Astronomy Cast Episode 56:
Jupiter

Fraser Cain: Last week we talked about rubble. This week, we're going to dig into the largest planet in the solar system, Jupiter – but will it all just be hot air?

There's so much to talk about that we decided to divide it into two shows. This week we'll talk about Jupiter, and next week we're going to cover it's moons, because they are a show of their own.

There's so much to talk about, so let's get started. All right Pamela; let's start with a dry collection of facts. Describe Jupiter.

Dr. Pamela Gay: Well, it's big. In fact, it's so big that Jupiter's mass is about 2.5 times the mass of all the rest of the planets and rocks and chunks of stuff that aren't part of the Sun, in the entire solar system combined. SO basically there's the Sun, there's Jupiter, and then everything else is way smaller.

It's so big that if it were just 13 times bigger, there would be deuterium burning in its core. It would be like one type of brown dwarf. If it were just 60 times bigger, it would actually be a full-fledged star with hydrogen burning in its core. We have a big world that a lot of people refer to as a failed star.

Fraser: That seems like quite a distance though. You say if it were "just" 13 times bigger it would be a brown dwarf and if it was "just" a "mere" 60 times bigger… that's a lot of material.

Pamela: But it's something that's thousands of times bigger than the Earth.

Fraser: True.

So are we a failed star?

Pamela: No.

Fraser: All right.

[laughter]

We don't have the hydrogen, so I guess that's the point. Okay, I'm obviously a little punchy today, so…

Pamela: I know, I know.

Fraser: So just go on.

Pamela: One of the things about Jupiter that makes it unique in our solar system is it actually gives off more light than it absorbs. So even if the Sun turned off, Jupiter would keep glowing. It would be giving off heat. It's such a big planet that the gravitational push from the outside toward the inside causes it to give off light in the infrared. It also has such an amazing magnetic field that particles coming off of Io, from its volcanoes, that are accelerated along magnetic field lines, end up giving off amazing amounts of radio light.

There are times when Jupiter's actually brighter in the radio than the Sun is. So this is an object that we just keep looking at in new colours and wavelengths of light, and keep discovering new things.

Fraser: I've actually done some articles about seeing Jupiter in x-rays.

Pamela: Yeah.

Fraser: So yeah, it really crosses the entire spectrum.

Pamela: its magnetic field is about the strongest in the solar system. It's several times stronger than the Earth's. Its auroras are caused not just by particles from the Sun streaming along its magnetic field, but also from particles being given off by its moons streaming along its magnetic field. It's auroras glow in the x-ray and you get these fabulous images with these glowing caps of the auroras as seen from satellites orbiting the Earth.

When you look at it through a telescope, Jupiter is one of the largest planets in terms of how much of your eyepiece it fills up, and it's not that close in the grand scheme of things – it can be 500 thousand kilometres away. So looking at it, we're looking at something fairly far away. It will be 31 arc seconds across.

To put that in perspective, a normal imager on a standard amateur telescope will have a 7-10 arc minute field of view. So this will be roughly a 12^{th} of your field of view.

Fraser: When I'm showing people things through my telescope, I show them the Moon (if it's up), Saturn, and Jupiter. Those three will blow people's minds.

With Jupiter, even with a small telescope, you see the bands across the planet, you see the moons… it's amazing to see.

Pamela: Yeah, and so you have this object 500 million kilometres away, and you see all these rich details. When comet Shoemaker-Levy 9 plunged into Jupiter, amateurs (with their backyard telescopes) could see basically the "splash-zones" on Jupiter, because the planet is so big that changes in its atmosphere, storms in its atmosphere are visible form the planet Earth.

Fraser: All right. So where did we get such a planet?

Pamela: It formed just like all the other planets, in a way. It was created out of materials from the solar nebula, and once upon a time, particles started colliding together and sticking. They grew and grew and grew, and exactly what mechanisms caused Jupiter to form so large and Earth to form so small we're still learning. These are details that are very mysterious in our current models.

Fraser: That was the question I was going to ask. You would think if most of the material ended up right around the Sun, why do we have small objects in the inner system and a huge bulk of material out on Jupiter's side?

