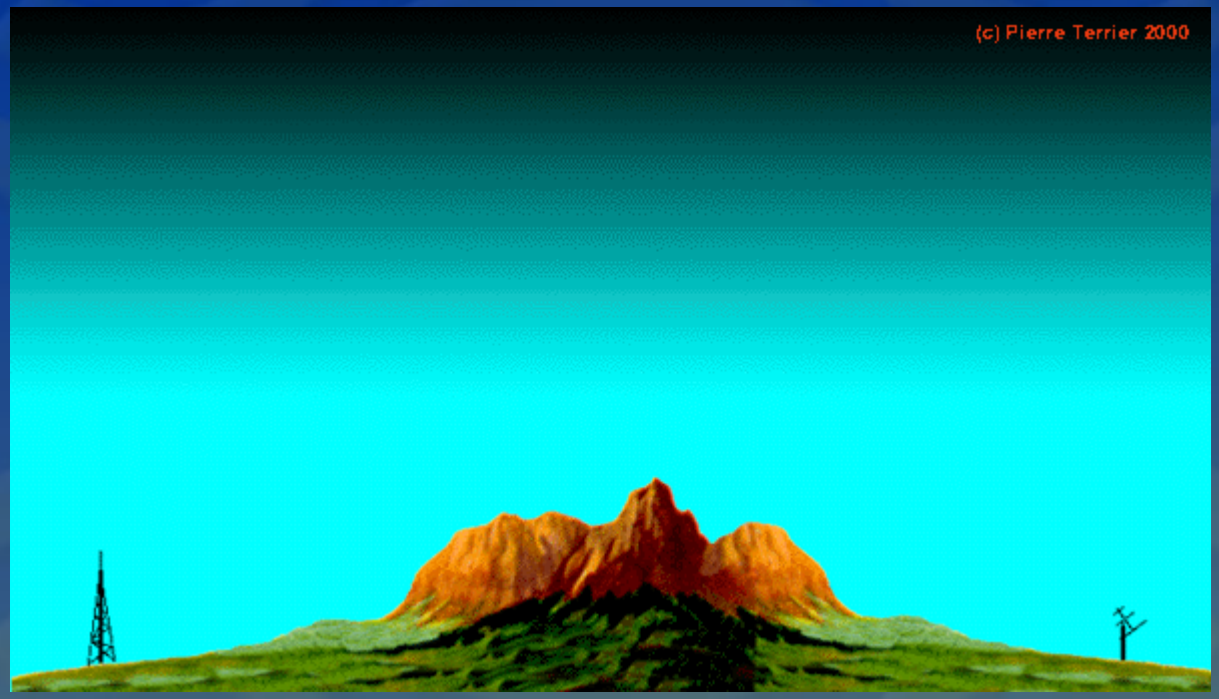
Meteor Trajectory from Multiple Station Head Echo Doppler Observations

