Concerning Nanotechnologies in the Field of Space Exploration

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Ever since we can remember, humans have been looking up at the stars and imagining what else is out there, how far does it go? Even today, our pop culture is flooded with science fiction exploring the starry canvas above us. Space exploration is romanticized and space travel trivialized. But maybe we are not actually that far away from breaking free. Moon landings and guided rovers through our solar system have been incredible feats, but the growth of nanotechnology is pushing us closer and closer to advanced space travel and exploration, as well as improving our astronomical abilities for studying the universe. Three of the most prominent fields of astronomy and space exploration benefiting from the growth of nanoscience and technologies must be transportation, human protection, and instrumentation. Some of the larger research areas of nanoscience pushing those areas of study are, but certainly not limited to, material advancements such as nanotubes, and the development of nanorobots.

Getting to and from, and travelling through space are the biggest road blocks currently faced, with regards to space travel. Current means of launch cost approximately $450 million and carry over 3 million litres of liquid propellant alone, simply for Low-Earth Orbit (Dunbar and Ryba, 2013). A space elevator could greatly reduce the cost of individual launches. A space elevator is a cable extending from the Earth into space, with a counterweight at its free end such that its center of mass is in geosynchronous orbit, keeping it upright and stable for vehicles to traverse (Globus *et al.,* 1998). Unfortunately though, finding a material that would hold has proven problematic. Carbon nanotubes may be the solution. Carbon nanotubes are cylinders formed of graphite, with diameters as small as 0.7nm (Globus et al., 1998) and possessing remarkable properties. To begin with, carbon nanotubes have very high tensile strength, theoretically withstanding 100GPa (near thirty times greater than that of Kevlar's 3.6GPa) (Pugno, 2007). These numbers however are estimated when measuring a cable with constant cross-sectional area; constant cross-sectional area in a cable unfortunately would result in instant and catastrophic failure, though, as the tension felt by the cable is greatest at its point of geosynchronous orbit. To reduce the stress, the cable must be thinner, and less massive, as it approaches Earth, thus, causing less pull on the end in synchronous orbit (Pearson, 1975). This tapering is where carbon nanotubes truly prove beneficial. A material such as Kevlar would require a tapering ratio of 2.6×10^8 (meaning the cable diameter at geosynchronous orbit would have to be 2.6

$\times 10^8$ times that of the diameter at the Earth's surface to maximize its strength) whereas carbon nanotubes would require a ratio of only 1.9 (Pugno, 2007), meaning less resources would be needed to build it.

Once leaving Earth though, we still must find a way to travel about space. Most of today's explorations rely on chemical rockets for launch and ion thrusters for maintaining orbit and interspace travel (the latter coupled with navigating through the gravitational fields of celestial bodies) (Atkinson, 2009). While electric propulsion (EP) has begun simplifying space travel, a new EP method using nanoparticles is ready to improve things again. Nano-particle field extraction thrusters (NanoFET) provide thrust by emitting electrostatically charged and accelerated nanoparticles (Berger, 2007a). The nanoparticles, (which may consist of conductive nanoparticles such as cylindrical carbon nanotubes, fullerene or possibly even metals such as nickel or copper nanoparticles) (Berger, 2007a), are stored in a non-conductive liquid (Berger, 2007a). The nanoparticles are then transported through the liquid to conducting plates energized with strong electric fields (Musinski et al., 2007). Once a nanoparticle comes in contact with a plate, it becomes electrically charged, and transported by the electric field to the liquid surface. If the particle has a strong enough charge to break the surface tension of the liquid, it is accelerated through a series of channels and ultimately ejected, producing thrust (Berger, 2007a) (Musinski *et al.,* 2007). By using nanoparticles as opposed to, say, ions, NanoFETs have an efficiency that cannot be compared. NanoFETs have an efficiency of over 80% (Musinski *et al*., 2007), meaning they can be used and manipulated for a variety of uses at both high and low specific impulses, such as providing attitude control and stabilization while in orbit, or navigating in deep space with less or even no dependence on planetary gravities (Berger, 2007a). This efficiency is measured using specific impulse, which is the amount of thrust gained with respect to the amount of propellant used, per unit of time (Musinski *et al*., 2007). Another promising aspect of NanoFETs is their size. Each individual emitter is merely 2 microns wide, and an array can be scaled to near any size necessary (Berger, 2007a) (Musinski *et al*., 2007). This scaling quality can greatly decrease the launch mass or increase payload capacity, depending on what is required (Berger, 2007a).

