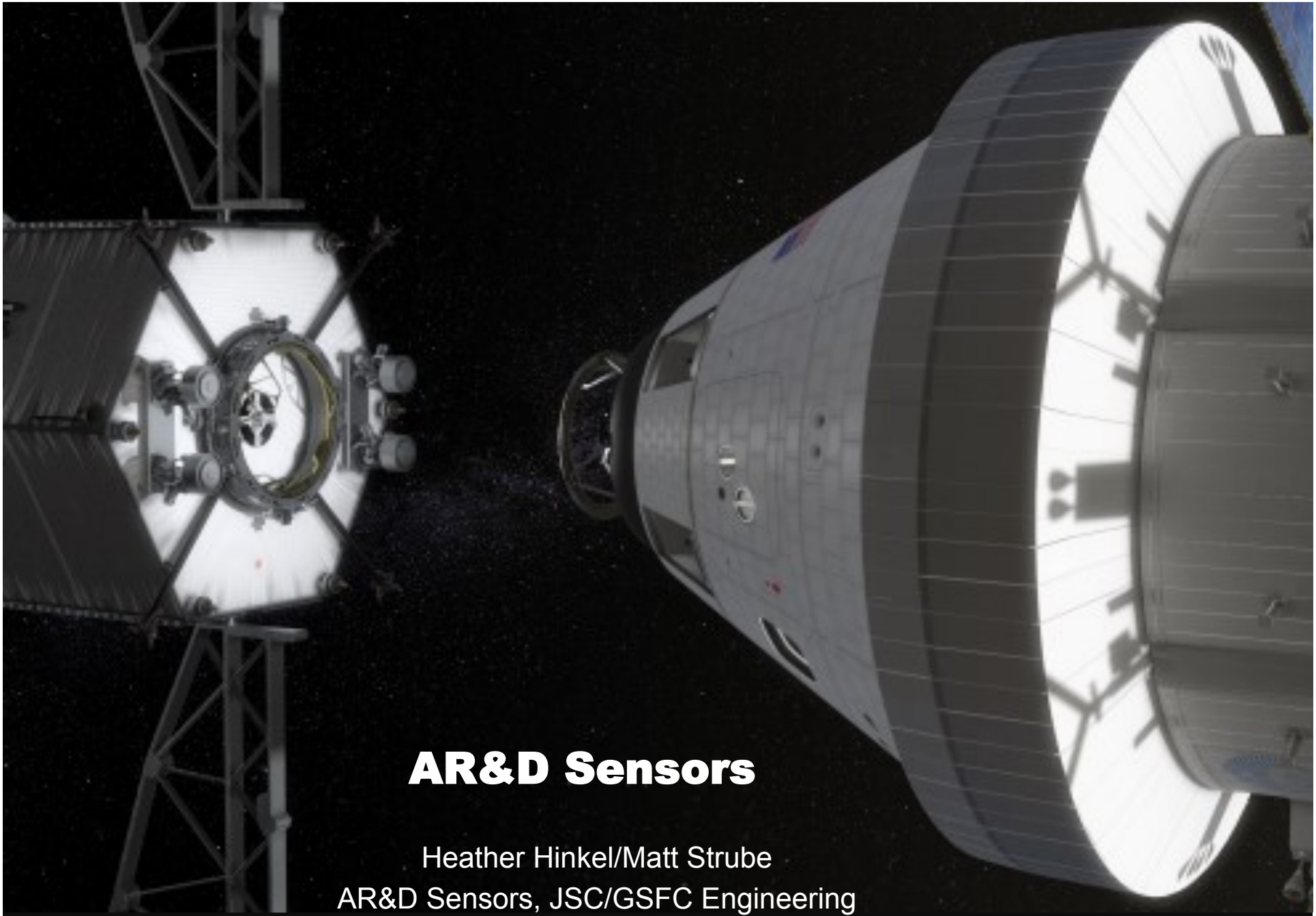

AR&D Sensors

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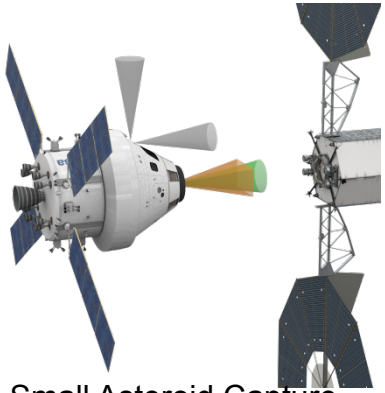
AR&D Sensors, JSC/GSFC Engineering

