what appears to be the only planet in the solar system that possesses intelligent life. Wicher's observation has shown that the 280 million years during which it has produced such eclipses encompasses the fraction of the planet's estimated 5 billion years of history during which it has had life of sufficient intelligence to benefit from having such eclipses.

Stephen W. Behnen's counterargument (August, page 70) suffers from a more basic fallacy: the fact that Pluto, during part of its orbit, comes nearer to the Sun than Neptune implies that each planet will exactly eclipse the other only if the two orbits lie in the same plane. In actual fact, they are inclined by nearly 16 deg with respect to one another. Thus, exact total solar eclipses can occur only if the Mendillo–Hart relation, $E_r = 1$, is satisfied near enough to the intersection of the orbital planes. A calculation shows that this is not the case. Measured relative to a polar axis originating at the Sun and aligned with Pluto's perihelion, the points at which Pluto would exactly eclipse Neptune are given by 24° 17′ and −24°13′, while the points at which Neptune would exactly eclipse Pluto are given by 43°41′ and −43°37′ (neglecting the effects of gravitational perturbations). At these points, the shadow of the eclipsing planet would miss the eclipsed planet by values ranging from 7.66×10^8 to 1.21×10^9 kilometers. As it turns out, however, even these encounters will be prohibited by a resonance between the motions of the two planets, as pointed out in a letter by William Jefferys that is being published concurrently.

Thus, there appears to be no justification, on the basis of the Mendillo-Hart proof, for sending missions to either Neptune or Pluto with the expectation of finding intelligent life.

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Stephen W. Behnen, in objecting to the "proof" of the existence of God offered by Michael Mendillo and Richard Hart, states that exactly total eclipses of the Sun by Neptune observed from Pluto, and vice versa, will occasionally occur because the orbit of Pluto passes within that of Neptune. Actually, because of a peculiarity in the orbits of Neptune and Pluto, this is not the case. C. J. Cohen and E. C. Hubbard[1] have found that Neptune and Pluto are locked into a resonance between their periods, and that as a result, the two planets cannot approach each other more closely than 18 Astronomical Units (1 AU = 1.5×10^8 km.). It is easy to show that as a result, the largest apparent diameter that either planet can ever subtend when observed from the other is 4 seconds of arc; this occurs when Neptune is observed from Pluto at a distance of 18 AU. On the other hand, the smallest apparent diameter subtended by the Sun from either planet is 39 seconds of arc, attained from Pluto when it is at aphelion. Thus, at most an annular eclipse is possible.

Even this event may be forbidden, because the orbital planes of the two planets intersect at a large angle. Although I have not verified this, it is quite possible that the resonance would prevent the two planets from ever lining up along the line of nodes containing the Sun, a condition that is necessary for an eclipse to occur.

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More night-sky paradox

The article on Olbers's paradox by Edward Harrison in the February issue (page 30) brought to mind a note titled "Why is the Sky Dark at Night" by David Layzer in *Nature* **209**, 1340–1341 (1966). Layzer, after detailed analysis, presented the following conclusions:

"The intensity of the background radiation field is limited by quite distinct physical effects in the three cosmologies considered here. In a static universe, it is limited (under present conditions) by the finite lifetime of the stars. In a steady-state universe the darkness of the night sky is a direct consequence of cosmic expansion. In an evolving universe, the situation is more complex. The stellar contribution to the background radiation field is limited in part by the finite lifetimes of stars and in part by the cosmic expansion. At radio wavelengths, free–free emission at an early stage in the cosmic expansion may be the most important contributor. The intensity of this radiation is limited partly by opacity and partly by the cosmic expansion. In addition, a vestigial radiation field ... may be present."

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The interesting article by Harrison on Olbers's paradox advances a novel resolution of that paradox using modern physical concepts. But the best part of Harrison's article is the heading of its last paragraphs, "Why Bother?" Thermodynamic equilibrium aside, Olbers's problem never had any merit to begin

continued on page 69

continued from page 15

with because it is based on the false conclusion that an infinite universe must contain at least one star along every line of sight. To show that this is false one need only assume that the universe contains a countably infinite number of stars, that is one star for every natural number. Such a universe would be most definitely infinite, but there would be more lines of sight for every observer in every plane than there would be stars for him to see. This is because the number of directions an observer can look in the plane is equal to the number of points on the circumference of a circle, and, as is well known, there are more points on the circumference of a circle than there are natural numbers. Hence the idea that a dark night sky is paradoxical depends upon the assumption that the universe contains an *uncountably* infinite number of stars. For an arbitrary observer in 3-space it depends upon the assumption that the entire volume of the cosmos is a continuum of stars. Under the latter, a dark night sky is impossible, but so is the idea of a star as a discrete entity.

To avoid appearing hypocritical I should note I have shown elsewhere that the classical idea of uncountable infinity is both troubled,[1] and inconsistent with physics.[1,2] However, under this newer view, which contradicts the idea that spacetime is dense, Olbers's paradox is meaningless because no infinity of stars need be assumed in order to wonder why the sky is black at night. (In this context Harrison's quantitative results might be very significant.) Sticking to the original context of the black-sky problem, as Harrison did, one finds that it lacks merit simply because it misconceives the well known properties of infinite cardinality as first described by Cantor.[3]

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THE AUTHOR REPLIES: I think it is important that we should try and understand the old static model and the paradox that has plagued it for so long. The original conclusion that the night sky is bright in a static model has been accepted without question by most people even up to the present day. Students in introductory astronomy courses are still taught that the darkness of the night sky is direct evidence that our universe is not static; they are taught that Olbers missed the chance of a lifetime in not realizing that darkness means expansion. In my article I have shown that the original conclusion was false. In a static universe, constituted similar to our own at present, the night sky is also dark and the existence of darkness does not prove expansion.

