SPECTRUM OF THE COSMIC X- AND GAMMA RAY BACKGROUND IN THE ENERGY RANGE 1 keV–1 MeV

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Abstract. Available satellite, rocket and balloon observations on cosmic X- and gamma ray background are critically examined to understand the spectral characteristics of the radiation. Appropriate corrections have been applied to the balloon observations to account for the multiple Compton scattering of X-rays in the atmosphere. It is shown that within the experimental uncertainties, all the available observations of cosmic X- and gamma ray background in the energy range 1 keV–1 MeV are consistent with a single spectrum of type

$$dN/dE = 30\, E^{-2.0\pm0.2} \text{ photons cm}^{-2}\text{ s}^{-1}\text{ sr}^{-1}\text{ keV}^{-1}.$$

1. Introduction

From a large number of observations on the omnidirectional cosmic X- and gamma ray background above 1 keV accumulated over the past few years, a steepening above 40 keV amounting to an abrupt break and a flattening above 1 MeV have been generally accepted as two significant features of the power law spectrum (Silk, 1970). While most of the rocket observations have yielded a value ranging between 1.4 to 1.7 for the power law exponent 'n' of the differential energy spectrum of X-rays in the range 1–20 keV, balloon observations above 20 keV generally give a value of $\sim$2.4 for the spectral slope. Beyond 1 MeV, the spectral exponent seems to reduce to $\sim$1.0. Although the excess X-ray flux and the consequent flattening of the spectrum beyond 1 MeV can be explained either by invoking a galactic source (Cowsik, 1971) or through the red shifted π° decay gammas produced in the remote past corresponding to a red shift parameter of $\sim$100 (Stecker, 1969), assumption of a break in the electron spectrum is essential to explain the sharp break in the X-ray spectrum at 40 keV.

In spite of the problems involved in such an assumption, the inverse Compton models have, hitherto, proved attractive due to their ability to explain the detailed spectral shape of cosmic X-rays. Recently, however, Cowsik and Kobetick (1971) have shown that even if the electron spectrum were to have abrupt breaks, such breaks will not be reproduced in the resulting X-ray spectrum due to the smearing resulting from the energy spread in the blackbody photons and the nature of the differential Compton scattering cross sections.

Except for the observations of Schwartz (1969), the evidence for the break in the spectrum near 40 keV has essentially come by comparing the data from rocket and balloon experiments. Practically all the balloon observations to date have only been corrected for exponential absorption of X-rays in the atmosphere without taking into

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account the corrections for the Compton scattering process. In this communication, we examine the effect of Compton scattering on the derived X-ray spectrum from observations at balloon altitudes and through a comparison of the rocket, satellite and balloon data, show that the energy spectrum of the omnidirectional background X-rays in the entire energy range 1 keV–1 MeV can be reasonably represented by a single spectral exponent.

2. Balloon Observations

For the case of photons undergoing single scattering and moving finally in the vertical direction, Makino (1970) has deduced the correction factor F_s which gives the extent to which an exponential extrapolation procedure overestimates the flux of primary X-rays at different energies. More explicitly F_s represents the ratio of the flux of primary X-rays which did not undergo Compton scattering to the total measured flux which includes the contribution from the scattered component. Hortsman and Hortsman-Moretti (1971) using Montecarlo techniques, have generalised these calculations to include the effects of multiple scattering. The modified spectra of the primary X-rays which have undergone scattering, have been derived by these authors for an atmospheric depth of 8 g cm^{-2} assuming two different free space spectra viz. 245 $E^{-2.5}$ and 40 E^{-2}.

