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RECONSTRUCTION DE TRAJECTOIRES DE MÉTÉORES

RETRAM
A network of passive radars to detect and track local meteors - first results

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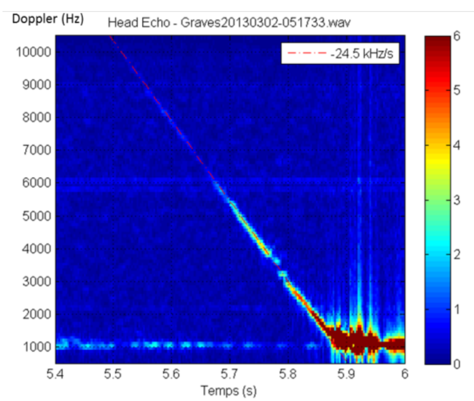
Outline of the presentation

- What is RETRAM
- Studied phenomenology
- Quick reminders on passive radar
- RETRAM setup for meteor detection & tracking
- Results and extensions
- NenuFAR and meteor detections

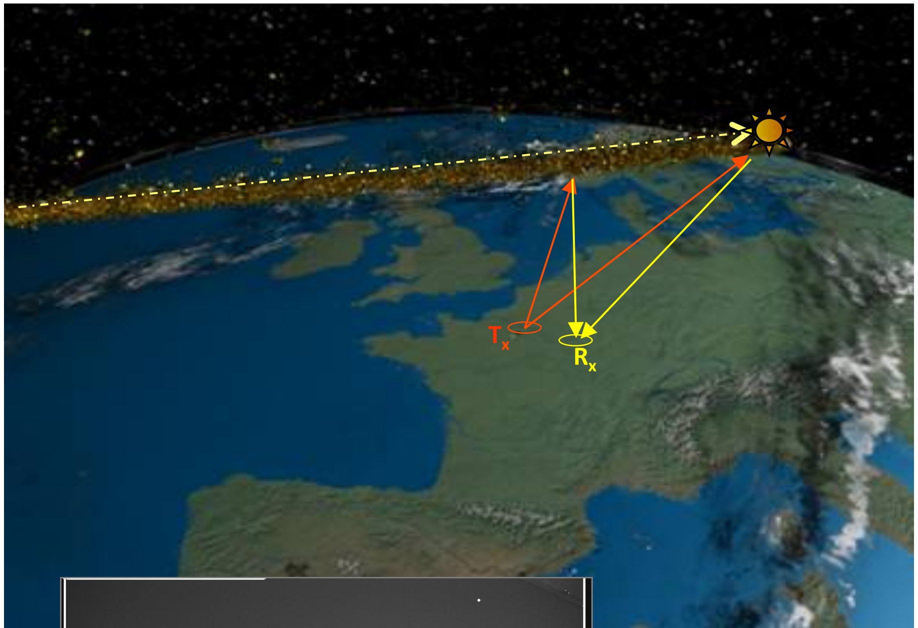
What is RETRAM ?

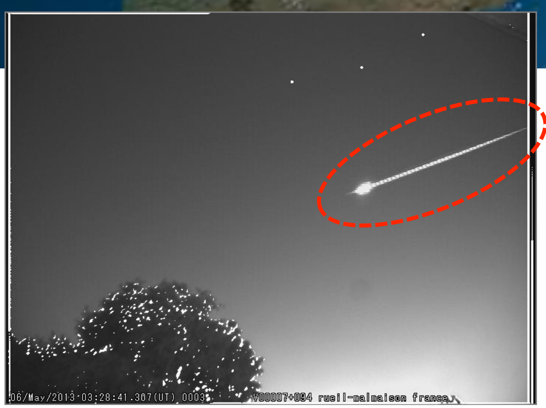
- **RETRAM** started as an amateur experiment to detect and track meteors heads and trails using <u>passive radar techniques</u>,
- Project started in 2012,
- First RETRAM station in Orsay (South Paris).



VHF Cross-pol yagis
VOR + FM

Phenomenology



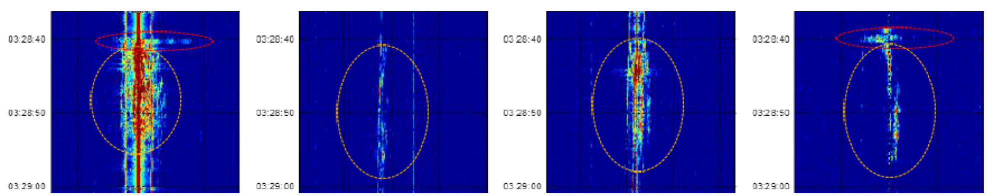


A meteor entering the atmosphere (~60 km/s) loses some of his matter (ablation) and heats surrounding air.

This temperature increase along the trail becomes reflective for RF signals (plasma).

RF transmissions coming from the ground are then scattered by both head and trail.

RETRAM uses this phenomenon to detect the falling body.



