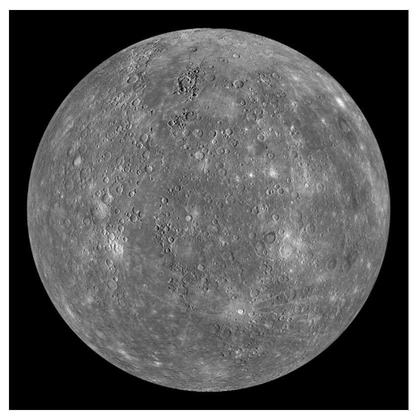

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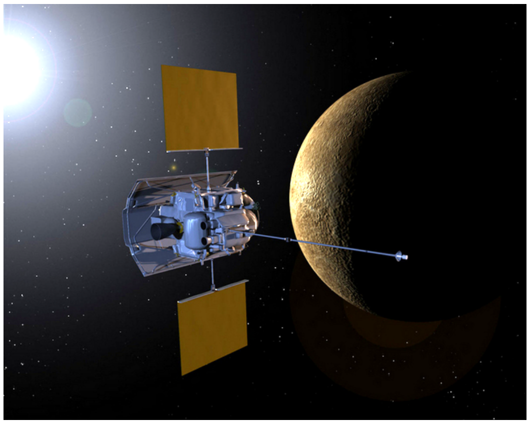
ADDITIONAL NOTES



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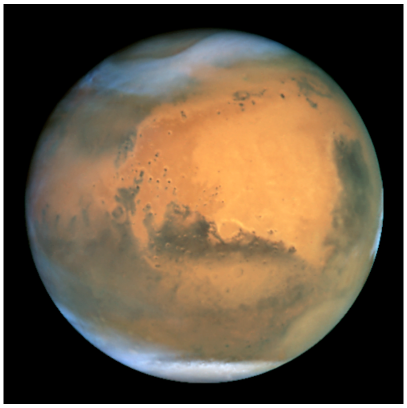

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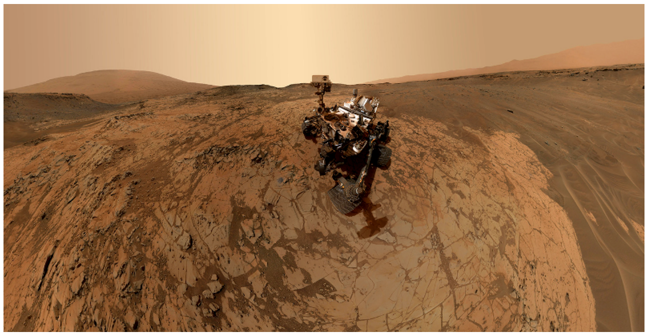

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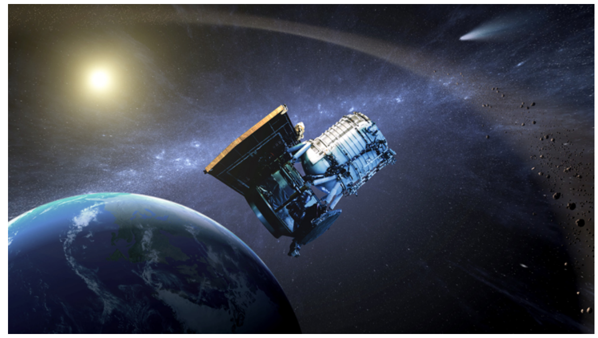

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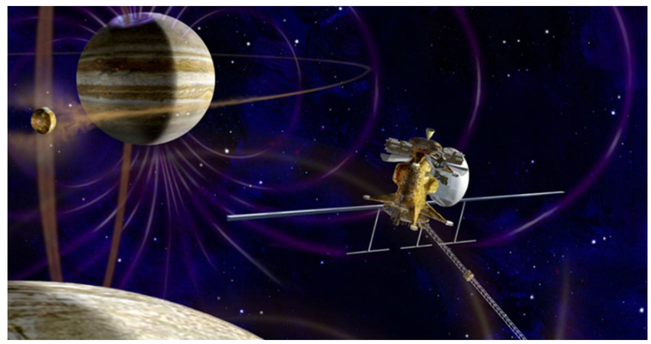

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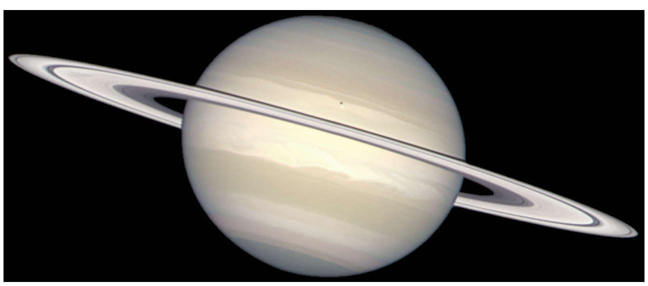

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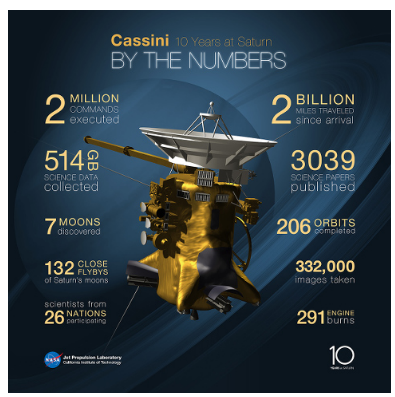

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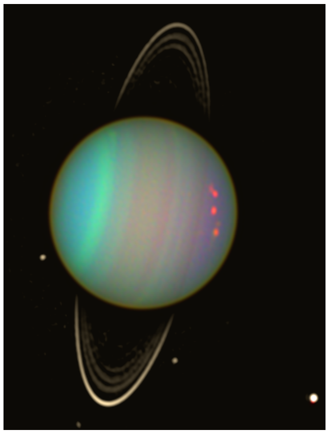
ADDITIONAL NOTES



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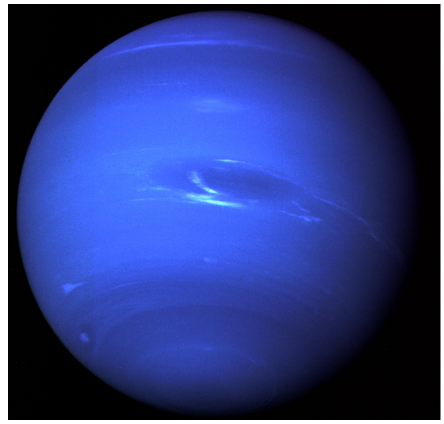

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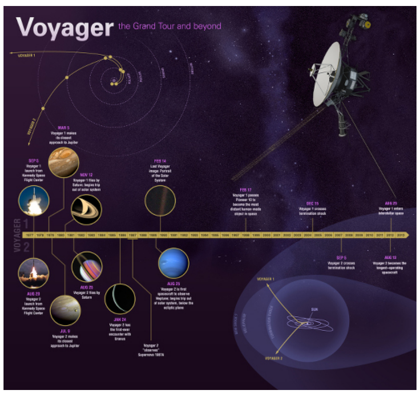

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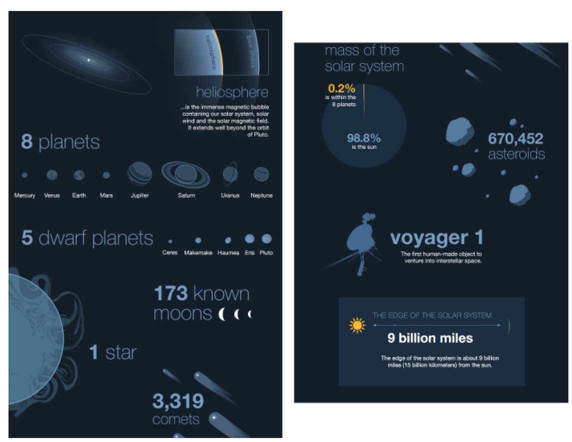

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ADDITIONAL NOTES

Size and Scale

Astronomy is an area of science where we have to deal with big numbers: large sizes. distances, etc.

To comprehend them, we often have to scale down to a comprehensible level.

Here are the rough *comparative* sizes of the major objects in the solar system:

25

Comparative Sizes in the Solar System

Sun: bowling ball, diameter 8.00 in.
Mercury: pinhead, diameter 0.03 in.
Venus: peppercorn, diameter 0.08 in.
Earth: peppercorn, diameter 0.08 in.
Mars: pinhead, diameter 0.03 in.
Jupiter: chestnut/pecan, diameter 0.90 in.
Saturn: hazelnut/acorn, diameter 0.70 in.
Uranus: peanut/coffeebean, diameter 0.30 in.
Neptune: peanut/coffeebean, diameter 0.30 in.
(Pluto: less than a pinhead).

26 https://www.noao.edu/education/work/Peppercorn/Peppercorn_Main.html

How far are the planets from the sun?

Put the "Sun" down, and walk away.
After 10 steps: Mercury.
Another 9 steps: Venus.
Another 7 steps: Earth.
Another 14 steps: Mars.
Another 95 steps: Jupiter.
Another 112 steps: Saturn.
Another 249 steps: Uranus.
Another 281 steps: Neptune.
(Another 242 steps: Pluto and co.)

27

(3) How many steps have you walked in all to get to Pluto and co.?

________________.

(4) Assuming a "step" is about three feet, what is that, roughly, in feet? (And in miles?)

______________ ___________________________

28

Some actual distances

Earth–Moon: $400{,}000$ km.

Earth–Sun: $144{,}000{,}000$ km.

Neptune–Sun: $4{,}500{,}000{,}000$ km.

29

Light Times

________________: _______________________

____________.

Speed of light*: __________________________.

*"Light" includes visible rays, radio waves, x-rays. . .

To get distance in light-seconds divide the distance in km, by c.

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ADDITIONAL NOTES

(5) Convert the previous distances to light times:

Earth–Moon: ____________light-sec.

Earth–Sun: ____________light-sec

or __________light-min.

Neptune–Sun: _______________light-sec or _______ light-hr.

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How do we know these distances?

For the nearby, rocky planets we simply bounce radio waves off them.

(6) If the distance to such a planet is d, the speed of radio waves is c, and the time taken for a signal to go there (or return) is t, how are these three related? __________________________

In practice, we measure round trip time, $2t$, then halve it.

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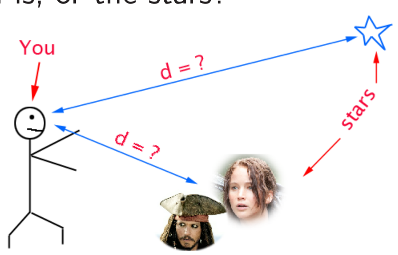
What about other objects? How do we know how far the sun is, or the stars?



(7) Bouncing signals won't work. Why?

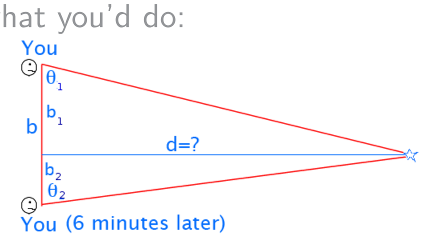
33 ____

(8) What are these men up to?

____

34 _____________________________

This is what you'd do:



$$tan\,\theta_1 = d/b_1 \quad \text{or} \quad d = b_1\,tan\,\theta_1, \qquad (1)$$

$$tan\,\theta_2 = d/b_2 \quad \text{or} \quad d = b_2\,tan\,\theta_2, \qquad (2)$$

35 and

$$b_1 + b_2 = b \quad \text{or} \quad b_2 = b - b_1. \qquad (3)$$

We then solve equation (1) for b_1 and work it into equation (2), using equation (3) to assist

$$b_1 = \frac{d}{tan\,\theta_1},$$

and so

$$d = (b - b_1)\,tan\,\theta_2$$
$$= \left(b - \frac{d}{tan\,\theta_1}\right) tan\,\theta_2.$$

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ADDITIONAL NOTES

Then solve for d:

$$d = b\,tan\,\theta_2 - \frac{d}{tan\,\theta_1}\,tan\,\theta_2.$$

$$d = \frac{b\,tan\,\theta_2}{1 + (tan\,\theta_2/\,tan\,\theta_1)}.$$

This formula works on earth and off it.

That's how you perceive depth: by an apparent shift in angular position. ____________

37

If there were no apparent shift in the position of the object, we would have $\theta_2 = \pi - \theta_1$. It follows that $tan\,\theta_2 = -\,tan\,\theta_1$.

In that case, the denominator in the formula for d would be

$$1 + (tan\,\theta_2/\,tan\,\theta_1) = 1 + (-\,tan\,\theta_1/\,tan\,\theta_1) = 0.$$

You cannot get d.

38

For objects that are far away you cannot measure the angular shift on a short baseline.

If you want to use this method to get distances to the stars, you need a long enough baseline, b, to give parallax. Nothing on earth is big enough.

(9) What do we use? ____________________

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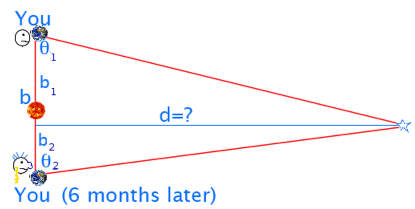
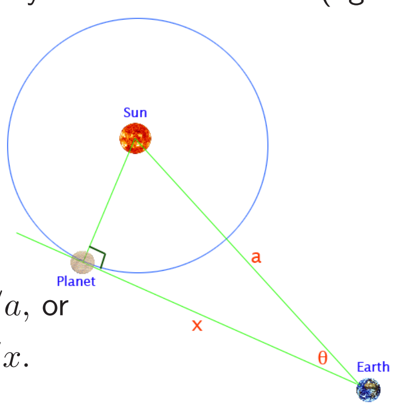


$$d = \frac{b\,tan\,\theta_2}{1 + (tan\,\theta_2/\,tan\,\theta_1)}$$

This gives the distance from the earth's orbital plane to nearby stars. But, how do we know b, the diameter of the earth's orbit?

40

Trigonometry rides to the rescue (again):



$cos\,\theta = x/a$, or

$a = cos\,\theta/x$.

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We get x by bouncing radio waves off the planet, and can measure θ. That gives us a, the earth-sun distance.

Once we know that, we can get distances to the most distant planets, and to nearby stars.

Trigonometry gives us the first rungs in what we call the "Cosmic Distance Ladder."

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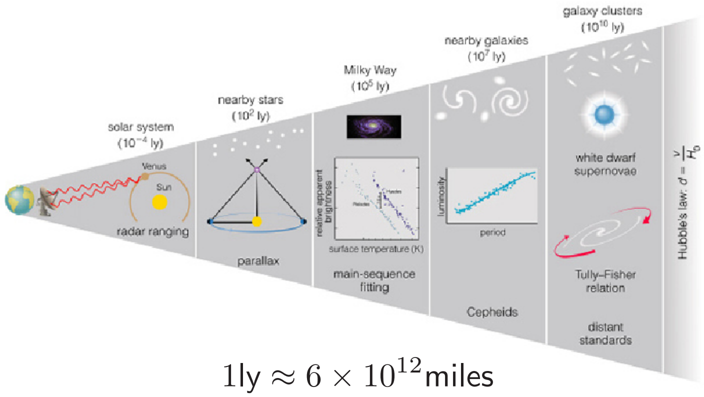
ADDITIONAL NOTES



$1\text{ly} \approx 6 \times 10^{12}$miles
(6 trillion miles)

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The last slide expressed distances in "scientific notation:" basically in powers of ten.

Knowing how to manipulates these quantities is an essential skill in astronomy.

If you multiply two powers of 10,

____

If you divide two powers of 10,

44 ____________________________

What are

(10) $10^{13} \times 10^{15}$? ____________________

(11) $10^{-3} \times 10^{5}$? ____________________

(12) $10^{5}/10^{7}$? ____________________

Note:

a) $10^{-n} = \dfrac{1}{10^{n}}$.

b) $10^{0} = 1$.

45

We'll mostly use the metric system and ___________ and powers of 10 to express quantity.

Sometimes, we'll use light-times: e.g., a light year, ____________________________________.

Another common solar system distance measure is the "AU" short for ______________________ ______________________________

46

Express as decimals

(13) 3/10 __________

(14) 4/5 __________

(15) 1/3 __________

(16) 3/100 __________

47

Distances are important in understanding the solar system (and the Universe).

Masses are important as well.

(17) What is the most massive object in the solar system? _______________

The next slide shows some of the most important solar system masses.

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ADDITIONAL NOTES

Sun: $\sim 2 \times 10^{30}$kg.
Moon $\sim 7.35 \times 10^{22}$kg.

Mercury $\sim 3.30 \times 10^{23}$kg.
Venus $\sim 4.87 \times 10^{24}$kg.
Earth $\sim 5.97 \times 10^{24}$kg.
Mars $\sim 6.42 \times 10^{23}$kg.
Jupiter $\sim 1.90 \times 10^{27}$kg.
Saturn $\sim 5.68 \times 10^{26}$kg.
Uranus $\sim 8.68 \times 10^{25}$kg.
Neptune $\sim 1.02 \times 10^{26}$kg.
(Pluto $\sim 1.27 \times 10^{22}$kg.)

49

Why are distances and masses so important in understanding the solar system, versus, say, shapes, colors, etc.? The latter are important, but distances and masses much more so.

Why?

To answer this we need . . .

50

. . . **A crash course in the world**

The whole world consists of two entities: ________ and ______________.

Examples of matter are your chairs, your bodies, and the stars.

Examples of interactions are the ______________ ________________________________.

51

These four are the only known interactions, also called forces.

Unlike the four fundamental forces, it may seem that matter is more complicated. Take our bodies:

(18) What are we mainly made of? ________ ________.

But there's other stuff: bones, flesh, hair, etc.

52

Similarly, if you look around the room, you'll see many different substances.

It's been known since the 1800s that the complexity of the material world is based on just a few basic things combining in different ways. These "basic things" are called ____________.

53

(19) Name some elements.

____

(20) How many natural elements are there?

____

(21) Elements come in basic "pieces." What are they called?

____

54

ADDITIONAL NOTES

But that's not the end of the story. Each atom has structure and is itself made up of three more basic things.

(22) What are the constituents of an atom called?

____

55

Protons and neutrons form the "nucleus" of the atom, and electrons swirl in a cloud around it.

Protons have positive electric charge, electrons an equal negative charge and neutrons are neutral. The electron cloud is "held in place" by the electric forces between them and the protons.

56

The simplest atom is that of hydrogen. It consists of a single proton and a single electron.

The nucleus is roughly 10^{-13}cm in radius and the electron cloud about 10^{-8}cm.
(23) That's factor of about 100,000. Why?

____

57

Can you subdivide further?

Not for electrons: they appear to have no internal structure.

But there's one step further for protons and neutrons: they have internal constituents which we call ____________.

58

At the micro level both matter and interactions are represented by particles, called ____________. (That's the plural. The singular is quantum.)

There are ____________ and ____________, distinguished by their __________. (Think of each as spinning like a top.)

59

Fermions are quanta of matter and have __________ spin.

Bosons are quanta of interactions and have __________ spin.

(Both are expressed as multiples of a basic spin unit.)

60

ADDITIONAL NOTES

All the known quanta

Fermions (matter)

6 “quarks”:
up, down, charm, strange, top, bottom
(combinations give the proton, neutron, etc.)
6 “leptons”:
electron, muon, tau and their neutrinos

61

Bosons (interactions)

Electromagnetism: Photon
Strong: 8 Gluons (hold the nucleus together)
Weak: W^+, W^-, Z^0 (radioactive decay)
Gravitation: Graviton??????

These 24-odd particles make up the world and all its interactions, along with a final particle called the Higgs boson.

62

The weak and strong forces are short range. They drop to zero outside the nucleus. They play no direct role in the structure of the solar system or the Universe.

Electromagnetism is long range, but most large objects are electrically and magnetically neutral. So this force, too, is irrelevant over large distances.

63

That leaves gravity. It and it alone determines the large scale structure of the Universe. It explains why the moon goes around the earth as it does, why planets move around the, why the sun rotates around the center of the Milky Way.

As we'll see next week, the strength of gravity depends on ____________ and _______________. That's why they're important.

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ADDITIONAL NOTES

ADDITIONAL NOTES

1

Reminder: The Importance of Gravity

The weak and strong nuclear forces are short range. They drop to zero outside the nucleus. They play no direct role in the structure of the solar system or the Universe.

Electromagnetism is long range, but large objects are electrically and magnetically neutral. Electromagnetism, too, is irrelevant over large distances.

2

That leaves ______________

Understanding it is intertwined with understanding the Universe on a large scale. Our understanding of one is closely tied to our understanding the other.

3

____
________, yet in some ways understand the least.

At a deep level, it's a magical force that doesn't, unlike electromagnetism or the nuclear forces, exist in the fabric of the Universe – _______________
________________.

But a simpler understanding works on the scale of the solar system and below.

4

The most immediate experience we have of gravity is that things fall.

If the earth were at the center of the Universe, as was thought, one could attribute the tendency of things to fall as their natural tendency to go to the center of the Universe because of their weight. That was the view of Aristotle, and co. (∼300 BC).

5

According to this view, the "heavens" were fixed (apart from the wandering planets) and objects fell because they were trying to get to the center of the Universe.

In the Aristotelian view heavier objects would fall more quickly.

6

Galileo spoiled all that in the 1600s by dropping things.

Around the same time it became clear that the "heavens" were more complicated than had been thought: planets had moons that went around them, for example.

The earth was not the center of everything.

ADDITIONAL NOTES

In the late 1600s, Isaac Newton fixed everything – the shenanigans in the heavens and why things fall to earth by

Newton's Law of Universal Gravitation

$$F_{\text{grav}} = G\frac{m_1 m_2}{d^2},$$

$$\underbrace{G = 6.67 \times 10^{-11}}_{\text{Gravitational constant}}\frac{N \cdot m^2}{kg^2}$$

7

In English:

Every object (mass m_1) attracts every other object (mass m_2) by a force proportional to the product of their masses and inversely proportional to the square of the distance between them.

$$m_1\bullet\underbrace{\longrightarrow\text{attractive gravitational force}\longleftarrow}_{distance\,=\,d}\circ m_2$$

8

Why is this a universal law? Because ____________

____

It applies to you and the earth, to a piece of chalk and the earth, to a piece of chalk and another piece of chalk, to the earth and the moon, to the sun and Jupiter, . . .

The law uses "proportionality." What's that?

9

If $y = x$ then the quantity y equals x.

If $y = 5x$ then y is ____________________ x. We write this as

$$y \propto x$$

This is true whenever $y = kx$ for any fixed k ("____________________________").

10

In Newton's gravitational law

$$F_{\text{grav}} = G\frac{m_1 m_2}{d^2}$$

the quantity G is the proportionality constant.

____________________ – same value for any two objects:

$$G = 6.67 \times 10^{-11}\,\mathrm{N} \cdot \mathrm{m}^2/\mathrm{kg}^2$$

(this is the value when you measure mass in kilograms and distance in meters).

11

We also need ______________________. If

$$y = k \times \frac{1}{x} = \frac{k}{x}$$

where k is fixed, then y is said to be inversely proportional to x.

12

ADDITIONAL NOTES

Assume $k > 0$. If

(1) $y = kx$, as x goes up, y ____________.

(2) $y = kx$, as x goes down, y ____________ .

(3) $y = \frac{k}{x}$, as x goes up, y ____________

(4) $y = \frac{k}{x}$, as x goes down, y ____________

13

Using Newton's law

$$F_{\text{grav}} = G\frac{m_1 m_2}{d^2}$$

(5) Does the gravitational force go up as the masses go up? __________

(6) Does the gravitational force go up as the distance increases? ____________________

14

We need to be more specific about *how much* the gravitational force goes up and down by.

The gravitational force on an object of mass m due to the earth (mass M_{E}) is

$$F = G\frac{mM_{\text{E}}}{d^2}$$

where d is the distance to the *center of the earth*.

15

In each case below, does the gravitational force on m go up or down, and by how much?

(7) m doubles: ________________________

(8) m triples: ________________________

(9) m halves: ________________________ ______________

16

How the gravitational force depends on distance is *slightly* trickier:

If the distance between the two objects goes up, the force ____________________________ __________.

17

In each case below, does the gravitational force on m go up or down, and by how much?

(10) d doubles: ________________________

(11) d triples: ________________________

(12) d halves: ________________________

18

ADDITIONAL NOTES

This means that if the distance between two objects doubles, one of their masses would have to go up by a factor of 4 in order to keep the force the same.

This is Newtonian gravity. The theory works spectacularly well, but not perfectly. . .

19

(13) What is the shape of a planet's orbit around the sun? ________________

Actually a ______________________.

The point of closest approach ("perihelion") of a planet's orbit swings around ("precesses"). This could not fully be explained by Newton's law.

The final explanation was startling.

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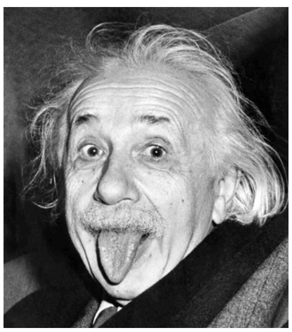
The story starts with him . . .



http://www.npr.org/blogs/13.7/2011/09/28/140839445/is-einstein-wrong

21

(14) Who's he?

____

(15) What's he most known for?

____

22

Summary of the Theory of Relativity

Theory developed between 1905 and 1916, primarily by Albert Einstein.

