INFRARED PLANETARY DETECTION AND COSMIC RAY ČERENKOV RADIATION

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Abstract. Infrared emission from a planet at a very small angular separation from its star offers the possibility for detection by interferometry from space. However it has been suggested that attention should be paid to interference produced by the infrared radiation that would be generated within the space package by cosmic ray protons. Quantitative examination reveals that both the primary Čerenkov flux and the secondary infrared emission from Čerenkov heating are negligible.

1. Introduction

A proposal for an instrument to detect nonsolar planets (Bracewell, 1978; Bracewell and MacPhie, 1979) utilizes a spinning infrared interferometer in space. The proposal was originally developed for NASA under Project Orion (Black, 1980) partly in response to a search for projects that would challenge existing space technology. Although the whole interferometer can be accommodated by the bay of the space shuttle it requires pointing stability comparable with the angular diameter of nearby stars, needs to be operated at very low temperatures and must possess highly symmetrical optics. These requirements certainly seemed a challenge five years ago but they are not in principle insurmountable and much progress has been made, especially in connection with the successful launching of the cooled infrared astronomical satellite (IRAS).

2. Čerenkov Emission

Two problems of a fundamental rather than technological kind, due to generation of Čerenkov infrared photons within the body of the satellite by pervasive and unavoidable cosmic rays, have been raised by Lerche (1980). In the IR band 19–21 μm one can show that the Čerenkov photon production in one mirror of the interferometer (10^4 cm^2 by 1 cm thick) is approximately 10^4 s^{-1} for an incident cosmic ray proton flux density of 1 cm^{-2} s^{-1} with mean energy around 5 eV. To do this let the incident flux density F of particles with energy U fall on a layer of thickness L and refractive index n. Then the flux density Φ of Čerenkov photons is given by

$$\hbar\omega\Phi = \frac{\mathrm{d}U}{\mathrm{d}x} LF.$$

The energy gradient $\mathrm{d}U/\mathrm{d}x$ depends on the refractive index n of the layer and on the particle velocity u through the relationship (Gray, 1972)

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$$\frac{dU}{dx} = \frac{e^2}{4\pi\epsilon_0 c^2}\left(1 - \frac{c^2}{n^2u^2}\right)\omega\, d\omega.$$

Thus

$$\Phi = \frac{e^2}{4\pi\hbar\epsilon_0 c^2}\left(1 - \frac{c^2}{n^2u^2}\right) d\omega LF.$$

Taking $1 - c^2/n^2u^2 = 1/2$, $L = 1$ cm, $F = 1\ \text{cm}^{-2}\,\text{s}^{-1}$, $d\omega = 9.4 \times 10^{12}\ \text{s}^{-1}$ we get $\Phi = 1.1\ \text{cm}^{-2}\,\text{s}^{-1}$ or a total flux of $1.1 \times 10^4\ \text{s}^{-1}$ from one mirror. Lerche contrasts this high photon production with the photon flux of $2\ \text{s}^{-1}$ expected to reach the mirror from the planet to be detected. He recommends that planning "should take into account the possible contamination of the expected low planetary photon rate by the cosmic ray induced Čerenkov photons."

However, photon production in the interior substance of a mirror is not comparable with photon flux of planetary infrared radiation being reflected by that mirror and focused on a detector, for the simple reason that the mirror substance is opaque while its surface is polished for high reflectivity. If instead of the 1 cm thickness we use the penetration depth of IR into a conductor, less than 1 μm, a reduction factor of 10^4 is introduced. A further reduction results from impedance mismatch at the surface; for example, a factor of 10 would be associated with a mirror reflectivity of 0.9. Furthermore, the fraction of Čerenkov photons thus escaping from the mirror is not focused on the detector but is diluted by a further factor of 10^9 by spherical divergence.

3. Čerenkov Heat

The second problem is that Čerenkov photons absorbed here and there in the flight package will generate heat and reradiate thermally "until a steady-state situation is reached when the infrared detector absorbs (and converts to photovoltaic electrons) as many photons per second as are produced within the package." No quantitative calculations are offered but one can estimate an upper limit to the steady state condition as follows. The energy density of all cosmic radiation is about $10^{-12}\ \text{erg cm}^{-3}$ (Allen, 1973). Such a low energy density could only produce a temperature of 3.4 K even in a black sphere raised to thermal equilibrium. At this temperature, thermal radiation in the 20 μm band to which the detector is sensitive is very small.

Let $B(T, \lambda)$ be Planck's function for the brightness of black-body radiation at temperature T and wavelength λ. Then with $\lambda = 20\ \mu\text{m} = 2 \times 10^{-3}$ cm,

$$\frac{B(3.4, 2 \times 10^{-3})}{B(128, 2 \times 10^{-3})} = \frac{\exp(hck^{-1} \times 128 \times 2 \times 10^{-3}) - 1}{\exp(hck^{-1} \times 3.4 \times 2 \times 10^{-3}) - 1} = 3 \times 10^{-90}.$$

This extremely small factor has to be offset by the fact that the thermally radiating mirror is at a distance of only 5 m while the planet is at a (standard) distance of 10 pc. After inclusion of the factor 10^{-32} for inverse-square law, attentuation we are left with a net reduction factor of 10^{58} working against Čerenkov heat radiation.

If the mirrors were refrigerated to liquid helium temperature the Čerenkov heat load would be a negligible fraction of the total; and if the mirrors were run at 30 K, which is more reasonable, then the Čerenkov heat would, because of the T^4 law, tend to produce a temperature rise of the order of only 1 mK. Thermal radiation reaching the detector in the 20 μm band from surroundings at 30 K is a design consideration, as with the IRAS that is now flying; but clearly Čerenkov heat can be neglected in the overall thermal design.

4. Conclusion

The conclusion is that no fundamental problem exists. Refrigerating to a very low temperature in the presence of moving sunlight, while it is perhaps difficult technology, will automatically take care of cosmic rays and, for that matter, starlight, which is of comparable energy density.

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