# Automatic fireball data modeling

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# Introduction

- European Fireball Network: automatic fireball observations above Central Europe
- the main instrument is the Digital Autonomous Fireball Observatory
- there are 14 stations in Czechia, four in Slovakia, one in Austria
- mechanical properties of meteoroids, spectra, statistics of impacts
- when the meteoroid entering our atmosphere is large and slow enough, it may produce meteorites
- it's a very cheap sampling of material from the main asteroid belt


EN191120 from Churáňov station

# European Fireball Network

Q what data we obtain?

- clear nights: we observe lightcurves, measure dynamics (height vs. time and length vs. time), spectra, video recordings, high resolution videos (meteoroid fragmentation)
- any weather: radiometric lightcurves (very sensitive photomultiplier)

# manual data modeling

- Firmodel program – semiempirical fragmentation model used to fit the data (Borovička et al. 2020)
- meteoroid flight through the atmosphere described by standard equations of motion, ablation and radiation + fragmentation
- data used: radiometric and photometric lightcurve, length and height
- trial and error approach to modeling
- takes a long time & occupies much of a workforce
- the solutions may not be unique
- difficult to estimate uncertainties

Q can we find an automatic approach?

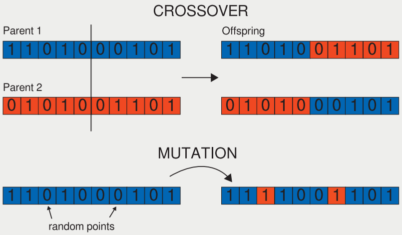
# FirMpik

- Firmodel + MPIKAIA = FirMpik
- Firmodel has been adapted for non-interactive use
- MPIKAIA (Metcalfe & Charbonneau 2003): genetic algorithm subroutine PIKAIA (Charbonneau 1995, 2002) parallelized with Message Pasing Interface (MPI)
- robust and speedy algorithm for global optimization
- usually finds the global extreme, does not get stuck in a local extreme
- allows vast parametric space exploration

# genetic algorithm

- algorithm inspired by simplified evolution rules
- problem parameter values (fenotype) are encoded to a genotype, to which we apply three basic rules

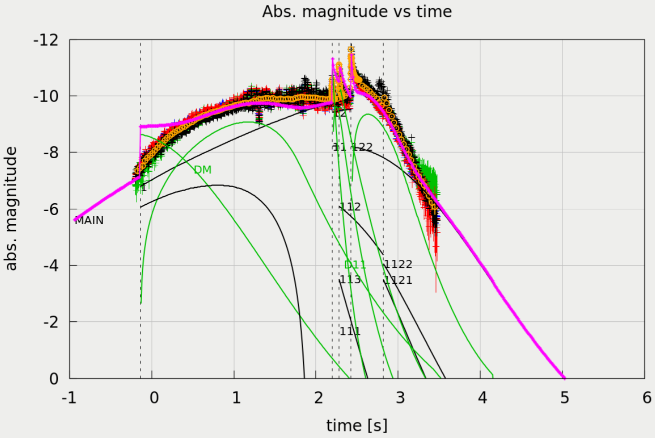
1. selection (only the fittest survive)
2. inheritance (offspring take after their parents)
3. variation (random mutations of the genotype)



# genetic algorithm

- we start with 50–100 random solutions (individuals), for each we calculate fitness function $1/\chi^2$ (or some other) $\leftarrow$ *this is the expensive part*
- next we create pairs from the individuals (based on their fitness) and mix their genomes (crossover)
- we apply mutations (random changes in the genome)
- last we replace an old generation with a new one and calculate their fitness
- we proceed until we reach some value of $\chi^2$ or number of generations (couple hundred)

# $1^{st}$ generation random solution



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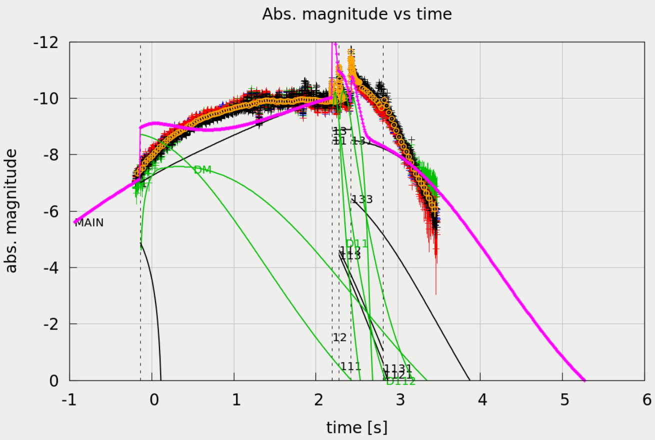

