Analysis of different methods used to compute meteors orbits

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Introduction

Guzet station

- ≠ measured and theoretic orbits (e.g. Draconids 2011, Leonids 1999)

Technical challenge: CABERNET

- 3 cameras, FOV = 40°x26°
- Spatial resolution 0.01°/pix
- Temporal resolution: 5-10 ms (electronic shutter at 100-200Hz)

→ **Need for a precise velocity**

→ **Reduction process?**

Usual methods

- Ceplecha, 1987

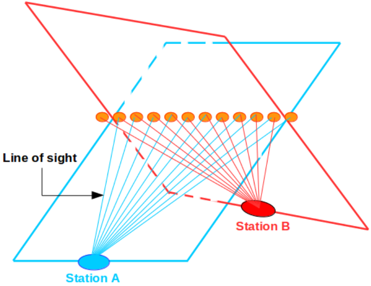
  Geometric, Dynamic, orbital, and photometric data on meteoroids from photographic fireball networks

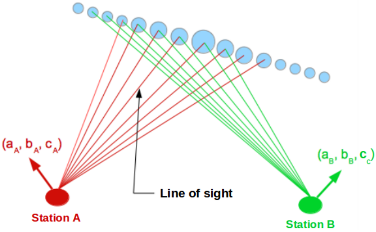
- Borovička, 1990

  The comparison of two methods of determining meteor trajectories from photographs

- Gural, 2012

  A new method of meteor trajectory determination applied to multiple unsynchronized video cameras

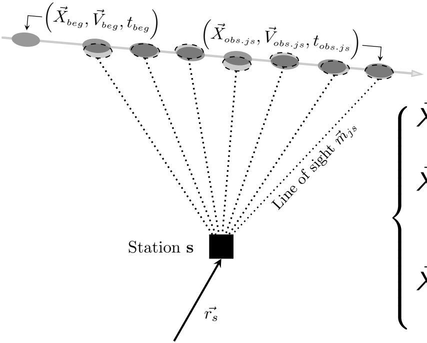




Usual methods

Multi-parameter fitting (MPF):

- 3 deceleration models (constant speed, linear or exponential deceleration)



$$
\begin{cases}
\vec{X} = \vec{X_{beg}} + \vec{V_{beg}} * t \\
\vec{X} = \vec{X_{beg}} + (\left\|\vec{V_{beg}}\right\| * t - a_1 * t^2) * \dfrac{\vec{V_{beg}}}{\left\|\vec{V_{beg}}\right\|} \\
\vec{X} = \vec{X_{beg}} + (\left\|\vec{V_{beg}}\right\| * t - a_1 * e^{a_2 * t}) * \dfrac{\vec{V_{beg}}}{\left\|\vec{V_{beg}}\right\|}
\end{cases}
$$

→ Complex optimization problem

Optimization methods

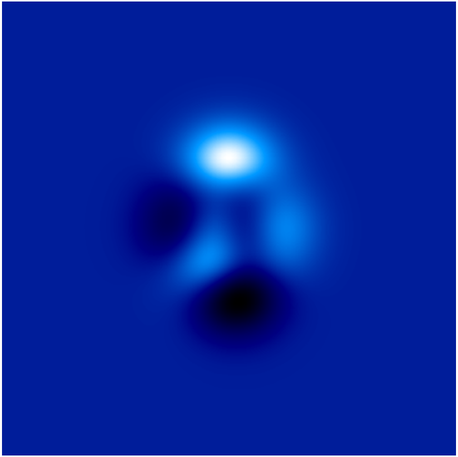
Techniques tested:

local:
- Analytical least squares
- Davidon-Fletcher-Powell
- Nelder-Mead (NM)
- Conjugate gradient

~ global:
- Simulated annealing + MCMC
- Simulated annealing + NM
- Particle Swarm Optimization (PSO)

Best strategy : PSO + LS

- $\nearrow$ **chances to find a global min.**
- **Large search space**



Example of the PSO

Optimization methods

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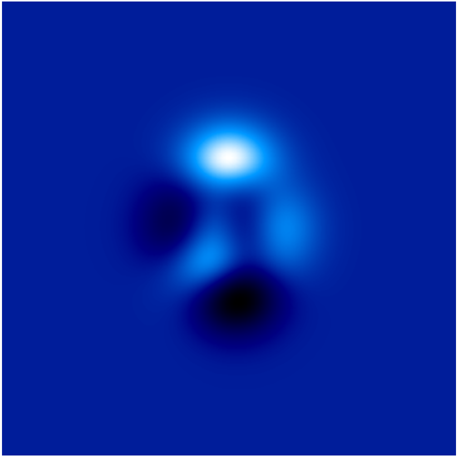
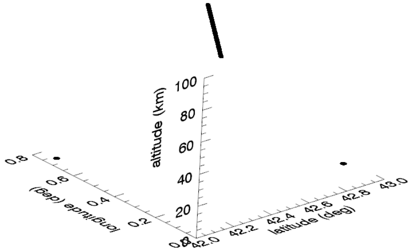
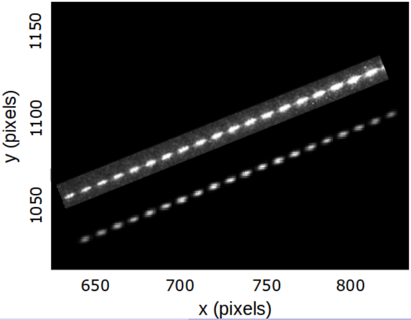


