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# Scattering Center Models for Feature Extraction in SAR Imagery

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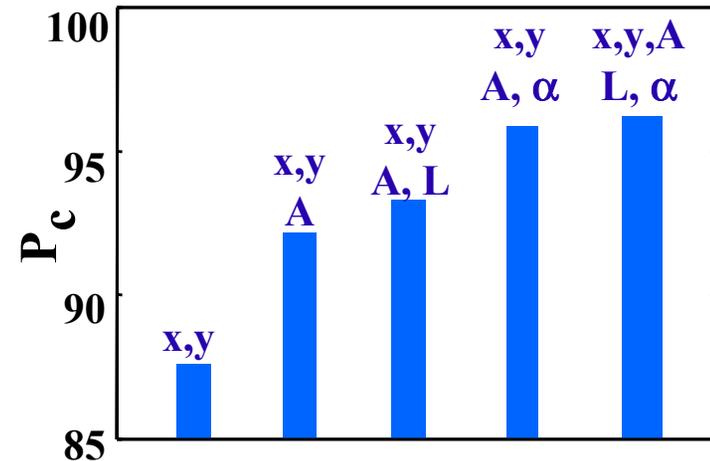
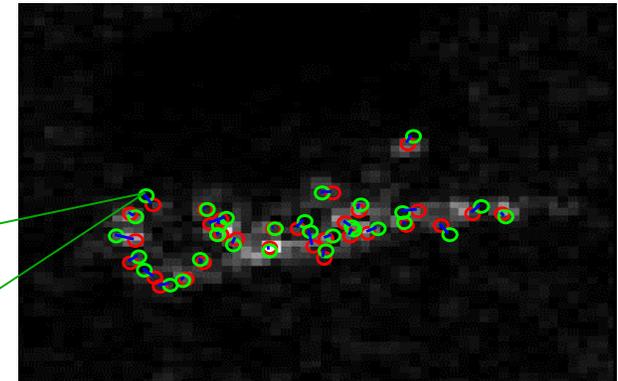
<http://eewww.eng.ohio-state.edu/ips>

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# Premises

- **In SAR imagery, both magnitude and phase are informative.**
- **Use simple scattering physics to guide feature selection.**
  - scattering centers with attributes
- **Features are intended for use in classification.**
  - feature utility becomes clear only in classification
  - feature uncertainty is a critical element of feature extraction

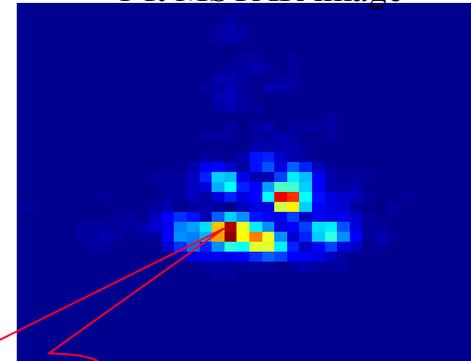
$x=35.2$  m  
 $y=46.3$  m  
 $A=9.43$  dB  
 $\alpha = 0.5$   
 $L=0.34$  m



# Attributed Scattering Centers

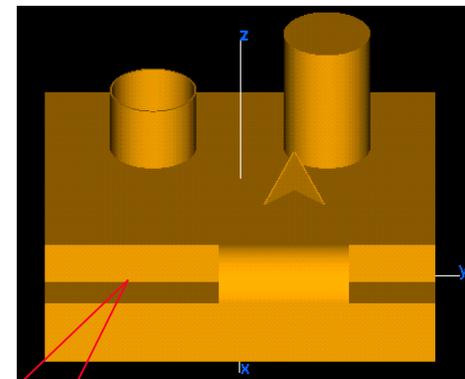
- SAR coherently senses backscatter as a function of
  - frequency
  - aspect
  - polarization
- Develop parsimonious parametric scattering model:
  - Geometric Theory of Diffraction
  - Physical Optics
- Estimate physically meaningful parameters

1 ft MSTAR image



Dihedral,  $L=1.10\text{m}$

SLICY target



Dihedral,  $L=1.16\text{m}$

# Attributed Scattering Center Model

$$E(f, \phi) = \sum_{k=1}^n \underbrace{A_k \left( j \frac{f}{f_c} \right)^{\alpha_k}}_{\text{Frequency Dependence}} \underbrace{e^{-2\pi f \gamma_k \sin \phi} \text{sinc} \left( \frac{2\pi f}{c} L_k \sin(\phi - \phi_k) \right)}_{\text{Aspect Dependence}} \underbrace{\exp \left( -j \frac{4\pi f}{c} [x_k \cos \phi + y_k \sin \phi] \right)}_{\text{Location Dependence}}$$

## Scattering Attributes

$A_k$	=	amplitude [H, V, X]
$x_k, y_k$	=	location
$\alpha_k$	=	frequency type
$L_k$	=	length
$\phi_k$	=	pose angle
$\gamma_k$	=	angle response

## Extract

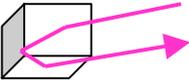
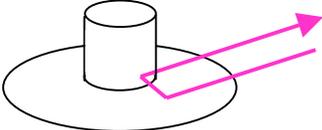
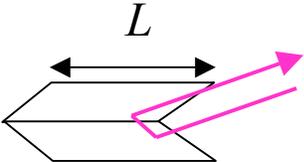
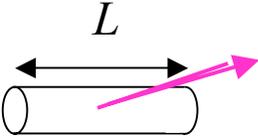
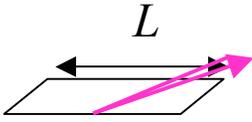
$x=35.2$  m  
 $y=46.3$  m  
 $A=9.43$  dB  
 $\alpha = 0.5$   
 $L=1.33$  m

