the radiation in the two images. In principle this could be done for the starlight from the galaxy, though this is rather faint and close to one of the quasar images. Alternatively, we might expect to find redshifted MgII absorption from any gas in the galaxy to determine this quantity, but already, from the spectra given by Walsh *et al.* in the original paper, we know that such lines are fairly weak. No doubt these observations and other detailed work will be done, but it would be somewhat surprising if the overall picture were to be very different from that we have now. □

Transient lunar phenomena

from David W. Hughes

THREE thousand million years is a long time for the Moon to be quiet and cold, but is it completely dead? Probably not, is the most reasonable answer. For more than two centuries terrestrial observers have recorded events which have been grouped under the title of transient lunar phenomena (TLP). The possible causes of these phenomena have always been subject to considerable debate and the latest debator is Allan Mills of the Department of Astronomy, University of Leicester. His review paper is published in a recent edition of the *Journal of the British Astronomical Association* (**90**, 219; 1980).

Over 1,400 TLP's have been observed and even though a considerable number of these can be rejected as instrumental, atmospheric or physiological artefacts a sufficient residue remain to warrant a detailed physical investigation. Glows, hazes, mists, brief colour changes and temporary obscurations of lunar surface features have been reported. Events seem to be restricted to specific lunar regions, about 300 having been reported from the crater Aristarchus, 75 from Plato and 25 from Alphonsus. They also occur near the boundaries of certain regular maria and near areas rich in rills. The highlands seem to be avoided, but this apparent paucity may be an observational selection effect. Occurrency frequency is not linked with solar activity but does peak when the Moon is at the perigee of its orbit, at times when tidal activity is maximised. Phenomena have been reported from both the sunlit and dark sides of the Moon. The areal extent on the lunar surface is on average 16 km across, this containing brighter spots of between 3 and 5 km in diameter. The average duration is about 20 minutes but some have been reported as persisting intermittently for a few hours. No permanent changes have been observed on the lunar surface after a TLP, thus justifying the use of the word 'transient'. Under very favourable seeing conditions TLP's have been seen to twinkle. Colour, if mentioned at all, tends to be described as weak, unsaturated, 'reddish' or 'bluish'.

Many possible explanations have been put forward, one of the first by Sir William Herschel who reported observing bright red glows in 1783 and 1787 and wrote a paper entitled "*An account of three Volcanoes in the Moon*". The phenomena looked like glowing charcoal thinly veiled with hot ashes and Herschel was obviously thinking of incandescence from hot lava on the lunar surface. Unfortunately, fresh lava regions have not been seen on the Moon, at Herschel's site or in other places. The visible radiation from the fresh lava would decrease rapidly although the infrared radiation would be much more persistent. No such infrared sources have been observed. The brightness is also too low. 1 km^2 of lava at 1,250 K appears as an orange-red 'star' of magnitude 5.5. Drop the temperature to 1,000 K and the magnitude becomes 10.5. This might just be visible on the dark side of the Moon but would be very hard to detect on the sunlit side.

Luminescence can be ruled out because the excitation source, the solar wind, is too weak.

Thermoluminescence can also be disregraded because even though it provides a means of storing energy the emission intensity of all known materials is still too weak to be seen from such a distance.

Triboelectric charging can occur when dust grains are rubbed together. Discharging in dust clouds above the Italian volcano Vesuvius during its 1944 eruption produced brilliant and frequent lightning strokes. The emission of light depends to an extent on the presence of gas so that a plasma can be generated. Diffuse glows occur at about 100 dyn cm^{-2} these being replaced by bright twinkling discharges as the pressure increases. The potential required to produce a discharge is related to the product of the gas pressure and the dust separation. This process will be discussed again later.

Other explanations for TLP's rely on short term modifications to the lunar surface reflectivity. One reason for the very low reflectivity of the lunar soil is the spiky 'fairy castle' structures formed by the dust grains. If these are flattened out the reflectivity increases and this flattening can be easily produced by fluidizing the upper dust layer by passing gas through it. There are two difficulties. Large quantities of gas are required to fluidize several sq. km. of lunar soil. A more pressing problem is that the enhancement in reflectivity is semi-permanent and this is ruled out by the 20 minute average duration of TLP's.

Middlehurst (*Phil. Trans. R. Soc. Lond. A* **285**, 485; 1977) compares the epicentres of deep moon quakes and high frequency teleseismic (HFT) shallow moon quakes with the areas of TLP activity. Most of the HFT sites are within 5° of at least one TLP site. The deep moon quakes originate 800 to 1,000 km below the surface, the shallow ones being much higher (the maximum depth found so far is 265 km). Middlehurst suggests that channels exist between HFT epicentres and the TLP's (the TLP's being almost vertically above the HFT's) and that gas is still escaping through these channels even though the escape rate is much smaller now than it was in the earlier days of lunar history.

Mills proposes a mechanism for TLP production which relies on gas escape but at a much lower rate than that required to fluidize the soil. The gas lifts off the very small particle fraction of lunar soil, producing a kind of moon smoke, and leaves the fairy castle structure intact. Unfortunately the scattering of light by smoke is a highly complex and incompletely modelled phenomena, which relies drastically on the particle size distribution. For particles with sizes below 0.1 λ (where λ is the light wavelength) the scattered light is highly polarised with an intensity proportional to λ^{-4}. For particles with sizes above 10 λ the scattered light is white and unpolarized. For intermediate sizes partial polarization occurs and the colours are unsaturated. As the scattering function is so complex, uniform sized dust can even produce red scattered light and volcanic dust in the stratosphere has been known to produce a blue moon.

The mass of moon smoke required to produce a TLP is of the order of 1 to 20 kg per sq. km. of lunar surface. Mills suggests that this could be blown above the moon's surface by episodic releases of gasses which have accumulated in fissures and faults in the lunar rocks. These releases are triggered by tidal forces and coincide with moon quakes. The smoke quickly falls back to the surface thus explaining the transitory nature of the phenomena.

Now this mechanism could solve the TLP problem for the sunlit regions of the lunar surface but what about the TLP's on the dark side of the moon? If they exist (and there is some doubt) Mills considers that triboelectric discharges provide the only reasonable explanation. Gases expanding from subsurface regions blow away a cloud of dust which becomes charged by interparticle friction and undergoes charge separation. This cloud discharges when the product of the pressure and the mean dust separation distance reaches about 1,000 dyn cm^{-1} and this condition is probably reached a few metres above the surface. The red colour is consistent with the gas being hydrogen.

Mills concludes that the triboelectric lightning discharges in gas-borne dust clouds can explain some TLP's especially those on the dark side of the moon. A more probable explanation requires less energy and less gas and simply relies on light being scattered by temporary clouds of moon smoke. □

David W. Hughes is in the Department of Physics, University of Sheffield.

0028-0836/80/240438-01$01.00