# Results from the Outer Planet Atmospheres Legacy (OPAL) Program

*Amy Simon*

*NASA Goddard Space Flight Center*

# Goals of OPAL

Yearly global maps of each of the outer planets

- Started with Uranus in 2014, and Jupiter and Neptune in 2015
- Saturn starting in 2018 (after Cassini ends in 2017)

Study trends in zonal winds, cloud activity, color, cloud height

- Other unexpected activity
- Not meant to supplant other focused science programs

All maps made available to science community for other studies

- First HLSP release coincides with first manuscript submission for that planet, no delay in subsequent Cycles

P pages

chive.stsci.edu/prepds/opal/

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# Outer Planet Atmospheres Legacy (OPAL)

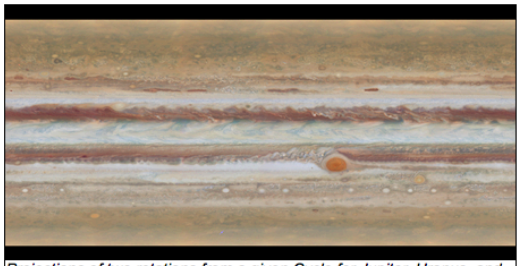
Simon et al., 2015, *ApJ*, 812, 55

See also: Wong et al., 2015, *LPI*, 46, 2606  Simon et al., 2016, *ApJ*, 817, 162

Introduction  Description of Data Products  Data Access

## Introduction

OPAL is a project to obtain long time baseline observations of the outer planets in order to understand their atmospheric dynamics and evolution as gas giants. The yearly observations from OPAL throughout the remainder of Hubble's operation will provide a legacy of time-domain images for use by planetary scientists. The project will ultimately observe all of the giant planets in the solar system (Jupiter, Saturn, Uranus, and Neptune) in a wide range of filters. The images are processed using an ellipsoid limb-fitting technique, with an additional fringe correction applied to the narrow-band filters only (e.g., FQ889N for Jupiter 2014-2015), which amounts to a few percent correction. Mosaics are created for each observed filter in a projection that spans 360 degrees of longitude. See the README files (on disk or in the tables below) for additional details on the data processing. The mosaics from each filter (in FITS format), as well as previews (in TIF format) are provided.



*Projections of two rotations from a given Cycle for Jupiter, Uranus, and Neptune. Watch how cloud features change between rotations.*

## Description of Data Products

Each file name begins with the same prefix: "hlsp_opal_hst_wfc3-uvis_". The name of the planet is the next part of the filename. Each rotation/epoch is differentiated by a calendar year and a letter, e.g., "jupiter-2015a" is the first rotation of Jupiter from Cycle 22, "jupiter-2015b" is the second rotation from Cycle 22, etc. Keep in mind that HST cycles span two calendar years, since they start in Oct. and run through Sep. of the following year. The next part of the filename includes the HST filter for that mosaic/preview image, followed by a version number and the file extension. File extensions are:

1. *_globalmap.fits* = Mosaic (projection) for the given filter.
2. *_globalmap-medium.tif* = Preview image (width x height ~ 900 x 450 px, varies by target).
3. *_globalmap-small.tif* = Preview image (width x height ~ 450 x 225 px, varies by target).
4. *_globalmap.tif* = Preview image (size varies by target).

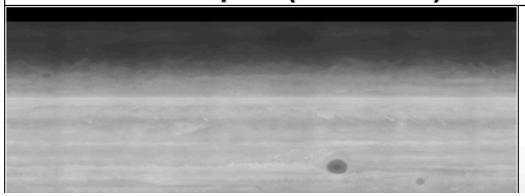
## Data Access

You can retrieve the images and previews from the table below, or directly at this URL.

| Cycle (Year) | Jupiter | Saturn | Uranus | Neptune |
|---|---|---|---|---|
| 22 (Oct 2014 - Sep 2015) | Load Table | | Load Table | Load Table |
| 23 (Oct 2015 - Sep 2016) | Load Table | | Load Table | |

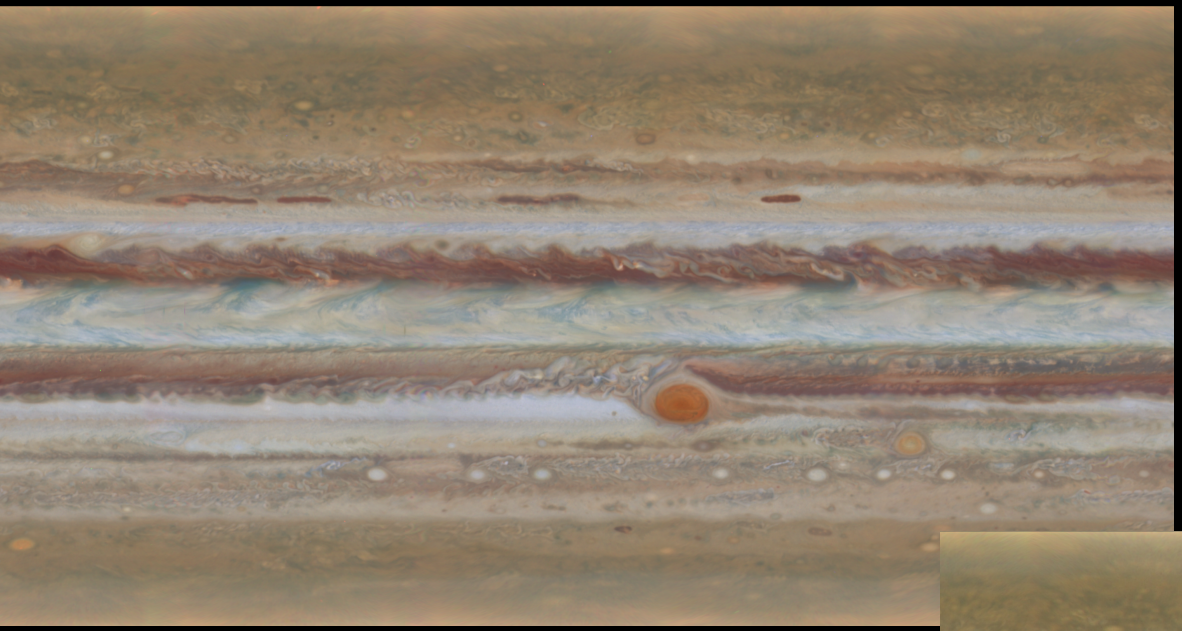
**Cycle 22** Download README | RotA Color | RotB Color

