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# GN&C and Sensors for Rendezvous and Capture

## Missile Systems Technology Applied to the On-Orbit Serving Challenge

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# Raytheon Space Activities

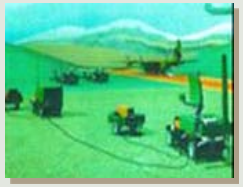
- Missile / space vehicle avionics
- Rugged space / missile sensors
- Vehicle GN&C
- Space Manufacturing
- Interceptor technologies
- Modeling and Simulation

**Missile Systems**

- Space based sensors
  - EO
  - IR
  - HSI
- Space packaging and quality

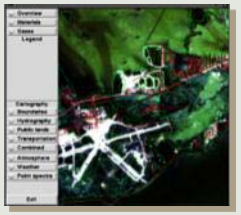
**Space and Airborne Systems**

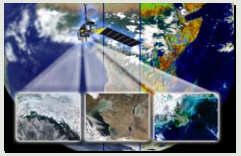
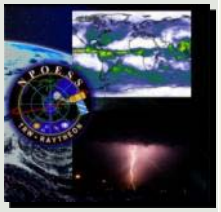
- Radar and communication technologies
- Networking technologies
- Raytheon Vision Systems



**Network Centric Systems**

- Satellite command and control
- Mission and resource management
- End-to-end information and network management
- Modeling and simulation
- Software re-use



**Intelligence and Information Systems**

- Logistics
- Range Support
- Training

**Raytheon Technical Services**

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# On-orbit Servicing: Raytheon Perspective

- **Raytheon's View of the Challenge**
  - **Autonomous Rendezvous and Dock (AR&D) as an Extension of Precision Engagement – The "Near Zero" Velocity Target Impact**
  - **Potential Human Interaction in the Real Time Process – Enabler or Source of Error?**
  - **Ideas are Not New But Implementation is Much More Accessible**
  - **System must also autonomously deliver servicing safely – Required for Overall Mission and Enterprise Success**
- **Technologies have evolved during the last two decades due to multi-billion investment by the Missile Defense Agency and other defense organizations**
  - **Basic technologies are now mature and modular: Propulsion, Electronics, Sensors, Guidance, control, navigation (GN&C), and tracking software**
  - **These technologies can be readily adapted and configured for spacecraft servicing, rendezvous and landing missions to planets, the moon, asteroids…**

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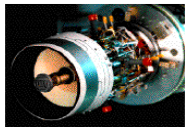
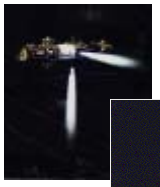
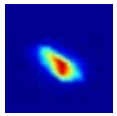
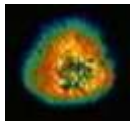
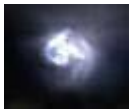
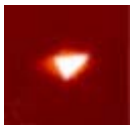
# Raytheon's Extensive Space Vehicle Experience

| 1985-89 | 1990-1994 | 1995-1999 | 2000-2004 | 2005-2009 |
|---|---|---|---|---|
| DELTA 180 (1986) | HEDI KITE 1 (1990) |  FTV-3 (1995) | SIT (2001) | **FM-2 (25 JAN 02)** |
| LEAP Contract (1987) |  ASAT/ DTB (1991) LEAP II (1992) | FTV-4 (1995) |  FTR-1A (2001) | **FM-3 (13 JUN 02)** |
| LEAP Liquid Hover (1988) | LEAP III (1993) | SM-3 ALI (1999) | EKV C0 (2002) | **FM-4 (21 NOV 02)** |
| | LEAP SDACS (1992, 1994) | |    EKV Intercepts at KMR (2000-2001) | **FM-6 (11 DEC 03)** EKV TB/CE (2004) |
| | | | | SM-3 Blk IA (2005) **FM-7 (24 FEB 05)** RV Hit (2005) **FTM-8 (17 NOV 05)** CE II (2005) **FTM-10 (22 JUN 06)** SM-3 Blk IB/II (2007) |

**Raytheon SV Technology Can Be Leveraged For Orbital Servicing**

# Design Considerations: Raytheon's View of the Orbital Servicing Challenge

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**Sensors**
- Visible
- RF
- LADAR
- IR

→

- Digital Video Electronics
- Signal Processing

→

- Flight System Navigation
- Sensor Data Fusion

→

- Flight System Guidance
- Targeting
- Fuel Management

→

- Flight System Control
- Autopilot
- Thruster/Wheel Management

## Design considerations

- Data fusion from multiple sensors as an enabler
- Sensor or subsystem failure resiliency and response
- Reliability vs. System Redundancy – Most Tactical systems are single shot devices with VERY high reliability
- Lateral Targeting Control Authority
- Upgradeable System Architectures
- Servicing mission will meld sensor data from many sources
    - Multiple on-board sensors: Optical, RF
    - Multiple off-board sensors: GPS, Target Beacon, Ground Updates
    - Ground radars
    - Space assets

