LUNAR SECTION PATRICK MOORE, *Director*

TRANSIENT LUNAR PHENOMENA—A NEW APPROACH

There can be few branches of observational astronomy in which theoretical speculation has produced such a proliferation of possible mechanisms seeking to explain the observed phenomena as that which currently surrounds transient lunar events. A great deal may be said for and against these proposals, but one thing is certain—no satisfactory solution to the problem has yet been devised, nor can it be devised until observational data of a sufficiently high quality are obtained upon which a scientific analysis can be based.

Traditionally the detection and observation of lunar transients has been the province of the amateur observer who has the time, the instrument and, above all, the inclination to undertake the prolonged and, frequently, fruitless search for these events. Probably this situation will prevail in the future and, during the past two years, the Lunar Section of the BAA has prepared itself to meet this obligation in the following ways:

1. A centrally co-ordinated network of specializing observers has been established whose resources can, by means of rapid communication, be brought into full operation at the first indication of lunar transient activity.
2. A standardized form of instrumentation, purpose-designed for the detection and observation of TLP, has been adopted by all observers.
3. An analysis system, specially devised to be applicable to the data acquired by the instrumentation in (2) above, has been adopted.
4. A new observer's report form that ensures the maximum acquisition of instrumental data from an event has now been adopted.

The Director has discussed the organization and co-ordination of the Network of TLP Observers. The instrumentation, analysis system and the new observers' report form are the subject of this review.

Whilst observers in the United States have concentrated primarily on colourless transients, we in the Lunar Section have always searched for coloured events and it is towards this type of event, usually red—but occasionally of another colour—that our main effort is directed.

As with all other astronomical observations an understanding of the observed lunar phenomenon can only be gained from the analysis of the light received, and to achieve this the spectroscope would be applied to the problem by the professional observer. The Moon, however, is not an incandescent body and it follows that most of the sophisticated techniques usually associated with the spectroscope are not applicable. Indeed, if applied to the Moon, the spectroscope would be downgraded to a simple detector of emission and absorption, as will be shown later. These functions can be accomplished with ease by the application of selected photometric filters whose transmission and absorption characteristics are appropriately chosen.

To illustrate this point, let us assume that a red transient event has been detected in an area of the lunar surface and that the event is prominent enough to be easily observed in integrated light. Since no part of the visible lunar surface is observed to be red under normal circumstances, it may be assumed that transient activity is responsible for the observed colour.

In order to present a red appearance to the observer the lunar surface in the event area must be behaving in one of two possible ways, such that:

(*a*) Only red light is being back-scattered towards the observer whilst other colours (wavelengths) have been removed by absorption or similar selective mechanisms, or

(*b*) An excess of red light has been added to the normal white-light albedo of the event area by a mechanism involving the local emission of red light.

In the case of absorption in (*a*) above, it is apparent that blue light must be absent, otherwise the observed colour would not be red. If then the event area is viewed in a blue filter which blocks all red light, the event area must appear 'lightless', i.e. black. The remainder of the field of view, however, continues to back-scatter blue light which is seen via the filter, so producing a blue field of view containing the black event area.

Similarly, if the event is due to a local emission of red light as in (*b*) above and the event is viewed via a red filter, the excess of red light originating in the event area is transmitted to the eye. Also transmitted is the red component of the remainder of the field of view, so that the red event must remain visible in the red filter surrounded by a red field of view. The prominence of the event within the field of view is proportional to its prominence in integrated light.

Absorption and emission mechanisms can, therefore, be individually identified using photometric filters. The observers of the TLP Network use the Wratten 25 (red) and 44a (blue) filters manufactured by Kodak Ltd. The W25, whilst passing red light, absorbs blue, and the W44a transmits blue whilst blocking red light.

Since the lunar environment precludes the existence of liquids, the two possible TLP mechanisms, absorption and emission, must be confined to solids and gases. The simple technique outlined above for the detection of 'basic' emission and absorption is, however, incapable of differentiating between the absorption and emission of light by solids and by gases: for this further refinement is required. These processes will therefore be treated individually in order to ascertain the effects which they produce when observed through the filters. To maintain clarity of meaning it will always be assumed that the observed phenomenon is red as seen in integrated light, but events of different colour may be treated in a similar way. The term 'filter-effect' will be used when the appearance of the event as seen through one or other of the filters is described.

The absorption of light by solids. The filter-effect produced by a red event due to the absorption by solids of all light other than red has been described above for the blue filter, i.e. within a blue field of view the event area appears black. In the red filter, however, there can be no obscuration of lunar surface detail in the event area since only static solids are involved. Nor can there be any enhancement or 'brightening' of the event area, since the emission of additional red light is not involved, and the red of the event is produced, as in the rest of the field of view, by the back-scattered red component of the solar spectrum.

The filter-effects given by a red event due to the selective absorption of light by solids are therefore:

Red filter	*Blue filter*
Normal—event not detectable. No obscuration of surface detail.	Event area black.

