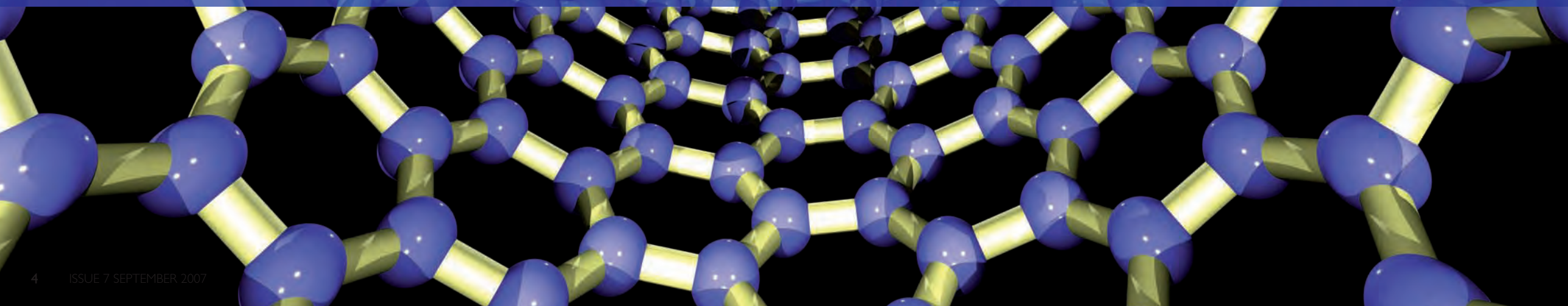


Seeing the Future

Chris Ewels argues that an unlikely alliance of microscopists and theorists may hold the key to public acceptance, or otherwise, of nanotechnology.

The back catalogue of the Royal Microscopical Society infocus magazine is a treasure trove of the very best examples of scientific imagery. When I first started flicking through them it was like looking through a window into a new world; a breathtaking, awe inspiring mixture of strange, beautiful and captivating images that microscopy can provide. As a computational physicist by trade, being asked to write for infocus is quite an honour, an exciting invitation with an 'access all areas' tourist visa into the secret world of the microscopists. It feels as if I've somehow sneaked myself onto the guest list of a party to which I shouldn't really be invited.



The theoretical images we were generating of defects in graphite and nanotubes five years ago are now being mirrored by genuine atomic resolution HRTEM images.

Microscopy is the very essence of science at its most visual. Microscopists are the visual documentalists of the microscopic (and now nanoscopic) world that we condensed matter physicists and chemists inhabit. Their images touch us in a way that words rarely can, and for me incite a twinge of jealousy - microscopists have the chance to do great science, and look good while doing it.

It is teaching my grandmother to suck eggs to talk of the revolution that microscopy has undergone in recent decades. Nonetheless, the images that have appeared over the last two years in Nature and other journals showing details of carbon nanostructures at atomic resolution are nothing short of jaw dropping. At the same time, computer modelling has come on in leaps and bounds, and we can now quantitatively model atomic systems containing hundreds to thousands of atoms routinely (calculations which during my PhD took three weeks on supercomputers at Exeter I can now repeat on my desktop PC in around 15 minutes, a somewhat depressing thought!). As a result it seems to me that we are living through a unique moment in science, as the two fields converge. The theoretical images we were generating of defects in graphite and nanotubes five years ago are now being mirrored by genuine atomic resolution HRTEM images. Gone are the days when theorists could speculate freely about atomic structure; the microscopists are bringing us to book.

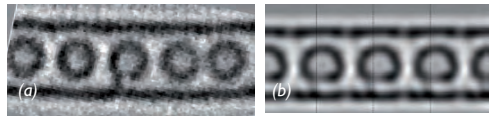


Fig. 1. Convergence of microscopy and theoretical modelling. The HRTEM image (Fig 1a) shows a carbon "peapod"; C_{60} fullerene molecules within a carbon nanotube, with one fullerene damaged by the electron irradiation in the microscope. Fig 1b is generated from a quantum chemical calculation of a similar system. (Microscopy image © A. Gloter (CNRS) and K. Suenaga (AIST), reproduced with kind permission).

Theoretical modelling has also undergone a quiet revolution with improvements in graphics and image simulation software, taking the step from a discipline associated primarily with reams of computer generated numbers into a genuinely visual science. Freely available raytracing software[1] means it is now easy to produce photorealistic "ball and stick" structures, and microscopy image simulations barely distinguishable from their experimental counterparts. Thus while scientific imagary used to be primarily the domain of the microscopists, it is now territory that you're sharing with the theoretical modelling community.

