Guidance, Navigation & Control building blocks for Space Servicing Vehicles & Active Debris Removal missions

(GNC B² 4 SSV & ADR)

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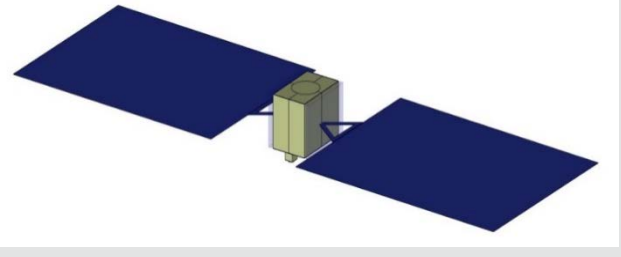
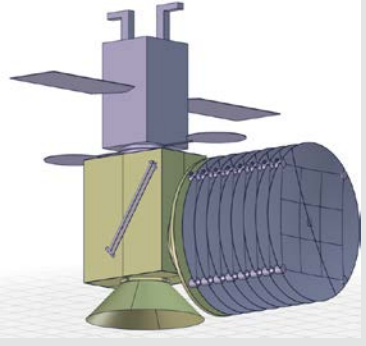
Requirements / sub-system functions (1/3)

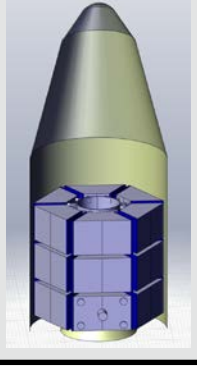
Mission Scenario 1
Deep Space Gateway Tug



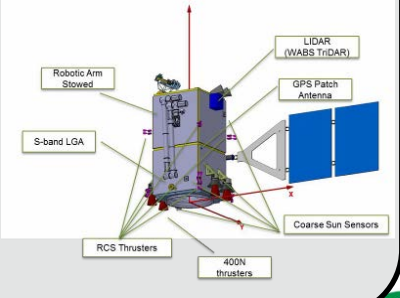
Mission Scenario 2
Antenna Assembly
for GEO S/C



Mission Scenario 3
Megaconstellation
ADR



Mission Scenario 4
ADR for a large
object in LEO



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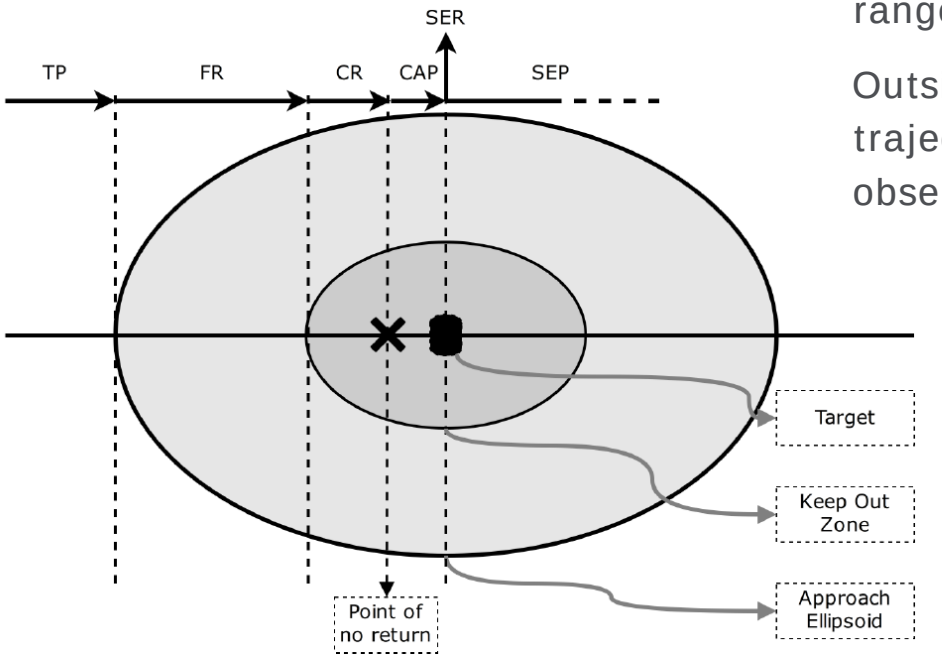
GNC engineering approach

- Try to harmonize GNC modes with ground operations and system needs
- Definition of GNC requirements and functionalities in a generic approach that can be easily ‘missionized’



Rendezvous phase ⇒ relative navigation (range & range-rate)

Outside **Approach Ellipsoid** ⇒ passively safe trajectories + range can be derived from other observations (navigation filter with long latency)

Inside **Approach Ellipsoid** ⇒ range obtained directly from sensor (e.g. NAVCAM+IP)

Keep-Out Zone ⇒ relative pose (attitude & COM position)

