Session 1. Planets, Satellites, and Asteroids

UNIQUE INFRARED STUDIES OF PLANETARY ATMOSPHERES: THE CASSINI/HUYGENS MISSION AND GROUND–BASED STUDIES

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Space flight missions have been in the forefront of astronomical discoveries in recent years and will continue to play an even greater role in astronomical and planetary studies in the year 2000 and beyond. Astronomical Space science missions require a great deal of supporting work to achieve their successes. Different disciplines of astronomy and space science, ground-based observations, laboratory and theoretical studies are needed to plan and execute the mission and to interpret measured data. They also provide a great opportunity for international cooperation and participation. Figure 1 illustrates the components that go into the planning and execution of space science missions. Ground-based studies play an important role in identifying measurement goals, and in providing complementary studies at higher spectral resolution, spectral coverage, and long term temporal coverage not possible with spacecraft. The NASA/ESA Cassini/Huygens mission to the Saturnian system and ground-based infrared heterodyne spectroscopic measurements provide an excellent example of the need and complementary nature of ground-based and space-based studies.

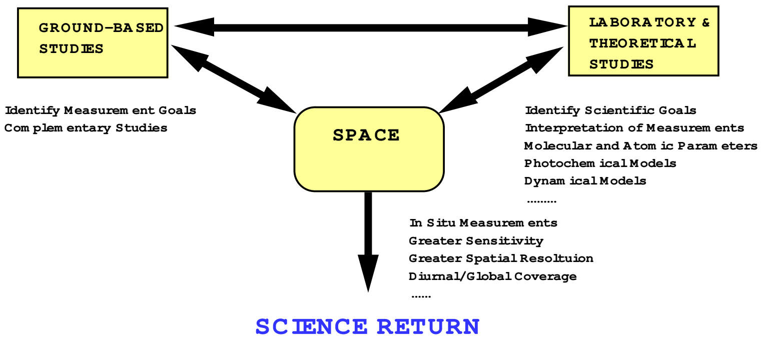

Figure 1: Components of space science missions

The Cassini/Huygens mission was launched October 15, 1997 with a scheduled encounter with Saturn July 1, 2004. Among the major goals of the mission is to study the composition, temperature structure and winds in the atmospheres of Saturn and Titan. En route to Saturn the spacecraft swings by Jupiter within ~140 Jovian radii (~10^7 km) on December 30, 2000 providing a unique opportunity to study Jupiter, its atmosphere and intense aurora.

The Composite Infrared Spectrometer, (Kunde *et al.*, 1996), on the Cassini spacecraft is a Fourier Transform Spectrometer covering the 3–1000 μm spectral region with three focal planes. The 9–16 μm region is covered by a 10-element linear array in focal plane 3, FP3 with a spectral resolution of 0.5 cm^{-1}. During the Jupiter flyby CIRS will be used to determine Jupiter's temperature distribution, hydrocarbon abundances, distribution of CO_2, $^{15}N/^{14}N$ ratio, and to study Jupiter's mid-infrared aurora. The CIRS field of view (FOV) on Jupiter

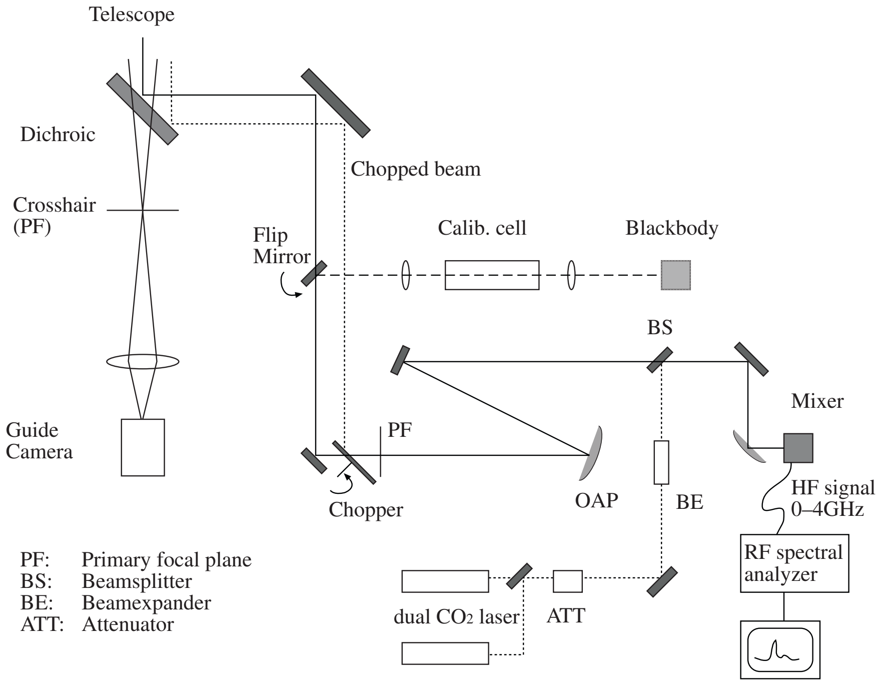

Figure 2: HIPWAC optical schematic

varies with distance, but at the time of closest approach is ~1 arcsec.

