AR&D Commonality Action Outbrief

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Agenda

- Action Background and Overview
- Executive Summary
- Action Work
  - Team Membership
  - Approach Taken
- Common AR&D solution description
  - Mission uses of common solution
- Upcoming AR&D Sensor Experiment - Raven
- AR&D Commonality Action Team Findings & Recommendations

AR&D Commonality Action Background

- W. Gerstenmaier issued an action at the Asteroid Initiative Mission Formulation Review (MFR) in July 2013 (summarized on the next page) to investigate whether there was sufficient synergy to implement a common sensor suite for AR&D

- JSC/H. Hinkel selected to lead NASA-wide multi-center team to address action

- Focus on utilizing TRL-Now sensors for common implementation for both robotic and crewed asteroid missions rather than duplicated development for each mission
  - Groundrule to meet a 2019 Robotic Asteroid vehicle launch
  - Establish simple, common solution that meets the needs of both asteroid missions, NOT new development or advanced technology

- Intent is to create common AR&D sensor suite specifications and consolidate into a single, common Agency sensor development across Programs to achieve cost and risk savings at the agency level
  - Standard solution is inherently NOT optimized in the context of a single mission
  - It is understood that each mission has unique requirements, but common sensors can be utilized differently to accommodate these unique needs
  - Software and integration remain unique to each mission

AR&D Commonality Action Executive Summary

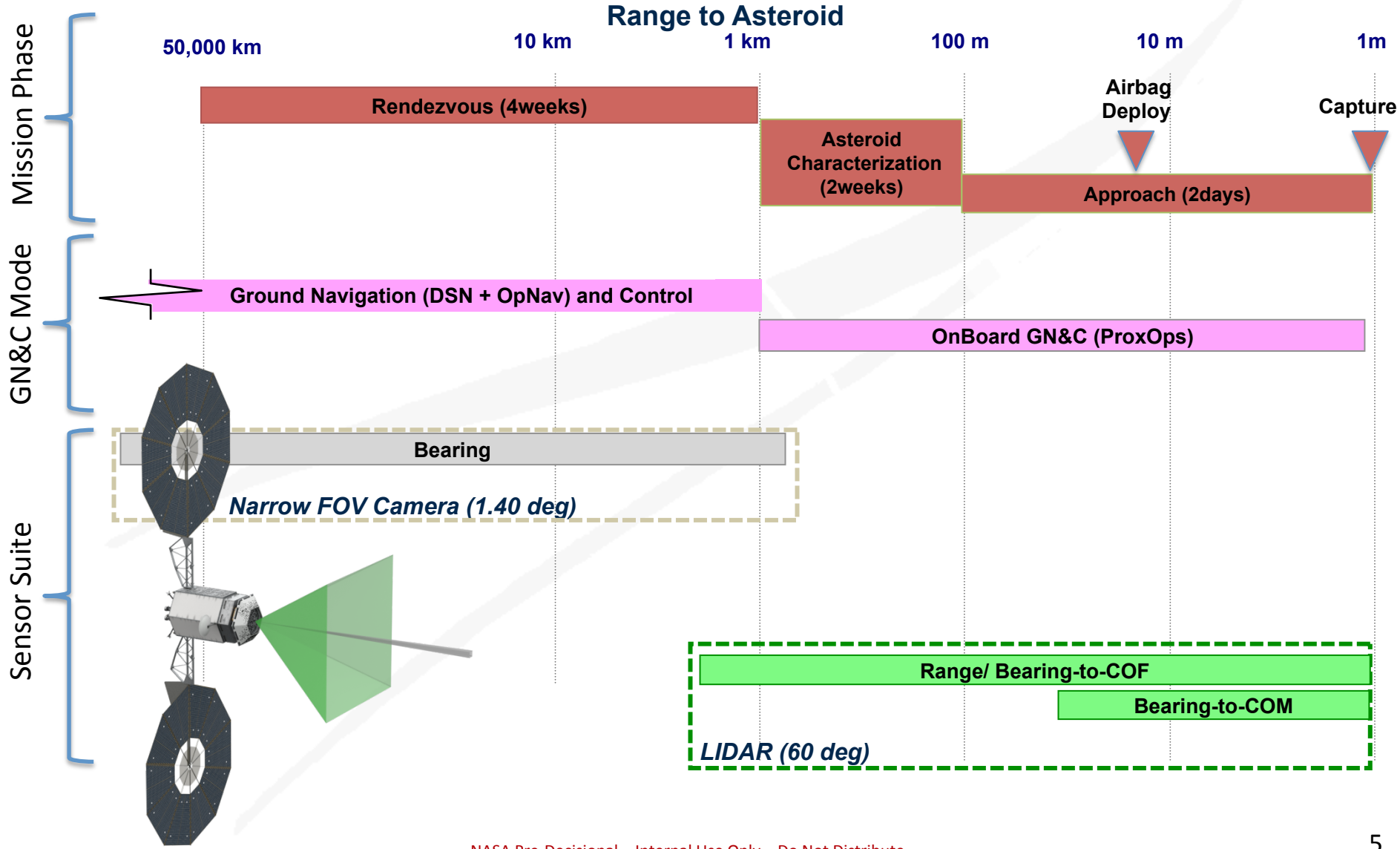
- Common suite to fulfill the key driving attributes of the Reference Robotic, Alternate Robotic and Crewed Asteroid missions
- Currently, each mission independently selected AR&D sensors
  - Multiple sensor development efforts
  - Costly for the agency

