Meteorol Atmos Phys (2012) 117:1–4
DOI 10.1007/s00703-012-0197-5

REVIEW ARTICLE

A mechanism to explain the spectrum of Hessdalen Lights phenomenon

G. S. Paiva · C. A. Taft

Received: 26 August 2011 / Accepted: 11 May 2012 / Published online: 26 May 2012
© Springer-Verlag 2012

Abstract In this work, we present a model to explain the apparently contradictory spectrum observed in Hessdalen Lights (HL) phenomenon. According to our model, its nearly flat spectrum on the top with steep sides is due to the effect of optical thickness on the bremsstrahlung spectrum. At low frequencies self-absorption modifies the spectrum to follow the Rayleigh–Jeans part of the blackbody curve. This spectrum is typical of dense ionized gas. Additionally, spectrum produced in the thermal bremsstrahlung process is flat up to a cutoff frequency, ν_{cut}, and falls off exponentially at higher frequencies. This sequence of events forms the typical spectrum of HL phenomenon when the atmosphere is clear, with no fog.

1 Introduction

Several rare and unexplained light phenomena can exist in the atmosphere. For example, ball lightning (Paiva et al. 2007), blue jets (Pasko and George 2002), red sprites (Pasko et al. 2000) and terrestrial gamma ray flashes (TGFs) (Paiva et al. 2009; Paiva 2009). Hessdalen Lights (HL) are unexplained lights usually seen in the valley of Hessdalen, Norway (Teodorani 2004). They have the appearance of a free-floating light ball with dimensions ranging from decimeters up to 30 m. HL often shows strong pulsating magnetic perturbation of about 5 Hz (Teodorani 2004). They are often accompanied by small, short-duration pulsating "spikes" in the HF and VLF radio ranges, sometimes showing Doppler features. HL explicitly shows visually some kind of "satellite spheres" around a central luminous core (Teodorani 2004).

No existing theory or model can account for all the (and sometimes contradictory) observations of HL. One explanation attributes the phenomenon to an incompletely understood combustion process in air involving clouds of dust from the valley floor containing scandium (Bjorn 2007). Some sightings, though, have been identified as misperceptions of astronomical bodies, aircraft, car headlights, and mirages (Leone 2003). A theory involves piezoelectricity generated under rock strain (Takaki and Ikeya 1998). Other recent hypothesis suggests that the lights are formed by a cluster of macroscopic Coulomb crystals in a plasma produced by the ionization of air and dust by alpha particles during radon decay in the dusty atmosphere (Paiva and Taft 2010). The absolute luminosity of light balls has been estimated to be about 19 kW.

Spectrum of the HL phenomenon appears to be a continuum with no resolved lines (Leone 2003). The light phenomenon, in both a photometric and spectroscopic sense, does not have the characteristics typical of a classic plasma of free electrons and ions (Teodorani and Nobili 2002). When the atmospheric transparency was low, which was most of the time, and when the orbs were low over the horizon, the intensity distribution (ID) profile was very similar to that of an image of a heated, glowing plasma, i.e., a Gaussian shape with exponential wings. When the atmosphere was clear, with no fog, the ID profile of the image was nearly flat on top with steep sides.

In this work, we present a model to explain the apparently contradictory spectrum observed in Hessdalen Lights (HL) phenomenon. According to our model, its nearly flat spectrum on the top with steep sides is due to the effect of

Responsible editor: J. Fasullo.

