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

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

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

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

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

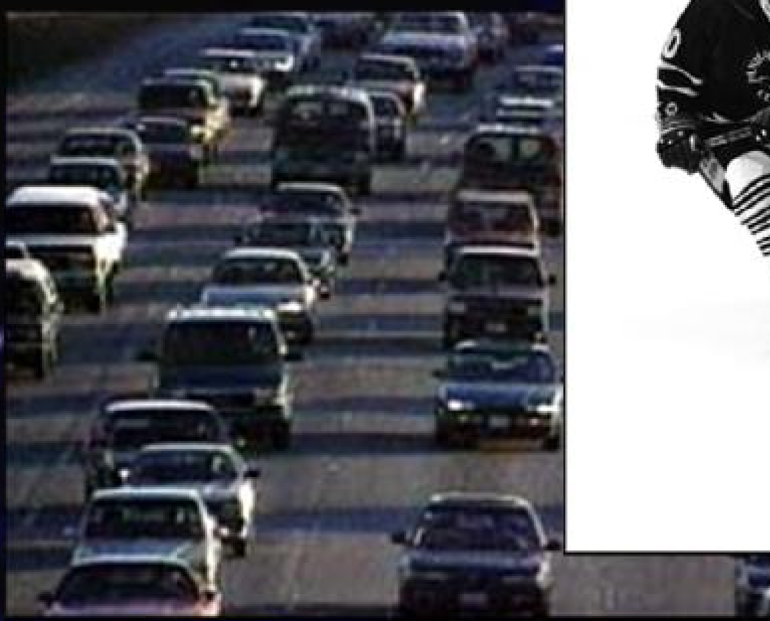
$$\int_\gamma f(z)\,dz = F(z(\beta)) - F(z(\alpha)).$$

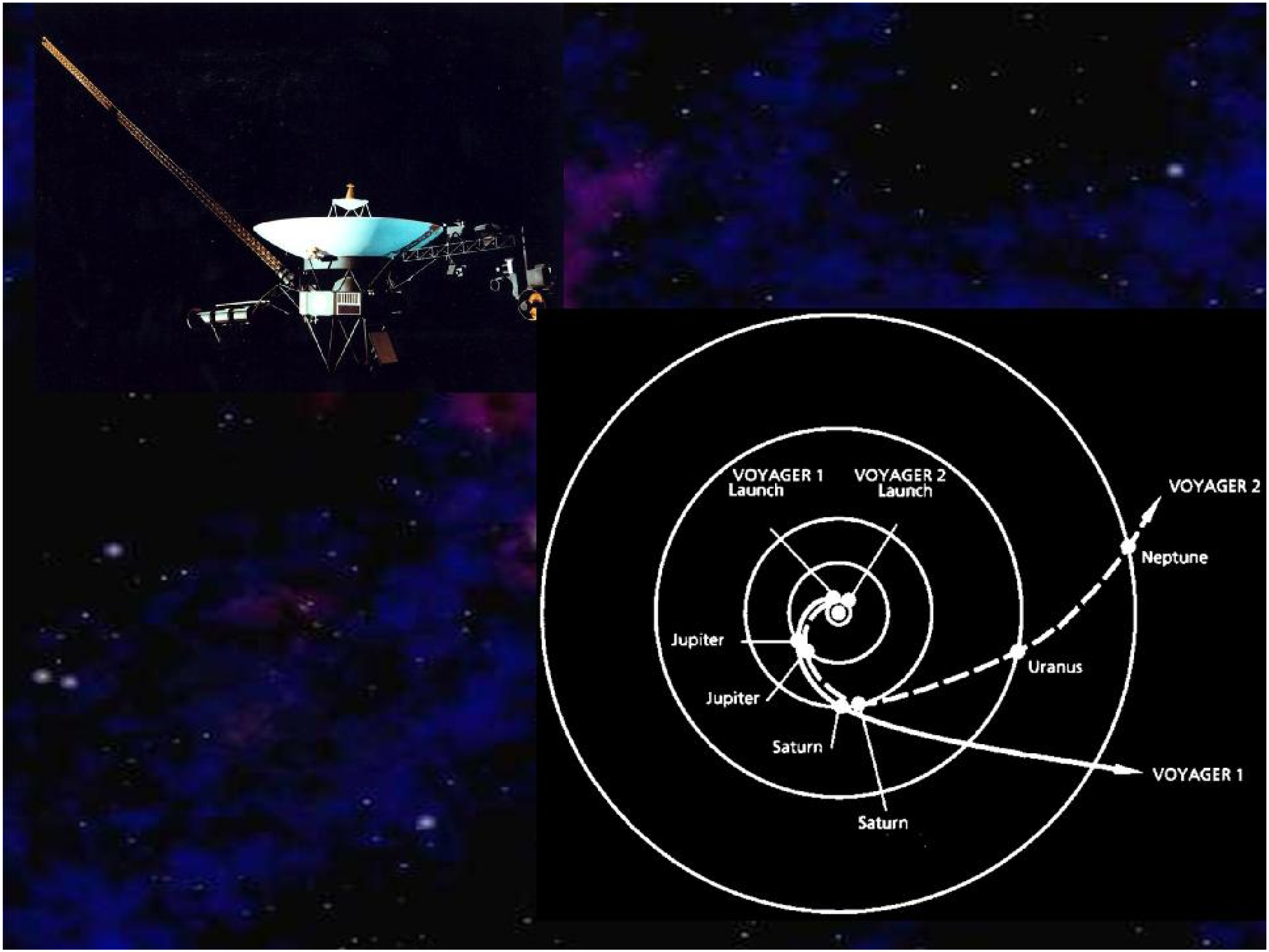
Newton's First Law

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.




VOYAGER 1
Launch
VOYAGER 2
Launch
VOYAGER 2
Neptune
Jupiter
Jupiter
Uranus
Saturn
Saturn
VOYAGER 1

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

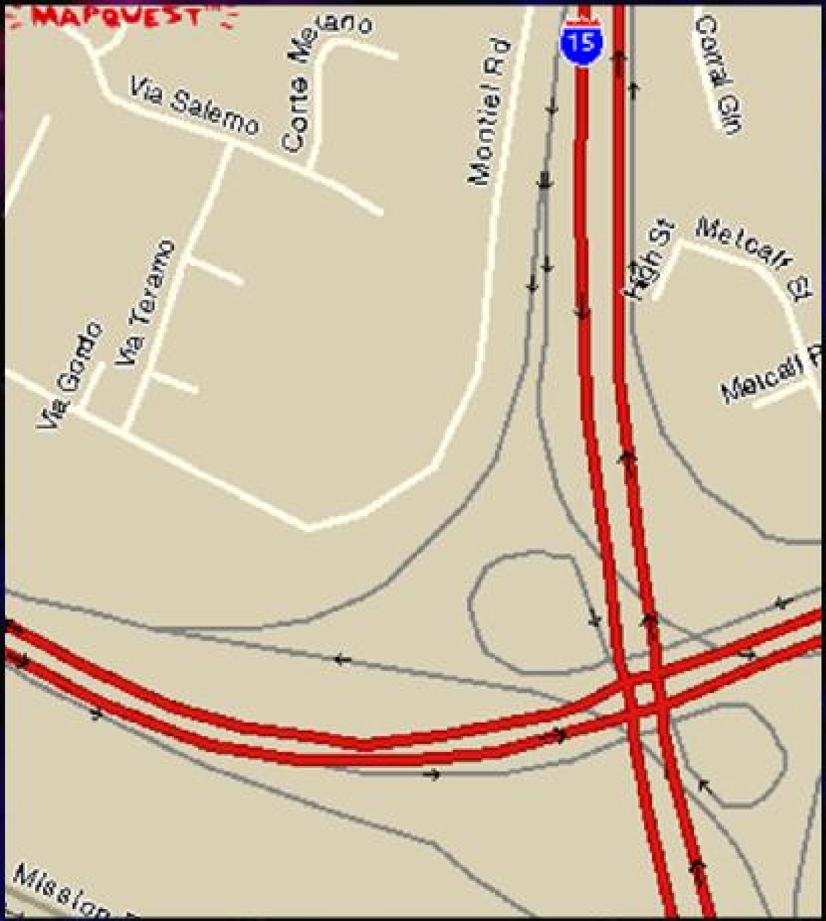
Speed + Direction

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

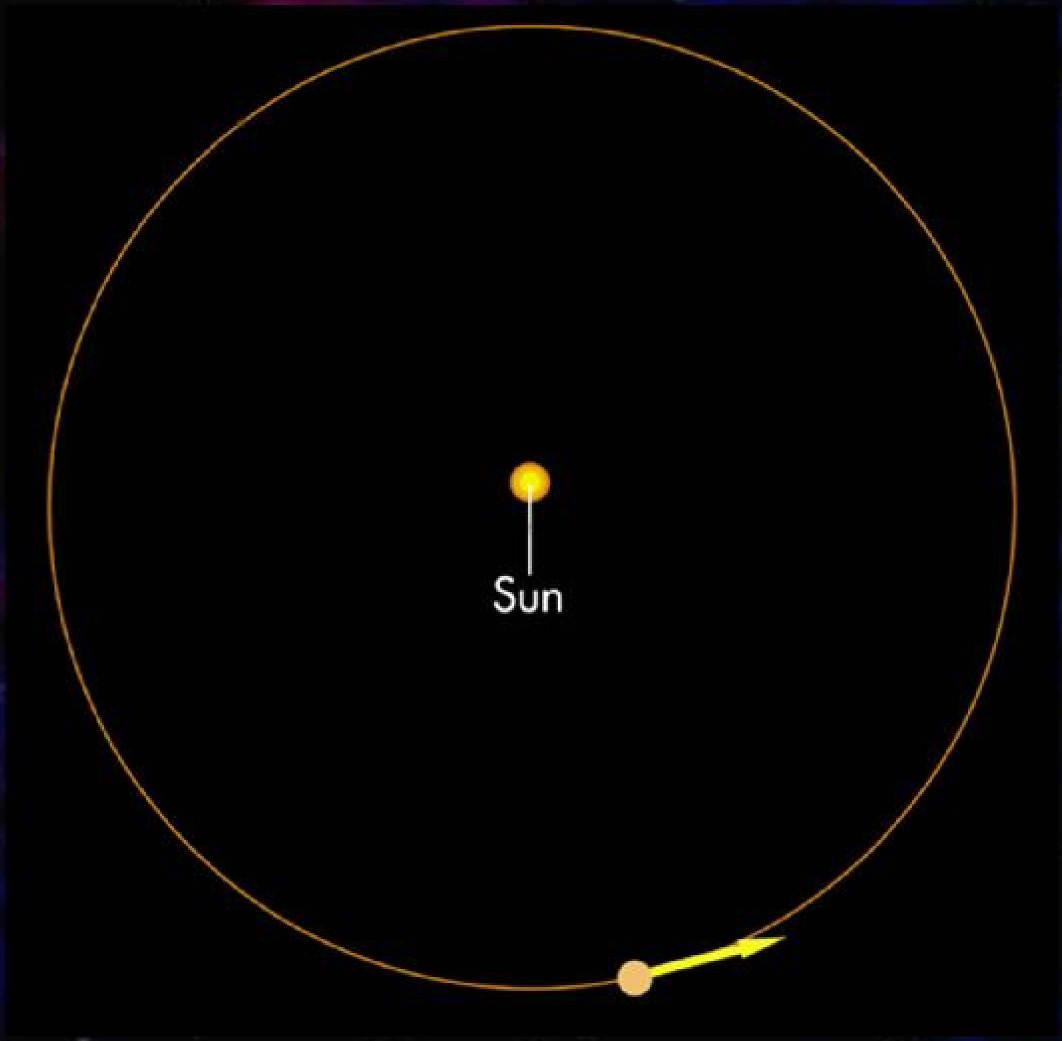
Acceleration:

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

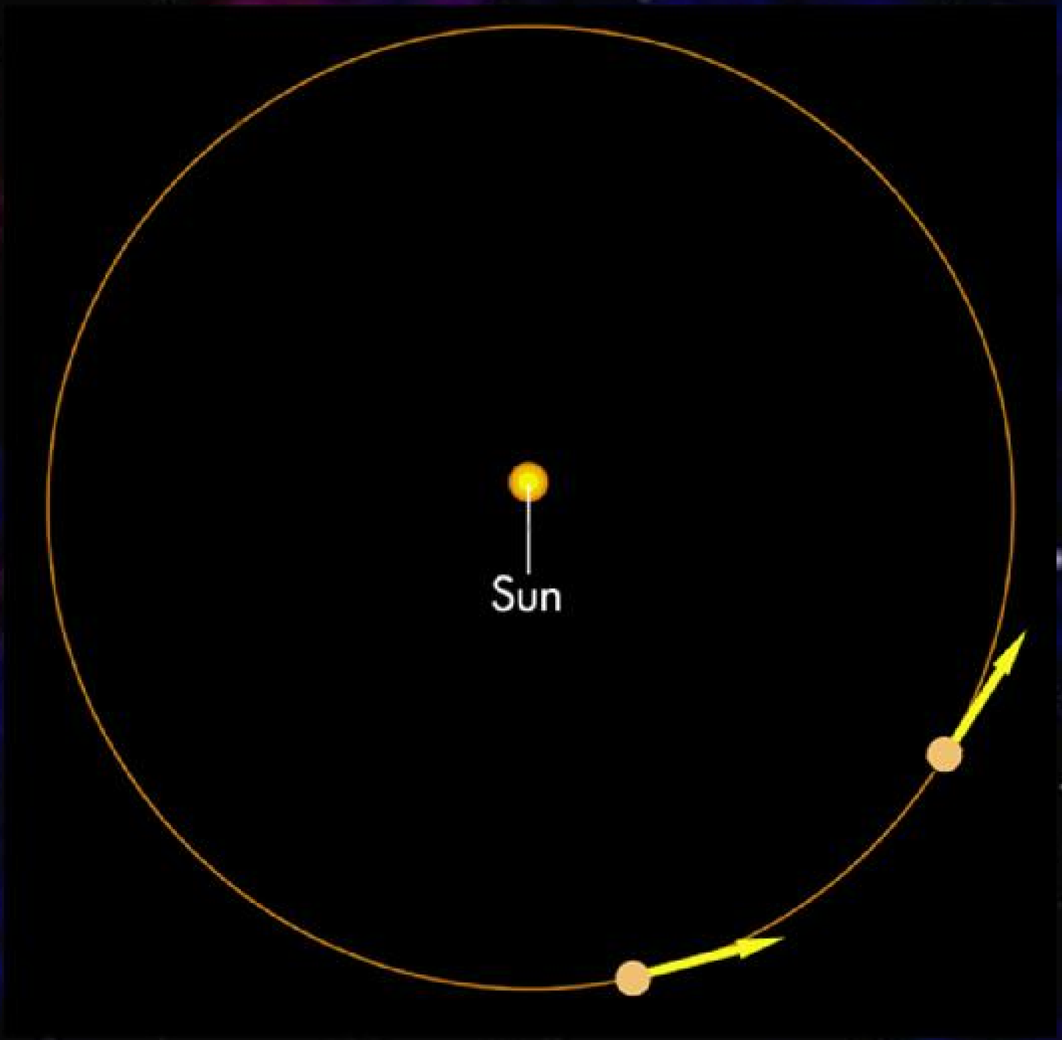
Is it possible to change your velocity without changing your speed?



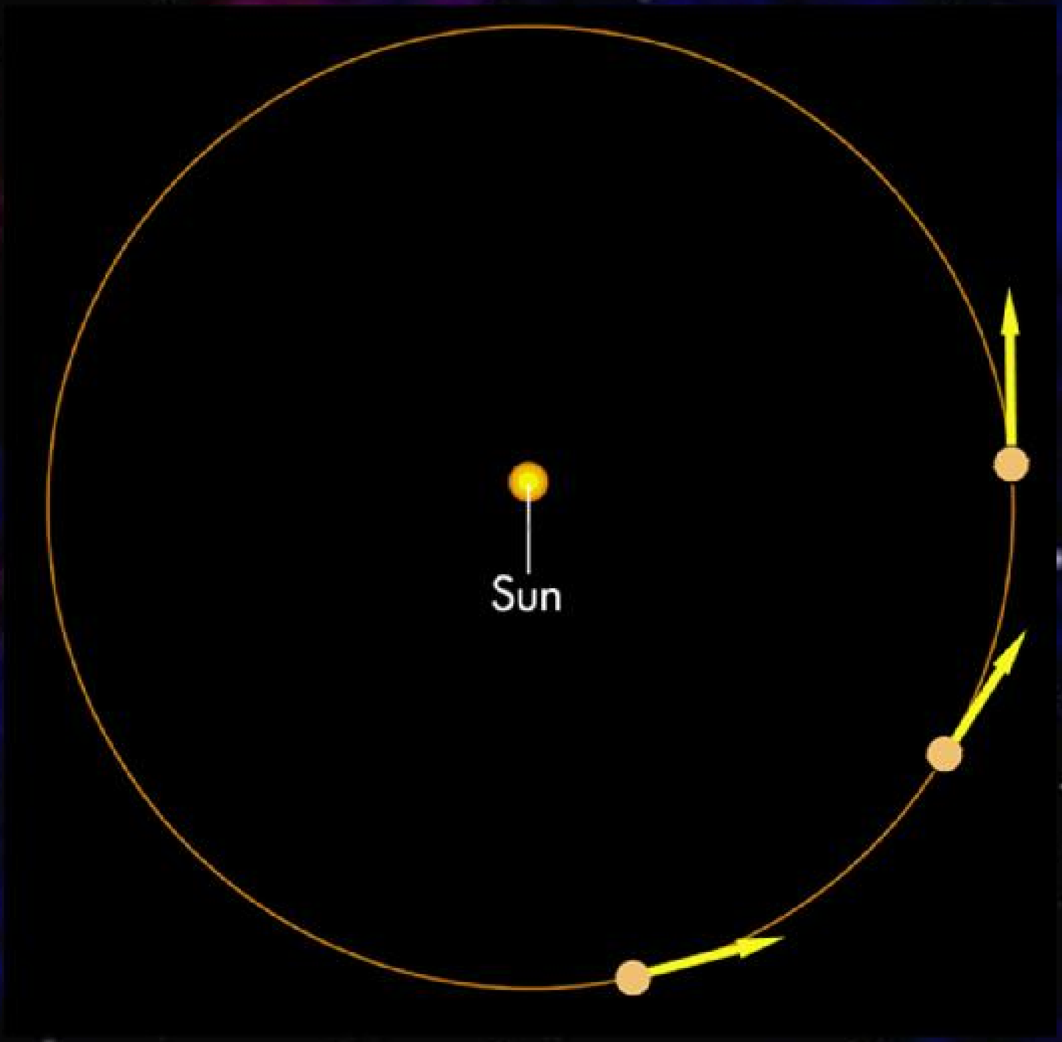
Is is possible to change your velocity without changing your speed?



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



Is is 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.