	Current Mission Plans		
	Reference	**Alternate**	**Crewed**
Visible Cameras	MSL camera	Custom x 2 plus OSIRIS-Rex camera	STORRM/Orion camera
3D LIDAR	Modified OSIRIS-REx science LIDAR	TBD LIDAR	STORRM/Orion VNS LIDAR

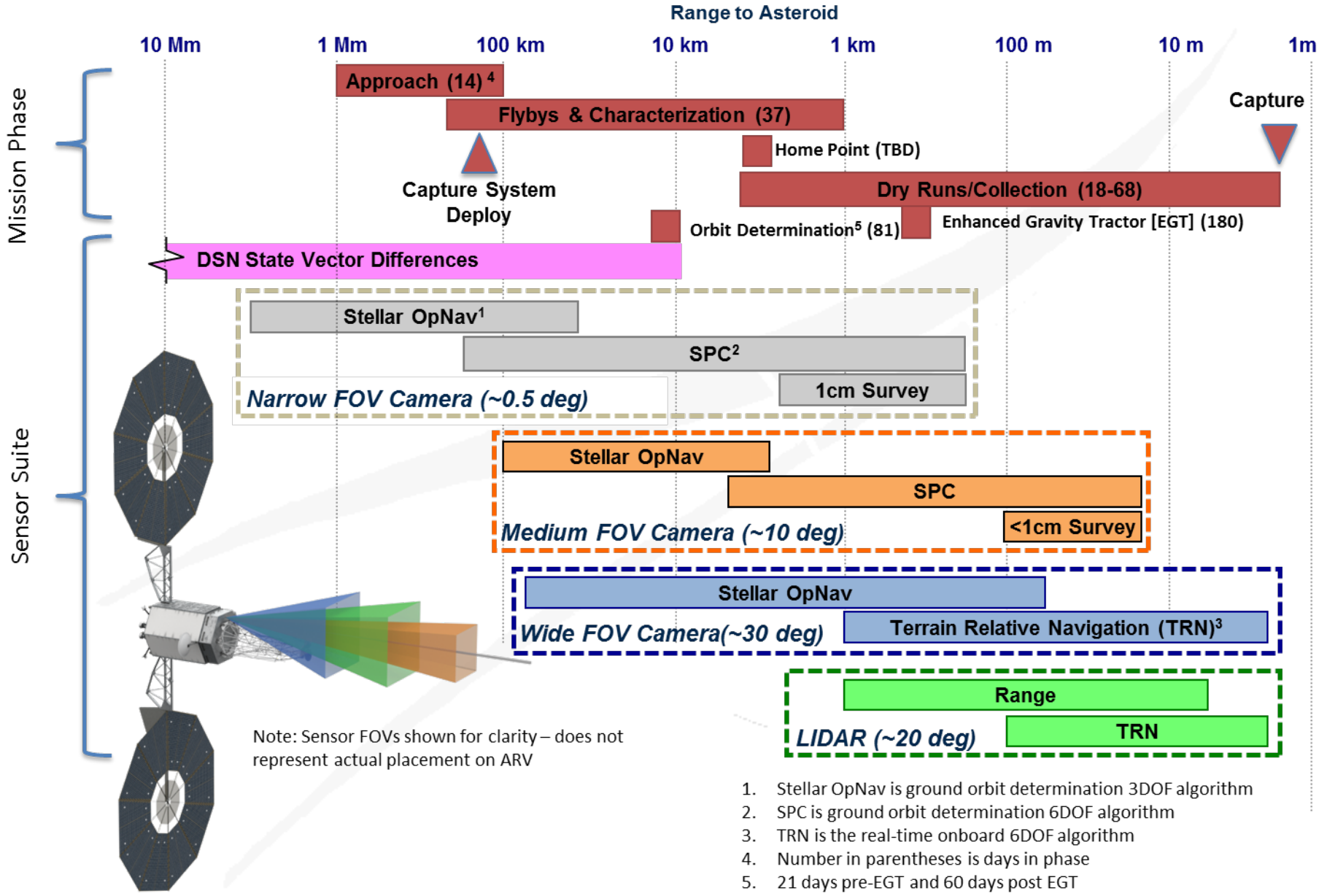
- AR&D Commonality Action team converged on a common AR&D Sensor Suite that will meet the key driving attributes of the Reference Robotic, Alternate Robotic and Crewed Asteroid missions
  - High and Medium resolution cameras (share backend electronics with selectable lenses)
  - 3D LIDAR
  - Viable candidates identified for each type of sensor to support Robotic Asteroid mission schedule
  - One development for each sensor type reduce Agency cost