Abs. magnitude vs time
abs. magnitude
time [s]
-12
-10
-8
-6
-4
-2
0
-1
0
1
2
3
4
5
6
MAIN
DM
13
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D11
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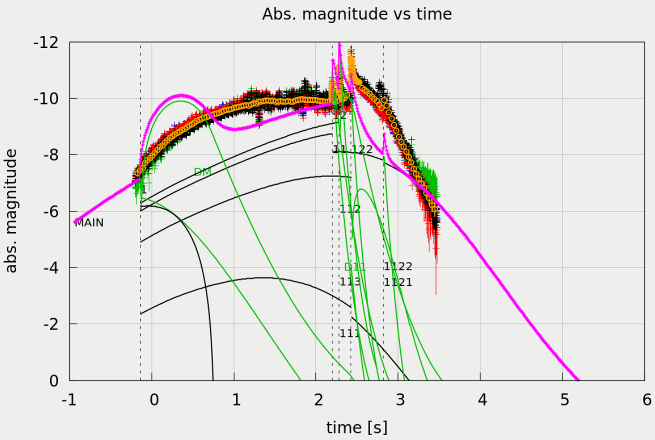
111
1131
1121
D112

## . . . one more



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3
4
5
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MAIN
DM
11122
112
D11
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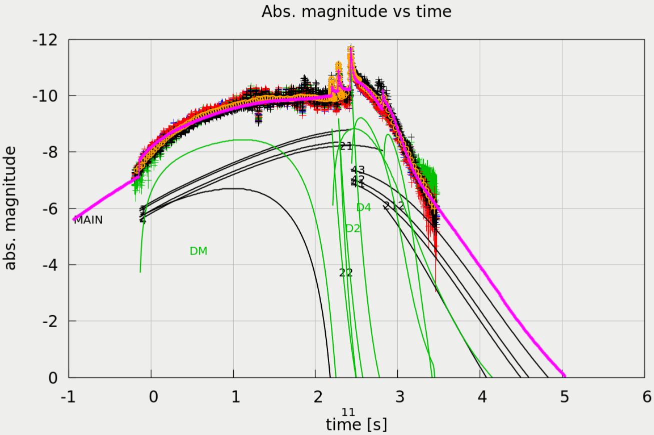
1122
1121
111

# $1^{st}$ solution, $\chi^2 = 18.6$



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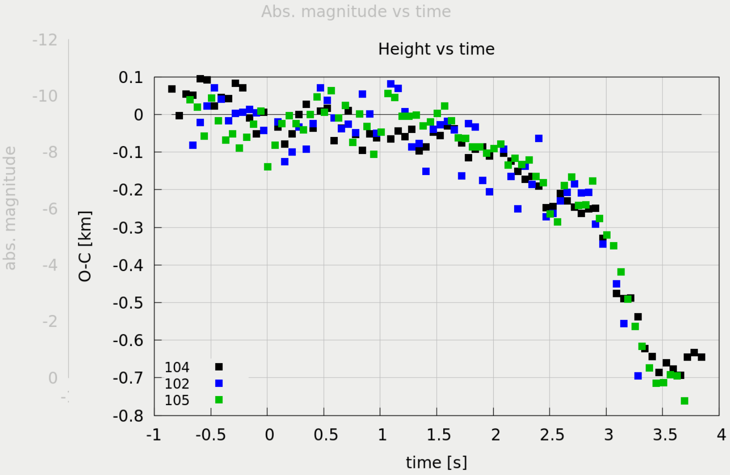

