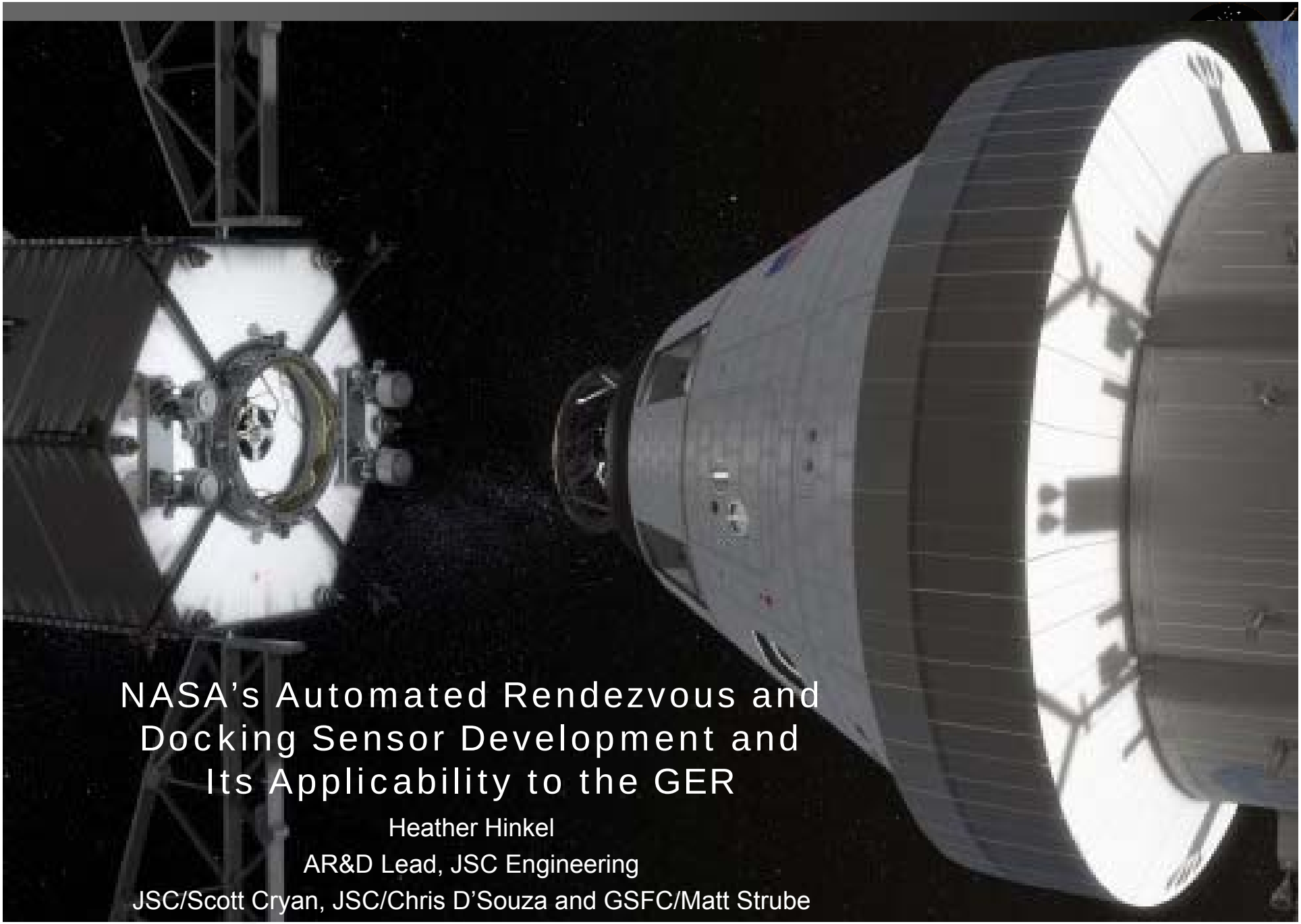

NASA's Automated Rendezvous and Docking Sensor Development and Its Applicability to the GER

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AR&D Commonality Action Background

- NASA is looking to reduce DDT&E of AR&D sensors across future deep space missions
  - Robotic missions to an asteroid
  - Crewed missions to a vehicle containing an asteroid
  - Lunar missions
  - Mars missions
  - Satellite Servicing
  - Autonomous landing and hazard avoidance

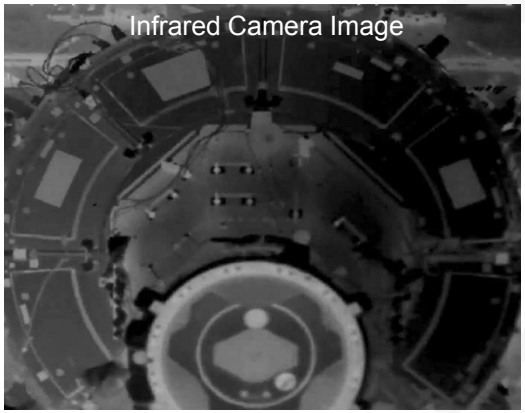
- Assembled a NASA-wide multi-center team to look at a common AR&D sensor suite to apply across missions (5 NASA centers and the NASA Engineering and Safety Council)

