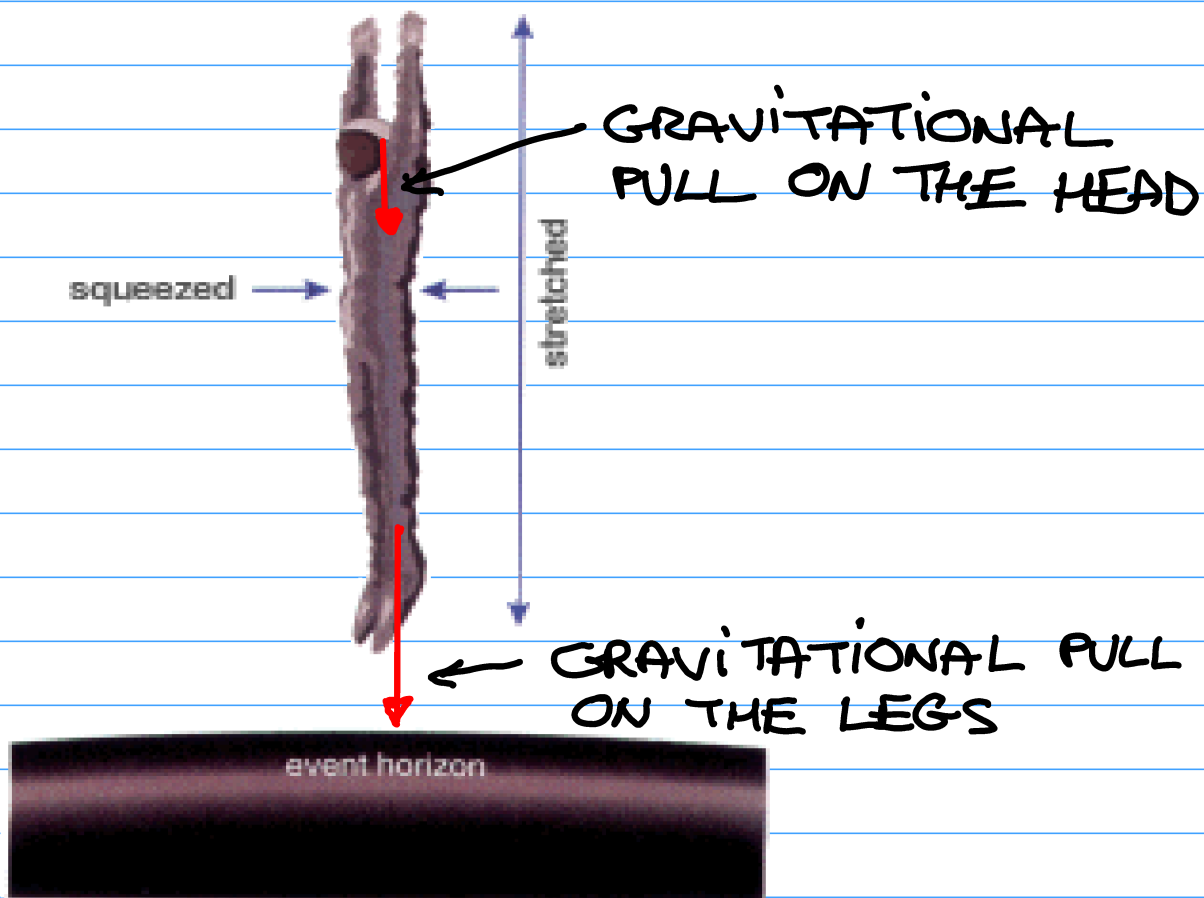


TIDAL FORCES, SATELLITES & RINGS

THE REAL OBJECTS ARE NOT ABSOLUTELY RIGID AND THEY DEFORM IF THE APPLIED FORCE IS SUFFICIENTLY STRONG

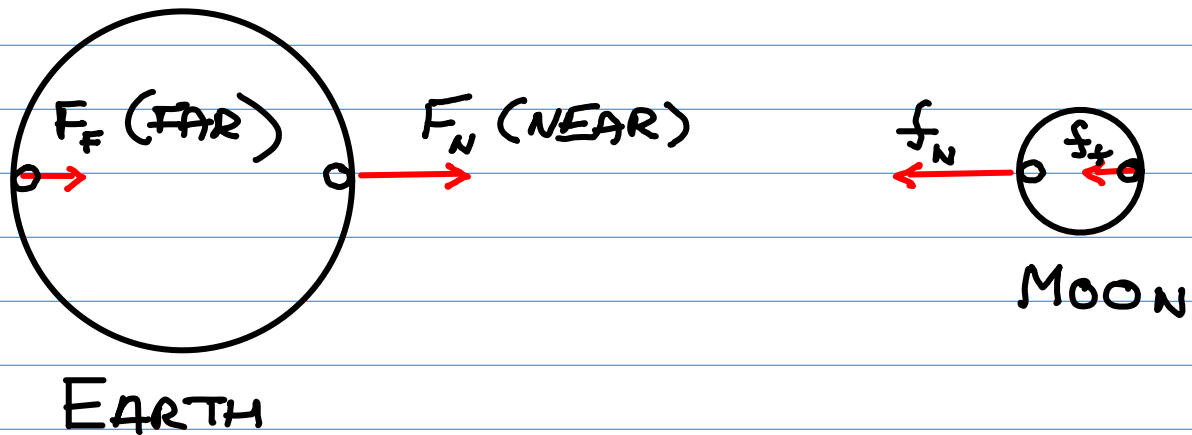


Tidal forces are lethal near the event horizon.