First version (1905), called Special Relativity. Einstein worked for a decade on extending it, till he succeeded in 1915 (published in 1916) with the General Theory. General Relativity has four main ingredients:

23

1. ________________________
2. ________________________________
3. _______________________________________

   ____

   ____
4. _____________________________________

   ____

24

ADDITIONAL NOTES

It's not all words:

Einstein's theory, expressed via equations,

$$G_{ab} \equiv R_{ab} - \frac{1}{2} g_{ab} R = \frac{8\pi G}{c^4} T_{ab}$$

$\downarrow$ $\downarrow$

Spacetime Geometry — Matter

Ricci Curvature, R_{ab} — Energy-Momentum

Curvature Scalar, R

Metric, g_{ab}

25

Einstein's first paper on relativity in 1905 led that year itself to . . .

26

DOES THE INERTIA OF A BODY DEPEND UPON ITS ENERGY-CONTENT?

BY A. EINSTEIN

September 27, 1905

The results of the previous investigation lead to a very interesting conclusion, which is here to be deduced.

27

The mass-energy paper was short (three pages) at the end of which Einstein concluded

If a body gives off the energy L in the form of radiation, its mass diminishes by L/c^2. The fact that the energy withdrawn from the body becomes energy of radiation evidently makes no difference, so that we are led to the more general

Page 3

In other words, $m = L/c^2$, or, as we know it,

$$E = mc^2$$

To get to this Einstein had to make a leap on what energy is.

28

Humans are not the only entities that have now figured out that small amounts of mass can lead to vast quantities of energy (c^2).

The sun (and other stars) have, as well.

But, on to curved geometry. . .

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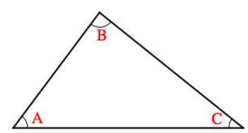
Introduction to Curved Geometry

A key feature of flat geometry is that the angles of a triangle always add to ________________



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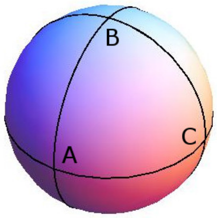
ADDITIONAL NOTES

Now look at a triangle drawn on the surface of a sphere:



(16) What does $\angle A$ seem to be? ______

(17) What does $\angle C$ seem to be? ______

31

Therefore, on a sphere

This is true of any triangle that you draw on a sphere with "straight lines" (lines of shortest distance).

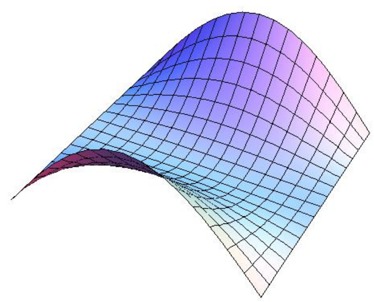
32

Surfaces where the angles of a triangle add to

- ______ have ______ ______.
- ______ have ______ , or are called ______.
- ______ have ______ .

33

A ______ is an example of a space with negative curvature:



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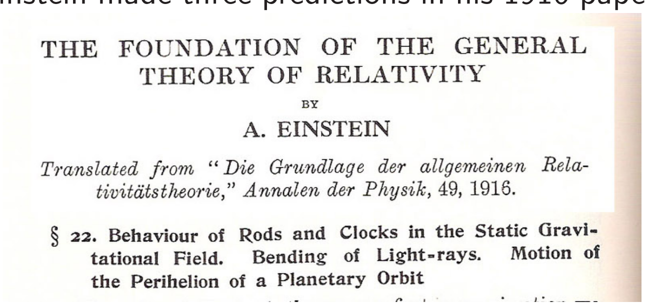
Einstein made three predictions in his 1916 paper:



THE FOUNDATION OF THE GENERAL THEORY OF RELATIVITY

BY

A. EINSTEIN

Translated from "Die Grundlage der allgemeinen Relativitätstheorie," Annalen der Physik, 49, 1916.

§ 22. Behaviour of Rods and Clocks in the Static Gravitational Field. Bending of Light-rays. Motion of the Perihelion of a Planetary Orbit

We'll discuss them in reverse order.

35

Einstein Test 3

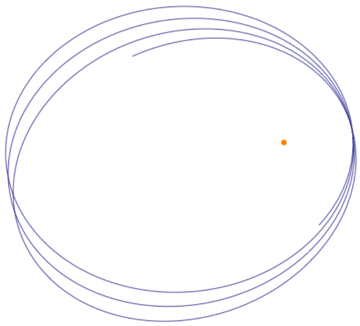
Motion of the perihelion of a planet

The ______ of a planetary orbit is ______

A planet (Mercury, e.g.) goes around the sun on an elliptical path. But, the path does not close: the perihelion is not at the same point every year.

36 This is called ______

ADDITIONAL NOTES



A precessing ellipse

37

Till Einstein, we could explain most of the precession, except for a small amount:

0.012° – every hundred years!

Einstein's proposal was that the matter of the sun warps surrounding spacetime geometry. Mercury moves on a straight line on this curved background.

Sounds weird, but you get exactly the extra 0.012° that you need.

38

Einstein Test 2

The bending of light

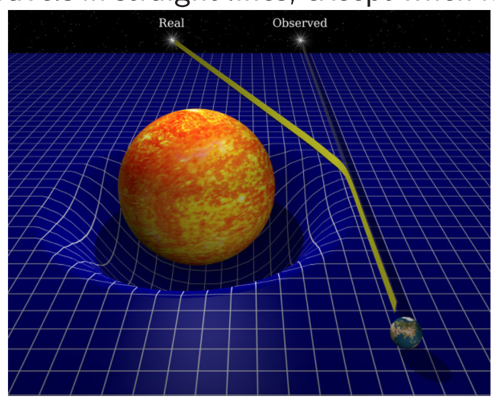
Light bends around objects like the sun.

Really? Does Gravity affect light?

Really (even though in Newtonian gravity, it's just mass that's involved).

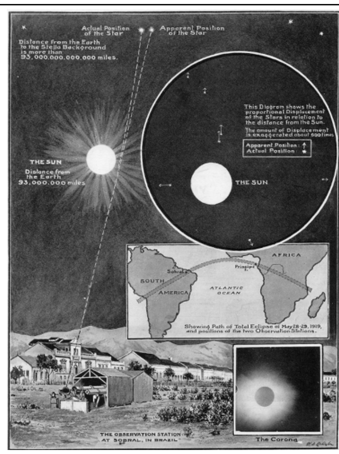
39

Light travels in straight lines, except when it bends:



40

The English astronomer Arthur Stanley Eddington, and others, proposed a test of Einstein's prediction of the bending of light, to be done during a solar eclipse in Brazil on May 29, 1919.



41

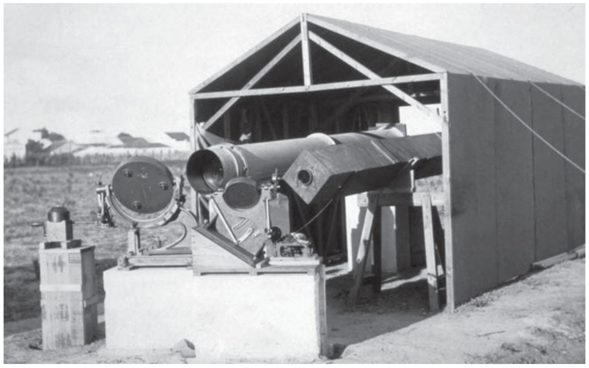
(18) Why solar eclipse? ______________________

____

42

ADDITIONAL NOTES

An expedition was organized:



43

They took photos with two telescopes in cloudy conditions of about a dozen stars near the sun during the eclipse, then of the same stars at night two months later.

(19) Why did they return two months later?

44

The team returned to England to compare and analyze the photographic plates.

They asked for a special joint meeting of the Royal Astronomical Society and the Royal Society of London for November 6, 1919, to make an announcement.

45

The prediction from Einstein's theory was that the angular positions of stars near the sun would shift by $1.75''$. The Eddington expedition results were

Telescope 1: $(1.98 \pm 0.12)''$

Telescope 2: $(1.61 \pm 0.30)''$

Given the small number of stars looked at, these are not completely convincing results.

46

Reaction at the meeting was mixed.

One person present called it

"the most important result obtained in connection with the theory of gravitation since Newton's day."

But another pointed to a portrait of Newton hanging in the room and urged caution:

"We owe it to that great man to proceed very carefully in modifying or retouching his Law of Gravitation."

47

Einstein had been kept informed as the data was analyzed. He had always been confident.

On September 27, nearly 6 weeks before the official announcement, he wrote to his mom:

". . . joyous news today. . . . the English expeditions have actually measured the deflection of starlight from the Sun."

48

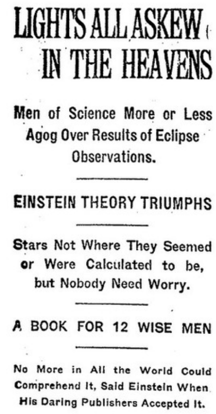
ADDITIONAL NOTES

The Press shared Einstein's enthusiasm. The London Times of November 7, 1919, one day later, carried a long article about the Royal Society meeting, headlined

REVOLUTION IN SCIENCE
NEW THEORY OF THE UNIVERSE

Three days later The New York Times got into it...

49


LIGHTS ALL ASKEW IN THE HEAVENS

Men of Science More or Less Agog Over Results of Eclipse Observations.

EINSTEIN THEORY TRIUMPHS

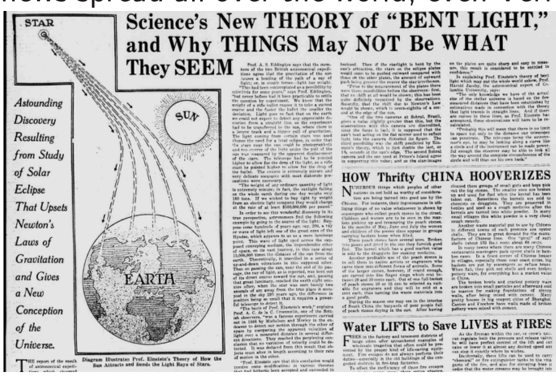
Stars Not Where They Seemed or Were Calculated to be, but Nobody Need Worry.

A BOOK FOR 12 WISE MEN

No More in All the World Could Comprehend It, Said Einstein When His Daring Publishers Accepted It.

50

The news spread all over the world, even Vermont:


Science's New THEORY of "BENT LIGHT," and Why THINGS May NOT Be WHAT They SEEM

Astounding Discovery Resulting from Study of Solar Eclipse That Upsets Newton's Laws of Gravitation and Gives a New Conception of the Universe.

HOW Thrifty CHINA HOOVERIZES

Water LIFTS to Save LIVES at FIRES

51

In 1921 Einstein visited New York:

52

Einstein Test 1

The behavior of rods and clocks

Space *and* time are warped.

The behavior of time is particularly interesting.

Clocks tick slightly slower on the surface of the earth than on the top of tall buildings or in planes.

Motion also affects the "flow" of time.

53

Tests of Time Alterations

a) In 1971 Keating and Hafele flew four caesium atomic clocks around the world on commercial aircraft, first traveling from east to west, then from west to east. The results of the experiment confirmed the relativistic predictions within 10%. The experiment was repeated in 1996 on a trip from London to Washington and back, a 14 hour journey. The result was within 2 ns of the prediction.

54

ADDITIONAL NOTES

b) Muon lifetime [Bailey,J. et al. Nature **268**, 301 (1977)]: Muons with "rest lifetime" of $2.198\,\mu$s were sped to high speed ($.999c$). The measured lifetimes at those speeds were found to be $64.368\,\mu$s, consistent with relativity.

55

c) paper in *Science*, 2010:

Optical Clocks and Relativity

C.W.Chou, D.B.Hume, T.Rosenband, D.J.Wineland

Science, 24 Sep 2010, Vol.329, Issue 5999, pp.1630-1633

"Observers in relative motion or at different gravitational potentials measure disparate clock rates. . . . We observed time dilation from relative speeds of less than 10 meters per second by comparing two optical atomic clocks connected by a 75-meter length of optical fiber. We can now also detect time dilation due to a change in height near Earth's surface of less than 1 meter."

56

d) GPS


Los Angeles Air Force Base

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GLOBAL POSITIONING SYSTEMS DIRECTORATE

Posted 4/8/2015 Printable Fact Sheet

The Global Positioning Systems Directorate is a joint service effort directed by the United States Air Force and managed at the Space and Missile Systems Center, Air Force Space Command, Los Angeles Air Force Base, Calif. The directorate is the Department of Defense acquisition office for developing and producing Global Positioning System (GPS) satellites, ground systems and military user equipment.

GPS is a space-based dual use radio navigation system nominally consisting of a minimum of 24-satellite constellation that provides positioning, velocity and timing to military and civilian users worldwide. GPS satellites, in one of six medium earth orbits, circle the earth every 12 hours transmitting continuous ranging signals. In addition to the satellites, the system consists of a worldwide satellite control network and GPS receiver units that acquire the satellite's signals and compute navigation solutions to provide positioning, velocity and timing to the user.

GPS provides the following:

24-hour, worldwide service
Highly accurate, three-dimensional location information
Precision velocity and timing services
Accessibility to an unlimited number of global military, civilian, and commercial users

Photos

Global Positioning Systems Directorate

Download HiRes

57

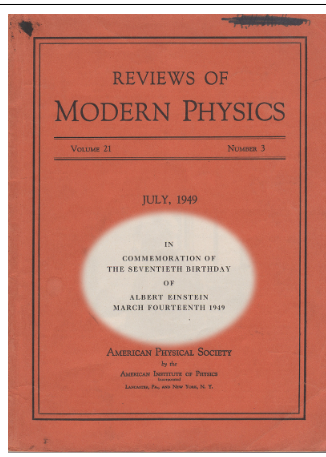
From: www.losangeles.af.mil/shared/media/document/AFD-100302-043.doc

3.3.1.1 Frequency Plan. . . . The SV carrier frequency and clock rates – as they would appear to an observer located in the SV – are offset to compensate for relativistic effects. The clock rates are offset by $\Delta f/f = -4.4647\times10^{-10}$, equivalent to a change in the I5 and Q5-code chipping rate of 10.23 MHz offset by a $f = 4.5674\times10^{-3}$Hz.

58

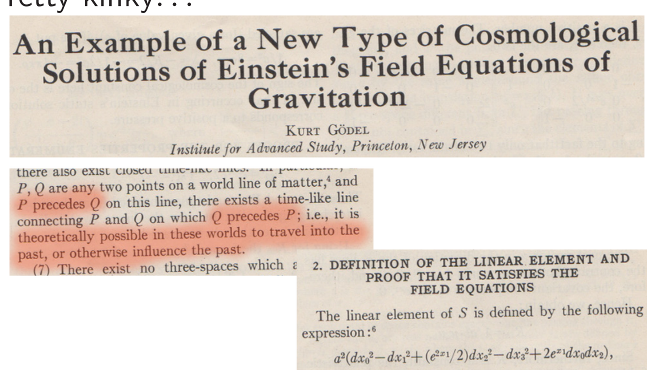
So time can be twisted in relativity.

How kinky can time get?



59

Pretty kinky. . .


An Example of a New Type of Cosmological Solutions of Einstein's Field Equations of Gravitation

KURT GÖDEL

Institute for Advanced Study, Princeton, New Jersey

there also exist closed time-like lines. In particular, if P, Q are any two points on a world line of matter,[4] and P precedes Q on this line, there exists a time-like line connecting P and Q on which Q precedes P; i.e., it is theoretically possible in these worlds to travel into the past, or otherwise influence the past.

(7) There exist no three-spaces which a

2. DEFINITION OF THE LINEAR ELEMENT AND PROOF THAT IT SATISFIES THE FIELD EQUATIONS

The linear element of S is defined by the following expression:[6]

$$a^2(dx_0^2-dx_1^2+(e^{2x_1}/2)dx_2^2-dx_3^2+2e^{x_1}dx_0dx_2),$$

60

ADDITIONAL NOTES

The story so far

(1) What is the most important force in understanding things on the solar system scale and beyond?

____

____

____

1

(2) What are the other forces?

____

____

____

2

(3) What astro-roles *do* the other forces play?

Electromagnetism: _________________________

____

____

Nuclear forces: ___________________________

3

But ____________________________ determines how astronomical objects move in the solar system, and even how things are shaped.*

* ____________________________________

____

4

(4) What shape are most astronomical objects?

____

(5) Why?

____

____

____

5

(6) Are there non-spherical objects in the solar system? ___________

(7) Name some. __________________________

(8) How can they be non-spherical?

____

____

____

6

ADDITIONAL NOTES

(9) If a massive body pulls itself into spherical shape through self-gravity, what prevents that same self-gravity from making it contract indefinitely?

____

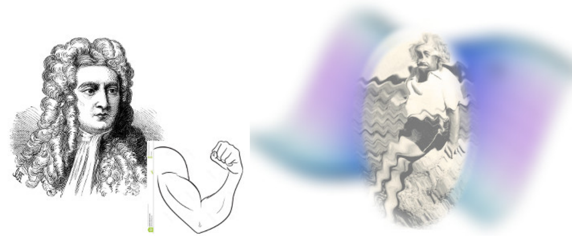
____

____

7

Which Gravity do we use?

Newtonian force or Einsteinian curved spacetime?



8

We believe Einstein's theory to be more "correct" than Newton's, but ____________________

____

For most solar-system considerations, Newton's theory is more than adequate – and it's easier.

Only for high-precision work, often involving very precise time measurements, do we need general relativity on the solar system scale.

9

Brief History of Planetary Motion

▷ ________________: ________________

________.

Till about the 1500s (Caludius Ptolemy, Greco-Egyptian, roughly AD 90–168, and others).

Backward motion of planets called "retrograde." Retrograde simulation:

10 http://www.nakedeyeplanets.com/movements.htm

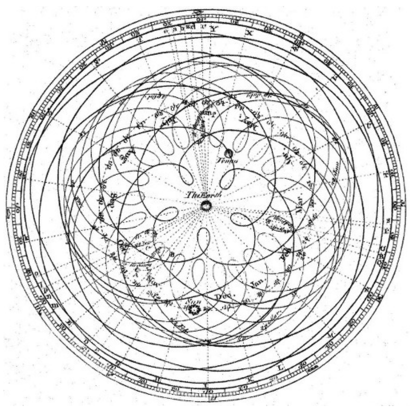
Ptolemy

11

Ptolemy

12

ADDITIONAL NOTES



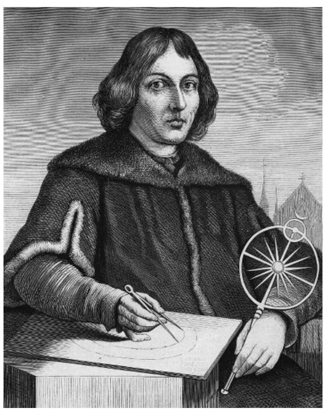
Epicycles needed to explain retrograde motion

13

▷____________________: ________________ ________.

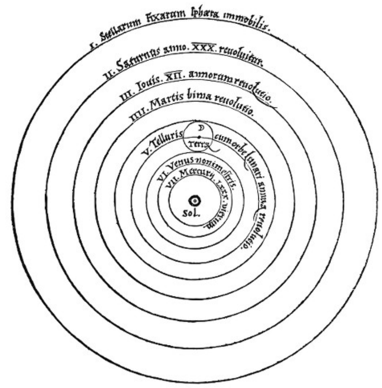
Early versions go back to the third century BC (Aristarchus), but the modern theory dates from around 1540 (Nicolaus Copernicus, Polish, 19 Feb. 1473 – 24 May 1543).

14



Copernicus

15



Copernican orbits

16

Detailed study of the heliocentric theory and the motions of the planets in it was made by Johannes Kepler (German, December 27, 1571 – November 15, 1630).

He distilled what he noticed into three laws, called ________ _______________

17

Johannes Kepler, 1610, unknown artist (Wikipedia)

18

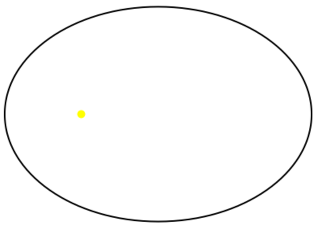
ADDITIONAL NOTES

Law 1, The Law of Ellipses:

____

____

____



19

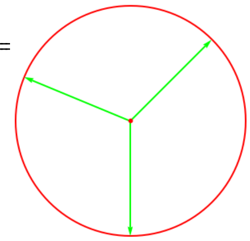
What's an ellipse? It's a cousin of the circle.

(10) What's a circle?

____

____

____



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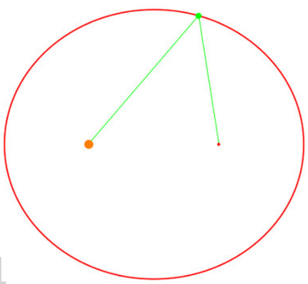
____

____

____



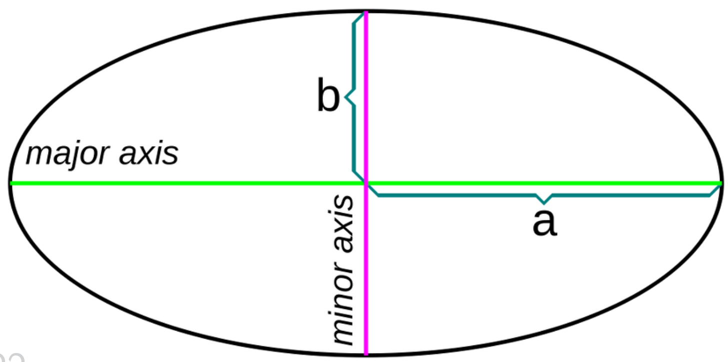
Pt. 1: ___ + ___ = ____

Pt. 2: ___ + ___ = ____

Pt. 3: ___ + ___ = ____

21

Ellipses and their Axes



22

The Eccentricity of an Ellipse

The long line is the major axis; a is the length of half of it (the _______________________).

The short line is the minor axis; b is the length of half of it (the _______________________).

The ___________________ of an ellipse is given by

$$e = \sqrt{1 - \left(\frac{b}{a}\right)^2}$$

23

(11) When is the eccentricity, e, zero?

____

____

(12) What shape does $e = 0$ (i.e., $a = b$) correspond to? _______________

(13) Can the eccentricity be less than zero?

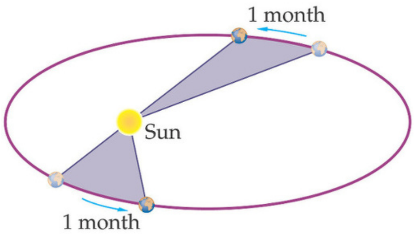
____

24 _____________________________________

ADDITIONAL NOTES

Law 2, The Law of Equal Areas:

A line from the sun to the planet sweeps out equal areas in equal times.



https://eloisechen.wordpress.com/

25

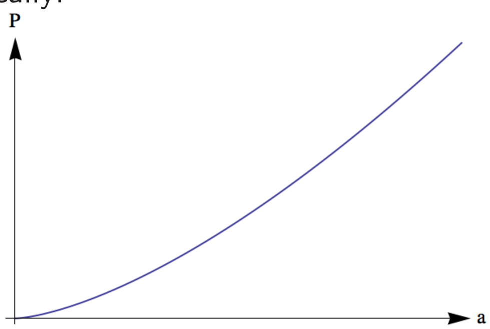
Law 3, The Law of Harmonies:

The square of the ____________ a planet's orbit (its "year") is proportional to the cube of its average distance from the sun (or the length of its semi-major axis).

$$P^2 \propto a^3$$

26

Graphically:



27

(14) As an object gets further from the sun, does its semi-major axis go up or down?

____

(15) Does its year get longer or shorter?

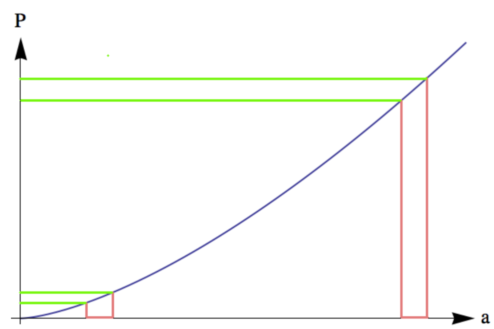
____

28

(16) If the semi-major axis goes up by a certain amount for a planet close to the sun, and by the same amount for a planet far from the sun, do the planetary years go up by the same amount?

____

29



30

ADDITIONAL NOTES

The Role of Gravity

Kepler's laws were used by Newton in formulating his law of gravitation.

He tailored his law so that Kepler's three laws follow from his formula (and so does much more).

We'll study how the law of gravitation is used in astronomy by studying how two objects behave under their mutual gravitational attraction.

31

The Gravitational 2-Body Problem

$$m_1 \bullet \underbrace{\rightarrow \text{ attractive gravitational force } \leftarrow}_{distance = d} \circ m_2$$

$$F_{\text{grav}} = G\frac{m_1 m_2}{d^2}$$

(17) Given this force between m_1 and m_2 how will they behave?

____

____

32

Situation 1: The two objects start at rest.

(18) What will their mutual gravitational attraction make them do? ________________________

33

(19) Will they meet at the center ($d_1 = d_2$)? If so, why? If not, which object will the collision be closest to?

____

The relationship is

34

(20) If $m_2 > m_1$, then $d_2 < d_1$. Why?