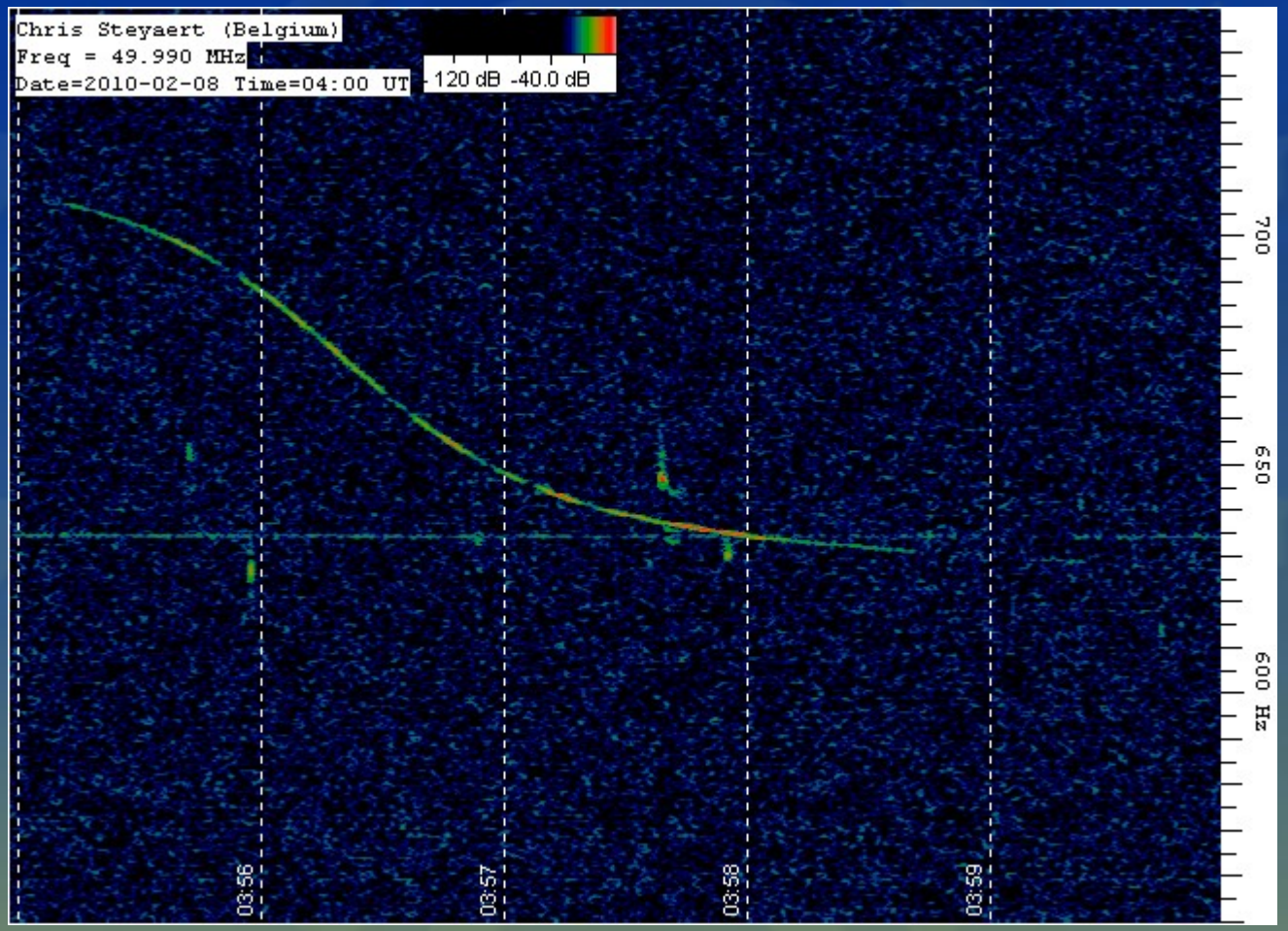
Chris Steyaert
steyaert@vvs.be

Principle

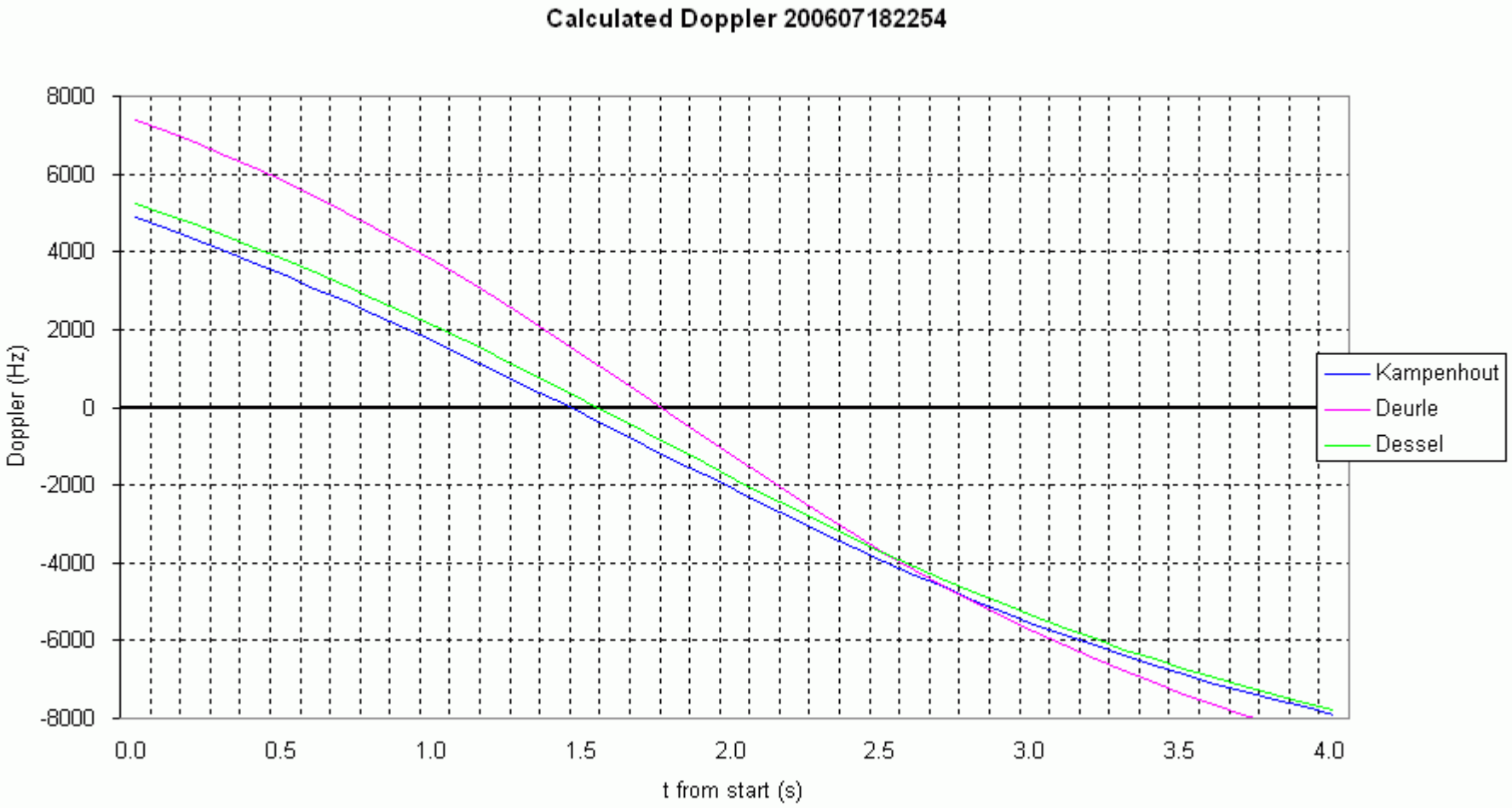


- Reflection on the path (mirror)
- Reflection on the head

Typical spectrogram

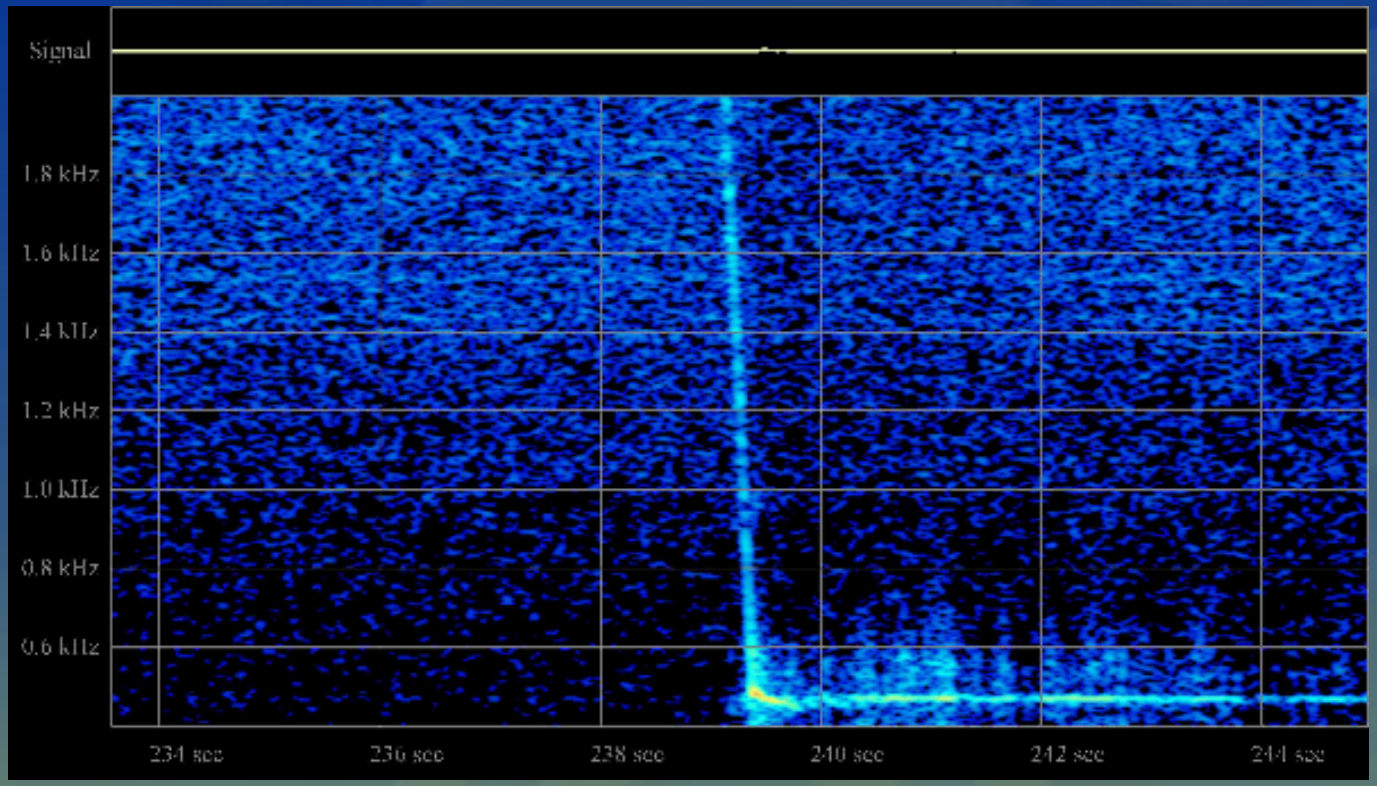