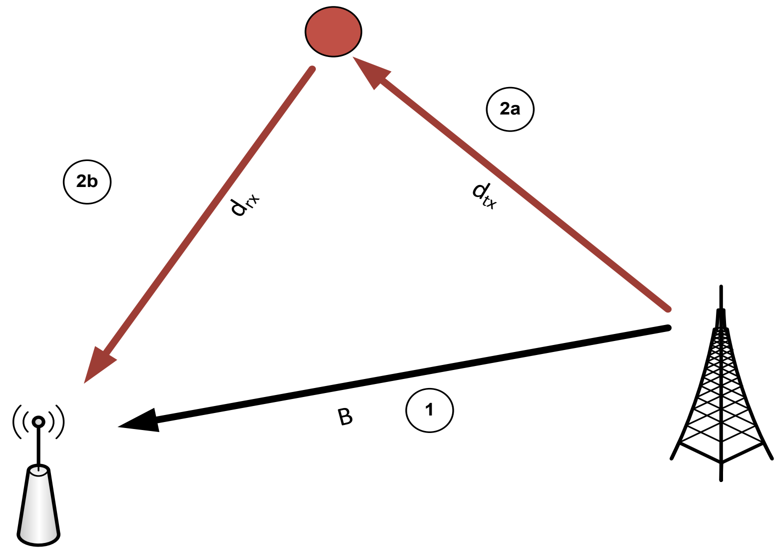
VOR signals scattered on meteor

Passive Radar theory
quick reminders

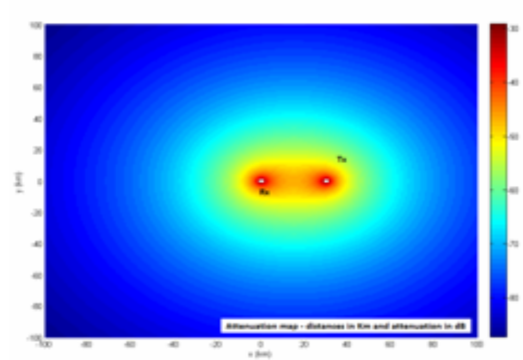
Passive Radar : « *a class of radar systems that detect and track objects by processing reflections from non-cooperative sources of illumination in the environment, such as commercial broadcast and communications signals* »
Wikipedia

Passive detection : fundamentals of passive radar

- Energy scattered on body and reaching receiver



$$P_r = \frac{P_t.\lambda.g_t.g_r.\sigma.f}{(4\pi)^3 (d_{tx}.d_{rx})^2}$$

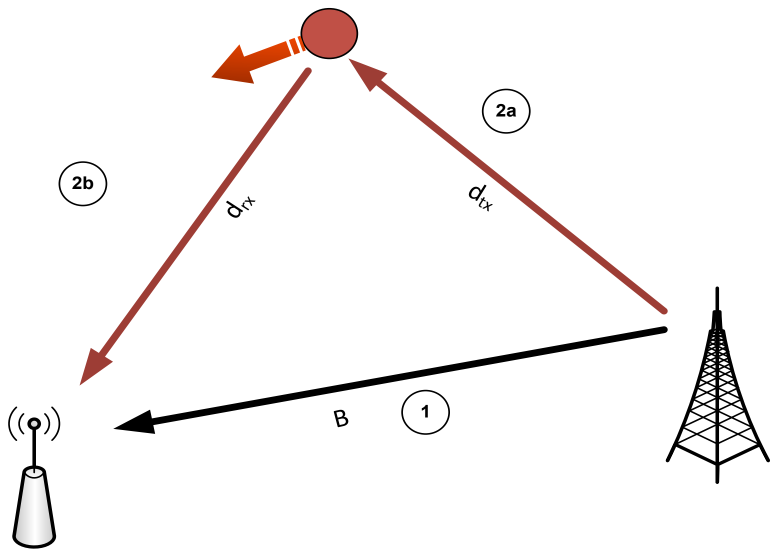


Where

- ***P_t*** is the power at the transmitter,
- ***g_t*** and ***g_r*** respectively antenna gains at transmitter and receiver,
- the bistatic radar cross section **σ**
- ***d_{tx}*** distance from object to transmitter,
- ***d_{rx}*** distance from object to receiver.

Is object and frequency dependant

Bistatic Doppler



Assuming the transmitted signal is written as :

$$s(t) = A(t).e^{j\omega(t).t+\Theta(t)}$$

Signal reflected on moving body is frequency shifted (Doppler effect) and becomes :

$$s(t) = A(t).e^{j\omega(t).t+\Theta(t)}.e^{jD_{opp}(t).t}$$

$$D_{opp}(t) = \frac{-1}{\lambda}\left[\frac{\partial d_{rx}}{\partial t} + \frac{\partial d_{tx}}{\partial t}\right]$$

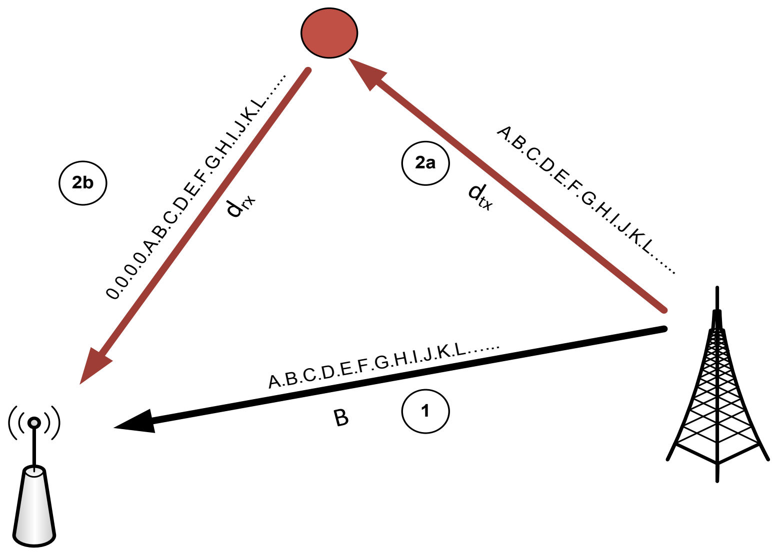
Signal 'visual interpretation' tricky because resulting Doppler shift is sum of two partial derivatives

Doppler Only target tracking can be done but needs many measurements and does not always work

Experiments using VOR transmitters were tried and abandoned: too complex and requires a path hypothesis.

