



# HABILITATION A DIRIGER DES RECHERCHES (HABILITATION TO CONDUCT RESEARCH)

presented by

Jean-Philippe OVARLEZ

Some Contributions to Methods of Analysis, Detection, and  
Estimation for Radar and SAR Imaging

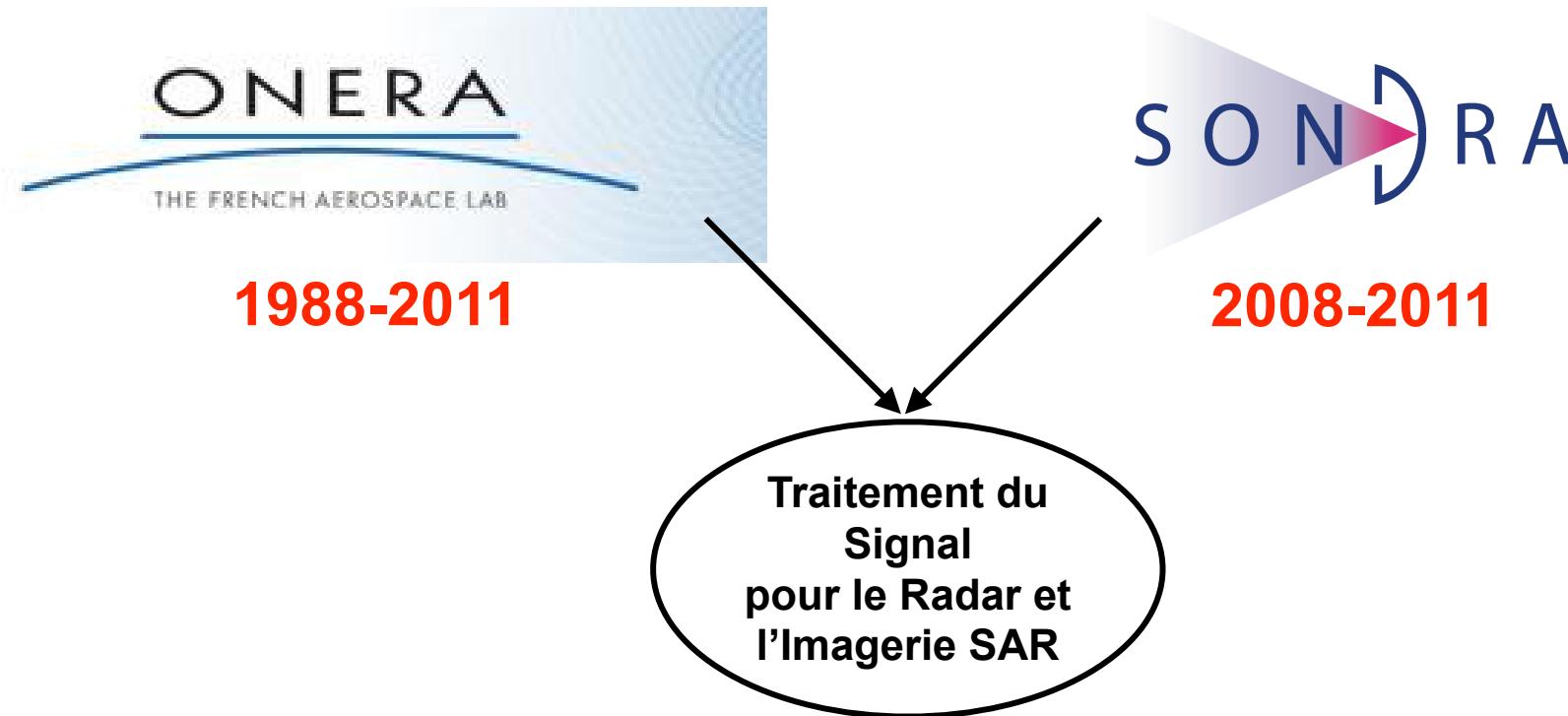


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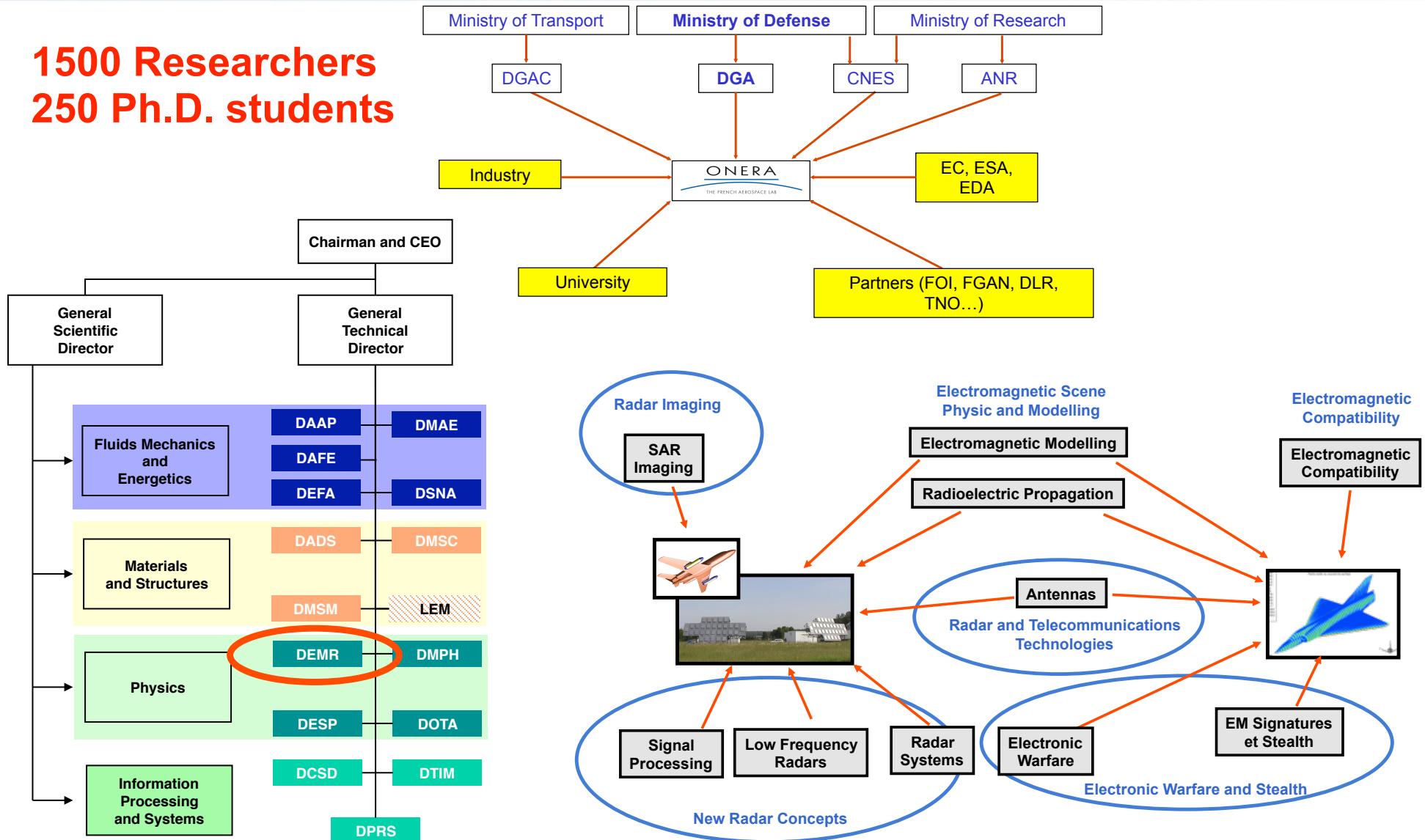
# Current Professional Position

- **ONERA Principal Scientist in TSI Unit (Signal Processing) in Electromagnetism and Radar Department (DEMR)**
- Attached in part time basis in the joint french-singaporean **SONDRA lab (Supélec)**



# Département ElectroMagnétisme et Radar (DEMR) de l'ONERA

1500 Researchers  
250 Ph.D. students



# SONDRA



Supélec – University of Engineering



**FRANCE**



Onera (The French Aerospace Lab)



**SONDRA**  
**(Supélec Onera Nus  
Dsta Research  
Alliance)**



National University of SINGAPORE



**SINGAPORE**



The Defence Science & Technology

**MISSION :** Researching in Electromagnetism and Signal Processing for developing future radars.

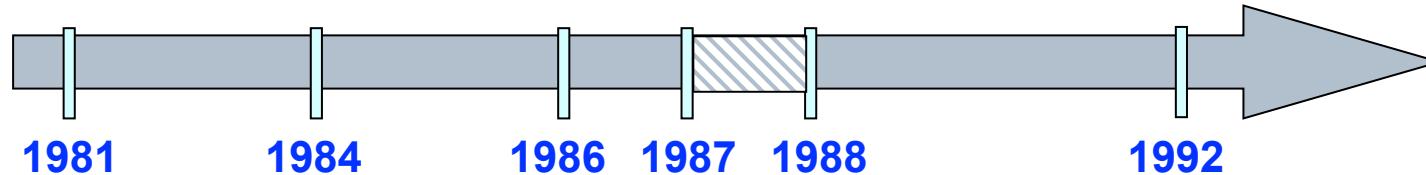
# Outline

- **Personal Background**
  - Education Background
  - Professional Background
  - Main axes of Contractual Studies
- **Thematics and Research Works**
  - Chronology
  - Radar Detection and Estimation
  - Radar/SAR Imaging
- **Synthesis of Research Activities**
  - Teaching Activities
  - Publications and Reports
  - Supervisions
  - Scientific and Administrative Responsibilities
- **Perspectives**