AR&D Sensors Needs

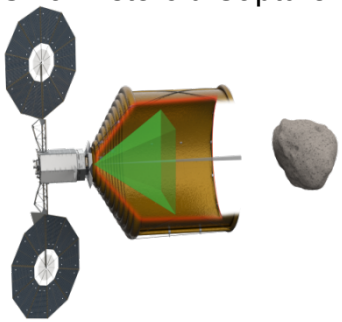
- **NASA needs automated rendezvous and docking/capture (AR&D) sensors for multiple missions**
  - Robotic Asteroid Redirect Mission (ARM).
  - Crewed segment of ARM
  - Satellite Servicing
  - Planetary or Planetary moon landing
- **NASA is pursuing a common suite of AR&D sensors to apply across multiple AR&D missions starting with the asteroid missions**
  - Visible cameras
    - Medium resolution (narrow angle) camera paired with selectable lenses per mission needs
    - High resolution (wide angle) camera paired with selectable lenses per mission needs
  - 3D LIDAR
  - Infrared camera
- **NASA created a common specification addressing environment and performance for each sensor which will fulfill each mission's AR&D needs**
- **NASA will provide the NRE and qualification of the suite of sensors that meet the common specifications**

AR&D Concept of Operations

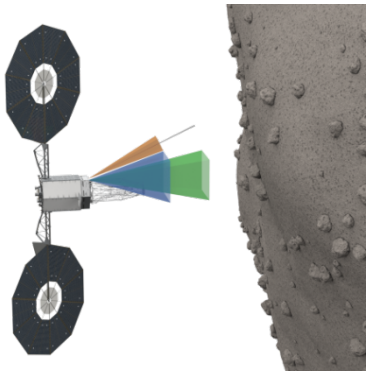
Crewed Asteroid Mission



Small Asteroid Capture



Robotic Boulder Capture

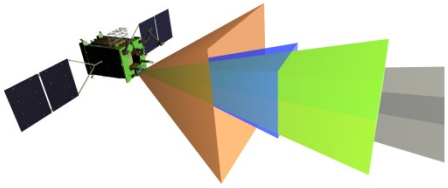


Long Range	Medium Range	Close Range	Application of Common Suite
S-Band Transponder for Range/Range Rate to reduce timeline; Star Tracker for bearing High Resolution Camera for bearing		3D LIDAR for precise alignment for docking High Resolution Camera for secondary pose	High Resolution Camera 3D LIDAR
Medium Resolution Camera for asteroid acquisition, spin rate and bearing to the asteroid		3D LIDAR for asteroid characterization and alignment for bag capture	Medium Resolution Camera 3D LIDAR
Medium Resolution Camera for bearing to the asteroid	Medium and High Resolution Cameras for spin rate, 3D map of the surface and boulder identification	3D LIDAR for 3D range images to the target boulder Medium and High Resolution Cameras for spacecraft pose and images of boulder collection areas	High Resolution Camera Medium Resolution Camera 3D LIDAR

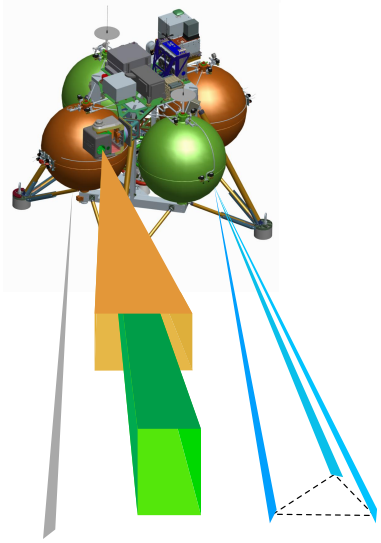
* Addition of infrared camera for robustness is being assessed