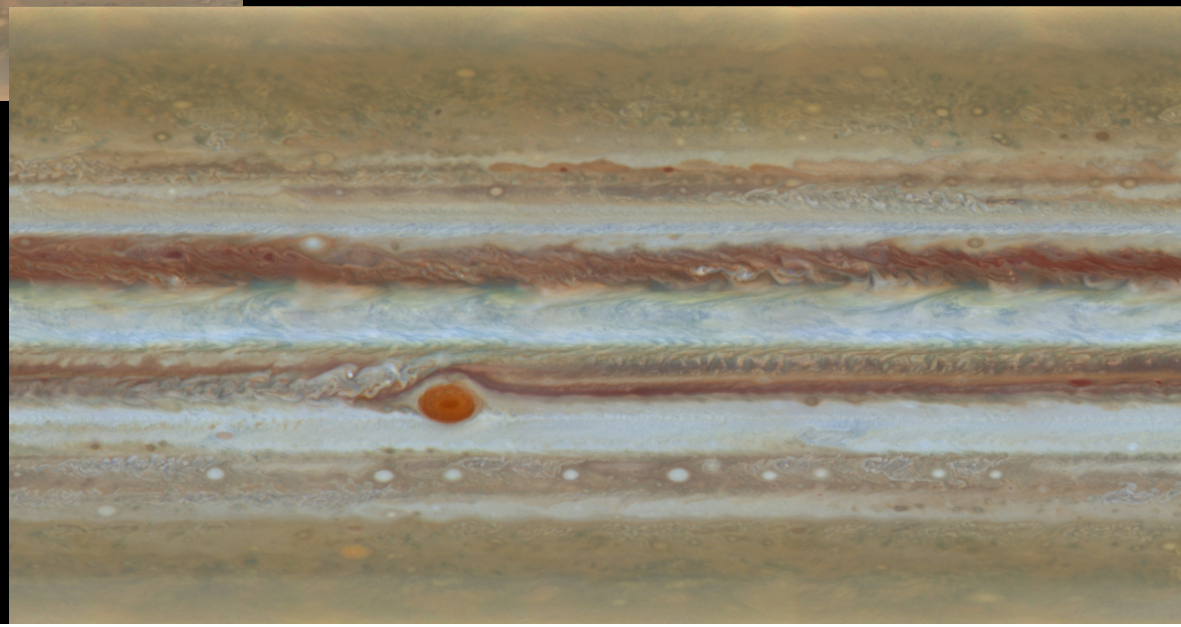
**Jupiter (Rotation A)**



F275W
IMG (FITS)
FULL (TIF)
MED (TIF)
SMALL (TIF)