____

To find out how much the more massive body moves, assume that $m_2 > m_1$. We can re-express

$$m_1 d_1 = m_2 d_2$$

as

$$d_2 = \frac{m_1 d_1}{m_2}.$$

35

(21) The mass of the earth is roughly 6×10^{27} gm. If you drop a 6 gm piece of chalk and it travels 1 m before it hits the earth, how much does the earth move?

$$d_2 = \frac{m_1 d_1}{m_2} =$$

36

ADDITIONAL NOTES

10^{-27} m is a millionth of a millionth of a millionth of a billionth of a meter.

The radius of a proton is a little under 10^{-15} m (called a __________).

(22) How many powers of ten is this bigger than the earth's movement in our situation?

____

____

37

It would take a mass 6 million million grams (or 6 billion kg) to make the earth move by the size of a proton.

That's why for all realistic calculations involving motion to (and from) the earth, we can take the earth as essentially fixed.

38

Situation 2: The objects start with initial velocities directly away from each other.

$$v_1 \longleftarrow \underset{m_1}{\bullet} \underbrace{\rightarrow \text{gravitational force} \leftarrow}_{d} \underset{m_2}{\circ} \!\rightarrow v_2$$

39

(23) What will happen?

____

____

____

____

An energy balancing allows us to calculate what will happen.

40

Which energies do you balance?

1) ____________________, energy due to motion:

2) ____________________________________ between two objects of masses m and M:

$$\text{Total Energy} = \frac{1}{2}mv^2 - \frac{GmM}{r}$$

41

To "balance energy" you ______________________ __________________________.

For example, If the objects reach a momentary state when they are both at rest at their maximum distance from each other, the energy balance is

$$\frac{1}{2}m_1 v_1^2 + \frac{1}{2}m_2 v_2^2 - G\frac{m_1 m_2}{d} = 0 - G\frac{m_1 m_2}{d_{\text{max}}}$$

42

This allows us to find d_{max}.

ADDITIONAL NOTES

If $d_{\text{max}} \to \infty$, we get a measure of how big the initial velocities must be for the two objects to separate infinitely far:

$$\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 - G\frac{m_1m_2}{d} = 0.$$

Or

$$\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 \geqslant G\frac{m_1m_2}{d}$$

for "separation."

43

This is used, for example, to calculate the escape velocity of a rocket ship from earth.

If $m_2 = m_{\text{earth}}$ and $v_2 = v_{\text{earth}} = 0$, and the subscripts 1 refer to the rocket, we have

$$\frac{1}{2}m_{\text{rocket}}v_{\text{rocket}}^2 + 0 \geqslant G\frac{m_{\text{rocket}}m_{\text{earth}}}{d}$$

Canceling m_{rocket} from both sides, we get

44

$$\frac{1}{2}v_{\text{rocket}}^2 \geqslant G\frac{m_{\text{earth}}}{d}$$

or

$$v_{\text{rocket}}^2 \geqslant 2G\frac{m_{\text{earth}}}{d}$$

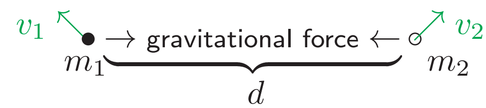
or

$$v_{\text{rocket}} \geqslant \sqrt{2G\frac{m_{\text{earth}}}{d}}.$$

This is the "escape velocity" formula for rockets leaving earth.

45

Situation 3: The objects start with random initial velocities.



(24) What will happen? ____________________

____

____

46

If one object is much more massive than the other, all the motion will come from the less massive one.

That's the situation in many solar system applications (as opposed to stellar dynamics where you can have equally massive stars orbiting each other in binary pairs).

47

Possible orbits when an object interacts gravitationally with a much more massive one:

▷ Ellipse (special case, circle)

▷ Hyperbola (border case, parabola)

Orbits in the 2-body problem are stable.

If there are three bodies, there's chaos...

48 http://tinyurl.com/dd67fu

ADDITIONAL NOTES

Light

(1) How do we know the rest of the astronomical Universe exists? (We cannot feel it, smell it, hear it or taste it.) ________________

(2) What do we need in order to see (besides our eyes)? ____________

1

What is Light?

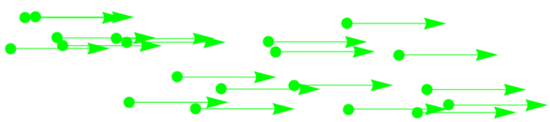
When people say "light" they usually mean visible light.

But it's one form of a larger phenomenon called ________________________. We'll use "light" to cover the whole spectrum.

Light has a dual nature: ____________ and ________

2

Light as a Particle



The individual particles ("packets of energy") are called ...______________ ________________ __________

3

The person who owned this nice pair of legs is responsible for the photon:

(3) Who is it?

4

Einstein used the "particle nature of light" to explain the ______________________.

This is the effect where light, shining on certain materials, sets up electric currents.

For most astronomical uses, however, it's the "wave nature of light" that's more important.

5

Light as a Wave

(4) What's a wave? ______________________

The two key attributes of waves are:

- ________________________________
- __________________________________

The speed of a wave, c, is related to these two by

6

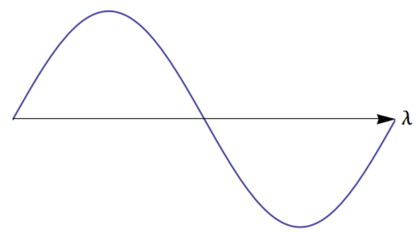
ADDITIONAL NOTES

(5) If two waves (A, B) have the same speed, but A has twice the wavelength of B, how are their frequencies related? ____________________________

(6) If two waves (C, D) have the same speed, but C has three times the frequency of D, how are their wavelengths related? ____________________________

7

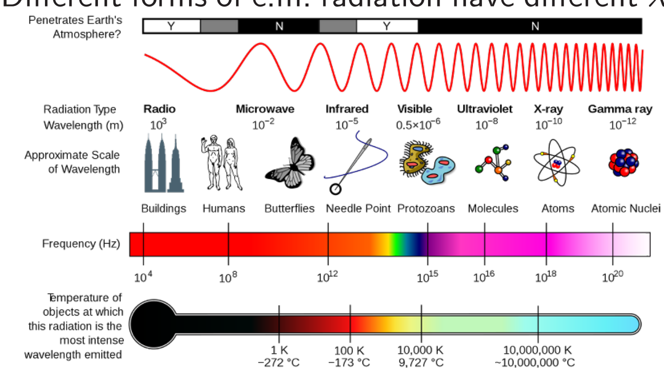
Visualizing wavelength



____

8

Different forms of e.m. radiation have different λs:



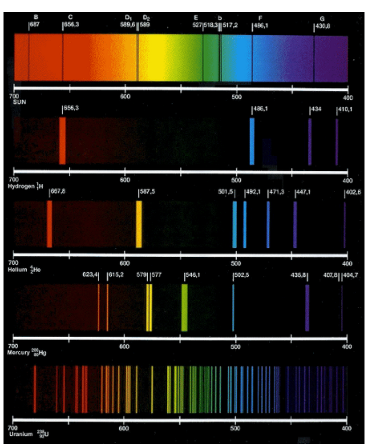
9

Spectral Lines

Elements emit radiation at characteristic wavelengths – a sort of signature of the element. These are called its ____________________.

The radiation from an astronomical object can be decomposed, via an instrument called a spectrometer, into its spectral lines. From those we can precisely identify the elements in the object.

10



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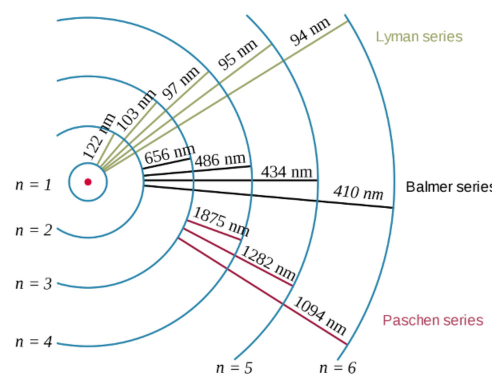
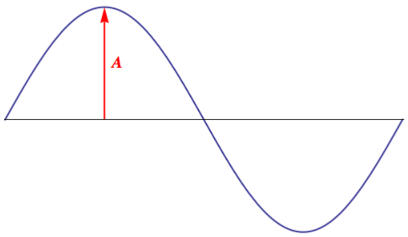


How spectral lines arise.

12

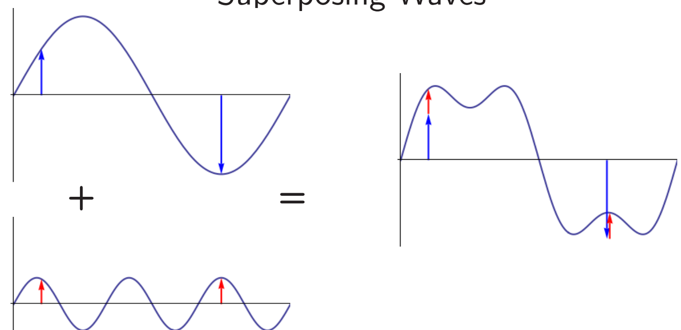
ADDITIONAL NOTES

Wave Amplitude



13

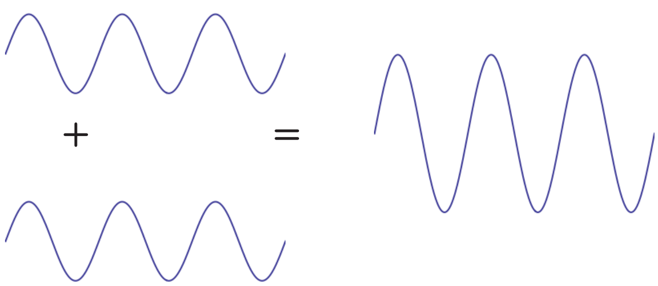
Superposing Waves



When two waves meet their amplitudes add, as shown.

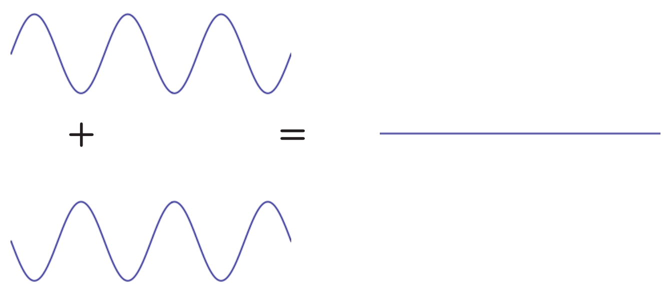
14

Constructive Interference



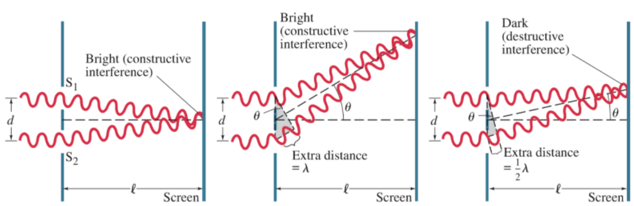
15

Destructive Interference



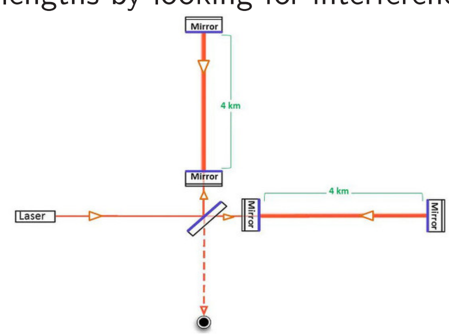
16

These effects, where waves can reinforce each other or cancel each other, lead to patterns of dark and light lines called an interference pattern.



17

A (Michaelson) interferometer detects changes in the arm lengths by looking for interference.

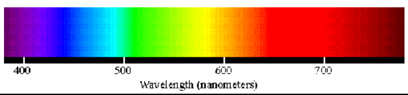


18

ADDITIONAL NOTES

The Doppler Effect

As objects move away from us, the wavelength of signals they emit gets stretched (gets longer) compared to normal. The faster an object moves from us, the longer the wavelength of the radiation from it and the "redder" it looks. This is called __________.



19

Similarly, as objects move toward us, the wavelength of signals they emit gets compressed (gets shorter) compared to normal.

The faster an object moves toward us, the shorter the wavelength of the radiation from it and the "bluer" it looks. This is called ______________.

(7) Can you explain this with frequencies? _______

20

____

____

21

Energy

The energy in an EM wave is proportional to the frequency:

____

As the frequency goes up, the energy goes ______

22

It's the energy in electromagnetic radiation that can be harmful.

(8) Is uv radiation likely to be more or less harmful than infrared? __________

(9) Why?

____

____

23

Next stop . . . telescopes . . .

24

ADDITIONAL NOTES

Telescopy

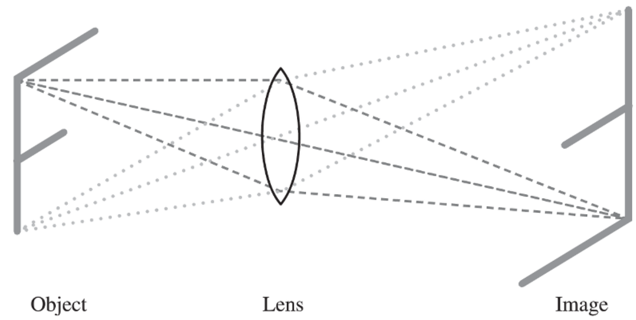
(10) How does light travel?

____

____

25

The bending of light causes ____________



____

26

On the previous diagram, different rays of light travel along different paths and reunite (“focus”) at the image.

There’s an interesting consequence:
(11) What would happen if part of the lens were taped off? Would part of the image disappear?

____

27 ___________________________

Refracting Telescopes

Lensing is the basis of class of cameras, telescopes, etc., called ____________________

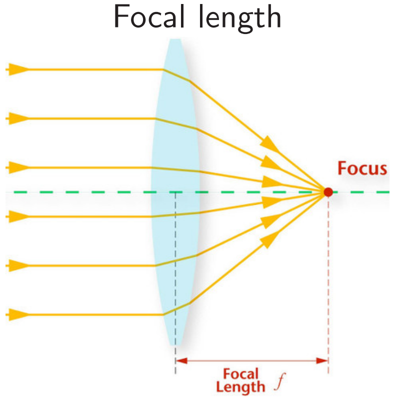
These are devices that work like the eye does.

A key attribute of a lens is its ____________
This is ______________________________

____

28

Focal length



29

Image Size

If an object “occupies” an angle θ (in degrees) in the field of view, then the image size, s, it makes on a seeing device with focal length f is

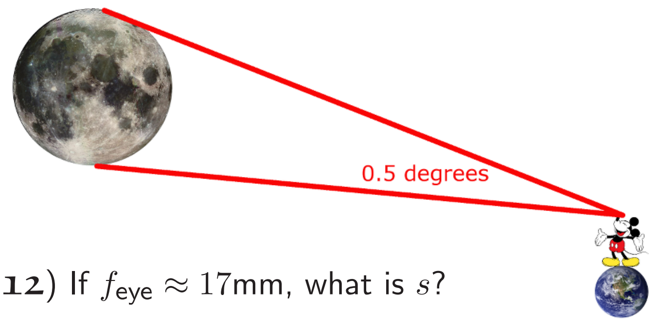
____

____

s has the same units as f.

30

ADDITIONAL NOTES



(**12**) If $f_{\text{eye}} \approx 17$mm, what is s?

31

That's the diameter of the image the moon makes on your retina.

(**13**) A telescope with a focal length that's a thousand times as long (17m), will make an image that's how large?

____

____

32

Image Resolution

Simply increasing the size of an image does not mean you'll see more detail.

You also need to increase the ______________

33

The ________________ of a device is the ________________________________ __________.

The formula (for resolution in degrees) is

where D is the diameter and λ the wavelength.

____

34

(**14**) Do you get better resolution with red light or blue?

____

(**15**) Looking at the formula for resolution, what might you change in a device to get better resolution across wavelengths?

____

35

(**16**) Visible light has an average wavelength of $\lambda = 5 \times 10^{-7}$ m. What is the resolution of a telescope with a 1 m lens (diameter)?

36

ADDITIONAL NOTES

The angles in angular resolutions are usually very small.

We use fractions of a degree when representing small angles:

$$\left(\frac{1}{60}\right)^\circ = 1' \text{ (one ________).}$$

$$\left(\frac{1}{60}\right)' = \left(\frac{1}{3600}\right)^\circ = 1'' \text{ (one ________).}$$

37

How to make better refracting telescopes

- ________________________________
- ________________________________

____

____

38

Problems with refracting telescopes

- Long tubes tend to ________
- Larger lenses are ________________

  ____
- Blurring due to ________________

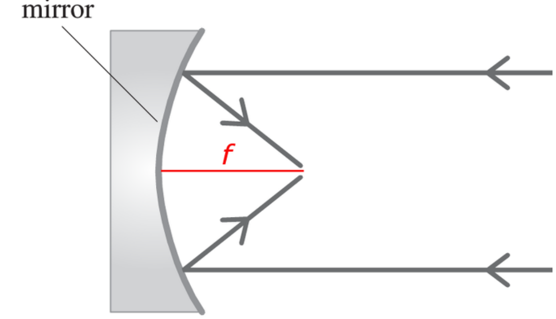
  ____

  ____
- Chromatic aberration: ________________

  ____

39

Reflecting Telescopes



____

40

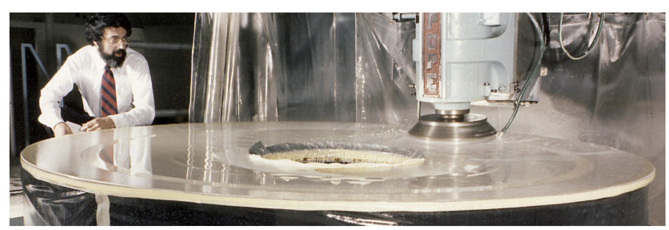
Advantages of Reflecting Telescopes

- ________________________________

  ____
- ________________________
- ________________________________

41

The mirror backing is often glass, because it can be shaped with high precision.



Polishing the mirror for the Hubble space telescope

42

ADDITIONAL NOTES

How much precision do you need?

It depends on the wavelength. For observations at wavelength λ, ________________________________

____

(17) Do you need a smoother surface for a radio telescope or an optical one?

____

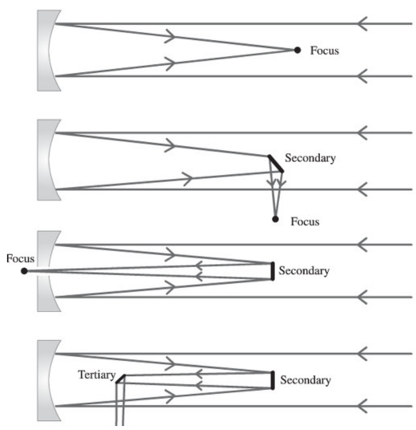
43 ____________________

The reflective surface depends on use: aluminum for visible wavelength, gold for infra-red, etc.

(18) Looking at gold, what says it's a better reflector at the red(ish) end of the spectrum than the blue? ______________

(19) There seems a flaw in reflecting telescopes. What? ________________________________

44



Different reflector models.

45

The blocking of light in the middle does not obscure part of the image, for the same reason as it does not for lenses.

It just ________________________________

The next few slides show you some telescopes used by astronomers.

46

▷ BICEP and Keck Arrays

We travel first to the South Pole:

47

• What does this telescope do?

Collecting for several years, starting in 2006, low-temperature microwave radiation from the very early Universe (around the "big bang").

The project is in its third phase, BICEP3.

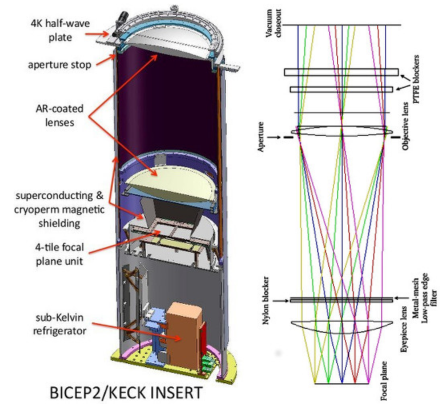
(An early announcement from BICEP2 in 2014 on the nature of "big bang radiation" was premature.)

48

ADDITIONAL NOTES

49

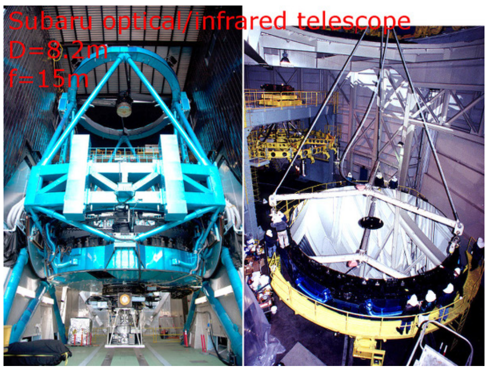
BICEP2 interior



50

BICEP2 schematics

▷ Subaru optical/infrared



51

Located on the summit of Mauna Kea, 4,205m high (dry, stable air).

(At least 13 telescopes from 11 countries there.)

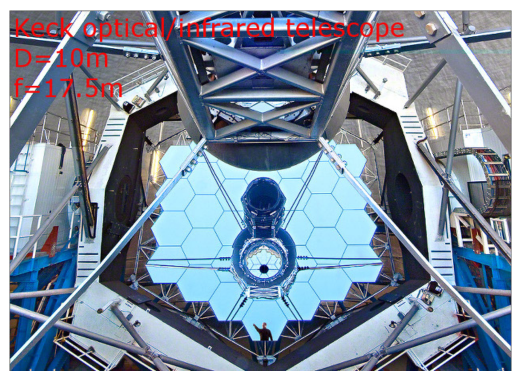
52

- What has Subaru done?
  - August 2013: Direct sighting of a Jupiter-like planet around another star.
  - January 2016: Start of hunt for “Planet X,” a possible Neptune sized planet beyond Pluto.
  - January 2017: Star forming galaxies in the distant (therefore, early) Universe.

http://subarutelescope.org/Pressrelease/list.html

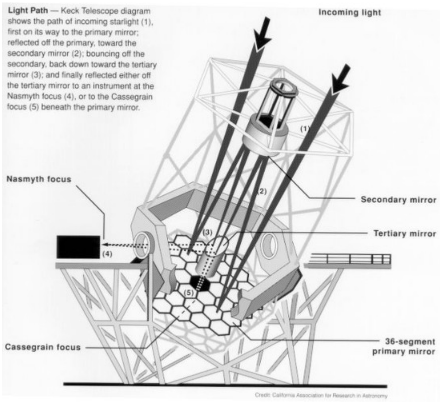
53

▷ Keck



54

ADDITIONAL NOTES



Diagram

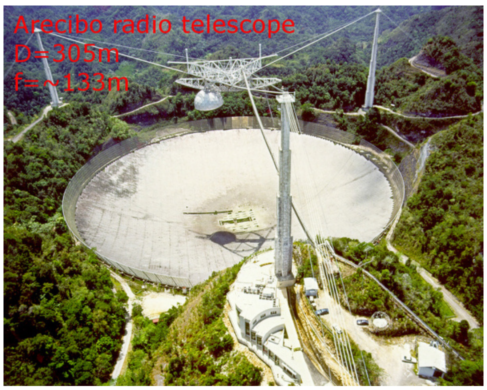
55

- What has Keck done?
  - March 5, 2015: 4-image cosmic lens.
  - March 5, 2015: Evidence for a past ocean on Mars from analysis of the atmosphere.
  - February 10, 2017: Dwarf star system with carbon, nitrogen, oxygen, and hydrogen.
  - Ongoing: Galactic center, UCLA group.

http://www.keckobservatory.org/recent/type/news

56

▷ Arecibo



57

A telescope in the ground? Look at rooftops:

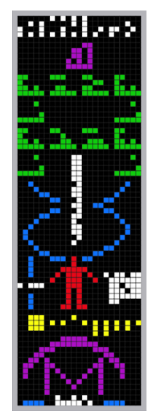
58

These are all satellite dishes:

Wavelengths: $\lambda \sim 1.5$–3cm

59

- What has Arecibo done?
  - 2017: Limits on g. waves.
  - Multi-year: Asteroid hunter.
  - 2011: Cold brown dwarfs.
  - 1974: Attempted CETI. $\longrightarrow$
  - 1974: T&H, binary pulsar.
  - 1964: Mercury rot. 59 days.

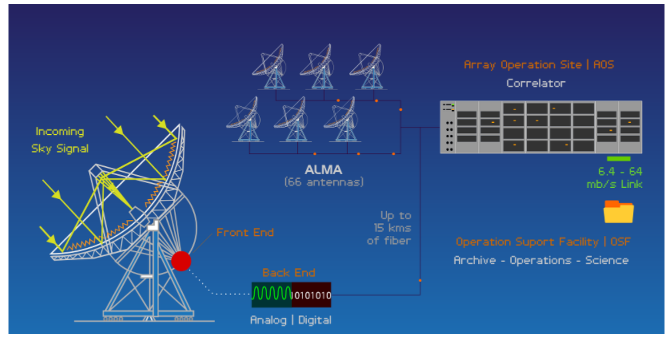


60

ADDITIONAL NOTES

▷ ALMA array

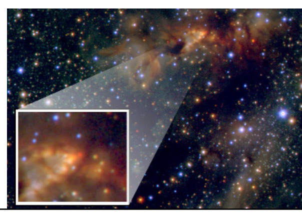
61



Schematic

62

- What has ALMA done?
  - February 2015: Star form., Sculptor Galaxy
  - December 2014: Black hole jets blowing away the Hydrogen from entire galaxies.
  - November 2014: Formation of stars $> M_{\odot}$.



