A rebuttal of the EMBLA 2002 report on the optical survey in Hessdalen

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Abstract – On August 2002, a scientific expedition to the Hessdalen valley (Norway) – code-named EMBLA – aimed at investigating on an unidentified atmospheric light-phenomenon, was carried out by the physics section of an Italian team of scientists. According to the EMBLA 2002 physics report, the evidence collected point at an unknown atmospheric light phenomenon "able to produce a luminous power of up to 100 kW". The photometrical and spectroscopical data collected by the team of scientists on August 2002 are analysed and reasons for rejecting the suggested conclusions are presented in this paper. Furthermore, it is proposed an explanation that satisfactorily explains the evidence in terms of a known phenomenon. In spite of this negative findings, the anecdotal evidence collected by this author at Hessdalen suggests that clearly-defined, specific studies into the field of anomalous aerial phenomena should be supported.

1. Introduction

Hessdalen is a valley stretching over 12 km of a thinly populated area (Bygdekatalog, 2000) of central Norway, south-east of Trondheim and near the Swedish border (Dalsbygda, 1992; Haltdalen, 1995). As from November 1981 a series of unidentified lights had been reported by the residents of the valley. According to the sighting reports the lights were seen hovering or moving around at various speed.

> These lights could be anywhere. Sometimes they were reported to be just above the roof of the houses, or just above the ground. Sometimes they could be high up in the air. Mostly the lights were reported to be below the tops of the mountains nearby. No one could give and explanations for these lights.
> The lights appeared to have different specific forms. This showed up on the photos. It could have a form of a bullet, with the sharp end down. It could be round as a football. It could be as a "Christmas-tree" upside down. The colours were mostly white, or yellow-white. […] The lights were occurring several times a day, but mostly during the evening or night time. […] There were more lights in wintertime. In summertime, lights were seldom seen at all. One reason for that might be that there is daylight almost whole night in summertime in Hessdalen. (Strand, 1985)

Since no official agency seemed to care about these unknown lights, in June 1983 a small group with five participants set up a "Project Hessdalen", under the directorship of Leif Havik, Odd-Gunnar Roed, Erling Strand, Håken Ekstrand, and Jan Fjellander. This group secured technical assistance from the Norwegian Defense Research Establishment, the Universities of Oslo and the University of Bergen. The project then involved three stations with observers and their cameras (some fitted with gratings); a spectrum analyser; an infrared viewer; a seismograph; a Geiger counter; a magnetograph; and a laser. Field operations at Hessdalen started on January 21 and ended on February 26, 1984 (Strand, 1985).

> Lights that were recorded to be below the contours of the mountains must have originated in the Hessdalen region, but lights that were recorded to be above the crest line may have originated at a great distance. Without triangulation or other information, it is impossible to determine the distances of the lights. However, some of the events that were seen as lights were tracked also by radar. If taken at face value, the radar measurements would imply speeds up to 30,000 kilometers per hour. […] During a period of four days, unknown lights were seen on 10 occasions, and the flux-gate magnetometer registered 21 pulsations, of which 4 appear to correspond with the observations of lights, suggesting an association between some of the unknown lights and magnetic disturbances. The gratings on the cameras were intended to obtain spectroscopic data: the spectra appear to be continuous, with no indication of either emission lines or absorption lines (Sturrock, 1998, 1999).

Project Hessdalen carried on further field work in the area during the winters of 1985 (Hynek, 1985) and 1986. The series of sightings allegedly ended in 1986. While photographical, spectrographical and radar data had been collected, Project Hessdalen did not find a definite answer, and investigators disagreed on the nature of the phenomenon. According to Roed, though the lights "seemed intelligent in their movements", they probably had some "complex" natural cause. On the contrary, Strand remarked that "if the lights were natural, it's strange that they existed for a five-year period and that they were recorded in Hessdalen and nowhere else" (Clark, 1998). Further studies and field works by other private researchers were carried on. As a results of these efforts, several sightings were explained as misperceptions of astronomical bodies and planes (Henke, 1987). Others turned out to be due to temperature variations in air levels causing the refractions of distant light sources (Krogh, 1985; Devereux, 1989). Notwithstanding this, a "residue" of "unidentifiable" lights reports was left (Devereux, 1989). While not reaching any more the "peaks" of activity occurred between 1982 and 1984, sightings of unidentified lights have been reported in the following years to some extent. Allegedly, the rate of observations is now about 20 reports per year (Sturrock, 1998, 1999).

To face this scientific "anomaly", in August 1998, under initiative of two assistant professors at Østfold College (Sarpsborg, Norway) – Erling Strand (former co-founder of Project Hessdalen), School of Computer Science, and Bjørn Gitle Hauge, Department of Engineering and Natural Sciences – it was set-up at Hessdalen a permanent Automatic Measurement Station (AMS) aimed at constantly monitoring the west side of the valley by means of automatic videocameras (Strand, 2002).

In August 2000 and 2001 a team of Italian researchers – physicists, engineers and technicians working at the CNR-IRA (National Council of Researches, Institute of Radioastronomy, Bologna, Italy) – jointly with the Østfold College researchers, carried out a set of measurements at Hessdalen both in the radio and in the optical wavelengths, code-named EMBLA Project (Hauge, 2001; Teodorani et al., 2000, 2001).

Since the EMBLA team was not officially charged by the CNR with this task, the missions required a source of financial support. This issue was solved through an ad-hoc civilian fund-raising committee established in July 2000. This committee (which was called CIPH: Italian Committee for Project Hessdalen) is a volunteers association, headed by Renzo Cabassi, whose aim is the promotion of the scientific study of Hessdalen-like phenomena (Cabassi, 2001; CIPH, 2002). Both 2000 and 2001 EMBLA missions were totally supported and founded by CIPH.

As a result of the radio-optical EMBLA 2000 mission, Teodorani et al. (2000) wrote that "without any sort of doubt unstructured and plasma-like lights often co-exist with 'structured objects'". The leaders of the optical EMBLA 2001 mission went so far as to conclude that "1) the luminous phenomenon is a thermal plasma; 2) the light-balls are not single objects but are constituted of many small components which are casually vibrating around a common barycentre; 3) the light-balls are able to eject smaller light-balls; 4) the light-balls change shape all the time; 5) the luminosity increase of the light balls is due to the increase of the radiating area" (Teodorani et al., 2001). During a workshop at Hessdalen, Teodorani (2002) openly stated that "the approximately globular shape of the plasmoids is due to a sort of 'central force' which simulates gravity and which gives the plasmoids the shape of a 'mini-star'. […] There is no doubt from the recorded data, that the phenomenon shows characteristics of self-regulation from an energetic point of view, and so far it is not possible to identify a mechanism of natural origin which is able to act spontaneously with such a surprising efficiency".

In the period 5-18 August 2002 a third EMBLA mission to Hessdalen was carried out. One of its outcome is a paper titled "EMBLA 2002 – An Optical and Ground Survey in Hessdalen", authored by Massimo Teodorani and Gloria Nobili:

> This time the scientific expedition consisted of two groups: an engineering group and a physics group. The engineering group was composed of Stelio Montebugnoli, chief of CNR-IRA radioastronomic station in Medicina (Bologna, Italy) and his assistant Marco Poloni. The physics group was composed by [Massimo Teodorani and Gloria Nobili] [and] was mainly devoted to five kinds of activities: 1) taking photographs of the light-phenomenon, 2) taking spectra of the light-phenomenon, 3) measuring the radiation field with a Geiger counter in some places, 4) collecting ground-samples which were suspected to be approached by the light-phenomenon, 5) proposing biophysical investigation (Teodorani & Nobili, 2002).

As far as one can tell from the Teodorani and Nobili's "ground-sample analysis", there is no case for believing that the "target sample" has any correlation with the luminous phenomena occasionally sighted by the Hessdalen inhabitants. (Teodorani & Nobili, 2002, p. 13) Since the data reported by the EMBLA physics team do not avail this author to cross-check the alleged "very close sighting of a light-orb", the ground survey topic is not discussed here.

Unlike the former missions, EMBLA 2002 was only partly founded by CIPH. In particular, the "physics group" was not financially supported by the committee (apart from the loan of a transmission grating) due to disagreements on the issue of the methodology of data collection and analysis accomplished during the previous years.

On the contrary, the EMBLA engineering team (headed by Stelio Montebugnoli, CNR Leading Technologist and Director) *did* receive a grant from the Italian Committee: the field measurements by means of a low power pulsed radar (Montebugnoli et al., 2002) and the engineering team expertise deserved this support.

In August 2002, though not made clear by Teodorani & Nobili (2002), the author of this paper was charged by CIPH to collect sighting reports by the residents in the valley and to evaluate the methodologies of data collection carried out at Hessdalen. At the same time, Flavio Gori (NASA Inspire Project) was charged with the recording and analysis of radio signals in the VLF region, with the aim of studying possible correlations between luminous phenomena and radio emissions (Gori, 2002). Gori and this author were supported and founded by CIPH in the accomplishment of these aims. CIPH field investigations at Hessdalen got under way on August 1 and ended on August 8, 2002.

2. The case for Hessdalen lights

As a matter of fact, the argument for an unidentified aerial phenomenon in the Hessdalen valley rests on different kinds of evidence, like eyewitness testimony, photos and videos by the AMS, non-optical instrumental records. While a comprehensive review of the evidence collected so far is outside the aims of this paper, a brief discussion will follow.

Eyewitness testimony

Though Teodorani and Nobili are firmly convinced that the phenomena called "unidentified flying objects" are so elusive that a scientific analysis is impossible (e.g. Teodorani & Nobili, 2002, p. 16), the "Case Studies" of the "*Scientific Study of Unidentified Flying Objects*" conducted by the University of Colorado under research contract with the U.S. Air Force demonstrate that quite the opposite is true and that *eyewitness* sightings about unidentified phenomena are amenable of scientific research (Condon & Gillmor, 1969).

In summing up what constitutes scientific evidence, during a symposium on unidentified flying objects sponsored by the American Association for the Advancement of Science, MIT physicist Philip Morrison remarked that the "absence of humans in the data link is [not] the criterion for good evidence" (Morrison, 1969). While submitting that there are such criteria, he added that "from the point of view of drawing inferences about events, a witness is simply an extraordinary subtle and complex instrument of observation".

Unidentified flying object reports have been showed to pose a scientific problem for decades. A number of astronomers and physicists were able to expose this to the scientific community: among them, the astronomer and former U.S. Air Force "Project Blue Book" consultant J.A. Hynek (1969, 1972); the astrophysicist and computer scientist J.F. Vallee (1965, 1966); the atmospheric physicist J.E. McDonald (1967, 1969); the CNES engineers C. Poher and A. Esterle (CNES, 1979-1983). This problem has to do with both psychology and physical science.

As regards the psychological side, it is well known that problems in perceiving events, retaining information in memory and retrieving information from memory are deeply rooted in eyewitness testimony (Loftus, 1979). Notwithstanding this a number of phenomena of potential scientific interest, like transient luminous phenomena in the low atmosphere, are so unpredictable in their occurrence that the only sources of evidence are involuntary witnesses (Corliss, 1982). To the aim of treating the involuntary human observer as a source of scientific data, specific techniques had been developed by several psychologists with long-standing interest in the methodological problems of studying unidentified flying objects reports (Shepard, 1968, 1979; Haines, 1976, 1979, 1980).

During the August 2002 on-site survey in the Hessdalen valley, the author of this paper and Flavio Gori had been collecting several sightings about unidentified lights and objects witnessed by valley inhabitants. While the body of anecdotal evidence collected so far by this author do not point at any specific constant of the alleged "Hessdalen phenomenon" as a whole, some eyewitness reports by the Hessdalen inhabitants still defy conventional explanation and would require further in-depth analyses. To make use of the acronym coined by E.J. Ruppelt, former chief of U.S. Air Force's *Project Blue Book*, the reported phenomena are UFO in the literal sense, i.e. Unidentified Flying Objects (Ruppelt, 1956).[1] These investigations will be reported in a separate article.

