What has

Wireless Internet and GPS are just two of the technologies our society uses every day — and both stem from astronomy.

by C. Renée James

astronomy done for *you* lately?

Seemingly disparate astronomy projects have led to technology that other fields have relied on: navigation, wireless Internet access, cancer therapy, and human-eye mapping.

Astronomy: Kellie Jaeger; NASA (JWST); *Astronomy*: Roen Kelly (black hole evaporation); Adrian Matthiassen/Photos.com (Parkes radio telescope); David Bukach (Stonehenge); mathieukor/Photos.com (GPS unit); © 2012 JupiterImages Corporation (map); © 2012 JupiterImages Corporation (keyboard); © 2012 JupiterImages Corporation (wireless graphic); Photos.com (eye) and *Astronomy*: Roen Kelly (laser illustration); NASA/Visible Earth (Earth's surface)

The summer of 2011 was a somber one for space enthusiasts. On July 6, the James Webb Space Telescope, Hubble's successor, fell squarely on the chopping block. Originally estimated to cost $1 billion and launch in 2007, the project has faced cost overruns and poor management. Numerous reports over the past decade have upped the cost and postponed the target launch date. Thus, Congress announced its intentions to kill it. (The most recent panel report, in November 2011, however, pushed back the launch until 2018 and estimated the final tab at $8 billion. Congress has since allowed the project to move forward.)

That same week in July, the final launch of the Space Shuttle Program occurred — an event that brought tears to the eyes of scientists, engineers, and space enthusiasts.

And if that weren't enough to depress astronomers, a concern grows about the fate of the wildly successful Kepler mission to discover planets around other stars. To continue science operations past November 2012, it needs $20 million per year. If funding isn't approved, the mission's search for an Earth-like world will come to an abrupt halt later this year, at the end of its originally funded lifespan.

Astronomy aficionados collectively gasp in horror at these news stories, but not everyone is so moved. One website discussing the shuttle's swansong featured the bitter comment: "What do they plan on accomplishing? Can they cure cancer up there?"

If the history of scientific research is anything to go by, then the answer to that question is, "They just might."

Amid the worst economy since the Great Depression, public frustration is palpable. Why, some demand, should we pay our hard-earned tax dollars to support some elite scientist studying things that we can't even pronounce and that we certainly will never travel to? Why stare at distant galaxies when real problems stare us in the face?

Tragically, what many fail to realize is that astronomical research has proven its worth to society time and time again. Those regular rhythms in the sky provided us with the tools to create calendars and clocks by which our societies plan nearly every commercial transaction. In a sense, astronomy drives every economy.

But that's ancient history. What follows are four ways that curiosity about our universe have benefitted society lately.

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Global Positioning System (GPS)

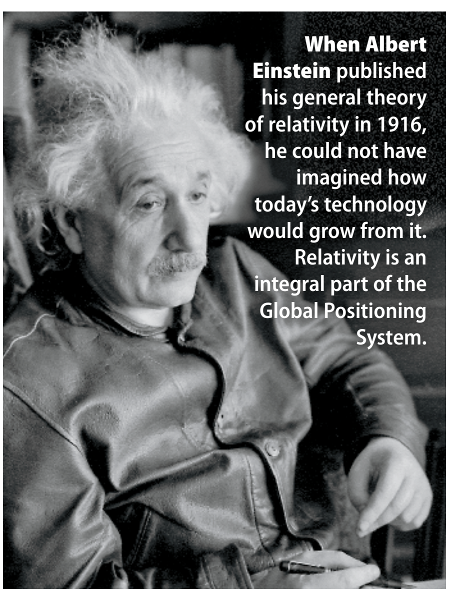
Curiosity helped us find our place

Nowadays, we rarely use paper maps to figure out directions; instead, we punch the destination address into a Global Positioning System (GPS) unit in the car or even our smartphone. The ability to precisely locate ourselves using GPS owes a great deal to the mental musings of Albert Einstein. In his attempts to understand gravity, he developed in 1916 a bizarre and unintuitive way of looking at space and time and their interaction with matter — his general theory of relativity.

The idea of warped space-time led to an observational victory in May 1919. Renowned British astronomer Sir Arthur Eddington guided an expedition to witness the deflection of starlight as it passed by the Sun during a total solar eclipse, thus proving that the Sun's mass warps space.