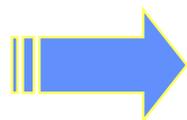
T72-sn132  
AZ=249.79, EL=17.18



# Scattering Primitives

## Frequency Dependence

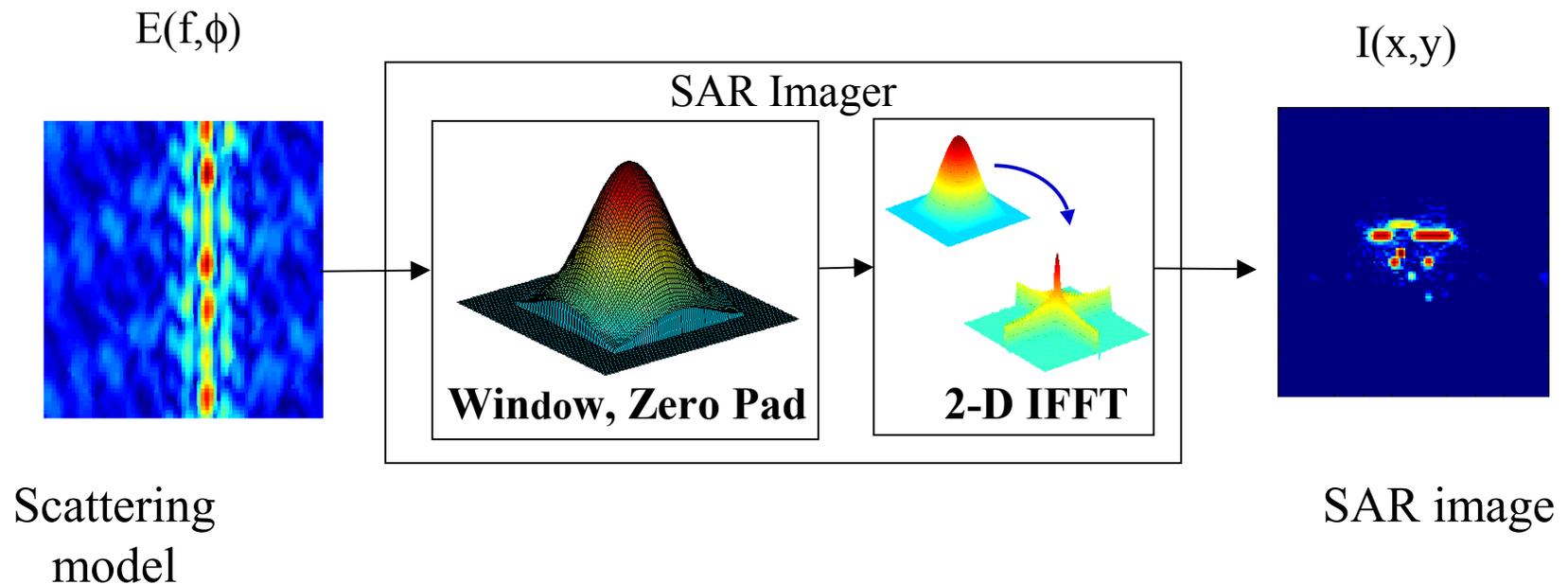
		$\alpha=1$	$\alpha=1/2$	$\alpha=0$
Aspect Dependence	$L=0$	 Corner Reflector	 Top Hat	 Sphere
	$L>0$	 Dihedral	 Cylinder	 Edge



Scattering parameters permit discrimination among target primitives using single-polarization SAR signatures

