Welcome to The Natural World N190: Life in the Universe

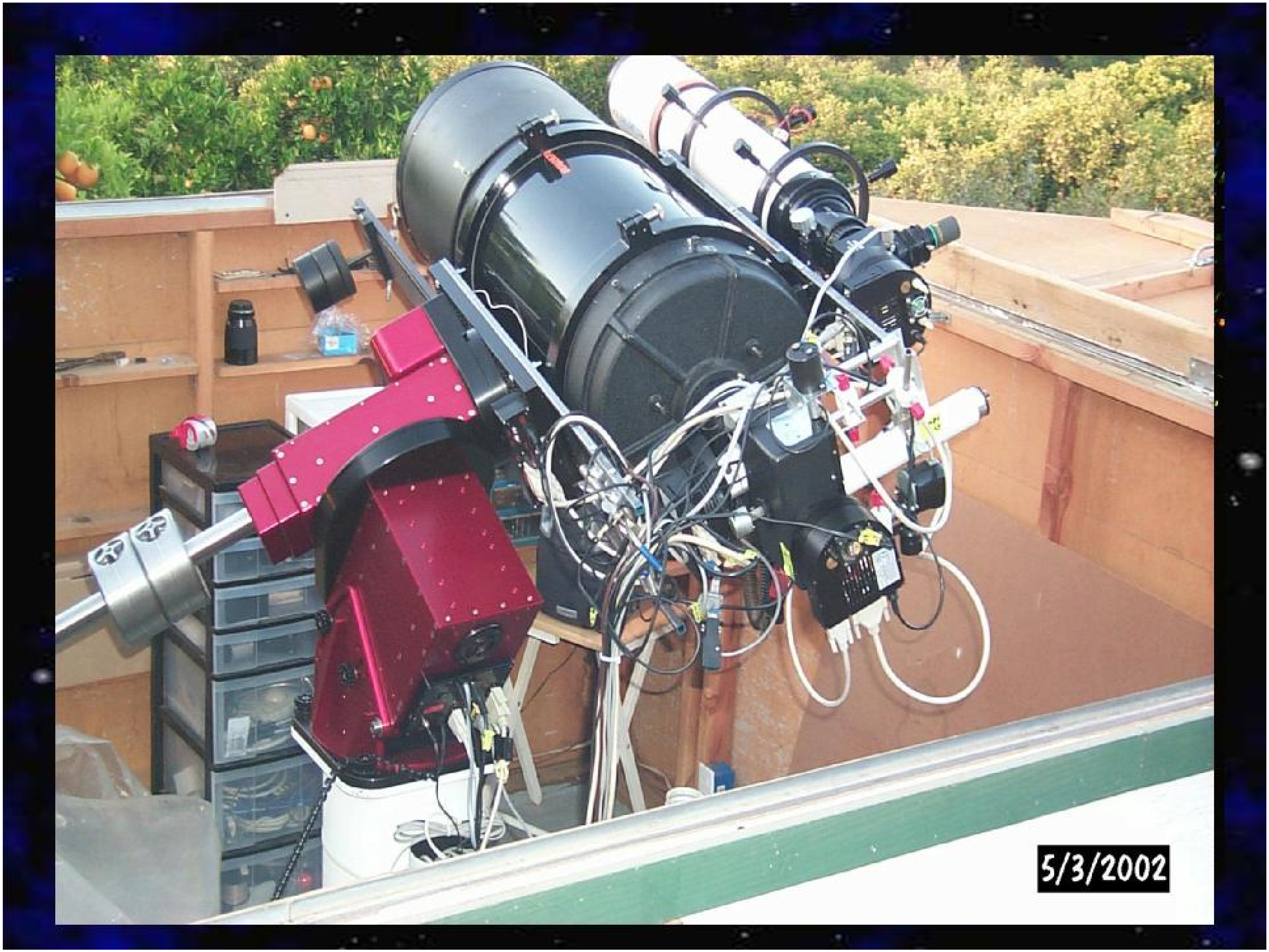
Dale E. Mais

Pharmacologist by trade-Biotechnology

-Women's health care

-Astronomy is my second career

dale.mais@mpiresearch.com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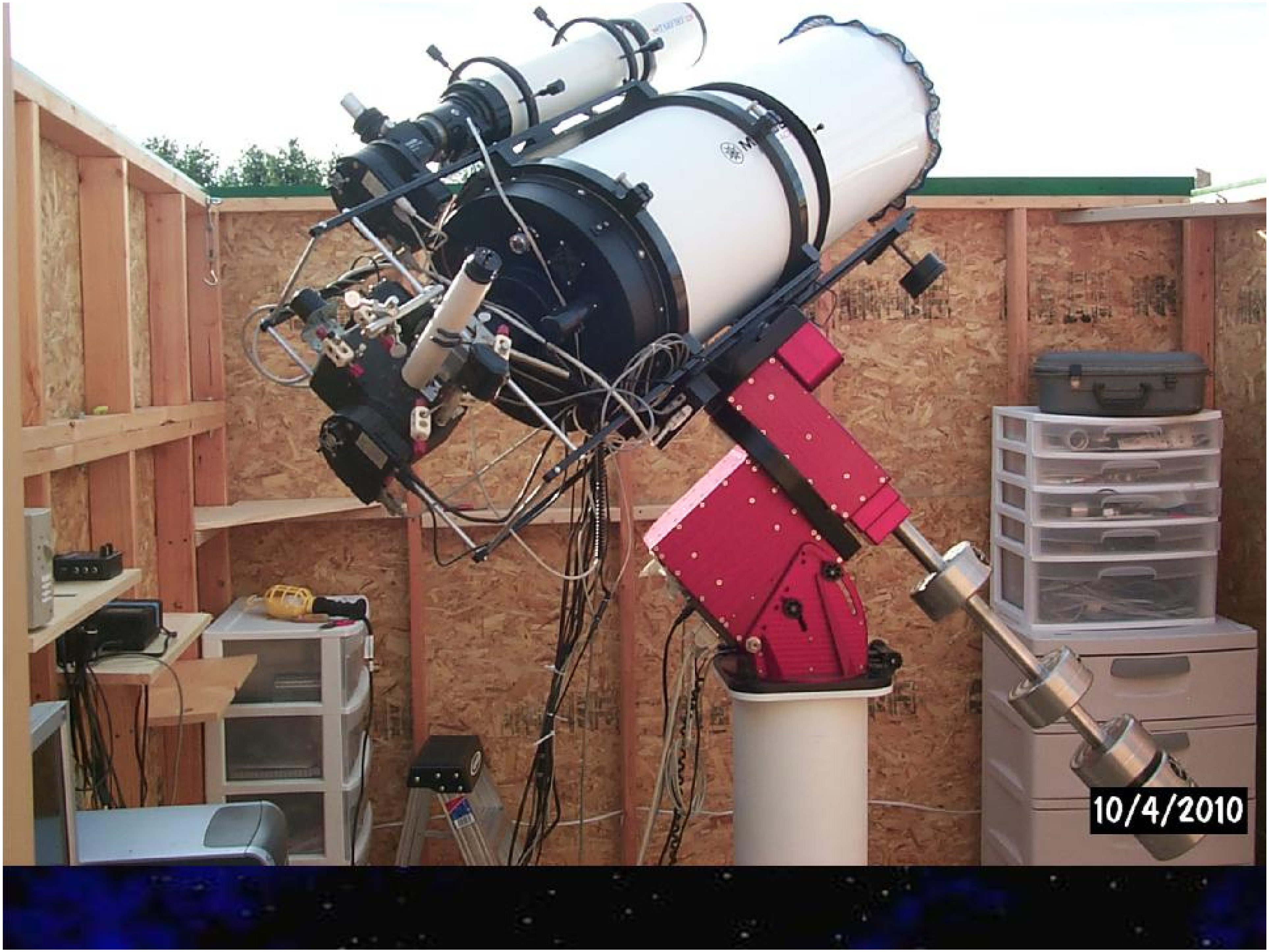
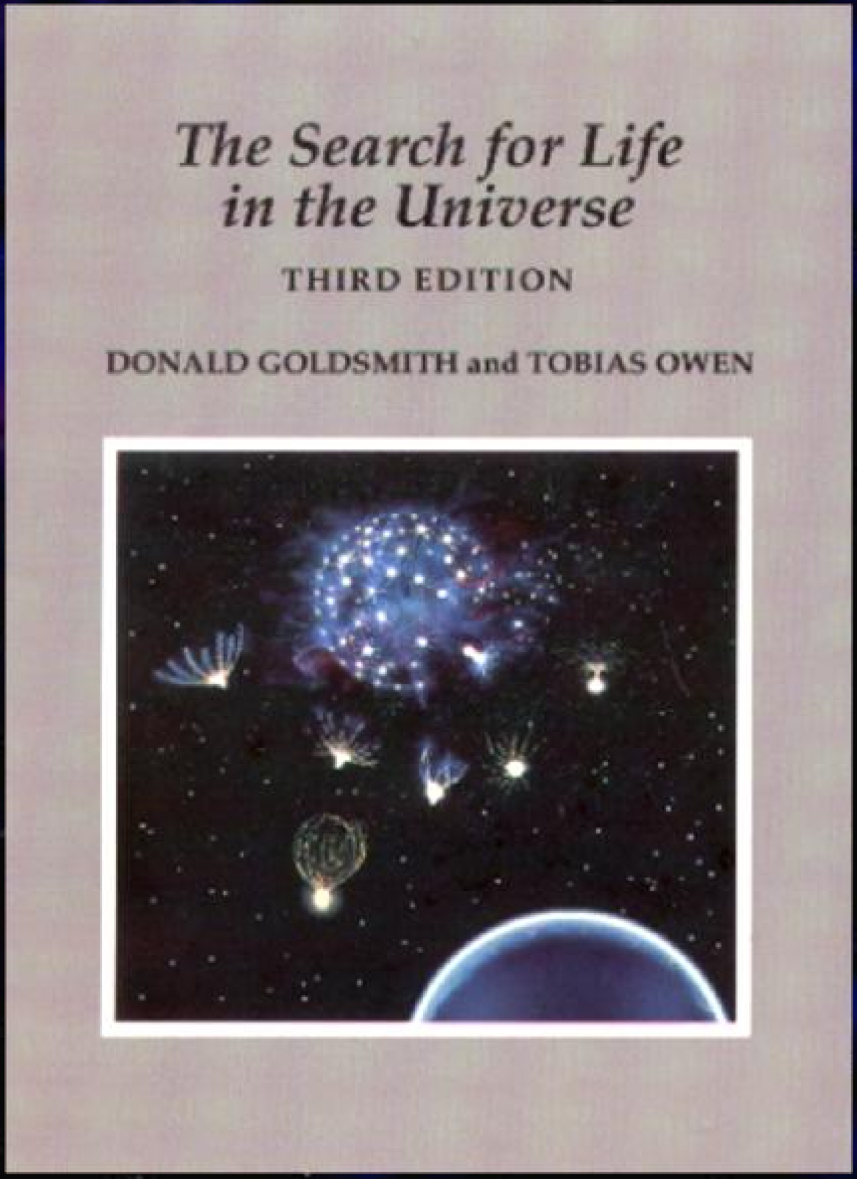

10/4/2010

"The Search for Life in the Universe"

3rd Edition

Goldsmith and Owen



- Powerpoint presentations online

@ mais-ccd-spectroscopy.com

- Frequent N190 refreshers
  - -chemistry
  - -physics
  - -astronomy
  - -biology
- Reading list soon...

Course Outline

Survey of the Solar System
- Distances
- Elements of life
- Our place in the galaxy

Stars
- Electromagnetic radiation
- Their classification
- Their life and death

Geological history of the Earth
- Formation of the Solar System
- Earth’s atmosphere and it’s evolution
- Has geology influenced life on earth?

Characteristics of life
- Definition
- Molecules of life
- Age of life

How do we search for Life
- Which stars do we search…there are a lot of them!
- How do we search
- What technologies do we use, both current and future ones

How many are out there?
- The Drake equation

Where are they all?
- Fermi’s paradox

Interstellar travel
- \- The laws of physics speak out!

All Powerpoint lecture slides are posted at my website as pdf files

Download and print if you wish
Take notes on
Can use on exams/quizes

Mais-ccd-spectroscopy.com

Go to links for Palomar College

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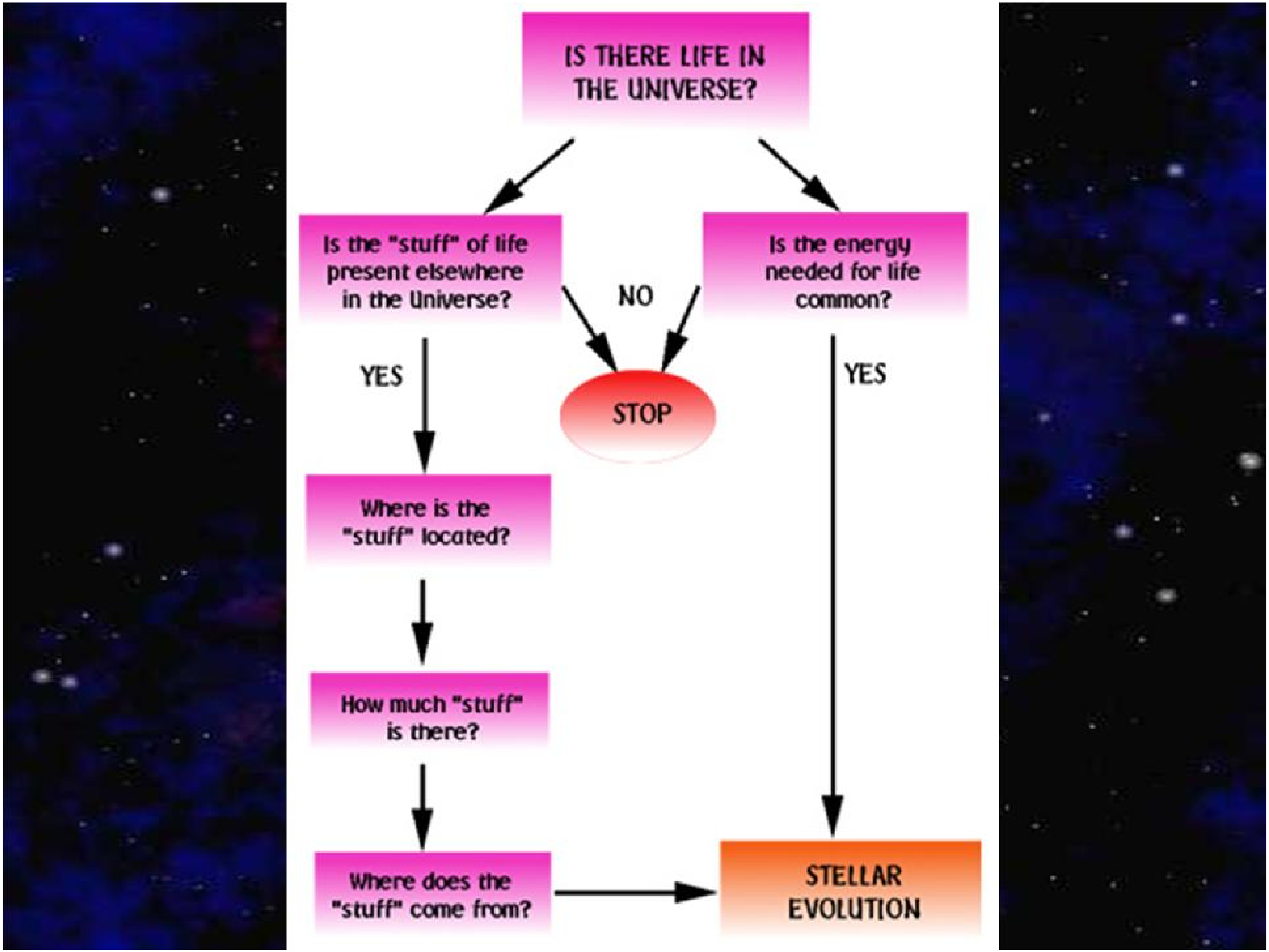
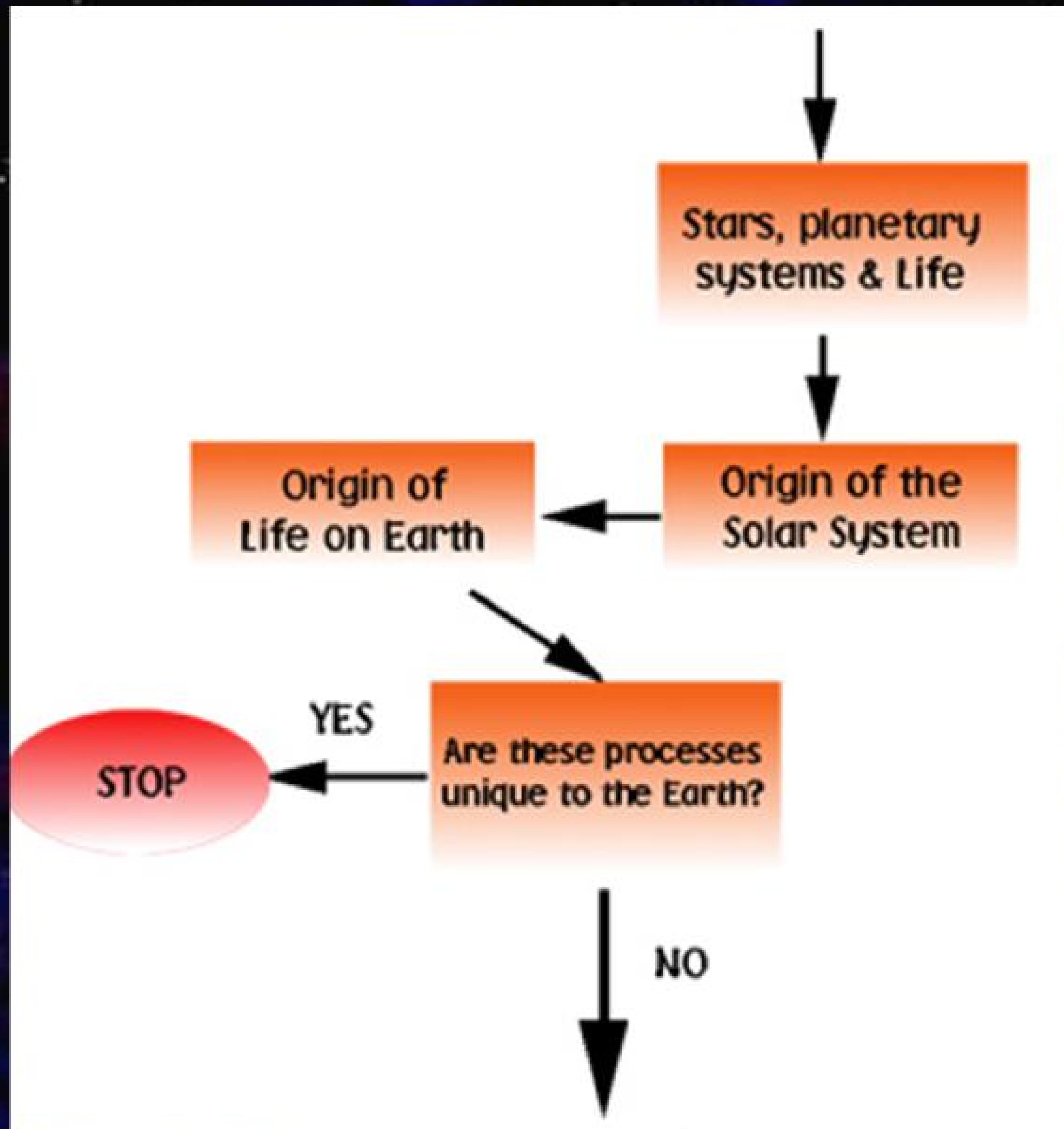
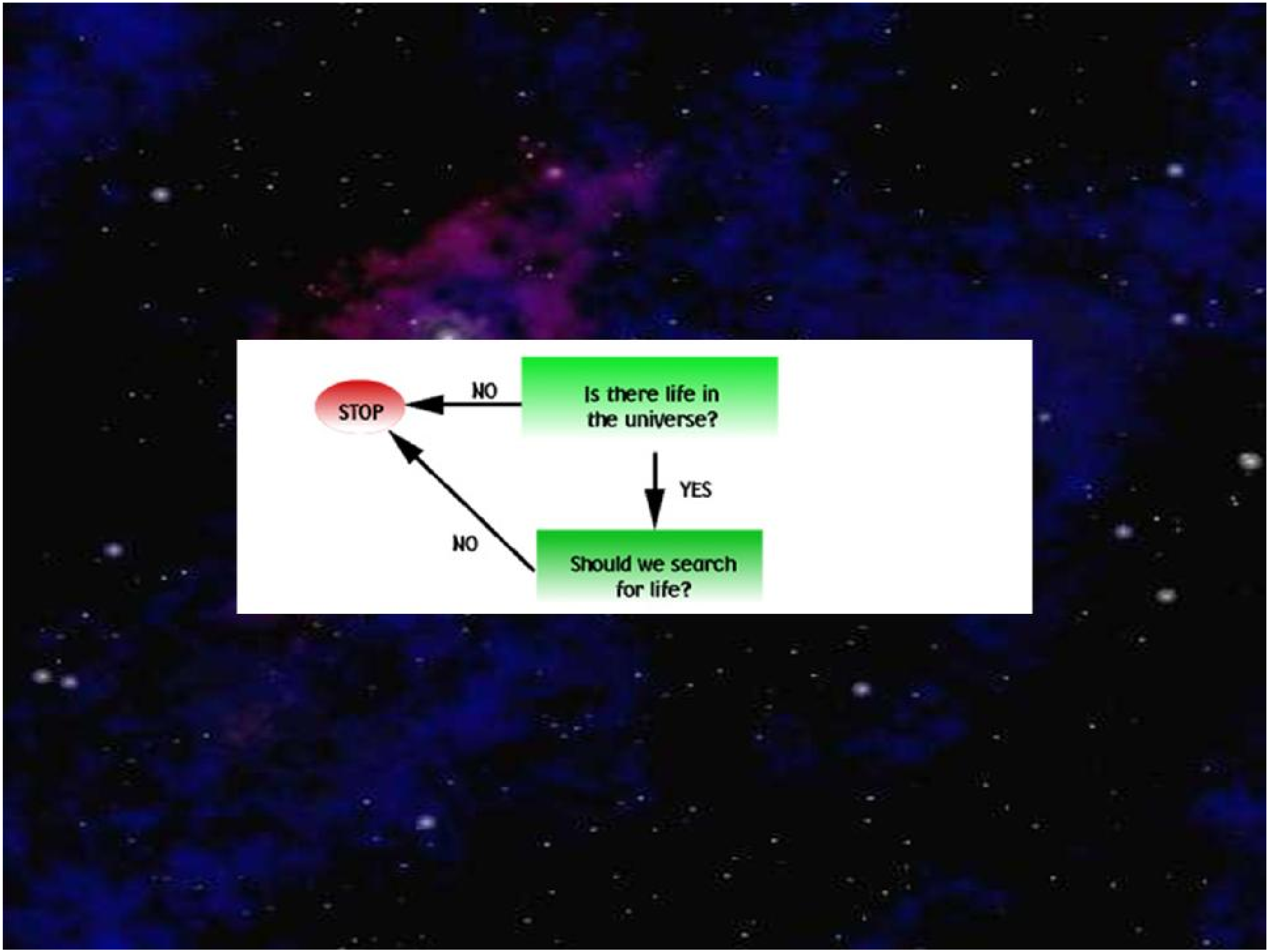
What should a “Life in the Universe” class cover??

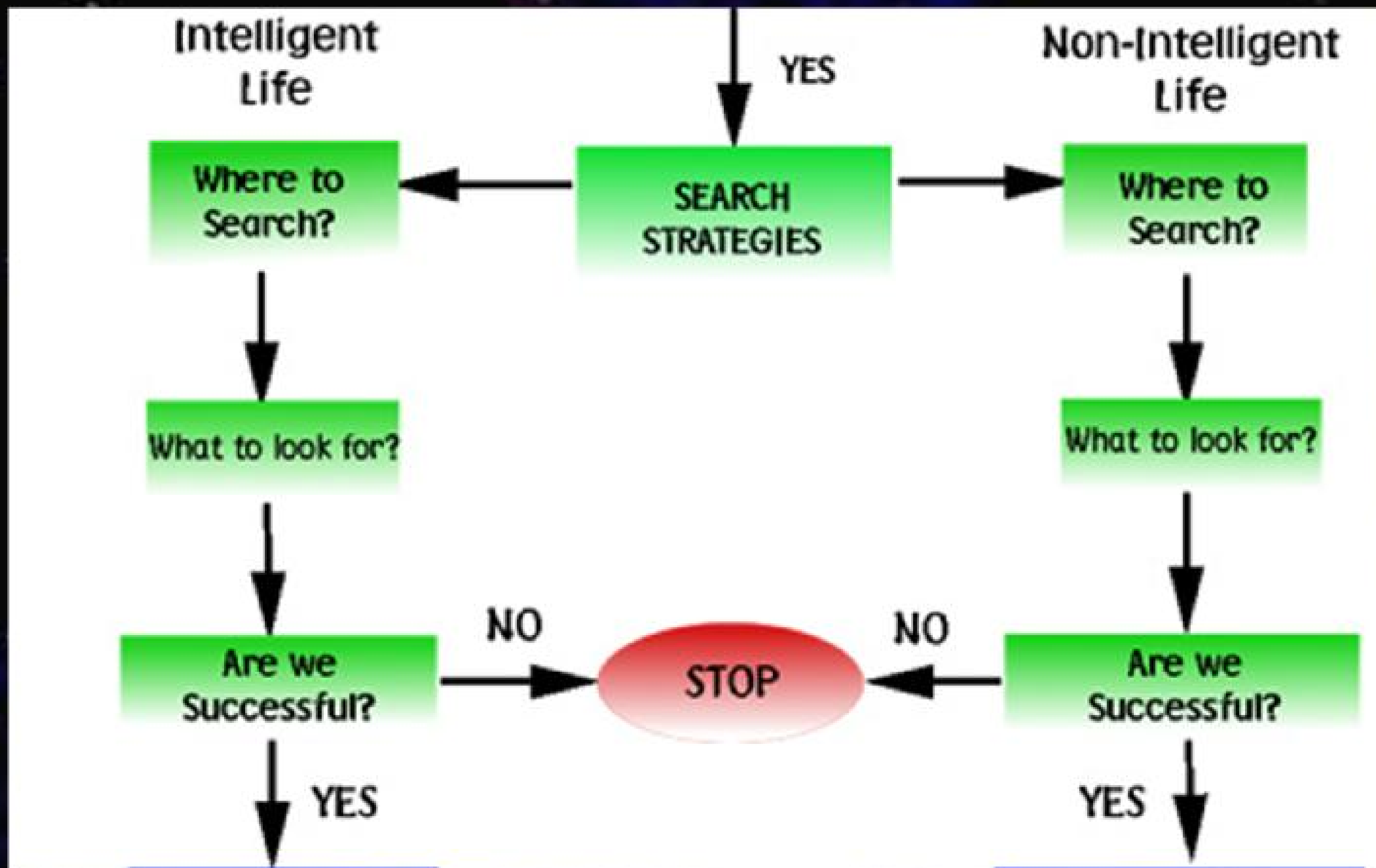

IS THERE LIFE IN THE UNIVERSE?
Is the "stuff" of life present elsewhere in the Universe?
Is the energy needed for life common?
NO
STOP
YES
YES
Where is the "stuff" located?
How much "stuff" is there?
Where does the "stuff" come from?
STELLAR EVOLUTION



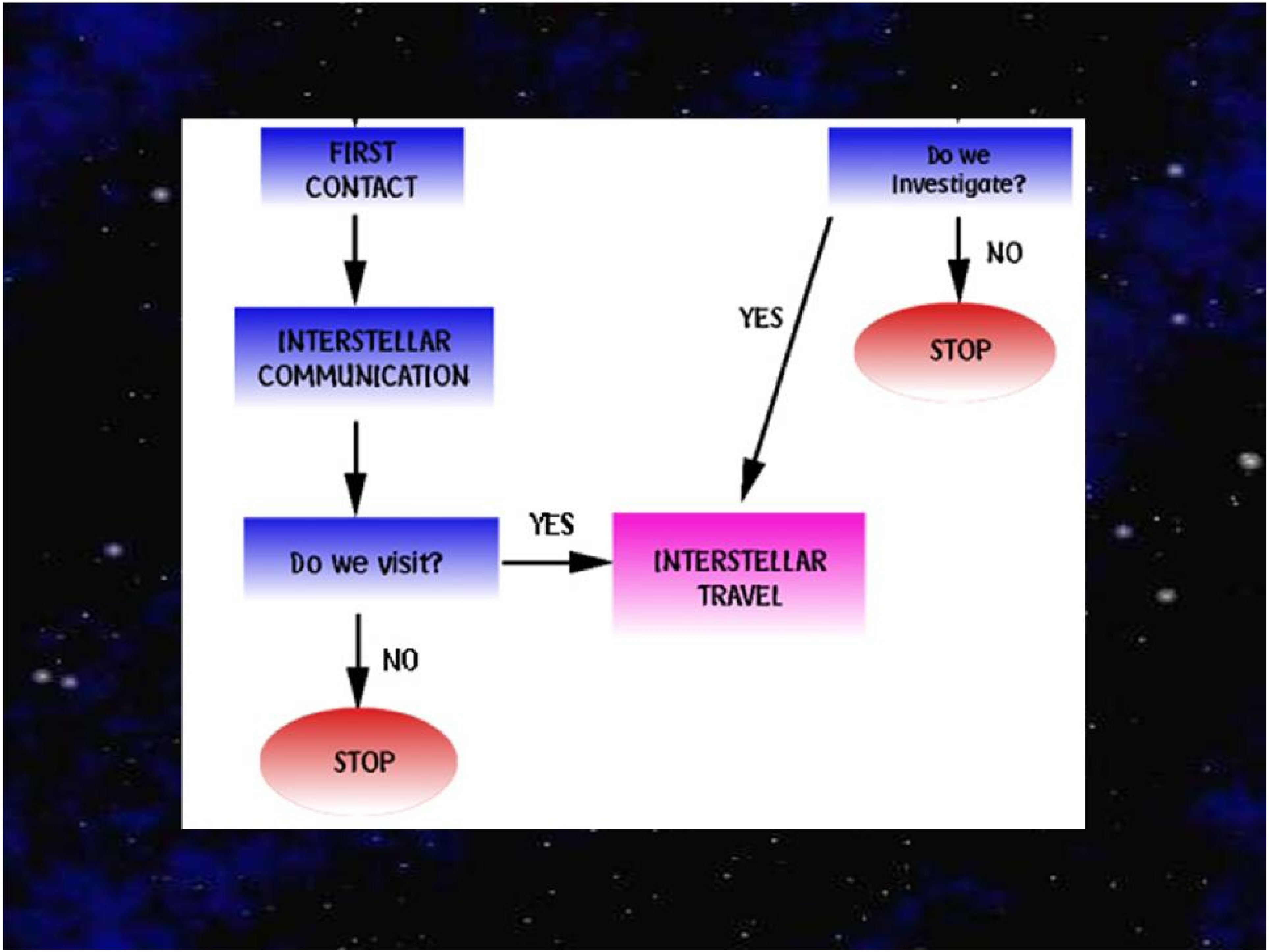
Stars, planetary systems & Life
Origin of the Solar System
Origin of Life on Earth
Are these processes unique to the Earth?
YES
STOP
NO



STOP
NO
Is there life in the universe?
YES
NO
Should we search for life?



Intelligent Life
YES
Non-Intelligent Life
Where to Search?
SEARCH STRATEGIES
Where to Search?
What to look for?
What to look for?
NO
NO
Are we Successful?
STOP
Are we Successful?
YES
YES


FIRST CONTACT
INTERSTELLAR COMMUNICATION
Do we visit?
YES
NO
STOP
INTERSTELLAR TRAVEL
YES
Do we Investigate?
NO
STOP

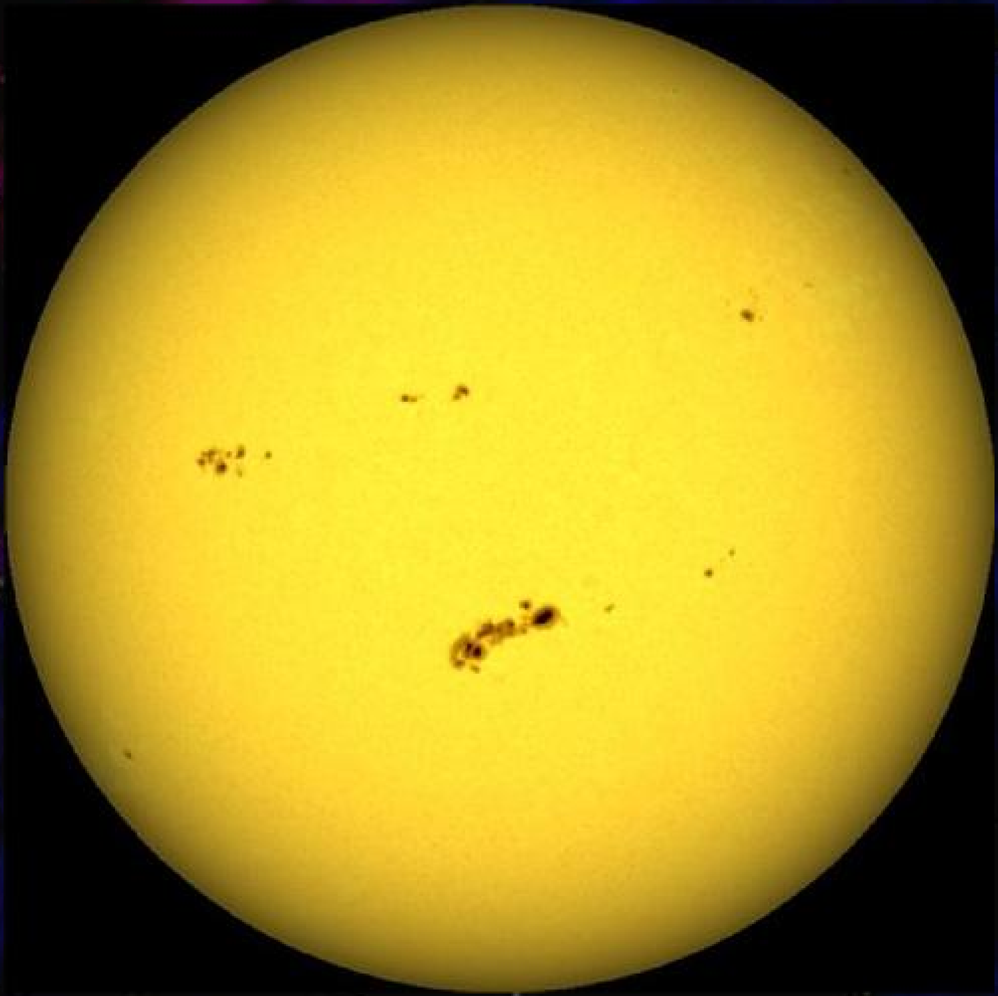
The Sizes and Numbers of Objects in the Universe

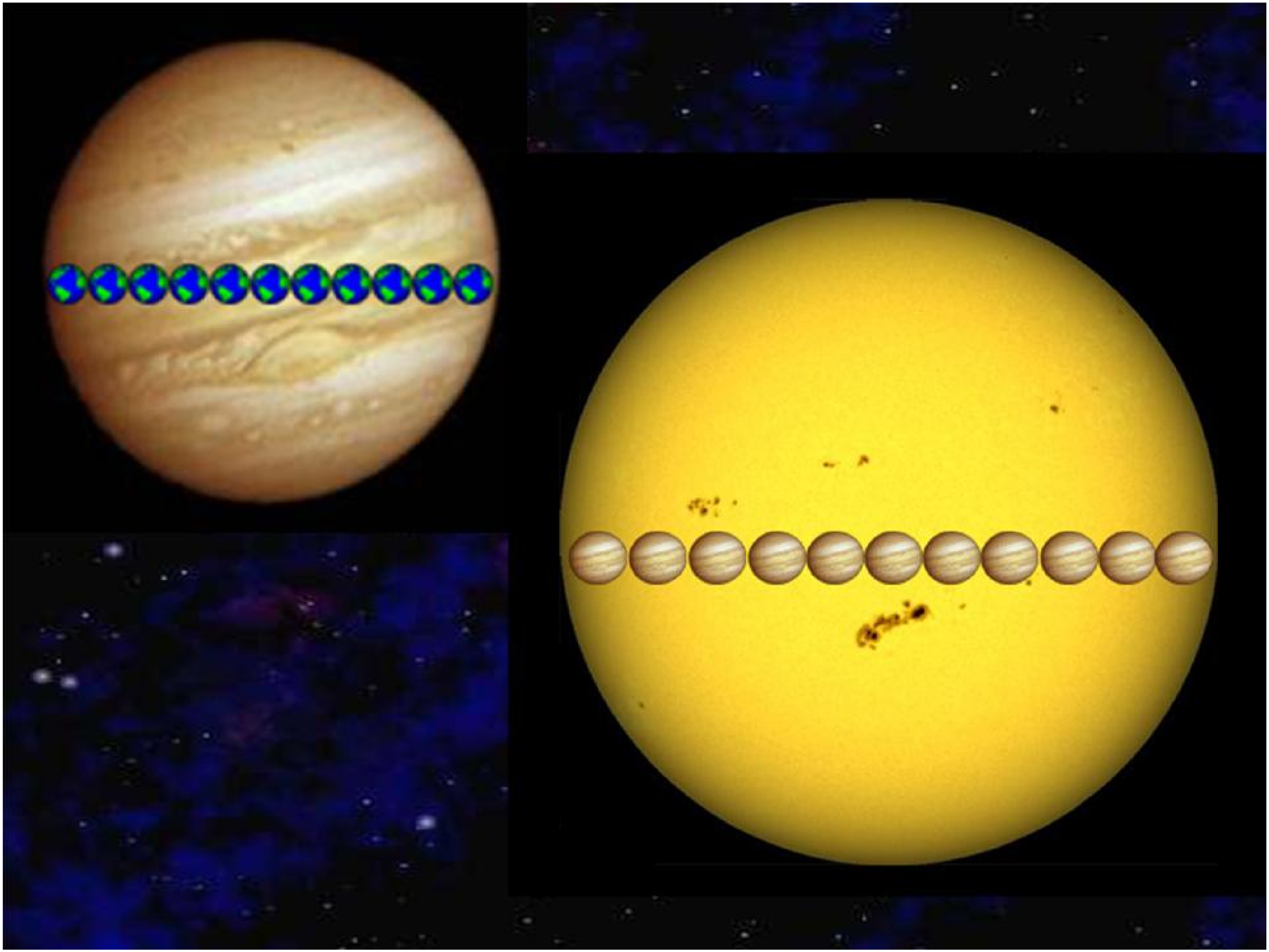
"CARL SAGAN AS AN INFANT"

"The COSMOS is all that is... or ever was... or ever will be"

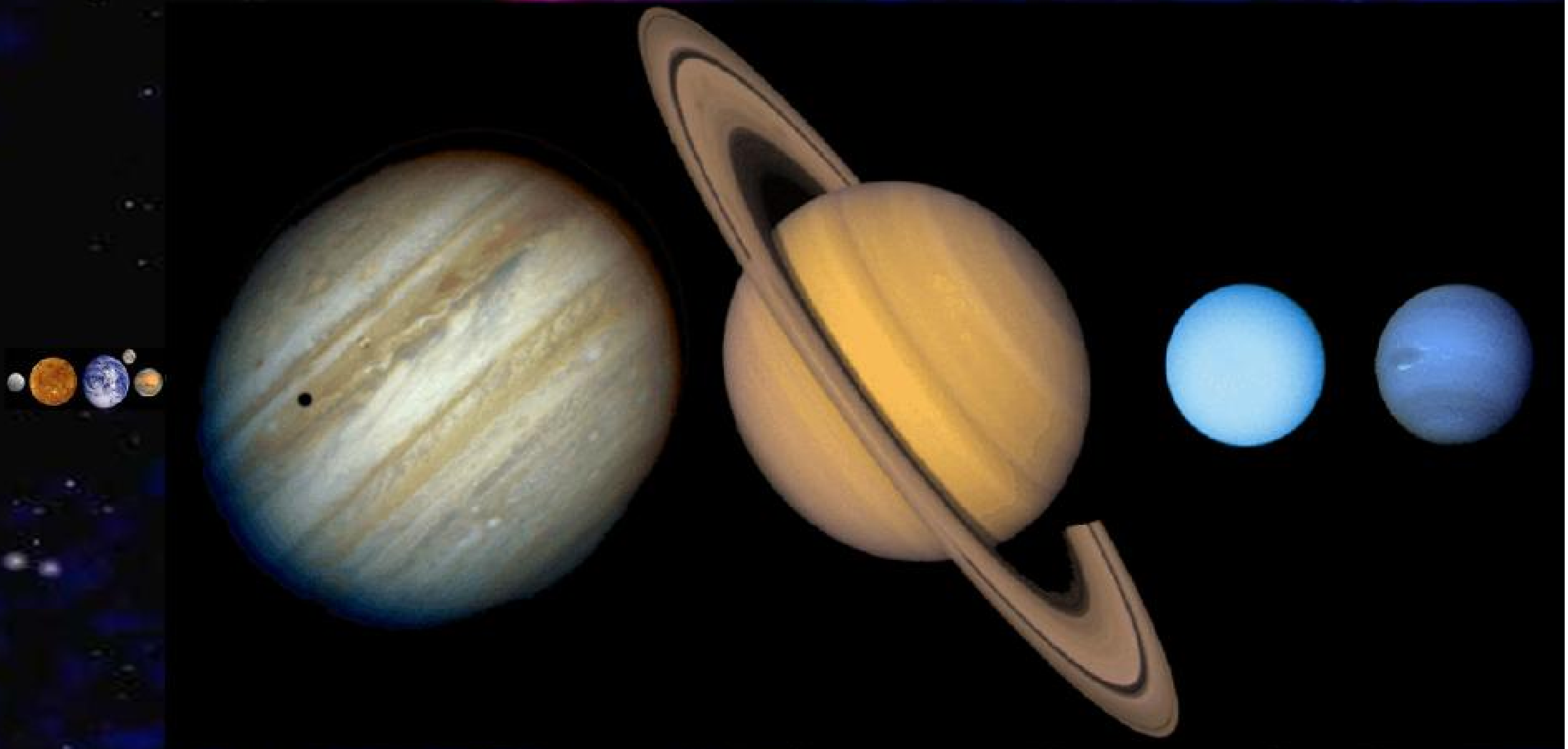
- Carl Sagan
COSMOS

Solar System Inventory: 1 Star



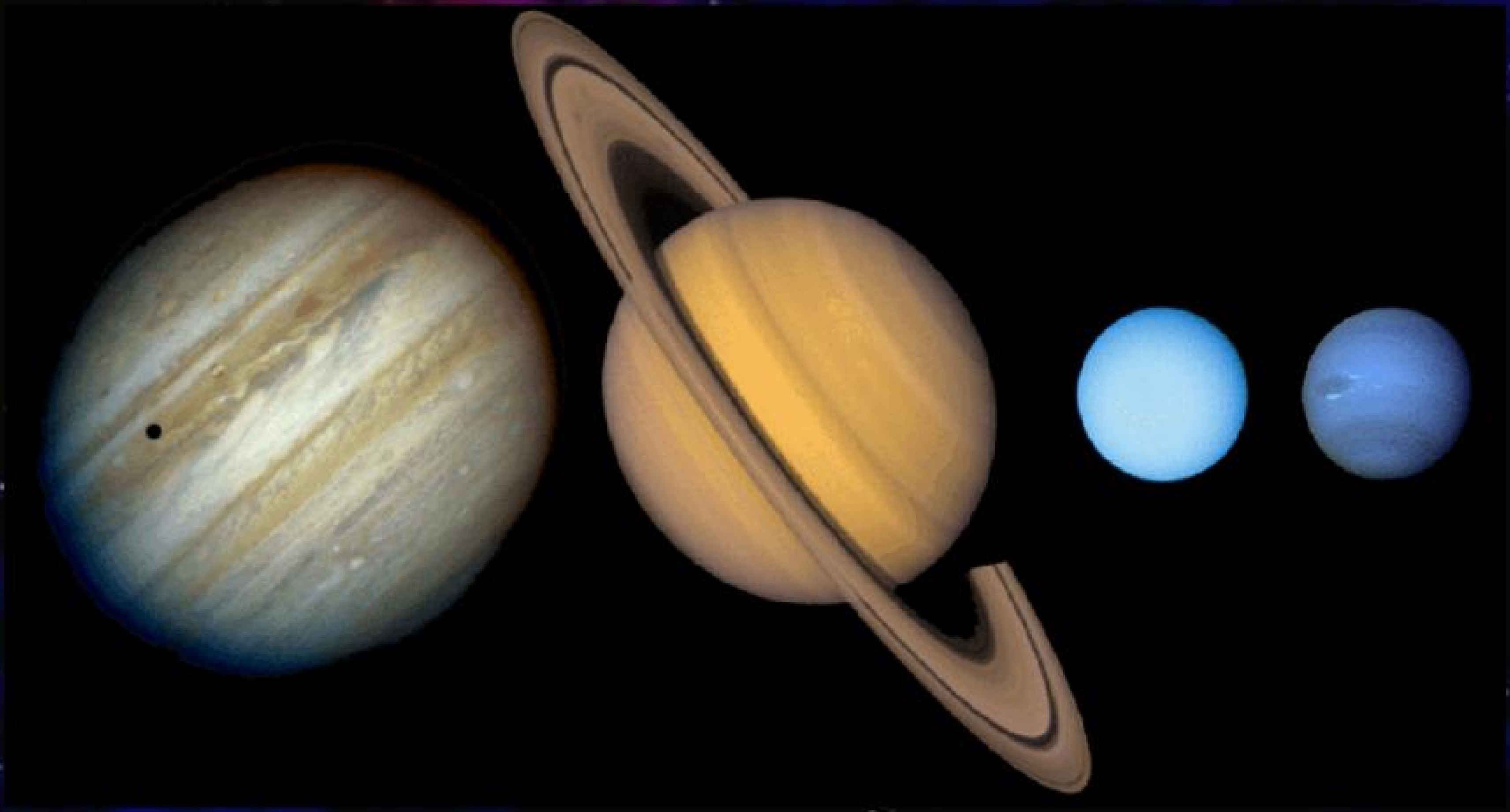


Solar System Inventory:
8 Planets



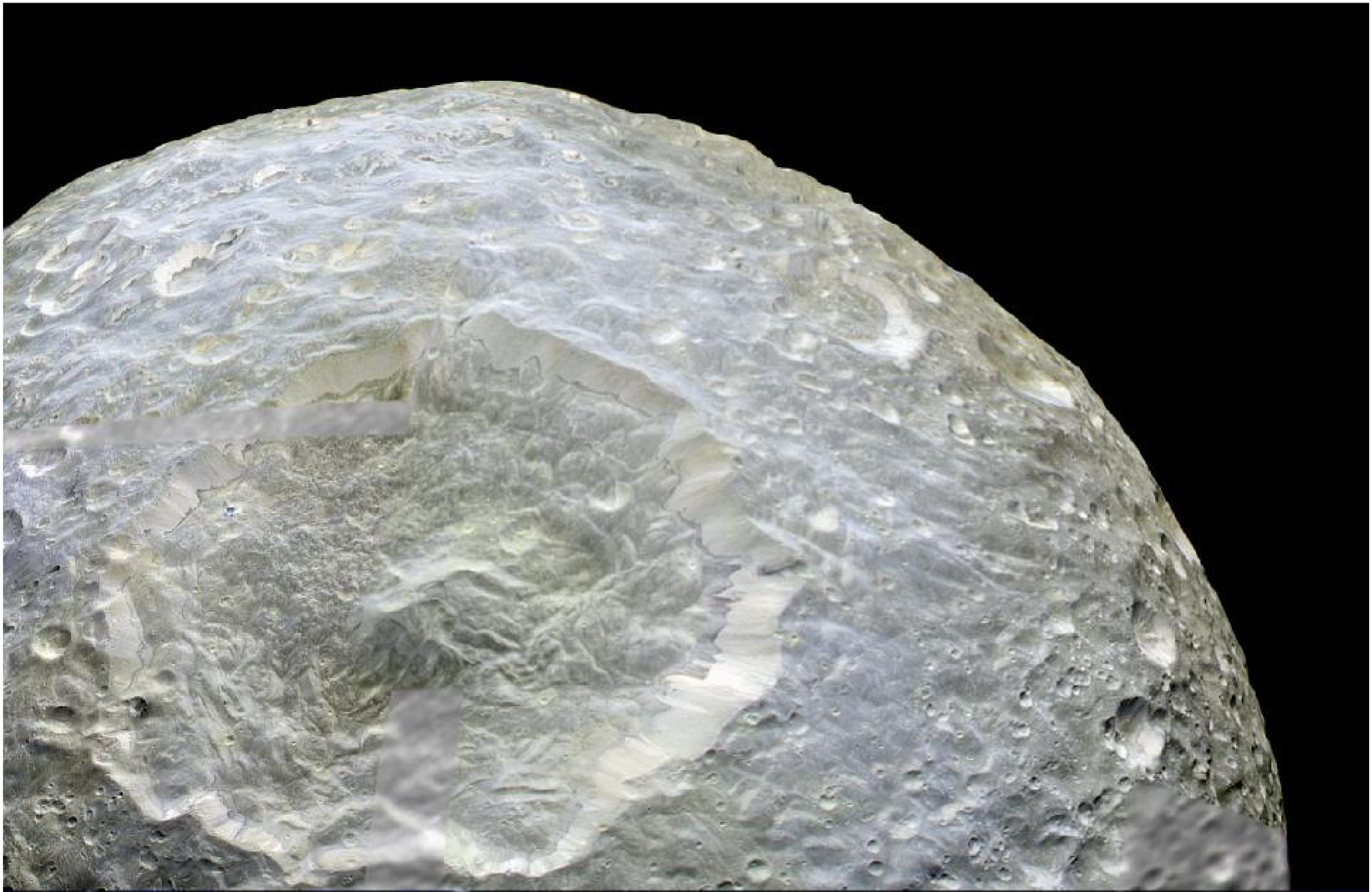
The Terrestrial Planets

The Jovian Planets



The Jovian Planets

The Jovian Planets

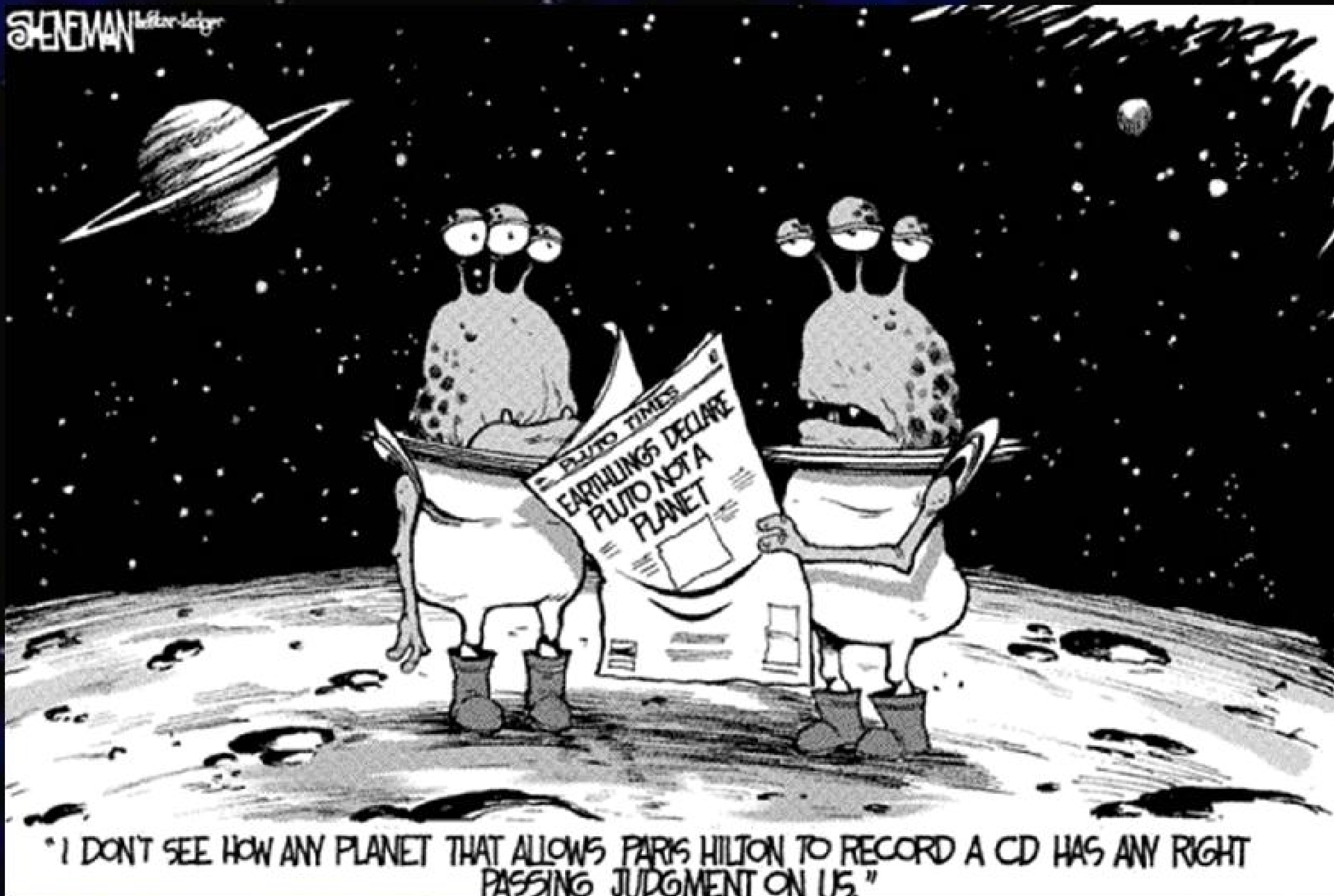


Mimas, from Cassini fly by, 2010

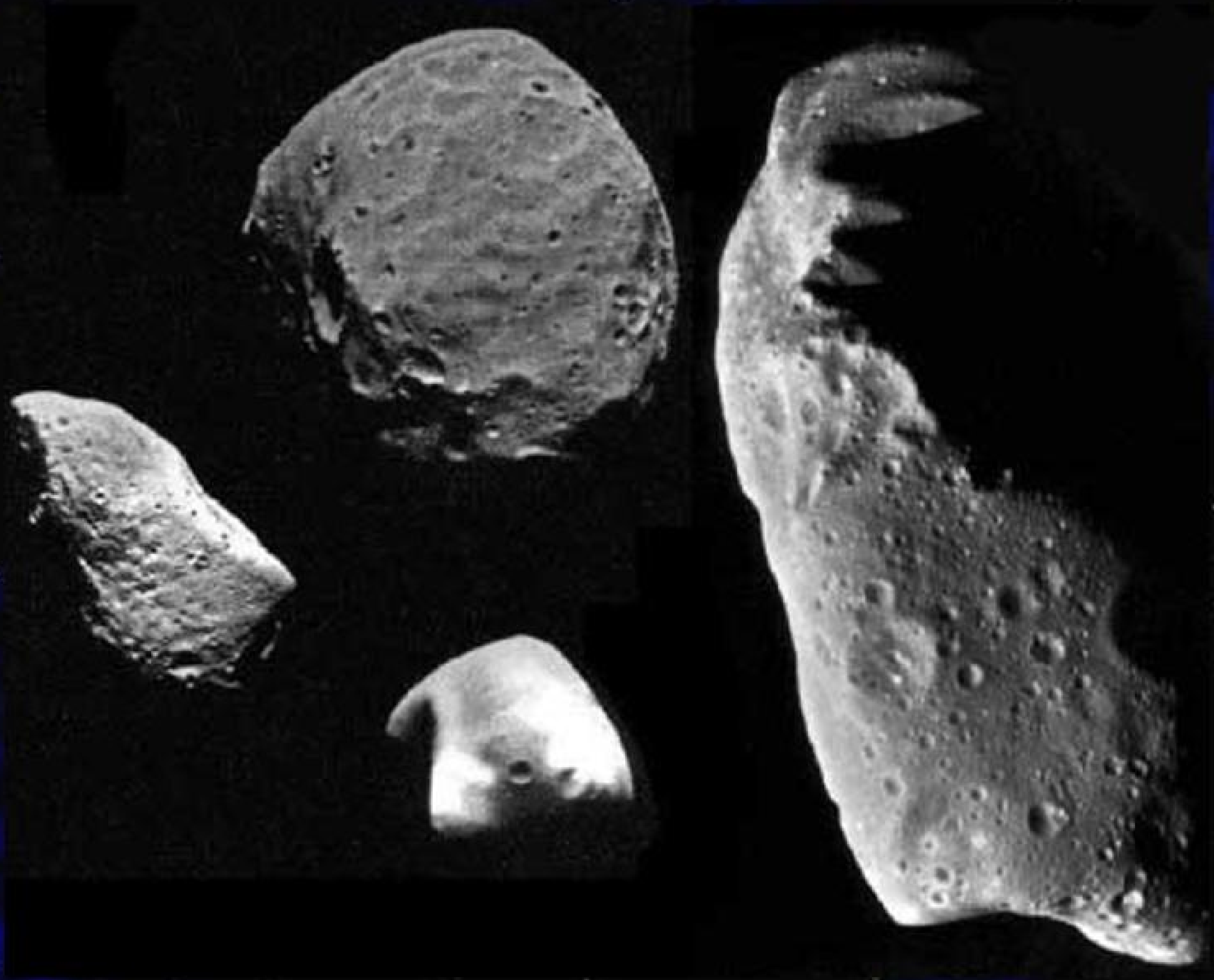
Solar System Inventory:

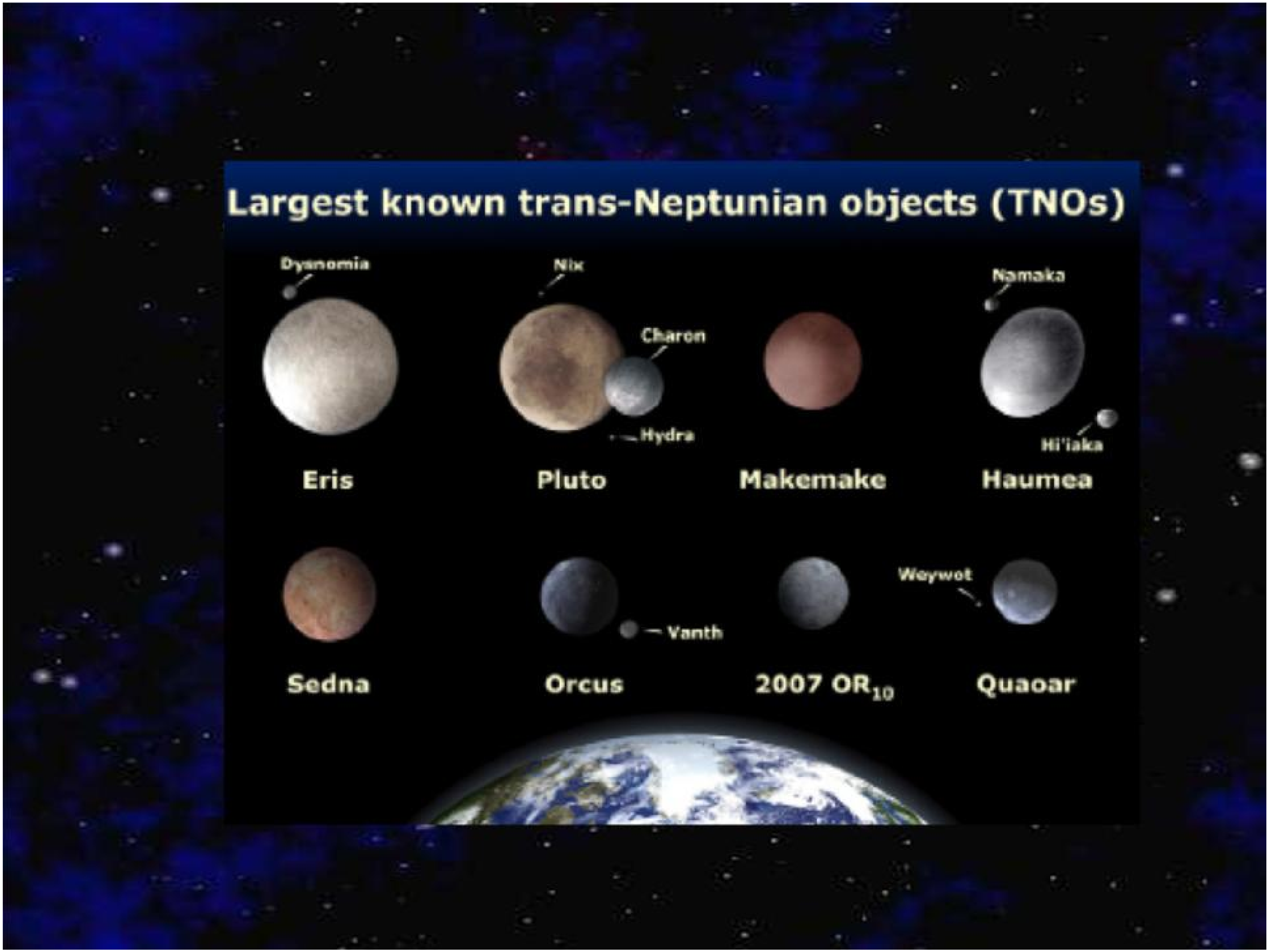
91 + moons

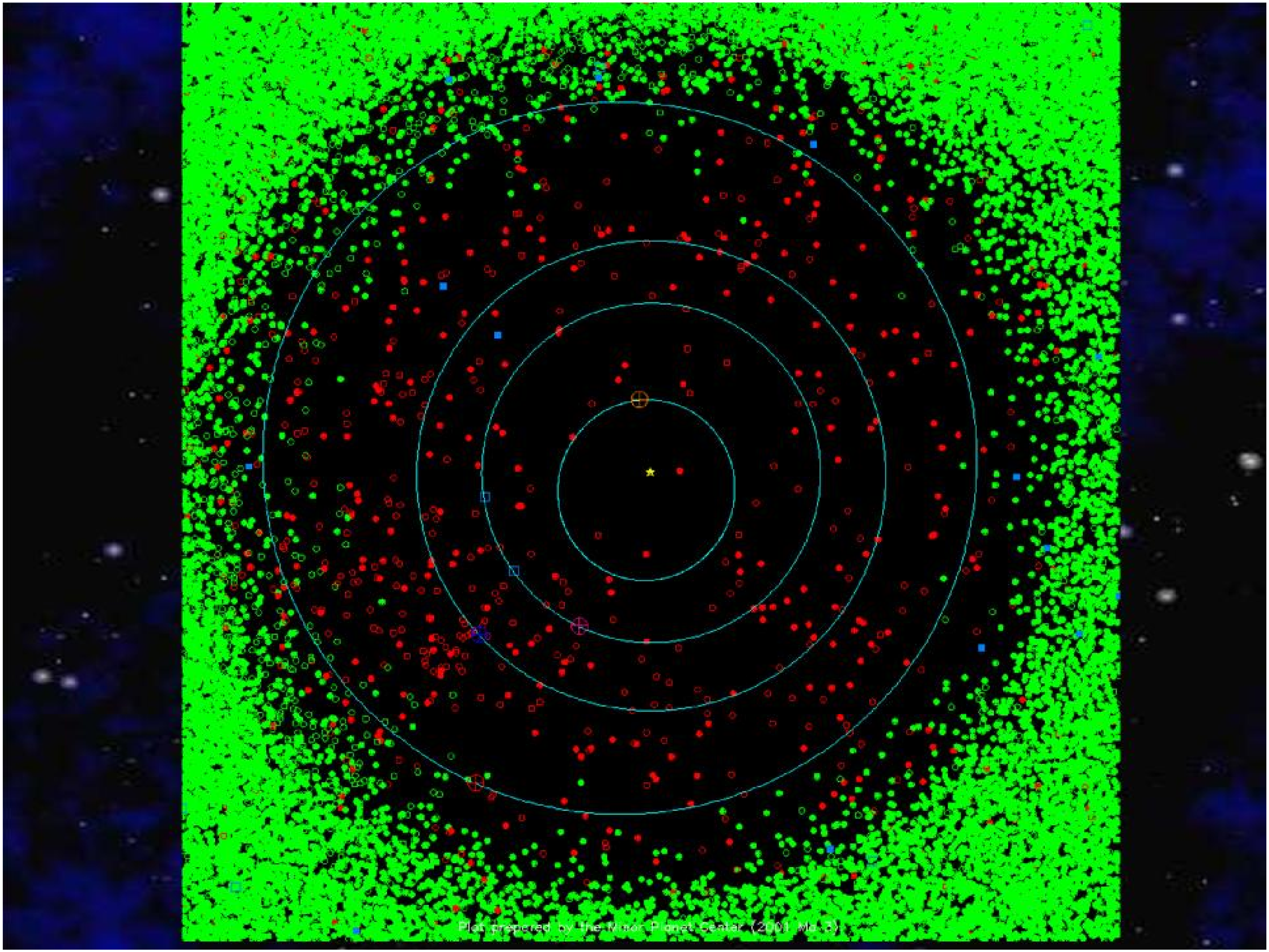
Solar System Inventory:
Countless numbers of Asteroids, Comets, Meteors, Dust


SHENEMAN
PLUTO TIMES
EARTHLINGS DECLARE PLUTO NOT A PLANET
"I DON'T SEE HOW ANY PLANET THAT ALLOWS PARIS HILTON TO RECORD A CD HAS ANY RIGHT PASSING JUDGMENT ON US."