	Missions		
	Reference	**Alternate**	**Crewed**
Visible Cameras	Medium Res	2 Medium Res, High Res	High Res
3D LIDAR	Yes	Yes	Yes

Reference Mission AR&D Description



Alternate Mission AR&D Description



1. Stellar OpNav is ground orbit determination 3DOF algorithm
2. SPC is ground orbit determination 6DOF algorithm
3. TRN is the real-time onboard 6DOF algorithm
4. Number in parentheses is days in phase
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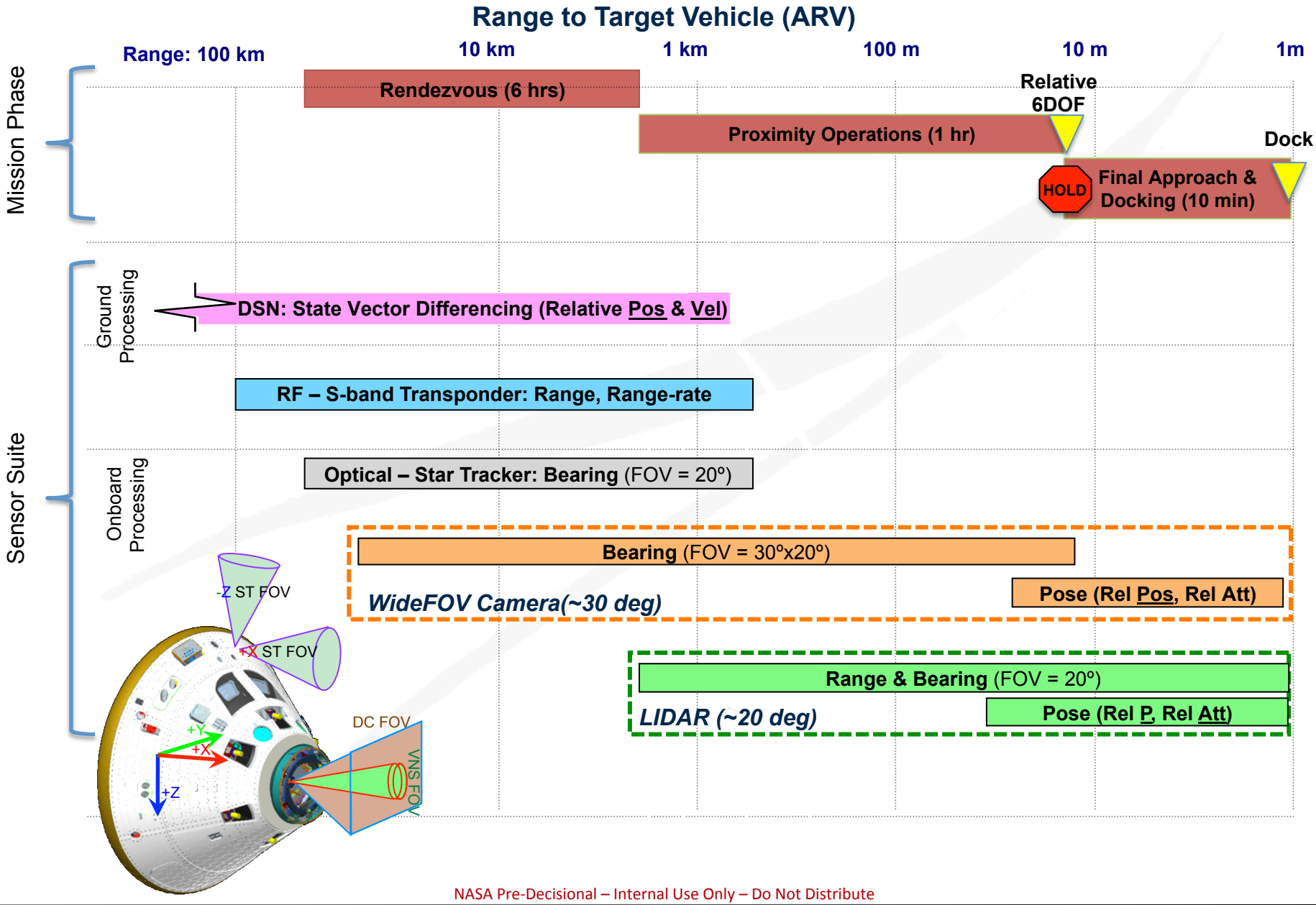
Crewed Mission AR&D Description