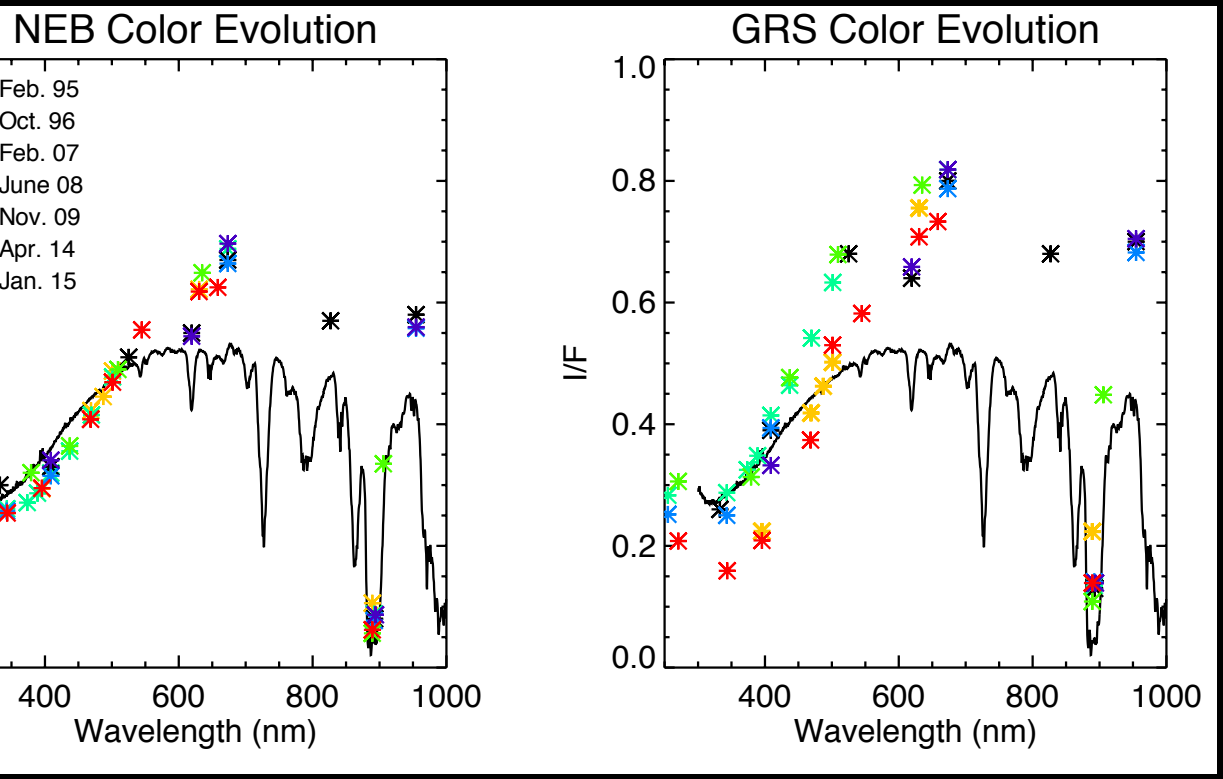
# upiter: January 2015, February 2016



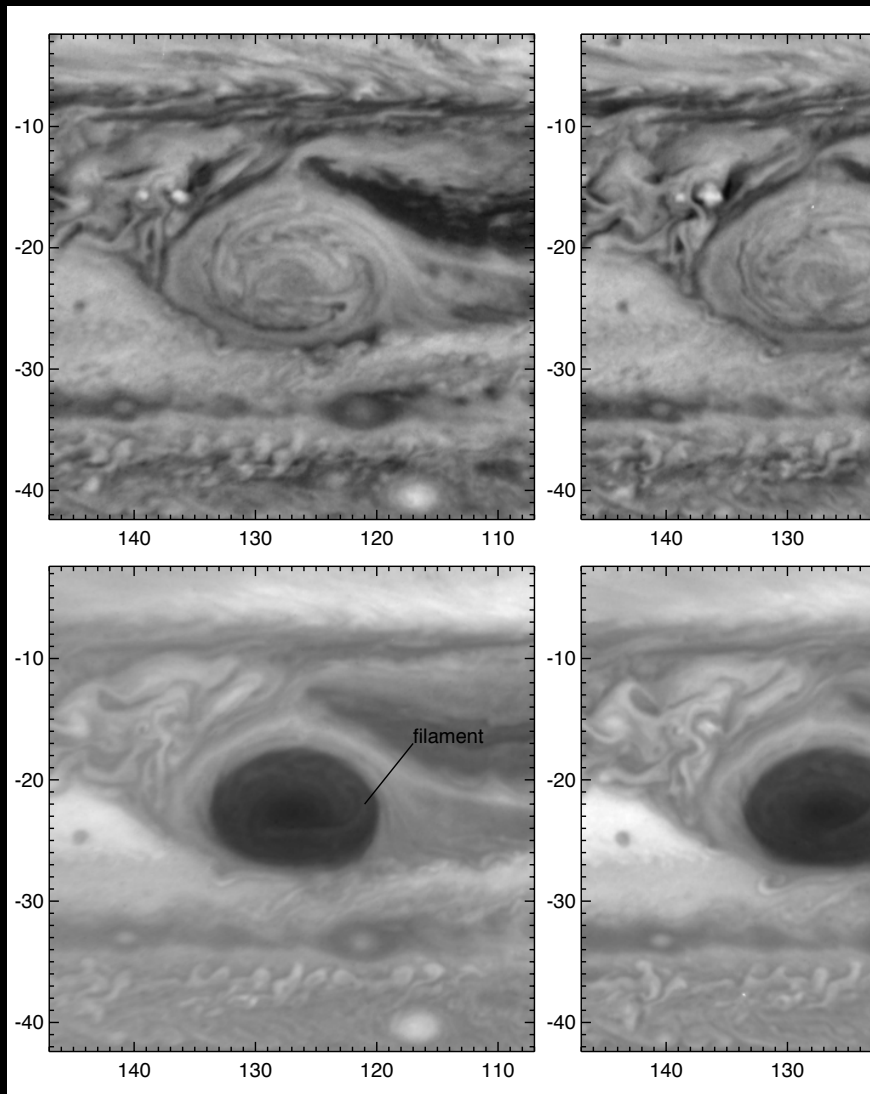


# upiter: Results

Simon, Wong and Orton, *ApJ* 812, 55

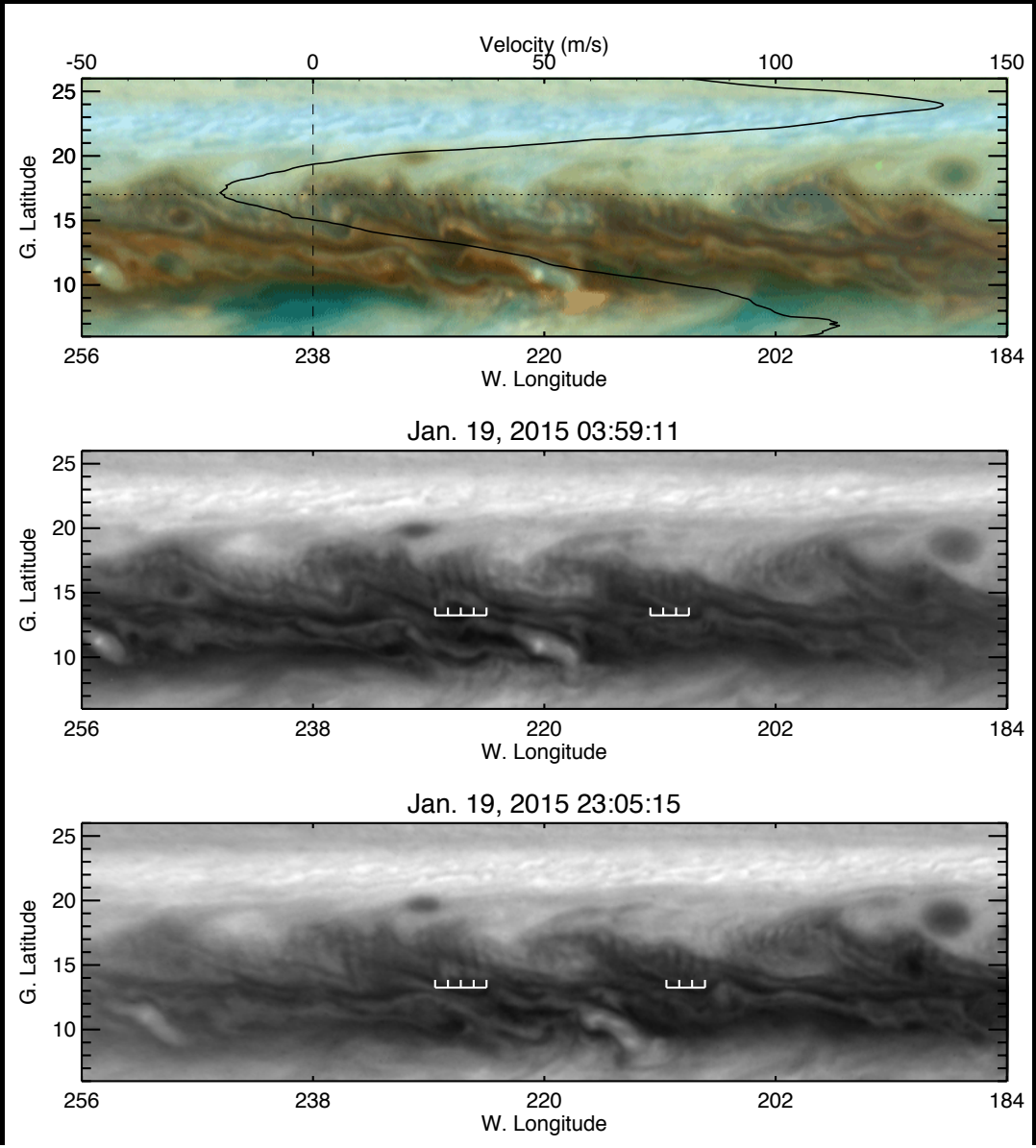