But what about time?

Because space and time are interwoven, massive objects stretch the rate at which time passes near them. The closer you are to an object with mass, theory says, the slower time ticks along. The effect is minuscule: A day atop Mount Everest is about 30 millionths of a second shorter than a day at sea level. By the 1950s, though, physicists had developed a precise timekeeping device that made use of natural atomic oscillations. Invented purely to test Einstein's relativity, this cesium atomic clock is accurate to within a billionth of a second.



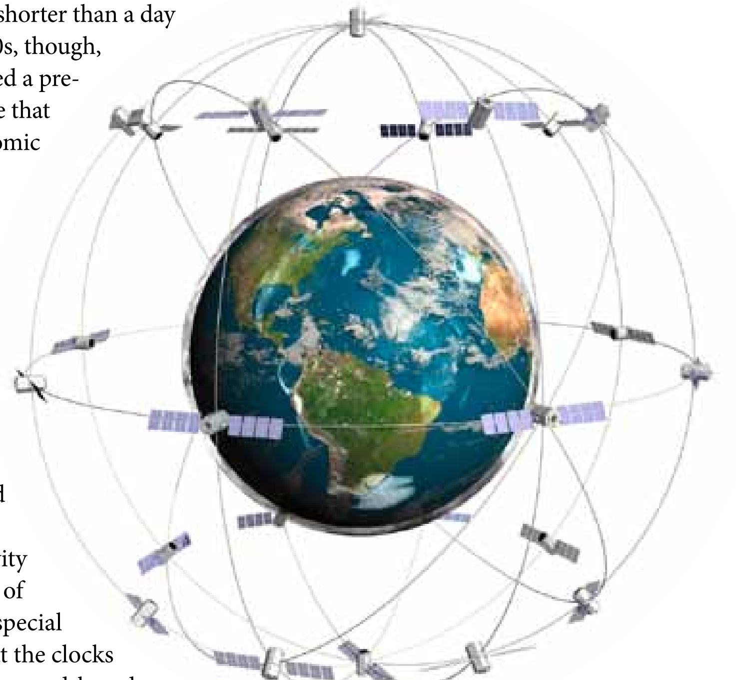
When Albert Einstein published his general theory of relativity in 1916, he could not have imagined how today's technology would grow from it. Relativity is an integral part of the Global Positioning System. University of New Hampshire, Lotte Jacobi Collection

In 1971, commercial airline jets carrying four cesium atomic clocks flew twice around the world — once eastward and once westward. Relativity theory (a combination of Einstein's general and special theories) predicted that the clocks would differ from the ground-based standard by a few ten to a few hundred nanoseconds, depending on their direction. When the planes landed and researchers checked the clocks, they determined that Einstein was right.

Again.

After this experimental success, these atomic clocks were neither relegated to the storage room nor only stationed in research physics labs. Concurrent with the development of the atomic clock had been another technological struggle: the Space Race. Following the launch of Sputnik in 1957, scientists began to realize that satellites could be used as "artificial guide stars" for global positioning (mostly monitoring the activities of "the other guys").

In 1978, researchers launched the first operational GPS satellites incorporating atomic clocks. Today, an armada of 30 satellites helps us find our place. Engineers programed the time-altering effects of relativity into these satellites because of their motions and altitudes.



The Global Positioning System (GPS) evolved from testing Einstein's relativity theory. While 30 GPS satellites orbit Earth, 24 constitute the navigation system that the public relies on (the other six are backups). © Pixac/Dreamstime.com

Residents of the 21st century have all but given up reading maps because of their heavy reliance on a technology that practically owes its existence (and certainly its usefulness) to what must have seemed a "pointless curiosity" about the nature of gravity. Moreover, the thought experiments that led Einstein to postulate relativity were performed nearly a century before anything useful came of them.

In an age of microwave meals and instant access, it's often hard to wait a year, much less a century, for a scientific idea to move into the real world, but relativity did just that. The current worldwide value of the GPS network is estimated to be nearly a half-billion dollars, and that says nothing of the value of the lives it has helped save.

