# Wideband Inverse Synthetic Aperture Radar (ISAR) Instrument to Explore Internal Structure of Small Planetary Bodies

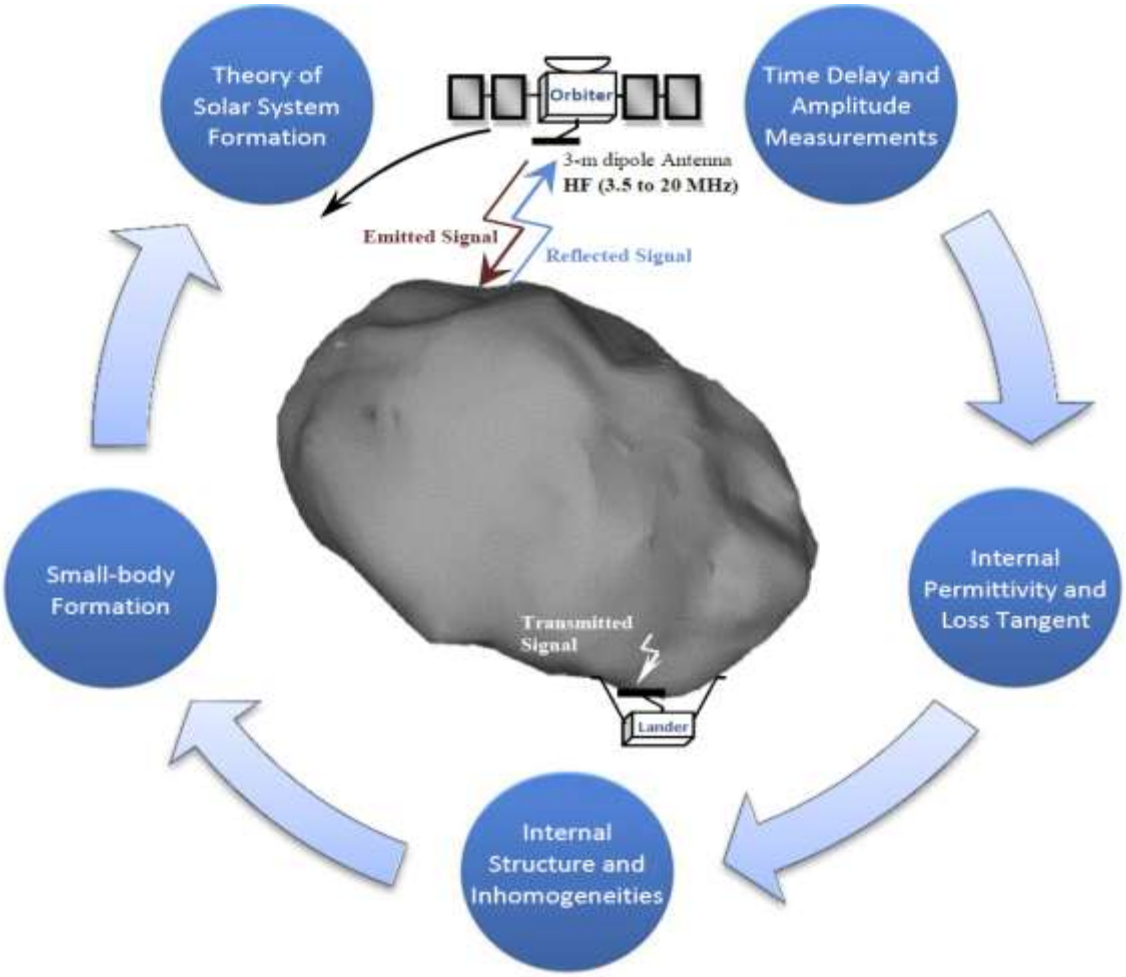
Manohar Deshpande (Code 555), Mehdi Benna (Code 699)
NASA Goddard Space Flight Center,

International Workshop on
Instrument for Planetary Missions
Oct. 10, 2012

1. This work was supported by NASA's IPP Program

2. Step Frequency Radar Instrument has been awarded US Patent in 2011

# What are Science Objectives?



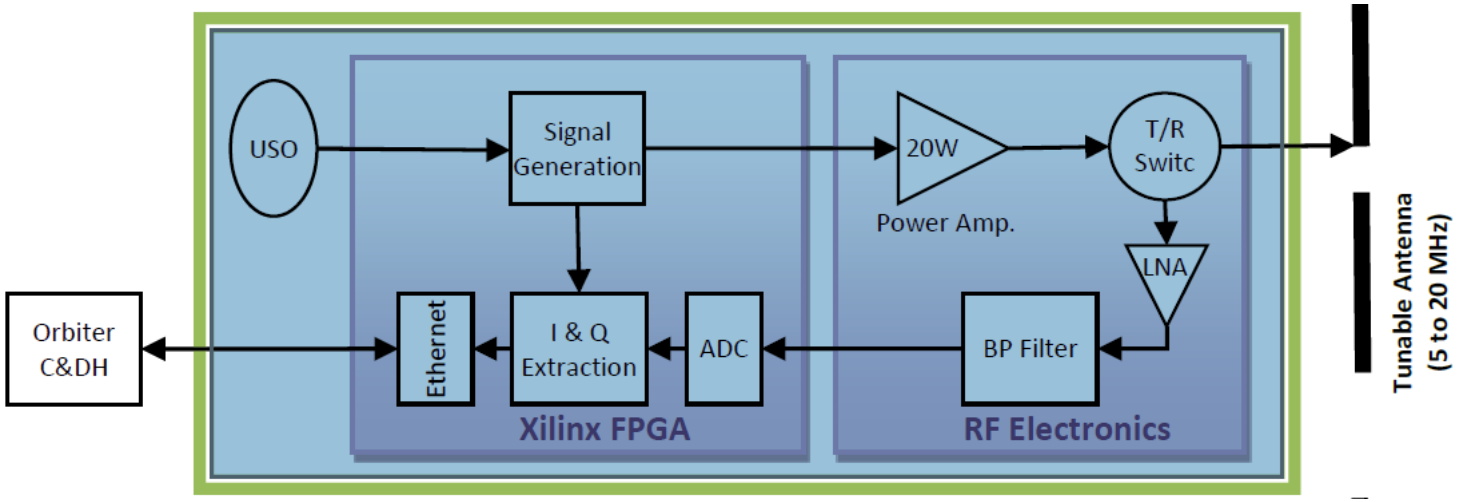
## Previous Missions Using Either Reflection or Transmission Tomography

