Window of opportunity: *conducting Earth sciences in the International Space Station era*

When the U.S. Laboratory element of the International Space Station becomes operational, astronauts will be able to conduct long-term, global monitoring of the Earth by operating remote sensing experiments and by taking photographs through the highest quality optical window ever installed in a crewed spacecraft.

The U.S. Laboratory, with its nadir window facing Earth, coupled with other new equipment and facilities to be installed aboard the laboratory, will offer scientists an unprecedented platform from which to study the planet.

"The station will allow us to monitor the Earth's processes from a long-duration perspective," said Dr. Kamlesh Lulla, chief of JSC's Office of Earth Sciences. "That's one major advantage – the ability to do long-term monitoring using photographs. In addition, we will be able to use the other research facilities aboard the station to devise experiments to complement our photographic observations."

The 20-inch-diameter circular window will be the centerpiece of a continuous program of an Earth remote sensing program. And the crew will have an incredible vantage point from which to view the planet due to the 51.6-degree inclination of the ISS, which allows it to fly over more than 75 percent of the Earth's surface, an area containing 95 percent of the world's population.

Manufactured by Corning, Inc., the four-piece window assembly consists of a thin exterior "debris" pane, primary and secondary pressure panes, and an interior "scratch" pane. The assembly also has an external shutter to protect the glass from micrometeoroid and orbital debris impacts. Allowing better than 98 percent of the visible light that falls on the exterior side of window to pass through undistorted to the interior side as compared to less than 80 percent with significant distortion for the shuttle's windows, the U.S. Laboratory's window assembly can be considered more a highly polished camera or telescope lens than a window and will require the same kind of care by the astronauts that one uses for lens when it comes to maintenance and cleaning.

The interior and exterior panes are designed to be replaceable in orbit. The exterior pane, which is susceptible to impact damage and contamination, can be removed by space-walking astronauts, returned to Earth for refurbishment, and then reinstalled. The interior "scratch" pane is also removable for those occasions when precision remote sensing instrumentation is needed to make measurements through the window port. The entire window assembly could be removed and replaced if necessary, but this would only be necessary if orbital debris damaged the debris pane, which is a low-probability event in a nadir-facing window.

The Office of Earth Sciences has been involved in the development of the window and other window-related activities from the start and supported optical calibration tests that were performed on the window assembly in April at the Kennedy Space Center.

"There are two aspects to the project, the hardware fabrication of the glass for the window and its maintenance, and the scientific use of the window-based facility," said Dr. Lulla. "My role is to ensure that robust, careful science will be done from the window. As a result, my responsibility is to make sure that the window is calibrated and that it will be properly maintained and operated so that the science can be done."