G. S. Paiva (✉) · C. A. Taft
Centro Brasileiro de Pesquisas Físicas, Rua Dr. Xavier Sigaud, 150, Rio de Janeiro 22290-180, Rio de Janeiro, Brazil
e-mail: gerson_trabalho@yahoo.com.br

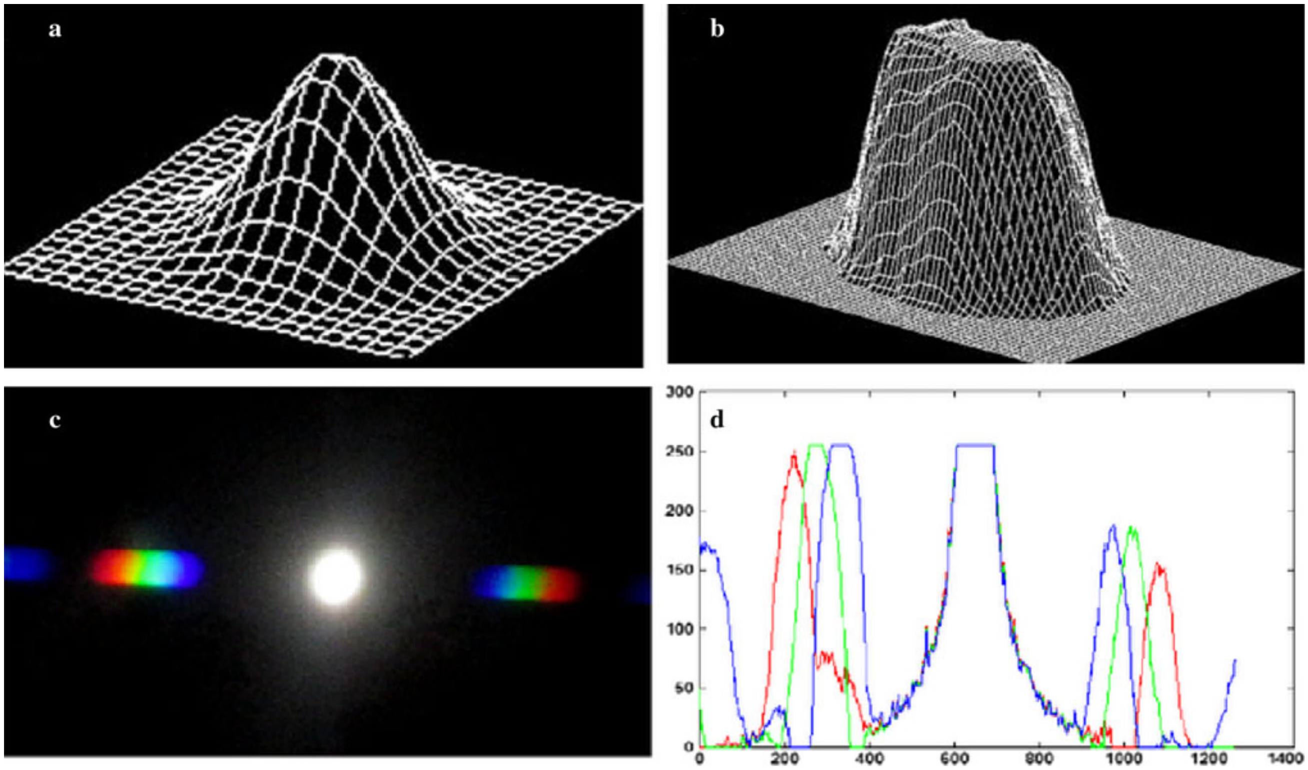

Fig. 1 Light distribution in the cases of: **a** a typical plasma, **b** a typical Hessdalen phenomenon (Teodorani 2004). The three dimensions of plot are *x*, *y*, and *z*. The first two define the area of the image, the last one defines the count level (relative intensity). **c** Super moon image, **d** super moon spectrum (Narayana 2011)

optical thickness on the bremsstrahlung spectrum. At low frequencies self-absorption modifies the spectrum to follow the Raleigh–Jeans part of the blackbody curve. This spectrum is typical of dense ionized gas. Additionally, spectrum produced in the thermal bremsstrahlung process is flat up to a cutoff frequency ν_{cut}, and falls off exponentially at higher frequencies via the Compton process. This sequence of events forms the typical spectrum of HL phenomenon when the atmosphere is clear, with no fog. Thermal bremsstrahlung and self-absorption processes can be produced by semirelativistic electrons in HL phenomenon (Paiva and Taft 2012).