1916 — Albert Einstein publishes his general theory of relativity

1919 — Astronomers perform the first test of general relativity

1971 — Jets carrying cesium atomic clocks test how mass alters time

1978 — First GPS satellite launches

1998 — President Bill Clinton announces plans to make GPS a dual-use system: both military and civilian

2011 — GPS satellite "constellation" expanded

Wireless Internet

Fundamental questions versus narrow projects

Hard-core opponents of curiosity-driven research could argue that it was inevitable that something useful would come of wrestling with one of nature's fundamental forces. In more recent times, however, scientists fill journals with jargon-laced, narrowly focused articles with titles like "Limits on cosmic radio bursts with microsecond time scales." This obscure 1978 article in *Nature* by John O'Sullivan, Ron Ekers, and Peter Shaver would seem to be a testament to the impracticality of more-modern research.

It all began with physicist Stephen Hawking's prediction in the early 1970s that black holes should ultimately evaporate. The less massive the black hole, the quicker it should pop out of existence. He suggested that primordial black holes (formed from fluctuations in the early universe) whose masses are less than about a trillion kilograms ought to have had enough time over the universe's existence to completely evaporate.

"Evaporate" is a misnomer. As the black hole's mass decreases, the rate at which it disappears should increase until it explodes with a colossal burst of energy — just shy of the Sun's luminosity — in microseconds.

Because of a limited observational range, this sort of event would have been extremely difficult to observe in the 1970s, but radio astronomers Shaver and Ekers realized that there should be a specific signal of radio waves associated with an exploding black hole. So, they brought Australian engineer and physicist O'Sullivan on board to help design a detector to look for such signals.

Their search proved fruitless, and a telling sentence in the abstract of the aforementioned paper seems to indicate that it was a waste of time and money: "No events attributable to black holes were observed."

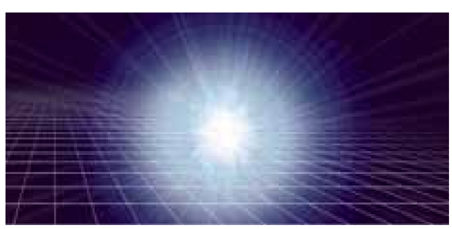
Instead of a dead end, however, their project turned out to be an unforeseen victory, largely because the faint radio signal would have been difficult to tease out of the noise. An exploding black hole theoretically emits a range of frequencies. Unfortunately, the signal's high-frequency radio waves travel through the charged particles of the interstellar medium slightly faster than their low-frequency counterparts, which get held up "shaking hands" with all the electrons. By the time the radiation reaches radio telescopes on Earth, these interactions have smeared it out, and the original signal is lost.

Multifrequency interference from man-made sources compounds that problem. What Shaver and Ekers wanted O'Sullivan to engineer was something capable of reconstructing the faint, smeared-out signal of a hypothetical primordial black hole.

A miracle, in other words.

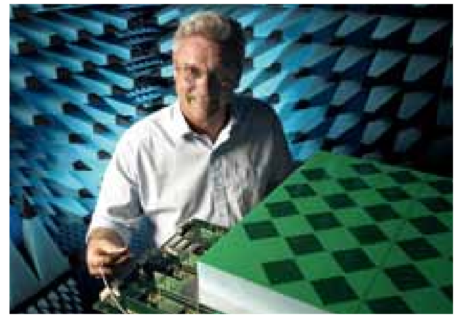
The radio astronomers attempted a number of filtering options for the various wavebands, each more complicated than its predecessor. O'Sullivan recalls, "I personally came away thinking there has to be a better way and started the very next week to look into ways of doing Fast Fourier Transforms using digital hardware." Simply put, a Fourier Transform is a mathematical method to reconstruct frequency and strength information from a complicated signal. A Fast Fourier Transform (FFT), as you might suspect, is a computational way to do this quickly.

After failing to detect exploding black holes, O'Sullivan returned to Australia to work with the Commonwealth Scientific and Industrial Research Organisation to design an FFT chip — the A41102, developed with Austek Microsystems — whose original purpose was to aid radio astronomy.



Astronomy: Roen Kelly

Primordial black holes are hypothetical objects that formed out of tiny density fluctuations in the early universe. Scientists looking for a signal from evaporating primordial black holes developed the basis of wireless technology in the process.



Chris Walsh, Patrick Walsh Photo Studio

Engineer John O'Sullivan worked with others to search for signals from evaporating black holes. He later extended that same technology to create the basis for reliable wireless networking.