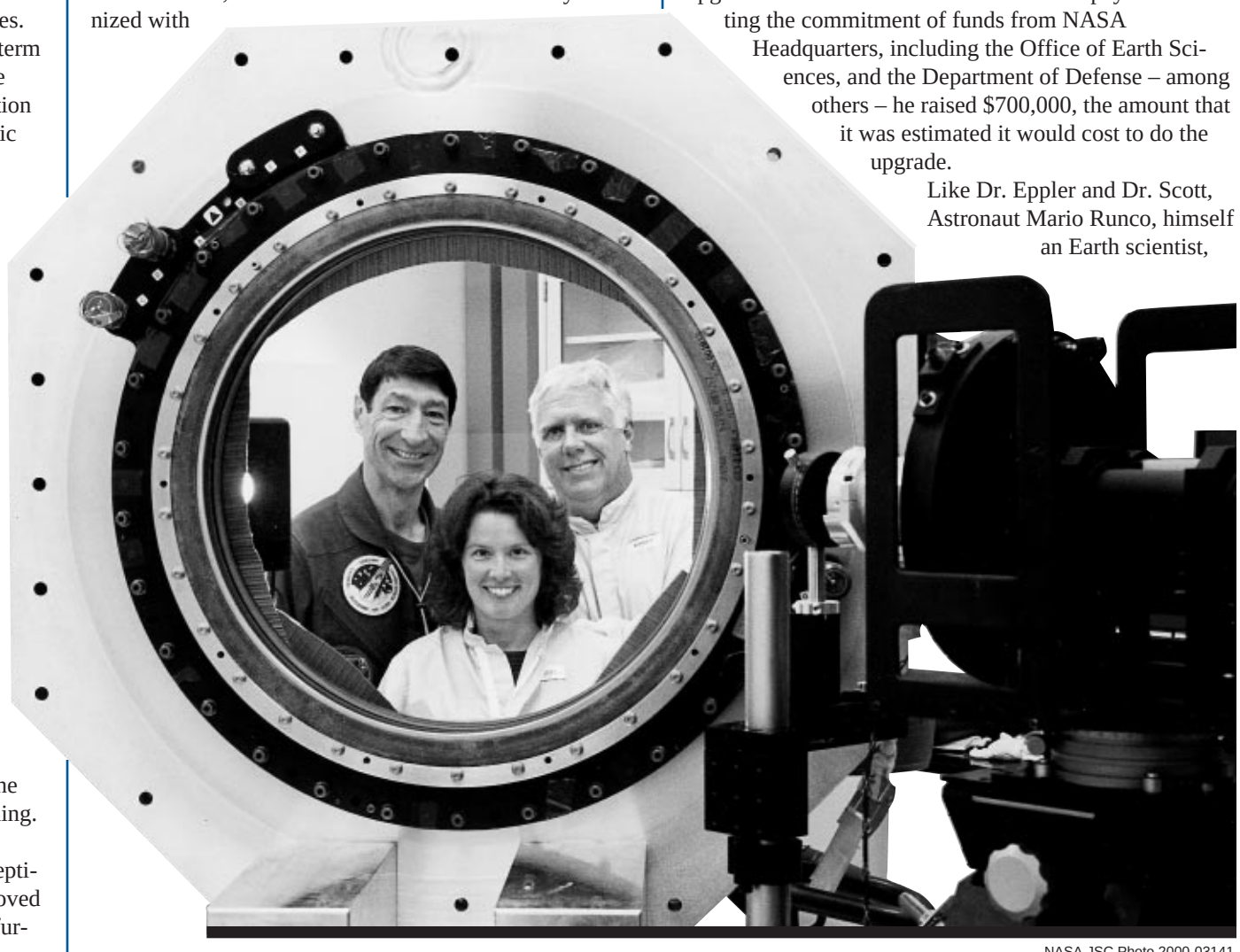
Dr. Lulla's office has also supported development of the Window Observational Research Facility (WORF), a rack structure located behind the window that will provide support services including power and mounting points to help position and operate cameras, sensors, telescopes, and other equipment. The WORF, which will be installed in the U.S. Laboratory once it is in orbit, will also allow astronauts to use the window for hand-held Earth observation photography taken aboard the station as well as support payloads that will conduct highly detailed radiometric remote sensing of the Earth's surface.

"The WORF will supplement and complement what we do with astronaut-acquired hand-held imagery," said Dr. Lulla. "That does not diminish the value of hand-held imagery because it is very vital. The WORF will be used to conduct well-planned science using many types of remote sensing instruments – multi- and hyper-spectral sensors as well as cameras. There still will be times when the crew will have to take hand-held photos of vital, episodic events. So the former will not replace the latter. I view them as complementary."

In addition to remote sensing experiments and hand-held photography that will be conducted in the WORF, payloads attached to the outside of the pressurized volume of the ISS will also make observations of the Earth.

"We see a three-pronged approach to Earth science for International Space Station operations," said Dr. Lulla. "First, the crewmembers will conduct observations through any of the station windows using hand-held instruments. Secondly, we will have use of the optical quality window and the WORF for precision remote sensing observations. Thirdly, Earth science will occur from payloads attached to the outside of the modules.

