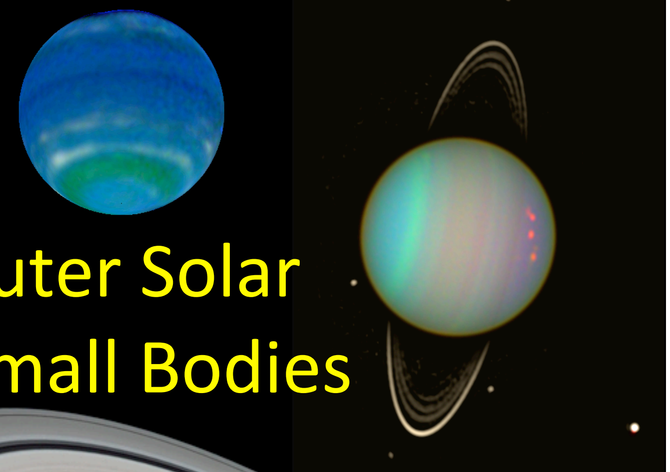
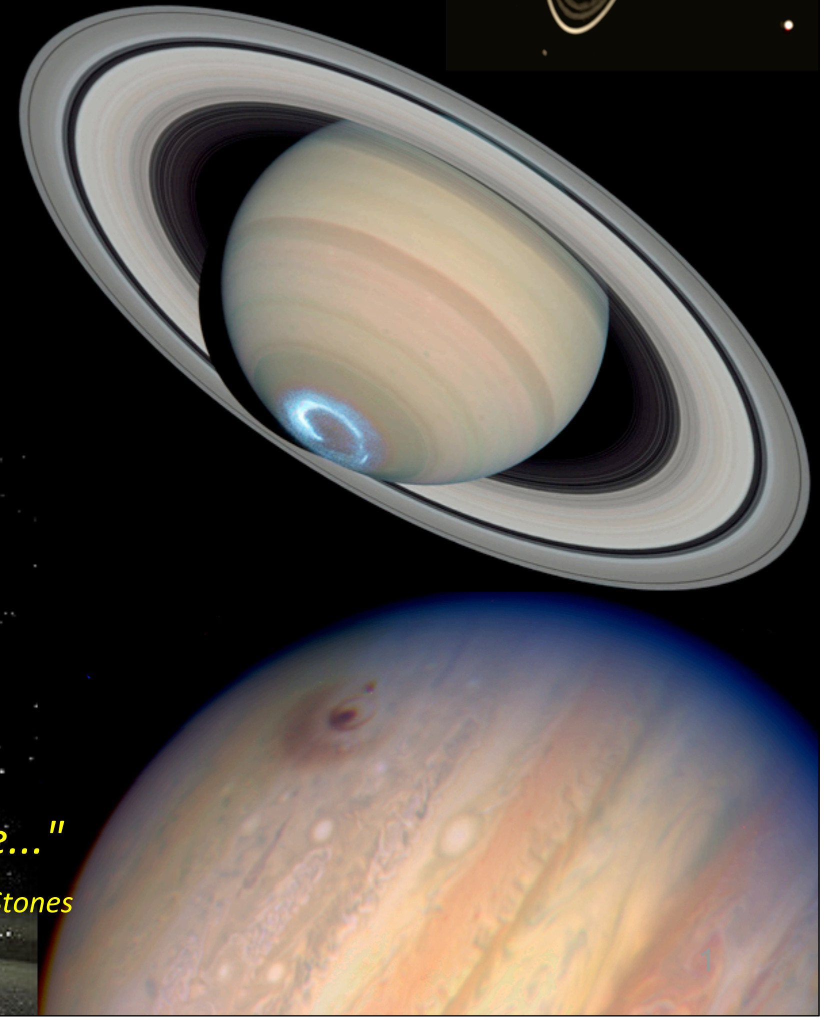
Kuiper

A Discovery-Class Observatory for Outer Solar System Giant Planets, Satellites, & Small Bodies

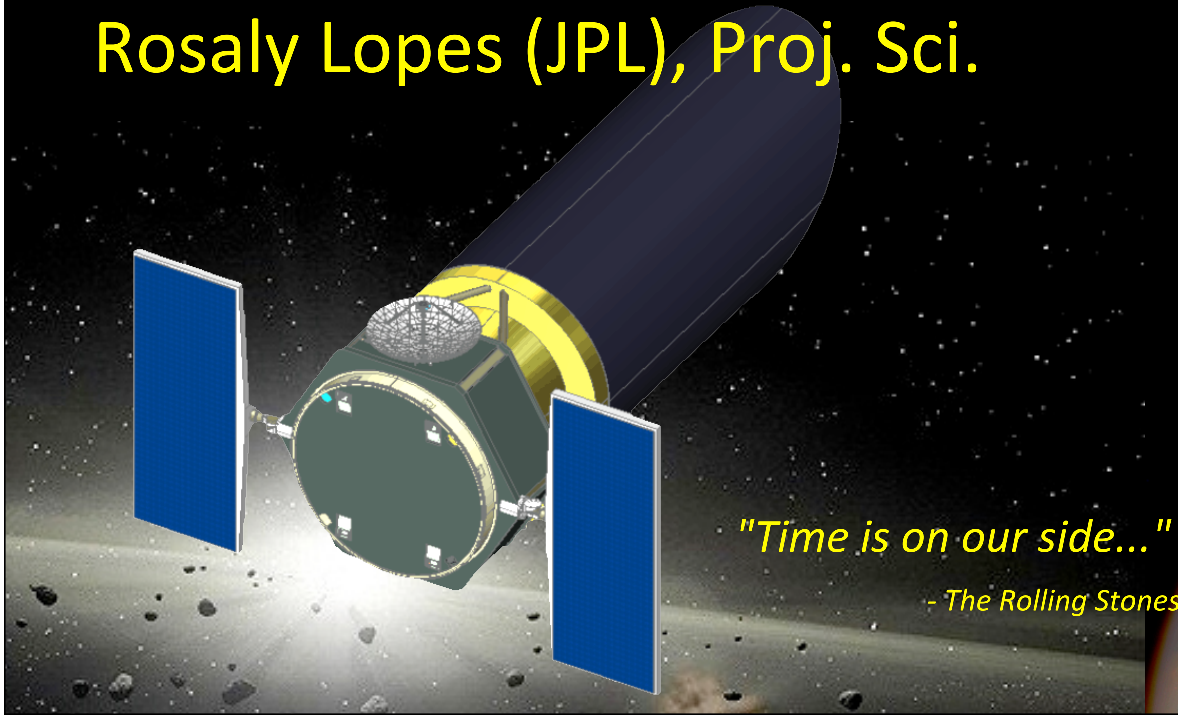




Jim Bell (ASU), PI

Nick Schneider (CU/LASP), DPI

Rosaly Lopes (JPL), Proj. Sci.



Filling a Science and Decadal Need...

- The recent Planetary Decadal Survey identified many important Outer Solar System science questions that can be directly addressed by Discovery-class investigations
- After the end of the Cassini and Juno missions in 2017, Outer Solar System science could face a decade or more without new data from missions
- Partly in response to that fact, the Decadal noted the critical role that space-based telescopic observations, especially those enabling significant time-domain and target coverage, can play in advancing key planetary science questions:

> "...a highly capable planetary space telescope in Earth orbit could be accomplished as a Discovery mission. Such a facility could support all solar system scientific research, not just that involving giant planets."
>
> - 2011 Planetary Decadal Survey, p. 208

- In the coming era of reduced access to the outer solar system, Kuiper is this recommended solar system telescope, providing breakthroughs in planetary science, as well as the high priority datasets needed to plan future outer solar system missions

Kuiper* is "Three Missions in One" for Revealing the Dynamic Evolution of the Outer Solar System

Three equal-priority science investigations in one three-year Discovery mission

Science Objectives: Directly addressing NASA Science Plan & NRC Decadal goals

Migration of the Giant Planets

Goal: Identify the dominant mode of planetary migration and planetesimal accretion by spectrally characterizing populations of small bodies.

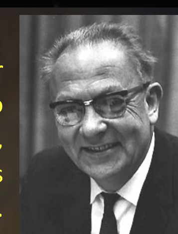
Cause of Eruptions from Active Moons

Goal: Determine the cause of eruptive events on icy satellites and track the flux of Io's volcanic material through the Jupiter system.

Engine of Giant Planet Atmospheres & Space Weather

Goal: Identify the mecha-nisms of global circulation, atmospheric dynamics, auroral physics, and external interactions in giant planets.

*Kuiper is named after astronomer Gerard P. Kuiper (1905–1973) who pioneered the study of the genesis, formation, and evolution of planets and planetary systems.

