Building the James Webb space telescope

By MASHA SAVITZ
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Suspended in space about 1 million miles from Earth, the James Webb Space Telescope (JWST)—planned for launch in 2013—aims to offer a window into the long-held secrets of the universe and our origins.

NASA hopes that its new progeny will help to answer fundamental questions about galaxies, such as: How did the very first galaxies form? How did we end up with the large variety of galaxies we see today? What is the relationship between black holes and the galaxy that hosts them—since we now know that extremely large black holes live at the centers of most galaxies?

These are just some of the galactic riddles that scientists hope the James Webb Space Telescope will answer.

By studying some of the earliest galaxies and comparing them to more recent ones, we may be able to better understand their growth and evolution. JWST, an infrared-optimized space telescope, designed to work primarily in the infrared range of the electromagnetic spectrum, will also allow scientists to gather data on the types of stars that existed in these very early galaxies.

Follow-up observations using spectroscopy of hundreds or thousands of galaxies will help researchers understand how elements heavier than hydrogen were formed and shaped as galaxy formation proceeded through the ages. These studies will also reveal details about merging galaxies and shed light on the process of galaxy formation itself.

Over 1,000 people in more than 17 countries are involved in developing the state-of-the-art telescope, in hopes of better understanding the nature of our cosmos.

One contributor is Lee Feinberg, NASA's optical telescope element manager at the Goddard Space Flight Center in Greenbelt, Maryland. He is also senior staff engineer in the Instrument Systems Technology Division at Goddard.

INFRARED OBSERVATORY: A full-scale model of the James Webb Space Telescope outside the Smithsonian Air and Space Museum in Washington, D.C. The telescope is designed to rival the aging Hubble Space Telescope. TIM SLOAN/AFP/GETTY IMAGES

On the project for over seven years, Feinberg has overseen the development of the three critical telescope technologies—lightweight mirrors, lightweight cryogenic structures, and wavefront sensing and control.

He is also co-chairing the Mirror Review Board that chose beryllium as the material for the telescope's primary mirror. He has been a significant contributor to the telescope flight architecture and test architecture, and has been NASA's lead in the overall development of the technology.

Creative, but very technical

A jazz musician by night, playing piano, keyboard, and composing, as well as a devoted husband and father of two, Feinberg has a unique relationship to creativity and cosmic exploration.

Unlike how he refers to his musical endeavors, Feinberg calls the creativity needed for the work on JWST "technical creativity."

"It's creative but very technical. No one [outside of NASA] understands it," Feinberg jokingly laments. An example of his creative problem solving emerged with the challenge of testing the enormous telescope. It required specific and potentially costly conditions, including keeping the telescope cold.

JWST will have a large mirror, 6.49 meter in diameter, and its sun shields alone are the size of a tennis court. Yet even with all these difficult variables, Feinberg came up with a new way to test the telescope that was more effective and cost efficient than previous methods. This problem-solving ability, "to think outside the box," Feinberg says is extremely important.

According to Feinberg, broad thinking, managerial skills, solid engineering, and science are the most valuable tools in tackling such a project. He points out that it is one thing to have conceptual knowledge, but quite another to be able to implement these ideas. This requires not only good communication but also a clear understanding of how all the elements of the system fit together in the big picture.

"You can't rest until you get it … there is an endless array of problems and puzzles to solve," explains Feinberg, who will often wake up at 3 a.m. with a jolt of inspiration. But for all his expertise, Feinberg is quick to point out that it is the collective talents of the team that help bring the project to fruition.

"There are 1,000 other devoted people on this project also getting up at 3 a.m. with REM-induced revelations," he notes.

Most astounding to Feinberg is the project itself—both its magnitude and complexity as a social phenomenon. "Humans can build things that no single individual understands the whole thing," he says.

Window to the future

The results of this very ambitious undertaking will potentially "revolutionize a whole bunch of fields," particularly the newly burgeoning field of Extra-Solar Planet science and studies of the atmospheres of other planets and around other stars. By measuring light at different wave lengths, scientists can assess the atmosphere's chemical composition to detect signatures of life.

