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Neptune long-lived atmospheric features in 2013–2015 from small (28-cm) to large (10-m) telescopes

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ABSTRACT

Since 2013, observations of Neptune with small telescopes (28–50 cm) have resulted in several detections of long-lived bright atmospheric features that have also been observed by large telescopes such as Keck II or Hubble. The combination of both types of images allows the study of the long-term evolution of major cloud systems in the planet. In 2013 and 2014 two bright features were present on the planet at southern mid-latitudes. These may have merged in late 2014, possibly leading to the formation of a single bright feature observed during 2015 at the same latitude. This cloud system was first observed in January 2015 and nearly continuously from July to December 2015 in observations with telescopes in the 2-10-m class and in images from amateur astronomers. These images show the bright spot as a compact feature at −40.1 ± 1.6° planetographic latitude well resolved from a nearby bright zonal band that extended from −42° to −20°. The size of this system depends on wavelength and varies from a longitudinal extension of 8000 ± 900 km and latitudinal extension of 6500 ± 900 km in Keck II images in H and Ks bands to 5100 ± 1400 km in longitude and 4500 ± 1400 km in latitude in HST images in 657 nm. Over July to September 2015 the structure drifted westward in longitude at a rate of 24.48 ± 0.03°/day or −94 ± 3 m/s. This is about 30 m/s slower than the zonal winds measured at the time of the Voyager 2 flyby. Tracking its motion from July to November 2015 suggests a longitudinal oscillation of 16° in

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amplitude with a 90-day period, typical of dark spots on Neptune and similar to the Great Red Spot oscillation in Jupiter. The limited time covered by high-resolution observations only covers one full oscillation and other interpretations of the changing motions could be possible. HST images in September 2015 show the presence of a dark spot at short wavelengths located in the southern flank (planetographic latitude −47.0°) of the bright compact cloud observed throughout 2015. The drift rate of the bright cloud and dark spot translates to a zonal speed of −87.0 ± 2.0 m/s, which matches the Voyager 2 zonal speeds at the latitude of the dark spot. Identification of a few other features in 2015 enabled the extraction of some limited wind information over this period. This work demonstrates the need of frequently monitoring Neptune to understand its atmospheric dynamics and shows excellent opportunities for professional and amateur collaborations.

1. Introduction

Early studies of the planet Neptune showed that, in spite of its large distance to the Sun, and unlike Uranus, its atmosphere is very dynamic with several sources of variability (Belton et al., 1981; Hammel, 1989; Ingersoll et al., 1995 and references therein). Historically, the small angular size of Neptune (maximum diameter of 2.3′′) resulted in a lack of spatially resolved observations of the planet until the arrival of the Voyager 2 in 1989 (Smith et al., 1989). The launch of the Hubble Space Telescope (HST) and the development of high performance Adaptive Optics (AO) on large ground-based telescopes allowed monitoring the atmospheric activity of the planet at high resolution. Neptune shows rapidly varying cloud activity, zonal bands that change over the years, long-lived dark ovals and sporadic clouds around them (e.g. Limaye and Sromovsky, 1991; Baines et al., 1995; Ingersoll et al., 1995; Karkoschka, 2011; Sromovsky et al., 2001b; Sromovsky and Fry, 2002; Fry and Sromovsky, 2004; Martin et al., 2012.; Fitzpatrick et al., 2014). Recently, spatially resolved observations of the planet have also become possible at thermal infrared (Orton et al., 2007; Fletcher et al., 2014), millimeter (Luszcz-Cook et al., 2013) and radio wavelengths (de Pater et al., 2014) opening the possibility to study the thermal structure of the stratosphere and the structure of the troposphere below the visible clouds (de Pater et al., 2014).

