The Hubble Outer Planet Atmospheres Legacy (OPAL) Program: 10 years of giant planet monitoring. A.A. Simon[1], M.H. Wong[2], G.S. Orton[3], [1]NASA GSFC, [2]U.C. Berkeley, [3]Jet Propulsion Lab/CalTech.

Introduction: The Outer Planet Atmospheres Legacy (OPAL) program began in 2014 as part of the Hubble 2020 legacy initiative. These observations were meant to cement Hubble's long-term legacy of high value data by ensuring a regular cadence of giant planet observations to fill temporal gaps between individual programs. As these planets have highly dynamic atmospheres, long-term trends tied to seasonal or other evolutionary cycles cannot be deduced without regular data collected using the same instruments and filters.

In addition to building up a long data base of consistent observations, serendipitous discoveries have been made along the way. All data are immediately available to the public, and the team also produces high level science products in the forms of global maps.

Jupiter: Hubble's exquisite spatial resolution and OPAL's global and temporal coverage allow detailed study of Jupiter's long-lived vortices, high speed narrow wind jets, and alternating, variable, bands of colored clouds. OPAL results have included studies of the Great Red Spot, zonal wind speeds, small atmospheric waves, long-term color trends, and more [2-6].

Saturn: Saturn observations began in 2018 after the end of Cassini. When first observed, Saturn was moving away from summer solstice, and almost immediately, cloud bands were observed to rapidly change color, as did the infamous north polar hexagon [7]. Although the atmosphere is the focus for OPAL, ring spokes were serendipitously observed in 2021 through 2024 [8].

Uranus: First observed in 2014, we have the longest span of data for Uranus. Over the lifetime of OPAL, the polar haze has substantially brightened [9]. The long OPAL coverage has aided other ground-based studies [10], and, in 2024, data were also used as low phase angle context imaging for New Horizons [11].

Neptune: The first Neptune images in 2015, immediately yielded a surprise: a small dark spot [12]. While that one disappeared, a new one formed in 2018, rivalling the size of the Voyager Great Dark Spot [13-14]. Continued imaging has shown this new spot to evolve and eventually fade away [15], even as bright clouds came and went over time.

Summary: The results cited here are a small subset of the results made possible by the OPAL monitoring of the outer planets. As of January 2025, 62 papers have cited OPAL data. With more than 10 years of data in hand, and continuing for the life of Hubble, we expect the scientific return to increase exponentially.

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References: [1] Simon et al. (2015) *ApJ* 812, 55. [2] Tollefson et al. (2017) *Icarus* 296, 163. [3] Simon et al. (2018) *AJ* 155, 151. [4] Simon et al. (2018) *AJ* 156, 79. [5] Simon & Wong (2024) *PSJ* 5, 259. [6] Tsubota et al. (2024) *Nat. Astron*, 10.1038/s41550-024-02419-0 [7] Simon et al. (2021) *PSJ* 2, 47. [8] Simon et al. (2023) *GRL* 50, e2022GL101904. [9] James et al. (2023) *JGRP* 128, e2023JE007904, [10]. Irwin et al. (2023) *MNRAS* 527, 11521. [11] Hasler et al. (2024) *PSJ* 5, 267. [12] Wong et al. (2019) *AJ* 155,117. [13] Simon et al. (2019) *GRL* 46, 3108. [14] Hsu et al. (2019) *AJ* 157, 152 [15] Wong et al. (2022) *Icarus* 387, 115123.