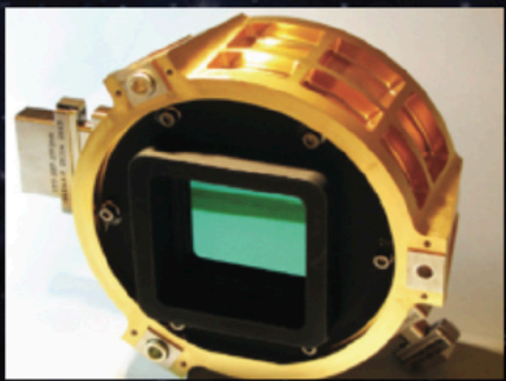


Simple mission design, no new technologies, two high heritage science instruments

Mission Overview

Launches 2/1/2021 on a low-performance launch vehicle [Atlas 401 or Falcon 9] to Sun-Earth L2 halo orbit. No planetary launch constraints. Three-year science mission starts within 3 months of launch. *Science investigations are completed by 2024.*

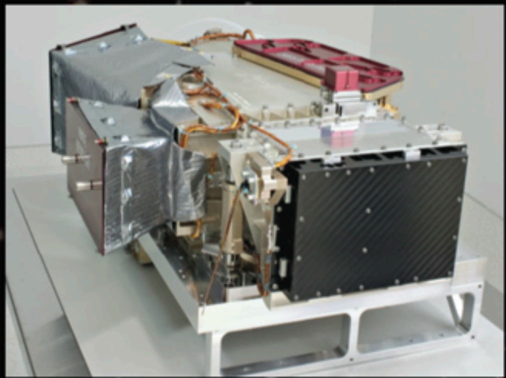
Instrument Complement



Heritage from Mastcam & JWST

VIS-NIR Outer Solar System Imager [400-1700 nm]

- High-resolution visible-NIR camera
- 86 x 86 arcsec FOV
- Imaging with filters
- Grism spectrograph



MAVEN spectrograph, simplified

UV Imager & Spectrograph [115-190 nm]

- UV spectrograph, 1 x 30 arcsec slit
- UV imager, 60 x 60 arcsec FOV

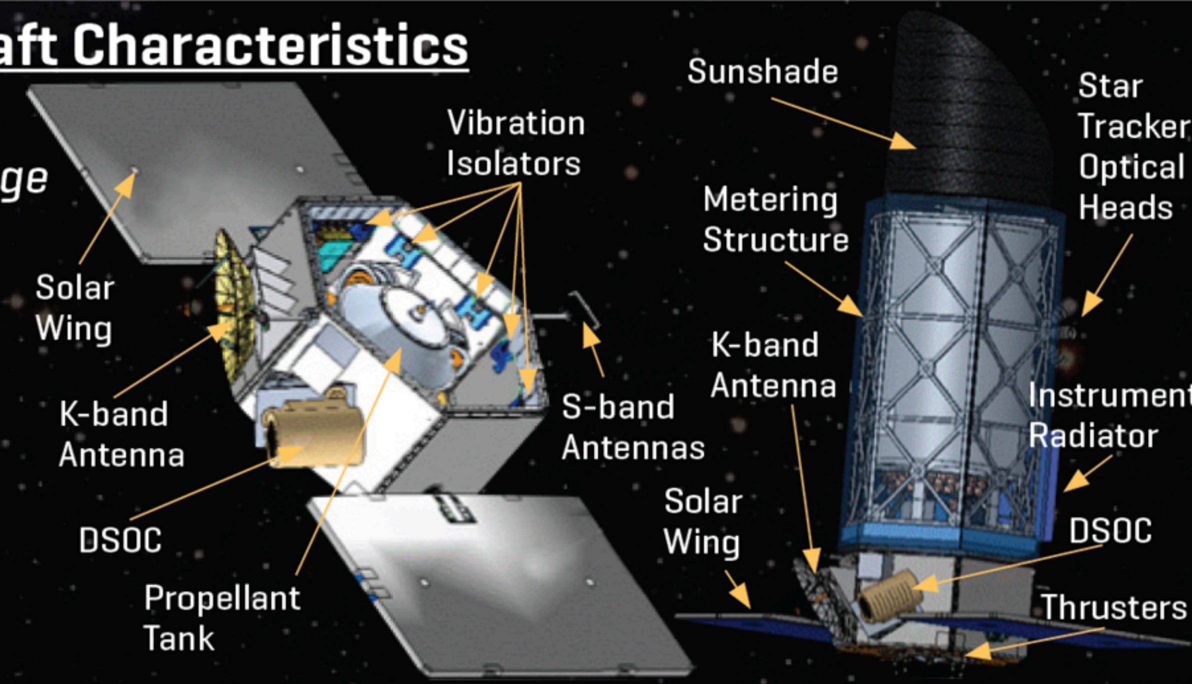
High heritage spacecraft bus, high heritage telescope based on WISE and Kepler missions

Key Telescope & Spacecraft Characteristics

Telescope: 1.2 m diameter light-weighted primary; 0.1 arsec image resolution at 425 nm

Spacecraft:

- Ball RS-300 product line
- 1008 kg (wet) launch mass
- Two-stage vibration isolation
- Average of 5.2 GB/day of science data downloaded via K-band to DSN



Science Team

Principal Investigator, Jim Bell (ASU), astronomer/planetary scientist, educator, public communicator, and President of the Planetary Society

Deputy PI: Nick Schneider (CU/LASP); **Project Scientist**: Rosaly Lopes (JPL/Caltech)

Co-Is: World leaders in outer solar system science, instrumentation, and observations

Small Bodies

Lead: M. Brown (Caltech)
K. Batygin (Caltech)
M. Buie (SwRI)
F. DeMeo (MIT)
W. Grundy (Lowell Obs.)
A. Hayes (Cornell Univ.)

Satellite Systems

Lead: A. Hendrix (PSI)
D. Grodent (Univ. Liège)
G. Holsclaw (CU/LASP)
J. Nichols (Univ. Leicester)
L. Roth (KTH)
O. Siegmund (UCB)
J. Spencer (SwRi)

Atmospheres & Magnetospheres

Co-Lead: M. Wong (UCB)
Co-Lead: J. Clarke (Boston U)
D. Banfield (Cornell Univ.)
L. Fletcher (Oxford Univ.)
H. Hammel (AURA)
M. Hofstadter (JPL/Caltech)
K. Sayanagi (Hampton Univ.)
A. Simon (NASA GSFC)

Kuiper is "Three Missions in One" for Revealing the Dynamic Evolution of the Outer Solar System

Three equal-priority science investigations in one three-year Discovery mission

Science Objectives: Directly addressing NASA Science Plan & NRC Decadal goals

SMALL BODIES

Determine what connections exist between composition and dynamics/ physical location of small bodies and what interactions with the external environment tell us about the formation and evolution of the outer solar system.

SATELLITE SYSTEMS OF THE GIANT PLANETS

Determine the processes and interactions that drive observable spatial and temporal variability of surfaces, atmospheres, and magnetospheres in giant planet satellite systems.

GIANT PLANETS ATMOSPHERES AND MAGNETOSPHERES

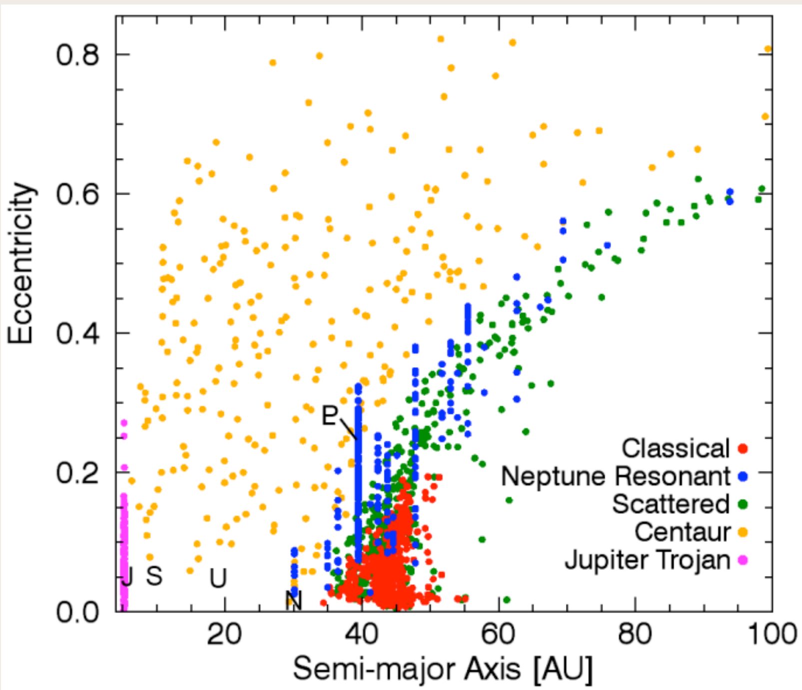
Determine the energetics and dynamics of giant planet atmospheres and magnetospheres.

To achieve these objectives, Kuiper acquires observations with cadences and sensitivities that current ground-based and space-based assets *have not and cannot be allocated to do*.

Testing specific Decadal-scale science hypotheses...

Small Bodies: Tracing Solar System Formation & Evolution

Kuiper will perform a statistically robust VIS-NIR spectral survey of key small body populations in the outer solar system. The spectra will have spectral coverage and SNR sufficient to classify thousands of objects based on color and band depth and to test hypotheses for their origins.



In a 3-year primary mission, we will get 400-1600 nm spectra of this *minimum* sample of objects down to V_{mag}~24 with SNR ≥ 20-50:

≥ 330 "Cold Classical" KBOs
≥ 240 "Hot Classical" (Scattered) KBOs
≥ 245 resonant KBOs
~98 (all known) Centaurs with V<23
~100 (all known) irregular satellites with V<23
≥ 600 Trojans of same size as the Centaurs

No new objects need to be discovered for us to meet our science goals (though we expect that many will be, providing us with significant science margin...)

