Enabling Planetary Missions with ILTN

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Keck INSTITUTE FOR SPACE STUDIES

Overview

ITLN characteristics

Planetary science goals that would benefit from ITLN

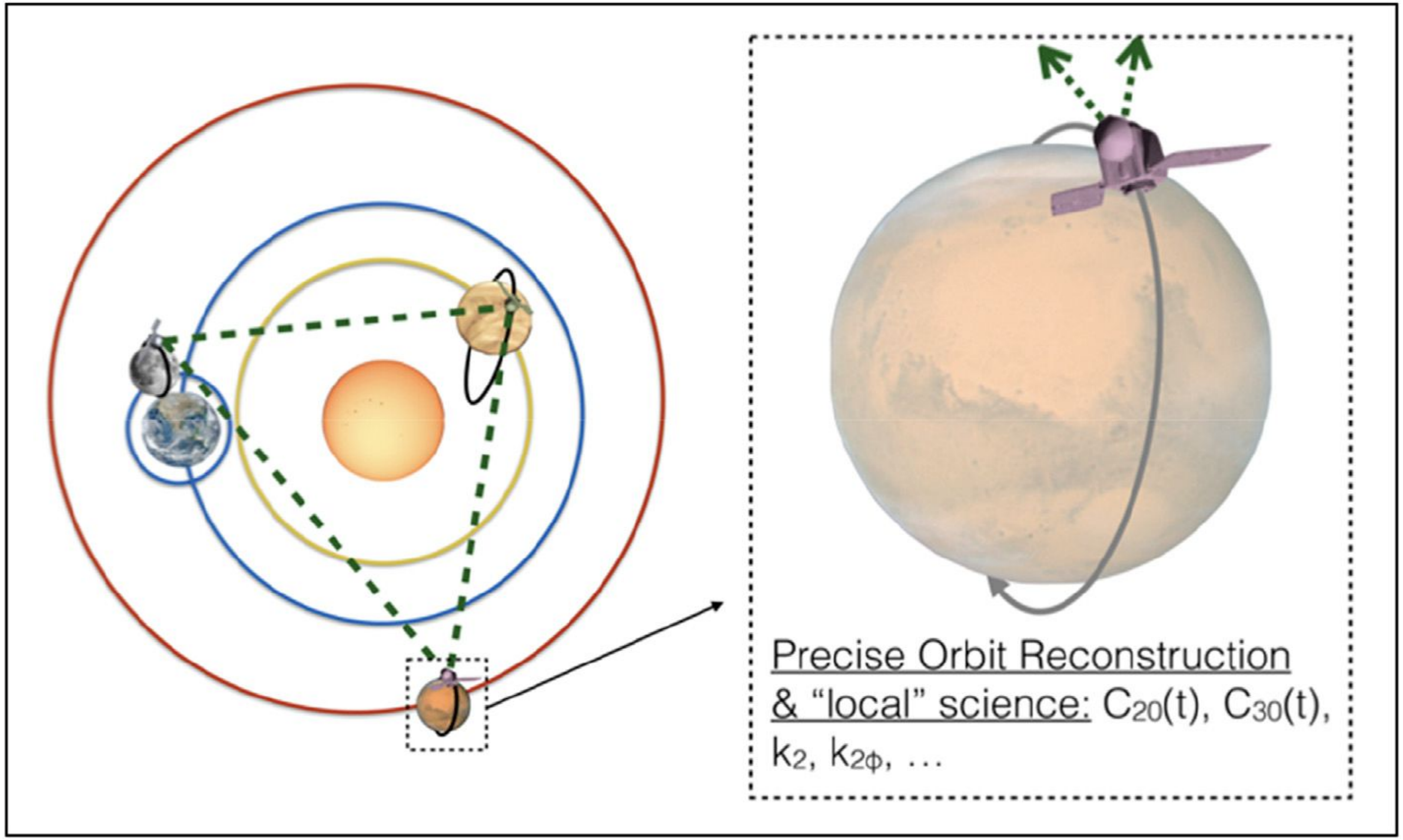
ITLN as infrastructure versus discovery-based mission