"Moreover, these external instruments can be synchronized with instruments in the WORF and with hand-held cameras. For example, we could have an automated instrument on the outside of the station measuring air quality on Earth in a certain area. While that instrument is operating, we could have the crew take photos by hand and, in addition, have a different remote sensing instrument measuring a different wavelength range in the WORF observing the same area. That way, we'll be able to get simultaneous remote sensing measurements in several different wavelength bands and supporting hand-held photos."



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Astronaut Mario Runco, Dr. Karen Scott of the Aerospace Corporation and Dr. Dean Eppler of Science Applications International Corporation look through the U.S. Laboratory nadir research window.

Plans did not originally call for the use of optical glass for the Earth-oriented window on the U.S. Laboratory. According to Dr. Dean Eppler, senior scientist with Science Applications International Corporation, the initial plan was to use general viewing glass, which is basically shuttle glass, which was in turn originally derived from X-15 aircraft window requirements. Designed primarily to support pilots so they could land the shuttle, this glass does not allow photographers to capture high-resolution imagery or allow the operation of precision remote sensing instruments.

Dr. Eppler worked with a team of people across the government and contractor community, NASA centers, and JSC divisions to have the window upgraded. "It's been a real team effort. We've had a lot of cooperation from management, the Payloads Office and the Space Station Program Office. Nobody ever said, 'No – you can't do this.' It was always, 'Tell us what you think you can do.' This window is going to be a feather in the station's cap when it's up."

Dr. Karen Scott, senior project engineer with Aerospace Corporation, has been the primary optical scientist for the development of the science window and the WORF. Scott was instrumental in writing the optical requirements for the science window and in showing the feasibility of the upgrade by ensuring an analysis was performed to show that the on-orbit thermal gradients and pressure loads would not degrade the window's performance. This analysis and additional optical testing of the general quality U.S. Laboratory windows were the technical data required to explain to management the value of an upgrade.

"In 1989, I performed some optical tests on the shuttle windows, so we knew the optical quality of those windows," said Dr. Scott. "In 1995 and 1996, Dr. Eppler and I performed more optical tests on two sets of 20-inch general quality International Space Station windows. With that information, we knew what an upgrade could provide."

Dr. Eppler has pushed for the space station's superior quality window since 1995. He sealed a deal with station management that he would not ask to have the window upgraded if he could not raise the funds to pay for it. Getting the commitment of funds from NASA Headquarters, including the Office of Earth Sciences, and the Department of Defense – among others – he raised $700,000, the amount that it was estimated it would cost to do the upgrade.

Like Dr. Eppler and Dr. Scott, Astronaut Mario Runco, himself an Earth scientist, has been a strong supporter of the laboratory's high-quality Earth-facing window. In addition to his support of the upgrade of the pressure panes and debris pane, he has been instrumental in upgrading the internally mounted scratch pane.

"Initially there were virtually no requirements for optical performance for the windows, and existing design requirements at the time only considered such items as structural performance or condensation prevention rather than to ensure that light passed through undisturbed," said Runco. "As a result, the first set of scratch panes delivered, for example, were very poor in optical transmission and were even tinted a very dark yellow. Fortunately, this was discovered early enough to be able to correct the problem without significant cost impacts."

That was the catalyst that drove the need for optical performance criteria for all windows. For the past year, Runco and Dr. Scott have been involved in determining requirements for all station windows, including those intended for hatch, photographic or scientific purposes. "So now you can pick which category you need for your use rather than just having one set of requirements for all windows," said Dr. Scott.

Remote sensing entails the characterization of a remote object by measurement of sunlight reflected from that object. When observing objects in orbit, the effects of the atmosphere must be removed from measured data because it absorbs and scatters light. One of the keys to using the science window for remote sensing work is that, like the atmosphere, the absorption and scatter induced by the three high-quality panes must also be understood.

From April 4-7 of this year, a series of tests were performed on the flight Lab science window, before its installation in the lab module, to characterize the absorption and scatter characteristics as a function of look angle. Dr. Scott led a team from the University of Arizona Remote Sensing Group that made calibration

Please see **WINDOW** on Page 5