Prepping for data from the Nancy Grace Roman Space Telescope

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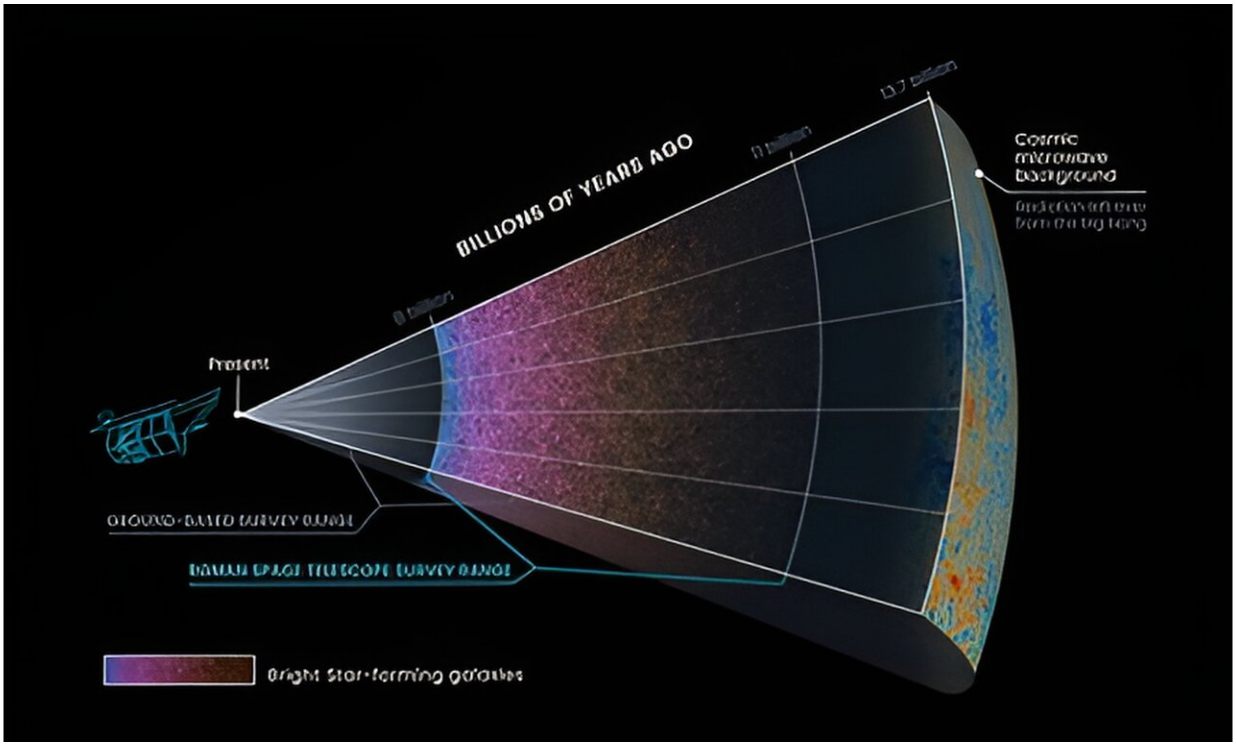

Diagram of Nancy Grace Roman Space Telescope's view into the distant universe (and deep past). Credit: Roman GRS mock (2021) visualized. Credit: Data provided by Z. Zhai, Y. Wang (Caltech/IPAC), and A. Benson (Carnegie); data visualization by J. DePasquale and D. Player (STScI).

As part of a plan to prepare for the quantity and range of data that will be coming in from the Nancy Grace Roman Space Telescope, currently scheduled to launch by May 2027, NASA has granted funding to five project infrastructure teams (PITs), which will write software, run simulations, and plot out optimal uses of the telescope's data stream.

Three of these PITs, each of which has received five-year, multimillion-dollar grants for their work, are based in Pasadena and affiliated with Caltech faculty and staff. Mansi Kasliwal (MS '07, Ph.D. '11), Caltech professor of astronomy, heads up the RAPID (Roman Alerts Promptly from Image Differencing) team; Yun Wang, senior scientist with Caltech's IPAC, is in charge of infrastructure for the galaxy redshift survey; and Olivier Doré, principal scientist at JPL, which Caltech manages for NASA, leads the weak-lensing team with Dida Markovic, the deputy principal investigator, who also works at JPL.