It may be noted in passing that the mechanism and its filter-effects define permanent colour, but the mechanism cannot be rejected on this count since, in the lunar environment, it *may* operate in a transient form. If it does, it can be recognized: if it does not, nothing is lost!

The absorption of light by gases. The end product—a red event in which other colours are absent—produces a black event area within a blue field of view, just as in the case of absorption by solids; i.e. the blue filter-effect is black. In the red filter the presence of gas above the lunar surface must be considered. Such a gas, if it is to produce a red event by absorbing other colours must, by lunar standards, have a high density. It follows that due to the associated refractive properties, it will give blurring of the telescopic image of the area in both integrated light and in the red filter. Gas-borne dust, picked up from the lunar surface during high-speed expansion into space above the surface, may also obscure surface detail.

The filter-effects given by a red event due to the selective absorption of light by gas are therefore:

Red filter	*Blue filter*
Obscuration of surface detail.	Event area black.

The filter-effect which segregates red events due to the absorption of light by solids from those due to the absorption of light by gases, is seen to be the obscuration of surface detail; this occurs only with events due to gas. The obscuration will also be apparent in integrated light.

The emission of light by solids. Luminescence and its allied mechanisms, thermo-luminescence, etc., encompass all the processes which are able to induce the emission of light by lunar surface materials except for emission due to direct thermal heating. The latter, as a TLP mechanism, will not be considered here, since an outflow of molten lava would be necessary to cause it and this would be evident to the observer.

In luminescence, and similar mechanisms applicable to minerals, energy in the form of electromagnetic radiation is absorbed and converted into visible light, which is then emitted. The incident radiation which is absorbed is located in the invisible portion of the electromagnetic spectrum, e.g. in the ultraviolet or in still shorter wavelengths. It is most important to note that, since abnormal absorption does not take place in the visible portion of the spectrum and the physical properties of the materials involved are not changed during emission, the white-light albedo remains constant whether emission is, or is not, operative.

In a red event due to luminescence or its allied mechanisms, red light is added to the normal albedo of the event area, which still contains, therefore, the normal blue component of back-scattered light. When the event area is viewed through the blue filter, the red light due to the luminescent emission is blocked, as is the red component of the normal albedo, but the blue component of the albedo passes through the filter to the eye, so leaving the actual event area blue. Since the remainder of the field of view is also rendered blue by the filter, the event area appears totally normal within the field of view, and the red event is undetectable through the blue filter.

Through the red filter, the red component of the albedo of the whole field of view, including the event area, is transmitted to the eye. Also transmitted is the red emission in the event area. Since the latter, depending on the surface material involved, will be at preferred wavelength(s) in the red, the total brightness at that wavelength (i.e. the emission wavelength plus albedo red at the same wavelength) will be seen as an 'enhancement' of the red event area within the red field of view.

The filter-effects due to a red luminescent (or allied) event are therefore:

Red filter	*Blue filter*
Event area bright, without obscuration.	Normal, i.e. event not detectable.

It should be noted that when the word 'normal' is used to describe a field of view containing an event, the meaning is that no trace of an event visible in either integrated light or the red filter is visible through the blue filter—or vice versa.

The emission of light by gases. Here, a low-density gas is raised to the light-emitting plasma state when energy is absorbed from an appropriate source and subsequently dissipated as visible light. The process is akin to, but more efficient than, luminescence in minerals, but fortunately, from the point of view of the detection of TLP mechanisms, a luminous plasma has one most important property not shared by luminescence. That property is *opacity*. The brighter the observed event, the greater is the degree of opacity, and both brightness and opacity at any given level of energy input are again dependent on the density of the gas.

For any event to be visible against the bright lunar background, a fair degree of brightness is required of the event. Hence a similar degree of opacity will be detectable in integrated light.

When a low-energy red plasma is viewed through a red filter, the opacity observed in integrated light is maintained when seen through the filter. If, however, a red plasma is viewed through a blue filter, the plasma loses its opacity completely and becomes quite transparent.

The properties of luminous gases outlined above indicate that when a red event of this type is observed in integrated light to be a 'bright' event, the observer will be looking, not at the lunar surface, but at the upper surface of an opaque luminous mass of gas which completely obscures the surface below. Since the opacity is retained when the event is viewed through a red filter, obscuration of the lunar surface will be present to the same extent as that observed in integrated light. In the red filter the event area will therefore appear bright within a red field of view.

A red plasma is transparent when viewed through a blue filter, and it would therefore appear at first sight that a red event at the lunar surface should disappear completely when viewed via the blue filter. However, a gas of sufficient density to render it capable of supporting a highly luminous plasma also possesses a number of properties which must be considered.

The gas is capable of absorbing some of both the incident and the back-scattered light passing through it. If red is partially absorbed, the emission of red, in the case of a red event, must more than compensate for this loss if the event is to appear bright in integrated light and in the red filter. This is not so with blue, since emitted blue is absent in a red event. A loss of blue implies a darkening of the event area when observed through the blue filter.

