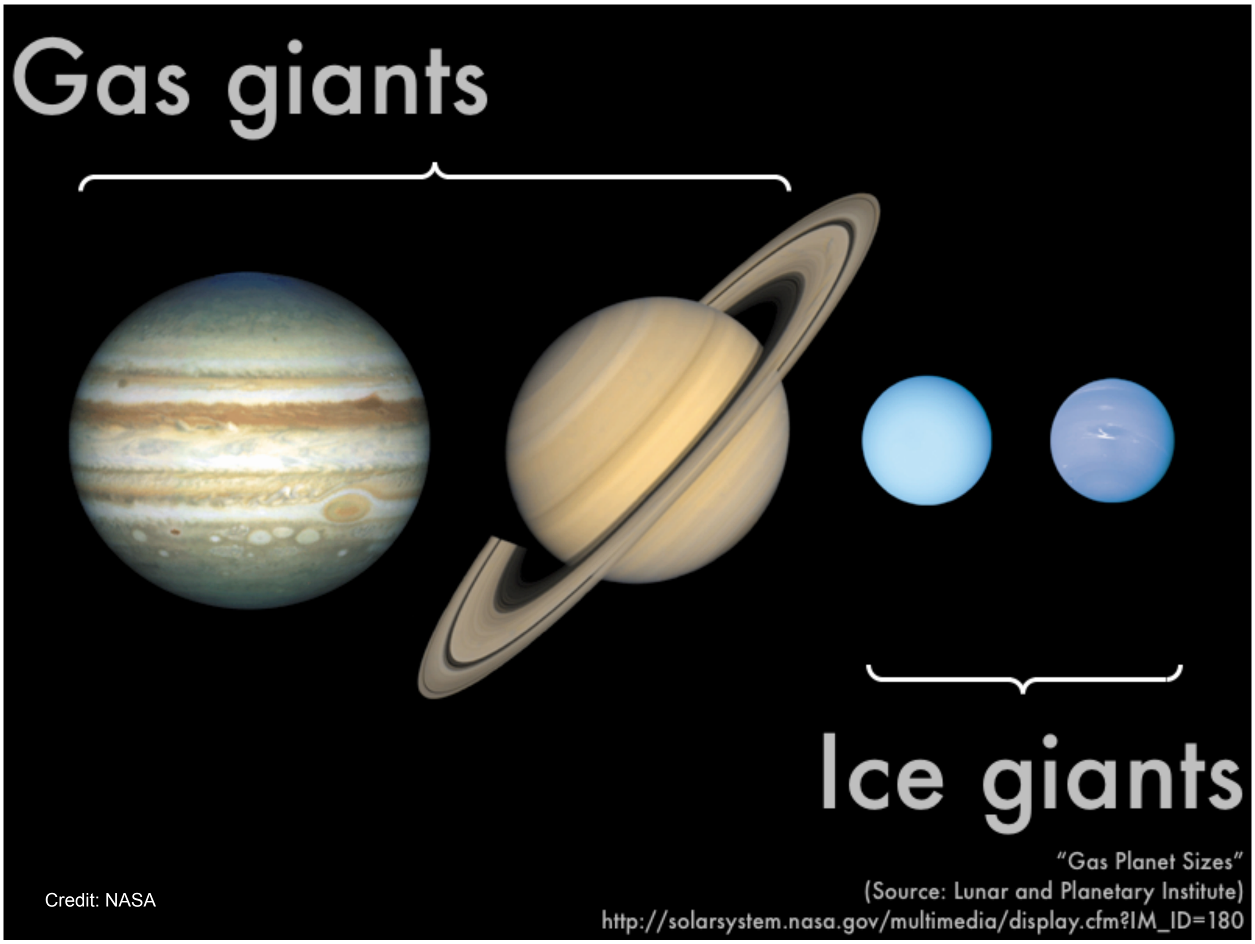
Jupiter from on high smiles at the perjuries of lovers.
Ovid