Great Red Spot remains intense orange color, still shrinking; internal structure has a reduced core and spiral cloud patterns



# upiter: Results

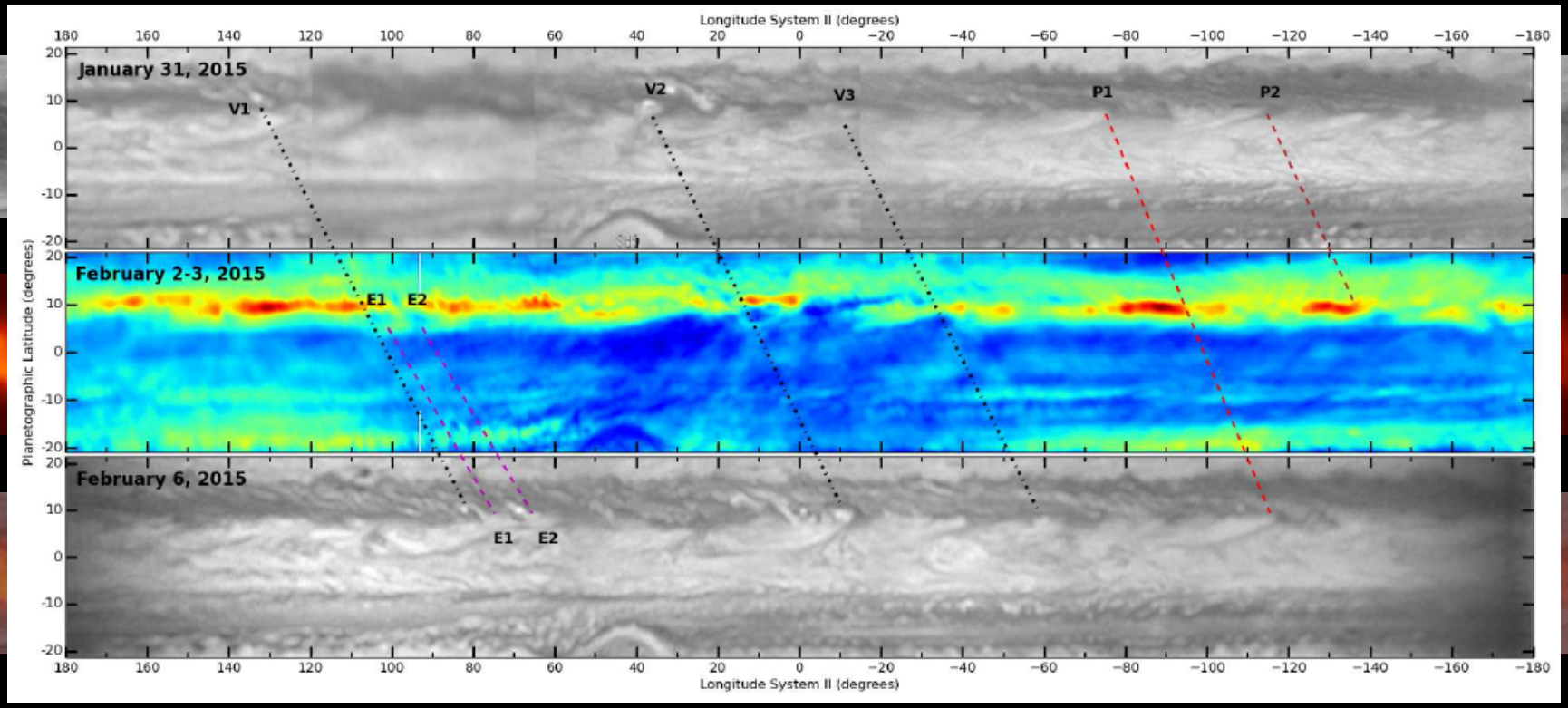
baroclinic wave spotted
ever before seen by Hubble
nalogous to mid-latitude cyclone
rmation on Earth