AR&D Action Approach

- Generated AR&D mission Concepts of Operations in a common format for the Reference Robotic, Alternate Robotic and Crewed Asteroid missions
  - Utilized the Concepts of Operations to identify common operational needs and navigation methodologies across missions
- Utilized the Concepts of Operations to identify the AR&D mission driving attributes
  - Applied priorities to attributes (must have, cost/risk driver, second tier needs, nice to have)
- Identified existing AR&D sensors
  - All sensors/technology readiness levels identified
  - Captured specifications of existing sensors
  - Ultimately ruled out new sensors/technologies due to available development schedule
- Determined which sensors were viable (including small modifications) to meet Robotic Asteroid mission schedule of launch in 2019
- Attended Asteroid Initiative RFI Synthesis Workshop and reviewed RFI responses to ensure common solution viable
- Created single “specification attributes” for each AR&D sensor type which would allow AR&D for all three asteroid missions

AR&D Action Approach – AR&D Concepts of Operations

Standardized Concepts of Operations created for Reference Robotic, Alternate Robotic and Crewed Asteroid Missions using common flight phases and technical specification areas.

- AR&D flight phases common to ALL AR&D missions
  - Rendezvous/Far Field
  - Proximity Operations/Near Field
  - Final Approach/Alignment
  - Mate (Capture, Dock, Undock)
- Technical Specification Areas in each phase
  - Objectives of Relative Navigation
  - Operating Ranges
  - Transition Criteria to next phase
  - Relative Navigation
    - Measurement Types
    - Sensor Types
    - Relative Navigation Accuracies
    - Algorithms
    - Duration Required
  - Relative Velocity Range (high/low)
  - Target Rotational Rate
- Looked in depth at relative navigation sensor types and measurement types

Flight Phases →

Technical Specification Areas ↓

ConOps Type (1 each for Blue, Orange, Red, Purple missions)	Far Field	Near Field	Final Approach	Mate	
	Rendezvous	Proximity Operations	Final Approach / Alignment	Capture	Docking
Purpose of RelNav	Acquire target vehicle and provide updates for long-range targeting. Enables large relative velocities closing into target vehicle in timely manner	Providing higher fidelity/accurate navigation solutions to approach target vehicle safely	Translate/align chaser vehicle to target vehicle. Nulling or matching body attitude rates (if present) prior to "docking". Requires high accuracy navigation soluion.	Maintaining relative position, attitude in order to grapple. Once grapple is complete, then RelNav is complete, assuming that grapple is sufficient for mission success.	Providing high fidelity, high accuracy relative state knowledge to enable soft capture, followed by hard-mate of docking mechanisms.
Operating ranges	>100km to 5km	5km to 20-30 m	20-30 m to Dock/Capture		
Transition criteria to next phase	LIDAR acquisition of target	LIDAR 6DOF solution	Alignment with target or fixture		
RelNav Con Ops					
Measurement types	Range Bearing (azimuth & elevation)	Range Bearing (azimuth & elevation)	Relative position Relative bearing	Relative position Relative bearing	Relative position Relative bearing
Sensor types	RF comm - range measurements Optical (visible, IR) - bearing measurement to centroid of target	LIDAR - acquisition around 5km RF comm - range measurements to supplement/augment LIDAR Optical (visible, IR) - bearing measurements to supplement/augment LIDAR. Distinguishing features enables transition to relative attitude determination	LIDAR - transition from 3D 6DOF Optical (visible, IR) - 6DOF based on target vehicle knowledge and image processing	DAR - transition from 3DOF to F ible, IR) - 6DOF based cle knowledge and e processing	LIDAR - transition from 3DOF to 6DOF Optical (visible, IR) - 6DOF based on target vehicle knowledge and image processing
RelNav accuracies	Bearing: ±1º to ±0.5º	LIDAR Bearing: ±0.5º	LIDAR Bear		
Algorithms					
Duration Required	9000 sec (100km to 10km) 1000 second (10km to 5 km)	~2000 sec (5km to 50 m)	~200 to 30		
Relative velocity range (hi and lo)	Initial = 10-20 m/s or more Transition to ProxOps = 1 m/s	Decreasing from 1m/s to 10 cm/s	Decreasing cm/s		
Target rotational rate					

LIDAR - transition from 3DOF to 6DOF

Optical (visible, IR) - 6DOF based on target vehicle knowledge and image processing

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

- Based on detailed study and discussion of the Concepts of Operations it was apparent that much commonality already existed across missions
- All missions were already utilizing visible cameras and 3D LIDARs
- All missions included IR cameras for robustness and/or situational awareness (NOT included in common AR&D suite since not required to perform mission)
- Differences were in the vendor selection and the application of specifications unique to each mission
- Individual missions had additional sensors included on the vehicle that were also utilized for AR&D
  - Required for other mission purposes
- Identified a common 'minimum' set of AR&D specific sensors

	Far Field	Near Field	Final Approach	Mate
	Rendezvous	**Proximity Operations**	**Final Approach/ Alignment**	**Docking/Capture**
Common across missions	Narrow Angle Camera - visible	Medium Angle Camera - visible	Wide Angle Camera - visible	Wide Angle Camera - visible
	Camera - infrared	Camera - infrared	Camera - infrared	Camera - infrared
		LIDAR	LIDAR	
Sensors unique to only some of the missions were excluded from the common suite	RF comm	RF comm		LIDAR
	Star tracker	Ground penetrating radar		
	LIDAR/laser range finder			

Two sensor types are common to missions and required to complete mission:
Visible cameras (Medium and High resolution) and 3D LIDAR
IR Cameras could be included as robust back up, if desired.