Two years later, O'Sullivan put together a team to work on a new project to pioneer the high-speed wireless network. But the low-power signals were tough to clean up, and a room's geometry caused reverberations that "smeared out" the signals, making it difficult to pull out useful information.

O'Sullivan recalls, "Looking at the problem was similar to the thinking which we applied many years before. … The search for pulses led to the FFT chip, and the FFT in turn underpinned an important first part of our wireless network solution."

In other words, the failed search for exploding black holes has become an integral part of modern life because all WiFi devices possess a component that was born in the attempt to disentangle the faint signals of these still-hypothetical objects. The creative spillover is now crucial in the $80 billion per year industry, not counting the economic transactions expedited by WiFi's presence.

O'Sullivan credits radio astronomy for providing interesting challenges: "I think perhaps one of the most profound impacts of astronomy … is the number of engineers and scientists who have been nurtured and trained in that challenging environment."

1974 Stephen Hawking hypothesizes that black holes emit particles and lose mass

1978 John O'Sullivan, Ron Ekers, and Peter Shaver complete search to find such "evaporating" black holes; they found none

1983 O'Sullivan joins the Commonwealth Scientific and Industrial Research Organisation radiophysics department

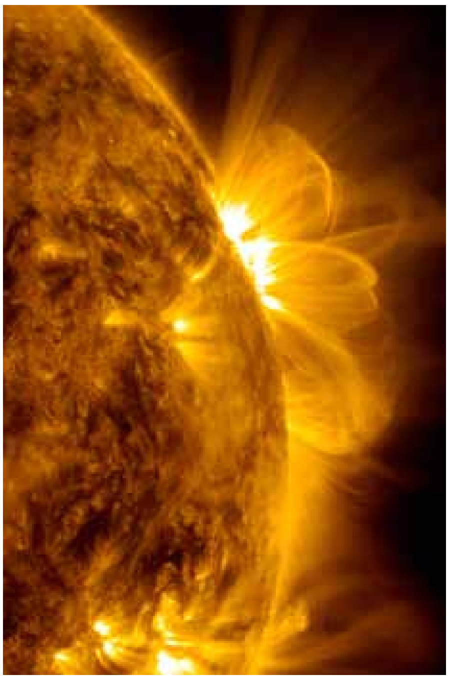
1996 O'Sullivan and colleagues receive U.S. patent for Fast Fourier Transfer (FFT) chip

1999 FFT chip is incorporated into wireless industry

Treating cancer with astronomy research

About that cure for cancer

It was the challenging and interesting environment that drew Ohio State University's Sultana Nahar and Anil Pradhan to astronomy. "Astronomy fascinates everyone," Nahar declares. Moreover, puzzling discrepancies tend to fascinate scientists. Together with Yan Yu from Thomas Jefferson University in Philadelphia, Pennsylvania, they found that exploring astrophysical disagreements has unexpected benefits.



The Sun's chemical composition continues to confound astronomers. Their search, however, has made advances in a seemingly unrelated area — cancer treatment. NASA/SDO

For astronomers, the Sun is the source of numerous internal contradictions. One of the field's embarrassments is that the concentrations of various elements in our nearest star are so poorly established. Different methods yield different values.

It would seem a minor quibble, but it turns out that a lot of stellar physics hinges on these values. At stake is scientists' understanding of not only the chemical composition of the Sun, but also stellar interior models, helioseismology, and the behavior of variable stars. According to one paper that Pradhan and Nahar authored in 2009, "The practical necessity of solving this problem can hardly be overstated."

Practical for astronomers, that is. But how about for the rest of the world?

At the heart of the problem is the exact interaction between the energy that nuclear fusion in the Sun's core produces and the atoms in each successive layer of our star as the light tries to escape. Only a generation ago, astronomers were resigned to generalizations about how various atoms block different wavelengths of light. This "opacity" helps dictate the temperature and pressure structure of the Sun, which constrains much of what we observe. Scientists applied these generalizations to other stars, which forced them to make star-to-star comparisons rather than report anything with much certainty.