Point of No Return ⇒ last chance to perform Collision Avoidance Maneuver (CAM)

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Requirements / sub-system functions (1/3)

- GNC shall ensure that during rendezvous phase outside the Approach Ellipsoid (AE) the SSV shall be in passively safe trajectories
  - If a planned maneuver is interrupted or not executed, collisions are avoided during at least DD days
  - DSG & GEO: AE @ 2 km (TBC) , DD = 7 days (TBC)
  - e.deorbit & ADR: AE @ 200 m , DD = 1 day (TBC)
- GNC shall provide reliable range and range-rate data relative to the target vehicle during all phases of rendezvous
- GNC shall be able to provide reliable 6 DOF relative state (pose) when the SSV is inside the Keep-Out Zone (KOZ)
  - KOZ @ 200 m (TBC)
- GNC shall be able to compute collision risk with the target vehicle continuously during the rendezvous phase

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Requirements / sub-system functions (2/3)

- GNC shall be able to execute Collision Avoidance Maneuvers (CAM)
  - At all times beyond **Point-of-No-Return**
- GNC shall ensure that after the a CAM execution the SSV shall be on a 7 day (TBC) safe free drift trajectory
  - 1 day (TBC) for e.deorbit & ADR cases
- Docking and cooperative capture
  - GNC shall allow docking to any particular docking port
    - Approach along straight line in orbital frame towards capture point
  - GNC shall determine the 6 DOF relative state for any docking envelope
    - The docking envelope is comprised of closing rate, lateral rate, pitch/yaw rate, roll rate, lateral misalignment, pitch/yaw misalignment and roll misalignment.

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Requirements / sub-system functions (3/3)

- Uncooperative capture
  - GNC shall allow approach along a straight line in inertial frame not requiring continuous thrust
    - Permits EP approach along target angular momentum vector
- GNC shall autonomously achieve and maintain a 3-axis stabilized attitude in any relevant reference frame during all rendezvous phases
- GNC system shall operate autonomously with no ground intervention between check points
  - Check points shall be at passively safe hold points
- GNC shall be able to interact with a robotic manipulator (if any)

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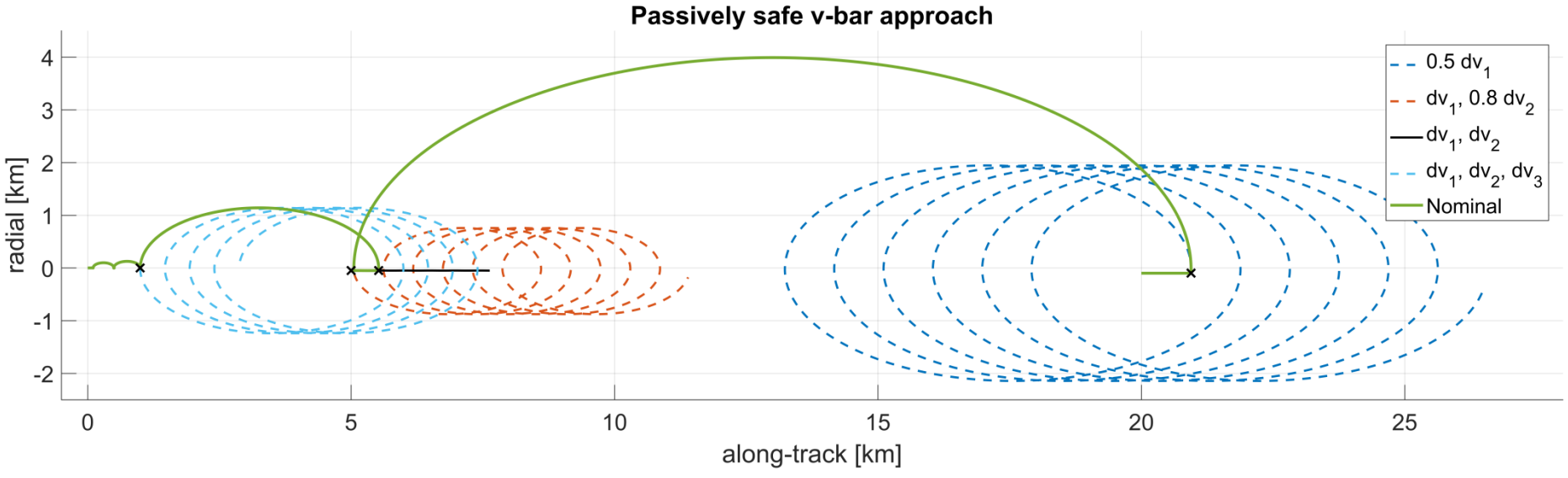
Baseline Design (MS1 & MS2)
V-bar approach



- 4 hops
- 8 radial manoeuvres
- 13.0 m/s
- T = 6 orbits

Passively safe at each point of the trajectory (also during manoeuvres)

