How Green is the Universe?

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IT is not often that astronomers get sucked into bio-politics. But the 1980s saw the start of a bitter feud that still rumbles around today — at least among some of America's conspiracy theorists. At its heart was a diminutive hero, a 200-g Mount Graham Red Squirrel *Tamiasciurus hudsonicus grahamensis* unique to the tree-covered Pinaleño Mountains, a small isolated mountain range in southern Arizona, of which Mt Graham is the highest peak. Thought to be extinct in the 1950s, this little survivor reappeared in small numbers on the 3 200 m mountain during the 1970s, and, in 1987, with a population of a couple of hundred, it was formally listed as endangered (U.S. Fish and Wildlife Service 1992; 2011).

Just a year later, the US Congress authorized the construction of a major international observatory at Mt Graham. The University of Arizona, based in Tucson and home to one of the world's foremost astronomy research groups, had outlined an ambitious programme of telescope-building. It would culminate in the Large Binocular Telescope, one of the world's biggest optical (visible-light) telescopes, and the prototype for an even larger project in the southern hemisphere.

It was not long before conservationists and astronomers found themselves at loggerheads over the future of the mountain. This was a situation of considerable discomfort to the world's astronomers, who like to see themselves as friends of the environment. Observational astronomy's endeavours are underpinned by an awareness of environmental issues. Its scientists cherish wilderness areas as vantage points for exploring the infinitely greater wilderness beyond. Moreover, they are more inclined than most to regard the Earth as a very special place in the Cosmos. They recognize that our planet's delicate balance of geophysical and atmospheric processes nurtures an environment that is as fragile as it is unique.

Had the dispute centred only on the well-being of the Mt Graham squirrel, it would probably have been resolved fairly quickly. The Arizona astronomers were anxious that the telescope buildings — and their subsequent usage — should have the least possible impact on the squirrels' habitat, and planned accordingly. Unfortunately, though, the environmental debate soon became entangled with another, equally sensitive issue. That was to do with the traditional ownership of the land. Mt Graham, like all other peaks in the region, is a sacred site for the Apache people and for Pueblo people who have prehistoric (Mogollon) shrines on the mountain predating the Apaches' arrival. Indeed both groups had been consulted in early observatory planning. While the mountain itself is hardly pristine, with holiday homes, visitor areas and educational camps occupying its flanks, the summit has remained unpopulated — though with substantial clear-cut logging. It was claimed that even minimal development of the mountain-top for astronomy would desecrate it, violating the rights of the San Carlos Apaches to practise their religion and traditions (Dougherty 1995).

Once again, it seems likely that compromise could have been quickly reached, had it not been for the attentions of an inflammatory press inciting a population that was, perhaps, genuinely fed up with having its access to local beauty spots restricted by scientific activities.

"Star Whores — Astronomers vs. Apaches on Mount Graham," raged one headline. Another commentator took a more sanguine view, asserting that "Arizona is the home of the OK Quarrel", where feuding is just a way of life. "Them's fightin' words", he said, quoting with evident satisfaction the "star whores" comment, and an astronomer's rejoinder that "people and squirrels live together fine" (Walker 1993).

Eventually, amidst unsurprising accusations of coercion and foul play on the part of the University of Arizona, the Mt Graham International Observatory was given the green light by an Act of the US Congress, and construction went ahead. An acceptable compromise was reached with the Apache Tribal Council, and an independent census of the squirrel population was commissioned. Surprisingly, it revealed a notable spike in occupied midden numbers during the early construction phase of the Large Binocular Telescope, from 1998 to 2001 (Arizona Game and Fish Department 2009). Since then, however, numbers have reverted to levels comparable with before, and are currently around 250 individuals.

Biologists now believe that it is a combination of natural circumstances that dictates the squirrel population (rainfall, cone crop, insect numbers, and the occurrence of major forest fires, such as a particularly disastrous one in 2004), rather than human activity. However with global warming, and the expected change in the tree population, as well as competition from introduced Abert's Squirrel *Sciurus aberti*, the long range prediction for the Red Squirrel remains bleak. The Large Binocular Telescope, at least partially absolved, was eventually dedicated in 2004, and fully operational by 2008.

Space catastrophe

The case of the Mt Graham squirrels is a rare example of astronomy openly falling foul of conservationists. But it does hint at a willingness on the part of astronomers to sup-

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press environmental considerations in order to pursue their scientific goals. And, for their cousins in the space industry — and, in turn, the governments that want a space industry — that willingness seems to know no limits. Here, there are real instances of environmental vandalism.