Testing specific Decadal-scale science hypotheses...

Small Bodies: Tracing Solar System Formation & Evolution

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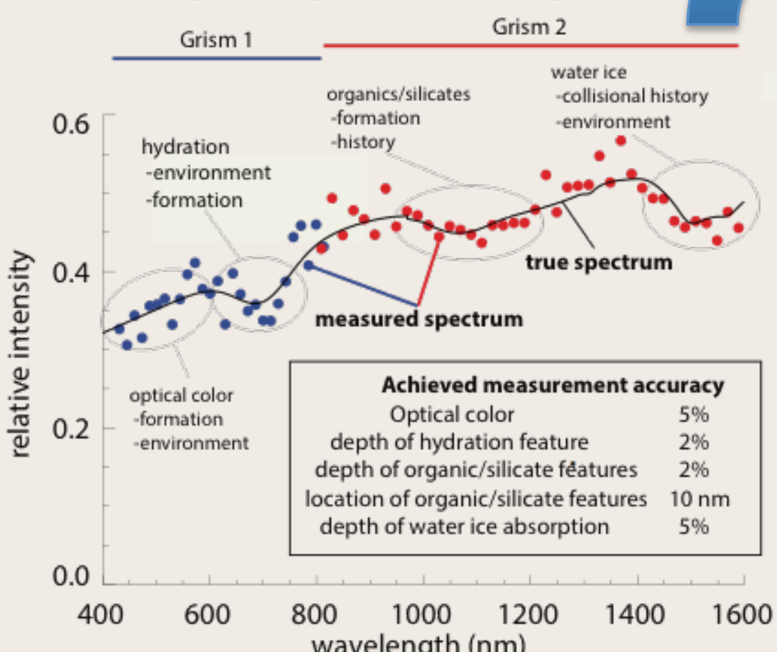
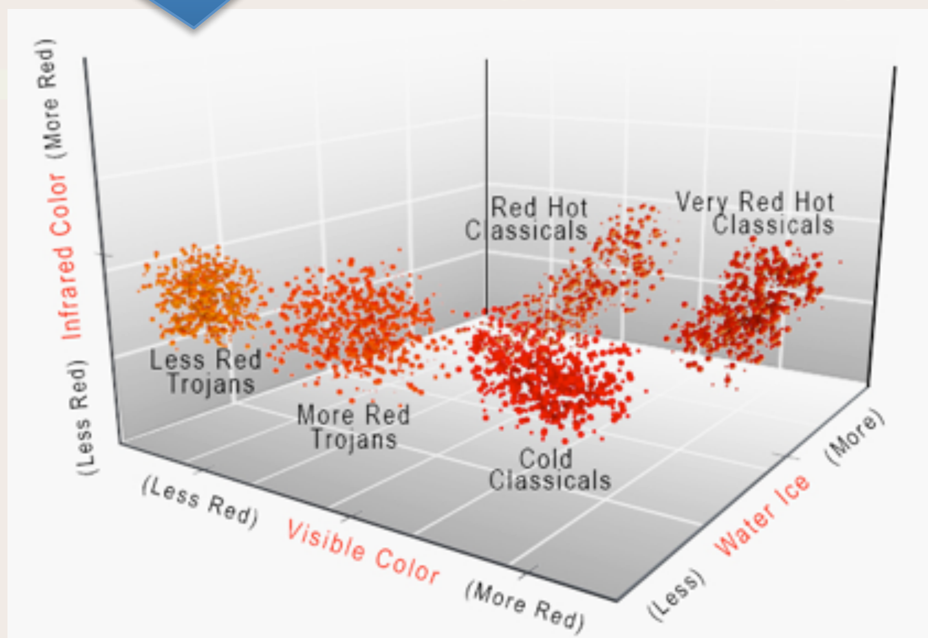
Kuiper's spectral survey...



...will classify thousands of objects



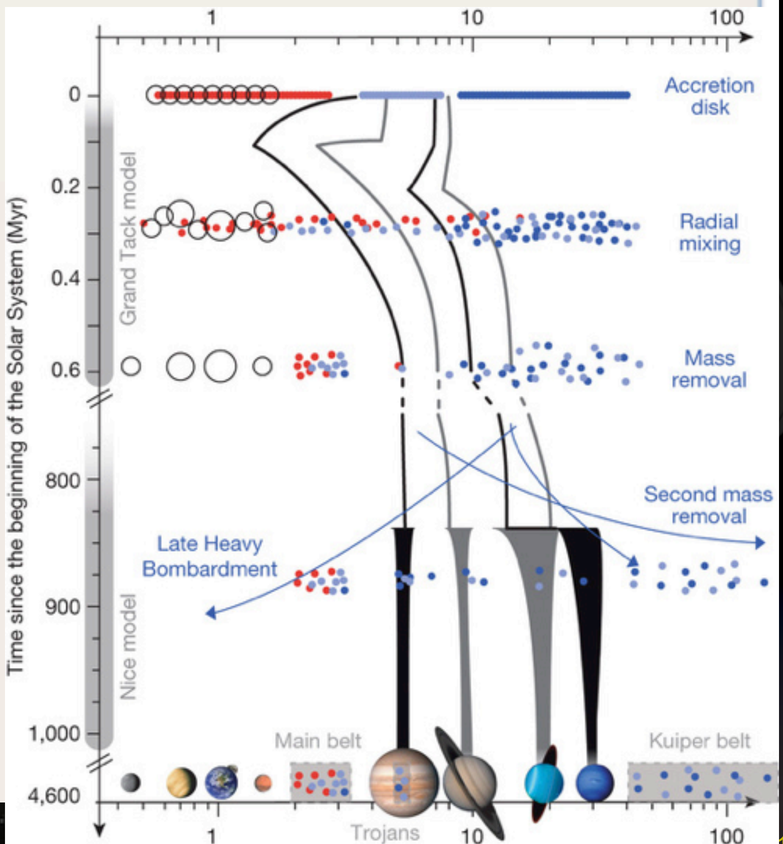
Testing specific Decadal-scale science hypotheses...

Small Bodies: Tracing Solar System Formation & Evolution

Objective S1. *Smooth Migration vs. Dynamic Instability*
Determine if the giant planets migrated smoothly to their present positions (as in "Grand Tack" models) or were catastrophically moved by dynamical instability ("Nice" models)

- The differences in the two major hypothesized modes of giant planet movement lead to *testable* statistical differences in the eventual distribution of primordial "cold classical" objects, especially the population scattered into resonances

- A second statistical test of these models is to determine if the Jupiter Trojans originated in the Kuiper Belt and were scattered ("Nice-like") or if they originated near Jupiter or closer to the Sun (consistent with smooth migration)



DeMeo & Carry, 2014

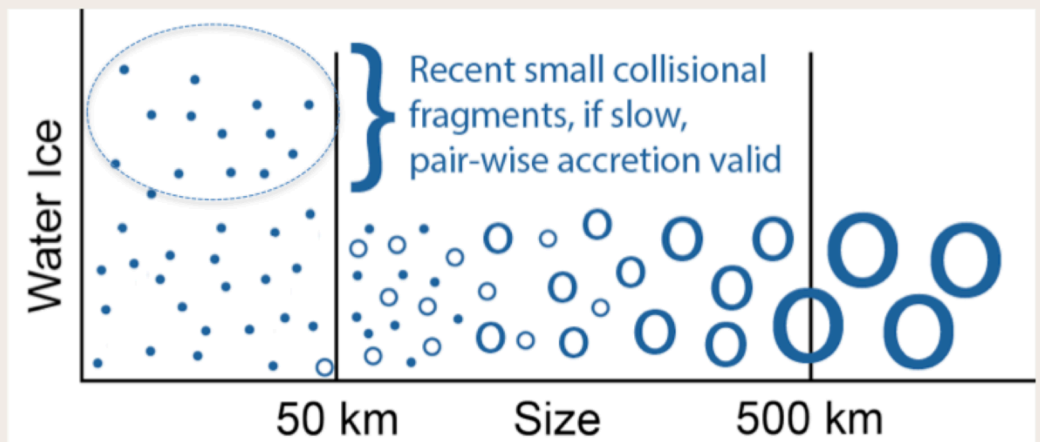
Testing specific Decadal-scale science hypotheses...

Small Bodies: Tracing Solar System Formation & Evolution

Objective S2. *Planetesimal Accretion*
Determine if the ≤ 50 km population of the outer solar system is collisionally active (predicted by models of mass loss by slow grinding), or not collisionally active (predicted by models in which large objects are directly created out of gravitational collapse).

- Did the planetesimal making the small bodies of the outer solar system form from slow pairwise accretion or through fast gravitational collapse?

