Group Meeting

Atmospheric entry and fragmentation of small asteroid 2024 BX1: Bolide trajectory, orbit, dynamics, light curve, and spectrum

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Outline

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3. Trajectory and orbit
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5. Meteorite strewn field
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I. Introduction

On January 20, 2024 at 21:48 UT, Krisztián Sárneczky at the Hungarian Piszkésteto Observatory discovered a small asteroid **2024 BX1**, which was on a collision course with Earth.

As determined by imminent impact monitoring services such as JPL's Scout, ESA's Meerkat and MPC's internal warning system, the collision should have occurred around 0:33 UT in the area of Berlin, Germany.

This prediction was subsequently confirmed by the observation of a very bright bolide (**Ribbeck**), it was seen by a large number of mostly casual observers, and it was recorded by the various instruments of the **European Fireball Network** and partly by the cameras of the **AllSky7 system**.

Fig. 1. Composite image of the Ribbeck bolide from video footage taken by the IP camera at the Frýdlant station.

II. Instruments and data

The bolide fortunately passed within range of the core of the **European Fireball Network (EN)**, especially the Czech part of the EN, whose centre is located at the Ondˇrejov Observatory.

We used a total of **17 optical records** (10 digital all-sky images and 7 video records) of which 15 were from the EN and **2 video records** were from the German part of the **AllSky7 network**.

In addition, we used **3 radiometric** and **3 spectral records** exclusively from the EN network to determine asteroid properties.

II. Instruments and data

Fig. 2 shows the uncalibrated radiometric light curve of the bolide taken from the Tautenburg Observatory in Germany and the Czech station R˚užová.

The signal at Tautenburg is higher because this station was closer to the bolide.

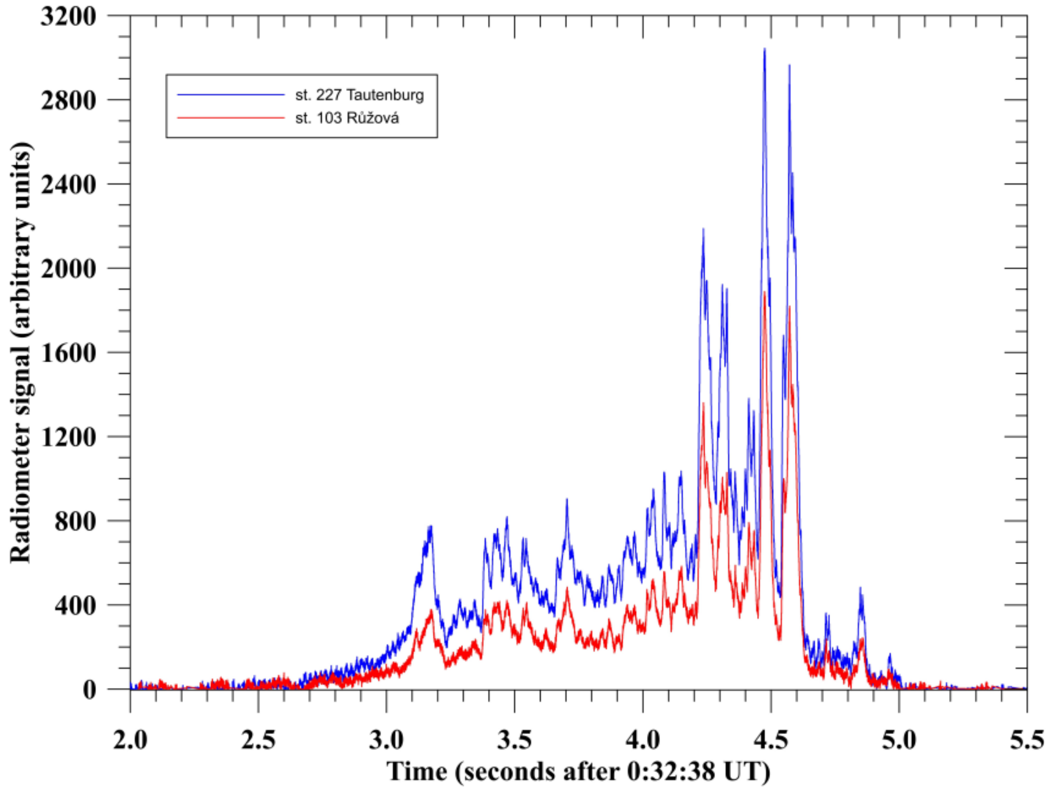


Fig. 2. Uncalibrated radiometric light curve of the Ribbeck bolide from stations 227 and 103. The reality of every visible detail in both LC's is confirmed by independent recordings from two stations 182 km apart.

