

Question 1:

Dear Cheap Astronomy – Can we clear all the PHOs from around Earth

A key feature of Cheap Astronomy's CSOTM proposal is that the most readily available source of resources to crash are near Earth asteroids and a small number of comets. This has the double benefit of putting all the raw materials in one place, plus you are clearing out potentially hazardous objects that could collide with Earth at some time in the future. Around 19 potentially hazardous objects carry some risk of impacting Earth in the next 100 years and all are well under 1 kilometer in diameter so seem good candidates to crash on the Moon, insofar as they should be relatively easy to move and will properly crash rather than fragmenting into rebounding shrapnel or creating orbiting dust clouds – and if you do somehow bollocks things up and send them towards Earth they aren't going to become mass extinction objects. One good example is the infamous Apophis, which was a worry when first discovered but these days it's no longer considered likely to impact the Earth any time in the next 100 years and is only 40 m in diameter anyway. If we're looking for a poster rock for CSOTM, it's Apophis.

The second in line is Bennu, which also has pretty much no chance of hitting Earth in the next 100 years. It is more of a worry though, being bigger at about half a kilometre in diameter. So we'd need to be well advanced in CSOTM procedures before taking on something this substantial. If it's not ringing any bells, Bennu was visited by OSIRIS-Rex in 2018 and it collected a sample in 2020 which was returned to Earth in 2023. The spacecraft is now renamed OSIRIS-Apex and will visit Apophis in 2029. It no longer has a sample collection and return device anymore but the plan is to have a good look around Apophis and probably blast its surface with retrofire so we get a peek at its subsurface composition.

We know from seeing Bennu up close and collecting a sample, that it's like a carbonaceous rubble pile asteroid, meaning it's more like dry clay than rock or metal and it's a large collection of small loosely bound particles rather than one solid object. This is likely to be a common finding amongst near-Earth objects, though we won't really know until we get a closer look at each one and we should expect we'll find a bit of variety out there. Nonetheless, there's limited value in collecting samples if we're just going to crash them on the Moon anyway, so we'd probably just have robot scouts with cameras to take a few snaps before attaching a rocket engine and sending them plunging to their doom on the Moon's surface.

We assume most asteroids are clay, rock or metal – or some combination of these three based on general observations of all asteroids, either in space or crashed on Earth – where some, or bits of some, do survive the impact on the surface as they have been slowed down by the atmosphere. However, some near Earth and potentially hazardous objects are comets, which are mostly water and or carbon dioxide ice, though perhaps with a rocky core. If we crash these comets on the Moon, some of the water ice might be heated sufficiently by the impact to dissociate into hydrogen and oxygen and some of it would just vaporize and then fall back to the surface as widely dispersed fine particles of ice or otherwise be blown into space by solar wind particles. So if you crash water ice it will be mostly irretrievable. This might be less the case with carbon dioxide ice, but there's not much economic value in that. So, perhaps then comets

steered into lunar orbit to harvest the water if that made economic sense - which would mean mostly dismantling the object and eliminating its risk to Earth anyway.

Again it's all about economics. Mining potentially hazardous near-Earth objects in their solar orbits sounds slow and fiddly and doesn't deal with the fundamental problem of them being ticking time bombs. Crashing them on the Moon at least takes them out of the picture and leaves all their raw material on the surface, some of which could be potentially mine-able – and no longer hazardous.

Question 2:

Dear Cheap Astronomy – Can we really deflect asteroids with rocket engines?

This is a follow up episode to our recent one about crashing near-Earth objects on the Moon. A listener wrote to critique a throw-away line we made about attaching a rocket engine to an asteroid, particularly if it was a rubble pile asteroid. They were too polite to say it's a dumb-idea, but yeah, it is probably a dumb-idea, well sort-of maybe.

The age of asteroid deflection is really with us now after the success of NASA missions like DART and Deep Impact. China is planning to launch an, as yet unnamed, asteroid deflection mission and there are a lot of good ideas out there about how to either deflect or fragment an asteroid on a seeming collision course with Earth – and none of them involve attaching rocket engines.

Here's a fun fact for you. Since the Earth orbital speed around the Sun is 30 metres a second and it's nearly 13,000 kilometres in diameter, it takes about seven minutes for it to move one planetary diameter. So, if an object is on a collision course with Earth, all you have to do is either delay or advance its arrival by up to seven minutes and it will miss. It's also the case that the earlier you shift its trajectory the less you have to shift it by.

One suggested strategy which does need a large amount of lead time is to paint part of an asteroid which will change its surface radiation absorption properties. Normally a sun-heated asteroid radiates that heat away, hence giving it a small push, which is known as the Yarkovsky effect. Painting some or all of the asteroid with a high-reflective paint stops that long-term effect and also gains as more immediate effect by acting like a solar sail. All you can really guarantee here is that there will be some change in the asteroid's trajectory – which direction it moves in is largely unpredictable, particularly if the asteroid is spinning. Also, you have to initiate this while the asteroid is so far away that there's probably still some uncertainty about it being on a direct collision with Earth anyway – and so, painting is largely useless as a method of directing the asteroid to a particular target like crashing on the Moon, for example.

A more accurate method is a gravity tug, essentially a moderate-sized spacecraft, which flies close to the asteroid so its mass generates enough gravity to pull the asteroid off its previous trajectory. This method can also be used to steer the asteroid onto a definitive alternate course and that course can continue being modified further, either by the same tug or by successive

rendezvouses with different tugs. However, like painting, this is a way of very slightly modifying an asteroid's trajectory so you have to start with a lot of lead time, particularly for larger asteroids.

If you don't have so much lead time, there's the kinetic impact method – where you crash something into the asteroid, imparting a kinetic energy, which is derived from both its mass and the velocity at which it hits the asteroid. This was demonstrably successful with the DART mission in 2022. With this method, you can be confident of achieving a change in the asteroid's trajectory, but it's not ideal for steering the asteroid onto a particular trajectory, since the effect of each impact will be a bit unpredictable. So, if you do want a fast and accurate trajectory-altering method this is where a rocket engine or engines come in. It's the least energy efficient and hence the most costly of the options mentioned so far. Part of the problem is that you'll need fuel and propellant, so the rocket engine not only has to shift the asteroid's mass, but also its own mass plus a sizeable fuel tank. But that then leads to perhaps the best of all options, a mass driver, which is some kind of electromagnetic slingshot device that you load up with bits of the asteroid and then firing them off into space, hence gaining a push in the opposite direction. So, no propellant needed. This is most useful for rubble pile asteroids where large chunks of rock are readily available to shoot into space. So, you land the catapult, which might be sufficiently powered by solar power and a bank of rechargeable batteries and use an attached robotic arm to grab and load nearby chunks of rock. Piece of cake.