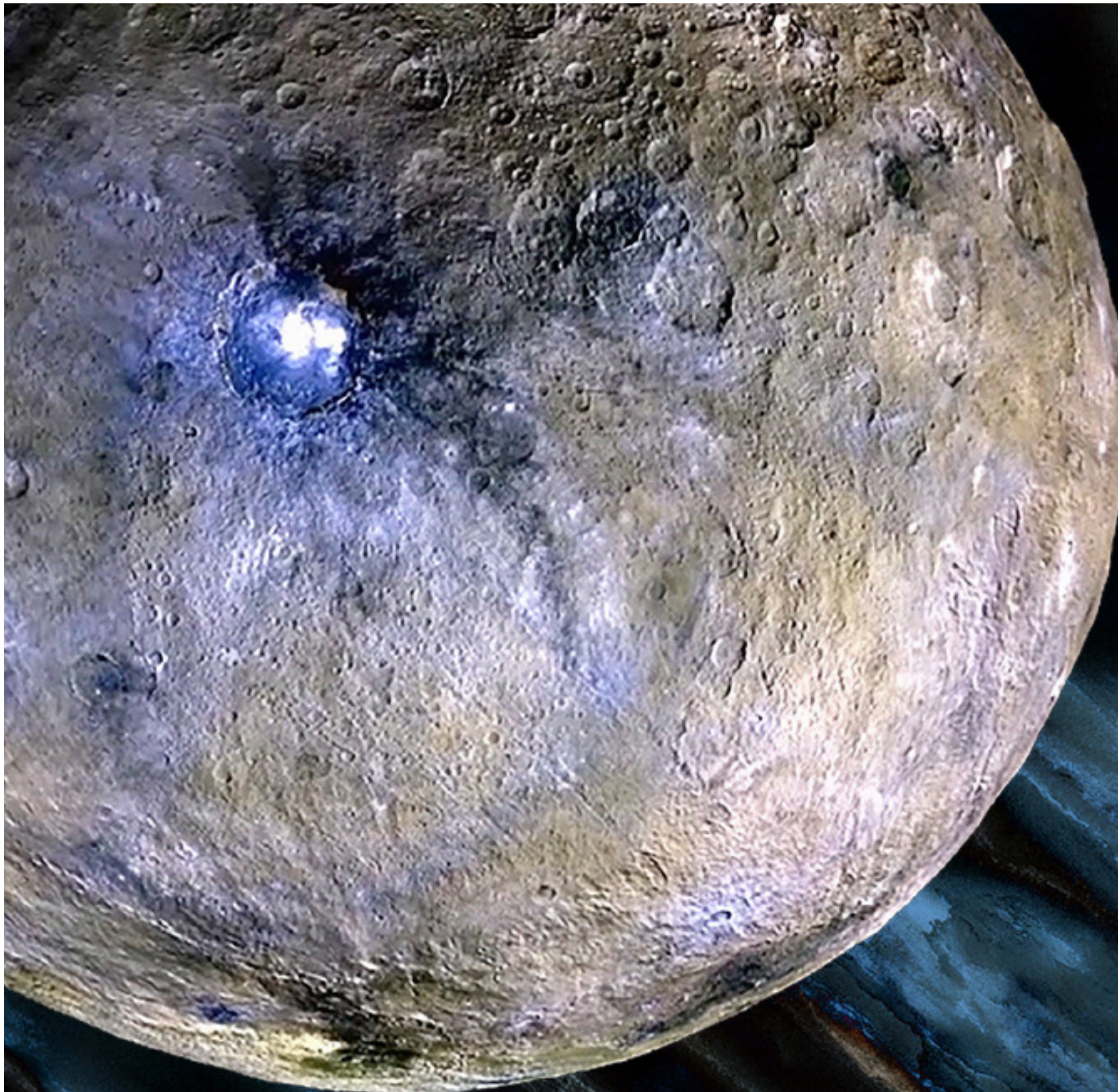

Jet Propulsion Laboratory
California Institute of Technology

sampling brines of an evolved ocean world

CERES

planetary mission concept study

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STUDY LEAD
John Brophy

And the Ceres Planetary mission Concept Study Team

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Private Company Contributors

Thank you!

