A rebuttal of EMBLA 2002 (*) report on the optical survey in Hessdalen: further comments

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Abstract – The recent hypothesis on the headlamps nature of the allegedly anomalous luminous phenomenon sighted on August 2002 in the Hessdalen valley by a scientific expedition (EMBLA) is shown to be viable from many different standpoints. Two critical papers published in the past weeks with the aim of refuting this solution are here reviewed and reasons for rejecting their general conclusions are here provided. Although the vehicle headlamps were likely farther than previously conjectured, this author shows that such a hypothesis is strengthened by the recently surfaced evidence concerning visual, topographical, photometrical and spectroscopic data. The goal of this paper is to make as low as possible the noise/signal ratio in the collection of data regarding the anomalous aerial phenomena. As from the available evidence, the data collected by the EMBLA 2002 physics team belong to the "noise" field.

Introduction

In August 2002, a team of Italian physicists, astronomers, engineers and technicians, jointly with two Østfold College researchers (Sarpsborg, Norway), carried out a survey in the Hessdalen valley (Norway). Although some members of the Italian team work at the CNR-IRA (Italian National Research Council, Institute of Radioastronomy, Bologna, Italy), they were not officially charged by the CNR with this task. The scientific mission, code-named EMBLA, was aimed at collecting optical and radar data on a so far unexplained luminous phenomenon reported by the residents of the valley since 1981 (Strand, 1985). One of its outcomes was a paper published by the "Project Hessdalen" web site (Teodorani & Nobili, 2002).

During the EMBLA 2002 mission, this author was charged by the Italian Committee for Project Hessdalen (CIPH, 2002) with the task of collecting sighting reports by the residents in the valley and to evaluate the methodologies of data collection carried out at Hessdalen. CIPH field investigations at Hessdalen got under way on August 1 and ended on August 8, 2002.

As it was shown by Leone (2003), the EMBLA 2002 *optical* survey in Hessdalen "was lacking both in the methodology of data collection and in the evaluation of the evidence" (ibid., p. 26). A thorough analysis of the topographical, photometrical and spectroscopic data collected by the EMBLA physics team led this author to draw the conclusion that the whole optical evidence reported by Teodorani and Nobili (2002) is consistent with, and points at, an explanation involving an unrecognised headlights source of light (Leone, 2003, p. 26). This paper enjoyed two different critical articles allegedly refuting the above-suggested conclusion (Teodorani, 2003; Nicolosi & Ricchetti, 2003).

As it will be shown in the following, the leader of the EMBLA 2002 optical mission looks at marginal issues and avoids the evidence conclusively pointing at a headlamps solution of the EMBLA 2002 observations (Teodorani, 2003). The second paper (Nicolosi & Ricchetti, 2003) addresses the topographical matter only, by successfully providing reasons against the Vårhuskjølen hill's road as a place of interest. Although this road is no longer tenable a candidate, Nicolosi and Ricchetti unawares provide new elements *for* the headlamps conclusion formerly suggested by Leone (2003).

As of now the available evidence allows to draw *definitive* conclusions on the physical nature of the source of light, and *tentative* conclusions on its actual position in the valley. The observations by Nicolosi & Ricchetti concern this second point and therefore don't achieve the status of "crucial experiment" with reference to the first one. Any eventual anomaly with respect to the actual light's position should be faced without neglecting the settled issue, i.e. the visual and spectroscopic evidence conclusively pointing at a headlamps solution of the EMBLA 2002 optical observations of that type of luminous phenomenon.

1. Nature of the light

Visual evidence

This author sighted the Hessdalen light phenomenon of August 2002 (Leone, 2003, pp. 5-7) extensively discussed in the EMBLA physics report (Teodorani & Nobili, 2002). However, according to the leader of the EMBLA physics team the author of this paper "totally failed to consider the correct light-phenomenon" (Teodorani, 2003, p. 2). What does he mean by "correct light-phenomenon"? The answer is in Teodorani & Nobili (2002, p. 2), where it was clearly stated that only "the […] blinking lights seen towards south from the Aspåskjolen spot were confirmed to be due to the 'Hessdalen phenomenon'". Notwithstanding Teodorani's complaints, this author precisely saw *this* blinking light, through a portable refractor telescope (having a 30 times greater resolution power than the naked eyes tools used by the EMBLA physics team). Most importantly, this author observed it *at the same time* as the EMBLA physics team did. This "blinking light seen towards south" turned out to be due to a pair of vehicle headlights (Leone, 2003). For a non-retouched photograph of this light see Fig. 1.

Fig. 1 – An example of "correct light phenomenon" according to the EMBLA physics team. This non-retouched photograph was shot from the Aspåskjolen spot in August 2002. The angular position of the light is the same as in the frames published in the EMBLA 2002 physics report (© CIPH, Hessdalen 2002).

According to Teodorani (2003, p. 2), this author "saw once a car, together with all of us (and to us this occurred routinely many times), and also evaluated probably correctly the distance of it, but the real phenomenon is not situated where the inexperienced author claims". These statements imply that this author saw vehicle headlamps, but that these sightings regard something different from the "real phenomenon". This hypothesis by the leader of the EMBLA physics team holds no water:

1. At the Aspåskjolen observation point, the EMBLA physics team's expectations were that the light had to appear low on the horizon toward a southerly placed "saddle", apparently between two high peaks (Hessjøhøgda and Nyvollhøgda).
2. Each time this specific light showed itself, the EMBLA physics team jumped up excitedly, calling the observers' attention toward the bright, stationary, point-like luminous phenomenon.
3. No confusion of optical stimuli was possible since this specific light was the only relevant source of light at that particular azimuth and angular elevation.
4. After the first sighting reported by Leone (2150Z, August 6), this author pointed the refractor telescope at the expected angular coordinates.
5. When the light did appear the second time, several actions were carried into effect: the EMBLA engineering team kept collecting radar data looking for eventual correlations with the optical sighting; the EMBLA physics team shot photographs and collected a spectrum; the CIPH team collected VLF data (Gori, 2002). At the same time, this author looked at this light through the refractor telescope and easily identified it as a pair of vehicle headlights.
6. According to Teodorani himself, this sighting (2105Z, August 7) concerned the "real phenomenon". As a "proof" of this, this author duly informed him about the outcome of the telescopic observation. He replied that he didn't believe this author because the sighting, in his expectations, concerned the same unexplained light witnessed since August 2000.

Summing up, both this author and the EMBLA physics team sighted the very same luminous phenomenon, the only difference being the inability of the EMBLA physics team to identify its nature or to set up the proper tools (i.e. a standard portable telescope) to allow this identification.

Since this light showed repetitive behaviour, appearance and position during the 2002 and former missions, it is suggested that behind every sighting by the EMBLA physics team *regarding such a specific light* there is a source of headlights nature. As the whole optical evidence reported in the EMBLA 2002 physics report concerns such a light, it is reasonable to conclude that the whole set of optical data collected by Teodorani in 2002 is explainable in this way.

Teodorani criticizes the way in which the CIPH scientific advisor carried out the azimuth measurement and the visual observation. As regards the angular coordinates he states that a conventional compass can furnish substantial errors and that "the error must be measured directly" (Teodorani, 2003, p. 2). He clearly failed to see that Leone (2003) reported an azimuth measurement (185°) *as well as* an error estimated upon the tool's accuracy (± 5°). He fails to see as well that this coarse measurement was just a secondary accomplishment that in no way entered into the estimates of angular position (see the following section).

It is agreed that this compass is not "a data scope able to perform precise measurement" (Teodorani, 2003, p. 2). However, the leader of the EMBLA physics team misses what the CIPH 2002 mission goals were (see Leone, 2003, p. 3), i.e. the collection of eyewitness reports, the evaluation of the methodology accomplished by the EMBLA surveys and the collection of VLF data (Gori, 2002). In no way the CIPH 2002 mission was intended to systematically collect optical data. On the contrary, since the optical survey of the Hessdalen valley was Teodorani's goal, one wonders why he didn't carry out any reliable angular position measurement.

For what concern the portable refractor observation, Teodorani is critical toward the employed tool – a "toy-telescope", in his opinion (Teodorani, 2003, p. 3) – and the accomplished methodology. One more time he fails to see that the collection of optical data was not one of CIPH 2002 goals. This author did not pretend that the sole visual observation was conclusive evidence. Thus, in order to corroborate the headlights observation, topographical, photometrical and spectroscopic analysis were discussed by Leone (2003). However, the plain fact that an inexpensive 60-mm portable refractor telescope (requiring a budget quite lower than the 1 million euros estimated by Teodorani & Nobili (2002, p. 18) as absolutely necessary to make significant steps in this research) was enough to identify a source of light that had baffled the 3-years long EMBLA missions, should be a matter of reflections.

Moreover, the "factual novelty" issue should not be forgotten. This author dutifully informed Teodorani (August 7, 2002) as well as the members of the CIPH committee (August 19, 2002) about the headlights explanation well before the publication of the EMBLA 2002 paper (October 9, 2002). Since this hypothesis showed to neatly account for the spectroscopic evidence and the other data reported by the EMBLA physics team, it displays a strong heuristic power: i.e. the spectrum collected by the EMBLA physics team is a genuinely novel fact fully accountable by a hypothesis grounded on this author's visual observation. [1]

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[1] Nicolosi (2003) has blamed this author's methodology concerning the visual observation issue. He has stated that the headlights visual observation is "an assumption not demonstrable and therefore not falsifiable". He has also stated that attempting, as this author did, a match between a visual observation and the expected apparent car headlights width at a given distance is "an unscientific method" since there is no demonstration that a) this author saw headlights, b) both Teodorani and this author saw the same source of light, and c) the headlights apparent width was close to the full moon size. Other Nicolosi's remarks concerned the status of human testimony in science: "the testimony […] can *only* have a statistical value" and "*cannot* determine quantitative quantities" [added emphasis].

It would be easy to refute these final assertions by means of counter-examples that show instances where the involuntary human observation of a non-repetitive phenomenon enabled the scientists to get quantitative data (the case-studies of meteorites and ball lightings come immediately to the mind). The indiscriminate use of absolute and negative qualifying words on such a delicate matter like the human testimony, far from being expression of a "scientific" methodology, is the hallmark of pseudoscience. As it was written by physicist Philip Morrison (1969), "a witness's statement should be regarded in much the same light as the reading of a barometer or the print-out of a computer: a large number of judgements, inferences, assumptions, and hypotheses are necessary to interpret it. The analysis of that chain is the essential feature of scientific evidence. Without that, there is no scientific evidence". When Nicolosi declares, without a discussion, that this author's testimony "has no scientific value", he is liable to the Morrison criticism.