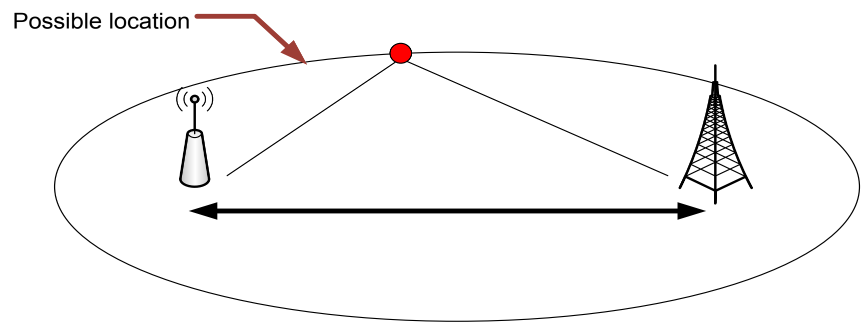
Signal delay

- Signal traveling from transmitter to object and then from object to receiver is time delayed



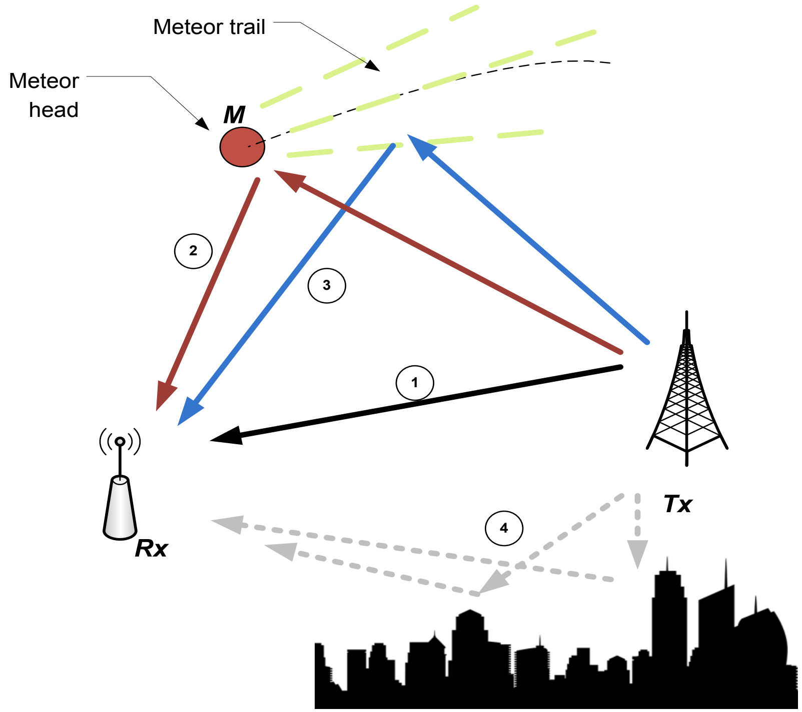
$$rx(t) = tx(t-\tau) = tx(t - \frac{d_{tx} + d_{rx}}{C})$$

Receiver gets time delayed signal + direct signal.
Delay estimation gives an ellipse of possible location



$$\tau = \frac{d_{tx} + d_{rx}}{C} = const$$

Signal collected by receiver



Finally the receiver collects :

(1) Direct signal from the transmitter
(2) Signal scattered on meteor head
(3) Signal scattered on meteor trail
(4) Signal from environment
(5) And… noise

$$rx(t) = \underbrace{k.tx(t-\tau_1)}_{1} + \underbrace{\sum_n \alpha_n .tx(t-\tau_n).e^{jD_{opp}t}}_{2+3} + \underbrace{\sum_m \beta_n .tx(t-\tau_m)}_{4} + \underbrace{\eta}_{5}$$

retram

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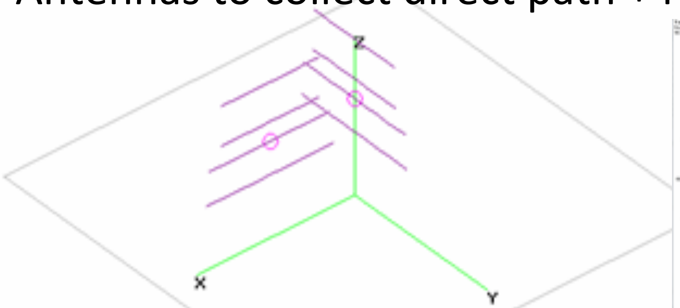
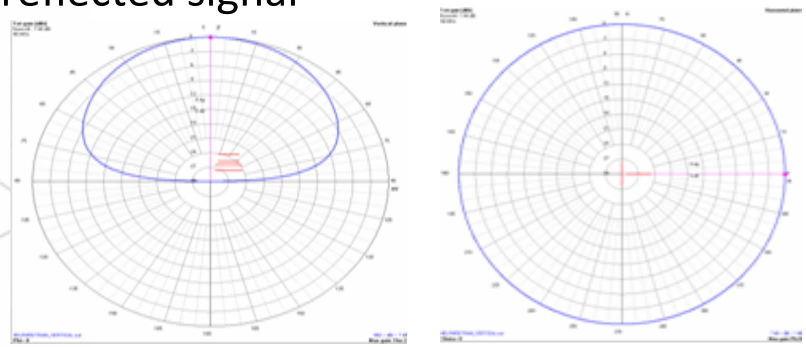
RETRAM setup for meteor detection & tracking