## State estimation of the target vehicle critical

- Relative position and velocity
- Pose
- Rotational states (possible non-principal component rotation)
- Approach and docking require quick, agile solutions and response

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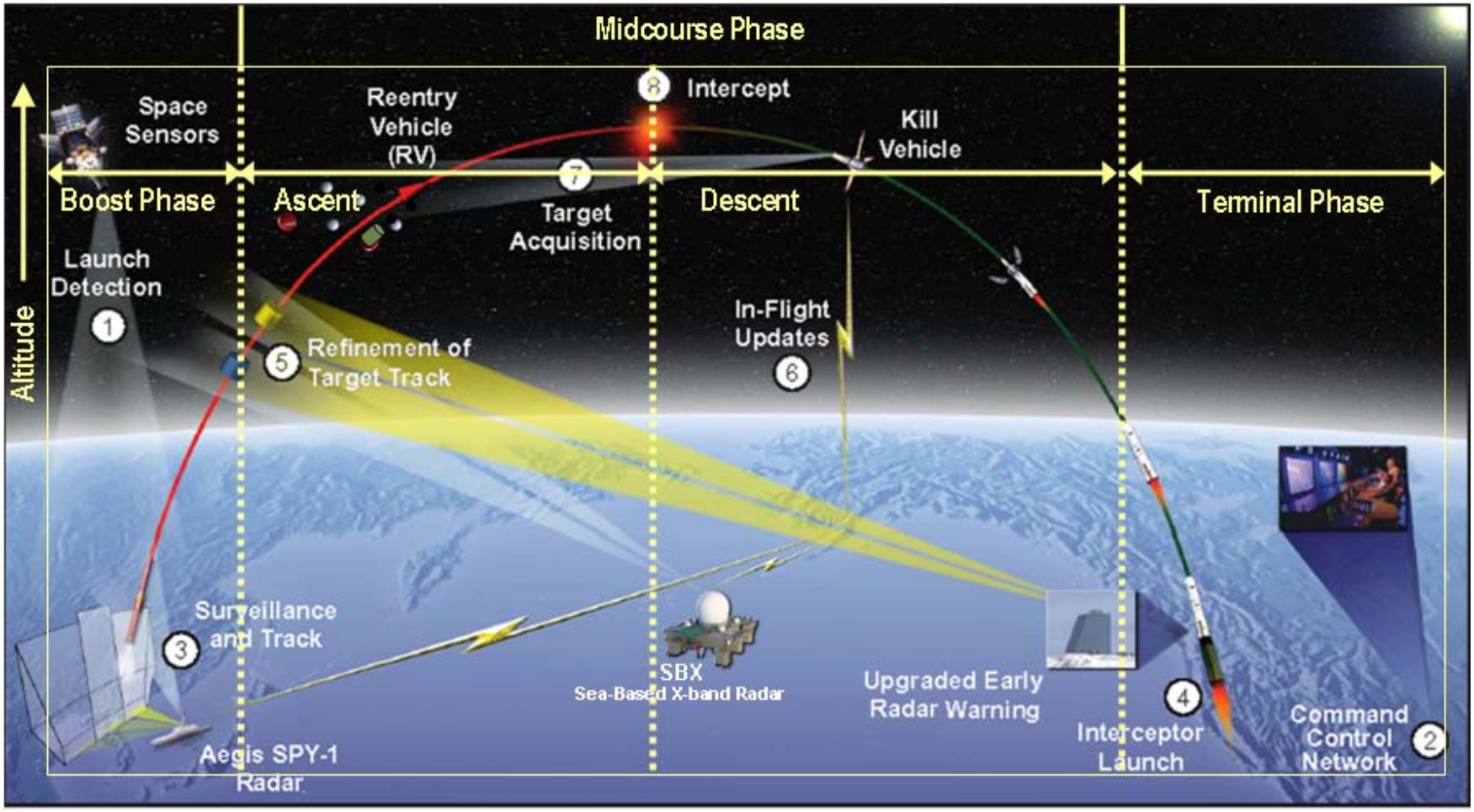
# Ballistic Missile Defense System




**BMDS is an Tactical Integrated System of Sensors, Space Systems and Command, Control and Communications emplaced to defend United States**

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# Raytheon Kinetic Vehicles – Overview