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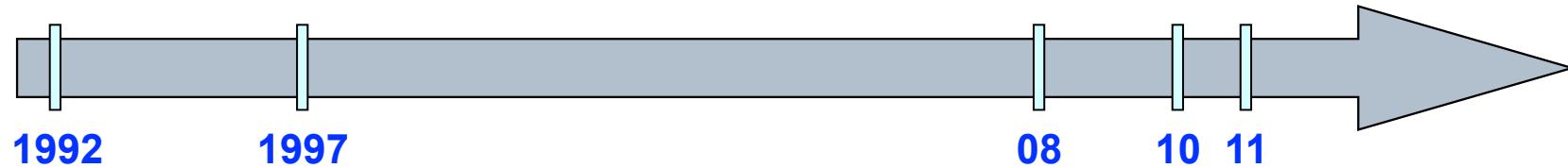
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# Education Background



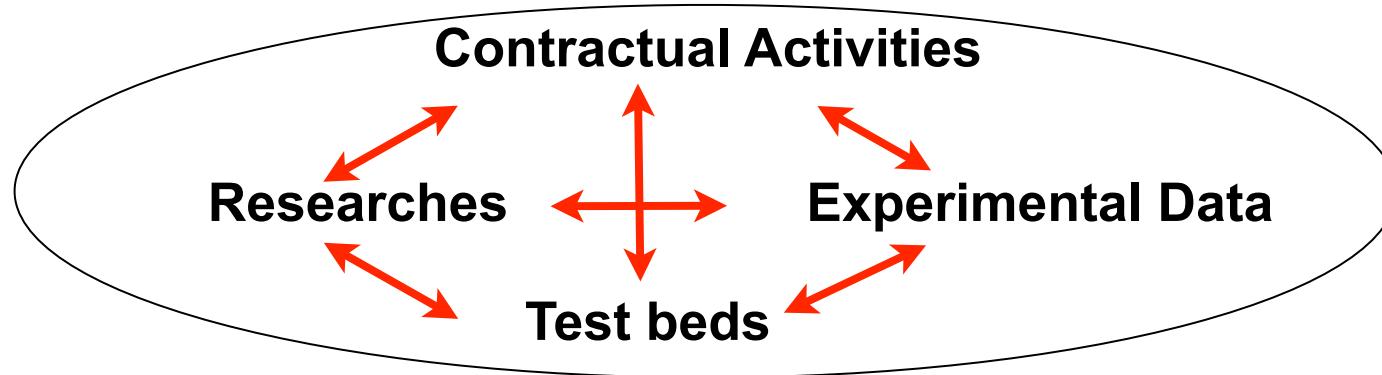
1981	Baccalauréat of Science
1981-1984	Schools preparing to «Gandes Ecoles» - Math option
1984-1987	ESIEA Electrical Engineering School
1986-1987	M. Sc. in Automatic and Signal Processing in Paris 11
1987-1988	Military Education and Training
1988-1992	Ph.D. Thesis in Physic ONERA/Paris 6 (Signal Processing) : <i>The Mellin Transform : A Tool for Broad-Band Signal Analysis</i>
1992	Research Engineer in l'ONERA

# Professional Background

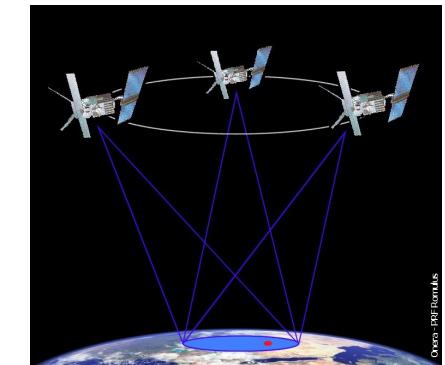


1992-1997	Research Engineer in the <i>Future Radars Unit of the Radar Systems Division in the Direction of the Synthesis Studies</i> in ONERA
1997-2011	Research Engineer in the Signal Processing Unit in the <i>Electromagnetism and Radar Department (DEMR)</i> in ONERA
since 2008	Attached Scientist (40%) in SONDRA Lab in Supelec : <b>Responsible of Signal Processing activities</b>
2010	One Year Attached Scientist (DGA grant) in DSO National Laboratories in Singapore <b><i>Robust Estimation Methods in Compound Gaussian Processes. Application to Radar</i></b>

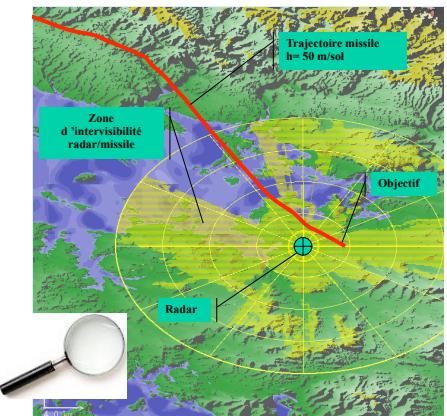
# Main Axes of Contractual Studies in ONERA



- Radar Imaging, SAR and ISAR
- New Radar Concepts (ex : ROMULUS)
- Analysis and Clutter Modelling
- Detection and Estimation (ex : MODEM)
- Radar and SAR Simulators



**ROMULUS**  
Radars Orbitaux  
MULTisatellites  
à Usage de Surveillance



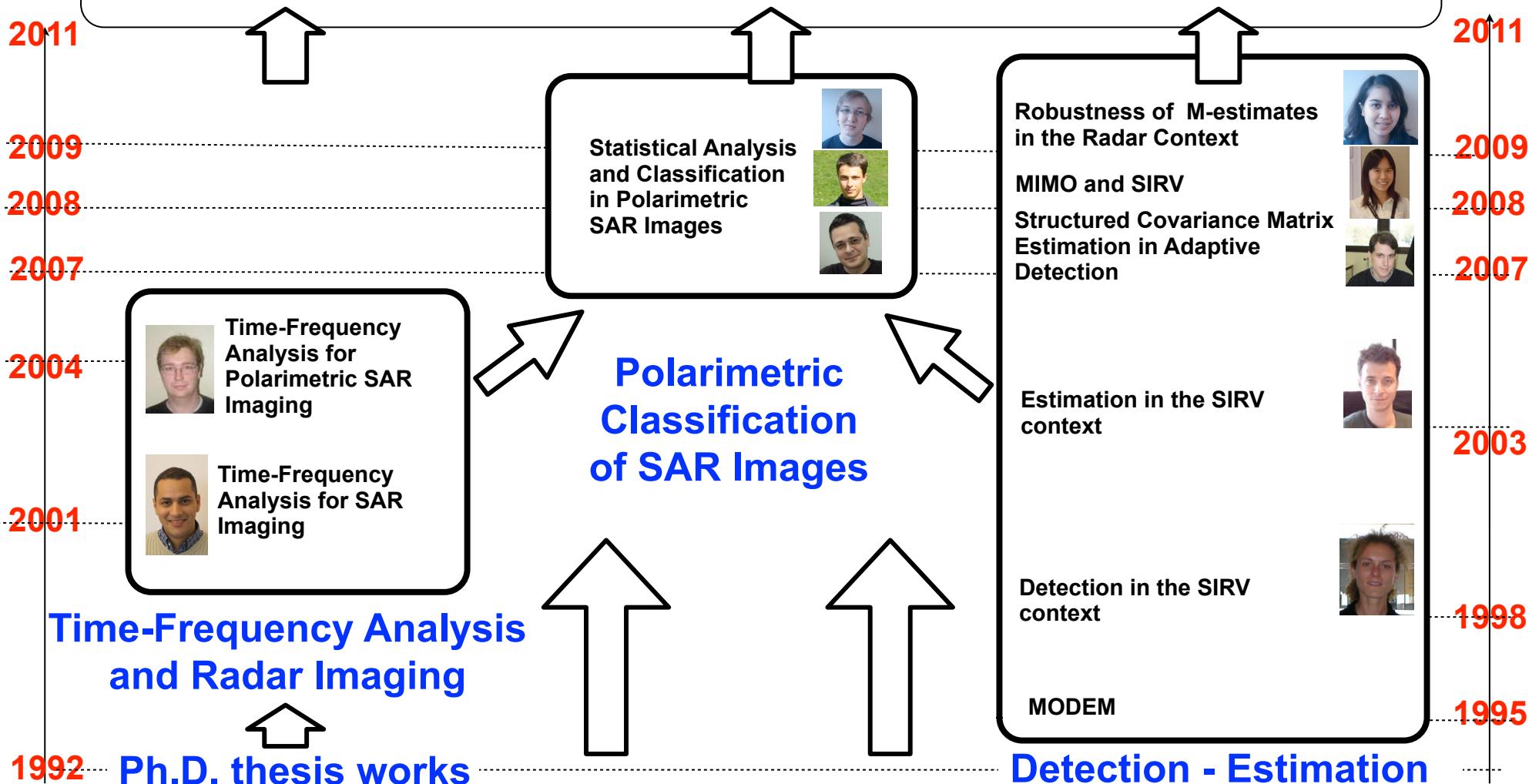
**MODEM**  
Modélisation de la  
DÉtectabilité des Missiles

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# Research Chronology

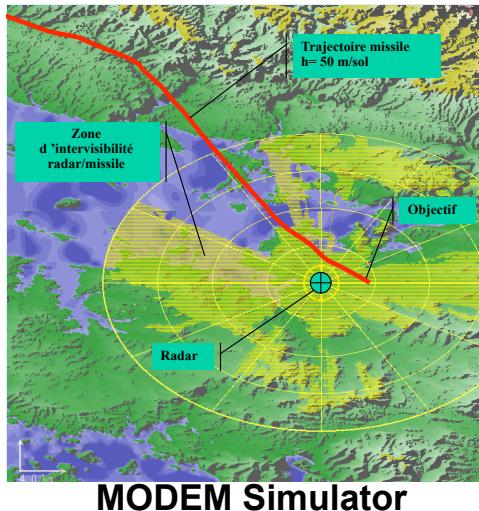
- SAR Images Analysis: Interferometry, Polarimetry, Multi Passes, Multi Band, Multi-Looks,
- Radar Detection : STAP, MIMO, SAR Détection, Hyperspectral Detection



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# Detection and Estimation for Radar



**1992 : MODEM Study:** Simulator evaluating the grazing-angle moving targets detection performance (sensitivity) of a radar and taking into account:

- the terrain
- the target,
- the radar and the propagation.