Automatic Measurement Station (AMS)

On September 30 - October 3, 1997, a workshop was convened at the Pocantico Conference Center in Tarrytown, New York, in which a scientific review panel, composed of nine scientists of diverse expertise and interests, met with several investigators on Unidentified Flying Object reports (Sturrock, 1998, 1999). The purpose of this four-day workshop was to review purported physical evidence associated with UFO reports, with a view to assessing whether the further acquisition and investigation of such evidence is likely to help solve the UFO problem, namely the determination of the cause or causes of these reports. The panel concluded that "it would be valuable to carefully evaluate UFO reports since, whenever there are unexplained observations, there is the possibility that scientists will learn something new by studying these observations" (Sturrock, 1998, 1999). During the workshop there was in addition a presentation (by Erling Strand) of investigations into recurrent phenomena that occur in the Hessdalen valley. As a result of this presentation, the panel concluded that

> there would be merit to designing and deploying a not-too-complicated set of instruments. These should be operated according to a strict protocol in regions where the probability of significant sightings appears to be reasonably high. It is recommended that, as a first step, a set of two separate video recorders be equipped with identical wide-angle objectives and installed on two distant fixed tripods to help eliminate the possibility that some of the apparent motions detected by video recorders are due to the operators' hand movements or ground vibrations. It would also be useful to set up two identical cameras, one of which is fitted with a grating. However, experience so far at Hessdalen indicates that a grating may not be adequate for obtaining spectroscopic information. In view of the great importance of spectroscopic data, it would be highly desirable

[1] "In many instances it has been positively proved that people have reported balloons, airplanes, stars, and many other common objects as UFOs. The people who make such reports don't recognize these common objects because something in their surroundings temporarily assumes an unfamiliar appearance. […] In determining the identity of a UFO, the project based its method of operation on a well-known psychological premise. This premise is that to get a reaction from one of the sense there must be a stimulus. If you think you see a UFO you must have seen something. Pure hallucinations are extremely rare" (Ruppelt, 1956, p. 15, 17). Although most Hessdalen lights sightings are caused by easily recognizable conventional stimuli, a few unexplained sightings are left.

> that special equipment be developed and deployed for obtaining high-resolution spectroscopic data from transient moving sources. This may be a nontrivial problem (Sturrock, 1998, 1999).

Following the Pocantico workshop, an automatic measurement station was installed in Hessdalen. As discussed in the Introduction, this station was developed and prepared by Erling Strand and Bjørn Gitle Hauge, at Østfold College, which is the present base of Project Hessdalen. This station includes a wide-angle b/w CCD-type camera in the visible region (the output from the CCD-camera is fed automatically to a computer which triggers a video recorder) and a set of two color CCD-cameras aimed at triangulating the phenomenon (Strand, 2002). Whenever a sudden light shows up in the view of the CCD-camera, an alarmpicture is sent to the Project Hessdalen web site and the videorecorder is started and run for 15 seconds. Although the large body of alarms are due to easily identifiable sources of light, a few optical stimuli remain unexplained and deserve further attention (Strand, 2002).

These systems are an important step toward the full application of the Pocantico workshop recommendations. It remains to be developed a special equipment for automatically collecting spectroscopic data from transient moving sources. This problem could be faced through an import of methods and equipments from the field of "meteor spectroscopy" (Majden, 1998; Majden & Borovicka, 1998).

Non-optical instrumental records

During the 1984 Project Hessdalen's field operations a number of high-strangeness – high probability[2] visual sightings were corroborated by instrumental records (Strand, 1985). On February 12, the observers directed a laser beam (633 nm; power = 0.4 ÷ 0.76 mW) on passing lights. Out of a total of nine times, the light responded all but once in a curious way: according to the witnesses a slow-moving, regularly flashing light "changed its flashing sequence from a regular flashing light to a regular double flashing light" (Strand, 1985). On February 27, a bright light was radar tracked moving at 8500 m/s (the radar was an "Atlas 2000", λ = 3 cm). On another occasion an unidentified light under constant visual observation showed up on radar only on every second sweep of the radar dish. "But in most instances – 33 in all – when radar showed something, the eye could see nothing, nor could the camera" (Clark, 1998). Now and then "spike-like signals" in the radar range were detected by the researchers, however "we did not see anything on the spectrum analyser at the same time we saw the lights" (Strand, 1985).

So far most of the non-optical evidence collected during the EMBLA missions is uncorrelated with the alleged luminous phenomenon. As regards the "spike-like" signals, "no luminous phenomena could be reported while the personnel was controlling the monitors of the radio spectrometers" (Teodorani et al., 2000, p. 6). For what concern the radar recordings, an unidentified echo was detected in 2002, however "it wasn't possible to see anything in the same point on the sky with binoculars and portable telescopes" (Montebugnoli et al., 2002). Other interesting readings in the VLF range were carried out by Gori (2002). These recordings were not correlated with visual sightings as well.

3. The August 2002 Optical Survey

According to the authors of the EMBLA 2002 physics paper, "several light-phenomena" were recorded last August, "in different positions" of the Hessdalen valley. While remaining "unidentified", the reports about these phenomena are not included in the EMBLA paper. The "confirmed 'Hessdalen phenomenon'" showed a repetitive pattern of behaviour (figure 1).

> *Only the pictures of a blinking light seen towards south from the Aspåskjolen spot, were confirmed to be due to the "Hessdalen Phenomenon" and therefore were considered for analysis*: 15 photos in total of this type of light were taken, of which 6 were used for analysis. The light-phenomenon at this precise position was seen almost every evening/night, mostly between 10 p.m. and midnight. In almost all cases the light appeared very close to the ground, it

[2] An operative definition of strangeness/probability indexes was suggested by Hynek (1972).

> blinked very fastly with a pulsation-rate of less than one half second and the entire performance lasted from 1 up-to 30 seconds, most frequently 5 seconds. This behaviour, sometimes, was reported more times during a single night [emphasis mine](Teodorani & Nobili, 2002, p. 2-3).

Fig. 1 – Photograph of the "blinking light" shot by the EMBLA physics team in August 2002 (source: Teodorani & Nobili, 2002).

It is interesting to remark that, according to Teodorani et al., this peculiar "blinking light" was frequently seen the former years also. In August 2000, this light was classed as "Type 1" (Teodorani et al., 2000, p. 9-10). In August 2001,

> *the very most part of the targets was due to very intense "blinking lights",* which were mostly seen from Aspåskjolen towards the South direction. These lights-phenomena lasted from 5 up to 60 seconds. The blink was always irregular. These "light-balls" were always seen on the top of the mountains (Teodorani et al., 2001, p. 16).

The EMBLA 2002 report is lacking of basic information about date/time of occurrence of this phenomenon. To rejoin at this obvious remark, the EMBLA physics team says that

> the date of appearance of the light-phenomena in general, has not been considered a relevant parameter for analysis, as the light-phenomenon […] is normally seen almost all the days. […] The parameter "time" […] is not at all objective from a real statistical point of view in the same way in which video data are acquired all the time in automated mode by the Automatic Measurement Station" (Teodorani & Nobili, 2002, p. 3).

It is not easy to understand the reasons leading the EMBLA team to not record parameters (like date/time) that could help an independent corroboration (or falsification) of their data, should other witnesses had seen the light phenomena, or should the Automatic Measurement Station had filmed a light. Furthermore, by not taking note of this basic piece of information the EMBLA researchers prevent themselves from obtaining an eventual triangulation of the phenomenon.

However, during the week-long stay at Hessdalen, the author of this paper had two chances to see the almost motionless and point-like light-phenomenon sighted and photographed by Teodorani and Nobili, from the "Aspåskjolen" site. The first sighting happened at about 2150 (UT), August 6; the second one at 2105 UT, August 7 (Leone, 2002).

While the EMBLA physics team observed it through naked eye or through the objective of a reflex camera, this author observed it through naked eye and (in one occasion) through a portable refractor telescope (Stein Optik, 60 mm in diameter, 30x – 90x in magnification). According to the physics team, the light showed a repetitive behaviour and was prone to appear always near the same spot (a comparison between last year's and this year's photos (Teodorani et al., 2001, p. 16-17; Teodorani & Nobili, 2002, p. 4) does support this contention). Therefore, following the first sighting quoted above, this author pointed the refractor at the place of interest and awaited for the developments. When the light did show up again the second time, the EMBLA team photographed it and collected its spectrum (see next sections). At the same time, this author looked at it through the refractor telescope and easily identified it as a pair of car headlamps.

Though this author duly informed Teodorani about this successful identification, the EMBLA 2002 physics paper fails to address the car headlamps explanation.

4. Linear and Angular Images Measurements

The whole set of visual, photometrical and spectrographical evidence reported in the EMBLA 2002 paper had been collected "from the Aspåskjolen observation point" (p. 7). Its exact geographical coordinates and altitude are left to the imagination of the reader. As much undetermined are azimuth and angular elevation of the luminous phenomenon. Since the EMBLA team collected the optical data about the luminous phenomenon from one observation point only, it is not possible to estimate the exact linear distance between phenomenon and observer and, therefore, the phenomenon's actual size. However, by fixing the camera on a theodolite, azimuth and angular elevation could be recorded with a fair degree of accuracy. The collection of these quantities is a matter of principle because they could enable a triangulation of the phenomenon, should other observations, from a different point of view, become available. It is disappointing to learn that the EMBLA team didn't accomplish this obvious methodology. On the contrary, they reversed it by taking for granted that the phenomenon's distance is a known quantity:

> […] *the phenomenon's distance* […] *is assumed to be approximately 9 km* [the hill Skarvan] from the Aspåskjolen observation point. This value for distance, which is deduced from Hessdalen maps, is confirmed also by one of the tracks of the top of the hills (towards South: compass reading from Aspåskjolen = 187.7°) which were recorded by the radar operated by the engineering group. (Teodorani & Nobili, 2002, p. 7) [added emphasis]

The "blinking light" observed through the refractor lenses showed to be due to two quite resolved car headlamps. The angular distance (through a 30x magnification power) was estimated to be larger than one full moon diameter (the full moon angular diameter is close to 0.5°). Should the 9 km estimate be correct, and assuming the two headlights to be 1 m distant one another, their angular distance would appear to be [30 · (1/9000) rad = $3 \cdot 10^{-3}$ rad] = 0.19°: a figure to much low to comply with the visual observation. As from the EMBLA paper, the 9 km figure "*is objective* only in the case of frame 5, as the light phenomenon […] *appears to occur very close to the trees of the top of the hill*. In the other cases, it is possible that the phenomenon is farer […]" (Teodorani & Nobili, 2002, p. 8) [added emphasis].

The 9 km estimate is likely wrong. It doesn't originate from an actual distance measurement and it is not supported by the photographical evidence. Since the photographs show a luminous phenomenon apparently in front of a mountain several kilometres away, the 9 km figure is, at most, only a maximum boundary of the distance.

The actual phenomenon's distance is much lower than the figure reported by the EMBLA physics team. To get a reliable estimate of this parameter photos and maps have been used: photographs of the luminous phenomenon shot during EMBLA missions; a southern landscape photograph shot by this author in August 2002, from the observation's point; 1:5000 economical maps (Hessdalskjølen, 1995; Vårus, 1995); 1:50.000 topographical maps (Dalsbygda, 1992; Haltdalen, 1995).

A few seconds after each sighting this author measured the phenomenon's azimuth by pointing a compass at the exact spot where the light showed itself: 185° (+/– 5°). By comparing a southern landscape photograph with the frames 1-6 (Teodorani & Nobili, 2002; p. 4) and figs. 8-9 (Teodorani et al., 2001; p. 16-17), it is possible to get a more precise estimate of the phenomenon's azimuth.[3]

The observation's point (called in the EMBLA physics paper: Aspåskjolen) is a grass field (Long.: 11°10'53" East; Lat.: 62°50'16" North; altitude: 690 m) in the northern Hessdalen valley, on the right side of a country road connecting Hessdalskjølen (along the main road FV576) to Åsbardet (Hessdalskjølen, 1995; Haltdalen, 1995).