## Exoatmospheric Kill Vehicle (EKV)

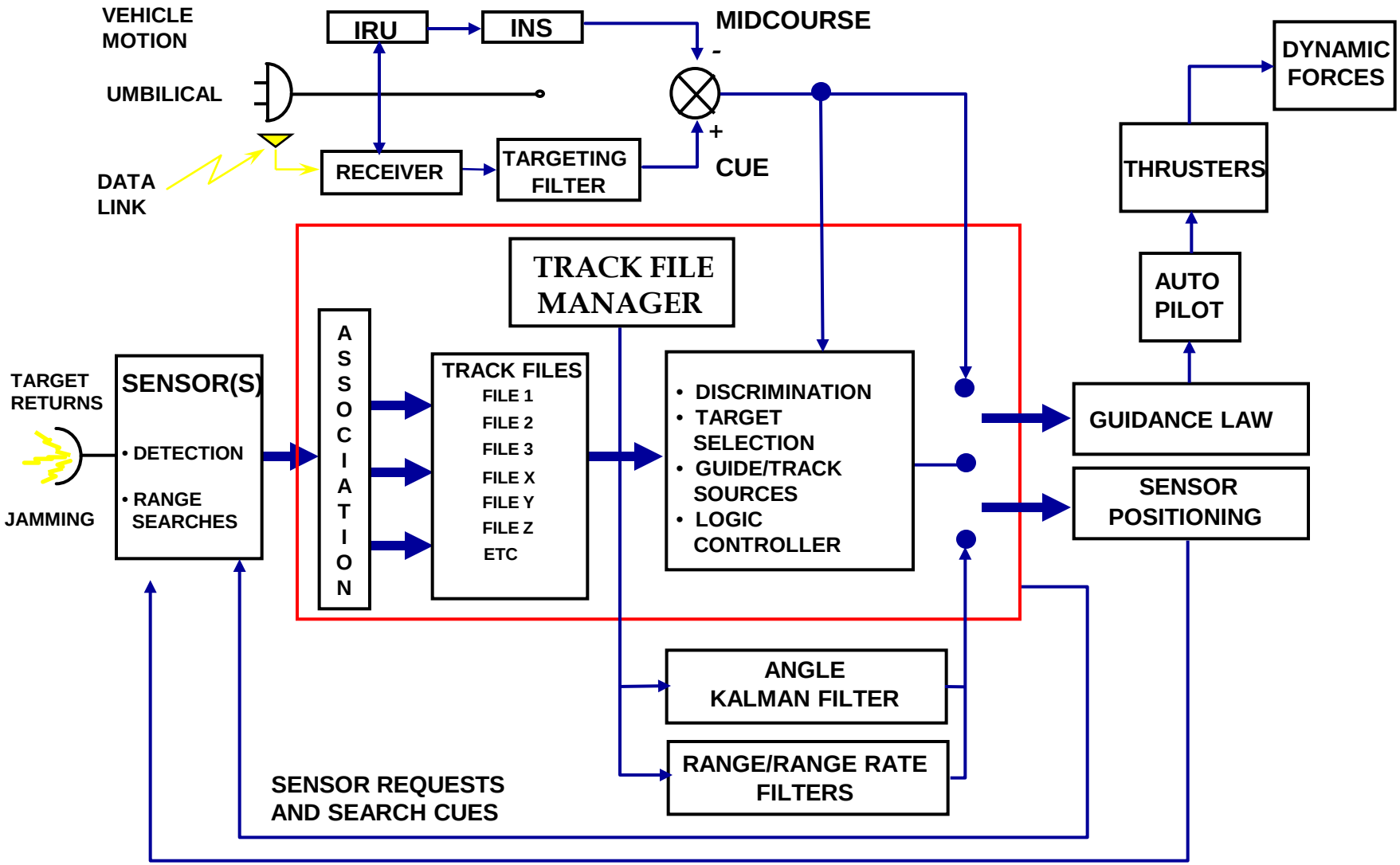
## SM-3 Kinetic Warhead (KW)

**<u>Key Sensor Design Requirements</u>**

- **Acquire unresolved targets at long ranges**
- **Perform absolute radiometry on point source targets**
- **Produce fine precision resolved imagery required for precision guidance**
- **Designed for space operation and high radiation environments**
- **Small, compact multi-spectral capability**

