Hi this is Steve Nerlich from Cheap Astronomy www.cheapastro.com and this is *Akatsuki Revisited*.

Faithful Cheap Astronomy listeners may recall that, back in May 2010, we covered how JAXA, the Japanese space agency, launched multiple spacecraft aboard a single HIIA rocket, which was all very efficient and impressively inexpensive. The multiple payload of the mission included IKAROS, a solar sail test mission, a bunch of pico-satellites and UNITECH 1, a deep space probe designed by some university students. But of course all these side-missions were just accompaniments to the primary payload Akatsuki, the Venus Climate Orbiter.

As it turned out all the accompanying missions worked out just fine, but as Akatsuki approached Venus in December 2010, the orbital insertion maneuver requiring a 12 minute engine burn, failed because the orbital maneuver engine failed after just a 3 minute burn – a fact which did not become clear until the spacecraft reappeared from behind Venus. With not just an engine failure, but critical time lost that might have otherwise allowed for a last-minute contingency maneuver, JAXA had little choice but to watch the half-tonne spacecraft slip past Venus into the lonely void beyond.

But of course, this is JAXA we're talking about, the people who worked out a bunch of extraordinary work-arounds to get the Hyabusa space probe to asteroid Itokawa in 2005 and also to get it and its sample return canister back home again, see CA episode 75.

So, as Akatsuki slipped past Venus in 2010, fresh plans were already being laid down. The thing with interplanetary missions is that you are working in a very dynamic environment. Earth is orbiting the Sun at 30 kilometres a second – so when you launch from Earth you immediately find yourself orbiting the Sun at 30 kilometres a second without having to expend a lot of energy. And if you turn towards Venus orbit, you will naturally accelerate as you move slip down the Sun's gravity well, meaning that you can also start approaching Venus' orbital velocity of 35 kilometres a second without expending a lot of energy.

And if you miss your Venus orbital insertion maneuver – well you are still travelling at 35 kilometres a second around the Sun – and in a vacuum. So the clever people at JAXA realized they could get Akatsuki back for a second attempt at Venus, just five years later – by going the long way round – that is, allowing the spacecraft to just coast right around the Sun.

Of course, one immediate problem with that plan was that Akatsuki had been designed for a maximum four year mission. Sure, it had an unlimited energy supply by virtue of its solar panels, but its batteries were only rated for four years of life. But no huge problem there, they could just put Akatsuki into a hibernation state, while it coasted around the Sun.

The huge problem to deal with was its orbital maneuver engine, the OME, which was clearly not working. And that problem needed to be dealt with long its return to Venus. It would have been absurdly fortunate had the spacecraft slipped beyond Venus' orbit on exactly the right trajectory that would have brought it back on exactly the right trajectory for a second attempt. So, during 2011, Akatsuki needed to make a number of engine burns to reshape its solar obit to put it back on the right path back to Venus.

In September 2011, the OME, the rocket engine that had failed before, was fired up. Just a couple of trial burns returned telemetry that indicated there was something fundamentally wrong with the engine, which was only delivering 10% of its expected thrust. Some clever forensic analysis of the telemetry data suggested there had been an unexpected salt build up which had disrupted flows and valve closures – meaning the engine had been fed too much oxidizer, which meant that it had burned too hot, which had then melted the throat of the combustion chamber – in other words, it was pretty-much space junk.

Attention then turned to the reaction control system, the RCS – composed of a series of smaller thrusters intended to orientate the spacecraft in different directions. The RCS thrusters were much less powerful than the OME, the orbital maneuver engine – but, since the OME was now space junk, JAXA calculated that slow prolonged burns of the RCS jets, might be just as effective as short blasts from the once-powerful OME.

Before the RCS jets were fired up, Akatsuki unloaded 65 kg of pointless oxidizer, oxidizer that was intended to feed the OME, but had since become useless mass since the OME was now also useless mass. Since mass equates to a lot of momentum, particularly when you are travelling at 35 kilometres a second, an extra 65 kg would have required a much longer RCS burn to change the spacecraft's trajectory.

Anyway, after ejecting the oxidizer in a direction that helped start Akatsuki's course change, a few burns of the RCS in November 2011, did effectively reshaped Akatsuki's orbit and put it on a proper return trajectory. Then Akatsuki went into hibernation. Fast asleep, it passed its halfway point, on 3 October 2013 – half way on its long and slow second approach to Venus.

Not much else happened until the spacecraft was woken in 2015 to perform four new correction burns – the first on the 17th July and the fourth on the 11th September – to put it in line for its second attempt at an orbital insertion maneuver, on the 7th December 2015.

The reason why this took five years is all about orbital mechanics. For Akatsuki to catch up to Venus, it has to be moving faster than Venus, but if it's moving a lot faster than Venus, it's going to shift up the Sun's gravity well away from Venus' orbit. So, with a need to conserve as much fuel as possible, all Akatsuki could do was move a tiny bit faster than Venus and then do a tiny course correction towards the end that would bring it back into line with Venus' orbit. That is why it took 5 years. Five years is 5 solar orbits for Earth, eight solar orbits for Venus and it was nine solar orbits for Akatsuki.

The December 2015 maneuver involved firing four of the RCS thrusters for a 20 minute continuous burn. This was something these delicate little engines, designed to deliver occasional little puffs of corrective thrust, had never been meant to do. But it worked and on the 7th of December, Akatsuki the Venus Climate Orbiter, successfully achieved an orbit around Venus. It was a highly-elliptical orbit with an apoapsis altitude of about 440,000 km and a periapsis altitude of about 400 km above the Venusian surface. This orbit has a period of 13 days and 14 hours and is moving in the same direction as Venus rotates.

Next steps are to further constrain Akatsuki's orbit down to a period of about 9 days, although its highly-elliptical shape will be retained, since this had been part of the original 2010 plan – intended to allow the

orbiter to fly very close in, while it made observations, and then pull right back out again to avoid too much atmospheric drag. And once a stable orbit is achieved in 2016, proper science operations will commence from April 2016.

Akatsuki's UV, IR and 1 micron cameras are all working fine. The one micron camera is still an infrared camera, but its shorter wavelength focus is intended to capture more energetic heat sources that are close to the ground, offering the best chance to capture any surface volcanism and any spectroscopic data about what the surface is made of.

Otherwise, Akatsuki will be studying the Venusian atmosphere and its dense cloud composition – and it will also look for lightning, observations of which might help us understand what role lightning played in Earth's primitive atmosphere – particularly whether such primeval lightning contributed to creating organic molecules. I mean, wouldn't it be a shocking, if they found phenomena equivalent to the Miller-Urey experiment in Venus' atmosphere?

Thanks for listening. This is Steve Nerlich from Cheap Astronomy, www.cheapastro.com. Cheap Astronomy offers an educational website where every spacecraft deserves a second chance. No ads, no profit, just good science. Bye.

(*Afterword*: Following the recent demise of the European Space Agency's Venus Express spacecraft, Akatsuki's arrival at Venus means we once again have human-built spacecraft orbiting 4 planets, Venus, Earth, Mars and Saturn – a figure which should rise to five planets if Juno can achieve a successful Jupiter orbit in July 2016).