PHY2003 ASTROPHYSICS I

Lecture 10. The Terrestrial Planets

Mercury

$a = 0.387\text{au}$, $e = 0.205$, $P = 0.24$ years $= 88$ Earth days,

Apparent magnitude $V \geq -2.0$

1 sidereal day (true spin rate) $= 58.6$ Earth days, 1 solar day (apparent rotation rate from surface) $= 176$ Earth days

Note that the spin to orbit periods imply a 2:3 spin-orbit *resonance*.

Mass $M_p = 0.06 M_\oplus$, radius $R_p = 0.38 R_{Earth} = 0.38 R_\oplus$, average density $\overline{\rho} = 5.4 \times 10^3$ kg/m^3.

We can approximate large planetary bodies as consisting of an iron core of density ρ_c and radius R_c, surrounded by a mantle of molten/solid rock of density ρ_m.

Mass of the core $M_c = \frac{4}{3}\pi \rho_c R_c^3$

Mass of the mantle $M_m = \frac{4}{3}\pi \rho_m R_p^3 - \frac{4}{3}\pi \rho_m R_c^3$

Mass of the planet

$$M_p = M_c + M_m = \frac{4}{3}\pi \left[\rho_c R_c^3 + \rho_m R_p^3 - \rho_m R_c^3\right] = \frac{4}{3}\pi \left[\rho_c R_c^3 + \rho_m (R_p^3 - R_c^3)\right]$$

Average density $\overline{\rho} = M_p/(4/3\pi R_p^3)$

$$\overline{\rho} = \rho_c \left(\frac{R_c}{R_p}\right)^3 + \rho_m \left[1 - \left(\frac{R_c}{R_p}\right)^3\right]$$

Inverting this equation:

$$\boxed{\frac{R_c}{R_p} = \left(\frac{\overline{\rho} - \rho_m}{\rho_c - \rho_m}\right)^{1/3}}$$

Iron has $\rho \simeq 13,000$ kg/m^3, silicate rock has $\rho \simeq 3,300$ kg/m^3.

Mercury has a very large iron core.

Surface has albedo $A = 0.06$, highly cratered from impacts. Since arrival of *Messenger* spacecraft in 2011, many areas of old volcanic activity have been identified .

Venus

$a = 0.723$ au, $e = 0.007$, $P = 0.62$ years $= 225$ Earth days

Apparent magnitude $V \geq -4.6$

1 sidereal day $= 243$ Earth days, 1 solar day $= 117$ Earth days

Note: Venus rotates in retrograde fashion.

Mass $= 0.815 M_\oplus$, radius $= 0.95 R_\oplus$, density $\overline{\rho_\oplus} = 5.2 \times 10^3$ kg/m^3.

Albedo $A = 0.76$ due to optically thick cloud cover (some transparency at infrared wavelengths). Cloud cover also gives rise to high surface temperatures of $\simeq 700$K, surface pressure $90 P_\oplus$.

Radar images show surface covered with faults and volcanoes, not known if still active today. Few impact craters due to thick atmosphere and severe erosion.

Earth

$a = 1.4985 \times 10^8$ km $= 1$ au, $P = 365.25$ Earth days, $e = 0.017$

1 Solar day $= 24$ hours.

1 Sidereal day $= 23.93$ hours.

Radius $R_\oplus = 6387$km, mass $M_\oplus = 5.97 \times 10^{24}$kg, mean density $\overline{\rho_\oplus} = 5.5 \times 10^3$ kg/m^3. As average density of surface rocks is 3300 kg/m^3 $\Rightarrow$ large iron core.

Central temperature at $\sim 3000K$, due to heating by radioactive decay of long-lived isotopes, leads to surface volcanism.

Surface is highly eroded due to action of atmosphere, oceans and plate tectonics. Atmosphere is 78% N_2, 21% O_2, composition is not in chemical equilibrium due to *life*.

Moon

$a = 384,400$ km, $P = 27.32$ Earth days, $e = 0.055$

1 sidereal day $= 27.32$ Earth days. Moon is in 1:1 spin-orbit resonance (orbital period = spin period), due to tidal friction.

1 solar day$= 28.5$ Earth days.

Radius $R_M = 0.27R_E$, mass $M_M = 0.012M_E$,
mean density $\overline{\rho_M} = 3.3 \times 10^3$ kg/m^3 $\Rightarrow$ no iron core.

Apparent magnitude $V \geq -12.6$ (full moon).

Surface has a visual albedo of $A \simeq 0.08$, heavily cratered, with old large basaltic (lava) plain scalled *maria*. These originated from very large impacts by asteroids and comets, which broke through the crust to the underlying mantle.

Far side of moon has no maria. This is possibly due to tidal stresses on crust by Earth, making the near-side crust of the Moon thinner. However, it has the largest impact basin so far identified in the Solar system - the South-Pole Aitken Basin.

Mars

2nd closest planet to Earth

$a = 1.524$ au, $e = 0.093$, $P = 1.88$ Earth years $= 687$ Earth days.

So orbit brings it into view about every 2 years.

Apparent magnitude $V \geq -2.9$

Mass $= 0.11 M_{\oplus}$, radius $= 0.53 R_{\oplus}$, density $\overline{\rho} = 3.9 \times 10^3$ kg/m^3

Small iron core.

1 sidereal day $= 1.03$ Earth days, axial tilt $= 25.2^{\circ}$

Telescopic observations show obvious changes on the surface over the course of a Martian year.

Two small moons, Phobos (27 x 20 km) and Deimos (15x12 km), probably captured asteroids from the asteroid belt.

Atmospheric composition 95.3% CO_2, 2.7% N_2, 1.6% Ar, 0.13% O_2. Surface temperature 130K–290K, surface atmospheric pressure $0.007 P_{\oplus}$. Atmosphere thin, but still able to support dust devils, weather systems and large dust storms.

The Martian Surface

Dark markings originally thought to be vegetation on surface, now known to be albedo markings, changes seen from year to year due to dust transport in the atmosphere.

North Polar cap composed of H_2O, South polar cap mostly CO_2. Polar caps recede during local summer, grow during winter. Surface CO_2 geysers seen in polar cap.

Surface is dominated by craters in Southern hemisphere, large plains in Northern hemisphere. Large shield volcanoes and canyon systems present, implying significant geological activity in past.

Olympus Mons is largest volcano identified in the Solar system, 27 km high. It is not known if any volcanoes are still active. Valles Marineris is a canyon system 4,000 km long, up to 10 km deep and 600 km wide.

Much evidence of past flowing water on surface - river channels, deltas and 'shorelines'. Orbital radar and surface landers show large amounts of sub-surface ice in polar regions.

Still unsolved problems are how much water did Mars originally have, and whether life ever evolved there.

Important recent results from Mars Global Surveyor (NASA), Mars Climate Orbiter (NASA), Mars Express (ESA), Mars Exploration Rovers (NASA) and Mars Science Laboratory (NASA):

- Evidence of ancient plate tectonics and significant magnetic field on Mars.
- Direct imaging of new impacts by meteorites and small asteroids on the surface..
- Many locations show sedimentation and crystallisation due to large bodies of salt water.
- Some water-rich rocks (clays) formed in the presence of neutral-ph water.
- Evidence of recent water flows in gullies on escarpments.
- Evidence of methane in atmosphere at certain positions.