Example of the PSO

Simulations: 'fakeors' (G. Barentsen)





Validation: ∼ realistic fakeors

- Q=60°, $V_\infty = 30\ km.s^{-1}$
- $\Delta t = 5\ ms$, error ϵ

Following the propagation models:

- Constant velocity
- Exponential deceleration

Disintegration model -AFM-:

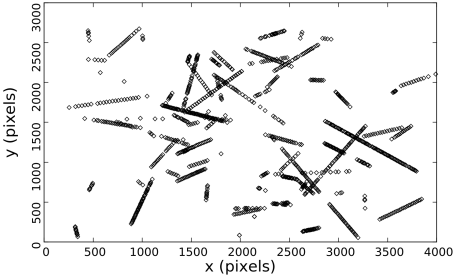
- Borovička et al. (2007)
- No fragmentation

→ error ϵ for CABERNET ?

Error on the centroids location

Estimate:

- 2D gaussian fit (classic/MoG)
  $\rightarrow$ formal errors $[\sigma_f]$
- χ^2 goodness of fit test (signif. 5%)
  $\rightarrow$ if success: estimate of the scaling variance σ
- Final uncertainty $\epsilon = \sigma * [\sigma_f]$



Centroids recorded by the Pic du Midi station which have passed the χ^2 goodness of fit test

CABERNET:

1200 centroids over the whole FOV $\rightarrow$ $\epsilon_x \sim \epsilon_y < 0.09$ pix $\sim 3''$

Accuracy on the velocity determination

Trajectory:

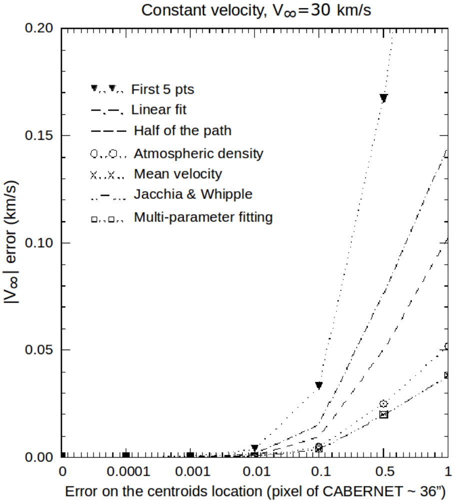
- Ceplecha (1987), Borovička (1990)

Velocity:

- Assuming no deceleration
  - Mean velocity, linear fit
- With deceleration
  - Atmospheric density (MSISE-90)
    $V(t)^2 = V_\infty^2 + K\rho(t)$
  - Jacchia & Whipple (J&W, 1961)
    $L(t) = L_0 + V_\infty t + Ce^{(Kt)}$

Trajectory & velocity:

- Multi-parameter fitting (MPF)



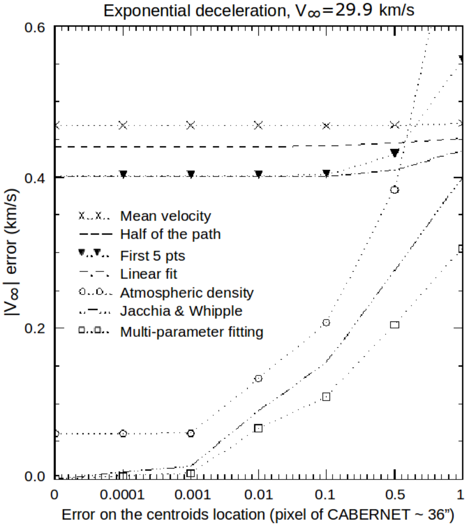
Accuracy on the velocity determination

Constant velocity:

- Mean $V \sim$ J&W $\sim$ MPF only for Q=60°
- MPF: accuracy « 1% on $\vec{V_\infty}$ for CABERNET

Exponential deceleration:

- Ignoring deceleration → very inaccurate
- MPF best solution, accuracy $\sim$ 1% on $\vec{V_\infty}$ for $\epsilon = 0.1$ pix