Asteroids (some are dwarf planets now)




Largest known trans-Neptunian objects (TNOs)
Dysnomia
Nix
Charon
Hydra
Namaka
Hi'iaka
Eris
Pluto
Makemake
Haumea
Weywot
Vanth
Sedna
Orcus
2007 OR10
Quaoar


Plot prepared by the Minor Planet Center

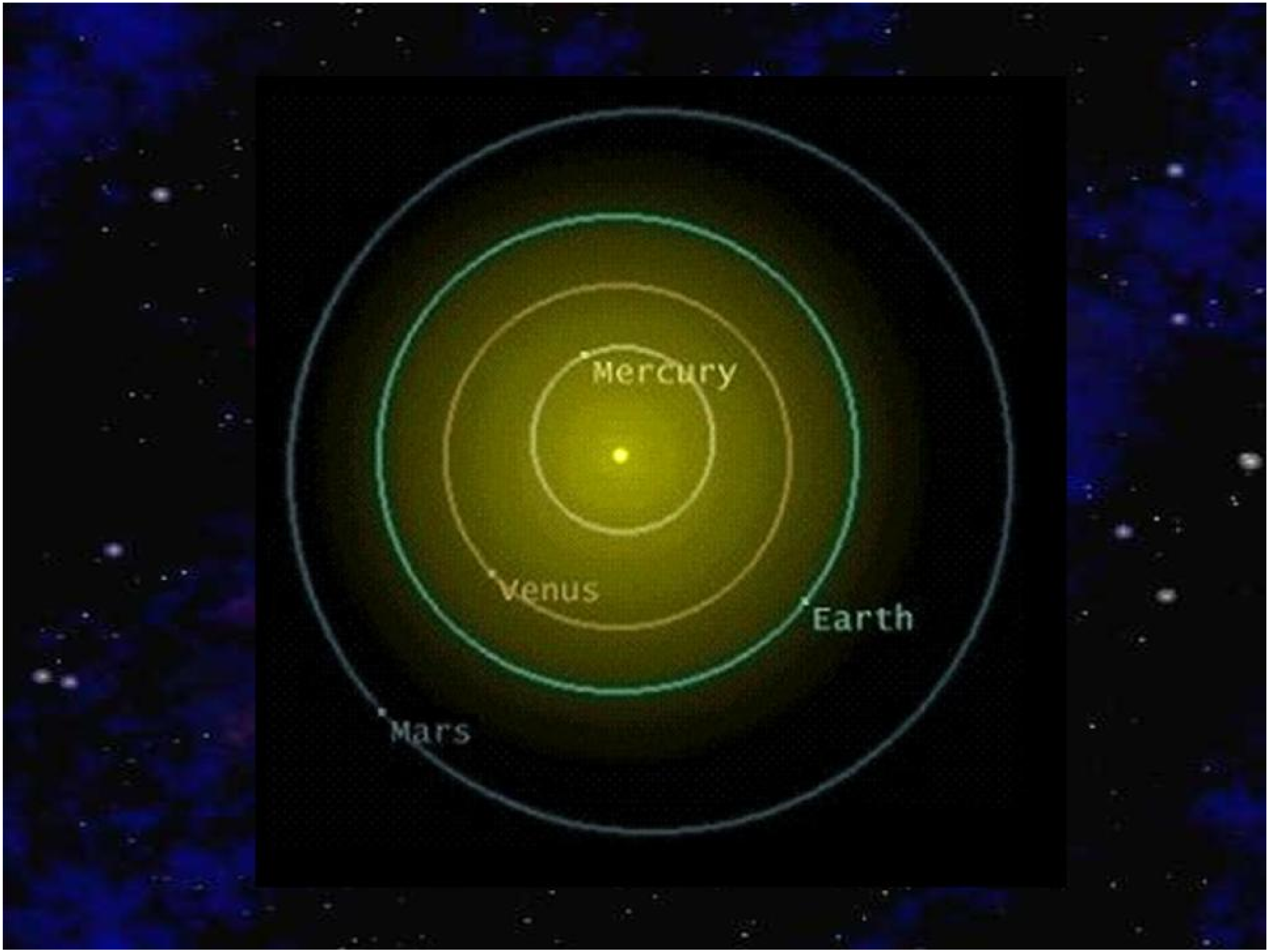
Terrestrial Characteristics:

- Metallic core
- Oxygen dominated (silicates)

Material	% (by mass)
Iron	35
Oxygen	30
Silicon	15
Magnesium	13
Nickel	2.4
Sulfur	1.9

Terrestrial Characteristics:

- Thin (or nonexistent) atmospheres
- Few (or no) natural satellites
- Closely spaced orbits


Mercury
Venus
Earth
Mars

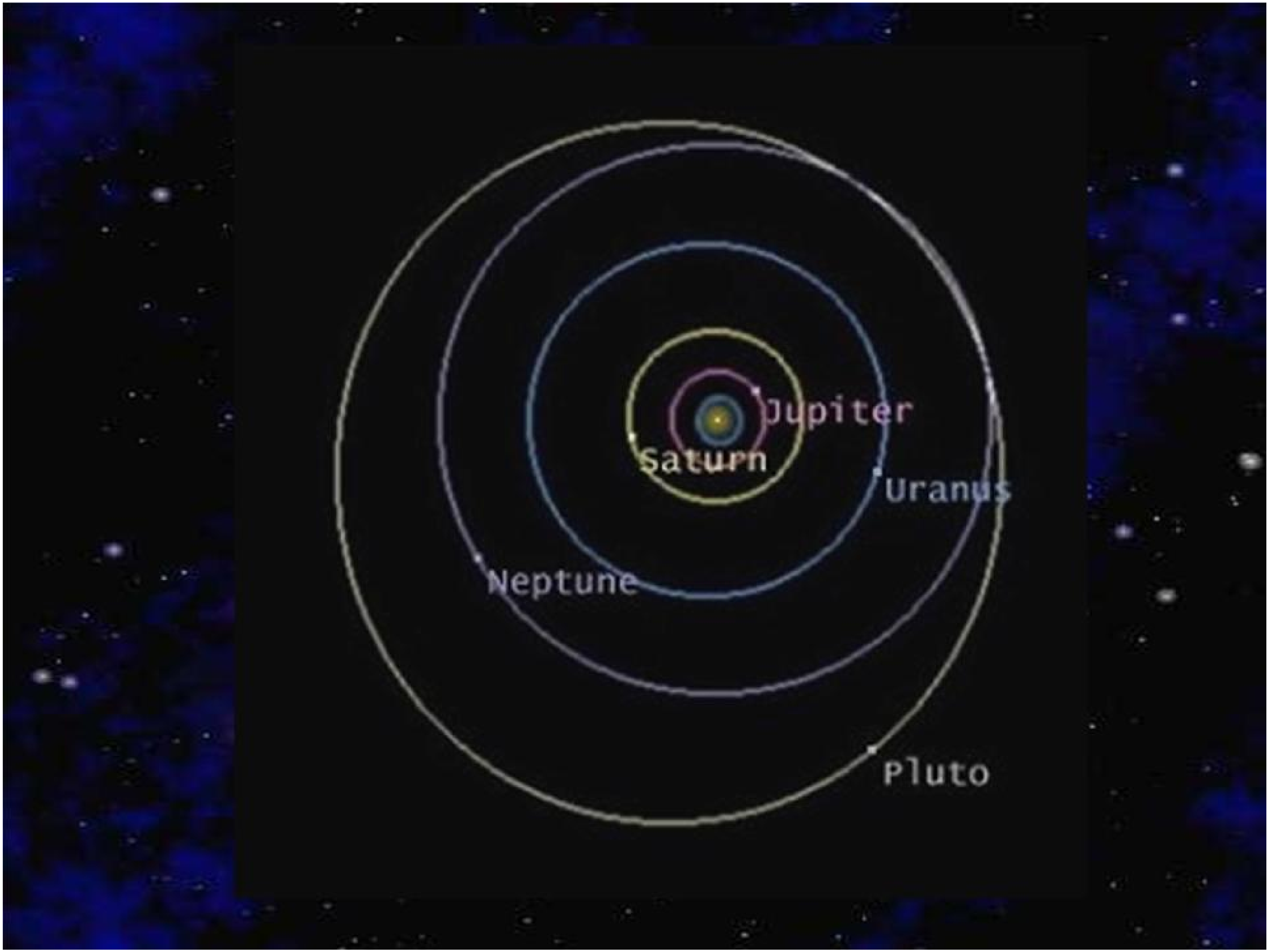
Jovian Characteristics:

- Solid metallic-rocky cores
- Hydrogen dominated

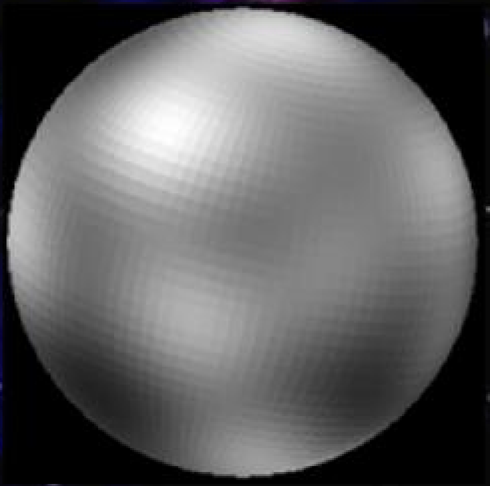
Material	% (by mass)
Hydrogen	74
Helium	24
Water	0.6
Methane	0.4
Ammonia	0.1
Rock & Metals	0.3

Jovian Characteristics:

- Thick gaseous atmospheres
- Many natural satellites
- Widely spaced orbits


Jupiter
Saturn
Uranus
Neptune
Pluto

Pluto-Like?



Cosmic Distances

Astronomical units of distance:

Astronomical Unit: The distance between the Sun and the Earth

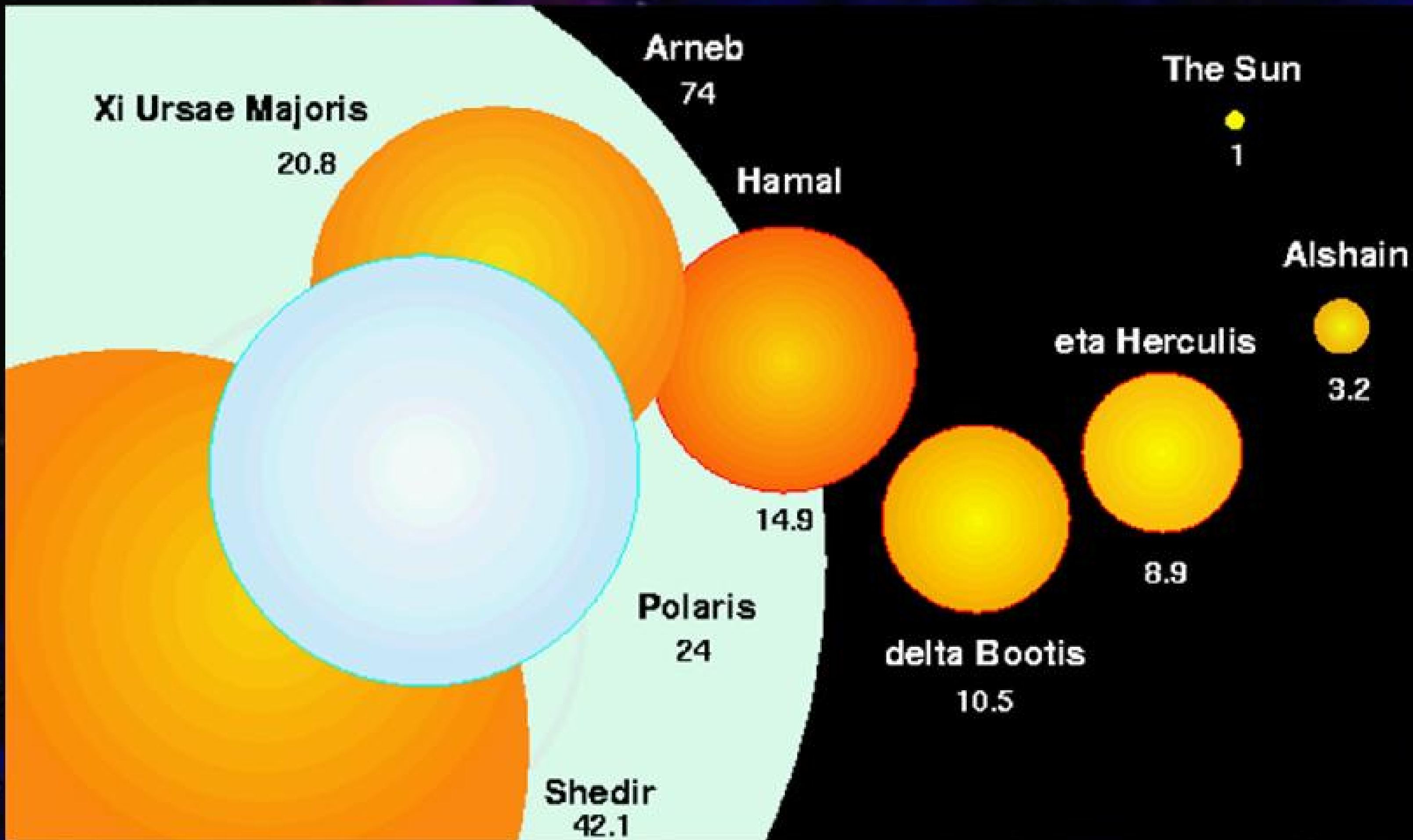
93 million miles

Light year: The distance light travels in a year

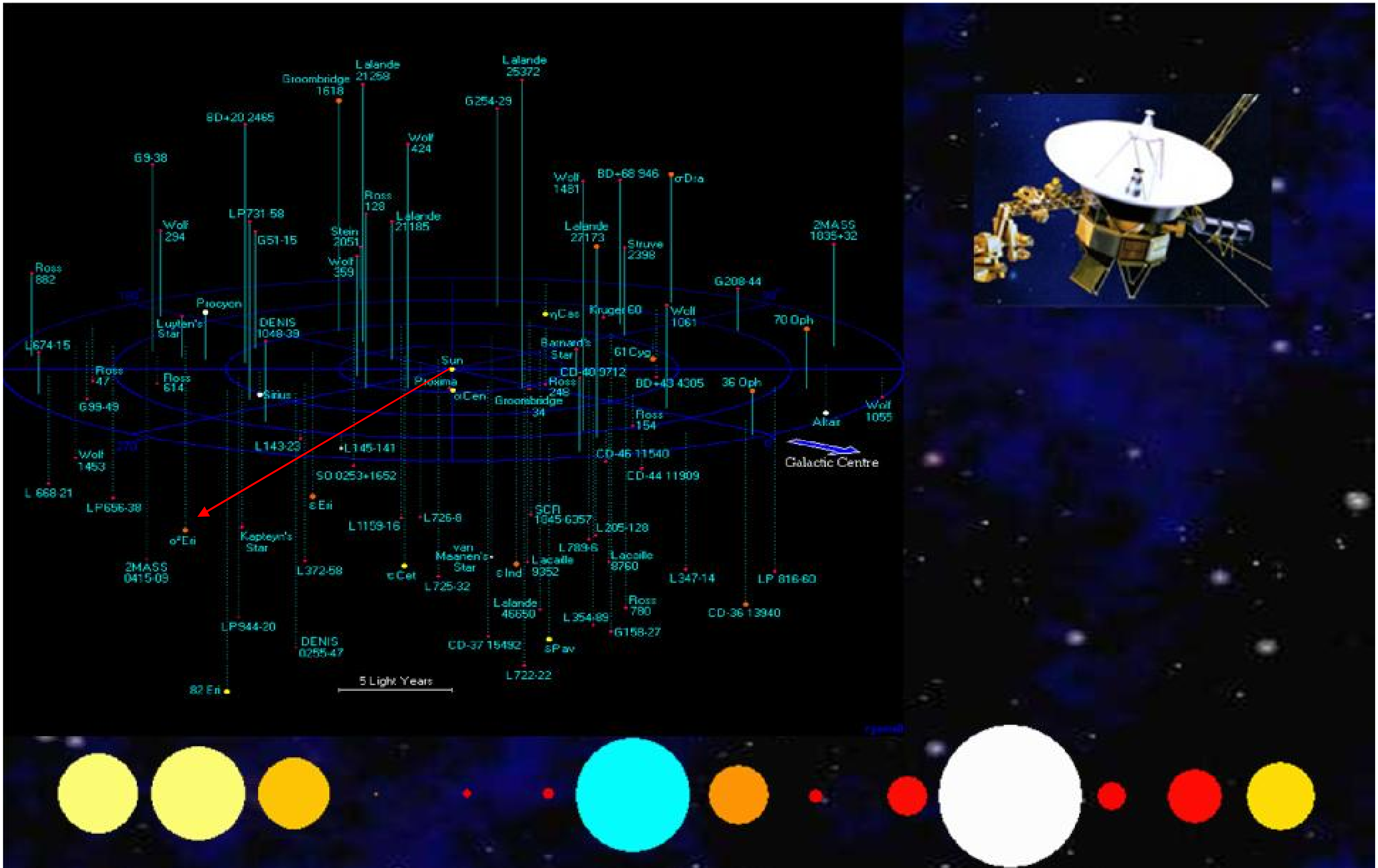
Speed of light: 186,282 miles/sec

Light year: 5.9 trillion miles

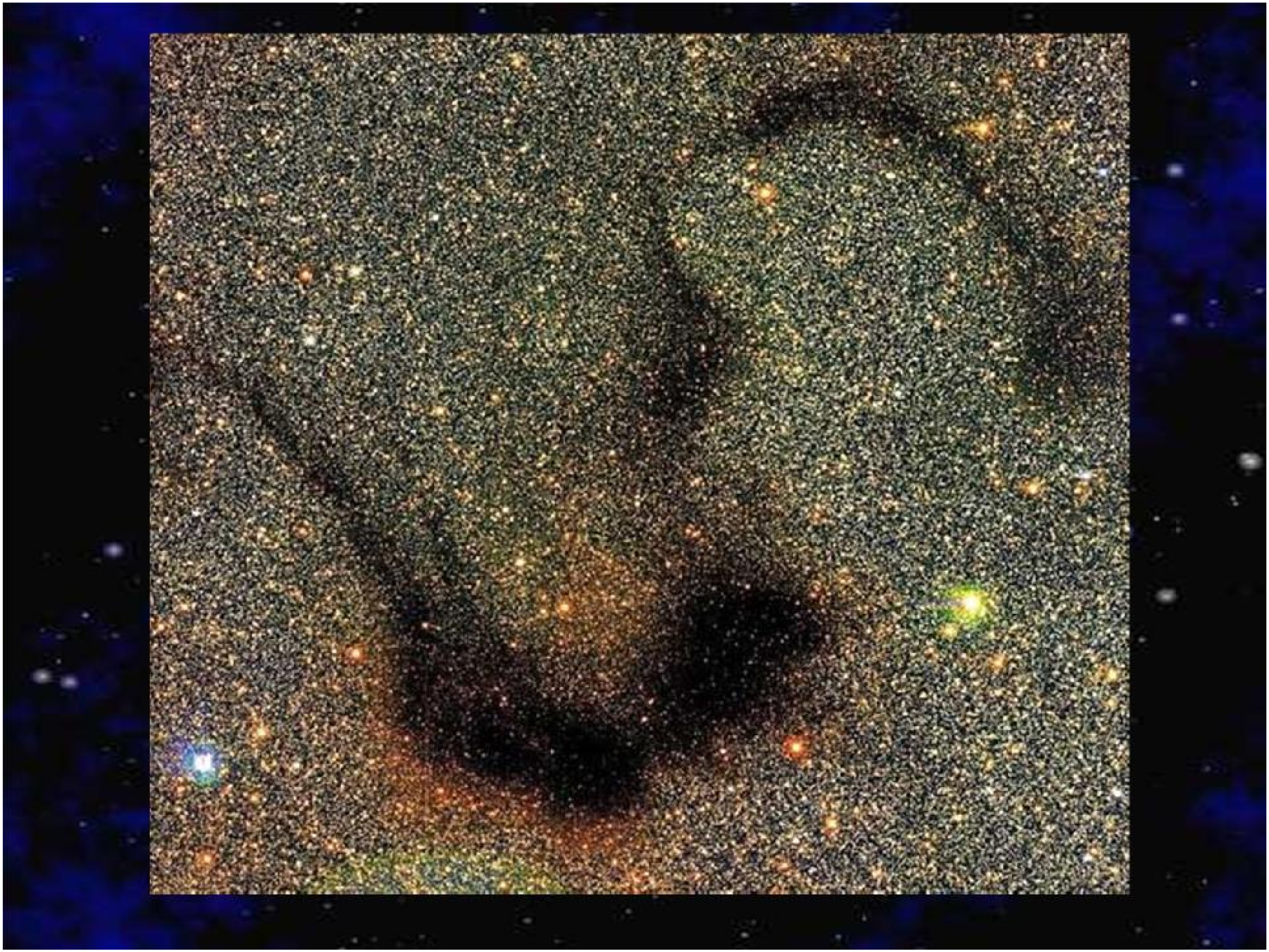
The Sizes of Stars in our Universe



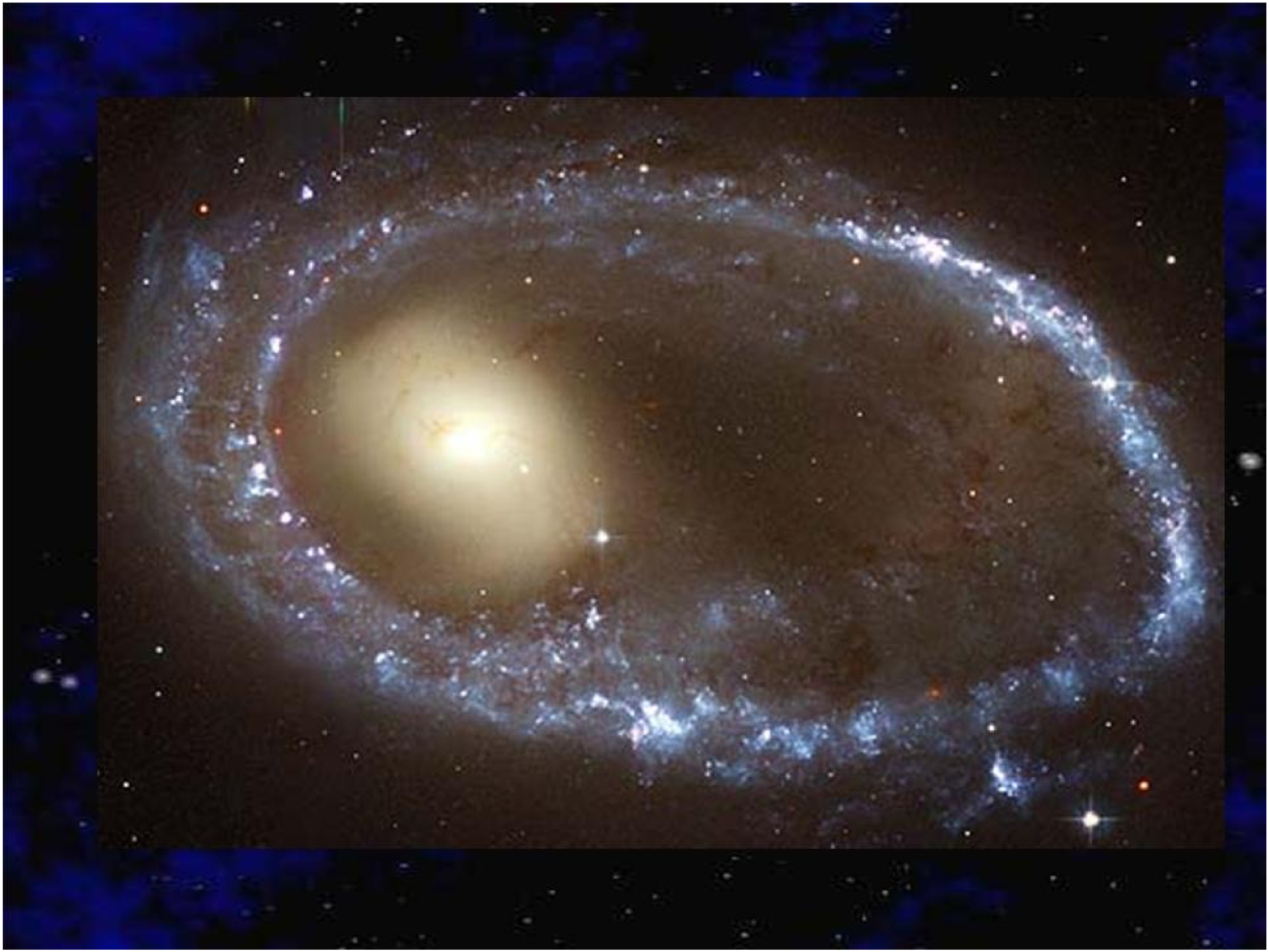
www.spacetelescope.org

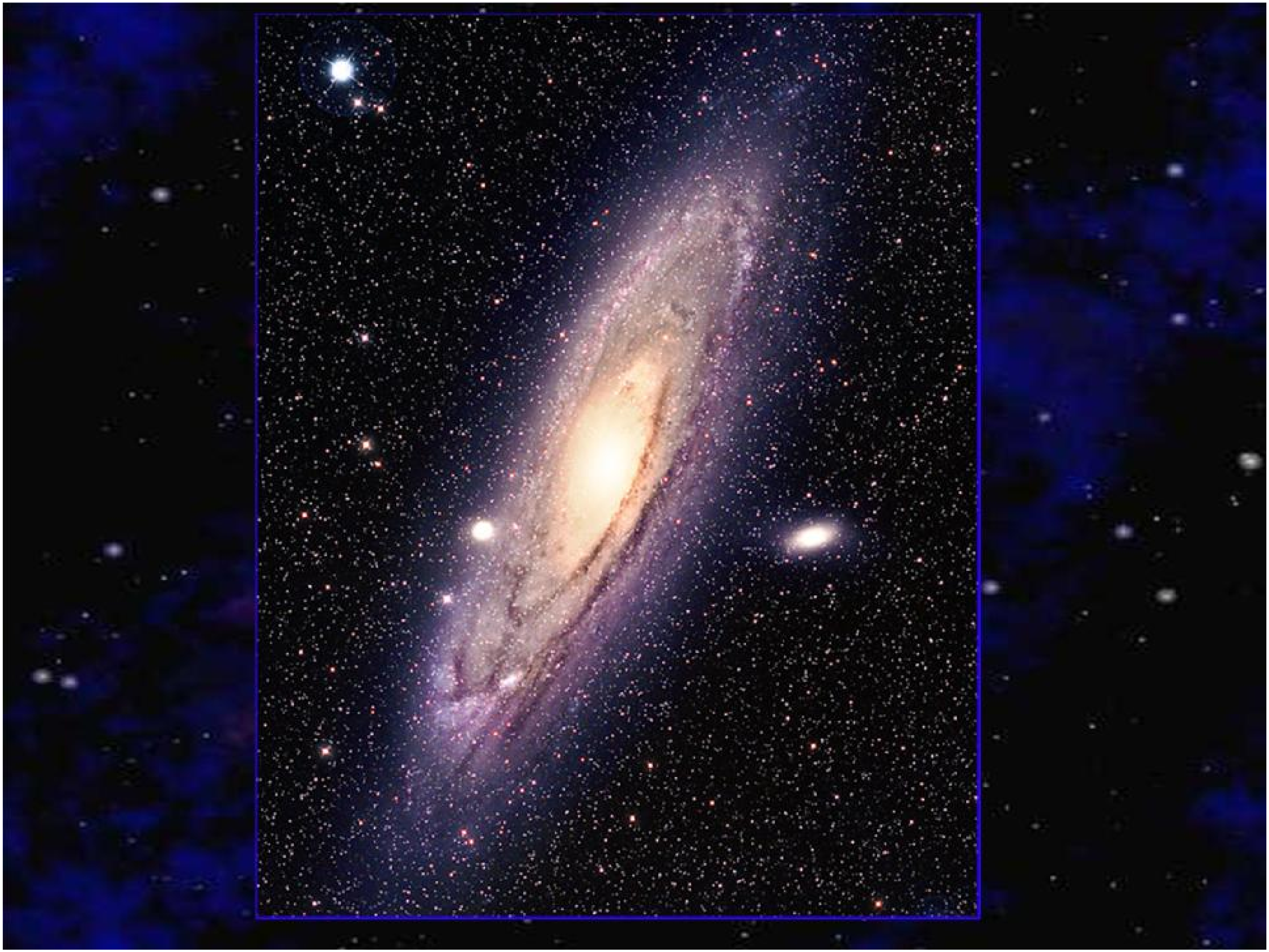


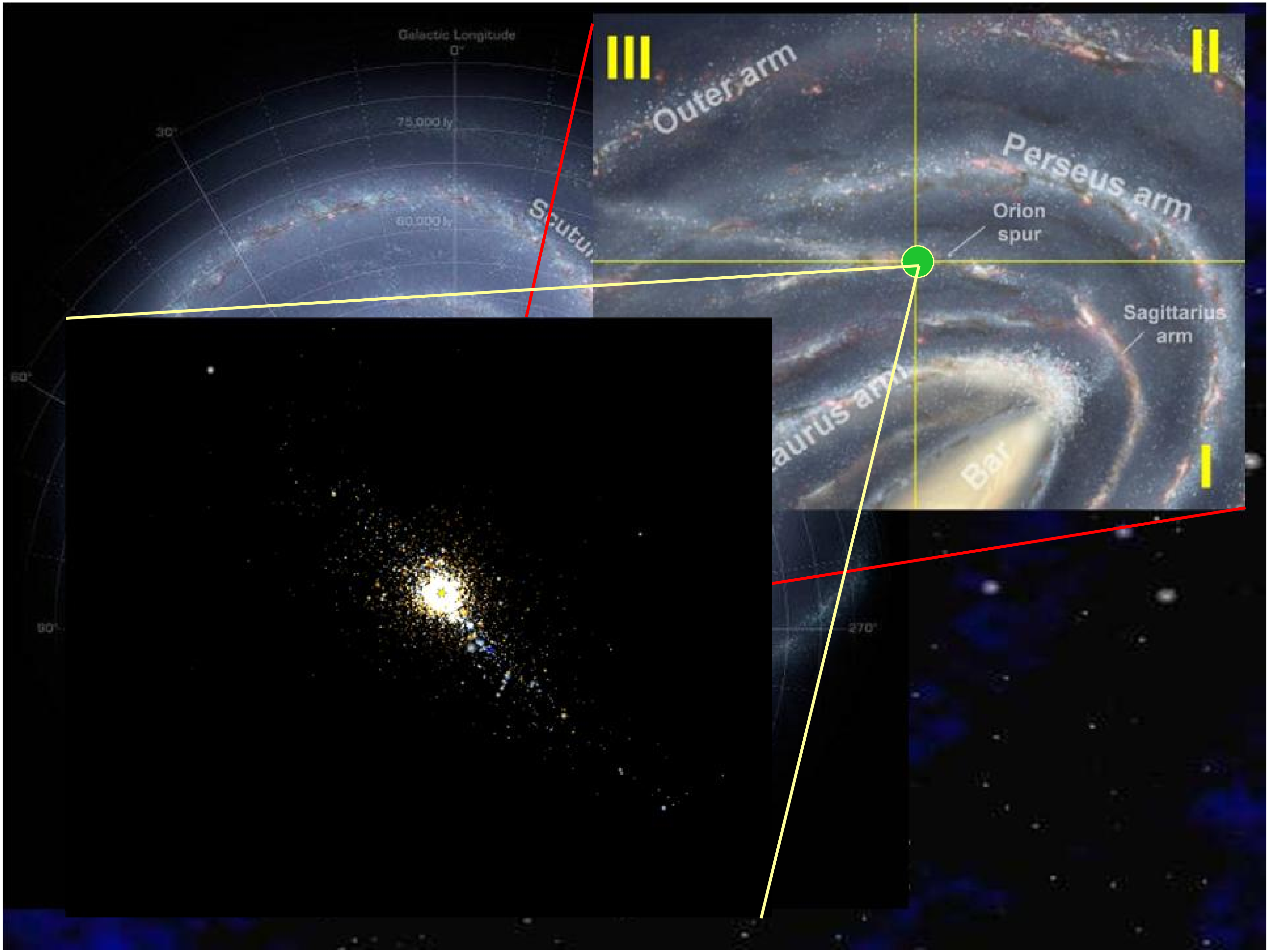
	Sun	α¹ Cen	α² Cen	Barnard's	BD +36° 2147	Lalande 21185	Sirius	ε Eri	CoD -36° 15693	61 Cyg A	Procyon	61 Cyg B	ε Ind	τ Cet
s.d.	1.0	1.20	0.90	0.06	0.14	0.15	1.43	0.77	0.20	0.52	1.77	0.36	0.69	0.85
l.y.:	0.0	4.39	4.39	5.94	8.20	8.31	8.60	10.49	10.73	11.35	11.40	11.42	11.82	11.89



The Distribution of Stars in the Universe







Galactic Longitude
0°
30°
60°
90°
270°
75,000 ly
60,000 ly
III
II
I
Outer arm
Perseus arm
Orion
spur
Sagittarius
arm
Bar

A New Scale of Things

Sun....the size of a volley ball

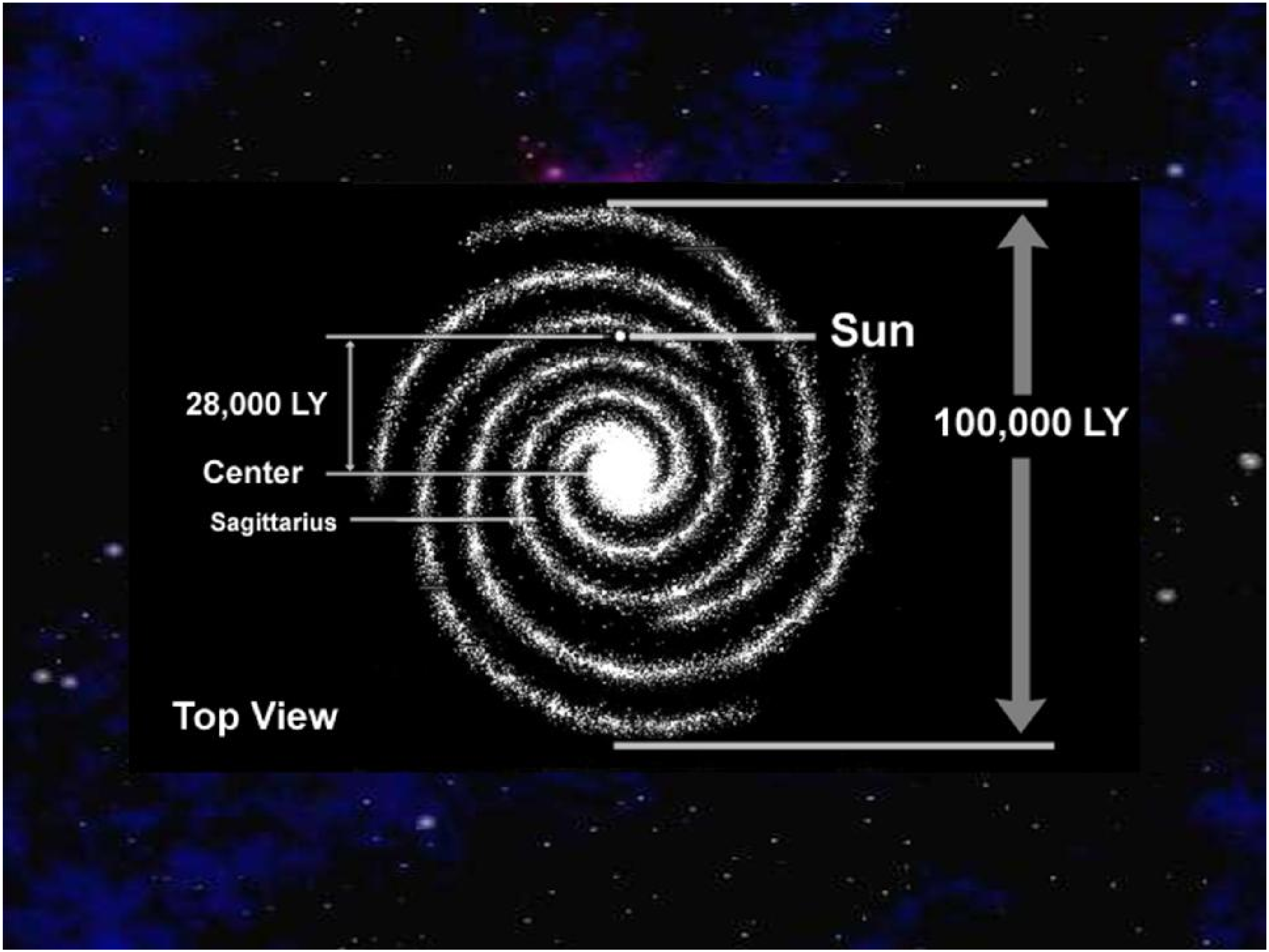
Earth....half the size of a BB, 100 yards away

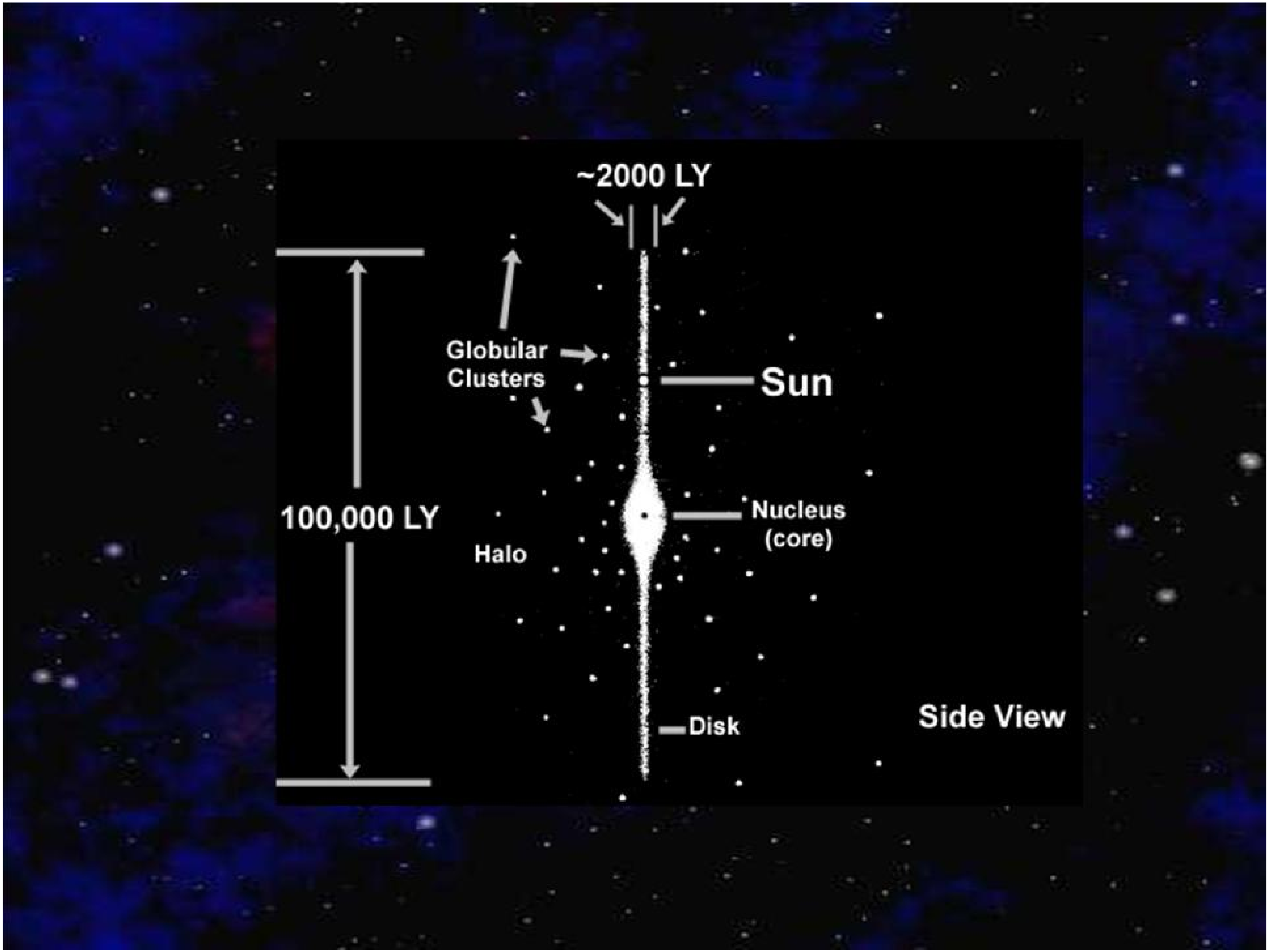
Solar System....ends at Notre Dame campus

Pioneer Space Craft....approaching Niles

Nearest star....State of New Mexico

Center of Milky Way Galaxy....40x farther then Earth-Moon


Sun
28,000 LY
100,000 LY
Center
Sagittarius
Top View



~2000 LY
100,000 LY
Globular
Clusters
Sun
Halo
Nucleus
(core)
Disk
Side View

How do we know how many stars there are in the Universe?


If we *literally* counted the stars in each galaxy...
1 per second, 8 hours every day...
38,000 years!

How many stars are in the Milky Way?

$$p^2 = \frac{4p^2}{G(m_1 + m_2)} d^3$$

$$m_1 + m_2 = \frac{4p^2}{G} \frac{d^3}{p^2}$$

$$m_{gal} + m_{sun} = \frac{4p^2}{G} \frac{d^3}{p^2}$$

$$m_{gal} \approx \frac{4p^2}{G} \frac{d^3}{p^2}$$

How many stars are in the Milky Way?

Orbital period_{sun} ~ 240 million years

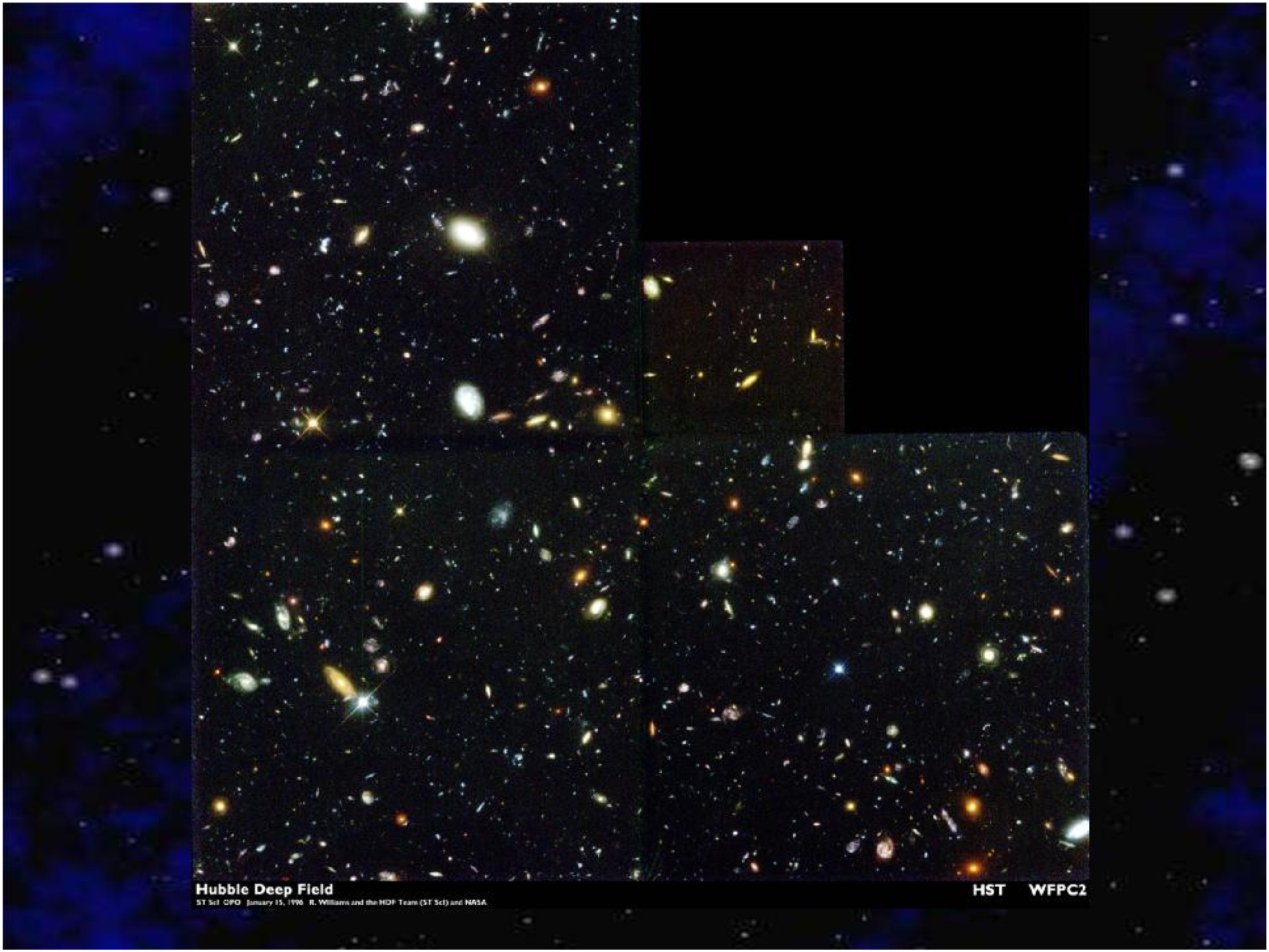
Orbital distance_{sun} ~ 28,000 light years

M_{gal} » 100 billion M_{sun}

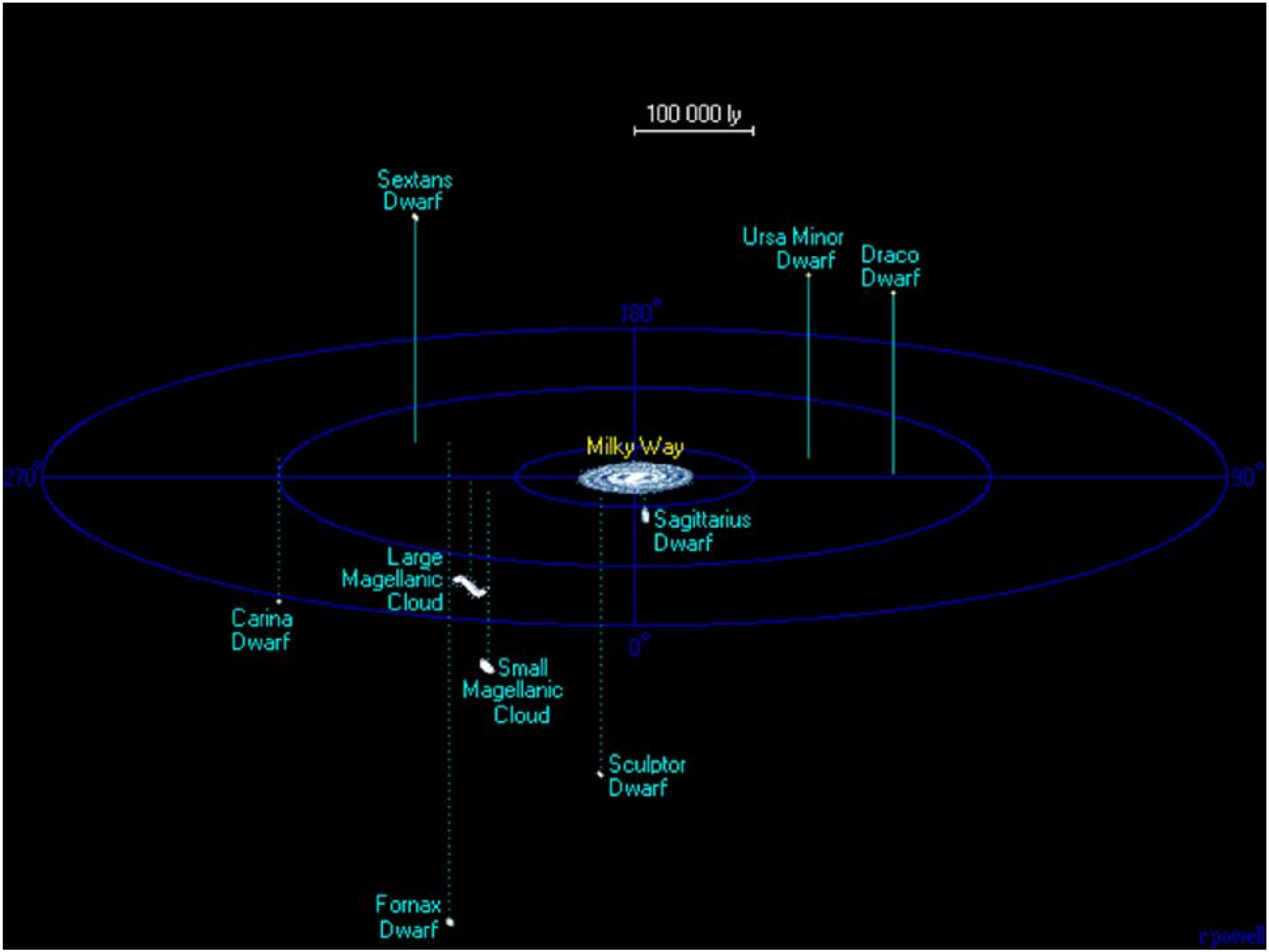
Does this represent the ***actual number*** of stars in our galaxy?

- Our Sun is an “average star” in mass and luminosity.
- The galaxy has many more low mass stars compared to high mass stars

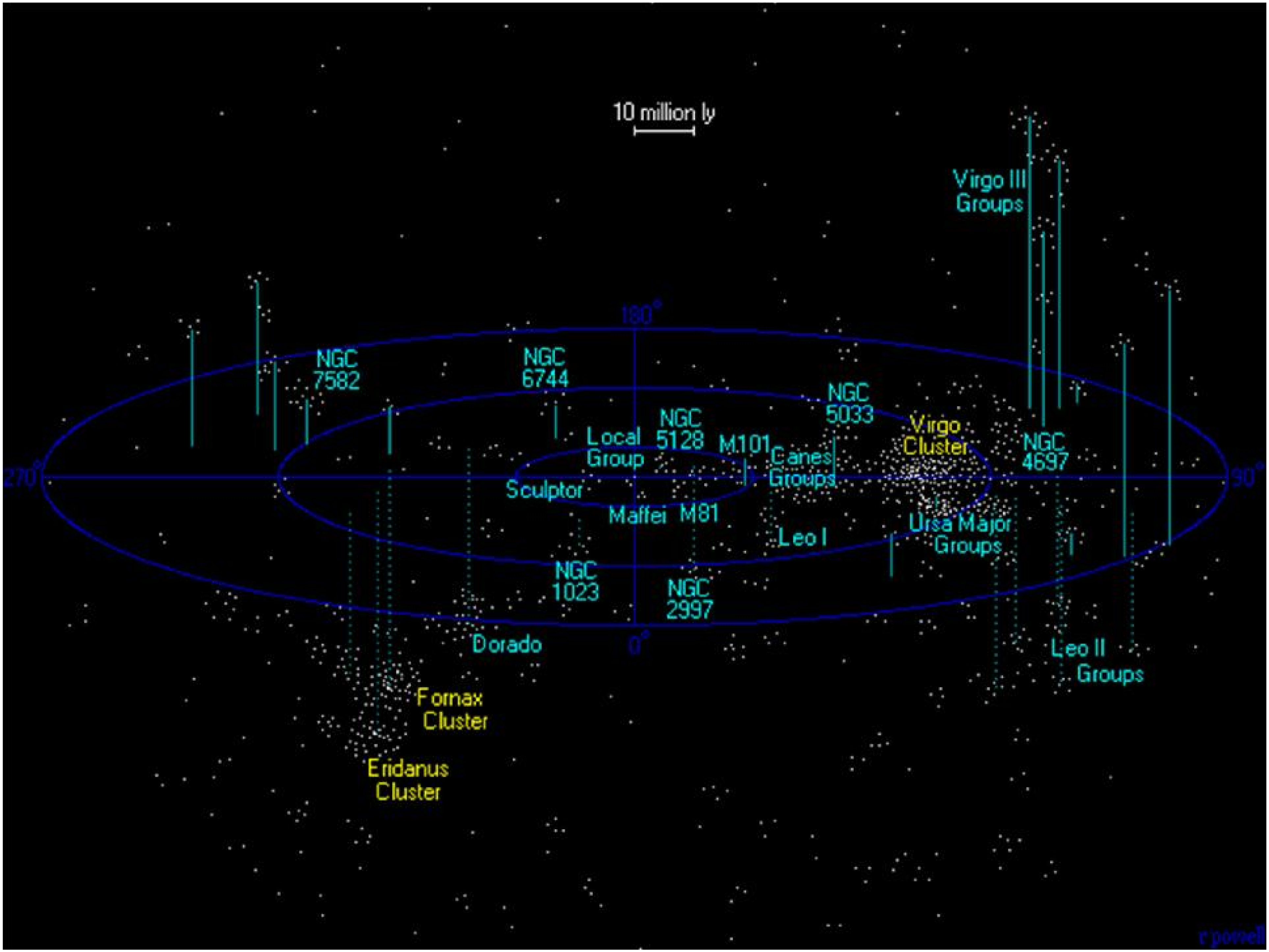
Adjusted estimate of stars in Milky Way: 300 – 400 billion stars

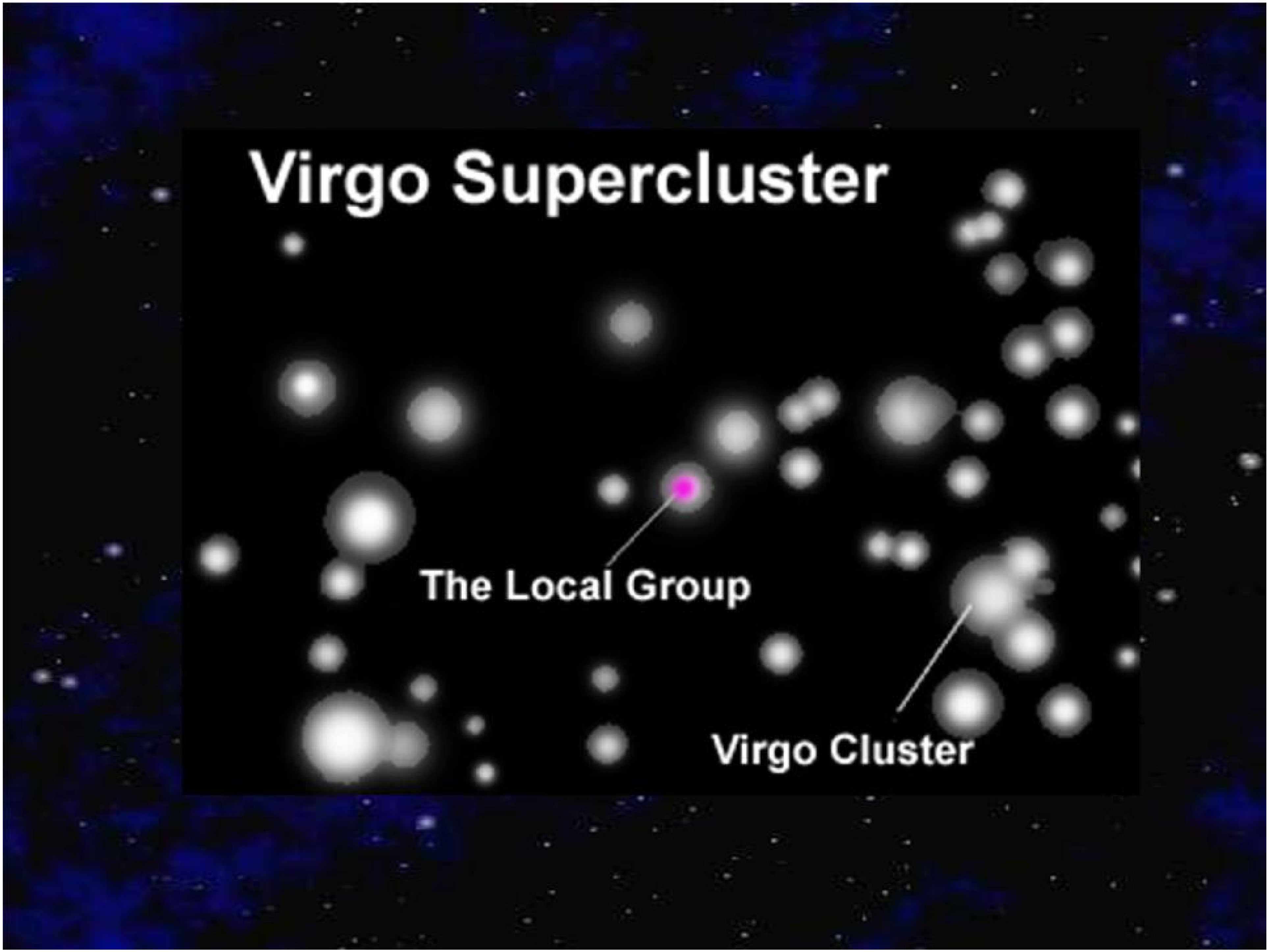

Hubble Deep Field
ST ScI OPO January 15, 1996 R. Williams and the HDF Team (ST ScI) and NASA
HST
WFPC2

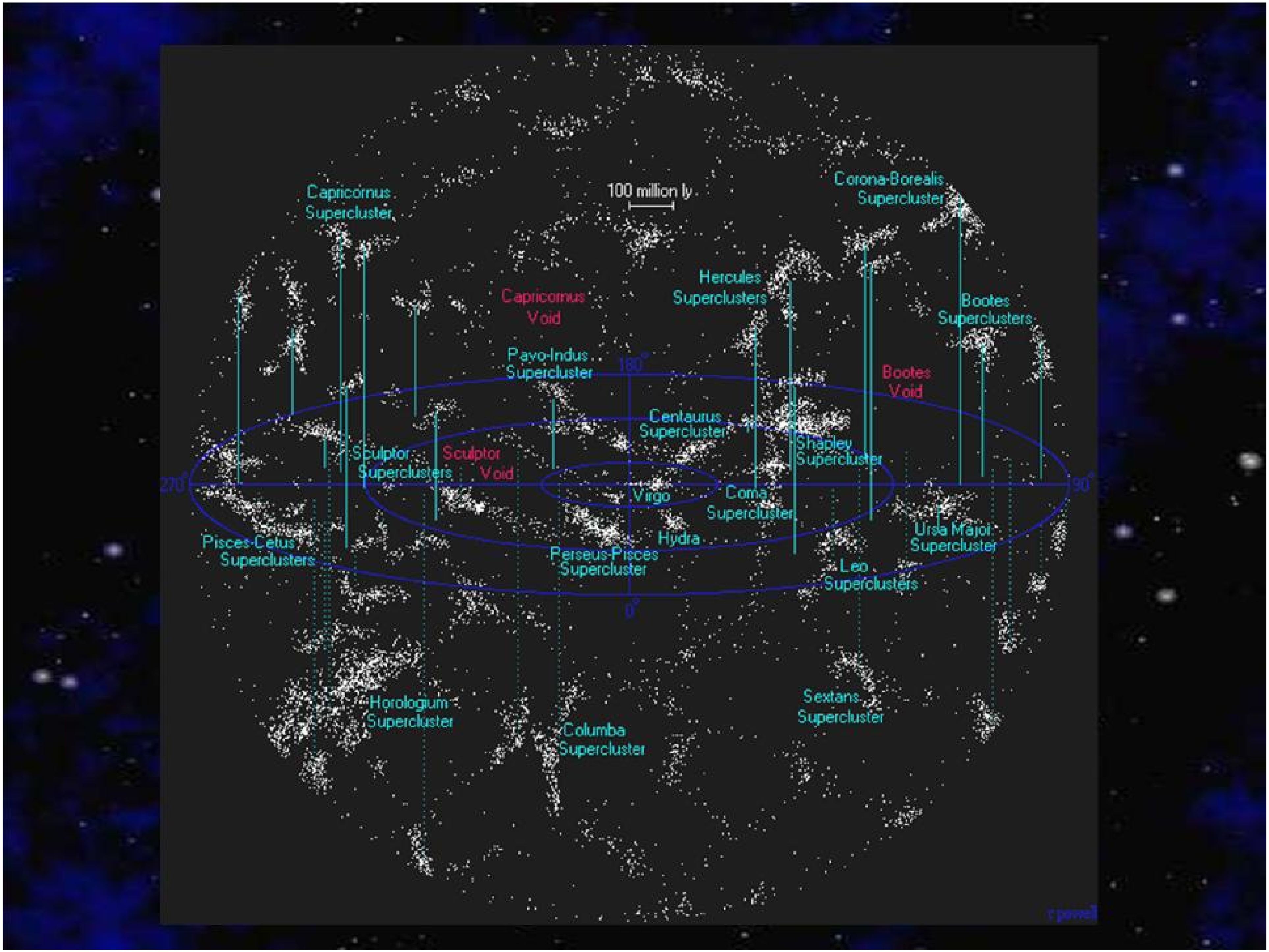
How are the galaxies distributed in the Universe?



