Introduction to Astronomy
Summary Questions Week 2

14 October 2019

1. Briefly sketch how the Solar System formed.

> **Solution:**
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> Initially, there was a giant *primordial gas/dust cloud*, which mostly consisted of hydrogen and helium, though various other elements and molecules were also present in smaller amounts. This cloud started *gravitational collapse*, likely after density inhomogeneities were enhanced through a passing *shock wave* (as could be triggered by a relatively nearby supernova explosion). Subsequently the core of the cloud collapsed to form a *proto-star*; while the rest of the gas and dust settled in a *disk*. Overdensities in this disk grew into *proto-planets*, which started to accrete ever more rapidly.
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> *Conservation of angular momentum* caused the proto-star to rotate rapidly compared to the disk. The phenomenon of *magnetic breaking*, where the Solar magnetic field interacts with conducting material in the disk, causes the proto-Sun to slow down, while the disk's rotation is sped up.
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> Eventually the Sun is massive enough to commence *nuclear fusion*. This initiates the *Solar wind* and produces *radiation pressure*. The combined result of these two effects is that gasses are blown out of the (inner) system, bringing *an end to planet growth*. Also, the heat from the now active Sun, combined with the strong particle wind, *evaporates the atmospheres* of the closest planets fully or partially. This effect is far less pronounced at the far reaches where the gas giants exist.
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> Subsequent *gravitational interactions* between the planets and smaller bodies, causes many of the smaller bodies to be thrown to the outer reaches of the Solar System; on highly eccentric orbits around the Sun. These bodies (which are observed as comets), form the *Oort cloud*. Also, at the furthest reaches of the Solar System, the density of the proto-planetary disk was too low to form large planets. The result is a large number of dwarf planets and smaller rocks. This area is called the *Kuiper belt*.

2. What is the definition of a planet? And of a dwarf-planet?

> **Solution:**
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> A planet is a celestial body that:
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> 1. is not a satellite;
> 2. orbits the Sun;
> 3. is massive enough to overcome rigid body forces, so that it assumes a nearly round shape;
> 4. has cleared the neighbourhood around its orbit.
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> A dwarf planet is a celestial body that only fullfills the first three of these conditions.

3. How can the density of a planet be determined?

Solution:

To determine the density, we need to know the *mass* and *size*.

The size can be determined through *occultations and eclipses*. The mass can be determined in a number of ways:

- by observing an *orbiting moon* and using *Kepler's third law* to get the mass of the planet, while *assuming* $M_{\rm moon} \lll M_{\rm planet}$ and after measuring the size and period of the lunar orbit;
- through a *fly-by* of a spacecraft (along the same lines as explained in the previous bullet point).

Alternatively, the density can be assumed through *extrapolation* from other, similar bodies (especially in the case of asteroids and Kuiper-belt objects).

4. How can the chemical composition of planets be measured?

Solution:

There are essentially four ways:

- *Spectroscopy*: by observing the reflected Sunlight and in particular any absorption or emission lines in this spectrum, the chemical composition of the planet's atmosphere can be deduced.
- *Reflectivity*: by analysing what fraction of the Solar light is reflected, the composition of the upper layer of the planet's composition can be constrained.
- *Dynamical flattening*: The amount of dynamical flattening depends on the rotation rate, but also on the type of matter inside the planet (gas, liquid, solid).
- *In-situ probes*: A lander can analyse the chemical constitution of the upper surface layer as well as the lowest atmospheric layer, directly. To some degree higher atmospheric layers can be analysed during the descent.

5. How can the interior of planets be measured?

Solution:

There are essentially five ways:

- *Dynamical flattening*: See question 4
- *Surface observations*: Specifically the presence of smooth surfaces indicate lava outflows and therefore some liquidity in the mantle and/or core. Fault lines can indicate plate tectonics, which also imply liquid or viscous layers below the solid surface. The presence and sharpness of craters can help date how long ago volcanic activity or plate tectonics were active, casting some light on evolution in the interior of the planet.
- *Thermal radiation*: By observing the (not reflected) thermal radiation from the planet, and comparing it to the incidence of sunlight (which can be derived from the Solar energy output, the size of the planet, its distance to the Sun and its albedo or fraction of reflected light), potential internal heat generation can be measured. This can help identify processes (and therefore structure and composition) in the core of the planet.
- *In-situ seismology*: By accurately measuring the strength and arrival times of various tremors following a quake (which could be caused by asteroid impacts, tectonic motion, volcanism or shrinking of the cooling planet), the number, constitution and thickness of layers in the planet's interior can be analysed. This is particularly possible on Earth and to some degree on the Moon (where seismological instrumentation has been active for many years), but is harder on other bodies because there is no permanent basis there and quakes are not that common.

- *Measurements from orbit*: In relation to the interior of planets, orbiters can provide important information on two fronts. They can probe the planetary *gravitational field*, which can, for example, indicate the thickness of the crust. It can also measure the planet's *magnetic field*. The presence of a (strong) magnetic field is indicative of a *magnetic dynamo*: a conducting liquid near the core of the planet, while absence of a magnetic field implies a mostly solid and non-conducting interior. Deviations from a magnetic dipole can be used to monitor the rotation of the planet's core, which is particularly useful in the case of gas giants, where the only visible rotation is that of the clouds in the upper atmosphere, which are driven by fast winds (caused by thermal instabilities) and therefore don't give a good measure of the actual planet's rotation speed.