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Temporally varying ethylene emission on Jupiter

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ABSTRACT

Ethylene (C_2H_4) emission has been measured in the poles and equator of Jupiter. The 949 cm^{-1} spectra were recorded with a high resolution spectrometer at the McMath–Pierce telescope at Kitt Peak in October–November 1998 and at the Infrared Telescope Facility at Mauna Kea in June 2000. C_2H_4 is an important product of methane chemistry in the outer planets. Knowledge of its abundance can help discriminate among the various proposed sets of CH_4 photolysis branching ratios at Ly-α, and determine the relative importance of the reaction pathways that produce C_2H_2 and C_2H_6. In the equatorial region the C_2H_4 emission is weak, and we were only able to detect it at high air-mass, near the limb. We derive a peak equatorial molar abundance of C_2H_4 of 4.5×10^{-7}–1.7×10^{-6} near 2.2×10^{-3} mbar, with a total column of 5.7×10^{14}–2.2×10^{15} molecules cm^{-2} above 10 mbar depending upon choice of thermal profile. We observed enhanced C_2H_4 emission from the poles in the regions where auroras are seen in X-ray, UV, and near infrared images. In 2000 we measured a short-term change in the distribution of polar C_2H_4 emission; the emission in the north IR auroral "hot spot" decreased by a factor of three over a two-day interval. This transient behavior and the sensitivity of C_2H_4 emission to temperature changes near its contribution peak at 5–10 microbar suggests that the polar enhancement is primarily a thermal effect coupled with vertical transport. Comparing our observations from Kitt Peak and Mauna Kea shows that the C_2H_4 emission of the northern non-"hot spot" auroral regions did not change over the three-year period while that in the southern polar regions decreased.

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1. Introduction

Ethylene (C_2H_4) was first detected on Jupiter by the Voyager IRIS experiment. Infrared emission by C_2H_4 was observed in an infrared auroral "hot spot" located in the region of the northern aurora, but not in other locations (Kim et al., 1985). Subsequently, Kostiuk et al. (1989) and Kostiuk et al. (1993b) confirmed the C_2H_4 enhanced polar hot spot emission. They interpreted the polar enhancement as due either to an 18-fold increase in abundance or to a 67–137 K increase in temperature at the 10-microbar level. Thermal emission from methane (CH_4), acetylene (C_2H_2), ethane (C_2H_6) and other hydrocarbons are also enhanced in Jupiter's polar regions (e.g. Kim et al., 1985; Jennings et al., 2001; Kunde et al., 2004) making the thermal explanation more likely, but not conclusive. Kostiuk et al. (1989) also detected C_2H_4 at Jupiter's equator. The equatorial emission also has been seen by Bézard et al. (2001). Equatorial C_2H_4 presumably represents the quiescent (non-auroral) atmospheric mixing ratio and is therefore crucial to constraining hydrocarbon photochemical models.

Atmospheric photochemical models of the outer planets have traditionally had problems predicting the ratio of C_2H_6 to C_2H_2 (e.g. see discussions in Allen et al., 1992; Romani, 1996; Moses et al., 2005). If free parameters in the model were adjusted to match the observed C_2H_2, then the predicted C_2H_6 was too low. If the observed C_2H_6 was reproduced then the predicted C_2H_2 was too high. Allen et al. proposed a reaction scheme to convert C_2H_2 to C_2H_6 via C_2H_4 formation (see Fig. 1). First, atomic hydrogen is added to C_2H_2 to form the vinyl radical, C_2H_3. Vinyl then reacts with either H or H_2 to form C_2H_4. Subsequent reactions with H convert the C_2H_4 first to the ethyl radical, C_2H_5, then to methyl, CH_3. Finally the CH_3 self-reaction forms C_2H_6. Thus observations of C_2H_4, the only stable species in this chain of reactions, offer an important insight to the coupled C_2H_2–C_2H_6 photochemistry.