FORCE OF GRAVITY $\propto \frac{1}{\text{DISTANCE}^2}$
↑
PROPORTIONAL TO

GRAVITATIONAL PULL ON THE LEGS IS GREATER THAN THE GRAVITATIONAL

PULL ON THE HEAD AND THERE IS A NET STRETCHING FORCE, SO-CALLED TIDAL FORCE.



$$F_N, F_F \propto M_{\text{MOON}}; f_n, f_f \propto M_{\text{EARTH}}$$

TIDAL FORCE ON THE EARTH EXERTED BY THE MOON = $F_N - F_F \propto M_{\text{MOON}}$

TIDAL FORCE ON THE MOON EXERTED BY THE EARTH = $f_n - f_f \propto M_{\text{EARTH}}$

HENCE, A MORE MASSIVE BODY EXERTS A BIGGER TIDAL FORCE - THE MOON IS STRETCHED MORE BY THE EARTH THAN THE OTHER WAY AROUND

CONSEQUENCES:

1) TIDES ON EARTH

NEAR SIDE:

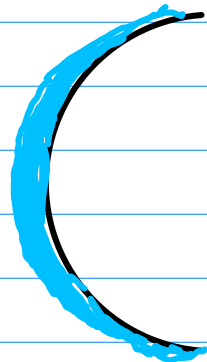
WATER IS PULLED AWAY FROM THE EARTH



→ TO THE MOON

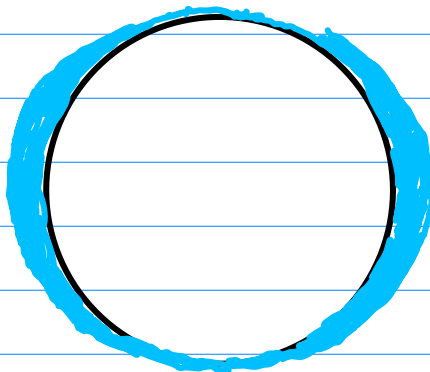
FAR SIDE:

EARTH IS PULLED AWAY FROM WATER



→ TO THE MOON

NET RESULT:



→ TO THE MOON

TWO TIDAL BULGES

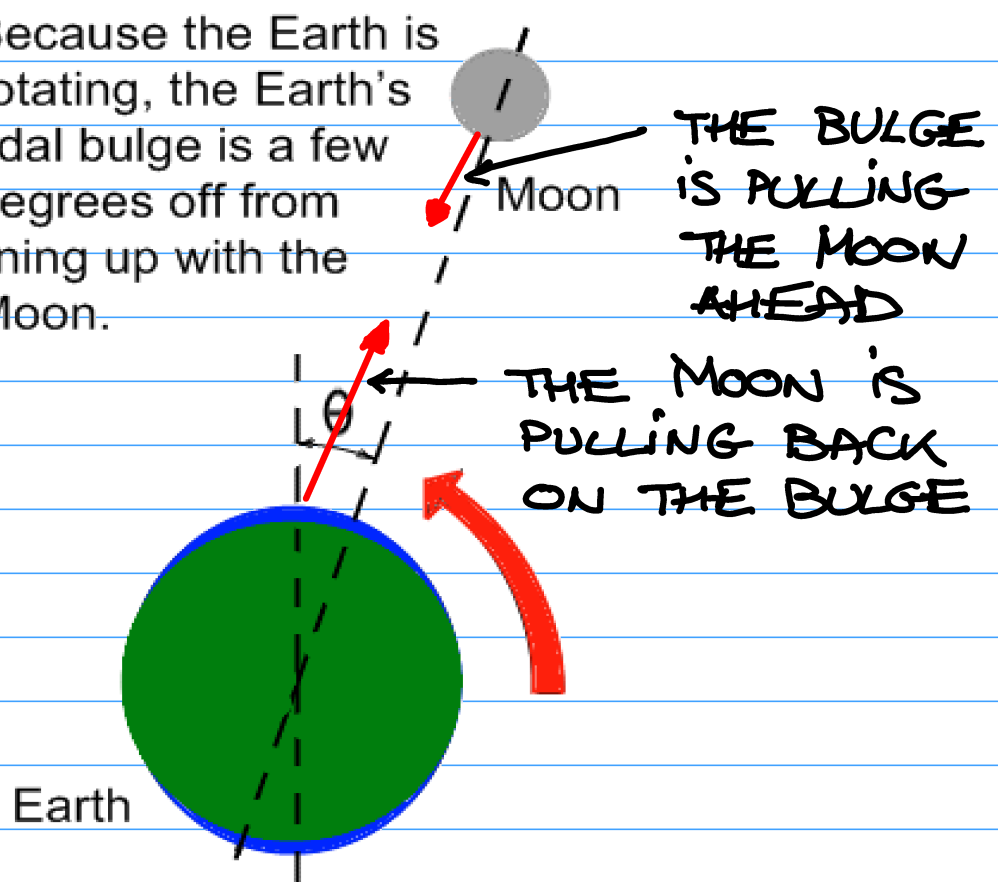
THE BULGES FOLLOW THE MOON WHICH REVOLVES AROUND THE EARTH ONCE A MONTH. THE EARTH SPINS ONCE A DAY. HENCE THERE ARE ABOUT TWO HIGH TIDES AND TWO LOW TIDES AT EACH

