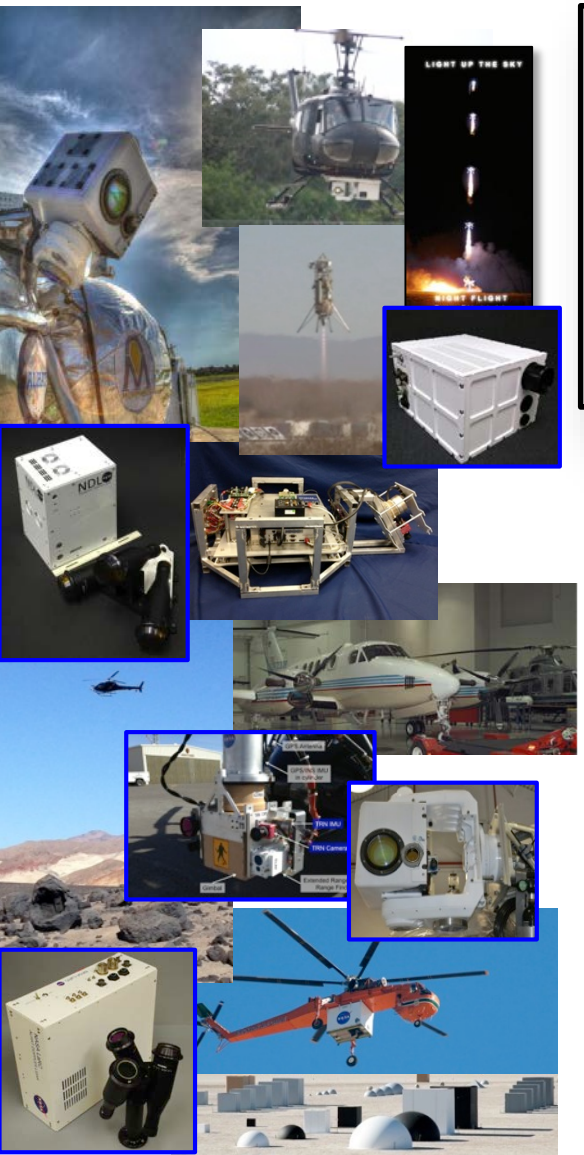
PL&HA

Precision Landing and Hazard Avoidance



NASA SPLICE Project: Development and Testing of Precision Landing GN&C Technologies