Simulated Doppler for observed fireball



Detailed head echo

Analysing the .wav file



Earlier research

- Manning et al., 1949.

  "Radio Doppler Investigation of Meteoric Heights and Velocities".

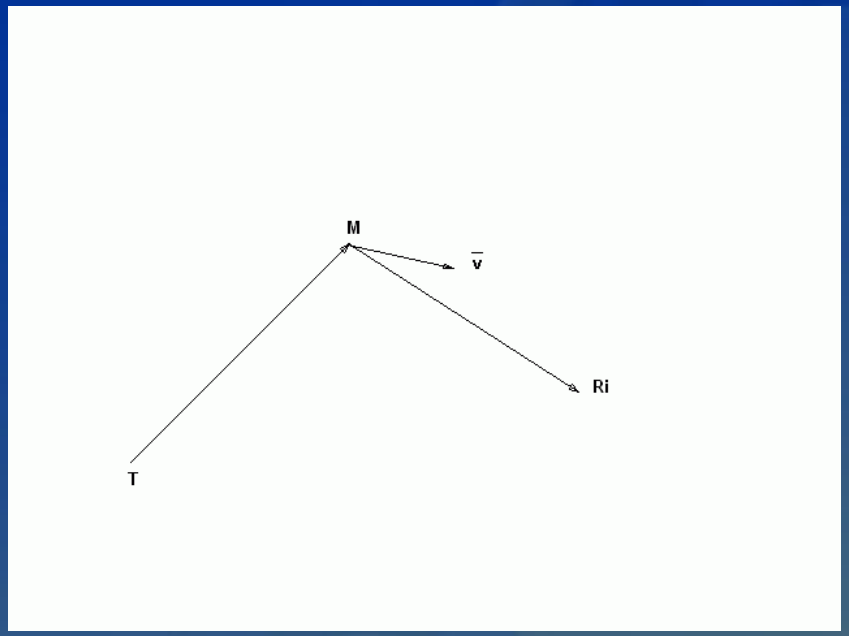
  Journal of Applied Physics, Vol. 20, p.475-479.

- Richardson, J. and Kuneth W. (1998).

  "Revisiting the Radio Doppler effect for forward-scatter meteor head echoes".

  WGN, Journal of the IMO. "26, 117-130".

Some maths



$$Doppl_T = -\frac{\overline{TM}}{\left|\overline{TM}\right|}\cdot\frac{\bar{v}}{c}f$$

