pendent optical path in one or both of the arms of the interferometer. By intelligently choosing the number, material and thickness of a series of glass plates, a nearly uniform, arbitrary phase shift can be introduced between two arms of an interferometer.

There are several constraints that make choosing the number, type, and thickness of materials a difficult problem, such as the size of the bandwidth to be nulled. Several solutions have been found for bandwidths on the order of 20 to 30 percent ($\Delta\lambda/\lambda_c$) in the mid-infrared region. However, uniform phase shifts over a larger bandwidth in the visible regime between 480 to 960 nm (67 percent) remain difficult to obtain at the tolerances necessary for exoplanet detection.

A configuration of 10 dispersive glass plates was developed to be used as an achromatic phase shifter in nulling interferometry. Five glass plates were placed in each arm of the interferometer and an additional vacuum distance was also included in the second arm of the interferometer. This configuration creates a phase shift of π radians with an average error of 5.97×10^{-8} radians and standard deviation of 3.07×10^{-4} radians. To reduce ghost reflections and interference effects from neighboring elements, the glass plates are tilted such that the beam does not strike each plate at normal incidence. Reflections will therefore walk out of the system and not contribute to the intensity when the beams are recombined.

Tilting the glass plates, however, introduces several other problems that must be mitigated: (1) the polarization of a beam changes when refracted at an interface at non-normal incidence; (2) the beam experiences lateral chromatic spread as it traverses multiple glass plates; (3) at each surface, wavelength-dependent intensity losses will occur due to reflection. For a fixed angle of incidence, each of these effects must be balanced between each arm of the interferometer in order to ensure a deep null.

The solution was found using a nonlinear optimization routine that minimized an objective function relating phase shift, intensity difference, chromatic beam spread, and polarization difference to the desired parameters: glass plate material and thickness. In addition to providing a uniform, broadband phase shift, the configuration achieves an average difference in intensity transmission between the two arms of the interferometer of 0.016 percent with a standard deviation of 3.64×10^{-4} percent, an average difference in polarization between the two arms of the interferometer of 5.47×10^{-5} percent with a standard deviation of 1.57×10^{-6} percent, and an average chromatic beam shift between the two arms of the interferometer of –47.53 microns with a wavelength-by-wavelength spread of 0.389 microns.

This work was done by Matthew R. Bolcar and Richard G. Lyon of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15830-1

Super Dwarf Wheat for Growth in Confined Spaces

Lyndon B. Johnson Space Center, Houston, Texas

USU-Perigee is a dwarf red spring wheat that is a hybrid of a high-yield early tall wheat (USU-Apogee) and a low-yield, extremely short wheat that has poor agronomic characteristics. USU-Perigee was selected for its extremely short height (≈0.3 m) and high yield — characteristics that make it suitable for growth in confined spaces in controlled environments. Other desirable characteristics include rapid development and resistance to a leaf-tip necrosis, associated with calcium deficiency, that occurs in other wheat cultivars under rapid-growth conditions (particularly, continuous light).

Heads emerge after only 21 days of growth in continuous light at a constant temperature of 25 °C. In tests, USU-Perigee was found to outyield other full dwarf (defined as <0.4 m tall) wheat cultivars: The yield advantage at a constant temperature of 23 °C was found to be about 30 percent. Originally intended as a candidate food crop to be grown aboard spacecraft on long missions, this cultivar could also be grown in terrestrial growth chambers and could be useful for plant-physiology and -pathology studies.

This work was done by Bruce Bugbee of Utah State University for Johnson Space Center. For more information, see www.usu.edu/cpl/Progression.pdf. MSC-24200-1

Fine Guidance Sensing for Coronagraphic Observatories

NASA's Jet Propulsion Laboratory, Pasadena, California

Three options have been developed for Fine Guidance Sensing (FGS) for coronagraphic observatories using a Fine Guidance Camera within a coronagraphic instrument. Coronagraphic observatories require very fine precision pointing in order to image faint objects at very small distances from a target star. The Fine Guidance Camera measures the direction to the target star.

The first option, referred to as Spot, was to collect all of the light reflected from a coronagraph occulter onto a focal plane, producing an Airy-type point spread function (PSF). This would allow almost all of the starlight from the central star to be used for centroiding. The second approach, referred to as Punctured Disk, collects the light that bypasses a central obscuration, producing a PSF with a punctured central disk. The final approach, referred to as Lyot, collects light after passing through the occulter at the Lyot stop.