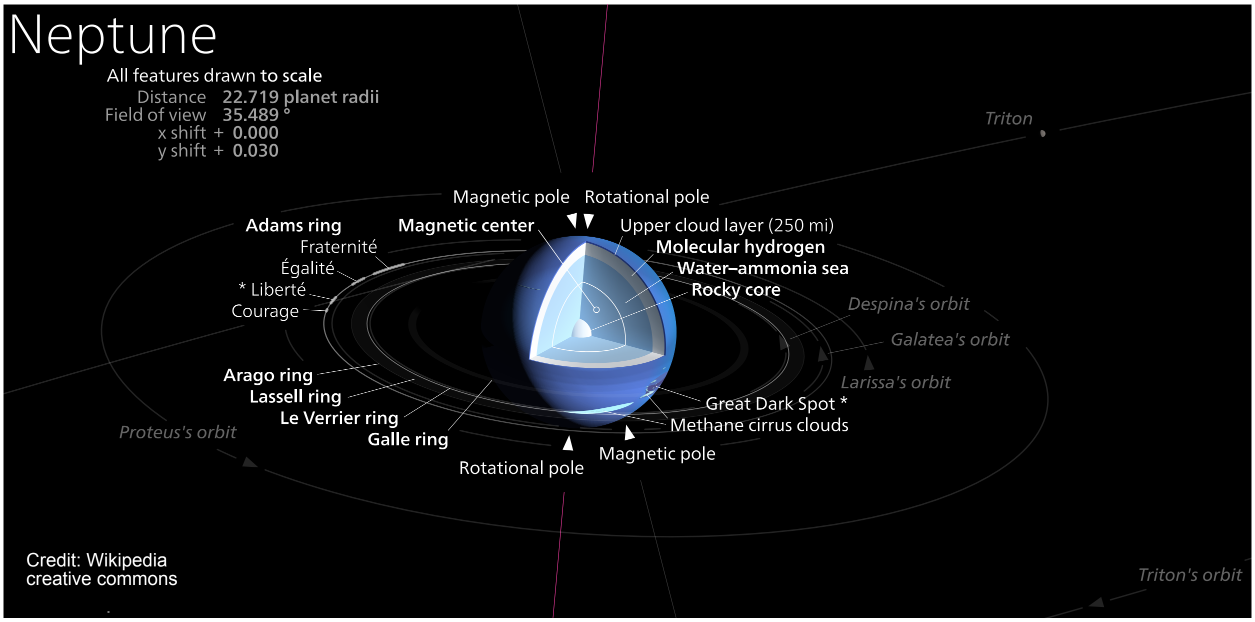
Saturn Floats

Hello AST 111! In this fantastic module we'll tour, compare, and contrast the interiors of the Jovian planets.

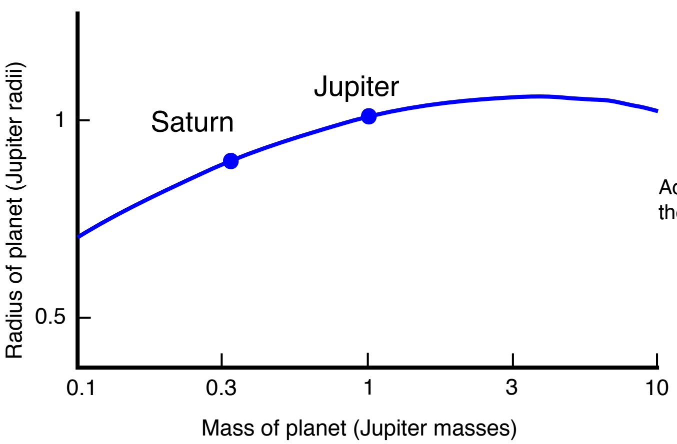


Jupiter and Saturn are made almost entirely out of hydrogen-helium, while Uranus and Neptune are made mostly of hydrogen compounds mixed with some metals and some rocks.