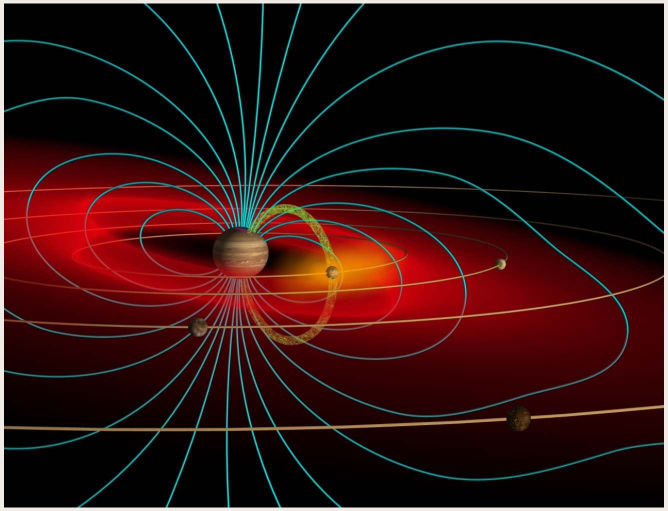
Slow planetesimal accretion builds populations that are then collisionally ground down. Freshly-exposed water ice, a signature of such collisions, should be visible in the fresh surfaces of the smallest bodies.

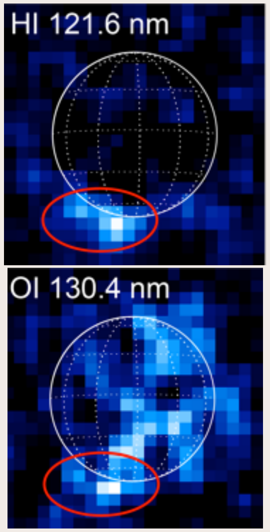


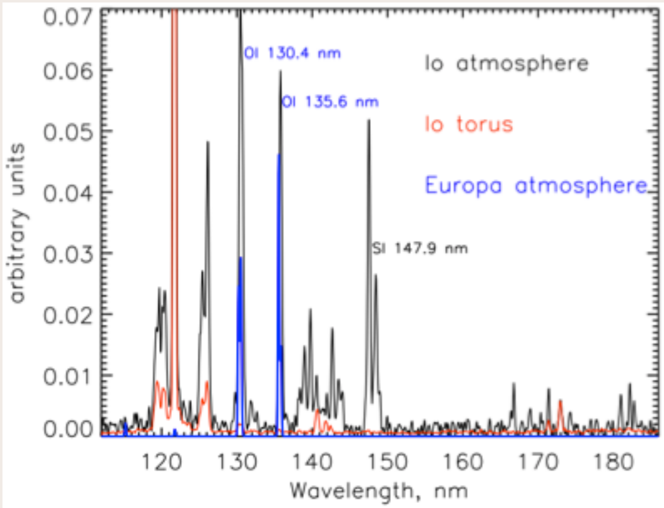
Testing specific Decadal-scale science hypotheses...

Satellites: Active Worlds and Extreme Environments

Kuiper observations of auroral emission of active moons will determine the underlying emission processes. Far-UV emissions may vary over months due to viewing geometry, over days with the changing orbital position of the moons, and over hours due to the fast rotating magnetospheric environments. Densely spaced Kuiper UV observations, combined with the ability to spatially resolve the key auroral phenomena, will discriminate between competing hypotheses of the emission processes and enable us to achieve specific Satellites Science Objectives.





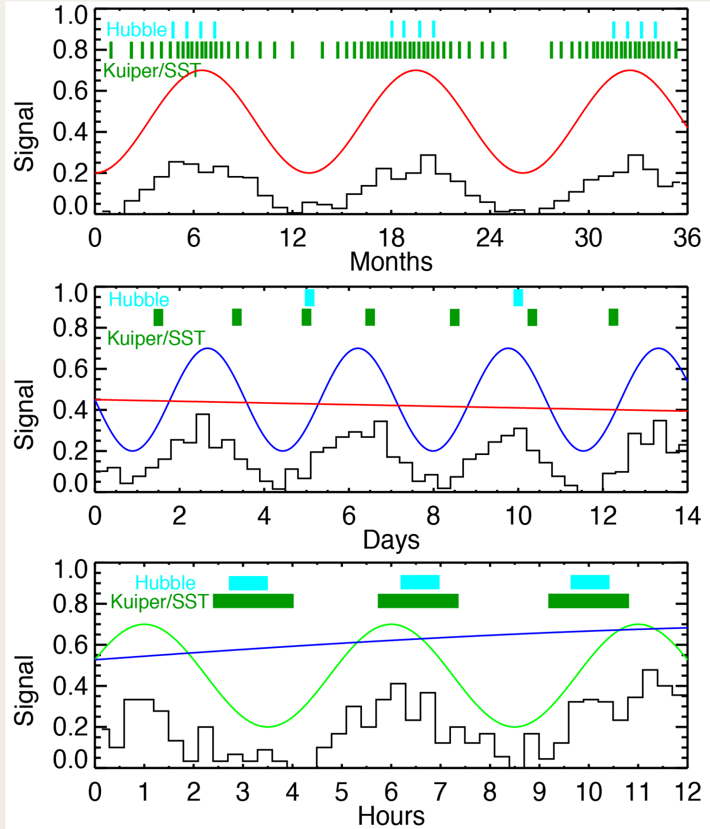


Testing specific Decadal-scale science hypotheses...

Satellites: Active Worlds and Extreme Environments

Objective M1. *Satellite Atmospheres*
Determine sources and temporal scales of variability in icy satellite atmospheres to test specific hypotheses for Europa, Enceladus, Ganymede, and Callisto.

- Is there transient Europa activity driven by endogenic or exogenic processes? Our extensive time-domain UV observation campaign will test whether Europa's plumes vary in brightness depending on tidal environment (daily to monthly timescales), magnetospheric variability linked to Jupiter's 10-hr rotational period, or if they are more episodic, like many volcanoes on Earth or some volcanic plumes on Io, with long periods of dormancy
- We will know the answer by 2024, helping to optimize *in situ* Clipper observations
- Similar studies of Ganymede, Callisto, and Enceladus will resolve similar endogenic/exogenic questions

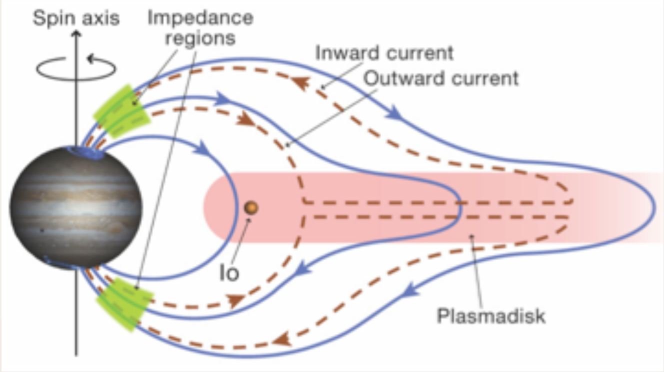


Testing specific Decadal-scale science hypotheses...

Satellites: Active Worlds and Extreme Environments

Objective M2. *Io-Jupiter System:*
Determine whether large volcanic plume eruptions drive variability in Io's atmosphere, atmospheric escape into the torus, and variability in the Io auroral footprint on Jupiter.

- Three mechanisms are plausible for driving variability of the Io torus, the Io footprint, and the sodium cloud within the system: Io explosive gas and dust plume activity, Io effusive volcanic eruption activity (with no plumes observed), and sputtering of Io's atmosphere and surface (magnetospheric variability causing sputtering).

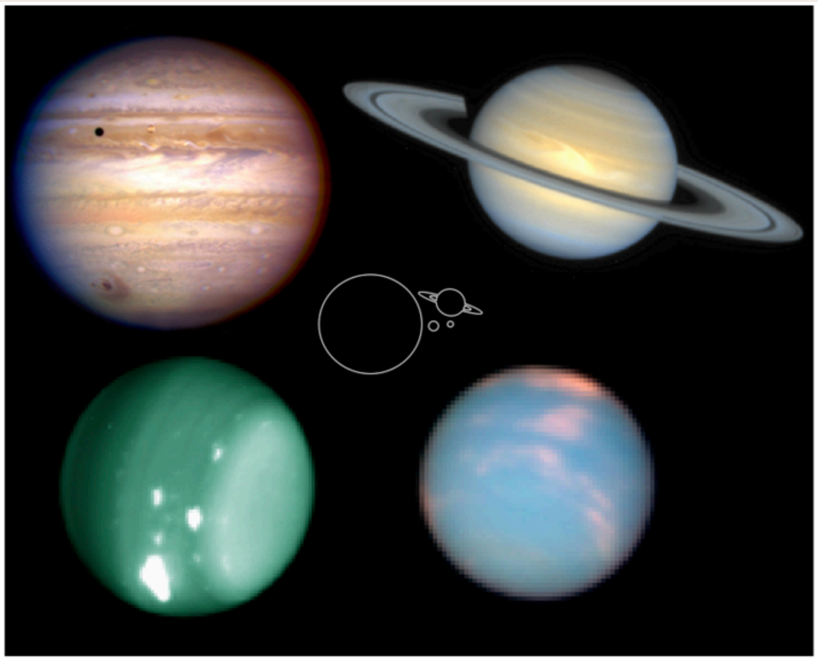


- Using UV spectral images of emissions at Io, its torus, and its footprint in the Jupiter aurora, as well as VIS-NIR color images of surface deposits generated by large volcanic plumes, we test hypotheses for the system's physical connections and mechanisms for generating large torus variations.
- Unprecedented temporal coverage spans the entire chain of causality from Io's volcanoes to its atmosphere, the torus, and the Jovian aurorae.