AR&D Action Approach - AR&D Attributes

- Mission:
  - Environment: Thermal, Pressure, Radiation
  - Internal/External mounting
  - Operating Regime (LEO, Trans-lunar, Deep space, etc.)
  - Mission Duration
    - Operational/Dormancy
    - Multiple Engagements
  - Range of operations - Minimum/Maximum
  - Field of view
  - Measurement accuracy
  - Processing/Output rate/Data rate/baud
  - Cooperative/Uncooperative
  - Wavelength/Eye-safe
  - Moving parts (mechanisms)
- Program/Project Requirements
  - Electronic parts
  - Requirements/policies
  - Fault Tolerance/Reliability
  - ITAR considerations
- Vehicle
  - Volume/mass/power constraints
  - Packaging considerations
  - Looking through windows/hatch

Identified attributes for sensors to be used in each class of AR&D mission. Attributes are "ranked" in importance to each mission to drive identification of common sensor solutions across missions.

AR&D Common Sensor Suite

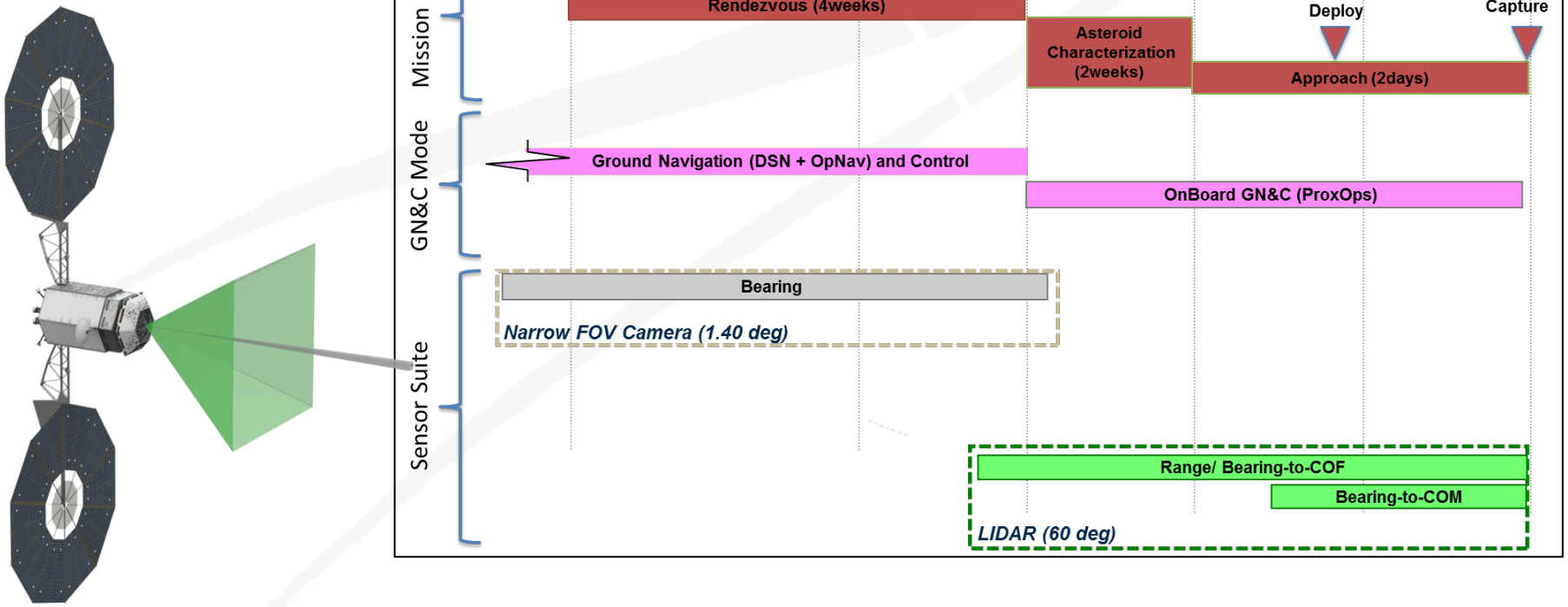
- Common sensors must meet key driving attributes of Reference Robotic, Alternate Robotic and Crewed Asteroid missions
  - Sensors can have core commonality with modular mission-specific add-on/modifications
  - Example: only crewed mission has eye safety concerns so a part can be easily added to change the laser wavelength to be eyesafe for the crewed mission
- Visible Cameras –
  - Common electronics backends for each medium and high resolution purposes
  - Quantity can be tailored to mission needs
  - Medium Resolution Camera Backend
    - 3 viable candidates identified
    - Narrow/Medium Field of View Applications
  - High Resolution Camera Backend
    - 2 viable candidates identified
    - Medium/Wide Angle Field of View Applications
  - Specific lens selected uniquely for each mission application
- 3D LIDAR –
  - 4 viable candidates identified
  - 3D LIDAR candidates (scanning/flash) require development/modification to meet mission needs