Pamela: We're still working out the details of planet formation. We know that they form from small things grouping together to form larger things, but there are some theories that say perhaps all of the planets ended up at one point in sort of an orbiting swarm, and through different gravitational interactions, they get flung out to their current places. That's not a really satisfactory theory.

There are theories that say the rocky planets formed in situ, the gas planets formed roughly where they are, but there was a certain amount of migration going on where gravitational interactions eventually ended up flinging Neptune and Uranus out to greater distances than where they formed.

Fraser: I guess we have seen other solar systems where there are gigantic planets many times the size of Jupiter that are orbiting within the orbit of Mercury. So clearly they can show up all kinds of places.

Pamela: Yeah, so we're not really sure how you end up with Jupiter where Jupiter is.

Fraser: Nobody knows. Right.

Pamela: One of the weird things is what you just said – we are consistently finding planets larger than Jupiter orbiting other stars. Larger is one of those adjectives that can mean many different things. It could mean the planet has a greater diameter. It could also mean the planet has a greater mass. It turns out you can't really get a planet that has a diameter greater than Jupiter's. Jupiter, in terms of how long it takes to go around the equator, how big it fills when you stick it that distance away from the Earth… it's about as big as you can get. If you added mass to Jupiter, it would actually shrink.

Fraser: Huh.

Pamela: That's just kind of weird to think about. What happens with Jupiter-like planets is as you add more mass, they start to condense. The gravitational pull on the atmosphere will squish the planet more effectively. Add more mass, planet gets smaller and smaller… until you add enough more mass and the planet becomes a star and bloats back out. So Jupiter's at that magical "just-right" combination of mass and density that allows it to be as big as it is.

Fraser: That's really cool. I didn't know that! That's amazing.

I know there was a planet recently discovered that had the consistency of cork, so it was actually larger and was a lot less dense… but as you're saying, that's the rarity. In most situations what you're getting is they get smaller as they get more massive.

Pamela: Yeah.

Fraser: Neat. Okay.

Now, Jupiter has some additional features that I thought we'd want to talk about. The first is the rings, which I think came as a big surprise.

Pamela: Yes. SO you look at Saturn, and you see these huge rings. They're really hard to miss. They're made out of ice crystals and chunks of ice. They're really visible, they reflect light very well.

You look at Jupiter and there are no rings to be seen in your typical, average, backyard telescope. In fact, if you look at Jupiter with Hubble, in general you don't see rings dancing around it. Its rings are made of dust.

With Jupiter's huge gravitational pull, when a piece of space rock flies through the solar system and hits one of its moons, the dust and gravel and whatever is thrown up during that impact, instead of getting gravitationally pulled back down to the moon, gets pulled off of the moon (or pulled out of the orbit of the moon) by Jupiter. As that dust and gravel that's thrown up into the air through these collisions orbits toward Jupiter, it ends up spiralling in. this spiralling material forms rings.

We also have rings from Io throwing material up into the atmosphere from its volcanic eruptions. All the material the moons are slowly moving is getting transformed into temporary gossamer rings that you pretty much only see when they are backlit by the Sun, or when you start looking in other wavelengths of light than the ones we see with our eyes.

Fraser: Are these rings like on Saturn, or is this more like water going down the drain? This material's all spiralling inwards, so it's just temporarily there before it gets consumed by Jupiter?

Pamela: It's hard to know at this point. The dynamics of this – yes, some of the dust is on its way into Jupiter, spiralling in. But if you had a single "hit moon with rock, dust gets thrown into air, dust goes into a spiralling orbit" it would probably eventually end up getting sucked into Jupiter because of the geometries of it. Some of that dust will have just the right trajectory, just the right angle of launch off of the moon that instead of spiralling toward Jupiter, it will get pulled into a stable orbit.

You also have the frictional effects of dust bumping up against dust, and all of these different things. They tend to tell us that the orbits are transitory, that all of this material will eventually end up getting consumed by Jupiter or occasionally ejected out of the system. But because there's stuff constantly hitting the moons, the rings are constantly getting replenished, so we see them as permanent objects. One particular grain of dust is probably only a temporary thing.

Fraser: Let's spend a little time talking about some of the most dramatic features on Jupiter, and those are its great storms – the Great Red Spot and others. Can you give a little description of those?