# SAR Image Mapping

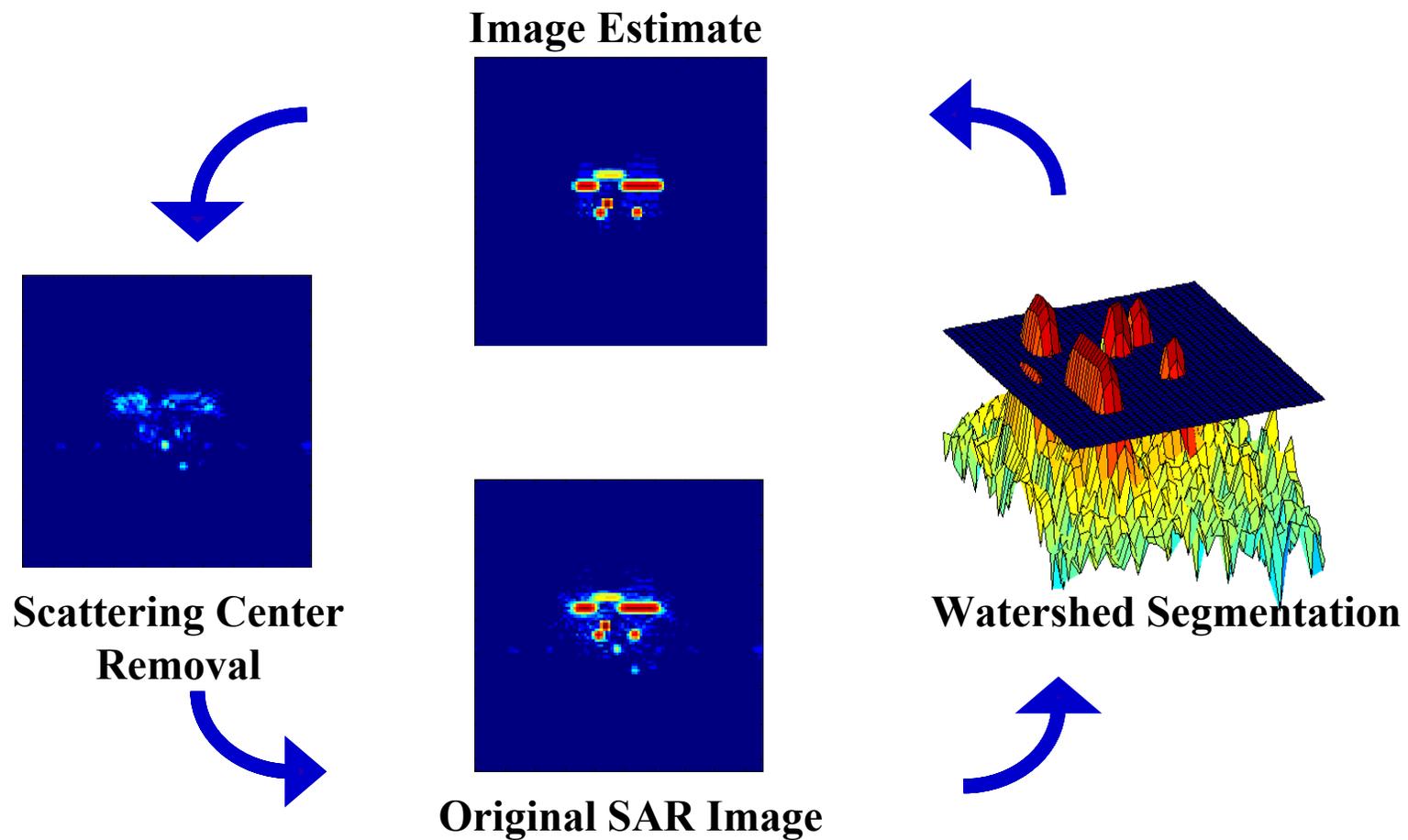
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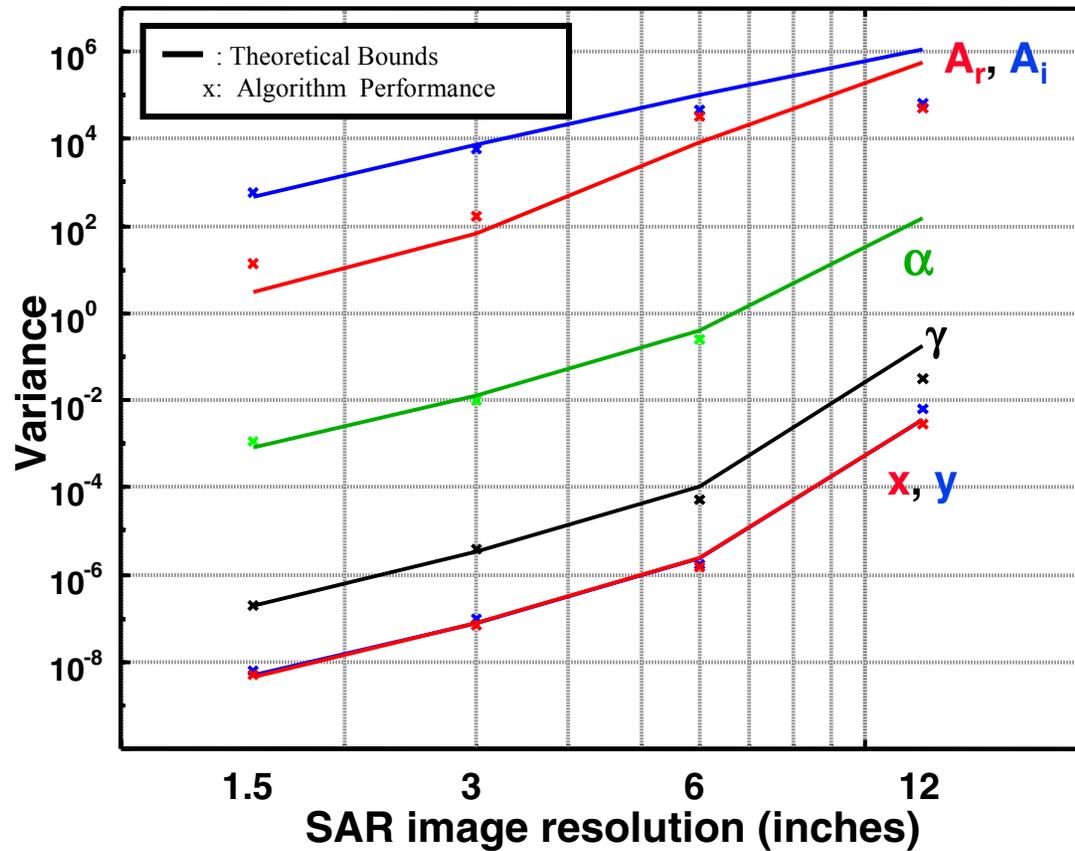
Frequency domain data is mapped to a sampled,  
**complex-valued** array by SAR imaging