II. Instruments and data

Table 1. Locations of the cameras, their distances to the fireball beginning and end, span of the recorded heights, total length, and used weights.

Station	Network No.	Camera	Coordinates (WGS84) Longit. E	Latitude N	h (m)	Distance (km) Beg	End	Height (km) Beg	End	Length (km)	W_T	W_V
Frýdlant	EN 6	DAFO	15.09047	50.91773	350	271.5	257.5	70.33	26.50	45.3	6	–
		IP				281.0	256.7	92.08	23.13	71.2	3	4
Polom	EN 10	DAFO	16.32225	50.35015	748	374.5	362.6	67.49	26.16	42.7	6	–
		IP				380.7	361.9	84.59	22.76	63.9	3	4
Jičín	EN 8	DAFO	15.34047	50.43439	279	322.7	310.6	70.53	27.47	44.5	6	–
		IP				330.1	309.7	90.36	23.16	69.4	3	4
Kunžak	EN 2	DAFO	15.20093	49.10729	656	442.2	433.7	71.50	27.17	45.8	6	–
		IP				447.0	433.2	89.77	23.93	68.0	3	4
Ondřejov	EN 20	DAFO	14.77994	49.91007	527	349.0	340.2	69.06	29.44	40.9	6	–
		IP				355.7	339.7	90.54	26.41	66.2	3	8
Růžová	EN 3	DAFO	14.28653	50.83411	348	246.7	233.4	74.12	30.36	45.2	6	–
Šindelová	EN 1	DAFO	12.59666	50.31740	595	265.0	261.5	68.95	49.28	20.3	6	–
Přimda	EN 11	DAFO	12.67807	49.66960	752	334.1	331.2	59.03	27.20	32.9	6	–
Kocelovice	EN 5	DAFO	13.83829	49.46724	525	370.1	363.9	67.74	27.12	42.0	6	–
Tautenburg	EN 27	SDAFO	11.71061	50.98168	338	205.5	200.3	85.61	65.38	20.9	2	–
Ketzür	AMS 16	AS7	12.63124	52.49502	45	82.5	26.4	80.52[a]	21.26	61.2	4	1
Lindenberg	AMS 22	AS7	14.12152	52.20867	125	157.4	113.9	93.32	22.60	73.0	3	1

EN: European Fireball Network **AMS**: American Meteor Society **AS7**: AllSky7 Global Network

DAFO: Digital Autonomous Fireball Observatory which produces all-sky photographic images and radiometric light curves

SDAFO: spectral version of the DAFO **IP**: Internet Protocol video camera

W_T and W_V: trajectory and velocity weights.

III. Trajectory and orbit

The bolide trajectory was computed by the least squares method of Borovicka (1990). The trajectory was first assumed to be straight. Corrections for curvature due to gravity were applied at the end.

Good consistency of all positional measurements is demonstrated. There is no significant systematic trend of any of the 17 records.