## At the beginning

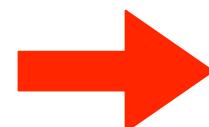
- Model mainly based on Gaussian assumptions,
- Only few clutter measurements available [Ulaby 1989],
- First publications [Billingsley 1993] rejecting the Gaussian behavior of the clutter.

## Problem under study to improve MODEM reliability:

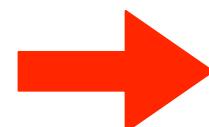
- Realistic clutter data and clutter models support for radar simulators,
- Conventional radar performance quantification against realistic clutter ?
- Derivation of optimal detectors.

# Existing Problems in Radar Detection

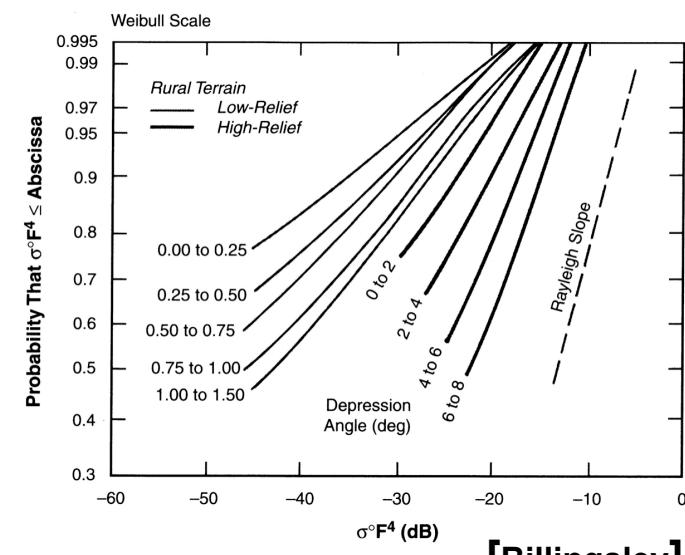
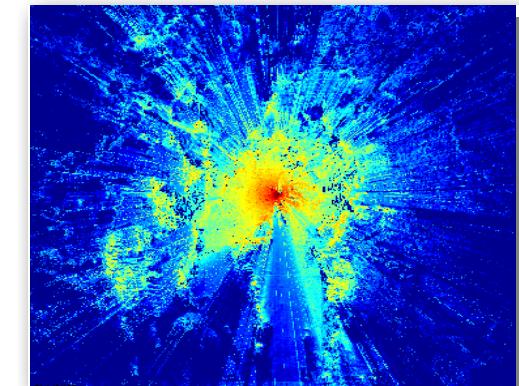
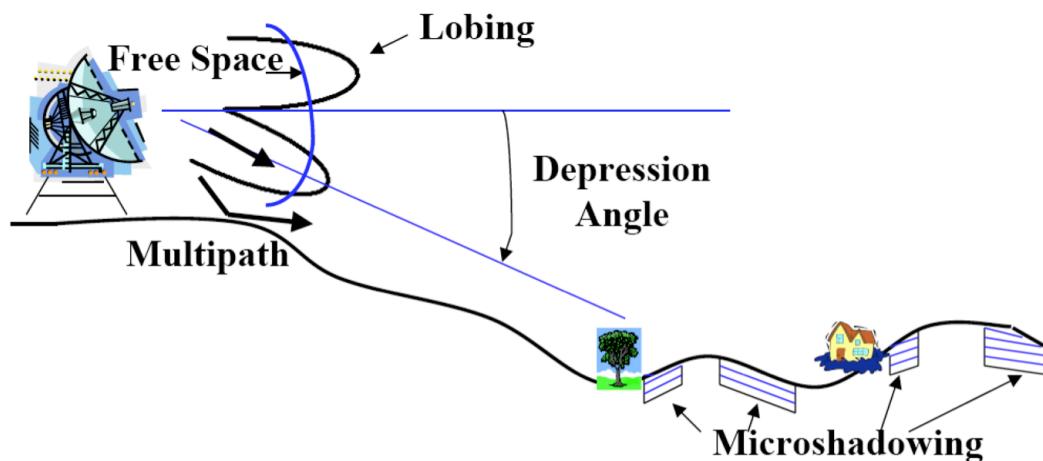
- «High Resolution» Radars: small number of scatterers per cell. Random number from cell to cell,
- Masking phenomena due to relief and above ground.



- Clutter Non-Gaussianity (*Limit Central Theorem not valid*),
- Heterogeneity of clutter areas.



Classical Radar Performance Decreasing.



# SIRV for Radar Clutter Modelling

## SIRV Clutter Modelling

**Spherically Invariant Random Vector : Compound Gaussian Process**

$$\mathbf{c} = \sqrt{\tau} \mathbf{x}$$

- $\mathbf{x}$  is a complex circular Gaussian  $m$ -vector (**speckle**) with covariance matrix  $\mathbf{M}$ ,
- $\tau$  is a positive random variable (**texture**) well defined by its pdf  $p(\tau)$ .

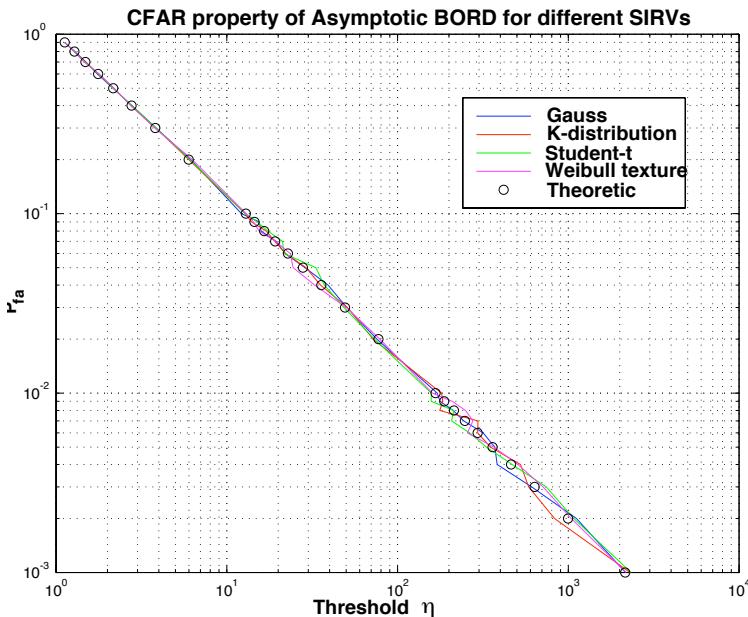
**Powerful Modelling that allows :**

- **to extend the Gaussian model (K pdf, Weibull, Alpha-Stable, ...),**
- **to take into account the heterogeneity of the clutter power with the texture,**
- **to take into account possible correlation existing on the m-channels of observation,**
- **to derive optimal or suitable detectors**

# SIRV Detectors

## Detectors developed in the SIRV context

- SIRV texture  $p(\tau)$  modelling with Padé Approximants [E. Jay Ph.D Thesis 2002],
- Normalized Matched Filter [Picinbono 1970, Scharf 1991], GLRT-LQ [Gini-Conte 1995],
- Bayesian estimation of the SIRV texture  $p(\tau)$  (BORD) [E. Jay Ph.D Thesis 2002].



Texture-CFAR property for the GLRT-LQ

Normalized Matched Filter

$$\Lambda(\mathbf{y}) = \frac{|\mathbf{p}^H \mathbf{M}^{-1} \mathbf{y}|^2}{(\mathbf{y}^H \mathbf{M}^{-1} \mathbf{y}) (\mathbf{p}^H \mathbf{M}^{-1} \mathbf{p})} \begin{cases} H_0 & \geqslant \\ H_1 & \leqslant \end{cases} \lambda$$

**$\Lambda(\mathbf{y})$  is SIRV CFAR  
 but needs to know the true  
 covariance  $\mathbf{M}$**

# Adaptive Detectors in SIRV Noise

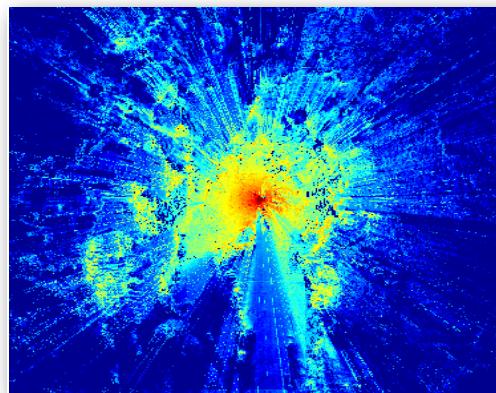
New detectors called **Adaptive Detectors** can be derived by replacing in the NMF a «*good estimate*» of the covariance matrix.

**ACE** : Adaptive Cosine Estimator

**ANMF** : Adaptive Normalized Matched Filter

$$\Lambda(\mathbf{y}) = \frac{\left| \mathbf{p}^H \hat{\mathbf{M}}^{-1} \mathbf{y} \right|^2}{\left( \mathbf{y}^H \hat{\mathbf{M}}^{-1} \mathbf{y} \right) \left( \mathbf{p}^H \hat{\mathbf{M}}^{-1} \mathbf{p} \right)} \begin{matrix} H_0 \\ \lessgtr \\ H_1 \end{matrix} \lambda$$

These detectors are SIRV-CFAR only for some particular estimates of  $\mathbf{M}$  !



$\hat{\mathbf{M}}$  ???