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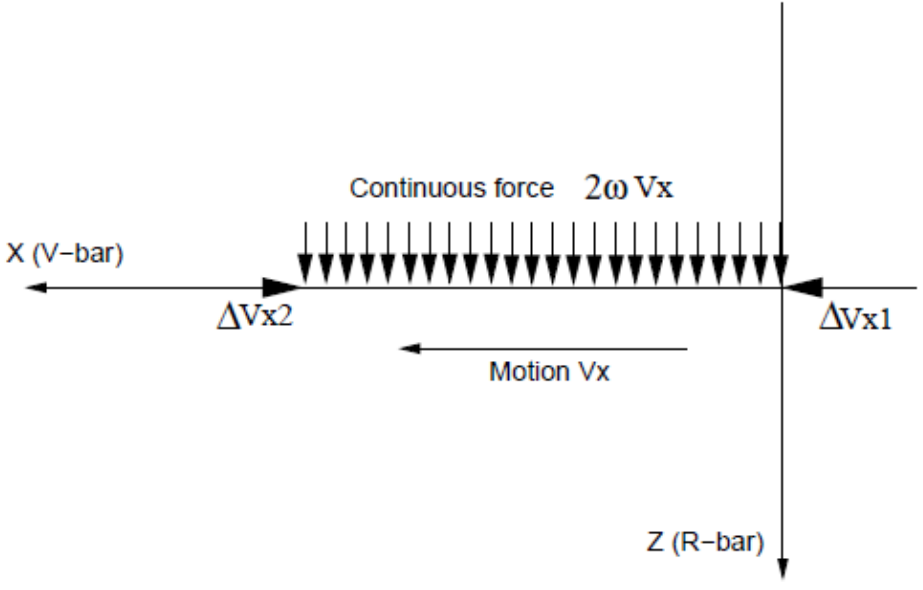
Baseline Design (MS1 & MS2)
Terminal approach (V-bar)



- Forced motion
- Continuous manoeuvres
- T = minutes

Not passively safe!

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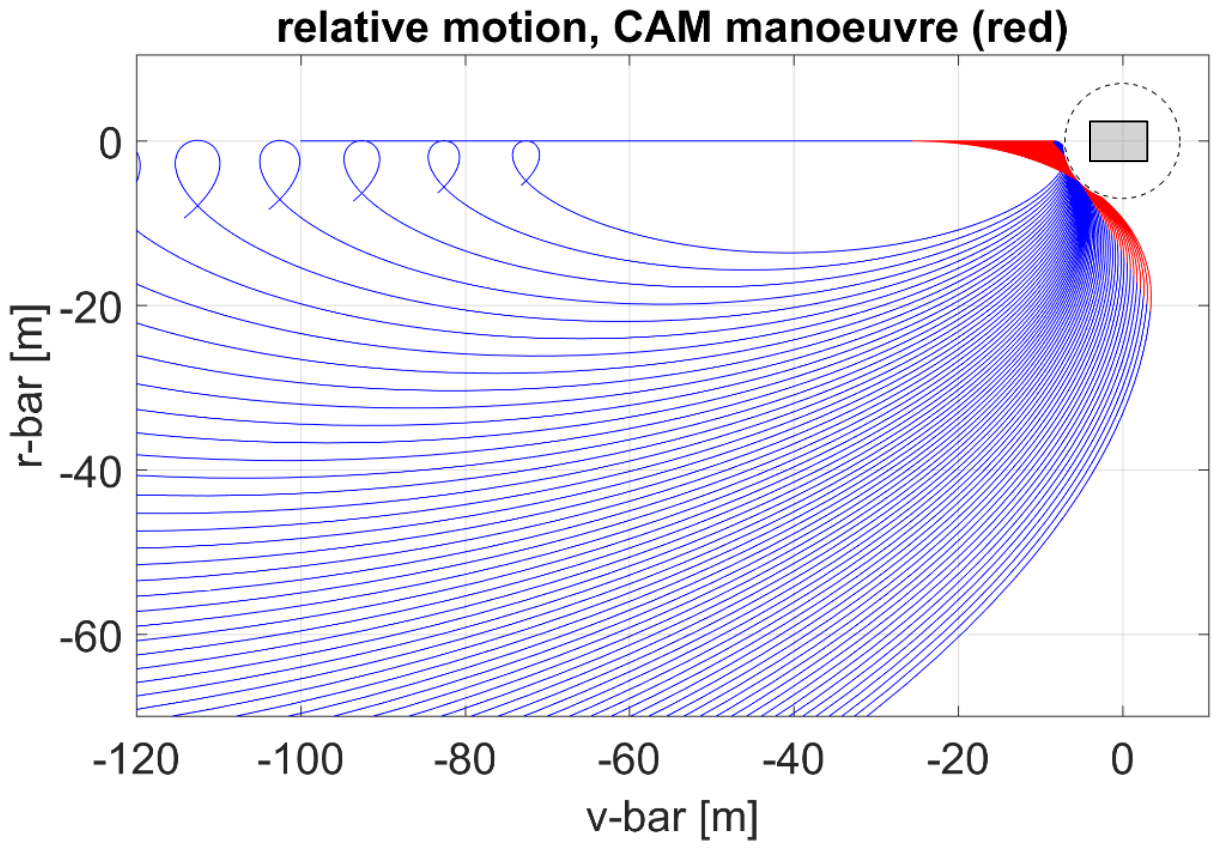
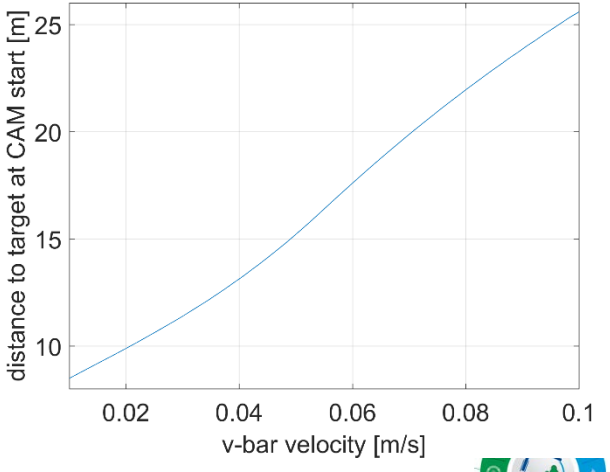
Baseline Design (MS1 & MS2)
Collision Avoidance Manoeuvre (CAM)