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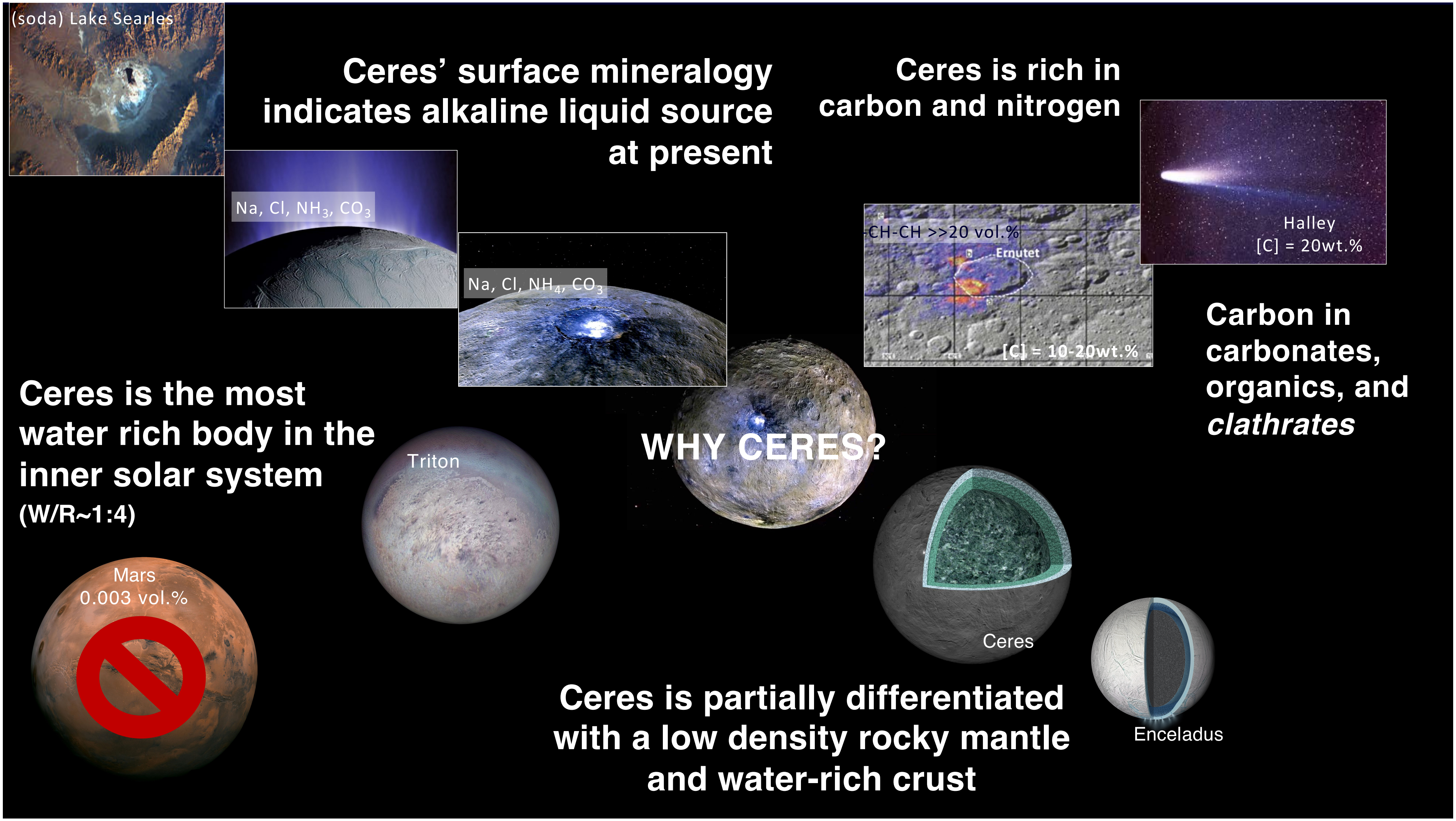
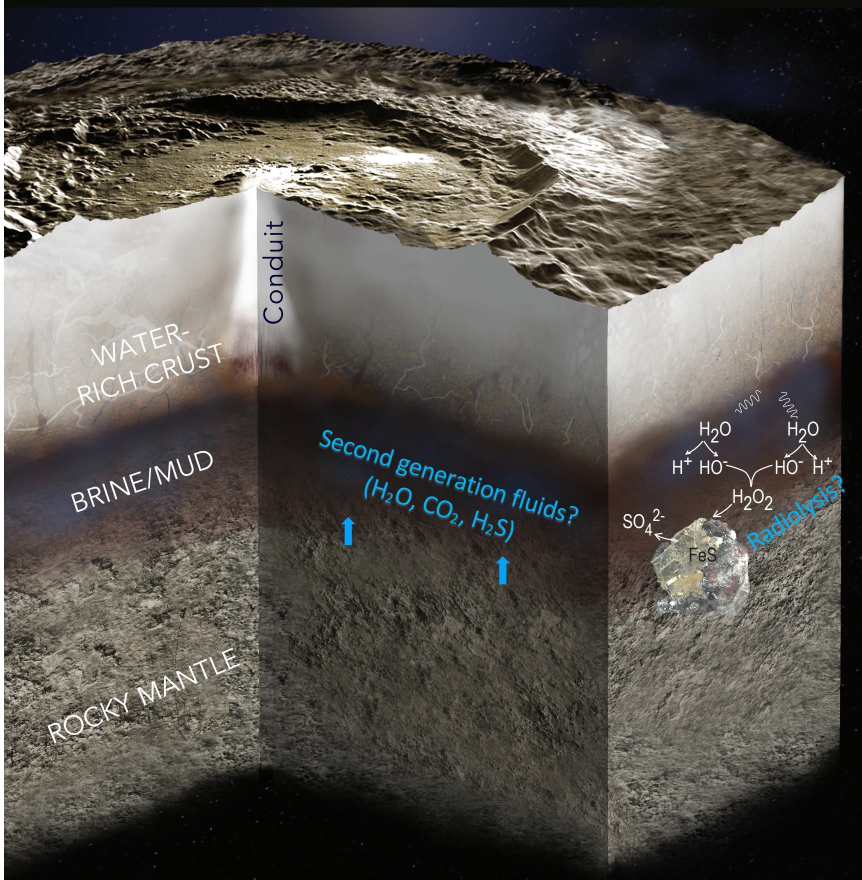
- Lockheed Martin Corp. (PoC: T. Linn)
- Deployable Space Systems (PoC: B. Spence)


(soda) Lake Searles
Ceres' surface mineralogy indicates alkaline liquid source at present
Ceres is rich in carbon and nitrogen
Na, Cl, NH3, CO3
Na, Cl, NH4, CO3
-CH-CH >>20 vol.%
Ernutet
[C] = 10-20wt.%
Halley
[C] = 20wt.%
Carbon in carbonates, organics, and *clathrates*
Ceres is the most water rich body in the inner solar system
(W/R~1:4)
Triton
WHY CERES?
Mars
0.003 vol.%
Ceres
Enceladus
Ceres is partially differentiated with a low density rocky mantle and water-rich crust

