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STUDIES OF ATMOSPHERIC PHENOMENA IN THE GIANT PLANETS WITH GRANTECAN

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RESUMEN

Las atmósferas de los planetas gigantes (Júpiter, Saturno, Urano y Neptuno) muestran una rica variedad de fenómenos dinámicos de diferentes escalas espaciales y temporales que se encuentran lejos de ser entendidos. La instrumentación en desarrollo para el telescopio GTC de 10 m, permitirá observar la dinámica de estos fenómenos al nivel de las nubes, su caracterización térmica y la distribución de constituyentes menores. Proponemos diferentes tipos de observaciones para el estudio de los vientos zonales, la meteorología (vórtices, tormentas convectivas, ondas) y la estratificación de las nubes superiores y las propiedades de sus partículas constituyentes.

ABSTRACT

The atmospheres of the giant planets (Jupiter, Saturn, Uranus, and Neptune) exhibit a rich variety of dynamical phenomena at different spatial and temporal scales that are yet not fully understood. The instrumentation under development for the 10 m GTC telescope will allow us to observe the dynamics of such phenomena at cloud level, and to characterize their temperature and minor constituent distributions. We propose different types of observations for the study of the zonal wind profile, meteorology (vortices, convective storms, and waves) and upper cloud layering and particle properties.

Key Words: **PLANETS AND SATELLITES: JUPITER, NEPTUNE, SATURN, URANUS**

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1. INTRODUCTION

Our knowledge of the atmospheric properties of the giant planets (Jupiter, Saturn, Uranus, and Neptune) relies on the information gathered by continuous observations with ground-based telescopes, data taken during the limited lifetimes of Earth-orbiting satellites (e.g., most recently, *ISO* and the *Hubble Space Telescope*, and finally (and most importantly), from a battery of spacecraft visits. There have been the following missions to the outer planets: 1) Jupiter flybies: *Pioneer 10* and *11* (1973 and 1974), *Voyager 1* and *2* in 1979, *Cassini* in 2000, and finally the *Galileo* probe in 1995 and orbital vehicle (1995–2003); 2) Saturn flybies: *Pioneer 11* (1979), *Voyager 1* and *2* (1980 and 1981), and the *Cassini* orbiter (starting 2004); 3) Uranus flyby: *Voyager 2* (1986); and 4) Neptune flyby: *Voyager 2* (1989). The only ongoing mission in the near future to the giant planets is the *Cassini* orbiter to Saturn, with no other approved project to the other planets yet. Thus, the study of the atmospheric phenomena that develop in these planets will remain, in the following years, in the observational domain of Earth-based and Earth-orbiting telescopes.

Observations of the giant planets with a 10 m class telescope such as Grantecan will be most probably short in time acquisition but will need to have very high spatial resolution to discern the smallest possible dynamical scales The first-light instrumentation (as described in this volume) will be sensitive to different properties of these atmospheres. The spectra of the giant planets consist basically of two parts: at wavelengths below $\sim 3\ \mu$m, we see sunlight reflected by clouds and haze, whereas at longer wavelengths we see the thermal emission from the planet as a black body at a given temperature. The distribution of clouds and haze in the lower stratosphere and upper troposphere will be sensed in the imaging mode by OSIRIS (the 0.3–1 μm wavelength range) and EMIR (1–2.5 μm). On the other hand, the 8–24 μm wavelength range covered by CanariCam will sense in addition to the cloud field, the temperature and composition distributions in the lower stratospheres and upper tropospheres. In the following, I present what I consider to be some important topics in the atmospheric research of the giant planets that can be addressed with such a telescope and instrumentation.

TABLE 1

DATA FOR GIANT PLANETS OBSERVATIONS

Planet	Rotation period [hr]	Diameter [arcsec]	Resolution [km]
Jupiter	9.925	45-48	225
Saturn	10.65	18-20	500
Uranus	17.24	3.7	1000
Neptune	16.11	2.3	1600

2. ATMOSPHERIC PHENOMENA STUDIES

Table 1 gives the minimum size of a resolved planetary feature in these planets assuming a seeing-limited resolution of 0.15 arcsec (wavelength range from 0.3 to 10 μm). Deconvolution techniques using the point spread function (PSF) from nearby satellites and/or the use of an adaptive optics (AO) system in the near-infrared (the EMIR window), will make further improvements in this resolution capability, dividing its value by a factor 2. On the other hand, because of the rapid rotation rate of these planets and the constraints produced on the observing window by the low declination of Uranus and Neptune at the latitude of the GTC, about two hours of observations per night during three consecutive nights would be required to cover all planetary longitudes.

