HUBBLE'S LONG-TERM OPAL (OUTER PLANET ATMOSPHERES LEGACY) PROGRAM OBSERVES CLOUD ACTIVITY ON URANUS. Michael H. Wong[1], Amy A. Simon[2], Glenn S. Orton[3], Imke de Pater[1], Kunio M. Sayanagi[4]. [1]University of California at Berkeley <mikewong@astro.berkeley.edu>, [2]NASA Goddard Space Flight Center, [3]Jet Propulsion Laboratory, [4]Hampton University.

Introduction: The Hubble Space Telescope's (HST's) Wide Field Camera 3 (WFC3) observed Uranus cloud features in 2014 on 8–9 November as part of the OPAL (Outer Planet Atmospheres Legacy) Program. The features are located near 30° N, where bright clouds have been previously seen in 1999, 2004, 2005, and 2011 [1]. These features may be convective in nature, or associated with vortices that are more difficult to detect, or both [1,2]. We will present an initial analysis of the November HST data.

Prior to the OPAL observations, bright features near 30° N were among those seen in infrared images of Uranus acquired at the Keck Observatory on 5–6 August 2014 [3]. In the interim, features were tracked in lower-resolution images by professional and amateur astronomers. Hubble images were also taken 14 October as part of a Target of Opportunity program focused on bright cloud outbursts (Program 13712, PI Sayanagi).

The OPAL program: Uranus observations on 8–9 November were acquired as part of the OPAL program, which targets Jupiter, Uranus, and Neptune until the end of the Cassini mission, and all four giant planets afterward. OPAL is the first of its kind: a long-term observing program for solar system science with HST that spans multiple years. Each year for the rest of the lifetime of HST and the WFC3/UVIS camera, the OPAL program will acquire consecutive pairs of global maps of the outer planets. The data immediately become publicly available to the community, enabling a range of science investigations into the climate, structure, and evolution of giant planet atmospheres.

OPAL data will enable studies of the atmospheres of the giant planets as they evolve on multi-year time scales. The growing number of discoveries based on archival HST data [4] demonstrates the importance of good temporal sampling in the archive. This is especially true in the outer solar system, where seasonal timescales span years to decades. Without a long-term program ensuring at least annual coverage, gaps in the archive have frustrated prior attempts to characterize dynamic processes, such as shifts in banded haze structures in Jupiter's atmosphere [5].

The aims of the annual OPAL observations of Uranus are to measure:

- variability in bright cloud activity,
- variability in zonal mean cloud/haze structure,
- variability in east-west winds.

These properties will constrain climate and weather variability, convective heat transport, and seasonal effects on a world with drastically different solar forcing than our own.

Uranus observations: A series of 8 HST orbits were scheduled to span all longitudes over two complete rotations of Uranus. A global map based on one of these rotations is shown in Fig. 1. Filters used were centered at wavelengths of 467 nm, 547 nm, 619 nm, 658 nm, 727 nm, 845 nm, and 924 nm. Raw and calibrated images were immediately available in the archive. Fully processed map data are being prepared for upload to the archive as High Level Science Products by the OPAL team.

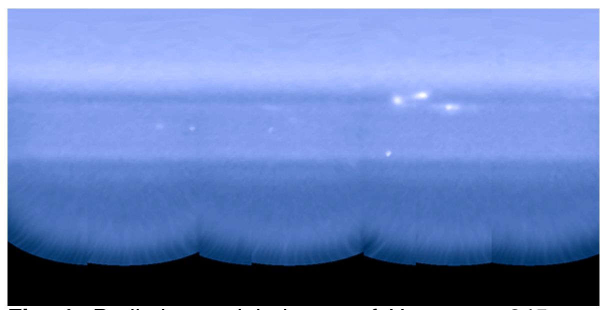

Fig. 1. Preliminary global map of Uranus at 845 nm, obtained with HST/WFC3 on 2014-11-09 as part of the OPAL program. A cluster of bright features appear at 30° N, where outbreaks of cloud activity have been seen previously around and after equinox in 2007 [1].

