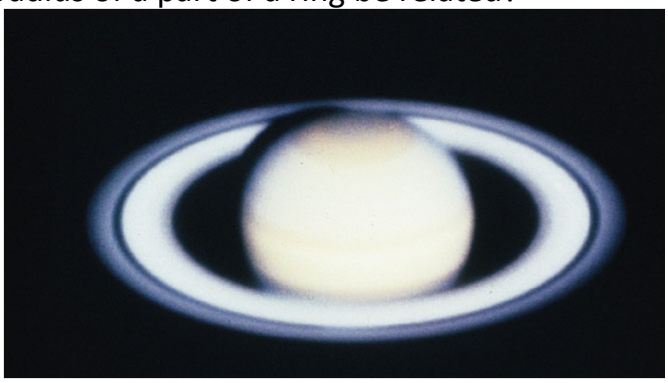
# Jovian Planets—21 Jan

- Are rings solid?
- Internal structure
  - Measuring mass
- Why does Saturn have rings and not moons? (Mon)

# Are the rings of Saturn solid?

- If the rings are solid, the inner part of a ring has the same rotation period as the outer part.
- If the ring is made of little particles, how should the period and radius of a part of a ring be related?

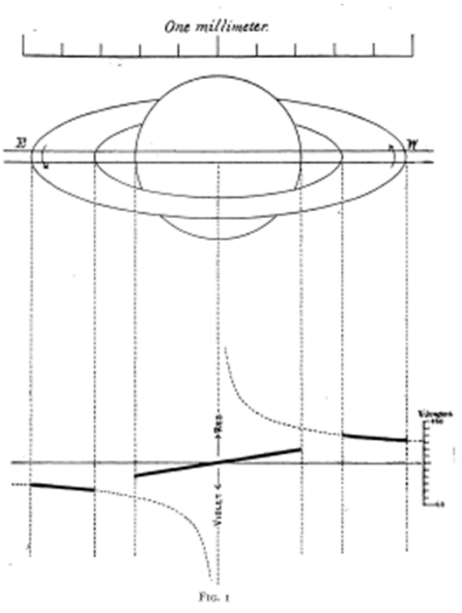


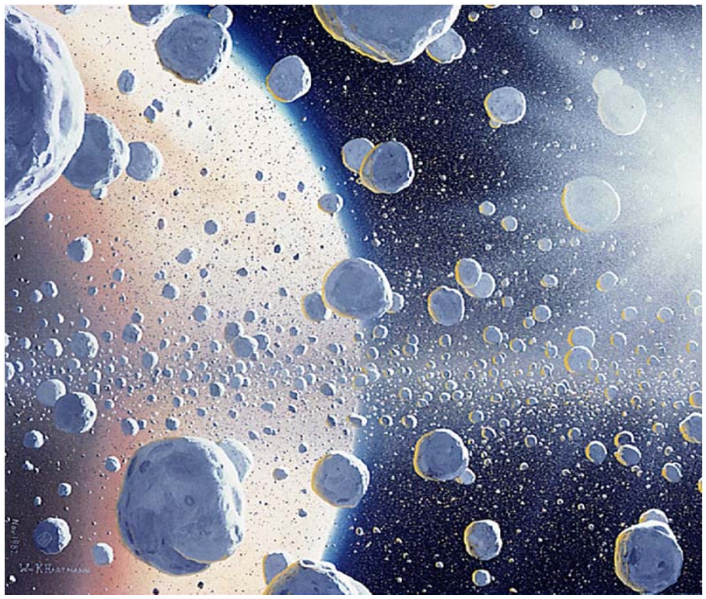
# Velocity of rings

- The velocity can be measured with the Doppler effect.
- If the rings are solid, how does velocity depend on radius?
- If the rings are made of particles, how does velocity depend on radius?

# Measurement

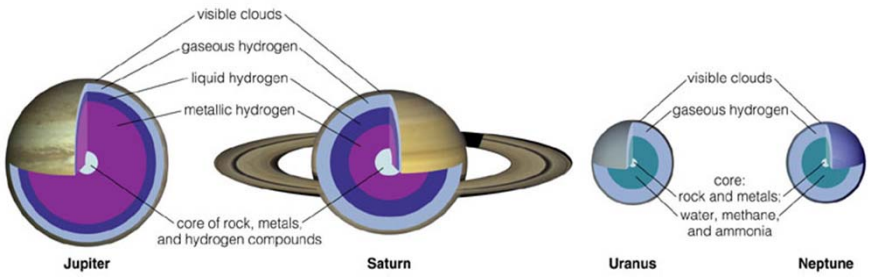
- Solid ring
$$v = \frac{R}{P} = R$$
- Kepler's 3rd Law
$$P^2 = R^3$$
$$v = R^{-1/2}$$
- Keeler, J. e., 1895, ApJ, 1, 416 measured the speed of the rings and showed they obey Kepler's 3rd law.





## Internal composition of jovian planets

- How do astronomers know the composition of the jovian planets? What are the data?



## Exploratory questions

- Estimate the internal pressure of a planet with mass M and radius R.

1. The pressure P is
   A. $GM/R^2$
   B. $GM^2/R^2$
   C. $GM^2/R^4$
   D. $GM^3/R^6$

## Pressure

| Planet | P[TPa] |
|---|---|
| Jupiter | 2.5 |
| Saturn | 0.4 |
| Uranus | 0.3 |
| Neptune | 0.3 |

- The internal pressure
  - 1TPa=$10^7$atm
- "Atomic pressure"
  - Coulomb force $F=e^2/a_0^2$, where e is charge of electron and $a_0$ is Bohr radius.
  - Atomic pressure $e^2/a_0^4$=30TPa
  - For n=2 level of hydrogen, radius is $4a_0$. ($E_2=¼E_1$ and $E=e^2/r$.) The atomic pressure is 0.12TPa.
- The pressure is high enough to modify the electronic structure of hydrogen.

## Is a gas giant gaseous in the interior?

- If the pressure is low, an electron is bound to its proton. The potential energy is

$$PE = -e^2/a$$

1. Write PE in terms of density $\rho$. Ignore constants.

## Is a gas giant gaseous in the interior?

- If the pressure is low, an electron is bound to its proton. The potential energy is

$$PE = -e^2/a$$
$$PE \sim -\rho^{1/3}$$

- If the pressure is high, Heisenberg's uncertainty relation restricts the momentum of the electron. $p\ a > \hbar$

$$KE = \frac{1}{2m}p^2 \sim a^{-2} \sim \rho^{2/3}$$

- At high density KE beats PE $\Rightarrow$ an electron is not bound to its proton. Hydrogen is a metal.

## Measurements & models

- Models: The pressure is so high that the phase of the gas giants is not gas in the interior.
  - Thermodynamic modes: Pressure vs density.
  - Phase transitions, e. g., gas to liquid.
- Measurements
  - Mass
  - Radius
- How can you measure the radius of Jupiter?

## Measuring mass

- The gravitational acceleration between me and Earth is

$$-GM/R^2$$

- To find Earth's mass, what can I measure ?