Raytheon Missile Systems

# Data Fusion System



# Mini-RF: Paradigm Shift in RF Payload Design

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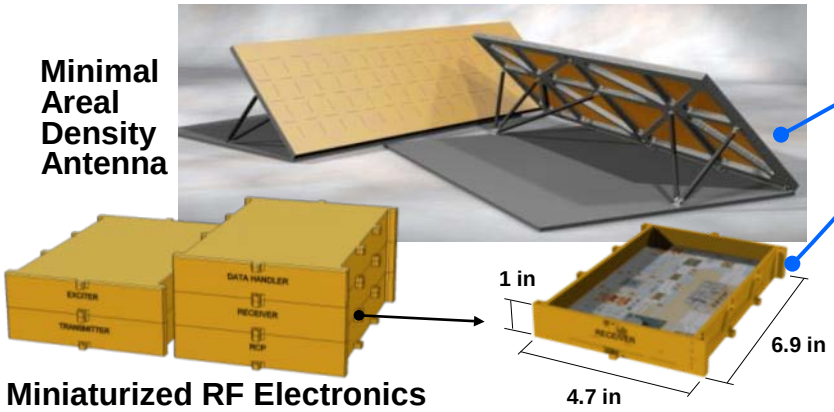
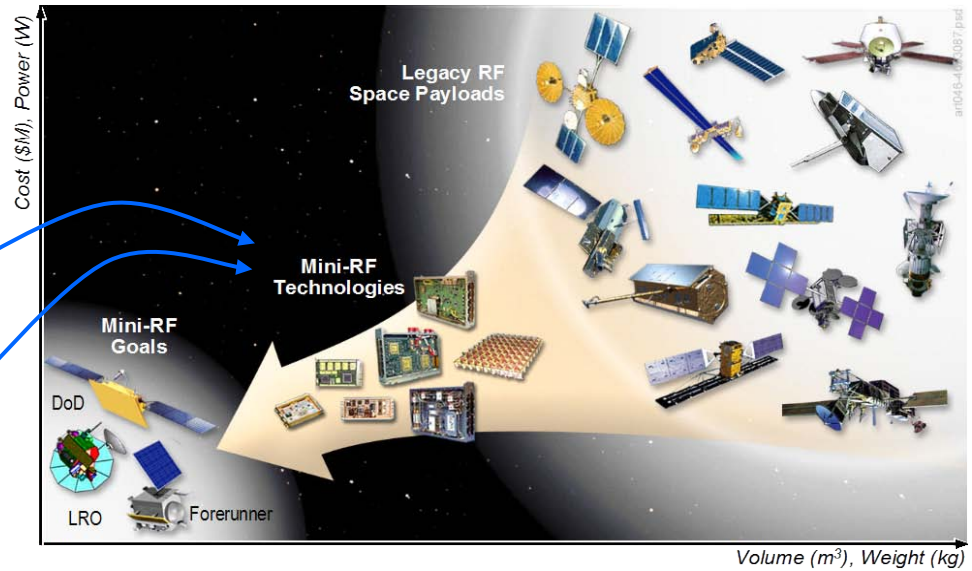
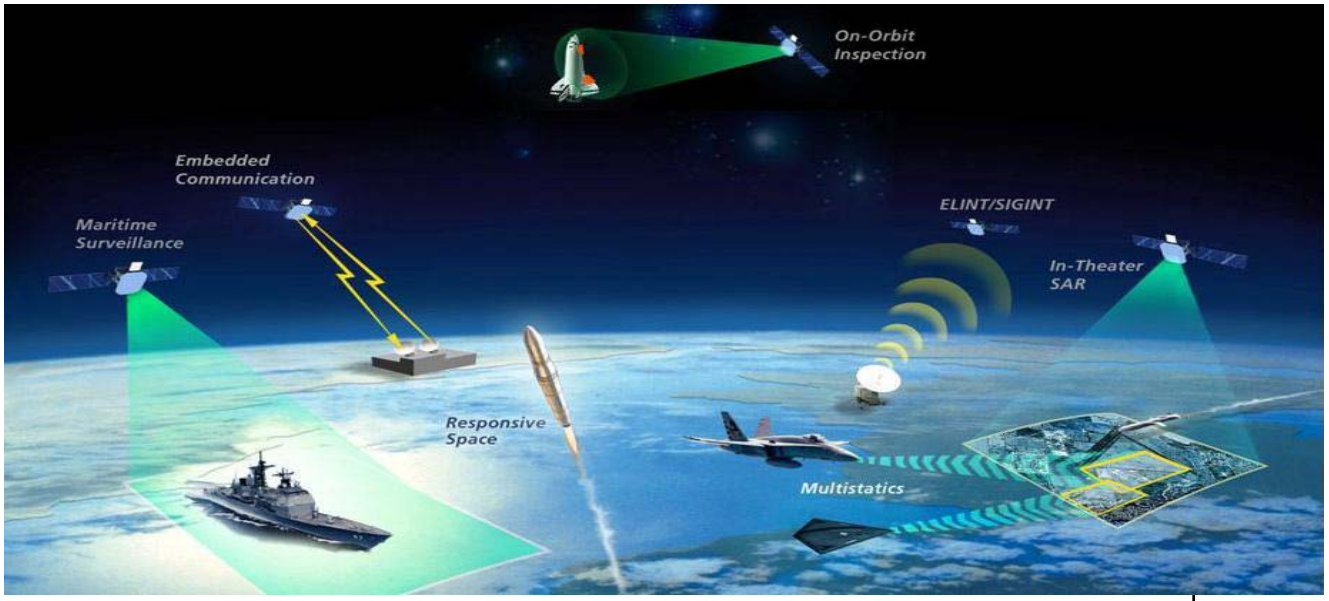
## Mini-RF Technical Innovations are Catalysts for Change