The "blinking light" appeared – by perspective – between two high peaks in the southern landscape: Hessjøhøgda in the right side (Long.: 11°08'21" East; Lat.: 62°41'47" North; altitude: 1057 m) and Nyvollhøgda in the left side (Long.: 11°10'32" East; Lat.: 62°40'29" North; altitude: 1044 m) (Dalsbygda, 1992). Tab. 1 lists the angular coordinates of this mountain tops as seen from the "Aspåskjolen" site (Dalsbygda, 1992; Haltdalen, 1995).

Mountain	Azimuth (°)	Angular elevation (°)
Hessjøhøgda	187.7	+0.023
Nyvollhøgda	180.9	+0.019

Tab. 1 – Angular coordinates of mountain tops from the "Aspåskjolen" site.

Through a set of linear and angular measurements of a positive color print of the southern landscape photograph (figure 2; for a photo showing a similar field of view see Cabassi (2001, p. 7)) and through the linear measurements of the light's image on the enlarged frames published in the EMBLA 2002 paper (Teodorani & Nobili, 2002, p. 4), it is possible to estimate the horizontal and vertical angles of the luminous phenomenon with respect to the top of the mountains.

Fig. 2 – Southern view of Hessdalen landscape from the "Aspåskjolen" observation point. It shows the Vårhuskjølen hill in the foreground. The "blinking light" appeared inside the red rectangle (see figure 1).

[3] In the strict sense the compass measurement has to be corrected by the magnetic declination. Since this quantity is currently lower than 1° in Norway (see http://www.ngdc.noaa.gov/cgi-bin/seg/gmag/fldsnth1.pl), i.e. lower than the compass accuracy, the magnetic declination is not considered here.

Let 1.00 be the distance between the two mountain tops. The apparent horizontal distance between the light and Hessjøhøgda is 0.38 and the apparent vertical distance is 0.14.

Feature	Azimuth (°)	Angular elevation (°)
"blinking light"	185.1 ± 0.2	– 1.0 ± 0.2

Tab. 2 – Angular coordinates of the luminous phenomenon from the "Aspåskjolen" site

Estimated light's angles are shown in Tab. 2. The azimuth figure is close to the on-site measurement described above. The error of each value is obtained through the Gauss propagation of errors by taking $\Delta x = 1$ mm in the length measurements on a 15x10 positive photographical print.

5. Site Visit Results and Analysis of the Topographical Charts

A comprehensive site visit was made by the CIPH team in last August. Photographs and general inspections were made of the Hessdalen area where the above quoted photographs had been taken. The on-site survey and the analysis of the topographical charts show that several hills are located along the direction of appearance of the phenomenon. The main ones, on the right side of the valley (looking towards South) are (arranged in order of decreasing distance from the observation point shown in figure 3): the Skarvan peaks, Heggsethøgda and Vårhuskjølen. The light appeared exactly on the edge of the Vårhuskjølen hill (figure 1). The ground is mainly covered by forests and seldom cultivated areas. There are no inhabited houses along the line of sight (which is roughly parallel to the Hesja river).

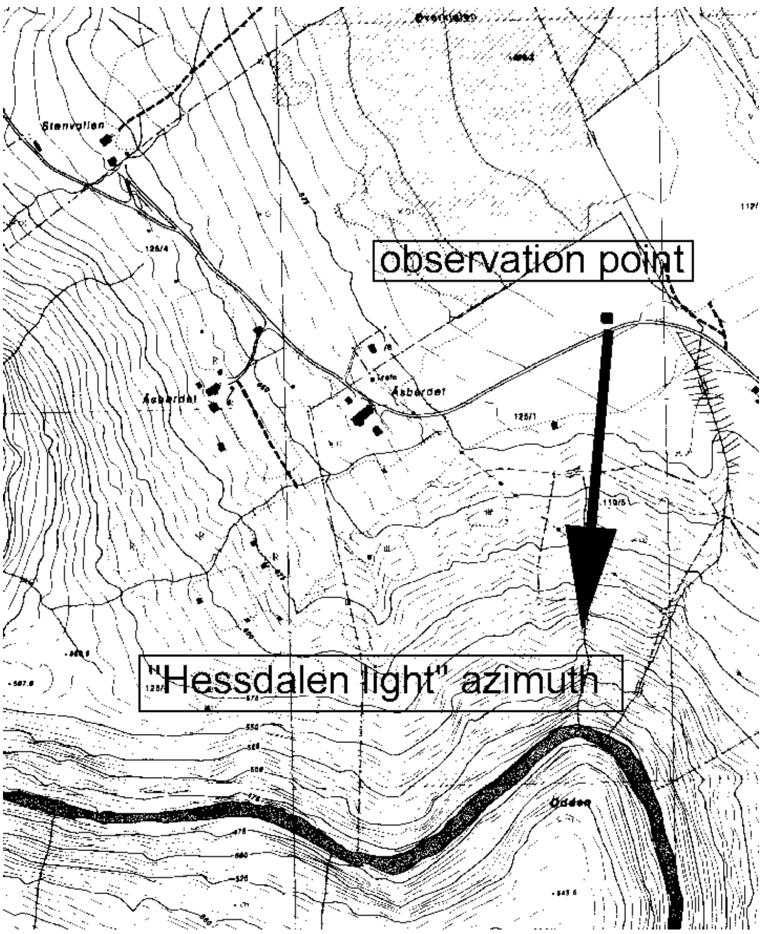

Fig. 3 – 1:5000 Hessdalen chart. The observation point was placed close to the highest stretch of a country road close to Åsbardet. The arrow points at the "blinking light" azimuth (~ 185°) (source: Hessdalskjølen, 1995).

The authors of the EMBLA 2002 physics paper fail to consider an important detail: one of the few artificial features along the line of sight is a private toll-road almost hidden by the forest trees. In this corner of Norway there are many similar private roads, which are open to the transit upon the paying of a toll to meet road maintenance expenses by the owners of the lands. This road turns around the Vårhuskjølen hill. It starts on a west-east course on the hidden side of the hill from "Aspåskjolen" and, after less than 1 km, it bends in a north-north-easterly course, roughly toward the observation's point. Following four bends, the road goes down the hill, crosses the Hesja river, and goes up the other side of the Hessdalen valley, joining the FV576 county road near the Myrheim houses (Vårus, 1995). The road bends in a north-north-easterly course at an altitude of about 675 m down to the first southerly directed bend (altitude = 625 m). This stretch of road is about 500 m long (figure 4).

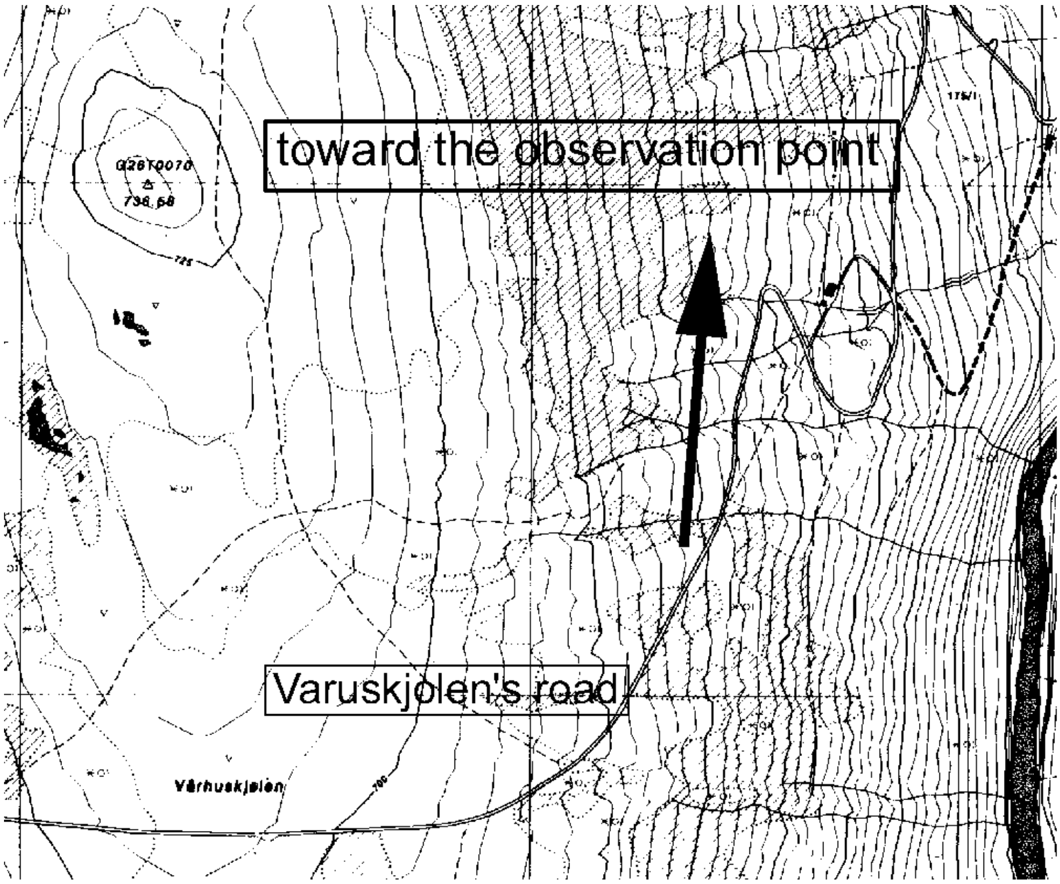

Fig. 4 – A particular of Vårhuskjølen's road at "blinking light" azimuth (~ 185°). See how the road bends toward the northerly placed observation point (source: Vårus, 1995).

In Tab. 3 are listed several information about three spots of this road as seen from "Aspåskjolen". The errors in the angles and distance estimates are due to the uncertainty of the location of the observation point (this uncertainty was deemed not relevant as regards the angle estimates of distant features like the above mentioned mountain peaks).

This error was evaluated by taking the length of the strip of the Aspåskjolen's road – where the optical and radar instruments were set up – higher than 690 m in altitude; this length is close to 50 m (figure 3).

Vårhuskjølen's road	Altitude (m)	Distance (m)	Azimuth (°)	Angular elevation (°)
Spot 1	675	2650 ± 20	187.8 ± 0.6	– 0.3
Spot 2	650	2465 ± 20	186.2 ± 0.7	– 0.9
Spot 3	625	2205 ± 20	185.5 ± 1.0	– 1.7

Tab. 3 – The Vårhuskjølen's road as seen from the observation's point.

Tables 2 and 3, respectively, give the results obtained in the quantitative evaluations of the angular coordinates of the luminous phenomenon and the Vårhuskjølen's road. The most striking result is the almost perfect match between the values of azimuth and angular elevation. Both of these *independent* parameters agree in placing the source of the luminous phenomenon toward the Vårhuskjølen's road direction (see figure 5). From both the azimuth and the angular elevation figures it follows that the "blinking light" was likely placed between spot 2 and 3, at a distance close to 2 km from the observation's point. The direction of the road path between spot 2 and 3 was almost parallel to the direction of sight of the light: the bending of the road oscillates between 0° (in a spot intermediate between 2 and 3) and 12°. The headlights of a car driving along this road toward "Aspåskjolen" have therefore to sweep the observation's point (whose bending would be about 5°). Furthermore, this car would be gently sloping down: this is exactly the behaviour shown by the luminous phenomenon (see the photo-frames in the EMBLA 2002 paper, where "the movement of the light-balls is indicated by [downwards] red arrows" (Teodorani & Nobili, 2002, p. 4)). Other information provided by the witnesses – like the "blinking effect" due to headlights behind trees – match well with the car on Vårhuskjølen's road hypothesis. Such a car had to be about 2.2 km far from the observation's point. The angular distance between the two headlights had therefore to be [30 · (1/2200) rad = $1.4 \cdot 10^{-2}$ rad] = 0.78°, or one and a half the moon diameter: a value consistent with the visual observation by the author of this paper.

