New meteorite recovered in northern Russia based on observations made by the Finnish Fireball Network

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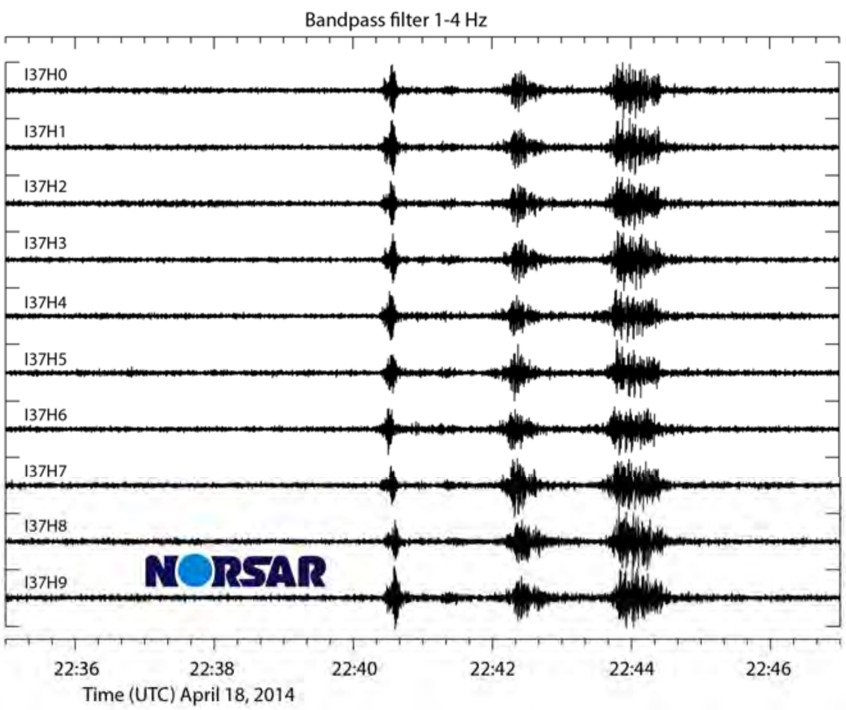
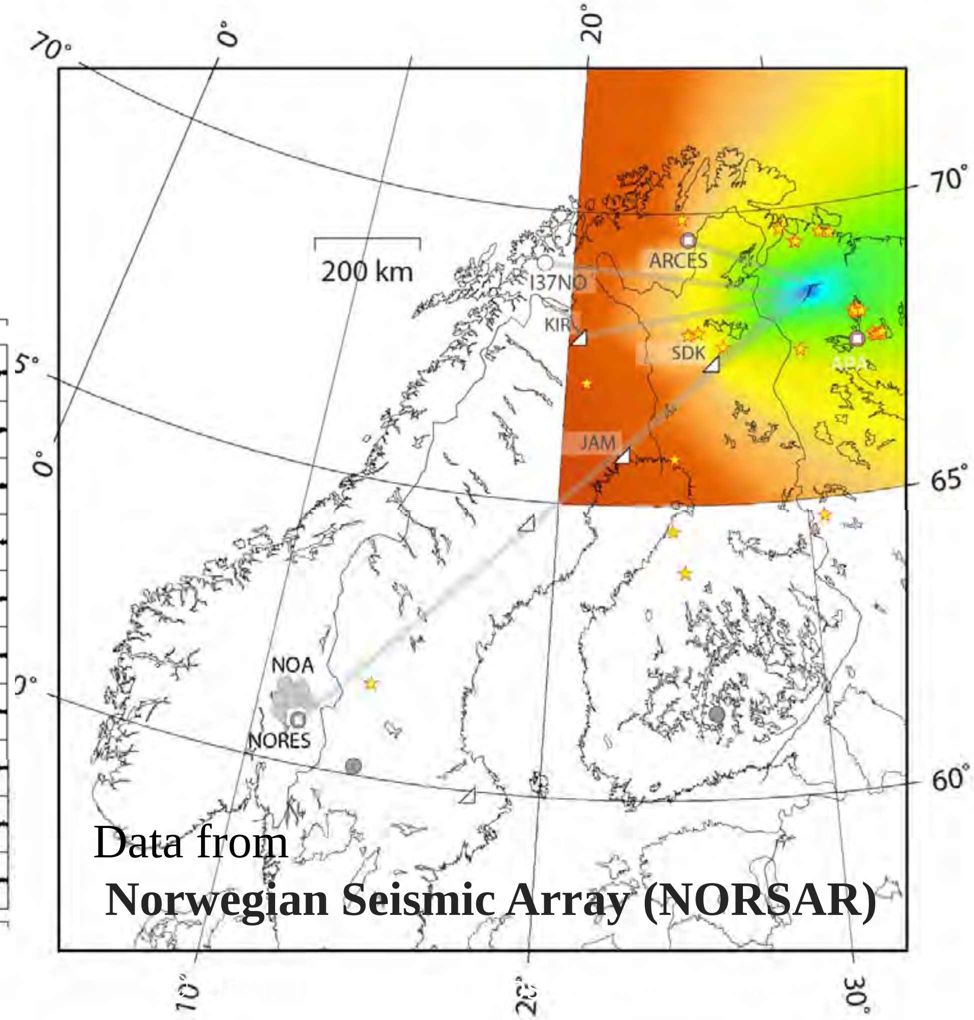
Kola fireball, April 19, 2014

Data from the infrasound stations KIR (Kiruna), JAM (Jämtön) and SDK (Sodankylä)