When light passes between media of different densities, refraction occurs. A lunar gas cloud expands to form a dome, the density of which is greatest in its central regions. Such a formation acts like a lens and refracts both incident and back-scattered light, so that some of the light which would be received if the event were absent, is not received. Additionally, blurring of surface detail would be apparent. Such loss of blue light produces a darkening of the event area when observed through a blue filter.

The high velocity of expansion may hold surface dust in suspension, resulting in additional absorption of both incident and back-scattered light which, in the case of red, is compensated for by the emission of red by the event, but remains uncompensated in blue light. Again, such loss of blue produces a darkening of the event when viewed through the blue filter.

Furthermore, when light of a different colour from that emitted by the luminous gas passes through the plasma, a form of destructive interference may occur, resulting, in the case of a red event, in a further loss of blue light. Of this particular effect I confess that I have no knowledge since the possibility of its existence was mentioned to me only recently by a low-energy plasma expert.

From the foregoing it is apparent that there are at least three and probably four properties of the gas cloud supporting a luminous event which, acting alone or in unison, remove blue light from the area occupied by the event, ensuring that when the event is viewed through the blue filter, darkening of the area will be observed.

The filter-effects due to a red luminous gas event are therefore:

Red filter	*Blue filter*
Event area bright, with obscuration.	Event area dark, with obscuration.

The brightness observed through the red filter is proportional to the brightness observed in integrated light. Since brightness and gas density are related parameters, the darkening seen through the blue filter can be expected to be approximately proportional to the brightness of the event in integrated light—the brighter the event, the darker the appearance in the blue filter.

The filter-effects of (*a*) the absorption of light by solids and gases and (*b*) the emission of light by solids and gases have now been derived. None of the filter-effects is identical and, in consequence, should any of these mechanisms operate at the lunar surface during an event, the nature of that event may be determined immediately. Since all possible (coloured) TLP mechanisms fall within the categories (*a*) and (*b*), it follows that events of every possible type can be identified.

Discussion

Whilst the filter-effects which have been derived form the foundations upon which the whole analysis sytem is built, only events of the first degree (maximum effect) have been considered. In the complete analysis system, the filter-effects for faint events have been determined, as have the filter-effects for events of colours other than red. Allowances have been made for the different apertures and, hence, different resolving powers, used by individual observers. All these data have been built into charts of the 'family-tree' type, enabling the identity of an observed event to be traced from its observed colour and the reported filter-effects.

Whilst none of the arguments used above can be accurately quantified, the statements made can be verified by reference to the physics of light and chromaticity. Where the properties of luminous gases are quoted, e.g. the filter-effects due to a red plasma, or the properties of luminescent materials, these may be determined by actual experiment. Such work has been carried out by the author. Where it is difficult to see particular filter-effects due to any of the mechanisms, it is useful to refer to the spectroscope in order to obtain a 'spectral profile' of the event. The spectral profile and the filter-effect for any mechanism should present exactly the same picture, or analysis, of the event mechanism.

The spectral primary green has not been mentioned. This is due to the fact that only red events have been under consideration and green, like blue, cannot be present in any significant quantity in a red event. If green were present, the rules governing the additive mixing of coloured light dictate that the observed colour of the event would be orange or yellow and not red. It must be borne in mind that a yellow event due to absorption by solids or gases may be either monochromatic or polychromatic. Moreover, if due to the emission of light by solids or gases, it is likely to be monochromatic, since, in both cases, when the energy input is restricted to low levels, emission takes place at a discrete wavelength peculiar to the solid or gas involved. The presence in the event area of more than one solid or gas in emission is also possible, but in all cases, the colour observed in integrated light and the initial determination of the event as due to absorption or emission, determines the possible monochromatic or polychromatic content as well as the effect of that content on the filter-effects—and vice versa. The status of green may similarly be determined and allowed for although, since the filters used are red and blue, it is of little significance until either a non-red or non-blue event is observed.

The light-emitting properties of lunar luminescent materials returned by Apollo have been investigated and found to be poor. Since the samples may not be representative of such materials in other areas of the lunar surface, particularly from the point of view of thermo-luminescence, this mechanism is included in this system. As with luminous gas, the emission of light is produced at atomic or molecular levels, light being the form in which the initially absorbed energy is dissipated.

The science of spectroscopy is dependent on the fact that, regardless of the mode of excitation, light production by the atomic/molecular process in a given medium remains invariable. Thus, for example, emission lines found in the spectrum of a stellar source may be identified against a laboratory determined standard. Likewise the optical properties of luminous gases above the lunar surface are the same as those determined for luminous gases in the laboratory. Filter-effects so determined are therefore directly relevant to lunar transient events due to luminous gas and to luminescence and its allied mechanisms.

This analysis system for lunar events cannot identify the exact gas or mineral involved in an emission-type event. This requires the spectroscope, and a number of these instruments will, it is hoped, shortly be available for TLP research at certain observatories within the UK.