Following Makino, we define F_s as

$$F_s = \frac{\phi_0 \, e^{-\mu t}}{\phi_s + \phi_0 \, e^{-\mu t}},$$

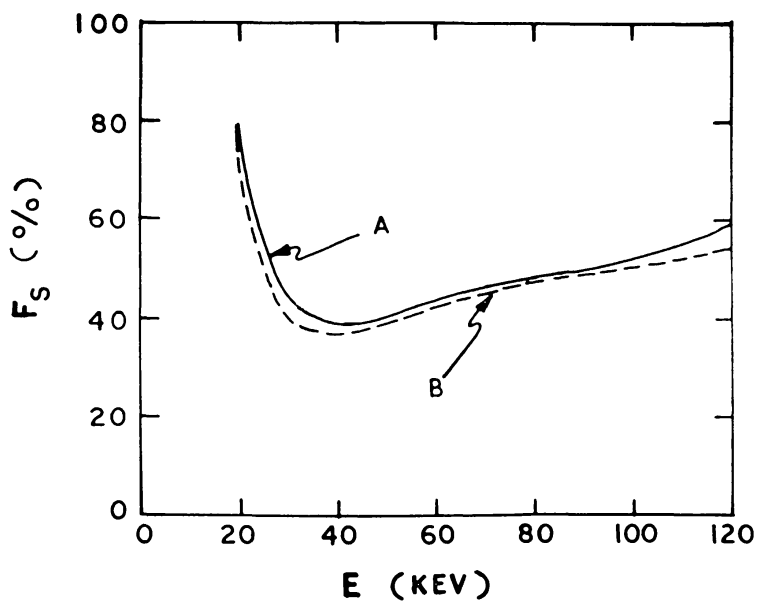

Fig. 1. Correction factor F_s for the case of multiple Compton scattering of X-rays in the atmosphere shown as a function of energy. Curves A and B correspond to two different assumed primary spectral shapes, viz. 245 $E^{-2.5}$ and 40 E^{-2} respectively as explained in the text.

where ϕ_0 and ϕ_s are the intensities of the primary X-rays and of the scattered component respectively, at an energy E, t is the depth of observation and μ is the mass attenuation coefficient. The values of F_s deduced from the curves of Hortsman and Hortsman-Moretti for the two different spectral shapes are shown in Figure 1. It is clear from the figure that the correction factors are not very sensitive to the assumed primary spectral shape.

Applying these correction factors to the exponentially extrapolated spectrum obtained by us earlier (Rangan *et al.*, 1969), we have deduced the revised spectral parameters of the cosmic X-radiation which are summarised in Table I. It may be mentioned

TABLE I

Summary of spectral parameters obtained by least squared fitting for the case of cosmic X-rays from balloon observation at 8 g/cm^{+2}

Type of correction	Spectral parameters K	n	Remarks
Exponential	162	2.4 ± 0.3	–
Multiple scattering	21.5	2.1 ± 0.2	Correction factors derived for an assumed primary spectral function 40 E^{-2}, i.e. curve B in Figure 1

that practically all the balloon observations made around the depth of 6 g cm^{+2} (Bleeker and Deerenberg, 1970; Agrawal *et al.*, 1969) will also lead to a primary spectrum similar to the one obtained here as the exponentially extrapolated spectra in all these cases are similar. Thus we observe that with correction for the multiple scattering, the balloon observations will yield a spectral index nearer 2.0 instead of the usually quoted value of 2.4.

3. Rocket and Satellite Observations

Even though the rocket and satellite observations do not suffer from the above complexity, many of these observations do contain errors due to the uncertainties in the secondary background corrections and detector responses. Besides, very few of the rocket and satellite observations cover the entire range of 1–200 keV. The early Ranger measurements of Metzger *et al.* (1964) covering the range 70 keV–1 MeV overestimated the spectral index ($n = 2.3$) of the photon spectrum mainly because of not considering the appropriate detector response function for spectral unfolding. Likewise, the break in the spectrum observed by Schwartz (1969) can be attributed to radioactive contamination (Dyer and Morfill, 1971).

Recent rocket results of Brini *et al.* (1971) in the range 25–200 keV ($n = 1.95 \pm 0.1$) and of Toor *et al.* (1970) in the energy range 4–70 keV ($n = 1.8$) both indicate a spectral index consistent with the balloon observations obtained after correction. Besides, both the above observations do not show any evidence of a break in the continuous spectrum

in the energy range considered. Rocket results in the energy range 1–40 keV (Hayakawa *et al.*, 1966; Seward *et al.*, 1967; Bowyer *et al.*, 1968; Gorenstein *et al.*, 1969; Baxter *et al.*, 1969; Prakasarao *et al.*, 1971) as well as OSO 3 observations in the range 7–40 keV (Schwartz, 1969) also support the contention that the cosmic X-ray spectrum in the entire energy range 1–200 keV can be explained adequately by a single spectral exponent.