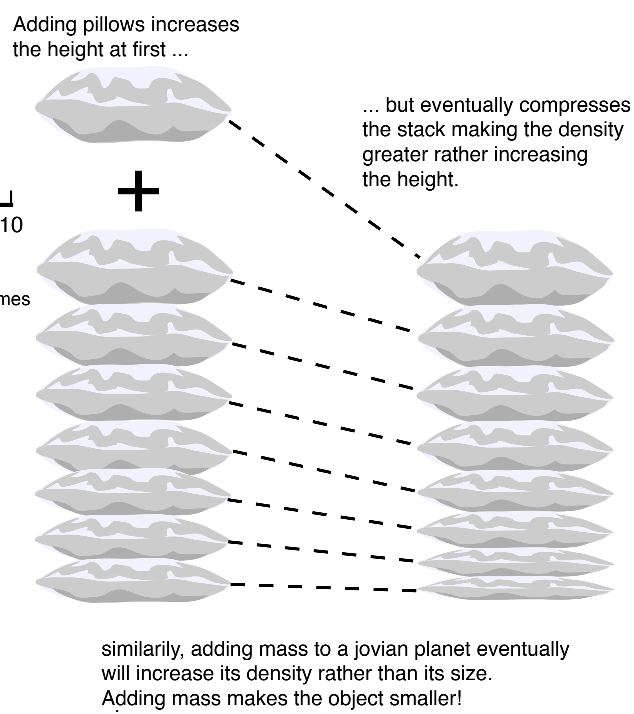
All four planets started beyond the frostline with roughly a couple of Earth masses worth of of rock and metal. Their differences are from the different amounts of hydrogen-helium gas they captured from the solar nebula. Jupiter captured the most, Saturn the next, and so on in a kind of temperature sequence. The further from the Sun the colder it is. This slows down the building of planetesimals.



Above is pretty illustration of Neptune. Included here just as an art appreciation moment!