	Missions		
	Reference	**Alternate**	**Crewed**
Visible Cameras	Medium Res	2 Medium Res, High Res	High Res
All **3D LIDAR**	Yes	Yes	Yes

Recommended sensor suite will meet the needs of Reference Robotic, Alternate Robotic and Crewed Asteroid missions

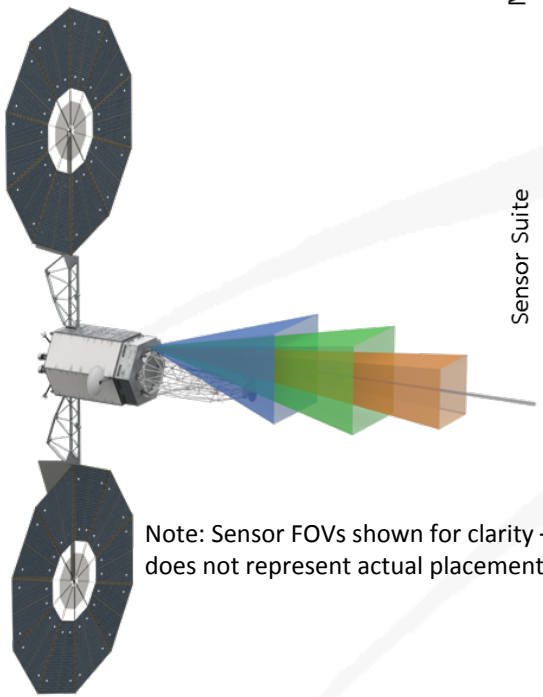
Reference Mission Use of Common Suite (ConOps as a Function of Range)

- Key Driving Requirements from Reference Robotic Mission
  - Deep Space Environment
  - Uncooperative Target
  - LIDAR Maximum Range/Low Albedo
  - LIDAR Field of View