# Recursive Parameter Estimation

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# Parameter Uncertainty

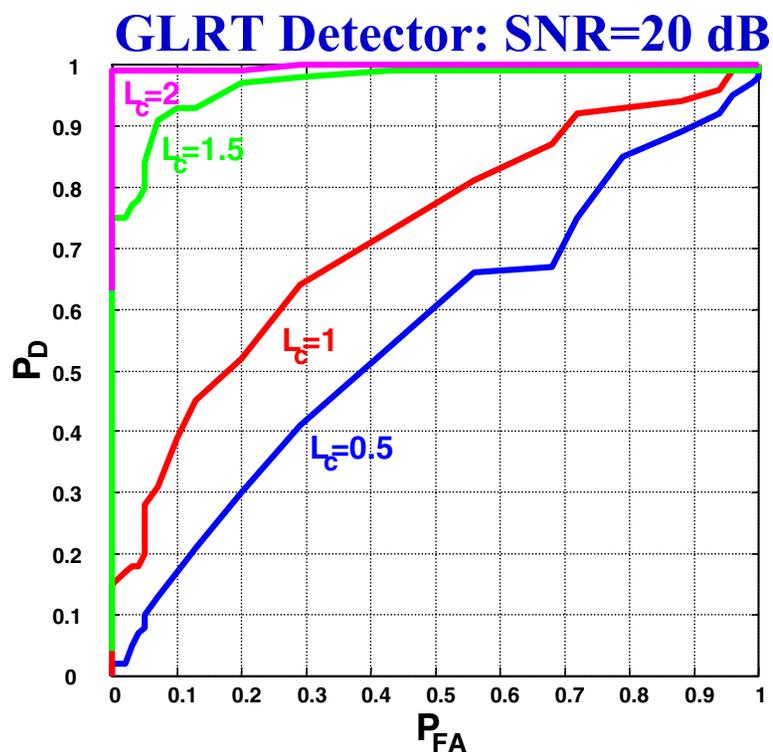


SNR = 20 dB

Estimation Theory is used to compute attribute uncertainty as a function of radar system parameters

Estimation accuracy increases with fractional bandwidth.

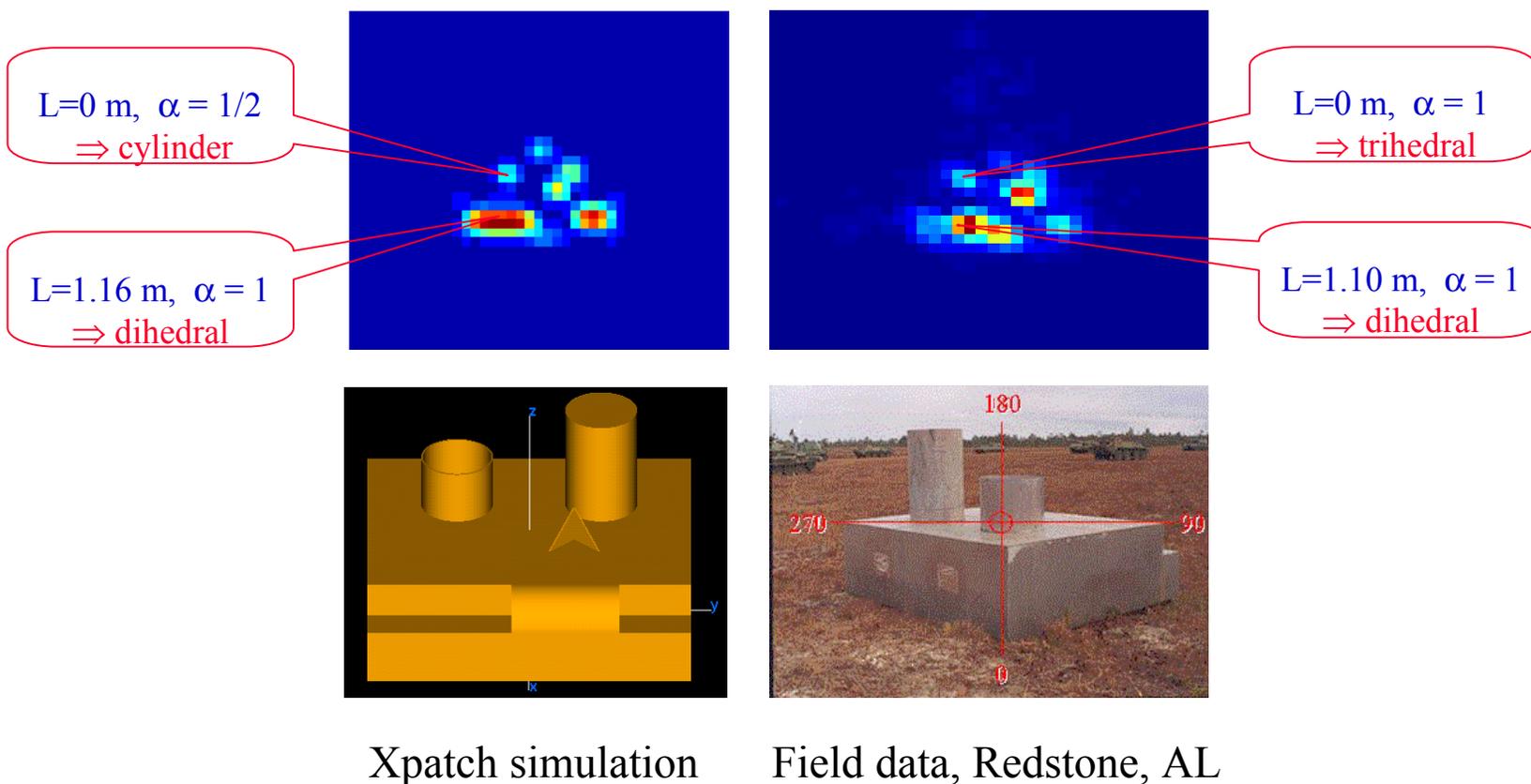
# Trihedral vs Dihedral Detection



$P_D$ : correctly detect a dihedral  
 $P_{FA}$ : incorrectly declare a trihedral as a dihedral