| Instrument | SHARAD | MARSIS | CONSERT |
|---|---|---|---|
| Country (Institution) | Italy (ASI) | Europe (ESA) | Europe (ESA) |
| Mission | MRO | MARS EXPRESS | ROSETTA |
| Type | GPR (RRT) | GPR (RRT) | 3DRT (RTT) |
| Target | Mars | Mars | Comet |
| Frequency | 15 to 25 MHz | 1.3 to 5.5 MHz | 90 MHz |
| Bandwidth | 10 MHz | 1 MHz | 1 MHz |
| Penetration depth | 1 km | 5 km | 2.5 km |
| Spatial resolution | 7 m | 70 m | 20 m |
| Antenna Size | 15 m | 40 m | 1.5 m |
| Reference | [Seu *et al.*, 2004] | [Picardi *et al.*, 2004] | [Kofman *et al.*, 1998] |

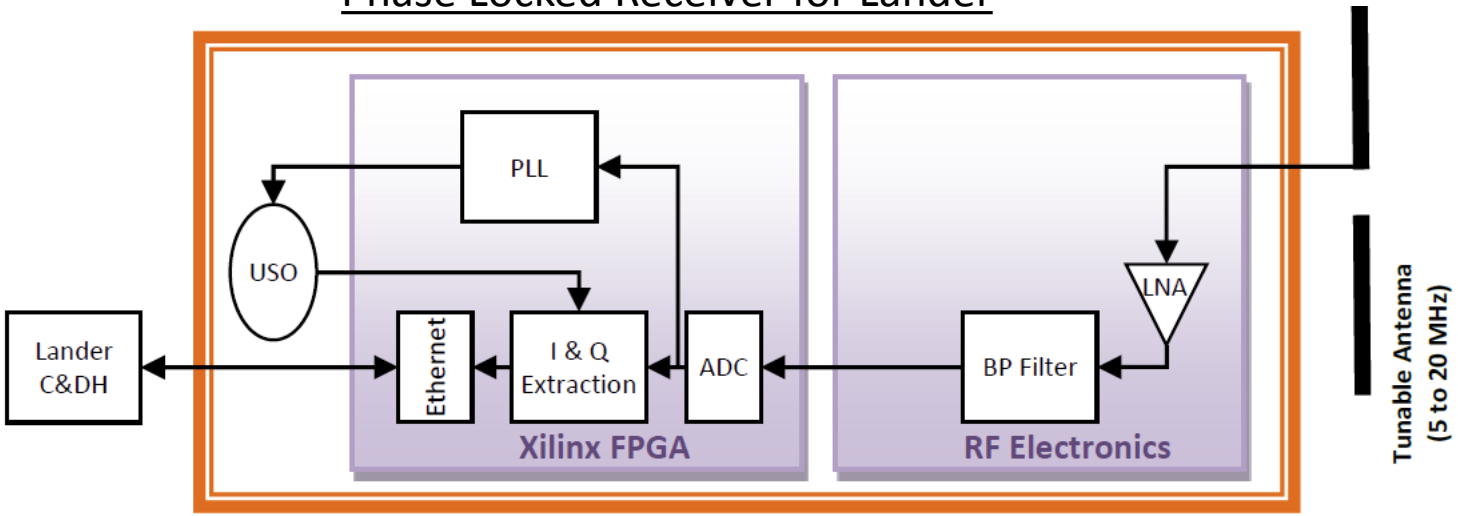
## Proposed Instrument Concept:

- Allows to perform both reflection & transmission tomography
- Frequency Range 3-20 MHz
- Bandwidth = 17 MHz (Instantaneous BW = 2 MHz, Overall BW = 17 MHz)
- Penetration Depth = 10 km
- Spatial Resolution = 8 m
- Compact Antenna Size (3m)