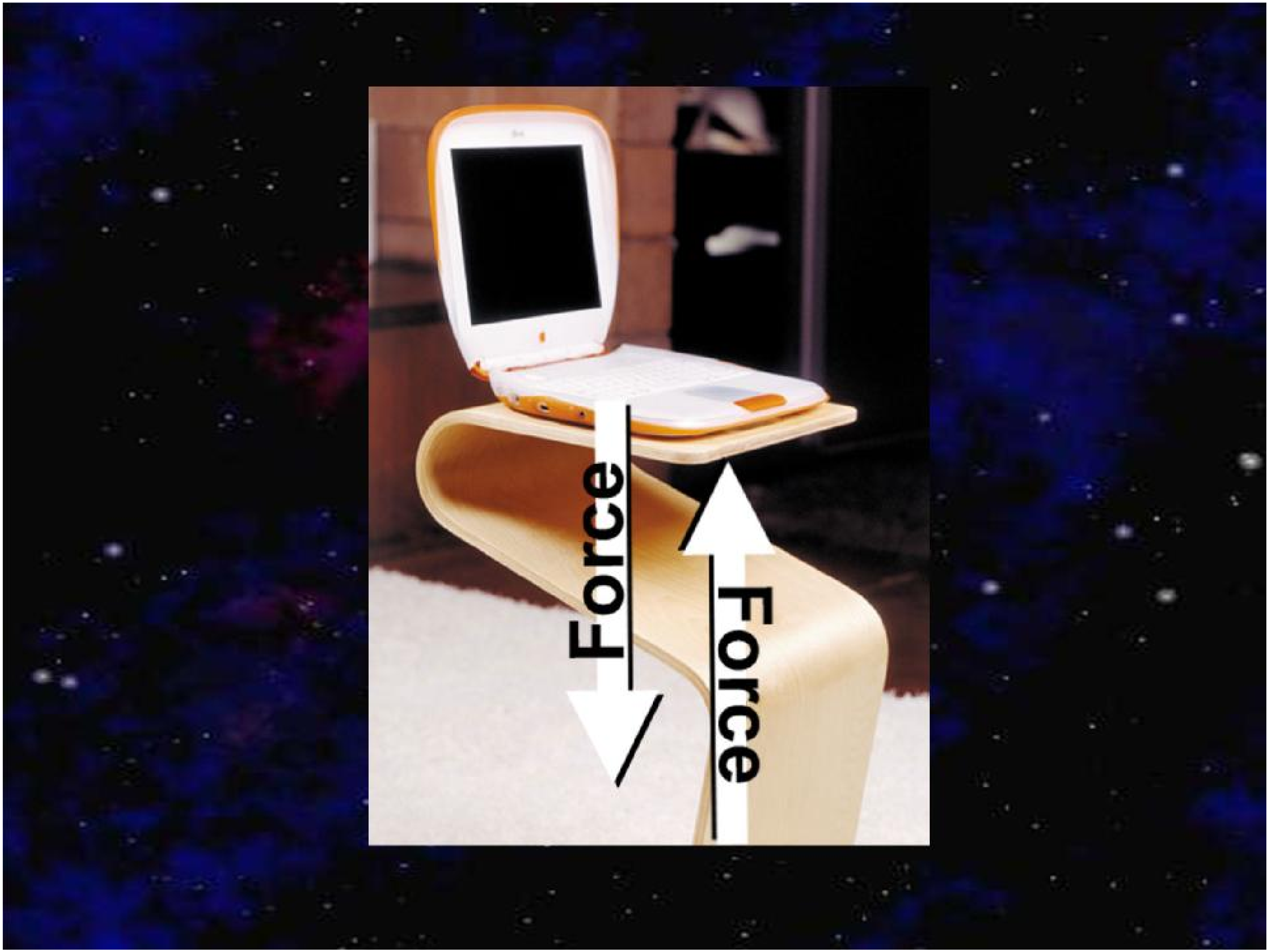
$$F = ma$$

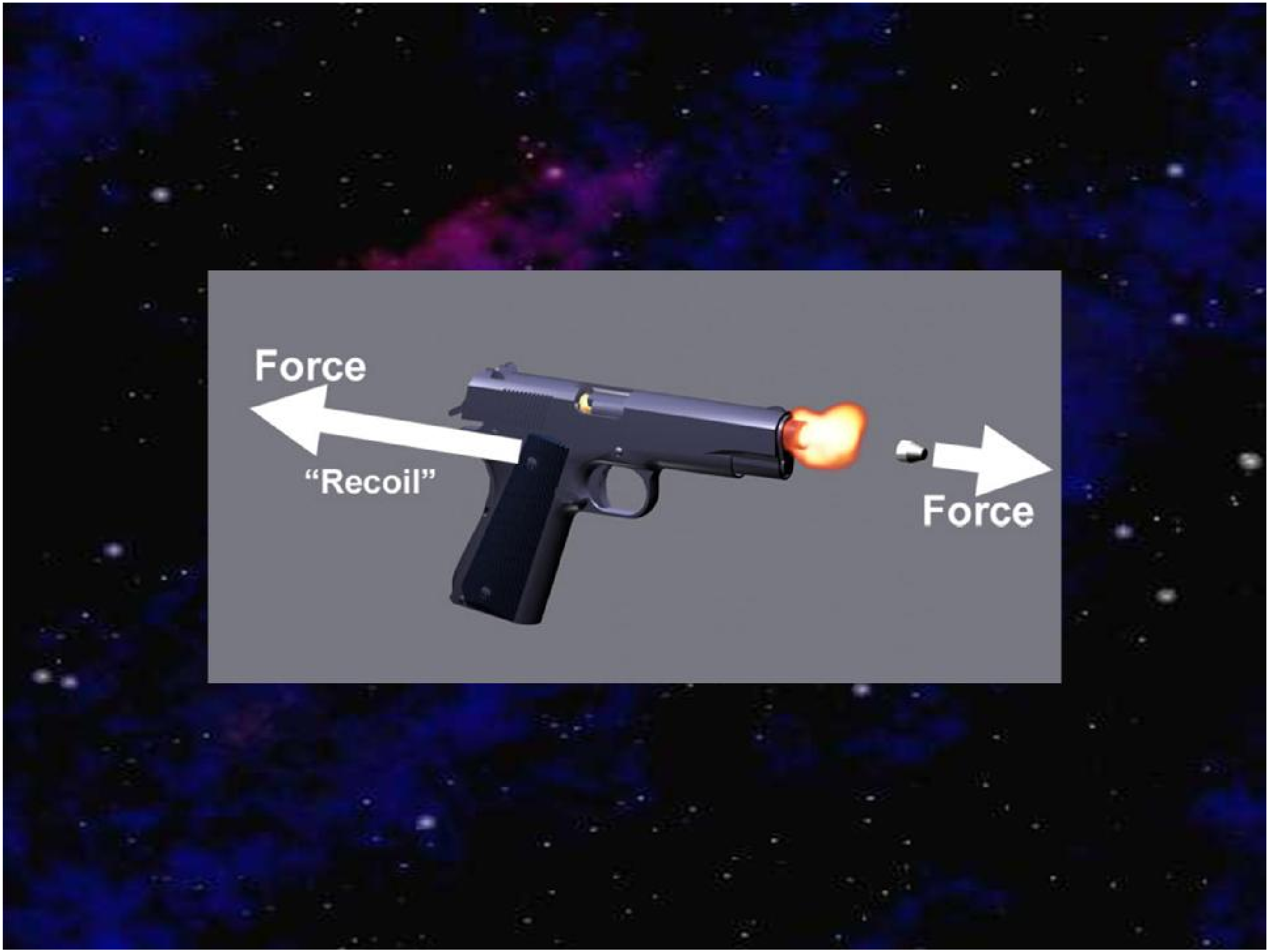
$$F = ma$$

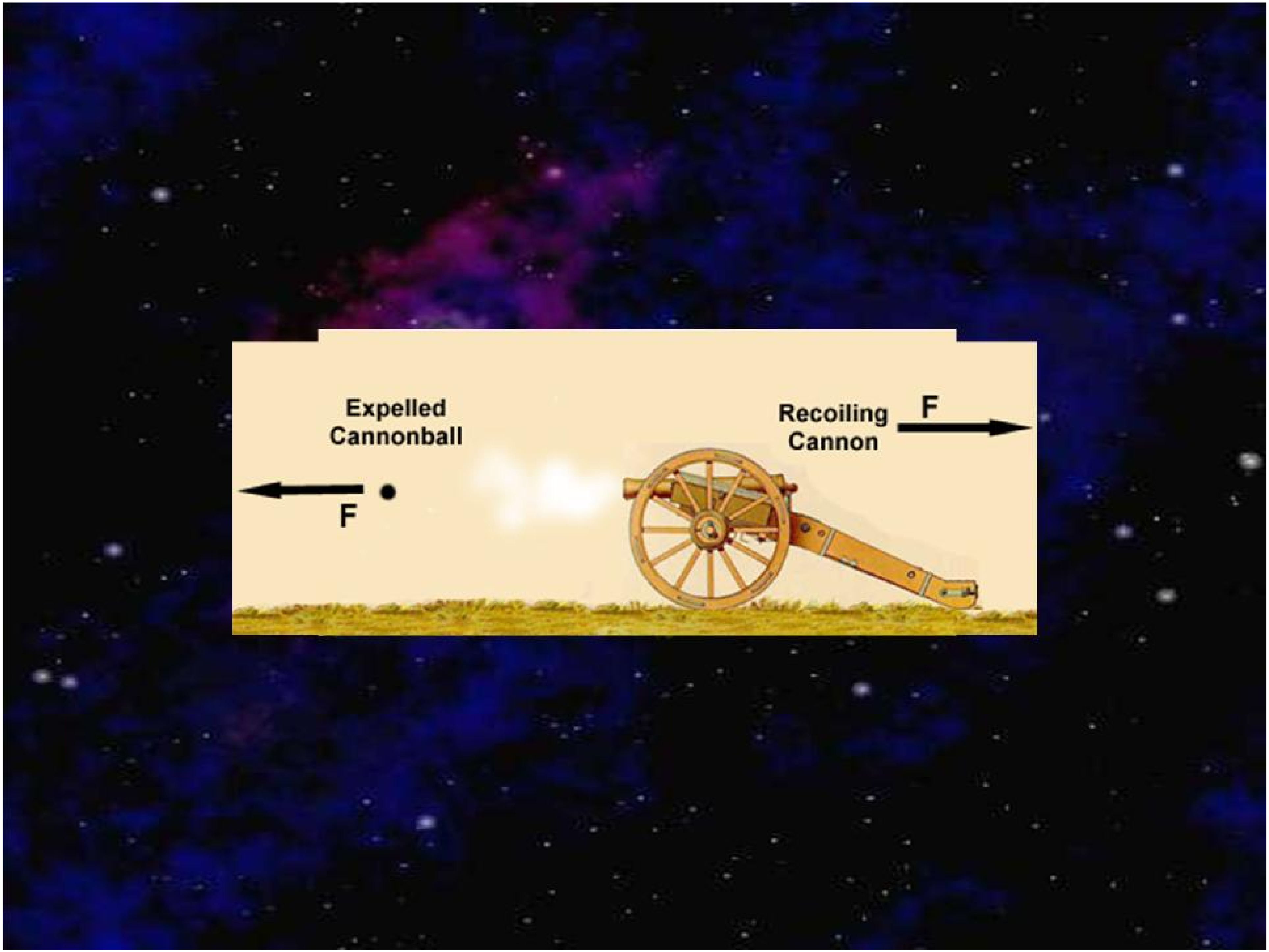
$$a = \frac{F}{m}$$

Newton's Third Law

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


Force
Force


Force
"Recoil"
Force


Expelled
Cannonball
F
Recoiling
Cannon
F


Upward thrust
Expelled gas

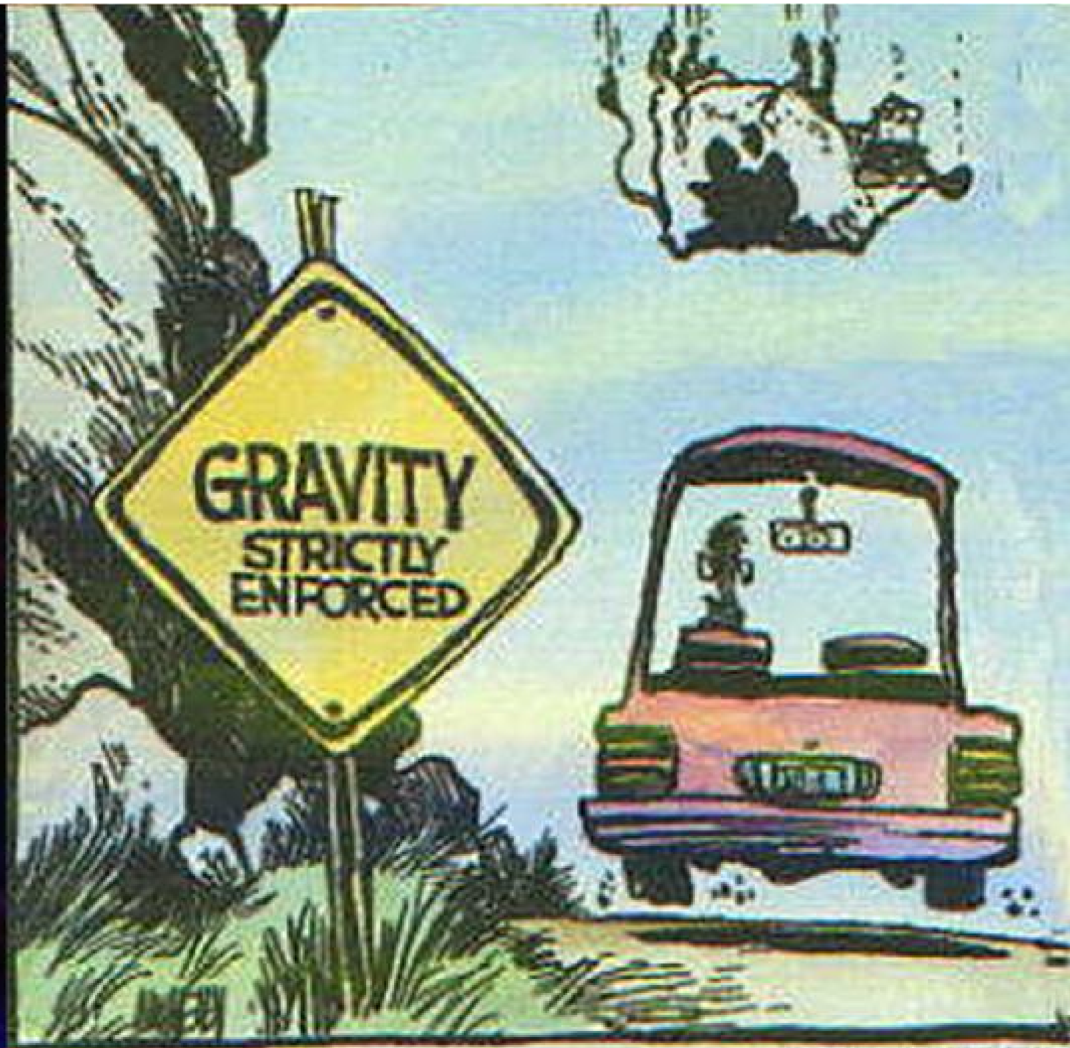


Illustration by Jeff MacNelly

Gravity is a contributing factor in nearly 73 percent of all accidents involving falling objects. And yet the so-called 'federal government' does nothing!

Newton's laws lead to the

Universal Law of Gravitation:

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

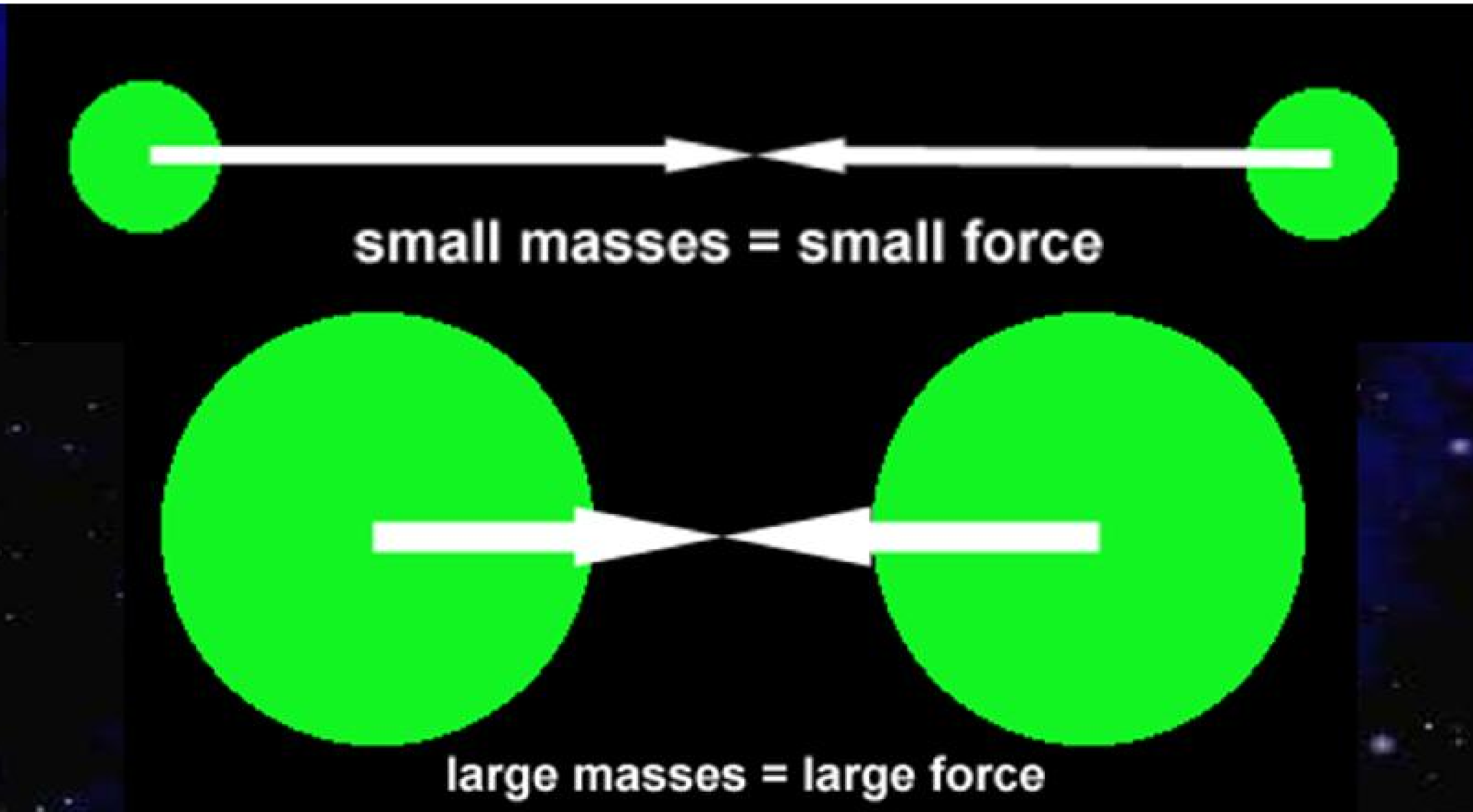
F = force of gravity

G = Universal Gravitational Constant

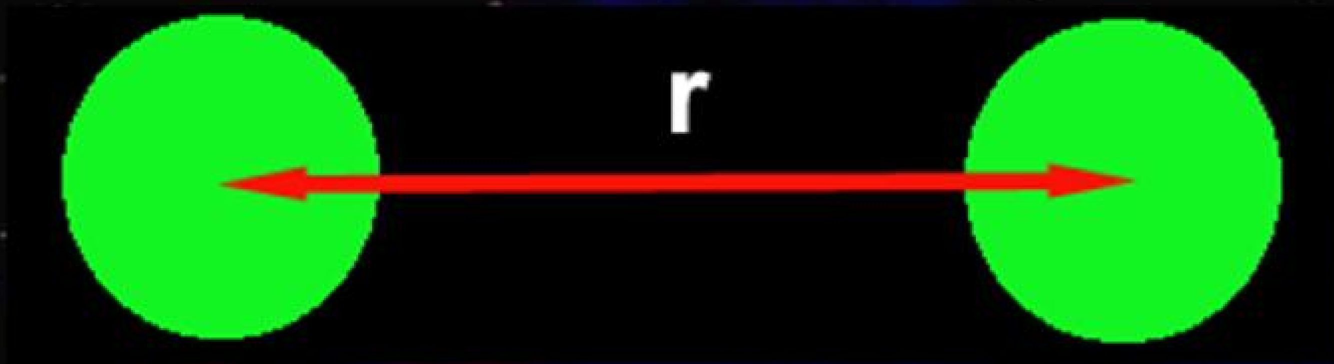
6.67 x 10^{-11} Newton m^2/ kg^2

m_1 , m_2 = masses of the two bodies

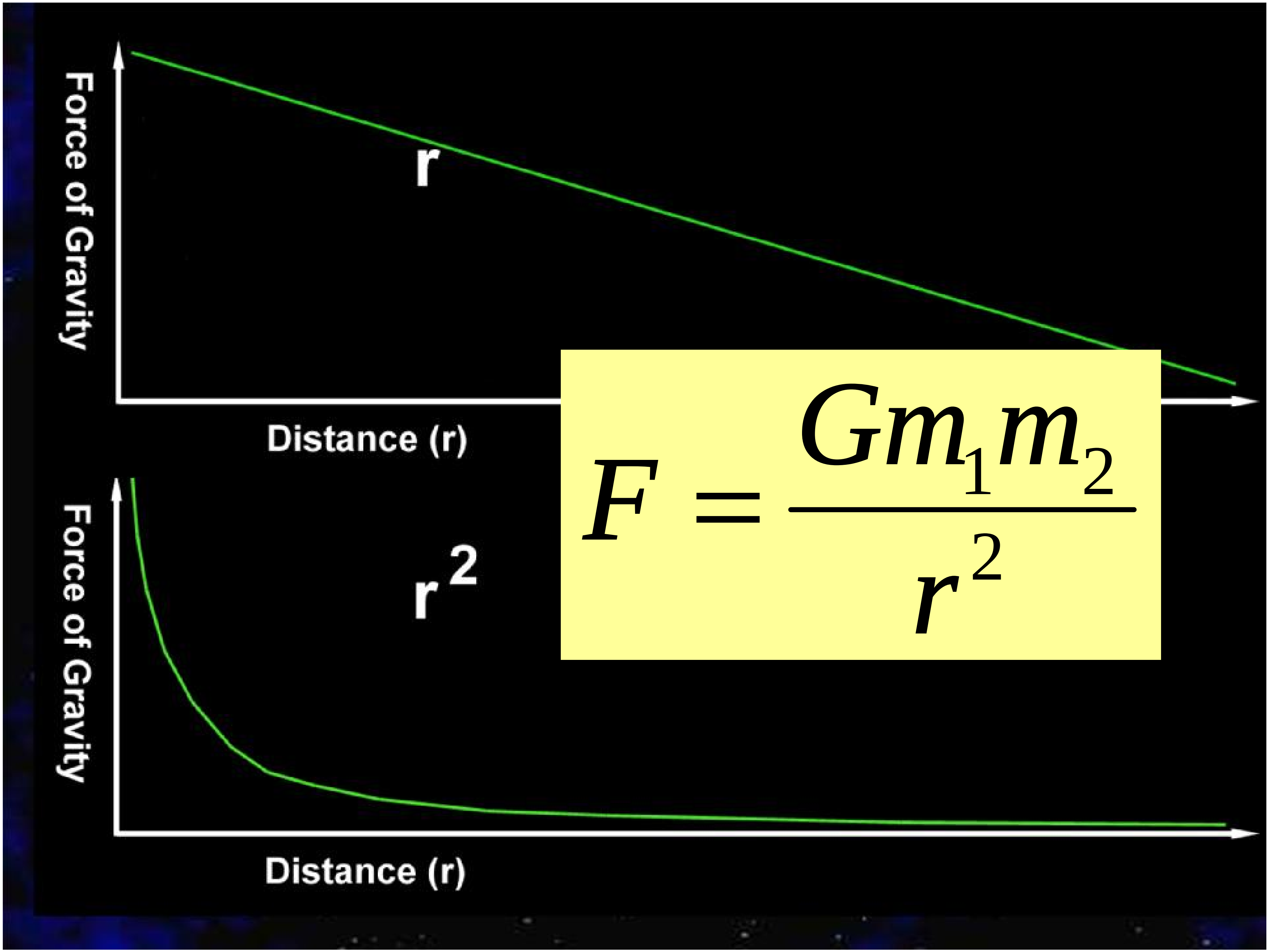
r = distance between the two bodies



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

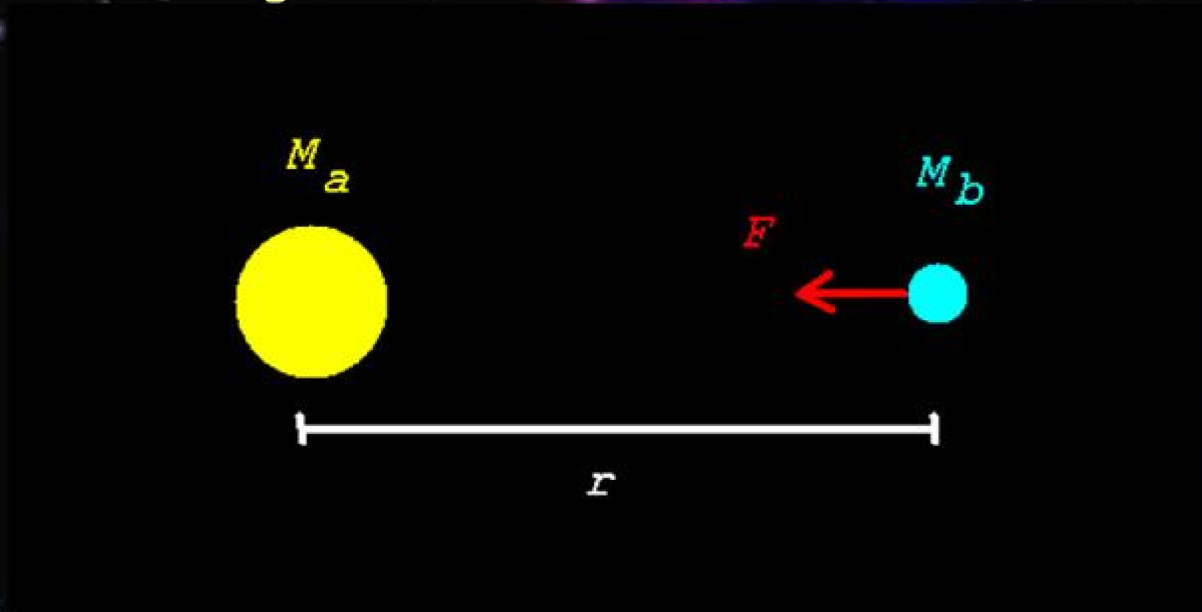


$$F = \frac{Gm_1m_2}{r^2}$$

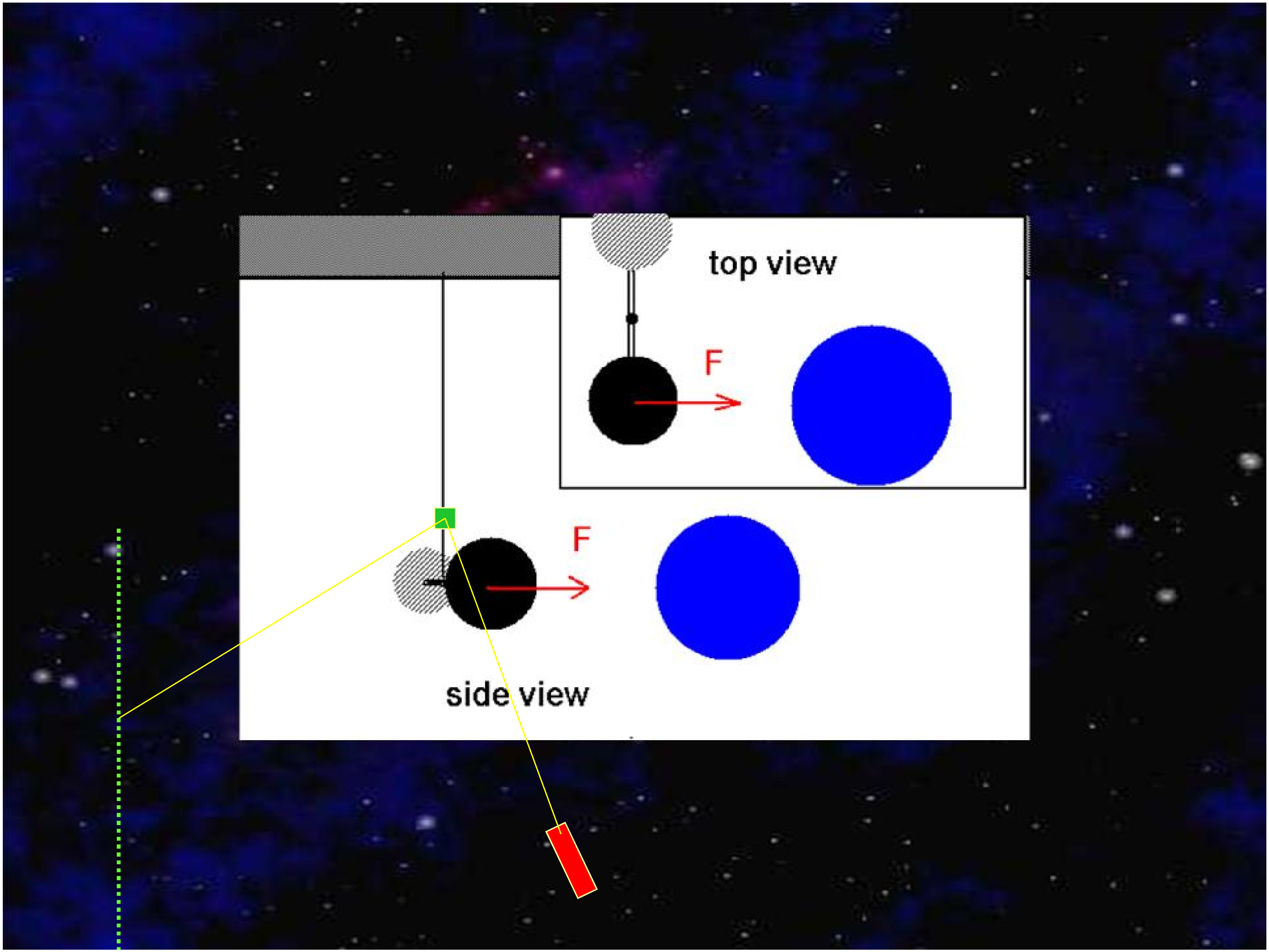


$$F = \frac{Gm_1m_2}{r^2}$$

Measuring Newton's Constant *G*



$$F = G \frac{M_a M_b}{r^2}$$


top view
F
F
side view

Q: Do all objects fall at the same rate?

- Ancient Greeks

NO!

- Galileo

YES!

- A prediction is made by Newtonian Mechanics...

Assume a large mass (M) and a small mass (m)

the acceleration due to the force of gravity (g):

Recall: **F = m *a***

where *a* = acceleration due to gravity (**g**)

So: **F = m g**

Recall:

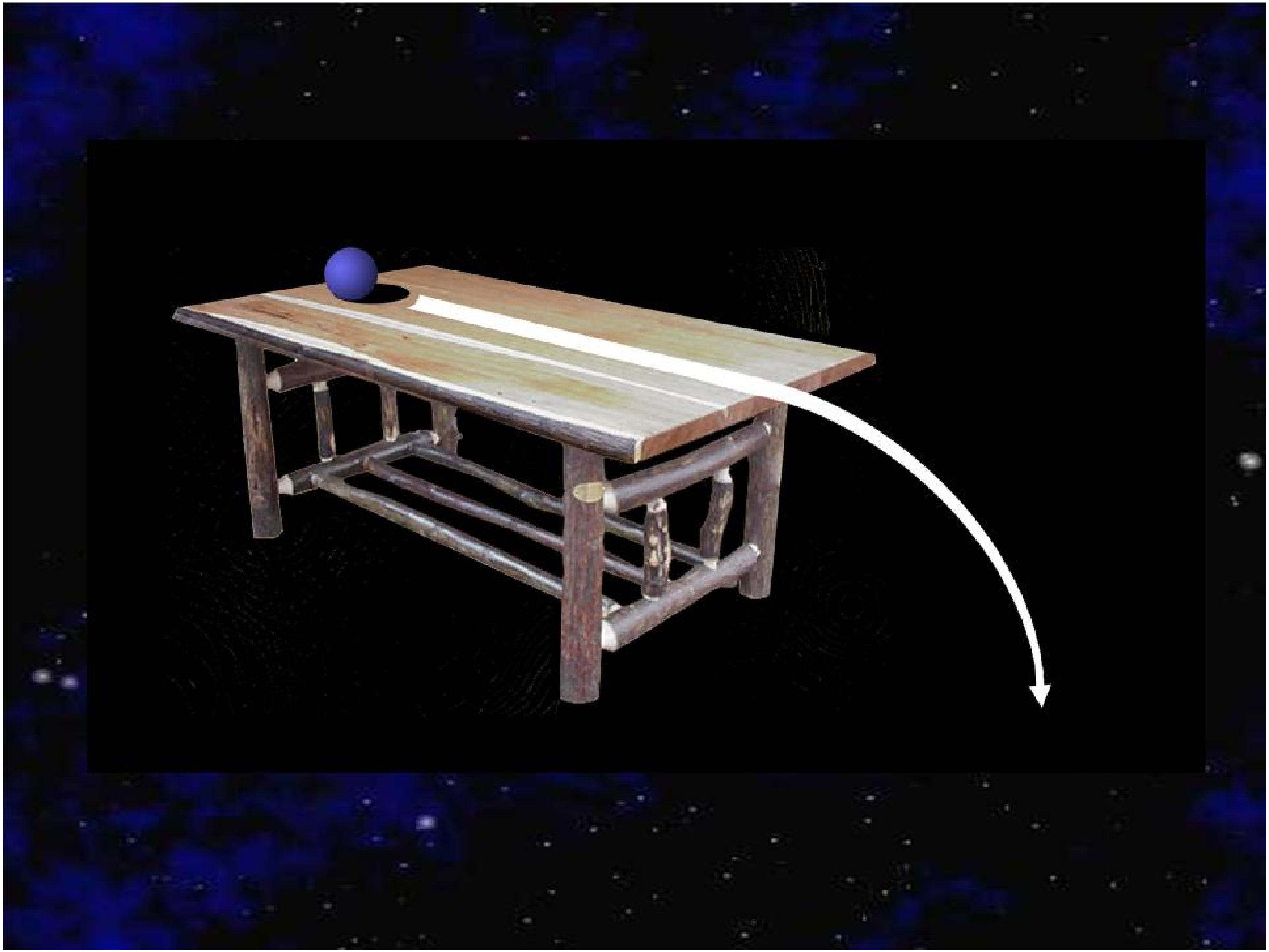
$$F_g = \frac{G m_1 m_2}{r^2}$$

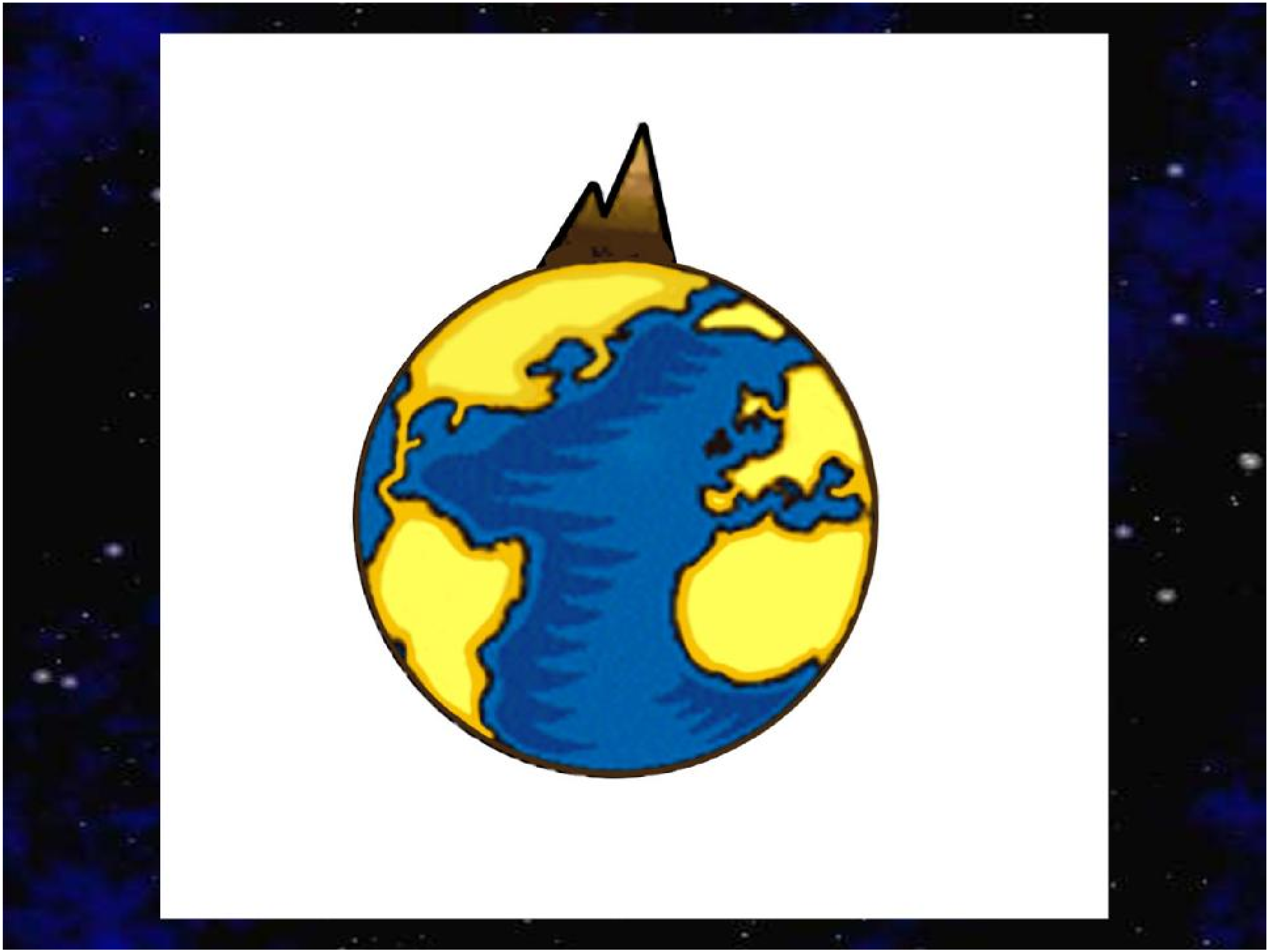
$$F_g = \frac{G m_{object} M_{Earth}}{r^2} = m_{object}\, g$$

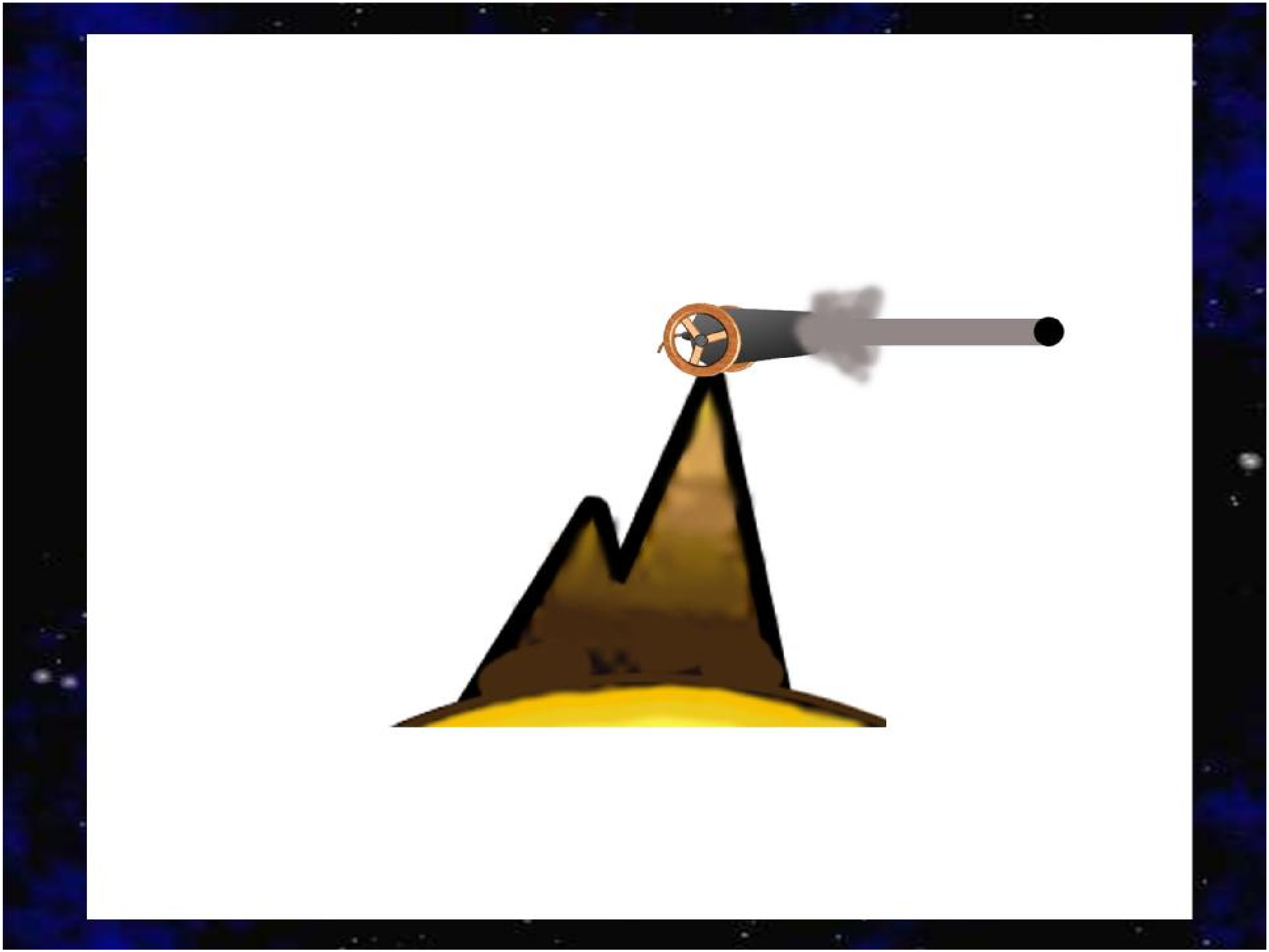
$$\frac{G M_{Earth}}{r^2} = g$$

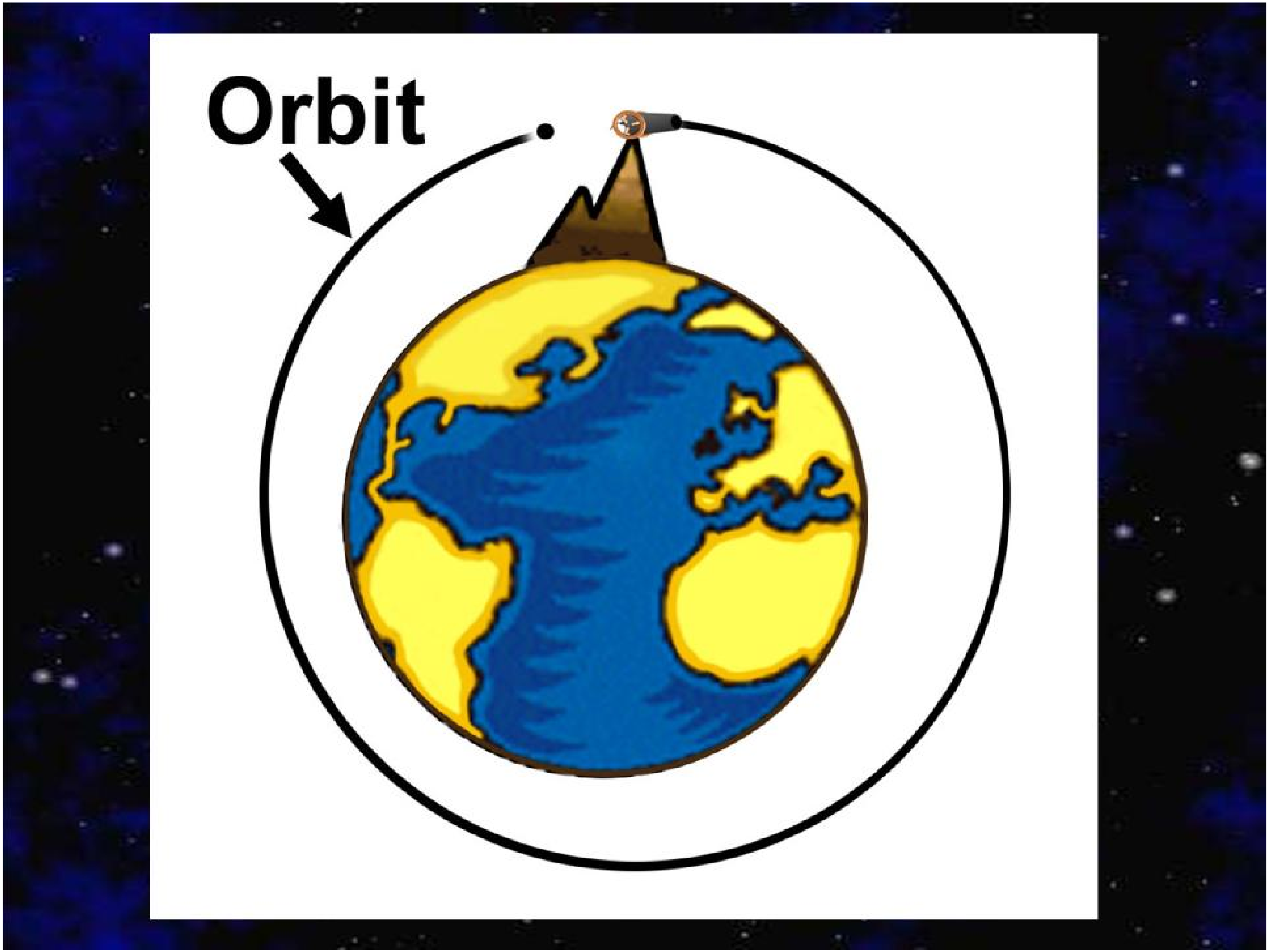
The acceleration due to gravity is <u>independent</u> of small body's mass!