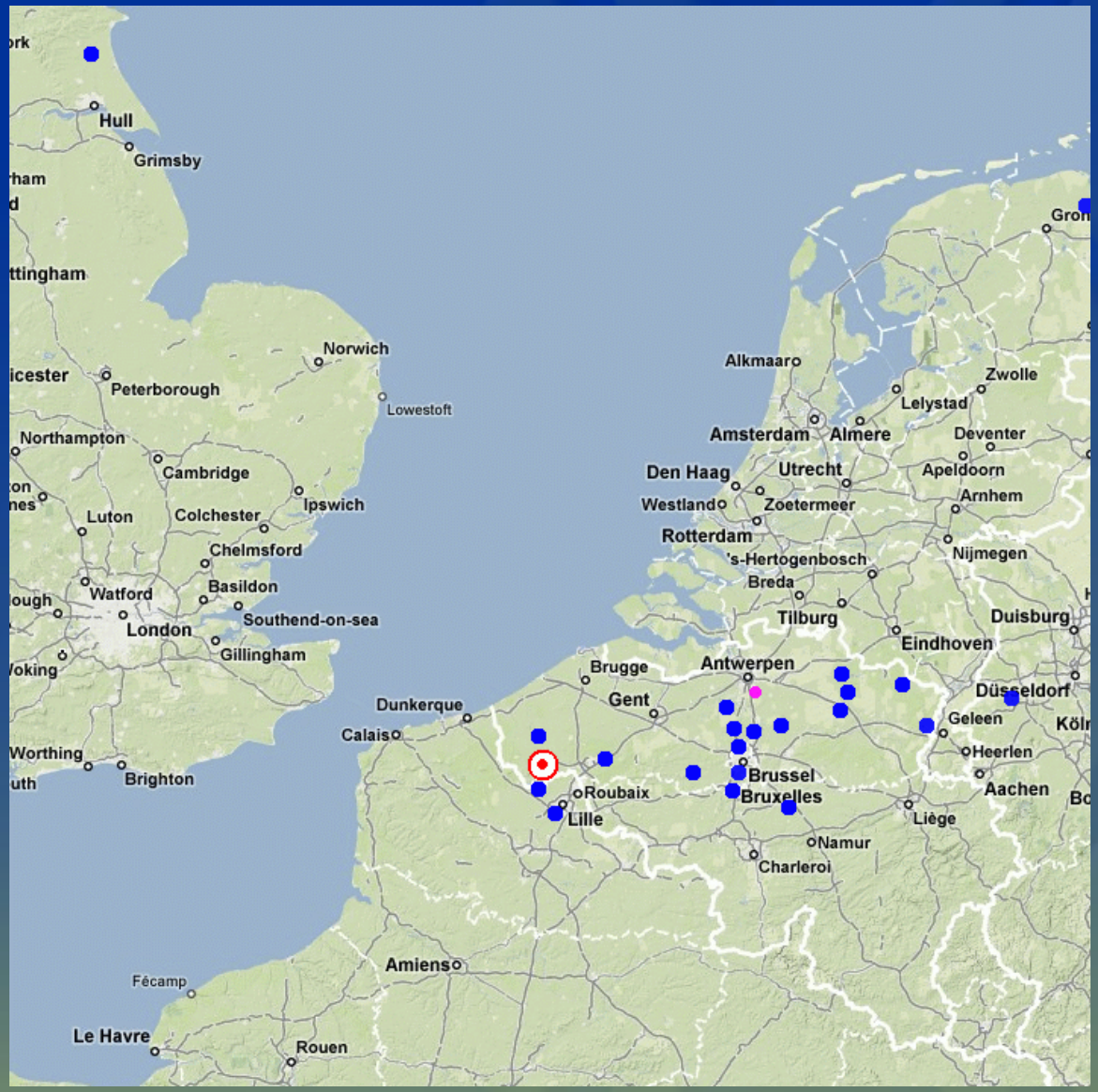
$$Doppl_{R_i} = -\frac{\overline{R_iM}}{\left|\overline{R_iM}\right|}\cdot\frac{\bar{v}}{c}f$$

$$\frac{\partial Doppl_T(t)}{\partial t} = -\frac{1}{\left|\overline{TM}\right|}\left[v^2 - \frac{\left(\overline{TM}\cdot\bar{v}\right)^2}{TM^2}\right]\frac{f}{c}$$

$$\frac{\partial DopplR_i(t)}{\partial t} = -\frac{1}{\left|\overline{R_iM}\right|}\left[v^2 - \frac{\left(\overline{R_iM}\cdot\bar{v}\right)^2}{R_iM^2}\right]\frac{f}{c}$$

6 observations →
position M (3 parameters) and velocity vector v (another 3) can be determined

