The origin of the Solar System

Astronomy 101
Syracuse University, Fall 2016
Walter Freeman

November 8, 2018

Announcements

- Exam 3 on Tuesday
  - The exam will cover everything since Exam 2
  - The high points of today's material and Ohana's talk yesterday may be on the exam
  - The bulk of the exam will cover the material on light and the Sun (in the study guide)

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- Exam reviews:
  - Friday 9:30-11:30 (me, in my office)
  - Saturday 10-1 (me, Physics Clinic)
  - Sunday 5:45-7:45 (Anna, Hall of Languages 114)

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- The special role of atmospheres – **the greenhouse effect and climate change**
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... and where we've been and where we'll go:

- Travel to the Moon; the current state of spaceflight
- How we might get to the stars
- ... and what we might find living there once we do

Your final projects

A few reminders:

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  - What you're doing, and why you need a group of that size
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- People doing visual art or poetry: remember you need to submit a companion piece with your project

Deducing the origin of the Solar System: what do we have to work with?

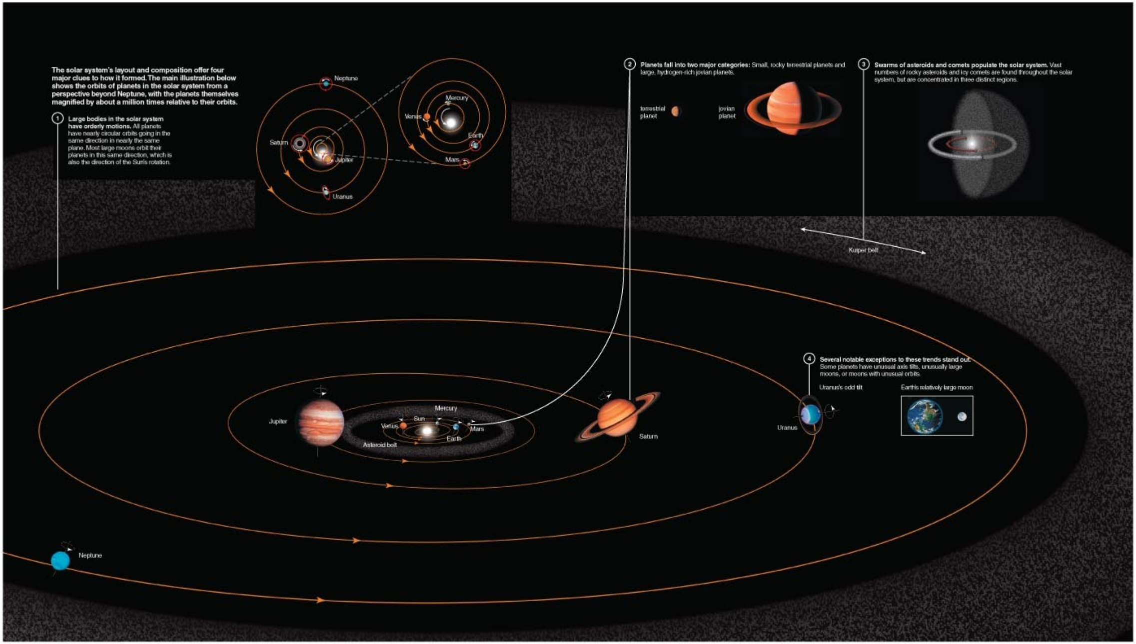
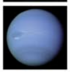
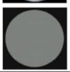


TABLE 6.1 The Planetary Data[a]