Gaussian MLE

$$\hat{\mathbf{M}}_{SCM} = \frac{1}{K} \sum_{k=1}^K \mathbf{c}_k \mathbf{c}_k^H$$

$$\hat{\mathbf{M}}_{NSCM} = \frac{m}{K} \sum_{k=1}^K \frac{\mathbf{c}_k \mathbf{c}_k^H}{\mathbf{c}_k^H \mathbf{c}_k}$$

[Gini-Conte]

# Estimation in SIRV Noise

For an unknown but deterministic texture parameter, the Maximum Likelihood Fixed Point estimate  $\hat{\mathbf{M}}_{FP}$  (FP) of the Covariance  $\mathbf{M}$  is found [Conte-Gini 2002] to be the solution of the following implicit equation:

## Fixed Point (FP)

$$\hat{\mathbf{M}}_{FP} = \frac{1}{K} \sum_{k=1}^K \frac{\mathbf{c}_k \mathbf{c}_k^H}{\mathbf{c}_k^H \hat{\mathbf{M}}_{FP}^{-1} \mathbf{c}_k}$$

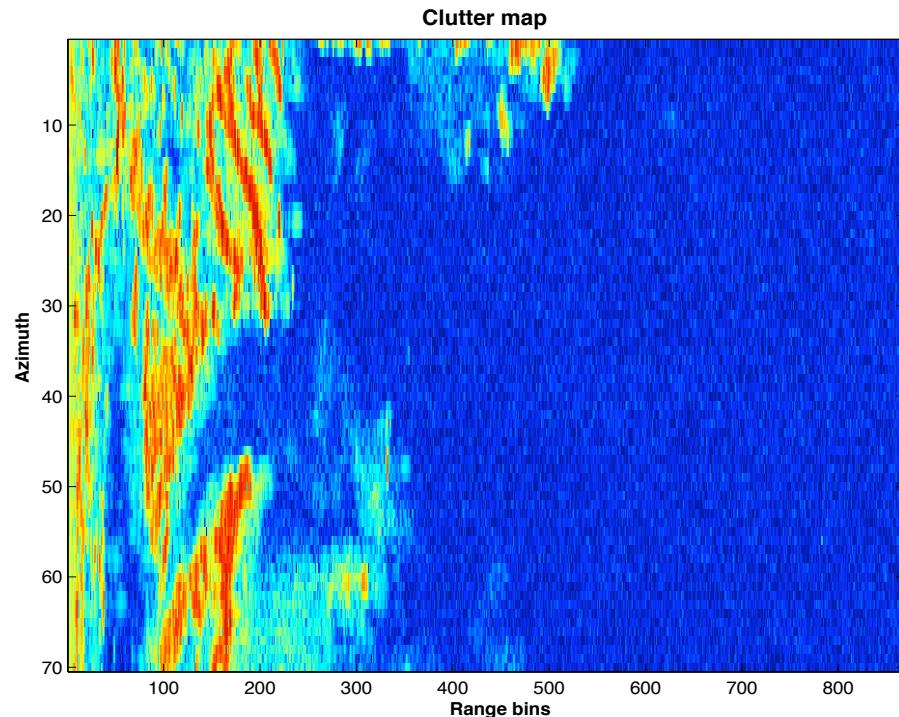
This estimate is an approached MLE in the general SIRV context,

[F. Pascal Ph.D. Thesis 2006]

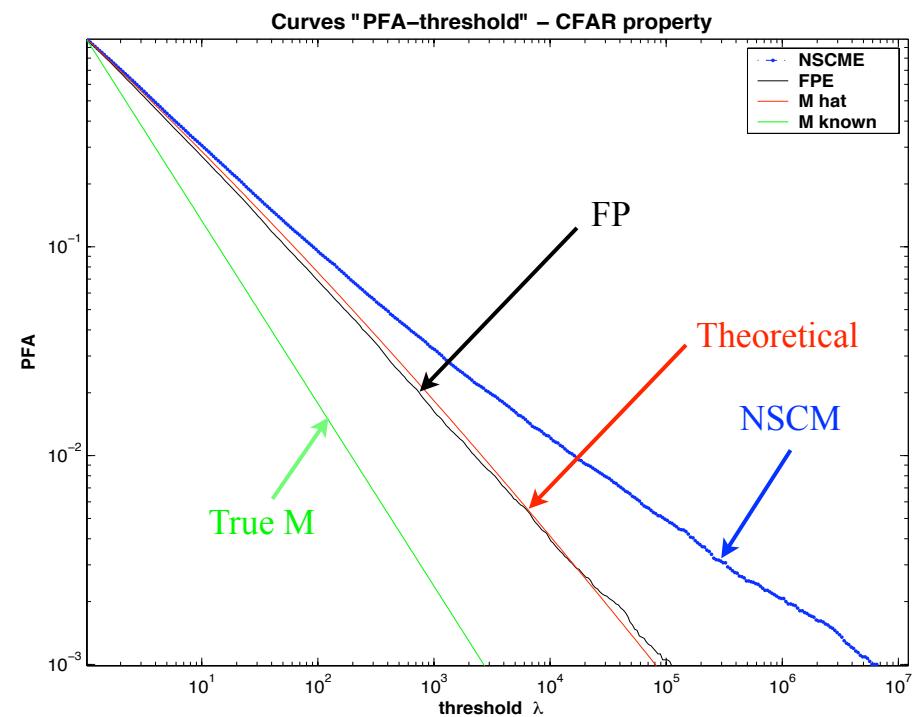
- **Consistent, unbaised, robust, asymptotically Gaussian estimate and supposed to be, at a fixed number K, Wishart distributed with  $mK/(m+1)$  degrees of freedom,**
- **Existence and unicity of the solution are proven. The solution can be reached by recurrence  $\mathbf{M}_k=f(\mathbf{M}_{k-1})$  whatever the starting point  $\mathbf{M}_0$  (ex:  $\mathbf{M}_0=\mathbf{I}$ ,  $\mathbf{M}_1=\mathbf{M}_{NSCM}$ ),**
- **Closed-form relationship between PFA and detection threshold.**

# SIRV and Experimental Data

- ANMF-FP Texture-CFAR property
- ANMF-FP Matrix-CFAR property



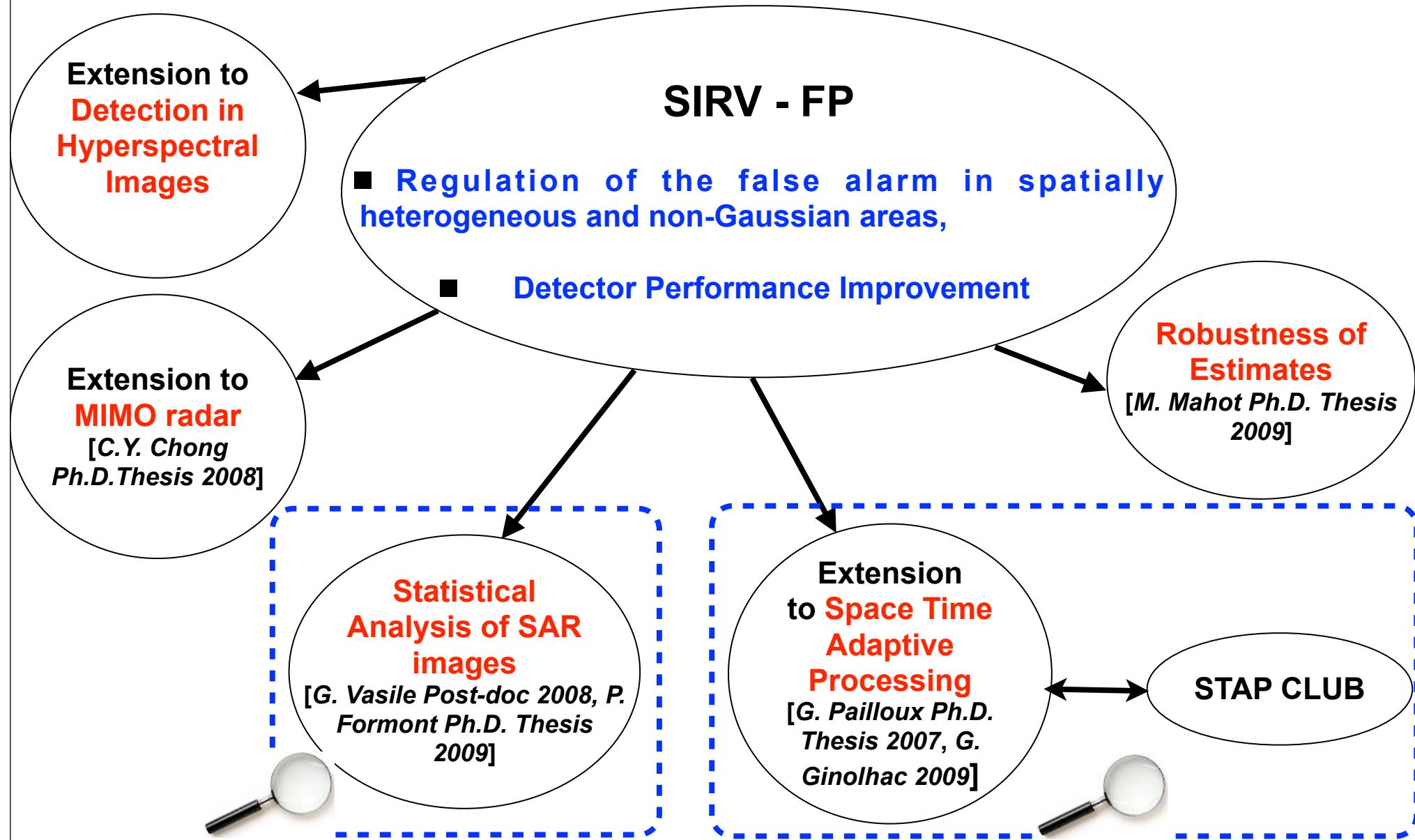
Radar azimuth-range bins map from  
THALES AIR DEFENCE