Observers' report form. Consideration of the filter-effects derived from the emission and absorption mechanisms for a red event will indicate that, if the event were blue, the filter effects would be the same excepting that they would be observed in the 'opposite' filter. For each filter the filter-effects may be summarized as follows:

	Filter effect	
Normal	Bright.	Dark.
	With surface detail.	With surface detail.
	Loss of surface detail.	Loss of surface detail.

The report form (figure 1) contains a column for the description of the observed event in integrated light and two further sets of columns, one for each filter, each set incorporating these filter-effects. The effects themselves are coded N—normal, A—with full surface detail, B—with loss of surface detail, so enabling the observer, by means of a tick, to enter his observation easily and accurately.

Since each mechanism exhibits its own filter-effects, the nature of the observed event can be determined without reference to the description of the event observed in integrated light. The latter, therefore, provides a useful cross-check on the filter-effects recorded in that, for example, the chromaticity of the event can be confirmed. In short, the red filter-effects should be compatible with the blue filter-effects, and both should be compatible with the integrated light observation. If such compatibility is not in evidence, then the observation

LUNAR SECTION TRANSIENT EFFECT FORM.

Co-ordinators:- The Mills Observatory, Balgay Hill, Dundee, Scotland.

This form should be sent to the Co-ordinators as soon as possible after observing any transient event at the lunar surface.

Name.................................... (print)
Address.............................. ....Phone..........
Lunar observing experience.................(years)
Instrument.................. magnification.......... Filters......(R).....(B)

Date................ Time..........GMT. Lunation No............
Feature or location............ ....
Duration of event............ ....
Approx. alt. of Moon..................
Confirmation. Observers at your site or elsewhere..........................
....

Description of event. Give particular attention to the general appearance, i.e. colour, shape, brightness obscuration etc. in integrated light. In the 'filter' columns below, tick N, A, or B, noting particularly the obscuration and darkening, if any, within the glow area. Include any other relevant information, stating the checks made to eliminate false colour from optical sources.
If the transient event is other than of the coloured glow type, please give the fullest possible account on this form. In the case of a colourless obscuration, tick the filter appearance in the same way as for coloured events.

General appearance in integrated light, i.e. without filters.	Appearance of the event area in filters: Tick N,A,orB. N:- Appearance Normal. A:- With full surface detail. B:- With loss of surface detail. Include other effects under 'general appearance'.									
	RED FILTER					BLUE FILTER				
	N	Bright		Dark		N	Bright		Dark.	
		A	B	A	B		A	B	A	B

FIGURE 1. Report form.

requires further investigation or, where an error is obvious, rejection. For instance, a recent report of a red event included ticks under "red filter", Bright—B (obscuration) and under "blue filter", Bright—A (no obscuration). Now it is impossible for an event, which appears bright through the red filter, to be bright also through the blue filter, unless the colour of the event is white or magenta, rather than red. Similarly the obscuration observed through one filter cannot disappear when viewed through the other.

Instrumentation. The Wratten 25 (red) and 44a (blue) filters have been mentioned. These are mounted in a slide or similar device which enables either to be inserted into the optical train in the region of, but not at, the position of primary focus. Provision for integrated light observation is also incorporated.

Two basic types of observation are obtained with the device, (*a*) the prolonged examination of a detected event in each filter in order to obtain detail of its 'fine structure' and (*b*) the more or less rapid interchange of the filters which draws attention to any differences exhibited by the event area, such as, for example, the 'bright in red', 'dark in blue' effects given by a luminous gas event, whose colour in integrated light is red. This filter-effect, incidentally, is the most commonly recorded.

Valuable information can also be obtained by comparing the integrated light appearance of an event with its appearance in both filters. Any differences in the shape, size, etc., of the event so determined should be included in the 'general description' column of the report form.

Historically, filter-effects were reported simply as 'positive blinks'—a term which can no longer be accepted since filter-effects, as indicated in this review, can be 'positive' in many different ways. In the two years which have elapsed since this new approach was adopted by the Lunar Section, few transient events have been observed, but those which have, have shown beyond doubt that the system is easily operated and that the necessary observational data can be readily obtained.

Again, historically, TLP observation and investigation were overshadowed by the inability to determine whether an event apparently occurring at the lunar surface was real or spurious; that is, produced by colour effects originating in the terrestrial atmosphere. Such effects were investigated by the author some 18 months ago, but the theoretical results and predictions remained unconfirmed by observation until 1975 February. Such effects will now be discussed.

Spurious Colour

When a coloured transient event occurs at the lunar surface, the mechanism responsible should indicate its presence by the appropriate filter-effects. If filter-effects are not observed, then no colour-producing mechanism is operative and the observed colour is spurious, having its origins either in the telescope optics or the terrestrial atmosphere.

Such was the case in 1975 February, March and April when colour was widely reported by members of the Network of TLP Observers. In this instance, the interior of Aristarchus and the inner bright walls of Plato were observed to be blue, to the north in Aristarchus and to the south in Plato, whilst red outlined the north inner wall of Plato. On occasion, when the Moon was low in the sky, all small bright areas on the dark maria were observed to be blue to the north, yellow in the centre and red to the south. Venus, and Saturn to a lesser degree, was similarly affected.

