The origin of the Solar System

Astronomy 101
Syracuse University, Fall 2020
Walter Freeman

November 3, 2020

Announcements: universal "makeup" policy

We have decided to allow *anyone* to make up any missed labs for full credit.

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You *must* do this "synchronously" – on Blackboard Collaborate.

If you want to make up a lab:

- Join Blackboard Collaborate with your group (if applicable) five minutes before the start of any lab section
- Tell the teaching staff there what you are there to make up
- They'll give you instructions and can help you with your work
- When you are done, send the work you just did to them in the way they specify
- They will read it *right there with you* and ask you questions if they have any
- You'll leave knowing what your grade is

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If you want to make up a project:

- Work with your group on the project as much as you are able
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- Tell the teaching staff there what project you are working on
- They'll give you instructions and can answer any questions you have
- When you are done, send the work you just did to them in the way they specify
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We will also be having a “last chance” makeup day during the scheduled finals time, since we won’t have a final exam. Details to come.

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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:

- You may work in a group (not necessarily "your" group) or by yourself
- If you're working in a group, you will need to include in your proposal:
  - What you're doing, and why you need a group of that size
  - What each person in the group will be doing
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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?

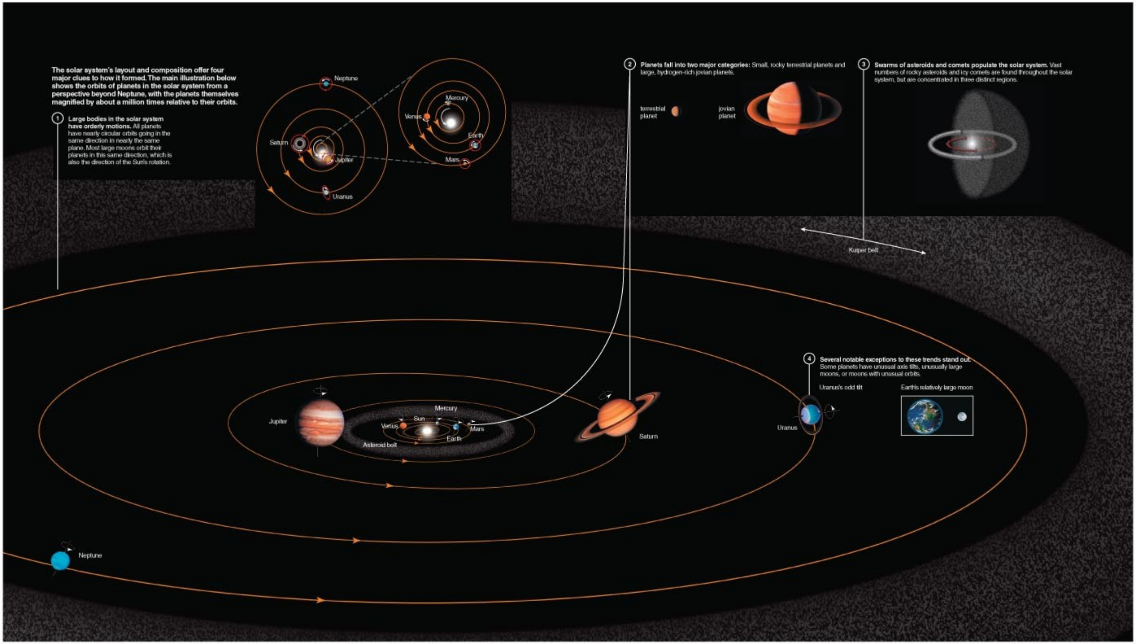

TABLE 6.1 The Planetary Data[a]

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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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

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

B: Kepler's laws require this

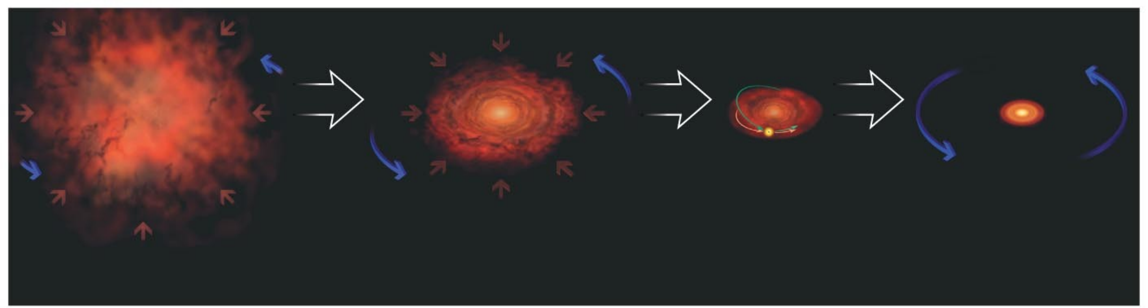
C: Over time the Sun's gravity pulls the planets into circular orbits and synchronizes their rotation

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

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Another conserved quantity is *angular momentum*. The angular momentum of an object is the product of:

- 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?