- Puts missile radar technologies in space
- Utilizes low cost missile design processes
- Miniature/Modular RF Components
- Multiple customers using building block approach
- Future potential for miniaturized RF payloads is vast



# Raytheon: A Key Partner on the Chandrayaan/LRO Mini-RF Product Team

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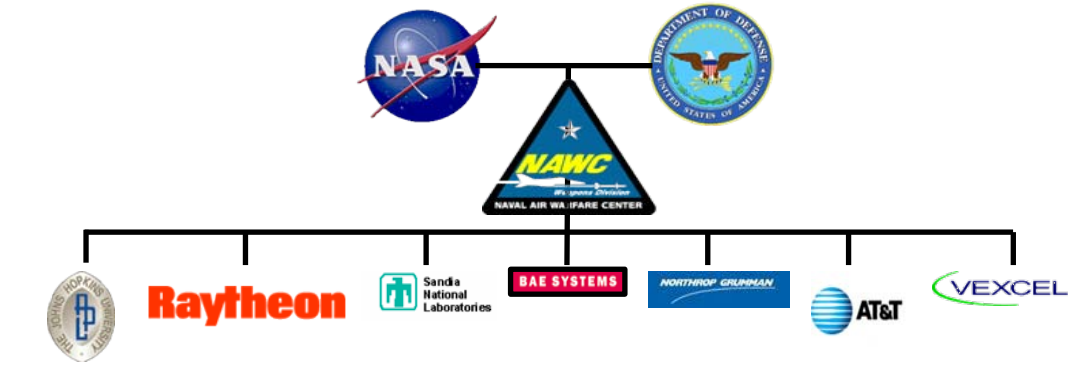
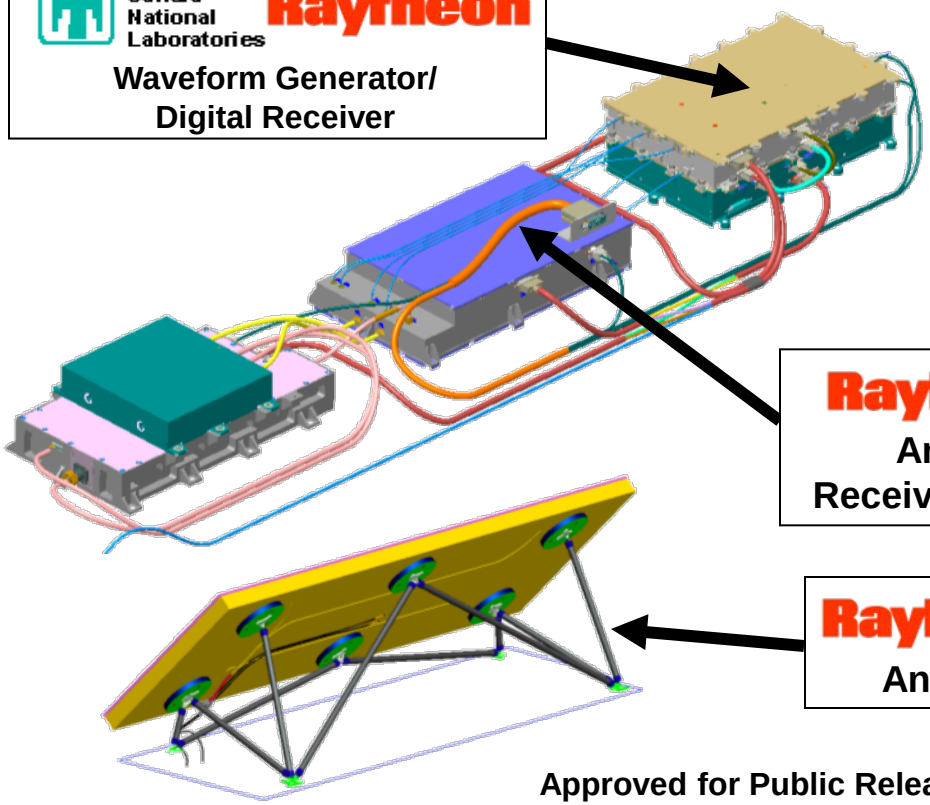



