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INFRARED ASTRONOMY FROM THE MOON

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The Moon offers some remarkable opportunities for performing infrared astronomy. Although the transportation overhead can be expected to be very large compared with that for facilities in Earth orbit, certain aspects of the lunar environment should allow significant simplifications in the design of telescopes with background-limited performance, at least in some parts of the thermal-infrared spectrum.

Why Leave the Earth To Perform Infrared Astronomy?

Infrared astronomy from ground-based telescopes is severely handicapped compared to that possible with observations from outside the atmosphere. A serious problem caused by the atmosphere is absorption (and reemission) of light in large swaths across the infrared spectrum. At wavelengths between 1 and 20 µm, less than half the spectrum of an astronomical source can be seen from the ground. At longer wavelengths out to roughly 1 mm, almost none of the light gets through to the telescope. Much of this absorption is due to water vapor, which can be substantially avoided by stratospheric telescope platforms, but large pieces of the spectrum remain obscured by species with longer scale height, such as carbon dioxide and ozone. Even at wavelengths at which the atmosphere is fairly transparent, thermal emission from a warm telescope and the atmosphere constitutes the ultimate limitation on infrared sensitivity to faint sources.

Although the effects of "seeing" are somewhat smaller at infrared than at optical wavelengths (i.e., the seeing disk is about half the size at 10 µm compared to that in the visible), most infrared imaging that is possible from the ground has been done in seeing-limited pixels. Observations from outside the atmosphere render the point source profile (PSP) completely diffraction-limited, and thus highly stable. Such PSP stability will allow us to take maximum advantage of superresolution techniques that allow the Rayleigh limit to be exceeded.

Why Go All the Way to the Moon?

The lunar environment offers certain advantages over Earth orbit for performing infrared astronomy. The modest lunar gravity, although perhaps an operational disadvantage in the construction of a large facility, yields the convenience of superb pointing stability. Lunar telescopes will not be subjected to the varying gravitational torques and residual atmospheric drag associated with Earth-orbiting telescopes. The lunar surface also provides exceptionally stable baselines for coherent infrared interferometry.

The vacuum on the Moon is superb ($\sim 10^{-12}$ torr), even by comparison to Earth orbit. Low Earth orbit (LEO) telescopes are expected to see strong emission lines as a result of excitation of residual atmospheric molecules by collision with the spacecraft. Special care must be taken with cryogenic LEO telescopes to avoid icing the optics with these residual gases. Neither of these effects is expected to be important on the Moon.

The combination of excellent lunar vacuum and the massive thermal shielding, provided, for example, by the walls of a crater near a lunar pole, provides an opportunity for efficient passive cooling of a lunar telescope. This is a great advantage in that cryogen consumption may be minimized or even avoided entirely. For a well-designed telescope, one that is radiatively decoupled from the lunar soil, is shielded from direct or diffracted sunlight, has a structure that is blackened to ensure excellent thermal coupling to the cold sky, and is isolated from dissipative electronics, the entire structure will efficiently cool as it passively radiates to space. How cold can a passively cooled lunar telescope get? Lunar soil cools to ~90 K by the end of the lunar night, and small, specialized Earth-orbit packages (the exteriors of which are bathed, throughout their orbits, by sunlight and earthlight) have been sustained passively to temperatures as low as ~100 K. Therefore, one can expect even better performance from a well-designed, optimally situated lunar telescope. Figure 1 is a comparison of the celestial background power with that from a telescope of different temperatures and illustrates the advantage of cooled optics. The solid lines indicate the celestial background, whereas the dashed lines indicate the background from a clean telescope. It should be noted that the background emission from a 300-K ground-based telescope is orders of magnitude higher than anything shown in this figure. We can see from this figure that, for example, if it is possible to passively cool a lunar telescope to ~60 K or less, celestial background-limited data can be obtained to a wavelength of about 200 μm.