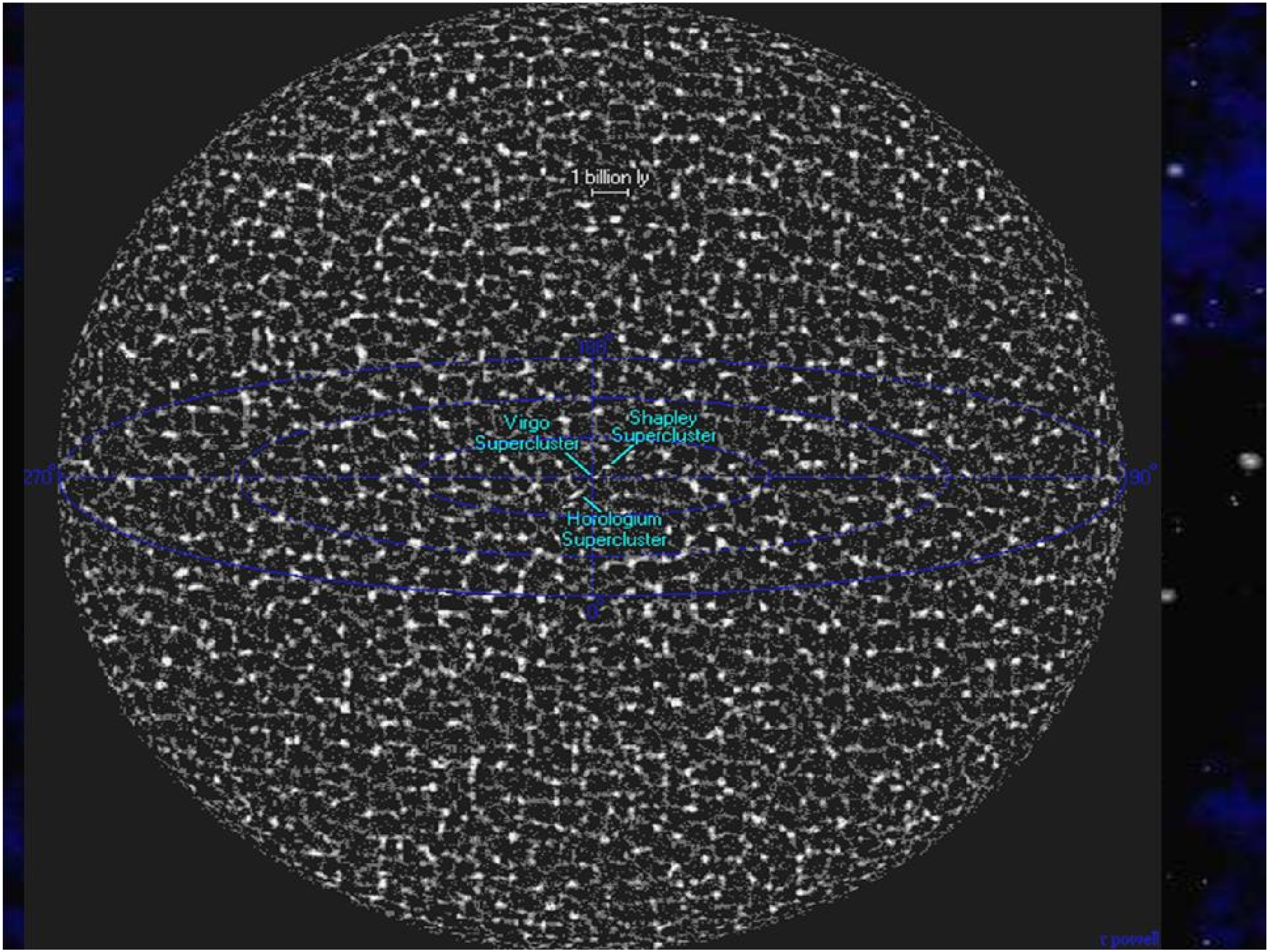
100 000 ly
Sextans Dwarf
Ursa Minor Dwarf
Draco Dwarf
180°
270°
90°
Milky Way
Sagittarius Dwarf
Large Magellanic Cloud
Carina Dwarf
0°
Small Magellanic Cloud
Sculptor Dwarf
Fornax Dwarf
r.powell


10 million ly
180°
270°
90°
0°
Virgo III
Groups
NGC
7582
NGC
6744
NGC
5033
NGC
5128
Local
Group
M101
Canes
Groups
Virgo
Cluster
NGC
4697
Sculptor
Maffei
M81
Leo I
Ursa Major
Groups
NGC
1023
NGC
2997
Dorado
Leo II
Groups
Fornax
Cluster
Eridanus
Cluster
r.powell

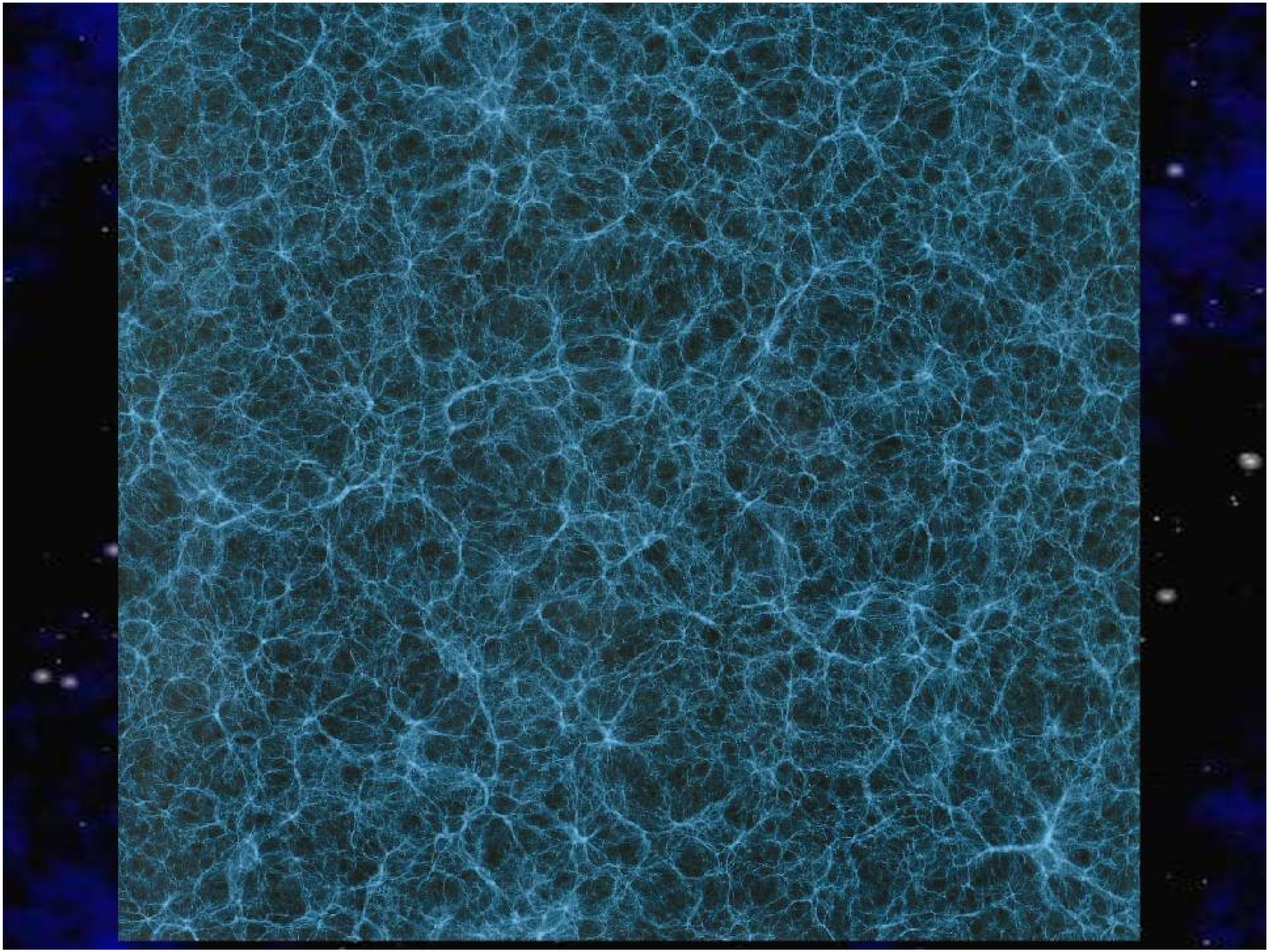

Virgo Supercluster
The Local Group
Virgo Cluster

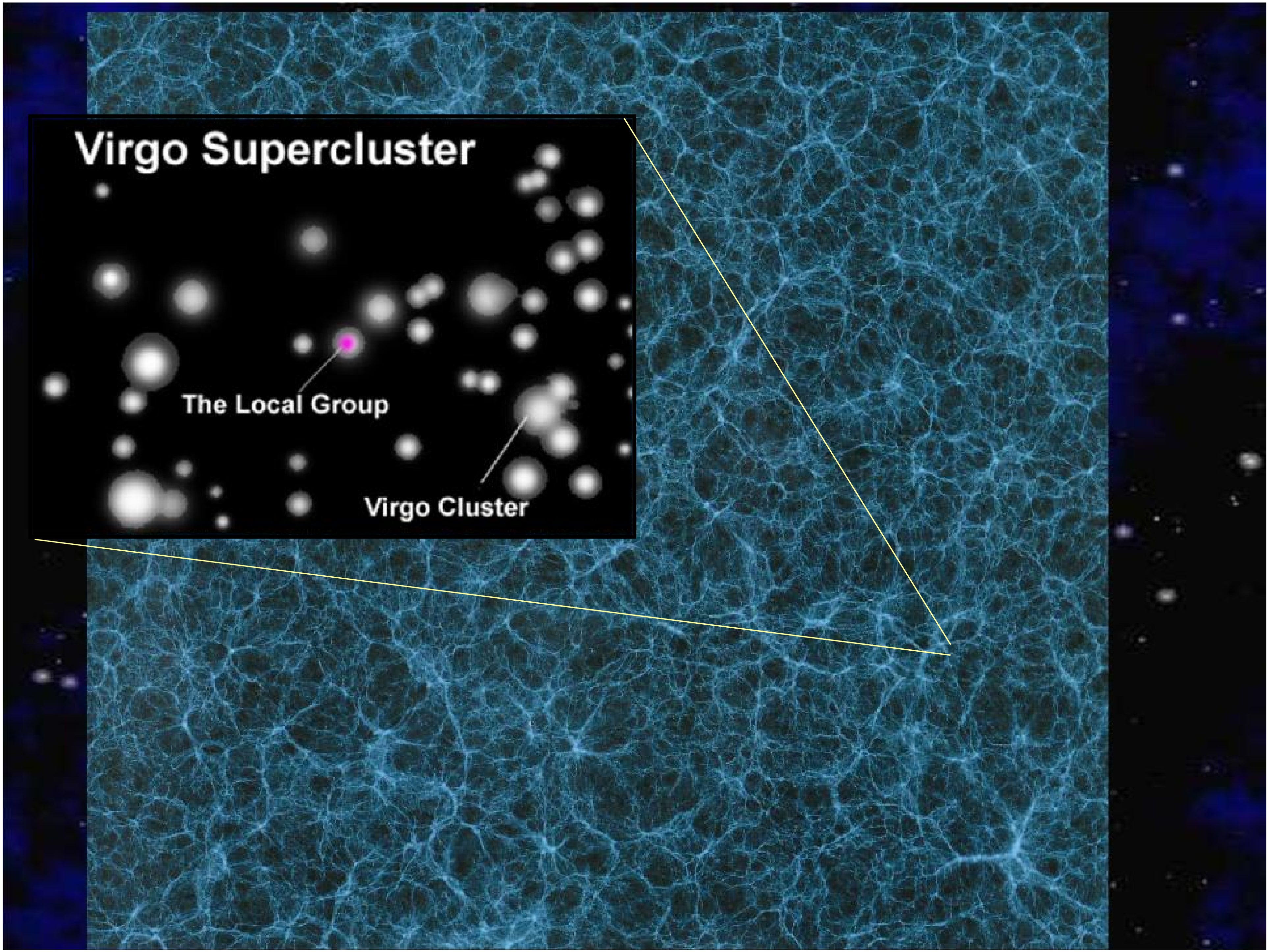


100 million ly
Capricornus Supercluster
Capricornus Void
Pavo-Indus Supercluster
Hercules Superclusters
Corona-Borealis Supercluster
Bootes Superclusters
Bootes Void
Centaurus Supercluster
Shapley Supercluster
Sculptor Superclusters
Sculptor Void
Virgo
Coma Supercluster
Hydra
Ursa Major Supercluster
Pisces-Cetus Superclusters
Perseus-Pisces Supercluster
Leo Superclusters
Horologium Supercluster
Columba Supercluster
Sextans Supercluster
180°
270°
90°
0°

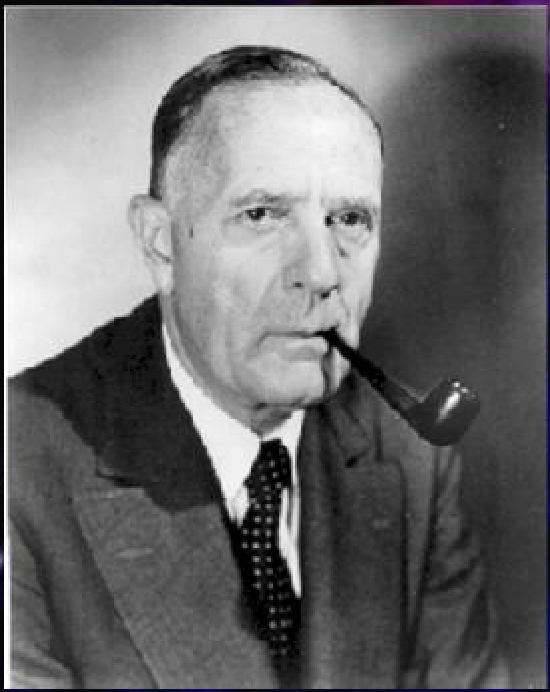


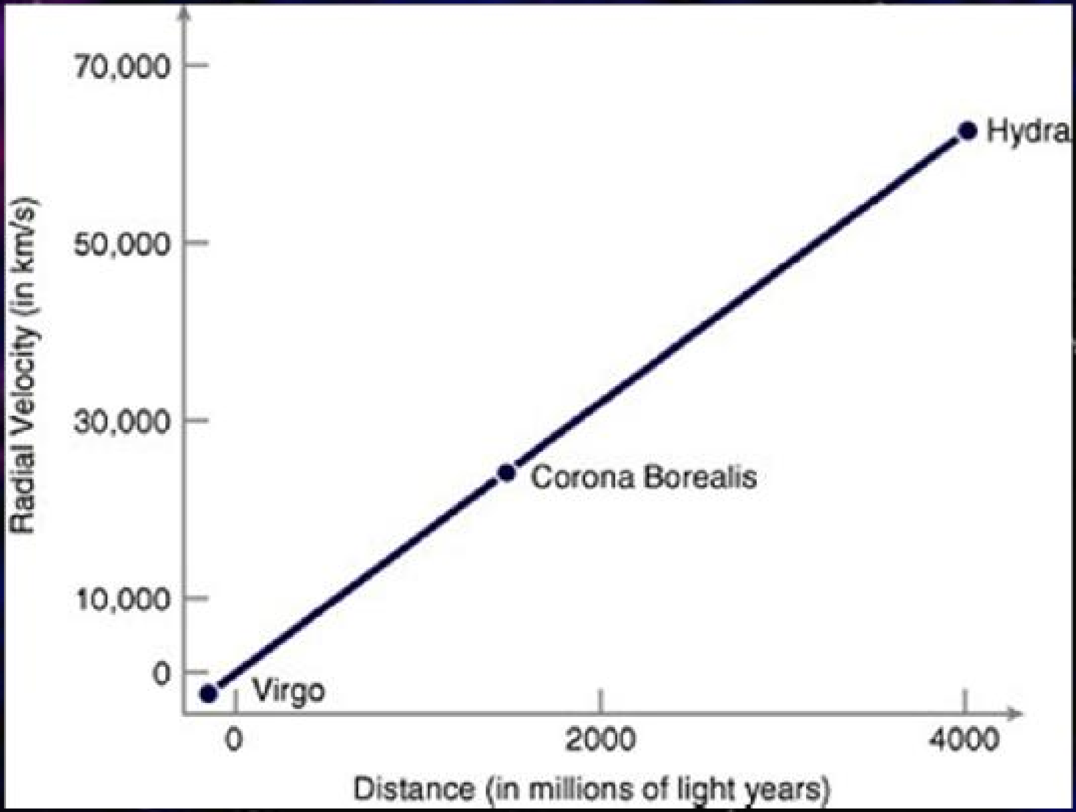
1 billion ly
180°
Virgo Supercluster
Shapley Supercluster
270°
90°
Horologium Supercluster
0°
r powell




Virgo Supercluster
The Local Group
Virgo Cluster

How do we know how *OLD* the Universe is?





Edwin Hubble - 1929

Edwin Hubble accomplished 2 great things:

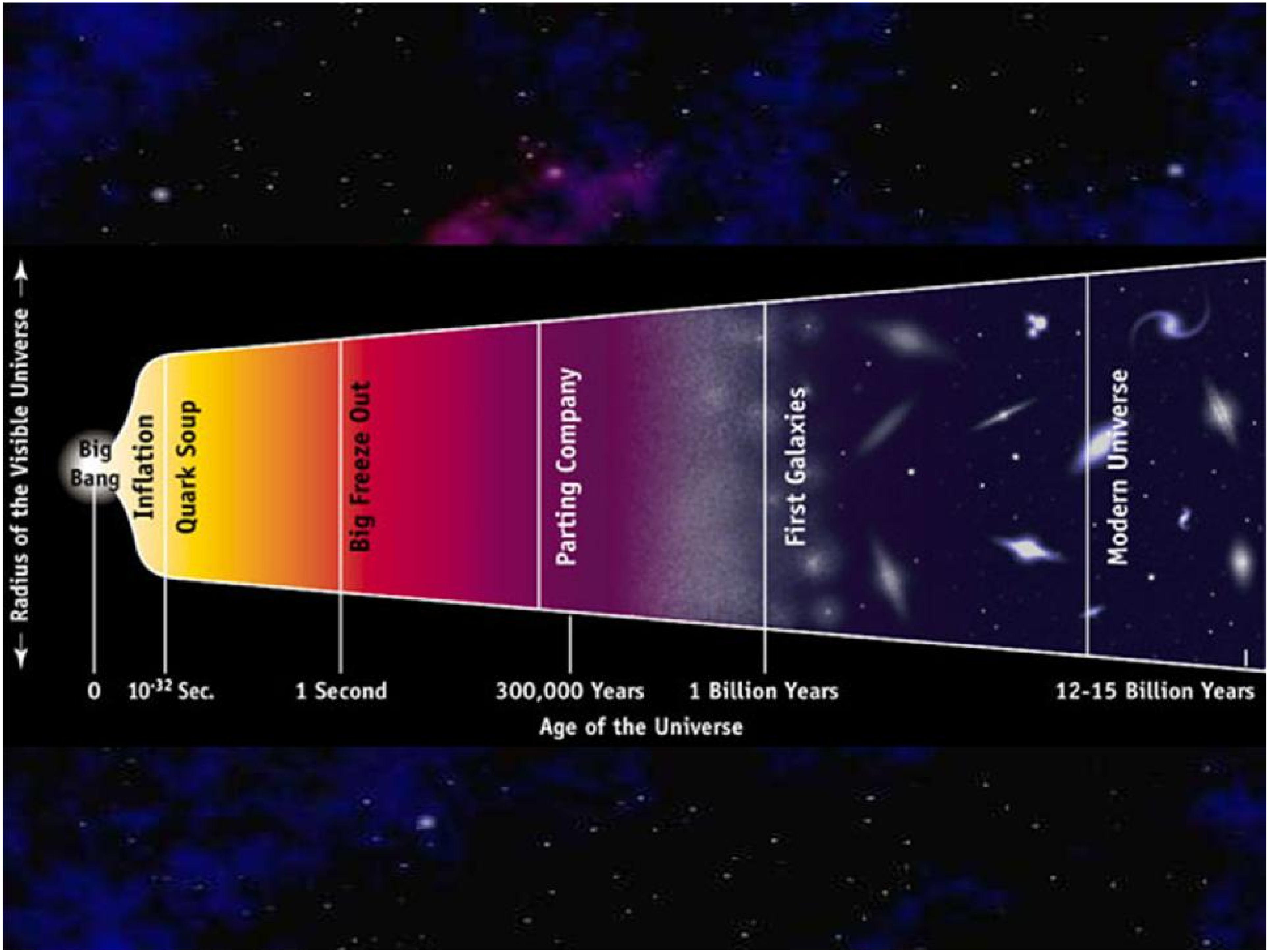
1. 1924 he was able to recognize Cepheids (variable stars) in nearby galaxies and once and for all showed that these were separate "island universes".

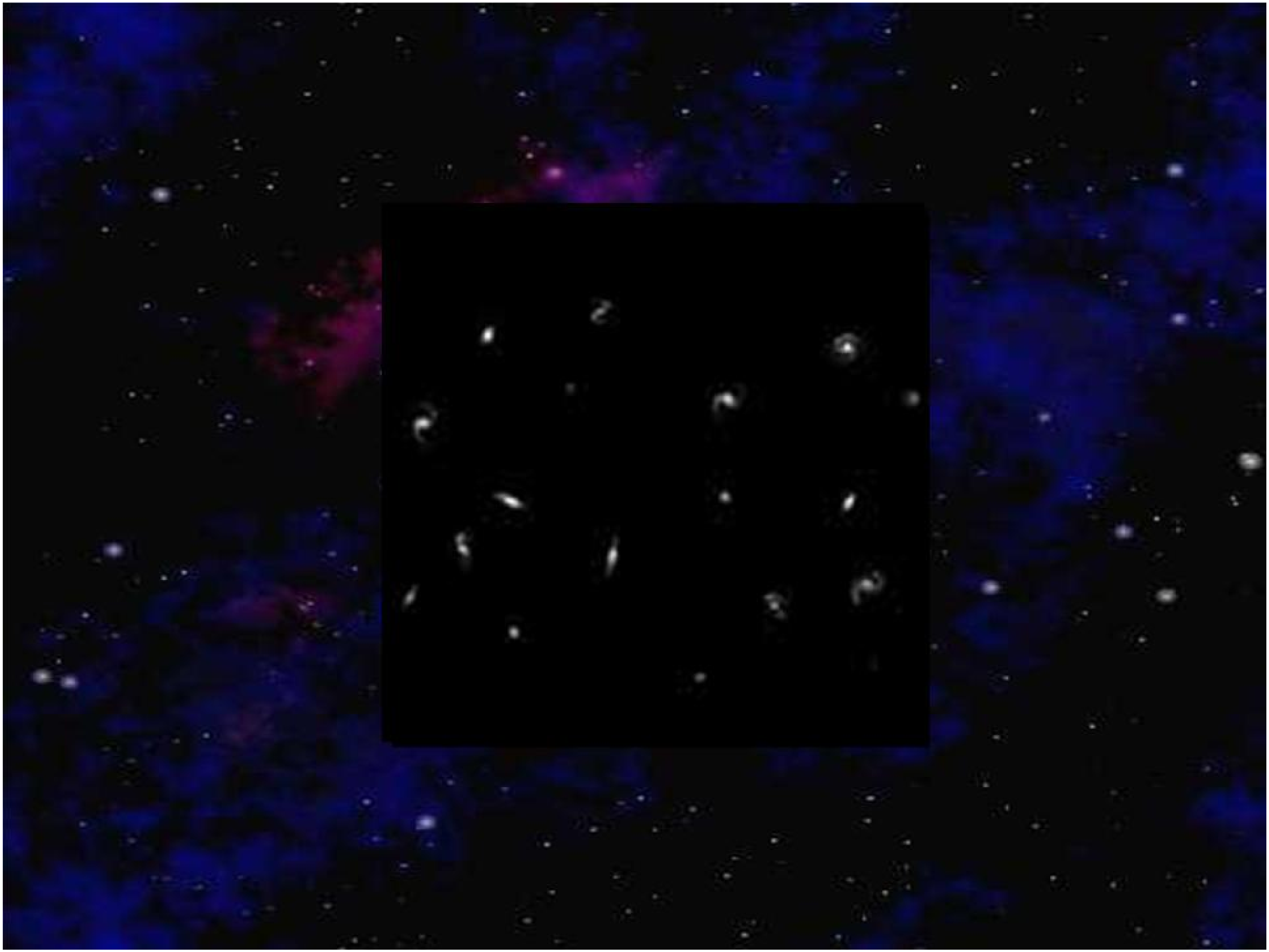
2. 1929 he showed through the analysis of red shifts of galaxies (spectroscopy) that the more distant a galaxy is the faster it is rushing away from us.

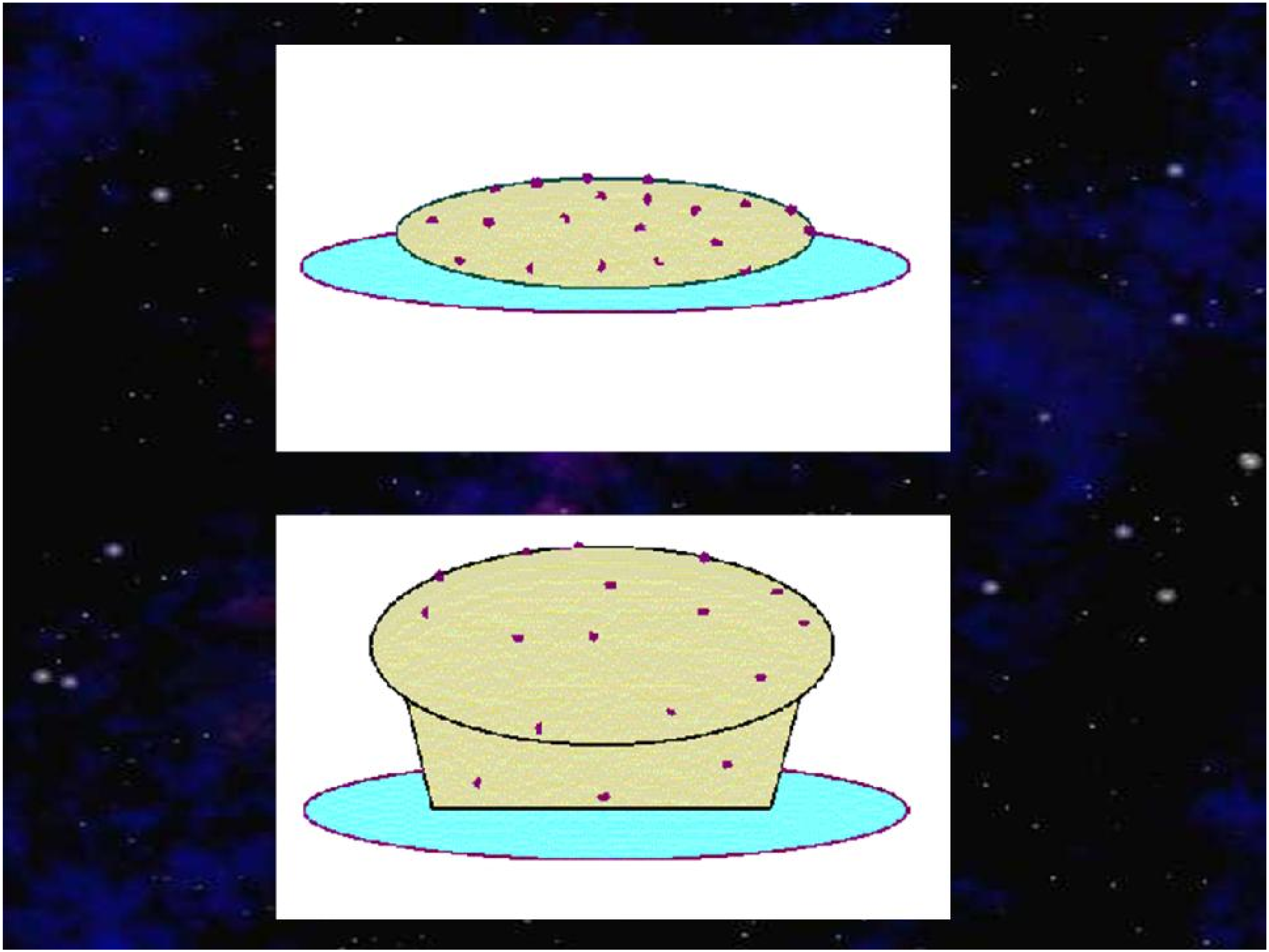
"Expanding Universe"

Sidebar: In 1916 Albert Einstein published his opus on General relativity. This theory *predicted* that the universe should be expanding!!! Since the prevailing thinking of the time was that the universe was static (not expanding or contracting), he added a term to his relativity equations that made the universe static.

Einstein 14 years later called it was his greatest scientific blunder.

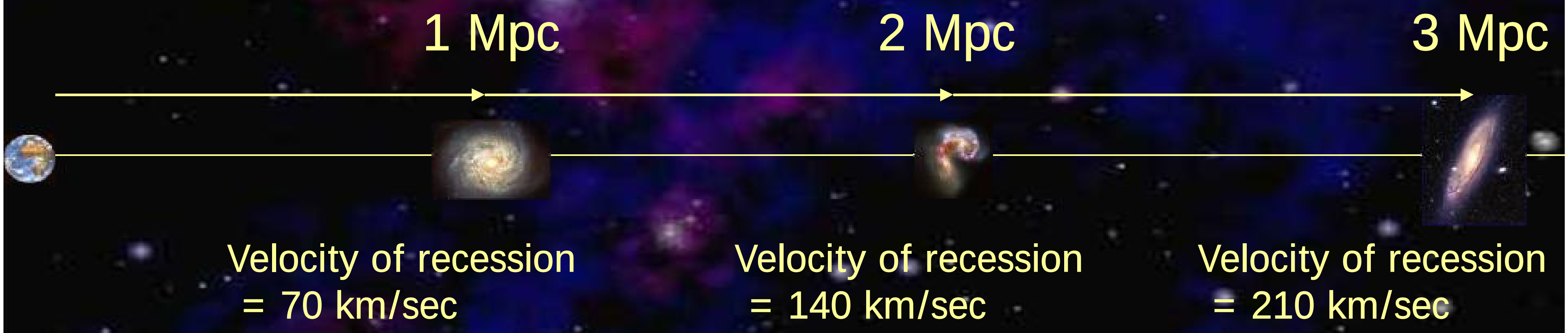

Radius of the Visible Universe
Big Bang
Inflation
Quark Soup
Big Freeze Out
Parting Company
First Galaxies
Modern Universe
0
10^{-32} Sec.
1 Second
300,000 Years
1 Billion Years
12-15 Billion Years
Age of the Universe





H_o = ~70 km/sec/Mpc

1 Mpc = 1 million parsecs = 3.26 million light years



It all depends on H_o

H_o – The "Hubble Constant"

- It is a measure of the slope of the line in the Hubble Diagram
- Represents the expansion rate of the Universe

$$Age\ of\ Universe = \frac{1}{H_o}$$

Current observations suggest:

$$H_0 = \frac{70 \frac{km}{\sec}}{Mpc} = \frac{20 \frac{km}{\sec}}{Mly}$$

Age of Universe ~ 14 billion years

The really big question:

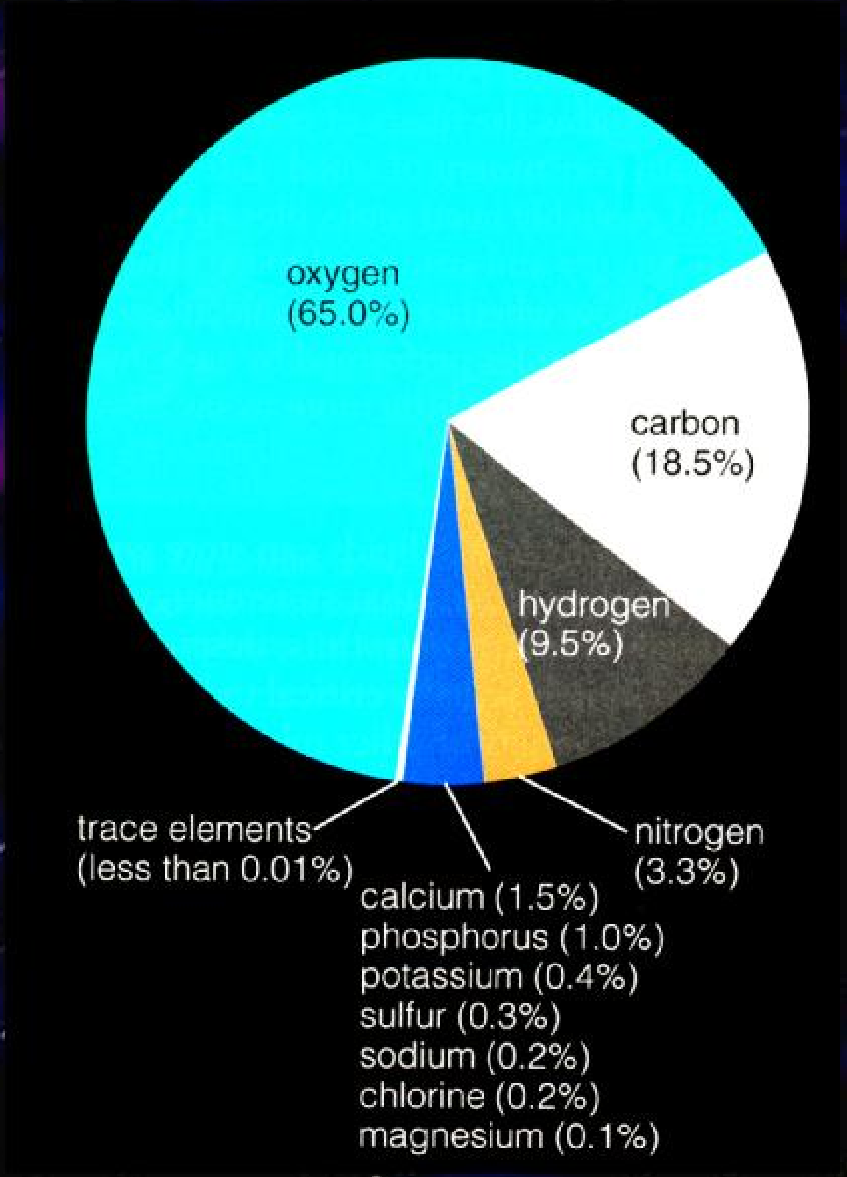
1. What is life?

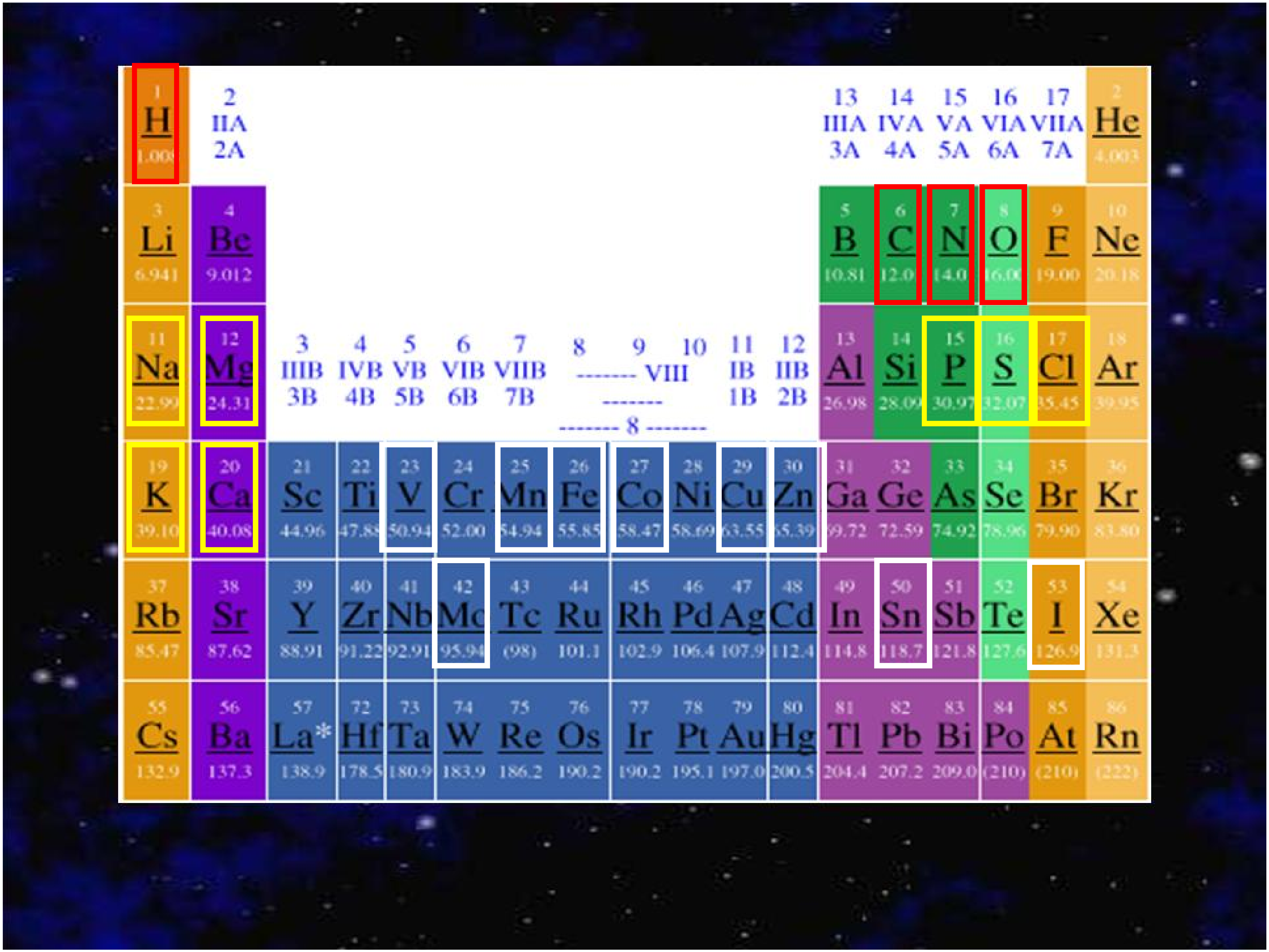
2. What is life made of?

What are the ingredients of Life?

C H O N !

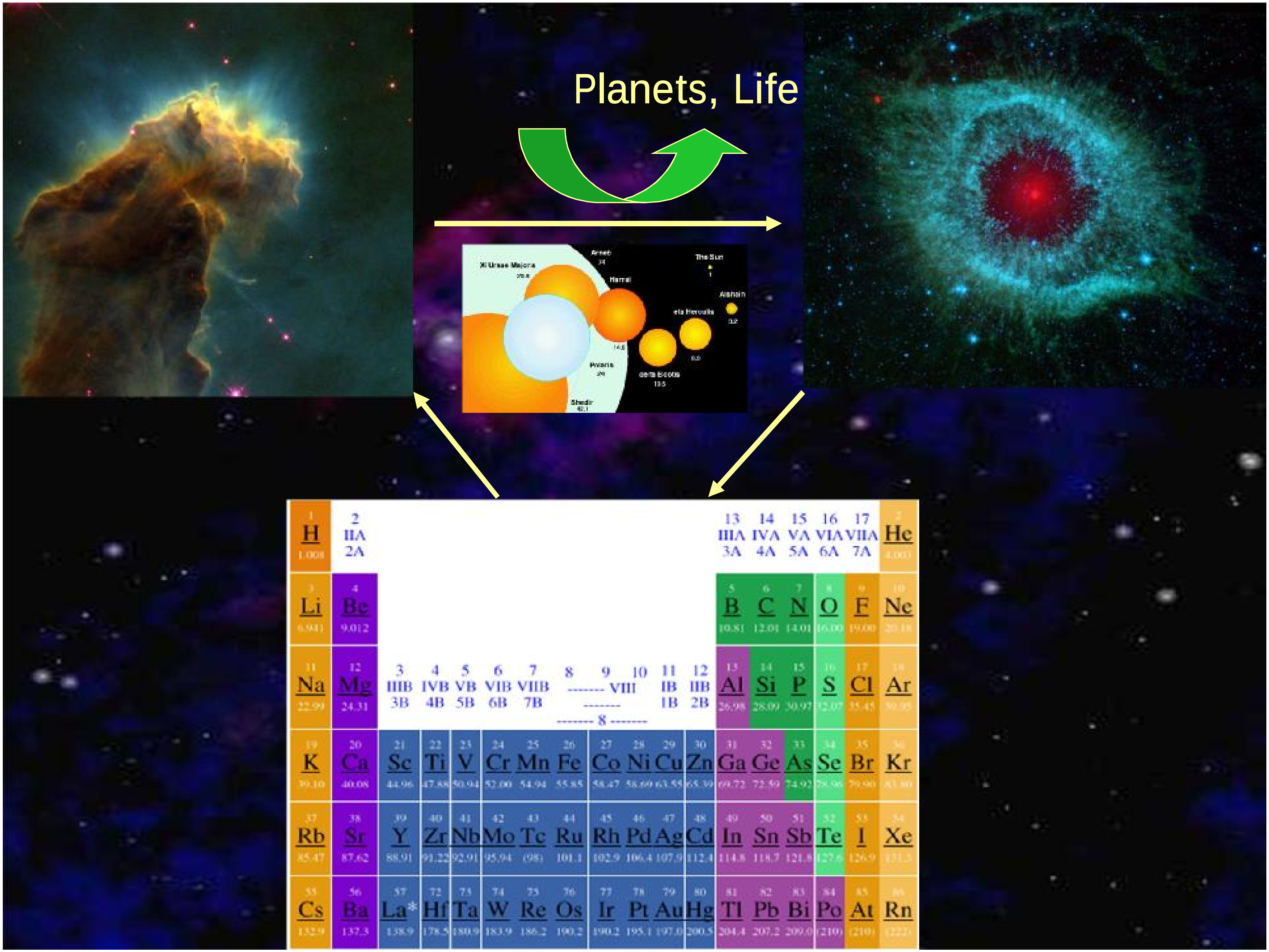
carbon, hydrogen, oxygen, nitrogen





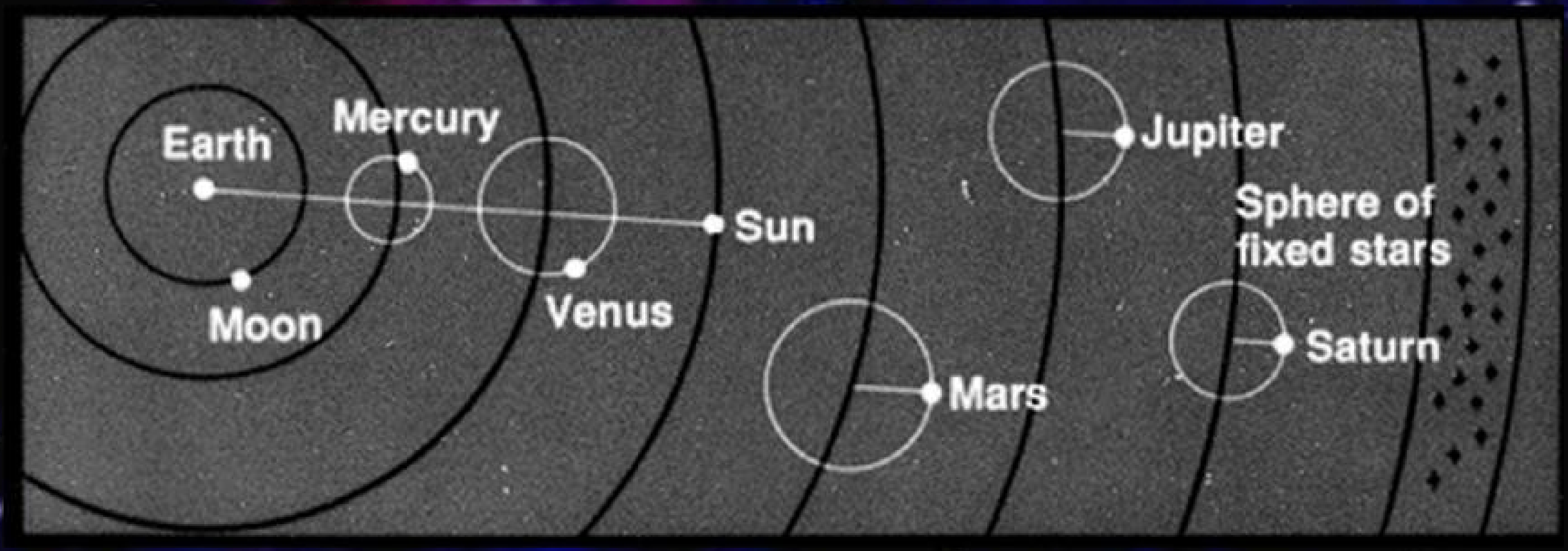
1 H 1.008
2 IIA 2A
13 IIIA 3A 14 IVA 4A 15 VA 5A 16 VIA 6A 17 VIIA 7A
2 He 4.003
3 Li 6.941
4 Be 9.012
5 B 10.81
6 C 12.0
7 N 14.0
8 O 16.0
9 F 19.00
10 Ne 20.18
11 Na 22.99
12 Mg 24.31
3 IIIB 3B 4 IVB 4B 5 VB 5B 6 VIB 6B 7 VIIB 7B 8 9 10 VIII 8 11 IB 1B 12 IIB 2B
13 Al 26.98
14 Si 28.09
15 P 30.97
16 S 32.07
17 Cl 35.45
18 Ar 39.95
19 K 39.10
20 Ca 40.08
21 Sc 44.96
22 Ti 47.88
23 V 50.94
24 Cr 52.00
25 Mn 54.94
26 Fe 55.85
27 Co 58.47
28 Ni 58.69
29 Cu 63.55
30 Zn 65.39
31 Ga 69.72
32 Ge 72.59
33 As 74.92
34 Se 78.96
35 Br 79.90
36 Kr 83.80
37 Rb 85.47
38 Sr 87.62
39 Y 88.91
40 Zr 91.22
41 Nb 92.91
42 Mo 95.94
43 Tc (98)
44 Ru 101.1
45 Rh 102.9
46 Pd 106.4
47 Ag 107.9
48 Cd 112.4
49 In 114.8
50 Sn 118.7
51 Sb 121.8
52 Te 127.6
53 I 126.9
54 Xe 131.3
55 Cs 132.9
56 Ba 137.3
57 La* 138.9
72 Hf 178.5
73 Ta 180.9
74 W 183.9
75 Re 186.2
76 Os 190.2
77 Ir 190.2
78 Pt 195.1
79 Au 197.0
80 Hg 200.5
81 Tl 204.4
82 Pb 207.2
83 Bi 209.0
84 Po (210)
85 At (210)
86 Rn (222)

The Stars:
Their life and death cycle allows for life

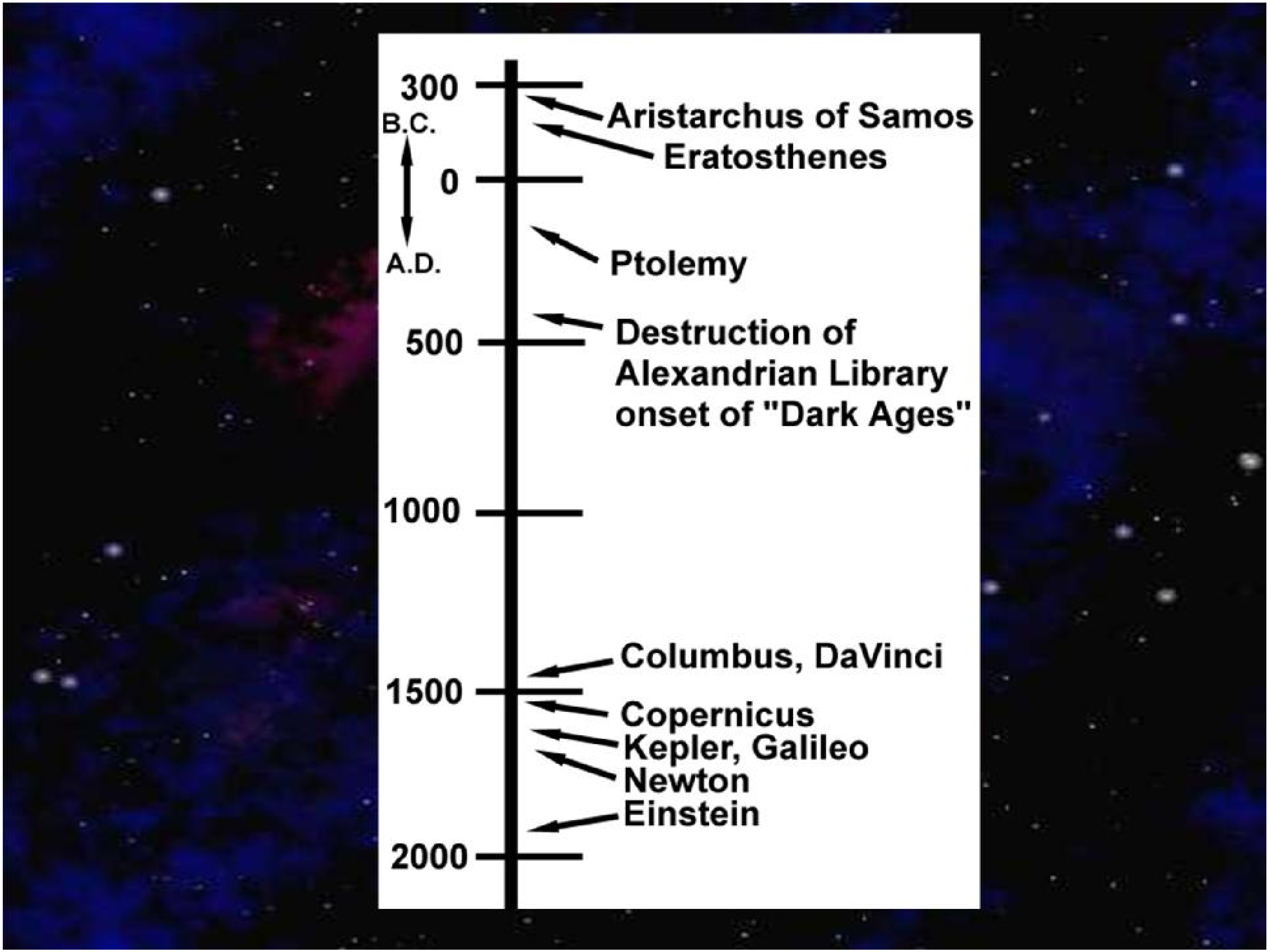

Planets, Life
H He
Li Be B C N O F Ne
Na Mg Al Si P S Cl Ar
K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr
Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe
Cs Ba La* Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn

A brief history on why we are where we are

The Ptolemeic System:



THE ASTRONOMICAL REVOLUTION


300
B.C.
0
A.D.
500
1000
1500
2000
Aristarchus of Samos
Eratosthenes
Ptolemy
Destruction of Alexandrian Library onset of "Dark Ages"
Columbus, DaVinci
Copernicus
Kepler, Galileo
Newton
Einstein

HELIOCENTRIC COSMOLOGY

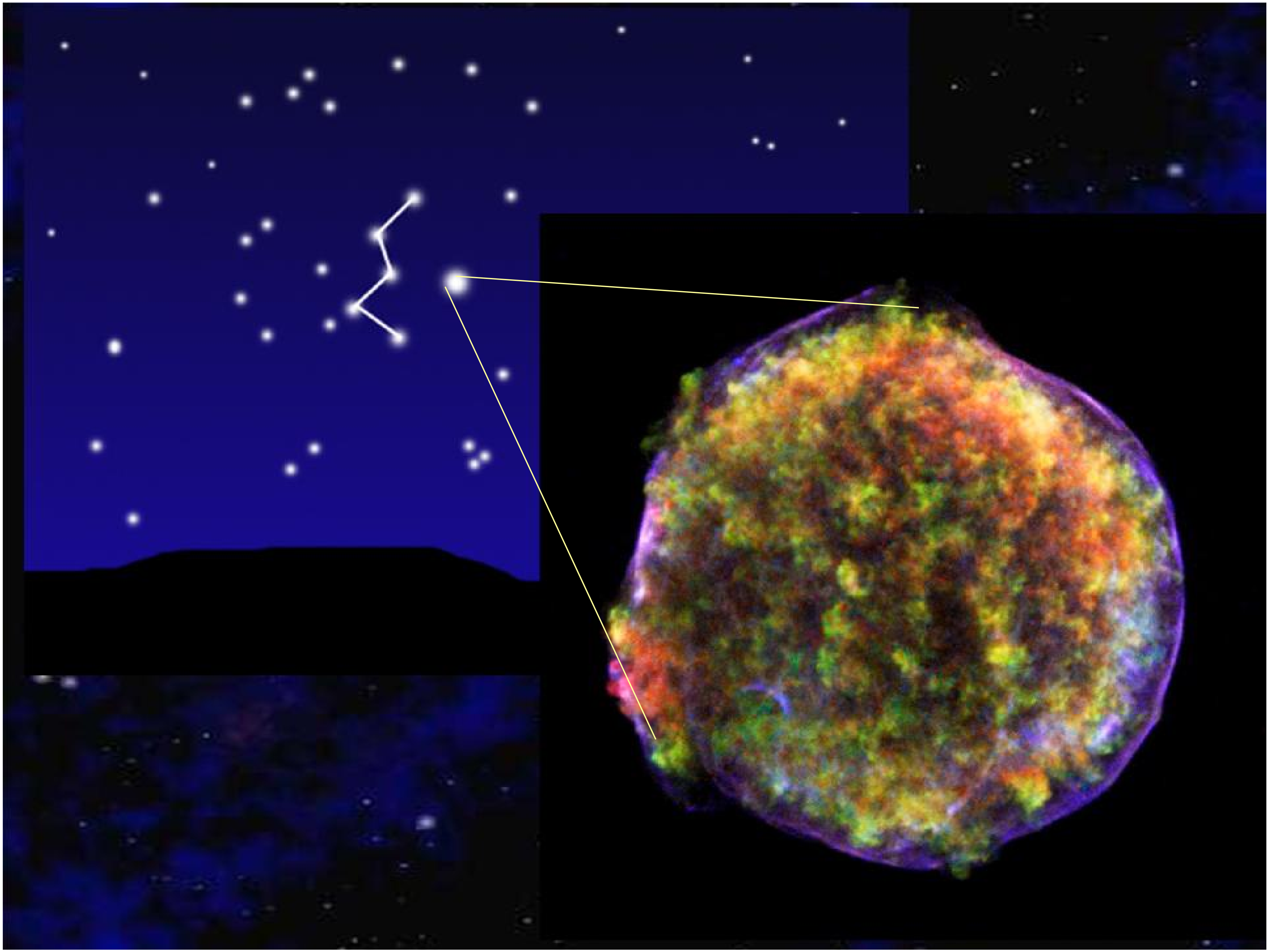
- The *<u>SUN</u>* is the center of the solar system and Universe. All planets, including the Earth, move around the Sun.