Orbiting Bodies








Orbit

Orbital velocity:

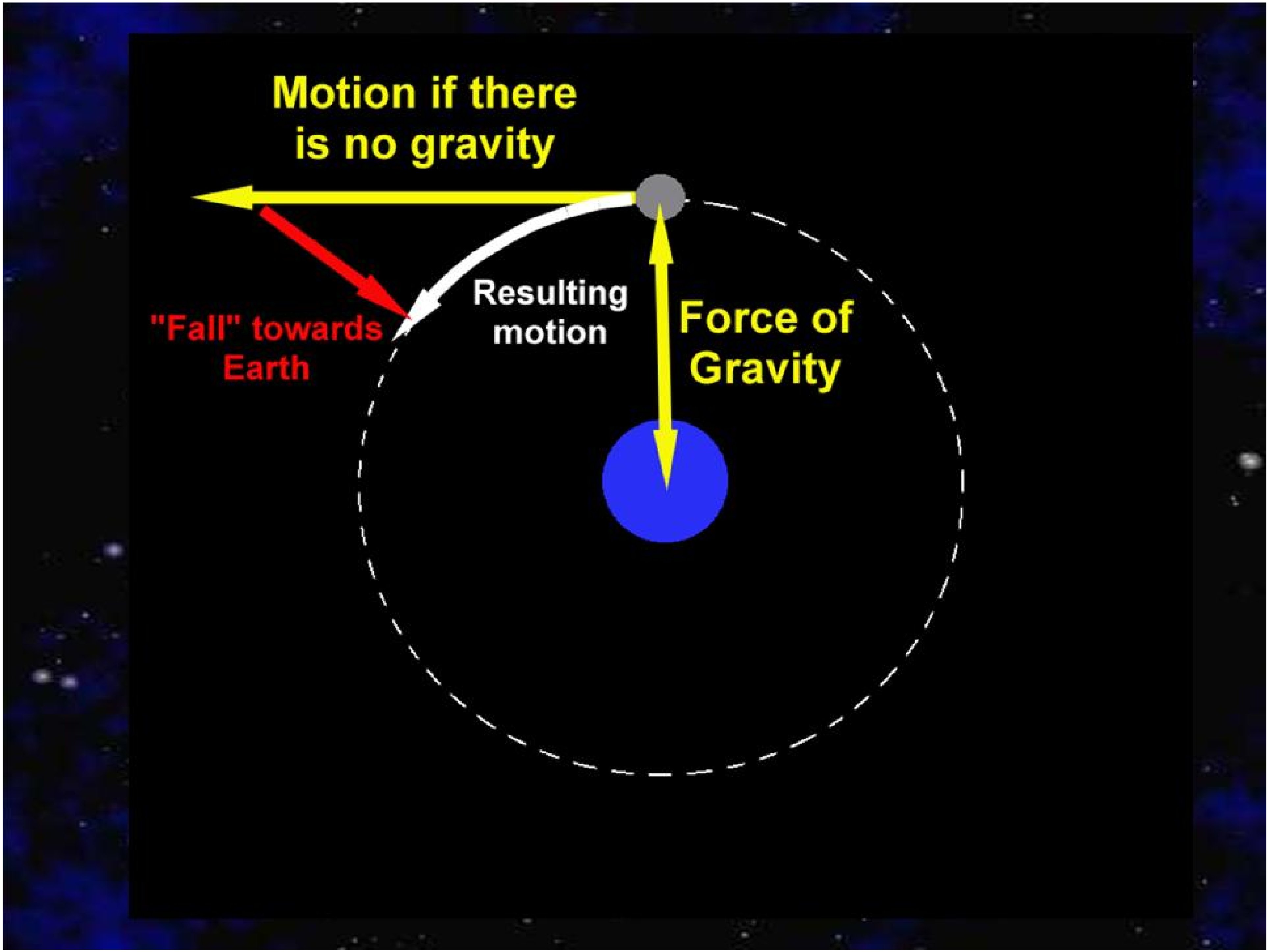
Minimum orbital speed:

17,500 miles per hour

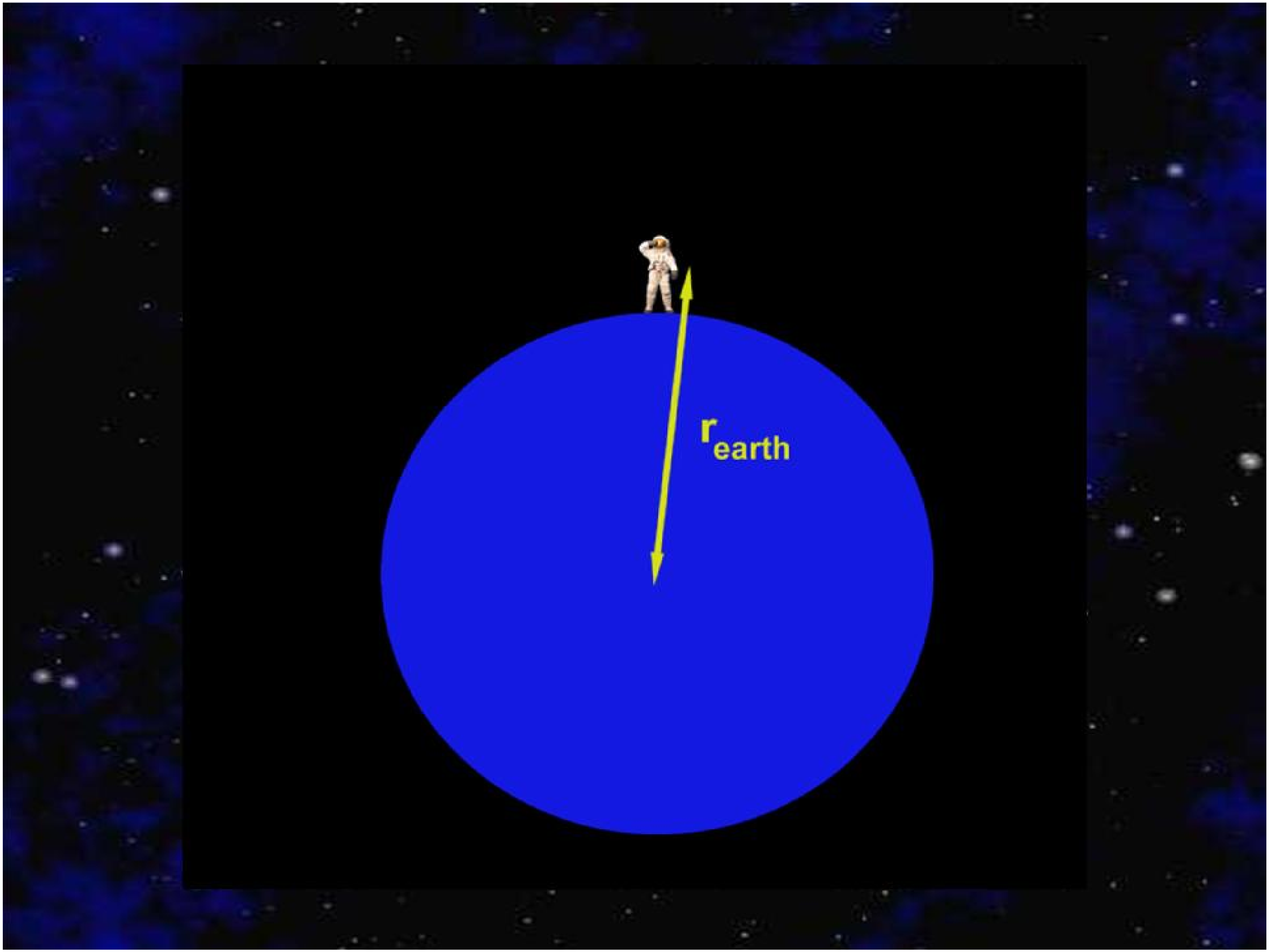
5 miles per second

Mach 25!

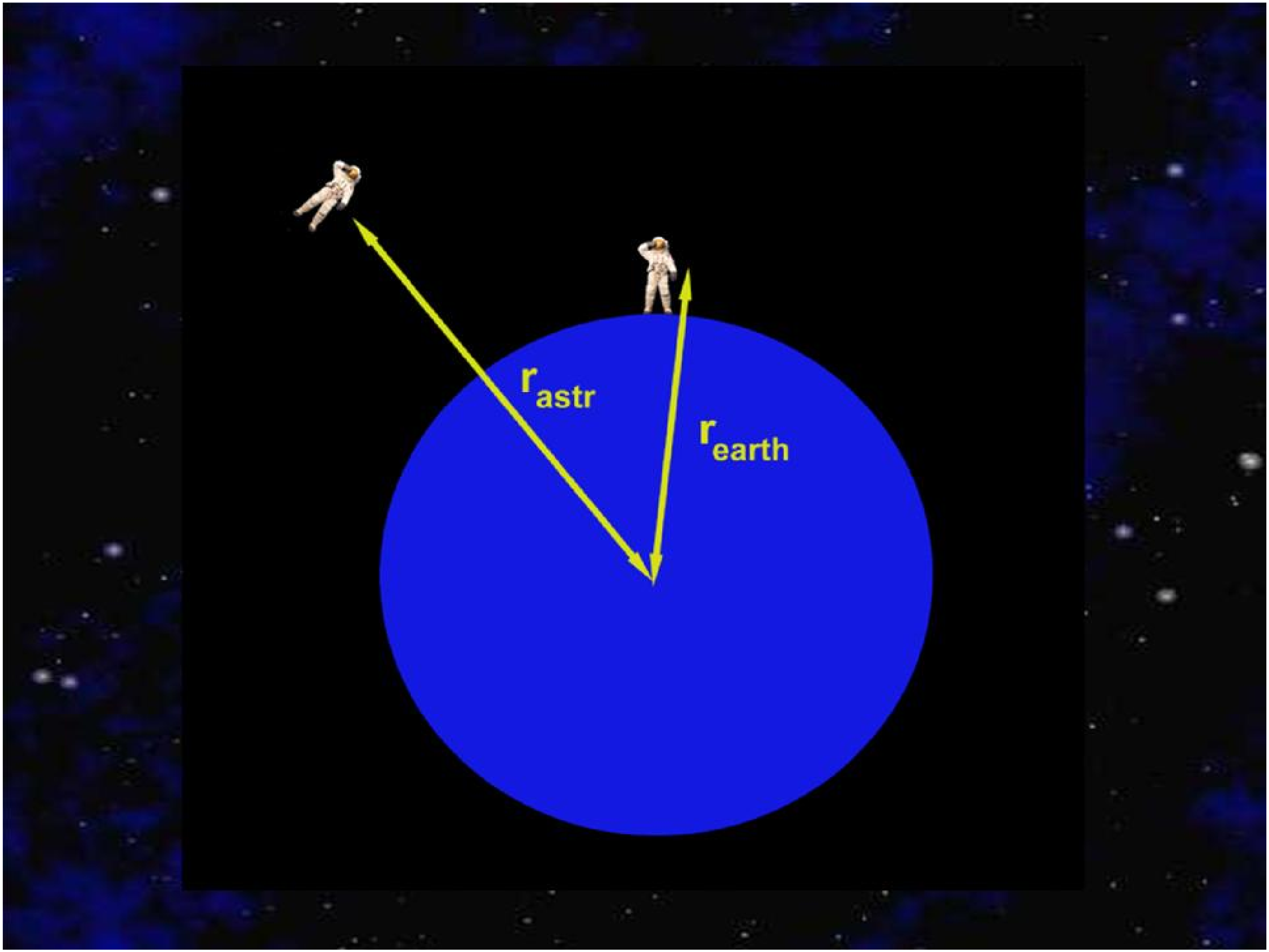

NASA


Motion if there is no gravity
Resulting motion
Force of Gravity
"Fall" towards Earth

Is a “weightless” astronaut *really* weightless?



r_{earth}



r_{astr}
r_{earth}

$$\frac{F_{orbit}}{F_{ground}} = \frac{\dfrac{Gm_1m_2}{r^2}}{\dfrac{Gm_1m_2}{r^2}} = \frac{\dfrac{GM_{earth}m_{astr}}{r_{orbit}{}^2}}{\dfrac{GM_{earth}m_{astr}}{r_{earth}{}^2}}$$

$$\frac{GM_{earth}m_{astr}}{r_{orbit}{}^2} \times \frac{r_{earth}{}^2}{GM_{earth}m_{astr}}$$

$$\frac{F_{orbit}}{F_{ground}} = \frac{r_{earth}{}^{2}}{r_{orbit}{}^{2}}$$

$$= \frac{(6370km)^2}{(6770km)^2}$$

$$\approx 89\%$$

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."

$P^2 = d^3$

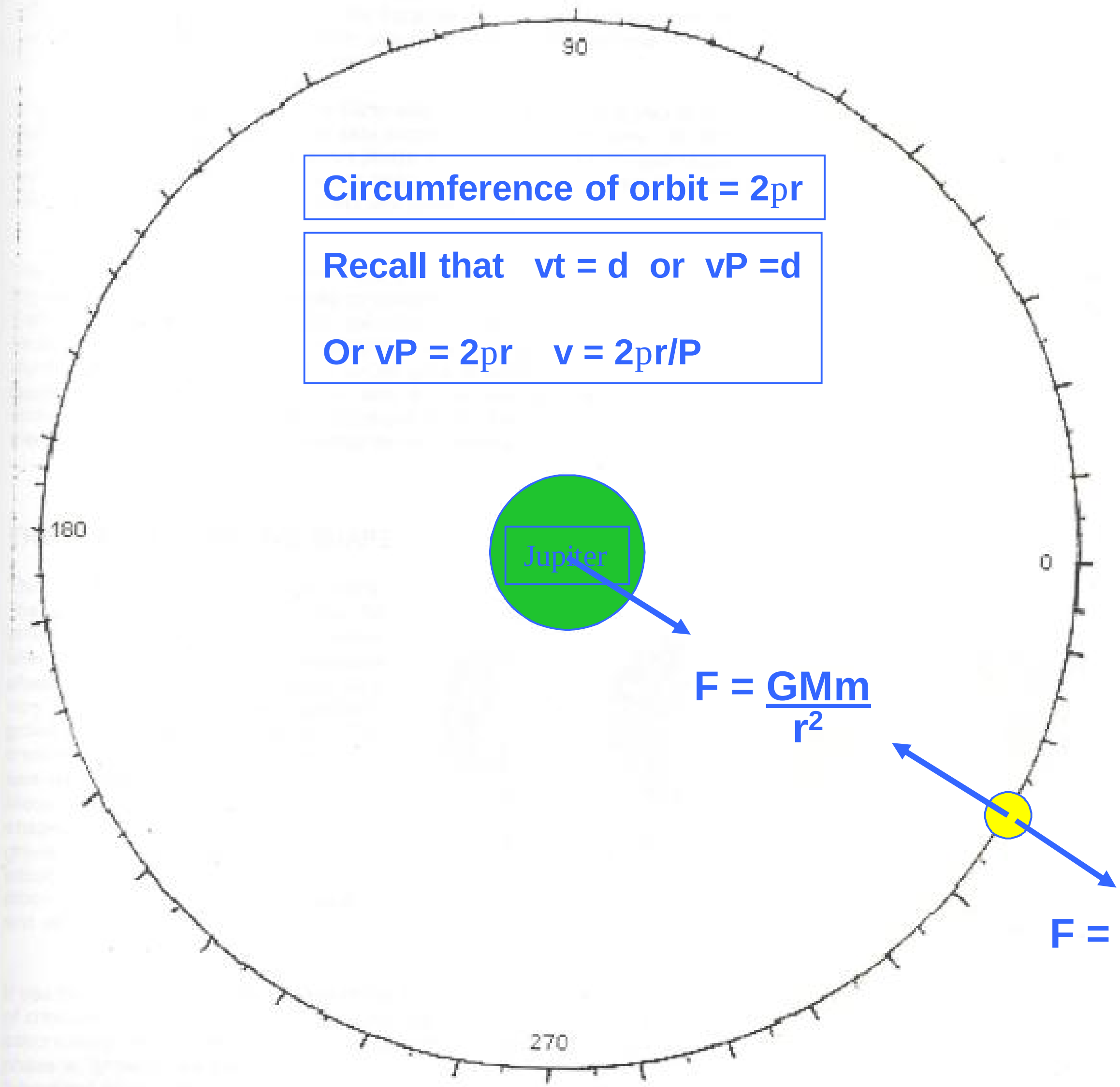
- P = Orbital Period measured in Earth years
- d = Orbital distance measured in A.U.'s
- Example: Jupiter

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....

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

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

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

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

Hubble back in business

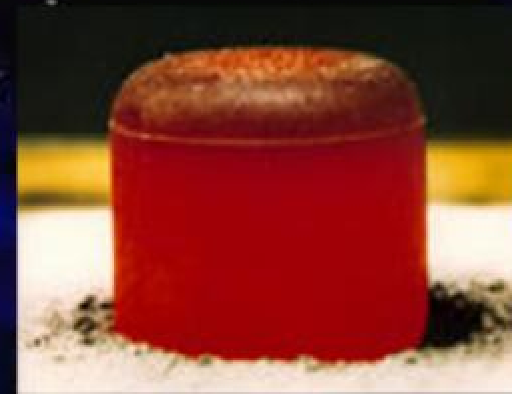
Hubble back in business

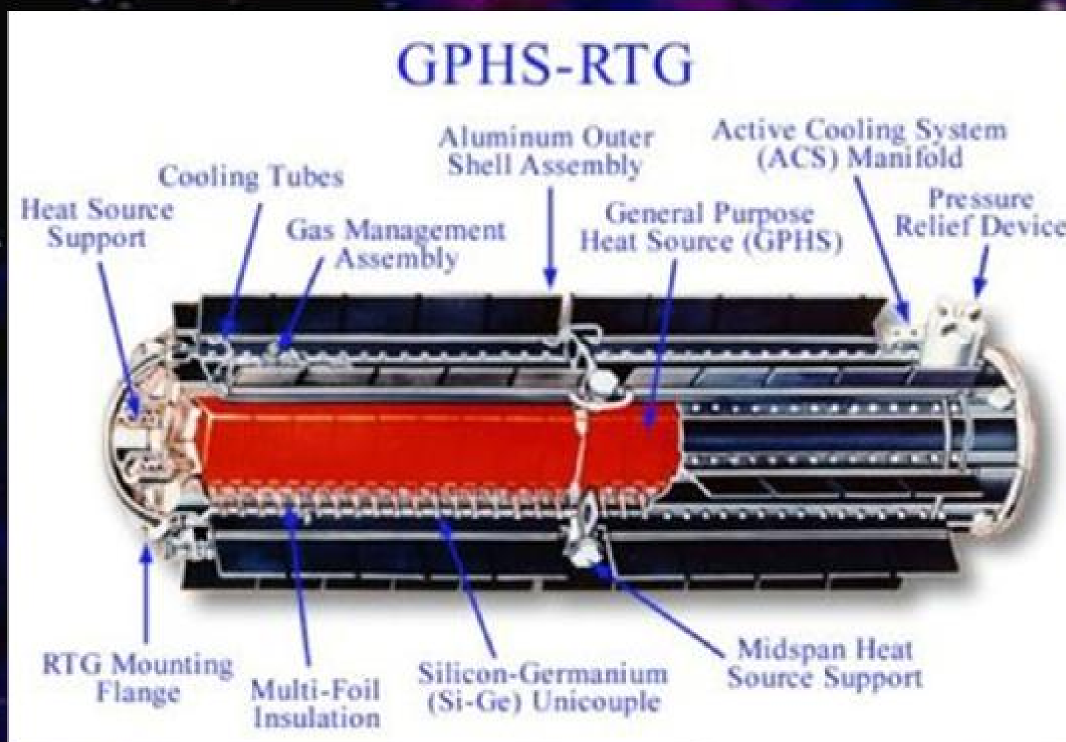
But how Universal is the Law of Gravity

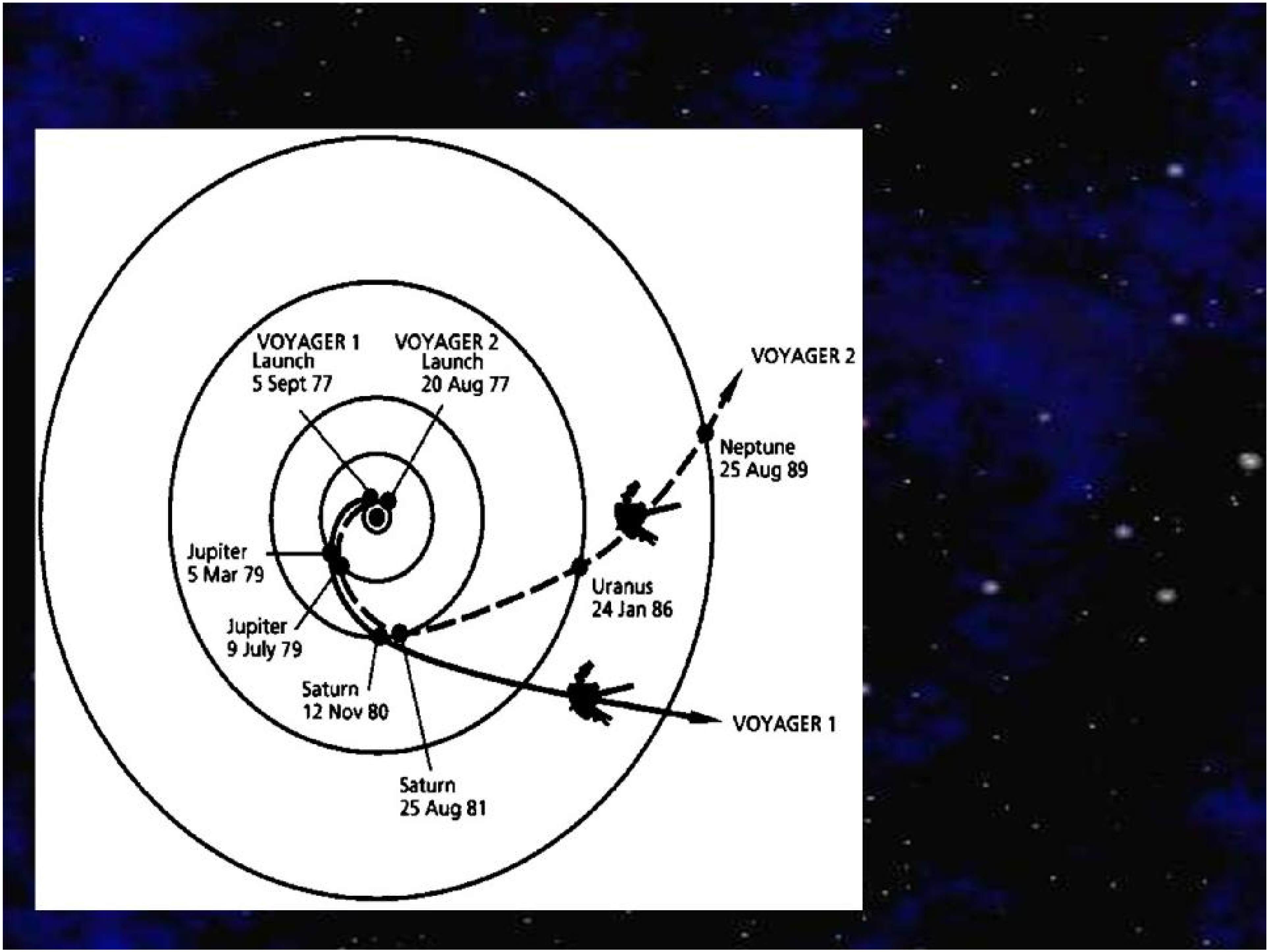
could heliocentric model plus Kepler's laws predict better than geocentric model