In Figure 2 we show the results of a number of rocket and spacecraft observations

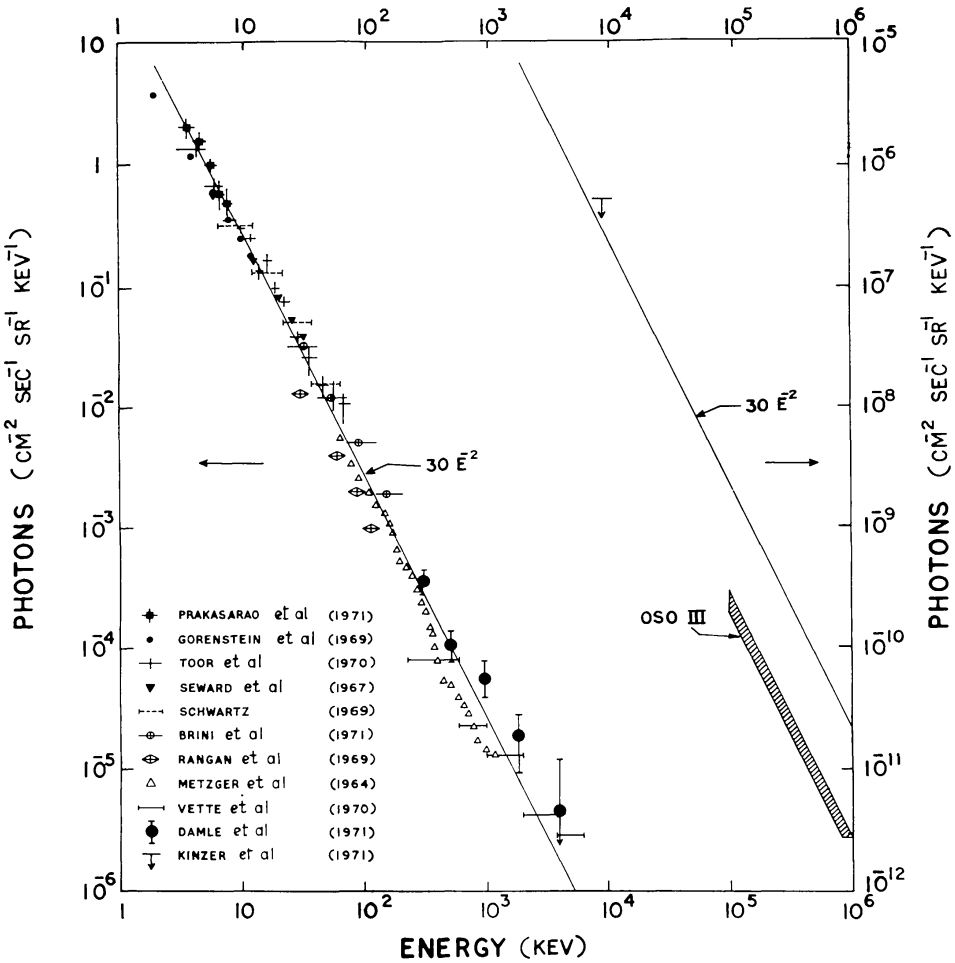

Fig. 2. Spectrum of the diffuse cosmic X- and gamma rays including the results of the balloon observation corrected for the effects of the multiple Compton scattering of X-rays.

along with the corrected balloon data. In the case of OSO 3 (Schwartz, 1969), only the results of low energy channels are shown as high energy channels were subject to large secondary background corrections. The Ranger results (Metzger *et al.*, 1964) correspond to energy loss spectrum and, as such, have to be folded through the detector response before direct comparison can be made with the rest of the results. This is especially important at higher energies. The observations chosen for showing in Figure 2 mostly pertain to measurements which covered a large energy range and

overlapped into the 20–200 keV energy region. It may, however, be noted that the corrected balloon intensities are slightly lower than those from rocket or satellite observations, which may probably be due to the overestimation of the atmospheric component.

The data presented in Figure 2 suggests that there is no detectable spectral break of the type discussed in the literature (Gorenstein *et al.*, 1969; Bleeker and Deerenberg, 1970; Silk, 1970) in the 1–200 keV energy interval. A spectral function of the type

$$dN/dE = 30E^{-2\pm0.2} \text{ photons cm}^{-2}\text{ s}^{-1}\text{ sr}^{-1}\text{ keV}^{-1}$$