Pamela: These are some of the most amazing storms in the entire solar system. Jupiter is this huge planet, and it's actually rotating way faster than the planet Earth.

So you have a planet that's radius is 11 times the radius of the Earth, and its day lasts a little over 9 hours. When you start looking at how fast things are moving at, say, its equator, you end up with things going more than 45 thousand kilometres per hour as they whip around at the equator. This high rotation rate ends up creating amazing turbulence in the atmosphere of Jupiter. The poles are pretty much stationary – they don't have very far to go as the planet rotates – but the equator is whipping around. You end up with turbulence where different areas of the atmosphere are moving faster than others. This creates the banding effect. We can do very good computer simulations to generate the bands that are visually seen on Jupiter.

Fraser: So those bands on Jupiter mostly just come from the differences of the rotation.

Pamela: Yeah.

Fraser: Huh. Okay.

Pamela: All the forces team up and you get these really neat bands. If you want to see a full discussion of this, there's a book at Sky and Telescope publishing by Kelly Beady that explains this really well.

Now, for reasons we don't understand, within these different bands, there are these small storms. These are the white ovals. Some of these white ovals are the size of the Earth.

Fraser: Small storms the size of the Earth.

Pamela: Yeah. Right, right.

So the scale you have to think about when you're thinking about Jupiter is completely different from what we're used to thinking about.

We're not entirely sure what causes these storms. We know they come and go – the Great Red Spot doesn't seem to go. That's one of the biggest mysteries of the planet Jupiter – what is the Great Red Spot. It's been there as long as people have been able to see it, and now it has a new friend, Red Spot Jr.

Fraser: I think Red Spot Jr. is great. We've seen it go from nothing to a collection of white storms, to a serious storm.

Pamela: Yeah. Jupiter is so big that people have been able to, from the surface of the Earth, make out details in its atmosphere, for well over a hundred years. Back in 1939, these white ovals were seen to form in some of its southern turbulent bands. We gave them names, they were very boring names of AB, CD and EF, by someone who clearly didn't have enough creativity in his life.

Fraser: Aren't there so many of these things that you run out of names?

Pamela: But… but still! There's got to be a better way to name these things!

Fraser: All right.

Hmm… someone should name the storms after us...

[laughter]

Pamela: So we've been keeping track of these things since 1939, and then back in 1998 two of these storms merged – D and E got together with B and C and formed the BE white oval. It sounds like some sort of a geometry assignment.

[laughter]

Fraser: No kidding!

Pamela: In 1999, we watched the, now two white ovals slowly approach one another until in 2000, they formed a single white oval, which was named BA. I love that, because of Phil, the Bad Astronomer – it's the Bad Astronomy white oval, is what my brain always goes too.

Fraser: Yup, he never stops talking about that!

Pamela: Then it started changing colour. So we had this white oval that all of a sudden, an amateur astronomer in the Philippians, Christopher Gogh, discovered this changing colour where all of a sudden Oval BA was starting to become the same colour as the Great Red Spot. People went back through archival images of when Jupiter was too close to the sun to watch very well, and started taking new images, and confirmed this colour change.

Since then, it's continued to grow and grow. We have this growing new hurricane that is the colour and similar in many ways to the Great Red Spot, and we've seen it since day one. Every couple of years, the Great Red Spot and Red Spot Jr. pass one another, and they get so close that people are like, "they're going to merge!" and each year they keep not merging.

Fraser: I guess the question was why did it turn red? Something about the storm got so powerful… is it scooping deeper into the atmosphere of Jupiter?

Pamela: That's part of what we think is happening. The cloud-layers on Jupiter are about 50km thick, and they consist of two different layers of clouds. There's a lower, denser, darker level and then on top of that, are water vapour. In these lower levels, there are things like ammonia. When comet Shoemaker-Levy 9 ploughed into Jupiter, we ended up with these dark spots of darker material that was churned up to the surface.

Fraser: Yeah, it really looked like bruises, like someone had just beaten up Jupiter.

Pamela: The crazy thing is if you look at Jupiter in terms of proportions by mass, it's 75% hydrogen, 24% helium and it's just 1% of the planet (by mass) that's everything else.

Fraser: The hydrogen and helium would just be clear, right? We wouldn't see anything.