POINT ON EARTH DURING A 24 HOUR PERIOD.

THE MOON MOVES BY ABOUT $\frac{360^\circ}{30 \text{ DAYS}} = 12^\circ/\text{DAY}$ AND THE INTERVAL BETWEEN SUCCESSIVE HIGH TIDES IS NOT 12 HOURS BUT 12 HOURS AND 25 MINUTES.

2) SLOWING DOWN OF EARTH'S ROTATION AND THE RECESSION OF THE MOON

Because the Earth is rotating, the Earth's tidal bulge is a few degrees off from lining up with the Moon.



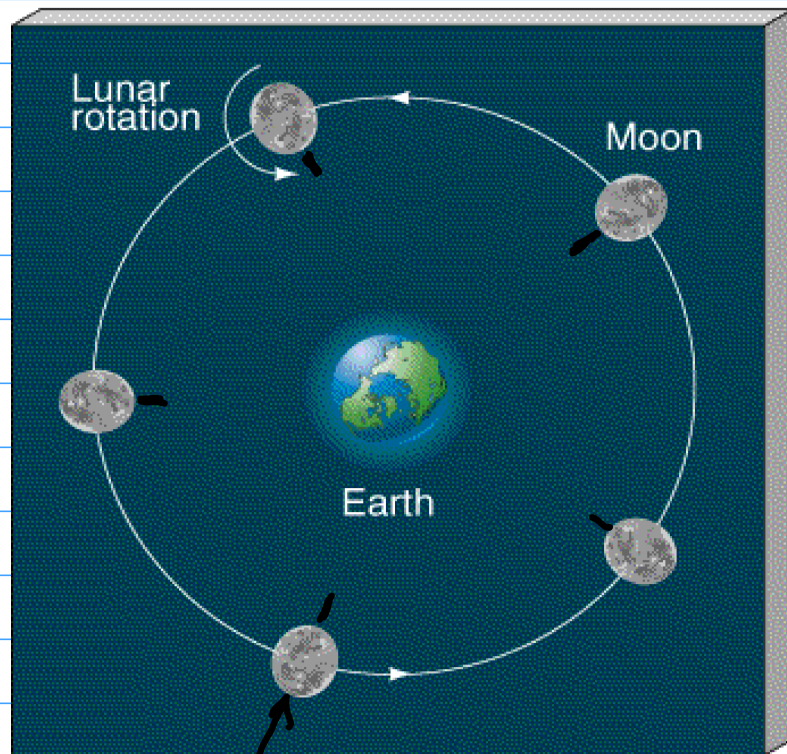
THE LAND MASSES EXERT FORCE ON WATER AS THE EARTH ROTATES CAUSING THE WATER BULGE TO OVERSHOOT.

THE MOON, IN TURN, TRIES TO ALIGN THE BULGE PULLING IT BACK. THIS IS TRANSFERRED TO THE LAND MASSES, CAUSING A SLOW DECREASE IN THE EARTH'S ROTATION RATE, I.E. THE LONGER DAYS. THE DAY INCREASES BY ABOUT 0.002 SECONDS PER CENTURY.

THE BULGE, IN TURN, EXERTS A FORCE ON THE MOON THAT HAS A COMPONENT ALONG MOON'S ORBIT - IT INCREASES THE MOON'S ORBITAL SPEED CAUSING IT TO GO INTO A HIGHER ORBIT. THE MOON IS DRIFTING AWAY AT A RATE OF 3.8 CM PER YEAR.

WHEN THE EARTH-MOON SYSTEM FORMED 4.5 BILLION YEARS AGO THE MOON WAS A LOT CLOSER (22,500 km) THAN IT IS NOW (384,400 km). ALSO, THE DAY ON EARTH WAS A LOT SHORTER (5 HOURS) THAN NOW (24 HOURS).