does reasonably satisfy all the observations over the entire 1–200 keV range and even beyond to about 1 MeV. The gamma ray observations at higher energies using balloon techniques (Damle *et al.*, 1971; Kinzer *et al.*, 1971) are also consistent with the spectrum suggested above. Extrapolation of the spectrum to gamma ray energies yields a value of 3×10^{-4} photons cm^{-2} s^{-1} sr^{-1} for the flux of gamma rays above 100 MeV. The extrapolated value as well as the revised OSO results (Clark *et al.*, 1971) are shown in Figure 2 for comparison. At this point, we would like to emphasize that the direct use of the spectral parameter values K and n for the comparison of different results has certain limitations owing to the following reasons. The choice of K and 'n' are always subject to some uncertainties as their values depend very much on the analytical method employed to derive them. In particular, the choice of mean energy (centroid mean or arithmetic mean) for a particular channel, the estimation of the slope of the spectral distribution by graphical means instead of through the least-squared fitting and giving equal weight to the data in different energy channels can collectively contribute to the discrepancies in the values of the spectral parameters of different measurements, and have to be taken into account for comparing the various spectral observations. We thus conclude that all the presently available observations on cosmic X- and gamma ray background flux are resonably consistent with their being represented by a power law spectrum with a single spectral exponent of $\sim$2.0 over at least the energy range 1 keV–1 MeV.

Acknowledgement

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ABSTRACTS OF FORTHCOMING PAPERS

G. S. Bisnovaty-Kogan and D. K. Nadyozhin: **The Evolution of Massive Stars with Mass Loss.** (Received 7 August, 1971.)

The evolution of massive stars is investigated on the phases of hydrogen and helium burning, taking into account the mass loss due to light pressure in optically thick media. The evolution on the stage of hydrogen burning near the main sequence occurs without mass loss. The large inverse density gradient appears in the outer layers of a 30 $M_\odot$ star after it goes into the region of red super-giants on the helium burning stage. This effect appears as a consequence of excess of luminosity of the star on the critical one in sufficiently large outer layer, where convection is not effective. So, the conditions for matter outflowing are formed. The sequence of self-consistent models is constructed with the core in hydrostatic equilibrium and hydrodynamically outflowing envelope. The rate of mass loss is not a given parameter, but it is found during the calculations as a proper number of the problem. The rate of mass loss occurs very intensively: $\sim 0.5\ M_\odot$/yr, the rate of matter flow is ~ 20 km/s. The star loses about 7.2 $M_\odot$ during 15 yrs. The rate of mass loss must sharply decrease or finish altogether when the matter near the hydrogen burning layer begins to flow out and the transformation of stellar structure must occur.

The evolution of a 9 $M_\odot$ star is calculated. The density in the envelope of this star is sufficiently large and the outer convective zone, which develops on the red giant stage, prevents the outflow of matter. The intensive matter outflow from such stars can take place on the carbon burning or more heavier element burning stage. The formation of infrared stars and Wolf-Rayet stars can possibly be explained by such a mechanism of mass loss so that the infrared star stage must precede the Wolf-Rayet star.

W. R. Webber, S. V. Damle, and J. Kish: **Studies of the Chemical Composition of Cosmic Rays with $Z = 3$–30 at High and Low Energies.** (Received 18 October, 1971.)

We have measured the chemical composition of cosmic rays with $Z \geqslant 2$ over an energy range from ~ 100 MeV/nuc. to > 2 BeV/nuc. using 2 new large area counter telescopes. One of these instruments was a 4 element $dE/dx \times Ex$ Range telescope, the other a 4 element $dE/dx \times$ Cerenkov $\times$ Range telescope. Two balloon flights with these telescopes at Ft. Churchill in the summer of 1970 provided a total of nearly 1000 Fe nuclei with a charge resolution ranging from ~ 0.10 charge unit at Carbon to ~ 0.25 charge unit at Fe. A detailed charge spectrum is obtained at both high and low energies. Some important differences exist between the present results and those obtained earlier, due in part to the improved statistical accuracy and in part to the improved background rejection of the present data. In particular, the abundance of Cr and Mn are each found to be $\sim 0.10 \times$ Fe in contrast to the earlier ratio of ~ 0.30 found by some workers for each of these nuclei. The abundance of these two nuclei, as well as others in the 15–25 range, shows no strong dependence on energy. We have extrapolated our composition data to the cosmic ray sources using a variety of interstellar path length distributions. The abundances of *all* secondary nuclei with Z between 3–25 are consistent only with propagation models which have vacuum path length distributions which do not differ greatly from exponential. The source abundances of nuclei with $Z = 15, 17, 18, 19, 21, 22, 23, 24$, and 25 are found to be $< 0.02 \times$ Fe. For the remaining nuclei, Na, Al, S, and Ca are found to have source abundances of 0.10, 0.14, 0.21, and 0.18 of Fe respectively. The source abundance of C and O relative to Fe is also much different than some earlier compilations. A comparison of solar and cosmic ray abundances reveals certain selective differences, rather than a systematic overabundance of heavy nuclei in cosmic rays, as has been suggested in the past. These differences are discussed in terms of a common nucleosynthesis origin of the two species of particles.

