DID MATERIALS SCIENCE FALL INTO A BLACK HOLE IN *INTERSTELLAR*?

I am a big fan of science fiction—books and movies. Recently, I finally watched the movie *Interstellar*.[1] It's a great movie with a fantastic cast (Michael Caine, Matthew McConaughey, Anne Hathaway, Jessica Chastain, Mackenzie Foy, John Lithgow, Ellen Burstyn, Casey Affleck, and Matt Damon to mention a few) and something for everyone. The premise of the movie is a future Earth facing an environmental apocalypse and efforts to avoid the end of mankind by finding an extraterrestrial home. If you can see the movie at an IMAX theater, that's probably the best way to experience it. I don't get to theaters much anymore, so I saw it on my television at home.

In addition to the environmental apocalypse, the movie contains amazing spacecraft, wormholes, black holes, relativistic effects, intelligent robots with a sense of humor, hints at beings from an advanced civilization, a tesseract (a hypercube),[2] communications backward in time, cryonic systems that enable a kind of biological stasis, elements of trust and betrayal, extraordinary heroics and cowardice, and love stories. Kip Thorne, professor of physics at Caltech, was one of the guiding forces behind the development of the movie and insisted that the science be as real as possible. There was a significant scientific effort to make sure that the images associated with the wormhole and the black hole, as well as the relativistic effects, were founded in our best knowledge of the science associated with these phenomena.

The movie is highly enjoyable, even if you don't understand (or care) about the science. Nonetheless, after watching the movie, I found that I had a lot of unanswered questions. My first effort to answer the questions led me to read the novelization based upon the movie.[3] This answered some of my questions, but raised even more.

Fortunately, there is additional help available. Thorne has written an excellent book (with Christopher Nolan, the producer of the film) discussing the science behind the movie—mostly about the wormhole, black hole, tesseract, orbital mechanics for planets and spacecraft, and relativistic issues, but also including a discussion of the biological aspects of environmental disasters.[4] A very helpful feature of the book is that Thorne labels each section with a T for true, EG for educated guess, or S for speculative. The book also points to parts of the movie where scientific accuracy had to be ignored for various reasons. Another aspect of the book that I like is that the authors are very generous in pointing to other materials (books, etc.) for those who are interested in diving deeper into the subject matter. Two of the books recommended by Thorne are *Black Holes* and *Time Warps: Einstein's Outrageous Legacy*[5] and *Warped Passages*.[6] I have found them very enjoyable and informative.

In regard to tesseracts, I remember in my distant youth reading a short story written by Robert A. Heinlein in 1941 entitled "And He Built a Crooked House" that was republished in a collection of Heinlein's work.[7] The story revolves around an architect who designs a house in the shape of an "unfolded" hypercube. On showing the house to the new owner shortly after an earthquake, the outside of the house is discovered to be very different than the design. On entering the house, it is soon determined that the earthquake collapsed the 3D design into a real hypercube. The adventures of the architect and the owners as they explore the tesseract are hilarious. After reading the short story, I remember spending time trying to contemplate a tesseract as well as other higher dimensional objects. All that came out of that was a series of excruciatingly intense headaches and a profound appreciation of geometry. The discussion of the tesseract in *The Science of Interstellar* bears little resemblance to