non, Wong and Orton, *ApJ* 812, 55

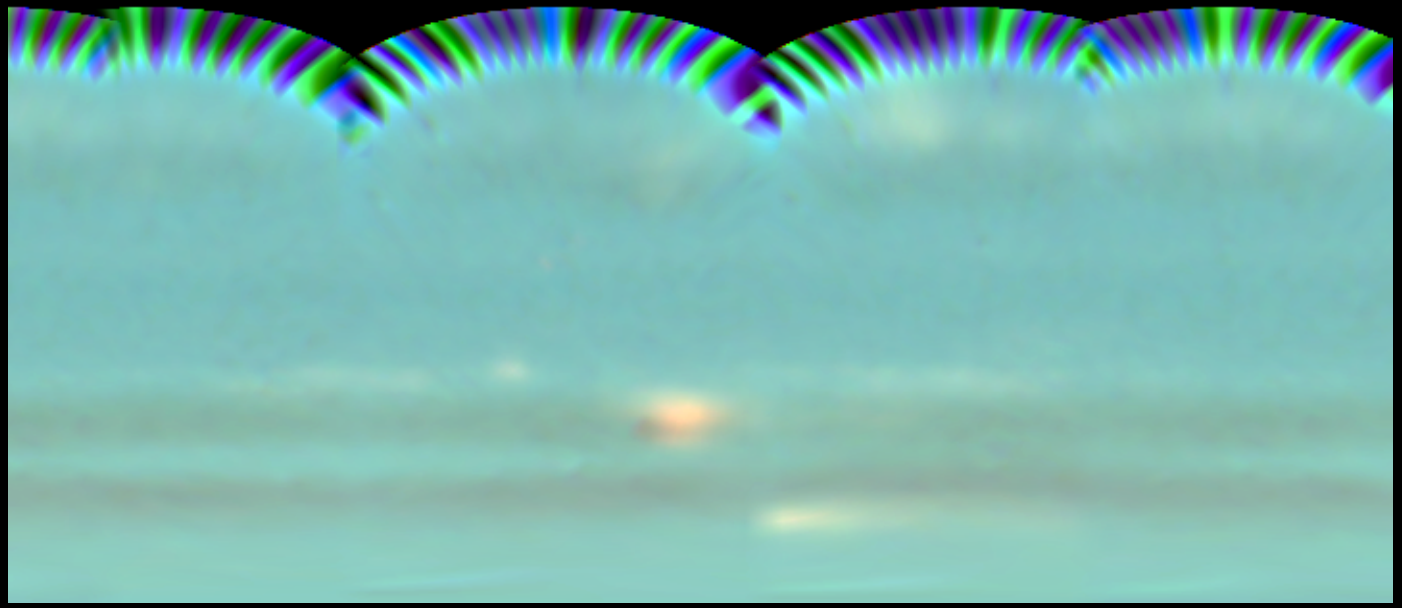
# upiter: Ongoing

g Visible, IR and Radio data!



