Question 1:

Dear Cheap Astronomy – How come Sun spots, prominences and flares only appear around the Sun's equator?

The best answer to this question is probably 'we don't know', since we have only a rudimentary understanding of why things work they way they do on the Sun – even though we have a wealth of observational data about how things work on the Sun.

For example, we know a sunspot cycle runs for around 11 years, commencing from one solar minimum – when there's a hardly any sunspots, through to a solar maximum when there's a hundred or more spots visible, before they slowly fade away again back towards another solar minimum. During each of the solar maximum, the Sun's magnetic poles flip so north becomes south and south becomes north. So when people talk about the solar cycle that's really two sets of sunspot cycles. The poles flip during the first sunspot cycle and then they flip back during the second sunspot cycle, completing one solar cycle. The poles last flipped around in 2014 – they will flip again around 2025 and then flip again around 2036, which will bring them back to how they were in 2014.

Given all this pole-flipping it should be clear we are dealing with some very large scale magnetic phenomena. The Sun is a big ball of plasma, which is composed of hot sub-atomic particles – mostly protons and electrons. Being hot means they are very energetic, which is why these positively and negatively charged particles have become dissociated. If you could cool everything down they would recombine to form neutral hydrogen and all the electromagnetic activity would fade away.

And not only is the Sun a big ball of hot magnetically-charged plasma, it's also a spinning ball. If you could stop the Sun spinning a lot of its exotic electromagnetic activity would fade away. You would still have a big ball of energetic magnetically-charged plasma, but without the spinning, the magnetism wouldn't become organised on a large scale to give the Sun magnetic poles or sun spots.

It's thought that sunspots are like little whirlpools in the Sun's magnetic field – stirred up by a combination of the Sun's rotation and the constant convection of hot plasma rising from the core to cool at the surface before sinking back down again. It's thought there may be many swirling currents of charged plasma beneath the Sun's surface and just now and again one of these currents gets whipped up tight into an elongated loop that penetrates the surface. We are talking about a loop of tightly spinning charged plasma – but it's equally a tightly spinning loop of magnetic flux- and it's these twisting streams of magnetic energy that then make the Sun's charged plasma do all sorts of weird stuff.

A sunspot is probably the top of a spinning magnetic vortex that is dragging plasma downwards against the normal upward flow of convection, which is why that point at the top of the vortex appears cooler and darker than the rest of the Sun's surface.

But elsewhere on the Sun's surface the same magnetic turbulence is hurling jets of plasma outwards from the surface, in flares, prominences and coronal mass ejections. An increase in sunspot activity towards solar maximum is always accompanied by an equivalent increase in these solar outbursts.

During the progression from solar minimum to solar maximum sunspots first appear at around 30 degrees latitude both north and south of the solar equator. Over time, the sunspots then appear to migrate with an increasing frequency towards the equator – although they neither reach nor cross the equator.

In this respect, sunspots are a bit like hurricanes and cyclones on Earth – which only appear in the tropics, north or south of the Earth's equator and they never cross the equator, since the Coriolos effect ensures that hurricanes in the northern hemisphere spin in the opposite direction to cyclones in the southern hemisphere. The nett effect at the equator is even laminar flow with no vortices.

The sunspots themselves cannot be compared to hurricanes or cyclones, but the underlying currents and vortices that cause sunspots may follow similar rules. And you get no cyclones or hurricanes near Earth's poles, nor any sunspots near the sun's poles, because the angular velocities near the poles of a spinning sphere are insignificant compared to the velocities around its equator.

I hope that answers your question.

Question 2:

Dear Cheap Astronomy - Since mass attracts mass due to spacetime curvature – do charged particles attract (or repel) each other in a similar way?

According to Einstein, gravity as the result of curved spacetime. You don't accelerate in a gravity field because some mysterious force is dragging you downwards. You accelerate because clocks progressively slow and lengths progressively contract as you move closer to a massive object.

In theory, the four forces, the strong, the weak, electromagnetism and gravity all involve attraction and are all mediated by particles – some observable like the gluon and some hypothetical like the graviton. In theory, the four forces can also be thought of as fields – for example, a gravity field or a magnetic field, although an electromagnetic field is the more technically-correct term.

James Clerk-Maxwell demonstrated mathematically and also experimentally that electric and magnetic fields should be considered two manifestations of the same thing – that is, an electromagnetic field. In his later career, Einstein had high hopes of achieving a similar outcome for the electromagnetic and gravitational fields – which he thought might represent two manifestations of some higher order physics. But the person who had successfully unified space and time into spacetime had no such luck with gravity and electromagnetism.

But anyway – what is electromagnetism? How does it work and does it work at all like gravity does? The physics of magnetic attraction is easy to observe, but difficult to explain. Magnetisable metals, like iron, nickel and cobalt have the spins of their outermost paired valence electrons aligned. This configuration explains why these metals are attracted to magnets, as well as being magnetisable themselves. Most other things in the Universe with a electromagnetic field first had their elements ionised and then had all the freed electrons spun around in a coordinated way – think of the Sun, Jupiter or even just a small coiled electromagnet here on Earth.

However, while spinning electrons are the source of electromagnetism – mediating the electromagnetic force is the job of a boson – and the boson involved in the electromagnetic force is of course the photon. After all, light is electromagnetic radiation. So, when a charge attracts an opposite charge, or when it repels a like charge, this is shown in a Feynman diagram as an exchange of virtual photons.

Such Feynman diagrams are a useful way of describing and predicting electromagnetic interactions, and real photons have been shown to transfer spin – at least in the quantum mechanical sense of the word spin. Nonetheless, an exchange of virtual photons – that conveniently appear when required and then disappear again – sounds more like a mathematical model, than genuine reality. But seeking a deeper meaning from field interactions doesn't help much either. A charged particle can bend the electromagnetic field in a similar way to how mass bends spacetime – and that bending of the electromagnetic field can alter the trajectory of another charged particle. But this doesn't easily explain why opposite charges attract and like charges repel.

Quantum field theory has an answer, even though it not a very satisfying answer. Masses are universally attractive because gravitons have spin 2, while charges differentially attract or repel because their electromagnetic force carriers, photons, have spin 1. If that helps you – well, great.

So, at the end of the day, it is quite difficult to explain why electromagnetism works, even though it clearly does work. For this reason, it's difficult to say whether there is any common mechanism underlying electromagnetism and gravity.

For the moment, the best way to explain electromagnetism is with quantum physics and virtual particles. At the same time, it's (ahem) relatively-easy explaining how gravity works without needing to worry about hypothetical gravitons at all. I think we'll just leave it there.