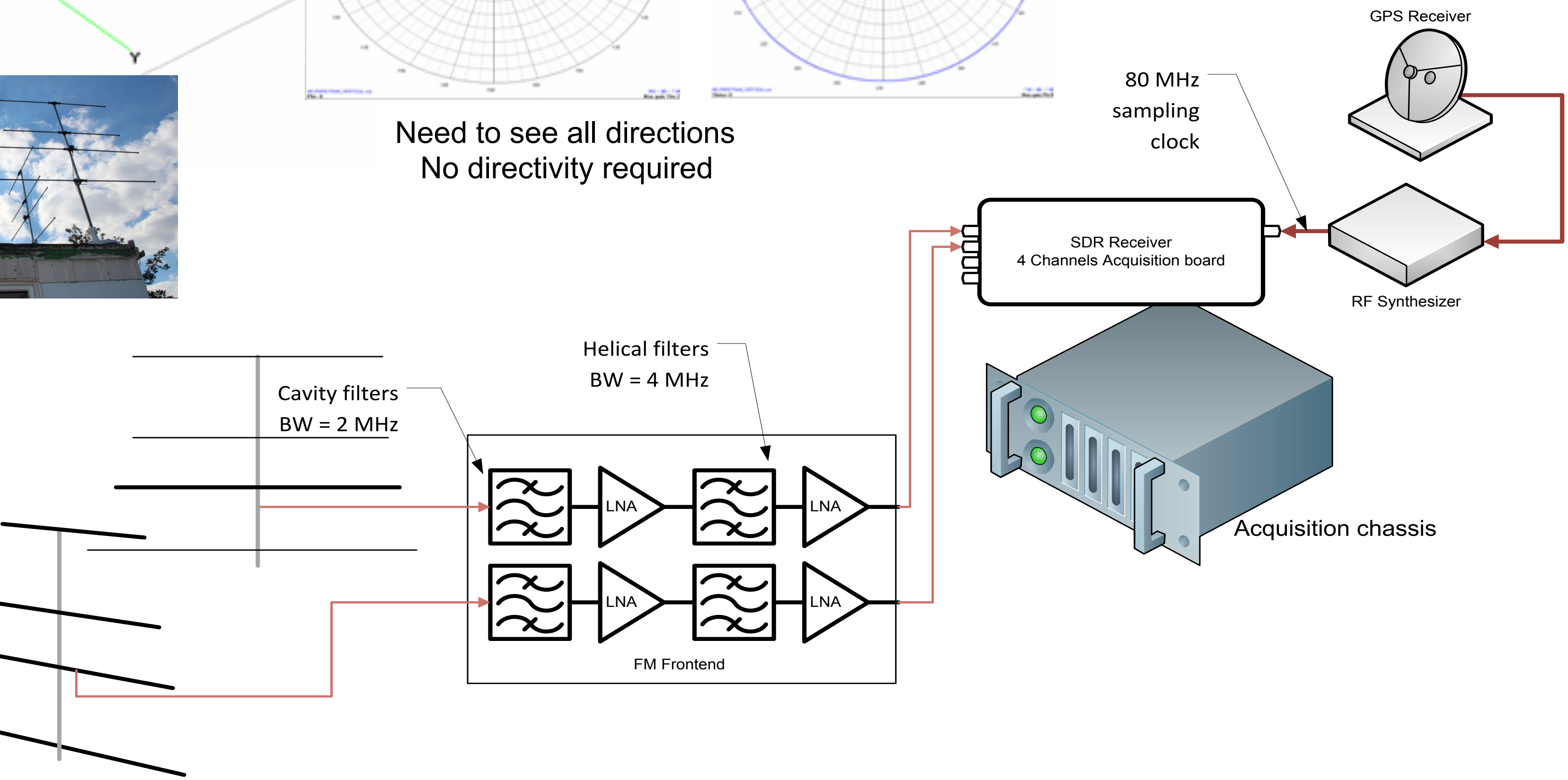
Experimental RETRAM receiver

Antennas to collect direct path + reflected signal



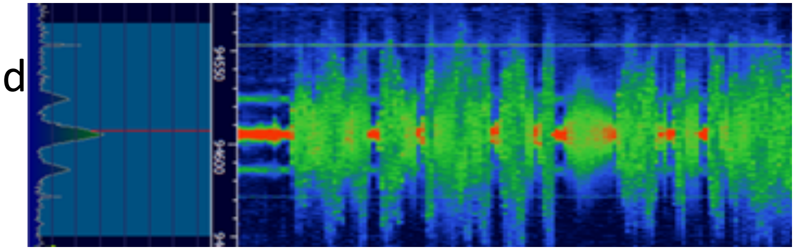


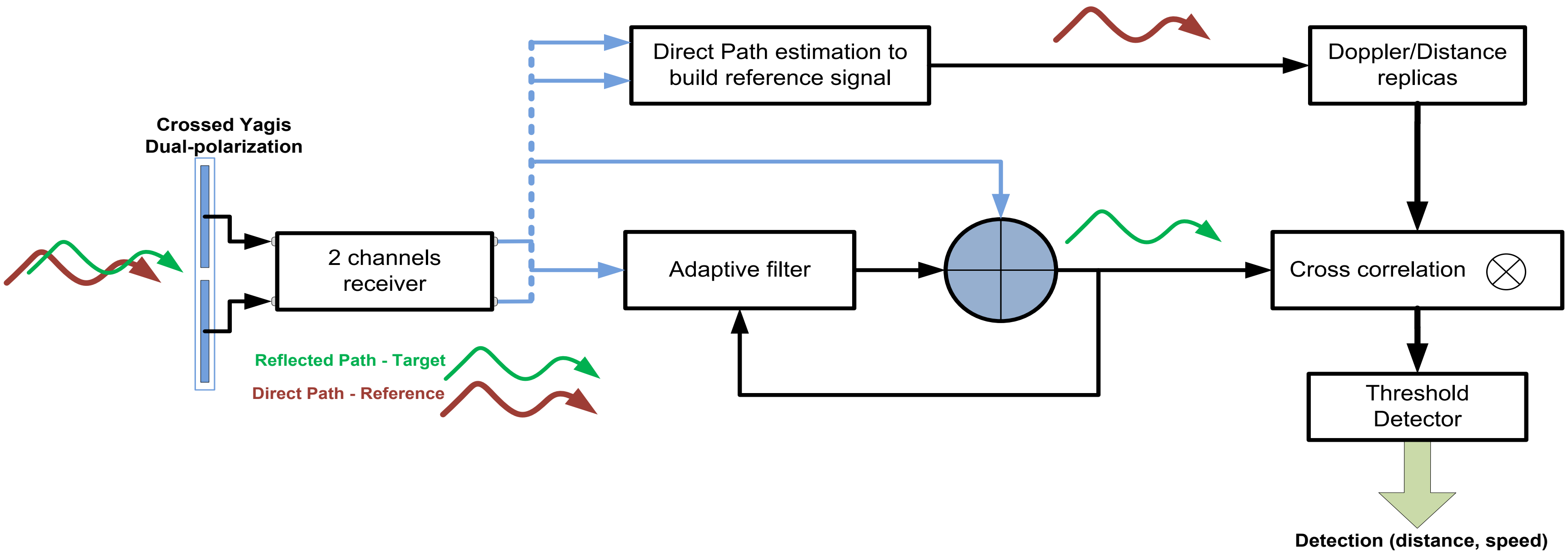
Need to see all directions
No directivity required