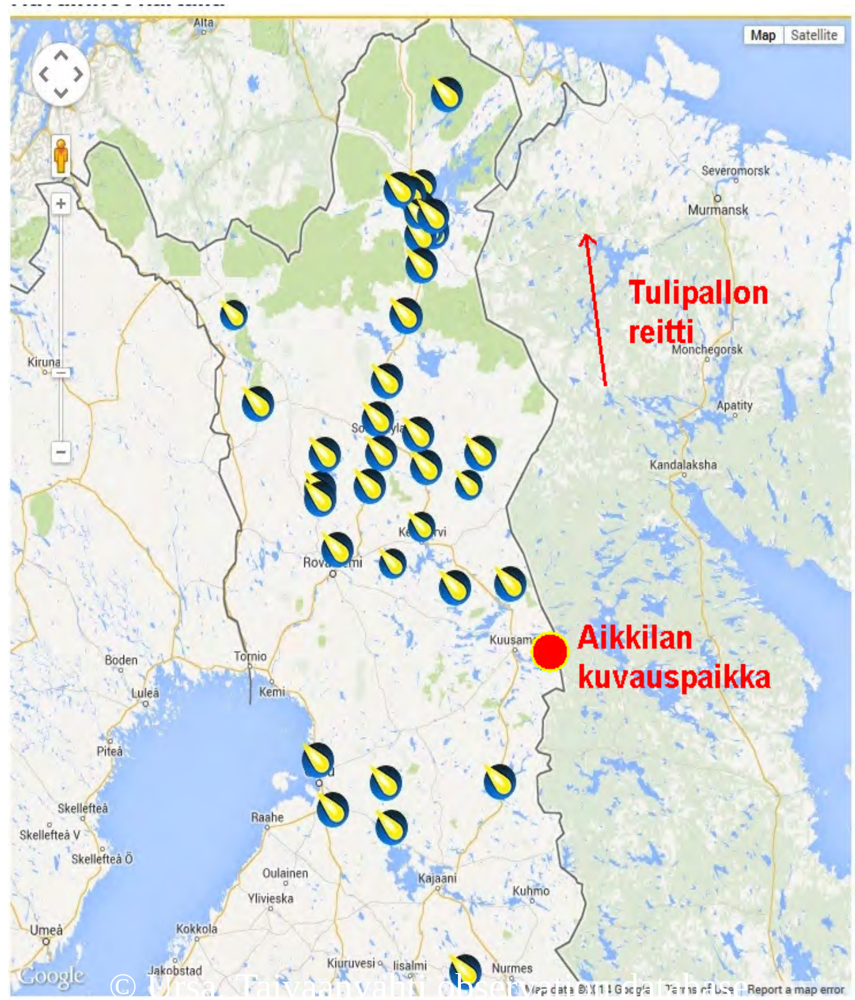




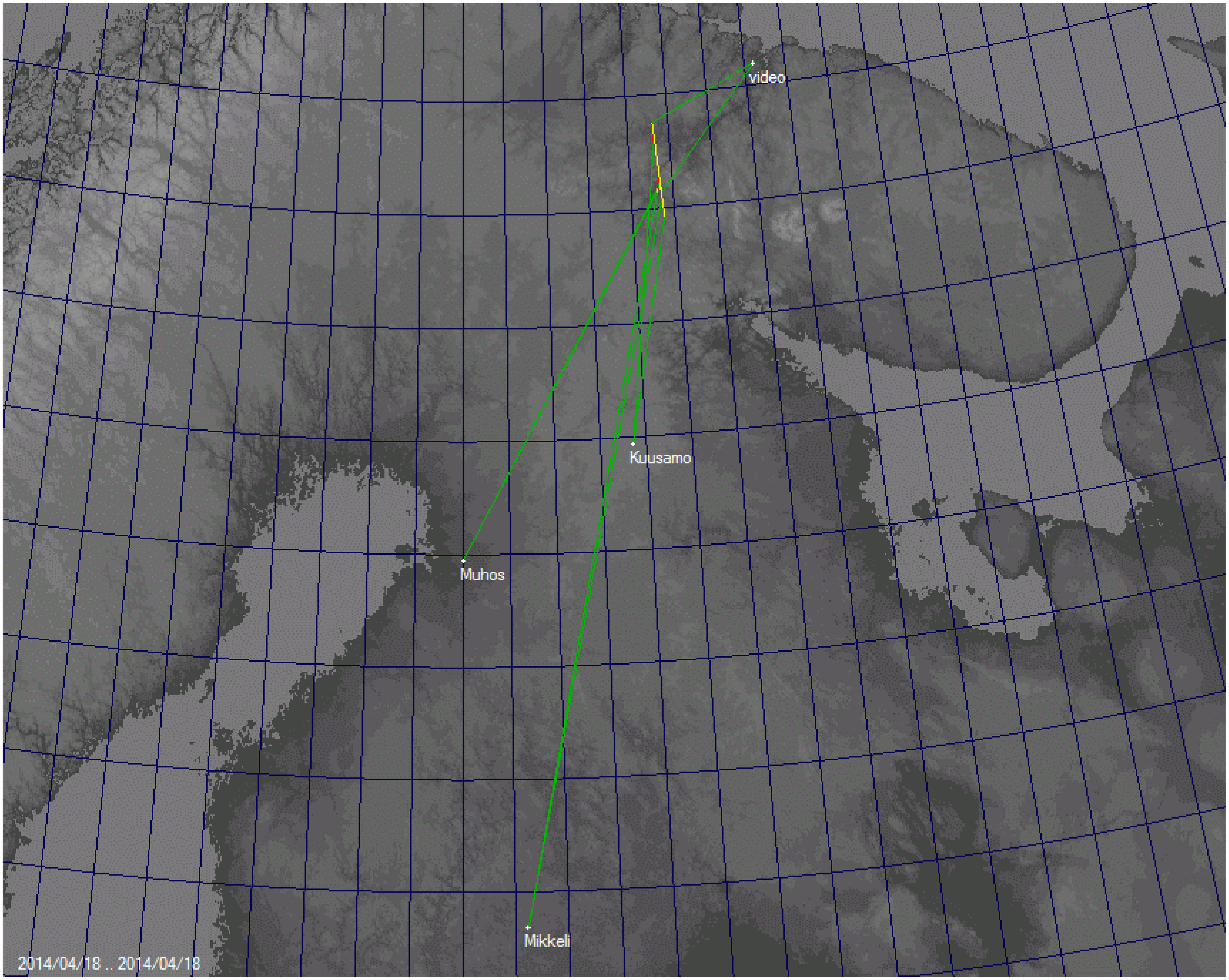
Data from
Norwegian Seismic Array (NORSAR)