Should Nicolosi's concept of scientific method be applied to the actual scientific enterprise, large sections of science could be labelled as non-scientific. His assertion that this author's visual observation is "an assumption not demonstrable and therefore not falsifiable" demonstrates this. Firstly he misunderstands the concepts of "justificationism" and "falsificationism": "all Hessdalen lights are plasma" is unprovable through the experience because we have no access to the whole universe of Hessdalen lights; however it definitely *is* a falsifiable assertion (at least according to some brands of falsificationism), since the observation of an Hessdalen *head*light would refute it. This example falsifies Nicolosi's statement that a non-demonstrable assertion is necessarily non-falsifiable. Secondly he seems to believe that a visual observation without photographs or other recording apparatus is expression of an "an unscientific method". This would qualify as non-scientific Tycho Brahe's naked eye observations that allowed Kepler to formulate his well known laws; Galileo's telescopic observations of Jupiter's satellites, Venus phases, Moon surface, etc. that shattered the powerful Ptolemaic worldview; large sectors of astronomy, stellar spectroscopy, atmospheric physics, and most of the empirical basis of the observing sciences up to the beginning of XX Century.

Notwithstanding Nicolosi's statement of the contrary, this author's visual observations at the Hessdalen valley are both verifiable and falsifiable:

a) the observation-based headlights hypothesis lead to previsions concerning behaviour and features of the light that could be checked by third parties by means of the proper observation tools (i.e. a cheap refractor telescope).

b) Nicolosi stated that there is no proof that both this author and Teodorani saw the same source of light. Since this author recorded date/time/azimuth of each visual observation of the famed light from Aspåskjolen, contrary to Teodorani's methodology, one wonders why Nicolosi did not address this weakness to the leader of the EMBLA physics team. Anyhow, this objection is over since the Teodorani's spectrum (independent of this author's sighting) nicely agrees with the headlights observation (see the following section). In order to explain this agreement without endorsing the headlights explanation Nicolosi is only left with the following baffling possibility: that the spectrum collected by Teodorani does not concern the light seen by Teodorani himself!

c) The discrepancy between this author's subjective estimate of the headlamps pair width (close to 0.5°) and the expected width according to the actual distance (0.15° - 0.22°, if the headlamps were 1 – 1.5 m apart and were placed as discussed in the following section) shows that even this hypothesis is not free from minor anomalies. Of course the *memory* of an angular width (moreover observed through an optical instrument) is conceptually different from the actual *perception* of a luminous stimulus positively identified right on the field, and in no way can falsify the whole contents of the refractor-assisted visual observation. It is possible that the overestimate is due to the observation of a known source of light apparently placed above a foreground ridge (Heggsethødga) close to the observer, under "constancy of size" phenomenon studied by the psychology of perception. Under certain circumstances, indeed, "the brain corrects the perception that depends initially upon the size of the retinal image, corrects it in accordance with other sensory data that indicate the distance from which the retinal image is projected. And the brain can do an excellent job in this kind of correction." (Boring, 1946, as reprinted in Leibowitz, 1965).

Spectroscopic evidence

In Leone (2003) it was thoroughly discussed the nature of the spectrum collected by the EMBLA physics team. In order to evaluate its compatibility with the headlamps hypothesis (justified by this author's visual observation), a simulation was carried out, and a striking discovery was made: on the ground of both the expected spectrum emitted by a standard halogen headlamp (3200 K) and the color film spectral sensitivity characteristics, a very close match was found between this theoretical spectrum and the experimental one collected by the EMBLA physics team. As reported by Leone (2003), this hypothesis was held in high esteem by a corporate scientist working for a leader lamps manufacturing firm (OSRAM). Independently of this author (who had submitted to him the spectrum collected by the EMBLA physics team in order to get a professional advise), and without knowing about the above quoted simulation, this scientist drew the following conclusions (R. Levin, personal communication, January 31, 2003):

> The light is an incandescent headlamp and the structure […] is an artefact of the measurement system. […] The spectral picture at the top of [the] spectrum […] 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. (Leone, 2003, p. 23)

As remarked by Leone (2003), the OSRAM scientist's expected spectrum shows a very close resemblance with the expected spectrum obtained by this author (number of "peaks", their relative heights, wavelengths). See figure 2.

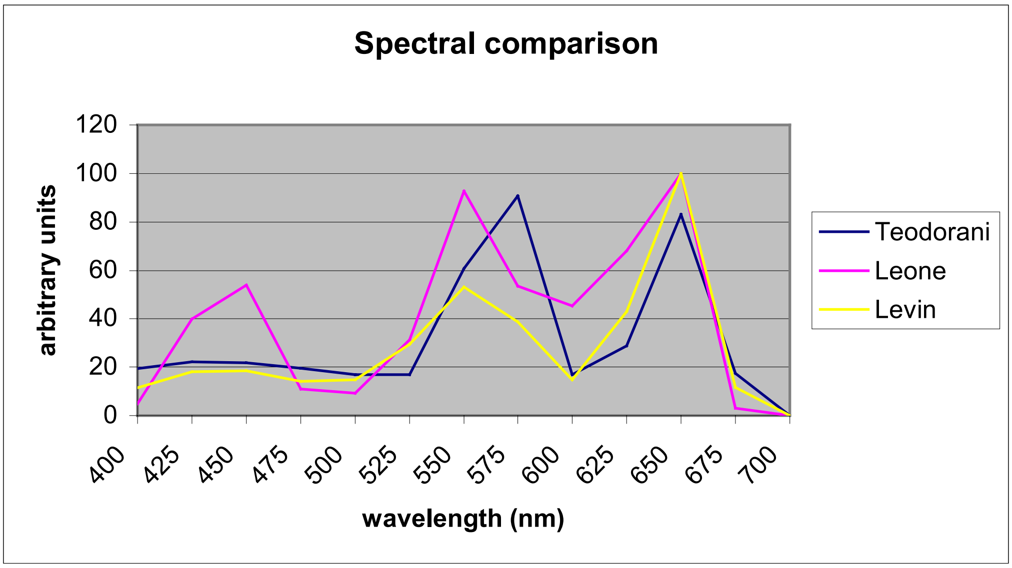

Fig. 2 – Spectral comparison between a) the EMBLA experimental spectrum, b) this author's spectrum and c) the OSRAM scientist's one (source: Leone, 2003).

The leader of the EMBLA physics team states that the "real anomalous phenomenon" (Teodorani, 2003, p. 2) has a different spectrum with respect to car headlights. Since he does not provide a definite criterion for discriminating the alleged "real anomalous phenomenon" from other spurious phenomena, here there are no factual corrections to be addressed.

On one hand Teodorani states that the expected spectrum of a car headlamp was "discussed only qualitatively", and on the other one he oddly avoids to carry out a quantitative simulation. Since he is the sole researcher owning *both* the raw spectroscopic data collected at Hessdalen *and* the theoretical solution suggested by this author, one wonders why *he* didn't accomplish a quantitative analysis.

He remarks that "the resulting spectrum, apart from some rough wavelength coincidences, is different from the sensitivity curve mostly because of different ratios between the three peak amplitudes and because of a much higher amplitude of the single peaks" (Teodorani, 2003, p. 4).

If this statement means that the resulting *theoretical* car headlamps & film sensitivity spectrum is different from the sole film sensitivity curve, it is a tautological assertion (see Leone, 2003, Fig. 11, 13).

If, on the contrary, Teodorani means that the *experimental* EMBLA spectrum is different from the film sensitivity curve, he misses the mark since what Leone (2003) has shown is that the *experimental EMBLA spectrum* closely matches the theoretical *car headlamps & film sensitivity curve*. To conclude, as Teodorani does, that there is "a poor 'best fit' between empirical data and simulation" (Teodorani, 2003, p. 4) would be a glaring example of *non sequitur*.

In order to quantitatively test the car headlamps explanation, this author analysed the EMBLA experimental spectrum vs. the theoretical one. The relationship between the experimental spectrum collected by Teodorani and the theoretical spectrum emitted by an incandescent source of light was determined by calculating the nonparametric Spearman rank correlation coefficient (Galeotti, 1983; Siegel & Castellan, 1992). The following methodology was applied:

- Since no raw data were available, linear measurements of EMBLA spectrum intensity and KODAK film sensitivity plots were carried out at 5 nm intervals (see Figure 3 – 4).
- The EMBLA values were multiplied by the reverse of the film spectral sensitivity. In this way it was obtained the source of light's theoretical spectrum independently of the film sensitivity correcting factor (Figure 5). This step was necessary in order to get two *independent* spectra.
- Each intensity value of the EMBLA spectrum was ranked from 1 to *n* (where *n* is the sample size, i.e. the number of classes in which the spectrum was divided) according to its magnitude.
- The theoretical spectrum emitted by an incandescent source of light (car headlamps) was ranked from 1 to *n* as well. Since an incandescent spectrum (3200 K) grows almost linearly in the visual range (Leone, 2003, p. 22), the rank is directly proportional with the wavelength.

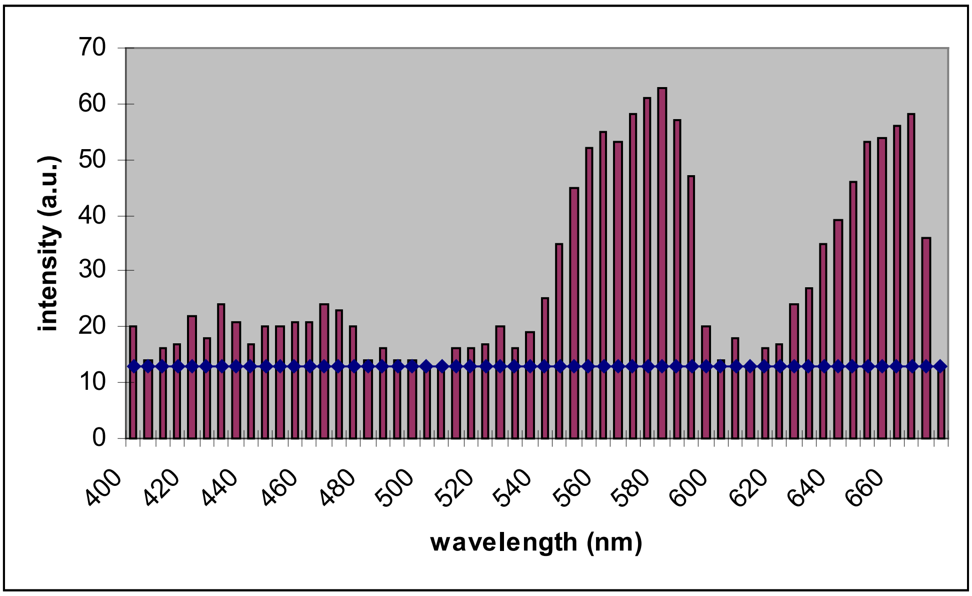

Fig. 3 – EMBLA experimental spectrum (source: Teodorani & Nobili, 2002).
The blue line indicates the noise level.