INVESTIGATING RECENT EVAPORITES DERIVED FROM DEEP BRINE RESERVOIR ENABLES NEW SCIENCE

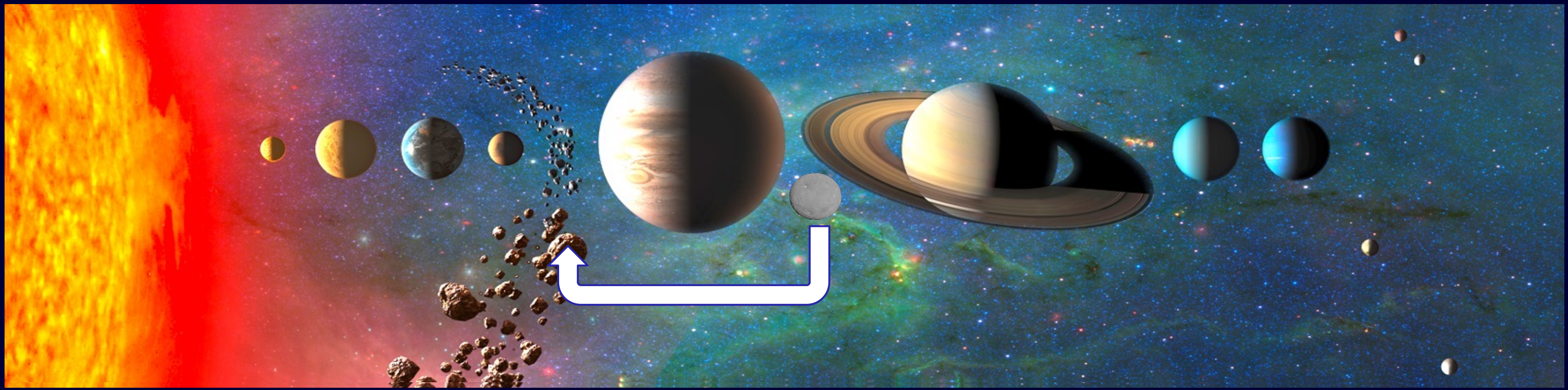


Young 92-km crater (<20 Ma) with fresh (0-2 Ma) salt exposure

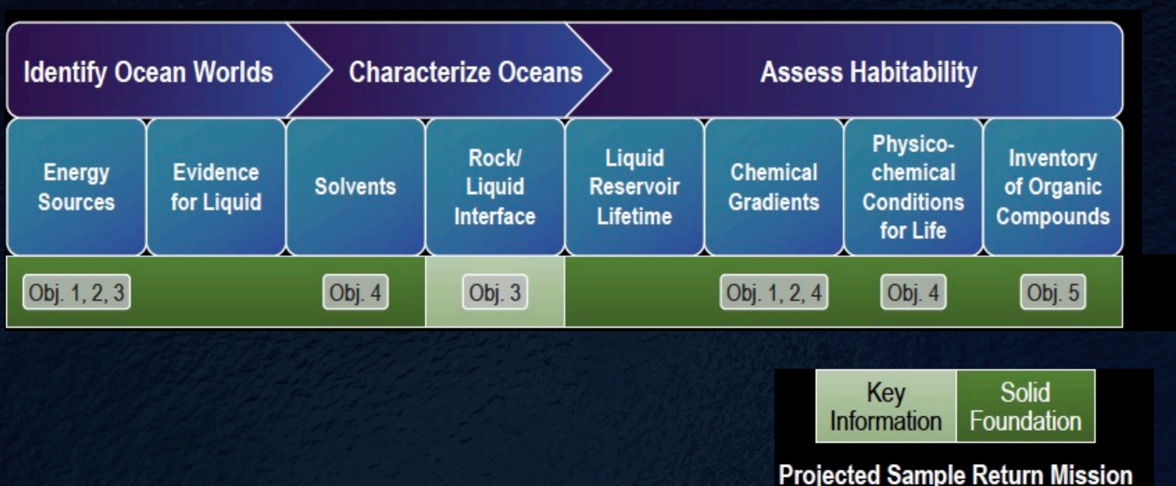
SCIENCE THEME	EXAMPLES OF TESTABLE HYPOTHESES	SIGNIFICANCE / PROJECTED IMPACT
Chemical evolution of long-lived liquid layer	Test if brines are **habitable**, if **chemical energy** is present	Informs the long-term habitability potential of OW Applies to dwarf planets, large icy moons
Carbon partitioning and fate of organic matter (OM) in long-lived liquid reservoirs	Determine OM **origin and formation mechanisms** Test if carbonates are derived from **OM degradation**	
Role of impacts in enabling long-term geological activity at an icy body with limited heat budget	Test the contribution of impacts as **external heat source** and drivers of **subsurface-surface material transfer**	Provides context for observations of other icy bodies (e.g., Europa Clipper, JUICE)

INVESTIGATING THE ONLY DWARF PLANET IN THE INNER SOLAR SYSTEM RETIRES KNOWLEDGE GAPS ON THE FORMATION OF HABITABLE WORLDS

SCIENCE THEME	EXAMPLES OF TESTABLE HYPOTHESES	SIGNIFICANCE / PROJECTED IMPACT
Genetic Relationships with icy moons and inner solar system volatiles	Test if Ceres originated from between giant planet orbits, Kuiper Belt, in situ (pebble accretion)	▪ Retires knowledge gap on the origin of volatiles in inner ss ▪ Narrows down likely early ss evolution scenarios → exoplanet science ▪ Potentially provides information on Ocean Worlds accretional environment



CERES: OCEAN WORLD SCIENCE CLOSE TO HOME



Obj. 1: Test if extrusion from a brine-rich mantle occurred during Ceres' recent history

Obj. 2: Test if endogenic activity is ongoing at Occator crater

Obj. 3: Map the distribution of brines below Occator crater

Obj. 4: Characterize Ceres' deep brine environment at Occator crater

Obj. 5: Characterize the evolution of organic matter in long-lived ocean

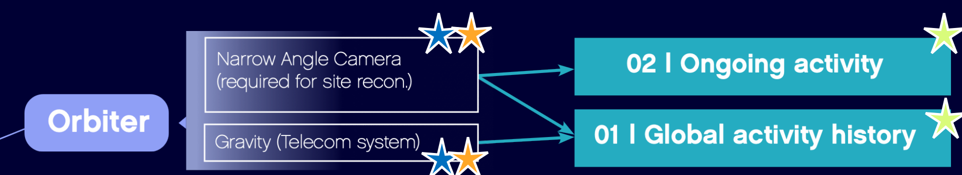
Obj. 6: Determine Ceres' accretional environment

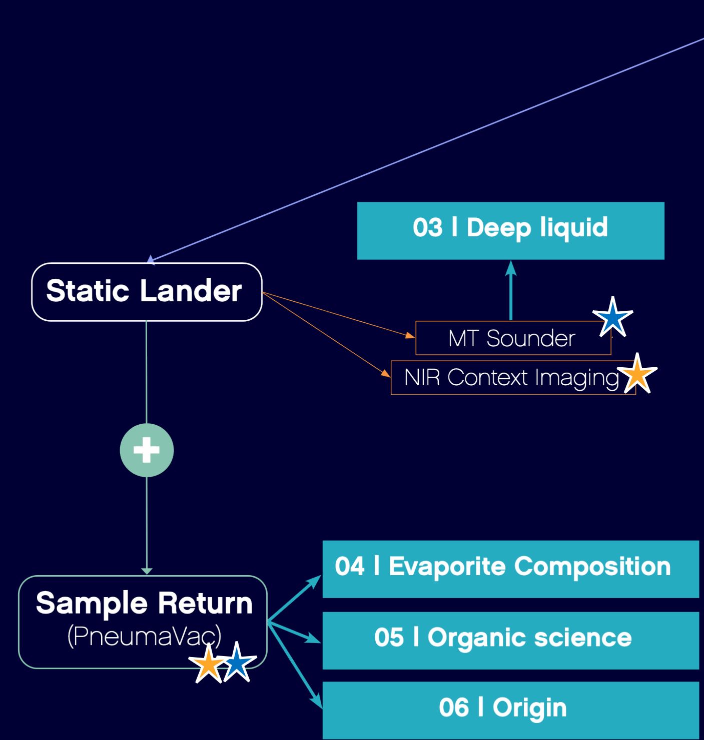
SAMPLE RETURN OPTION

New Frontiers $FY25 (50% reserves)