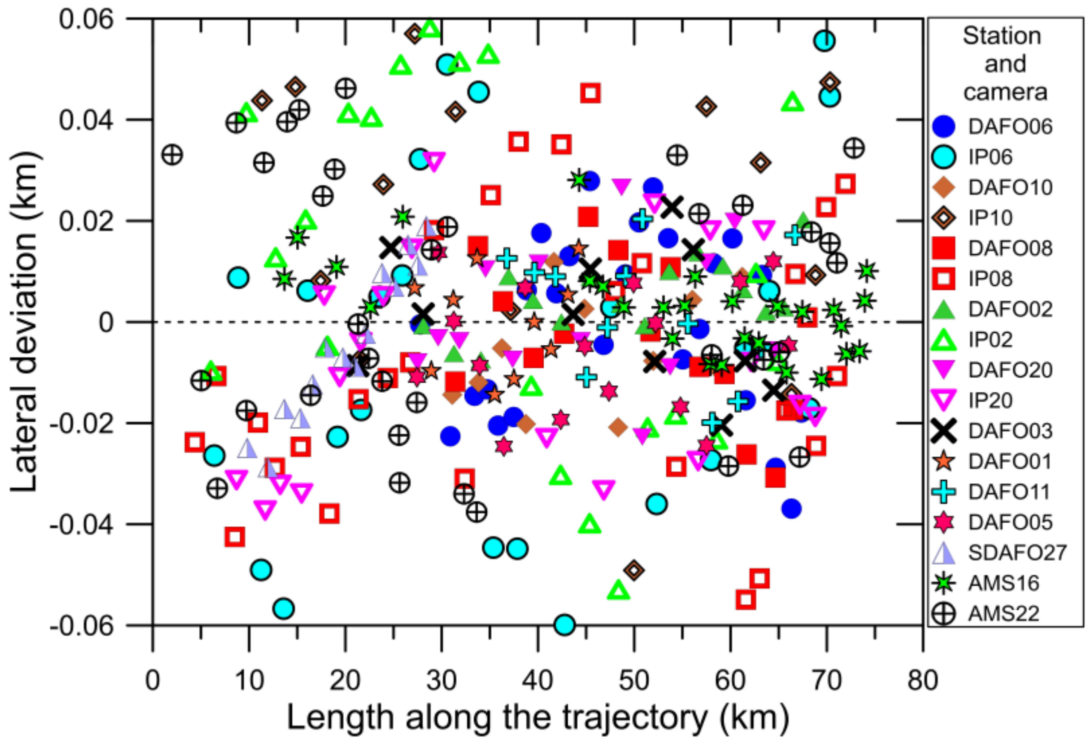


Fig. 3. Lateral deviations of all measured points on the luminous path of the fireball from all available records (17). Note that the Y-axis scale is highly enlarged and that one standard deviation for any point on the fireball trajectory is only 20 m.

III. Trajectory and orbit

All important trajectory data

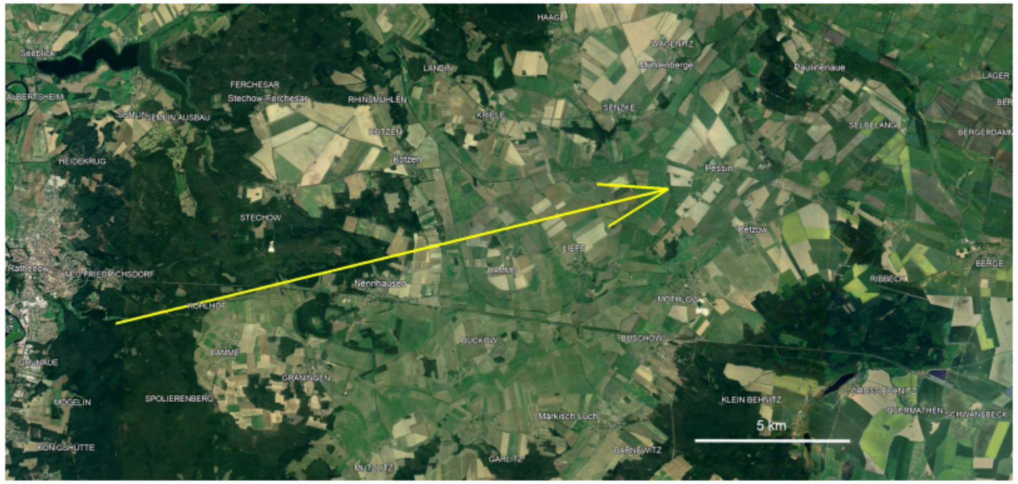
Table 2. Atmospheric trajectory data of the Ribbeck bolide.

	Beginning	Terminal
Height (km)	93.315 ± 0.004	21.256 ± 0.003
Longitude (° E)	12.38009 ± 0.00008	12.64232 ± 0.00006
Latitude (° N)	52.58959 ± 0.00006	52.63502 ± 0.00005
Slope (°)	75.557 ± 0.008	75.74 ± 0.02
Azimuth (°)	74.01 ± 0.03	74.22 ± 0.03
L (km) / T (s)	74.42/ 5.95	

Notes. Height is above the sea level. Azimuth is taken from south. L is the length and T is the duration of the recorded trajectory.

