Possible origin of the first iron meteorite with an instrumentally documented fall. I. Kyrylenko[1] , O. Golubov[1], I. Slyusarev[1], J. Visuri[2], M. Gritsevich[2,3,4,5], Yu. N. Krugly[1], I. Belskaya[1], V. G. Shevchenko[1], [1]Institute of Astronomy of V. N. Karazin Kharkiv National University, 35 Sumska Str., Kharkiv 61022, Ukraine, [2]Finnish Fireball Network, Ursa Astronomical Association, Kopernikuksentie 1, Helsinki 00130, Finland, [3]Finnish Geospatial Research Institute, Geodeetinrinne 2, Masala 02430, Finland, [4]Department of Physics, University of Helsinki, Gustaf Hällsrömin katu 2a, Helsinki 00014, Finland, [5]Institute of Physics and Technology, Ural Federal University, Ekaterinburg 620002, Russia

Introduction: The meteorites of iron composition represent less than 4% among ~65,000 officially classified meteorites [1]. To date, only 38 meteorites that have been published have enough detection data to reliably reconstruct their heliocentric orbits before their entry into the Earth's atmosphere [2]. The absence of iron meteoroids with precisely determined orbits severely hampered the ability to locate the source of iron meteorites in the main asteroid belt. This has been recently changed by a bright fireball detected over Scandinavia on November 7, 2020, at 21:27:04 UTC [3]. A 13.8 kg meteorite fragment has later been recovered in Sweden. Although the chemical and isotopic contents of the meteorite has not yet been measured, its metallic composition is certain [4]. Such an event is a unique possibility to investigate the delivery mechanisms of iron meteorites and to search for reservoirs of metal in the Solar System.

Results:

Orbital elements of the meteoroid. The fireball has been observed from Denmark, Finland, and Norway. The instrumental records obtained by the Finnish Fireball Network and the Norwegian meteor camera network allowed us to reconstruct the orbit of the meteoroid. The analysis of the atmospheric trajectory based on the α-β criterion [5] is consistent with the iron composition of the object. The newest data-processing software FireOwl [6] of the Finnish Fireball Network was used to retrieve the trajectory and orbit of the meteoroid, the result of which was verified with Meteor Toolkit [7] software. The orbital elements determined from these observations imply that the meteoroid possessed an Apollo-type near-Earth orbit [4]. The semi-major axis and eccentricity of the iron meteoroid in comparison to the orbital parameters of near-Earth asteroids and meteoroids with known heliocentric orbits are shown in Fig. 1.

Past dynamical evolution of the meteoroid. Simulation of the meteoroid orbit into the past using the GENGA package [8] demonstrated the possibility of close encounters with the Earth. It means that the orbit cannot be simulated into the past precisely and can be investigated only in the statistical sense.

The pre-selected parent body candidates were numerically integrated backwards in time to find close encounters with the meteoroid within the range of 0.5 Myr. The results implied either that the meteoroid's orbit is not sufficiently precise to define its parent body, or that the meteoroid separated from its parent body earlier than 0.5 Myr ago.

YORP lifetime estimate. The YORP effect can accelerate the rotation of meteoroids and result in their disruption by centrifugal forces. Assuming the typical values for the YORP coefficients of irregularly-shaped bodies [9] and the tensile strength of iron meteorites [10], we arrived at the YORP lifetime of the meteoroid of the order of at most 20 Myr. This leaves enough time for a meteoroid formed in the main belt to travel to the near-Earth region via a resonance.

Source region of the meteoroid in the main belt. The determined orbit of the meteoroid allowed us to estimate the statistical possibility of its source regions using NEOPOP software [11]. The results indicate ν_6 secular resonance with Saturn and 3:1 mean motion resonance with Jupiter to be the most plausible sources of the meteoroid. These resonances are the main suppliers of the near-Earth asteroids from the main belt [11]. The numerical simulation of meteoroid clones is roughly consistent with the results of the statistical model.

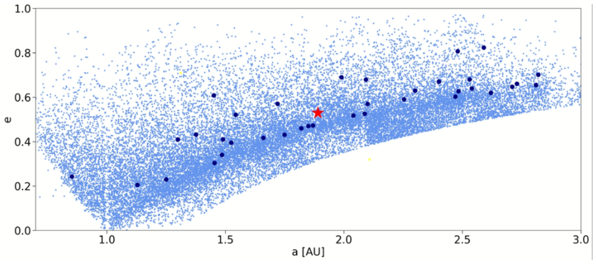

Fig.1 Comparison of the semi-major axis of the iron meteoroid (red star symbol) with those of near-Earth asteroids (sky-blue dots) and meteoroids with known heliocentric orbits [2] (blue circles).

Discussion:

The meteoroid could have left its parent body either due to the destruction of the parent body by the rotation produced by the YORP effect [12], or as the result of a collision with another asteroid. From the size of 1 m (IMO) and the tensile strength of iron meteorites [10], we estimate the disaggregation time of the meteoroid to be at most 20 Myr, which is enough for the meteoroid to reach its current orbit from the main belt as a separate body. The forthcoming information of its CRE age can verify our predictions about the origin of the meteoroid.

Conclusions:

The first instrumentally documented fall of an iron meteorite grants a one-of-a-kind opportunity to investigate the source regions of the metallic asteroids in the Solar system. The instrumental data were used to reconstruct the pre-atmospheric orbit of the meteoroid. The resulting orbit is typical for near-Earth asteroids and has the orbital parameters within the range of those of stony meteorites (Fig. 1). The statistical model and numerical simulations point to the ν_6 secular and J3:1 mean motion resonances as the most plausible sources of the meteoroid. The YORP timescale of 20 Myr is enough for the meteoroid to travel from the main asteroid belt to a near-Earth orbit. The long YORP timescale can also explain why the numerical simulations were unable to determine the parent body of the meteoroid.

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