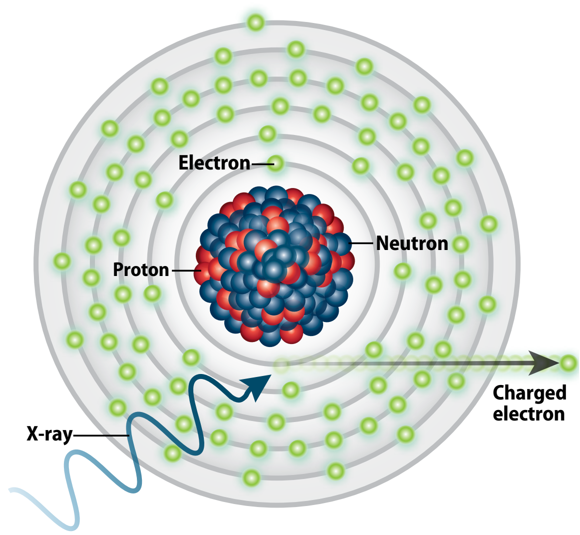
Intrigued with the inconsistencies and recognizing the growing power of computers, physicist Michael Seaton (1923–2007), along with a team of collaborators that included Pradhan and Yu, launched the Opacity Project in 1983. The Iron Project followed in 1992, and together these efforts channeled the combined expertise of dozens of astronomers, computational physicists, and atomic physicists into divining with unprecedented precision how atoms in the layers of the Sun and other stars interact with the light trying to escape.

Nahar joined Pradhan and Yu at Ohio State University in 1990. By 2003, however, Yu had left to join the ranks of medical physicists, but stayed in touch with his former colleagues and continued to collaborate with them — a connection that would prove invaluable.

Eventually, the Opacity Project stumbled upon something unexpected. At certain wavelengths, particularly in the X-ray region, some atoms interact very strongly with the radiation. These "resonance" frequencies increase the overall opacity. This knowledge modified astronomers' understanding of the Sun's atmosphere and its composition. And the new insight into the interaction between X-rays and matter also helped researchers calibrate some of the results from the Chandra X-ray Observatory.

But it didn't end there.

Heavy elements like gold, which is chemically unreactive and also nontoxic and therefore safe to use inside the human body,



When an X-ray with a specific wavelength strikes a gold atom, it kicks out an inner electron. An electron on a higher energy level then falls to fill its place, emitting an X-ray and electron in the process. If scientists place a gold nanoparticle into a cancerous tumor, this process could destroy the cancer by flooding it with radiation and electrons. *Astronomy*: Roen Kelly

1922 Scientists discover that if an inner electron is kicked out of a heavy-element atom (like gold), an outer electron will fall to replace it, thus kicking out another electron

1983 Opacity Project begins to determine how the atoms in layers of the Sun and other stars interact with the light trying to escape

1992 Iron Project begins to study the collision processes of iron and iron ions

2011 Scientists announce that gold nanoparticles inserted into cancerous tumors can act via the effect discovered in 1922 and kill cancer cells interact particularly strongly with specific X-ray frequencies. In some cases, an X-ray hits a gold atom and kicks out an inner electron. An electron in the next energy level falls to occupy the new, lower-energy opening, and itself releases an X-ray, which kicks out another electron.

When tuned to the right frequency, a source acting on a gold atom could open the floodgates of energetic particles and radiation. Placed correctly, a small amount of gold hit with that specific X-ray frequency could flood and kill a cancerous tumor.

That realization introduced another exciting development: nanotechnology and the use of gold nanoparticles for cancer therapy. Although this may not be the complete cure for cancer that the public seeks from science, it can certainly make the treatment less excruciating and more effective.

Pradhan states, "Our work exemplifies fundamental science and the underlying symbiosis between apparently disparate branches of science. That is where new ideas arise."

Australian engineer John O'Sullivan, the "father of WiFi," echoes the sentiment, saying that one of the key ingredients to innovation is "having people with different training backgrounds working together on new problems because it's precisely in these areas between disciplines where interesting things tend to happen."

"I like to see our economy and activities as a sort of ecosystem," O'Sullivan states. "If we cut any one of those levels back, we threaten the existence of the whole ecosystem. Not all pure research activities will lead to applied research, and many applied research efforts will lead nowhere."

"In our case," Pradhan continues, "we have X-ray spectroscopy of black hole environments, atomic physics of stellar interiors, radiation astrophysics, and nanotechnology, all combined to focus on an application which no particular area would have suggested."

