Astronomy Cast Episode 192

The Chandra X-Ray Observatory

Fraser: Astronomy Cast Episode 192 for Monday May 31, 2010, The Chandra X-Ray Observatory. Welcome to Astronomy Cast, our weekly facts-based journey through the cosmos, where we help you understand not only what we know, but how we know what we know. My name is Fraser Cain, I'm the publisher of Universe Today, and with me is Dr. Pamela Gay, a professor at Southern Illinois University Edwardsville. Hi Pamela, how're you doing?
Pamela: I'm doing well, how are you doing Fraser?
Fraser: Very well. Now you and I were just talking about this, but we just want to remind all of our listeners that we are going to be at DragonCon...
Pamela: Labor Day weekend...
Fraser: Labor Day weekend... in Atlanta, Georgia. It's a great party. 20,000 people there... amazing costumes... we're going to do a live show... we're going to be on panels... we're going to be, like, wandering around aimlessly... looking for people to go out for lunch with... So, yeah, if you're going to be coming to DragonCon, we're going to be there.
Pamela: And looking a little further ahead in time, for those of you who like to plan ahead, like we do, in October we're going to be at the US Science and Engineering Festival. There's a National Mall outdoor event on October 23 and 24, and I'll be in a Galaxy Zoo booth, also with Moon Zoo and other Zooniverse projects, and Fraser and I are going to be doing a stage show event. So come and support the show, see the two of us live, and check out all the amazing exhibits. Anyone who's anyone doing science is going to be at this amazing event letting you play with their science.
Fraser: We're going to find out if we can translate a podcast to a stage show... that's the question.
Pamela: I think we'll be ok.
Fraser: My money's on "yes." Alright, let's get on with the show. So the Chandra X-Ray Observatory is the third of NASA's great observatories, sent into space aboard the space shuttle to view the universe in high-energy x-ray radiation. This is the territory of supernovae, super-massive black holes, and neutron stars--some of the most extreme places in the universe. Now I actually started Universe Today back in 1999, and so within like 3-4 months of when I started working on the website, Chandra launched on the space shuttle. So I have a real good connection... I've been reporting on Chandra now for like 11 years...
Pamela: That's amazing...
Fraser: Yeah, I know... so as observatories go, this is the one that I'm actually quite familiar with, with a lot of its research, and so I've seen the things come out of it. But for those who haven't been reporting on it for 11 years... and once again, last week we talked about Chandrasekhar the person, and now we're going to talk about Chandra the X-Ray Observatory... Chandra the robot, based on the man. So, let's go back in history and take a look at the concept of Chandra. What's the idea here?
Pamela: Well, back in the '70s, NASA started putting together plans for a set of great observatories. They ended up with four different missions, the Hubble Space Telescope

was the first to go up, then there was the Compton Gamma Ray Observatory, which I think says that there's probably a fourth dude named Compton in our future. Next to go up was the Chandra X-Ray mission, and then Spitzer was the last of the great observatories. Now Chandra... the idea for the mission... and it was originally the AXAF mission... the absolutely unpronounceable acronym mission... it was really conceived and proposed to NASA in 1976. The idea was put forward by Riccardo Giacconi and Harvey Tananbaum and it was to fill a gap in our ability to understand the universe. There's so many things that give off x-ray emissions... shocked gases, compressed gases in clusters, gas that gets heated up as it falls into black holes, all these things—they're emitting x-rays. Stars emit x-rays. And we couldn't see it! And not being able to get information is annoying, and so they started in the late '70s and through the '80s and '90s working to design this amazing telescope that allows half arc second resolution of x-rays. Just learning how to focus x-rays has been a challenge.
Fraser: Right, and we can't see gamma rays because they're blocked by the atmosphere as well. So, I guess that's why the Compton Gamma Ray Observatory was put up. But unless you build a space telescope, you're not going to be able to see any x-rays at all.
Pamela: Right. And so we had to figure out how to build, how to focus, how to understand all that was needed to detect x-rays. It took a while. A lot of the work was done at the Smithsonian Astronomical Observatory at Harvard, and today, in fact, Chandra Center is located in Boston with joint support from the Smithsonian, from MIT, and at the Chandra Center. But they figured it out, and the science that's come out of this mission is truly amazing. When I started graduate school, black holes were one of those things that everyone knew existed. But...
Fraser: Mathematically....
Pamela: Right. And we all pointed at the same couple of binary systems saying, "That probably is a black hole." As I imitate older, male faculty members... but there was no evidence, and that is so annoying! But with Chandra, we were finally able to start looking at things and say, "That's the signature of a black hole." And that was perhaps the first really amazing thing Chandra brought us.
Fraser: So how did Chandra get up into space, then, because, I mean, you're...
Pamela: I did skip a step. We do need to launch the mission, don't we?
Fraser: Yeah, yeah... sorry, don't mean to rein you in, there.... it's very exciting... I can't wait... but let's at least talk about how it made it into space.
Pamela: It was actually launched on the space shuttle Columbia. The early great observatories were all designed for space shuttle launches. The original thought was to grab them, bring them back down to Earth, do things to them, and take them back up periodically. With Hubble, it got left up there and continued to be serviced by the space shuttles, most recently last year, but with Chandra there were some changes to it towards the end of the design cycle, and it was actually put into a highly elliptical orbit that would cause it to spend most of its orbit out beyond the Earth's radiation belts. The Van Allen radiation belts are actually fairly damaging to the instrumentation on Chandra. They actually had to remove one of the instruments from the focal plane when going through the Van Allen Radiation Belt to help protect it from getting zotted by too many rays. So it's now in an orbit that takes it a third of the way to the moon once per orbit and then cycles back closer to Earth and that's usually when we get the data, but it can't be serviced. But remarkably enough, this mission that was planned for five years has had an