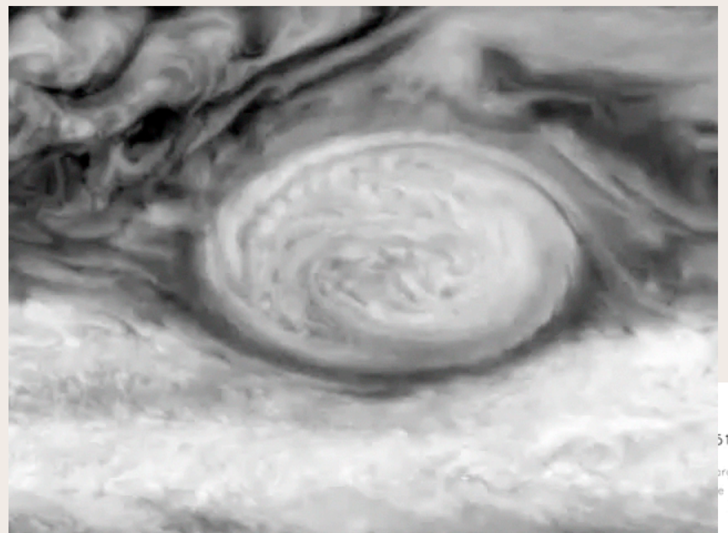
Testing specific Decadal-scale science hypotheses...

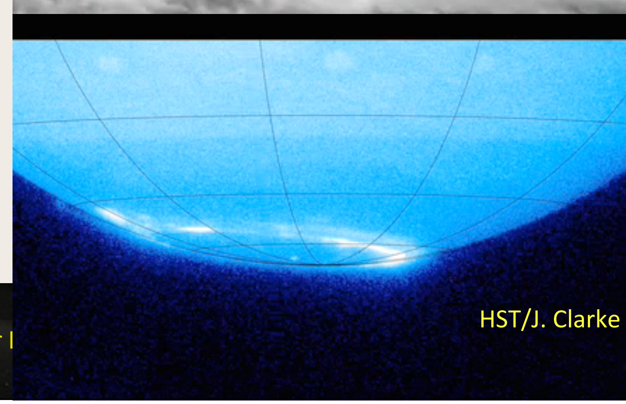
Giant Planet Atmospheres & Magnetospheres: The Time Domain

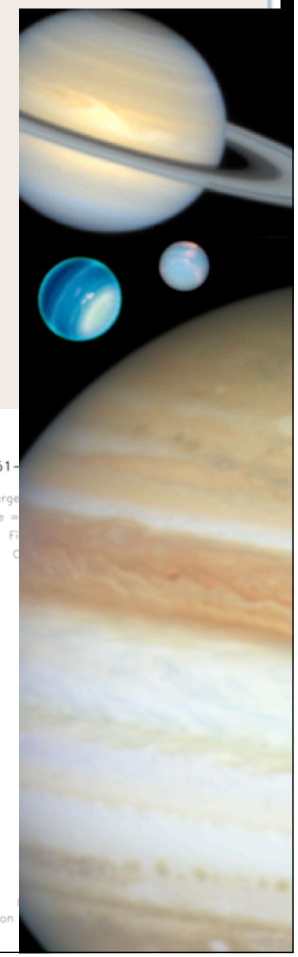
The Kuiper time-domain discovery space: Planetary monitoring over timescales of 1-100 days reveals the workings of important atmospheric processes. Kuiper will provide complete temporal and spectral coverage to address key Science Objectives related to convective heat transport, zonal jet variability, planetary waves, and vortex evolution.



Kuiper's 1.2-m primary provides 0.1" resolution at 425 nm. Here Jupiter, Saturn, Neptune, and Uranus (clockwise from upper left) are shown at Kuiper resolution. [credit: HST, Keck, K. Sayanagi, M. Wong]

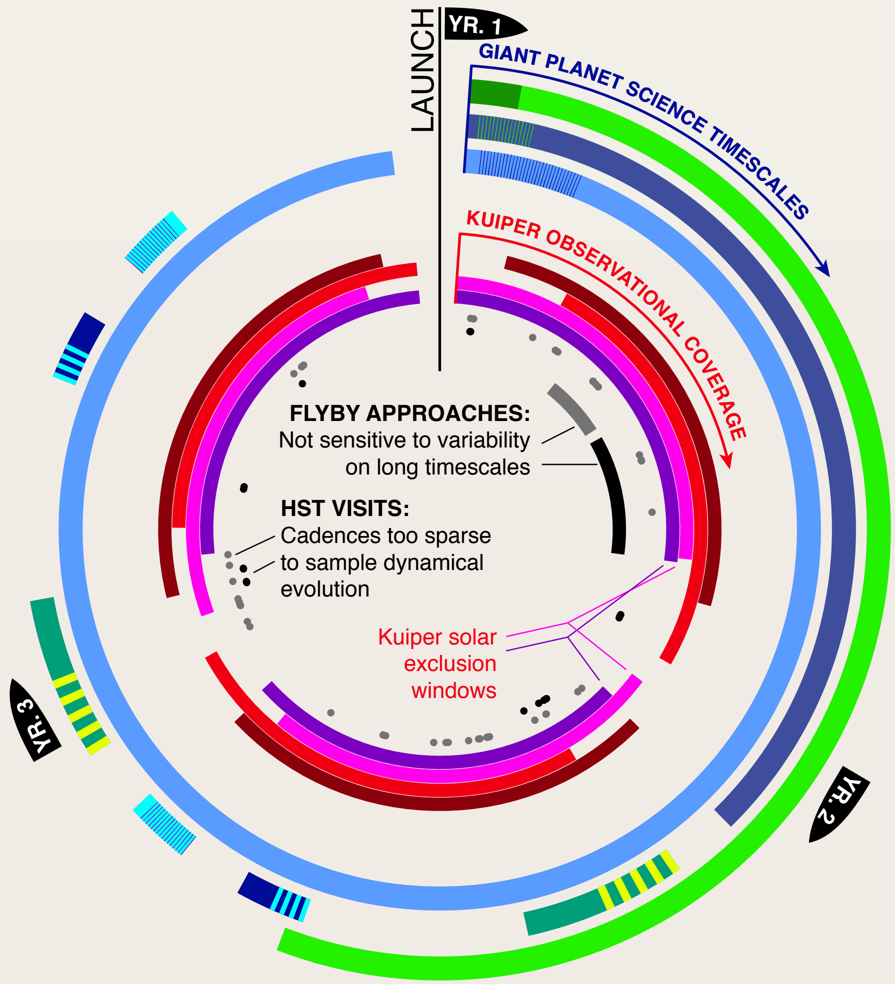






Testing specific Decadal-scale science hypotheses...

Giant Planet Atmospheres & Magnetospheres: The Time Domain



GIANT PLANET PHYSICAL TIMESCALES

- **Ice giant vortices**
- **Ice giant convective storms**
- **2D wind field**
- **Auroral variation**
- **Jovian convective storms**
- **Rossby waves**

Variability timescales range from 10 hr (wind tracers, aurorae) to 20 days (ice giant vortices).

Statistical/evolution timescales range from 28 days (solar wind rotation) to years (zonal jets).

KUIPER'S COVERAGE

- **Jupiter**
- **Saturn**
- **Uranus**
- **Neptune**

Kuiper's temporal coverage extends for long enough to characterize statistics and evolution of atmospheric and magnetospheric processes. Kuiper's fast cadences sample variability of auroral emissions, trace turbulent and wave motions, and measure convective transport.

PRIOR OBSERVATIONS

- **Flyby approach sequences**
- **Best 3 yrs of HST coverage** (1994–1997)

Flyby/approach sequences (Voyager, Cassini) were too short to characterize statistics and evolution of atmospheric processes. HST lacks the sustained temporal cadence needed to sample dynamics.

Past observational history is comparative and not meant to imply observations contemporaneous with Kuiper.

Testing specific Decadal-scale science hypotheses...

Giant Planet Atmospheres & Magnetospheres: The Time Domain

Objective G1. *Giant Planet Atmosphere Dynamics*
Determine the time-variable 3-D transport of energy and momentum in the diverse atmospheres of the four giant planets.