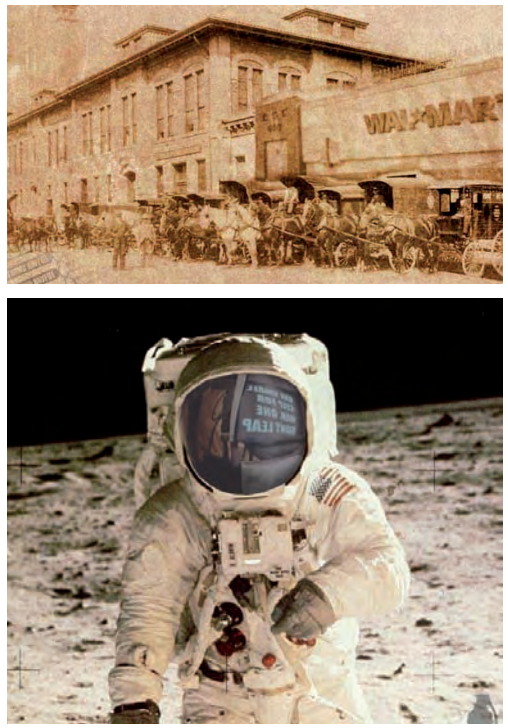


Fig. 2. The power of the dark side – Photoshop has been exploited brilliantly on the Web to subvert and modify classic images (images © www.somethingawful.com).

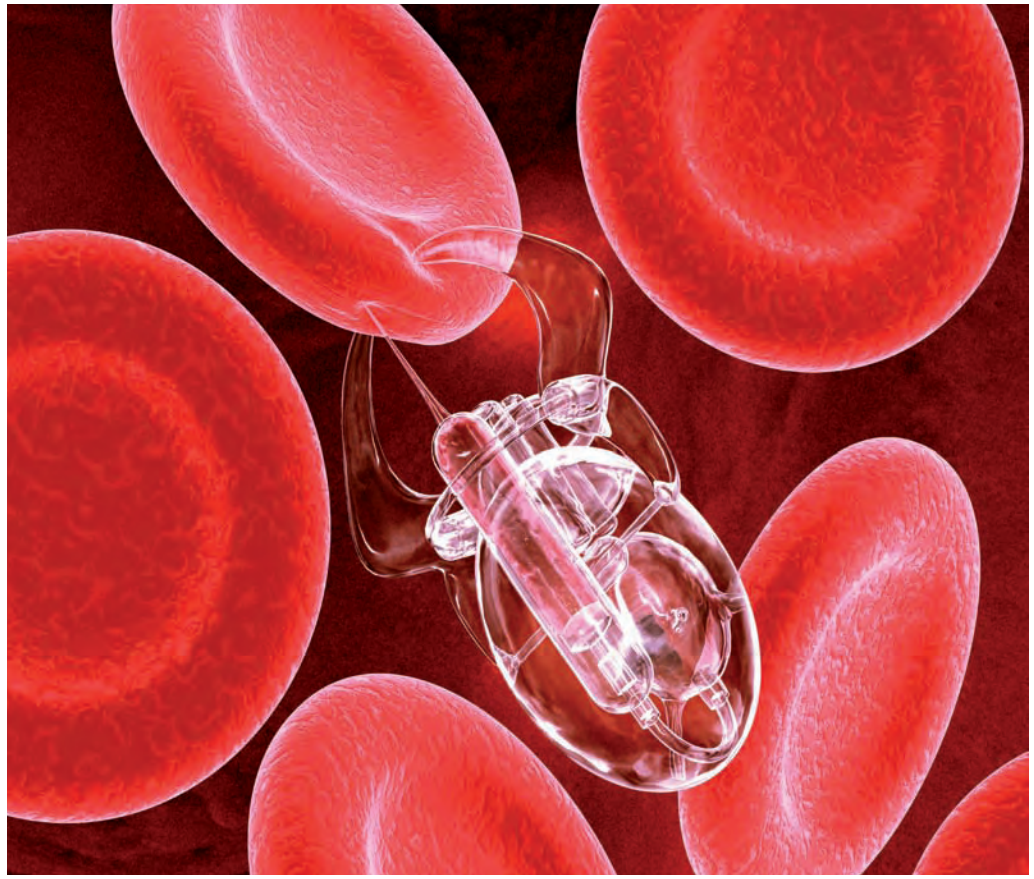


Fig. 3a. Nanoinjector with Red Cells; we can spot the science fiction, but can the public? © 2002 Coneyl Jay. All rights reserved[1].

Much of the value of microscopy images is rooted in their accurate portrayal of the 'truth'. In the quest for a great, iconic scientific image, it's essential to resist the call of the 'dark side': the seductive temptation to 'Photoshop'. Photoshop and its equivalents allow easy and undetectable manipulation of the hard facts of an image, something that has been brilliantly exploited on the Web to subvert political and scientific events (Figure 2 shows a couple of my favourites). Part of me is morbidly curious to see if and when fake photoshopped microscopy images will be first uncovered in a scientific publication. It is always disappointing to read in the small print beneath an image that it's actually a montage – a manipulated image serves to chip away at the integrity of microscopy. The related problem for the theoretical modelling community is the urge to play with our images, something that I've also been guilty of (see the floating fullerene). It is critical to mark what is a genuine representation of the science, and what is us having some purely speculative fun.

