content of the surface waves, distinct, inversely dispersed Rayleigh waves with periods of about 8 to 15 seconds were recorded at Addis Ababa, Ethiopia ($\Delta = 35.5°$), from both events in Algeria. In contrast, Gumper at Lamont has found that earthquakes in Algeria recorded at Addis Ababa generate Rayleigh waves belonging to the normally dispersed portion of the continental group-velocity curve in the period range 15 to 36 seconds.

In Fig. 2, we have plotted the individual station determinations of $M_s$ for the 27 February 1965 event in Algeria as a function of azimuth. The $M_s$ values are relatively high in the east-northeast and northwest directions. This effect is evident in the seismograms from Shiraz (Iran), Quetta (Pakistan), New Delhi (India), and Shillong (India) where Rayleigh waves of relatively larger amplitudes were recorded. All of the variations in $M_s$ values may be an effect of the propagation path or of structural asymmetry in the geologic setting of the source region.

Well-developed Love waves from the event of 27 February 1965 were recorded at seven of the 34 stations which recorded distinguishable Rayleigh waves. These seven stations cover the range of 16° to 125° in azimuth. The presence of these Love waves is a further indication that some asymmetrical forces were acting at the origin (*13*).

The events in southern Algeria generated much smaller surface waves than would be expected from earthquakes of comparable body-wave magnitudes. The results illustrate a significant difference in the $M_s$ versus $m_b$ relationships between earthquakes and large underground explosions. Although this difference has been investigated previously (*14*), it assumes a new importance as the result of the study of these three recent explosive events.

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14 March 1967

## Isotropy of Cosmic Background Radiation at 4080 Megahertz

Abstract. *We have examined an 18-hour-long record made as part of our program of measurements of the fluxes of a number of discrete radio sources. Since our radiometer employed an absolute reference, it was possible to obtain absolute background data from the reference region observed around each of the 29 sources investigated that day. From the study of a plot mode from this data, we conclude that there is no large-scale deviation from isotropy of more than 0.1°K at 4080 megahertz.*

In the original report of our measurement of the background temperature at 4080 Mhz (*1*) we stated that it was "within the limits of our observations, isotropic, unpolarized, and free of seasonal variation." While the total limit of error in our absolute value was 1.0°K, only the incremental calibration of the reference termination and, to a lesser extent, our determination of atmospheric absorption contributed to the error in our isotropy measurement. The estimated error in our isotropy measurement was therefore approximately 10 percent. Our coverage at that time included points on the zenith where the background temperature was measured and the paths of decreasing elevation (generally to the south) along which we measured the atmospheric radiation. In addition, some data along lines of constant declination, never more than a few hours in length, were taken (i) with the antenna pointed at our zenith (declination $\approx$ 40°), (ii) in the region near Cas A, and (iii) across the galactic plane at five declinations (*2*). The latter two were largely base lines for drift-curve observations. In all these cases, our clear-weather observations were consistent with the conclusion that any variations observed were caused by radiometer noise fluctuations and the warming of the reference termination.

We have received a communication from D. W. Sciama which suggests (*3*) that the universe may be anisotropic on a scale of $Z \approx 1$, with associated anisotropy in the microwave background. We have therefore reexamined our 4080 Mcs records in order to place, if possible, a limit on the anisotropy of the background radiation lower than the one described above, and with more systematic sky coverage. We are reporting here the results of the analysis of a record that provides a sensitive test for anisotropy and yet covers a large portion of the available sky. In particular, it covers the region near the north galactic pole, which has been reported by Strittmatter *et al.* (*4*) to contain a large number of highly redshifted quasars.

The observations were made, during an 18-hour period on 4 and 5 March 1965, as part of a program of measurements of the fluxes of a number of discrete radio sources. Since the radiometer employed an absolute reference, it was possible to obtain absolute

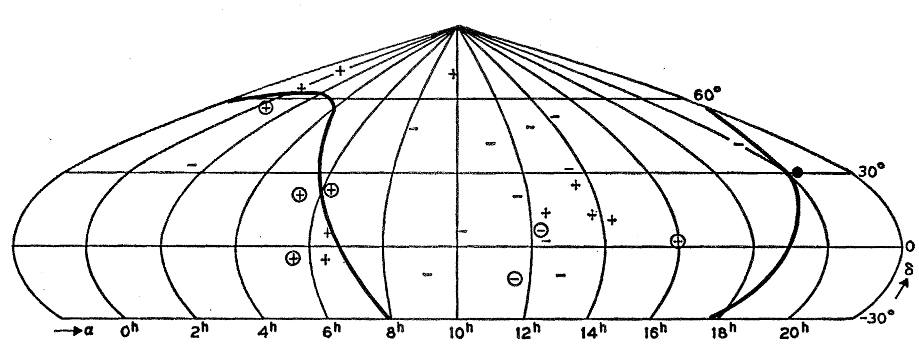


Fig. 1. Relative background temperature at various points in the sky. Plus signs indicate higher than average temperatures and minus signs lower. Points with deviations greater than 0.1°K have been circled.

background data from the reference regions observed around each of the 29 sources investigated that day. The raw data obtained from the record is the difference in temperature between the reference termination and the antenna terminal for each direction.