- Measure the dynamical linkage and energy exchange between jets, eddies, and vortices to test the hypothesis that jets and eddies maintain a closed loop: eddies supply the momentum to the jets while jets also shed the excess momentum as waves and vortices.
- Test whether convective events on small to large scales can replenish the energy dissipated by eddies, jets, waves, and vortices using vertically-resolved data over unprecedented timescales (hours to years)
- Characterize and study the rates and effects of small impacts into giant planets

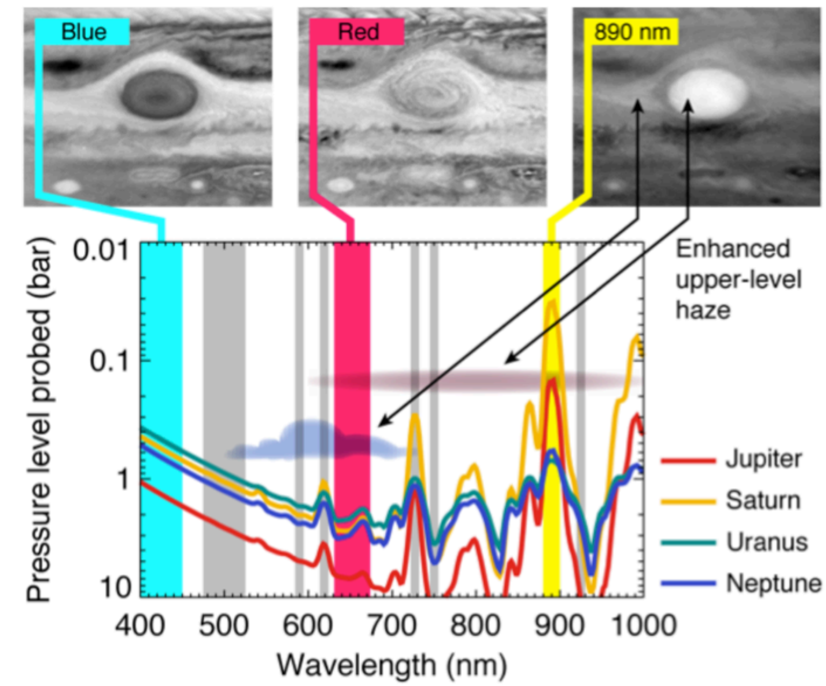


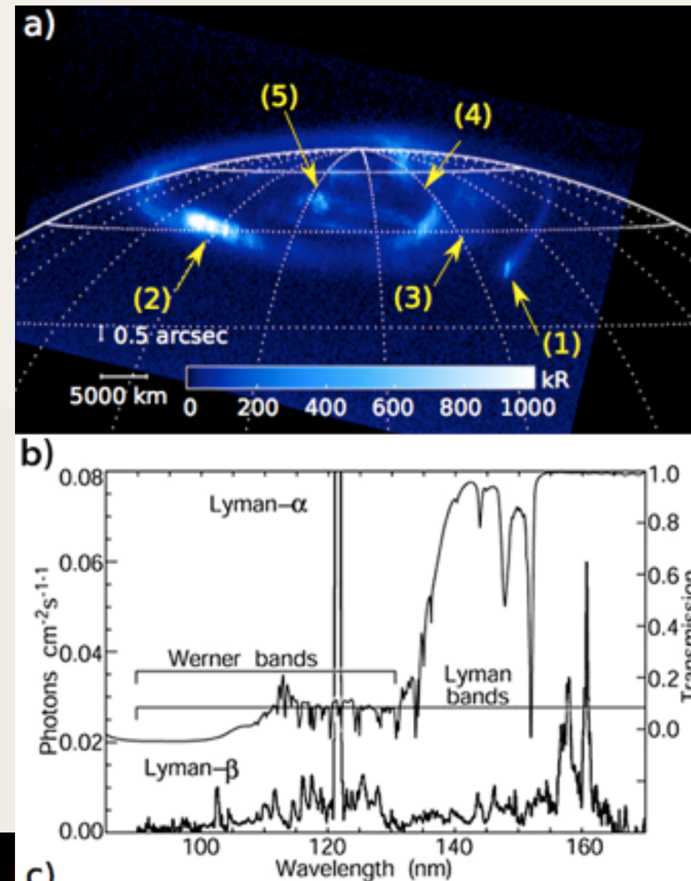
Figure D-11. Kuiper's filters (vertical bars) sample a broad range of altitudes using differences in Rayleigh scattering and methane absorption. Long observation campaigns at unprecedented temporal sampling track the 3-D evolution of clouds and hazes. The HST snapshots above (at Kuiper resolution) illustrate the expected variations.

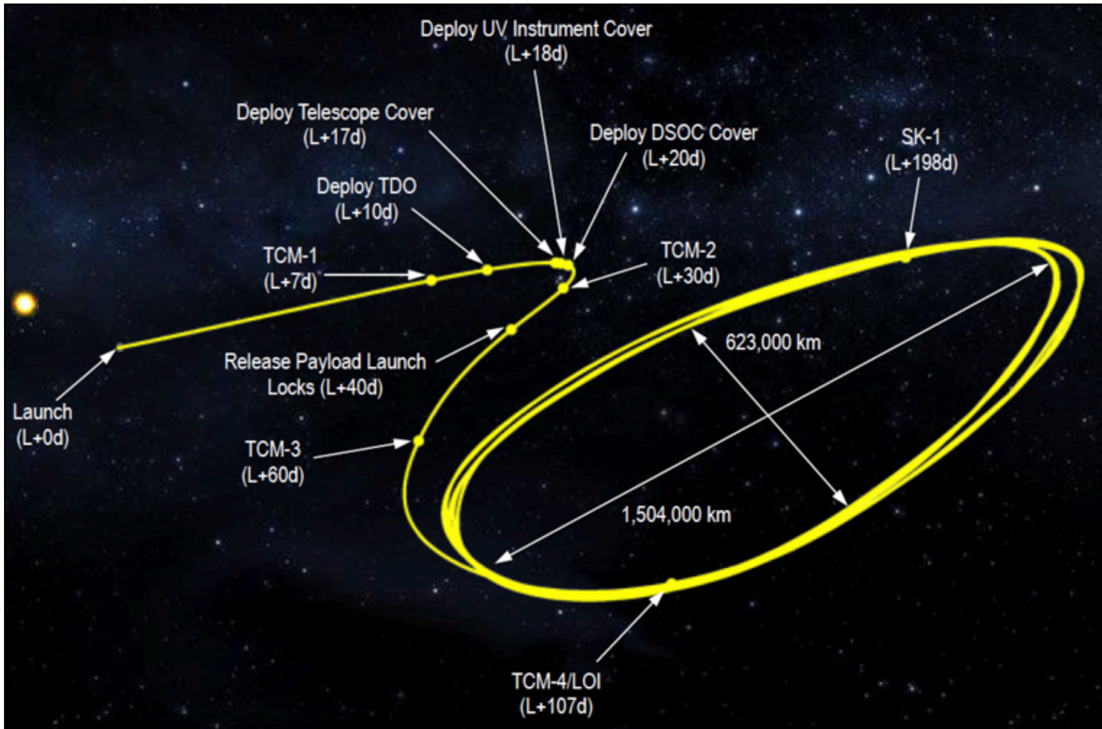
Testing specific Decadal-scale science hypotheses...

Giant Planet Atmospheres & Magnetospheres: The Time Domain

Objective G2. *External Interactions*
Determine the physics of magnetospheric and auroral processes at giant planets, specifically the importance of the solar wind vs. internal processes, magnetic field and configuration, and internal plasma sources.

- Determine the role of solar wind control vs. internal processes in controlling giant planet magnetospheres
- Determine how the vastly different magnetic field strengths and configurations control each giant planets' magnetosphere and auroral processes
- Understand how giant planet magnetospheres vary in response to internal and external processes, establishing the basic principles that will make extrapolation to exoplanet systems robust





L2 orbit enables rapid commencement of science observations (L + 30d), and is well above the UV background induced by the Earth's geocorona