Images typically provide the first crucial introductions to a new subject, and are instrumental in shaping people's perceptions of that subject thereafter. It is for this reason that microscopists and theorists have such a key role to play as nanotechnology takes its first tentative steps onto the public stage.

A good image tells more than its own story – it becomes iconic. Already we have several such iconic images in nanotechnology, and it is useful to look briefly at four of these (Figure 3) which have become visual standard bearers for the field.

No doubt you have seen most or all of these at some time or another; on websites, accompanying articles, or during powerpoint presentations. As scientists we can draw clear distinctions between

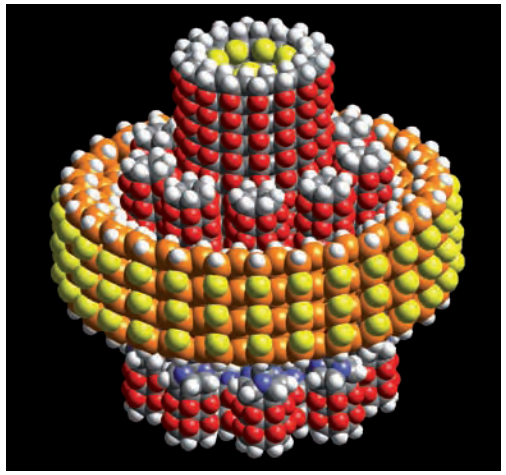


Fig. 3b. Planetary Gear, K Eric Drexler, www.imm.org. Designs for molecular machine parts, produced by K. Eric Drexler, or by K. Eric Drexler and Ralph C. Merkle, that appear on the Web sites of the Foresight Institute and the Institute for Molecular Manufacturing (IMM) are copyrighted by IMM.

them. While undeniably excellent images, Figures 3a and 3b are fanciful science fiction simulations, bearing little if any relation to what nanoscience is, or is capable of. On the other hand Figures 3c and 3d are elegant aesthetic examples of the very essence of nanoscience (and as a bonus, one image from microscopists, one from theorists!). However I doubt this is a distinction many members of the public without some training would be able to draw. While the careless use of fictional images to illustrate nanotechnology in the public arena may seem unimportant, too many "nanobots" or "nano-construction factories" can lead to unrealistic expectations, create unnecessary panic and confusion, and cloud important issues which the public has every right and responsibility to engage with.

The question is then, what determines which images get to become the icons of a new field of science? While it would be nice to say that the quality, design and impact of the images is the sole factor, my suspicion is that it is much more to do with availability. The traditional route to obtain images for journalists, newspaper editors and television broadcasters was to search through catalogues of stock images from image banks. But as in all walks of life, this traditional distribution route is under attack from the Internet. Firstly, this is because the public's sources of information have vastly diversified in the Internet age; whereas books or the TV were a common first point of contact for a new subject, now it is as likely to be Wikipedia or the first few web pages that come up from a Google search. In addition, traditional communicators are increasingly discarding their stock library images and turning to the Internet for rapidly available, cheap images, to illustrate articles on breaking science and technology, particularly for fields such as nanotechnology, where there may not be many stock images yet available.

I have some personal experience of this, which started with some computer generated images I produced in early 2001 while working at Sussex

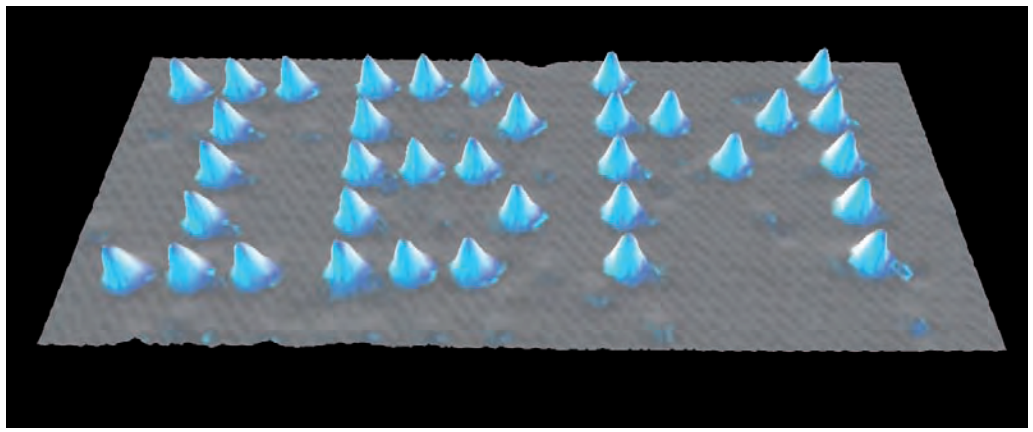


Fig. 3c. IBM spelled out with Xenon atoms on a Nickel (110) surface, imaged by STM[2].