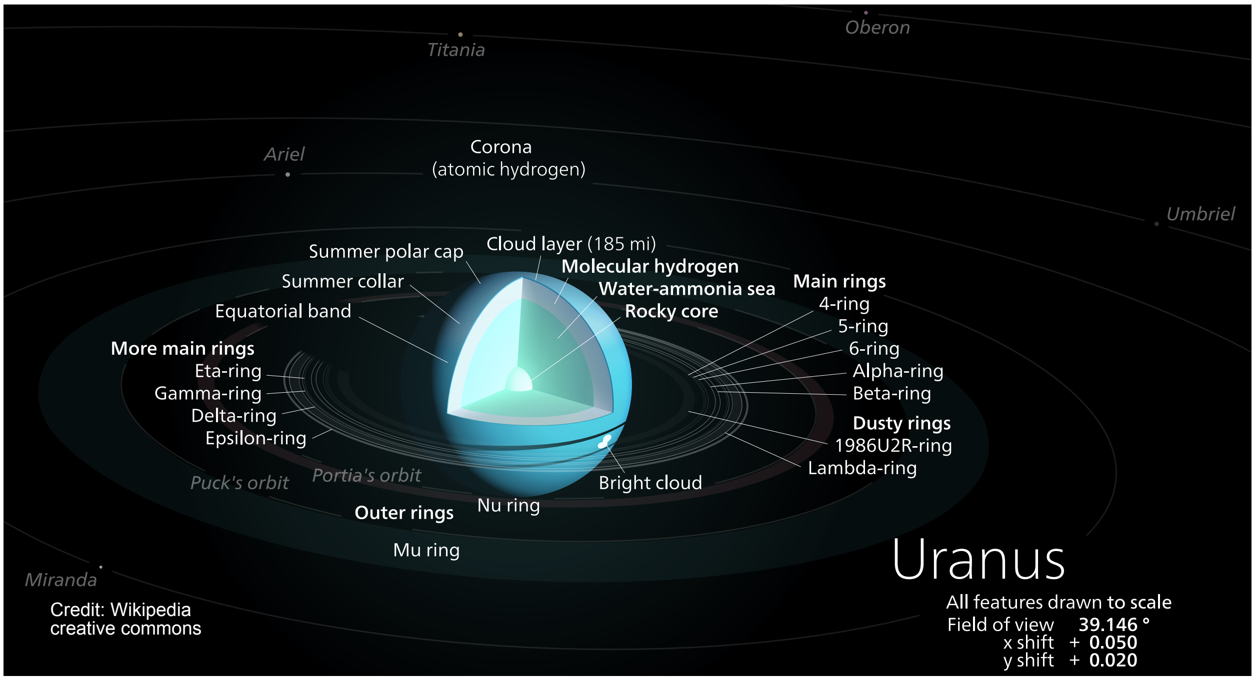


Credit: F.X. Timmes



Its not obvious how the size of the Jovians correlates with their masses. For example Jupiter is three times more massive than Saturn, but only a little bit larger in radius. How can that be?!

The answer has to do with the behavior of gases at large densities. Let's do an analogy from everyday life. Start with a fluffy pillow. Now add the same kind of fluffy pillow on top of the first pillow. Keep adding pillows. Initially the pillows in the stack stay fluffy and the stack grown in size -- Saturn. But as you add more pillows, the bottom pillows start to lose their fluff and compress. It'll get to the point where adding another fluffy pillow does not increase the size of the pillow stack much because the bottom pillows get compressed -- Jupiter.

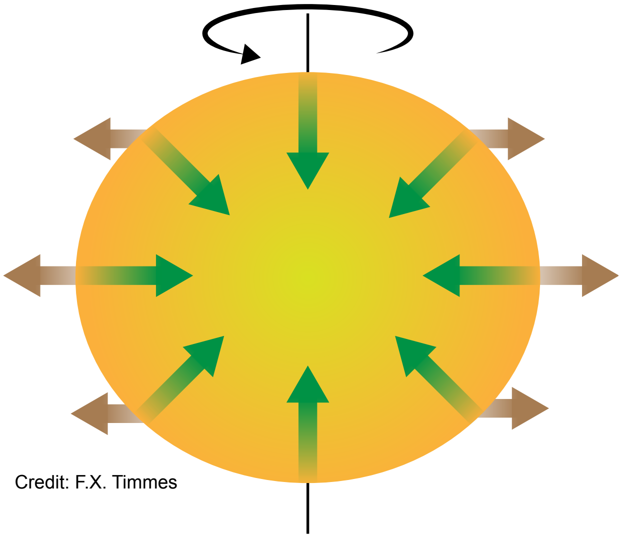


By the way, Saturn is light and fluffy enough that its density is less than 1 gram per cubic centimeter - the density of water. So if you had a big enough bathtub, Saturn floats!

By this logic, you would predict that Jovians smaller than Saturn would have even a smaller density. But when you go out and look at it, Uranus and Neptune have a higher density. This is simply telling you that they did not accrete as much hydrogen-helium compounds from the solar nebula as Jupiter and Saturn did. In other words, they have a larger fraction of rock and ice in their core. An illustration of Uranus is shown above, also an art appreciation moment.