3) MOON'S SYNCHRONOUS ROTATION



"DARK" SIDE OF THE MOON

ALSO,

THE TWO SATELLITES OF MARS (PHOBOS AND DEIMOS) HAVE SYNCHRONOUS ROTATION;

FOUR LARGEST GALILEAN SATELLITES OF JUPITER (AND FOUR MORE) HAVE SYNCHRONOUS ROTATION;

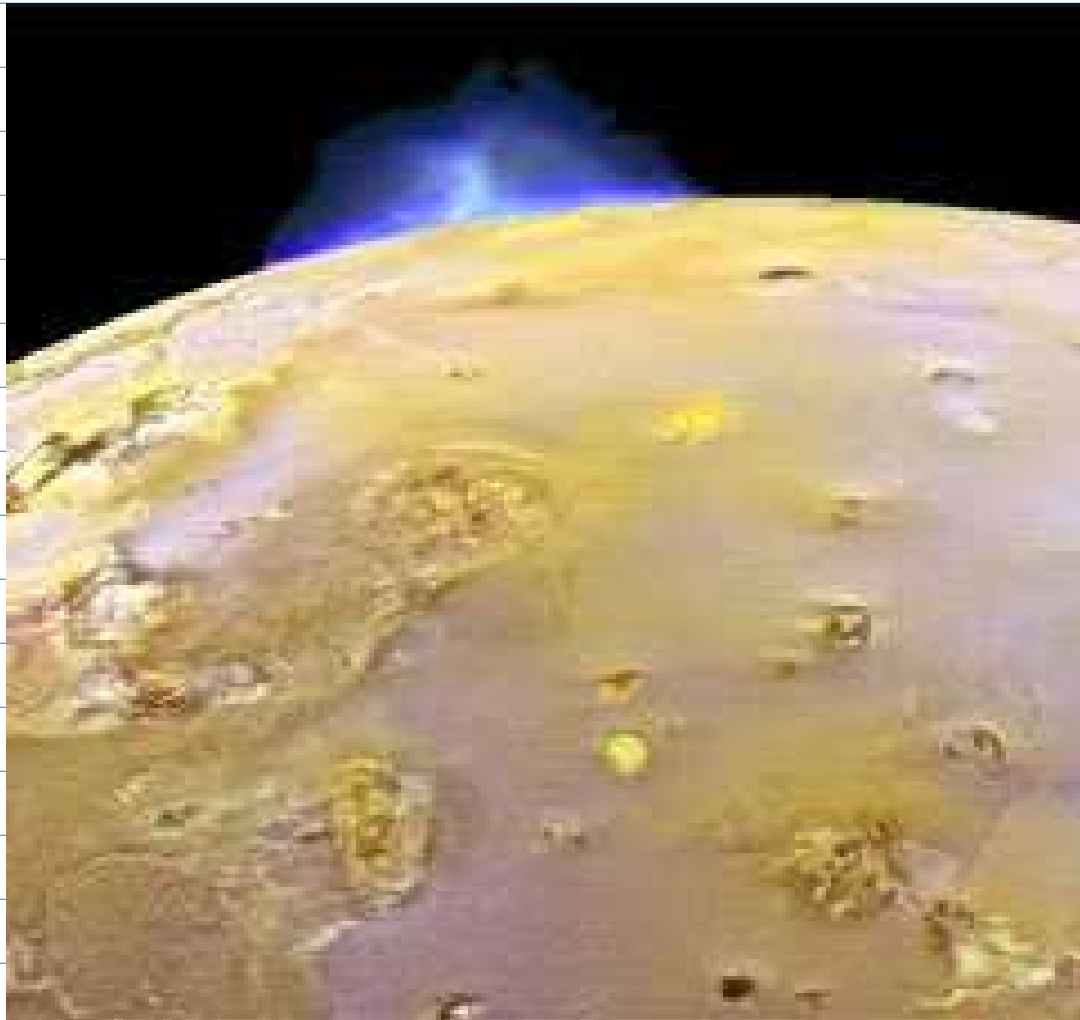
15 SATELLITES OF SATURN HAVE

SYNCHRONOUS ROTATION ;

