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MEteor TRajectories and Origins (METRO) Reconstruction of the trajectories of meteroids using the BRAMS interferometer

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Outline

1. **A brief introduction about WP1**
2. **How to use interferometer to derive the trajectory of meteors:**
   1. **The theory of J. Jones**
   2. **The BRAMS interferometer**
   3. **Some results**
      1. **At the frequency of the balise**
      2. **Underdense meteor**
      3. **Some particular cases**
3. **Summary, perspectives**

WP 1: Observation and data analysis

- WP 1.1 : Meteor count and data selection
- **WP 1.2 : Multipoint trajectory determination**
- WP 1.3 : Verification of BRAMS trajectories
- WP 1.4 : Observability conditions
- WP 1.5 : Meteor flux model and elemental mass deposition rate
- WP 1.6 : detailed analysis of meteor reflections
- WP 1.7 : Visual meteor brightness and spectroscopy

WP 1.2 : Multipoint trajectory determination

- Geometrical approach : search for a trajectory tangent to a set of ellipsoids whose focii are known (position of the receivers and the transmitter) Nedeljkovich et al., 2005
- Timing approach : search for a trajectory using the time of appearance of the meteor signal. It requires at least 6 stations to determine the 6 unknowns (3 DoF for position and 3 DoF for velocity)
- **Assisted trajectory reconstruction**: using the BRAMS interferometer to infer the direction of the reflection point + 3 additionnal stations (Jones et al., 1999).

Measurem ... eors
with an in

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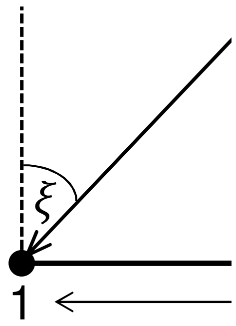
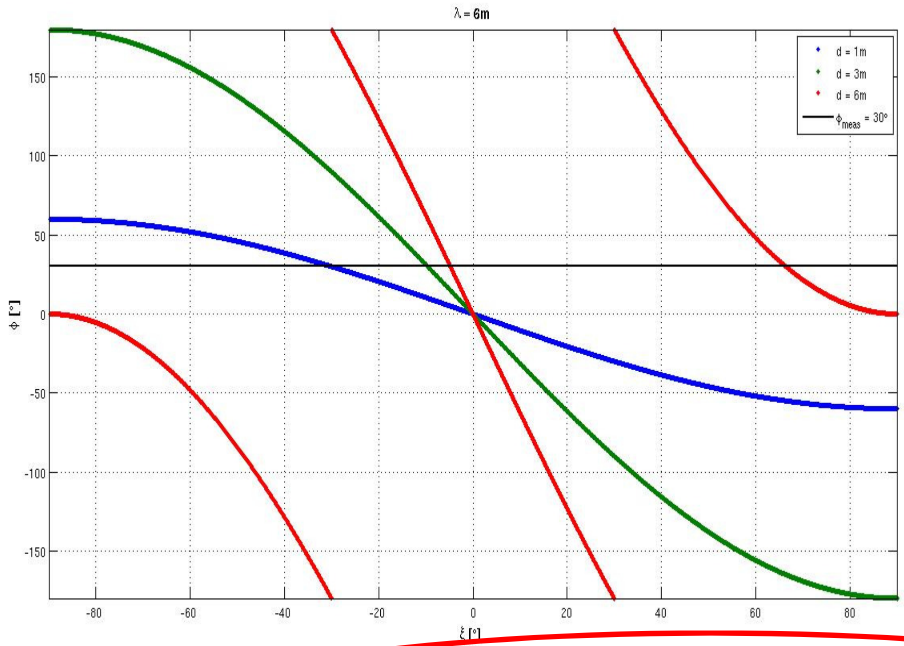
From Jones et





ection (ξ)of the
educed from the
gnal on antenna 1
nna 0 given by:

$$= -2\pi \frac{d}{\lambda} sin(\xi)$$

But : since $\phi_{10} \epsilon [-\pi;\pi]$ → ξ determined unambiguously in $\left[-\frac{\pi}{2};\frac{\pi}{2}\right]$ only if $d < 0.5\ \lambda$

But : if $d < 0.5\ \lambda$:

- the error $\Delta\xi = \frac{\lambda\Delta\phi_{10}}{2\pi d cos(\xi)}$ is important
- The mutual coupling between both antenna becomes so important that the measured values of ϕ can be in error.

According to Jones, the best compromise between weak mutual coupling effect and weak error in AoA is to set the separation between antenna to a multiple of 0.5λ greater than 1.5λ

But :