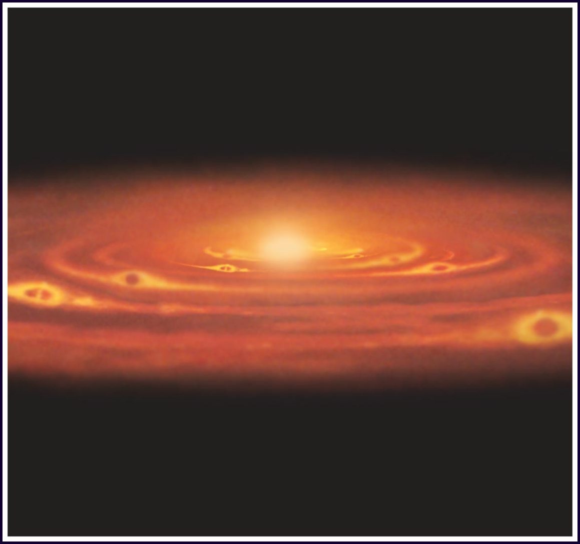
A: They're needed for life, and our solar system is special; they aren't found in other solar systems

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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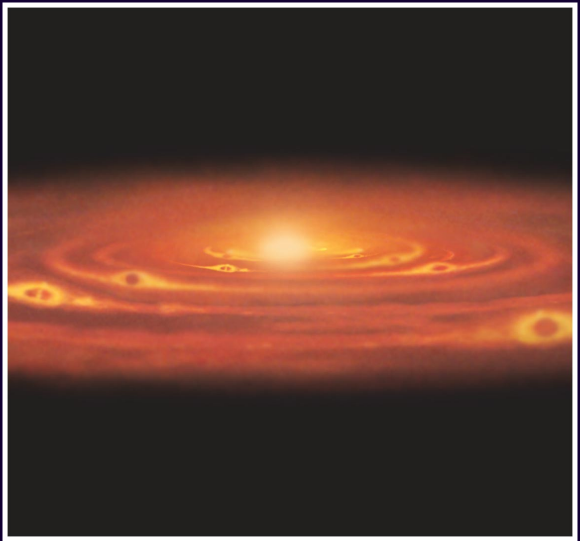
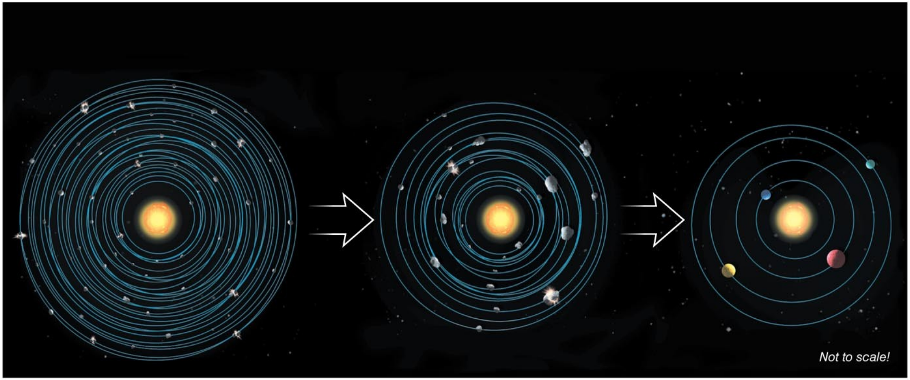


At the center, where the gas is most dense, hydrogen accumulated, until gravity was strong enough to kindle fusion. The Sun was born.

What about the planets?



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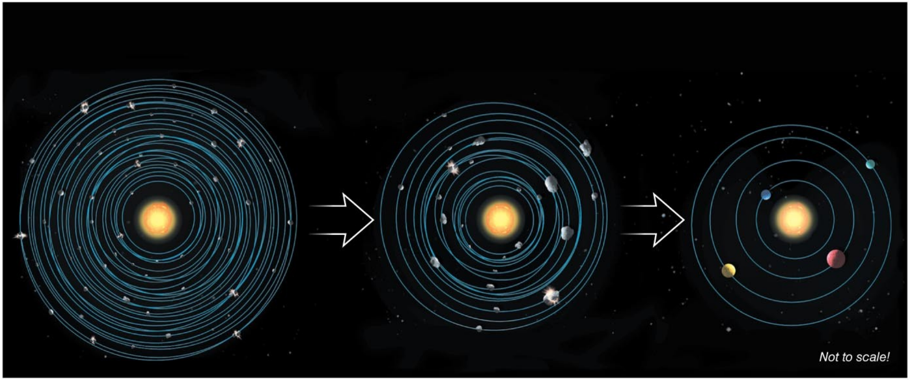

The planets condensed out of bits of dust that first formed by static electricity, then as they grew larger, by gravity.

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

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...