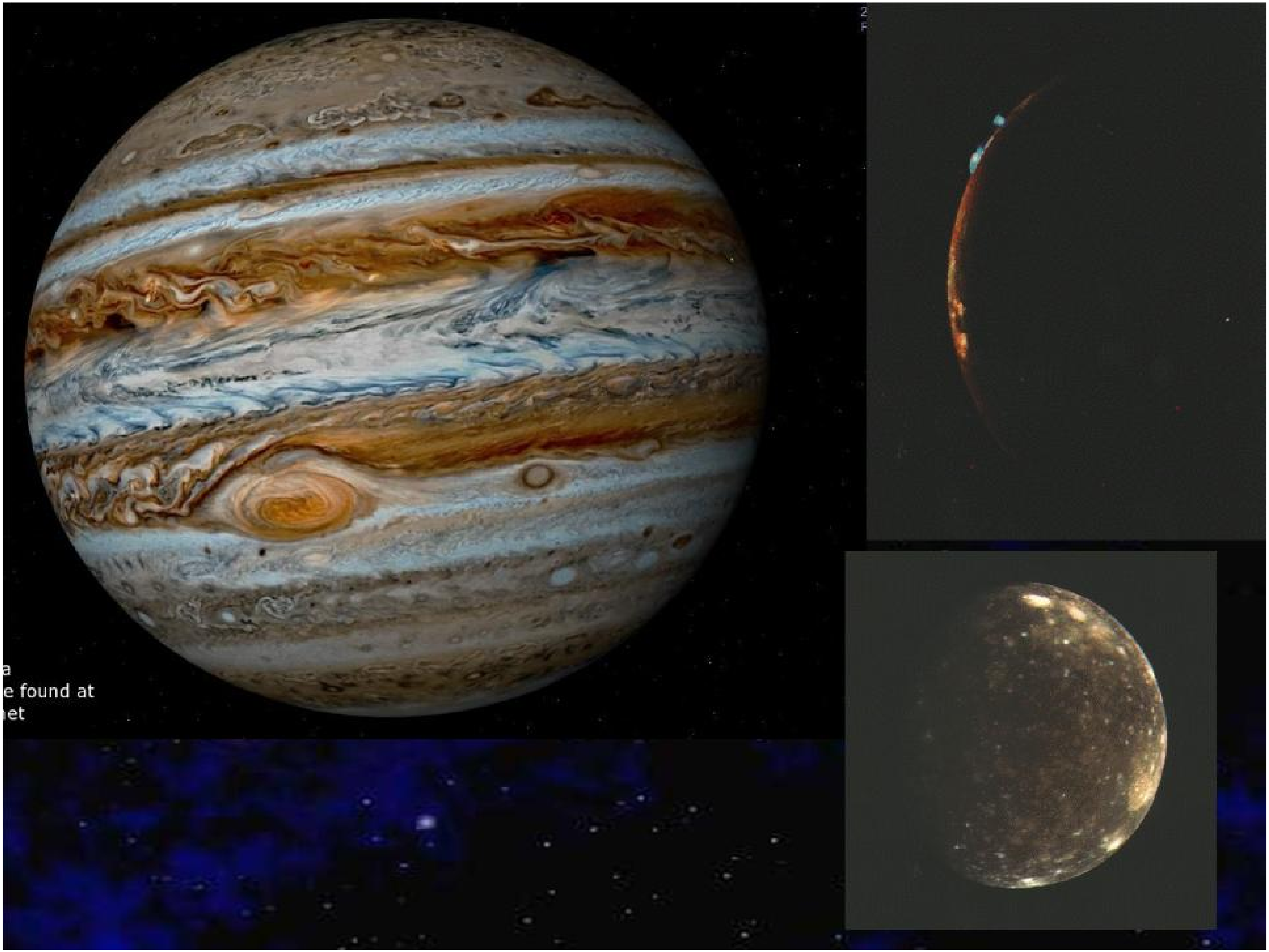
- Solar System travel
  Venus Transit
- Star Cluster orbit

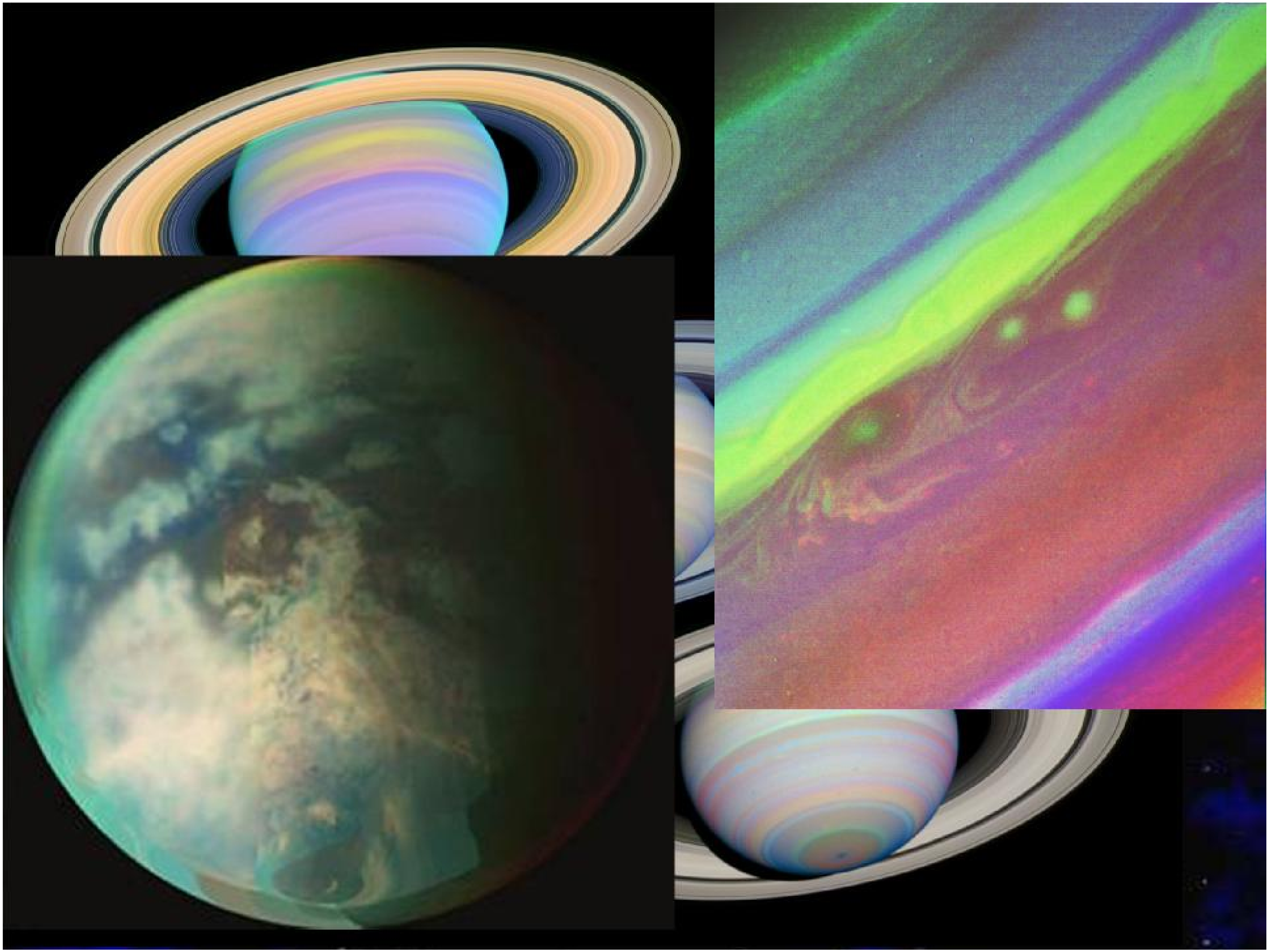
Voyager 1(118 AU) and 2(96 AU): **(32:50, 28:38)**
1977-20011 and going strong

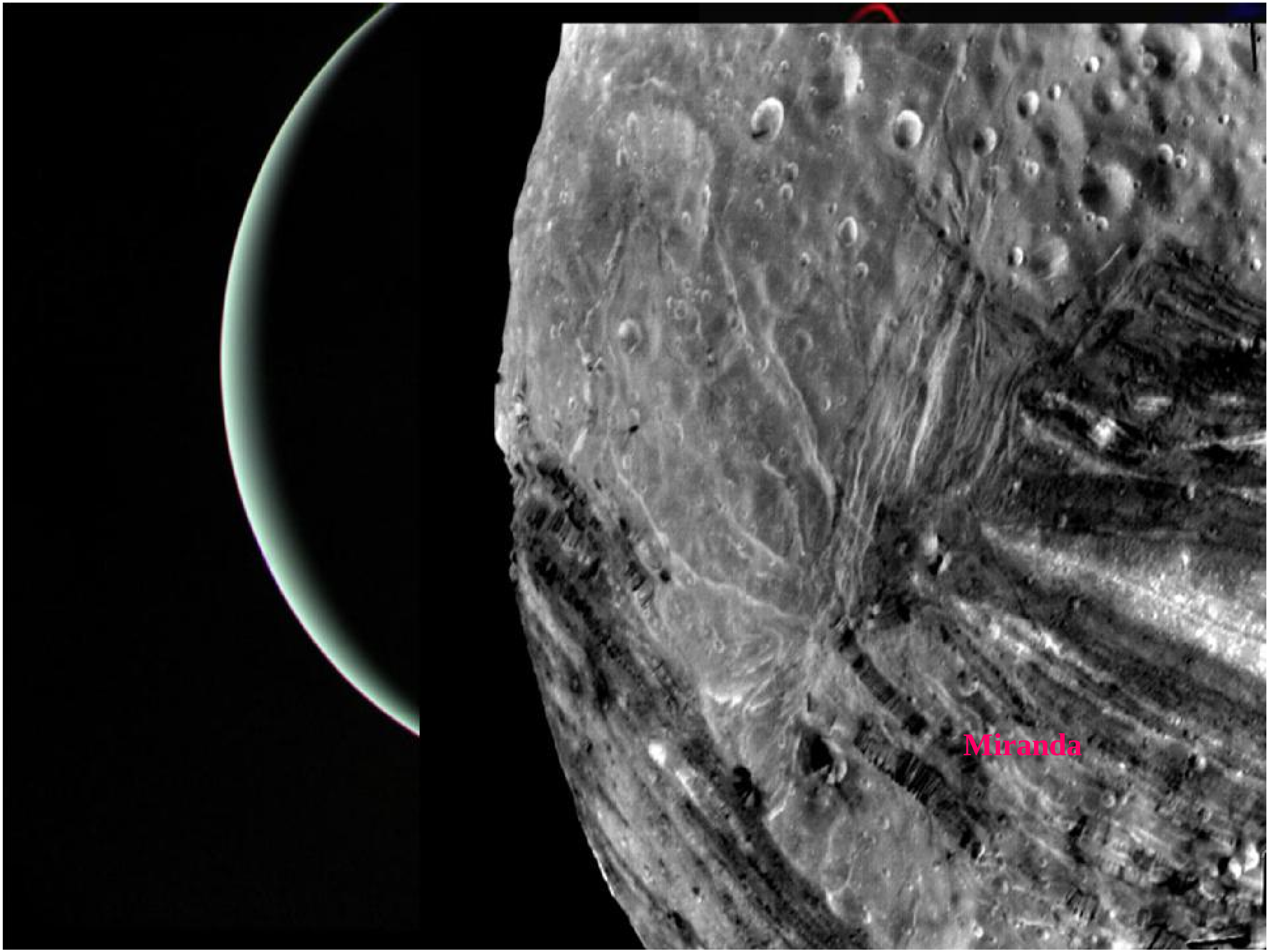


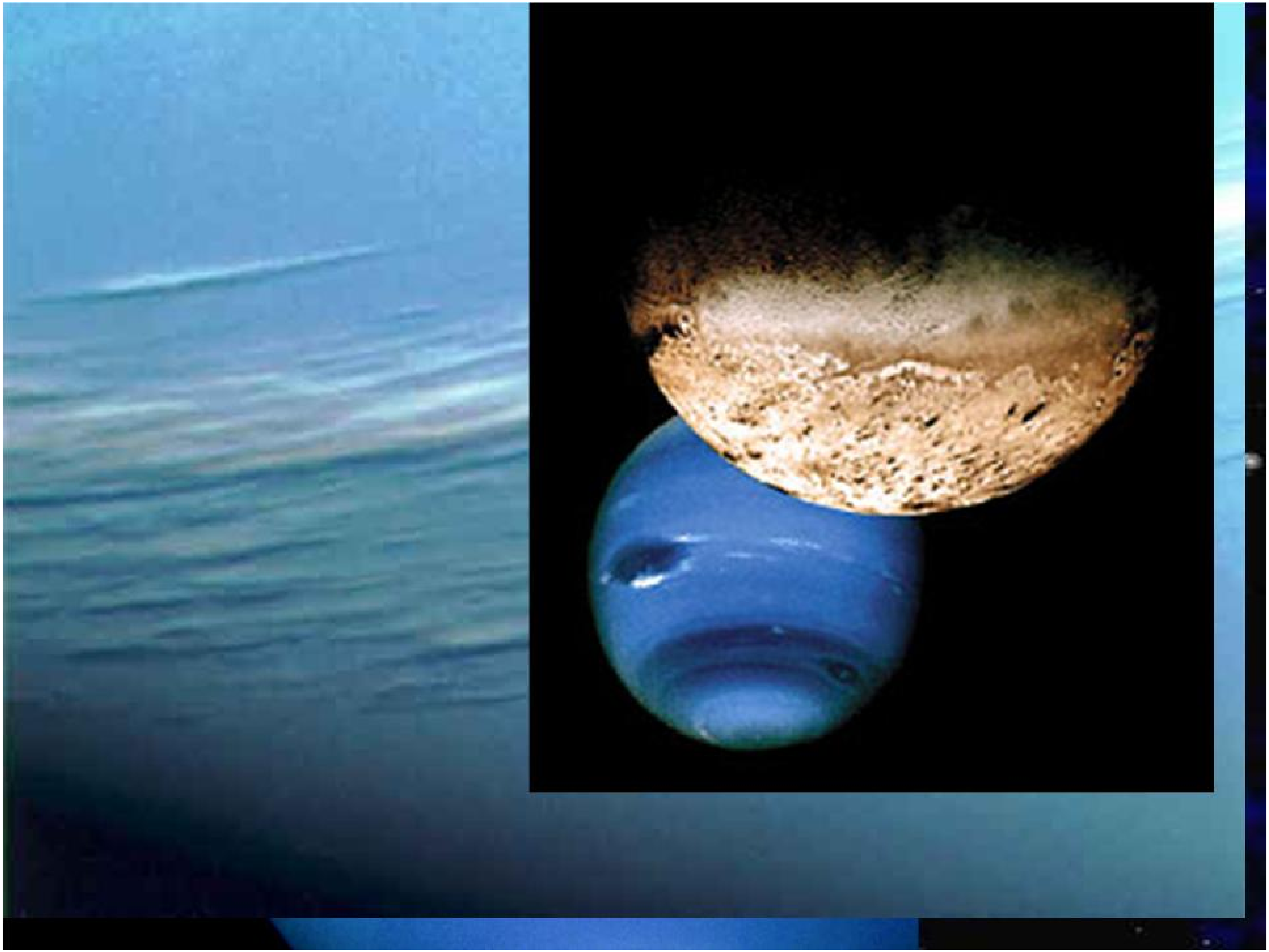

GPHS-RTG
Aluminum Outer Shell Assembly
Active Cooling System (ACS) Manifold
Cooling Tubes
Heat Source Support
Gas Management Assembly
General Purpose Heat Source (GPHS)
Pressure Relief Device
RTG Mounting Flange
Multi-Foil Insulation
Silicon-Germanium (Si-Ge) Unicouple
Midspan Heat Source Support

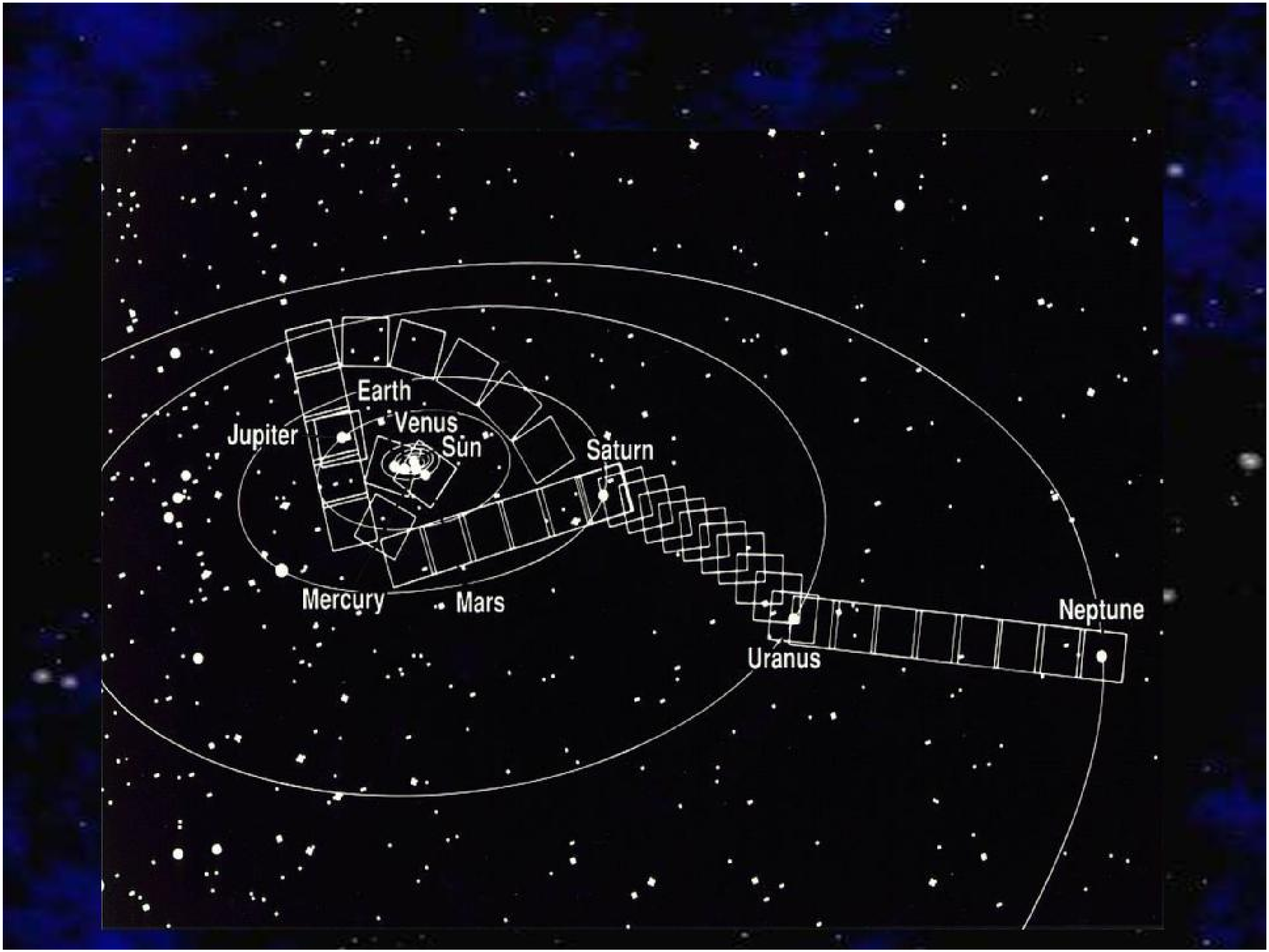

VOYAGER 1
Launch
5 Sept 77
VOYAGER 2
Launch
20 Aug 77
VOYAGER 2
Neptune
25 Aug 89
Jupiter
5 Mar 79
Uranus
24 Jan 86
Jupiter
9 July 79
Saturn
12 Nov 80
VOYAGER 1
Saturn
25 Aug 81