Single Element Architecture

- ★ Low cost objective
- ★ Contribution possible
- ★ High-heritage subsystem



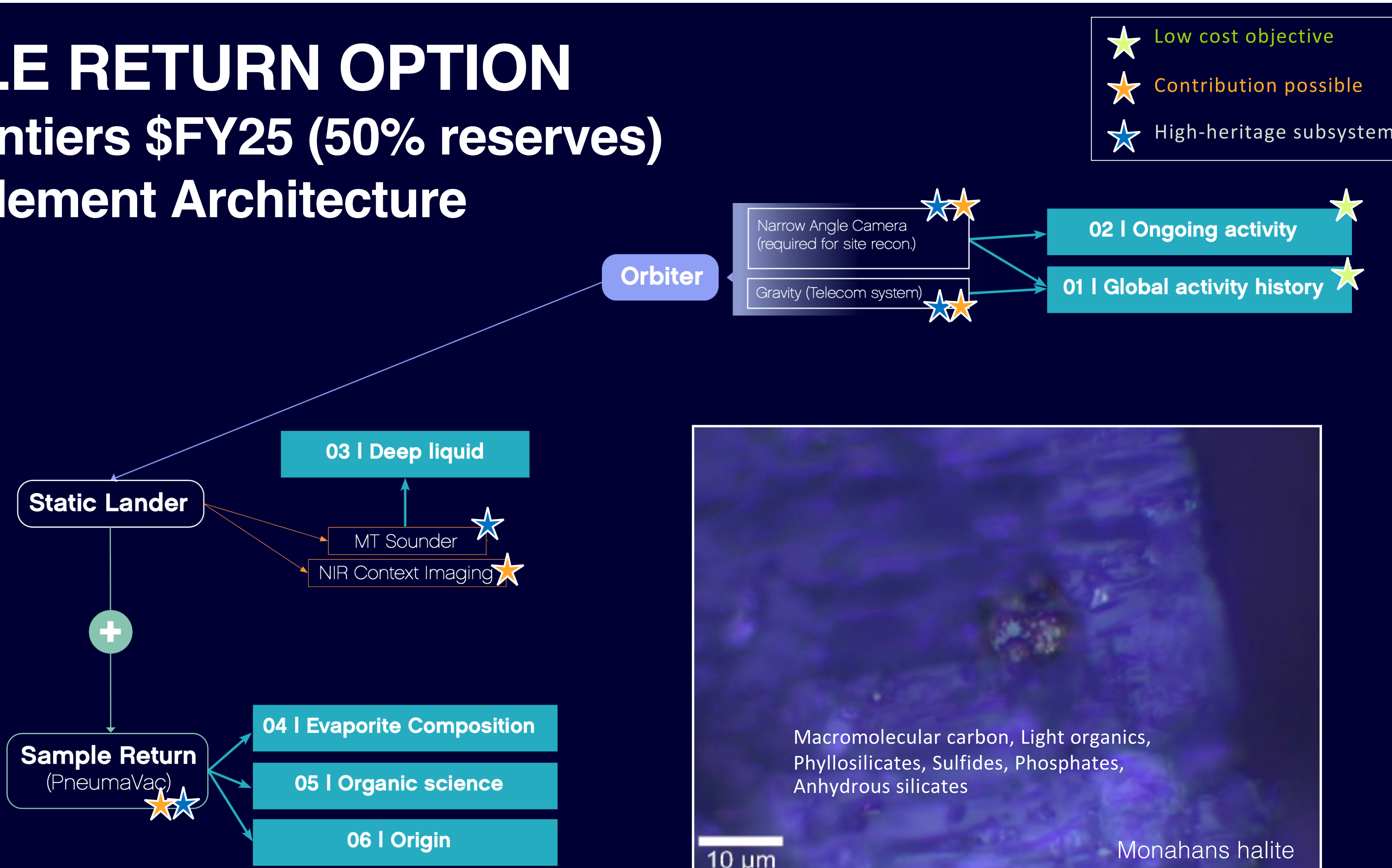


Objectives	Driving Measurements
1- Test if extrusion from a brine-rich mantle occurred during Ceres' recent history	High-res color imaging and gravity measurement of multiple landforms that may be of cryovolcanic origin
2- Test if endogenic activity is ongoing	Imaging at <5 m/pix of Occator crater faculae
3- Map the distribution of brines below Occator crater	Magnetic and electric field at Vinalia Faculae (200 m baseline)
4- Characterize Ceres' deep brine environment	Elemental, mineralogical, and isotopic composition of salts and rock
5- Characterize the evolution of organic matter in long-lived brines	**Elemental, mineralogical, and isotopic composition of organic matter mixed with rock and salts (10 nm scale)**
6- Determine Ceres' Origin	**Ratios of elemental abundances, isotopic ratios of volatiles and minor elements (<<1 wt.%) sampled in salts and rock**

SAMPLE RETURN OPTION

New Frontiers $FY25 (50% reserves)

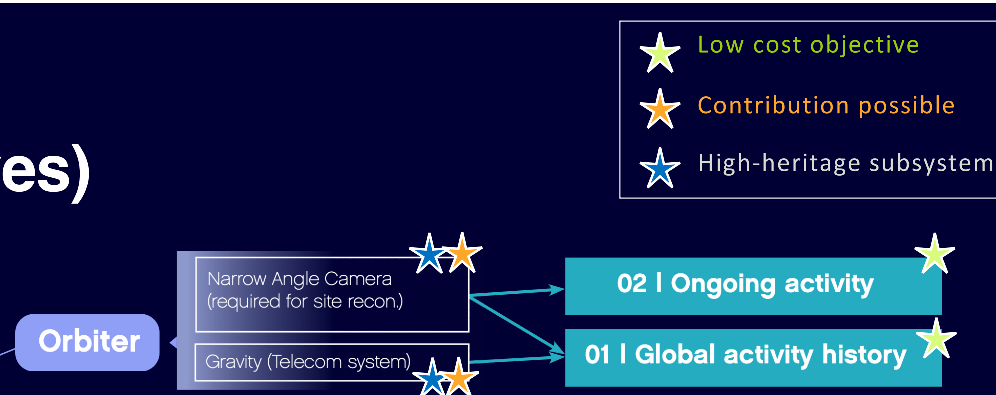
Single Element Architecture

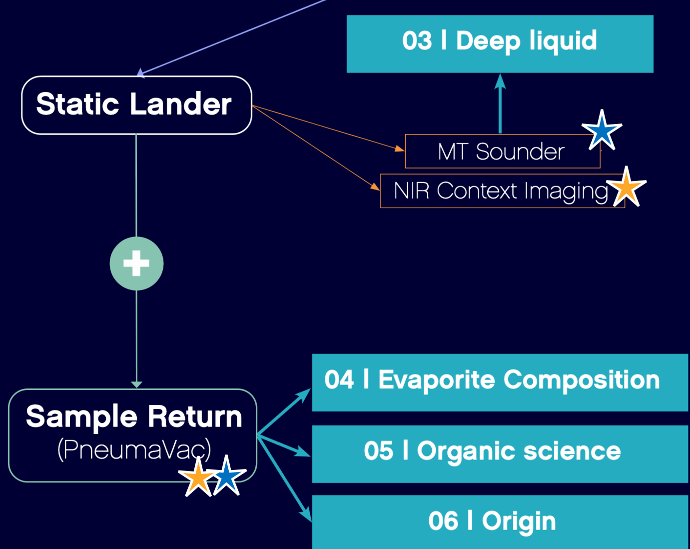


SAMPLE RETURN OPTION

New Frontiers $FY25 (50% reserves)