R. K. Manchanda, S. Biswas, P. C. Agrawal, G. S. Gokhale, V. S. Iyengar, P. K. Kunte, and B. V. Sreekantan: **The Spectrum of Diffuse Cosmic X-Rays in the 20–125 keV Range.** (Received 19 October, 1971.)

Diffuse cosmic X-rays in the energy range 20–125 keV were measured in four balloon flights from Hyderabad, India during 1968–70 using almost identical X-Ray telescopes mounted on oriented platforms. The results from these flights show that the spectrum of the diffuse cosmic X-Rays can be represented by the form $dN/dE = 29\ E^{-2.1\pm0.3}$ photons/(cm^2 sr s keV) in 20–125 keV interval after corrections for photo-electric absorption and Compton scattering effects in the atmosphere. The best fit spectrum of all published results in the energy interval 20–200 keV can be represented by the form $dN/dE = 36\ E^{-2.1\pm0.1}$ photons/(cm sr s keV) after similar corrections are effected, and there is no need for a change of spectral index in this energy interval. The intensity at 20 keV obtained from the above spectrum agrees well with that given by the spectral form $dN/dE = 10.E^{-1.7\pm0.1}$ photons/(cm sr s keV) in the energy interval 1–20 keV in several rocket experiments. Therefore it is concluded that if there is a break in the spectrum, it occurs between 10 and 20 keV with a change of spectral index by about 0.5, or the index is continuously changing from 1.7 ± 0.1 to 2.1 ± 0.1 in 10–20 keV interval. The implications of the results are briefly discussed.

E. R. Seaquist: **Circular Polarization of Synchrotron Radiation in the Presence of Hydromagnetic Waves.** (Received 27 July, 1971; in revised form 26 October, 1971.)

It is shown that relativistic electrons in the presence of circularly polarized hydromagnetic waves emit synchrotron radiation which is partially circularly polarized. The relation between the degree of polarization of the radiation and the energy density and wavelength of the waves is derived, and the factors determining the sense of polarization are discussed. Waves of the type required are generated by pitch angle anistropies in a relativistic electron gas. An application of the result to conditions expected in quasistellar objects shows that the degree of circular polarization of synchrotron radiation in these objects may be of order 1% or greater.

Wilbur K. Brown: **A Galactic Formation Model Based on Post-Big Bang Fragmentation.** (Received 6 September, 1971; in revised form 28 October, 1971.)

A new model of galactic formation is presented. A primeval distribution of angular momentum is derived, which rests on the postulated presence of mass flows at the early stage of the post-big bang universal expansion, when fragmentation occurs. The shape of any particular fragment and its orientation with respect to the mass flow predestine the morphology of the galaxy that will be produced in the subsequent collapse.

A fragment-to-disk mapping transform allows examination of the galactic disk mass distributions that result from the postulates of the model. One class of distribution adequately describes the observed luminosity profiles of elliptical galaxies. Another class indicates the allocation of a large mass fraction to an extended disk, and the intrinsic two-sided symmetry of the model further indicates that the disk formation process will begin with the establishment of two major spiral arms.

B. R. Durney and J. O. Stenflo: **On Stellar Activity Cycles.** (Received 29 October, 1971.)

The relation between the average magnetic field B, the angular velocity Ω, and the period P of stellar activity cycles is studied. For the calculations we have used Leighton's (1969) model for the solar cycle with the additional assumption that the differential rotation and the cyclonic turbulence (Parker, 1955) (that is the 'sunspot tilt' or the 'α-effect') are both proportional to Ω. We then find that B is roughly proportional to Ω and that P decreases with increasing Ω. The period of the solar cycle increases therefore with the age of the Sun.

D. A. Mendis, T. E. Holzen, and W. I. Axford: **Neutral Hydrogen in Cometary Comas.** (Received 2 November, 1971.)

The strong Ly-α radiation observed recently in comets Tago-Sato-Kosaka and Bennett can be ex-

plained in terms of the resonant scattering of solar Ly-α radiation on neutral hydrogen formed by the photo-dissociation of H_2O which is vaporised from a nucleus having an ice core. A complete hydrodynamic description of an atmosphere composed of H_2O and its daughter products OH, H and O coupled through frictional interaction as well as production and loss processes is given. Numerical results are computed in a typical case, and it is found that a temperature of about 3000 K for the cometary atmosphere provides the best fit with observation.