Pamela: They have colours resulting from their temperature, but yeah – generally really boring. These nuances of colour are coming from 1% of the mass of Jupiter, basically. So somehow these storms are churning up material from deeper layers that has a different colour.

Fraser: Even deeper than that thick lower deck?

Pamela: It's unclear where it's coming from. We're still learning. Galileo sent us back some data as it plunged through the atmosphere of Jupiter to its death, when we killed it. Because there's the potential for life on the moon Europa in the Jupiter system, when we were done using Galileo to study Jupiter, scientists made the very conscious decision that, while it was still working, while we recognized it was near the end of its useful life, that they were going to drop it into the atmosphere of Jupiter, get what information they could, and let it die a useful death.

We got some information that way. We got some information from what comet Shoemaker-Levy 9 brought to the surface… but it's hard to go out and measure, "aha – at this level, we have this much ammonia, at this level we have this much water."

Fraser: Right, it was never really planned to do this kind of a mission. This was one last little piece of science, as opposed to a mission designed to descend through the cloud decks and gather as much data as it goes.

Pamela: Right. So we're getting a lot of our data from secondary methods. For instance, we know there's water vapour in the atmosphere of Jupiter because we observe lightening. Lightening generally happens because water can carry charge, and when you get water vapour, you can end up with lightening – we see lightening. That's a secondary detection method that helps us understand the atmosphere of Jupiter.

Fraser: Let's talk a little bit about the construction of Jupiter. If you went down through Jupiter – if you could survive – what would it look like?

Pamela: We don't quite know if its centre is solid or not. That's one of the great questions: what is at the centre of Jupiter? We just don't know.

One of the things we do know about Jupiter because of its amazing magnetic field, is that it has metallic hydrogen. This metallic hydrogen basically acts like charged particles that, as they spin, as they rotate around the core of Jupiter, they drive a magnetic field. Whenever you get moving charged particles, whenever you get moving ionized particles, you can generate a magnetic field.

Fraser: So here on Earth, we've got a solid core of iron that's spinning, so we get a magnetic field. On Jupiter, it could just be turning metallic hydrogen, performing that same function.

Pamela: Yes.

Fraser: That doesn't tell us if there's a solid core.

Pamela: Right.

Fraser: Okay.

Pamela: So as you go through its layers, it's pretty much just denser and denser gas as you go deeper into the star, because the atmosphere is just weighing down on all of this hydrogen and helium. When you get the hydrogen at a high enough density, it becomes what we call metallic hydrogen, which is capable of generating these magnetic fields.

So it's not all that exciting. You don't see the solid core, here's the molten layer, here's the crust… it's not the cool cut-through that you get when you look at a terrestrial planet. It's pretty much a boring cut through of a star that didn't become a star. What it does is what's cool. It creates this amazing magnetic field that creates these amazing auroras. There are mazars that are created by the magnetic fields at the poles. These are basically natural lasers that accelerate particles so that they give off microwave light. So there are microwaves coming off the poles of Jupiter.

Fraser: Now here on Earth, our magnetic field keeps us nice and safe from radiation from space. Would you be nice and safe from radiation close to Jupiter?

Pamela: Yes, but you'd have to go through radiation belts to get there, and the radiation belts actually gave some satellites a hard time. The first missions to explore and do flybys, Pioneer 10 and 11 encountered these radiation belts and they survived – they were fine – but we hadn't been fully knowledgeable about just what they were getting into prior to that point.

So yes, you have to fly through some heavy radiation, but once you fly through it and get through the ionized particles that are streaming along the magnetic fields going – for instance there's magnetic field lines that go from Io to the poles of Jupiter. Once you get inside all of that – yeah, you're protected from solar radiation, you just have to worry about radiation from everything getting accelerated from within the Jupiter system.

Fraser: Let's talk about that radiation, because it's fierce, isn't it?

Pamela: Anytime you get accelerated particles you can end up with high-energy photons flying off in all different directions. It causes problems. So we see bursts of radio signals that are coming from the magnetic fields and the satellites have encountered these radiation belts… it's a complicated system that you have magnetic fields that are getting generated within the planet, and then these field lines end up getting strengthened because they capture ionized particles that are coming off of, for instance Io. Io just keeps coming up – it's like the coolest sidekick a planet could have.

