

# Optical phenomena associated with the launch of a ballistic missile "Bulava" December 9, 2009

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**Abstract.** There are certain types of optical phenomena observed in the upper atmosphere which associated exclusively with the launches of solid propellant rockets. In this article we consider some types of such phenomena observed during "Bulava" launch. First - the development of large-scale dynamic structures. The second class of phenomena is the observation in the region of rocket flight rather compact structures with intense turquoise (blue-green) glow. The development of spiral cloud determined by specific mode of engine operation and rocket rotation. Turquoise glow arises from excitation of molecules AIO, formed by the interaction of metallic aluminum contained in combustion products with atmosphere components.

**Key words:** Upper atmosphere, solid fuel rocket exhaust, AIO emission, dynamics of combustion products clouds.

## 1 Introduction

An unexpected fairy show was occurred suddenly over the Norwegian Arctic December 9, 2009 early in the morning. A spiral glow larger than the Moon enchanted in the night sky above the polar provinces Tromsø, Finnmark, Trøndelag. Slowly rotating the spiral has become a significant part in the coverage of the sky light halo with disk-like shape. Blue-green beam rushing to the ground from the center of the halo went on a rotation basis in the form of a corkscrew.

The lively discussion of the likely nature of the spectacle, observed people in Scandinavia was in this day on the network forums around. Norwegian media were overcrowded breathtaking images of eyewitnesses. The beautiful sight was observed residents throughout northern Norway, indicating its considerable height above the Earth.

Various hypotheses to explain the observed phenomenon were suggested. They extended from the invasion of aliens to a more or less serious explanation. Thus, one of the hypotheses assumed that the "UFO over Norway has organized a new sky resort to attract attention or advertising the show was that the sky shone a spotlight. This trick is said to have been used previously, but now the organizers simply have to add capacity. According to another hypothesis, witty kids joked with a laser pointer on the streets.

The real explanation for the observed effects, as always, was much more prosaic. ITAR-TASS in the press-service information and the Defense Ministry confirmed that on Dec. 9, 2009 at 06:45 UT (09:45 Moscow time) from an underwater position submarine TK-208 "Dmitry Donskoy", which was in the White Sea was made a test launch of a new Russian ballistic sea-based missile "Bulava". The test was unsuccessful. Following examination of the telemetry data revealed that the first two stages of the rocket worked in normal mode, but at a subsequent, third phase of the flight path there was a technical failure.

In the framework of bilateral agreements Russia has provided information on the technical characteristics of its newest missile the "Bulava". It is three-stage rocket. Two first stages are solid-fuel ones, working on composite propellants. The third stage of the rocket, probably, also is solid-fuel one. Flaps for release of gases provide the maneuvers of the rocket.

## 2. Features of development of rocket gas-dust cloud

Prior to the separation of the second stage the rocket launch picture (Fig. 1a) does not particularly different from the "classical" event. For comparison Fig. 1b shows a photograph of a missile launch «Minotaur» from Vandenberg on Sept. 23, 2005



Fig. 1. Rocket track visible as a result of the scattering of sunlight on the products of combustion. During a) the White Sea launch b) during the Vandenberg launch

In both cases, the regions of rockets flight were illuminated by sunlight, while observers were on the night side of Earth. The difference in light conditions is that the «Minotaur» launch took place at evening, when observers were far east from the start point and the launch of the "Bulava" took place in the morning hours and, of course, it was possible to watch it by witnesses, who reside in the regions to the west from a launch position. It was not possible to observe this effect at the Russian territory (Murmansk region and Karelia) because at the launch time (~ 9:45 MSK) the angle of the sun dipping below the horizon was small ~ 6°, which corresponds to the height of the Earth's shadow about 30 km and at enough bright sky the launch was not seen.

A large amount of collected observations provided a unique opportunity for a correct assessment of geometrical parameters of the observed phenomena. This work was done in [1]. Fig. 2 shows the obtained by the author estimates the size of various segments of the observed phenomena.

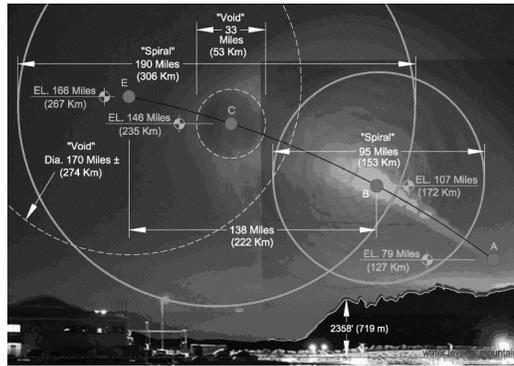


Fig.2. Composite picture of the development of optical phenomena observed in Norway during the launch the rocket on Jan. 9, 2009, obtained by combining a large number of photos.

The most interesting features of the optical effects that accompanied by the launch of the rocket, are presented: cyan (blue-green) the color of the missile track at altitudes up to  $\sim 100$  km, the development of spiral structure in the region of the separation of the second stage of the rocket, the development of expanding around the location of the missiles "black hole" during the last stage of the phenomenon.

### 2.1 Development of the "black hole".

The most obvious is the last of listed above effects. Actually there is no "black hole" is not developed. Engine stopped injected matter into the atmosphere just after switch off the third-stage and all the combustion products are ejected earlier, continued to fly apart. The rate of spread is determined by the speed of the combustion products into the atmosphere, their pressure and temperature. Engine injected matter into the atmosphere and injection velocity may be  $2-3 \text{ km / sec}^2$  in normal mode of the engine in the upper atmosphere. While deviations from normal operation mode exhaust velocity should be considerably less than this value.