Extracting Doppler and delay : signal processing

FM broadcast signal – approx 100 KHz band with limited autocorrelation (depends on content)



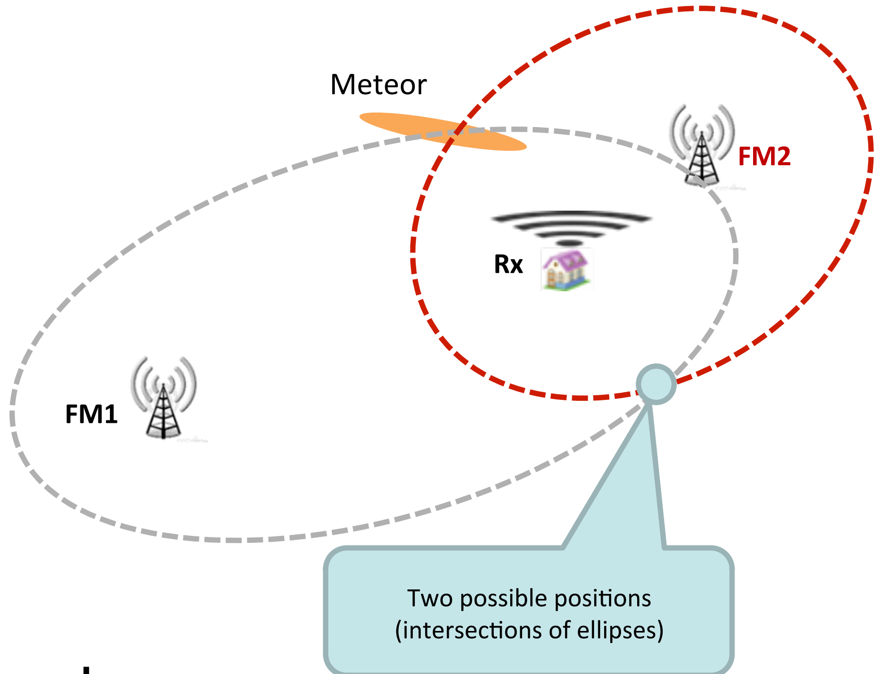


$$rx(t) = k.tx(t-\tau_1) + \sum_n \alpha_n.tx(t-\tau_n).e^{jD_{opp}t} + \sum_m \beta_n.tx(t-\tau_m) + \eta$$

Adaptive filtering to attenuate unwanted signals

Processing ambiguity

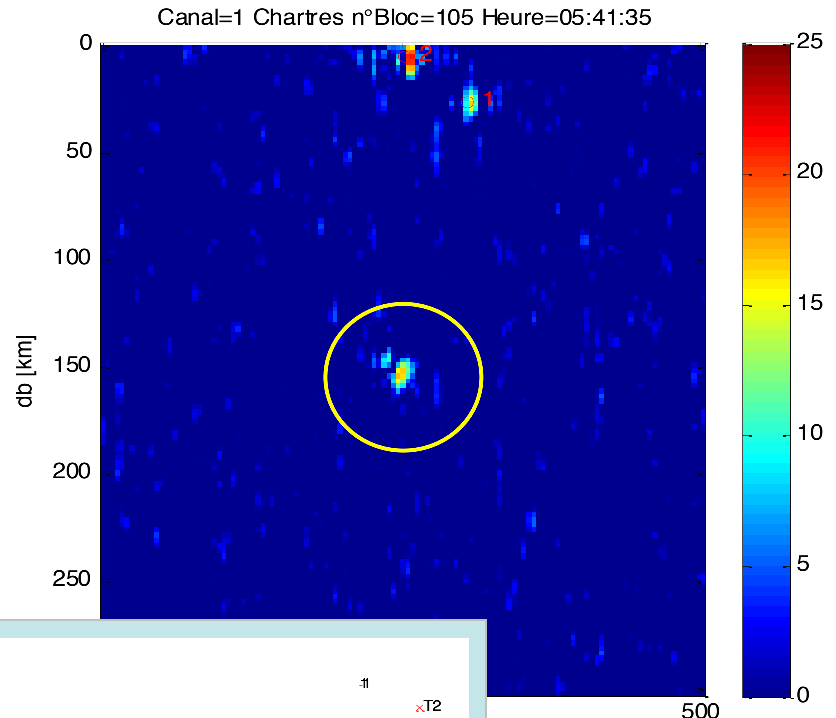
- At the end of the process we have a set of (distances, Doppler) estimations
- Using one receiver and two transmitters does not solve the location problem