Ground-based measurements of Jupiter will be made during the flyby period using the Goddard Space Flight Center infrared heterodyne spectrometer, Heterodyne Instrument for Planetary Wind And Composition, HIPWAC (Schmuelling *et al.*, 2001). The instrument will cover the 9–12 μm spectral region with a much higher spectral resolution 0.00086 cm^{-1} and 0.00017 cm^{-1} than CIRS. Fully resolved spectral lines of ethane C_2H_6 and ethylene C_2H_4 near 12 and 10.5 μm, respectively, will provide complementary data on molecular abundances, temperature, and their altitude and north-south distribution, as well as the mid-infrared aurora. The HIPWAC spectral resolution permits the measurement of true line shapes and thus enables the retrieval of both abundance and temperature information, particularly in the hot auroral regions. The mid-infrared aurora has been studied in this way over a long-term period (*e.g.*, Kostiuk *et al.*, 1987; Kostiuk *et al.*, 1993; Livengood *et al.*, 1993). The FOV on Jupiter is 1 arcsec throughout the period and thus will provide higher spatial information at times before and after the closest approach, supporting the CIRS measurements. The schematic of the HIPWAC optical front end is given in Fig. 2. The telescope source beam is collimated and combined with an expanded CO_2 laser local oscillator beam at the ZnSe beam splitter and the combined beams are focused onto a HgCdTe photodiode mixer (Spears, 1977). The difference frequency between the laser and source beam generated in the photomixer is in the radio frequency (RF) region of the spectrum and preserves the intensity and frequency information of the source within ~4 GHz of the laser frequency. This RF signal is amplified and fed into a RF filter bank where it is analyzed and the data stored on a computer. A detailed description of the heterodyne technique and its application is given in Kostiuk (1994).

An example of the retrieval of both abundance and temperature information from infrared heterodyne spectra is given in Fig. 3. Ethane emission lines from the north auroral region are shown at 25 MHz (0.00086 cm^{-1}) resolution (right side). The solid line is a model fit to the data (histogram). In the upper plots a nominal thermal profile shown on the left was used and the C_2H_6 abundance was varied. Even with an unreasonably large abundance, mole fraction $= 25 \pm 8 \times 10^6$ a good fit can not be obtained. Modifying the thermal profile as shown in the lower plots as well as abundance, a good fit is obtained. Results show that the auroral emission is dominated by a significant increase in temperature in the upper stratosphere. Some chemical effects may also be present as indicated by the near two-fold increase in ethane abundance over the ~3×10^6 global quiescent mole fraction. The contribution functions indicating the pressure altitude regions contributing to the emission are shown on the left. CIRS observations can measure changes in ethane emission, but can not discriminate between temperature and abundance contribution to the measured emission spectra.

The science goals on Jupiter for CIRS and HIPWAC during the Cassini flyby period are given in Table 1.

Once at the Saturn system Titan's atmosphere and surface are primary targets of the Cassini mission and its