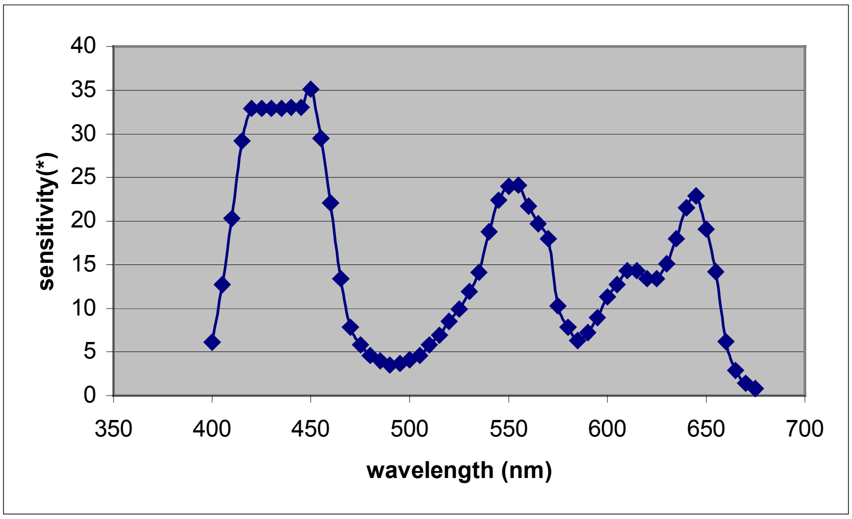

Fig. 4 – Spectral-sensitivity curve of Kodak Ektachrome 100 films (source: Kodak Ektachrome 100, 2002). (*) Sensitivity = reciprocal of exposure (erg/cm^2) required to produce specified density.

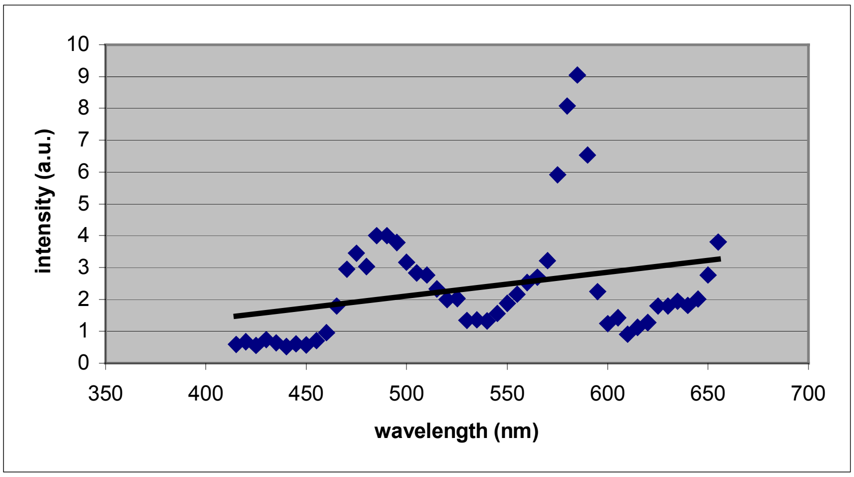

Fig. 5 – EMBLA spectrum / film sensitivity ratio. The continuous line (linear fit) is the expected linear incandescent spectrum.

As a final step it was computed the Spearman correlation coefficient between the spectrum obtained by computing the EMBLA spectrum / film sensitivity ratio (Figure 5) and an incandescent lamp spectrum (3200 K). The Spearman coefficient is listed in Tab. 1. See the Appendix section for details on the sample.

Data series	Sample size	r	p-value
EMBLA vs. halogen headlamps	50	0.383	<.01

Tab. 1 – Spearman correlation coefficient estimate.

This result shows a fairly strong relationship between the data series. The correlation between the EMBLA experimental spectrum and the expected headlamps theoretical spectrum is significant at the

.01 level (Holl, 1990; Siegel & Castellan, 1992), i.e. the probability that this coincidence is due to random factors is less than 1%.

However, figure 3 shows that the spectroscopic data collected by the EMBLA physics team are very close to the noise level in several ranges of wavelength (λ < 415 nm; 480 nm < λ < 535 nm; 600 nm < λ < 620 nm). Should only the classes outside of these ranges be considered (see Figure 6), the Spearman rank coefficient would be far more significant.

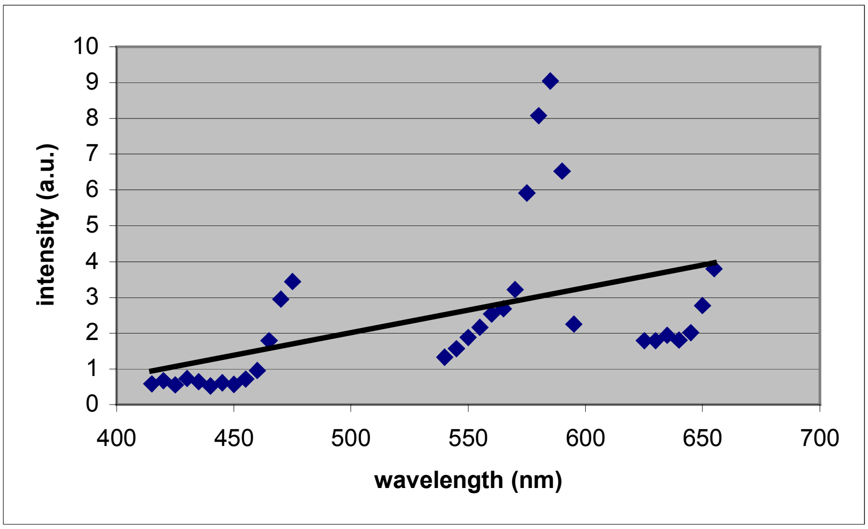

Fig. 6 – EMBLA spectrum / film sensitivity ratio (leaving out the ranges: λ < 415 nm; 480 nm < λ < 535 nm; 600 nm < λ < 620 nm). The continuous line (linear fit) is the expected linear incandescent spectrum.

As reported in Tab. 2, the likelihood that the correlation between the EMBLA spectrum and the incandescent headlamps is due to the chance becomes vanishingly small.

Data series	Sample size	r	p-value
EMBLA vs. halogen headlamps	33	0.730	<.001

Tab. 2 – Spearman correlation coefficient estimate as from spectrum plotted in Fig. 6.

As previously discussed, one source of error in the EMBLA experimental spectrum is the low signal/noise ratio as regards several ranges of wavelength. Notwithstanding this, the correlation between experimental and theoretical spectra – under the car headlamps hypothesis – is strong and unquestionable.

The expected theoretical spectrum obtained by multiplying an incandescent headlamps spectrum and the film sensitivity curve is shown in Fig. 7 (continuous line). Its higher resolution with respect to the spectrum shown in Fig. 2 is due to the smaller sampling interval of EMBLA data (5 nm). In Fig. 7 the EMBLA experimental spectrum is also plotted. This superposition shows that a further possible source of discrepancy – apart from the low signal/noise ratio – is a sort of wavelength shift toward the cyan-green direction. This effect is manifest by the peak wavelengths corresponding to both the magenta- and the cyan-forming layer as shown by the EMBLA spectrum.

Such an outcome is hardly surprising given the characteristics of the employed film. According to the Kodak Ektachrome 100 technical sheet concerning the adjustments for long and short exposures, significant color shifts in the cyan direction (right end of the spectrum) are possible consequences of exposure longer than 1 second.

> No filter correction or exposure adjustment is required for exposures from 1/10,000 to 1/10 second. At 1 second, use a CC05M filter and increase exposure by 1/3 stop. *We do not recommend exposure times longer than 1 second. At longer exposures, significant color balance shifts in the cyan-green direction or contrast mismatch may occur* [emphasis added] (Kodak Ektachrome 100, 2002).

Since the EMBLA physics team made use of alleged average exposures close to 5 seconds, this shift feature of the EMBLA experimental spectrum is explainable in this way. A comparison between the expected theoretical spectrum and the EMBLA's one (Fig. 7) shows that the magnitude of this shift is not constant in the visual range and seems to be larger at higher wavelengths. Low signal/noise ratio and shift effect are the likely causes behind the apparent oscillations around the expected linear incandescent spectrum (see Fig. 5 – 6).

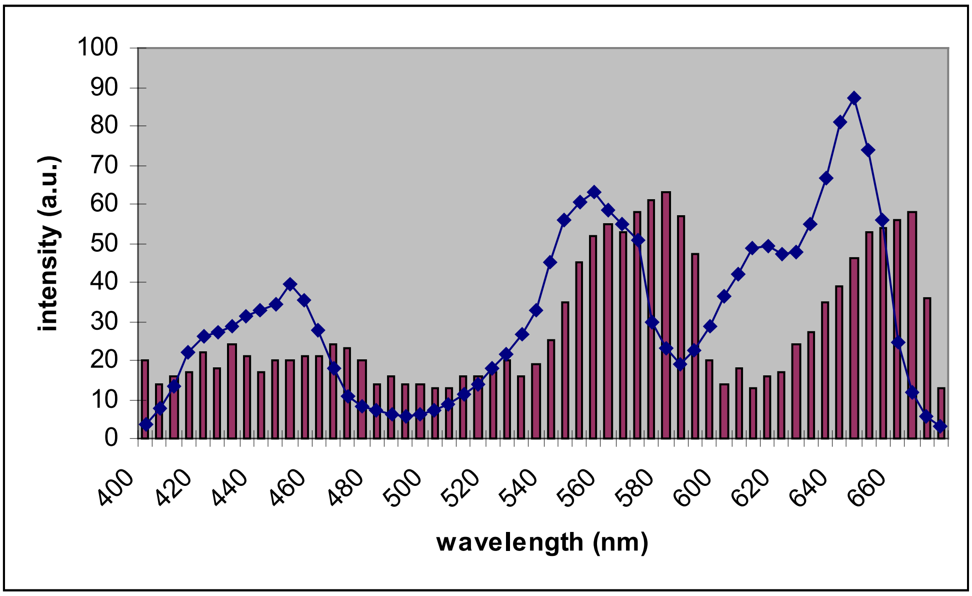

Fig. 7 – EMBLA experimental spectrum (histogram) vs. headlamps & film sensitivity theoretical spectrum (line). The experimental spectrum looks to be shifted toward the right side, with respect to the theoretical spectrum. This effect is likely due to a higher than recommended exposure time.

The resulting car headlamps & film sensitivity theoretical spectrum has only a qualitative meaning since the maximum theoretical height (at 555 nm) was chosen in such a way as to match the experimental maximum height (at 580 nm). Since a) the EMBLA physics team published the spectroscopic data in arbitrary units only (Teodorani & Nobili, 2002, p. 11), b) the magnitude of errors are unknown (but likely very high), and c) the EMBLA experimental spectrum was affected by extended low signal/noise ranges and likely shift effect due to time exposures greater than suggested by the film manufacture firm, these items prevent from computing a reliable goodness of fit test (such a χ^2 test). Notwithstanding this, the results obtained via the Spearman rank correlation coefficient establish beyond any reasonable doubt the strong correlation between the EMBLA experimental data and the expected light's theoretical spectrum.