- Approach velocity: 1—10cm/s
- Minimal distance to target: 7m

- **Point-of-No-Return**: 8—26m



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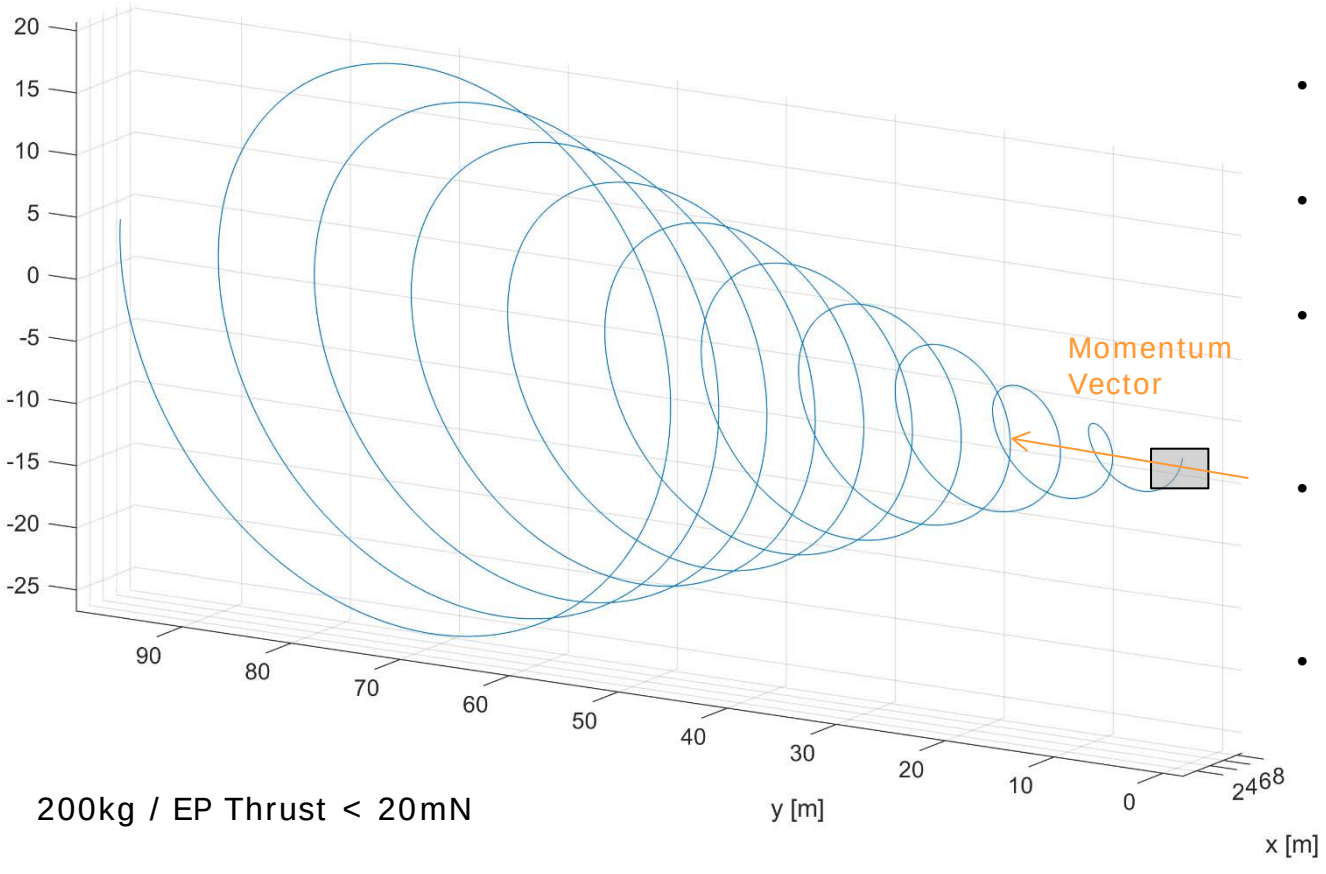
Baseline Design (MS3 & MS4)
Fixed Inertial Frame Approach



