POLICY FORUM: ASTRONOMY

Laser Telemetry from Space

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A challenge to Earth-viewing satellites and astronomical space stations is the enormous rise in projected rates of data gathering and transmission. Detector arrays have exhibited progressively higher sensitivities and dynamic ranges that have enabled exquisitely high spectral, spatial, or time resolution. Space missions now on the drawing boards will gather data at rates of several gigabits per second (Gbps) (*1*). The accumulated information will need to be periodically telemetered to the ground in brief intervals to permit ground stations to sequentially interrogate an armada of spacecraft in different orbits in the course of a day. Downloading data during such brief sessions will require telemetry capable of transmitting at rates of the order of 100 Gbps. But current systems are orders of magnitude too slow.

To sidestep this problem, many observers have placed their hopes on onboard data compression, a technique that culls out significant data for transmission to ground and discards the rest. However, data compression is based on the assumption that the characteristics of a data stream are known; evidence for unanticipated, surprising new natural phenomena may be inadvertently discarded. Also, unpredictable noise spikes need to be identified, characterized, and their memory effect on detector sensitivity, amplifier gain, and other instrumental parameters clearly defined (*2*). Reliable use of data is possible only if the full data set is transmitted.

Telecommunications are vital to the astrophysical, geophysical, meteorological, climatological, and Earth-resource communities. If work starts on a near-infrared (near-IR) telemetry system today, an effective system can be available in 10 to 15 years to service missions now on the drawing boards. The U.S. National Academy of Sciences has recognized the problem (*3*), but concerted action will be required to prevent a crisis in the form of a data transmission bottleneck.

Available bandwidth limits existing radiotelemetry systems. Data transmission rates are directly proportional to transmission bandwidth, which never exceeds a small fraction of the electromagnetic "carrier" wave frequency that the transmitted data modulate. Although telemetry systems now approach bandwidths of 8 GHz, bandwidth cannot dramatically increase unless carrier frequencies increase proportionally.

Telemetry systems in the K band, with carrier frequencies ranging as high as 40 GHz, are gradually coming into use. But atmospheric absorption becomes a serious problem if this frequency is increased by more than another order of magnitude. Current international allocations for transmission between Earth and space range only up to 275 GHz (*4*), because atmospheric gases strongly absorb above this frequency and prevent transmission. A leap of a factor of 1000 is needed to reach near-IR frequencies, where the atmosphere again transmits well. Fortunately, much of the technology required for near-IR telemetry has been developed for fiber telecommunications particularly in the 1500- to 1600-nm band (*5*). The European Space Agency (ESA) recently demonstrated near-IR laser communication between the SPOT-4 and ARTEMIS orbiting satellites (*6*, *7*). Initial tests used data rates of only 50 Mbps. This can be increased by factors of thousands without basic changes of principle but will require increased signal power, a suitable transmitter, and adequate onboard memory. Well-separated mountaintop receiving stations around the globe are also needed to receive transmissions from spacecraft in various orbits.

Ground receiving stations are simply large optical telescopes, which we know how to build. On high mountaintops, the atmosphere transmits signals from space to ground with a satisfactory efficiency of 70% at 1500 to 1600 nm. Signal power onboard spacecraft can be provided by existing laser diodes with EDFA (erbium-doped fiber amplifiers) or Raman amplifiers, both in extensive use at 1550 nm in the telecommunications industry (*8*). To obtain sufficient bandwidth, dense wavelength-division multiplexing (DWDM), another widely employed technique, can be used (*9*). The spacecraft transmitter can be a 1-meter-class telescope with high pointing accuracy and adaptive optics to assure a properly collimated beam. The only component not readily available is the onboard memory required to store several days' worth of collected data.

A data gathering rate of 1 Gbps accumulates $\sim 10^{14}$ bits of information in the course of a day. Commercially available solid-state memories store up to ~128 gigabytes of memory, or $\sim 10^{12}$ bits. At current growth rates, the required factor of ~100 increase in memory capacity will become commercially available within 10 to 15 years.

The total cost of building and maintaining a laser telemetry system is likely to be comparable to the cost of one medium-sized space mission. Based on current costs, three fully equipped, 10-meter-aperture ground stations might cost roughly $200 million. Research and development of the satellite-borne portion of the laser telemetry system is likely to cost in the range of an additional $100 million to $200 million. Once these initial investments have been made, installation of transmitters on individual spacecraft plus mission operations costs should be comparable to those of radio telemetry systems.

In the United States NASA has supported development work (*5*). ESA's demonstration of laser communication between two satellites in Earth orbit is especially reassuring (*6*, *7*), as communications between a spacecraft in deep space and a ground station on the rotating Earth involve similarly accelerating transmitters and receivers, requiring comparably precise aiming of the telemetry laser beam.

Work toward a near-IR telemetry system carries little risk and will rapidly pay for itself in the efficiency with which data can be gathered and transmitted. However, progress will come about only with the allocation of sufficient resources by NASA and ESA (the two lead agencies in the field) and the focused attention of the scientific community.

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References and Notes

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