P<sub>fa</sub>-threshold relationship

**Very good fit between theory and experimentation**

# Research around SIRV and Fixed Point Methodology



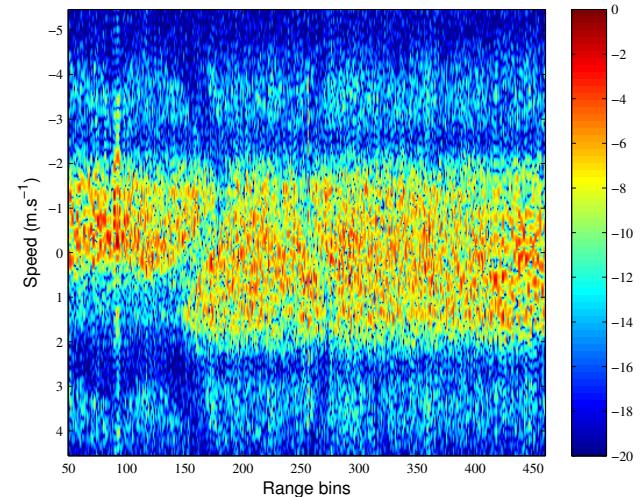
Organizer and leader since February 2007

Goals: Open collaborative project

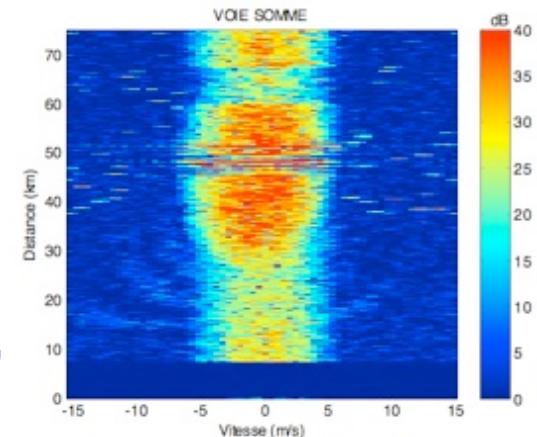
- To propose STAP data (synthetic and experimental) for STAP algorithms evaluation,
- To gather existing experimental STAP databases and simulators
- To develop fruitful exchanges between researchers and Ph.D. students.

## BILAN

- 4 meeting / year, 1 Web site: <http://clubstap.free.fr>,
- Special Issue «Traitement du Signal » in preparation,
- Extension to Europe,



DGA/CELAR data



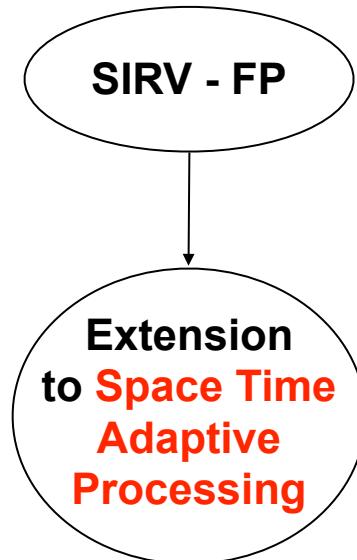
ONERA Data

## Main Participants

- ONERA, THALES (F. Le Chevalier, L. Savy, M. Montécot), DGA (J. Samson CELAR)
- ENS Cachan (P. Forster, G. Ginolhac)
- LSS (S. Marcos)
- SONDRA (F. Pascal)
- ENSEIRB (Y. Berthoumieu, E. Grivel)
- ISAE (O. Besson, S. Bidon)
- IETR (L. Ferro-Famil)
- ...

STAP Club is a catalyst for «STAP» Ph.D. students:  
**G. Pailloux (ONERA), S. Beau (LSS), S. Bidon (ISAE), J. Petitjean (ENSEIRB)**

# SIRV for STAP



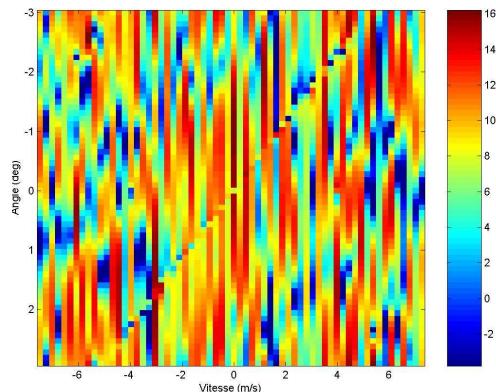
## Fit of SIRV + FP to STAP : detectors + estimators

Reduction of number of secondary data ( $K \gg 2m$ ):

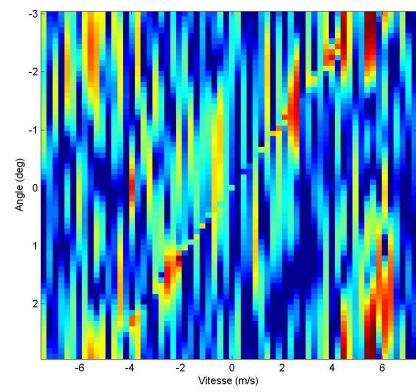
- Exploiting persymmetric structure of the Covariance [G. Pailloux Ph.D. Thesis 2009],
- Sub-spaces techniques [Ginolhac et al 2009].

Robustness of  $\hat{M}$  to secondary data contamination:

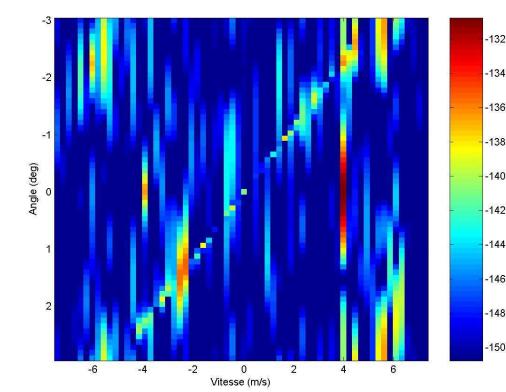
- Robustness of the NSCM and FP estimates [M. Mahot Ph.D. Thesis 2009] : Robust Statistics [Huber 1972] - M-Estimateurs [Maronna 1976].



AMF + SCM



Low Rank AMF + SCM



Low Rank ANMF + NSCM

Example : Secondary Data contaminated by a target with velocity -4m/s ( $K = 410 \ll N=512, r = 46$ )

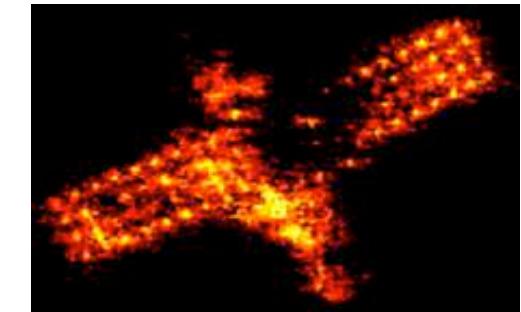
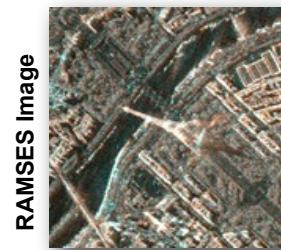
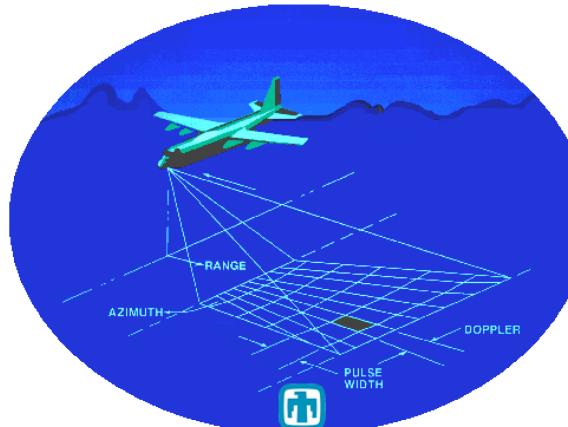
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# Radar/SAR Imaging



ONERA RAMSES Image

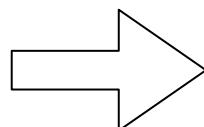


ONERA ISAR Image



ONERA RAMSES Image

Radar Imaging allows to build more and more precise images :

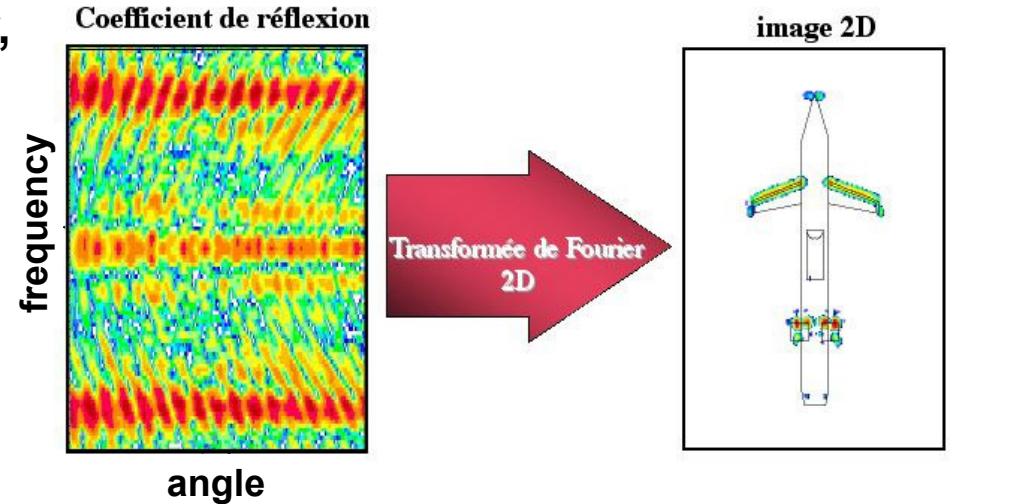


- Need to use very high bandwidth and long integration time (high azimuth bandwidth)
- Spectral, Angular, Polarimetric Non-stationarity of scatterers
- Complexity of Scene Analysis - Classification becomes difficult

# Physical Characterization of SAR Scatterers

Conventional Fourier Imaging (laboratory, SAR, ISAR) :

- Assumptions of white and isotropic bright points
- does not exploit the potential non-stationarity of the scatterers



Nevertheless :

- Imaging in laboratory : Highlighting of Coloration and Anisotropy of reflectors [J.P. Ovarlez Ph.D. Thesis 1992],
- Same ascensions on Very High Resolution SAR images !