Requirements development

Community engagement

Advocacy and proposals

Strengths and weaknesses



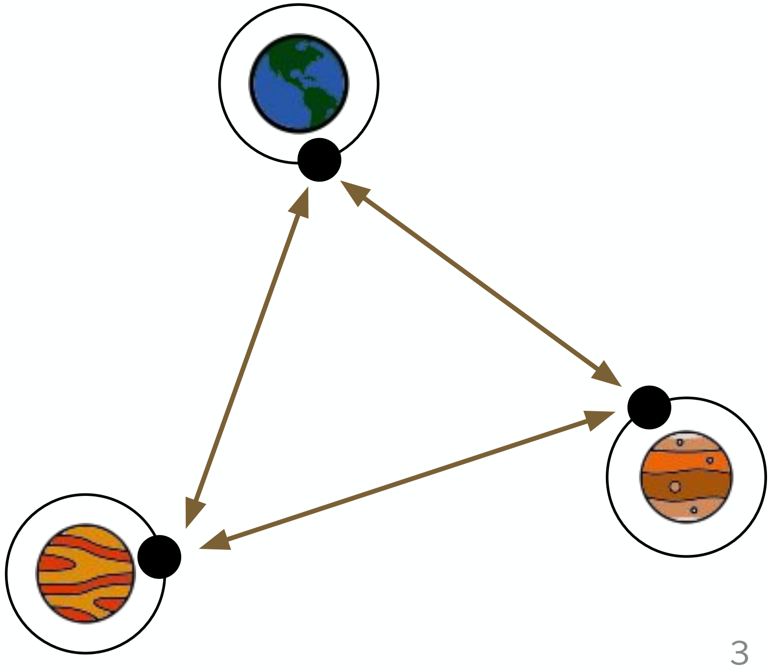
ITLN Characteristics

ITLN is a method for measuring distances and positions across the solar system using laser signals exchanged between spacecraft that would improve ranging by up to three orders of magnitude and rotation rate measurement accuracy by over ten orders of magnitude.

- Uses laser transponders
- Distances are calculated between spacecraft by measuring the timing of laser pulses between spacecraft
- Determines positions of centers of mass of host planets
- Improves planetary geodesy and navigation
- Would orbit Venus, Earth, and Mars

Observations of planet orbits have been from Earth.
ITLN provides another perspective of the orbits via a continuously changing triangle.

Smith et al, 2018

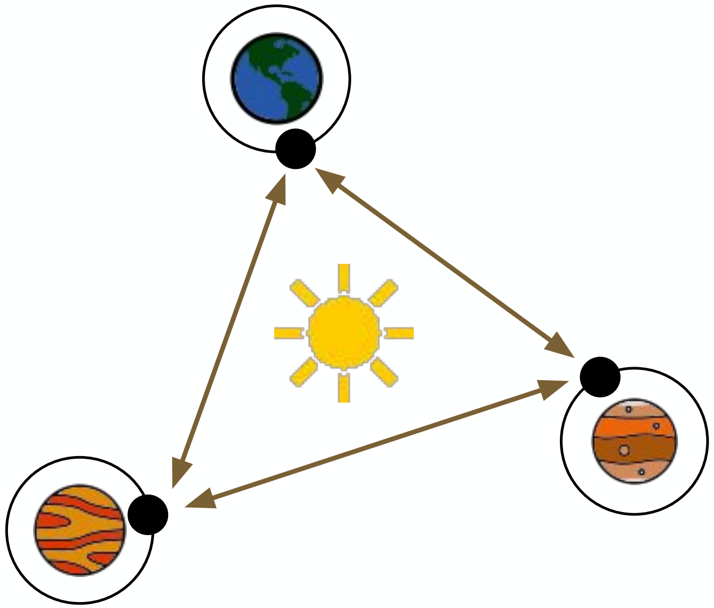


Planetary Scale Ring Laser Gyroscope

Pulses move in both directions around planetary circuit

Average enclosed area ~1AU^2

Positioning of inner solar system improved by three orders of magnitude



4 m one-component G ring laser at the Geodetic Observatory Wettzell, Germany. In this alignment, the ring laser is sensitive to rotations around a local vertical axis only (and insensitive to translations)