## Low Frequency Transceiver for Orbiter




## Phase Locked Receiver for Lander



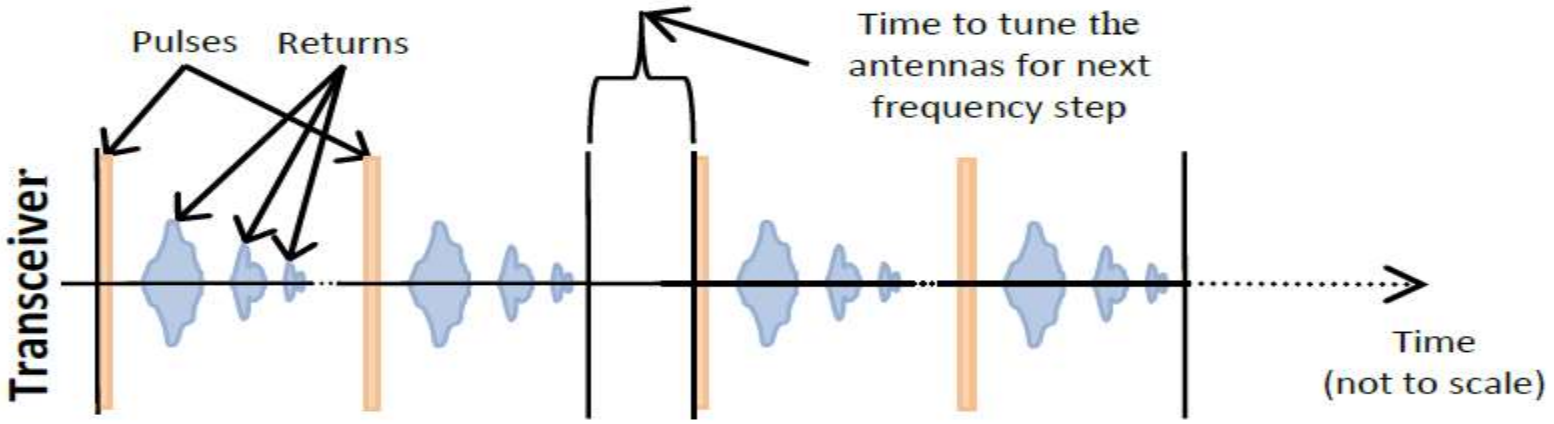
# Low Frequency RF Tomography Hardware

Radar Signal Generation
Data Processing Units

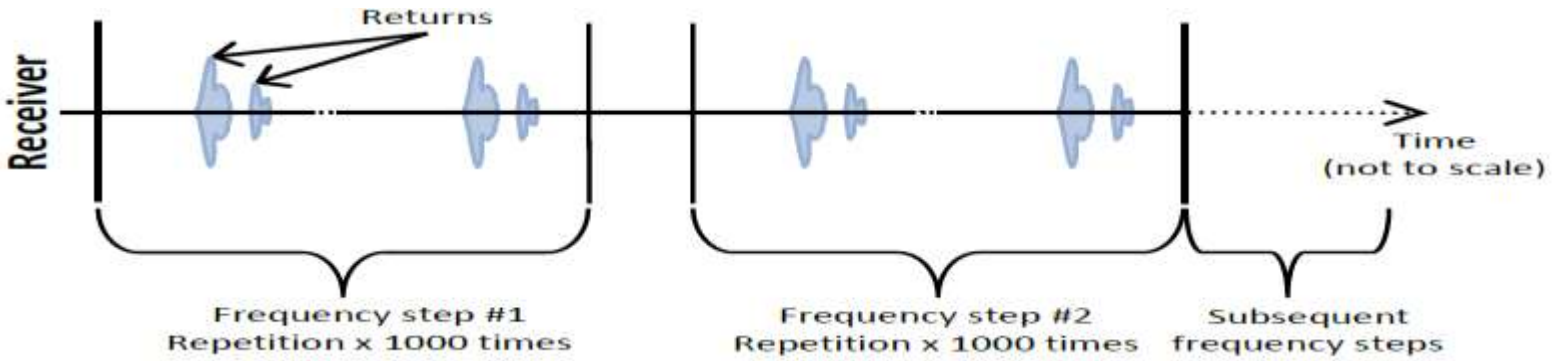
RF Front End

Compact Low Frequency
Tunable Antenna

## Step Frequency Radar Operation




- Transmit multiple pulses of the same carrier frequency and record return signals ( to increase SNR)
- Allow a time gap for electronic tuning of antenna
- Increment the frequency and repeat these two steps



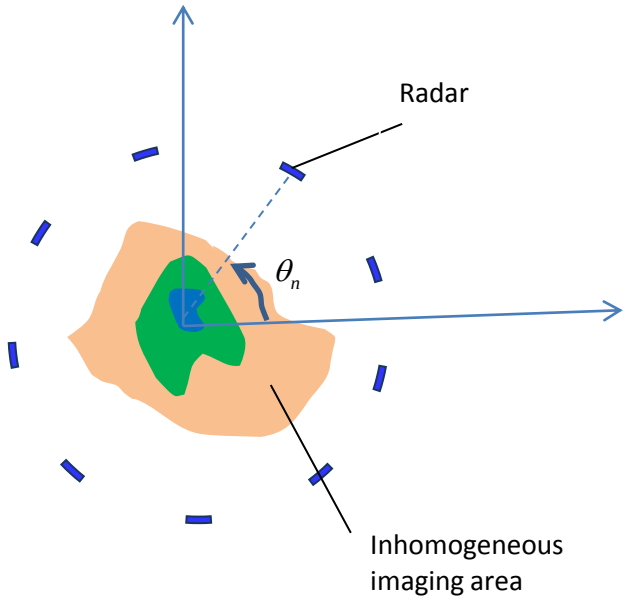
# Data Processing and Retrieval Methods

- Microwave tomography
  - Measurement:
    For every position of orbiter, measure reflected and transmitted signal as a function of frequency. $R(f,\theta)$ $T(f,\theta)$
  - Reflectivity Image (RCS Image)