The exact time corresponding to the beginning of the bolide shown in the Table is **$0^h32^m38^s.48$ UT.**

The ground projection of the atmospheric trajectory (18.5 km)



III. Trajectory and orbit

Table 3. Apparent and geocentric radiant and velocity and orbital elements (J2000.0) of the Ribbeck meteorite fall.

		Bolide	Asteroid
entry velocity	v_∞ (km/s)	15.199 ± 0.008	-
apparent radiant	α_R (deg)	119.546 ± 0.011	-
	δ_R (deg)	46.739 ± 0.007	-
geocentric radiant	α_G (deg)	114.592 ± 0.013	-
	δ_G (deg)	44.902 ± 0.009	-
	v_G (km/s)	10.476 ± 0.012	-
	a (A.U.)	1.3344 ± 0.0007	1.3343797
	e	0.3740 ± 0.0004	0.3740191
	q (A.U.)	0.83534 ± 0.00016	0.8352962
	Q (A.U.)	1.8334 ± 0.0015	1.8334632
	ω (deg)	243.602 ± 0.016	243.60428
	Ω (deg)	300.092	300.14142
	i (deg)	7.264 ± 0.009	7.26653
	P (years)	1.5414 ± 0.0012	1.5414134

Notes. Orbital elements from ground-based telescopic observations of the asteroid in space for the epoch 2023 Sept. 13.0 TT are in the right column for direct comparison (MPEC 2024-B76)

- The orbital elements determined from pre-collision observations are presented in the right column, providing a unique opportunity to compare the results of the two independent methods.

- The heliocentric orbit calculated from the bolide data agrees very well with the asteroid data.

IV. Light curve and fragmentation

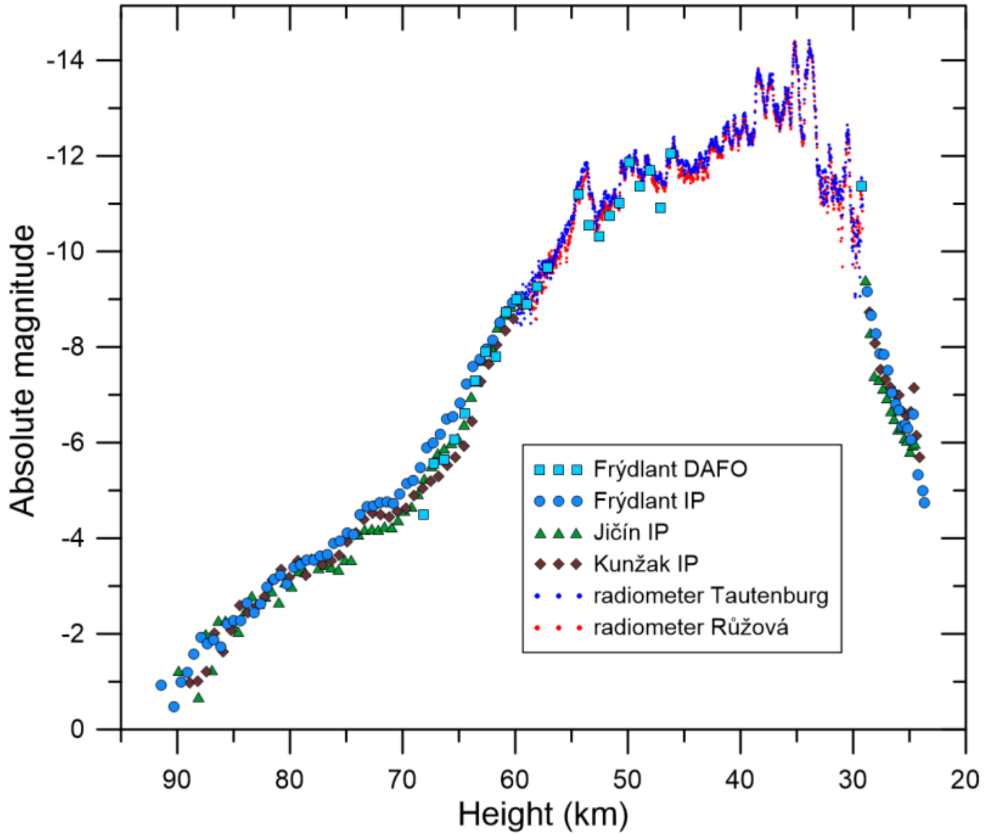


Fig. 5. Calibrated light curve as a function of height combined from various instruments.