Single Element Architecture





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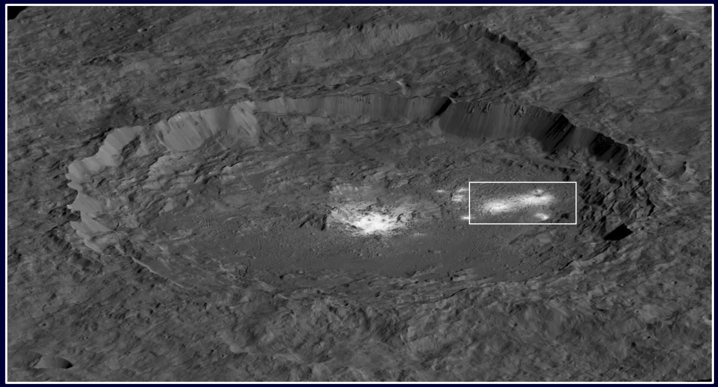
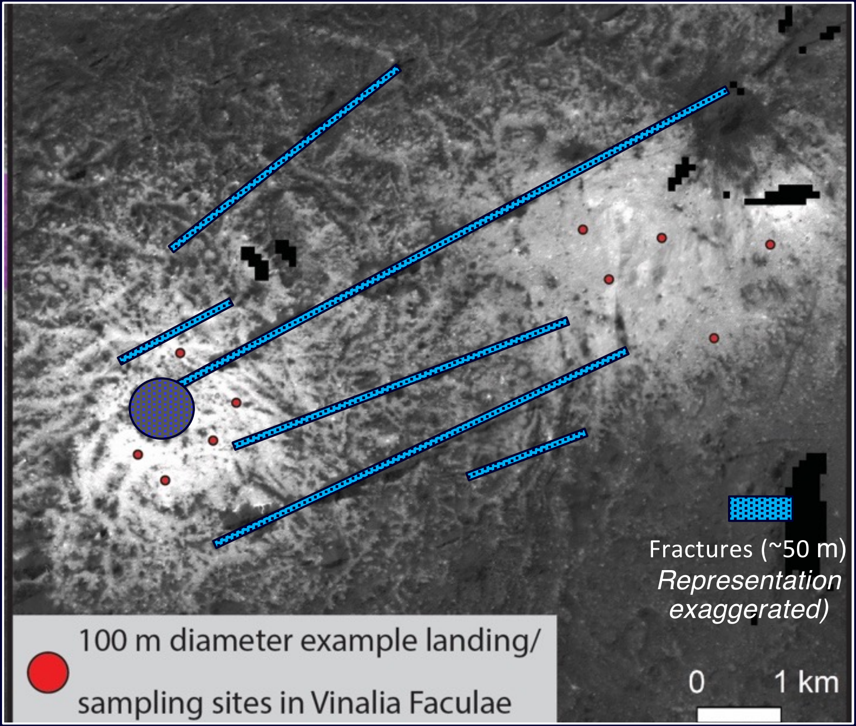


Occator crater – 92 km diameter

TARGET IS <2 Ma VINALIA EVAPORITES

Allows sampling both bright and dark materials associated with vents and/or fractures from a static lander



State of knowledge:

- Dawn (<5 m/px) indicate many possible safe sites adequate for science
- Analysis indicates loose material

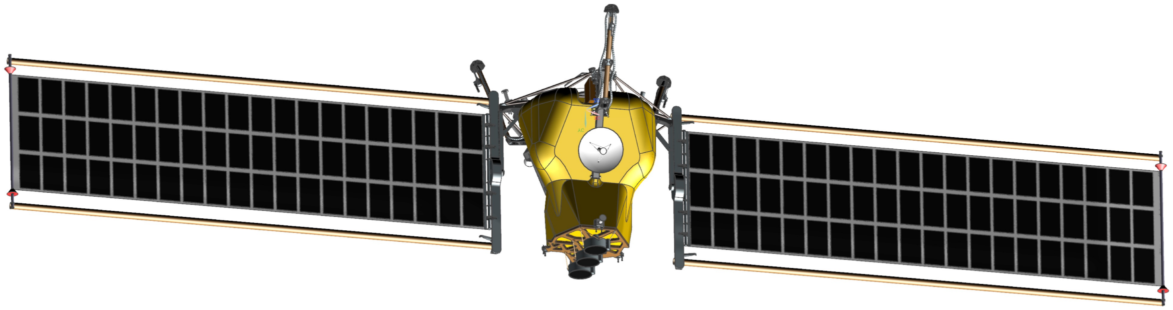
Approach to Landing

- Landing site imaging at <30 cm/pix
- Requirement to land outside of large fractures (<5% of surface area)
- TRN allows <50 m landing ellipse – input from M2020 TRN Lead A. Johnson

Approach to Sampling

- Use PneumaVac system (Honeybee Robotics, e.g., Dragonfly): sample loose material with drilling capability as backup
- Preliminary analysis indicates that sample mass requirement (~100 gm) is met with margin from 2 PneumaVac