Range Image: $rcs(\frac{r}{c},\theta) = ifft(R(f,\theta))$

Cross-Range Image: $image(\frac{r}{c},x) = fft(rcs(\frac{r}{c},\theta))$

Simple Mathematical Model



## Retrieval of Physical Parameters (Permittivity)

- Inverse Synthetic Aperture Radar (ISAR) processing gives 2-D reflectivity map.

- From the reflectivity map it is necessary to estimate permittivity

- Retrieval Methods Used in Other Fields
  - Medical imaging
  - Non-destructive testing
  - Industry process imaging
  - Multi-phase flow monitoring

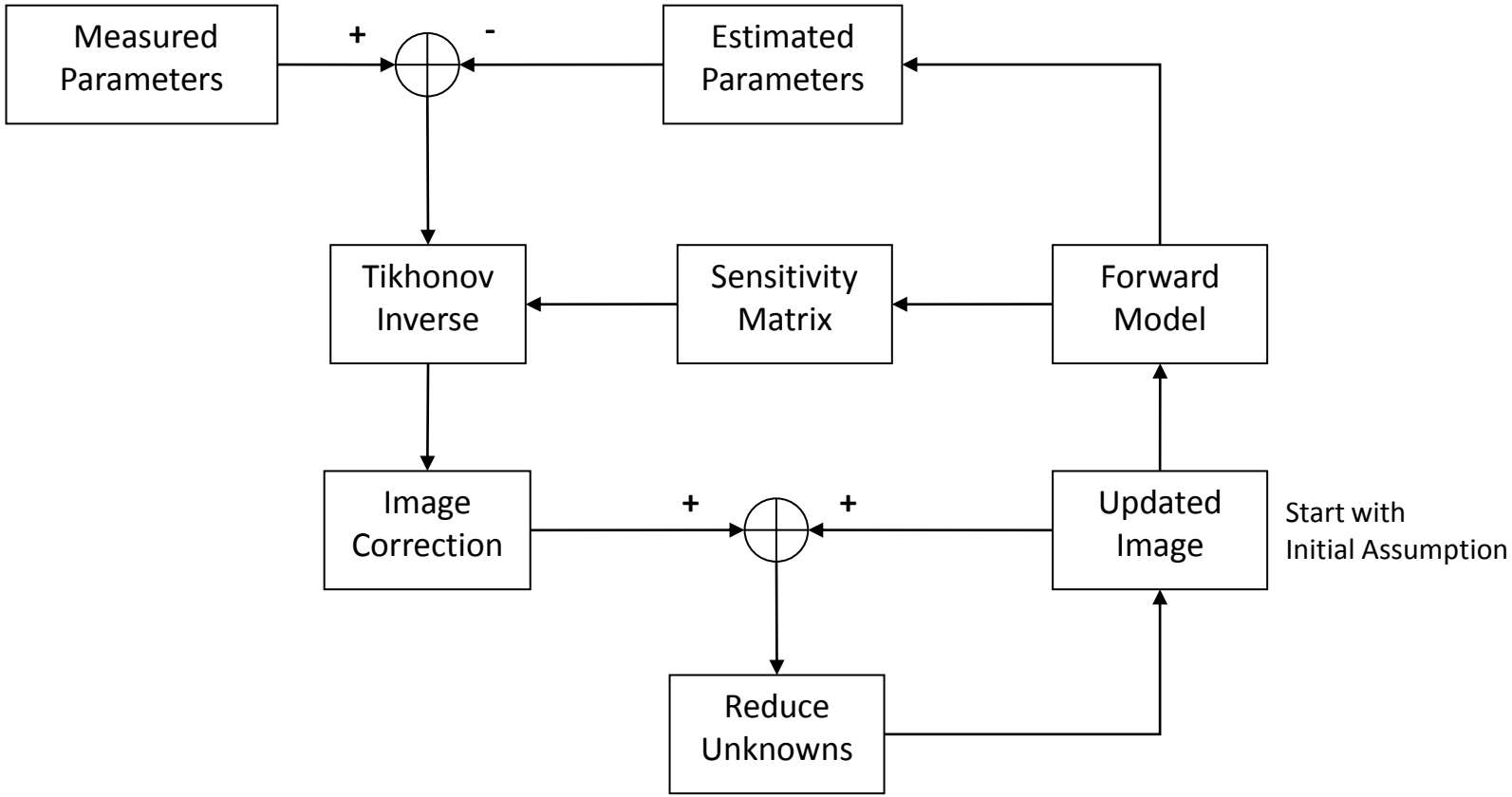
Extension to
Planetary subsurface sensing

# Inverse Algorithm

- Iterative Nonlinear Tikhonov Algorithm with Constraints (INTAC) (*)
- Validated with simulated data.