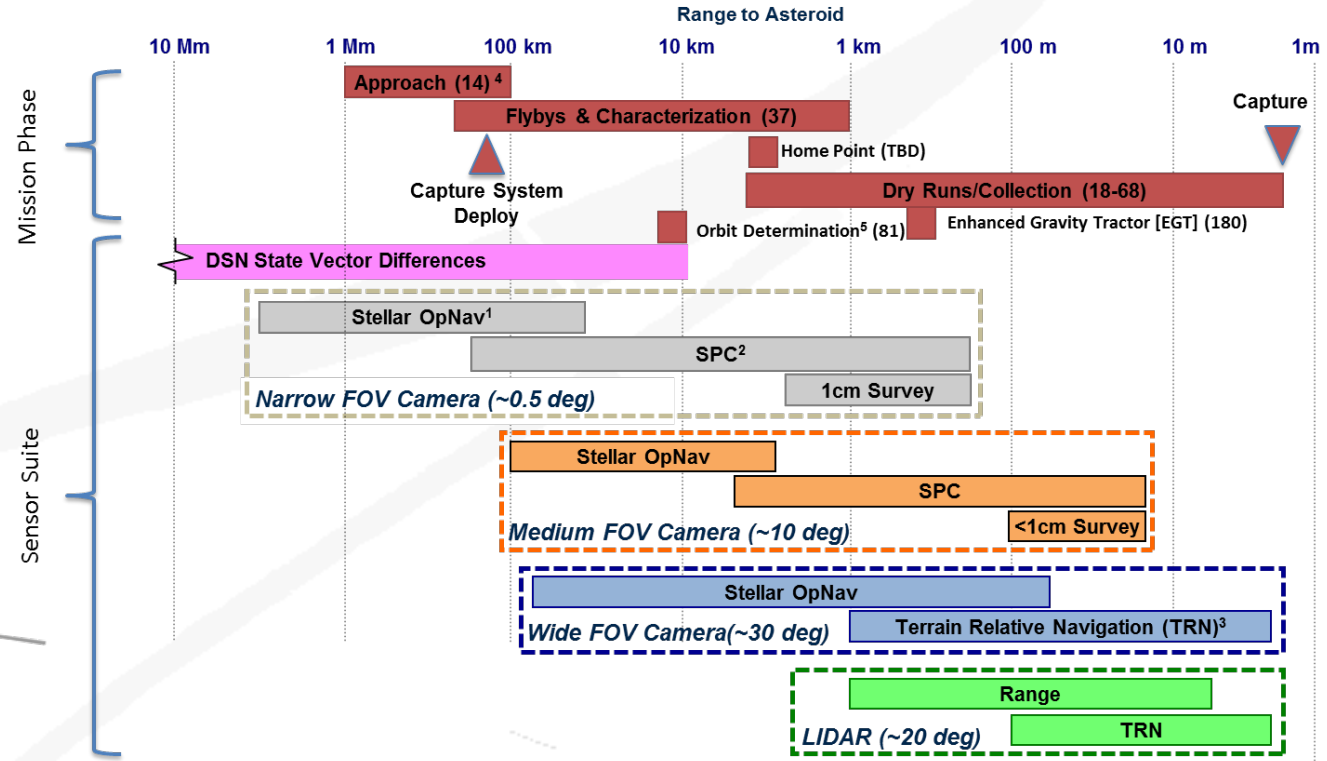


Alternate Mission Use of Common Suite (ConOps as a Function of Range)

- Key Driving Requirements from Alternate Robotic Mission
  - Deep Space Environment
  - Uncooperative Target
  - Mission Duration
  - Camera Resolution



Note: Sensor FOVs shown for clarity – does not represent actual placement on ARV



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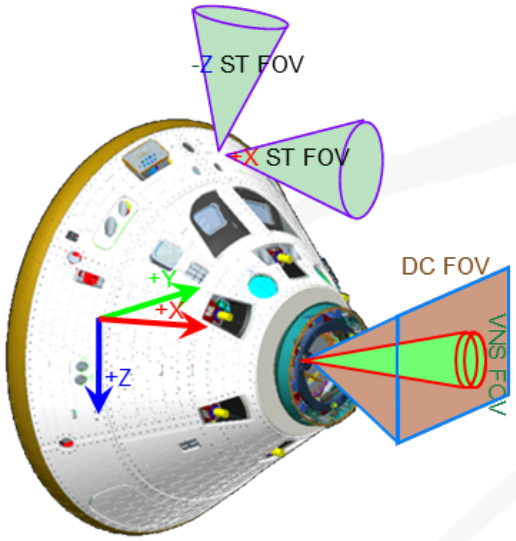
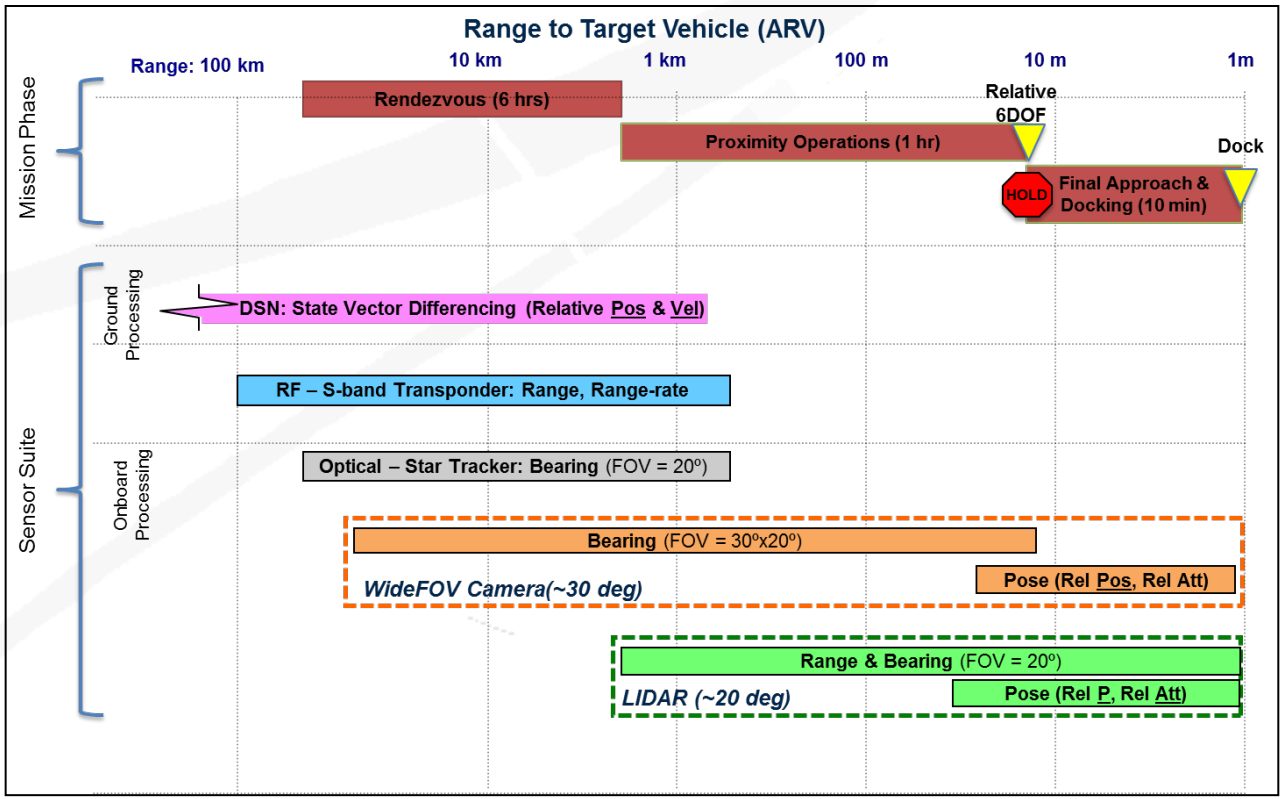
Crewed Mission Use of Common Suite (ConOps as a Function of Range)