The Roman Space Telescope project began in 2010 under the name Wide-Field InfraRed Space Telescope (WFIRST), promising to provide the same image precision obtained by the Hubble Space Telescope but with a field of vision at least 100 times larger, making it possible to survey the sky that much faster. The mission's observations of galaxies and supernovas will tell us much about the history and expansion of the cosmos. With another technology demonstration instrument on board, the coronagraph, exoplanets in other star systems can be imaged. WFIRST was named the top priority for astrophysics in the 2010 Astronomy and Astrophysics Decadal Survey, a list of research goals undertaken every decade by the National Research Council of the National Academy of Sciences since the 1960s.

In 2020, WFIRST was renamed in honor of Nancy Grace Roman, who served as NASA's Chief of Astronomy and Solar Physics from 1961 to 1979 and lobbied relentlessly for the construction of the Hubble Space Telescope. "The Roman mission was conceived quite a while ago," Kasliwal explains, "but so much has changed since then. "We now have actually seen light, or electromagnetic radiation, from powerful cosmic events associated with gravitational waves."

These new findings have opened avenues for those who, like Kasliwal, Wang, and Doré, are intent on making the best possible use of Roman's infrared observing run. "The Roman hardware is already built and being tested," Wang says, "but the observing plan and software are still under development, so we can help to optimize it."

Kasliwal's PIT team is responsible for the creation of an alert system—RAPID—that tells astronomers where they might find interesting new phenomena to observe. RAPID achieves its goal through a process known as image differencing. "We take an image again and again of the same piece of the sky. Then we compare the images to see what has changed," Kasliwal says. "We're looking for fireworks, cosmic fireworks … anything that explodes, anything that is changing before our eyes. This is called time-domain astronomy. Time-domain astronomy is undergoing a revolution because we have so many very sensitive telescopes now that are capable of understanding the dynamic universe."

Working with the Zwicky Transient Facility and Palomar Gattini IR, optical and near-infrared telescopes at Caltech's Palomar Observatory, which survey the entire night sky, has given Kasliwal the experience she needs to design the RAPID system for the Roman Telescope. "As the Roman data arrive, we will continuously be doing image differencing. When we see something that's changed, we'll issue an alert,'" Kasliwal explains. "We have a lot of practice in doing this at Palomar. We take an image, compare it to previous images, and then send out an alert seven minutes later, so astronomers all over the world know exactly where in the sky something interesting is happening."

To get RAPID up to speed before the Roman Telescope's launch, Kasliwal says she is expanding a team of scientists and software professionals to "deliver a data pipeline that will be reliable and robust, a service to the community." At this point, RAPID has a core team of six staff scientists housed at IPAC and in the Cahill Center for Astronomy and Astrophysics on the Caltech campus. Each member brings their own expertise in machine learning, alert pipelines, supernovae, stars, asteroids, and so on. "Right now, we are working with simulations," Kasliwal says. "We inject scenarios into these simulations, such as the appearance of a tidal disruption flare—that's when a star gets really close to massive black hole and gets ripped up—to learn what Roman's data stream might look like."

The Roman Telescope will also be able to share tasks with NASA's James Webb Space Telescope, another infrared observatory that has been orbiting the sun since December 2021. "Roman will be the discovery engine," Kasliwal says, "and then the James Webb Space Telescope can do spectroscopic follow up and detailed characterization. This will allow us to learn what elements a particular neutron star merger, for example, is composed of."

One primary question the Roman mission is poised to answer is how quickly the expansion of the universe is accelerating.

To better understand the big bang that birthed our universe, imagine a fireworks show with an enormous explosion filling the sky, the sort that is known as a coconut shell. It begins with a dramatic explosion of sparks from a pinpoint center. These sparks flare out swiftly and evenly in all directions from the center before they gradually slow down and die out. This is not what is happening in our universe. Its expansion is getting faster rather than slowing down.

