

## Long-Term Monitoring of the Outer Planets with JWST

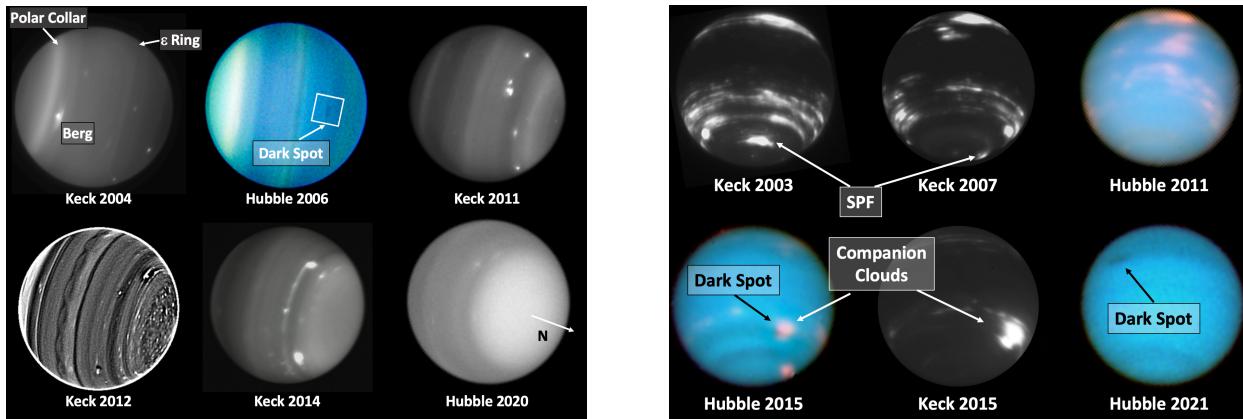
Amy Simon (NASA GSFC) on behalf of co-authors on page 2

**Motivation:** The atmospheres of the Solar System's giant planets are temporally variable, with changing cloud color, aperiodic small-scale and global storms, seasonal cloud and haze thickness variability, as well as sudden thermal and chemical variations, Fig. 1. As our giant planets serve as the model for many, more sparsely-observed, exoplanets, it is particularly important to understand how gas giant atmospheres respond to both internal and external forcing over time. Changes at and above the cloud tops provide windows into the deeper dynamical mechanisms, energy budgets, and bulk properties of the gas giants, all of which are critical for understanding exoplanet populations and the formation of our own Solar System.

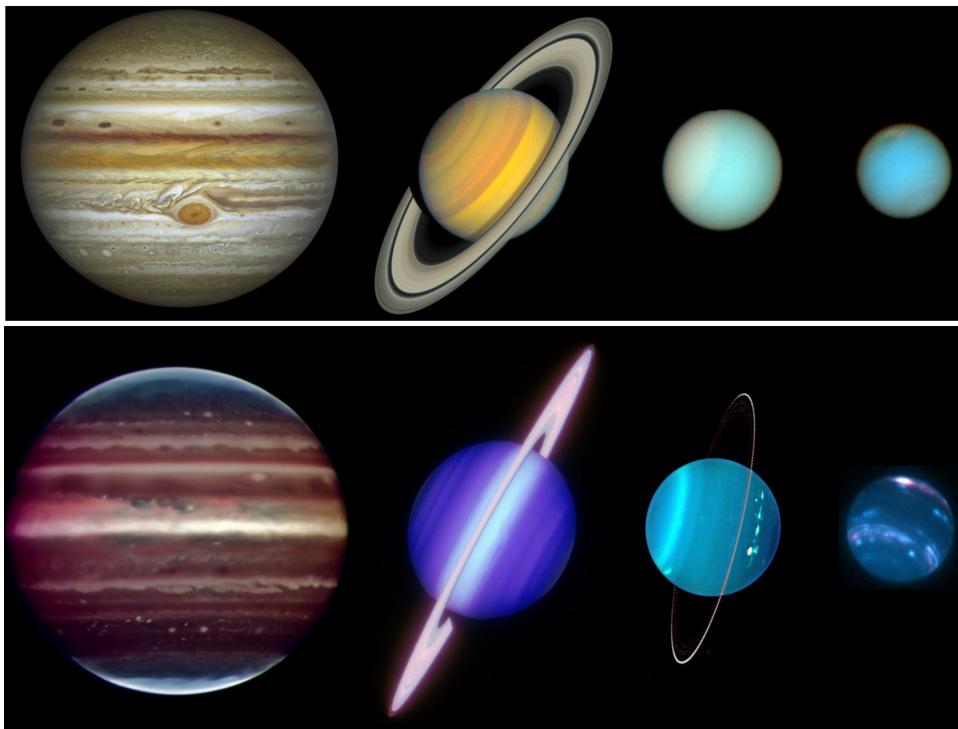
**Results from Hubble long-term monitoring:** The Hubble Outer Planet Atmospheres Legacy (OPAL) program has provided yearly observations of the outer planets since 2014 for trending atmospheric changes on very long timescales (e.g., a year on Jupiter lasts 12 Earth years). These observations cover two full rotations of each planet with a range of filters from the near UV to near IR [1]. This program has documented changes in visible wavelength large storms, as well as changes in cloud cover and wind fields, and made serendipitous discoveries of new Neptune dark spots, Jupiter waves, Saturn ring spokes, and other phenomena [2-5]. Since its inception, more than 50 papers have been published with OPAL data, but given the long timescales of atmospheric variability for these planets, these data are just now beginning to show their full potential as tools for analysis of the gas giants and the forces that influence them.

**Need for JWST Monitoring:** Dedicated missions to the outer planets are infrequent, especially those that both span a long time period and cover a wide range of wavelengths from the UV to the IR, for example, Cassini. At the same time, major atmospheric events are unpredictable, such as medium-scale convective storms on Saturn [6,7], or even the possible outbreak of a major storm in the southern hemisphere, which has never been observed. While Hubble covers visible wavelengths well, IR data are key to understanding the atmospheric dynamics on these planets. Near-IR wavelengths can be used to track composition (spectra), as well as upper-level winds above the clouds (imaging). Mid to far-infrared data are necessary for understanding the global energy budget; the balance between reflected sunlight and emitted internal heat drives energy and momentum transport within an atmosphere and are now known to be variable [8]. Additionally, we do not yet understand the influence of external factors, such as the solar cycle, as recently noted for Neptune [9]. A more complete understanding of the factors that influence planetary weather is needed to place the giants planets into context within our observations of exoplanets, requiring long-term, regular, broad wavelength coverage. JWST data augment existing Hubble and ground-based programs with expanded wavelength coverage. The potential for consistent IR data at very high spatial resolution over very long time scales is unique to JWST.

**Ideal JWST Data:** Although Hubble can observe for tens of hours, such resources would be prohibitive for JWST. Ideally, repeated imaging and spectral data from opposing hemispheres would be of high value (that is, observations spread half a rotation and a full rotation apart provide nearly full longitude coverage, as well as wind pairs, respectively). However, even singular data sets near in time to Hubble observations would also be highly valuable as JWST data sound very different atmospheric levels than do Hubble visible data, Fig 2. Specific science goals are discussed in other companion white papers.



**Fig. 1.** Changes in Uranus (left) and Neptune (right) over time [reproduced from 10].



**Fig. 2.** Comparison of the outer planets at visible (top) and near-IR (bottom) wavelengths, [from 10].

#### References:

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