The lunar observations showed that filter-effects were not produced, despite concentrated efforts on the part of some observers to detect some slight effects.

Not all reports and analyses have been published to date (1975 June 3) but reference may be made to the BAA Lunar Section Circular for 1975 April [**10** (4)] in which there appears a summary of the reports and an analysis, for the period 1975 February 22 to 28, of the blue phenomenon in Aristarchus.

A consideration of the observational evidence, *excluding* filter-effects, indicates that the 'event' was spurious since:

1. The colours observed were pronounced when the Moon was low but decreased with increasing altitude. This process was repeated on each night during the period.

2. The blue colouration was of such an intensity that, had it been at the lunar surface, all observers, regardless of location, would have observed it—but they did not. Mrs Winifred Cameron, NASA, in subsequent private communications, has failed to report any observations of blue in Aristarchus by members of the ALPO network, for the same period.
3. The onset and end of the blue observations coincided exactly with the establishment and decline of a 'cold' anticyclone whose effects terminated on 1975 February 28.
4. Photoelectric scans of Aristarchus whilst it appeared blue, failed to produce any abnormality in the instrumental read-out when this was compared with that of Tycho. Under high Sun, the photoelectric brightness of Aristarchus is exactly 0·66 that of Tycho when both measures are taken at a resolution of 15 km at the lunar surface. At this resolution the measures relative to Aristarchus represent the mean brightness of the object, that is, including the dark bands or a portion thereof, which may be present within the area of crater being scanned. The instrument (built by the author) has an eyepiece that projects an enlarged lunar image upon a fine ground-glass screen, at the centre of which is mounted a Motorola 2N5777 NPN silicon passivated photo-Darlington amplifier. Subsequent amplification stages ensure linearity of response. The instrument has the spectral response of silicon, i.e. peak sensitivity at 8000 Å in the near infrared, 70% response in the visible red at 6700 Å, but with a relatively poor response in blue of 30% at 4700 Å (approximately).

   If the blue observed in integrated light had been a residual blue after absorption of other wavelengths, it follows that the instrument would have read very low, since only blue light would have been present and the instrument is comparatively insensitive to this. On the other hand, had the blue been due to an emission of blue added to the normal albedo, the instrument would have read 'albedo plus blue'; that is, higher than normal. The blue phenomenon was not accompanied by obscuration and could not therefore have been due to a blue gas plasma, which, by absorbing some red back-scattered light, might, by coincidence, have negated an emission of blue as 'seen' by the instrument and thus given a normal reading for the crater. The only possible conclusion that can be reached, therefore, is that the observed blue was part of the blue component of the light normally back-scattered to the observer from Aristarchus, but displaced from its normal position within the 'white light' of Aristarchus so as to appear alone, thus ensuring that it was seen by the photo-cell as part of the light normally back-scattered by Aristarchus, and so producing a normal reading.

Thus, in addition to negative filter-effects, all other aspects of the recorded data indicate the spurious nature of the phenomenon, and the clue to its origins is indicated in the reports.

It has already been pointed out that, in the case of small bright objects situated on the dark plains, and including Aristarchus on occasion, the colour observed was red to the south, blue to the north, with yellow central to the object when the Moon was very low and the colours brightest. All such small objects at the distance of the Moon may be regarded as point sources of white light against dark backgrounds, and it follows that, since yellow, when observed, was centred on the objects, what was being seen was a dispersion spectrum without deviation of each point source, exactly as would appear in a direct-vision spectroscope. Moreover, the north to south orientation of the observed colours defines the optical normal to which, by the first law of refraction, the incident ray, the refracted ray and the plane of the interfaces producing refraction, are related.