5 LARGE SATELLITES OF URANUS HAVE
SYNCHRONOUS ROTATION ;

2 LARGE SATELLITES OF NEPTUNE
(PROTEUS AND TRITON) HAVE
SYNCHRONOUS ROTATION

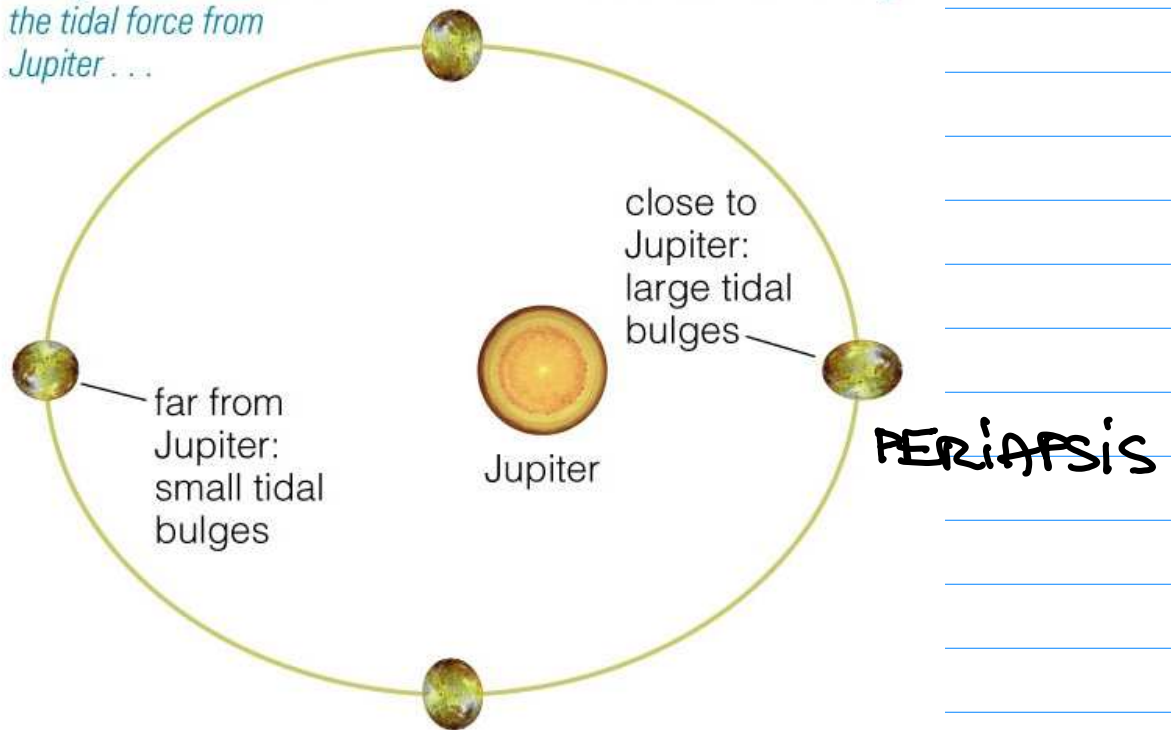
4) VOLCANISM ON IO



Io's elliptical orbit means continual changes in the strength and direction of the tidal force from Jupiter...

... and the changing tides flex Io's interior and cause tidal heating.

APOAPSIS



Io's ORBIT IS ELLIPTICAL AND THE TIDAL STRETCHING VARIES IN A PERIODIC WAY - IT IS LARGEST AT PERIAPSIS AND SMALLEST AT APOAPSIS. THIS PERPETUAL FLEXING LEADS TO THE HEATING OF IO'S INTERIOR - THE TIDAL HEATING.

PLANETARY RINGS:

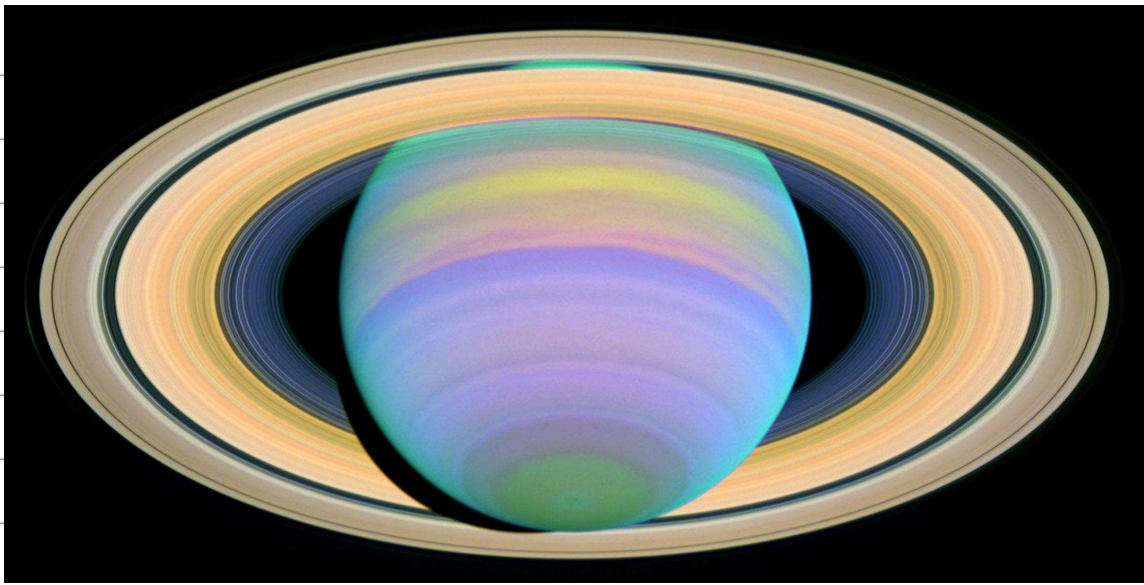
JUPITER:



RING DISCOVERED IN 1979 (VOYAGER 1).
IT CONSISTS OF VERY FINE DUST PARTICLES.