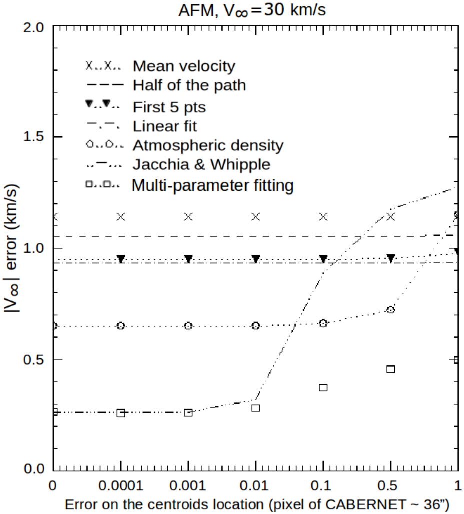


Accuracy on the velocity determination

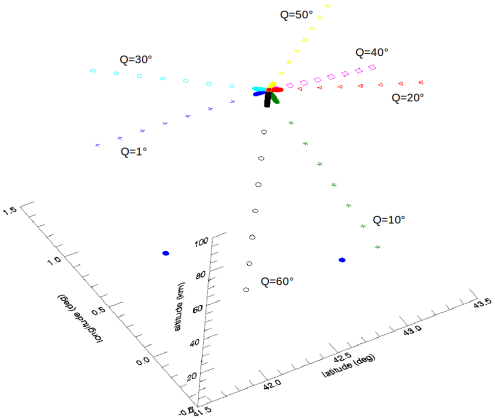
Disintegration model:

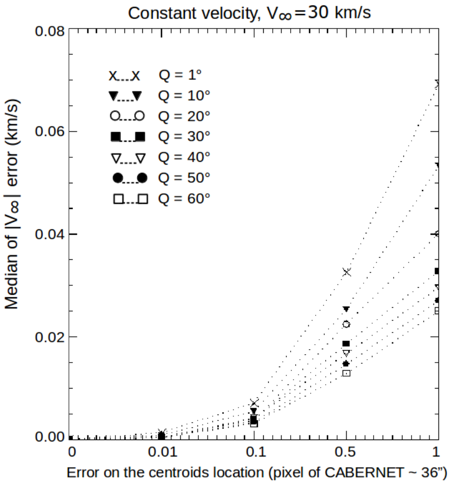
- Deceleration of 4.5% between V_∞ and $\vec{V_{end}}$
- Estimate of $(\vec{X_{beg}}, \vec{V_{beg}})$: MPF better
- Accuracy of 1.25% for CABERNET
- Deceleration $\not\simeq$ exponential: initial error of MPF and J&W

→ Validity of the deceleration model ?



Influence of the geometry





Limitations

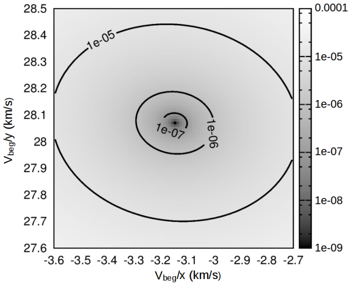
- Local minima/ill-conditioned problem ?

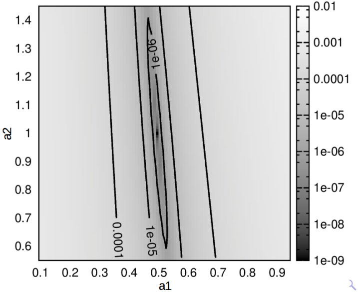
Test: Ideal geometry, exp. deceleration

- Small changes → large variation
- Conditional ellipsoids
- Covariance matrix
- $CN = \frac{||J(x)||_\infty}{||f(x)||_\infty / ||x||_\infty} > 1$

→ **Propagation models ill-conditioned (especially exponential)**

→ **Worse if $\epsilon \nearrow$**





Conclusions

Error on the location of the centroids

- Fit 2D-gaussian
- CABERNET: accuracy < 0.09 pixel $\sim$ 3"

Accuracy of some velocity computations

- PSO good implementation of the MPF
- MPF most accurate technique to compute $\vec{V_\infty}$ for each ϵ
- MPF allow velocity computation even for low convergence angles
- Precision of 1-2% for CABERNET and $\vec{V_\infty} = 30\ km.s^{-1}$

but...

