Reports

Faint Ring around the Spiral Galaxy M82

Abstract. *Photography of fainter surface brightnesses than heretofore detected shows a very unusual feature in the vicinity of the spiral galaxy M81. If this faint feature is synchrotron radiation from electrons exploded by the neighboring galaxy, M82, then the existence of an overall magnetic field in M81 can be established and calculated at a few microgauss. Other properties of M81 and its companion are implied and can be derived from further observation.*

Experiments aimed at photographing fainter and fainter luminous features in galaxies have been made recently at Mount Wilson and Palomar Observatories (*1*). The wavelength band between 4700 and 5400 Å, stopping just short of the bright night sky emission line at 5577 Å, was selected as the darkest possible region in which to observe. During the last sunspot minimum (1964), the night sky was, on the average, the darkest possible. Long-exposure photographs (50 minutes) were obtained at that time with this technique; the 48-inch (120-cm), *f*/2.5 Schmidt telescope at Mount Palomar was used. Various objects were explored, but particularly groups of galaxies were observed in an attempt to find connections or perturbations in their faintest, outermost regions. In some groups, several identical long exposures were viewed stacked together in front of a strong light. During inspection in this way of the well-known intermediate spiral (Sb) galaxy, M81, an unexpected and puzzling feature was discovered.

The photographic reproduction of M81 (cover) shows this unusual feature, namely, the very faintly luminous ring around one end of the M81 spiral. Two approximate, but independent, methods of estimating the brightness of this ring indicate that its surface brightness is about 0.005 (half of 1 percent) brighter than that of the night sky.

I would like to advance a tentative explanation for this surprising phenomenon. The over-exposed image at the top of the picture (north) is the exploding galaxy M82 (*2*). It is a source of very high-energy electrons. Since the projected distance between M81 and M82 is about 1×10^5 light years, a time less than the time since the explosion, M81 must have some of these high-energy electrons impinging on it. Furthermore, if M81 has an overall magnetic field, these electrons will be bent from linear flight paths and radiate their energy, principally according to the strength of the magnetic field they find themselves in.

If this is the explanation, then an important possibility is opened up, namely, the possibility of measuring for the first time the strength of the overall magnetic field of a galaxy. In fact, preliminary calculations indicate that the magnetic field strength at the distance of the ring from M81 (about 20 kiloparsecs) must be a few microgauss. Because of the weak dependence of the magnetic field strength on the measured or estimated parameters in the equation, this computation of field strength must be accurate to within a factor of 2 or 3.

There are three empirical reasons for believing this ring to be caused by the proximity of M82: (i) the ring is situated on the side of M81 which is toward M82; (ii) the ring is stronger and better defined in the direction in which M82 appears to be exploding most of its material (along the M82 minor axis); and (iii) the plane of the ring is tilted away from the M81 major axis, toward M82.

The proposed mechanism for the formation of the ring is roughly as follows:

As the electron blast front impinges on M81 it will encounter the strongest magnetic field in the direction of the center of M81. If the field is higher than a few microgauss, the radiation half-lives of the electrons will be short, and the energy will burn out from the center to a direction away from the center where the magnetic field is lower. Further away from the center than this, the field will be too weak to trap the electrons and make them radiate. Therefore, a ring of radiation results. An additional consideration is that, if the M81 field is a dipole shape with axis along the M81 axis of rotation, there will be some migration of the radiating electrons away from the center and toward the poles. In the photograph of the ring which is shown, an apparent cusp appears in the end of the ring above the M81 plane and nearest M82. This could be taken as evidence the field lines are converging toward the M81 rotation axis. (A model has been proposed in which a spiral galaxy has a dipole field along the axis of rotation and still has the field in the spiral arms running along the arms (*3*).

There are several other interesting features shown in the reproduced photograph. The inserted "normal" photograph of M81 taken with the 200-inch (500-cm) telescope shows a set of roughly three parallel bars of absorption (presumably dust grains or some such fairly opaque material) lying on the side of the M81 major axis, which is toward M82. These thin, straight dust bars cutting across the spiral pattern have been known for 50 years, but they were so unique among galaxies in general that there seemed no possibility of explaining them by any natural mechanism within the spiral. The suggestion now is that obviously they too are results of the explosion in M82, the blast front either interacting with material in the M81 disk or projecting down onto the luminous M81 background. If these dust bars are explained by such a mechanism, then it seems likely that the energy involved in the M82 explosion must be considerably raised from the already very large energy (10^{56} to 10^{57} ergs) previously computed (*2*).

Another feature of interest in the

print showing the faintest luminous features is the small extensions of the spiral arms out beyond the burned-out oval of the main body of M81. They trace back to join the main spiral arms tangentially. In other words, the brighter spiral arms lie only inside these outer radii and lag behind (opposite to the inferred direction of rotation) the faint, leading arms. Since the bright arm consists of very young stars, and older stars in our own galaxy lag behind these arms (*4*), the implication is that this very faint leading arm in M81 consists of a larger percentage of even younger but fainter material (that is, a greater percentage of *pre*-stellar material).