SATURN:

IT HAS SPECTACULAR RINGS FIRST
OBSERVED BY GALILEO

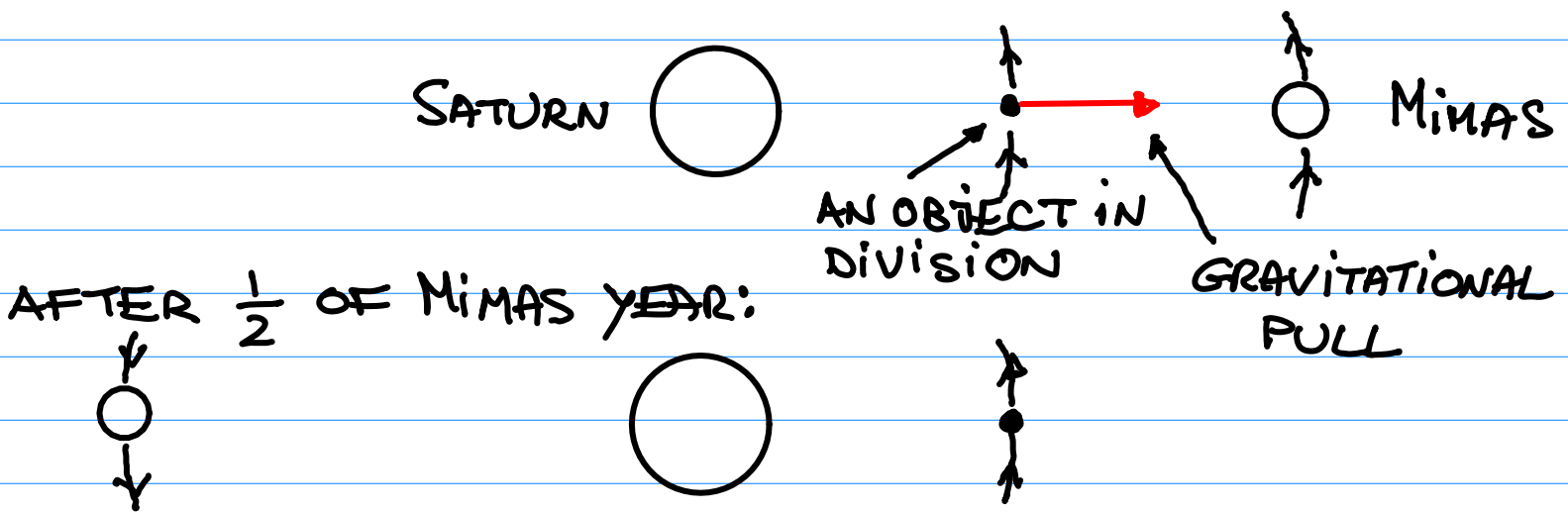


- THE RINGS CONSIST OF CHUNKS OF ICE OR ROCKS COVERED WITH ICE ; THEY HAVE A VERY HIGH ALBEDO ;
- THE CHUNKS RANGE IN SIZE FROM A PING PONG BALL TO A HOUSE ;



- THEY STRETCH 274,000 km TIP TO TIP,
BUT THEY ARE LESS THAN 100m THICK;

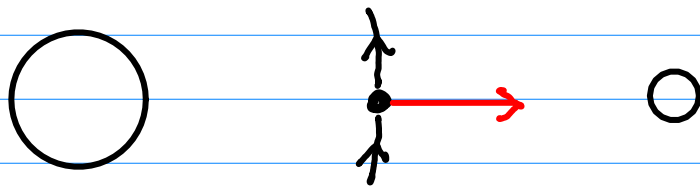
- THE RINGS ARE DIVIDED BY GAPS;
THE BIGGEST IS CALLED CASSINI
DIVISION. THIS DIVISION IS CAUSED
BY SATURN'S SATELLITE MIMAS:



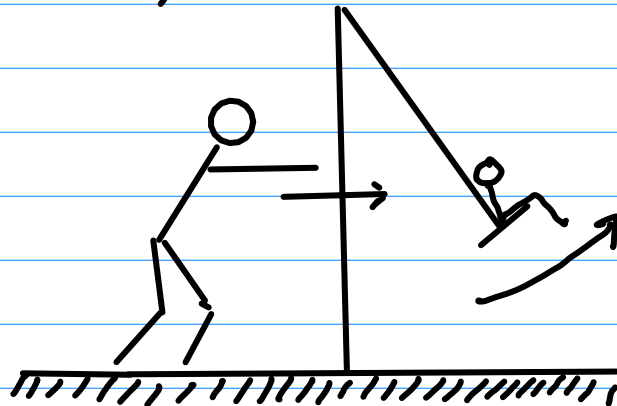
AFTER $\frac{1}{2}$ OF MIMAS YEAR:

The diagram shows Saturn on the right and the object from the previous diagram on the left. Two downward-pointing arrows are positioned between Saturn and the object, indicating the time interval.