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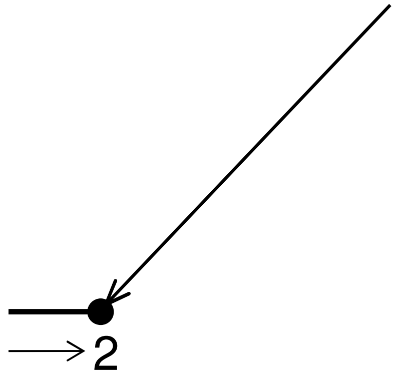
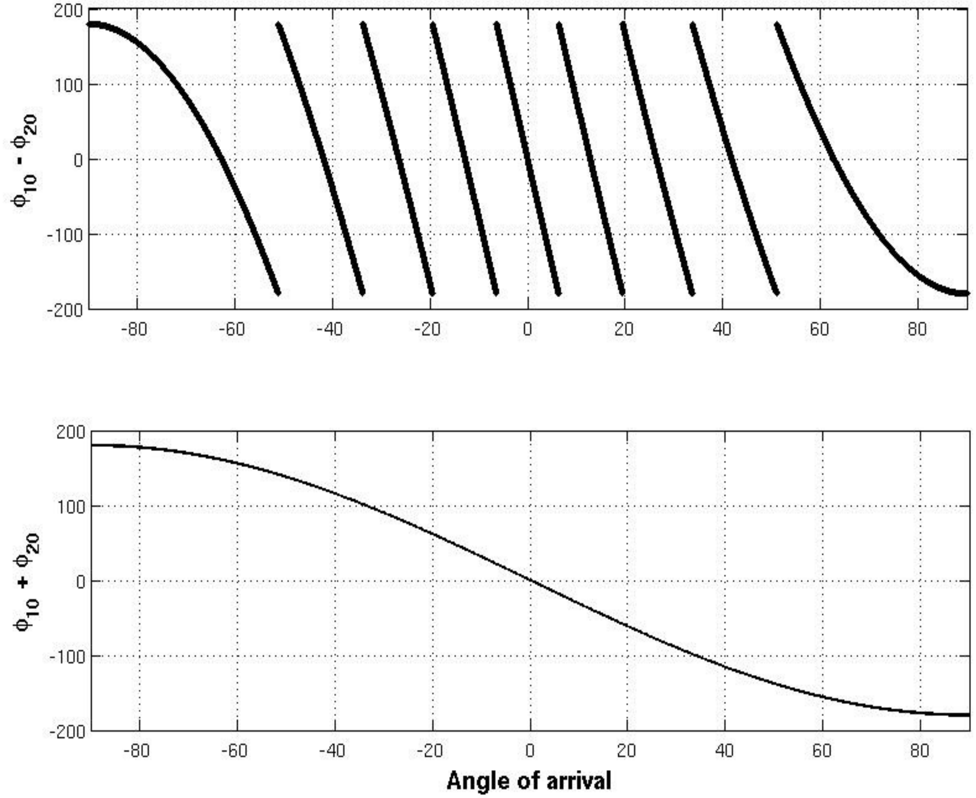
Solution to avoid ambiguity: add a 3rd antenna



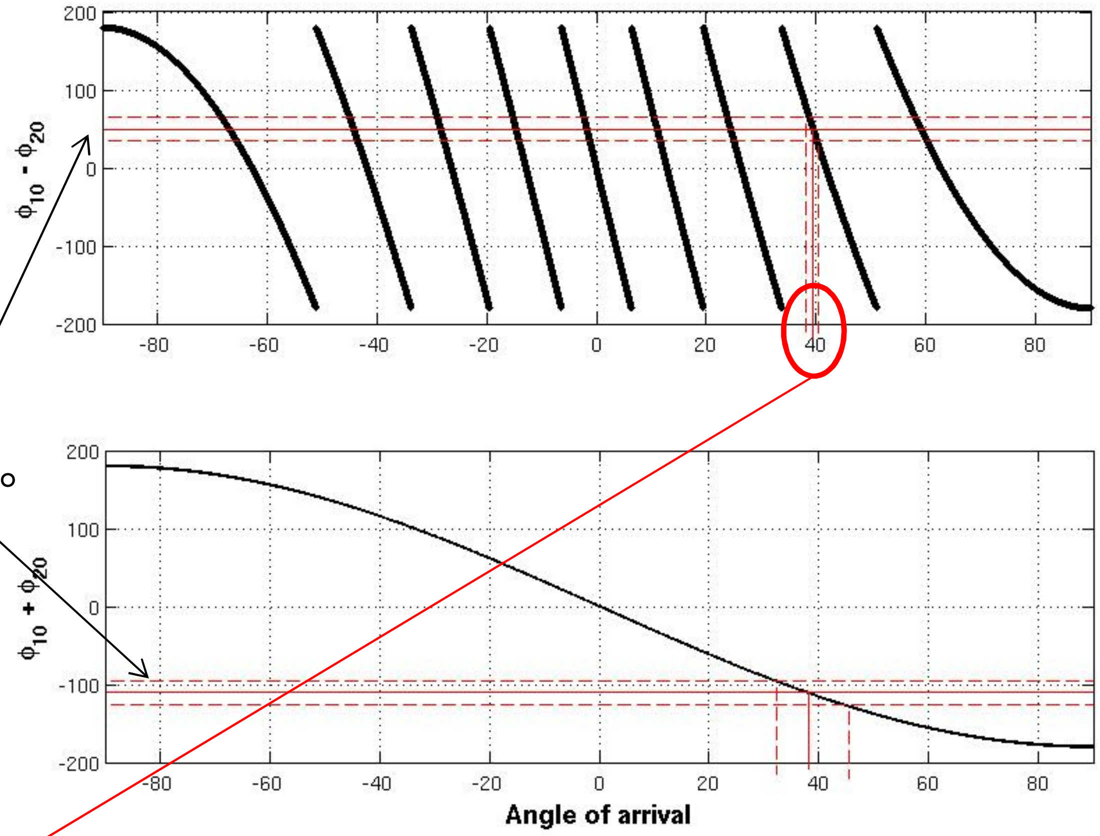


$$\xi) = -\frac{\lambda}{2\pi}\frac{(\phi_{10}-\phi_{20})}{d_1+d_2}$$ → Ambiguous Accurate

$$\xi) = -\frac{\lambda}{2\pi}\frac{(\phi_{10}+\phi_{20})}{d_1-d_2}$$ → Unambiguous Inaccurate