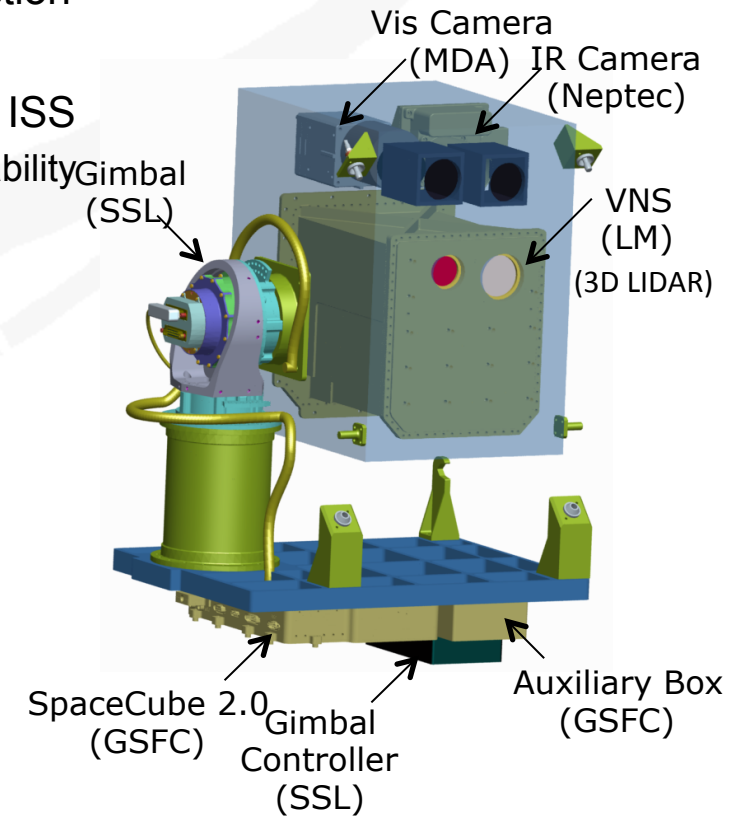
- Key Driving Requirements from Crew Mission
  - LIDAR Minimum Range/Accuracy
  - Eye Safety
  - Mass/Volume/Packaging (2 each LIDAR and WideFOV camera must fit in the Orion hatch window)





Currently Funded AR&D Experiment – Raven (GSFC)

- Raven will have GSFC/JSC Co-Principal Investigatorss
- Raven includes sensors similar to the common AR&D suite but would need additional requirements on sensors to meet the common specification attributes identified in the action
- Raven is a technology development experiment to the ISS
  - Provides an independent visiting vehicle monitoring capability
  - Raven will fly on the DoD STP-H5 Payload
- Raven hardware:
  - Two-axis gimbal for sensor pointing
  - Relative navigation sensors
    - Visible camera
    - Infrared camera
    - 3D LIDAR
  - Onboard reconfigurable avionics
  - Non-cooperative and cooperative pose and navigation algorithms



- Hardware delivery: Dec 2014; SpaceEx Launch: Feb 2016

AR&D Commonality Action Findings

- AR&D Commonality Action Team succeeded in identifying a common AR&D sensor suite to fulfill the key driving attributes of the Reference Robotic, Alternate Robotic and Crewed Asteroid missions
  - Common development at the Agency level can be applied across Programs
  - One development for each sensor type will reduce Agency cost
  - Common AR&D Suite consists of:
    - High and Medium resolution cameras (share backend electronics with selectable lenses)
    - 3D LIDAR
    - IR Camera can be included for robust solution
  - Viable candidates identified for each type of sensor to support Robotic Asteroid mission schedule
  - Reviewed Asteroid Synthesis Workshop RFI's related to AR&D
    - RFI responses corroborate common AR&D sensor suite

	Missions		
	Reference	**Alternate**	**Crewed**
Visible Cameras	Medium Res	2 Medium Res, High Res	High Res
3D LIDAR	Yes	Yes	Yes