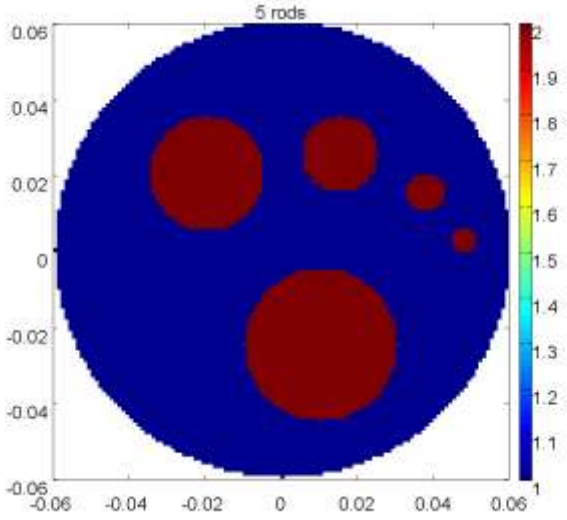
(*) Xu, Feng, Manohar Deshpande, “Iterative Nonlinear Tikhonov Algorithm with Constraints for Electromagnetic Tomography,” Journal of Selected Topics in Applied Earth Observations and Remote Sensing, Sept. 2011

# Flow Chart of Parameter Retrieval Algorithm

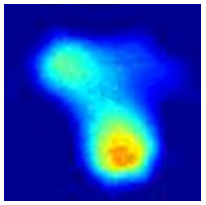


# Examples

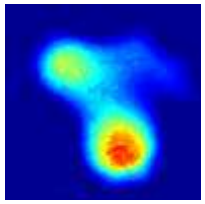
- 2D ECT
  - 12 electrodes on circular boundary
  - Two-phase system
  - Ground truth: 5 rods