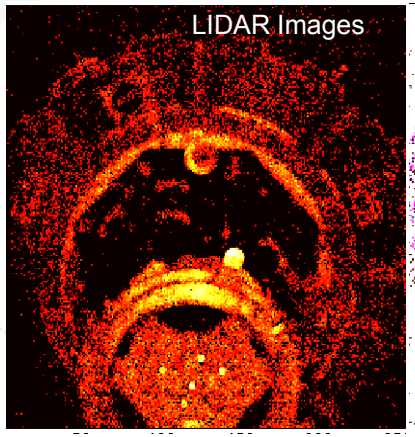
- Team successfully identified the types of sensors and performance needed for a common AR&D sensor suite

- Team is currently creating common AR&D sensor suite specifications to consolidate into a single, common Agency sensor development to apply across Programs to achieve cost and risk savings at the agency level

AR&D Action Approach - AR&D Common Sensor Types Result

- Based on detailed study and discussion of the Concepts of Operations for the above missions it was apparent that commonality existed across missions for the following sensors:
  - Visible cameras
  - 3D LIDARs
  - Infrared cameras for robustness/situational awareness
- Individual missions had additional sensors included on the vehicle that were also utilized for AR&D which were not included in the common suite (Star trackers, communication link)





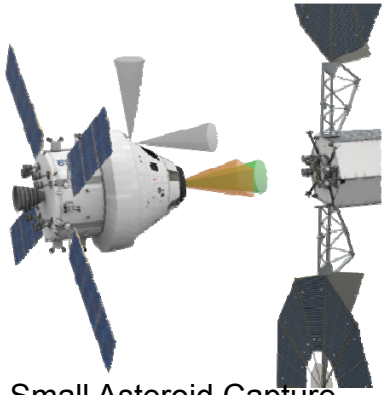
AR&D Common Sensor Suite

- Initial focus was for common sensors to meet key driving attributes of Capture a Small Asteroid/Pick up a Boulder off a Large Asteroid Robotic missions and Crewed Asteroid missions
  - Viable candidates exist for all sensor types
  - Sensors can have core commonality with modular mission-specific add-on/modifications
  - Example: only crewed mission has eye safety concerns so a part can be easily added to change the laser wavelength to be eye-safe for the crewed mission
- Visible Cameras –
  - A common electronics backend for medium resolution purposes and a common electronics backend high resolution purposes
  - Quantity can be tailored to mission needs
  - Medium Resolution Camera Backend
    - Narrow/Medium Field of View Applications
  - High Resolution Camera Backend
    - Medium/Wide Angle Field of View Applications
  - Specific lens selected uniquely for each mission application
- 3D LIDAR –
  - 3D LIDAR candidates (scanning/flash) require development/modification to meet mission needs

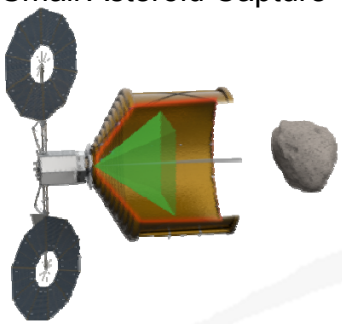
	Missions		
	Robotic Small Asteroid Capture	**Robotic Boulder off Large Asteroid**	**Crewed**
Visible Cameras	Medium Res	2 Medium Res, High Res	High Res
All **3D LIDAR**	Yes	Yes	Yes

AR&D Concepts of Operations

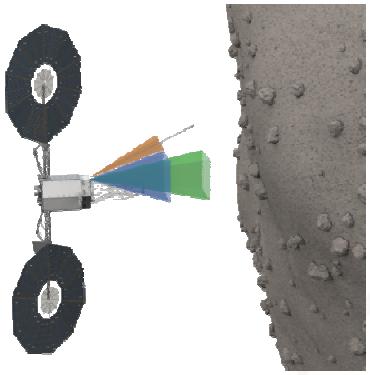
Crewed Asteroid Mission



Small Asteroid Capture



Robotic Boulder Capture

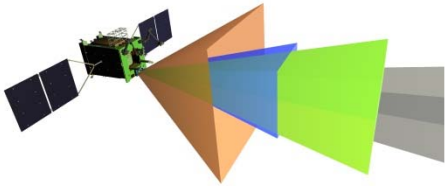


Long Range	Medium Range	Close Range	Application of Common Suite
S-Band Transponder for Range/Range Rate to reduce timeline; Star Tracker for bearing High Resolution Camera for bearing		3D LIDAR for precise alignment for docking High Resolution Camera for secondary pose	High Resolution Camera 3D LIDAR
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