Sandia National Laboratories Raytheon
Waveform Generator/ Digital Receiver



Raytheon
Analog Receiver/Exciter

Raytheon
Antenna

LRO Spacecraft in Test at NASA GSFC

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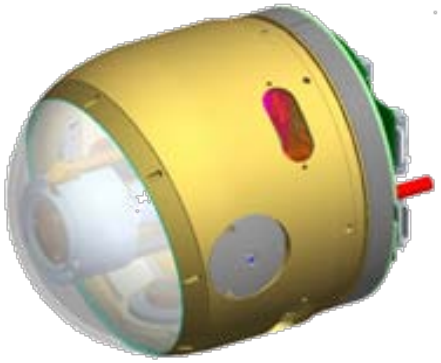
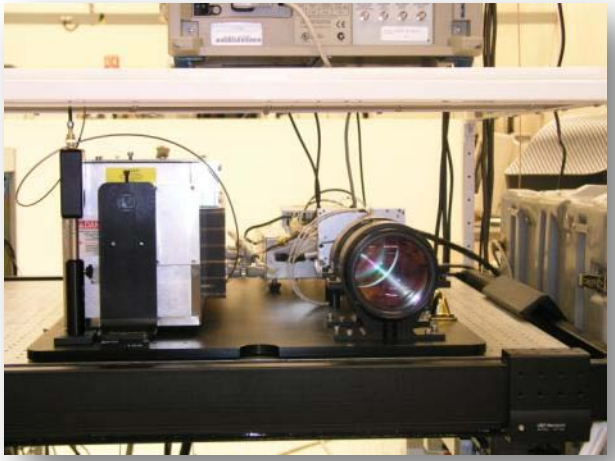
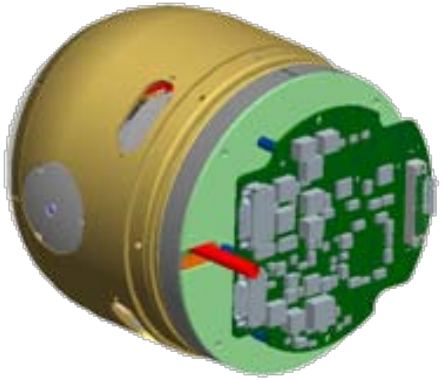
# AR&D Advantages of LADAR

- Laser radar (LADAR) provides a third dimension of high resolution data.
  - Improved Identification / classification
  - False alarm rates much lower than other systems
- LADAR sensors can be packaged with smaller and lower cost solutions than a dual mode IR/RF sensors







**Flash LADAR- Affordable, compact, effective.**

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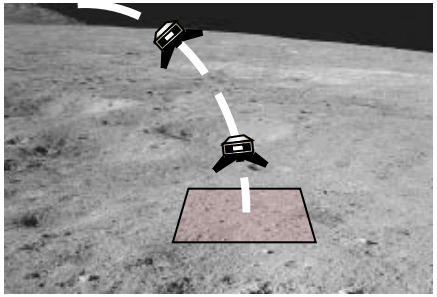
# Raytheon-NASA LADAR Evaluation

## NASA MSFC Docking Experiment:

- Objective: Demonstrate utility of LADAR in support of AR&D Missions
- Approach: Test CLAS LADAR seeker and modified ATR code in 300 meter Tunnel

Autonomous Rendezvous & Docking

Autonomous Landing & Hazard Avoidance



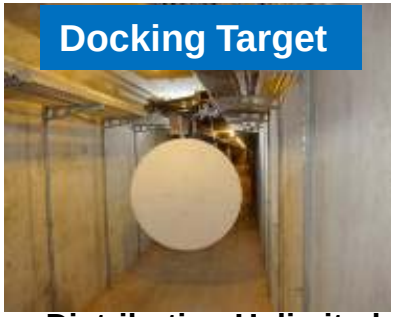
NASA LADAR Interest Areas

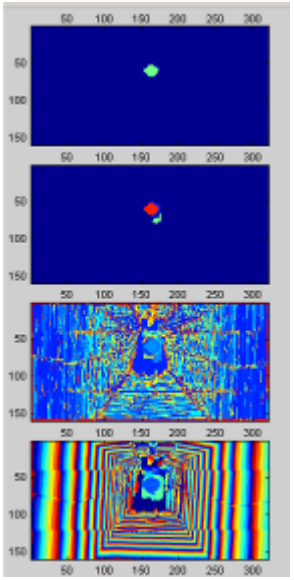
## Critical Success Factors:

- Demonstrated Docking Hatch Acquisition
- Demonstrated Accuracy of Target Location and Attitude
- Demonstrated Successful Docking Loop Closure
- Demonstrated LADAR reliability

CLAS LADAR

Docking Target





Real-time Algorithm Target segmentation

# Common Tri-Mode Seeker (CTMS)

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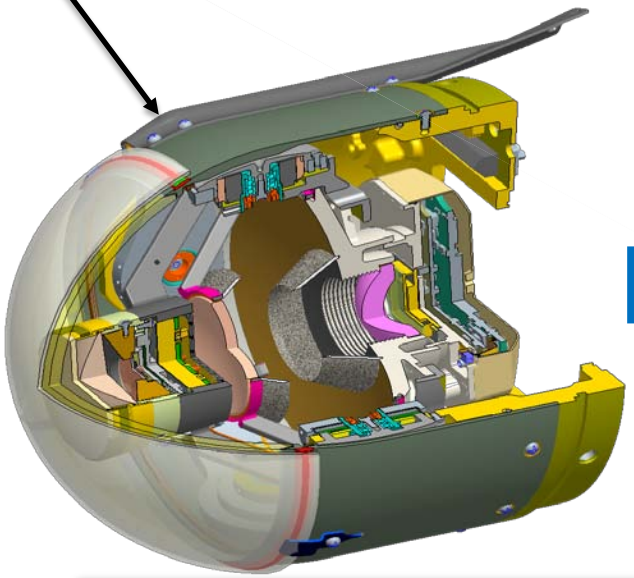
- Guidance Unit Function
  - Interface to fire control platform confirming accurate target selection
  - Deliver target angular line-of-sight signals, relative to the missile body axis, to the Control Section; enabling the missile to impact the target.



- Multi Mode Seeker Function
  - Produce data suitable for guidance electronics processing to generate LOS vector to target
- Seeker Modes
  - Infrared Imager
  - Semi Active Laser (SAL)
  - Radar

**Combining Functions in a Single, Compact, Low Mass, Low Power, Multi-Band Sensor Package Suitable for Multi-Product Usage**

Approved for Public Release, Distribution Unlimited

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# Raytheon Space Sensor Suite

Multi-function star tracker

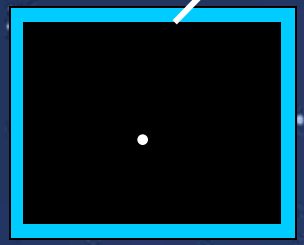
High resolution imaging of dark or sunlit RSOs

Pulse & image receiver

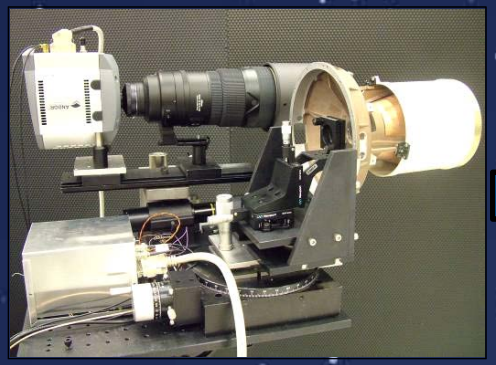
Detect sunlit RSOs > 5000 km

Pulsed illumination

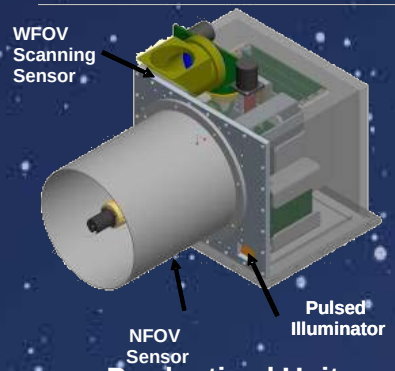
Active RSO range and attitude determination



- Mass: < 8 kg
- Power: < 50 W Peak
- Service Life: 5 years in GEO/Cislunar Space



Brassboard Unit




Productized Unit

## Sensor Summary

- Missile style packaging – rugged, compact
- Legacy missile defense algorithms
- Low cost COTS radiation tolerant electronics
- Rendezvous and Proximity Operations:
  - Measure range to an object from 5 meters at <10 km
  - High resolution imaging of objects at <2 km