• The absolute calibration (using stars) from all these systems is in good agreement.

• The bright part of the bolide was well covered by the radiometers, which are linear detectors with high dynamic range.

• The bolide reached the maximum brightness of −14.4 absolute magnitude in two almost equally bright flares at heights 35.2 and 33.9 km.

• The last observed flare occurred at 24.5 km.
(The flares are signs of meteoroid fragmentations.)

IV. Light curve and fragmentation

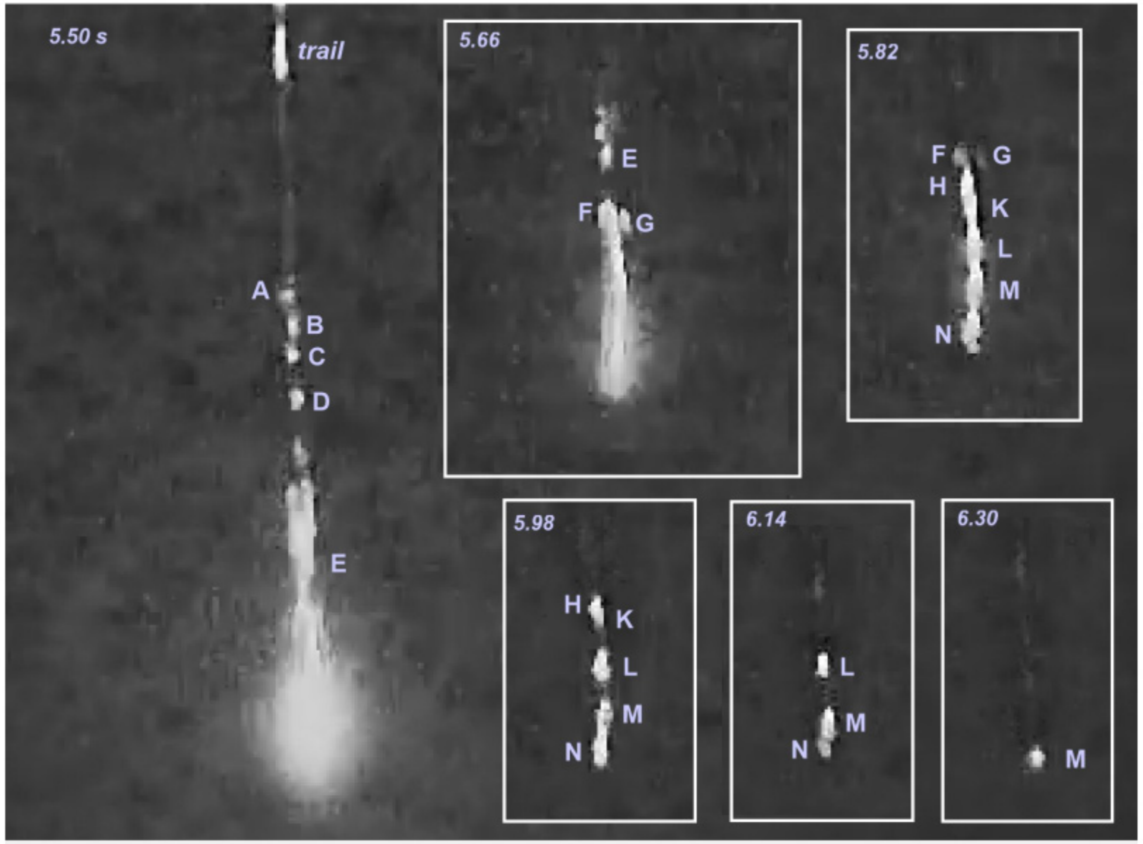


Fig. 6. Bolide images on six individual frames from the ALLSKY7 AMS 16 video. Fragments which could be measured are marked with capital letters. Time is given in seconds from 0:32:38 UT.