AFTER 1 MIMAS YEAR:

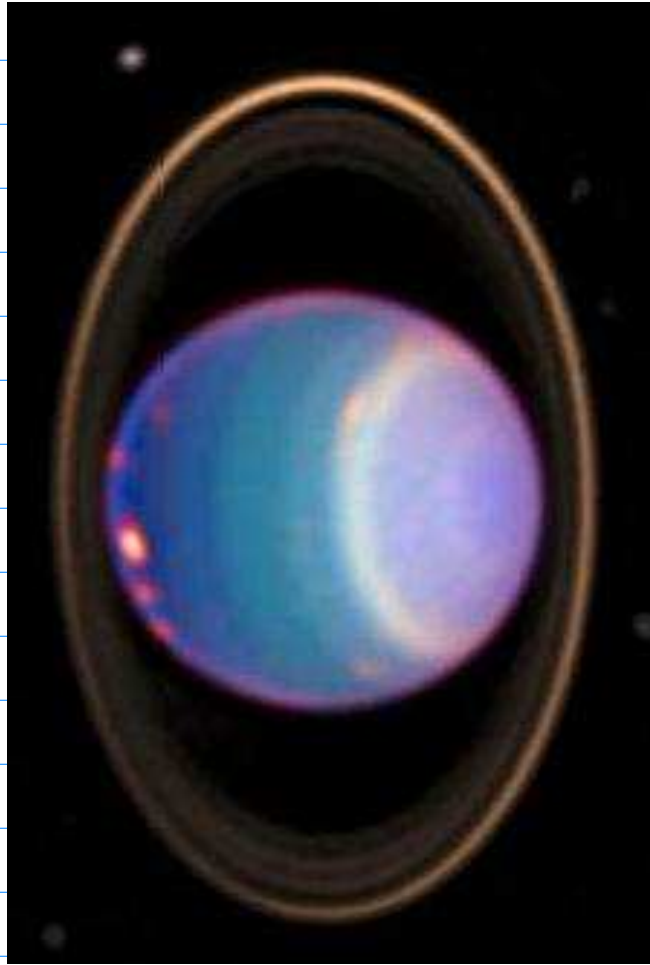


ANALOGY: A RHYTHMIC PUSH OF A CHILD ON A SWING



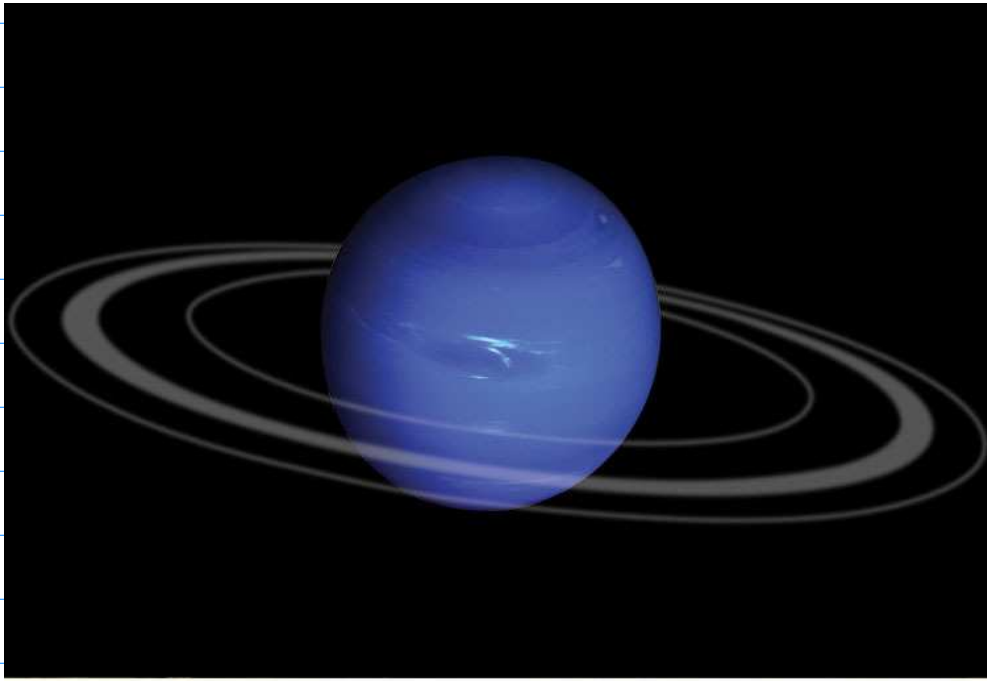
THE RESONANT GRAVITATIONAL PULL
TAKES THE OBJECT OUT OF THE GAP.

URANUS:



THE RING DISCOVERED IN 1977 BY
OCCULTATION; SINCE THEN 9 VERY
THIN RINGS WERE DISCOVERED BY
VOYAGER 2. THEY ARE MADE OF
DARK MATERIAL WITH VERY LOW ALBEDO.