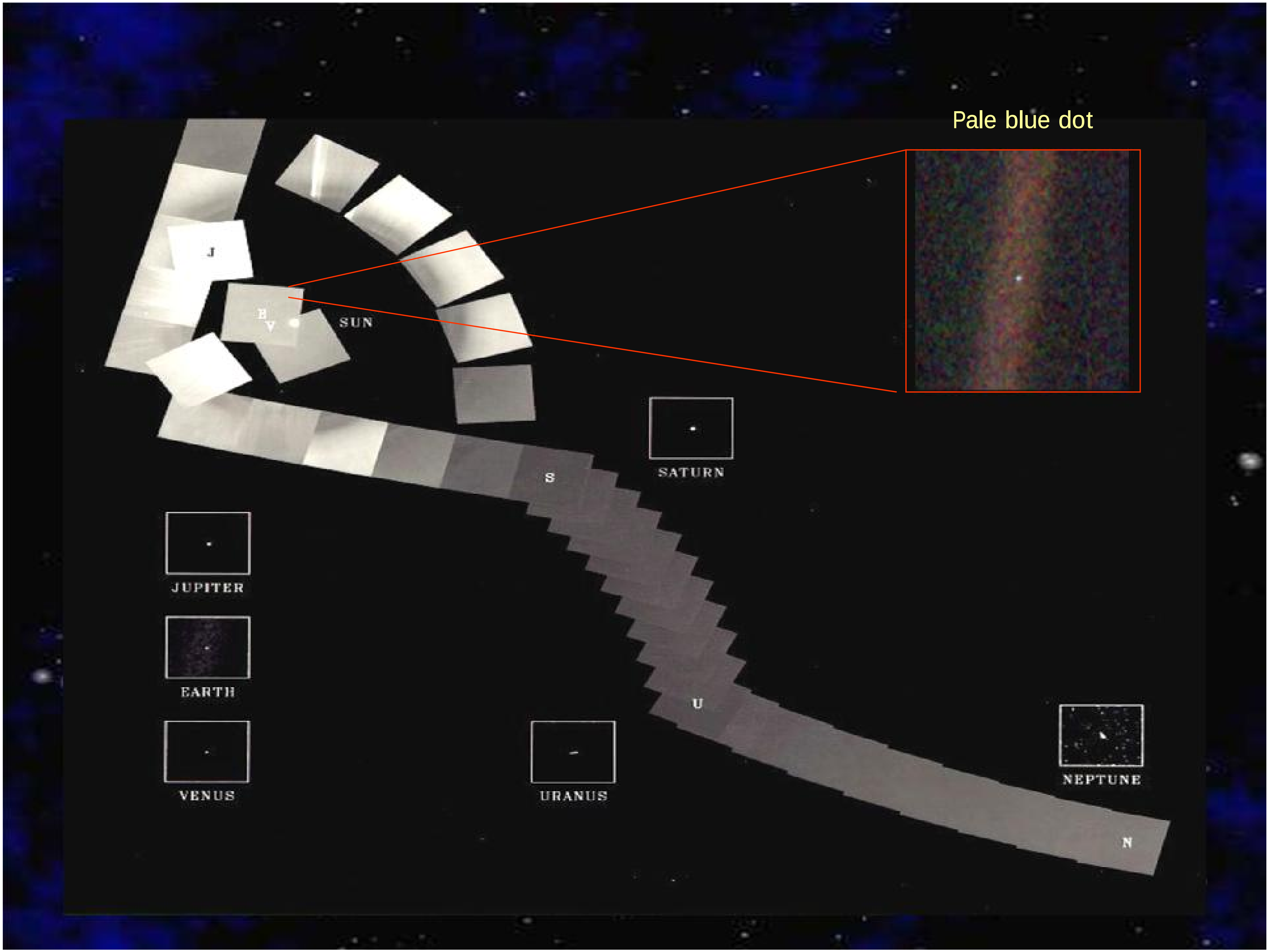

a
e found at
net

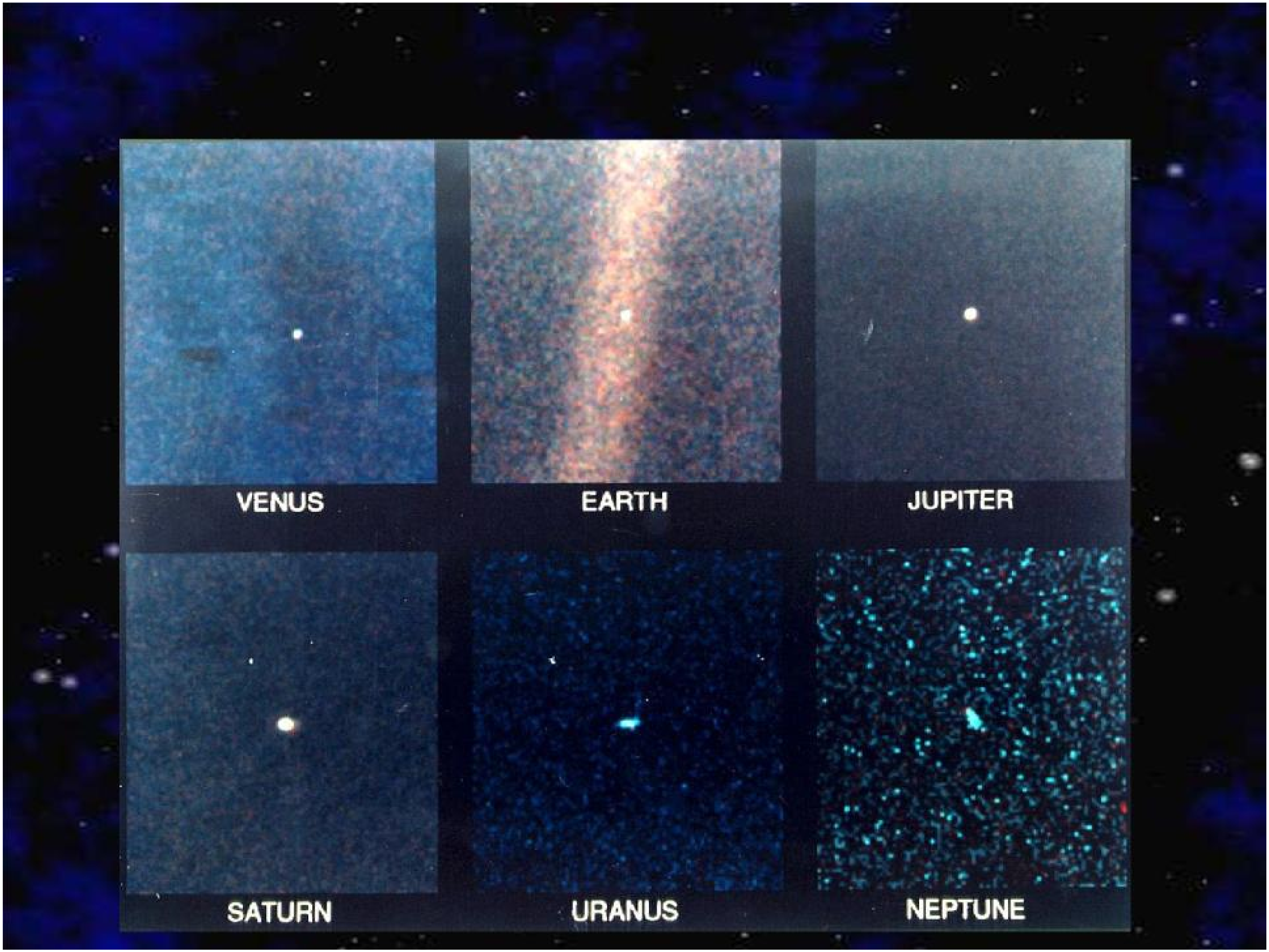



Miranda

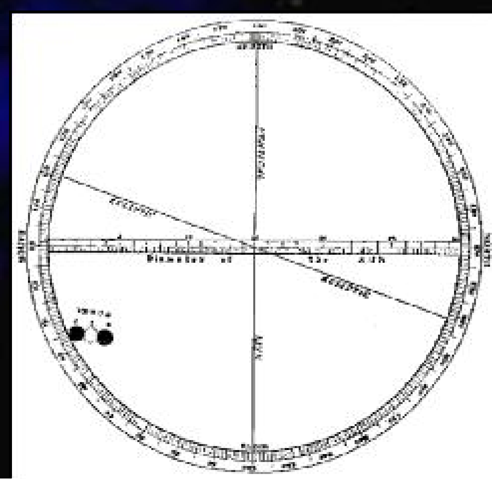



Earth
Venus
Jupiter
Sun
Saturn
Mercury
Mars
Neptune
Uranus


Pale blue dot
J
E
V
SUN
S
SATURN
JUPITER
EARTH
U
VENUS
URANUS
NEPTUNE
N


VENUS
EARTH
JUPITER
SATURN
URANUS
NEPTUNE

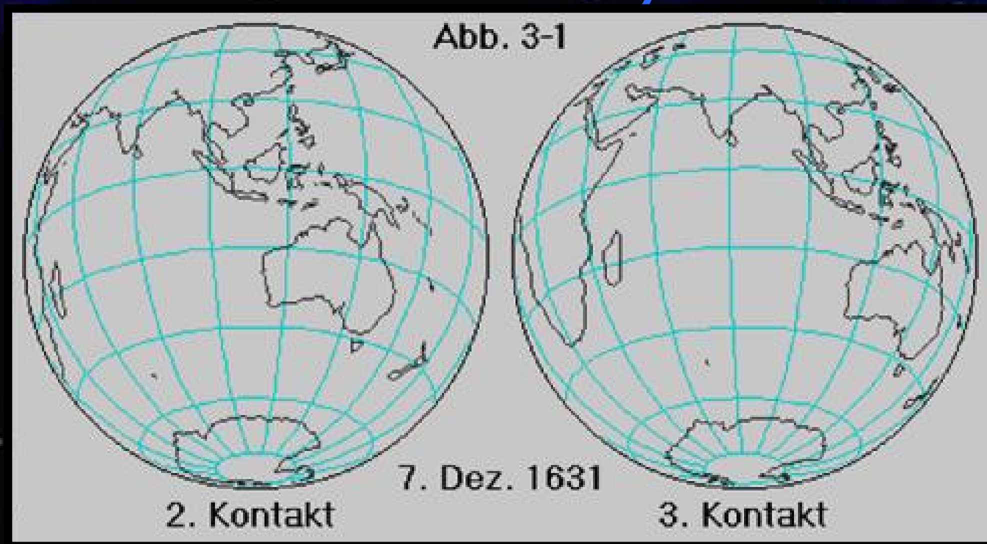
Twice in a Lifetime!



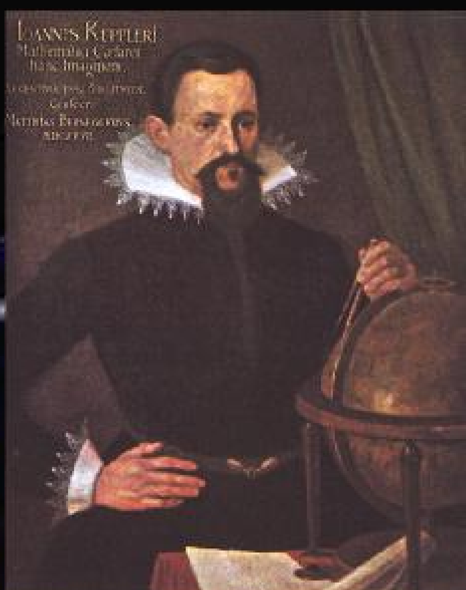
TRANSIT DATES

- December 1631
- December 1639
- June 1761
- June 1769
- December 1874
- December 1882
- June 2004
- June 2012
- December 2117
- December 2125

December 6, 1631

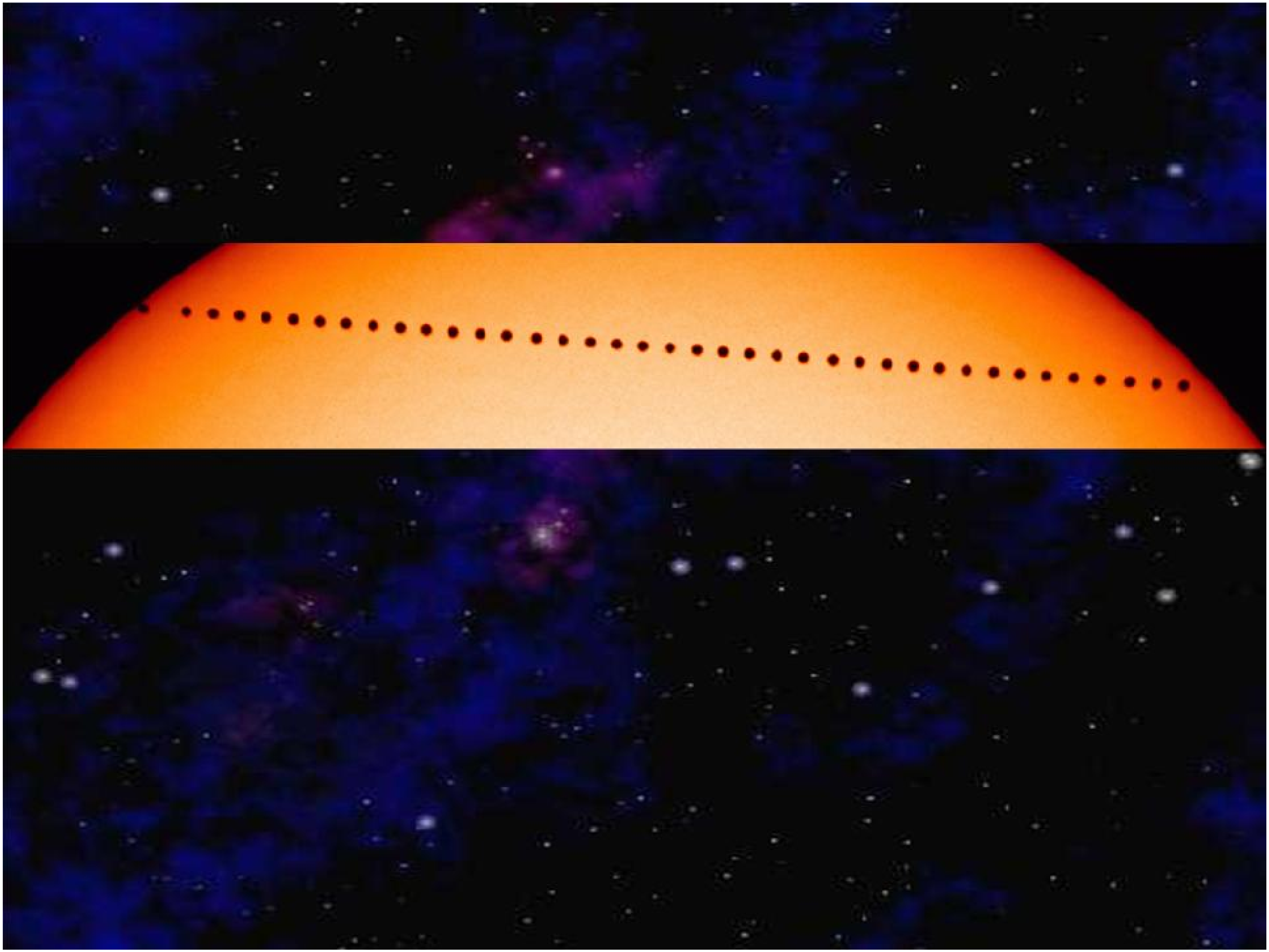


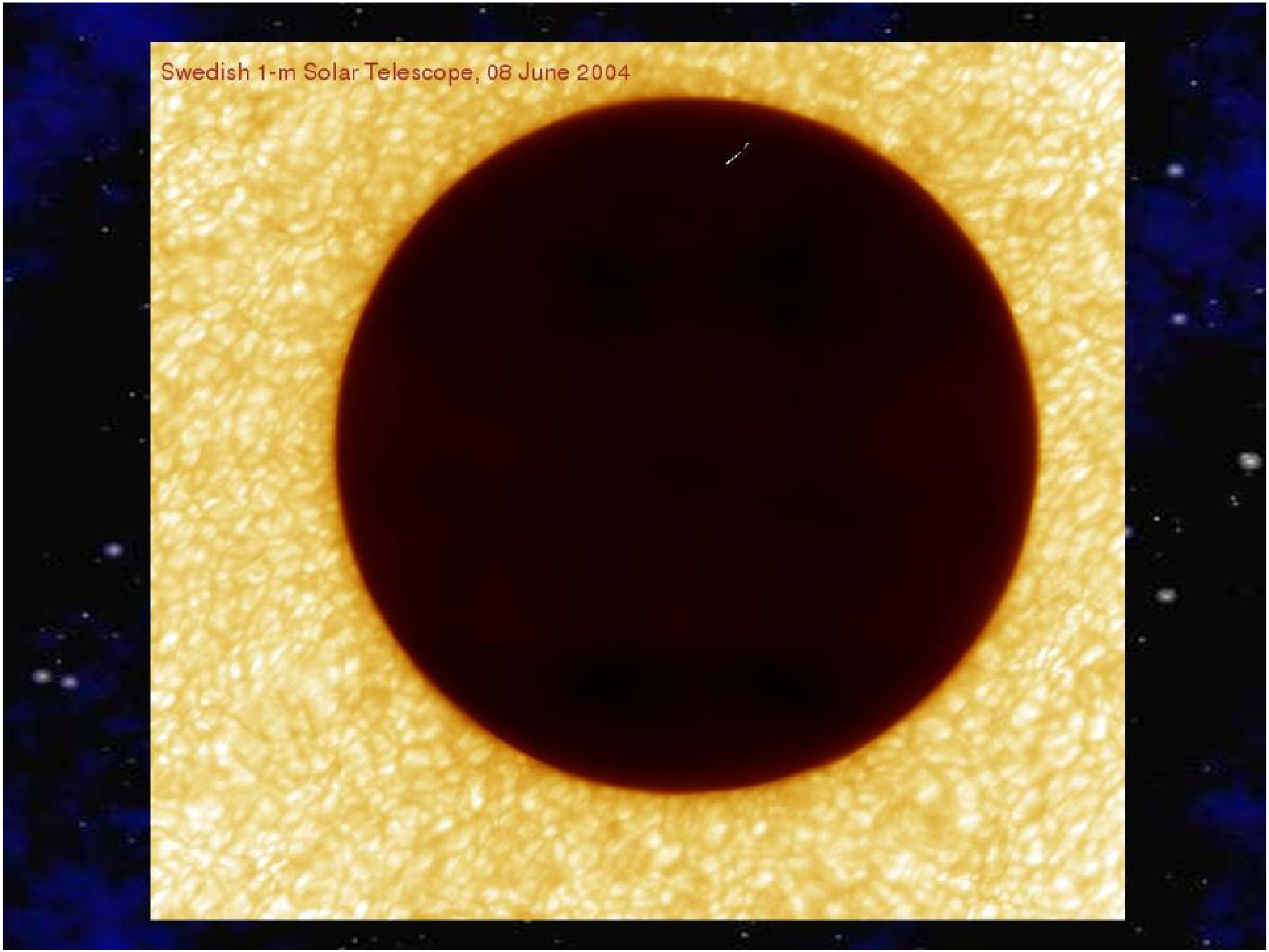
Pierre Gassendi
(1592-1655)