Example

- With $d_1 = 2.5\lambda$ and $d_2 = 2.0\lambda$,
- we have measured
  - $\phi_{10} - \phi_{20} = 50° \pm 15°$
  - $\phi_{10} + \phi_{20} = -110° \pm 15°$



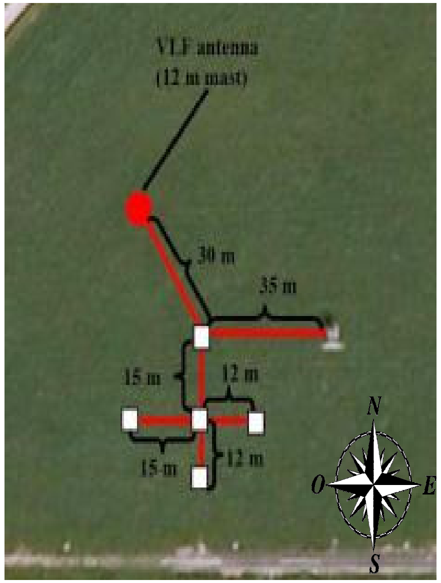
$$\xi = 39° \pm 0.7°$$

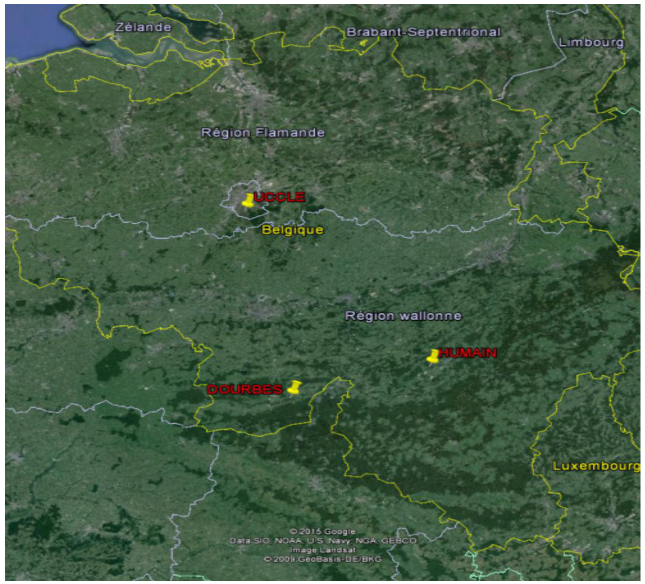
To obtain the trajectory:

- Once we have the direction of the reflection point, it is possible to compute the <u>height of this reflection point</u>:
  - For shower meteors, it can be obtained since we know the direction of the radiant
  - For sporadic underdense meteors, it can be estimated from the exponential decay of the power profile (with a good atmospheric profile, e.g. MSISE-00)
  - For sporadic overdense meteors, it can be estimated using the method developed by Carbognani et al. (2000).
- 3 other stations are required to have the full trajectory of the meteor.