VVS beacon / receiving network

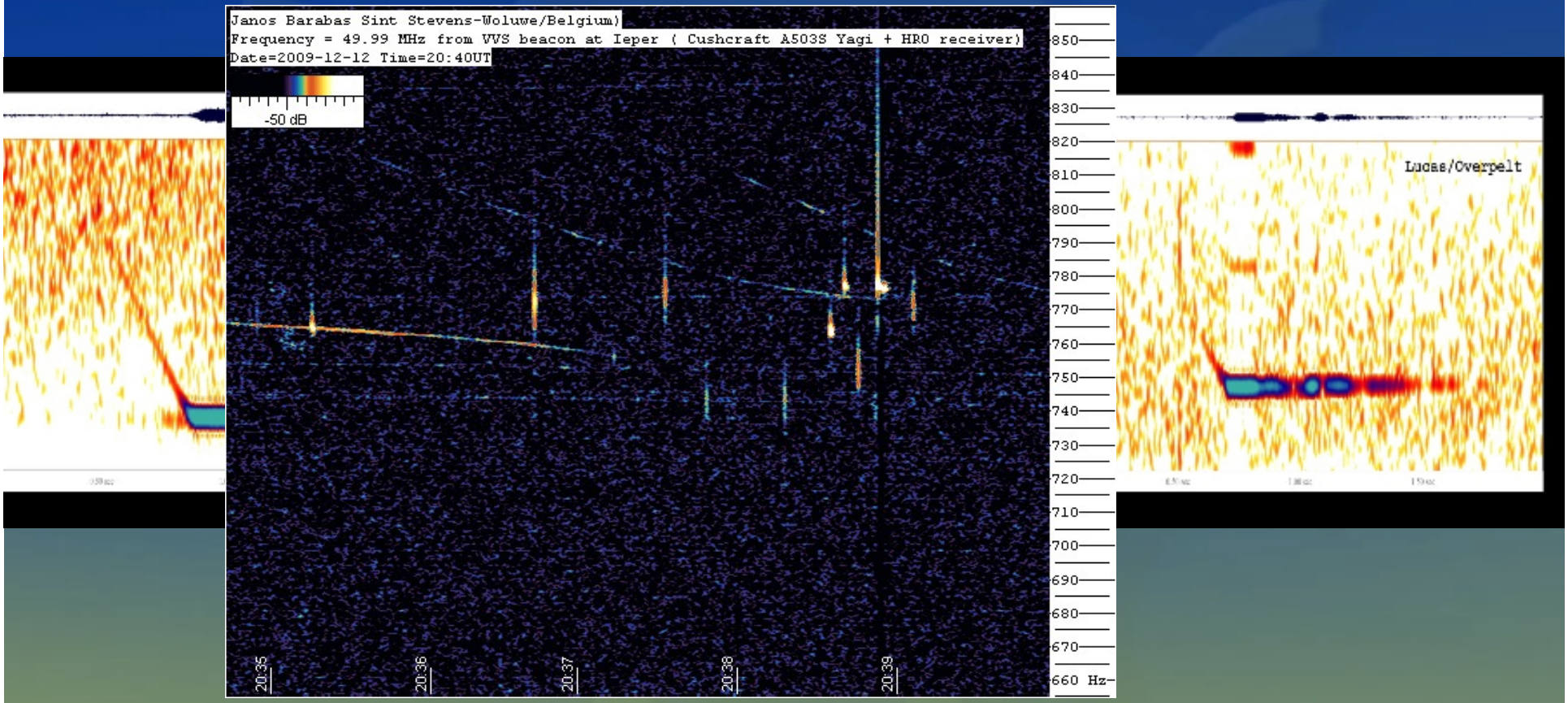


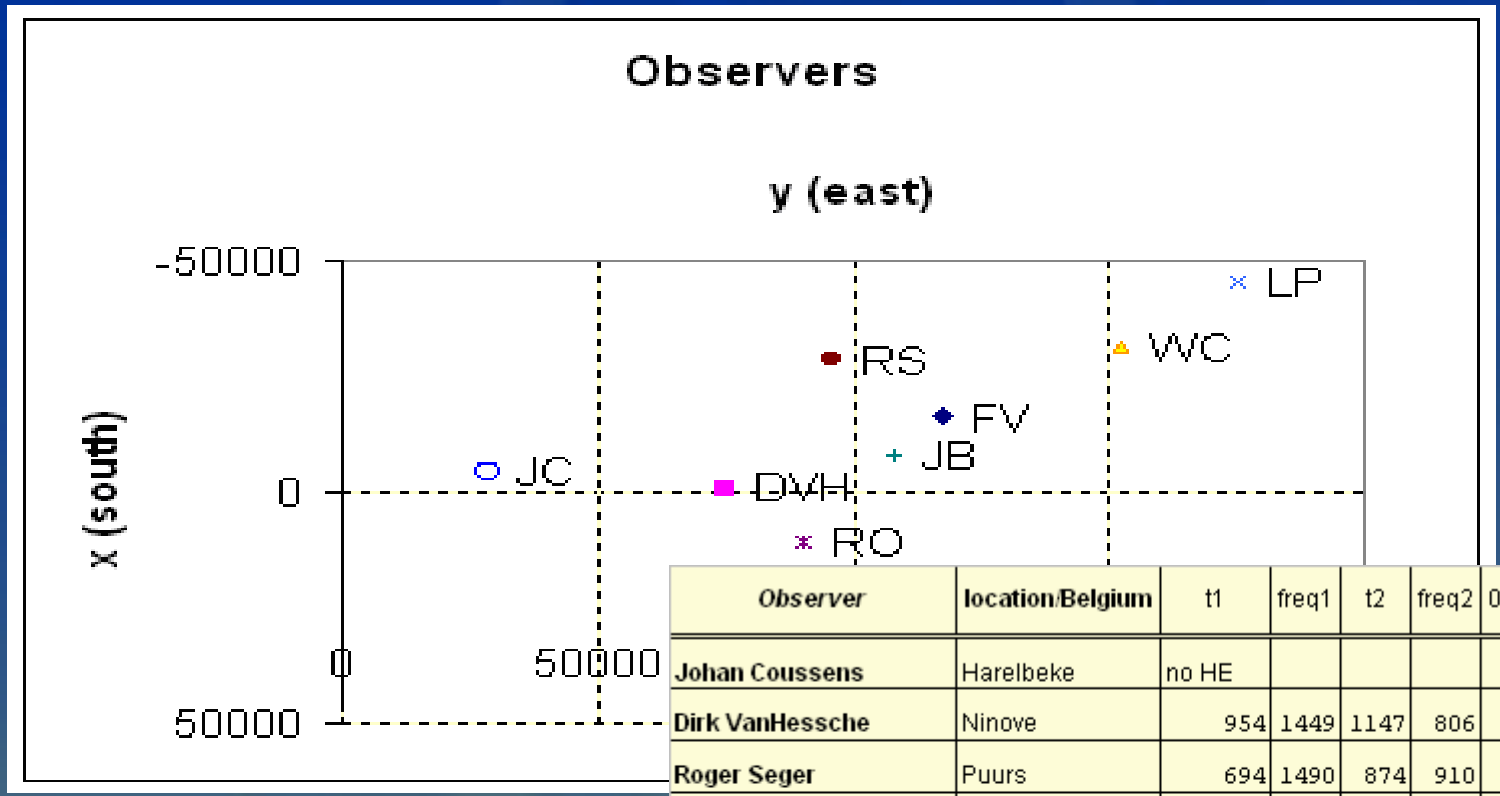
VVS - beacon
regular VVS-beacon observers
irregular or soon to become beacon observers
regular observer of Eastern European transmitters