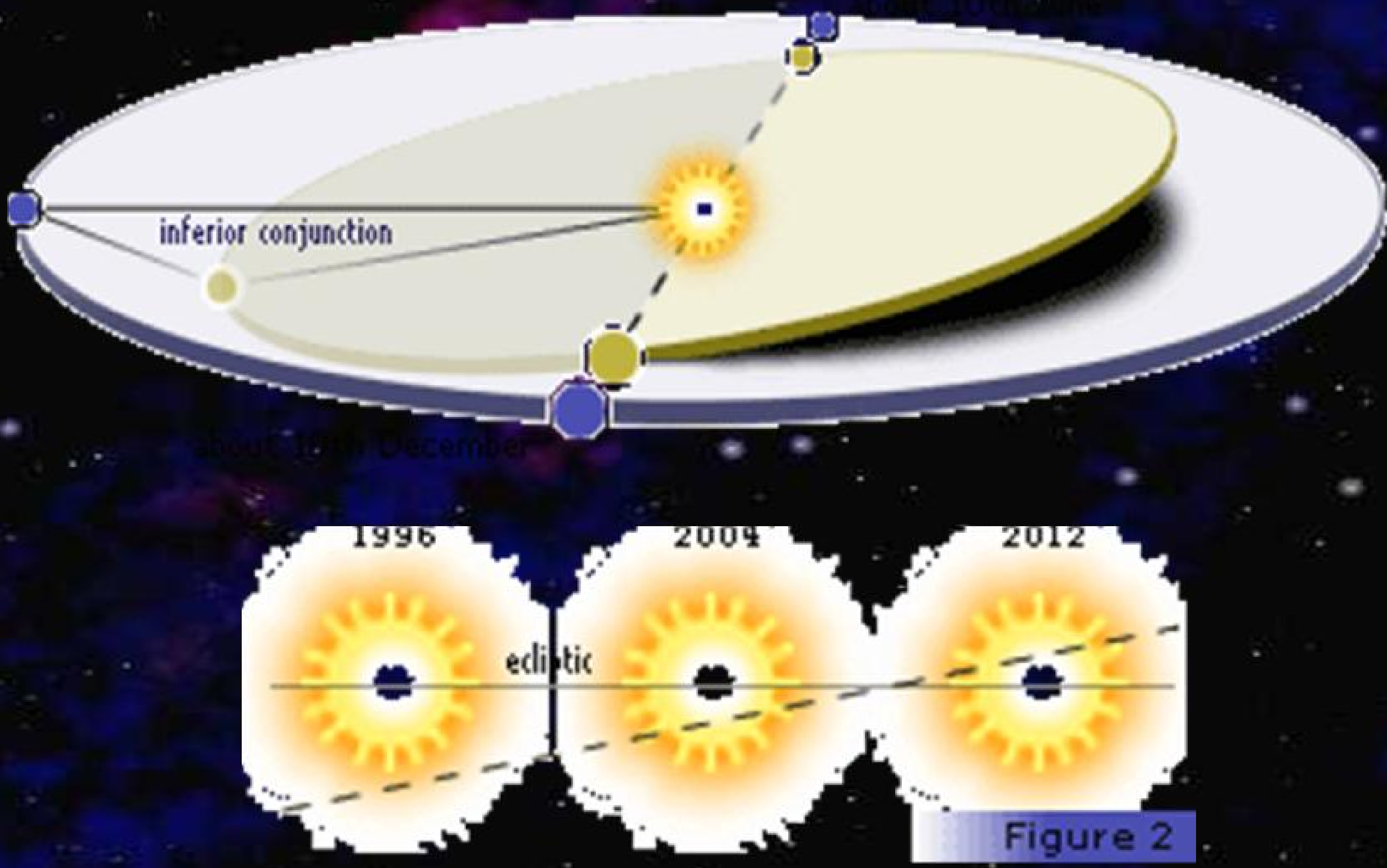
Joannis Kepler
(1571-1630)

- **There are no records to suggest that anyone ever observed this event.**
- **Kepler predicted it would not be visible in Europe, so he requested that mariners keep a lookout for it.**
- **Pierre Gassendi (1592-1655) tries and fails to observe it**