IV. Light curve and fragmentation

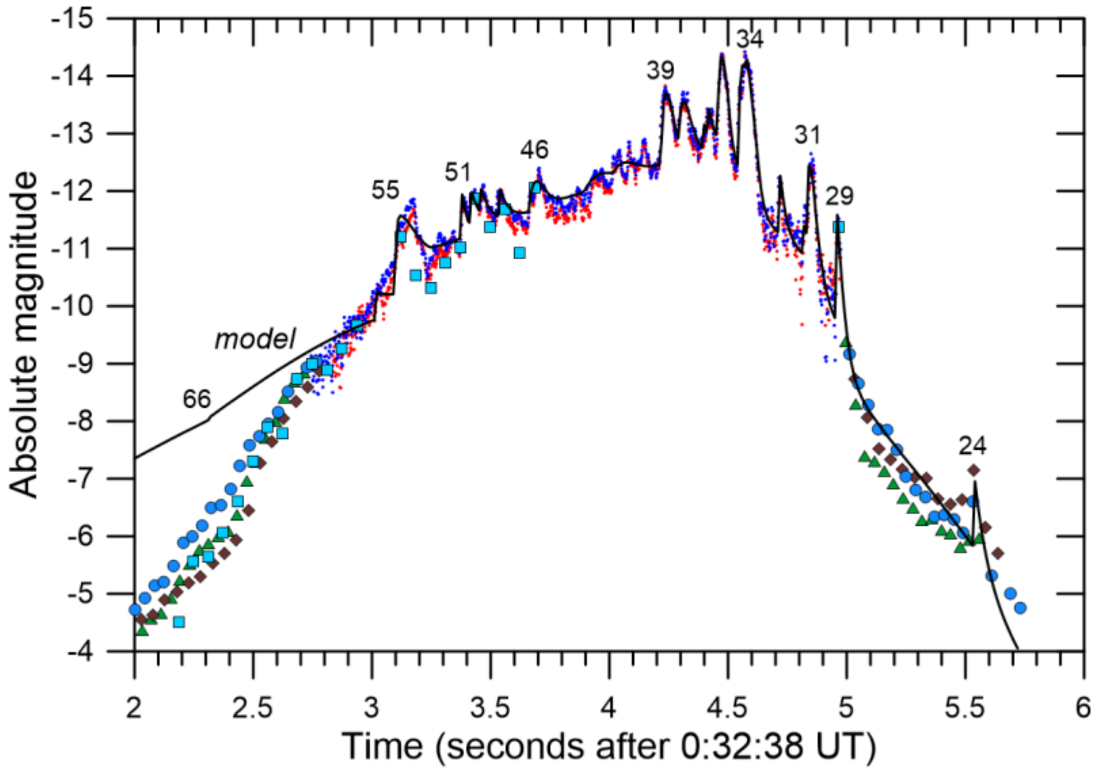


Fig. 7. Observed (symbols) and modeled (solid line) light curve as a function of time. The symbols are the same as in Fig. 5. The numbers give approximate heights in km of selected features on the light curve.

- We have modeled the fragmentation using the Semiempirical Fragmentation Model described in Borovicka et al. (2020).
- The first major, and in fact catastrophic, fragmentation started at a height of 55 km and was demonstrated by the first flare.
- The major fragmentation ocurred at heights 39–29 km.