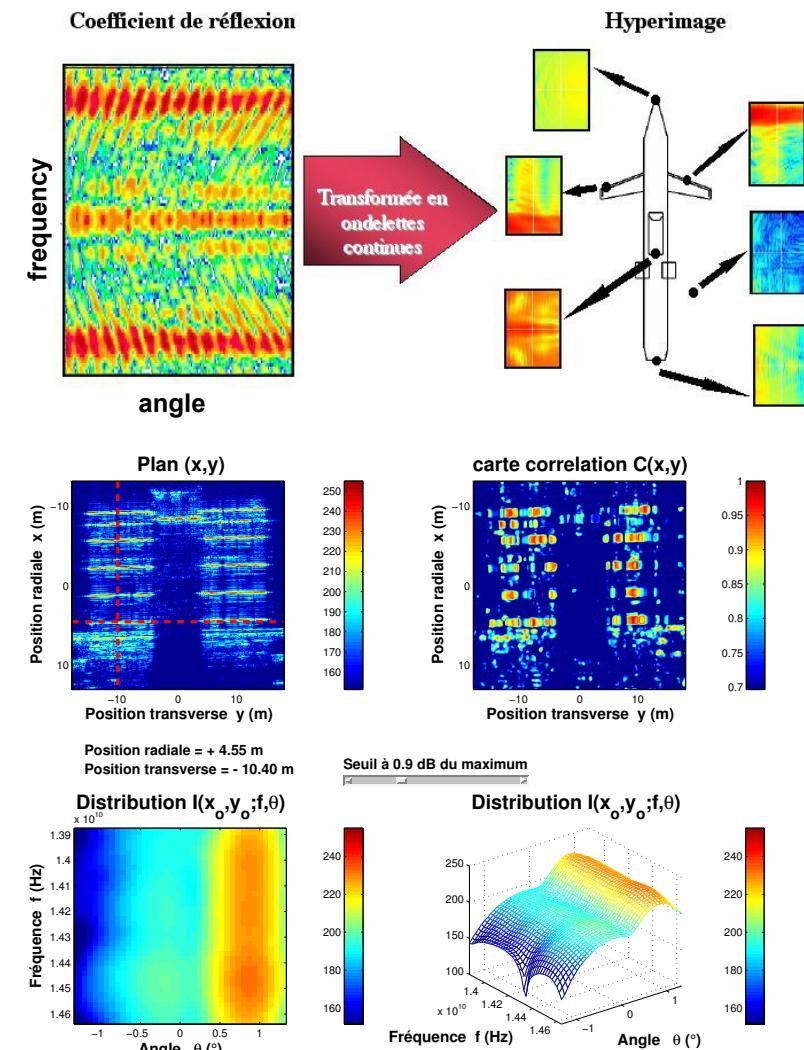
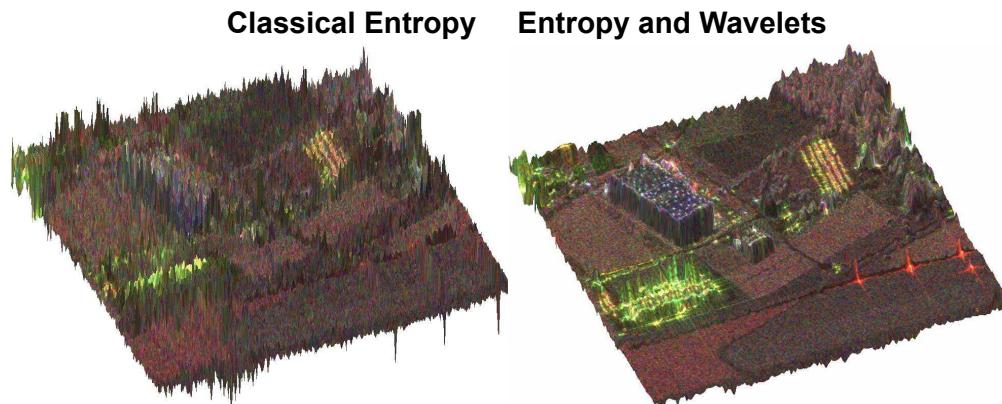


# Time-Frequency Analysis for SAR Imaging

**Time-Frequency Analysis allows to highlight the coloration and anisotropy properties of SAR reflectors.**

**ATF Applications on SAR images [M.Tria Ph.D.  
 Thesis 2004] :**

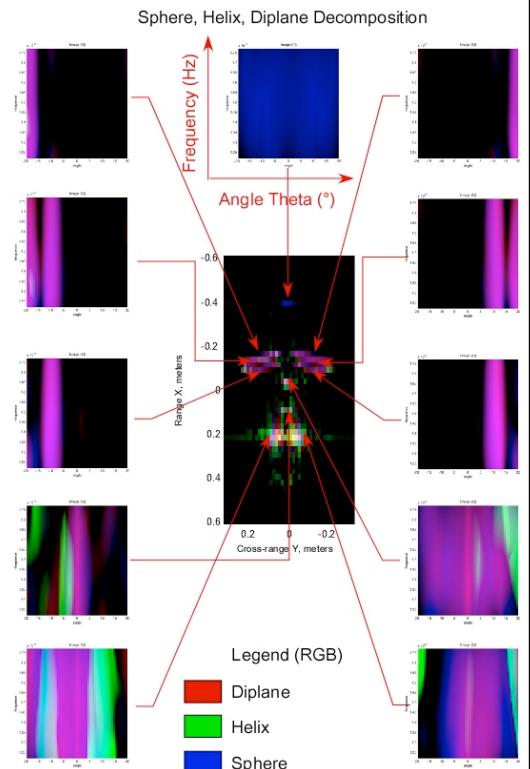
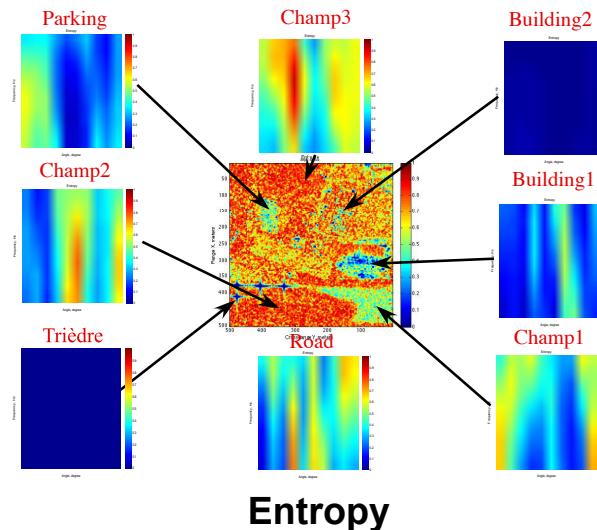
- RCS Analysis
- EM Phenomena Analysis,
- Signatures Extraction,
- Classification,
- Maximization of interferometric entropy by wavelets [M. Tria - E. Colin].



# Time-Frequency Analysis and Polarimetric SAR Imaging

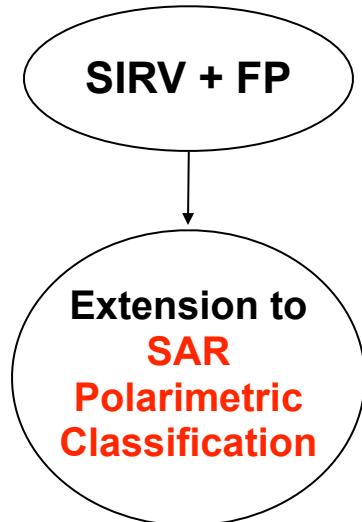
**Natural Extension of Time Frequency Analysis for SAR imaging to coherent (Pauli, Krogager, Cameron) and non-coherent (H/alpha, Freeman Durden) polarimetric decompositions [M. Duquenoy Ph.D. Thesis 2009]**

- Moreover, Time-Frequency Analysis allows to highlight the polarimetric (coherent) non-stationarity of SAR scatterers.
- TFA application to non-coherent polarimetric decompositions (Best Student Paper Award Eusipco 09 - M. Duquenoy)



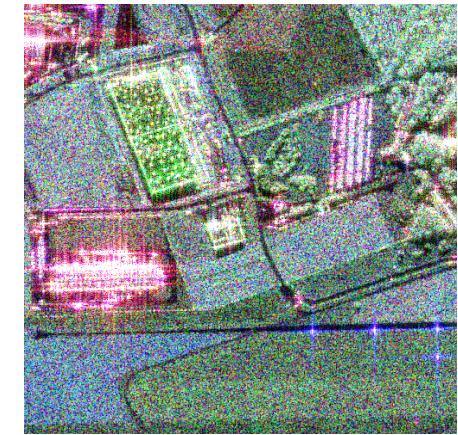
Krogager Coherent Decomposition with Wavelets

# SIRV and Classification of Polarimetric SAR Images

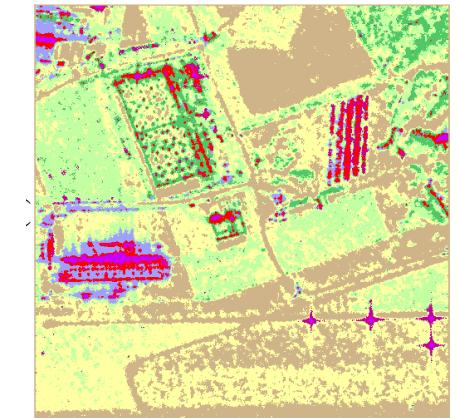


**Natural Extension of SAR Images statistical to non-cohérente polarimetric classification ( $H/\alpha$ , Freeman Durden) [G. Vasile Post-doc 2008, P. Formont Ph.D. Thesis 2009, L. Bombrun Post-doc 2009]**

