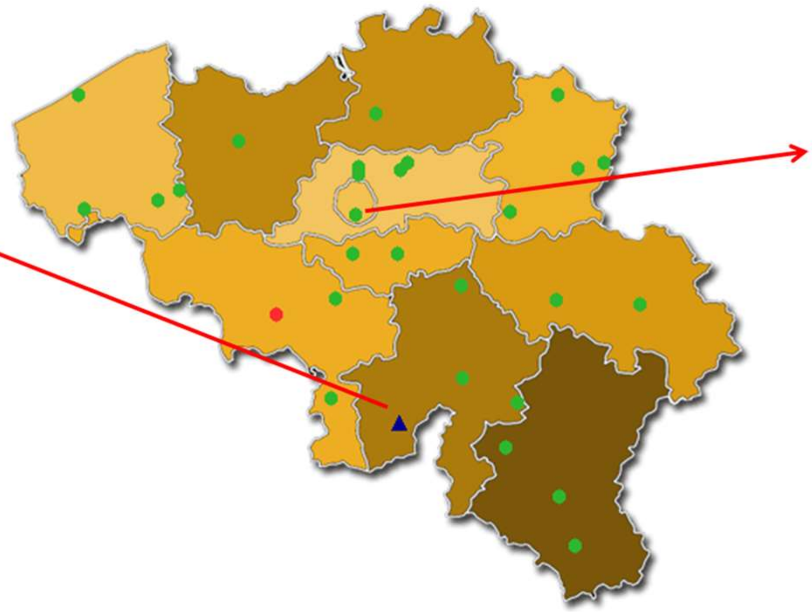
Ionization profile of meteors from simultaneous video and radio forward scatter observations

H. Lamy[1], M. Anciaux [1], S. Ranvier [1], A. Calegaro [1], C. Johannink[2],

[1] Royal Belgian Institute for Space Aeronomy, Brussels, Belgium

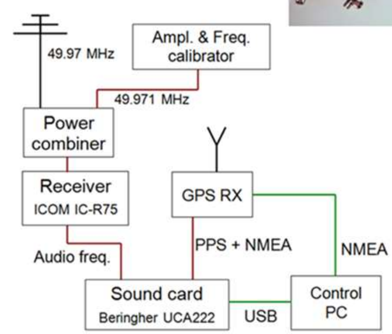
[2] Dutch Meteor Society, Gronau, Germany

The BRAMS network

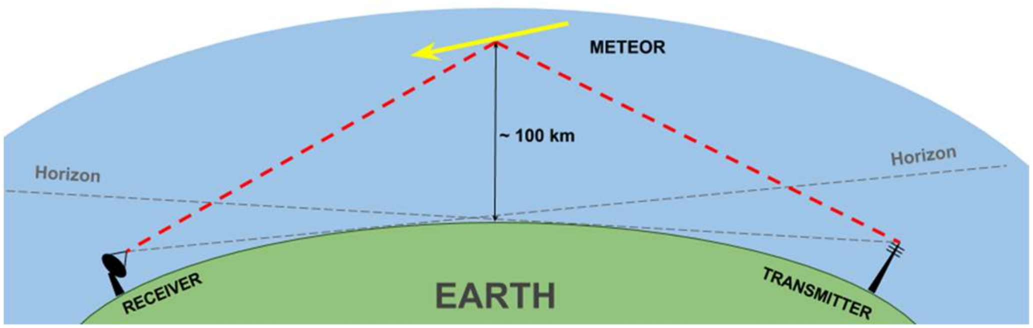


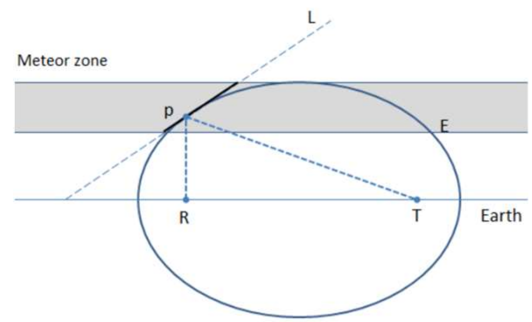
Tx characteristics

- ✓ Crossed dipole + 8m × 8m metallic grid
- ✓ 49.97 MHz
- ✓ 150 W
- ✓ pure sine wave
- ✓ circular polarization