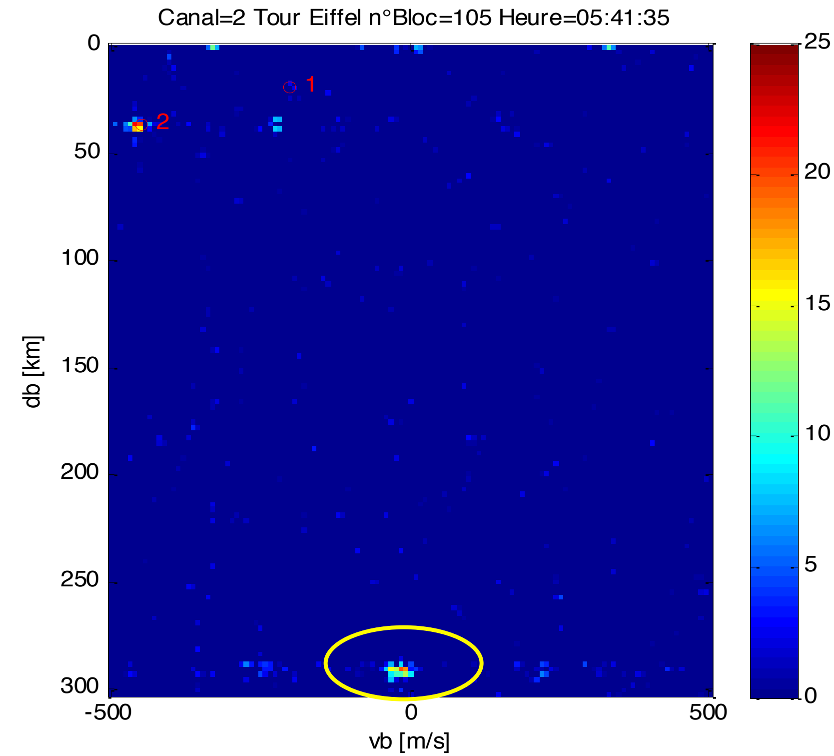


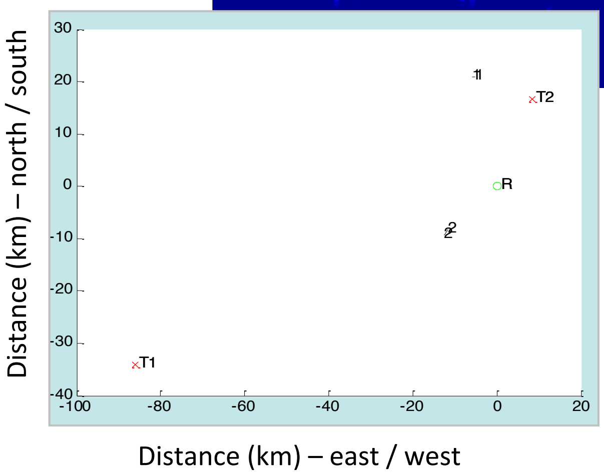
More receivers + transmitters required
→ **going to a network of stations**

First results and extensions

Trail detection – Perseids 2013





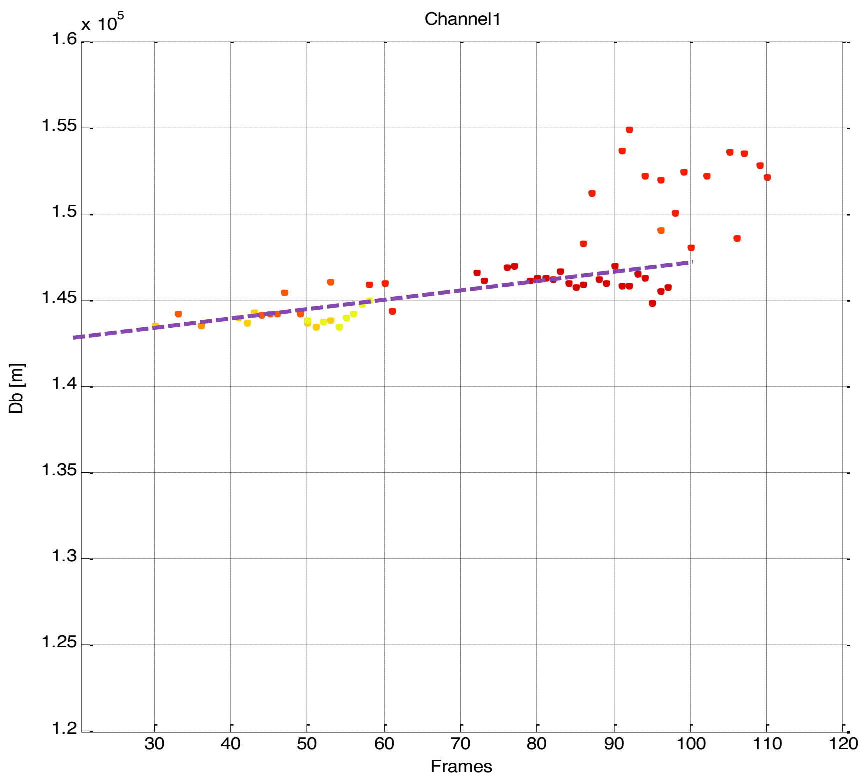


System tuned to work with :

- First FM transmitter in Chartres (T1)
- Second transmitter on top of Eiffel Tower (T2)
- Receiver in Orsay