Another possible method of transportation may be a solarsail. The idea of a solarsail is analogous to that of an ocean ship's sail catching wind, but instead of catching wind, the solarsail works off the principle that energy has mass (Drexler, 1986). The sail is made of mirrors that are so thin, and so light that they generate thrust simply by reflecting light waves (Globus *et al*., 1998). Sheets of aluminum only tens of nanometres thick (Globus et al., 1998) yet hundreds of metres across (Drexler, 1987) collect and reflect enough sunlight so that the sail can slowly and steadily increase its velocity from the smallest force to hundreds of kilometres/second, with accelerations of 14km/s a day (Globus et al., 1998). Unfortunately the biggest setback is in manufacturing the sails. The solarsails should have their materials sent up to space

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and put together there, as an optimal apparatus would be too frail to survive exiting the earth's atmosphere (Drexler, 1986).

However, launching metal vehicles into the void of space is one thing, and sending them up in the name of science while carrying humans is another. A significant concern is transporting humans safely and swiftly in space. This means a lightweight ship with few complexities that can withstand the high velocities, pressures and forces of launch, as well as the extreme low pressure and temperatures of outer space. Building spacecraft out of carbon fibre and carbon nanotubes would then appear to be an ideal solution, however, another material may prove even better: boron nanotubes (Berger, 2007b). Isotopically enriched boron nanotubes share the same structure as carbon nanotubes, allowing them many of the same fascinating properties as carbon nanotubes, (including strength), but they also have higher chemical stability and higher resistance to oxidation (Berger, 2007b). On top of that, boron-10 has a propensity to capture neutrons, making boron nanotubes great at storing energy as well as an excellent radiation shield (Berger, 2007b). This is obviously not only good for protecting valuable equipment on board, but is extremely valuable in protecting the crew.

Another way to improve human safety is through altering the spacesuit. One of the most active fields of research for improving spacesuits is that of active materials. Active materials are named for their ability to act and react within their environment. In the context here, active materials are composed of nanoscale machines, or nanorobots, that act in unison together (Globus *et al.,* 1998). Acting in unison, these nanorobots are often referred to as a swarm (Mavroidis et al., 2004), as they move as one, interacting and even sharing information (Globus *et al.,* 1998). The active material takes up as much volume in the suit as it can, making it as strong as steel. It can change its texture: soft, rough, smooth; it can stretch and bend as the nanorobots work together fitting every movement of your body as a second skin. The material in theory can even shape to the surface of anything you touch, relaying the same texture to your finger pads on the inside, as if you were wearing no material at all. The nanorobots can even be programmed to absorb sunlight or convert your carbon dioxide into reusable oxygen (Drexler, 1986). And if any accident occurs that might injure the wearer of the suit, the nanorobots can respond by providing drugs or medical aid in emergency, while also repairing itself through self-assembly, to keep from further exposure (Mavroidis *et al.*, 2004). (This same self-assembly could be used for repairing small cracks in the hull of a ship, or along a space elevator cable as well) (Globus *et al*., 1998).

Advancements in instrumentation do not stop at nanorobots though. The National Aeronautics and Space Administration (NASA) has developed "blacker-than-black" material that absorbs more light than previously before seen (Keesey, 2010). The blacker-than-black material uses multiwalled carbon nanotubes to trap light, and to stop it from reflecting off instrumentation and affecting measurements (Keesey, 2010). To simplify things, the carbon nanotubes needed for the process can easily be grown on the instruments themselves (Keesey, 2010), a much simpler task then having to meticulously coat each instrument with the light-absorbing paint that was previously used. This new material not only simplifies the job, but allows NASA to retrieve data that was previously not accessible, such as objects in high-contrast areas, like a distant planet about its star (Keesey, 2010).

The field of space exploration is quite evidently not ready to sit back and let the universe pass us by, and the research discussed within this paper is only a shimmer in a sky of bright stars. Advancements in nanostructures, quantum and nanocomputers, and superconductivity continue on as well. Whether it is allowing us to navigate the worlds with a material thinner than a soap bubble, keeping us safe with nanorobots that can act before we even realize there is a problem, or supplying us with valuable data for bringing us closer to our dreams, the advancement of nanotechnology continues every day to draw us closer to a reality that has only been fiction in the past and closer to the stars we look up at in the night sky.

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