Murmansk / Kola fireball, April 19, 2014

- The fireball was very bright and was witnessed in Russia, Finland, and Norway
- Finnish Fireball Network imaged the fireball from Kuusamo, Mikkeli and Muhos sites
- Dash-board video made in Snezhnogorsk



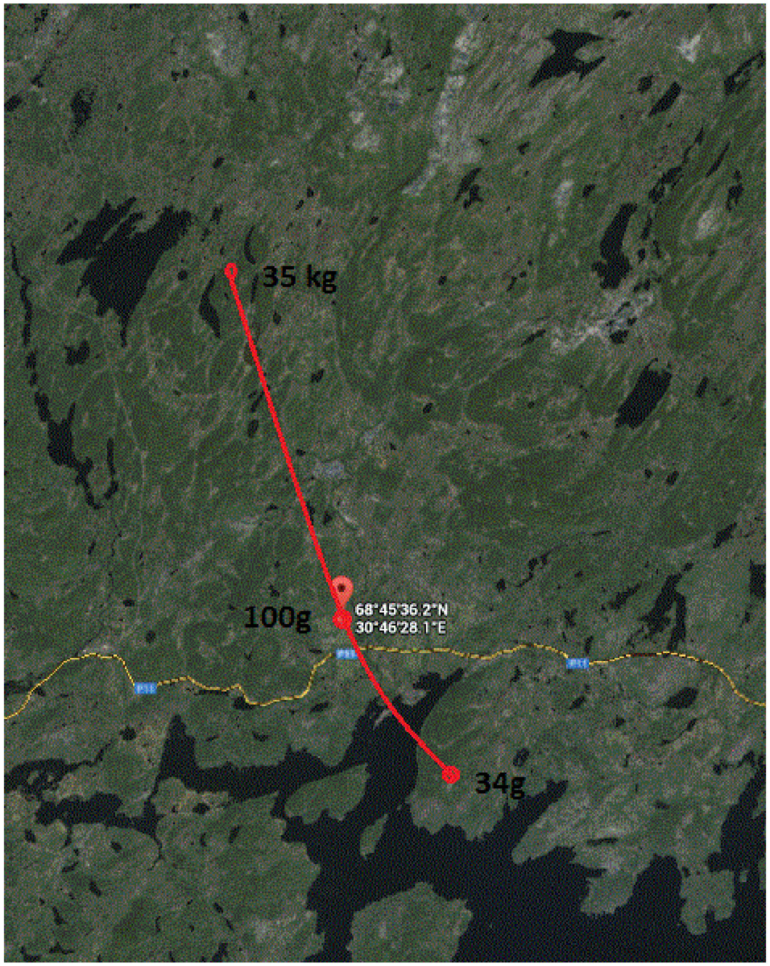