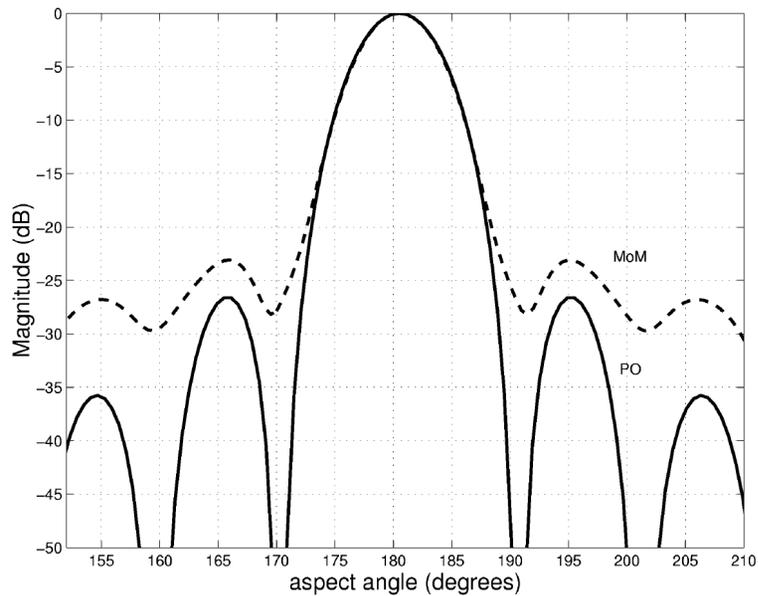
$L_c$  = Dihedral length in crossrange resolution units.

# Simulation and Field Measurements

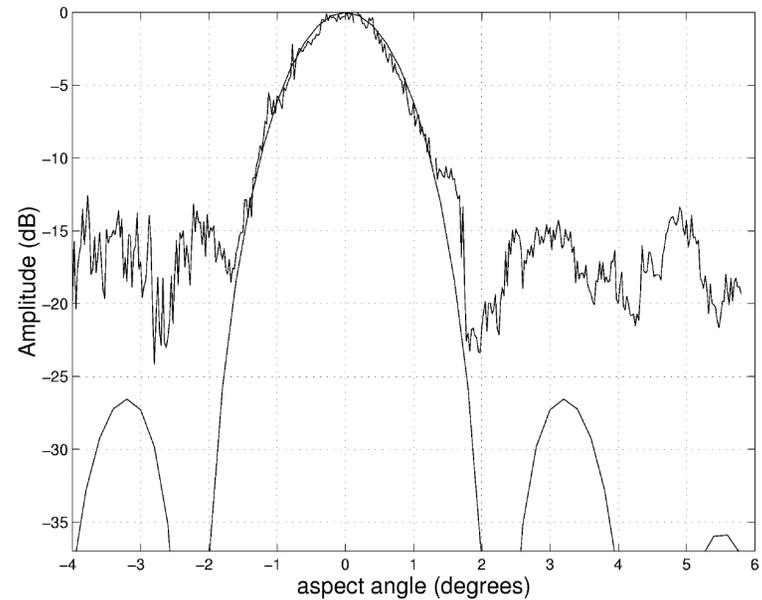


# Simulation and Field Measurements: Aspect Behavior

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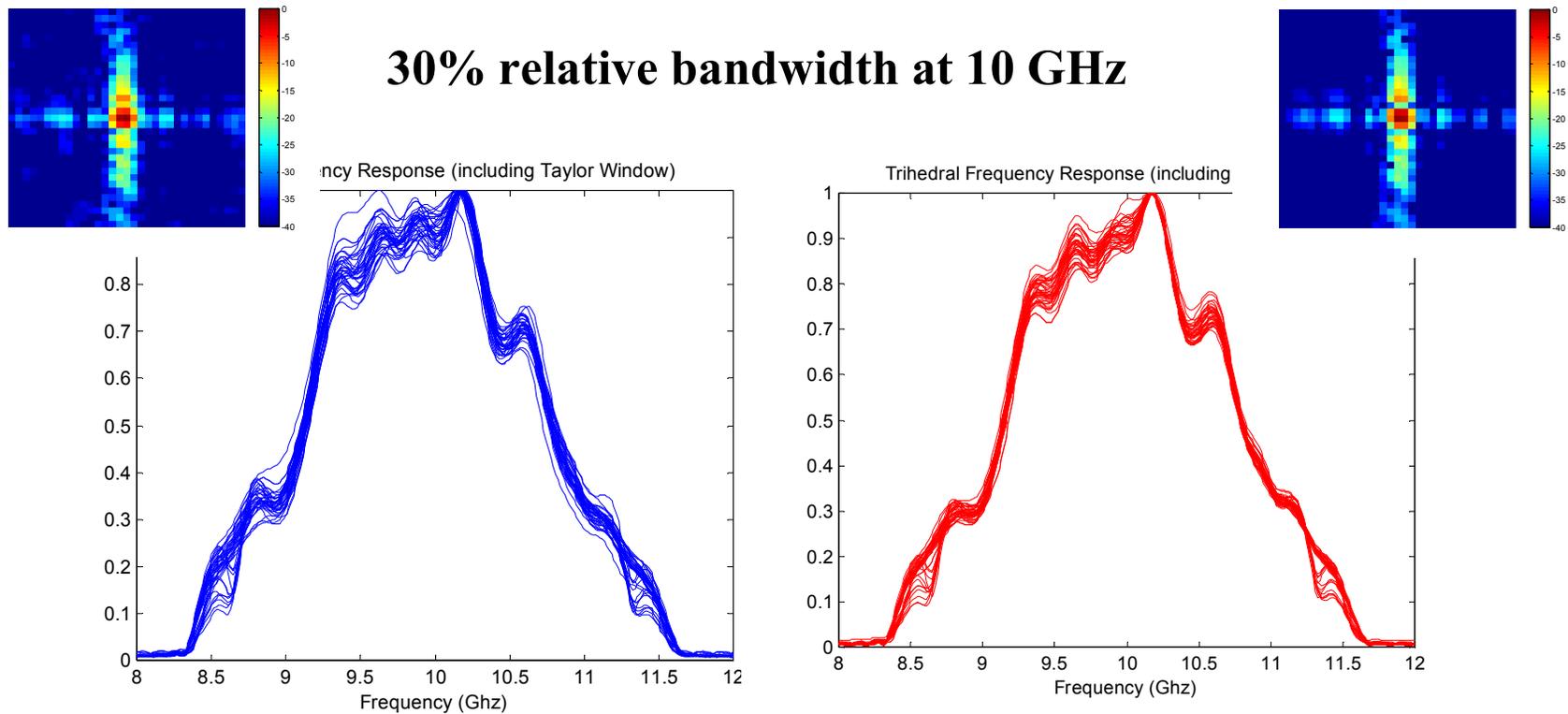