Nicholas Copernicus (1473 – 1543)

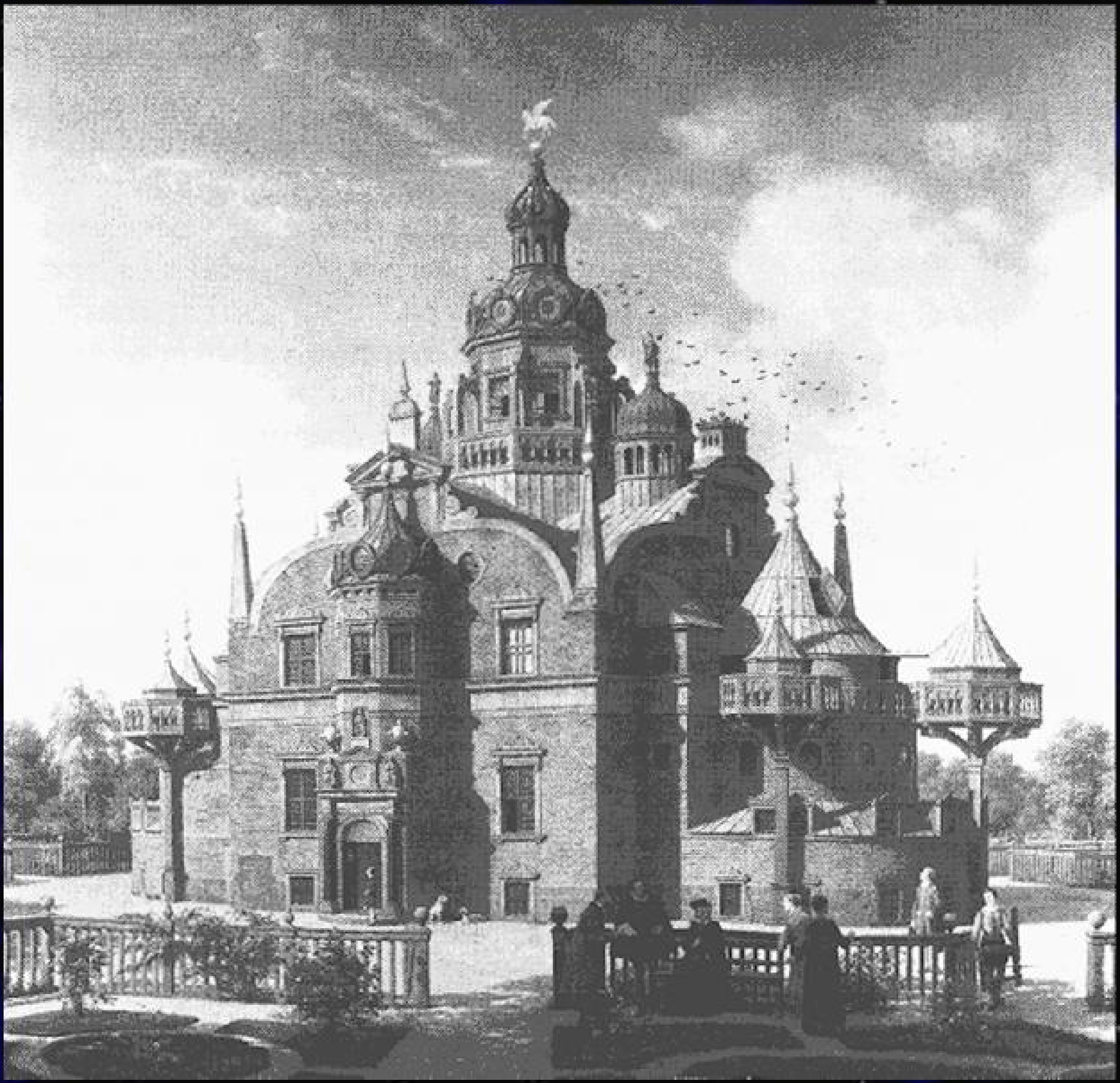
Andreas Osiander

"...declare that the fundamental principles laid down in this book are merely abstract hypotheses convenient for the purposes of calculation only"

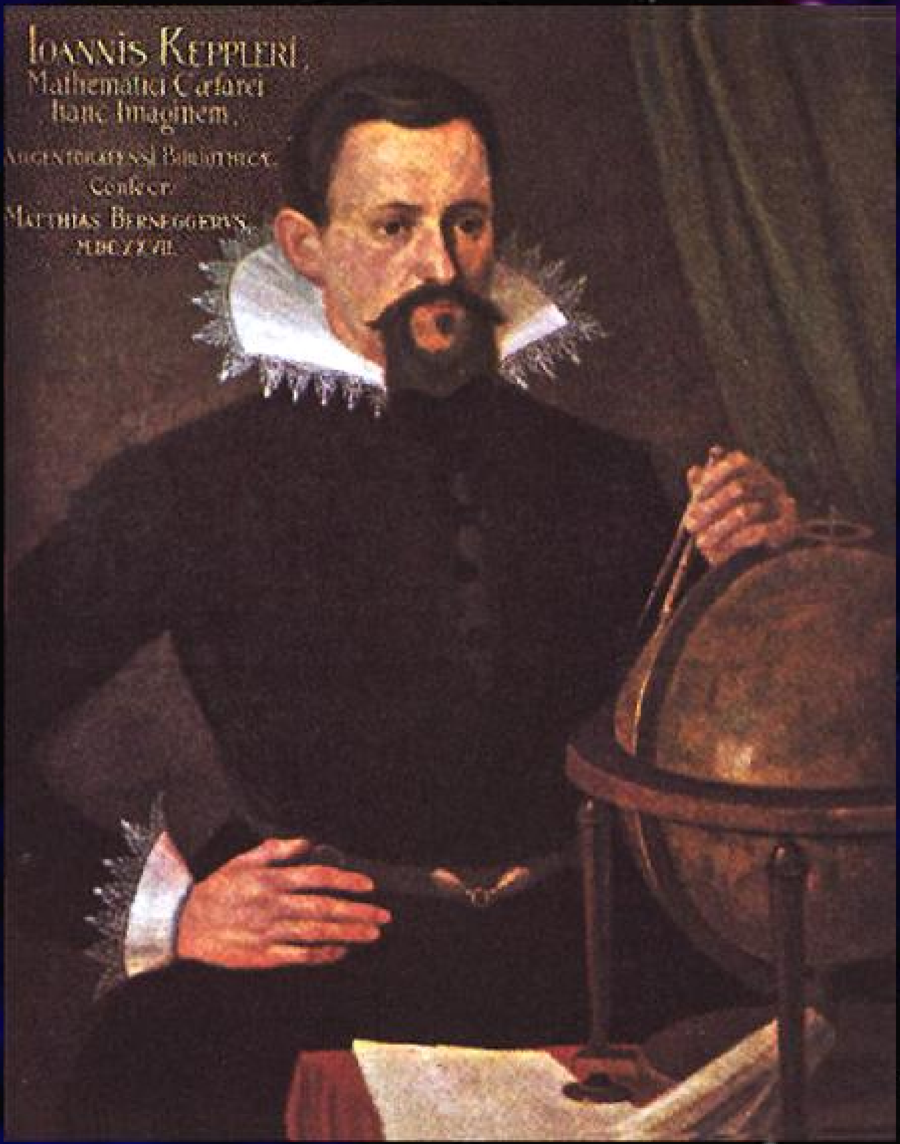
Tycho Brahe (1547 – 1601)

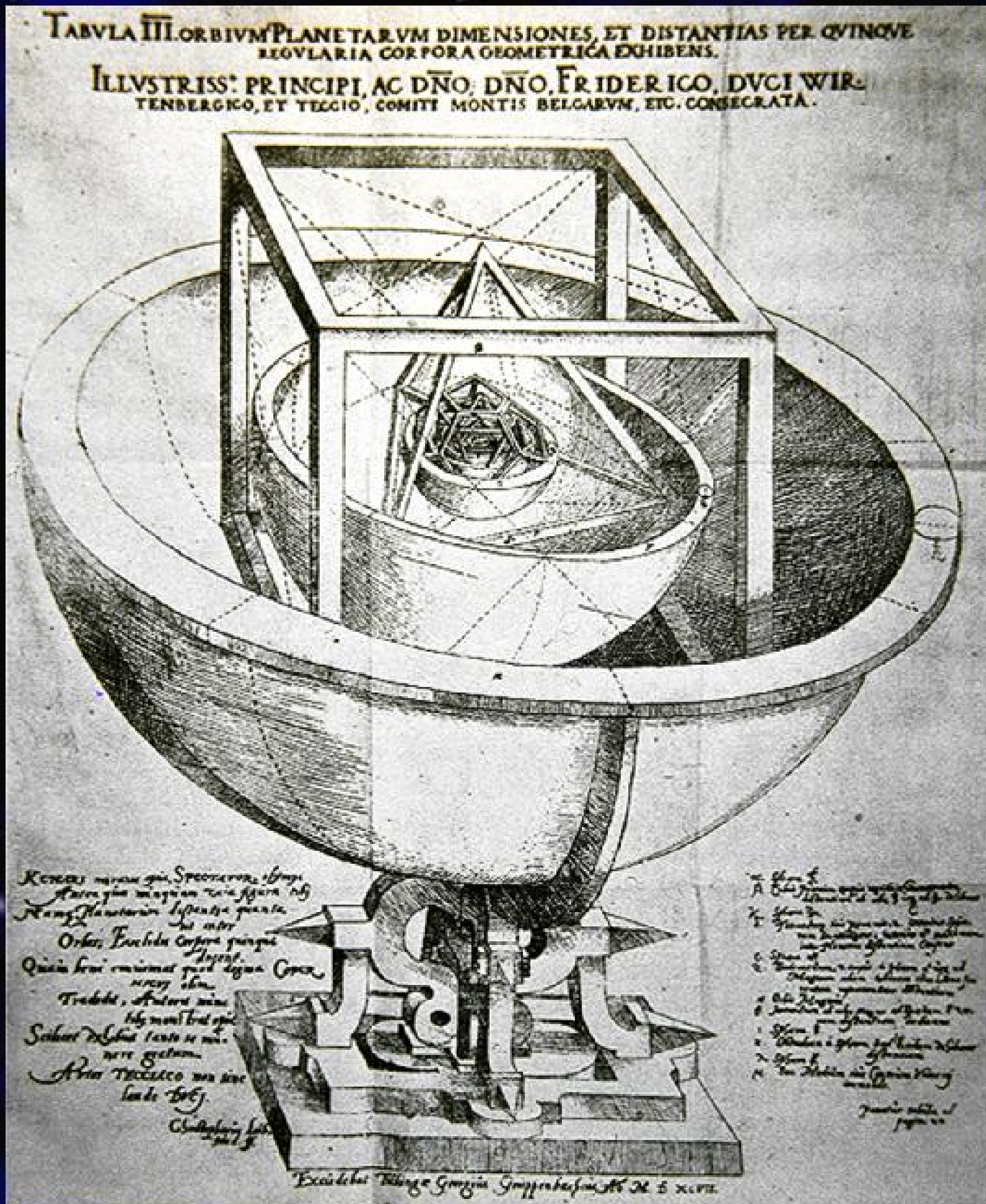


Uraniborg (1577 – 1597)



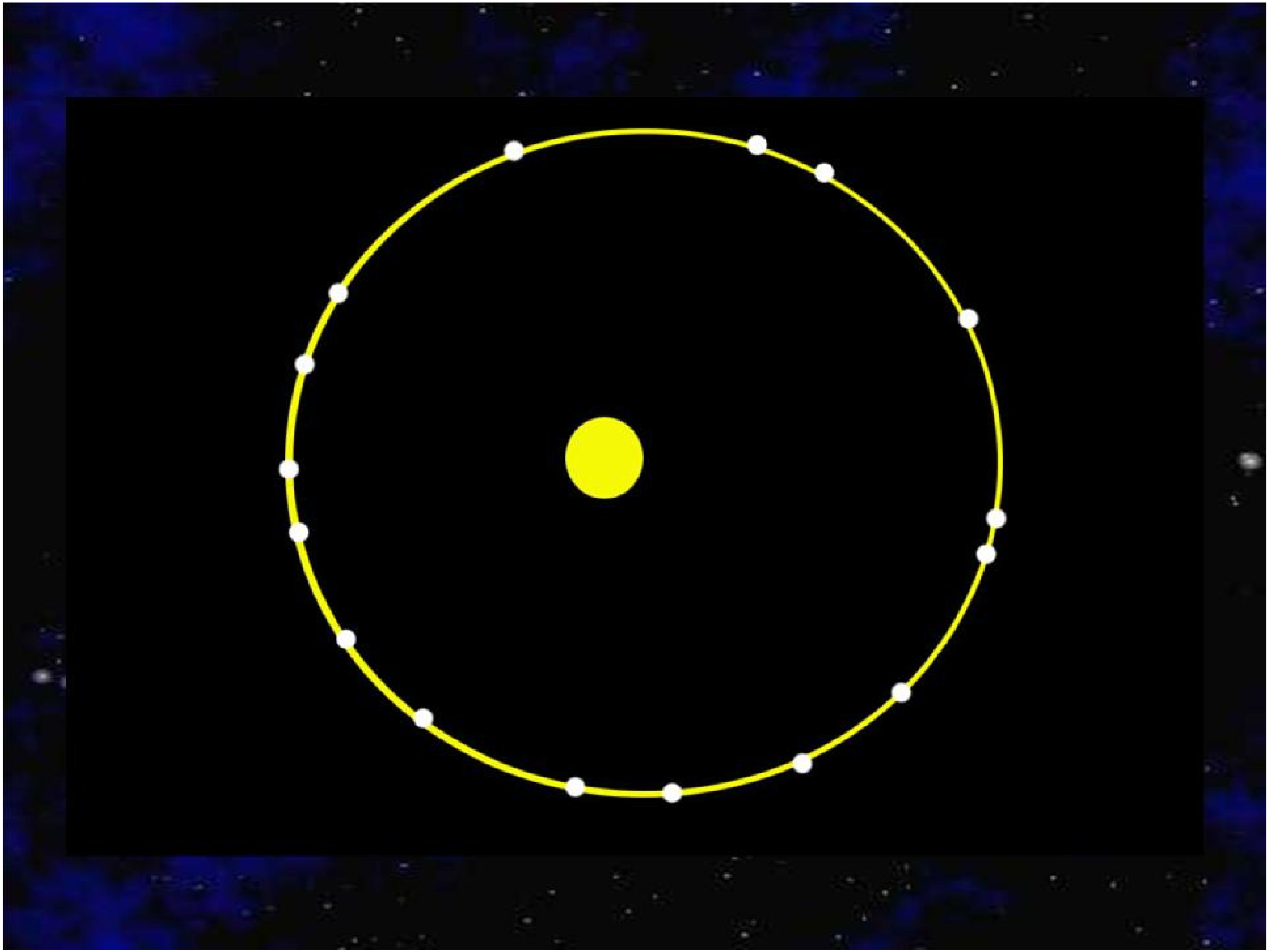
Johannes Kepler (1571 – 1630)





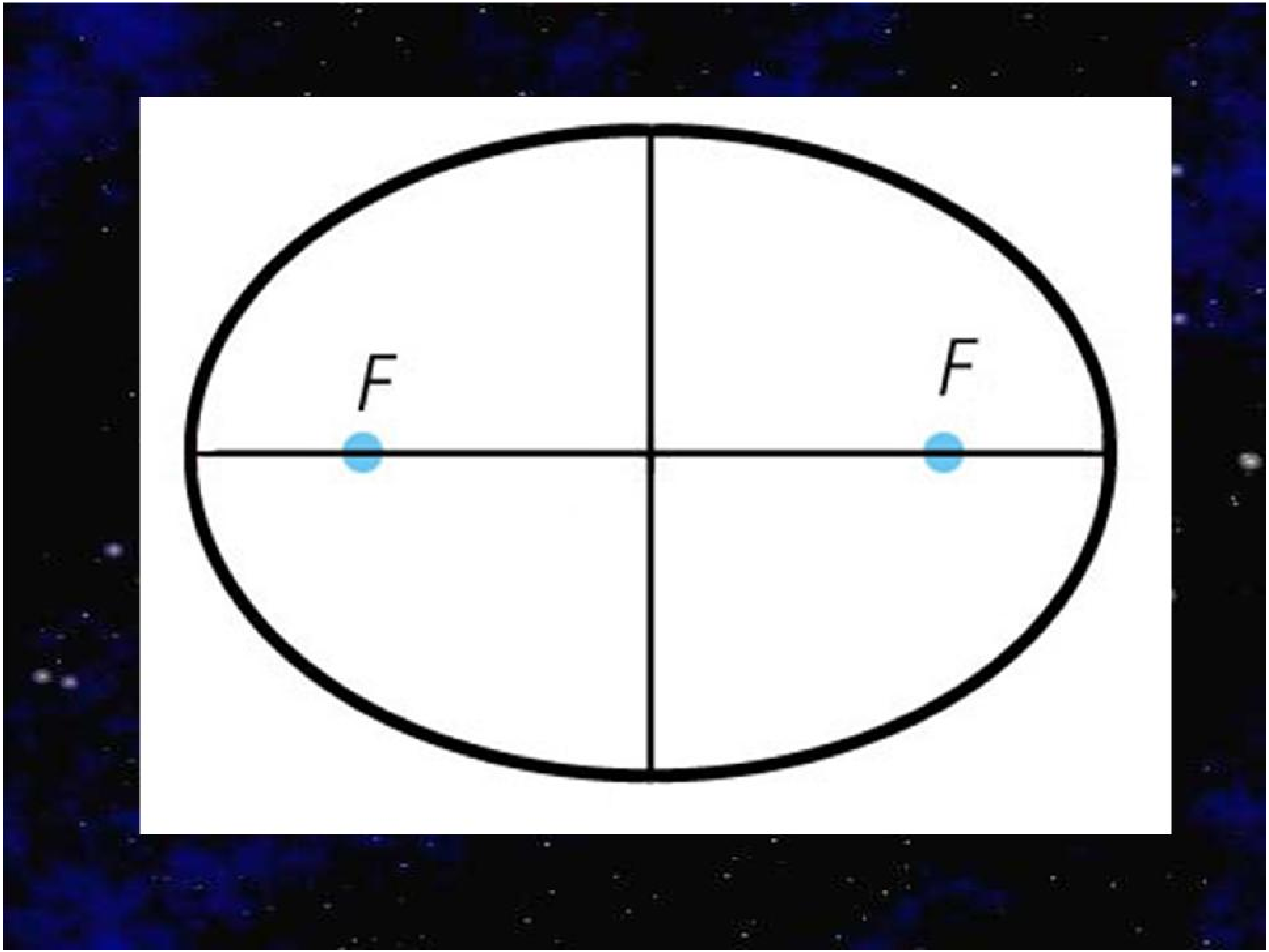
The Paradigm shift !!

Kepler’s Laws of Planetary Motion



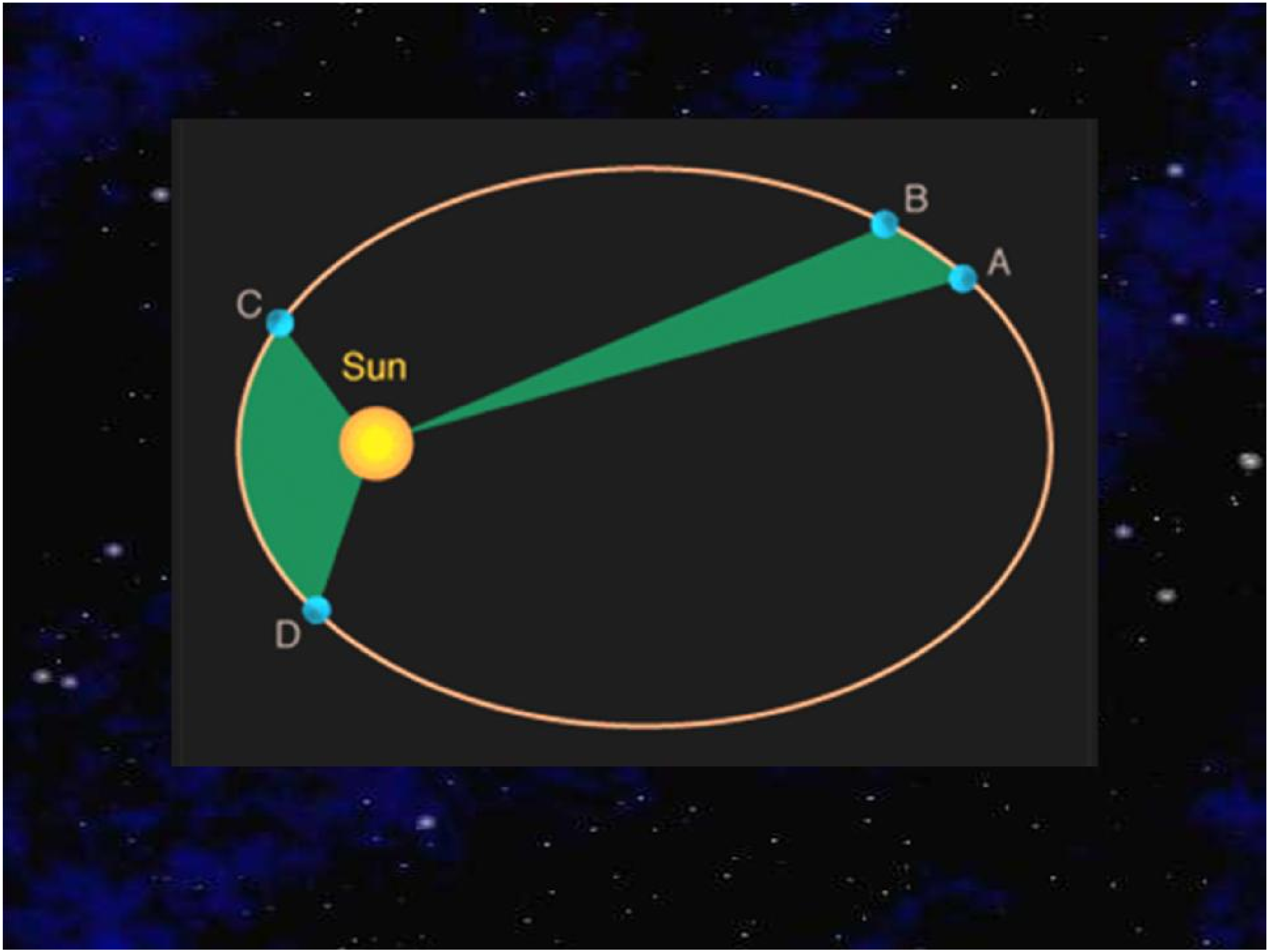
Kepler's 1st Law:

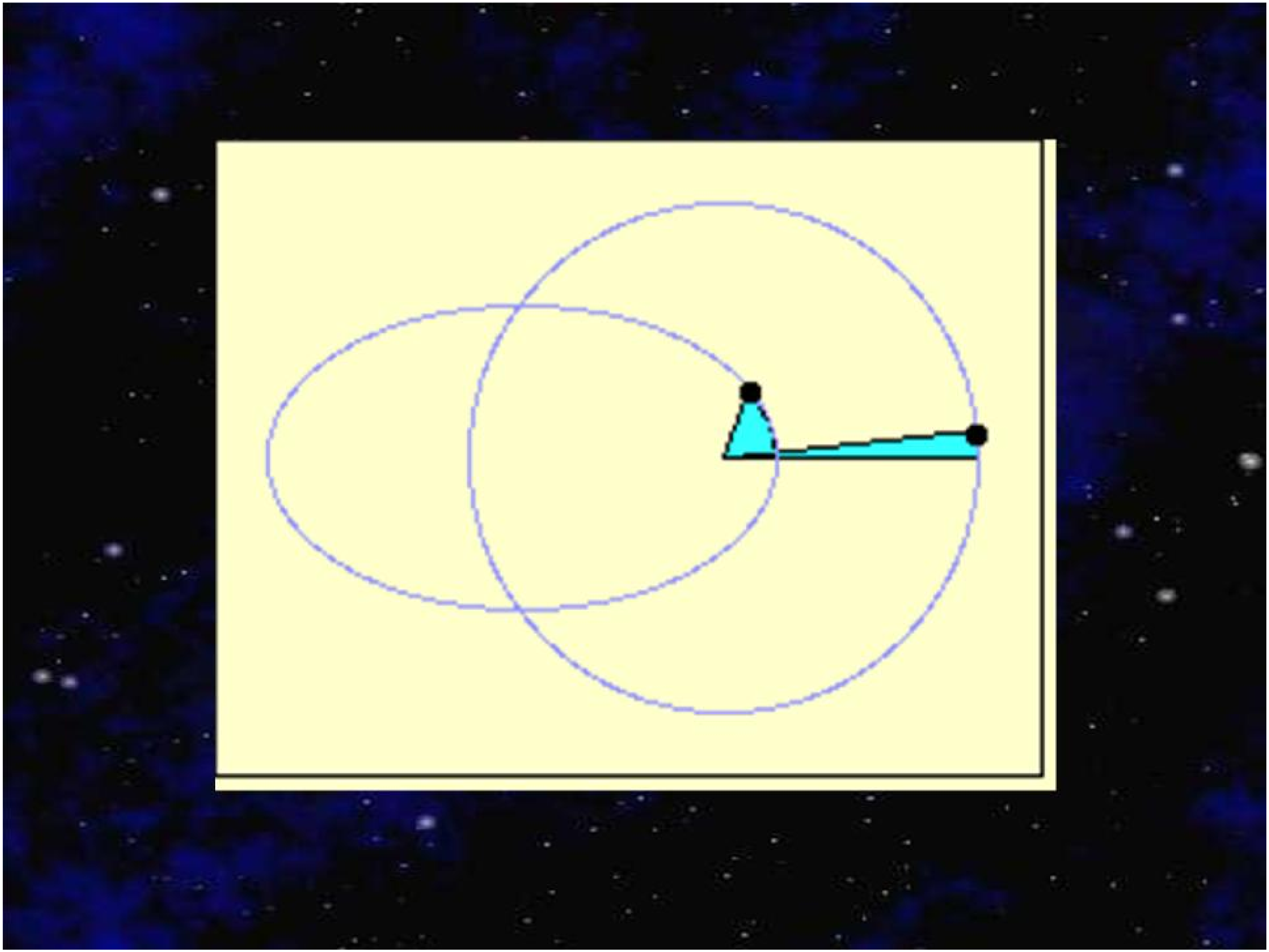
"The orbit of a planet about the Sun is an ellipse with the Sun at one *focus*"


F
F

Kepler's 2nd Law:

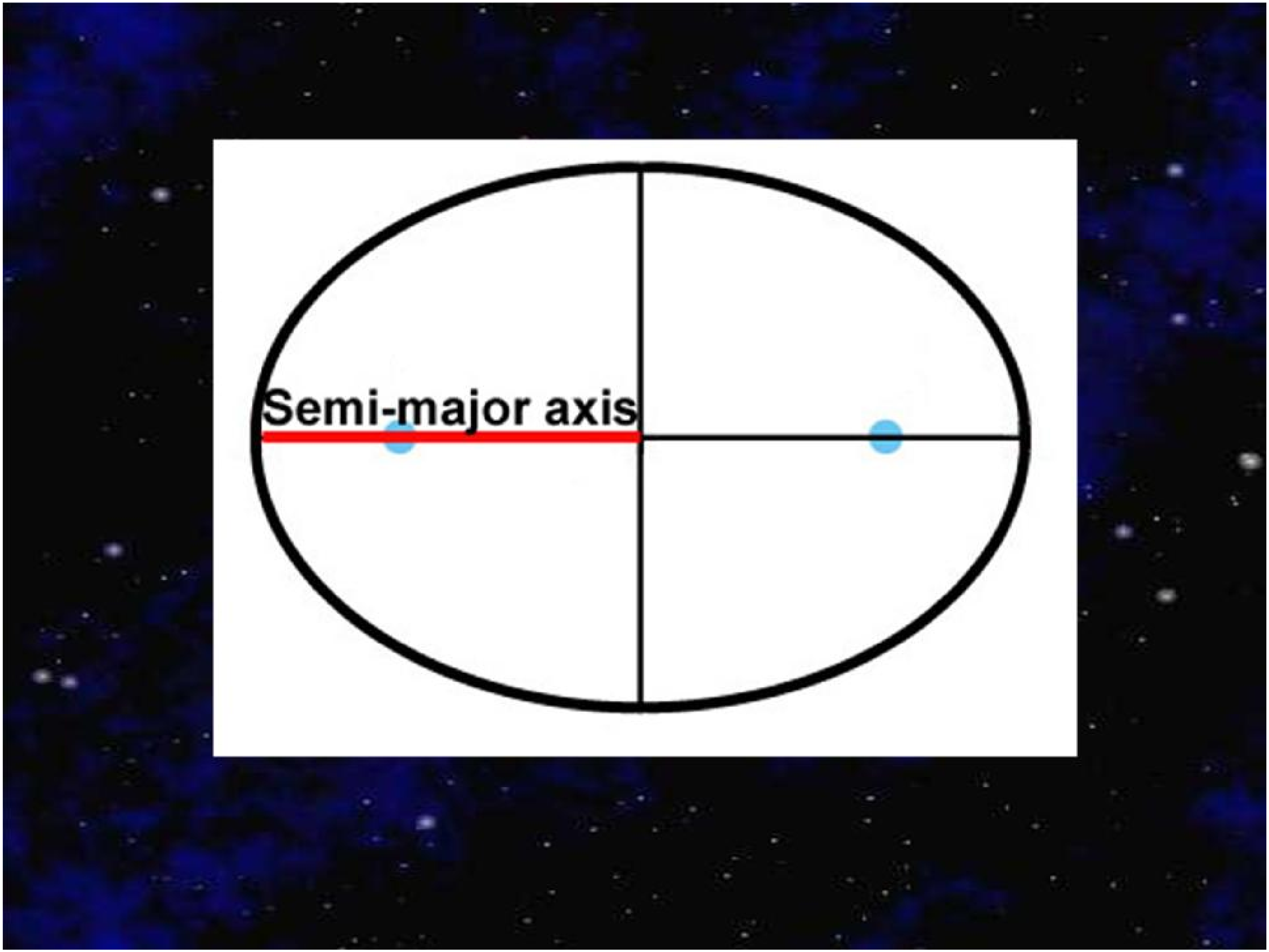
"A line joining a planet and the Sun sweeps out equal areas in equal intervals of time."


B
A
C
Sun
D



Kepler's 3rd Law:

"The squares of the sidereal periods of the planets are proportional to the cubes of their semi-major axes."


Semi-major axis

Kepler's 3rd Law:

"The squares of the sidereal periods of the planets are proportional to the cubes of their semi-major axes."

$P^2 = d^3$

- P = Orbital Period measured in Earth years
- d = Orbital distance measured in A.U.'s
- Example: Jupiter

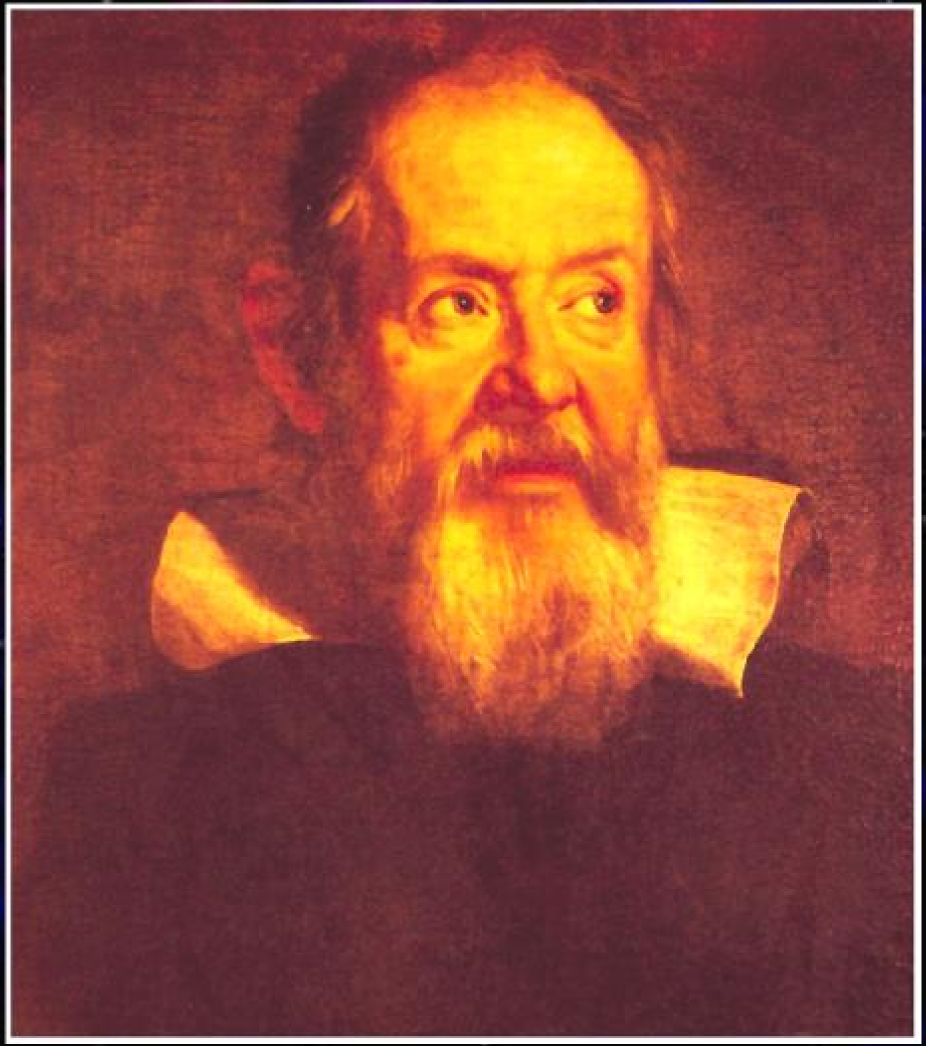
P = 11.86 years

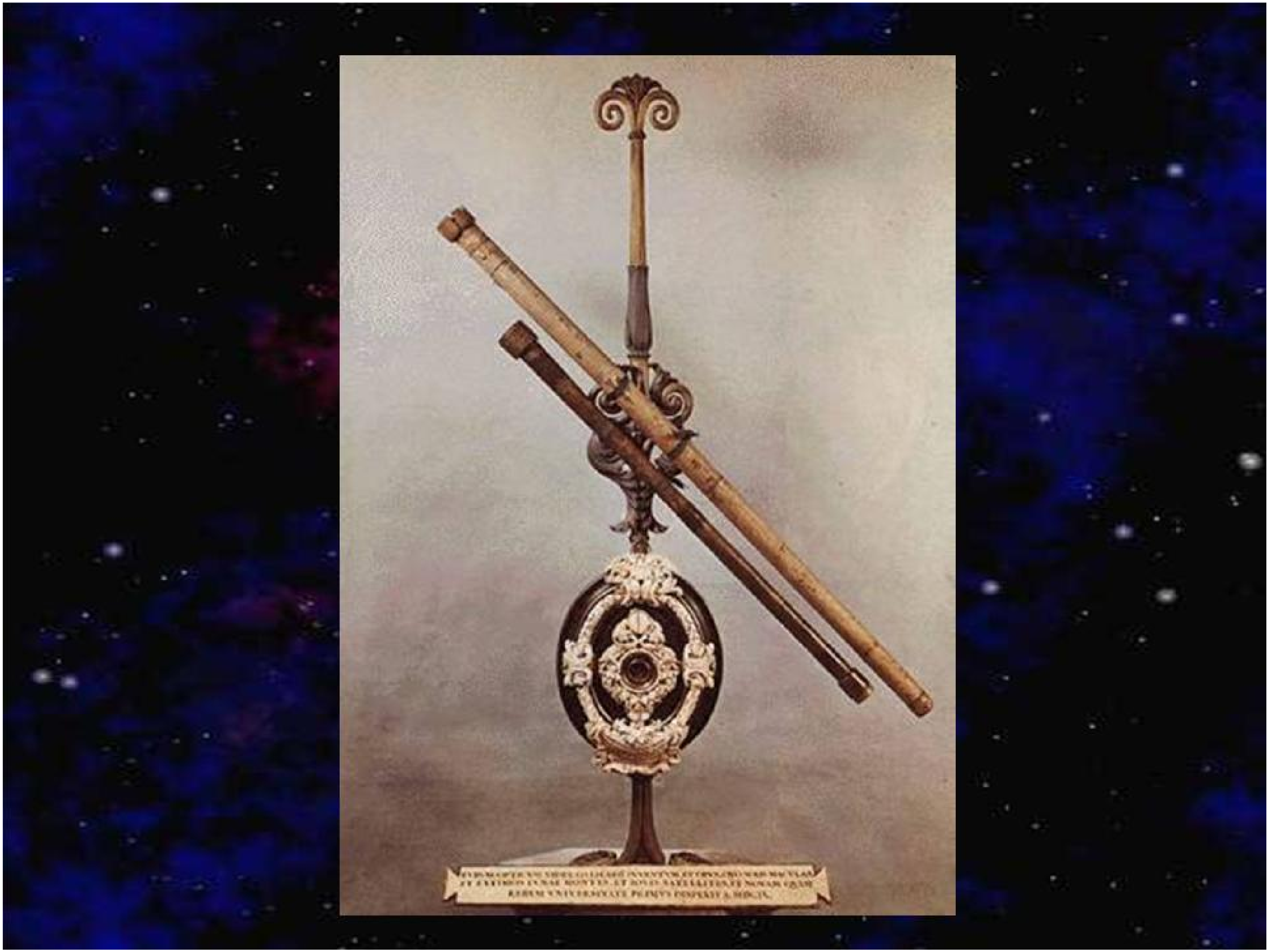
P^2 = 140.6

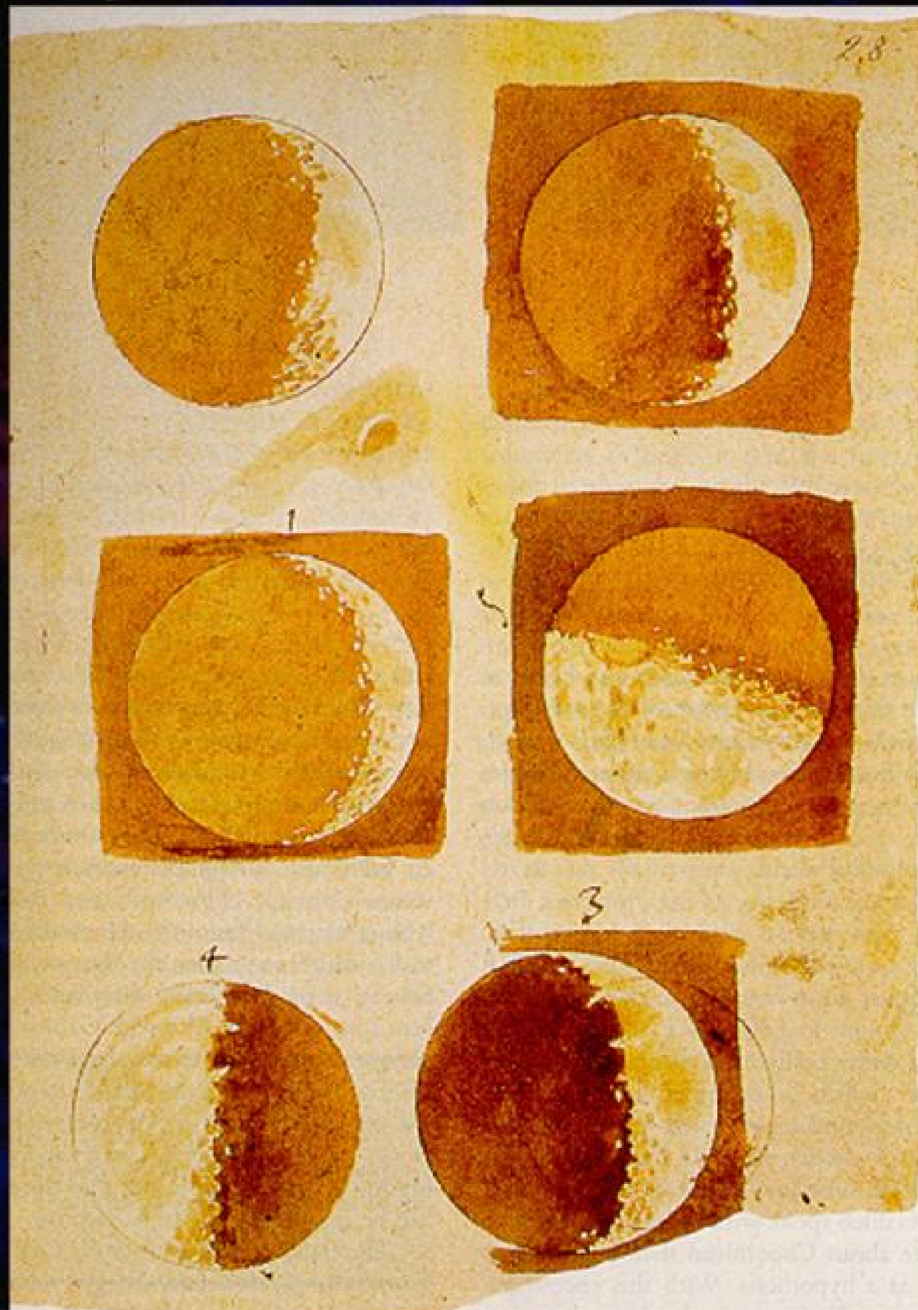
d = 5.2 A.U.

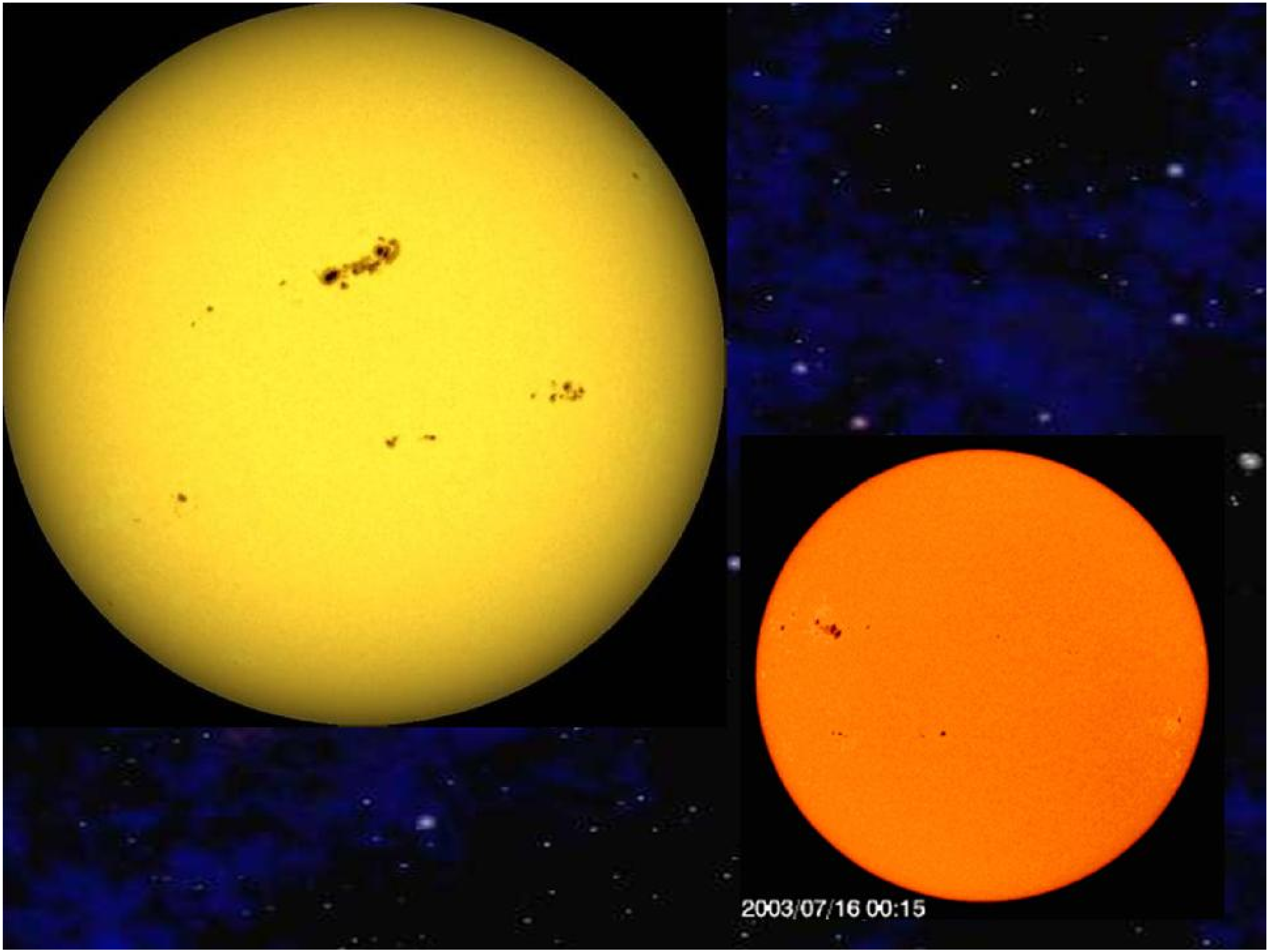
d^3 = 140.6

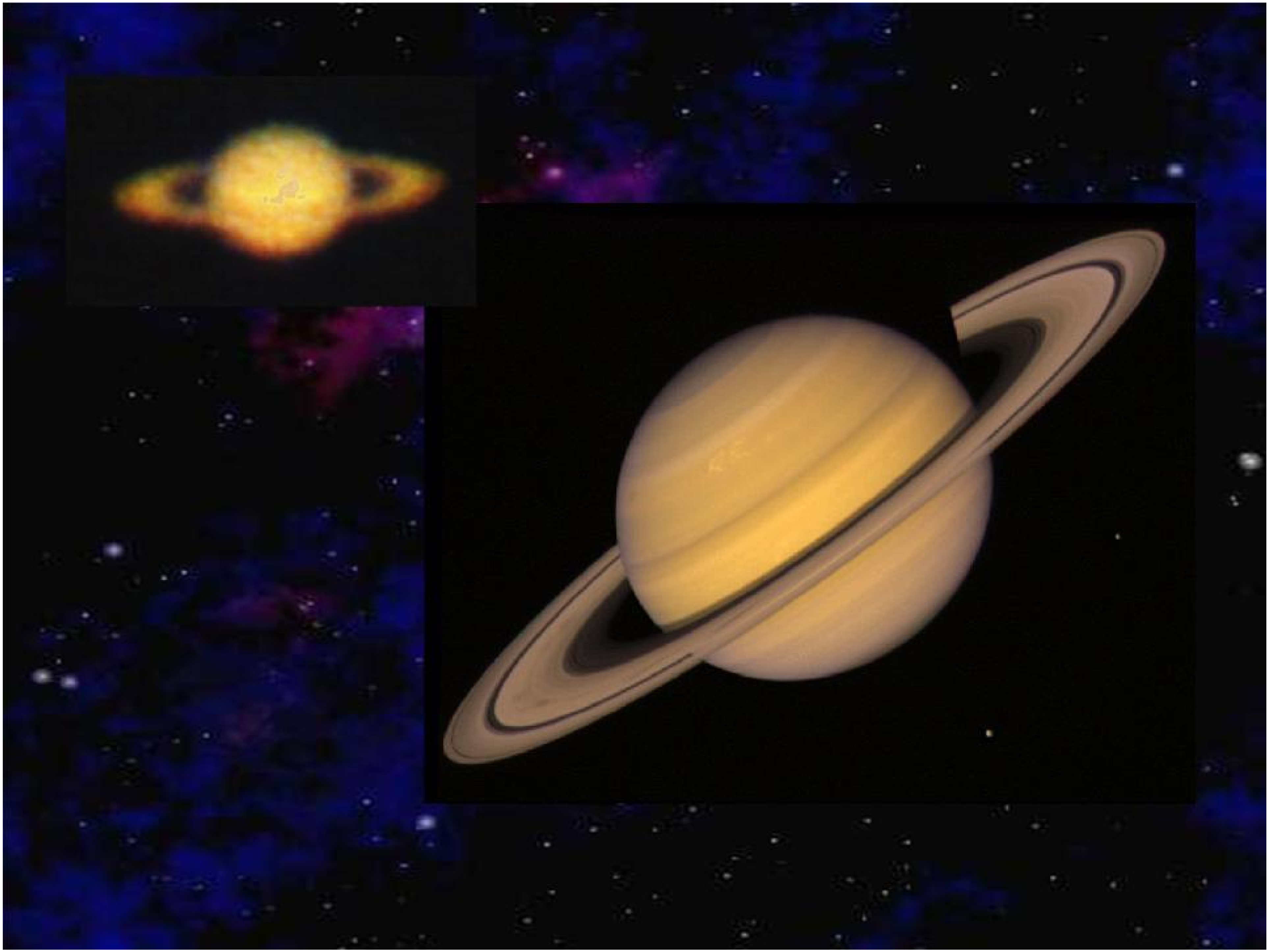
Galileo Galilei (1564 – 1642)

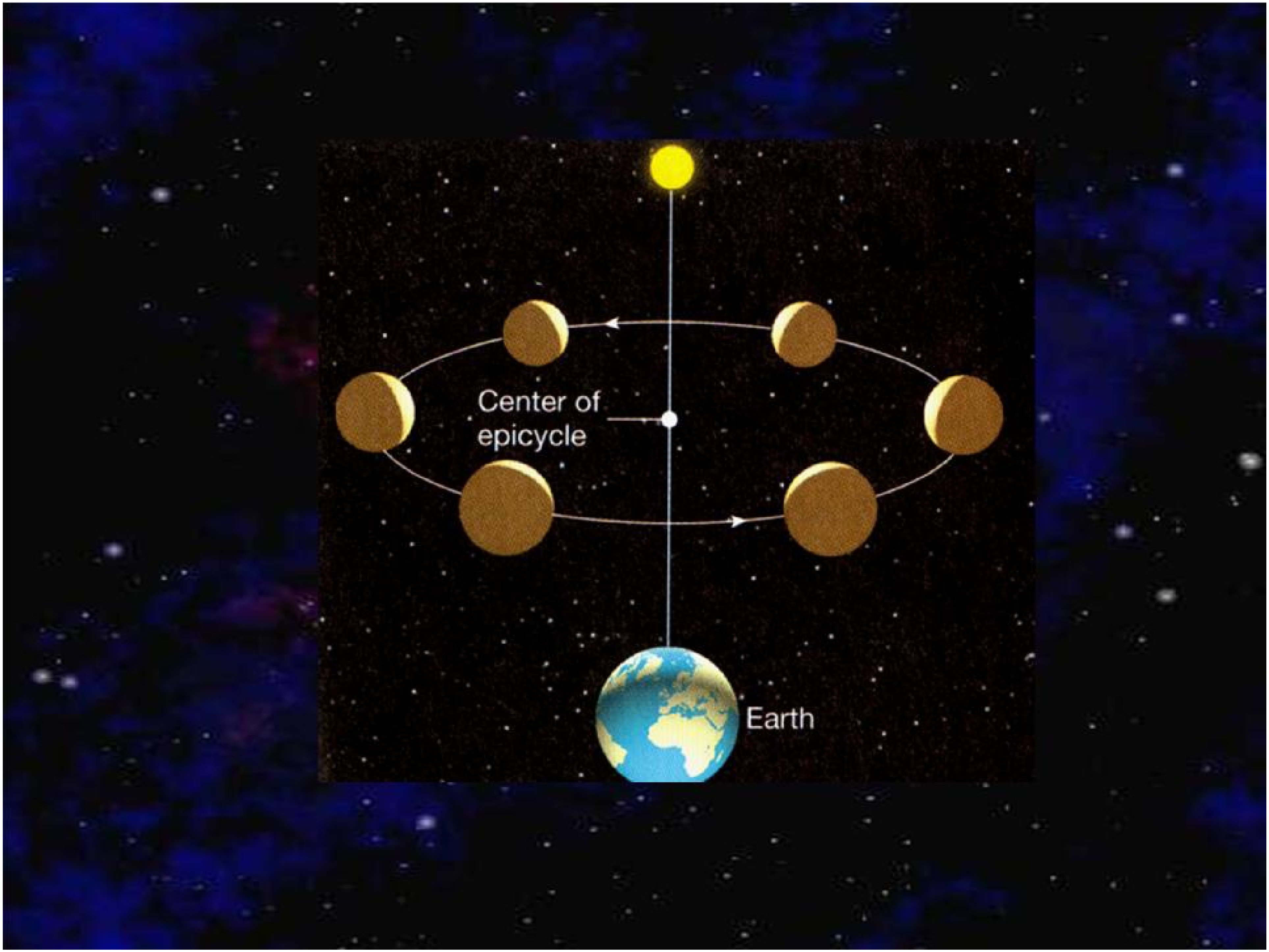


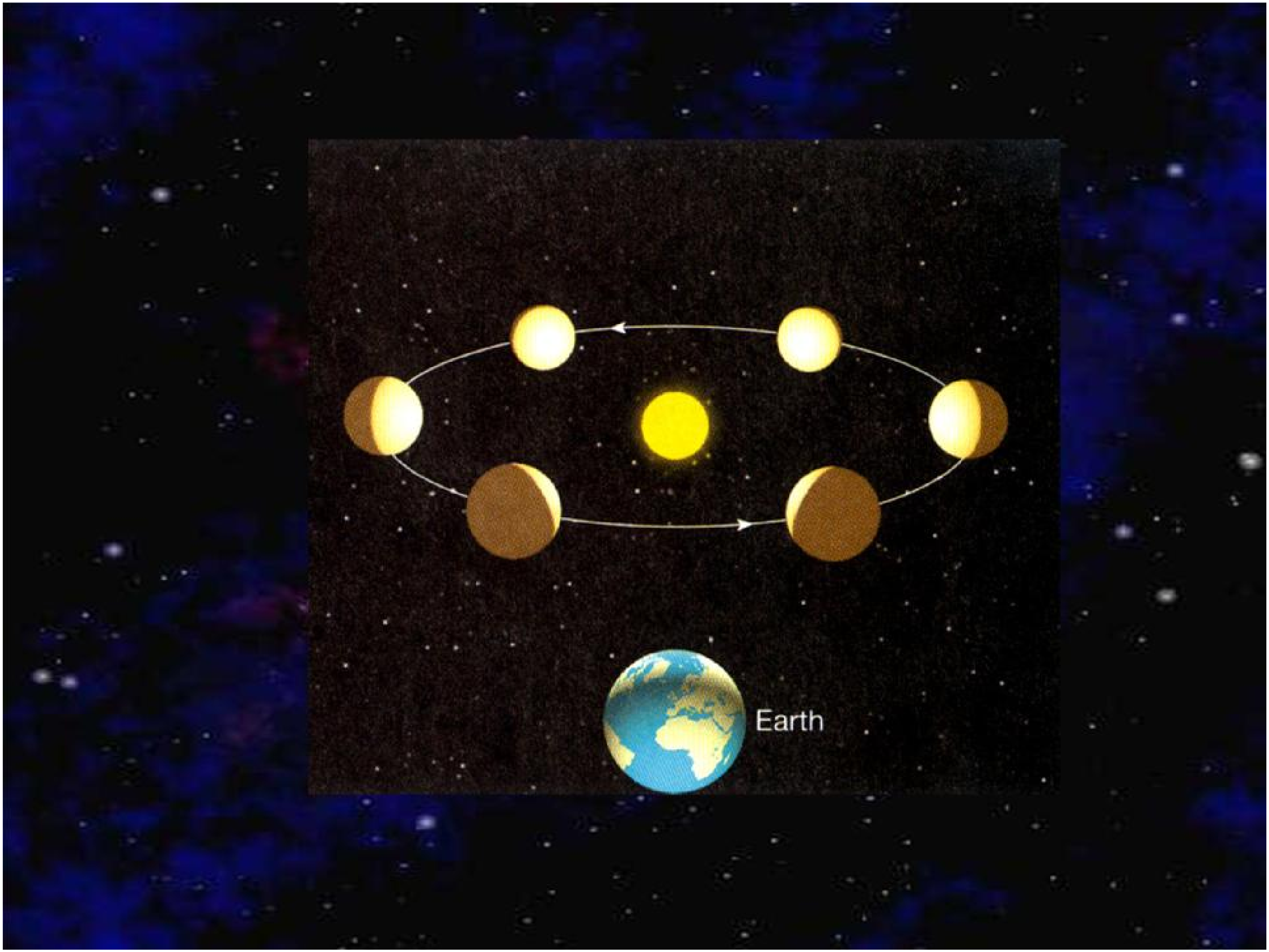


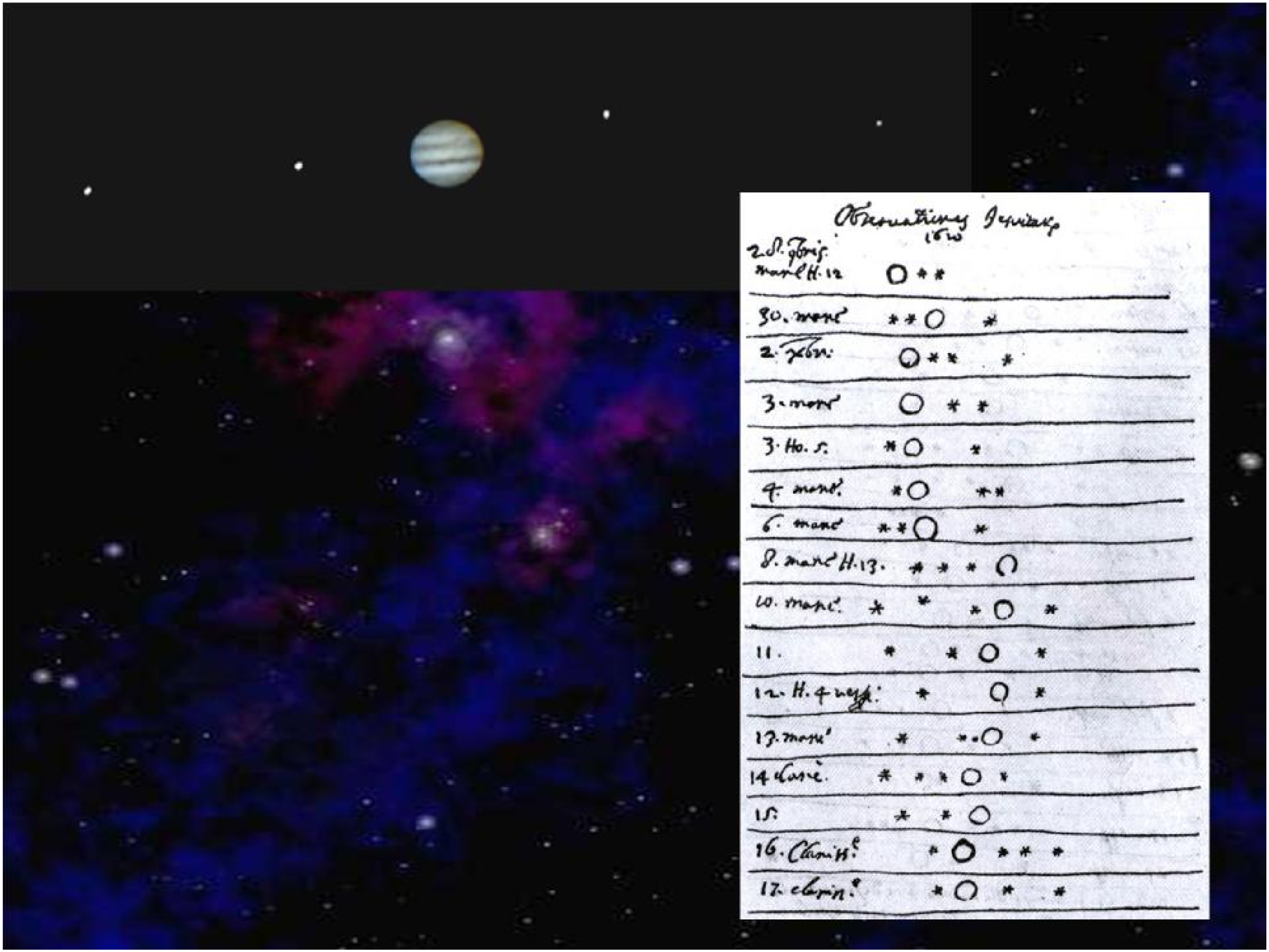



2003/07/16 00:15




Center of
epicycle
Earth


Earth



THE HISTORY OF ASTRONOMY

"It is therefore impossible that reason not previously instructed should imagine anything other than that the Earth is a kind of vast house with the vault of the sky placed on top of it; it is motionless and within it the Sun being so small passes from one region to another, like a bird wandering through the air."

-Johannes Kepler

"Our ancestors were eager to understand the world but had not quite stumbled upon the method."

- Carl Sagan

Isaac Newton (1642 – 1727)

The miracle years: 1665-1666

The Principia: 1686

$$\frac{dz}{dt} = \frac{\partial z}{\partial x}\,\frac{dx}{dt} + \frac{\partial z}{\partial y}\,\frac{dy}{dt}.$$

$$\frac{dy}{dx} = \frac{dy}{du}\cdot\frac{du}{dx}.$$

$$f_1(u_1, \ldots, u_p)$$

$$\int_a^b f(x)\,dx = F(b) - F(a).$$

$$\int_\gamma f(z)\,dz = F(z(\beta)) - F(z(\alpha)).$$

Newton’s First Law

A body at rest remains at rest unless acted upon by an outside force…

Newton's First Law cont'd

… a body in motion remains in motion moving in a straight line at constant speed unless acted upon by an outside force.

Inertia:

An object’s natural tendency to resist changes in motion.

Mass:

A measure of the amount of material that makes up an object.

Weight

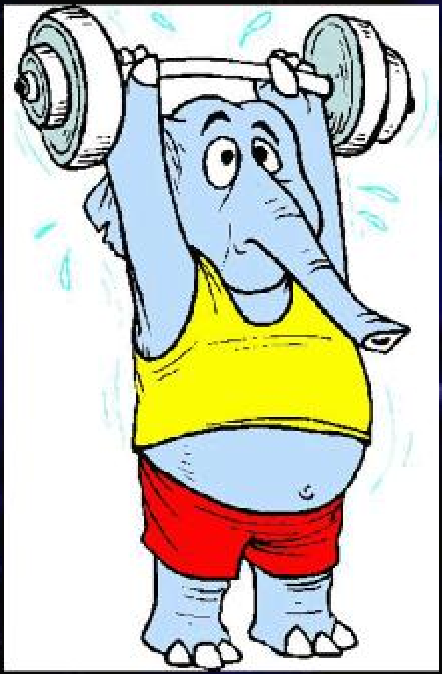
A measure of the gravitational force between two bodies.

$W = mg$

W: weight

m: mass

g: gravitational acceleration



Mass

A measure of the amount of an object's inertia

Speed:

The rate at which something moves.

$$\frac{miles}{hour}$$

$$S = \frac{D}{T}$$

Velocity

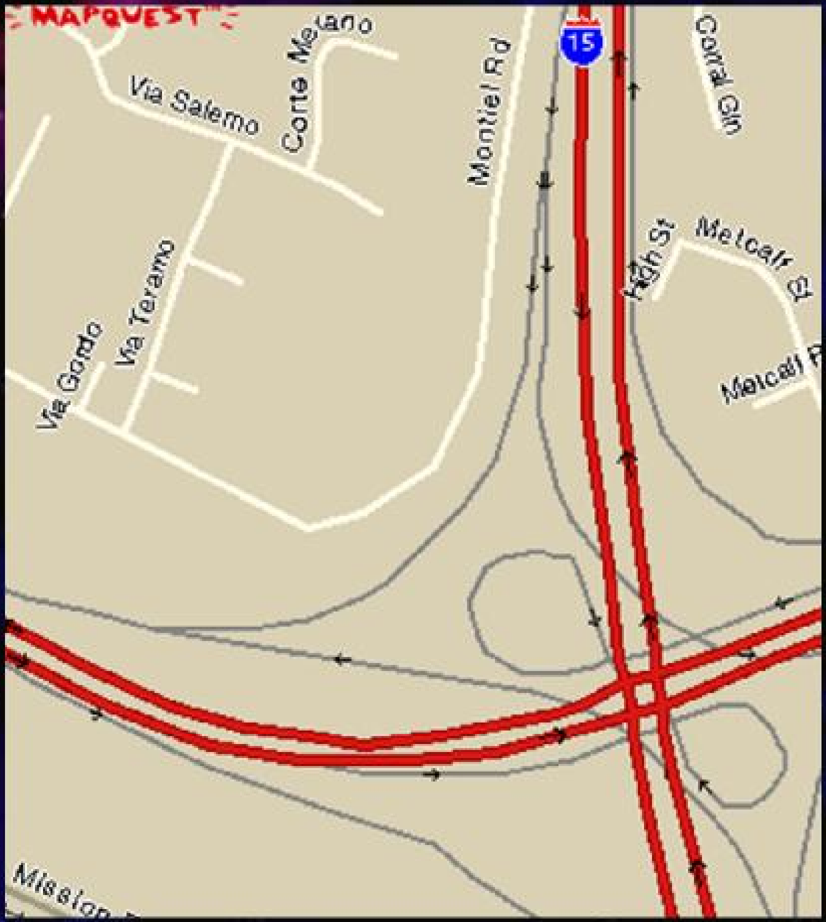
Speed + Direction

$$\frac{miles}{hour}\,Northbound$$

Acceleration:

$$\frac{change \quad in \quad velocity}{change \quad in \quad time}$$

Is it possible to change your velocity without changing your speed?