How the character of the spiral galaxy changes on the photographs which register the faintest surface brightnesses is also of interest. The interarm region fills in, an indication that there is some luminous material in the general disk. The system grows from one having a diameter of a little more than 15 kpc on ordinary photographs to one that is almost 30 kpc in diameter on the composite photograph.

In summary, it seems that by a stroke of good fortune a relatively nearby spiral galaxy has been recently subjected to a very unusual outside perturbation. By studying the effects of the M82 explosion on M81 we can learn a good deal about a normal spiral galaxy. We can also hope to learn more about the intriguing and powerful explosion that took place in the neighboring peculiar galaxy. Because synchrotron radiation should be strongly polarized, optical polarization plates have been taken, and their study should yield further information on the ring. Detailed radio mapping of the region would also be extremely valuable to check on the synchrotron radiation hypothesis and to obtain an accurate estimate of the total energy radiated by the ring over all wavelengths.

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References

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Photometry at Cerro Tololo, Chile: Effects of Mount Agung Eruption

Abstract. *Extinction effects of the volcanic dust injected into the stratosphere by the violent eruption of Mount Agung, Bali, 17 March 1963, were studied. Visual extinction coefficients were measured photoelectrically for 153 nights during the period from March 1963 to September 1964. The data indicate that the dust is now widely dispersed and that its effects may persist for several more years. A study of the wavelength dependence of the extinction shows that the dust is a neutral scattering agent. The total global amount of airborne volcanic material is crudely estimated at 10^{12} grams as of September 1964.*

Moreno and Stock (*1*) reported on the greatly increased atmospheric extinction on Cerro Tololo, which could be attributed to volcanic ash in the stratosphere deriving from the Mount Agung eruption of 17 March 1963; they gave photoelectrically measured visual extinction coefficients for the period from March to November 1963. Our work extends these observations through September 1964 and also examines the wavelength dependence of the excess extinction. All observations were made with a 16-inch (40-cm) reflector.

The coefficients for 153 nights are plotted in Fig. 1. Most of the gaps in the data result from either cloudy periods, nights with insufficient observations, or the use of equipment that did not permit an extinction determination.

About 50 days after the eruption on Bali (115°E, 8°S) the arrival of a dust cloud over Cerro Tololo (71°W, 30°S) was detected by a sharp rise in the visual extinction from the normal 0.125 to about 0.32 magnitude. A subsequent decline of 0.08 magnitude indicated that the cloud still contained a central condensation at that time. There followed a gradual increase until late September 1963, when the coefficient peaked slightly above 0.4 magnitude. Since that time a slow decline has indicated that the preeruption atmospheric conditions may be restored after several years.

The dust has now dispersed over a wide range of latitude. Its initial appearance at Tucson, Arizona (32°N), has been described by Meinel and Meinel (*2*), who derived an altitude of 22 km for the upper extent of the main concentration. A faint secondary layer at 53 km was also reported. From visual observations made on Cerro Tololo, Stock reports that the horizontal visibility has not been affected. Also, the twilight phenomena produced by the dust seem unchanged when observed from aircraft near 10-km altitudes. Thus most of the material is probably confined between heights of 10 and 20 km, although, as Meinel and Meinel have suggested, some of it must have been injected into the mesosphere.

Mossop (*3*) has studied the nature of this volcanic dust from samples gathered during U-2 flights at 20-km altitude. The last reported sample, taken on 7 April 1964 (145°E, 43°S), showed a concentration of 35 volcanic dust particles per liter; the particles had a median size of 0.2 μ. When collected, the particles were heavily coated with a water-soluble material thought to be sulfuric acid. Judged from the particle sample shown by Mossop (*3*, fig. 7), the median radius of these composite particles is several microns.

Because of the large size of the composite particles compared to the wavelengths of visible light, one would expect the excess extinction to be neutral. As such it would present no serious problem for those phases of photometry concerned only with color indices. However, a precise magnitude measurement is impossible under current conditions if one fails to measure accurately the extinction each night. The short-period fluctuations (Fig. 1) are large compared with the night-to-night variations observed prior to the eruption and with errors in the observations (probable error < 0.01 magnitude). The fluctuations indicate that the dust has a patchy distribution; this condition makes it impossible to define a mean extinction coefficient for magnitudes that would be valid for even a few consecutive nights.

A photoelectric scanner (*4*) was used to study the wavelength dependence of the extinction. During the nights of 11, 12, and 20 September 1964, the extinction was measured at the following eight wavelengths that were chosen to avoid disturbing effects of absorption features in the stellar spectra: λ3200, λ3350, λ3500, λ4200, λ4650, λ5000, λ5500, λ5900 Å. The slit width was about 80 Å.

The results for the three nights were combined (Fig. 2, curve *A*). Unfortunately, no corresponding preeruption