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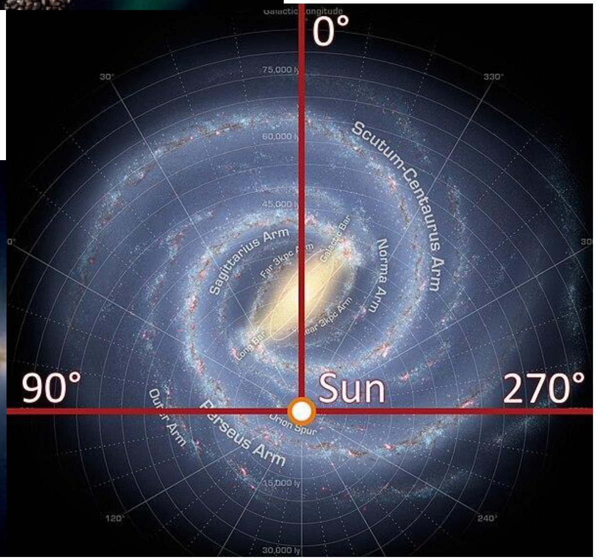
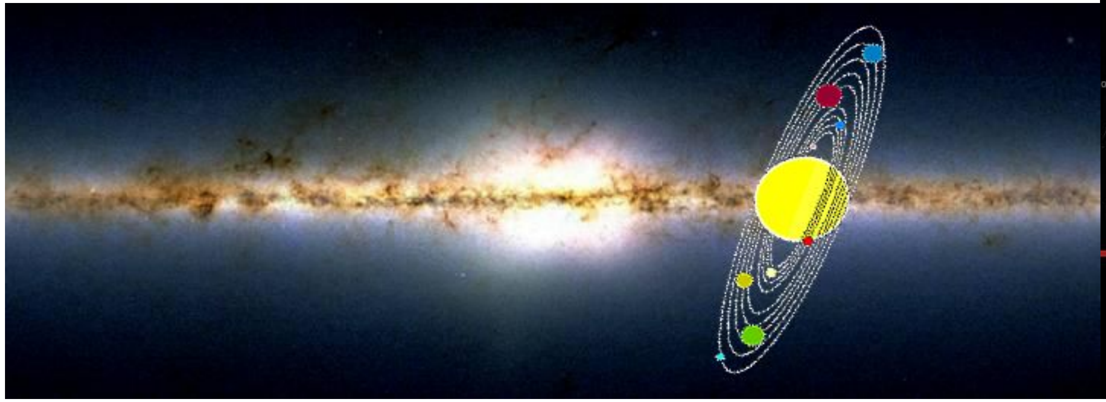
Possible ILTN Science Applications

Astrophysics

- Solar system expansion rate
- Mean galactic rotation rate
- Gravitational wave detection

- Solar gravitational flattening
  - Structure of solar interior and variability
  - Impacts on precession of planetary orbits

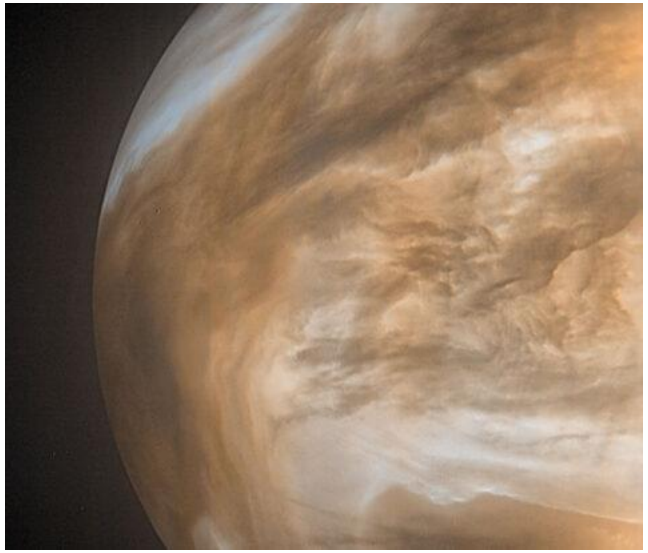




Possible ILTN Science Applications

Planetary Science

- Planetary geodesy (shape, gravity field, and rotational dynamics)
  - Planetary interiors and evolution: mass distributions
    - e.g. Seasonal variability of Mars polar caps, dynamical motions of Venus' dense atmosphere
    - Time-variable long-wavelength gravity field less than spherical harmonic degree and order 4
    - Motion of Venus' atmosphere
  - Orientation of orbited planet
  - Orbit determination and navigation: reference frame
- Orbit perturbations by asteroids
  - Some asteroids may be difficult to detect
  - ILTN would provide search capability



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Programmatic Considerations

NASA Science Mission Directorate (SMD)

- Astrophysics
- Biological and Physical Sciences
- Earth Science
- Heliophysics
- Planetary Science

Discover the secrets of the universe
Search for life elsewhere
Protect and improve life on Earth and in space

European Space Agency (ESA)

- Astronomy
- Solar System Science
- Fundamental Science

What are the conditions for planetary formation and the emergence of life?
How does the Solar System work?
What are the physical fundamental laws of the Universe?
How did the Universe originate and what is it made of?

