# SOLAR SYSTEM ORIGINS--SYNTHESIS

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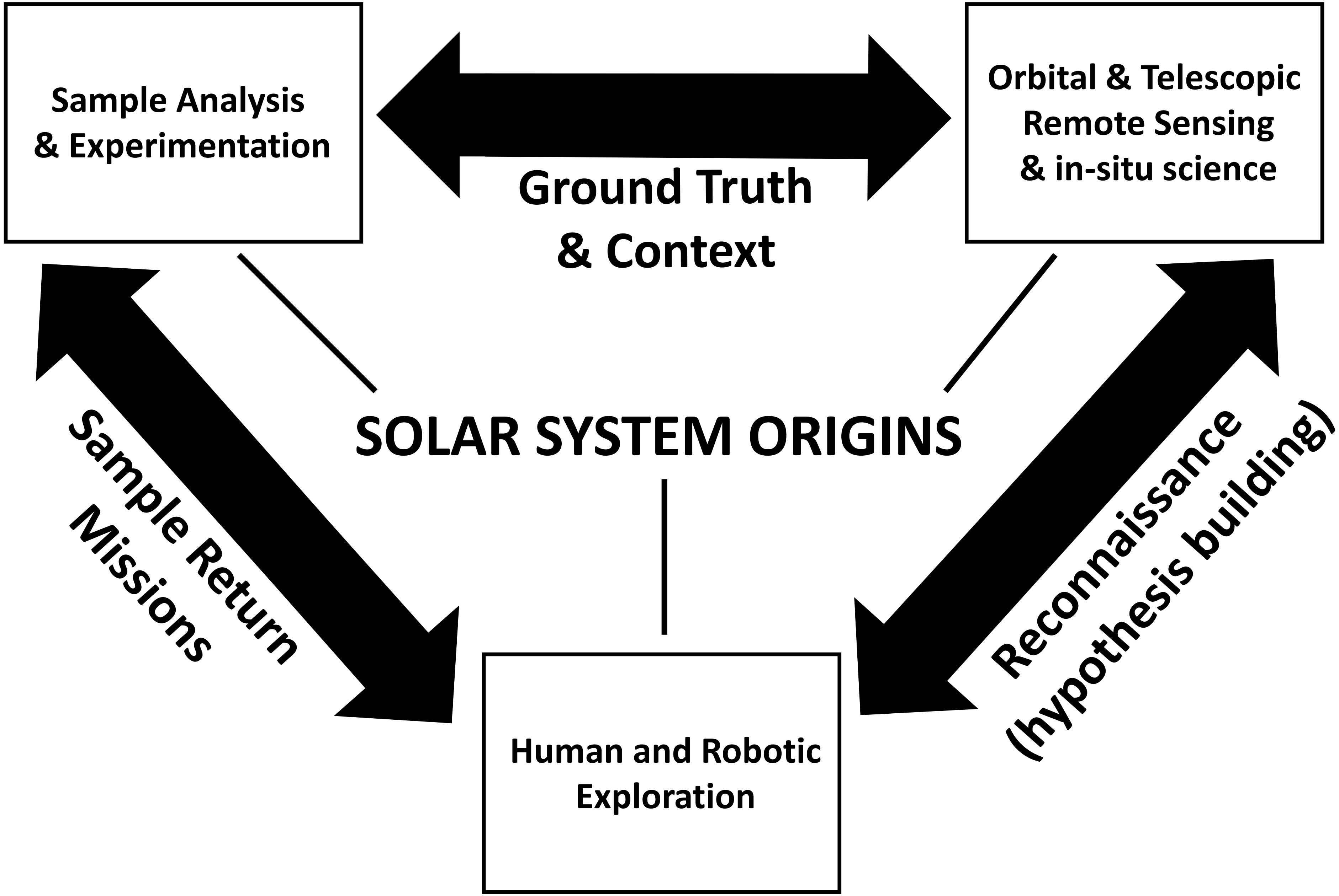
# Primary Origins Science Questions to answer by 2050

- What is the origin, distribution, and timing of volatiles/organics throughout the solar system?
- What is the degree of mixing within the protoplanetary disk during planet formation?
- How common is the origins story for our own solar system, and how does it compare to exosolar systems?
- How much variation exists in the geochemical behaviors of elements in the protoplanetary disk, planetary embyros, and planets, and how does this affect the internal structure of planetary bodies and their thermochemical evolution?