Kola fireball, April 19, 2014

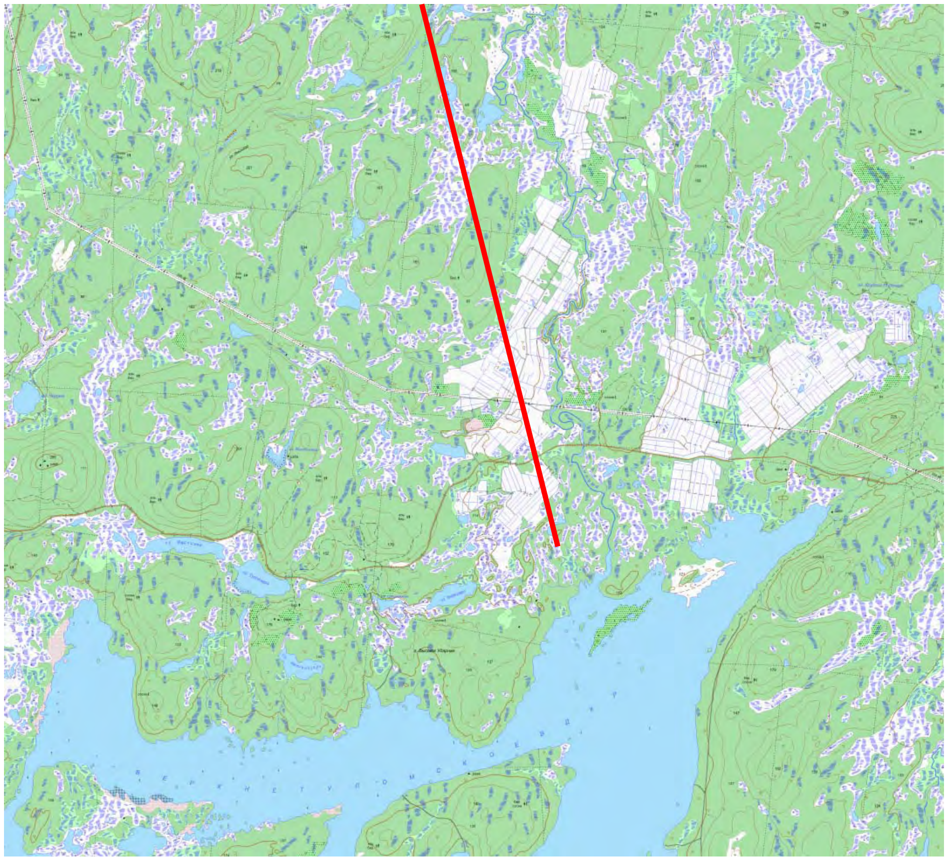


Kola fireball, April 19, 2014

Kola fireball, April 19, 2014

Projection of the fireball track





Visualization of the fireball

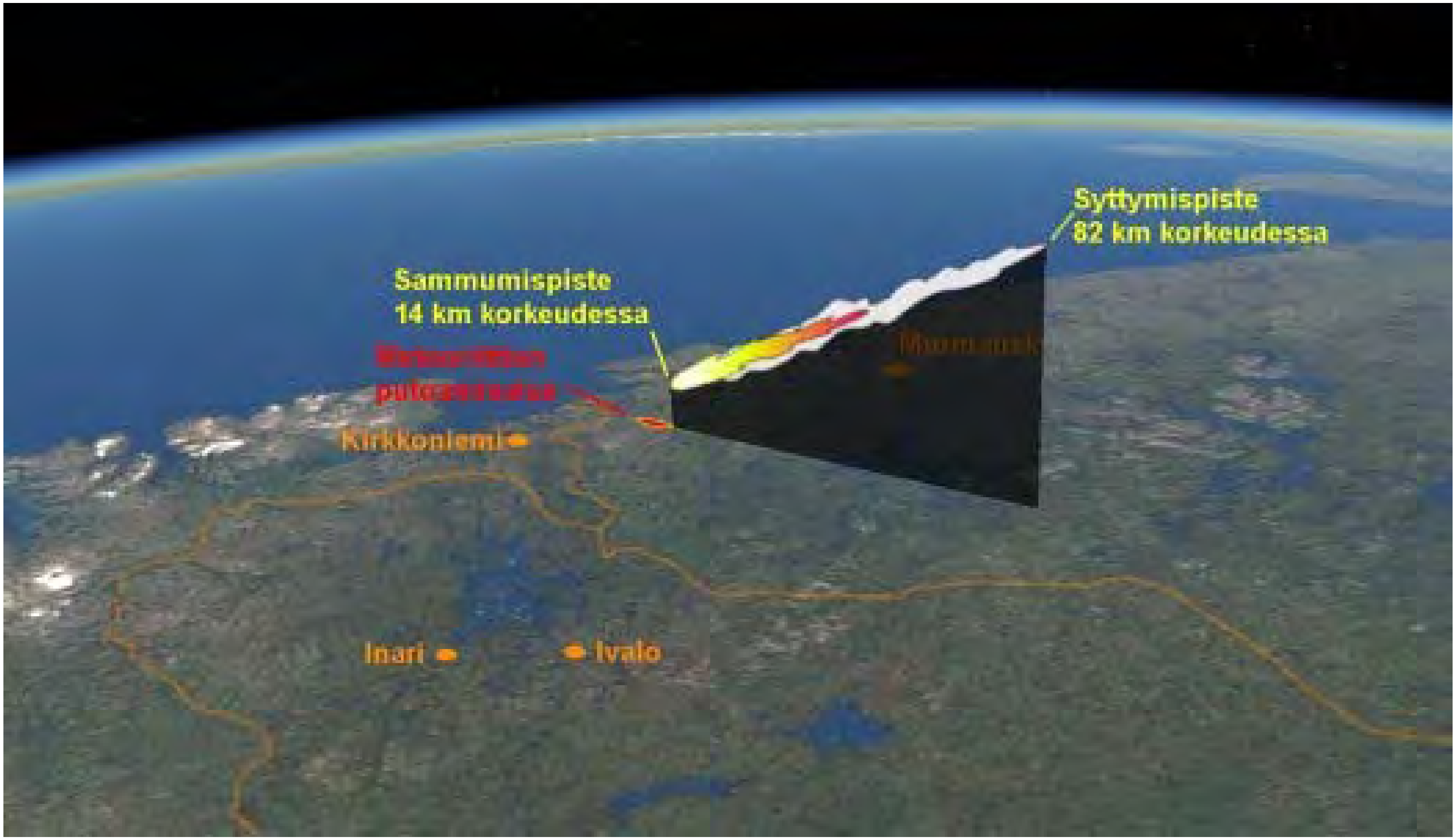
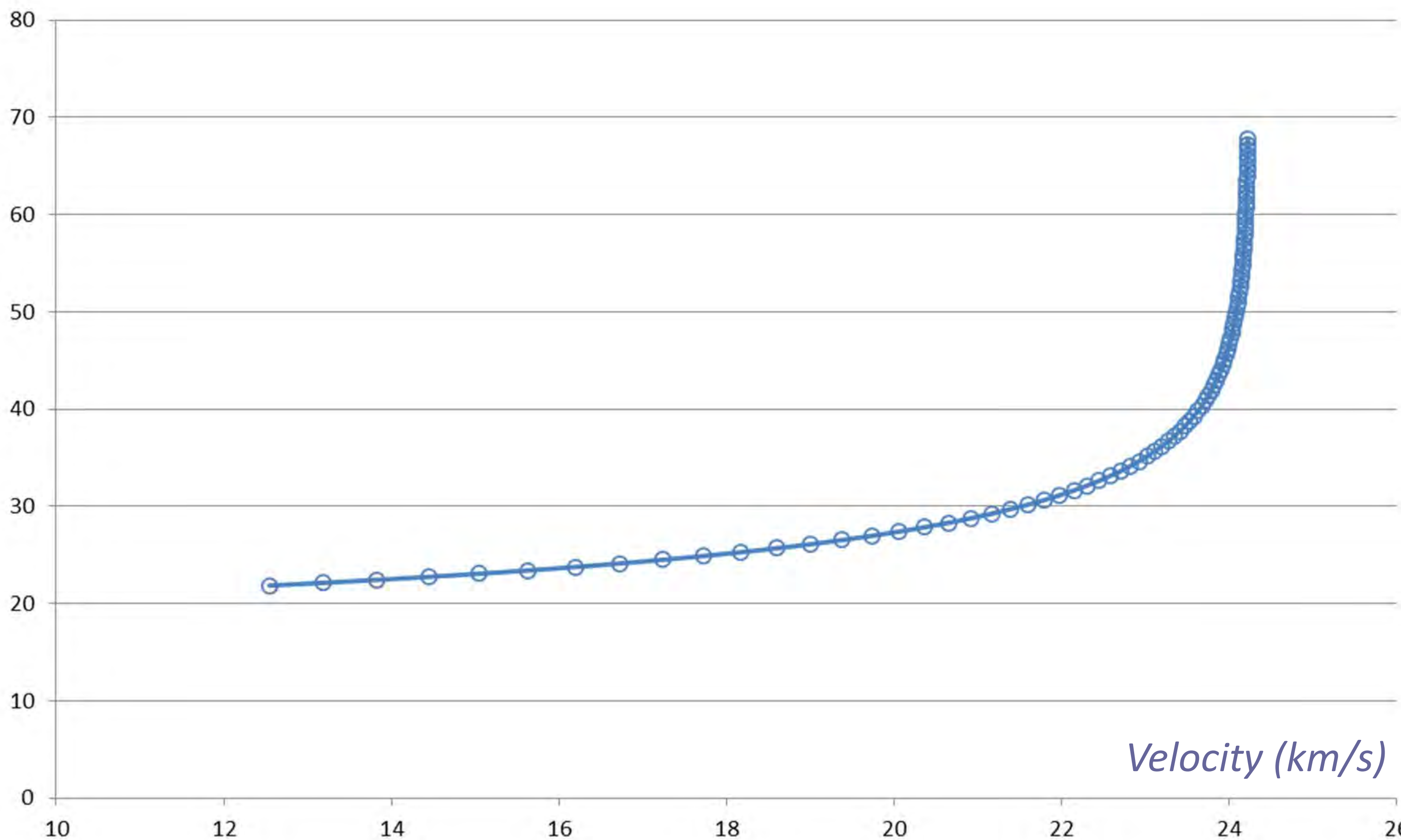