Decadal Surveys

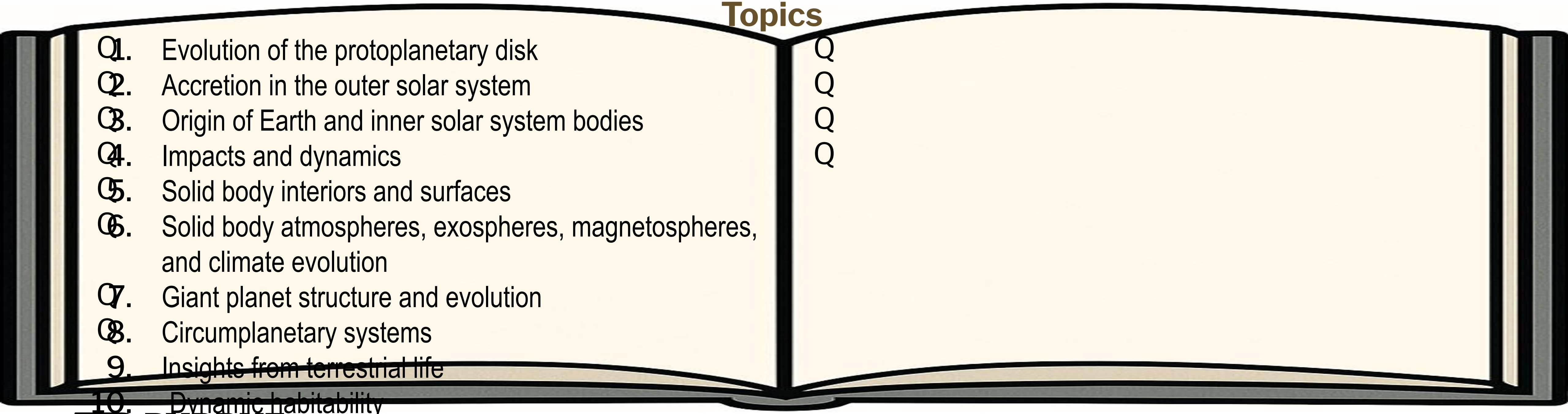
Astrophysics

- *2023 Pathways to Discovery in Astronomy and Astrophysics for the 2020s*

Planetary Science

- *2022 Origins, Worlds, and Life; A Decadal Strategy for Planetary Science and Astrobiology 2023–2032*

Priority Science Decadal Survey Topics



Q1. Evolution of the protoplanetary disk
Q2. Accretion in the outer solar system
Q3. Origin of Earth and inner solar system bodies
Q4. Impacts and dynamics
Q5. Solid body interiors and surfaces
Q6. Solid body atmospheres, exospheres, magnetospheres, and climate evolution
Q7. Giant planet structure and evolution
Q8. Circumplanetary systems
9. Insights from terrestrial life
10. Dynamic habitability
11. Search for life elsewhere
12. Exoplanets

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Science Priorities

- First three questions related to origin, formation, evolution
- Difficult to map ILTN to these

Panels are arranged by planets or classes of solar system bodies

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Science Priorities

- Next three questions are more relevant
- Questions 7–12 less relevant

Parameters that ILTN may be able to estimate depending on spacecraft orbits:

<u>Host Planets</u>
Precession, nutation & rotation
Obliquity, tides, moment of inertia
Low-degree gravity, seasonal changes
Heliocentric orbits

Smith et al, 2018

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Decadal Survey Technology Priorities

For This Decade and Beyond

- Planetary defense
  - Advancement of planetary defense technologies to address characterization and mitigation objectives require development in the coming decade.
  - Applicable Destinations: Small bodies
- Subsurface Access
  - Priority future missions targeting surface/subsurface exploration require access to pristine/unmodified materials. Technologies include drills, melt probes, tethers, submersibles, emplaced communication nodes, telemetry from the probe/drill tip, and materials capable of meeting stringent planetary protection requirements.
  - Applicable Destinations: Earth, Moon, Mars, small bodies, ocean worlds

Technologies proposals require sound science justification that aligns with NASA programmatic goals.
Consider starting with technology development mapped to current decadal survey.