AR&D Concept of Operations (cont'd)

Satellite Servicing



ALHAT



Long Range	Medium Range	Close Range	Application of Common Suite
Medium Resolution Camera for bearing	Medium and High Resolution Cameras for terrain relative nav bearing	High Resolution Camera for coarse range and pose 3D LIDAR for range, bearing and pose IR Camera for bearing, coarse range and pose	Medium Resolution Camera High Resolution Camera 3D LIDAR IR Camera
Laser altimeter for ranging	High Resolution Camera for terrain relative navigation and coarse velocity Doppler LIDAR for precise 3D velocity, range and ground relative pose	3D LIDAR for hazard detection and hazard relative navigation Doppler LIDAR velocity/altitude IMU dead reckoning	High Resolution Camera 3D LIDAR

AR&D Sensor Environmental Commonality Specification

Attribute	Units	Specification	Notes
Operational Regime	NA	Deep space and cis-lunar	
Mission Duration	Years	> 7	
Sensor On-time	Hours	> 1600 (not for all sensors in the suite)	The suite is used as described in the supporting materials on the BAA website. Accounting for duty cycling, the on-time could be shorter.
Operational Thermal Range	deg C	-30 to +50	Survival temperature range should be wider than the operational.
Tested Partial Pressure	Pa	< 1e-5	The actual environment will be a hard vacuum.
Total Ionizing Dose (*)	kRad Si	> 100	Computed TID should account for sensor on-time and mission elapsed time, which are different from each other
Single Event Upset Rate	Upsets/ day	< 1e-2	Computed rates should be for functional upsets only that require a power cycle or configuration reload from stored memory.
Asteroid Size	Meters	2-500	Small sizes apply to reference mission and larger sizes apply to alternate
Asteroid visible albedo (*)	%	> 3	Depends on material make up with 3% being a minimum
Docking target reflectance (*)	%	> 90	Docking target to use retro-reflectors
Sun Exposure Survival	Hours	Indefinite	No requirement to operate with Sun in view

* Modular specification

AR&D Commonality Performance Specification

	Visible Camera	Infrared Camera	LIDAR	Notes
Minimum Operational Range	1 m	1-2 m	1 m	Ranges closer than 1 m are being explored for Orion may be addressed by proposers.
Maximum Operational Range	> 50,000 km (bearing only)	100m to 200 km (bearing only)	2-3 km (range and bearing)	LIDAR: ~2-3 km initial detection range.
Operational Field of View	Rendezvous: 0.5 – 1.5 deg Prox Ops: 30 – 45 deg	Typically max of 30 and min of 20º, but is application dependent. Ability to utilize appropriate lenses required.	±30º ARV ±10º Orion	LIDAR: ARV requires ±30º to "capture" target, ensuring bag does not snag. Orion requires ±10º to ensure relative measurement accuracy throughout AR&D/C.
Angular Resolution	Rendezvous: < 8 urad/pixel Prox Ops: < 300 urad/pixel	Prox Ops: < 300 urad/pixel	< 1.5 mrad / measurement	
Range Accuracy	NA	NA	Precision: 2 cm (1-sigma) within a frame Accuracy: 2 cm (1-sigma) at 2 m separation	
Wavelengths (*)	400 – 700 nm	8 – 14 um	ARV: no restrictions Orion: Eye safe	Eye safety could be met with system protections or laser output frequency
Frame Rates	5 – 10 Hz	3 – 5 Hz	5 – 10 Hz	
Dynamic Range	> 1000:1	> 1000:1	NA	For a single exposure

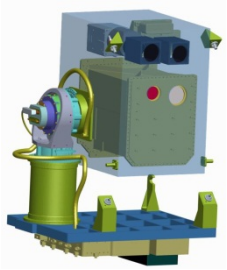
* Modular specification

Current State-of-the-art for AR&D Sensors

NASA is pursuing developing a common rendezvous sensor suite consisting of visible and infrared cameras and 3D LIDAR for a wide range of missions