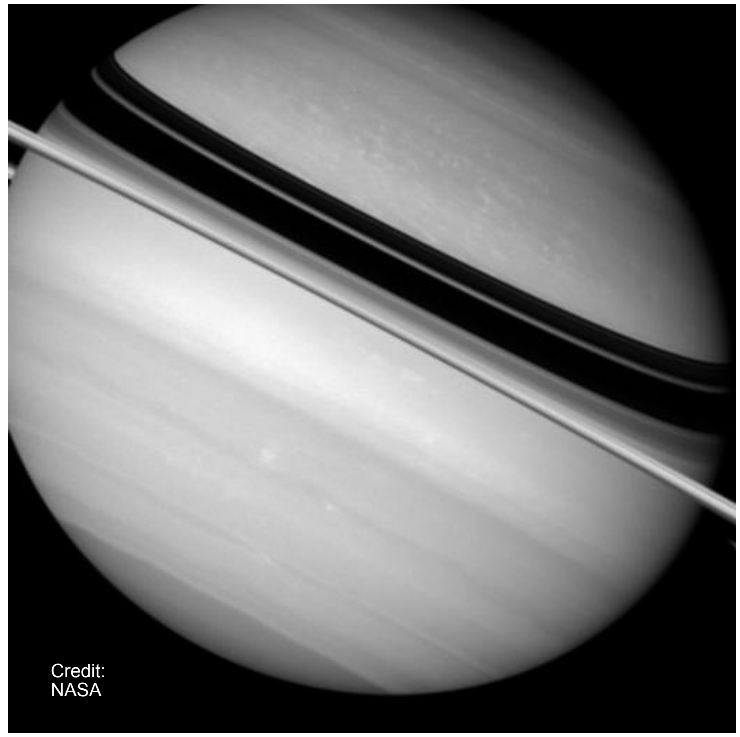
The Jovian planets are squished. They're squished because they're rotating relatively rapidly. You already know this intuitively, perhaps from being on a merry-go-round. Stand in the middle of the merry-go-round and you hardly feel any outward pull. Stand on the edge of the merry-go-round though, and you feel a bigger outward pull. Same effect on the Jovian planets, as shown in the illustration below. Its strongest on Saturn because Saturn has a fast rotation period of just 10 hours. Saturn is about 10% wider at its equator than it is at its poles, as shown by the illustration below. Wow, he whole planet ships around in 10 hours! Expect that to set some pretty fearsome winds.

gravity pulls material toward the center,
but rotation pushes material outward
near the equator.



Credit: F.X. Timmes

this is why Saturn is
not spherical at the 10% level.