"This is contrary to our expectations," Wang says, "because if matter is all there is in the universe, the expansion of the universe should be decelerating today. Its acceleration requires the existence of something other than matter: perhaps a form of energy. We call it dark energy because it's not visible to us. We don't know if this is truly an unknown component of energy, or if we need to modify our theory of gravity (i.e., Albert Einstein's theory of general relativity) to account for these observations. It's a huge mystery, one of the most exciting and challenging problems in cosmology and physics today."

There are three ways of measuring the acceleration of the universe's expansion, and the Roman Telescope will utilize all of them. The first is by looking at Type Ia supernovas, as has been done before. Because these supernovas all have roughly the same level of luminosity, they have been described as "cosmological standard candles." When closer to us, they shine brighter. When farther away—which is also back in time, since we are looking at light that travels to us from billions of years ago—they appear dimmer.

The second way is through a phenomenon called weak gravitational lensing, the slight bending of light from galaxies due to the gravity from matter lying between us and the galaxies. The measurement of the resultant subtle changes in the shapes of galaxies probes the distribution of cosmic matter as well as the activity of dark energy. Doré's team will concentrate on this effort.

"Gravitational lensing allows us to conduct a complete census of matter. With the Roman Telescope, we will conduct such a census over a very large swath of the universe, which will teach us so much more about the universe," Doré says. "By creating these teams, NASA recognizes it will take the richness and diversity of a very broad scientific community to make the most of this unprecedented observatory."

Wang's team will build the infrastructure for the third way of measuring the acceleration of the expanding universe, a galaxy redshift survey. This survey enables astronomers to visualize the three-dimensional distribution of galaxies in the universe, probing the cosmic expansion history as well as the growth history of large-scale structure in the universe, both of which are sensitive to dark energy. (The term redshift refers to the distance of galaxies; the farther a galaxy, the more it will shift, or stretch, light into redder wavelengths due to the expansion of the universe.) The Roman galaxy redshift survey PIT consists of 11 participating institutions led by Caltech. The team includes leaders from all the current and planned galaxy redshift surveys from ground-based facilities, as well as the European Space Agency's Euclid mission.

"The Roman Telescope will observe galaxies that are very far away," Wang explains. "These are ideal tracers of the large-scale structure of the universe. The Roman Telescope uses these galaxy tracers over a very wide redshift range—that is, closer and farther away—which translates into a very wide range in the history of the cosmos. With this information, we can almost read off the expansion rate of the universe at various distances from us. But by having additional data sets using Type Ia supernovas and weak gravitational lensing, we can cross-check our results. That's why I'm confident that within 10 years we should be able to find some real answers to our questions about what causes the accelerated expansion of the universe."

Wang says she was drawn to the excitement and romance of astronomy and continues to delight in it. "I was born a romantic," Wang says. "When I was a baby, my dad would recite ancient Chinese poetry to calm me down. Then when I was growing up, I recited poetry to myself while looking at the night sky. I grew up in a rural area. It was very dark, so the sky was spectacular. Later, when I was attending Tsinghua University, I went to a colloquium on cosmology. I was astounded and thought, 'Wow, you mean you can actually study the whole universe using science?' After that, I was obsessed with becoming a cosmologist."

Kasliwal learned about infrared astronomy when she was an undergraduate at Cornell University majoring in engineering physics. "I was always interested in astronomy, but I had no idea what it meant to be an astronomer," Kasliwal says. "It just sounded like a crazy dream at that point. But then I got a job in the lab of Jim Houck, who built the infrared spectrometer on the Spitzer Space Telescope, a NASA infrared space telescope that operated for more than 15 years. I got to see Houck's team collect data and be so excited learning something new every single day about the universe. That's what really piqued my interest in astronomy. The universe keeps you on your toes. There's never a dull moment."

Meanwhile, Wang says she is "not afraid to think big." She adds, "I just think about what matters, what's important, what are the key questions that should be asked. The reward will hopefully be the discoveries. There will be discoveries one way or the other!"

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