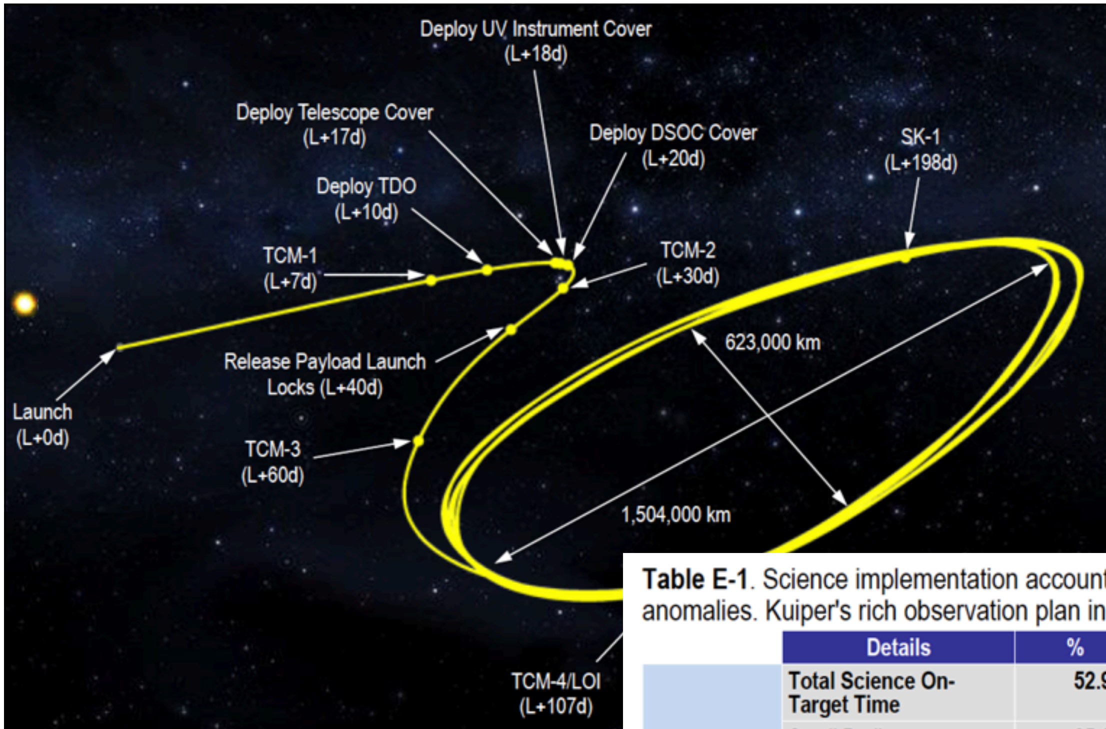


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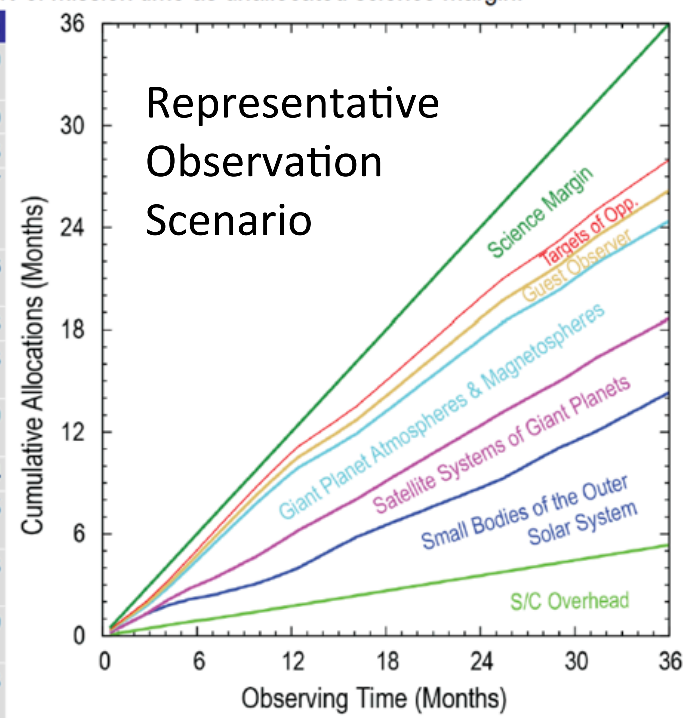
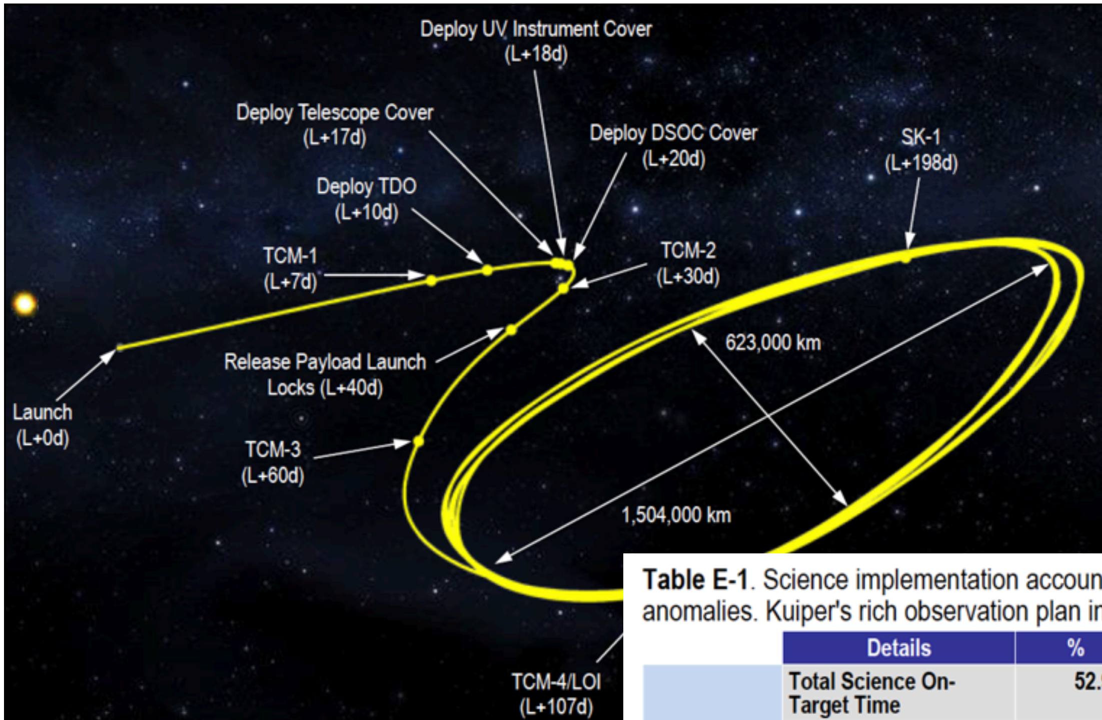
Table E-1. Science implementation accounts for instrument performance margins and is resilient against flight anomalies. Kuiper's rich observation plan includes 22% of mission time as unallocated science margin.

	Details	%	Months
Science	**Total Science On-Target Time**	**52.9%**	**19.0**
	Small Bodies	25.0%	9.0
	Satellite Systems	12.0%	4.3
	Giant Planet Atmospheres and Magnetospheres	15.9%	5.7
Science Enhancement	**Total Science Enhancement Time**	**10.0%**	**3.6**
	Guest Observer Program	5.0%	1.8
	Target of Opportunity Program	5.0%	1.8
Science Margin	**Unallocated Science Margin**	**22.1%**	**8.0**
Overhead	**Total Overhead**	**15.0%**	**5.4**
	Slew and Settle Time (between observations)	4.2%	1.5
	Science Instrument Calibrations	2.1%	0.8
	Download and Tracking (including DSOC)	2.6%	0.9
	ACS Calibrations and Anomalies	6.1%	2.3





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Includes funds budgeted for 3 - 5 Participating Scientists

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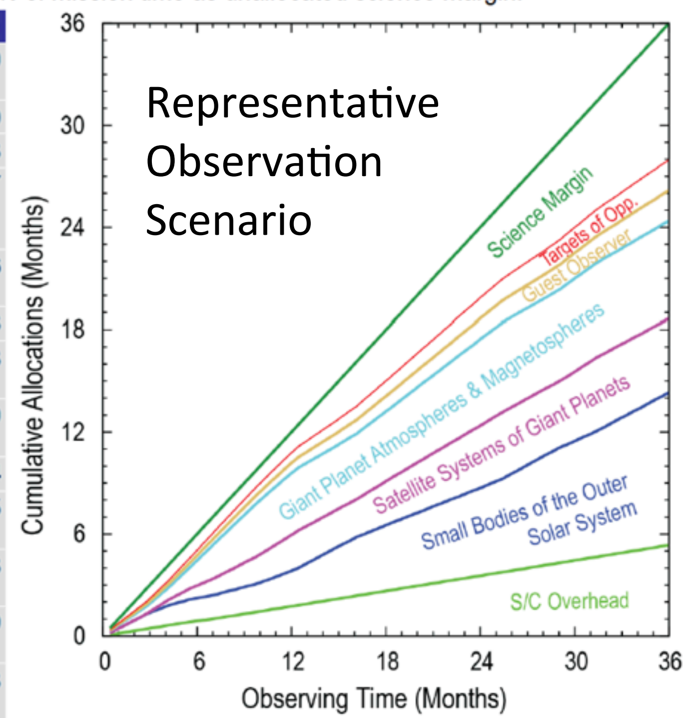

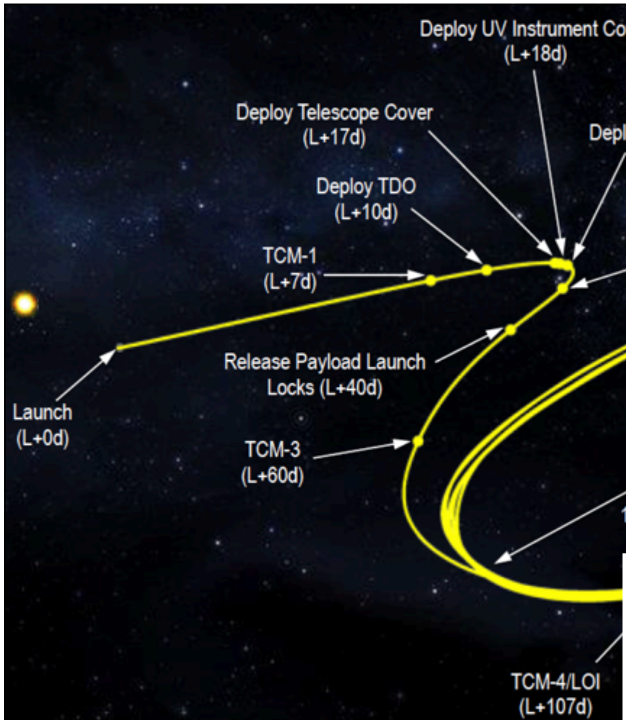

L2 orbit enables rapid commencement of science observations (L + 30d), and is well above the UV background induced by the Earth's geocorona

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Each of these two pools of available community (competed) time is equivalent to *twice* the annual average allocation of HST time for *all* Solar System targets

