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# Benešov bolide—surprising outcome of exceptional story after twenty years

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We report results of a new analysis of the very bright fireball of absolute magnitude −19.5 which was recorded by four all-sky cameras and two spectral cameras at three Czech stations of the European Fireball Network on May 7, 1991, at $23^{\mathrm{h}}03^{\mathrm{m}}48^{\mathrm{s}}$ UT. This fireball is well known as the Benešov bolide.

## 1 Introduction

Very precise data on the Benešov bolide with regard to atmospheric trajectory, heliocentric orbit, fragmentation history, composition and possible impact location based on detailed analysis of these photographic observations were published in several papers (e.g., Spurný, 1994; Borovička and Spurný, 1996; Borovička et al., 1998a; Borovička et al., 1998b). It makes this event one of the best documented and studied bolides in history. Moreover, this bolide belongs to the rarest category of so called superbolides, i.e., events caused by meter-sized meteoroids with initial masses exceeding 1000 kg. This meteoroid penetrated very deep in the atmosphere (last photographed point was at 16.7 km), and, already from the initial analysis, it was evident that a non-negligible part of its mass had fallen on the ground. Despite great efforts and many attempts, no meteorite was found in the weeks and years after the fall. At that time, only three instrumentally observed meteorite falls were known: Příbram (Ceplecha, 1961), Lost City (McCrosky et al., 1971), and Innisfree (Halliday et al., 1978).

## 2 Results and discussion

In the spring of 2011, just before the twentieth anniversary of this extraordinary event, we re-measured all available all-sky records and re-analyzed these data. We used slightly different methods and new approaches which we gradually developed for the analysis of several recent instrumentally observed meteorite falls, as described by, e.g., Spurný et al. (2003), Borovička et al. (2003), Spurný et al. (2010), and Spurný et al. (2012). We obtained a new and consistent picture of the Benešov event, which resulted in a slightly revised impact location and suggested us a new strategy which could lead to the recovery of Benešov meteorites after 20 years. We realized that the largest number of meteorites should originate from catastrophic disruption at 24.3 km, where the bolide reached maximum brightness in a major flare (Borovička and Spurný, 1996; Borovička et al., 1998a). The vast majority of these meteorites should survive as really small pieces in the mass range from 1 g to 10 g. According to our models, such cloud of small fragments could contain several thousands of pieces and, thanks to the almost vertical trajectory of the Benešov bolide, it remained relatively compact during about 7 minutes of dark flight. We found that the predicted impact area for these small fragments covers a cultivated field. If this scenario is correct, then, after 20 years of intensive agricultural utilization of this field, these fragments should be uniformly spread over an about 30 cm thick layer of soil, and at least some of them should be close enough to the surface to be detectable. From very detailed spectral records, we knew that the bulk composition of the meteoroid was chondritic (Borovička and Spurný, 1996). This justified the use of metal detectors for the search, because, after 20 years, meteorites might no longer be distinguishable visually from terrestrial stones and slags.

Reality completely confirmed all our assumptions and highly surpassed our expectations. Four small highly weathered fragments irregular in form and completely without fusion crust with a total mass of 11.7 grams, respectively weighing 1.54 g (H5), 7.72 g, 1.99 g, and 0.38 g (all three LL3.5), ordered according to time of find, were recovered exactly in the predicted impact area for the corresponding masses, namely within 40 m from the highest probability line (two during the first day of searching on April 9, 2011, the third one 10 days later, and the fourth one on April 25, 2012).

Although all fragments are very small and their weathering grade is high (W3 for all pieces), their interior was well preserved for reliable analysis (except for the smallest fragment, where only basic classification was possible). The meteorite is a polymict breccia containing three recognized lithologies with different texture, chemical, and mineralogical composition. The largest portion of the specimens found is an LL3.5 chondrite. The first recovered fragment was classified as an H5 ordinary chondrite. Fragmentary achondritic clast (of 4.8 × 2.6 mm in size) was found within a thick section of the largest sample, and is cemented to the LL3.5 chondrite lithology by irregular veins of impact melt.

## 3 Conclusions

The results presented in this paper are pioneering in many aspects. We proved that, in some special cases, it is still possible to predict and find meteorites a long time after the fall. However, the most important result is in the heterogeneity of the recovered meteorites. This case clearly shows that larger meteoroids can be compositionally very complicated bodies. We discovered that the Benešov meteoroid consisted of at least three different types of material. A similar heterogeneity was observed also for the Almahata Sitta meteorite (Bischoff et al., 2010). This case also implies that it is very useful to study as many fragments as possible from a single fall, because there can be significant differences among them.

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