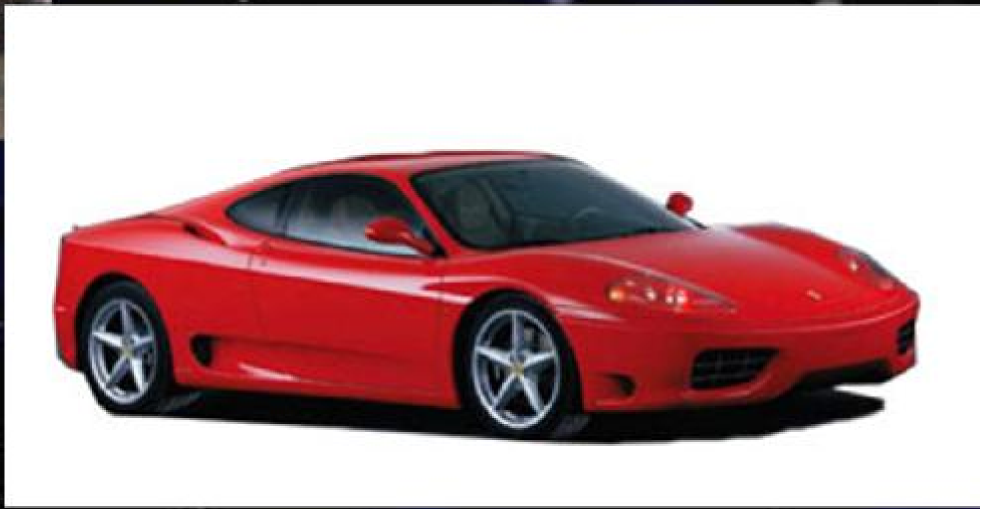
Newton's Second Law

The acceleration of an object is directly proportional to the applied force and inversely proportional to its mass.

$$F = ma$$

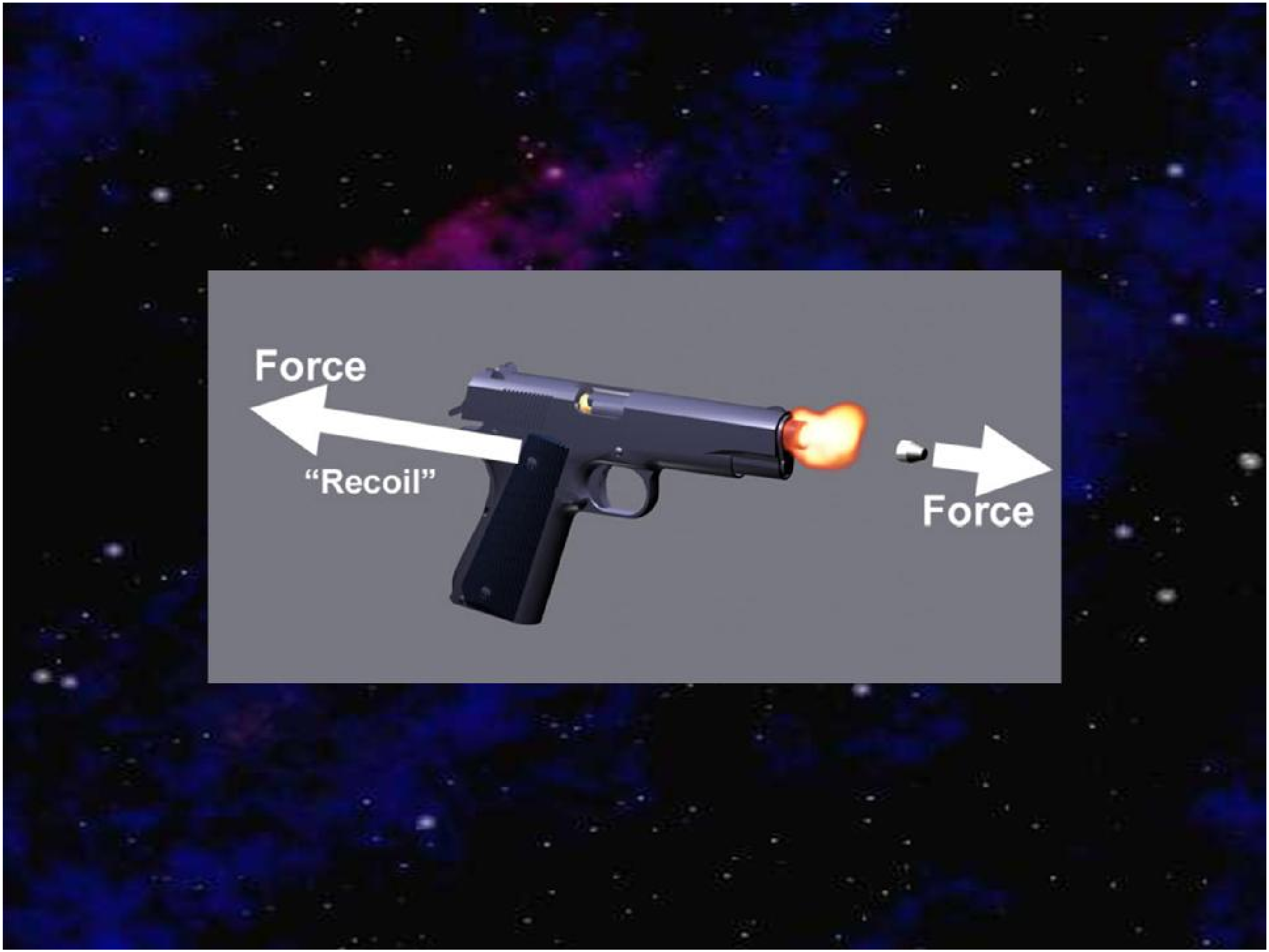
$$F = ma$$

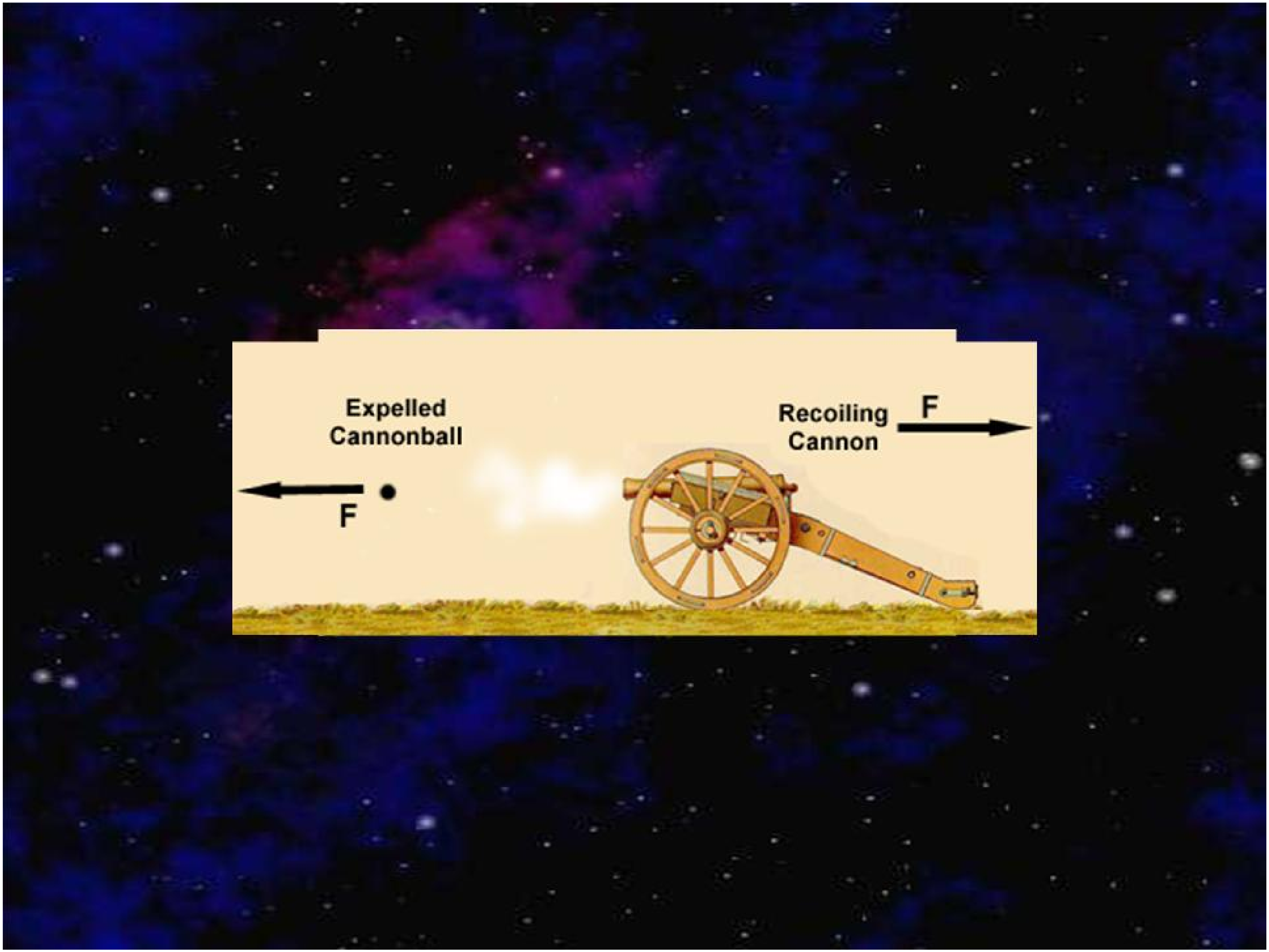
$$a = \frac{F}{m}$$



Newton’s Third Law

For every force there is an ***equal*** but ***opposite*** force.


Force
"Recoil"
Force


Expelled
Cannonball
F
Recoiling
Cannon
F


Upward thrust
Expelled gas

Newton's laws lead to the

<u>*Universal Law of Gravitation*:</u>

$$F = \frac{G m_1 m_2}{r^2}$$

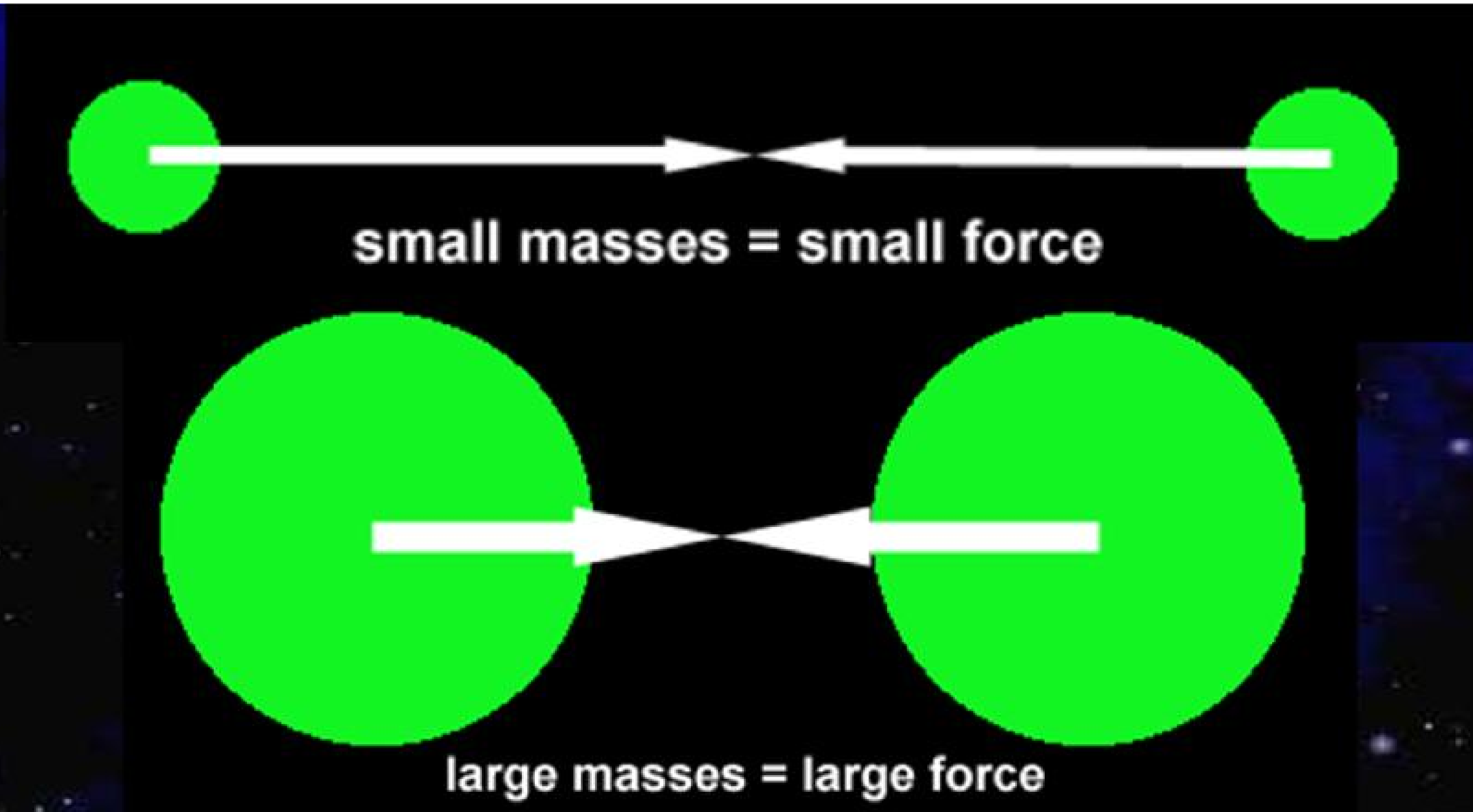
F = force of gravity

G = Universal Gravitational Constant

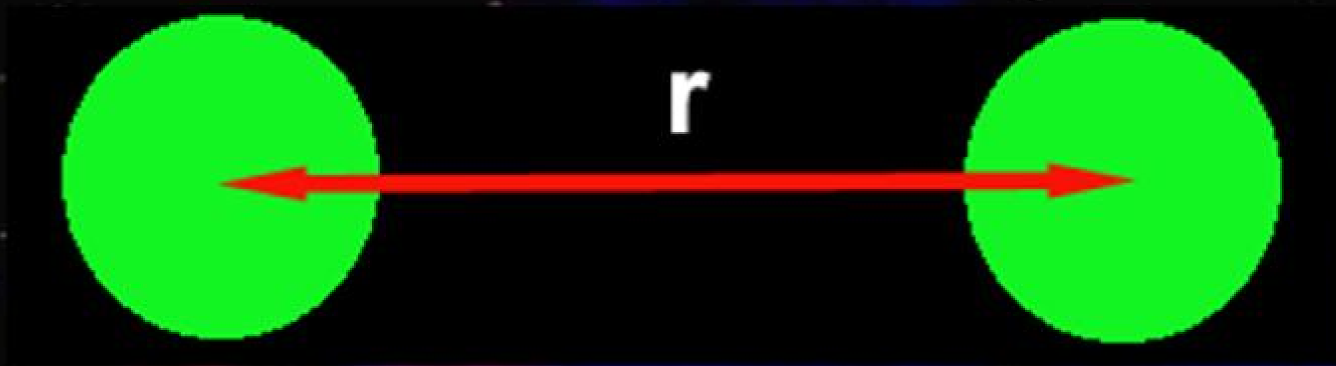
6.67 x 10^{-11} Newton m^2/ kg^2

m_1 , m_2 = masses of the two bodies

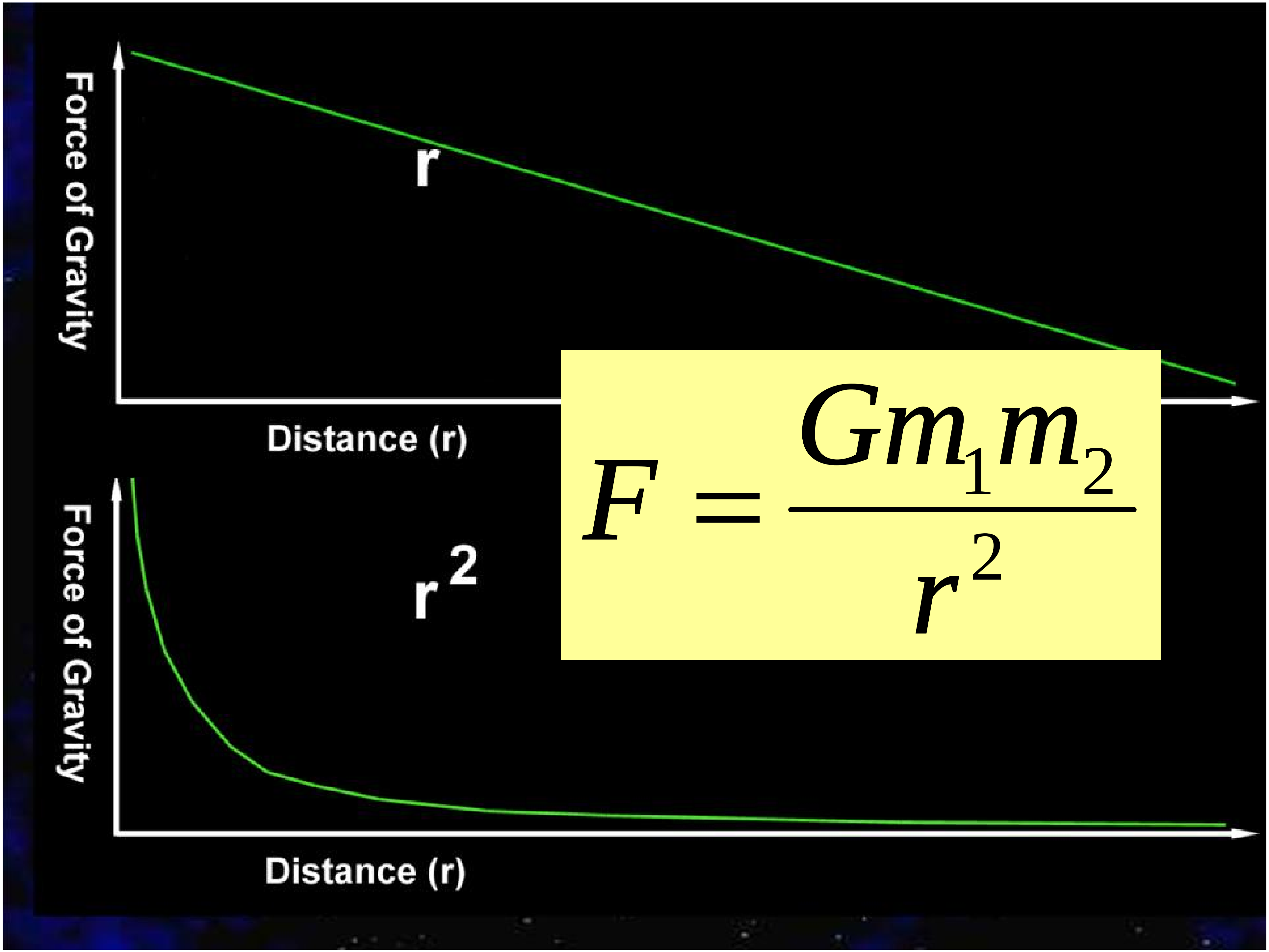
r = distance between the two bodies



$$F = \frac{Gm_1m_2}{r^2}$$

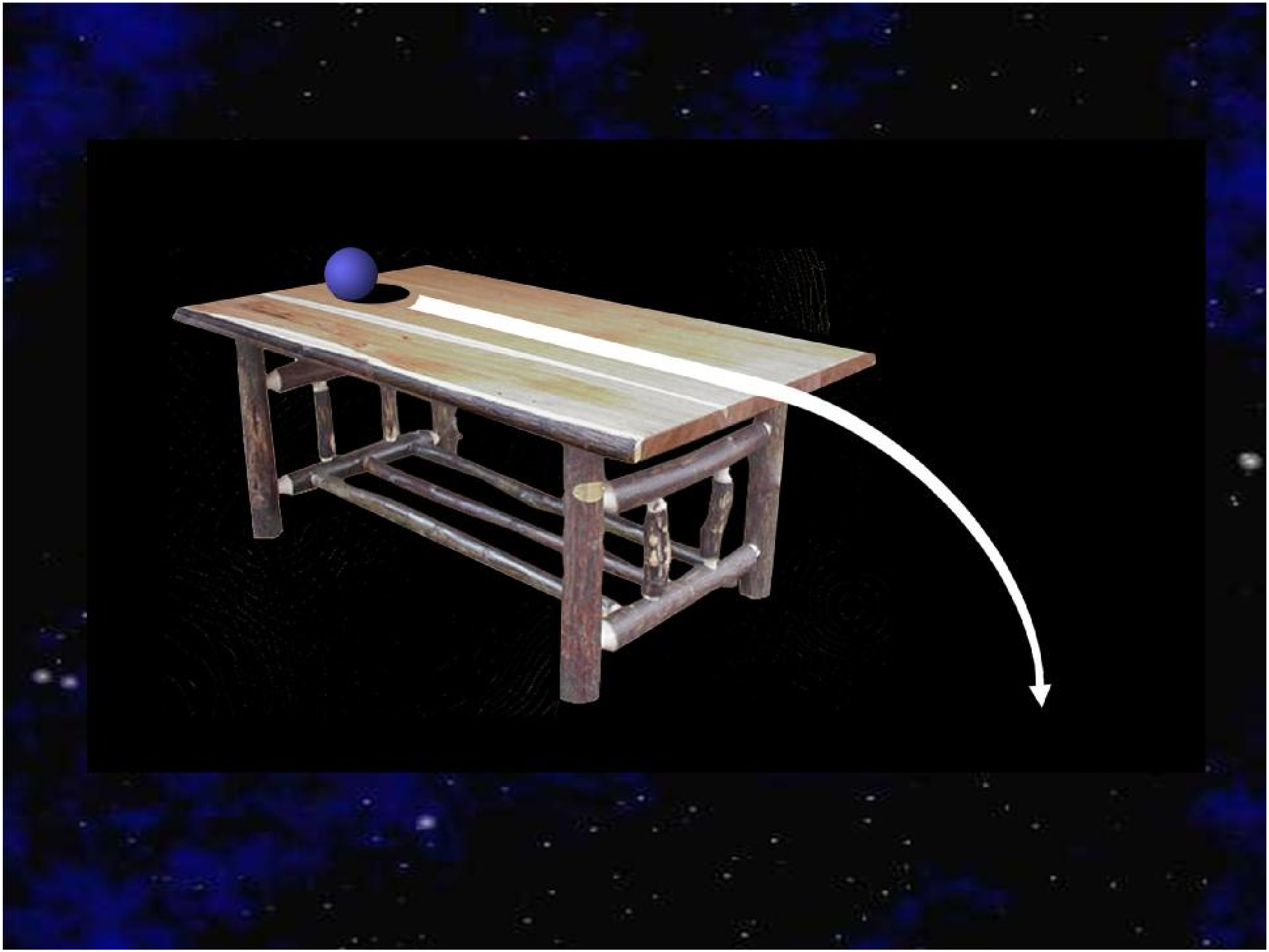


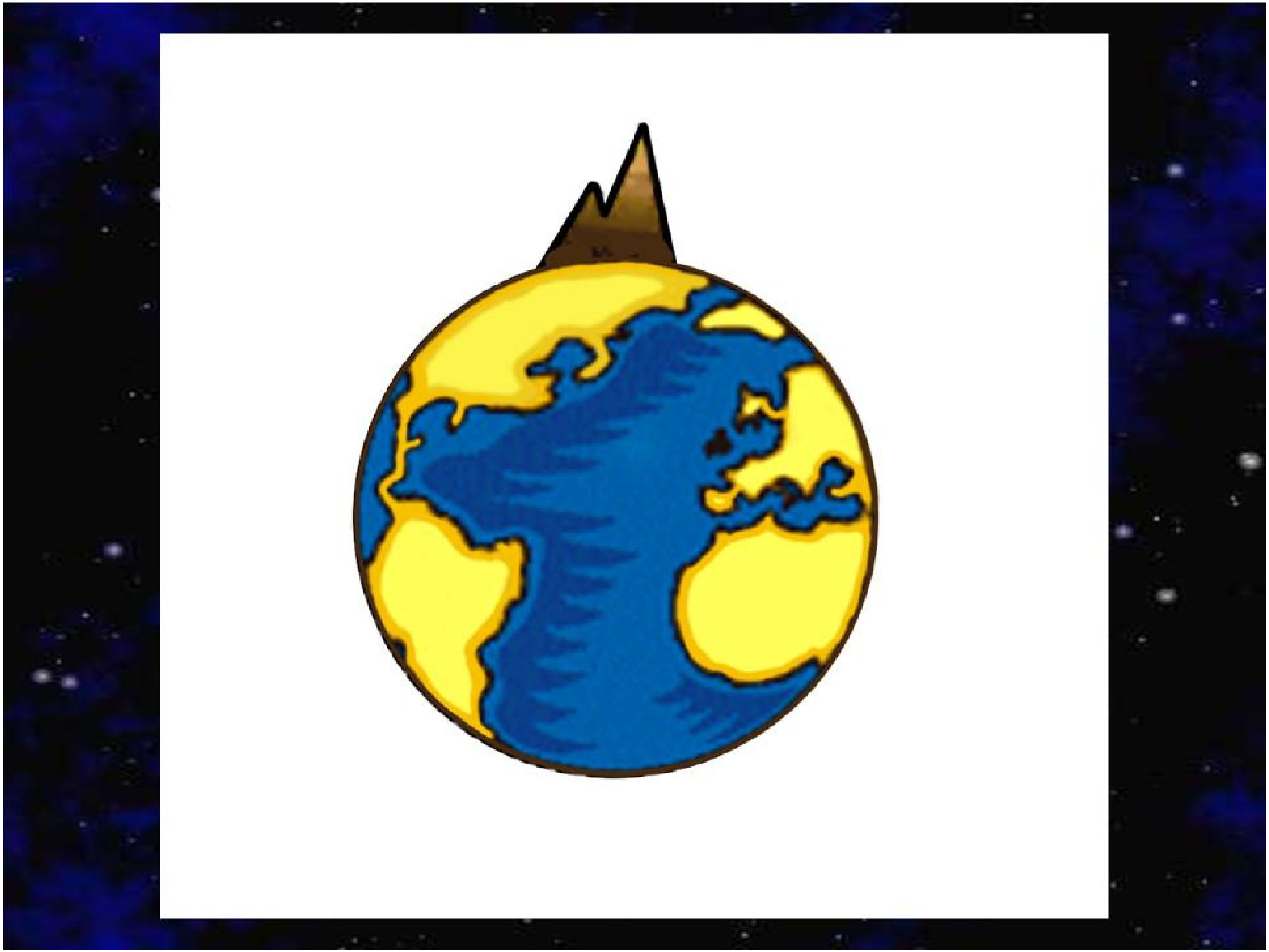
$$F = \frac{Gm_1m_2}{r^2}$$

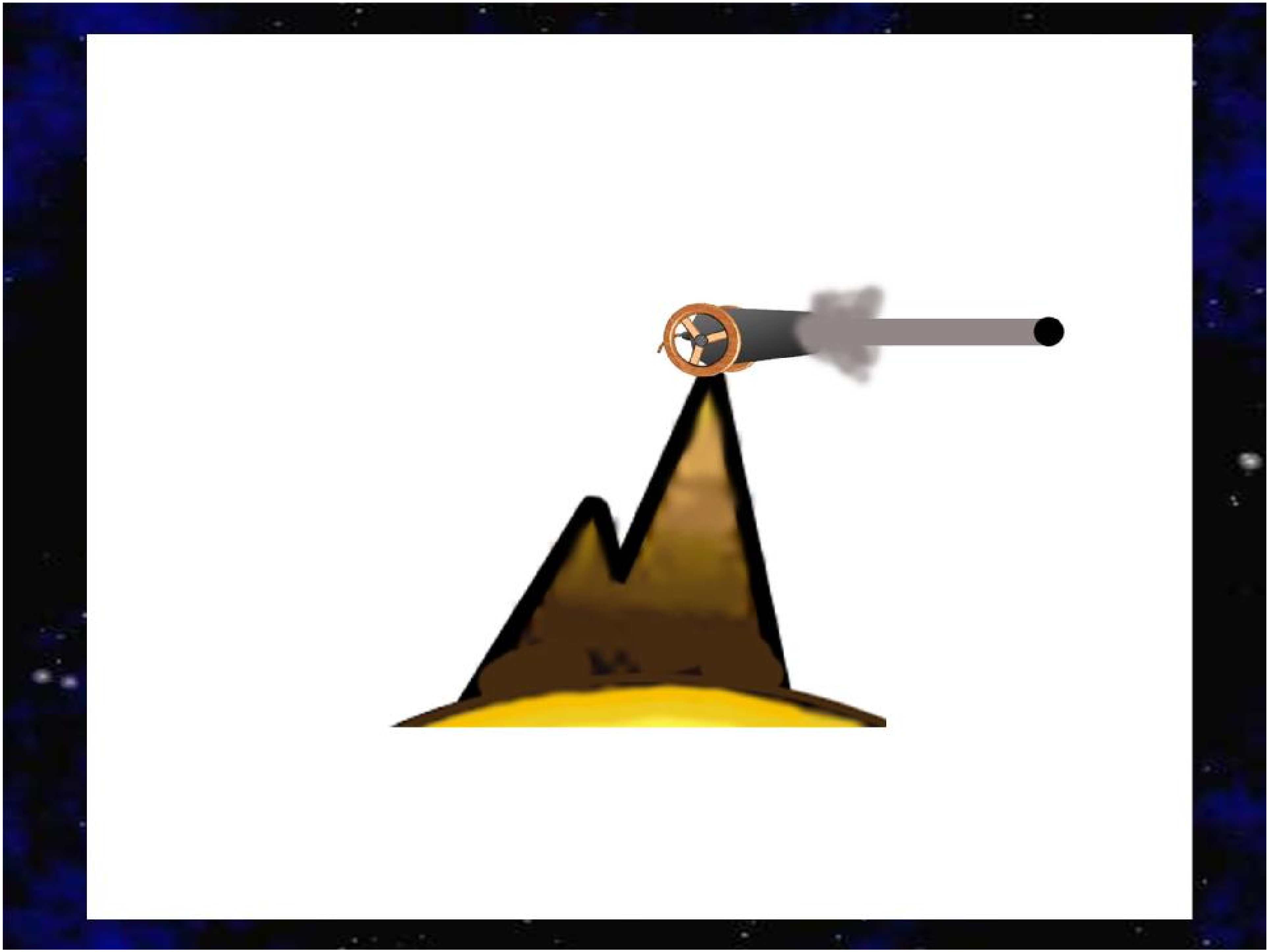


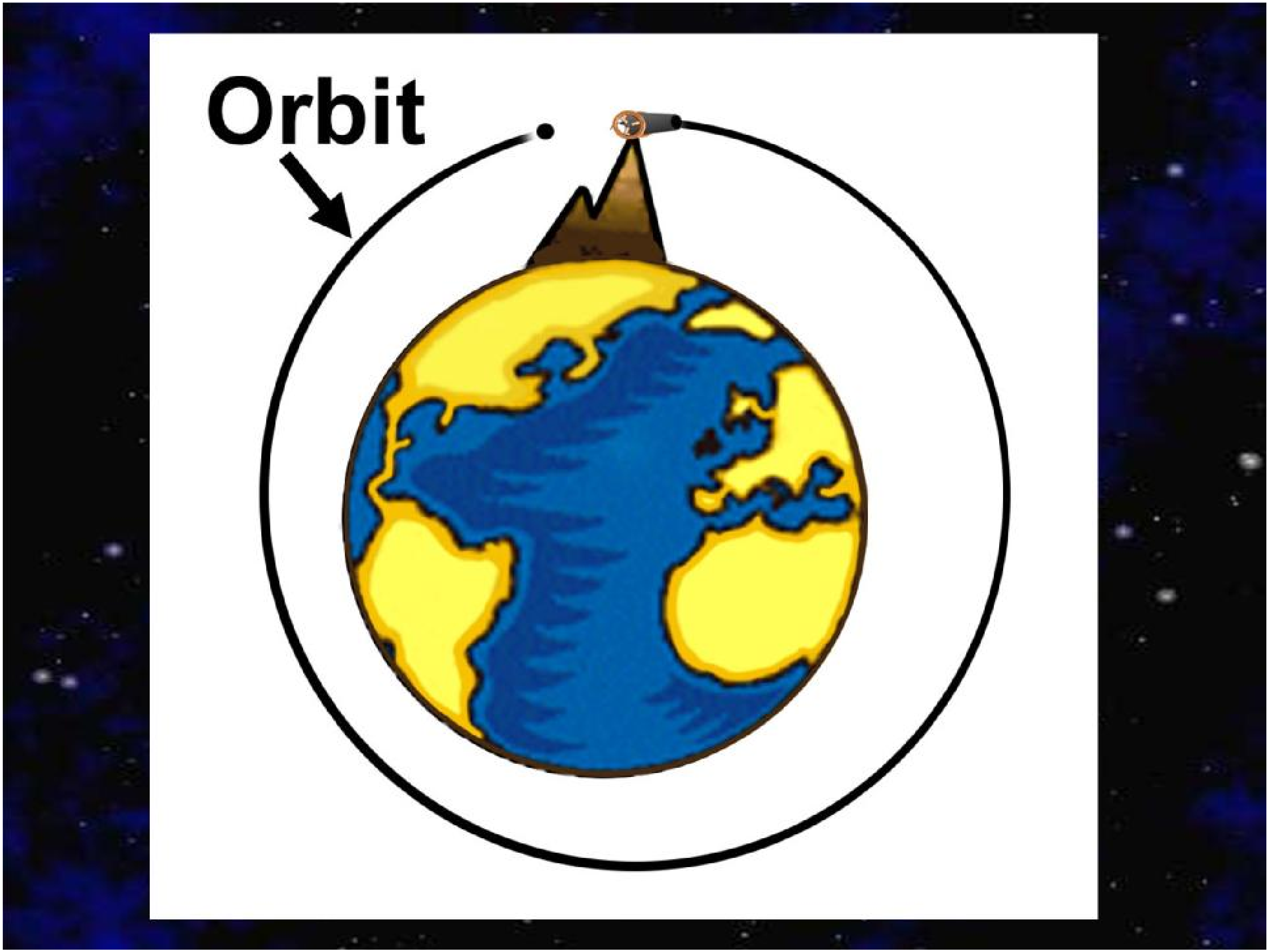
$$F = \frac{Gm_1 m_2}{r^2}$$

Orbiting Bodies








Orbit

Orbital velocity:

Minimum orbital speed:

17,500 miles per hour

5 miles per second

Mach 25!


NASA

Lets return to Kepler’s 3rd Law

Kepler’s 3rd Law:

"The squares of the sidereal periods of the planets are proportional to the cubes of their semi-major axes."

$P^2 = d^3$

- P = Orbital Period measured in Earth years
- d = Orbital distance measured in A.U.'s
- Example: Jupiter

P = 11.86 years

P^2 = 140.6

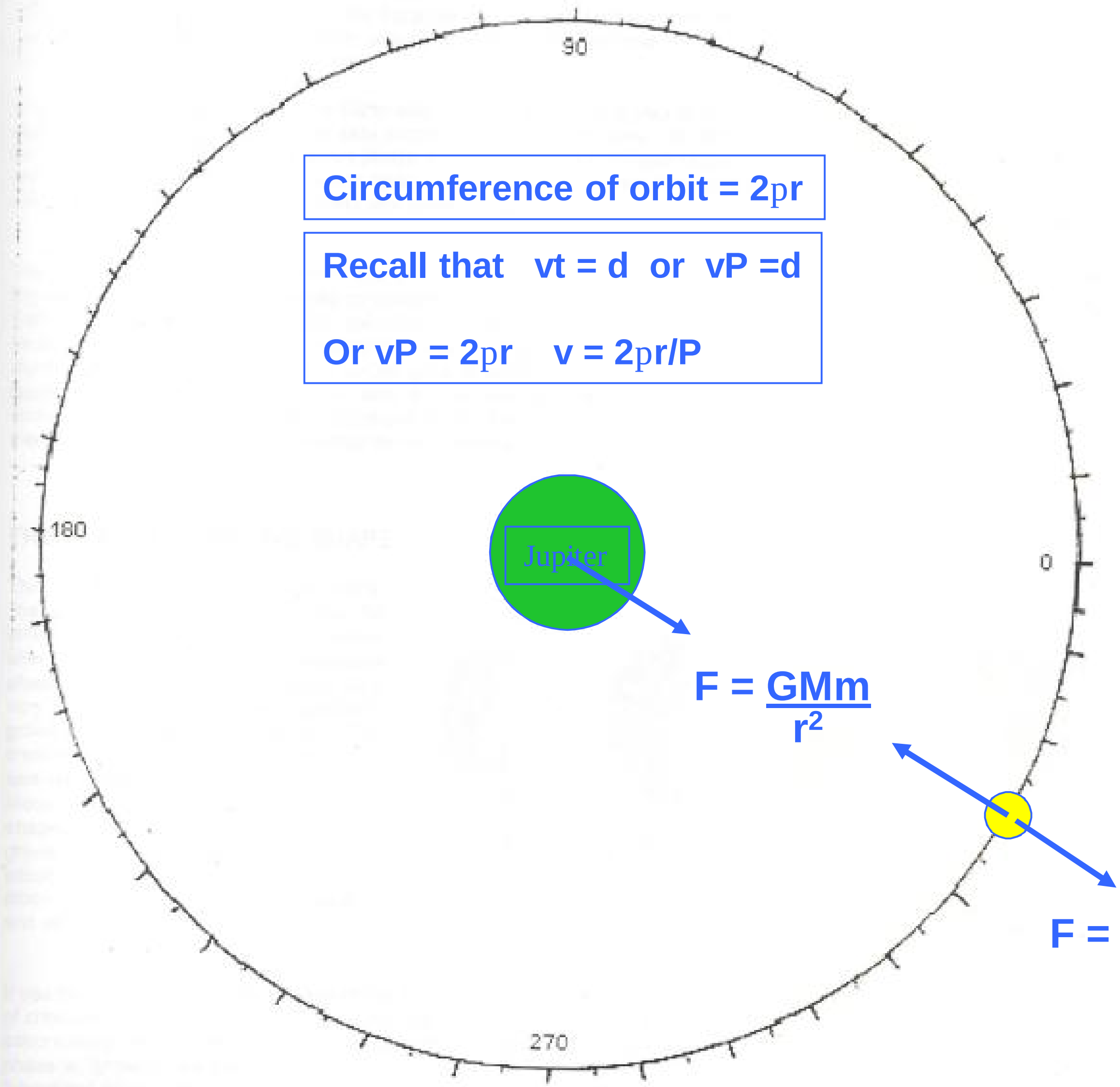
d = 5.2 A.U.

d^3 = 140.6

Circumference of orbit = 2pr

Recall that vt = d or vP = d

Or vP = 2pr v = 2pr/P



$$F = \frac{GMm}{r^2}$$

$$F = \frac{mv^2}{r}$$

So we have….

$$F = \frac{GMm}{r^2} \qquad F = \frac{mv^2}{r} \qquad v = \frac{2\pi r}{P}$$

$$\frac{GMm}{r^2} = \frac{mv^2}{r} \longrightarrow \frac{GMmr}{r^2 m} = v^2 \longrightarrow \frac{GM}{r} = v^2$$

$$\left(v = \frac{2\pi r}{P}\right)^2 \qquad v^2 = \frac{4\pi^2 r^2}{P^2} \longrightarrow \frac{GM}{r} = \frac{4\pi^2 r^2}{P^2} \longrightarrow$$

$$\frac{4\pi^2}{G} \bullet \frac{r^3}{P^2} = M$$

The Nature of Light

What is the *speed* of light?

The Speed of Light

- Accurately measured in a vacuum:

186,282 miles per *<u>second!</u>*

11 million miles per minute

671 million miles per hour

5.9 trillion miles per year

The Speed of Light

- Light's finite speed has important and bizarre consequences.

- It takes time for light to travel a given distance.

Moon:

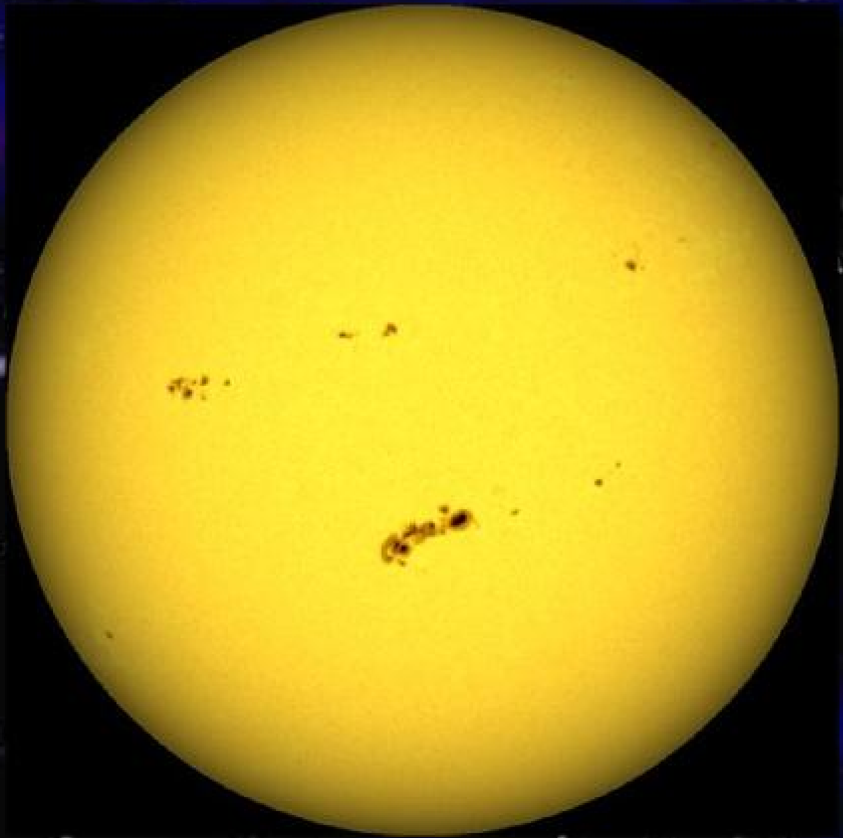
234,000 miles

1.25 seconds

Sun:

93 million miles

8 minutes 19 seconds



Betelgeuse:

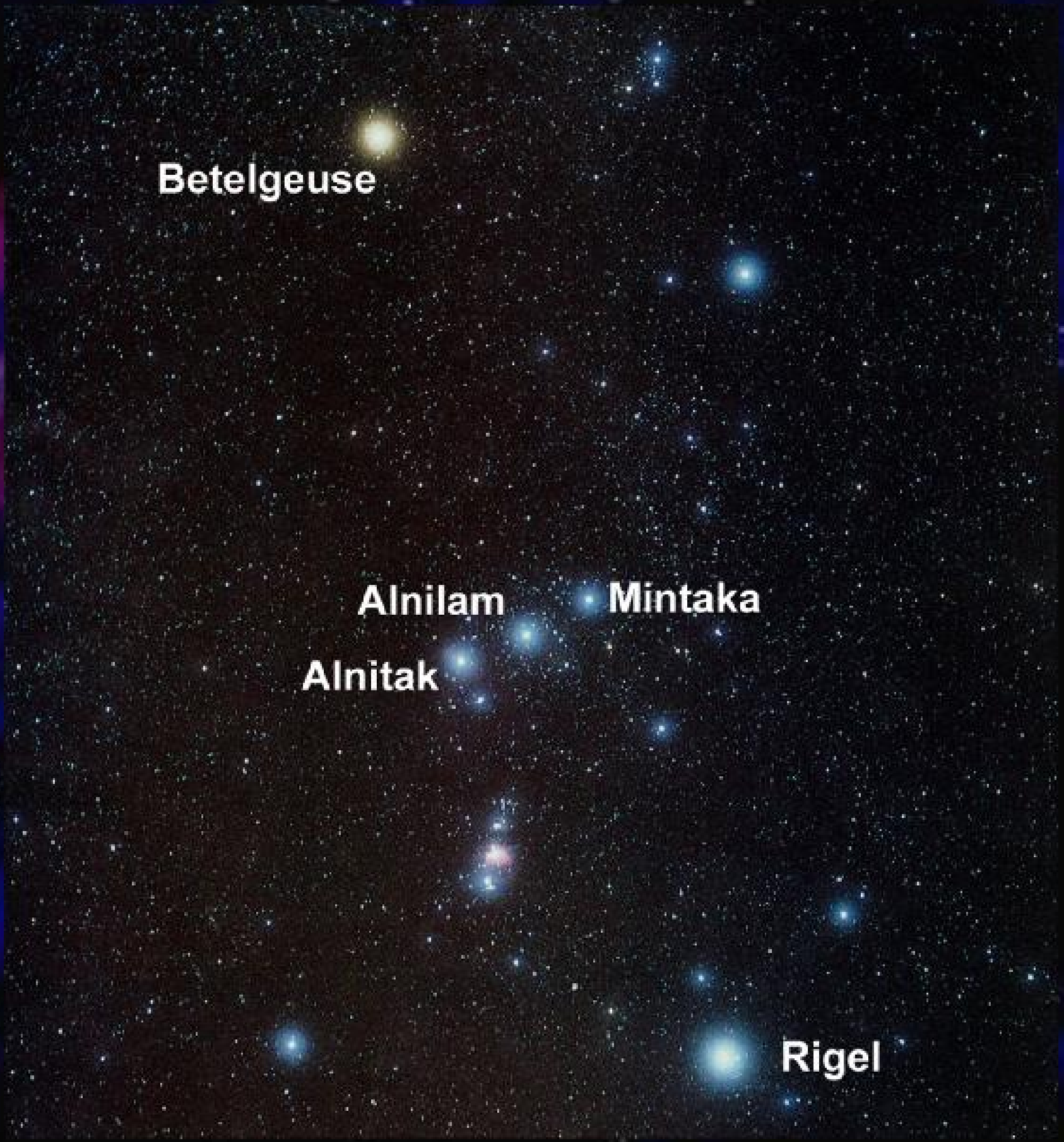
427 years

Rigel:

773 years

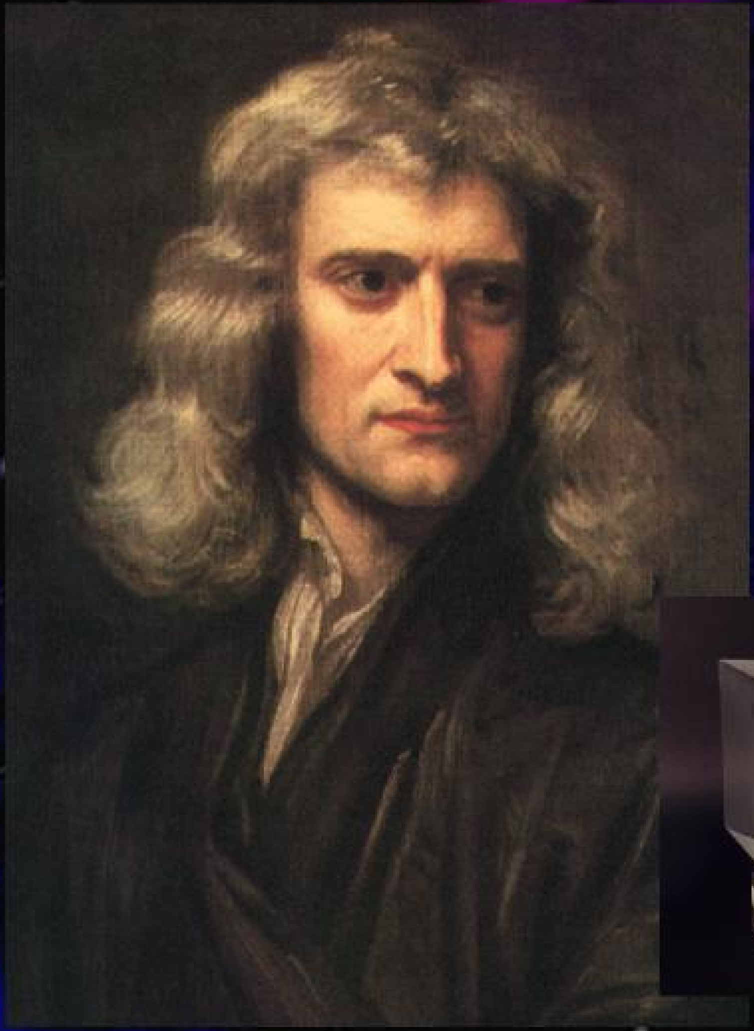
Orion Nebula:

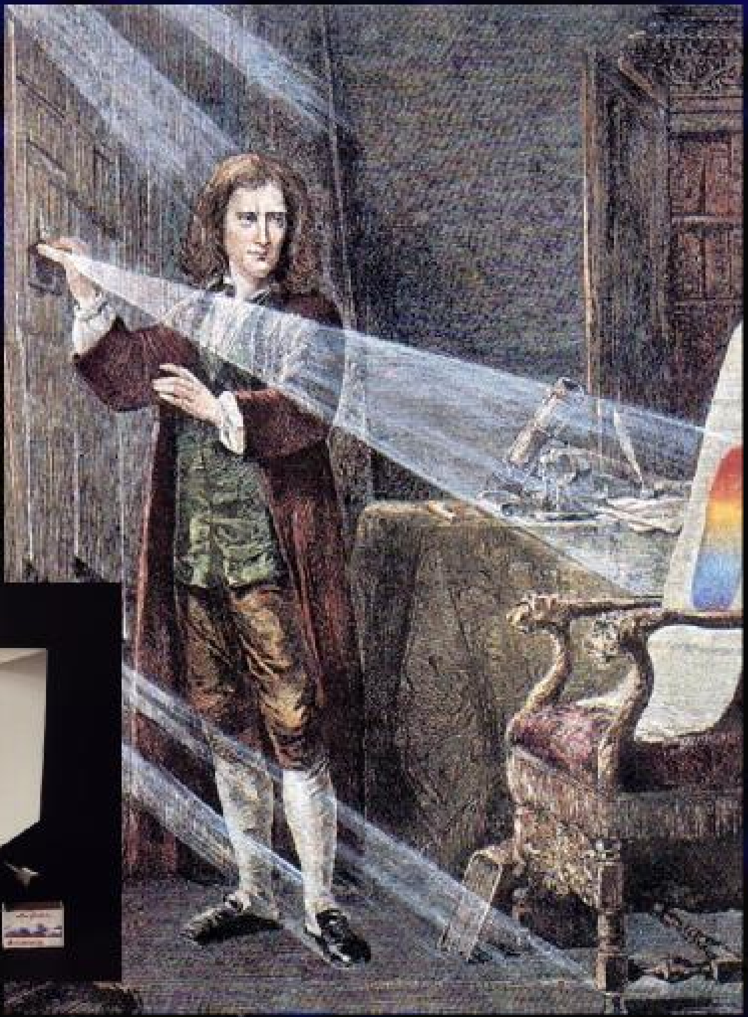
1600 years

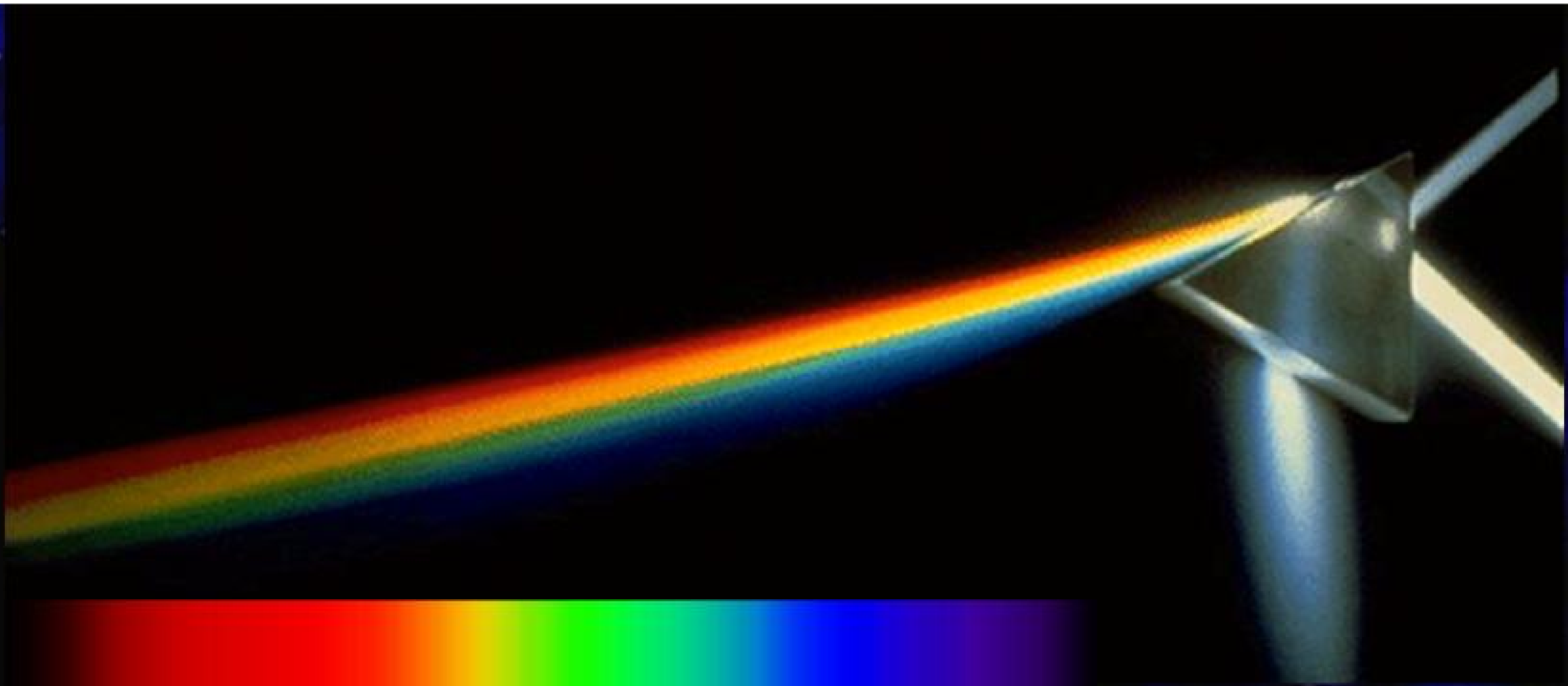


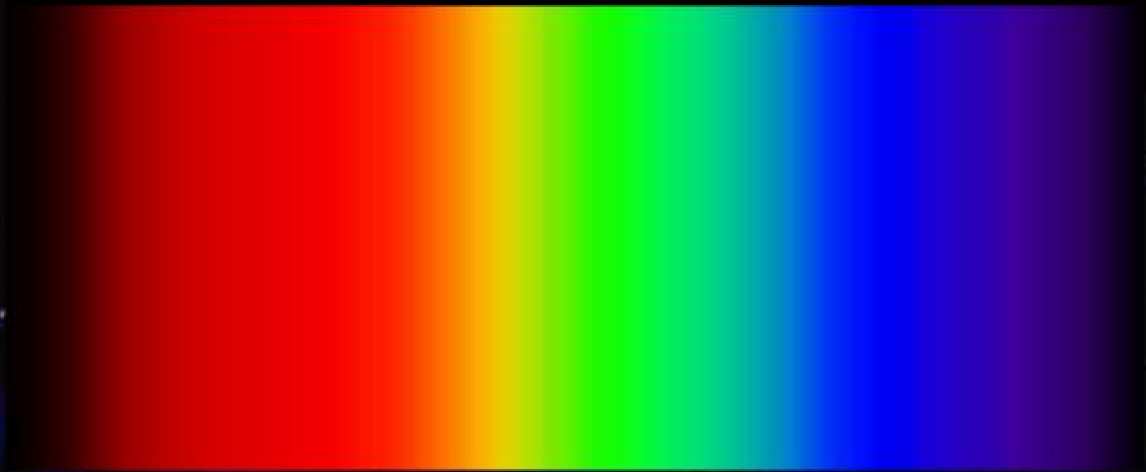
How does light ***travel*** ?