Illustration by Mikko Suominen / “Tähdet ja Avaruus”

Height (km) vs Velocity (km/s)



Fb_entry program, Lyytinen & Gritsevich, 2013

Used parameterisation

$$\alpha = \frac{1}{2} c_d \frac{\rho_0 h_0 S_e}{M_e \sin\gamma}, \quad \beta = (1-\mu)\frac{c_h V_e^2}{2 c_d H^*}, \quad \mu = \log_m s$$

α characterizes the aerobraking efficiency, since it is proportional to the ratio of the mass of the atmospheric column along the trajectory, which has the cross section S_e, to the body's mass

β is proportional to the ratio of the fraction of the kinetic energy of the unit body's mass to the effective destruction enthalpy

μ characterizes the possible role of the meteoroid rotation in the course of the flight

Matching first integrals of dynamical eqs.

- Initial conditions

$y = h/h_0 = \infty$,
$v = V/V_e = 1$,
$m = M/M_e = 1$

$$m(v) = \exp\left(-\beta \frac{1-v^2}{1-\mu}\right)$$

$$y(v) = \ln 2\alpha + \beta - \ln(\overline{E}i(\beta) - \overline{E}i(\beta v^2))$$

where by definition: $$\overline{\mathrm{Ei}}(x) = \int_{-\infty}^{x} \frac{e^z dz}{z}$$