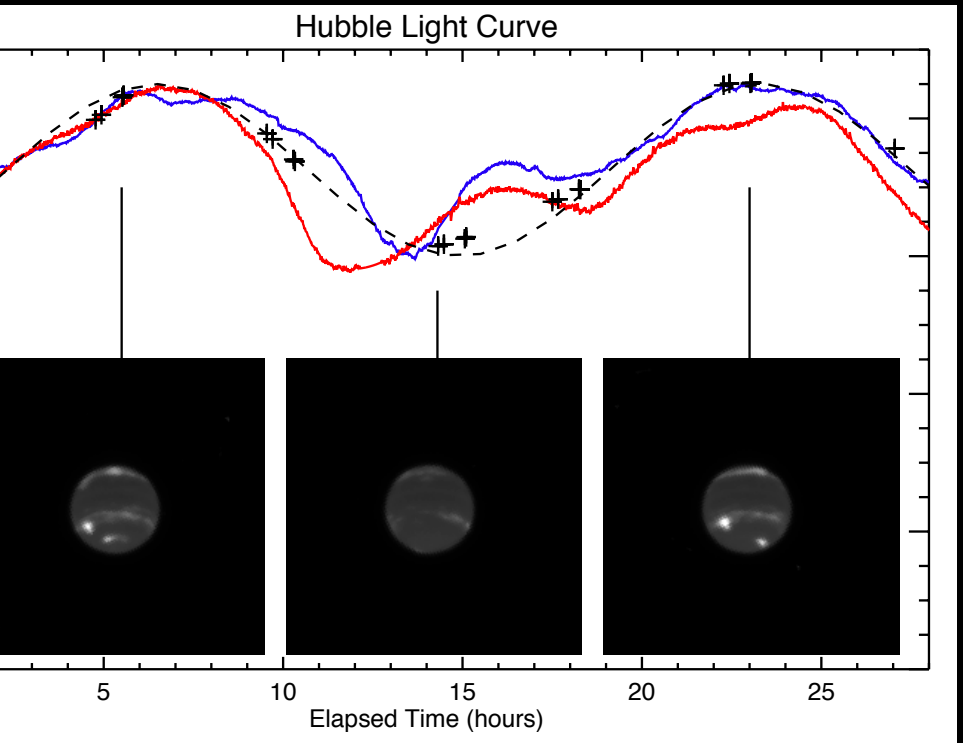

Cosentino et al., submitted

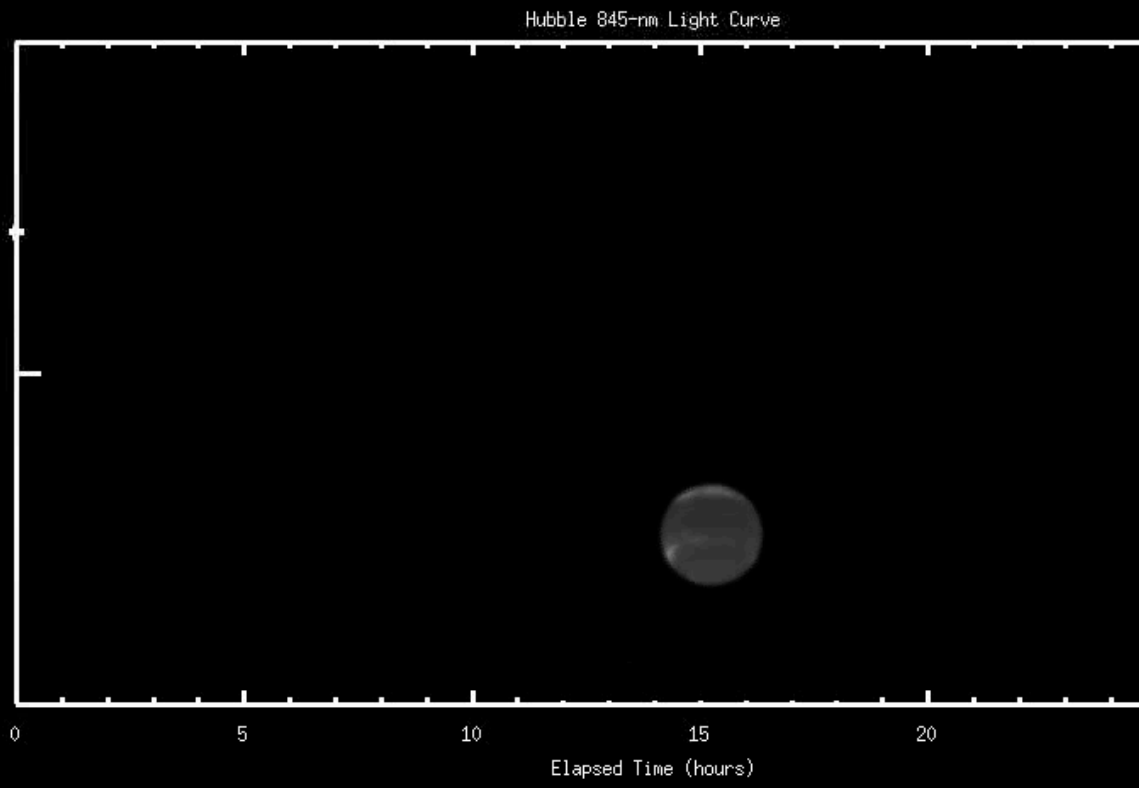
# Neptune: November 2015 and Oct. 2016



# Neptune: Results

place Kepler K2 light curve into context
erm variability (from clouds) important for
anding brown dwarf light curves



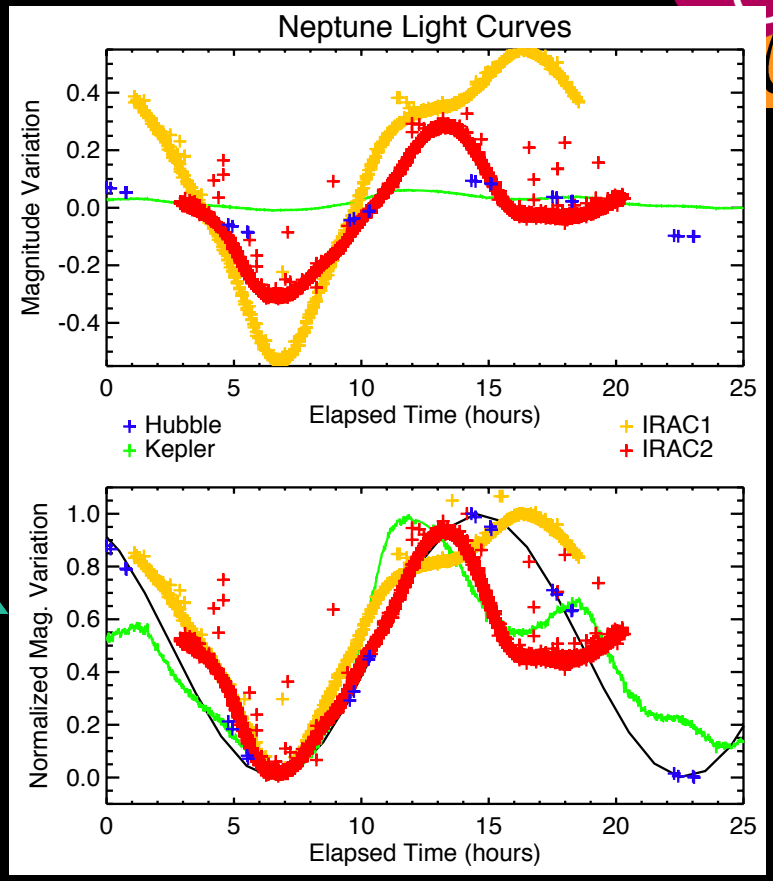

Simon et al ApJ 817, 162

# Neptune: Results

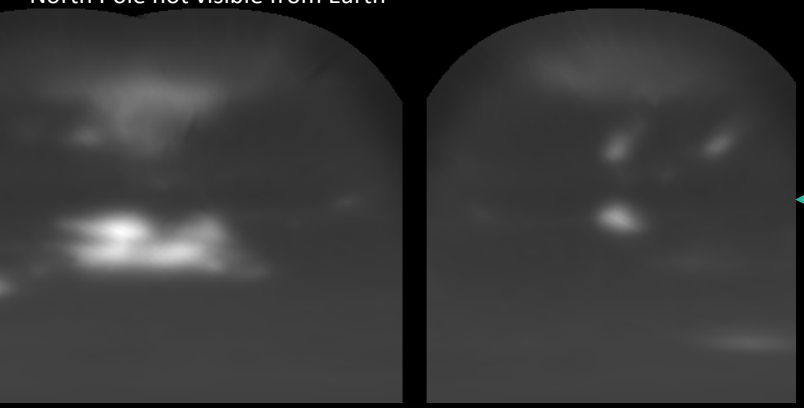
ptune was observed in the infrared by Spitzer/IRAC in Feb
16 and compared with visible data from Kepler and Hubble

plitude of brightness variations are caused by wavelength
sitivity; only the very highest clouds are seen at visible
velengths

ptune's rotation period (black line) dominates the light
ves, but deviations indicate rapid evolution of large cloud
tures