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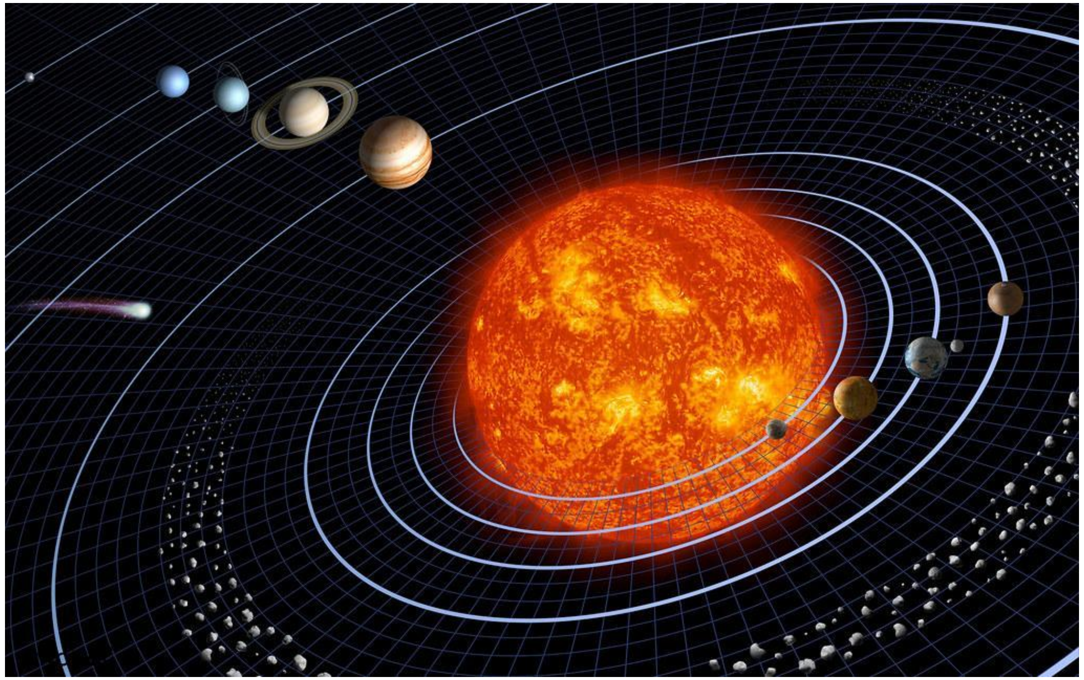
Concept: Solar System Expansion Rate

- Sun's gravity field governs scale of solar system
- Mass of sun is decreasing but likely not at a constant rate
  - ILTN is sensitive to change in mass of the sun
- Mass loss allows solar system to expand and changing scale and velocity of planet orbits
- Understanding the orbits and rate of expansion can provide insight into Sun's deep interior processes
  - Need to separate other effects on planet orbits