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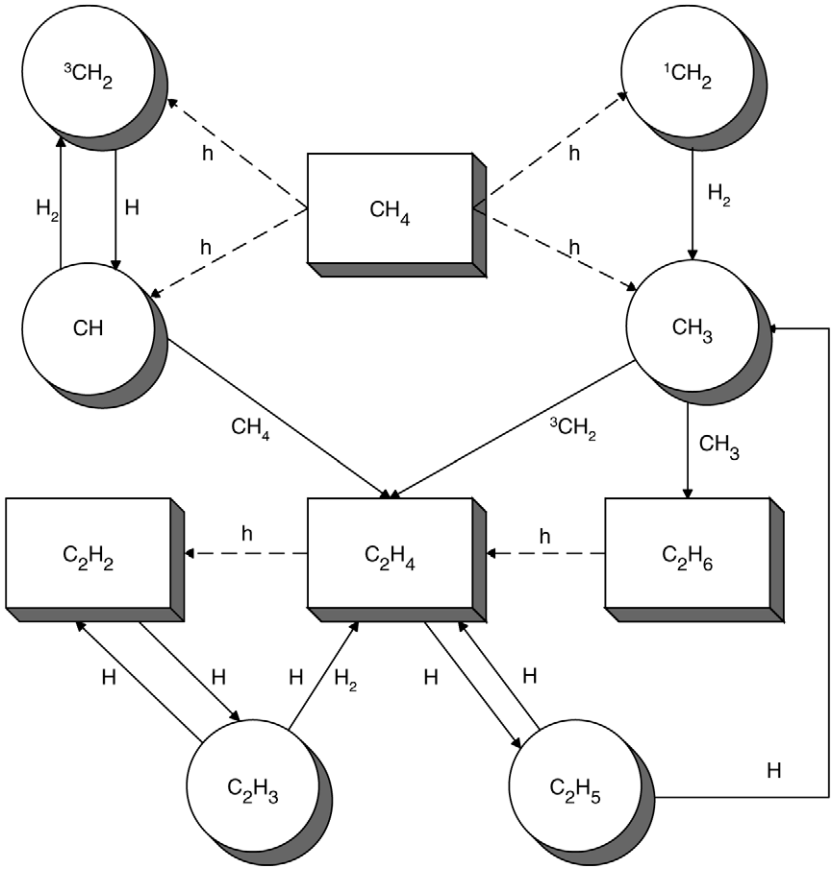

Fig. 1. Simplified methane photochemistry flow diagram showing the major photochemical pathways going from CH_4 photolysis to C_2H_4 production and loss. Rectangles are stable compounds, circles are free radicals, solid lines represent chemical reactions and dashed lines represent photolysis. $^1CH_2$ is excited (singlet) state methylene and $^3CH_2$ is ground state (triplet) methylene.

A successful model will give the observed abundances for C_2H_2, C_2H_6, and C_2H_4 simultaneously.

Additionally, Schulz et al. (1999) showed in the modeling of their detection of C_2H_4 on Neptune that its predicted abundance is sensitive to the model choice of CH_4 photolysis branching ratios at Ly-α. The solar Lyman-alpha line is the dominant source of dissociating photons for methane in the stratospheres of the jovian planets. Presently, there is no consensus among laboratory studies on the values of the CH_4 photolysis branching ratios at Ly-α (Mordaunt et al., 1993; Heck et al., 1996; Brownsword et al., 1997; Smith and Raulin, 1999; Wang et al., 2000). In the absence of firm laboratory data, C_2H_4 observations may offer an alternative constraint on the branching ratios.

Ethylene is ideal for studying the auroral processes in the stratosphere. Among the hydrocarbons that exhibit polar emission, C_2H_4 is the best probe of very high altitudes because its contribution function for thermal emission peaks in the 5–10 microbar range, whereas contribution functions of acetylene and ethane peak at lower altitudes, down to 10 mbar. These three hydrocarbons might be expected then to show a decrease in sensitivity to auroral energy deposition corresponding to their decreasing altitudes. Indeed, recent spectra taken by CIRS on Cassini during its encounter with Jupiter show C_2H_4 emission enhanced by a factor of about 6 inside the auroral region, C_2H_2 by a factor of 4 and C_2H_6 by a factor of only 1.3 (Jennings et al., 2001).

2. Observations

We observed ethylene line emission from Jupiter on two different occasions, one at the McMath–Pierce telescope of the National Solar Observatory at Kitt Peak, the other at NASA's Infrared Telescope Facility (IRTF) on Mauna Kea. In both cases, we used Celeste, a cryogenic grating spectrometer (Jennings et al., 1994) that operates in the 5 to 25 μm range with resolving powers of 10^3 to 3×10^4. It is equipped with a 128×128 Si:As Blocked Impurity Band (BIB) detector array and a 18×33-cm^2 grating ruled at 31.6 m m^{-1} and blazed at 63°. Selection of a grating order is accomplished with a circular variable filter. We observed the spectral range 948–950.5 cm^{-1} at both observatories. This spectral range includes several of the stronger lines in the central "Q-branch" of the ν_7 band of ethylene. Observational details are summarized in Table 1 and molecular line information in Table 2.

Table 1
Observational details.

Obs.	Date	UT time	Effective exposure	Slit orientation	CM long. covered (S_{III})
McM–P[a]	10/27/98	04:30–08:01	179.4 min	CM[c]	100°–228°
McM–P	10/29/98	03:14–09:09	251.2 min	CM	355°–210°
McM–P	11/01/98	01:26–08:38	329.8 min	CM	22°–283°
IRTF[b]	06/21/00	17:10–21:49	173.4 min	CM	167°–345°
IRTF	06/22/00	16:58–21:59	233.5 min	EQU[d]	319°–141°
IRTF	06/23/00	16:44–21:24	206.8 min	CM	101°–270°

[a] McMath–Pierce Telescope of the National Solar Observatory, located on Kitt Peak, Arizona.
[b] NASA's Infrared Telescope Facility, located on Mauna Kea, Hawaii.
[c] North–south orientation over the central meridian.
[d] East–west orientation over the equator.

The first set of observations took place on October 27, 29 and November 1 1998 at Kitt Peak. At that facility Celeste is mounted on the main spectrograph table which turns to track image rota-