*To answer these questions, we need to do so in the context of comparative planetology and comparisons between planetary systems: To understand the origin of the solar system, we need to study the entire solar system*



Sample Analysis
& Experimentation
Ground Truth
& Context
Orbital & Telescopic
Remote Sensing
& in-situ science
SOLAR SYSTEM ORIGINS
Sample Return
Missions
Reconnaissance
(hypothesis building)
Human and Robotic
Exploration

# Important targets for Exploration

- Exodisks/exoplanets
- Comets
- Moons of the outer Solar System
- Kuiper belt objects
- Ice Giants
- Asteroids (human & RS)
- Phobos & Deimos (human & RS)
- Moon (human)
- Mars (human)

# Potential 2050 Vision

- Through a combination of telescopic observations and flyby missions, we have captured our fist glimpses of new worlds, and better views of little known worlds, and we have begun to prioritize these targets for in-depth analysis by future missions
- We have sent humans back to the Moon, we have sent them to Mars, and humans have visited asteroids.
- There is also a consistent human presence beyond low-Earth orbit

# Important targets for Remote sensing

- Mars
- Asteroids
- Exodisks/exoplanets
- Comets
- Mercury
- Venus
- Ocean Worlds (Europa, Enceladus, etc.)
- Phobos & Deimos
- Gas Giants and Ice Giants

# Potential 2050 Vision

- Geochemical remote sensing (i.e., orbiters, landers, and rovers) have been used as reconnaissance tools for sample return target selection
- Telescopic observations of exodisk and exoplanet systems provide important data about the uniqueness/commonness of our solar system
- Concerted efforts to map the chemistry, mineralogy, and internal structure of the listed bodies have established testable hypotheses to be answered with future sample return or in-situ science missions
- In-situ analysis of the stable isotopic compositions of volatiles within the gas giants and other outer solar system bodies has helped to prioritize sample return target selection

# Important targets for Sample Return

- Mars
- Asteroids
- Moon
- Comets
- Mercury
- Venus
- Ocean/Icy Worlds (Europa, Enceladus, Titan, etc.)
- Phobos/Deimos

# Potential 2050 Vision

- In collaboration with other space agencies and commercial enterprises, we have completed robotic sample return missions from the listed targets
- Advances in understanding solar system origins, workings, and life have been improved by Human exploration and human-assisted sample return missions from the Moon, Mars, and asteroids

## Modeling/Research Efforts

- Sample analysis of planetary materials
- Collection and analysis of remote sensing data (telescopic, orbital, and in-situ) to understand chemical evolution and internal structure of solar system bodies and exodisks/exoplanets
- Experimentation to tie process to observation
- Utilize all three approaches above to quantify inputs for origins models

## Potential 2050 Vision

- The origin and distribution of volatiles/organics and timing of their delivery can be better assessed now that we have sampled targets from the inner and outer solar system
- Samples of all the inner planets has facilitated the measurements needed to test mixing models within the protoplanetary disk
- The increase in our understanding of planetary formation and evolution has developed from combined efforts to study our own solar system as well as exoplanet systems
- Experiments, informed by returned samples and in-situ science, have expanded our understanding of the geochemical behavior of the elements, which has aided in refining models of the thermochemical evolution of the planets

## Technology Development

- Sampling: tools, systems, encapsulation and return
- Advanced curation capabilities (i.e., cold curation down to 10 Kelvin, bio-logical-organic-inorganic cleanliness, contamination knowledge)
- Instrumentation (state of the art lab facilities on Earth and remote sensing capabilities)
- Long-duration human presence beyond low-Earth orbit
- Improved power, communications, and propulsion
- Improvements in launch-lift capabilities to escape and enter gravity wells

## Potential 2050 Vision

- We will be able to collect, return, and curate samples of gases, liquids, and solids that remain under the temperatures and physical states at which they were collected
- With all of the investment in sample return missions, there has been a proportionate effort to advance and maintain the scientific and technological capabilities of sample analysis lab facilities on Earth
- The continued effort to understand the origins of our solar system and beyond demands a concomitant effort to grow a diverse and socially healthy workforce to conduct the science and advance the technology
- A consistent human presence in space increases the throughput and frequency of sample return opportunities

# Summary of the Vision

- To study the origins of solar systems will also provide a lot of the data needed to study life and solar system workings
- In-situ science and sample return have complimentary strengths and the decision of which to implement should be based on hypothesis-driven science and a healthy understanding of the resolution needed to test that hypothesis
- Exploration is not only fun, exciting ad inspiring, it also provides us with opportunities to build hypotheses to be tested by future missions and laboratory studies
- Our understanding of solar system origins will only approach reliable answers by building models that merge datasets from sample analysis, experimentation, and remote sensing/telescopic/robotic observations
- Many advances in technology will be needed to mitigate the estimated costs of the ambitious plans outlined for solar system origins over the next 33 years, but if we focus on the costs today, we will subdue our dreams for the future.
- A diverse, socially healthy, and continually growing workforce within a planetary science field that has programmatic balance will enable fresh ideas that are not limited by thinking that has stagnated