THE ZODIACAL LIGHT AND THE NATURE OF INTERPLANETARY GAS

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In an interesting letter Biermann\textsuperscript{1} has recently outlined plausible reasons for supposing that a stationary interplanetary gas does not exist, but rather that the polarized component of the zodiacal light is due to scattering of sunlight by corpuscular radiation from the Sun. The purpose of this note is to consider again the observational data in this very difficult subject, and its bearing on theories of the zodiacal light and interplanetary gas.

The difficulties of observing the zodiacal light and of obtaining reasonably accurate and reliable data free from systematic errors are very great. The reasons for this are known, although not always well appreciated. The surface brightness of the zodiacal light itself is low, and under good observing conditions only a small part of it near the horizon is as bright as the inevitable sky background. Further, as the cone of the zodiacal light is wide it is necessary to observe a large area of sky in order to measure the background brightness, the irregularities of which make the interpolation to the observed position in the zodiacal light very uncertain. Even under good atmospheric conditions observations cannot be profitably made when the Sun is less than about 18° below the horizon and this forces us to observe at large zenith distances, where atmospheric absorption is great and may also vary irregularly with zenith distance. Under these conditions the relationship between the atmospheric extinction for a point source, which can be fairly easily determined, and that for a source of large area, is uncertain.

It is particularly difficult to avoid systematic errors when a search is made over a long period of time for a possible seasonal fluctuation of brightness, or for a slow variation to be correlated with the solar cycle. Errors can then easily arise from a seasonal variation of the inclination to the horizon of the ecliptic, which closely defines the axis of symmetry, or from a probable variation of background sky brightness with solar activity. Visual observations of brightness are particularly susceptible to systematic error of this kind. There are considerable difficulties in making sure that a short period fluctuation of brightness is really due to a fluctuation in the zodiacal light brightness and not merely to a fluctuation in the night sky brightness. When observers are faced with these difficulties it is not surprising to find a conflict of opinion about even the basic observational facts. For example, we are still uncertain whether or not the brightness of the zodiacal light is constant in time. On the one hand there are the clear results of Elvey and Roach,\textsuperscript{2} and those of Huruhata.\textsuperscript{3} Elvey and Roach, working over a period of 12 months, find a regular variation over a range of 50 per cent. Huruhata has made observations over a period of 4 years. These observations show a rapid fluctuation over a period of a few days as well as a great change from year to year, amounting to a factor of $\times 7$. The data of Thorn,\textsuperscript{4} giving a variation with
sunspot cycle, are less convincing because they refer to visual measures which are strongly influenced by variations of sky brightness. The well known visual data of Jones\(^6\) show a large variation of brightness, and Hulburt\(^6\) has shown that these variations are well correlated with magnetic activity. Jones’ data were obtained in the tropics, although at sea level. However, we do wish to emphasize that even this correlation does not necessarily mean that the brightness of the zodiacal light is varying. The human eye is easily deceived by a change of background brightness, and indeed there is a strong correlation between sky brightness and magnetic activity.\(^7\) On the other hand there is the equally clear evidence of Regener\(^8\) who cannot find any significant variation during 14 months’ observation, even though he observed at times with the ecliptic at an inclination to the horizon of only 33°. It is important to note that most of these observations were made during a period of low solar activity. Similarly, there is a contradiction between the results of Behr and Siedentopf\(^9\) and those of Roach\(^10\) concerning the colour of the zodiacal light.

These difficulties of observation will only be diminished by use of better observing sites. There are at least two reasons why an observing site should be located in the tropics. First, the ecliptic near the horizon is never far from the vertical and the seasonal variation of its inclination does not produce a large variation of absorption. Second, the sky may be expected to be darker than elsewhere, and not so liable to variation of brightness, either of long or short period.\(^11,12\) It is also important to use a high altitude site preferably not less than 10,000 ft. above sea-level. The most favourable elongations for measurement are in the range 28° < E < 40°, where the zodiacal light is still fairly bright relative to the sky and atmospheric absorption is not excessive. The high altitude minimizes this absorption, which in any case becomes troublesome near the horizon, and avoids much of the trouble arising from surface haze and dust.