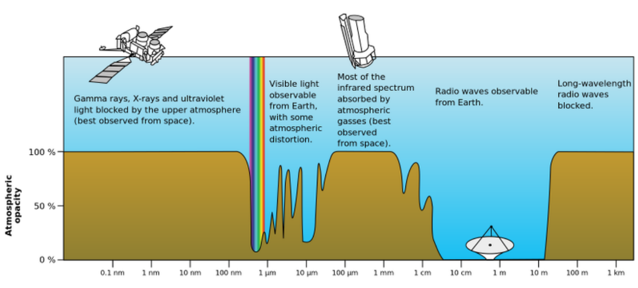
63

These were telescopes based on earth. They have limitations:

- ______________________________
- ____
  ____
  ____
- ____
  ____

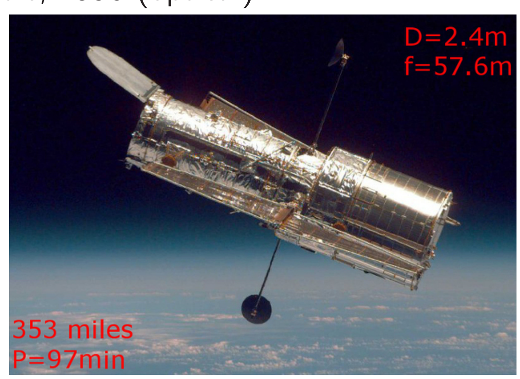
64

At certain wavelengths, we need telescopes based in space:



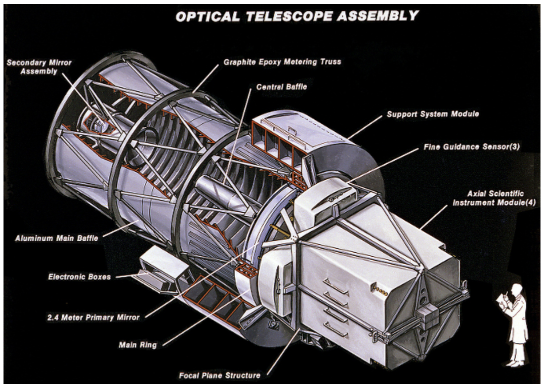
65

▷ Hubble, 1990 (optical)



66

ADDITIONAL NOTES



Inside Hubble

67

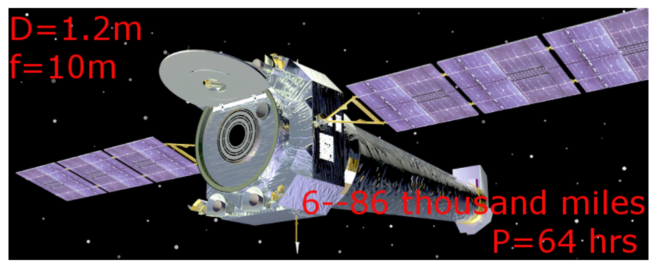
Fixing Hubble

68

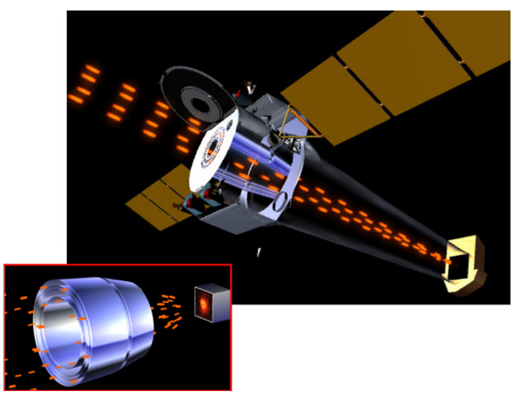
- What has Hubble done?
  - 2001: Planet forming disks common around stars; found planets.
  - 1999–2002: Age of Univ.: ~ 13 giga-yrs.
  - 1998–2001: Accelerated expansion of Universe.
  - 1997: Black holes at centers of galaxies.
  - 1996: 1,000s of pictures of galaxy evolution.

69

▷ Chandra, 1999 (x-ray)



70



The Chandra "mirror"

71

- What has Chandra done?
  - January 2015: Bright X-ray flare from MW black hole.
  - 2012: Halo of hot gas around MW.
  - 2006: Strong evidence for dark matter.
  - 2002: Possible evidence for quark stars.
  - 2000: Possible mid-sized black holes.

72

ADDITIONAL NOTES

1

We'll discuss the Earth's

- ______
- ______
- ______
- ______
- ______
- ______

Note: We'll use "$\sim$" to mean "roughly" ("approximately").

2

Shape and Size

Shape: ______

______

Size: Equatorial radius: ______

Polar radius: ______

(1) Which is bigger? ______

______.

3

(2) What is the rough radius in cm?

______

(3) Is there a reason for the polar flattening?

(Hint: Same reason we have day and night.)

______

______

4 http://www.scientificamerican.com/article/earth-is-not-round/

The shape of the earth is an ______

______ http://tinyurl.com/zzqjjvo

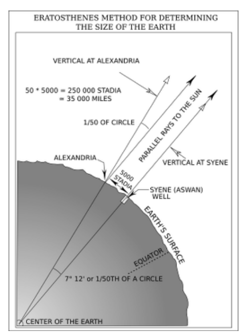
(4) Think about for later: what might the flattening tell you about the interior of the earth?

(5) How do we know the radii of the earth?

______

(6) How do we know the circumference? ______

5 ______



When the sun was overhead at Syene, it made an angle of $\sim 7°$, or roughly 1/50th of $360°$, with the vertical at Alexandria.

So, $C = 50 \times$ A-S distance, giving $R \approx 7{,}000$ km.

– Eratosthenes (around 200BC).

6

ADDITIONAL NOTES

Mass (M) and Density (ρ)

M ________________

Average ρ ________________

The surface of the earth is mainly water ($\rho \sim 1\,\mathrm{g/cm^3}$) and rock ($\rho \sim 2.7$–$3.5\,\mathrm{g/cm^3}$).

(7) Can you conclude anything about the density of the interior of the earth?

7 ______________________________

(8) How do we know the mass of the earth?

____

____

(9) How do we know the average density of the earth? ______________________________

8

(10) Using the value of the radius on slide 4 what is the volume of the earth in cm^3?

9

(11) Using M from slide 7 what is ρ_{earth}?

That is the *average* density of the earth.

But know more than just that.

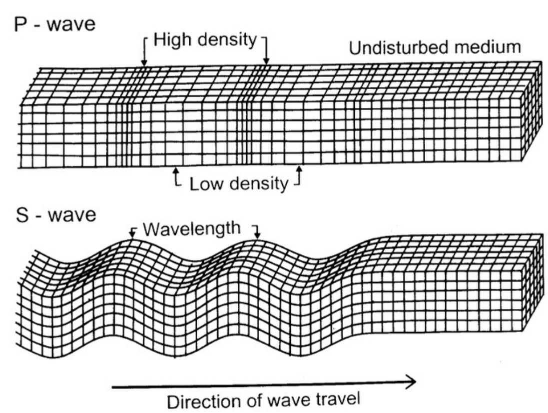
10

We study the composition earth's layers from the transmission of earthquake waves through it.

There are two types of earthquake waves that travel through the body of the earth:
______________ and ______________.

By recording which waves arrive at different points on earth from an earthquake we can determine if

11 the earth is entirely solid or has liquid in the core.



P and S waves

12

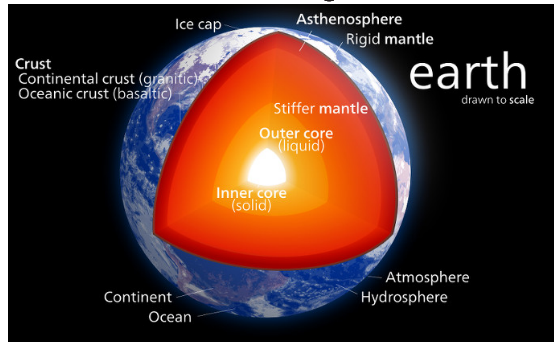
ADDITIONAL NOTES

P waves are ________: they vibrate back-and-forth in the direction of motion. ________________

S waves are ________: they vibrate perpendicular to the direction of motion. ________________

13

This structure is what emerges:



14

Now go back to Q4 and answer it.

____

____

This is born out by the earthquake measurements.

15

Age

Best estimate: ________________

(12) How do we get the age of the earth?

____

Most atomic nuclei are stable. But some spontaneously fall apart: this is called ________________

16

(13) What gives nuclei stability?

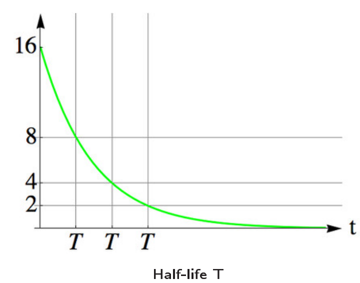
____

(14) What causes radioactive decay?

____

17

The ________ of a radioactive substance is the time taken for half of it to decay. The half-life is a constant for a given substance.



18

ADDITIONAL NOTES

Some elements come both in stable form and radioactive (different numbers of neutrons in the nucleus disrupts balance of strong and weak forces).

Examining organic remains and ______________ ____________________________________ allows you to estimate how old they are.

These methods (we also look at lunar rock samples) give an age of ____________________.

19

Atmosphere

About ________________________________ ____________, relatively heavy gases. There are virtually no light gases, such as Hydrogen and Helium.

(15) Why? [Hint: What keeps you on earth (apart from the lure of this course)?] ____________ ________________________

20

The atmosphere protects us from dangerous radiation (________________), especially a layer of ozone about 20–30 km above the surface.

(16) What's ozone?

____

____

____

21

(17) Is ozone a friend or foe?

____

____

____

____

____

22

(18) Why are uv and x-rays dangerous?

____

____

23

The atmosphere thins as you go higher; at a height of about 100 km, it's thin enough that the dastardly twins, uv and x-, can do their deadly work.

They knock electrons off atoms to produce ______ (atoms with net charge).

This atmosphere layer is called the ________. It reflects radio waves and helps in communication.

24

ADDITIONAL NOTES

Magnetism

The earth's core is ____________

Currents in it have electric charge and the motion produces magnetic effects.

A current that moves in a circle produces a perpendicular magnet.

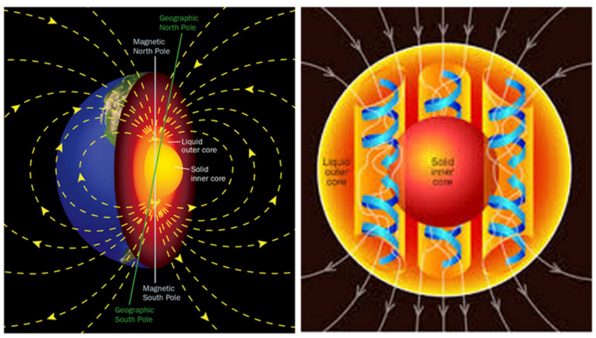
25

(19) How does this explain the alignment of the earth's magnetic poles? ____________

The dynamic nature of the earth's interior, means that the magnetic polarity is not fixed. The polarity appears to reverse every 2- or 300,000 years.

http://www.nasa.gov/topics/earth/features/2012-poleReversal.html

26



How the magnetic field might arise.

27

Motion and Alignment

(20) From the sun's pov, what two main motions does the earth have?

____

(21) How are the two aligned?

____

28

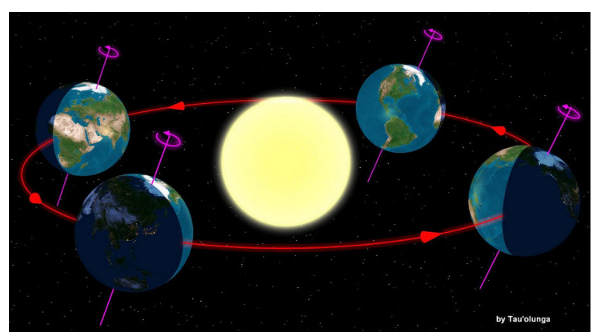
What causes the seasons? It's tempting to think the elliptical orbit is the culprit: we are closer to the sun at some times than others.

But that's not the *main* reason for earth.
(22) Why not? (Hint: Think like an Australian.)

____

29

(23) So, explain the seasons. ____________



30

ADDITIONAL NOTES

Life on Earth

(24) What's "Life" anyway?

(a) ______________________________

(b) _______________

(c) ______________________________
____

(d) ______________________________
____

31

That's a broad definition, and it allows for forms of "life" that are very different from what we normally consider life. Some far-fetched possibilities:

- Fred Hoyle, an important astronomer, once suggested that certain molecular clouds in interstellar space might show these characteristics.
- Computer code can be written to learn, adapt and reproduce.

32

Sticking to more conservative views . . .

(25) What might be needed for our way of life?

- ___________
- ______________________________
- _______________
- ______________________________
  ____

33

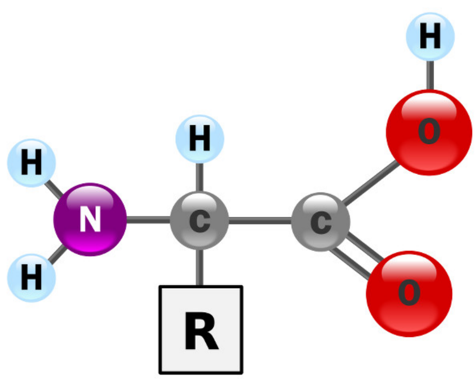
The Origin of Life on Earth

In order to understand life in the Universe, in general, ______________________________
____

All life on earth is based on a class of complex molecules called ____________

Proteins are chains of __________________
____

34



Example of an amino acid (Wikipedia)

35

The origin of life on earth is a tough, "chicken-and-egg" question:

____
____
____

But modern cells can't copy _____________
____

36

ADDITIONAL NOTES

In 1952 Stanley Miller and Harold Urey simulated conditions on the early earth to see if amino acids could spontaneously form.

Water (H_2O), methane (CH_4), ammonia (NH_3), and hydrogen (H_2) were sealed in a glass flask filled with water-vapor. Electrical sparks were fired to simulate lightning.

37 Several amino acids were formed.

But the step to forming proteins and self-replicating molecules under early-earth conditions is elusive.

Elusive enough, that some researchers argue that life may have first formed elsewhere, and brought to earth on meteorites.

Others are conducting experiments under early-earth conditions. It's an open research question.

38

The Origins of Life Initiative

A project based at the Harvard-Smithsonian Center for Astrophysics, the largest astronomical research facility in the world. It includes researchers from the University in Cambridge, the Harvard Medical School and the Massachusetts General Hospital.

39

"We seek to understand how the initial conditions on planets, including our own Earth and planets around other stars, dictated the origins of life and its subsequent evolution."

Projects at the initiative involve astronomers, chemists, biologists, etc.

What are they doing?

40

- ______________________________ __________
- ______________________________ __________
- ______________________________ __________
- ______________________________ __________

41 http://astronomy.fas.harvard.edu/people/zoe-r-todd

Review of Basics

▷ Distance and Scale

Units

(26) AU? ______________________________ ______________________________.

(27) ly? ______________________________ ______________________________

42

ADDITIONAL NOTES

Exponential notation: 10^n.

Typical distances:

- Earth–moon: $\sim 4\times 10^5$ km (little over 1 light-sec).
- Earth–sun: $\sim 1.44\times 10^8$ km. (about 8 light-min)
- Neptune–sun: $\sim 4.5\times 10^9$ km.

Speed of light: $\sim 3\times 10^5$ km/sec.

Think also in "normal" language (millions, etc.).

43

▷ The Structure of the World

(28) What are the two main "ingredients"?

(29) Each is represented by types of particle ("quanta"). What are the two main types?

(30) Examples?

44

(31) Familiar matter is built out of atoms. What is the structure of an atom?

____

____

____

____

45

(32) How many fundamental interactions/forces are there, what are they called, what do they do?

(a) ________________________________,

(b) __________________________________,

(c) ____________________________________
________________________________, and

(d) _____________________________________
____

46

Gravitation is the most important force in astronomy. Our understanding was shaped by Isaac ("I am the law") Newton, then modified significantly by Einstein.

Kepler's laws, etc., are a consequence of the fundamental theories of Newton and Einstein.

47

ADDITIONAL NOTES

1

We'll discuss the Moon's

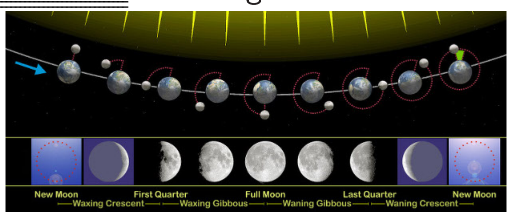
- ________________
- ________________
- ________________
- ________________
- ________________
- ________________
- ________________

2

The motion of the moon

The moon ________________________________

________ The diagram



suggests that there will be two "periods" associated with the moon's revolution.

3

The ________________ of the Moon (or any solar system body) is the time for it to return to the same position relative to the Sun as seen on Earth, i.e., the time between two recurrences of the same phase; e.g., between full moon and full moon. It is ________________

4

The ________________ of the Moon is the time for it to return to the same position against the background of stars. It is ________________

The moon also rotates around its axis, relative to the stars. The period (time for one full cycle) is

____

5

(1) Are the two numbers the same? ________

____

The equality of rotational and sidereal periods tells us something about what we see of the moon.

(2) What is it? ________________________________

____

6

ADDITIONAL NOTES

Mass and Size

- Mass of moon: ________________________
- Radius of moon: ________________________
- Radius of orbit of the moon: ________________

7

The Phases of the Moon

The moon looks different on different days. These visual differences are called ________ .

8

Phases are a visual effect, and require light. What's the origin of

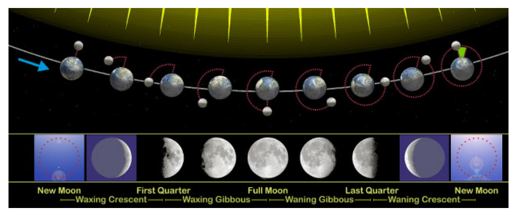
(3) sunlight? ______________

(4) moonlight? ______________

(5) Is there a difference? ________________
____
____

9

(6) What causes the phases of the moon?
____
____



10

Eclipses

(7) What are they and how many types are there?
____

- ____________________________________
  ____
- ____________________________________
  ____

11

Each of these types has two sub-types:

- ___________ if the sun is completely covered by the earth, from the moon's perspective ___________________, or if it is completely covered by the moon from the earth's perspective ______________________
- ____________ in both cases if the ___________ ___________

12

ADDITIONAL NOTES

(8) Is the earth smaller than the sun or bigger?

____

(9) Is the moon smaller than the sun or bigger?

____

(10) Then how can the earth or the moon completely blot out the sun? (I.e., how are total eclipses possible?) ______________________________

____

13

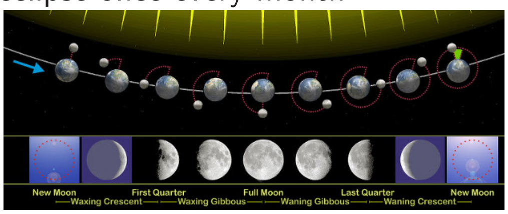
(11) Are eclipses relatively frequent (once a month for each type, say) or infrequent? ____________

List of eclipses:

http://eclipse.gsfc.nasa.gov/eclipse.html

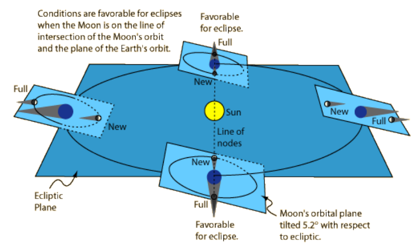
14

But the phases diagram suggests there ought to be an eclipse once every month



(12) Why is there not? ________________

15



____

____

____

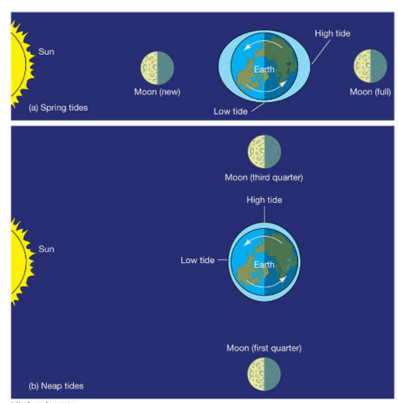
16

The Influence of the Moon on the Earth

(13) What phenomenon on earth is caused by the Moon? _______________

(14) What aspect/attribute of the Moon causes this? ___________________________

17



Tides

18

ADDITIONAL NOTES

The sun is 27 million times more massive than the moon. Does it contribute to tides as well?

If tides are caused by gravity, mass is a factor: the greater the mass, the greater the gravity.
(15) What else plays a role in gravitation?

____

____

____

19

Tidal forces are ____________________________

____

These forces are ____________________________, like gravitational forces, but are ____________________

____

____

20

(16) By what factor is the sun's tidal force *reduced* compared to that of the moon? Express your answer in powers and gazillions. ________

____

____

21

(17) Taking into account both mass and distance, how do solar tidal forces compare to lunar?

- Mass: ________________________________

  ____

  ____
- Distance: ______________________________

  ____

22

- Therefore: ____________________________

  ____

23

The Origin of the Moon

Many theories have been proposed:

- The Moon is a ____________________
- It broke off from the earth (______________).
- The moon and earth formed together (____________________).

24

ADDITIONAL NOTES

The leading theory today is the

______________________________:

A Mars-sized body collided with Earth $\sim$ 4.5 billion years ago. Debris from Earth and the other body accumulated to form the Moon. It was in a molten state. After about 100 million years, most of this had crystallized, with less-dense rocks floating upward and eventually forming the lunar crust.

25

- After an early time of volcanism, the moon has been inactive and nearly unchanged.
- It has __________________________ less than one hundred trillionth (10^{-14}) of Earth's atmospheric density at sea level.
- So, __________________________ asteroids, meteoroids, etc., hit the surface grinding it into fragments, leaving it covered with charcoal-gray, powdery dust and rocky debris.

26

The Composition of the Moon

Light areas of the moon are known as __________ and the dark as __________ (Latin for seas). The "seas" are impact basins that were filled with lava between 4.2 and 1.2 billion years ago.

The crust seems mainly oxygen (isotopes), iron and silicon. There are traces of nitrogen and carbon. There's evidence for water at the poles.

27

(**18**) Could there be life on the Moon?

____

Also the temperature ____________________

____

____

28

Missions to the Moon

- 1959–1976: U.S.S.R.'s Luna program of 17 robotic missions; three sample returns.
- 1961-1968: U.S. Ranger, Lunar Orbiter, and Surveyor robotic missions pave the way for Apollo human lunar landings.
- 1969: Neil Armstrong is the first human to walk on the moon.
- 1994–1999: Clementine and Lunar Prospector data ____________________
- 2003: The European Space Agency's SMART-1 lunar orbiter inventories key chemical elements.

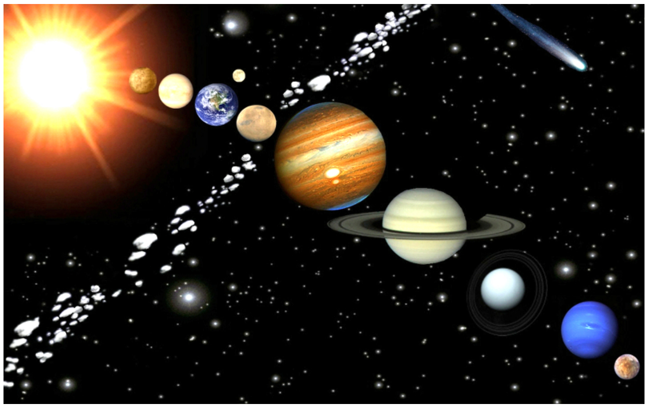
29

- 2007–2008: Japan's second lunar spacecraft, Kaguya, and China's first lunar spacecraft, Chang'e 1, both begin one-year missions orbiting the moon; India's Chandrayaan-1 soon follows in lunar orbit.
- 2009: NASA's LRO and LCROSS launch together, beginning the U.S. return to lunar exploration. In October, LCROSS was directed to impact a permanently shadowed region near the lunar south pole, resulting in ______________________
- 2011: Twin GRAIL spacecraft launch to map the interior of the moon from crust to core, and NASA begins the ARTEMIS mission to ____________________ ___________________

30

ADDITIONAL NOTES

ADDITIONAL NOTES



1

(1) What's the Solar System?

It includes

- ◦
- ◦
- ◦

(Re-read/read: Nasa's "What is a planet?")

2

As you all know, October 2010–August 2012 was the year of the solar system.

(2) What's wrong with that statement?

(3) What's right with that statement?

3

What do we know? (And how do we know it?)

▷ Formation of the Solar System

4

Decipher this lingo from the Harvard-Smithsonian Center for Astrophysics:

"Roughly 4.5 Gyr ago, the Solar System formed in a disk surrounding the proto-Sun. Within this disk, the gas giants grew to their current sizes in a few Myr; the rocky planets took a few tens of Myr to reach their present masses."

5

Why do we believe this?