extended mission and has now planned to go for ten years... well it's already surpassed ten years actually, it's now 10 years and 10 months along... it's estimated that it has at least a 15 year life expectancy at this stage. So that's pretty amazing... it's another one of those missions that was built and built well and is extending far beyond what was hoped for initially.
Fraser: Alright, now you can talk about the science.
Pamela: Thank you! So it allowed us to find where are the black holes.
Fraser: Right, but I mean obviously black holes are black... they absorb all the radiation—I'm assuming even x-ray radiation so how can Chandra see a black hole?
Pamela: Well, the neat thing is when you shock gas hard enough, it gets hot. And hot gas starts emitting in the x-rays. And so when we look towards black holes, we see both material that's getting destroyed as it falls in... it flickers in the x-ray, and also, much more interestingly, we end up seeing these bubbling shock waves of material around black holes where, as you look in, you'll see it literally looks like soap bubbles in the x-ray where when the black hole was active... when it was feeding... when something was getting destroyed... the process of having the matter get sucked in is highly energetic. It's highly luminous as well, and all that light pressure, that radiation pressure, can clear out bubbles, and these bubbles... the edge of the bubbles pushing outwards shocks the gas that the bubble is hitting. So you have radiation pressure going outwards, just like air going into bubble gum. And the edge of the shock bubble is where the radiation is colliding with the interstellar material. And these beautiful bubbles are found in our own galaxy, they're found in other galaxies, allowing us to know not only do we have the black hole Sag A star which Chandra discovered from its x-ray emission before we were able to image the stars orbiting so closely to it, but we're also able to see these same amazing really cool structures in other galaxies.
Fraser: So, if I understand correctly, we've got a super-massive black hole, it's feeding on material, the material is crushed around it so tightly that it's becoming like a star around it... nuclear fusion is getting going, and what you end up with is the light pressure blowing out of this mutant star... this temporary star... and that's blowing out cavities around the super-massive black hole.
Pamela: Right. This is talked about as black hole blow-back. And there's some really, really amazing images in the Chandra galleries.
Fraser: And so this is some of the more exciting stuff... you've got black holes, you've got these high energy x-rays streaming out of the neighborhoods around them, but some of the even more significant discoveries are not quite as exciting, as you said. It's like hot gas...
Pamela: Well, yeah, but it's hot gas jetting out of black holes...
Fraser: Right, or galaxies colliding together...
Pamela: And clusters colliding!
Fraser: Right.
Pamela: One of the coolest discoveries to come out of Chandra, and this is one of the ones that actually in some ways may have sounded the death knell for modified Newtonian dynamics, the alternative to dark matter in theories trying to... well no, it's not that there's invisible stuff, it's that we don't understand gravity... No, we understand gravity, and we know we understand gravity because the images from Chandra allow us to look at clusters, and the important one here is the Bullet cluster. And when you look at