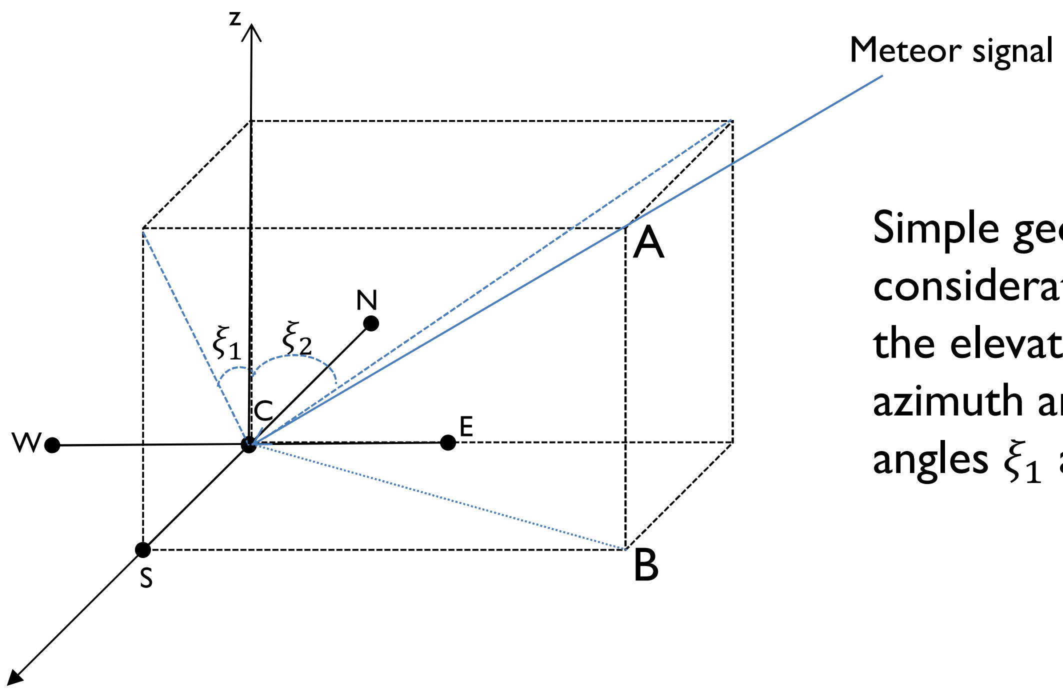
BRAMS interferometer

- Located in Humain (50.16°N, 5.22°E)
- 5 antenna configuration: 2 orthogonal sets of 3 aligned Yagi antenna with the central one common to the two sets.
- All antennas are mounted vertically to decrease the influence of the ground
- In principle it allows to determine the angle of arrival of the signal without ambiguity with an accuracy ~1 °





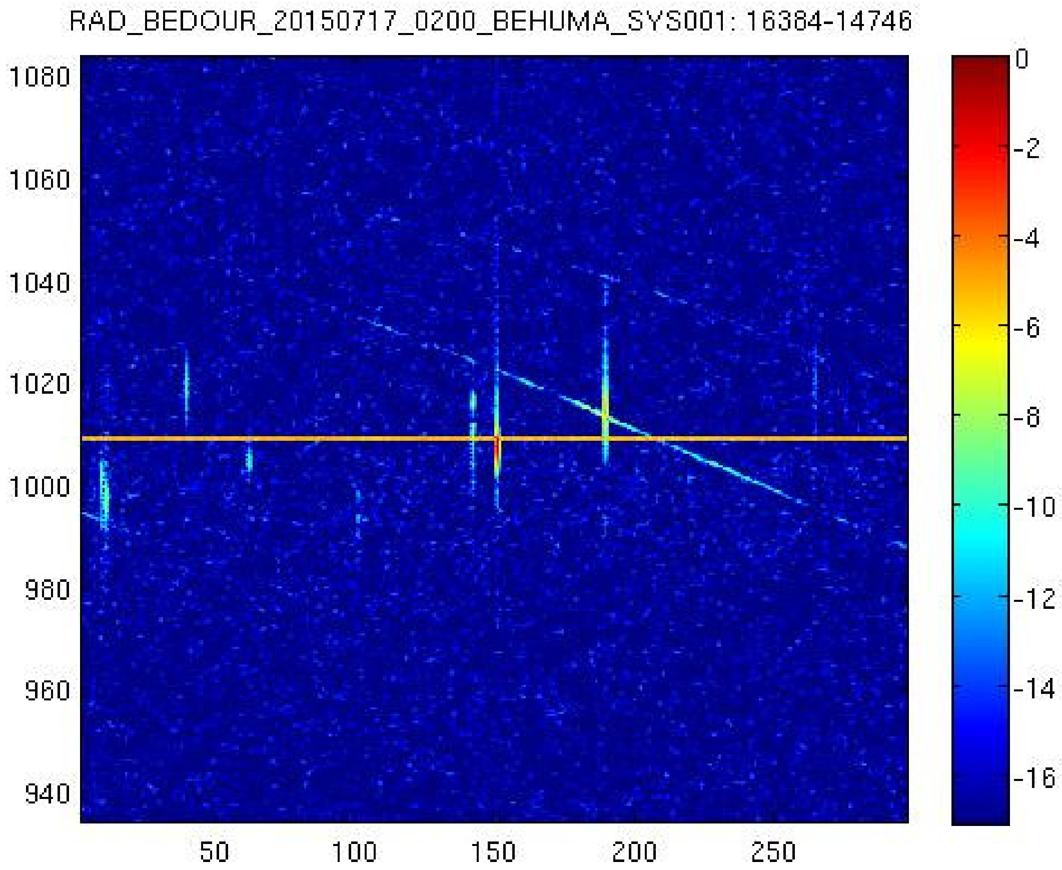
BRAMS interferometer



Simple geometrical considerations allow to calculate the elevation angle (ACB) and the azimuth angle (NCB) from the angles ξ_1 and ξ_2

Some results

We use a spectrogram deduced from measurements performed in Humain the 17th july, 2015 (02h00)