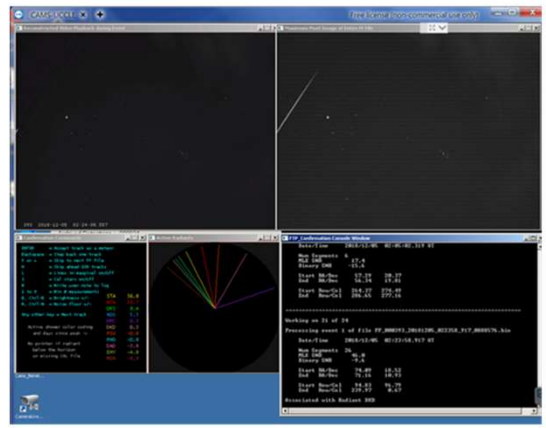
BRAMS observations : specularity condition

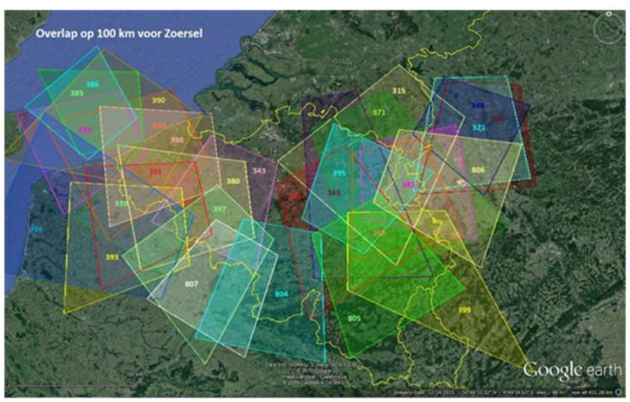




The specular reflection point *p* along the meteoroid path *L* must be tangential to the ellipsoid with Rx and Tx as focii.