EM Models: Dihedral



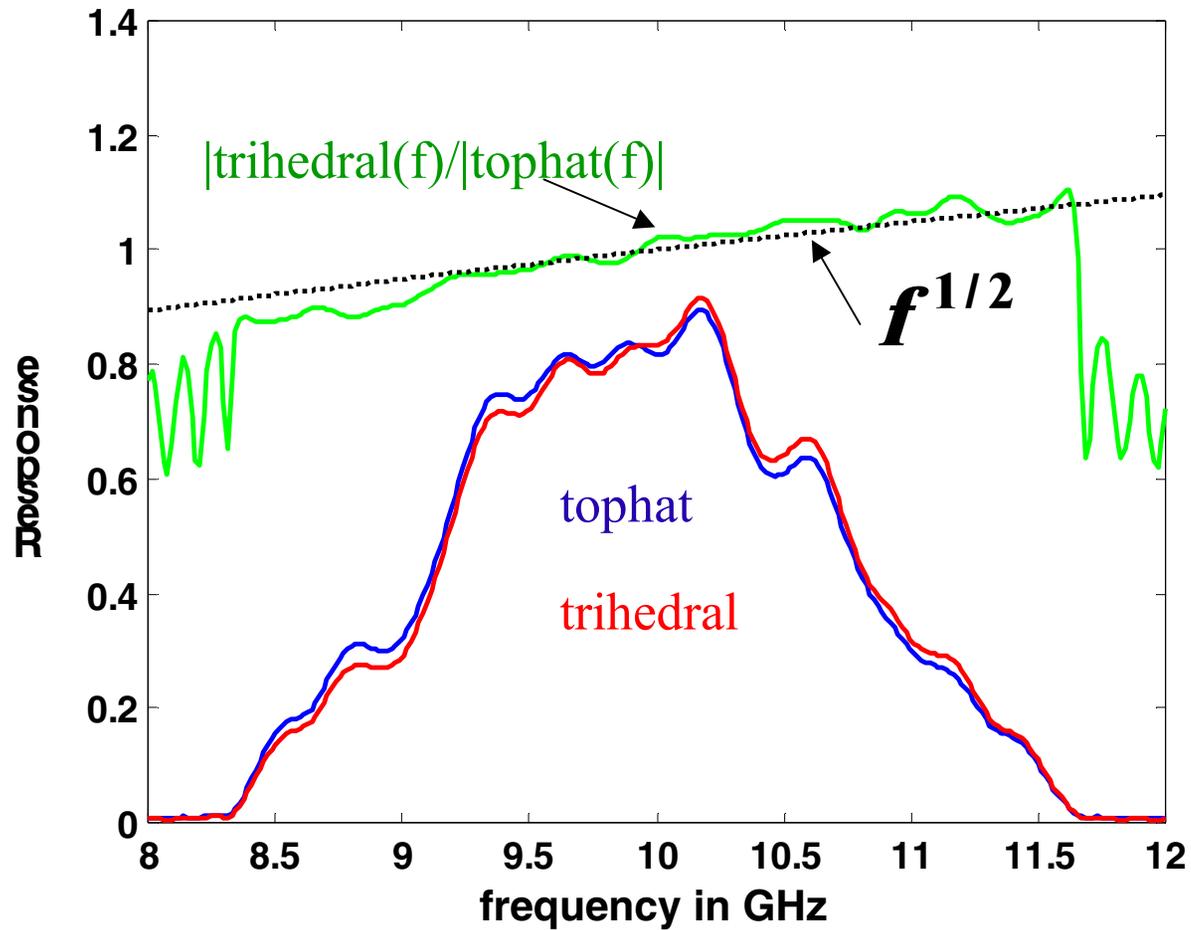
UWB measurement

# Frequency Responses in UFSAR



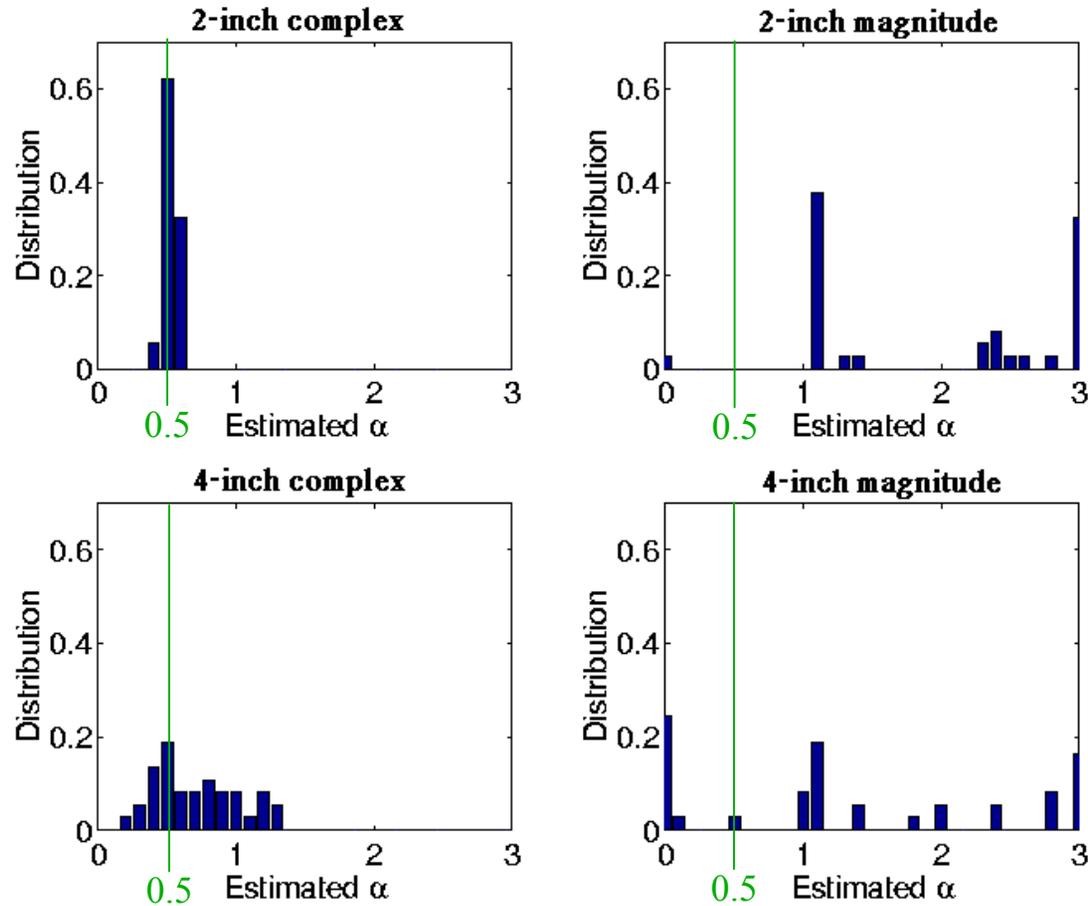
Frequency response of **tophats** and **trihedrals** from 40 GUS scenes

