Hi, this is Janet for Cheap Astronomy, www.cheapastro.com. This is SISS, Science on the ISS – and today's episode is *The outside.*

If you read up about the ISS, it won't be long before you come across the terms *docking* and *berthing*. Both derive from nautical parlance where a vessel approaching a dock can either make its own way in – or it can be maneuvered in – by tugs boats, for example. The end result is the same, the vessel gets tied up at port – the distinction is about how it got there. If it's docked, it did it itself, if it's berthed, it had help.

Translating all this to the context of the ISS – a piloted spacecraft will generally dock at a docking port under the control of the pilot. An automated vehicle with no pilot will approach and stop at a safe distance, before an ISS crew member takes over to maneuver it in to berth.

Docking is the preferred procedure for piloted spacecraft because it's quicker. What's important about that, is that it's also quicker to *undock* – which you might need to do in an emergency. If you've seen the movie *Gravity*, you'll appreciate that any docked spacecraft is a potential lifeboat. Passively-berthed cargo resupply ships don't have on-board life support, nor do most have heat shields for re-entry, apart from the Space X Dragon spacecraft. But, even though they're of no use as lifeboats, cargo resupply vessels are vital to keep the astronauts and the ISS itself in good operating condition. On the US segment of the ISS, resupply vessels are slowly maneuvered in to berth with CBM ports, standing for *common berthing mechanism* ports. These CBM ports are larger in diameter than docking ports, since they are designed to move cargo rather than people – although, if need be, CBM ports can be modified for use as docking ports.

Of course, all these principles only apply to the US segment of the ISS. On the Russian segment, manned Soyuz spacecraft and unmanned Progress cargo vessels both have the same basic design and hence both use the same port diameter – so either a piloted Soyuz or an unpiloted Progress can both dock on the same ISS ports. A Progress vessel can dock using a fully-automated on-board system – although, if need be, ISS personnel can take over, control its approach manually and hence berth it.

But anyway, back on the US side, all the passive shepherding that's involved in berthing cargo vessels is managed by the legendary Canadarm – although, in the context of the ISS, we are actually talking about the Canadarm 2.

While every Space Shuttle orbiter has had its own Canadarm, making five in all, there's only one Canadarm 2 on the ISS. And just so we're clear – although it's spelt *Canadarm,* it's always *Canada-arm* – because it's an arm… from Canada.

The Space Shuttle Canadarms were awesome. A bit like a human arm, each had a shoulder joint, each had an elbow joint and each had a wrist joint at the business end – with an *end-effector* attached – that could not only latch onto things, but could also relay power and data to those things. The reach of the original Canadarms was around 15 metres. The reach of the Canadarm 2, now on board the ISS, is 17 metres – but there's a lot more to Canadarm 2 than just an extra two metres.

Canadarm 2 can do something extraordinary that Canadarm couldn't. When Canadarm 2 is working, its shoulder remains attached to the ISS while its elbow bends and its wrist and end-effector lift and manipulate things. But while its shoulder is attached to one ISS Power Data Grapple Fixture (a

PDGF), it can reach out to grab onto another PDGF and then uncouple from the first PDGF – so Canadarm 2 can move like an inchworm. PDGFs are distributed across all the modules on the US segment, as well as on the Russian Zarya module, so Canadarm 2 can move over the outer surface of all those ISS modules. Furthermore, across the main truss of the ISS, there's the Mobile Base System, the MBS, which is a flat trolley on rails that can transport things 108 metres across the truss, which runs perpendicular to the line formed by the interconnected ISS modules.

On top of all that, another Canadian innovation is Dextre, the Special Purpose Dexterous Manipulator, which is essentially a multi-limbed, multi-jointed robot. Dextre can become a hand with fingers for Canadarm 2. To move a piece of equipment around the station, Canadarm 2 grabs onto the MBS – remember that's the trolley on rails – attaches Dextre to its free end and then Dextre grabs on to the equipment that needs moving and then they all ride the MBS trolley along to a point where Dextre can either dexterously maneuver the equipment into place – or otherwise Canadarm 2 can disembark at that point and move them all off-rail using PDGF grapple holds.

So when Canadarm 2 isn't berthing or unberthing resupply vessels, it's climbing over the ISS's outer surfaces, generally with Dextre in tow. Most of this part of its job is about maintaining the ISS's external infrastructure, which is managed in a very systematic and pro-active way. Rather than waiting until something breaks down and the astronauts have to drop everything to do a spacewalk, most external components of the ISS, that are prone to wear and tear, are replaced on a regular basis – whether or not they are actually broken.

What makes this work is a large collection of spares, called Orbital Replacement Units, or ORUs. ORUs are various components of the external infrastructure of the ISS – like batteries, storage tanks, electronic devices and antennae. These ORUs can be swapped in and out according to a predetermined schedule. Different ORUs come in many different shapes and sizes, but all follow standard design specifications – with standard power sockets, standard data interfaces and good, old standard nuts and bolts. And most ORUs have attachments that can be grabbed by Dextre's various Tool Changeout Mechanisms – while bigger ORUs with a grapple fixture can be handled directly by Canadarm2. All the spare ORUs are kept in easy reach on the External Stowage Platforms, which are open to space, but do have power outlets for any of the ORUs that need to stay powered up while stored.

But of course, we should remember this is the *International* Space Station. Canadarm 2 can attach to grapple fixtures on the Zarya module of the Russian segment of the ISS, but that's as far as it can go. To date, the Russians have got by with two *Strela* cranes, which are two unpowered poles, which a space-walking cosmonaut can orientate by hand and then telescopically extend up to 14 metres using a hand-crank. The Strela cranes can then be used to move cargo or even other space-walking cosmonauts. The Strela cranes are all the Russians really need since any piloted or unpiloted spacecraft coming to the Russian side of the ISS dock rather than berth, so there's no need for something as big and as complex as Canadarm 2.

Nonetheless, in 2017 the European Robotic Arm, the ERA, will be added to the Russian segment, along with a whole new science module called Nauka – which will replace the older and smaller Pirs module. The ERA will be able to connect with grapple fixtures positioned around the Russian Orbital Segment and so it will be able to move all over the Russian segment, from the Zvezda to the Zarya module. The ERA isn't as long or as strong as Canadarm 2, but it doesn't need to be since it still won't need to do any cargo vessel berthing. However, it *will* play a similar role to Canadarm 2 in managing a range of routine maintenance tasks around the outer surfaces of the Russian segment.

So, hopefully you are getting the big picture now. While the astronauts are beavering away *inside* the ISS, things can get just as busy on the *outside*. Routine maintenance and ORU swap-outs are mostly managed by ground personnel who will use devices like Canadarm 2 and the ERA as *tele-manipulators*. They use hand controls and video feeds relayed from the station so they can drive these devices as though they were extensions of themselves – and since ground personnel can work in shifts, these devices can be worked on a 24/7 basis if need be.

Having ground personnel manage these external maintenance tasks, frees up the most expensive components on the ISS – the astronauts – to keep doing yet more fabulous science. Nonetheless, spacewalks are still regularly needed for any external work that isn't routine.

Finally, it would be remiss not to mention the Remote Manipulator System which operates from the Japanese Kibo module. The RMS is a 10 metre arm whose sole purpose is to do science on the ISS. It moves objects to and from Kibo's *Exposed Facility*, a platform that allows people to conduct outside science experiments – that is, *outside* in the cold vacuum of space.

Thanks for listening, this is Janet for Cheap Astronomy www.cheapastro.com. Cheap Astronomy offers an educational website that lets you look inside what's outside. Bye.