BASELINE FLIGHT SYSTEM — CRUISE CONFIGURATION

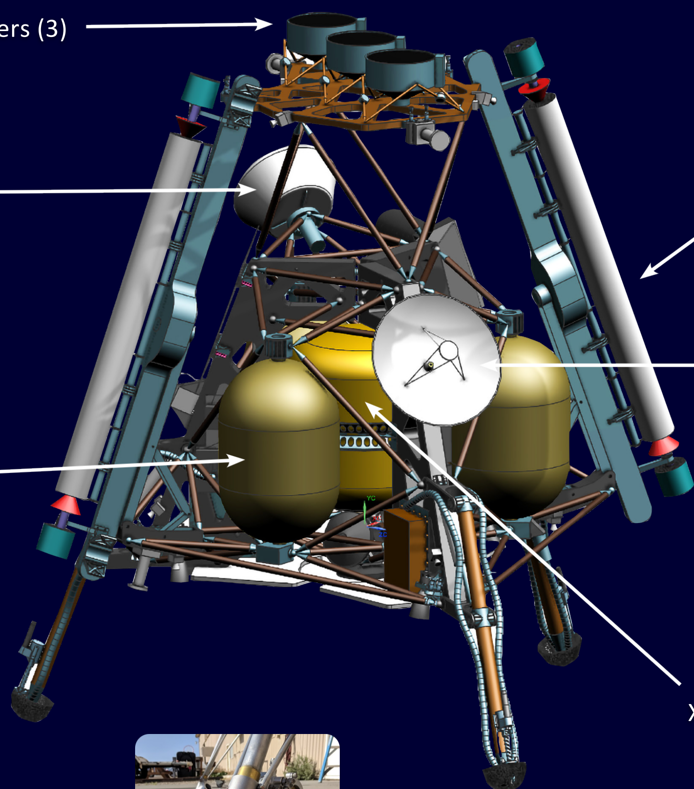


- 27.5-kW solar array (BoL at 1 au)
- 1.5-m dia. high gain antenna
- 3 NEXT gridded ion thrusters
- Hydrazine monopropellant system for deorbit, landing, and takeoff

- Launch Mass: 4669 kg
- Earth Return Mass: 2269 kg
- Xenon Mass (with margin): 1320 kg
- Hydrazine Mass (with margin): 1200 kg

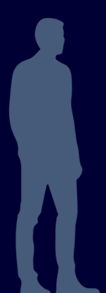
- Option 4: 5-meter fairing, with high performance range, equivalent to the Falcon Heavy reusable
- Regular launch opportunities permitted by solar electric prop
- Mars gravity assist in most cases
- ~6.5 yr trip inbound and 4.7 yr outbound
- Total mission duration ~12.5 yrs including 500 d stay at Ceres

BASELINE – STOWED CONFIGURATION



1-m ground clearance, consistent with landing site reconnaissance and certification

Preliminary planetary protection categorization of inbound mission IVb-like (PPO)