Photo	Planet	Relative Size	Average Distance from Sun (AU)	Average Equatorial Radius (km)	Mass (Earth = 1)	Average Density (g/cm^3)	Orbital Period	Rotation Period	Axis Tilt	Average Surface (or Cloud-Top) Temperature[b]	Composition	Known Moons (2013)	Rings?
	Mercury		0.387	2440	0.055	5.43	87.9 days	58.6 days	0.0°	700 K (day) 100 K (night)	Rocks, metals	0	No
	Venus		0.723	6051	0.82	5.24	225 days	243 days	177.3°	740 K	Rocks, metals	0	No
	Earth		1.00	6378	1.00	5.52	1.00 year	23.93 hours	23.5°	290 K	Rocks, metals	1	No
	Mars		1.52	3397	0.11	3.93	1.88 years	24.6 hours	25.2°	220 K	Rocks, metals	2	No
	Jupiter		5.20	71,492	318	1.33	11.9 years	9.93 hours	3.1°	125 K	H, He, hydrogen compounds[c]	67	Yes
	Saturn		9.54	60,268	95.2	0.70	29.4 years	10.6 hours	26.7°	95 K	H, He, hydrogen compounds[c]	62	Yes
	Uranus		19.2	25,559	14.5	1.32	83.8 years	17.2 hours	97.9°	60 K	H, He, hydrogen compounds[c]	27	Yes
	Neptune		30.1	24,764	17.1	1.64	165 years	16.1 hours	29.6°	60 K	H, He, hydrogen compounds[c]	14	Yes
	Pluto		39.5	1160	0.0022	2.0	248 years	6.39 days	112.5°	44 K	Ices, rock	5	No
	Eris		67.7	1200	0.0028	2.3	557 years	1.08 days	78°	43 K	Ices, rock	1	No

[a]Including the dwarf planets Pluto and Eris; Appendix E gives a more complete list of planetary properties. [b]Surface temperatures for all objects except Jupiter, Saturn, Uranus, and Neptune, for which cloud-top temperatures are listed.
[c]Includes water (H_2O), methane (CH_4), and ammonia (NH_3).

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- An enormous hydrogen/helium star, with trace elements, at the middle
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Even further out:

- The Kuiper belt:
  - Lots of small icy bodies (Pluto and Eris among them)
  - Orbit roughly along the plane of the solar system
- The Oort cloud:
  - Contains trillions of comets
  - More distant than the Kuiper belt
  - Roughly spherical

Organized motion

All the planets orbit in the same plane in nearly circular orbits going in the same direction. Most rotate in the same direction, too. Why might this be?

A: Long ago all the planets were in contact with each other

B: Kepler's laws require this

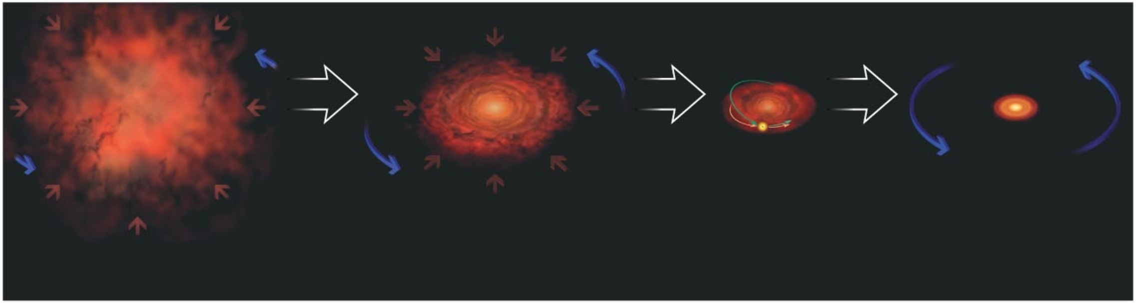
C: Over time the Sun's gravity pulls the planets into circular orbits and synchronizes their rotation

D: The planets all formed from the same chunk of the Sun that was knocked off billions of years ago

E: It's just a coincidence

Organized motion

The Solar System formed out of a cloud of gas that collapsed under its own gravity.



What should happen to its rotation as it shrinks?

A: It should slow down, because of friction between the gas

B: It should slow down, because of the mutual gravitation between the different pieces

C: It should speed up, because spinning things that shrink in size spin faster

D: It shouldn't change, because nothing is applying a twisting force to it

E: It should slow down, because spinning things that shrink in size spin slower

Angular momentum

Physics is very fond of conservation laws. We already met one: the conservation of energy.