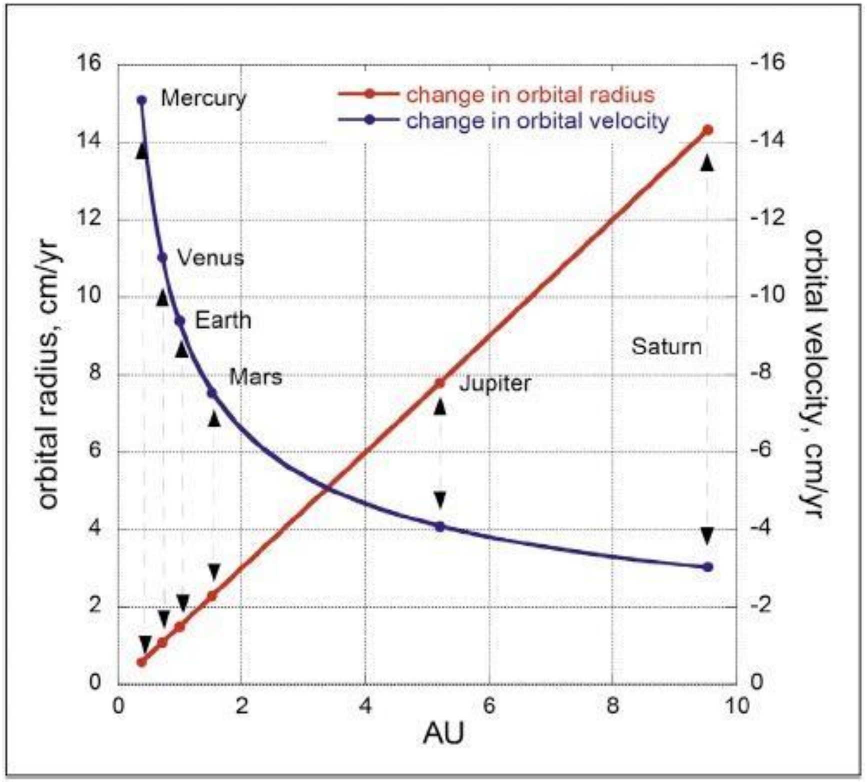


~1.5 cm/yr/AU

Smith et al, 2018

Observations: Solar System Expansion Rate

- Orbiters around three bodies (Venus, Earth, and Mars)
- Laser ranging transponders to measure distance between spacecraft
- Measure for several years
- Geophysical parameters of the orbited bodies
  - Spacecraft orbit
  - Body ephemerides: calculated positions at specific times
  - Dynamics of the central bodies
- Geodetic parameters of solar system can provide
  - Expansion
  - Sun
  - Theoretical physics



The spacecraft that will orbit the host planets measure their distances from each other, nominally to an accuracy of a few centimeters using the asynchronous transponder approach discussed below. The resulting range and range-rate observations will be used to determine the spacecraft orbits about the host planets and the trajectories of the planet centers of mass.

Smith et al, 2018

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ITLN as Infrastructure versus Discovery-based Mission

Infrastructure

- ILTN would be useful for navigation and reference frame determination
- Can work with sponsors directly to develop technology, demonstrations, and implementation
- Enables proposals to multiple science areas