- Approach along momentum vector of target
- i.e. fixed approach vector in inertial frame
- One ellipse per orbit (not avoidable b/c of orbit dynamics)
- Thrust only in radial & normal direction (twice per orbit)
- Target always seen by relative navigation cameras

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Equipment – MS1 & MS4

SSV	#	Weight [kg]	Power [W]
GPS Receiver	2	0.02	0.85
Inertial Reference Unit	2	4.5	14
Sun Sensor	6	0.1	0
Star Tracker	2	2.6	12
LIDAR Rendezvous Sensor	2	8	30
Multispectral Camera (near range)	2	2	6
Narrow Angle Camera (far range)	2	4	4
		43	**65**

Relative Navigation

AM (only MS1)	#	Weight [kg]	Power [W]
GPS Receiver	2	0.02	0.85
Inertial Reference Unit	2	4.5	14
Sun Sensor	16	0.1	0
LIDAR Rendezvous Sensor	2	8	30
Multispectral Camera (near range)	2	2	6
		31	**51**

Relative Navigation

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Equipment – MS2

SSV	#	Weight [kg]	Power [W]
GPS Receiver	2	0.02	0.85
Inertial Reference Unit	2	4.5	14
Sun Sensor	6	0.1	0
Star Tracker	2	2.6	12
Multispectral Camera (near range)	2	2	6
Narrow Angle Camera (far range)	2	4	4
		27	**38**

Relative Navigation

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Equipment – MS3

SSV	#	Weight [kg]	Power [W]
GPS Receiver			
Inertial Reference Unit			
Sun Sensor			
Star Tracker			
Multispectral Camera (near range)	2	2	6
Narrow Angle Camera (far range)	2	4	4
		12	**10**

Satellite Bus

Relative Navigation

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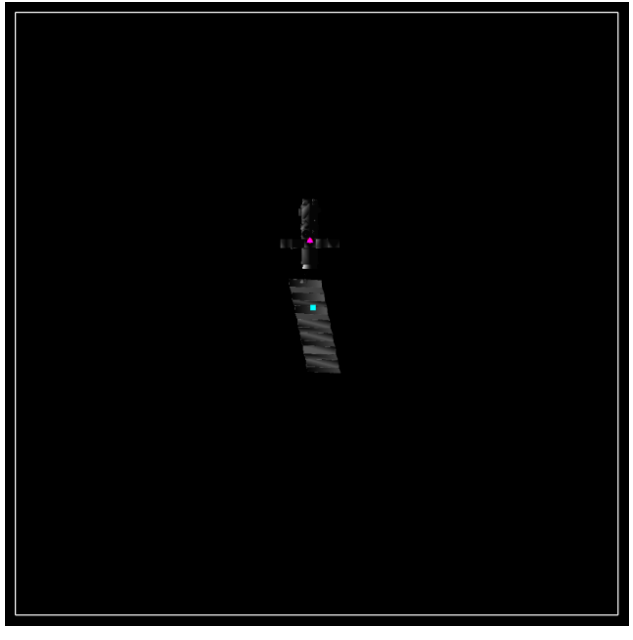
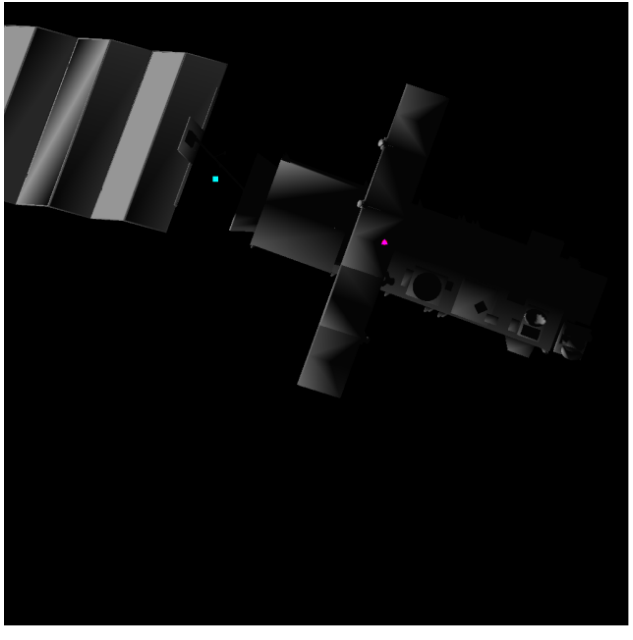
Vision-based Navigation Building Blocks (1/5)