Gritsevich, 2009

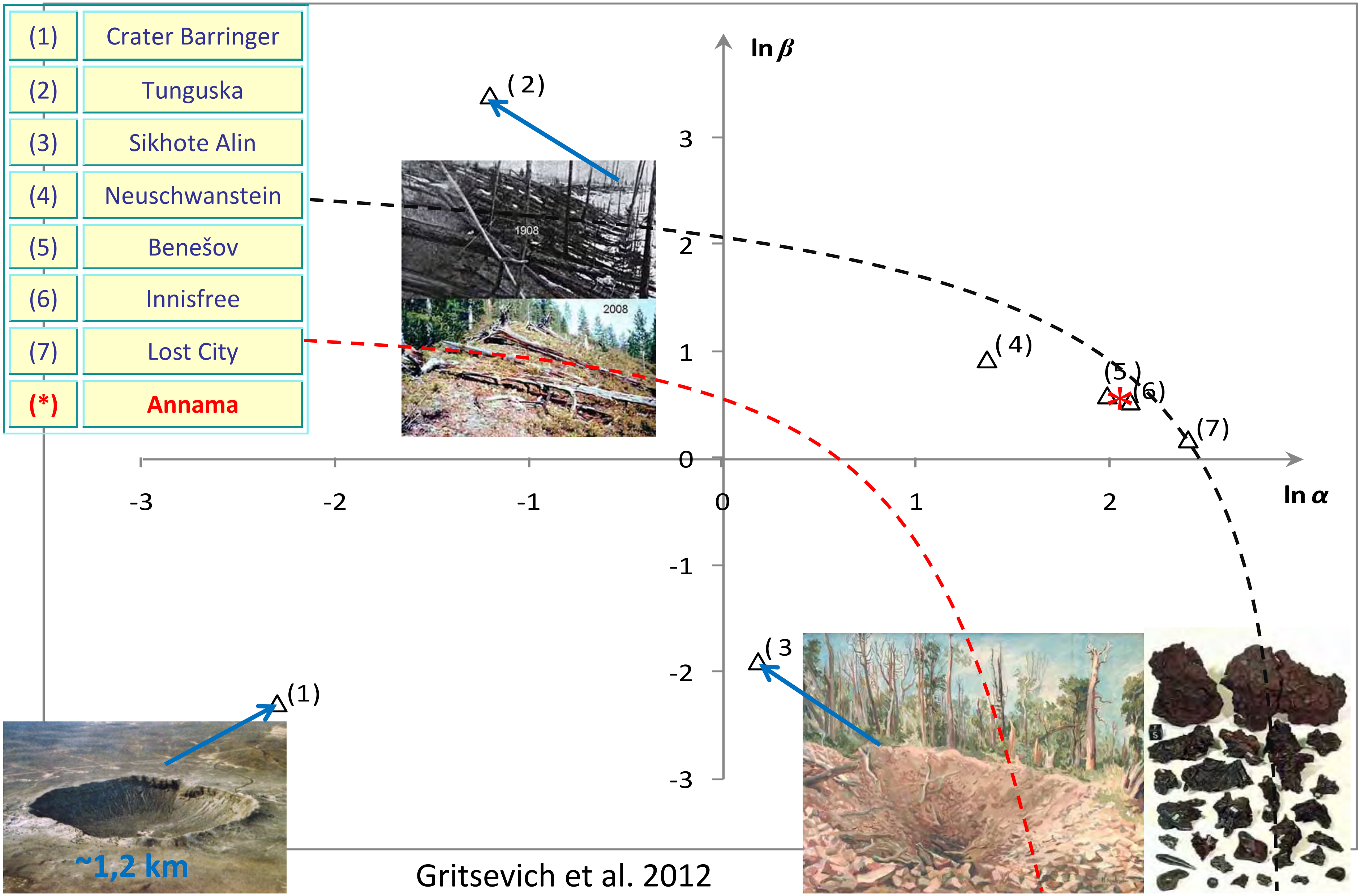
Results of calculations

V*e*, km/s	**γ**	**α**	**β**	$\mathbf{M_e}$	$\mathbf{M_t}$
24,23	33,7°	8,33	1,61	476 kg	13,8 kg

Fit well to the other meteorite falls

fireball	V*e*, km/s	sinγ	α	β
Annama	**24,23**	**0,55**	**8,33**	**1,61**
Lost City	14,15	0,61	11,11	1,16
Innisfree	14,54	0,93	8,25	1,70
Neuschwanstein	20,95	0,76	3,92	2,57

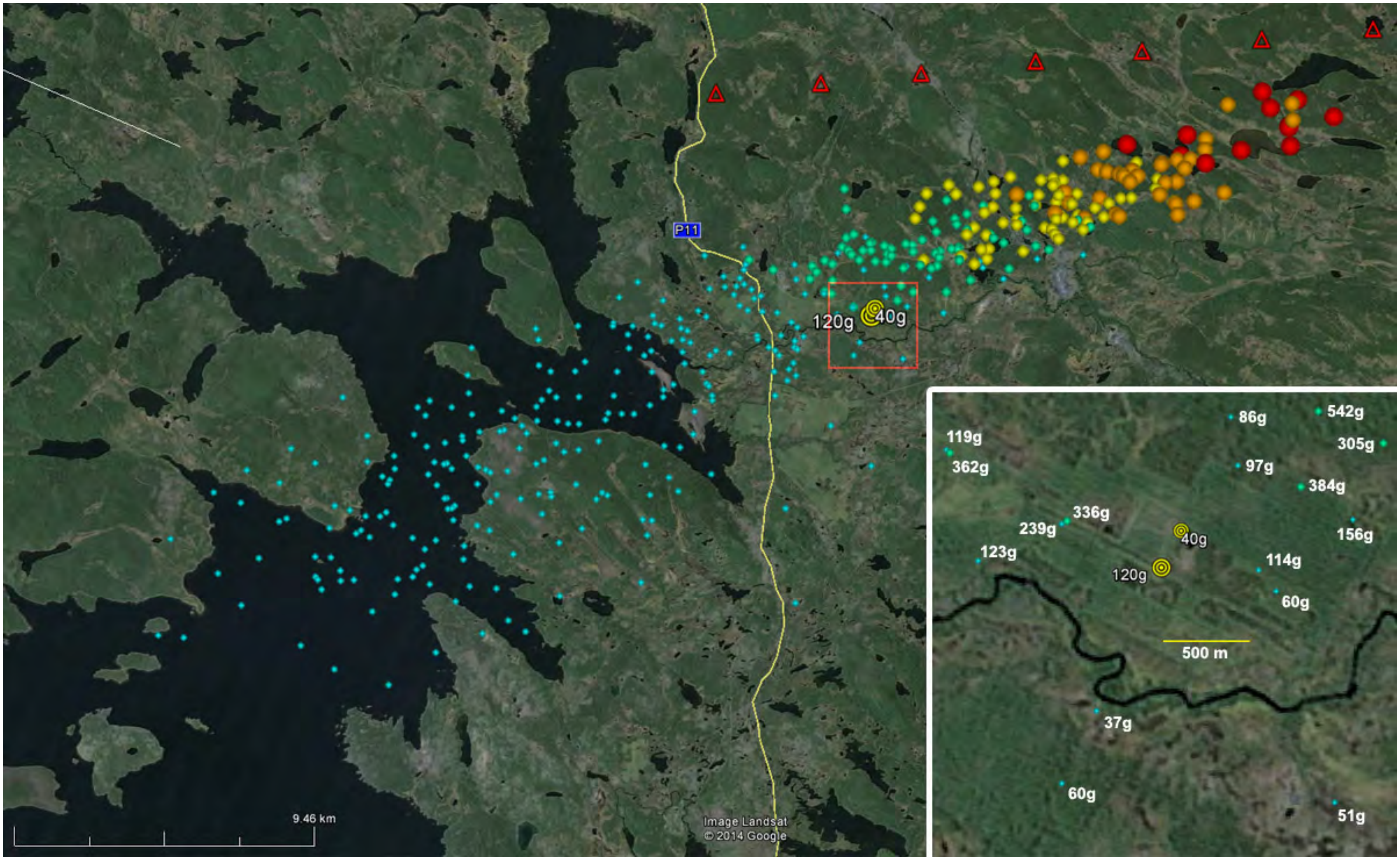
Fit well to meteorite /crater production criteria