Dr. Carolina Restrepo

Hazard Detection Lead for NASA SPLICE Project

Dr. John M. Carson III

Project Manager for NASA SPLICE Project

Michelle M. Munk

NASA EDL System Capabilities Leadership Team (SCLT) Lead

STMD EDL Principal Technologist

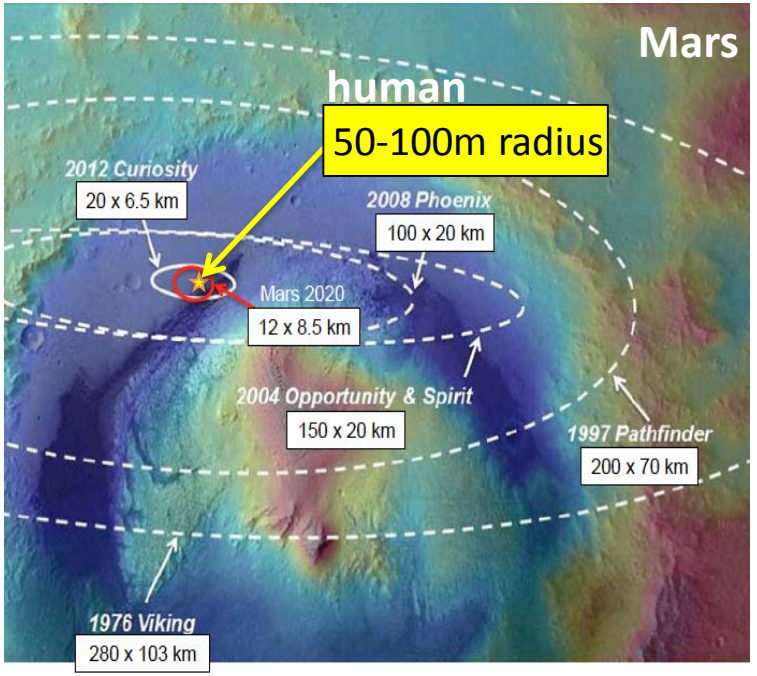
July 31, 2018

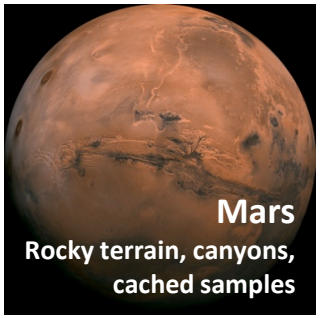
Cleared for External Release

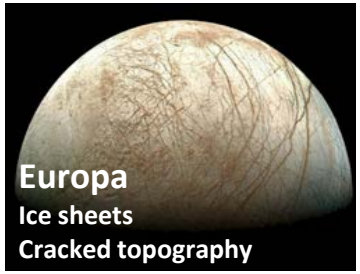
Charts herein include content provided by multiple NASA centers and supporting institutions.

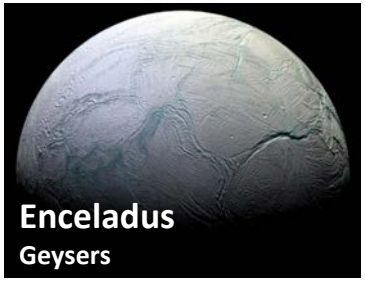
The Motivation for PL&HA Technology

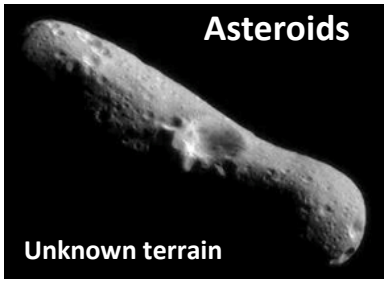
- Enable landing at locations that pose significant risk to vehicle touchdown or payload deployment (including near pre-positioned surface assets)
- Technology has been deemed critical in NASA and NRC Space Technology Roadmaps and architecture studies for future robotic and human missions
  - Required for future human landings on Mars
  - Enabler for robotic exploration of new destinations











What is the NASA PL&HA domain?

- **NASA development, testing and infusion of GN&C technologies for controlled, precise and safe landing**
- Investments have come through **multiple HQ Directorates** (STMD, SMD, HEO) and have included **multi-center collaboration** in past & present projects:
  - ALHAT (Autonomous precision Landing and Hazard Avoidance Technology)
  - LVS (Lander Vision System)
  - COBALT (CoOperative Blending of Autonomous Landing Technologies)
  - Lander Technologies (LT)
  - ILS (Intelligent Landing System)
  - SPLICE (Safe & Precise Landing – Integrated Capabilities Evolution)
- Domain includes technologies for sensors, algorithms, avionics, software & techniques for missions (**robotic or human**) having various Concepts of Operation (ConOps) and various terrain illuminations (light/shadow/dark)

Johnson Space Center
Houston, Texas

Jet Propulsion Laboratory
California Institute of Technology

Langley Research Center
Hampton, Virginia

Goddard Spaceflight Center
Greenbelt, Maryland

Marshall Spaceflight Center
Huntsville, Alabama

Terrain Sensing and Recognition Functions

PRECISION LANDING FUNCTIONS

SAFE LANDING FUNCTIONS

De-Orbit Coast

Terrain Relative Navigation (TRN)
Reduce Navigation Dispersions During Breaking Burn and Eliminate Map Tie Error

Braking Burn

Powered Descent

Hazard Detection and Avoidance (HDA)
Detect Crater, Rock and Slope Hazards and Select a Reachable Safe Site

not to scale

Hazard Relative Navigation (HRN)
Navigate Precisely Relative to Hazards Detected On-Board to Land at Specified Safe Site

Terminal Descent

Divert Maneuver

Safe Site

IMU

TRN Imaging

HDA/HRN Imaging

Velocity & Ranging

COBALT

ALHAT

PL&HA

ALHAT Overview

Autonomous precision **L**anding
Hazard **A**voidance **T**echnology

- ALHAT combined autonomous guidance, navigation and control algorithms capable of characterizing the landing surface while identifying and avoiding lander-sized hazards in real time
- ALHAT flew on JSC's Morpheus Lander as a self-contained payload with the goal of prototyping future hazard avoidance & hazard relative navigation systems for future robotic or human landers