# Frequency Response in GUS Data



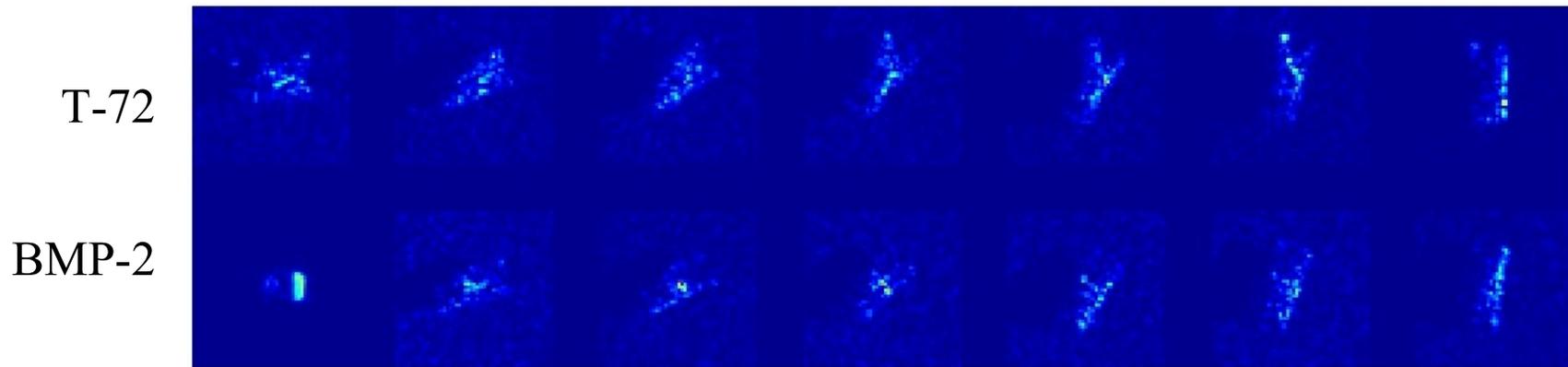
# Curvature Estimates, $\alpha$

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# Bayes Matching

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## **MSTAR Public Targets:**