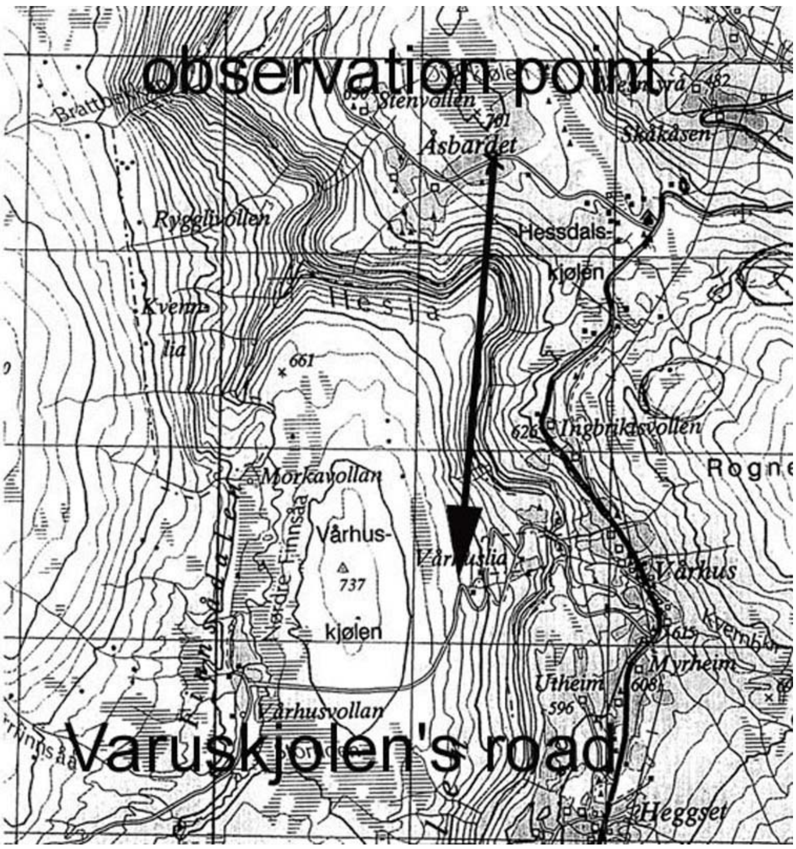

Fig. 5 – 1:50 000 Hessdalen chart. The blinking light azimuth matches well with azimuth and bending of a stretch of Vårhuskjølen's road: a pair of car headlights would sweep the observation point (source: Haltdalen, 1995).

6. Estimate of Optical Power Output

Over the past years several researchers attempted to estimate the optical power output in cases of sightings of unidentified light sources. Special efforts had been made to derive estimates from photographical evidence (Maccabee, 1979, 1980, 1987, 1999) and witnesses' statements (Vallee, 1990, 1998; Ballester & Fernández, 1987). These studies develop interesting methodologies to calculate optical power output by inverting standard photometric equations. As it was remarked,

> obvious cautions are immediately raised by this exercise. By definition the source of luminosity is an unknown phenomenon. We do not know if the light is a primary manifestation of its internal physical state (as would be the case for the sun) or a secondary one, as would be the case for the moon or an automobile headlights. We do not even know if most of the electromagnetic energy is released in the visible domain to which human witnesses and most cameras react (Vallee, 1998).

As reported above, in 2002 the EMBLA physics team collected a large body of documentary evidence about a repetitive luminous phenomenon. Should these reports meet sufficient criteria of reliability to yield quantitative data regarding distance and brightness, rough estimate of power output could be obtained. Although the photographs of the phenomenon enabled them to get reliable brightness estimates, it is unfortunate that the team failed to arrive at a correct estimate of the distance (see sections 4 and 5).

According to the authors of the EMBLA physics paper, by applying the technique of "aperture photometry" to a photographic sequence (Teodorani and Nobili, 2002, p. 4),

> it was possible to estimate an order of magnitude of the energy emitted by the light phenomenon. This task has been accomplished by using the software Iris, after previous enhancement and resizing (image interpolation) operations have been carried out by using software Adobe Photoshop 5.5, by means of which small portions of a given photograph have been taken. Aperture photometry has been then applied by measuring the light-phenomenon on photo-frames by using concentric circles whose external radius matches exactly the radius of the light ball: in this way the apparent luminosity is directly calculated as a value in erg/sec, then by multiplying by a factor 1 x 10^{-7}, the same parameter is obtained in watt (Teodorani & Nobili, 2002, p. 7).

Teodorani and Nobili obtains the absolute luminosity (L_{ABS}) of the phenomenon through the formula $L_{ABS} = L_{APP} \cdot 4\pi d^2$, where L_{APP} is the apparent luminosity and d is the phenomenon's distance (in meters). L_{APP} is evaluated "by knowing that $L_{APP} = L_{EXP} / t$, where t is the exposure-time (in seconds) and L_{EXP} is the luminosity actually recorded from the photo frame". Their results are outlined in a table where the absolute luminosity is reported to be in the range $3.6 \cdot 10^4 - 1 \cdot 10^5$ W. In order to assess the reliability of this estimate, let's analyse the authors' arguments.

1) The distance d "is assumed to be approximately 9 km". As outlined in section 2 and 3, this value is over-estimated. The correct figure is likely between 2.0 and 2.5 km. This mistake was originated by wrong assumptions on the light's position.

2) The EMBLA team assumes a uniform radiation in all directions (a 4π radiator). Since the optical survey was carried out from a single observation's point and no independent corroboration of a *simultaneous* sighting from a different perspective is at present available, this is a gratuitous assumption. On the contrary, the visual observation through a refractor telescope shows that the sources of light were not-uniformly-radiating car headlights.

3) According to the table published by the authors, both L_{APP} and L_{ABS} are expressed in watt. Since the figures listed in the L_{ABS} column are obtained by computing it as $L_{ABS} = L_{APP} \cdot 4\pi d^2$, and d is expressed in meters, the meaning of L_{APP} figures is unclear.

In order to avoid any misunderstanding, some information about optical quantities, units of measurement and symbols, are given in the Tab. 4 below.

Energy Q	**Radiometry**	**Photometry**	**EMBLA paper**
Power (Flux) dQ/dT	*Radiant Flux* Φ (W)	*Luminous Flux* Φ_V (lm)	$\mathbf{L_{ABS}}$
Intensity (Power per unit direction) dQ/dtdω	*Radiant Intensity* I (W/sr)	*Luminous Intensity* I_V (lm/sr = cd)	
Flux Density (Power per unit area) dQ/dA	*Irradiance* E (W/m^2)	*Illuminance* E_V (lm/m^2 = lx)	$\mathbf{L_{APP}}$
Flux Density (Flux per unit viewing solid angle) Φ/Aω	*Radiance* L (W/m^{2}sr)	*Luminance* L_V (lm/m^{2}sr = nt)	

Tab. 4 – Quantities and units of measurement in radiometry and photometry (lm = lumen; cd = candela; lx = lux; nt = nit).

Summing up, Teodorani and Nobili assume a far, homogeneous and point-like source of light. Thus, they estimate the total luminous power output (L_{ABS}) by multiplying the intensity (I) by the solid angle (4π):

$$L_{ABS} = 4\pi \cdot I = E \cdot 4\pi d^2 \tag{1}$$

i.e.,

$$L_{ABS} = L_{APP} \cdot 4\pi d^2 \tag{2}$$

However, the questionable assumptions by Teodorani and Nobili almost certainly lead them to over-estimate the absolute luminosity. As regards frame 5 – where it occurs the largest value for L_{APP} – inserting the values for distance and apparent luminosity into the above equation yield, according to Teodorani and Nobili (2002, p. 7), an absolute luminosity of about

$$L_{ABS} = L_{APP} \cdot 4\pi d^2 = 9.8 \cdot 10^{-5} \cdot 4\pi\left(9 \cdot 10^3\right)^2 = 10^5 W \tag{3}$$

where L_{APP}, contrary to what is reported in the EMBLA physics paper, is in W/m^2, as it is requested by the dimensional analysis (see Tab. 4).

In their paper, Teodorani and Nobili estimate the distance at 9000 m. A more correct estimate is given by our investigation since the source of the light was actually located at about 2.2 km from the observation point (A). Therefore, one can calculate the apparent luminosity (in W/m^2) at any point (P) using the following equation:

$$\frac{L_{APP}^{P1}}{L_{APP}^{P2}} = \frac{\left(P2 - A\right)^2}{\left(P1 - A\right)^2} \tag{4}$$

If P2 and P1 are respectively distant 2200 and 25 m from the observation point (A), the above formula leads to:

$$L_{APP}^{25} = 7.7 \cdot 10^3 \cdot L_{APP}^{2200} \tag{5}$$

which gives $L_{APP}^{25} = 0.76$ W/m^2 (frame 5). The conversion between photometric units (which take into account human physiology) and straight radiometric units is given by the following: (photometric unit) = (radiometric unit) · (683) · V(λ), where V(λ) is the "luminous efficiency", and is a function of the wavelength (photopic curve). Basically the luminous efficiency tells us how efficiently the eye picks up certain wavelengths. Should the emission be a 555 nm monochromatic line, V(λ) = 1, and the radiometric 0.76 W/m^2 would correspond to the photometric 519 lux. Since this source radiated over a spectrum (see the following section), it is necessary to integrate according to the "photopic" curve. A crude approximation would led to a figure somewhere between 50 lux (red light, λ = 650 nm, V(λ) = 0.1) and 519 lux (green light, λ = 555 nm, V(λ) =1). As the emission spectra shows two big peaks, one at 650 nm and the other one at 570 nm, the maximum apparent luminosity at 25 m should be likely less than half the value at 555 nm. As from the above analysis, L_{APP} at a distance of 25 m from the phenomenon, *should be, at most, equal to a few hundreds of lux*.

The motor vehicle headlamps illumination is regulated by rigid international regulations issued by the *United Nations Economic Commission for Europe*. In case of a single headlamp designed to provide a driving beam and a passing beam, the maximum illuminance (E_M) – measured on a vertical screen set at a distance of 25 m in front of the headlamp – "shall in no case exceed 240 lux"[4] (ECE Regulation, 2002, p. 18). Usually, a car holds two headlamps. According to this regulation the maximum luminous intensity (I_M) emitted by all car headlamps shall not exceed 225 000 cd. Therefore, independently of the number of headlamps, "the maximum luminous intensity of the driving beam expressed in thousands of candelas shall be calculated by means of the formula $I_M = 0.625\ E_M$" (ibid., p. 18). This formula follows from equation (1) and leads to:

$$E_M = \frac{I_M}{d^2} = \frac{225000}{25^2} = 360 \text{ lx} \tag{6}$$

Thus, the luminous phenomenon photographed by the EMBLA physics team meets, as a rough order of magnitude, with the international regulations on car headlamps maximum illuminance.

7. Discussion of the Luminosity/Size Law

Through a post-processing of video frames captured during the EMBLA 2001 mission, Teodorani and Nobili take light time-variability into account. Their suggested explanation for the collected data is that

> *the luminosity of a blinking and standing still light-phenomenon is growing even if the light-phenomenon apparently expands (increase of R).* Thermodynamics tells us that when plasma-ball [this is the suggested source for the Hessdalen lights, according to the EMBLA physics team (Teodorani et al., 2001)] expands it must cool rapidly […] with a drastic decrease of luminosity (intensity per pixel), but that doesn't happen with the Hessdalen phenomenon and luminosity is subject to a linear grow due to an apparently exclusive dependence of luminosity on the parameter R^2 (Stefan-Boltzmann law) which in this specific case is very strong compared with the very weak dependence of luminosity on parameter T_E [effective temperature]. (Teodorani & Nobili, 2002, p. 8-9).

Let A be the apparent size of the luminous phenomenon "as reported by a Canon XM-1 videocamera", and k a constant. According to a "graph showing the increase of apparent luminosity with size of a standing still blinking light ball" (Teodorani & Nobili, 2002, p. 9), it follows:

$$L_{APP} = kA \tag{7}$$

[4] The illuminance is measured on the point of intersection (HV) between the optical axis and the screen (ECE Regulation, 2002, p. 18).