2016 Hubble 2D Global Map Projection (red wavelength)
North Pole not visible from Earth

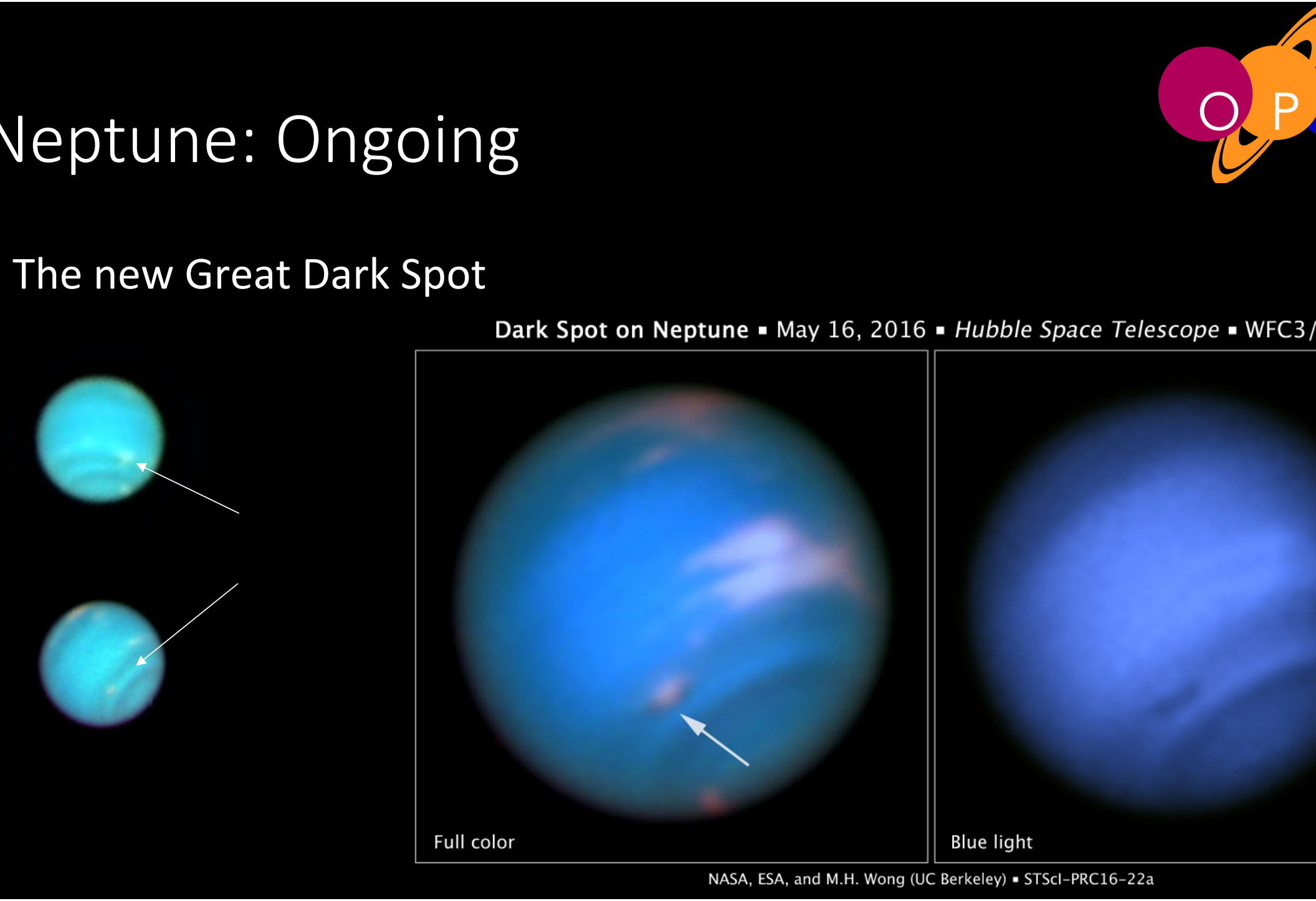



Imaging provides ultimate ground-truth, important for interpreting variability in light curves from unresolved stellar objects and exoplanets

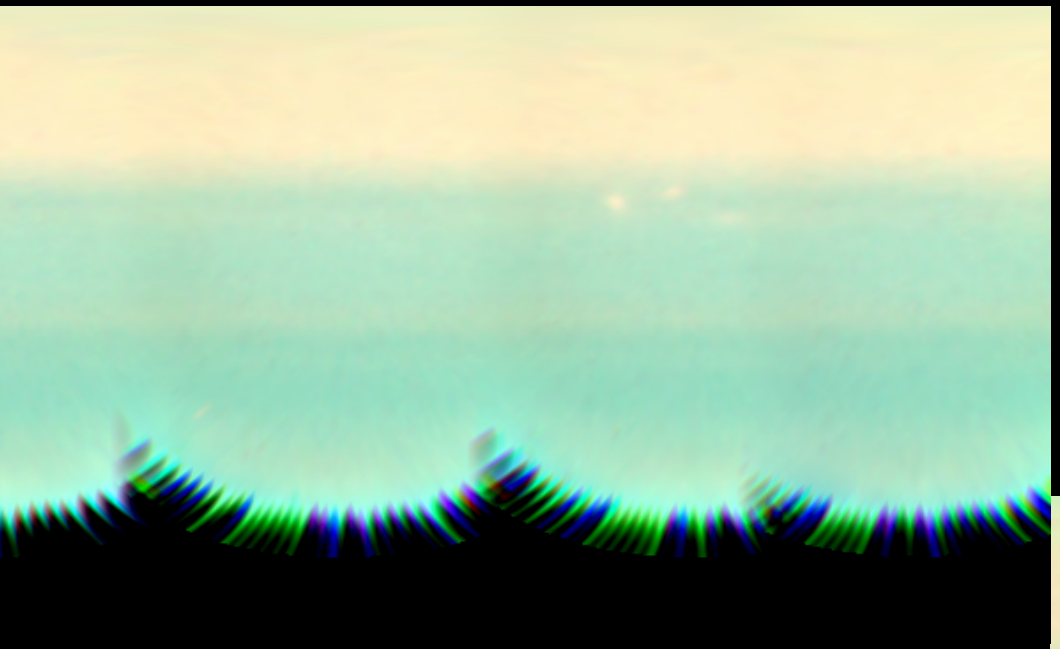
Stauffer et al., *Astronomical Journal*, in press