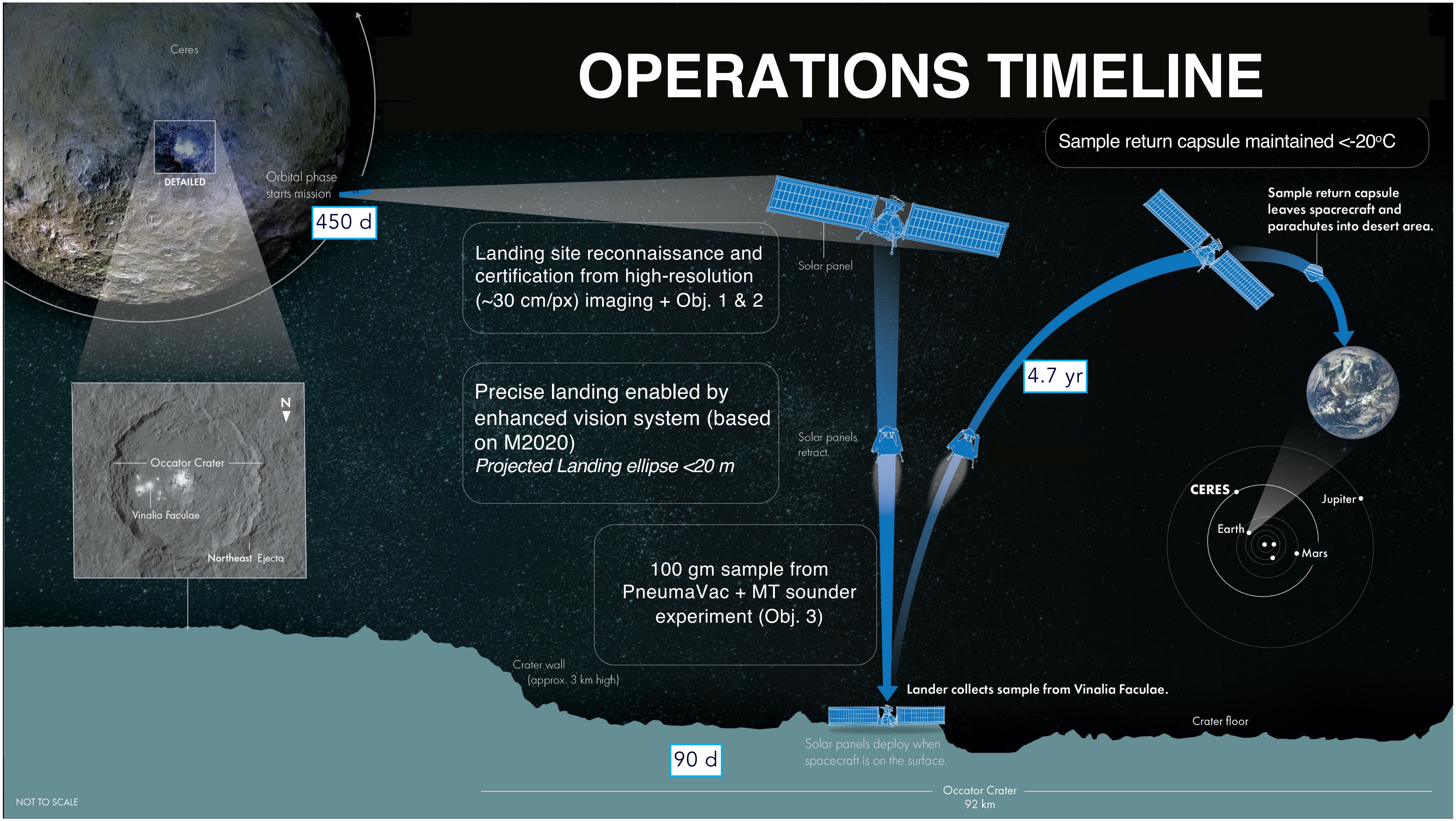


Not shown:
Multi-layer insulation

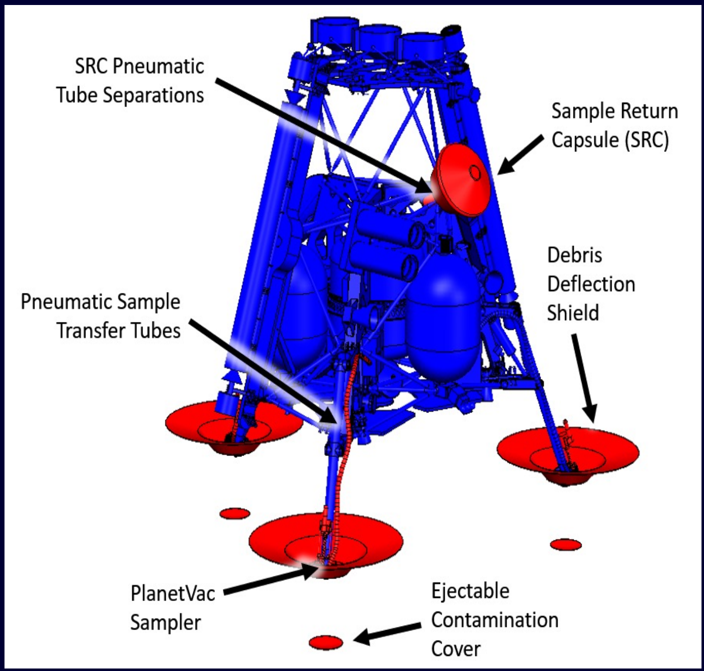
PneumaVac Sampling system in three feet (Honeybee Robotics, based on Dragonfly)

CERES

OPERATIONS TIMELINE



SAMPLING REQUIREMENTS

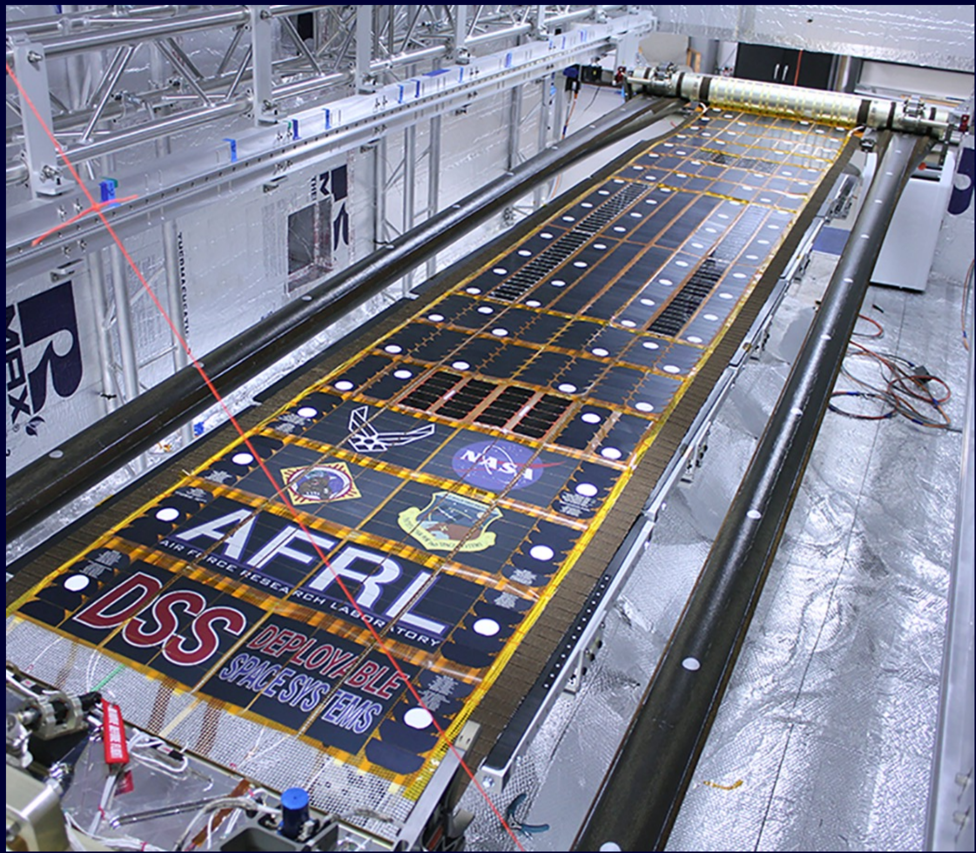


Sample Canister
Hold up to sample mass of: 200 g (100 g and 100% margin)
Particulate contamination control to >ISO 5 and non-volatile organic residue limited to level A/2
Return at ≤-20°C to prevent reaction between anhydrous material and liquid water in the spacecraft.
Prevent atmospheric leakage into the SRC during and after Earth entry until SRC recovery;
Maintain internal pressure < 10^{-7} torr after SRC closure through SRC recovery

- Vinalia evaporites likely to have been emplaced recently – or at least cannot prove otherwise
  - Not subject to sufficient TID for sterilization (>500kyr for 2.5 MRad)
  - If backcontamination concerns lead to Cat V restricted mission, then would leverage Mars Sample Return infrastructure investments
  - Alternative option is to seek salt deposits that are older – impact on Objective 5 to be assessed
- No requirement on stratigraphy preservation
- 100 gm sample mass requirement (~50 cm^3) based on the diversity of techniques (esp. destructive and semi-destructive) involved for addressing Obj. 4-6