Gritsevich et al. 2012

Numerical simulations

North →



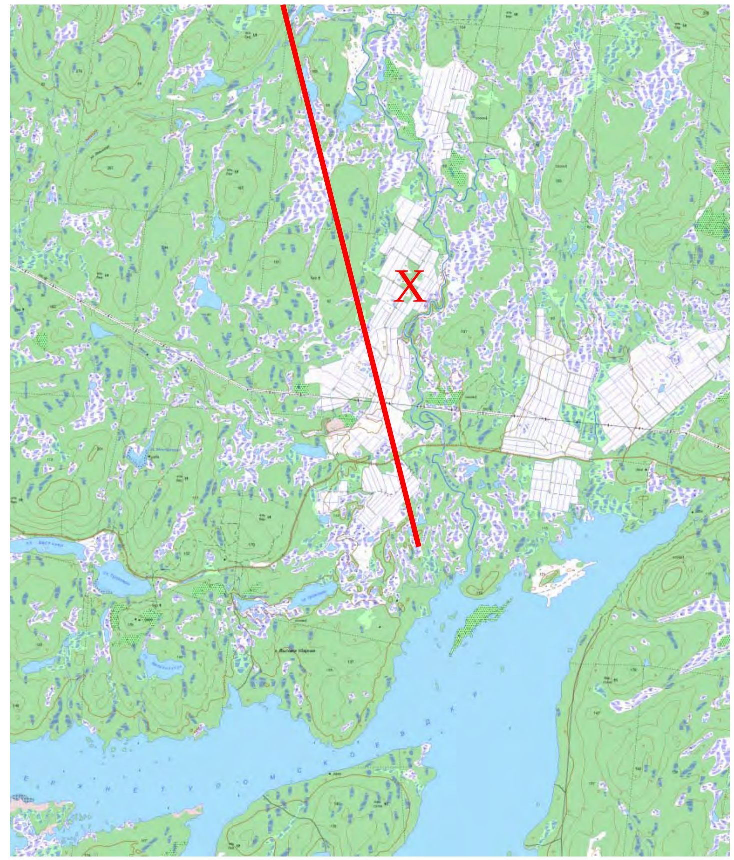
Color code of simulated fragments: blue are <0.3 kg, green 0.3 - 1 kg, yellow 1 - 3 kg, orange 3 - 10 kg, red >10 kg

5 days meteorite expedition

120.35 g

May, 29 first meteorite recovered ☺

The second meteorite found on May, 30



Annama meteorite

- Analysis done in June at the Czech Geological Survey &Univ. Helsinki
- H5 ordinary chondrite
- S2 shock level
- W0 weathering degree
- Bulk density 3,5 g/cm^3
- Grain density 3,8 g/cm^3
- Porosity 5 %

Further recovery campaigns

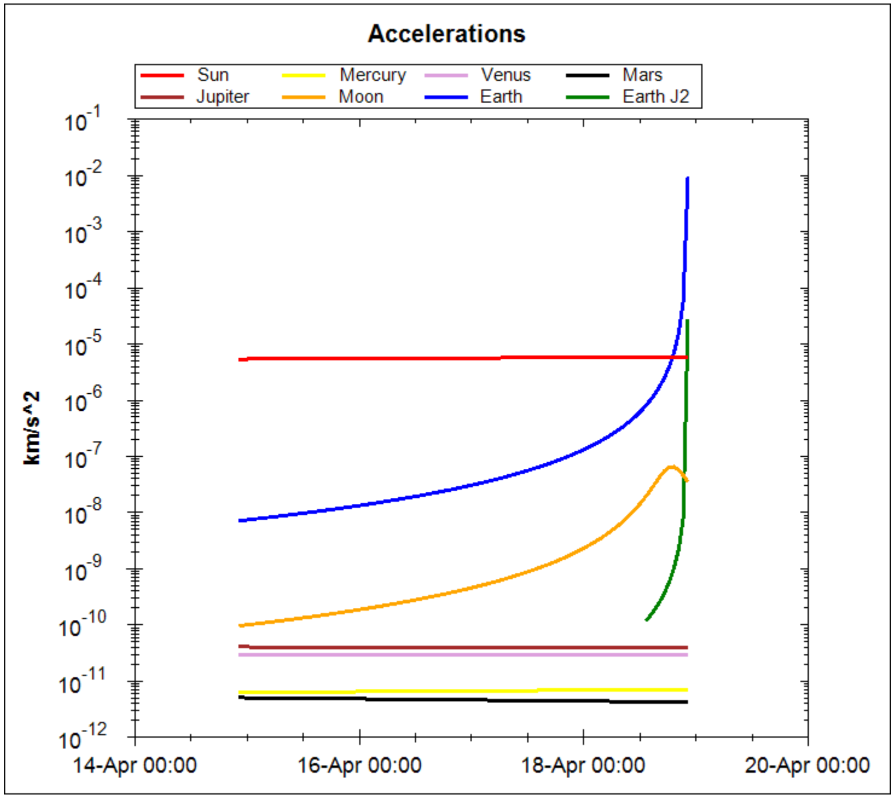
- Next campaign is considered in October 2014 (TBC)
- Landing area is surrounded by wetlands
- Recovery of remaining fragments is difficult..

