1. Science aim/goal: Comparative Climate & Thermal Evolution of Giant Planets

Explore the thermal history, present-day climate and circulation patterns of the four Giant Planets as archetypes for brown dwarf and exoplanetary atmospheres.

2. (i) Scientific Importance: Knowledge gaps in 2025-2030

The dynamic atmospheres of the four giant planets exhibit a wealth of physical and chemical phenomena, providing an extreme test of our understanding of planetary climate. They are our closest and best examples of a class of astrophysical objects (including brown dwarfs and exoplanets) that are commonplace in our galaxy. Sounding far-IR emission, which probes the bulk of the radiated internal energy, can reveal the spatial and temporal variability of temperature, winds, aerosols, and chemical species. That information can be used to trace the redistribution of energy and material throughout the different atmospheric layers, which governs the internal thermal evolution of a planet as it cools over billions of years. To date, only the Voyager spacecraft has been capable of mapping the far-IR spectral range on all four planets (and Cassini at Saturn, Fig. 1), and provided only limited low spatial resolution snapshots of these ever-changing atmospheres. FIR Surveyor will open up the time domain to understand the thermal evolution and dynamic climates of these worlds. Furthermore, the abundance of helium remains poorly understood on all giant planets but Jupiter (where it was sampled by the Galileo probe), and is a crucial component of the story of their formation. The helium abundance can be uniquely determined from far-IR spectroscopy.

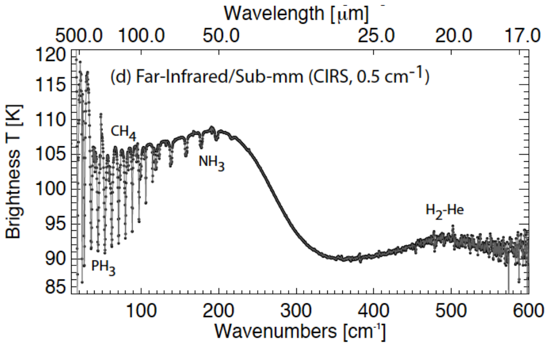

Figure 1 Far-IR spectra of Saturn as measured by Cassini/CIRS, showing the rotational lines at the longest wavelengths and the smooth collision-induced continuum that allows temperature, windshear, aerosol, para-H2 and helium sounding. Comparable, repeatable, and spatially-resolved measurements are desired across the discs of each giant planet. From Fletcher et al., 2015, http://arxiv.org/abs/1510.05690

(ii) Measurements Required: Spectral Mapping at Moderate Resolution

Broadband far-IR spectral mapping covering the 15-500 μm range with moderate spectral resolution (R~300) is required to determine the vertical temperature profile, atmospheric stability and windshear, along with the opacity of cloud-level aerosols and abundances of helium (a key constraint on giant planet formation and thermal evolution) and para-hydrogen (a tracer of atmospheric circulation and dynamics). Spatial resolutions of 0.2” or better are required to map these variables on Neptune to a level surpassing Voyager, and to surpass the capabilities of mid-IR thermal sounding from Earth (current 8-m class facilities). Wide fields of view of ~50” are required to prevent the need for mosaicking across Jupiter. Global spatio-spectral maps would be repeated at regular intervals to track evolving phenomena over a variety of timescales, from hours (storm eruptions), to weeks (belt/zone variations) and years (seasonal changes). Higher spectral resolutions R>500 (R>1000 preferred) in the 50-500 μm region supplement thermal sounding by accessing rotational lines of ammonia (a key cloud-forming condensable), phosphine (dynamic motions tracer), methane (a further thermometer), water vapour and CO (tracing exogenic influxes of cometary or micrometeoroid material), HD (a planetary formation tracer) and potentially water ice in regions of powerful upwelling (e.g., thunderstorms). Together, these measurements permit a comprehensive comparative mapping of the 4D atmospheres, and characterization of the internal and external processes governing their evolution.

(iii) Uniqueness to 10μm to few mm wavelength facility:

Thermal mapping in the upper tropospheres and stratospheres can be achieved today from mid-IR wavelengths from ground-based telescopes (8-10 m class), but (i) these do not access the collision-induced H_2-He continuum that probes the deeper atmosphere near the main cloud decks; (ii) they do not permit sounding of the helium, para-hydrogen and rotational features of the variety of gases listed above; and (iii) they cannot be accurately calibrated due to terrestrial contamination. Extension of the FIR Surveyor range to 10 μm would be beneficial for cloud/aerosol mapping simultaneously with temperatures, something which has not been previously possible for the Ice Giants. Extension to 7 μm would permit stratospheric sounding from methane (near 7.7 μm), ethane (12.3 μm) and acetylene (13.2 μm). SOFIA can access the 17-37 μm region, but at a low spatial resolution from a 2.5-m mirror.

(iv) Longevity/Durability: (with respect to expected 2025-2030 facilities)

The large angular sizes and high brightness of Jupiter and Saturn renders them largely inaccessible to JWST in the 5-28 μm range, and spatial resolution across Uranus and Neptune will be low. ALMA cannot address the broad-band spectroscopy desired here. Mid-IR thermal instruments pending for 30-40m ELTs typically have small fields-of-view, rendering giant planet observing unfeasible. No planned outer solar system mission (e.g., ESA/JUICE) has broadband far-IR capabilities. Uranus and Neptune missions are not likely to reach their destinations in the timeframes discussed here. WFIRST will not offer the desired spatial resolution nor far-IR coverage.

3. Table:

Parameter	Unit	Required value	Desired Value	Comments
Wavelength/band	μm	15-500	7-1000	Broadband spectra.
Number of targets		4	4	Compare four giant planets.
Survey area	$deg.^2$	10 arcsec	50 arcsec	10” could be mosaicked, 50” preferable.
Angular resolution	arcsec	0.5	0.1	To surpass current capabilities.
Spectral resolution	$\Delta\lambda/\lambda$	300	1000	
Bandwidth		Wide		Full spectrum simultaneously.
Continuum Sensitivity (1 σ)	K	1 K	0.1 K	(equivalent to 200/20 mJy for a 0.2” resolution at 100 μm)
Spectral line sensitivity (1 σ)	$W\ m^{-2}$	N/A	N/A	
Signal –to-noise		10	100	
Dynamic range		50-200 K Blackbody		Brightness temperature range from Jupiter to Neptune.
Field of Regard		N/A	N/A	
Cadence		1 year	Week, Month, Year	Repetition over a variety of timescales

4. References : Fletcher et al., (2016), Icarus 264, p137-159; Orton et al. (2014), Icarus 243, p471-493; Fletcher et al., (2014), Icarus 231, p146-167.