V. Meteorite strewn field

A map of the computed strewn field

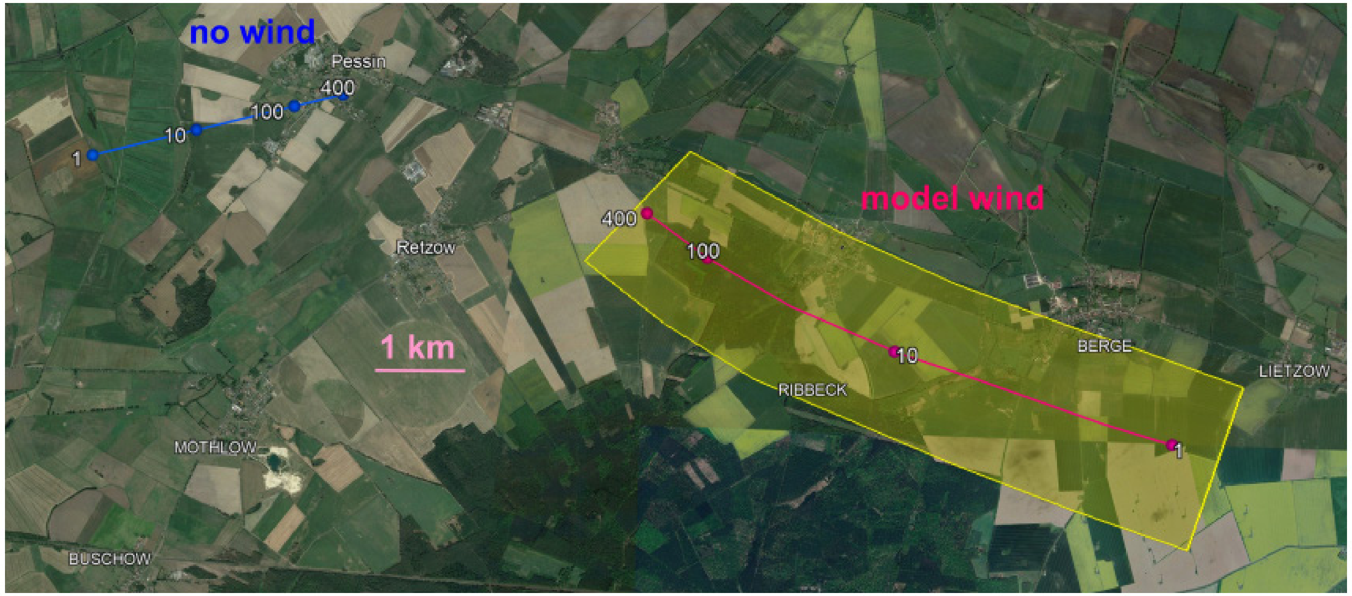


Fig. 9. Map of computed meteorite fall locations for the hypothetical case of no atmospheric wind (blue) and with the usage of the ALADIN wind model (red).

The strewn field map was in fact made available already on January 22 and dozens of meteorites were already found in the designated area.