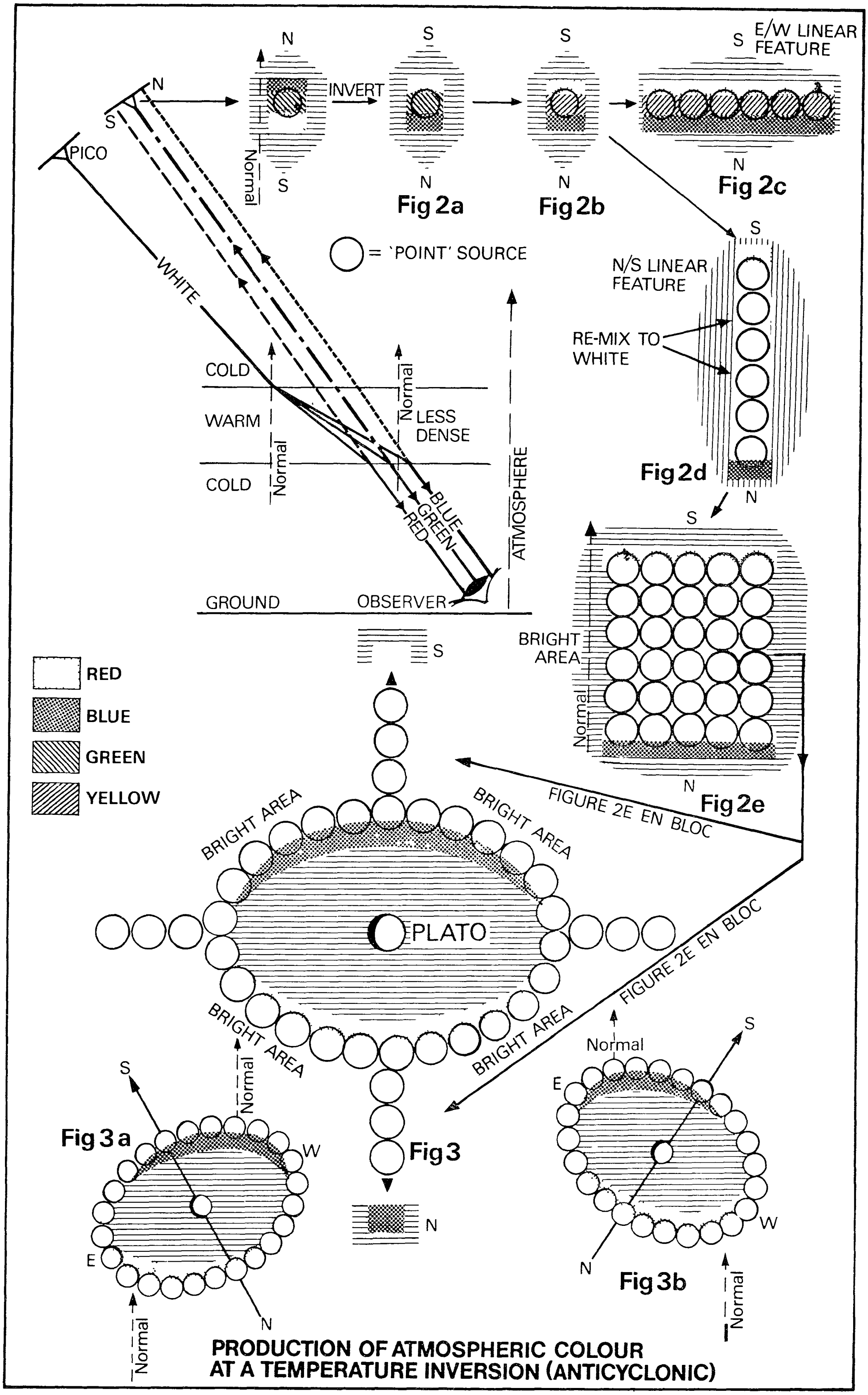
If the approximation of lunar direction 'north–south' is extended downwards to the Earth's surface, the imaginary line so projected forms a perpendicular to that surface, and it follows that the interfaces producing refraction must also be parallel to the Earth's surface. In short, the media in which the spectra are produced must be layers of diverse density within the atmosphere, parallel to the surface.

During the colour phenomena of February 22–28, a 'cold' winter anticyclone of high stability and high central pressure persisted, centred on southern Scandinavia. The 1032 mb isobar remained virtually stationary, running roughly north to south down the Irish Sea. The Meteorological Centre, Manchester, confirmed that, within this system, marked and severe inversions of temperature were present at all times at low altitude and at 1000 m to 1200 m. These were described as "many layers of warm, cold and freezing air" and it follows that where such temperature variations existed, appropriate density variations would also exist. Within any anticyclone there is always a general subsidence of the air mass as a whole, resulting in adiabatic warming. The clear skies associated with such systems do, however, permit marked cooling of the Earth's surface by radiative losses to space, with the result that the air in contact with the surface cools, resulting in the production of mist or fog.

The complex situation may therefore be resolved to a simple model in which there is a layer of warm air above a low-level layer of cold, with a further layer of cold above the warm. Figure 2 illustrates the production of spurious colour within this model. To maintain optical accuracy the colour is shown as if seen direct by the eye with north in its correct position. Figure 2 (*a*) shows the directional inversion due to the telescope optics which puts south to the top and, of course, also inverts the spectrum. In figure 2 (*b*) green is shown mixed with red to form yellow and with blue to form blue-green, a process attributed to atmospheric shimmer since green as such was not observed during the period.

A fine, bright, east to west orientated lunar feature against a dark background may be considered to consist of a number of point sources positioned side-by-side at right angles to the normal. Since each point source produces its own spectrum a line of colour will be produced, red to the south and blue to the north. Such colours will be termed 'edge-colours' since they appear at the interface between bright and dark. This is illustrated in figure 2 (*c*).

A similar fine bright feature is shown in figure 2 (*d*) but the orientation is now north to south. The point sources making up this feature are aligned along



FIGURES 2 AND 3.

the normal so that the 'edge-colours' can appear only at N and S, the spectra produced by intermediate point sources re-mixing to white.