- **ALL** missions: camera-based **LOS-only** relative navigation
  - Image processing based on centroiding
  - Unscented Kalman Filter for COM-COB correction
  - Semi-autonomous attitude guidance





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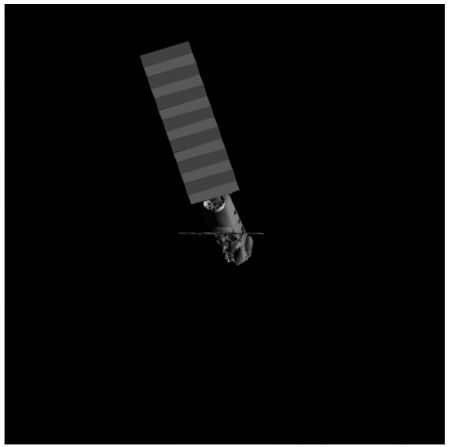
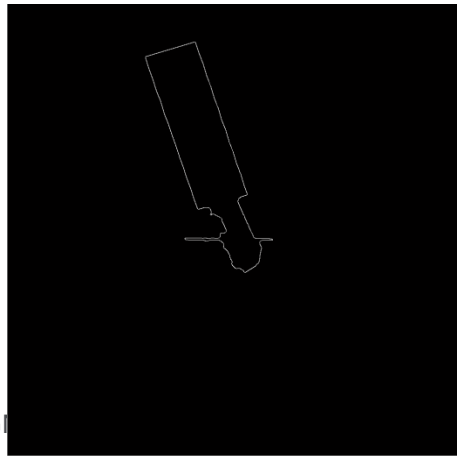
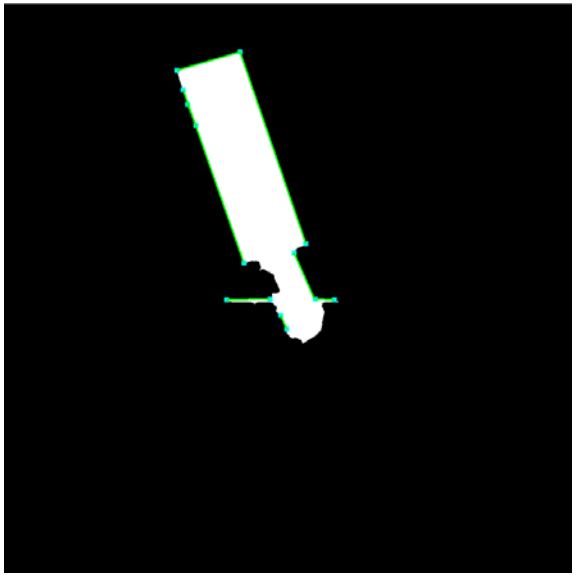
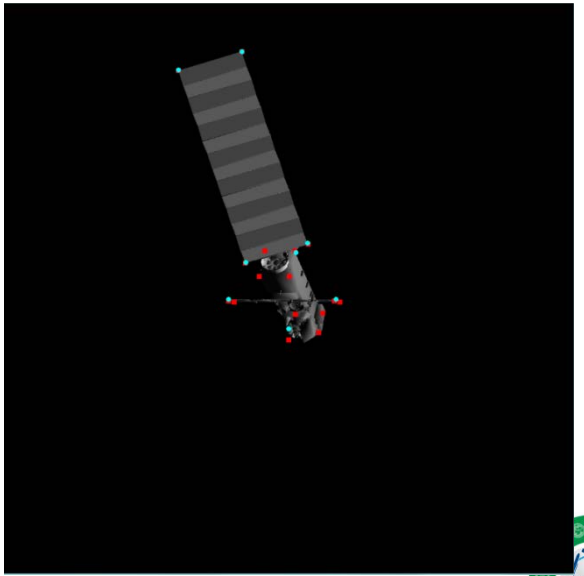
Vision-based Navigation Building Blocks (2/5)

- **ALL** missions: camera-based relative pose estimation navigation
  - Image processing based on ‘corner’ detection at line intersection
  - Unscented Kalman Filter including ‘corner’ matching
  - FDIR and/or closed-loop GNC inside KOS