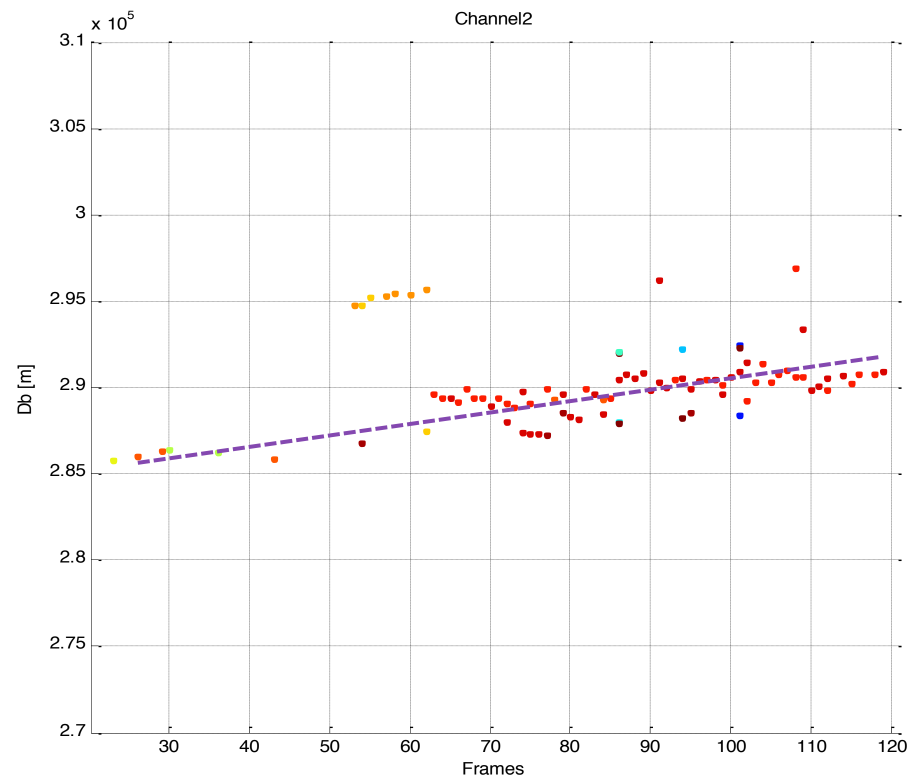
Trail evolution – Perseids 2013

Bistatic distance to Chartres FM TX



Time : 1 frame = 0,33s

Bistatic distance to Eiffel Tower



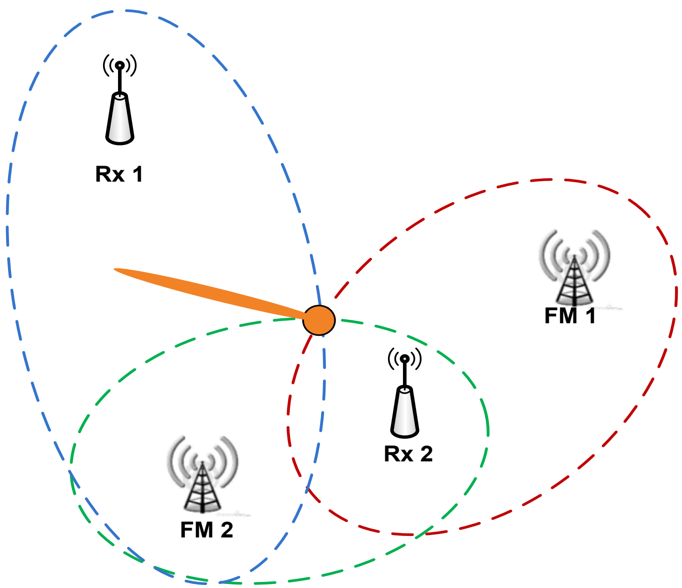
Time : 1 frame = 0,33s

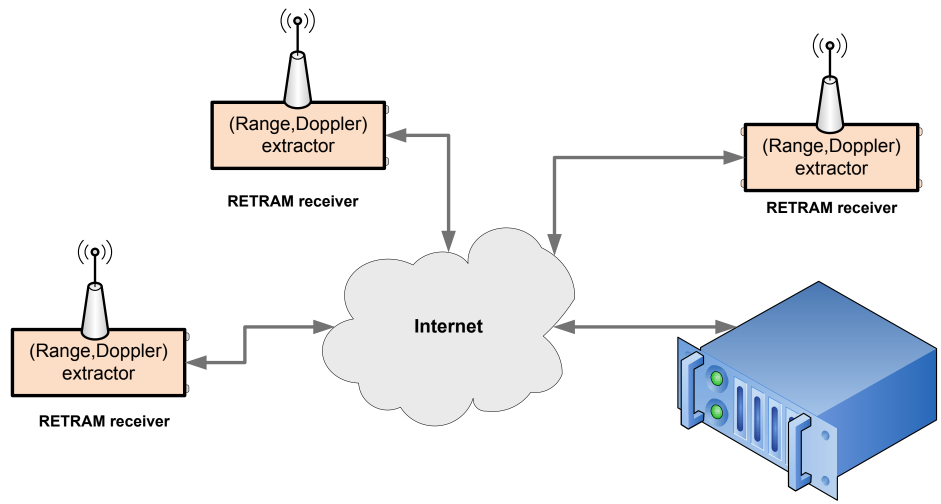
This plot shows the evolution of the distance / speed for one meteor trail during the 2013 Perseids Shower (12/08/2013 3h41 UTC)

What do we detect ?