-
-
-
  - ◦
  - ◦
  - ◦

6

ADDITIONAL NOTES

Star-forming region, M17

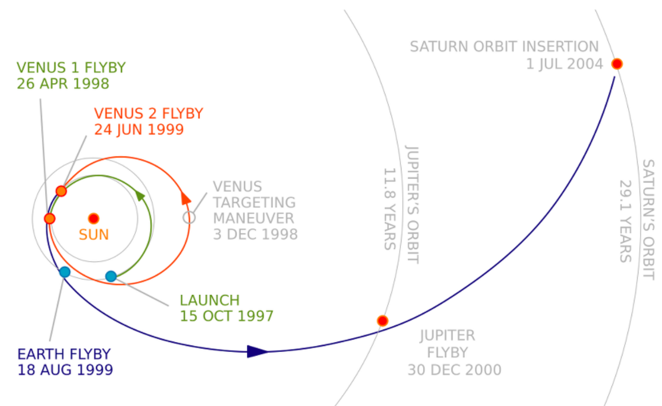
7

Overall Picture

▷ Location and exploration

- In the "Orion Arm" of the Milky Way Galaxy. Studies and observations suggest there are billions of other solar systems in our galaxy (and billions of galaxies in the Universe.)
- NASA's Voyager 1 and Voyager 2 spacecraft exploring outer reaches.

8



Cassini: Gravity assist

9

▷ Age, mass, distance

- ________________________________
- ________________________________ ________________________
- We xpress solar system distances in AU: ______ ________________________________ ________________________________

10

▷ Planets, etc.

- Four planets closest to sun called __________ (solid, rocky surfaces).
  Names: ____________________________
- Next two called ______________
  Names: __________________
- Last two called ______________
  Names: ___________________

11 Why icy? ______________________

- Dwarf planets seem to exist in an icy zone beyond Neptune, the _______________ (many comets originate here).
- ________________________________, including planets, some dwarf planets and a couple of moons.
- _________________________. Some formed with planet, others captured, and at least one came from giant impact. Which? _______

12

ADDITIONAL NOTES

Periods and semi-major axes of the planets

Planet	P (years)	S-m axis (AU)
Mercury		
Venus		
Earth		
Mars		
Jupiter		
Saturn		
Uranus		
Neptune		

13

Rounding to the nearest whole number,

(4) What's a Mercury year in Earth months?

____

(5) What's a Mars year in Earth months?

____

Onward to a detailed study of the planets.

14

Mercury

15

▷ Distances, size, times, temperatures

- ○ ____________________________________
  ____
- ○ ______________________________
  Sun size appears roughly ________________
  ____

16

- ○ ____________________________________
  ____
- ○ ____________________________________
  ____
- ○ ___________________
  ____
  ____
- ○ __________________________
- ○ _________________________

17

(6) Are there seasons on Mercury?

____

(7) Why such temperature extremes?

____

18

ADDITIONAL NOTES

▷ Composition and structure

- ____
- ____

19

▷ Around Mercury

- ______________________________

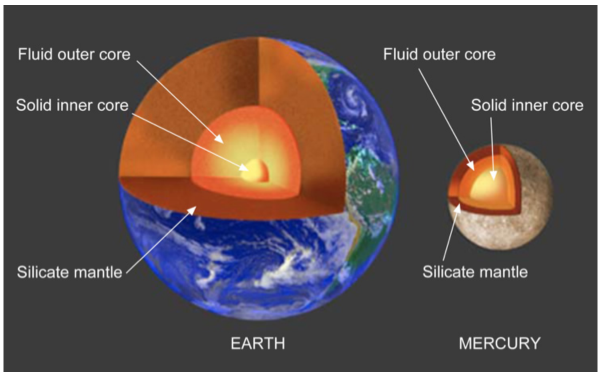
▷ Missions

- ____

▷ Life

- ____

20



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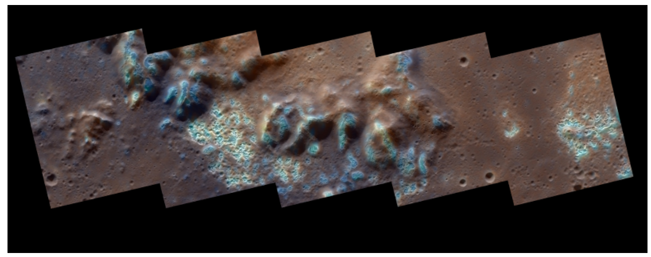

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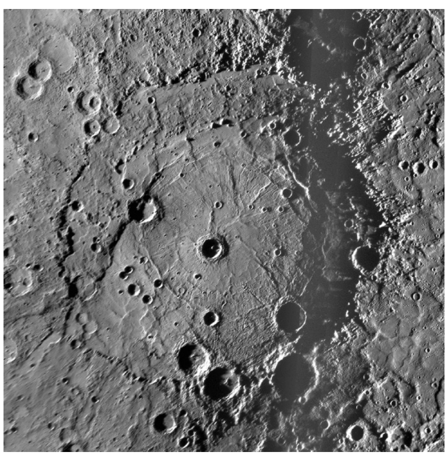
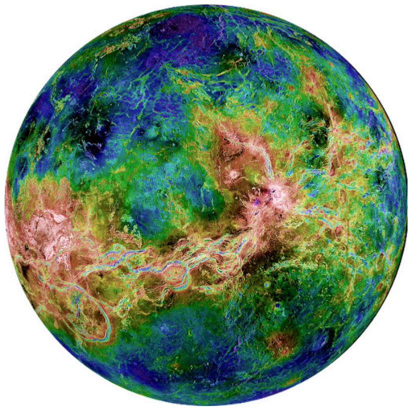


23

Venus

24

ADDITIONAL NOTES



25

▷ Distances, size, times, temperatures

- ____________________
- ____________________
- ____________________
- ____________________

26

- ____________________
- ____________________
- ____________________

(8) Are there seasons on Venus?

____

(9) Why such temperature extremes?

____

27

▷ Composition and structure

- ____________________
- ____________________
- ____________________

28

▷ Around Venus

- ____________________

▷ Missions

- ____________________

▷ Life

- ____________________

29

Akatsuki Mission

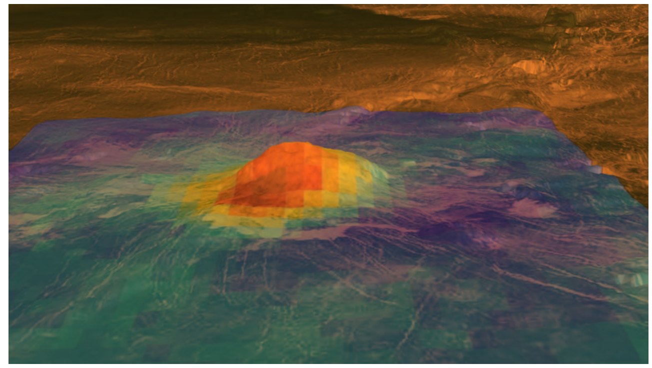
- Launched by Japan in May 2010.
- Scheduled to arrive 7 months later, but rockets failed and craft flew by Venus.
- Secondary rockets were used to maneuver it into position so that the gravity of Venus would capture it 6 years later.
- Entered Venus orbit in December 2015.

30

ADDITIONAL NOTES

- Craft is about the size of a refrigerator; carries 5 cameras that record at different wavelengths.
- Mission is to study why Venus winds rotate so fast: around the planet every 4 days, while planet rotates every 243 days.
- First results being presented now: it's found a white almost pole-to-pole streak in the atmosphere above a highland that seems fixed above the ground.

31



Volcano on Venus

32

ADDITIONAL NOTES

1

▷ Distances, size, times, temperatures

- ____________
- ____________
- ____________
- ____________

2

- ____________
- ____________
- ____________

3

(1) Are there seasons on Mars? ____________

There's an additional factor influencing seasons.

(2) What? ____________

http://www.nytimes.com/2018/07/05/science/earth-sun-aphelion.html

4

▷ Composition and structure

- ____________

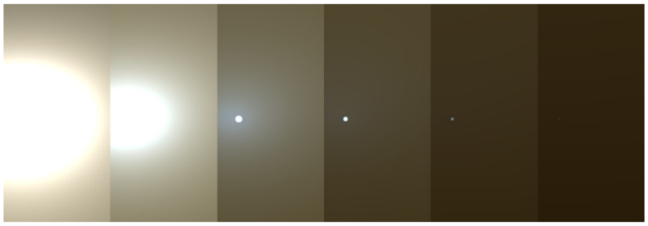
5

- Atmosphere: ____________
- Mars has seasons, ____________

6

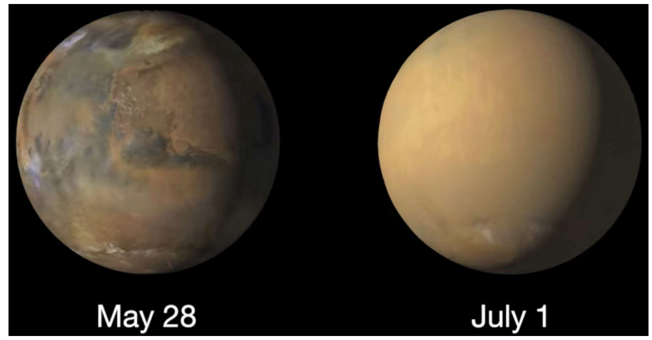
ADDITIONAL NOTES

Martian dust storms can encircle the planet. One, spotted in late May, 2018, covered the whole planet by late June and only began receding in late July.



Sun from Curiosity rover on Mars

7



From Earth

8

(3) Mars is much colder than Earth. Why?

____

____

▷ Around Mars

- ____

9

▷ Missions

- ____
  ____
  ____
  ____
  ____

10

▷ Life

- ____
  ____
  ____

11

Mars Reconnaissance Orbiter

Mission: search for water on Mars, past or present.

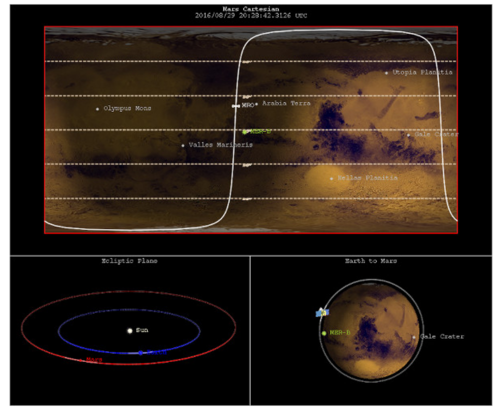
- Launch: August 12, 2005, Cape Canaveral, Florida.
- Weight: 2,180 kilograms (4,806 pounds) at launch, including fuel.
- Electrical Power: Solar panels.

12

ADDITIONAL NOTES

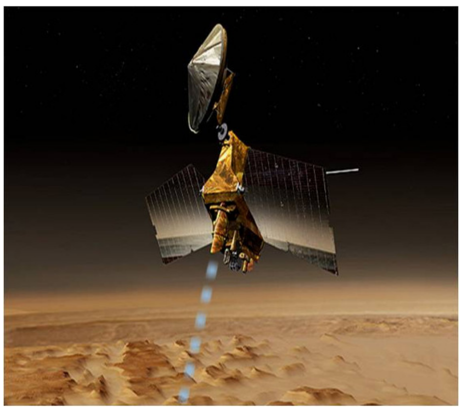
- Arrival: March 10, 2006; rockets slowed it so that it could be captured by Mars.
- Initial orbit: Highly elliptical (closest ~ 300 k; furthest $\sim 44{,}000$ km); period ~ 35 hrs.
- Underwent "aerobraking" till November 2006: the spacecraft used friction from the Martian atmosphere to slow down and to change its initial orbit to a two-hour, near-circular orbit ~ 250–300 km above surface.

13



http://mars.nasa.gov/mro/mission/whereismro/

14



15

▷ ________________________________

- Changing dark streaks on certain Mars hillsides have been known for some time.
- ________________________________ ________________________________ ________________ They appear in several locations when temperatures are above -10° F (-23° C), and disappear at colder times.

16

▷ ________________________

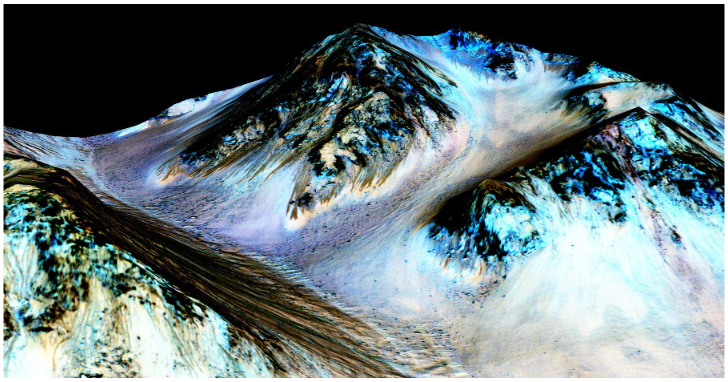
- A salt is a substance that arises from the interaction of an acid and a base.
- A ________________ has water molecules.
- Spectroscopic analysis of RSL in 2015 suggested there were hydrated salts such magnesium perchlorate, magnesium chlorate and sodium perchlorate in RSL at peak activity.

17

- This has been interrupted as a seasonal flow (trickle?) of salty water (brine) down hillsides.
- Although it would be too cold for plain water to flow on Mars, "salty water" has a lower freezing point.
- Some perchlorates have been shown to keep liquids from freezing even low as -70 Celsius.

18

ADDITIONAL NOTES



RSL on Mars

19

There's more evidence for water on Mars:

In late July, 2018, Italian astronomers from the European Space Agency?s Mars Express mission announced that a 12-mile-wide underground liquid pool had been detected by radar measurements near the Martian south pole.

http://www.nytimes.com/2018/07/25/science/mars-liquid-alien-life.htm

20

How much water did Mars have?

Some scientists speculate that a third of Mars might have once been covered by an ocean. This is still a subject for debate: Does what we now see of the surface have the characteristics of a former ocean bed?

If there was an ocean, what happened to it?

21

The ExoMars Mission

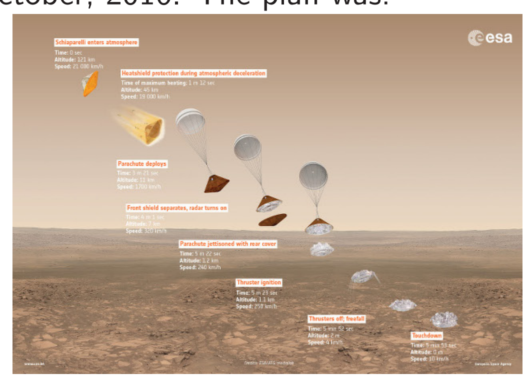
- Original proposal by Nasa in 2008 for an orbiting science lab around Mars to study if atmospheric methane around Mars might be biological in origin.
- Agreement signed in 2009 for the Mars Exploration Joint Initiative, to bring in the resources of the European Space Agency (ESA).

22

- On 13 February, 2012, NASA withdrew (no $).
- On 15 March the ESA announced it would go ahead with in partnership with the Russian space agency.
- Launched 14 March, 2016, Baikonur Cosmodrome, Kazakhstan.
- Scientific craft on board: Trace Gas Orbiter and Schiaparelli lander.

23

- Schiaparelli lander separated from TGO on 16 October, 2016. The plan was:



24

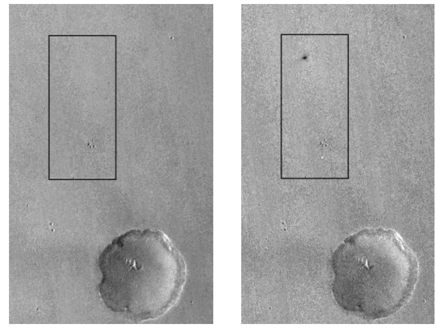
ADDITIONAL NOTES

- Communication provided by the Giant Meter Radiowave Telescope array in India (30 radio telescopes over 25 km).

- Signal was lost one minute from landing.

25

MRO pictures (29 May and 20 October, 2016):



Black & white dots thought to be craft, parachute.

26

- The TGO was injected into Mars orbit on 19 October, 2016; it will go through several months of aerobraking to adjust its speed and maneuver it into a 400 km high circular orbit, with science activities beginning in late 2017.

27

Should we go to Mars?

There are proposals that we might want to send people to Mars to explore, experiment, and live.

(4) What might be reasons to do this?

(5) What conditions on Mars are like Earth?

(6) What are not?

28

Proposal 1: Mars One

http://www.mars-one.com/mission/roadmap

Video:

https://www.youtube.com/watch?v=n4tgkyUBkbY

Candidates:

http://www.iflscience.com/space/mars-one-mission-whittles-potential-candidates-down-final-100/

29

Proposal 2: SpaceX

https://tinyurl.com/ycuk67x4

Video:

https://tinyurl.com/jkzeo71

30

ADDITIONAL NOTES

ADDITIONAL NOTES

Jupiter

1

▷ Distances, size, times, temperatures

- Radius: ____________
- Distance from sun: ________
- Day: ______ Year: __________
- Eccentricity: ________
- Average temperature: _________
- Mass: ____________
- Axis inclination: _______

2

▷ Composition and structure

- Surface:
  - Gas-giant, no solid surface.
  - Inner, solid core about size of Earth.
  - Resembles a star in composition.
  - Swirling cloud stripes; massive, long storms (e.g., Great Red Spot).
- Atmosphere: ____________________

3

▷ Around Jupiter

- __________ moons, ____ rings.

▷ Missions

- ______________________________
____

▷ Life

- ______________________________
____

4

(1) Do you expect distinct seasons on Jupiter? Why or why not?

____
____

(2) How many Earth hours would a day on Jupiter be?

5

The Great Red Spot

This is Jupiter's most prominent feature.

- ________________________
  Earlier observations of a spot that go back to the 1600s may have been of another spot.
- ____________________________

6

ADDITIONAL NOTES

- ____
  ____
  ____
- ____
- ____

7

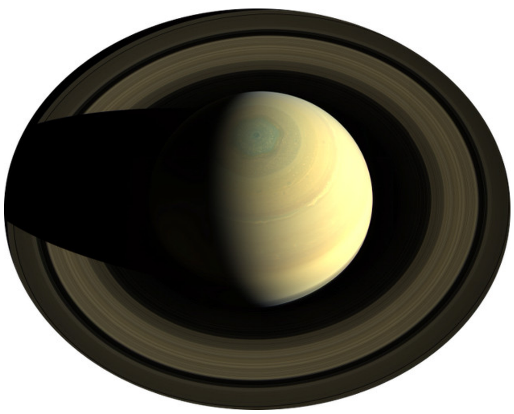
Other Jupiter news:

Twelve possible new moons were announced in mid 2018 (first seen in 2017).

They were discovered accidentally as astronomers were looking at distant regions of the SS, and Jupiter happened to be in the field of view.

8

Saturn



9

▷ Distances, size, times, temperatures

- Radius: ____________________
- Distance from sun: ____________
- Day: ____________ Year: __________________
- Eccentricity: ____________
- Average temperature: ______________
- Mass: __________________
- Axis inclination: __________

10

▷ Composition and structure

- Surface:
  - Gas-giant, no solid surface.
  - Rings likely < 50 meters thick: individually orbiting bits of ice and rock, sizes from sand-grains to barn-size boulders.
- Atmosphere: ________________________________

11

▷ Around Saturn

- _________________ moons, ___ rings.

▷ Missions

- ____
____

▷ Life

- ____
____

12

ADDITIONAL NOTES

(3) What are some reasons that both Jupiter and Saturn might be inhospitable to our way of life?

____

____

13

The Rings of Saturn

Although it is now known that all the gas giants have rings, Saturn's are the most prominent.

- ____
  ____
  He thought they were "handles" or large moons on either side of the planet. "I have observed [Saturn] to be tripled-bodied."

14

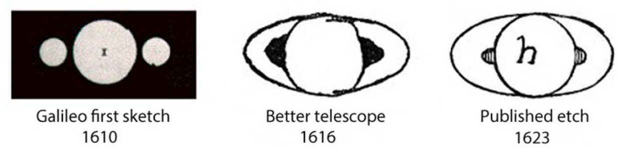
In 1612, the rings seemed to have disappeared; by 1616 they were back.

(4) Explain this.

____

____

15



Galileo's sketches

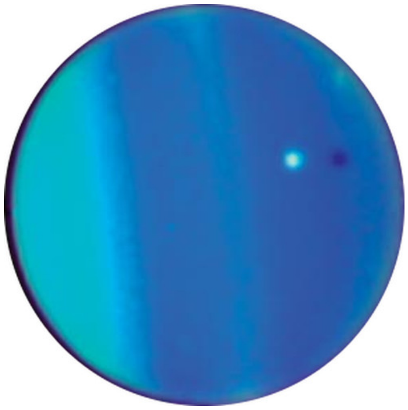
16

17

18

ADDITIONAL NOTES

Uranus



19

▷ Distances, size, times, temperatures

- Radius: ____________
- Distance from sun: ________
- Day: ______ Year: _________
- Eccentricity: _______
- Average temperature: ________
- Mass: __________
- Axis inclination: ______

20

(5) What might day and night be like on Uranus?

21

▷ Composition and structure

- Surface:
  - Ice giant.
  - 80% or more of its mass is made up of a mix of icy materials: water, methane, and ammonia, above a small rocky core.
- Atmosphere: ____________________

22 ______________________

▷ Around Uranus

- ___ moons, ____ rings.

▷ Missions

- _____________

▷ Life

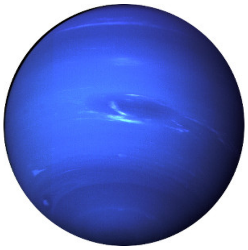
- _______________________

23

24

ADDITIONAL NOTES

Neptune



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▷ Distances, size, times, temperatures

- Radius: ________________
- Distance from sun: ___________
- Day: _______ Year: ________________
- Eccentricity: __________
- Average temperature: ___________
- Mass: _______________
- Axis inclination: ________

26

▷ Composition and structure

- Surface:
  - Ice giant.
  - Mostly a combination of water, ammonia, and methane over a possible heavier, Earth-sized, solid core.
- Atmosphere: ________________________________

27

▷ Around Neptune

- ______________ moons, ____ rings.

▷ Missions

- _________________

▷ Life

- _______________________________

28

ADDITIONAL NOTES

ADDITIONAL NOTES

ADDITIONAL NOTES

ADDITIONAL NOTES

1

A list of moons

▷ Mercury:

▷ Venus:

▷ Earth:

Name:

▷ Mars:

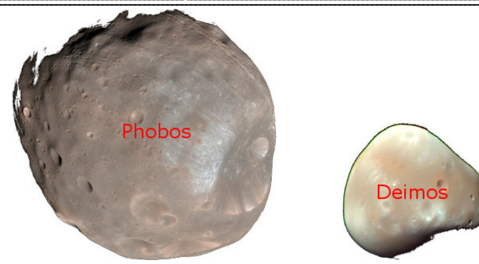
Names:

2

(1) The inner planets have fewer moons than the outer. Why might that be the case?

3

(2) Is there an anomaly – a planet much less massive than the earth but with more moons?



4

(3) What's weird about them?

5

(4) Why do we say the radius of Phobos is $8.5 \times 9 \times 11$ km? Seems an odd way to express a radius.

(5) Why are Phobos and Deimos less spherical than our moon, or any of the planets?

6

ADDITIONAL NOTES

Phobos is not done with its strange properties. It hovers only __________ km above the surface of Mars, a little over the distance from New York to Paris.

It also zips around Mars in about __________

7

(6) Is the zippiness of Phobos related to its irregularity or to its low altitude?

____
____

____
____
____

8

▷ Jupiter: ______________________________

Io	Metis	Aitne	Carpo
Europa	Callirrhoe	Eurydome	Eukelade
Ganymede	Themisto	Euanthe	Cyllene
Callisto	Megaclite	Euporie	Kore
Amalthea	Taygete	Orthosie	Herse
Himalia	Chaldene	Sponde	Adrastea
Elara	Harpalyke	Kale	Hermippe
Pasiphae	Kalyke	Pasithee	Helike
Sinope	Iocaste	Hegemone	
Lysithea	Erinome	Mneme	
Carme	Isonoe	Aoede	
Ananke	Praxidike	Thelxinoe	
Leda	Autonoe	Arche	
Thebe	Thyone	Kallichore	

9

History:

The four largest moons ______________________
______________, are called the Galilean satellites after Galileo Galilei, who first observed them in 1610.

They are still the most important moons of Jupiter.

10

____
______________ Surface is covered by sulfur in different colorful forms. As Io travels in its slightly elliptical orbit, Jupiter's immense gravity causes "tides" in the solid surface that rise 100 m (300 feet) high on Io, generating enough heat for volcanic activity and to drive off any water. Io's volcanoes are driven by hot silicate magma.

11

____
____
______________ It is thought to have twice as much water as does Earth. This moon intrigues astrobiologists because of its potential for having a "habitable zone." Life forms have been found thriving near subterranean volcanoes on Earth and in other extreme locations that may be analogues to what may exist on Europa.

12

ADDITIONAL NOTES

____ ____, and is the only moon known to have its own magnetic field.

____ ______________ – a visible record of events from the early history of the solar system. However, the very few small craters on Callisto indicate a small
13 degree of current surface activity.

Io has a core, a mantle of partially molten rock, topped by a crust of solid rock coated with sulfur.

Europa and Ganymede both have a core, a rock envelope around the core, a thick, soft ice layer, and a thin crust of impure water ice. __________ ____.

Layering at Callisto is less well defined and appears
14 to be a mixture of ice and rock.

Ganymede's period is twice Europa's, which is twice Io's. Every time Ganymede goes around Jupiter once, Europa makes ___________ orbits and Io makes ___________ orbits.