I have discussed Bruce Shore's letter with David Layzer and I believe it is correct to say that both Layzer and I are in basic agreement. Shore may not have been aware that the paper he refers to was prompted in part by an earlier paper of my own. Also the passage quoted by Shore is not supplemented by Layzer's equations and therefore fails to convey the force of Layzer's arguments. A more complete statement is as follows: In a static model the condition for a low-intensity background radiation field is $t^* \ll \tau$, where t^* is the luminous lifetime of stars and τ is the thermodynamic time scale. (The finiteness of t^* is a necessary but not sufficient condition.) In a steady-state model the condition for a dark night sky is either $T \ll 4\tau$ when $T < 3t^*$, or $3t^* \ll 4\tau$ when $T > 3t^*$, where T is the expansion time. (Cosmic expansion ensures that the radiation field remains constant, but does not by itself guarantee that it is of low intensity.) In an evolving model the conditions for a dark night sky are similar: either $t \ll (1 + \alpha)\tau$ when $t < t^*$, or $t^* \ll (1 + \alpha)\tau$ when $t > t^*$, where t is the age of the model. To understand why the sky is dark at night it is necessary to think quantitatively in terms of three time scales. The general condition for a dark night sky in all models, whether static, evolving or steady-state, is roughly that the luminous lifetime or the expansion time, whichever is the smaller, is small compared with the thermodynamic time scale.

Allen Allen's remarks are interesting and of course correct if we regard stars as mathematical points. But stars have finite size and subtend a finite element of the solid angle of the sky. According to the bright-sky theory a static and spatially infinte universe is uniformly populated with luminous stars of n per unit volume. An observer's line of sight in any direction therefore intercepts a star at a finite characteristic distance

$$\lambda = (n\sigma)^{-1}$$

where $\sigma = \pi R^2$ is the area of a stellar disk and R is a typical stellar radius. Thus, the required number of luminous stars to cover the whole sky is

$$N = 4\pi n\lambda^3/3 = 4\pi/3n^2\sigma^3$$

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There are an infinite number of stars in a spatially infinite universe, but around each observer only the finite number N is needed to cover the entire sky. In Allen's mathematical model we have $\sigma = 0$ and $N = \infty$, and quite rightly in this particular case it is then questionable whether a bright sky is in principle possible. (For instance, if S is the radius of the universe and we keep the product SR constant as $S \rightarrow \infty$, it then follows that $\lambda/S \rightarrow \infty$, and a bright sky is impossible.) The value of N is estimated as follows: Let $\rho \approx 10^{-30}$ g cm^{-3} be the average density of stellar material in the universe and let also $\rho^* \approx 1$ g cm^{-3} be the average density of matter within stars; we then obtain

$$N = \left(\frac{4}{3}\right)^3 \left(\frac{\rho^*}{\rho}\right)^2 = 10^{60}$$

and this is the number of stars required to create a bright sky. A spatially closed homogeneous and isotropic static universe contains a finite number N', say, of stars that may be less than N. In this case light circumnavigates the universe $(N/N')^{1/3}$ times to create a bright sky.

One can criticize many of the original physical assumptions of the bright-sky theory, but I do not think the paradox it poses can be dismissed or resolved by mathematical arguments of the kind raised by Allen. Many have criticized the paradox on the grounds that it is basically meaningless, and it is therefore important to realize that it is quite easy to construct models in which the night sky is not dark. An Einstein static model of density $\rho > 10^{-17}$ g cm^{-3}, for example, has a thermodynamic time scale (in which light circumnavigates more than 10^6 times) that is less than the luminous lifetime of stars, and in such a model the night sky is bright. At the risk of cluttering up the argument with details, I should perhaps also mention that the Einstein model is dynamically unstable. The time scale of this instability is approximately the time it takes for light to circumnavigate only once. We therefore require an Einstein static model of density $\rho > 10^{-5}$ g cm^{-3} in order that the thermodynamic time scale be less than the instability time scale. It is then quite easy to show that this particular bright-sky model contains only 10^4 stars of solar mass.

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Models of the sun

At the end of Barbara Levi's account of the solar-oblateness measurements by Henry Hill and his collaborators at the University of Arizona (September, page 17), there is mention of the possible relation of these measurements with the problem of solar neutrinos. It is remarked that the low neutrino flux is consistent with models of the Sun with a rotating core such as Robert Dicke's model.

In the context of solar neutrinos, it is misleading to lump all solar models with a rotating interior under a single heading. In fact, Dicke's model of the Sun, in which most of the mass rotates rigidly with a period of about one day, yields practically the same high neutrino flux as a nonrotating model.[1] Among models with a rotating interior, of which a variety have been discussed during the last few decades, it appears that only those including a *small* rotating core (of the order of one tenth of a solar mass) in a state of *rapid* rotation (in the sense that rotation affects appreciably the pressure gradient in the model, corresponding to a period of the order of one hour) can produce the desired reduction in neutrino flux.[2]

Whatever the merits and drawbacks of this class of models, which have been discussed in recent literature,[3] they imply an internal structure and rotational history for the Sun sufficiently different from that proposed by Dicke to make them definitely distinct.

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Reactor safety study

"State and Society" in the November issue (page 87) reports on a \$3-million 14-volume reactor-safety study just released by the AEC. The overall conclusion is "the risks to the public from potential accidents in nuclear-power plants are very small." This is, if I remember correctly, the n-plus-one-th study by the AEC with the same conclusion in the past several years.

I call to your attention an article starting on page one of *The New York Times* of 10 November 1974. The title of the article is "AEC Files Show Effort to Conceal Safety Perils," and the article, written by David Burnham from an examination of letters and memos written by industry and commission officials in the past ten years, bears out the title.