- Past trials were conducted during main known showers only,
- Did not detect head-echoes during this period (mostly confirmed by other observers),
- Detected several meteor trails (speed very low),
- Objects detected at more than 350 Km (bistatic d.)
- Need all day long system to detect less-frequent head-echoes (wavelength used here does not help to detect small objects)

First steps towards a networked system



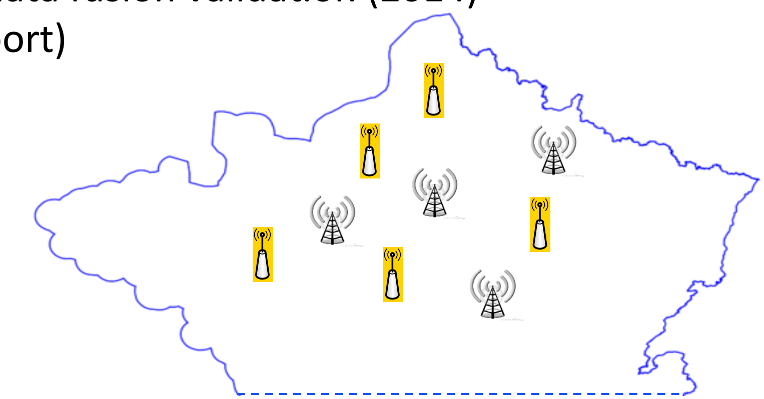


Step 1 : extend current architecture to new locations around Paris for data fusion validation (2014)

- West : Rambouillet Amateur radio club F6KKR (with City funding support)
- East : Marne la Vallée

Step 2 : Open collaboration with scientists and other groups

Step 3 : develop a lower cost system for extended system coverage



NenuFAR and meteor Radio detection

NenuFAR and Meteor detection

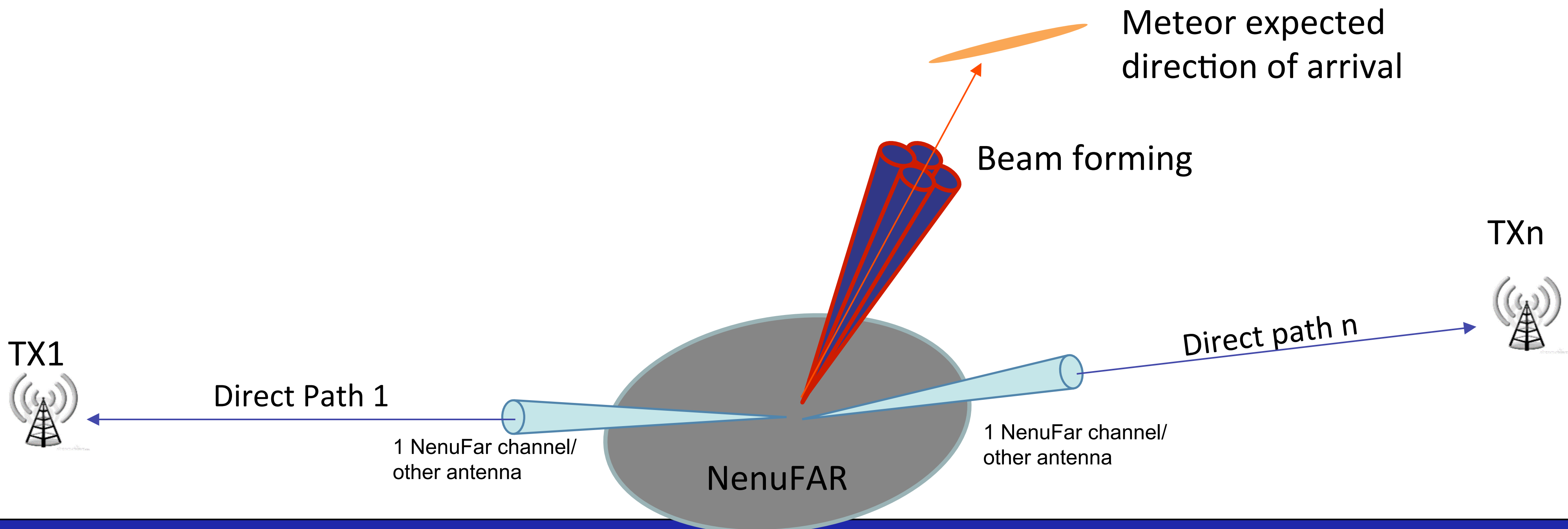
Supposes signal scattered on meteor and reflected to ground:

1. **Frequency coverage ?**
2. **Ability to collect direct path at low elevation ?**
3. **Location of object not known a priori → need to receive and post beam form for focusing (or focus on expected radiant)**

Many antennas with beam forming capabilities : improved direct path cancellation on receiving array

→ <u>Capacity to detect smaller objects (weaker signals)</u>

→ <u>Beam forming for DOA estimation to limit ambiguity (replaces multiple stations)</u>



Thank you !

Questions ?

More details on www.retram.org

Backup slide

	Radioastronomie		Météores	
Observations	Prédictible	La fenêtre d'observation est adaptée à l'objet. Le temps d'enregistrement est adapté. Le Temps RT est maitrisé	Non prédictible	Temps d'observation long. Temps de RT très important pour des durées d'observation très courtes.
Détection	Prédictible pour la plupart des cas	Temps d'observation limité et adapté	Signaux très variables	Phénomène furtif et à forte migration => traitement adapté
Sensibilité	Elevée	Intégration longue	Faible	Intégration faible / Migration
Ouverture angulaire	Etroite	Zone couverte réduite souvent limitée par le RT	Large	Direction d'arrivée non prédictible sauf pour certains essaims
Résolution angulaire	Elevée	La résolution angulaire contribue à l'analyse	Faible	Pas nécessaire sauf si cela était important pour la localisation
Bande passante instantanée	Elevée	Contribue souvent à l'observation et à la capacité de détection	Faible	Liée à l'illuminateur du système passif. Peu ou pas de système large bande.
Principe	Rayonnement direct	Les rayonnements des différents objets sont observés et analysés	Type Radar passif	Nécessite un illuminateur connu et maitrisé.
Radar Passif	NA	Objets éloignés	Illuminateur maitrisé et adapté	- Compatible Bande NENUFAR - Possibilité de réception du trajet direct (référence temporel) - Bande passante compatible de la précision recherchée