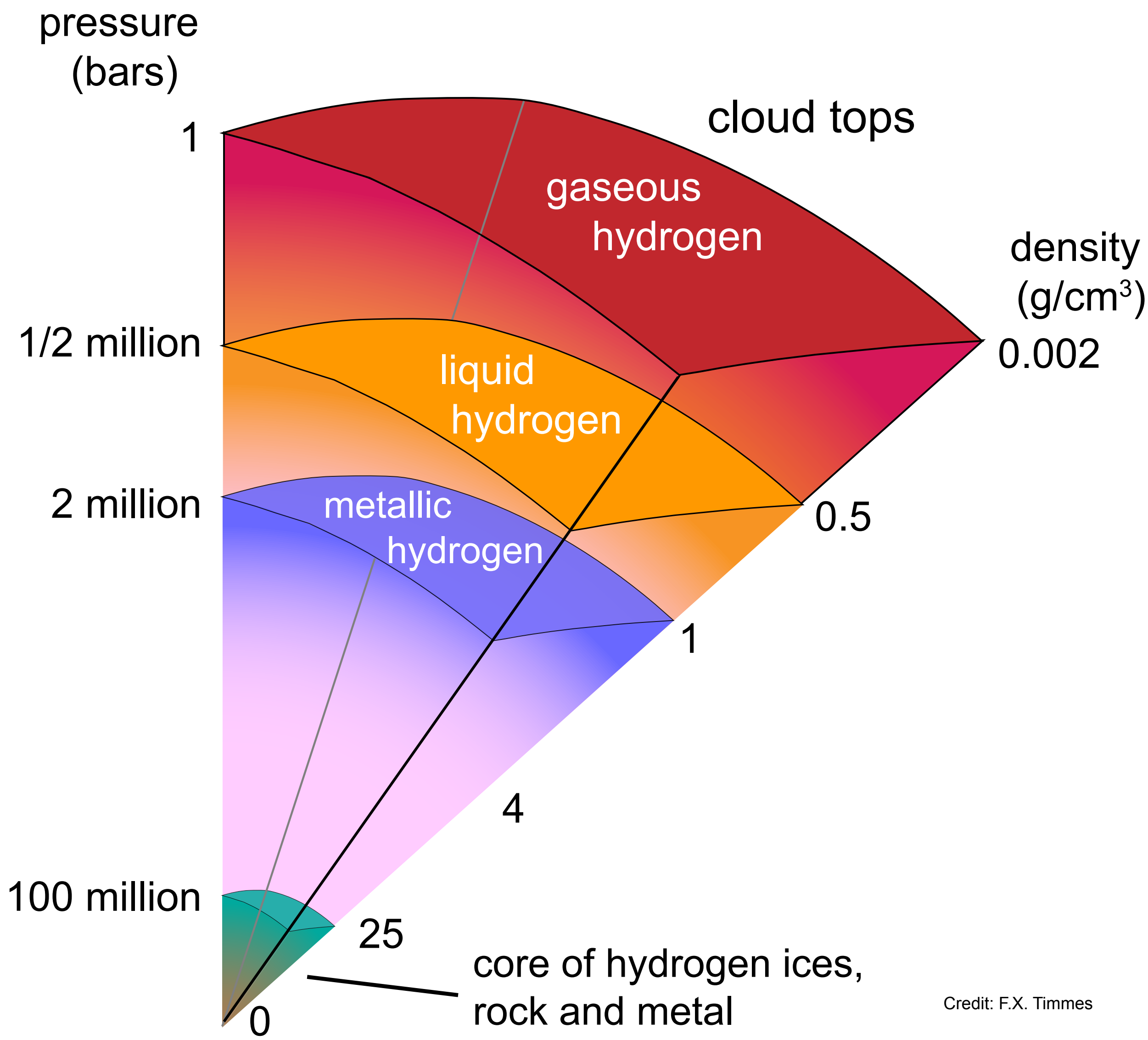


This equatorial bulge helps exert an extra little gravitational tug, which does a number of things. One, it helps keep Saturn's rings in line, as suggested by the image below. Two, it also helps keep the moons of Saturn more closely to the equatorial plane than they would be otherwise.

As briefly mentioned above, the cores of all four jovian planets are similar - about 4 to 10 Earth masses of ices, rock, and metal. They all began with about the same “seed”, and their differences come from capturing different amounts of gas from the solar nebula. Jupiter captured ~300 Earth masses of gas, Saturn about 1/4 as much, while Uranus and Neptune captured only a few Earth masses. This makes sense as icy planetesimals in the cooler outer regions of the solar nebula took longer to form before the solar wind cleared the nebula.

What are the Jovian planets like on the inside? Well, like the terrestrial planets, the Jovian planets have layered interiors. The Jovians though have much higher internal pressures because the Jovians are much more massive. This gives rise to phases of matter that do not exist inside the terrestrial planets.