Feinberg points out that other telescopes in history inevitably revealed more information than had been intended or foreseen. "There are always new discoveries with new telescopes. You can't even anticipate the discoveries."

In his youth, he recalls having an interest in cosmology, grappling with God, the universe, and man's purpose. He had a keen curiosity to explore how the universe came to be and how it evolved. Was it all by chance—or by design?

"Einstein got it right," suggests Feinberg of his understanding of God as infinite.

So what motivates the philosophical and easy-mannered Feinberg to do the job that he refers to as a "pressure cooker"? He mentions the cosmological aspects, the implications of the findings, and the contribution that this work will potentially bring to our generation as being particularly rewarding. But most of all, Feinberg is inspired by the thrill of seeing images people have never seen before.

"All these images are things that might tell us about our history or our future," he says.

"I want to be there when the first images come down to the ground; this is the greatest feeling there is."

Robot algorithm uncovers the scientific laws hidden in raw data

National Science Foundation

Using the digital mind that guides their self-repairing robot, researchers at Cornell University have created a computer program that uses raw observational data to tease out fundamental physical laws. The breakthrough may aid the discovery of new scientific truths, particularly for biological systems, that have until now eluded detection.

Reporting in the April 3 issue of Science, Cornell University researcher Hod Lipson and his doctoral student Michael Schmidt report that their algorithm can distill fundamental natural laws from mere observations of a swinging double pendulum and other simple systems.

Without any prior instruction about the laws of physics, geometry, or kinematics, the algorithm driving the computer's number crunching was able to determine that the swinging, bouncing, and oscillating of the devices arose from specific fundamental processes.

The algorithm deciphered in hours the same Laws of Motion and other properties that took Isaac Newton and his successors centuries to realize.

The new breakthrough is not far removed from Lipson's earlier NSF CAREER award work to develop Starfish, a robot with a "self-image" that could repair itself when damaged.

"The way the robot managed to recover from damage was to create a dynamical model, a self-image," said Lipson. "It then used that model to make predictions about itself."

A dynamical model is a mathematical representation of the way in which a system's components influence each other over time. Lipson and Schmidt realized that if a robot can create dynamical models from data about itself, why not attempt to model the surrounding world as well?

When Lipson and Schmidt experimented with that approach, they learned their algorithm was rediscovering laws that were well known to scientists and engineers, suggesting the algorithm should be able to help uncover new laws for data sets that are less well understood.

"What is fascinating is that in the same way a robot created a dynamical model of itself using robot pieces, we now can create models not from motors and joints, but from components of mathematical objects, like variables, symbols like + and -, and other mathematical operators and functions," said Lipson.

While the algorithm can work with almost any data set, for this experiment Lipson and Schmidt used motion-capture data of pendulums and oscillators—similar to the motion-capture techniques used for special effects in movies. The researchers then fed the data to a computer running the new algorithm, a process modeled on the one driving their Starfish robot.

The computer began its analysis with a broad suite of mathematical building blocks, expressions that the computer could combine to recreate patterns in the data set. Using a computational process called symbolic regression, a process inspired by biological evolution, the computer then took the assemblage of expressions and competed them against each other to find matches that reflected the data.

The goal was to find those aspects of the data that were invariant, that did not change from one observation to the next.

"When you look at a pendulum, for example, some things go up, some go down," said Lipson. "But to recognize that when something goes up another specific thing always go down to keep the total sum constant, this is a key to understanding the observations in a deeper sense—such as recognizing the laws of conservation."

The computer retained the mathematical expressions that were invariant and abandoned those that were not, leaving a set of expressions that matched the data set and predicted future behavior. Because such a process could find patterns that are merely coincidental, the new algorithm also contains a critical step that compares subcomponent expressions, evaluating invariant equations to show that they are meaningful and represent actual natural laws, proof that the results are truly predictive.

Ultimately, a human still has to take the final list of a dozen or so expressions and figure out what they reflect in reality—for example, which expressions are describing a motion or energy-conservation law, or something totally new. Humans are still critical to the process. The computer serves as a data miner to find the laws, but a human must interpret them and give them meaning.

"Physicists like Newton and Kepler could have used a computer running this algorithm to figure out the laws that explain a falling apple or the motion of the planets with just a few hours of computation," said Schmidt, "but a human still needs to pick the appropriate building-blocks and framework, as well as give words and interpretation to laws found by the computer."

