Climate Variability on the Seasonal Giant Planets

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Summary: Saturn, Uranus, and Neptune display substantial variability in atmospheric circulation, chemistry, and clouds over seasonal and sub-seasonal timescales. These can only be disentangled via multi-year campaigns to reveal the natural cycles of variability shaping Solar System giant planets. ***We propose regular multi-wavelength IFU spectroscopy (NIRSpec and MIRI/MRS) to build an unprecedented climate database for these three worlds as our closest and best examples of seasonal giant planets across our galaxy.***

Science Background - the Need for a Climate Database: While Hubble's OPAL programme could provide exceptional imaging to track storms and winds on giant planets, only JWST has the ability to provide spectroscopy. This opens the door to explore the atmospheres of the seasonal giants in three dimensions, from their cloud-forming weather layers, high into their stratospheres and thermospheres, something which could never be accomplished via imaging alone. Reflected sunlight (NIRSPec) and thermal emission (MIRI/MRS) spectra can be inverted to measure temperatures and winds, gaseous composition to trace chemistry and slow circulation patterns; the growth and dissipation of seasonal aerosols, and the long-term variation of ionospheric temperatures. Unlike Jupiter, seasonal changes in sunlight and decades-long winters control the circulation and meteorological activity on Saturn, Uranus, and Neptune. But observations in a single cycle, such as the GTO spectroscopic observations during Cycle 1 (Fletcher+2021), capture only snapshots of these complex, evolving systems. To understand the drivers of atmospheric variability, either external (solar wind, insolation and the solar cycle, magnetospheric phenomena) or internal (belt-zone variability, storm eruptions, wave phenomena, etc.), the community needs a long-term database of these seasonal giants with a regular cadence of observations (ideally annual).

Observations of **<u>Saturn</u>** would extend the legacy of Cassini, which explored Saturn from southern summer to northern solstice. MIRI/MRS observations in 2022 revealed the seasonal reversal of Saturn's "Hadley" circulation and the changes to the polar vortices 5 years after summer solstice (Fletcher+2023), alongside changes to clouds and the equatorial "heartbeat" (the stratospheric oscillation, akin to Earth's QBO). The proposed programme would track Saturn's seasonal circulation through equinox (2025) and on to the southern summer solstice (April 2032), which, combined with Cassini, would provide an ***unprecedented database spanning a whole Saturnian year.***

MIRI and NIRSpec observations of **<u>Uranus</u>** (Jan 2023, Roman+2023) captured the growing polar cap of aerosols during northern spring, revealed the stratospheric circulation patterns for the first time, showed evidence of auroral control of ionospheric emission, and revealed the thermal glow of Uranus' rings. Uranus' thermosphere has been cooling since H3+ was first discovered (Melin+2019), and no one knows how Uranus' thermospheric temperatures, stratospheric chemistry/circulation, and tropospheric storm activity, will change as the planet approaches northern summer solstice (2030) and autumn equinox (2050). Detailed characterisation of the changing climate of Uranus by JWST would set the ***long-term context for NASA's forthcoming flagship mission to the Uranian system*** in the 2040s.

Finally, despite **<u>Neptune's</u>** long (~40-year) seasons, unexpected sub-seasonal variations and cooling have been tracked from Earth (Roman+2022). As Neptune approaches northern spring equinox (April 2046) we will capture glimpses of the north polar region for the first time in history. Will Neptune's storm activity evolve in response to changing solar cycle and other processes? Will we witness the emergence of a north polar vortex? And with Neptune's H3+ being detected for the first time by NIRSpec (Melin+2023), will we witness similar thermospheric changes as on Uranus? ***All these require the start of a long-term programme of Neptune monitoring with JWST.***

Community Benefit: Environmental conditions (temperature, humidity, winds) underpin all <u>numerical simulations</u> of how planetary meteorology, dynamics, and chemistry work under extreme conditions. The ionospheric variability provides a window on how planets interest with the <u>solar wind and wider</u>

heliosphere as seasons change. Spectroscopy from a stable platform, with broad spectral coverage and high resolution, will provide a record of these parameters that is unsurpassed. A single spectral cube addresses high priority science from multiple sub-communities: e.g., those studying tropospheric meteorology; or stratospheric circulation; or solar wind interactions. Long term climate monitoring, following the example of HST/OPAL, is virtually impossible to achieve through regular GO proposals as many changes will only be detectable via comparisons over multiple cycles. And as studies of Brown Dwarfs and Exoplanets begin to reveal variability in atmospheres beyond our Solar System, these communities will turn to the knowledge of our own seasonal giants to understand the mechanisms - seasonal and sub-seasonal - driving climate variability. ***JWST offers a unique chance to construct a comparative, long-term climate database for these worlds.***

Feasibility: The GTO Cycle-1 programme for the giant planets revealed the rich science possible with latitudinally-resolved spectroscopy. Unlike OPAL, we do not propose global mapping or wind measurements, and instead focus on long-term changes from north to south. Neptune and Uranus fit perfectly within the IFU fields-of-view, and a 4-point dither for both NIRSpec (1.6-5.3 µm in the G235H/F170LP and G395H/F290LP settings) and MIRI (4.9-28.5 µm) required a total time of ~4.2hrs per planet in programmes 1248-49. Saturn is more complex, requiring moving the FOVs parallel to the central meridian to acquire a latitude scan. Programme 1247 mapped only the northern latitudes with MIRI (3 tiles, ~1.3hrs per tile). ~5 tiles would enable a full latitude scan, requiring ~13 hours for both NIRSpec and MIRI. ***Thus, all three seasonal giants could be characterised by JWST with ~22 hours per cycle; or a focussed Ice Giant project would require ~9 hours.***

References:

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