Orbit determination

The orbit was determined by numerical integration of the equations of motion:

$$\ddot{\bar{r}} = -\frac{GM_{sun}}{r^3}\bar{r} + \ddot{\bar{r}}_{Earth}(r,t) +$$
$$\ddot{\bar{r}}_{Earth\_J2}(C_{2m}, S_{2m}, r, t) + \ddot{\bar{r}}_{Moon}(\bar{r},t) +$$
$$+\sum \ddot{\bar{r}}_{planets}(\bar{r},t) + \ddot{\bar{r}}_{atm}(\bar{r},t).$$

The equations were integrated back in time up to the intersection of the meteoroid’s orbit with the Hill sphere of the Earth



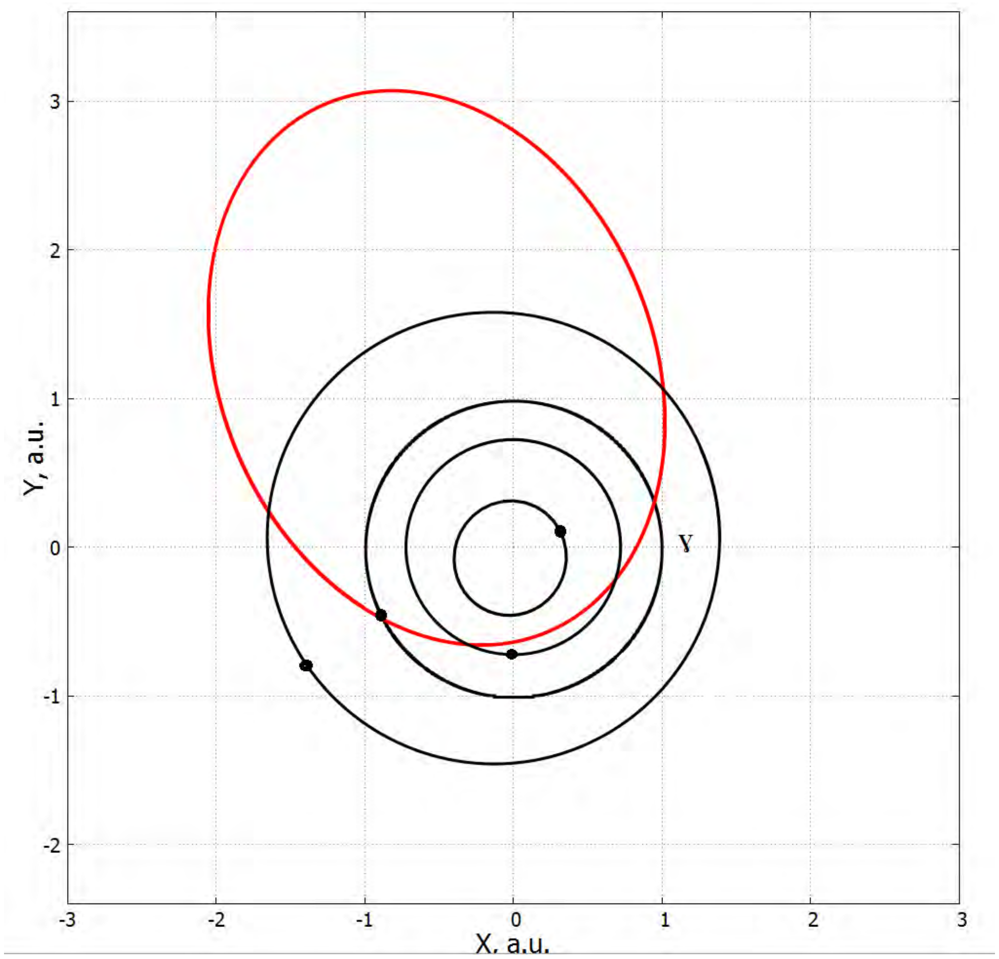
Preatmospheric accelerations in motion of the meteoroid

Dmitriev et al. 2014

Orbital parameters

Name	Annama 20140418	RMS
Epoch	2014-04-18T22:14:30	
B, deg	67.932	
L, deg	30.762	
H, km	83.87	
Az, deg	176.1	±0.20
El, deg	34.3	±0.40
V, km/s	24.23	±0.50
Epoch	2014-04-14T22:14:30	
a, AU	1.99	±0.12
e	0.69	±0.02
i, deg	14.65	±0.46
Ω, deg	28.611	±0.001
ω, deg	264.77	±0.55
M, deg	342.10	±1.81

Apollo-type orbit of the meteoroid



Search for similar orbits

Meteorite	*A, a.u.*	*e*	*I,°*	*Ω,°*	*ω,°*	*Tisserand (T)*	*Dsh*
Annama 20140418	**1.99±0.12**	**0.69±0.02**	**14.65±0.46**	**28.611±0.001**	**264.77±0.55**	**3.49±0.20**	**±0.01**
Meteorite	*A, a.u.*	*e*	*I,°*	*Ω,°*	*ω,°*	*ΔT*	*Dsh*
Grimsby (Canada, 2009)	2.04000	0.51800	28.070	159.865	182.956	0.011	inf
Apollo asteroids	*A, a.u.*	*e*	*I,°*	*Ω,°*	*ω,°*	*ΔT*	*Dsh*
(2005 NE7)	2.04703	0.64736	9.520	80.452	306.861	0.0001	0.089
(2013 LY28)	2.02037	0.65922	15.417	262.677	82.827	0.006	0.060
(2012 HJ8)	1.91545	0.72116	13.691	126.024	334.138	0.048	0.063
(2012 TT5)	2.07631	0.65506	15.225	12.369	272.254	0.058	0.200
(2006 EV52)	2.01650	0.70754	15.937	168.557	167.089	0.058	0.246
(2004 HF12)	2.13400	0.65080	13.363	22.643	104.974	0.100	0.104
(1996 TC1)	1.86751	0.72007	14.531	5.012	258.813	0.106	0.223
(2006 WK130)	2.10739	0.68226	13.800	72.162	276.955	0.112	0.167

Conclusions

- 22nd meteorite with known orbit
- Freshly recovered (within 6 weeks)
- Successful trajectory reconstruction & meteorite recovery (only about few hundred meters from the nominal landing site prediction)
- Successful joint international effort
- Similar ‘scaling’ parameters as for the Innisfree meteorite
- H5 ordinary chondrite, S2W0
- Known physical properties (bulk and grain density, porosity, magnetic susceptibility)