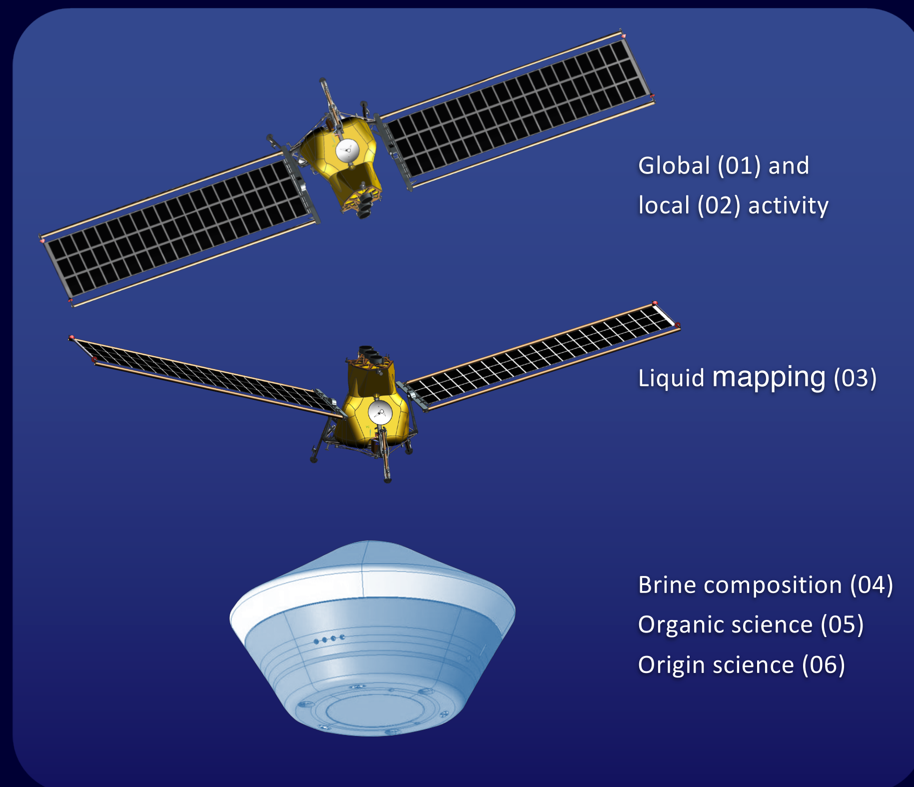
OPEN ITEMS AND TECHNOLOGY DEVELOPMENTS

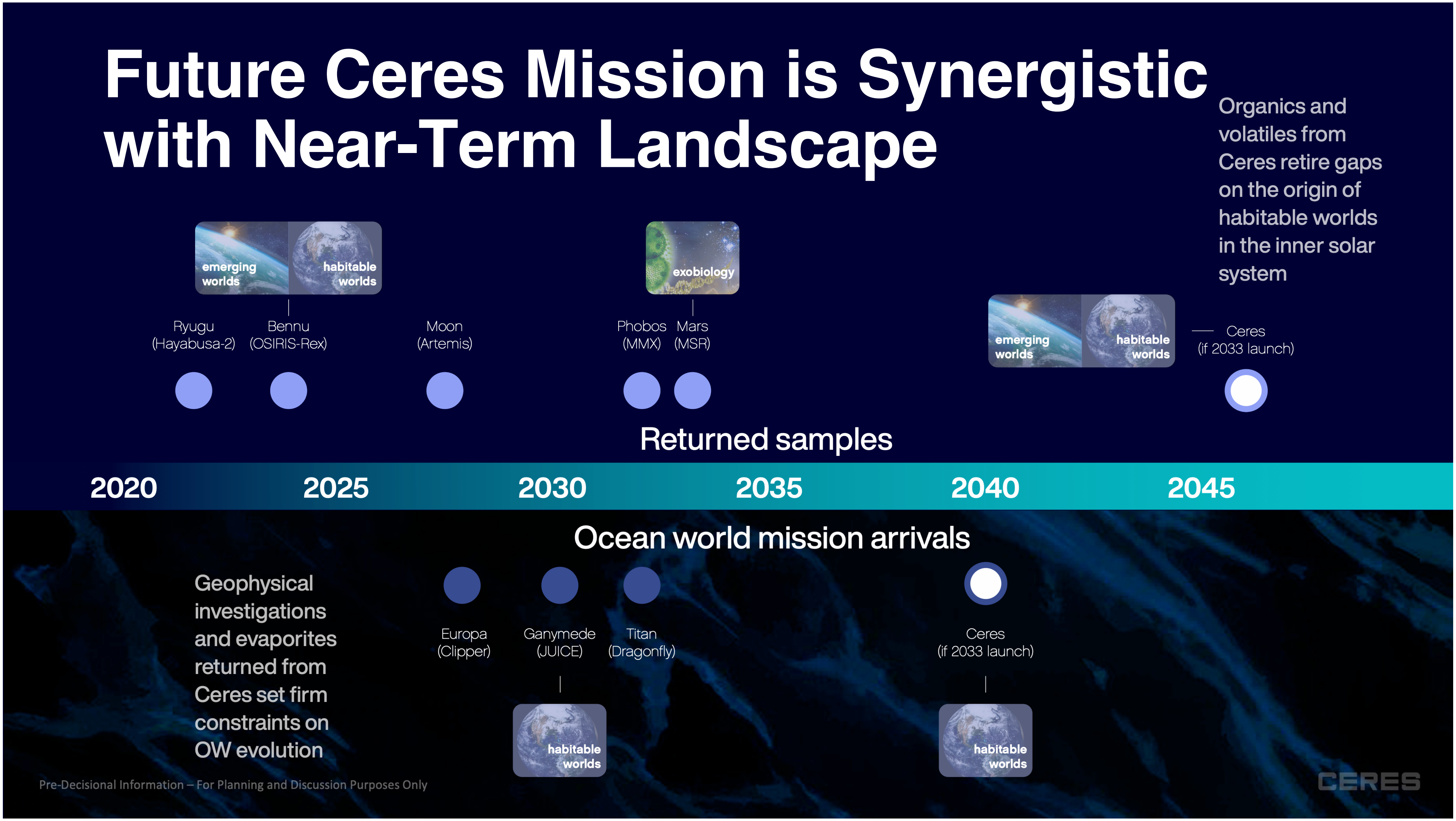
- CML 4 Concept
  - Open trades: thruster location, drop altitude, SRC
  - Up to $150M of possible contributions and descopes (e.g., point spectrometer, shorter orbital/in situ ops, target older brine region, SRC)
- Standard Engineering: Sample transfer from sampling system to return capsule needs to be refined
- Technology Maturation: ROSA partially demonstrated on ISS and lunar conditions; needs to be assessed in Ceres' conditions
- Needs formal planetary protection categorization



CERES IS A COMPELLING NEW FRONTIERS TARGET

- **Sample return from Ceres' evaporites is high science return per $$**
  - **OW Science, Origins, Processes in a single mission**
  - **Complementary to OW missions planned in next decade**
- **Close distance to Earth and low gravity → single element architecture**
  - **Feasible with TRL5+ technologies**
  - **13-yr roundtrip; 3 objectives achieved at Ceres**
- **Leverages NASA's >$100M investments in ground-based facilities and benefit from decade-long analyses**




Future Ceres Mission is Synergistic with Near-Term Landscape
Organics and volatiles from Ceres retire gaps on the origin of habitable worlds in the inner solar system
emerging worlds
habitable worlds
exobiology
Ryugu (Hayabusa-2)
Bennu (OSIRIS-Rex)
Moon (Artemis)
Phobos (MMX)
Mars (MSR)
emerging worlds
habitable worlds
Ceres (if 2033 launch)
Returned samples
2020
2025
2030
2035
2040
2045
Ocean world mission arrivals
Geophysical investigations and evaporites returned from Ceres set firm constraints on OW evolution
Europa (Clipper)
Ganymede (JUICE)
Titan (Dragonfly)
Ceres (if 2033 launch)
habitable worlds
habitable worlds
Pre-Decisional Information – For Planning and Discussion Purposes Only
CERES