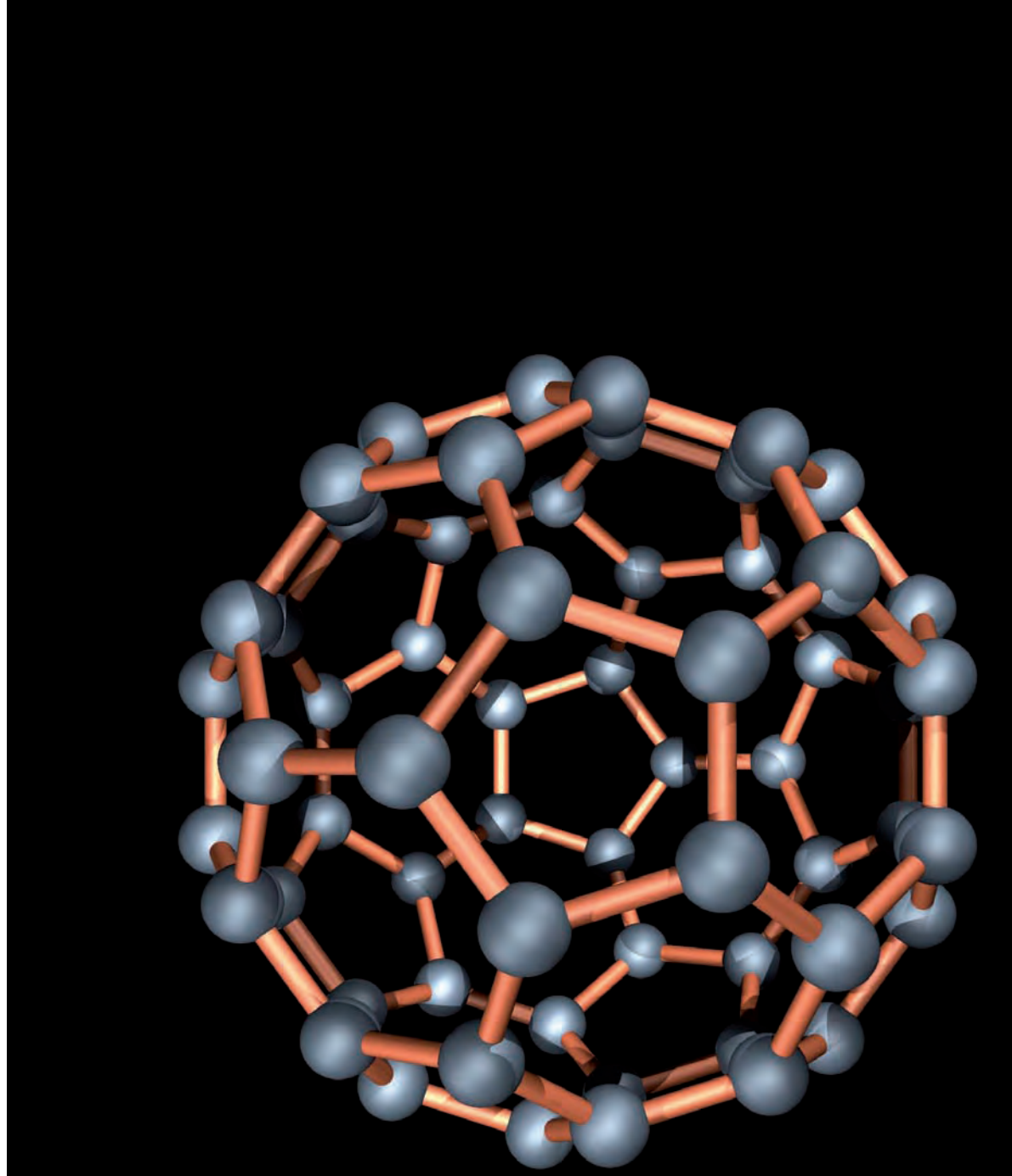


Fig. 3d. C_{60} buckminsterfullerene.