Video

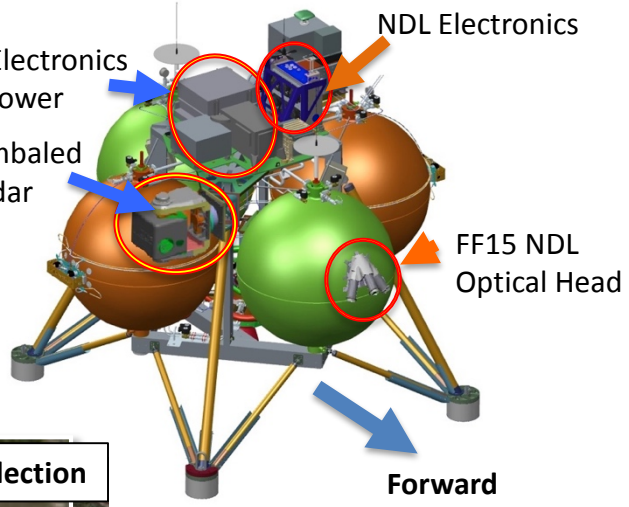
Johnson Space Center
Houston, Texas

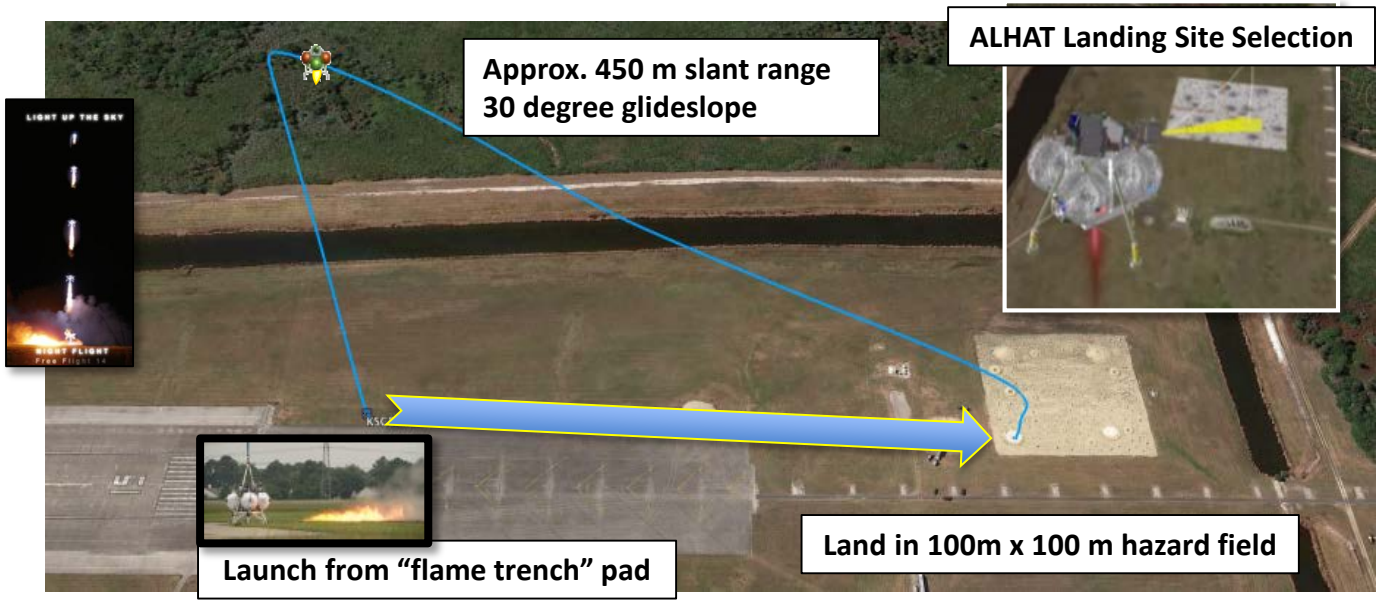
Langley Research Center
Hampton, Virginia