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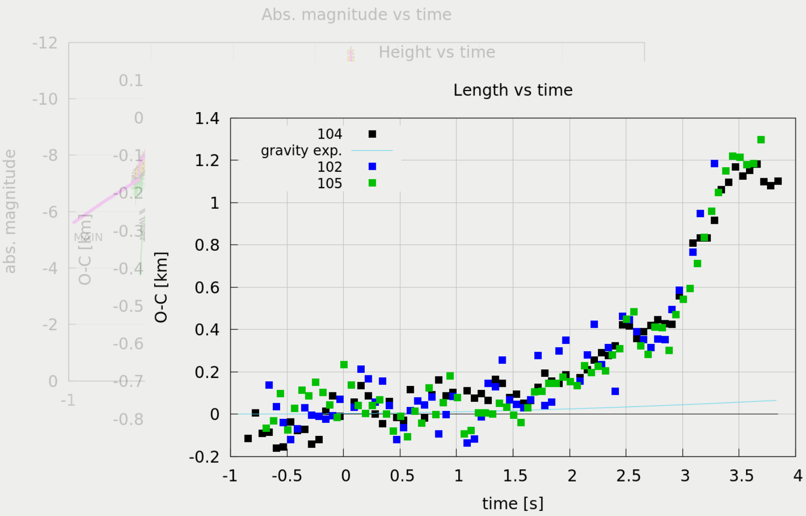
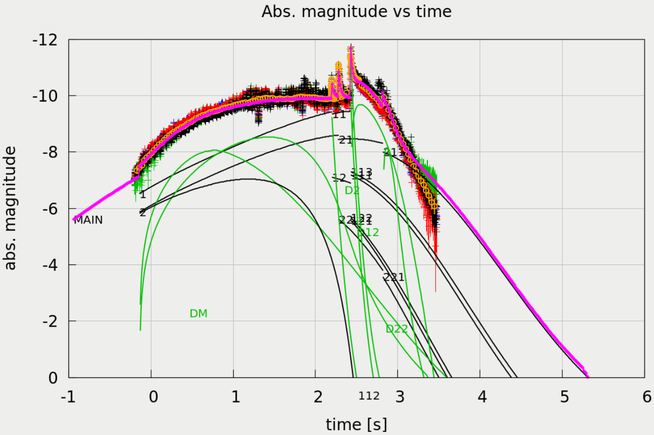


# $2^{nd}$ solution, $\chi^2 = 17.0$



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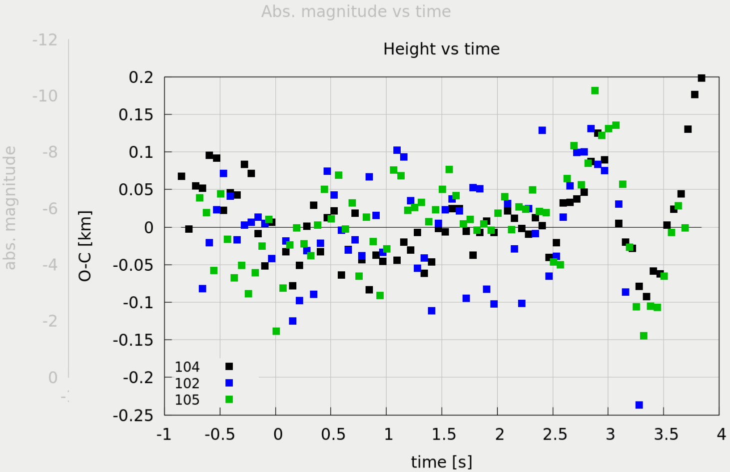