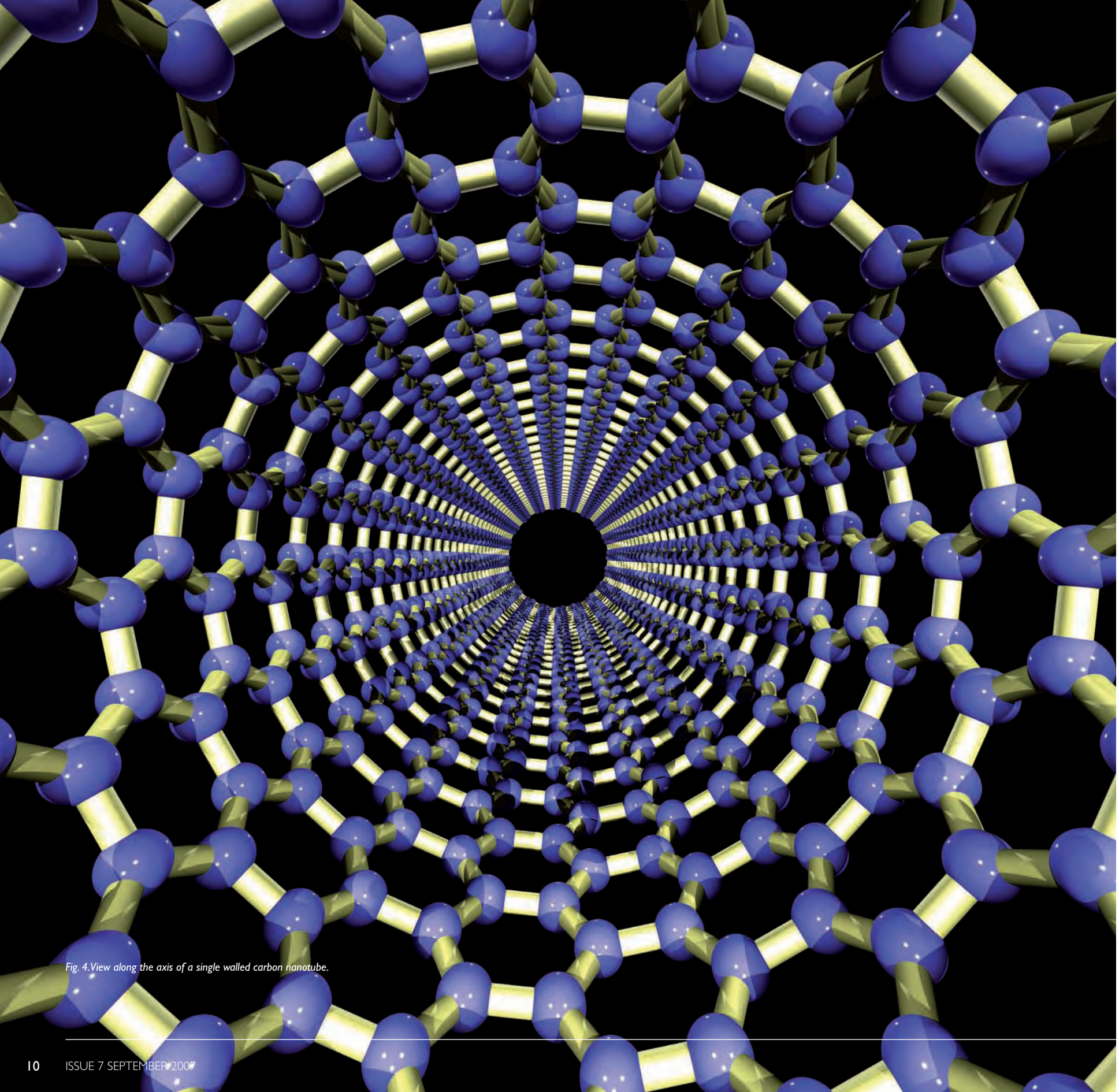


Fig. 4. View along the axis of a single walled carbon nanotube.

University as a postdoc with Professor Heggie. On a whim I decided to put the pictures on my personal website, called them a "nanotechnology image gallery", and have gradually been adding pictures to the collection ever since[3]. For most of its life the site has received a fairly consistent 100-150 visitors a day, and to my surprise it has generated quite a lot of attention. Over the years I have been contacted regularly about the images, and the nature of the emails paints a short history of the childhood, adolescence and burgeoning maturity of the field of carbon nanoscience.

In 2002 the emails I was receiving were primarily from high tech magazines and the like, wanting images to match "visions of the future" type stories, as well as some of the first popular science books on nanotechnology. In 2003, more 'nano fairs' and technology meetings wanted the images, as well as the first legal firms looking to set up nanotechnology branches of their businesses. Just as people were beginning to wake up to the possible commercial benefits of "nano", so they were to the risks; at the same time I was contacted by "The Ecologist" who used an image for their cover story on the ecological disaster brewing on the horizon that was nanotechnology.

By the end of 2003 the magazine base contacting me was also broadening, since nano- was starting to hit the mainstream and other specialisms were reporting on how nano- may affect their industry sector. The RIBA architectural journal, property management journals, RFID specialists and later trade industry magazines for the food sector and the like started requesting image use. Meanwhile as "nano-" started becoming "technologically hip" the larger firms were keen to be seen at the cutting edge, and for example, Hewlett Packard used some of my images in their "HP+" TV campaign in a short-lived nanotechnology ad. At the same time the first signs of the emerging nanotechnology business sector, with firms wanting images for magazine adverts; although this was primarily selling nanotubes rather than nanotube based end products.

Fig. 5. Born in Stardust. C_{60}, the carbon molecule which arguably started the whole nanoscience revolution in the eighties, was originally discovered by accident - by a group of scientists trying to understand the formation and behaviour of carbon molecules in interstellar gas clouds.