10 tgts x  $\sim 275$  aspects = 2747 image chips

## **Class (and pose) means:**

A, x, y from 10 largest peaks;  $\alpha$ , L from Bayes probabilistic model

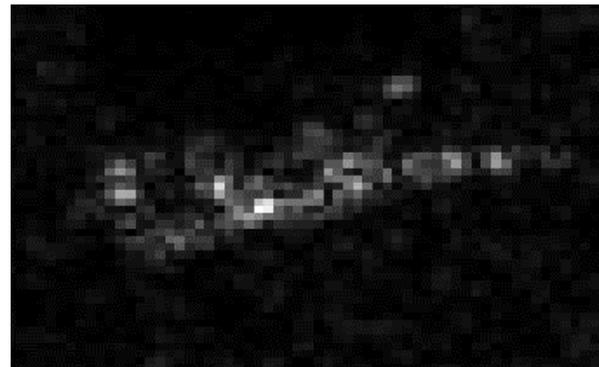
## **Monte-Carlo:**

10 realizations /chip = 27,470 realizations

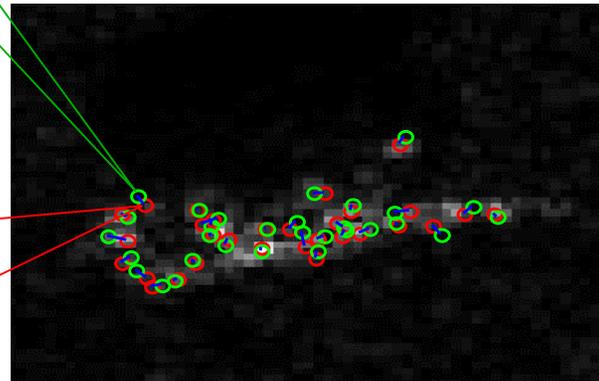
# Bayes Feature Matching

t72-sn132-157  
AZ=249.79, EL=17.18

Extract  
 $x=34.8$  m  
 $y=46.9$  m  
 $A=4.53$  dB  
 $\alpha = 1.0$   
 $L=0.72$  m



Predict  
 $x=35.2$  m  
 $y=46.3$  m  
 $A=9.43$  dB  
 $\alpha = 0.5$   
 $L=0.34$  m



- MSTAR public data (2747 chips)
- 10 target classes
- 10 scattering centers per chip
- Bayes feature matching

**Result:**

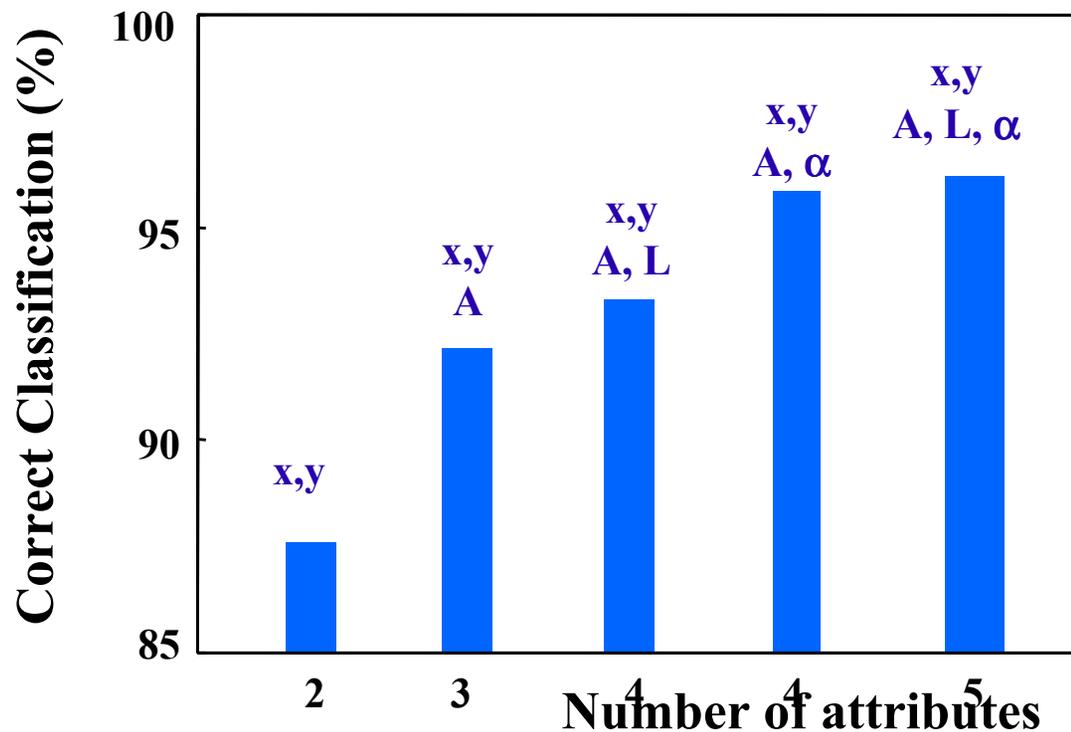
$P_{ID} = 87\%$  location only

$P_{ID} = 97\%$  with L,  $\alpha$ , A

**Match score = 17.26**

# Classification using Attributes: Results

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10 Scattering Ctrs  
 $Pd=0.5, \lambda=3$

Predicted ATR performance improves with scattering attributes.

# Summary: Research Perspective

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**Parametric models  
encode prior information  
about scattering physics**

$x=35.2$  m  
 $y=46.3$  m  
 $A=9.43$  dB  
 $\alpha = 0.5$   
 $L=0.34$  m

**Estimation theory gives  
fundamental limits on  
feature accuracy**

- resolution
- scatterer types

**Use classification performance to  
measure feature utility.**