The moons all keep the same face towards Jupiter as they orbit, meaning that each moon turns ________ on its axis for every orbit around Jupiter.

15

Pioneers 10 and 11 (1973 to 1974) and Voyager 1 and Voyager 2 (1979) offered color views from their flybys of the Jupiter system.

From 1995 to 2003, the Galileo spacecraft made observations from repeated elliptical orbits around Jupiter, passing as low as 261 km (162 miles) over the surfaces of the Galilean moons.

16

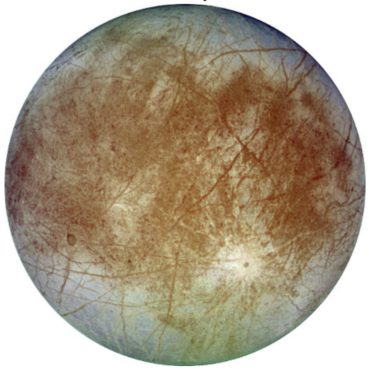
Close-up images taken by Galileo of portions of Europa's surface show places where ice has broken up and moved apart, and where liquid may have come from below and frozen smoothly on the surface.

The low number of craters on Europa lead us to believe that a subsurface ocean may exist. The heat needed to melt the ice in a place so far from
17 the sun is thought to come from inside Europa.

18

ADDITIONAL NOTES

Europa



19

- ____________________
- ____________________
- ____________________
- ____________________
- ____________________

20

▷ Saturn: ____________________

Mimas	Kiviuq	Narvi	Loge
Enceladus	Atlas	Methone	Skoll
Tethys	Prometheus	Pallene	Surtur
Dione	Pandora	Polydeuces	Greip
Rhea	Pan	Daphnis	Jarnsaxa
Titan	Ymir	Aegir	Tarqeq
Hyperion	Paaliaq	Bebhionn	Anthe
Iapetus	Tarvos	Bergelmir	Aegaeon
Erriapus	Ijiraq	Bestla	Calypso
Phoebe	Suttungr	Farbauti	Thrymr
Janus	Mundilfari	Fenrir	Kari
Epimetheus	Albiorix	Fornjot	
Helene	Skathi	Hati	
Telesto	Siarnaq	Hyrrokkin	

21

History:

1655, Christiaan Huygens discovered first known moon of Saturn, Titan.

1671–1684, Giovanni Cassini made the next four discoveries: Iapetus (1671), Rhea (1672), Dione (1684), and Tethys (1684).

1789, William Herschel discovered Mimas and Enceladus.

22

1848, Hyperion; and 1898, Phoebe.

1966, Epimetheus and Janus.

By 1997, when Cassini-Huygens was launched, Saturn's moon count had reached 18.

The number of known moons soon increased with high-resolution imaging techniques used on ground-based telescopes. The Cassini mission has discovered several more moons since its arrival at Saturn.

23

Details:

Two moons orbit within gaps in the main rings. Some, such as Prometheus and Pandora, interact with ring material, shepherding the ring in its orbit.

Some small moons are trapped in the same orbits as the larger moons, Tethys and Dione.

Janus and Epimetheus occasionally pass close to each other; they periodically exchange orbits.

24

ADDITIONAL NOTES

Titan is the second largest moon in the solar system: ____________________. Hides its surface with a thick nitrogen-rich atmosphere, similar to the Earth's atmosphere of long ago, before biological organisms developed. Atmosphere is approximately 95% nitrogen with traces of methane.

Earth's atmosphere extends about 60 km into space, Titan's extends nearly 600 km.

25

Iapetus has one side as bright as snow and one side as dark as black velvet, with a huge ridge running around most of its dark-side equator.

Mimas has an enormous crater on one side, the result of an impact that nearly split the moon apart.

26

Enceladus displays evidence of active ice volcanism: Cassini observed warm fractures where evaporating ice evidently escapes and forms a huge cloud of water vapor over the south pole.

Hyperion has an odd flattened shape and rotates chaotically, probably due to a recent collision.

27

▷ Uranus: ____________

Cordelia	Rosalind	Ariel	Sycorax
Ophelia	Mab	Umbriel	Margaret
Bianca	Belinda	Titania	Prospero
Cressida	Perdita	Oberon	Setebos
Desdemona	Puck	Caliban	Ferdinand
Juliet	Cupid	Stephano	Francisco
Portia	Miranda	Trinculo	

(7) What might these moons be named after?

____

____

28

History:
1787, Wiliam Herschel finds largest moons: Oberon, Titania. William Lassell finds Ariel, Umbriel.

1948, Gerard Kuiper finds Miranda.

1986, Voyager 2 ten more, 26–154 km in diameter: Juliet, Puck, Cordelia, Ophelia, Bianca, Desdemona, Portia, Rosalind, Cressida and Belinda.

29

Since then, the Hubble Space and other telescopes have raised the total to 27.

Hard to spot: they're tiny – as little as 12–16 km across, and dark. (About 2.9 billion km from Sun.)

All the inner moons appear to be roughly half water ice and half rock. The composition of the moons outside the orbit of Oberon unknown; likely captured asteroids.

30

ADDITIONAL NOTES

Details:

Miranda, the innermost and smallest of the five major moons, has a surface unlike any other moon that's been seen. It has giant fault canyons as much as 12 times as deep as the Grand Canyon, terraced layers and surfaces that appear very old, and others that look much younger.

31

Ariel has the brightest and possibly the youngest surface. It has few large craters and many small ones, indicating that fairly recent low-impact collisions wiped out the large craters that would have been left by much earlier, bigger strikes. Intersecting valleys that are pitted with craters scar its surface.

32

Umbriel is ancient, and the darkest of the five large moons. It has many old, large craters and has a mysterious bright ring on one side.

Oberon, the outermost of the five major moons, is old, heavily cratered. Unidentified dark material appears on the floors of many of its craters.

Cordelia and Ophelia are shepherd moons that keep Uranus' thin, outermost ring well defined.

33

Between them and Miranda is a swarm of eight small satellites unlike any other system of planetary moons. This region is so crowded that we don't yet understand how the little moons manage to avoid crashing into each other. They may be shepherds for the planet's narrow rings, and we think there must be more moons, interior to any known, to confine the edges of the inner rings.

34

▷ Neptune: ____________

Triton
Nereid
Naiad
Thalassa
Despina
Galatea
Larissa
Proteus
Halimede
Psamathe
Sao
Laomedeia
Neso

35

History:

William Lassell (using brewery business to finance telescopes) spotted Triton on 10 October 1846 – just 17 days after a Berlin observatory discovered Neptune. Triton is Neptune's largest moon.

Dutch-American astronomer Gerard Kuiper (for whom the Kuiper Belt was named) found Neptune's third-largest moon, Nereid, in 1949.

36

ADDITIONAL NOTES

Proteus, second-largest moon: too dark and too close to Neptune for older telescopes. It is slightly non-spherical; thought to be at the mass limit before gravity pulls it into a sphere (4.4×10^{19} kg).

Proteus and five others discovered by Voyager 2. They are among the darker objects in the solar system. Astronomers using ground-based telescopes found seven more in 2002–03.

37

Details:

Part of Triton's surface resembles a cantaloupe. Ice volcanoes spout what is probably a mixture of liquid nitrogen, methane and dust; it instantly freezes, then snows back to surface.

Triton's icy surface reflects so much of what little sunlight reaches it that the moon is one of the coldest objects in the solar system, about $-240°$C.

38

Triton is the only large moon in the SS that circles its planet in a direction opposite to the planet's rotation (a retrograde orbit).

($\mathbf{8}$) Does this make it seem likely that Triton was formed with Neptune or was captured?

____

39

The disruptive effect this would have had on other satellites could help to explain why Nereid has the most eccentric orbit of any moon – almost seven times as far from Neptune at one end of its orbit as at the other end.

40

Neptune's gravity acts as a drag on the counter-orbiting Triton, slowing it down and making it drop closer and closer to the planet. Millions of years from now, Triton will come close enough for gravitational forces to break it apart – possibly forming a ring.

41

42

ADDITIONAL NOTES

Origin of moons

43

The two less massive planets with moons – Earth and Mars – got theirs another way, we believe.

(9) How did Earth get its?

(10) How did Mars get its?

44

Should we explore the SS? This guy is relevant:

45

Ocean organisms that can survive

▷

▷

▷

▷

46

(11) What's that to us astronomers?

In fact they not only survive, they do fine:

Microbial life found living on the exterior of the International Space Station, say reports

Plankton in phases of development "found on the surface of the ocean" has been discovered on the exterior surface of windows of the ISS

James Vincent | @jjvincent | Friday 22 August 2014 | 64 comments

Astronauts go on space walks to clean windows.

47

(12) That's good news and bad. Why?

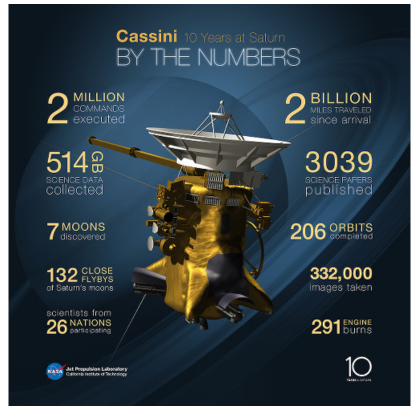
48

ADDITIONAL NOTES

Outer Missions Looking for Life

- ▷ Cassini: Saturn and its moons
- ▷ Europa: Jupiter and its moons

49



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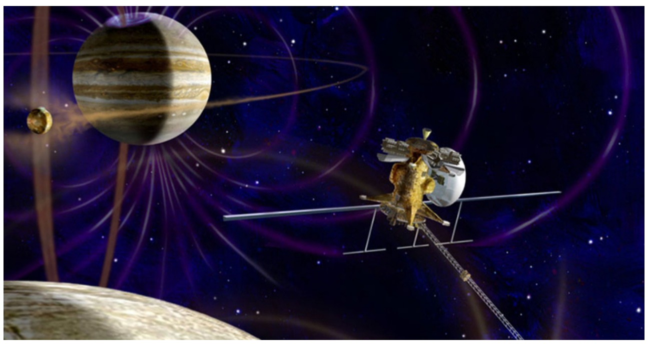


Europa mission to Jupiter and its moons

51

ADDITIONAL NOTES

ADDITIONAL NOTES

ADDITIONAL NOTES

ADDITIONAL NOTES

1

Eris (center top), Ceres (center), Pluto and its moon Charon (left).

2

▷ What's a planet?

Our idea of what a planet is has evolved.

The ancient Greeks had seven planets:
The Sun, Moon, Mercury, Venus, Mars, Jupiter, Saturn.

(1) Why these? ____________

3

1500–1600 (Copernicus, Kepler, Galileo):
Mercury, Venus, Earth, Mars, Jupiter, Saturn.

- Sun at "center" of this system.
- Moon is satellite of earth.
- Jupiter has moons, too.

4

With telescopes/calculations, new "planets" found:

1781: Uranus
1801: Ceres (between Mars & Jupiter). Dethroned by 1900s: other objects discovered in that region.
1846: Neptune
1930: Pluto. Dethroned in the 2000s, as other objects of similar size (e.g., Eris), were found in the outer reaches of the solar system.

5

What *is* a Planet?

Still debated. One proposal: an object in space massive enough for gravity to make it roughly spherical.

(2) What might be potential problems with using this as the sole definition? ____________
____
____

6

IAU: 2006 definition

A planet is a solar system object that

- ____________
- ____________
- ____________
- ____________
  ______

ADDITIONAL NOTES

“Clearing the neighborhood”

This means that an object has become gravitationally dominant in its orbit, and there are no other bodies of comparable size other than its moons and other objects under its gravitational influence.

A large body which meets the other criteria for a planet but has not cleared its neighborhood is classified as a ____________

7

(3) What mechanism might lead an object to “clear its neighborhood.” (Hint: think of a cosmic vacuum cleaner.)

____

8

Based partially on work of Stern and Levison,2002.

They proposed that a parameter, Λ, be used to tell if “planetary bodies control the region surrounding them.”

where m is the mass of the object and a the length of its semi-major axis. If $\Lambda > 1$, they proposed, the object would clear its neighborhood.

9

Λ for different objects

Object	Λ
Earth	1.53×10^5
Jupiter	6.25×10^5
Pluto	2.95×10^{-3}
Ceres	8.32×10^{-4}

(4) Are the Λ's for two very different from the other two? ______________

10

Facts about the dwarf planets

- ________________________________
  ____
  ____
- ____________________________
- ________________________________
  ____
  ____
  ____

11

- ________________________________
  ____
  ____
- ________________________________
  ____
- ________________________________
  ____
  ____

12

ADDITIONAL NOTES

○ ____
____
____
____

○ ____

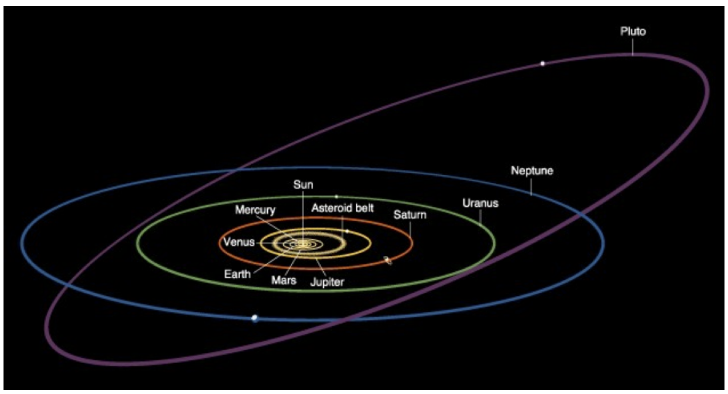
13

New Horizons: Pluto and Beyond

Launched 2006

Began sending back pictures in the summer of 2015 – our first detailed pictures of Pluto's surface.

14



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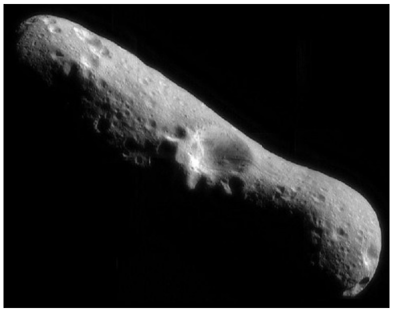
17

18

ADDITIONAL NOTES

Asteroids, Meteoroids, Comets

Asteroids



19

Rocky objects orbiting sun, too small to be planets. Ceres, the largest, is a dwarf planet.

Tens of thousands in main asteroid belt, a donut-shaped ring between orbits of Mars and Jupiter.

Asteroids passing close to Earth called near-earth.

All of the asteroids combined would still be much smaller than our Moon.

20

Days and years vary on asteroids. A day on asteroid Ida takes 4.6 hours, and a year is 4.8 Earth years.

(5) How do these compare with Ceres?

____

(6) If one pair is similar, why might that be?

____

____

21

▷ Asteroid facts

- ____________________
- ____________________
- ____________________
- ____________________

22

- ____________________
- ____________________
- ____________________

23

Meteoroids, Meteors, Meteorites

- ____________________
- ____________________
- ____________________

24

ADDITIONAL NOTES

- ____
- ____
- ____

25

- ____
- ____
- ____

26

Comets

27

Cosmic snowballs of frozen gases, rock and dust roughly the size of a small town.

____

28

Comets have ____

Short-period comets ____

Long-period comets ____

29

Days on comets vary. One day on comet Halley varies between 2.2 to 7.4 Earth days (the time it takes for comet Halley to rotate or spin once).

Comet Halley makes a complete orbit around the sun (a year in this comet's time) in 76 Earth years.

Comets do not have moons or rings.

30

ADDITIONAL NOTES

Comets may not be able to support life themselves, but they may have brought water and organic compounds – the building blocks of life – through collisions with Earth and other bodies in our solar system.

31

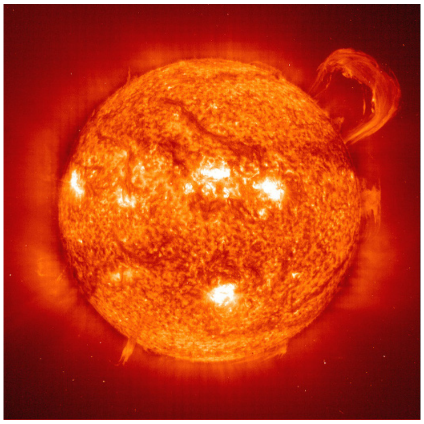
(7) Comet Halley last appeared in 1986. There's a comet in the Bayeux Tapestry, from the year 1066 (the tapestry which chronicles the overthrow of King Harold by William the Conqueror at the Battle of Hastings). Could that be comet Halley?

32

ADDITIONAL NOTES

ADDITIONAL NOTES

ADDITIONAL NOTES



1

The sun is a ball of gas, almost entirely ____________ ____________ and ____________________

It's held together by ____________________

It contains ____________ of the mass of the entire solar system.

2

Everything that's "held together" is held together by a basic force.

(1) How many are there, and what are they?

____________________________________ ______________

3

(2) What holds an atom together and how?

________________________ ________________________ ____________________________________

(3) What holds the nucleus together (despite the like charges on the protons repelling each other)?

________________________ __________________ ____________________________________ ____________________________________

4

(4) What keeps your nose on your face?

____

(5) What holds the earth together?

____

(6) What holds you to earth?

____

(7) What keeps the solar system together?

__________ ______________________________

5

Different parts of the sun rotate at different rates. At the equator, the sun spins once about every 25 Earth days, but at its poles the sun rotates once on its axis every 36 days.

(8) How can this happen?

____ ____

6

ADDITIONAL NOTES

(9) What's the first thing you notice about stars?

____

Stars shine because they give off energy. We measure energy in a unit called a ______.

The _________ of a star is the energy it gives off every second; unit is J/s, called a ____________.

The luminosity of a star is its "actual brightness."

7

If measured in Watts, the luminosity of the sun is

The earth's entire energy consumption in 2012 was 5.6×10^{20} J. That means that the sun's energy could supply, *every second*, the annual energy needs of a **million** earths.

8

(10) From what did I concoct a "million"?

9

What Makes a Star Shine?

353. Maintenance of the Solar Heat. — The question at once arises, if the sun is sending off such an enormous quantity of heat annually, how is it that it does not grow cold?

(*a*) The sun's heat cannot be kept up by *combustion*. As has been said before, it would have burned out long ago, even if made of solid coal burning in oxygen.

(*b*) Nor can it be simply a *heated body cooling down*. Huge as it is, an easy calculation shows that its temperature must have fallen greatly within the last 2000 years by such a loss of heat, even if it had a specific heat higher than that of any known substance.

As matters stand at present, the available theories seem to be reduced to two, — that of Mayer, which ascribes the solar heat to the energy of meteoric matter falling on the sun; and that of Helmholtz, who finds the cause in a slow contraction of the sun's diameter.

Young, 1900

10

(11) What does make a star shine? [What's the fuel for the energy (light, heat, etc.) it produces?]

____

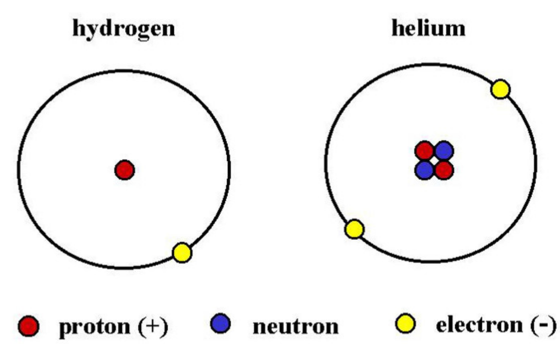
(12) What equation governs the conversion of mass to energy? ____________________________

____

____

11 ________________________________

How it happens: ______________________________



12

ADDITIONAL NOTES

(13) The masses of a proton and a neutron are roughly the same. An electron is roughly $10{,}000$ times less massive. (So the mass of an atom is essentially the mass of its nucleus.) Based on masses alone, roughly how many Hydrogen atoms would you need to make one Helium? ____________

13

(14) Atomic masses are measured in atomic mass units (amu). The mass of Hydrogen is 1.00794 amu and the mass of Helium is 4.00260 amu. How much bigger or smaller are the masses of 4 Hydrogen atoms than one Helium?

14

(15) One amu is 1.66054×10^{-27} kg. Convert the previous answer to kg.

(16) What's 0.048 as a percentage? _____

(17) What's 10^{-9} in words? __________

(18) What's 10^{-27} in terms of 10^{-9}, and in words?

15

That's a tiny amount of missing mass: $< 5\%$ of a billionth of a billionth of a billionth of a kg.

(19) $c \approx 300{,}000{,}000$ m/s. What's c^2 in 10^n?

____

(20) How many atoms are there, very roughly, under "normal" conditions in one cubic centimeter?

___________________.

16

Given the largeness of those numbers, missing mass of $\approx 0.05 \times 10^{-27}$ kg can lead to a lot of energy ($E =$ __________).

(21) How much energy per reaction?

____

(22) How much energy "per cubic cm"?

____

17 ______________________

Summary: The basic nuclear reaction that powers stars is called ____________.

Four nuclei of H fuse to form one He:

$$4\text{H} \longrightarrow \text{He}$$

The reaction releases energy because the mass of the Helium is slightly less than the mass of the four Hydrogen nuclei. The energy *ultimately* leaves the surface as visible light.

18

ADDITIONAL NOTES

Fusion is difficult to achieve because it needs a high temperature and density.

(23) Why, do you think?

____

____

____

19

Fusion requires a temperature of $\sim 13{,}000{,}000^\circ$ C.

The temperature at the center of stars like the sun is about $15{,}000{,}000^\circ$ C and the density is about 150 g/cm^3 (10 times the density of lead).

That's enough for fusion.

20

The temperature and density decrease as you move outward from the center of the star.

The nuclear "burning" is almost completely shut off beyond the outer edge of the core of stars like the sun at about 25% of the distance to the surface (or 175,000 km from the center).

The temperature here is half its central value and the density drops to about 20 g/cm^3.

21

Fusion in stars is a three step process:

1) ______________________________________

____

2) ______________________________________

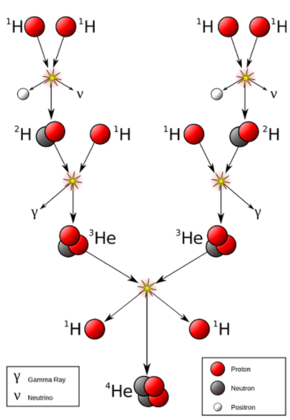
____

____

3) ______________________________________

____

22



23

The electromagnetic energy ______________________________________

____

____

____

The neutrinos ______________________________________

____

24

ADDITIONAL NOTES

Solar neutrinos were detected in 1964. The detector was placed $5{,}000$ feet deep in a mine.
(24) Why? ______________________________
The detector was simply a $100{,}000$ gallon tank filled with dry-cleaning fluid: the chlorine in the fluid interacts with neutrinos!

Initially, it seemed there were not enough neutrinos. This was solved by assigning them mass.

25

History of the idea that fusion makes stars shine:

- 1920: Eddington suggests that H fusing to form He might be the source of energy in stars.
- 1928: Gamow calculates conditions for the electric repulsion between protons in H to be overcome.
- 1929: Houtermans & Atkinson make first calculations of H $\longrightarrow$ He reactions in stars like the sun.
- 1938: Bethe constructs a full theory of this process.
- 1940s onward: Hoyle and others extended these ideas to show ______________________ of heavier elements.

26

In order fully to understand what it is that our scientists are seeking and the problems that stand in the way of controlled fusion power, we must start with a German scientist named Dr. Frederic Houtermans, one of the first men ever to theorize about hydrogen energy.

HOUTERMANS was first to publish solar fusion theory.

I met Dr. Houtermans last summer at the Geneva conference, and he told me about the birth of his idea which later grew into the H-bomb. In 1928 he was deeply absorbed in wondering about the source of energy in stars. "Oh, I was doing other things, too," he told me with a twinkle. "I was courting a very pretty girl." When he was not courting, Houtermans' calculations led him to rule out chemical energy as the source of heat in stars. Instead, he hit upon the idea of energy coming from a thermonuclear process—heat evolved from the violent action of atoms deep inside the fiery furnace of a white-hot star. Convinced that he was on the right track, the young scientist, together with his colleague Robert Atkinson, published his discovery. One night, with the stars shining in the heavens, he pointed toward them and proudly exclaimed to his girl, "I know what makes them shine!"

From "Limitless Power," Ralph Lapp, Life Magazine, October 8, 1956

27

To summarize:

What makes the Stars Shine?
Jason Socrates Bardi. January 23, 2008
Phys. Rev. Focus 21, 3
https://physics.aps.org/story/v21/st3

"Physicists at the turn of the 20th century realized that the existing paradigm for stellar energy production was wrong. The old theory, that the sun's energy was produced by gravitational contraction, could supply only 30 million years of stellar energy, but biologists and geologists were estimating the earth was much older. . . .

28

"A long series of discoveries beginning with Einstein's relativity in 1905 led up to Bethe's discovery of the correct nuclear reactions. Hydrogen fusion seemed like a good candidate because according to $E{=}mc^2$, the small mass difference between the fusing hydrogen and the resulting helium would liberate an enormous amount of energy. Also, spectral analysis in the 1920s revealed that most stars, including the sun, are mostly hydrogen. . . .

29

"Following Bethe's work, astrophysicists were able to work out many details of stellar physics, which led to a view of stars almost as living beings. As Bethe concluded his Nobel lecture, 'Stars have a life cycle much like animals. They get born, they grow, they go through a definite internal development, and finally they die, to give back the material of which they are made, so that new stars may live.'"