The plight of farmers in the Altai Republic is a case in point. These unfortunate people live downrange of Kazakhstan's Baikonur Cosmodrome, where Russian spacecraft are launched. They are variously bombarded with spent first-stage rockets, debris from aborted launches, and unburnt toxic fuel.

Why Baikonur? Considerations of safety suggest that a space launch facility should have unpopulated country to the east (the prevailing launch direction for orbital flight), so that debris falling back to Earth will do minimal damage. At Cape Canaveral, that role is filled tolerably well by the Atlantic Ocean. Geography is not always helpful, however, and the old Soviet Union had to make do with less than ideal circumstances. In fact, the choice of Baikonur was almost accidental. Back in the 1950s, when the Cold War was in its infancy, the isolated town of Tyuratam in Khazakstan was selected as the principal test site for inter-continental ballistic missiles, because it was surrounded by huge tracts of boggy, unpopulated territory in which radio guidance towers could be built. Later renamed Baikonur, this became the USSR's (and subsequently Russia's) major space launch facility.

But there is another legacy of the Cold War era in the shape of the Proton Rocket, which quickly became the Soviet Union's workhorse medium-lift launch vehicle, and is still central to the Russian space programme. Proton is fuelled with nitrogen tetroxide and UDMH (unsymmetrical dimethyl hydrazine), highly dangerous fluids that are both toxic and corrosive. And, in the matter of unpopulated territory to the east, Baikonur is now sadly lacking. A few hundred kilometres downrange of the space centre is the Altai region of Siberia, whose farmers effectively live on the front line.

Imagine a rural landscape in which, several times a month, blazing pieces of space debris rain down, spewing excess toxic fuel. Through a classic piece of Soviet-era policy-making, occupants of an officially-designated drop zone are given 24-hours notice of possible impacts, but should damage or injury result, they are not entitled to any compensation. That is reserved for folk living outside the zone.

The result of this has been increasing protest within the affected region of the Kazakh steppe. Locals complain not only of animal deaths through contact with toxic propellants, but also of serious illness among the human population. They say that the efforts of authorities to clean up the landscape by removing contaminated debris has declined since the collapse of the Soviet Union. There is a flip-side, however, in the burgeoning trade in scrap metal from rocket bodies, fuel tanks and external boosters. Altai is probably the only place in the world where farmers work the land with traditional implements fashioned from space-grade titanium alloy.

There are other environmentally-hazardous consequences of the space age that are probably better known than the plight of the Altai famers. A couple of dozen or so spacecraft have been launched with plutonium-based thermoelectric generators supplying their on-board power, most recently NASA's *New Horizons* mission to the dwarf planet Pluto in January 2006. With a history that includes several failed launches, radioisotope-powered spacecraft remain an extremely controversial issue.

More familiar still is the accumulation of orbiting debris in the Earth's environment. This material ranges from flecks of paint (which famously chipped the Space Shuttle's windows, due to their high relative velocity) to complete upper-stage rockets that remain in space after their payloads have been nudged into their operational orbits. There are currently around 800 active satellites in orbit, but a vastly greater number of defunct components remain in space. US authorities (notably the North American Aerospace Defense Command) currently track some 22 000 pieces of debris with dimensions above 10 cm, but uncatalogued pieces smaller than this are numbered in millions.

There is no doubt that these objects pose a significant threat to the utilization of space. Spacecraft of every kind, including crewed vehicles, are under threat from them. While, in many cases, their orbits will decay (resulting in atmospheric re-entry and harmless burn-up), the timescale for this can be tens, hundreds, or even thousands of years. Collisions involving spacecraft have already occurred. In February 2009, for example, a US communications satellite, Iridium 33, and a deactivated Russian satellite, Cosmos 2251, collided over the Earth's north pole, producing large plumes of debris following the original orbits of the two spacecraft.

Who is responsible for this pollution? The Outer Space Treaty of 1967 is clear that objects in space remain the property of their original owners, but the mechanism for claims against any damage caused by these objects is far from straightforward. With today's exploitation of space extending not only to the commercial sector, but also into tourism, there is a growing body of opinion that the Treaty no longer matches reality, and is overdue for review.

It is only within the last few years that any serious thought has been given to the means by which space pollution might be alleviated. One promising suggestion is to equip all new space vehicles with an inflatable helium balloon a few tens of metres in diameter, which can be deployed once the craft has finished its useful life. The additional drag imposed on the satellite by the residual atmosphere at orbital height would be enough to reduce typical orbital decay times from decades or centuries to months.

