This is SISS, Science on the ISS, the International Space Station – and today's episode is *It's very cold in space.*

Well, it is very cold in space, but on average it's a moderate 3.7 Kelvin, which is the current temperature of the cosmic microwave background that pervades the entire universe – including all those huge voids of vacuum, which is what space is mostly about. Nonetheless, even in those huge voids of vacuum it is not unusual to come across the occasional hydrogen ion. So if you want a real vacuum and you want a really cold vacuum, you need technology. These days we find it pretty easy to create much more complete vacuums than you could ever find in nature and we also find it pretty easy to create temperatures that are a darn sight colder than 3.7 Kelvin.

A warm atom has its electrons in particular shells. Put it in a cold place and it will begins to cool by releasing photons as its electrons drop to low energy shells. Such radiative cooling is not a smooth process. Instead, its *kerchunk*, an electron drops to a lower shell and releases a photon. The nothing happens for a while until *kerchunk*, another electron drops. Cooling only seems like a smooth process at the macro level because all the different atoms in a macroscopic object are going *kerchunk* at slightly different times. Eventually, all atoms reach a point where their electrons have no more shells to drop down to. This is as cold as they can ever get. Indeed, we think there is an ultimate ground state for all the different fundamental particles, as well as the ions and electrons that make up atoms.

To make a particle this cold you not only have to isolate it from radiative heat sources, but also distance it from other particles. Consider the compressed contents an aerosol can. Regardless of how warm or cold the contents are under pressure, if you spray the aerosol, thereby releasing its particulate contents from being in close proximity with each other, the spray will become colder than it was in the can.

Now, at this point in the podcast you might reasonably ask what all this has to do with the ISS. There is a reason why we can create very, *very* cold conditions on the ISS, colder than anything we could manage on Earth – and it's not because it's very cold in space. In fact, as with most science on the ISS, it's all about microgravity.

In a gravity well like Earth, particles get crowded up against other particles when they approach an unyielding surface. When particles are forced closer together they inevitably heat up. So while we can readily achieve temperatures below 3.7 Kelvin on Earth, it's hard to keep it that cold for any appreciable length of time and to get down to within a few picoKelvin of absolute zero, we need to take gravity out of the equation.

Low temperature technologies are a growing area of importance. For example, we've known for many years that very cold things can develop superconductivity, meaning they offer no resistance to the passage of an electric current. Superconductors are currently in use across a wide range of industries and sciences. Good examples are sensitive radio telescopes that depend on superconductivity to reduce the background noise of the telescope's own detection equipment.

To further explore what happens at really, *really* cold temperatures, we flew the Lambda Point Experiment and also the Confined Helium Experiment into orbit aboard space shuttle missions in the nineties, in both cases investigating the behaviour of cold liquid helium. Helium exists as a gas down to temperatures of 4 Kelvin, while hydrogen liquefies at around 20 Kelvin. This is partly because helium is a noble gas and is so inert that it can barely interact with itself to form a fluid. But at 4 Kelvin it eventually does and if you keep cooling helium down even further, to around 2 Kelvin, which is called its lambda point, it forms a superfluid.

A superfluid has no viscosity, so for example, it can flow through minute holes that it wouldn't have fit through as an ordinary fluid. In this very cold regime, there are Bose-Einstein condensates, which are very cold collections of bosons. There are also Fermi condensates, which are very cold collections of fermions. If it's helpful, just remember that all Bose-Einstein condensates are superfluids, but not all superfluids are Bose- Einstein condensates. The remainder include Fermi condensates, but also a number of other states of matter that we are yet to fully organise into categories. This is still a pretty new area of physics.

Probably the most useful thing to remember about stuff at very cold temperatures, is that it behaves weirdly. Some insight into what might be going on can be gained by considering Heisenberg's uncertainty principle, which says that you can't simultaneously know a particle's position and its momentum. But if you cool a particle down towards absolute zero, it's not going to have any momentum – which means you know what its momentum is: zero. And if it has no momentum you also know where its position is too: right there, where it stopped moving.

The theory goes that once you reduce a collection of atoms to their ultimate ground state they all become identical. In a warmer collection of atoms, this never happens, since all the individual atoms and their sub-atomic particles are constantly jiggling and oscillating and so are never in quite the same state. But not only do very cold particles became identical, they kind of become *the same* particle. This is why we use the word condensate – individual components cease to be individual components.

Whatever the correct physical interpretation of very cold matter may be, a collection of superfluid helium is observably weird. If you put it in a cup, it will climb the walls to get out. If you spin the cup, the superfluid won't spin with it. A collection of superfluid helium acts as though it wants to ensure that you can never quite nail down exactly where it is, or exactly what it is. It is a macroscopic quantum object.

Studying macroscopic quantum objects in space isn't just a case of satisfying scientific curiosity and better understanding the fundamental architecture of the universe. As we noted earlier, superconductors represent a very useful and economically-significant area of technology. No-one is likely to fly stuff to the ISS, at around $10,000 a kilogram, unless there's good reason to think it might lead to something economically-significant.

So, you might ask, what's next? In 2016, we launch the Cold Atom Laboratory to the ISS. With better technology and more time in orbit than previous experiments, CAL will be able to cool things right down to around 100 picokelvin above absolute zero, meaning the ISS will harbour the coldest place in the Universe – unless the aliens have already come up with something better.

CAL is expected to enable the study of macroscopic quantum objects at the touch of a button (well, OK maybe a few buttons and OK there might even be some dials involved, but you know what I mean) and CAL will make it possible to observe the behaviour of different gases when cooled below their lambda points, which is when they stop beings gases and become superfluid condensates. Hopefully, this are of study will generate some useful technological and industrial spin-offs and if we just happen to gain a deeper understanding of what the Universe is made of and what the underlying infrastructure of matter is really like, well no-one will really mind.