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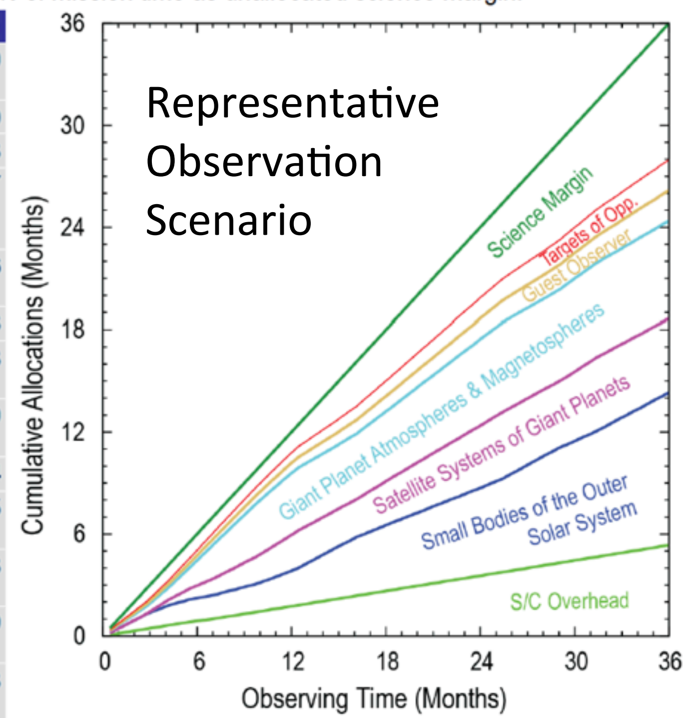
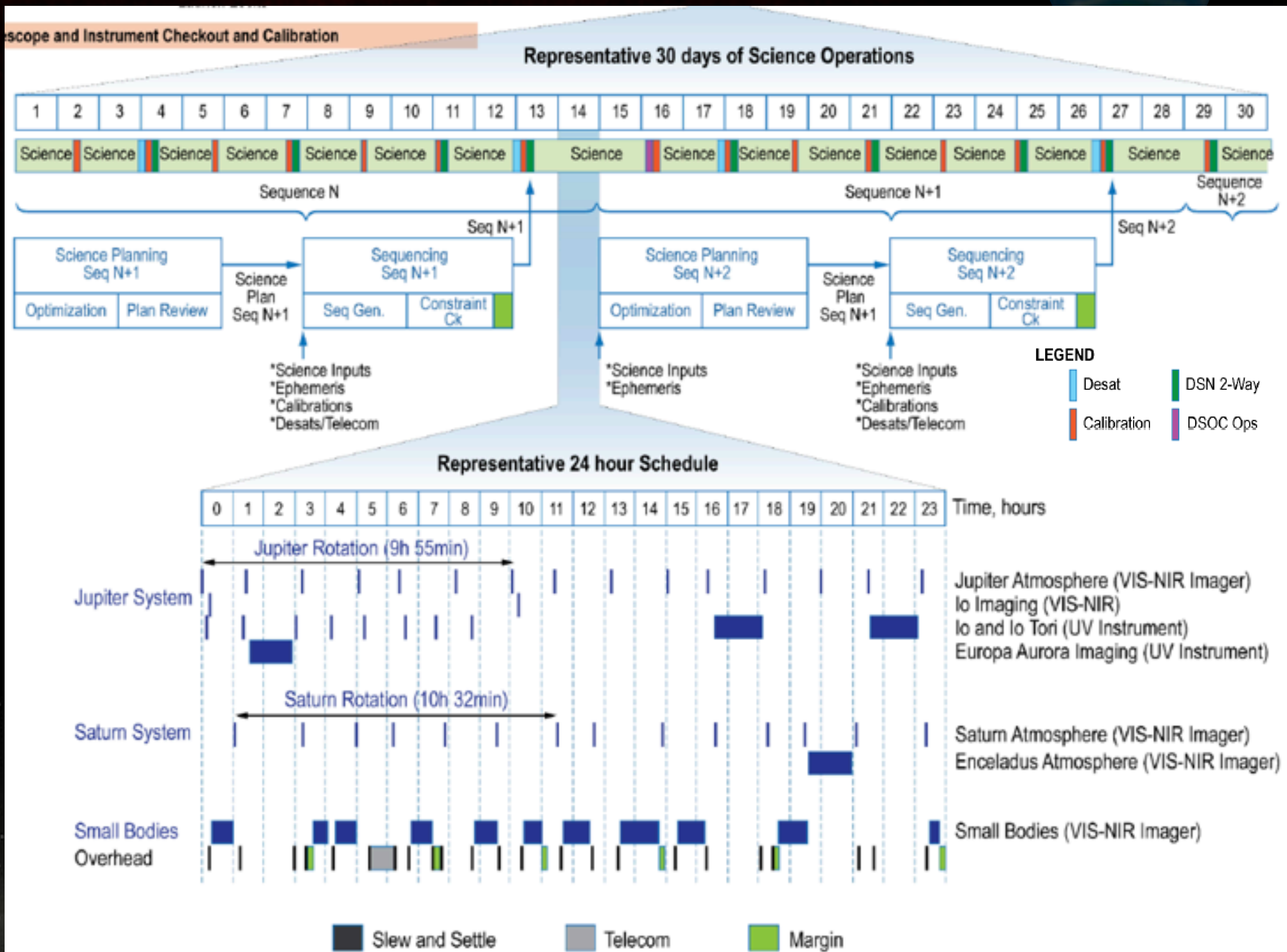


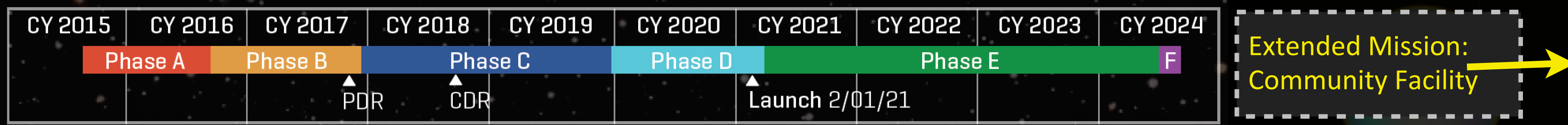
Optimized & scripted observation planning, *a priori*



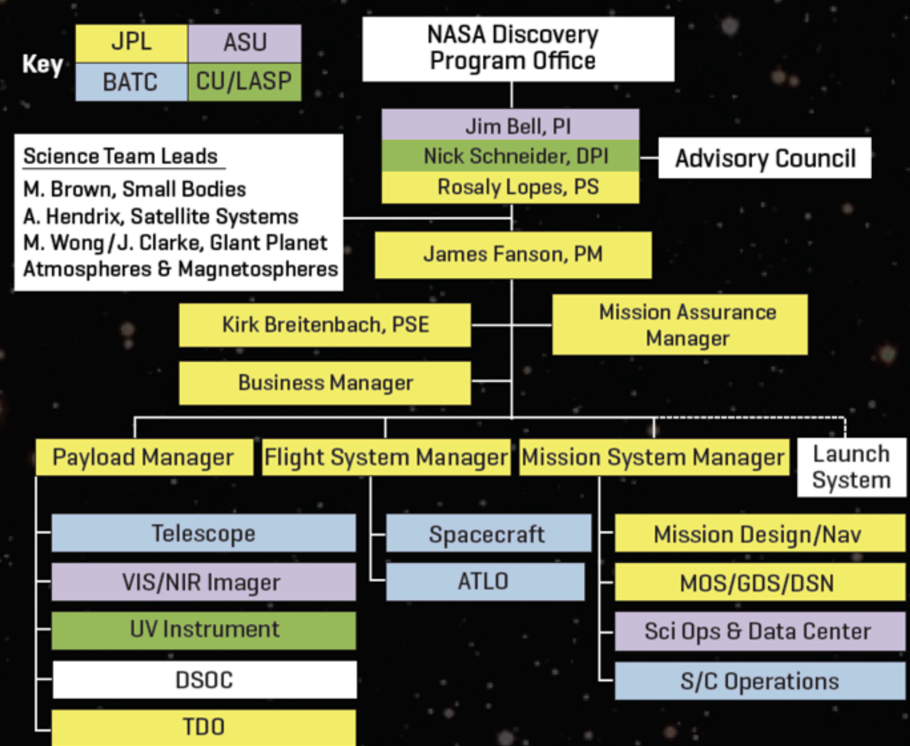
Kuiper's observations are generally planned in advance, but the operations scheme is flexible enough to enable changes in science objectives or constraints, or interrupts to accommodate Targets of Opportunity.

Kuiper: Schedule, Management, and Cost

Schedule Summary



Mission Management & Participating Organizations



- Flexible launch date accommodates NASA programmatic needs
- Primary mission science completed “early” -- by mid-2024
- Major partners have worked closely together on many previous flight development and operations projects
- Kuiper’s total Phase A-D development cost is almost $60M below the cap, including 27% cost reserves and substantial funded schedule margin
- Cost estimate verified against NASA CADRe data from WISE and Kepler, also implemented by JPL/BATC

Kuiper:
Exploring the Outer Solar System Through Time

The Kuiper outer solar system observatory will do what no telescope has ever been able to do: observe diverse outer solar system phenomena over long time spans – hours, weeks, and years – to learn how all four complex, active giant-planet systems work.

Between frames of these multi-spectral "movies" of the giants and their active moons, Kuiper collects spectra of at least 800 (and likely several thousand) small bodies in the four primary dynamical groupings of the outer solar system. This compositional map traces the migration history of the giant planets.

Kuiper is a low-risk, high-heritage, high science value *Outer Solar System mission* that provides timely results that address NASA Science Plan goals and answer key Decadal questions. These results are needed to plan and optimize the science return from the next generation of outer planets flyby and orbiter missions.