This does not solve the existing problem of course. While a recent initiative from the Russian Space Agency might eventually result in a clean-up of defunct communications satellites in geostationary orbit (at their height of 36 000 km), there is no obvious solution to the problem of low-orbit space junk. The best we can hope for seems to be for time to take its toll by natural orbit decay.

Light (and darkness) on the horizon

So. There you have it. The decision to have space programmes was made independently of whether scientists would use them. Astronomers and space scientists merely took advantage of the opportunity. So who is to blame for the resulting mess? Astronomers, space scientists, governments — or the electorate?

There is another side to this coin, though. If one looks at the broader outcomes, there are some remarkably positive aspects. Perhaps surprisingly, then, it is the thesis of this article that, far from being ecological vandals, astronomers and space scientists can be advocates for good environmental management.

In seeking examples of the conservation value of these sciences, one need look no further than the promotion of environmentally-friendly outdoor lighting by optical astronomers. Although astronomers have no wish to dim the streets of the world's cities into depressing twilight zones, they do advocate good lighting design as a means of preventing ground-based astronomy's eventual demise.

Most people agree that the ability of astronomy to address the Big Questions is something worth preserving — even if its more esoteric results are usually relegated to the status of a filler in the evening news bulletin. But everyone is interested in our origins and the origin of our planet, in our ultimate fate, and in the intriguing question of whether there are living organisms beyond Earth.

What is perhaps less well-known is the way in which astronomical research is carried out. Information comes to us from the heavens primarily in the form of electromagnetic radiation. Astronomers use every part of the electromagnetic spectrum to make their observations, but have to rely on space-borne or balloon-borne telescopes for all but visible-light, infrared and radio work. Scientists using these particular wavebands have the luxury of being able to make their observations from the ground. But all ground-based astronomy — including radio astronomy — is susceptible to the detrimental effects of human-made interference.

Probably the highest-profile optical telescope today is the Hubble Space Telescope, launched in 1990 and still providing front-line data to the world's astronomers by virtue of its vantage point above the atmosphere. However, this orbiting telescope is but one tiny part of the optical astronomer's armoury. Its 2.4 m diameter mirror is eclipsed by the 8 m mirrors of today's largest class of ground-based telescopes, and disappears almost out of sight compared with the 25 m to 40 m giants that are around the corner. Ground-based telescopes are alive and well, and today, there are no fewer than 13 new instruments with mirrors larger than 8 m in diameter, sited on remote mountain-tops around the world. But ground-based telescopes do need dark skies.

The one thing that surprises most visitors to an observatory site is not how dark the night sky is, but how much light actually comes from it. When there is no moon in the sky, the absence of light pollution renders the stars dazzling. A closer look, however, reveals that it is not just the stars that are bright. The sky itself is luminous, a phenomenon made more obvious by the presence of clouds, which appear jet black against their background. They contrast strikingly with their counterparts in a brightly-illuminated city sky.

What causes this natural sky-glow? The brightest component is due to auroral emissions in the upper atmosphere at specific wavelengths. In addition, there is a continuous-spectrum background whose sources include illuminated dust in the Solar System, faint stars within our own Milky Way Galaxy and, at the very faintest level, the light of distant galaxies that are indistinguishable from one another.

Any celestial object that an astronomer wishes to investigate is superimposed on this sky background, and usually the background dominates the observation. Often, astronomers are looking for faint objects whose brightness is less than one percent of the natural sky background. Little wonder that any increase in the background glow due to artificial light simply renders these objects invisible. In that respect, there are few natural environments as sensitive to pollution as the night sky.

Pierantonio Cinzano at the University of Padua has mapped the world's light pollution using night-time images from space (to show upward-pointing light sources) combined with the known propagation characteristics of the atmosphere by molecular and aerosol scattering (Cinzano, Falchi & Elvidge 2001). The process is highly refined, taking into account the curvature of the Earth, and shows that two-thirds of the world's population live in light-polluted conditions. More dramatically, about one-fifth of the population can no longer see the Milky Way.

Cinzano's studies also show that light pollution is encroaching on many of the world's major observatory sites. This leads to the conclusion that remoteness is not enough to protect an observatory, and steps have to be taken to reduce the spread of light pollution. The steps can be legislative or educational, but should emphasize the message that light-pollution is bad news for everyone. Not only are sky-watchers and nocturnal animal species directly affected, but the ill effects of obtrusive lighting on human circadian rhythms are now starting to be recognized (e.g., Smolensky 2007). And, of course, the carbon footprint of light shining where it is not needed is of universal concern.