Neptune's global circulation is dominated by a broad retrograde westward equatorial jet with a peak velocity of 350 m/s that diminishes at higher latitudes until it gives way to prograde winds from mid-latitudes to the South Pole (and presumably also in the North polar region not yet observed) in a narrower eastward jet with a peak velocity of +300 m/s at −74°S (Sánchez-Lavega et al., 2017). These winds were first measured in images at visible wavelengths from the Voyager 2 spacecraft in its flyby of the planet in 1989 (Stone and Miner, 1991; Limaye and Sromovsky, 1991; Sromovsky et al., 1993). Later wind measurements were obtained from images acquired by Adaptive Optics instruments on the Keck II telescope operating in the near infrared at 1–2.3 μm (Fry and Sromovsky, 2004; Martin et al., 2012; Fitzpatrick et al., 2014; Tollefson et al., 2017) and from HST images in the visible (e.g. Hammel and Lockwood, 1997; Sromovsky et al., 2001b; Sromovsky and Fry, 2002). These observations are sensitive to clouds and hazes from 0.1 to 0.6 bar (Fitzpatrick et al., 2014). Zonal wind profiles from those measurements are generally consistent with the one derived from Voyager 2. However there is a large dispersion of velocities in analysis of features tracked over short time periods when compared to the Voyager results (Limaye and Sromovsky, 1991; Martin et al., 2012). Part of this variability might be caused by vertical wind shear (Martin et al., 2012; Fitzpatrick et al., 2014), specially close to the Equator where vertical wind shear can be on the order of 30 m/s per scale height from Voyager IRIS data (Conrath et al., 1989) and similarly from IR data in 2003 (Fletcher et al., 2014). Most of this variability seems linked to the different apparent motions of bright and large features observed over long time-scales compared with smaller and fainter clouds observed only for a few hours and in many cases affected by their interaction with large features nearby. Therefore, sources of variability in zonal wind measurements include intrinsic variability of the small clouds, vertical wind shear, and the short time differences from consecutive images used for some measurements that introduce uncertainties that add to the real variability.

Studies of Voyager-2 images in the visible (Baines et al., 1995) and recent observations in the near infrared and at radio wavelengths (de Pater et al., 2014) conclude that the overall cloud structure of the planet consists of different vertical layers that vary with latitude and time (Irwin et al., 2016). The main cloud deck level (made of methane ice crystals), observed only at wavelengths not sensitive to methane absorption is estimated to lie at around the 2–3 bar level (Irwin et al., 2011). At southern tropical to mid-latitudes a belt of hazes, visible in methane absorption bands, is located at P ∼300–600 mbar and is overcast intermittently by a stratospheric haze possibly made of condensed hydrocarbons at 20–30 mbar that could arise from changing temperatures or from materials brought up from the troposphere. The latitudinal position, overall activity and latitudinal extension of this bright belt changes from year to year. For instance, in 2013 it extended roughly from −45° to −27° with diffuse latitudinal limits and it acquired a more compact structure in 2015 with a latitudinal size from −42° to −21° At northern mid-latitudes the main cloud seems quite similar while the stratospheric clouds seem to be located a bit higher, near 10 mbar. Based on maps of the thermal emission and hydrocarbons abundances in Neptune's stratrosphere obtained from Voyager observations in the mid infrared, Conrath et al. (1991) and Bézard et al. (1991) proposed a global circulation of the atmosphere with rising cold air at mid latitudes and overall descent at the Equator and the polar latitudes. This global circulation has been further explored to explain also the cloud structure in the planet by de Pater et al. (2014). This overall structure matches Neptune's distribution of ortho/para hydrogen and thermal structure at the time of the Voyager-2 encounter (heliocentric longitude L_S = 236°, Conrath et al., 1989). It also matches the visual aspect at near infrared wavelengths (1.2–2.3 μm) for the last few years, which is characterized by bright belts of clouds at northern and southern mid-latitudes as well as occasionally bright south polar features. This visual aspect of the planet corresponds to early autumn in the south hemisphere (southern summer solstice was in 2005 and heliocentric longitudes from 2013 to 2015 were 287° to 293°). An analysis of vertical wind shear in the equatorial region, however, is consistent with upwelling at $P >$ 1 bar, suggesting a more complex circulation pattern, such as a stacked-cell circulation with reversed flow above and below 1 bar (Tollefson et al., 2017).

A challenge to our understanding of the atmosphere is the sparse temporal sampling of high-resolution images of the planet. Much better temporal sampling has been achieved within the last few years by amateur astronomers using small telescopes of 50 cm or smaller to monitor some of Neptune's atmospheric