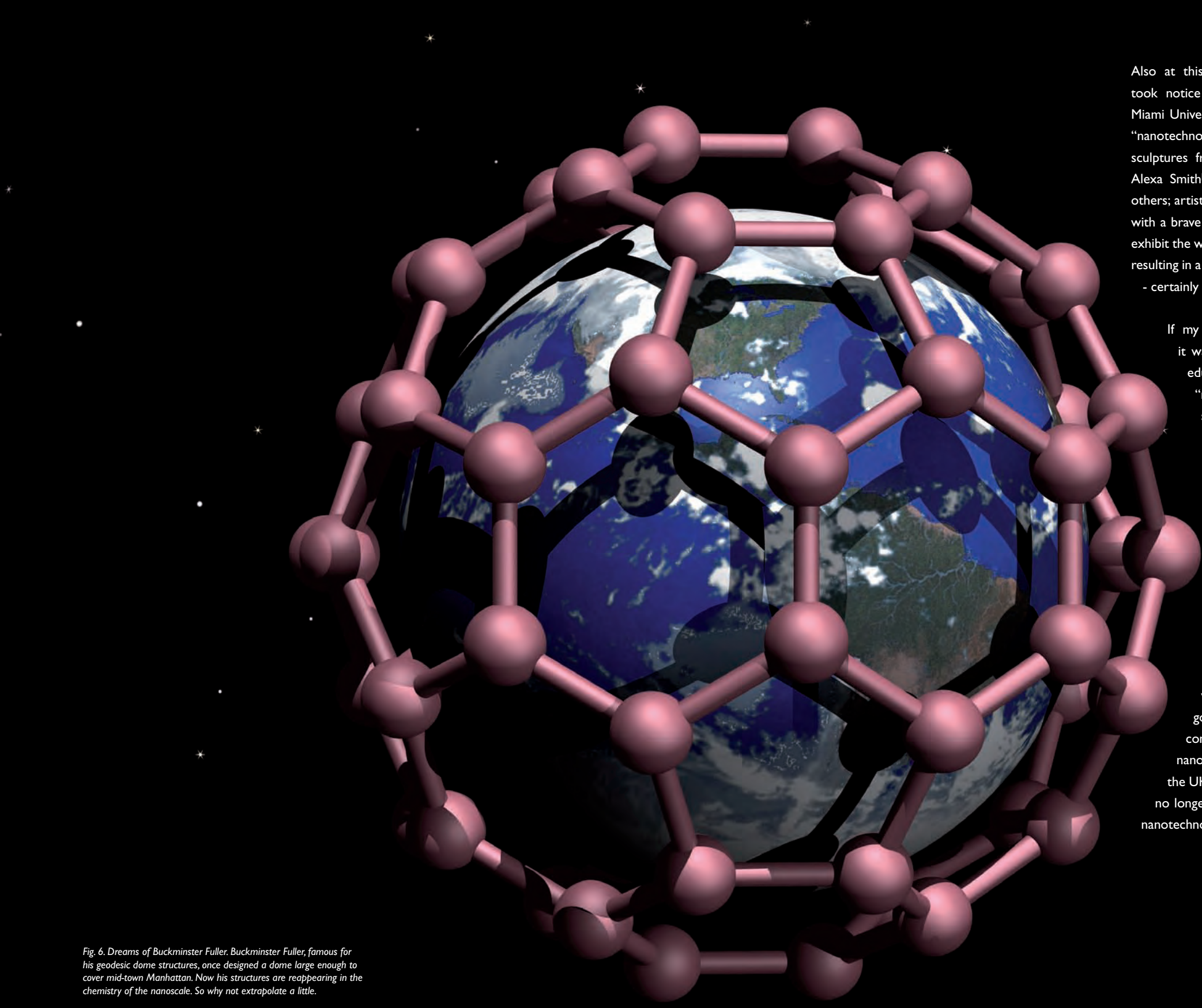


Fig. 6. Dreams of Buckminster Fuller. Buckminster Fuller, famous for his geodesic dome structures, once designed a dome large enough to cover mid-town Manhattan. Now his structures are reappearing in the chemistry of the nanoscale. So why not extrapolate a little.

Also at this stage, a surprise – the art world took notice of nano. I was contacted by the Miami University Art Museum in Ohio, who ran a "nanotechnology" themed art exhibition featuring sculptures from Buckminster Fuller, paintings by Alexa Smith[4], and some of my images amongst others; artistic reviews followed![5] Contrast this with a brave early attempt at NanoteC in 1999 to exhibit the work of the eponymous Sho Takahashi[6], resulting in a pretty scathing piece in the Guardian[7] - certainly ahead of his time...

If my website requests are any measure, it was towards the end of 2004 that the educational market really woke up to "nano". Initially I was contacted by science popularisation magazines, then programmes on "the Discovery Channel", and then later in 2005, the start of many requests for images for school textbooks. I suppose this more than anything was the sign that "nano" had truly grown up, as nanotubes were sufficiently well established within the scientific canon as to merit being taught to high school students.

The parallel sign of "nano" maturity was new requests for images from governmental sources. The European commission wanted images for their nanotechnology brochures and publicity, the UK government for their "nano" reports: no longer the wild young scientific adolescent, nanotechnology was in need of regulation.