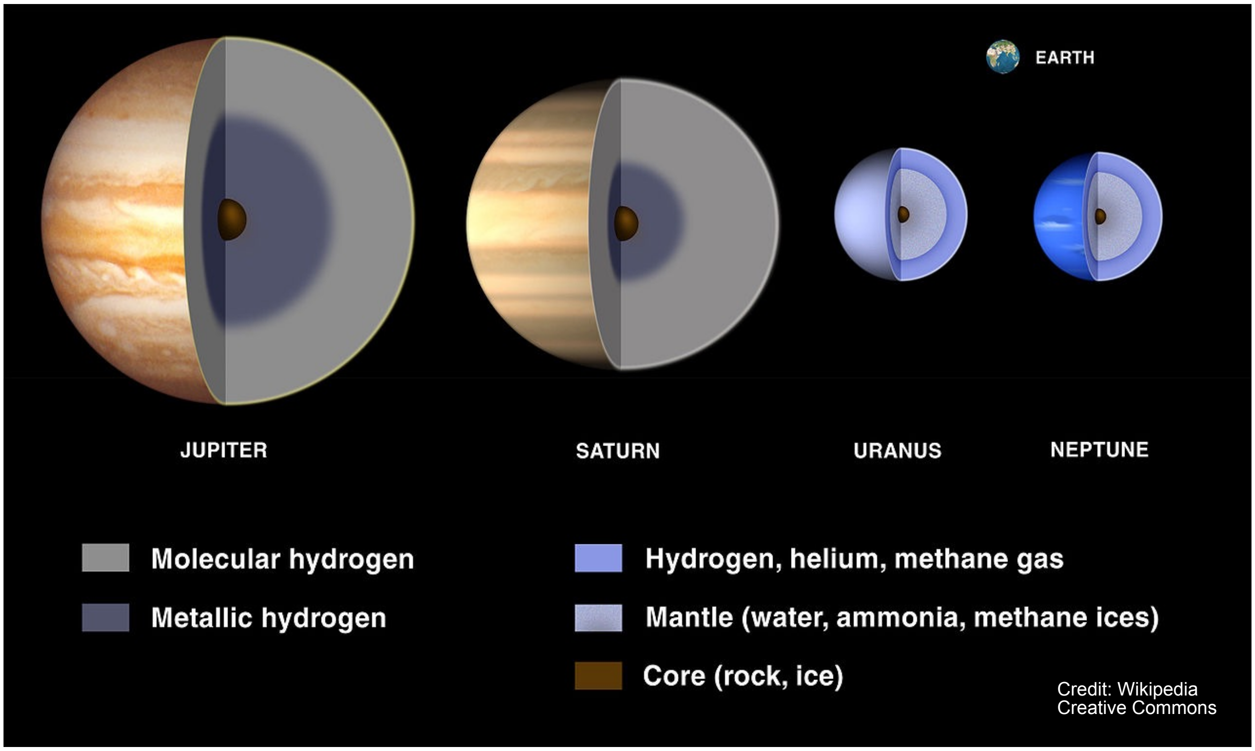
The illustration below shows the internal structure Jupiter. The left axis of the slice gives the pressure in bars. Remember 1 bar is the pressure as Earth’s surface, The right axis of the slice gives the density. As you go inwards starting from the top you have regular gases. That's the atmosphere of Jupiter. But as you go inwards the pressure is big enough to liquify hydrogen. As you go further inwards towards the core, the hydrogen undergoes a phase transition to become metallic hydrogen. Metallic hydrogen has all kinds of fun properties. Like being a superfluid, meaning the material flows without any resistance. Like being a superconductor, electric current, encounter no resistance. This big ball of superconducting material is partially what gives rise to Jupiter's enormous magnetic field.



Continuing onwards to the core you'll encounter the crushed original seed material from which Jupiter started. About 10 Earth masses to an Earth mass's worth of material

The differences between the Jovians have mainly to do with how much hydrogen-helium they created and the different forms that it takes under the extreme pressures. This is shown in the illustration below. We did Jupiter as the prototype, where you have the clouds, gaseous hydrogen, liquid hydrogen, and metallic hydrogen. Saturn has the same thing, but not quite to the same extent, because didn't accrete as much material. So it's a bit fluffier. It's got a larger region of liquid hydrogen before it goes into the metallic hydrogen phase. Uranus and Neptune don't get to the same pressures in order to form the metallic state. Both pretty much have a gaseous state on the outside and a liquid hydrogen state on the inside.

Thanks! Bye Bye.


EARTH
JUPITER
SATURN
URANUS
NEPTUNE
Molecular hydrogen
Metallic hydrogen
Hydrogen, helium, methane gas
Mantle (water, ammonia, methane ices)
Core (rock, ice)
Credit: Wikipedia
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