Question 1:

Dear Cheap Astronomy – What's in a black hole?

Answer: don't know – and coming up next week we investigate where the edge of the universe is… OK, just kidding. The whole idea of an event horizon is that anything lying beyond it is unknowable – that is, we will never get any observational evidence about what lies beyond it. There are hypotheses like Hawking radiation where information trapped inside the black hole may be eventually returned to the wider Universe as the black hole evaporates, but that's information in a purely physics sense – it couldn't be interpreted to tell you anything about what was inside the black hole before it evaporated. And like most thinking about black holes, Hawking radiation and evaporating black holes are just ideas – which are unlikely to be testable any time soon.

The standard science communication line is that a black hole contains a singularity of infinite density. Here at Cheap Astronomy we like to dismiss explanations that have infinites in them – which are either lazy explanations or plain bad math. After all, since black holes do increase in mass when new material falls into them, that means their density will grow from infinite to infinite plus one. So, here at Cheap Astronomy, we think it's better to say that all the mass in a black hole occupies a Planck unit of volume – that is one Planck unit of distance cubed. The whole idea of a Planck unit is to acknowledge there is always a point at which physical parameters become indivisible, so a Planck unit of distance isn't zero, but you can't have half a Planck unit. One Planck unit is as short and small as anything can be.

So how come we can keep adding more and more mass and still have it all compress down to a volume of just one Planck unit of distance cubed? Consider the humble atom with a nucleus surrounded by an electron cloud – which is said to have a scale equivalent to a fly in the middle of the dome of St Paul's cathedral. But throw a bunch of atoms into the crushing gravity of a star and the nuclei and electrons disassociate into a plasma leaving much less empty space between the particles. And, if it's a large star, when it ages and dies it may form a neutron star – where the electrons and protons are crushed together to form neutrons. So the whole star is just neutrons with very little empty space between them – that kind of density means a teaspoon of neutron star matter has the same mass as Mt Everest.

The next stage after a neutron star is where no-one can quite agree. With even more crushing gravity the neutron matter might collapse down into its composite quarks, but that kind of density is about where you get so much gravity that light can't escape – so whatever happens, happens behind an event horizon. It could be that the quarks are just point particles, with no intrinsic size or volume of their own so you could just keep cramming an endless number of quarks into one Planck volume – adding to its mass and its density without ever increasing its volume.

But others argue that quarks just can't behave like that. For example, it's been proposed that on the way down to collapsing into a singularity the infalling quarks are subject to a repulsive force arising from Heisenberg's uncertainty principle, which works to prevent them from all from occupying the same location at the same time. Indeed it's further suggested this repulsive Heisenberg-ish force is sufficient to make them all rebound outwards, so reducing the density and hence the gravity, so that all that degenerate quark matter will ultimately emerge out of the black hole in the form of a Planck star. But because time runs very, very slowly inside a black hole, this process is still going – so it may take eons more before the contents of the first black holes ever formed in the Universe do finally re-emerge as the first Planck stars that anyone has ever seen – if anyone is still around to see them.

If that all sounds a bit fanciful… well, yes, it does. But this is what black hole physics is all about. In the absence of any real data there's room to make all sorts of hypothetical postulates about what's going on inside and you just leave it to others to try and prove you wrong. So, what's really in a black hole? Don't know.

Question 2:

Dear Cheap Astronomy – Can you really have planets around a black hole?

This is yet another reference to the movie Interstellar, which was built around the premise of a black hole called Gargantua having three orbiting planets. This is an entirely theoretical scenario, as we've never observed a black hole with orbiting planets, but it is plausible. After all, a black hole is a significant, dense, gravity-generating mass – particularly in Gargantua's case, since it is clearly a supermassive black hole, even if that's not specifically stated in the script.

Of course, to have planets you need some tightly-constrained Goldilocks conditions. The planets could have been wandering rogues that got caught in the black hole's gravity field, or they might have accreted within the black hole's accretion disk. But, either way they'd have to at just the right distance and with just the right orbital trajectory to retain an orbit that doesn't decay. And since black holes can grow in mass-density as they consume more mass, that tenuous balance is always at risk. Secondly, to have planets that have liquid water and in one case just the right atmospheric temperature, pressure and composition that you can whip your helmet off requires some extremely tight Goldilocks conditions. The black hole's accretion disk is the heat source. It is entirely possible that an accretion disk could generate just the right amount of heat in just the right radiation spectrum but the long-term stability of that narrow-range output is doubtful. If the black hole isn't being constantly fed with new material, its radiative output will decline and if it is being fed with new material there's always a risk that its radiative output could increase unpredictably and perhaps dramatically.

So, if we do find an Earth-like planet in orbit around a supermassive black hole, it would confirm our assumption that nearly anything is possible in this vast Universe – but at the same time we'd be unlikely to decide that it's an ideal place to colonise.

Anyhow, back to Gargantua and its three planets. The first is called Miller's planet is an ocean world which has a tidal bulge of water that appears to whip around the planet – although really the bulge is fixed and it's the planet that is moving underneath it. But with a bulge that big, with that much water mass – it's likely the planet's rotation would be effected, slowing it down until the planet becomes tidally locked. Also, with that much gravitational stretch, not just the ocean, but the planet's crust would be stretched and would likely go molten, evaporating all the water and turning the world into something like Io – the pizzafaced moon of Jupiter. Kip Thorne, who provided the technical advice for the movie, proposed in his companion book that the planet really is tidally locked and just oscillates back and forth during its orbit around the black hole, so giving the tidal bulge a wave-like motion, but not all the way around the planet.

The second planet, Mann's planet, just turns out to have weird frozen clouds, so not much help there – and Dr Mann appears briefly as a psychopathic nutcase with a PhD who nearly destroys the mission – once again showing that anyone with a PhD is just plain trouble. But then Edmund's planet turns out to be that cringeworthy stalwart of all science fiction plots – an alien world where astronauts can just whip their helmets off because what could possibly go wrong.

Anne Hathway (playing Brand) whips her helmet off to enact Plan B which involves frozen embryos transported from Earth. Plan A was apparently a Golgafricham solution, letting everyone on the dying Earth believe the mission was going to discover a new space travel technology that would rescue everyone. But despite most of the cast endlessly bursting into tears, Plan A does eventually work out because of all that weird $%#& with the bookshelves. Here at Cheap Astronomy it's only from reading the background fan pages that we've been able to piece together what was actually going on. All the physics in the movie was relatively straight forward (small astronomy joke there), but the plot… not so much – although the robots were good.