H. Dehnen and O. Obregón: **Exact Cosmological Solutions in Brans and Dicke's Scalar-Tensor Theory II.** (Received 6 November, 1971.)

In addition to our previous paper (Dehnen and Obregón, 1971) the exact cosmological solutions of Brans and Dicke's scalar-tensor theory allowing a power law between the gravitational constant κ and the radius of curvature R of the universe are sought in case that – in contrast to our previous paper – the initial condition $R(t=0)=0$ is avoided. There exist two different types of solutions especially for the closed space of positive curvature and for positive values of the freely available parameter ω of the scalar-tensor theory. The radius of curvature and also the gravitational constant increase at first with respect to time and decrease after reaching a maximum value, in contradiction to Dirac's hypothesis whereafter the gravitational constant should decrease with time in an expanding universe. The age of the universe following from these solutions is in accordance with the observations.

I. B. W. Pendred and I. P. Williams: **Star Formation in the Galaxy.** (Received 8 November, 1971.)

A previous theory of the authors regarding the planetary system is generalized in an attempt to include star formation. It is found that the theory predicts the correct mass and radius for stellar clusters and also the general shape of the galaxy.

Vittorio Castellani and Francesca A. D'Antona: **Current Problems on Asymptotic Branch Stars.** (Received 11 November, 1971.)

An effort is made to select, from the available observational data, information concerning the asymptotic branch stars. Particular care is devoted to derive luminosity functions for these stars in clusters representative of selected classes. Some theoretical predictions are briefly made. It is stressed that, from a theoretical point of view, the comparison between the one-shell H-burning evolutionary characteristics and the corresponding ones for the A.B. phase could be expected to provide a powerful means of investigation.

I. P. Chamaraux, Th. Montmerle, and M. Tadokoro: **Intergalactic Ionized Hydrogen in Nearly Groups of Galaxies.** (Received 16 November, 1971.)

Stability of the nearest 14 groups of galaxies is investigated by means of Jacobi's criterion. In this way these groups are found strongly unstable, except perhaps two. The result is unaltered when we discuss the validity of the assumptions needed for the computations and when we take into account the inaccuracy of the data. This apparent instability is tentatively explained by presence of intergalactic ionized hydrogen in each group. Physical parameters of the gas are derived by means of the general modified form of the virial theorem and through the assumption of the equipartition among several modes of energy.

The main results are the following: the ratios of the gas mass to the sum of the masses of the member galaxies are of the order of 10, densities ϱ_g of the gas are about 10^{-29} to 10^{-28} g/cm^3, and temperature are of the order of 10^5 K. Values of each physical parameter of the gas show little change from one group to the next. As significant correlation: $\varrho_G \propto \varrho_g^{0.9}$ is obtained between ϱ_g and the density ϱ_G of the visible matter for the various groups; it may be compatible with the assumption that the intergalactic gas is a remnant of the condensation of the galaxies. Then it is shown that, at present, the observations are not opposed to our treatment. Finally, it is noticed that detection of intergalactic gas in the groups investigated will be very difficult, except if this gas is strongly cloudy.

D. F. Falla and A. Evans: **On the Mass and Distance of the Quasi-Stellar Object 3C 273.** (Received 17 November, 1971.)

For the QSO 3C 273 we derive, on the basis of two different theoretical models, expressions for a lower limit to the mass of the QSO, as a function of its distance. We conclude that an appreciable gravitational redshift component is consistent with the observational data only if the QSO mass is at least Galatic in magnitude. The setting of an independent upper limit to the QSO mass $M \lesssim 10^{10} M_{\odot}$ could indicate that the QSO redshift is predominantly cosmological in nature.

Ch. Friedemann and R. H. Giese: **Re-Calculation of Efficiency Factors for Radiation Pressure.** (Received 18 November, 1971.)

Corrected values of the efficiency factor Q_{pr} of light pressure are presented for spherical particles of graphite and metallic materials.

Kari Lumme: **On the Formation of Saturn's Rings.** (Received 18 November, 1971.)

It is shown that the formation of Saturn's ring C can be explained by the action of solar radiation pressure on the small ring particles. If the age of the rings is 1.6×10^8 years, the predicted optical thickness of ring C, as a function of the distance from the planet, can then be shown to be in agreement with the measured one. The disruption of a solid satellite as the origin of the rings is shown to be quite plausible. If, in Roche's limit, the molecular cohesion is taken into account, the disruption distance of a satellite having the mass of the rings seems to be in agreement with the average distance of the ring system.