2.1. *General circulation*

The general circulation of the giant planets is dominated at the main cloud deck level (pressure range ~200–800 mbar) by a system of zonal jets (i.e., the mean motions take place along the parallels), alternating their east–west direction with latitude. Jupiter has 15 eastward jets (Limaye 1986) with maximum flow speeds of 180 m s^{-}, Saturn has seven to eight eastward jets with flow speeds reaching 500 m s^{-1} at the equator (Sánchez-Lavega et al. 2000), Uranus has two broad eastward jets (maximum speed about 200 m s^{-1}) and one westward jet of -100 m s^{-1} (Hammel et al. 2001), and Neptune has mainly one broad westward jet with velocity -400 m s^{-1} (Limaye & Sromovsky 1991). At present, there is no consensus concerning the origin of such circulations, nor on their main driving sources (internal and/or external heating, plus latent heat transformations Ingersoll 1990; Gierasch & Conrath 1993; Dowling 1995. One way to address this point is to search for temporal changes in the zonal wind profiles (for example, testing their stability and maintenance against the seasonal forcing).

Cloud tracking of individual elements at each latitude (the resolution here should be better than 0.5 deg for Jupiter and Saturn and ~2 deg for Uranus and Neptune), yield the longitudinal drift rate of the target and finally its wind velocity with respect to the internal rotation rate (in Table 1 the rotation period of each planet is given). Alternatively, one can use a temporal correlation between two east–west brightness profiles to derive the mean drift rate as a function of latitude. The accuracy in the wind velocity determination is of the order of the size of the feature divided by the tracking time, and for features with sizes equal to the resolution limit, a miminum tracking time of 24 hr is required to get velocity errors below ~5 m s^{-1}.

For Jupiter, this kind of analysis has been performed recently using high resolution imaging with the *HST* (García-Melendo & Sánchez-Lavega 2001). For Saturn, a study is under way using the *HST* and ground-based images (Sánchez-Lavega et al. 2000). The *HST* imaging has also allowed us to make the first improvements on Uranus' wind profile (Hammel et al. 2001) and to complement and study changes in the Neptune profile (Sromovsky et al. 2001). But more systematic observations at high resolution are needed, in particular for Uranus and Neptune. For these two planets, imaging in the near-infrared wavelength range (1–2.5 μm) is very useful because of the possible use of AO systems, and also because high altitude clouds are common and have high contrast when imaged at 2.12 μm (in the wing of the hydrogen absorption band) and in the 2.3 μm methane absorption band (de Pater 2000).

Above the clouds, meridional temperature measurements at different levels (from ~4 to 400 mbar), and the use of the thermal wind relation from meteorology, allows us to retrieve the dependence of the zonal wind velocity on altitude outside beyond the equatorial latitudes. This requires that spatially resolved measurements of the infrared flux be converted to temperatures through radiative transfer modeling. The horizontal temperature resolution inferred from such measurements is much less than that from imaging information, but has served to infer that, globally, the winds decrease in intensity with altitude in the jovian atmospheres (Gierasch & Conrath 1993). CanariCam spectra and images could also constrain the vertical wind shears, particularly for Jupiter and Saturn. The required precision in the temperature retrievals should be $\sim$0.2 K and the vertical resolution below one scale height ($\sim$20–40 km).

Below the clouds, there is only direct information of the winds for the ojvian case at the latitude and longitude of the *Galileo* entry probe site (a "hot spot" region, see next section) (Atkinson et al. 1998). These levels are not accessible to remote sensing, so inferences concerning the winds beneath the cloud deck must be indirectly constrained through dynamical modeling.

2.2. *Meteorology*

Different types of meteorological features and dynamical processes can be monitored in the optical range at the nominal resolution of the GTC (Table 1):

1. Vortex genesis and interactions (anticyclones and cyclones). Closed vortices have been observed in all the planets with the probable exception of Uranus. Of special interest are, for example, the large-scale "Great Dark Spots" that form on Neptune and have been observed to migrate in latitude (Hammel et al. 1995). Another example of an important occasional phenomenon was the recent merger of three long-lived and large-scale white ovals on Jupiter (Sánchez-Lavega et al. 2001) (see Figure 1).

2. Convective storms are transient phenomena detached from background clouds by their brightness and rapid evolution. A good example are the Great White Spots that developed on Saturn in 1990 (Sánchez-Lavega et al. 1991) and 1994 (Sánchez-Lavega et al. 1996), and the South Equatorial Belt disturbances on Jupiter (Sánchez-Lavega et al. 1996b).

3. Waves at cloud level. Examples are Jupiter's south polar wave (Sánchez-Lavega et al. 1998) and Saturn's northern hemisphere polar "hexagon" (Godfrey 1988; Sánchez-Lavega et al. 1993) and mid-latitude "ribbon" (Sromovsky et al. 1983).

4. Hot spots in Jupiter's North Equatorial Belt: genesis and demise, interactions, zonal distribution and motions (probable wave nature (Ortiz et al. 1998)). Confirmation and optical counterparts to the recently discovered Saturn cold spots (Yanamandra-Fisher et al. 2001).