The data were first corrected for variations in antenna temperature, with elevation, due to both atmospheric absorption and antenna feed polarization changes. This latter effect is the result of the receiver being stationary as the antenna elevation changes. At the time of these measurements the effective temperature of the two principal polarizations of the antenna differed by about 1°K. This effect was due to higher horn loss (later corrected) and higher back lobe levels in the longitudinal polarization. The constraints of scheduling observations caused us to observe several high-declination sources at low elevations, and thus our results are not critically dependent on the parameter used in making these corrections.

When these corrected temperature differences were plotted as a function of time of observation, we found, as expected, a linear variation in their mean corresponding to a "warming" of the reference termination of 0.033°K/hr. The measured points were divided into four classes and plotted on a map of the sky (Fig. 1). Points above the mean line are indicated by plus signs and those below by minus signs. Deviations greater than 0.1°K are circled (*5*). In only one case (3C410) is the deviation greater than 0.2°K, and that source is near the galactic plane. Its location is marked by a filled circle. From a study of this plot we conclude there is no large-scale deviation from isotropy of more than 0.1°K.

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5. We feel that the possibility of losing a large-scale east-west slope in the process of subtracting the "warming" of the reference termination from the data in this manner is small, since our data cover almost the full range of right ascensions ($20^h$ to $16^h$). In addition the warm-up rate of the reference termination is in excellent agreement with that found on other occasions when different observations were made.

7 April 1967

## Rotation of the Sun

Abstract. *Dicke has interpreted his recent measurement of the sun's oblateness as implying a fast (1.8-day period) rotation of the solar radiative interior. We find that differentially rotating solar models, such as the one proposed by Dicke, are unstable. The rate of turbulent diffusion in the unstable regions of these models is so rapid that it appears to preclude a fast-spinning solar interior. As a corollary of the stability analysis, we conclude that the loss of a significant fraction of a star's angular momentum must be accompanied by the mixing of material below its convective zone. Such mixing inevitably leads to the depletion of lithium in the star's photosphere.*

Dicke (*1*) has recently measured a solar oblateness of $5 \times 10^{-5}$ and has ascribed this observation to a rapidly rotating solar radiative interior (*2*). In any model of this kind, the angular momentum per unit mass must somewhere decrease with distance from the rotation axis. We have found the flow in a region of this type to be unstable to small perturbations. The physical nature of the instability and its implications are our main concern here.

For simplicity, we focus our attention on a cylindrically symmetric, differentially rotating, compressible fluid. A fixed gravitational field is assumed to act radially inward (toward the rotation axis). In the unperturbed state there is a balance between the gravitational, centrifugal, and pressure forces. We consider an axisymmetric perturbation of the basic state which consists of the interchange of fluid rings initially located at different radii. The displacement of the fluid rings is assumed to take place so slowly that they are always in pressure equilibrium with their surroundings. For the moment, we shall neglect the effects of thermal conductivity and viscosity. Therefore, there is no heat transfer between a displaced fluid element and its surroundings, and each fluid ring retains its initial angular momentum. If energy is released by the exchange of fluid rings, we would expect the motion to be unstable. The two types of energy that need to be considered are the kinetic energy of the fluid, due to its rotational motion, and its potential energy, due to its position in the gravitational field.

In regions where the angular momentum per unit mass decreases outward from the rotation axis, it is well known that rotational kinetic energy is released by the interchange (*3*). Where the density field is stably stratified (as it is in the radiative interior of the sun) work must be done to supply the gravitational potential energy needed to interchange the rings. In the solar model proposed by Dicke, the work required to exchange fluid rings adiabatically is always greater than the rotational kinetic energy that can be released by their interchange. This has led Dicke to claim stability for his model (*2*). However, stellar perturbations are neither adiabatic nor inviscid. The smoothing of temperature fluctuations by radiative transfer will always act to diminish the temperature difference between the displaced rings and their surroundings. This will reduce the work required to overcome the stable stratification in the solar radiative interior. No matter how large a displaced fluid element may be, if it moves sufficiently slowly its temperature will approach that of its surroundings. Thus, finite thermal diffusivity in the solar interior may be expected to produce instability (in regions where the angular momentum per unit mass decreases outward) even though stability is predicted for adiabatic perturbations. We must bear in mind that the release of rotational kinetic energy during the exchange of fluid rings depends upon the retention of angular momentum by the displaced rings. Thus, viscous diffusion will act to destroy the source of energy that drives the instability. In the sun, thermal diffusion is much more rapid than viscous diffusion; the ratio of thermal diffusivity to kinematic viscosity in the solar interior is of order $10^5$. Therefore, the temperature of a displaced fluid ring will closely approach the temperature of its surroundings before angular momentum can diffuse either into or out of the ring. Hence, viscosity will not prevent instabilities from arising in regions where the angular momentum per unit mass decreases outward.

Our heuristic discussion of stability, which is based on energetic considerations, does not provide a rigorous proof of instability. Even if an exchange of fluid rings is energetically favorable, the fluid may not possess modes that can release the energy. In other words, the motions that were considered in the heuristic discussion may not be compatible with the fluid equations. For this reason, we have verified the heuristic stability criterion by means of a complete linear perturbation analysis (*4*).