The study includes generation of representative images for each option by the science team, followed by an engineering evaluation of a centroiding or a photometric algorithm for each option. After the alignment of the coronagraph to the fine guidance system, a "nulling" point on the FGS focal point is determined by calibration. This alignment is implemented by a fine alignment mechanism that is part of the fine guidance camera selection mirror. If the star images meet the modeling assumptions, and the star "centroid" can be driven to that nulling point, the contrast for the coronagraph will be maximized.

This work was done by Paul Brugarolas, James W. Alexander, John T. Trauger, and Dwight C. Moody of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47067

Single-Antenna Temperature- and Humidity-Sounding Microwave Receiver

This technology has applications in imagers and broadband communications.

NASA's Jet Propulsion Laboratory, Pasadena, California

For humidity and temperature sounding of Earth's atmosphere, a single-antenna/LNA (low-noise amplifier) is needed in place of two separate antennas for the two frequency bands. This results in significant mass and power savings for GeoSTAR that is comprised of hundreds of antennas per frequency channel. Furthermore, spatial anti-aliasing would reduce the number of horns. An anti-aliasing horn antenna will enable focusing the instrument field of view to the "hurricane corridor" by reducing spatial aliasing, and thus reduce the number of required horns by up to 50 percent.

The single antenna/receiver assembly was designed and fabricated by a commercial vendor. The 118–183-GHz horn is based upon a profiled, smooth-wall design, and the OMT (orthomode transducer) on a quad-ridge design. At the input end, the OMT presents four very closely spaced ridges [0.0007 in. (18 µm)]. The fabricated assembly contains a single horn antenna and low-noise broadband receiver front-end assembly for passive remote sensing of both temperature and humidity profiles in the Earth's atmosphere at 118 and 183 GHz. The wideband feed with dual polarization capability is the first broadband low noise MMIC receiver with the 118 to 183 GHz bandwidth.

This technology will significantly reduce PATH/GeoSTAR mass and power while maintaining 90 percent of the measurement capabilities. This is required for a Mission-of-Opportunity on NOAA's GOES-R satellite now being developed, which in turn will make it possible to implement a Decadal-Survey mission for a fraction of the cost and much sooner than would otherwise be possible.

This work was done by Daniel J. Hoppe, David M. Pukala, Bjorn H. Lambrigtsen, Mary M. Soria, Heather R. Owen, Alan B. Tanner, Peter J. Bruneau, Alan K. Johnson, Pekka P. Kangaslahti, and Todd C. Gaier of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47351

Multi-Wavelength, Multi-Beam, and Polarization-Sensitive Laser Transmitter for Surface Mapping

This laser transmitter can be used for precision mapping and remote sensing.

Goddard Space Flight Center, Greenbelt, Maryland

A multi-beam, multi-color, polarized laser transmitter has been developed for mapping applications. It uses commercial off-the-shelf components for a low-cost approach for a ruggedized laser suitable for field deployment.

The laser transmitter design is capable of delivering dual wavelengths, multiple beams on each wavelength with equal (or variable) intensities per beam, and a well-defined state of polarization. This laser transmitter has been flown on several airborne campaigns for the Slope Imaging Multi-Polarization Photon Counting Lidar (SIMPL) instrument, and at the time of this reporting is at a technology readiness level of between 5 and 6.

The laser is a 1,064-nm microchip high-repetition-rate laser emitting energy of about 8 microjoules per pulse. The beam was frequency-doubled to 532 nm using a KTP ($KTiOPO_4$) nonlinear crystal [other nonlinear crystals such as LBO (LiB_3O_5) or periodically poled lithium niobiate can be used as well, depending on the conversion efficiency requirements], and the conversion efficiency was approximately 30 percent. The KTP was under temperature control using a thermoelectric cooler and a feedback monitoring thermistor. The dual-wavelength beams were then spectrally separated and each color went through its own optical path, which consisted of a beam-shaping lens, quarter-wave plate (QWP), and a birefringent crystal (in this case, a calcite crystal, but others such as vanadate can be used).

The QWP and calcite crystal set was used to convert the laser beams from a linearly polarized state to circularly polarized light, which when injected into a calcite crystal, will spatially separate the circularly polarized light into the two linear polarized components. The spatial separation of the two linearly polarized components is determined by the length of the crystal. A second set of QWP and calcite then further separated the two beams into four. Additional sets of QWP and calcite can be used to further split the beams into multiple orders of two.

The spatially separated beams had alternating linearly polarization states; a half-wave plate (HWP) array was then made to rotate the alternating states of