VI. Spectrum and composition

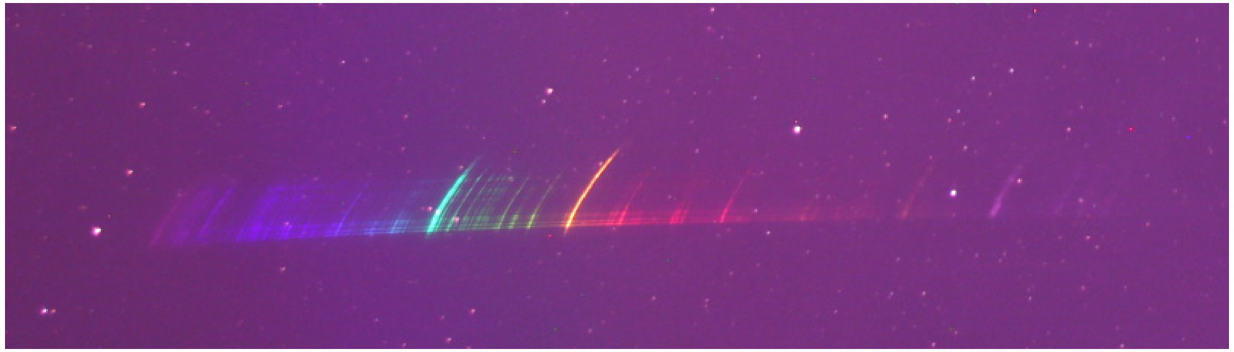


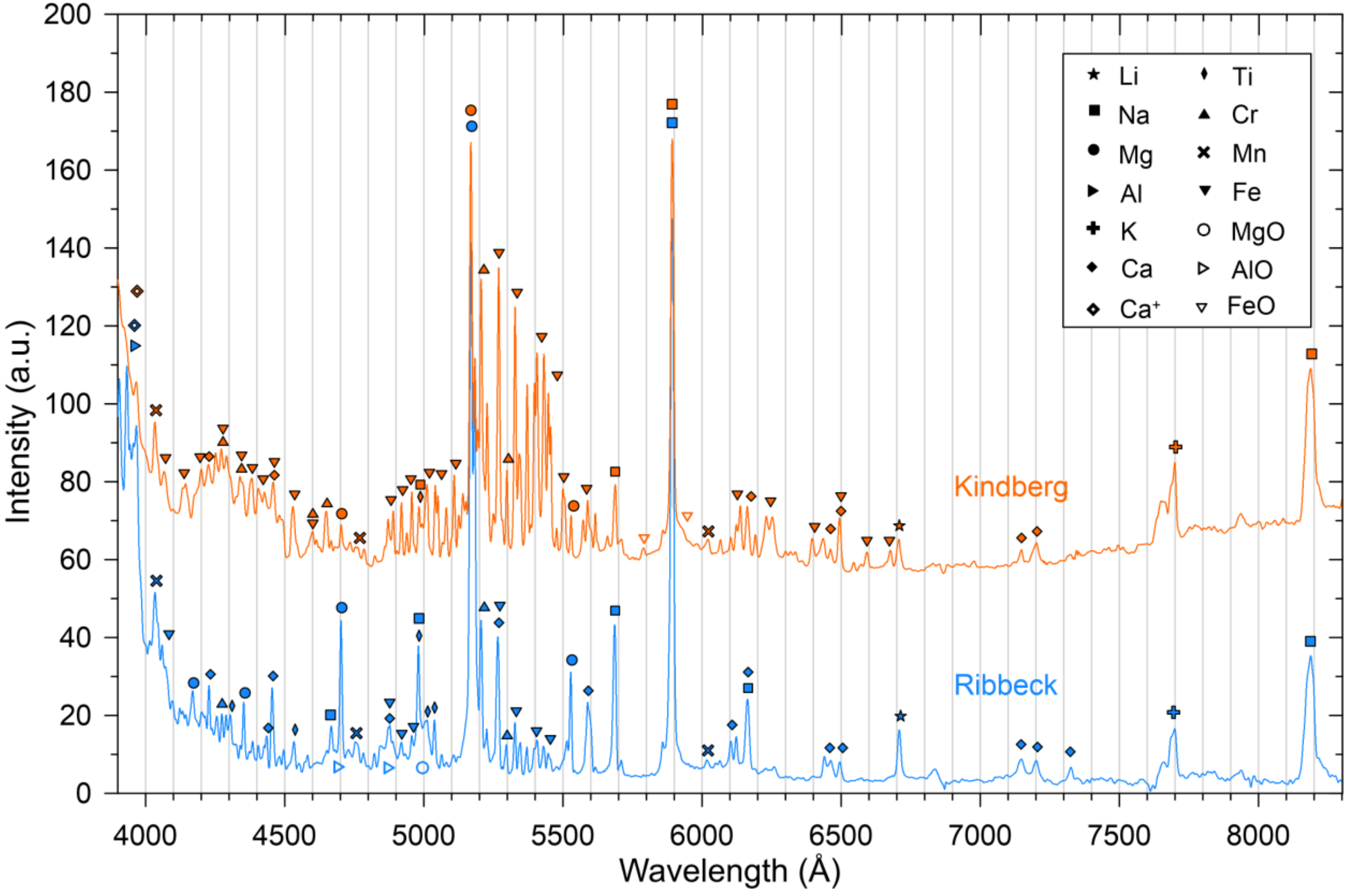
Fig. 10. Original color image of the Ribbeck bolide spectrum with stars in the background. The bolide moved from top to bottom. The wavelengths increase from left to right. The curvature of spectral lines is due to the geometry of the fish-eye lens.

- The bolide spectrum taken by the SDAFO at Tautenburg.

- The bright green line belongs to magnesium and the yellow line is of sodium.

VI. Spectrum and composition

Comparison of spectra of the Kindberg and Ribbeck bolides in the range 3900 – 8300 Å.



- The spectrum of Kindberg was taken by another SDAFO of the EN network in Churánov station. Both bolides had similar speeds.
- A significant difference: In Ribbeck, the Fe lines are much fainter or absent and many lines of Mg, Na, and Ca are seen.
- Strong depletion of Fe is evident and pointed out an enstatite ($MgSiO_3$) rich material even before the meteorites were found.

VII. Discussion and conclusions

- Asteroid 2024 BX1 was the eighth asteroid discovered shortly before colliding with the Earth.

- 2024 BX1 bolide occurred within the range of the EN network, which provided precise and multi-instrumental data including detailed radiometric light curve and spectrum.

- Our final estimate of the asteroid size from the bolide model is 0.44 m, for the mass 140 kg.

- 2024 BX1 was probably the smallest natural body ever observed telescopically in space.

- As the efficiency of asteroid discoveries increases and the bolide network expands, more such events can be expected.

Thanks