In order to explain the linear relationship between apparent luminosity and apparent size, Teodorani and Nobili remark that

> this experimental evidence, which shows that in these light-phenomena temperature remains constant or decreases very little during the expansion of the radiating surface, would be highly anomalous if the luminosity increase is due to a single light-orb, but can be explained very well if the apparent "expansion" of the radiating surface is not due to the inflation of a single light-ball, but to the sudden apparition of many other light-balls very close to the first one. (Teodorani & Nobili, 2002, p. 9).

i.e. they assume that the apparent size is correlated with the real size of a number of alleged "light-balls". However, this assumption is of doubtful reliability, since the data plotted in the pixels number vs. countings number graph are likely due to a saturated source of light.[5] Calling S the number of countings that saturate one pixel, and N the apparent radium of the saturated source (in pixels), the total number of countings S_{tot} is given by the number of saturated pixels plus the number of pixel in an unsaturated circular corona, one pixel in radium:

$$S_{tot} = S\pi(N-1)^2 + \left[aS\pi N^2 - aS\pi(N-1)^2\right] = S\pi(N-1)^2 + \pi aS(2N-1) \qquad (8)$$

where a is a parameter arbitrarily changing between 0 and 1. The saturation figure S can be obtained from the graph (and it is equal to the maximum number of countings divided by the number of pixels of the source that had that countings number). The term in square brackets gives the dispersion of countings by a N-radium source, provided that S is known. The function thus obtained is quite similar to that plotted in the EMBLA graph, and the saturation hypothesis agrees with the linear relationship between apparent size and luminosity (the real size of the source is not proportional with the number of pixels; this number depends only on the total apparent luminosity). The changes in S_{tot} could be due to trees along the line of sight, apparent rotation of the car headlamps, or a combination of both.

8. Criticism of the Effective Temperature Estimate

In the section "Spectroscopy" the EMBLA physics team discusses the characteristics of the "spectrum of a Hessdalen light-phenomenon obtained with a ROS grating in connection with a Praktika BX-20 reflex camera equipped with a 270 mm lens" (Teodorani & Nobili, 2002, p. 11). This section follows the one where the authors obtain through photometrical calculations the "total energy" emitted by the lights (Teodorani & Nobili, 2002, p. 7). By means of the Stefan-Boltzmann law (under the hypothesis that "the phenomenon behaves like a light-ball composed of ionised particles which are in thermodynamic equilibrium") the EMBLA team obtains the allegedly effective temperature of the phenomenon and remarks that:

> The color temperature which is deduced spectroscopically *doesn't match* the "effective temperature" which is deduced from photometry (Teodorani & Nobili, 2002, p. 12).

While the alleged photometrical effective temperature is between 8853 and 10 878 K, the spectrum analysis lead the EMBLA team to obtain figures in the 4400 – 6300 K range. This outcome is not surprising since their photometrical estimates follow a questionable evaluation of the parameters involved. A few comments are in order.

1) As regards the phenomenon's dimension, they state that "it is possible to make a comparison with the dimension of the trees" and that "an average value of R = 10 m can be assumed" (Teodorani & Nobili, 2002, p. 7). Since a) the phenomenon was not completely stationary, b) the frame was

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[5] The author wishes to thank Michele Moroni for bringing to his attention the saturation issue as well for some important corrections and improvements to his initial calculation on the apparent luminosity – apparent size issue. (M. Moroni, personal communications, February 22, 2003; March 13, 2003).

obtained from a long time exposure, c) the trees heights are over-estimated due to the over-estimate of the distance, the 10 m assumption is groundless.

2) The EMBLA physics team assumes "the validity of equation $L_{ABS} = 4\pi R^2 \sigma T_E^4$, where R is the radius of the luminous phenomenon, σ = 5.6697 x 10^{-8} J s^{-1} m^{-2} K^{-4} is the Stefan-Boltzmann constant, T_E is the Effective Temperature" (Teodorani & Nobili, 2002, p. 7).[6] As remarked by the physics team, this assumptions is made "by arbitrarily hypothesizing that the phenomenon behaves like a light-ball composed of ionised particles which are in thermodynamic equilibrium (black body theory)" (ibid.). This arbitrary assumption is made worse by a set of calculation mistakes. According to the table listing the estimated effective temperature, this quantity would range between 8853 and 10 878 K. However, this result doesn't match with the Stefan-Boltzmann law. As regards Frame 1, the following figures are reported by the EMBLA team: L_{ABS} = 61 041 W; *Total Energy* = 3.05 · 10^{12} erg (3.05 · 10^5 J); T_E = 9622 K. By putting into the formula the parameter figures estimated by the EMBLA physics team itself, the "correct" effective temperature would be lower than the ambient temperature:

$$T_E = \left(\frac{L_{ABS}}{4\pi R^2 \sigma} \right)^{1/4} = \left(\frac{61{,}041}{4 \cdot 3.14 \cdot 100 \cdot 5.67 \cdot 10^{-8}} \right)^{1/4} \cong 171 \text{ K} \tag{9}$$

The EMBLA team's treatment of the L_{ABS} unit of measurements is the likely source for this mistake. It turns out that the reverse estimating of the absolute luminosity (from the T_E figure reported by Teodorani and Nobili), yields

$$L_{ABS} = 4\pi R^2 \sigma T_E^4 = 4 \cdot 3.14 \cdot 100 \cdot 5.67 \cdot 10^{-8} \cdot (9622)^4 = 6.1 \cdot 10^{11} \text{ W}, \tag{10}$$

a figure 10^7 times higher than the figure reported by Teodorani and Nobili, i.e. erroneous by a numerical factor equal to the conversion factor from W to erg/s.

9. Spectrum Analysis

As from the preceding section, the correctly estimated effective temperature (from the unreliable assumptions discussed above), is meaningless and in open contradiction with the figures obtained through the spectroscopical data. On the contrary, as it will be shown here, there is no meaningful contradiction of figures between the spectrum analysis outcome and the car headlamps hypothesis.

According to the EMBLA physics team,

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6 The total power per unit area from a blackbody radiator (L_{ABS}/A) can be obtained by integrating the Planck radiation formula over all wavelengths. The radiated power per unit area as a function of wavelength is

$$\frac{dL_{ABS}}{d\lambda}\frac{1}{A} = \frac{2\pi hc^2}{\lambda^5 \left(e^{hc/\lambda kT} - 1\right)}$$

Its integration gives the final form of the Stefan-Boltzmann law:

$$\frac{L_{ABS}}{A} = \frac{2\pi^5 k^4}{15 h^3 c^2} T^4 = \sigma T^4 = \left[5.6697 \cdot 10^{-8} \frac{W}{m^2 K^4} \right] T^4$$

Therefore, if the radiator is spherical shaped, it follows:

$$L_{ABS} = 4\pi R^2 \sigma T^4$$

> By using the Praktika reflex camera in connection with a ROS grating [lent by the CIPH], it was possible to obtain several spectra both of known lights and of the suspected Hessdalen light. The grating characteristics were judged suitable for point-like lights such as the light-sources above. Spectra of streetlights with very well identifiable lines were used as "calibration lamps" in order to permit the position-wavelength calibration of the spectrum of interest. In this case the spectrum of a high-pressure sodium lamp (typically yellow light) was used, even if high-pressure mercury lamps (typically white light) were considered as well. […] Several test-spectra were obtained as well of other luminous sources such as car and tractor lights, xenon, crypton and tungsten flashlights, halogen lamps, fire-flames, neon lights, LED lights: all of these were used as "comparison camp". […] Only one of 3 spectra (out of 10 attempts) was considered for analysis, as the other two ones were considered too noisy. […] The spectrum acquired this year appears as a continuum spectrum with no resolved lines, and shows to be constituted by two big peaks at 5750 and 6600 Å and one much smaller double peak at 4500 Å. (Teodorani & Nobili, 2002, p. 10-11)

As remarked above, Teodorani and Nobili obtain three values of temperature (6300, 5100 and 4400 K) "by arbitrarily assuming that the spectrum is due to some kind of ionised and/or excited gas of ions and electrons in thermodynamic equilibrium" (Teodorani & Nobili, 2002, p. 12). The spectrum is shown in figure 6.

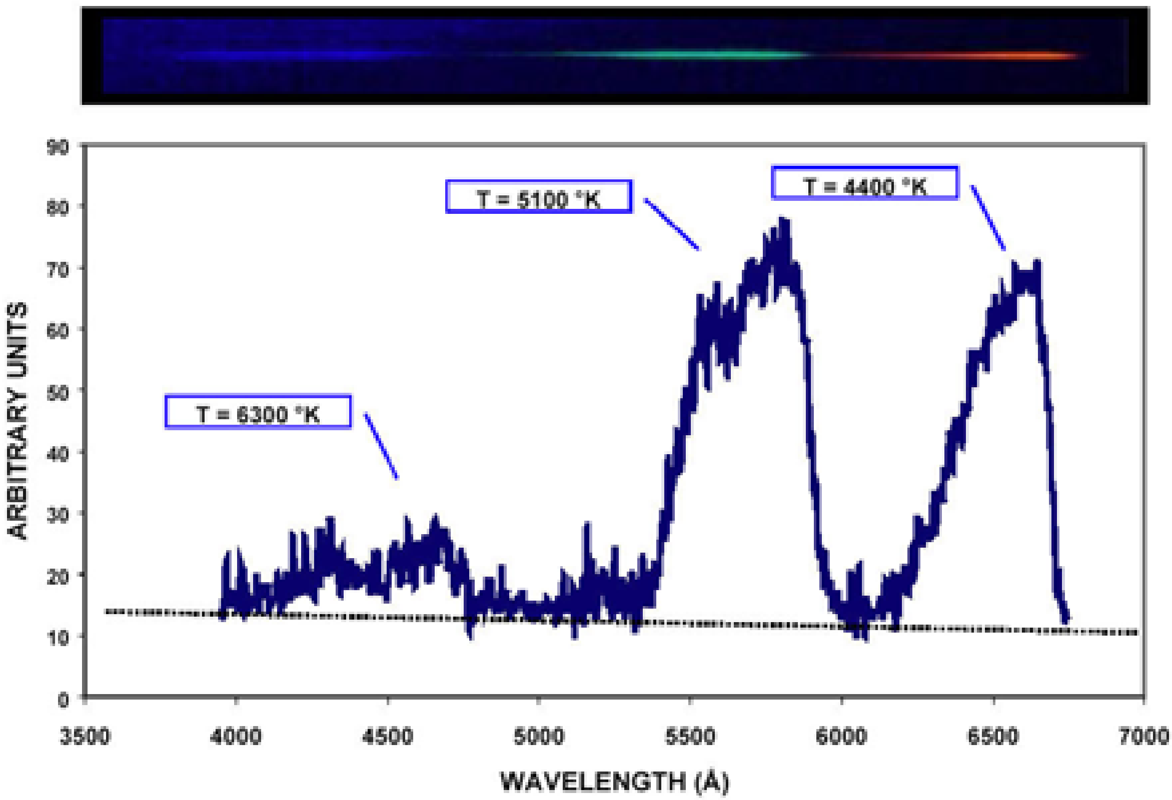

Fig. 6 – Spectrum obtained by the EMBLA physics team in August 2002 (source: Teodorani & Nobili, 2002).

Due to some analogies with the spectra emitted by fluorescent tube, Xenon burner, white flame carbon arc, fluorescent illuminator, flashbulb and "daylight" cool white tubes, they are led to suggest that "the recorded spectrum might be due to several composite light-sources, which may be more or less similar to common artificial illumination, but not necessarily the same devices which produce such an illumination from a chemical-physical point of view" (ibid.) Notwithstanding this they expressed another interpretation, "which is possibly more realistic": the three peaks "are due to a blend of many very close emission lines" (ibid.). Among the suspected elements they list: Silicon mixed up with Neon (5750 Å peak); Oxygen, Nitrogen, Neon, Argon and Sodium (4500 Å); Calcium and Sodium mixed up with Silicon (6600 Å). Other weaker spectra collected by Teodorani and Nobili would be allegedly similar to the one shown in the EMBLA paper:

> After verifying that the main spectral peaks do not change position in wavelength and shape (the third one is too weak to be seen in faint spectra) in 3 different spectra taken at different times of separate light-events, we have another demonstration of the fact that R, the radius of the light-emitting area, is the only parameter which is responsible of luminosity variations and not the temperature T. Therefore, *the constancy of color temperature is an ascertained fact.* (Teodorani & Nobili, 2002, p. 14)

With a view to addressing this result it is important to analyse the two basic types of automotive lightning: incandescent and high-intensity discharge.