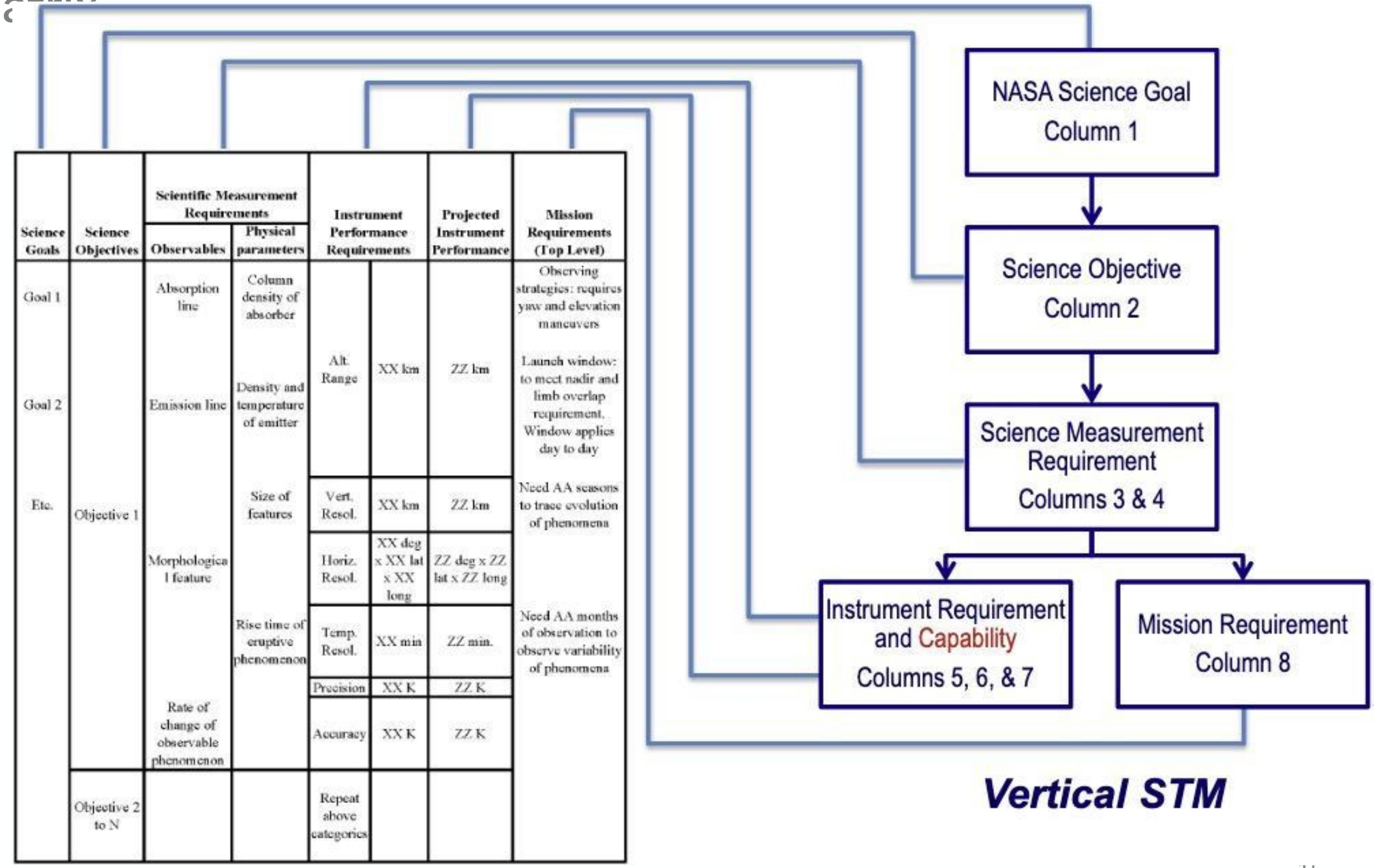
Proposed mission

- Possibility longer timeframe
- Need to address unique well-defined science challenge
- Opportunities for substantial funding in shorter timeframe

Requirements Development

Science Traceability Matrix

- Flow Down science goals and objectives to instrument and mission requirement
- Follows the scientific method
- Goals are broad and established by NASA and National documents (e.g. decadal surveys)
- Objectives are specific and capable of being validated
- Testable hypothesis driven predictions



Science Goals	Science Objectives	Scientific Measurement Requirements: Observables	Scientific Measurement Requirements: Physical parameters	Instrument Performance Requirements		Projected Instrument Performance	Mission Requirements (Top Level)
Goal 1	Objective 1	Absorption line	Column density of absorber	Alt. Range	XX km	ZZ km	Observing strategies: requires yaw and elevation maneuvers
Goal 2		Emission line	Density and temperature of emitter				Launch window: to meet nadir and limb overlap requirement. Window applies day to day
Etc.		Morphological feature	Size of features	Vert. Resol.	XX km	ZZ km	Need AA seasons to trace evolution of phenomena
				Horiz. Resol.	XX deg x XX lat x XX long	ZZ deg x ZZ lat x ZZ long	
			Rise time of eruptive phenomenon	Temp. Resol.	XX min	ZZ min.	Need AA months of observation to observe variability of phenomena
				Precision	XX K	ZZ K	
		Rate of change of observable phenomenon		Accuracy	XX K	ZZ K	
	Objective 2 to N			Repeat above categories			

Feldman,

Key Requirements

- Spacecraft altitude high enough
  - To be unperturbed by plant’s atmosphere
  - To use higher harmonics of gravity field for better determination of spacecraft orbit
- Orbit
  - Minimize restriction of observations between spacecraft
  - Avoid sun-synchronous or true polar to not be fixed in inertial or solar orientation
- Ground-based possible
  - More stable
  - Introduces atmospheric errors including seasonal
  - Errors from site movement due to planetary rotation, tides, or other effects

Community Engagement

- Make a clear, comprehensive, and compelling report for this KISS ILTN study
- Convene follow on workshops
- Organize special sessions at professional conferences
- Publish
- Participate in decadal surveys

Advocacy and Proposals

- Engaging the community helps build advocacy
- Build ILTN in pieces
  - Develop ILTN capability
  - Refine ILTN science
- Submit proposals to relevant calls - must be responsive to the call
- Publications provide sound basis for proposals

Strengths and Weaknesses

Strengths

- Clear objectives
- Understandable measurement
- Addresses fundamental science questions
- Potential practical application