We'll study this cycle: birth, life, and death of the sun and other stars.

30

ADDITIONAL NOTES

The Birth of Stars

- ____
- ____
- ____

31

The mass of the core determines its destiny.

The possibilities for stellar formation are:

- $M < 0.08 M_\odot$: ____________________
- $0.08 M_\odot < M < 0.5 M_\odot$: ____________________
- $0.5 M_\odot < M < 5 M_\odot$: ____________________

32

- $5 M_\odot < M < 7 M_\odot$: ____________________
- $M > 7 M_\odot$: ____________________

33

The Life of Stars (like the sun)

- 50Myr: ____________
- 10Gyr: ____________________
- 1 Gyr: ____________________
- 170 Myr: ____________________

34

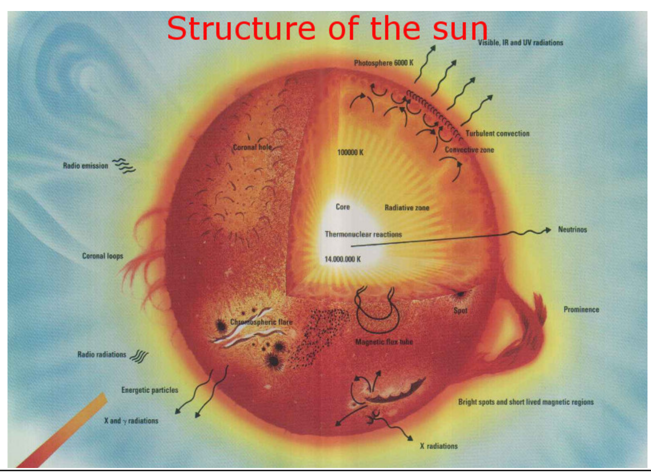
The Structure of the Sun

The sun has six regions:

Interior: the core, the radiative zone, the convective zone

Outer: the photosphere (visible), the chromosphere, the corona

35



36

ADDITIONAL NOTES

The sun's visible surface (______________) is 500 kilometers thick.

Sunspots in the photosphere are areas with strong magnetic fields that are cooler, and thus darker.

Sunspot numbers fluctuate every 11 years as part of the sun's magnetic activity cycle. Also connected to this cycle are bright solar flares and huge coronal mass ejections that blast off the sun.

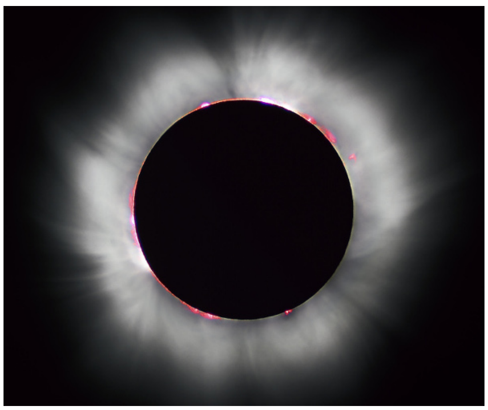
37

The temperature of the photosphere is $\sim 5{,}500°$ C.

Above the photosphere is the thin chromosphere and the corona (crown). Visible light from these regions is usually too weak to be seen against the photosphere. (Except when?)

Above the photosphere, temperature increases with altitude, reaching as high as $2 \times 10^{6°}$ C. Coronal heating has been a mystery for more than 50 years.

38



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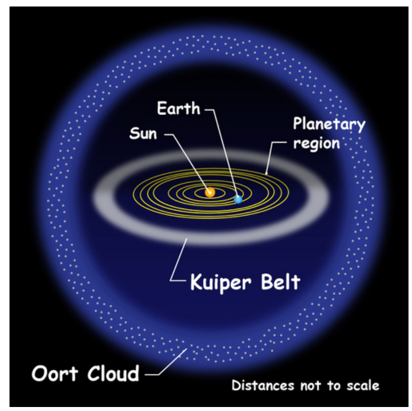

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ADDITIONAL NOTES

ADDITIONAL NOTES

The Space Elevator

Based on "safe rotation rates" around the earth: The speed at which you must travel to avoid either crashing to earth or escaping from it.

where r is the radius of the orbit and m (which cancels) the mass of the orbiting object.

1

(1) Solve for v.

$v =$

2

Calculate v for
(2) $r \approx R_{\text{Earth}} \approx 6.4 \times 10^6$ m.

$v =$

3

If other orbital radii are expressed as a multiple of the earth radius, kR_{Earth}, the safe orbital speed would be

$$v = \frac{2 \times 10^7}{\sqrt{kR_{\text{Earth}}}} = \frac{2 \times 10^7}{\sqrt{R_{\text{Earth}}}} \cdot \frac{1}{\sqrt{k}}$$

$$= \frac{18{,}000}{\sqrt{k}} \text{ m/s.}$$

4

(3) What is the safe orbital speed at an orbital radius of a trillion earth radii?

5

(4) What is the circumference of the earth?

(5) How many seconds in a day?

(6) What is the rotational speed of the earth at the equator?

6

ADDITIONAL NOTES

As you move from close to the surface of the earth to far away, the safe velocity drops continuously from 8×10^3 m/s, *faster than the earth's rotation*, to close to zero, *slower than the earth's rotation*.

So, somewhere in between, the orbital speed will exactly match the rotation of the earth.

A satellite orbiting the earth above the equator at that speed will appear to be stationary overhead.

7

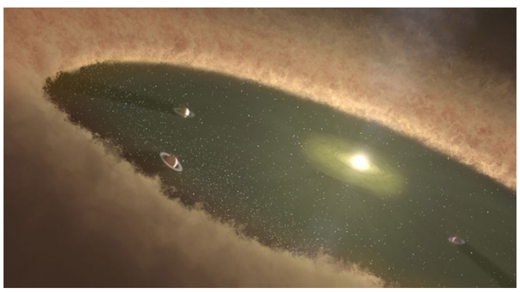
The height of such an orbit above the earth's surface would be about 36×10^3 km.

The space elevator proposal calls for a station at that height above the equator to pull things into orbit along a rope of sufficient tensile strength

8

Other Solar Systems

An artists conception, based on real observations:



9

Speculation about other solar systems goes back to ancient Greek times.

More "recently" (1584) Giordano Bruno speculated that there were "countless suns and countless earths all rotating around their suns." He was accused of heresy.

Serious work on the rest of the Universe began with Edwin Hubble in the 1920s.

10

He found that small nebulae (hazy patches) in the sky were neighboring islands of stars far outside our own galaxy, each containing hundreds of billions of stars.

Hubble used a telescope on a mountain top.
(7) Why mountain top? ________________

Today we use space telescopes (including one that bears his name).

11

Picture taken by "Hubble:"

12

ADDITIONAL NOTES

It seemed highly probable there'd be planets around other stars, given that there is a large number of stars in our galaxy and a large number of galaxies. (Estimates of both are in the 100s of billions.)

But over 70 years went by after other galaxies were found, without convincing proof of __________. Several times discoveries of extrasolar planets were announced, only to prove false.

13

1994, Alexander Wolszczan:

First widely accepted extrasolar planets.

Two or three planet-sized objects orbiting a pulsar, rather than a normal star. (A pulsar is a remnant of a stellar "supernova explosion.")

14

1995, Michel Mayor and Didier Queloz:

First discovery of a planet orbiting a star similar to the sun (star 51 Pegasi). About half the mass of Jupiter, with a period of 4.2 Earth days(!).

New class of planets called Hot Jupiters: hot, massive planets orbiting closer to their stars than Mercury.

15

16

Three months later, Geoffrey W. Marcy and Paul Butler and team confirmed the previous discovery, and found two more planets.

By the end of the 20th century, several dozen "worlds" discovered, many after months or years of observation.

The count now is in the thousands.

17

(8) Why the recent flood of discoveries?

____

- ____________________
- ____
  ____
- ____
  ____
  ____

18

ADDITIONAL NOTES

Missions

2006: French CoRoT mission. First dedicated "exoplanet" space mission; searches for planets that pass in front of their host stars.

Has contributed dozens of confirmed exoplanets.

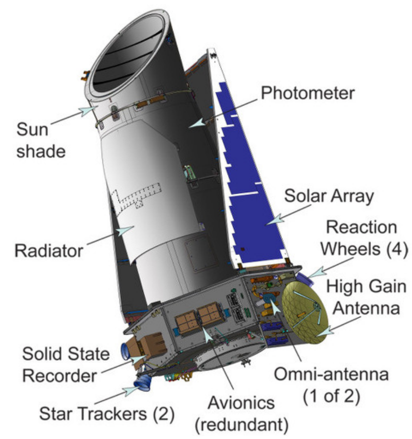
19

2009: NASA's first exoplanet mission, Kepler.

Kepler has found that small planets are likely to be the most common in the galaxy, and that our sun is an unusually calm star. Kepler has found exotic, multi-planet solar systems and hot Jupiters of very low density.

20


21



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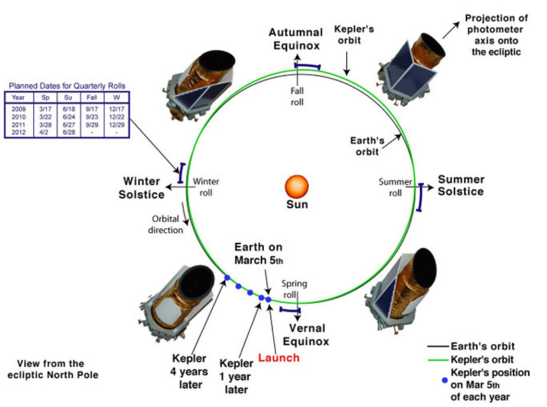

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24

ADDITIONAL NOTES

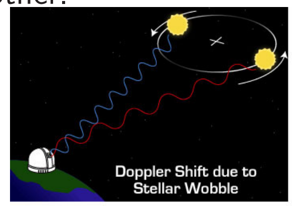
(9) Finding exoplanets is not easy. Why?

- ____
- ____
- ____

25

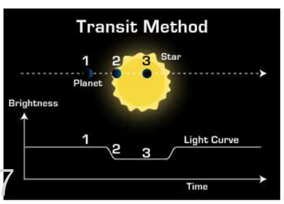
Methods for finding exoplanets

▷ ______________________ as star and planet rotate around each other.



26 ____

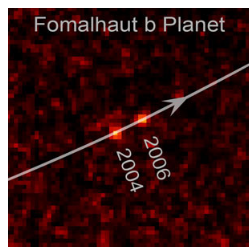
▷ ________________. ________________________________



Kepler and CoRoT spacecraft monitor large numbers of stars for the dimming caused by a transit. Kepler has discovered more than 1,000 potential exoplanets this way.

27

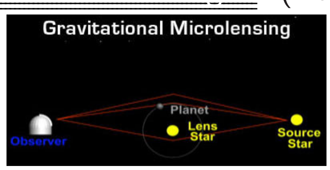
▷ ______________________.



Specialized optics have made a few exoplanet images possible. One method uses a masking device to block the light of a star so that its planets can be seen more clearly.

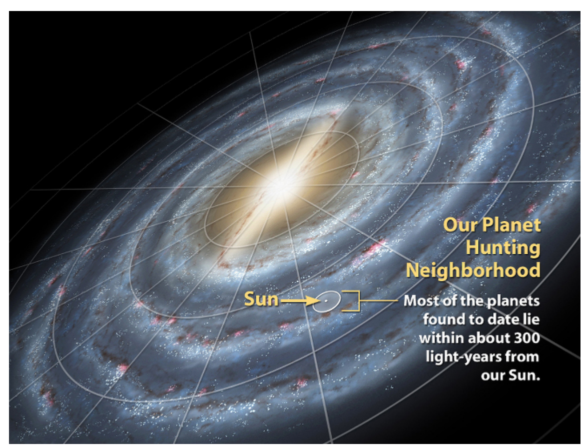
28

▷ ____________________________. (Relativity.)



____

29 ____



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ADDITIONAL NOTES

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ADDITIONAL NOTES

Your name: ______________________

Arvind Borde

AST 9: Homework 1

1] How long in km is a light-minute?

2] If your friend says "You look light-years younger" how much younger are you?

3] Calculate $10^3 \times 10^{-3}$.

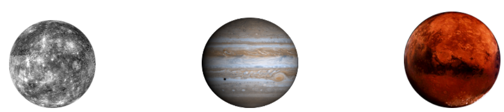
4] Which is the largest planet?

5] If you bounce a radiowave off the head of your friend and it takes 2-millionth of a second to return to you, how far is your friend from you?

6] What do your eyes have in common with methods used by astronomers to figure the distance to nearby stars.

7] Does the parallax method work better for relatively nearby objects or for very distant ones?

8] Which planets are these and why?



Your name: ____________________________

Arvind Borde

AST 9: Homework 1b

1] What is the most massive object in the solar system other than the sun?

2] Matter is one of two basic entities that make up the world. What is the other?

3] There are two basic types of particle that all matter is composed of. What are they? How many particles are there of each type?

4] What are the four basic forces? Which of these is most important in determining the large-scale structure of the Universe? Why?

Your name: ______________________

Arvind Borde

AST 9: Homework 2

1] What are some of the difficulties with the view that the Earth is the center of the Universe?

2] If $y \propto x$ and x doubles, what will happen to y?

3] If you unexpectedly gain mass overnight to double what you were, would the gravitational force between you and the earth change, and by how much?

4] Saturn is roughly ten times as far from the sun as the earth is. If the earth were suddenly to pack up and move to Saturn's orbit, how would the gravitational force between it and the sun change?

5] The sun is much more massive than the earth. Why does its gravitational pull not pluck us off the earth? (If you've always wanted a summer home, what better place than the sun?)

6] Can you ever see Venus at midnight? How about Jupiter? Explain your answer in both cases.

7] What is the perihelion of a planetary orbit? What does the "precession of the perihelion" refer to?

8] A "year" for a planet is the time taken for it to complete one orbit around the sun. Expressed in earth years, the years on the 8 planets are 0.2 (Mercury), 0.6 (Venus), 1.0 (Earth), 1.9 (Mars), 11.9 (Jupiter), 29.4 (Saturn), 84.0 (Uranus), and 164.8 (Neptune). Is there a pattern linking the length of a year to distance from the sun? Using all the gravity at your disposal, why is this the case?

Your name: ____________________________

Arvind Borde

AST 9: Homework 2b

1] According to the theory of relativity, gravity is not a true force. What is it?

2] What attribute of an object is connected to the curvature of spacetime that it causes? (Color? Shape? Charge? Mass?)

3] If you shine a ray of light then chase after it at half the speed of light, at what speed will the ray recede from you?

4] What are the three effects explained (or predicted) by Einstein when he proposed the final version of the theory of relativity?

5] The sun gives off lots of energy. Which equation from relativity might be used to predict what produces this energy?

Your name: ______________________________

Arvind Borde

AST 9: Homework 3

1] Does Kepler's second law teach us that a planet speeds up as it gets closer to the sun, or slow down?

2] The area of a triangle is $(1/2) \times$ base $\times$ height. If the height halves, how should the base change in order to keep the area fixed? If a planet is twice as far from the sun at its furthest point as it is at its closest, how might you guess the the orbital spends at the two points might be related? Why?

3] If we measure the semi major axis of a planetary orbit in A.U. (Astronomical Units) and the period in earth years, Kepler's third law simplifies (more-or-less) to $P^2 = a^3$. In other words, $P^2/a^3 = 1$. Check this for all the solar system planets.

Periods and semi-major axes of the planets

Planet	Period (years)	Semi-major axis (A.U.)	P^2/a^3
Mercury	0.24	0.39	
Venus	0.6	0.72	
Earth	1.0	1.0	
Mars	1.9	1.5	
Jupiter	11.9	5.2	
Saturn	29.4	9.5	
Uranus	84.0	19.2	
and Neptune	164.8	30.1	

4] We have seen that the smallest value of the eccentricity, $e = \sqrt{1 - \left(\frac{b}{a}\right)^2}$, is zero, when $a = b$. What might you deduce the largest value of e can be? Why? (Hint: it will occur when the semi-major axis, a, is much, much bigger than the semi-minor, b.)

Your name: ______________________________

Arvind Borde

AST 9: Homework 3b

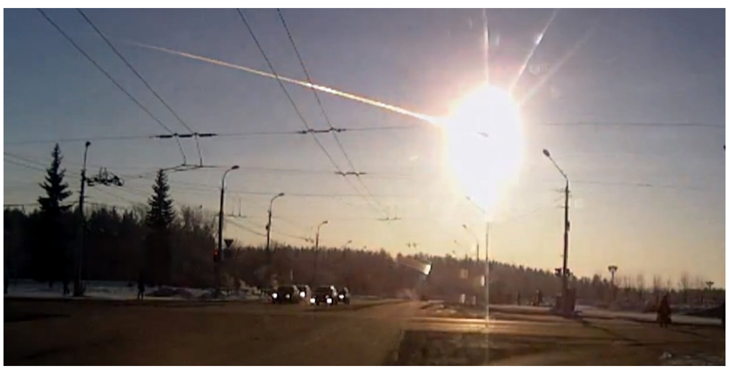
1] The general 2-body problem in gravity asks if can calculate what will happen when 2 bodies of masses m_1 and m_2 with initial velocities v_1 and v_2, respectively, and an initial separation d interact gravitationally.

$$v_1 \nwarrow \underset{m_1}{\bullet} \underbrace{\to \text{gravitational force} \leftarrow}_{d} \underset{m_2}{\circ} \nearrow v_2$$

As said in class the answer is "yes." We can calculate precisely how each body will subsequently move.

The 3-body problems asks if we can calculate what will happen when 3 bodies interact gravitationally, if we know their initial separations and velocities. Do a web search to find out what we know in this case, and write down the source you used. Also print out and bring at least one picture of possible behavior.

2] In 2013 an asteroid with an initial mass of 12 million kg entered the earth's atmosphere. It exploded in the atmosphere above Russia and released energy equivalent to over 20 Hiroshima atomic bombs.



Assume that this asteroid came from the asteroid belt and "fell" (meaning it was pulled to earth solely by the gravitational force of the earth) 300 million km. Had it hit the earth head-on in a direct collision, how much would the earth have moved toward it prior to colliding? (Mass of earth is about 6×10^{24} kg.)

3] When we consider the sun-earth system, why is it OK to consider the sun as stationary and the earth as moving around it?

4] If two objects are moving way from each other initially, will gravity always force them to slow to a halt and fall back to each other? What is the key concept that allows us to analyze and predict what will happen here?

5] Read the NASA article "What is a planet?" that's linked on the course web page and list in your own words a summary of the four characteristics of a planet.

Your name: ____________________

Arvind Borde

AST 9: Homework 4

1] Is light a wave or a particle?

2] What is a photon?

3] The frequency of a light wave can be measured as the number of waves that go past in a time unit. The speed of light is approximately 300 million meters/sec and the wavelength of orange light is roughly 6×10^{-7} meters. How many waves of orange light will go past you in one second? (Use the relationship between speed of a wave, wavelength and frequency.)

4] If two waves (Wave A and Wave B) have the same speed, but Wave A has three times the wavelength of Wave B, how are their frequencies related?

5] What is the Doppler effect?

6] Is it possible to identify an element by the radiation it emits?

7] If the frequency of an electromagnetic wave doubles, how does its energy change?

Your name: ______________________________

Arvind Borde

AST 9: Homework 4b

1. Which of the ground-based telescopes that we discussed in class might not have its observations affected by the earth's rotation?

2. How smooth does the surface of the Arecibo telescope seem compared to the surface of the Subaru? (See class notes for pictures.) If the smoothnesses seem different, why might it be OK to have different degrees of smoothness in the two cases? For a radio telescope that's distinctly not smooth, see the picture on the right of a radio telescope at Stanford University. Why might it work as a reflector?

3. If a telescope with focal length $30\,\mathrm{cm}$ "sees" an object taking up 2° of its view, how big is the image in the telescope?

4. If an object makes an image that's $0.5\,\mathrm{mm}$ on your retina, how many degrees of your view does it occupy?

5. When you zoom into an object optically with your camera (not electronic zoom), does the lens extend or contract? Why?

6. Why is a ground-based x-ray telescope not a great idea?

7. What is the resolution in seconds of telescope with a $0.5\,\mathrm{m}$ diameter lens at visible light?

8. We've seen in class that some telescopes are dual-purpose: they detect visible light and infra-red. Were the telescope in the question above capable of this, would it have higher resolution in infra-red or lower (compared to visible light)?

9. What diameter lens do you need on a telescope that can resolve up to a thousandth of a second?

Your name: ______________________________

Arvind Borde

AST 9: Homework 5

1] Can the sun ever be overhead at the north pole? Why or why not?

2] What is latitude? What are the tropics of cancer and capricorn? (You may look these up if you wish.) Is there a connection between the latitudes of these tropics and something we have discussed in class?

3] Is the earth slightly flattened at the poles or at the equator?

4] We have seen that the earth's core has two parts, inner and outer. Are they both solid? Both liquid? What is their nature?

5] The outer core is made up of iron and nickel. Is your experience of them that they are usually solid or liquid? The temperature of the outer core is between 4 and 5.5 thousand degrees celsius (4,000–5,500° C). How might that temperature affect whether the outer core is solid or liquid? (Try to be precise and look up any information that might be pertinent.)

6] This requires a bit more thought/googling than the previous. The inner core is also composed of iron and nickel and is at a temperature of roughly 5,500° C. What additional factor might make its nature (solid v. liquid) different from the outer core?

7] What observations allow us to conclude that the earth might have liquid in its core?

8] What is the main method used to determine the age of the earth? Are there any hidden assumptions in the method?

9] If you have 24 grams of a radioactive substance and it takes 100 years for it to decay to 12 grams, how many further years will it take to decay to 3 grams? Will it, in principle, ever decay completely (to 0 grams)?

10] Is the earth's atmosphere mainly light gases or heavy? Why?

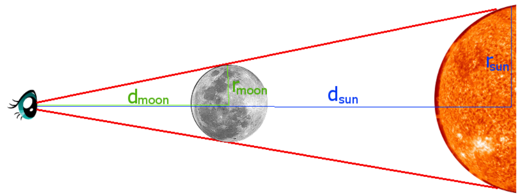
11] What layer of the atmosphere chiefly protects us from harmful radiation? How high is it? What layer is useful in communication? How high is it?

Your name: ____________________

Arvind Borde

AST 9: Homework 6

1] Here's a diagram that illustrates (not to scale, obviously) how a solar eclipse can be total:

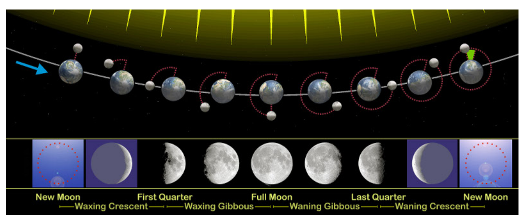


For the moon to more-or-less cover the sun, the moon and the sun need to have more-or-less the same *apparent size* (i.e, look as if they have close to the same size). The condition for that is

$$\frac{d_{\rm sun}}{r_{\rm sun}} \approx \frac{d_{\rm moon}}{r_{\rm moon}}.$$

The radius of the sun is $\sim 7 \times 10^5$ km and its distance from us is $\sim 1.5 \times 10^8$ km. The radius of the moon is $\sim 1.74 \times 10^3$ km and its distance from us is $\sim 3.84 \times 10^5$ km.
Does the condition for equal apparent sizes hold for the sun and moon?

2] Keeping in mind that it's possible to faintly see the moon even in daylight, answer the questions below using this diagram as a guide



(a) Is it possible to see a full moon at noon? (b) Is it possible to see a new (crescent) moon at midnight? (c) Can you deduce from the photograph below where the sun might be hidden, and very roughly what time it might be?

3] Newton's Law tells us that the gravitational force on you "caused" by an object of mass M a distance d from you can be expressed as $F_{\rm grav} \propto M/d^2$. The mass of the sun is $\sim 2 \times 10^{30}$ kg and that of the moon is $\sim 7.4 \times 10^{22}$ kg. Using the distances from question 1, calculate M/d^2 for the sun and the moon. Which is greater and by how much? The tidal force, on the other hand is $F_{\rm tidal} \propto M/d^3$. Do the same sun/moon calculation here, and note which is greater.

4] Does the moon exert appreciable tidal forces on *your* bodily fluids? One of the units of force is a Newton. It's roughly the weight of a small apple in your hand on earth. A 60 kg person will have roughly 40 kg of water in her/him. To get the tidal force of the moon on this person's fluids, take the answer for M/d^3 for the moon from above and multiply it by 40. To covert to Newtons, however, you must *divide* by 10^{20}. How's them apples?

Your name: ____________________

Arvind Borde

AST 9: Homework 6b

1] What, if anything, does the advice to layer your clothing in the winter have to do with temperature extremes on the moon?

2] Question 2 on HW 3b (Week 3, Thursday) showed a picture of a large meteorite flashing through the air and exploding over a region in Russia. Could such an event have occurred just above the moon? Why?

3] Why do we consider it unlikely both that the moon could once have fully been part of the earth or even formed with it, on the hand, or could be a completely different body captured by the earth, on the other?

4] What *elements* crucial for life as we know it (look at week 5 stuff to remind yourself of this) are missing on the moon?

5] Name one factor (apart from elements) that we consider crucial for life that the moon lacks and one that we now think it has.

6] What are the light and dark areas of the moon called? Is one of the names a possible misnomer?

7] Has an attempt been made (or is it being made) to probe the inner structure of the moon?