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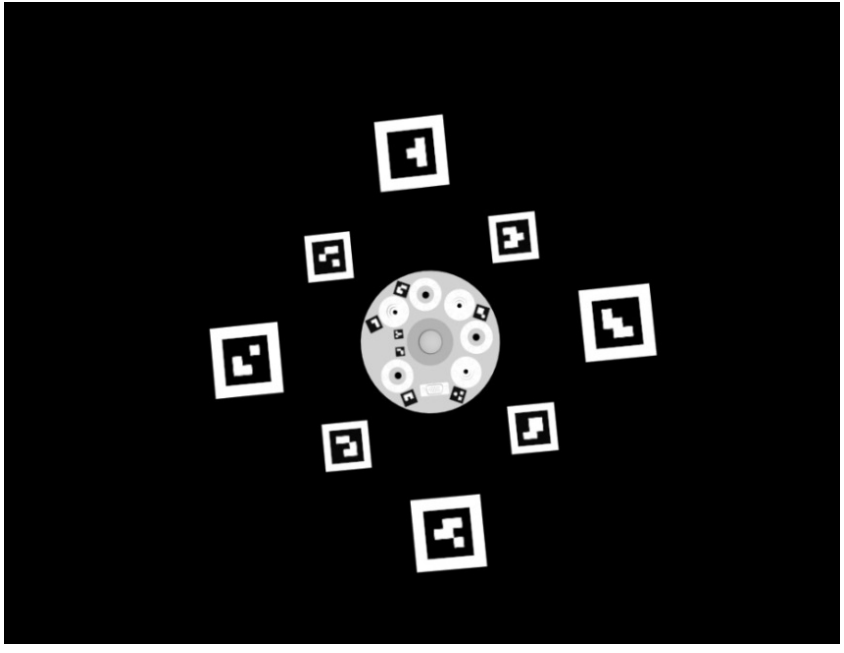
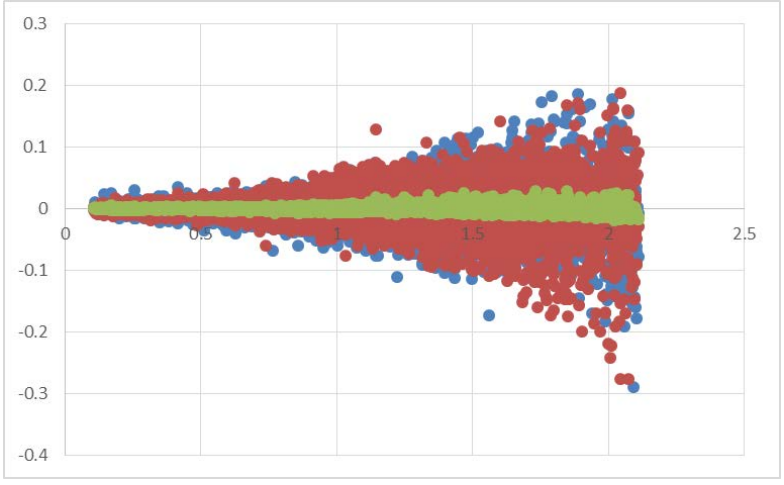
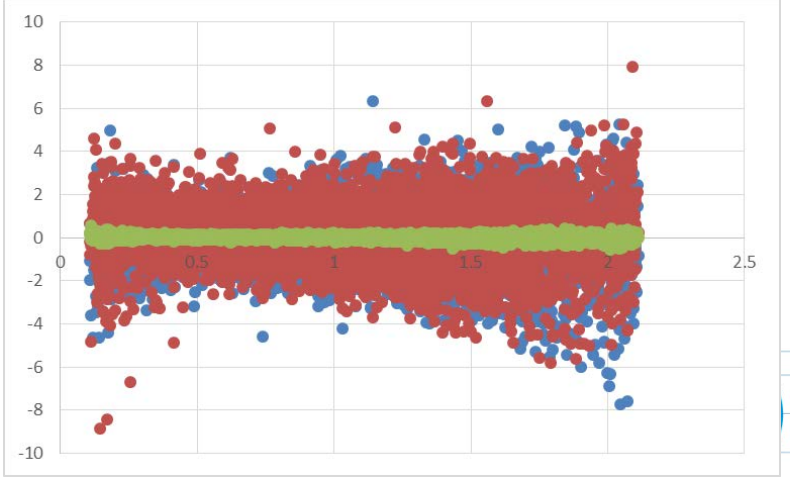
Vision-based Navigation Building Blocks (3/5)

- **MS1 & MS2**: Docking or capture **cooperative** target
  - Use (multi-spectral) markers