And now? By 2006 the education requests had largely taken over everything else, and in particular "nano" appears to have become a major tool in the science popularisation arsenal. After receiving tonnes of emails from groups of school children round the world asking about applications of nanotechnology, whether it could cure cancer, whether we in Europe still researched on rats, etc, I did some research on the web and found out that Lego was running a world-wide science challenge, one section of which was for the competing teams to design some world-changing nanotechnology based application[8]. Hats off to Lego for this; I've no idea if it was a success overall, but if the emails I received were anything to go by, the children were fascinated and genuinely excited by the whole thing.

So what conclusions to draw from this? The famous 'democratisation of the web' means that anyone can now be a publisher, and from my own experience it seems that it's pretty easy to do. There are a few things that contributed to the website's success, but one of them was my credentials as a genuine scientist working in the field, and specifically, that the images are representations of real quantum chemical calculations, with structures that have genuinely been synthesised in the laboratory (unless clearly marked otherwise). Authenticity counts for a lot. The other thing is the site's simplicity. The images are clearly defined as representing nanotechnology, with further caption and subject information available if needed, but no need to sort through laborious database systems, register and log into the website. This allows rapid browsing and casual visitors to quickly dip in and out. This brings me to my next point – there is a huge opportunity here! The RMS represents an enormous wealth of fantastic authentic scientific images, produced by some of the world's best microscopists. I suspect that an image gallery on the RMS website, with the copyright and usage conditions clearly marked, could become the next 'one-stop shop' for scientific imagery for a wide range of media outlets.

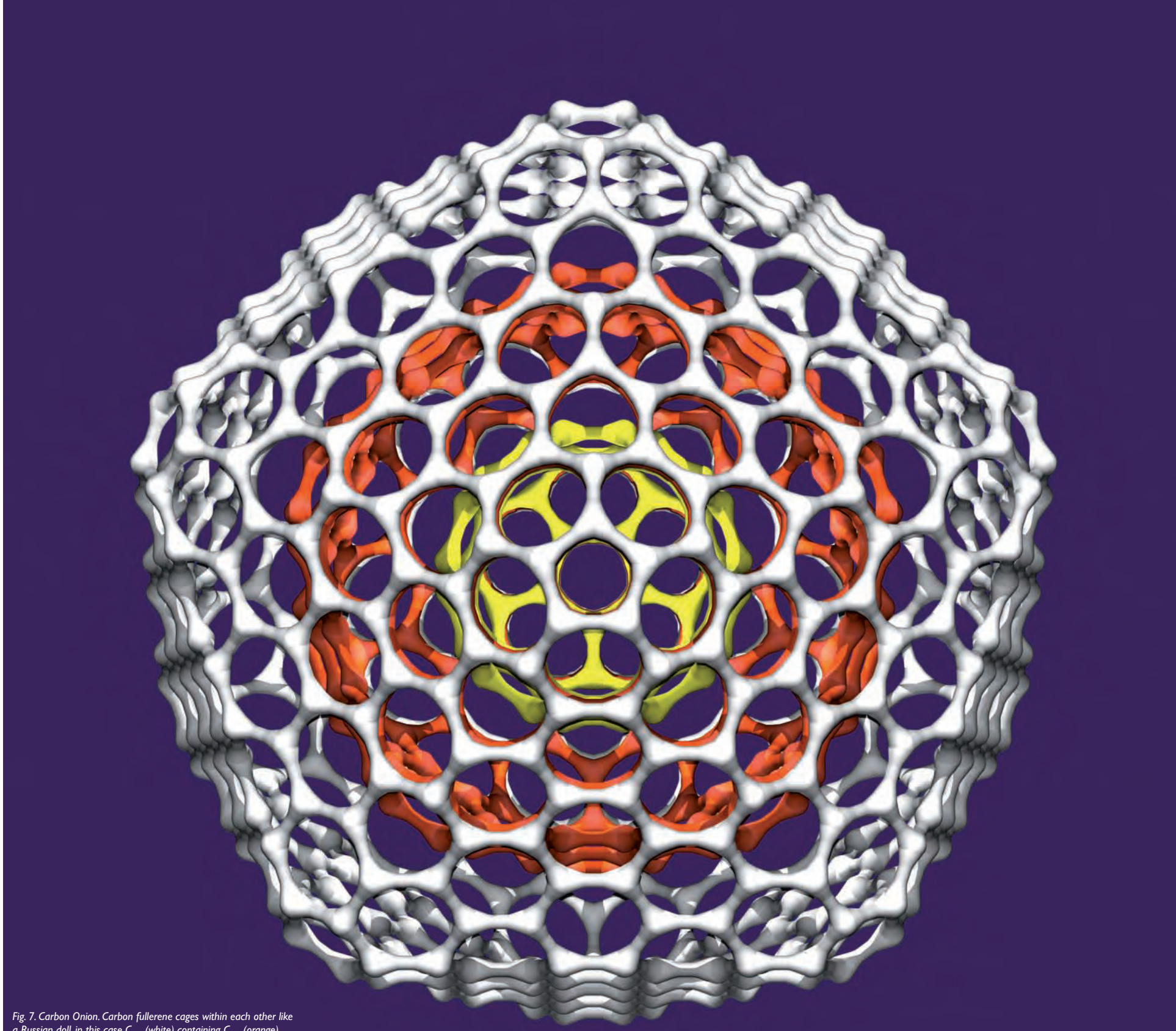


Fig. 7. Carbon Onion. Carbon fullerene cages within each other like a Russian doll, in this case C_{540} (white) containing C_{280} (orange) containing C_{60} (yellow). Rather than the traditional ball-and-stick representations, this image was intended to look more organic.