The CAMS-Benelux network



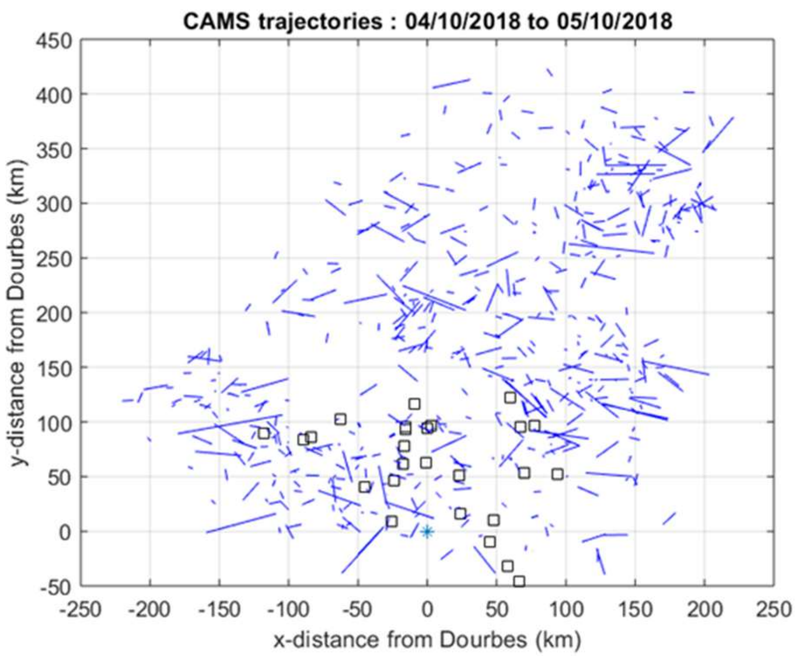


Credit: Paul Roggemans

Provide very accurate trajectories, speed and deceleration measurements

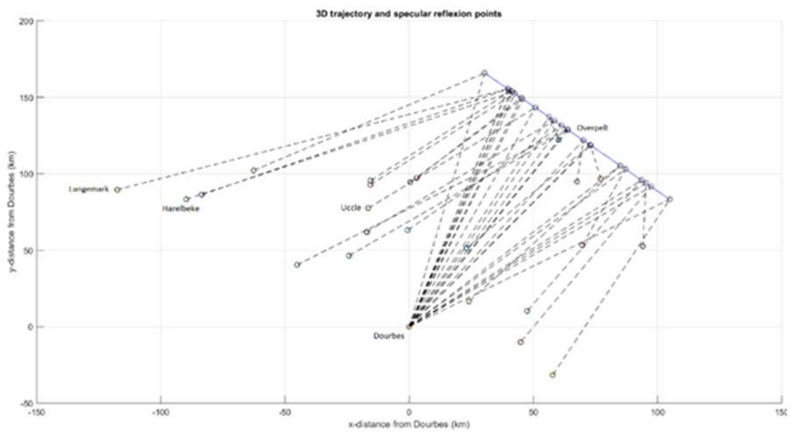
$$d_o(t) = d(t=0) + V_\infty t - |a_1| \exp(a_2 t)$$
$$V_o(t) = V_\infty - |a_1 a_2| \exp(a_2 t)$$
$$A_o(t) = -|a_1 a_2^2| \exp(a_2 t)$$

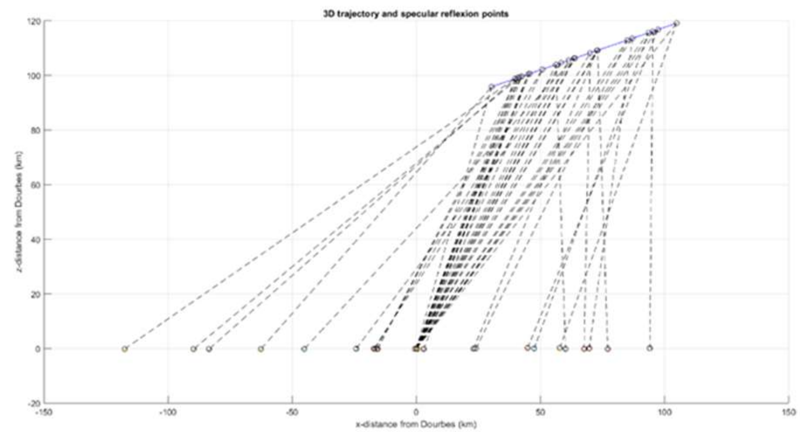
CAMS data



Night from 04 to 05/10/2018 : 522 CAMS trajectories projected on the ground. Center of the coordinates is the BRAMS Tx in Dourbes. Rectangles represent the BRAMS Rx stations active at that time