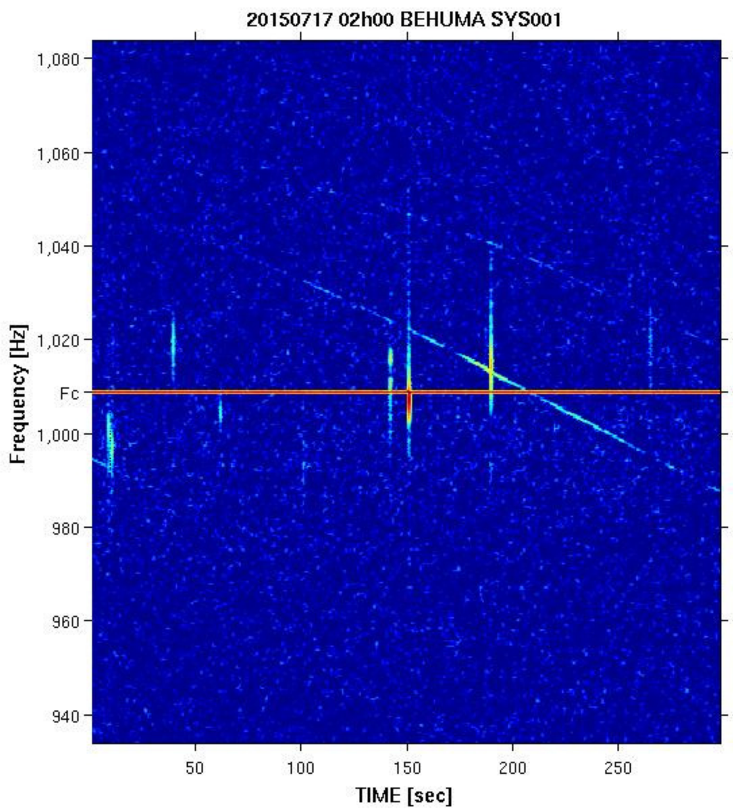


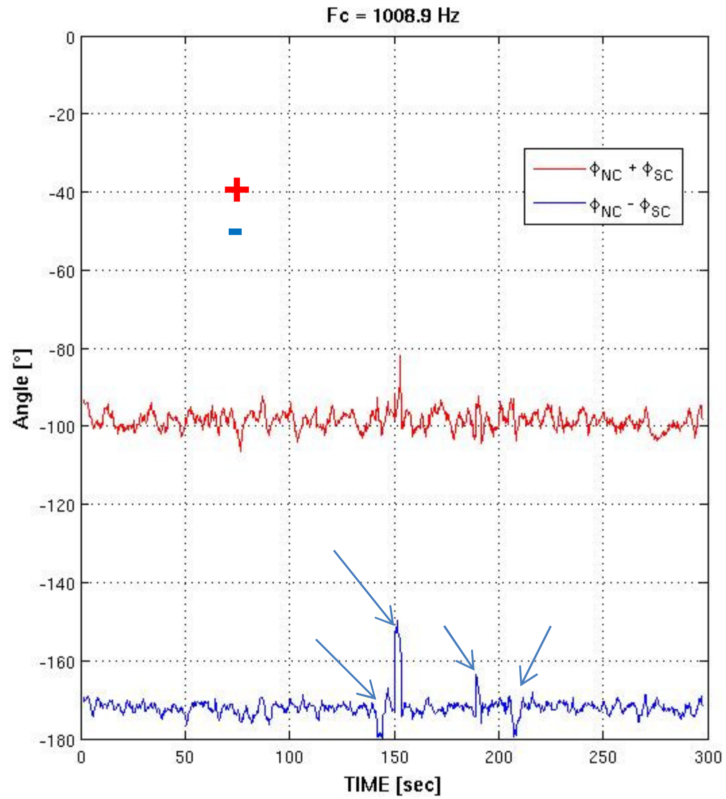
- We use a moving temporal window of 3 seconds to calculate the phase of this signal as a function of time for the frequencies of interest.
- We present in the following slides $\phi_{NC} - \phi_{SC}$ and $\phi_{NC} + \phi_{SC}$ as a function of time where

$$\phi_{NC} = \phi_{North} - \phi_{Center}$$
$$\phi_{SC} = \phi_{South} - \phi_{Center}$$

Similar results are obtained using east and west antennas.

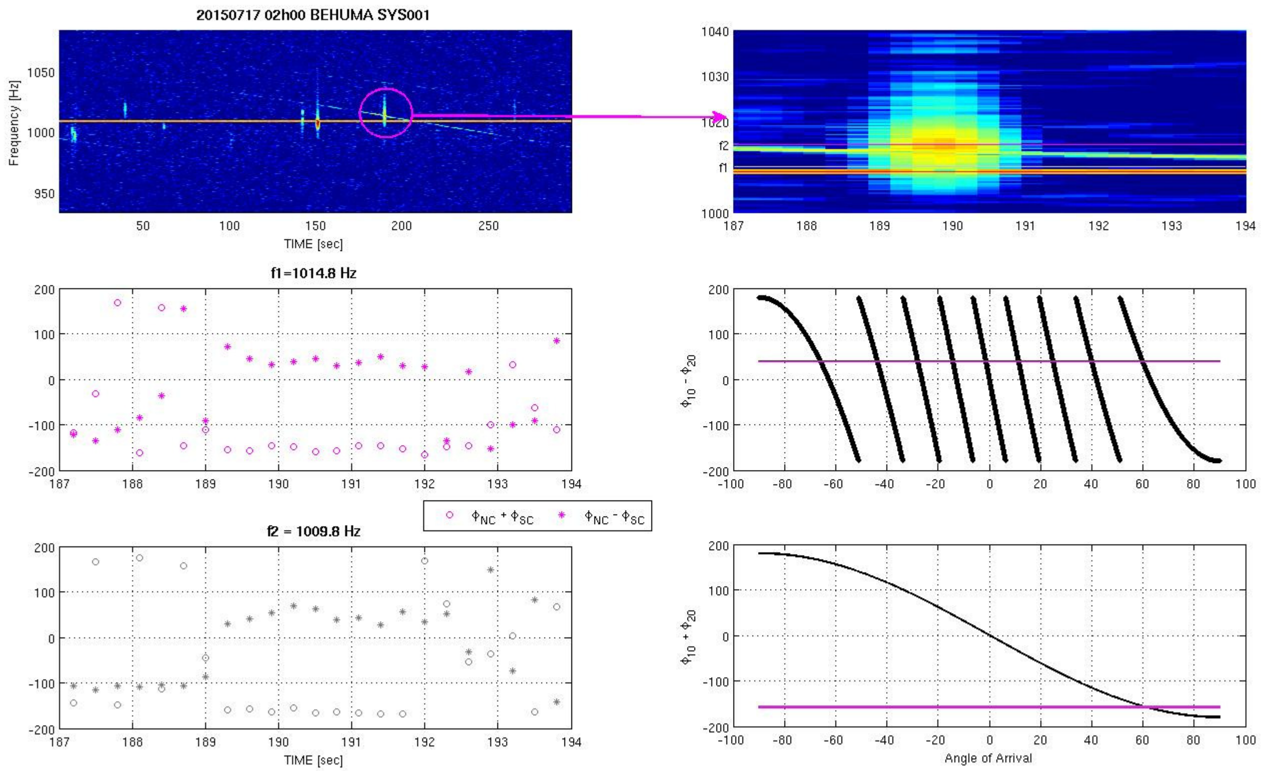
At the frequency of the beacon (f=1008.9 HZ)