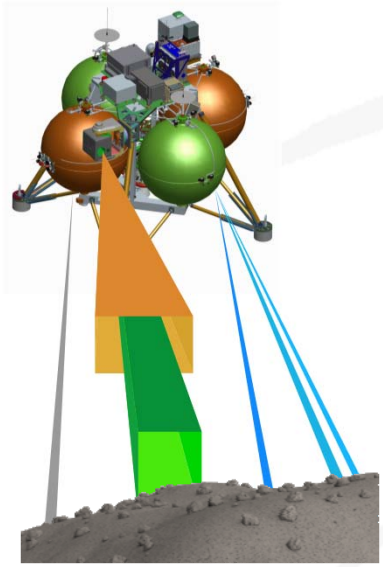
* Addition of infrared camera for robustness is being assessed

AR&D Concepts of Operations (cont'd)

Satellite Servicing



Moon/Mars Landing



	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 3D velocity, range and ground relative pose	3D LIDAR for hazard detection and hazard relative navigation (range and bearing) 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

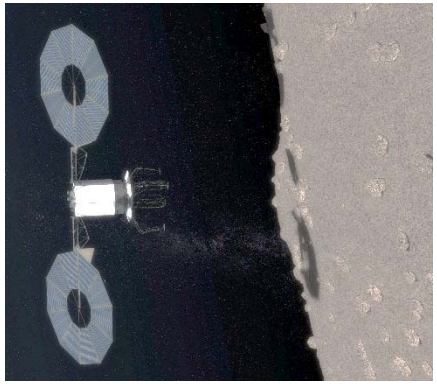
	Visible Camera	Infrared Camera	LIDAR	Notes
Minimum Operational Range	1 m	1-2 m	1 m	Ranges closer than 1 m are being explored for Orion may be addressed by proposers.
Maximum Operational Range	> 50,000 km (bearing only)	100m to 200 km (bearing only)	2-3 km (range and bearing)	LIDAR: ~2-3 km initial detection 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	< 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

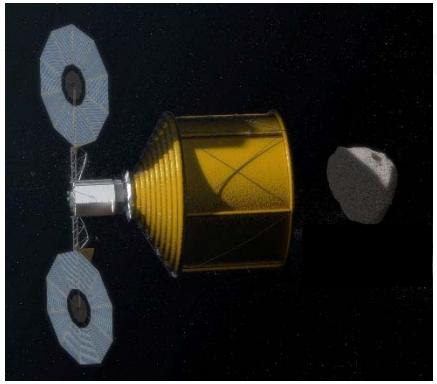
* Modular specification

AR&D Common Sensor Suite Applicability to the GER

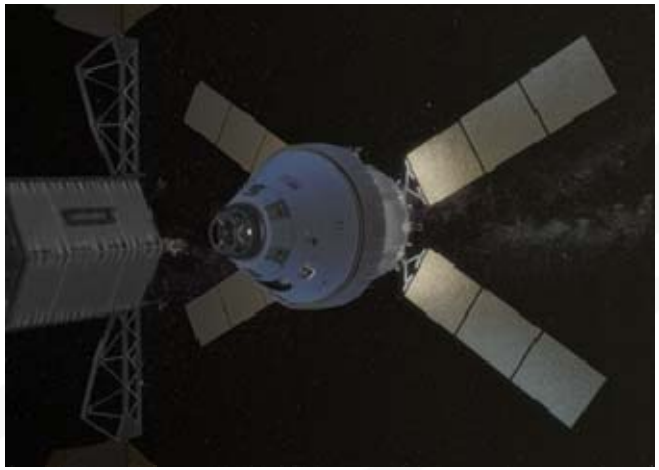
- A common AR&D sensor suite consisting of visible cameras, infrared cameras and a 3D LIDAR supports AR&D concepts on GER paths moving towards Mars

Inter-planetary Objects



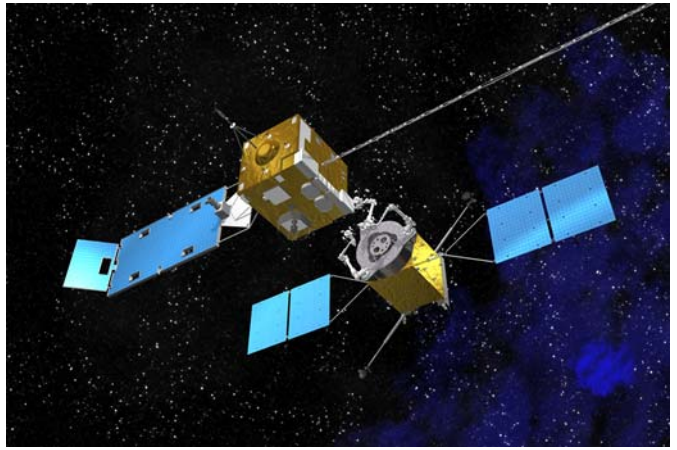


Vehicle-to-vehicle Docking



Moon/Mars Landing

Satellite Servicing



- NASA welcomes ideas for:
  - Any other AR&D Concepts of Operations missing
  - Partnerships to develop these sensor types to support future AR&D missions