Your name: ______________________

Arvind Borde

AST 9: Homework 7

1] In the late 1700s the German astronomer Johann Bode published a book whose title translates (i'm told) to "Manual for Knowing the Starry Sky". He had a formula in it that he attributed to an earlier astronomer, Johann Titius. It seemed to predict where the orbits of the planets after Mercury should lie. If we number the planets by n, where Mercury is the first planet ($n = 1$), Venus the second ($n = 2$), etc., then the formula is

$$.4 + \left(\frac{3}{40}\right) \times 2^n$$

where the 0.4 is taken from the Sun-Mercury distance. This is called the Bode-Titius Rule. Calculate the predicted distances from this rule and complete the following table. (The "S-m (AU)" column is the known distance.)

Bode-Titius Rule

Planet	n	S-m (AU)	BT Rule
Mercury	1	0.39	.4
Venus	2	0.72	
Earth	3	1.0	
Mars	4	1.5	
???	5	???	
Jupiter	6	5.2	
Saturn	7	9.5	
Uranus	8	19.2	
Neptune	9	30.1	

The line with the question marks in it was a puzzle for Bode. He said "After Mars there follows a space ... in which no planet has yet been seen. Can one believe that the Founder of the universe had left this space empty?" What do we now think this space represents? Is there a significant disagreement with the predicted and the known distances anywhere else on the table?

Translate the column heading "S-m (AU)" above into plain English (see HW3).

2] The title of a scientific paper says "A lower limit of 9.5 Gyr on the age of the Galactic disk." Translate this into plain English.

3] What are the reasons to believe in the theory that our solar-system formed out of a giant dust and gas cloud?

4] Which of the planets are likely to have hard surfaces?

5] The earth is the only planet that can support life because it is the only one with an atmosphere. True or false? Why?

6] Which of these is the best estimate we now have of the number of possible solar systems in the Universe: 0, 1, a million, a billion, a billion-billion? Why?

7] Have we sent missions to explore the outermost parts of the solar system? How were the fuel considerations dealt with?

Your name: ______________________

Arvind Borde

AST 9: Homework 7b

1] If there were people on Venus, they'd all have birthdays on the same day. True or false? Explain.

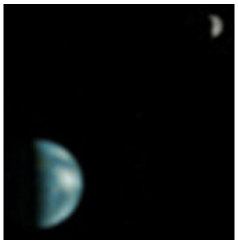
2] When a Mercurian (inhabitant of Mercury) has a birthay, he/she knows the next one will be no more than two days later. How is that possible?

3] Which of the planets we've so far studied is our Moon most like? In what way?

4] Would we be able to breathe easily on Mercury? On Venus? For the same reason, or different?

5] Does the sun rise in the East or West on Mercury? Why? And how are East and West determined on other planets, anyway?

6] This is a photo of Earth (bottom left) taken by the Mars Global Surveyor. Draw a sketch to explain why only part of the Earth seems visible. What might the object in the top right corner be?



Your name: ______________________________

Arvind Borde

AST 9: Homework 8

1] Fill out the first four lines on the Planets table I gave you. You may have to do a web search for some values for Earth (eccentricity, etc.) or a hunt in your notes.

2] One column heading says **Orbit "radius"**. Why the quotation marks?

3] Take the square root of each number in that column. Cube your answer, then multiply by 365. (For example, for Mercury calculate $\sqrt{39}$, cube that answer and multiply by 365.) Do you get a number that closely matches another number in the row for that planet? If so, why?

4] While I gave you day and night temperatures for the other planets, I gave you only one temperature for Venus. Why?

5] Mars has half the radius of Earth, but its *land* area is close to that of Earth. Ponder. Then explain.

6] Is there liquid water on Mars? Was there liquid water on Mars?

7] Why does Mars have seasons?

8] This is a photo of the rusty medical building at Stony Brook. What does it have to do with Mars?

Your name: ____________________________

Arvind Borde

AST 9: Homework 8b

1] What are "Recurring Slope Lineae"?

2] Is it more accurate to say that we have found pure liquid water on Mars or liquid brine? What is the significance of the brininess for the liquidness?

3] What methods were used to determine that there are hydrated salts in the RSL?

4] What is RSL anyway?

Your name: ____________________

Arvind Borde

AST 9: Homework 9

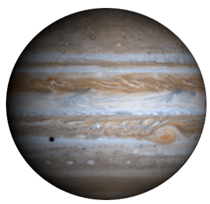
1] Fill out the rest of the planetary table, if you have not already done so.

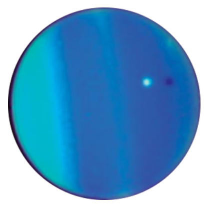
2] The composition of Jupiter makes it similar to a star. Why? (We've mentioned how the sun works previously in class, but you may need to look up the composition of the sun.)

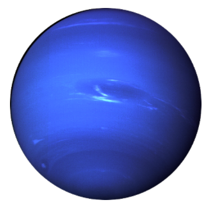
3] If you went to JIU (Jupiter International University), not LIU, and the semester was 1/3 of a Jupiter-year long, how many Jupiter days would that be? To compensate for the pain, how many hours might a workday be?

4] Neptune was discovered in 1846. How many years have elapsed since its discovery? (Round to the nearest year.) Can there be a second, different answer to this question? Explain.

5] Here are Jupiter, Uranus and Neptune. (I've left out Saturn because the rings are distracting.) Notice the bands in their appearance. Notice the angles of the bands. Was the camera rotated at random angles when the picture was taken, or might the angles of the bands be related to how the planet behaves? What aspect of planetary behavior?







6] What might the tiny black dots be in the pictures of Jupiter and Uranus above?

7] What pattern do you notice overall in the average temperature on a planet as you get further from the sun? Does this make sense? Is there a planet that breaks the pattern? Which is it and why does it do so?

8] It's sunrise on Venus. Should you look West or East to view it? Is there another planet on which sunrise might be in the same general direction? Why?

9] Do the planets that have rings also have larger amounts of something else than the other planets (ones that don't have rings)? What? Does it seem plausible that there might be a connection?

10] We'd seen that the equatorial radius of the Earth is 6,378 km while the polar radius is 6,357 km. What is the reason for this "flattening at the poles"? The numbers mean that the polar radius of the Earth is 99.7% of its equatorial radius. Saturn has the lowest such percentage of any planet: the polar radius is only about 90.2% of the equatorial. Jupiter is next with a value of 93.5%. The ratio for all other planets is greater than 97.7%, with Mercury and Venus topping the chart at 100%. Why do you think Mercury and Venus are at the top, and Saturn and Jupiter at the bottom?

11] Jupiter is about 300 times as massive as the Earth but its radius is only about 11 times as big. Do you expect it, on average, to be more dense than the Earth or less?

12] These are some of the units we use to measure time: years, months, days, hours, minutes, seconds. Initially, all arose from astronomy. Which seem to you primary, or directly related to astronomical phenomena, and which seem secondary (defined as multiples or as subdivisions of the primary ones)? Some of these are now defined independently of astronomical considerations. Take your best guess at which. (Hint: where might you need greater precision, and are astronomical definitions likely to give you that?)

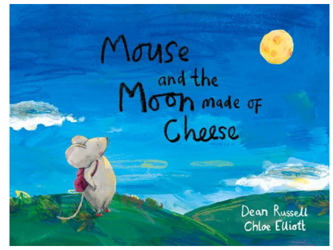
Your name: ______________________

Arvind Borde

AST 9: Homework 10

1] The largest moon is the solar system is Ganymede, a moon of Jupiter. Its radius is slightly greater than the 0.4 times the radius of earth. How does that compare with the radii of the planets? (Is it bigger than any?)

2] You may have heard as a child that the moon is made of cheese, and you've probably been wondering all your lives, "Which cheese?" Two scientists set off to investigate. They published a paper in 1970 on their findings (Schreiber E, Anderson OL, *Properties and composition of lunar materials: Earth analogies.* Science. 1970 Jun 26;168(3939):1579-80). They sent sound waves ("seismic waves") through various materials. Here's some of what they found:



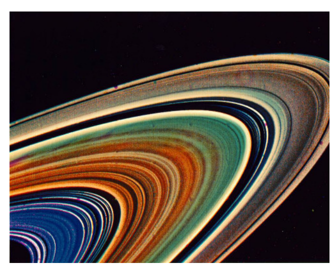
Seismic velocities (km/sec)

Earth rocks		**Moon rocks**		**Cheese**	
Granite	5.90	Moon basalt 1	1.84	Italian Romano	1.74
Earth basalt	5.80	Moon basalt 2	1.25	Vermont Cheddar	1.72
Sandstone	4.90	Near-surface	1.20	Wisconsin Muenster	1.57

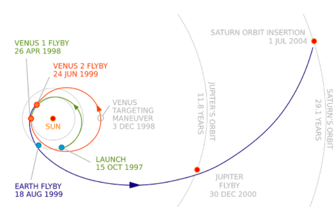
The seismic velocity is proportional to the density. Based on this,

(a) Is the density of the moon closer to that of cheese or to that of earth rock?
(b) Can you conclude from this that the moon might be made of cheese?
(c) The moon rock results are based on samples collected by astronauts.
Are they likely to tell us about the density nearer the surface of the moon or in its interior?
(d) Can you think of a reason why surface lunar rocks might have lower density?
(Hint: what is the moons surface constantly subjected to?)

3] On the right is a highly colorized photo of Saturn's rings. Do they seem continuous or do they seem to have gaps? If you see gaps, might they be spaces for something that Saturn has an abundance of? What?



4] We'd discussed the Cassini mission to Saturn in Week 7. Why did the spacecraft loop around the inner planets? Another satellite, Huygens, piggy-backed on Cassini, then separated near Saturn and landed on its moon, Titan. Why did it not land on Saturn directly?



5] Europa has some of the ingredients necessary to support life (water, oxygen). But we're still not sure it has one key ingredient (or set of ingredients). What's that?

6] Have we found life anywhere in the solar system?

Your name: ____________________

Arvind Borde

AST 9: Homework 11

1] The formula for the Stern-Levison parameter, Λ, involves $m^2/a^{3/2}$, where m is the mass and a is the length of the semimajor axis. If $\Lambda > 1$ the object is supposed to have sufficient gravitational power to "clear its neighborhood," if $\Lambda < 1$, then not. Remember that $a^{3/2}$ means "take the cube of the square root of a." Have you seen $a^{3/2}$ anywhere before? (How soon you forget homework 8.) What other planetary attribute is $a^{3/2}$ proportional to?

Λ and decreasing "Clearing Power"

Object	Λ	Mass (earth masses)	Year (earth years)	Mass^2/Year
Jupiter	1.30×10^9	318.00000	12.00	8.43×10^3
Saturn	4.68×10^7	95.00000	29.50	3.06×10^2
Uranus	3.84×10^5	15.00000	84.00	2.68
Neptune	2.73×10^5	17.00000	164.80	1.55
Venus	1.66×10^5	0.81500	0.62	1.08
Earth	1.53×10^5	1.00000	1.00	9.99×10^{-1}
Mercury	1.95×10^3	0.05500	0.24	1.25×10^{-2}
Mars	9.42×10^2	0.10000	1.88	5.31×10^{-3}
Pluto	2.95×10^{-3}	0.00200	247.70	1.61×10^{-8}
Eris	2.15×10^{-3}	0.00280	557.00	1.41×10^{-8}
Ceres	8.32×10^{-4}	0.00016	4.60	5.57×10^{-9}
Haumea	2.68×10^{-4}	0.00070	285.40	1.72×10^{-9}
Makemake	2.22×10^{-4}	0.00067	309.88	1.45×10^{-9}

a) The Λ column goes down steadily and there's a big jump between Mars and Pluto. Do you agree?
b) The last column goes down steadily and there's a big jump between Mars and Pluto. Do you agree?
c) Why do the Λ column and the last column behave the same?
d) "Clearing power" *largely* depends on mass: more mass, higher on the table. Do you agree?
e) Is that rough pattern broken anywhere? Why?
f) One of the entries in the last column is wrong (deliberately). For one buck, which?
(The error does not affect the answer to the previous questions. I may be crazy, but I'm not a lunatic.)

2] From your planetary table, which planet has the greatest eccentricity? What is that eccentricity? Apart from that eccentric character, is there a planet with eccentricity greater than 0.1?

3] The eccentricities of the dwarf planets are these: Ceres (0.07976), Makemake (0.159), Haumea (0.18874), Pluto (0.2482), Eris (0.44177). Would you say that the dwarves have less eccentricity than the other planets, on average, or more?

4] We said that the atmospheres of Pluto and Eris expand and contract as they get closer to or further from the sun. What might make gases expand as they get closer to the sun and contract as they get further? (More or less light? Stronger or weaker gravitational effects? More or less heat? Some other factor?)

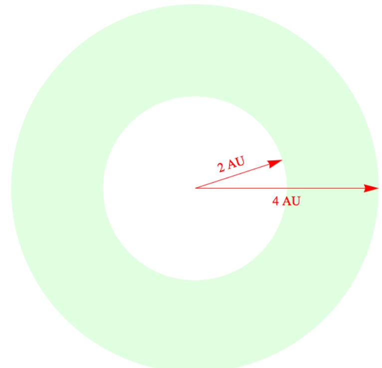
5] Why is this expansion and contraction effect more pronounced in the case of Pluto and Eris compared to planets such as earth? (Hint: the answer would stare you in the face if you glanced upward.)

Your name: ____________________

Arvind Borde

AST 9: Homework 11b

1] The asteroid belt extends from roughly 2AU to 4AU. Assume that the belt is roughly flat. Using the formula for the area of a circle (πr^2) and the conversion that an AU is roughly 1.5×10^8 km,



a) What is the area of the belt in km^2?
b) If there are a billion asteroids, how many per square-km?
c) Does your answer suggest the asteroid belt is crowded or not?
d) In one of the Star Wars movies C-3PO says this to Han Solo: "Sir, the possibility of successfully navigating an asteroid field is approximately three thousand seven hundred and twenty to one." Could this be true of our asteroid belt?

2] We've seen before that the ratio of the length of a year on a planet to $a^{3/2}$ is constant. Why? What is a? We've seen, also, that if the planetary year is measured in earth years and a in AU, that the ratio is 1. That means that in these units a "year" is roughly equal numerically to $a^{3/2}$. Use this, and the information in question 1, to calculate the longest and shortest possible years on an asteroid.

3] Below are historical depictions of comets in art with the dates on which the comets appeared. Which of these could have been Comet Halley?

1264

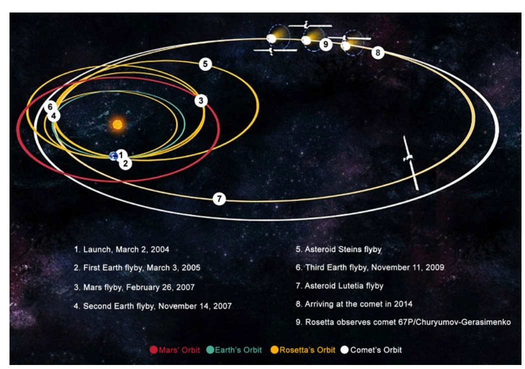
1401

1456

1556

http://io9.com/the-greatest-representations-of-comets-in-the-history-o-1648504019

4] The orbit of the Rosetta spacecraft is shown on the right.



a) Why did it loop around the Earth and Mars before heading to the comet (Comet 67P, Churyumov-Gerasimenko)?
b) The picture shows large solar panels sticking out from the craft. The comet it was trying to catch was traveling at over 67,000 km/hour (between the speeds of Mars and Jupiter). On earth, vehicles that travel fast need to be streamlined and can't have large flat panels sticking out. Why is that not a factor in space missions?
c) When Rosetta arrived at the comet, they were at 2.9 AU from the sun. What region of the solar system is that?

5] In movies, comets are sometimes depicted as visibly moving across the sky as people gaze at them. The high speed of the comet that Rosetta landed on, may make this seem a plausible depiction. Is it?

Your name: ____________________

Arvind Borde

AST 9: Homework 12

1] Let's check how much energy there is in 1 gm of matter. The unit of energy below will be an "erg." A 100 Watt bulb uses 10^9 ergs/second. A gallon of gas yields 12×10^{14} ergs of energy.

a) The speed of light is $c = 3 \times 10^{10}$ cm/sec. Calculate $E = mc^2$ for $m = 1$ gm.

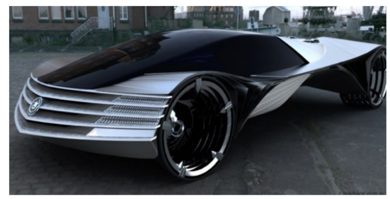
b) How many seconds would that power a 100 W bulb?

c) How many seconds are there in a year? Convert the answer in (b) to years.

d) How many gallons of gas is the answer in (a) equivalent to?

"In breaking news on the energy and technology front, Laser Power Systems, a U.S. company based out of Connecticut is developing a method of automotive propulsion using the element thorium to produce electricity."
October 20, 2013
http://politicalblindspot.com/car-runs-1-million-miles-on-8-grams-of-thorium/

Car Runs 1 Million Miles on 8 Grams of Thorium

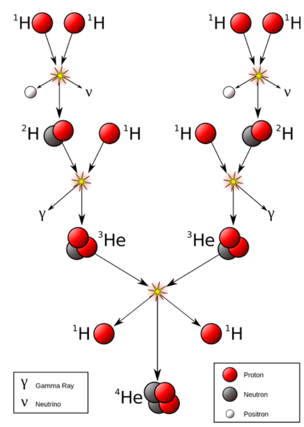


2] As we said in the class, fusion in the sun is a three-step process:

a) Two protons collide to produce deuterium (a variant of hydrogen), a positron (an anti-electron), and a neutrino.

b) A proton collides with the deuterium to produce a another helium variant (helium-3) and a gamma ray (high-frequency electromagnetic wave).

c) Two helium-3s collide to produce a normal helium nucleus, releasing two protons.

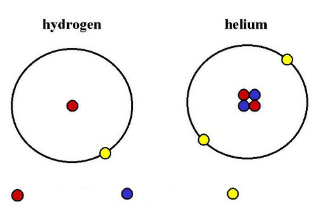


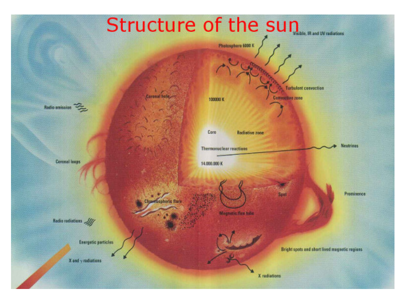
a) At what stage(s) is energy released that can escape from the sun?

b) At what stage is light released that can escape from the sun?

c) Which form of energy gets out quicker?

3] Where in this diagram of the sun on the right are the nuclear reactions that "fuel" it going on? Why just in that region?





4] Identify the colored dots in the diagram above as electrons, protons and neutrons.

Your name: ____________________

Arvind Borde

AST 9: Homework 13

1. Have we found exoplanets in our galaxy or out of it?
2. What are the methods we've used to find exoplanets?
3. Why is it hard to find exoplanets?
4. What improvements have made it easier recently to find exoplanets?
5. What are exoplanets, anyway?

The planets: basic facts at a glance

Planet	Radius (Earth radii)	Orbit "radius" (AU)	"Day" (Earth days)	"Year" (Earth days)	Eccentricity	Temp, Day/Night (C)	Mass (Earth masses)	Axis inclination (degrees)	Composition and features	Atmosphere	Moons/Rings	Missions
Mercury												
Venus												
Earth												
Mars												
Jupiter												
Saturn												
Uranus												
Neptune												

LONG ISLAND UNIVERSITY – C.W. POST

AST 9	**Arvind Borde, Introductory Astronomy I, Fall 2018**	3 credits

Classes	Tu/Th | §2: 11:00–12:20, PH 230.
Website	`http://arvind-borde.org/courses/ast9/`
Instructor	Arvind Borde | `arvind.borde@liu.edu` | `http://arvind-borde.org/`
Office	________; telephone: (516) 299 2447. Hours: T, Th, 12:30–2:00 pm, or by appointment.
Bulletin	Astronomy 9 is half of a one-year course in introductory astronomy. Topics include the celestial sphere, the solar system, planetary motion, configurations and phases of the moon and planets, and eclipses. No pre- or co-requisites. Students taking this course to fulfill the science core requirement must take AST 9A - Astronomy Lab.
Text, etc.	Notes, handouts, NASA's solar system site (http://solarsystem.nasa.gov/).
Rules	**Do:** attend all classes, come on time, stay for the duration, pay attention. **Don't:** talk among yourselves, be disruptive, text, have your cell phone out. Violating any of these will be marked as an absence and will lead to further disciplinary action. Three or more violations will lead to an automatic F. You may use a computer or tablet to take notes, but must be prepared to sit in the first row if asked.
Homework & Tests	Weekly homework is provided. You must attempt it the day it is assigned. If you have difficulties, see me or a tutor *that week itself*. HW will be discussed in the class immediately following. Specific questions will be answered in class, but not general ones about the whole assignment. You must have the homework available in the course workbook. You must bring the homework and workbook with you if you want extra help in my office. It is your responsibility to catch up on material you miss for any reason. You should expect to spend 6 hours a week on this course outside class. Tests are "open-notecard" ($3'' \times 5''$) and will be based mainly on material and homework covered the previous week, but familiarity with all material covered up to that point is expected. You may use a dedicated calculator (not cell phone or tablet computer) on all tests. *There are no make-up tests. If you miss a test for any reason you will get a score of* -1 *on it.* You must keep all your tests through the semester. See complete test schedule on this syllabus.
Grades	First see the rules above. There will be 13 tests. Your 11 best scores will each count 9% toward your grade. The remaining 1% is for overall attendance and class performance.
Note	Last day to drop: September 18. Last day to withdraw: November 9.

I have understood the syllabus, course requirements, grading method, and rules, and agree to abide by them. I have retained a copy of this syllabus for my records. I have filled out the form overleaf.

Signature: ______________________________ Date: ________________

Name: ____

Name (print clearly):

Major:

Last 2 science classes class taken (what? when? where?):

Career goals:

Dream goals (If earning money were not an issue what would your perfect life be like?):

Science weaknesses (if any):

Science strengths:

Anything in particular that you wish to learn in this course:

LONG ISLAND UNIVERSITY – C.W. POST

AST 9 **Arvind Borde, Introductory Astronomy I, Fall 2018** 3 credits

Classes	Tu/Th | §2: 11:00–12:20, PH 230.
Website	`http://arvind-borde.org/courses/ast9/`
Instructor	Arvind Borde | `arvind.borde@liu.edu` | `http://arvind-borde.org/`
Office	________; telephone: (516) 299 2447. Hours: T, Th, 12:30–2:00 pm, or by appointment.
Bulletin	Astronomy 9 is half of a one-year course in introductory astronomy. Topics include the celestial sphere, the solar system, planetary motion, configurations and phases of the moon and planets, and eclipses. No pre- or co-requisites. Students taking this course to fulfill the science core requirement must take AST 9A - Astronomy Lab.
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YOU MUST HAVE THIS SYLLABUS WITH YOU IN EVERY CLASS

AST 9.002 | **LIU – POST** **Introductory Astronomy I** Arvind Borde (arvind.borde@liu.edu) | Fall 2018

Week	Tuesday	Test	Thursday	score	%
Week 1			*Thursday, September 6* **Scale**		
Week 2	*Tuesday, September 11* **Gravity**; Homework 1 review. Homework 1b review (if needed)	Test 1	*Thursday, September 13* Homework 2a review Topic continues	score	%
Week 3	*Tuesday, September 18* **Planets** Homework 2b review (if needed)	Test 2	*Thursday, September 20* Homework 3a review Topic continues	score	%
Week 4	*Tuesday, September 25* **Light** Homework 3b review (if needed)	Test 3	*Thursday, September 27* Homework 4a review Topic continues	score	%
Week 5	*Tuesday, October 2* **The Earth** Homework 4b review (if needed)	Test 4	*Thursday, October 4* Homework 5a review Topic continues	score	%
Week 6	*Tuesday, October 9* **The Moon** Homework 5b review (if needed)	Test 5	*Thursday, October 11* Homework 6a review Topic continues	score	%
Week 7	*Tuesday, October 16* **The inner planets I** Homework 6b review (if needed)	Test 6	*Thursday, October 18* Homework 7a review Topic continues	score	%
Week 8	*Tuesday, October 23* **The inner planets II** Homework 7b review (if needed)	Test 7	*Thursday, October 25* Homework 8a review Topic continues	score	%
Week 9	*Tuesday, October 30* **The outer planets** Homework 8b review (if needed)	Test 8	*Thursday, November 1* Homework 9a review Topic continues	score	%
Week 10	*Tuesday, November 6* **Some special moons** Homework 9b review (if needed)	Test 9	*Thursday, November 8* Homework 10a review Topic continues	score	%
Week 11	*Tuesday, November 13* **The dwarf planets and other bodies** Homework 10b review (if needed)	Test 10	*Thursday, November 15* Homework 11a review Topic continues	score	%
Week 12	*Tuesday, November 20* **The star of the system** Homework 11b review (if needed)	Test 11	**Thanksgiving**	score	%
Week 13	*Tuesday, November 27* **Other topics**; Homework 12 review. Homework 12b review (if needed)	Test 12	*Thursday, November 29* Homework 13a review Topic continues	score	%
Week 14	*Tuesday, December 4* Homework 13b review (if needed)	Test 13	**Final appointments: TBA**	score	%