Both curves are almost constant (with some noises) and particular strucures emerge when we have also the signal of a meteor or of a plane

Underdense meteor (two differents frequencies)



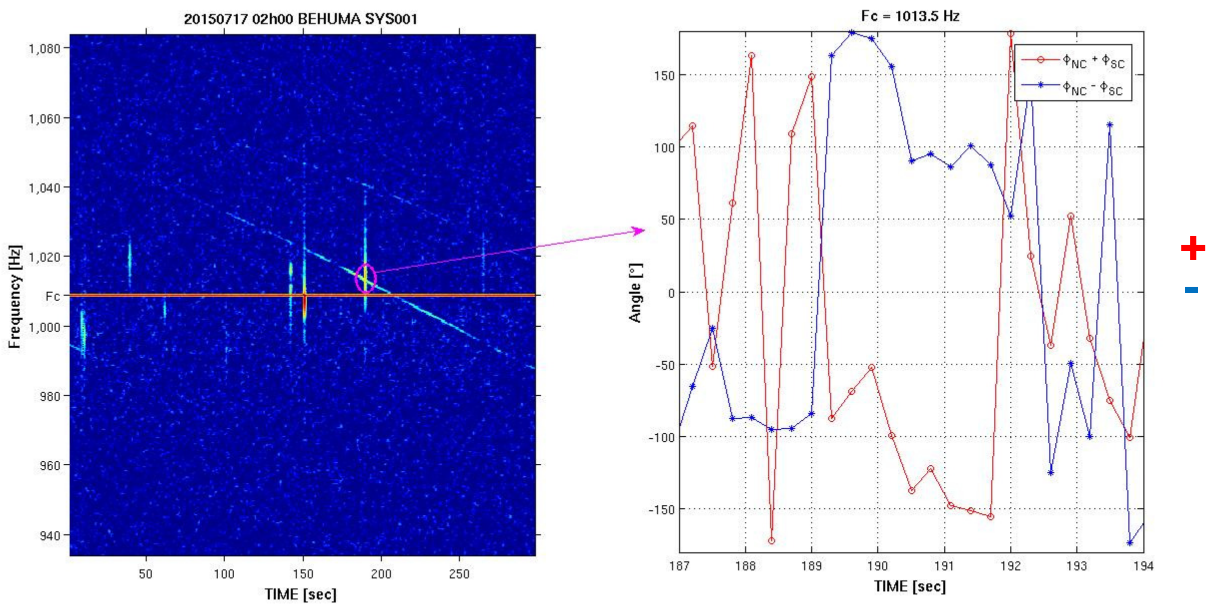
Before and after the meteor, sums and differences (of phase differences) are somewhat noisy.

During meteor, sums and differences are constant.