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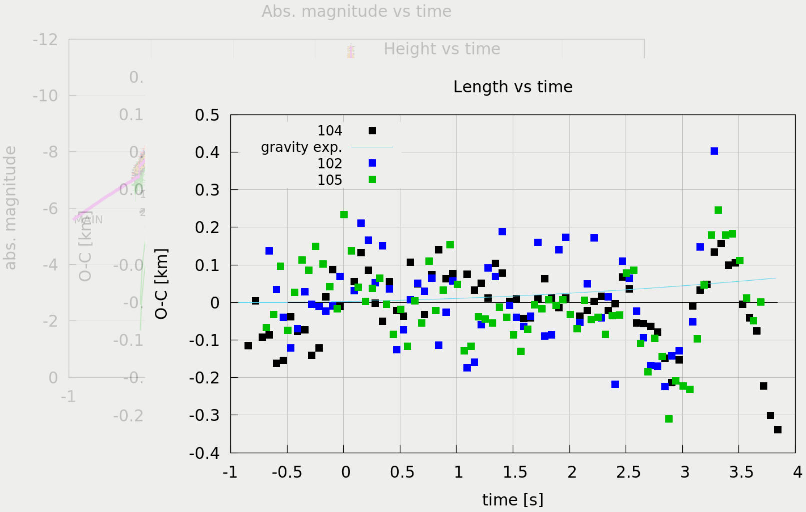
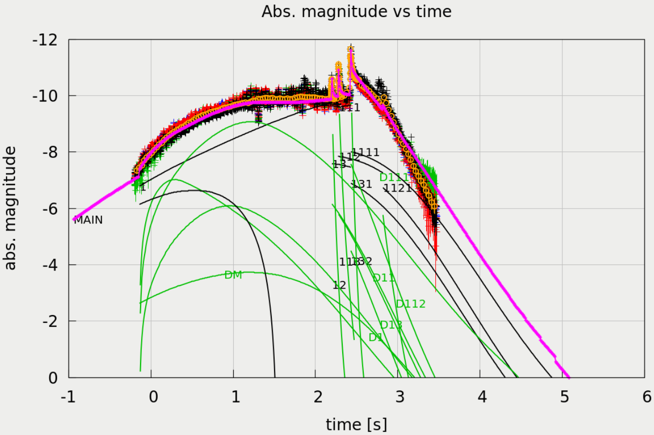


# $3^{rd}$ solution, $\chi^2 = 16.4$



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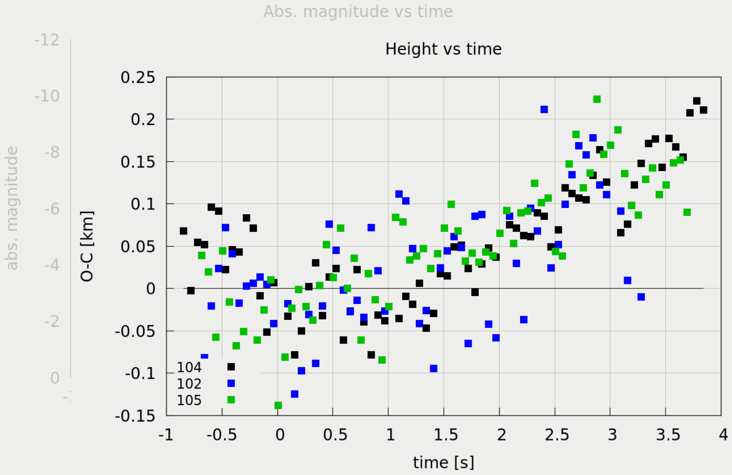

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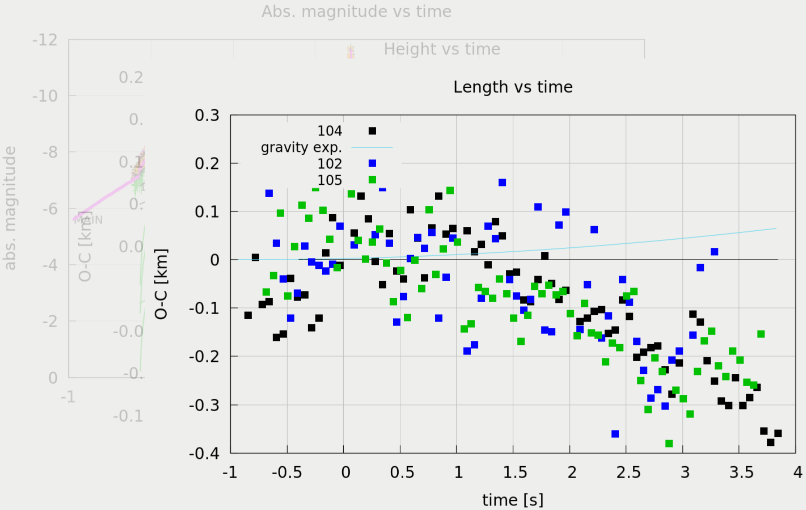
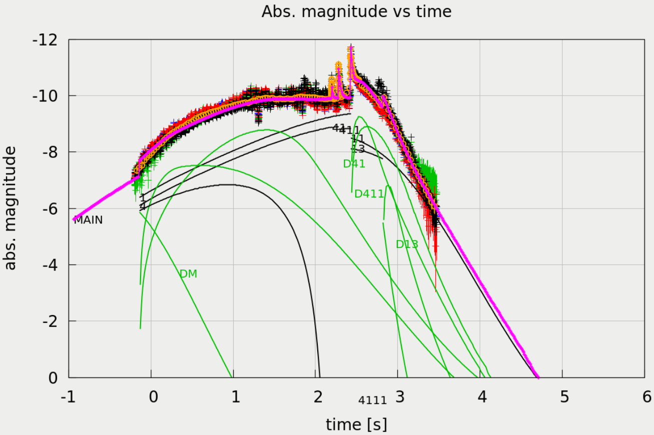