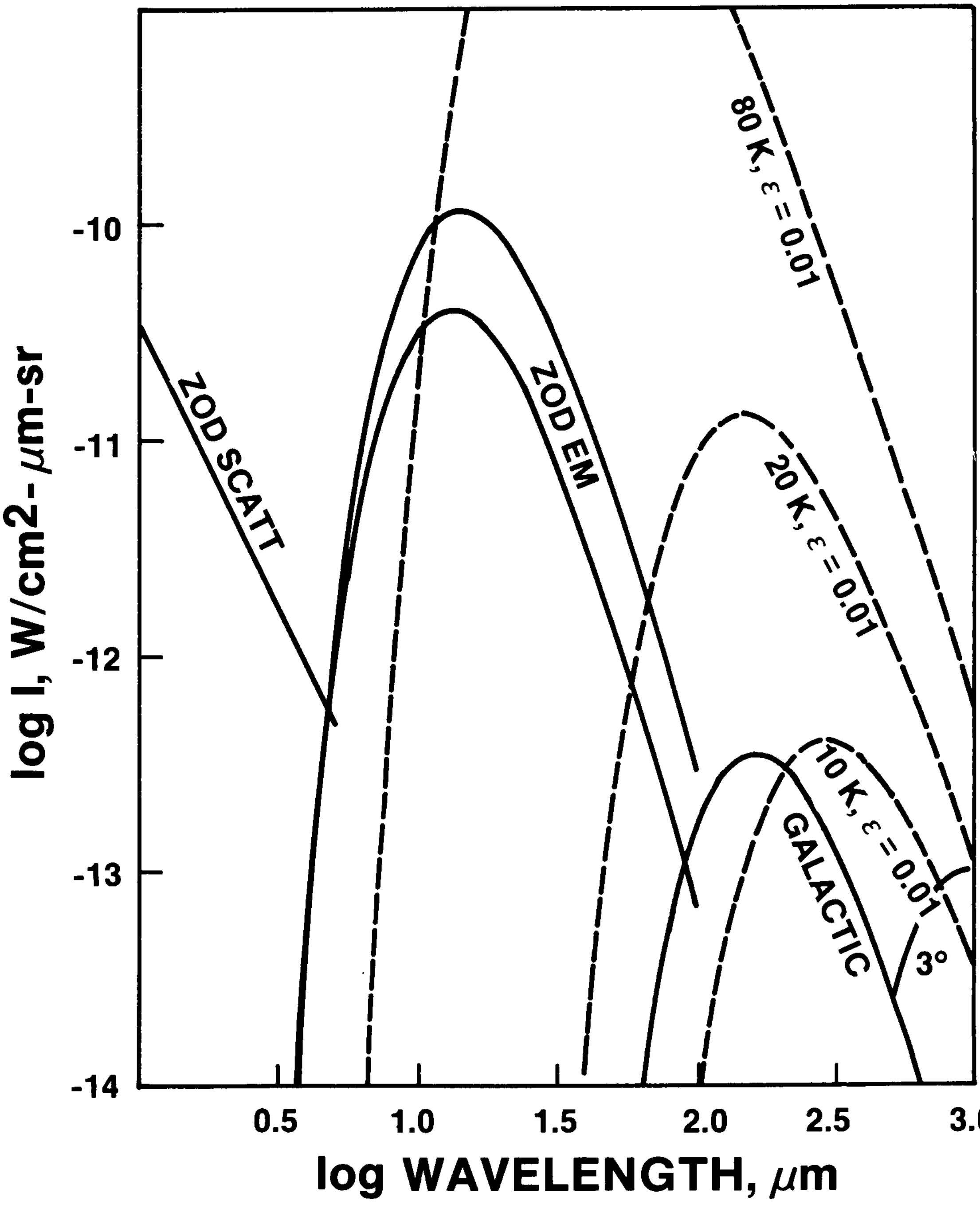

Figure 1.- Comparison of celestial background power (solid lines) with background power from a clean telescope of different temperatures (dashed lines).

PART III
LUNAR RADIOFREQUENCY TELESCOPES

The response of those who attended the workshop and the number of papers that were written on radio astronomy indicate that participants are enthusiastic about the possibilities afforded radio astronomy by the establishment of a lunar base. Some interesting new applications of current ground-based radio telescopes and the opening of the last window in the electromagnetic spectrum at very low frequencies make radio astronomy observatories on the Moon a particularly attractive idea.

In the first paper, F. D. Drake proposes the use of the natural bowl shape of craters on the Moon to construct large, single-dish antennas similar to the design of the Arecibo telescope in Puerto Rico. In the second paper, R. Linfield describes the manner in which a lunar version of the very large array (VLA) radio telescope would vastly improve our ability to perform astrometry, with accuracies increasing by two orders of magnitude over the VLA in New Mexico. The primary advantage of having a lunar VLA radio telescope stems from the absence of a lunar troposphere. The increase in radio interferometry baselines to ultralong dimensions between the Moon and the Earth is discussed in the next two papers by J. O. Burns and by B. Dennison. Burns describes an extension of the very-long-baseline technique currently used with ground-based telescopes which will produce a resolution of 0.4 μarcsec at 300 GHz. Dennison notes that at frequencies less than approximately 5 GHz, such an ultra-long-baseline interferometer will be limited by scattering from the interstellar medium. In the fifth paper, J. Douglas and H. Smith discuss opening the low-frequency window to astronomy by placing a telescope on the lunar far side. The natural insulation of the Moon will filter out the manmade interference from the Earth at a frequency of a few megahertz. The lunar far side is virtually the only location in the inner solar system for a practical very low frequency array. In the final paper in part III, B. M. Oliver explores the possibilities of using lunar-based radio antennas in search of intelligent extraterrestrial communications.