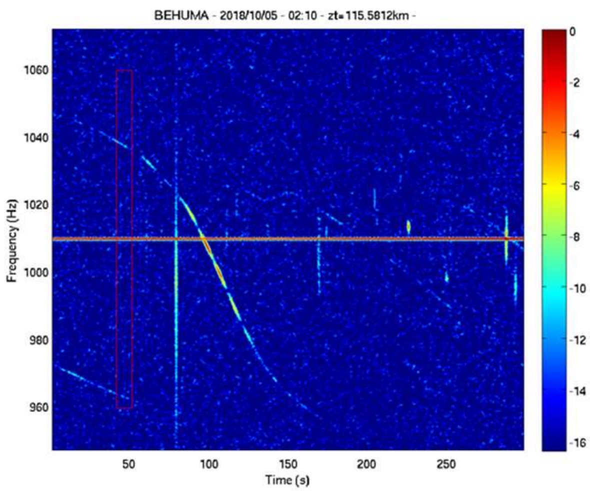
CAMS data



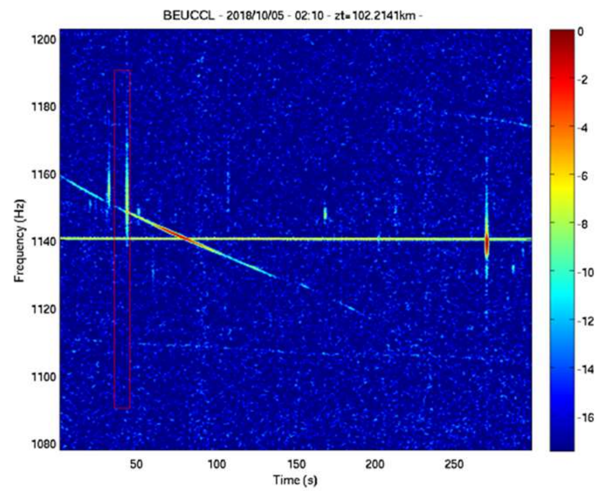


For Trajectory 320, we compute the positions of the theoretical specular reflection points for each combination (Rx,Tx). (Left) : projection of Traj 320 on the ground (XY plane), (right) = projection of Traj 320 in the XZ plane. The positions of specular reflection points are shown