# Applying Raytheon Technologies to Space Serving Missions

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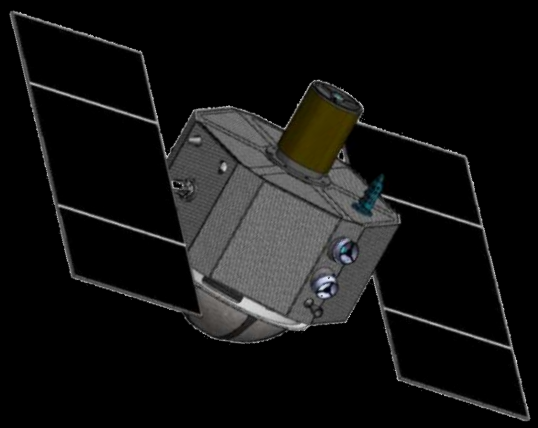
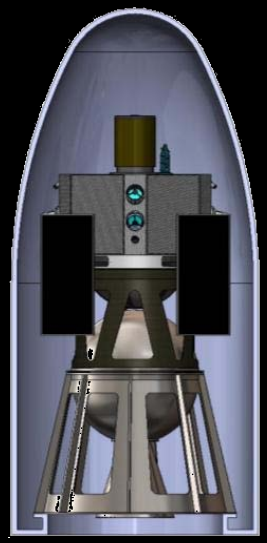
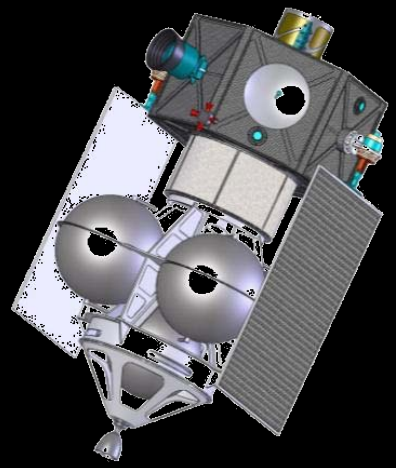
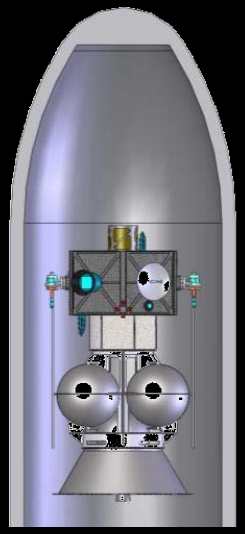
**Pegasus/SRM Space Servicer**



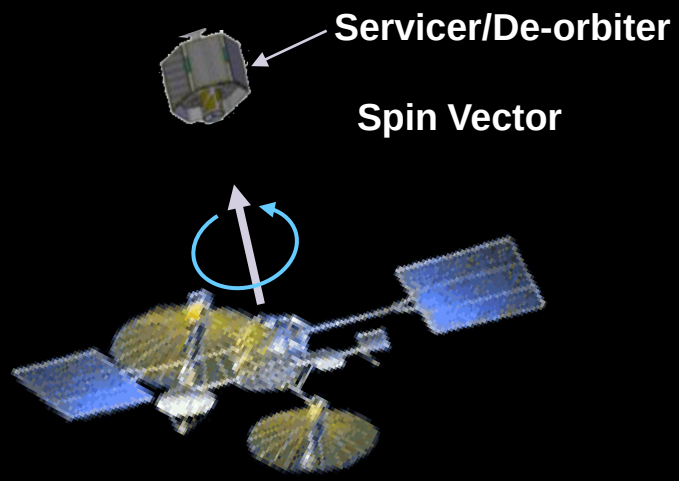


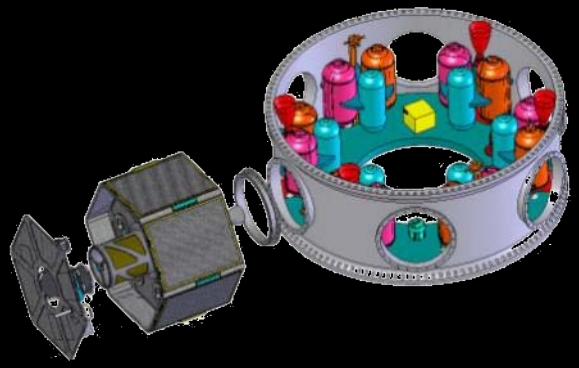
**Minotaur V/Multi-Stage Space Servicer**





**EELV/ESPA S/C Deployed Space Servicer**



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