Any bright extended area of the lunar surface may be considered to consist of an infinite number of point sources, each of which produces its own spectrum. Since, in the bright area, all such spectra overlap, the colours produced re-mix to white and 'edge-colours' cannot appear until the bright area interfaces with a dark area, a situation which may not occur until the lunar limb is reached if the area in question is in the 'highlands' regions, where, in high Sun conditions, there are few such interfaces. Spurious colour will not, therefore, appear in objects such as Tycho in which abrupt bright/dark interfaces are absent. Figure 2 (*e*) illustrates this situation. It is worth noting that, if one point source at the lunar surface is producing a spectrum, *all* point sources over the entire lunar surface must be producing spectra. Where adjacent point sources share similar brightness or darkness, as in the highlands or plains generally, the spectra produced must be appropriately bright or dim, and will therefore re-mix to low albedo white in the plains and to high albedo white in the bright highlands. At a bright/dark interface the edge-colour produced by the 'last alignment of point sources' representing the limit of the bright area cannot be neutralized by the far dimmer spectra of the adjacent dark area and hence the edge-colour persists. Such colour is always aligned, as shown in the figures, at right angles to the normal. Should a bright area interface gradually with a dark area, the intensity of spectra produced will decline gradually also, so enabling the declining spectra to re-mix to the corresponding 'white'. The production of spurious colour is therefore precluded at such gradual interfaces. These considerations explain the apparently selective production of colour as observed, and enable predictions as to the location of spurious colour to be made.

In 1975 March, colour was widely observed in Plato. The fundamentals governing the production of spurious colour as outlined above will now be applied to Plato, since the results of such an exercise can be compared with actual observational data.

As seen from any observing site, the optical normal to any horizontal refracting layer within the Earth's atmosphere is a perpendicular erected at right angles to the observer's (horizontal) horizon. All such perpendiculars meet at the observer's zenith. The north point of the lunar axis must oscillate to the east and west of the perpendicular in sympathy with the Moon's progression across the sky from east to west and its position on the ecliptic; the lunar axis thus tilts relative to the perpendicular during the course of each night and each lunation.

Figure 3 assumes that the Moon is in the south and that the lunar axis is approximately parallel to the normal, the latter passing centrally through Plato. Plato has a dark floor which is surrounded by bright areas on all sides, and the interface between dark and bright is abrupt, so that edge-colour produced by spectra of point sources at the limits of the bright areas remain visible, since the dark-area spectra are unable, because of their dimness, to re-mix the edge-colour to white. A bright area has been shown to produce edge-colours located as in figure 2 (*e*), and it is apparent that if figure 2 (*e*) is transposed *en bloc* to the south side of Plato, the edge-colour that will appear on the dark floor of the south interior, outlining the bright south interior wall, is blue. Similarly transposing figure 2 (*e*) to the north side of Plato, the edge-colour red must appear at the bright/dark interface of the floor and the bright interior north wall. The east and west bright/dark interfaces are aligned along the normal and the spectra produced re-mix to white, precluding colour in these areas. Since there are no abrupt bright/dark interfaces in the region surrounding Plato, the individual point source spectra produced throughout these areas re-mix to white, and colour is not seen. Indeed, except in conditions producing 'livid' colour, colour is not again seen until the north limb is reached, where the colour observed will be blue. Likewise on the Mare Imbrium (south) side, changes from bright to dark are not abrupt and colour will not be seen. Again it may not reappear until the southern limb is reached, when the edge-colour observed will be red. At the limb in equatorial regions, since once more the point sources are aligned along the normal, edge-colour will be absent.

It is therefore possible to predict from purely theoretical considerations exactly where colour will appear in Plato and at the lunar limb in anticyclonic conditions with which severe temperature inversions are associated. These positions are tabulated below for comparison:

Feature	*Colour* (*theoretical*)	*Colour* (*actual*)
	PLATO	
N. Wall	Red	Red
S. Wall	Blue	Blue
E. Wall	Nil	Nil
W. Wall	Nil	Nil
	LUNAR LIMB	
North	Blue	Blue
South	Red	Red
East and West	Nil	Nil

when the lunar axis and the perpendicular are approximately parallel as indicated above.

When the lunar axis is tilted relative to the perpendicular, the observed colour must, by the first law of refraction, maintain its station relative to the perpendicular, so that the orientation of colour relative to a lunar feature appears to change position according to the amount of tilt of the axis.

The 'rotation' of colour in Plato is illustrated in figures 3 (*a*) and (*b*), where axial tilt displaces the blue to the south-west and the red to the north-east in (*a*), and red to the north-west and blue to the south-east in (*b*), in agreement, once again, with the observational data of 1975 March and April.

Colour observed at the lunar limb is subject to positional change in similar manner, but this is of little observational significance, since it is obviously spurious when observed. Its presence may, however, be taken by the observer as a fair indication that spurious colour is likely to be observed in small bright objects against dark backgrounds or at abrupt bright/dark interfaces on the lunar surface, and that the orientation of limb colour will be approximately repeated in other objects in which colour appears. From figures 2 and 3, given the observed colour at the limb, the expected colour to be observed in various parts of the object being examined can be determined.