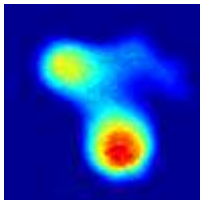
iter. 100



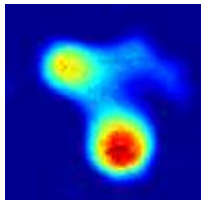
iter. 200



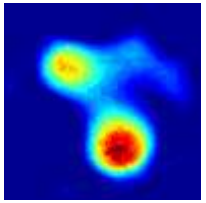
iter. 300



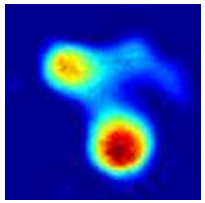
iter. 400



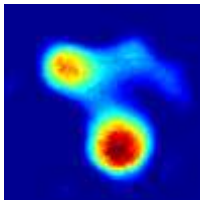
iter. 500



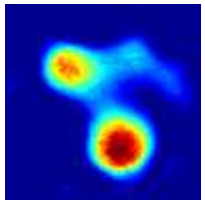
iter. 600

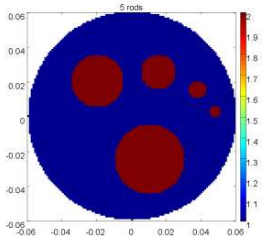


iter. 700



iter. 800

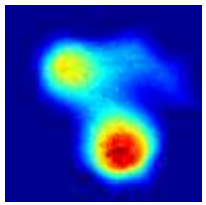




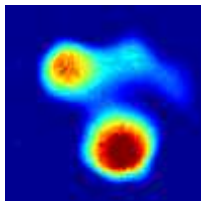

ILBP

INTAC

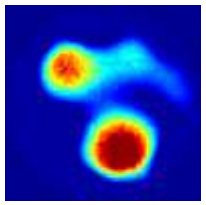
Iter. 0



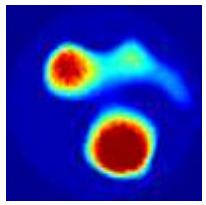
Iter. 2



Iter. 3

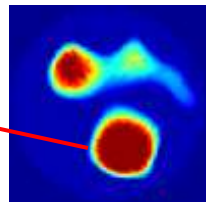


Iter. 8

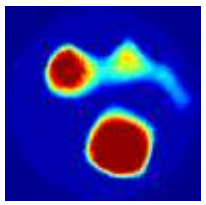


Higher resolution

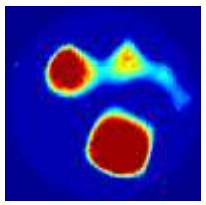
Iter. 15



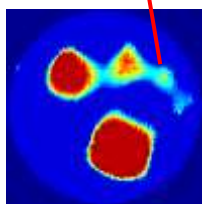
Iter. 30



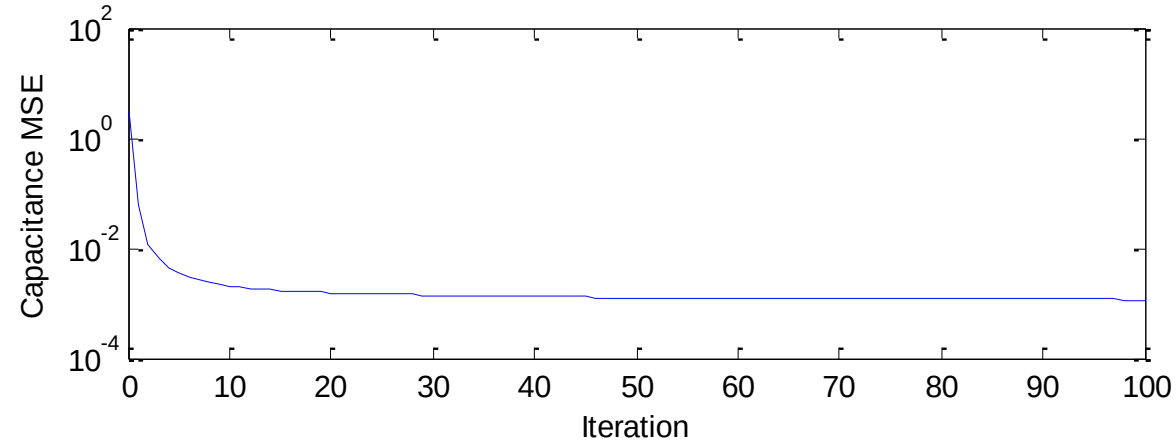
Iter. 50

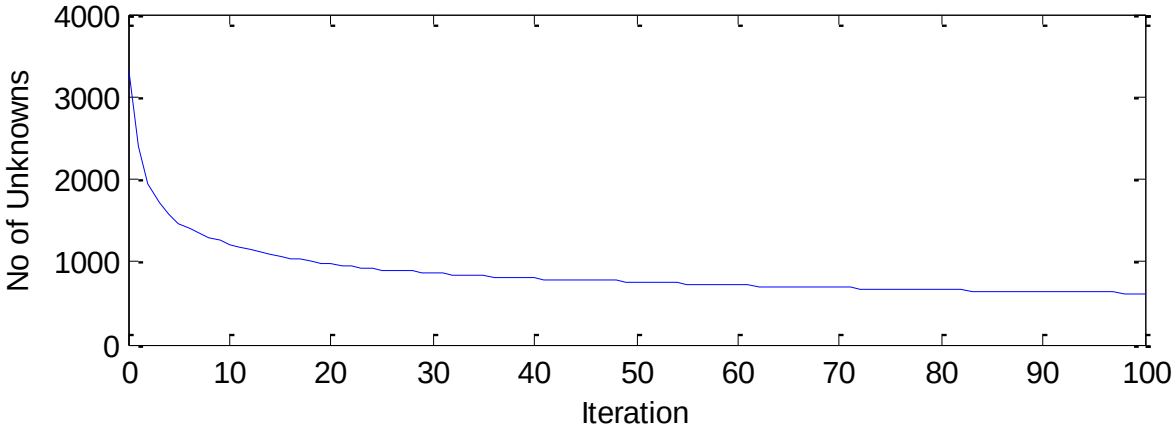


Iter. 100



Sharper

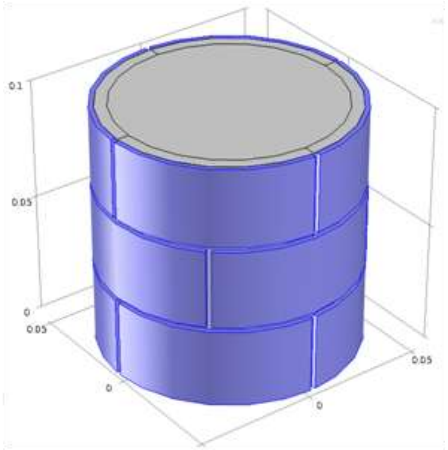


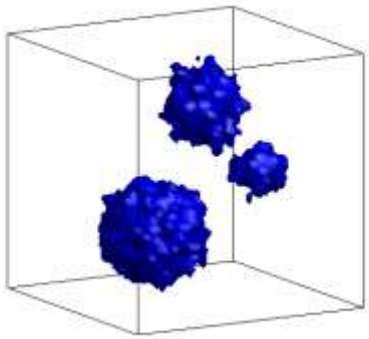




Both MSE and number of unknowns quickly declined.

# Examples

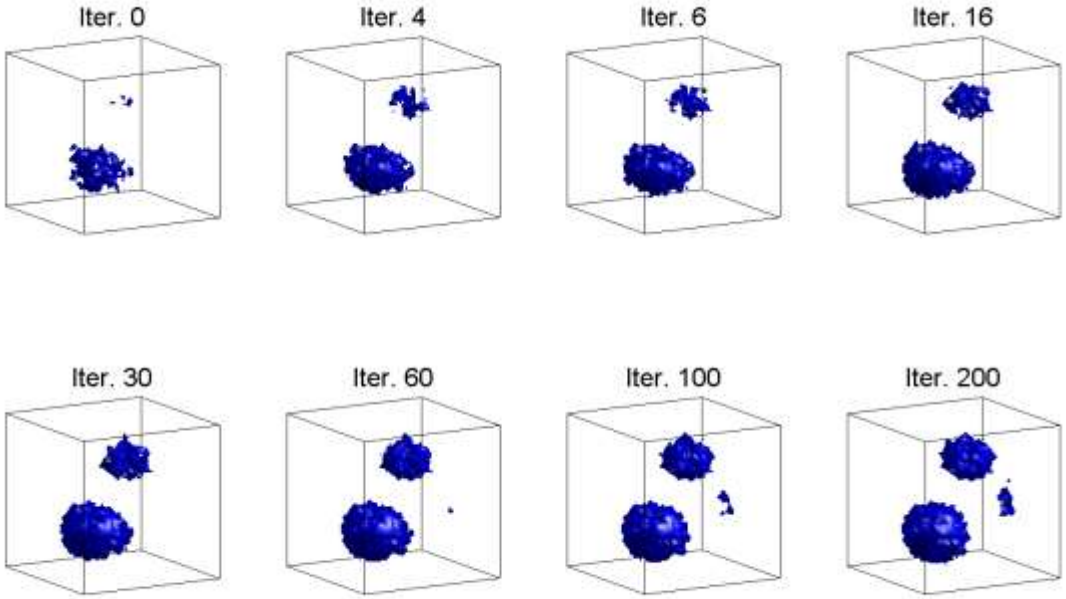
- 3D ECT
  - 3 rings
  - each consists 4 electrodes
  - cryogenic fuel tank under zero-gravity
  - Two-phase system