it you can see shocked gas from where the two clusters are starting to collide. But then you can also see these orbs of dark matter imaged via gravitational lensing. So you look very carefully at the images and measure the distortions in the background galaxies and by looking at the distortions you can figure out, well, this was distorted by dark matter, this wasn't distorted by dark matter. So by combining Chandra which gives us the gas, and by looking at gravitational lensing of background galaxies, we can map dark matter and gas and we can see that the two are segregated... they aren't together. And this is just a fabulous result... we know dark matter is stuff because of Chandra.
Fraser: Right, and that there are situations where the dark matter can be separated from the galaxy and the gas that's in the galaxy so that you can actually see it as a separate entity. So that whole idea of not understanding gravity has just gone out the window.
Pamela: And we've now seen this in multiple different clusters. In addition to the Bullet cluster we can also see it in the ever-so-poetically-named MACS J0025.4 -1222. And we can also see it in a much more mixed-up way in Bell 520. So all these different systems are showing us evidence of where the dark matter and where the gaseous materials are located by using Chandra to give us the gas content.
Fraser: And I think one of the other things that's really interesting is when astronomers will use several of the great observatories to do some of their images. So they'll take an image of the same part of the sky in x-ray and then they'll merge that with images from Hubble and then they'll merge that with images from Spitzer and you get almost like three different colors in one image; but it's not colors, it's three different wavelengths that are telling you completely different things. So you see the gas with Spitzer, you see the visual stars with Hubble, and then you can see the dense objects or the colliding gas or the hot gas areas thanks to Chandra. And when you have these working together, it tells a much better story.
Pamela: And I know there's a lot of people out there who don't like false color, but the combined images of the great observatories scientifically paints such a new and interesting picture... especially when looking at supernovae... where we're able to see for the first time the neutron stars in the centers, and the gas jets they're emitting, and the materials around them. That was one of Chandra's first targets was actually looking at just supernovae and giving us a new view on these well-known objects. What we learned was really, really astonishing. Go out, look at a supernova. Look at it again in the Chandra galaxies. Cas A is another example of these amazing systems where we see so much for the very first time. The Crab Nebula is really my favorite.
Fraser: Yeah, well and I think one interesting one as well is supernova 1987a which was in the Large Magellanic Cloud, and it only happened... what... 25 years ago... right?
Pamela: Yeah.
Fraser: I remember when it happened... it was in the news.
Pamela: Our good friend Phil Plait researched it.
Fraser: Oh really? I didn't know that! And so we can see it year after year expanding... this shockwave bubble expanding out from where this supernova exploded. And you can see the hot gas... these filaments and knots of hot gas where the supernova is colliding with the nebula that's around it because the supernova exploded in a star-forming nebula and is now clearing out a lot of space and starting new solar systems and forming them... so you can imagine these knots of gas might be denser pockets... the locations of future solar systems.