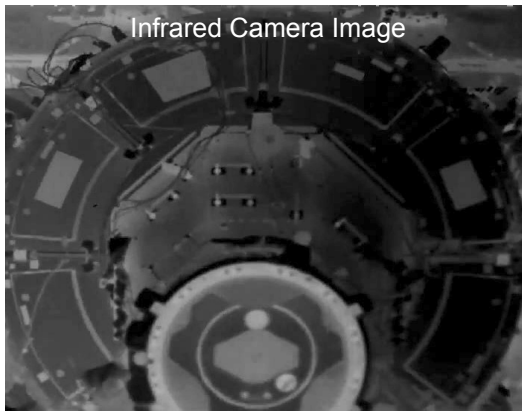
State-of-the-Art **TRL = 6**

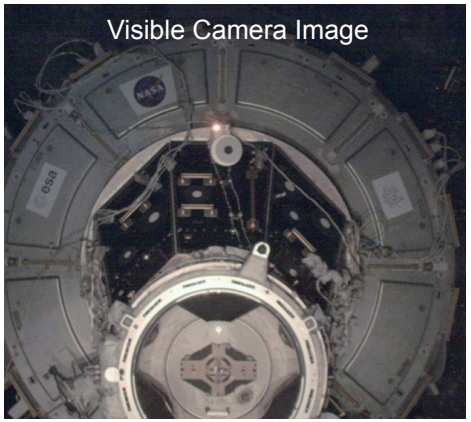
- Visible Camera: High and medium resolution cameras (share back-end electronics with selectable lenses) – flight heritage on multiple Shuttle and other on-orbit flight tests; modification needed to meet ARM environments
- IR Camera: Flight heritage on multiple LEO missions
- 3D LIDAR: Flight heritage on multiple Shuttle flight tests with significant ground testing; modification needed to meet ARM performance levels
- Upcoming Raven flight test to test state-of-the-art of all three sensor types

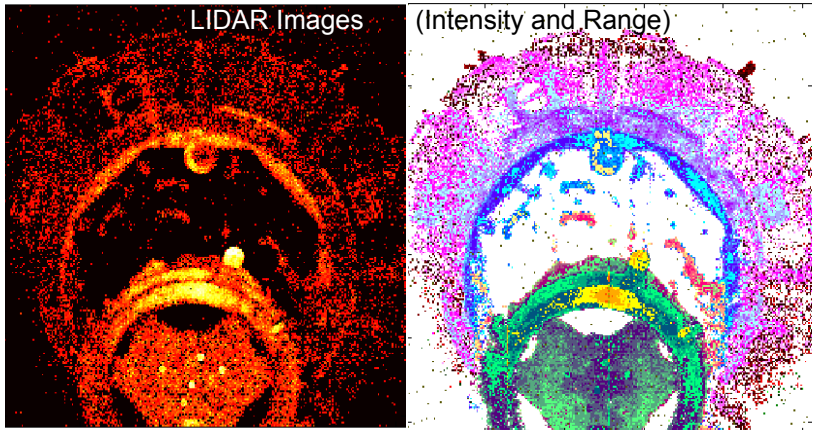


Raven demo on ISS

Mission Need	Visible Camera	IR Camera	3D LIDAR
Minimum Range	1 m	1-2 m	1 m
Maximum Range	> 50,000 km (bearing only)	100-200 m (bearing only)	2-3 km (bearing & range)
Field of View	Rendezvous: 0.5-1.5 deg Prox Ops: 30-45 deg	20-30 deg	±30 deg ARV ±10 deg Orion







AR&D Sensors Status

- **NASA released a BAA to fund selected sensor vendors to upgrade their current visible and infrared cameras and 3D LIDAR sensors to satisfy a common specification in the areas of:**
  - Design
  - Risk reduction
  - Technology maturation

- **Schedule:**
  - BAA development contracts Q4 FY14 – Q2 FY15
  - Common AR&D RFPs around Q2 FY15
  - Flight qualification complete around Q4 FY16

- **Point of Contact:**
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