Conclusions

The production of spurious colour discussed above depends on anticyclonic weather systems of the 'cold' winter variety, with temperature inversions. Many weather systems produce temperature and density 'layering' in which the orientation of the observed colours would be inverted, and it is apparent that the study of lunar transients must also involve an appreciation of the meteorological situation existing at the time of reported phenomena. Since the orientation of colour relative to a specific feature can be predicted, as can the actual colour to be expected, there will no longer be confusion of such colour with real transients. There is, however, no reason to assume that all TLP are due to spurious colour since, historically, filter-effects associated with specific mechanisms have been recorded—being predominently filter-effects due to luminous gas, i.e. the event area appearing bright in the filter of the same colour as the event and dark in the other, with obscuration in both.

The analysis system predetermines the filter-effects due to TLP mechanisms. The filter-effects are derived from the known optical and physical properties of solids and gases in emission and absorption, with due consideration being given to chromaticity. It therefore follows that the system provides a sound 'standard' against which observational data can be compared and the mechanism of any observed event can be determined. The filter-effects of complex events involving more than one basic mechanism have also been derived, but these have not been included here primarily due to restrictions of space.

Perhaps one of the most puzzling aspects of filter observations is the fact that spurious colour in a lunar feature is not visible in the filters. Taking, for example, the recent blue observations in Aristarchus, it is obvious that this blue cannot appear in the red filter, since it is absorbed. Nor is there any absorption of red from the red component of the light normally back-scattered from the area. The red filter-effect is therefore 'normal'.

In the blue filter, back-scattered blue from the whole field of view passes to the eye along with spurious blue in the event area so that, at first sight, it would seem that the area should be 'enhanced' in this filter, as in an emission-type event. Such enhancement does not, however, take place, for the following reason: whereas in an emission event blue is, by virtue of the emission process, concentrated at a discrete wavelength, a spurious blue, being a portion of the back-scattered solar spectrum, is not so concentrated. The spurious blue thus has a wide wave-band in the blue which exactly matches the 'pass-band' of any blue filter both in colour and intensity, and the event remains undetectable. The concentration of blue light at a discrete wavelength in an emission event constitutes a 'mismatch' at that wavelength which is apparent as enhancement or 'brightness' in the filter. Regardless of the foregoing, observations of limb colour in filters adequately demonstrate that, provided the colour is not 'livid', it remains invisible in the filters (and it would be prudent to abandon the search for coloured TLP in such conditions anyway!).

In the 'blue Aristarchus' observations under discussion, blue appeared alone at most times. When the Moon was low with conditions at their most adverse, red and yellow were also present, but these gradually disappeared with increasing altitude until only blue remained. The sequence was repeated on a number of nights during the period 1975 February, March and April, confirming the theoretical considerations of wavelength, refractive index and angle of incidence, that this should occur. It may be said, in short, that blue appears alone because it suffers the greatest angular deviation.

During the colour-producing period mentioned above, colour was seen to 'flare' and 'fade' on many occasions. These phenomena are easily understood when it is realized that atmospheric conditions are responsible, and that the inversion layers are moving overhead at all times in sympathy with the general clockwise rotation of an anticyclonic system as a whole. It is apparent that zones of varying intensity within the inversion layers must be passing across the field of view and that, as these vary from slight to intense, the colour produced in the lunar feature will vary accordingly in intensity, and appear or disappear in features whose brightness is critical.

Plato, both in the foregoing text and in figures 3, 3 (*a*) and 3 (*b*), has been treated schematically only. The 'real' Plato does not quite conform to this picture in that its west and east walls contain colour-producing features which operate individually. On the west inner wall, just north of the large landslip, is a bright area whose southern edge interfaces abruptly with the dark floor where the bright area extends towards the east. At this interface the colour red should appear according to the predictions given by figure 2 (*d*), whilst blue should be seen on the north side of this small bright area where the boundary of the area runs westwards towards the inner wall of Plato. This was confirmed exactly by observations during 1975 March.

In the eastern wall of Plato is an east–west orientated gap of small width. The gap produces a dark interface with the bright portions of the wall to the north and south of it. Again by application of figures 2 (*d*) or 2 (*e*) it will be seen that blue should appear on the south side of the gap, whilst red should be seen on its north side. These manifestations of colour were also confirmed observationally during the period.

The 'reversal' of the positions occupied by red and blue at these two features is simply due to the fact that the first is a bright area against a dark background and the second, the gap, is a dark area within a bright area. The transposition of figure 2 (*e*) to each side of each feature, *en bloc*, shows the theoretical and observed colour at the interfaces between bright and dark. A similar exercise using figure 2 (*e*) indicates the colour distribution to be expected within the 'steeple' shadows cast by the eastern wall in sunrise conditions; phenomena also observed during the period. These colours were faint due to the low albedo of the floor of Plato and were detected only by a small minority of observers.

All colour phenomena observed within Plato during the period in question are therefore seen to be entirely spurious and the reports are devoid of any suggestion that, concealed within the spurious, there may have been some genuine lunar activity.

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