The zodiacal light is now commonly supposed to be due to the scattering of sunlight by dust and free electrons in interplanetary space. But it certainly cannot all be due to gas, otherwise its polarization would be about 60 per cent, whereas the observed polarization at elongation \(E = 35°\) is only 22 per cent.\(^9\) On the other hand most astronomers believe it cannot all be due to dust because the polarization is too high. The great problem is to decide how much of the total brightness, if any, is due to electron scattering. If we suppose that the polarization of the dust component at elongation \(E = 35°\) is zero,\(^13\) then the observed brightness and polarization give an electron density\(^14\) at 123R\(_0\) (0.57 A.U.) about \(10^3\) cm\(^{-3}\). Use of other observations\(^16\) gives an electron density at 1 A.U. about 600 cm\(^{-3}\). It is satisfactory that this value agrees approximately with that obtained by Storey\(^16\) for regions in the vicinity of the Earth, using observations of whistling atmospherics.

We must emphasize however, that the hypothesis of an interplanetary gas existing as far out as the Earth’s orbit in concentrations of this order depends almost solely upon the very uncertain interpretation of a very difficult measurement—that of the polarization of the zodiacal light—and we shall now advance arguments in support of the view that an interplanetary gas makes no appreciable contribution to the polarization of the zodiacal light. The effect of an appreciable contribution to the
total polarization from dust has already been considered by van de Hulst, 28 and by Whipple and Gossner. 29

Recent work 17 on the comet Arend-Roland has shown that the polarization of the continuum in its spectrum can reach 25 per cent. Probably the continuum is due to scattering of sunlight by solid matter in the comet. The fact that the solid material of a comet scatters light having a polarization of the same order as that of the zodiacal light shows that we need not assume the presence of an electron component in the zodiacal light. Laboratory measurements by Kloeverstrom and Rense 18 of the degree of polarization of light reflected by meteorites have indeed shown that the zodiacal light polarization is not too great to be attributable to dust alone. The data from comets are no more than pointers to the solution of the problem, but the hypothesis of an interplanetary gas leads to at least one difficulty which cannot be easily avoided. Measurements 15 of the zodiacal light under good conditions in the Pacific, using an aircraft, have shown that, on this occasion at least, the symmetry axis of the zodiacal light was inclined to the ecliptic at an angle of only 0°.28. These measurements were made with the ecliptic at an inclination of 19° to the vertical, at a high galactic latitude, and between elongations 25° and 42°.5 where the disturbance of the symmetry from irregularities of the background is a minimum. Assuming that the dust component is symmetrical about the ecliptic, the axis of symmetry of the assumed electron component is unlikely to be more than 1° from the ecliptic. 15 This observation suggests that the gravitational influence of the Earth is the dominating force on the electrons, but it is difficult to believe that any gravitational forces dominate electromagnetic forces arising from weak stray magnetic fields in the solar system. The difficulty, which has also been discussed by Ópik, 19 can be most simply solved by supposing that the electron component does not exist.

This seems to be the most powerful argument against the existence of an electron component, but there are other questionable features of the electron density distribution. We have shown 14 that if the polarization of the dust component at elongation $E = 35°$ is zero, then the polarization of the zodiacal light at greater elongations can be accounted for only by making one of two possible assumptions. Either the polarization of the dust component at greater elongations is negative, or else there is a sudden cut off of electron density (corresponding to a sudden decrease of ionization) at about 1 A.U. from the Sun. The comet studies already mentioned make the first assumption unlikely. The second assumption is not impossible, but seems unlikely. Another disturbing fact is that the electron density gradient near 1 A.U. is unexpectedly small. The accretion theory of the solar corona gives the smallest gradient of any theory, yet even this gradient is much greater than that which is observed. 20

Although the argument concerning the symmetry of the zodiacal light cannot easily be refuted, we emphasize the importance of obtaining a clear and unambiguous separation of the zodiacal light into the two components by direct observation.* At this stage the only unquestionable conclusion that can be drawn about an interplanetary gas is that it exists at least to the distance from the Sun corresponding to the elongation at which the

* Preparations are now being made at the Cambridge Observatories to attempt the separation by some hitherto untried methods,
polarization of the outer corona and zodiacal light is a minimum, viz., approximately 5°, corresponding to a distance from the Sun of about 0.1 A.U.