Australia's national observatory at Siding Spring in north-western NSW is protected by the Orana Regional Environmental Plan (REP) No.1 (NSW Government 2008). This covers an area of radius 100 km centred on the 3.9 m Anglo-Australian Telescope, the largest in the country. In the central part of the REP zone, "full cut-off" outdoor fixtures (which permit only downward illumination) are mandatory. Beyond the REP zone, though, there is no overarching legislation to protect the skies of the observatory— even though the night-time glow of the Sydney–Newcastle conurbation (at a distance of about 350 km) can be seen, as predicted by Cinzano's model.

The astronomers of Siding Spring Observatory take a pragmatic view of this problem. They do not necessarily want to see lights switched off — but they do want them better designed. To some degree, at least, the developers, makers and sellers of outdoor lighting fixtures hold the future of Australian optical astronomy in their hands.

The un-greening of Mars

The idea of astronomers becoming activists in the fight against light pollution has no real equivalent in the space world. Of course, there are strident voices within the industry demanding a clean-up of the Earth's environment — it is in their own interests to do so. Likewise, there are outspoken critics both inside and outside Russia of the ongoing use of toxic propellants in launch vehicles like Proton.

Rather, one has to look at the outcomes of space exploration, and here there are some positives for the environment. Pierantonio Cinzano's work using space images of the night-time Earth is but one small example of this. The entire field of terrestrial remote sensing would not exist had it not been for space exploration, and the Earth is much better for it. Land-use surveys, logging surveillance, ocean temperature surveys, ice-cap melt rates — the list is almost endless, and is growing daily. We live in an age in which we know our planet better than at any other time, and we all benefit from it.

It is worth looking further afield, however, to seek other evidence of space science's contribution to the Earth's well-being. One of our nearest neighbours, Mars, is helping us to understand our own planet's behaviour. Mars is a world about half the size of Earth, and about 50 per cent further from the Sun than we are. Of all the Solar System's planets and moons, it is the world most similar to our own, having a rocky surface and predominantly clear skies in a dust-dry atmosphere that has about one per cent of the pressure of ours. Being further from the Sun, Mars' surface temperature is lower than Earth's, and, near the equator, ranges between about -78°C and -8°C — always below freezing point. By coincidence, its orbital tilt is similar to Earth's, and its day only a little different, at 24h 40m.

The exploration of Mars using robotic spacecraft has reached epic proportions since the first Viking landers successfully touched down on the planet's surface in 1976. At present, there are three active satellites orbiting Mars (Mars Odyssey, Mars Express and Mars Reconnaissance Orbiter) and two venerable NASA rovers on the surface (Spirit — which has been immobile and silent since March 2010 — and Opportunity). A third rover, Curiosity, will be launched to the planet this year.

Though its surface is dry and dusty, Mars is now known to have considerable deposits of water ice on and beneath its surface. Extensive polar ice-caps have been known since the first telescopic studies, but orbital imaging has revealed ice-patches around several craters, an ice lake in Mars' northern plains, and what looks like dust-covered pack-ice covering an area the size of the North Sea close to the equator. When NASA's Phoenix Lander sampled the northern arctic in the Martian summer of 2008, it found an extensive layer of ice a few centimetres below the surface. The spacecraft also detected the presence of a natural antifreeze in the form of mineral salts capable of lowering the freezing point of water by as much as 70°C — enough to allow the possibility of pockets of liquid water.

Meanwhile, the geology of Mars has provided increasing evidence of an ancient ocean once having occupied much of its northern hemisphere. Both the mineral composition of the surface and its geomorphology point to the former existence of large bodies of water, with well defined coastlines, estuaries, beaches and sea-cliffs. The putative ocean is thought to have existed some 3.8 billion years ago, when the planet was only 800 million years old. But it would have required a thicker atmosphere than today's to allow greenhouse processes to sustain a similar mean temperature to that of the modern Earth.