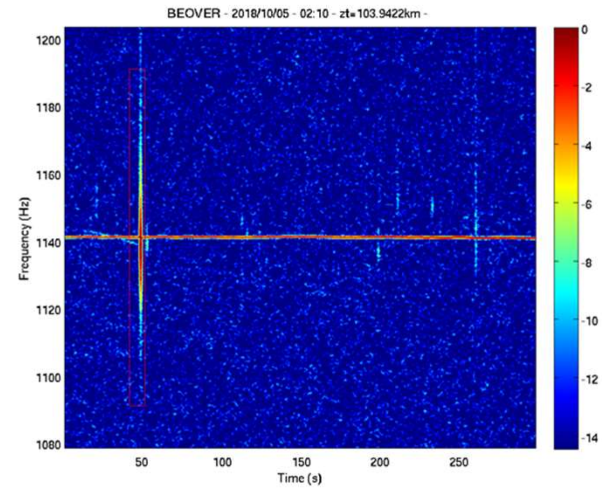
Corresponding BRAMS spectrograms



Humain – Z_s = 115.6 km



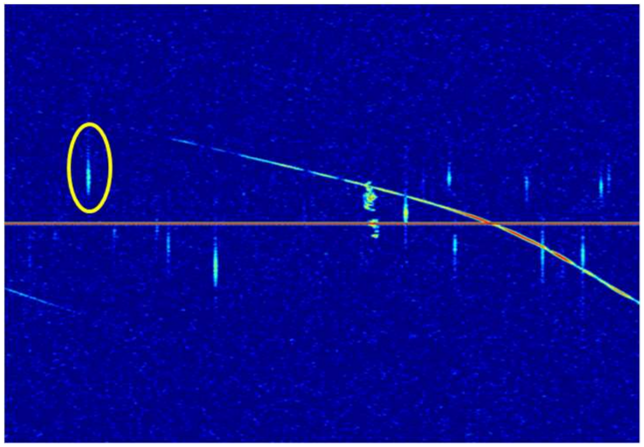
Uccle – Z_s = 102.2 km

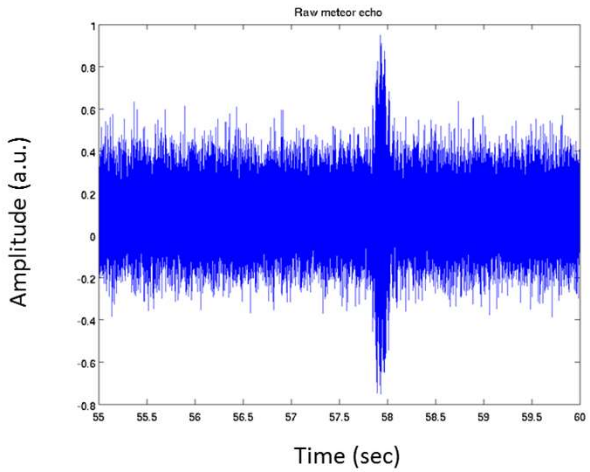


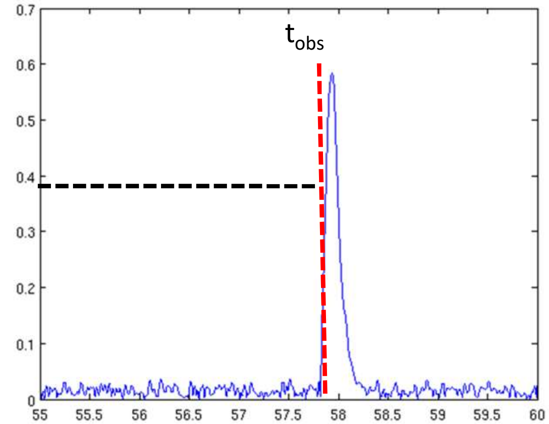
Overpelt – Z_s = 103.9 km

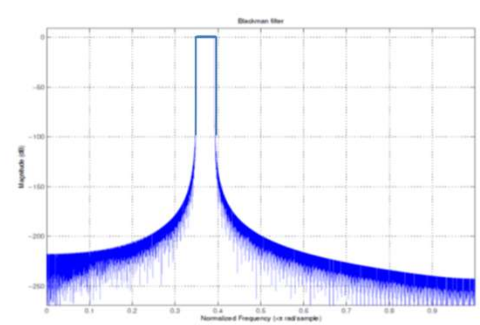
Depending on the altitude z_s of the specular reflection point, we expect to see a meteor echo (or not) at a time given approximately by the predicted time of appearance of the specular reflection point. Time resolution of the spectrograms is $\Delta t \sim 3$ seconds. The red rectangles are centered on this predicted time. The results were very consistent. For example, the altitude of the reflection point for the Humain station (left spectrogram) is too high to produce enough ionisation and significantly reflect the incident radio wave.

Meteor profiles for “isolated” meteor echo









The next step is to compute the meteor profile (Integrated power vs time). For the (spectrally) isolated meteor circled in yellow on the spectrogram (left), the task consists then in filtering the raw meteor echo (center) using a bandpass filter (Blackman filter, center bottom) to obtain the power profile (right).

Meteor profiles for meteor echoes superimposed with the “direct” signal

For the meteor echoes superimposed with the direct signal coming from the Tx, we reconstruct the latter by carrying out FFT on 6 seconds:

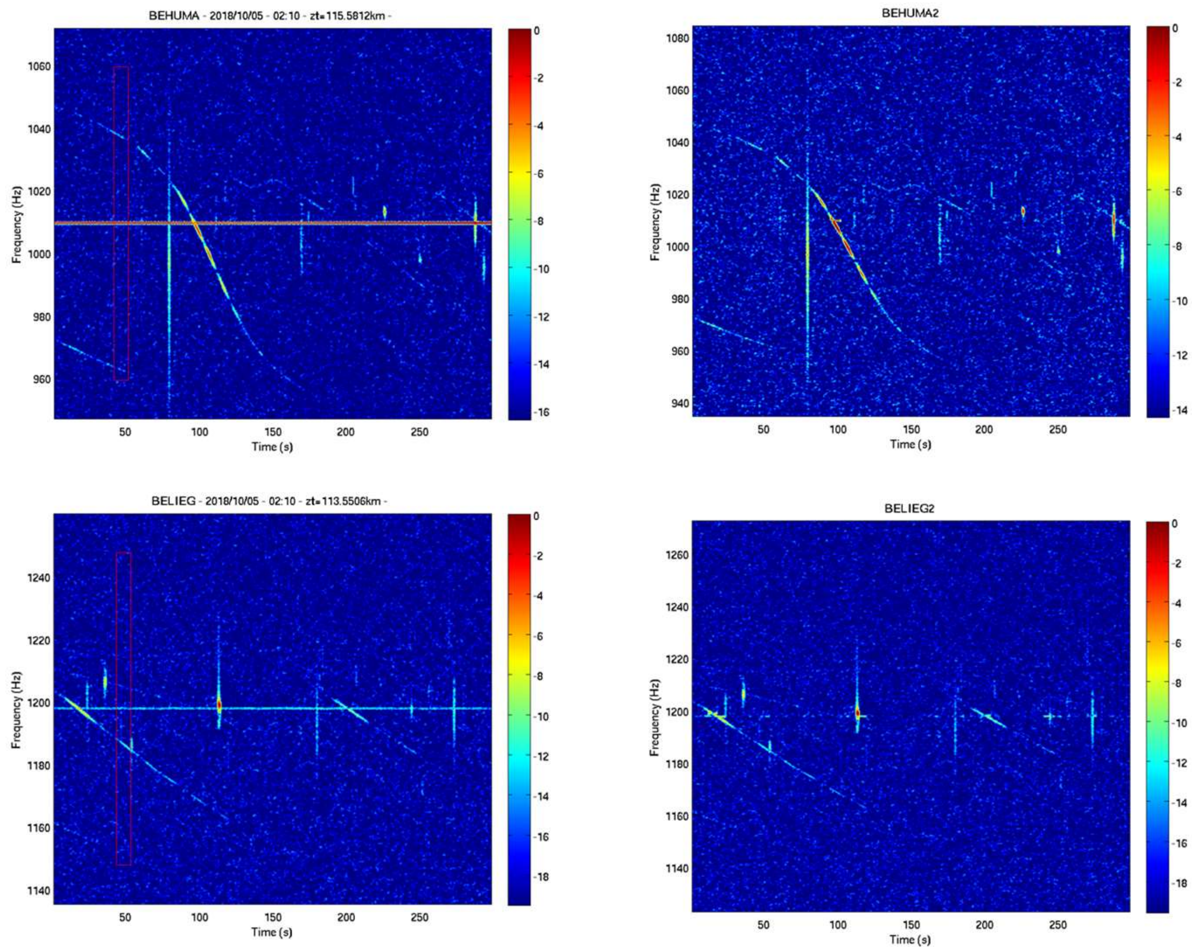
$$\mathbf{A} \sin(\omega t+\phi)$$

We then subtract it from the raw data.

We show here 2 examples of spectrograms before and after the subtraction of the reconstructed direct signal (Humain on top and Liège on bottom)

We then can filter out all other frequencies like for “isolated” meteor echoes.

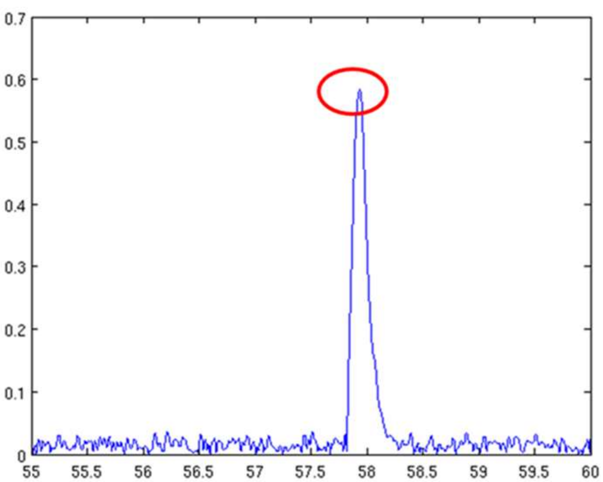
Subtraction of the signals due to reflection on airplanes is still under development.