Opportunities

TBD

Weaknesses

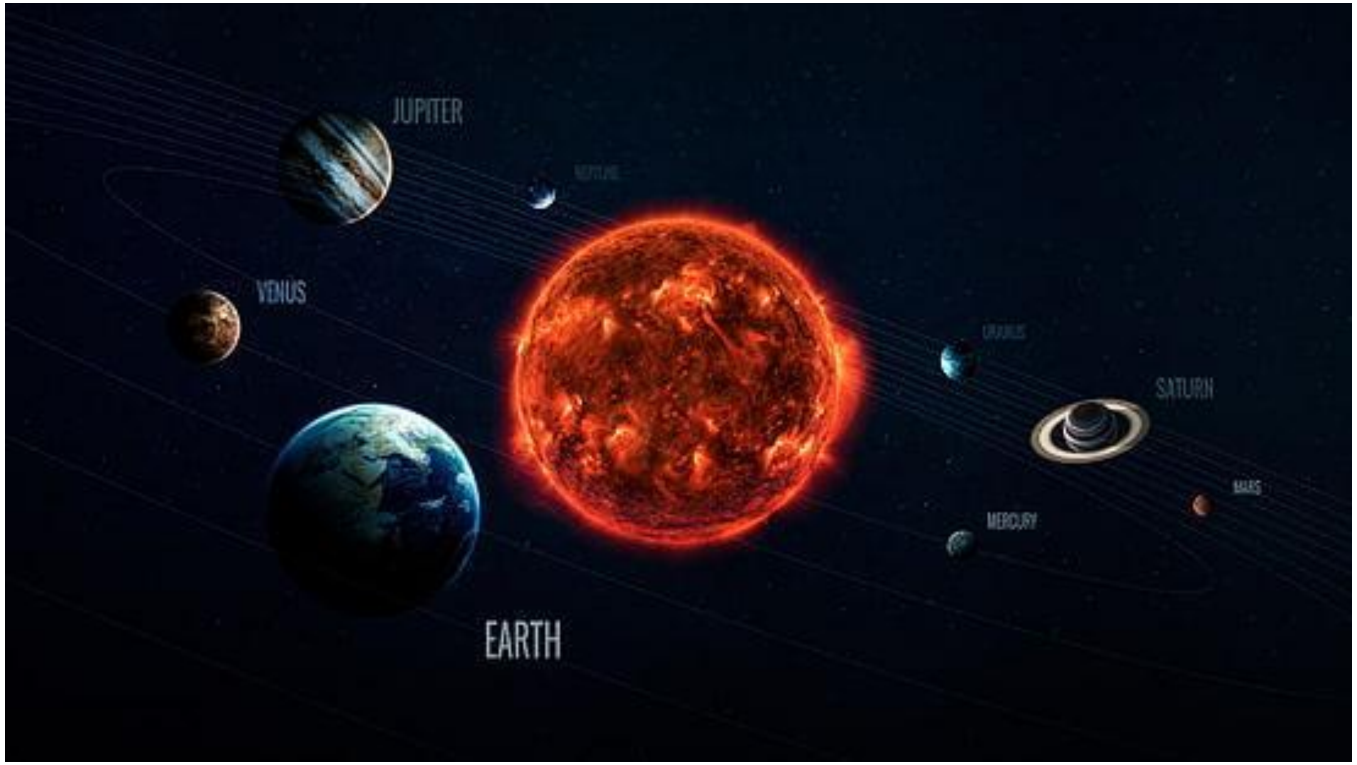
- Doesn’t fit within traditional programmatic boundaries
- Doesn’t address one planet
- Supports astrophysics and planetary science

Threats

Enabling Planetary Missions

Summary (Next steps)

- Science maturation
  - Map to current goals
  - Publish new ideas
- Technology maturation
  - Propose to relevant calls
  - Mature ITLN components
- Continue workshops
  - KISS workshop is a great place to start; Write a compelling report
  - Convene special sessions at relevant meetings
- Develop input for next decadal survey



Take the long view and stay coordinated

ILTN in the Voice of Dr. Seuss

In space where the planets all dance and they spin,
A new kind of network is ready to begin!
With lasers that zip from one craft to another,
They measure with magic you'll see like no other.

They bounce laser pulses both to and fro,
From Venus to Earth, on to Mars they then go.
They time every tick, and they track every trace,
To map out positions all over space!

No longer just Earth with its telescoped view,
Now triangles shift with a cosmic debut.
The planets are plotted with dazzling precision,
Improving maps with our new laser mission.

They study the Sun and its flattening shape,
Detecting the waves that ripple and scrape.
We'll observe the solar system expand,
And calculate galactic rotation so grand.

So ILTN's mission is clever and planned,
To measure the cosmos with laser in hand.
From gravity fields to the planets' own spin,
It's science with style—let the mapping begin!

References

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