Worked out real case

12 Dec 2009, 20h38 UT Geminid

sure about identification?





Observer	location/Belgium	t1	freq1	t2	freq2	0-freq	slope (Hz/sec)	*t_0-freq*
Johan Coussens	Harelbeke	no HE						
Dirk VanHessche	Ninove	954	1449	1147	806	762	**-3332**	*1160*
Roger Seger	Puurs	694	1490	874	910	851	**-3222**	*892*
Roland Oeyen	Lembeek	648	1819	1062	414	274	**-3394**	*1103*
Janos Barabas	Zaventem	1074	1464	1236	932	780	**-3284**	*1282*
Felix Verbelen	Kampenhout	586	1290	810	614	488	**-3018**	*852*
Willy Camps	Tessenderlo	746	1165	876	814	729	**-2700**	*907*
Lucas Pellens	Overpelt	615	921	684	732	658	**-2739**	*711*

standard Geminids radiant
α = 113 º, δ = +32 º
at the location of the beacon:

Az = 257 º, *h* = 34 º

Numerical procedure

- 'Simplified ' procedure for streams:
  - velocity vector is known (v = 34400 m/s)
  - starting value for M = (0, 0, 90000)
- Miminize the Doppler and Doppler rate errors

  M = (-16000, -18000, 96000) at t = 0
- For the mid point of the head echoes:

Observer	ti	x	y	z
Verbelen	0.698	-17522	-10396	82573
Van Hesso	1.051	-15261	-20191	75792
Camps	0.811	-16797	-13536	80399
Pellens	0.650	-17833	-9048	83506
Oeyen	0.855	-16515	-14759	79553
Segers	0.784	-16970	-12786	80919
Barabas	1.155	-14590	-23095	73782

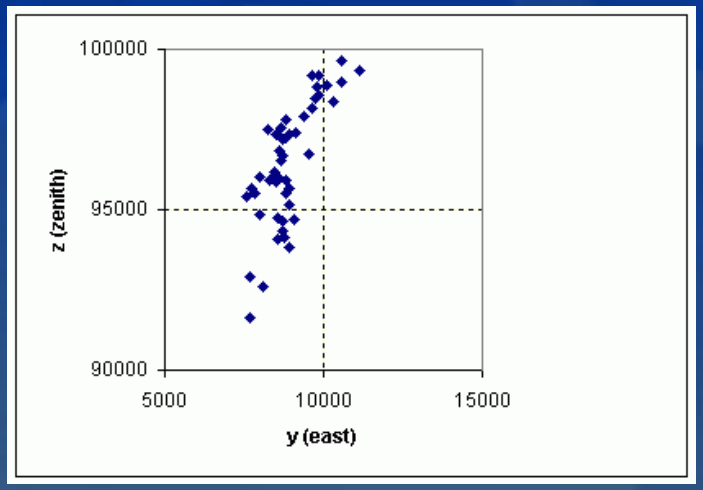
Observer	(O-C)dD/dt	(O-C)Doppl
Verbelen	-125.2	-191.2
Van Hessche	309.9	-227.5
Camps	6.2	499.8
Pellens	-307.4	277.5
Oeyen	-86.0	-151.2
Segers	-57.2	-407.1
Barabas	41.7	956.8