The alternative hypotheses suggested by the EMBLA physics team (LEDs, blend of lines emitted by the atmospheric gases, etc.) neglect the role of the Kodak Ektachrome color film. Contrary to Teodorani's claim, a simple match between the EMBLA spectrum and the spectrum emitted by an ad hoc Light Emitting Diode or an ad hoc selection of chemical elements of the periodic table (independently of their potentials of ionisation, abundance in the low atmosphere and so on) would not be enough to corroborate such alternative hypotheses. As suggested by the former methodology, step 1 in any kind of attempt to suggest alternative hypotheses to the vehicle headlamps one would be to subtract the color film factor out of the experimental spectrum. However, as shown by the Spearman correlation coefficient this procedure unequivocally leads to a continuous spectrum quite close to a blackbody radiator, i.e. a halogen car headlamp-like spectrum. Teodorani's spectrum of car headlights allegedly taken in Hessdalen in 2002 is useless since it cannot be checked: it lacks of basic data on typology of *that* vehicle headlamps (gas discharge or halogen?), exposure time, photographic film used, distance car – observer and so on.

Teodorani (2003) also avoids the issue concerning the glaring contradictions between the color temperature deduced spectroscopically and the "effective temperature" deduced from photometry. As demonstrated by Leone (2003, pp. 15-16), the EMBLA physics team hypothesis ("the phenomenon behaves like a light-ball composed of ionised particles which are in thermodynamic equilibrium" (Teodorani & Nobili, 2002, p. 7)) lead to inconsistent results. A detailed analysis of Teodorani's methodology shows that these inconsistencies (an effective temperature lower than the ambient one; no connection with the spectroscopic results) are the outcome of both the above arbitrary assumption and a set of calculation mistakes.[2]

As from the correlations listed in Tab. 1 and 2, and the other evidences reported in Leone (2003), the burden of proof that the "blinking light" was *not* a pair of vehicle headlamps lies now on the EMBLA physics team side.[3]

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[2] Teodorani (as cited by Sabadin, 2003) has stated that this author was mistaken concerning his estimate of effective temperature. Firstly he has remarked that the Stefan-Boltzmann equation "is used to study the stars and not the headlights", apparently agreeing with Leone (2003) that this equation is of doubtful relevance to the study of his unrecognised vehicle headlights. Secondly, in his opinion the 171 K value (Leone, 2003, p. 16) would be wrong because his L_{ABS} value was put into the Stefan-Boltzmann equation, "without transforming the watt into erg/s", i.e. a 10^7 factor, before calculating the temperature.

Teodorani's analysis is incorrect. According to the Stefan-Boltzmann Law (see, for example, Piragino & Pisent, 1984, pp. 572, 579), the energy radiated by a blackbody radiator per second (L_{ABS}) per unit area (A) is proportional to the fourth power of the absolute temperature and is given by (using Teodorani's notation):

$$L_{ABS} / A = \sigma T^4 \quad \left[J m^{-2} s^{-1} \right]$$

where $\sigma = 5.6697 \cdot 10^{-8}$ W m^{-2} K^{-4} (or J s^{-1} m^{-2} K^{-4}). *This is the very same constant value reported by Teodorani & Nobili* (2002, p. 7). As it is evident, both this constant and the other quantities (L_{ABS}, A, T) are *already expressed* in SI units, and therefore there is no justification behind the suggested change of unit. To change the L_{ABS} measurement into erg/s, as Teodorani does, would lead to an inconsistent figure, devoid of any physical value. A numerical example will demonstrate the correctness of this process. If one introduces into the above equation the values of absolute luminosity and area concerning the Sun *and expressed in SI units*, then follows because of $L_{ABS} = 3.9 \cdot 10^{26}$ W and $R = 6.96 \cdot 10^8$ m,

$$T = \left(\frac{L_{ABS}}{4\pi R^2 \sigma} \right)^{1/4} = \left(\frac{3.9 \cdot 10^{26} W}{4 \cdot 3.14 \cdot 4.84 \cdot 10^{17} m^2 \cdot 5.67 \cdot 10^{-8} W m^{-2} K^{-4}} \right)^{1/4} = 5800 K$$

in perfect agreement with the actual solar temperature (see http://www.astro.wisc.edu/~dolan/constants/calc.html). *The same process*, through the L_{ABS} and R value reported by Teodorani with reference to the Hessdalen "blinking light", would led to an effective temperature of 171 K (Leone, 2003, pp. 15-16). This demonstrates the problem.

Furthermore, Teodorani's approach is not persuasive due to another, deeper, theoretical reason. He stated that the Stefan-Boltzmann Law gives a luminosity "in the visual range $\Delta\lambda$ = 3800-6800 Å [i.e. = 380-680 nm]" (Teodorani & Nobili, 2002, p. 7). This is incorrect. This formula concerns the *bolometric* luminosity, and therefore the total power per unit area from a blackbody radiator. If the temperature is close to the solar one (5800 K) there is only a slight difference between these two luminosities. However, at temperature as low as 3200 K the difference is already close to two orders of magnitude, and at a temperature equal to 171 K, the gap would reach 49 orders of magnitude! Thus, by inserting into the equation, as Teodorani did, the luminosity in the 380-680 nm range, would lead to an effective temperature in no way correlated (not even as order of magnitude) with the object temperature (Michele Moroni, personal communication, 2003, June 2).

[3] Concerning the ground-sample analysis topic, Teodorani (2003, p. 5) states that the sample was collected "on a precise spot where a light phenomenon was seen almost on the ground by some Hessdalen inhabitants", thereby avoiding one more time to provide precise data on this subject. Therefore, "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" (Leone, 2003, p. 3).

2. Position of the light

Topographical evidence

Nicolosi & Ricchetti (2003) build a simplified Digital Elevation Model of the Hessdalen region. By means of a digitalisation of 1:50 000 scale map (Haltdalen, 1995) they get the following results:

- Vårhuskjølen road's azimuth: the same values as reported in Leone (2003, p. 11);
- Vårhuskjølen road's elevation: the same values as reported in Leone (2003, p. 11);
- "blinking light" azimuth: 185° (in agreement with Leone (2003, pp. 7-9);
- "blinking light" elevation: + 0.4° (instead of –1.0°, as reported in Leone (2003, p. 9).

As correctly remarked by Nicolosi & Ricchetti, this blinking light elevation is incompatible with the Vårhuskjølen road's one. The figure formerly quoted by this author was originated by an underestimate of the height of two mountaintops (Hessjøhøgda and Nyvollhøgda). However, as it is shown by the two researchers, their result *does* support the method applied by Leone (2003), since upon rectifying the mountaintops angular altitude, this method would lead to a blinking light elevation figure (0.3° ± 0.4°) in agreement with the estimate obtained by Nicolosi & Ricchetti (0.4°). They arrive at a result that requires just one formula: $arc\ tg\ [(H_{peak} - H_{obs.point})/d]$, where H_{peak} and $H_{obs.point}$ are the altitudes of peak and observation point and d is the respective distance.

While they deserve to be praised for having cleared up this matter, their conclusion about an alleged incompatibility between their result and the headlamps explanation follows from a logical leap. In order to be an acceptable conclusion, Nicolosi & Ricchetti had to demonstrate: 1) that apart from the Vårhuskjølen road there are no other places where a headlight equipped vehicle can travel at the angular coordinates of interest, and 2) that the luminous power output is inconsistent with the light emitted by a couple of headlamps in the 4-12 km range from the observation point. Both propositions are accepted by Nicolosi & Ricchetti: the first one is implicitly granted for certain since they look at the Vårhuskjølen road only; the second one is assumed true without a quantitative evaluation and a careful analysis of the methodology of measurement followed by the EMBLA physics team. However, as it will be shown in the following, both propositions are likely wrong and the headlamps hypothesis get strengthened out of the revised blinking light angular elevation.

a) Light's angular coordinates

As far as the *only* angular measurement recorded by the EMBLA physics team is concerned – namely, the blinking light azimuth – the value (185°) obtained through the Digital Elevation Model (Nicolosi & Ricchetti, 2003, p. 4) is in agreement with Leone's (2003, p. 9) result (185.1° ± 0.2°) and in contradiction with the figure (187.7°) reported by the EMBLA physics team (Teodorani & Nobili, 2002, p. 7). Noteworthy is the absence of information on the ranges of error both on the Nicolosi & Ricchetti's and in the Teodorani & Nobili's paper. In table 3 are listed the blinking light's angular coordinates obtained by this author and by Nicolosi & Ricchetti.

Authors	Azimuth (°)	Angular elevation (°)
Leone	185.1 ± 0.4	0.3 ± 0.4

Nicolosi & Ricchetti	185	0.4

Tab. 3 – Light's angular coordinates.

Leone's estimate is obtained through linear and angular measurements of both a positive color print (18 cm x 10 cm) of a photograph of the southern Hessdalen landscape (Leone, 2003) and the "frame 5" published in the EMBLA's report. The errors are due to the low resolution of the photograph employed[4] and are estimated as follows: angular width / linear width ratio = 0.16 °/mm (via a measurement of the apparent distance between the Hessjøhøgda and Nyvollhøgda mountaintops); since each linear measurement has to face two limiting factors – i.e. the meter's accuracy (± 1 mm) and the uncertainty on exact spatial position of both landscape feature and "blinking light" – a linear uncertainty of ± 2 mm is assumed. This corresponds to ± 0.3°. As the measurement of the blinking light angular coordinates is given by a *difference of two* linear measurements (see Leone, 2003, p. 9), the global uncertainty has to be estimated through the Gauss propagation formula[5]

Nicolosi & Ricchetti's estimate of azimuth was found through an overlapping of their model and "frame 5". Their model was built by means of a 1:50 000 Hessdalen valley map. The angular elevation estimate was obtained in an indirect way, i.e. by drawing a tangent to the Heggsethødga ridge from the observation point. Thus, it was neither an outcome of a real measurement, nor a value independent of the azimuth estimate. Its reliability rests on the accuracy of the model, whose higher limit is given by a) the low resolution of a 1:50 000 map and b) the uncertainty on the observation point position. Notwithstanding these obvious limiting factors, Nicolosi & Ricchetti are unclear on the confidence interval of the values they report.

Important data on the real position of the source of light can be inferred through a geometrical analysis of the whole set of frames reported by Teodorani & Nobili (2002, p. 4). In Fig. 8 are plotted the apparent light positions with respect to the Heggsethødga ridge (frames No. 4 and 6 were discarded since their contrast were not enough to allow reliable measurements). Since the four frames show minor tilts around the lens axis, the effective light positions were changed accordingly before superimposing one image on another.

