The core source is presumably to be identified with the well-known jet extending from the nucleus of M87. In a separate observation, Bolton has found the radiation from the core to be $\gtrsim 3\%$ polarized at 958 Mc. At very much higher frequencies, the radiation from the core should dominate. However, existing measurements at about 8000 Mc require that the spectrum of the core becomes steeper above 1420 Mc.

Preliminary analysis of brightness distributions in 130 sources has shown that such a complex structure is quite common. Some sources contain a core plus a halo, while others display a double peaked structure resembling that of Cygnus A.

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Estimation of the Dispersion of Redshift for Field Galaxies. JERZY NEYMAN AND ELIZABETH L. SCOTT, *Statistical Laboratory, University of California, Berkeley 4, California*.—It is assumed that the redshift Z of a field galaxy at distance D is a random variable with expectation HD , where H is the Hubble constant, and with variance $\sigma^2 = E(Z - HD)^2$ independent of distance. The problem treated is the estimation of σ^2 using the values of redshift Z and of apparent magnitude m of field galaxies in a catalogue, that is, subject to selection. The theory developed assumes (i) a catalogue of field galaxies resulting from an effort to include all galaxies observable with given instruments; (ii) the galaxies in the catalogue are reliably classified into morphological types fine enough to ensure that the ease of observing any two galaxies of the same type depends on their apparent magnitude only. Working in Euclidean space, it is found that among catalogue galaxies of a fixed type: (a) the regression of Z on $x = 10^{m/5}$ must be linear, $E(Z|x) = Ax$; (b) the regression of $Y = (Z - Ax)^2$ on x has the form $E(Y|x) = \sigma^2 + Bx^2$. Here A and B depend on the type of galaxy; the actual shape of the two regressions may be vitiated if the classification of galaxies is not fine enough. The formula for $E(Y|x)$ implies that the estimation of σ^2 reduces to that of the intercept of a quadratic regression. Preliminary results using the data of Humason, Mayall, and Sandage indicate that σ^2 must be small.

Tidal Deformations and the Origin of the Moon. ERNST J. ÖPIK, *Department of Physics, University of Maryland (on leave from Armagh Observatory, Northern Ireland)*.—Results of a provisional survey of the ellipticities of lunar craters in selected areas of Kuiper's *Atlas* are discussed. The rms random ellipticity is found to be 0.070 near the center, 0.096 near the limb, and is probably due to oblique impact. Small preferential components of ellipticity are indicated and interpreted as possible after-effects

of past tidal deformations. Formulae for tidal-rotational deformations of line elements on an elastic nonresisting surface are given. The smallness of the preferential effects is in itself significant, without regard to their absolute value. They suggest that the craters were formed when the earth-moon distance was of the order of 30 000–50 000 km. The undamaged appearance of the craters except for impact erosion and flooding, and the absence of signs of major crustal deformations indicates that since crater formation the moon could not have been at a closer distance. From theoretical rates of accretion as based on probabilities of interplanetary collisions, possible modes of origin of the moon are discussed. If the pre-mare craters mark the end of a continuous process of accretion which built the moon, the observed small systematic deformations of the craters are only compatible with the moon having accreted from a cloud of fragments circling the earth in direct orbits at a distance of 5–8 earth radii or greater. The assumption of different processes for accretion of the moon and for the formation of pre-mare craters leads to improbable consequences. Only when the preferential ellipticities are discounted as due to other causes or to chance, is it possible to accept the alternative of the moon having accreted from interplanetary material orbiting the sun. Accretion must then have run simultaneously with tidal evolution following initial tidal capture, the pre-mare craters having formed at a distance of over 200 000 km from earth as the final stage of this accretion.

Free-Free Emission in the Radio-Frequency Range. LUDWIG OSTER, *Yale University Observatory, New Haven, Connecticut*.—Classical and quantum-mechanical calculations for the free-free emission (bremsstrahlung) of electrons in a completely ionized plasma are critically investigated. Avoiding altogether the sometimes misleading assumptions found in the literature, it is concluded that the several classical computations are in complete agreement with the quantum-mechanical approach. Numerical coefficients are derived for a Maxwellian distribution of electron velocities. It is shown that for temperatures below, roughly, 550 000°K the classical results can be safely used; however, for higher temperatures quantum corrections are required. Finally, examination of the problem of a cutoff of the ion's Coulomb potential shows that this cutoff can be neglected for all frequencies above the plasma frequency in the range where the refractive index is effectively unity.

