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The JWST Giant Planet Atmospheres Programme

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1. Overview

The James Webb Space Telescope (JWST) will be the premier observatory for infrared planetary science over the coming decade, revolutionising our views of cold, distant targets that have remained out of reach to ground-based facilities. For planetary atmospheres, JWST offers an unprecedented opportunity to explore the weather and climate in three dimensions, from the turbulent cloud layers to the chemically-rich stratospheres, via spatially-resolved spectroscopic mapping in the 1-30 µm range. This presentation will summarise the *JWST Giant Planet Atmospheres programme* during the first year of science operations (Cycle 1, 2022-23), which is set to observe all four giants. These observations have been made possible by a combination of Guaranteed-Time Observing (GTO), Early Release Science (ERS), and General Observing (GO), and their combination permits comparative planetology of the Gas and Ice Giants. This presentation will: (i) summarise the science goals at each planet; (ii) discuss the available toolkits for data reduction, mapping, and spectral interpretation; and (iii) advocate for a ground-based campaign to support the JWST observations.

2. Giant Planet Observations

Ice Giants: Uranus and Neptune

Comparing the atmospheric dynamics and chemistry of Uranus and Neptune will provide new insights into the processes shaping intermediate-sized and chemically-enriched worlds. Voyager's infrared observations were largely limited to the far-IR, and despite recent advances in ground-based observations (Fletcher et al., *doi:10.1016/j.icarus.2013.11.035*, Roman et al., *doi:10.3847/1538-3881/ab5dc7*) and disc-integrated spectroscopy (Orton et al., *doi:10.1016/j.icarus.2014.07.010*; Rowe-Gurney et al., *doi:10.1016/j.icarus.2021.114506*), Ice Giant stratospheres have remained largely inaccessible. JWST MIRI 5-28 µm spectroscopic maps of Uranus (**GTO1248**) and Neptune (**GTO1249**) will reveal spatial gradients of temperature and chemicals, to diagnose the circulation and chemistry of Ice Giant stratospheres for the first time (Moses et al., *doi:10.1016/j.icarus.2018.02.004*), and link it to meteorological activity in the troposphere. Simultaneous NIRSPEC 2-5 µm spectroscopy of Uranus (**GTO1248**) will reveal aerosol structures in the troposphere, and H_3^+ emission in the ionosphere. Both Uranus and Neptune will be observed several times over a full rotation to construct global maps. MIRI observations of Neptune will be repeated when the Ice Giant returns to the Field of Regard (FoR), to search for the sources of temporal variability of mid-IR emission (Roman et al., EPSC2021) over timescales of months (**GO1604**).

Expected dates: Uranus window 1 (2022-08-05 to 2022-09-26), Uranus window 2 (2022-12-22 to 2023-02-09), Neptune window 1 (2022-06-11 to 2022-08-02), Neptune window 2 (2022-10-31 to 2022-12-19).

Gas Giants: Jupiter and Saturn

The Gas Giants provide a crucial test of JWST's capabilities to explore extended, rotating, moving, and bright targets. Indeed, the angular sizes of Jupiter and Saturn means that mosaics are required to map atmospheric regions of interest, and the high surface brightness means that MIRI observations are expected to saturate beyond 11 µm (Jupiter) or 16 µm (Saturn). On Jupiter, we have selected two scientific targets: the Great Red Spot will be targeted via mosaics with MIRI (5-11 µm, **GTO1246**) and NIRSpec (1-5 µm, **ERS1373**), to understand how the circulation of this archetypal anticyclone influences its temperatures, composition (e.g., ammonia as a cloud-forming volatile, phosphine as a tracer of vertical mixing), and aerosols. Secondly, Jupiter's south pole will be observed with NIRSpec and MIRI (ERS1373) to understand how energy propagates from the aurora (via H_3^+ emission) to the stratosphere (via methane emission). **ERS1373** will also use NIRCAM imaging (1-5 µm) to measure atmospheric motions at multiple levels in Jupiter's clouds and tropospheric hazes. For Saturn's atmosphere, MIRI 5-16 µm spectroscopy (**GTO1247**) offers the opportunity to revisit the seasonally-evolving giant five years after the demise of the Cassini mission. Saturn's summertime hemisphere will be mapped from the pole to the equator, capturing the demise of the polar stratospheric vortex since summer solstice in 2017 (Fletcher et al., *doi:10.1038/s41467-018-06017-3*). The atmospheric observations are part of wider programmes to capture MIRI, NIRSpec, and NIRCAM imaging of Jupiter and Saturn's satellite and ring systems (**GTO1247/ERS1373**). Finally, a target-of-opportunity programme (**GO1424**) will respond within 2 weeks to unforeseen extreme events on either Jupiter or Saturn, providing NIRSpec and MIRI spectroscopic maps of cometary or asteroid impact sites, or the eruptions of significant new storms. In the event of a trigger, this would be repeated twice to capture the evolution of the feature.

Expected dates: Jupiter window 1 (2022-06-23 to 2022-08-15), Jupiter window 2 (2022-11-06 to 2022-12-27), Saturn window 1 (2022-05-10 to 2022-07-01), Saturn window 2 (2022-09-27 to 2022-11-16).

3. Data Analysis Toolkit

We will present the current status of data analysis tools:

- **Forward-Modelled MIRI spectra:** the suite of radiative transfer and spectral analysis tools

(NEMESIS, Irwin et al., *doi:10.1016/j.jqsrt.2007.11.006*) have been adapted to simulate MIRI 5-28 μm spectra in all 12 sub-bands (disperser, detector, and grating combinations), generating idealised synthetic cubes from temperature, composition, and aerosol maps from existing data and/or photochemical models (e.g., Moses et al., *doi:10.1016/j.icarus.2018.02.004*).

- **MIRI simulations:** Synthetic spectra are passed to the MIRISim package to generate MIRI detector images, testing assumptions about exposure times, dither patterns, and background subtraction. Detector images are them passed to the MIRI calibration pipeline, reconstructing MIRI cubes as if they were taken by the observatory.
- **Data processing:** MIRI and NIRSpec spectral cubes are then passed through an image navigation pipeline to construct maps, so that multiple dithers/exposures can be coadded.
- **Spectral inversion:** NEMESIS will then be used to assess retrievability of the original temperature, composition, and aerosol inputs, preparing the techniques required for the real data in 2022.

4. Ground-Based Support

Giant planet atmospheres evolve significantly with time, and spatial, temporal, and spectral context information will be required to fully exploit the JWST observations. For example: observations of Jupiter's Great Red Spot will rely on precise positioning information in early 2022; spatial variations in thermal emission related to storms/vortices on each world will require visible-light context imaging; and candidates for impact events and significant storm eruptions will need to be rapidly assessed to determine the use of triggered observations. We advocate for a programme of ground-based support, both from professional and amateur observers, in the times preceding the FoR windows specified above. Amateur observers should continue to make use of the PVOL database (http://pvol2.ehu.eus/pvol2/) - see presentation by Hueso et al. (EPSC2021-80) for further details.