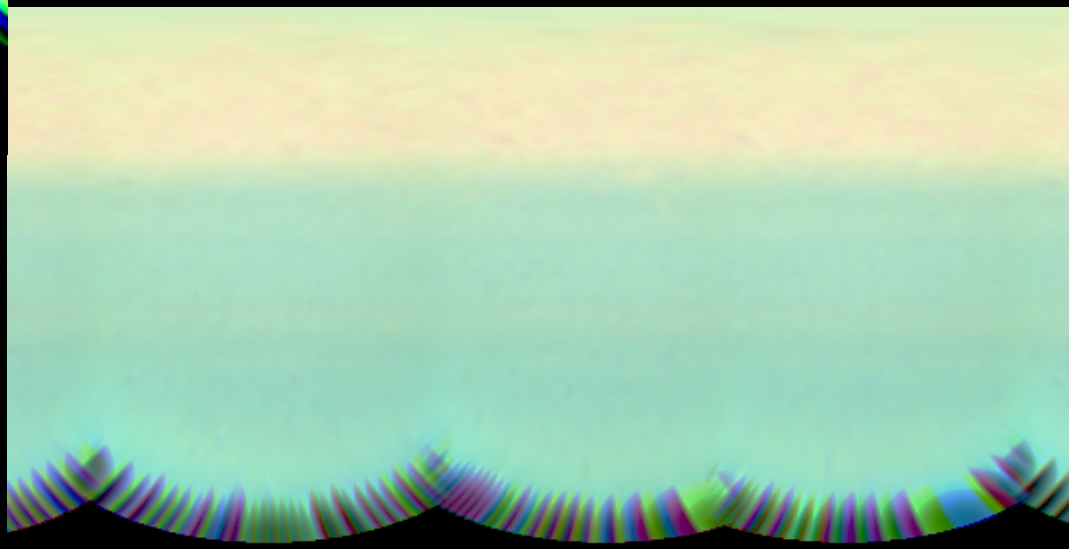
# Neptune: Ongoing

## The new Great Dark Spot

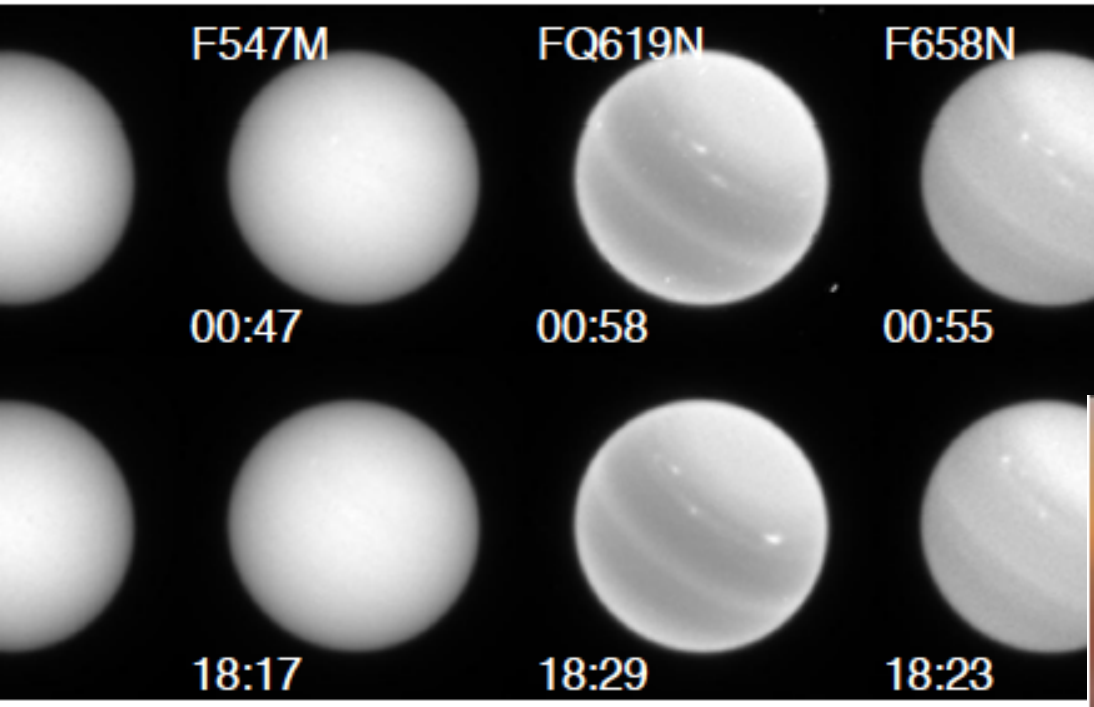


# Uranus: Nov. 2014, Sept. 2015, 2016





# Uranus: Results

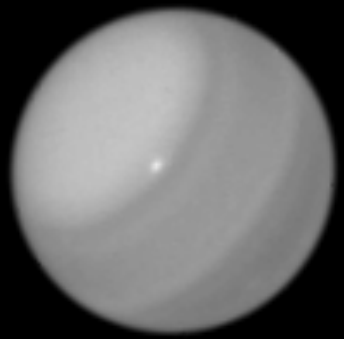


actually had quite a bit of cloud activity, less in 2015
bined with ground-based SINFONI and IRTF data to
ve cloud structure
t over such a broad wavelength range!
ct deep cloud, methane ice cloud, and hazes

Irwin et al., *Icarus* submitted

# Uranus: Ongoing

- New 2016 images show more distinct clouds.



# Summary

OPAL has already been scientifically productive

- 3 published papers, several more submitted or in prep

Formed a number of new collaborations and projects beyond our proposed science

Allows us to plan for simultaneous observations with other facilities

Value of multi-wavelength observations has been demonstrated (IRTF/VLT/VLA/Keck/others)

Supports other missions (an upcoming Juno periapse will coincide with next Jupiter observations)