Pamela: And there's some really fabulous things even with much more... in some ways simpler systems... there's the Cat's Eye Nebula for instance. Looking at it you can start to see again the high-energy shocked gas and this is a cooler system with a white dwarf. And it really lets you see where are the shocks, and that's information we didn't used to have. It makes for much more fascinating images. But, the thing I think a lot of us forget, and so far we've managed to forget it for 18 minutes, is Chandra's also gotten pointed back at the earth. You can use Chandra to start to observe aurora and it can be used to see exactly what's happening as these high-energy particles from the sun are interacting with our own atmosphere.
Fraser: That's pretty cool.
Pamela: It's very, very cool.
Fraser: I know that the x-rays that Chandra gathers are so valuable that they'll even use the time in between, so when Chandra is slewing from one target to another, it has to sort of go past all this other space and all of that data is actually made available to astronomers as well. As it moves the track is maintained and any x-rays that happen to bounce into its detectors along the way, they'll use that as well. They're actually starting to piece together whole sky surveys, thanks to some of the random data that Chandra has gathered.
Pamela: The serendipitous observations....
Fraser: Yeah, I mean with Chandra... especially with x-rays... you really need to focus on one target, wait a long time, and gather all those precious photons at that high energy.
Pamela: Proposals are written for kiloseconds...
Fraser: For kiloseconds... I don't understand...
Pamela: So you say, "I need 16 kiloseconds on object. That means you need 16 thousand seconds observing something.
Fraser: So... several hours.
Pamela: Right. So for instance when I was observing galaxy clusters with the McDonald Observatory 107-inch, we could get pretty good observations in 900 seconds of fairly distant... admittedly by local standards... so something a couple tenths of a Z away... clusters... 900 seconds, there's all your galaxies, move on, find your next cluster. But to look at closer objects and end up using sometimes many, many more seconds to get at the x-ray data... you're literally counting one photon at a time.
Fraser: And so what do you think is the connection between the observatory and Chandrasekhar? Why was it named after him?
Pamela: Well, a lot of the really cool objects that are getting observed with it are the types of things that, well, Chandra's theories explained why they're possible and why we should go looking for them. The white dwarf inside of the Cat's Eye Nebula, the many different neutron stars, the pulsars, all of these objects... he's the one that predicted these. And then black holes... he's the person who figured out that well, if this mass gives you neutron stars then this greater mass... oh, oh dear... this collapses even more. These are his objects and these are the objects detected by the Chandra Observatory.
Fraser: And, so the last thing I'd like to talk about is how exactly does Chandra work? Because we've talked a bit about x-ray observatories in the past... With a visible light observatory you've got a mirror, and photons come in and they're focused by this mirror and you use a CCD camera to record the image. But I know that x-rays are much higher energy and they're trickier to get a hold of.

Pamela: Yeah, that would be an understatement.
Fraser: So how does Chandra do that when mirrors don't work?
Pamela: What they do instead is they have nested cylindrical surfaces, and these nested surfaces slowly, using basically grazing incidence angles, reflect the light... getting it down to the detector. So the light comes in, it reflects off the inner edges, goes to a slightly better angle, gets focused a bit more, until it finally hits the detector.
Fraser: So, it's like you're nudging it.
Pamela: You're nudging it ever so carefully.
Fraser: Right, because there's no way to actually make them bounce, but you can just change their angle a little bit. So then would you say that we're not actually... it's not like we're focusing a huge area, like you might with say Hubble or a like great big observatory, you're mostly just getting a little more focus than you would...
Pamela: They actually are able to focus the telescope very, very well, it's just a different technology. So with Hubble you are going to get tenths of an arc second. But with Chandra you're still getting half an arc second of resolution, which is better than most ground-based telescopes can get. The telescopes on an average night, not a great night, not a horrible night, but an average night at McDonald we were looking and 1-2 arc seconds of good sky seeing. So here, Chandra is getting better than that, and it's getting better than that with x-rays. This is one of the profound things about Chandra Observatory is when we first started building x-ray observatories in the '70s, you basically pointed and said that giant area of the sky, there's x-rays there somewhere. There's been a billion fold increase, literally, in sensitivity and resolution combined that allow Chandra to count individual photons coming off of distant objects and resolve them at the same resolution that you get from the best ground-based telescopes under average conditions.
Fraser: So you said that Chandra will have maybe a 15 year life span, and we're ten years into it... What's going to be next? What will replace Chandra? Because this is something that you've got to have an x-ray observatory going...
Pamela: So we want Chandra to keep working... it would be awesome, but we do have to plan for the future. And being scientists, we do want to eventually get even better data... we do want to be able to collect more photons in less time and at higher resolutions. So right now there's a joint mission being planned named the International X-Ray Observatory... it's a joint mission between the European Space Agency, NASA, and JAXA which is the Japanese space agency. And they're hoping to launch it around 2020. Now the thing to remember is that everything in NASA is in flux right now, and strangely everything seems to be set for 2020, so expect that date to slide, expect that name to change, expect anything to be possible.
Fraser: Humans landing on the moon... finding Earth-sized planets with their x-ray observatories....
Pamela: Yeah, that one's not going to happen. But if you put a comma in there, I'll go with it. Finding Earth-sized planets, finding a better x-ray observatory. Yeah, let's go with that.
Fraser: So the replacement could go up in 2020.
Pamela: We're hoping...
Fraser: Right. And it will be more better.
Pamela: Yes.

Fraser: Cool. Alright, well that explains everything. Thanks a lot, Pamela!
Pamela: Well, it’s been my pleasure, Fraser.