The most striking result is that the apparent lights' angular elevation is constant independently of their apparent azimuth (Fig. 8).

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[4] The values of uncertainty quoted in Leone (2003, p. 9) were somewhat conservative estimates.

[5] The Gauss propagation formula is $\sigma_z = \sqrt{\left(\frac{\partial z}{\partial y}\right)^2 \sigma_y^2 + \left(\frac{\partial z}{\partial x}\right)^2 \sigma_x^2}$, where σ are the uncertainties, and z, y, x are the angular measurements involved. Since the angular position of the blinking light is given by a formula z = y – x, and $\sigma_x = \sigma_y = 0.3°$, it follows $\sigma_z = 0.3 \cdot \sqrt{2} \cong 0.4°$, as reported in Tab. 2.

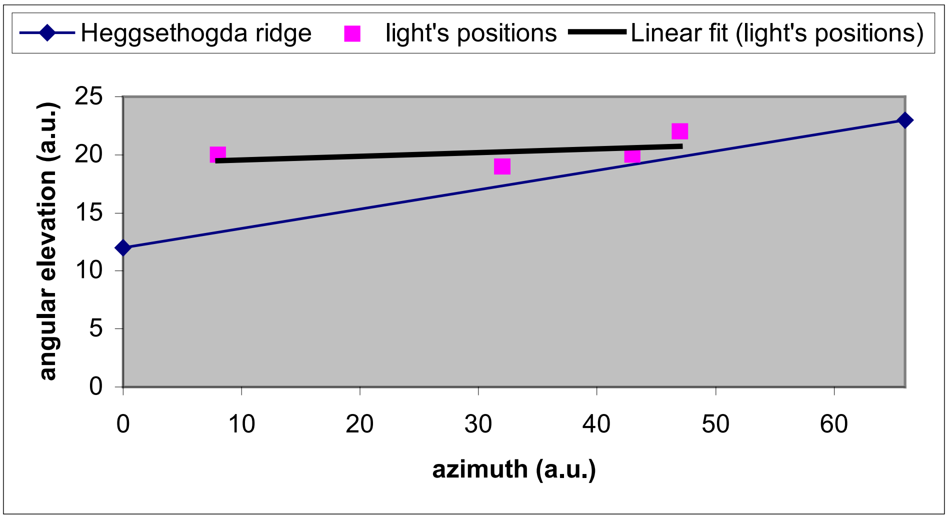

Fig. 8 – Light's apparent positions vs. Heggsethødga ridge: geometrical elaboration based on four frames published by Teodorani & Nobili (2002, p. 4, Fig. 1).

Another striking result concerns the apparent position of the intersection point between two mountains in the background (Hessjøhøgda and Nyvollhøgda) which is visible near the upper left side of the EMBLA frames. From the analysis of frames No. 2, 3 and 5 (No. 1 is discarded since it does not show this feature) it turns out that the angular distance between this intersection point and the light does not change of the expected ratio with respect to the apparent angular light's displacement.

Frame	Light - left border angular distance (x_1)	Light - mountains intersection point angular distance (x_2)	Δx_1	Δx_2
No.	mm	mm	mm	mm
2	32	23		
3	47	29	+15	+6
5	42	26	+10	+3

Tab. 4 – Measurement of angular distances in three EMBLA frames (source: Teodorani & Nobili (2002, p. 4)).

Tab. 4 shows that the apparent angular horizontal displacement between the light and the mountains intersection point is less than half the corresponding displacement between the light and the left border of the frame (as demonstrated by the raw of trees in the foreground, each frame looks at the same part of the Heggsethødga hill; therefore, the frame edges can be used as a reference mark).

Contrary to the EMBLA physics team claims that "the processing shows that the light-phenomenon was occasionally seen up to several tenths of meters above the ground" and "the excursion of the phenomenon movements can be evaluated as about 100 meters orthogonally to the observer" (Teodorani & Nobili, 2002, p. 3), the results discussed above point at a different conclusion. Both effects (constancy of apparent angular elevation and anomaly in the apparent light's displacement) could be easily explained by means of a unique hypothesis: the light is placed on the hill behind Heggsethødga (i.e. Løbergsvollen-Heggsetvollen). According to this hypothesis the change of light's azimuth, far from being real, is just the outcome of unrecorded shifts by the EMBLA observation point. At the Aspåskjolen site, the cameras were not fixed from one evening to another, and shifts up to a few dozens of meters commonly occurred. Displacements of this order of magnitude are consistent with the apparent movements observed in the EMBLA frames.

Should the light be placed over the Heggsethødga hill, a "real" displacement of the light on the Heggsethødga ridge (Δx_1) would lead to an equal "apparent" displacement with respect to the background mountains. Tab. 4 demonstrates that this is not what happened. On the contrary, if the light is on the Løbergsvollen-Heggsetvollen hill it is expected that the effect of observation point shift affects the apparent positions on the frames according to the inverse of the distance from the Aspåskjolen site. Therefore, if such a shift changes of a given factor the apparent azimuth of the Heggsethødga ridge, the expected azimuth change of a car headlamp on the Løbergsvollen-Heggsetvollen hill would be much smaller (of a factor close to the ratio of distances, i.e. 4.2 / 11.5) and far smaller would be the expected change of the mountains in the background. This expectation qualitatively agrees with the measurements of EMBLA frames as reported in Tab. 4.

b) Country roads angular coordinates

Upon the basis of the formerly available angular data the Vårhuskjølen road hypothesis (Leone, 2003, pp. 10-11) was a legitimate one. The mere fact that it is no longer tenable – in the light of the estimates by Nicolosi & Ricchetti, corroborated by this author's method (see the above section) – in no way imply a confutation of the headlamps hypothesis. This conclusion by Nicolosi & Ricchetti is a methodological mistake. Through the corrected values of angular coordinates of the blinking light, both this author and Nicolosi & Ricchetti agree on the following "facts":

1) the light is placed at an azimuth close to 185°;
2) the light is *apparently* placed on the rim of the Heggsethødga hill.

From these data they conclude that the light could be located in the range Heggsethødga – Løbergsvollen-Heggsetvollen. The next step, in any effort intended to test the headlamps hypothesis, would be to look for eventual country roads in this range. Did Nicolosi & Ricchetti look into this possibility? If they did, there in no mention of it in their paper. As previously reported by this author:

> 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. (Leone, 2003, p. 9)

Following the data discussed in the former section, it is compelling to look for any such road on the Løbergsvollen-Heggsetvollen hill. The analysis of the topographical maps shows that at least a road of required angular coordinates does exist. It is a private road joining the Hessjøen lake (720 m in altitude) to the FV576 country road (that crosses in a south-north way the whole Hessdalen valley) close to Fjellheim. To locate this country road in the 1:50 000 Hessdalen valley maps (Dalsbygda, 1995), the standard reference is: 32VPQ103579. This road (760 m in altitude) is about 11 500 m south of Aspåskjolen and enjoys an unobstructed view from the observation point. Furthermore, it points toward the observation point, according to a roughly south-north fashion (Tab. 5).

azimuth	185.2° ± 0.3°
angular elevation	0.3° ± 0.1°

Tab. 5 – Angular coordinates of the Løbergsvollen-Heggsetvollen road (1:50 000 topographical map).

This road shows an excellent agreement with the "blinking light" position reported by both Nicolosi & Ricchetti and this author (Tab. 3). The error on the azimuth is mainly due to the actual position of the observation point, while the error on the angular elevation is given by the length of the road. The length of the interested stretch of road – several tenths of meters – is consistent, as order of magnitude, with the average duration of each sighting, under the car headlights hypothesis.

Although the former observations lead support to the Løbergsvollen-Heggsetvollen hypothesis, it is appropriate to check also the situation on the Heggsethødga ridge. By drawing a line whose bending is 185° from the observation point frame of reference, this author discovered that in correspondence to the Heggsethødga ridge, the ideal line crosses a *traktorveg*, i.e. a cart track (as translated in Haltdalen, 1995).[6] This road borders a forest and marsh area, goes down toward the Hesja river and ends at Heggset. To locate this cart track in the commercially available 1:50 000 Hessdalen valley topographical map (Haltdalen, 1995), the standard reference is: 32VPQ111653. This stretch of the cart track starts in the Heggsethødga ridge and roughly points toward north, i.e. toward the observation point. The altitude pattern of the landscape shows that this stretch of road is unobstructed by the hill in the foreground (Vårhuskjølen) or by the Heggsethødga ridge itself.[7] (see Tab. 6).

azimuth	184.1° ± 0.7°
angular elevation	– 0.1° ± 0.1°

Tab. 6 – Angular coordinates of the Heggsethødga road (1:50 000 topographical map).

As it is evident, even without considering the geometrical analysis of the whole set of EMBLA frames, the obtained figures are still within the range of error of the blinking light's position, but their agreement is quite less satisfying than with the Løbergsvollen-Heggsetvollen road.

Thus, the outcome of this topographical analysis is a strong corroboration of the headlamps hypothesis. By means of the very same criteria adopted by Nicolosi & Ricchetti – a) 185° in azimuth and b) ideal line drawing along the Heggsethødga ridge – there is a good agreement, within the measurement error, between the angular coordinates of the light and those concerning at least one country road placed along the line of sight. This road points – unobstructed – toward the observer and is nearly horizontal in the stretch of interest. It runs on the edge of the Løbergsvollen-Heggsetvollen hill at an altitude of 760 m. This first approximation result means that motor vehicles driving there could beam toward the observation point. This road is not affected by some minor anomalies that weakened the Vårhuskjølen road hypothesis, namely: a sensible downward slope that could hardly account for a continuous sighting up to 30 seconds in length, unless a very slow speed is implied; a vertical offset in the headlights axis due to the downward road and the big depression angle; the apparent light's hovering above the ridge (frame 1). Another less likely possibility is the Heggsethødga's cart track, which is nearly horizontal and runs at an altitude of 680 m.

It is fair to emphasize that, at present, the best candidate is the Løbergsvollen-Heggsetvollen country road. Here follow the main reasons: better angular coordinates; better typology of road (the high frequency of sightings is apparently much more consistent with the car traffic on a private country road rather than with the vehicle circulation on a small cart track); better explicative power of the evidence surfaced from the geometrical analysis of the whole set of the EMBLA frames; better explanation of the apparent hovering above the Heggsethødga ridge.

Photometrical evidence

Leone (2003) demonstrates that the optical power output by car headlamps driving on a road 2200 meters away from the observer is consistent with the EMBLA measurement of apparent luminosity.[8]

[6] Hornby, A.S. (2000). Oxford Advanced Learner's Dictionary of Current English [sixth edition] [p. 180]. Oxford: Oxford University Press: "cart track: a rough track that it is not suitable for ordinary motor vehicles".