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- Its mass, multiplied by
- ... how quickly it spins, multiplied by ...
- ... how far its mass is from its center.

Since angular momentum is conserved, it doesn't change unless an external agent applies a twist to something.

We can also get to Kepler's second law from here!

The primordial universe contained only hydrogen and helium. Where do you think the heavier elements (“metals”) came from?

A: They’re needed for life, and our solar system is special; they aren’t found in other solar systems

B: All stars contain small amounts of metals

C: Nuclear fusion in the Sun builds them out of hydrogen and helium

D: Nuclear fusion in earlier stars forges heavier elements out of lighter ones; those stars have since exploded

A spinning cloud of gas

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At the center, where the gas is most dense, hydrogen accumulated, until gravity was strong enough to kindle fusion. The Sun was born.

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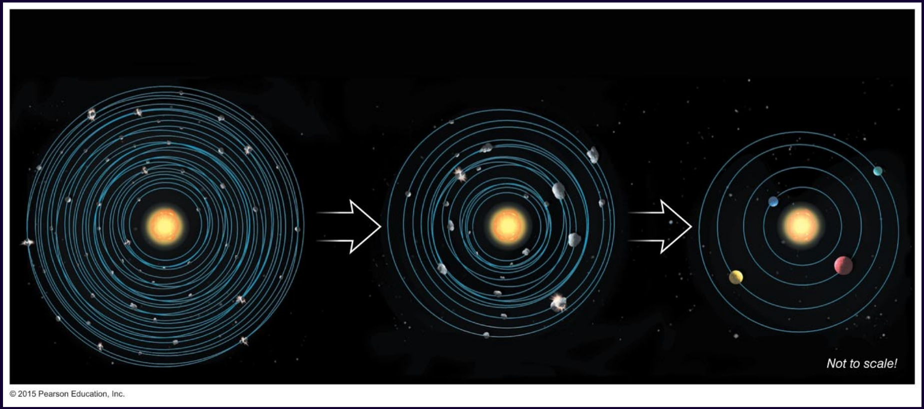

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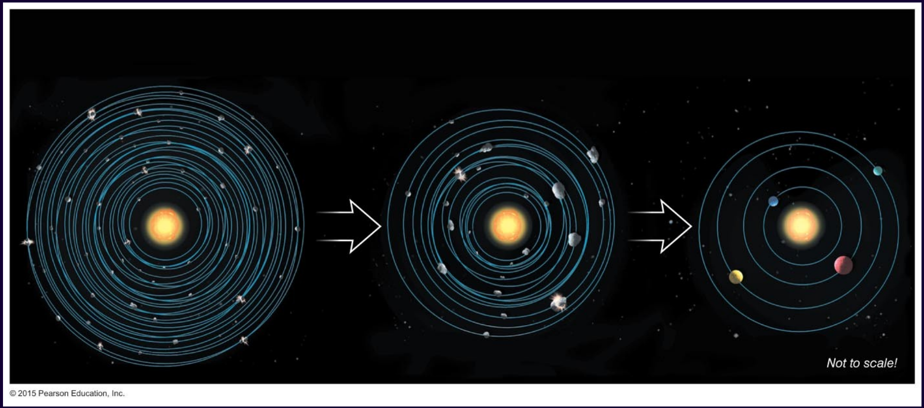

The planets condensed out of bits of dust that first formed by static electricity, then as they grew larger, by gravity.

The gas giants were large enough that they accreted a great deal of gas as well.

Complete *Lecture Tutorials* pp. 111-112.

We will have some time for Exam 3 review after this.

Why are there different sorts of planets?

The primordial nebula contained different constituents which condense at different temperatures:

- Hydrogen and helium: never condense in the nebula (98%)
- Hydrogen compounds (water, methane, ammonia): condense at less than 150K (1.4%)
- Rocks: condense at 500-1300K (0.4%)
- Metals: condense at 1000-1600K (0.2%)

Further out it is colder, and those hydrogen compounds could condense to form the jovian ("Jupiter-like") planets.

So here we are...