Fraser: Don't talk too much about Io! Don't ruin it for next week!

[laughter]

Pamela: So the particles it gives off are then adding in to enhance this magnetic field because they're accelerating along, a moving charged particle creates more magnetic field… all of this creates more charged particles that are accelerating and the potential to give off more radiation and you end up with belts of radiation.

Fraser: Yeah. I think we'll talk about the moon's point of view, but being on one of the moons of Jupiter is like one of the most dangerous places you can be in the solar system because of that radiation. It's just relentless. The spacecraft – every time Galileo went through those belts, NASA kept saying, "Galileo might die from this radiation!"

[laughter]

"We might not talk to it again – but here's hoping" and every time Galileo went through it got a little beat up.

Now there was one other interesting thing about Jupiter that I think we should talk about, and that is that we might need it for life here on Earth, right?

Pamela: This is actually one of those highly debated things. For a long time, a couple of decades, everyone was like "we need Jupiter, it protects us from incoming rocks, it captures comets" and when Shoemaker-Levy 9 came along and first got shredded and then eaten by Jupiter, it was like, "yay, there's the proof – Jupiter protected us!"

Fraser: Thanks Jupiter!

Pamela: There was some recent modelling done. In the models they asked the question what happens if there's no Jupiter and you have the same distribution of space rocks that we assume we started with? What happens if Jupiter's a little bit smaller (say, replace Jupiter with Saturn at the same location) ? And they ran the situations and saw how many rocks hit Earth.

What was discovered was if you just yank Jupiter out, then some of the rocks that end up entering Earth-crossing orbits, don't. they happily stay out in the outer solar system and never come anywhere near the Earth. They are not a hazard at all.

Put Jupiter in there, and Jupiter's gravitational pull grabs on to some of these failed comets, some of these asteroids, changes their orbits, and puts them on trajectories straight toward Earth – not a good thing. But then it usually catches them later and either flings them out of the solar system or eats them politely.

Now, if instead of having Jupiter there you have a Saturn-sized planet there, Saturn has enough gravity to take those rocks and comets, fling them at the Earth… but not enough gravity to then fling them out of the solar system or eat them. Which means that if you replace Jupiter with Saturn, you'd actually do really bad things to the planet Earth. If you just got rid of Jupiter… it's probably a zero-sum game, because while yes, it protects us from some things, it also flings things at us.

Fraser: So it's just a wash.

Pamela: It's just a wash. But that's only one set of models.

Fraser: Yeah. Right.

Pamela: We're still figuring this stuff out. It's a complicated solar system out there – there are a lot of rocks to keep track of.

Fraser: No kidding.

Okay, we're going to go to one last controversial thought. You mentioned that we're fairly certain that there's water in Jupiter's high atmosphere, and you know the cliché – we find water here on Earth, we find life.

(laughter)

Could there be life on Jupiter?

Pamela: That's a question that a lot of people have asked. There are actually some really neat sci-fi stories about this, for instance Arthur C. Clark's *A Meeting with Medusa*. It's in his collection *A Wind from the Sun*. He and Sagan and Edwin Saul-Peter at various times have all asked the question "could there be life in the atmosphere of Jupiter?"

The question is one of these that we don't know how to envision life like that, because there's no solid ground to stand on. These three great men thought of things like perhaps we could have bubble life, things that do photosynthesis in the atmosphere that are able to form out of what few particles there are that aren't hydrogen and helium. They actually imagined creatures that might be many kilometres across.

Now the thing is, if there were creatures that big, Galileo would've seen them. Galileo didn't see any kilometre-across bubble life forms in the atmosphere of Jupiter, but it still makes for some good stories, and you know there are a lot of gas giants out there. Even if Jupiter doesn't have them, maybe we can find them somewhere else.

Fraser: I know there are microbes in the atmosphere here on Earth that are so light they can last long periods of time, just way up high in the atmosphere, so who knows?

Pamela: Who knows.

Fraser: I guess someone needs to build that probe to slowly descend into the atmosphere and see what it can find.

We are totally out of time. This is great. There was actually some other stuff I'd still like to talk to you about, so maybe we'll sneak it in next week, or maybe we won't.

This transcript is not an exact match to the audio file. It has been edited for clarity.