[7] Slightly different values are obtained through the 1:5000 "Økonomisk kartwerk" maps regarding the Holtålensør-Trøndelag area published by Statens kartverk, Sør-Trøndelag. The maps of interest are coded "CR 112-5-4 – Engesvollen" (Engesvollen, 1995), "CR 112-5-2 – Vårus" (Vårus, 1995) and "CR 113-5-4 – Hessdalskjølen" (Hessdalskjølen, 1995). The Heggsethødga ridge is covered by Engesvollen (1995) and Vårus (1995). These discrepancies are likely due to the different geometrical projections employed in the 1:50 000 topographical maps and in the 1:5000 maps. The requirement of consistency of data requires perhaps to deem more acceptable (while less precise) the estimate of road coordinates obtained through the 1:50 000 topographical map. It should be remembered indeed that the blinking light coordinates were deduced by this author through mountaintops coordinates drawn by 1:50 000 maps.

[8] Teodorani has checked the calculation made by Leone (2003, pp. 12-14) agreeing with the conclusion of this author on the consistency between the hypothesis of headlamps 2200 meters far from the observer and the apparent luminosity of the

The leader of the EMBLA physics team states that "a car headlight as seen forehead is much stronger than the real Hessdalen light" (Teodorani, 2003, p. 2) and suggests that the optical power output is not consistent with the illuminance by vehicle headlamps. Nicolosi & Ricchetti (2003, p. 12) suggest as well that the photometry contradicts the headlamps explanation (albeit through a remark in contradiction with Teodorani's) since "the power out evaluation is […] underestimated [and] clearly incompatible with car headlamps". As far as the place topography and laws of optics are concerned, both Teodorani's and Nicolosi & Ricchetti's contentions are not supported by any evidence.

This author made clear that "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" (Leone, 2003, p. 14).

As reported by Teodorani & Nobili, the maximum apparent luminosity L_{APP} of the blinking light was $9.8 \cdot 10^{-5}$ W/m^2. Let d_1 and d_2 be two general terms of distance between the light and the observation point. According to the following equation

$$\frac{L_{APP}^{d1}}{L_{APP}^{d2}} = \frac{d_2^2}{d_1^2} \tag{1}$$

one can estimates the apparent luminosity (W/m^2) at a general distance (Leone, 2003, p. 13). In order to get from these values an illuminance estimate it is required to carry out a conversion between photopic and radiometric units. The definition of "candela" (cd = lm/sr, see Leone (2003), p. 13) – unit of luminous intensity – states that there are 683 lm/W at 555 nm. This definition assumes a monochromatic light source. In the cases of sources having a spectral content, like the blackbody spectrum of a halogen headlamp, the conversion is less straightforward. This conversion involves integrating the product of the light source (W) and the V_λ (luminous efficiency) over the wavelengths of interest. The luminous curves for standard observers have been specified by the International Commission on Illumination (C.I.E.) in 1924 and adopted by the International Commission on Weights and Measures in 1933 (Engel, 1968). The relative values of the luminous efficiency (eye responsivity) for the different wavelengths may be found in PHLOX (2003) and are plotted in figure 9.

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blinking light (Teodorani, as cited by Sabadin, 2003). Since the Vårhuskjølen road is no longer considered a likely candidate, this topic would seem unimportant. However, the matter concerning this photometrical estimate will be discussed here because of its methodological significance. According to Teodorani's estimate, by assuming a distance = 2.2 km instead of the 9 km assumed by Teodorani & Nobili (2002), L_{ABS} should be 17 times smaller than the 100 kW estimated by the EMBLA physics team. This is correct. L_{ABS} (2.2 km) = 100 kW x $(2.2 / 9)^2 \cong$ 100 kW / 17 = 5.96 kW. By dropping the 4π radiator assumption (justified by the non-isotropy of vehicle headlamps), Teodorani comes to the conclusion that "the luminosity falls off of a 213 factor (17 x 4 x 3.14), leading to a value close to 450 W", a figure "within the order of magnitude of car headlamps". While agreeing with this author on the consistency of this outcome with the car headlamps hypothesis, Teodorani's correct conclusion follows from an ambiguous estimate. As discussed by Leone (2003, p. 13, equation 1), the total luminous power output is given by the formula:

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

where I is the *radiant intensity* (W/sr), E is the *irradiance* (W/m^2) and d is the distance. Thus, by dividing L_{ABS} for 4π one gets the radiant intensity I, i.e. a power divided by solid angle, expressed in W/sr, *and not* a mere power (W) as incorrectly stated by the leader of the EMBLA physics team. The correct outcome is therefore I ≅ 450 W/sr. The photometrical equivalent of the radiometrical radiant intensity is the so-called *luminous intensity* I_V, whose unit is the lm/sr = cd (lm = lumen; cd = candela). The change from W/sr to cd requires the multiplication for both a numerical factor (683) and the "luminous efficiency" $V(\lambda)$. As discussed by Leone (2003, p. 14), since the light emitted by the vehicle headlamps is not monochromatic, it was legitimate to assume $0.1 < V(\lambda) < 1$ (see in this section an exact quantitative estimate): $3 \cdot 10^4\, cd < I_V < 3 \cdot 10^5\, cd$.

Since the maximum luminous intensity emitted by all car headlamps shall not exceed 225 000 cd (see the ECE Regulation, quoted in Leone (2003), p. 14), one finds that a blinking light at the pointed out distance would meets with the international regulations on car headlamps maximum illuminance, in agreement with the conclusion formerly reached by this author.

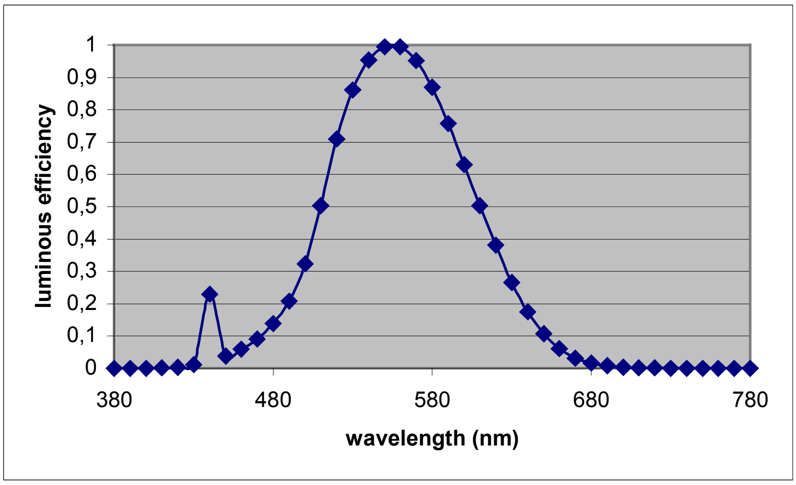

Fig. 9 – Luminous efficiency curve for the eye (source: PHLOX, 2003).

If E_V is the illuminance (lx), E_λ is the irradiance (flux density) at the wavelength λ (Wm^{-2}), V_λ is the luminous efficiency function and K_m = 683 lm/W, the illuminance is given by the formula:

$$E_V = K_m \int_0^\infty E_\lambda V_\lambda d\lambda \tag{2}$$

This means that the energy radiated per second at a certain wavelength by a halogen headlamps spectrum has to be multiplied by the luminous efficiency curve (Fig. 10).

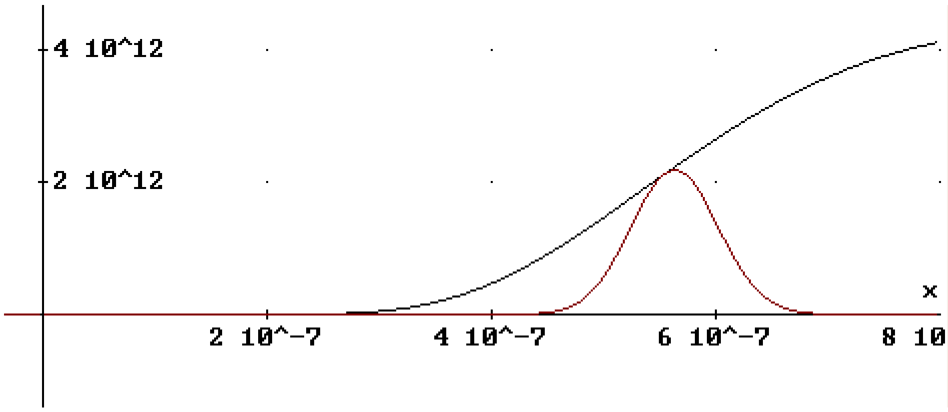

Fig. 10 – 3200 K halogen spectrum (black line) and luminous efficiency curve for the standard observer (red line) in the visual range of wavelengths.

Let E be the irradiance (W/m^2) in the 380-680 nm range and $\overline{X}$ the average of the final curve plotted in Fig. 10. In order to obtain the conversion factor between lx and W/m^2 the equation (2) can be written as:

$$E_V = K_m \int_0^\infty E_\lambda V_\lambda d\lambda = K_m \overline{X} E \tag{3}$$

$\overline{X}$ can be estimated as the ratio between the areas subtended by the two curves plotted in Fig. 10. Its value is 0.38.

If d_1 = 25 m (standard distance for the international regulations on motor vehicle headlamps illumination issued by the *United Nations Economic Commission for Europe* (ECE Regulation, 2002, p. 18)) and d_2 = 11 500 m (distance between the Løbergsvollen-Heggsetvollen road and the observation point), the formula (1) leads to:

$$L_{APP}^{25} = 2.1 \cdot 10^5 \cdot L_{APP}^{11500} \tag{4}$$

If the source of light was a pair of vehicle headlamps 11 500 m far away, L_{APP}^{11500} = (3.5 ÷ 9.8) x 10^{-5} W/m^2 (Teodorani & Nobili, 2002, p. 7), the formula yields L_{APP}^{25} = (7.4 ÷ 20.7) W/m^2.

Thus, from (3) follows: E_{Vmin} = 7.4 x 0.38 x 683 = 1920 lx and E_{Vmax} = 20.7 x 0.38 x 683 = 5370 lx.

Since the maximum headlamps illuminance allowed by the ECE regulations is E_M = 360 lx (Leone, 2003, p. 14), it follows that the illuminance – under the hypothesis that the vehicle headlamps were situated on the Løbergsvollen-Heggsetvollen road – is about one order of magnitude larger than what expected from car headlights. If, on the contrary, the vehicle headlights will turn out to be placed on the Heggsethødga road, the optical power estimate would be lower of a $(4.2 / 11.5)^2$ = 0.13 factor. Therefore, under this second possibility the result would be consistent with ECE regulation on maximum headlights illuminance.

Since the nature of the source of light is a settled topic (see section 1), and the Løbergsvollen-Heggsetvollen road looks to be the better candidate, the above outcome would call into question the reliability of EMBLA physics team's photometrical measurements.

In order to understand the reasons for this apparent anomaly it is necessary to review the methodology followed by the EMBLA physics team in the estimate of the apparent luminosity.