Isaac Newton







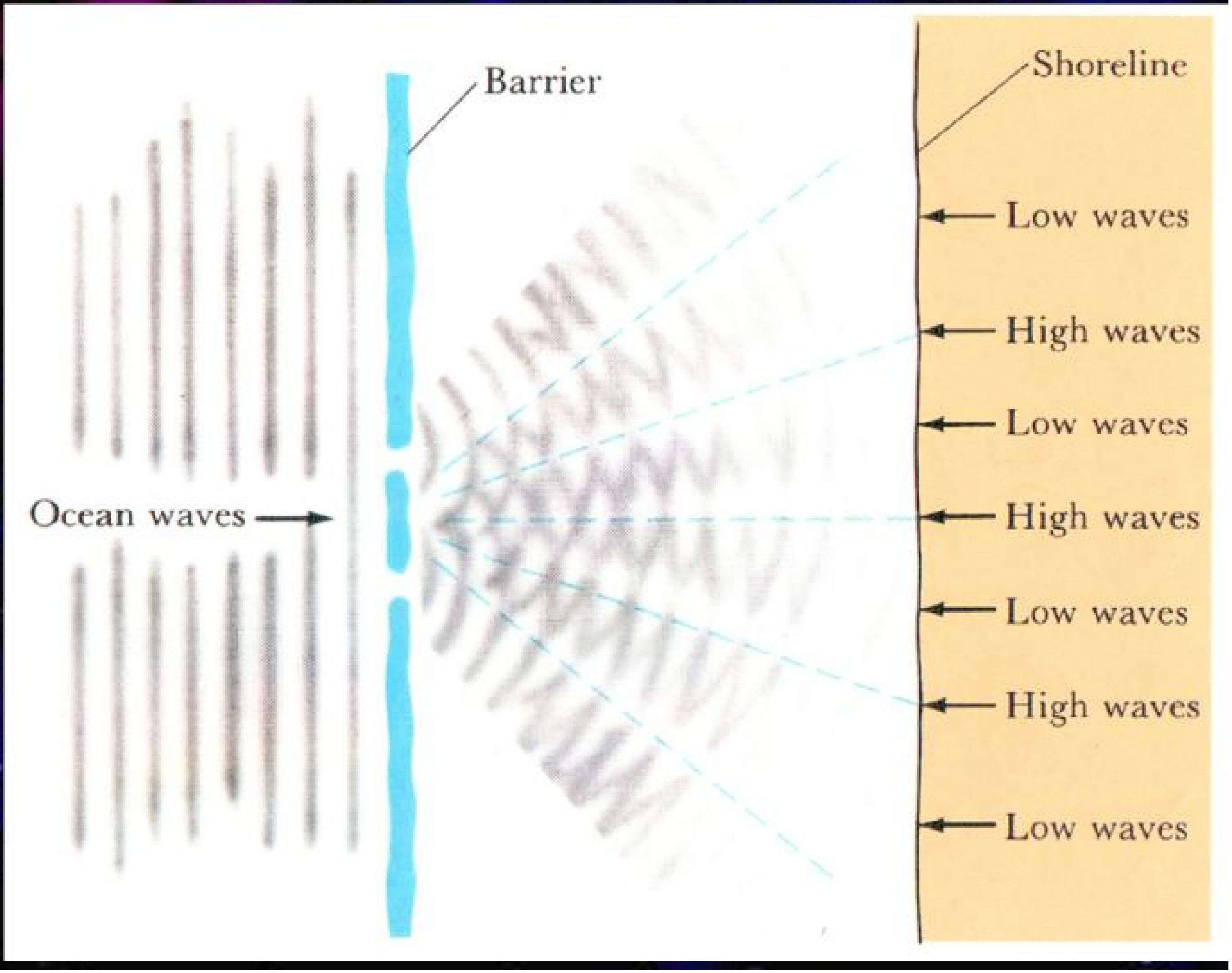


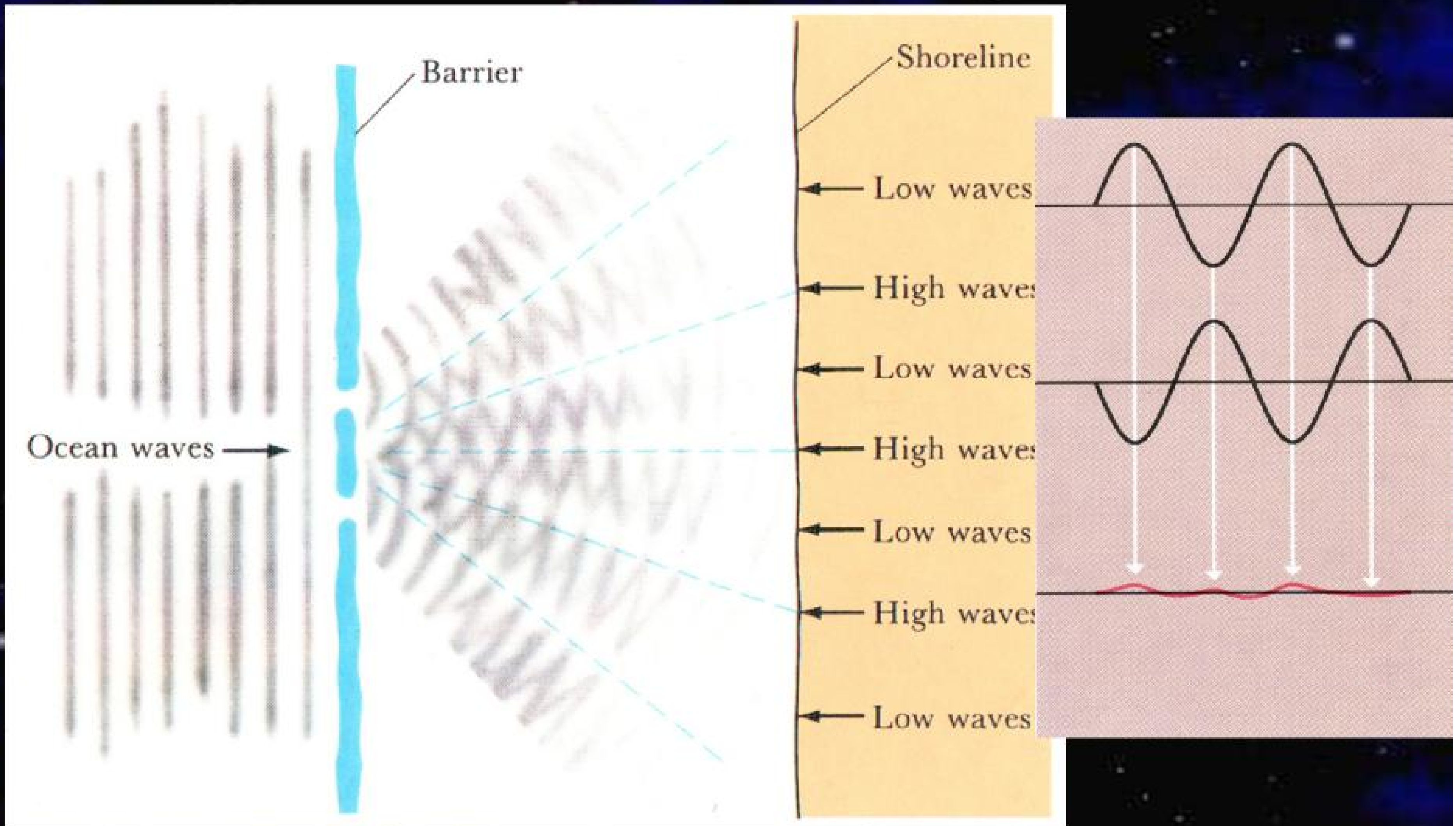
ROY G. BiV

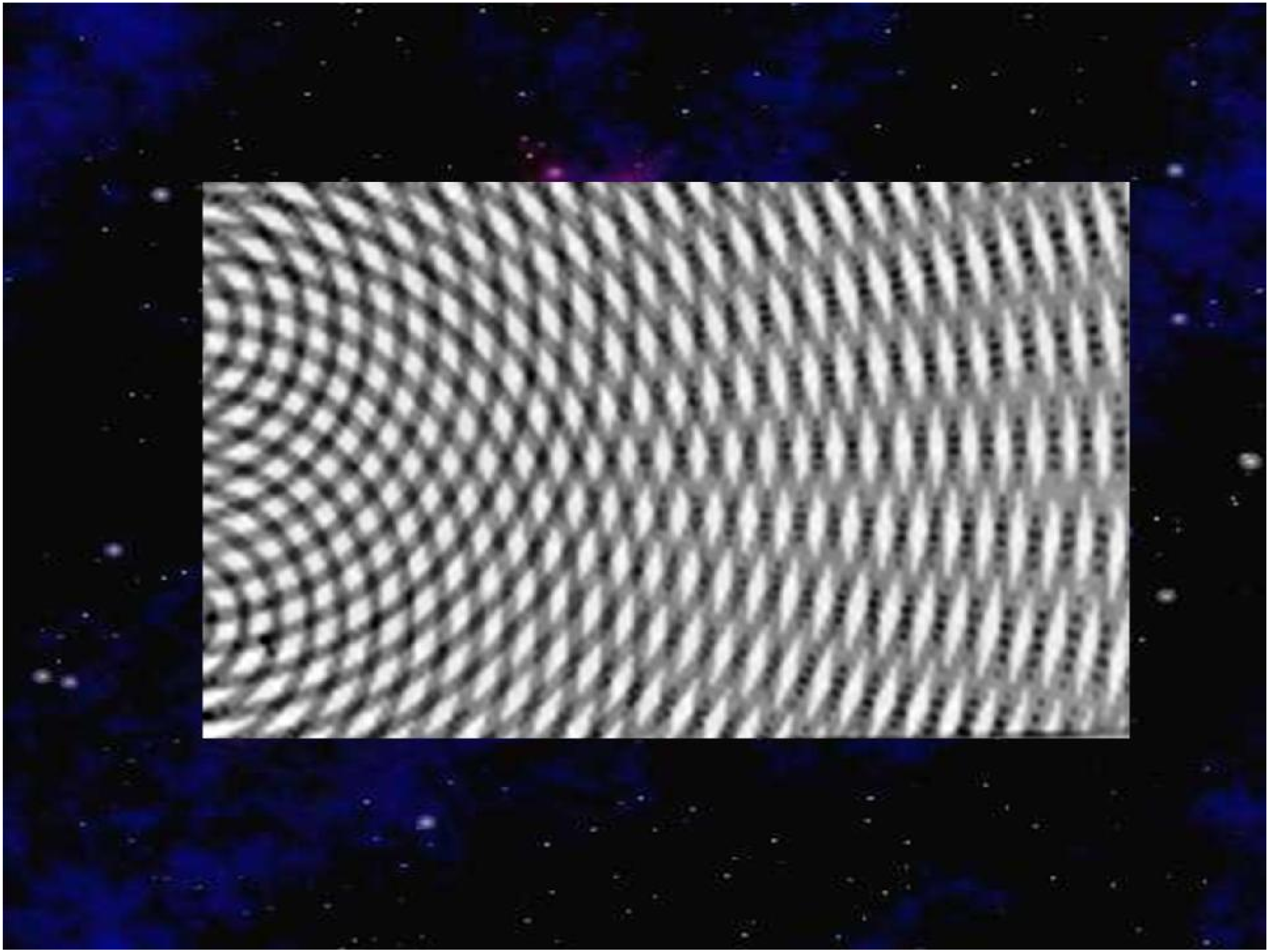
Light must behave as a *packet* of energy...

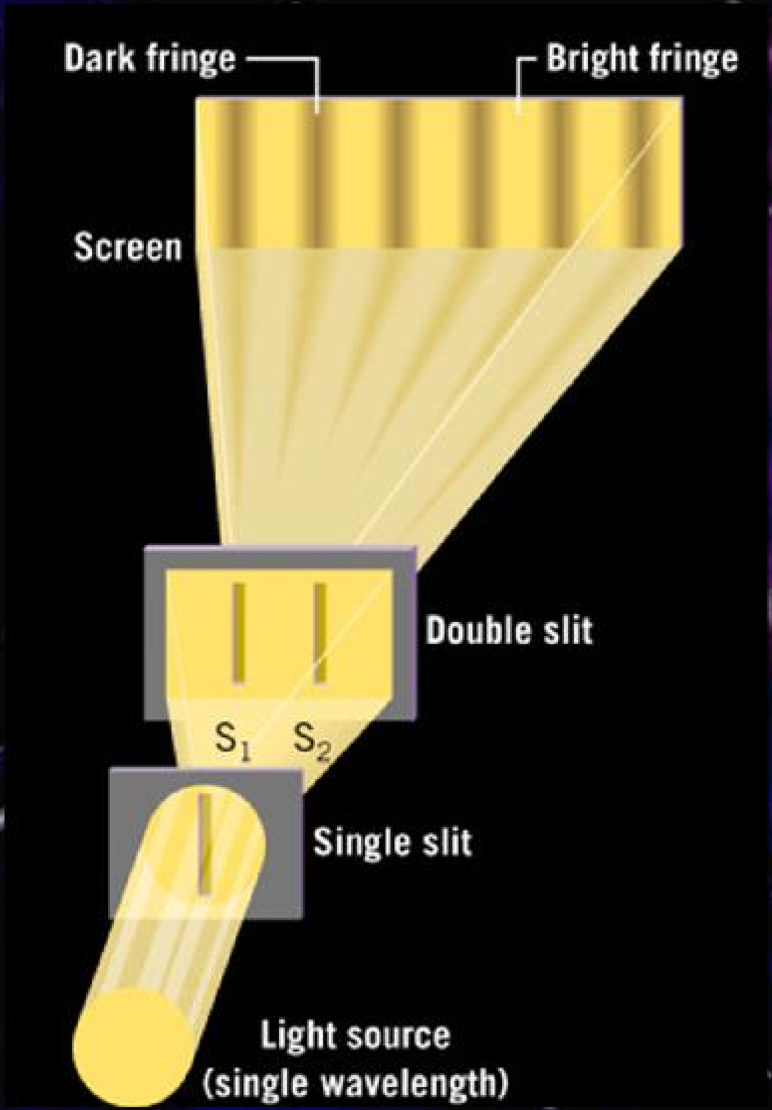
How does light *behave*?

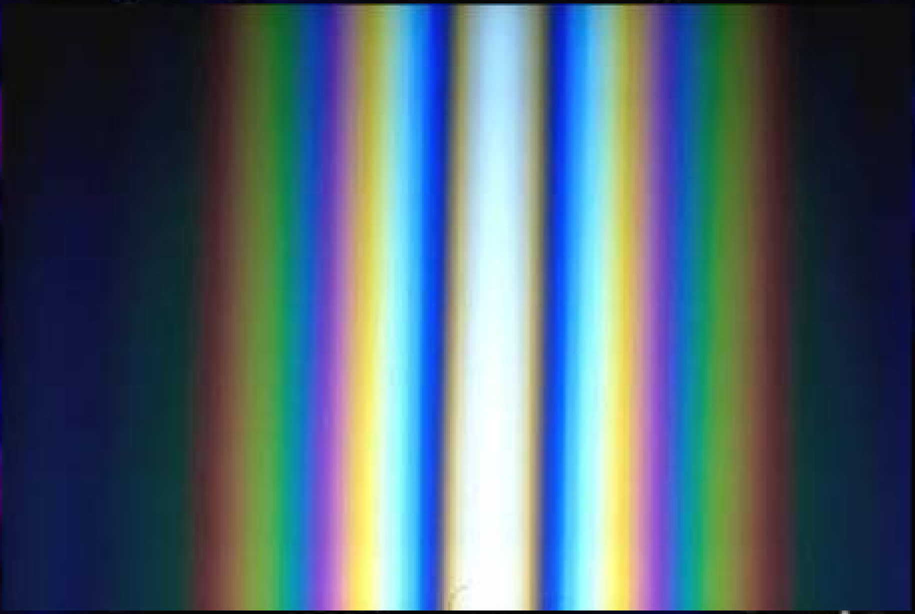
Thomas Young




Barrier
Shoreline
Ocean waves
Low waves
High waves
Low waves
High waves
Low waves
High waves
Low waves

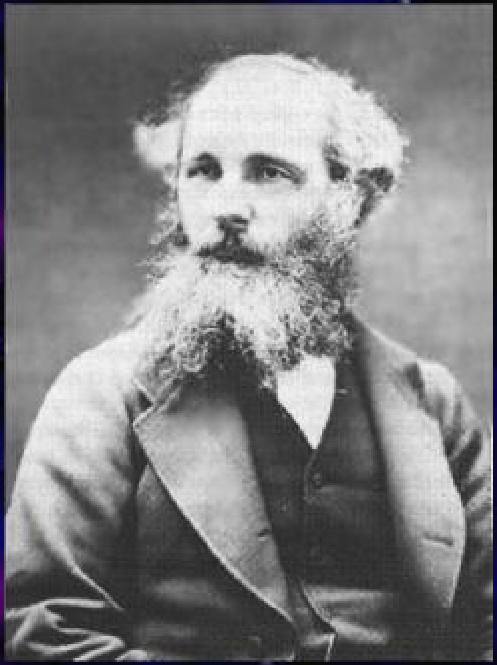






Light must behave like a *wave* of energy...

What *is* light?



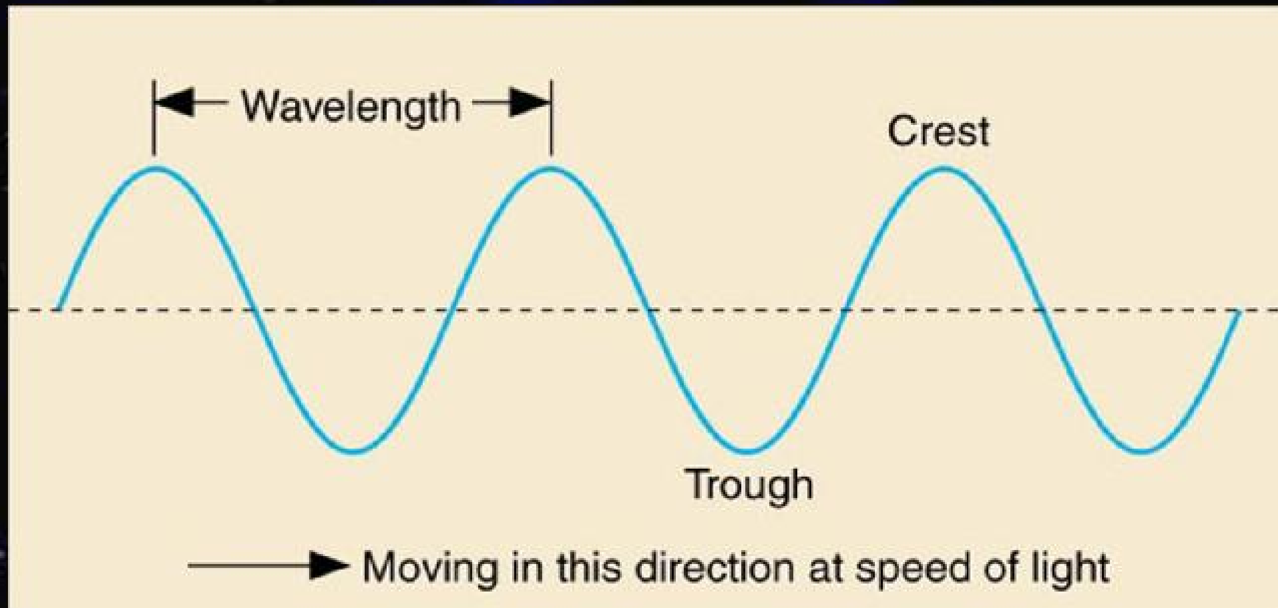
James Clerk Maxwell

What we commonly refer to as "light" is actually the combination of *electricity* and *magnetism*.

ELECTRO*MAGNETIC* ENERGY

ELECTROMAGNETIC RADIATION

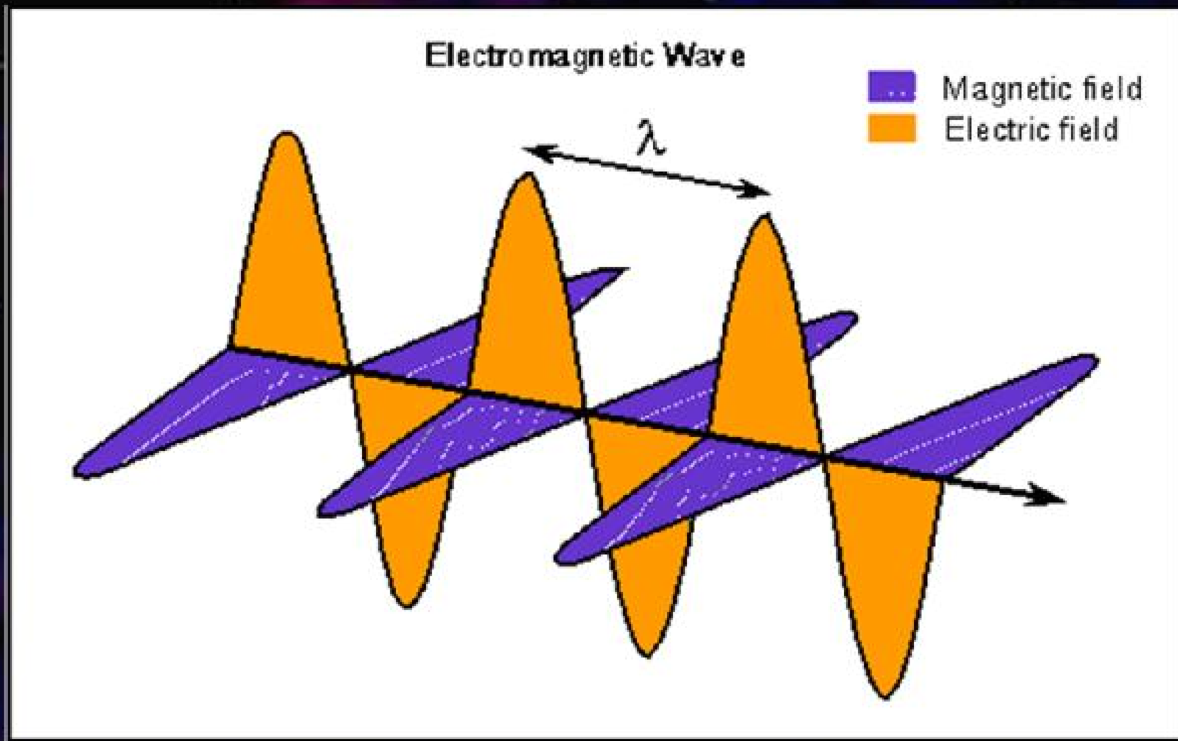
Wave Mechanics



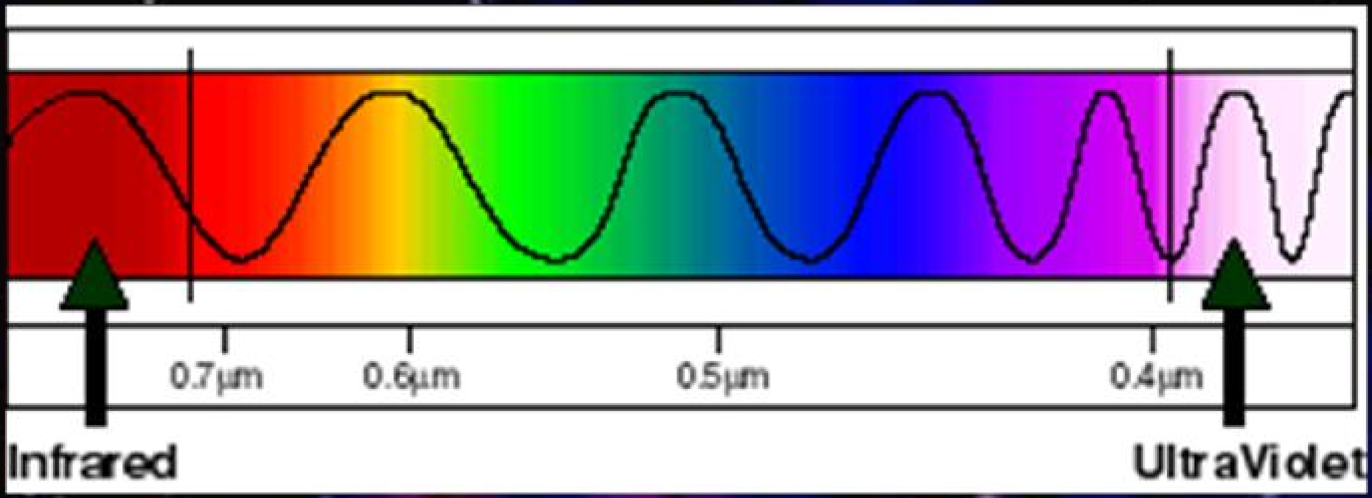
Wavelength (l)

- The distance between two successive wave peaks or valleys
- Wavelength for light is measured in **Ångstroms**

where 1Å = 10^{-10} meters

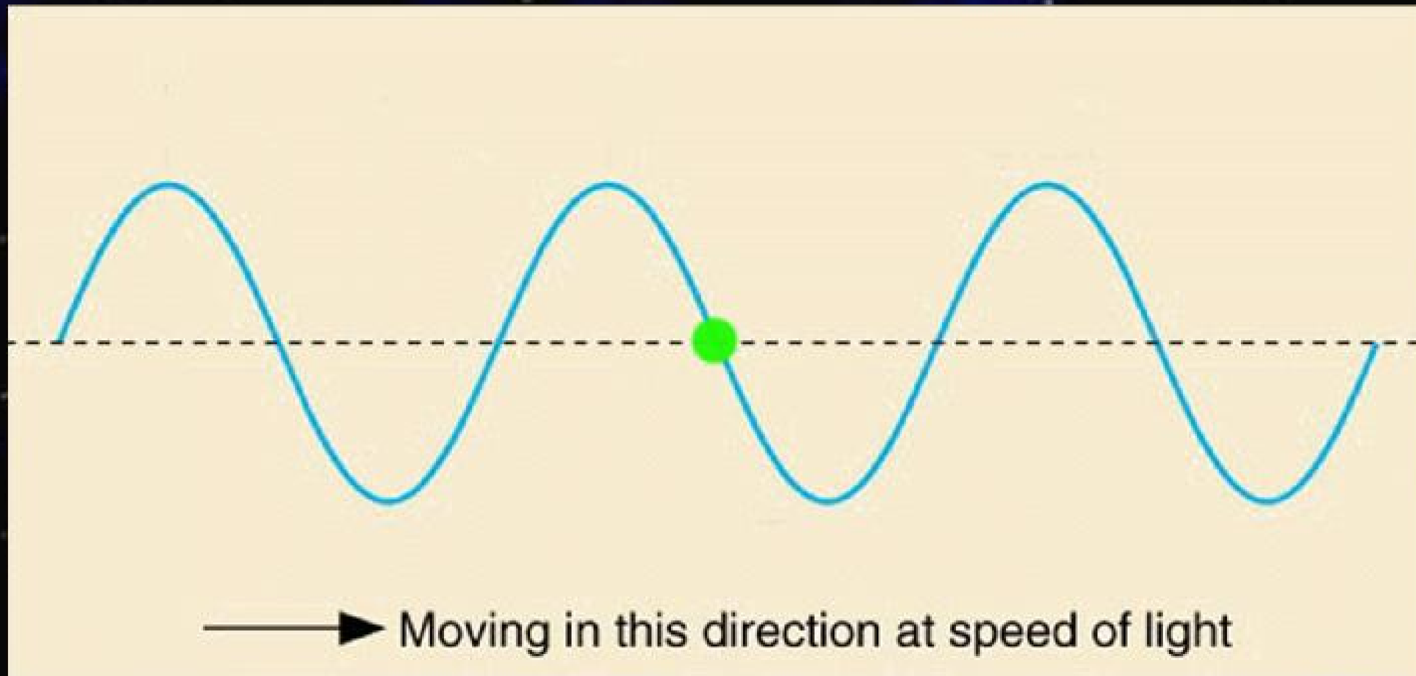


Electromagnetic Wave
Magnetic field
Electric field
λ



Range of wavelengths for visible light:

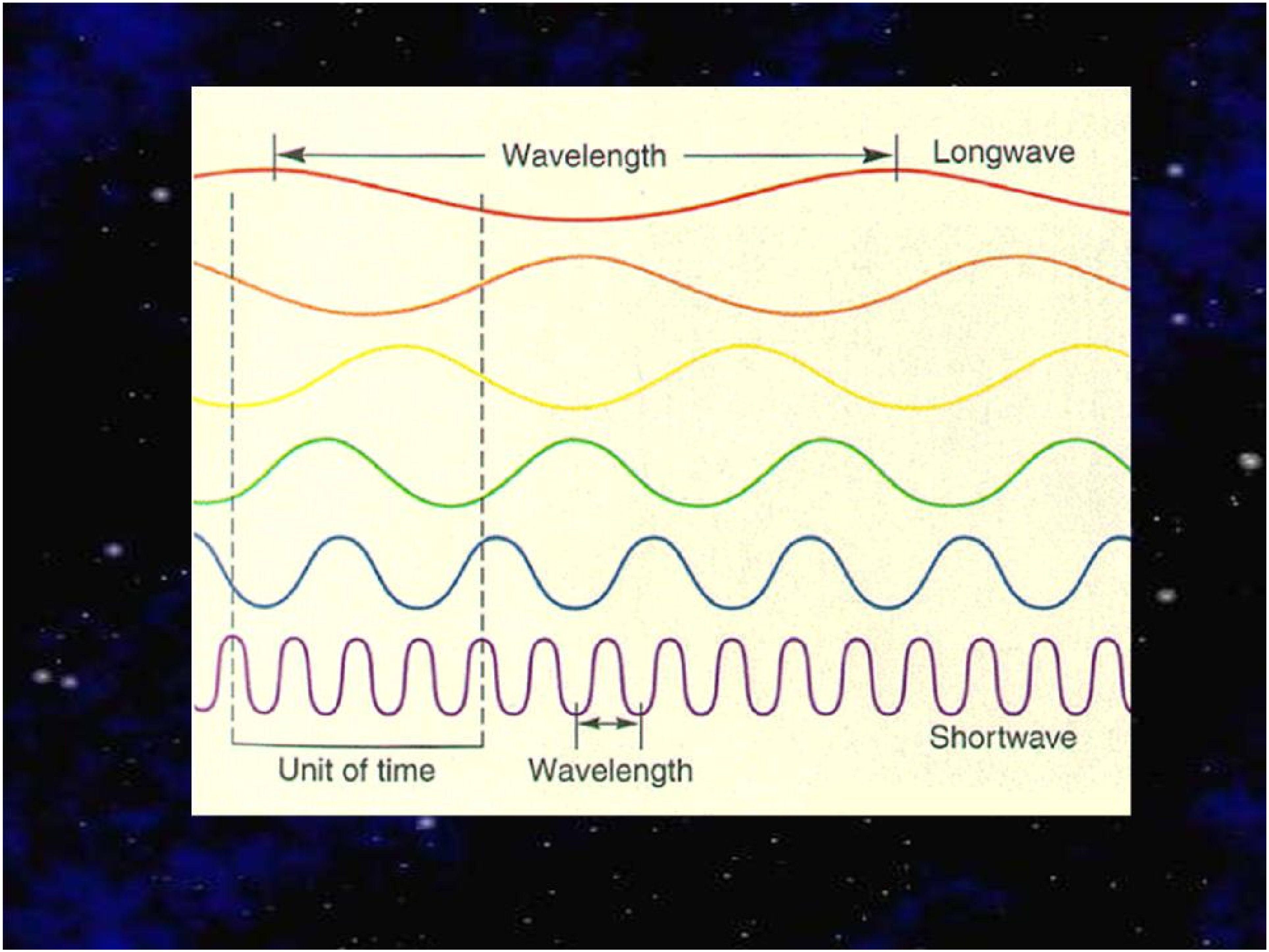
7000 Å – 4000 Å

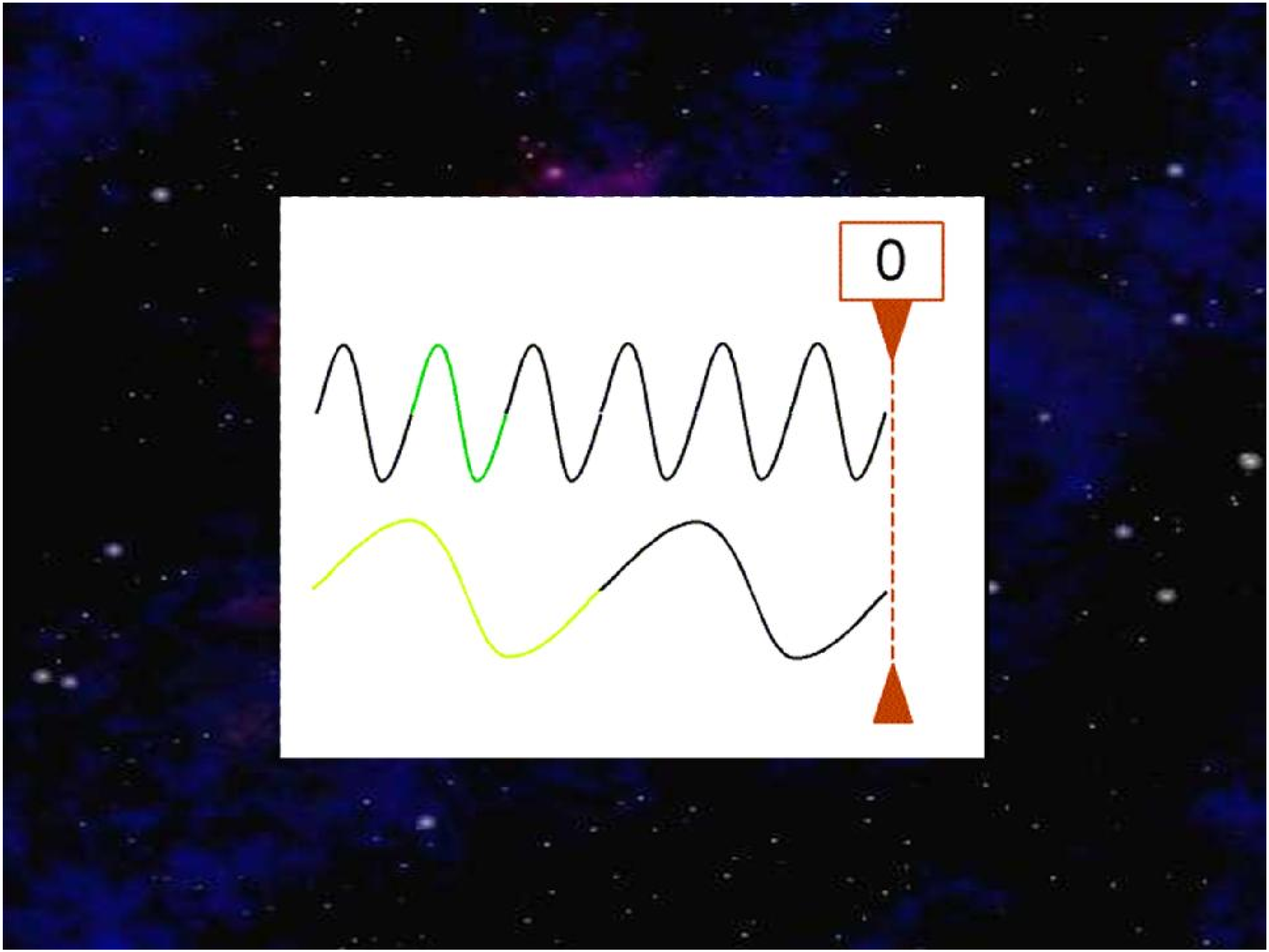


Frequency (n)

The number of cycles per second that pass a given point.

Hertz (Hz) where 1Hz = 1 cycle/second


Wavelength
Longwave
Shortwave
Unit of time
Wavelength

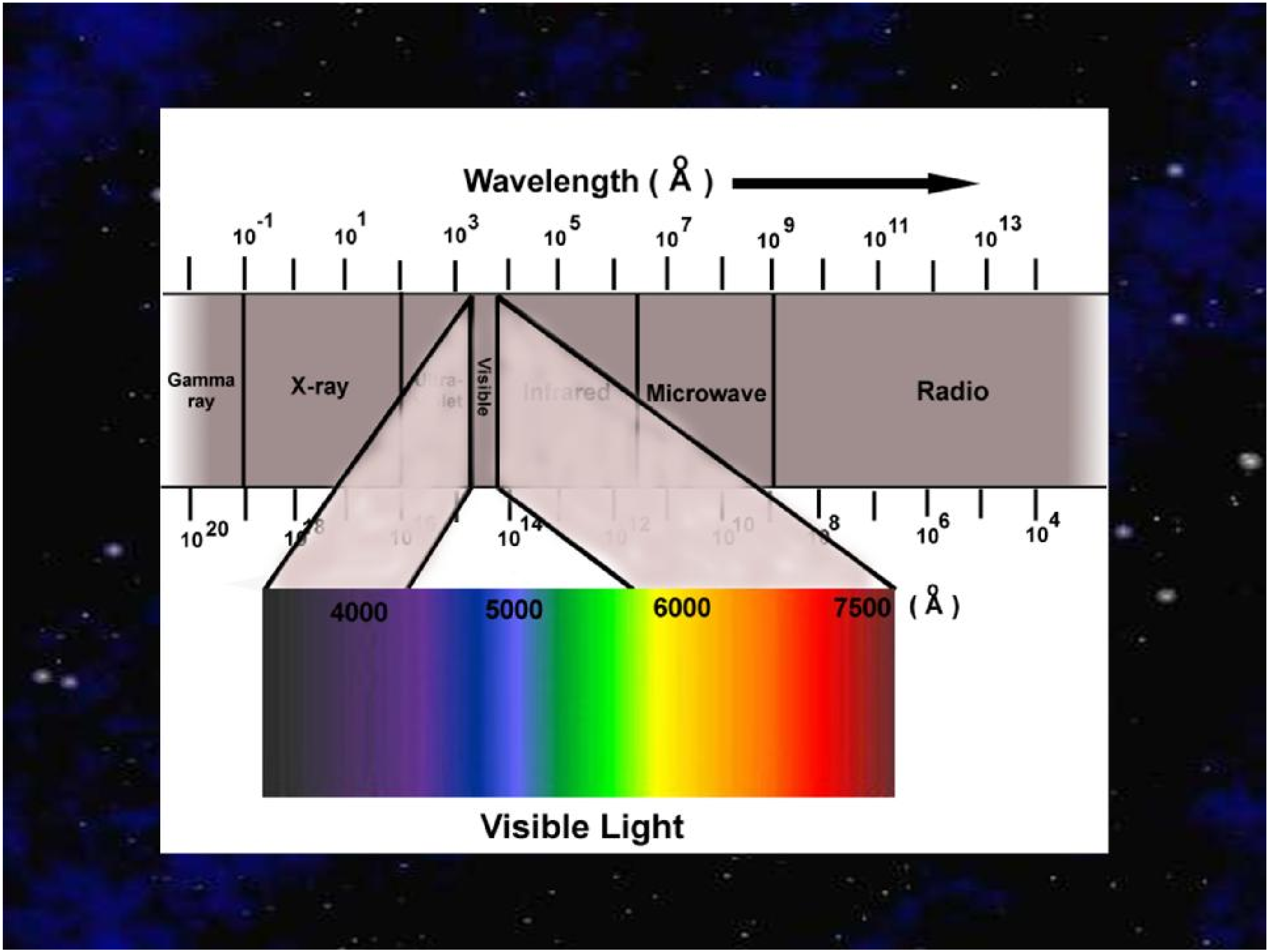

0

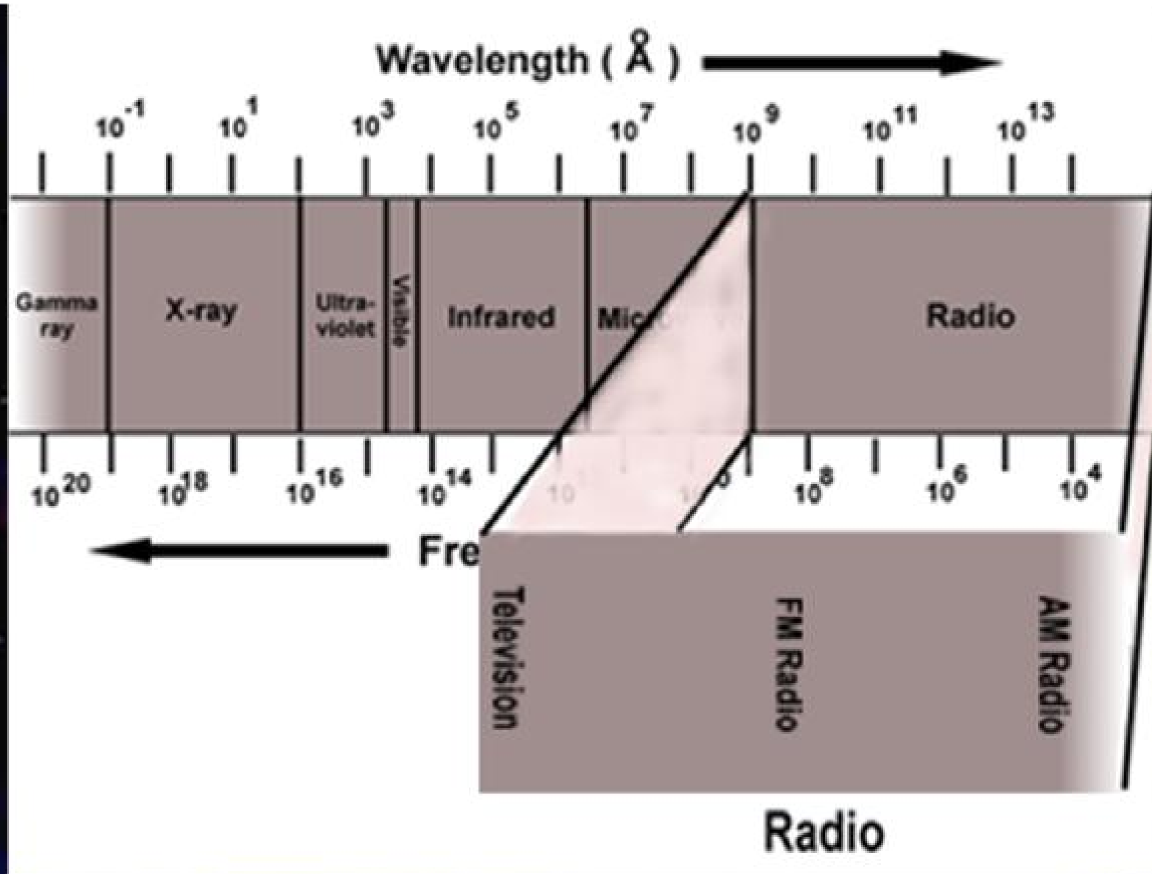
How are wavelength and frequency related?

Speed = wavelength x frequency $c = l \; u$

$$u = \frac{c}{l}$$

$$l = \frac{c}{u}$$


Wavelength (Å)
10^-1
10^1
10^3
10^5
10^7
10^9
10^11
10^13
Gamma ray
X-ray
Visible
Microwave
Radio
10^20
10^14
10^6
10^4
4000
5000
6000
7500
(Å)
Visible Light



AM Radio

540 KHz – 1650 KHz

1825 ft – 598 ft

FM Radio

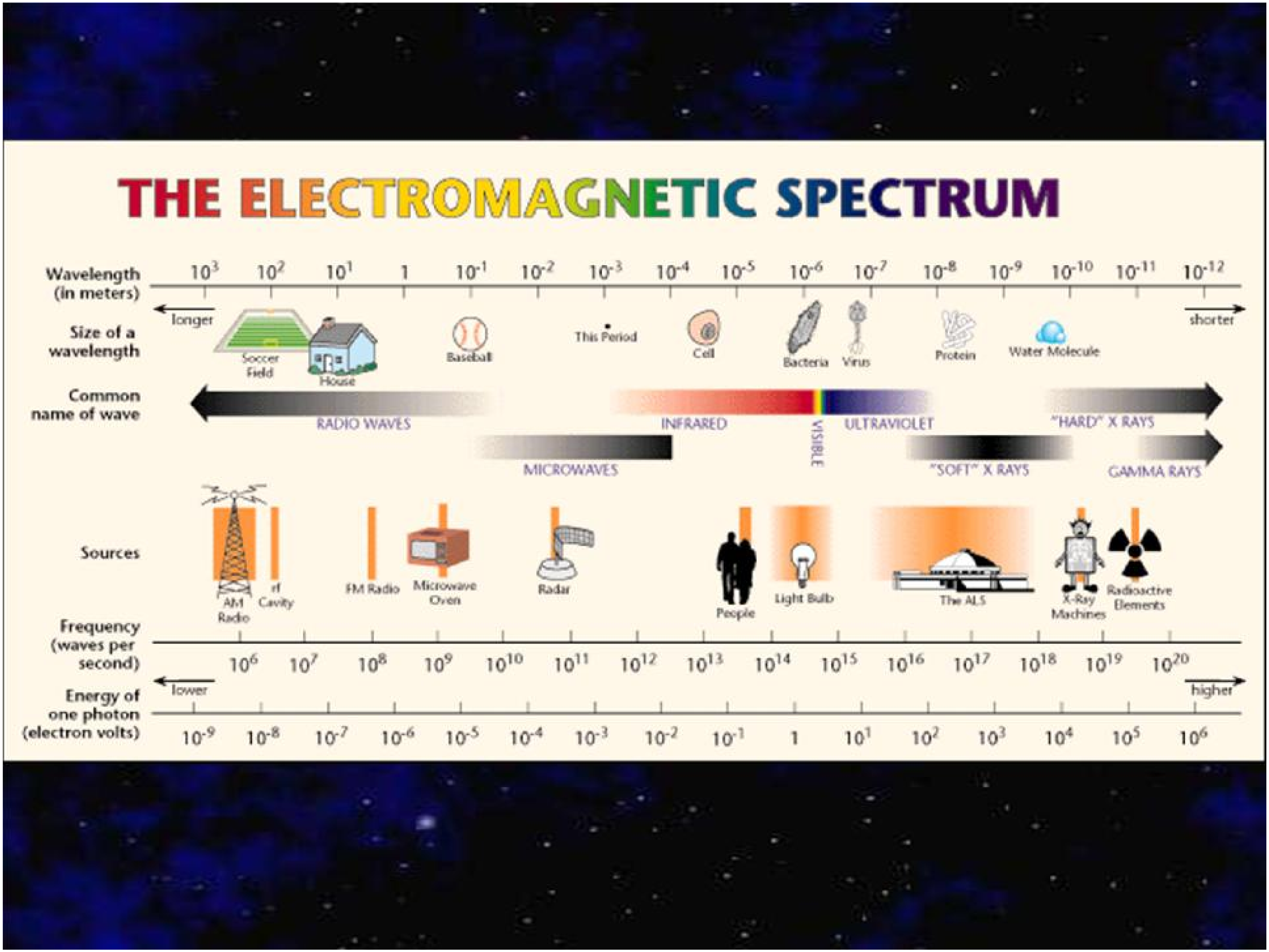
88 MHz – 108 MHz

11.2 ft – 9.2 ft

Television

1 GHz – 100 GHz

1 ft – 1/10 inch


THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
10^3 10^2 10^1 1 10^-1 10^-2 10^-3 10^-4 10^-5 10^-6 10^-7 10^-8 10^-9 10^-10 10^-11 10^-12
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
Sources
AM Radio
rf Cavity
FM Radio
Microwave Oven
Radar
People
Light Bulb
The ALS
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
10^6 10^7 10^8 10^9 10^10 10^11 10^12 10^13 10^14 10^15 10^16 10^17 10^18 10^19 10^20
lower
higher
Energy of one photon (electron volts)
10^-9 10^-8 10^-7 10^-6 10^-5 10^-4 10^-3 10^-2 10^-1 1 10^1 10^2 10^3 10^4 10^5 10^6

How are Wavelength, Frequency and Energy Related?

"Light is composed of packets of energy (particles) called <u>*PHOTONS*</u> "

Each photon carries an associated energy with it

$$E = \frac{hc}{l} \quad OR \quad E = hu$$

Example:

Photon energy for red light:

E=0.00012 calories

Photon energy for blue light:

E=0.00021 calories

Short l = High Energy

Long l = Low Energy

Example:

Photon energy for red light:

E=0.00012 calories

Photon energy for blue light:

E=0.00021 calories

1 Calorie = amount of energy needed to raise temperature of 1 gram (~ 1 teaspoon) of water 1 degree C

red light = 8333 photons
blue light = 4761 photons

James Clerk Maxwell

Maxwell's Equations

$$\nabla \cdot \mathbf{D} = \rho$$

$$\oint_S \mathbf{D} \cdot d\mathbf{A} = \int_V \rho dV$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\oint_S \mathbf{B} \cdot d\mathbf{A} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\oint_C \mathbf{E} \cdot d\mathbf{l} = -\frac{d}{dt} \int_S \mathbf{B} \cdot d\mathbf{A}$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

$$\oint_C \mathbf{H} \cdot d\mathbf{l} = \int_S \mathbf{J} \cdot d\mathbf{A} + \frac{d}{dt} \int_S \mathbf{D} \cdot d\mathbf{A}$$

Michael Faraday

Electromagnetic Radiation and Temperature

__Everything__ in the Universe has a temperature associated with it.

Temperature can be thought of as a measure of the average velocity of atoms or molecules.

TEMPERATURE SCALES:

FAHRENHEIT (°F)

32° = freezing point of water

212° = boiling point of water

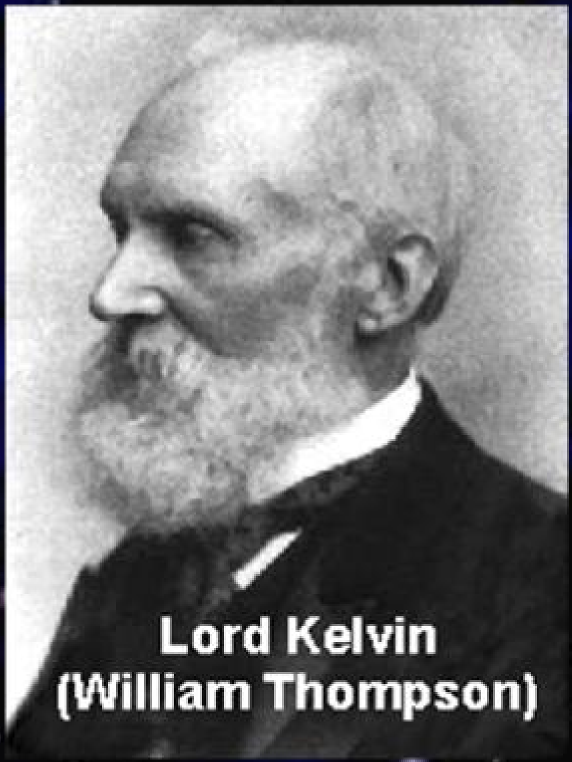
CENTEGRADE (°C)

0° = freezing point of water

100° = boiling point of water

$$T_F = (\tfrac{9}{5} T_C) + 32 \qquad T_C = (T_F - 32)\tfrac{5}{9}$$

Absolute Scale

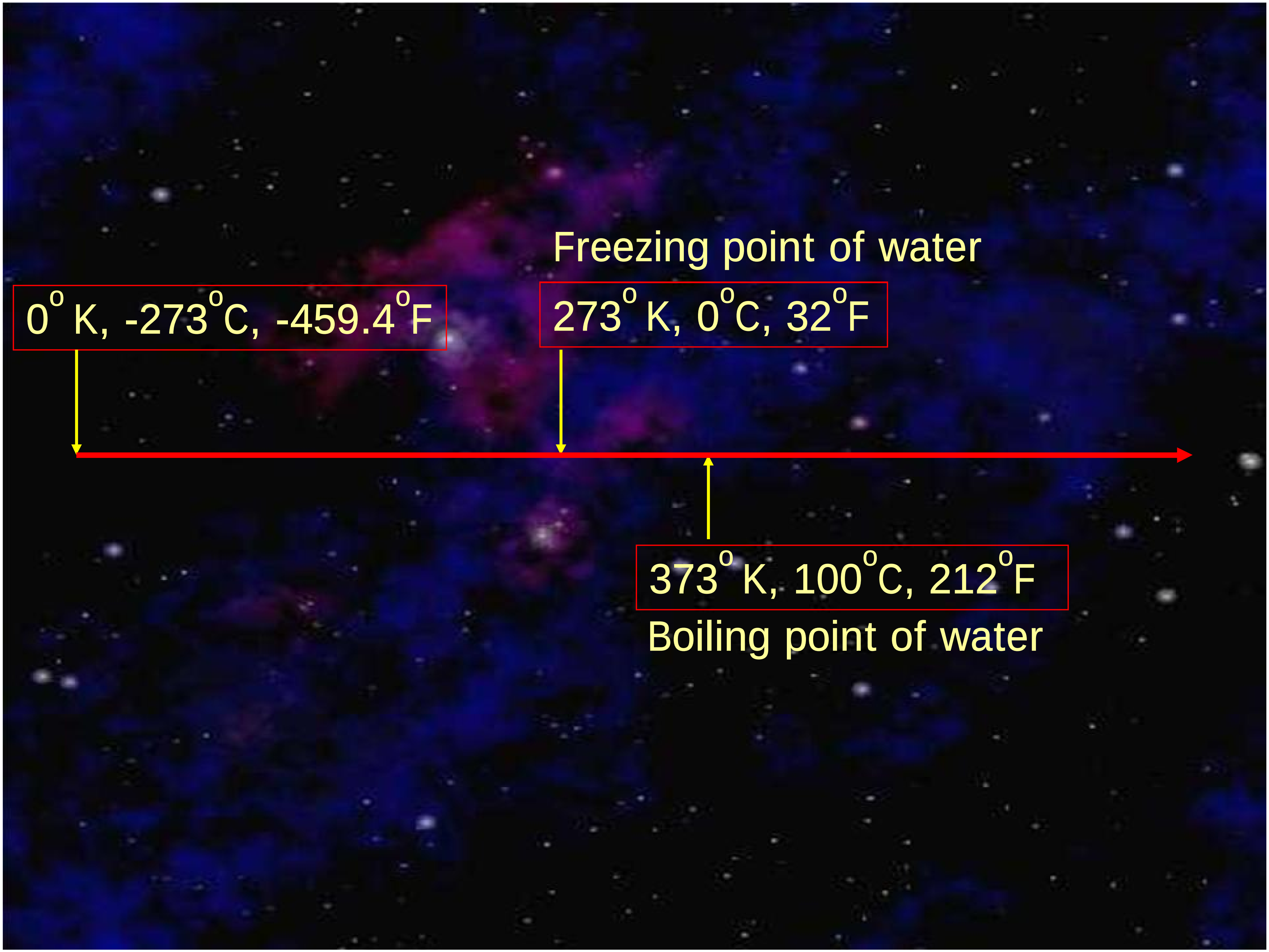


KELVINS (K)

Based on theoretical limit for temperature

Absolute Zero Ø 0 K

Uses same increment as CENTIGRADE


Freezing point of water
0° K, -273°C, -459.4°F
273° K, 0°C, 32°F
373° K, 100°C, 212°F
Boiling point of water

Josef Stefan (1879)

$$E \propto T^4$$

Everything in the Universe has a temperature associated with it.

Objects in nature will emit energy based upon their temperature.

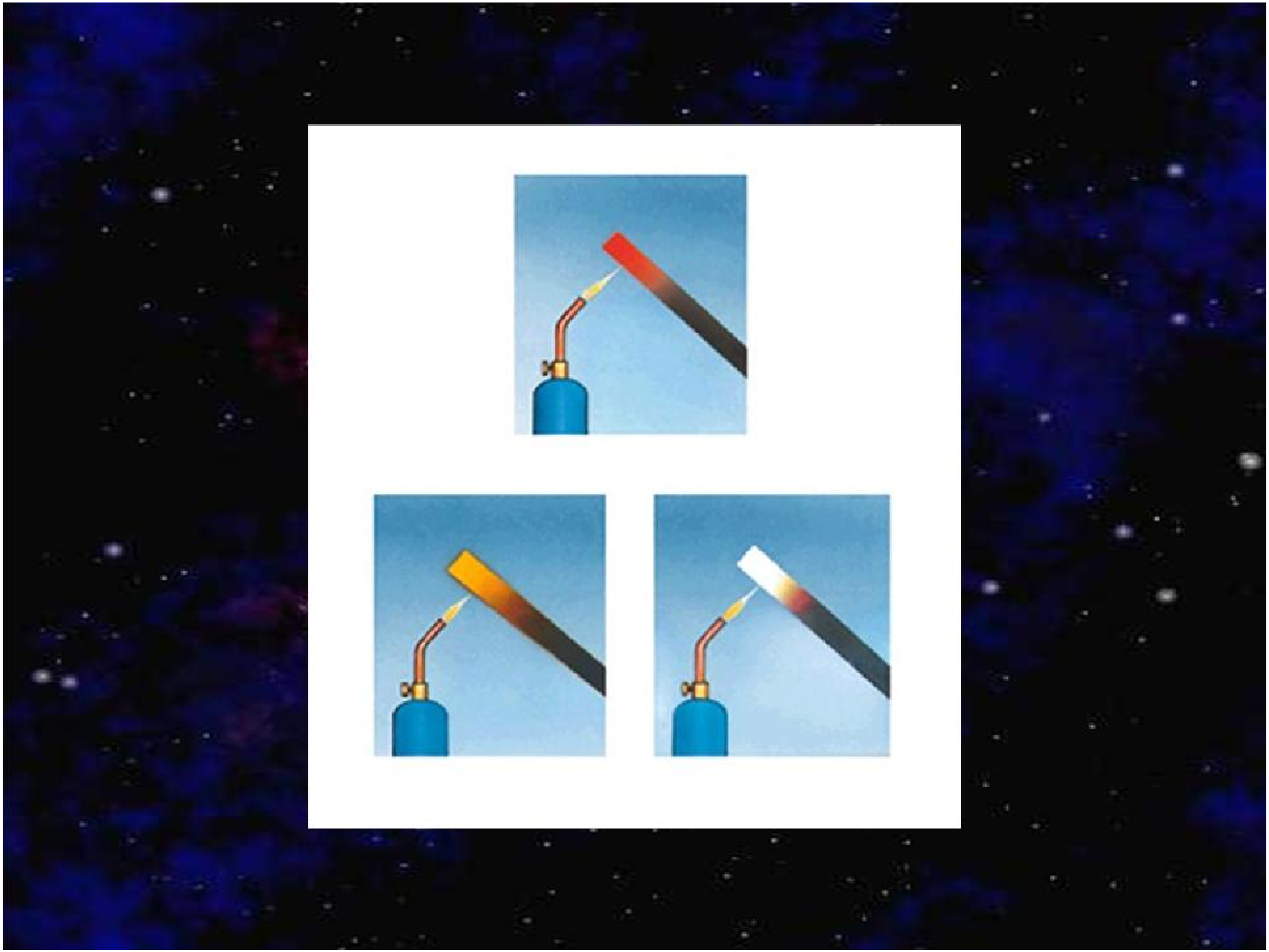
BLACKBODY RADIATION

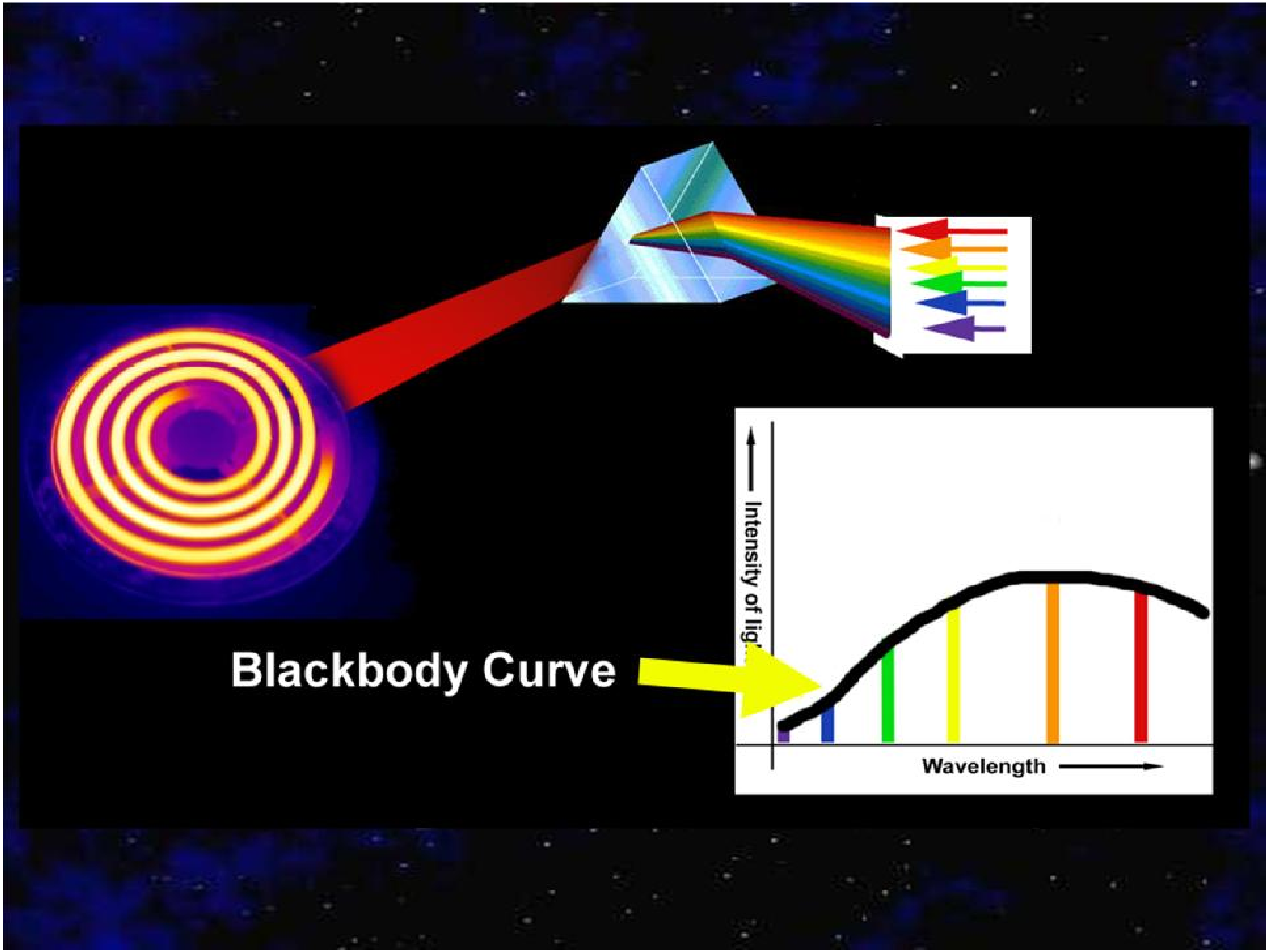
Thermodynamic Rules for Blackbodies:

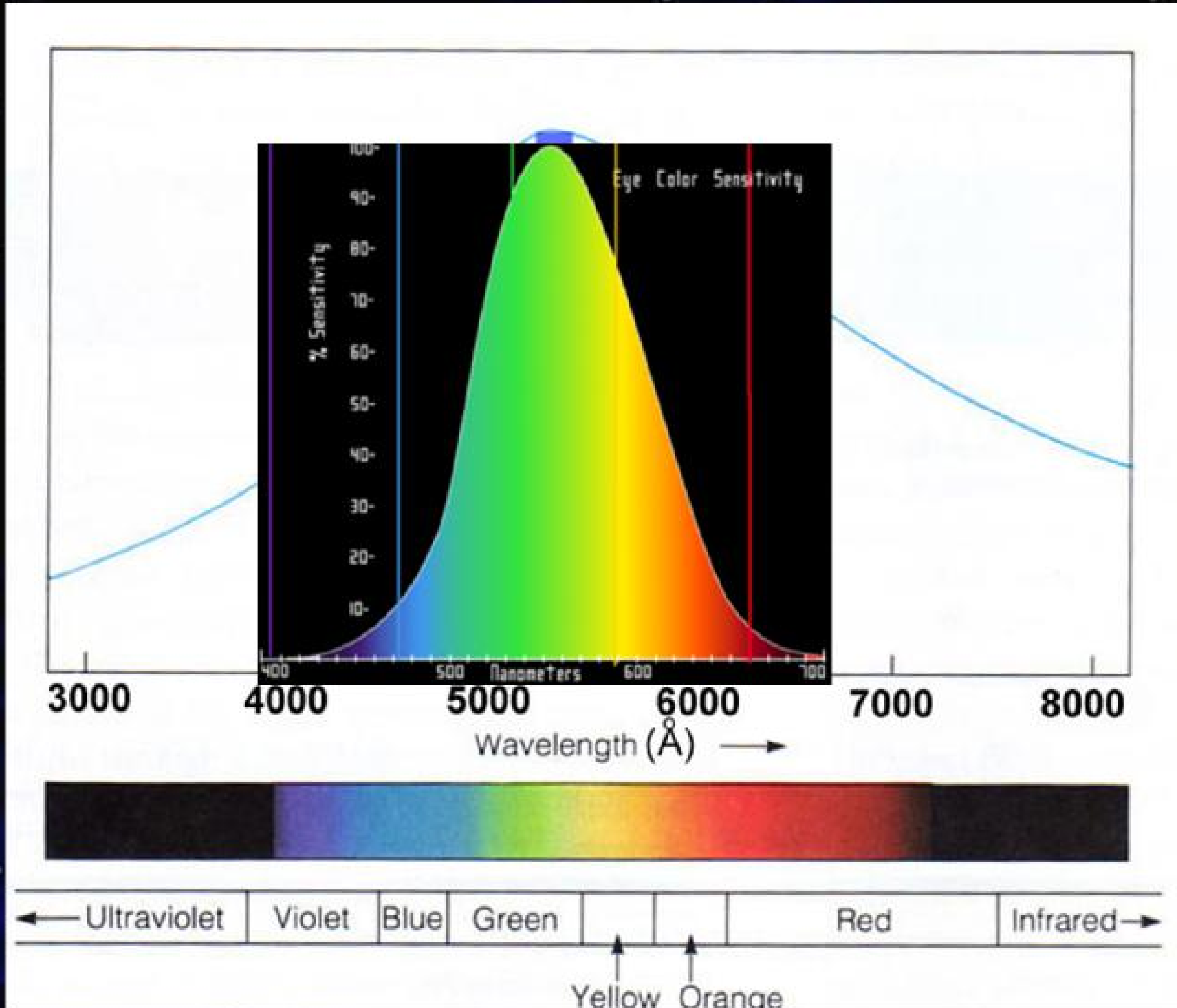
1. An object that reflects *NO* light.