- In the incandescent headlamp the light is produced by a tiny coil of tungsten wire that glows when it is heated by an electric current. The filament temperature in a tungsten light bulb generally ranges from 2800 to 3200 K with greater luminosities achieved at higher temperatures. Unfortunately, as the filament temperature is increased, the rate of its evaporation increases, leading to a shorter lifetime of the bulb due to bulb darkening. To reduce the evaporation of the filament, an inert gas, or a mixture of inert gases, is added to the bulb. Longer lamp life and increased efficacy are achieved in the *tungsten-halogen lamp*, or halogen bulb, which adds a halogen to the filling gas and utilizes a reversible chemical reaction between the tungsten and the halogen. In halogen lamps, the evaporated tungsten is returned to the filament by a chemical transport process, which prevents blackening of the bulb. The regenerative cycle allows a higher filament temperature to be used (Rechtsteiner & Ganske, 1998). As regards the spectrum, while a standard incandescent light has a *color temperature* close to 2800 K, an halogen headlamp usually reach 3200 K. In recent years new halogens providing up to 4000 K have been put on the market (OSRAM, 2000a). The sun, too, is an incandescent body: standard (or "mean noon") sunlight is established as 5400 K. Not surprisingly this color temperature corresponds to a wavelength close to the figure of maximum retinal sensitivity (555 nm). As a consequence of these figures, the tungsten filament lamps emit mainly in the infrared range. Thus, at visible frequencies the spectrum is a continuum flat line increasing with the wavelength. The ECE Regulations (1992, 2002) list administrative provisions and technical requirements concerning headlamps using halogen filament lamps of the following categories: H_1, H_2, H_3, HB_3, HB_4, H_7, H_8, H_9, HIR1, HIR2 and/or H_{11}.

- High-Intensity Discharge lamps (HID) use an electric arc to produce intense light. The arc is produced by means of a capsule (bulb) with two adjacent electrodes positioned in close proximity. The capsule sends these two leads to an electronic HID ballast. The ballast is an electronic module that acts as an ignition box to fire up the gas discharge. The HID capsule is vacuum-sealed with a rich mixture of noble gases as well as alkali earth metal salts. In this set-up the noble gases and metal salts are actually used as part of the lightning processes. An high-powered arc of electricity is established across both electrodes, which excites xenon gas into discharging photons (Wang, 2002). Standard HID headlamps provide light at 4100 K. However, in recent years the HID automotive technology developed headlamps achieving 5400 K, i.e. close to the sunlight color temperature (OSRAM, 2000b). As the color temperature increases, the color of the light moves from yellow to white to blue-white. HID headlights provide light at a higher color temperature than standard halogen headlights, which gives them a crisp white appearance. The problem is that a discharge lamp doesn't emit its radiation in a nice smooth curve with emission at all wavelengths. A discharge source has big "spikes" in its output spectrum which come from the particular elements used in the fill mix forming the arc. The method normally used is to match the output of the arc source to an incandescent source and then take the color temperature of the incandescent source. When it's matched like this the color temperature of the discharge source is referred to as its "*Correlated Color Temperature*" which provides a helpful approximation (Wood, 2000). The ECE Regulations (1996, 2001) list administrative provisions and technical requirements concerning headlamps using gas discharge lamps of the categories D1S/D2S and D1R/D2R.

Thus, each type of headlamp has its own specific color temperature, and this parameter is independent of the apparent size of the luminous phenomenon. In short, this result agree with the "constancy of color temperature" phenomenon.

As reported above, the spectrum obtained by the EMBLA physics team (figure 6) was "constituted by two big peaks at 5750 and 6600 Å and one much smaller double peak at 4500 Å" (Teodorani & Nobili, 2002, p. 11). Was the source of light an incandescent headlamp or a gas discharge one? Although the discontinuities in the Hessdalen spectrum seems to point at a discharge source, the search for an HID culprit meets no success. While the intensity of HID D2 and D4 spectral emission is highest between 550 and 600 nm – due to emission lines at 569 nm (Scandium) and 589 nm (Sodium) – where the EMBLA spectrum shows the wide peak around 575 nm, other features are not consistent with the spectrum obtained by the EMBLA team. Noteworthy is the absence of the big 660 nm "peak" (Schimke & Grundmann, 2002). D2 and D4 spectrum are shown in figure 7.

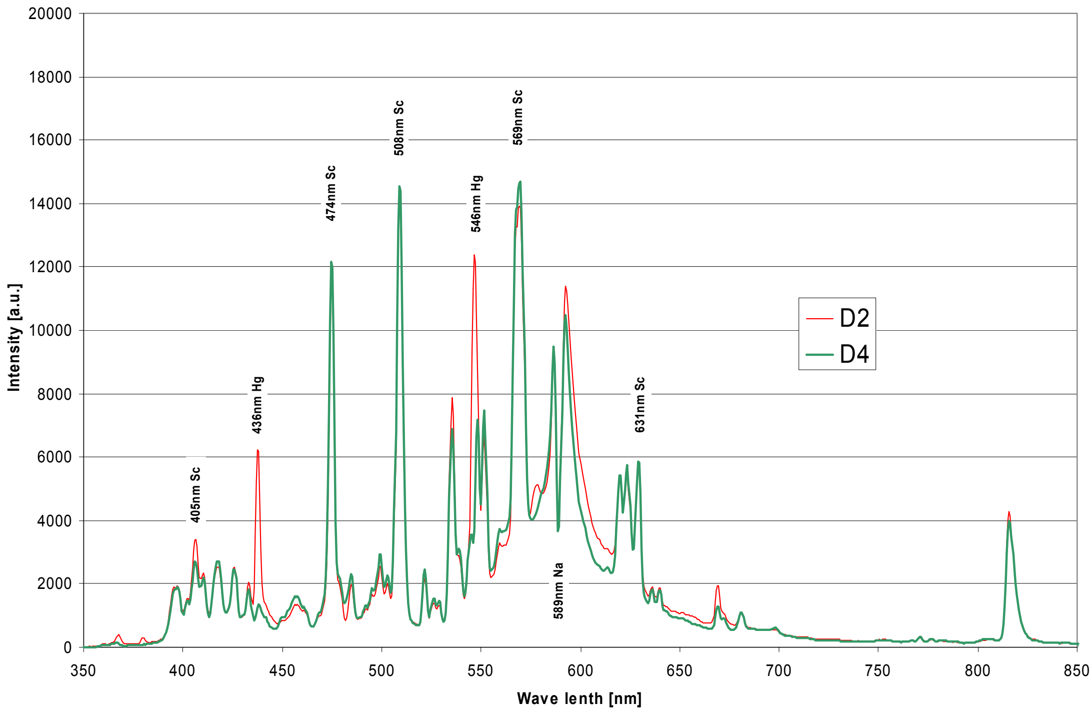

Fig. 7 – Spectral comparison of D2 and D4 headlamps (source: Schimke & Grundmann, 2002).

Better results are obtained by considering an halogen (incandescent) headlamp. In figure 8 is represented a typical spectrum of an incandescent lamp.

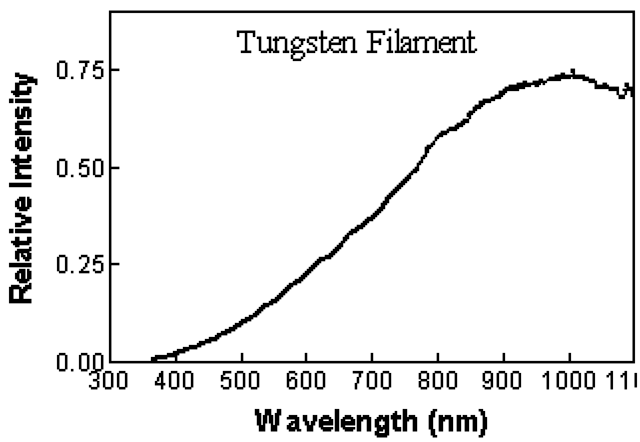

Fig .8 – Spectrum of a tungsten filament within a white light bulb (source: Rechtsteiner & Ganske, 1998).

As it is evident, the spectral distribution of light from incandescent lamps is continuous and follows a blackbody distribution very closely. While there are no emission lines or bands, it is interesting to remark that, in analogy with the spectrum obtained by the EMBLA team, most of the emission in the 400-700 nm range is at high wavelengths.

10. The Halogen Car Headlamps & Color Film Hypothesis

Although the high wavelengths emission of an incandescent source of light agree with the general spectroscopic result of the EMBLA optical survey, the "anomalous" issue of the "peaks" at 6600, 5750 and 4500 Å is yet to be settled. Is the presence of the emission "peaks" in the spectrum obtained by the EMBLA physics team really at odds with the expected spectrum of halogen headlamps?

In order to answer to this question it is important to consider both the source of light and the measurement system, i.e. the photographic film. As a matter of comparison, in figure 9 is shown the spectrum of an incandescent car headlamp at 50 m (Louange, 1983).

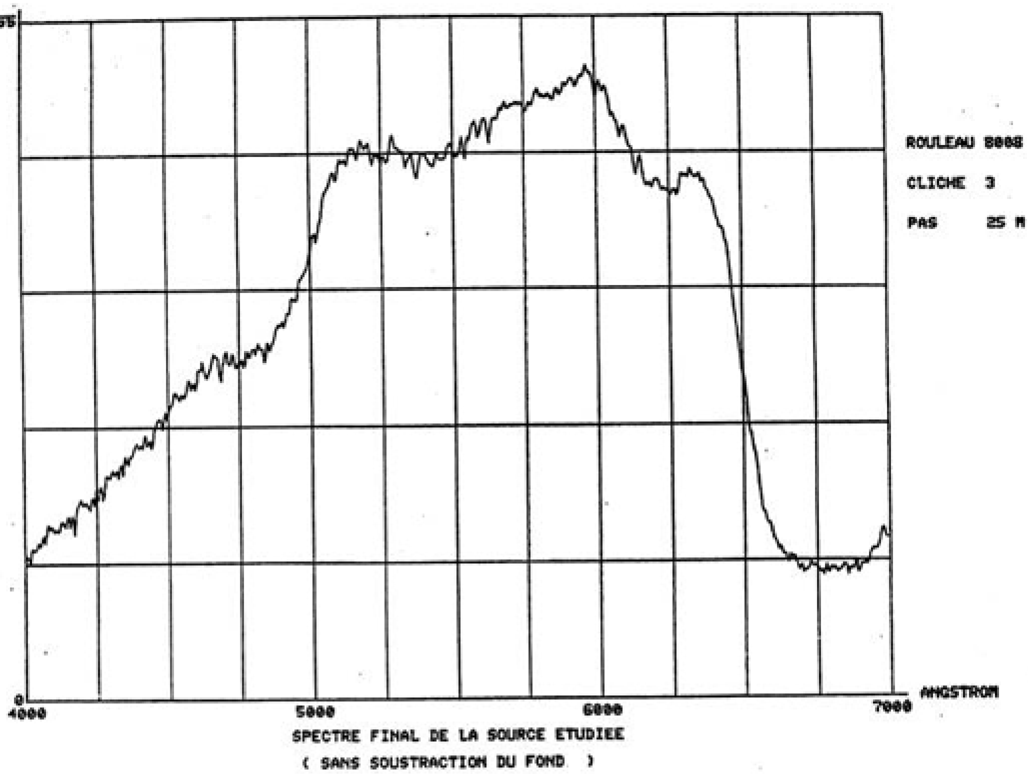

Fig. 9 – Spectrum of an incandescent headlamp at 50 m (source: Louange, 1983).