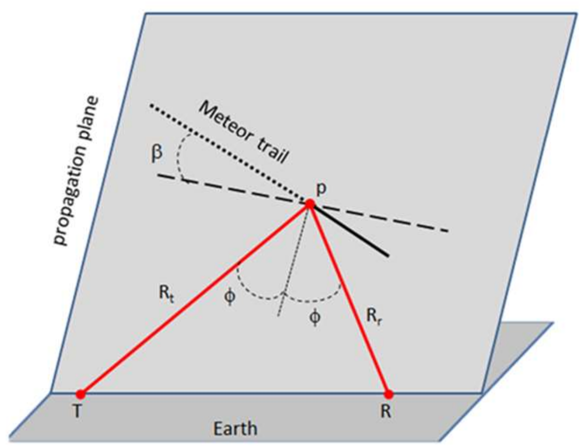


Determination of peak power and electron line densities

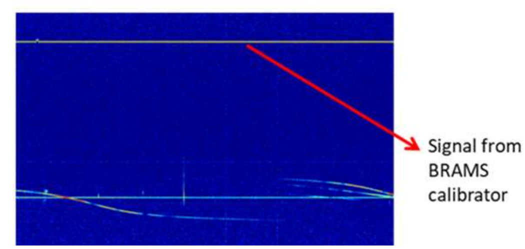
For underdense meteor echoes, the peak power (**red circle on the left figure**) is given by the formula below (Mc Kinley 1961). Since we use the CAMS trajectory, all geometrical parameters (in the numerator and **see central picture**) can be calculated. For the gains of the antenna G_T and G_R, we use numerical simulations (**right picture**). The polarisation factor $\sin^2 \gamma$ is unknown since our 3-elements Yagi antennas are sensitive to only one polarisation. Here we tentitavely take this factor equal to ½. The only remaining unknown is therefore the electron line density α at the specular reflection point. The peak power measure is initially in arbitrary units and is converted into Watts using the signal from the BRAMS calibrator whose amplitude is stable and well known. This signal appears by construction 500 Hz above the direct signal from the Tx (see spectrograms at the bottom right)

$$P_{\text{peak-under}} = \frac{P_{\mathrm{T}} G_{\mathrm{T}} G_{\mathrm{R}} \lambda^3 r_e^2 \alpha^2 \sin^2 \gamma}{16\pi^2 R_{\mathrm{T}} R_{\mathrm{R}} (R_{\mathrm{T}} + R_{\mathrm{R}})(1 - \sin^2 \phi \cos^2 \beta)},$$





Simulation of the antenna gains: azimuth (left) and elevation (right)



Comparison with results from ablation models

For each BRAMS receiving station which detects a meteor echo, an estimate of the electron line density α at the reflection point can be obtained. Since the trajectory and initial speed are known from CAMS data, an ablation model such as e.g. the one from Vondrak et al (2008) can be run for a set of reasonable mass values (and a reasonable composition) to compute (among others) the mass deposition profile along the meteoroid trajectory. From the mass deposition profile, a profile from the ionisation can be obtained as well. The idea is then to pick up the value of the mass that minimizes (in least square sense) the difference between simulated values and values obtained from the BRAMS data. This part is still in development.

$$\frac{dV}{dt} = -\Gamma V^2 \frac{3\rho_a}{4\rho_m R} + \rho_m g$$

$$\frac{1}{2}\pi R^2 V^3 \rho_a \Lambda = 4\pi R^2 \varepsilon\sigma (T^4 - T_{env}^4) + \frac{4}{3}\pi R^3 \rho_m C \frac{dT}{dt} + L\frac{dm}{dt}$$

$$\boxed{q = -\frac{\beta}{\mu V}\frac{dm}{dt}}$$

$$\frac{dz}{dt} = -V\cos(\chi)$$

$$\frac{dm_i^A}{dt} = \gamma\, p_i S \sqrt{\frac{\mu_i}{2\pi k_B T}}$$

$$\frac{dm^A}{dt} = \sum_i \frac{dm_i^A}{dt}$$

Limitations

Mc Kinley's formula is strictly valid for underdense meteor echoes. More difficult to apply for overdense ones (due to e.g. effects of winds or turbulence). For those with intermediate electron line densitie, the formula from Pecina et al could be generalized to the forward scatter case.

More information?

- I will be available during the chat on Wednesday 9
- You can contact me by e-mail at herve.lamy@aeronomie.be for questions, suggestions or collaborations.
- If needed, we can organize a Skype or Webex conference.
- Thank you!