Supposing that future observations demonstrate irrefutably the existence of an electron component in the zodiacal light, it is useful to consider Biermann's theory, that this component can be identified with solar corpuscular radiation, in more detail. A similar theory has been developed by Sengupta who suggests that most of the corpuscles are sufficiently slow to be travelling in closed orbits around the Sun. A fundamental difficulty of all theories of this type is the interpretation of the plane of symmetry of the electron component. If the electrons are emitted by the Sun, it is reasonable to suppose that they start, at least, by being symmetrical about the solar equator. Yet, on the occasion when the above observations of symmetry were made the angle between the ecliptic and the solar equator was 7°.

There does not yet exist a direct measurement of the particle density of solar corpuscular radiation. The calculation of Unsöld and Chapman is based upon the work of Brück and Rutland who attempted to observe a displaced K absorption line arising from these particles. Their data should now be regarded as an upper limit. The work has since been repeated by Smyth who is able to say that the expected increase in absorption following a moderately intense flare is less than 0.5 per cent. This corresponds to an equivalent width of about 0.01 A or less. When this value is inserted in Unsöld and Chapman's calculations we obtain an upper limit $3 \times 10^3 \text{cm}^{-3}$ for the particle density. This value is based on the supposition that the particles in the stream occupy a length of 0.1 A.U. However, the electrons supposed to contribute to the zodiacal light scatter along a line of sight which is of the order of 2 A.U. in length. Hence, to compare the electron density of corpuscular radiation with the electron densities currently deduced from zodiacal light measurements, we have to reduce the corpuscular radiation densities by a factor of about 20, giving an equivalent density in the solar system of $1.5 \times 10^3 \text{cm}^{-3}$. It is true that this is of the order of magnitude currently deduced, but it does represent an upper limit for the equivalent density in exceptional conditions following a moderately intense flare. The conclusion is that during normal quiet conditions corpuscular radiation cannot contribute the required interplanetary electron density. If in fact corpuscular radiation can be observed in the zodiacal light as Biermann suggests, and the ratio of densities during storm conditions and quiet conditions is as much as he suggests ($10^8 : 1$), then the change in zodiacal light brightness during a storm (at least $10^2 : 1$) would be so great that it could not possibly be overlooked. If large changes in zodiacal light brightness which are correlated with magnetic storms can be demonstrated conclusively, then Biermann's hypothesis is confirmed. But from the observational evidence available it is unlikely that the brightness varies by a factor of more than $\times 2$. As already pointed out, such small changes of brightness are difficult to observe and the data so far available are unacceptable. It may be easier to decide first on other grounds whether or not an electron component of the zodiacal light exists at all.
October 1957  An Eighteenth Century Discussion of Algol

References

(1) L. Biermann, The Observatory, 77, 109, 1957.
(4) A. Thorn, J. B. A. A., 49, 103, 1939.

AN EIGHTEENTH CENTURY DISCUSSION OF ALGOL

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In 1783 an eighteen year old deaf mute from Yorkshire, John Godricke, discovered the periodic variation of Algol. In his report of this discovery, communicated to the Plumian Professor at Cambridge, Antony Shepherd, and published in the Transactions of the Royal Society, Godricke added: "If it were not perhaps too early to hazard even a conjecture on the cause of this variation, I should imagine it could hardly be accounted for otherwise than either by the interposition of a large body revolving around Algol, or some kind of motion of its own, whereby part of its body,