The spectrum shown in figure 9 was obtained with a grating (Makrolon) in connection with a Minolta Hi-Matic 24x36. The film was an Ilford FP4 (b/w, 125 ASA). The spectrum was collected as a result of tests on the methodology of use of diffraction gratings carried out in the 1980s by the GEPAN (a department of CNES – the French space agency – devoted to the study of "unidentified aerial phenomena"). These tests allowed the GEPAN to build a catalogue of spectra emitted by several known sources of light (as a reference tool to enable the evaluation of photographs regarding unidentified flying lights). As expected in the Ilford sensibility curve (ILFORD, 1983) – see figure 10 – this spectrum shows a cut at 650 nm (Louange, 1983).

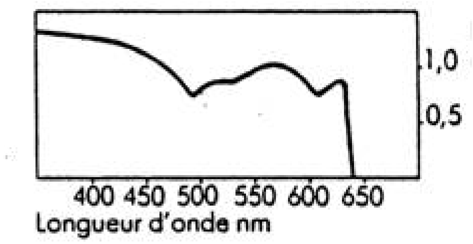

Fig. 10 – Spectral-sensitivity curve of the Ilford FP4 film used by the GEPAN (source: Louange, 1983).

It is important to note that the reflex camera used to take the Hessdalen spectrum used a film (Kodak Ektachrome 100) whose curve of spectral sensitivity is not flat in the range 400-700 nm. In figure 11 is shown such a curve (Kodak Ektachrome 100, 2002). Since the film used by the EMBLA physics team had spectral-sensitivity curves as of figure 11, it is expected – in analogy with the spectrum collected by the GEPAN – that the spectrum of an incandescent light has a red-end edge at about 650 nm, in correspondence of the cyan sensitivity cut. This is exactly what the Hessdalen spectrum shows. The "second strong peak [at 6600 Å]" (Teodorani & Nobili, 2002, p. 12) is therefore the outcome of the Kodak Ektachrome 100 film spectral-sensitivity curve rather than a proper emission peak.

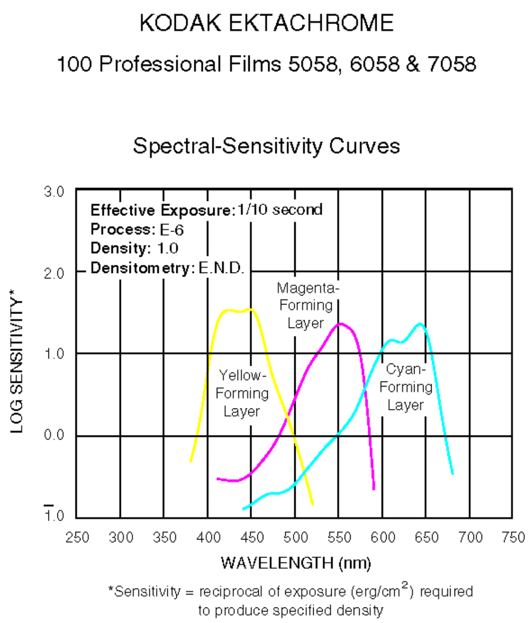

Fig. 11 – Spectral-sensibility curves of the color film used by the EMBLA team (source: Eastman Kodak, 2002a).

While color films and panchromatic B&W films are sensitive to all wavelengths of visible light, rarely are two films equally sensitive to all wavelengths. *Spectral sensitivity* describes the relative sensitivity of the emulsion to the spectrum within the film's sensitivity range. The photographic emulsion has inherently the sensitivity of photosensitive silver halide crystals. As shown in figure 11, the Kodak Ektachrome 100 film has three spectral sensitivity curves – one each for the red-sensitive (cyan-dye forming), the green-sensitive (magenta-dye forming), and the blue-sensitive (yellow-dye forming) emulsion layers. The data are derived by exposing the film to calibrated bands of radiation 10 nm wide throughout the spectrum, and the sensitivity is expressed as the reciprocal of the exposure (erg/cm^2) required to produce a specified density. The radiation expressed in nm is plotted on the horizontal axis, and the logarithm of sensitivity is plotted on the vertical axis to produce a spectral-sensitivity curve (Eastman Kodak, 1997). This film replicates colors as seen by the human eye: our eyes have three sets of sensors (*cones*) with peak sensitivities at light frequencies that we call red (580 nm), green (540 nm) and blue (450 nm). Light at any wavelength in the visual spectrum range from 400 to 700 nm will excite one or more of these three types of sensors.

A preliminary look at the Kodak curves shows that the maximum intensities are at wavelengths close to the alleged "peaks" in the spectrum obtained by the EMBLA physics team (figure 6). Is this coincidental? Not at all.

As it is well known, an ordinary camera equipped with a transmission diffraction grating or a prism can be used to photograph a wide range of spectra. However, the collection of photographic spectra require carefulness in the choice of the film. As regards the astronomical spectra (i.e. point-like source of light, like the "Hessdalen lights"), "colour film is not worth the effort since the dominant spectral features in the image are due to the colour filters within the film: you don't get a smooth gradation in colour. Even with B&W film, you have to be careful with the rather rapid changes of sensitivity with wavelength *which show up as broad bands in the spectrum*" (Fosbury, 1999).

The first step in analysing the possibility that the "peaks" in the spectrum obtained by the EMBLA team are the outcome of halogen light collected by means of a film of given spectral sensitivity is to estimate the theoretical relative intensity vs. wavelength. According to the Planck law, the blackbody irradiance $E_{\lambda,T}$ is given by (see section 8):

$$E_{\lambda,T} = \frac{2\pi hc^2}{\lambda^5} \frac{1}{\left(e^{hc/\lambda kT} - 1\right)} \tag{11}$$

where h is the Planck's constant ($6.63 \cdot 10^{-34}$ J s), k is the Boltzmann's constant ($1.38 \cdot 10^{-23}$ J K^{-1}), c is the speed of light ($3 \cdot 10^{8}$ m s^{-1}), λ is the wavelength and T is the absolute temperature. Thus, in the visual range the spectrum of a blackbody radiator at 3200 K – corresponding to a typical halogen headlamp (OSRAM 2000a) – is roughly rectilinear (see figure 12).

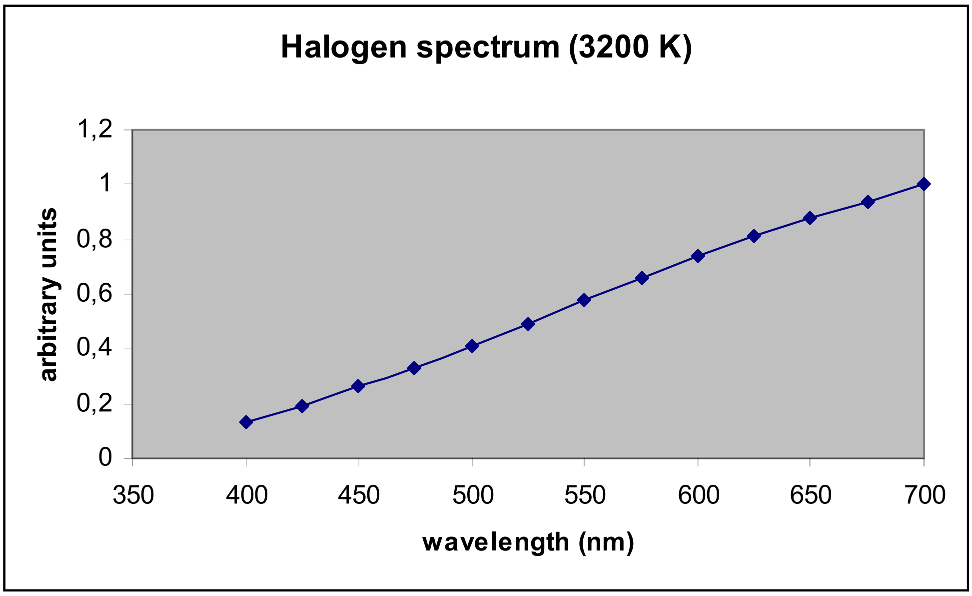

Fig. 12 – Spectrum of a blackbody radiator at 3200 K.

The second step is to estimate the effective power per unit area collected by the photographic film. This step is accomplished by rectifying the above figures according to the logarithm of the spectral sensitivities of the yellow, magenta and cyan forming layers of the film (figure 11). The relative intensities shown in figure 12 are multiplied by the film's spectral sensitivity values (figure 11) at 25 nm intervals. The outcome is plotted in figure 13.

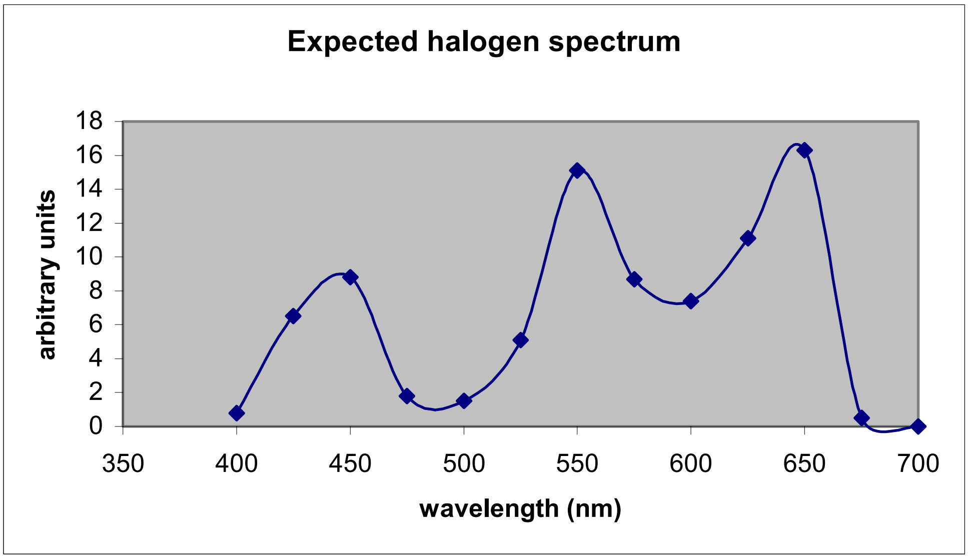

Fig. 13 – Power per unit area collected by the Kodak film vs. wavelength.

The third, and last, step, is to compare the expected spectrum obtained via the above hypotheses with the spectrum collected by the EMBLA team. Following figure 13, it appears that the expected spectrum emitted by a common halogen headlight, photographed by means of a Kodak Ektachrome 100 film, closely matches the spectrum collected by Teodorani and Nobili (see table 5).

coincidence	*Teodorani & Nobili's spectrum*	*Halogen headlamps + Kodak film spectrum*
1	three broad bands	three broad bands
2	4500, 5750, 6600 Å	4500, 5500, 6500 Å
3	highest "peaks" at 5750 and 6600 Å	highest "peaks" at 5500 and 6500 Å

Tab. 5 – Parallelisms between the spectrum obtained by the EMBLA physics team and the one that it is expected on the headlamps hypothesis.

Independently of this author, R. Levin (personal communication, January 31, 2003) – an OSRAM Sylvania corporate scientist – has evaluated the spectrum collected by the EMBLA physics team. In his judgement this spectrum is an artifact of the measurement system. This conclusion agrees with the evidence discussed in this section. According to the OSRAM scientist,

> The light is an incandescent headlamp and the structure [...] is an artifact of the measurement system. [...] The spectral picture at the top of [the] spectrum [Fig. 6] suggests that the light source spectrum is spectrally spread across the film [...]. Color film does not have a flat response curve. Rather, there are three relatively narrow responses, one for each color channel. I don't have curves for Ektachrome immediately available, but I will use a standardized typical response for colored film (ANSI Ph3.37-1969 developed for evaluating selective transmission of photographic lenses). When I multiply this by a incandescent headlamp spectrum, the results are quite similar to [the Hessdalen] spectrum. I don't know what specific film [it was] used, so I didn't balance the relative response between the three bands, but I think that this demonstrates the problem. A panchromatic B/W film could record that actual spectrum.

The results obtained by the OSRAM scientist, under the hypothesis that the spectrum is the outcome of both halogen headlamps and a color film, are shown in figure 14.