2. An object that absorbs *ALL* light that falls upon it.

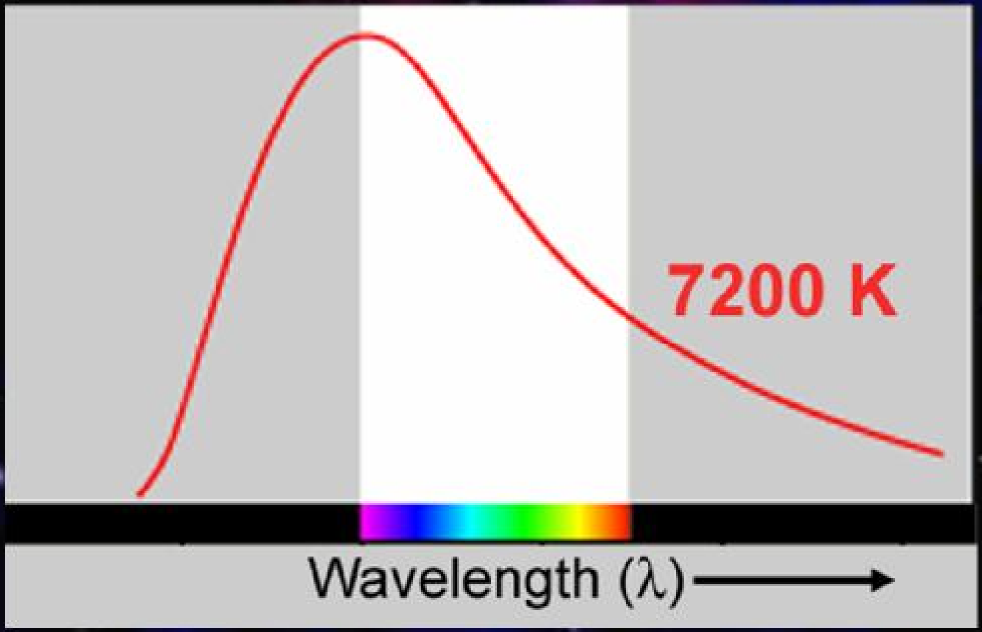
3. An object that emits light as a result of its temperature *only*.




Blackbody Curve
Intensity of lig...
Wavelength


100-
90-
80-
70-
60-
50-
40-
30-
20-
10-
% Sensitivity
Eye Color Sensitivity
400
500
Nanometers
600
700
3000
4000
5000
6000
7000
8000
Wavelength (Å)
Ultraviolet
Violet
Blue
Green
Red
Infrared
Yellow
Orange

Wilhelm Wien (1897)



Wilhelm Wien (1897)

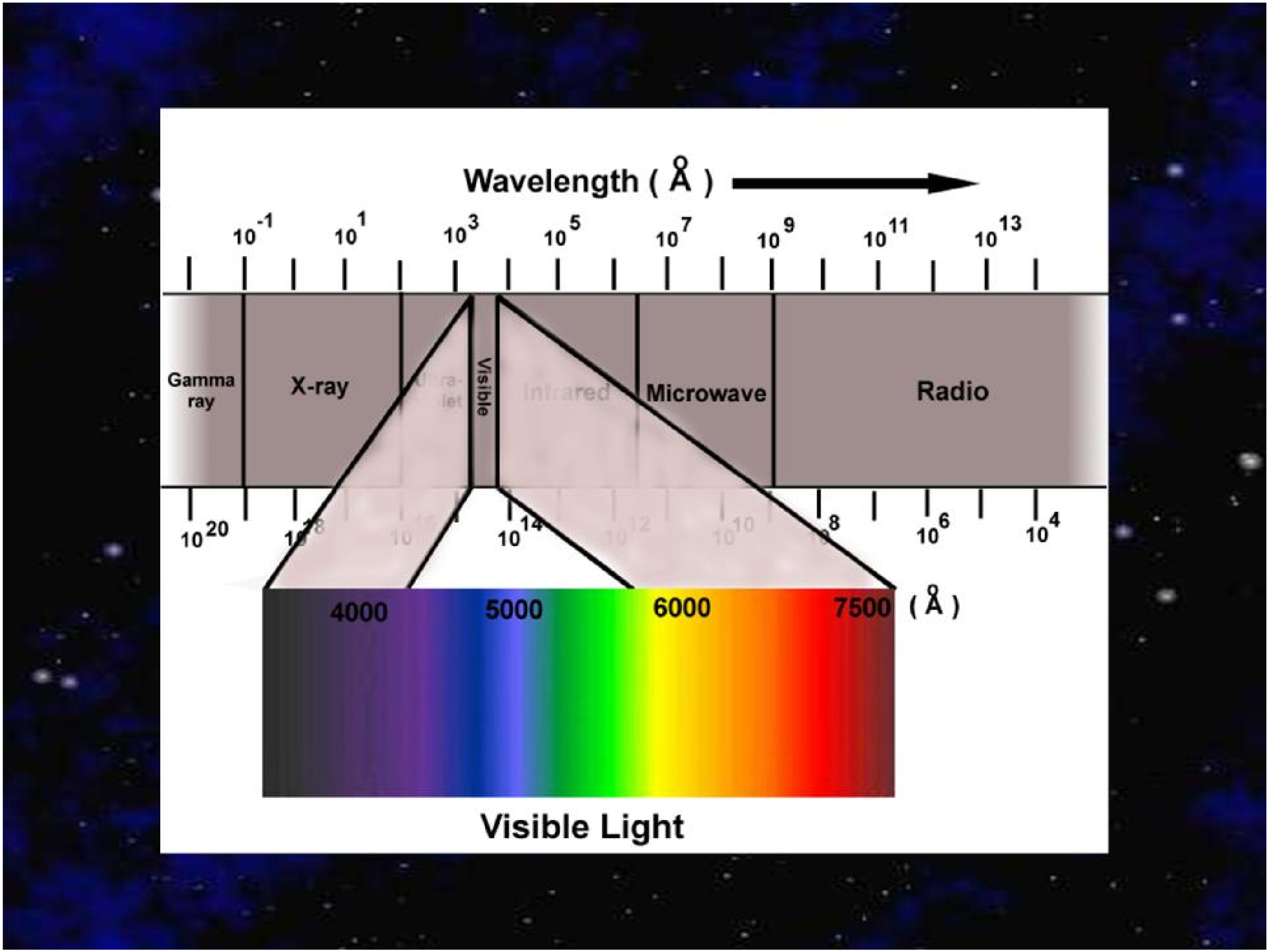
$$l_{max} = \frac{2.9\times10^{7}}{T}$$

$$T = \frac{2.9\times10^{7}}{l_{max}}$$

Example of Wien's Law:

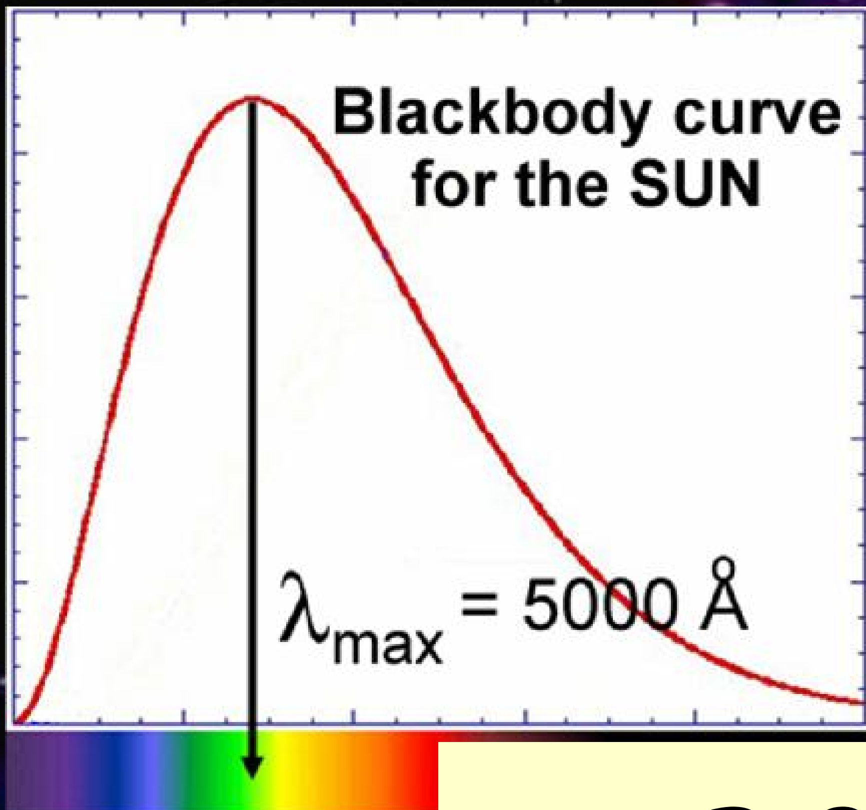
How to find the cat in the dark...

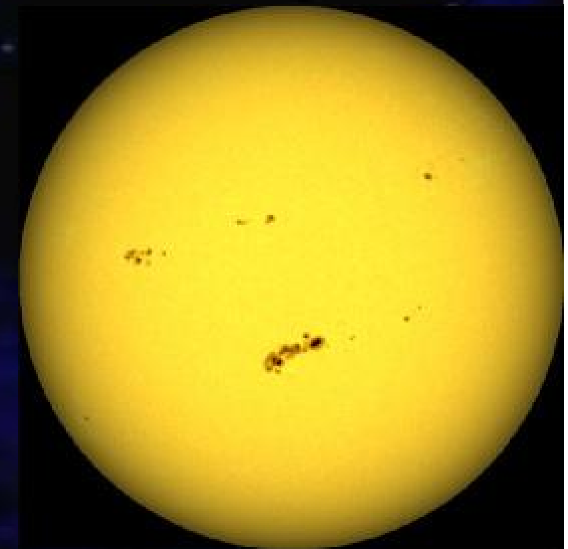
$$l_{\max} = \frac{2.9\times10^{7}}{T} = \frac{2.9\times10^{7}}{311} = 93247\ A$$



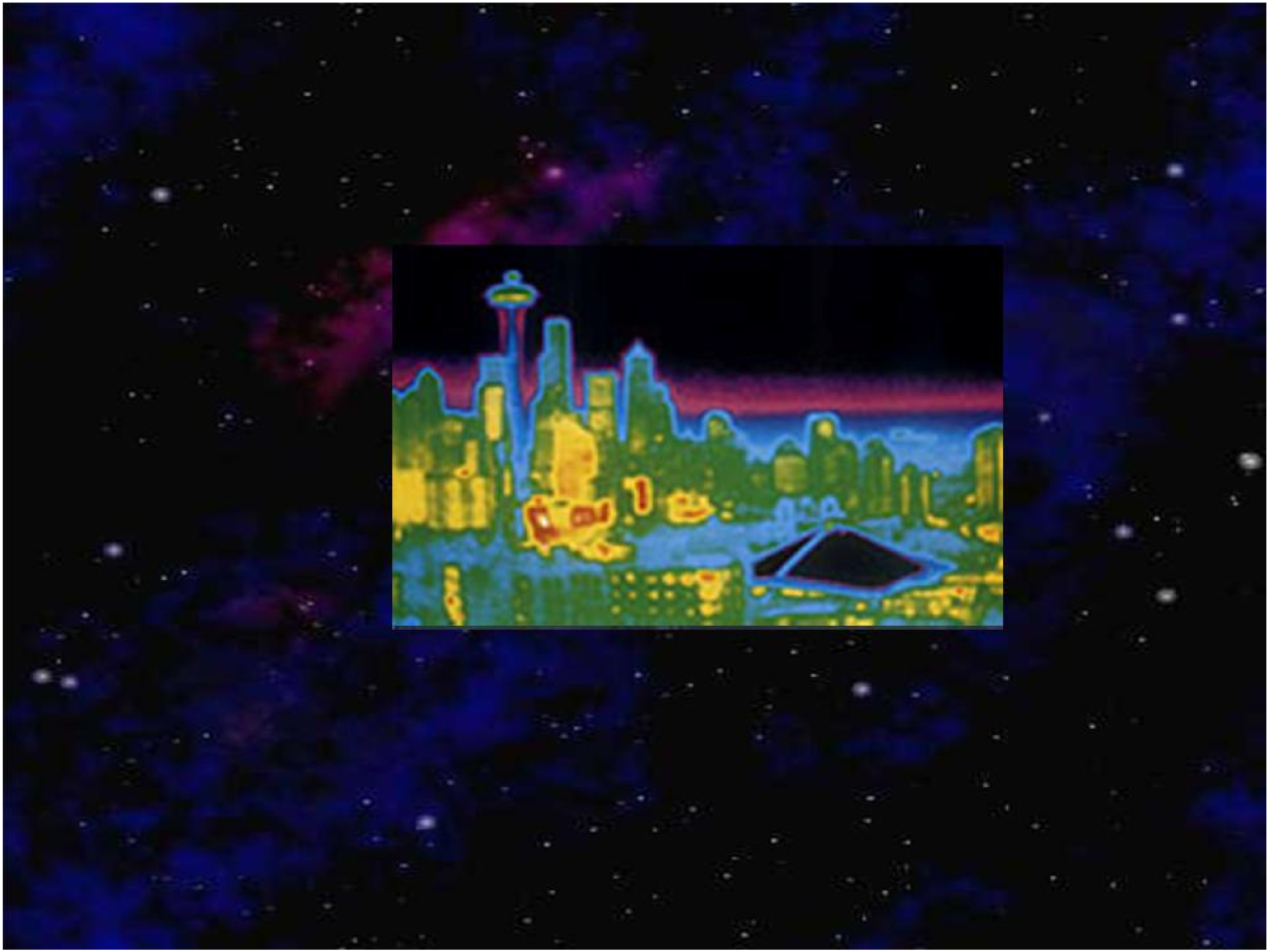
Wavelength (Å)
10^-1
10^1
10^3
10^5
10^7
10^9
10^11
10^13
Gamma ray
X-ray
Visible
Microwave
Radio
10^20
10^14
10^6
10^4
4000
5000
6000
7500
(Å)
Visible Light

Temperature of the Sun

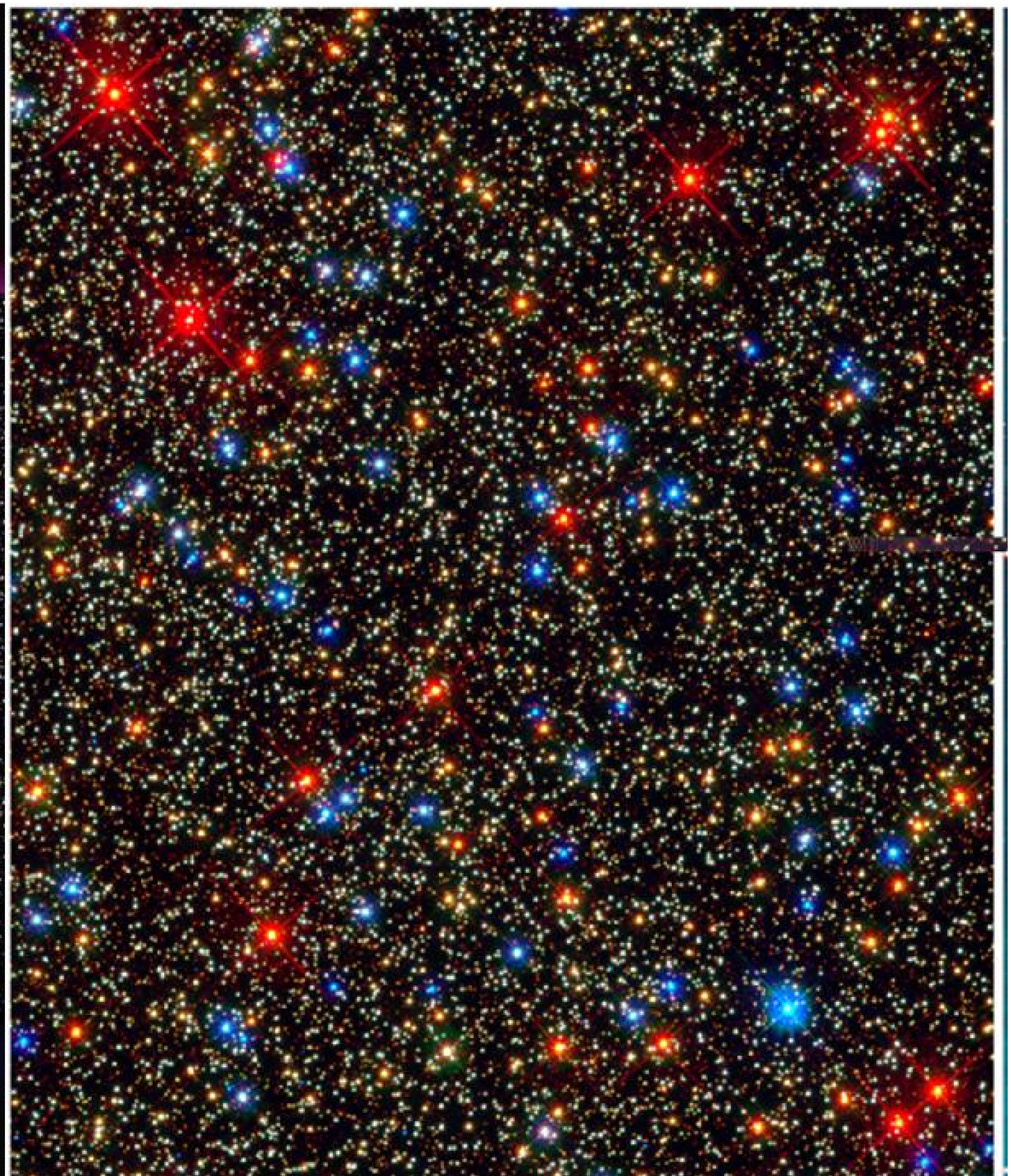




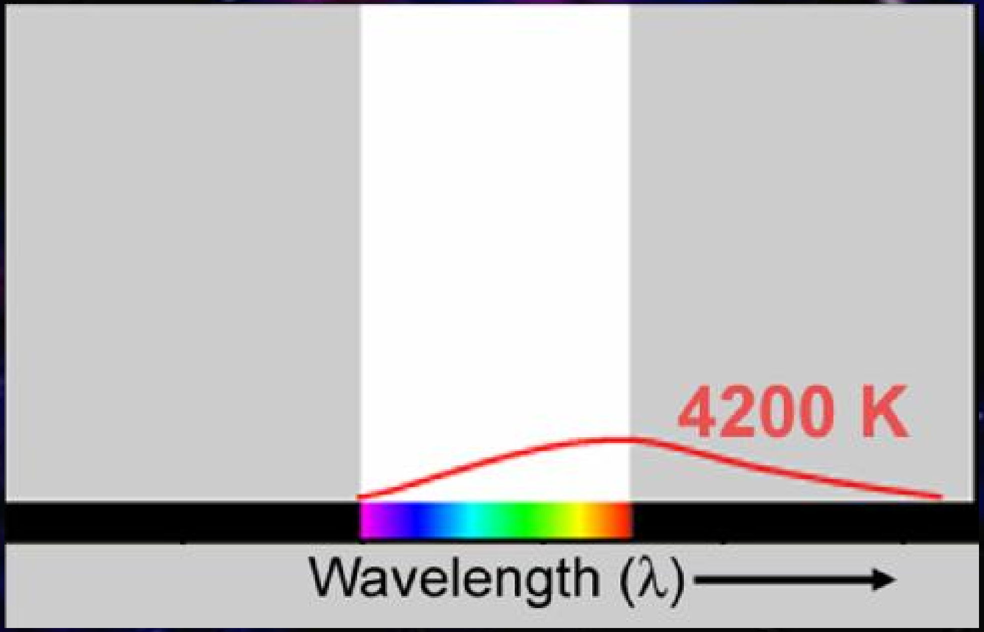
$$T = \frac{2.9 \times 10^{7}}{5000 A} = 5800 K$$



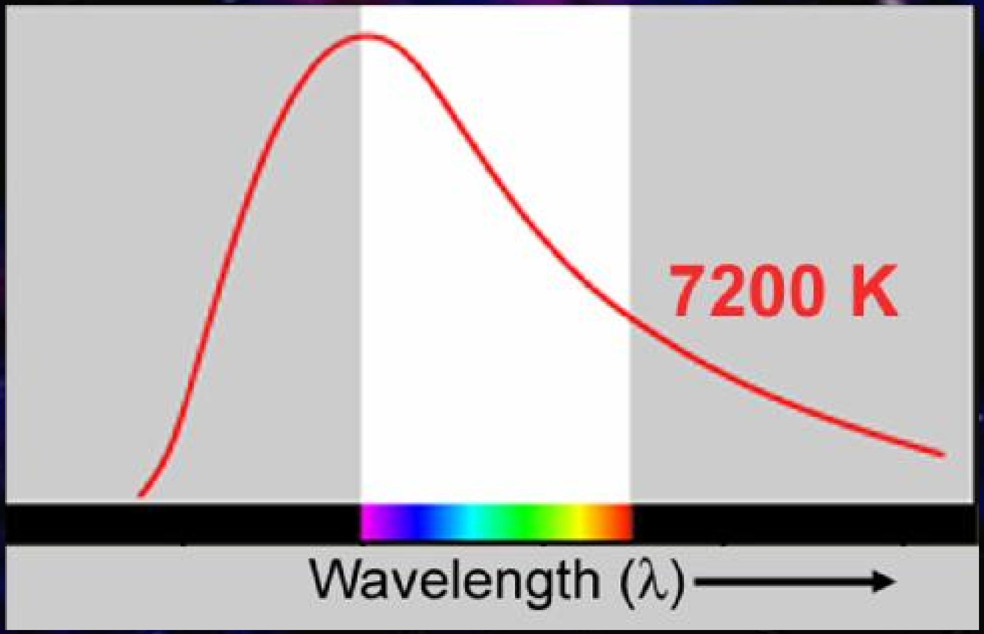
Star Colors

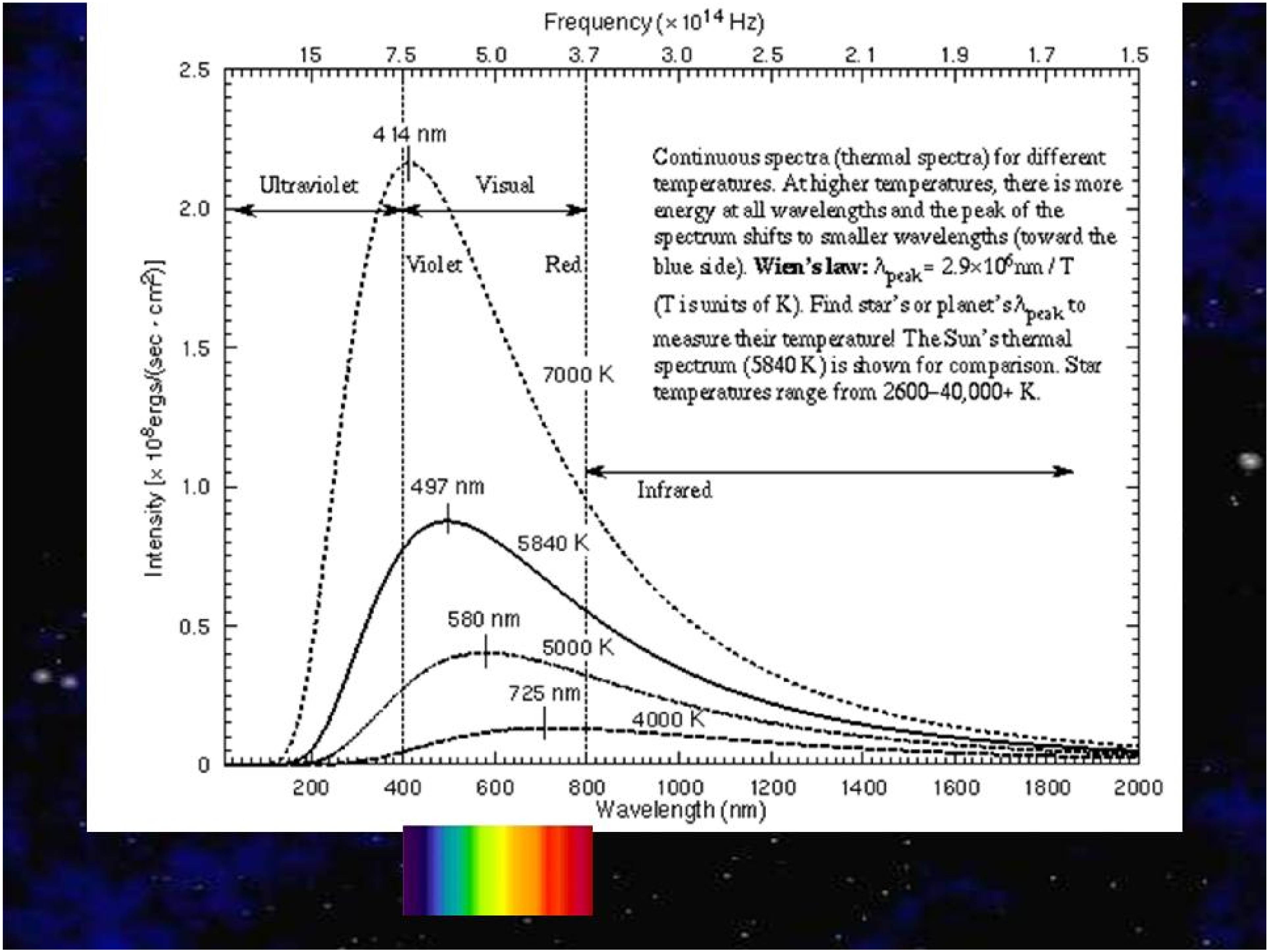


Star Colors



Star Colors



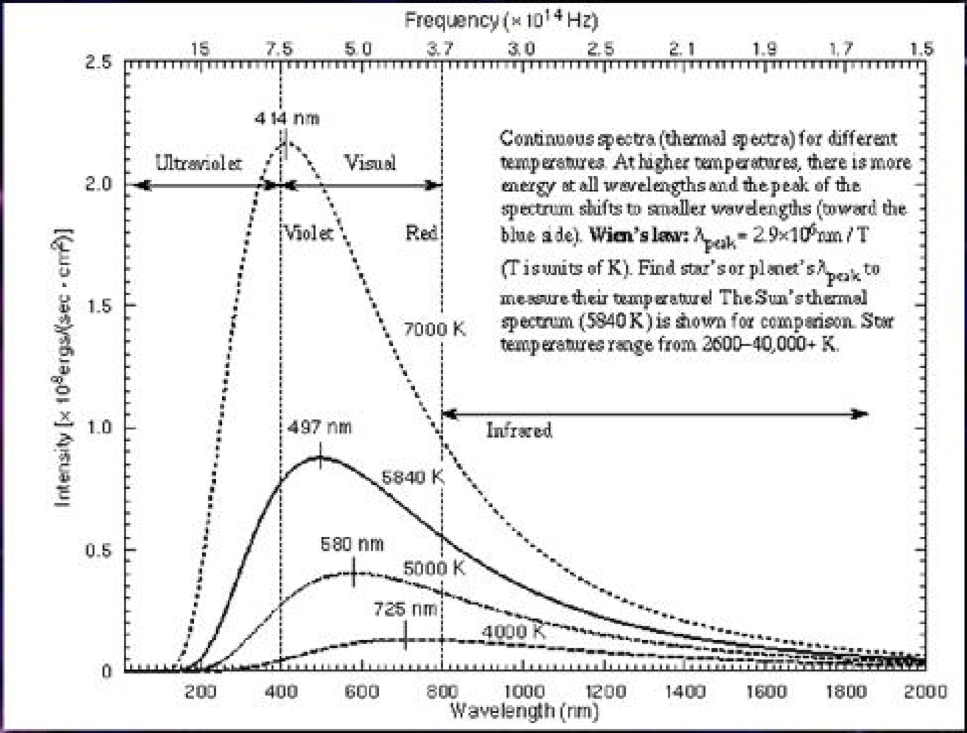


Frequency (× 10^{14} Hz)
15
7.5
5.0
3.7
3.0
2.5
2.1
1.9
1.7
1.5
2.5
2.0
1.5
1.0
0.5
0
Intensity [× 10^8 ergs/(sec · cm^2)]
414 nm
Ultraviolet
Visual
Violet
Red
7000 K
Infrared
497 nm
5840 K
580 nm
5000 K
725 nm
4000 K
200
400
600
800
1000
1200
1400
1600
1800
2000
Wavelength (nm)
Continuous spectra (thermal spectra) for different temperatures. At higher temperatures, there is more energy at all wavelengths and the peak of the spectrum shifts to smaller wavelengths (toward the blue side). **Wien's law:** $\lambda_{peak} = 2.9\times10^6$nm / T (T is units of K). Find star's or planet's λ_{peak} to measure their temperature! The Sun's thermal spectrum (5840 K) is shown for comparison. Star temperatures range from 2600–40,000+ K.

$$I(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}.$$

$dI/d\lambda = 0$

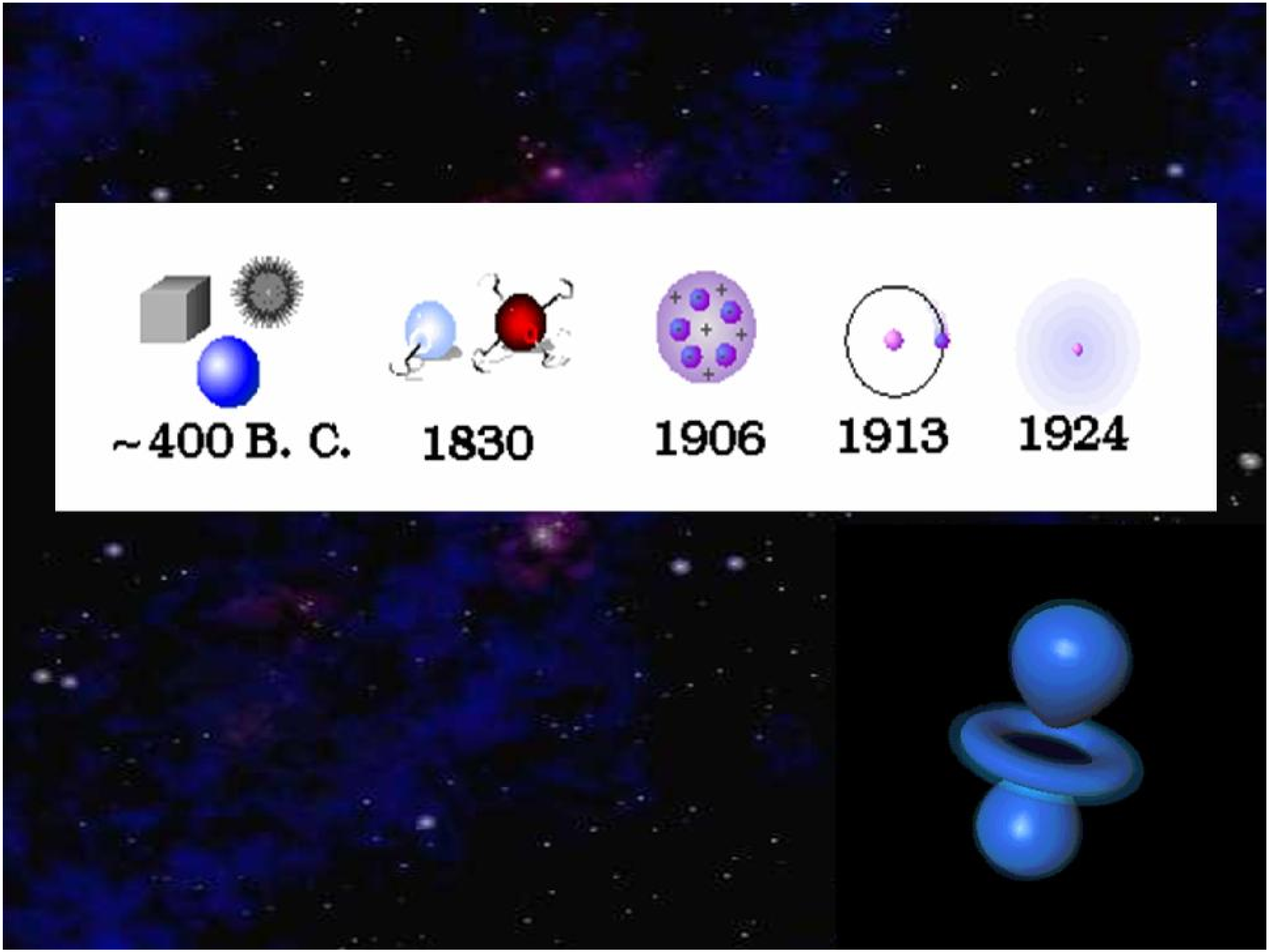
$$l_{max} = \frac{2.9\times10^7}{T}$$



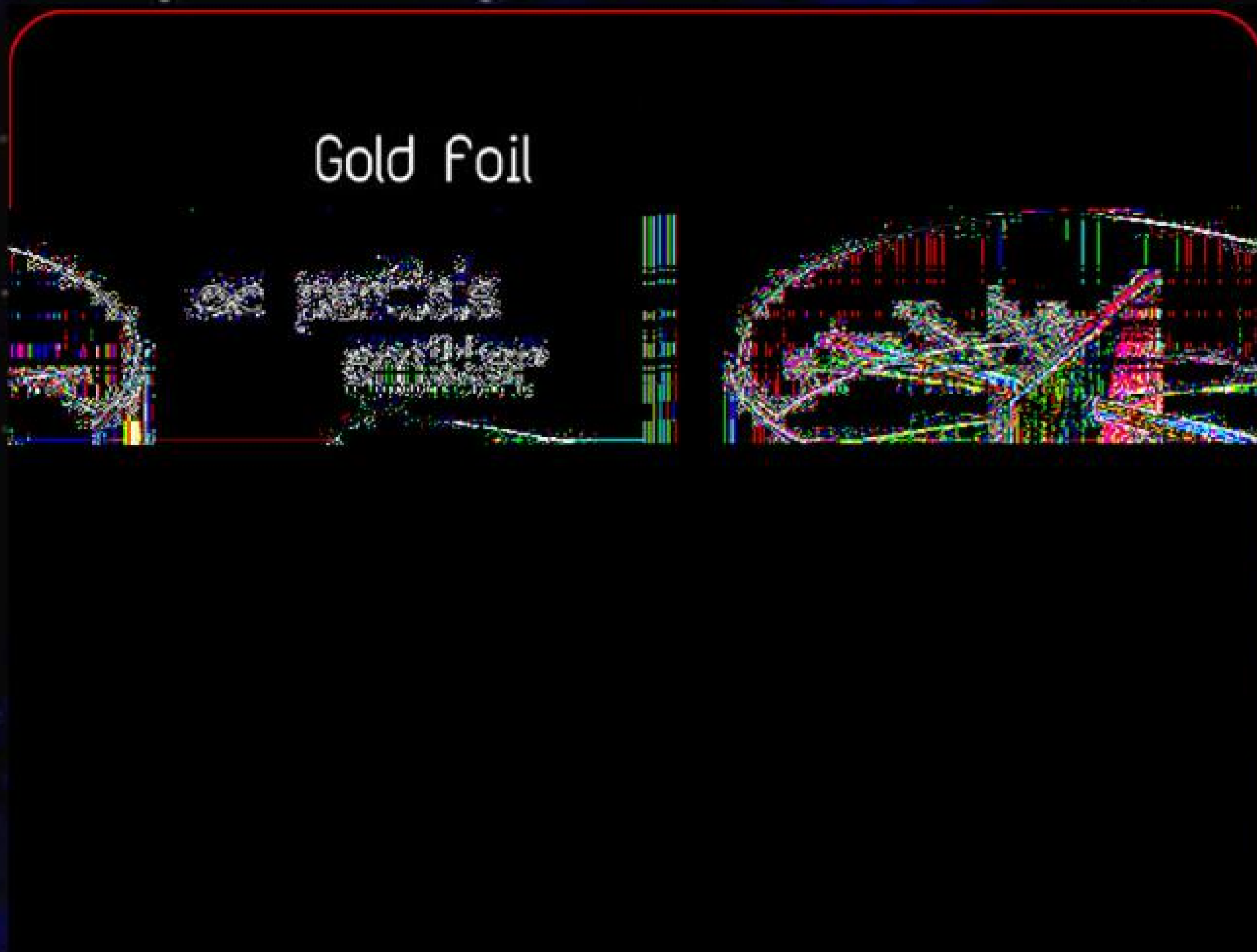
$\int$ I dλ

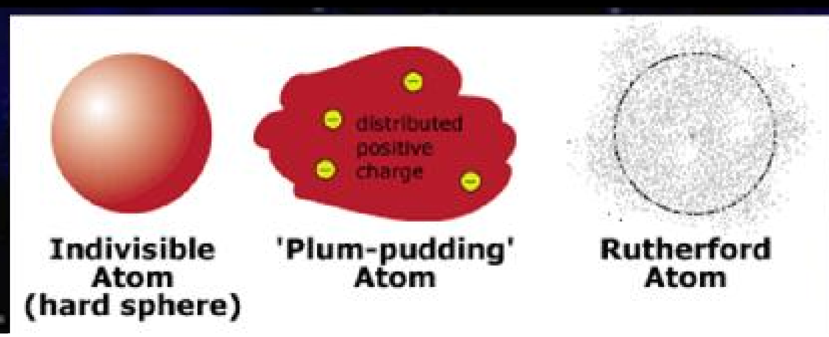
$$I = sT^4$$

$$\sigma = \frac{2\pi^5 k^4}{15c^2h^3} = 5.670400 \times 10^{-8}\,\mathrm{J\,s^{-1}m^{-2}K^{-4}}.$$

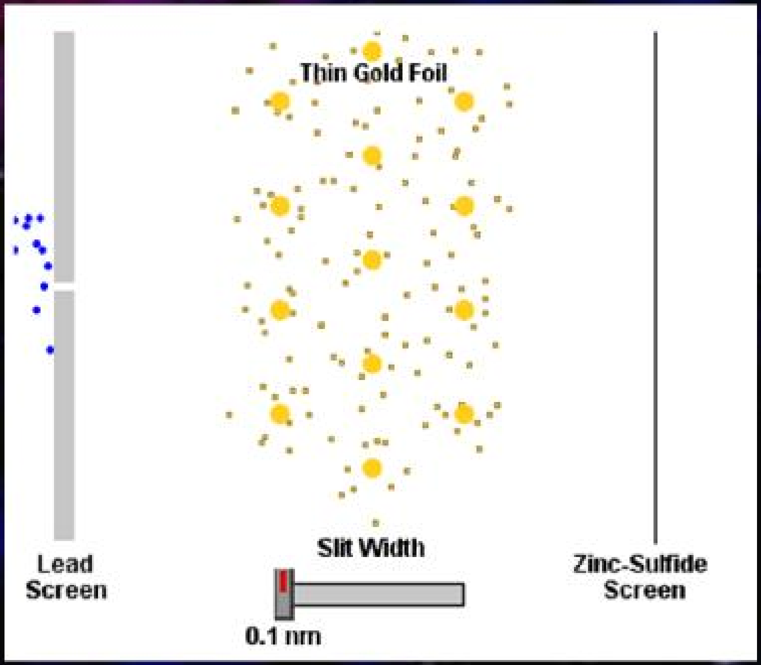

~400 B. C.
1830
1906
1913
1924

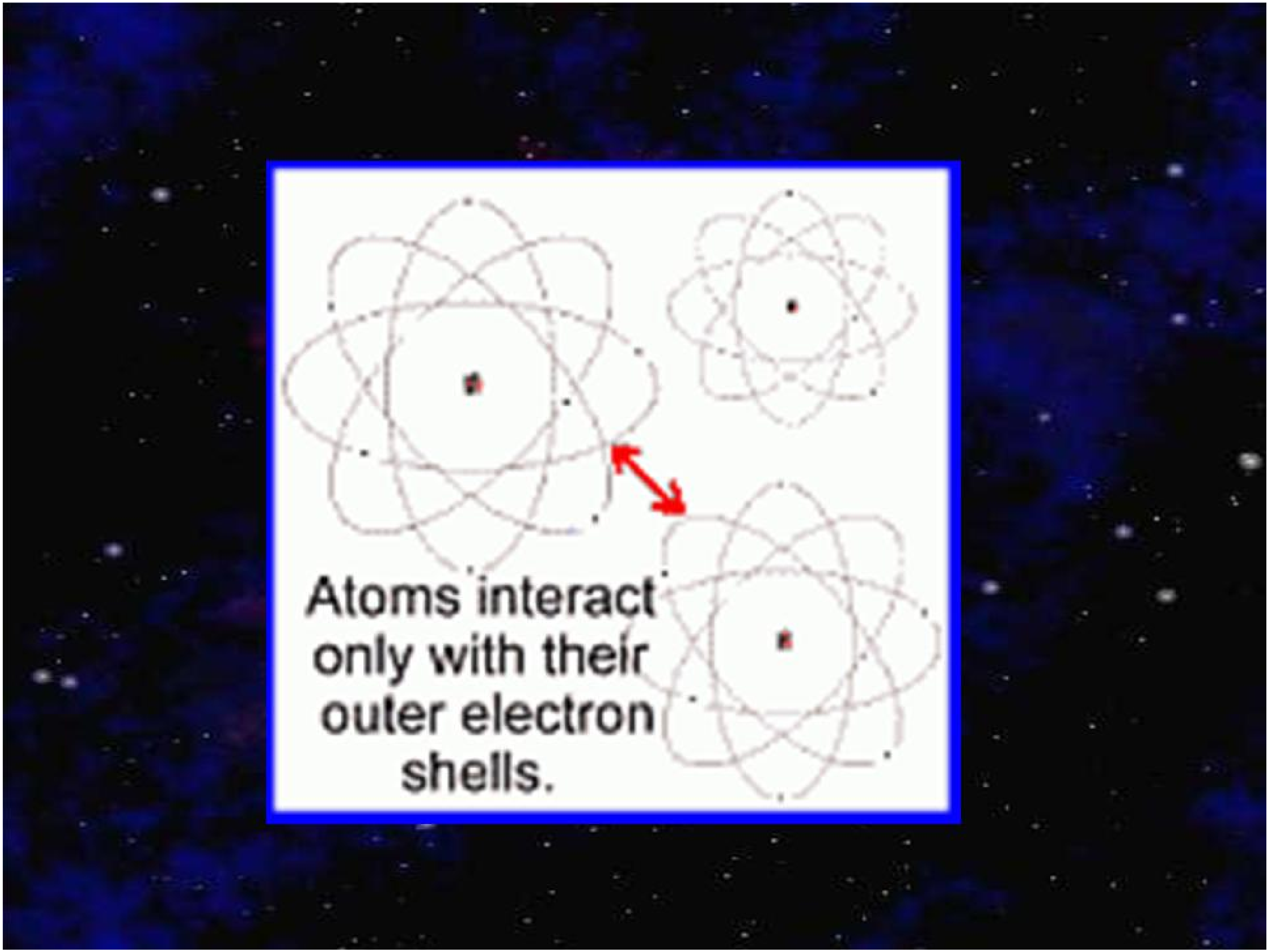
Ernest Rutherford, 1911

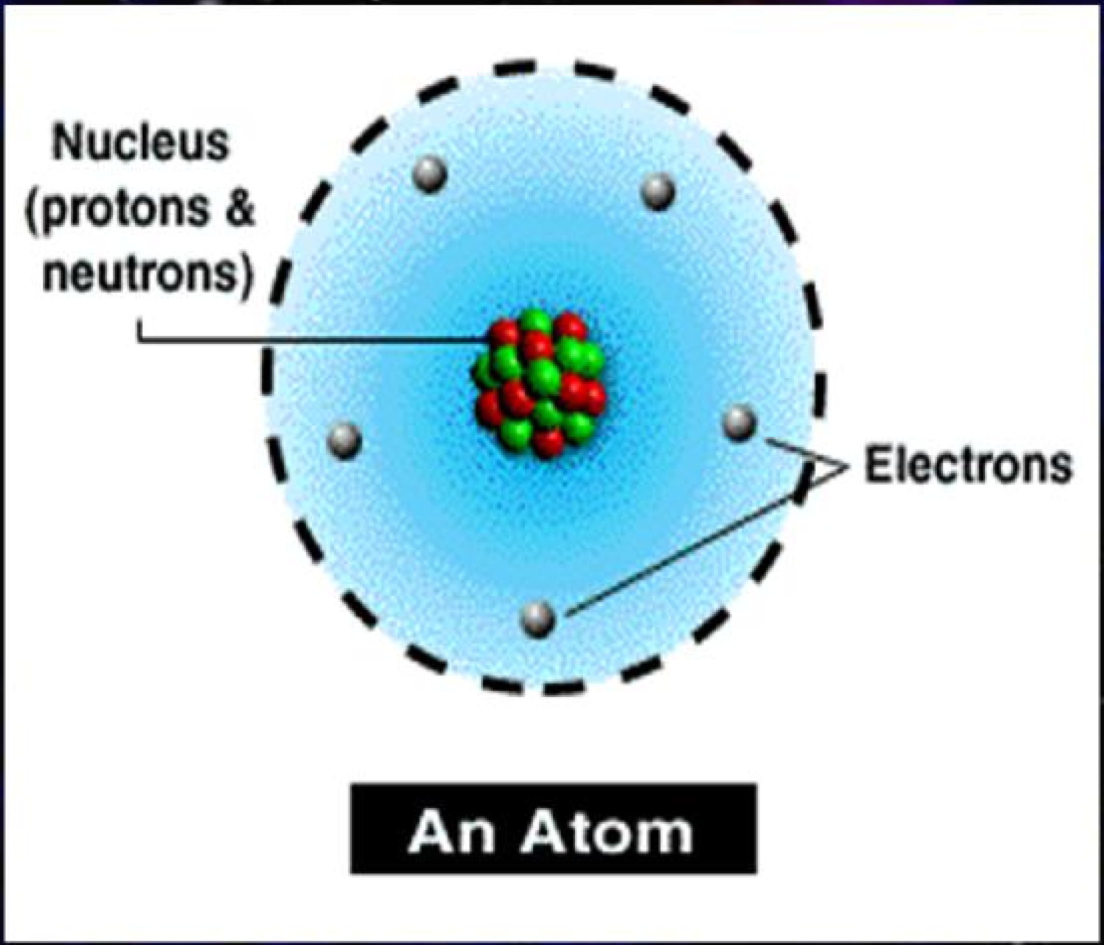




Ernest Rutherford, 1911




Atoms interact
only with their
outer electron
shells.



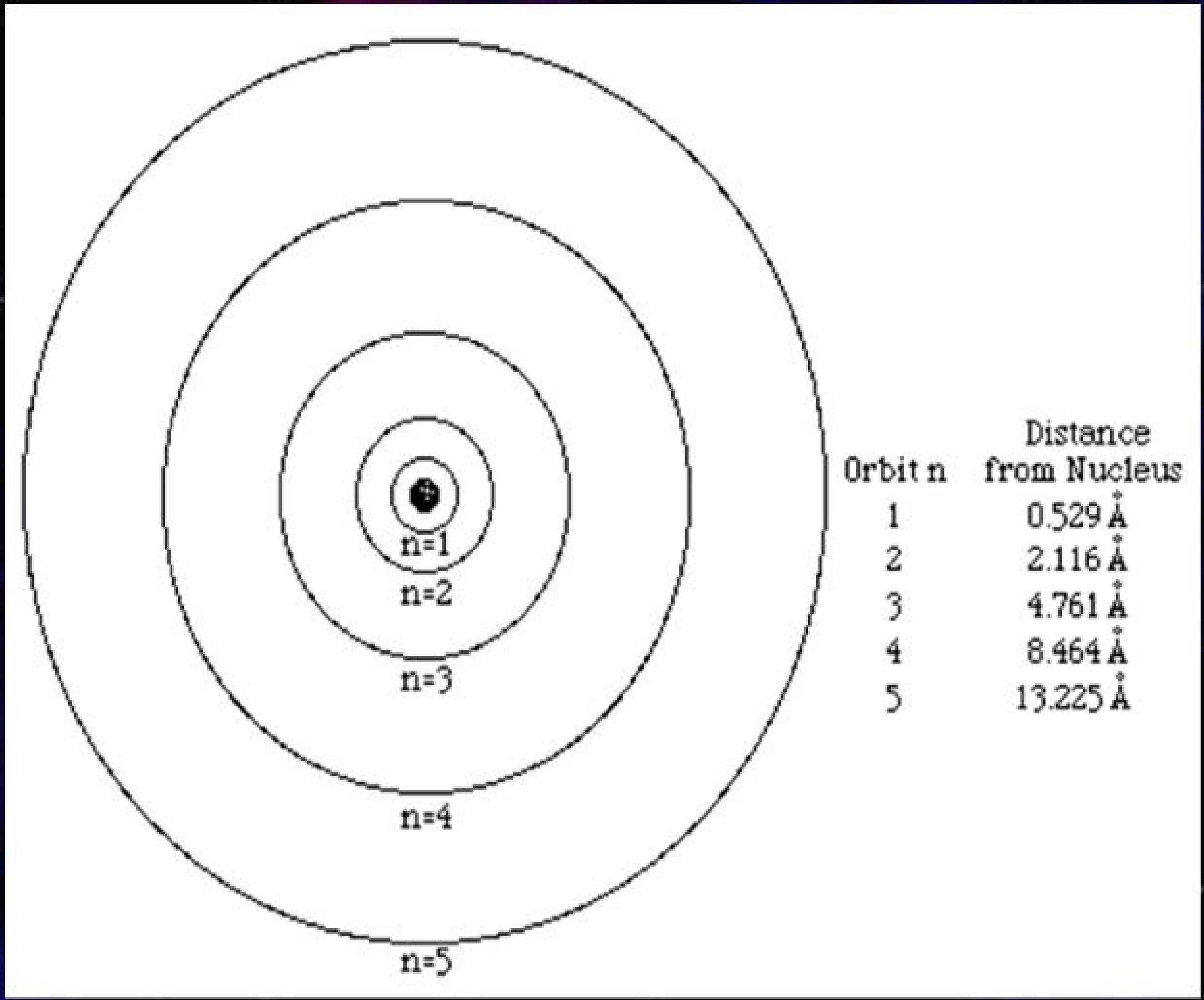
Protons: + charge
determines chemistry

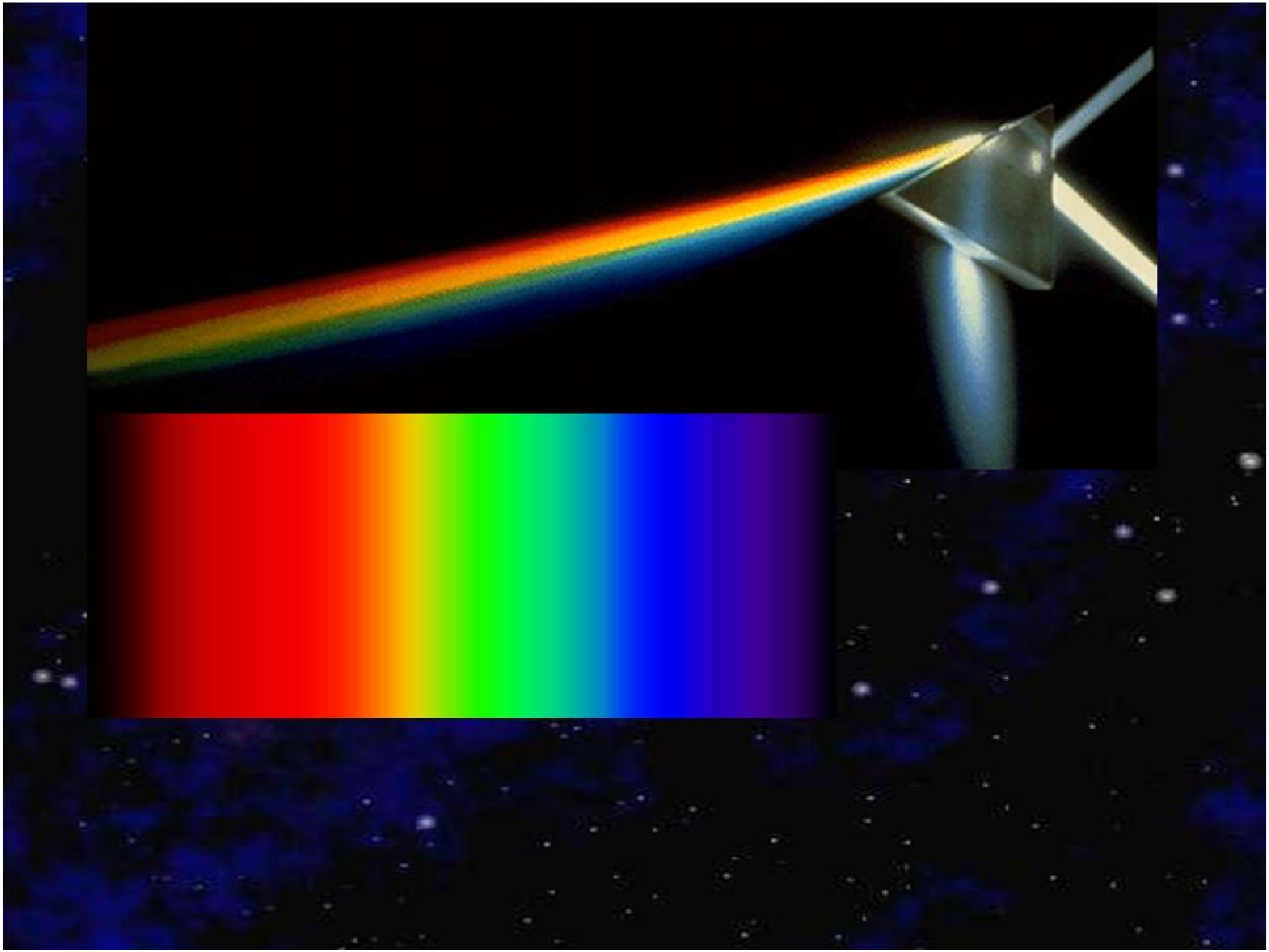
Neutrons: no charge
adds stability
adds mass

Electrons: - charge
interacts with rest of
world interacts with
light

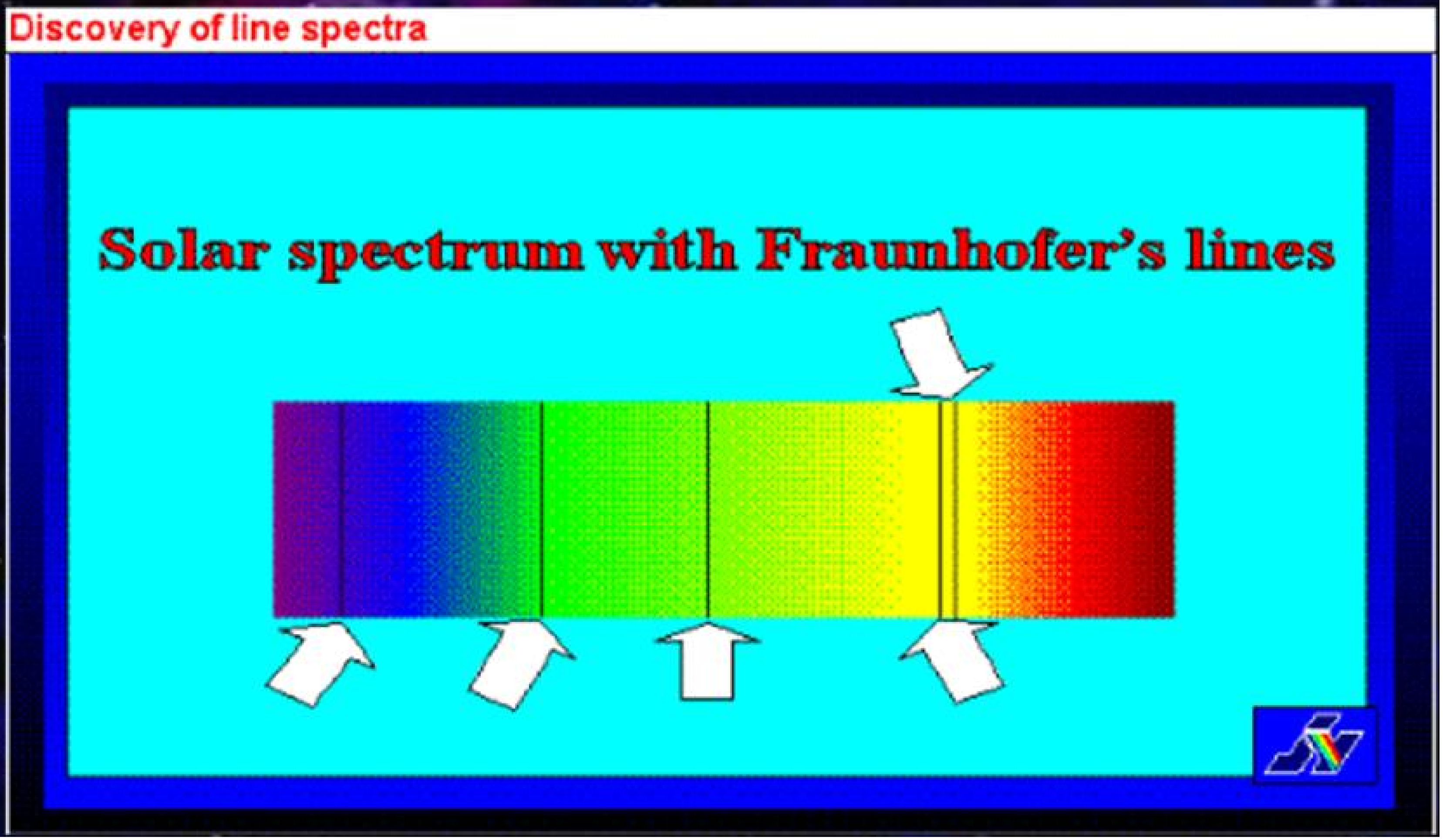
1 H 1.008	2 IIA 2A											13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8	9 ------- VIII ------- ------- 8 -------	10	11 IB 1B	12 IIB 2B	13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.47	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 La* 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 190.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.5	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (210)	85 At (210)	86 Rn (222)