Fig. 8. Nanoship. Carbon nanotubes can be grown using ultra-hot gases within a chemical vapour deposition reaction chamber; this image tries to capture the particles cooling and clustering. A homage to 1970s Sci-Fi book covers!

Lego and others have started to use "nano" for schools based science communication projects, but there are plenty of other opportunities for the microscopy community to get involved. I was recently contacted by Susana Trasobares[9] about ES4FUN[10], a schools outreach project they ran at Cadiz University, Puerto Real, that is great fun and 100% microscopy.

They arranged for around 500 children to visit, dressed them in various coloured T-shirts, and took them to the department car park. Then from the roof of the building, aided by PhD student helpers on the ground armed with megaphones and walkie-talkies, they organised the children into different patterns, taking photographs and film from the rooftop. In the afternoon the children saw presentations from the scientists, where they revealed the purpose of the exercise – the children had been recreating different atomic resolution microscopy images: nanoscale catalyst particles on supports, and fullerenes within carbon nanotubes, fusing due to the damage caused by the flux of the electron beam, amongst others. The scientists showed the original microscopy images, the child-scale recreated ones, and discussed the science surrounding it. The event was a huge success and they have plans to repeat it, next time looking at more dynamic effects in materials such as dislocation glide and phase segregation. There's no question that the microscopy provides a great way to draw people into these difficult and sometimes quite inaccessible subjects, and the idea of recreating the images in the car park is a work of genius!

It is images that are going to shape the public response to nanotechnology. Whether these will be biological slices through inflamed tissue containing nanoparticles, "brave new world" images of little robots lugging red blood cells round like soldier ants, or electron micrographs of nanoscale components in some self-assembled solar cell I don't yet know. One thing I am sure of however, is that images are the key for communicating nanoscale science with the public. And as the creators of these images, this makes microscopists and theorists the keyholders.



Fig. 10. The ES4FUN schools project, communicating nanoscience through microscopy. Bottom: Children arrange themselves to form image of a "peapod", large fullerene C84 molecules containing two Gd atoms, themselves sitting within a carbon nanotube. Top:The same structure after two of the fullerene molecules have fused. (images ©ES4FUN). Central image: ©Alexandre Gloter (CNRS-AIST), showing these two structures in HRTEM.

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[1] *www.foresight.org/nanomedicine/Gallery/Captions/Image193.html*

[2] *D.M. Eigler, E.K. Schweizer. Positioning single atoms with a scanning tunneling microscope. Nature 344, 524-526 (1990).*

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[3] *www.ewels.info*

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[5] *For an artists perspective on "nano": www.petitemort.org/issue03/27_nanoart*

[6] *www.softxs.ch/sho/*

[7] *www.guardian.co.uk/life/science/story/0,,923076,00.html*

[8] *www.firstlegoleague.org/default.aspx?pid=21380*

[9] *susana.trasobares@uca.es*

[10] *www.uca.es/dpto/C143/ES4FUN.They are happy to discuss the project via ciencias.es4fun@uca.es.*

All images ©Chris Ewels, www.ewels.info, unless otherwise specified.

Fig. 9. Floating Fullerenes. Nanoscience is a subject defined by its dimension (if a buckyball was as big as a football, a football would be as big as the earth). Sometimes it's fun to play with that a little... This functionalised fullerene $C_{60}F_{15}(C_6H_3)_3$ (the fluorine is underwater) comes from the work of Roger Taylor and Adam Darwich.

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Chris Ewels graduated from Oxford University in 1993 after studying 'Metallurgy and the Science of Materials,' with a fourth year at the Max Planck Institute for Powder Metallurgy.

He received a Ph.D. in 1997 from the University of Exeter UK, for computational studies of oxygen defects in silicon. He then moved to Sussex University where he worked on radiation induced defects in graphite and carbon nanosystems. At Sussex he joined the Vega Science Trust with Sir Harry Kroto, where he created an online science TV channel and developed a passion for public communication of science. In Paris he worked at ONERA and was then a Marie Curie Individual Research Fellow at the Université Paris Sud within the electron microscopy group of Professor Christian Colliex. In 2006 he took up a permanent post with the CNRS at the Institute of Materials in Nantes. His work focuses on computer modelling of point and line defects in nanoscale carbons and oxides, and he has authored over 50 journal publications including five book chapters. His interest in science communication continues, having recently exhibited his nanoscience art in the US (www.ewels.info). He writes regularly for national and international newspapers and websites. In 2006 he received the European Marie Curie Excellence Award.