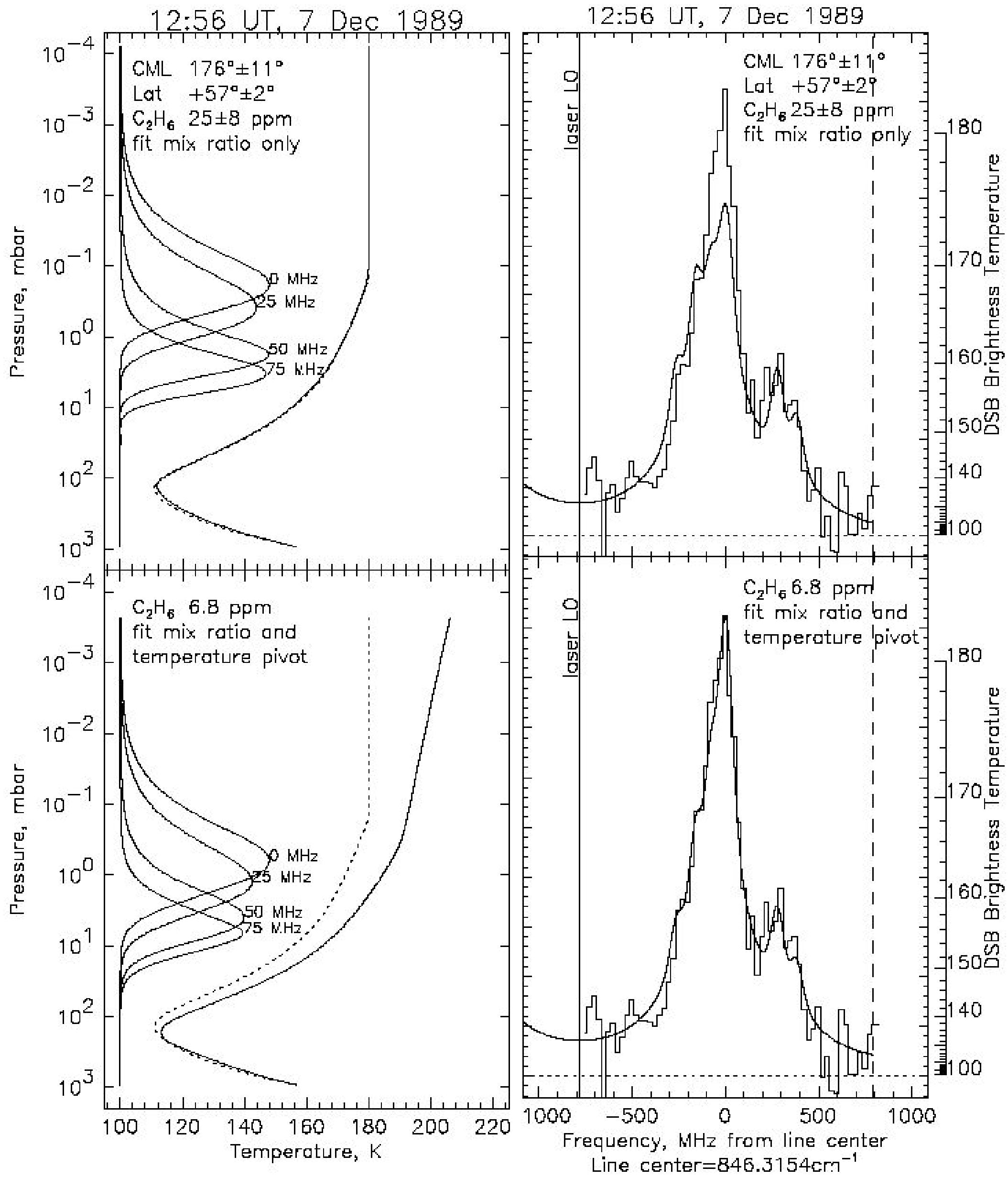

Figure 3: Jupiter's north ethane aurora

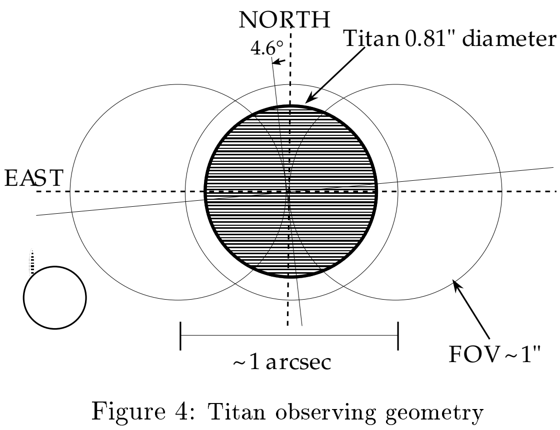

Figure 4: Titan observing geometry

Table 1:

CIRS FP3 SCIENCE GOALS ON JUPITER	HIPWAC SCIENCE GOALS ON JUPITER
Determine temperature distribution 10 to 1 mBar	Determine temperature distribution to < 0.1 mBar
Abundance and distribution of hydrocarbons *e.g.*, C_nH_m	Determine abundance and temperature from single line C_2H_6, C_2H_4
Sources of higher order HC's photochemistry *vs.* aurora	Equator *vs.* pole measurements
Mid-IR aurora	Temperatures and variability – additions to long term study; probe to 10 μBar
Determine $^{15}N/^{14}N$ ratio in NH_3	–
Meridional distribution of CO_2	–

PERFORMANCE PARAMETERS		
Spectral coverage	9 – 16 μm	9 – 12 μm
Spectral resolution	0.5 cm^{-1}	< 0.0008 cm^{-1}
FOV	Dec. 16, 2000: 2 arcsec Dec. 30, 2000: 1 arcsec	1 arcsec on 3-meter telescope $\sim$0.3 arcsec on 10-meter telescope