The Simplest: Hydrogen

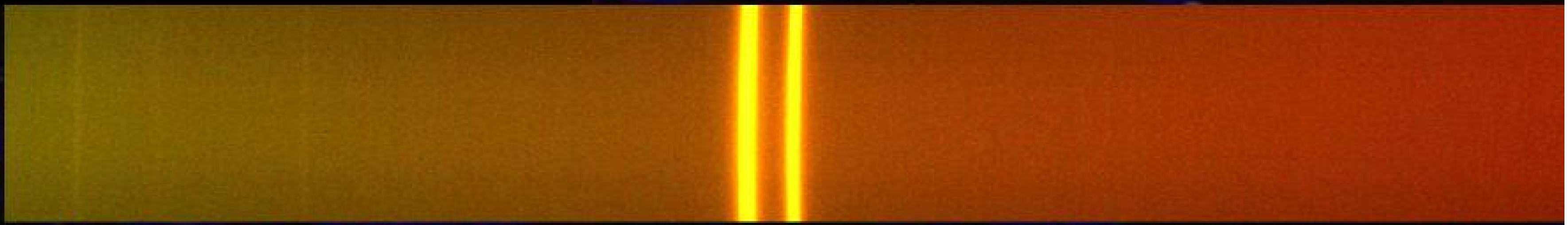




Josef Fraunhofer, 1787-1826



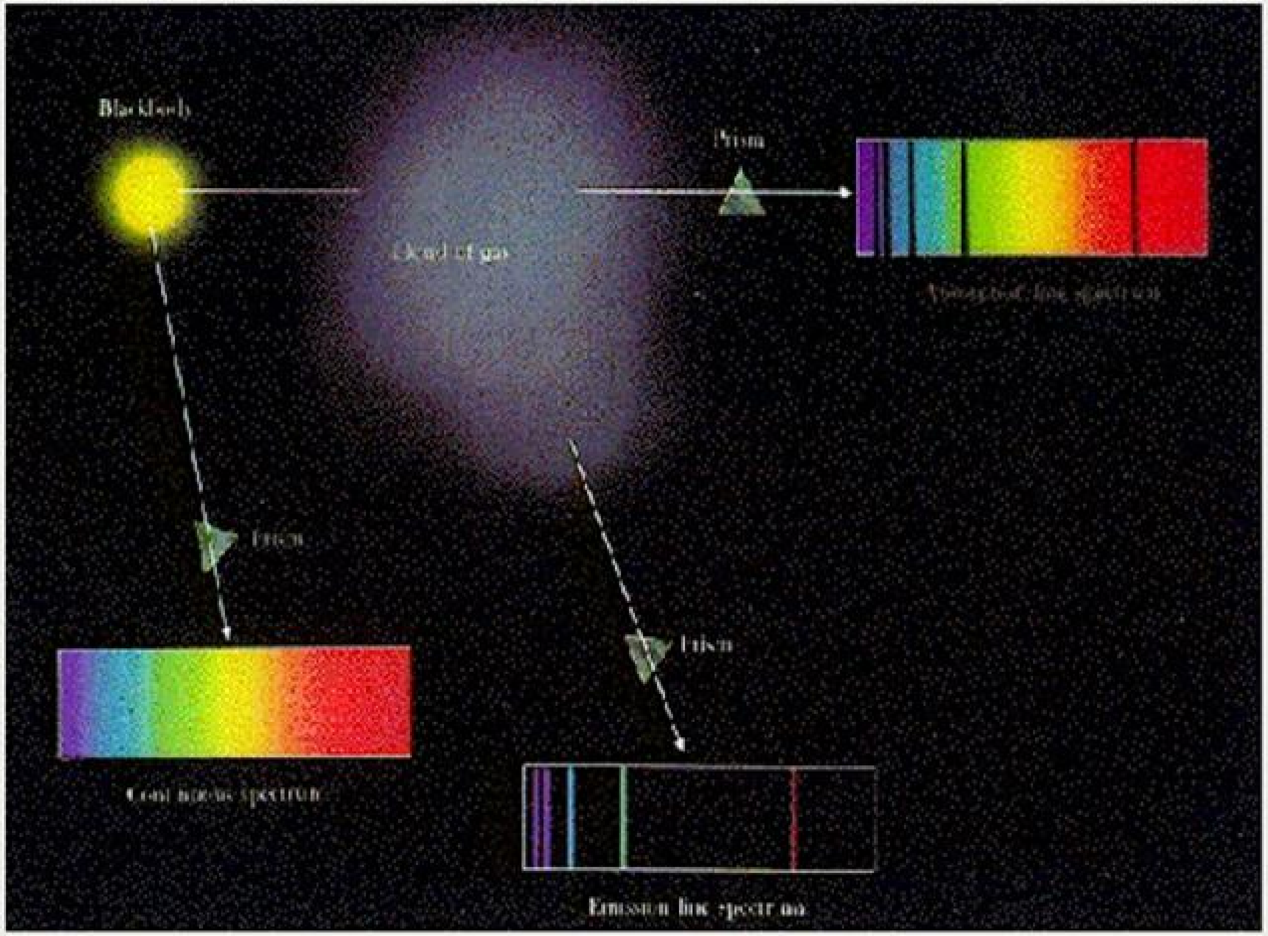
The Sodium Story

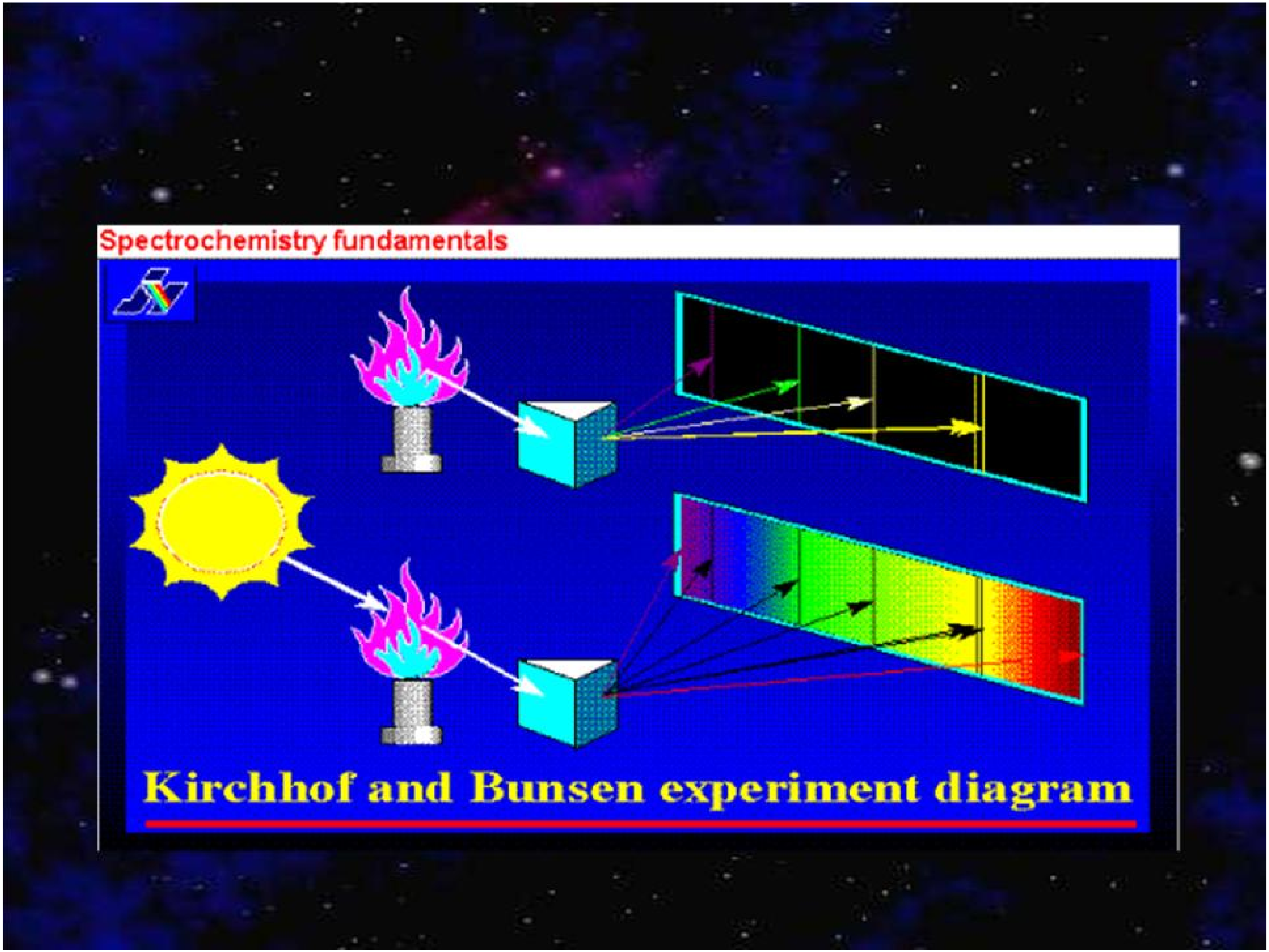


Kirchhoff's Laws

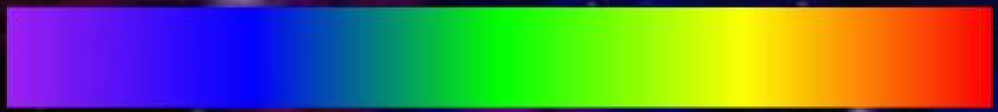
Bunsen

Kirchhoff

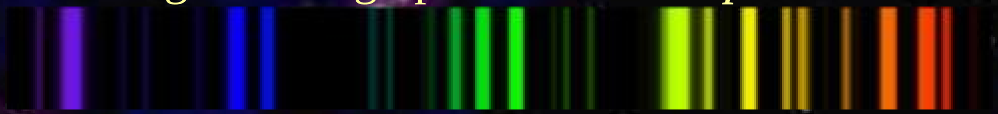



Spectrochemistry fundamentals
Kirchhof and Bunsen experiment diagram

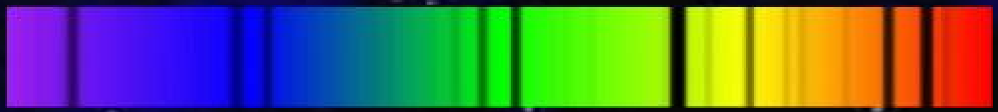
•from hot objects are *continuous*, like a rainbow



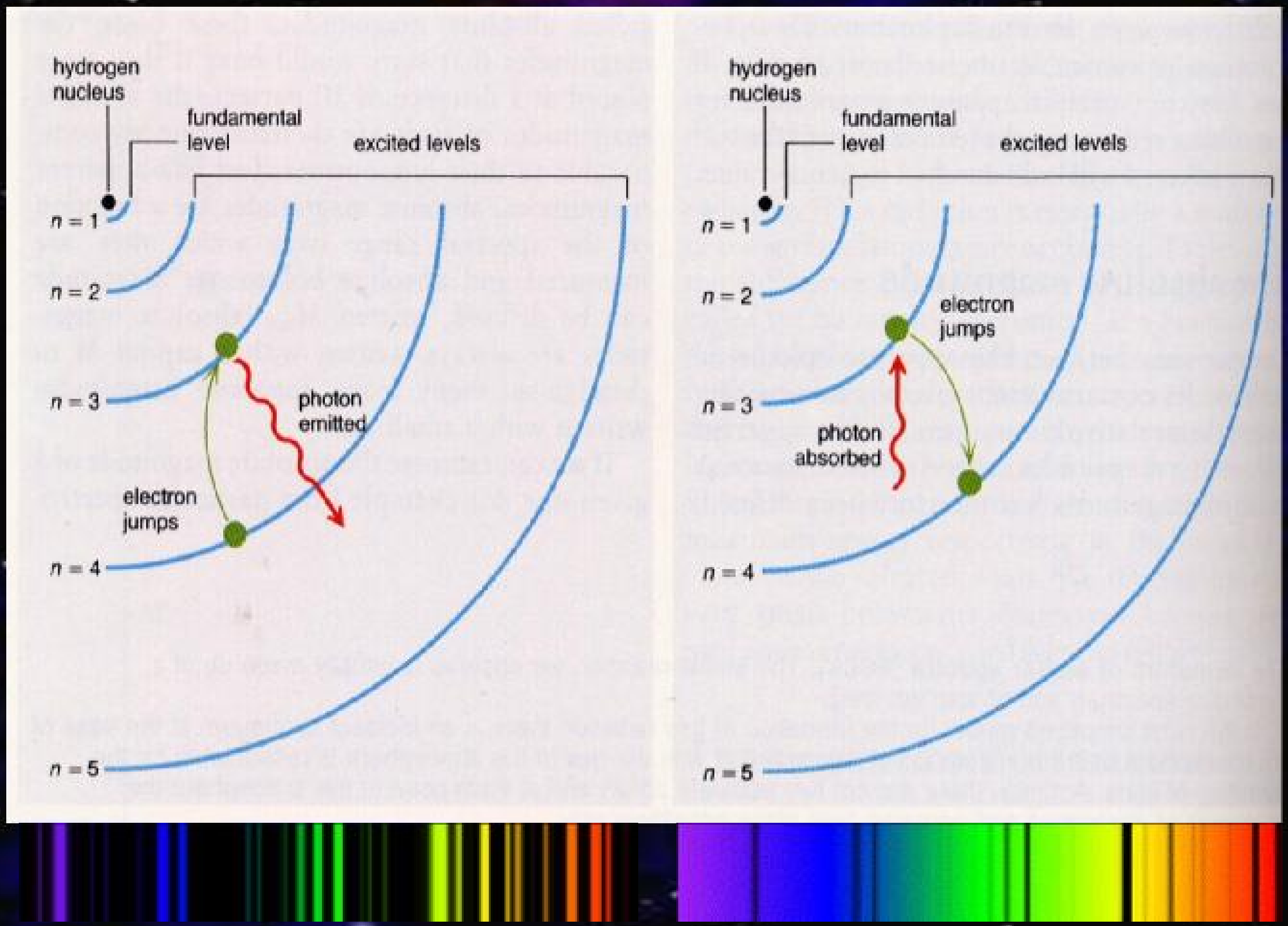
•atoms only emit light of specific colours, revealing their fingerprints as a *line spectrum*



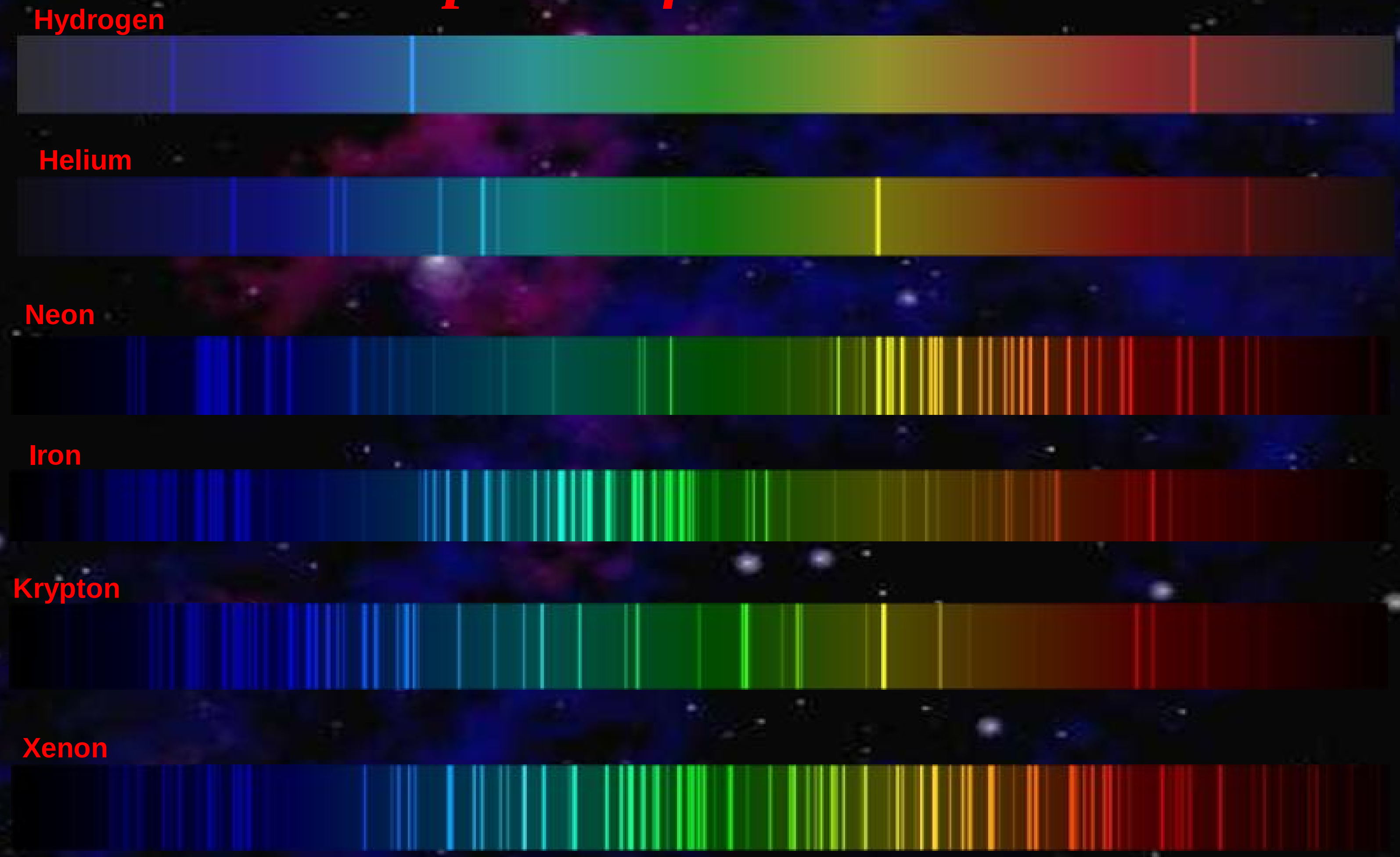
•atoms in front of a hot object absorb light at these colours, giving an *absorption spectrum*

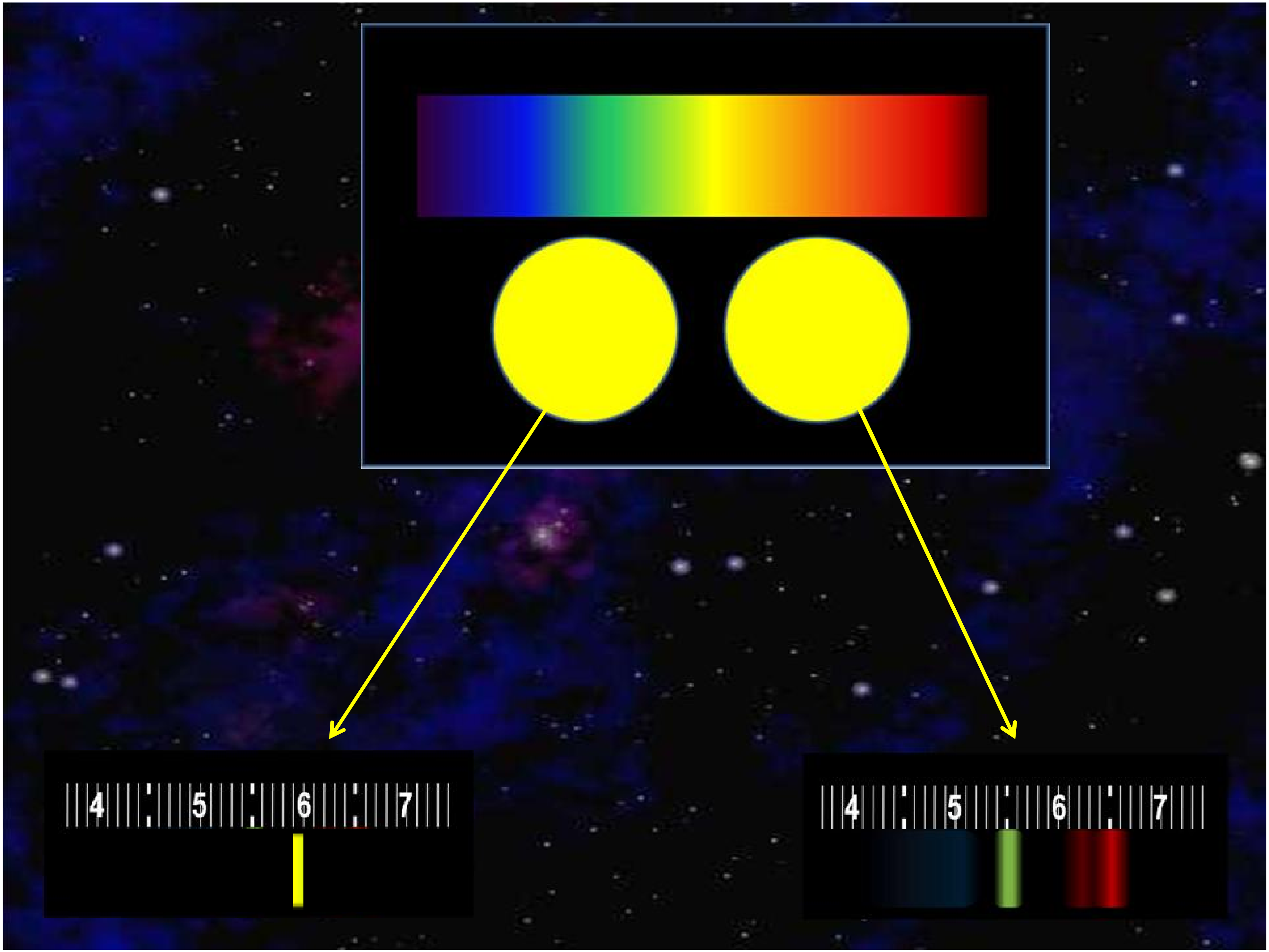


Generation of Emission or Absorption Line Spectrum

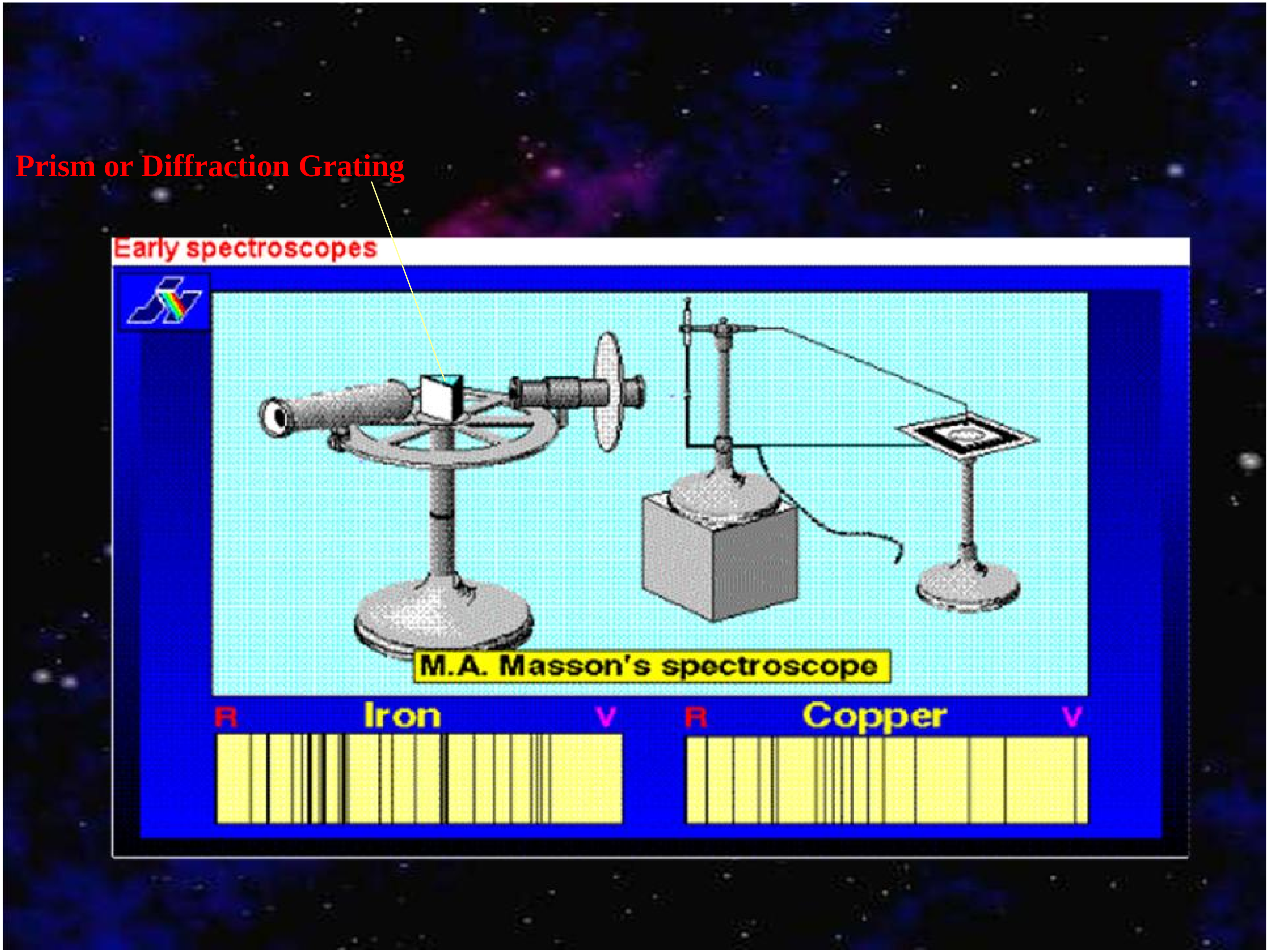


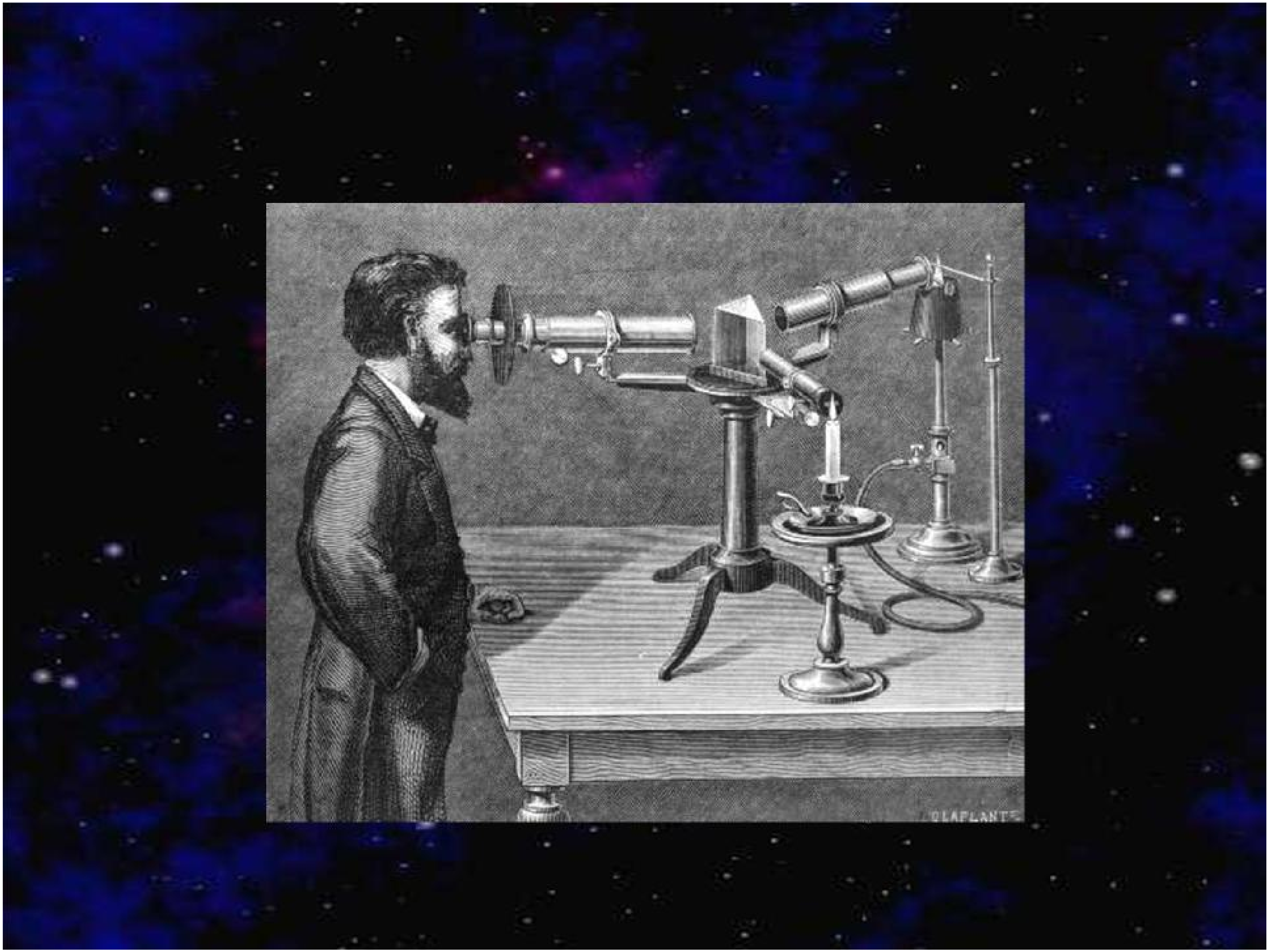
Visible Spectra of common Elements



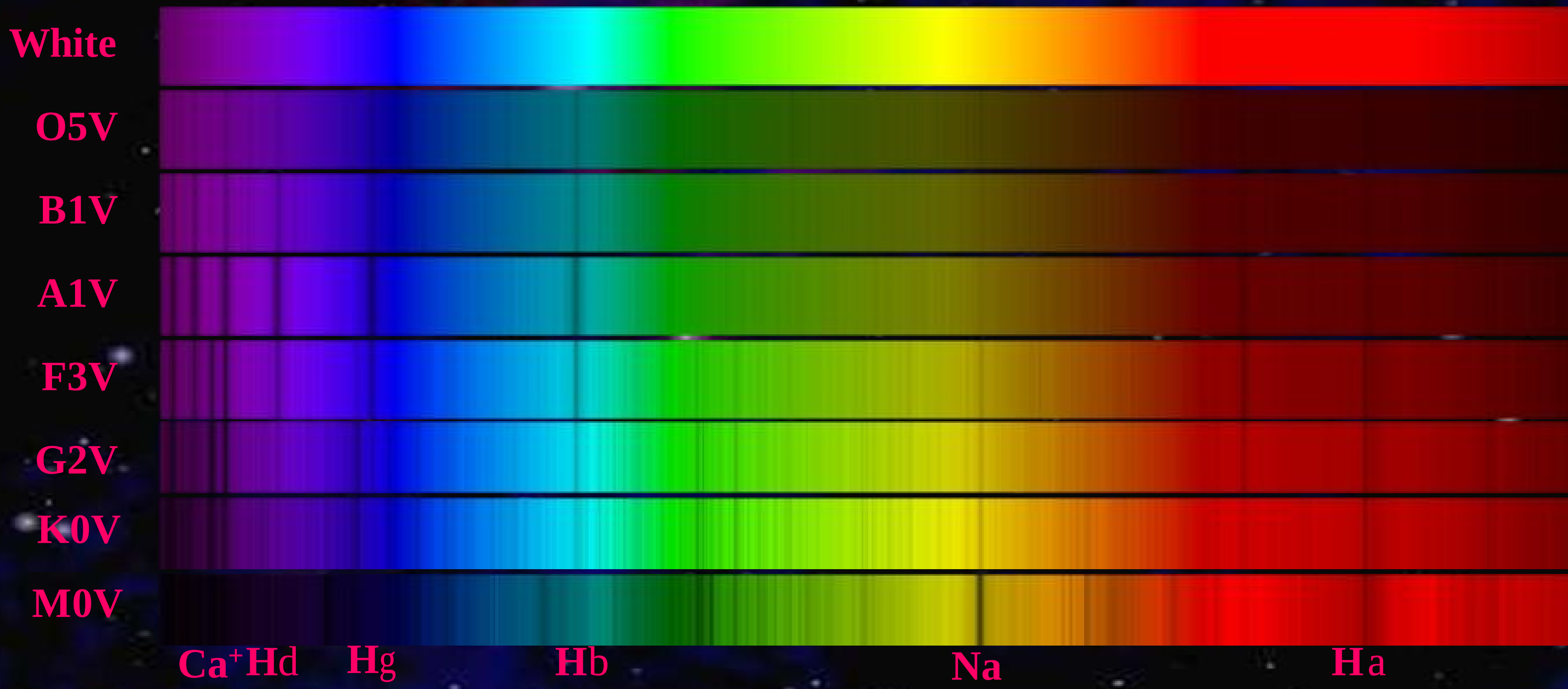


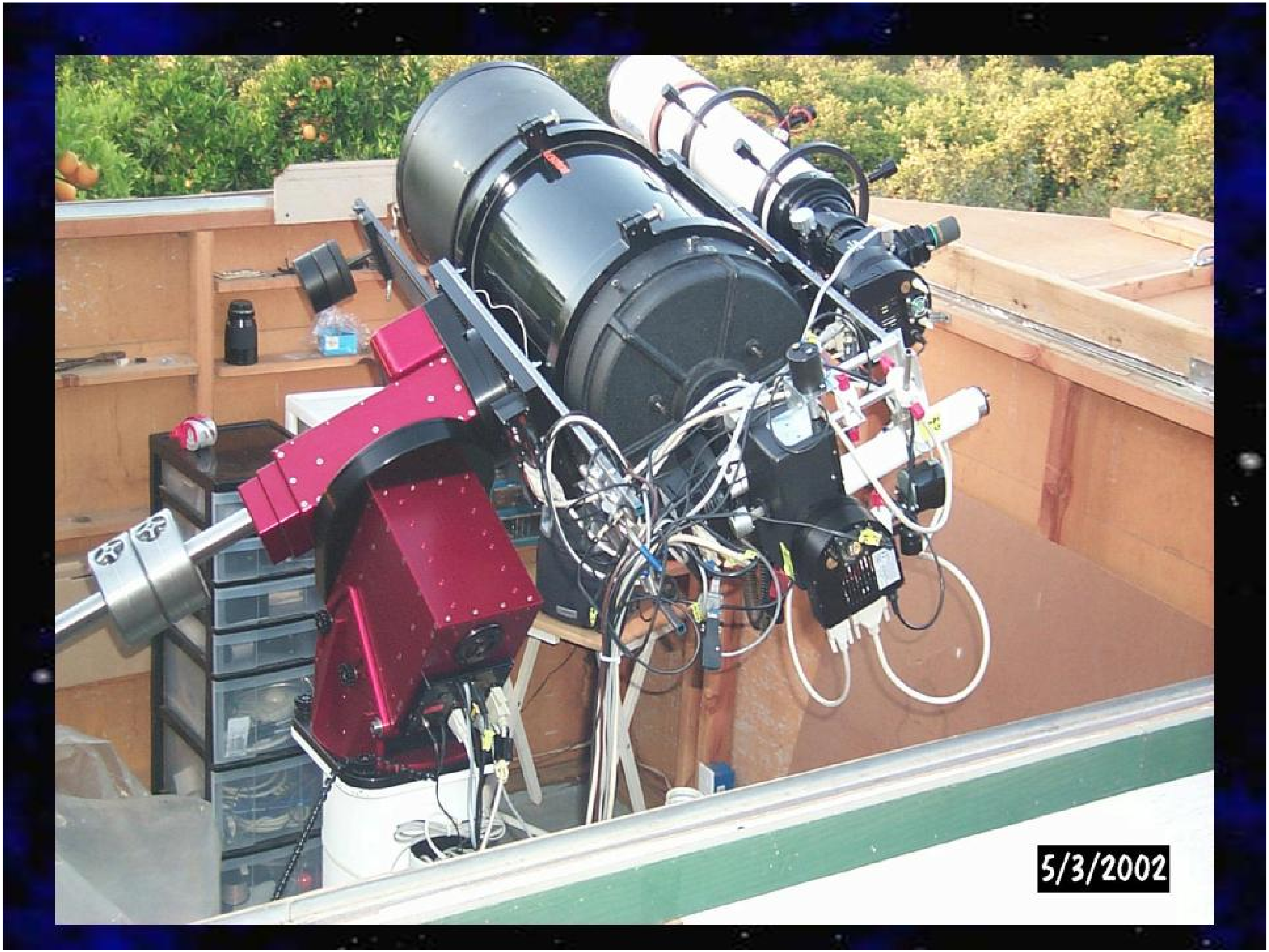
4 5 6 7
4 5 6 7

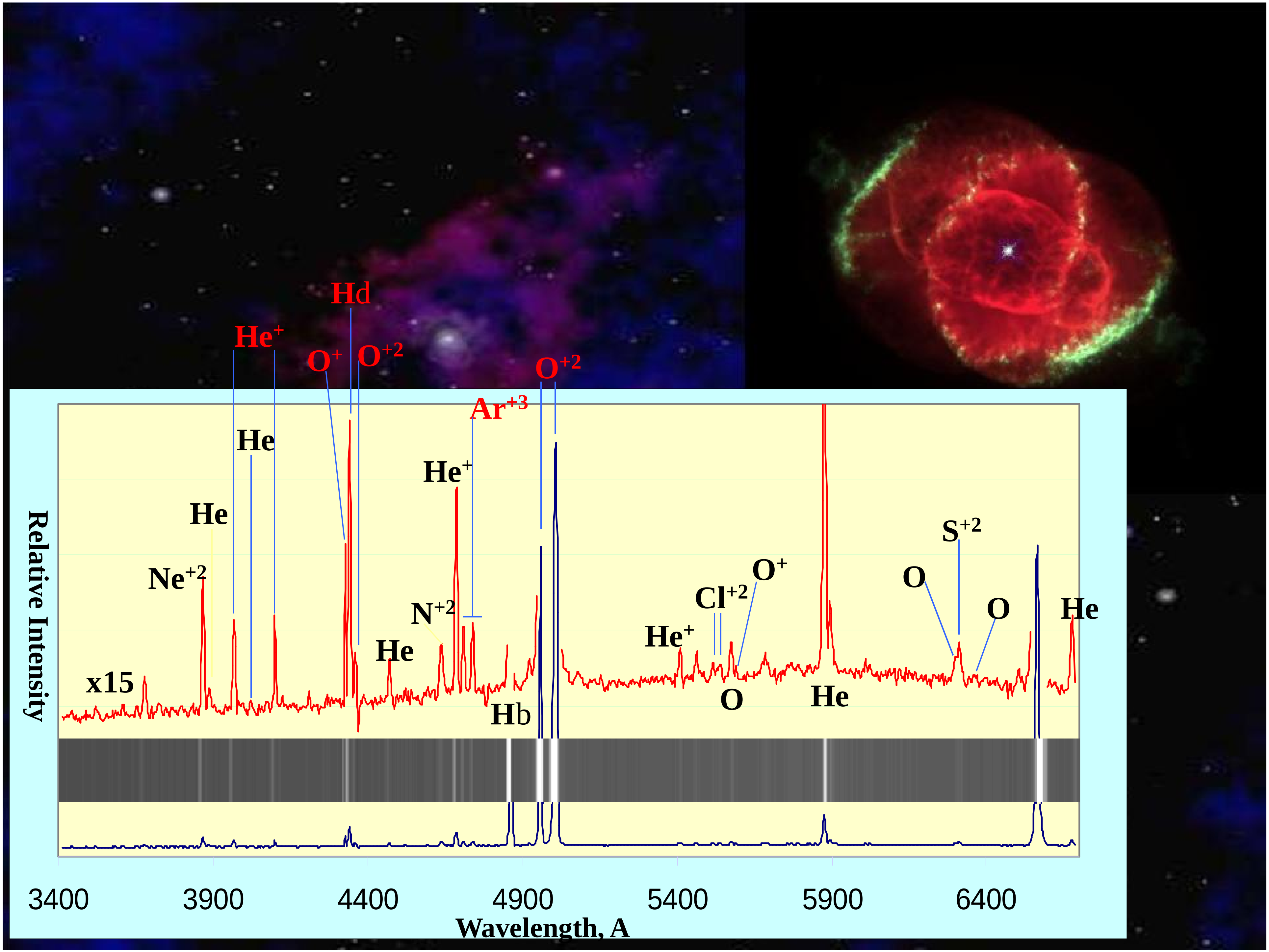

Prism or Diffraction Grating
Early spectroscopes
M.A. Masson's spectroscope
R
Iron
V
R
Copper
V

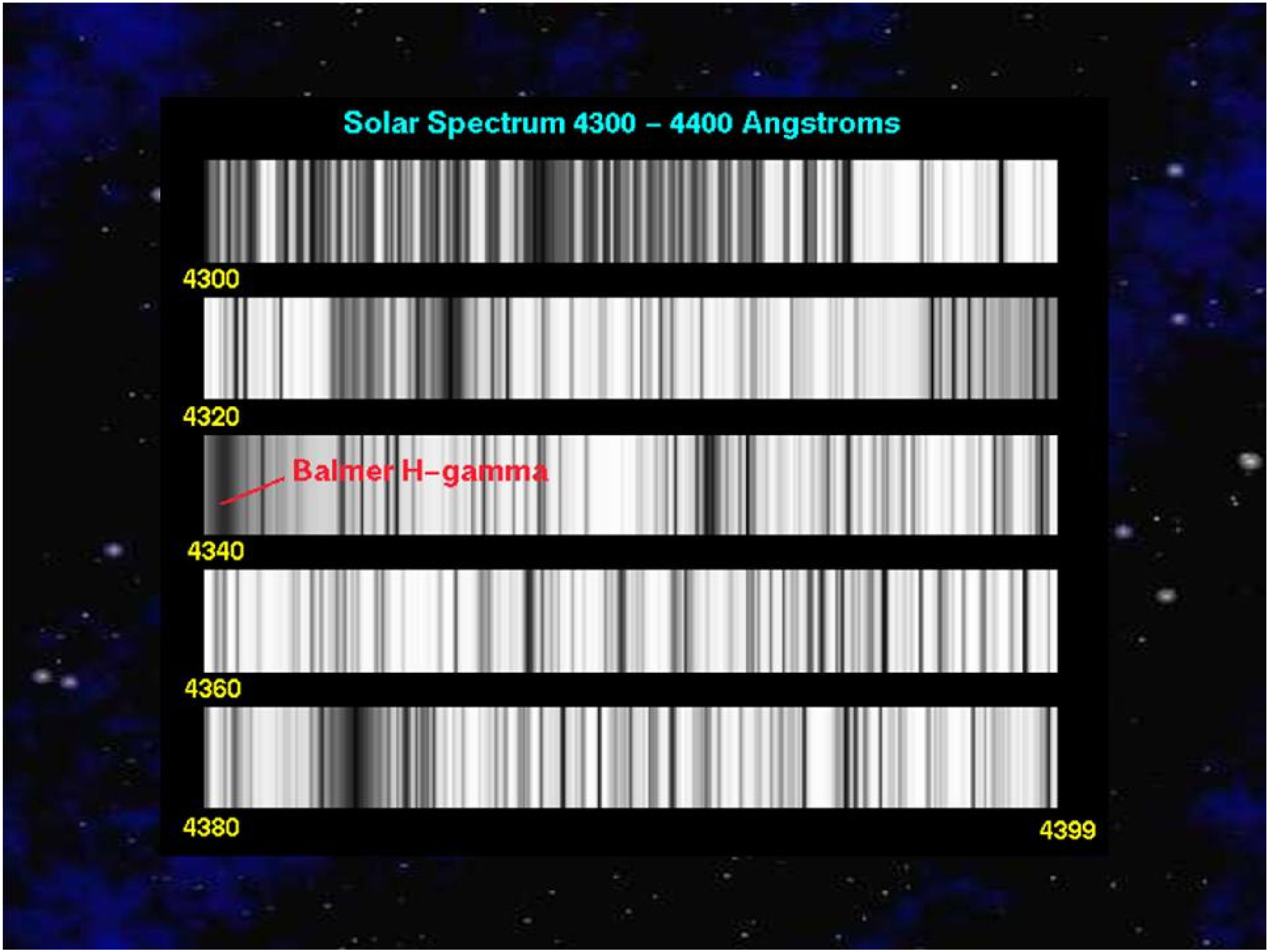


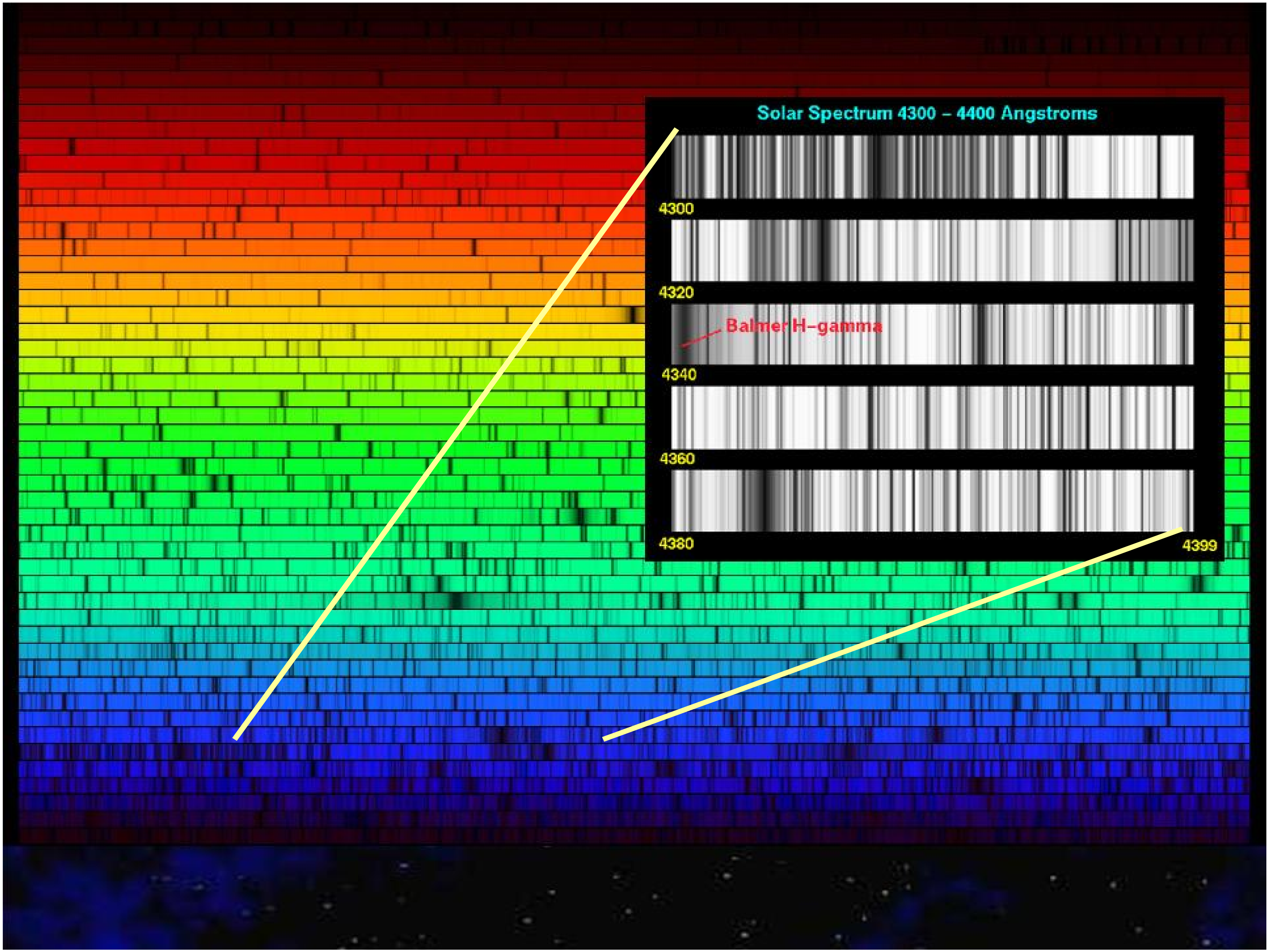
Spectral Sequence in Color



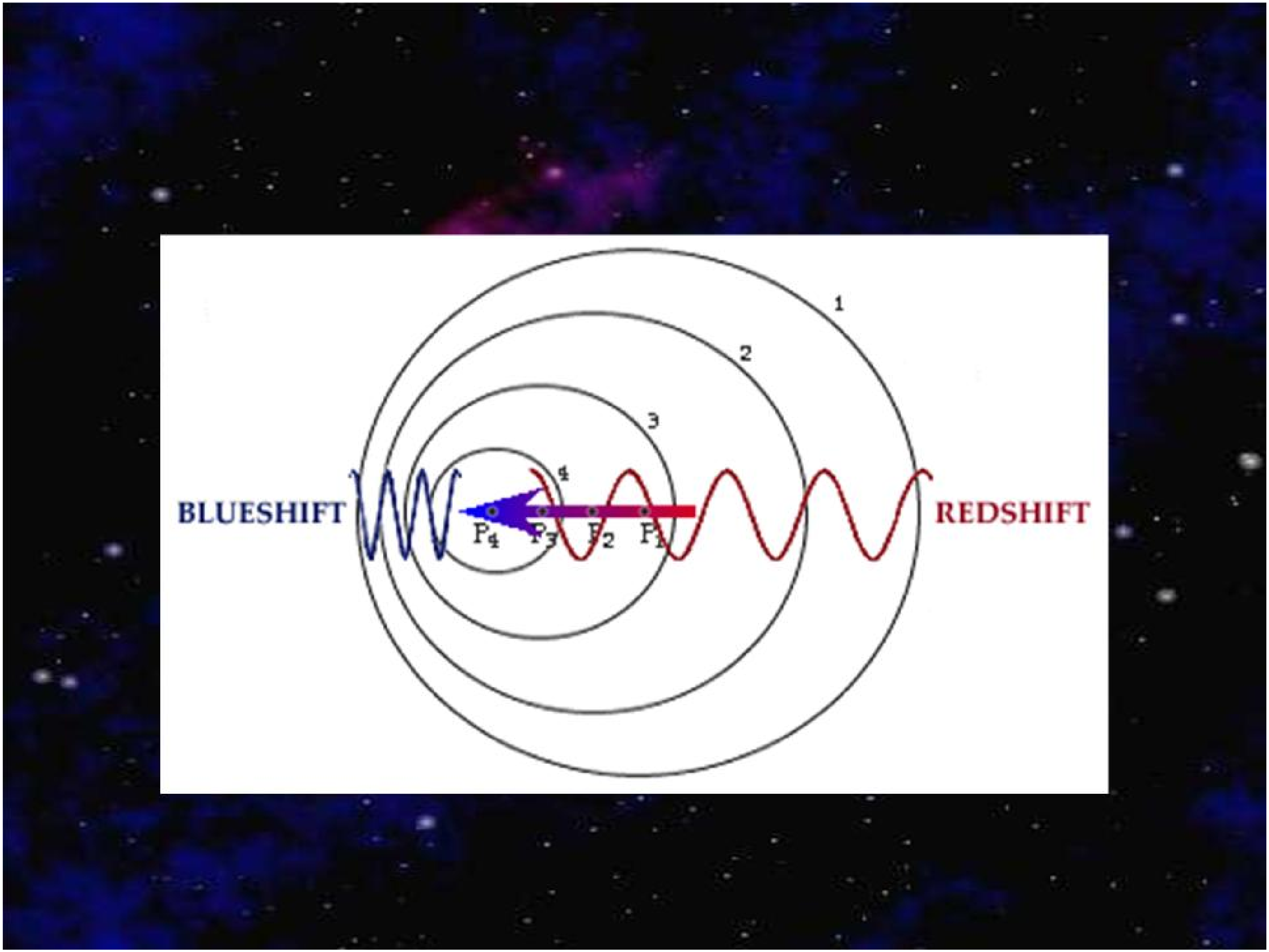

5/3/2002


Hd
He+
O+
O+2
O+2
Ar+3
He
He+
He
Ne+2
N+2
He
x15
Hb
S+2
O+
Cl+2
O
O
He
He+
O
He
Relative Intensity
3400
3900
4400
4900
5400
5900
6400
Wavelength, A


Solar Spectrum 4300 – 4400 Angstroms
4300
4320
Balmer H-gamma
4340
4360
4380
4399

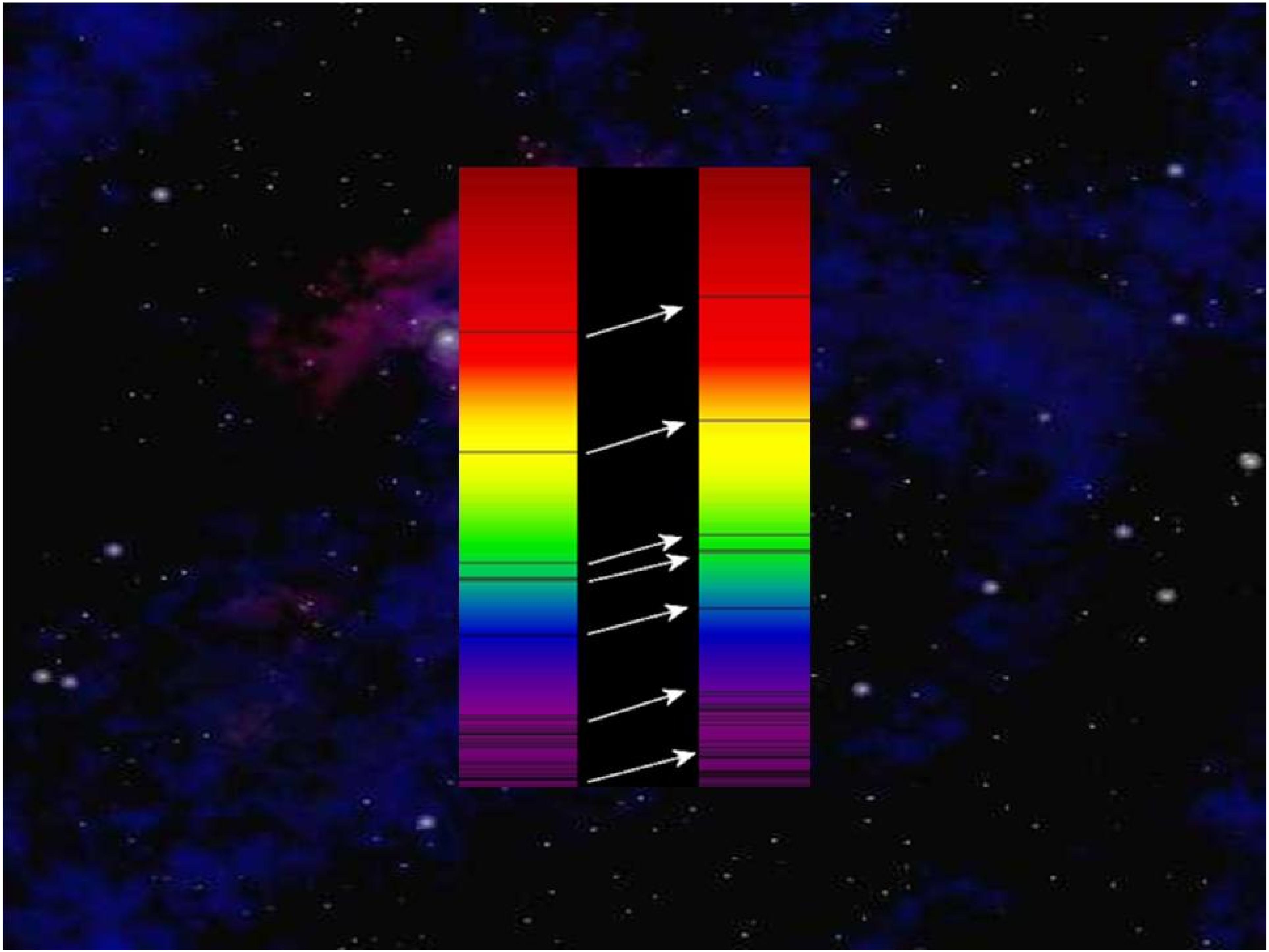


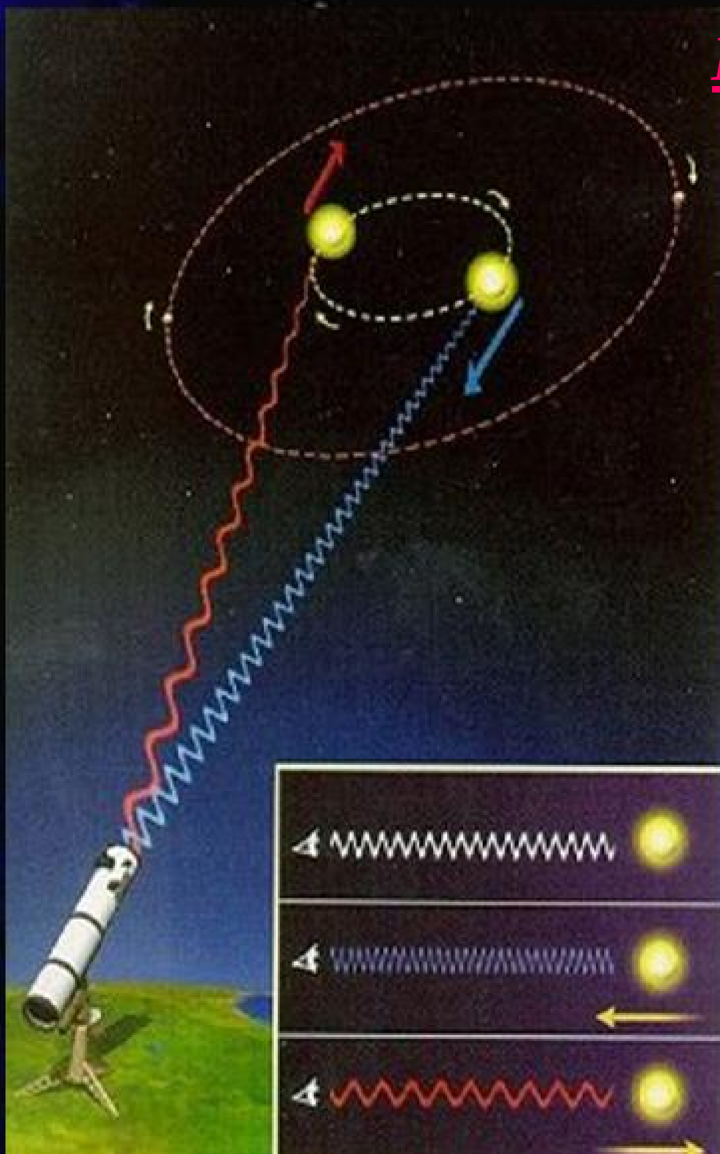
Solar Spectrum 4300 – 4400 Angstroms
4300
4320
Balmer H-gamma
4340
4360
4380
4399


1
2
3
4
BLUESHIFT
REDSHIFT
P4
P3
P2
P1

esa

www.spacetelescope.org

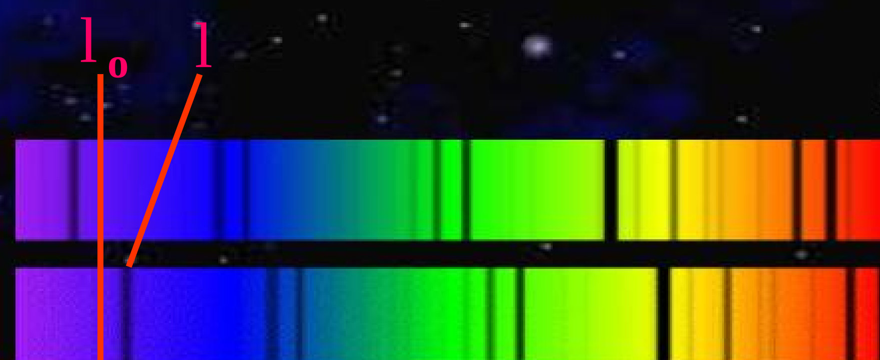




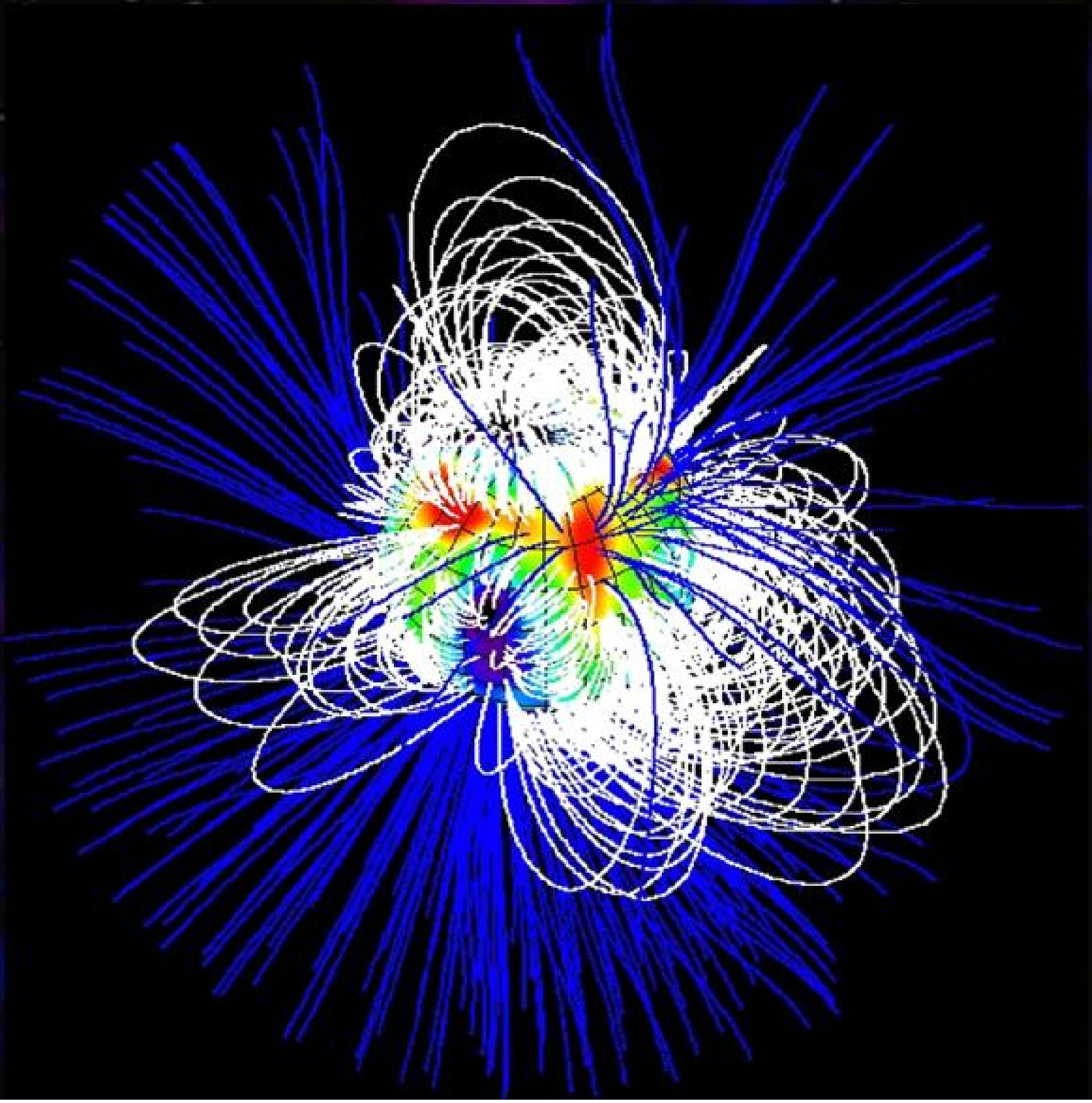
Doppler Shift of Light: measuring the speed of objects

$$z = v/c = (l - l_o)/\, l_o$$

v = velocity of object
c = velocity of light (300,000 km/sec)
l_o = rest wavelength
l = measured wavelength



Magnetic Field Map of star FU Aurigae



In 1835, Auguste Comte, the French philosopher and founder of sociology, said of the stars:

"We shall never be able to study, by any method, their chemical composition or their mineralogical structure... Our positive knowledge of stars is necessarily limited to their geometric and mechanical phenomena".