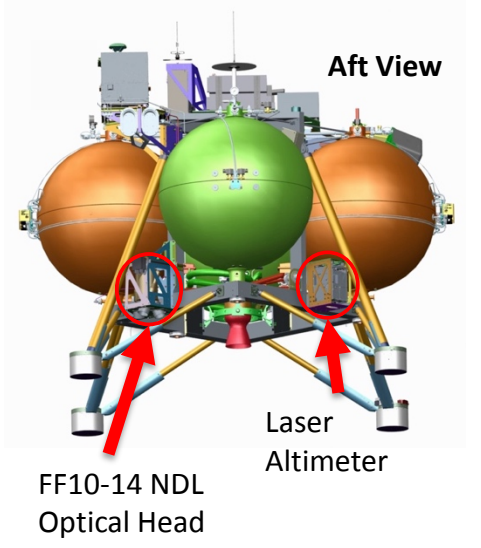
Jet Propulsion Laboratory
California Institute of Technology

2014 ALHAT on Morpheus 1.5B

- Six flights: three open-loop & three closed-loop
- Tested safe and precise landing technologies
  - NDL (Gen-2), HDS (Gen-1), Laser Altimeter
  - TRN was not a part of the Morpheus tests
- Successfully demonstrated integration and flight testing of ALHAT capabilities and techniques
- Performed one flight test in darkness

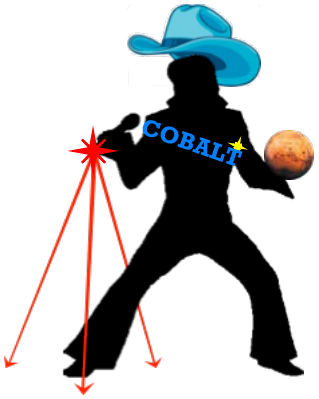






PL&HA

COBALT Overview



Co-**O**perative **B**lending of
Autonomous **L**anding **T**echnologies

- A platform to mature TRL and reduce risk for spaceflight infusion of GN&C PL&HA technologies into near-term robotic and future human missions
- Self contained and could be modified to test different GN&C technologies on different host vehicles

Video

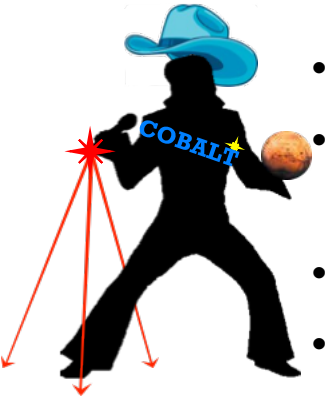
Johnson Space Center
Houston, Texas

Langley Research Center
Hampton, Virginia

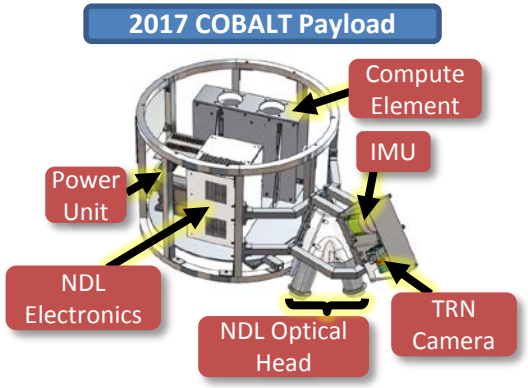
Jet Propulsion Laboratory
California Institute of Technology

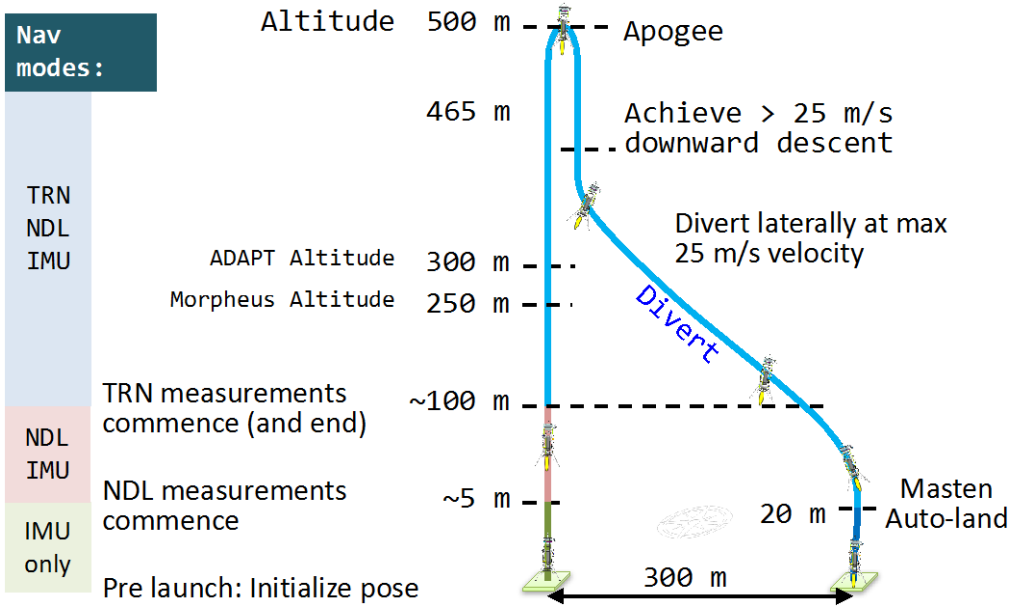
2017 **COBALT** Flights on Masten Xodiac