- **Polarimetric Covariance Matrix** and **texture estimation** on spatially non Gaussian or heterogeneous areas,
- **Extension of Polarimetric Whitening Filter** used in image «*unspeckeling*» to SIRV context (related in fact to the SIRV texture estimate).
- **Extension to SIRV context** of Polarimetric SAR image classifications (unsupervised  $H/\alpha$ , Freeman Durden, ...),
- **Analysis of new Riemannian distances** for deriving the covariance matrix of the  $H/\alpha$  centers of class (**Geometry of Information**)

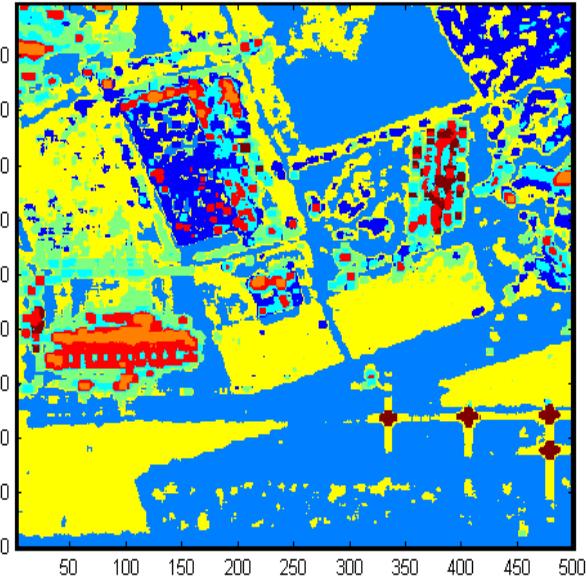


$I_1/I_3/I_2$

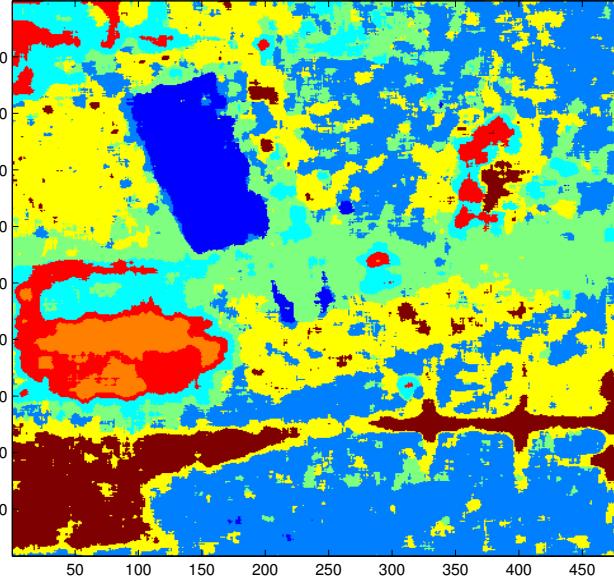


Classification Wishart  $H/\alpha$   
avec SCM

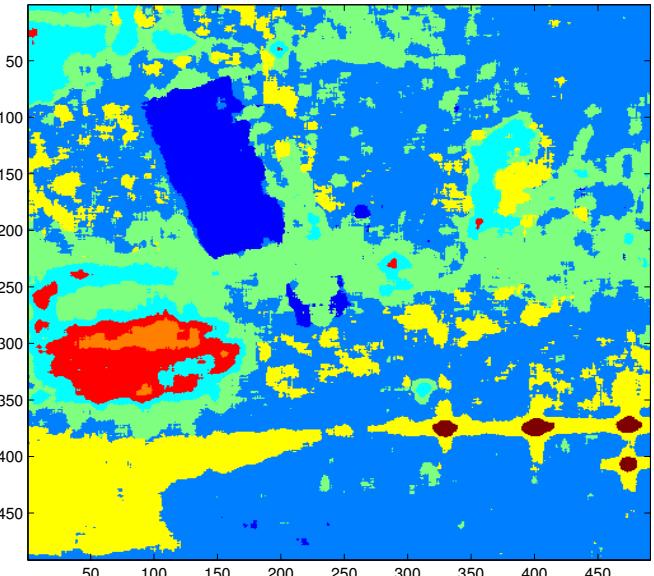
# SIRV and Classification of Polarimetric SAR Images



$M_{scM}$  Wishart  
distance - Euclidean  
Mean



$M_{FP}$  Wishart  
distance - Euclidean  
Mean



$M_{FP}$  Wishart  
distance - Riemannian  
Mean

Information  
highly correlated to the  
texture

More informative, «less visual»  
but  
totally independent on the texture

# Radar/SAR Imaging

## SIRV and Time-Frequency Analysis for SAR Imaging

### Synthesis

- Behavior analysis of SAR image scatterers
- Target classification (coherent polarimetry) - Recognition
- Clutter classification (texture, non-coherent polarimetry)
- Coherency analysis for interferometry

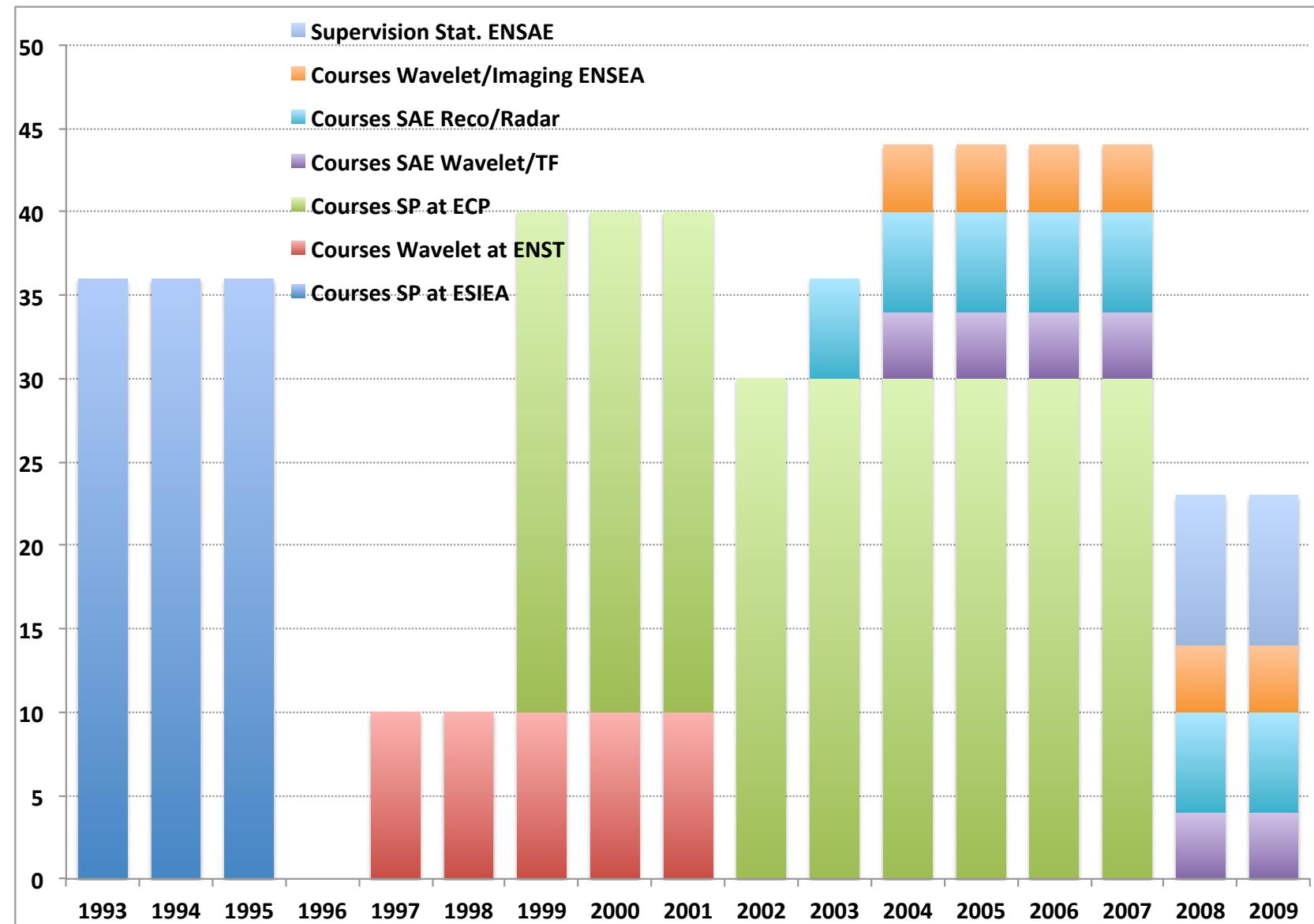
### Potential Applications

- Change detection (multi temporal)
- Target detection (stationary or moving) in SAR images

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- **Perspectives**

# Teaching Activities



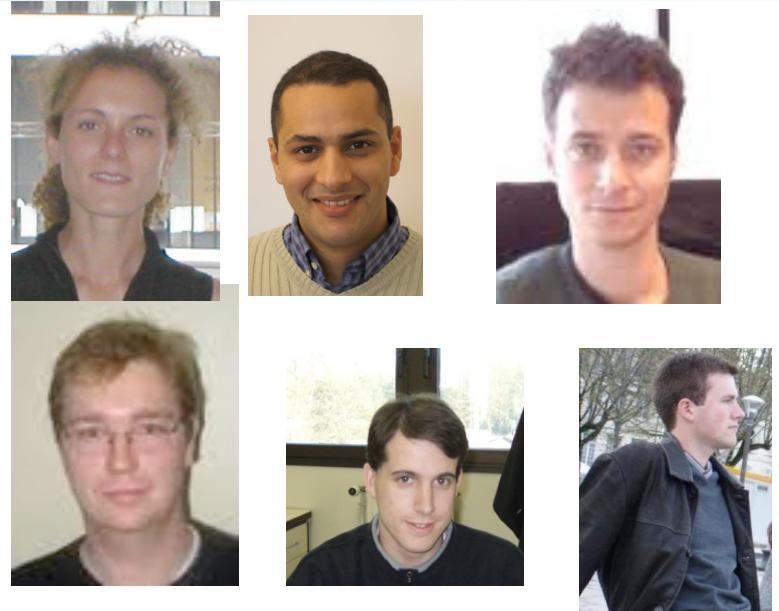
# Publications and Reports

Publications	Total
ONERA Technical Reports	42
Journals	16
International Conferences	52
National Conferences	11
Invited Conferences	4
Patent	1
Thesis	1
Journals in review	4
Invited Seminar(GDR, IEEE, SEE, CNES, ...)	15
Book Chapters	5