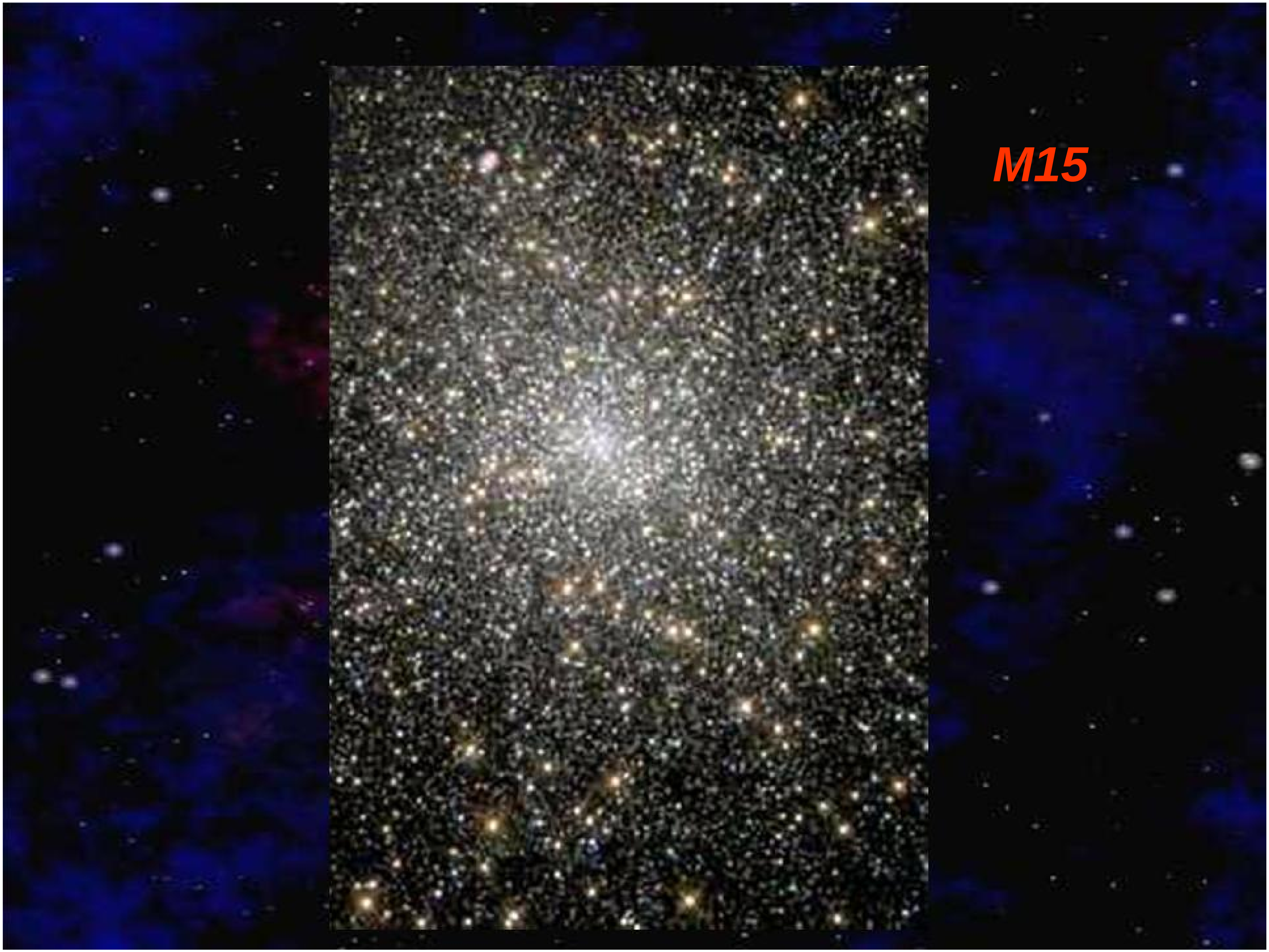



Swedish 1-m Solar Telescope, 08 June 2004

It’s All in the Geometry

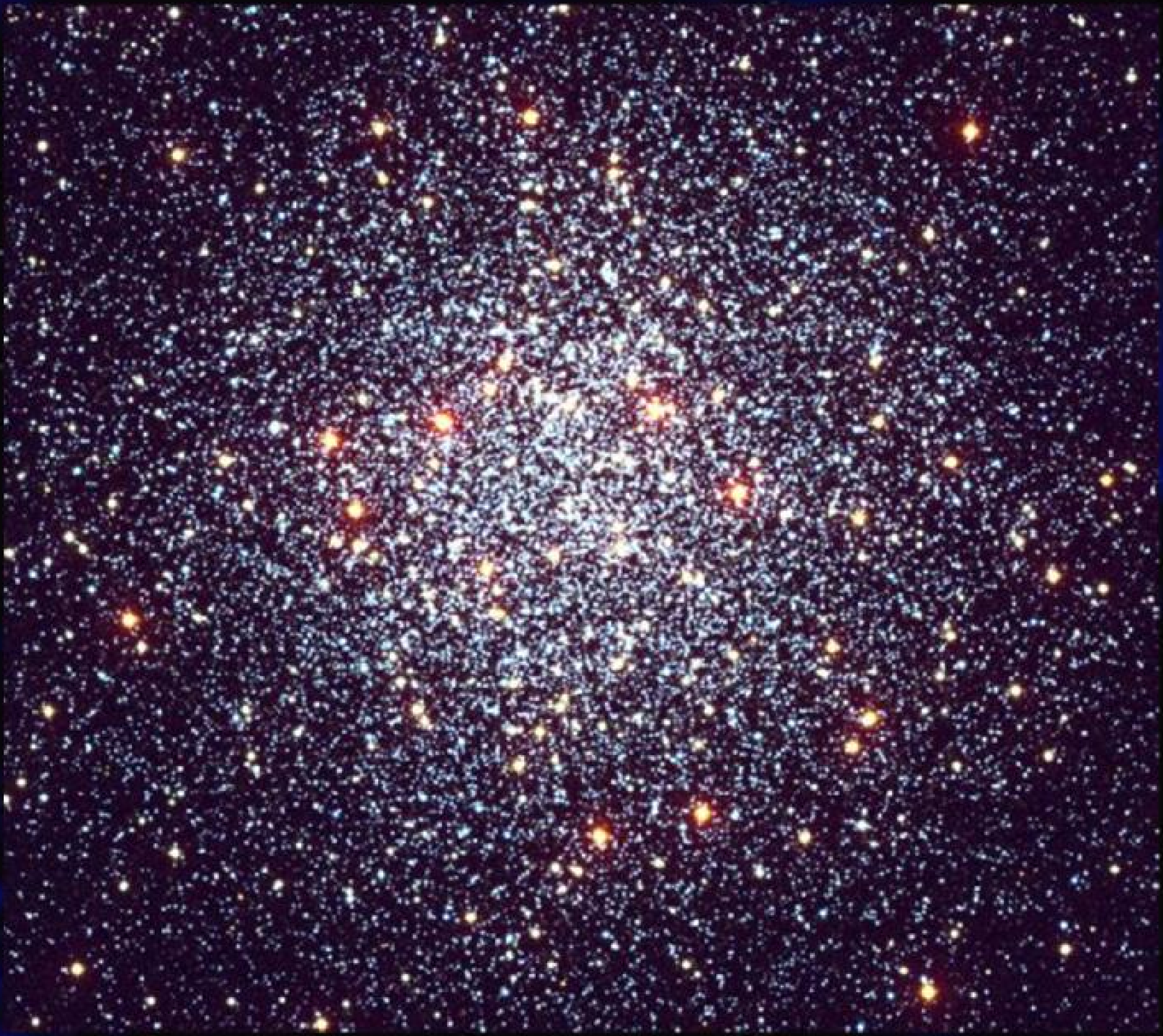


November 10, 2084

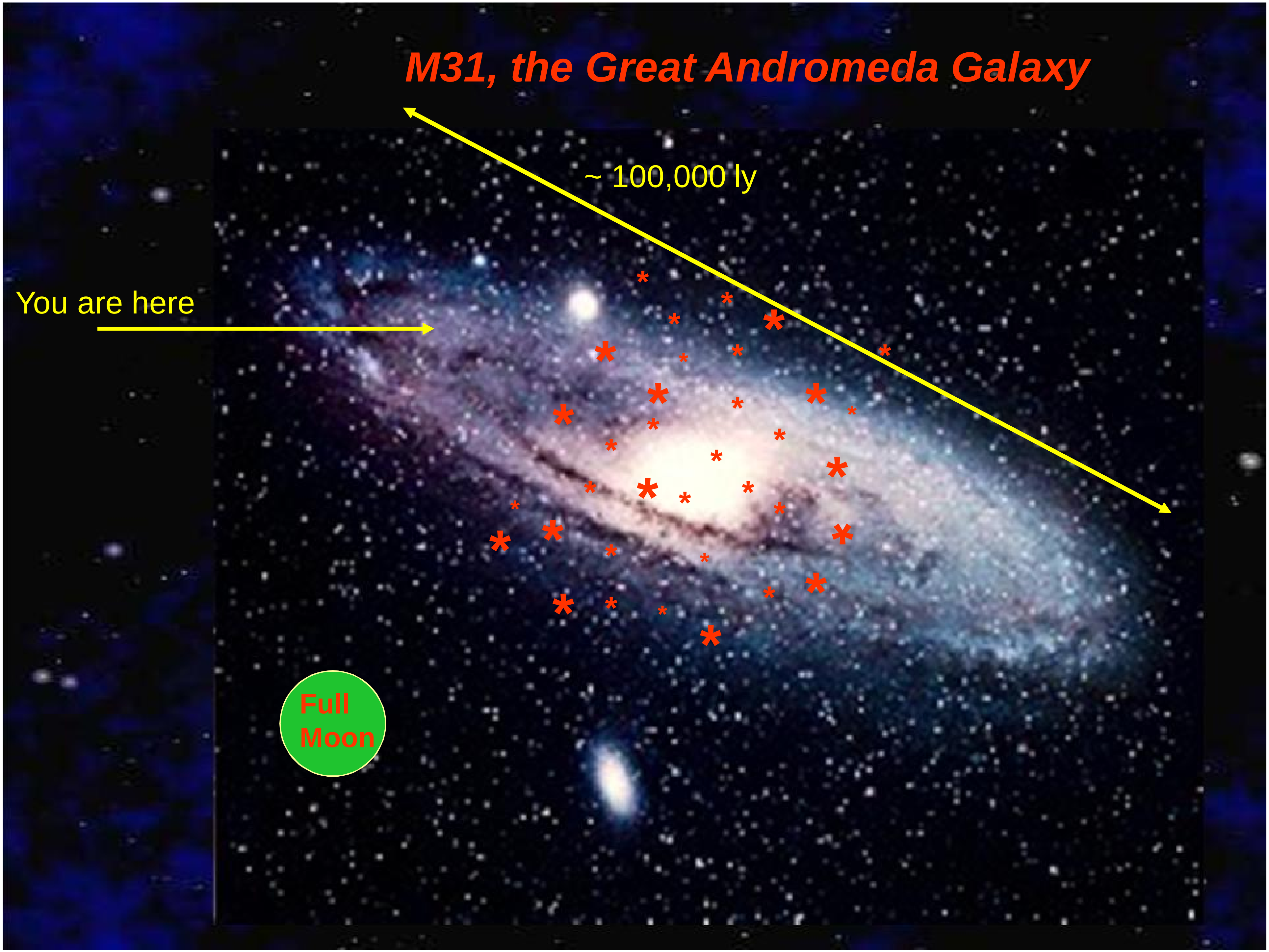

M15

M55

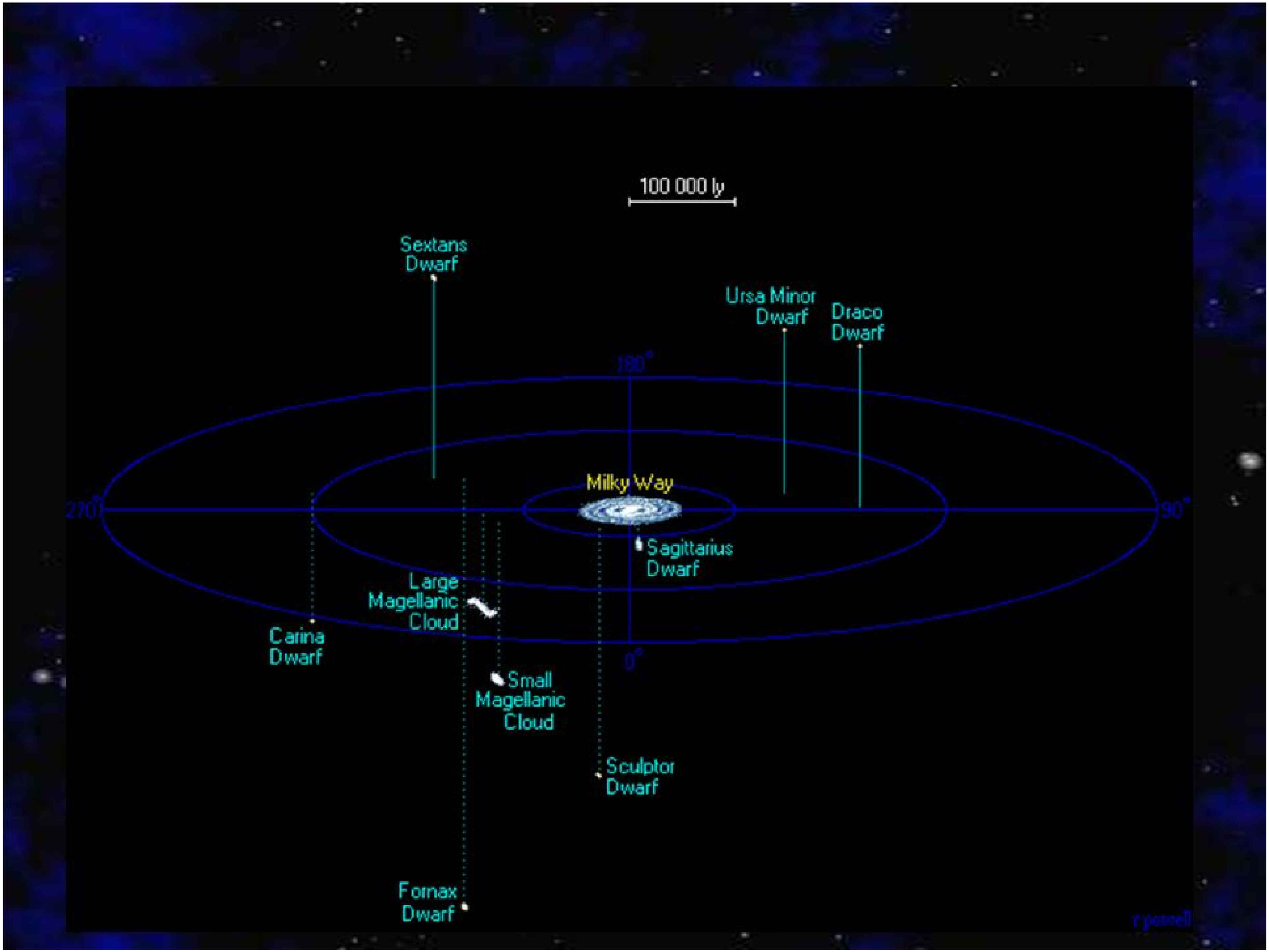
Globular star cluster




© Anglo-Australian Observatory



M31, the Great Andromeda Galaxy
~ 100,000 ly
You are here
Full
Moon


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

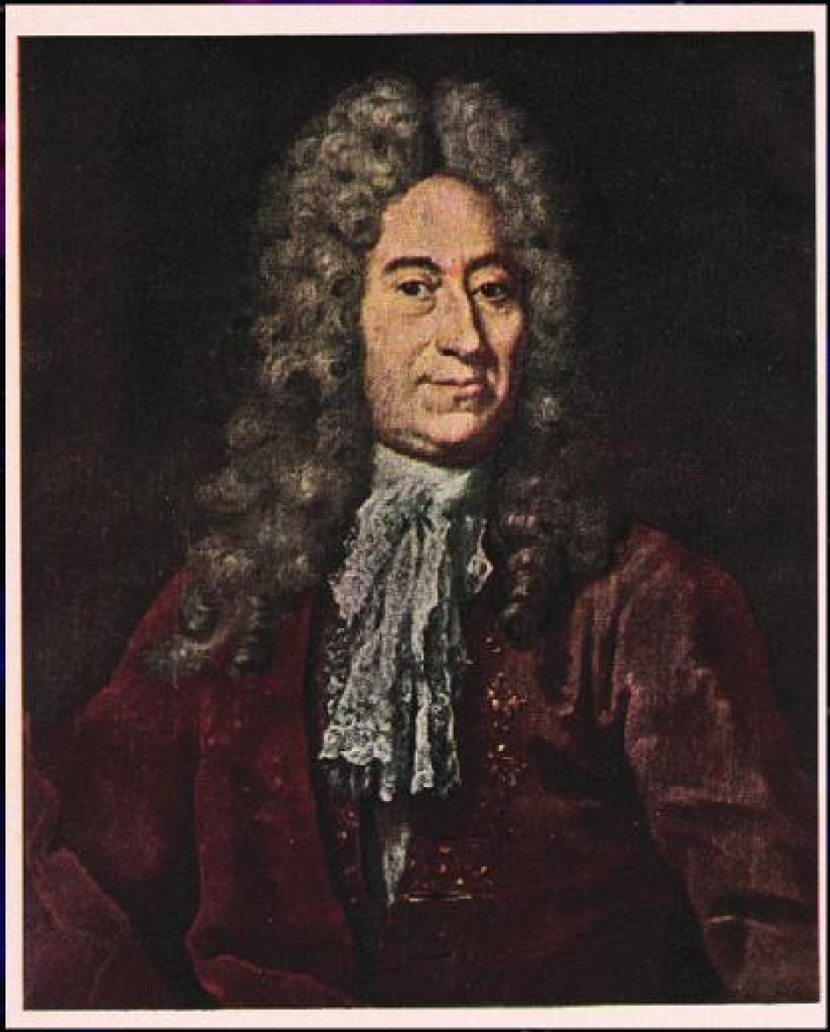
The Nature of Light

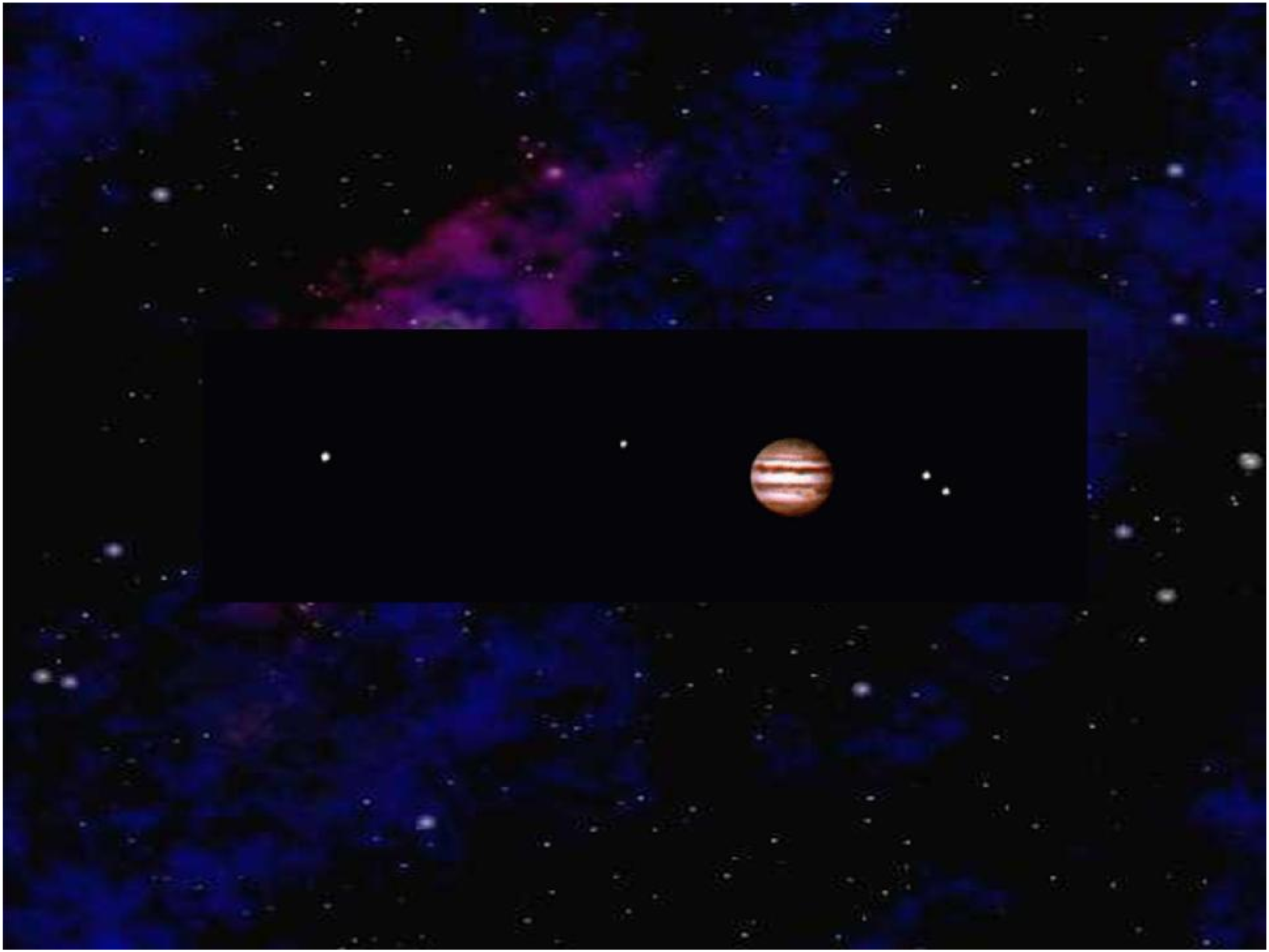
- Astronomy is observational not experimental (in general)
- All things in nature radiate energy as light.
- If we can understand the nature of light, then we can understand the nature of the objects emitting the light.

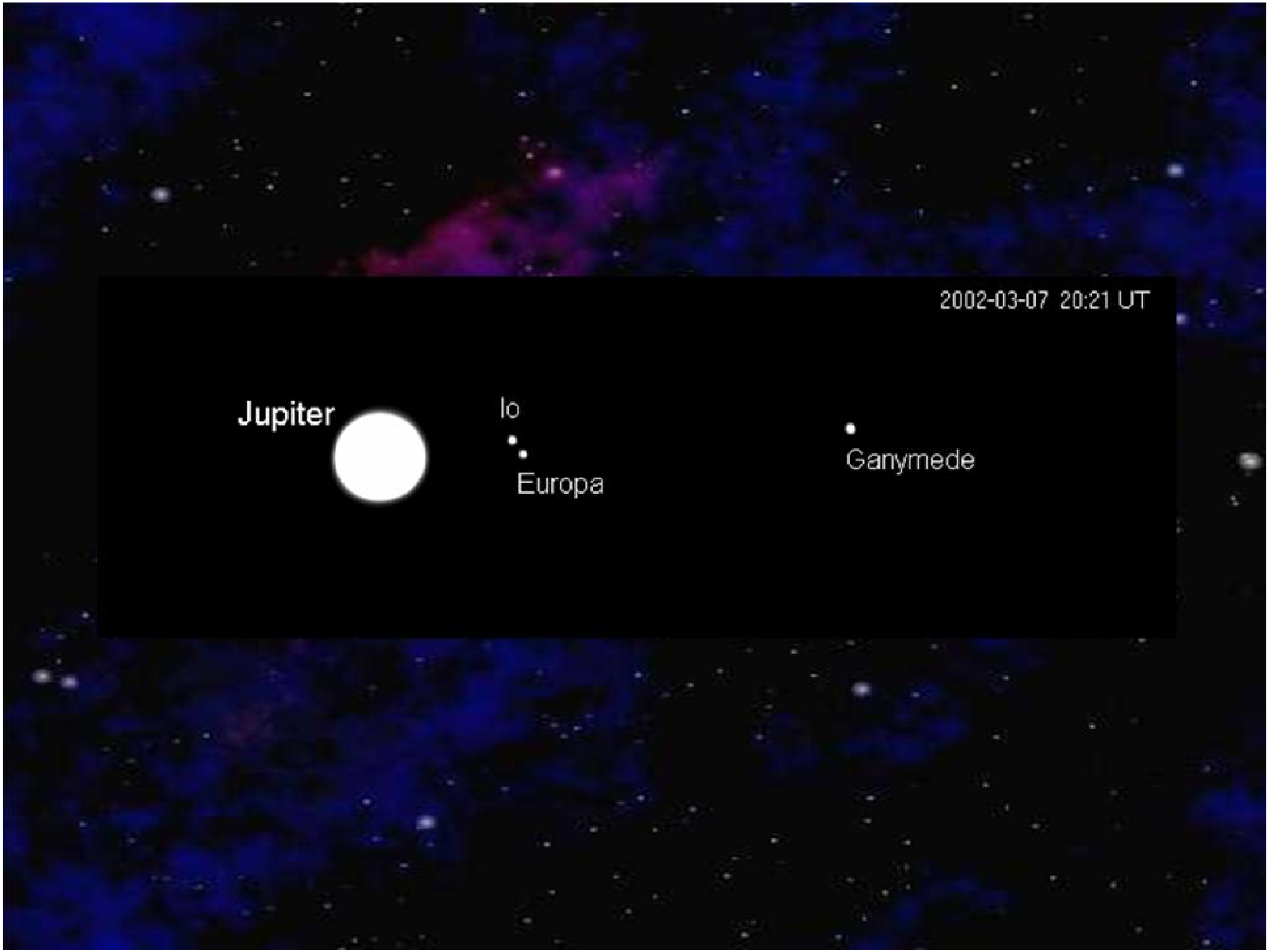
- What is light?
- How does light behave?
- What can we learn from light?

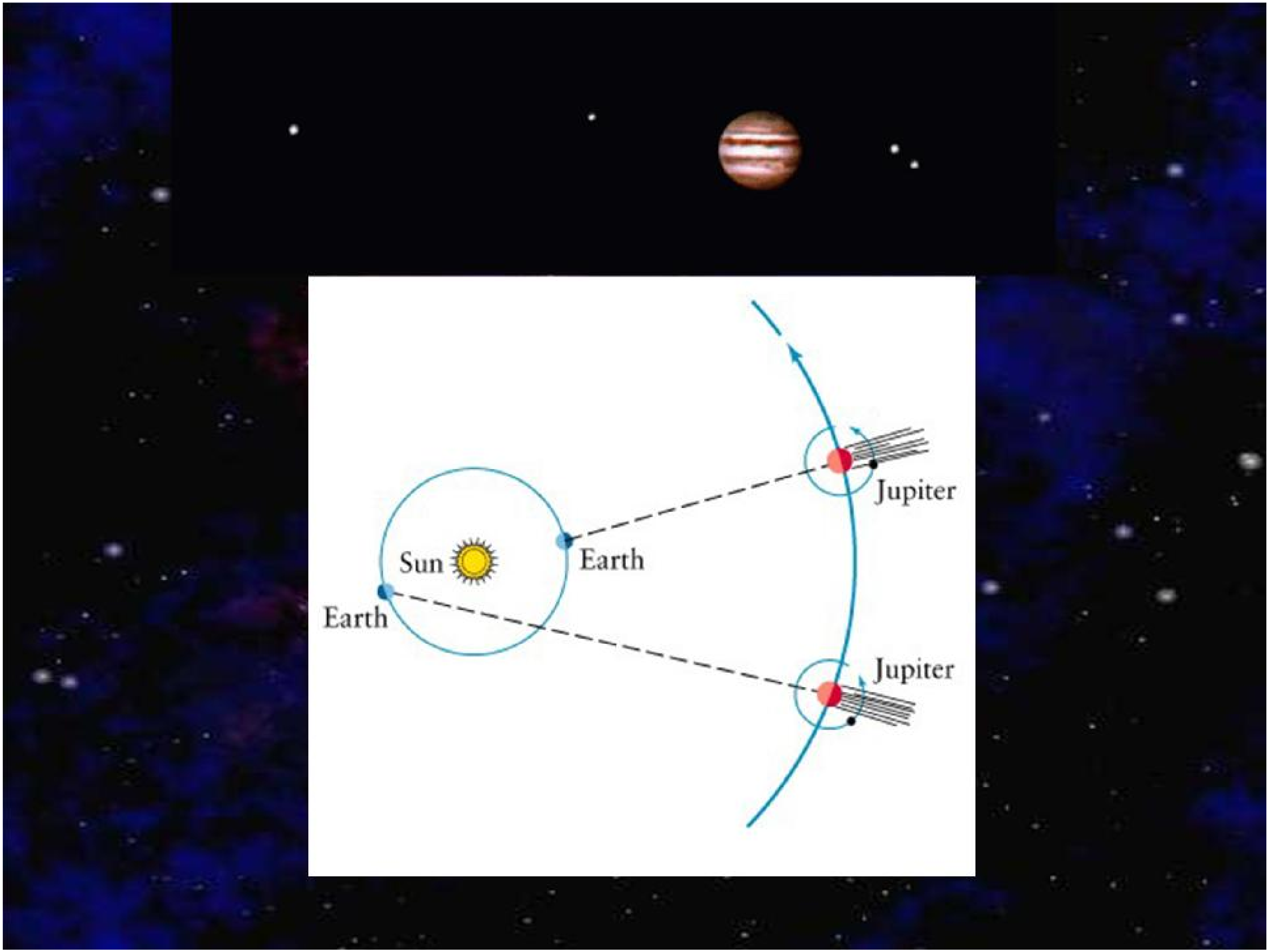
What is the ***speed*** of light?

Ole Roemer (1676)






2002-03-07 20:21 UT
Jupiter
Io
Europa
Ganymede


Jupiter
Earth
Sun
Earth
Jupiter

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:

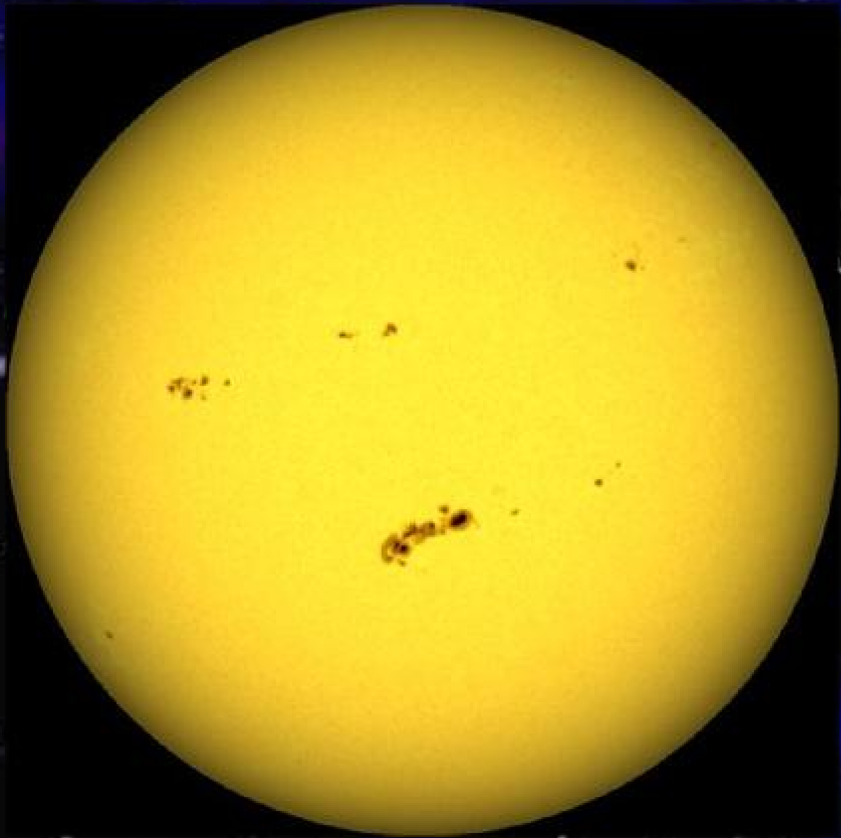
234,000 miles

1.25 seconds

Sun:

93 million miles

8 minutes 19 seconds



Jupiter:

400 million miles

36 minutes

Betelgeuse:

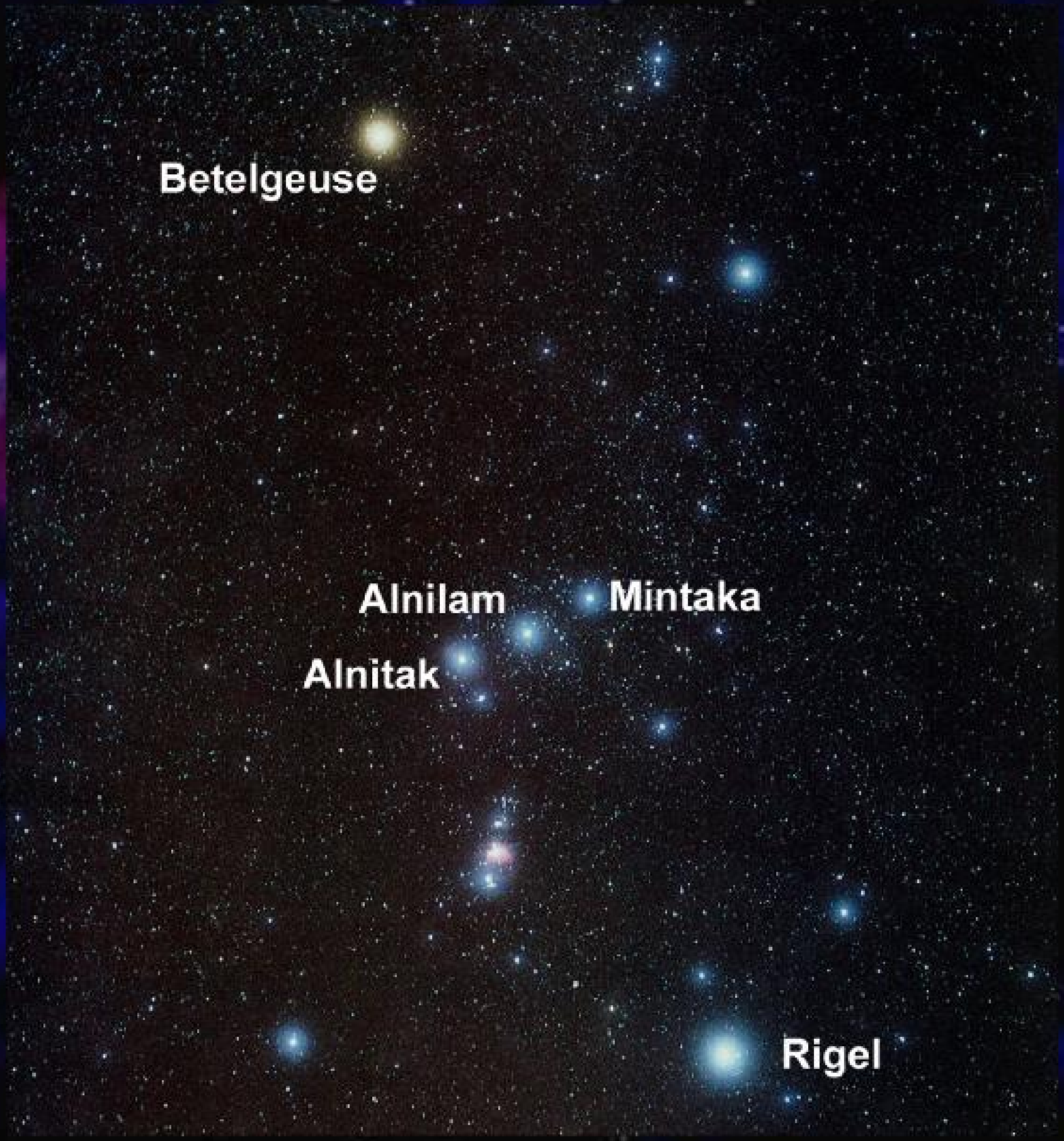
427 years

Rigel:

773 years

Orion Nebula:

1600 years



M51 galaxy:

23 million years

Light year

The distance a beam of light will travel in one years time.

5.9 **Trillion** miles

5,900,000,000,000 miles

Betelgeuse:

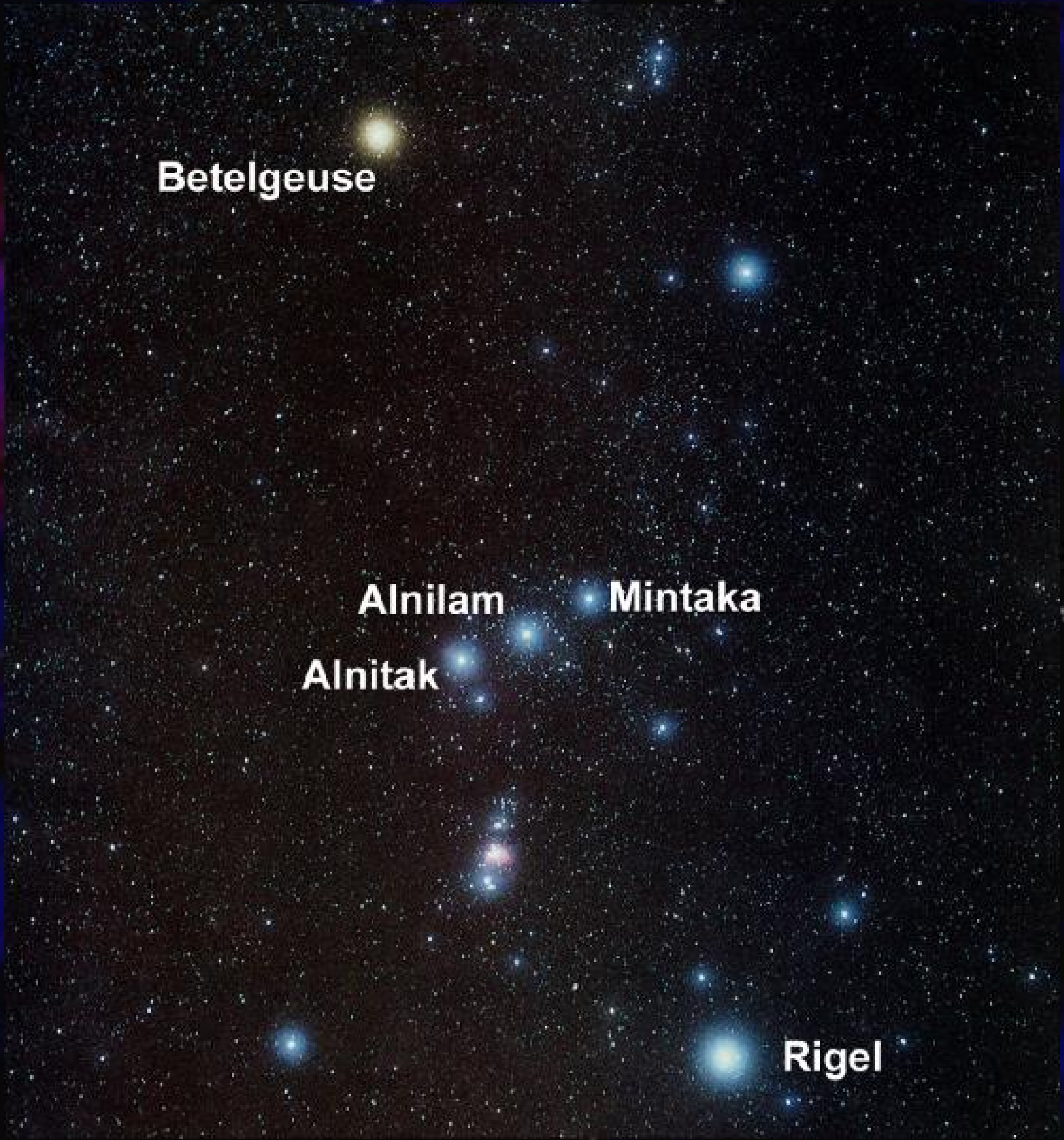
427 *light years*

Rigel:

773 *light years*

Orion Nebula:

1600 *light years*



M51 galaxy:

23 million *light years*

Thus, looking into space is to travel in a time machine