Big Questions for Cosmic Ray Scientists

If we knew all the answers to the questions below, the HiSPARC experiment would not be worth doing, nor would there be a world-wide community of cosmic ray scientists. These are **big** questions. We can maybe tackle some of the little questions that need to be understood before we can help with the big questions.

Where do cosmic rays come from?

Progress has been made on this question since cosmic rays were first discovered. Firstly, scientists were able to say where they did *not* come from (e.g. the Earth) by flying particle detectors in balloons and discovering that cosmic rays got more intense as they climbed. Then, it was realised that mostly they do not come from the Sun. (There are reasons to think that some lower energy cosmic rays come from the Sun, but they probably cannot penetrate the Earth's magnetic field, so we will not see them.) We can now be sure that most of what we will see comes from outside the Solar System.

When we eliminate a lot of potential sources, we are left with just a few possibilities. When we have eliminated all the possibilities, except for one, we have the answer. (It is likely, however, that there are different answers for different types of cosmic ray.)

What are Cosmic Rays?

What we see in our detectors in not the original cosmic ray particle. We see a shower of *secondary particles*. How much can we find out about the original particle?

We do know some things, because of measurements above the atmosphere and deductions from things we can measure on the ground, such as the total energy of everything we detect in a shower.

The mix of particles in the original cosmic rays (i.e. as seen in space) can probably tell us something about where they come from.

How are they Made?

On the Earth we make high energy particles in particle accelerators. These are large, delicate, *precision* machines and we have to feed them with a *lot* of electrical energy to get a relatively small amount of energy into the high energy particles. (At ISIS, probably less than 10% of the electricity going into the accelerator gets into particles.)

How does nature manage this very difficult trick with jumbles of hot gas threaded by random magnetic fields? Is it inefficient, like our Earth-bound accelerators, or can it be done more efficiently when you work on *very* large scales (say with a few thousand light years)?

A lot of the radio emissions coming from the sky are produced when high energy particles – effectively cosmic rays still in space - whirl around magnetic field lines, and as a result we know something about the amount of energy that has actually been fed into high energy particles inside many astrophysical objects (like supernova remnants) and we know something about how much escapes from there into interstellar space (and eventually some get to us). The energy demands are staggering even if you assume high acceleration efficiencies. If the efficiency is as low as in our own accelerators the energies involved are completely mind boggling – *much* more than you can get from nuclear fusion in stars - and we have to start thinking about very exotic physics.)

Is particle acceleration easier if you can work on very large length scales (light years) and do not have to bend proton beams around in very small circles?

How Do They Get to Us?

How much to cosmic rays get bent by magnetic fields in space before they get to us? Is the direction from which they arrive any indication of where they come from? (This might depend on the energy of the ray.) How long does a typical cosmic ray spend travelling in space before it gets to us? (There *are* ways to work this out – Google beryllium 10.) All cosmic rays travel at a whisker below the speed of light – so they *could* cross our galaxy in about 100,000 years. If they spend longer than this, on average, travelling, where have they been?

If some cosmic rays come from very, very large distances (as is possible with the ultra-high energy rays) they have to travel a long way through the universal *microwave background*. They have to push the photons of the background out of the way as they travel and each time they do they lose a bit of energy. How far can a cosmic ray travel before it loses most its energy? Can it get here from a *quasar*? What does the so-called OMG particle tell us about this question? (This was a single proton with the energy of a tennis serve.)

Can the HiSPARC array help us detect more particles like the OMG particle?

Knowing more about cosmic rays can tell us quite a lot about the amounts of energy involved in the most spectacular astrophysical events, like supernova explosions, and active galactic nuclei (AGNs).

If you want to predict our weather on Earth the first thing that you need to understand is how much energy is coming from the Sun. If we want to predict “space weather” in our Solar System, we also watch the Sun – it is still the energy source. Similarly, if we want to understand how entire galaxies evolve over cosmic time scales (and become able to form stars like our Sun capable of nurturing life) we need to understand the energy flows around the galaxy - galactic “space weather”. Where does the energy come from? (Supernovae are probably important – but are they *all* we need to worry about?) Where does it go to? Cosmic rays are one of the way in which we try to get a handle on this questions.

Energy, Energy, Energy! When faced with a situation they do not fully understand astrophysicists always ask first: How much energy? Where does it come from? Where does it go?

In real science everything is connected.