Conclusions

Limitations

- Propagation models ill-conditioned
- Difficult to optimally determine $\vec{V_\infty}$ and deceleration parameters
- Difficulty $\nearrow$ with ϵ: acceptable for a small error (as for CABERNET)

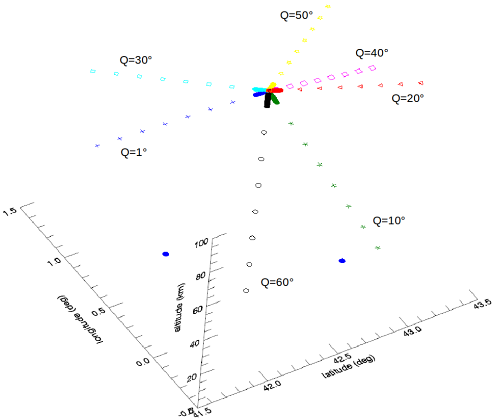
Future extensions :

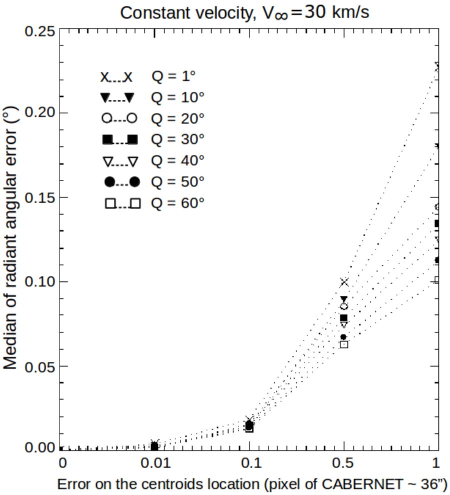
- Find well-conditioned deceleration model

Thank you for your attention!

You haven't taken the test yet ?
Please come to see me !

Influence of the geometry





Error on the centroids location

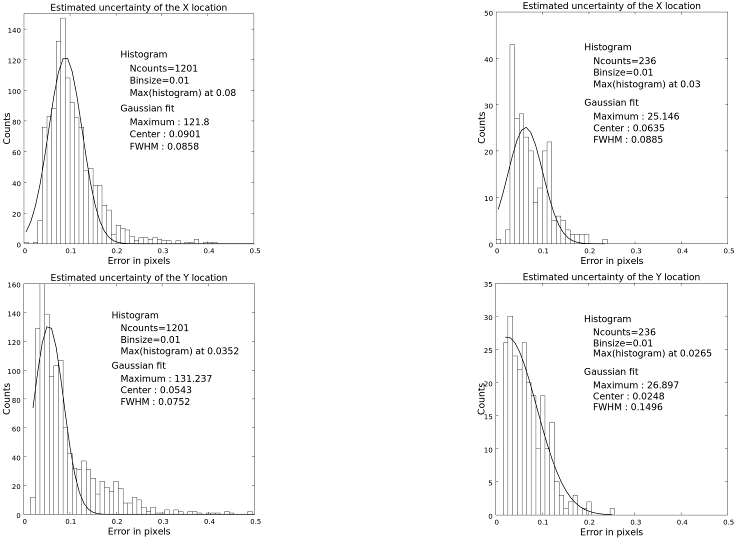
	Classic gaussian		MoG function		model_min(ϵ)	
	ϵ_x	ϵ_y	ϵ_x	ϵ_y	ϵ_x	ϵ_y
most frequent ϵ	0.080	0.035	0.030	0.027	0.067	0.035
center of histogram distribution	0.090	0.054	0.064	0.025	0.087	0.052

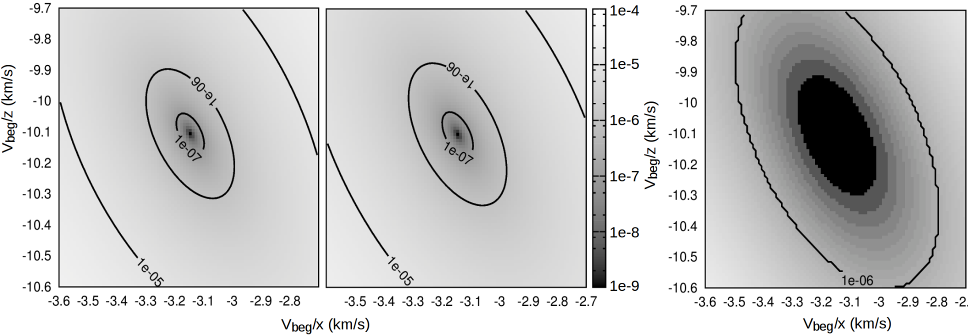
Results of the error determination in pixels - Pic du Midi

	Classic gaussian		MoG function		model_min(ϵ)	
	ϵ_x	ϵ_y	ϵ_x	ϵ_y	ϵ_x	ϵ_y
most frequent ϵ	0.077	0.070	0.046	0.062	0.077	0.040
center of histogram distribution	0.084	0.074	0.080	0.074	0.083	0.066

Results of the error determination in pixels - Montsec

Error on the centroids location





Conditional maps of the cost function for different values of V_{beg}/x and V_{beg}/z. The first and second plot present the conditional maps for a constant velocity and for an exponential deceleration. The last plot on the right illustrates the difference between the first two ones.

Influence of the geometry