### 2.2 Development of a spiral.

The spiral structure of gas-dust cloud formed during the third stage booster rocket, linked to its "somersaults", i.e. rotation is not only about its own axis, but also in the plane almost perpendicular to the line of sight. This is evidenced by the form of clouds, formed by the combustion products of the third stage. It is easy to find (Fig. 3) that the compression ratio of the ellipse formed by the expanding spiral, i.e. ratio of its minor and major axes is  $\sim 0.85$ . This corresponds to the angle between the plane of "tumbling" of the last stage and the direction of the line of sight from the place of observation  $\sim 60^\circ$ . A probable reason for such a "tumbling" may abort of stages separation.

Expansion of the combustion products is virtually a hemisphere  $[2,3]$ , when using of rocket engines in the upper atmosphere due to the high rate of underexpanded combustion products (the ratio of pressure at the nozzle to external pressure  $> 10^5$ ). It is likely that the third stage engine took place in the off-design and products of incomplete combustion of fuel from the engine nozzle due to expire in the form of a dense jet with speeds significantly lesser design because, while expanding spiral and its branches enlarged in the transverse direction.

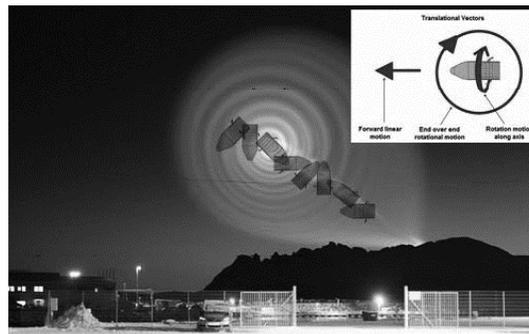


Fig. 3. Scheme of the spiral structure after the separation of the second stage.

### 2.3 Turquoise glow.

Blue-green (turquoise) forms in the mesosphere frequently observed during solid-fuel rocket launches in the twilight conditions. Typically, these formations are sufficiently compact form "clouds", localized at the separation of rocket stages, and sometimes represent a characteristic diffuse winds "striated" trail - see Fig. 4a. Spectral observations conducted by aurora research program showed that the emissions of these formations are dominated by emissions of Al, AlO, Li (Fig. 4b).

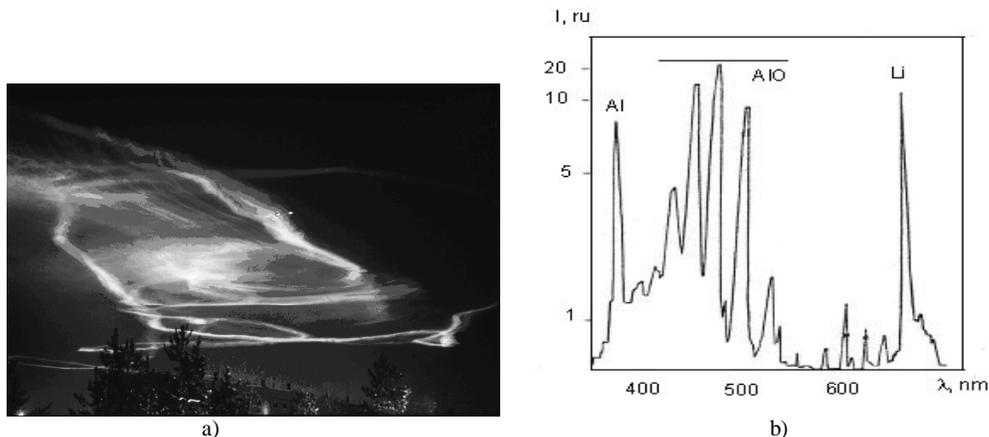


Fig. 4. a) "Turquoise" smeared winds trail left by the passage of solid-fuel rocket, b) spectrum of gas-dust cloud formed by the combustion products of solid-propellant ballistic missile engine.

Metallic aluminum, lithium compounds and other components can be used in solid rocket fuels as admixtures to improve combustion stability [4,5], and aluminum oxide can be formed by the oxidation of aluminum by atmospheric oxygen. It is also possible a different mechanism of formation of AIO. One of the main components of the combustion products of solid propellant missiles is aluminum oxide  $Al_2O_3$  (~ 40% by weight [6]), which represents the fine fraction. At high temperatures (1300 K) as a result of accession to the molecules of aluminum oxide may be the formation of aluminum oxide AIO, located in a gaseous state. Blue-green fluorescence was also observed repeatedly during active experiments with injection of high atmospheric trimethylaluminum or combustion of aluminum thermite charges [7,8]. Mechanisms of chemiluminescent emission AIO not well understood, but it can be considered established that in the twilight conditions, the observed blue-green emission arise from resonant scattering of sunlight. In particular, this radiation is determined by the excitation of transitions  $B^2\Sigma \rightarrow ^2\Sigma$  AIO molecules in the wavelength range 4374 Å - 5424 Å. [9]. Long-term "afterglow" AIO, ie glow for ~ an hour after the passage of the rocket is determined by the relatively small diffusion coefficient sufficiently heavy molecules.



Fig.5. Contrasted picture of "turquoise" track observed more than 40 minutes after the flight of the rocket.

### 3. Conclusion

The spiral structure of gas-dust cloud formed during the second stage separation is determined by combustion products injection from nozzle of "somersaulting" third stage rocket at not on the regular mode engine work. The "turquoise" luminescence in rocket flight region is connected with resonance scattering of sunlight by molecules AIO formed at interaction metallic Al in solidfuel with atmosphere components.

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