# MODELLING FIREBALL NETWORK DATA IN THREE DIMENSIONS

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**Introduction:** Dedicated camera networks have been established around the world to capture fireball phenomenon with the aim of triangulating trajectories for orbit determination and meteorite recovery (e.g. [1]). Multi-station data have typically been triangulated using the assumption that the meteoroid travels along a straight line path. The single body theory of meteoroid aerodynamics has be used to model the disruption of the body along this straight line, in most cases using least squares approaches.

Here we define the aerodynamic equations in 3D and apply it to the particle filter approach of [2] to estimate the meteoroid velocity and mass from multi-station fireball observations.

**Model equations:** To model a trajectory in 3D, the single dimension dynamic equations, using vector notation, become :

$$\frac{d\mathbf{v}}{dt} = -\frac{\kappa\rho_a}{m^{1/3}}||\mathbf{v}||\mathbf{v} + \mathbf{g}$$

$$\frac{dm}{dt} = -\kappa\sigma\rho_a m^{2/3}||\mathbf{v}||^3$$

where $\mathbf{v}$ and $m$ are the velocity vector and mass of the meteoroid, $\mathbf{g}$ the local gravity vector, $\rho_a$ the atmospheric density and $\kappa$ and $\sigma$ the shape and ablation parameters [2]. Along with position, the mass, velocity, and unknown shape and ablation parameters can define the 'state' of a meteoroid at any time during its entry.

**3D Particle Filter:** Similar to other Bayesian filtering methods, a particle filter is performed in three reoccurring phases: initialisation, prediction and update. The initialisation phase creates a set of particles with a broad range of values for each of the 'state' parameters that will allow the filter to fully explore the parameter space. These particles are then iteratively propagated through the model equations and weighted with respect to an observation. In three dimensions, the observations are allowed to be the raw line-of-sight (azimuth and elevation) measurements as seen by an observatory at that time. This removes the need for any straight line assumptions on the meteoroid trajectory and allows the angular errors in each azimuth and elevation to be accounted for and propagated individually.

**Results:** A 21 second long fireball was captured by the Desert Fireball Network over South Australia on the 12th of December 2015. It was analyzed using both a straight line assumption and a 3D particle filter. The divergence of the estimated meteoroid position with respect to the individually triangulated points is shown in Fig. 1. A 3D visualisation can be seen in Fig. 2.

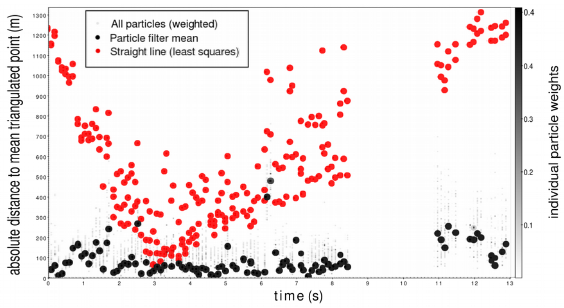


**Figure 1.** The absolute distance between individually triangulated observations (y=0) and the predicted position of a meteoroid using the straight line assumption (red) and a 3D particle filter (means shown in black, individually weighted particles shown in grey-scale).

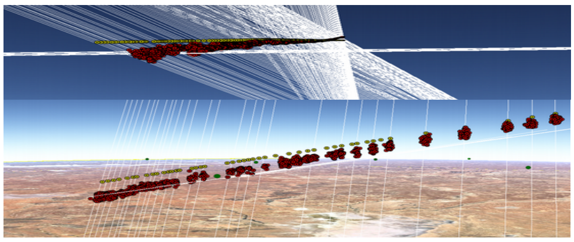

**Figure 2.** Google Earth visualisation; white rays are line-of-sight observations from 4 different DFN observatories (green ground stations), yellow points show straight line least squares estimates of meteoroid position, red points show position of individual particles predicted using a 3D particle filter.

**Conclusions:** We show that for some cases, a straight-line meteoroid trajectory does represent an oversimplification and may not reliably fit the position of a meteoroid to the observational data. A 3D particle filter adapts to the raw observations providing a robust analysis of errors. This iterative Monte Carlo approach also estimates meteoroid state values throughout the trajectory, including unknown trajectory parameters.

**References:** [1] Bland, P. A. et al. (2012) *Aust. J. Earth Sci., 59*, 177-187. [2] Sansom, E. K. et al. (in rev.) *AJ.*