Question 1:

Dear Cheap Astronomy – Part 2 (of) just how dangerous are cosmic rays?

In the previous episode we covered the dangers of particle radiation in space travel. To recap, sure electromagnetic radiation can kill you, but if your outside of Mercury's orbit it's unlikely the Sun's electromagnetic radiation will kill you as long as you have adequate radiators to lose any heat that you gain. Also a modicum of shielding should be adequate to reflect most shortwave radiation – remembering Earth's flimsy ozone layer is adequate to shield our planet from wavelength's shorter than ultraviolet.

The real danger is particle radiation. A sub-atomic particle that's been accelerated up close to the speed of light is not going to bounce of your hull, it will hit and essentially explode, fragmenting itself and whatever it hits, into smaller particles that continue forward to collide with the next layer of particles, and so on until some of that secondary radiation eventually reaches the crew within.

All this happens at the subatomic level so the astronauts would be oblivious to it in the absence of radiation detectors. They might die from cancer years later but could experience more immediate problems if the radiation wipes out their bone marrow leading to anaemia and immunosuppression after a few days. They would likely recover from that, but having the whole crew incapacitated for days or weeks while they're flying a spacecraft is not a good scenario.

In the context of space, we call particle radiation cosmic rays. Within the Solar System most cosmic rays arise from the Sun. The Sun has a constant output of particle radiation called the solar wind, but there are also occasional accelerated outbursts of particles, called solar particle events as well as much larger scale coronal mass ejections. All our Apollo lunar astronauts flew outside the Earth's magnetosphere for several days with no ill effects, but had one of their flights coincided with a large coronal mass ejection moving in their direction, NASA might have aborted a landing or otherwise shortened the mission with the aim of getting the astronauts home quickly, since such radiation exposure wouldn't kill them outright, but might have brought on incapacitating radiation sickness within a matter of days.

On a mission to Mars there are no such quick abort options. So prevention through shielding is a necessity. Apparently, the best shielding against cosmic rays, which are predominantly high energy protons, is a material rich in hydrogen – that is, protons. So water is good as are hydrocarbons, such as plastics, and also ahem human waste. So we could route the plumbing through one part of the hull and also store the ahem in another part for shielding. Current thinking for lunar missions is much simpler. Once a coronal mass ejection is known to be approaching the crew will grab loose storage bags and other containers and build a makeshift igloo around themselves for temporary protection until that burst of particle radiation has passed.

However, there are also more deadly cosmic rays out there. Galactic cosmic rays come from outside the Solar System with enough kinetic energy to punch through the heliopause against the outward push of the solar wind. There are also even more powerful extragalactic cosmic rays that first punch through the galaxy's interstellar wind and then the heliopause as well. The greater danger these cosmic rays pose now has us planning to fly humans to Mars during a solar maxima. That is we'd rather deal with the worst particle radiation the Sun can offer – with the hope that the extra outward push of the solar wind during a solar maxima might slow down some of the incoming galactic and extragalactic cosmic ray particles. As to the origin of these astonishingly high energy cosmic rays and how we might hope to protect astronauts from them, where some water, poo and a few storage bags just won't cut it, is a matter for part 3.

Question 2:

Dear Cheap Astronomy – Part 3 (of) just how dangerous are cosmic rays?

As we discussed in Parts 1 and 2, when people talk about needing to protect astronauts from radiation, we are really talking particle, rather than electromagnetic, radiation. Particle radiation from the Sun, particularly from an energetic outburst like a coronal mass ejection is dangerous, but manageable, on short trips say to the Moon and back. It's more of a concern on longer trips, since the pathology of radiation is mostly about cumulative dose. So, one or two Apollo missions to the Moon didn't enhance cancer incidence amongst the lunar astronauts, but ten or twenty might have. That's partly because of an increased likelihood of encountering something like a coronal mass ejection, but it's also just from longer exposure to the background radiation of the solar wind.

But, as we then mentioned in part 2, there are some much deadlier cosmic rays out there – galactic and extragalactic ones. We don't know for sure that a lunar crew never came into contact with one of these, but they're ones we particularly worry about with a Mars mission. Again, one might not kill you, but ten could.

We've been monitoring cosmic ray collisions with Earth upper atmosphere for a long time now. In 1991, a particularly high energy collision was observed, thereafter called the omigod particle – where the kinetic energy it imparted to a subsequent air shower of subatomic shrapnel was equivalent to being hit by a baseball moving a 100km/hr or a bowling ball dropped from shoulder height. So next time you hear that experiments like the Large Hadron Collider could destroy the world or even the Universe – remember there are vastly more energetic collisions that take place right over our heads and have been for billions of years, indeed they are commonplace across the Universe.

But anyway, a collision with such a high energy particle is still a subatomic event so it wouldn't punch a hole in your spaceship, but would almost certainly send a wave of secondary particles right through the hull. irradiating the crew. The faster the primary particles are moving prior to impact, the more kinetic energy they add to all the secondary radiation that's produced.

Cosmic ray particles from the Sun, thrown outwards by intense solar magnetic turbulence move close to the speed of light – say around 99.9% of it. Then there are rarer mid-range energy particles that might be thrown out by sources elsewhere in the galaxy, such as supernovae or neutron star mergers – events that are often accompanied by a gamma ray burst but also by burst of outflung particles that might be moving at 99.999% of SoL – those extra point 9s representing a lot of extra kinetic energy being carried by those particles.

And then there's the much rarer ultra high-energy cosmic ray particles, like the 1991 omigod particle, which are moving at 99.999999 etc % SoL. Although do seem to be in a class of their own, it's not yet-settled whether they are all extragalactic. One possible source are the active galactic nuclei of distant galaxies that are pumping out jets of high energy particles across the Universe, but it might also be that ultra high energy particles could also come from inside our galaxy, perhaps from a particularly energetic collision of two accreting black holes or something similarly cataclysmic.

High and ultra high-energy cosmic ray particles represent a rare but more lethal hazard to deep space astronauts, where the longer the mission, the more likely you are to encounter them. Protection from these on a long duration mission to Mars may require some higher tech solutions. A hull with multiple layers of varying materials including Kevlar and polyethylene with those layers separated by airgaps might work. NASA has also investigated materials like hydrogenated boron nitride nanotubes both as hull material but also woven into a fabric for spacesuits.

We might even consider active shielding in the form of a locally generated magnetic field around a spaceship. The power requirements for this look prohibitive unless you are flying with nuclear power, but that may well be what we end up doing – where future commanders might find themselves saying Shields Up.