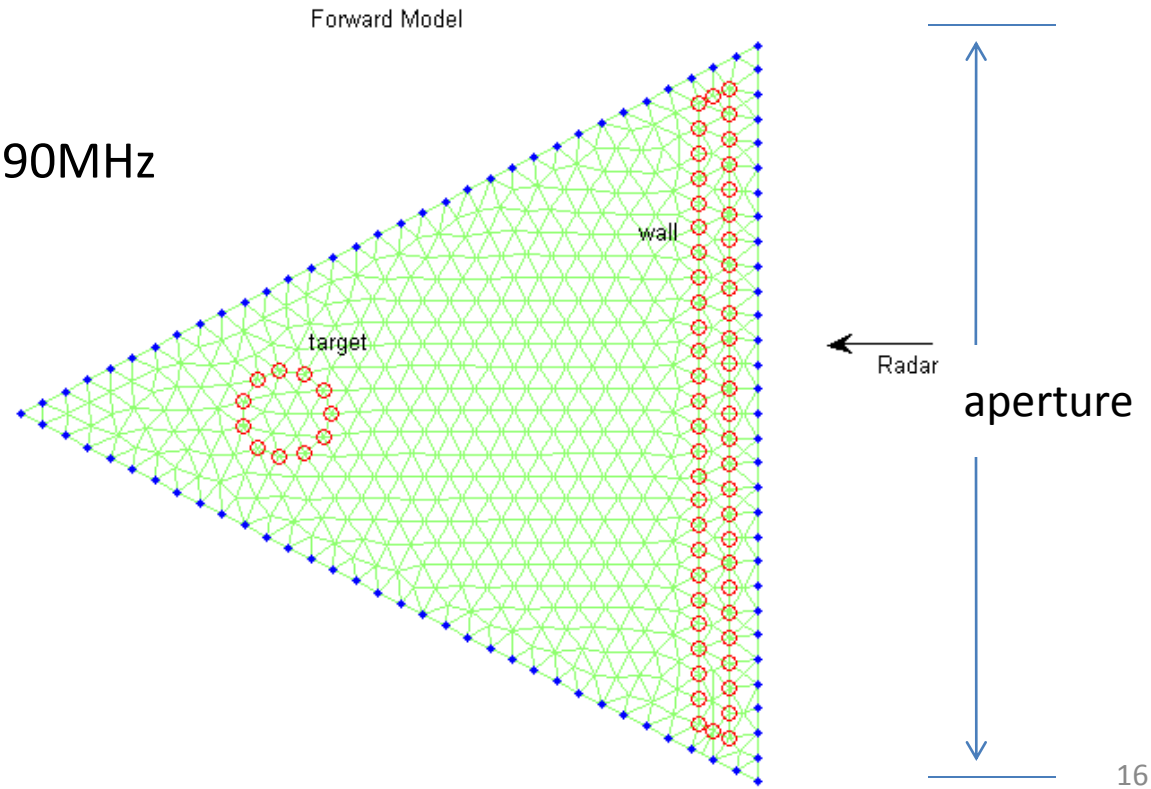
Ground truth

Reconstructed distribution of floating bubbles

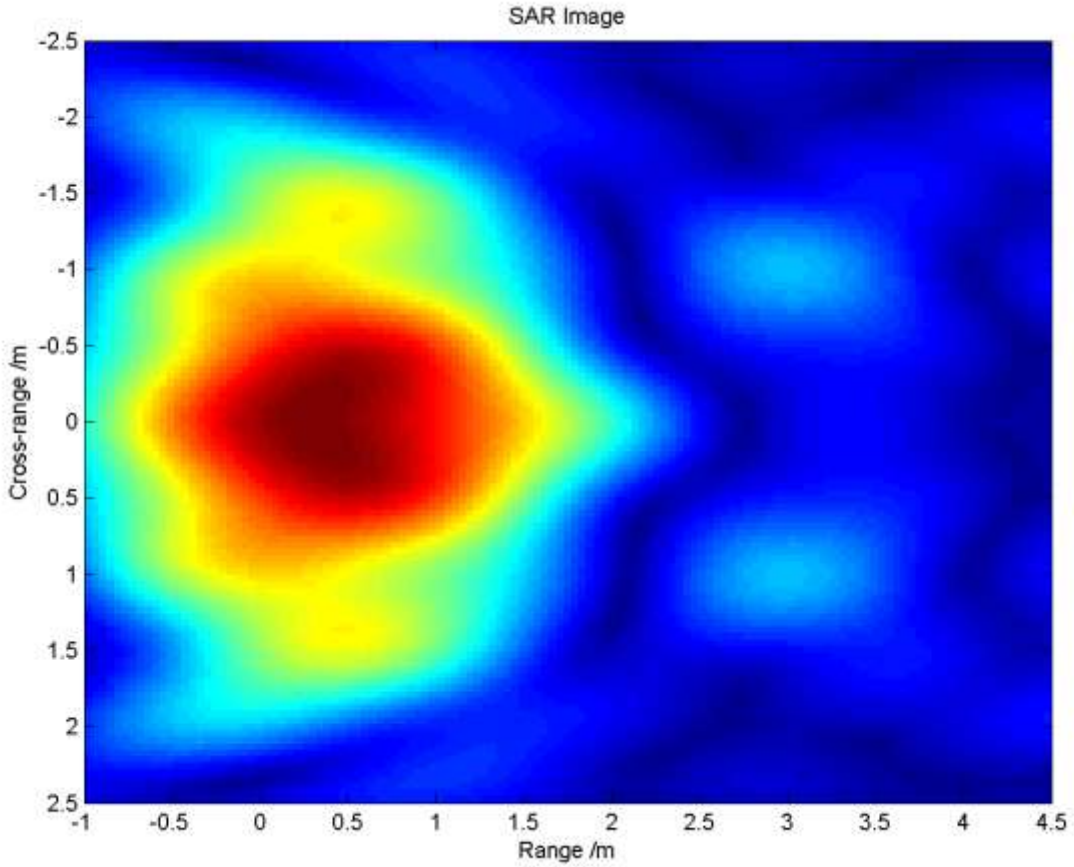


# Examples

- Through-Wall Imaging
  - Fixed transmitter
  - Sliding receiver
  - Bandwidth: 110-190MHz
  - Aperture: 120deg

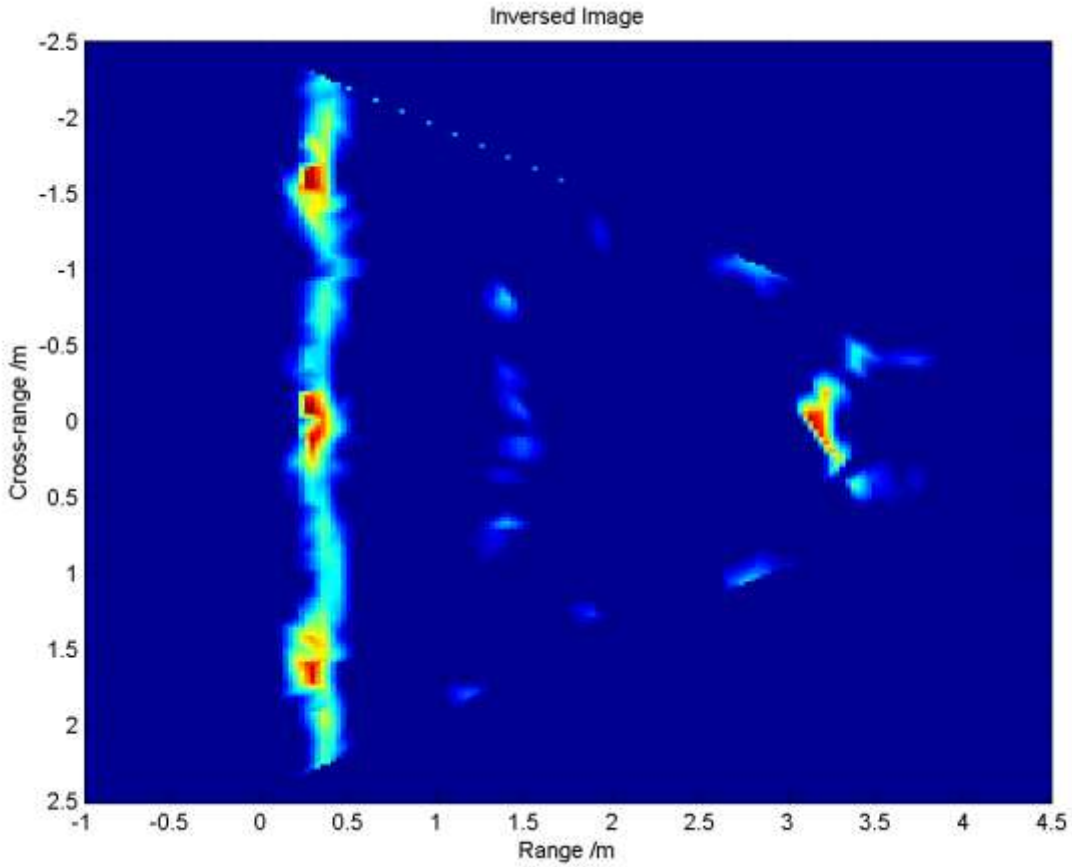


Conventional SAR image




Range resolution: 1.875m
Cross-range resolution: 0.95m

Image formed via INTAC




Sharper image
Higher resolution

# Conclusions

- Wideband low frequency ISAR radar for planetary subsurface exploration
- INTAC parameter retrieval method is superior over conventional imaging methods for SAR processing
- INTAC incorporates a priori knowledge to eliminate uncertainties
- Require fast forward model for real-time application
- Seeking partnership with others for deployment to perform field testing