Heating of the Solar Chromosphere, Plages, and Corona by Magnetohydrodynamic Waves. DONALD E. OSTERBROCK, *Institute for Advanced Study, Princeton, New Jersey*.—The energy carried upward by sound waves generated in the hydrogen

convection zone can be estimated as 3×10^7 erg/cm² sec, though the numerical result is highly uncertain because of its great dependence on the turbulent velocity field. The spectrum of this noise is a broad band with maximum near the frequency of 0.01 cps. The waves propagate in the so-called "fast" mode, and become increasingly magnetohydrodynamic in character as they run out through the chromosphere, because of the negative density gradient. Little if any energy is emitted by the hydrogen convection zone in the "slow" or "Alfvén" modes, and these modes are in addition strongly absorbed in the photosphere. The cross sections for collisions between neutral atoms and ions in the chromosphere are large, and as a result the dissipation of the fast-mode waves by the frictional damping mechanism is very small. The waves build up to shocks, and the dissipation of these shocks is the main energy source for the chromosphere. The dissipation of the shocks is worked out using a similarity principle, in a way analogous to the Brinkley-Kirkwood theory of the dissipation of pure gas-dynamic shocks. At great heights, where the magnetic field dominates, the shocks become weaker, the dissipation decreases, and the rays are refracted back downward toward the photosphere. However, at these heights collisions between shocks must be expected to feed some energy into the slow mode and Alfvén mode, and these modes then propagate straight up the magnetic lines of force, with essentially no weakening by refraction, and carry energy into the corona. The plages are regions of larger magnetic field, where the refraction and shock-collision effects are more important; in addition there probably is extra generation of noise in the hydrogen convection zone below them.

The Frequency of Double Galaxies in Clusters.

THORNTON PAGE, *Van Vleck Observatory, Wesleyan University, Middletown, Connecticut*.—Systematic identification of double galaxies on Palomar Atlas prints now underway at the Van Vleck Observatory is expected to provide statistical evidence of the manner of formation and stability of these systems. It is necessary, of course, to estimate and deduct the number of "optical pairs," a quantity that will vary widely with surface density of individual objects (e.g., in clusters).

The classical formula due to G. Polya (*Astron. Nach.* 208, 175, 1919) is generally used (Holmberg, E., *Lund Ann.* No. 6, 1937; Page, T., *Astrophys. J.* 116, 63, 1952) to argue that $N_2^*(m, S)$, the total number of observed pairs of magnitude less than m and of separation, S , is far greater than $N_2(m, S)$, the number expected on chance over the whole sky. Actually, the expected number in a limited area will deviate widely from the mean because of variation in the surface density, $n_1(m)$, the number of single

galaxies of magnitude less than m per square degree.

Applying Polya's formula for the probability that an individual galaxy in a random distribution will have its nearest neighbor between θ and $\theta + d\theta$ radians, $W(\theta) d\theta = 2n \sin\theta \cos^{2n-1}\theta d\theta$, one finds that the number of "unambiguous chance pairs" per square degree is expected to be

$$n_2(m, S) = \pi n_1^2(m) S \exp[-2\pi n_1(m) S^2].$$

Subtracting this from the observed surface density of pairs, we have the estimated number of physical pairs in a cluster, and, if spherical symmetry is assumed, the space density, $d_2(m, S)$. Allowing for the projection of space separation, R , into the projected angular separation, S , this yields the frequency distribution of R among double galaxies in a cluster.

Furthermore, $d_2(m, S)$ may be compared with the space density of individual galaxies in the cluster, $d_1(m)$. If the formation of physical pairs is due to capture, d_2 will be proportional to d_1^2 , a relation subject to observational verification, and the constant of proportionality is related to the velocity dispersion and past history of the cluster.

A Hydrogen-Line Interferometer. V. RADHAKRISHNAN, D. MORRIS, AND R. W. WILSON, *California Institute of Technology, Pasadena, California*.—A new and promising technique for the study of interstellar 21-cm absorption has recently been tried at the Caltech Radio Observatory. The twin 90-foot paraboloids were operated in a narrow-band interferometer arrangement at 1420 Mc. The fringe pattern obtained with the antennas tracking a point source had an amplitude proportional to the "visibility" of the source within a 6-kc bandwidth at a frequency which could be continuously varied by tuning the second local oscillator.

An improvement in sensitivity over single-dish operation was obtained by virtue of the increased collecting area and the absence of switching. The real merit of the system, however, for absorption studies, was in that it made the difficult determination of the "expected" profile redundant. The emission from the extended hydrogen clouds was resolved out and the amplitude versus frequency pattern obtained was essentially the spectrum of the point source within the beam. It was possible, for example, to clearly detect an absorption feature at +4 km/sec in the spectrum of 3C-123, whose intensity is only one-fiftieth that of Cas A. Parametric or other low-noise amplifiers should bring a vast number of point sources within reach of such investigation.

The sources Cas A, Cyg A, Sgr A, and the Crab, Orion, and Omega nebulae were observed with the interferometer. In most cases there were small but significant differences from single-dish values in optical depths and/or linewidths. These differences