2 The model

According to Teodorani, spectrum of the Hessdalen lights phenomenon appears as a continuum with no resolved lines (Leone 2003) and air turbulence or even fog is able to smooth greatly the spectrum at its base and induce the growth of exponential wings in the spectrum of an illuminated solid body. This happens normally with the light of the stars (the most typical plasma objects) when they are observed through the atmospheric layers—in such a case the "seeing disk" is larger with increasing atmospheric turbulence, which results in the exponential wings of Gaussian shape of their spectrum much more broadened. In the three-dimensional analysis of the intensity distribution of the lights, it appeared that the radiant power is due to a heated substance. Nevertheless, the light phenomenon, in both a photometric and spectroscopic sense, does not have the characteristics typical of a classic plasma of free electrons and ions (Teodorani 2004). This intensity distribution (ID) shape is what one would expect for the image of an approximately spherical and solid-like object that radiates the same in all directions (uniform luminosity; see Fig. 1a, b), for example, the moon spectrum (Fig. 1c, d) (Narayana 2011).

Bremsstrahlung is electromagnetic radiation produced by the deceleration of a charged particle when deflected by another charged particle, typically an electron by an atomic nucleus according to $p + e \leftrightarrow p' + e' + \gamma$ (Rybicki and Lightman 1979). Bremsstrahlung radiation indicates the presence of an ionized gas or plasma. Astrophysical examples include thin plasmas such as in stellar atmospheres, hot and dense plasma such as in the central regions of active galactic nuclei (AGN) or other objects which are accreting matter. In a medium which is optically thin, any internally generated radiation is essentially free to escape from the emitting region without further interaction with

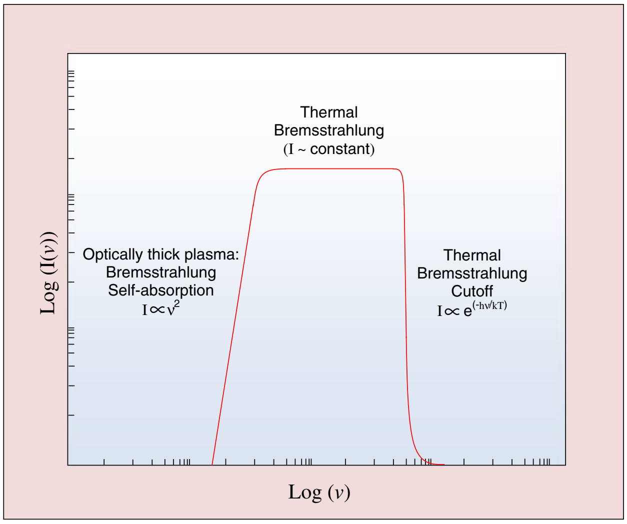

Fig. 2 Effect of optical thickness on the bremsstrahlung spectrum. At low frequencies self-absorption modifies the spectrum to follow the Rayleigh–Jeans part of the blackbody curve. This spectrum is typical of dense ionized gas such as found in star formation regions. The bremsstrahlung self-absorption dominates at low frequency ($I_\nu \propto \nu^2$) for optically thick plasmas; flat region ($I_\nu \sim$ constant) and cutoff ($I \propto e^{(-h\nu/kT)}$) regions of thermal bremsstrahlung dominate at higher frequencies. Exponential cutoff is due to the fact that the electrons cannot produce photons with energy ($h\nu \gg kT$), which is approximately their thermal average energy

the medium. If the medium is optically thick, radiation generated is only moving a short distance within the medium (relative to its size) before being absorbed again—the shape of the spectrum is set by the balance of both emission and absorption processes. In an optically thick region, this amounts to constraining the spectrum to be not more efficient than a black body. Consequently, the spectrum turns over at low frequency a drop with a power–law dependence identical to the drop-off in intensity at low frequency seen in the Rayleigh–Jeans part of the blackbody spectrum (Fig. 2).