Huygens Probe (Lebreton, 1997). Knowledge of global circulation on Titan is particularly important. Titan's rotation period is long 16 days, making it the second slowest rotator (next to Venus) in our Solar System. Dynamics in atmospheres of slowly rotating bodies is poorly understood. The magnitude and direction of the resultant cyclostrophic circulation can not be determined from theory and indirect methods using thermal field data (Flasar, 1998) and stellar occultation (Hubbard *et al.*, 1993) can not determine wind direction. Direct measurements are needed to constrain theories of atmospheric dynamics in slowly rotating bodies (Hourdin *et al.*, 1995; Del Genio and Zhou, 1996). In addition, winds will transport the Huygens Probe horizontally during its parachute descent, determining its ultimate landing site and the length of time that communications can

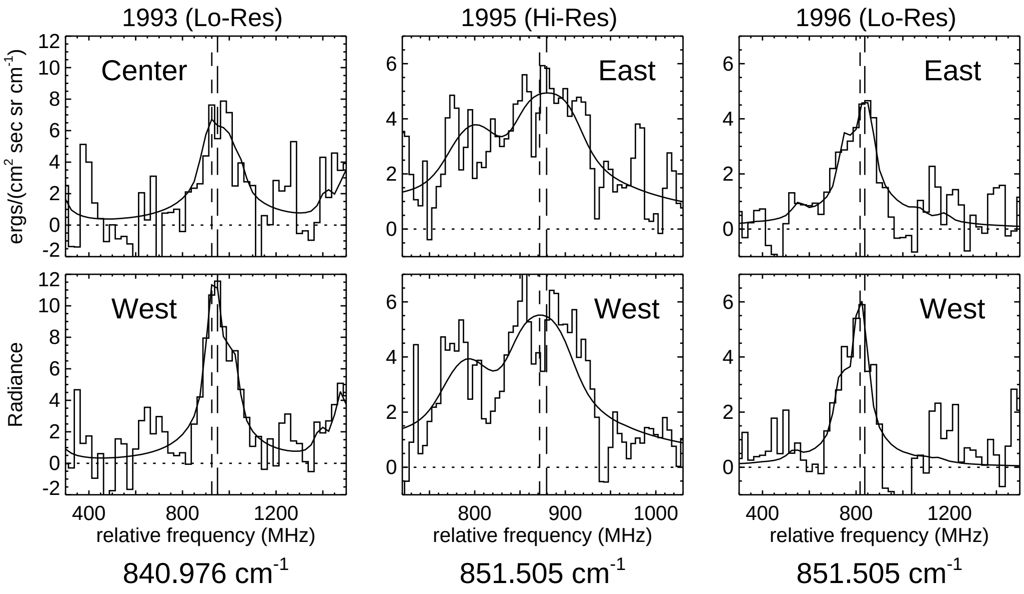

Figure 5: Doppler shift of ethane lines on Titan

be maintained and data transferred between the Orbiter and the landed Probe. Because the wind direction has not previously been determined, the direction of transport cannot be predicted with sufficient confidence to plan for it. Current mission plans attempt to mitigate the winds' effect on communication time by establishing a conservative error ellipse symmetric about zero wind velocity. This approach will limit the length of time for surface investigations. Knowing the magnitude and sense of the winds, the orbiter antenna pointing with respect to the probe entry point can be optimized for the longest possible communications and for surface studies, thus increasing the scientific information that can be retrieved from Titan.

Infrared heterodyne spectroscopy (IRHS) measurements of Doppler-shifted ethane (C_2H_6) emission line shapes from Titan's stratosphere (Kostiuk *et al.*, 1997) can be used to directly measure the direction and magnitude of Titan's zonal winds. Observations of the C_2H_6 emission lines near 11.8 μm from the ν_9 band were made in August 1993, in October 1995, and in September 1996, using the Goddard IRHS instrument at the Coude focus of the NASA Infrared Telescope Facility (IRTF) on Mauna Kea, Hawaii. The observing geometry is given in Fig. 4. Ethane line shapes and frequency positions were measured with the FOV positioned at the east limb and at the west limb on Titan's disc. Differences in the retrieved east and west line frequency positions (Fig. 5) after removing effects of systematic errors are attributed to Doppler shifts from a zonal wind field projected along the respective lines-of-sight. A prograde zonal wind with speed 210 ± 150 m/s, in the direction of Titan's rotation, was retrieved with 94% probability (Kostiuk *et al.*, 2001). The uncertainty, due primarily to the large 1 arcsec FOV on the limb of a 0.81 arcsec Titan (see Fig. 4), is too large for modification of the Huygens Probe release scenario. Since the heterodyne FOV is diffraction limited, using an 8-meter telescope (*e.g.*, Gemini North) would reduce the FOV to $\sim$0.3 arcsec and decrease the wind uncertainty by a factor of $\sim$5 in an equivalent integration time. This is the next goal of HIPWAC observations in support of the Cassini/Huygens mission. Besides data for the Huygens Probe release, results will provide complementary data for the Doppler Wind Experiment on Huygens (Bird *et al.*, 1997) and constraints on dynamical models for slowly rotating atmospheres.

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