Discussion: One of the most bizarre characteristics of Uranus is its small or non-existent internal heat source. The magnitude of the planet's intrinsic luminosity depends on measurements of the Bond albedo, which controls the amount of solar radiation absorbed, and the total emitted thermal flux. Voyager 2 made the only complete determination of these quantities to date, at a single epoch. But the planet's intrinsic luminosity may vary with time [6]. Understanding the variability of convective heat transport is an important part of determining whether Uranus may actually have a significant intrinsic luminosity after all, in a time-averaged sense.

It is not even clear whether these bright spots are convective in nature. At first glance, the Keck discovery image bears a strong resemblance to convective plumes seen on Jupiter in 2007 (Fig. 2). However, by November (Fig. 3) the cloud morphology was more difficult to distinguish between that of a convective storm with trailing plume, or a group of orographic clouds associated with an anticyclonic vortex such as was first seen on Neptune by Voyager [2].

The jovian convective plumes in Fig. 2 were similarities to the Saturn storm in 2010-2011 in that the storms circled Jupiter and Saturn at a different rate than the zonal mean. When the storms reached all the way around to the ends of their tails (which had dispersed following the zonal mean flow speed), the eruptions ceased [7,8]. These systems were easily viewed by amateur astronomers, enabling a very high temporal sampling rate. But on Uranus, the temporal evolution of the bright features is not as clear, because only large professional telescopes are able to resolve the storm morphology, at much more scattered opportunities.

The association between these large outbursts and the genesis of anticyclonic vortices was clear in the case of Saturn [8], absent in the case of Jupiter [7], and unclear for the ice giants. “Dark spots” may form on Uranus in response to bright cloud outbursts, but are difficult to detect and characterize. Although anticyclonic vortices on Neptune are visible as dark spots [2], some features with similar appearance on Uranus may be vortices while others may simply be local minima in haze densities [9,1]. Our presentation will describe whether a detailed analysis of the data is able to reveal dark spots on Uranus created by the bright cloud outbursts of 2014.

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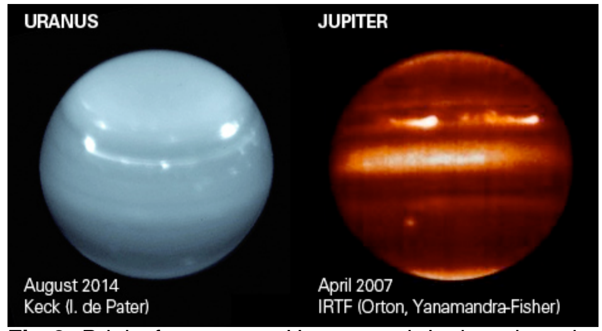

Fig 2. Bright features on Uranus and Jupiter share intriguing similarities. Trails of aerosol material are dispersed away from the plume centers by wind shear. On Jupiter, this is due to continual aerosol production in the plume, whose base traveled at a different speed than the winds at the top of the plume [7]. On Uranus, the temporal evolution of the system is less clear, because temporal coverage is sparser at the high resolutions needed to distinguish morphology such as the plume trail. Image at left courtesy of the Keck Observatory website (see [3]); image at right from [7].

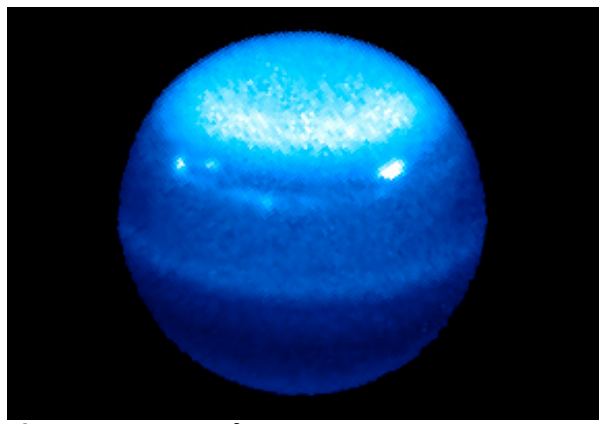

Fig 3. Preliminary HST image at 924 nm, acquired as part of the OPAL program on 2014-11-09, three months after the Keck image in Fig 2. Further analysis of the complete OPAL dataset will seek to distinguish whether the cloud morphology, particle properties, and vertical structure are more consistent with a convective storm and trailing plume, or with a group of orographic clouds associated with a vortex such as was first seen on Neptune by Voyager [2].