A first questionable step accomplished by the Teodorani & Nobili's paper involves the "time" parameter.[9] The EMBLA physics team assumed "an average realistic duration of the light phenomenon t = 5 seconds […]: this is just the value of the 'real exposure-time' which is considered from photos containing the light phenomenon" (Teodorani & Nobili, 2002, p. 7). By assuming this exposure time, they evaluated the apparent luminosity L_{APP} through the equation $L_{APP} = L_{EXP} / t$, where "L_{EXP} is the luminosity actually recorded from the photo frame" (ibid, p. 7). As the EMBLA physics team did not record the actual length of each blinking light sighting, one wonders if the hazy knowledge of this parameter could account for the above discrepancy. Teodorani and Nobili themselves remark that "the entire performance [of the light] lasted from 1 up to 30 seconds, most frequently 5 seconds" (ibid., p. 3). If in certain instances the duration of the sighting lasted up to 30/5 = 6 times the value arbitrarily assumed, this would imply that some L_{APP} estimates could be up to 6 times over-estimated with respect to data reported by the EMBLA physics team. Thus, the uncertainty of the length of time parameter *could* account for most of the discrepancy between the experimental data and theoretical estimates concerning headlamps 11.5 km far away from the observation point.

Alternative estimate of luminous intensity

[9] At extreme illumination levels or exposure times, the effective sensitivity of the film is lowered so that predicted increases in exposure time to compensate for low illumination, or increases in illumination to compensate for short exposure time, fail to produce adequate exposure. This condition is called "Reciprocity Law Failure " because the Reciprocity Law (the amount of exposure (E) received by the film is proportional to light intensity (i) on the film multiplied by the exposure time (t); therefore, E=it) fails to describe the film sensitivity at very fast and very slow exposures. Furthermore, for color films, the photographer must compensate for both film speed and color balance changes because the speed change may be different for each of the three emulsion layers. However, color contrast changes cannot be compensated for and contrast mismatch can occur. It is unclear if the EMBLA physics team considered these effects in estimating the exposure time.

Because the above discussion calls into question the reliability of EMBLA physics team's photometrical data, an alternative estimate of the luminous intensity from an actual positive print is here derived. The tested photograph was shot in August 2002 and concerns the luminous phenomenon analysed by the EMBLA physics team (Fig. 1). As no densitometry equipment was available for use in this investigation, only a crude approximation estimate is attempted. In order to check the consistency between the luminous intensity and the headlamps explanation, the present estimate is derived under the assumption that the light source was a "point" source unresolved by the camera (as it is obvious when headlamps at 11.5 km are involved). This assumption, with reference to the EMBLA physics report, was already considered by Maccabee (2002).

As it was shown by Maccabee (1987, 1999), one can calculate the luminous intensity in lm/sr, or cd (see Tab. 4 in Leone, 2003), of a point source using the following equation:

$$I_V = \frac{H \cdot A_i \cdot R^2 \cdot e^{bR}}{T \cdot A \cdot t} \tag{5}$$

This equation "can be found by inverting standard photometric equations which give the image exposure in terms of the source intensity" (Maccabee, 1987; p. 165). HA_i is the photometric energy deposited within the boundary of the image (lm·s), where H is the average film exposure level (lm·s/m^2) and A_i is the image area (m^2). R is the range from the camera to the light source (m), b is the atmospheric extinction (m^{-1}), T is the transmission of the camera lens, t is the exposure duration (s), and A is the area of the lens aperture (m^2). The area is given by:

$$A = (\pi/4) \cdot (F/f\#)^2 \tag{6}$$

where F is the focal length of the lens (28 mm in this case) and $f\#$ is the aperture setting on the camera (2.8 in this case). Therefore, $A = 7.85 \cdot 10^{-5}$ m^2.

The image area A_i is approximated as a circle whose radius is 0.05 mm.[10] R is assumed to be equal to 11 500 m (Løbergsvollen-Heggsetvollen distance from the observation point). The corrections due to the atmospheric extinctions (e^{bR}) and the transmission of the camera lens (T) can be approximated as 1, since they do not affect in a sensible way this order-of-magnitude estimate. The parameter t is assumed equal to 5 seconds. The final quantity left to calculate the source intensity is the average H over the whole image. The film manufacturers provide the characteristic curves for the film, which give a graphical representation of the film's response to light (also called HD curves or D-Log*E* curves). On this family of curves the image density (D) is plotted as a function of the logarithm of H. The shape of the curve represents the tonal response of the film to a wide range of exposures and to one particular processing condition. As the slope of the curve decreases, the ability of the film to record the contrast between different exposures also decreases, and stops completely as the curve becomes horizontal. The right side of the curve reaches the "shoulder" (Eastman Kodak Company Staff, 1997). In this section, on increasing exposure the rate of density-increase gradually declines until a maximum point is reached. This is called "Maximum Density". Beyond this point exposure variability cannot be recorded as density variability. In order to evaluate the H parameter, the exposure corresponding to the maximum density of the film used to shot the photograph (Kodak Gold 200) is here considered. The characteristic curves, on the three colors R, G, B, are plotted in Fig. 11 (KODAK GOLD 100 and 200 Films, 2000).

[10] This linear measurement was carried out by means of the software Photoshop 5.0 on a scannerized image of the positive color print. This measurement was corrected according to the geometrical ratio between the 12x18 cm positive print and the 24x36 mm negative film.

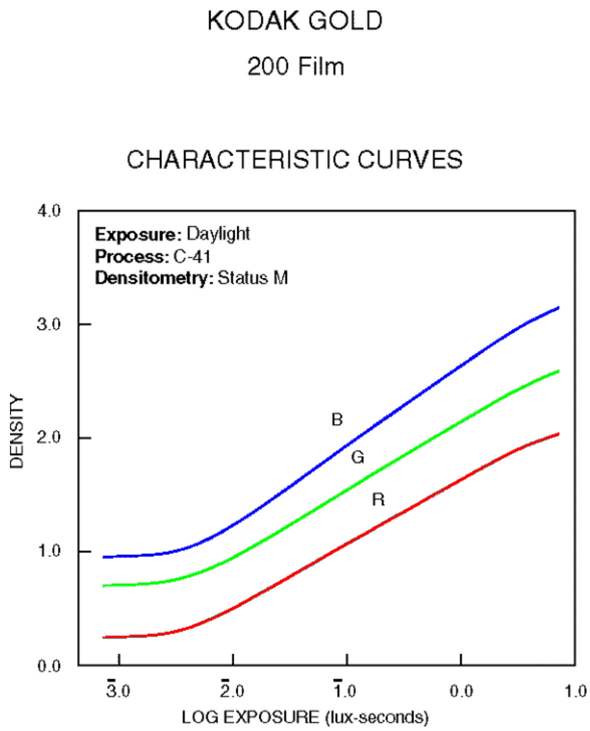

Fig. 11 – HD curves of Kodak Gold 200 film (source: KODAK GOLD 100 and 200 Films, 2000).

The right side of the curves corresponds to an over-exposition of the image. The maximum value of Log H from the curves supplied by the Kodak company is 1.0. This corresponds to H = 10 lx·s (or lm·s/m^2). Therefore, it will be assumed that the interested area of the film was over-exposed and was illuminated by 10 lx·s.

From the above data, equation (5) yields $I_V = 2.6 \cdot 10^4$ cd, a value well below the maximum luminous intensity emitted by car headlamps, i.e. $2.25 \cdot 10^5$ cd (see the ECE Regulation, quoted in Leone (2003), p. 14). This rough estimate shows that the luminous intensity of the blinking light reported by the EMBLA physics team is consistent with what expected from car headlamps. Moreover, this outcome corroborates the conclusion that the photometrical estimates of apparent luminosity reported in the Teodorani & Nobili are not quite reliable.

Conclusion

The purpose of this study was to test the evidence produced by the EMBLA 2002 physics team: namely, that the August 2002 mission in the Hessdalen valley had demonstrated the certain existence of an unknown light-phenomenon, made of "light-spheroids", whose optical power is of the order of 100 kW. The results were clear-cut. The spectrum collected by the EMBLA physics team matched closely the expected spectrum emitted by halogen headlamps and collected with a photographic emulsion of given spectral sensitivity. This outcome was in agreement with the contents of the refractor-assisted visual observation carried by this author in Hessdalen (August 2002), alongside the EMBLA physics team. Both spectrum and visual observation pointed at a vehicle headlamps source of light.

These negative results surprised the leader of the EMBLA physics team and other researchers who were confident in the reliability of the Teodorani & Nobili paper. While one of their objections regarding the angular elevation of the unidentified light showed to be correct, the overall remarks by these critics fail to refute the conclusion suggested by this author. Crucial was their avoidance of the issue concerning spectroscopic evidence (Leone, 2003). In this regards, the spectrum collected by the EMBLA physics team was shown to match the expected spectrum under the halogen headlamps hypothesis at a high degree of statistical significance. This result is consistent with: a) the repetitive pattern (as of angular coordinates, length of sightings, general behaviour, etc.) exhibited by the "blinking light" sighted by the EMBLA physics team in the 2000-2002 period and by this author on August 6-7, 2002; b) the location of at least one country road of proper azimuth, angular elevation and alignment with respect to the observation point; c) the luminous intensity emitted by this source of light (notwithstanding the unclear methodology accomplished by the EMBLA physics team in this regards).

Since the whole optical evidence reported by the EMBLA 2002 physics report regards such a specific light, it is legitimate to conclude that the headlamps hypothesis fits all the optical data collected during the August 2002 mission. In order to test this hypothesis it is suggested to carry out in the future a counter-experiment by means of a refractor telescope of sufficient magnification power set up at the Aspåskjolen observation point. Furthermore, it is suggested to triangulate the light from two different viewpoints. A careful monitoring of vehicle traffics and exact times of vehicle transits on the roads of interest will allow to definitely settle the topic concerning the exact position of the headlamps.

Summing up, apart from the exact location of the interested road, the conclusion reached by Leone (2003) concerning the headlights hypothesis get through the raised objections. This author's evaluation on the EMBLA optical survey – "lacking both in the methodology of data collection and in the evaluation of the evidence" – is confirmed as well.

The successful explanation of the EMBLA 2002 optical observations does not entitle us to believe that this analysis explains away the whole set of Hessdalen sightings of unidentified lights and objects. As previously cautioned by this author, the subject of the anomalous aerial phenomena observed in the Hessdalen valley deserves further attention. However, a continued effort into this subject is not likely to get reliable results unless a serious program of collection of eyewitness testimony and of intensive scientific surveillance for appearance of the alleged luminous phenomenon is set up.

Appendix

Tab. A – B present the EMBLA data and the spectral sensitivity data of the Ektachrome 100 films.