In the future, Lipson and Schmidt plan to use the new approach for biological systems. Biology is notoriously complicated to model, and finding fundamental laws for such systems can be difficult. With the new algorithm, the enormous data sets that researchers collect about biological systems may yield invariants, unchanging aspects that may reveal underlying fundamental laws.

DIGITAL MIND: Cornell University researchers Hod Lipson (R) and Michael Schmidt hold up a double pendulum. JONATHAN HILLER/CORNELL UNIVERSITY

Innovations in dairy science

By Debbie Lockrey-Wessel, M.Sc.
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A new wave of health-conscious food products is making its way to grocery stores. These new products contain reduced amounts of fat (saturated and trans-fat), simple sugars, salts, and artificial additives and increased amounts of fiber, antioxidants, and omega-3 fatty acids. However, altering traditional formulas can affect the texture and flavor of food products and make them less appealing to the consumer.

Dairy products are one of the foods for which the formulas are being researched and revised. Scientists at Agriculture and Agri-Food Canada (AAFC) are giving this grocery staple a closer look and creating new ways of using milk ingredients in processed foods.

Their goal is to develop strategies to better use milk solids, improve the flavor and texture of functional dairy foods, and support the emergence of a new generation of high-quality processed foods that appeal to consumers.

Drs. Michel Britten, Daniel St-Gelais, and Gilles Robitaille at AAFC's Food Research and Development Center in Saint-Hyacinthe, Quebec, are examining milk separation technologies, characterizing milk fractions, and formulating processed food with health-enhancing properties.

"Milk, a complex mixture of over 2,000 constituents, is recognized as a healthy food," suggests Dr. Britten. "Current technology allows these components to be separated, purified, and commercially used for their nutritional and technological properties in many other food products."

For example, large amounts of dairy ingredients are used to control the texture and moisture of cheese and yogurt; dairy protein concentrates or isolates help control the texture of processed foods; two other proteins (soluble rennet casein and whey protein isolates) help improve the nutritional and sensory quality of processed food; while purified proteins and protein fragments such as beta-casein and caseinomacropeptide (CMP) provide a source of bioactive peptides (proteins with positive health benefits) in nutraceuticals and functional foods.

Federal scientists are developing an integrated process to generate multiple ingredients from nonfat milk solids and increase their value. "Our goal is to improve the fractionation process to increase the recovery, yield, and purity of ingredients," emphasized Dr. Britten. "Improving these ingredients also creates opportunities to improve processed food quality."

A related project examines the impact of cow and goat's milk protein fraction on the quality of fermented dairy products. "The protein fraction ratios are different in the five goat breeds present in Canada," says Dr. St-Gelais.

"By examining these ratios, we can improve our knowledge of the impact of these substances on how well the liquids flow, and the sensorial properties of various dairy products. This information will help produce enriched milks with improved properties which can then be used to produce superior hard and soft cheeses and yogurts."

The antimicrobial activities of components from cow and goat milk are also being examined to compare their anti-inflammatory properties, antibacterial activity against pathogens such as E. coli and salmonella, and their role in preventing pathogens from attaching to target cells.

"It is now accepted that the benefits of milk consumption are not limited to nutritional functions," say Dr. Robitaille.

"We hope to identify beneficial milk components or mixture of components and determine how milk origins and preparation conditions affect antimicrobial activities. With further research, these ingredients could substitute traditional antibiotics in animal feed and prevent disease in the human gut."

Protecting and delivering bioactive compounds in functional foods is also being addressed. Bioactive ingredients such as vitamins, antioxidants, peptides, and omega-3 can be destroyed by food processing conditions or during storage. AAFC scientists are examining various encapsulation techniques and capsule materials to ensure superior protection and delivery of the selected bioactive ingredients.

"Dairy products have been through some amazing transitions which benefit the health and wellness of Canadian consumers," emphasized Dr. Britten.

"We hope our research efforts will help transition the dairy and food processing industry into the next generation of value-added functional dairy foods, and support the emergence of a new generation of high quality processed foods," he said.