# manual solution, $\chi^2 = 16.2$



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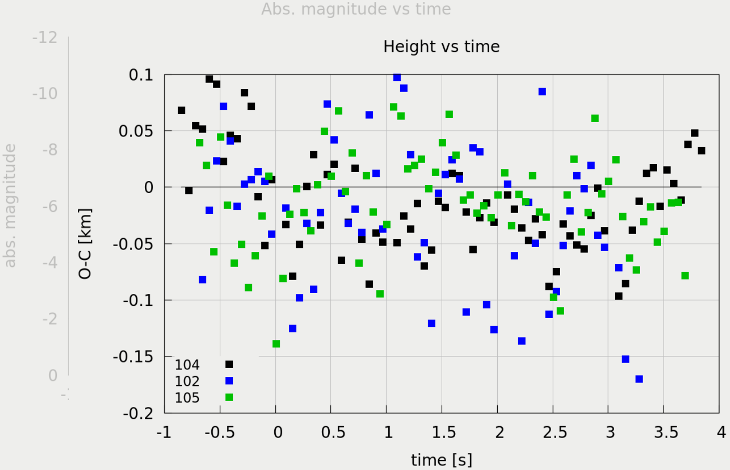

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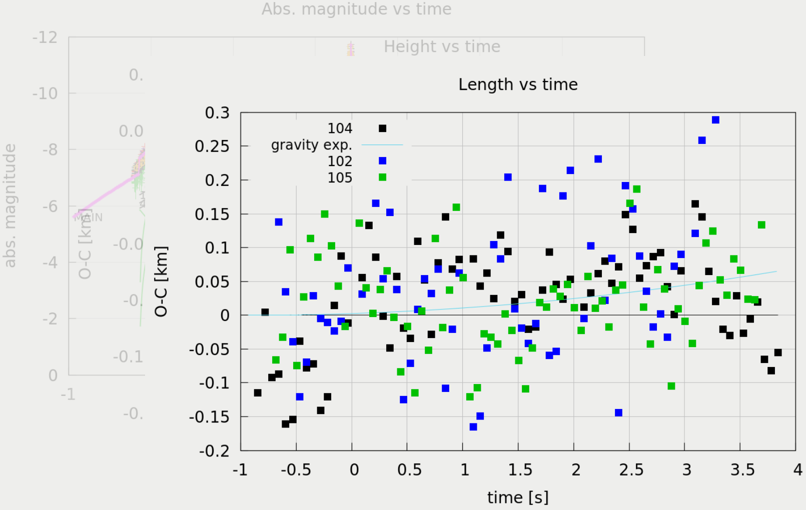

# comparison

FirMpik solutions

- total 15–17 fragments
- initially 4–5 fragments (1–3 eroding)
- their mass (1.5–4.2, 1.15–1.95, 0.12–1.6, 0.2–1.0; 1.17) kg

Manual solution

- total 12 fragments
- initially 4 fragments (2 eroding)
- their mass (2.6, 1.5, 0.5, 1.88) kg

# further work

- investigate the distribution of the solution parameters (fragment numbers, masses, erosion parameters, etc.)
- that should also give us uncertainties of the solution
- blind test on several distinct fireballs to check robustness of the method
- apply this method to a larger dataset of fireball observations (mechanical strength, mass distribution of fragments, etc.)

## takeaway

- we developed FirMpik program for automatic modeling of fireball data
- it is based on parallelized genetic algorithm
- further tests should prove its robustness and reproducibility of the results
- it should serve for faster analysis of large fireball datasets

# references


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