We can use these values to compute the angle of arrival

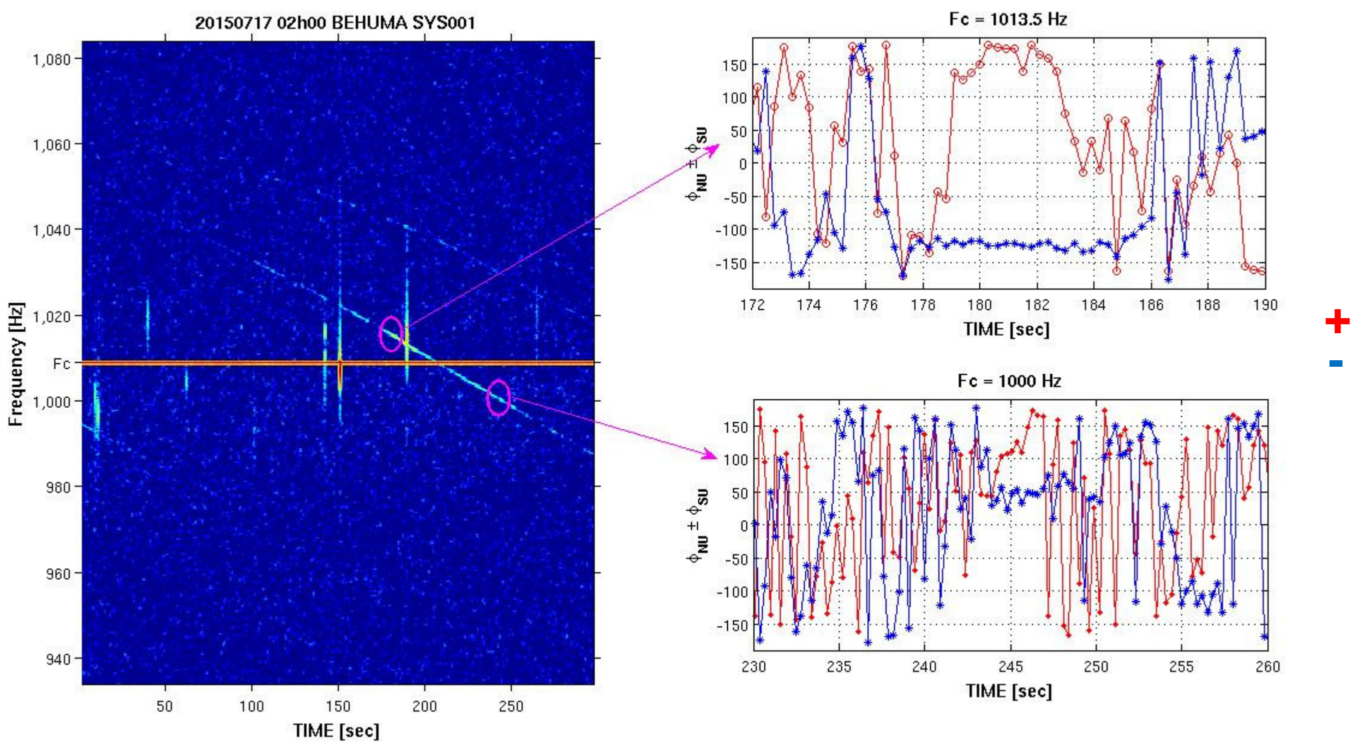
As expected, we found the same values whatever the frequency used

Underdense meteor + plane



During meteor, sums and differences are not constant
We cannot use these values to compute the angle of arrival

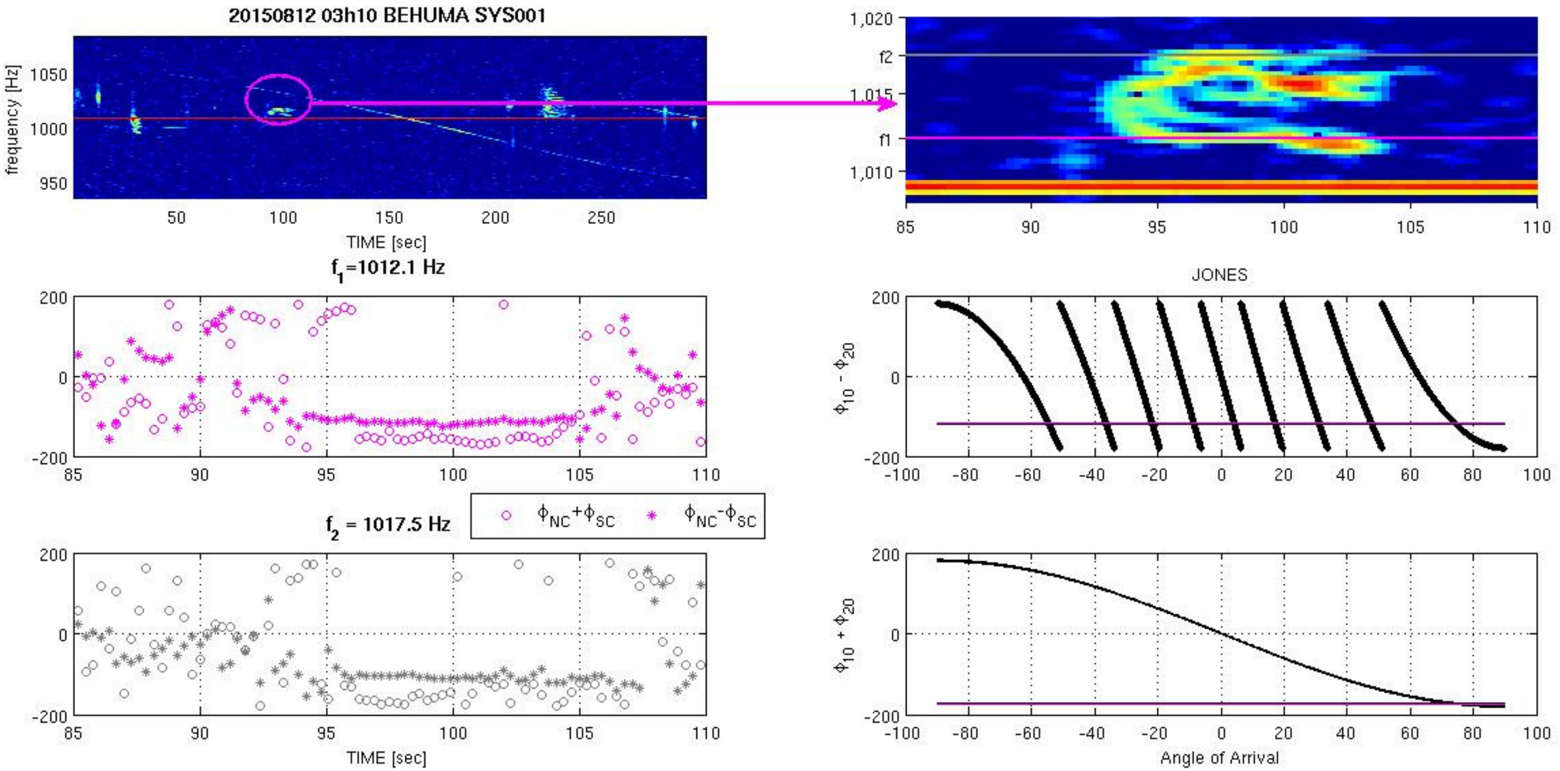
Only plane:



Differences are almost constant but not the sums.
Need to check this with other examples

Some particular meteors

C meteor

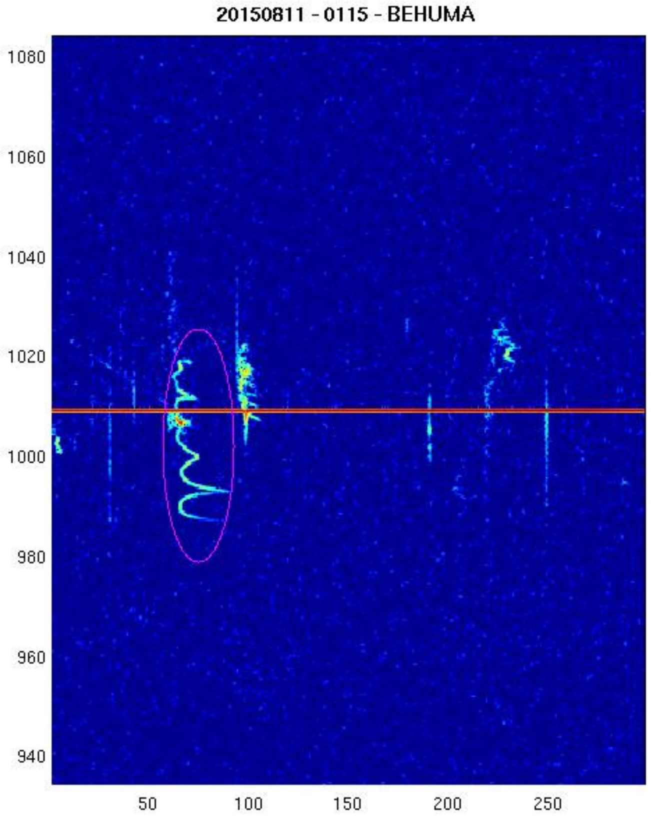


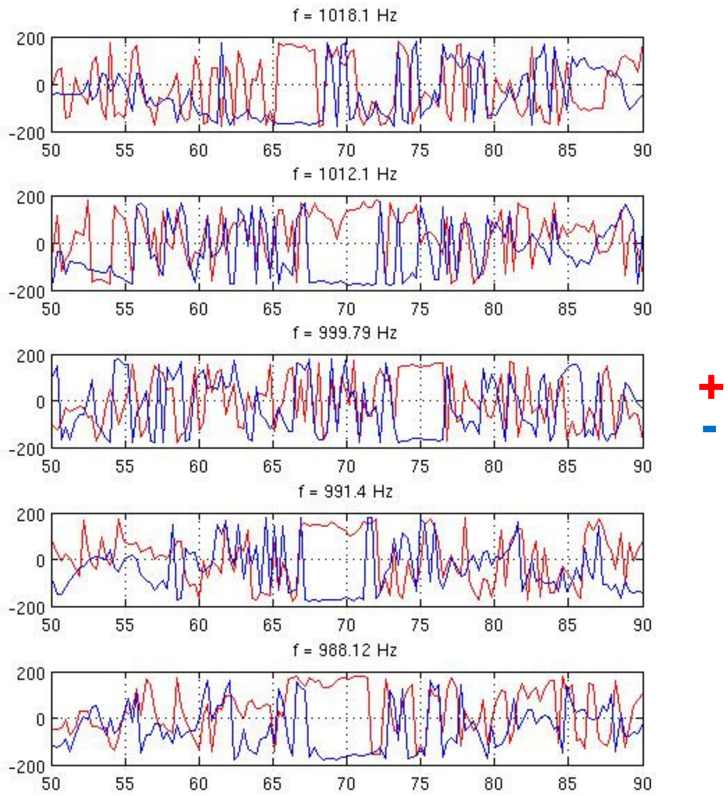
During meteor, sums and differences are constant at the two frequencies (the upper and lower part of the 'C')

The same AoA is found using both values

Some particular meteors

ε meteor





Same structures observed

Conclusions, open questions, …

- Jones method seems to work properly using BRAMS interferometers
- Validation required: maybe by using a drone
- Need to detect the meteor temporally and frequentially and to reject frequencies contaminated by airplane (in an automatic way)
- When a meteor is well detected:
  - Do we need to use all the frequencies where we observe the meteor and integrate them? Or only the frequency with the brightest signal? Or …
- …