Whether this atmosphere was primordial, or resulted from later asteroid impacts, is still in doubt. Either way, something happened to change things. A clue comes from Mars' almost complete lack of magnetic field, suggesting the absence of a liquid iron core. The interior of the planet is much cooler than Earth's, and unable to sustain plate tectonics (although there is evidence of past activity, including the Solar System's tallest volcano). That, in turn, suggests that a regulated cycle like the Earth's, in which atmospheric and planetary carbon is exchanged via the oceans and mantle, might have shut down early in the planet's history. Its greenhouse thermostat would have ceased to exist and Mars' blanket of atmospheric carbon dioxide would have dissipated, allowing the surface temperature to fall to its present frigid levels. Some of the ocean's water would have evaporated into space, having dissociated into its component atoms, while the rest would have been frozen into the ice deposits we see today.

And the real culprit is not the planet's greater distance from the Sun compared with Earth's, but its smaller size. It seems that Mars was simply too small to sustain the tectonic processes that regulate our own atmosphere. Our understanding of the Earth's large-scale mechanisms is significantly enhanced by our ability to study an additional, and quite different, example of planetary geophysics in the shape of our diminutive neighbour.

The view from above

There is one further aspect of spaceflight that is worth mentioning in the context of raising environmental awareness. Unlikely as it might seem, the fledgling space tourism industry may have something to offer in improving our planet's well-being.

At present, we are on the brink of a revolution in humankind's access to space. The 450 or so individuals who, to date, have experienced spaceflight first-hand have done so almost entirely under the auspices of government-sponsored exploration. The few exceptions are a handful of unbelievably wealthy folk, who have taken advantage of unoccupied seats on Soyuz supply missions to the International Space Station in a $150-million commercial deal brokered with the Russian Space Agency.

But a few visionary entrepreneurs want to change that, and bring the experience of space to a much wider clientele. The idea is to provide a suborbital flight, which will carry passengers to the edge of space where they can see the curvature of the Earth and experience the phenomenon of weightlessness. They will look down on the atmosphere from the blackness of space.

The flights will be made in rocket planes carrying half a dozen or so passengers at a time, with a simple ascent-descent flight profile. Typically, a 90-second rocket burn will result in a maximum speed of some 1.5 km/sec. This is well below the threshold for orbital flight (7.8 km/sec), but is sufficient to hurl the craft up to a height of 100 km after the motor has shut down, allowing three or four minutes of weightless free-fall before braking commences.

Leading the charge is Richard Branson's Virgin Galactic, whose *Enterprise* rocket plane is the first of five planned vehicles in Virgin's space fleet. It will commence each flight slung under the wing of an unconventional jet aircraft — the "mother ship". Taking off from Virgin's "Spaceport America" at Upham, New Mexico, the *Enterprise* will be ferried to a height of 15 km before being released and pitched upwards to make its dramatic powered ascent. Having reached apogee, the rocket plane will then fall back to Earth, turning into a glider to land in much the same manner as a Space Shuttle. The *Enterprise* has already been test flown in its glide mode, and will undertake its first rocket-powered tests later this year. Flights with fare-paying passengers — of whom there are already several hundred on the waiting list — are expected to begin in 2012.

Despite the fact that the fare is some US$200,000, Virgin Galactic is confident of its market for such flights, and expects the price to fall as the project progresses. Safety is paramount — nothing would damage the infant venture more than the loss of a rocket plane and its passengers. On the other hand, over-regulation could stifle progress in this next step in tourism, so legislators face a delicate balance in exercising control — one not seen, perhaps, since the early days of aviation.

Before you raise your hands in horror at the thought of well-heeled joy-riders hooning into space — and to hell with the atmosphere — there are a couple of additional points to consider. First, despite the relative toxicity of the *Enterprise's* hybrid propellant mix, its total carbon footprint per passenger per flight is less than half that of a one-way transatlantic flight. And, initially, at least, space-rides will be small in number. By the time space tourism becomes big enough to rate as a significant atmospheric polluter, the technology is likely to have improved considerably in its green credentials.

Perhaps even more significant, though, is the sentiment that will be evoked among tomorrow's space tourists. We have all felt something of it ourselves in viewing images of the Earth from space, whether it be the famous Apollo 8 "Earthrise" image of 1968, or recent snapshots from the newly-installed Cupola — the "bay-window" of the International Space Station. We cannot help but marvel at the fragility of the environment that sustains the biosphere. That thin blue membrane of air visible from space — a vanishingly small envelope around what is itself only a modestly-sized planet — is compelling in its message of the frailty of our surroundings.

Seen at first hand from space, this can only underline the true nature of the vulnerable world in which we live. Indeed, many astronauts have commented that they have gained a profound regard for the environment after their experience of spaceflight. The fact that for the first few years at least, space tourism will be the province of the rich and influential gives this author some hope that the message will finally get through.

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Biography

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