Furthermore, Pradhan and Nahar are in agreement that oncologists and other cancer researchers would not have independently stumbled upon the resonance phenomenon currently employed for both diagnosing and treating cancer. To do so would have required detailed research of photon-atom interactions, something that instead fell to atomic physicists and astronomers who sought reconciliation between solar models and observations.

Optics and the JWST

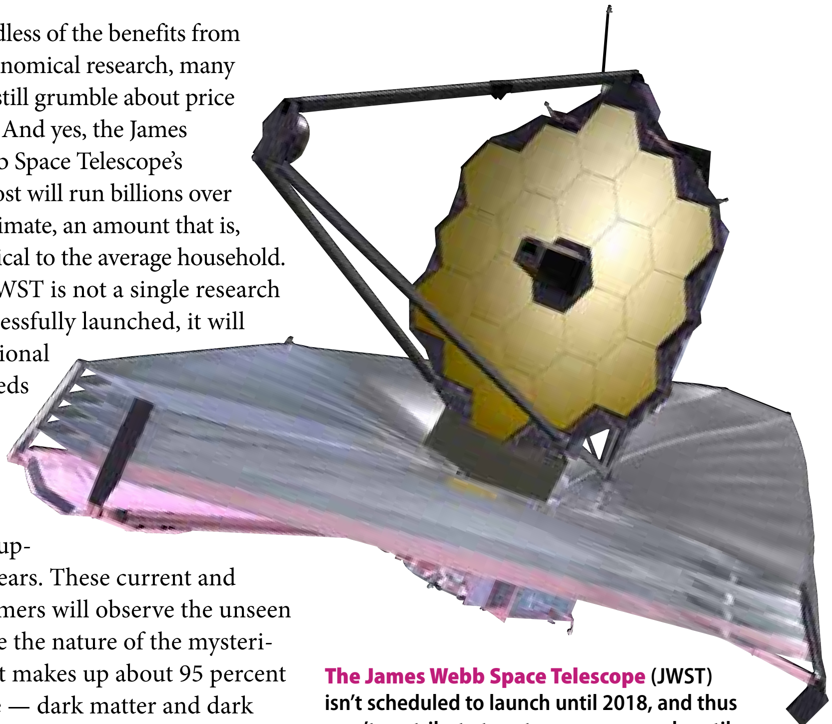
Focusing on the positives

Regardless of the benefits from astronomical research, many will still grumble about price tags. And yes, the James Webb Space Telescope's (JWST) final cost will run billions over the original estimate, an amount that is, well, astronomical to the average household.

However, JWST is not a single research project. If successfully launched, it will be an observational tool for hundreds of astronomers, thousands of students, and innumerable support staff for years. These current and future astronomers will observe the unseen and even probe the nature of the mysterious "stuff" that makes up about 95 percent of the universe — dark matter and dark energy. Muses John O'Sullivan, of the Commonwealth Scientific and Industrial Research Organisation in Australia, about the prospect: "Who knows? But when we do comprehend dark energy and dark matter, the resulting paradigm shift might quite possibly turn more than our understanding of the universe on its head."

JWST has already impacted our lives in positive ways. Because of the precision required when engineering its optics, the project spawned a new technology that can map the topography of optical surfaces faster and more precisely than ever before.

What this means to the average taxpayer is that laser surgery, contact lens fitting, and ocular diagnostics are more accurate because of JWST. And considering that more than 100 million people in the United States alone wear some sort of corrective lens, and more than 4 million laser eye surgeries are performed annually, the benefits of pure astronomical research start to appear much clearer.



The James Webb Space Telescope (JWST) isn't scheduled to launch until 2018, and thus won't contribute to astronomy research until then. However, JWST technologies have already proved useful in other fields. NASA

Optical mapping technologies developed for the James Webb Space Telescope's optics system are also benefitting contact lens fittings and laser eye surgeries. Detailed information about the eye's shape takes minutes to obtain, instead of hours, thanks to this technology. Illustration: *Astronomy*: Roen Kelly; eye: Photos.com

Visit www.Astronomy.com/toc to learn about other examples of astronomy research that benefits society.

1996 — Planning for the Next Generation Space Telescope begins

2002 — Project is renamed the James Webb Space Telescope

2011 — Six of the 18 mirror segments pass optical testing; NASA releases information about how JWST optical mapping technology can help laser eye surgeries and contact lens fittings