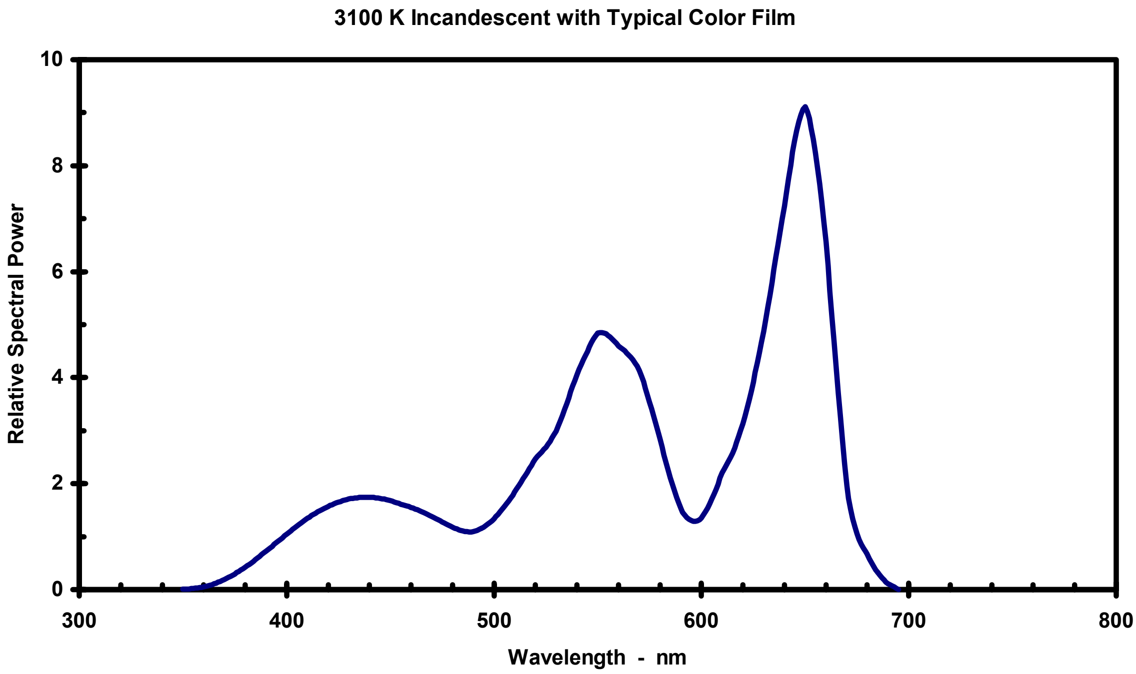

Fig. 14 – Incandescent spectrum with typical color film (R. Levin, personal communication, January 31, 2003).

The analogies between this hypothetical spectrum, the hypothetical spectrum obtained by this author, and the experimental spectrum collected by the EMBLA physics team are noteworthy (see the spectral comparison plotted in figure 15). Thus, each "peak" is explainable through the concurrence of two factors, namely: an incandescent source of light (most of the collected radiation is at long wavelengths – the apparent peaks at 6600 and 5750 Å are the highest ones); a non-flat spectral-sensitivity (that makes the apparent peak at 4500 Å raise above the noise level in spite of the incandescent halogen spectral distribution). Summing up, the spectroscopical evidence conclusively points at a conventional explanation behind the luminous phenomenon photographed at Hessdalen in August 2002.

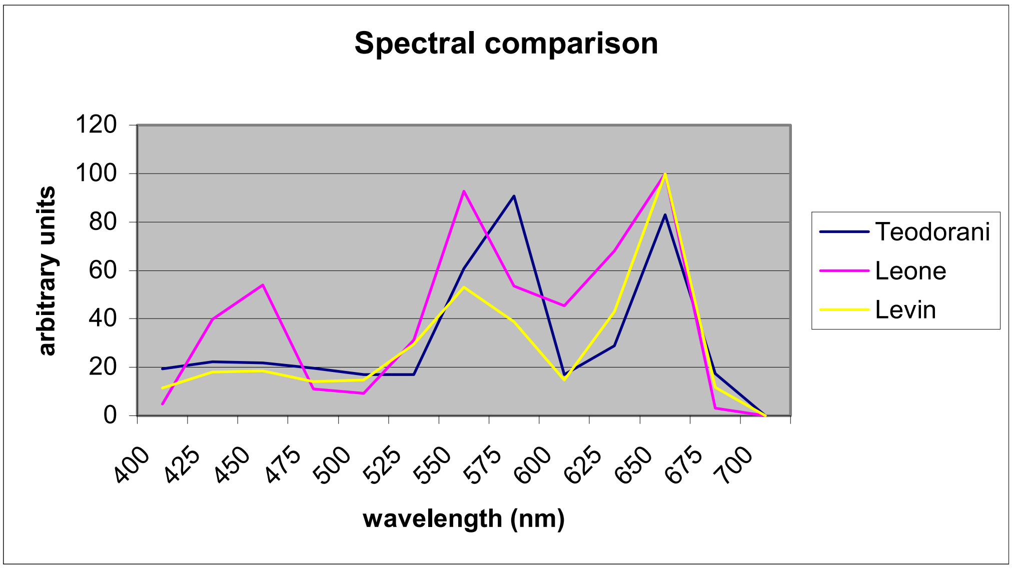

Fig. 15 – Spectral comparison between a) the EMBLA experimental spectrum, b) this author's spectrum and c) the OSRAM scientist's one (both b) and c) are made under the hypothesis of halogen source + color film).

11. Anomalous Lights vs. Headlights

As discussed above, some allegedly anomalous lights reported in the Hessdalen area turn out to be due to conventional car headlights. This *does not* mean that the whole set of Hessdalen sightings about unidentified lights are explainable in this way. On the contrary, this is to say that the car headlights can be a source of deception. The EMBLA 2002 optical survey mission proves that even scientific investigators are not exempt from this mistake.

As it is shown by the anomalous observations published in the mainstream scientific literature[7], low-level nocturnal lights have been documented for centuries as will-o'-the-wisps, jack-o'-lanterns, ghost lights, fireships, corpse lights, and many other names. Examples of spots where frequent low-level nocturnal lights have been thoroughly studied are: the Brown Mountain Lights (North Carolina), the Tri-State, Ozark, or Hornet Light (Oklahoma); the Marfa Lights (Texas); the Min-Min Lights (Australia); the Yakima Lights (Washington State); and the Hessdalen Lights, of course (Corliss, 2001).

While a small residue of difficult-to-account-for sightings seems to remain, at many of the sites of renown, "the great majority of lights-sightings can be reasonably explained in terms of refracted man-made lights (automobiles, street lights, etc.)" (Corliss, 2001, p. 291). As the following paragraphs will show, the Hessdalen headlights enjoy a wide companionship.

Since the late 1800s the *Brown Mountain Lights* have been showing up in North Carolina. Two formal, government-supported scientific studies plus additional investigations by some private research groups were devoted to this phenomenon (Corliss, 2001, pp. 299-301). Both government sponsored studies blamed human activity for all the sighted lights. In 1922, U.S. Geological Survey scientist, G.R. Mansfield "attributed 47 percent of the lights to *automobile headlights*, 33 percent to locomotive headlights, 10 percent to stationary lights and 10 percent to brush fires" (Kane, 1983, as cited in Corliss, 2001, p. 300). Further field investigations showed that there is a small fraction of observations still requiring a convincing explanation (Frizzell, 1984, as cited in Corliss, 2001, pp. 300-301).

As regards the *Tri-State Lights,* "several scientists who have looked into the Tri-State apparitions have come away convinced that everything can be explained in terms of the atmospheric refraction of *automobile headlights*" travelling on a lonesome stretch of country road called the "Devil's Promenade" (Corliss, 2001, p. 302). Among the scientists who studied this phenomenon there was Project Blue Book consultant J.A. Hynek (1973, as cited in Corliss, 2001, p. 302).

The *Marfa Lights*, named after a small ranching community in West Texas, can be seen just about every night. However, "just as with most of the Brown Mountain Lights and some of the apparitions of the Tri-State Spooklight, almost all of the Marfa Lights are easily shown to be nothing more than the *headlights of automobiles* cresting a hill on Highway 67, 24 miles [39 km] south of Marfa. Triangulation on the lights confirm this, as do high-power-telescopic observations" (Corliss, 2001, p. 304; see also: Bunnell, 2001; Lindee, 1992).

In August – September 2000, a firm in the business of providing airborne sensor and satellite analysis of various terrain covers throughout the world carried out an analysis of the Marfa Lights. Through a computer-generated soil distribution combined with the U.S. Geological Survey topographic maps and a proper elevation model, this analysis concluded that "car headlights shining in the direction of the Observation Site, reflected along the concave surface of soil alongside of Highway 67, are the source of the Lights. The highly reflective soil acts as a mirrored surface that creates the observed phenomena" (Alto Technology, 2001). Nevertheless, there are two classes of data that still remain unexplained: firstly, some Marfa Lights were seen as early as 1883 by cattlemen – long before automobiles and Highway 67; secondly, several anecdotes published in the literature allegedly describe close encounters with Marfa Lights (Corliss, 2001, p. 304).

[7] For an historical essay on the Sourcebook Project, devoted to the identification and collection of anomalies reports published in the scientific literature, see Corliss (2002). See also the seminal works by Charles Fort (1941, 1974).

Conclusions

This analysis of the Hessdalen 2002 optical survey lead the author of this paper to draw the conclusion that the whole evidence reported by Teodorani and Nobili (2002) is consistent with the car headlamps explanation. Several different pieces of evidence point at this conclusion: the "blinking light", upon observation through a portable refractor telescope by the author of this paper, turned out to be due to a pair of car headlights; the luminous phenomenon appeared in close proximity of a country road, whose angular coordinates (azimuth and angular elevation) from the observation point agree with the "blinking light" ones; its luminous power output is consistent with the luminous emission by an hypothetical car moving on the above country road; its spectrum is consistent with the spectrum emitted by a car headlight. This hypothesis is easily verifiable (or falsifiable) through a controlled experiment by means of a pair of car headlights.

Thus, contrary to EMBLA physics team claims: a) the luminous phenomenon observed and photographed in August 2002 does not emit "a power of the order of 100 kW"; b) its increase in luminosity is not caused "by many lights-spheroids surrounding an initial 'light-seed'"; c) it does not hover "tens of meters over the top of the hills" (Teodorani & Nobili, 2002, p. 17).

It has been the intent of this paper to show that the August 2002 optical survey in Hessdalen was lacking both in the methodology of data collection and in the evaluation of the evidence. Notwithstanding this, the subject of the luminous phenomena observed in the Hessdalen valley deserve further attention (see section 2). However, a continued effort into this subject is not likely to get reliable results unless a program of collection of eyewitness testimony and of intensive scientific surveillance for appearance of the alleged luminous phenomenon is set up. The information recorded during the 1984 field mission is suggestive but not conclusive, and the researchers in the field of anomalous aerial phenomena need better phenomenological foundations. These foundations require a careful attention to both the methodology of collection of eyewitness testimony and the issue of "objective" evidence. As regards the first issue, it is absolutely necessary to follow some minimal guidelines to avoid the risks of leading the witness, misunderstanding his words, doing wrong inferences from his testimony and so on. Since several years such guidelines are followed by the most serious civilian groups devoted to the study of unidentified flying object reports (Randles, 1976; SOBEPS, 1979; Fowler, 1983; Russo, 1993). The optical data collected by the Østfold College's AMS are an helpful contribution to the second issue, i.e. the intensive scientific surveillance of the valley. While the collected data still require an in-depth analysis to identify conventional stimuli, the Strand and Hauge's station is an important step in the correct direction (Strand, 2002). As remarked at the Pocantico workshop, "this automatic station will hopefully prove to be but a first step in the development of a network of stations" (Sturrock, 1998, 1999). The methodologies and tools employed by the EMBLA engineering team (Montebugnoli et al., 2002) could led to interesting results as well, provided that the optical counterpart does not led astray the focus of EMBLA missions as it has occurred in the questionable 2002 optical survey.

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