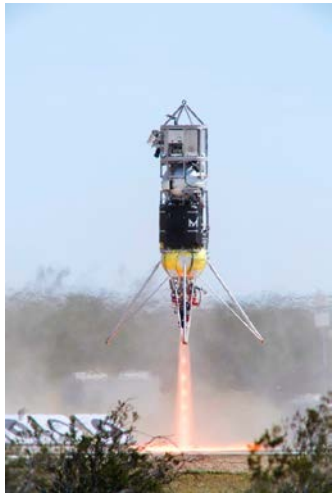
PL&HA



- COBALT: CoOperative Blending of Autonomous Landing Technologies
- Platform to mature TRL and reduce risk for spaceflight infusion of GN&C PL&HA technologies
- Multi-center collaboration: JSC, Langley, JPL
- Multi-directorate partnership: STMD & HEOMD







Portfolio of Current PL&HA Technologies

Controlled (Soft) Landing
Velocity and/or Range Sensing

HEO/STMD/SMD

Navigation Doppler Lidar (NDL) TRL 5+ (6 in FY19)
Line-of-site velocity of 200 m/s (±1.7-cm/sec, 1σ)
Line-of-site range of 4+ km (±2.2m, 1σ)
dev & test in ALHAT/Morpheus, COBALT, & SPLICE

HEO/STMD

Long-range Laser Altimeter (LAlt) TRL 4
Range in vacuum, 50+ km (5 cm, 1σ)
dev & tested in ALHAT/Morpheus

SMD/other

Optical Velocimetry (many in development) TRL 3+
Estimates from image-based feature tracking and optical flow

Precise Landing
Terrain Relative Navigation (TRN)

SMD/STMD/other

Passive-Optical/Camera-Based
(requires illuminated terrain: applicable to most missions)

- **JPL Lander Vision System** (LVS): camera + IMU + dedicated computing **to be TRL 9 with Mars2020**
- **TRN solutions also available from APL, Draper & elsewhere** in dev for multiple mission concepts
- **JPL Intelligent Lander System** (ILS) in dev for Europa Lander concept

HEO/STMD

Active/Lidar-based TRL 3-4
(dark/shadowed or illuminated terrain)
dev & tested in ALHAT

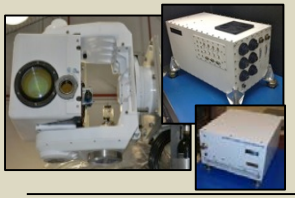
PL&HA Computing

STMD

Descent & Landing Computer (DLC)
HPSC (High Performance Spaceflight Computing) multicore A53 (extendable) + FPGAs (extendable) + PL&HA sensor interfaces
(in dev & test within SPLICE) TRL 3 (5 in FY2020)

Safe Landing
Hazard Detection (HD) and Hazard Relative Nav (HRN)

HEO/STMD



Hazard Detection System (HDS) prototype TRL 4
flash lidar + gimbal + dedicated IMU + dedicated computing
Range, 1 km (±8cm, 1σ). Generates 100mX100m map & safe landing sites within 10-12 sec dev & tested in ALHAT/Morpheus

STMD/SMD

Hazard Detection Lidar (HDL) in dev & test within SPLICE TRL 4 (5 in FY2020) uses many flight heritage parts
Scan array lidar + FPGA. Provides long-range altimetry and rapid medium- & short-range high-resolution terrain maps

SMD

JPL Intelligent Lander System (ILS) in dev for Europa Lander concept

Overview of NASA SPLICE Project (FY2018-FY2020)