S. P. S. Anand: **The Equilibrium and Stability of Uniformly Rotating Gaseous Systems in Hydromagnetics. I. Mathematical Technique.** (Received 19 November, 1971.)

The theory for investigating the equilibrium and stability of a uniformly rotating gaseous system with a prevalent magnetic field is developed by using the virial tensor approach. Most of the discussion in this paper depends on the assumption that on the surface of the system, the magnetic field is zero. In Appendix A, however, we have considered the case in which the surface magnetic field is non-zero.

We have obtained the nine modes of oscillations, grouped into the transverse shear, toroidal and pulsation modes. From this analysis we have also found the conditions under which the sequence of a uniformly rotating axially symmetric configuration in the presence of a magnetic field should have a point of bifurcation, that is, a point where objects with genuine triplanar symmetry branch off. This condition is also generalized in the Appendix to include the effects of differential rotation and non-zero surface magnetic field.

Applications to the cosmogonic fission problem, the study of the pulsation of rotating magnetic stars and some radio astrophysical problems are briefly discussed.

Gordon E. Bromage: **Profiles of the Diffuse Interstellar Lines.** (Received 19 November, 1971.)

The possibility that the diffuse interstellar lines and bands are but structure in the continuous extinction by dust grains is considered in detail. The lines are assumed to arise from impurities in the grains. Profiles of the strongest diffuse features are computed for a wide variety of host grain types and sizes, including size distributions of particles, and spheroidal and coated spherical grains.

New observational profiles, of which '4430', '4765' and '4885' have been derived from automated spectrophotometry of electronographic spectra, are also presented; and comparison is made between theory and observation. The most useful tool of comparison is found to be the ratio of maximum apparent emission in the violet wing to maximum apparent absorption, ϱ. This ratio increases with size of the host particle, and with both real and imaginary parts of its refractive index; but is independent

of the observed variations in strength and width of a particular line. The ratio is larger for '4430' than for the other lines.

Taking into account current opinion as to the composition of interstellar dust, the observations may be explained by the presence of impurities in either silicate grains with effective radii of about 120 nm, or possibly graphite grains about 50 nm in radius coated with a thin dielectric condensate. None of the observed profiles are at variance with the hypothesis that all the lines arise from the same impurities in the same type of grains. The concentration of such impurities needed to reproduce the observed line profiles and strengths is only about one in 10^4 atoms in the grain.

V. Castellani and N. Panagia: **Self-Accretion of Matter Red Subluminous Stars and Early Evolution of Low-Mass Stars.** (Received 20 November, 1971.)

Low-mass stars during their pre-main sequence contraction phase are expected to be surrounded by a certain amount of the primordial gas. At low luminosities, accretion of this gas can make the stars to follow a peculiar evolutionary course which can account for certain types of red subluminous stars. The efficiency of the accretion mechanism can also account for some peculiarities in the spectra of the stars of low mass.

B. Thüring: **Die Ablenkung des Lichtes an der Sonne und die Änderung seiner Geschwindigkeit und Wellenlange.** (Received 24 November, 1971.)

In 1968 I. I. Shapiro published the first results of Radar-Echo-observations on Venus and Mercury in the neighbourhood of upper conjunctions with the Sun; the observations indicate a decrease of the velocity of light passing the Sun. Soldner's theory is disproved; and the general relativity is in accord with the observed facts. But not this theory alone. In this publication the deflection of light, decrease of the velocity of light, and displacement of spectral-lines are explained with the aid of a wave theory. Hereby the assumption of a material medium causing light-waves is sufficient, the density of which is below that of the empirical vacuum; hence, the medium must have a small inhomogeneity h radial to the Sun, and the Maxwell-equations contain small additional terms (Equation 3). They lead to the field equations (4) and (5). The protophysical fundamentals of the wave theory (6), (8), (9), (10a) lead to the equations of phases of wave (12). If we assume that the behaviour of the light passing the Sun is independent (in first approximation) from the form of wave (F), the equation (22) of wave phase is deduced for simple-periodic waves of light. Figure 1 outlines the slope and deflection of the ray of light by the Sun. Section 5 contains the solution of (22); and section 6 the results. The constant of inhomogeneity $\delta = \frac{1}{2}\, 10^{-5}$ (of radius of Sun) produces a deflection (39) of light passing the Sun. The length of waves of the light approaching the Sun is decreasing to a minimum and is increasing with increasing distance from the Sun until the former value ((43) and (44)). The velocity of light approaching the Sun is decreased to a minimum and increases with increasing distance from the Sun until its former value ((46) and (47)).