We would now like to generalize the results to a population of electrons with a certain velocity and density distribution. The total emission by all particles in this population is called thermal bremsstrahlung. Let us calculate the temperature of HL considering its luminous intensity. The absolute luminosity of light balls has been estimated to be about 19 kW (Teodorani 2004). The velocity distribution of the particles in this ionized cloud is given by the Maxwell distribution (Luo and Zhang 2004):

$$f(V) = 4\pi\left(\frac{m_e}{2\pi kT}\right)^{3/2} V^2 e^{-\left(\left[\left(m_e V^2\right)/2kT\right]\right)}. \quad (1)$$

The typical impact parameter b in the cloud, between the electrons and positive ions is set by the number density of the electrons, n_e, and the number density of the ions n_i. If we integrate the expression of intensity (in the flat part of the spectrum):

$$I = \frac{8Z^2 e^6}{3\pi c^3 m_e^2 V^2 b^2} \quad (2)$$

where Z is atomic number of ion, e is the elementary charge, m_e is the rest electron mass, over velocity V and impact parameter b, one obtains the total emitted power e_{ff} in the cloud per unit volume:

$$e_{ff} = g_{ff}\frac{2^5 e^6}{2m_e c^3}\left(\frac{2\pi}{2m_e k}\right)^{1/2} T^{-1/2} Z^2 n_e n_i e^{-([h\nu/kT])} \quad (3)$$

this spectrum cuts off in ν at approximately $h\nu/kT$, so the cutoff is a useful means of determining the temperature of the cloud. The subscript "ff" refers to the term free–free, which is also frequently used to denote this kind of emission (the electrons and protons are moving freely in the interaction—i.e., they are not bound into some other system). The expression includes a term, Gaunt factor, g_{ff} which is of order unity over a wide range of temperature and density conditions. In cgs units (erg cm^{-3} s^{-1}) the power emitted is

$$e_{ff} = 1.4 \times 10^{-27} T^{1/2} n_e n_i Z^2 g_B \quad (4)$$

correct to within 10 % for sub-relativistic temperatures. Here, g_B is the frequency averaged Gaunt factor for the thermal distribution of velocities, and is of order unity. Let us consider mean electron density for HL as being $n_e = n_i = 10^{11}$ cm^{-3} (Dawson and Jones 1969). No reliable diameter measurements for this luminous phenomenon exist. Attempts of triangulation (Adams 2007) are highly questionable and the available data are consistent with a number of conventional alternative hypotheses (Leone 2007). For the sake of convenience, let us assume that HL is a spherical light ball presenting a diameter of about 10 m (Teodorani 2004) that emits a maximum optical power of 19 kW (=19 × 10^8 erg/s; this value of power was estimated by Teodorani (2004) based on images produced by the well-known streetlights in Hessdalen. However, no evidence exists indeed to support the view that the stationary light leading to the 19 kW estimate was an isotropic radiator. If this assumption is dropped one obtains a luminous intensity estimate in agreement with what expected by vehicle headlights; we found a total emitted power is in the range of e_{ff} $\sim$4 erg cm^{-3} s^{-1}. Considering $Z = 1$, we found $T \sim$600. This value is lower than calculated by Teodorani (2004), 5,000 K. This last temperature is obtained considering the phenomenon with a spectrum showed in Fig. 1a (i.e., black body radiation).

3 Conclusion

We conclude that HL is probably a cold plasma. This fact explains the absence of combustion or fire when the phenomenon occurs amongst the trees, in the forest. Of course, the absence of combustion, deemed to be a successful prediction of the authors' model, could also be an expected consequence of much more mundane explanations [for example, vehicle headlights (Leone 2006)]. However, we believe that the Teodorani spectrum (Fig. 1b) is correct (real) and it does not result from intrinsic factors of the instrumentation in itself (bad choice of film, long exposure times) as suggested by Leone (2006). We can see that the spectrum of Fig. 2 (bremsstrahlung spectrum) is similar to the pure (real) spectrum observed in HL phenomenon (Fig. 1b) when the atmosphere is clear, with no fog. Thus, probably the HL spectrum is caused by high energy electrons in the thick atmospheric plasmas accelerated upward by electric field from rocks under the ground (Paiva and Taft 2012), forming a thermal bremsstrahlung spectrum with flat top and steep sides of an optically thick plasma in ID image. This characteristic simulates the spectrum of an illuminated solid body. The authors make clear that the reason for their belief in the genuineness of the Teodorani spectrum is its similarity with a bremmstrahlung spectrum. However, a comparison with other conventional spectra was not carried out.