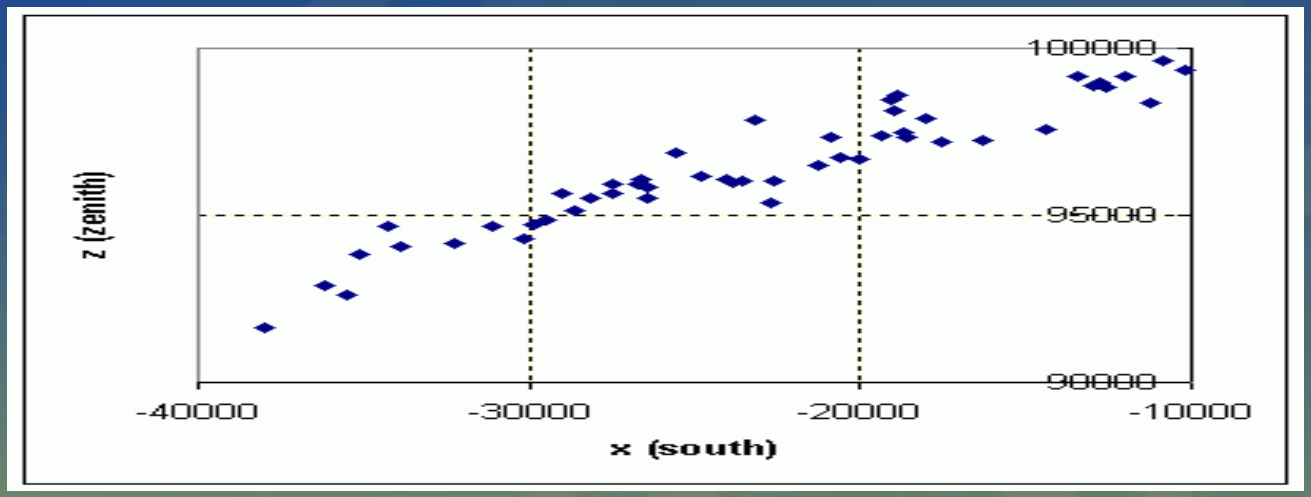
- Why Coussens no HE?

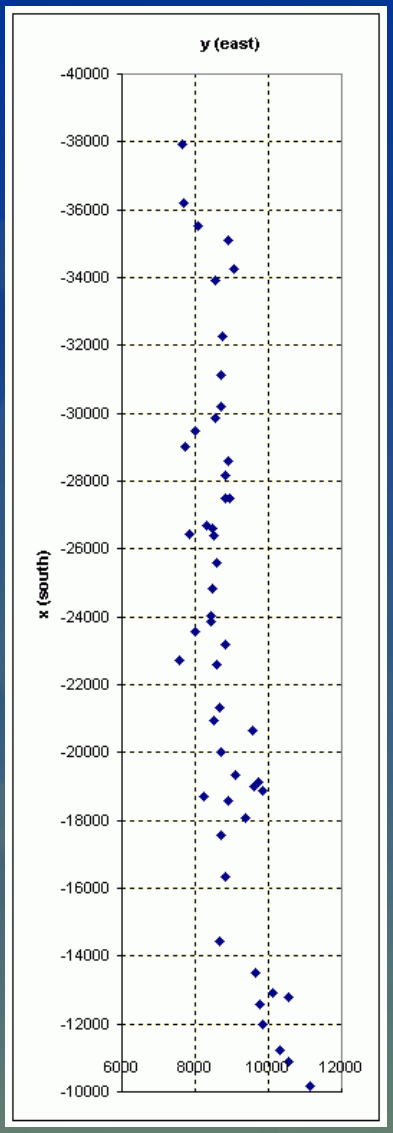
Sensitivity analysis

- Error source
  - timing accuracy (NTP synchronised)
  - outlier removal?
- Monte Carlo simulation
  - Std dev 5 ms

Simulation results







Conclusions / the future

- Accuracy
  - Several km, strongly depending on geometry of the receivers around the transmitter
  - Sensitive (few %) to speed
- Need better time reference
- Full procedure for non-stream meteors
- Number: average 10 / day ? Statistics of head echoes
- Automate the analysis

Thanks to

- The beacon observers
- BIPT (Belgian Inst. Post and Telecom)
- Felix Verbelen
- Gaspard De Wilde
- David Entwistle
- Astrolab IRIS, Zillebeke
- VVS
- Pierre Terrier