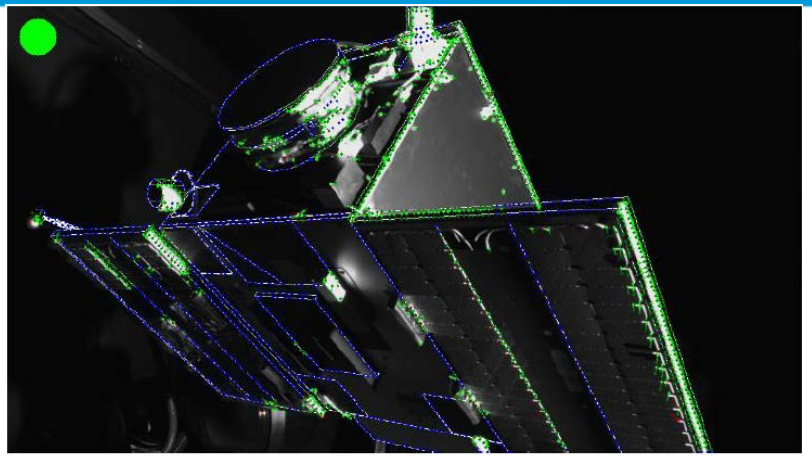


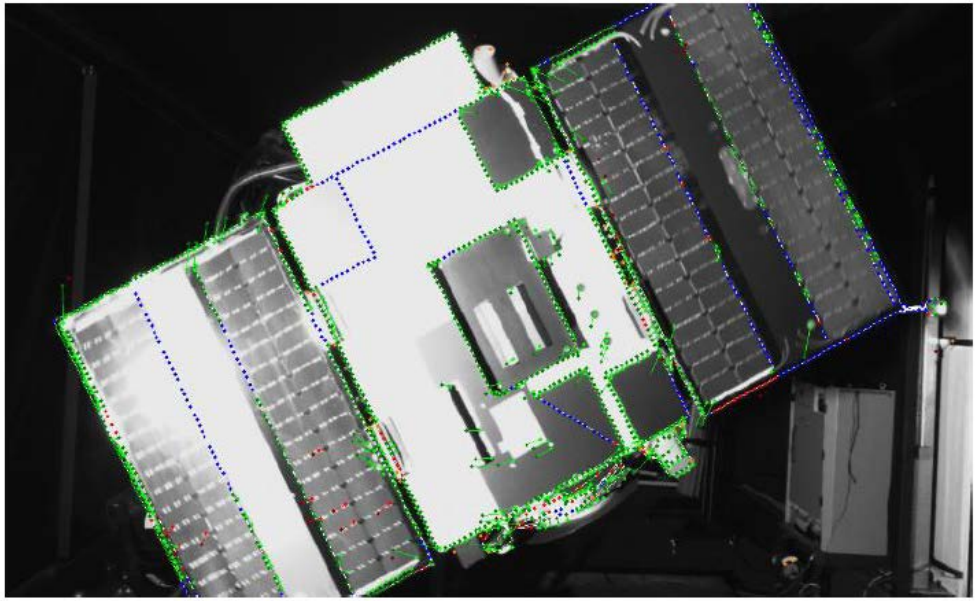


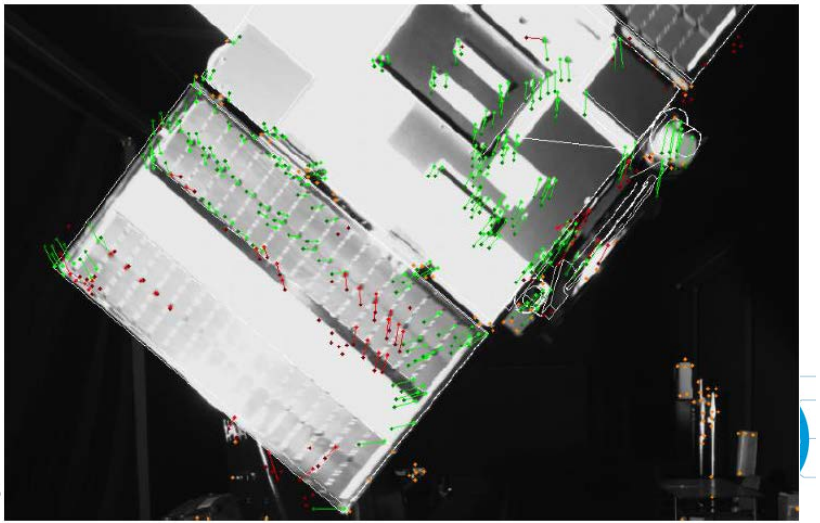


Vision-based Navigation Building Blocks (4/5)

- **MS3 & MS4**: Capture or contactless detumbling **uncooperative** target
  - Model matching aided by unknown feature tracking







Conclusions

- Identification of GNC building blocks to cover GNC requirements for SSV & ADR missions
- Passively safe trajectories need to be designed considering all sources of uncertainty and error (e.g. navigation, maneuver execution error)
- Some technologies are better known
  - Optical relative navigation for far rendezvous
  - 3D LIDAR based terminal rendezvous and docking
- Some other requires more development
  - Relative pose estimation for tumbling targets
  - Contactless detumbling
  - Terminal approach using EP

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