Acknowledgments We acknowledge financial support from CNPq and Faperj (Brazil).

References

Adams MH (2007) Characteristics of the August 7, 2002 recurring Hessdalen Light determined by video and triangulation. In: Cabassi R, Conti N (eds) International Project Hessdalen workshop. Lo Scarabeo, Bologna, pp 107–133 (http://www.ciph-soso.net/SOSO/IPHW2006.html)

Bjorn GH (2007) Optical spectrum analysis of the Hessdalen phenomenon. Preliminary report. pp 1–12 (http://www.itacomm.net/ph/2007_HAUGE.pdf)

Dawson GA, Jones RC (1969) Ball lightning as a radiation bubble. Pure Appl Geophys PAGEOPH 75:247–262

Leone M (2003) A rebuttal of the EMBLA 2002 report on the optical survey in Hessdalen. Italian Committee for Project Hessdalen, pp 1–27 (http://www.itacomm.net/ph/rebuttal.pdf)

Leone M (2006) Questioning answers on the Hessdalen phenomenon. J Sci Explor 20:39–68

Leone M (2007) On a triangulation of an alleged "Hessdalen light". Italian Committee for the Project Hessdalen (http://www.itacomm.net/ph/2007_LEONE-IPHW.pdf)

Luo B, Zhang S-N (2004) Thermal bremsstrahlung radiation in a two-temperature plasma. Chin J Astron Astrophys 4:275–278

Narayana KL (2011) Super moon sky, weather scenario and astronomy study during 19th March 2011 to 26th March 2011. Vol 2011, Issue No. 3, (http://trusciencetrutechnolgy.blogspot.com.br/2011/03/super-moon-sky-weather-scenario-and.html) Accessed 19 Mar 2011

Paiva GS (2009) Terrestrial gamma-ray flashes caused by neutron bursts above thunderclouds. J Appl Phys 105:083301-083301-4

Paiva GS, Taft CA (2010) A hypothetical dusty-plasma mechanism of Hessdalen lights. J Atmos Solar Terr Phys 72:1200–1203

Paiva GS, Taft CA (2011) Color distribution of light balls in Hessdalen Lights phenomenon. J Sci Explor 25(4):735–746

Paiva GS, Pavão AC, Vasconcelos EA, Mendes O Jr, Silva EF Jr (2007) Production of ball-lightning-like luminous balls by electrical discharges in silicon. Phys Rev Lett 98:048501-1

Paiva GS, Pavao AC, Bastos CC (2009) "Seed" electrons from muon decay for runaway mechanism in the terrestrial gamma ray flash production. J Geophys Res 114(D13):3205

Pasko VP, George JJ (2002) Three-dimensional modeling of blue jets and blue starters. J Geophys Res 107:1458

Pasko VP, Inan US, Bell TF (2000) Fractal structure of sprites. Geophys Res Lett 27:497–500

Rybicki GB, Lightman AP (1979) Radiative processes in astrophysics. Wiley, New York, pp 13–14

Takaki S, Ikeya MA (1998) Dark discharge model of earthquake lightning. Jpn J Appl Phys 37:5016–5020

Teodorani MA (2004) A long-term scientific survey of the Hessdalen phenomenon. J Sci Explor 18:217–251

Teodorani M, Nobili G (2002) EMBLA2002: Optical and ground survey in Hessdalen. Project Hessdalen Articles and Reports (http://hessdalen.hiof.no/reports/EMBLA_2002_2.pdf)