λ (nm)	I (a.u.)
400	20
405	14
410	16
415	17
420	22
425	18
430	24
435	21
440	17
445	20
450	20
455	21
460	21
465	24
470	23
475	20
480	14
485	16
490	14
495	14
500	13
505	13
510	16
515	16
520	17
525	20
530	16
535	19
540	25
545	35
550	45
555	52
560	55
565	53
570	58
575	61
580	63
585	57
590	47
595	20
600	14
605	18
610	13
615	16
620	17
625	24
630	27
635	35
640	39
645	46
650	53
655	54
660	56
665	58
670	36
675	13

Tab. A – EMBLA experimental spectrum (data plotted in Fig. 3).

λ (nm)	Sensitivity (*)
400	6.1
405	12.7
410	20.3
415	29.2
420	32.9
425	32.9
430	32.9
435	32.9
440	33
445	33
450	35.1
455	29.5
460	22.1
465	13.4
470	7.8
475	5.8
480	4.6
485	4

490	3.5
495	3.7
500	4.1
505	4.6
510	5.8
515	6.9
520	8.5
525	9.9
530	11.9
535	14.1
540	18.8
545	22.4
550	24
555	24.1
560	21.7
565	19.7
570	18
575	10.3
580	7.8
585	6.3

590	7.2
595	8.9
600	11.3
605	12.7
610	14.3
615	14.3
620	13.4
625	13.4
630	15.1
635	18
640	21.5
645	22.9
650	19.1
655	14.2
660	6.2
665	2.9
670	1.4
675	0.8

Tab. B – Spectral-sensitivity data of Kodak Ektachrome 100 films (data plotted in Fig. 4). (*) Sensitivity = reciprocal of exposure (erg/cm²) required to produce specified density (source: Kodak Ektachrome 100, 2002).

The formula for the rank (Spearman) correlation coefficient is $r = 1 - \frac{6\sum d^2}{n(n^2-1)}$ where *r* is the correlation coefficient and *d* is the difference in rank. Tab. C lists the ranks and Spearman coefficients obtained from the EMBLA / film sensitivity ratio (obtained by dividing the data listed in Tab. A – B) vs. the expected ranks concerning an incandescent source of light (see Fig. 12 in Leone, 2003, p. 22). Instead of using the actual data, the data points in each set are ranked from 1 to *n*. The *d* parameter is calculated as a difference between couple of ranks at each wavelength value.

As it is possible to see in the column concerning the EMBLA / film sensitivity ratio, some wavelengths get equal intensities. In case of coincidental values (*ties*), the usually applied statistical methodology lies in fixing to each identical value the average of ranks they would get if there would not be any coincidence (Siegel & Castellan, 1992, p. 303-304).

λ(nm)	EMBLA / film sensitivity data		Incandescent headlamps theoretical spectrum			
	Data (a.u)	Rank	Data (a.u.)	Rank	d	d²
400	3.28	X	0.14	X	X	X
405	1.10	X	0.15	X	X	X
410	0.79	X	0.16	X	X	X
415	0.58	4	0.18	1	3	9
420	0.67	7	0.19	2	5	25
425	0.55	2	0.20	3	-1	1
430	0.73	9	0.21	4	5	25
435	0.64	6	0.23	5	1	1
440	0.52	1	0.24	6	-5	25
445	0.61	5	0.25	7	-2	4
450	0.57	3	0.27	8	-5	25
455	0.71	8	0.29	9	-1	1

460	0.95	11	0.30	10	1	1
465	1.79	21	0.32	11	10	100
470	2.95	37	0.33	12	25	625
475	3.45	41	0.35	13	28	784
480	3.04	38	0.37	14	24	576
485	4	44.5	0.38	15	29.5	870.25
490	4	44.5	0.40	16	28.5	812.25
495	3.78	42	0.41	17	25	625
500	3.17	39	0.43	18	21	441
505	2.83	36	0.45	19	17	289
510	2.76	34	0.47	20	14	196
515	2.32	31	0.49	21	10	100
520	2	26	0.51	22	4	16
525	2.02	28	0.52	23	5	25
530	1.34	16	0.54	24	-8	64
535	1.35	17	0.56	25	-8	64
540	1.33	15	0.58	26	-11	121
545	1.56	19	0.60	27	-8	64
550	1.88	24	0.61	28	-4	16
555	2.16	29	0.63	29	0	0
560	2.53	32	0.65	30	2	4
565	2.69	33	0.67	31	2	4
570	3.22	40	0.68	32	8	64
575	5.92	46	0.70	33	13	169
580	8.08	48	0.72	34	14	196
585	9.05	50	0.73	35	15	225
590	6.53	47	0.75	36	11	121
595	2.25	30	0.77	37	-7	49
600	1.24	13	0.78	38	-25	625
605	1.42	18	0.80	39	-21	441
610	0.91	10	0.82	40	-30	900
615	1.12	12	0.83	41	-29	841
620	1.27	14	0.85	42	-28	784
625	1.79	21	0.86	43	-22	484
630	1.79	21	0.88	44	-23	529
635	1.94	25	0.89	45	-20	400
640	1.81	23	0.91	46	-23	529
645	2.01	27	0.92	47	-20	400
650	2.77	35	0.93	48	-13	169
655	3.80	45	0.95	49	-4	16
660	9.03	49	0.96	50	-1	1
665	20	X	0.98	X	X	X
670	25.7	X	0.99	X	X	X
675	16.25	X	1	X	0	0
					Σd^2	12856.5
					r	**0.383**

Tab. C – Spearman correlation coefficient between EMBLA / film sensitivity spectrum and incandescent headlamps spectrum. The data at the edges of the film sensitivity curve were neglected due to the corresponding poor reliability of EMBLA data (these ones are printed in grey color).

The Spearman correlation coefficient reported in Tab. C is significant at the .01 level, i.e. the probability that this coincidence is due to random factors is less than 1% (Da Zar, 1972, as reported in Siegel & Castellan, 1992, p. 437). Tab. D lists the Spearman correlation coefficient as computed by leaving out the low signal/noise data (for the ranges see Fig. 3) collected by the EMBLA physics team.

λ(nm)	EMBLA / film sensitivity data		Incandescent headlamps theoretical spectrum			
	Data (a.u)	Rank	Data (a.u.)	Rank	d	d^2
400	3.28	X	0.14	X	X	X
405	1.10	X	0.15	X	X	X
410	0.79	X	0.16	X	X	X
415	0.58	4	0.18	1	3	9
420	0.67	7	0.19	2	5	25
425	0.55	2	0.20	3	-1	1
430	0.73	9	0.21	4	5	25
435	0.64	6	0.23	5	1	1
440	0.52	1	0.24	6	-5	25
445	0.61	5	0.25	7	-2	4
450	0.57	3	0.27	8	-5	25
455	0.71	8	0.29	9	-1	1
460	0.95	10	0.30	10	0	0
465	1.79	14	0.32	11	3	9
470	2.95	24	0.33	12	12	144
475	3.45	27	0.35	13	14	196
480	3.04	X	0.37	14	X	X
485	4	X	0.38	15	X	X
490	4	X	0.40	16	X	X
495	3.78	X	0.41	17	X	X
500	3.17	X	0.43	18	X	X
505	2.83	X	0.45	19	X	X
510	2.76	X	0.47	20	X	X
515	2.32	X	0.49	21	X	X
520	2	X	0.51	22	X	X
525	2.02	X	0.52	23	X	X
530	1.34	X	0.54	24	X	X
535	1.35	X	0.56	25	X	X
540	1.33	11	0.58	14	-3	9
545	1.56	12	0.60	15	-3	9
550	1.88	17	0.61	16	1	1
555	2.16	20	0.63	17	3	9
560	2.53	22	0.65	18	4	16
565	2.69	23	0.67	19	4	16
570	3.22	26	0.68	20	6	36
575	5.92	29	0.70	21	8	64
580	8.08	31	0.72	22	9	81
585	9.05	33	0.73	23	10	100
590	6.53	30	0.75	24	6	36
595	2.25	21	0.77	25	-4	16
600	1.24	13	0.78	38	-25	625
605	1.42	18	0.80	39	-21	441
610	0.91	10	0.82	40	-30	900
615	1.12	12	0.83	41	-29	841

620	1.27	14	0.85	42	-28	784
625	1.79	14	0.86	26	-12	144
630	1.79	14	0.88	27	-13	169
635	1.94	18	0.89	28	-10	100
640	1.81	16	0.91	29	-13	169
645	2.01	19	0.92	30	-11	121
650	2.77	25	0.93	31	-6	36
655	3.80	28	0.95	32	-4	16
660	9.03	32	0.96	33	-1	1
665	20	X	0.98	X	X	X
670	25.7	X	0.99	X	X	X
675	16.25	X	1	X	0	0
				Σd^2		1614
				r		**0.730**

Tab. D – Spearman correlation coefficient between EMBLA / film sensitivity spectrum and incandescent headlamps spectrum. The coefficient is computed by leaving out the low signal/noise data (in grey color).

The Spearman correlation coefficient computed under the hypothesis of neglecting the low signal/noise EMBLA data is significant at the highest level. If *n* = 33 and the two-tails probability is p = 0.001, the critical value of the Spearman coefficient is 0.554. Since the match between the EMBLA / film sensitivity spectrum and an incandescent headlamp one led to *r* = 0.730, this means that the chances that the spectrum collected by Teodorani is different from a car headlamp one are far less than one out of 1000.

By multiplying the spectral sensitivity curve and the expected incandescent spectrum (3200 K), it is obtained the theoretical spectrum plotted in Fig. 7 (continuous line). The data are reported in Tab. E.

λ (nm)	I (a.u.)
400	3.5
405	7.9
410	13.4
415	21.8
420	25.9
425	27.2
430	28.7
435	31.4
440	32.9
445	34.2
450	39.3
455	35.5
460	27.5
465	17.8
470	10.6
475	8.4
480	7
485	6.3
490	5.8
495	6.3
500	7.3
505	8.6
510	11.3
515	14.1
520	17.9
525	21.4
530	26.6
535	32.7
540	45.2
545	55.7
550	60.7
555	63
560	58.5
565	54.7
570	50.8
575	29.8
580	23.3
585	19.1
590	22.4
595	28.5
600	36.5
605	42.2
610	48.6
615	49.2
620	47.3
625	47.9
630	55
635	66.5
640	81.2
645	87.3
650	73.6
655	56
660	24.7
665	11.8
670	5.8
675	3.3

Tab. E – This author's theoretical spectrum (data plotted in Fig. 7).

(*) Note
Since 2002, the acronym "EMBLA" has been commonly used to make reference to joint Norwegian-Italian missions. As a matter of fact, however, the "Project EMBLA" was a protocol of collaboration - valid for the year 2000 only - between the Østfold College of Sarpsborg, Norway and the CNR (Italian National Council of Research) Istituto di Radio Astronomia - Radiotelescopio di Medicina (Bologna), Italy.

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