N. A. Barricelli: **The Transmission of Mass and Angular Momentum from a Satellite or Planetary System to its Primary.** (Received 25 November, 1971.)

In this paper the main implications of basic properties detected in the satellite systems of Jupiter, Saturn and Uranus, and presented by the author in an earlier contribution (Barricelli, 1971 b) are investigated. The similarity between the primary periods in the three systems, their appearent relation to the axial rotation periods of the three planets and other features suggesting that collisions with the planetary surfaces may have played a role in the evolution of the three satellite systems are interpreted by assuming that in each case a satellite of unusually large size was originally disintegrated at the Roche limit of its primary. The disintegration of large satellites and their fusion with the respective planets is assumed to be a normal feature in the latest stage of planetary growth and the main cause of axial rotation in the respective planets.

These assumptions make it possible to give a selfconsistent interpretation of the similarity between the axial rotation periods of the three planets and their relation to the primary periods (as defined by Barricelli, 1971 b) in the three systems.

Similar assumptions when applied to the Earth–Moon system make it possible to understand why the Moon in its closest approach to the Earth is found to have been almost exactly at the Roche limit (Gerstenkorn, 1955; MacDonald, 1964), a coincidence which is too good to be accidental. According to this interpretation our Moon is a portion (representing about one third) of our original satellite, which survived its approach to the Roche limit and the ensuing fusion process with the Earth. It can be shown (see text) that under certain conditions this could leave a residual satellite with a stationary distance from the Earth (which in retrospect would be identified as its lowest distance from the Earth) at the Roche limit.

The only other case in which we have observational evidence of parts of a satellite surviving its fusion process at the Roche limit is represented by the rings of Saturn and possibly the small innermost satellite Janus which seems to have been feeding on the rings.

S. S. Kumar: **On the Formation of Jupiter.** (Received 1 December, 1971.)

Arguments are presented to show that Jupiter could not have been formed as a star of mass 0.001 $M_{\odot}$ and that the observed excess energy is not due to gravitational contraction from an extended, gaseous state.

Zdeněk Kopal: **The Effects of Viscous Friction on Axial Rotation of Celestial Bodies.** (Received 10 December, 1971.)

The aim of the present paper will be to formulate explicitly the differential equations which govern three-dimensional rotation of deformable self-gravitating bodies of arbitrary structure, and consisting of fluid material whose viscosity is an arbitrary function of spatial coordinates: with special respect to a description of the effects of viscous friction exhibited in binary systems which consist of a close pair of such configurations.

In Section 2, which follows brief introductory remarks outlining the problem, we depart from the fundamental equations expressed in terms of the velocity components of deformation, arising from dynamical tides that are raised on the rotating configuration by the attraction of its companion. In Section 3, the magnitude of such velocities in the rotating frame of reference (arising from possible eccentricity of the orbit of the two bodies, as well as from the asynchronism between their rotation and revolution) will be specified in terms of the physical characteristics of each particular system; and in Section 4 we shall similarly evaluate the moments and products of inertia of the rotating configuration.

In Section 5, we shall focus our attention on the effects on rotational motion of the time-dependent deformations which the components undergo in the course of each orbital cycle as a result of the dynamical tides; and in Section 6 we shall detail the general effects on rotation arising from the viscosity; while in the subsequent Section 7 we shall specify these more explicitly for the case of simple rotation about an axis perpendicular to the orbital plane of the system.

A numerical application of the results of this section to the Earth–Moon system (the components of which will be regarded as yielding to mutual tidal distortion) discloses that – at the present distance of these bodies – the rate at which viscous friction of bodily tides tends to equalize their rotation and revolution works some 10^4 times more effectively on the Moon than on the Earth. This should satisfactorily account for the fact that the Moon has attained a state of synchronous rotation (and probably maintained it most of the time throughout its long astronomical past), while our Earth is still far from this state today.

In the concluding Section 8 of this paper we generalize the results of Section 7 to the case of spheroidal configurations, the axial rotation of which is fast enough for the cross-products between rotational and tidal distortion to become significant. Lastly, in Appendix A we express the velocity components arising from dynamical tides in terms of the spherical polar (rather than rectangular) coordinates; and evaluate the rate of the dissipation of the kinetic energy into heat, through viscous tides, of different types within the orbital cycle (Appendix B).