NEPTUNE:

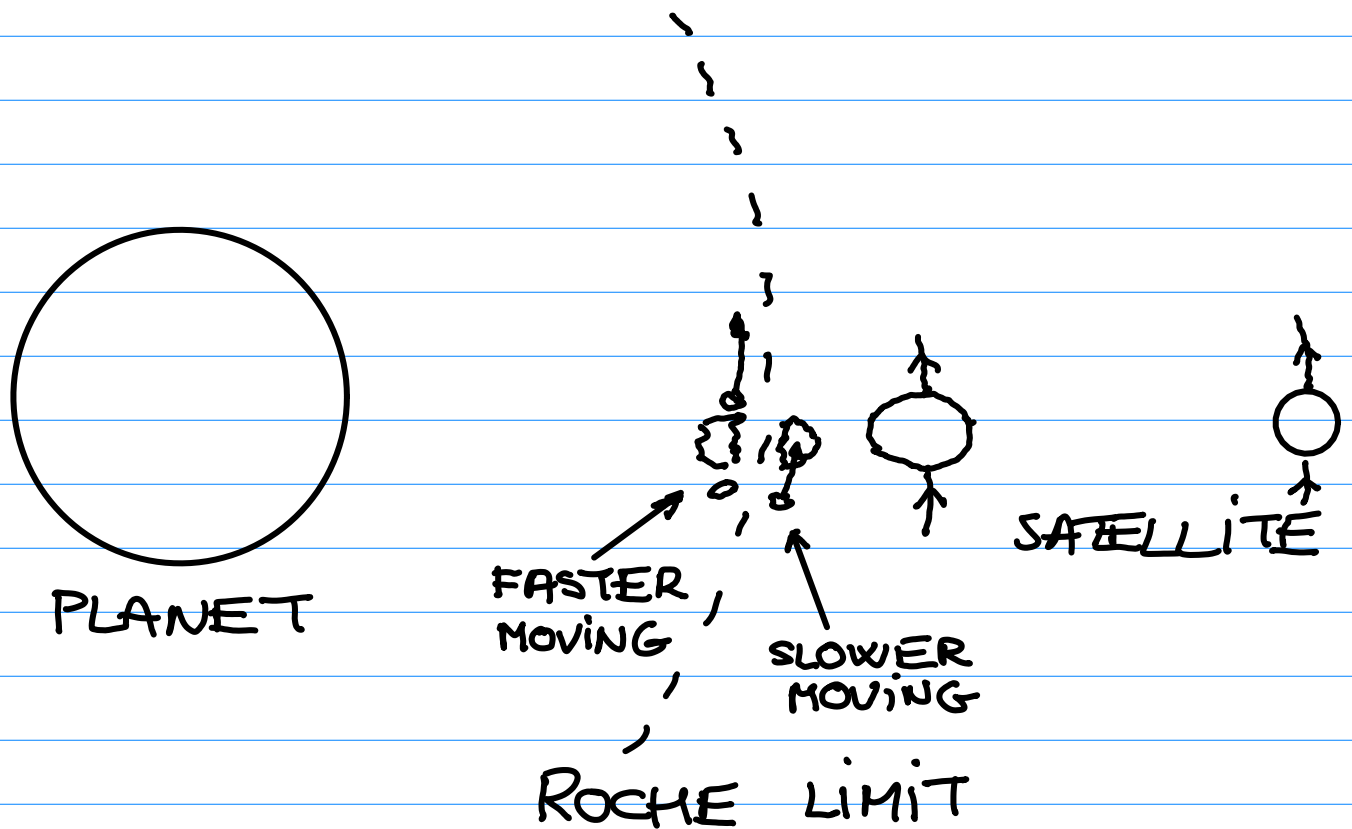


FIRST DISCOVERED IN 1984 AND IN 1989 VOYAGER 2 FOUND THIN NONUNIFORM RINGS

WHY DO THE RINGS FORM AND NOT ANOTHER SATELLITE?

THE TIDAL FORCE INCREASES AS THE DISTANCE BETWEEN THE SATELLITE AND THE PLANET DECREASES BECAUSE THE FORCE OF GRAVITY VARIES AS $1/\text{DISTANCE}^2$

ROCHE LIMIT: THE CRITICAL DISTANCE INSIDE WHICH THE TIDAL FORCE ON A SATELLITE IS SUFFICIENT TO DISRUPT IT.



THE DIFFERENCE IN SPEEDS CAUSES THE BROKEN UP MATERIAL TO FORM A RING.

FOR A SATELLITE HELD TOGETHER BY ITS OWN GRAVITY THE ROCHE LIMIT IS APPROXIMATELY

2.4 TIMES THE RADIUS OF THE PLANET.

OUR MOON COULD NOT REMAIN INTACT
BODY MUCH CLOSER TO EARTH THAN 18,000 km.

EXAMPLES:

JUPITER : RING AT 1.8 TIMES THE RADIUS OF
JUPITER.

SATURN : RINGS BETWEEN 1.1 AND 2.5 TIMES
THE RADIUS OF SATURN.

URANUS : 9 THIN RINGS BETWEEN 1.5 AND
2 TIMES THE RADIUS OF URANUS.

NEPTUNE : 4 THIN RINGS BETWEEN 1.7 AND
2.5 TIMES THE RADIUS OF NEPTUNE.