- Multi-Directorate, Multi-Center PL&HA project
  - Centers: JSC, LaRC, GSFC, AFRC, MSFC, JPL (in planning for FY19-20), KSC (FY19-20)
  - Directorates: STMD-GCD, HEOMD-AES, STMD-FO, SMD-PSD
    - STMD-GCD: oversight and support for all SPLICE elements
    - HEOMD-AES: support for NDL element and synergy with cFS-based flight software development
    - STMD-FO: support for suborbital flight test element (COBALT portion)
    - SMD-PSD: support for NDL path-to-flight components
- Project Components (Elements)
  - NDL: Implement an **NDL (Navigation Doppler Lidar) Engineering Test Unit (ETU) & Achieve TRL6** in FY2019
  - ConOps: Develop a **multi-mission PL&HA requirements matrix** for relevant robotic science & human exploration destinations (to drive PL&HA infusion & investment)
  - Avionics: Develop an **HPSC-surrogate DLC (Descent & Landing Computer) to TRL 5** for future COBALT tests and spaceflight infusion missions
  - HD: Design, develop, and test a **multi-mission HDL (Hazard Detection Lidar) to TRL 5** with relevance to future robotic & human missions
  - HWIL Sim/SW: Evolve **HWIL sim/test capabilities and PL&HA flight software** to foster PL&HA infusion into NASA & US commercial missions
  - Field Test: conduct NDL environmental tests, validate NDL & HDL performance on airborne vehicles, and lead **closed-loop COBALT flight tests** on the Xodiac suborbital rocket

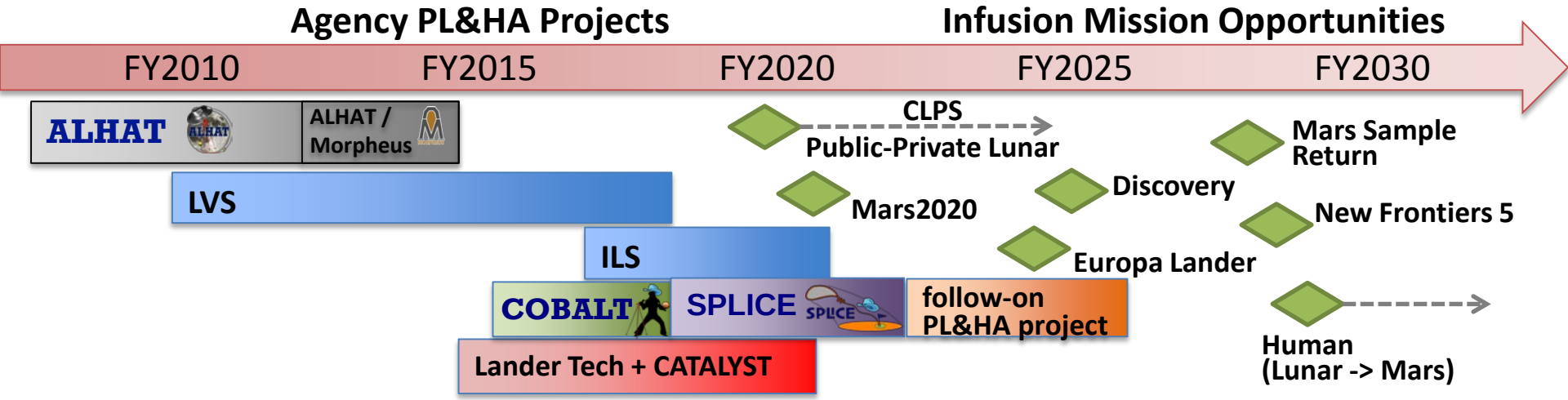
PL&HA Development & Infusion Strategy

Goal

- Develop multi-mission technologies that become part of the standard suite of GN&C capabilities
- Develop technologies for robotic missions that also feed forward into future human missions

Approach

- Develop and maintain a PL&HA knowledge base that captures robotic and human mission needs
- Prioritize technologies that promote multiple robotic missions and align to human mission needs
- Form a cross-directorate strategy and leverage multi-center/multi-project partnerships



PL&HA

Closing Remarks

- The NASA PL&HA domain includes a diverse suite of GN&C technologies for precise and safe landing
- Many of these PL&HA technologies are approaching readiness for infusion into near-term robotic science missions
- PL&HA capabilities enable new mission concepts by enlarging the trade space of feasible landing sites for surface exploration
- Development of PL&HA technologies for robotic missions also benefits future human missions