Other meteorological phenomena have also been observed in the thermal infrared:

5. Thermal waves and related phenomena. Meridionally oscillating temperatures have been observed in the stratosphere ($\sim$ 20 mbar) and upper troposphere ($\sim$ 250 mbar) of Jupiter (Orton et al. 1991; Orton et al. 1994). Temperatures are retrieved from measurements of the thermal infrared flux at the wavelengths of the CH_4 emission (7.8 μm, stratosphere) and H_2 collision-induced absorption (18.2 μm, troposphere). These are two well-mixed gases whose emission is sensitive to the temperature. This wavelength range is well covered by CanariCam, which should therefore provide high resolution images with good thermal sensitivity (relative brightness temperatures should be measured with a precision $\sim$0.2 K). This can be done not only for Jupiter, but also for Saturn, and perhaps for Uranus and Neptune (at least at 8 μm).

Another aspect that can be addressed with CanariCam observations is the compositional and/or thermal seasonal variability, as derived from time series of images obtained with filters centered on the hydrocarbon emissions. Long-term changes in Saturn's polar regions have been detected in this way (Gezari et al. 1989; Ollivier et al. 2000). The emission at 11.7 μm (ethane, C_2H_6) senses the tropospheric level ($\sim$500 mbar) and emission at 13.3 μm (acetylene, C_2H_2) senses a level close to the tropopause ($\sim$250 mbar). Similar studies can be addressed for the other planets. Determination of the gaseous abundances would require a precision of at least 20%.

The correlation of observations of meteorological phenomena in the broad spectral range covered by the GTC instrumentation will be one of the major contributions. For example, the clouds associated with a new convective storm can be tracked at different levels with images obtained at selected wavelengths in the 0.3 to 2.5 μm (Sánchez-Lavega et al. 1996), and at the same time, differences in the temperature and minor components (e.g., ammonia, ethane, and acetylene) relative to neighboring clouds could be retrieved. These will be altogether essential ingredients for future dynamical modeling.

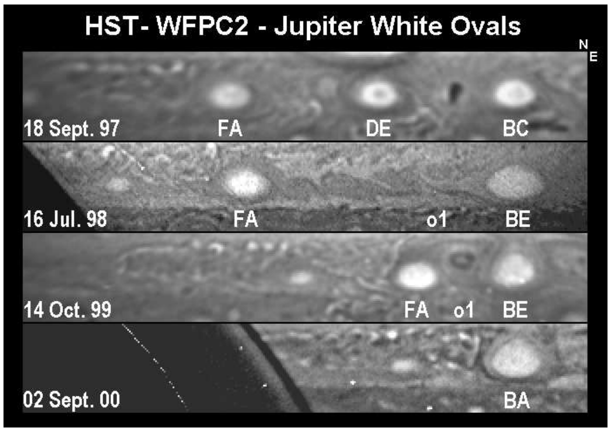

Fig. 1. Mosaic of the sequential merger of the three jovian white ovals (BC, DE, and FA) from 1997 to 2000 at the wavelength of the methane absorption band in 890 nm . See (Sánchez-Lavega et al. 2001) for details.

2.3. *Cloud vertical structure and particle properties*

As indicated, the optical and near-infrared wavelengths sense the reflected light from the cloud layers and haze in the lower stratosphere and upper troposphere (within a pressure range from $P \sim 5$ mbar to 2 bar). The diffuse reflected sunlight includes Rayleigh scattering by hydrogen and helium, and absorption from gaseous bands. Photometrically calibrated images at selected wavelengths in the ultraviolet, in the methane bands and in their adjacent continua, can be used to retrieve the layered vertical distribution of clouds and haze, and the properties of the constituent particles (single scattering albedo, or Mie parameters if assumed to be spheres) as a function of latitude. These data are important for diagnostics of the heating and cooling mechanisms operating in the troposphere. The methane absorption bands at 619, 735, and 890 nm are particularly useful since they sense different atmospheric levels. High resolution images with filters isolating these bands are necessary because of the calibration problems with the *HST* at the methane band wavelengths. Typically, limb-to-limb variations of the reflectivity (along a parallel circle), or the reflectivity variations when tracking discrete cloud targets from limb to limb, can be used for the radiative transfer modeling, (e.g., Acarreta & Sánchez-Lavega 1999). Adequate modeling of the albedo will require better than 5% precision.

3. CONCLUSIONS

The GTC must play a significant role in the studies of atmospheric phenomena in the giant planets. In the case of Jupiter and Saturn, the main contribution could be the study of occasional phenomena (convective storms, vortex genesis, mergers, interactions) and long-term phenomena (thermal waves and disturbances, stability of the zonal wind system). The GTC instrumentation could also contribute to complement and support the observations of the *Cassini* mission to Saturn. For Uranus and Neptune, regular observations are required because of the limited data at present available on circulation and meteorology. The use of AO will make the GTC fully competitive.

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