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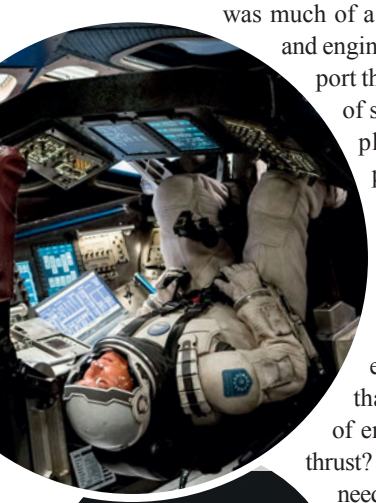
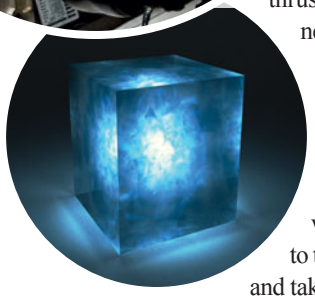
the ideas in the short story by Heinlein. The tesseract in Heinlein's story connects rooms in the house to other locations far away. The tesseract in *Interstellar* plays a much more serious role. It is the basis for backward communications in time that help the protagonists save the human race. If I had access to one of those, I'd send a message back to myself in 1984 to invest heavily in Microsoft. A tesseract (sometimes called an Infinity Stone) also plays a role in several films that are part of the Marvel Cinematic Universe (e.g., *Thor, The Avengers, Captain America*). In those films, the tesseract is a source of great power that can generate what appears to be either a wormhole or a gateway to other universes or an alternate reality.[8]

I find all of these concepts fascinating. What I did not find in the movie, the novelization, or *The Science of Interstellar* was much of a discussion of the materials science and engineering that would be required to support the technologies discussed. What kind of stresses and strains would a tesseract place on any objects that it encompassed? What materials would be needed in order to construct a gravitational field generator that could open a stable wormhole connecting two specified points in space?





The spacecraft in *Interstellar* apparently have significantly more thrust than existing spacecraft. What kind of engines and fuels could provide such thrust? How would we get the total energy needed from fuels that could be contained in the limited volume of the spacecraft shown? What materials were used for the spacecraft structures? They are exposed to tremendous forces, including the rocket thrust, forces associated with traversal of the wormhole, proximity to the event horizon of a black hole, landing and takeoff from different planets, and extreme orbital maneuvers. Spacecraft today would have a very difficult time handling those stresses. In fact, spacecraft materials today can be destroyed by collision with very small objects (cm sized or less) traveling at enormous speed with respect to the spacecraft.[9] Exposure to ionizing radiation and displacement damage through energetic particles found in the space environment can lead to structural weakening and failure of materials.[10] Although we can and have produced spacecraft that have made it to interstellar space (e.g., Voyager[11]), those spacecraft are much more limited than the space vehicles depicted in *Interstellar*. We have no way today of producing such vehicles.

The astronauts in *Interstellar* survive long trips in space through some kind of suspended hibernation produced in cryonic chambers. Although commercial organizations exist today that will store a human body in a cryogenic suspension, the process has only been used on people at their death.[12] Unfortunately, no one has shown as yet that people stored in such suspensions can be revived, much less that they could lead a normal life after years in cryogens. If such a technology were available, the advantages would be extraordinary. People that were dying of any disease could be held in a biological stasis until a cure for their disease was discovered, at which point they could be reanimated, cured, and allowed to resume life.

Interstellar contains robots that seem to be intelligent. Although we are currently producing microprocessors with extraordinary processing powers, we have no processors or combinations of processors that have produced anything close to human intelligence, much less an intelligence with a sense of humor. The estimated computational power required to simulate the real-time response of a human brain is 36.8 petaflops.[13] Although some supercomputers have approached that number, there is still a long way to go before true artificial intelligence is demonstrated, much less one that could fit inside the volume of one of the robots in *Interstellar*.

The android Data in the television series "Star Trek: The Next Generation" had what was called a positronic brain.[14] The idea of a positronic brain has a rich history in science fiction. The nature of Data's brain was never well described, but Data relied on peripherals for other aspects of his existence. For example, he needed a special microelectronic device (a chip) installed so that he could experience emotions. The robots in *Interstellar* seem to have a sense of humor as well as other emotions, but we are never given much insight into the technology behind that, much less the materials science.

There is much, much more in the universe of *Interstellar* that could benefit from a good exposition of the materials science. Perhaps one of you will write such a book. If so, I promise you that I will buy it.

Steve Moss

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