# Supervisions

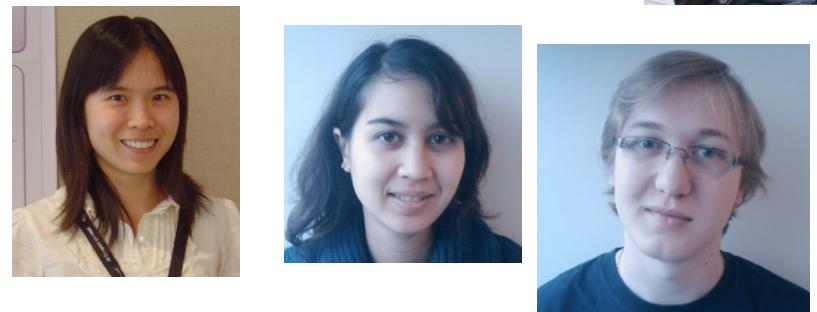
## Ph.D. Students

- 1998 - Emmanuelle Jay (ONERA/MNRT 50%)
- 2001 - Mohamed Tria (ONERA 70%)
- 2003 - Frédéric Pascal (ONERA 50%)
- 2004 - Mickaël Duquenoy (ONERA 50%)
- 2007 - Guilhem Pailloux (ONERA 50%)
- 2007 - Julien Totems (ONERA 20%)
- 2008 - Chin Yuan Chong (SONDRA, participation)
- 2009 - Mélanie Mahot (DGA 20%)
- 2009 - Pierre Formont (DGA/ONERA 20%)



## Post-doc

- 2007 - Gabriel Vasile (CNES 100%)
- 2009 - Lionel Bombrun (GipsaLab, participation)



## University Supervisions - Coopérations

- Patrick Duvaut - David Declercq (ENSEA)
- Messaoud Benidir (LSS), Frédéric Pascal (SONDRA)
- Philippe Forster, Pascal Larzabal (ENS Cachan)
- Eric Pottier, Laurent Ferro-Famil (IETR)
- Nadine Martin, Gabriel Vasile (GipsaLab)



# Where are they now ?

- **Emmanuelle Jay** : Researcher in quantitative finance in QuantValley, Paris
- **Mohamed Tria** : Research Engineer in Noveltis, Toulouse
- **Frédéric Pascal** : Assistant Professor in Supelec/SONDRA, Paris
- **Mickaël Duquenoy** : Thales, DGA, unemployed
- **Guilhem Pailloux** : Engineer in DGA, Paris
- **Julien Totems** : Ph.D., to be defended 15/02/2011, ONERA Chatillon
- **Chin Yuan Chong** : Ph.D. in SONDRA - DSO National Laboratories
- **Mélanie Mahot** : Ph.D., SONDRA/ONERA, Paris
- **Pierre Formont** : Ph.D., SONDRA/ONERA, Paris
- **Gabriel Vasile** : Researcher CNRS, GipsaLab, Grenoble
- **Lionel Bombrun** : Post-doc in ENSEIRB, Bordeaux

# Scientific and Administrative Responsibilities

## ONERA/SONDRA Responsibilities

<b>2003</b>	<b>Principle Scientist</b>
<b>2004 - 2009</b>	<b>Member of the Scientific Committee of the ONERA Physic Branch</b>
<b>2009 - 2014</b>	<b><i>Ph.D. students and Ph.D proposal evaluation in the ONERA Physic Branch, seminars, ...</i></b>
<b>2006 - 2007</b>	<b>Elected Scientific Council President of the DEMR Department</b>
<b>2007 - 2008</b>	<b><i>Seminars proposals et organizations, Ph.D. students and Ph.D proposal evaluation in the DEMR department</i></b>
<b>since 2007</b>	<b>Organizer and Leader of the STAP Club</b>
<b>since 2008</b>	<b>Responsible of Signal Processing Activities in SONDRA</b>

# Scientific and Administrative Responsibilities

## Other Scientific Activities

- Reviewer for Traitement du Signal (french), Signal Processing, IEEE Transactions on Signal Processing, IEEE Transactions on Image Processing, IEEE Transactions on Geoscience and Remote Sensing, IEEE-ICASSP, GRETSI, EUSIPCO,
- Member of the Scientific Committee of the IEEE-Radar 2004 conference,
- Member of the Scientific Committee of the IEEE-Radar 2009 conference,
- Member of the Scientific Committee of the CIP2010 conference, Second IAPR International Workshop on Cognitive Information Processing (Elba, Italy),
- Chairman for the IEEE-RadarCon 2008 (Rome) conference,
- Chairman for the IEEE-Radar 2009 (Bordeaux) conference.

# Outline

- **Personal Background**
  - Education Background
  - Professional Background
  - Main axes of Contractual Studies
- **Thematics and Research Works**
  - Radar/SAR Imaging
  - Detection and Estimation for Radar
  - Applications : STAP, SAR Classification, Hyperspectral
- **Synthesis of Research Activities**
  - Teaching Activities
  - Publications and Reports
  - Supervisions
  - Scientific and Administrative Responsibilities
- **Perspectives**

# Perspectives

## New Thematics of Research

- Target Detection (stationary or moving) in the mono or multi-channels SAR images (with joint use of Time-Frequency Analysis and SIRV)
- Fixed Point extension to Interferometry, Coherency
- Change Detection (multi temporal)
- Waiting FP7 decision: GipsaLab - ONERA - DLR - EDF - IREA : *Non-Linear, Non-Stationary, Non-Gaussian Multidimensional SAR Processing For Complex Scene Understanding*

## Ph.D. Supervisions and Projects

- Robust Statistic - Study of the M-Estimators, Non-stationarity of the clutter : M. Mahot
- Clutter Classification (texture, non-coherent polarimetry) : P. Formont
- Ph.D. Thesis scheduled for 2011 on Hyperspectral Detection (jointly with GipsaLab and DSO)

# Small Wink on my Ph.D. Works 1992

## The Mellin Transform: a Tool for Broadband Signal Analysis

$$M[Z](\beta) = \int_0^{+\infty} Z(f) f^{2i\pi\beta-1/2} df$$

### ■ Invariant Transformation to any scale change $a$

$$\begin{array}{ccc} Z(f) & \xrightarrow{U} & UZ(f) = \sqrt{a} Z(a f) \\ \downarrow & & \downarrow \\ M[Z](\beta) & \longrightarrow & M[UZ](\beta) = a^{-2i\pi\beta} M[Z](\beta) \end{array}$$

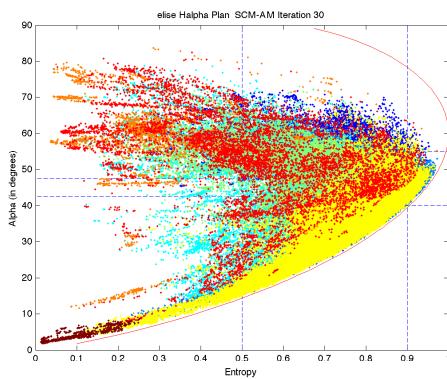
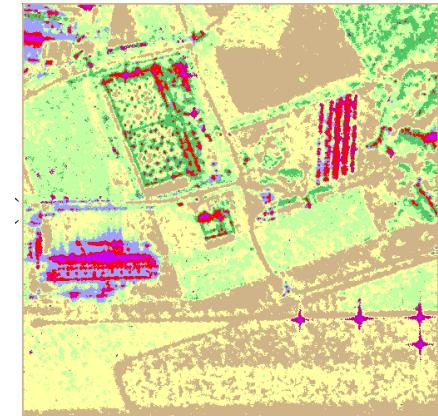
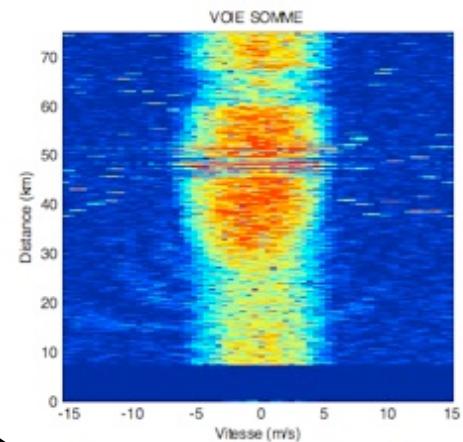
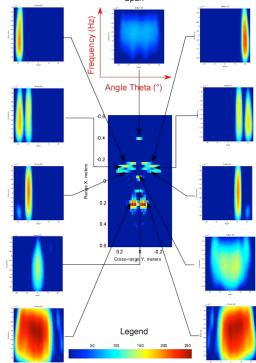
■ Allows to compute easily and ingeniously broad-band radar ambiguity functions, affine Time-Frequency distributions (wavelet), Cramer Rao bound for scale estimator, ...

■ Its multiplicative convolution property allows to factorize the SIRV PDF !!!!

$$(p_1 * * p_2)(u) = \int_0^{\infty} p_1\left(\frac{u}{u'}\right) p_2(u') \frac{du'}{u'} \longrightarrow M[p_1 * * p_2](\beta) = M[p_1](\beta) M[p_2](\beta)$$

See J.M. Nicolas's works on the use of Mellin Transform for computing and deriving in a closed form the SIRV texture PDF in SAR images !!!

# QUESTIONS



**QUESTIONS ???**

